RESEARCH AREAS IN SPACE

RESPOND

CAPACITY BUILDING & PUBLIC OUTREACH (CBPO)

Indian Space Research Organisation

Bengaluru

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A Document for Preparing Research Project Proposals

RESPOND & AI
Capacity Building & Public Outreach (CBPO)
ISRO-HQ, Bengaluru

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Message

ISRO undertakes research and development of launch vehicles, satellite and applications for meeting the societal needs. Towards this, ISRO actively fosters partnerships with industry and academia to advance space research and technology development. The ISRO–Academia partnership is one of the important pillars in India's space research ecosystem, designed to foster innovation, indigenous technology development and skill-building. It helps to bridge the gap between fundamental research and mission-driven engineering. As ISRO unveils the Research Areas in Space – 2025, reaffirming ISRO's commitment to fostering a research environment that is forward-looking, inclusive and aligned with the dynamic needs of the nation and the evolving global space landscape.

The **"Research Areas in Space - 2025"** document details the organization's current and forthcoming research and development priorities. It is the aggregation of various research domains and serves as a blueprint for academic institutions aiming to align their research endeavours with ISRO's strategic objectives. From building robust and efficient launch systems to advancing satellite platforms that support critical communication, navigation and remote sensing services, to expanding our capabilities in planetary exploration and deep space science - the research agenda is both ambitious and grounded in practical national imperatives.

Catering to the Space Vision 2047, this document comprises of six major research areas Launch Vehicles, Satellite Technology, Human Space Flight Centre, Earth Observation, Space Sciences, Space Policy and management. The Research Areas in Space - 2025 document is not merely a technical reference - it is an invitation to researchers, scholars, engineers, entrepreneurs and students to contribute meaningfully to India's space journey. It calls upon our scientific community to think boldly, act responsibly and innovate with purpose. Together, let us chart new paths, unlock new knowledge and build a spacefaring future that uplifts every citizen and reflects the aspirations of our nation.

May 04, 2025

(डॉ. वी. नारायणन / Dr. V. Narayanan)

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Preface

The "Research Areas in Space - 2025" document represents a pivotal step in advancing India's space exploration and technology development, building upon the legacy of the Indian Space Research Organisation (ISRO) and its comprehensive vision for harnessing space for national and global benefit. As a successor to the "Research Areas in Space - 2023" document, this edition encapsulates ISRO's evolving priorities, emerging technological paradigms, and the growing role of academia and industry in shaping the future of space research.

In 2025, ISRO continues to champion innovation in space science, technology, and applications, aligning with its mission to address national needs while contributing to global scientific advancement. This document serves as a guiding framework for academic institutions and researchers, particularly through ISRO's **Space Technology Cells (STCs)** and **Regional Academic Centres for Space (RAC-S)** and **Space Technology Incubation Centres (STICs).** It outlines critical research domains—spanning Launch Vehicle technology, Satellite Technology, human spaceflight, earth observations and space-science —that are poised to drive ISRO's ambitious programs, including Gaganyaan, Chandrayaan-4 & 5, Next Generation Launch Vehicle, Venus Orbiter Mission and Bhartiaya Antariksh Station.

The dynamic landscape of space research demands collaborative efforts to tackle complex challenges from sustainable space operations to cutting-edge remote sensing and artificial intelligence applications. By fostering partnerships with premier academic institutions and encouraging innovative proposals, ISRO aims to catalyze transformative solutions that align with its programmatic goals. This document not only highlights current and upcoming R&D requirements but also underscores ISRO's commitment to nurturing a vibrant ecosystem of scientific inquiry and technological excellence. The execution of R&D projects at academic institutions and engaging students in these projects can be a stepping stone towards their future engagements with Indian Space Programme.

We invite professors, researchers, scientists, and technologists to engage with the opportunities outlined herein, contributing to India's journey toward becoming a global leader in space exploration and technology. Together, we can unlock the vast potential of space to address pressing challenges on Earth and beyond.

April 30, 2025

(एम. गणेश पिल्लै/ M. Ganesh Pillai)

General Instructions

1. "***Research Areas in Space***" is a comprehensive document highlighting ISRO's major programmes, current and upcoming R&D requirements of ISRO. This document will exclusively cater to the advanced research requirements of ISRO wherein Space Technology Cells (STCs), Regional Academic Centre for Space (RAC-S) and Space Technology Incubation Centres (S-TICs) established at various IITs/NITs and premier institutes across the country can select and generate R&D proposals. The faculty of these institutes are encouraged to submit their project proposals in these diverse research areas.
2. To enable the faculty to prepare suitable proposals of relevance to space programme, a detailed list of R & D areas /sub areas/topics and a brief write up about the topic have been given in this document.
3. The concerned ISRO/DOS centre interested in the research topic is given in brackets after the areas/sub areas/problems.
4. In the case of STC's the proposals are invited only from the faculty of the same institute and it is to be submitted to the convener of STC's only. Whereas, in the case of RAC-S/STIC, the faculty from any academic institute of the concerned region can also submit the proposals to the Coordinators of RAC-S and STIC's based on the call for proposals by the respective institutes (list of RAC-S/STIC coordinators provided in Annexure-4 & 5). Further, the submitted proposals will be subjected to critical evaluation by ISRO/DOS Centres. The proposal will be evaluated on the basis of novelty, methodology, approach, deliverables, experience of the PI in the subject area, duration of the project, budget etc.
5. The Projects having envisaged outcome as a product or process of business/commercial potential shall be submitted through S-TICs.
6. The evaluation reports of the proposals received from the ISRO/DOS centres will be further reviewed by the Joint Policy Committee (JPC) of STC , Joint Policy Management Council (JPMC) of RAC-S and Joint Management Committee (JMC) of S-TICs before its recommendation for funding support.
7. The age limit for the Principal Investigator is below 65 years (sixty-five) including the project period.
8. One hard copy and a soft copy of the proposal shall be submitted to the respective STCs/ RAC-S/ S-TICs.
9. "Application for Grant of Funds including the project proposal" and "Form-C" shall be submitted in the prescribed formats only. Formats are given in the Annexure -1 & 2.
10. Conveners of STC/RAC-S/S-TICs shall submit a soft copy of the proposal to the respective ISRO/DOS centre. The addresses and e-mail ids of Respond Coordinators of respective ISRO/ DOS centres are given in Annexure -3.
11. For any other information kindly visit ISRO ***https://www.isro.gov.in/academia.html***

CONTENTS

LAUNCH VEHICLE

A	**Area**	**Mechanisms for Extra-terrestrial Missions (VSSC)**
A1	**Sub Area**	**Percussive Penetration Mechanisms (VSSC)**
A1.1	**Design and development of percussion based penetration mechanism for near zero gravity environments (VSSC)** For extracting relevant sub surface scientific information from Moon, Mars, Asteroids etc., probes with sensors have to inserted into the soil of the planetary body. (Similar to ChaSTE in Chandrayaan 3). When conventional penetration mechanisms are used, the weight of the lander in the planet limits reaction force available and thereby limiting the depth of penetration. In such cases, Percussion based penetration systems can be used to penetrate deeper, while limiting the reaction load. This is done by introducing a counter mass, percussion mass and springs to the system, in addition to the probe mass. The system exhibits dynamic behaviour, and continuous stroke of probe can be achieved with much lower reaction. The objective of the research work is to model the system and arrive at the configuration of the systems, for various gravity environments and demonstrate it in horizontal or near horizontal orientation in earth. The model should also take into consideration the force exerted by the planetary soil on the probe.	
B	**Area**	**Structural Dynamics (VSSC)**
B1	**Sub Area**	**Structural Dynamics and Vibration Control (VSSC)**
B1.1	**Design and Development of Microgravity Active Vibration Isolation System (MAVIS) for Space Station Experimental Payloads (VSSC)** Research platforms employed on-board the space station for conducting microgravity experimentsare very sensitive tovibrations caused by space station activities. MAVIS is an active isolation system for the research platforms from these disturbances. The proposed systemis a basic demonstration of an Active Vibration Isolation System (AVIS), which will be suitably scaled up further to suit the requirements of research platforms being used for space station. The AVIS consists of a base platform and a payload platform, which are connected by means of suitable motors/actuators, isolators and precision accelerometers as shown in the figure below. A suitable control strategy to be adopted for the design of the controller to limit (1/10 times) the vibration disturbancesreaching the payload platform in the frequency range of 1-25 Hz. The experiment is planned to demonstrate on a laboratory level.	
B2	**Sub Area**	**Finite Element Code Development (VSSC)**
B2.1	**Dynamic Response of LV structures under impact loading (VSSC)** The proposal aims to get the code for carrying out the dynamic response analysis due to impact loading Structures considered will be composite, nanocomposite and sandwich	

	structures. Material deformation and failure to be included. Code to carry out the analysis is expected to be delivered as part of the project. Code to be validated with the existing experimental results or new experiments may be carried out to validate the results. Software should include following material models (but may not be limited to) • Elastic material model with Failure • Elastoplastic material model with Failure • Orthotropic material model with Failure • Fiber Composite material model with Failure • Anisotropic Plastic Material model with Failure • Piecewise Linear Plasticity model with Failure • Crushable Orthotropic material model with Failure • Mooney-Rivlin Rubber Model with failure • Foam Material (Polypropylene) • Foam Material with Hysteresis Software should include following models (but may not be limited to) • Constant Modulus Shear Model • Linear Viscoelastic Shear Model • Polynomial Shear Model • Hydrodynamic Yield Model • Mohr-Coulomb Yield Model • Von Mises Yield Model • Johnson – Cook Yield Model • Tanimura-Mimura Yield Model • Zerilli-Armstrong Yield Model • Rate Power Law Yield Model • Polynomial Yield Model • Steinberg – Guinan Yield Model Software should include following Material Failure (but may not be limited to) • Max Plastic strain failure model • Max Equivalent Stress and Minimum Time Step Failure Model • Jhonson-Cook Failure Model • Max Equivalent Stress Failure Model

B2.2	**Topology Optimization of Launch Vehicle Structures (VSSC)** Using topology optimization launch vehicle structures can be optimized for minimum mass meeting frequency constraint. Also optimum fiber orientation and varying ply thickness can be achieved through this methodology for composite structure. This proposal involves to develop the methodology of topology optimization for ply optimisation and perform dynamic response analysis Software should be able to solve following problems (These problems are only for validation. Software should be General purpose for Topology Optimization) • Discrete Fiber Angle Optimization of General Shell Structure • Compliant MEMS mechanism Design • Topology optimization of plate structure under stress, buckling, frequency and manufacturing constraints	
C	**Area**	**Design of Launch Vehicle. AI, Machine learning (VSSC)**
C1	**Sub Area**	**Finite Element Code Development (VSSC)**
C1.1	**Software for the Generative design of Launch Vehicle Structures using AI** Generative design is a method of using AI algorithms to generate and evaluate multiple design alternatives based on input from user. This design process can take many constraints into account including performance requirements, manufacturing process and materials to generate optimized designs. This proposal is to develop software for the Generative design of the launch vehicle structures. • Topology optimization of Cylinder structure under stress, buckling, frequency and manufacturing constraints • Topology optimization of Cone Frustum structure under stress, buckling, frequency and manufacturing constraints	
D	**Area**	**Materials and Manufacturing (VSSC)**
D1	**Sub Area**	**Metal Joining (VSSC)**
D1.1	**Development of technology for friction stir welding using bobbin tool for high thickness aluminium alloys (VSSC)** Conventionally the friction stir welding of propellant tanks is performed using standard fixed pin tool. The fixed pin FSW needs rigid backing plate to support the work piece, which adds the complexity especially during cir-seam welding. Also, fixed pin requires high downward force since it is supported only from one side. The un-even heat distribution in fixed pin tool leads to increased residual stresses and high chances of root defects.	

	For the propellant tanks of thickness 12 to 14 mm, bobbin tool FSW technology is suitable due to the following advantages a) Elimination of backing plate b) Reduced welding downward forces c) More uniform heat distribution d) Reduced residual stress and distortion e) Better material flow and weld quality f) Welding at higher welding speed (low HI) Work Envisaged: • Design and development of bobbin tool technology for high thickness aluminum alloy (AA2219) weldments (12 mm and 14 mm). • Optimization of bobbin tool (pin and shoulder), downward force and process parameters on the mechanical properties and defect formation in AA2219 weldments. • Numerical modelling and experimental validation of bobbin tool FSW for high thickness weldments. Thermal (temperature profile, heat distribution) and mechanical aspects (residual stress and distortion) to be studied. • Detailed mechanical properties (tensile properties at ambient and cryogenic temperatures-77K) and microstructural characterization of optimized BT-FSW AA2219 welds.	
D2	**Sub Area**	**AI/ML in Materials Engineering (VSSC)**
D2.1	**Deep Learning based Microstructure and Mechanical Property Correlation in High-Strength Low-Alloy Steel (VSSC)** This study aims to leverage deep learning techniques for the quantification of microstructural features, phase fractions, and prior austenite grain size (PAGS) in high-strength low-alloy steel(0.3C-CrVMo(ESR)/D6AC steel),establishing robust correlations with mechanical properties. The research focuses on integrating convolutional neural networks(CNNs) with metallurgical characterization techniques to automate thesegmentation and quantification of microstructural phases such aspearlite, ferrite, bainite, and martensite. High-resolution optical and scanning electron microscopy (SEM) - Electron-Back Scattered Diffraction (EBSD) images will serve as input for deep learning models trained to classify and quantify phases and grain structures. • Date generation: Generation of different microstructure (martensite, lower bainite, upper bainite, pearlite and their mixtures) and corresponding mechanical properties in high strength low alloy steel through heat treatment (Experiments: 40-50 Nos).	

	• Data Acquisition: Optical and SEM images of 0.3C-CrVMo(ESR)/D6ACsteel samples subjected to different heat treatments. • Phase Quantification: Deep learning-based segmentation of ferrite, bainite, and martensite phases. • Prior Austenite Grain Size Estimation: Reconstruction using deeplearning models trained on etched micrographs. • Mechanical Properties Correlation: Linking microstructural parameters with tensile strength, hardness, and fracture toughness using machine learning regression models. • Validation: Validation will be done using new set of parameters. (Variation - ±5%).	
E	**Area**	**Propellants, Polymers and Chemicals (VSSC)**
E1	**Sub Area**	**Propellant (VSSC)**
E1.1	**Development of a lab scale prilling process for producing spherical ammonium dinitramide (ADN) oxidizer (VSSC)** Ammonium dinitramide (ADN) is a 'green' high energy oxidizer envisaged for use in solid and liquid propellants. The as-synthesised ADN is needle shaped with high aspect ratios which makes them not suitable for use in solid propellants. In order to use ADN for solid propellants, the as-synthesised ADN has to be converted into spherical particles by a suitable prilling methodology viz., emulsion crystallization, melt crystallization or spray crystallization so as to get ADN with two different average particle sizes viz., 60±20μ and 200±50μ with aspect ratios > 0.9. The spherical particles of ADN shall also be coated suitably with organic or polymeric material like 'stearic acid', 'cellulose derivatives', PMMA, PVA etc.,/inorganic material like 'aerosil' to prevent agglomeration and moisture ingression. The coating thickness shall be in the range of 2-5μ. Work Envisaged: 1. To evolve a suitable lab-scale process for producing spherical particles of ADN from as-synthesised ADN. Sample quantities of ADN for spheroidisationstudies shall be collected from VSSC/ ISRO. 2. Characterization of the produced spherical particles viz., particle size distribution, density and shape characteristics. 3. To identify suitable coating methodologies for the spherical ADN particles and undertake coating trials & characterization of the coated particles. 4. Subsequently, VSSC/ ISRO shall undertake the ignitability studies of coated ADN and compatibility with propellant ingredients viz., binder, plasticizer, metal fuel etc., to functionally characterize the spherical ADN particles. 5. Demonstration of both processes (spheroidization and coating of ADN) in a scale of 100-200g to VSSC.	

E1.2	**Theoretical modelling of cracking reaction of Endothermic fuel in the wall channel of scramjet combustor of an air breathing propulsion engine based on experimental studies (LPSC)** Air breathing/hypersonic propulsion is vital for advanced Space Transportation System for low cost access to space. As the air breathing engine propelled vehicle speeds increase (Mach no.>6), thermal problems multiply because of the effect of the increase in stagnation temperature of the inlet air. Although thermal effects can be mitigated to some extent by improved materials and passive cooling techniques. However, sustained long duration hypersonic flight in atmosphere requires substantial heat sink. As an effective solution, the fuel with high heat sink capability itself can be used as a coolant for engine elements. Since preheating of the fuel is desirable before combustion, it can be circulated through heat transfer passages embedded inside the hot scramjet engine parts. Thus, the fuel removes the excess heat from the engine and in process; it is regenerative heated to the desired temperature. Traditional fuels use only sensible heat for cooling whereas endothermic fuels (C7-C16, aromatics, cyclic compound, catalyst, additives etc.) provide cooling through two routes, namely absorption of sensible heat from combustor wall and through the use of endothermic cracking reactions of fuel. The fuel can provide about 50% more heat sink capacity if it undergoes endothermic thermal cracking reactions at high temperature. As per design requirement the cracking chamber temperature and pressure is in the range of 800-900°C and 30-40 bar respectively. In order to understand the cracking behaviour of the fuel under the desired pressure and temperature it is necessary to model the cracking reaction inside the flow channel. 1. Experimental studies need to be conducted for capturing the intermediate for the cracking reaction for different grades of fuels. Intermediate may be captured through carrying out cracking reaction in conjunction with Laser/spectrometer. Further, based on the experimental data a details, a kinetic reaction rate mechanism shall be developed. The proposed chemical pathways/rate shall be developed as a Chemkin model that can be clubbed with CFD code for estimating the necessary cracking performance parameters. 2. This proposal also envisages the modelling and performance analysis of heat transfer and cracking reaction of the fuel though the channels of different dimensions (Length/Width/Diameter). Configuration of the channel will be provided by VSSC. 3. The modelling of the reaction shall cater the requirement of understanding of temperature / pressure profile of the channel, cracking profile (conversion vs length of the channel), product profile (concentration of products like C,C1,C2,C5,C6 etc. with length), chance of coke formation, heat extracted in the channel, & pressure profile analysis.

	4. The study shall be extended for different fuels (JP-7, RP-1, JP-8) with varying composition. The effect of different kinds of additives (cracking initiators, coke inhibitor, cetane improvers, ignition delay improves, soot improvers etc.) on the chemical pathways also shall be studied. 5. Further, a comparative study needs to be conducted to find out the effect of MOC of channel tubes (SS316, TiO2 coating, Platinum coating, Alumina coating etc.). A theoretical kinetic shall be attempted to capture the interaction of wall with different kind of intermediates. 6. Finally, a consolidated study report shall be submitted. The report must contain the following, • Details of experiments and experimental set up for capturing cracking mechanism • A detail chemical pathways for cracking of different fuels JP-7, JP-8, RP-1 etc. • A spectrum of all the possible intermediates captured through optical sensors. • A reaction kinetics /chemkin file that can be interfaced with CFD model in COMSOL/ ANSYS FLUENT • Effect of % of additives on the cracking performance (P,T, coke, species, heat sink, phase fractions) • Effect of Geometry on the cracking performance and heat sink performance. • Effect of tube MOC on the coking and cracking parameters. A detail CFD model in COMSOL/ANSYS/or .exe format that can predict the cooling channel performance for a combination of different fuels, additives, & combinations of tube MOC.
E2	**Sub Area** — **Chemicals (VSSC)**
E2.1	**Development of high temperature ceramic catalysts for monopropellants (VSSC)** Conventional monopropellant based on hydrazine is catalytically decomposed using an active metal supported on a ceramic substrate. The use of new high performance monopropellants viz., ammonium dinitramide (ADN) and hydroxyl ammonium nitrate (HAN) requires a high temperature tolerant and structurally resistant catalyst. The combustion temperatures of these monopropellants are in the range of 1500-1700°C which requires a suitable high temperature ceramic catalyst with a suitable active metal. The proposed catalyst shall essentially consists of a high temperature ceramic support viz., alumina (heat treated at 1500°C), hexaaluminate, alumino silicate etc., with an active metal (20-30%) viz., Ir, Pt etc., Work Envisaged: 1. To identify and evolve a suitable ceramic support with a temperature capability of 1500-1700oC.

	2. To undertake shape forming studies to produce granulates of different sizes viz., 1-2mm, 2-3mm etc., 3. To carry out impregnation of the ceramic substrates with active metals (20-30%) and characterization of the catalyst. 4. Demonstrate the process in a lab-scale and supply of the catalyst (50-100g) to VSSC for evaluation in a thruster.	
E3	**Sub Area**	**Energetic Materials (VSSC)**
E3.1	**Development of Energetic Metal Organic Frameworks (EMOFs) (VSSC)** The development of high perfromance pyros require that energetic materials must contain high energy and be safe to handle and store. Therefore, significant research in the domain of energetic materials has been dedicated to the designand synthesis of high-energy and insensitive materials. However, with the improvement of the energy level of energetic materials, their safety is always compromised. To adjust the material structure and coordinate the contradiction between material energy and stability through an effective combination and reasonable arrangement of chemical bonds and structural motifs has become the research focus on energetic materials in the world. Energetic Metal–organic frameworks (EMOFs) have gained much attention because of their stable skeletons, controllable structural designs, and tuneable properties. Since EMOFs possess the merits of good heat stability and higher performance, have potential applications in the high energy field by the utilization of highly energetic ligands as coordination ligands. It is porposed to take up synthesisof EMOFs having high thermal stability (>250°C) &high density (>2.0 g/cc). High nitrogen EMOFs can also be synthesized for gas generating applications. Will be useful for high performance gas generators, high explosives for applications such as inflation and separation systems.	
E4	**Sub Area**	**Characterisation at cryogenic temperatures ≤ 20 K (VSSC)**
E4.1	**Cryogenic characterisation of foams and polymers (VSSC)** Liquid oxygen and liquid hydrogen is used as cryogenic propellants. Various polymers such as polyimides and foams are used for thermal insulation, thermal protection purposes in cryogenic tanks and associated systems. It is essential to study the behaviour and characterisation of such foams and polyimide films at low temperatures to the order of 20 K and below. It is also proposed to have a cryogenic characterisation facility for the evaluation of following properties:	

Materials to be tested	Properties to be evaluated
Rigid PU foam	Thermal conductivity
Polyimide film	Tensile strength
Cryo adhesive	Compressive strength
Flexible insulation materials	Specific heat
Premoulded foam pad	Interface properties
	CTE
	Visco elastic properties

E5	Sub Area	Computational Modelling (VSSC)

E5.1

Computational Modelling of polyurethane foaming process (VSSC)

- Polyurethane foam process involves complex simultaneous reactions involving exothermicity. To understand the complexity and kinetics of the reactions computational modeling will be highly essential. This will also help to predict the product properties.
- Computational model is to be developed to understand the foam expansion process for manufacturing applications and how in homogeneity affects the structural response of the product, including long term stability.
- Study shall include the kinetics determination of the formulation taking into account the variation of isocyanate index, surfactant, catalyst & blowing agent.
- Extent of reaction and viscosity variation during the course of reaction needs to be predicted for a stipulated kinetics and environmental conditions.
- Computational modelling of foam expansion to design a mould filling process.
- Physical, mechanical and thermal property prediction via the developed model. Effect of processing conditions on the cell size and final properties may also be studied.
- Prediction of bubble size and bubble distribution may be attempted thus making it more predictive for foaming and aging.

Validation of prediction with respect to experimental values may be done.

E6	Sub Area	Theoretical chemistry (VSSC)

E6.1

Theoretical analysis about Venus atmosphere's corrosive effects towards designing structural materials for missions (VSSC)

Design of materials for futuristic Venus missions is a challenge due to the peculiar nature of the atmosphere. At the Venus surface, the atmosphere consists mostly of CO_2 and N_2, as well as trace amounts of SO_2; H_2O, CO, OCS, HCl, HF, and H_2S with a temperature of 467°C and a pressure of 9.2 MPa. Even though a plethora of literature is

	available regarding the Venus atmosphere and its chemistry. There exist limited reports regarding the correlation of Venus atmosphere chemistry with corrosion of materials. A theoretical understanding of the molecular cluster formation, photolytic degradation of different molecular species in the Venus atmosphere and their interaction with different structural materials will enable us to understand the material reactions arising from the trace quantities of corrosive constituents in the Venus atmosphere. This study will give more insight while designing/processing of structural and electronics materials that need to operate for months unprotected from the Venus surface environment.	
E7	**Sub Area**	**High performance Polymers (VSSC)**
E7.1	**Development of Polybenzimidazole (PBI) fibers (VSSC)** Polybenzimidazole is a high performance synthetic polymer (capable to form strong fibers) with exceptional thermal (>500°C) and chemical stabilities and does not exhibit a melting point. It is prepared by the condensation polymerization of tetramines with dicarboxylic acids at high temperatures. Ithas limited solubility in solvents, which restricts the fiber spinning process. The country does not have the technology of PBI fibers. The plan involves • Supply of PBI polymer in resinous form (Polyphosphoric acid as solvent)/in solid form by VSSC (100-200 g level) • Identification of suitable solvent for dissolving PBI to facilitate spinning. Preparation of PBI fibersusing solution or melt spinning technology by party.	
E8	**Sub Area**	**Nonisocyantae polyurethane coating (Antimicrobial coating) (VSSC)**
E8.1	**Nonisocyante polyurethane based biocompatible antimicrobial coating (VSSC)** Antimicrobial coating for space mission is highly anticipated. Here the proposal is focussing on the development of antimicrobial coatings based on nonisocyanate polyurethane. The coating should be biocompatible and should not contain any VOC (solvent free). The objective of this proposal is to 1. Synthesis of Hybrid polyhydroxyurethanes/ Hybrid non-isocyanate polyurethanes (HPHU/HNIPU)from synthetic (PDMS based) as well as by using bio-based molecules such as vegetable oils, fatty acids, terpenes etc., via. the synthesis of cyclic carbonate by the incorporation of CO_2 into an epoxy. 2. The synthesis of HPHU by the addition of bio compatible epoxy into cyclic carbonate followed by reaction with bio based polyamines. 3. The HPHU synthesised by the above mentioned routes will be evaluated for physical, thermal, mechanical and morphological properties. The coating realized should be evaluated for microbiological analysis and biocompatibility and cytotoxic studies.	

<table>
<tr><th>E9</th><th>Sub Area</th><th>Sprayable TPS Application Technology (VSSC)</th></tr>
<tr><td>E9.1</td><td colspan="2">Development of a reinforced matrix coating system capable of mixing liquid resin & reinforced material externally to apparatus prior to impact on substrate (VSSC)

Coating substrates with reinforced resin matrices, such as liquid resins reinforced with fibers, glass micro spheres, or other reinforcing materials, conventionally requires mixing the liquid resin with the reinforcing material and then spraying the mixture on to the substrate. However this is limited due to the low sprayability of the liquid resins which are typically highly viscous, the limit in attainable coating thickness, and the high amount of waste material generated.

Pumping of high viscose liquid resin through the lines and nozzle of a spray coating apparatus is difficult and requires large amounts of energy. In order to reduce energy requirements and to simplify the spray coating process, the viscosity of the liquid resin is often reduced by mixing the liquid resin with a solvent. Typically, however, solvents useful in spray coating processes are generally environmentally hazardous.

Conventional spray coating processes comprise combining a liquid resin, solvents, reinforcing material, and other conventional constituents such as curing agents, biocides, etc., in a vat to form a mixture. This mixture is then pumped from the vat through lines to a nozzle where it is atomized and sprayed onto the substrate. Once the mixture has been applied to the substrate, the solvent is removed there from by the natural evolution of volatile gas and/or by applying heat to the mixture to fasten the solvent evolution.

The proposal is to design and model an application system where in a high viscous liquid resinis atomized and dispensed towards the substrate through a standard liquid nozzle located at the axis of the apparatus and a stream of fluidised (in air) solid filler particle (viz. Cork powder, glass micro-balloon) is introduced peripherally around the resin jet. The mixing of reinforcing solid and resin occurs at the exterior of the applicator due to the local pressure difference prior to the impact on the substrate.

Objectives of the respond project are,
1. Design of a suitable applicator system.
2. Modeling & simulation of the system and optimization of design.
Fabrication of prototype model, demonstration of performance and validation of design.</td></tr>
<tr><th>E10</th><th>Sub Area</th><th>Polymers (VSSC)</th></tr>
<tr><td>E10.1</td><td colspan="2">Development ofNanofiltration& Reverse Osmosis Membranes for Water Recovery Systems of Space Habitat (VSSC)

Membrane-based water purification system are state of art and highly effect method for water recovery and reuse from various sources such as</td></tr>
</table>

	• Urine (primary source of wastewater). • Grey water (from hygiene, cleaning & shower). A combination of reverse osmosis (RO) and filtration technologies along with distillation & chemical treatment to purify water is used. However a more energy efficient and high water recovery systems are possible only with cascade of specially designed RO and nano filtration membranes. Nanofiller based membrane filtration systems are often preferred over the existing systems to overcome the issues like energy, size and durability and also to remove heavy metals, organic pollutants and bacteria. **Advantages:** Use of nano materials (CNTs, graphene, Silver nano particle etc.) embedded polymeric membranes are the most promising options for high-performance, energy-efficient water purification in space due to their ultra-high permeability, tuneable pore size, antibacterial properties and anti-fouling properties. **Scope of the work:** To develop a working prototype of an efficient membrane based filtration system using Nano filtration+ Reverse osmosis membrane (Polyamide thin film composite (TFC) with integrated aquaporin proteins with polysulfone as support material for purifying soap/ shower water with the following features: • Capacity of water filtration 30 lit/day • Water recovery >98% • Permeate flux high & nearly constant at all times • Low energy consumption • Fouling can be reduced or eliminated by physical cleaning (Avoid chemical cleaning) • Overall weight/mass should be less	
F	**Area**	**Energy System (VSSC)**
F1	**Sub Area**	**High energy density battery system (VSSC)**
F1.1	**Development of Si nanowires infused Graphite anode materials for Ultra high energy density battery systems (VSSC)** • Silicon remains a promising material for Li ion battery anodes since it provides the highest known specific capacity (4200 mAh/g Vs. Graphite 372 mAh/g, 10 times). Presently Si nano material's as a composite form are commonly used for high energy Li ion batteries designs with limited silicon content 5-20 % and the utilization are limited to >1000 mAh/g for containing the volume expansion and the associated capacity degradations. • Scope of further energy density improvement to realize ultra high energy density class battery systems (> 400 Wh/kg) relies on the successful development of 3D nano	

	architecture like Si nanowires embedded graphite composites combining high Li storage and cycle life characteristics suitable for real world applications. Advantages: As a direction oriented Si nanowires, it is able to swell without breaking and have the advantages of high surface to volume ratio and enable better Si capacity utilisation in the composite matrix. Si nanowires infused in Graphite able to withstand more volume change without undergoing pulverisation unlike particles and limited cracking thereby extended the cycle life. This kind of nano structures exhibits add-on advantage of shorter diffusion path for Li ionic species, thus offering the possibility of fast charging and higher discharging rates compared to 2D Nano composites.	
G	**Area**	**Formal Verification (VSSC)**
G1	**Sub Area**	**Language Compiler for Microprocessor, Formal Verification (VSSC)**
G1.1	**Formal Verification of Vikram3201 Ada Cross-Compiler (VSSC)** The research proposal aims at formal verification of in-house developed Ada cross-compiler for Vikram3201, a 32-bit processor with indigenous instruction set architecture. Ada cross-compiler has been developed in-house and used for development of flight software for Vikram3201-based embedded systems. The research is aimed at formally proving that the compiler is error free.	
H	**Area**	**Model-based Software Development Framework (VSSC)**
H1	**Sub Area**	**Software development framework using Model-based techniques to provide a Low-Code/No-Code platform for future NGC flight software development (VSSC)**
H1.1	**Low-Code Software Development Platform for OBCs (VSSC)** • Software development process in general is transitioning from a traditional manual programming model to Low-Code/No-Code based software development process • Visual Programming, Model based Development, Formal Specification etc. all are different approaches to this general goal • This proposal envisions such a platform to auto generate software from GUIs, configuration files, specifications etc. instead of manual software coding • The platform shall support customization for in house safe subset of high level languages and Instruction Set Architecture of indigenous processor for generating Assembly functions	
H2	**Sub Area**	**Launch vehicle sequential system (VSSC)**
H2.1	**High power Laser diode device design, development and realization (VSSC)** Design and realization of high power laser diode with 975nm wavelength. Power level shall be adjustable with input current to the laser diode. Power output shall be programmable from 3watt to 10watt by adjusting input current to laser diode.	

I	Area	Sensing Systems (VSSC)
I1	Sub Area	Instrumentation, Data Acquisition and Telemetry VSSC)
I1.1	**Graphene-based Sensors and Sensing Systems (VSSC)** Graphene is a two-dimensional material that exhibits superior electrical and mechanical properties when compared to Silicon for sensing and electronic device realization. Realization of sensors based on Graphene platform is expected to lead to high performance, low-power, miniaturized sensing systems suitable for aerospace application. Increased sensitivity, improved operational ranges and better accuracy are expected performance gains from these sensors. Sensors and sensing systems for parameters such as pressure, strain, vibration, acoustics, humidity, gas detection and biomedical health monitoring and Hall effect sensors are suitable candidates for development. This involves development of sensor, signal conditioning / interrogation electronics, packaging, calibration and compensation as required.	
J	Area	Radio Sounding system development for Planetary Ionospheric studies (VSSC)
J1	Sub Area	Scientific probes, Sensing Antennae & RF Systems (VSSC)
J1.1	**Wideband transmitting and receiving antenna for RF; Efficient RF transmitting and receiving systems with onboard RF data processing (VSSC)** The atmosphere of planetary bodies like Moon is characterized by the absence of a unified magnetic field. This allows the direct interaction of solar wind with planetary surface and atmosphere, which in turn leads to the formation of an 'ionosphere'. Such an ionosphere would be an ideal plasma laboratory to understand the behaviour of plasma in the absence of a unified magnetic field. The plasma distribution, both spatial and temporal, would depend on the magnetic field conditions unique to the heavenly body. A typical requirement for such a measurement in the case of a lunar mission is as follows: the transmitter sweeps in the frequency range of 90KHz to 1MHz. The sounding is proposed to be done in about 200 discrete steps. The pulse width is variable in the range of 5-40µs, with preferably a pulse repetition frequency of 500Hz. The envisaged peak pulse power is 5W. The project envisages development of an RF transceiver system with front-end antenna suitable for this. The system will thus aid the investigation of the temporal variations of magnetic field in the lunar or planetary ionosphere in the vicinity of its surface under varying solar conditions.	
K	Area	Superconductor based Electromagnetic Cage (VSSC)
K1	Sub Area	Superconductor, high current electronics, cryogenics (VSSC)
K1.1	**Development of a superconductor based electromagnetic cage for active radiation shielding in outer space (VSSC)**	

	The proposal aims to develop and prototype a high temperature superconductor based electromagnetic cage which can offer active radiation shielding in outer space. This will offer protection against the harmful effects of radiation and thereby enable long term survivability of human in outer space.	
L	**Area**	**Avionics-Communication Systems (VSSC)**
L1	**Sub Area**	**Development of a Fully deterministic variant of the Ethernet protocol for communication in a multi computer architecture with capability of data rates beyond 100Mbps (VSSC)**
L1.1	**Fully deterministic variant of the Ethernet protocol for interprocessor communication in a multi computer architecture with capability of data rates beyond 100Mbps (VSSC)** The proposal aims to develop a fully deterministic variant of the Ethernet protocol which will enable the development of avionics architecture with multiple computers interconnected by this high speed serial link. The developed protocol should be capable of communicating beyond 100Mbps.	
M	**Area**	**Superconductor based electromagnetic field generator for gravity generation (VSSC)**
M1	**Sub Area**	**Superconductor, high current electronics, cryogenics (VSSC)**
M1.1	The proposal aims to develop and prototype a high temperature superconductor based electromagnetic field generatorwhich can generate a rotating field to spin human habitat modules for generating gravity.	
N	**Area**	**Aerospace Engineering (VSSC)**
N1	**Sub Area**	**Development of Tools (VSSC)**
N1.1	**Tool Developement (VSSC)** With the advent of higher computing power, fidelity of numerical simulations is also increasing. Second order RANS simulations are routinely carried out for aerodynamic design and characterization. Improved fidelity can be achieved by carrying out Large Eddy Simulations with higher order of accuracy. Towards this, a higher order solver is essential which can be based on Discontinuous-Galerkin (DG) or the Flux-Reconstruction (FR) framework which has shown promise in the recent past. As the configurations on which the solver will be used are not amenable for structured grid, the solver has to be based on 3D unstructured grid topology with mixed elements such as tetrahedrons, hexahedrons, triangular prisms and pyramids. Additionally, most of the flows over launch vehicles and re-entry bodies are high Mach number flows. Hence the solver should be designed for compressible flows with shocks.	

N1.2	**Software for three dimensional polyhedral mesh generation on arbitrary geometries (VSSC)** Grid generation is an integral part of a CFD simulation process. Conventionally, mixed element grids involving tetrahedrons, hexahedrons, pyramids and triangular prisms have been used in an unstructured solver. But in recent past, polyhedral grids have shown promising results in terms of accuracy and robustness. Hence an automatic polyhedral grid generator which can generate a grid on an arbitrary geometry is sought.	
N1.3	**Development of empirical tool or simplified mathematical tools for prelimiary aerodynamic data generation for wingbody configuration for ground proximity conditions (VSSC)** Detailed moving mesh based CFD simulations are computationally expensive and time consuming and this makes it non-feasbile for detailed preliminary investigations during design phase. Empirical tools or simplified mathematical tools are promising candidates to generate aerodynamic data for winged body configurations during design phase with quick turn around time. Once the configuration is finalized, designers can make use of computationally expensive moving mesh based CFD solvers. Currently we have high fidility robust CFD solvers to handle the second part for accurate data generation. Proposals are invited to develop empirical/mathematical tools capable of generating aerodynamic data for winged body configurations, accounting for dynamic ground proximity, with reasonable and acceptable levels of accuracy. Typical parameters expected from the tool includes sink rate, aspect ratio, height above ground, and other essential design parameters. Results should be validated for minimum two cases, supplied by VSSC or published in literature. Source code and executable files should be installed in VSSC computational facility and proper training to be given to our Engineers.	
N2	**Sub Area**	**Additive Manufacturing, 3D Printing (VSSC)**
N2.1	**Design and realisation of 3D printable sandwich deck plates with provision for internal cooling (VSSC)** Presently, aluminium sandwich deck with honeycomb core support avionics packages in launch vehicle and satellites. These deck plates are process, schedule and cost intensive. In addition to this, thermal dissipation systems are provided in and around the deck for dissipating the heat generated by avionics packages. The proposal is to design a 3D printable sandwich deck with aluminium skin and lattice type core along with internal cooling veins system which is capable of supporting the structural and thermal environment. The proposed system shall be printed in a single go with internal cooling veins ensuring minimal post processing options.	

N3	**Sub Area**	**Composite Lattice structure (VSSC)**
N3.1		**Development of theoretical models of composite lattice cylinders and cone type structures (VSSC)** Composite filament wound lattice structures are evolving optimized construction for aerospace applications. Comprehensive theoretical model for lattice design are limited. The proposed topic is the development of a comprehensive theoretical model capable of predicting the structural behaviour (deflection and strains), possible local and global failure modes of cylindrical and conical structures under compression, tension and bending loads. The theoretical model shall be validated using FE and proto hardware testing.
O	**Area**	**Aerodynamics (VSSC)**
O1	**Sub Area**	**Experimental aerodynamics (VSSC)**
O1.1		**Development of Background Oriented Schlieren system for use in Trisonic wind tunnels (VSSC)** The proposal envisages development of a background oriented schlieren setup for a viewing area of 500mm diameter in a trisonic wind tunnel. Design and procurement of required optics (if necessary) Development of algorithm for measuring density preferably in Matlab. Validation with standard 2D wedge and 3D cone models Demonstration of the BOS in ISRO Tri-sonic Wind Tunnel on a Crew Module. (VSSC TWT possess necessary windows, light source and collimated beam).
O2	**Sub Area**	**CFD, Unsteady Simulations, Large separated flows (VSSC)**
O2.1		**Computational investigation of dynamic stability derivatives for semi-ballistic re-entry modules (VSSC)** Semi-ballistic re-entry modules are used for ferrying crew to and from space. The module spends significant time in atmospheric phase while nominal reentry. During abort missions, the module may experience re-orientation from an angle much away from desirable trim angle, hence undergoing large pitching motion. These modules are reported to be dynamically unstable at subsonic and transonic speeds in literature. Accurate computation of these phenomena is essential for precise simulations of its behaviour prior to parachute deployment. Unsteady CFD simulations capturing the time lag effects in large separated flows pave the way to study the underlying reasons and possible solutions for undampingbehavior. Apart from high fidelity simulations, data processing and usage also plays a significant role.

<table>
<tr><th>O3</th><th>Sub Area</th><th>Experimental aerodynamics (VSSC)</th></tr>
<tr><td>O3.1</td><td colspan="2">Development of forced rotation roll damping rig for use in Trisonic wind tunnels

The proposal envisages development of a forced rotation roll damping rig for roll damping coefficient estimation in trisonic wind tunnels.

Roll speed: 35 RPM to 2000 RPM

The proposal consists of measuring the RM of rotating model using a balance / torque cell, rotating the model at various constant speeds, speed measurement, a feedback circuit for maintain the speed and suitable control system. The scope of work includes design and finalization of required motors, slip rings, hall effect sensors, angle measurement system, software for control, simulation results etc and purchase order specifications for each items.</td></tr>
<tr><td>O3.2</td><td colspan="2">Methods to specify the size and shape of Boundary Layer trips on wind tunnel models at low and high Angle of Attack in subsonic regime (VSSC)

During lift off of launch vehicles, the vehicle AOA continuously decreases from 90° to 0°. Typically scaled wind tunnel models are used in WT for obtaining loads at various aoa. At higher AOA, in order to get the loads accurately, the flow field on both the WT model and in flight should be same. Hence, various kinds of BL trips are used on WT models to simulate the flight Reynolds number. This proposal seeks an appropriate procedure for arriving at the size and shape of boundary trips on a variety of wind tunnel models in the angle of attack range of 0° to 90°.

Experimental investigation to derive the procedure/methodology/pattern to distribute the boundary layer trips on typical scaled down models of slender body (SSLV/ Gaganyaan/TVP etc), blunt body (Crew Module) and lifting body (RLV, GEV) at subsonic speeds and demonstrate aerocoeffcient independence with speed by proper BL tripping in speeds upto 80 m/s at various angles of attack and wind plane angles. Alternatively tunnel flow turbulence can be increased by use of appropriate grids and TBL on model can be demonstrated.</td></tr>
<tr><td>O3.3</td><td colspan="2">The development and integration of Delayed Detached Eddy Simulation (DDES) and Wall model Large Eddy Simulation (WMLES) for in-house solver PRAVAHA (VSSC)

1. To develop DDES and WMLES and integrate them into the existing in-house solver “Parallel RANS Solver for Aerospace Vehicle Aerothermodynamic Analysis (PRAVAHA)” which is cell centered finite volume solver on unstructured grid (C++ language to be used).
2. Implement Kinetic Energy and Entropy Preserving schemes on polyhedral mesh elements along with adaptive schemes in the vicinity of shock.</td></tr>
</table>

	3. Implement various wall models for WMLES. 4. The validation of the solver w.r.to boundary layer flows (with and without separation) and shock-boundary layer interaction with existing literature for realistic engineering geometries (external flow over launch vehicle& supersonic jet flows). Demonstration of these solver in predicting the noise levels for supersonic jets and external flow over launch vehicles.	
O3.4	**Experimental Fluid Structure Interaction study to understand parachute dynamics (VSSC)** Parachute system is an essential system for recovery missions. We need to generate sufficient experimental data and the same is not available to the required level. Proposals are invited to carry out the parametric studies using a series of experiments. Experimental database for parachutes with various parameters like wiser length, flyout angle, flyout length, material flexibility, multiple parachutes and fore-body effect needs to be generated. We are looking for proposals from academia and/or industries, having necessary facilities or capable of establishing the necessary facilities for performing fundamental experiments to understand parachute dynamics, (both single and cluster).	
P	**Area**	**Propulsion (VSSC)**
P1	**Sub Area**	**Hybrid Motor (VSSC)**
P1.1	**Modelling of fuel regression and pressure behaviour in Hybrid Motor (LPSC)** Burn rate of solid fuel in Hybrid Motors depend on convective heat transfer to the fuel grain, fuel pyrolysis and oxidiser flow rate and its evaporation. For obtaining the pressure-time behaviour and oscillations in a hybrid motor, the coupling of the LOX evaporation and the heat transfer based fuel regression needs to be modelled. The temperature variation in the fuel grain and the recession of the fuel grain due to regression also need to be modelled. A conjugate heat-transfer based model to predict the pyrolysis rate of HTPB fuel based on heat-flux at the fuel surface and the moving mesh to account for the recession of the fuel grain due to burning needs to be developed and implemented, along with a suitable combustion model in a CFD package to enable full transient pressure behaviour of the hybrid motor.	
Q	**Area**	**Aerothermal (VSSC)**
Q1	**Sub Area**	**Radiant heating (VSSC)**
Q1.1	**Design and Development of a Graphite strip heater to operate at temperature above 3000degC in ambient sea-level condition (LPSC)** Graphite radiant heaters can achieve very high heat flux for long duration. And the shape of heater can be appropriately made to suit the specimen. The current technology of quartz sealed tungsten filament-based lamps to simulate high heat flux have a limitation owing to the oxidation of tungsten and melting of quartz.	

	1. Development of tantalum carbide or similar high temperature coating to prevent oxidation of Graphite at high temperature 2. Selection of fine grain Graphite grade compatible for the coating and operation at temperature >3000degC 3. Develop procedure such as plasma spray for coating application on Graphite strip heater element. 4. Develop a small scale test setup with stepdown transformer, rectifier and filters for heating the graphite heater to temperatures above 3000degC. Demonstrate the survivability of coating for repeated use at temperature >3000degC for sustained heating for 30 minutes.
Q2	**Sub Area** — **Non-linear Control (VSSC)**
Q2.1	**Design techniques for the transient behavior of systems with Lyapunov based control design in spacecrafts and satellite launch vehicles (VSSC)** Lyapunov based control design always ensure the stability of the non-linear systems. However, till date this technique lacks a standard methodology for the design of the transient behaviour unlike in linear systems, where they are approximated as 2^{nd} order systems for performance analysis. Transient performance is critical for systems like launch vehicles and spacecrafts as there are numerous uncertain sources of disturbances possible to impact while in flight. Development of this technique will boost the scope of implementation of Lyapunov based control algorithms for future applications which ensures stability along with the expected transient phase response.
R	**Area** — **Photonic Thruster (LEOS)**
R1.1	**Development of CNT (carbon nanotube) ablating film for laser based propulsion systems (LEOS)** CNT-based ablating films will have better specific impulse and low dead mass compared to other materials which are being used in ablating film fabrication. The current proposed research is towards the realization of the CNT-based ablating film for micro-newton thruster applications employing the carbon nanotube-based films developed based on the spray coating method. Ablation films are required for the thrusters with a thrust of the order of micro-Newton. The parameters, namely specific impulse and momentum coupling coefficient of ablating films, play a major role in deciding the performance of the thruster. Thrust level of micro-Newton thruster: approx. 100 µN; specific impulse :> 650 s; laser power:~ 15 W pulse laser source (~0.1 to 10 ms pulse at 10-20 Hz repetition rate). The main objectives of interest are a) development of CNT-based ablating film for micro-Newton thruster applications; b) characterization of properties, namely adhesion, durability of ablating film on the substrate, and laser ablating properties; and c) fabrication of 1-meter-long ablating film.

S	Area	Range Operations (SDSC SHAR)
S1	Sub Area	Meteorology (SDSC SHAR)
S1.1	**Enhancing Space Launch Vehicle Safety through X-Band Doppler Weather Radar Assimilation in NWP Models (SDSC SHAR)** Space launch operations are highly sensitive to weather conditions, particularly during the critical launch window. Severe weather events such as heavy rainfall and thunderstorms can pose significant risks, necessitating accurate and timely weather predictions. This research proposes the integration of high-resolution X-band Doppler Weather Radar data into Numerical Weather Prediction (NWP) models using advanced data assimilation techniques. The objective is to enhance the accuracy of Nowcasting and short-term forecasts, thereby optimizing weather assessments and ensuring the safety of space launch operations.
S1.2	**Hybrid Data Assimilation Techniques for Upper Winds, Monsoon Rainfall, Rapid Cyclone and Thunderstorm, and Lightning Prediction in Launch Environments (SDSC SHAR)** Hybrid data assimilation methods that merge traditional meteorological data—such as Automatic Weather Stations (AWS), wind profilers, lightning observations, and ceilometers—with high-frequency inputs from X-band radars and satellite imagery. The integrated approach aims to accurately capture the fast-evolving dynamics of severe weather systems, including upper winds, monsoon rainfall, cyclones, thunderstorms, and lightning activity. Such advancements are critical for enhancing the reliability of weather predictions, ultimately providing essential decision-making support for safe and efficient space launch operations.
S1.3	**AI-Driven Upper Wind Forecasting for Enhanced Space Launch Safety: Integrating High-Resolution Wind Profiler and GPS Radio Sonde Observations (SDSC SHAR)** Research proposal focuses on developing a scientifically rigorous, AI-driven framework for short-range prediction of upper atmospheric wind conditions critical to space launch operations. By integrating high-resolution wind profiler measurements with GPS radio sonde vertical profiles, the project aims to design and implement advanced data assimilation techniques and machine learning models. These models will capture the dynamic atmospheric variability over short time horizons, thereby providing high-fidelity forecasts essential for optimizing launch trajectories and mitigating aerodynamic risks. The approach promises to enhance operational decision-making and overall mission safety by delivering timely and accurate wind predictions in the complex upper atmospheric environment.

S1.4	**B. AI-Enhanced High-Resolution Short-Range Forecasting of Near-Surface Winds for Space Launch Operations (SDSC SHAR)** Research proposal aims to develop state-of-the-art AI/ML models for the high-resolution, short-range prediction of near-surface winds (up to 100m) tailored for space launch operations and lift-off wind monitoring. By integrating diverse datasets—including long-term climatological observations, reanalysis data, and forecast outputs from ECMWF and WRF NWP models—the project seeks to capture fine-scale wind variability essential for launch safety. Advanced data assimilation and machine learning techniques will be employed to fuse these heterogeneous sources, resulting in improved real-time forecasts that support critical decision-making during launch operations and Liftoff.
S1.5	**Rainfall prediction and type classification over the East-coast of India (SDSC SHAR)** This research aims to predict rainfall patterns and classify the types of rainfall over the east coast of India using multiple meteorological instruments i.e., Micro Rain Radar (MRR), Ceilometer, Liquid Precipitation Monitor and Satellite observations. The Liquid Precipitation Monitor will provide measurements on real-time liquid precipitation, Ceilometer will inform about Cloud height and MRR offers vertical profiles of rain rate, liquid water content and drop size distribution at 22.24 GHz. A possible outcome of the study is an integrated model to predict rainfall intensity and type (e.g., Convective, Stratiform, Intermittent etc.) with high accuracy. This will enhance weather forecasting capabilities for localized rainfall prediction.
S1.6	**Weather forecast at local region using foundational weather models (SDSC SHAR)** Recent advancements in foundational weather models, such as Microsoft's ClimaX, Huawei's Pangu-Weather, and Google's GraphCast, have demonstrated superior predictive capabilities compared to traditional Numerical Weather Prediction (NWP) models like GFS and WRF. These deep learning-based models leverage global reanalysis datasets and have shown remarkable skill in medium-range forecasting. In this context, an open-source weather and climate foundational model, pre-trained on ERA-5 reanalysis data, can be fine-tuned using high-resolution local meteorological observations from the ASRF observations. By integrating multi-source observational datasets, including ground-based sensors, remote sensing products, and reanalysis data, the model can be adapted to enhance regional forecasting accuracy. Furthermore, embedding spatiotemporal meteorological features into the model will allow for improved downscaling and high-resolution forecasts tailored to specific local conditions. This approach aims to bridge the gap between global-scale predictions and localized atmospheric dynamics, enabling more precise short- to medium-term weather forecasting.

S1.7	**Water isotope analysis over the East-coast of Indian region during Cyclonic events (SDSC SHAR)** This research aims to analyse the water isotope composition over the Chandipur region of eastern India during cyclonic events to better understand the impact of extreme weather on the local hydrological process. By studying the stable isotopes of water, the research can investigate cyclonic rainfall, evaporation and water vapour transport affect the isotopic signatures. Data will be collected periodically before, during and after a cyclonic event to trace the movement and transformation of water at the eastern part of India. This research can contribute to improved understanding of cyclone-induced hydrological behaviour.
S1.8	**Aromatic VOCs at Major Road junctions in Metropolitan cities in India (SDSC SHAR)** The scope of the research aims to analyze the concentration and sources of aromatic volatile organic compounds at major road junctions in metropolitan cities of India. The Thermal-Desorption Gas Chromatograph Flame Ionisation Detector (TD-GC-FID) and Volatile Organic Compound (VOC) analyzer can measure the levels of key aromatic VOCs which are primarily emitted from vehicle exhaust, industrial activities and traffic congestion. This study can assess the temporal and spatial variation in VOC concentrations and contribute to understanding and the impact of vehicular emissions on air quality and public health in urban settlements.
S1.9	**Ionospheric observation using Ionosonde (SDSC SHAR)** This research aims to enhance understanding of atmospheric dynamics. Ionosondes, which measure the electron density and later structure of the ionosphere can provide valuable data on ionospheric anomalies, radio signal propagation and space weather events. This study is expected to contribute to improved space weather forecasting, calibrate communication & navigation system at regions influenced by coastal geography.
S1.10	**Investigation of interaction among aerosol, cloud and rainfall over the East coast of India during Indian Summer Monsoon (SDSC SHAR)** This research aims to investigate how atmospheric aerosols which are tiny particles suspended in the air, influence cloud formation and impact the amount of rainfall by influencing cloud microphysical properties. The key points in this research it to better understand the impact of aerosols and their effects as parametrization in Numerical Models or in AI-based Foundation Models. In this context, data from Robotic Sun Photometer, Aethalometer, Nephelometer, Ceilometer, Cloud Radar etc. can be used along with satellite imagery data for evaluating the role of aerosol-cloud-rainfall association.

<table>
<tr><td>S1.11</td><td colspan="2">Middle & upper atmospheric study using VHF atmospheric Radar (SDSC SHAR)
This study of the middle and upper atmosphere aims to advance the understanding of atmospheric dynamics and ionospheric interactions. In this work, phenomena such as atmospheric waves, turbulence ionospheric irregularities which affect communication systems & satellite operations are to be studied. Detailed analysis of turbulence and wind dynamics helps to better understand atmospheric circulation patterns and their impact on global weather systems.</td></tr>
<tr><td>T</td><td>Area</td><td>Solid Motor Performance & Environmental Test Facility (SDSC SHAR)</td></tr>
<tr><td>T1.1</td><td colspan="2">Developing a jet noise source localisation technique using a microphone array with appropriate beam forming algorithms (SDSC SHAR)
Locating the jet noise sources in the lift-off scenario of a launch vehicle will benefit highly in the suppression of the noise sources. Present method proposes to use an array of microphones and employ suitable algorithm and develop a code to locate the noise sources.</td></tr>
<tr><td>T1.2</td><td colspan="2">Modelling and evaluation of damping in threaded joints of load cells and its impact on measuring dynamic force components (SDSC SHAR)
During static test, the thrust load transfer is through threaded joints. The thread damping is important with respect to the dynamic thrust measurement. The objective is to model and experimentally evaluate the threaded joint damping for unsteady load transfer.</td></tr>
<tr><td>U</td><td>Area</td><td>Vehicle Assembly and Launch Facilities (SDSC SHAR)</td></tr>
<tr><td>U1.1</td><td colspan="2">Automated Stage Preparation with minimum human intervention (SDSC SHAR)
As the launch frequency increases, human intervention, in repetitive work, will have a tendency for delay and error. In this regard, automated Rocket stage preparation infrastructure with an ability to prepare stages swiftly and with minimum error (Six Sigma accuracy) is a gamechanger. The project can be initiated with automation of the Pneumatic Test Consoles (PTC) which can conduct all the leak tests independently and provide data comparison and data analysis automatically using AL/ML in order to increase launch frequency. Following are the features which the user interface shall have:
1. Connect and forget technology for stages.
2. Remote monitoring of live leak test data (Secured Data sharing to different agencies).
3. Machine learning based leak check result interpretation. Saves time and increases launch frequency.
4. Automated presentation and reporting system to streamline data.
5. Failure modes and troubleshooting procedures to pin point leak.
6. Enhanced interchangeability for different stages for different global clients. Increase in utilisation of the facility.
7. Automated T&E, saving facility readiness time.
Future implication of AI- Based stage preparation.</td></tr>
</table>

V	Area	Liquid Propulsion (LPSC)
V1.1		**Evaluation of Passive Devices for Control of Combustion Instability in Liquid Engines (LPSC)** Combustion instability is a phenomenon that sometimes occurs in liquid rocket engines and can lead to damage/destruction of the hardware. It can be controlled by passive techniques such as slots, baffles, resonators etc. It is necessary to model the combustion instability in the presence of these dampeners and evaluate their effectiveness under different operating conditions. The effect of variation of geometric parameters is to be quantified. Combustion instability model for liquid rocket engine with passive dampeners.
V1.2		**Development of Physics Based Model to Predict the Soot Formation in the Combustion Chambers of Methane - Oxygen and Isrosene - Oxygen Engines (LPSC)** Development of a physics based combustion model to predict soot formation as a function of liquid engine operating parameters such as chamber pressure and mixture ratio. The chemical kinetics, reaction mechanism, species and their desired properties required for combustion modelling have to be formulated through standard published literature for both methane-oxygen and Isrosene-oxygen propellant combinations. The developed model has to be validated with the test data provided by LPSC or with the relevant data available in the open literature. Expected Deliverables are: Quantification of soot formation during methane-oxygen and Isrosene-oxygen combustion in liquid rocket engines. A combustion model to predict the effect of mixture ratio and other operating parameters of the engine on the degree of soot formation.
V1.3		**Model based estimation of pressure evolution in a Liquid methane tank ullage with internal feed tunnel under dynamic conditions & cryogenic engine operation (LPSC)** Development of discretized mathematical model to estimate ullage pressure and temperature across the ullage volume and calculate the mean mass temperature of the ullage volume during ascent phase & engine operation. The discretized model of the ullage is to be generated for simulating the real time internal thermodynamics & heat transfer phenomena of the ullage during ascent phase & engine operation. The heat transfer modeling in both dome and shell area to be done to estimate the pressure evolution in the tank during the expulsion time of liquid. The node of the ullage is getting increased during the expulsion time and radial and axial heat transfer to be estimated such that the pressure change due to collapsing of the ullage gas due to the exposure of internals during the expulsion of low temperature liquid from the tank.

V1.4	**CFD modelling of thermal stratification in uninsulated cryogenic propellant tank (LPSC)** The LOX and LCH4 tanks being developed for NGLV are proposed to be uninsulated. The high heat in-leak into the cryogenic propellant will lead to significant vaporization of the propellant and may lead to boiling near walls. Additionally, the frost formation on the tank outer wall determines the heat in-leak into the propellant. Furthermore, the formation of thermally stratified layer near the liquid-vapor interface, evolution of tank pressure and fluid temperature needs to be determined during tank filling process and subsequent operations. Subsequent to lift-off, the aerodynamic loads on the propellant tank will result in fluid sloshing and affect the fluid behaviour and heat transfer to the propellant that needs to be considered in the model. In this regard, a comprehensive CFD model is required to be developed for modeling of the heat and mass transfer phenomena in the un-insulated cryogenic tank during tank filling and lift-off phases. The model must include the frost formation on the tank outer wall, and determine the temperature and pressure evolution in the liquid and vapour in the tank. The CFD model is required to be developed preferably in ANSYS Fluent based on Volume of Fluid method, and must incorporate the mass transfer dynamics of the propellant. The model must be validated with the data available in literature /ISRO's test data.
V1.5	**Numerical simulation of single and multiple swirl injector performance in throttleable spacecraft engines (LPSC)** Single and multiple coaxial swirl injectors are used in the liquid rocket engines used in propulsion systems of satellites, lunar and planetary landers etc. A part of propellant acts as coolant for the thrust chamber by virtue of the conical spray from the injector. In throttle able engines, the injector spray pattern changes with the change in propellant flow rates, which in turn will affect the cooling of the combustion chamber wall. Further, the wall cooling is also affected by the injector-injector interaction. It is important to understand the injector flow behavior under all operating conditions during design cycle of the engines, prior to hardware fabrication and testing. Simulation of primary breakup of the propellants injected at the nominal and throttles operating conditions is of importance in this regard. Via this proposal it is envisaged to develop a detailed numerical model of primary breakup in MMH/NTO based spacecraft engines which employ multiple coaxial swirl injectors at nominal and throttled operating conditions.
V1.6	**Lunar regolith transport from multi-engine firing during planetary descent (LPSC)** Planetary descent into an atmosphere-free celestial body generates engine plume flow fields that transition through continuum, rarefied and free-molecular regimes. For multi-engine landers, plume-plume and plume-surface interactions result in complex plume

	gas and regolith flow structures. The eroded particle flux from the ground exhibits complex structures as a consequence of the three-dimensionality of the plume flow and plume-plume interactions. The eroded regolith flow resulting from multi-engine landers exhibit directional jetting, where the particles motion tend to concentrate near symmetry planes between adjacent nozzles as well as symmetry planes bisecting each nozzle. Such features cannot be captured using an axisymmetric approach. This research call is for the development of a parallelized three-dimensional two-way coupled DSMC-regolith excitation/transport solver that is capable of simulating the expansion of plume gases from multiple engines of a lander, and their interaction with planetary regolith and the ensuing regolith transport.	
V1.7	**Two Phase Flow Modeling in Cryogenic Propellant Feed Lines (LPSC)** Cryogenic engines make use of propellants such as liquid Hydrogen and liquid Oxygen at sub-cooled temperatures. The propellant is fed to the engine from the storage tank via. feed lines that are typically of 70-400mm diameter. The feed lines are either super insulated or foam insulated and are initially at ambient temperature (≈298K). The feed lines are required to be chilled to respective cryogenic temperatures of the fluid (≈20K for Hydrogen feed line and ≈80K for oxygen feedline) prior to the start of engine operation to avoid undesirable flow oscillation. The chill down process is complex in nature due to varying two phase flow boiling regimes and heat-in-leak conditions. In this regard, a validated conjugate numerical model is to be developed to simulate the following: • Feedline chill down from ambient temperature to the respective propellant temperature. The model must include heat transfer correlations which will be invoked based on wall temperatures and fluid quality • The model has to capture the effect of pipe orientations viz. horizontal, vertical and inclined on the chill down characteristics • In case of large diameter feed lines, stratifed flow predominates and thermal bowing of feedline may occur. The model should be able to capture this flow regime and the associated thermal gradients The time varying temperature evolution of the feedline in axial and circumferential direction and the time taken for feedline chilling completion are some of the important parameters to be compared. The flow regime transition at different points in the feedline.	
W	**Area**	**Advanced Propulsion Systems and Control Electronics (LPSC)**
W1.1	**Regenerator Studies on Free Piston Stirling Engine (Fpse) (LPSC)** The work aims at optimising the regenerator using the available FPSE with LPSC to achieve highest possible thermal efficiency. The heat transfer in the regenerator is studied simulating the oscillatory nature of the flow. The objective of this is to experimentally measure the friction factors and Nusselt numbers in oscillating flow of regenerator	

	matrices that will be used in Stirling engines that are planned for space power generation. The experimental data will be analyzed and usable correlations of the friction factor and Nusselt number will be provided. The aim of the study is to optimise the regenerator to enhance the efficiency of the LPSC FPSE from the existing 18-20% (theoretical) by at least 25% using the regenerator. Expected Deliverables are: • Optimised regenerator design for the FPSE designed by LPSC.
W1.2	**Multi-Plume Interaction Studies of Clustered Hall Thrusters (LPSC)** The performance of a thruster in a cluster may be different from a standalone situation. One interest is to investigate the plume interactions, especially in the complex and important near field locations. To accurately simulate the plasma plumes from a cluster of Hall thrusters requires an accurate modelling of the complex physical plume mechanism. Traditionally, the computational simulation of plasma plume flows into vacuum is performed with a hybrid particle-fluid approach. The Direct Simulation Monte Carlo (DSMC) method models the collisions of the heavy particles (ions and atoms) while the Particle In Cell (PIC) method models the transport of the ions in electric fields. This study is intended to simulate the detailed three-dimensional plume structures and plume interactions. Expected deliverables are: • Simulation of Electron temperature, plasma density and plasma potential profile downstream of single SPT thruster (plume) • Effect of clustering of three SPTs on above plasma parameters • Prediction of overall thrust, efficiency and specific impulse of clustered system
W1.3	**Mathematical modelling of Stirling thermoelectric converter (LPSC)** Stirling thermo-electric converters have been reported to provide a thermal-to-electrical conversion efficiency of 25-30%in comparison to that of 5-6% for Radioisotope thermoelectric generators. This makes Stirling thermo-electric converters a preferable choice for deep-space missions where the solar energy is insufficient for generation of electrical power. Further, the free-piston Stirling generators with linear alternator are reported to be ideal for use in space due to the clearances between moving parts resulting in their long life. However, the Stirling generators are complex dynamic machines that involve displacer and piston reciprocating at high frequencies (~100Hz) within a cylinder. The mathematical modeling of various heat transfer processes in the heater, cooler and regenerator along with the dynamic motion of fast moving parts in the free-piston Stirling generator with linear alternator is essential for their design, performance evaluation, and optimization for flight use.

	In this regard, the present proposal is for the requirement of a mathematical model of Stirling thermo-electric converter to simulate the thermodynamic process of the gaseous helium working gas, the various energy losses that take place in the generator during thermal-to-electrical power conversion, and the dynamic forces acting on the moving displacer and piston. The model is required to be generic that can be used for performance evaluation of Stirling generator of various power ratings. The model is required to be validated with the available literature data.	
W1.4	**Design and development of high efficiency 5kW rated configurable and scalable converter using wide band gap devices for Aerospace application (LPSC)** Design, modeling, simulation, characterization and development of high efficiency (>95% at max power and >90% at minimum power of 500W) 5kW rated configurable and scalable DC-DC converter operating at input voltage of 60-100V and output voltage of 300-600V. Scope of the work: 1. Configuration finalization and topology selection. 2. Design and small signal modelling of proposed converter. 3. Characterisation of wide band gap devices (like GaN, HEMT, SiC etc.) for proposed design. 4. Design, simulation and characterization of electromagnetics for proposed design. 5. Configuration studies on control scheme (digital hybrid control) for proposed configuration for meeting configurability, scalability requirements so that converters can be synchronized (in parallel or series combination) and work together to meet the output voltage and power requirements. 6. Implementation of programmable digital control loop gain, current limit, control strategies. 7. Design iterations based on proto model testing and realization of engineering model meeting converter requirements in terms of voltage/power and efficiency requirements.	
X	**Area**	**Sensors & Transducers for Liquid Propulsion (LPSC)**
X1.1	**Development of a Quantity Sensing System and Cryo Compatible Electrical Heater for a Cryogenic Super Critical Storage Vessel (Hydrogen & Oxygen) in Space Environment (LPSC)** A quantity sensing system and cryo compatible electrical heater for a super critical storage system for Hydrogen and Oxygen is to be developed. The container will be spherical in shape with approximately 1m inside diameter. The storage pressure will be	

	higher than 1.3 MPa for LH2 & 5.1MPa for LOX. Pressure inside the container shall be maintained above critical pressure using electrical heaters. A cryo compatible electrical heater and an accurate quantity sensing system for cryogenic fluids have to be developed. The sensor system should be able to give dependable results in the following scenario. At ground in the loading condition with the liquid in saturated condition. During operation in space environment with the fluid in super critical phase in varying temperature conditions. The tank pressure will be above critical values. Based on the feasibility, independent proposals can be submitted for quantity sensing system and electrical heater. A capacitance or RF based system is preferred over temperature and pressure-based measurements considering both the operating regimes and preferably single system for different regime. Expected Deliverables are: 1. Detailed design, documentation and test results of the sensor / heater system. 2. Working prototype (non-flight) including sensor / Heater.
X1.2	**Design and Development of Eddy current based speed sensor for Cryogenic Turbopumps (LPSC)** To design and develop an eddy current-based speed sensor with an integrated signal conditioner capable of accurately measuring the rotational speed of turbo pumps in launch vehicles upto LH2 temperature. Presently, turbopumps utilize ferromagnetic-type inducer blades, which are coupled with inductive speed sensors to measure the inducer blade speed, subsequently determining the turbopump speed. However, the increasing demand for lightweight designs in launch vehicle applications necessitates the use of non-magnetic materials like aluminum or titanium for the inducer blades of turbopumps. These materials pose a challenge for conventional inductive-type sensors, which rely on the ferromagnetic properties of the blades for accurate measurement. The objective is to design an eddy current-based speed sensor capable of working with non-magnetic materials such as aluminum and titanium. The sensor should deliver precise and reliable speed measurements for the turbopump, under low-temperature conditions (-253 ° C) that are typical in aerospace environments.
X1.3	**Design and Development of Flow Meters Using Fiber Optic Sensors for future launch vehicle applications (LPSC)** Flow measurement of propellants such as Liquid Hydrogen (LH2), Liquid Oxygen (LOX) and Isrosene (a semi-cryogenic grade kerosene) is critical for ensuring the proper operation of propulsion systems in space applications. Precise flow measurement of

	propellants is essential during engine testing, stage filling, and propellant management. Optical fiber sensors, specifically Fiber Bragg Grating (FBG), offer unique advantages due to their high precision, resistance to harsh environments, and ability to operate in extremely low-temperature conditions. Their compact design and lack of moving parts make them well-suited for demanding aerospace conditions. Conventional flow meters often face performance limitations in cryogenic environments due to issues such as thermal contraction, mechanical wear, and susceptibility to electromagnetic interference (EMI). The main objective is to design, develop, and validate an optical fiber-based flow meter capable of accurately measuring the flow rates of cryogenic/semi-cryogenic propellants under extreme conditions. The developed flow meter should be highly reliable, precise, and able to withstand the demanding temperature and pressure profiles associated with fluids. Scope: • Sensor Design: Design a fiber optic-based flow sensor suitable for cryogenic/ semi-cryogenic applications, including material selection and packaging. • Prototype Development: Fabricate a functional prototype with optical sensing, signal conditioning, and integration hardware. • Testing and Calibration: Test the sensor using Liquid Nitrogen and calibrate against standard flow meters. • Performance Analysis: Evaluate accuracy, repeatability, thermal stability, and response time. • Optimization: Refine the sensor design based on test results for improved performance. • Documentation: Submit detailed design with know-how documents, test data, and a final technical report.	
Y	**Area**	**Materials & Manufacturing for Liquid Propulsion Systems (LPSC)**
Y1.1	**Forming Limiting Diagram (FLD) Generation and Optimization of Cold forming of KC20WN Cobalt Based Super Alloy for Rocket Nozzle Divergent (LPSC)** Presently developmental PS4 divergent with KC20WN material is realised through spinning and welding route in two half and joined together. The present proposal is study the spinning/flow forming of KC20WN to optimise the processing parameters and heat treatments towards realisation of divergent without cir-seam weld configuration. The scope of works includes. • Optimisation of spinning/flow forming parameter for KC20WN material towards realisation of nozzle divergent. • Detailed Microstructural and Mechanical characterisation of spun/flow formed KC20WN. • Optimisation of associated Heat treatment process.	

Y1.2	**Development of high entropy alloys/high performance alloys for application in solenoid valves (LPSC)** Soft magnetic materials presently in use are typically limited to one or two in number. These alloys have limitations in terms of permeability and saturation flux density which hinders device miniaturisation. Also, for high performance alloys available in the market today, poor corrosion resistance restricts their usage. Hence, an optimum alloying composition which would give an optimum combination of soft magnetic properties, good corrosion resistance and strength and also amenable to annealing, is required to be developed. High entropy alloys (HEA)/high performance alloys are the need of the hour. High temperature resistance also may be required for thruster valves directly mounted on the thrusters to be capable of withstanding soak back temperature excursions. The proposed work could involve application of AI & ML tools for the development of a model for identifying the correct material mix for developing the alloy. Modelling and experimentations to occur simultaneously. The model has to be updated and trained based on data availability. Synthesis of the alloy also to form part of the project. Finally the alloy has to be characterised using SEM, XRD and tested for corrosion (for eg. using salt spray method), magnetic and mechanical properties and improvements demonstrated.
Y1.3	**Electropolishing of stainless steel and Aluminium alloy parts used in launch vehicle & SC applications (LPSC)** Coupon level validation of electro-polishing of various grades of stainless steels like AISI 304L, AISI 202, 430, 15-5 PH & MDN 59 and aluminium alloys like AA6061 T652 & AA7075 T7352 (prior to anodization) as a single substitute for passivation, mechanical polishing & de-burring.
Y1.4	**Waveform engineering for MIG Welding power source to reduce residual stress in XH67 Nickel-based alloy (LPSC)** Nickel-based alloy XH67 are vital in high-temperature oxygen rich environments but suffer from significant residual stresses during thick section welding, leading to distortion and potential strain age cracking. Waveform engineering in MIG welding, which controls current and voltage patterns, offers a novel approach to mitigate these stresses. 1. Investigate the effects of MIG welding waveforms (e.g., pulsed, double-pulsed, modified short-circuit) on heat distribution and cooling rates in nickel-based alloys. 2. Simulate residual stress formation using finite element modeling (FEM) under various waveform conditions. 3. Weld test coupons and measure residual stresses via neutron diffraction/XRD or hole- drilling methods to validate simulations. 4. Optimize waveform parameters for minimal residual stress and high weld quality.

Y1.5	**Heat Treatment Optimization for DED and LPBF-Printed Inconel 718 Parts (LPSC)** AM processes like DED and LPBF produce Inconel parts with distinct microstructures (e.g., fine grains/ residual stresses) compared to conventional methods. Standard heat treatments may not suffice, requiring tailored approaches to unlock the full potential of AM parts. • Analyze the as-built microstructure of DED and LPBF-printed Inconel parts using optical microscopy, SEM, and X-ray diffraction. • Test heat treatment variables (e.g., temperature, time, cooling rate) to study microstructural changes, including grain growth and stress relief. • Optimization of Sub-Critical Annealing for Residual Stress Relief in Laser Powder Bed Fusion (LPBF) Components without Inducing Powder Sintering. • Measure mechanical properties (e.g., tensile strength, hardness, fatigue life) of treated samples to determine optimal conditions. • Formulate heat treatment guidelines specific to DED and LPBF Inconel parts.	
Y1.6	**Development and Qualification of advanced FSW techniques foe welding high thickness AA2219 aluminium alloy for fabirication of launch vehicle propellant tankage (LPSC)** Development and qualification of advanced FSW techniques viz. bobbin tool friction stir welding (BT-FSW), robotic FSW, friction plug welding, for welding high thickness AA2219 aluminum alloys (more than 13 mm) for fabrication of launch vehicle propellant tankages. Objective : i. Design and realization of bobbin tool for FSW (BT-FSW) to meet optimum weld strength requirements. ii. Qualification of BT-FSW for welding higher thickness AA2219 aluminum alloys. iii. Qualification of robotic FSW process for higher thickness aluminum alloys. iv. Design and development of friction plug welding process for FSW repairs. v. Weld parametric studies & preparation of Weld Procedure Specification (WPS) for the aforesaid welding processes.	
Y2	**Sub Area**	**Non- Destructive Evaluation of Liquid Propulsion Systems (LPSC)**
Y2.1	**Non-Destructive Residual Stress Assessment in Additively Manufactured metallic parts through Ultrasonic (LPSC)** Residual stress can set during Additive Manufacturing, due to cyclic thermal expansion / contraction, which can lead to distortions, cracking, and failure. Amongst the popular methods available for its assessment, ultrasonic methods are non-destructive, portable and have potentiality to apply on actual parts. Few probable ultrasonic approaches	

	include: measurements of stress-induced longitudinal and shear wave acoustic velocity variations, measuring nonlinear coefficient of critically refracted longitudinal waves etc., to name a few. The proposal is to establish a viable approach to non-destructively assess the residual stresses using ultrasonics and its implementation on AM parts of various alloy grades viz., In-718, SS316L, AlSi10Mg, Ti6Al4V, Cu-Cr-Zr etc. The objective is to develop a suitable procedure to assess the residual stresses in AM parts using ultrasonics, performing RS measurements on standard specimens as well as parts printed to actual configuration. The results shall be validated using two or more of other established methods such as Neutron Diffraction, XRD, Barkhausen Noise, hole drilling methods etc.

HUMAN SPACE PROGRAMME

<table>
<tr><th>A</th><th>Area</th><th>Human Research, Space Medicine and Space Biology (HSFC)</th></tr>
<tr><th>A1</th><th>Sub Area</th><th>Personalized Nutrition for Space Diets (HSFC)</th></tr>
<tr><td>A1.1</td><td colspan="2">Macronutrient Optimization (HSFC)
Study how India metabolisms (e.g., insulin resistance, lipid partitioning) respond to space food formulations (often designed for Western populations).
Test diets with adjusted carbohydrate-to-fat ratios to mitigate risks of hyperglycaemia or dyslipidaemia in microgravity.
Engineer nutrient-dense, culturally familiar foods (e.g., plant-based proteins, spice-infused meals) to maintain dietary compliance and metabolic health.</td></tr>
<tr><td>A1.2</td><td colspan="2">Micronutrient Supplementation (HSFC)
Investigate vitamin D requirements (critical for bone health and immunity), given Indian's baseline deficiency and lack of sunlight in space.
Assess iron metabolism, as Indians may have genetic predispositions to anaemia.
Design nano/micro-carriers to enhance bioavailability of critical micronutrients (e.g., vitamin D, iron etc.) in space food formulations.</td></tr>
<tr><td>A1.3</td><td colspan="2">Gut Microbiome Interactions (HSFC)
Analyse how traditional Indian dietary components (e.g., fiber, spices) interact with the gut microbiome in space, which affects nutrient absorption and inflammation.</td></tr>
<tr><th>A2</th><th>Sub Area</th><th>Exercise Countermeasures (HSFC)</th></tr>
<tr><td>A2.1</td><td colspan="2">Muscle Preservation Strategies (HSFC)
Evaluate resistance/weight-bearing exercise protocols to offset Indian's lower baseline muscle mass and higher risk of sarcopenia in microgravity.
Test hybrid regimens (e.g., vibration therapy, electrical stimulation) to enhance muscle protein synthesis.
Carryout muscle atrophy studies on suitable organisms due to microgravity and test of countermeasures.</td></tr>
<tr><td>A2.2</td><td colspan="2">Visceral Fat and Inflammation (HSFC)
Study how microgravity exacerbates visceral adiposity-driven inflammation and insulin resistance, and design aerobic exercises to mitigate this.</td></tr>
<tr><td>A2.3</td><td colspan="2">Adaptive Resistance Training Devices (HSFC)
Develop compact, microgravity-compatible resistance systems (e.g., electromagnetic or pneumatic-based) to counteract muscle atrophy, tailored to Indians' lower baseline muscle mass.</td></tr>
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A2.4	**Biomechanical Feedback Systems (HSFC)** • Integrate wearable motion sensors with AI-driven feedback to ensure proper exercise form and maximize efficiency in confined spaces.	
A2.5	**Efficacy of yoga and breathing techniques (HSFC)** • Study and develop yoga and breathing protocols to mitigate the effects of spaceflight on human body.	
A3	**Sub Area**	**Bone Health in Microgravity (HSFC)**
A3.1	**Bone Loss Mechanism (HSFC)** • Compare bone resorption rates in Indian vs. Caucasian astronauts, given differences in baseline bone mineral density (BMD). • Test bisphosphonates or other anti-resorptive therapies adjusted for Indian physiology.	
A3.2	**Calcium-Vitamin D Synergy (HSFC)** • Optimize supplementation to counteract microgravity-induced bone loss, considering genetic variants in vitamin D receptors.	
A3.3	**Mechanical Loading Devices (HSFC)** • Develop platforms to apply controlled mechanical loads on bones, counteracting microgravity-induced bone loss in astronauts.	
A3.4	**Smart Drug Delivery Systems (HSFC)** • Develop biodegradable implants or transdermal patches for sustained release of bisphosphonates, vitamin D, or calcium, tailored to genetic variations in vitamin D receptors common in Indians.	
A4	**Sub Area**	**Metabolic and Cardiovascular Monitoring (HSFC)**
A4.1	**Early Detection of Metabolic Syndrome (HSFC)** • Develop biomarkers (e.g., adipokines, inflammatory cytokines) to monitor insulin resistance and ectopic fat accumulation in real-time.	
A4.2	**Cardiovascular Deconditioning (HSFC)** • Study vascular endothelial dysfunction under space stressors (e.g., radiation, fluid shifts) in Indians, who are prone to earlier CVD. • Test nitric oxide-boosting interventions (e.g., dietary nitrates) to improve endothelial health.	
A5	**Sub Area**	**Synergistic Effects of Spaceflight Stressors (HSFC)**
A5.1	**Combined Stressor Studies (HSFC)** • Simulate spaceflight conditions (e.g., radiation + microgravity + circadian disruption) to assess cumulative impacts on Indian physiology.	

A5.2	**Radiation Sensitivity (HSFC)** • Evaluate if Indians' predisposition to oxidative stress (linked to metabolic diseases) increases radiation vulnerability. • Carryout radiation studies on extremophiles and murine models for the purpose of studying the effect, inherent protection mechanism and drug efficacy for mitigation including traditional medicines.	
A5.3	**Space Analog studies (HSFC)** • Conduct studies on analog astronauts mimicking spaceflight stressors in understanding physiological adaptation response. • Investigate how genetic/epigenetic factors (e.g., thrifty genotype) influence stress responses. • Test applicable countermeasures in analog studies.	
A5.4	**Bed rest studies (HSFC)** • Investigate how genetic/epigenetic factors (e.g., thrifty genotype) influence stress responses. • Study the physiological and psychological adaptations of Indian astronauts during spaceflight, emphasizing genetic, dietary, and metabolic uniqueness. This should Include studies on bone/muscle loss, cardiovascular deconditioning, and mental health using appropriate microgravity analogs like head down tilt bed rest or dry supine immersion. • Test applicable countermeasures.	
A6	**Sub Area**	**Telemedicine and AI-Driven Diagnostics (HSFC)**
A6.1	**AI-Powered Predictive Analytics (HSFC)** • Train machine learning models on Indian health data to predict risks (e.g., metabolic syndrome, CVD) and recommend personalized interventions during missions.	
A6.2	**Digital Twin Technology (HSFC)** • Create computational models of Indian astronauts' physiology to simulate responses to space stressors and test interventions virtually.	
A7	**Sub Area**	**Diagnostic tools (HSFC)**
A7.1	**Multi-Biomarker Wearable Patches (HSFC)** • Continuously monitor glucose, cortisol, vitamin D, and inflammatory markers (e.g., IL-6) through sweat or interstitial fluid. Integrate flexible electronics with machine learning to flag deviations (e.g., prediabetic trends) and recommend dietary adjustments.	

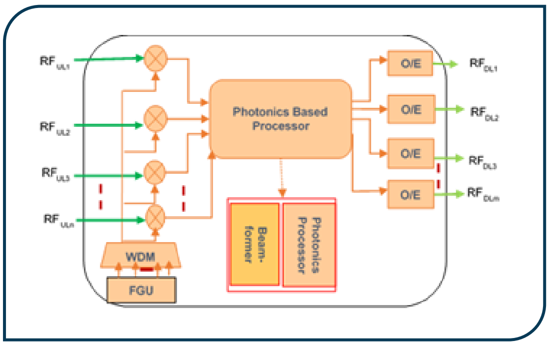
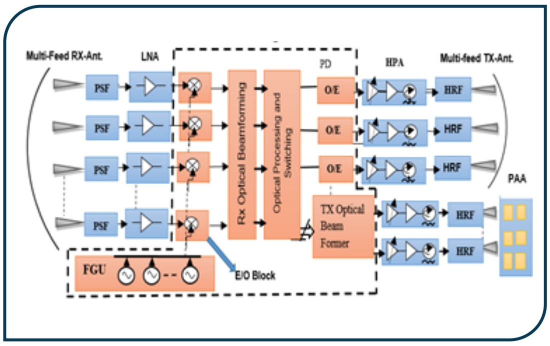
A7.2	**Compact Blood Analyzer with Microfluidics (HSFC)** • Perform CBC, lipid profiling, and HbA1c tests using finger-prick blood samples using Microfluidic chips pre-loaded with reagents for anaemia and dyslipidaemia detection having Self-cleaning mechanisms to function in microgravity.	
A7.3	**Breath-Based Metabolic Analysers (HSFC)** • Detect acetone (marker for ketosis), ethanol (gut microbiome imbalance), and nitric oxide (vascular health) in exhaled breath using Miniaturized gas chromatography-mass spectrometry (GC-MS) systems with AI pattern recognition.	
A7.4	**Bone and Muscle Health Scanners (HSFC)** • Develop Portable DEXA (Dual-Energy X-ray Absorptiometry) with features such as Low-radiation, handheld to track bone mineral density loss.	
A7.5	**Gut Microbiome Sequencer (HSFC)** • Develop Pocket-sized DNA sequencer with CRISPR-based detection of pathogenic bacteria.	
A7.6	**Ocular Pressure and Retinal Sensors (HSFC)** • Monitor intraocular pressure (risks from fluid shifts) and retinal changes (early diabetic retinopathy detection) using portable Fundus cameras with auto-diagnostic algorithms.	
A7.7	**Autonomous Dental Diagnostic Tools (HSFC)** • Develop AI-powered intraoral cameras with spectral imaging to identify enamel erosion or gum inflammation.	
A7.8	**Compact, Autonomous Ultrasound Devices (HSFC)** • Develop handheld, AI-guided ultrasound systems with automated probe placement and image interpretation to monitor Visceral fat accumulation,Cardiac function (e.g., ejection fraction, vascular stiffness) and Muscle atrophy (sarcopenia) and bone density loss (osteoporosis). The device should have Anti-drift stabilization for microgravity imaging preferably with Radiation-hardened components and low-power operation.	
A7.9	**3D/4D Ultrasound Imaging (HSFC)** • Develop volumetric ultrasound systems to assess organ morphology (e.g., liver for NAFLD, kidneys for stone risks) in microgravity.	
A8	**Sub Area**	**Biosignal Processing Research Areas (HSFC)**
A8.1	**Real-Time Signal Denoising (HSFC)** • Develop algorithms to filter motion artifacts (e.g., during exercise) and electromagnetic interference in spacecraft environments.	

A8.2	**Multi-Modal Signal Fusion (HSFC)** • Integrate ECG, EEG, EMG, and respiratory data to holistically assess stress, fatigue, or neurovascular health.	
A8.3	**Artifact Removal in Microgravity (HSFC)** • Address unique challenges like fluid shift-induced signal distortions (e.g., altered blood pressure waveforms).	
A8.4	**Cognitive State Monitoring (HSFC)** • Process EEG and heart rate variability (HRV) to detect mental fatigue or anxiety, triggering VR-based relaxation modules.	
A9	**Sub Area**	**Microbial Studies in Spacecraft Environments (HSFC)**
A9.1	• Investigation of microbial interactions, biofilm formation & symbiosis in spacecraft environments for improving crew health management & spacecraft maintenance. • Study pathogen behaviour and beneficial microbes in closed habitats to prevent infections and enable bioregenerative systems. • Characterize microbiome shifts in Indian astronauts. • Develop antimicrobial coatings and probiotics. • Develop & test new sterilization and decontamination techniques for space missions to ensure the safety & cleanliness of spacecrafts& habitats.	
A10	**Sub Area**	**Drug Development (HSFC)**
A10.1	**Drug efficacy (HSFC)** • Study physiological adaptations of Indian astronauts to microgravity and space radiation, with emphasis on medical countermeasures, drug efficacy, and personalized healthcare. • Does microgravity alter drug pharmacokinetics (absorption, distribution, metabolism, excretion) in Indian physiology. • Can traditional Indian medicines (e.g., Ashwagandha for stress, Turmeric for inflammation) retain efficacy in space.	
A10.2	**Drug stability and packaging (HSFC)** • Test stability of common medications (antibiotics, analgesics) and Ayurvedic formulations in simulated microgravity (clinostats) and on ISRO's microgravity platforms of PSLV and SSLV spent stage, Gaganyaan and future BhartiyaAntariksha Station. • Analyse degradation profiles using HPLC/mass spectrometry. • Develop novel drug packaging to improve shelf life and efficacy.	

A10.3	**Drug delivery(HSFC)** • Develop novel drug Delivery mechanisms for space usage including endodermal patches.	
A10.4	**Traditional Medicine Validation (HSFC)** • Screen and test Ayurvedic formulations for use in space conditions in murine models and humans.	
A11	**Sub Area**	**Space Biology (HSFC)**
A11.1	**Cellular & Molecular Biology (HSFC)** • Research on the effects of microgravity, radiation & other stressors on cellular processes, gene expressions & mutations, protein synthesis, cell signalling & tissue regeneration. • Explore cellular repair mechanisms, stress responses & aging in the context of long-term spaceflight missions. • Develop & refine molecular tools & biomarkers for monitoring cellular health & detecting potential issues in astronauts.	
A11.2	**Plant Biology (HSFC)** • Study plant growth, development & reproduction in space environments to support life support systems & nutritional requirements for long-duration missions. • Study plant stress responses & adaptations to spaceflight conditions including changes in gene expression, morphology & physiology. • Develop & optimize growth systems & nutrient delivery methods for efficient plant/ crop cultivation in microgravity environments.	
B	**Area**	**Microgravity Research (HSFC)**
B1	**Sub Area**	**Physical & Chemical Science in Microgravity (HSFC)**
B1.1	**Crew fire safety: Novel methods for fire (smoke) detection and mitigation(HSFC)** Flames behave radically different without buoyancy-induced convection of microgravity environment. Hence, the behavior of fire and smoke differs significantly in the confined microgravity environment of a space station, making it critical to develop effective methods for the timely detection and mitigation of fire. This is essential to ensure the safety of crew and protect vital equipment on-board. The scope of this study will involve advancing the understanding of fire behavior in microgravity, and developing novel fire detection/ mitigation methods for space station conditions.	
B1.2	**Bubble mitigation strategies for micro-channels (HSFC)** Bubble formation is a common phenomenon observed in flow of liquids, especially in a microchannel it becomes a major challenge as it can impede the flow of the liquid. It is important to develop bubble mitigation methods to prevent bubble formation and ensure seamless flow behavior. The scope of this study will involve understanding the bubble formation behavior in micro-channels and develop mitigation methods for the same.	

B1.3	**Novel strategies for the use of methane in space stations (HSFC)** A general method for regenerative environmental control and life support system of space stations is to perform Sabatier reaction and use CO_2 and H_2 in the presence of a catalyst to control the CO_2 levels. This reaction leads to formation of Methane and water. This methane is expelled out of space station using a vacuum exhaust system. However, there may be ways to use this methane for applications and operations on the space station. The scope of work involves studying the physical and chemical aspects of methane usage in microgravity conditions.	
B1.4	**Droplet in microgravity: Spreading dynamics, contact-line studies, evaporation, oscillation and spreading (HSFC)** Droplets behave in a different manner in microgravity. Many aspects of the droplets such as spreading, contact-line & wettability, evaporation, oscillation and even the shape of droplet have a prominent effect on critical technologies such as development of coatings, combustion, in-situ printing, microfluidics, etc. There is an increased focused on using droplets for studies and development, this spans from droplet-based combustion to droplet – based bio-printing to optimizing industrial processes on Earth. The scope of this study is to investigate the aforementioned aspects of droplets in microgravity to enhance the understanding of droplets in space and assist the development of products and processes designed for microgravity.	
B2	**Sub Area**	**Equipment for Supporting Microgravity Research (HSFC)**
B2.1	**Development of next generation microfluidic cards with integrated imaging (HSFC)** Microfluidic cards are required for conducting research that require automated precise control of fluids. It can be a platform that becomes a habitat for micro-organisms. It can also be used for conducting drug development, developing biosensors, etc. Overall, it is a versatile platform that has multiple applications for studies on space station. The scope of the study involves development of microfluidics card based platform for space, involving identification of bio-compatible materials, microchannel fabrication techniques and integrated imaging methods.	
B2.2	**Novel energy efficient refrigeration technologies (HSFC)** Biological studies in space station are heavily dependent on supporting equipment. Refrigerators are one of the most power hungry yet essential supporting equipment. The scope of work involves studying novel energy efficient refrigeration technologies meeting envelop, mass and power constraints of typical space station scenario.	
B3	**Sub Area**	**Space Agriculture (HSFC)**
B3.1	**Development of plant growth habitat for space station (HSFC)** A plant-based food production system is crucial for supporting sustained human presence in space, and acts ideal supplement for crew diet. However, growing plants in	

	space requires developing controlled environment for providing water, lighting, temperature, relative humidity, Carbon dioxide, and nutrients in required proportions. The scope of work involves developing plant growth chamber compatible with space station conditions.	
C	**Area**	**Human Spaceflight & Advanced Technology (SAC)**
C1	**Sub Area**	**Optical and Quantum Related Technologies (SAC)**
C1.1	**DWDM based 200 Gbps FSO link demonstration for future Terabit optical communication (SAC)** Terabits of data rate will be required for future high-speed links for LEO satellites and Intersatellite links for LEO constellations. Also high throughput satellites require 100s of Gbps data to be transmitted through multiple gateways. RF bands are facing saturation and limited to strict frequency regulation, leading to a requirement of large number ground stations for feeder links. Increasing frequency demand from terrestrial wireless communications also puts restriction RF frequencies and on feeder locations due to signal isolation requirement and practical operational issues. Multiple feeder stations call for multiple terrestrial links involving multiple operators and puts signal security at stake. Technologies developed will be utilized for high data rate links for satellite-based links (LEO –ISL, LEO GEO, GEO-Ground) as well as for optical feeder links for high throughput satellites. A single optical feeder Station can cover vast geographical areas without number of RF feeder stations and their terrestrial links, which requires vast amount of ground infrastructure. These technologies can be extended to Terabits links for future Optical communication and HTS links.	
C1.2	**Multi Wavelength Fiber Laser Generation Technique (SAC)** Multi-wavelength laser generation from a single source of laser has attracted considerable attention among researchers over the last few decades. The MultiwavelengthFiber Laser Sources have potential Applications in dense wavelength-division-multiplexed (WDM) in High Throughput Satellite in optical communication, optical instrument testing and characterization. Such light sources are particularly in-demand because they provide an efficient and economical solution to increase the flexibility of WDM system. It has various advantage such as low cost and low insertion loss. The requirements for such optical sources are a high number of channels over large wavelength span, moderate output powers with good optical signal to noise ratio (OSNR) and spectral flatness, single longitudinal mode operation of each laser line, tunability and accurate positioning on the ITU frequency grid. Technologies developed in this research will be utilized for optical feeder link for high throughput satellite.	

	The scope of the work shall include to explore the several techniques used for multi wavelength generation namely comb filter, cascaded modulation, Brillouin scattering technique, and arrayed waveguide grating.
C1.3	**Compact Optical Terminal Development for Optical Inter-Satellite Link (SAC)** The upcoming data rate requirement need a paradigm shift from conventional RF satellite link to free space optical link. RF link has some advantage over free space optical (FSO) link where atmosphere is involved. But for inter-satellite link, FSO link is the only viable solution in terms of size, weight and power. The added advantage of FSO link is high data rate, narrow beam width, low EMI/EMC etc. ISRO has initiated the development for FSO inter-satellite link. The base band data will be modulated using optical carrier which has frequency in THz. Using a compact terminal consisting of optical telescope, optical communication subsystems and pointing acquisition and tracking (PAT) mechanism, ISL can be realized. This will also effective reduce the number of ground segment and will add space diversity.
C1.4	**Multi Wavelength Fiber Laser Generation Technique (SAC)** Multi-wavelength laser generation from a single source of laser has attracted considerable attention among researchers over the last few decades. The MultiwavelengthFiber Laser Sources have potential Applications in dense wavelength-division-multiplexed (WDM) in High Throughput Satellite in optical communication, optical instrument testing and characterization. Microwave Photonic-based on-board processing will be a feasible solution to meet the high-speed processing demand of next-generation broadband satellite system with added advantage of lower mass, lower volume, less power consumption and better EMI performance. The research areas in MWP are Microwave Photonic Filter, Photonic switching and Beam forming. PIC based approach for the above areas are also initiated.  *General Architecture of Microwave Photonics based Processing*  *Photonics based Multi-beam Payload Architecture*

C1.5	**High Power Er Doped Fiber Amplifier (SAC)** High power optical amplifier (EDFA) is inevitable for the realization of free space optical communication link. This is the device, which amplify the 1550 nm optical signal directly without the need of any electrical conversion. Er- doped fiber is popularly used as the gain medium for optical amplifier. The Pump laser will provide the required population inversion in Erfiber. Different pumping topologies e.g. forward pumping (co-propagation), Backward pumping (Counter propagation) and Bi-directional pumping (Co+ Counter propagation) is explored in the development to maximize the Gain, Saturated power and minimize the noise figure. Fiber fusion and thermal management of fiber plays the crucial role on the operation life EDFA. For any type of optical communication payload, EDFA serves the purpose of power house to sustain the communication link. Though many commercial EDFAs are available, those are meant for ground applications. For space based EDFA, there are lots of design challenges in thermal design, optical fiber assembly, high power electronics aspects. SAC have initiated the in-house development of EDFA in different phases with mid and high power output targets. This development is being carried out in phases. At present 5W output at ambient has been realized.
C1.6	**Higher Order Optical Switch For Low Latency Applications (SAC)** The increasing user demands required high throughput microwave and optical payloads where onboard signal processing in photonics domain is the most viable option to meet the latency requirements of reconfigurable networks. In photonic switching there are several techniques such as optical MEMS, Semiconductor optical amplifier, waveguide and thermal. In this technology, selection and hardware realization of the switch will be explored which has capability of high switching order (16*16 or higher), switching latency (few nano sec.) in optical C-band. The Cross talk (-40 dBc or better), polarization independent, transparent to data rate up to 10 Gbps with suitable tele command and telemetry provision are the key features of the hardware.
C1.7	**Digital Signal Processing for Optical Coherent Receiver in BPSK, QPSK or Advanced Modulation Format (SAC)** For advanced optical communication formats e.g. BPSK, QPSK, 8-PSK etc., the post processing of electrical signal is inevitable after detection through coherent receiver with single polarization (X channel) or dual polarization (X and Y channel) multiplexing. Several impairments cause the optical signal distortion and those effects need to counter through algorithm. Main algorithm stage conventionally consists of Bessel filtering, Resampling, Quadrature imbalance, non-linearity and Chromatic dispersion compensation etc.

	The data rate is typically more than 10 Gbps. In such high data rate, the DSP using FPGA is very challenging. There is a scope of code development for FPGA to mitigate the effects.
C1.8	**High Sensitivity Optical Low Noise Amplifier (SAC)** Low Noise optical amplifier (EDFA) is the front end of the optical receiver section and it is inevitable for the realization of free space optical communication link. This is the device which amplify the weak incoming optical signals for the detection by photodiode. Single Mode Er- doped fiber is popularly used as the gain medium for optical amplifier. The Pump laser will provide the required population inversion in Erfiber. Different pumping topologies e.g. forward pumping (co- propagation), Backward pumping (Counter propagation) and Bi-directional pumping (Co+ Counter propagation) is explored in the development to maximize the Gain with minimal added noise figure and improved sensitivity. To improve the link margin for the compact optical terminal the noise floor of the low noise amplifier should be as low as possible to provide the best amplification with minimal noise in incoming modulation signal. SAC have initiated the in-house development of EDFA in different phases and development is being carried out in phases. At present -63 dBm with 50 dB gain at ambient has been realized as the state of the art worldwide.
C1.9	**Modeling of atmospheric turbulence parameters using radiosonde data and estimation of localized Fried parameter(r_0) for new OGS location (SAC)** Clear air turbulence phenomena affect the propagation of an optical beam because the refractive index randomly varies in space and time. Mainly, random variation of the refractive index of air depends on the air mixing due to temperature variation in the atmosphere. In fact, sunlight incident upon the earth's surface causes heating of the earth's surface and the air in its proximity. These effects happen at different points in the atmosphere, and hence it is worth discussing the structure of the earth's atmosphere briefly. There are many parameters to be considered for the atmosphere but the major points are Refractive index structure constant (C_n^2) & Coherence length (r_0). C_n^2 determines the strength of turbulence and depends on the geographical location, altitude, and time of day. Close to ground, there is the largest gradient of temperature associated with the largest values of atmospheric pressure (and air density), therefore one should expect larger values of C_n^2 at sea level. Typical value of C_n^2 for a weak turbulence at ground level can be as little as 10^{-17} $m^{-3/2}$, while for a strong turbulence.

it can be up to 10^{-12} $m^{-3/2}$ or larger. The refractive index structure constant is related to the temperature structure constant as $C_n^{\,2}$:

$$C_n^2(h) = 0.00594(v/27)^2(10^{-5}h)^{10}\exp(-h/1000) + 2.7\times10^{-16}\exp(-h/1500) + A_0\exp(-h/100)$$

C_T is the temperature structure constant:

$$C_T = \left(\left\langle (T_1 - T_2)^2 \right\rangle\right)^{1/2} r^{-1/3}$$

Theoretical models of measuring refractive index profile: Hufnagel-Valley Model (HV Model):

$$C_n^2 = \left(\frac{78p}{T^2}\times10^{-6}\right)^2 C_T^2$$

Where h is the altitude, v is the rms wind speed & A_0 is the turbulence level at ground level.

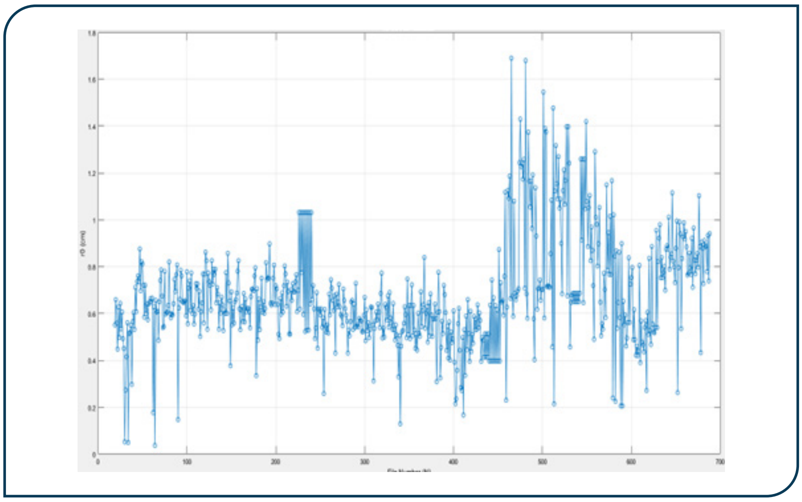
HV model is generally valid for mid-latitude regions where turbulence such as temperature gradients, humidity and wind speed differ from that of the Indian mainland.

Then defining r_0 which is the diameter of an equivalent aperture where the telescope resolution is approximately the same (diffraction limited) in absence of turbulence: the larger r_0 is the smaller the effects of turbulence on the propagating wave. Also, it depends on Zenith angle, wavelength, structure constant variation, Height, etc.:

$$r_o = 1.67\left[\sec(\theta)k^2\int_{h_o}^{H} C_n^2(h)dh\right]^{-\frac{3}{5}}$$

where θis the angle from the zenith in the slant path

As per the above equation turbulence, in a space-to-Earth satellite link one should expect large atmospheric coherence length at the satellite (uplink), and smaller r_0 with more severe phase distortion at the ground station receiver (downlink). We measured the r_0 for Delhi throughout the year using Radiosonde data, which captures variations in temperature and pressure with altitude as shown below.



Variation of r_0 for 1 year of Delhi

C2	Sub Area	Atomic Clock Related Technologies (SAC)
C2.1	**Chip Scale atomic clocks (SAC)** Atomic frequency standards are the back-bone of the satellite navigation technology. SAC has developed indigenous atomic clocks for India's navigation programme – IRNSS (NavIC). The key concepts of atomic clocks involve atomic spectroscopy; RF & microwave electronics; microwave cavities; optics; low noise detection schemes and digital electronics. In view of supporting the in-house R&D activities, further detailed theoretical modelling can aid our practical work. Herewith, the following proposed research on theoretical and experimental studies can enhance our activities towards the optimization of atomic clocks. In the Coherent Population Trapping scheme, the use of microwave cavities can be avoided to build atomic clocks. This can, in principle, bring down the size to a considerable extent. The recent advances in chip-scale atomic clocks has been possible due to CPT methods. Research need to focus on development of physics package of chip-scale atomic clocks. Primary area of research include fabrication of Rb/Cs filled micro-fabricated cell, Modulation of VCSEL for CPT interrogation and assembly of VCSEL and Cell along with optics and heaters.	
C2.2	**Studies on light-shift effects in atomic clocks and analyses of on-board clock jumps (SAC)** Rubidium atomic clocks are the widely used clocks in GNSS for space based navigation. These Rb clocks are prone to onboard frequency jumps, which results in the error on the navigation signals. It is of utmost importance to understand the source of the jumps in the Rb clocks. The prima facie understanding has brought to notice that light-shift effect is the main cause of these jumps. However, a detailed study is needed to quantitatively understand the physics behind these jumps. Moreover, in this study the other potential parameters such as the radiation effect, magnetic effects etc. need to be addressed which may result in giving rise to clock frequency jumps.	
C2.3	**Trapped mercury-ion atomic clock (SAC)** The trapped mercury-ion atomic clocks can reach stabilities and drifts, which are 1 and 2 orders (respectively) better than the rubidium lamp based RF clocks. These are strong potential candidates for the future deep space navigation missions alongside the current NavIC missions. The area of research include study, design and demonstrate the trapped mercury-ion-clock physics package meeting state of the art specifications.	
C2.4	**Extraction of pure elements and their isotopes for atomic clock (SAC)** Atomic clocks rely on the precise and stable oscillations of atoms to measure time. Elements are available in naturally occurring compounds. The extraction of pure elements and their isotopes is crucial for atomic clocks to ensure precision,	

	stability and consistency in timekeeping. Pure natural mix of Rubidium, its isotopes (Rb87 and Rb85) and Mercury isotopes (Hg202 and Hg199) are primarily used in space atomic clock. Detailed research is required to develop efficient methods for extraction and storage of such pure elements.
C2.5	**Development of PLL based synthesizer IC for Atomic Clocks (SAC)** Frequency Synthesizer is a crucial subsystem to generate precise RF signals in order to interrogate atomic transition levels. Development of PLL based synthesizer IC with low phase noise will greatly help in reducing electronic complexity and realization time of atomic clocks. PLL Synthesizer IC to be developed with 10MHz (sine) input reference should have minimum 2 outputs with following capabilities, A. 6GHz to 8GHz or wider main RF output, with a provision to frequency modulate it with input signal of DC to 1KHz. B. 30MHz to 100MHz or wider reference digital (CMOS/TTL/LVTTL/LVCMOS) output for digital electronic circuits.
C2.6	**Travelling Wave Tube Amplifier (TWTA) (SAC)** It is one of the critical technology elements used for efficient high power amplification in space borne payloads. Amongst all microwave amplifiers, TWTA offers unique combination of power, gain, efficiency and bandwidth. Research opportunity in the field of TWTA is primarily oriented around. A. Development of large signal simulation tools. B. Study & development of special UHV grade materials & special coating techniques. on UHV material suitable for high temperature brazing. C. Development of methods for texturing on copper surface for reducing SEE. D. Techniques for measurement of high temperature stress & strain in complex shapes. E. Design & development of long life high reliable space cathode. Future research areas include development of A. Very high peak power Pulse TWTAs for radar applications. B. Folded waveguide TWTA and Coupled cavity TWTAs for higher frequency band power amplification. C. Brazed Helix technology useful for higher CW power. D. Microwave Power Modules – combination of Solid state amplifier and TWT with advantages of both the technologies. E. Flexible TWTAs for dynamic allocation of frequency, BW & power. F. Filtered Helix TWT with improved harmonic suppression. G. Cold cathodes.

	H. Mini TWT that can be placed right at the back of phased-array antenna. I. High power source that can be beamed to Microwave rockets.	
C3	**Sub Area**	**Human Spaceflight Related Technologies (SAC)**
C3.1	Human Spaceflight and Advanced Technology Area of ISRO has a well-defined roadmap for conducting space flights with humans and development of technologies to support the missions. Unlike other missions carried out by ISRO so far where mostly observation or service-oriented hardware was flown as payload, HSP will carry humans (as payloads). This creates bundle of opportunities for development of human centric technologies in a large spectrum of domains and disciplines. Some of the technologies fall under the category of 'must haves' while others can be innovative in nature, giving alternatives to existing technologies or enhancing certain aspects of mission. SAC is developing various systems towards HSP where audio, video and text communication systems will enable end to end two-way communication between ground command and astronauts. The technologies involved in this service include following: 1. Compact, space qualified camera systems. 2. Baseband units to switch, encode, compress video and audio streams. 3. Noise cancellation based audio communication systems with versions, which can be wearable and can be panel mounted. 4. Modems for RF communications. 5. RF communication network elements like Solid state power amplifiers, switches, filters etc. 6. Antenna systems including phased array antenna. ECLSS (Environmental Control and Life Support System) is system of systems which helps maintain earth like atmosphere inside habitat volume of crew module. This primarily includes maintaining optimal oxygen level, removing carbon dioxide and maintaining PTH (Pressure, Temperature, Humidity). SAC is engaged in developing EMS (Environmental Monitoring System) which measures the values of oxygen and carbon dioxide concentration in cabin environment along with PTH values. Methane and ammonia are by product of metabolism in human body. Carbon monoxide is emitted when something burns. EMS will also measure concentration of these trace gases to keep check on environmental quality and hazard prevention. A portable version of EMS called, HEM (Handheld Environment Monitor) also is developed. Astronauts can use it to check presence of CO2 pockets, origin of trace gases, tracing source of fire, emergency backup of EMS etc.	

Fire is one of the prominent hazard on board human spaceflight mission. Detection of fire is complex and many pronged approach is needed to evaluate a fire scenario. At the same time, one false alarm can cause unnecessary mission abort. An array of sensors and integration of data from all the sensors is necessary as part of fire detection architecture. UV flame sensors and optical smoke sensors are first line of detection supported by data from thermal cameras and temperature sensors. Change in gas concentration indices also are included in decision making before raising fire alarm. Dousing fire is manual and water mist based fire extinguishers will be used on board this mission.

First point of interaction for astronauts with their module is display system. As primary situational awareness instrumentation, display system receives data from mission computer in the form of parameter values like path, position, velocity and altitude of orbiter module and displays it as combination of graphs, bars and text. Another set of information is Environmental Control and Life-support Subsystem (ECLSS) parameters and medical parameters of astronauts that displays on separate pages. Mission status, date and time, list of tasks, warnings, alarms, text chat, video conferencing etc. are facilitated through display systems. Astronauts can navigate between pages using peripheral buttons on display. They can also command variety of actions using these peripheral buttons, which change its role based on current context or display page.

In addition to large LCD displays, a dot matrix display is developed which will show only critical parameters in alphanumerical formats.

Cabin lights are designed with white LEDs with intensity and color temperature control to automatically sync with time of the day. This feature would help maintain circadian rhythm of astronauts.

The most significant and critical phase of any human spaceflight mission is atmospheric re-entry and subsequent rescue of astronauts at rendezvous point of landing. Various systems are planned and being developed at SAC to support this phase of mission.

Radar Altimeter will be mounted beneath crew module to gauge exact altitude of crew module and pass it to mission computer so that parachutes can be deployed at right moment during descent phase. Location transmitter will read the precise location of landing after splash down through NavIC and GPS and relay the data to rescue team waiting at a safe distance in sea. An LED based high power VFB (Visible Flash Beacon) mounted on top of crew module will aid the rescue team in visibly locating the module in sea. Finally, a satellite phone in hands of astronauts with global coverage gives them ability to stay in touch with mission control even in last mile of mission.

Following areas are identified where academia can contribute directly. Driving factors of development shall be low mass, smaller volume, low power, environmental qualification for space and human rating aspects in design. Introduction of new technologies and

	improvement in existing technologies for HSP, both are seen as potential contribution from academia in this program. Indigenous development of these systems also adds value. The developed technique should also consider feasibility of implementation without affecting any of the existing functional requirements. Reliability aspects are of utmost importance in HSP. Hence, development should target reliability aspects right from concept formation stage and should be followed until building successful prototypes. Certification of every system for HSP is a significant aspect of development. Software used in such systems also undergo spell of certification. Certain design aspects in hardware and software must be built from beginning to aid certification process towards induction of hardware in an HSP mission.
C3.2	**Development of measurement systems and sensors for gas concentration (SAC)** Human Spaceflight requires continuous measurement of concentration of major air constituents (O_2, CO_2, CH_4, NH_3 & CO) and more than 200 trace gases including trace volatile organic compounds (VOC) at ppm to ppb levels, which are relevant to astronaut's health. These are by-products of metabolism/combustion/chemical reactions in the cabin. Measurement of these gases can be achieved by discrete sensors for each gas or by holistic techniques like spectrometry. Both approaches have their own advantages. Handheld measurement systems can use discrete sensors to build compact, light-weight and battery powered systems. Other techniques can be used to measure array of gases from the same sample. Indigenous development of compact and lightweight sensors and other systems using laser, chromatography, Fourier transform techniques etc. have good potential for present and future applications in HSP.
C3.3	**Development of mitigation techniques for Communication blackout during re-entry (SAC)** A spacecraft entering the Earth's atmosphere is enveloped by a plasma sheath which results in complete loss or a severe decrease in the strength of RF signals between the re-entry vehicle and the ground. This is referred as Communication Blackout. It results in loss of voice communications and data telemetry during the re-entry of manned space vehicles. The black-out duration can be up to 10-15 minutes and it occurs during the most crucial part of the vehicle's flight. It coincides with the maneuver phase and eliminates ground support during this vital portion of the re-entry phase. In case of an accident during re-entry, this phase is important for post accidental analysis. Due to its criticality, it is important to develop techniques to mitigate this problem. The theoretical study and the analysis should be validated through the practical experiments. Practical experiments may be conducted in the suitable plasma environment to validate the following:

	• Dependence of EM wave attenuation on plasma profile. • Dependence of EM wave attenuation on operating frequency w.r.t. plasma frequency. In principle, the most obvious way in which the reentry communication blackout problem can be alleviated is by designing the communications system with a system margin greater than the plasma signal attenuation encountered during reentry. Typical plasma attenuation may exceed 100 dB, thus the required system margin is unrealistically large and cannot be achieved in practice. Hence, other alleviation techniques should be investigated which can be used in conjunction with the system margin. Worldwide many experiments have been done using following techniques to overcome communication blackout: • By avoiding attenuation region in plasma sheath: Higher Frequency method. • By reducing concentration of electrons in plasma sheath: Aerodynamic shaping, Injection of coolants. • By altering the properties of plasma to minimize its interaction with the electromagnetic waves: Magnetic Field Method. Development of techniques to enable communication during this phase or to mitigate complete communication black-out can help existing and future missions of HSP. Experiments and finding that can aid to the understanding of phenomenon also can be seen as value addition.
C3.4	**Development of wireless communication systems (SAC)** Introduction of wireless networking enhances communication in the vicinity of a spacecraft and also facilitates many aspects of communication within a spacecraft including mobile crew monitoring and communication, environmental monitoring and control, structural monitoring, and situational awareness. Wireless system designs should also consider conditions of operational space environment. It is required to develop wireless systems that demonstrate reliable data transfer across avionics components, subsystems, and interfaces to simplify system integration, reconfiguration, and testing. Solutions that enable new avionic architectures and provide capabilities that expand mission performance while decreasing the Size, Weight, and Power consumption and cost of the resulting spacecraft are highly desirable. Applications include sensors communication within habitat volume, communication during Extra Vehicular Activities, video capturing of separation events etc.
C3.5	**Active Noise Cancellation for Crew Cabin System (SAC)** Due to the presence of various payloads, instruments and other systems, the on-board environment is inherently very noisy. Such high noise exposure for longer mission

	durations can cause damage to crew hearing system, result in crew efficiency reduction and also hamper with on-going communication. To reduce the effect of continuously present noise on crew communication system, an active noise cancellation system can be designed and developed. With the help of active noise cancellation, resultant noisy environment can be reduced and improved QoS communication can be provided. • Development of algorithm for Active Noise Cancellation in audio band. • Development of ANC circuitry.
C3.6	**Study of In-flight identification and quantification of species in water for long term space missions (SAC)** Long Duration Human Spaceflight requires continuous monitoring of water quality to ensure crew health and safety. Water monitoring equipment like colorimetric water quality monitoring kit (CWQMK) are already a part of the ISS. For our future space station and interplanetary travel requirements, it is important to initiate the developments of these systems. These instruments would have immense applications in future space station, interplanetary travel and other long duration space missions. Development of apparatus, test setups for experiments related to above subject, evaluation of data received from such experiments and development of mitigation techniques for observed ill effects can help in current and future missions of HSP.
C3.7	**Assessment of flame spread of large scale microgravity fire (SAC)** Materials with high flammability must be assessed for the flame spread rate using HEAT AND SMOKE RELEASE RATE TEST (Reference: NASA-STD-6001) Understanding nature of flame, process of combustion, rate of spread, mass consumption, quantity and rate of heat release etc. can be taken up as study. Additionally, apparatus, test setups and identification of methodology, both on ground as well as in micro gravity also is needed to further the understanding of the subject.
C3.8	**Microbial monitoring in microgravity environment i.e. Non- culture based in flight monitoring with species identification and quantification (SAC)** Microgravity can affect the growth and survival of microbes. The research on this topic is essential to achieve safe and healthy long duration space habitation. Non-culture based in-flight monitoring with identification and quantification of microbial species is targeted for the development. This research would help in understanding the relationship between humans and microbes, which may be affected hugely in microgravity. It will enable the understanding

	of how and where microbes proliferate in confined environment in space.Test setups and instrumentation required for remote observations can be developed to achieve the above mentioned purpose followed by findings and conclusions that may become input or directive for future missions.
C3.9	**Disinfection technique and technologies for microbial control of water systems and environment in microgravity (SAC)** Disinfection and de-contamination are highly essential to achieve safe and healthy long duration space habitation. ISS has a decontamination system which was designed with crew members' safety in mind by using high-power, ultraviolet, light-emitting diodes (UV LEDs) to sanitize surfaces. This cleaning process takes only a matter of minutes before and after the crew conducts the experiments. The sanitation process also removes airborne contaminants -- such as biological and chemical impurities -- and cleans up spills inside the glovebox, providing optimal accommodations for cell science and life science research. It also has an exchangeable glove system that was redesigned to be better suited for these types of studies. These disinfection systems based various technologies like the Ultraviolet Germicidal Irradiation (UVGI) method etc. are essential for long duration space missions/Space Stations for disinfection/removal of microorganisms. Other alternate techniques also can be developed which are safer and more efficient.
C3.10	**Application of AI and ML in crewed missions (SAC)** Currently, System controls are based on ground based command or crew inputs through button/switch controls which require specific user action. Warning systems are based on predefined criteria and thresholds. AI and ML are relatively in nascent phase as far as space systems are concerned. However, the potential of technique and its application in future cannot be ignored. Hence, exploring possibilities of AI and ML in HSP is encouraged with all potential applications. Some are listed below. 1. Voice based system commanding mechanism without restricting/requiring use of any limb action. 2. An early warning system which learns from previous data to warn on possible occurrence of a hazard.
C3.11	**Compact fire suppression systems for crewed missions for micro gravity applications (SAC)** On board fire in HSP is one of the most serious on-board hazards. Every HSP mission carries fire suppression system. FSS should be safe for humans, should be quick and efficient in dousing fire, should be clean and its application should be safe for onboard electronics. Fine water mist based FSS is in use onboard ISS now. Indigenous development of compact, portable, easy to use and safe FSS is needed for current and future HSP missions.

	Research in microgravity is indispensable to disclose the impact of gravity on biological processes, organisms, materials, fire and functional systems. "True" weightlessness, for more than a few seconds at least, can only be achieved in space or zero-g flights in atmosphere. Drop towers, drone based agile platforms etc. have potential to bring out microgravity experiment platform. Test setups, approaches, new ideas to carry-out such tests can be used in existing and future missions of HSP.
C3.12	**Next generation fire detection systems (SAC)** Fire is one of the most critical on-board hazard for any HSP mission. Detection fire is of paramount importance. Sensors must have very high sensitivity to variety of fire, flame and electric spark. At the same time, it should offer high immunity to false detection. Most mission experiences have reported early detection by humans through smell, rather than on-board sensors. Development of "Electronic Nose" which can detect very low concentrations of combustion products can help in early detection of fire. Fire is detected by measurement of concentration of specific gases, heat, temperature, flame etc. Novel approaches n detection, new parameters that can aid to detection of fire also is needed to enhance the fire detection scenario.
C3.13	**Display and other situational awareness technologies (SAC)** Visual information (for situational awareness) is made available to the crew either through print pages or displays. A more effective method should allow crew to quickly access context based information. Development can be focused on fixed and portable display devices with higher efficiency (lower size, mass and power) and better human centric aspects, taking advantage of advancement in display panel technology like flexible films displays etc. Augmented reality based devices can be used to provide context based information to the crew for information such as visual alert, holographic communication and object information. AI and ML can be included in such systems to make them more efficient and effective.
C3.14	**Instrumentation for docking (SAC)** Docking of spacecraft with space station or other manned modules for human or cargo transfer is an autonomous activity in most contemporary HSP missions. ISRO envisages development of these technologies to support automated or assisted docking while in orbit. Laser based or other types of ranging systems, camera based video systems, RF based systems are required for beacons, altimetry or distometry, velocimetry, optical flow techniques, close range photogrammetry and other parameters of situational awareness either in assist mode or in close loop mode for automated docking. Development of sensors, integrated systems and demonstration models can help in future docking missions of HSP.

SATELLITE TECHNOLOGY

A	Area	SATCOM and Navigation Payloads (SAC)
A1	Sub Area	System Engineering (SAC)
A1.1	**LEO Constellation for Regional Coverage: (SAC)** Advance technological changes in satellite communication has led to reduced payload manufacturing cost & launch cost per kg to Low Earth Orbit (LEO) orbit which has made LEO orbit a popular choice for broadband connectivity from space. LEO orbit has major advantage of lower latency and ability to cater smaller user terminals. Broadband LEO constellation can complement the terrestrial networks by serving unserved and improving Quality of Service (QoS) in underserved region. Such networks can be integrated with future technologies like 5G, 6G & Internet of Things (IoT) where connectivity between the devices is a prime requirement, which is major concern for devices located in extreme topography with no terrestrial connectivity. The research areas in this field include: • Development of algorithm for inter-satellite link dynamic routing/handover for data downlink/uplink to/from gateways • System studies on integration of LEO broadband constellation & future terrestrial 6G technologies • Development of on-board resource management algorithm based on user demand • System study and algorithm development for LEO-GEO & LEO- Medium Earth Orbit (MEO)-GEO multilayer constellation routing • Development of single aperture multi-beam, compact and light weight antenna integrated with compact lightweight trans-receiver module • Development of compact ISL terminals for LEO-LEO and LEO-GEO communication • Compact ISL terminals for LEO-LEO, LEO-GEO communication: compact optics, pointing and tracking system, optical modulators etc. • Development of translucent/transparent on-board processing digital system based on commercial processor/FPGA technology	
A1.2	**Software Defined radio based Satellite architectures for Future Satcom systems (SAC)** In present scenario, low cost small satellites (Micro or Nano Satellites) are being launched or planned for launch on LEO orbit to provide communication services over the Globe. Small satellites provide an efficient and cost effective solution to different communication services as compared to bigger satellite platforms targeted for GEO orbit. Due to their low mass, power and volume envelope, the payload also has to be designed considering these constraints.	

	Software defined radio (SDR) based payload architectures can provide solution for compact/miniaturized design which requires low mass, low DC power consumption & less volume. Present SDR systems can receive/transmit signals directly at RF level up to C-band. This will eliminate the requirements of the complex frontend hardware which in turn provides savings in mass, volume and DC power consumption. SDR based communication payload architecture is well suitable for Indian Nano Satellite Bus (INS) and Indian Micro Satellite Bus (IMS). SDRs will also be useful for future communication payloads for GEO/LEO satellite. • Common RF transceiver (single chip/module) having RF front end and Digital subsystems (direct sampling based ADC and DAC modules) to operate from UHF to Ku band frequencies. • Studies and implementation of different signal processing algorithms for regenerative processing and flexibility in terms of channelization and bandwidth. • Development of integrated wideband RF front end with LNA, Bandpass Filters & Precautionary and Liquidity Line (PLL) on RF Transceiver module. • Development of Direct Sampling based ADC and DAC modules which can be integrated with wide band RF front end.
A1.3	**Hybrid Satellite/Terrestrial networks and their compatibility with 5G cellular system (SAC)** As the spectrum resources are becoming limited and trend is towards delivering high speed data rates in both satellite and terrestrial mobile communication. Hybrid network of terrestrial and satellite systems complementing each other shall be developed for ubiquitous coverage, seamless connectivity and high data rates. Research areas in this direction are: • Studies on Satellite – Terrestrial system architecture compatible with 5G Networks • Channel modelling considering both land-mobile and earth-to-space channels • Investigation of Multiple-Input Multiple-Output (MIMO), precoding and other signal processing techniques for enhancing capacity of mobile satellite systems and ensuring coexistence of terrestrial and satellite systems. • Protocol level integration of satellite and terrestrial system and development of satellite-5G testbed. • Investigations on satellite platforms and terminal architectures complementing terrestrial 5G networks.
A1.4	**Development of signal processing and resource allocation algorithms for multi gigahertz on-board processors (SAC)** With the advancement in signal processing capabilities, the trend is towards channelization and processing of wideband signals covering gigahertz bandwidth.

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Similarly, the necessity to dynamically and efficiently allocate a communication payload's on-board resources such as power and bandwidth over the desired coverage requires the development of algorithms for beamforming-precoding, beam-hopping etc.
Research areas in this direction are:

Development of signal analysis algorithms for wideband signals (multi-gigahertz bandwidth). Sparse signal analysis/compressed sensing based algorithms can be targeted.
Development of translucent processing algorithms which bridge transparent and regenerative payloads through partially decoding packets on satellite.
Development of algorithms for beam-hopping, digital beamforming, and precoding for efficient spatial allocation of on-board resources.
Satellite system design and architecture for multi-gigahertz signal processing payload.

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<tr>
<td>A1.5</td>
<td>
Studies on Advanced Navigation systems (SAC)
Satellite navigation has become a key infrastructure element worldwide, enabling numerous applications along with great economic activity. These systems have been conceived as cornerstone of the national security and playing that role effectively. The significance of these systems is evident from the fact that currently there are six global navigation satellite systems (GNSS) which are either operational, under deployment or modernization. The system capability is evolving in both civil and defence domains. Indian Regional Navigation Satellite System(IRNSS) system is now a full-fledged operational system which is providing navigation services over Indian region. The evolving user requirements and global scenario will certainly require continuous research and development to acquire and utilize newer technology in this field. Few such potential areas are enlisted below:

Use of IRNSS signals for navigation with "signals of opportunity" of terrestrial networks.
Systems studies for autonomous satellite navigation for MEO constellation.
Development of simulation tools for situation awareness for navigation end users supporting their mission planning. Such tools will consider the complete navigation systems and provide the information about the system accuracy, availability, integrity and reliability for any operational situation.
System studies on provision of standalone Positioning, Navigation and Timing (PNT) services for the missions on extra-terrestrial bodies like Moon/Mars.
End-to-end performance analysis of IRNSS signals in LMS channels using software/hardware simulation platform.
Research on security features of navigation signals such as anti-spoof and message authentication.

</td>
</tr>
</table>

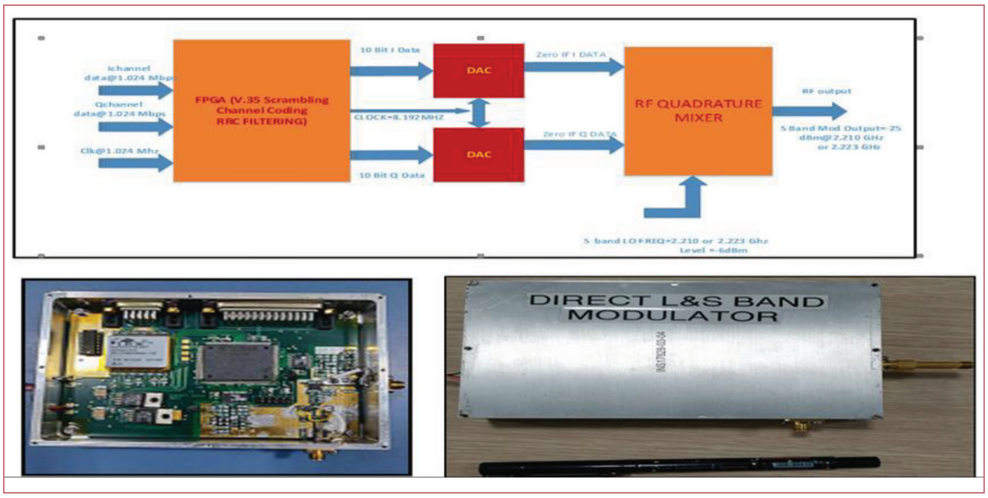
	• Studies on navigation signal generation, multi-level signal/sub-carrier design and multiplexing using multicarrier constant envelope modulation schemes. • Studies of various signal modulation schemes like Minimum Shift Keying (MSK), Gaussian Minimum Shift Keying (GMSK), Orthogonal Frequency-Division Multiplexing (OFDM), etc. as potential candidates for the future navigation signals. Studies should also include overall receiver performance analysis for such signals. • Studies of interference mitigation techniques like wavelet based de-noising or other compressive sensing methods on receiver performance. • Research in utilizing space service volume capability of GNSS signals. • Clock ensemble algorithm development for improvement of on-board timing system performance.
A1.6	**Space based Automatic Dependent Surveillance-Broadcast (ADS-B) and Automatic Identification System (AIS) (SAC)** Automatic Identification System (AIS) is a universal ship-borne terrestrial system used to improve the maritime safety and efficiency of navigation by enabling ship to ship and ship to shore communication. Automatic Dependent Surveillance-Broadcast (ADS-B) is the aircraft surveillance technology in which aircraft provide data such as position, velocity, and identification from on-board aircraft systems. AIS and ADS-B both rely on message transmitted by users regarding their navigation status/location. Space based AIS and ADS-B augment the surveillance capability beyond the terrestrial system range with global coverage (remote, polar and oceanic areas), unrestricted by location. AIS & ADS-B payloads, hosted on low earth orbit (LEO) platforms receive AIS/ADS-B messages, process them and relay them back to ground for usage by service provider to end user. Satellite receives the message from multiple AIS and ADS-B terminal at a same time which causes on-board message collision or messages may get garbled. Since, this is an upcoming area, there are several challenges: • Development of On-board algorithm for detect, de-collision and decode of AIS and ADS-B message in low SNR (<9 dB). • Development of low-size, weight and power (SWaP) digital processor. • Development of low noise sensitivity (<-105 dBm) AIS and ADS-B RF front end.
A1.7	**Next Generation Data Relay Satellite System (NexGen-IDRSS) (SAC)** ISRO has conceived and is developing a Data Relay Satellite System i.e. IDRSS primarily to provide Data Relay Services to Gaganyaan mission. In addition, it is also capable of providing TM/TC services to LEO satellites as well as high data rate relay link from

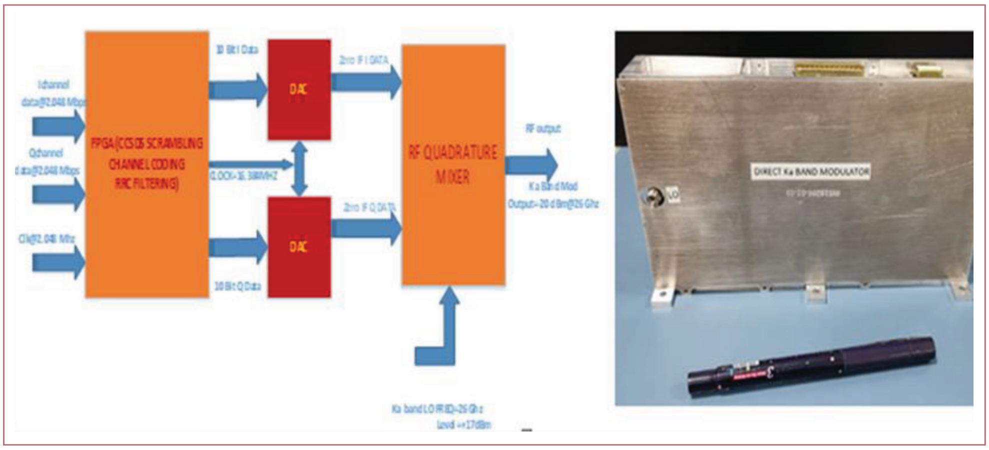
	Antarctica. However, IDRSS first generation of satellites are targeted for specific missions. In addition to the services provided by the IDRSS 1st generation satellites, next generation of IDRSS satellites will have enhanced capabilities to provide higher data rate services to a variety of users. Some of the services, which will be targeted through these satellites, are: • High Data rate relay link from Antarctica station • Audio/Video/data relay to Human space flight mission. • High data rate relay from LEO imaging satellites. • Audio/Video/Broadband Internet services for Bhartiya Antariksh Station. The payload will require following technologies to be developed to cater to these services: • Large Deployable Antennas of the order of 4.5 mts in foldable configuration for better G/T and EIRP performance in S-band • Advanced Phased Array Antenna for targeting multiple LEO satellites for TM/TC operation • Microwave/Optical Intersatellite links for High Data rate optical communication between satellite to satellite and satellite to ground operation. • Advanced single channel Mono-Pulse Tracking system.
A1.8	**Interplanetary Communication System (SAC)** The recent increase in lunar missions, like landing, manned lunar mission and returning on the South Pole region and demonstration of technologies related to robust thermal systems for the operation of spacecraft for more than one lunar day (~14 Earth days) for exploration of the lunar South Pole region, paves the way for planning future lunar missions. Further, interplanetary missions like Venus and Mars landing missions are also planned by ISRO. The planned lunar and interplanetary missions would require interplanetary communication system for supporting a moon habitat, high resolution imagery, interplanetary exploration and safety-of-life service for manned missions. The interplanetary communication system requires constellation of small satellites, deep space data relay satellite network and RF beacon system for establishment of high data rate connectivity, local network, connecting with International Mobile Telecommunication (IMT) systems and search & rescue system in emergency situation. **Interplanetary Communication System Network:** *Utilization:* Support for future human missions to moon and future interplanetary missions with high-speed data communication. *Technologies:* • New waveform, network protocol design as per existing terrestrial standard

	• Interoperable communication system design • Re-configurable, miniaturized antenna/RF/Digital subsystems, advanced one/two-way ranging, orbit determination, and autonomous operation • Tolerance to extreme temp. variation, radiation, vibration, shock, etc. • Satellite aided search & rescue system based on position estimates using Doppler tracking • RF beacon deployment mechanism on the moon or Mars surface • Reliable and continuous communication among lander, rover and orbiter for long-term exploration	
A1.9	**Millimetre-wave Satellite Communication Systems (SAC)** The ever increasing demand for data and the proliferation of digital communication devices has led to a spectrum crunch in conventional satcom bands. To increase the available bandwidth for user terminals in Ku and Ka bands, it is proposed to shift the hub frequencies in Q/V bands or W band. While there are several challenges such as limited technological readiness and severe atmospheric impairments, the advantages obtained from freeing a large section of Ku/Ka spectrum are quite significant. Similarly, it is also proposed to have LEO constellations in Q/V bands offering high data rate broadband using small user terminals. Towards this several technologies and studies can be carried out: Research areas in this direction are: • Channel modelling and availability analysis for Indian land and Indian ocean regions in Q, V and W bands. • Design of phased array based multibeam transmit/receive antennas for high data rate communication incl. development of beamforming core chips.	
A2	**Sub Area**	**Digital Systems for Future Communication Satellites (SAC)**
A2.1	The current success of satellites is primarily in the fixed satellite services, broadcast satellite services and broadband/internet-related satellite services. In the satellite communication business, the trend for ever-increasing capacity, flexibility and availability of service, as well as increasingly more affordable, more compact, lighter, and even more stylish and ergonomic ground and personal terminals, has become need of the present. It is also believed that satellites in future still play a key role in providing mobile services despite the setbacks that came with early market failures. Onboard digital signal processing has potential for offering innovative satellite services. Availability of space-qualified high-capacity high-speed Field Programmable Gate Array (FPGAs), availability of high-speed Analog to Digital Converters (ADCs) / Data Assimilation Converters DACs and development of specialized-function Application Specific Integrated Circuits (ASICs) have made advanced services a reality. Managing	

<table>
<tr><td></td><td colspan="2">mass, power, complexity, functionality and reliability for such payload is of paramount importance for offering services at acceptable cost. The emphasis worldwide is on:
• Increasing the performance (i.e. service availability)
• Quality of experience(i.e. less delay)
• Reducing cost/bit of information
• Efficient use of spectrum
• Network integration with terrestrial system
• Flexibility (i.e. reconfigurable payloads)
• Integration with navigation and observational satellite systems
• Security of communication
• Resistance to interference and jamming
The accomplishment of above tasks would require developing techniques for:
• Innovative and efficient spectrum processing and sensing algorithms
• Innovative techniques, protocols and architecture
• Innovative business models
The satellite technology is divided in to two major category
1. Communication satellite related technology
2. Navigation satellite related technology.</td></tr>
<tr><td>A3</td><td>Sub Area</td><td>Communication Satellite Related Technology (SAC)</td></tr>
<tr><td>A3.1</td><td colspan="2">Advanced Coding and Modulation for Satellite Communication (SAC)
Recently the terrestrial communication system of fiber optical cables has grown tremendously. In order to develop a harmonious infrastructure with terrestrial communications systems, the speed of satellite communications must be increased to meet the speed of terrestrial communications system. It is useful to consider a so-called Internet satellite and its development.
One generation of 10 years may be long, but it must be reasonable because it may be about a generation of infra structure. An Internet satellite is meant one that provides fixed, broadcast and mobile satellite communications.
Current Situation and challenges
Most of the communication satellite in ISRO like Indian National Satellite (INSAT) and Geosynchronous Satellite System (GSAT) class of series satellites used mostly Quadrature Phase Shift Keying (QPSK) and Binary Phase Shift Keying (BPSK) modulation system. The reason of using these modulation systems, because of their simplicity and better performance compare to other modulation systems in satellite communication scenario. They are still the popular choice, even in worldwide satellite communication</td></tr>
</table>

scenario. There are two major approaches for modulator design heterodyne and homodyne. Heterodyne approach basically involves two level of up conversion i.e. the first modulation at Instruction Fetch (IF) label and then up conversion to desire Radio Frequency (RF) frequency. In homodyne approach involves direct conversion from zero IF to desired RF frequency. Till now mostly all major modulator design is based upon heterodyne based approach. But now current state of art design is based upon homodyne approach. Following figures shows direct S and Ka band modulator design for Gaganyaan project. The challenges are left in these modulation are to handle high data rate, where the hardware or component used earlier design will not be useful. The other challenges are reduction of size and power consumption of such system. So, high data rate system using our current modulation scheme with reduces size and power is the current challenges.





Block Diagram and DVM model of Ka Band Modulator

A3.2

Channel coding for satellite communication (SAC)

The large distance between the transmitting spacecraft and the receiving earth station and the limited transmitting power result in a very poor signal- to-noise ratio at the receiver side. The consequence is a large amount of transmission errors. At the same time, the data bits are highly compressed before transmission to allow as large as possible a number of images to be transmitted in the limited data rate. But especially compressed data bits are very sensitive to transmission errors. Therefore, channel coding method is also one of the most important technologies.

Current Situation and challenges

Currently most of the satellite made by ISRO used convolutional code with different code rate 1/2, 3/4, 7/8 in concatenation with Reed-Solomon (RS) code in some of the satellite. This type of channel codec works well since last 20 years in satellite communication world. However due to increasing in demand of quality of service and several upcoming deep space explorations, it is now essential that change channel codec for future mission. The Consultative Committee for Space Data Systems has suggested few of the channel code for future satellites and deep space explorations. The current state of the art channel codec is

- Turbo convolutional codes(TCC)
- Turbo product code (TPC)
- Low density Parity check code(LDPC)

New channel coding Scheme

For our satellites and deep space mission Turbo convolutional code and LDPC code are the two main area of thrust for future mission.

- **Turbo Convolution Code**

Parallel-Concatenated Convolutional Codes (PCCC), known as turbo codes, allows structure through concatenation and randomness through interleaving. The Consultative Committee for Space Data Systems (CCSDS) Telemetry Channel Coding Recommendation establishes a common framework and provides a standardized basis for the coding schemes used by CCSDS Agencies for space telemetry data communications. This standard traditionally provides the benchmark for new and emerging coding technologies Turbo codes have an astonishing performance of bit error rate (BER) at relatively low Eb/No. Turbo codes were chosen as a new option for this standard in 1999, only 6 years since their official presentation to the international community: this was the first international standard including turbo codes. The reason was the significant improvement in terms of power efficiency assured by turbo codes over the old codes of the standard. In Chandrayaan-1 mission of ISRO, we have used Turbo convolutional code as per CCSDS standard 131.0-B-1 for low data rate telemetry application. We have also planning to use this turbo code for human space program.

- **Low density parity checks code (LDPC)**

The another important error correcting code, whose performance close to Shannon limit know as low density parity check code. The LDPC code is also a close contender of turbo code. LDPC codes have a remarkable performance with iterative decoding that is very close to the Shannon limit. When compared to the decoding algorithm of convolution code, LDPC decoding algorithm has more parallelization, low implementation complexity, low decoding latency, as well as no error-floors at high Signal-to-Noise Ratio (SNR) as turbo code. The next generation satellite communication systems e.g. digital video broadcast satellite/terrestrial (DVB-S2/T2) have readily adopted LDPC code for Forward Error Correction (FEC), mostly due to its near Shannon performance at very low signal to noise ratio. However, the channel code performance also depends upon the modulation scheme.

The use of advanced channel coding techniques (e.g. TC and LDPC codes) is the state-of-the-art technology used in current satellite systems to provide broadcasting services to fixed terminals in the Ku/Ka frequency bands into two-ways (i.e. Digital Video Broadcasting – Second Generation (DVB-S2) in the forward link and Digital Video Broadcasting – Return Channel via Satellite (DVB-RCS) in the return link, respectively), in which the Additive white Gaussian noise (AWGN) channel is usually assumed. In particular, DVB-S2 considers irregular LDPC codes of either 16200 or 64800 bit code words and 11 coding rates (i.e. ranging from 1/4 to 9/10). With respect to DVB-RCS, double-binary turbo codes are assumed with 12 frame sizes (i.e. ranging from 48 to 752 bit couples) and 7 coding rates (i.e. ranging from 1/3 to 6/7).

Sync word less Concatenated RS and convolutional code encoder and decoder development

The recommended concatenated coding system in satellite communication consists of a Reed-Solomon outer code and a convolutional inner code (which is Viterbi decoded). In typical scenario there is requirement of sync word for synchronization for RS decoder, which lead to reduce the overall efficiency of data transmission and also the overall throughput. The proposed activity will remove the requirement of sync word in each data packet which will improve the overall data efficiency. The proposed activity will be useful for future payload like Gaganyaan etc.

Digital Processors for High Throughput Satellites.

Conventional high throughput satellites employ limited, RF based processing due to unavailability of wideband signal processing hardware. For future high throughput satellites, it will be necessary to employ processing techniques to distribute the on-board resources in an optimal fashion and extract the maximum possible throughput. The relevant research areas would be:

1. Development of system on chip with integrated wideband, direct sampling data converters and RF transceivers.
2. Development of on-board partially or fully reconfigurable, failure tolerant, Multi-core Processor based signal processing system

	3. Development of multi-channel wideband adaptive signal processing system for digital beamforming and channelization in broadband multi-beam communication payloads. 4. Data compression algorithms for inter-board data communication. **Precoding for V/High Throughput Satellites** Precoding is to counteract the multibeam interface when high/full frequency reuse is employed in V/HTS so that noncomplex UTs can maintain a high Signal to Interference plus Noise Ratio (SINR), even the same carrier frequency is used by adjacent beam. To achieve this precoding employs the channel state information (CSI) toward each UT to mitigate the interference. Signal processing for optimization of precoding matrix and implementation of Precoding function in next generation V/HTS. Some research areas are calculation of Precoding Matrix, and Efficient Implementation of Precoding Matrix in satellite.	
A4	**Sub Area**	**Navigation Satellite Related Technology (SAC)**
A4.1	**Modulators for Navigation Satellites (SAC)** This Satellite Navigation has revolutionized the navigation world, opening new opportunities in an increasing number of sectors that require high precision. ISRO has taken up the project for the implementation of an independent regional navigation system currently known as Navigation with Indian Constellation (NavIC). The project Indian Regional Navigation Satellite System (IRNSS) envisages establishment of regional navigation system using a combination of Geostationary Orbit (GEO) and Geosynchronous Orbit (GSO) spacecraft's. NavIC is already providing two types of services restricted and unrestricted services or public domain services in L5 and S Band. Binary offset carrier (BOC) and Binary phase shift keying (BPSK) is use for these services. In NavIC, we are using different method for combining these two modulation scheme in order to get constant modulation envelope i.e., the total transmitted power does not vary over time. So that the transmitted information is not contained in the signal amplitude and the transmitted signal amplitude becomes less critical. However, in future NavIC satellite we are going to transmit L1 band signal also for better interoperability and compatibility. In L1 band, we need comply the power spectral density of Multiplexed binary offset carrier (MBOC) modulation. There are other navigation players, who are transmitting their own custom modulation scheme in L1 band. These are mention below. • **CBOC:** The Composite BOC is the solution adopted by Galileo for the Open Service in E1/L1. • **TMBOC:** The Time-Multiplexed BOC is the solution adopted by GPS for L1C. • **Quadrature Multiplexed BOC:** Adopted by compass. A suitable modulation scheme, which comply MBOC power spectral density may design and develop to complete the future requirement.	

A4.2	**Coding Scheme (SAC)** Like other wireless communication signals, navigation signals are subject to noise, multipath and shadowing effects which may induce errors in the received data. Modern navigation signals employ some techniques to detect and correct these errors. Galileo, modernized GPS as well as space-based augmentation systems (SBAS) (e.g. Wide Area Augmentation System (WAAS), European Geostationary Navigation Overlay Service (EGNOS)) messages make use of FEC. In the following the various error protection techniques used by these systems are described and some details are given for the encoding and decoding processes. The fundamental principle of channel coding is to add redundancy to the navigation message, which is used by a receiver to detect or correct possible errors in the received symbols. The redundant bits added by the encoder are a function of the original information. The original bits may or may not be directly visible in the encoded message. In the first case the encoding is called systematic while in the second case it is called non-systematic. Channel coding techniques can be further divided into block codes and convolutional codes. Block codes operate on fixed sized blocks of data, each of which are encoded separately, while convolution codes operate on a continuous stream of input data. Both kinds of codes are employed in Global Navigation Satellite System (GNSS), a few of which are detailed in following Table.

CODING SCHEMES USED IN GNSS SIGNALS

System	Signal	Message	Coding
GPS	L1 C/A	LNAV	none
	L1C	CNAV-2	block: BCH & LDPC
	L2C	CNAV	½-rate convolutional
	L5	CNAV	½-rate convolutional
Galileo	E1-B	INAV	½-rate convolutional
	E6-B	CNAV	½-rate convolutional
	E5a	FNAV	½-rate convolutional
	E5b	INAV	½-rate convolutional
SBAS	L1	SBAS	½-rate convolutional

	Recently china (Compass) is also transmitting signal in L1 band having own custom Bose-Chaudhuri-Hocquenghem (BCH) and LDPC codes. In NavIC signal, we are also planning to transmit L1 band signal for better interoperability and compatibility. So there will be a need to develop custom channel coding of navigation signals.
A4.3	**Optical Interconnects for High Speed Signal and LO distribution (SAC)** There is a need for High bandwidth (BW) serial data transmissions. Optical Interconnects are required to minimize power consumption, mass and volume. They are practically lossless propagation in an optical fiber within a Digital sub-systems module. The other significant advantages are Immunity to Electromagnetic Interference (EMI) and Electro Magnetic Compatibility(EMC), are mechanically flexible and galvanic ally isolated and provides low phase noise degradation.

A4.4	**High-Performance DSP for Software Defined Payloads (SAC)** To meet the requirement of high speed and reconfigure software defined payloads, a high performance Digital Signal Processors (DSP) processor which can meet space electronics quality guidelines are required. Their performance should be benchmarked for following applications 1. DVB-S2 modem: 2 Gb/s transmit, 1 Gb/s receive 2. Fast Fourier Transform FFT (complex 16 bit fixed-point): 150 GOPS (Giga Operations per Second)
A4.5	**Digital Cancellation Scheme for High-Order Passive Intermodulation Interference (SAC)** Passive intermodulation (PIM) is a phenomenon that additional signals at new frequencies (not only the harmonic frequencies) are generated when signals containing two or more different frequencies are processed at the passive devices, such as duplexes, cable connectors, waveguides and antennas. PIM would worsen the antenna gain-to-noise-temperature (G/ T) value, thereby further disrupting the whole system. A full-digital PIM canceling adaptive scheme can be explored based on Least Mean Square LMS algorithm.
A4.6	**Onboard Clock Ensemble for clock anomaly handling (SAC)** To improve the clock accuracy in future navigation payloads it is required to generate the output frequency signal based on an ensemble of input clocks with optimized performance and improved robustness by clock anomalies handling. Following three algorithms can be developed: Measurement Filtering (MF), based on a cascade of low-pass recursive filters with exponential window functions. Clock Fault Detection and Correction (CFDC), with associated logic based on MF outputs, onboard Clock Ensemble (ONCLE), based on weighted averaging according to filtered frequency information covering clock anomaly handling.
A4.7	**On-board Autonomous Orbit Determination of Navigation Satellites using inter-satellite ranging (SAC)** Autonomous orbit determination of a navigation constellation is the process by which the orbit parameters of navigation satellites are autonomously calibrated onboard the satellites without the need for external aids. It commonly uses a satellite onboard data processing unit and a filtering method to process the measurements of inter-satellite ranges. The onboard data processing unit is the main module of autonomous navigation systems.

<table>
<tr><td rowspan="1">A4.8</td><td colspan="2">FPGA/ASIC Design Methodology (SAC)
Following areas for research in FPGA/ASIC Design for onboard signal processing:
• 28 nm Fully Depleted Silicon On Insulator (FD SOI) to be evaluate for low power Application-Specific Integrated Circuit (ASIC) development for future high speed Digital Subsystems
• Formal Verification to Verify Single Event Upset (SEU) Mitigation Techniques for increasing design reliability
• High Level Design Methodology for faster design rollout
• Linux Operating system for space applications.</td></tr>
<tr><td>A5</td><td>Sub Area</td><td>Development of Ferrite Material for Space Use (SAC)</td></tr>
<tr><td>A5.1</td><td colspan="2">Microwave circulators and isolators are used in communication payloads to improve impedance matching and to avoid multiple reflections. Ferrite material is used in the waveguide junctions because of its non-reciprocal properties, resulting in circulation when magnetized.

Understanding the structure of the ferrite material requires knowledge of chemistry, theory of magnetism in ferrites, the non-reciprocal characteristic of ferrite junction at microwave frequencies due to gyromagnetic effect, which involves physics and advanced mathematics.

The important properties of a ferrite are:

Saturation Magnetization, Ms: This property is related to the spontaneous alignment of electron spins parallel to the applied magnetic field.

Gyromagnetic Line width, ΔH: It is a measure of ferrite magnetic losses in the vicinity of ferromagnetic resonance.

Effective line width, ΔHeff: It is a measure of ferrite magnetic losses for off-resonance operating points (below and above resonance).

Spin wave line width, ΔHk: It is a measure of attenuation factor of spin waves excited above a power level.

Magnetization temperature coefficient, α: It is a measure of relative change in magnetization with respect to temperature.

Curie Temperature, Tc: Temperature above which ferrite material has no magnetic properties.

The table below shows the ferrite material properties sought for to be used in circulators for space use:</td></tr>
</table>

Application	Requirement	Material Property
Low Power Circulator/ Switch	Low Insertion loss, Wide Bandwidth, Compact	Minimum **ΔHeff, α** Maximum **ε** **Ms** as per the frequency
High Power Circulator/ Switch	Low Insertion Loss, High average and peak power handling	Minimum **ΔHeff, ΔHk, α** **Ms** as per the frequency High **Tc**

Research undertaken/to be taken up in Ferrite Devices at SAC

1. Low power and High power Wideband Coaxial circulator
2. High power waveguide circulator at Q-V band and millimeter wave
3. Ferrite Phase shifter
4. High power and low power Ferrite switches

A6	Sub Area	Amplifier Technology (SAC)

A6.1

The microwave and RF amplifiers present in various communication and navigation payloads includes low, medium and high power amplifiers over different frequencies ranging from UHF to Q/V-bands. III-V group (Gallium Arsenide (GaAs) and Gallium Nitride (GaN))based semiconductor technology in the form of discrete RF transistors and Monolithic Microwave Integrated Circuits (MMICs, packaged & unpackaged) are being utilized for the design and realization of high performance solid state amplifier circuits and subsystems.

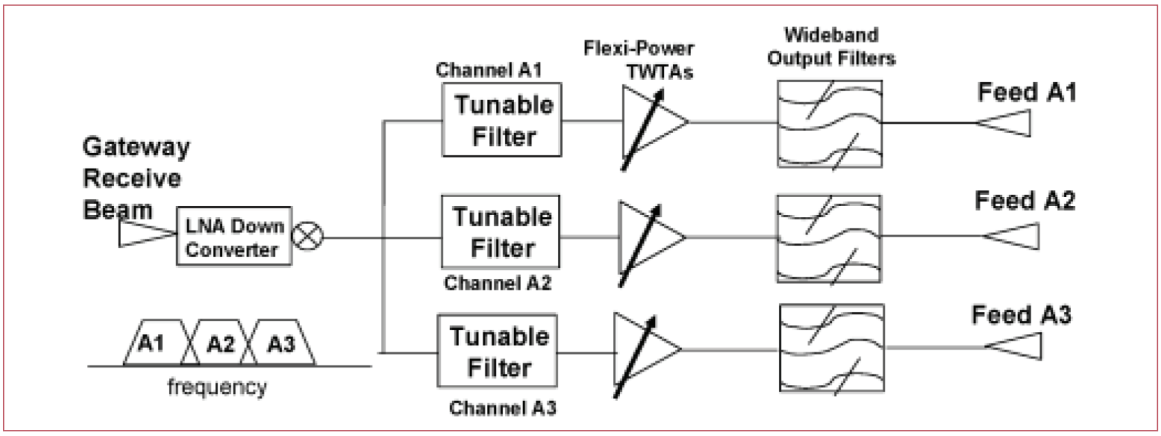
The next generation satellite communication systems require high output power amplifiers with high efficiency and linearity in small size, low weight having better reliability. To meet the desired performance from amplifier subsystems, control circuits like digital attenuators, phase shifters, voltage variable attenuators, switches etc. are also designed, realized and successfully used in various payloads in the development of channel amplifiers and Solid State Power Amplifier SSPAs. At the lower end of frequency spectrum, at UHF to C-band, availability of GaN technology is offering newer breakthrough in realizing the power amplifiers which may even be replacing Travelling Wave Tube Amplifier (TWTA) in future satellites.

The Indian Regional Navigational Satellite System (IRNSS) provides regional navigation satellite system using a combination of GEO and GSO spacecraft over the Indian region. GaN based SSPA are emerging as a viable alternative to TWT amplifiers especially at L and S-band used in these navigation satellites.

Scope of the work exists in the area of simulation and design of medium to high power compact SSPA with size comparable to TWTA or even smaller. ISRO had already designed, developed and successfully demonstrated communication at Q/V-band in one of its

	mission. High throughput satellites are being proposed at millimeter wave band in future, requiring further technology development utilizing state-of-the-art techniques in the development of miniaturized driver amplifiers and high power SSPAs with highly efficient RF power combining techniques. There is a requirement of wideband, high power MMIC power amplifier designs upto V-band. To achieve higher power, low loss combining techniques and development of planar or 3D miniaturised RF power dividers and combiners are required at these frequencies. ISRO had also designed and developed a 2-channel Switch Matrix at Ka-band utilizing high isolation Single Pole, Double Throw (SPDT) switch MMICs and split block assembly. There is research scope in developing state of the art packaging technique for preserving high isolation from such RF switches. There is also research scope in development of thermal modelling and thermal management techniques for high power amplifier MMIC. Multi-function MMIC design & development for driver amplifiers and multi-channel transmit modules are also new areas of research. Areas of research are: • Wideband, high power SSPA & Channel amplifiers in UHF, L, S, C, Ku, Ka and Q/V-band. • GaN based high power compact SSPAs at UHF, L and S-Band. • High power amplifier GaAs and GaN MMIC designs. • State-of-the-art technology for design & development of compact SSPA at Q/V-band with waveguide RF interfaces. • Spatial power combining techniques at millimeter wave frequencies. • High efficiency Continuous Waves (CW) SSPAs with associated thermal & power management. • Implementing Efficiency enhancement techniques in S, C, Ku-band Power amplifier. • Thermal modelling & thermal simulations of MMIC power amplifiers. • Modelling & simulation of entire amplifier module consisting of MMICs for the effects of bondwires, package cavity etc. on RF performance at Ku-band & beyond. • Design & development of ASIC for the tele-command interface control circuit for channel amplifier & SSPAs. • Design & development of high isolation switches and voltage variable attenuators at Ku & Ka-band.	
A7	**Sub Area**	**Reconfigurable Filters for Satellite Communication (SAC)**
A7.1	The use of reconfigurable payloads in satellite provides significant advantage over current state-of-art satellite configurations. Re-configurability of payload allows for multimode and multifunctional operation. Agility opens the way for reconfigurable	

payloads that can be tuned during mission time while in orbit. The ability to reconfigure the operating frequency band offers key advantage to adapt long-lifetime satellites to rapidly evolving user requirements.



Flexible Payload Configuration

A switchable filter bank can act as alternative solution to a tunable filter where discrete flexibility is required. One such approach, used in the past, employs multiple IMUX and OMUX units, addressing different frequency plans, with extra RF switching functionality to change between them. This solution, however, is costly both in terms of added component costs and the increased mass and volume of the satellite.

Reconfigurable Filters

Microwave Filters used in the communication payload have very stringent in-band and out-of-band requirements. If Tunable/Reconfigurable filters are used to replace these filters in payloads, they must meet these stringent requirements. In particular, they must have High Q, maintain required bandwidth, must have reasonable return loss and should provide required rejections at specified frequency points. These filters should also be able to meet average and peak high power requirements. High Q filters presently used in the satellites are primarily made from 3-Dimenssional Waveguide Cavity Resonators, Dielectric Resonators or Coaxial Resonators. Filters made from these resonators meet all the stringent requirements of the payload including high power handling. Depending upon the application, frequency of operation and power handling requirement, one of the above resonator technology is chosen for realizing payload filters. Tunable/ Reconfigurable filters required for the satellites will also be required to be realized using these 3D resonator technologies to meet payload requirements. Most of the present day research has been focused on micostrip based tunable filters or SIW based tunable filters. The important constraints related to High power, High Q applications makes these reconfigurable technologies unsuitable for payload applications.

Recently, some progress has also been made in the tunable 3D high Q filters using mechanical motors, piezoelectric actuators and micromechanical switches for aching

	desired tenability. Some of the major challenges involved in the development of such 3D high Q tunable filters are: • Maintaining required bandwidth and reasonable Return Loss over wide tuning range. Non-uniform variation in resonant frequency of various resonators of the filter and variation in coupling values (External & Internal) of the filter with frequency could lead to degradation in Return loss of the tunable filter. • Maintaining High Q over wide tuning range. Tuning of resonator over wide tuning range could lead to significant reduction in its Q-factor. • Ensuring High average power handling capability and required Multipaction margin of 6dB. Implementation of tuning mechanism should not lead to degradation in power handling capability of the filter. • Qualification of Tunable filter for Space Application. Tunable Filter along with its tuning mechanism, should endure QM level environmental tests. • Ensuring required Reliability of the tunable filter and its tuning mechanism over its operating life. Reliability of the tunable filter could be impacted due to wear and tear of moving parts or due to increase in the number of parts. • Minimizing the power consumption and complexity for the tunable filter. **Recent Advances in Reconfigurable Filters:** Though, the optimal design of Tunable/Reconfigurable microwave filter suitable for payload application is yet to be developed, many researchers around the world are at work with this goal in mind. To obtain a tunable cavity filter and thus a tunable mux, the resonant frequencies of the resonators that comprise the filters must be reconfigured. Depending on the resonant mode and its electromagnetic field distribution used in the cavities, this can be achieved by different approaches. These approaches have led to various results in terms of achievable unloaded Q factor, spurious-free tuning range, or mechanical simplicity. Tuning can be performed using mechanical, magnetic, or electrical commands. Some of the recent advances in the field of 3D tunable filter are given below:
A7.2	**Mechanically Tunable waveguide cavity filters (SAC)** **a) Bellow-Mounted Tunable Filters (SAC)** Waveguide cavity filters have been widely used in satellites, due to the high-Q and high-power handling capability. In addition, cross-coupled circular-waveguide dual-mode filters, typically operating in TE113 mode, offer mass and size reduction and excellent RF performance. Mechanically tunable waveguide cavity filter maintains both High-Q and high-power-handling capabilities. A mechanically tunable waveguide filter can be implemented using bellows. The bellows is a flexible electroformed copper structure which acts as a tuning element. It is a thin-walled (nominally 0.002-in thick) metallic

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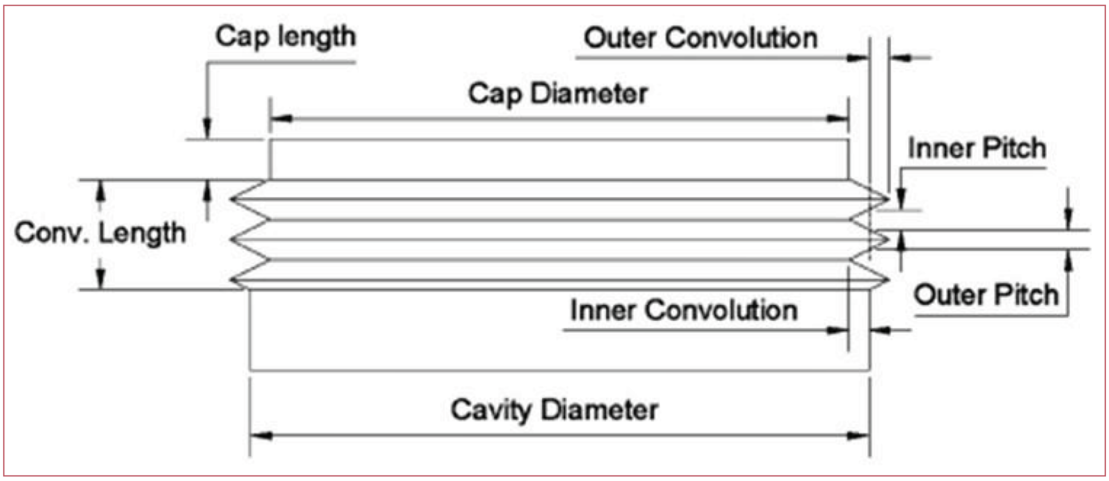
closed-end piston with a designed profile and specific number of convolutions. The bellows-mounted tunable filter offers a very low loss performance over a wide tuning range. A very stable transmission response over a very wide tuning range is also a distinctive feature of this technique. However, there is a tradeoff between RF and mechanical performance when designing a bellows profile. Mechanical operating characteristics are maximized by increasing the number and amplitude of convolutions, whereas RF performance relies on bellows with fewer convolutions.



Fully Tunable TE011 Cavity Filters (SAC)

A fully tunable filter for a completely flexible transponder requires tunability of both the bandwidth and center frequency of the filter. RF performance of the filter should be maintained over wide tuning range. In cylindrical cavity filter operating in TE011 mode, electric field strength and current distribution approach zero at the edge of the cavity end walls making it possible to use tuning discs without Q degradation, which in turn leads to the potential for incorporating small and low power consumption motors due to the contactless tuning feature. A movable plunger with diameter smaller than or equal to that of the cavity is used for filter tuning.

The A contactless plunger is used to provide a reactive short-circuit condition at the back of the metal disc ensuring good electrical contact, creating a near shortcircuit condition. This type of plungers consists of quarter-wavelength transformers. The three-section plunger incorporates two low-impedance sections and one high-impedance section. Providing an RF enclosure to the resonator prevents unwanted modes from interfering and degrading the operating TE011 mode. The achieved Q of approximately 10,000 for a Ku band filter is reported in the literature. This design, however, has narrow spurious free window due to presence of low-Q TM111 mode.
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Coaxial Tunable Filters (SAC)

Coaxial resonators offer moderate-Q and have been implemented for satellite channel-filtering applications. Coaxial technology is suitable for tunable filter applications
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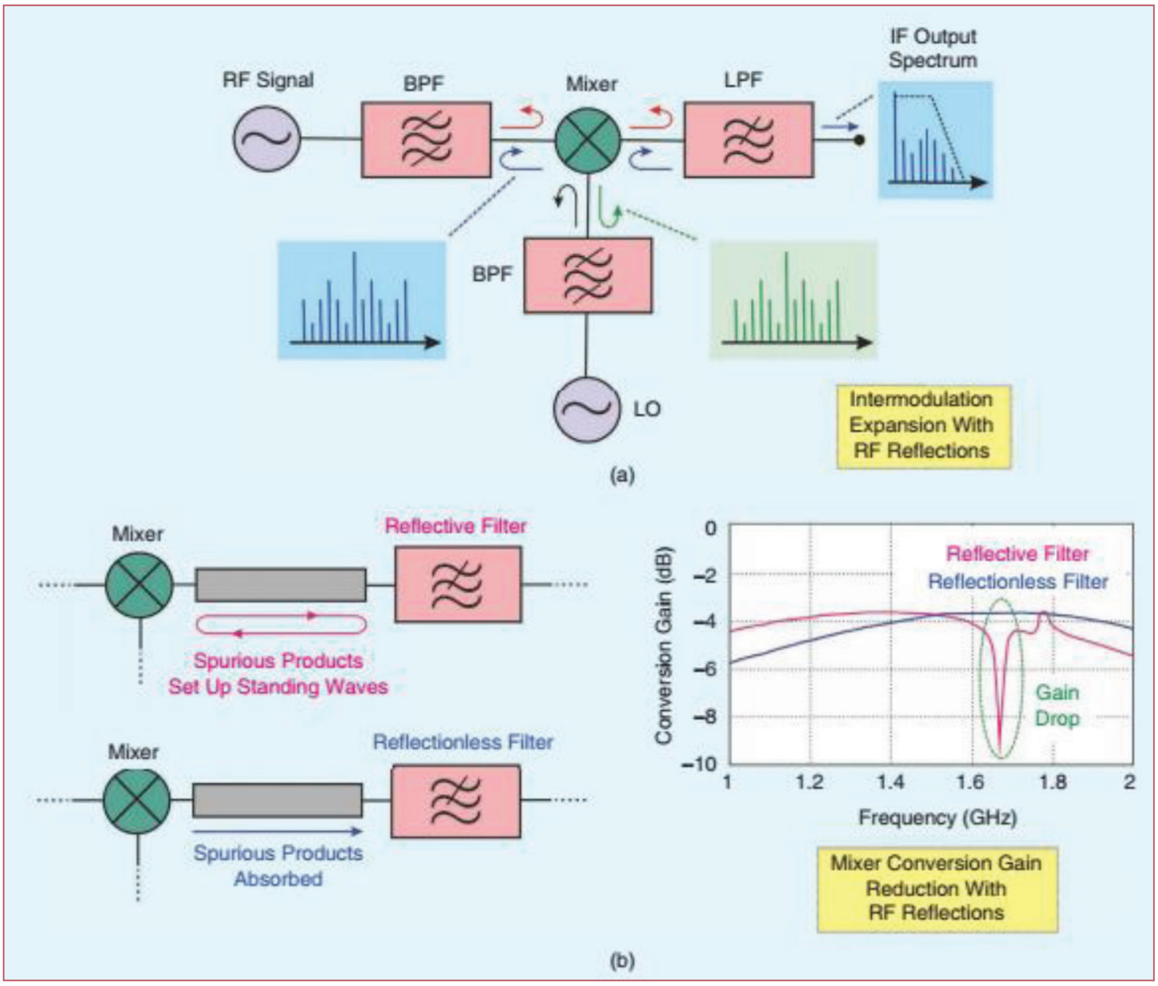
	because of the ease of tuning, which is a well-known characteristic of coaxial resonators. A design of a manually tunable coaxial filter is shown in following figure. In this design, Tuning is achieved by rotating a shaped cam above the resonator post which in turn changes the capacitive loading of the resonator. Variation in capacitive loading required for tuning resonant frequency of coaxial resonator can also be achieved by varying the height of tuning disk used at the top of the resonator.	
A8	**Sub Area**	**Synthesis and Analysis of Microwave Filters Based on Available Computational Methods (SAC)**
A8.1	To design a microwave filter, synthesis of electrical circuit is required. Synthesis generates complex polynomial for filter transfer function. Coupling matrix synthesis is a popular approach for extraction of the electrical parameters from the complex polynomials. The extracted parameters of coupling matrix are the circuit building blocks for a required filter response realization. The coupling matrix can be configured/modified for any desired topology of the filter and its corresponding (transmission/Reflection) response. Methods for direct optimization of the coupling matrix for desired transmission/reflection response are also available in literature. Prospective and retrospective use of the coupling matrix for any desired RF response for adaptive resonator topology can be very helpful for time efficient and better electrical performance designs. Software development for numerical electromagnetic analysis and optimization of standard geometries like rectangular, circular, coaxial resonator based microwave filters with GUI will initiate efforts towards indigenization of Electro-Magnetic (EM) solvers. The scope of software development can be further expanded to more complex geometries. Numerical electromagnetic techniques like Mode matching, Finite Element Method (FEM), Finite-difference Time Domain (FDTD) can be used depending the nature of geometry. The existing Commercial EM tools are highly expensive and hence good amount of foreign exchange can be saved after successful completion of this activity. **Reflectionless Microwave filter** A long-overlooked opportunity to enhance the signal-to-noise ratio (SNR) and dynamic range within a signal chain and to reduce harmonics/spurious content within these circuits is to address a seemingly innate property of filters: their out-of-band reflective behaviour. Reflectionless filters utilize a novel circuit topology to effectively eliminate the standing waves created by traditional filters without additional components (such as pads). This unique property gives designers a new way to improve the system performance of a wide array of broadband circuits, or any circuits suffering from out-of-band impedance mismatch. The typical performance of conventional filters (reflective filters) only exhibited a matched impedance at its ports within the filter's pass-band.	

The stop-band regions of these filters are intentionally designed to have very poor impedance match. As a result, undesired stop-band signals, including harmonics, interference, and noise, are all reflected from the filter ports back through the signal chain. If these unwanted signals are reflected back to another reflective device, a standing wave effect emerges. This standing wave will persist and build on itself until the attenuation of the transmission path between the two reflective components dampens and absorbs the unwanted signal energy. The reflectionless filter is a set of filter topologies and designs that inherently exhibit a broadband matched impedance. The major advantage of reflectionless filter topology is that these filters are readily cascadable, so sharper roll-off and greater stop-band rejection may be achieved by adding filters as modular building blocks. The figure below shows the improvement of the receiver chain with the introduction of reflectionless filter.

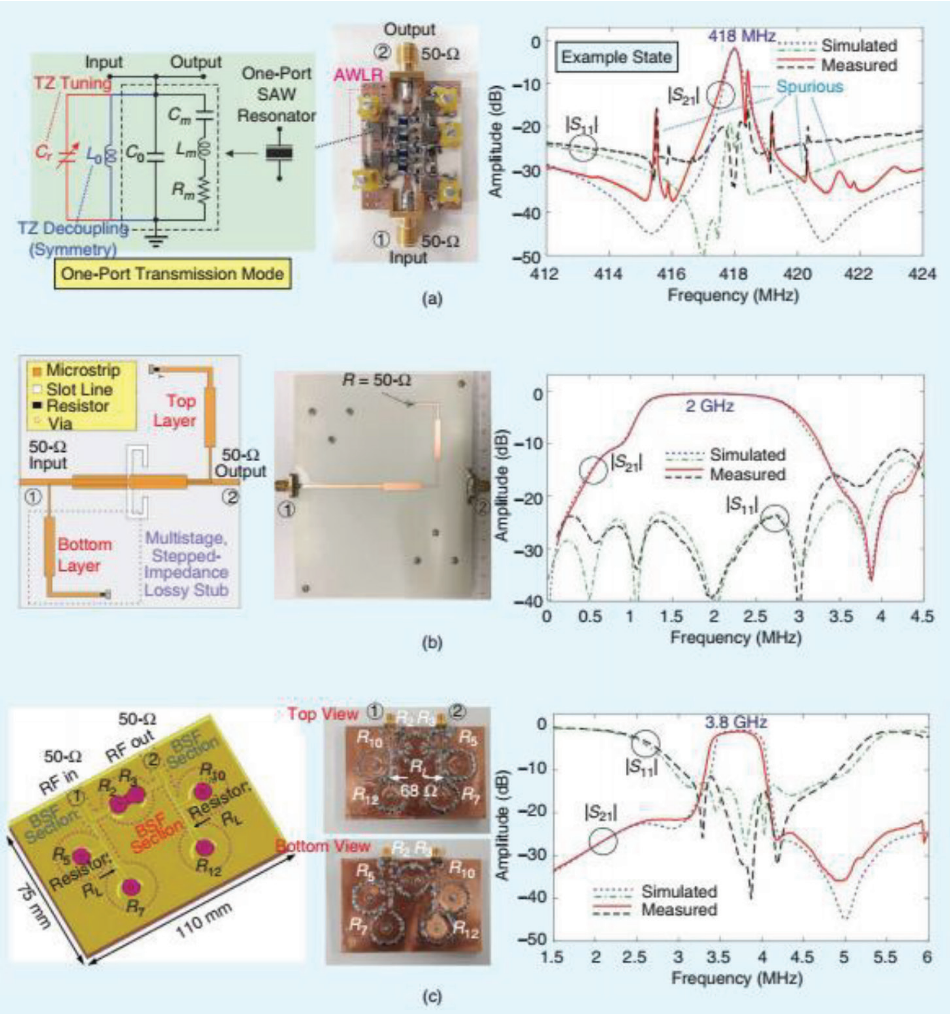


The problems of (a) intermodulation expansion in a receiver's low-conversion stage due to multiple out-of-band RF signal power reflections produced by reflective-type filters and (b) mixer conversion gain reduction resulting from generated standing waves in interconnection transmission lines. LPF: low-pass filter; IF: intermediate frequency.

Recent Advancements

Reflectionless Bronchopleural Fistula (BPF) devices developed mostly in planar realizations. However, to much lesser extent they are also have been demonstrated in other technologies. Below are the technologies where nonplanar reflectionless BPF components have been demonstrated are shown in figure:

1. **MMIC and low-frequency technologies:** Reflectionless BPFs in MMIC technologies are demanded for modern, energy-efficient, compact RF front-end chains. A theoretically perfectly matched symmetrical BPF network with even- and odd-mode subcircuit compensation, an integrated, passive, two-port absorptive BPF is developed. This prototype exhibits a quasi-elliptic-type bandpass filtering response centered at 2.5 GHz with return loss levels above 15 dB from dc to 10 GHz for a chip area of 1 mm2. It should be noted that commercial counterparts of this solution are already available showing promise for deployment in future RF transceiver modules. On the other hand, although, thus far, they are used only in low-pass filtering components (which can be easily extended to BPF ones after appropriate lowpass-to-bandpass frequency transformations), the novel classes of reflectionless filters for very low-frequency applications. The future need is to demonstrate and extend this concept for Ku and Ka-band.
2. **Acoustic wave technology:** BPFs in acoustic wave realizations are leading frequency-selective devices in mobile communications systems, due to their high quality factor (Q) and compact footprint However, most show some major limitations in terms of their very narrow operational bandwidth and frequency-static filtering transfer function being mostly of the reflective type and because of their spurious mode creation. By efficiently combining the acoustic-wave lumped, element resonator (AWLR) concept presented in for enhanced-bandwidth, quasi-elliptic-type BPF realization with the complementary diplexer approach.
3. **Multilayer technology:** The exploitation of microstrip-to-microstrip vertical transitions with slot line resonators in multilayer schemes has proven its potential in the development of ultra-wideband BPFs aimed at broadband and RF receivers. Using this concept and the lossy-stub-loading philosophy for reflectionless BPF design, new ultrawideband BPFs that simultaneously exhibit a very broad, symmetrical, reflectionless behaviour can be developed shown in figure.



Examples of reflectionless BPFs in nonplanar technologies. (a) An input reflectionless AWLR- based BPF using a complementary diplexer approach for TZ tuning. (b) A symmetrical, reflectionless, wideband BPF on multilayer technology using input/output multistage lossy stubs. (c) A symmetrical reflectionless BPF with substrate-integrated coaxial resonators using a two-port complementary diplexer approach.

Ceramic filters

As the name implies, RF & IF ceramic bandpass filters are manufactured from ceramics that exhibit the piezo-electric effect. One of the most common ceramics used is known as Lead Zirconate Titanate (PZT), lead zirconium titanate. The ceramic element uses its very high Q mechanical resonances to provide the resonant feature. They have bandwidths that are typically measured between 0.05 and 20% of the operating frequency. Often the Q levels range between around 500 up to 10 000.

Ceramic filters are electronic components that are widely used in IF and RF bandpass filter applications for RF circuit design in radio receivers and transmitters and the like. They may also be used as resonant elements in a variety of electronic circuit designs.

A9	Sub Area	Receiver & Frequency Sources Technologies (SAC)
A9.1	Compact, low power consumption and small volume are the system requirements of all times. In this direction a major emphasis and thrust has been provided over the years for development of miniature Low-Noise Amplifier LNAs, Receivers and Frequency converters over frequencies ranging from UHF to Q/V band. MMIC technologies combined with advance packaging techniques are being utilized for various communication and navigation payloads. Higher operating bandwidths and gain requirements combined with stringent spurious performance poses a challenge for development of compact systems as stringent filters are also to be incorporated. Areas of Research are: 1) Beam Forming Receiver 2) Receiver Design for Doppler Shift 3) Flexible Receivers in terms of frequency and bandwidth 4) Design and development of RF switches, Variable Valve Actuation (VVA) and Video Graphics Array (VGA) upto Q/V band 5) Fully integrated Receiver (RF, Local Oscillator (LO) & DC/DC in single package) 6) Medium Power Beacon Sources 7) Design of Synthesizer Integrated Circuit (IC)s	
A10	**Sub Area**	**Electronic Power Conditioners (SAC)**
A10.1	Electronic Power Conditioners designed to supply power in wide range for RF (Transmit and receive section) and Digital Processors of communication and navigation payloads. EPCs are designed with efficient power conversion topology, high switching frequency, EMI mitigation, low output noise, output voltage sequencing, load sharing, temperature compensated output voltages and categorized as miniaturized low power for RF front end, highly efficient high power for power amplifiers and high peak current channelizer for digital processors. EPC from 1 W to 650 W output power designed and developed for space applications are modular HMC based EPC card embedded in Receiver package, EPC for dynamic load switching of digital processors, EPC for pulsating load of iRAFS, EPC for Modulators, high power EPCs for 250 W SSPAs etc. New EPC development emphasizing the high frequency miniaturized EPCs, advance noise mitigation techniques in compact footprint of EPC, very low voltage (~0.8V) and high peak current EPCs for digital processors, efficient very low noise modular supply for digital devices. to meet the requirement of subsystems of upcoming digitized SDR, HTS and LEOCOM communication payloads.	
A10.2	**GaN FET based EPCs (SAC)** Wide bandgap semiconductors such as the Gallium Nitride (GaN), and Silicon Carbide (SiC) are promising transistor technologies for future generations of power electronics	

	circuits. GaN FET-based DC-DC converter is useful for space applications in that GaN FET has a high immunity and it becomes less susceptible for any false turn-on due to ionizing radiation. **GaN FET EPC for LEOCOM** The present EPC (40W-50W output power) design using Teledyne GaNFET TDG650E60BEP as power switching element is realized to power 15W C-band SSPA. All the components are available in space grade except the GaNFET which is a plastic package and hence, qualified only for LEO applications. In an effort to miniaturize EPC size while increasing efficiency, it becomes challenging task in high power EPCs to achieve required goal. **GaN FET EPC for GEOSAT:** The present EPC (10W output power) design using Intersil GaN FET ISL70024 (Intersil Driver ISL70040) as power switching element is realized to power low power RF subsystems. All the components are available in space grade. Achieved efficiency of the converter is 70% at 10W output power and 400KHz switching frequency. Further increase in switching frequency (above 500 KHz) with high frequency PWM controller is being designed and development is in progress. EPC is featured with no wall mount components, can be integrated in same package with RF subsystem.
A10.3	**Active EMI Filter (SAC)** With increase of switching frequency of dc-dc converter reduces the size and weight of the power supply on the one hand, and leads to more serious EMI problems on the other hand. Conventionally, a second-order passive electromagnetic interference (EMI) filter is used to mitigate the conducted EMI noise generated by the power converter. These passive LC filters tend to be bulky and could occupy up to 30% of the system volume. Active EMI filters, on the other hand, offer dynamic and adaptive filtering capabilities, enabling precise control over the attenuation of EMI across a broad frequency spectrum. The presently designed AEF has been tested with two EPC boards having switching frequency of 110KHz and 230KHz. AEF was able to attenuated the switching frequency noise around 37 dB and 20 dB respectively.
A10.4	**15 W HMC Module for low power RF subsystem (SAC)** With the advent of advanced high-throughput communication satellites, requirement of RF front end subsystem will be in larger number, hence the development low power HMC dc-dc converters that can cater power supply requirement of all types of low power RF subsystem is very essential. This low profile HMC module can be used as embedded card in package of with RF subsystem. It will improve EMI performance and compactness of package. Hybrid DC- DC converter is realized by implementing the ICs chip and wire technology, by increasing the switching frequency which drives the ability to use smaller magnetic components. Most of the low voltage DC to Dc converters Module available is operating at internal switching frequency up to 500 Khz for space use, few of them are design for 1MHz.

	The present Triple output 15W HMC at switching frequency 510 KHz is designed by using flyback converter topology along with post regulators for better cross regulation with turn -ON/OFF voltage sequencing between positive and negative supply lines. Protection features are ULVO, current protection with primary as well as secondary side current sensing circuit at positive voltages and foldback at negative output voltage line. HMC includes TM and TC interface circuit. Efficiency of HMC is around 65 % at max load condition. This low profile HMC is suitable for all types of low power RF subsystem i.e., Rx, DA, LNA, converters and other sub systems. Size of the HMC is 75 * 105 * 16 mm^3.
A10.5	**90W HM-EPC module along with post regulators (SAC)** The evolution of new generation FPGAs demands highly efficient and reliable power management systems to meet their growing performance requirements. EPC along with post regulators need to be designed in well-coordinated manner to manage number of output power rails required by digital subsystems. The EPC is designed with active clamp forward converter with synchronous rectification. A low power flyback converter is also implemented to derive low power output and generating housekeeping supplies. The Substrate level testing is completed. Size of HMC is 3.2"x 3.2" x 0.7". Whereas post regulators are designed with advanced POL and LDO regulators. HMC with three tunable outputs (0.8V-1.9V @9A, 1.8V to 2.5V @4.5A, 1.8V to 5V @1A) is to be designed. Some of the post regulators demand PMBus controlled low voltage and high current output like 0.8V @45A. Droop control, fast dynamic response, capacitive loading, low PARD and stringent load regulation; are the major challenges. GaN based Synchronous buck converter is tested for the application.
A10.6	**Planar Technology Development (SAC)** Towards the self-reliant, in-house Planner technology development will put thrust to low profile miniaturized DC to DC converters for payloads. Developed single output Transformer for 100W EPC, Vin: 70 ±5V, Vout: 5V ±1V OR 3.5V ±1V @ 10Amp.
A10.7	**Development of Digital controller simulator for EPC realization (SAC)** Development of software and hardware toolkits shall be carried out, that allow fast prototyping of any power controller. Digitally Programmable controller reference kit can be developed, which is a hardware board that contains DPC chips and auxiliary circuits along with all its signal interfaces. Once connected to PC and power components, it allows designer to program power controller algorithm, that will help faster implementation and realization. **Scope of research proposal:** • Complete theoretical analysis of EPC including modelling and simulation with suitable topology selected.

	• Simulation and circuit optimization for dual& four phase controllers • Incorporation of advanced techniques to miniaturize the size and increase the efficiency of the EPC like low magnetic loss, synchronous rectification etc. • Miniaturize the design with high frequency operation and use of GaN switching device. • Designing of efficient HMC layout maintaining signal integrity while reducing board size and obtaining higher switching frequency above 500 kHz up to 1MHz. Implementation of planar magnetics within the HMC. • Low loss Turn -On sequencing circuit for multiple high power output voltage lines in a single converter. • Loss breakup analysis to maximize EPC efficiency. • Complete theoretical analysis of AEF with EPC including modelling and simulation. • Implementation of AEF in higher switching frequency converters above 500 kHz up to 1MHz. • Designing of efficient Printed Circuit Board (PCB) layout maintaining signal integrity while reducing board size and obtaining higher switching frequency above 500 kHz up to 1MHz. • Further optimization of compensation network to achieve desired attenuation over wide range of frequency. • Realization and delivery of AEF + EPC with compliance of electrical specifications. • Realization and delivery of EPC with compliance of electrical specifications of all of the subsystems.	
A11	**Sub Area**	**RF Characterization of Communication and Navigation Payloads (SAC)**
A11.1	**Planar Technology Development (SAC)** Communication payloads include bent pipe, SDR based and spectrum processing configuration. Navigation payloads have data transmitter type configuration, which provide Position, Velocity and time solution to user. These payloads are characterized for different parameters such as IO transfer curve, frequency response, group delay, noise figure frequency conversion error, 3rd order intermodulation, spurious etc. for communication payloads & Error Vector magnitude (EVM), BER, phase noise, carrier suppression, magnitude/phase imbalance (IQ imbalance), absolute delay, code/carrier coherency etc. for navigation payloads. These parameters are characterized using an Automated Test System (ATS). The ATS is an interconnection of stimulus and measurement equipment to test a transponder (communication/navigation) in an automated fashion. The data is processed on a controller to provide the parametric results, which needs to be complied with the payload specifications. The processed data is displayed and	

stored in variety of formats such as excel, pdf, text, database etc. The ATS is generally developed on platforms such as LabVIEW, Matrix Laboratory (MATLAB), and Python etc.

ISRO is actively involved in development of payloads for variety of user applications for which high speed ATS development is required to test payloads in production mode as well as applying suitable DSP algorithms for estimation of various parameters.

Payload testing also requires design and development of various ground components (low power and high power) such as Switching & Interconnect Network, switch matrix, waveguide/coaxial adaptors, couplers, dividers, high power waveguide terminations etc. to enable realization of ground test setup for communication and navigation payloads. Future research scope exists in ongoing activities:

- Development of web based Miniaturized ATS to characterize payloads from UHF to Q/V band and above, having very narrow to very wide bandwidths (5 KHz to 500MHz), using DSP techniques.
- Development of fast phase array antenna (PAA) measurement technique (in near/far field conditions) for LEO payloads
- Design of PAA test setup as well as qualification in thermovac & compact antenna test range (CATR) chamber.
- Characterization of multiple transponders in parallel using DSP techniques.
- Mismatch Fault isolation analysis using time domain techniques.
- Design and development of very high power waveguide terminations (> 2KW) at Ku and Ka band
- Design and development of high power pressure windows at S, C, Ku and Ka bands (quartz or alumina based).
- Design and validation of stimulus for various scenarios for communication, navigation, ADS-B, AIS, Radar, spectrum processing.
- Development of efficient technique for ground setup RF calibration setup for wideband multibeam/communication payloads.
- Feasibility analysis of Artificial Intelligence and Machine Learning (AI/ML) concepts application in analysis of payload test data generated during multiple phases of testing.
- Query based trend analysis on centrally stored payload test data, generated at different geographical locations.
- 5G NTN testbed design & development.
- Array antenna diagnostics & practical phase shifter uncertainty demonstration using deep learning approach.
- Measurement of nonlinearity with memory effects.

	• Test methodology for characterization of multi-beam payload with reduced test interfaces • G/T measurement in ALC mode • Characterization & calibration of multi-port amplifier • Document processing & information retrieval using large language modelling • Near field characterization of payloads having phased array fed reflectors	
B	**Area**	**Satcom & Satnav Applications & Associated Technologies (SAC/IISU/URSC)**
B1	**Sub Area**	**SATCOM Applications and Technology Development (SAC)**
	Space Applications Centre, ISRO, Ahmedabad is responsible for SATCOM Applications and Technology development for eventual use of Societal and Strategic users of the country. Besides meeting the application needs, the Centre continues to work on development of state-of-the-art technologies for SATCOM with an intent to indigenise technology and product development. In the last two years, the Centre has been into the establishment of more than 25 SATCOM Gateway stations in Ku/Ka band to meet national enterprise VSAT communication demand using upcoming HTS class of satellite. In the Mobile Satellite Service domain, the Centre has developed applications like Real-time Train-tracking Information System (RTIS), MSS Network for Tracking of Sub-20m boats, Real-Time Aircraft Tracking System etc. to meet the custom requirements of user ministries. Besides these efforts, the centre also focuses on development of technologies like SATCOM baseband ASIC development, MMIC development for RF Sub-systems, Signal Processing algorithms for SATCOM baseband technologies to enable communication on the move (COTM) for Airline, Maritime and Land Applications. The Centre specializes on baseband technology development pertaining to FSS and MSS. The Centre is working on development of advance technologies for miniaturization (Satcom Baseband ASIC), cost and power efficient battery operated MSS terminal development to support voice communication, IoT and M2M communication using MSS satellites. The Centre is also exploring the opportunity to promote development of RF and baseband sub-system technologies indigenously by collaborative efforts. While efforts are ongoing to achieve self-reliance, there are many new technologies still that need development in the domain of Satellite Communication Ground Systems like more powerful processors/ASICs, new source/channel encoding-decoding capabilities, user terminal miniaturization and baseband algorithms that can enhance user mobility, versatility, performance in a cost effective manner. This document incorporates research areas relevant to the satellite communications ground segment and application development to meet the near future requirements.	

B1.1	**Baseband Technology Development (SAC)**
B1.1.1	**Non Orthogonal Multiple Access (NOMA) based Multi-beam High Throughput Satellite /Ultra High Throughput Satellite System (SAC)** Researchers are invited to explore the potential of Non-Orthogonal Multiple Access (NOMA) technology in Satellite Communications (SATCOM) systems. To submit a proposal, researchers should provide mathematical analysis and explain how NOMA can be integrated into existing satellite systems from a system-level perspective. Specifically, they are encouraged to propose methods for combining NOMA with pre-coding techniques, outline an implementation plan, and demonstrate the effectiveness of NOMA in low signal-to-interference (C/I) conditions. Additionally, researchers are invited to develop and evaluate receiver algorithms that can handle multi-user detection and successive interference cancellation (SIC) at the receiving end. The goal is to improve spectrum utilization efficiency and reduce co-channel interference in SATCOM networks. Researchers should propose innovative solutions for NOMA-based systems in various application scenarios.
B1.1.2	**Algorithm and Implementation of real-time Wideband Spectrum Sensing (WSS) and Automatic Modulation Recognition AMR) system for Blind Signal Detection (SAC)** Blind Signal Detection (BSD) relies on sophisticated algorithms to efficiently analyze wideband signals and identify modulation types in real-time. To further enable its practical application, researchers are invited to propose novel approaches for automatic spectrum sensing and modulation recognition systems. These proposals should also address the challenges of identifying communication streams, demodulating signals, and monitoring interference. In addition, BSD systems can benefit from advanced techniques such as carrier-in-carrier (CIC) or PCMA-based methods for more accurate identification. Researchers are encouraged to submit their ideas for efficient spectrum sensing and modulation recognition systems that include: • Interference detection and mitigation strategies • Signal demodulation plans with implementation details • Methods for identifying blind scramblers and channel coding techniques By tackling these challenges, researchers can contribute to the development of reliable BSD systems that enable more efficient and effective use of communication resources.
B1.1.3	**Advance Baseband Technologies for Vocoderless audio communication for Satellite Phone (SAC)** In the Ongoing research of efficient datarate communications, vocoderless audio communication is provided through satellite link in ultra low datarates. This unique

	choice of vocoderless audio communication and the ultra-low data rates allows and paves the way for miniaturized low power satellite terminal with voice and data communication. It will also allow massive number of devices to be supported simultaneously due to efficient utilization of bandwidth. This novel research development will help providing voice and data communication in existing low bandwidth channels. This research is aimed at realizing the low power Miniaturized Satcom Voice and Data terminal with two-way communication capability for strategic applications aimed at ultra-portability.
B1.1.4	**Baseband Technology for Search and Rescue (SAR) systems of ISRO (SAC)** ISRO operates INSAT satellite(s) equipped with a 402-MHz Search and Rescue payload as well as 406 MHz Data Relay Transponders that are being used for SAR operations using different types of distress beacons of maritime, aviation and land users. • Researchers are encouraged to submit their proposal for development of MEO-SAR emergency locator transmitters with requisite Letter of Undertaking (LUT) processing algorithm. • Data Relay Transponders are usually of 200 to 350 kHz bandwidth and being non-regulated band suffer from interference from users. The nature of interference being non-time dependent and sweeping nature causes the communication loss. Researchers are encouraged to submit development proposal in interference resistant waveform for sensor data reporting in burst mode of transmission that can offer better quality of service. • Proposal on development of Mixed signal ASICs for SAR user terminals are encouraged.
B1.1.5	**MSS/DRT Network for data collection from Oceanic Platform (SAC)** ISRO has already established a network with multiple GSAT satellites carrying MSS transponders & INSAT satellites carrying Data Relay Transponders (DRT) transponders. Also more next generation satellites with advanced MSS/DRT transponders & larger antenna will be coming up in future. This network can be potentially utilized for data collection & relaying applications from oceanic platforms. This network can facilitate the data collected by different oceanic sensors deployed at different locations to be communicated to control centre in near real-time. The network can have hybrid reconfigurable terminals which can communicate in both MSS & DRT bands & provide unified interface with sensors. Researchers are encouraged to innovate and propose design of ASICs, low-profile planar antenna system with beam-forming capability and suitable waveform for robust communication and leading to low power miniaturized system realization. A very low bit-rate (25-300 bps), fast acquisition, spectrally efficient spread spectrum burst demodulator design will add value to the proposal.

B1.1.6	**Baseband Sub-systems of Ground Network with multi-homing capabilities for Gaganyaan (SAC)** ISRO has been working on the Gaganyaan Project, which will also include development of audio/video processing system for ground segment. All ground stations are connected to Master Control Centre (MCC) through multiple ground links to achieve failsafe transmission reliability and service quality. For real-time multiplexed streams comprising audio, video and data, the reliability requirement is different for each type of data stream. So there is a need of an efficient transmission technique for such multiplexed streams with different reliability parameter settings for each stream over a multi-homed networking environment. It is also required to have a suitable handoff mechanism in case of link failover with minimum handoff latency. Researchers are encouraged to propose a custom protocol stack for seamless multimedia communication over multi-homing network.
B1.1.7	**Design and Simulation of digital beam-forming / electronic beam steering-techniques for high frequency COTM/SOTM (Communication on the Move / Satcom on the Move) applications) (SAC)** The Indian Space Research Organisation (ISRO) has designated specific frequency bands for its satellite services, including the S-band for Mobile Satellite Service and Ku/Ka band for aeromobile broadband services. To optimize performance and support critical communication protocols, researchers are sought to develop advanced technologies. Specifically, proposals are invited for the design and development of efficient electronic beam steering systems that can mitigate interference in the S/Ku/Ka frequency bands used by ISRO's satellite services. The proposed systems should also ensure seamless switching between different communication modes (COTM/SOTM). Additionally, researchers are encouraged to submit proposals for: Compact mechanically steerable antenna systems suitable for aero-mobile applications Hybrid systems that combine mechanical steering with electronic beam control for improved efficiency and reliability The goal is to develop cutting-edge technologies that can enhance the performance and effectiveness of ISRO's satellite services.
B1.1.8	**Development of baseband signal processing elements for aero-mobile terminals (SAC)** The demand for in-flight broadband connectivity is on the rise, driven by increasing expectations for high-performance services from aircraft operators. As a result, more airlines are investing in on-board broadband systems, leading to growing demands for reliable and efficient connectivity.

	To meet these demands, ISRO's satellite-based broadband network uses Ka-band satellites and ground equipment to provide high-throughput services to aircraft in flight. However, the challenge lies in offering affordable, low-cost terminals that can support a multi-beam network with high-performance capabilities. Researchers are invited to submit innovative designs for Ultra-High Throughput Satellite (UHTS) class modem technology, which must enable: Wide and fast acquisition capabilities, Support for large drifts in satellite position and velocity, State-of-the-art access schemes, such as mobility management techniques for aero-mobile broadband These advanced technologies will be essential in enabling low-cost, high-performance terminals that can provide reliable broadband services to aircraft in flight.
B1.1.9	**Design & Simulation of physical-layer waveform for high mobility wireless channel (high Doppler-delay channel) (SAC)** Providing reliable wireless communications for high mobility terminals remains one of the main challenges faced by satellite high-mobility communication systems. because the high Doppler frequency offset, Doppler rate & delay caused by the high-mobility nature of the mobile terminal, and low signal-to-noise ratio (SNR) circumstances caused by limited satellites' link budgets degrade the system performance seriously. This is a very challenging aspect in LEO broadband communication. Most of algorithms mainly focused on the estimation and compensation of Doppler frequency rate and Doppler frequency offset, rather than reducing the influence of Doppler effect in the communication system. To solve such a problem in high-mobility satellite communications advance physical layer waveform may be proposed which is insensitive to Doppler & delay. Researchers are encouraged to offer innovative solution in form of algorithm, simulation model as part of their proposal.
B1.1.10	**Generation and performance evaluation of candidate waveforms for NB IoT and NTN (SAC)** With the evolution of Internet of Things (IoT), education, healthcare, commerce, and energy has put strong pressure on current generation of wireless networks to improve their services by including Non Terrestrial Networks (NTN) for better coverage and seamless connectivity. The explosion of smart devices and applications has resulted in the largescale use of the IoT requiring huge data rates, latency, frequent sensing, and computation that can exceed the capabilities of current networks. As the requirements in these applications continue to increase, NTNs will have to offer good energy efficiency, improved spectral efficiency, very low latency, and high mobility. To meet these requirements, the radio interface of NTN will have to be flexible and improvised. Therefore, new modulation methods, access techniques and waveforms capable of supporting these technological changes need to be generated and evaluated. Researchers are encouraged to offer innovative solution in form of algorithm, simulation model as part of their proposal.

B1.1.11	**Design & Simulation of baseband technologies for LEO Broadband communication (SAC)** The LEO Broadband Communication Network consist of Ka/Ku band user terminal, Space segment & Ka-band Satellite Gateway. Satellite Orbit propagation & Scheduling, automatic antenna pointing/beam steering, beam acquisition/ switching, Space resource management, Satellite handover & security are the major technology challenges. Researchers are encouraged to propose innovative efficient solutions/algorithms for above challenges. Researchers may also propose detailed hardware & software architectures of various baseband systems in User Terminals & satellite gateways.
B1.1.12	**Design & Simulation of waveforms for Extremly Low SNR Satellite communication (SAC)** The satellite communication industry is experiencing a surge in demand for mobile broadband and Internet of Things (IoT) applications. These emerging use cases require the development of compact, low-cost, and energy-efficient user terminals that can operate reliably at extremely low signal-to-noise ratios (SNR) (-30dB or lower), while maintaining high bandwidth efficiency. Researchers are encouraged to submit innovative proposals for: Efficient waveforms that can effectively transmit data in adverse channel conditions. Advanced signal processing algorithms that enable robust acquisition, synchronization, and reliable operation of receivers under dynamic channel conditions, including extremely low SNR and high Doppler frequencies. Furthermore, researchers are invited to propose efficient multiple access schemes and signal processing technologies that can maximize capacity in satellite communication networks, ultimately enabling the widespread adoption of mobile broadband and IoT applications. The goal is to develop novel waveforms and signal processing techniques that can overcome the challenges of operating at extremely low SNR, while maintaining high bandwidth efficiency and reliability.
B1.1.13	**Geolocation of interference using terrestrial technology (SAC)** To disrupt satellite-based communications, it is observed that an interference signal is being transmitted at the same operating frequency by some unknown source. This interference signal makes it difficult for the intended receivers of the ongoing communication to demodulate the received signal. The location of such malicious transmitter that is transmitting the interference signal is unknown. This research proposal is therefore aimed at processing the interference signal to estimate the location of such malicious transmitter.

	This research proposal envisages the use of multiple ground based receivers to receive the signal transmitted by a malicious transmitter and process this signal to estimate the geo-location of the transmitter. The work/ algorithm must not use any aerial borne receiver platform and should only consider ground-based receivers that are receiving the transmitted signal. Researchers are encouraged to offer innovative solution in form of algorithm, simulation model as part of their proposal.
B1.1.14	**Optimizing PQC for resource constrained IoT Devices (SAC)** The emergence of Internet of Things and cyber security for spacecraft applications are two important areas that demand the adoption of an increasing number of security standards which in turn requires implementation of a diverse set of cryptographic primitives. This poses tremendous challenges in the design and implementation of PQC standards in a single embodiment. The implementation of standards should handle large key sizes and at the same time should not be too expensive in terms of speed and energy. This requires optimization of cryptographic primitives implemented in hardware. The hash module, NTT and multiplication processes, compression and decompression and sampling need to be implemented with minimum number of resources. The design should also ensure that the security in not compromised with such optimization.
B1.1.15	**Enhanced Spread Spectrum Aloha Technology Development (SAC)** Enhanced Spread Spectrum Aloha (E-SSA) is an asynchronous access protocol especially conceived to provide messaging services over the satellite return link. Protocol is slightly modified version of the robust 3GPP Wideband Code Division Multiple Access (W-CDMA) random access waveform (asynchronous burst transmission). The absence of synchronization mechanisms simplifies deployment and activation of the terminals. A wide range of applications based on burst transmissions not significantly capacity-demanding have been envisaged, such as telemetry, environment and traffic monitoring, emergency alerts, fleet management, highway tolling, forecast predictions. Researchers are encouraged to submit their proposal for ESSA system simulation and Receiver design and implementation plan.
B1.1.16	**IoT enabled terminal development (SAC)** Implementation of IoT/M2M via satellite deals with mainly two issues: First, the physical layer level: terminal related constraints (limited in power, energy, and antenna size), channel (potentially with masking and multipath) and the space segment to ensure proper link budget allowing the communication. On the other hand, the need to provide access to the resource to a large number of terminals. The access layer should also be able to interface with larger networks architectures. There are two possible ways of realizing IoT/M2M via satellite. The first scenario involves the use of a satellite relay terminal that interfaces with terrestrial access technology

	sensors (backhaul communication link). The second scenario is based on direct communication with sensors / objects via satellite constellation. Research proposals are invited for implementation of low power, low cost terminals, waveforms and other sub-system technology to support IoT over Satellite & Terrestrial networks.
B1.2	**Ground Segment Network and Hardware Technology Development (SAC)**
B1.2.1	**Indigenous VSAT sub-systems technology development (SAC)** In today's scenario, there is an increasing need to indigenize the baseband subsystems of Very Small Aperture Terminals (VSAT) due to their stringent power, size, and operational requirements. To meet these demands, researchers are encouraged to submit innovative proposals for designing and developing indigenous solutions for VSAT technology. Specifically, researchers are invited to propose: Efficient, low-cost designs for RF subsystems commonly used in VSAT terminals, such as: • Battery Disconnect Unit (BDC) • Block upconverter (BUC) • SSPA (Supervisor Security and Privacy Assurance) Rapidly deployable VSAT terminals that can quickly establish communication links in emergency disaster situations. These designs should feature advanced antenna and RF technologies, supported by state-of-the-art baseband technology for: • Quick antenna pointing • Establishing reliable communication links from mobile platforms with limited power space availability Extending interfaces to terrestrial devices for providing backhaul connectivity through the satellite. The goal is to develop innovative solutions that can meet the complex requirements of VSAT terminals, while promoting indigenization and reducing dependence on imported technologies.
B1.2.2	**Development of Low Profile Ku/Ka band terminal for Mobile Satellite Service (SAC)** ISRO is aiming at realizing the mobile satellite service in Ka-band. Researchers are encouraged to submit their proposal for Ka-band Mobile Satellite Service system solutions with their feasibility and recommendations; Proposals for terminal design, Proposal for protocol stack development for seamless overlay with existing MSS services, in case needed. Innovative ideas are encouraged from researchers towards providing reliable MSS services in Ka-band along with sub-system design proposals.

B1.2.3	**Portable HUB baseband system development (ESIM)(SAC)** Earth stations in motion (ESIM) address a complex challenge – how to provide reliable and high-bandwidth Internet services to what are – literally – moving targets. They provide broadband communications, including Internet connectivity, on platforms in motion. There are currently three types of ESIM: ESIM on aircraft (aeronautical ESIM), ESIM on ships (maritime ESIM) and ESIM on land vehicles (land ESIM). Earth Stations in Motion (ESIMs) are the result of the most modern satellite technological developments and are designed to be used on aircraft, ships and land vehicles. They are small size terminals, with high-precision tracking capabilities, associated with state-of-the-art Ka-band satellites providing high-power multiple spot beam coverage, allowing transmission rates in the order of 10-50 Mbits/s. Recognizing that there is a need for global broadband mobile-satellite communications and that part of this need could be met by allowing ESIMs to communicate with fixed-satellite services (FSS). The advances in satellite and earth station technology make ESIMs the best solution for users on the move and bring the benefits of high performance FSS networks to communities that have yet to benefit from true broadband offerings. Researchers are encouraged to submit their proposal for design, development and implementation of different ESIMs.
B1.2.4	**Internet Protocol for Satellite Network (SAC)** In recent years, many routing algorithms have been proposed for LEO satellite networks. Routing Internet traffic over satellites can be addressed using two alternative approaches. We can simply consider each satellite as a node in the Internet and use a traditional protocol stack. However due to the long round trip time (RTT) delay between the satellites and the terrestrial infrastructure, problems such as routing instability and slow convergence will be even worse than only using the terrestrial Internet. On the other hand, we can consider the satellite network a separate autonomous system (AS), with its own protocols. In this case, an IP packet will be encapsulated in a suitable way when entering the constellation, and rebuilt when inserted back in the terrestrial network at destination. The routing problem is divided into two sub problems: Up-and-Downlink (UDL) routing and Inter satellite link (ISL) routing. Again, to ensure quality of services, research in this field is growing and there are various open issues and research areas in the field of Satellite Networks like – • Reducing the routing overhead of a dynamic QoS routing in a different traffic is a challenge. • GEO satellites have advantage of technological maturity and good coverage but due to high delay and attenuation limits, transmitting real time information becomes a problem. A single layer LEO satellite network has poor performance on transmitting

	long distance. How to combine advantage of both the satellite to improve network performance. Multicasting datagram in the satellite networks to achieve larger coverage area on the terrestrial infrastructure is also a potential research area.
B1.2.5	**Adaptive protocol (SAC)** To cope with the highly dynamic behaviour associated with the wireless environment and mobility, it is widely recognized that protocols should be able to adapt to a wide variety of situations. While protocols in the wired network also adapt to different conditions in a very limited way, usually at connection-setup time. Once a connection in a wired network is established, the underlying conditions will remain relatively stable, other than occasional congestion. This is often not so in wireless mobile networks. The wireless link experiences a range of conditions e.g., fading, transient service outage, high error rates, burst error patterns, and highly unpredictable traffic on shared links. Furthermore, mobility exacerbates the situation by introducing handovers, motion-induced effects, rerouting actions, and limited battery life. Adaptive protocols provide productive ground for advanced protocol research. As nearly all protocol research has been done on relatively static protocol architectures, there is much to learn about how to select a different protocol on the fly when the original one no longer provides the required level of service. Protocol adaptation may be realized in several ways. Active networking, in which packets may contain executable instructions (in addition to headers and data), provides one approach to implementation. The efficient implementation of adaptive protocols in both hardware and software present interesting research problems. Some of the challenges are listed below: • End-to-end protocol design that dynamically switches from one interface to the other, transparently to the application and its user • Protocol stack development to support adaptiveness • Development of principles to allow on-the-fly protocol selection in wireless mobile networks. Identify techniques for deciding when to select a new protocol, for switching protocols, and for efficiently implementing this feature in software and hardware.
B1.2.6	**SATCOM in Non-Terrestrial Network (NTN) of 5G (SAC)** With the advent of 5G terrestrial network, Satellites are being proposed as an integral NTN component. ISRO is keen on extending its reach to be a part of next generation 5G communication, especially in the light of new satcom policy of the Govt of India. Researchers are encouraged to submit their research proposal for system and sub-system design for facilitating NTN component in 5G using SATCOM.

B1.2.7	**Q/V Band Propagation Study (SAC)** Presently Alphasat is the only satellite operating in Q/V band for European region available for such studies. Recently with GSAT-29, ISRO had established a limited capacity communication system for experimental purpose between Ahmedabad & Delhi. Due to congestion in higher band and bandwidth availability & demand, a very strong push for Q/V band is expected in future. Very high signal impairments and no availability of validated models for the Indian Region indicate a need to investigate this hereunto neglected area. These will serve as vital input for future satellite designs and deciding QoS and availability figures. Modelling and associated mathematical studies, development or realization of RF subsystems, beacon from satellite, pan-India study; Academia & Foreign Collaboration may be explored.
B1.3	**ASIC Technology Development (SAC)**
B1.3.1	**Design and Development of miniaturized, multiband S, L, UHF band) / S-band Low Power Wideband Transceiver Mixed Signal ASIC for SATCOM terminal (SAC)** The mixed signal ASIC will comprise of comprise of front-end LNA, filter, transceiver with built-in LO for full duplex operations, gain& filter blocks, ADC-DAC etc. The selected architecture should have all imbalance measurement and compensation techniques built into it. The device calibration feature will be an added advantage. The research proposal should address the development of low power, low cost custom RF wideband transceiver ASIC in S/L/UHF-band to support communication using miniaturized handheld and battery operated SATCOM terminals. The proposal should include all specifications of each sub-block, the reconfiguration parameters etc.
B1.3.2	**Design and Development of RF-ASIC to support implementation of low-power, cost-effective electronic beam steering capabilities for aero- mobile communication in Ka/Ku band. (SAC)** Aero-Mobile terminal in Ku-Band/Ka-Band with beam steering capability could be miniaturized using RF-ASIC. Researchers of this domain are encouraged to submit their proposal for design and implementation of RFIC for miniaturized, power and cost efficient terminal implementation.
B1.3.3	**Development of low cost terminal with Commercial-off-the-shelf (COTS) ASICs for RF front-end (MMIC and LTCC based RF Frontend for miniaturization) (SAC)** The important aspect of any terminal is it being hand held and light weight this trend we have observed in terrestrial mobile phones as day by day they are becoming light and small. If we consider the Satcom terminals, the miniaturization is current necessity of the situation as to be better usable and appealing for the consumers. The miniaturization is happening on the baseband front by the development of Application Specific IC's and

	single board setup where whole baseband is being included. Hence, the miniaturization on the RF part needs to be done in order to decrease the weight and the size so that the whole terminal can be small and light. There are a few techniques to reduce size & weight of the RF section. One of the most-utilized techniques is MMIC design in place of discrete microwave circuits where discrete active and passive components are integrated using either transmission lines on different substrates chosen according to frequencies. Monolithic Microwave Integrated Circuits (MMICs) contain active, passive, and interconnect components all on single wafer and can operate at frequencies from hundreds of MHz to hundreds of GHz. The size advantage obtained is very drastic as MMIC are of size of um to mm whereas the Microphone MIC circuits are in range of cm. Most of today's MMICs are fabricated on III-V compound substrates such as GaAs, InP, and GaN. This new technique enables us to make the circuits like LNA, Mixer, Power amplifier etc on a single Silicon doped chip, which are instead made using discrete components. Another miniaturizing technique lies in a type of packaging technology named Low Temperate Co-fired Ceramics (LTCC) where the technology is used for robust assembly and packaging of electronic components. It also offers may features like embedded components like capacitors resistors and inductors, as the passive components are available they can be utilized to make filters. The technology also allows us to make Substrate Integrated Waveguide filters. Further as the MMICs are bare dies, they need packaging, and interconnection LTCC proves to be the best option, which results in an integrated on a single RF module, which is very space efficient, and light weight. Furthermore, Antennas can also be made in order to make a more integrated space efficient and lightweight RF module which contains everything from Antenna to the IF signal. The utilization of all these techniques can yields us miniaturized RF frontend, which can be of similar size of that of a compact baseband card thereby yielding us a small, and light weight hand-held terminal, which can be comparable to modern day mobile phones. • **Modem ASIC development for Ultra High Data Rate System (100 Mbps- 2 Gbps)** • **Mixed Signal ASIC development with built-in low cost SATCOM transceiver for various low-power IoT applications**
B1.3.4	**Power Saving technique (Backend ASIC design) of ultra-low power Software Defined Modem (SDM) ASIC (SAC)** Satcom baseband modem ASIC is being developed for various Satcom ground applications. Typical application of Modem ASIC, which are battery, operated & demands low power consumption. The Modem ASIC supports multiple mod-code & wide range

	of data rate. Based on application ASIC is configured by Serial Peripheral Interface (SPI)/ Universal Asynchronous Receiver-Transmitter (UART) interface. Currently even when a simple configuration is running, the power of entire core is ON and the clock is active. Idea is to implement various power saving technique in frontend/backend ASIC design to suspend functionality of partial design or full design based on applications. Following power saving modes can be thought of considering nature of applications: a. **Fully sleep mode:** This mode is very useful in case of burst transmission & reception. Device will consume minimal power when not active. In this case, only configuration core is always active. Modem core is enabled whenever required & kept shut for rest of the time. Typical applications: Reporting Terminal, b. **Partial sleep mode:** This will be useful in almost all applications. This mode will disable the non-functional block for a particular configuration. In only Viterbi is used is active then other decoder should be shutdown. Entire receiver chain can be turn off in case of transmit only terminal & vice-versa. Typical applications: Two way MSS Vessel tracking terminal Sleep mode can be implemented using following methods **i. Clock gating** **ii. Power gating** **iii. Multi-Voltage level**
B1.4	**Applications and Tools Development (SAC)**
B1.4.1	**Development of Hybrid Network for Real-time Person or Asset Tracking using Machine to Machine Communication Technology and Indian Navigation System. (SAC)** Currently, ISRO has developed satellite-based solution for tracking of personnel and assets like vehicles and fishing boats. Although this solution is extremely useful in remote locations where terrestrial, network coverage is sparse or not existing at all, there is similar need for such solutions in areas, which are widely covered by terrestrial networks. A hybrid solution is proposed which can enable communication of mobile terminals using both SATCOM and terrestrial networks. This will greatly save the satellite resources and enable us to serve more number of users. The network will consist of terminals having the ability to communicate their location and other significant information with the hub via satellite and terrestrial networks. The terminal will be equipped with NavIC receiver to detect its location. It should have the intelligence to detect the availability each of this network and switch between them as and when required.

	As an extension of this functionality, the terminal should be intelligent enough to detect the presence of similar neighbours (terminals) around it. This may be achieved via point-to-point communication using Bluetooth/Wi-Fi. The Hub can also assist in finding neighbours. The terminal can find its neighbours and can directly contact them in emergency. A smartphone may interface with the terminal for visual representation of location and other information. Mobility management and interface for interaction between terminals also needs to be developed. • Development of Spectrum and Waveform Analysis tool using low cost SDR platforms. • Hub No Man's Sky (NMS), Network Control Program (NCP) and Web-based tools for effective Decision Support System • Propagation studies, Advance Fecal Microbiota Transplantation (FMT) development and inclusion for improved QoS • SATCOM System definition, Unified protocol stack and Test Bed development of 5G with Non-Terrestrial Networks (NTN) element • NTN standardization efforts and Capacity Development Activities • Development of mobility management algorithm and Hub Network Management System for different application
B1.4.2	**Satellite Communication On The Move (SOTM) (SAC)** Satellite communications-On-The-Move (SOTM) is a communication capability used for high speed satellite connectivity in moving vehicle. SOTM terminal with vehicle mounted automatic tracking antenna will provide two-way, high-speed communications on the move under various operational conditions using HTS (High Throughput Satellite). Using SOTM terminal, it is possible to provide high speed satcom connectivity for aero-mobile, land or marine applications. ISRO has developed prototype Ku band SOTM receive terminal with 0.6m antenna using 2 axis (Az and El) stabilized servo based system and demonstrated it for live DTH reception in moving vehicle. Research proposals are invited for • Mechanism and Control system design for 3 axis/4 axis automatic antenna steering and tracking of targeted satellite within +/- 0.1 degree accuracy for Ku band transmission. • Solutions for estimating highly accurate heading information by INS (Inertial Navigation System)/ Sensor in dynamic magnetic environment. Magnetometer is not providing proper heading under dynamic magnetic field condition. • Technology for Low cost INS with GNSS without compromising performance. • Compact and light weight Ku/Ka band flat panel/planner array antenna/ Carbon Fiber Reinforced Polymer (CFRP) reflector for mechanically steered transmit-receive SOTM system.

	• Design and development of efficient electronic beam steering system for Ku/Ka band operations as well as hybrid scanning system (electronic + mechanical) • Design and development of system to test pointing accuracy of SOTM in lab environment and algorithms to find out misalignment.
B1.4.3	**Satellite Network Simulator (SNS) (SAC)** The project's main objective is to develop a Satellite Network Simulator, which is used to generate and collect data-driven insights into the satellite network-level planning and design activities. The simulator will allow an estimation of bandwidth and power requirements to attain a target system-level capacity. The simulator will model the Variable Coding and Modulation (VCM), Adaptive Coding and Modulation (ACM), and Uplink Power Control (ULPC) systems that will be executed in an operational satellite network. Using the simulator, the system engineer will determine the attainable data rates attained in the clear sky and the rainy conditions and gather insights into the potential avenues of removing or reducing the bottlenecks so that the overall system capacity is improved. SNS is being developed in Python language with features viz. to carry out the forward and return link budget calculations, rain fade modelling, capability of providing DR site suitability recommendation, ULPC/ACM simulations, selectable DVB-S2 and S2X modcods in both forward and return link and evaluation of system availability. It will be useful for System engineering, network planning, throughput evaluation at different fading levels of existing & future High throughput satellites in higher frequency bands.
B1.5	**New Frontiers in SATCOM (SAC)**
B1.5.1	**Development of High Data Rate (HDR)/ Ultra High Data Rate (UHDR) modems for Home broadband service (SAC)** SATCOM based Home broadband service is one of the emerging field. Ultra High Data Rate Modems will be essential component of this technology. These modems should be capable of supporting upto 1Gbps receptions capability for offering broadband services equivalent to terrestrial broadband, to remote users. The major design challenges for such UHDR modems include reconfigurable hardware platform & high-speed data processing subsystems including demodulation loops, high throughput advanced FEC Encoder/Decoders & multi-core baseband data processing engines.
B1.5.2	**Indigenization of Future HTS Gateways (SAC)** ISRO is inclined towards providing Direct to Home Broadway connectivity using HTS Satellites. This will require Gateways & antenna system in large quantities. Aim is to bring down the overall cost with indigenization efforts. Today, across the globe three major market players are operating and have maximum market share. The trend is to implement gateways in frequency band of Ka or higher band.

	Researchers and Industry partners are encouraged to innovate and propose efficient design of 9/11m antenna system, RF-sub-systems, NavIC based TFGU, Hub Monitoring and Control System, Antenna Tracking System etc. which can reduce design and production lead time, be cost effective and mass producible design.
B1.5.3	**Device and method for fragmenting virus/microbe using RF radiation (SAC)** A non-thermal method of virus inactivation (in-vitro) especially SARS-CoV-2 by physically fracturing the viral outer envelope using microwave radiation at its precise natural frequency has been developed at SAC. A generic theoretical approach has been identified to calculate the natural frequency of any spherical virus. Nanoparticle Tracking Analysis (NTA) & real time Real Time Polymerase Chain Reaction (RT-PCR) analysis was performed to test the efficacy of the developed prototype on Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2). On detailed analysis of test results it was found that the device was efficient enough to eliminate up to 99% of SARS-CoV-2 upon one minute of exposure. Antiviral efficacy of developed prototype is successfully tested for various virus contaminated surfaces such as glass, metal, ceramic and laminate and achieved up to 99.99 % SARS-CoV-2 viral elimination within five minutes of radiation exposure time. Patent granted (patent no. 465801) for the invention titled "Method and Device for fragmenting virus/microbes using RF radiation at resonance frequency" by the Indian Patent Office (IPO). **Research Areas include:** • Design and development of miniaturized decontamination system which removes airborne contaminants -- such as biological (virus/microbes) and chemical impurities. • Implementation of the technology for destruction of mosquito larvae at an early stage. • Sanitization of spacecraft using resonance frequency technique to avoid spread of microorganism during interplanetary travel.
B1.5.4	**SATCOM based solution for Early Warning Disaster Management for extreme weather conditions (SAC)** To enhance the efficiency and reliability of the EWS at unmanned Glacial locations in events like GLOF (Glacial Lake Outburst Flood), an all-weather SATCOM solution is envisaged to provide reliable communication links for data transmission. In extreme low temperatures and remote sites, providing power with proper backup for communication setup is challenging, due to non-availability power grid and continuous power requirement of the equipment and limitation of battery backup. Also, even light rain and snow/ice accretion on antenna surface can form a water film causing signal degradation during outdoor operations especially at remote unmanned locations where the power available is restrained to solar generation. Hence, VSAT solutions with heater

	and/or manually clearing the deposited snow/water film from the antenna surface is not feasible. Therefore, there is a need for low cost, durable water/snow repellent coating/materials which can facilitate un-interrupted VSAT operations at unmanned remote locations.
B1.5.5	**Passive flat panel antennas for Ext. C band operations (SAC)** The flat panel antennas offer several advantages over traditional parabolic antennas including compact size, light weight design and ease of installation. The development is required for passive flat panel antenna in ext. C band covering the transmit frequency range from 6.725 to 7.025 GHz and receive frequency range from 4.5 to 4.8 GHz. Keeping in mind the advantages of flat panel antenna, the scope of this research is to design and develop passive flat panel antenna in ext. C band covering the transmit frequency range from 6.725 to 7.025 GHz and receive frequency range from 4.5 to 4.8 GHz. The desired antenna gain should be more than 26 dBi and power handling capacity of up to 5W. The panel size should be restricted to sub 1-meter range preferably around 0.6-0.7 m.
B1.5.6	**SATCOM Based Beyond Visual Line of Sight (BVLOS) Operations (SAC)** SATCOM Based Beyond Visual Line of Sight (BVLOS) Operations refers to the use of SATCOM technology to enable drones or Unmanned Arial Vehicles (UAVs) to operate beyond the pilot's visual line of sight range. BVLOS operations are essential for long range missions especially in areas where traditional line of sight communication is impractical or disaster stricken areas where terrestrial infrastructures are not available. Currently SAC ISRO is developing SATCOM solution for telemetry and control of UAV to enable BVLOS connectivity. SAC is developing MSS terminal and customized MAVLink protocol for low data rate & high latency GEO satellite communication link. In future, Ku band SOTM terminal is to be developed to support high data rate video communication. Research proposals are invited for • Latency and throughput optimization techniques for MSS channel • Hybrid communication system which combines all other possible communication link with SATCOM link to ensure seamless connectivity • Electronically steered antenna for video, telemetry and control data communication • Multi-constellation integration into a single unified system for uninterrupted coverage across different geographic locations • Cybersecurity protocol for SATCOM to protect against hacking, spoofing or jamming attempts.
B1.5.7	**IoT and AI-enabled Remote Healthcare Monitoring in Tele-Medicine (SAC)** The integration of Internet of Things (IoT) and Artificial Intelligence (AI) has the potential to revolutionize the healthcare industry by enabling remote monitoring, early disease diagnosis, and proactive treatment. This research proposal aims to explore the application

	of IoT and AI in tele-medicine, leveraging wearable devices and sensors to continuously collect patient data, which can be utilized for improved treatment outcomes and faster disease diagnosis. Research Objectives of this proposal are as under: • To design and develop an IoT-based tele-medicine system that integrates various wearable devices and sensors (e.g., accelerometer, altimeter, digital camera, electrocardiogram, electromyograph, electroencephalogram, electrodermograph, location GPS, microphone, oximeter, Bluetooth proximity, pressure and thermometer) to collect patient data. • To develop an AI-powered analytics platform that can process and analyze the vast amount of data generated by IoT devices, identifying patterns and anomalies that may indicate potential health risks or disease progression. • To investigate the application of machine learning algorithms in predicting disease diagnosis and prognosis based on IoT-collected data. • To evaluate the efficacy and feasibility of the proposed tele-medicine system in improving patient outcomes and enhancing overall quality of life. To implement the mentioned proposal, a comprehensive review of existing research on IoT, AI, and tele-medicine will be conducted to identify gaps and areas for improvement. The IoT-based tele-medicine system will be designed and developed, incorporating various wearable devices and sensors. Patient data will be collected from the wearable devices and sensors, which will be transmitted to a centralized server for processing and analysis. Machine learning algorithms will be applied to analyze the collected data, identifying patterns and anomalies that may indicate potential health risks or disease progression. Expected Outcomes of this project are as under: • Development of an IoT-based tele-medicine system that integrates wearable devices and sensors for continuous patient monitoring. • Creation of an AI-powered analytics platform that can process and analyze vast amounts of data generated by IoT devices. • Identification of machine learning algorithms that can accurately predict disease diagnosis and prognosis based on IoT-collected data.	
B2	**Sub Area**	**Satellite-Based Navigation (SATNAV) Technology & Applications (SAC)**
	India has developed its own navigation system named NavIC (Navigation with Indian Constellation). The NavIC constellation is a combination of GEO and GSO satellites which are presently transmitting L5 (1176.45 MHz) & S (2492.028 MHz) band signals that are received by the user devices equipped with NavIC receivers. In receiver segment, various types such as User Receiver, Reference receiver, Timing Receiver and messaging	

	receivers are being developed by SAC and through transfer-of-technology (ToT) and other collaboration modes, by private companies. These receivers are capable of providing pseudo-range (Code phase) and carrier phase measurements which can be processed to provide metre- to cm-level position accuracies. Real Time Kinematic (RTK) solutions based on differential positioning concept and Precise Point Positioning (PPP) are techniques used to provide very high accuracy positioning upto cm-level accuracy. Receivers equipped with these capabilities are usually dual frequency equipment and use very precise carrier phase measurements. These receivers have very wide applications in the field of survey & land records, geodesy, 5G, testing driverless / autonomous cars and precision agriculture. Also, NavIC chips as well as NavIC-in-mobile platforms are coming up and may be used for ubiquitous location-based services etc. Furthermore, there are various scientific and technical applications which can be addressed by using NavIC and other GNSS receivers, Inertial Navigation System (INS), ground-based navigation system such as Pseudolite system developed at SAC etc. Different algorithms are required to process these multi-constellation receivers equipped with INS and other navigation aids. Therefore, new algorithms, software and solutions are required to be developed. This document highlights various research areas in Satellite Navigation to cater applications in various fields. Use of GNSS measurements has also been very promising in meteorological applications such as estimation of Integrated Water Vapour (IWV) which is ingested in Numerical Weather Prediction (NWP) models etc. Space weather is also one of the very important aspect which is being addressed using GNSS signals. This section relevant to applications deriving from ISRO's navigation satellites constellations is broadly divided into two major segments of technology development and GNSS applications which largely include scientific applications also.
B2.1	**Technology Development (SAC)** NavIC signals in general may be prone to interference with other GNSS satellite signals such as GPS, Galileo and Beidou. The NavIC S-band signal in particular may experience interference from commercially used S band spectrum by Wi-Fi and WiMax services. Therefore, interference/jamming detection and mitigation algorithms and techniques need to be vitally developed.
B2.1.1	**Joint optimization of signal waveforms, spreading codes, and multiplexing scheme (SAC)** Many existing constant envelope multiplexing (CEM) design approaches rely on the assumption that the spreading sequences of different component signals are perfectly orthogonal. However, in real-world scenarios, the imperfect orthogonality of these sequences can cause slight distortions in the correlation function following multiplexing, which may lead to an inherent bias in code tracking. A promising direction for future

	research involves the integrated design of spreading sequences, chip waveforms, and CEM. An initial attempt was made to address this, where the symmetry of the code sequence was incorporated as a constraint in the optimization framework, resulting in a notable reduction in the inherent bias of code tracking.
B2.1.2	**Constant envelope multiplexing for general modulations (SAC)** The constant envelope multiplexing (CEM) discussed so far for GNSS are primarily designed for memoryless DSSS signals with multilevel chip waveforms, where instantaneous waveform value transitions are assumed. This assumption implies that the components being multiplexed maintain sufficient side lobes outside their main spectral lobe. Since the multiplexing operation occurs in the digital baseband using digital logic, and the envelope constancy must only be preserved up to the high power amplifier (HPA) input, the assumption of instantaneous transition remains approximately valid, provided that the bandwidth of the up-converter before the HPA is sufficiently wide. Consequently, envelope distortions caused by chip transitions have not been a major concern for a long time. However, as spectrum resources become increasingly scarce, more complex chip waveforms with higher spectral efficiency, such as the prolate spheroidal wave function (PSWF) waveform, are being proposed for future satellite navigation signals, particularly in the C-band. Additionally, advanced modulations, such as continuous phase modulation (CPM) and chirp spread spectrum (CSS), are being considered as alternatives to DSSS. For signals with continuous transitions in their waveforms and memory-based modulation, existing CEM techniques are not directly applicable. Therefore, the development of CEM techniques capable of accommodating signals with more general spreading waveforms or even non-DSSS signals presents an area of promising research. Preliminary results are emerging in this domain, such as the combination of two components into a CPM signal.
B2.1.3	**Lunar-PNT Systems for Autonomous Navigation (SAC)** This research focuses on designing and developing PNT systems tailored for autonomous lunar exploration. Traditional Earth-based GNSS systems are not feasible for the Moon due to the lack of infrastructure, so a lunar-specific PNT system needs to be developed. This includes studying the Moon's gravitational environment, using lunar landmarks for positioning, and leveraging celestial navigation methods. The research would explore potential integration with lunar orbiters to provide continuous coverage, as well as solutions to address challenges such as lunar terrain-induced errors, dust storms, and the absence of a global positioning network. It also involves examining the integration of advanced sensors, like altimeters and gyroscopes, with the PNT system for precise navigation on the lunar surface.
B2.1.4	**Impact of Lunar Environmental Conditions on PNT Signal Integrity (SAC)** This research examines how the unique environmental conditions of the Moon—such as extreme temperature variations, dust storms, and radiation—impact the performance

	and reliability of PNT signals. It would explore the effects of these factors on radio signal propagation, system accuracy, and signal degradation over time. The research would propose solutions to mitigate these effects, such as the use of low-frequency or high-frequency signals that may be less susceptible to lunar environmental disturbances. Additionally, it would investigate the potential for signal interference from the Moon's regolith or interactions with solar and cosmic radiation. Ultimately, this topic aims to ensure robust, reliable, and accurate PNT performance for future lunar missions and long-term lunar bases.
B2.1.5	**Impact of LEO Satellite Dynamics on Time Synchronization and PNT Accuracy (SAC)** This research addresses the effects of the unique orbital dynamics of LEO satellites on time synchronization and overall PNT accuracy. Due to the high velocities and rapidly changing orbits of LEO satellites, precise synchronization of their onboard clocks with the ground or other satellites is challenging. The study would focus on the impact of these dynamics on time error propagation, clock drift, and potential signal interference, and propose advanced algorithms for time synchronization across satellite constellations. The research would also consider the challenges of maintaining synchronization over long durations and during rapid orbital manoeuvres, which can lead to varying signal delays. The goal is to develop robust methodologies to ensure accurate timekeeping and PNT performance for LEO satellite-based services, essential for applications like remote sensing, real-time navigation, and global communication.
B2.1.6	**Configurable GNSS Universal Correlator Architecture ASIC for various NavIC Applications: (SAC)** Development of NavIC + GNSS Baseband ASIC (NavASIC v3) @ 28nm node is carried out at SAC to cater the requirements of high performance, low power and small size navigation receiver for civil and strategic users. It has massive correlator based fast acquisition engine for direct acquisition of NavIC Authorised Long-codes; thereby achieving the critical Time to First Fix (TTFF) requirement of the order of 10-15 sec. It consists of 100 tracking channels to process all-in-view open GNSS civilian signals along with NavIC SPS and authorised signals. It also has external code generator interface so that same ASIC can also be catered to future Navigation signals. The chip is targeted at 28 nm technology node for optimized power, performance and area (PPA). ASIC design consists of ~50 Million NAND2 equivalent gates. SAC carried out ASIC Architecture design, FPGA prototyping, Front-end design (RTL and gate level netlist synthesis) & verification whereas Back-end design and fabrication through MPW run was outsourced to Indian vendor. ASIC architecture is designed such that it is having a lot of configurability for usage in variety of applications with different operating modes. 32-bit dual core processor is used along with GNSS hardware correlators, timing and measurement modules for Baseband signal processing & Navigation solution computation.

	ASIC has state-of-the-art Partial Matched Filter with FFT based acquisition engine for fast and direct acquisition of optimized Long code with time assistance from RTC along with support for acquisition of open NavIC & GNSS signals. ASIC also has four 2046 tap matched filter based acquisition modules which support epoch to epoch integration required for acquisition of signals having same PRN code duration and data-bit period along with support for BPSK(10) signals. This ASIC has total 100 tracking channels, which are configurable for processing of NavIC-SPS, Short/Long signals, and open GNSS signals, which are having different modulations, PRN code rate, length and data rate. The configurability is achieved by universal acquisition & tracking correlator design for processing of different types of signals. ASIC can also process Pseudolite signals. ASIC can accept digitized IF inputs either in real or complex format from multiple GNSS RF signal bands such as L1, L2, L5 and S. This ASIC also has external code streaming interface for accepting PRN codes from an external chip. ASIC has inbuilt anti-jamming module for CW and Pulse interference mitigation. ASIC also has clock-gating and power-gating feature for power savings in different operating scenarios. The design is partitioned in multiple blocks (total 20) & each block is synthesized separately (hierarchical synthesis) with UPF flow (for power gating) & were connected through top module with wrapper logic. On-chip PLL IP is used for generating different processor clock frequencies depending on the application requirement. RTL and netlist design has been thoroughly verified by Design & SQA teams using different test vectors & verification strategies. FPGA prototype & emulation of ASIC has been carried out & tested with simulated scenarios of NavIC and GNSS signals using GNSS simulator. The chip peripherals include three UARTs, one SPI core with multiple slave selects, one I2C core along with dual MIL-1553B RT core. The gate-count of this ASIC is ~50 million with 6.5mm x 6.5mm die size & 15mm x 15mm flip-chip BGA package. Initial board bring-up & testing is carried out and first cut Positioning is obtained successfully in intermediate 64 pin CQFP package. Power consumption of this ASIC is 180mW to 600mW range in different operating modes. Thorough testing in final BGA package is under way. This ASIC has dual core Sparc V8 processor, so that for various applications like vehicle tracking, RTK, DGNSS operations; there is no need to have external processor in addition to this ASIC. New Algorithm development can run in any one of the core, while other core will continuously do PVT positioning.
B2.1.7	**Development of CMOS /BiCMOS RFIC (SAC)** SAC is involved for design and development of NavIC based receiver for broad range of applications, like Civil, Military and Space applications. It is required to develop

	Complementary Metal-Oxide Semiconductor (CMOS)/BiCMOS Bipolar Complementary Metal-Oxide Semiconductor, Radio Frequency Integrated Circuit (RFIC) to have multi-chip module solution along-with indigenous baseband ASIC and to have miniaturized NavIC Rx. for various applications. Commercial and space grade RFIC is required with the following blocks: • Tri band integer PLL/ Fractional PLL. • Triband / wideband LNA • Image reject Mixer Narrow band and wideband • Variable gain amplifier • Low drop out regulator • Complex filter for IF range • SPI interface to control the overall receiver block • Multibit ADC: Multibit low power ADC is required to meet high Anti-jamming capability. ADC specifications: a. Bit resolution: 16 bits b. SFDR: 86dB c. Sampling clock: 50MHz d. ENOB: >14 bits • MEMs based Temperature Compensated Crystal Oscillator (TCXO): Satellite application of space-grade NavIC receiver required high acceleration sensitive TCXO. MEMs based TCXO can meet the 0.5 ppb/g acceleration sensitivity. MEMs based capacitive resonator is suitable choice for space application and piezo resistive resonator can meet ground application.
B2.1.8	**Construction and selection of balanced and near balanced Pseudorandom Sequences with lower correlation values and large linear complexity (SAC)** Spreading PRN codes are utilized in satellite navigation for ranging, spectrum spreading and satellite identification in Code Division Multiple Access (CDMA) based GNSS systems. Considering future navigation signals, there is an increasing demand of spreading codes families of various Length, family size, and correlation properties PRN sequences to be used in communication and satellite navigation should have certain statistical and correlation properties. While designing a sequence for satellite navigation, it is desirable for sequence to be balanced, have low value of out of phase auto-correlation and cross-correlation, have well behaved distribution of one and zeros and should be easily implementable in hardware. Since the sequences in sequences in the field of satellite navigation are also modulated by data or overlay codes thus, it is also desirable the sequences have

	low values of out-of-phase odd auto-correlation and odd cross-correlation as well. Sequences with longer length or time-period greater than few milliseconds are often partially cross-correlated in a navigation receiver. Large linear complexity sequences are a potential candidate for signals with anti-spoofing capability. This work involves designing of a PRN code family where each PRN sequence of the code family should have the properties of randomness. The code family set should have sufficient number of codes to satisfy a global constellation of satellites and enough for supporting the augmentation system, if any. It also involves selection criteria determination and to compare the performance of a set of codes against the performance parameter matrix to find optimum codes. Performance parameters for code selection include sequence balance; run length, orthogonality, auto- and cross-correlation histograms at various Doppler offsets, excess line weight and values for the low auto-correlation functions.
B2.1.9	**Design and Development of True Random Number Generators (SAC)** Random numbers are of paramount importance in field such as cryptography, Monte Carlo simulations, randomized algorithms etc. In contrast to Pseudo Random Number Generator, physical (true, hardware) random number generators extract randomness form physical processes that behave in a fundamentally nondeterministic way, which makes them better candidates for true random number generation. TRNG are useful for key generation in field of encryption and authentication of satellite navigation signals. This work objective is to develop a true random number generator, which produces random numbers that passes through the criteria of randomness, which is given by a series of statistical tests of National Institute of Standards and Technology NIST Test suit, Diehard battery of randomness tests etc. In general, TRNG suffers with unequal probability of occurrences of one and zero which is known as bias. Thus, the developed TRNG should also include the post processing mechanism of bias removal. Some of the RNG constructions are as follows- • Noise-based RNGs • free running oscillator RNGs • chaos RNGs • quantum RNGs • The resources utilized by TRNG, its throughput and frequency of operation are some of the design criteria which needs to be considered while choosing an architecture. The generated random numbers should pass through randomness property measured using statistical test.
B2.1.10	**Multi constellation and multi frequency GNSS positioning algorithms (SAC)** Owing to the complementary nature of the various GNSS signals / services, there is a worldwide trend for deriving position solutions of more than one GNSS signal. Known as multi-GNSS, this has the potential of providing an accuracy superior than any of the

	GNSS signals when used singly; complementing the number of satellites in case of lower availability and / or blockage and extension to the space service volume (SSV). Employing more than one frequency (multi-frequency) to obtain the positioning solution offers the advantages of enhanced accuracy, resolution of ionospheric effects, etc. Potential research areas in these two domains may be satellite selection, triple-frequency for ambiguity resolution, inter-system/signal/frequency bias estimation, etc.
B2.1.11	**Multi constellation and multi frequency GNSS positioning algorithms (SAC)** GNSS Security, Vulnerability, Encryption, Authentication (SAC) • Key exchange Algorithms: IRNSS RS service for authorized users involves encryption and to improve security, encryption keys are changed regularly to avoid brute force attack and cryptanalysis from unauthorized users. IRNSS RS receivers deployed in field will have to be communicated with changed keys. • Key Distribution/Key management for GNSS strategic applications • RAIM, Advanced RAIM and TRAIM Algorithms • Spreading Code Encryption for very long code using stream/block ciphers • Block-chain technology for authentication/security of GNSS services • Geo-encryption • Message Authentication Techniques for NavIC
B2.1.12	**Multi constellation and multi frequency GNSS positioning algorithms (SAC)** **Precise Satellite Relative Location Estimation System for Tandem Satellites operation (SAC)** Design & development of "precise Baseline/Orbit determination system" for Tandem Satellites operation. Following are important research area in this topic: 1) High-precision GNSS receiver 2) Precise orbit & Baseline determination 3) Implementation Dynamic Force Models 4) High-precision orbit propagation
B2.1.13	**Navigation Simulators (SAC)** The design and development cycle of GNSS Receivers is highly dependent on the signals provided by GNSS Simulators right from conceptualization to product development cycle. Following are important research areas in Navigation Signal Simulation: 5) Low-cost NavIC Simulator 6) Handheld GNSS Simulator 7) Interference Simulator for GNSS bands 8) Low-cost Navigation Educational Kit

	9) Seamless indoor/outdoor navigation with NavIC and other Signals of Opportunity/ Technologies 10) LEO GNSS and NavIC + LEO GNSS Simulators
B2.1.14	**Software Defined Radio (SDR) based NavIC system Development (SAC)** SDR is a popular trend that allows the configuration of generic receivers that may be customized based on specific user requirements. Potential domains for research proposals in this area may be: 1) NavIC-GNSS receiver 2) NavIC-GNSS simulator 3) SDR for RTK and PPP 4) SDR for Pseudolite-based navigation System 5) SDR for GNSS + Pseudolite System
B2.1.15	**Pseudolite-NavIC-GNSS receiver algorithm Development (SAC)** Pseudolite System is ground-based navigation system which may provide very accurate position within a localized area. These are low-cost systems and can be easily integrated with other GNSS systems. Following topics may be taken for development of new algorithms: 1) Successive Interference Cancellation to mitigate near-far problem in Pseudolite 2) Pseudolite-NavIC-GNSS hybrid user position algorithm/ Extended Kalman Filter (EKF)/ Unscented Kalman Filter (UKF) based algorithms 3) Time synchronization algorithms with GNSS 4) Signal acquisition & tracking in pulse-CDMA mode 5) Pseudolite indoor-positioning algorithms 6) Multipath mitigation algorithm 7) Algorithms for bi-directional Pseudolite based system for interplanetary scenario like Mars, Moon etc. 8) Pseudolites for landing application at Indian airports
B2.1.16	**LEO GNSS: (SAC)** Position, Navigation and Time (PNT) services can be provided by mega-constellations in LEO orbits, which are otherwise primarily meant for providing communication and broadband internet services across the globe. Following are the research areas in this domain: 1) System engineering aspects 2) Doppler Positioning and Velocity Algorithms 3) New navigation processing algorithms for acquisition and tracking 4) GNSS+LEO constellation designs and algorithms

B2.1.17	**Differential Positioning & RTK Receiver Algorithm Development for NavIC (SAC)** Differential positioning is a technique which provide cm-level accurate position and transmits corrections from a base or reference receiver at accurately known location to a rover receiver through UHF/VHF link. This technique assumes that both base and rover receivers are observing common set of satellites. Differential positioning is performed using both pseudo-range and carrier-range measurements. Following algorithms may be developed: 1) Integer Ambiguity (AI) resolution in carrier-phase measurements 2) Carrier Phase-Based Positioning 3) Low-cost single frequency RTK receiver algorithms 4) RTK correction generation & dissemination module in RTCM format 5) GNSS Corrections: RTK, RTK-PPP, PPP 6) Network RTK for India 7) NTRIP based interface for NavIC 8) High-accuracy Post-processed RTK positioning algorithms
B2.1.18	**Precise Point Positioning (PPP) Receiver Algorithms (SAC)** Precise point positioning (PPP) is a technique using Global Navigation Satellite System (GNSS) satellites to achieve decimetre level or better position accuracy using a single receiver. This technique relies on the availability of highly precise ephemeris and clock products from a network of reference receivers without using a base station. PPP also requires a dual-frequency receiver with precise carrier range measurements. However, nowadays single frequency-PPP is also being attempted by researchers. Precision usually in this case means a horizontal position accuracy of 10 cm or better. 1) Precise ephemeris & clock product generation & dissemination 2) EKF-based PPP algorithms 3) Low-cost single-frequency PPP algorithms 4) Multi-constellation PPP 5) PPP-AR (Ambiguity Resolution) algorithms 6) High accuracy Post-processed PPP algorithms 7) PPP-INS positioning algorithms 8) PPP-RTK positioning algorithms 9) PPP with Pseudolite or GNSS + Pseudolite system
B2.1.19	**Atmospheric Studies (SAC)** NavIC L5 and S Band signals along with other GNSS signals can be used for estimation of better ionospheric TEC and relevant model development. These signals are useful for ionospheric scintillation studies and also for tropospheric model development.

	• Ionospheric studies over the Indian Region a. Real-time ionospheric Total Electron Content (TEC) & scintillation map generation b. Ionospheric tomography model development • Tropospheric Studies a. Tropospheric model development for Indian region b. Tropospheric mapping function development • Weather Monitoring and forecast through NavIC S-Band a. Thunderstorm detection using Machine Learning/Deep Learning Techniques b. Multipath and Soil Moisture model development using AI/ML/DL
B2.1.20	**Other Topics (SAC)** 1) Short delay Multipath Mitigation Techniques in GNSS Receivers 2) S band interference in Satcom and Satnav applications 3) Spoofing Detection: Using Multiple antennas, Signal time of arrival 4) NavIC data processing in RTKLIB 5) Robust positioning with Civilian GNSS signals. 6) Ground Testing of Rubidium Atomic Clocks. 7) Navigation Solution with Multi-Constellation. 8) Ground Characterization of On-board Atomic Clock performance. 9) Effect of Wi-Fi, 3G/4G/5G on NavIC/GNSS Signals. 10) Design of Global Indian Navigation constellation. 11) Cooperative & peer to peer positioning 12) Positioning for Autonomous systems (robot, drones, marine vehicles) 13) Time to First Fix (TTFF) reduction in GNSS receivers 14) Assisted NavIC 15) Design and development of NavIC Data Post-processing Tools (GAMIT, Berneze, RTKLIB like s/w) 16) Design of NavIC Advisory generation and dissemination (like GPS's NanU)
B2.2	**GNSS Applications (SAC)**
B2.2.1	**Precision Agriculture (SAC)** India is an agricultural country. Produce of agricultural products can be optimized using GNSS techniques such as RTK and PPP. This entails significant savings of equipment usage, fuel consumption, potential for manual error, etc. and can significantly enhance productivity. Following algorithms/solutions may be developed: 1) RTK-based precision agriculture solutions 2) PPP-based precision agriculture solutions 3) Low-cost or community-based solutions (e.g. village-level)

B2.2.2	**Mobile Application Development (SAC)** • The availability of NavIC-enabled mobile phones will provide improved accuracy and availability as these mobile phones use all-in-view (multi-constellation) based processing. Besides GNSS, other sensors in the mobile phones can aid in improving accuracy as well as availability of position solution in the places with weak or blocked GNSS signals. Mobile applications can be developed for fusion of GNSS and sensor data for location-based services. • NavIC-GNSS mobile App for location based services using GIS map • Mobile-based train tracking App for Railways including paperless ticketing • NavIC/GNSS based Navigation App for blind/physically impaired person • Android Studio based positioning using raw NavIC/GNSS observables • NavIC/GNSS anomaly reporting
B2.2.3	**Scientific Applications (SAC)** The following research activities may be suggested for scientific applications of GNSS. One may extend this work in future for finding the cloud dynamics and even for hydrology. This, however, is possible when the measured data is highly dense in nature. With more precision in measured data, it may also be utilized for finding the cyclonic condition and movements. Especially, NavIC S-band signals may be very useful for weather studies. Also, networked GNSS data may be utilized for earthquake research and hazard mitigation. Data from available network over India, may be collated, in one hand to find the crustal movements, while the post-earthquake signatures on ionosphere may be studied, on the other hand, to identify and index the strength of the earthquake and its extent. 1) Modelling Equatorial TEC perturbation 2) Forecasting of ionospheric scintillation 3) Integrated Water Vapour (IWV) estimation using GNSS 4) Cyclone tracking & Precipitation prediction 5) Seismic studies using TEC
B2.2.4	**Other Applications (SAC)** 1) Marine Applications 2) Disaster Management using GNSS & GAGAN 3) NavIC/GNSS-based navigation for UAV 4) GIS application involving NavIC/GAGAN and ISRO's geospatial database Bhuvan 5) GNSS based spacecraft attitude determination 6) Application/software for vehicle parking system including automatic toll collection 7) NavIC based biometric bracelet 8) Low-Cost Surveying and Land Record Mapping using NavIC & GAGAN Receivers

	9) GNSS for Smart City applications 10) IRNSS Messaging based Applications 11) Timing Applications of NavIC	
B3	**Area**	**Navigation (IISU/URSC)**
B3.1	**Sub Area**	**Lunar Surface Navigation System (IISU)**
B3.1.1	Towards lunar landing and further lunar navigation, an Earth-independent navigation system is to be established on Moon surface which is essential for robotic/crewed missions on moon. For lunar surface navigation, a novel self-configurable and self initializable navigation system independent of Earth based communication/reference is proposed. At first, a lunar surface based coordinate system will be fixed by the rover at its landing point. With respect to the fixed lunar coordinate frame, rover will be propelling compact IMUs in different precisely known directions so as to place them in locations with best geometrical configuration. As the IMUs are accurate for short duration, the locations of IMU landing points on lunar surface will be precisely known w.r.t the fixed lunar reference frame. Further, these IMUs in different locations with known precise coordinates will be acting as pseudo-lite stations w.r.t which rover will be able to do lunar surface navigation accurately. **Objective and Scope** Establishment of lunar surface navigation for local navigation of the rovers • Design and realization of accurate and highly miniaturized inertial navigation systems-Micro INS (Mass <0.2kg) • Actuator based deploying/projecting mechanisms for placing the micro INS at different locations for best geometrical configuration • Realization of CDMA communication between the INS and rover • Position fix by ranging using the micro INS transmitters • Development of integrated navigation system with micro INS, LiDAR, Visual odometry etc.	
B3.2	**Sub Area**	**Pulsar based Absolute Navigation for Advanced Space Missions (IISU)**
B3.2.1	Pulsars are natural celestial sources which broadcast highly regular timing pulsations which lead to the proposal for design and development spacecraft navigation system for GPS denied environments as well as for interplanetary missions. Two types of pulsars are studied-radio pulsation and X-ray pulsation outputs. Since radio pulsars are very faint, huge antenna systems make them impractical for navigation system development. Whereas X-ray pulsars can be detected with very small X-ray detection system with size less than a m2. To enable precise timing measurements of these X-ray pulsars, development of high sensitive detector system with low power, sub micro second timing accuracy on each X-ray photon received.	

	The basic measurement that yields position and time information is the arrival time of a pulsar pulse at the detector. This arrival time is then compared to the expected arrival time based on a timing model of the pulsar that has been developed from years of observations at ground-based radio telescopes. The difference between the observed and predicted arrival time can be translated directly into a correction in the position of the detector in the direction of the pulsar being observed. Observations of multiple pulsars can thus be combined to provide full three-dimensional position information.	
B3.3	**Sub Area**	**Orbit Determination (AI-ML Based Orbit Determination Enhancements) URSC**
B3.3.1	Conventional Orbit Determination (OD) techniques use ground station tracking measurements or on-board sensor data (GNSS Rx, INS …) along with precise orbit models. The challenges in this approach include precise knowledge of density model (in case of LEO orbit), accurate estimation/modelling of SRP (Solar Radiation Pressure for MEO/GEO orbits) and account the environmental un-certainties such as Solar flux, Geo-Magnetic index etc., Certain cases the system will also suffer from limited observability from the ground/on-board measurements leading in degradation of the estimated orbit. AI/ML techniques are used to improve the space weather prediction by training the data available (past history). Combining traditional data will also aid in predicting the behaviour of the orbit based on the seasons, and other environmental conditions, filling the gaps created due to data paucity. Algorithms can be developed using data available for missions with precise orbits and measurements. These data can be trained and developed algorithms can be compared with the avialable precise orbits.	
B3.4	**Sub Area**	**Lunar PNT (Algorithms Development for Lunar Navigation Systems)** **Accurate PVT (Position, Velocity and Timing) information is becoming crucial for Lunar missions for precise landing, docking, re-entry applications. Hence Autonomous Lunar Navigation is being conceived in various phases (URSC)**
B3.4.1	**Earth Based GNSS and Earth Station support (URSC)** In this approach, ground based (Deep Space Network Stations) and Earth Based GNSS Receivers will be providing the PVT Services (from GTO through landing and re-entry to the Earth). This involves development of high sensitivity GNSS Rx with dual-frequency and multi-Constellation (GPS, NavIC, GALILEO) capability and Inter-Satellite link (RF based) and Ranging payload. SNG Role: Development of GNSS Rx, On-board Orbit Determination and Timing algorithms on Integrated Avionics Platform	

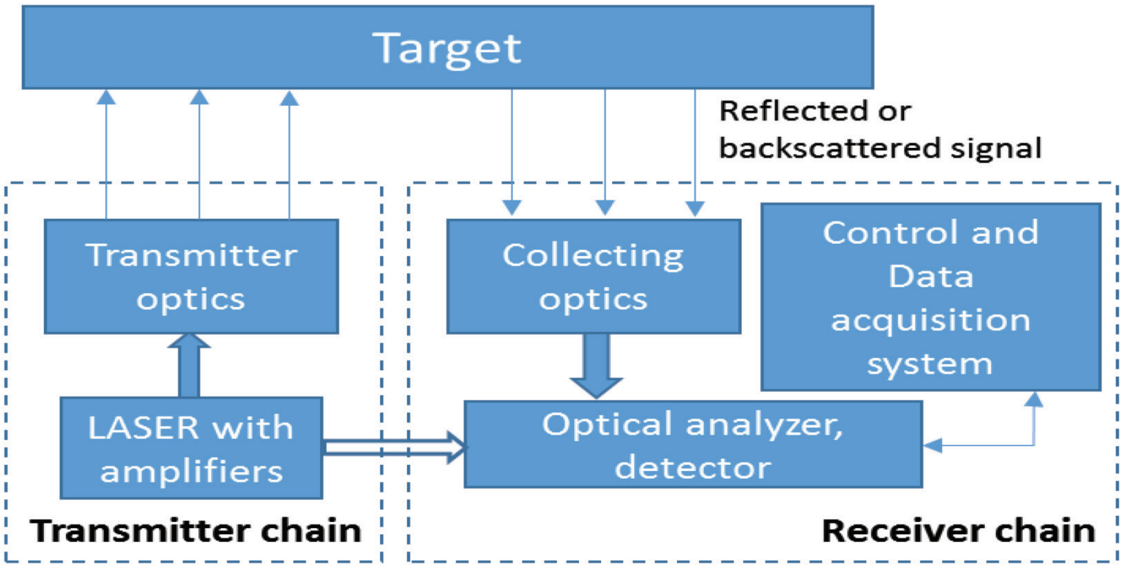
	• On-board Relative OD [Fusing GNSS, ISR and other sensor measurements] for docking at GTO, LTO and Lunar orbits • On-board Relative Propagators • On-board Propagator for Earth and Lunar Orbits • Anti-Jamming Algorithms (To support GTO and re-entry phases) • Ground based Precise Orbit Determination
B3.4.2	**Independent Lunar Navigation (URSC)** Development of "Moon-GPS" constellation using smaller, cost-effective S/c around the Moon orbit servicing the area of interest on the Moon surface with navigation payload ROLE: • Navigation System Design (Space Segment, Ground Segment and User Segment, Signals) • Constellation design for Moon orbiting Satellites with minimum number of S/c meeting the coverage and DOP requirements • Development of On-board ODTS (Orbit Determination-Timing System) for navigation service • Feasibility studies on on-board clocks (OCXO, CSAC, Atomic clocks) for meeting navigation requirements • Co-ordination for inter-operability and compatibility with other Lunar PNT systems • On-board nav-processor • Standards for co-ordinate frames, timing references compatible with other systems • Derive Lunar-SIS ICDs, Performance standards • Ground algorithms (for Orbit Determination, Time Synchronization)
B3.4.3	**GNSS Receivers (Anti-Jamming & Spoofing GNSS Receivers) (URSC)** The positioning of LEO S/c is being carried out using on-board GNSS Rx to provide independent and accurate orbit information. These Rx provides advantage over ground ranging stations in-terms of infra structure, accuracy, autonomy and serve as primary source for relative navigation for docking missions and also provides precise timing on-board to OBC and payloads. On the other hand, these receivers, being in LEO regions, are vulnerable to jamming and spoofing of GNSS signals from ground or through space-based systems. This creates outages in the availability of GNSS based solution and spoofing can even lead to estimation of erroneous orbit, posing a severe threat. Hence it is essential to develop anti-spoofing and anti-jamming systems and algorithms on-board to maintain the integrity and provide seamless PVT service. It involves: • Detailed study on the GNSS signals getting jammed, mitigation adopted by other systems, possible choice of frequencies and proposal of antenna design to reject

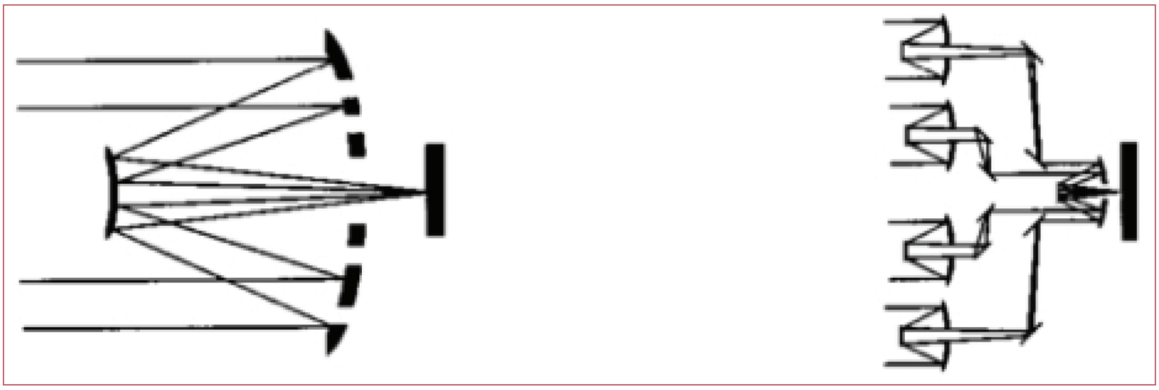
	these signals (direction antenna, filters) and advantage of multi-frequency and multi-constellation Rx • In-corporation of authentication mechanisms, along with SDR (Software Defined Radio) integration • Development of RAIM algorithm on-board (Anti-spoofing) • Possibility of fusing GNSS measurements with other sensor data	
B3.4.4	**Multi-User Detection and Signal Processing Techniques (URSC)** The space-based AIS receiver typically receives signals from a large number of SOTDMA (Self-Organized Time Domain Multiple Access) cells over the receiving antenna footprint. Therefore, a high number of SOTDMA cells are visible to the satellite and the organized structure is lost resulting in message collisions which the satellite receiver may or may not process. All the received signals are sent back to ground station. The problem is to process the received overlapped signal and identify the ships from the collided messages and extract data of each ship separately. For Future Missions we need the following • To implement Multi-User Detection algorithm on-board • Feasibility of extending the concept to ADS-B (Automatic Dependent Surveillance Broadcast) to detect aircrafts	
C	**Area**	**Antenna Systems (SAC)**
C1	**Multimode Vortex Beam Generating Common Aperture Antenna for future OAM based communication systems (SAC)** Orbital Angular Momentum (OAM) communication offers a promising solution by utilizing the unique properties of vortex beams. This research topic aims to investigate the design and implementation of multimode vortex beam generating antennas to enhance the capacity and efficiency of future OAM-based communication systems. Vortex beams can carry multiple OAM modes simultaneously, increasing the data throughput significantly. However, effective generation, control, and reception of multimode vortex beams requires advanced antenna designs and signal processing techniques.	
C2	**Controlled Radiation Pattern Antennas for Anti-jamming GNSS Terminals (SAC)** Jamming and interference can drastically degrade the GNSS position, navigation and time availability even to the extent of complete cease in service. The low power GNSS signals from space are overpowered by the excessive noise generated by the jammers, which consequently saturates the user GNSS receiver front-end. The anti-jamming terminals have the capability to find the direction of interference and have the ability to mitigate this interference by creating nulls in the antenna pattern in the direction of the interference. Generally, these terminals are capable of mitigating interference from multiple jammers. The number of simultaneous nulling direction depends on the number of radiating elements used in the terminal. This generally creates a compromise between the size of the terminal and the number of simultaneous nulling possible.	

C3	**Design & Development of Terahertz Array Antennas for Space and Ground applications (SAC)** The proposed research work will be catering THz communications and imaging systems. Developing antenna systems at these frequencies will help in solving many problems related to antenna realization, integration and characterization. Design and development of terahertz array antennas involves selection of suitable radiating elements (Horn, slots, patch etc.) and design of appropriate feeding mechanism (waveguide, SIW, Gap WG etc.). Emphasis to be on the antenna realization technology also (silicon micro machining, metallization, CNC fabrication etc.) as it forms an important step. The RF design has to take care of all the limitations arising from the realization methodology. The design should also address the scalability of antenna architecture to achieve higher antenna Gains. Suitability of material selection for space missions to be addressed.
C4	**Development of Graphene-based Flexible Wearable Antennas (SAC)** The research aims to develop a graphene-based flexible wearable antenna for UHF (300 MHz – 900 MHz) and L&S-band (1–3 GHz) communication. Graphene's exceptional electrical, mechanical, and thermal properties make it an ideal candidate for next-generation antennas that need to be flexible, lightweight, and capable of high-performance under diverse environmental conditions. The research scope includes. Investigating the electrical conductivity and RF performance of graphene in comparison to traditional materials like copper.
C5	**Curved reflectarray for dual band dual circularly polarized Ka-band multiple beam antenna missions with reduced apertures (SAC)** HTS missions at Ka-band are achieved by utilizing multiple beam antenna technology using multiple apertures. The objective of present technology is to reduce the number of apertures by illuminating a curved reflectarray with a dual circularly polarized feed. The dual band reflectarray so designed may have the capability to reflect the LHCP beam positively offset by half beamwidth and RHCP beam negatively offset by half beamwidth thus generating a beam lattice. Two such reflectors can give dual frequency/polarization four colour scheme for achieving high throughput. Complete study to achieve desirable gain and carrier to interference ratio (C/I) with prototype development may give confidence for further study to expose to harsh space environment conditions and qualification.
C6	**Design and development of dual polarized low profile metallic lens antenna (SAC)** Recently, with emerging application at microwave, mm waves and THz frequencies the antennas must necessary be low-profile, lightweight and high gain systems with wide-angle-scanning/multi-beam capabilities. Traditional solutions for the said constraints are reflectors antennas and planar arrays. Reflectors antennas are bulky, whereas array

	antennas are lossy. Lens antennas, which are not popular at low frequencies due to their large size, offers a better solution in this context, due to their wide-scanning capability, broadband behaviour and focusing properties. The lens antennas can transform various type of divergent electromagnetic waves into plane waves if their geometry is properly designed and right material is used. Lens antenna can be made from either dielectric material or purely metal. Both materials are capable of collimating the incoming spherical electromagnetic waves by correcting the phase differences. At high frequencies, metallic Lens antenna have attractive electromagnetic properties such as high directivity, wide angle beam scanning, wide impedance bandwidth, low loss, high aperture efficiency etc. Therefore, at high frequency applications, metallic lens antenna is considered a more promising solution in comparison to phased arrays or other beamforming techniques. Also the structural complexity is less for this antenna category.	
C7	**Plasma antenna (SAC)** The plasma antenna is an emerging technology that partially or fully utilizes ionized gas as the conducting medium instead of metal to create an antenna. The key advantages of plasma antennae are that they are highly reconfigurable and can be turned on and off, which is good for stealth and resistance to electronic warfare and cyber attacks. The plasma can be freely moved to the desired geometry of the reflector by plasma diode which enables the beam to be steered quickly without the need for mechanical motion. When the gas is not ionized, it allows other antennas to transmit and receive without any interference which is a very useful feature.	
D	**Area**	**Electro-Optical Sensor Technology (SAC)**
D1	**Sub Area**	**EO Sensor System Design, Simulation and Characterization (SAC)**
D1.1	**Development of physics-based models for simulation of Electro-Optical Sensors (SAC)** Design and development of EO sensors is a very complex process and requires a thorough understanding of the system behaviour and assessment of its possible outcomes before one embarks on the development of physical system. A physics-based model of EO sensors can significantly help in understanding and visualizing performance aspects and also extensive trade-off studies. The model shall capture the functional/behavioural characteristics of various subsystems such as optics, detectors, electronics and also shall account for various instrument effects arising due to their complex interplay at highest abstraction level. The model shall help in simulating final data/images for a proposed EO sensor configuration to enable visualization and quantitative assessment of instrument	

	to the design parameters/system, environment/on-board processing/viewing geometry, etc. Based on the model a software tool needs to be developed that should interface with COTS design software systems in Optical/Mechanical/Electrical domain and available RT models for atmospheric effect simulations. In other words, an end-to-end model shall be developed starting from simulation of ground targets, illumination conditions, observation geometry, intervening medium/atmosphere, at-sensor radiance, sensor characteristics, boundary conditions (under which the sensor is performing) leading to digital counts. The input scene to the sensor model can be typical laboratory targets, actual ground 3D targets or images acquired from the other sensors. This is an exciting research field and will help in the development of a comprehensive model and simulation tool for upcoming ISRO missions.
D1.2	**Design and development of on-board calibration system for absolute calibration of EO sensors (SAC)** Extensive pre-flight absolute calibration of EO sensors are carried out in laboratory for establishing the transfer function of the EO sensors. However, due to launch loads, in-orbit operating environment, and natural aging process of its components, the sensor characteristics tend to change. This has significant impact on accuracy of Digital Number (DN) to radiance conversion process, which in turn affects the remote sensing parameter retrieval accuracies. Hence, it is important to design and develop appropriate on-board calibration system(s) for periodic calibration and updation of the sensor response function to ensure desired accuracy in DN to radiance conversion. The calibration system should ensure both radiometric and spectral calibration from visible to Infrared Radiation (IR) spectral region. These sources can be passive or active. Research is invited in the areas of design and development of on-board calibration sources e.g. Blackbody for IR calibration (high emissive nano-particle coating), diffuser plate for Visible/Near-Infrared (VIS/NIR) calibration, doped diffusers or active sources for spectral calibration. These systems are required to be compact and stable over long period of time. This can significantly help in improving the accuracy of payload data.
D1.3	**Design and development of a proto-type LIDAR system (SAC)** Light Detection and ranging (LIDAR) measures distance or characteristics of the target by illuminating that target with a laser light. A narrow laser-beam can map physical features with very high resolutions. Typically, light is reflected via backscattering. LIDAR can be used for ranging, surface profiling and atmospheric studies (clouds, aerosol and wind). Suitable combinations of wavelengths can allow for remote mapping of atmospheric contents by identifying wavelength dependent changes in the intensity of the returned signal. A LIDAR typically comprises of a transmitter chain, receiver chain and associated electronics. Critical components of LIDAR system are high power laser system (100mJ

	 **Typical LIDAR system** or more with pulse duration of ~10ns), large aperture collecting optics (>1m aperture size), detection system (time gated photon counting, interferometry, etc.). Research opportunity exists in design and development of high power continuous and pulsed lasers, large optical apertures, focal plane based on time gated detectors and interferometry systems leading to proto-type development of LIDAR system.
D1.4	**Image Simulators and Algorithms for Characterization of Imaging Sensors (SAC)** EO sensors undergo extensive pre-flight testing and performance characterization to ascertain sensor behaviour and demonstrate performance compliance against specifications. Currently, static targets such as bar targets, slits, and flat field targets are used as input scenes for the EO sensor testing and characterization. However, this limits test capability in terms of temporal, spatial, and spectral variations in the scenes that an EO sensor sees in the actual remote sensing scenes. Research opportunity exists for design and development of synthetic scene simulators to generate dynamic scenes for EO sensor testing and characterization. Digital Mirror Device and Digital Light Processing can be potentially used for generating Multi-spectral and Hyper spectral scenes. The research in this field involves design and development of hardware and software system for generating suitable synthetic scenes having required dynamic variations, development of methods/algorithms for EO sensor performance estimation using the sensor output and evaluation in terms of image quality metrics, etc.
D1.5	**System configuration and simulation studies for Sparse Aperture telescope (SAC)** The angular resolution of a traditional telescope is diffraction-limited and is given by 1.22λ/D, where λ is the wavelength and D is the size of the optical system aperture. However, the optical system aperture is limited by the current glass-making technology and the cost involved. In order to overcome this limit, the technique of optical synthetic

	aperture have been reported in the literature. The optical synthetic aperture consists of several telescopes (as shown in figure below) with smaller apertures, phased in a manner to generate an equivalent large aperture.  *Common Secondary Mirror* *Multi Telescopes* This emerging field offers significant research opportunities in terms of studying feasible system configuration, perform extensive simulation studies, develop advanced processing techniques for generating improved resolution imagery from the acquired data, etc. The research will lead to development of a small-scale prototype for demonstration and validation of design and processing techniques.
D1.6	**System design, simulation studies and control system development for Segmented mirrors based EO sensor (SAC)** A segmented mirror is an array of smaller mirrors designed to act as segments of a single large curved mirror. The segments can be either spherical or asymmetric. They are used as objectives for large reflecting telescopes. To function, all the mirror segments have to be polished to a precise shape and actively aligned by an active optics system using actuators built into the mirror support cell. In this research field opportunity exist to study feasible system configuration, develop simulation model, design and develop metering, actuation and control systems to maintain the segments in required shape and orientation to get the desired performance. This research aims to develop a small-scale prototype for demonstration and validation of the involved technology elements, and processing techniques.
D1.7	**Extending Super Resolution concept to Spectral Domain (SAC)** Extraction of finer spectral resolution information from Hyper-spectral Imagery, given a large number of relatively coarser resolution images with overlapping spectrums. Similar to super-resolution imagery, if data is collected with a given spectral bandwidth, but with finer spectral sampling compared to the bandwidth, then it should be possible to generate images having narrower spectral bandwidth. The scope of the work includes development of models and simulation studies to demonstrate the concept and also develop a proto-type system to study hardware implementation aspects.

D1.8	**Design and development of Active cavity radiometers (SAC)** Active cavity radiometers (ACRs) is one type of pyrheliometer used for measurement of direct beam solar irradiance. It is an electrically self-calibrating, cavity pyrheliometer used to measure total and spectral solar irradiance. They can be suitably tuned for measuring radiation from UV to IR spectral region. These radiometers remain stable over long duration and thus can be used as a calibration standard for relative calibration of uniform illumination sources or spectro-radiometers. Various research opportunities in the field includes studying active cavity radiometers, define feasible system configuration, perform extensive simulation studies and develop a proto-type model for demonstration.	
D1.9	**Long range 3D imaging using flash LIDARs (SAC)** 3D Flash LIDARs have emerged as a potential imaging sensors for real time terrain mapping, 3-D measurements, guidance and navigation to support in rendezvous and soft landing missions, etc. A 3D flash LIDAR provides depth information of objects in the scene in addition to their 2D spatial distribution. The technological elements in 3D flash LIDARs involve Laser head, receiver optics, focal plane unit and electronics system with embedded image processing techniques for 3D measurements etc. This research envisages design and development of a proto-type 3D flash LIDAR imaging systems that involves system configuration studies, simulation studies, realization of small scale proto-type with COTS components, development of electronics system with embedded processing capabilities, performance characterization and field studies.	
D1.10	**Design and development of high-resolution imaging system with active optics correction elements (SAC)** High resolution imaging system generally employ large aperture optical systems and are generally affected by launch loads and orbital environmental conditions, which induces large amount of aberrations effects leading to loss of MTF in the acquired images. Active optics correction systems enable corrections of these deformations using an actively controlled optical surface in the telescope chain. The proposed study aims to design and develop an active optics correction based EO sensors for future missions.	
D2	**Sub Area**	**Focal Plane Detection Systems (SAC)**
D2.1	**CCD and CMOS sensor fabrication process modelling and simulation studies (SAC)** CCD and CMOS image sensors are mainstay sensor technology employed in spaceborne imaging systems. State-of-the-art imaging systems require custom development of these sensors. Sensor fabrication process and device modelling and simulation studies are very important milestone in the development of these sensors. SEDA has developed a dedicated modelling and simulation lab for design of these sensors as it allows more leverage to meet custom requirements. The lab is equipped with various simulation tool kits such as Technology Computer-Aided Design (TCAD) and MATLAB etc.	

	The research opportunities include modelling of CMOS and CCD based optical image sensor fabrication process to estimate key performance parameters such as quantum efficiency, cross talk, sensitivity, dynamic range, charge handling capacity, etc.
D2.2	**Modelling and simulation studies on Superlattice structure-based SWIR and MWIR sensors (SAC)** Infrared imaging detectors are increasingly being used in the focal plane of spaceborne imaging systems as it offers unique opportunities for variety of remote sensing applications. SEDA has taken up modelling and simulation activities for design of exotic sensors operating in Short-Wave IR (SWIR), Medium-Wave IR (MWIR) and Low-Wave IR (LWIR) spectral range. Research opportunities in this field includes TCAD and MATLAB modelling of Type-II superlattice structure for sensitivity in IR ranges, development of methodologies for higher temperature operation by suitably modifying stack to reduce dark current and development of techniques for enhancement of Quantum efficiency beyond 50%.
D2.3	**Design and development of high power NIR and SWIR LASER modules (SAC)** Spaceborne LIDAR systems are gaining attention of the remote sensing community as it offers variety of applications in surveying, geodesy, geomatics, geomorphology, seismology, forestry, atmospheric physics, laser guidance, and laser altimetry etc. One of the important elements in the LIDAR system is high power Light Amplification by Stimulated Emission of Radiation (LASER) system. Currently SEDA is exploring design and development of the of high-power NIR & SWIR laser modules. The research opportunities include design and development of laser head, amplifier circuits, pump sources, drivers, diffractive optical elements, cooling system etc for long distance 3D measurement and flash LIDAR applications.
D2.4	**Thermal Background modelling for integrated IR detector cooler assembly (IDDCA) (SAC)** Thermal background is one of the major sources of noise and offset in the IR detector system. Hence, it is important to estimate thermal background flux in the IDDCA to implement effective thermal control system. The research opportunities include development of physics-based model for estimation of thermal background in a given IDDCA configuration using various software tools such ray-tracing tool, thermal analysis tool, result visualization and quantitative estimation in Labview/Matlab etc. These modelling efforts will help in understanding the source of thermal background and enable improved design of IDDCA and the imaging system.
D2.5	**Design and development of drive circuits for CCD sensors (SAC)** The research opportunity exists in design and development of CCD based image sensor drive circuitry for minimization of noise floor and clock induced charges. The design shall adopt different circuit design techniques for shaping CCD clocks (-10V to +15V, drive

	capacitance: 500pF, frequency: 10MHz) for maximization of stable video and reference sampling zones.
D2.6	**Design and development of Photonics Integrated circuits (PIC) based system on chip (SAC)** System-on-chip significantly helps in integrating various image sensor circuit function in a very small footprint, thereby saving resources on payload/spacecraft. The research focuses on design and development of integrated circuits for clock and data multiplexing / demultiplexing, modulation/ demodulation, laser driver, laser and photodetector, packaging of imaging detector with PIC based chipset to miniaturize focal plane detector proximity electronics.
D2.7	**Design and development of High speed Event detector (SAC)** The research focuses on design and development of CMOS image sensor pixels for automatic thresholding, target detection and tracking applications. Fast occurring events could be observed by identifying them within the pixel at analog level by using programmable thresholding circuitry. The pixel level circuitry initiates readout by raising appropriate flag. Such flags help row – column circuitry to readout events of interest at high frame rate, up to 50kHz. Once of the possible application could be automatic detection and radiometry of lighting events.
D2.8	**Development of process flow for CMOS chip debug (SAC)** The research opportunities exist in the de-processing, micro-surgery, hot electron imaging active micro-probing, and IR microscopy, etc for debugging of CMOS chips. After we fabricate any chip, it is quite challenging to debug possible problems areas (design, fabrication, assembly, integration, packaging and testing) if it does not meet the desired performance. We have to develop some of the chip debug tools to be able to debug complex chips. These sort of tools and technologies would also help to identify possible reasons for yield reduction.
D2.9	**CMOS pixel process development at 180nm (SAC)** The research opportunities exist in Pinned photodiode-based pixel (7 to 50micron pitch) development to meet charge handling requirement from 30ke to 3Me. This research will lead to development of pixel process for TDI CMOS focal plane arrays.
D2.10	**Packaging of Infrared detector arrays for multispectral application (SAC)** This research focuses on development of techniques using industry for butting of smaller arrays to form large arrays, integration of filter / cold shield / lens, assembly of detector onto cold table mounted with flexible thermal link for cooling down to 50K and minimization of thermal load by utilizing new interconnect materials.

D2.11	**Design and development of Ultraviolet detectors based on wideband gap semiconductors (SAC)** Photon detectors based on wide band gap semiconductors have recently garnered considerable attention due to its suitability in development of highly sensitive ultraviolet detectors. The scope of research includes comprehensive review of literature in the field, understand the mechanism of these sensors, inherent advantages and disadvantages of those detectors, explore suitable materials for producing these detectors, etc.
D2.12	**Development of curved sensors (SAC)** Curved image sensors have emerged as novel technology that can decouple the traditional constraints between field-of-view (FOV), resolution and image quality. Usage of curved sensors relaxes the stringent imaging performance requirements on the optical systems at extreme fields. Many research groups are working on the device fabrication technologies. The scope of the research in this field is to explore various fabrication process technologies, carry out design and simulation studies for pixel architecture for curved sensors, address issues/challenges in the field and attempt to develop proto-type curved sensor for characterization studies. This research will lead to adaption of such curved sensors in the future spaceborne missions.
D2.13	**Metamaterial based absorber surfaces for image sensors applications (SAC)** Metamaterial structures have attracted substantial attention due to their ability to obtain desired effective permittivity and permeability by carefully designing its structure. It has resulted in the discovery of exotic phenomena such as negative refraction, cloaking, perfect absorption etc., which are not possible with ordinary materials. Broadband metamaterial absorber shows a promising prospect in applications such as controlled reflectors, solar cell, infrared detection. Junyu Li, Haoran Zhou et al have developed deep subwavelength plasmonic metamaterial absorbers for infrared detection (Conference on Laser and Electro-Optics (CLEO) 2019 © OSA 2019). In this study, a metal-insulator-metal based infrared plasmonic metamaterial absorber consisting of deep subwavelength meander line nano-antennas(MLAs) based array was fabricated and experimentally demonstrated the absorption from 11 μm to 14 μm with a pixel pitch of 1.47 μm. Plasmonic metamaterial absorbers (PMAs) are arrays of subwavelength-spaced metallic nano-objects (also termed as optical antennas) whose primary function is to concentrate the propagating light into regions much smaller than the wavelength and efficiently dissipate the optical energy into heat via localized surface plasmon resonances (LSPRs). The proposed research aims to explore CMOS compatible metamaterial absorber structure, simulation of absorption characteristics of these materials, explore fabrication feasibility, etc.

D2.14	**Dilute Magnetic Semiconductor (DMS) material synthesis for spintronics applications (SAC)** A new class of materials known as dilute magnetic semiconductor (DMS) are semiconductor materials that exhibit both ferromagnetism (and a similar response) and useful semiconductor properties. If implemented in devices, these materials could provide a new type of control of conduction. Whereas traditional electronics are based on control of charge carriers (n- or p-type), but magnetic semiconductors would also allow control of quantum spin state (up or down). DMS have been a major focus of magnetic semiconductor research. These are based on traditional semiconductors, but are doped with transition metals instead of, or in addition to, electronically active elements. Due to their novel properties of change and spin control, they have generated huge interest among the scientific community as a strong candidate for the fabrication of spin transistors and spin-polarized light-emitting diodes.
D2.15	**Optical Beam Steering Photonic Chip for Lidar (SAC)** In a Lidar, a laser beam is formed to concentrate the optical power within single pixel instead of the whole scene, which makes it a point-wise measurement system. To form an image, the beam is scanned through the FOV Namely, a beam scanner. Scanning LiDAR achieves higher signal-to-noise ratio (SNR) at the cost of lower points per second (i.e. point throughput) and slower frame rate, and more importantly, at the cost of having a beam scanner. Beam scanner is often realized through mechanical actuation of either the source itself or the discrete optics around the source. While mechanical optical beam scanner design is already an established domain of engineering, there is a fundamental challenge associated with achieving good control precision and reliability goals for automotive vehicles using a low-cost mechanical system. To reduce the unit cost of a scanner module and make it feasible for consumer electronics, various solid-state beam scanning solutions are the preferred option. There are many approaches to realize a photonic chip for Optical beam steering like MEMS Switch based array of grating coupler, Optical phased array, true time delay based beam steering, etc. The beam steering chip shall define the beam width of less than 0.2 degree and shall steer the beam within 20 degrees in both axes.
D2.16	**On-chip nano wire grid fabrication for polarization sensing (SAC)** Traditional imaging systems have focused on capturing and replicating the imaged environment in terms of colour and intensity. One important property of light, which the human eye is blind to and it is ignored by traditional imaging systems, is polarization. Polarization of light caused by reflection from materials contains information about the surface roughness, geometry and other properties of the imaged environment. Polarization-contrast imaging has proven to be very useful in gaining additional visual information in optically scattering environments, such as target contrast enhancement in hazy/foggy conditions, depth map of the scene in underwater imaging, presence

	of ice in clouds or non-spherically shaped dust particles and in normal environmental conditions, such as classifications of chemical isomers, classifications of pollutants in the atmosphere, and non-contact fingerprint detection among others. In addition, polarization of light has found a niche in many biomedical applications, such as imaging for early skin cancer detection, cell classification and retinal surgery. Wire grid polarizer is compatible with complementary metal-oxide-semiconductor (CMOS) technology, and it can be fabricated monolithically by using metal layers for wiring. Using deep-submicron CMOS technologies, which allow the design of metal patterns finer than 100 nm. The angle (0, 45, 90 and 135 degree) of the polarizer on each pixel can be designed.	
D3	**Sub Area**	**Design and Development of Optical Systems (SAC)**
D3.1	**Optical systems using freeform surfaces (SAC)** Freeform optics offers more degrees of freedom to optical design that can benefit from a compact package size and a large field of view for imaging systems. The introduction of freefrom optical surfaces in a space instrument offers the possibility to improve its performance, its volume and weight or a combination of both. Motivated by the advances in modern optical fabrication and metrology, freeform optics has found place in many applications. The freeform mirrors are manufactured by diamond turning based on a feedback modification strategy. Freeform optics involve optical designs with at least one freeform surface which, according to the International Organization for Standardization (ISO) standard 17450-1:2011, has no translational or rotational symmetry about axes normal to the mean plane. Integration of freeform optics and surfaces into imaging systems remains a major challenge. However, the new degrees of freedom introduced by freeform optics designs are the driver to overcoming these challenges. These additional degrees of freedom enable many potential advantages, including system miniaturization, reduced component count and even entirely new optical functionality that will have a profound effect on the optics industry. Research activity that can be taken up is to utilize freeform surfaces to design future telescopes with wide field of view. One particular study can be carried out to show how the freeform optics can be used to miniaturize/improve the performance of an optical system. Another interesting research activity is the fabrication and testing of free form surfaces (IR/ Visible range.	
D3.2	**Chalcogenide optics in dual-band IR Applications (SAC)** The development of dual-band IR sensors that image both MWIR and LWIR on the same image plane challenges the optical designer to create refractive lens systems with one aperture. In the past, classic materials such as Ge and ZnSe have been combined with more exotic materials such as barium fluoride (BaF2) and gallium arsenide (GaAs)	

to focus light across a wide range of IR wavelengths. Material limitations create unique challenges for wideband chromatic correction. Existing and new formulations of chalcogenide glasses provide additional indices of refraction and dispersion characteristics for chromatic correction as well as thermo-optic properties for athermalization. Chalcogenide glass is an increasingly important tool for the optical designer, providing a versatile material for many applications—from thermal imaging to hyperspectral imaging. The properties of these amorphous glasses are useful over a broad spectral range, from the near-infrared (NIR) at 700 nm well into the LWIR spectrum.

Chalcogenide glasses consist of mixtures of the Group 16 elements selenium (Se), sulphur (S), and tellurium (Te), and various Group 14 and 15 elements such as arsenic (As), germanium (Ge), tin (Sn), and others. These glasses are well suited for imaging in the IR regime because of their high transmission, low dispersion, and low refractive-index change with temperature. By changing concentration ratios, glass properties can be tailored for index of refraction, dispersion, glass transition temperature, and other properties. This gives the optical designer or the lens manufacturer more freedom than traditional IR materials. As traditional IR materials such as Ge and zinc selenide (ZnSe) rise in cost, the use of chalcogenide glasses is becoming more widespread. Chalcogenide materials offer substantial savings today in both the raw material cost and in fabrication methods such as molding technology. They also provide numerous benefits to systems with stringent specifications. There are many sources for chalcogenide glasses, including Vitron GmbH (Jena, Germany), SCHOTT North America (Duryea, PA), and IRradiance Glass (Orlando, FL), which produces a number of glass types along with custom melts.

Rochester Precision Optics developed moulded micro- and nanostructures in chalcogenide glasses. The optical properties of chalcogenide optics can be altered by nanoscale surface textures. Antireflective structures that reduce reflectance significantly reduce glare and improve transmission.

Unlike a thin-film coating that creates interference effects, nanostructures are not bandwidth-limited. Hybrid structures have demonstrated performance over dual-band regions (3–12 μm), showing promise for future applications such as high damage threshold for lasers, super hydrophobicity, and antifogging. While these functionalities have been shown on the development scale, there are still great challenges in developing industrial fabrication methods that can reduce the cost of such nanostructured materials.

This rapidly evolving world of high-volume, low-cost IR optics, along with the expansion of extremely demanding dual-band IR applications, has created a requisite for use of chalcogenide glasses. Chalcogenide materials have the ability to be altered and provide optical and systems designers many more options than historic IR material offerings without compromise.

<table>
<tr><td></td><td>The scope of the proposal is as follows:
• Study of feasibility for use of chalcogenide glasses for spaceborne remote sensing application.
• Design of dual band IR common optics using chalcogenide glasses that will image both MWIR and LWIR on the same or different imaging sensors.
• Collaboration with indigenous industry and universities for realization of Chalcogenide optics via. Fabrication, assembly and testing for achieving the desired performance goals.</td></tr>
<tr><td>D3.3</td><td>Adaptive test techniques for Aspherics and Freeform surfaces (SAC)

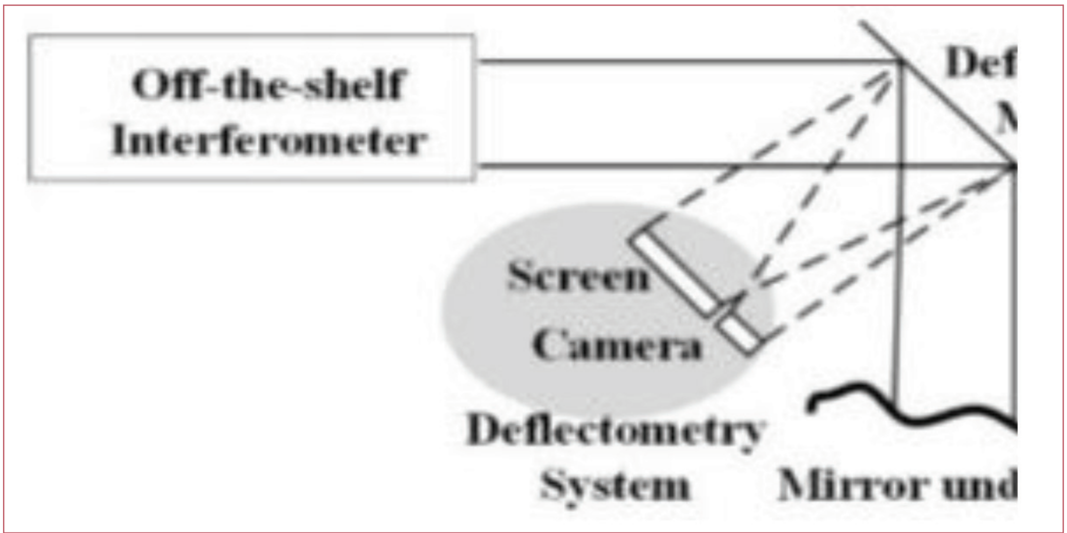
During the manufacturing of optics, the in-process (i.e., not-yet-completed) optical surface must be accurately measured to correctly guide the iterative fabrication process. The customized null element makes the process time taking and costly.

Also, for interferometric surface form measurement of final freeform surfaces the measurement is limited by the Nyquist criteria, which is often encountered due to large slope of freeform surfaces.

To overcome this, one of the current techniques is Adaptive interferometric null testing method

The adaptable null component may be a Spatial Light Modulator or Deformable Mirror.

1) Test set-up using deformable mirror



When an unknown test optic is first inserted into the metrology system, non-ideal (e.g., partial) interference fringes could be observed.

Next, the DM is driven based on the results from the algorithm recovering near-null interference fringes. This creates an online null condition for the freeform surface. The interferometer measurements, along with the results from the Deflectometry System are combined to produce the final surface shape data.</td></tr>
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The algorithm, that is used for fringe restoration will be heavily influenced by the merit function which is provided as the required target. A smart choice of this merit function will result in a quicker and more efficient convergence (to the ideal or threshold value.)
Limitation of the method: DM has limited range of stroke of actuators and can only compensate mild free form departures.
The DM will be developed and characterised by industry/academia, which can further be integrated in to the test set up at SAC. The other important part of the test set up i.e. Deflectometry system used to monitor the DM surface can be developed jointly by SAC & academia.
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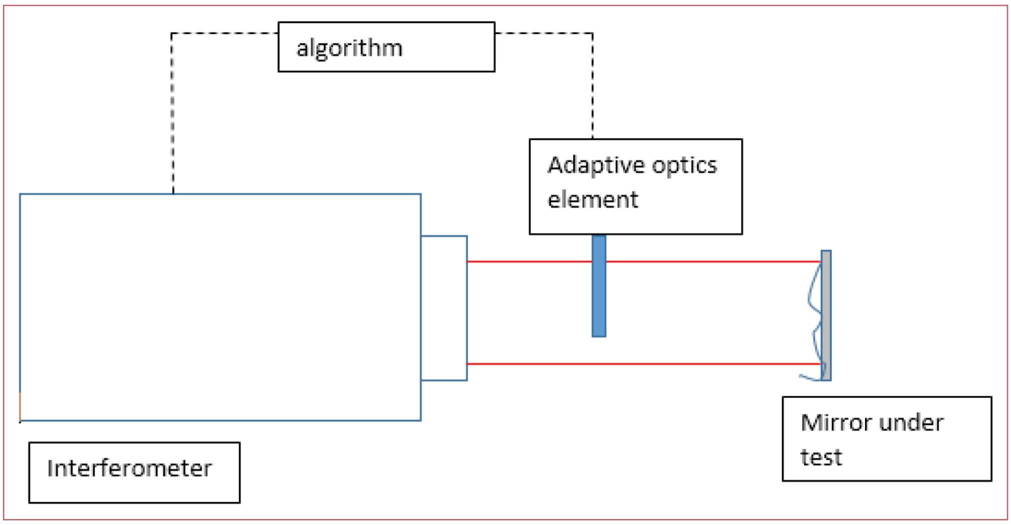
<tr>
<td>D3.4</td>
<td>
Test set up using Spatial Light Modulator (SAC)
The DM-based null test is adaptive and economical compared to CGH; however, DM has limited range of stroke of actuators and can only compensate mild free form departures.
A high-definition (i.e., >1080 pixels, <5 μm pitch) spatial light modulator (SLM) circumvents the limitation of the DM.
The phase conjugation algorithm is additionally utilized for turning resolvable fringes into null ones. Finally, local severe surface figure error is extracted from the SLM phase and the null test result by reverse optimization based on ray trace model.


TDP is already going on. Collaboration may be sought on development of algorithm. The commonly used algorithms for such applications are widely used in Machine Learning applications. Some of the algorithms are

Stochastic Parallel Gradient Descent
Simplex Optimization
Genetic Algorithm
Simulated Annealing

Simulation can be carried on supplied data and later verified experimentally at SAC.
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D3.5	**Tilted Wave Interferometer (SAC)** The use of aspheric and freeform surfaces becomes more and more important in the design of modern optical systems. These surfaces offer additional degrees of freedom to the optical design, allowing to improve the optical imaging as well as to reduce the number of surfaces needed for an optical design. However, testing of such surfaces is still a difficult task. This issue can be addressed using the technique of Tilted Wave interferometer. TWI is non-null, full-field interferometric measuring technique for aspheric and free-form surfaces with a new degree of flexibility. The interferometer uses a set of tilted wave fronts to locally compensate the deviation of the surface under test from its spherical form. Also since its non-null technique, hence the costly optics is not required for testing. The main difference of this approach to the scanning type interferometers is that the acquisition of the data is highly parallelized, since all test wavefronts are applied to the surface in only four steps. Further, the surface under test (SUT) does not have to be moved during the measurement process. Both these advantages lead to a very short measurement time of far under a minute.
D3.6	**Optical Design of telescope for space observatory for study of Exoplanets (SAC)** Planets that orbit around other stars are known as Exoplanets. Exoplanets are very hard to see directly with telescopes. They are hidden by the bright glare of the stars they orbit. Therefore, indirect methods such as radial velocity, transit photometry/spectroscopy and timing variation methods are used to detect exoplanets. In some cases, direct imaging method is also used to find exoplanets. The telescope to study exoplanets can consist of a single instrument (eg. Characterising ExOPlanets Satellite (CHEOPS) of European Space Agency (ESA)) or a cluster of instuments (eg. Habitable Exoplanet (HabEx) of National Aeronautics and Space Administration (NASA)). The design options include Ritchey-Chritien (RC) or a three mirror anastigmat (TMA) design followed by science instruments. The spectral range of these telescopes generally include ultraviolet (UV), visible and near-infrared (near-IR), shortwave infrared (SWIR) and sometimes midwave infrared (MWIR) regions. The telescopes include both imaging and spectroscopic capabilities. Stray light suppression using effective baffling is very important as the faint light from exoplanets should not be suppressed by any other light coming from earth or stars. Research in this field is invited for the development of optical systems for upcoming exoplanet missions.
D3.7	**Design and development of Volume Holographic Grating (VHG) (SAC)** VHGs are widely used in ground based astronomical spectrometers with moderate to large diameter telescopes ranging anywhere between 8 meters to 10 meters. These have also been extensively used in gas sensors where spectral peaks with very narrow bandwidths are required to match with gas absorption spectra. They are suitable for

	both ground and spaceborne applications. Considering the major advantage of higher number of grooves/mm and consequently finer spectral bandwidth of few picometer, the VHG have been used in multiple global space missions like Sentinel 3A and Rosetta etc. This research proposes design, fabrication and characterization of a plane/curved VHG for spaceborne imaging spectrometers for astronomical observations and environmental monitoring. The fabrication of VHG basically involves writing of a typical pattern by optical interference between two coherent laser beams (reference and object beams) superposing in a photosensitive material making fringes in the material by means of a periodical variation of the refractive index (i.e. a sinusoidal profile) throughout the volume of the photosensitive material. The technique enables writing 600 to 6000 grooves/mm on a substrate diameter upto 850 mm. Scope of the research • Modelling of the grating with peak efficiency at required wavelength mainly catering to VNIR and SWIR, fabrication and characterization. • Indigenous/ in-house development of the holographic exposure system to record fringe pattern of desired frequency and orientation using photo-polymer coated plane/curved glass substrate. • Indigenous / in-house development of photo-polymer or gelatin like films. • Development of a suitable processing technique so that modulation pattern is accurately reproduced after a wet-dry processing cycle. • Exploring feasibility for space usage and carrying out related testing.
D3.8	**Computer Generated Holograms (CGH) (SAC)** Aspheric and freeform optical surfaces are frequently used in spaceborne/airborne sensing instruments as they help in reducing the number of optical components in the system, thereby reducing the size and weight of the sensing instruments. Aspheric surfaces are usually tested using null interferometric testing methods: either refractive (null lens) or diffractive (Computer generated Holograms). A Computer Generated Hologram (CGH) is produced via computer synthesis, where the object does not exist physically but it is expressed in mathematical terms. CGH's can generate any shape of wavefront including freeform. Two types of CGH's are used: Amplitude CGH (chrome pattern on glass) and Phase CGH (Pattern etched on glass). High precision and high resolution CGH's can be fabricated using microlithography technologies like electron beam lithography and laser beam lithography. These microlithographic techniques are common in semiconductor industry for integrated circuits (IC) fabrication. Scope of the Research: • Resist (e-beam or photo resist) coating,

	• Electron beam / Direct Write Laser (DWL) Lithography for resist patterning, • Resist development, Metallization (E-Beam evaporation), • Lift-off or Wet Chemical Etching for Amplitude CGH and Glass dry etching for Phase CGH.
D3.9	**Design and development of Strip Filters in VNIR spectral range (SAC)** Strip filters are interference filters. The strip filter assembly can be developed using butcher block technique. In this the filter strips catering to different spectral bands are glued together to form an array. Using the coating facility (SYRUSpro1110) at thin film lab SEDA, the required band pass filter (B1-B4) coatings will be developed. These filters are then diced into strips of required widths using the dicing facility in the lab. Four filter strips belonging to different bands (B1-B4) will then be glued together to form the filter arrays. These activities can be carried out at SAC. In order to use it on board, one needs to block the stray radiations at the junction of the strips, for which masking coating needs to be applied, which also defines precisely the clear aperture of each filter strip. For this purpose, we need to use lithography followed by masking coating deposition followed by dry etching. At present these facilities are not available in the lab, hence the facilities available at other institutions can be utilized for this purpose.
D3.10	**Development of band pass filters with controlled thickness variation across the filter length (SAC)** The interference band pass filters are sensitive to angle of incidence. Not only the central wavelength shifts due to angle but also the shape and transmission changes at higher incidence angles. This becomes more significant in case of narrow band pass filters. In optical payloads with large field of view, it becomes almost mandatory to design the tele centric optics in order to minimize this effect. This in turn makes the design very complicated and may require aspheric components, which are difficult to fabricate. In order to reduce spectral shifts due to large angles, a band pass filter can be design to compensate for this shift by introducing controlled variability in the filter thickness. The variability can be introduced by designing the appropriate masks, which will be filter specific. By replacing conventional filters by these variable filters, the optical design can be made very simple. The design of these filters will be done in house. Development of the controlled thickness variation of the coating across the filter will be taken up in collaboration with Academic institutions.
D3.11	**Development of IR filters (SAC)** For payloads, involving IR imaging we need filters catering to the spectral range from 3 – 15 microns. The proposal is to design the filters in house and get it coated with the help of institutions within India. At present, the thin film lab does not have the facilities to develop the coatings in the IR spectral range. These activities can be taken up with the help of other institutions within India.

D3.12	**Development of Rugate Notch Filters (SAC)** Notch filters are optical filters that selectively rejects a portion of the spectrum, while transmitting all the other wavelengths. Notch filters based on the principle of optical interference can be fabricated using Rugate dielectric stack, which provides high reflection in a narrow wavelength region and high transmission outside. These filters act as mirrors for a narrow band of wavelengths. In the free space optical communication as well as in space based detect ability and identification of submersibles. In this high energy, LASER pulse is transmitted from ground based station towards a space based mirror that scans over a specific oceanic area looking for returns from underwater objects. These filters can replace the reflectors. This will reduce the background noise, as they will only reflect the narrow band of wavelengths around the LASER wavelength. They are also useful in the RAMAN spectroscopy and fluorescence based imaging.	
D3.13	**AI enabled design of next generation optics/optical systems (SAC)** The traditional design method for imaging optics is to first find a starting point, and then perform optimization. However, for freeform system design, proper starting points with similar system specifications and special nonsymmetrical configurations are very rare, which greatly increases the possibility of using extensive human effort. Use of Deep learning algorithms (Artificial Neural Network (ANN) in particular) can significantly aid in finding optimized starting points for imaging system design. This research work envisages development of an intelligent framework where the entire design process need not be repeated again and will result in faster development of EO payloads. A typical AI enabled design framework. This approach offers several advantages, particularly in the situation where there are limited existing designs and patents and knowledge is limited. The intelligent framework developed can be used to learn from the previous added designs. Moreover, designers do not have to manage the starting point exploration or analytical/numerical design process.	
D3.14	**Zerodur, Silicon Carbide, Schott Glass blank development (SAC)** Zerodur, Silicon Carbide, Schott Glass blank materials are required for the fabrication of Optics (reflective/Refractive telescope). Zerodur is glass ceramic and its CTE is nearly zero and used for reflective optics development. Schott glasses are used for refractive optics development. Indigenous development of these blanks will significantly aid in payload design and developmental activities for future ISRO missions.	
D4	**Sub Area**	**Electronics System Design and Development (SAC)**
D4.1	**Development of Integrated Circuits for Harsh Environment Operation (SAC)** Harsh Environments are defined as environments, which are characterized by high/low temperatures, extreme vibration loads, harsh chemical environment, high radiation etc.	

	The electronics or systems required to operate under such harsh/extreme conditions have application such as in aircraft engines, automotive, oil-well drilling and space exploration like near to Sun and planets like Venus where the surface temperature is appx. >400°C. Hence there is a requirement of development of electronics and sub-systems (both commercial and space) which can operate under extreme environments. Present technology used in development of integrated circuits are mostly Silicon which is suitable for reliable operation when the temperature is <150°C. The other technology Silicon-On-Insulator (SOI) can operate upto temperatures <300°C. Hence, these ICs are susceptible to damage in high temperature and radiation environment and hence require additional distancing and shielding, thereby putting restrictions to where these circuits can be placed. Recent developments have shown use of wide bandgap (WBG) semi-conductors like Silicon Carbide (SiC), Gallium Nitride (GaN), diamond etc. These materials have shown tremendous resistance to harsh temperature and radiation. Development of an integrated (like SiC-CMOS) circuit technology enables development of integrated circuits which are stable in harsh environments. The benefits are improved reliability, reduction in size / weight and power for cooling systems (which are typically required when conventional electronics (Si or SOI) is used) and possibility of direct sensing and control systems in harsh environment.
D4.2	**System Modelling and Controller Development for IR Payloads (SAC)** Various control systems are used in IR payload for controlling the temperature of various Opto-mechanical elements. IR detector requires temperature control of IDDCA cold tip, detector window, Blackbody and other elements within few mK accuracy and stability. There is a need to develop an executable model of the system including the plant using first principle methods or other methods (using experimental data). MATLAB or other modelling tools can be used for developing the executable model. Methodology: • In first principle method, equations governing the working principle of the plant are developed. Consideration to material properties and interfaces are given to develop accurate relationships between controlling variable and controlled variable. If information related to operation of some blocks are not available, field data (experimental data) can be used to model these blocks. • Above models are simulated and Controller is tuned and optimized for best performance in terms of overshoot, rise time, settling error and stability. • Additional logic e.g. safety logic can be included for protection against over current / voltage.

	• Controller architecture algorithm should be selectable / programmable. • This PID controller is to be implemented in Micro-controller/FPGA. To achieve this translation from the system level model to HDL or C language is required. This can be achieved using C Code or HDL coder toolboxes or similar tools/ methods. • Generated HDL/C Code are simulated and compared against the results from system level model. • Final validation is done by doing Hardware in loop tests with the actual FPGA/Micro-controller.
D4.3	**ASIC: Design, Simulation, Fabrication and Modelling (SAC)** The scope the activity covers Analog, Digital and Mixed signal ASIC design, simulation, verification, layout, tape-out and fabrication. The main motivation is miniaturization and indigenization of electronics in the form of low power ASICs and Readout Integrated Circuits (ROICs) with objective of integrating multiple functionality in a single device. The ultimate goal is to integrate individual blocks to realize "System on Chip (SOC)". Some of the ASICs, but not limited to, are multi-channel Analog Front end device for detector signal processing, High data rate Serializer-deserializer, High precision low noise multi-output voltage reference, programmable bias generator and regulators (negative and positive), Bipolar high speed high capacitive CCD clock drivers, IR detector ROICs, multi-channel temperature controller, switches etc. Design and development of radiation hardened library covering standard cells and devices is also covered under the scope. ASIC modelling either software or based on implementation in FPGA/microcontroller of various ASICs to be part of various system level simulations and optimizations is also envisaged.
D4.4	**Modelling of Special Components, Interfaces, Hardware (SAC)** Modelling of various state of the art mixed signal devices, detectors, interfaces etc is envisaged. Font-End design (detector proximity electronics) of an electro-optical payload faces lot of constraints w.r.t system requirements, detector used, real estate availability, harness routing, mechanical design, optical ray diagram, thermal requirements, grounding scheme, hardware in the vicinity etc. Also almost all electro-optical payloads are unique for each mission w.r.t above constraints and it becomes impractical and non-optimal to use a common standardized design for front end electronics. Hence development of various models of components, detectors, interfaces taking into account mechanical constraints, layout, routing, signal integrity, thermal issues, pcb size, circuit topology, grounding scheme, hardware in the vicinity etc needs to be developed. The development of this kind of integrated model will help in better understanding of the system performance at early stage and faster realization of the hardware.

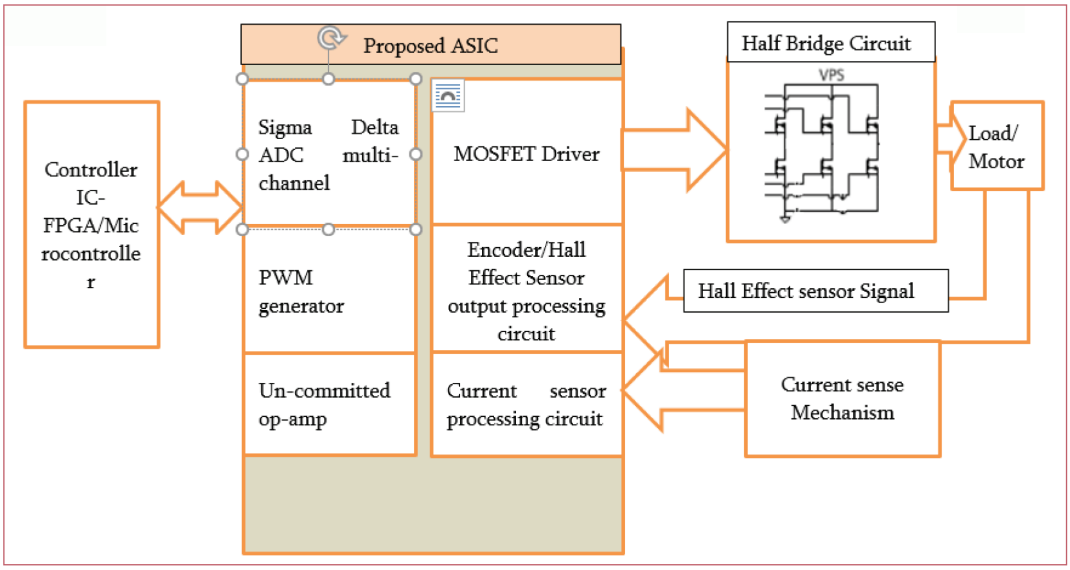
D4.5	**Generic Multi-Channel Front-End and Digital Proportional-Integral-Derivative (PID) Controller with actuator interface ASIC for Temperature Control (SAC)** Electro-optical payload cameras have many elements like detector, calibration source, optical elements etc. which need stabilized temperature for proper functioning. Range of temperature depends on system engineering, physics involved in device working and overall mission performance specification. Passive cooling is popular and simpler method for temperature control. Cooled object (achieved through deep space radiative coupling) is heated using close loop system to maintain defined temperature. In this scheme, Thermistor or Platinum Resistance Thermometer (PRT) are used as temperature sensor. Foil heater of required capacity are used as actuator. Control is either based on On/Off method or PID method. Other type of temperature control uses active cooling where very low temperature (<200K, cryo-temperature) is to be achieved. This approach uses transistor Vbe to sense cryo-temperature. Linear or Brushless Direct Current (BLDC) motor is used to achieve cooling. Actuator drive signal is 50Hz AC sine wave or Two/ Three phase pulses. In general, any digital domain based temperature controller has (a) Temperature Sensor (b) Signal conditioner (c) Digitizer (d) PID or On/Off control logic (e) Interface control signals for actuator driver (f) Driver for actuator excitation. ASIC proposed for blocks (b), (c), (d) and (e) is multi-channel (typically eight) independent temperature signal conditioning channel ASIC, with versatile and generic design, planned to support multiple application of temperature control. Offset and gain control in signal conditioner blocks is required to allow temperature control using PRT and Thermistors. 3 PRT, 3 Thermistor and 2 Transistor based channels are planned. Digital interface (Low Voltage Complementary Metal Oxide Semiconductor (LVCMOS)/ Low-Voltage Differ-ential Signaling (LVDS)) is planned for actuator driver control. 2 On/Off actuators control, 4 PID actuator control and 2 motor actuator control are planned. Digital PID controller should be programmable using CAN or any other interface for adaptability to multiple applications.
D4.6	**ASIC development of Generic N-channel MOSFET drivers and PWM generator with integrated Current and Hall Effect sensing mechanism and sigma delta ADC (SAC)** The main objective of development of this ASIC is complete indigenization of space grade motor drive electronics. Generic design of Metal-Oxide Semiconductor Field Effect Transistor (MOSFET) driver is aimed for half bridge control. The ASIC envisaged also has integrated current sense amplifier, hall effect sensing, Pulse-width modulation (PWM) generator and ADC. N-channel MOSFET drivers are mainly used in N-channel Metal-Oxide Semiconductor (NMOS) based drive circuits of stepper motors, BLDC

motors, Cryo-coolers etc. A MOSFET driver is a type of power amplifier that accepts PWM signals and produces a high current (>1A) / high voltage (>10V) drive input for the gate of a high-power transistor (such as power MOSFET) with fast switching frequencies (>100KHz) and dead time (~500ns).

Current sensor amplifies a small differential input voltage developed by the current flowing in a sense resistor at the load side. The processing circuit processes the electrical signal generated by Hall Effect sensor or resolver output. Modern Sigma-delta converters offer high resolution, high integration, low power consumption, and low cost, making them a good ADC choice. Multi-channel delta sigma ADC is required for processing control parameters e.g. Load current, voltage etc. The Independent PWM Generator (switching frequency > 100KHz) block is required to generate pulses for carrier-based pulse width modulation converters. The block can be used to fire the MOSFETs of single-phase, two-phase, three-phase bridges. PWM resolution of >10 bit is preferred. PWM generator shall provide internal or external reference input for modulation and shall have a bypass option for providing input from external FPGA/uC. An uncommitted (low bandwidth, precision) op-amp is required, so they can be tuned based on the application. The gain resistor of op-amps should be external to allow the buffer and filtering of required signals. Typical specifications and block diagram of the ASIC is as below.

Typical Specifications:

- 4 High and 4 Low side outputs
- >1A drive per output
- High side voltage/bootstrap voltage > 50V
- Programmable dead time up-to 500ns
- 3 Current sensors
- 4/8 channel sigma delta ADC, >12 bits, >100ksps
- 6 bi-level inputs for Hall sensors
- Resolver interface (optional)
- Optional Buffered PWM inputs (3.3V or 5V)
- In-built PWM Generator with bypass option
- PWM resolution: better than 10 bits
- PWM frequency > 100KHz
- Duty cycle range: 5% to 95%
- Un-committed Op-amp (BW- 1MHz, typical)
- Serial programming

	Block Diagram: 
D4.7	**Reconfigurable System-On-Chip based solution for satellite on-board computing (SAC)** High speed computing has always played an important role in on-board data processing and control. On-board computing has been represented mainly by the on-board computer (OBC), which is the kernel of the On-Board Data Handling (OBDH) system that is central to the overall satellite design and its operations. The OBDH system is an integral part of the satellite platform and in many missions extends to comprise various elements of payload electronics. In future missions, there is need for advance technologies that can be achieved via miniaturized multi- System-on-Chip (SoC) processor designs. Now a day, the increasing requirements of on-board reconfiguration and on the fly programming capability, system-on-a-programmable-chip (SoPC) designs has emerged as a major enabling technology. It is envisaged that the application of the SoPC concept to on-board computing will result in radical improvements and unleash new capabilities. In addition to the benefits of SoC design, such as reduction of size, complexity and cost, it can provide the means to build flexible and modifiable on-board computing systems. The SoC platform can be configured to meet different mission requirements. The SoC on-board computer (SoC-OBC) consists of mainly soft IP cores, programmable gate arrays including the LEON/ Advanced RISC Machine (ARM) processor and multiple peripheral devices. A purpose-built Direct Memory Access (DMA) controller handles the data transfers between the peripheral cores and the main memory. The AMBA AHB and AXi buses is for interfacing of high-performance system modules. The Advanced Microcontroller Bus Architecture (AMBA) Aadhaar Payment Bridge (APB) bus supports peripheral functions with minimal power consumption and reduced interface complexity. The CAN, High-level Data Link Control (HDLC), SpaceWire and space fibre network interface controllers and the EDAC block are typical components and interfaces for use in space.

	Designing On-board Computer consisting of programmable system on chip hardware is really challenging and this will provide the common miniaturized hardware platform for multiple missions along with providing seamless solutions and flexibility of programming, controller, data processing and standard interfaces. **Scope of Research:** • Design and development of On-board computer hardware encompassing mainly Programmable System on chip(PSOC), Rad hard FPGA, high end memories and all standard interface CAN/Spacefibre/Serdes/LVDS interfaces along with SI and PI analysis with industry collaboration. • Soft cores IP design for standard interfaces and Logic • Standard Memory DDR2/3, ONFI controller designs. • External peripheral interfaces design &development. • Embedded processsor/LEON/ARM processor interface with FPGA. • Onboard partial n selective configuration. • Space fibre codec n network design and development.
D4.8	**Real time image processing in on-board Space systems (SAC)** Target detection and tracking has gained significant importance in many applications, including optical communication, inter-satellite communication, motion detection, reconnaissance and surveillance in which the major is to reveal trajectories of the targets. Considering the recent developments, many electro-optical systems are in need of full automation for achieving this task. Therefore, many multi-tracking algorithms include two fundamental stages as the automatic, time independent detection of targets; and association of the detections in the temporal space. Problems remains to be challenging mainly due to unknown and changing number of targets; noisy and missing observations; interaction of multiple targets. Moreover, all these challenges are needed to be solved in a time efficient manner for real-time applications in space systems. **Scope of Research:** • Study and implementation of object detection algorithm for low SNR targets and its real time implementation in on-board FPGA hardware • Tracking algorithm development: Kalman for tracking and trajectory prediction. • Study/development of Optical Flow algorithm for planetary landing. • DSP based real /near real time data processing for signal analysis and image processing. • Real Time decision making for Landing System. • Machine learning techniques along with computer vision techniques need to be studied and implemented for the targets required for obstacle detection, landing site and surveillance. • Real Time Operating System (RTOS) optimisation for on board

D4.9	**Power supply systems for Space missions (SAC)** Payloads for Remote sensing and planetary exploration missions require state of art Power Supply electronics to cater to various requirements of Camera Electronics sub systems. These Power Supply Electronics requires to meet several stringent requirements such as multi-output voltage lines in range 3.8V to 24V, very low noise (≤20mV), high efficiency (>70%), EMI 461E complaint, inbuilt input power protection and output short circuit protection. The following technologies are of particular interest in future Power Supply electronics development a. Very Low noise (≤5mV), Low power (<10W), highly efficient (>80%) complying with EMI 461E standard, space grade isolated power supply /module. b. Multi-output (3 to 4 voltage lines in range 3.8V to 24V), high efficiency (>80%), Medium Power (25W – 100W), Low noise (≤15mV) complying with EMI 461E standard isolated space grade power supply c. Development of Hybrid Micro Circuit (HMC) based miniaturised dual output (+3.8V and +5.6 V) DC-DC converters with high efficiency (>75%), medium power (> 30 W), inbuilt EMI filter and having EMI/EMC compliance to MIL-STD-461E. d. Development of housekeeping and protection circuitry in the form of HMC to monitor and protect power supply electronics from various fault conditions such as Overvoltage and under-voltage protection, Over temperature protection, Overcurrent protection and Output Short circuit protection e. Development of Rad-hard non-isolated synchronous buck converters for wide input voltage (10-30VDC), adjustable output voltage (from 3V to 80% of Vin) and high output current (>10A).
D4.10	**Optical data transmission system for Nano/micro payloads (SAC)** High resolution wide swath imaging typically requires payloads and satellites of large dimensions & weight. Huge amount of data requires to be transmitted to ground requiring multiple transmitters further increasing the mass and size. Cost of such satellites is too high. Development time is large and penalty associated with any component under performing/ malfunctioning is large. Alternative approach is to develop a constellation of Nano satellites to cater to above requirements. However traditional Nano satellites suffer from low data transmission capability and poor pointing accuracy. To overcome this problem it is proposed to develop a Nano satellite utilizing optical data transmission. However incorporating a traditional Optical Communication Terminal (OCT) is not feasible in the mass and power constraints of a Nano platform. It is therefore proposed to develop & demonstrate a miniaturized Optical data transmission system to enhance the capabilities of ISRO's small satellites.

D4.11	**Single Board Controller based Payload & Mainframe Electronics for High Resolution Nano Satellites (SAC)** Traditional ISRO Nano satellites (~10Kg) are capable of providing ~20m resolution from LEO orbits. However higher resolution & lower mass is desirable for future Nano missions. A Nano Satellites consists of following subsystems: • Payload sub-systems (Sensor, Electronics, Optics, Mechanical) • Mainframe subsystems (Attitude Control system ,OBC, RF system) • Electrical Harness • Mechanical Frame/Housing for Payload and Mainframe • DC-DC for payload • DC-DC for Mainframe Present approach has dedicated electronics for various functions of the payload and satellite mainframe e.g. • Sensor Bias, Sensor Control, Sensor data processing, Compression , Data Formatting, Data Transmission is managed via 2-3 Boards. • Payload DC-DC Electronics Board • Satellite mainframe OBC Board, ADCS Board, RF Board. • Mainframe DC-DC Electronics Board For reducing the overall satellite mass (<5kg) while improving payload performance (resolution, swath, SNR), miniaturization & integration of various Electronics is proposed. A Single Board High Performance Controller along with a bus structure shall be developed carrying out functions of Sensor Bias, Sensor Control, Sensor data processing, Compression, Data Formatting, Satellite mainframe OBC, ADCS, RF Data Transmission.
D4.12	**Space qualified flexible EMI Shielding and Radiation resistant coatings and enclosures for Onboard Electronics (SAC)** High speed electronics systems, miniaturization of PCBs, Electronics packages, small payloads and other such advanced capabilities, electronic sub systems requires highly populated PCBs / Packages / harnesses to support their functionality and performance requirements. Such compact/dense packaging causes EMI effects. Traditional metal EMI shields take too much space thereby reducing the overall competitive functionality of electronic devices and increases the size as well. Therefore, more recently, the research focus is on flexible coatings and enclosures developed from nanocomposites. Therefore, we feel the requirement of the development of MIL-STD-461E compliant flexible EMI shielding and radiation tolerant enclosure, which can be easily applied and adapted onto a PCB design and very sensitive signal lines. The required composites should suite the needs of ISRO especially like space-qualified

	material, high thermal stability, flame retardant and durable for mission life of more than 10 years. These composites can be explored for designing materials that can shield radiation and protect PCBs and harnesses without much overheads. The qualification of these composites, but not limited to, should include Thickness measurement test, thermal shock test, thermos vacuum test, humidity test, coating peel test, outgassing test etc. The design of enclosures should be in a way that they don't need to be electrically grounded to the PCB, thus simplifying or eliminating masking. This should also be able to address EMI issues on the PCB, in between tightly packed semiconductor devices and can be tuned to absorb EMI at specific required frequencies. The design must also take care that they could be applied at the end of a product design cycle. These enclosures should not affect the electrical performances and sub system functionality at ground and at onboard. The shielding performance also need to be brought out for frequency range up to 1GHz with respect to the material thickness.
D4.13	**Gigabit Interfaces for Spacecraft data flow (SAC)** Next generation payloads will have a suite of cameras and measurement systems. The capability to cater to more than 50 million pixels aggregate for processing, formatting, storage and distribution prior to near real time compressed data transmission calls for Gigabit interfaces to handle Terabyte data volumes. This has to be handled by three major methods, (a) Gigabit physical data interfaces between FPGA, memory, data serializer and lane drivers, (b) high end FPGAs to meet throughput and capability, (c) design of high bandwidth PCB traces and characterization of transmission cables, (4) reliable data interface protocol. New components have been identified to provide low jitter clocks, GTY interface for > 1Gbps data interface and matched connectors to meet SI. New in-house protocols based on SpaceFibre which is compliant to ECSS-E-ST-50-11C for high speed serial data transfer between subsystems is being developed. This complex firmware will offer virtual channel buffer controller and flow control, integrated Quality of Service (QOS) based on priority, bandwidth reservation and scheduling for each channel, optional data scrambling, Control word generation and framing of the data packets, broadcast messages and Flow Control Token(FCTs), Generation and acquisition of broadcast messages, interleaving data, broadcast, Idle frames and FCTs based on precedence to generate a data stream along with Fault Detection Isolation and Recovery(FDIR) logic. This will push the serial link speed to greater than 6.25 Gbps.

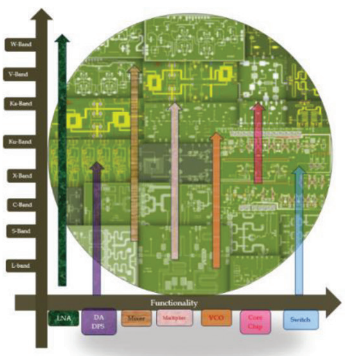
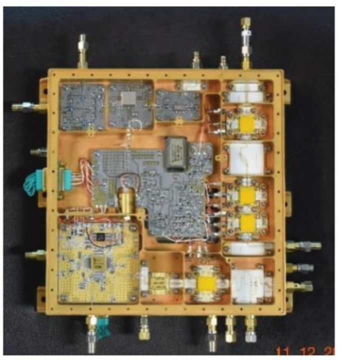
D4.14	**Smart and efficient payloads with AI/ML (SAC)** The traditional method in remote sensing is to transmit all the pixels to ground for offline post image processing. This consumes satellite resources in terms of bandwidth, complexity size and weight. A more efficient way is to define imaging areas in real time on-board and transmit useful data as demanded by users. This can be could-free imaging zones, class segmented objects like fire zones, or contextual binary data like quantitative presence or absence of user defined features. Artificial learning algorithms (AI) using Deep Neural Networks are used to train a suite of models for various features, multi-classification and contextual data with coordinates. These models, when implemented in FPGA based SoC ena ble control of on-board imaging, reduce bandwidth by data volume reduction and significantly aid the user by faster turnaround time. This research work envisages development of vast database, training, development intelligent framework and work-flow for FPGA porting, elaborate lab testing of real camera with real/ synthetic images.	
D4.15	**Neuromorphic computing-Low complexity Artificial Intelligence (SAC)** Present CNN network architectures are computationally intensive and consume high power compared to human brain. The human brain works on change detection and ends spikes of information. The Neuromorphic computing mimics the human brain more closely and is based on spiking neural network (SNN). This reduces the computational and power requirements significantly. Our goal is to deploy this SNN model inside FPGA and develop end to end system for feature detection, tracking application, etc. An intelligent flow based on Brainchip Akida is being developed. These involve training, quantizing, fine-tuning with Quantization Aware Training (QAT), and converting a model into a hardware-optimized format and performance evaluation to finally infer from images.	
D5	**Sub Area**	**EO sensor System AIT and Performance Characterization (SAC)**
D5.1	**Design and development of smart test setups (SAC)** Test setups help in simulating spacecraft mainframe interfaces, control and command of the sensor, and data acquisition for performance evaluation. Currently, test setups are custom developed for each EO sensor considering its interface, functional and operational requirements. However, in view of the upcoming demand for variety of EO sensors, there is a potential scope of research and development for smart test setups for EO sensor testing. The smart setups are easily reconfigurable to cater to variety of sensors, they have fault tolerant designs, and are self-calibrating to enable faster turnaround time and ensure precision measurements of EO sensor performance parameters.	

D5.2	**EMI analysis and mitigation techniques (SAC)** During AIT, various electronics subsystems, test setups and associated harness assemblies exhibit complex interplay and results in a complex EMI environment. This causes various random and fixed pattern noises in the EO sensor data, which can significantly impact radiometric quality of the imaging sensor. Hence, it is very important to identify the potential noise sources and develop suitable mitigation techniques. This offers a research opportunity for design and development of EMI analysis tool, which accounts for various noise sources in the sensor chain including electronics component level noise, crosstalk, signal coupling effects, ground noise coupling, engineering noise coupling, etc. and helps to analyse complex EMI scenario, identify the noise sources and help in developing suitable mitigation techniques. Available COTS software modules can be suitably used in the proposed analysis tool.
D5.3	**Development of new methods for EO sensor performance evaluation (SAC)** SNR and MTF are two key performance parameters that are used as performance markers for comparative studies. Many methods exist for performance evaluation in terms of MTF and SNR, however, considering the stringent requirements of EO sensor performance in upcoming future missions, many new methods are required to be developed. This offers significant research opportunity in this field. We need to develop efficient, simple and robust methods for SNR and MTF measurements. Also, study shall identify new performance markers and develop suitable methods for its implementations.
D5.4	**Thermal analysis model of harness assemblies (SAC)** Thermal analysis of EO sensors and spacecraft systems are carried out to evolve suitable thermal design and implementation approaches. Generally, thermal analysis of all electronics subsystems are carried out to evolve suitable thermal implementation scheme. However, thermal modelling and analysis of harness assemblies are generally ignored, although they are passive dissipating element in every spacecraft system. Thermal modelling of harness assemblies is very critical as it helps derive rerating specifications, avoid potential arching conditions, helps in improving performance of thermal control system.
D5.5	**Design and development of machine/deep learning methods for payload test data analysis (SAC)** Large amount of data is acquired during ground testing of EO sensors. These data sets help in analysing EO sensor performance under various operating and environmental conditions. However, analysing huge data sets to bring out minute but potential performance degradations is very difficult with traditional approaches. There is an opportunity to develop machine learning techniques to analyse large amount of data acquired for various EO sensors.

D5.6	**Machine Learning Techniques for Fault Diagnosis using TM data (SAC)** Complex EO sensors employ large number of interconnected subsystems to perform imaging task. The performance of all subsystems are monitored through the large number of telemetry (TM) channels such as voltage, current, temperature, timing information, configuration details etc. TM data is acquired during ground testing and also during in-orbit phases resulting in huge amount of TM data. These TM parameters allow designers to monitor the health of the sensor. Machine learning techniques can be developed to analyse the large amount of TM data to observe even subtle performance deviations that can help in diagnosing the faults in the operations of EO sensors.
D5.7	**Development of harness embedded panels for plug and play AIT (SAC)** Interconnection harness constitute an integral and important part of the EO sensor and satellite system. Various electro-mechanical constraints in implementing the harness interconnection calls for significant efforts in the design and development of EO sensors. Literature survey shows innovative concept of harness embedded panels, which significantly helps in saving precious volume on resource constrained satellite systems. We envisage to develop such harness embedded panels for Indian remote sensing sensors. In this arrangement harness is run within the panel thickness and connectors are available on top and bottom surface of the panel as end points for package interconnection. The proposed research work involves exploring innovative design of harness embedded panels, structural analysis, usage of smart materials and proto-type development, etc.
D5.8	**Development of efficient algorithm for image reconstruction for compressive imaging sensor (SAC)** Compressive imaging (Optical domain compression) is an emerging field that allows design and development of single pixel camera systems for imaging. Significant efforts have been reported in the literature for development of single pixel camera systems as an alternative to current commercial cameras. However, not much study has been carried out in exploring the feasibility of developing a spaceborne imaging system architecture based on optical domain compression. Currently, we are working on a single pixel camera architecture for spaceborne applications. The research opportunities exist in development of efficient algorithm for image reconstruction using the images acquired by a compressive imaging sensor and carry out extensive bench marking against available methods.
D5.9	**Development of robust image quality metric and suitable methods for its estimation using in-orbit images (SAC)** In-orbit image quality evaluation of EO sensors is a continuous evolving research field. This research work envisages development of a robust image quality metrics and suitable methods for its estimation from in-orbit images.

D5.10	**Development of methods for accurate estimation of SNR and MTF from in-orbit images (SAC)** EO sensors undergo extensive ground testing during development phase. However, post launch performance deviations are generally observed due to various instrument effects due to launch loads and orbital environmental conditions. On-board and vicarious calibration methods are employed to assess the in-orbit SNR and MTF performance of EO sensors. However, the achieved accuracies in deriving performance parameters always suffer from limitations either from measurements or the methods itself. The proposed research work will first study the available methods and suggest new approaches for accurate estimation of these performance parameters.	
D5.11	**Development of techniques for quantitative estimation of MTF contributions from various elements in the EO imaging sensor chain (SAC)** In-orbit images generally suffer from MTF degradations due to instrument behaviour in the orbital conditions, platform vibrations and jitter, and atmospheric conditions. Extensive characterization is carried out in laboratory using standard targets and also in-orbit using stellar and various calibration targets. It is important to quantitatively ascertain MTF contribution from each elements of the imaging instrument to understand anomalous behaviour (if any) of one or more elements using the laboratory data and in-orbit images. This research work envisages development of methods/techniques to quantitatively measure/derive MTF contribution from each element in the EO sensor chain. Also, extensive validation studies to be performed using available EO sensor data.	
D5.12	**Design, development and characterization of Spacefiber interface-based data transmission board (SAC)** Spacefiber interface is an emerging technology for transferring huge amount of data running up to 40 Gbps and can have multiple channels for increasing the data Tx rates. The interface protocol is based on Spacewire. The Spacefiber protocol has wires or fibres as physical layer for data transmission. This research work envisages comprehensive study of Spacefiber interface, design and development of a bread-board functional model and extensive characterization of the developed data transmission board.	
D6	**Sub Area**	**Ground Checkout Systems for EO Payload Testing (SAC)**
D6.1	**Computer based Multichannel High Speed Digital Data Acquisition System (SAC)** High Resolution EO cameras generate high speed data (of the order few Gbps). Evaluation of these cameras during various phases of testing, calls for design & development of High Speed Digital Data Acquisition System. Data Acquisition System receives incoming digital data from payload and transfers it to the computer. Data Acquisition System comprises of Data Formatter, Data Acquisition Modules installed in the computer and Data Acquisition Application. Data Formatter receives the digital data from payload over multiple chains with required electrical interface (LVDS, serializer/deserializer (SERDES)),	

	formats it and transfers packed data to Data Acquisition Modules. Acquisition application acquires data from Data Acquisition Modules. Out of different options for transferring the high speed data to computer, Camera link interface based transfer is one suitable option. Camera link interface supports high data transmission rates (2.04 Gbps for BASE mode, 5.44 Gbps for FULL mode & even higher for extended FULL mode configuration) & can be used to transfer very high speed data from Data Formatter to computer. Camera link's transmission method requires fewer conductors to transfer data. Hence it reduces the hardware components, interconnecting cables and simplify the Data Acquisition System configuration. Design & development of High Speed Data Acquisition System which involves Data formatter (Data Input – Multi channel, SerDes interface) along with the Data Acquisition Application can be taken up for data transfer rate upto 4.0 Gbps using camera link i/f in-house which will be very useful during the testing of High Resolution EO cameras.
D6.2	**Comprehensive Automation of Test Benches (SAC)** Automation of Spectral Response Measurement (SRM) test bench using a Bentham mono-chromator has been very successful and because of the same, the spectral characterization for all payloads works smoothly and effortlessly. Complexity of the payloads have increased which demands more and more testing and that too repeatedly in different conditions. The 1553 bus based TC and TM systems simplify the tasks and have been implemented and are successfully working. Integrated testing becomes a laborious process when carried out by the test engineers and has chances of errors. A scheme is proposed which has a generic architecture to combine instrumentation, data acquisition, parametric evaluation and a final output generation. The 1553 bus based instrumentation provides both the TC and TM functions. Tele-commands issued can be verified thru the telemetry for the confirmation. Synchronized data acquisition request can be made, followed by data processing to compute a set of parameters. This process is repeated for all modes of operations of the payload under a given test condition. At the end of execution of all operations, post-processing can be carried out over the data-set. Such instructions can be combined as a macro and executed as and when required. For Microsat-2A (LWIR and MIR) payload calibration, there was a requirement to acquire and record the data of all seven exposures for different temperature settings ranging from 180K to 340K. To cater to this requirement, automation feature was developed for payload commanding to change the exposure, acquire and record the data and generate the results simultaneously. With the automation, the task could be completed with about a factor of three improvements in timings as compared to manual task. This shall be an in-house development with the participation of focal persons from integration team, software and instrumentation developer for one test case project.

D6.3	**Knowledgebase Creation and Information Extraction (SAC)** A huge database of information is available for all E/O payloads developed so far by SEDA. This information contains automatically archived test results, TM data, raw data, logs and manually uploaded documents. The information is structured at sub-system level and project level under categories such as Results, Issues, Discussions and Solutions. This will provide contents for to create a knowledge base for future generation projects. An interface on top of this, using Natural Language Processing (NLP) techniques can be developed. This interface shall accept the queries in human-understandable natural language and provide answers by processing the information. Academia has subjects related to Information Retrieval, Data Mining and alike under broad topic of Artificial Intelligence. Students from academia can be involved in the projects.	
D6.4	**Development of learning algorithm for fault identification and recovery of EO payload by analyzing the video data, telemetry and commanding sequences (SAC)** Electro Optical camera/payload consists of multiple subsystems i.e. Detector, Optics, Camera electronics and mechanical subsystems. To meet the performance specifications, it is required that all these subsystems operate to their best potential. During the course of integration and calibration of subsystems, lot of payload calibration data and payload telemetry is generated in response to the commanding sequences given to the payload. During this phase of payload integration, problems are observed which can be due to multiple reasons like faulty commanding sequence, improper cabling or faulty behavior of any subsystem. To diagnose these problems at the earliest, a learning algorithm needs to be developed which can continuously analyze the video data, telemetry and commanding sequences given to the payload and build a model of the payload over time. This algorithm will not only help during the payload integration phase but also during satellite integration and in-orbit operations of payload.	
E	**Area**	**Microwave Remote Sensors (SAC)**
E1	**Sub Area**	**Microwave Frequency Generation and Receiver Technology (SAC)**
E1.1	Brief Overview of the research done in SAC for the realization of frequency sources and receivers for various microwave remote sensing payloads is as follows.  *MMIC details*  *PLL based Synthesiser up Ku band*	

	For realization various multifunctional MMICs have been designed upto W band namely Low Noise Amplifier, True Time Delay Shifter, Digital Attenuator, Digital Phase Shifter, Sub-Harmonic Mixer, Voltage Controlled Oscillator, Multi Throw Switches, High Power Protection Switch, Multipliers, Driver Amplifier, Multifunction Core Chips which has been successfully utilized for the development of various systems. SAC has developed frequency generators upto mmWave frequency either directly or indirectly through Phase Locked Loop (PLL). There is persistent effort to deliver higher performance, higher functionality, smaller size, lower power consumption designs based on latest technologies. The photograph of one such frequency generator system based on PLL technology upto Ku band has been developed successfully and appears below.
E1.2	**Development of Rydberg Atom Based Electric Field Sensors (SAC)** A highly tunable, self-calibrated atomic sensors based on Rydberg atoms offer ground-breaking advancement in the microwave field sensing and quantum technologies. As atoms act as the basic sensing unit, the detection frequency can be easily tuned without further change in hardware. The system is self-calibrated in nature, owing to the invariability of atomic parameters. As these sensors use atoms to measure the filed amplitude, they barely distort the impinging field. Atomic excitation to Rydberg state is achieved out by two highly stable and counter propagating lasers namely the probe and control laser. The frequency tunability is achieved by varying the control laser parameters. This research work deals in the development of highly tunable self-calibrated atomic sensors along with the necessary opto-mechanical components.
E1.3	**Design and Development of SiGe Based PLL-Frequency Synthesizers (SAC)** Bi-CMOS SiGe based phase lock loops (PLL) can play a critical role in generation of highly stable (both long and short-term stability) and widely tunable frequency generation blocks. It consists of an integrated VCO, programmable or fixed frequency divider, phase frequency detector (PFD) and the loop filter. The PFD must have dead zone of less than 300ps with an operating frequency up-to 200 MHz A differential charge pump along with the external loop filter provides the VCO control voltage. A multi capacitor bank based VCO enhances the Bandwidth of operation. The output frequency is dependent on the input reference frequency and the division ratio, a programmable divider helps in varying the operating frequency. This research work deals with the design and development of all the sub-circuits and its integration necessary for PLL based frequency synthesizer up-to 100GHz.

E1.4	**Design & Development of multifunctional mm-wave/sub-mm wave MMICs (SAC)** This research area involves design and development of multi-functional mm-wave/ sub-mm wave MMICs viz. low noise amplifiers, mixers, medium power amplifiers etc. using technology having InGaAs/ InAlAs hetero-structures with high Indium content/ InP. The developed MMICs will be used in receivers for climatic study, weather forecasting and astronomical applications.	
E1.5	**Schottky Barrier Diode (SBD) based sub-mm wave receiver front-ends (SAC)** This research area caters to design & development of sub-mm wave SBD-based receivers for inter-planetary exploration missions. Receiver front end can either be mixer with IF LNA or RF LNA followed by mixer and IF LNA, depending on availability of RF LNAs at such high frequencies. Sub-harmonic mixer topology is preferred owing to difficulties in generation of high-power LO signals at high fundamental frequencies.	
E1.6	**SIS-tunnel junctions based sub-mm wave/terahertz receiver front-ends (SAC)** The superconductor–insulator–superconductor tunnel junction (SIS) based sub-mm wave receivers, operating at ~ 4K temperature, can achieve state-of-the-art noise performance of the order of 2-5 times the quantum limit. This research work involves design & development of cryogenically cooled (operating at ~ 4K) SIS based receiver front-ends at sub-mm wave and terahertz frequency bands.	
E1.7	**mm-wave Single-Chip Receiver using RFIC technology (SAC)** This research area involves design and development of miniaturized single-chip receiver core-chip at mm-wave frequency band using RF CMOS/ BiCMOS technology. This will lead to considerable reduction in size, weight, and power (SWaP) which is prime consideration for space-borne electronics.	
E2	**Sub Area**	**Digital Controls, Data Acquisition, Processing (SAC)**
E2.1	Microwave sensor digital electronics group is responsible for design, development and delivery of on board digital control sub-systems, on board ASICs, digital data acquisition, signal processing of sub-systems, near real-time SAR data processing system and ground checkout units for various digital sub systems. Following research areas are identified for future microwave remote sensing payloads:	
E2.2	**Payload Control and Tracking Unit (PCTU) (SAC)** The development of a Payload Control and Tracking Unit (PCTU) involves designing a highly reliable and efficient system to manage payload operations in space. This includes hardware and software integration to ensure seamless communication, control, and data handling between the spacecraft and ground stations. Presently, PCTU is implemented to actuate scan mirror and fine scanning mirror (FSM) to bring the optical beam into line of sight with ground station.	

	This proposal is for development of future PCTU which takes input of spacecraft orbital parameters such as attitude, velocity etc. The orbital parameters can be used to predict errors in pointing and according a closed loop tracking can be initiated to bring payload in line of sight with accuracy of better than 10urad. These orbital parameters will also be used for computation of point ahead angles and point ahead mirror must be actuated in closed loop to align optical transmitter.
E2.3	**Time to Digital Converter (TDC) with 10ps accuracy(SAC)** Time-to-Digital Converters (TDCs) are used for high-precision event time stamping. Currently, TDCs are implemented using FPGA carry chain delay lines, but they suffer from inaccuracies due to routing variations within the FPGA fabric. Various calibration techniques can be applied to enhance precision. Additionally, TDCs are highly sensitive to temperature fluctuations, making temperature compensation techniques essential for ensuring stable performance and improved accuracy. This proposal is for the design and characterization of TDC in FPGA/ASIC for 10ps accuracy. Following activities are required for this: • Designing of Time to Digital Converter (TDC) using carry chain/buffers. Precise routing between inter element for minimal variation of sub clock period. • Calibration of TDC through standard source with accuracy of one order better than requirement. • Implementation of thermal compensation techniques for correcting response over temperature. Characterization of TDC over temperature for 10ps accuracy.
E2.4	**System on Chip with RISC-V processor and embedded FPGA for Space Application (SAC)** This proposal focuses on the development of a reconfigurable fabric core (eFPGA) and its integration with a RISC-V microprocessor. The eFPGA will comprise an array of basic logic units (LUTs, flip-flops, etc.), a routing matrix, a custom DSP block, and onboard digital systems designed for interplanetary and small satellite missions, which require miniaturization, energy efficiency, flexibility, and sufficient computing resources. A System-on-Chip (SoC) integrating a microprocessor soft core and an embedded FPGA (eFPGA) offers an optimal solution for applications demanding low power and high flexibility. The eFPGA core will be developed as a soft RTL core and interfaced with the microprocessor via the AHB/AXI bus. Users will have the ability to configure various parameters, including array size, I/O count, and memory size. Additionally, the bitstream generation flow for the eFPGA core will be designed to be compatible with available open-source synthesis and place-and-route (P&R) tools.

	To ensure reliability in space environments, the eFPGA will incorporate fault-tolerant features, making it suitable for radiation-prone applications. The primary target application for this eFPGA is the implementation of control and signal processing functions for microwave remote sensing payloads.
E2.5	**Design and Development of Matched Filter Correlator ASIC (SAC)** A Digital Correlator ASIC for Microwave SAR is a high-performance, low-power integrated circuit designed to process received radar echoes efficiently. SAR systems require real-time signal correlation to reconstruct high-resolution images of targets from microwave signals. The digital correlator ASIC accelerates this process by implementing parallel cross-correlation computations, reducing computational load on general-purpose processors while improving speed and power efficiency. The research work involves various aspects of design and development: • Design and development of high-speed, parallel-processing correlator architecture for efficient SAR signal processing. • Implementation of low-latency data streaming and optimized memory management for continuous radar data processing. • Development of optimize correlation algorithms for range/Doppler processing and pulse compression. • Testing & Validation of design by post-silicon testing with real microwave SAR data to validate performance, perform radiation hardness testing for spaceborne applications of ASIC and thermal analysis for high-power environments and design optimize for reliability, ensuring minimal signal distortion and noise impact.
E2.6	**Design and Development of Digital Spectrometer ASIC (SAC)** The Design and Development of a Digital Spectrometer ASIC focuses on creating a high-performance, low-power integrated circuit for real-time spectral analysis in applications such as radio astronomy, remote sensing, and communications. The research involves designing an optimized Fast Fourier Transform (FFT)-based architecture for spectral decomposition, incorporating a 6-bit high speed ADC (2 to 4 GHz Instantaneous bandwidth) along with wide analog input bandwidth support (8 to 10 GHz), a programmable Voltage Gain Amplifier (VGA), a Phase Locked Loop (PLL) based frequency synthesizer, a demultiplexer, a poly-phase filter bank, a programmable windowing function, a Fast Fourier Transform (FFT) core, a frequency-domain data analysis block, a programmable time accumulator of frequency-domain voltage or power, a data readout block, a Serial Peripheral Interface (SPI) for the ASIC's programming and low-speed data interchange, a low-voltage differential signal (LVDS) interface for high-speed data transfer, a digital control unit and ASIC testing features. This research aims to develop a robust, scalable, and power-efficient spectrometer ASIC for deployment in radio telescopes, deep-space communication, and scientific instrumentation, contributing to advancements in spectral signal processing technologies.

E2.7	**Scrubbing techniques for SEU mitigation and On-board Reconfiguration (SAC)** Scrubbing techniques play a critical role in mitigating Single Event Upsets (SEUs) in spaceborne and aerospace electronics, where radiation-induced bit flips can compromise system reliability. SEU mitigation is achieved through periodic configuration memory scrubbing, which detects and corrects errors in FPGAs and ASICs used in satellite payloads, avionics, and deep-space missions. The development work involves implementing error detection and correction (EDAC) mechanisms, such as cyclic redundancy check (CRC), Hamming codes, and Triple Modular Redundancy (TMR), along with Partial and Dynamic Reconfiguration to ensure system resilience. Additionally, autonomous onboard reconfiguration is being developed to enable real-time recovery by reloading fault-free configurations stored in redundant memory banks. The scope of this research extends to radiation-hardened FPGA architectures, AI-driven fault prediction models, and low-power scrubbing techniques, ensuring robust operation.
E2.8	**IP Core development for fault tolerant Double Data Rate 4 (DDR4) memory controller (SAC)** IP Core development for Single Event Functional Interrupt (SEFI) mitigation for DDR4 SDRAM memory chips. This IP Core will mitigate Single Event Upsets (SEUs) and SEFI in a radiation environment. This work involves, • Development of a controller that handles address mapping, read/write operations from user and mitigates SEU and SEFI errors in background • Design verification, synthesis and implementation targeting several FPGA platforms like Xilinx, RTG4, NanoXplore and ASIC. • Test the IP core in a radiation environment to estimate the correctness of the IP core.
E2.9	**Design and Development of Generic RADAR Waveform Synthesis ASIC (SAC)** A Generic RADAR Waveform Synthesis ASIC is a specialized integrated circuit required to generate and manipulate diverse radar waveforms in real time. It is crucial for modern radar systems, including synthetic aperture radar (SAR), phased array radar, Radar Altimeter and Ground penetrating radar (GPR) application. This capability is achieved by a high sampling data converter (DAC) and a processor or FPGA to generate the required waveform for different applications (linear frequency modulated signal (LFM) for SAR, Frequency Modulated Continuous Wav signal (FMCW) for altimeter and Step Frequency Continuous Wave (SFCW) for GPR). Given the widespread use of such devices in microwave payloads and the ongoing push for miniaturizing digital electronics, the design and development of an indigenous Generic RADAR Waveform Synthesis ASIC is proposed.

	The proposed work includes, • Design and development of a high-speed dual-channel DAC (12-bit, 500 MSps) and Direct Digital Synthesis (DDS), integrated onto a single chip using a 65nm CMOS process node. • Radiation hardened design for use in space applications. • Integration with controller ASICs to provide a truly single chip solution for a wide range of RADAR applications. This will reduce the SWaP (Size, Weight, and Power) requirements and miniaturize the electronics and free up processing resources of the central controller of the digital subsystems.
E2.10	**Design and Development of Telemetry ASIC (SAC)** Telemetry ASIC is a Mixed signal ASIC. It can receive analog (thermistor) and digital telemetry signals and can send them over serial link. It will have RS422/SPI interface along with ADC, modules. The objective of the proposal is to develop a miniaturized integrated single chip solution while presently this functionality is achieved with discrete components like FPGA, ADC, Mux etc. The proposed work includes, Radiation hardened design for use in space applications, where digital modules will be designed using RHBD library and analog modules will be having RHBD layout techniques. It will be fabricated using 180nm CMOS process and the design should be modular, addressable and scalable design, based on no. of TM channel, multiple devices can be used.
E2.11	**Signal Processing algorithms for RADAR Velocity meter (SAC)** This research focuses on developing and optimizing signal processing algorithms for Pulse Doppler RADAR-based velocity meter for Doppler shift estimation, range Doppler processing and clutter suppression to accurately measure object velocity. Key techniques such as FFT, kalman filtering, wavelet Transform and Machine learning based motion estimation will be explored for improved accuracy and noise reduction. The following research areas are identified, • Designing algorithms and scheme for precise measurement technique • Real time unambiguous velocity estimation from a Doppler radar
E2.12	**NVMe IP for FPGA (SAC)** This IP will be useful for design and development of a digital design involving NVMe based memories for high-speed data recording and playback. NVMe protocol-based IP is need to be employed to maintain data integrity and reliable operation of data processing and storage. The main aim of the research would be to develop an efficient controller logic for NVMe protocol supported memories. Also, the research must focus on real time optimal implementation EDAC algorithm and efficient low overhead file system amenable for implementation on FPGA/ASIC.

E2.13	**Digital ASIC for Radar Altimeter Processor (SAC)** MRSA/SAC has developed a RADAR altimeter based on FMCW technique. Presently design and development of Pulsed based Radar Altimeter is under progress in MRSA/SAC. These systems will be used in precise altitude and velocity measurements. The proposed work includes, Turnkey development of digital ASIC for Radar Altimeter Processor and MMCM development for Radar Altimeter System.
E2.14	**Signal Processing Platform for Terrain Relative Navigation and Hazard Detection and Avoidance (HDA) applications (SAC)** Future generation of landing craft will autonomously map the surface, using vision, microwave, and/or laser-based sensors, during the terminal phase of powered descent and then, in real-time, choose and divert to a safe landing site in order to avoid hazards using Hazard Detection and Avoidance techniques. This will also require accurate position and velocity data during descent phase in order to ensure safe soft landing at the pre-designated sites. Following are the research areas • Processing algorithms (for feature identification, feature matching, HDA, Position estimation, velocity estimation, image generation etc.) for real time microwave/optical based imaging sensors. • Algorithms for "pose estimation" for mission targeted to small bodies like asteroids. • Algorithms for "Natural Feature Tracking". • Applications of AI and ML in Position Localization and Hazard Avoidance.
E2.15	**On-board SAR Processor ASIC (SAC)** The aim of On-board SAR Processor (OBSP) RH Digital ASIC is to acquire SAR raw data and generate well-focused images as a final output. It will have LVDS interface with the master FPGA. The objective of the proposal is to develop a low power, miniaturized solution which will comprise of major signal and image processing techniques to generate image from the raw data. Moreover, design of OBSP ASIC will be radiation hardened in nature which will enable it to be used in future planetary missions and other space applications.
E2.16	**Development and Realization of GNSS Remote Sensing Signal Simulator (SAC)** In order to test GNSS RS signal reception with configurable scenarios, a GNSS (direct signal) and GNSS-RS (reflected signal) signal generator is required with the capability to simulate navigation messages to allow positioning, as well as simulating any user-defined, direct and reflected path with satellite handovers. This capability to simulate specular and scattered reflections is required to test the Delay-Doppler map (DDM) calculations in the GNSS RS Receiver. The proposed work involves modelling of the direct navigation signal & and the corresponding reflected signal, received at LEO satellite in the operational scenario of a GNSS Remote Sensing spacecraft. The developed simulator should have the following capabilities:

	• GPS L1 C/A and IRNSS SPS signal generation with proper Ephemerides and Almanac information. • GNSS transmitting and receiving LEO satellites orbit simulation; • Any user-defined path should be able to be uploaded, either on the Earth or in orbit, with as much temporal resolution as necessary. • Estimation of location of the specular reflection point and glistening zone (area where scattered power is collected); • Reflected surface scattering coefficient generation based on geophysical parameters • It shall be able to model and generate both direct and reflected signals, on rough or smooth surfaces incorporating tropospheric and ionospheric effects on both direct and reflected signal. • Graphical input/output user interface (GUI). • Generation of IF/RF direct and reflected navigation signals.	
E3	**Sub Area**	**Power Electronics (SAC)**
E3.1	Electronic Power Conditioners (EPCs) required for the various RF and Digital subsystems of Microwave remote sensing payloads are being designed and developed in-house at SAC. These EPCs have shown excellent performance on-board ISRO's microwave payloads flown so far. To mention a few, major successfully completed in-house developments are: • Power Conditioning and Processing Unit for TR Modules of C-band SAR payload involving HMCs and planar magnetics. • Multi-output pulsed EPC for TR integrated modules of X-band SAR. • EPCs for GaN based Dual-Pol Pulsed Transmitters of Chandrayaan-3 SAR. • High power EPC for X-Band 250W GaN Solid State Power Amplifiers. • HMC based Point of Load (POL) converters (up to 13V). • HMC based Controller for DC-DC converter and pulse Modulator • 100W EPC for digital Subsystem of NISAR • EPC for S-band TRiM (NISAR) • EPC for RF subsystems of RISAT-2B • Multi-output EPC for MHS payload. Apart from above, High Voltage EPC for indigenous pulsed TWT have been demonstrated and its qualification for space version is under advanced stage. Power ASIC design and development activities have also been taken up and are at advanced stage. Higher efficiency, smaller mass and volume, efficient thermal design and EMI/EMC compliance are the major driving parameters for any space-borne EPC design.	

E3.2	**Digitally controlled multi-output DC-DC Converter (SAC)** This research focuses on development of Digitally controlled energy efficient multi-output DC-DC converter with fast transient response and MHz switching frequency. The work involves design, simulation, and proto-type development of highly efficient multi-output EPC for high-speed digital circuits with FPGAs. The EPC should have programmable output ON/OFF sequencing with fast transient response.
E3.3	**High frequency GaN FET based high voltage EPC for pulsed TWTA (SAC)** This proposal is for design & development of topologies and packaging aspects of High frequency GaN FET based high voltage EPC for pulsed TWTA. The work involves study, simulation and comparison of various design topologies/ configurations for high voltage EPC for multi collector pulsed TWT with Beam focus electrode for pulsed operation. The work also involves analysis and implementation of space grade high voltage potting materials and high voltage packaging aspects for realization in space environments.
E3.4	**Thick Film hybrid + HMC based EPC system (SAC)** This proposal is for design and development of the following systems, • Thick Film hybrid + HMC based EPC with in-house developed ASIC LDOs & POLs for target of lower mass/volume and higher efficiency • Thick Film hybrid + HMC based Pulsed EPC with in-house developed HMC PMC for target of lower mass/volume and higher efficiency.
E3.5	**Rad hard miniaturised POL and LDO (SAC)** This proposal is for design and development of Rad hard, efficient and very compact high voltage (15V) POL as well LDO.
E3.6	**Development of software tool for design, modelling and analysis of planar power transformer and power inductor. (SAC)**
E3.7	**Miniaturized circuit protection module (SAC)** This proposal is for Miniaturized circuit protection module DC-DC converters for Aerospace applications. The protection circuit comprises of Resettable eFuse, input plug-in inrush current limiter and Under Voltage Lock-out (UVLO). The work involves design, simulation, and optimization of Generic front-end protection circuit for DC-DC converters. The final circuit may be implemented on a power ASIC or HMC.
E3.8	**Integrated EPC for Multiple Subsystem Stacks (SAC)** This proposal includes analysis, design and development of advanced EPCs, which can supply power to multiple subsystem stacks with individual control of commanding and Over Current Protection. This work involves several challenges viz. • Electrical circuit modelling and simulation of circuit. Supplying power to multiple subsystems and meeting output voltage sequencing requirement of each individual.

	• Dynamic switching load with fast transient response and converter stability. • Selectable RF load at spacecraft through Tele-command. • Protection of EPC in case of single/ multiple subsystem failures such that there is no impact on remaining subsystems if one or multiple subsystems fail to which EPC is supplying power. • Thermal effects of subsystem failures on EPC.	
F	**Area**	**Signal & Image Processing & Data Product (SAC/NRSC)**
F1	**Infrastructure mapping and monitoring using AI/ML techniques from Synthetic Aperture Radar (SAR) Data (SAC)** Synthetic Aperture Radar (SAR) is an active microwave sensor that can take images of targets during day as well as night and can also penetrate cloud cover. The high resolution images acquired by SAR can be used to map and monitor various infrastructure such as highways, airports, railway, bridges, buildings, vegetation etc. With availability of large amount of images from past, current and future SAR missions, a software for classification and temporal monitoring of government and non-government assets can be very useful for administrative purposes. The prime focus of this research is design and development of AI/ML based technique for identification and classification of infrastructure in the readily available SAR image datasets. The infrastructures thus identified can be added to a library which can be referred by government/non-government agencies for various planning and temporal monitoring activities. It will also enable the monitoring of the areas for which optical images may not be available around the year due to cloud cover/ day-night issues. SAR Images from RISAT-1 / RISAT-1A(EOS-04) / RISAT-1B (EOS-09) missions can be used for this activity.	
F2	**Moving Targets identification and their parameter estimation from SAR Images (SAC)** During Synthetic Aperture Radar (SAR) imaging, the sensor is flown in an Aircraft/ spacecraft, pulses are sent and the return echoes are recorded. While processing, the range and the relative motion between sensor and target (earth) is utilized to generate images. In SAR, the background region, called clutter, is the region of interest and it is assumed to be stationary and SAR image focusing is done. Moving targets likes cars, trains, etc. in the images are defocused and/or displaced and may appear as artifact in the image. Primary focus of this research is algorithm and corresponding software development for • Moving Target detection using state of art along track interferometry techniques • Moving Target detection in Raw/Processed SAR datasets • Estimation of target parameters like position and velocity • Focusing of moving targets in SAR images • Removal of artefacts from SAR images generated due to moving targets	

	Getting information of moving targets for SAR image will provide valuable information in utilization of SAR images in strategic applications. Artefact removal and refocusing of moving targets in SAR images will result in enhanced SAR image quality. Additionally, the work will help in designing the state of the art SAR systems for moving target indication.
F3	**Passive Bi-static SAR Image Formation using GNSS Signals (SAC)** Synthetic Aperture Radar (SAR) are microwave sensors and have day night & all weather imaging capability. In SAR, pulses are transmitted from Airborne/Spaceborne platforms and return echoes are recorded. These return echoes are used to form the high resolution SAR images using signal processing methods. Image formation, in cases where receivers are at different platform than the transmitter, is termed as passive bistatic SAR image formation. Globally, around the earth, many microwave systems are working in microwave frequency range suitable for SAR image formation. Navigations systems like GPS & IRNSS, are such type of systems primarily operating in L & S Band. Reflected signal corresponding to the signals transmitted from these systems are being recorded in passive receiver (like GNSS-R onboard Microsat-2C, CyGNSS). These are signals of opportunity which are highly reliable & stable and can be used for SAR image formation as well.Design and development of techniques for SAR image formation from GNSS signals and corresponding software implementation is the primary focus of this research. This research has the potential to generate SAR images using low cost receiver only systems with enormous applications.
F4	**Hyperspectral and LiDAR Data Fusion for Enhanced Remote Sensing Analysis (SAC)** **Introduction:** Remote sensing technologies, such as Hyperspectral Imaging (HSI) and Light Detection and Ranging (LiDAR), provide valuable environmental and geographical data. While HSI offers detailed spectral information across a wide range of wavelengths, LiDAR captures precise three-dimensional (3D) spatial data, enabling high-resolution topographic measurements. Integrating these two datasets can significantly enhance our ability to analyze complex environments by combining spectral, spatial, and geometric features. The research should explore and implement recent trends in machine learning and deep learning models to achieve the hyperspectral and LiDAR fused output. **Research Objectives:** The goal of this research is to develop a robust framework for the fusion of Hyperspectral and LiDAR data to improve object detection, land cover classification, and environmental monitoring. The research objectives are as follows 1. To explore the potential benefits of fusing hyperspectral and LiDAR data for improved landscape classification, particularly in vegetation and urban areas.

	2. To develop and assess fusion algorithms that leverage both the spectral and spatial dimensions of these datasets. 3. To evaluate the fusion's ability to detect and characterize environmental features such as vegetation health, urban structures, and terrain variation. **Expected Outcomes:** The fusion of hyperspectral and LiDAR data will enable more accurate and efficient classification of land cover types, particularly in challenging environments where either modality alone may be insufficient. It will also enhance our understanding of environmental changes over time, providing a powerful tool for monitoring ecosystems, urban development, and natural disasters.
F5	**Development of Foundation Model for Satellite Images (SAC)** **Introduction:** Satellite imagery plays a pivotal role in addressing global challenges such as climate monitoring, disaster management, urban planning, and defence. However, the vast volume and complexity of satellite data require advanced analytical tools. Foundation models, pre-trained on large-scale datasets, have revolutionized fields like natural language processing and computer vision. Developing a foundation model specifically for satellite images can unlock unprecedented capabilities in automating analysis, improving accuracy, and enabling cross-domain applications, thereby enhancing decision-making for space organizations and stakeholders. **Objectives:** 1. To design and train a foundation model tailored for satellite imagery, leveraging large-scale datasets from diverse sources. 2. To enable multi-task learning for applications like land cover classification, object detection, and change detection. 3. To improve generalization across geographic regions, sensors, and resolutions. 4. To provide an open-source framework for fine-tuning and deployment in downstream tasks. **Scope:** The project will focus on developing a scalable, transformer-based architecture trained on datasets of Indian landscape from different Indian satellite (e.g., HRSAT, Cartosat, Resourcesat, NISAR, Microsat, RISAT etc.) catering data across different modality of optical and infrared data to SAR data, high-resolution data to coarse resolution imagery. The model will be evaluated on benchmark tasks and real-world use cases, ensuring adaptability to various space organization needs.

	Methodologies: 1. Data Collection and Preprocessing: Curate a diverse dataset of satellite images with annotations for supervised and self-supervised learning. 2. Model Design: Implement a vision transformer (ViT) or hybrid CNN-transformer model optimized for multi-spectral and multi-temporal data. 3. Training: Utilize self-supervised learning techniques (e.g., masked autoencoding) to pre-train the model on unlabeled data, followed by fine-tuning on specific tasks. 4. Evaluation: Benchmark performance on tasks like segmentation, classification, and anomaly detection using standard metrics. **Possible Outcomes:** 1. A robust foundation model capable of handling diverse satellite imagery tasks. 2. Reduced dependency on task-specific models, saving time and computational resources. 3. Enhanced interoperability across datasets and sensors, enabling seamless integration into existing workflows. **Benefits to our organizations:** The foundation model will empower our organization to automate routine analyses, improve disaster response, monitor environmental changes, and optimize resource allocation. It will also foster innovation by enabling researchers and developers to build specialized applications with minimal effort. By leveraging cutting-edge AI techniques, this project will provide a versatile tool for space organizations, driving advancements in global sustainability, security, and scientific discovery.
F6	**Utilizing Neural Radiance Fields for Multi-View Geometry Reconstruction in Satellite Imagery for DEM and DSM Generation (SAC)** **Introduction** Digital Elevation Models (DEM) and Digital Surface Models (DSM) are crucial for various geospatial applications, including topographic mapping, urban planning, and environmental monitoring. Traditional methods for DEM/DSM generation, such as photogrammetry and LiDAR, can be computationally expensive and sensitive to data quality. Additionally, photogrammetric approaches require high-quality stereo pairs with consistent lighting conditions, while LiDAR is costly and limited by accessibility constraints. The increasing availability of high-resolution satellite imagery presents an opportunity to explore alternative methodologies that can leverage deep learning techniques for enhanced 3D reconstruction. Neural Radiance Fields (NeRF) have demonstrated impressive results in reconstructing 3D geometry from sparse 2D images by modeling volumetric scenes with high fidelity.

	However, existing NeRF implementations are optimized primarily for synthetic or ground-based images, with limited studies addressing large-scale aerial or satellite-based reconstructions. This research aims to bridge this gap by developing a NeRF-based framework tailored for multi-view satellite imagery, enabling accurate and scalable DEM and DSM generation. If successful, this approach could significantly improve terrain modeling efficiency and precision, benefiting industries such as agriculture, disaster response, and military reconnaissance. In addition, this method has direct applications in high resolution satellites such as HRSat and Cartosat. **Objectives** 1. Investigate the feasibility of applying NeRF to reconstruct high-fidelity 3D structures from multi-view satellite images, considering factors such as atmospheric distortions, varying resolutions, and occlusions. 2. Develop an optimized pipeline for training NeRF on satellite datasets to generate DEM and DSM, incorporating domain-specific modifications such as multi-scale feature representations and geospatial constraints. 3. Compare the accuracy, resolution, and computational efficiency of NeRF-based reconstruction with traditional photogrammetry and LiDAR-based methods to assess its viability for large-scale applications. 4. Explore potential enhancements to NeRF, such as integrating hybrid neural representations, incorporating auxiliary sensor data (e.g., synthetic aperture radar), and leveraging super-resolution techniques for improved terrain detail extraction. **Expected Outcomes** 1. A validated framework for leveraging NeRF in DEM and DSM generation from satellite imagery. 2. Improved elevation models with enhanced resolution and accuracy compared to traditional methods. 3. Insights into the applicability and limitations of NeRF in large-scale remote sensing tasks.
F7	**Automatic Road Extraction Using High-Resolution Satellite Imagery (SAC)** **Introduction:** This research focuses on developing an automatic road extraction model using high-resolution satellite imagery and deep learning techniques. Road networks are critical for transportation, urban planning, and disaster management. However, manual road extraction from high resolution satellite images is time-consuming and error-prone. This study proposes a deep learning-based framework leveraging Convolutional Neural Networks (CNNs) and Transformer-based architectures to enhance road detection accuracy, reduce occlusions, and improve computational efficiency. The research aims

	to develop a robust model that generalizes across different environments and datasets, contributing to remote sensing and geospatial analysis applications. **Research Objectives:** 1. Develop an automatic road extraction model using high-resolution satellite imagery. 2. Improve segmentation accuracy using deep learning techniques. 3. Address challenges such as occlusions, varying road textures, and illumination differences. 4. Evaluate model performance on multiple datasets for better generalization. 5. Optimize computational efficiency for real-time or near real-time applications. **Expected Outcomes:** This research aims to develop a high-accuracy road extraction model applicable to urban planning, disaster response, and autonomous navigation, improving road segmentation in complex environments.
F8	**Satellite Data Reception & Ingest Systems (NRSC)** **1. Realization of Low Noise Amplifiers for Satellite Data Reception Ground Stations (NRSC)** A Low Noise Amplifier (LNA) is an essential component in radio frequency (RF) and microwave communication systems. It is designed to amplify weak signals while introducing minimal noise, improving the signal-to-noise ratio (SNR) in a system. In the receive chain, the first amplifier after the antenna contributes the most to the system noise figure. RF low-noise amplifiers (RF LNAs) are designed to increase the desired RF signal amplitude without adding distortion or noise. **2. Design and realization of Ka band, Q band Components (NRSC)** The Ka band (25.5 -27.0 GHz), Q band (33 GHz to 42) GHz are segments of the microwave frequency spectrum used in radar, Satellite Communications and scientific research. RF components like Oscillators & Signal Sources, Power Amplifiers (PAs), Mixers & Frequency Converters, Filters & Duplexers, Waveguides & Transmission Lines, Phase Shifters & Attenuators, Switches & Circulators operated in the respective frequency range shall be realized to achieve low loss, high gain, and efficient signal processing. Each component is designed with specific materials, structures, and circuit techniques to optimize performance for a given RF application. These active and passive RF components are utilized for development of RF systems (viz. Up-converters, down-converters, frequency translators, etc.) in ground stations for data reception. **3. Design and development of Modular / Compact Block Up/ Down Converters for Ka & Q bands (NRSC)** The requirement is for the design of compact Block Up/Down Converters with good phase noise synthesizers using MMIC based surface mount components. They can

be digitally tuned for different frequencies required. The target specification for Ka-band converters is to translate the input frequency range from 25.5 to 27.0 GHz to an output range of 2400 +/- 750 MHz and vice versa. For the Q band Converters, the input frequency range of 37.5 - 41.0 GHz shall be converted to an output range and vice versa suitable to the Receivers band width processing capability.

4. Design, Development and Demonstration of Modular Frequency Synthesizers (NRSC)

Frequency Synthesizers shall be designed to provide Local Oscillator signal for up/down conversion of received RF signals in S, X and Ka band. These synthesizers shall be developed with good phase noise and higher output power with the provision for tuning to any frequency in the specified range. The frequency stability shall be better than 1ppm.

5. Design and development of IF Matrix operating at (2.0 – 3.0 GHz) using SMD Technology or Pin Diode Switches (NRSC)

Solid State switches and Pin diode switches realized with MEM technology and having isolation greater than 60 dB with programmable gain in the path of the "Non – Blocking" IF Matrix can be designed and developed for ground station applications.

6. 3D Modelling, Structural Analysis & Design of X-Y Tracking Pedestal (NRSC)

3D Modelling, Structural analysis & design of X-Y tracking pedestal suitable for 7.5M diameter parabolic reflector with Cassegrain feed arrangement (for both aluminum and Carbon fibre material) with full hemispherical coverage. The antenna must track LEO satellites from 300 KM orbit onwards to receive data in X band from 8.0 to 8.4 GHz frequency with an operating wind condition up to 60 KMPH and wind gust up to 80 KMPH.

7. Design of Optical Modem for an Optical Ground Station (NRSC)

An Optical Modem for an Optical Ground Station (OGS) is a specialized subsystem that enables high-speed optical data transmission between ground stations and satellites or ground-to-ground free-space optical (FSO) links. These modems are essential for next-generation laser communication (Lasercom), providing higher bandwidth and lower latency than traditional RF-based systems. Key Components of an Optical Modem include Optical Transmitter, Optical Receiver, Modulator/Demodulator, Photodetector, Optical Fiber Interface, Error Correction & Signal Processing catering to the specifications of Transmission Speed (1 Gbps to 400 Gbps) , Modulation Format (NRZ, QAM, PSK,OFDM) and error correction capabilities.

	8. Study of suitable Materials / Design Approach and Innovative Manufacturing Methodology for large CFRP Reflectors for Future Tri axis-Tri band Ground Station Antenna Systems (NRSC) When the ground station antenna is to be designed for data reception in higher frequencies. The selection of materials for reflectors plays a major role. The material must be such that the surface profile is not affected under any weather conditions while in operation, as any change in surface profile accuracy affects the overall gain of the antenna system. The surface profile accuracy is affected by thermal gradient in conventional aluminum reflectors. As an alternative to this it is proposed to use composite material such as CFRP for making the antenna reflectors that offer high Specific strength, high specific weight and low coefficient of thermal expansion without any compromise on RF properties. **9. Study of suitable Materials / Design Approach and Innovative Manufacturing Methodology for large CFRP Reflectors for Future Tri axis-Tri band Ground Station Antenna Systems (NRSC)** When the ground station antenna is to be designed for data reception in higher frequencies. The selection of materials for reflectors plays a major role. The material must be such that the surface profile is not affected under any weather conditions while in operation, as any change in surface profile accuracy affects the overall gain of the antenna system. The surface profile accuracy is affected by thermal gradient in conventional aluminum reflectors. As an alternative to this it is proposed to use composite material such as CFRP for making the antenna reflectors that offer high Specific strength, high specific weight and low coefficient of thermal expansion without any compromise on RF properties.
G	**Area** | **Electronics & Microelectronics Design, Fabrication & Testing Technologies (SAC/URSC)**
G1	**Sub Area** | **Research areas in Quantum Device Design and Fabrication (SAC)**
G1.1	**Single & Entangled Photon Sources (SAC)** For the implementation of Quantum Key Distribution (QKD) using single or entangled photon based protocols, hardware required is the single or entangled photon source. Currently the QKD demonstration is carried out using the photon sources made of Spontaneous Photon Down Conversion (SPDC). But, these sources are probabilistic sources and Quantum Key rate is limited by their generation rate. Faster key generation requires the Bright sources of Single or Entangled photons. QD based sources are capable of generating both single and entangled photons. They are also deterministic in nature and brightness is also high. But, the only drawback of low temperature operation. Two level systems (QDs, 2D materials, Defect centers in high bandgap materials) are capable of generating single or entangled photon sources, but the wavelength and

	operating temperature depends on the choice of materials. Design and fabrication of QD based quantum photon sources is very challenging and in campus we have the ongoing activity on design and fabrication of quantum sources working at 800 nm & 1550 nm. Proposals (both Design and Fabrication aspects) are invited to work on Bright Quantum Sources using any of the materials, but high temperature operated systems are preferred.	
G1.2	**Single Photon Avalanche Diodes (SAC)** Implementation of Quantum Key Distribution (QKD) also requires the Single Photon Detectors. Currently Superconducting Nanowire Single Photon Detectors (SNSPD) are the most efficient for detection at 800 & 1550 nm wavelengths. They are having good Photon Detection Efficiency and high speed detection, but their operating temperature is 4K or blow. Also, Semiconductor based Single Photon Detectors Namely Single Photon Avalanche Diodes (SPAD) are pursued for near room temperature operation. Silicon based SPADs are in operation near 800 nm and Ingas based SPADs are operated for 1550nm. But, SPAD performance is not as that of SNSPD, but any improvement in performance is an advantage. Now a day, 2D materials based single photon Detectors are also paving the way due to their high detection efficiency and rate. Proposals are invited for development of highly efficient Single Photon Detectors using 2D materials, any other materials or ways to improve the efficiency of existing technologies.	
G2	**Sub Area**	**Research areas in Active and Passive Device and Component Technologies (SAC)**
G2.1	**Development of re-grown Ohmic-contact for RF GaN HEMT (SAC)** AlGaN/GaN on SiC based HEMTs offer very high power densities at microwave and mm-wave frequencies. Ohmic contact resistance is one of the most important metrics for evaluating the HEMTs suitability for high power, high frequency applications. Ohmic contact formation via MOCVD "regrowth" of an n+ GaN layer to side contact to the 2DEG is a promising approach to reducing the contact resistance of GaN heterostructures. Low Ohmic contact resistances on the order of tenths of Ohms/mm can be reproducibly achieved using this technique. Proposals are invited for the development of reproducible ohmic contact regrowth technique for SAC identified GaN heterostructures. The fabricated samples shall be jointly evaluated by the PI and SAC engineers and detailed process recipe for the developed process shall serve as the deliverable of the project.	
G2.2	**Pospieszalski and Pucel type noise model development for GaN HEMT (SAC)** Unlike GaAs LNAs, which require RF limiters or other protective circuitry to handle high-power signals degrading the overall noise figure, GaN HEMTs are sufficiently robust to	

	endure high power surges without the need for such protective measures, resulting in a lower noise figure and improved signal integrity. The development of noise models for GaN HEMTs is essential for accurately predicting device performance by simulations. We invite proposals for the development of Pospieszalski and Pucel-type noise models tailored to SAC GaN HEMT devices. The scope of the work includes: 1. Development of Pospieszalski and Pucel type noise model on SAC devices. 2. Study of bias dependence of noise model parameters on these models. 3. Integration of noise model with ADS software using Verilog-A code. 4. Design of 2 stage LNA using developed model at X band. 5. Subsequent validation and model refinement using characterization.
G2.3	**Nonlinear HEMT model for AlGaN/GaN switch applications (SAC)** GaN HEMTs are a promising technology for TR module development due to their ability to integrate various components—such as LNAs, switches, PAs, DAs, and DPS—on the same wafer. GaN-based switches can handle exceptionally high power levels, making them ideal for demanding applications. In switch design, a cold FET model (Vds = 0 V) is typically used. To ensure accuracy, the model must precisely capture voltage swings at both the gate and drain while maintaining continuity in current and its derivative. Additionally, it should accurately predict breakdown behavior, which is crucial for determining the input power level of the switch. Proposals are invited for Nonlinear HEMT model development for AlGaN/GaN switch application. The scope of work should include 1. Development of nonlinear HEMT model for AlGaN/GaN switch application. 2. Integration of model with ADS software using verilog code. 3. Design of X band high power switch (1 dB compression point better than 40 dBm) 4. Measurement verification of switch and further improvement in models if required.
G2.4	**Simulators for SAW filter design (SAC)** Surface Acoustic Wave (SAW) filters provide efficient RF filtering in a compact footprint, in the frequency range of 10 MHz to 3 GHz. In spite of the prevalence of these devices in modern communication equipment, general purpose design tools for the simulation of these filters are non-existent. The scope of the proposed research work, hence, shall be to develop accurate simulation tools for the prediction of SAW filter performance. Target specifications and fabrication support shall be provided by SAC. The accuracy of the developed tools shall be checked against the measured performance of fabricated filters.

G3	Sub Area	Research areas in Microelectronic Interconnects and Packaging (SAC)
G3.1	**Development of micro-via formation, micro-via filling and wafer planarization processes for Wafer Level Packaging (SAC)** Wafer level packaging (WLP) of high frequency devices/circuits offers immense miniaturization and improved performance in terms of reduced parasitics. The process uses a bonded cover wafer to hermetically seal the devices/circuits, at the wafer level, followed by dicing of the sealed devices/circuits. This is in contrast to the conventional approach, where the device/circuit dies are first singulated from the wafer and then suitably packaged. The access to the device pads, in WLP, is provided through vias in the cover wafer, which are completely filled using electroplating techniques. Post filling of the vias, the surface of the cover wafer is planarized, to make it suitable for subsequent lithographic processes. Proposals are invited to develop production friendly processes for micro-via formation, micro-via filling and wafer planarization processes, in the (Si/SiC/Quartz) cover wafer, for their subsequent patterning and bonding to device wafer. The via-filled and planarized wafers shall be vetted for their suitability for bonding with the device wafer. Detailed process recipes shall serve as the deliverables of the project.	
G3.2	**Development of Silicon micromachined THz interconnects (SAC)** High transmission losses associated with planar transmission lines obviates their use at mm and sub-mm wavelengths. Metal waveguides realized through fine CNC milling techniques have hence become the preferred medium for signal transmission at THz frequencies. However, they need accurate hand alignment and are non-compatible to planar integration with THz active and passive devices. Since the last few years, Deep Reactive Ion Etching (DRIE) based Silicon micromachining has shown immense promise for the realization of THz interconnects and hence are being actively pursued in research. Proposals are invited for development of DRIE based Silicon micromachining processes for realizing THz interconnects. The scope of the proposed work shall include (a) development of Si micromachining processes for THz interconnects suitable up to 500 GHz and (b) demonstration of performance through fabrication and testing of interconnects. The process recipes developed and the hardware realized shall serve as the deliverables of the project.	
G3.3	**Development and integration of Ferrite material compatible with DuPont 951 LTCC tape system and realization of circulator (SAC)** Low Temperature Cofired Ceramics (LTCC) is a 3D glass-ceramics multilayer packaging technology that enables the embedding of passive components such as resistors, inductors, capacitors, filters, and power dividers. As the demand for more compact and	

	lightweight components increases, there is a need to integrate diverse materials like ferrite. The development and integration of ferrite materials compatible with the Dupont 951 LTCC tape system are crucial for the realization of circulators. This integration requires careful consideration of sintering compatibility, ensuring that the materials can withstand high temperatures while maintaining proper shrinkage matching during the firing process. Proposals are invited for development of Ferrite materials compatible with Dupont 951 tape system The scope of work should include 1. Development of compatible ferrite materials 2. Integration with LTCC modules 3. Design of X band circulator in LTCC 4. Realization of circulator using developed process 5. Testing of circulator
G3.4	**Development and Integration of High-K Materials Compatible with the DuPont 951 LTCC Tape System (SAC)** To enhance the integration density and reduce the size in electronic circuit, it is essential to incorporate as many components and elements as possible within the LTCC system. Middle or High-K materials (K > 300) are crucial for fabricating capacitors with values of 100 pF or higher. Usually a middle-k or high-k dielectric is integrated as screen-printed thick film or green tape in the multilayer modules during lamination. These materials must remain compatible with the LTCC process, particularly during the firing operation, to ensure reliability and performance. Proposals are invited for development of High -K material compatible with Dupont 951 tape system The scope of work should include 1. Development of High K materials 2. Integration with LTCC modules 3. Realization of capacitor using developed process and subsequent testing.
G3.5	**Brazing/Attachment media for Ceramic /Quartz substrates for high reliable micro assembly (SAC)** This work shall include selection of reliable micro assembly Candidate material based on thermomechanical modelling and experimentations for the following applications: A) Void free low temperature (~ 300 degC) attachment media and process of large ceramic substrate (1"x1 "to 3"x5") attach over metallic carrier plates suitable to withstand -55 to +125 degC temperature cycle regime. Configuration study and recommendations on metallic carrier mechanical properties are also to be devised for reliable assembly for a given substrate configuration/design.

		Simulation & experimental study of attachment void v/s over RF performance up to Ka Band Amplifier circuit made with discrete elements and alumina substrates. B) Void free, thin bond line thickness (~ 200 nm) attachment media and process of quartz substrate (with 25:1 aspect ratio) attachment on metallic carrier plate, suitable to withstand 0 to – 4K temperature cycle regime.
G4	**Sub Area**	**Research areas in Micro and Diffractive Optical Component Technologies (SAC)**
G4 .1		**Development of 45° Bending Mirror for out-of-plane coupling in Polymer Optical Waveguides for Optical Interconnects (SAC)** Bending Mirror is one of the simple solutions for out-of-plane coupling of light between optical waveguides and optoelectronic devices fabrication. In this type of coupling, light is reflected due to either a metal coating or total internal reflection at the end of a polymer waveguide. A PCB compatible 45° bending micro mirror is to be fabricated on polymer optical waveguides using tilted beam photolithography. After successful fabrication, the mirror needs to be characterized for coupling efficiency. The activity shall include the following: a. Survey and selection of required materials and process as per detailed SAC requirements. b. Development of fabrication process. c. Component demonstration and measurement of coupling efficiency.
G4 .2		**Development of Precision Slits / Apertures / Bar Targets (SAC)** Precision slits, apertures and bar targets are one of the essential components for realization / calibration of optical imaging cameras. These components when fabricated with high precision provide a well-defined desired image without problems like beam scattering etc. The precision slits / apertures / bar targets may be fabricated in Si (with appropriate optical coatings) or in metal foils (of appropriate metal) so that it works with the visible and IR spectrums. The coated Si substrate / metal foil shall work as an opaque material with the gaps in them allowing the light to pass through as per the design of the pattern. The activity shall include the following: a. Survey and selection of required materials as per detailed SAC requirements. b. Development of fabrication process, typically Si through etch / Lithographie, Galvanoformung, Abformung (LIGA) based processes. c. Process, component demonstration and qualification.

<table>
<tr><td>G4 .3</td><td colspan="2">Development of Deformable Mirror (SAC)

Deformable mirror is an integral part of a variety of modern adaptive optics system, which are used to correct the optical aberration of the wave front. It is carried out by deforming the shape of a membrane (mirror) in response to an applied control signal.

A Polysilicon Multi-Users MEMS (PolyMUMPS) type or similar process is to be developed for Fabrication and Packaging of the deformable mirror array device. It is desirable that fabrication and packaging be followed by relevant characterization steps to validate the performance of the device.

The activity shall include the following:
a. Survey and selection of required materials and process as per detailed SAC requirements.
b. Development of the fabrication process.
c. Process, component demonstration and qualification.</td></tr>
<tr><td>G4 .4</td><td colspan="2">Development of Reflective Optical Coating over PMMA Resist (SAC)

Optical coating is an important process in several micro/diffractive optical devices in order to alter the way light interacts with them. To achieve required reflectance in the desired wavelength range appropriate reflective optical coatings are used. This application requires reflective optical coating on 2D/3D shapes fabricated over Poly Methyl Methacrylate (PMMA), a polymer.

This work requires the development of optical coating over 950K PMMA Electron Beam Sensitive Resist. The structure shall have either binary or greyscale resist pattern over planar or non- planar substrates of irregular sizes. The coating shall have excellent adhesion with resist (PMMA) and shall preferably be abrasion free.

The activity shall include the following:
a. Survey and selection of required materials as per detailed SAC requirements.
b. Development of optical coating process over Patterned PMMA Resist Structures.
c. Process, coating performance demonstration and qualification.</td></tr>
<tr><td>G5</td><td>Sub Area</td><td>Research areas in Microfabrication Process Technologies (SAC)</td></tr>
<tr><td>G5.1</td><td colspan="2">Development of Electron Beam Sensitive and Dry Etch Compatible High Resolution Resist (SAC)

Electron beam lithography has been an attractive technology to delineate nano-structures. These patterned structures can further be transferred on underlying metals (such as Aluminium in this case) using Dry Etching technique. This process requires the resist to be electron beam sensitive as well as dry etching compatible. Scope of Work includes a Dry etching compatible electron beam sensitive resist with its developer is to be prepared.</td></tr>
</table>

	The activity shall include the following: a. Survey, selection and development of required materials for synthesis of resist, developer etc. as per detailed SAC requirements. b. Process, material demonstration and qualification - Process with Aluminium Deposition, Electron Beam Lithography, Aluminium Dry Etching over an area of 15mm x 15mm with 70nm half pitch (preferable 40nm) Binary Grating structures.
G5.2	**Development of Electron Beam Sensitive and Lift off Compatible Resist (SAC)** In many standard micro-fabrication processes, Electron beam lithography and lift off process is inevitable. Electron beam lithography, a direct write technique, uses resists like PolyMethyl Methacrylate (PMMA) resist with its co-polymer for the lift off process. This process requires formation of an undercut resist profile, which helps in achieving smoother metal lift off. Proposals are invited for the development of Electron beam resists with its co-polymer, suitable developer and removal agent (as per detailed SAC requirements)that should be able to support metal lift off process. The activity shall include: a. Survey, selection and development of required materials for synthesis of resist, developer, remover etc. as per detailed SAC requirements. b. Process demonstration using the developed material.
G5.3	**Development of Dry Film Resist for Thin Film Integration on LTCC (SAC)** Low temperature co-fired ceramic is a useful technology for RF applications. Integration of multilayer structure in LTCC is based on thick film processing. Development of dry film resist (DFR) is required for thin film integration on LTCC. This is needed for the fabrication of certain circuit elements having smaller (<100μm) features. **Scope of Work:** A Dry Film Resist is to be developed and using it process needs to be demonstrated meeting SAC requirements. The LTCC contains slots (cavities) and may have process-induced warpage, bow etc. The activity shall include the following: a. Survey, selection and development of required materials, resists, developer, plating chemistries, suitable equipment etc. b. Development of fabrication process, which includes seed-layer deposition, DFR lamination, lithography, electroplating, seed layer etching etc. c. Process demonstration using developed resist.

G5.4	**Electrically controlled tunable integrated devices using Magneto-electric (ME) composites (Thin film/Bulk & Thin film/thin film) for microwave integrated circuit applications (SAC)** The emerging research area of Magneto-electric devices where the magnetic characteristics are controlled by an electric field and/or the electric characteristics are controlled by a magnetic field, the magnetoelectric (ME) effect, is a very attractive subject for novel microwave circuit applications. The composite systems usually include Ferrite-Ferroelectric/Piezoelectric combinations. In such bilayer system, the ferrite, when driven to Ferromagnetic Resonance (FMR) and an electrical signal is applied; the FMR frequency can be shift thereby facilitating tunable characteristic. It is proposed to develop suitable composite material system with at least one component in thin film form and demonstrate dual-tunable integrated microwave components like tunable inductor, phase-shifter, attenuators, filters etc. using the developed material system.	
G5.5	**Studies on energy dependent Secondary Electron Yield of Carbon Nanotube (CNT) coatings on OFHC Copper for high frequency (Ka band) TWT (SAC)** One of the prime objectives of very high frequency (e.g. Ka band) TWT especially for Space use, is to reduce the secondary electron emission (SEE) from Multistage Depressed Collectors (MDC) so as to improve the TWT efficiency. Variety of techniques have been investigated and being deployed for the intended objective. One of the recent research areas is developing CNT coating on conducting surface of collector which is expected to reduce secondary electron yield by a factor compare to other materials like Graphite. The activity aims to develop suitable method for CNT synthesis, deposition of CNT coating on OFHC cupper collector surface and characterizing the SEE.	
G5.6	**Development of Nanostructured Magnetostrictive thin films for Surface Acoustic Wave Applications (SAC)** Surface Acoustic Wave (SAW) devices are widely used in communications such as filters, delay line etc. Conventional SAW devices consist of metallic IDT on top of piezoelectric film or substrates. Research involves the development of high quality thin films of giant magnetostrictive materials (e.g. Fe-Si) which exhibit high magnetostriction coefficient suitable for low insertion loss SAW devices.	
G6	**Sub Area**	**Research areas in Electronic Fabrication (SAC)**
G6.1	**On-Line Process Monitoring of Organic Additives in Copper Electroplating Baths for PCBs (SAC)** Copper Electroplating is one of the vital technologies in printed circuit fabrication processes. For Space industry, circuit board fabricated requires maximum efficiency and superior product quality in process. To achieve good via quality, plating solution requires constant monitoring of several key components in plating bath. There are few organic additives which cannot be determined through normal titration, but these additives play pivotal role in shaping final copper layer.	

	We need to develop the process analyzer which allows in process measurement and control of these additives and its concentration in plating solutions thereupon maintaining optimal plating conditions and improving overall efficiency and reliability of plated product in manufacturing. This research may benefit in various aspects as follows: • Cost saving through minimizing waste and maximizing efficiency of plating additives. • Mitigating risk of defects by consistent monitoring of additives. • Optimizing plating performance by maintaining narrow range and superior quality.	
G7	**Sub Area**	**Research area in Electronic Calibration (SAC)**
G7.1	**Calibration of Test & Measuring Equipment used in the field of Optical Communication (SAC)** SAC is involved in development of optical communication devices like optical amplifier, photonics Analog to Digital convertor, optical switches, O-E & E-O convertors which are used in high speed optical links etc. For Testing of these devices Test & Measurement Equipments are used like Tuneable Laser Sources, Optical Power Meter, Optical Attenuator and Optical Spectrum Analyzers. So seeing increase in optical payload activity; SAC calibration facility is working for upgradation in the field of optical communication. For this Calibration lab is trying to establish the traceability for optical parameter especially in the band of 1550±20 nm and trying to find out the ways for calibration/validation of test & measuring equipment in optical communication field.	
G8	**Sub Area**	**Research Areas in the field of Surface Treatment Process Technologies (SAC)**
G8.1	**Process Development to realize Electroforming Process for Aluminium Component (SAC)** Electroforming is a technique used in fabrication of complex contoured components with high dimensional tolerances which are difficult to fabricate using conventional machining methodology. At present, electroforming process of copper components on Aluminium mandrels has been successfully realized at SAC. Copper has disadvantage of high density of 8.9 grams/cc. Hence, efforts are invited to carry out in depth feasibility study to realize electroforming process of Aluminium components and develop detailed process & setup for the same. This process can be used for mm-wave components.	
G8.2	**Development of Electroless Gold Plating Process (SAC)** Gold plating on aluminium 6061T6 boxes and Kovar carrier plates is being carried out for EMI/EMC requirements, corrosion protection, solder ability etc. Hence, efforts are invited in the area of Electro less gold plating process using either cyanide based or non-cyanide based chemistry for plating aluminium 6061T6 alloy	

	components/Kovar substrates with plating thickness of >=2 microns of gold. Once developed, this process will be used for all ISRO projects as per requirements.
G8.3	**Indigenous Development of Black Thermal Control Paints for Space use (SAC)** Thermal Paints are used to impart desired thermo-optical surface properties to space hardware. Black thermal paint with improved emissivity and solar absorptivity values and with very good adhesion to various base surfaces like Aluminium Alloy 6061, Silver plated Aluminium Alloy, Electroless Nickel plated Aluminium Alloy, Anodized Aluminium alloy, SS-316, CFRP etc., is proposed to indigenously develop and qualify for space use. Black Thermal paint shall meet outgassing properties as per ASTM E 595 / ECSC-Q-ST-70-02C) and pass various qualification tests like humidity test, Thermo-vacuum test, Thermal cycling test and adhesion test etc. Hence efforts in research, development, testing and qualification and production of sprayable Black thermal paints, preferably environment friendly, are invited. The broad scope of work and specifications are: - 1. Development of primer system/s, preferably 1K, compatible for (1) Aluminium Alloy 6061, (2) Silver plated Aluminium Alloy, (3) Electroless Nickel plated Aluminium Alloy, (4) Anodized Aluminium alloy, (5) CFRP, (6) SS-306. 2. Development of Black thermal paint (top coat) with outgassing properties., CVCM $\leq$ 0.1% and TML $\leq$ 1% and Thermo-optical properties., Emissivity $\geq$ 0.9 and solar absorptivity $\geq$ 0.9.
G8.4	**Development of a Compact Water Electrolyzer Prototype for Gaganyaan Missions (SAC)** A critical aspect of sustaining long-duration missions in space is the efficient generation of life-supporting gases, particularly oxygen and hydrogen from water. Proposal outlines the design and development of a compact water electrolyzer prototype, optimized for space conditions, which will facilitate the electrolysis of water to produce oxygen for breathing and hydrogen for fuel. 1. To design and fabricate a compact water electrolyzer that utilizes a suitable membrane for enhanced efficiency in electrolysis. 2. To develop an effective oxygen filtration and collection system to ensure the purity of generated oxygen. 3. To create a hydrogen filtration and collection cylinder capable of safely storing the produced hydrogen for possible fuel applications during the Gaganyaan missions.
G8.5	**Development of High Emissivity >0.9) and Low Solar Absorptivity (<0.2) Oxide Coating using appropriate process on Al6061 Aluminium Alloy (SAC)** The efficient thermal management of spacecraft and microwave devices such as Traveling Wave Tube Amplifiers (TWTAs) is crucial for enhancing performance and

	reliability in space environments. This project aims to develop a white oxide coating on aluminum alloy Al6061 that achieves a high emissivity of greater than 0.9 and a low solar absorptivity of less than 0.2. Such a coating will facilitate effective heat removal, ensuring optimal operational conditions for critical aerospace components. 1. Formulate an oxide coating process that includes specific bath compositions, process parameters, and conditions tailored for Al6061. 2. Achieve a coated surface with emissivity values exceeding 0.9 and solar absorptivity below 0.2. 3. Validate the coating's performance through rigorous testing against established space environment criteria, including heat resistance at 500°C, thermal cycling, outgassing, and thermo-vacuum conditions.
G8.6	**Research Areas in the field of Space Environment Simulation and testing technologies (SAC)** Environmental Testing is an important activity in the process of Payload development. Facilities have several hot and cold chambers and Thermo-vacuum chambers up to 6.5m Dia. which meets the environmental test requirements of various payloads being developed at SAC, Ahmedabad. Establishment of new facilities and augmentation of existing facilities to accommodate special test requirements is a continuous process. This demands innovative solution to emerge in close collaboration with the academic institutions and industrial research units.Collaborative efforts are invited from academic institutions in following upcoming requirements/research areas as outlined below.
G8.7	**Super Insulated Cryogenic Transfer Lines (SAC)** Vacuum jacketed Cryogenic transfer lines are an integral part of a thermal vacuum system, as they offer compact size footprint, extremely low heat inleak, aesthetic layouts, ease of installation and lower long-term maintenance costs. The scope of this work will involve development for non-metallic, light weight; low loss cryogen transfers lines especially for efficient distribution of Liquid nitrogen. The functional temperature range to be considered for the SI lines should be -196degC to +50degC.
G8.8	**Pulse-Tube Cryo Cooler (SAC)** Pulse tube cryo-coolers have been evolved in recent years and matured as a promising technology for meeting the challenging cooling requirements of space industry. They provide significant advantages in terms of overall size, extremely lower vibration levels, and higher reliability. These coolers have been used in ground segment testing of space hardware as well as for onboard applications.

	The scope of this work shall entail development of compact, low cost single stage/ double stage Pulse Tube cryo-coolers to facilitate testing tiny devices at low temperature as well as for low cooling requirement for IR/CCD detectors. Expected cold tip temperature for this development activity is 80K with ~10-watt cooling capacity @80K, which can be verified in existing facilities at SAC with appropriate set-up.
G8.9	**ThermoAcoustic Cooler (SAC)** Thermoacoustic coolers can provide a very compact, simple & reliable way for producing the desired refrigeration effect. This cooler also has an advantage of using inert gases and produces very low environmental impact. The scope of this work will involve development of acoustic coolers for small detector cooling application and handling heat from the heat sinks etc.
G8.10	**Mixed Gas Refrigeration System(SAC)** The recent advancements in the development of mixed gas refrigeration systems has generated considerable interests in potential application of such systems, which were earlier out of reach for mechanical refrigeration systems particularly for cryogenic temperatures. The scope of this work shall involve development of mixed gas refrigeration based thermal system for compact climate test chambers and thermal vacuum chambers. The researchers shall be responsible for design, simulation, analysis, optimization & realization and testing of thermoelectric coolers. The expected lowest temperature for mixed gas refrigeration system is -150degC in cascade mode. The performance of the realized system will be tested and verified against the target specifications.
G8.11	**Contamination Control study (SAC)** Contamination control plays an extremely important role particularly in realization of electro-optical payloads, where any unintended activity/process can lead to severely impact the mission life. The present proposal entails a study, simulation and analysis of various forms of contaminations like surface and airborne particulates, surface and airborne molecular contaminants in and around thermo-vacuum chambers. Carryout in–depth measurement of such contaminants using APC, PFO, RGA, TQCM available and carry out detailed process study as well as make recommendations in this regard for implementation.
G8.12	**Liquid nitrogen consumption and optimization study (SAC)** Liquid nitrogen is a fluid of choice for majority of thermal vacuum chambers due to its characteristics like low temperature of liquefaction, very wide temperature range in

	single phase, large latent heat of evaporation and lower cost. As LN2 is utilized across the facilities in majority of thermal vacuum chambers, its overall usage and optimization is equally important. The present proposal will involve Study and analysis of Liquid Nitrogen consumption in Thermo-vacuum test facility with respect to different type of tests being carried out in different LN2 based thermo-vacuum chambers. Study and analyze transfer, static and flash losses taking place in various system elements during thermo-vacuum tests and carry out detailed process study as well as make recommendations in this regard for implementation.
G8.13	**InfraRed imaging system for temperature monitoring (SAC)** Real time temperature monitoring of different critical components and surfaces during a thermal vacuum testing necessitates availability and utilization of an accurate & fast response-based temperature measurement system. Temperature sensor mounting at the required locations on a subsystem is an essential but laborious and time intensive activity, and an IR based imaging system can provide a non-contact type real time temperature monitoring inside a thermal vacuum chamber. The present scope of work involves a development of IR mapper-based temperature measurement system for monitoring the package temperature inside a thermal vacuum chamber, thereby eliminating the need of physically temperature sensor mounting. The required temperature range for the measurements is, from -40degC to +85degC.
G8.14	**Design and realization of XHV system (SAC)** Achieving Extreme High vacuum has been a holy grail of vacuum science. Simulation of interstellar space, processing of some advanced semiconductor devices, surface science experiments and measurements are few important applications for XHV level. The present scope of work will involve development of a small experimental cavity/ volume XHV system for achieving better than 1e-12 mbar vacuum.
G8.15	**Zero-Boil-Off System (SAC)** Zero-Boil-Off (ZBO) systems can provide considerable savings for mission critical cryogens particularly for interplanetary missions. These systems become more critical for human space missions needing long duration in space. ZBO-Zero Boil Off Cryogenic system will demonstrate long term storage & saving of cryogen (Experimental system) with minimal cryogen losses from the storage tanks due to natural boil-off. The proposed prototype may also be utilized as a platform for future interplanetary type missions which will certainly have this requirement. The proposed study will involve study of different options, simulation and analysis of ZBO system, realization of an experimental system to validate the theoretical models and to make proposal for an operation system.

G8.16	**Cryogenic Radial fan Blower for Thermal Conditioning Unit (SAC)** The devices under test (DUTs) in a Thermal Vacuum chamber need to be heated or cooled by radiation and conduction heat transfer in a maximum temperature range typically ranging from +100°C to -100°C under high vacuum conditions. A Thermal Conditioning Unit (TCU) is a dense gas circulation based closed loop system, which is used to achieve this stringent temperature excursion requirement with required temperature uniformity. A Cryogenic radial fan/blower (which is a centrifugal blower) is the heart of this TCU, which is used to circulate this dense gas, generally Nitrogen. A Thermal Conditioning Unit is developed in house in SAC under TDP, but the cryogenic blower in this TCU is still to be indigenize. The present study will involve the design, development, testing, and delivery of VFD driven high RPM cryogenic centrifugal blower, with a wide temperature range operation (-100°C to +100°C) for the performance parameters defined as follows

Sr. No.	Specification	Value	Remarks
1	Fluid-Medium	Nitrogen gas	
2	Mass flow rate	80 - 350 kg/hr	Or wider
3	Inlet/outlet size	50 NB	With CF 65 Flange end connections
4	Inlet pressure	6 bar	Or higher
5	Inlet Temperature range	-100°C to +100°C	Or wider
6	Material Of construction	SS-304L/316L	Or suitable material catering to this temperature range
7	Differential pressure	300mbar to 1000mbar	Minimum
8	Rotational speed	Controllable as per requirement	With variable frequency drive-VFD to control the mass flow rate specified in spec. 2
9	Power	3 Phase 415V 50 Hz	

G8.17	**Bayonet couplings (SAC)** Bayonet couplings are vacuum jacketed cryogenic couplings and are regularly used in the field distributions lines for cryogenic applications as well as directly on the cryogenic equipment for ease of connection and disconnection. These specialised mechanical couplings provide a leak tight connection with minimal heat transfer and allow safe and efficient transfer of cryogenic liquid (like liquid nitrogen). The present study will involve the design, analysis, development, testing, and delivery of two sets (1/2 inch NB size) of bayonet joints (both male and female components with their seals and clamping system) for the transfer of liquid nitrogen.

G8.18	**Micro-Pirani gauge for vacuum measurements (SAC)** Pirani gauges are the mainstay of sub-atmospheric pressure measurement systems in the process industry as well as in the R&D labs for myriad applications. The Pirani gauges have a limited sensitivity towards the lower pressures (or the improving vacuum levels), and this limitation can be overcome with the introduction of Pirani element at miniaturised level. Such sensors are already available from the import sources, and hence the proposal is invited to develop these sensors indegeously. The present study will involve the configuration, design, simulation, and prototyping the sensor for measuring the vacuum levels in the sensor cavity in the range of 1000mbar to 1e-4mbar.	
G8.19	**Three stage Cascade Refrigeration System (SAC)** The recent advancements in the development of three stage cascade refrigeration systems has generated considerable interests in potential application of such systems, which were earlier out of reach for mechanical refrigeration systems particularly for cryogenic temperatures. The expected lowest temperature from three stage cascade refrigeration system is -120 °C. The principle of cascade system is very simple. But realizing the mechanical system with such a low temperature with non-CFC refrigerant is another aspect. The scope of this work shall achieve for fast transition rate with cryogenic range temperature cycle tests in climate test chambers. The researchers shall be responsible for design, simulation, analysis, optimization, realization and testing of refrigeration systems with use of non-CFC and non-HCFC refrigerants.	
G9	**Sub Area**	**Research Areas in Thermal Engineering (SAC)**
G9.1	**Cryo Coolers and related Drive Electronics (SAC)** Cryo-coolers and its associated technologies need to be developed for cooling of various kinds of detectors/systems in cryogenic temperature ranges up to 4.2K. Sterling Type Pulsed Tube Cryo-cooler (STPC) is promising candidate for such requirement for Space use due to less mass and power requirement. Following are the envisaged development requirement for Cold-Head Assembly Pressure Wave Generator (PWG) Cooler Drive Electronics (CDE)	
G9.2	**Variable Emissivity Coated (VEC) Micro-electromechanical System (MEMS) radiators (SAC)** Technologies/process related to development of VEC/MEMS based radiators for optimizing radiator size for deep space missions need to be developed. Collaboration is envisaged in any experimental/numerical aspect of the same.	

G9.3	**Cooling technologies for ultra-low temperature range cooling (SAC)** **(a) Adiabatic demagnetization refrigerator (ADR)** It is a cooling technology based on the magneto caloric effect. This technique can be used to attain extremely low temperatures (below 0.5K). The basic operating principle of an ADR is the use of a strong magnetic field to control the entropy of a sample of material, often called the "refrigerant". The operation of a standard ADR proceeds roughly as follows. First, a strong magnetic field is applied to the refrigerant, forcing its various magnetic dipoles to align and putting these degrees of freedom of the refrigerant into a state of lowered entropy. The heat sink then absorbs the heat released by the refrigerant due to its loss of entropy. Thermal contact with the heat sink is then broken so that the system is insulated, and the magnetic field is switched off, increasing the heat capacity of the refrigerant, thus decreasing its temperature below the temperature of the heat sink. In practice, the magnetic field is decreased slowly in order to provide continuous cooling and keep the sample at an approximately constant low temperature. Once the field falls to zero or to some low limiting value determined by the properties of the refrigerant, the cooling power of the ADR vanishes, and heat leaks will cause the refrigerant to warm up. Collaboration is envisaged in development of various subsystems and critical technologies related to ADR like salt pill, Magneto Resistive Heat Switches, Superconducting Magnets, etc. Development of numerical code for modelling of magneto calorific effect (MCE) and system level modelling of ADR also need to be taken up in joint academic collaboration. **(b) Optical Cooling:** Optical refers to a number of techniques in which atomic and molecular samples are cooled down to near absolute zero. Laser cooling techniques rely on the fact that when an object (usually an atom) absorbs and re-emits a photon (a particle of light) its momentum changes. For an ensemble of particles, their temperature is proportional to the variance in their velocity. That is, more homogeneous velocities among particles corresponds to a lower temperature. Laser cooling techniques combine atomic spectroscopy with the aforementioned mechanical effect of light to compress the velocity distribution of an ensemble of particles, thereby cooling the particles.
G9.4	**Heat Diffusion/Transportation devices for heat transfer through conduction of miniature high heat flux electronics device/system (SAC)** In space conduction is the prime mode of heat transfer from heat source to space exposed sink. Thermal management of High dissipating miniature electronics devices is quite challenging. Through this topic, expects researcher to explore various passive means of heat diffuser and high heat conductive devices, easy to interface with the heat source and offers efficient heat transportation.

<table>
<tr><th>H</th><th>Area</th><th>Semiconductor Technology for Microelectronics Design (URSC)</th></tr>
<tr><td>H1</td><td colspan="2">Development of GaN HEMT for Spacecraft Avionics (URSC)

A large number of radiation hardened MOSFET power transistors (VDS of 100-250V and drive @ 8-30A) are being used in spacecraft avionics. These devices are becoming obsolete and has to be realized in advanced technology.

Gallium nitride (GaN) technology facilitates the creation of a new generation of power transistors capable of operating in the challenging radiation conditions of space. GaN power semiconductors offer significant improvements in electrical performance over traditional silicon power MOSFETs. GaN devices and integrated circuits (ICs) realized with GaN HEMTs excel in higher frequencies, have increased efficiency, greater power densities and superior radiation tolerance at a reduced size compared to silicon MOSFETs.

Aim of the proposal is to develop radiation tolerant GaN technology for high power HEMTs for spacecraft avionics. This includes technology development, device modelling and development of PDKs for circuit design with the developed device models using industry standard EDA tools.</td></tr>
<tr><th>I</th><th>Area</th><th>Mechanical Engineering Systems (SAC/URSC)</th></tr>
<tr><th>I1</th><th>Sub Area</th><th>Research areas in Mechanical Design and Development of Microwave Remote Sensing Payloads (SAC)</th></tr>
<tr><td>I1.1</td><td colspan="2">Evaluation of material mechanical properties after plastic deformation (SAC)

Behaviour of metal components beyond linear elastic range has remained a gray area in the field of space payload component development. Understanding variation of mechanical properties post plastic deformation will enable accurate life estimation and mass optimization in payload components. For comparison one can take example of an L-angle realized using matching and the other realized by bending a sheet of same material and cross section. The structural behaviour of both the components will be in a way that machined component will be more rigid than the formed component.

The study will enable us to mathematically understand the behaviour, which can be further included in analysis programs to predict accurate life of metals components and joints, where metal forming is inevitable. Such applications are forming of connector and CQFP pins, formed structural components.

It's expected to evaluate mechanical properties, evolve mathematical formulation, FE code for behaviour of metals post plastic deformation & Experiment set-up for validation of the mathematical code.</td></tr>
</table>

I1.2	**Suppression of structural dynamic response in Multi-level Stacked electronics package assemblies (SAC)** Payload subsystems are stacked one over the other in order to reduce footprint of electronics subsystems on spacecraft deck. With each level increase in package stacking, the structural dynamic response of the stack on the top increases, which forms limiting factor for the packages/ devices planned to be stacked on the top. A methodology to reduce structural dynamics responses on the stack-up top, without compromising thermal coupling between packages, will enable further reduction in footprint by accommodating more packages on stack-up top.
I1.3	**Numerical simulation of Wire rope isolators under vibration environment (SAC)** Wire rope isolators have been widely used in transportation industry ranging from Rail, road, sea, air to Space transportation. The isolation products made of wire ropes cater to both vibration isolation as well as shock suppression and provide a robust solution to the transportation industry. The products are robust, durable & reliable. However, the behaviour of such product is less understood in FE environment. Through, the characterization details of each type of isolator are widely available, if a capability of 'simulating wire rope isolator behaviour' in FE environment is developed, it will enable us to explore many more geometries/ topologies/ arrangements and various loading conditions along with the behaviour of suspended system.
I1.4	**Measurement of structural & thermal material properties of adhesives for a temperature range of 4K to 500K (SAC)** Objective of this research is to carry out measurement of structural material properties of adhesives such as Elastic modulus, Poisson's Ratio, yield strength, ultimate strength, shear strength, surface hardness, thermal expansion co-efficient and thermal properties such as thermal conductivity, specific heat capacity. Epoxy based structural, thermal and Room Temperature Vulcanizing (RTV) adhesives, which are used for Aerospace applications, can be considered for the purpose of evaluation of the above mentioned properties for a temperature range of 4K to 500K. This results obtained from this research should be compiled in a report for use of structural and thermal designers.
I1.5	**Active cooling methods for Microwave packages of space payloads (SAC)** With increase in heat dissipation densities due to increase in power of RF devices and miniaturization of subsystems, current passive cooling techniques have a limitation, which can be overcome by design of compact Active cooling for such devices, which enables utilizing the device capabilities to the fullest. The proposed cooling methods may include Phase change materials, Thermo-electric coolers, micro heat pipes etc.

I1.6	**Deployable Radiators (SAC)** Spacecraft and space payloads largely depend upon Passive cooling using radiator plates for thermal control and heat management, without using spacecraft power. Though beneficial, the technology is constrained with the limited radiation area that comes withing the assigned payload volume. A deployable radiator is stowed while being accommodated inside payload fairing on launch vehicle and can be deployed in space, when payload is operational and thermal management is needed. Many such examples including deployable thermal shield for JWST are already working in orbit and have proved their effectiveness. Though, smaller deployable radiators associated to payload subsystems are commonly not observed. Technologies associated with deployable radiators to obtain improved thermal control of payload are required to be explored.
I1.7	**Effect of Annealing (Heat Treatment) on Thermal Contact Resistance of Copper and Aluminium at Cryogenic Temperature (SAC)** Objective of this study is to examine effect of annealing on Thermal Contact Resistance of metal-to-metal joints. This study is to be done for annealed samples as well as for non-annealed samples to quantify the variations. All experiments are to be done in cryogenic temperature range of 4-10K or 20-40K or 80-100 K or in all ranges. Experiments are to be done using OFHC Copper and various metal joint combinations such as 1) Oxygen free High Conductivity (OFHC) Copper to OFHC Copper. 2) Aluminum to OFHC Copper 4) OFHC Copper to Tellurium Copper (TeCu) 4) Aluminum to Tellurium Copper (TeCu) etc. Effect of bulk material conductivity and thermal contact resistance is to be studied after machining annealed samples to achieve better surface roughness. All the results are to be consolidated and guideline based on the experiments is to be made.
I1.8	**Design and Development of Thermal Link to achieve Thermal Contact at Cryogenic Temperature based on Differential Contraction (SAC)** Cryostat used for ground based astronomical telescopes consists of Cryogenically cooled front-end electronics to improve the system sensitivity. Cryostat for these applications consists of a vacuum enclosure and to achieve cryogenic temperature, GM Cryocoolers are used. GM Cryocooler cold head is inserted inside Cryostat and is anchored with components to be cooled using Flexible metal straps. Cryogenically cooled electronics is mounted on a separate structure having multiple stages to maintain different temperature inside Cryostat. These stages are separated using low thermal conductivity rods. This structure is assembled inside Cryostat and required thermal contact is made to achieve temperatures at various stages of structure during operation.

	required thermal contact is made to achieve temperatures at various stages of structure during operation. Proposed thermal link will be used to achieve required thermal contact between Cryocooler Cold Head and Front-end electronics structure. Thermal link will be made of two parts, first part (external Housing) will be assembled inside Cryostat and second part (Internal Housing) will be assembled on the structure over which electronics is mounted. External housing assembled inside Cryostat will be anchored with Cryocooler Cold head using Flexible straps/braids. Internal Housing assembled on the electronics structure will be inserted inside Cryostat. External housing will receive the structure during assembly and structure will be connected with Cryostat vessel. During Cool down both parts of thermal link will contract to establish heat conduction path. Thermal path shall be established by achieving differential contraction by specific geometry of both parts of link or by selection of different combination of materials. This proposal is Design and Development of Thermal link along with realization and testing of a prototype, which can be used for above-mentioned application. Developed thermal link shall be compatible for operating temperature as low as ~ 3 K and thermal contact resistance of the link shall be in order of ~ 0.4 K/W @ 4 K and ~ 0.6 K/W @ 80K~100K.
I1.9	**Design and Development of Vertically stacked Graphite structure as Thermal Interface Material with thin metallic fillers to achieve very high out of plane thermal conductivity (SAC)** Graphite or similar material sheets can be used to design and realize TIM to achieve very high out of plane conductivity. These sheets shall be formed in a laminated structure along with thin metallic layers adjoining these graphite layers to achieve required thermal conductivity as well as stiffness. Contact pressure to join these laminates shall also be optimized to achieve minimum possible thermal resistance. Thermal management of electronic subsystems having very high dissipating electronic devices is a challenge. With the advancement in Technology, heat flux of devices are also increasing giving rise to a local hotspot. For thermal management of such high dissipating application, specifically designed thermal interface materials are required. This proposal is for design and development of thermal interface material (TIM), which will be used to effectively transmit heat in out of plane, to reduce thermal gradient from device to the heat sink. These vertically stacked fillers would be required in form of blocks of different sizes with maximum footprint of 50 mm x 50 mm and thermal resistance of ~ 0.3 cm^2.K/W.

<table>
<tr><td rowspan="1">I1.10</td><td colspan="2">Design and Development of Material Based Solutions for Efficient Heat Conduction Technologies (SAC)

In order to effectively transport of heat from source to sink, advanced materials with excellent thermal conduction performance are usually implemented. Heat spreaders and thermal interface materials facilitate efficient heat transfer. In past, large varieties of novel materials have been developed by different agencies worldwide to achieve effective heat conduction path.

Evolution of materials designed for spacecraft thermal management reflects a shift from isotropic metals to carbon-reinforced polymers, and moving forward to advanced materials including carbon-carbon composites and annealed pyrolytic graphite (APG). Typically, composites are composed of at least two disparate substances. A primary substance acts as a host matrix, whereas another serves as the reinforcement, commonly in the form of fibers embedded in the matrix. With thermosetting compounds such as epoxy, bismaleimide, and polyimide often employed as standard matrix materials, both ceramic and metal matrix composites have garnered considerable interest for use in the aerospace sector in recent years due to their weight saving feature as well as the high-temperature capability/oxidation resistance characteristics.

This proposal is for design and development of such high thermal conductivity composite materials, which can be used as thermal interface material (TIM) for thermal management of space-borne systems. Typical range of in-plane Thermal Conductivity shall be greater than 800 W/m.K and shall be developed in form of square sheets of 100 mm in thickness of 0.1 mm & 0.2 mm.</td></tr>
<tr><td>I2</td><td>Sub Area</td><td>Research areas in Composites and Advanced Materials Applications (SAC)</td></tr>
<tr><td>I2.1</td><td colspan="2">Modelling and analysing the curing parameters and predicting the thermo-elastic distortions in the fibre-reinforced polymer composites (SAC)

During curing process of the composites, process-induced residual stresses occur because of mainly mismatch in thermal expansion coefficients of the constituents, chemical shrinkage of the resin and non-uniform curing of the composite laminates. Severe residual stresses can result in transverse matrix cracks and delamination after processing. Composite parts are prone to bending or warpage due to thermal gradients and residual stresses build up.

To predict the actual distortion, accurate mathematical modelling is required which addresses chemical reactions, heat generation, heat conduction, selection of the mould material and other relevant parameters. Critical mechanical component of this model are evolution of stress and progressive damage analysis. The outcome of the study and analysis will be helpful in determining optimum process parameters. The scope is to develop a mathematical/analytical model of the temperature and curing pattern in</td></tr>
</table>

	polymer composites using a thermo-chemical model, and coupling it with a thermo-mechanical model to predict the residual stresses and viscoelastic response of the material, predict distortion and damage in the polymer composite using a continuum damage model. Deciding optimum process parameters of the curing.
I2.2	**Development of acoustic holography-based testing and fault diagnosis techniques for payload structures (SAC)** Conventional vibration-based fault diagnosis methods are contact-based and require the mounting of vibration sensors such as accelerometers close to locations of interest on the engineering equipment. This limits their application in actual situations specifically for simultaneous testing of various payload components with different shapes and sizes, monitoring of large surfaces and parts difficult to access. Further, in contact-based measurements, it is always difficult to decide proper measurement positions and identify the exact location of fault. Research is required to explore advanced methods to overcome these challenges. The near-field acoustic holography (NAH) is a promising technique where an array of microphones can be installed near the structure to record the acoustic-field in a non-contact way and use the acoustic information to detect as well as locate the faults. NAH is an effective technique for visualizing sound field data from multi-channel measurements and has been frequently used for sound source recognition at any observed. Development of this technique will be helpful in testing of all the sensitive payload structure which have borderline margin of safety.
I2.3	**Development of High Strain Tolerant Infusion Grade Resin System for the Space Applications (SAC)** Resin systems are the essential elements for the Development of the Composites materials and components. The resin systems are primarily responsible for the load transferring between the reinforcement materials and protecting it for the environmental effects. The composites material exhibits linear behaviour against the applied load near to its fracture. Large strain tolerant resin system will lead this for the foldable structure to minimize the space requirements by folding it in the launch vehicle envelope. The development of the large strain tolerant (>20 %) resin system will pave the way for minimizing the space about 50% in the stowed conditions.
I2.4	**Design, FE Simulation and Development of Elastic Foldable Reflector for Large Aperture Antenna (SAC)** Antenna Reflector are the main element for the satellite communication. Due to requirement of the large shape antenna for the future space missions and limitations for the space in the launch vehicle for the accommodation, elastic foldable antenna reflectors are the prime candidate for the future satellite based communications and navigations.

	Development of the large aperture antenna reflectors (at least 2.5m diameter) for the foldable volume <50% to be targeted for stowing. Non-linear FE simulation to be carried out for folding, deployment and stability conditions. A prototype reflector is to be developed and characterized.
I2.5	**Development of shape configurable/deformable parabolic reflector using shape memory alloy (SMA) or equivalent actuation (SAC)** Development of large flexible antennas is becoming critical today; such antennas can be realized with shape memory alloy actuated mechanism. It can be reconfigured in space for variable antenna footprint, and hence can be utilized for signal transmission to different geographical locations. Requirement of changing the shape is quasi-static and hence SMA based actuators and very much suitable for this application.
I2.6	**Metallization of composites for enhancing electrical and thermal conductivity for development of RF components (SAC)** Light weight & high modulus composite structures are the need of the current Space scenario. These composite structures provides excellent load carrying member as well as maintaining dimensional stability in harsh space environment. The use of composites are limited to only structural parts. To utilize in realizing RF parts, there is need of improvement of electrical and thermal conductivity of the composites. Metallization on a composite part itself calls for the various qualification and always leaves uncertainty in terms of quality. The biggest challenge is survival of the metallization in extreme space environment in the orbit. There are various methods, which may be tried for metallization: • Conductive surface coating or metallization of CFRP. Surface activation & Electro plating or Electro-less plating. • Development of Electrically Conductive Prepregs /Resin system (lamination) for Space grade composite systems. • Development of carbon-carbon composites with excellent electrical and thermal conductivity for realization of RF components. • Metallization of CFRP may also be done by inclusion of graphene/CNT at layup stage. Existing properties of CFRP: Electrical Conductivity: 104 S/m Electrical Resistivity: 10-3 Ω.m Thermal Conductivity: < 1 W/m/K Desired properties of CFRP: Electrical Conductivity: 107 S/m Electrical Resistivity: 10-8 Ω.m Thermal Conductivity: > 50 W/m/K

I3	Sub Area	Research areas in Antenna Alignment and Integration (SAC)
I3.1		**Development of retroreflective targets to for generating points cloud using optical metrological tools (SAC)** In development of spaceborne antennae & payloads; measurement and alignment play a very critical role. All components of the payload are required to be placed at its designed position within a very tight tolerances for its efficient performance. The metrology tools used for the purpose is optical photogrammetry tools. This photogrammetry camera flashes light over the component under measurement, which is represented by a number of reference points by using retroreflective target. This target reflects back the light which is captured by camera and processed to represent as a dot point. These point clouds are monitored for any change and correction of component position. These targets are essential consumable accessory which is required to be manufactured indigenously to be available easily and economically to widen the measurement of components. Therefore, study in this area is required to understand the optical behaviour of metrology system to synchronize with photogrammetry system within high accuracy. The target may be developed and can be tested to make it operational.
I3.2		**Development of mathematical model for optimization of surface profile RMS in segmented reflector antenna (SAC)** The segmented antenna with stringent surface RMS for Ground based is a challenging from Antenna assembly, integration and alignment aspects. Since wavelength at higher frequency comes to sub-mm level, it calls for very stringent alignment of each panel of the segmented antenna systems. In line with this, each panel shall be aligned with respect to global antenna in six degrees of freedom. So overall surface RMS requirement of segmented antenna is very stringent. To achieve overall antenna RMS, the individual panel rigid body correction need be corrected by using provided 5 control points on each reflector panels from given measured point cloud data. This requires mathematical model for calculation of control points of all panels for optimization / correction of overall surface profile RMS of antenna.
I3.3		**Research areas in Mechanical Design and Development of Communication Payloads (SAC)**
I3.4		**TPG Encapsulated High Conductivity Plates/chassis for High Power Subsystems (SAC)** Technologies/process related to development of Thermal Pyrolytic Graphite (TPG) encapsulated high conductivity plates. These plates can be of Stainless Steel, Copper and Aluminum with TPG encapsulated within. Collaboration is envisaged for the development of different encapsulation techniques based on Electroforming, bonding, soldering or any integration methods such that it effectively produce a high conductivity plate.

I4	Sub Area	Research Areas in Production Technologies (SAC)
I4.1		**Micromachining of metal components (SAC)**

Micromachining of metal components (SAC)

Mechanical housing for mm and sub-mm wave length front end RF components are having micron scale features interconnected with one-another. Fabrication of mechanical housing for these components are very challenging. Post fabrication, dimensional inspection is also critical and require special instruments. Materials, which is used for making mechanical housing, will be primarily OFHC Copper, Tellurium Copper, Al 6061-T6 etc. Typical feature size and Geometrical tolerances for these mechanical housings for mm wavelength components are as follows and are made using precision milling machines or pulse laser machining. These dimensions would reduce further for sub-mm wavelength components. An image showing a similar component is given here for better visualization of job. This proposal seeks to utilize existing capabilities and infrastructure with academia for fabrication of such components.

Existing capabilities and infrastructure with academia for fabrication of such components.

Sr. No.	Feature size (Length x Width x Depth)	Tolerance (mm)
1	3.30 x 0.30 x 0.05 mm	+0.015 -0
2	1.484 x 0.52 x 1.016 mm	+0 -0.05
3	0.285 x 0.909 x 0.546	+0 -0.01

Sr. No.	Geometrical Tolerance	Value
1	Flatness	0.01 mm
2	Perpendicularity	0.01 mm
3	Parallelism	0.01 mm
4	Position	0.025 mm
5	Surface Roughness	0.025-1.6

I4.2

Development of Flexible Mandrel for bending of Rectangular Waveguide (WR) sections (SAC)

Rectangular waveguides are used in communication satellites for transmission of RF signals because of low signal loss characteristics. Application of the same on satellite panels, require bending in both cross section dimensions i.e. width as well as height direction, as per below images. At present, fusible alloy is used for bending applications.

It is required to design and develop a flexible mandrel to support inside cavities during bending applications. So that we get finished product without distortion in cross-section and damaging the inner surface finish. Both surface finish and uniformity of cross section along the length of the waveguide, are crucial features to transfer RF signals with minimum losses.

Following are the parameters which should be considered while designing and development of the Flexible Mandrel:

- Material: Aluminium alloy 6061 (Annealed condition)
- Wall thickness: 0.635 mm
- Inner dimensions of rectangular waveguide section and required bending radii :

Width (mm)	Height (mm)	Mean Bending Radii in plane of broad side, E-Plane (mm)	Mean Bending Radii in plane of narrow side, H-Plane (mm)
19.05	9.52	35	30
15.74	7.87	35	30
12.95	6.47	25	20
8.63	4.31	20	20
7.11	3.55	20	20

Targeted Specifications:

- Flexible Mandrel which can support inner walls of the Waveguide section while bending operation.
- Mandrel shall be drawn out of the sections without damaging the inner walls.
- Single section may also have both types of bends, mandrel flexibility shall be such that it can be drawn out from both bends.

I4.3

Realization of "Flexible" Waveguide and establishing Fabrication Process for repeat Production (SAC)

Microwave Sensors and Payloads require Waveguides as Transmission Line Elements to route High Power RF Signals across multiple Functional building blocks of the Integrated System. In certain cases Such Units are located across places having relative motions (rotations or translations). To route RF Power across such interfaces having relative motion, there is an option of using suitable "Flexible" Waveguide. Such waveguide is expected to mainly offer H plane and E Plane Bending upto the extent of 90 degrees. The Sizes to be explored for development are WR62, WR75, WR90 and WR28(Ka band, Ku band, X band). In international market, there exists sources and technology to realize such Flexible waveguides. Make-In-India sources are to be established for which, through this opportunity, proposals are being sought from resourceful academic teams/collaborators to Realize Products at First Stage and thereby Establish Fabrication Process for further Repeat Production. For better understanding of Flexible waveguides, it is recommended that a simple internet search may be done with the key

	word "Flexible waveguide". They can be visualized as Metallic Corrugated Bellows, the profile being rectangular instead of circular for tube as well as for Mating Flanges at either ends. It should be possible to Implement Surface Treatments like Silver Plating onto the Product. The surface Finish of internal cavity to be of best achievable order to minimize RF Losses. The Product should be compatible for use-application in Vacuum environment with operating temperatures, typically, upto +/-100 degree Celsius.	
I5	**Sub Area**	**Research Areas in Mechanical Design and Development for Optical Payloads (SAC)**
I5.1	**Design and Development of vibration isolation system with hybrid D-struts for space payloads (SAC)** This research work focuses on the design and development of actively controlled D-struts (three parameter vibration isolators) for space payload of mass up to 100 Kgs. The three parameter vibration isolators, which are also called D-struts (dual struts), are low frequency vibration isolators which are better absorbers as well as better isolators as compared to conventional spring-mass-damper (two parameter) vibration isolators. In the D-strut isolator the damper is elastically connected, due to which it offers 40 dB/decade roll-off in the isolation region as compared to 20 dB/decade roll-off of two parameter isolator; while maintain the absorbing capacity in the transmissibility region. Hybrid D-struts consist of an active actuation element to control and suppress the vibration loads. The design of a single D-strut is independent of the payload mass as opposed to the conventional isolator which are designed for a particular payload mass.	
I6	**Sub Area**	**Spacecraft Structure (URSC)**
I6.1	**Vibration Attenuation using Metamaterials (URSC)** Vibro-acoustic Metamaterials are materials engineered and specifically designed to control, manipulate, and mitigate vibrations and sound waves in ways that exceed the performance of conventional materials. It consists of a base structure with multiple resonators on it. The local resonators are to be strategically placed on the base structure and they are to be tuned for a resonant frequency at which vibration attenuation is required. For spacecraft applications mass efficient and design optimisation of space grade resonators to achieve vibration mitigation in a wider frequency band is required. Vibro-acoustic metamaterials are an innovative solution in the vibration reduction methods for space structures. Vibration attenuation is essential for the optimal performance of critical subsystems in remote sensing, communication, and interplanetary spacecraft.	
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I6.3	**Multi-scale Modelling of Structural Components (URSC)** Multi-scale modelling is a methodology in which multiple models at different scales are used simultaneously to describe a system. Conventional structural analysis considered homogenized material properties. However to account for heterogeneity, it is essential to develop analytical models to a scale lower than the conventional material characteristics estimation. Objective of the work is to develop analytical model for capturing heterogeneity and anisotropy in microscale. Conversion of micro scale to macro scale for incorporating as localized homogeneity. Algorithm to convert micro to macro material models. Software to map / transfer the localized property to conventional FE model. Finally, macro level results to be translated to micro level by means of localisation technique.
I6.4	**Design and development of Lattice structures for Space applications (URSC)** The lattice structure consists of helical and hoop ribs intersecting each other in a regular pattern. The ribs provide both membrane and bending stiffness of the structure. It is important that the ribs are made by continuous filament winding and have a unidirectional structure demonstrating high specific strength and stiffness. These advantages mostly relate to the unidirectional nature of the grids in a lattice and the one-step manufacturing process that allows for the integration of all the structural features in a single process, saving cost and time. Design and development of Tertiary and Secondary structural members will be carried out to gain confidence. Successful progress may lead to develop an efficient Primary Structure.
I6.5	**Development of Self-healing Composites (URSC)** Micro cracks, de-bonds, de-lamination in composites due to changes in environmental conditions or due to external forces like debris can be life limiting problem in space. Self healing or autonomic healing is a way to address this problem which can effectively extend the life of structure with better structural integrity. A suitable self healing method involving development of suitable materials and manufacturing techniques to be developed and demonstrated for satellite structural applications.

16.6	**Development of CNT based multifunctional nano-composite laminates for structural, thermal and electrical applications (URSC)** To develop multifunctional nano-composite material for spacecraft structural applications. CNT based nano-composite improve thermal and electrical conductivity of composite material along with higher stiffness and strength. At present this is still a challenge to be realized for practical applications. The objective is to realize space grade composite prepregs with low density CNTs paving way for light weight prepregs with enhanced structural and thermal properties.
16.7	**Structural Health Monitoring (SHM) of Spacecraft structural members (URSC)** To develop damage detection and quantification methods for typical damages in spacecraft structural members made of composite and or honeycomb sandwich. This includes damage to material and failure of sandwich embedment / structural joints, theoretical and experimental studies on damage detection using guided wave using PZT sensors / Fiber optic sensors and experimental demonstration of implementation of above methods on Spacecraft structural members with sensors, actuators and necessary acquisition, data processing and instrumentation.
16.8	**Analytical Modeling Direct Field Acoustic Testing (DFAT) to estimate acoustic and structural responses (URSC)** Spacecraft has a few sub-systems that are critical for acoustic loads and the design is primarily to withstand the loads. Those sub-systems needs to be qualified for the expected acoustic loads. The qualification can be performed in diffused acoustic field in a reverberation chamber or in direct acoustic field. The Direct Field Acoustic Testing is emerging technique in aerospace industries. This technique is handy, as the test setup is portable and there is a scope for response limiting for critical components. However achieving the required Sound Pressure Level (SPL) in direct field is a challenging task. The achievable SPL depends on the test setup like characteristics of Speakers, Sub-woofers & Horn, its position and arrangements and also the test specimen (spacecraft/sub-system) dimensions. Considering the test setup details, expected SPL at multiple locations for the initial test setup around the specimen needs to be estimated. The structural responses on the specimen for the test frequency range needs to be estimated and the results needs to be test correlated. Objective of the analytical model development is to predict the sound pressure levels around the test specimen and predict the structural responses at the test specimen/spacecraft sub-systems during DFAT.
16.9	**SMART materials like piezoelastic, electrostrictive and magnetostrictive materials (URSC)** There are several applications in which the vibrations to be reduced. Development of active isolator is one of the aims. In some applications large actuating force needs to

	be applied. There are cases where the shape control need to be achieved. These can be achieved by employing the above materials in suitable manner. The collaboration is in working with such materials.
16.10	**Inflated structure for Space application (URSC)** Recent Technological advantages have presented a new possibility to the space community with ultra light Inflatable structures. These can be used for solar sails, balloons, for large light weight antenna, space habitats etc. The term inflatable structure indicates that a compact configuration will be launched into space and then deployed by pressurization using a gas or other means to its full intended form. For some of the applications, rigidization of an inflatable structure is necessary whereby; following deployment via inflation, the structure is physically rigidized to the point where it will maintain its intended shape without reliance on continued pressurization and will be capable of taking load.
16.11	**Development theoretical models for prediction of response to acoustic excitation (BEM, SEA) (URSC)** Estimation of responses to acoustic excitation at low frequencies are carried out using Boundary Element Method (BEM). For estimating the responses at higher order modes, Statistical energy Analysis (SEA) is used. Significant amount of work in this direction is already carried out. But there are still some differences between such predicted responses and the experimentally seen responses. Need to fill this gap.
16.12	**Image processing techniques (ultrasonics, thermography, speckle interferometry) (URSC)** Composite and honeycomb sandwich panels are widely used in spacecraft. The quality is assessed through NDT techniques such as ultrasonics, thermography, and speckle interferometry. They are image based techniques. Some of the images need further processing to reveal the defects. The work is to develop image processing techniques / algorithms such that the defects are revealed.
16.13	**Estimation of micro-vibration and its mitigation techniques (URSC)** Micro-vibrations are generated in the spacecraft while in orbit. Estimation of these disturbances is essential. Development of mathematical models to realistically estimate these disturbances are being investigated. Techniques other than finite element based are looked up on. Once the models are reliable ways to mitigate, passive or active, also need to be addressed.
16.14	**Development of theoretical models for prediction of response to high frequency shock (spectral element, wave propagation techniques, Statistical energy analysis) (URSC)** The high frequency shock responses can be estimated using spectral elements / wave propagation techniques / Statistical Energy Analysis. Some amount of work in this

	direction is already carried out. Several spectral elements including for honeycomb sandwich construction are developed. Responses are determined using wave propagation techniques. But still there are unresolved issues. Looking for collaboration in these works.	
I6.15	**Unconventional manufacturing technique for composites (URSC)** Autoclave processing is normally done and it needs large autoclaves and is costly. VARTM is also being used for specific applications. New processing techniques are being evolved which are of out of Autoclave. Looking for other techniques for specific applications that will benefit compared to autoclave processing.	
I6.16	**Curing induced deformation and stress in composites (URSC)** Curing process used for the manufacturing of composite structures results in built-in stresses. This results in shape deformations. The work involves understanding of curing stresses, their mathematical modelling, experimental verification and ways to reduce them. Some amount of work is already carried out, some specific development is looked up on.	
I6.17	**Articulated Boom Deployment Mechanism (URSC)** Articulated booms are a crucial component of many satellite systems, serving a variety of functions from deploying solar arrays to positioning antennas and scientific instruments. The boom is typically made of light-weight materials such as aluminium or CFRP tubes, and is stored in a compact configuration during launch to minimize its size and weight. The main challenge is the need for precise control over the deployment and positioning of the boom. Articulated boom mechanism consists of an articulated boom on which various appendages and spacecraft can be assembled and deployed away from spacecraft. The boom will have rotational degree of freedom at joints. Depending on the requirement the boom can be segmented into multiple arms. Each arm is connected to other with single degree of freedom joint along with a dual Gimbal or pointing mechanism as per requirement. Articulated boom mechanism is a 4 DOF system configured with 4 drive actuators to deploy the reflector 2 meters away from Spacecraft. It is configurable and modular design which can be scaled to meet users requirements. Full scale reflector deployment with Boom and Hold down is already demonstrated. Flight worthy product is under fabrication for qualification.	
I7	**Sub Area**	**Spacecraft Mechanism (URSC)**
I7.1	**Autonomous Capture and Rigidization Mechanism (ACRM) (URSC)** In On Orbit Servicing (OOS) Mission, a new technology needs to be developed for servicing Satellites with capabilities of capturing non-cooperative target to increase the	

	life of existing satellites in GEO/LEO. The basic idea is to provide life extension to an aging non co-operative spacecraft (Client) and still be able to utilize its payload services. Servicer spacecraft equipped with capture technology approaches towards the client spacecraft nearing end of life with low velocity using closed loop guidance with proximity sensors in the loop to enhance its life. ACRM facilitates to capture, rigidize and release an existing, non-co-operative, client spacecraft in LEO/GEO Orbit, using a gripper mechanism mounted on robotic arm of a Servicer spacecraft. Servicer spacecraft to possess the ability to capture and release multiple times, allowing it to service multiple satellites. The major constituents of the system include a six DOF Robotic arm, the Gripper mechanism, Rigidisation mechanism and real time tracking and kinematics software.
I7.2	**Sun Shield Deployment Mechanism (URSC)** Future missions envisages payloads at the SUN-EARTH L2 point to obtain high precision simultaneous spectroscopy of astronomical point sources such as starts and other localized object which will be a step forward in our quest to understand the universe and its origins. The payload requires a thermal background of 50K-100K to meet the science requirement of photon noise dominated observations. A deployable sunshield is meant to provide this background requirement. Deployable sun-shield mechanism is being designed and developed to protect instruments/ payloads from sun light and keep them at extremely low temperatures. This mechanism should rigidly hold, deploy and tension the sunshield to provide required optical properties. Presently folding pattern is being studied on the scaled model. The large Sunshield is required to be deployed to keep the Infrared space telescope based payload under cold conditions (Temp = 80K) and to be positioned between the spacecraft mainframe structure and payload.
I7.3	**18m Un-Furlable Antenna (18m UFA) (URSC)** Spacecrafts required for Geo mobile communication are configured with an Unfurlable Antenna of diameter up to 18m. Due to its large size and limitation of the launcher envelope, it is essential to keep appendages in the stowed condition during launch and is deployed in the orbit. In order to position the UFA at its required optical position, long booms / large arms are required. It is practically not feasible to realize a boom / arm with lengths between 10 m to 15 m. Hence multiple booms / arms are required to position the UFA at its optical position. Thus there is a need to develop a novel hinge mechanism to deploy the booms. Also, the hinge has to be compact and should be capable of holding the UFA at its required position and orientation with respect to the spacecraft during spacecraft manoeuvres.

	The development of 18m Unfurlable Antenna uses the concept of the 6m UFA for the reflector deployment, which is flown in GSAT-6 spacecraft. The boom deployment mechanism is a new development with a new novel hinge design. The UFA in stowed configuration is approximately 1m in diameter and 5m in height. The reflector is predominantly made of carbon composites. The structural elements of the reflector are made of high modulus carbon composite tubes and the reflector surface is made of cable net supported metallic reflective mesh.
I7.4	**Rover Descent Mechanism for Heavy/Large Rovers (URSC)** The rover descent mechanism is being designed to facilitate the controlled deployment of large, heavy rover weighing up to 400 kg from the top deck of lander-craft to ground. Configured with 2 arms secondary panel and 4 bar linkage, the mechanism enables a deployment angle of more than 150º to transfer the rover from top deck to ground by achieving a vertical descent up to 3.4 meters. Arms of secondary panel is adaptable to challenging terrains, capable of safely deploying the rover on uneven surfaces with boulders up to 300 mm in size. Mechanism is planned to be used on Chandrayan-5 mission. Rover descent mechanism comprises of primary and secondary panel deployment which are initially held down in stowed configuration. Mechanism initially deploys Secondary panel to form a ramp for transferring rover from top deck to ground. Mechanism is configured with cable-controlled deployment of four bar linkage mechanism to transfer rover from a height of up to 3.4 m to Ground.
I7.5	**Deployable Langer Leg Mechanism (URSC)** For exploring and conducting in-situ experiments a lander craft is required which travels along with the propulsion module as piggy back and gets separated from the propulsion module. The lander craft then travels towards the moon and places the rover/payloads on the lunar surface for scientific operations. The lander carries the scientific payloads on the lunar surface giving information about the moon soil properties, composition of the rock & minerals. The Chandraayan-2 & 3 also have a legged type lander mechanism. In Chandrayaan-2 &3, the lander legs are fixed in configuration. However, for CH-4 & CH-5, a deployable lander leg mechanism is being developed to get wider foot print for better stability. Deployable Lander Leg mechanism is designed and demonstrated for soft landing on Lunar surface for 2000kg large Lander. The mechanism is envisaged with compact stowing of lander leg mechanism towards the vertical deck for better stowed stiffness and has provisions for honeycomb damper for lateral load attenuation.

17.6	**Radial Fold Solar Array Mechanism (URSC)** The design envisages development of Light Weight, Low Volume, High Specific Power and scalable Solar Array Mechanism for LEO, GEO, Interplanetary and Planetary Landing Missions. Radial fold solar array mechanism overcomes the difficulties posed in the rolling of the flexible solar cell populated substrate. The Radial Fold solar array mechanism is a novel deployment mechanism designed to meet the increasing energy needs of spacecraft. This mechanism deploys the solar array blanket with solar cells bonded on it and supported by radial spars. These spars are connected to C-channels which are interconnected with geared links. The array deploys through a single-axis rotation mechanism, where the panels unfold from a compact, stowed configuration into a circular arrangement. Key features of RFSA include its use of gears and links for deploying in a circular accordian fashion, its ability to fold into a compact configuration for launch, and its capacity to expand into a large surface area once in space that can generate more power. The primary objective of developing RFSA is to achieve compact stowage volume on spacecraft, high specific energy and low shock deployment mechanism. Its practical applications range from powering small satellites to large space stations, highlighting its versatility and adaptability for various mission requirements.
17.7	**Sample Collection and Positioning Mechanism (URSC)** Soil Collection and Positioning Mechanism (SCPM) is two, orthogonal, axis linear drive mechanism. It is part of ISRO Sample Analysis Package (ISAP). ISAP consist of a Raman Spectrometer along with SCPM to analyze the Lunar soil sample delivered by the sample handling system of REsource Investigating Water Analyzer (REIWA) onboard CH-5 Rover. The Sample handling system of REIWA will deliver the Lunar soil sample along with the sample holder to the ISAP. One of the objectives of SCPM is to collect the Lunar soil sample along with the sample holder delivered by REIWA. Once the sample is successfully collected by SCPM, it requires to be placed under Raman spectrometer of ISAP. Hence, the second important objective of the SCPM is to position the Lunar soil sample under the Raman Spectrometer at required location.
17.8	**Auger Mechanism (URSC)** Sub-surface sampling is planned to be conducted in Chandrayaan – 4 using a deep drilling mechanism (DDM). It is planned to carry out drilling to a depth of ~ 1m below the lunar surface and collect sample core. The cored sample needs to preserve depth information for detailed study on Earth. A 1 m rotary hollow drill for collecting lunar sub-surface soil sample is proposed. The hollow drill enables the mechanism to collect lunar soil samples within the drill and subsequently push the sample out for return to earth and for further analysis. The drill along with the mechanism is assembled on the lander on a drill descent mechanism to

	lower or lift the drill and the mechanism is held on the deck by hold down mechanism. The drill consists of a rotating hollow spiral auger, two concentric & stationary inner tubes, a cover mechanism and a rotating drill bit assembled at the bottom of the drill. The soil sample is collected within the inner tube of the two stationary tubes. The outer auger is translated downward/upward with the platform without rotation, by a lead screw mechanism. The rotary motion of the drill is provided using a geared mechanism; both rotary motion and feed for drill are independent of each other. The drill is lowered into the lunar surface using the drill feed and rotary mechanism. The soil samples are collected inside the drill in discrete 25 cm samples.	
18	**Sub Area**	**Spacecraft Thermal Systems (URSC)**
18.1	**Design and Development of Oil-Free Compressor for High-Temperature Application in Microgravity (URSC)** Vapor compression heat pumps have the potential to meet the future requirement of thermal management in large spacecraft due to its ability to achieve high heat flux dissipation and precise temperature control. Compressor plays a crucial role in a vapor compression heat pump system. In terrestrial heat pump systems, oil-lubricated compressors are most commonly utilized. These compressors depend on gravity to ensure efficient oil circulation within crucial components like Piston, bearings, seals, and other contact surfaces, as well as effectively manage the refrigerant/oil mixture in two-phase heat exchangers. Lubricating Oil tends to separate from the refrigerant in most terrestrial oil-lubricated compressors-based refrigeration systems using oil gas separators with the help of gravity. However, in microgravity environments, the absence of gravity poses challenges for gas-liquid separation, which can compromise cooling efficiency of heat exchanger and also inadequate lubrication can lead to system failure at critical areas and at crucial times. To address these challenges associated with gas liquid separation in oil lubricated compressor for microgravity application, Oil-free compressors are desired. Development Requirements: • Design and Development of an oil- free compressor for microgravity applications • Fabrication and testing of a prototype compressor • Integration of variable speed control for adaptive thermal management. • Performance evaluation under high temperature conditions.	
18.2	**Development of Consumable based (evaporation / sublimation) cooling system for space environment (URSC)** Passive thermal cooling technology using sublimators is suitable for missions with volume constraints and short mission durations. Sublimators utilize water, a consumable, whose high enthalpy of sublimation can result in significant heat rejection. It works on	

	the principle of sublimation of ice into water vapour into the vacuum of space. Liquid water from on board reservoir is supplied to and freezes in a porous membrane. Heat load from spacecraft electronics or payload provides the enthalpy of sublimation of ice, causing it to change to vapor, as the ice front is exposed to environment through pores. This will provide the required cooling of systems Development Requirements: • Design and Development of consumable based cooling system for space environment • Mathematical modelling • Fabrication and performance evaluation of a prototype model	
I8.3	**In-Situ Resource-Based Insulation for interplanetary missions (URSC)** Thermal insulation is critical for maintaining temperature stability in spacecraft, rovers, and planetary habitats while minimizing power consumption. The use of in-situ resources for insulation can significantly reduce reliance on Earth-supplied materials, enhancing the sustainability of long-duration missions. One potential approach is CO_2-based gas-gap insulation for Mars missions, which leverages the local atmospheric CO_2 to create an effective thermal barrier for rovers and habitats. Another promising method is regolith-based insulation for both lunar and Mars missions, which not only provides thermal protection but also serves as a radiation shield. This study will involve computational fluid dynamics and thermal modeling to evaluate the effectiveness of these insulation techniques under planetary conditions. Experimental testing will focus on the thermal performance of CO_2 gas-gap insulation under varying pressures and the insulation capabilities of compressed or sintered regolith. The possibility of hybrid insulation concepts that combine CO_2 gas-gap insulation with regolith-based shielding will also be explored to maximize thermal and radiation protection while optimizing mass and power requirements. This research aims to develop self-sustaining, energy-efficient insulation solutions for future planetary exploration missions. Development Requirements: • Thermal mathematical modelling • Experimental evaluation of insulation capabilities	
J	**Area**	**Systems Reliability and Safety (SAC)**
J1	**Sub Area**	**Research Areas in Material and Process Development (SAC)**
J1.1	**Development of Nanoparticle-Enhanced MWCNT reinforcement in PEEK Matrix Hybrid Nano Composites for Space Antenna Applications (SAC)** Space missions have strict weight limits for payloads. Antennae used in space mission must be designed to be as lightweight as possible to minimize the overall weight of the antenna system. Structural elements including Ribs are generally made up of metals which makes them heavy in weight. Development of light weight structure is one of the	

	major challenges involved in the realisation of the antenna. Polymer nanocomposites are materials that incorporate nanoparticles into a polymer matrix material to enhance the properties of the resulting composite. These nanocomposites often show enhanced strength and stiffness compared to their micro or macro counterparts. The inclusion of nanoparticles can significantly improve the mechanical, thermal, electrical, or optical properties of the nanocomposite. A thorough investigation on characterization of these nanocomposites could position them as viable candidates for structural elements and Antenna ribs, potentially leading to reductions in both weight and cost. **Scope:** The scope of the proposed research includes thorough analysis and characterization of the developed nanocomposite with the desired properties that could make them suitable candidates for radial rib antennae fabrication for space missions. The properties that are to be taken into consideration may also include- • Resistance to Corrosion and Flammability • Mechanical Strength and Thermal Stability • Microstructural Analysis **Anticipated Benefits:** Use of nanoparticles into a polymer matrix material shall ensure better mechanical, electrical and thermal properties, at lesser weight than metal which shall benefit it in incorporating more transponders and subsequently effectiveness of payload.
J1.2	**Weldability of Additively Manufactured (AM) 3D Printed AlSi10Mg Alloy (SAC)** The Additive Manufacturing (AM) process in which feedstock material which is in the form of powder, wire and sheet; is converted into a dense metallic object by melting and solidification with the use of various heat sources types like Arc, Plasma, Beam-Laser and Electron Beam and Ultrasonic Vibration in case of sheets. By now use of the welding process for additive manufacturing is common, use of arc welding heat sources like GMAW, GTAW, Plasma, and SAW are reported for additive manufacturing. The most widely used heat source for additive manufacturing is a LASER. The Laser Powder Bed Fusion (LPBF) process is widely reported with additive manufacturing of complex parts in small batches. One of the limitations from a commercial perspective is the size of the build chamber. Different elements of one component can be manufactured separately and welded subsequently. Thus, the size of the build chamber can be solved if additively manufactured parts are welded. Overall work done in the domain of welding of additively manufactured components is limited. Based on the above research gap, the current proposal objective is the Welding of AM-AM, AM-Wrought, and AM to Cast using solid-state and fusion welding processes (Friction Stir Welding, GTAW & LBW) for AlSi10Mg will be investigated.

	Scope: The scope of the project is to deliver the data set on behaviour of AM welded joints using fusion and solid state under different space environments. Thermal shock, Thermo Vacuum, Humidity tests will be investigated and its mechanical & metallurgical comparison with normal joints. **Anticipated Benefits:** Large complex designs can be developed using additive manufacturing process and subsequent welding process developed, this will help in mass optimization higher strength, manufacturing time reduction and meeting intricate design requirement of space payloads. This will be helpful in development of up to C Band Feed Cluster.
J1.3	**Development of CNT based blackest-black material for blackbody (SAC)** SAC is involved in the development of optical remote sensing payloads. These payloads involves space borne cameras working in infra-red (IR) and visible band. These on-board IR cameras do need in-orbit high-precision calibration regularly after a certain time period. The calibration is basically done with respect to a blackbody surface having ultra-high emissivity (>99.5%). The blackbody typically need to possess excellent temperature stability and uniformity along with ultra-high emissivity. Of late, Carbon Nano Tubes (CNTs) based coatings have provided remarkable light trapping properties in comparison with conventional ultra- black coatings. An array of 'vertically aligned nano tubes' creates a forest-like structure of aligned, equally-spaced, high-aspect-ratio carbon nanotubes. The spacing of the tubes is such that virtually all of the light arriving at the surface enters the spaces between the tubes and is absorbed after multiple reflections between neighbouring tubes. **Scope:** The scope of the proposed research includes development of vertically aligned CNT on the Aluminium substrate. This includes: - • Development of the technology for growing the vertically aligned CNTs on electrically conductive substrate preferably Aluminium alloy. • Surface emissivity performance evaluation and validation in MWIR and LWIR spectral regions (3-14 micro-meter wavelength) Space qualification, including shock, vibration, thermal cycling, outgassing, no particle fallout (PFO) and no significant mass loss. **Anticipated Benefits:** • Indigenous development of ultra-emissive black body surfaces. A customizable high quality blackbody source for in-orbit calibration for all IR based space missions.

<table>
<tr><th>J2</th><th>Sub Area</th><th>Research Areas in Quality Control of Electronic Systems (SAC)</th></tr>
<tr><td>J2.1</td><td colspan="2">

Defect Dataset Augmentation using Generative Adversarial Networks (GAN) (SAC)

Scope:

Deep learning algorithms have vast application in the field of automated inspection of electronics assembly. However, there capability are limited by the scarcity of training data. Defects datasets of electronics assembly exhibit Long Tail effect, i.e. the number of defect classes are more but the number of images in each class is less. To overcome these challenges traditional Image augmentation techniques such as image rotation, brightness/contrast variation, random cropping of images are incorporated but with limited success. Generative Adversarial Network have gained interest in the recent past due to their robust application in image augmentation techniques.

- The purpose of this project is to explore the application of different GAN architectures such as Conditional GANs, CycleGAN and Wasserstien GAN to generate high quality synthetic data of defects observed in electronics assemblies.
- To study the modifications that can be implemented in the GAN models to best suit the generation of data pertaining to electronic assemblies.
- Generate synthetic data that closely resemble the real data and augment the defect dataset to train deep learning model to automate the inspection process.

Anticipated Benefits:

Image augmentation using GAN will help in developing a more robust defect dataset that could be used to train deep learning models that can detect defects in electronics assemblies with high accuracy.

</td></tr>
<tr><td>J2.2</td><td colspan="2">

Automated High-Precision Measurement System for Substrates with DXF Comparison and Tolerance Analysis (SAC)

In space industry, precision and reliability are paramount. The substrates used in subsystems require precise dimensional verification to ensure optimal performance. This research aims to develop an advanced automated measurement system tailored for the substrates used in satellite electronic subsystems.

Scope:

➢ **Input Handling:**

- Upload high-resolution images of substrates in standard formats (e.g., JPEG, PNG).
- Import DXF files to define reference dimensions and design patterns.

➢ **Image Pre-processing:**

- Apply advanced noise reduction and contrast enhancement for clean inputs.
- Correct lens distortion, perspective skew, and align images for consistent measurement.

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</table>

	➢ **Object Detection and Measurement:** • Automatically detect multiple features on substrates, including length, width and other geometric details. • Accurately segment and measure features on complex or overlapping patterns. • Maintain measurement precision within ±3 micrometres using robust calibration techniques. ➢ **Tolerance Management:** • Provide an interface for users to define allowable tolerances for each measurement parameter. • Highlight measurements that fall outside the defined tolerance range. • Enable batch application of tolerances for similar patterns or dimensions. ➢ **Comparison with DXF Design:** • Extract reference dimensions from the DXF file. • Compare measured dimensions with the DXF specifications. • Report deviations, highlighting values exceeding tolerance limits. ➢ **User Interface:** • Design a user-friendly platform to upload images, import DXF files, and define tolerances. • Display annotated images with measurements and color-coded indicators for dimensions within or outside tolerance limits. ➢ **Reporting:** • Generate detailed Word or PDF reports, including: Annotated images of patterns with measured dimensions, Tabular comparisons of measured versus reference dimensions with deviation and tolerance analysis, Summary of compliance with defined tolerances. ➢ **Calibration and Accuracy:** • Incorporate a calibration process using known scale markers. • Ensure system maintains ±3 micrometre accuracy under defined operational conditions. **Anticipated Benefits:** ➢ **Efficiency:** Automates measurement, reducing inspection time, Fatigue and costs; with micrometre-level accuracy, meeting stringent quality demands and delivering reliability.

<table>
<tr><td rowspan="1">J2.3</td><td colspan="2">

Quality Inspection of RF/Electronics Hardware using Artificial Intelligence/Machine Learning Techniques (SAC)

Scope:

Defects in electronics hardware such as PCBs are characterized by smaller size, more diverse types and more complex features. As such many of the existing Deep learning algorithms cannot be readily applied to the task of detecting defects in electronics hardware. The aim of this project is thus to develop deep learning algorithms for detection of defects in relatively complex electronic/RF hardware trained on a defect dataset comprising of defect images taken at various magnification levels with diverse background and varying illumination level.

- Develop a deep neural network based algorithm to identify defects in electronics/RF hardware in real time as well as in offline scenario.
- Developed algorithm must be agnostic to the magnification level of the image, background of the electronic board, illumination intensity and size & location of defects and must be robust enough to identify micro defects with complex features.
- Explore the application of Transformer model and attention mechanism in the development of algorithm.

Anticipated Benefits:

Automating the quality inspection of RF/electronic hardware will reduce manual intervention and subjectivity. Improve the turnaround time by reducing the time required for inspection.

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<tr><td>J3</td><td>Sub Area</td><td>Design & Development of Automation for Deep Space Extravehicular Activities (SAC)</td></tr>
<tr><td>J3.1</td><td colspan="2">Long duration human space missions involve several maintenance tasks which need to be performed at regular intervals. These include solar panel inspection, structural integrity checks and other anomaly monitoring tasks. Extra-vehicular activities (EVA) require astronauts to exit the crew cabin in order to access the maintenance sites, which may be tens of meters away from the habitation zone. Owing to harsh sub-zero thermal and vacuum conditions in deep space, any sub-system failure while carrying out the above mentioned tasks, is extremely dangerous and may result in loss of human life. The present research proposes to explore the feasibility of novel remote controlled automation techniques which could substitute the astronauts in EVA by a customized robot mounted on a maneuverable platform which would travel to the maintenance site. This would ensure human safety in addition to system reliability, during extra-vehicular activities.</td></tr>
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	Scope: The scope of the proposed research includes design and thorough analysis of customized robot for automation of deep space extravehicular activities. This includes - • Establishing optimal control laws for various manoeuvre scenarios. • Simulating/ prototyping ground based pose stability and robotic arm maneuverability. • Simulating/ prototyping air based pose stability and robotic arm maneuverability. • Explore and document safe propulsion technologies for robotic automation. **Targeted outcome:** The following are the expected deliverables for the proposed research. • Demonstration and delivery of fully functional robot working on ground without human intervention. • Demonstration and delivery of fully functional robot working in air without human intervention. • Design, thorough analysis and simulation of fully functional robot mounted on a maneuverable platform for deep space usage. **Anticipated Benefits:** • Such Respond Proposals shall be useful in realisation of BAS (Bharat Antriksha Station), which ISRO has proposed. • This will reduce and may eliminate astronauts working directly in harsh sub-zero thermal and vacuum conditions in deep space, which is extremely dangerous and may result in loss of human life. This will also increase system reliability during extra-vehicular activities by substituting direct human intervention by machines.	
K	**Area**	**Cyber Services & Information Technology (SAC)**
K1	**Sub Area**	**Research Areas in Cyber Services and Information Security (SAC)**
K1.1	**Development of AI-based IT-Services (SAC)** **Scope:** • To develop a solution to automate IT-Service management activities using AI/ML techniques to support predictive maintenance. • To develop an AI-powered virtual assistants to provide IT-support and maintenance services to end-users. • To develop an end-to-end ticketing system for all IT-services support and maintenance. **Anticipated benefits:** • Effective and efficient dissemination of IT-services and provide insights & recommendations to improve the overall end-user satisfaction. • Aid in enhanced troubleshooting, auditing and real time monitoring.	

K1.2	**Development of Botnet Detection & DNS Security Solution (SAC)** **Scope:** • To develop techniques for identify and detect botnet activity on a network using AI/ ML techniques. • Implementation of various AL/ML detection techniques namely, host-based, behavioural-based and signature-based. • Implementation of GUI Dashboard for botnet activity alerts. **Anticipated benefits:** • Aid in monitoring and maintenance of the overall cyber services.
K1.3	**Development of Botnet Detection & DNS Security Solution (SAC)** **Scope :** • To develop a distributed & scalable Generic Log Analyser for collecting, storing, analysing and reporting the network devices, servers, desktops and software application events recorded as part of respective logs of different formats using AI/ ML techniques. • The large data sets for different log types will be analysed using data mining techniques without changing the core algorithms. • Implementation of GUI Dashboard for reporting the network events recorded as part of various server logs. **Anticipated benefits:** • GUI Dashboard for alert on specific events. • The developed software will be utilised for the purpose of system auditing and performance improvement activities. • Aid in monitoring and maintenance of the overall cyber services.
K1.4	**Establishing a Software Defined Network (SDN) (SAC)** **Scope:** • To establish a Secure & Scalable SDN Infrastructure. • To integrate SDN with the existing network infrastructure and protocols. • To develop standard programmability options for configuring and managing the network infrastructure. **Anticipated benefits:** • Enabling centralised management and orchestration of network resources. • Aid in faster troubleshooting, increased scalability and real time monitoring.

K1.5	**Development of AI-powered Email Security (SAC)** **Scope:** • To analyse emails from a human perspective, understanding context and intent behind every message. • To use Natural language processing (NLP) techniques that can detect sophisticated phishing attacks, spear phishing, and other types of email-borne malware that traditional security measures often miss • To perform sentiment analysis on emails to identify emotional cues that may indicate a potential threat or malicious intent. • To implement enhanced authentication which uses machine learning algorithms to analyse sender behavior, IP addresses, and other factors to verify the authenticity of incoming emails. **Anticipated benefits:** • Handling the cases where traditional security measures often miss • Enhancing security posture of Email which is the most accessible and critical IT service
K1.6	**Active Directory (AD) Security and Threat Detection (SAC)** **Scope:** • Passwordless authentication • Real-time monitoring and detection of suspicious activity within AD using AI/ML, such as tracking admin actions, policy modifications, group membership changes, abnormal logon patterns, privilege escalations, identity based attacks, etc. • Infrastructure as Code for AD: Managing AD configurations and policies. **Anticipated benefits:** • Aid in the security of Active Directory.
K1.7	**Development of Blockchain Identity Management (SAC)** **Scope:** • Development of a decentralised identity management based on blockchain based solutions. **Anticipated benefits:** • Aid for managing user identities in distributed environment.
K1.8	**Development of Data Analytics in Data Transfer and File Share Services (SAC)** **Scope:** • Data Analytics in Data Transfer Service such as average download size, total data transfer within a day, types of transferred files, etc and File Share Services such as logged in users, file share analysis, user quota usage, public/private shares, etc.

	Anticipated benefits: • Aid for monitoring and usage analysis in the data transfer and file share services. • GUI dashboard for the monitoring and management of services.
K1.9	**Design Vehicle Monitoring Surveillance System (SAC)** **Scope:** • To design a Vehicle Monitoring System (VMS) which shall track vehicle in-and-out movements using existing CCTV Surveillance System within SAC campuses. • System should record license plate numbers and store data in a database. **Anticipated Benefits:** • Help real-time reporting on vehicle. • Help in supporting emergency response and incident investigation efforts.
K1.10	**Design Head Count Surveillance System (SAC)** **Scope:** • To design a Headcount System using existing CCTV Surveillance System • It shall be integrated with existing Biometric Access Control System. • It should count number of staff entering & exiting the BACS peripheral gates. **Anticipated Benefits:** • Help real-time number of staff inside SAC Campuses. • Store head count data in a database for further processing.
K1.11	**Other cyber services and information security related topics includes (SAC)** • Breach detection and response solutions • Cryptography and cryptoanalysis • Indigenous hardware-based VPN • Kiosk for Virus/malware sanitisation • Malware Sandbox • Network Admission Control • Security of air-gap networks • Secured data flow between different trust networks • Secure cloud techniques • System Forensics • Perimeter and endpoint security • Progressive Web App (PWA) Service • Zero day vulnerability detection • Zero Trust Network Access

K2	Sub Area	Research Areas in Multimedia Technology and IT Services (SAC)
K2.1		**Development of AI-powered DocBot Solution (SAC)** **Scope:** • Create a chatbot that reads rule books like Service Rules, purchase manual, office orders, etc and answer the user's queries. • The system should extract and organise content from rule books using document parsing and NLP techniques. • Use natural language understanding and contextual search to retrieve relevant information, providing concise answers based on the user's queries. **Anticipated Benefits:** • Help users in getting clarifications about Promotion / Review / Leave / Pay-Scales, etc. • Help users to resolve their query related to indent, tender, procurement policy etc.
K2.2		**Development of AL/ML based automated Database Query System (Talk2DB) (SAC)** **Scope:** • Software to generate SQL from natural language, evaluate results, and produce reports/charts based on user requirement on-the-fly. • NLP module to parse user queries and normalize text. • SQL generation module to translate queries into equivalent SQL statements. • Query evaluation module to execute SQL queries and provide performance feedback. • Reporting module to extract data and generate reports in various formats. **Anticipated Benefits:** • Users can interact with databases using an intuitive GUI. • Users can quickly generate complex SQL queries without needing to code. • Insightful reports and charts enable data-driven decision-making. • Automated query evaluation reduces the risk of errors and improves query performance. • To simplify the database management tasks.
K2.3		**Development of Augmented & Virtual Reality System (SAC)** **Scope:** • To develop immersive interfaces that simulate real-world environments. • To develop overlapping digital information onto the real world for enhanced user experience with AI integration to support object recognition and tracking. **Anticipated benefits:** • To provide simulated and interactive experiences that reduces timeline and improves overall user experience.

K2.4	**Other IT services and multimedia related topics includes (SAC)** • Immersive visualisation • e-Learning platform • Animation technology • Multimedia content generation	
L	**Area**	**Mission Control (URSC/IISU)**
L1	**Sub Area**	**Reaction Sphere for S/C Attitude Control & Space Robotics Applications (URSC)**
L1.1	The growing demand for low-cost microsatellites and the upcoming deployment of LEO mega constellations with high requirements on precision attitude control and pointing will likely increase the need for development of high performance and low weight attitude control devices. The conventional reaction wheels are capable of providing single axial torque per device respectively uses a single axial motor. Therefore, it is difficult to reduce the weight and size of a spacecraft since at least three wheels are required to control three-axis attitude of a spacecraft. Reaction sphere enables three-dimensional rotation of a spherical rotor and provides three-dimensional torque so that mounting only one proposed device can be sufficient to control three-axis attitude of a satellite. To achieve the same performance of three reaction wheels, a reaction sphere is expected to consume less on-board resources Reaction sphere is an iron ball covered with permanent magnets and held in position with magnetic levitation through magnetic fields generated by a number of electric coils. The sphere, acting as a rotor, is accelerated about any axis of rotation with a 3D motor. • The magnetically suspended reaction sphere actuator is a type of angular momentum-based actuator. It uses magnetic bearings to suspend a single reaction sphere in a frictionless environment. The rotor is capable of rotating in any direction, providing 3-axis control of a spacecraft's attitude. The rotor is suspended by a series of permanent and electromagnetic poles that generate a magnetic field to levitate the sphere. The stator can drive and tilt the rotor through various methods. The mechanism has the unique capability of producing spherical angular momentum storage, which allows for more efficient and precise attitude control. Reaction spheres rotate spacecraft either with an equal-and-opposite torque about their rotation axis when accelerated about that axis, similar to reaction wheels, or with a more efficient gyroscopic torque used to reorient their rotation axis, similar to control moment gyroscopes (CMGs).	

	Compared to conventional reaction wheels and CMGs, reaction spheres can potentially generate higher torque and store more angular momentum for **lower SWaP** (Size, Weight, and Power), lower pointing jitter, longer mission durations due to the elimination of mechanical bearings and gimbal structures and the ability of the single reaction sphere to rotate the s/c about multiple axes. Involving many difficulties and challenges, reaction spheres are still promising actuators in spacecraft attitude control for the benefits brought by the 4π rotation. Reaction sphere has been used **in robotics for spherical joints** such as to mimic the wrist. Furthermore, technologies driven by research and development of reaction spheres also contribute **to robotics and automatic controls** where motions of joints are required. Reaction sphere can perform high torque maneuvers by rotating its spin axis while maintaining a constant spin rate. In addition, the torques generated in the reaction sphere around different axes are naturally decoupled, which will simplify the controller design. Requirements would be development of hardware and control algorithms as given below. **Part 1:** Realization of Hardware: Development of proto model of reaction sphere with actuation system • Geometry of the 3D motor on a magnetic bearing for the reaction sphere; In the ideal case 8 permanent magnets for the rotor and 20 coils for the stator. • The reaction sphere's rotor can be accelerated about any desired axis and moved in any direction continuously without any disruption using a 20-pole stator that produces an 8-pole rotating field. **Part 2:** Development of control strategy for microsatellite (100 kg class) attitude control through dynamic modelling and simulation with reaction sphere actuator.
L2	**Sub Area** — **Advanced Guidance Navigation and Control for Elliptical Orbit rendezvous and Docking (URSC)**
L2.1	The project requires research on advanced guidance, navigation, and control (GNC) strategies for rendezvous and docking (RvD) operations in elliptical orbits. The goal is to develop robust, adaptive algorithms to handle the dynamic challenges associated with elliptical orbit environments, such as varying velocities, gravitational perturbations, and increased orbital uncertainties.

	The research shall be conducted and demonstrated in two distinct phases: 1. **Low Eccentricity Orbit Phase:** Focus on developing and validating GNC algorithms for elliptical orbits with low eccentricity. This phase aims to establish baseline control strategies and navigation solutions that account for moderate orbital perturbations and dynamic constraints. 2. **High Eccentricity Orbit Phase:** Extend the developed solutions to highly eccentric orbits, where more significant variations in velocity and gravitational forces occur. This phase will emphasize adaptive control techniques and real-time navigation for precise trajectory correction and docking under extreme orbital conditions. Key objectives include: • Developing robust guidance algorithms to mitigate orbital perturbations. • Designing adaptive control strategies for real-time trajectory correction. • Formulating integrated solutions for accurate state estimation and navigation. • Validating the methodologies through high-fidelity simulations testing. The research outcome will contribute to critical space operations, including satellite servicing, debris removal, and interplanetary mission rendezvous.
L2.2	**Design and Development of Soft Robot for Terrestrial Planetary Exploration (URSC)** Planetary exploration is one of the most challenging tasks in the field of space exploration. In highly unstructured environments, soft robots can explore topographies using structural deformation. NASA has developed a pop-up flat-foldable robot for planetary surface detection. This robot can climb slopes or cross caves through folding deformation, providing significant mobility advantages. Traditional space robots primarily utilize rigid structures, resulting in limited degrees of freedom, which restricts their operational capabilities. Soft robots are made from compliant materials that are flexible and robust, making them ideal for tasks like grasping irregular objects, navigating rough terrain, and repairing equipment in space. Even though they are suitable to interact with dynamic and unpredictable space environments but, they should sustain low-gravity, ultrahigh vacuum environments, withstand extreme temperatures and space radiation. There is a need for the development of potential soft materials, identifying fabrication methods, appropriate design/modelling schemes, actuation and suitable sensors and control methods all in the frame work of soft robots. **Materials** are the basis for the fabrication, actuation, and control of soft robots. The soft materials used in conventional soft robots are often difficult to adapt to unstructured

	environments. Potential soft materials, such as liquid metal, temperature-resistant elastomers, and smart nanostructured protective coatings, offer several feasible options for future soft space robots. **Manufacturing** of parts in the space industry is small in quantity and highly customized. 3D printing techniques have been used to manufacture soft sensors, soft actuators, and even integrated soft robot systems. By precisely controlling the relative stiffness of each local unit, 3D-printed soft robots can achieve programmable deformation. 4D printing with extra time dimension, can fabricate structures that are time deformed using stimuli. **Design** of soft robots is extremely complicated due to nonlinear materials and multi physical field coupling. Soft robots with the ability to actively control stiffness allow for adaptable and versatile interactions between robots and space environments. **Modelling** has primarily focused on soft material modelling, deformation kinematic modelling, and flexible structure contact dynamics. Establishing a constitutive model for soft materials is the basis for understanding the kinematics of soft robots. **Actuation** using energy sources such as electricity, heat, and light. Smart material actuators have been used to actuate soft robots to perform tasks such as flight, crawling, capturing, and transportation. **Flexible** sensors have several advantages, including lightness, low energy consumption, and adjustable mechanical properties, which make them easier to integrate in soft space robots. Flexible sensors based on nanomaterials have been widely used to measure suitable parameters for their control. **Control** of soft robots can be classified into model-based and model-free methods depending on whether the control system contains a mathematical model of the controlled process. The current proposal is for demonstrating a soft robot for planetary exploration as terrestrial vehicle. The research should identify suitable material that meets the space requirements, identify an appropriate fabrication method, define a design methodology with relevant constitutive model of the material for its characteristics, simulate the deformation kinematics and contact dynamics and demonstrate the smart actuation of the soft robot along with the flexible sensors and control technique. The research work identified is multi domain and multi physics problem, the work should yield the proof-of-concept demonstration of a soft robot as a terrestrial vehicle for space exploration requirements. Multiple proposals can be proposed in the various sub-topics which can be inter disciplinary also.

L3	Sub Area	Space robotics and AI (IISU)
L3.1	1. **Dynamic modeling and simulation;** This includes flexibility studies, rover control algorithms for area control and capture control. 2. **Guidance and control of free flyer, space robots;** This will include modeling of orbital dynamics and space free flyer dynamics 3. **AI based object grasping and manipulation in space environment;** This includes Collaborative manipulation tasks, parameters identification of non-co-operative targets.	
M	**Area**	**Communication and Power Area (URSC)**
M1	**Sub Area**	**Optical Homodyne Receiver For Data Transmission System Supporting 10 Gbps (URSC)**
M1.1	The increased demand for high data rate satellite links has resulted in migration from microwave frequencies to optical frequencies. Optical frequencies offer advantages such as: • Large bandwidth • Unregulated spectrum availability • High directionality of signals leading to reduction in transmitted power • Greater immunity to interference While several optical domain techniques have been gainfully employed for terrestrial communication, the usage of optical technology to satellite links has been largely limited to On/OFF Keying. Development of an Optical Homodyne Receiver for enabling detection of digital phase modulated optical signals can improve the efficacy of the optical data transmission system, as established in literature. Design and realization of an Optical Homodyne Receiver and associated technologies for supporting satellite data transmission at rates of 10 Gbps and beyond forms a problem of interest to Communication Systems of several satellites. The problem can encompass broader areas such as study of atmospheric effects on optical signal transmission and corresponding mitigation techniques, study and development of optimum modulation techniques for optical data transmission from satellites to ground, techniques for improving the robustness of optical satellite links etc.	
M1.2	**Development of pre-distortion algorithm for variable modulation/coding -based system with amplitude/phase non-linearity (URSC)** The pre-distortion algorithm for the transmit channel becomes much more complex when the modulation and coding schemes become variable. Further to this taking care of amplitude and phase non-linearity adds to the design complexity. Design of these algorithms to support various types of devices operating at different frequencies is essential to use the channels at maximum efficiency.	

M1.3	**Simulation and modelling of multipath reflection for future landing missions (URSC)** The multipath reflection from various surfaces may cause an issue for the landing missions at various planetary bodies. The multipath may distort the radiation pattern coming to the ground station disrupting the radio channel. An accurate model for this will help in the antenna accommodation study and operations for future landing missions.	
M1.4	**Development of algorithms to predict the gravitational field of small bodies using radio occultation system (URSC)** Radio occultation payloads are passive technologies which is used to estimate, temperature, pressure, electron content, vapour pressure profile with the help of precise electronics packages. These payloads may be used to estimate the gravitational field of planetary bodies to create a gravitational map. These may be created using two-way radio occultation along with inter satellite system to avoid earth's ionospheric disturbances. These technologies will be helpful in future landing missions for less known bodies.	
M1.5	**Miniaturised Diplexers at UHF band (URSC)** On MARS surface, in-situ communication between lander, rover and orbiting satellites require UHF transceivers. URSC is involved in the design and realisation of these transceivers. To have seamless connectivity among them, their high power transmitter and highly sensitive receiver are requiring to be isolated sufficiently. UHF transceivers operate with 5-10MHz bandwidths in 400 MHz – 440 MHz band. To have a common antenna for simultaneous transmission and reception, it requires a diplexer with at least 90 dB isolation between transmitted and received signals. The proposed diplexer is expected to perform normal under Martian environment under the influence of 20 Watts (CW) of RF power. Miniaturized diplexer with less than 500 grams in weight is expected to have an insertion loss of less than 2dB and return loss of at least 15 dB.	
M2	**Sub Area**	**Battery (URSC)**
M2.1	**Space qualified Li-ion cell of wide operating temperature range with high cycle life (URSC)** Li-ion cells have limited temperature especially when used with large number of charge-discharge cycles (say, 50,000). A Li-ion cell which works between -40 to +70dgC while supporting large cycles will enable compact battery designs & suitable for harsh environments of other planets.	
M2.2	**Remaining Useful Life (RUL) model replacing life cycle tests for space application of li-ion cell (URSC)** Space application of Li-ion cell starts after sufficient life cycle data from tests running for few years. A model for RUL for the cells which replaces life cycles with highly reliable prediction will pave the way for the use of state-of-the-art cells with immediate effect.	

M2.3	**Generic Chemical modeling of Li-ion cell for the non-nominal conditions (URSC)** The space application needs to use the cell with life cycle data without exposure to launch & post-launch environmental conditions. Certain amount of overcharge/over discharge may be seen under anomalous conditions. The model needs to estimate the performance over life after aforesaid exposures.	
M3	**Sub Area**	**Advanced Power Technologies (URSC)**
M3.1	**Integrated Power modules for space applications (URSC)** Control, power switch & protections integrated into one package/chip leading to miniaturization and simplifying the design.	
M3.2	**Anisotropic Magneto resistive current sensor (URSC)** Contactless current sensor with good sensitivity, accuracy , low power consumption.	
M3.3	**PCB interconnection connectors (URSC)** Space qualified Connector (plug/socket) to connect PCBs without usage of Motherboard for signal and power.	
M3.4	**Isolated High voltage high current dc/dc (URSC)** 40-50V output, 12-10A isolated dc/dc for powering user systems using analog control.	
M3.5	**PCB embedded passives (URSC)** Embedding passive components like resistors, capacitors and cores inside PCB to improve the power density.	
M3.6	**SiC devices for space application (URSC)** Silicon carbide based devices can operate at higher voltages, higher temperatures and higher frequencies and can hence simplify the thermal management.	
M4	**Sub Area**	**Power Converter (URSC)**
M4.1	**Digitally controlled dc-dc converters (URSC)** Conventional converters draw current even when the load is not connected to them. This results in power loss & generated heat. Digital control aimed at turning OFF the converter when there is no load connected, will result in power saving to a great extent.	
M4.2	**3D integration techniques for dc-dc converters (URSC)** Traditional converters involve multiple components which lead to larger form factor and lower efficiency. 3D integration aims to overcome these limitations by bringing components closer together in vertical structure.	
M5	**Sub Area**	**Power Electronics (URSC)**
M5.1	**High Current & High Voltage IGBT development for space application (URSC)** IGBTs are ideal devices for power electronic applications related to power grid protection and high current solid state relay. Space qualified IGBTs are currently not available. This development can find applications in future missions like BAS.	

M5.2	**Development of Power MOSFET with in-built isolated gate driver and logic level interface (URSC)** Availability of such a device can greatly bring down the challenge/complexity in designing a reliable power electronic converter/ inverter. Most of the implementation challenges are related to the MOSFET drive circuitry.	
M5.3	**Space qualified Pseudo Capacitor development (URSC)** These are energy storage devices which packs very high energy as well as power density. Very useful for satellite power bus, which demands huge power for few hundreds of milliseconds, like in high resolution radar imaging satellites. Pseudo capacitors can be used as a distributed energy/power storage device enhance the supply power density of the bus.	
M5.4	**Space qualified PB embedded heat pipes & flexible plus stick able heat exchange ribbons/ heat pipes (URSC)** These will be very useful in increasing the power density of all power electronics converters by enhancing the conduction of heat from highly dissipative devices to the ambient/base.	
M5.5	**Piezo Electric Power Inductors (URSC)** These are piezo electric crystals developed specifically to act as inductors in power circuits. These can be a production friendly and compact replacement for inductors in power electronic converters.	
N	**Area**	**NavIC Ground Segment Related Research Works (ISTRAC)**
N1	**Sub Area**	**Atomic Clock-Navigation Related Technology (ISTRAC)**
N1.1	**Piezo electric Power Inductors (URSC)** Modern hydrogen masers are designed to compensate for temperature sensitivity through the use of a precision thermal control system. In many masers, a precision feedback thermal control system compensates for the effects of cavity pulling. In order for the microwave cavity to maintain resonance with the hydrogen transition frequency, the cavity must maintain tight volumetric tolerances. Fluctuations in the ambient temperature can cause the cavity to expand and contract. Thus, the thermal control system is responsible for actively regulating the temperature of the cavity such that ambient temperature perturbations do not alter the resting temperature of the cavity. By maintaining a temperature set-point, the cavity maintains a fixed volume and the resonance characteristics are not changed in spite of ambient temperature fluctuations. Therefore, the frequency stability achieved by the maser is directly associated with the performance of its precise thermal control system.	

N2	Sub Area	NavIC Time and Frequency Dissemination (ISTRAC)
N2.1	**Low Noise Time & Frequency Transfer using optical medium (ISTRAC)** Time and frequency transfer plays a crucial role in the field of Navigation and positioning. Precise timing facilities (PTF) generate the system time for the NavIC constellation which are co-located with the Navigation Control Centers (NCC) where time and frequency is disseminated. A low-noise frequency transfer technology using optical fibers to achiever ultra-stable frequency dissemination over long distances will be developed. The system is based on high stability and low attenuation of optical signals, using ultrastable laser sources, advanced modulation and demodulation techniques, and active noise cancellation methods. The developed system shall achieve minimum transfer noise and maintain high frequency stability better than 10-14 @ 1sec over long distances. This technology shall be used for precise NavIC time and frequency transfer applications.	
N2.2	**Design and development of mitigation techniques for in-band interference due to 5G signals (ISTRAC)** IRNSS CDMA Ranging (IRCDR) stations are operating in the frequency band of 3400MHz to 3425MHz. 5G services have been rolled out across India in the frequency band of 3370 MHz - 3470 MHz. This frequency band includes the frequency band allocated for IRCDR stations. The 5G services causing in-band interference to the IRCDR stations, and interrupting its normal operations. To ensure the uninterrupted operations of the IRCDR stations, there is a need for developing an in-band interference mitigation technique.	
N2.3	**Design and development of multipath mitigation techniques and algorithm using advanced correlators in baseband signal processing (ISTRAC)** Multipath can be mitigated at antenna level, signal design level, baseband signal processing and at navigation data processing. The proposal is to design and develop advanced correlator technologies in order to detect multipath signals and mitigate the impact so that the receiver doesn't lose the lock even in high multipath area.	
N2.4	**Development of post processing software for precise positioning using NavIC triple frequency measurements (L1, L5 and S) (ISTRAC)** At present, NavIC L1, L5 and S band signals are available for positioning, navigation and timing services in Indian region. This research proposal aims for the development of post processing software engine to estimate the precise position of a surveyed location using NavIC RINEX data. The software shall be able to provide solutions using single point positioning and differential based positioning method.	
O	**Area**	**Radar Systems (ISTRAC)**
O1	**Sub Area**	**Photonic Systems (ISTRAC)**
O1.1	**Design and development of Photonic Transmitter (ISTRAC)** The design of photonic transmitters for radar systems represents a critical frontier in radar technology, offering transformative advantages in terms of bandwidth, power	

	efficiency, and signal integrity. The objective of this proposal is to study and design Photonic Transmitter for Radar applications. The following are the problem statements: • Study of different Photonic techniques for RF Signal generation • Study of different modulation techniques like Optical Heterodyning/photomixing, direct modulated laser technique, modelocking technique. • Design of basic RF generating equipment like Electro-optic MachZehnder Modulator, Multiplexer, Optical Amplifier and high-speed photodiode. • Configuration of the Basic Lineup of a Photonic Transmitter with above modules. • Develop a low-cost, bench-top, lab based proof of concept of a Photonic transmitter.	
O2	**Sub Area**	**Antenna Systems (ISTRAC)**
O2.1	**Metasurface antenna for adaptive beamforming (ISTRAC)** Meta-surfaces have revolutionized electromagnetic (EM) wave manipulation by offering unprecedented control over wave propagation and other forms of EM radiation. These planar structures are composed of sub-wavelength unit cells, which impart desired phase, amplitude, and polarization responses to incident EM waves. By engineering these properties at the sub-wavelength scale, metasurfaces provide remarkable flexibility in shaping EM wavefronts, making them pivotal technology in areas such as optics, photonics, and communications. One of the key applications of digital coded metasurface antennas is in beamforming, where the direction of the main lobe of the radiated beam is controlled to focus energy in a specific direction. Typically, the inputs of the desired beam direction parameters, such as azimuth and elevation angles, are provided to the FPGA, which processes them using algorithms based on Fourier transforms, phase gradient techniques, or other optimization methods to determine the optimal digital code sequence for the entire metasurface. In the next stage, the FPGA communicates with the metasurface via digital-to-analog converters or directly through digital control lines, updating the bias voltages to the integrated electronic components. As a result, the entire metasurface reconfigures its EM response, enabling beam steering or even simultaneous multi-beam operation. Thus, the potential benefits of digital coded metasurface antennas are enormous. Their ability to rapidly adapt to changing operating states and perform multiple functions within a single device makes them particularly attractive for next-generation radar applications.	
O2.2	**MEMS based Joule Thomson Cryo-Cooler (ISTRAC)** The need for MEMS-based Joule-Thomson cryogenic systems in radar applications arises from the increasing demand for compact, lightweight, and energy-efficient cooling solutions to enable advanced radar functionalities. MEMS-based cryogenic systems address these challenges by leveraging microscale components and efficient thermodynamic processes to deliver precise and reliable cooling performance within a compact footprint.	

	• To Design, Analyze, Fabricate, Integrate and Testing of MEMS based Closed Loop Joule Thomson Cryo-cooler for electronic device cooling (LNA). • Design, fabrication and Testing of MEMS based Joule Thomson Cryocooler. • Micro-cooler, which is capable of generating 1W Cooling Power using Nitrogen (at 77K). • Multi stage Cryo-cooler for lower temperature less than 77K • Analyzing and implementing Cryogen mixtures for reducing the inlet pressure • Identify and Integrate the MEMS cooler with total system for cryogenic closed loop cooling system. • Testing and Evaluation.	
O3	**Sub Area**	**Radar Signal Processing (ISTRAC)**
O3.1	**Waveform designs that can resolve target masking (which is due to difference in range and rcs) and range coupling (which is due to high velocity of debris) (ISTRAC)** Effective waveform design can mitigate this by shaping the transmitted signal to enhance the separation between closely spaced targets or those with differing RCS values. Waveforms with high range and Doppler resolution help to resolve target masking by providing better separation between targets in both range and velocity. Pulse compression is a key waveform design strategy to overcome target masking by improving range resolution without increasing pulse duration. Using long-duration pulses modulated by frequency (chirp) or phase can compress the pulse in time, offering finer range resolution and distinguishing targets with different RCS or range. Adaptive waveforms can dynamically adjust their parameters, such as pulse width, frequency, and modulation scheme, based on realtime radar measurements. Target masking by encoding the radar return from different targets, even when they are located at similar ranges or exhibit different RCS. UWB waveforms provide extremely wide bandwidth, enabling high-resolution imaging of targets. These waveforms are ideal for resolving target masking and range coupling because they allow the radar system to detect small differences in both range and velocity, even in environments with high clutter or rapidly moving debris. By transmitting multiple, independent waveforms from different antennas, MIMO radar increases the chances of distinguishing targets with different RCS or velocities, even in complex environments with closely spaced or high-speed debris.	
O3.2	**Design a sparse array configuration for large antenna arrays by using optimization algorithms (ISTRAC)** Sparse array design is to minimize the number of antenna elements and the physical aperture size without sacrificing performance. Sparse array designs use optimization techniques to distribute antenna elements in a way that reduces side lobes, keeping them below a certain threshold while ensuring that the main beam remains focused.	

	array design algorithms aim to maximize directivity by optimizing the antenna positions so that energy is concentrated in the desired directions. Sparse arrays, when designed properly, can minimize scan loss by optimizing element spacing and distribution across the aperture, ensuring that the array maintains a consistent radiation pattern over a wide scanning range. The spacing between antenna elements is too large relative to the wavelength, leading to false beams. The sparse array design by simulating the radiation pattern, side lobes, directivity, and other performance metrics. The number of elements with the need for low side lobes and minimal grating lobes. Sparse array designs are particularly useful in real-world applications where space, weight, and cost constraints are significant, such as in satellite communication systems or radar networks. Using optimization techniques and EM simulations ensures that these sparse arrays provide robust performance, even in challenging environments, while minimizing the impact of side lobes, scan loss, and grating lobes.
O3.3	**Sparse MIMO RADAR DOA estimation and Beam forming Algorithms for real time applications (ISTRAC)** The sparsity allows for improved performance in terms of spatial resolution and signal processing efficiency. Sparse MIMO systems benefit from reduced element counts without significantly sacrificing the accuracy of DOA estimates, achieved through advanced algorithms. Beamforming in sparse MIMO radar involves steering the antenna array's radiation pattern towards specific directions to improve target detection and tracking. CS algorithms exploit the sparsity of the signal to reconstruct the full array response, offering better performance with fewer antenna elements. Realtime DOA estimation in sparse MIMO radar requires algorithms that can quickly and efficiently compute target angles, even under dynamic conditions. Sparse MIMO radars often operate over wide frequency bands, and wideband DOA estimation allows them to estimate target directions more accurately by utilizing the frequency diversity. Cognitive beamforming in sparse MIMO radar allows the system to adapt its beamforming strategy based on real-time feedback about environmental conditions and interference. The real-time applications of sparse MIMO radar demand low-complexity algorithms to minimize computational overhead while still achieving high accuracy in DOA estimation and beamforming.
O3.4	**MIMO and Sparse array automated calibration Algorithms (ISTRAC)** Calibration is critical in MIMO and sparse array radar systems to ensure that the system operates with high accuracy and minimal errors. It involves compensating for imperfections in the antenna elements, signal paths, and other system components that could affect the signal quality, such as phase shifts and amplitude mismatches. Sparse arrays typically have fewer antennas than traditional full arrays, making calibration more challenging due to irregular spacing and potential mutual coupling between elements.

	MIMO radar systems involve multiple transmit and receive antennas, making real-time calibration crucial for accurate direction-of-arrival (DOA) estimation and beamforming. Self-calibration methods are widely used in MIMO and sparse arrays, where the radar system uses known reference signals or target information to automatically correct for misalignments and errors. Phase and amplitude calibration is essential for ensuring that signals from all antenna elements are coherently combined. Automated algorithms use reference signals or feedback loops to adjust the phase and amplitude of each element in real time, ensuring the array operates as a coherent whole and improving performance in applications like DOA estimation and beamforming. In sparse arrays, mutual coupling between elements can cause interference and performance degradation. Automated calibration algorithms can detect and compensate for these effects by modeling the coupling between adjacent antennas and adjusting the signals accordingly to minimize their impact on the radar system's performance. Adaptive calibration algorithms allow MIMO and sparse arrays to adjust their calibration parameters over time as the environment or system performance changes. Each sub array or antenna group can perform local calibration, and the results are aggregated, allowing for efficient and scalable calibration across large arrays with minimal human intervention.
O3.5	**Mitigation of Non-linear receiver effects through signal processing techniques (ISTRAC)** Non-linear effects in receivers occur when the input signal amplitude exceeds the receiver's linear operating range, leading to distortion such as harmonic generation, intermodulation, and clipping. Linearization methods aim to reduce the distortion caused by non-linearities by using compensation algorithms, such as memory polynomial models or digital predistortion (DPD). Non-linear channel estimation techniques estimate the channel impairments caused by non-linearity in the receiver. These methods use training sequences or pilot signals to model and compensate for non-linear distortions, helping to restore signal integrity and improve detection performance. By isolating and processing the components affected by non-linearity, this technique helps to filter out unwanted distortion and retain the original signal's essential features. Digital predistortion (DPD) is a widely used technique in mitigating non-linear distortion, where a model of the non-linear receiver is used to generate a predistorted signal that cancels out the distortion. By applying the inverse of the non-linear behavior before transmission, DPD ensures that the received signal is less affected by non-linearities. These models learn the complex, non-linear relationships between the transmitted and received signals and can effectively compensate for distortions caused by non-linear receivers, improving the system's overall performance.

O3.6	**Antenna Array Signal processing algorithms for DSN Array (ISTRAC)** The Deep Space Network (DSN) is a network of large radio antennas used for communication with spacecraft in deep space. Antenna array signal processing algorithms are crucial for enhancing the reception of weak signals from distant spacecraft, overcoming challenges like noise, interference, and Doppler shifts. Doppler shift is a significant effect in DSN communications due to the relative motion between the spacecraft and the ground station. Signal processing algorithms are employed to compensate for these shifts in frequency, allowing for accurate demodulation of signals despite the changing relative velocities. Deep space communication often involves very weak signals with low signal-to-noise ratios (SNR). Detection algorithms, such as matched filtering or Maximum Likelihood Detection (MLD), are used to enhance signal detection in these low-SNR conditions by maximizing the likelihood of correctly interpreting the received signal. MIMO signal processing algorithms are employed to increase the communication capacity of DSN arrays. By utilizing multiple antennas to transmit and receive signals simultaneously, MIMO techniques can enhance the data throughput and reliability of the system, especially in conditions with high noise or fading. Channel estimation is essential for accurate signal recovery in DSN systems, as the transmission medium between the spacecraft and ground station can vary significantly. Accurate time and frequency synchronization between the DSN ground station and spacecraft is crucial for coherent signal processing. Techniques like Kalman filtering or extended Kalman filters (EKF) help track the spacecraft's position and velocity, enabling the system to adjust the array's beam direction in real time, ensuring continuous communication with minimal dropouts.	
O4	**Sub Area**	**Antenna Array Design (ISTRAC)**
O4.1	**Antenna Array design for DSN & Distributed antenna Array optimization and EM simulation (ISTRAC)** The DSN antenna array design is critical for ensuring reliable communication with spacecraft over vast distances. High gain and directivity are essential in DSN antenna arrays to focus energy toward distant spacecraft, improving signal reception. Array design techniques like parabolic reflector or phased arrays are used to achieve high gain and steerable beams for precise tracking of spacecraft. Minimizing side lobe levels and avoiding grating lobes are crucial for maintaining high-quality signal reception and preventing interference from unwanted sources. Optimization algorithms adjust antenna placement to minimize side lobe power while maintaining main beam integrity, ensuring clean communication with spacecraft. Beamforming algorithms optimize the radiation pattern of the antenna array to focus on the spacecraft's direction. EM simulations are essential in antenna array design to model how the array interacts with electromagnetic waves, ensuring it performs as expected in real-world conditions.	

	Through EM simulations and optimization, the design can be fine-tuned to maintain consistent performance across the required frequency bands without sacrificing beamforming or directivity. EM simulations ensure that all antennas in the array work in harmony, with consistent time and phase alignment, improving signal quality and reducing errors in communication. Through distributed antenna array design and optimization techniques, large, efficient arrays can be implemented with fewer physical components, while EM simulations guide the design to meet performance metrics such as directivity, side lobe suppression, and low grating lobes.	
O4.2	**Achieving High Combined SINR in the presence of RFI and spatially correlated interference from planets (ISTRAC)** High SINR leads to better signal clarity and reliable data transmission, which is crucial for deep space communications or satellite networks operating in challenging environments. RFI (Radio Frequency Interference) occurs when unwanted electromagnetic signals from terrestrial sources, satellites, or even planetary bodies interfere with the desired communication signals. This interference reduces SINR and can degrade system performance, making it essential to implement strategies for mitigating its impact. Spatially correlated interference this interference is often difficult to mitigate due to its broad spectral coverage and correlated nature, which makes it challenging to separate from the desired signal. By steering beams toward the spacecraft and away from sources of RFI and planetary interference, beamforming increases the received signal strength while minimizing interference. Space-time processing methods, such as MIMO (Multiple Input Multiple Output) or spatial diversity, allow for the exploitation of spatial correlations in the interference signal. By using multiple antennas at different spatial locations, these techniques help in improving SINR by separating the desired signal from spatially correlated interference sources, including planetary emissions. Polarization techniques utilize the different polarization properties of the interfering and desired signals to improve SINR. By designing antennas that can selectively receive signals based on polarization, the system can reduce interference from RFI and spatially correlated planetary signals that may have different polarization characteristics.	
O5	**Sub Area**	**Deep Space Systems (ISTRAC)**
O5.1	**Signal processing for Deep space communication (ISTRAC)** The primary challenge is maintaining signal integrity despite issues like high noise levels, Doppler shifts, and signal degradation due to the large distance between spacecraft and Earth. Signal processing algorithms, such as matched filtering and error correction coding, are crucial for improving SNR and enabling the recovery of weak signals amidst background noise and interference. Equalization techniques like adaptive filters or decision feedback equalization (DFE) are used to mitigate distortion and recover the transmitted signal with minimal degradation.	

	These coding schemes help detect and correct errors introduced by noise or interference, ensuring data integrity even in challenging deep space environments. This improves signal strength and reduces interference, ensuring that the signal is received with minimal distortion, even in the presence of noise and interference. Deep space communication can experience interference from various sources, such as terrestrial RFI (radio frequency interference) and galactic noise. Adaptive filtering and interference nulling techniques are used to suppress these unwanted signals, allowing the system to focus on the target spacecraft signal.	
O5.2	**DSN Array Automated Calibration under atmospheric turbulence over the array (ISTRAC)** The Deep Space Network (DSN) comprises large antenna arrays used to communicate with spacecraft in deep space. Accurate calibration of these arrays is essential for maintaining high-quality communication, especially in the presence of environmental disturbances such as atmospheric turbulence. Atmospheric turbulence refers to variations in the atmosphere's refractive index caused by temperature and pressure changes. This turbulence distorts the received signals, leading to phase errors, signal degradation, and reduced communication. Automated calibration is crucial for maintaining consistent performance in the DSN arrays, especially under variable conditions. Atmospheric turbulence can introduce phase errors and amplitude fluctuations in the received signal. Automated calibration algorithms continuously adjust the phase and amplitude of individual antenna elements to correct these errors, ensuring the integrity of the received signal from the spacecraft. Beamforming is highly sensitive to phase shifts and amplitude changes caused by atmospheric turbulence. Adaptive algorithms, such as LMS (Least Mean Squares) or RLS (Recursive Least Squares), are used for real-time turbulence compensation in DSN arrays. By constantly analyzing signal quality and applying correction algorithms, the system can adapt to atmospheric turbulence and maintain optimal performance throughout the communication link.	
O6	**Sub Area**	**LEO/MEO/GEO Satellite Constellation for Drone Warfare (MCF)**
	Drones, or Unmanned Aerial Vehicles (UAVs), have become an integral part of modern military operations. Initially developed for reconnaissance and surveillance, drones have evolved into versatile platforms capable of executing various missions, from intelligence gathering to precision strikes. However, the full potential of UAVs is realized when enhanced with satellite connectivity, removing the limitations of traditional line-of-sight or terrestrial-based communication, and enabling real-time communication and coordination across vast distances and hostile environments.	

	A satellite constellation for drone warfare enables long-range, reliable communication and navigation, crucial for tasks like intelligence gathering, real-time video streaming, and Beyond-Visual-Line-Of-Sight (BVLOS) operations, even in GPS-denied environments. Satellite communication enables coordinated swarm operations, where multiple drones work together to accomplish complex missions. The future deployment of UAVs in military operations only looks to increase with advancements in artificial intelligence (AI), swarming technology, and autonomous decision-making being key growth drivers. For instance, satellite-connected AI-powered drones, capable of identifying targets autonomously, making decisions in combat scenarios, and communicating with other drones, is the need of the hour. All of these technological advances will require the reach and reliability of remote satellite connectivity to execute on a global scale. Following are the research areas 1. LEO/MEO/GEO constellation design for UAV communication with inter satellite links. 2. Security Protocols Development for UAV communications. 3. Smart Antennas on UAV for satellite communications and inter swam communication. 4. Drone Operations in GNSS signal denied Environment i.e. Jamming and spoofing conditions.	
07	**Sub Area**	**Passive Ranging System (MCF)**
	The ESA & ESA-Like tone ranging is the most widely used conventional ranging scheme which is a based on the sequential transmission of tones to determine the slant range from the earth station to the spacecraft. This ranging method requires the active transmission and reception of the ranging signal via a dedicated ground system, ground-space link, and dedicated transponder. Moreover, if there are more number of co-located spacecraft in a given longitude, the current ranging system is not able to cater the requirement to carry out the ranging at a given rate and accuracy. Ranging operation planning, allocating earth station resources, and integrating multiple stations for better ranging accuracy are the points that need further consideration when carrying out ranging with such a conventional approach. The Passive ranging based ranging determination is an alternative to the active and semi-active tone-ranging system. This technique works on the I/Q data correlation where some RF signal (usually telemetry signal radiated from spacecraft) is captured by the RF sensor placed at different geographically separated earth stations at the same time and later correlation is performed between the captured signals. This technique has the following advantages over the other alternate-ranging system:	

	• Requires only RF sensors at receive path with reduced complexity. • The lack of active transmission eliminates the risk of interfering with the other satellites. • High-rate measurement guarantee immediate maneuver detection. • Continuous data collection and hence continuous spacecraft tracking in all weather conditions. Improves space-situational awareness (SSA). • No demodulation or decoding is needed to process the range data as opposed to the tone-ranging system. • The passive ranging approach offers an "always on" ranging approach. Ranging measurements run in the background, continuously and independently from the rest of the spacecraft operations. **The research areas** 1. System design which correlates the down link signal collected at geographically separated sensors. 2. Timing synchronization of geographically separated sensors for accurate TDOA measurements. 3. Accurate Orbit determination with the TDOA measurements.	
P	**Area**	**Satellite Communications/Spacecraft Operations (LEOS)**
P1	**Sub Area**	**Satellite Health Monitoring (LEOS)**
P1.1	**All Fiber Magneto-Optic Current Sensor (AFMOCS) (LEOS)**	
Q	**Area**	**Satellite Communications/Electro-Optical Sensor Technology (LEOS)**
Q1	**Sub Area**	**Alignment and Co-phasing of Segmented Optics (LEOS)**
Q1.1	**Position sensor for precision alignment of segmented mirrors (LEOS)**	
Q1.2	**Segmented telescope mirrors co-phasing scheme for near-diffraction limited performance (LEOS)**	
Q2	**Sub Area**	**Development of in-situ Aspheric Profile Measurement Systems (LEOS)**
Q2.1	**In-situ aspheric profile measurement setup for high-precision telescope mirrors (LEOS)**	
Q3	**Sub Area**	**Lasers, LiDARs and Laser Spectroscopy (LEOS)**
Q3.1	**Development of high-energy pulsed fiber lasers (LEOS)**	
Q3.2	**3D-imaging flash LiDAR (LEOS)**	
Q3.3	**Development of a handheld LIBS-based analytical instrument for agriculture applications (LEOS)**	

EARTH OBSERVATIONS

A	Area	Geoscience (IIRS / NESAC / NRSC / SAC)
A1	Sub Area	Cryospheric Studies (NESAC / SAC)
A1.1	**Himalayan snow (SAC)** SAC has been generating sub-basin wise snow cover products database using Advanced Wide Field Sensor (AWiFS) data since 2004 in the Himalayan region. These products are the best available time series snow cover products having fine spatial and temporal resolution so far in the world. INSAT-3D/R/S provides daily snow cover products at India Meteorological Department (IMD) from geostationary platform. Snow products have been used in snow melt runoff estimations, in understanding of accumulation and ablation pattern of snow in different climatic zones of HKH region, and in assessing the snow cover trends to ever-changing climate. However, there are important challenging areas where research is needed to address cryosphere studies. These are estimation of annual seasonal snow mass using photogrammetric/interferometric and scattering mechanism using PolSAR data. Snow parameter retrieval (s.a. snow density, wetness, SWE) using SAR/Hyperspectral data, Radiative transfer modelling and role of snow parameters in climate model will be helpful to understand the impact of climate on Himalayan mountains. Disaster applications such as Avalanche, GLOF etc. are other crucial areas of research. Development of snow-melt runoff at high altitude area, suitable site selection for micro hydroelectric projects using geospatial modelling and real time assessment of discharge for Indian rivers using satellite data are important in the field of surface hydrology.	
A1.2	**Himalayan glaciers (SAC)** Inventory and monitoring of Himalayan glaciers within periphery of IGB basins has been a foremost requirement of our nation to know the stock of glacier stored water, and variations in dimensions of glaciers as an impact of climatic variations. SAC has carried out extensive work in this direction using data from Indian sensors such as AWiFS, LISS III and LISS IV of Resourcesat series satellite. The glacier inventory in IGB basins is available at VEDAS portal of SAC for visualization. However, automatization of glacier feature extraction and change detection from space platform in Himalayan region are the research areas to be addressed. Glacier mass balance is important to assess the status of their current response to climate change, and requires improvement in estimates to minimize the uncertainty. Major research domain in mountain glacier region includes geodetic mass balance estimation with field validation at sub-basin scale using Cartosat-1 & future stereo mission, improvement in Accumulation Area Ratio (AAR) and Mass Balance relationship in HKH region, retrieval of ice velocity, snow/ice facies using SAR/PolSAR data, understanding the glacier dynamics, Regional Climate model for future projection, GLOF risk assessment, and impact assessment on cryospheric elements in different scenarios.	

A1.3	**Himalayan Permafrost (SAC)** The permafrost is very important element of Cryosphere studies. The distribution and changes occurring at permafrost in the mountainous HKH region as a result of climatic variations needs to be known in view its importance to ecology and land cover changes. Exploration of Permafrost might give new insights to high altitude environmental changes through optical, thermal and active microwave data. Estimation of permafrost zonation, geomorphological signatures, degradation and interaction with SAR/PolSAR data are essential to understand the dynamics of permafrost in high altitudes of HKH region to assess the impact of climate change.
A1.4	**Himalayan snow melt run off models (NESAC)** • Improvements and development of snow melt run-off models. • Applications of snow melt run off for irrigation and hydro-power requirements. • Impact of climate change on Himalayan snow & glaciers.
A1.5	**Polar ice sheets (SAC)** One of the most challenging research area in polar ice sheets is estimation of ice sheet mass balance and resulting sea level rise. State of art techniques, development of algorithms utilizing SARAL/AltiKa data and analysis of results have been demonstrated at SAC through various studies. It needs to be expanded further by using globally available LASER/RADAR altimetry datasets. Another important research area is to investigate the dynamics of polar ice sheets using optical, SAR data along with incorporating numerical Ice sheet modelling, studying causes and linked processes for ice shelf instability. Development of techniques to automatize monitoring of ice shelves margin and calving events, to access the impact of various surface melt processes on the polar ice dynamics and exchange of surface energy fluxes are another important activity in polar ice sheet studies.
A1.6	**Polar sea ice (SAC)** One of the major contribution of SAC in polar ice studies is extraction of sea ice area from ISRO's Scaterrometers data and understanding its spatial-temporal variability. Technique development has been demonstrated to measure sea ice thickness using data from SARAL/AltiKa. It needs to be a continuing activity by using other globally available LASER/RADAR altimetry datasets to enrich and analyse long-term trend in sea ice thickness. More research is required to address trend in sea ice extent, concentration, thickness, snow depth over sea ice, sea ice drift estimation, sea ice albedo & feedback mechanism, sea ice modelling and understanding the oceanic and atmospheric driving factors for global sea ice variability. Automatic techniques using multi-sensor approach along with iceberg detection and tracking are needed for improving sea ice advisories required for safer ship navigation during Indian Scientific Expedition to Antarctica.

A2	Sub Area	Geology (IIRS / SAC)
A2.1	**Geological Remote Sensing: Exploration of Submarine ground water discharge using thermal remote sensing (IIRS)** Submarine Groundwater Discharge (SGD) is an important process of the sub surface hydrological cycle in the transitional environments where land meets sea. Owing to its complex structural/ hydro-morphogeological controls, seasonal and temporal variability, difficulty in detection, importance and effects of SGD remain largely underexplored. Hence, mapping potential SGD and assessing their potential impact areas in coastal ecosystems of Indian Peninsula is surging up as one of the strategically important research front. As per the general pre-requisite, the fact that relatively cooler groundwater discharging to warmer coastal waters manifests in the thermal band of satellite imagery acquired during the suitable period of the year remains to be the mainstay of this research. Spaceborne thermal infrared imaging instruments in the satellites like LANDSAT, ASTER, MODIS, ECOSTRESS etc. employed to derive sea surface temperature and standardized temperature anomaly maps and other surficial head related phenomenon provide critical help in identifying and characterizing SGD areas. In addition, this this research front aims to quantify the SGD and its potential effect in geological environment, specially where there is a dearth of potable ground water and environmentally protected areas. Subsurface controls like the lithology, consistency of primary and secondary porosity and permeability of aquifer system, local and regional geotechnical parameters including rock strength and patterns of joint/ discontinuities play a major role enabling the subsurface flow of groundwater from land to sea, which can often validated by resistivity and other surface geophysical proxies. The proposed project holds promise to showcase the potential of space borne thermal infrared sensor for the detection of SGD from space and can be helpful for the ISRO upcoming satellite mission like TRISHNA (Thermal Infra Red Imaging Satellite for High-resolution Natural Resource Assessment). In essence, the project shall aim at understanding heterogeneous subsurface lithology, structural controls (shallow subsurface fracture systems), porosity (both primary and secondary)/ permeability and variation on hydraulic conductivity play a role in estimation of nature and extent of SGDs. Establishing the inter-relation of variation in shore pore-fluid salinity vis-a vis SDG occurrences (including their future potential locations) will be one of the mainstay of the project. Additionally, it has to be observed if surface deformations (like subsidence, if any) features act as surface proxies for locating/ defining extent of SDGs. And, thereby, research findings should lead to characterization of shallow subsurface geological and hydrogeological controls to understand aquifer settings for SGDs, through remote sensing with special emphasis to thermal imaging techniques.

A2.2	**Mineral Exploration (SAC)** Although large part of the country has been conventionally surveyed and location of most of the economic mineral deposits have been investigated in detail, still new mineral deposits needs to be explored to meet ever-increasing demand of the industries. Mineral exploration using conventional techniques involve geological mapping followed by geophysical and geochemical investigations, pitting, trenching, exploratory drilling, estimating reserves etc. Remote sensing based methods have been so far limited to updating the existing geological/structural maps and in identifying hydrothermal alteration zones as a useful guide. Alteration halo is much more widespread of rocks surrounding a mineral deposit that are caused by solutions that formed the deposit. Research is required to explore integrated use of multispectral, hyperspectral, thermal and radar data along with high resolution DEM (space-borne as well aerial), geochemical and geophysical data sets in diverse geological and environmental settings to identify and map new mineral prognostic zones with special focus on Rare Earth Elements, base metals and precious metals. Methods for automated mapping of minerals associated with alteration zones, development of spectral-geochemical relationship using spectral and geochemical datasets need to be developed. Research is also required for quantification of spectral changes in reflectance spectra due to hydrothermal alteration process associated with mineral prospects using advanced laboratory based spectral and geochemical studies.
A2.3	**Geo-Archaeology and Palaeochannel (SAC)** Space based geo-archaeological exploration along with geo-spatial tools is one of the most fascinating geoscience application. It involves interpretation of multi-sensor satellite data to explore new archaeological sites, understand development, preservation and destruction of archaeological sites in context of regional scale environmental changes, evolution of physical landscape and impact of human groups by applying concepts and methods of geosciences (especially geology, geomorphology, hydrology, sedimentology, pedology and exploration geophysics). Research is required to develop methods/approach to explore archaeological sites using multi-sensor satellite data (Radar and high resolution multispectral data in particular) in conjunction with geospatial database of known archaeological sites. It is required to understand impact of neo-tectonic activities and palaeo-climatic changes on evolution of ancient civilisations. Another field is the detailed study of the palaeochannel. The lost River Sarawsati is one of the prominent study demonstrating the potential of Remote sensing data for palaeochannel study. Emphasis of on ground water potential site mapping also take advantage of palaeochannel.
A2.4	**Ground Water (SAC)** Groundwater geohydrology research is at the heart of the food-water-energy nexus. Geological framework intrinsically controls sustainable development and management of groundwater resources in any area. Armed with multi-sensor observations and huge

	archive of time series data repository of various geospatial proxies, depth to water table is modelled using advanced geospatial and machine learning based algorithms at a high temporal resolution. Water policies and governance needs to be customized not only based on public demand but the inherent geohydrological properties of any region. Such remote sensing based modelling provides a holistic overview of the different controls on groundwater. Groundwater potential mapping using remote sensing techniques presents a promising research area that should be efficiently explored. Integrating satellite imagery with GIS allows for the identification and delineation of groundwater potential zones (GWPZs), offering a spatially efficient approach to resource assessment. A particularly valuable aspect of this research lies in the use of the Analytic Hierarchy Process (AHP), which, when combined with remote sensing data, can weigh crucial factors such as slope, rainfall, geology, geomorphology, land use/land cover (LULC), and soil type, for enhancing the accuracy of groundwater potential mapping. Mapping geological formations, including lineaments and fractures, is essential for understanding groundwater flow and identifying recharge areas. Additionally, incorporating morphometric analysis with total rank method, which examines watershed aerial, linear, and relief characteristics (drainage density, basin shape, relief ratio, and stream frequency etc.), adds another layer in assessing groundwater potential. This comprehensive and multi-faceted approach offers great potential for refining groundwater management practices at larger scales and can significantly contribute to sustainable water resource planning. Differential Interferometric measurements have demonstrated the potential application for monitoring the GW depletion/recharge and associated land subsidence / rebound. With the future launch of NISAR and existing Sentinel mission, these studies will provide a holistic picture. Research is needed in the analysis and interpretation of the remote sensing data especially interferometric data for ground water exploitation and recharge.	
A3	**Sub Area**	**Marine and Coastal Geoscience (NRSC /SAC)**
A3.1	**Marine Geosciences (SAC)** Sea surface height measurements from satellite altimeters are extensively used to retrieve marine geoid and gravity data sets. High precision measurements from satellite altimeters such as the SARAL/ALtiKa and the recent SWOT have significantly improved the accuracy and resolution of the marine gravity field. Altimeter derived geoid undulation and free-air gravity anomalies over Indian Ocean needs to be utilised to understand plate tectonic processes relating to oceanic ridges, subduction zones, formation of marine sedimentary basins and the evolution of continental margins. Higher resolution marine gravity field is also essential for marine exploration.	

A3.2	**Coastal Geosciences (SAC)** Coastal zones are the interface between land and ocean and are dynamic fragile ecosystem, where interaction among complex natural coastal processes, coastal hazards, vital habitats and human activities occur and integrated studies for sustainable coastal zone management are required for protecting life, property and environment. Some of the major coastal geoscience research area includes coastal sediment transport modelling using satellite retrieved parameters, understanding coastal processes and causes of coastal erosion, dynamics of various coastal processes and its impact on evolution of coastal geomorphology, modeling coastal erosion and developing methods to predict shoreline changes, use of advanced automated methods to delineate shoreline (high Threshold Logic (HTL)/ Less than Truckload (LTL)) from satellite data, understanding impact of coastal processes on critical/vital habitats, understanding impact of predicted sea level rise on coastal zone, understanding coastal hazards and vulnerability/risk assessment, developing techniques for automated coastal landforms/ wetlands/land use/land cover mapping, detecting and monitoring coastal pollution, understanding impact on coastal ecosystem and developing models for integrated coastal zone management.
A3.3	**Space-Based Monitoring of Saline Ingress in Indian Coastal Regions (NRSC)** Coastal groundwater dynamics, including saline ingress and submarine groundwater discharge (SGD), significantly impact coastal agriculture, freshwater availability, and marine ecosystems. This study is proposed to utilize satellite remote sensing techniques to monitor these processes by analyzing multi-source satellite data such as optical, SAR and thermal data. Changes in land cover, vegetation stress, soil moisture, and water clarity serve as key indicators of salinity intrusion and groundwater discharge. By integrating these satellite observations with in-situ salinity and groundwater flow measurements, the study aims to develop a predictive model for sustainable coastal management. The findings will support early warning systems, freshwater conservation, and policy decisions to mitigate the adverse effects of changing coastal groundwater conditions.
A3.4	**Characterization and Spatial Mapping of Seagrass Ecosystems in Indian Coastal Regions using high Resolution Satellite data (NRSC)** This research develops advanced remote sensing techniques to charactering and mapping seagrass meadows along India coastline, addressing gaps in spatial coverage and temporal monitoring. By integrating high-resolution multispectral and hyperspectral satellite data, it enhances detection accuracy and overcomes limitations of traditional field surveys. Temporal analysis will track seagrass changes, identifying threats to these ecosystems. The findings will support conservation efforts, inform coastal policies, and enhance ecosystem management. This approach ensures cost-effective, large-scale monitoring, addressing data scarcity and enabling sustainable coastal resource management.

A4	Sub Area	Hydrology (IIRC / NESAC / SAC)
A4.1	**Advanced R&D for Wide swath altimetry (SAC)** Monitoring Water level from space platform is important to augment existing ground network in remote and inaccessible regions including Trans-Boundary Rivers. There is need to develop advanced approach to estimate water level from Nadir Microwave as well as LIDAR based altimeters. Estimation of water velocity and discharge has been challenge from remote sensing observations, methods need to be developed to address river discharge and storage volume using nadir and high resolution interferometric wide swath altimetry.	
A4.2	**Data Assimilation techniques for improved hydrological fluxes (SAC)** Assimilation of hydrological variables in physics-based process driven hydrological models needs to be carried out for improved water flux simulations including Himalayan river catchment, due to challenging terrain and transboundary catchments.	
A4.3	**High resolution Soil Moisture Retrieval (SAC)** A majority of prior investigations into soil moisture estimation using SAR have predominantly relied on single-frequency data sourced mainly from C-band remote sensing systems. Development of multi-frequency and multi-polarization SAR models for retrieval of soil moisture taking into account forthcoming sensors such as NISAR, EOS-09 etc.	
A4.4	**Wetland Health modeling (SAC)** Comprehensive eco-hydrological assessment of wetlands is essential for conservation, planning and management of wetland eco-system. There is a need to develop a framework for wetland health monitoring using remote sensing observations with focus on water quality, spatial and temporal variability, eutrophication modelling, impact of climate change, biological indicator, pollution source etc.	
A4.5	**Isotope Hydrology (SAC)** Satellite-observed isotope ratio for estimation of catchment scale water balance has not been studied for Indian basins. With availability of long-term isotope datasets in the recent years, it is necessary to quantify surface water fluxes using water isotopes. Sensor system studies need to be carried out to define the next generation of sensors capable of detecting isotope ratios from ultrafine measurements.	
A4.6	**Submarine Ground Water Discharge (SAC)** Quantification of water flow into ocean through sub marine ground water discharge is a challenge for Indian coast. High resolution thermal remote sensing observations from drone and space borne platforms provide initial signals of SGD in coastal region. There is need to identify the hot spot regions of SGD in Indian coast and develop model to estimate the discharge of fresh water going into the ocean.	

A4.7	**Surface and ground water interactions and understanding the impact of anthropogenic activities (SAC)** How surface and ground water availability is changing in space and time using SWOT, GRACE and LSM models along with science of changing water cycle which is accelerating/decelerating from local to regional to global scales.
A4.8	**Hyperfine hydrological modelling to address the social hydrology involving local drivers of change (SAC)** There is need to setup the hydrological models at much finer spatial resolutions (~ 50 meter) and simulate the water fluxes to provide the solutions at local scales and addressing the social hydrology.
A4.9	**Lake thermal Modelling under changing climate scenarios (SAC)** Lack of thermal observations and modelling of Indian freshwater systems lead to poorly constrained weather predictions and climate processes. In this context, how does increasing anthropogenic stress and climate change affect thermal dynamics of fresh water ecosystems?
A4.10	**Long term changes in available hydrological ECVs and linkages with hydro-climatic extremes (SAC)** Is there any positive or negative linkages/feedback between hydrological variability and extremes events for possibility of early detection mechanism through satellite observations?
A4.11	**Paleochannel study for sustainable groundwater management (IIRS)** Paleochannels are mainly remnants of the ancient river system that act as a source for fresh groundwater reservoirs, making them crucial for understanding regional hydrology. These paleochannels are filled with younger sediments and varying geological compositions ranging from unconsolidated to well-cemented sediments. Integrated geospatial and geophysical technology have transfigured the ability to map and analyze the buried ancient river network. The surface expression and morphology mapping of the paleochannels can be detected using remote sensing techniques such as Microwave/LiDAR/aerial photography. Also, data obtained from high-resolution optical, multispectral, and hyperspectral sensors can characterize the geological landforms of that area and these features shall help in analyzing the mineralogy, lithology, paleo geomorphology, topography, climate change and role of active tectonics in the formation and detection of the paleochannels. Geophysical methods such as electrical resistivity tomography (ERT), Seismic reflection/refraction tomography and ground penetrating radar (GPR) play a vital role in quantifying the characteristics (structural/ hydrological properties/water storage potential) of these buried paleochannels. The study of these paleochannels can provides a comprehensive viewpoint on human societies, environmental changes, and water systems both past and present.

	This project aims to deliver insights about the characterisation and quantification of palaeochannels through the implementation of geospatial alongwith geophysical techniques. It will also examine the relation among palaeomorphology, climate change and tectonic activity, thereby highlighting how these factors significantly sculpt the ancient fluvial environment. Consequently, this study will also focus on establishing kinship between archaeological features and paleochannel systems, which will further help in perceiving an idea of the palaeochannel contribution in understanding the past civilization and resource utilization.	
A4.12	**Terrain Characterization in Hydrological Properties of Soils (NESAC)** Developing / improving models for terrain characteristics of soil (Texture, Structure, Saturated hydraulic conductivity (Ksat), Consistence, Bulk density, Available water capacity (AWC))with respect to hydrological properties.	
A5	**Sub Area**	**Geo Hazards (NESAC / SAC)**
A5.1	**Study of potentially hazardous geological events (SAC)** This theme focus on the study of geodynamical processes related to potentially hazardous geological events using advanced space based techniques. Space geodetic techniques such as GNSS and InSAR have been extensity used to understand the strain accumulation and release processes and there by the seismic hazard in regions like the Himalayas and active seismic zones in peninsular India. Other active areas of research include quantification of land subsidence due to over exploitation of ground water, coal, hydrocarbons and crustal deformation associated with volcanos and slow-moving landslides using geodetic measurements for hazard assessment.	
A5.2	**2D Flood Inundation Modelling - Simulation of flood Inundated Areas for a Given Discharge using DEM and other Inputs from Satellite Data (NESAC)** To explore the applicability of hydro-dynamic equations in various conditions of overland flood wave propagation on different floodplain topographies. Inter comparison of different DEM products for 2 dimensional hydraulic simulations.	
A5.3	**Flood Early Warning System (NESAC)** Calibration and validations of all distributed river/tributary models in Brahmaputra and Barak river valleys with available hydro-logical and river geometry datasets. Sensitivity analysis of various model parameters to understand the hydrologic response of various types of river catchments in the said study area.	
A5.4	**Flood Hazard Zonation and Risk Assessment in Major Riverine and urban Flood Prone Catchments (NESAC)** Applicability of various approaches of flood hazard zonation such as flood frequency based hydraulic simulations, inundation occurrence based FHZ and NESAC developed multi-criteria analysis in both riverine and urban flooding conditions.	

A5.5	**Integration of Satellite Based Inputs Along with DEM for Forecasting a Flood Discharge and to Provide Early Warning (NESAC)**	
A5.6	**Thunderstorm Now-casting Modelling (NESAC)** Developing AI & ML based Thunderstorm now-casting model.	
B	**Area**	**Geospatial Data portals and Information Science (NESAC / NRSC / SAC)**
B1	**Sub Area**	**Bhuvan (NRSC)**
B1.1	**Real time Statistical Analysis, behavior & sensitivity of users in accessing Bhuvan Geo-Portal (NRSC)** Collection of log data from geo-portal web applications plays a vital role in taking decisions on certain aspects like deriving insights, business intelligence, security measures are some of the examples. Data analysis contains collecting, processing, and interpreting data from the web services / Applications to derive insights. Behavior Analysis includes how much time the user has spent on the webpages and what services it has been consumed. This analysis will help in maintaining the web application in effective use. User sensitivity analysis in the spatial domain on a web portal typically involves evaluating how variations in spatial parameters or user input affect outcomes or decision-making within a geographic or spatially enabled application. The factors that impact analysis are traffic metrics, performance metrics, user experience, content and feature and technical infrastructure impact. The key steps to represent the study are define the boundary of objective, considerable key variables, create a baseline, simulate changes, measurable outcomes, evaluation methods, clear visual representation of results.	
B1.2	**Blockchain technology for verifying geospatial based crowd sourcing data integrity (NRSC)** Blockchain can provide data integrity, transparency, and security for geospatial crowdsourcing applications. Crowdsourced geospatial data is widely used in applications such as disaster response, urban planning, environmental monitoring, and navigation. A major challenge is ensuring data integrity, authenticity, and reliability, as malicious actors or errors can compromise data quality. Blockchain technology offers a decentralized, immutable, and tamper-proof solution for verifying geospatial data. The study must focus on navigation and mapping services representing crowdsourced GPS data can be verified to prevent misrepresentation, enhance accuracy for Bhuvan maps.	
B1.3	**Deep Learning-Based Image Compression for High-Resolution Satellite Images for Web Hosting and Analysis (NRSC)** The Satellite images are crucial for remote sensing applications like, urban studies, water resources studies, agriculture studies, environmental monitoring, etc. High-resolution	

	satellite images are used to host and overlay on the results of such applications. Which results in requirement of significant storage and bandwidth, making efficient compression method a need. Traditional compression methods (JPEG, PNG) lead to quality loss or inefficient storage, motivating the use of deep learning-based approaches. The study must focus on deep learning approaches for image compression like satellite, aerial and drone data to host on web. Implement for web host and analysis with two examples, performance metrics and comparisons. The study must also focus on image fidelity, adapting different models for different type of sensors and its resolution.	
B1.4	**Quality assessment techniques for crowdsourced geospatial data (NRSC)** Assessing the quality of crowdsourced geospatial data is critical for ensuring its reliability in applications like mapping, decision making tools, and infrastructure monitoring activities. The Quality Assessment Techniques for Crowdsourced Geospatial Data must adhere to geospatial data quality standards addressing the minimum quality parameters like positional accuracy, thematic accuracy (correctness of attributes details), temporal accuracy (Timeliness of updates and relevance over time), completeness, logical consistency (data structure rules) and usability. The study must also represent data biasness, AI driven checks and scalability to handle large datasets with real time verification techniques.	
B1.5	**Generative AI models for cloud replacement in satellite images (NRSC)** Cloud replacement in satellite images using generative AI is a promising research area focused on generating realistic, cloud-free images by reconstructing obscured regions. Cloud cover significantly reduces the usability of satellite imagery for critical applications such as land use monitoring, disaster management, and agricultural assessment. To address this challenge, the study should propose the development of an advanced Generative AI model capable of intelligently identifying and replacing clouds with contextually accurate data, ensuring spatial consistency, preserving fine details, and maintaining spectral accuracy. It should leverage state-of-the-art generative models like Generative Adversarial Networks (GANs), Diffusion Models, and Transformers to achieve high-quality cloud removal.	
B2	**Sub Area**	**Visualization of Earth Data & Archival System –VEDAS (SAC)**
B2.1	**Algorithms / Procedures for Time Series Visualization (SAC)** VEDAS is responsible for archival and dissemination of thematic data and data products available within SAC. Large amount of spatial time series data is collected over time and visualization of available spatiotemporal data is essential for exploring and understanding structures and patterns, and to identify unusual observations or hidden patterns. However, the volume of data available and number of concurrent users that may be accessing the data challenges current time series map visualisation. The start and end time of episodic events or span of intensive observations may also be dynamic.	

	So algorithms are required to be developed and modern techniques are required to be used for visualization of large spatio-temporal (ST) datasets ordered in time for animated mapping. This will be further used for exploring or monitoring unusual observations in large datasets like NDVI, snow, temperature, solar insolation etc.	
B2.2	**Data Analytics and Knowledge Discovery (SAC)** To understand and appreciate a natural phenomenon and attach cause and effects to an evolution, there is a growing demand of rendering "on the fly" multi-layer information. There may be concurrent users accessing same set of data. So there is motivation to parallelize computation to improve turn around time of a service. The research initiatives will be useful steps towards achieving this goal. Design & Development of parallelizable algorithms for interactive geospatial data analysis with high temporal resolution. Design & Development of parallel execution frameworks and/or distributed computing libraries for geospatial data processing operations. Design and Development of scalable general purpose systems/algorithms for removing noise from spatiotemporal datasets. Design and Development of scalable general purpose systems/algorithms for predictive analytics from spatiotemporal datasets. Design and Development of data-mining algorithms for spatial-temporal datasets. Design and Development of scalable techniques for semantic segmentation of orthoimagery.	
B2.3	**Super Resolution Image Generation (SAC)** Super Resolution is an Image Processing technique which is used to enhance the image resolution of scene from a number of lower resolution images of same area by reducing effects of noise in the reconstructed image. In case of satellite images, this can be seen as a powerful tool of getting high resolution multispectral images (spatial) from low resolution panchromatic images. This will facilitate improved (in spatial scale) Land cover for better natural resource management.	
B2.4	**Web Enabled Sensor System for Efficient Resource Management (SAC)** There is need to develop a prototype and demonstrate the applicability of wealth of information that can be gathered by set of remotely located instruments. Instruments can measure the meteorological conditions as well as ambient conditions and transmit the data to a central hub. Air quality monitoring of a region is a one such example where measurements of PM2.5 and PM10, concentrations of target gases (NOx and SOx – for example), their dispersal (based on wind direction and speed), temperature and humidity are all required by administrators and managers to issue advisory and / or take pro-active preventive measures.	
B3	**Sub Area**	**Meteorology and Oceanography Data Archival Centre – MOSDAC (SAC)**
B3.1	**Advanced Data and Computing Architecture (SAC)** • Optimized Data Cubes for multi-dimensional aggregation of satellite images and their spatiotemporal analysis.	

	• Techniques for forecasting and in-painting in Data Cubes • High Performance Computing of satellite images on Cloud
B3.2	**Data Visualisation and Web Processing (SAC)** • Advanced data rendering and fast visualization techniques of 2D and 3D satellite data. • Fast Tiling and caching techniques for visualization of satellite Images. • Development of techniques for automatic on-demand web mashup generation. • Cloud and Semantic enabling of Web Processing Services.
B3.3	**Data Security and Information Dissemination (SAC)** • Data encryption and compression techniques for multicasting of satellite data • Customization and optimization of multi-cast protocol using critical distance of client nodes to cater to requirements of real-time data dissemination. • Content based data multicasting. • Information and Data security models for small devices. • Location aware satellite data dissemination for mobile devices.
B3.4	**Data Mining and Web Analytics (SAC)** • Real time analytics for Big Earth Data • Pattern recognition based techniques for Event detection • Geospatial feature extraction using deep learning techniques • Automated event tracking (Cyclone, dust storm, etc.) using machine learning techniques • Region growing algorithms for identification and tracking of meteorological and oceanographic events (Fog, bloom, convective initiation, etc.)
B3.5	**Data and Information Lifecycle Management (SAC)** • Automated algorithms for value evaluation of data and information • Techniques for automatic Quality checking of data • Techniques for Persistent identifier management • Techniques for generation of Linked data • Faceted search and Browsing of satellite images • Semantic annotation and labelling of satellite images
B3.6	**IoT and Sensor Network (SAC)** • IoT enabled sensor network for acquisition of weather data • Smart weather data acquisition systems • RTOS based Data acquisition system • Virtual Sensors for Weather data acquisition • Optimal data capture and processing in Sensor Network

B3.7	**Virtualization and Cloud Computing (SAC)** • High Performance Cloud for Satellite Image Processing • Network Virtualization and Software Defined Network • Software Defined Storage	
B4	**Sub Area**	**Geo-Web Services portal of NESAC (NESAC)**
B4.1	**Advanced Data and Computing Architecture (NESAC)** • Optimized Data Cubes for multi-dimensional aggregation of satellite images and their spatiotemporal analysis. • Techniques for forecasting and in-painting in Data Cubes • High Performance Computing of satellite images on Cloud	
B4.2	**Data Visualisation and Web Processing (NESAC)** • Advanced data rendering and fast visualization techniques of 2D and 3D satellite data • Fast Tiling and caching techniques for visualization of satellite Images • Development of techniques for automatic on-demand web mashup generation Cloud and Semantic enabling of Web Processing Services	
C	**Area**	**Urban Planning and Urban Climate Studies (IIRC / NESAC / NRSC / SAC)**
C1	**Sub Area**	**Urban Feature Extraction (NESAC / NRSC / SAC)**
C1.1	**Urban Feature Extraction - Road Network Delineation (SAC)** Transportation networks such as roads and railway lines are important for several urban applications including disaster management, urban planning, impervious surface extraction, urban growth modelling etc. The automatic methods such as template matching, object-based classifiers and machine learning methods such as neural networks, support vector machines, deep learning etc. can be used to efficiently extract road network from very high-resolution optical and SAR images acquired by Indian Remote Sensing satellites.	
C1.2	**Urban Feature Extraction - Impervious Surface / Urban Area Mapping (SAC)** The mapping of urban land cover remains a challenging task owing to the high spectral and spatial heterogeneity of urban environment. The accuracy of urban area extraction can be improved by combining multi-temporal, multiresolution and multi-sensor optical and SAR earth observation data.	
C1.3	**Urban Feature Extraction - 3D Building Reconstruction (SAC)** The 2D and 3D information of buildings and other urban structures are needed not only for impressive visualisation of urban areas, but also as an input in several urban applications like population estimation, roof-top solar energy potential assessment,	

	visibility studies etc. Building extraction from high-resolution satellite images in urban areas is an intricate problem. Techniques are to be developed for automatic extraction of buildings from Very High Resolution optical data. The availability of very high-resolution imagery from Cartosat series data necessitates development of techniques and algorithms for 3D building reconstruction.	
C1.4	**Assessment of urban infrastructure quality using High Resolution satellite image and AI/ML (NRSC)** Rapid urbanization of Indian cities has resulted in the emergence of slums, informal settlements, and sprawls characterized by inadequate housing, limited road connectivity, poor sanitation, and insufficient basic infrastructure. Traditional ground-based methods of identifying and mapping these impoverished areas are labour-intensive and time consuming, limiting effective policy interventions. High-resolution satellite imagery coupled with advanced artificial intelligence (AI) and machine learning algorithms, offers a promising alternative to systematically and objectively identify and map slums and other poverty clusters. Utilizing remote sensing for urban infrastructure quality assessment enables precise, timely, and scalable detection of vulnerable urban settlements. Such an approach could significantly enhance targeted policy-making, resource allocation, and urban planning decisions, ultimately improving the living standards and socio-economic conditions of urban populations across India.	
C1.5	**3D surface Modelling and Features Capturing of UAV/UAS data (NESAC)** Development of efficient model for extraction of 3D surface from UAV/UAS data.	
C2	**Sub Area**	**Urban Climate (IIRS / NRSC / SAC)**
C2.1	**Understanding and modelling fog in urban areas (IIRS)** Urban growth leads to complex urban morphologies, consisting of dense, high-rise structures interspersed with fragmented greenspaces. All of these have profound impacts on the local atmospheric processes, including fog formation and dissipation. The intricate arrangement of buildings, streets, vegetation, and open spaces influences local meteorological conditions such as wind flow, temperature variations, and humidity distribution, all of which are critical factors in fog dynamics. Urbanization introduces artificial heat sources, increased surface roughness, and altered moisture balance, leading to significant modifications in fog patterns compared to surrounding rural areas. The urban heat island (UHI) effect, caused by heat-retaining materials like concrete and asphalt, often reduces fog persistence by increasing near-surface temperatures. However, in certain conditions, urban structures can also trap moisture and limit airflow, creating localized pockets where fog may persist longer. Additionally, pollution and aerosols from transportation and industrial activities contribute to the condensation process, influencing fog intensity and composition. Understanding these interactions is essential for urban climate studies, as fog affects visibility, transportation, public health,	

	and energy consumption. High-resolution urban morphology data can enhance numerical weather prediction models to improve fog forecasting in cities. This is particularly relevant in densely populated urban regions where visibility reduction due to fog poses risks to mobility and safety. By integrating advanced remote sensing technologies, urban climate modeling, and in-situ observations, this project aims to quantify how different urban forms influence fog events. Such studies are crucial for developing climate-responsive urban designs that mitigate negative impacts while preserving ecological balance. In an era of rapid urban expansion and climate change, understanding the complex interplay between urban morphology and fog is vital for ensuring resilient and adaptive city planning, particularly in regions prone to frequent fog events.
C2.2	**Assessment of urban precipitation extremes in changing climate (NRSC)** Despite significant advancements in our understanding of precipitation processes in recent years, there remain several gaps in knowledge that need to be addressed in order to gain deeper insights into the mechanisms involved in urban precipitation processes. The scope of the proposed research is to examine the sensitivity of urban precipitation extremes using INSAT-derived rainfall. To identify the factors that influence the rainfall patterns in regional as well as large-scale processes and quantify the impact of urbanization on regional rainfall patterns.
C2.3	**Urban Heat Island (SAC)** Spatial and Temporal Distribution of Urban Heat Islands on Land Surface and Near Surface Atmosphere Development of models for deriving day-time and night-time air temperature from satellite-derived land surface temperature and vegetation indices can assist in identification and analysis of spatial and temporal distribution of urban heat islands. Impact of Land Cover Types on Urban Heat Islands The changes in land use-land cover pattern anddeclining vegetation cover in cities are predominant factors influencing the growth of urban heat islands in the cities. Satellite data derived land use land cover information can be compared with the temperature profiles to assess the impact of land cover on urban heat islands.
C2.4	**Vulnerability Profiling of Capital Cities of NER (NESAC)** Urban areas are susceptible to disasters (man-made or natural). It is the need of the hour to make a rapid vulnerability assessment of urban areas in order to understand what is required for building disaster resilience community. The potential impact of different parameters on urban services arising from the geographical setting of a city; the nature, size and density of its settlements; and the existing coping capacity of its society and governance system can be studied to create vulnerable profile of urban areas.

D	Area	Signal & Image Processing & Data Product (NESAC / NRSC / SAC)
D1	**Sub Area**	**Synthetic Aperture Radar (SAR) Data processing and products (NRSC / SAC)**
D1.1		**Infrastructure mapping and monitoring using AI/ML techniques from Synthetic Aperture Radar SAR Data (SAC)** Synthetic Aperture Radar (SAR) is an active microwave sensor that can take images of targets during day as well as night and can also penetrate cloud cover. The high resolution images acquired by SAR can be used to map and monitor various infrastructure such as highways, airports, railway, bridges, buildings, vegetation etc. With availability of large amount of images from past, current and future SAR missions, a software for classification and temporal monitoring of government and non-government assets can be very useful for administrative purposes. The prime focus of this research is design and development of AI/ML based technique for identification and classification of infrastructure in the readily available SAR image datasets. The infrastructures thus identified can be added to a library which can be referred by government/non-government agencies for various planning and temporal monitoring activities. It will also enable the monitoring of the areas for which optical images may not be available around the year due to cloud cover/ day-night issues. SAR Images from RISAT-1 / RISAT-1A(EOS-04) / RISAT-1B (EOS-09) missions can be used for this activity.
D1.2		**Moving Targets identification and their parameter estimation from SAR Images (SAC)** During Synthetic Aperture Radar (SAR) imaging, the sensor is flown in an Aircraft/ spacecraft, pulses are sent and the return echoes are recorded. While processing, the range and the relative motion between sensor and target (earth) is utilized to generate images. In SAR, the background region, called clutter, is the region of interest and it is assumed to be stationary and SAR image focusing is done. Moving targets likes cars, trains, etc. in the images are defocused and/or displaced and may appear as artifact in the image. Primary focus of this research is algorithm and corresponding software development for • Moving Target detection using state of art along track interferometry techniques • Moving Target detection in Raw/Processed SAR datasets • Estimation of target parameters like position and velocity • Focusing of moving targets in SAR images • Removal of artefacts from SAR images generated due to moving targets Getting information of moving targets for SAR image will provide valuable information in utilization of SAR images in strategic applications. Artefact removal and refocusing of moving targets in SAR images will result in enhanced SAR image quality. Additionally, the work will help in designing the state of the art SAR systems for moving target indication.

D1.3	**Passive Bi-static SAR Image Formation using GNSS Signals (SAC)** Synthetic Aperture Radar (SAR) are microwave sensors and have day night & all weather imaging capability. In SAR, pulses are transmitted from Airborne/Spaceborne platforms and return echoes are recorded. These return echoes are used to form the high resolution SAR images using signal processing methods. Image formation, in cases where receivers are at different platform than the transmitter, is termed as passive bistatic SAR image formation. Globally, around the earth, many microwave systems are working in microwave frequency range suitable for SAR image formation. Navigations systems like GPS & IRNSS, are such type of systems primarily operating in L & S Band. Reflected signal corresponding to the signals transmitted from these systems are being recorded in passive receiver (like GNSS-R onboard Microsat-2C, CyGNSS). These are signals of opportunity which are highly reliable & stable and can be used for SAR image formation as well.Design and development of techniques for SAR image formation from GNSS signals and corresponding software implementation is the primary focus of this research. This research has the potential to generate SAR images using low cost receiver only systems with enormous applications.	
D1.4	**Multi-Satellite SAR Image Co-Registration (NRSC)** Multi-satellite Synthetic Aperture Radar (SAR) image co-registration is essential for accurate time-series analysis, change detection, and thematic applications. Co-registration between SAR images acquired in different frequency bands (L-S, L-X, L-C, S-C, etc.) presents significant challenges due to variations in wavelength, polarization, and imaging geometry. Misalignment between images can lead to errors in classification, interferometry, and geophysical parameter retrieval. The research should aim to develop novel image processing techniques, integrating advanced machine learning and deep learning models, to achieve sub-pixel accuracy in multi-band SAR image registration. The study shall explore feature-based, texture-based, and pixel-offset methods to improve spatial alignment. The developed methodology can be validated on openly available SAR datasets covering diverse landscapes, ensuring robustness and accuracy. The research will contribute to enhancing Analysis Ready Data (ARD) for improved SAR applications, including **disaster monitoring, environmental assessment, and resource mapping.**	
D2	**Sub Area**	**Hyperspectral and LiDAR Data processing and Products (SAC)**
D2.1	**Hyperspectral and LiDAR Data Fusion for Enhanced Remote Sensing Analysis (SAC)** Remote sensing technologies, such as Hyperspectral Imaging (HSI) and Light Detection and Ranging (LiDAR), provide valuable environmental and geographical data. While HSI offers detailed spectral information across a wide range of wavelengths, LiDAR captures precise three-dimensional (3D) spatial data, enabling high-resolution topographic measurements. Integrating these two datasets can significantly enhance our ability to analyze complex environments by combining spectral, spatial, and geometric features.	

<table>
<tr><td></td><td colspan="2">The research should explore and implement recent trends in machine learning and deep learning models to achieve the hyperspectral and LiDAR fused output.

The goal of this research is to develop a robust framework for the fusion of Hyperspectral and LiDAR data to improve object detection, land cover classification, and environmental monitoring. The research objectives are as follows.

1. To explore the potential benefits of fusing hyperspectral and LiDAR data for improved landscape classification, particularly in vegetation and urban areas.
2. To develop and assess fusion algorithms that leverage both the spectral and spatial dimensions of these datasets.
3. To evaluate the fusion's ability to detect and characterize environmental features such as vegetation health, urban structures, and terrain variation.

The fusion of hyperspectral and LiDAR data will enable more accurate and efficient classification of land cover types, particularly in challenging environments where either modality alone may be insufficient. It will also enhance our understanding of environmental changes over time, providing a powerful tool for monitoring ecosystems, urban development, and natural disasters.</td></tr>
<tr><td>D2.2</td><td colspan="2">LIDAR Remote Sensing for Land Applications (SAC)

• Development of processing algorithms for LIDAR data for land applications, which includes Tree height and structure mapping.
• Development of fusion techniques for LIDAR and fine resolution optical data for species diversity mapping.</td></tr>
<tr><td>D3</td><td>Sub Area</td><td>Satellites Data Processing and Development of Data Models / Products (IIRS / NRSC / SAC)</td></tr>
<tr><td>D3.1</td><td colspan="2">Data Product Pixel Quality layer generation using Machine learning (NRSC)

The revolutionized remote sensing technology plays a vital role to monitor and understand planet's surface, atmosphere and environment. The huge data generated by remote sensing (RS) satellites presents both an opportunity and a challenge for effective analysis and interpretation. Optical RS images are hindered by clouds and cloud shadows for feature extraction. Similarly hill shadows and zero-fills may impact the classification accuracy. Snow and clouds need additional attention. Water is also to delineated in some cases to derive geo-physical parameters of interest. It would be a good practice to delineate these pixels and to provide the classified information in separate pixel-quality layer for more accurate geo-physical parameter retrieval. It is also mandatory to have a pixel quality layer for next-generation Analysis-Ready-Data(ARD) products to maintain the interoperability among global sensors. Presently the deep learning techniques have emerged as a potential tool for automatic classification of RS images with significant advantages over traditional state-of-art methods.</td></tr>
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	The proposed research is to realize pixel quality information layer from a multispectral data product by amalgamating relevant ML models for feature delineation at pixel level.
D3.2	**Development of BRDF (Bidirectional Distribution Function) models for accurate estimation of Surface Reflectance (NRSC)** Wide swath optical images are often acquired by sensors with large field of view that results in directional reflectance effects over non-Lambertian surfaces due to surface reflectance anisotropy and changes in the solar and viewing geometry. This uncertainty effects the radiometric normalization and cross-validation of sensors. These effects are often described by the bidirectional reflectance distribution function (BRDF) and can be non-trivial. Sensor View angle Effects are significant than the solar geometric effects. Current state of art techniques to retrieve surface reflectance from TOA radiance assumes the object under study as lambertian but in reality it is not. The proposed research is focused on the quantification of angular effects in surface reflectance and computation of coefficients to derive nadir adjusted reflectances for all operational wide swath IRS data products.
D3.3	**Artificial Intelligence and Machine Learning (AI/ML) approach for processing Ocean Colour satellite data for Chlorophyll retrieval (NRSC)** Processing of Ocean colour data for retrieval of bio-geophysical products like Chlorophyll, Kd etc. is quite complex, which involves radiative transfer theory, bio-optical algorithms, complex quality flagging etc. This study aims to attempt use of AIML tools for processing optical ocean colour satellite data, which has advantage of improved accuracy, faster processing & automation, better handling of missing data, fusion with other data sets, adaptability and scalability.
D3.4	**Building a Quantum Computing-Based Foundation Model for Feature Extraction from High-Resolution Oblique Satellite Imagery Obtained from Small Satellite Constellations addressing Intra-Class Variance and Large-Scale Distortion (IIRS)** Quantum computing offers a powerful means to process large-scale satellite datasets by representing high-dimensional multivariate model states. This project aims to develop a foundational model that can accurately extract high-resolution features, such as trees and buildings, from satellite images taken from oblique geometries using quantum algorithms. The model will be designed to handle satellite parameters similar to those of small satellite systems, with resolutions ranging from 5 meters to 50 centimeters. It will ensure robustness and accuracy in feature extraction at less than half a pixel without requiring preprocessing, addressing challenges like intra-class feature variance and large-scale distortion due to relief and view angles. The objectives of the project include developing quantum algorithms capable of handling high-dimensional multivariate models and addressing issues related to

	intra-class feature variance and distortions. The project will also focus on building a foundational model that accurately extracts high-resolution features from oblique satellite images and is agnostic to satellite parameters. Additionally, the project will evaluate the performance of the quantum algorithm and foundational model against traditional methods, assess improvements in accuracy, processing time, and robustness, and demonstrate practical applications through case studies. The deliverables will include a fully developed quantum algorithm, a robust foundational model, a comprehensive performance report, detailed case studies, and complete documentation with source code and usage instructions.
D3.5	**Development of Foundation Model for Satellite Images (SAC)** Satellite imagery plays a pivotal role in addressing global challenges such as climate monitoring, disaster management, urban planning, and defence. However, the vast volume and complexity of satellite data require advanced analytical tools. Foundation models, pre-trained on large-scale datasets, have revolutionized fields like natural language processing and computer vision. Developing a foundation model specifically for satellite images can unlock unprecedented capabilities in automating analysis, improving accuracy, and enabling cross-domain applications, thereby enhancing decision-making for space organizations and stakeholders. The objective of studies are as follows: 1. To design and train a foundation model tailored for satellite imagery, leveraging large-scale datasets from diverse sources. 2. To enable multi-task learning for applications like land cover classification, object detection, and change detection. 3. To improve generalization across geographic regions, sensors, and resolutions. 4. To provide an open-source framework for fine-tuning and deployment in downstream tasks. The scope of studies are as follows: The project will focus on developing a scalable, transformer-based architecture trained on datasets of Indian landscape from different Indian satellite (e.g., HRSAT, Cartosat, Resourcesat, NISAR, Microsat, RISAT etc.) catering data across different modality of optical and infrared data to SAR data, high-resolution data to coarse resolution imagery. The model will be evaluated on benchmark tasks and real-world use cases, ensuring adaptability to various space organization needs. **Methodologies:** 1. **Data Collection and Preprocessing:** Curate a diverse dataset of satellite images with annotations for supervised and self-supervised learning.

	2. **Model Design:** Implement a vision transformer (ViT) or hybrid CNN-transformer model optimized for multi-spectral and multi-temporal data. 3. **Training:** Utilize self-supervised learning techniques (e.g., masked autoencoding) to pre-train the model on unlabeled data, followed by fine-tuning on specific tasks. 4. **Evaluation:** Benchmark performance on tasks like segmentation, classification, and anomaly detection using standard metrics. **Possible Outcomes:** 1. A robust foundation model capable of handling diverse satellite imagery tasks. 2. Reduced dependency on task-specific models, saving time and computational resources. 3. Enhanced interoperability across datasets and sensors, enabling seamless integration into existing workflows.
D3.6	**Utilizing Neural Radiance Fields for Multi-View Geometry Reconstruction in Satellite Imagery for DEM and DSM Generation (SAC)** Digital Elevation Models (DEM) and Digital Surface Models (DSM) are crucial for various geospatial applications, including topographic mapping, urban planning, and environmental monitoring. Traditional methods for DEM/DSM generation, such as photogrammetry and LiDAR, can be computationally expensive and sensitive to data quality. Additionally, photogrammetric approaches require high-quality stereo pairs with consistent lighting conditions, while LiDAR is costly and limited by accessibility constraints. The increasing availability of high-resolution satellite imagery presents an opportunity to explore alternative methodologies that can leverage deep learning techniques for enhanced 3D reconstruction. Neural Radiance Fields (NeRF) have demonstrated impressive results in reconstructing 3D geometry from sparse 2D images by modeling volumetric scenes with high fidelity. However, existing NeRF implementations are optimized primarily for synthetic or ground-based images, with limited studies addressing large-scale aerial or satellite-based reconstructions. This research aims to bridge this gap by developing a NeRF-based framework tailored for multi-view satellite imagery, enabling accurate and scalable DEM and DSM generation. If successful, this approach could significantly improve terrain modeling efficiency and precision, benefiting industries such as agriculture, disaster response, and military reconnaissance. In addition, this method has direct applications in high resolution satellites such as HRSat and Cartosat. **Objectives** 1. Investigate the feasibility of applying NeRF to reconstruct high-fidelity 3D structures from multi-view satellite images, considering factors such as atmospheric distortions, varying resolutions, and occlusions.

	2. Develop an optimized pipeline for training NeRF on satellite datasets to generate DEM and DSM, incorporating domain-specific modifications such as multi-scale feature representations and geospatial constraints. 3. Compare the accuracy, resolution, and computational efficiency of NeRF-based reconstruction with traditional photogrammetry and LiDAR-based methods to assess its viability for large-scale applications. 4. Explore potential enhancements to NeRF, such as integrating hybrid neural representations, incorporating auxiliary sensor data (e.g., synthetic aperture radar), and leveraging super-resolution techniques for improved terrain detail extraction. **Expected Outcomes** 1. A validated framework for leveraging NeRF in DEM and DSM generation from satellite imagery. 2. Improved elevation models with enhanced resolution and accuracy compared to traditional methods. 3. Insights into the applicability and limitations of NeRF in large-scale remote sensing tasks.
D3.7	**Automatic Road Extraction Using High-Resolution Satellite Imagery (SAC)** This research focuses on developing an automatic road extraction model using high-resolution satellite imagery and deep learning techniques. Road networks are critical for transportation, urban planning, and disaster management. However, manual road extraction from high resolution satellite images is time-consuming and error-prone. This study proposes a deep learning-based framework leveraging Convolutional Neural Networks (CNNs) and Transformer-based architectures to enhance road detection accuracy, reduce occlusions, and improve computational efficiency. The research aims to develop a robust model that generalizes across different environments and datasets, contributing to remote sensing and geospatial analysis applications. **Research Objectives:** 1. Develop an automatic road extraction model using high-resolution satellite imagery. 2. Improve segmentation accuracy using deep learning techniques. 3. Address challenges such as occlusions, varying road textures, and illumination differences. 4. Evaluate model performance on multiple datasets for better generalization. 5. Optimize computational efficiency for real-time or near real-time applications. **Expected Outcomes:** This research aims to develop a high-accuracy road extraction model applicable to urban planning, disaster response, and autonomous navigation, improving road segmentation in complex environments.

D4	Sub Area	Data Mining (NESAC)
D4.1	**Algorithms for Knowledge Extraction from Big Data (NESAC)** Large volumes of data that cannot be stored in normal relational databases are being generated every day from the remote sensing satellites. Many software elements extract information from the raw data generating information in unstructured form such as images, log files, user orders in pdf, word etc. There is a need for developing efficient data mining algorithms to tag the data sets for facilitating efficient build up of archival and retrieval. • In general data mining algorithms work on data sets that are of reasonable size and cannot handle BIG data • Develop Parallel Algorithms for mining the classification rules to facilitate data archival in an optimal manner • Develop mining algorithms that are Incremental and can learn and unlearn from the continuous satellite data acquisitions Develop algorithms for extracting meaningful trends in the customer ordering, build customer satisfaction index, predict the future sales or potential sensors or popular products etc.,	
E	**Area**	**Atmospheric Science and its applications (NESAC / NRSC / SAC)**
E1	**Sub Area**	**Climate Modelling (NESAC / NRSC / SAC)**
E1.1	**Seasonal Prediction of Indian Summer Monsoon rainfall (ISMR) using Climate Model (SAC)** The Indian summer monsoon (ISM) occurring every year from June through September, is one of the most dominant features of the global hydrological cycle. It causes more than 75% of annual rainfall over the country during this period. Although, the onset of the monsoon over Kerala in India takes place at the start of June with the seasonal reversal of wind over the Arabian Sea with a consistent manner from year after year, the seasonal prediction of ISMR during the recent times become more and more challenging. It is mainly due to several external factors both natural and manmade viz. the fast changing climate, the manmade changes in land-use-land-cover, The fast growing infrastructure development activities in large scale over a landmass that significantly modify the respective land surface properties, heat and water budget, composition of atmospheric gases, aerosols etc. One of the biggest challenge is to model these changes and incorporate the impact of them in medium to long-term model prediction. Therefore, there is a recognized need to demonstrate the state-of-art seasonal prediction of ISMR describing both the spatial and temporal variability of rainfall in conjunction with the satellite and in-situ observations. A seasonal prediction system has been setup at Space Applications Centre (SAC) Ahmedabad in research and operational mode.	

	The experimental prediction of ISMR has been generated through 50-member ensemble CAM model simulation during April every year and updated monthly till September. Each ensemble member has been started with different initial conditions and sea-surface boundary conditions. End of season (EOS) validation has been conducted every year to measure the model prediction skill and to identify the shortcomings and lacuna of the prediction system. It is a continuous evolving process of the prediction system to improve its skill of prediction year after year.	
E1.2	**Climate Change & LULC Dynamics (NRSC)** The relationship between climate change and LULC dynamics is complex and bi-directional. Addressing both challenges requires coordinated efforts to reduce emissions, protect and restore ecosystems, and adapt to changing climatic conditions. Sustainable land use practices and effective climate policies are key to mitigating the impacts of both phenomena. Monitoring LULC and understanding its interactions with climate change are critical for informed decision-making. Remote sensing, geographic information systems (GIS), and climate modeling are often used to track LULC changes and predict their impacts on future climate scenarios. There is a need to model climate driven LULC change using machine learning algorithms and understanding impact of carbon sequestration and its dynamics.	
E1.3	**Satellite based Cloud Microphysical applications (SAC)** Data from multitude of satellite sensors are used to derive information about cloud microphysical parameters. The study of cloud processes in microscale is also carried out to improve our understanding of many meteorological phenomena like monsoonal active and break phases, tropical cyclone development, intrusion of dust into thunderstorm and its impacts. In addition, we are also experimenting on different schemes to generate a merged cloud microphysical product from optical sensors onboard different satellites.	
E1.4	**Climate Change Impact assessment (NESAC)** Anticipated/Ensuing climate change is expected to alter the water resources availability, demand and use patterns. Many uncertainties remain about the extent of these climatic changes, as well as about their societal implications. Assessment of vulnerability and resulting risk to water resources due to climate-change impacts is necessary to work out appropriate adaptation and mitigation strategies.	
E2	**Sub Area**	**Weather Prediction (NESAC / SAC)**
E2.1	**Impact of Atmospheric Chemistry on Weather Prediction (SAC)** Atmospheric aerosols have a large influence on air quality and, also in the well-being of human and ecosystem. Aerosols affect the earth-atmosphere radiation budget directly by scattering and absorbing the incoming solar radiation and indirectly by influencing the processes of formation of clouds and precipitation. Assimilation of satellite derived aerosols and other chemical constituents in NWP along with the chemical transport modelling have been planned . The impact of chemical data assimilation on mesoscale weather prediction will be also studied.	

E2.2	**Satellite and radar based weather nowcasting (SAC)** Satellite and radar data is being used for development of algorithms for nowcasting and tracking of cloud and precipitating systems. INSAT-3D/3DR data is extensively used for monitoring cloud growth and also for predicting the flow fields associated with precipitating systems. The research outputs feeds into the operational nowcasting application hosted on the MOSDAC webportal for societal benefit. In conjunction, Doppler weather radar (DWR) data is also used for developing algorithms to track and predict the movement of convective systems. Polarimeteric radar has also been used to develop Hydrometeor classification algorithm for more potential lightning prediction. Furthermore advanced AI/ML are been experimented on, for better accuracy and longer lead time. In near future blending of data / model outputs from different sources is future.
E2.3	**Assimilation of Satellite Data in Numerical Weather Prediction Models (SAC)** Accurate prediction of high-impact weather events and the area of the greatest threat represent a major challenge for planners to minimize the loss of lives and damage to property. Advance research is being planned to carry out non-linear data assimilation of satellite measurements in the numerical weather prediction (NWP) models. ISRO is aiming at improving short-range weather forecasting using satellite observations. For this activity various satellite observations are ingested in the NWP model using advance data assimilation techniques. In addition, research is also focused to improve NWP prediction using combination of Data Assimilation and Machine Learning methods.
E2.4	**Cyclone Track and Intensity Prediction Using Satellite Data and Numerical Models (SAC)** Advance and accurate prediction of tropical cyclones is highly important for issuing the warnings and saving the lives. Real-time winds obtained from scatterometer (SCATSAT-1) are used for tropical cyclogenesis predictions of all the low-pressure systems formed in the North Indian Ocean. The cyclone track and intensity prediction is being done using numerical models and satellite data that involves empirical and dynamic modelling and assimilation techniques. The cyclone centric satellite products are generated, which are very useful for cyclone positioning and its structure and intensity estimation.
E2.5	**Deep Learning Based Convective Cloud Detection using INSAT-3D/3DR/3DS data (NESAC)** Thunderstorms, as mesoscale convective systems, can result in severe weather events such as lightning, heavy rainfall, and hail. Cloud properties are often employed as indirect indicators for identifying thunderstorms, with satellite data proving invaluable in offering wide-area, short-term measurements of moisture and atmospheric volatility. Deep learning models, with properly labelled data, can efficiently learn intricate patterns and relationships, enabling precise segmentation and classification of complex non-unformed structures such as clouds.

E2.6	**Heavy rainfall prediction over Indian region using Satellite Data, Radar data and Numerical Weather Prediction models (NESAC)** Accurate heavy rainfall prediction is crucial for mitigating weather-induced disasters such as floods and thunderstorms. Satellite-derived real-time wind data from INSAT-3D/3DR play a vital role in improving monsoon rainfall simulations through data assimilation techniques in Numerical Weather Prediction (NWP) models. These observations are particularly valuable in data-sparse regions, such as the complex terrain of India, where conventional ground-based measurements are limited. In addition to satellite wind data, radar observations provide critical information on reflectivity and radial velocity, enhancing the simulation of convective systems. Radar data can be assimilated using both direct and indirect methods. The indirect approach, where water vapor information is derived from reflectivity and then assimilated into the model, has been shown to improve forecasts of isolated heavy rainfall events. Advanced data assimilation techniques, including 3DEnVAR, Hybrid-ETKF, and Hybrid-EAKF, offer a sophisticated framework for incorporating these diverse observational datasets into NWP models, leading to improved rainfall forecasts and better disaster preparedness.	
F	**Area**	**Physical Oceanography (Development of Blue Economy) (SAC)**
F1	**Sub Area**	**Numerical Models related to Ocean Studies (SAC)**
F1.1	**Assimilation of Satellite/In Situ Data in Numerical Ocean Prediction Models: Observation System Studies Experiment (SAC)** Assimilation of Satellite/In Situ Data in Numerical Ocean Prediction Models: Observation System Studies Experiment (OSSE). Advance research is being carried out for assimilation of satellite derived parameters salinity, temperature, sea level, wave height, ocean color and wave spectrum) in ocean prediction models. This involves development of various assimilation techniques for improving the initial condition in the models. Apart from satellite data, lot of in situ measurements (glider, HF Radar, wave rider buoys etc.) are also being taken in the present. The outputs from these models are routinely available on the mosdac.gov.in through the "Ocean Eye" and disseminated on request through an automatized email based system. In order to identify gap areas in the current space based observing systems, observing system simulation experiments are performed for defining future sensor missions. This require intensive modelling and optimization techniques to ascertain the importance of satellite-based and in situ-based observations and to suggest optimum sensor characteristic. Model tuning by parameter estimation using data driven techniques (like AI/ML) can be an important step in improving the model simulations.	

F1.2	**Study on Coastal dynamics Using Satellite and High Resolution Numerical Models (SAC)** Coastal dynamics are extremely important to understand as it has significant implications on coastal population. Currently following research topics are being envisaged in SAC: • Storm surge and coastal inundation: In this component, numerical models and satellite data are used to simulate and forecast the storm surge and inundation along the Indian coasts during the event of cyclone. Impact of satellite derived winds is also studied. This activity will be further extended to generate vulnerability maps for Indian coasts due to storm surge inundation in the climate change scenario. • Oil spill trajectory forecasting is extremely important for planning the mitigation steps in order to minimize the damage to the marine ecosystem due to an event of oil spill. Advection based models have been developed in house in order to identify the source of tar balls found on the beaches of various Indian coasts. Further research with high resolution satellite currents (from combination of SWOT and Oceansat-3) and introducing complexities in the trajectory models is being carried out. Finite time Lyapunov exponent (FTLE) fields derived from satellite currents are available on MOSDAC that help to forecast pathways of oil spill.	
F1.3	**Seasonal Ocean Prediction with Coupled Atmosphere-Ocean Models (SAC)** Forecast of anomalous oceanic conditions (Dipole/El Nino) at least one season in advance is of high importance as it has direct influence on the Indian Summer Monsoon. These seasonal to long term forecasts are required to be done by making synergistic use of satellite observations and couple Ocean Atmosphere models. Effect of satellite data assimilation on the skills of these forecasts are also required to be assessed. Regional Sea level rise is analyzed from the 36 years of altimeter observations and the mechanisms responsible for difference in Service-level Agreement (SLA) rise rates in different basins (Arabian Sea and Bay of Bengal) are being studied. One of the major challenges is the coastal sea level rise, for which the only source of observations are the tide gauge stations because of the non-availability of altimeter data near to the coast. Hence it is required to develop AI/ML based/dynamical techniques for interpolating/downscaling sea level observations from altimeter to the coastal regions by making use of numerical models and tide gauge stations. This is an important activity which will further help in identification of vulnerable zones in the climate change scenario.	
F2	**Sub Area**	**Oceanography studies (SAC)**
F2.1	**High Resolution Oceanography (SAC)** In the view of high resolution (temporal and spatial) satellite observations from synthetic aperture radar, forthcoming Oceansat-3, Surface Water and Ocean Topography mission (SWOT) mission, and optical imageries, high resolution oceanography is fast becoming a reality. Synergistic use of these information will be key to understanding many	

	unresolved processes at sub-mesoscale level, which can help in better ocean estimation. Interaction of mesoscale scale dynamics (eddies) with sub-mesoscale is another interesting area of research for energy cascading. Region specific high resolution models with relocatable grids are being utilized for this purpose.	
F2.2	**Ocean Reanalysis and Air Sea Interaction Studies (SAC)** One of the future goals is to develop a methodology to generate high quality three dimensional ocean reanalysis product for last 30 years based on satellite observations and numerical ocean model. This will be utilized not only for various oceanic process studies but also to initialize seasonal prediction coupled models. Some of the reanalysis fields that are currently being generated are of sea level, currents and chlorophyll. Research is also being carried out in generating merged products (like for e.g. SST) by combining observations from various Indian and International missions in order to provide continuous and gridded space-time observations for various applications and process studies. Efforts are also being carried out to generate high resolution salinity field from low resolution satellite observations using Lagrangian based techniques. These fields will be useful for fine scale process studies.	
G	**Area**	**Geophysical Parameters and Applications (NESAC / SAC)**
G1	**Sub Area**	**Geophysical Parameter Retrievals (NESAC / SAC)**
G1.1	**Retrieval of Geophysical Parameters from Satellite Data (SAC)** ISRO has planned for launching a number of meteorological and oceanographic satellites in near future. Presently it has INSAT-3D/3DR satellites in the orbit. In near future, it has plan to launch many satellites in Geostationary and polar orbits for the same such as Oceansat-3 and INSAT-3DS. This also includes many advanced sensors such as Microwave Temperature Sounding Unit (TSU) and Humidity Sounding Unit (HSU) in future missions. There is also possibility of inclusion of an advanced microwave radiometer similar to GPM Microwave Imager (GMI) in future missions. Future generation of INSAT satellite may also have advanced imager, lightning imager and hyperspectral sounder on-board. It is a challenging work to retrieve geophysical parameters from the sensor data of these satellites. This involves Radiative Transfer modelling, Geophysical Model Function development and the Inverse modeling techniques.	
G1.2	**Retrieving vertical Profile of Temperature and Humidity using Radio Occultation (RO) Data (NESAC)** Vertical profiles of atmospheric temperature and humidity are important parameters in atmospheric research, especially for weather forecast and climate change studies. Radio Occultation technique is an effective method to retrieve these profiles by receiving radio signals from GPS navigation satellites. The method makes use of the fact that degree of refraction of radio waves while passing through the atmosphere depends on gradient in air density which in turn depends on temperature and humidity.	

G1.3	**Other Research Areas related to Parameter Retrieval (SAC)** • Cloud/Rain type classification using INSAT/Kalpana observations. • Study of cloud micro physics using 157 GHz of MADRAS and INSAT data • Combination of INSAT-3D Imager and Sounder products to improve the quality of a few critical atmospheric products, such as atmospheric stability, total WV contents, SST etc. • Improved tracer selection, tracking and height assignment methods for Atmospheric Motion Vectors (AMV) retrieval from VIS, MIR, WV, TIR1 channels. • Retrieval of high-resolution winds is a challenging research area that may be attempted with Geo imagine Satellite (GISAT) satellite.	
G2	**Sub Area**	**Applications of Geophysical Parameters (SAC)**
G2.1	**IRNSS/GNSS Applications (SAC)** IRNSS/GNSS offers unique opportunity to retrieve atmospheric geophysical parameters such as TPW. ISRO may also develop satellite-borne receivers for IRNSS/GNSS reflectometry, which has potential to provide various surface parameters including sea surface height, intense sea surface wind speed and direction under severe weather conditions, soil moisture, ice and snow thickness, etc. Theoretical modelling and simulations of the reflectometry observations is desired for the retrieval of the parameters. Until IRNSS receivers are not available, International missions such as TDS-1 and Cyclone Global Navigation Satellite System (CYGNSS) can be used to validate the simulation studies and retrieval algorithms.	
G2.2	**Merged Data Products (SAC)** Develop data fusion methods to derive most optimized products using a synergy of observations. The examples are (a) Optimized temperature/humidity profiles using IR and microwave sounders (b)Optimized SST and rainfall products from IR and Microwave imagers.	
G2.3	**Advanced System Studies for New Sensor Definition (SAC)** For measurements of atmospheric and Oceanic parameters, new advance sensors have to be defined for future satellites. System studies are being done with the help of Radiative transfer models to define the appropriate frequency, NEDT/SNR and bandwidth of new sensors. Sensitivity analysis is also being carried out to understand the error budget and appropriate resolutions (both spatial and temporal)required for the retrieval of geophysical parameter.	
G2.4	**Development of Procedures for Long Term Records of Essential Climate Variables (SAC)** Long term records of essential climate variables such as SST, wind, radiation budget, water vapour, clouds, ozone, precipitation, sea surface salinity, sea level, sea state, etc.,	

	which are defined by Global Climate Observing System (GCOS), are necessary for characterising the trends in earth's climatic variations. Measurements from different satellite instruments suffer from different accuracies and biases due to evolution/performance of the instruments and/or retrieval algorithms. Thus there is need to intercalibrate the instruments/parameters to reduce the measurement biases among them.	
G3	**Sub Area**	**Geophysical Product Validations (SAC)**
G3.1	**Validation algorithms (SAC)** Development of automatic procedures for validating various satellite derived geo-physical parameters from Indian satellite missions (INSAT-3DR/3DS, Oceansat-3/3A, GISAT-1A and TRISHNA etc.) by following the Protocol development on measurements, instrument operation, quality control, and calibration standards. Presently, the most important exercise of validating sensor derived geo-physical products are done using community vetted matchup methodology and qualifying various data sets (in-situ, contemporary missions, climate data sets, data from various collaborative agencies, etc.).	
G3.2	**Validation of Hyperspectral Satellite Data (SAC)** Development of techniques for the assessment and refinement of hyperspectral remote sensing retrievals of chlorophyll-a and other phytoplankton pigments, Phytoplankton Functional Types (PFTs) and phytoplankton specific absorption.	
G3.3	**Integration of CHEMTAX and HPLC for Algorithm Validation (SAC)** Development of new algorithms for the use of CHEMTAX-HPLC derived phytoplankton community composition to validate and refine ocean colour algorithms for pigment-based estimates of phytoplankton diversity, algal bloom, primary production etc. in Indian Ocean region using satellite data and sea-truth measurements.	
G3.4	**Enhancing validation in ultra-oligotrophic and coastal waters (SAC)** Improvement in validation efforts in very low-chlorophyll regions and optically complex coastal waters (using the sea-truth data collected during ship and boat cruises) by incorporating new bio-optical models, adaptive atmospheric correction, and regional algorithms tailored to case-2 waters.	
H	**Area**	**Marine Biology and Ecosystem (SAC)**
H1.1	**Bio-Optical characterization of estuaries, brackish water lagoons and coastal wetlands (SAC)** Estuaries, lagoons and wetlands are important components of marine ecosystem, heavily influenced by anthropogenic activities and susceptible to climate change. These are categorized as optically complex waters (OCW). Challenging areas of research are	

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- Accurate estimation of optically active components such as chlorophyll concentration, coloured dissolved organic matter (CDOM) absorption, total particulate matter and total suspended sediments in optically complex waters.
- Development of atmospheric correction models for accurate estimation of remote sensing reflectances in OCW.
- Hyperspectral characterization of optical constituents in VIS-NIR region.
- AI –ML based techniques for retrieval of optical constituents in OCW.

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<tr><td>H1.2</td><td colspan="2">

Marine Living Resource Management (SAC)

Climate change is profoundly effecting habitat, breeding and population dynamics of marine living resources. Some of the challenging areas of research in this field are

- Habitat identification of endangered marine organism using geospatial information
- Site suitability for mariculture using remotely derived parameters and in-situ observations in GIS based models
- Ocean colour remote sensing in zooplankton, secondary production and tertiary production studies
- Ocean colour remote sensing for microbial ecosystems
- Habitats of large pelagics using remotely sensed parameters and fishery data

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<tr><td>H1.3</td><td colspan="2">

Biodiversity and ecosystem Studies (SAC)

Climate change and global warming is rapidly effecting species biodiversity with native population replaced by few fast growing species and loss in biodiversity. Major areas of research are

- Ocean colour remote sensing in biodiversity studies of micro and macroalgae of Indian marine waters
- Optical and biological studies of harmful and beneficial algal blooms using remote sensing
- Optical and biological characteristics of benthic ecosystems (Sea grass, Seaweeds, benthic microalgae)
- Phytoplankton fluorescence and physiological studies
- Impact of ocean acidification on biodiversity
- Climate change studies on phytoplankton functional groups, size classes and ecosystem structure.

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<tr><td>I</td><td>Area</td><td>Development of Applications Techniques (SAC)</td></tr>
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Microwave Techniques Development (SAC)

Microwave remote sensing instruments, like Synthetic Aperture Radar (SAR), Scatterometer, Radiometer, Altimeter and Ground Penetration Radar (GPR), provide valuable inputs for geophysical parameter retrievals, monitoring and investigative

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	studies. Though, data from these sensors is regularly processed using various retrieval algorithms, to cater to corresponding user applications, there is still a huge scope to develop and employ advanced techniques to fully exploit the data for maximum utilization. There is also requirement to simulate and demonstrate newer techniques, which will enable definition of future microwave sensors. With the above requirements in perspective, following are the potential areas of research: • Development of techniques to simulate new SAR configuration data eg., Geosynchronous SAR (GeoSAR), bistatic SAR, GEO-LEO SAR and their processing algorithms, to study geophysical parameters retrieval accuracies. • Development of polarimetric SAR modelling for varied scenarios of target, terrain & canopy configurations. • Development of subsurface models for polarimetric GPR simulations. • Development of object/feature detection techniques using GPR and Wall-Penetration radars, and their performance evaluation. • Development of processing methodologies for Rail-mounted Interferometric SAR system for land subsidence monitoring; system development, demonstration of processing methodology and its performance evaluation. • Full-wave numerical Maxwell Model 3D simulations for microwave scattering from forests including detailed 3D modeling of forest canopy structure. • Signal processing techniques for forest mapping using 3D-SAR Tomography and Higher dimensional SAR Tomography; applications of SAR tomography for forest mapping in plains and hill slopes. • Development of techniques for root-zone soil moisture estimation. • Development of Polarimetric SAR models for Permafrost characterization in Himalayan regions. • PS- and DS-InSAR based algorithms for land-deformation estimation; Algorithms for Landslides. • damage assessment from SAR data; development of regular monitoring system with alert generation capability.	
I2	**Sub Area**	**Hyperspectral Techniques Development (SAC)**
I2.1	**Hyperspectral Techniques Development** Hyperspectral remote sensing combines imaging and spectrometry. Most of Earth's surface materials contain characteristic absorption features which are very narrow in the spectral appearance, hence using high spectral resolution sensors called hyperspectral sensors, we can detect hundreds of very narrow, contiguous spectral bands throughout the visible, near-infrared, mid-infrared and thermal infrared portions	

of the electromagnetic spectrum. The very high spectral resolution facilitates fine discrimination between different targets and its inherent chemical compositional characteristics based on their spectral response in each of the narrow bands. Sophisticated and complex data analysis methods are required due to high dimensionality and size of the hyperspectral data, the spectral mixing and contamination in the measurement process such as noise and atmospheric effects. Therefore, we need to explore and develop advance hyperspectral data analysis techniques and tools, which may be organized in different themes: data fusion, spectral unmixing, classification, target detection, physical parameter retrieval etc.

- To explore Residual-3D-CNN, standard computer vision models such as LeNet-5, AlexNet, VGG, Darknet, Squeezenet to Hx classification with different learnable filters such as using 1D, 2D and 3D to see their effectiveness for remote sensing data classification.
- Another relevant challenge is to integrate spatial-contextual information in spectral-based classifiers for hyperspectral data to take advantage of the complementarities. For Example: 3D deep convolutional neural networks (CNN).
- The challenge in vegetation (multi-crop, forest species) classification now is learning temporal information from time series hyperspectral data. The addition of the time domain to the learning model apart from contextual and spectral information adds an additional dimension to the input data making the learning process much more challenging.
- Current research on simultaneous contextual information extraction and temporal information extraction can also be further explored by combining the concept of Convolutional and Recurrent neural Network (RNN) such as Convolutional Long Short-Term Memory (LSTM) or Convolutional Gated Recurrent Unit (GRU) to the temporal image data. This can be very effective for time series data classification.
- Physics inspired Deep-Learning based Inversion models for geophysical parameter retrieval.
- To explore hypersharpening based methods for denoising which are based on component substitution (CS) and multiresolution analysis (MRA).
- The unmixing based strategies such as Hyperspectral Image Superresolution via Subspace-Based Regularization (HySure) and CNMF (Coupled Non Negative Matrix Factorization) have great potential even when Spectral Response Function (SRF) has limited overlap.
- A possible future for further performance improvement lies in developing hybrid approaches that combine the advantages of different classes of methods such as MRA and Unmixing. Current Unmixing approaches rely mostly on the assumption of Linear Unmixing Model which can be further extended to Bi-linear or Non-Linear based models.

	• VNIR-Hx and thermal-Hx data Fusion and Hyperspectral, LIDAR and SAR data fusion for precision agriculture, soil characteristics, forest biomass etc. studies. • To develop physics-inspired and sparse based non-linear un-mixing models. • Real-Time robust spectral unmixing algorithm and tools which can be used for airborne or drone based sensor data. • Development of high performance / parallel computing model for spectral unmixing (Sparse unmixing models depend on spectral library which takes too much time). • Dictionary Learning based Estimation and data recovery for sub-pixel classification of Hx data. For eg. soil property estimation from mixed pixels.	
J	**Area**	**Applications of Remote Sensing in Agriculture, Forestry & Ecosystem (IIRS / NESAC / NRSC / SAC)**
J1	**Sub Area**	**Agriculture (NESAC / NRSC / SAC)**
J1.1	**Crop production, yield and Price Forecasting (SAC)** • Monthly forecast of major crops & long-lead forecast • Automated crop yield estimation thorough process-based model • Prediction of market arrival & price through statistical and AI/ML approaches • Acreage of rabi pulse types, Kharif onion through Opti-SAR observations • Fodder type-wise area, yield & production • Site suitability of medicinal plants	
J1.2	**Agro advisories and crop loss assessment (SAC)** • New Drought product from Satellite and its use in crop loss • Prototype demonstration of Digital agro-climatic atlas • Horticulture-specific weather-based insurance product using satellite data • Local-scale / high-resolution weather forecast using AI/ML • Modelling macro/micro climate & animal disease prediction	
J1.3	**Precision Agriculture (SAC)** • Resource-use efficiency (Crop Water Productivity, Nutrient Use Efficiency), Soil carbon dynamics. • Fodder nutrient, Active medical ingradient & pesticide residue investigation (UAV, satellite hyperspectral, thermal, Imaging microscopy – Experiments, analysis, data fusion). • Investigations on Solar-Induced Fluorescence (SIF) & hyperspectral related to photosynthesis & early disease detection.	
J1.4	**3D soil mapping (NRSC)** 3D soil mapping is an advanced technique that involves creating detailed, three dimensional representations of soil properties across a landscape. This method utilizes a	

	combination of field data collection, geophysical surveys, remote sensing, and modeling to capture variations in soil characteristics such as texture, moisture content, organic matter, pH levels, and nutrient distribution. The result is a spatially accurate map that provides a more in-depth understanding of soil variability, which can be essential for precision agriculture, land management, and environmental monitoring. The advantage of 3D soil mapping lies in its ability to offer a more comprehensive view of the soil profile, going beyond traditional 2D maps. The need of the hour is to map the soil properties three dimensionally using geo- statistical approaches like radial basis function (RBF), krigging or data mining tools such as neural networks, Cubist, random forests, etc. or a combination of both. Besides, the 3-D visualization of soil properties using open source tools like openGL with geo-spatial querying will provide a new dimension to the way the soils are looked at. Such information will form a base line to develop 3D process based models involving pedo-transformations.
J1.5	**Assessment of Carbon Sequestration Potential of Plantation crops using Geospatial Technology (NRSC)** Carbon sequestration is one of the efficient methods to mitigate carbon emissions and reduce global warming. The plantation crops encompassing a diverse array of tree species, offer a unique chance to sequester a considerable amount of atmospheric carbon dioxide. These woody trees store 25–100 times more carbon than agricultural crops. Assessing the carbon sequestration (CS) potential of plantation crops is vital for GHG mitigation, strategic planning, and carbon trading. Quantifying CS in diverse agroforestry ecosystems remains a challenge, necessitating cost-effective methodologies. While eddy-covariance flux towers provide accurate flux measurements, they are expensive and can cover small area. Geospatial technologies, such as UAV-mounted sensors and LiDAR, offer biomass mapping for efficient CS estimation. A comprehensive methodology should integrate techniques to assess Above-Ground Biomass (AGB), Below-Ground Biomass (BGB), Soil Carbon, and Necromass. This study is proposed for assessment of carbon sequestration potential of plantation crops using field and UAV based approach and its up scaling to regional and national using satellite data.
J1.6	**Impact of Aerosol on Agricultural Productivity (NESAC)** Atmospheric aerosols alter energy balance of the earth atmosphere system through scattering and absorption of radiation and also by modifying cloud properties. Through scattering and absorption, atmospheric aerosols reduce surface reaching solar radiation, which in turn affect agricultural production. In addition, aerosols affect large scale circulation systems such as Indian summer monsoon and associated rainfall. Changes in rainfall will have significant effect on agricultural production.
J1.7	**Soil Nutrient Management for Precision Agriculture using Hyper Spectral Data (NESAC)** To study develop model/algorithm using hyperspectral imaging for precision farming.

J1.8	**Soil Carbon Sequestration (NESAC)** Developing methodology/model to estimate soil carbon sequestration status using different resolution satellite data.	
J1.9	**Understanding Shifting Cultivation as a Driver of LULC Change (NESAC)** Identifying space based indicators to link shifting cultivation as a driver for LULC changes and its impact.	
J2	**Sub Area**	**Forestry and Ecosystem (IIRS / NESAC / NRSC / SAC)**
J2.1	**Integrating Acoustics and Geospatial Technology for Monitoring Biological Communities in Soundscapes (IIRS)** Soundscape ecology is an emerging field that explores how biological, geophysical, and anthropogenic sounds shape ecosystems. Wildlife monitoring within soundscapes provides crucial insights into species distribution, habitat use, and responses to environmental changes. Traditional wildlife monitoring methods, however, are often resource-intensive, prone to observer bias, and limited in their ability to detect elusive or nocturnal species. Acoustic monitoring, which involves recording and analysing animal vocalizations, offers a non-invasive and cost-effective alternative. It enables researchers to study biodiversity patterns, track species activity, and assess the impacts of anthropogenic disturbances on wildlife communication within soundscapes. Geospatial technology, including Geographic Information Systems (GIS) and remote sensing, plays a critical role in mapping habitat dynamics, tracking species movements, and modelling biodiversity trends. When integrated with bioacoustics, geospatial tools can spatially analyse soundscape data to correlate wildlife activity with habitat conditions and human-induced pressures such as deforestation, urbanization, and industrial noise. This combination allows for a deeper understanding of how species interact within their acoustic environments and how soundscapes are altered by ecological changes. The proposed project aims to integrating acoustic recordings with geospatial tools for assessing impacts on wildlife activities across diverse landscapes with varying degrees of human impact. AI/ML-based automated species recognition will be employed to classify sounds, detect ecological disturbances, and track population trends within soundscapes. By merging bioacoustics data with geospatial analytics, study will be able to visualize patterns of species presence, identify key habitat corridors, and assess shifts in biodiversity due to environmental stressors. This interdisciplinary approach represents an innovative, non-invasive solution for long-term ecological monitoring. By harnessing the power of acoustics and geospatial technology, the project will contribute to a more comprehensive understanding of soundscapes, inform conservation strategies, and support biodiversity protection efforts in rapidly changing environments.	

J2.2	**Monitoring tree plantations and Retrieval of Biophysical Parameters using temporal data (NRSC)** Growth monitoring of various tree formations (plantations, tree clusters, scattered farmland trees etc.) has several crucial applications for environment, agriculture and climate change research. This project is envisaged for retrieval of several key biophysical tree parameters by integrating temporal satellite, UAV and LiDAR data along with field data. These parameters include tree height, Diameter at Breast Height (DBH), canopy area and volume, Leaf Area Index (LAI), Above Ground Biomass (AGB) etc., which are essential metrics for ecosystem monitoring. Time-series analysis of multi-sensor, high resolution datasets of tree resources can reveal patterns of short-term and long-term tree growth trends, along with disturbance incidences. This procedure can be semi-automated /automated using advanced analytical techniques for upscaling to larger regions towards carbon stock assessment and REDD+ initiatives of the country.
J2.3	**Impact of Rural & Watershed Development activities towards Climate Resilience (NRSC)** Watershed development programs play a crucial role in poverty alleviation, livelihood enhancement and sustainable management of land, water, and natural resources, particularly in rainfed regions. As climate change, environmental degradation, and water scarcity intensify, there is an urgent need for a science-driven approach to watershed and rural development. By integrating emerging technologies, geospatial tools, and data-driven policy frameworks, these programs can be optimized to enhance climate resilience and ecosystem sustainability. This study aims to comprehensively evaluate the impact of various watershed and rural development initiatives, to analyze their influence on key environmental parameters, including: • Increase in green cover through afforestation and agroforestry interventions. • Expansion of water spread areas due to improved rainwater harvesting and storage. • Enhanced irrigation availability supporting multi-cropping and agricultural diversification. • Evapotranspiration studies to assess water use efficiency and vegetation health. • Runoff estimation for improved water conservation planning. • Changes in land surface temperature (LST) as an indicator of microclimatic modifications.
J2.4	**Forest carbon mapping (SAC)** Accurate estimation of vegetation biomass is crucial for accounting carbon sequestration and emissions from forest ecosystem. Advancement in remote sensing technology has enabled more precise quantification of forest above-ground biomass with lower levels

J2.4	of uncertainties in estimates. Following are the research areas that are proposed under this theme: • Development of algorithm and tool for forest above-ground biomass using multi-sensor remote sensing data/ PolInSAR / SAR tomography • Multi-sensor based remote sensing for biomass estimation of scrublands and grassland. • Development of framework for quantification of carbon sequestration potential of forests/ ecosystems
J2.5	**Modelling and retrieval of 'blue carbon' and 'teal carbon' to assess the role of wetlands in climate change adaptations and resilience (SAC)** Blue carbon is the carbon dioxide that is stored in coastal and ocean ecosystems, such as mangroves, seagrasses and salt marshes. Whereas, Teal carbon is the carbon stored in non-tidal freshwater wetlands, including vegetation, microbial biomass and organic matter. These carbons are major contributors to global carbon sequestration playing key roles in regulating greenhouse gases. Identifying and measuring the amount of these carbons is a part of the effort to understand how these wetlands can help with climate change adaptations and resilience. Following are the research areas that are proposed under this theme: • Modelling and retrieval of 'blue carbon' and/or 'teal carbon' from coastal and inland ecosystems to assess their role in climate change adaptations and resilience • Quantification of Essential Ecosystem Services for assessments and development of framework for monitoring climate change impacts on ecosystem services.
J2.6	**LiDAR remote sensing (SAC)** Applications of LiDAR remote sensing in forestry and ecosystems studies is advancing fast in the recent times due to the proliferation of terrestrial, airborne and space-borne LiDAR scanning instruments. Also, LiDAR has been proven to complement other sensors viz. optical, radar and hyperspectral for studies related to vegetation and land. Development of various processing and analysis tools has aided to this and has made LiDAR a powerful tool for studying and monitoring vegetation and land ecosystems. Following are the research areas that can be addressed using LiDAR remote sensing: • Retrieval of vegetation allometric parameters and above-ground biomass using LiDAR data. • Applications of LiDAR remote sensing for habitat mapping, forest health monitoring and vegetation monitoring for understanding the climate change adaptations and resilience • Development of automated tools using AI/ML for LiDAR based forest vegetation mapping

J2.7	**Desertification & Land Degradation (SAC)** Desertification and land degradation constitutes one of the most alarming geo-environmental global problem affecting two third countries of the world on which one billion people live (one sixth of world's population). Land degradation is reduction or loss of productive land due to natural processes, climate change and human activities. Desertification is land degradation in arid, semi-arid and dry sub-humid areas (also known as Drylands). The processes of desertification and land degradation are observed to have accelerated during recent years globally. There is a need to stop and reverse the process of desertification and land degradation. It is required to develop advanced digital classification techniques using object based approaches, machine learning/ artificial neural network for automated land degradation mapping using multi-temporal and multi-sensor satellite data, vulnerability and risk assessment and developing action plans to combat land degradation.
J2.8	**Forest Species Discrimination & Forest Biophysical Parameters Retrieval (NESAC)** Penetration and all-weather capability of SAR along with sensitivity of SAR data towards physical, geometrical and di-electrical properties of forest trees and plantations of various shapes, sizes and structures along with all-weather & penetration capabilities of SAR can successfully be used to retrieve various biophysical parameters of forest like forest above ground biomass, tree height etc. Availability of multi-parametric SAR along with advance SAR techniques like SAR Interferometry, Hybrid polarimetry, fully.
J2.9	**Assessment, Monitoring and Management of Wetland Ecosystem using Radar Remote Sensing (NESAC)** Wetlands play an important role in ground water recharge and also provide unique habitats for wide range of flora & fauna. Therefore, wetlands have significant biodiversity resources. However, the recognition of biodiversity conservation values of the wetlands has been neglected for a long time. As a result of this, there is an alarming loss of wetlands. The alarming loss of wetlands all over the globe had initiated an inter-governmental treaty which provides the framework for National action and International cooperation for the conservation and wise use of wetlands and their resources. This treaty was signed in Ramsar, Iran, in 1971 and is known as 'Ramsar Convention'. In order to monitor wetlands, on local, regional and national levels, there is an urgent need to develop user friendly and cost effective tools. Remote sensing can play an important role for assessment, monitoring and management of wetland ecosystem. Lot of work has already been done in the field of wetland studies using data from conventional remote sensing sensors operating in optical and infrared region of the electromagnetic spectrum. However, for studies of wetland, optical remote sensing data exhibit a few limitations. In contrast to radar remote sensing, the major limitation with optical data is uncertainty of getting cloud free data during monsoon (rainy) season. The analysis during monsoon season is of prime importance as it is the main

	source of water that controls the ecosystem of most of the inland wetlands. Moreover, sensitivity of optical data for physical, geometrical, dielectrical and textural variation of vegetation (both terrestrial and aquatic) is also limited as compared with Radar data operating in the microwave region of the electromagnetic spectrum, which is highly sensitive for these properties of various components of a wetland ecosystem. Capability of microwave signals transmitted from the Synthetic Aperture Radar (SAR) sensor to penetrate vegetation cover and to sense the moisture content of the earth materials, allows microwaves to monitor the wetland ecosystem more accurately as compared to optical remote sensing tools.	
J2.10	**Forest Meteorology and Ecosystem Modeling (NESAC)** Forest plays an important role in governing the energy and mass exchange over a region. Quantification of energy fluxes helps in modeling regional climate. SAC is involved in development of 24 Micrometeorological station network in India which are taking continuous measurements in agriculture and natural vegetation system. There is need to develop land surface process models to quantify the fluxes with reference to surface and atmospheric forcing. Most of the biogeochemical modeling depends on phenological understanding of different vegetation types. There is need to carry out ground experimentation as well as satellite modeling to estimate the phenological matrices of different vegetation types. Such efforts would lead to develop the forest growth simulation models. Modeling NPP using satellite measurements such as INSAT-CCD is an important future thrust area. There is need to develop process based model to quantify the net primary productivity and ecosystem level productivity. Network of annual biomass measurements are needed to validate the NPP products. It is known that biomass modeling is limited with optical measurements due to saturation of optical light in denser canopy. Radar based approaches provide improved assessment. It is proposed to develop LIDAR based modeling to account the height of the forest in the estimation of forest biomass. Detection of forest fire and development of fire alarm system based on bioclimatic indices is an important research area which will be carried out using INSAT-3D satellite data.	
K	**Area**	**Air quality, Atmospheric Trace gases and Aerosols (NESAC / SAC)**
K1	**Sub Area**	**Atmospheric Trace Gases (NESAC / SAC)**
K1.1	**Advanced Trace Gas Retrieval (SAC)** Utilizing Differential Optical Absorption Spectroscopy (DOAS), combined with ground-based FTIR and LIDAR, will enhance methane and carbon dioxide retrievals from space. The integration of polarimeter data enables improved characterization of aerosols, aiding in the correction of atmospheric interferences that impact gas retrieval accuracy.	

K1.2	**Regional Monitoring of Trace and Green House Gases (NESAC)** Trace and green house gases in earth atmosphere are important as they affect both air quality and radiation balance of the earth atmosphere system. Anthropogenic activities influence abundance of many of these gases in the atmosphere. In view of this, it is necessary to have continuous monitoring of these gases and changes in their concentrations over different regions to understand anthropogenic impacts on global climate change.	
K2	**Sub Area**	**Aerosols (NESAC / SAC)**
K2.1	**LIDAR-Based Vertical Profiling of Aerosols (SAC)** Developing models for vertical particulate extinction and backscatter profiles using satellite and ground-based LIDAR will provide critical insights into pollution transport and atmospheric layering. This will enable high-precision monitoring of aerosols from urban pollution, industrial emissions, and biomass burning.	
K2.2	**Transport of Chemical Constituents of Atmosphere using WRF chemical Transfer modelling (NESAC)** Atmospheric dynamics lead to dispersion and transport of chemical constituents in atmosphere from their source regions to distant locations. In order to understand effects of chemical constituents in earth atmosphere, their transport from source regions to other locations has to be examined. Transport of chemical constituents in atmosphere can be investigated in detail using models such as WRF.	
K2.3	**Aerosol Characterization and its Impact on Solar Radiation (NESAC)** Atmospheric aerosols, one of the major climate forcing agents, affect earth atmosphere radiation balance through aerosol radiation interactions and aerosol cloud interactions. Despite the efforts being carried out for past few decades, atmospheric aerosol remains one of the major sources of uncertainty in climate forcing estimates. Better understanding of aerosol impacts on weather and climate demands adequate incorporation of aerosol parameters in climate models, which needs accurate measurements of aerosol characteristics.	
K2.4	**Aerosol Optical Thickness and Atmospheric Correction over Land (NESAC)** Calibration and radiometric normalization is the key issue in future remote sensing activities related with biophysical parameter retrieval and climate change. Atmospheric correction of the satellite data is a challenge. Most important input for atmospheric correction involved estimation of Aerosol optical thickness (AOT) either from network of ground observations or satellite data. Retrieval of AOT sensors like Resourcesat series is a challenge. There is need to develop simplified correction approach including AOR inputs using dark dense vegetation approach. There is further need to develop instrumentation with capability of polarized measurements and LIDAR sensing.	

K2.5	**Algorithm development for Atmospheric Aerosols (NESAC)** Algorithms for atmospheric aerosols using satellite over plain & hilly land and oceans, Aerosol transportation and climate studies.	
K2.6	**Active Fire Detection (SAC)** A multi-sensor approach using thermal infrared data will improve active fire detection, fire intensity assessment, and plume evolution tracking. Using geostationary satellite data, aapplications towards crop residue burning monitoring will help quantify aerosol and gas emissions, assessing their impact on ambient air quality and regional pollution events. AI-based forecasting models will further aid in early warning systems and mitigation strategies.	
K2.7	**AI/ML-Driven Downscaling and Data Fusion (SAC)** Incorporating AI/ML algorithms for data fusion and downscaling will enhance the spatial and temporal resolution of trace gas and aerosol datasets. Machine learning will optimize retrieval techniques, while data assimilation models will improve air quality forecasting and climate predictions.	
K2.8	**Ultrafine Radiative Transfer Simulation (SAC)** High-resolution radiative transfer simulations will improve understanding of gas-aerosol interactions, aiding in the refinement of retrieval techniques. These simulations will also help quantify radiative forcing effects, crucial for climate modeling and mitigation strategies.	
K2.9	**Observing System Simulation Experiments (SAC)** Conducting OSSEs will help evaluate the performance of future satellite missions by simulating atmospheric observations under various scenarios. These experiments will guide sensor design, retrieval algorithm development, and mission planning, ensuring optimal coverage and accuracy for atmospheric monitoring.	
K3	**Sub Area**	**Aerosol Remote Sensing (NESAC / SAC)**
K3.1	Simulation studies and specifications development of a hyperspectral sensor for retrieval of aerosol layer heights and aerosol characterization, and development of retrieval algorithms.	
K3.2	Atmospheric corrections of VNIR sensors is a challenge in absence of SWIR channels. In this direction, there is need to develop methods for AOD and surface reflectance retrieval for VNIR sensors such as AWiFS, Linear Imaging Self Scanning (LISS-III), Cartosat-2 etc.	
K3.3	Mapping and analysing the patterns of ground level particulate matter (an important factor to determine the ground level Air-Quality) using satellite data and modelling.	
K3.4	Development of models to estimate particulate matter using satellite data specifically for Indian atmosphere. The quantification of factors leading to harmfully high levels of particulate matter.	

K3.5	Development of on-board Parallel/FPGA algorithm for real-time application of hyperspectral data. (SAC)	
K3.6	Simulation of synthetic hyperspectral data using Radiative Transfer and Ray tracing models. (SAC)	
K3.7	**Surface Energy Budgeting using Remote Sensing (NESAC)** Surface energy budgeting assumes importance as the surface energy balance is one of the major factors affecting hydrostatic stability and mixing of atmospheric constituents such as pollutants in lower atmosphere. Remote sensing can be used for surface energy budgeting over large spatial extends to understand changes in surface energy balance and related effects in earth atmospheric boundary layer characteristics and associated processes Atmospheric Transport (role in determining the distributions of chemical species in the atmosphere, understanding process, circulation, vertical transport, atmospheric stability, turbulence etc) Trace gases measurement and monitoring (understanding trace gases, evolution, transportation, processes, measurements analysis and modelling.	
L	**Area**	**Aerial Remote Sensing using UAV (NESAC)**
L1.1	**Segmentation of Aerial / Satellite Data (NESAC)** Segmentation becomes more important with increasing spatial resolution of imagery. Texture in high-resolution aerial and high resolution satellite images requires substantial amendment in the conventional segmentation algorithms. The potential applications of this segmentation process are (1) Automatic 3D model generation (2) automatic DEM generation from DSM (3) Automation in Quality Checking of vector maps and many more.	
L1.2	**Design & Assembly of UAV Components-Payloads, Communication Components etc., UAV Data Acquisition, Processing, 3D Feature Capturing, Construction of 3D Surface Model/DEM, Automatic Object or Pattern Recognition (NESAC)**	
L1.3	**Development of Long Range Communication System for UAVs (NESAC)** Most of the commercial UAVs available today come with a communication range of 5-10 kms in clear line of sight. However for some applications like medicine delivery in remote/ disaster areas, river mapping/monitoring applications require long communication range 40-50 kms for real time transfer of telemetry and data. A low cost, low weight and range communication system will improve the capabilities of existing UAV systems.	
L1.4	**Development of Data Processing Software for High Volume UAV Data Processing (NESAC)** Processing of UAV data is a unique challenge due to its large volume. Few of the commercial softwares used for generation of complete data products such as DEM/DTM, 3D point cloud, contour maps etc are very costly and require high end systems. There is	

	a need for developing in house data processing software using open source tools with end to end data processing capabilities which do not require very end computers.	
L1.5	**Real time UAV Data Processing for Disaster Monitoring Applications (NESAC)** Data acquired from UAV surveys is downloaded after the survey and processed in the lab. Due to the high volume of data, the processing takes lot of time and real time quantitative analysis from the data cannot be made. A real time data processing technique where data is downloaded to ground station in real time as the flight progresses and put into software where maps/models are generated simultaneously and automatically will be helpful for quick disaster response and assessment.	
L1.6	**Improvements in Battery Capacity used in UAVs (NESAC)** Lithium Polymer batteries are being used as source of electric power in the present UAV systems which gives a maximum flight endurance up to 1 hr with different combinations. It is required to develop low weight high capacity batteries to further improve upon the flight endurance of UAVs using different materials and techniques.	
L1.7	**Automatic Detection of tree Height, Leaf Area Index, Canopy etc. for Biomass Estimation (NESAC)** Developing models for UAV data processing for automatic detection of tree height, canopy etc.	
L1.8	**Tree Species Detection from LiDAR Waveform Data (NESAC)**	
M	**Area**	**Atmospheric Dynamics and Coupling (NARL)**
M1	**Sub Area**	**Observations, Modelling and Simulations (NARL)**
M1.1	**Modelling of atmospheric tides (NARL)** Atmospheric tides are generated due to solar insolation absorption by water vapour, ozone, nitrogen and oxygen molecules. They play a major role in determining the thermal structure, circulation and ionospheric variabilities. The atmospheric tidal solutions can be obtained by solving Laplace tidal equations, which are basic fluid dynamical equations and necessary heating. The equations can be solved to get the height and latitudinal profiles of different modes of tides.	
M1.2	**Generation and propagation of atmospheric wave modes (NARL)** The upper atmosphere is governed by dynamics in addition to radiation and chemistry. The atmospheric waves play a major role in determining the dynamics of the upper atmosphere. The waves range from acoustic gravity waves to planetary scale waves. They have different generation mechanisms, namely, latent heat release in the deep convection, land sea thermal contract, orography, instability mechanisms etc. It is necessary to understand the generation mechanisms of different atmospheric waves and their vertical propagation, which depend on the background winds and thermal structure.	

M1.3	**Numerical simulations of stratospheric sudden warming and their global influence (NARL)** Sudden stratospheric warming is the sudden rise in temperature in the cold polar stratosphere during some winters. It occurs due to anomalous growth of planetary waves and their interaction with background wind. Though it occurs at high latitude stratosphere, it Influences globally. The occurrence of SSW and their effect needs to be understood through numerical simulations.	
M1.4	**Gravity wave-tidal -mean flow interactions (NARL)** Tidal variability at mesospheric heights influences E-region electrodynamics, as the latter is mostly governed by tidal wind dynamo mechanism. The tidal variability can be influenced by gravity wave tidal interaction. Momentum deposition by gravity waves can accelerate/decelerate the mean wind and affect the amplitude and structure of tides. The eddy diffusion of gravity waves can affect the tidal variabilities. It is important to understand how gravity wave stress affects tidal amplitudes and background circulation.	
M1.5	**Simulations of QBO, SAO and Intra-Seasonal Oscillation (NARL)** Equatorial middle atmosphere is characterized by quasi-biennial oscillation (QBO) in the lower stratosphere, semi-annual oscillation in the upper stratosphere and mesosphere. Besides, middle atmospheric parameters exhibit intraseasonal variability. The equatorial waves play major role in driving these oscillations. It is aimed to develop a model, which can simulate these long-period oscillations with realistic wave forcing and background wind parameters.	
M1.6	**Influence of lateral wave forcing on tropical weather and climate (NARL)** Tropical weather and clime is Influenced by potential vorticity intrusions. These intrusions trigger deep convection and control rainfall. How the extra tropical atmosphere Influences the tropical weather and climate needs to be understood quantitatively. In addition, annular modes can Influence the tropical weather. What is the impact of these extratropical forcing on Indian monsoon needs to be investigated.	
M1.7	**Saturn's upper atmosphere (NARL)** Plasma in the Saturn's upper atmosphere, magnetosphere, radiation belts, interaction with its rings and moons, the rotation period of Saturn.	
N	**Area**	**Weather and Climate (NARL)**
N1	**Sub Area**	**Modelling and Computer Simulations for Weather Prediction (NARL)**
N1.1	**Estimating wind and solar energy resources over Indian region and the development of forecasting system for predicting wind potentials using mesoscale Weather Research and Forecasting model (NARL)** Increasing concerns over the global warming and environmental pollution prompts the policy makers to look for the alternate energy resources in place of the conventional	

	energy sources. Solar and wind energy are prominent renewable energy resources to us the last few decades, though considerable effort has been made to use renewable energy resources effectively in the western countries, Asian region still lags in the effective utilization of these alternate resources. One of the primary steps in renewable energy field is the resource assessments for identifying the optimal locations for extracting the winds and solar energies which needs high resolution wind and solar data sets.
N1.2	**Development of fully coupled ocean-atmospheric model for improving the forecasts of Indian Summer Monsoon at medium-range and seasonal time scales (NARL)** The relative failures of numerical weather prediction models to capture the observed variability of Monsoon on medium range to seasonal time scale and failure to estimate the intensity of extreme events prompts to search for in-abilities of the atmospherics models. One of such problems in NWP models is the lack of precise ocean feedback to atmosphere which is highly essential for understanding and predicting monsoon behavior from long range to medium-range temporal scales. Development of fully coupled ocean-atmospheric model can certainly improve the forecast skill of NWP model for prediction Indian Summer Monsoon at medium-range and seasonal time scales.
N1.3	**Analysis of extreme weather events over Indian region using numerical modelling tools (NARL)** Understanding tele-connections and the analysis dynamical and physical mechanisms behind the frequent occurrence of extreme rainfall events over Indian region is essential for improving the physical parameterizations in NWP models. The recent studies over Monsoon variability reveals the number of extreme weather events during monsoon seasonare increasing, potential mechanisms are extremely required to models these process and predicting accurately.
N1.4	**Development optimal assimilation methods for assimilation X-band DWR in NWP models (NARL)** Commencement of dense network of X-band Doppler weather radar provides us opportunity to have various profiles of hydrometeors which can effectively assimilated in numerical weather prediction models using different assimilation strategies for improving operational weather prediction systems. Development of optimal assimilation methods are highly essential for effective assimilation of hydro-meteors and radial velocities from the dual polarized Doppler weather radar (ISRO X-band DWR) data for improving the forecasts of mesoscale convective systems such as thunder storms, cyclones and extreme heavy rainfall events.

N2	Sub Area	Convection/Precipitation/Boundary Layer (NARL)
N2.1	**Understanding the decadal changes in solar radiation flux at surface and relation with sunspot activity/solar cycle (NARL)** Pyrheliometer can be used to measure direct beam radiation from the Sun and it can be used to measure the total hemispherical radiation (beam + diffuse radiation). The duration of sunshine intensity can be measured using a photoelectric sunshine recorder. Changes in solar radiation flxes during active Sun period vs. quiet period over a longer period of time is proposed to be studied for one or more latitudes.	
N2.2	**Understanding the decadal longwave emission by atmosphere and by earth (NARL)** Earth emits longwave radiation which is responsible for keeping the atmosphere warm. Longwave radiation from earth's surface can be measured using a pyrgeometer.Long term analysis needs to be done to understand the decadal changes in long wavee missions by the earth.	
N2.3	**Studies on logarithmic wind profile of boundary layer (NARL)** Wind speed and direction data obtained from anemometers field at logarithmic spacing in a 50 m tower is to be analysed to understand the log-profile of wind in the boundary layer. The study needs to extended over a longer period to understand the robustness and changes for the season and for different weather conditions.	
N2.4	**Understanding cloud characteristics and properties using lidars (VIS & IR) (NARL)** Visible and IR lidar data range-time-intensities need to be analysed to detect clouds passing over the location. Cloud characteristics like base, top height, thickness, optical thickness, frequency of occurrence, non-sphericity of particle can be studied for a longer period.	
N2.5	**Cloud radiative forcing studies over Gadanki (NARL)** The radiation fluxes reaching the earth surface measured using shortwave, long wave and broadband radiometers/ pyranometer, pyrheliometer could be utilised. Differences in fluxes in the presence and absence of clouds gives the cloud radiative forcing.	
N3	**Sub Area**	**Radiation, Aerosols and Trace gases (NARL)**
N3.1	**Development of low cost nephelometer (NARL)** Nephelometer is an important instrument for aerosol optical properties which are needed to be known for the climatic effects. Current nephelometer technology uses halogen lamp and heavier parts, which are not suitable for balloon borne observations. Recent advancement in LED technology makes it possible to develop light weight low cost nephelomter with similar performance. This will be employed for the developing spaceborne nephelometer for the regular and campaign mode observations.	
N3.2	**Development of OH analyzer (NARL)** Hydroxyl radical (OH-) is an important oxidiser in troposphere and responsible for the removal of green house gases. However due to high reactivity, very short life time, their	

	concentrations are diffiult to measure. Since there is no commercially available OH analyzer, it will be developed in house.	
O	**Area**	**Signal and Data Processing (NARL)**
O1	**Sub Area**	**Parameter Retrieval Algorithm Development (NARL)**
O1.1	**Lidar signal inversion methods (NARL)** There are different types of light scattering, namely, Rayleig, Mie, Resonance, and Raman. These scattered signals can be used to retrieve atmospheric parameters, namely temperature, scattered ratio, density of metal species, lidar depolarization ratio. Improvements in the retrieval methods are needed to retrieve these parameters more accurately.	
O1.2	**Retrieval of temperature and minor constituents in the atmosphere from the satellite based radiance measurements (NARL)** The radiance measured from the satellite borne radiometer at the limb viewing for different wavelength channels can be used to retrieve temperature and minor constituents. Usually the 15 um CO_2 emission is used as the mixing ratio of CO_2 is nearly constant. By inverting raditative transfer equation, the temperature and mixing ratios of chemical constituents can be derived.	
O1.3	**Radar signal processing (NARL)** From the time series of in phase and quadrature phase off the radar signals, noise removal and cogerent integration for desired number of pulses, spectrum is obtained to compute the mean Doppler, Doppler width. The Doppler frequency obtained from three non coplanar directions is used to obtain wind information and the Doppler width is used to study turbulence.	
O1.4	**Improvements in satellite rain retrievals using advanced statistical or physics based algorithms (NARL)** There was large variation among algorithms in the magnitude of the satellite-estimated rainfall, but the patterns of rainfall tend to be similar among algorithm types. Compared to the radar observations, most of the satellite algorithms over erestimated the amount of rain falling in the region, typically by about 30%. Patterns of monthly observed rainfall were well represented by the satellite algorithms.	
P	**Area**	**Radar and Lidar Instrumentation for Atmospheric Probing (NARL)**
P1	**Sub Area**	**Developoment of Radar and Lidar Accessories/Techniques (NARL)**
P1.1	**Time dependent attenuator for Lidar signal (NARL)** The time-dependent variable attenator is used to reduce the dynamic range of lidar signals. The attenuator consists of a Pocket cell between two crossed electronically to attenuate the large signals from close ranges but to transmit for-range signal returns to their full extent. The signal dynamic range can be reduced even by a factor of 100.	

P1.2	**Development of a fiber optic based IF filter for lidar to solve the problem of temperature dependence of filters (NARL)** Optical fibers are made from silica (glass) and hence carry some ingerent advantages such as usability in harsh, high temperature and rugged environments and immunity to electromagnetic interference. Besides, silica is also a chemically passive material and hence it is not affected by corrosive factors that might be present in the environment. Multiplexing capabilities that allow distributed sensing applications.
P1.3	**Digital up-converters (NARL)** Analog Devices digital up/downs converters serve as the frequency translator and digital filter between data converters and digital signal processing blocks. These products enables highly programmable and configyrable receive and transimt signal chains, allowing multichannel, multicarrier radio platforms. They also meet the digital data conversion requirements for many types of radar and communication applications.
P1.4	**Digital synthesizer for radar exciter (NARL)** A radar exciter provide coherent frequency and timing relationships performed by direct digital synthesis, cpable of creating high-resolution wideband waveforms for radar systems. The exciter provides fully cogerent receiver local oscillator signals at radar frequency band as well as requisite, auxiliary high frequency clock signals.
P1.5	**Digital beam forming techniques (NARL)** Beam forming is a signal processing technique used in antenna arrays for directional signal transmission or reception by combining elements in an antenna arrays for directional signal transmission or reception by combining elements in an antenna array in such a way that signals at particular angles experience constructive interference while others experience destructive interference and it be used at both the transmiting and receiving ends in order to achieve spatial selectivity. Digital beamfoming has the advantage over its analog counterpart that the digital data streams can be manipulated and combined in many possible ways in parallel. To get many different output signals in parallel. The signals form every direction can be measured sitmultaneously, and the signals can be integrated for a longer time when studying far-off scatters and simultaneously integrated for a shorter time to study fast-moving scatterers. Imaging radars need to be tested with different beam forming techniques (Founder, capon to state a few) to select the technique, which will give high spatial and temporal resolution.
P1.6	**Clutter removal techniques (NARL)** Various non-atmospheric signals contaminate radar windd profiler data, which produce bias in estimation of moments and wind velocity. Especially, in Ultra High Frequency (UHF) wind profilers, ground clutter severely degrades wind velocity estimation. Moreover, noise dominates the clear air signal at higher heights. It is necessary to eliminate the clutter signal to detect the weak atmospheric signals buried inside the noise and to improve the SNR. Wavelet analysis is a powerful tool to differentiate the

	characteristics of the ground clutter and noise from the atmospheric turbluence echo at the time series level.	
P1.7	Radar imaging radar is kind of radar equipment used for imaging. A typical radar technology includes emitting radio waves, receiving their reflection, and using this information to generate data. For an imaging radar, the returning waves are used to create an image. When the radio waves reflect off objects, this will make some changes in the radio waves and can provide data about the object, including how far the waves travelled and what kind of objects they encountered. Using the acquired data, a computer can create a two or three dimensional image of the scatterers. Current radar imaging techniques rely mainly on Synthetic Aperture Radar (SAR) and Inverse Synthetic Aperture Radar (ISAR) imaging. Monopulse radar 3-D imaging is an emerging technology.	
P1.8	Dual –polarized broadband antenna array is used for UHF profiler radar applications. It needs to have differentially prove-fed, stacked patch antenna features high port-to-port isolation and correspondingly good cross-polarization characteristics. Besides, it should have high efficiency and good port-to-port matching. It has to give good polarimetric performance over a wide scan range without excessive calibration requirements.	
P1.9	**Design and development of solid state TR modules for radar applications (NARL)** The transmit/receive (T/R) module is a key component of radar antennas. Significant improvements in T/R module efficiency will reduce overall power consumption, simplify the thermal design and increase reliability. By miniaturizing the T/R modules, they can be used for both conventional found based phased array antennas and in lightweight antennas for the ISRO space missions.	
Q	**Area**	**Calibration and Validation (SAC)**
Q1	**Sub Area**	**Optical Sensor Calibration(SAC)**
Q1.1	**Vicarious calibration (SAC)** Development of new Cal-Val sites can be established in synchronous with satellite over passes in collaborative mode for various Indian satellite missions (INSAT-3DS, GISAT series, TRISHNA missions etc)For. Presently, the vicarious (absolute) calibration is performed through simulation of top-of Atmosphere radiance for calibration gain and offset calculation. For this purpose we developed ocean site at Kavaratti and land site at Little Rann of Kutch (mostly in campaign mode).	
Q1.2	**Relative sensor calibration (SAC)** Development of advanced techniques for the relative sensor calibration exercises for the radiometric performance monitoring of Indian satellites can be performed through land, ocean, snow and deep convective cloud targets. Presently, the sensor performance is cross verified with contemporary sensors using synchronous nadir pass and its measurements. These exercises are performed by normalizing the central wavelength and out-off band contribution in case of optical sensors. Exploring of radiative modelling of satellite sensor measured radiance though ground truth measurements.	

	Deep convective clouds, Ray-Tracing Techniques over desert and ocean sites can also be explored for optical sensors calibration both in high and coarser resolutions.	
Q1.3	**Moon calibration (SAC)** Development of algorithm for the Radiometric performance monitoring using moon data.	
Q2	**Sub Area**	**Microwave Sensor Calibration (SAC)**
Q2.1	Development of advanced techniques for the data quality evaluation of ISRO's future scatterometer can be explored. At present novel approach for data quality evaluation of Scatterometer (OSCAT-2/3 and ScatSat-1) are being worked out where one can relate the parameters available at different levels of product to geophysical parameters.	
Q2.2	For scatterometer calibration, the essential points includes: i) the monitoring of on-board calibration data to keep a check on transmitted power and ii) regular monitoring of time series of backscattered or brightness temperature over invariant sites like Amazon rainforest, Sahara Desert, Antarctic snow are required.	
Q2.3	Development of techniques and new Altimeter calibration and validation site in India with FRM (Fiducial Reference Measurements) standards using data from a suitable sites.	
Q3	**Sub Area**	**Geo-Physical Products Validation (SAC)**
Q3.1	**Validation algorithms (SAC)** Development of automatic procedures for validating various satellite derived geo-physical parameters from Indian satellite missions (INSAT-3DR/3DS, Oceansat-3/3A, GISAT-1A and TRISHNA etc.) by following the Protocol development on measurements, instrument operation, quality control, and calibration standards. Presently, the most important exercise of validating sensor derived geo-physical products are done using community vetted matchup methodology and qualifying various data sets (in-situ, contemporary missions, climate data sets, data from various collaborative agencies, etc.)	
Q3.2	**Validation of Hyperspectral Satellite Data (PACE-OCI) (SAC)** Development of techniques for the assessment and refinement of hyperspectral remote sensing retrievals of chlorophyll-a and other phytoplankton pigments, Phytoplankton Functional Types (PFTs) and phytoplankton specific absorption.	
Q3.3	**Integration of CHEMTAX and HPLC for Algorithm Validation (SAC)** Development of new algorithms for the use of CHEMTAX-HPLC derived phytoplankton community composition to validate and refine ocean colour algorithms for pigment-based estimates of phytoplankton diversity, algal bloom, primary production etc. in Indian Ocean region using satellite data and sea-truth measurements.	
Q3.4	**Enhancing validation in ultra-oligotrophic and coastal waters (SAC)** Improvement in validation efforts in very low-chlorophyll regions and optically complex coastal waters (using the sea-truth data collected during ship and boat cruises) by incorporating new bio-optical models, adaptive atmospheric correction, and regional algorithms tailored to case-2 waters.	

SPACE SCIENCES

A	Area	Space Situational Awareness (ISTRAC)
A1	Sub Area	Space Surveillance (ISTRAC)
A1.1	**Space debris detection and characterisation in optical images (ISTRAC)** Reflected sunlight from Earth-bound resident space objects (RSOs) creates trails in the digital images obtained via ground as well as space based optical/NIR/IR telescope sensors. Instantaneous image noise reduction, calibration, RSO streak detection, identification and cataloguing is essential for the orbital determination process. This research proposal will be dedicated to the development of a software application as a solution for image reduction as well as calibration and Artificial Intelligence based RSO streak detection and identification on the fly.	
A1.2	**Space object characterisation using Remote Sensing data mining (ISTRAC)** Remote Sensing satellites collect data of Earth from orbit that includes any space object passing through the Field-of-View (FOV). This information is usually filtered out for remote sensing applications. The research is towards understanding and developing an automated software to ingest the remote sensing (RS) satellite images and process the image to identify for presence of any space object. The objective is to extract the dimensions and shape of the space object through existing RS images. The shape data of space objects thus captured might be crucial for space object catalogue maintenance and other SSA applications. Initially, the study may be focused towards RS optical image processing and later may be extended to other frequency domain observations.	
A1.3	**Day time observation of Space object using telescope (ISTRAC)** Observation of space objects through optical telescope gives the data of space object from which information of its position can be derived. The main hindrance for optical observations is climatic conditions and restriction of observations to night time. The research is to study and propose a conceptual design for day time passive observation of space objects. The objective is to compare various methods available for day-time observation of space debris and finalise a method along with required details for realisation.	
A2	Sub Area	Planetary Defense (ISTRAC)
A2.1	**Space-based sensors for NEO threat mitigation (ISTRAC)** Planetary defense addresses the risk estimation and mitigation of Near-Earth asteroid impact with the Earth, which are known to have had catastrophic effects in the past, including mass extinction of several species. Almost all space-faring agencies have their own planetary defense programmes and in light of the growing interest in this area, it is necessary to develop awareness and build technical capabilities in this area through suitable research. Detection, monitoring and characterization are the essential prerequisite of planetary defence.	

	Near Earth Objects (NEOs) coming from day sky having a diameter 10 m or more is difficult to be detected by any ground based or near-Earth space-based observational facilities. But at the same time, they can be hazardous as was the case for Chelyabinsk event in 15 February 2013. The proposed research aims to conceptualize realizable space-based sensors for NEO detection and monitoring to avoid missing detection during close fly-by. The sensor needs to be located at an optimal place in deep space for timely detection of the asteroid to enable determination of the orbit, approach velocity, mass etc. and predict the highest possible accurate atmospheric entry point.
A2.2	**End-to-end automated telescope system design for NEO detection and monitoring (ISTRAC)** India's geographic location belongs to the void region where the International Asteroid Warning Network (IAWN) lacks ground-based sensors for asteroid monitoring. Ground based asteroid detection system in India, scanning the ecliptic plane with large field-of-view and high sensitivity will be advantageous for high cadence NEO detection and possible discoveries. This planetary defence driven project of setting up ground-based sensor will be coupled to a dedicated and integrated software application for automated detection of asteroids, measuring their astrometry, photometry and finally, accurately report to MPC. The software should facilitate a minimum human interaction by optimized and automatic task completion algorithms. The observations will not only be limited monitoring and discoveries of NEO but also their characterization in terms of rotation period, sizes, shapes and properties of their surfaces.
A2.3	**Binary asteroid system characterization (ISTRAC)** Scientific understanding of binary asteroids is important in the context of planetary defence to identify the impact threat and define the mitigation strategy. It is estimated that 15% of asteroids are double (or triple) body systems. The proposed research is aimed to detect and characterize spin-orbit interaction of binary systems through modelling the data obtained from optical observations as well as archived survey data and derive binary nature of the asteroid system such as the orbital period of the primary and secondary bodies, spin state, spin-orbit coupling, their size ratio and accurate orbital parameters. The existing binary system catalogue will be augmented and strengthened not only by the discoveries of new binaries but also by follow up observation of the known ones.

A3	**Sub Area**	**Space Debris Mitigation (ISTRAC)**

A3.1	**Disposal of inclined geosynchronous objects (ISTRAC)** Currently, IADC guidelines to address disposal of GEO objects within GEO protected zone, namely with i = 15 deg. Finding stable graveyard orbits for disposal of objects inclined GSO (such as IRNSS) so that the disposed objects would not re-enter the GEO protected region within a span of at least 100 years is one of the research areas. The study requires simulation of orbital evolution for different types of GEO objects, taking into account different perturbations (luni-solar attraction, Geo-potential, Solar Radiation pressure) over a very long durations with suitable propagation (usually semi-analytical) models.

A3.2	**Lunar space debris mitigation and post mission disposal (ISTRAC)** The vast distance and limited deep space tracking stations contribute to greater observational uncertainty and the poorer knowledge of defunct spacecraft/space objects in deep space, in addition to orbit prediction under multi-body dynamics which can sometimes exhibit chaotic effects. At present, the lunar orbit is sparsely populated with a handful of lunar orbiters. Even then, till date, both Chandrayaan-2 orbiter and the Korea Pathfinder Lunar Orbiter have undergone 4 collision avoidance maneuvers each. With the renewed interest in the exploration of the Moon, an increasing number of lunar missions are foreseen in the near future. With the lessons learnt from an unrelentingly increasing orbital congestion in Earth orbit, it is desirable to contemplate on guidelines that would ensure the safety and sustainability of space operations in lunar orbits, which should be aimed at preserving the pristineness of the lunar environment to the extent possible so as to enable unhindered scientific explorations in future. Formulating such guidelines requires detailed technical studies on the orbital evolution, assessing the efficacy of different disposal options (Earth return, heliocentric, Lunar graveyard orbit, lunar impact). In addition, the options should also take into consideration the tenets of already established Outer Space Treaties and COSPAR Planetary Protection Policies.	
A3.3	**Resolution of Multiple On-orbit Conjunction Risks (ISTRAC)** The risk of collision between two objects is usually quantified in terms of the minimum separation between two objects (the miss distance) and probability of collision (Pc). As of now, multiple critical conjunctions/close approaches within a short time period (a few hours) happen rarely for an operational satellite, hence, most of the prevailing collision avoidance strategies address mitigating the collision risks between one pair of objects (the primary and the secondary) at a time. The lead time also plays a significant role in the delta-v (velocity change) required for collision avoidance. However, the future scenario will call for multiple conjunction risks to be mitigated and it also needs to be ensured that resolving one critical conjunction would not lead to worsening situation for the others. Furthermore, the optimal solution for maximizing miss distance and/or minimizing probability of collision requires firing in a direction not necessarily aligned with that of the thruster. The scope of study for finding the apt strategy for mitigating multiple conjunction risks which can find more practical and widespread implementation.	
A4	**Sub Area**	**Array Signal Processing (ISTRAC)**
A4.1	**ISAR RADAR signal processing for space debris imaging (ISTRAC)** By utilizing the relative motion of the debris and the radar platform, ISAR exploits the Doppler shifts in the received signal to create detailed two-dimensional images of objects in space. ISAR signal processing techniques need to handle these challenges by resolving fast-moving targets and differentiating debris from other potential sources of interference. In ISAR systems, the Doppler shift caused by the relative motion of the radar	

	and the target is used to generate an aperture in the range direction. By processing the received signal over multiple radar pulses, Doppler frequency variations allow for fine resolution of space debris in the image. ISAR processing provides both range resolution (distinguishing objects based on distance) and azimuth resolution (distinguishing objects based on their relative angle). ISAR uses advanced signal processing techniques like motion compensation and Doppler filtering to enhance the resolution of the resulting radar images. ISAR imaging can be achieved by processing multiple radar returns over time, from different angles of observation. Advanced clutter rejection algorithms, such as adaptive filtering and time-frequency analysis, are used in ISAR systems to suppress noise and clutter, ensuring that the focus remains on the debris. By combining ISAR imaging with track-before-detect algorithms, the radar system can provide near-instantaneous updates on the location, trajectory, and potential collision risks of debris in space.
A4.2	**Signal Processing Optimization for MIMO Cognitive radar in Space Debris Tracking (ISTRAC)** The Proliferation of space debris poses a significant threat to active satellite and crewed mission in Earth's orbit. To mitigate the treat effectively, advanced radar system are essential for accurate detection, tracking and characterization of debris Objects. Among these radar technologies, MIMO (Multiple Input and Multiple Output) Cognitive radar shows promising potential due to its ability to adaptively adjust its operational parameters based on environmental conditions and mission objectives. However, signal processing remains a critical bottleneck in harnessing the full capabilities of MIMO cognitive radar for space debris tracking. • To formulate signal processing of MIMO radar signal using compressed sensing for complexity reduction. • To develop an algorithm to handle sparse and noisy radar measurements characteristics of space debris. • To compose interference cancellation algorithm for the detection of fast moving debris. • To formulate MIMO radar with appropriate antenna positioning and transmit covariance matrix for user defined beam pattern of antenna. • Design MIMO Cognitive radar Waveform optimized for space debris tracking, considering factors such as range resolution, Doppler sensitivity and interference resilience. Adaptive Waveform design algorithms show adjust pulse characteristics based on target properties and environmental conditions. • Develop Cogtnitive algorithms to dynamically optimize radar parameters such as pulse repetition frequency, waveform bandwidth, and transmit power based on real time observations and mission objectives. • Development of Signal processing algorithms capable of operating in real time to support timely decision-making and response.

A5	Sub Area	Adaptive Debris Detection Algorithm (ISTRAC)
A5.1	**MIMO RADAR based detection and tracking algorithms for space debris radar (ISTRAC)** MIMO radar can transmit a variety of waveforms from different antenna elements, enhancing the radar's ability to detect targets at different ranges and velocities. Adaptive beamforming allows MIMO radar systems to dynamically steer the radar beams towards targets of interest, enhancing the signal-to-noise ratio (SNR) and improving the detection of space debris. Utilizes multiple transmit and receive antennas, which increases spatial resolution and provides better angular discrimination. MIMO radar systems can use clutter suppression techniques to distinguish between space debris and unwanted background noise. The Doppler shift in the received signals allows MIMO radar systems to estimate the velocity of space debris with high accuracy. This is essential for tracking the movement of debris and predicting its future position, which is vital for collision avoidance and orbital management. Data fusion techniques integrate information from different radar channels to improve the overall detection reliability and accuracy in dynamic environments. These algorithms process the radar returns as they are received, providing up-to-date information about the position and velocity of debris in real-time for situational awareness and response. By simulating space debris scenarios, including various sizes, trajectories, and sensor configurations, designers can fine-tune radar waveforms and signal processing algorithms to maximize detection and tracking performance in real-world conditions.	
A5.2	**Cognitive MIMO RADAR algorithms for adaptive resource allocation and scheduling based on target classification and detection for adaptable environmental condition (ISTRAC)** By dynamically modifying waveforms, transmission power, and resource allocation, cognitive radar systems optimize performance for varying environmental conditions, such as clutter, interference, or atmospheric changes. Adaptive resource allocation in cognitive MIMO radar allows the system to optimize power, frequency, and waveform distribution based on the characteristics of the detected target. Once the target is classified, the radar can adapt its resource allocation, focusing more energy on accurately tracking or identifying high-priority targets (e.g., large space debris or objects with unknown trajectories). The system adjusts waveform parameters (e.g., frequency, pulse duration) and antenna configurations to maximize performance under different environmental scenarios, ensuring robust detection and tracking. By prioritizing targets that require urgent tracking or monitoring, the radar system optimizes its scanning efficiency and reduces unnecessary overhead, improving overall performance in time-sensitive operations. Cognitive MIMO radar optimizes energy consumption by adapting the power transmitted based on the detection requirements of the environment and the target. It dynamically adjusts its waveform	

	parameters to avoid or mitigate interference, ensuring that the radar remains effective even in congested or hostile environments, such as during electronic countermeasures. The system prioritizes targets based on their classification and detection status, adapting its resource allocation to ensure continuous, accurate tracking of high-priority objects, such as fast-moving space debris.	
B	**Area**	**Planetary Geology (IIRS)**
B1	**Sub Area**	**Lunar and Martian Geology (IIRS)**
B1.1	**Geological characterization of lunar and Martian surface features using recent National and International Missions (IIRS)** Availability of High-resolution optical, multispectral, hyperspectral sensors and elevation data from various lunar and Martian missions can be utilized to characterize geological features like impact basins, craters and volcanoes and related landforms by analysing them for mineralogy, lithology, morphological, topographical and structural interpretation. These data with utility for identification, spectral-compositional analysis, geomorphic evolution and chronological study can be integrated with ground based Spectral-compositional study of various igneous exposures in conjunction with geochemical study to understand and correlate their mineralogy, composition, formation conditions, and environment in similar setup at the Moon and Mars. The proposed project aims to have a detailed geological analysis of landforms (Volcanic and Impact) and lithology (mafic and silicic) on Moon and Mars by generating comprehensive geological map, mineral map and quantification of morphological features using multi-sensor planetary datasets to understand their nature of occurrence, associated mineralogy, morphological characteristic and geological evolution.	
B2	**Sub Area**	**Planetary Analogues Study (IIRS / SAC)**
B2.1	**Investigation and Detailed characterization of Indian based potential analogue sites for Moon, Mars and Venus (IIRS)** Terrestrial analogue sites on the Earth are crucial locations to explore and understand the geology, geochemical processes and paleo-environmental conditions similar to that on other planetary bodies including the Moon, Mars and Venus. India with its diverse geological past, its distinct geography and varied geological features is a natural laboratory for research on geological processes, evaluating mineral resources and explore habitability among these analog sites. These locations include volcanic landforms, impact craters, distinct lithologies and landforms. The proposal envisage to systematic investigate, analyze and characterize the geological and geochemical properties of important potential analogue sites for Moon and Mars through use of a multidisciplinary methodology that incorporates fieldwork, remote sensing, and laboratory-based geochemical study. The study will examine how these results may	

	affect plans for future Moon and Mars missions, specifically with regard to choosing landing locations for astrobiological research, mineral resource and human exploration. The proposed project aims at development of database (spectroscopic, geochemical and geological) for Indian-based Martian, Lunar and Venus analog sites that can be used for astrobiology and planetary science study to provide inputs for ISRO's future rover and lander mission to the Moon and Mars.	
B2.2	**Pre-investment Studies for Future Planetary Missions (SAC)** • Characterization of potential landing sites for Chandrayaan-4 & 5 and follow-on missions. • Modelling and simulation studies catering to sensor definitions of future payloads. • Analysis of data from global missions to understand the surface and atmospheric processes , and to identify the science gaps and proposing instruments for addressing them.	
C	**Area**	**Planetary Science, Astrobiology, SAR Remote Sensing (SAC / PRL)**
C1	**Sub Area**	**Planetary Mineralogy and Geochemistry; Raman Spectroscopic Analysis of Planetary Materials; Detection of Biosignatures in Extraterrestrial Environments (PRL)**
C1.1	**Exploration of planetary minerals and astrobiology signals using Raman spectroscopy (SAC / PRL)** Investigating planetary surfaces for their mineral composition and possible astrobiological indicators is essential for comprehending planetary evolution and assessing the potential for extraterrestrial life. Raman spectroscopy, a highly sensitive and non-invasive analytical technique, has proven to be a valuable tool for on-site planetary studies. This research seeks to evaluate the capability of Raman spectroscopy in identifying significant planetary minerals and detecting possible biosignatures in extraterrestrial settings. The study will involve simulating planetary environments, examining Raman spectral characteristics of key minerals, and differentiating between abiotic and biotic signatures. To enhance detection accuracy, advanced spectroscopic data analysis methods, including machine learning and comparative spectral databases, will be utilized. The outcomes of this research will aid future planetary missions by optimizing instrument design and improving the effectiveness of Raman spectroscopy in identifying traces of past or present life beyond Earth. This research aims to provide essential insights for future space missions, particularly those utilizing Raman spectroscopy as a key component of rover and lander instruments. By combining studies of planetary mineralogy with astrobiology, this study will enhance our understanding of planetary habitability and contribute to the ongoing search for life in the universe.	

C2	**Sub Area**	**Planetary Geology and Surface Processes; Geophysical Parameter Retrieval and Surface Characterization; Geomorphological and Structural Mapping of Planetary Bodies**
C2.1	**Advancing Planetary Surface Analysis: Geophysical and Structural Insights from Spaceborne SAR Data (SAC)** The study of planetary surfaces is essential for understanding their geological evolution, surface dynamics, and potential habitability. Spaceborne Synthetic Aperture Radar (SAR) has become a crucial tool in planetary exploration, offering high-resolution imaging capabilities that penetrate atmospheric and surface layers, providing valuable geophysical and structural information. This research aims to utilize SAR data to analyze and characterize key surface and subsurface features of planetary bodies. The study will focus on extracting geophysical and structural parameters using advanced SAR techniques. These methods will help assess surface roughness, dielectric properties, and structural properties. By integrating SAR-derived insights with other remote sensing data, this research will enhance our understanding of planetary geological processes and surface evolution. The findings of this study will contribute to ongoing and future planetary exploration missions. By refining SAR data processing techniques, this research will improve planetary surface mapping, facilitate subsurface investigations, and support the broader goal of exploring planetary environments for scientific and exploration purposes.	
C3	**Sub Area**	**Dust Devils (PRL)**
C3.1	Convective vortices (dust devils) inject dust into the atmosphere, which is then transported by global winds and strongly moderates the Martian climate system directly through the radiative impact of local and global dust storms, and indirectly by affecting the complex ion photochemistry. We are studying the characteristics of such dust devils on Mars through modeling and remote sending observations.	
C4	**Sub Area**	**Photochemistry Coupled GCM of Mars and Venus (PRL)**
C4.1	The current climate of Mars and Venus is controlled by interactions between chemical tracers (such as ozone), water vapour and dust aerosols, coupled through dynamics and radiative processes. Scientists at PRL are studying these interactions with varying levels of complexity. The latest efforts are to understand the couplings through a photochemistry coupled general circulation model (GCM). The current focus is also to understand boundary layer processes (through which the surface forcings influence the free atmosphere) through mesoscale modeling.	
C5	**Sub Area**	**Planetary Lightning (PRL)**
C5.1	The current climate of Mars and Venus is controlled by interactions between chemical tracers (such as ozone), water vapour and dust aerosols, coupled through dynamics	

	and radiative processes. Scientists at PRL are studying these interactions with varying levels of complexity. The latest efforts are to understand the couplings through a photochemistry coupled general circulation model (GCM). The current focus is also to understand boundary layer processes (through which the surface forcings influence the free atmosphere) through mesoscale modeling.	
C6	**Sub Area**	**Planetary Remote Sensing (PRL/SAC/IIRS)**
C6.1	Remote sensing data from Moon, Mars along with other planetary bodies are useful to understand the evolution of these planetary bodies. They are used to understand surface and geological processes such as impact cratering, glaciation and volcanic activities using surface and subsurface analysis.	
C7	**Sub Area**	**Understanding Planetary processes through Meteorites and Planetary Samples (PRL)**
C7.1	Isotopic and noble gas studies of meteorites and planetary samples can help us understand the origin and formation process of planetary bodies. It also gives us time line of materials evolution in the proto solar system and time scale information in the early solar system. Analysis of organic matter from various meteorites can provide the constraints on thermal and aqueous alteration taking place at the Asteroidal region. Carbon isotopic studies in carbonaceous Chondrites can help understand the origin, identification of C bearing reservoir and migration of volatiles in early solar system.	
C8	**Sub Area**	**Planetary Environmental Simulations and Analogue Studies (PRL)**
C8.1	Laboratory measurements of planetary analogous materials under simulated environments provide key support to the definition of science and measurement objectives of ground-based, orbital, and lander observations; instrument design and calibration; mission planning; and analysis and interpretation of retrieved data. The main aspect of such a work would be to design and develop environmental chambers/ facility of different scales and capabilities that can simulate astrophysical and planetary environments and conduct experiments using analogous samples under these environments. Study of analogues found on Earth can reveal processes we might expect on planetary bodies. For example, identification of new impact structures in Indian Subcontinent and meteorite expedition in hot and cold deserts in India could be useful areas of investigation.	
C9	**Sub Area**	**In-situ technologies for planetary surface and sub-surface science (PRL)**
C9.1	We are at the verge of a new epoch of robotic exploration of solar system bodies. The next generation of scientific missions to planetary bodies of our Solar System requires development of advanced robotic technologies for in-situ surface and sub-surface science (for examples core drilling and sample collection techniques). These missions	

	have also motivated initiation of the design and development of highly capable and miniaturized science instruments for carrying out in-situ surface and sub-surface science.	
C10	**Sub Area**	**Outer solar system studies with emphasis on Icy bodies/satellites (PRL)**
C10.1	Comets are among the least altered objects in our solar system. They can preserve the chemical and physical signatures of the protoplanetary disk that formed the solar system. In addition, the discovery of the first interstellar comet 2I Borisov opens the doorway to studying comets in exo-planetary systems. In our group, we study the hydrodynamical conditions and the formation of simple through complex molecules in the cometary atmosphere and the cometary nucleus.	
C11	**Sub Area**	**Planetary Plasma Physics (PRL)**
C11.1	**Investigating Plasma Environments on the Moon (PRL)** The aim is to investigate unique lunar plasma environments with significant implications for solar wind/ ambient plasma interaction with the lunar surface. The SARA instrument on the Chandrayaan-1 has confirmed the existence of the mini-magnetosphere in the strong magnetic anomaly region of the Moon. This region produces a unique plasma environment by shielding the surface from the solar wind and reducing the effect of space weathering. Understanding the governing plasma interactions in this region is crucial for estimating dust dynamics and transport around the Moon. The lunar Permanently Shadowed Regions (PSRs), with permanent darkness and complex local surface topography, present another unique plasma environment. The local relief, namely the craters and mountains, obstruct the solar irradiation and cause mini-wakes around the leeward wall. It alters the electrical configuration in the vicinity of the local structures and significantly affects the local dust and plasma behaviour. The retention, dynamical evolution, and loss of water ice and other volatiles are affected in these two environments. The combined influence of lunar magnetic anomalies and PSRs are of particular interest, which might offer potential advantages for resource extraction and long-term lunar habitation.	
C11.2	**Protoplanetary Disk Dynamics and Structure Formation: MHD Effects (PRL)** The focuses on investigating non-ideal magnetohydrodynamic (MHD) effects on protoplanetary disk (PPD) dynamics, particularly in the context of structure formation. Recent evidence supports planetary formation through gravitational instability, highlighting the importance of understanding the underlying mechanisms. Non-ideal MHD processes, including Ohmic diffusion, ambipolar diffusion, and the Hall effect, are crucial in resolving the angular momentum and magnetic flux problems during PPD formation.	

	The non-ideal MHD effects may yield insights of the propagation of thermal and gravitational modes and associated instabilities in rotating, partially ionized magnetized plasmas. These mechanisms are the key in understanding the formation of various astrophysical and planetary structures.	
C11.3	**Plasma processes near-Earth space & its implications (PRL)** The plasma processes in LEO and MEO ionospheric regions become essential as their interaction with orbiting bodies/ debris produces different waveforms. These waveforms can eventually be the signature for detecting sub-cm size debris floating around the earth in space. These small pieces can have disastrous effects on essential assets, capable of disabling an instrument or a critical flight system on a satellite, and are considered the highest mission-ending risk to most of the operating robotic spacecraft. The proposal intends to characterize the possible waveforms and their practical implications. Another interesting aspect is the exploring the dust dynamics under microgravity conditions. Electromagnetic processes dominate such a low gravity and give an opportunity to understand the short range electromatic forces responsible for forming dust structures and coagulations. The dust behaviour and mutual electromagnetic interactions, are the basis for understanding the dust cluster and cloud formation in space. This study is quite relevant to the scientific experiments in the forthcoming GaganYaan and planned Indian space station.	
C11.4	**Connecting Whistlers and lightning in the Venusian atmosphere (PRL / VSSC)** Wave-particle interactions lead to the acceleration and scattering of particles, the damping or the growth of waves, and the emission of radiation. The interactions in which waves exchange energy with the particles play a crucial role in several phenomena occurring in space plasma, planetary atmosphere, and laboratory. A specific process involves whistlers generated by atmospheric lightening and electron plasma oscillations associated with suprathermal particles in the upstream solar wind. Such whistler modes are detected in the Venusian atmosphere at satellite altitudes; however, their connection with discharge/ electrification is still not understood. The proposal may include the investigations on generating possible plasma waves, and summarizing its role in growth and developing instabilities and contributions to the energies of the suprathermal charged particles. It is also meant to predict whether whistler waves produced by lightning can propagate in the region of 300-500 km above the surface of Venus and, if so, under which conditions.	
C12	**Sub Area**	**Compositional Maps of the Moon (URSC)**
C12.1	**Sub-pixel Resolution Compositional Maps using CLASS X-ray Fluorescence Data (URSC)**	

	CLASS on Chandrayaan-2 has yielded several thousands of X-ray fluorescence spectra over a period of 5 years. These are of various spatial resolutions as solar activity is variable. With a knowledge of the geological context, an algorithm to extract sub-pixel resolution information from CLASS is sought. A possible example is the Pixon reconstruction method which is an image re-construction technique.	
C13	**Sub Area**	**Solar Wind Interaction with Induced Magnetospheres of Planets (VSSC)**
C13.1	**Physics-based Modeling of Solar Wind Interaction with Induced Magnetospheres of Venus and Mars (VSSC)** Venus and Mars lack an intrinsic magnetic field, unlike Earth. However, they possess an induced magnetosphere around them due to continuous solar wind flow draping the planetary body. Limited in situ observations by past and current spacecraft of the induced magnetospheres of Venus and Mars lack a global picture of the magnetosphere dynamics. Physics-based models, specifically the Magnetohydrodynamic (MHD) model, provide a crucial global perspective on their structure and dynamics. The proposed research will use MHD/hybrid modeling to simulate and analyze the complex interactions between the solar wind and these non-magnetized planetary bodies. The primary objectives of this study include evaluating the impact of the solar wind and transient solar phenomena such as Interplanetary Coronal Mass Ejections (ICMEs), Corotating Interaction Regions (CIRs), and Interplanetary (IP) shocks on the induced magnetosphere and plasma environment of Venus and Mars. This investigation will advance our understanding of space weather effects on planetary atmospheres, atmospheric escape mechanisms, and plasma dynamics, laying the groundwork for future planetary exploration. By bridging observational gaps through high-fidelity simulations, this research will offer critical insights into solar-planetary interactions, supporting planning and science from ISRO's current and future planetary missions. The developed model needs to be validated against available magnetic and plasma observations from past missions around Venus and Mars. Upon the completion of this project, we expect to have a validated MHD model code /software package for simulating the solar wind interaction with Venus and Mars.	
D	**Area**	**Space and Atmospheric Sciences (PRL)**
D1	**Sub Area**	**Investigations on Near-Earth Environment (PRL)**
D1.1	**Heliosphere, solar wind, energetic particles and Space weather (PRL)** In view of the successful Aditya-L1 mission and the excellent data coming from the Aditya Solar wind Particle EXperiment (ASPEX) payload, research on heliospheric physics has been initiated. ASPEX consists of Solar Wind Ion Spectrometer (SWIS) and Supra-	

	Thermal and Energetic Particle Spectrometer (STEPS). SWIS is a low energy spectrometer for solar wind studies based on the variations in the protons (H+) and alpha (He+2) particles and solar wind bulk parameters like density, velocity, temperature etc. On the other hand, STEPS is a high energy spectrometer for studies on energetic ions in the interplanetary medium. Excellent data from ASPEX have opened up new avenues for heliospheric physics research that include properties, characteristics, origin, acceleration, anisotropy of solar wind and energetic particles. The impact of transient interplanetary disturbances like Interplanetary Coronal Mass Ejections (ICME), Stream Interaction Regions (SIR) and Solar Energetic Particles (SEP) on the terrestrial and planetary space weather can also be investigated using ASPEX data. Therefore, using ASPEX data and combining with other measurements, significant progress can be made in understanding heliosphere, solar wind, energetic particles and Space weather.
D1.2	**Magnetosphere-Ionosphere-Thermosphere (MIT) Coupling (PRL)** The energy and momentum transfer from the solar wind and magnetosphere to the Ionosphere-Thermosphere (IT) system changes the electric field, ion drifts, electron density, neutral density, neutral wind, etc. For a comprehensive assessment of the impact of space weather at the IT heights, various space and ground-based experiments are used to understand the plasma and neutral processes and their interactions during geomagnetic storms and magnetosphericsubstorms.
D1.3	**Wave particle interaction at the radiation belt (PRL)** The wave particle interaction at the terrestrial radiation belt, acceleration of radiation belt electrons and the role of solar wind shocks are investigated.
D1.4	**Equatorial, middle and high-latitude upper atmospheric phenomena (PRL)** The equatorial, middle and high-latitude processes are replete with unique atmospheric processes of their own. This is essentially due to the configuration of magnetic field lines which are different at different latitudes and thereby affect the neutral plasma motion in different ways at different latitudes. The horizontal nature of magnetic field orientation over geomagnetic equatorial, and low-latitude regions generates dynamo effect which gives rise to equatorial electric fields and several associated processes such as the equatorial electrojet, plasma fountain effect/equatorial ionization anomaly, neutral anomaly, equatorial temperature and wind anomaly, and convective ionospheric irregularities, among others. Particle precipitation at high-latitudes during geomagnetic storms/space weather events present additional source of energy and momentum to the earth's upper atmospheric regions which contribute to the generation of neutral and plasma waves and setting up of winds and creation of plasma irregularities. Several state-of-the-art radio propagation techniques, magnetic measurements, and in-house built optical techniques are used to answer highly pertinent questions of global importance and global scales.

D1.5	**Daytime upper atmospheric neutral wave dynamics (PRL)** The solar ionizing radiation incident in the daytime upper atmospheric regions gives riseto several phenomena due to availability of additional energy and differential heating that sets up driving forces in several directions. While radio measurementsare available for the investigation of the ionized part of the upper atmosphere, the neutral part of the atmosphere can be studied by the naturally occurring optical airglow emissions. New in-house built techniques and approaches have been evolved at to enable the measurement of these airglow emissions in the day time against the strong solar scattered background contribution. A new field of day time optical aeronomy has emerged, wherein investigations of neutral gravity waveactivity that exists in the daytime, is now possible. Several new insightful results have been obtained and there exists a great potential in this nascent area of research.
D1.6	**Space Weather effects at high- and mid-latitude ionosphere thermosphere system (PRL)** The high- and middle-latitude ionosphere-thermosphere regions are especially affected by the particle precipitation at high latitude and ensuing electric fields and currents that are formed in the auroral oval wherein convective cells are formed. The local time dependence and simultaneous role of substorms, shocks, disturbance dynamo etc. in generating the extreme electric field disturbances in the ionosphere are investigated. Daytime polar cusp aurora, polar cap patches, stable auroral red arcs, stable auroral polarization streams, storm enhanced density plumes, and associated affects are of research interest in the characterization of space weather effects on the terrestrial ionosphere thermosphere system.
D1.7	**Impact of mid-latitude ionospheric processes and irregularities on low latitudes (PRL)** The impact of Medium Scale Travelling Ionospheric Disturbances (MSTID) on low latitude ionospheric electrodynamics is investigated. Further, the characterization of mid latitude irregularities at the transition region of low-mid latitude boundary is also being carried out in recent times.
D1.8	**Vertical coupling of atmospheric regions (PRL)** Earth's atmospheric regions are organized with respect to its temperature structure. Different regions are governed by different convective and dynamic processes and so have been conventionally considered to be behaving independent of one another. Due to multipronged daytime, nighttime, optical, radio, magnetic, re-analysis, and other global datasets it has been shown that efficiency in vertical (upward) coupling of atmosphericregions is solar activity dependent over long timescale with greater

	efficiency during low-solar activity epoch. On smaller timescales tropospheric convective storms (few hours) and stratospheric sudden warming events (several days) give rise to vertical coupling of atmospheric regions. Several ensuing processes, mechanisms, and consequences of such vertical coupling is a topic of research that's being pursued in PRL.
D1.9	**Investigations of Mesosphere Lower Thermosphere (MLT) region (PRL)** MLT region is dominated by the effect of waves (planetary, tides end gravity waves) that originate in the lower atmosphere and propagate upwards which consequently gain large amplitudes that leads to wave breaking and momentum deposition.Multi-wavelength airglow observations using optical techniques, measurements of mesospheric rotational temperatures using OH Meinel and O_2 atmospheric bands (both ground andsatellite based),and modelling studies are required for a comprehensive understanding of the processesin the MLT region.The topics of interest are: Couplings (vertical, latitudinal, longitudinal) of the atmospheres under varying geophysical conditions, atmospheric waves in the MLT region, long-term changes in the MLT region, effects of Sudden Stratospheric Warming(SSW) from high-latitude on global MLT dynamics, Mesospheric Temperature Inversion(MTI) and it's possible causative mechanism, high frequency waves inthe MLT region.
D1.10	**Wave dynamical coupling in lower and middle atmosphere (PRL)** Atmospheric waves (gravity waves, tides, planetary waves) are most important coupling agents in the lower and upper atmospheric processes. They are generated in the lower atmosphere due to various disturbances and propagate upwards. Their interaction with background wind and other waves leads exchange of their energy with the surroundings at different altitudes. Additionally, the low latitude regions are substantially influenced by a number of unique wave activities due to maximum solar incident radiation and resulting large scale convection activities compared to the mid and high latitudes. Therefore, investigation of equatorial dynamics draws an additional importance to address global scale atmospheric dynamics.
D1.11	**Variability of upper atmospheric wind and temperature (PRL)** As the upper atmosphere is affected by the forcings from both top and bottom, the dynamical state of it varies significantly over various scales. The variability can be found effectively in the dynamical parameters, e.g. wind, temperature etc. Therefore, by investigating the variability of these parameters one can delineate the dominant processes occurring therein.

D1.12	**Upper atmospheric modelling over the equatorial and low latitudes using advanced techniques (PRL)** A broad range of user applications are crucially reliant or affected by the state of the ionosphere. As such, modeling and correction of these impacts is subsequently highly sensitive to the choice of ionospheric representation. The equatorial and low latitude ionosphere exhibits high degree of variability due to the presence of electrodynamic processes such as the Equatorial Electrojet (EEJ), Equatorial Ionization Anomaly (EIA), etc. Consequently, the height distribution of ionospheric electron density significantly vary with time, season, latitude, longitude and solar activity. Quantitative representation of the short and long term variations of different ionospheric parameters is a major requisite to develop accurate ionospheric models over the low latitude sectors. Developing new methodologies and formulations by employing Artificial Intelligence and Machine Learning (AI/ML) tools will bring new avenues to characterize low latitude ionospheric variabilities towards achieving improved accuracy in model development.	
D2	**Sub Area**	**Atmospheric Aerosols and Trace Gases (PRL)**
D2.1	**Radiative and Climate Impacts: Observations and Modelling (PRL)** To characterize different aerosol types and gaseous pollutants, their spatial and temporal variations, understand their linkages with physical, chemical and dynamical processes, and study their impact on environment, radiation budget and climate. 1. Atmospheric Aerosols: Characterization, Radiative and Climate Impacts. 2. Biomass burning and Aerosols. 3. Trace Gases: Chemistry, Transport and Effects.	
D3	**Sub Area**	**Cloud Research (PRL)**
D3.1	**Investigations of Atmospheric Clouds and Boundary Layer Characteristics (PRL)** To characterize different types clouds their structures, Cloud BaseHeights, Wave-cloud interactions, Microphysics of clouds, Clouddynamical features. Dynamics of atmospheric Boundary layer.	
D3.2	**Development of Indian Lidar Network (ILIN) (PRL)** To investigate Atmospheric Cloud characteristics, Boundary layerdynamics, Vertical distribution of atmospheric water vapor and otheratmospheric constituents over different regions of India; we areestablishing a network of Lidar laboratories (ILIN) in the differentparts of India covering different regions (North, South, North East, West and Central India).	
E	**Area**	**Solar Physics (PRL)**
E1	**Sub Area**	**Helioseismology (PRL)**
E1.1	Helioseismology is based on precise measurements of solar acoustic oscillations. The study of the solar global oscillations during major flares have shown that such energetic	

	transients taking place in the solar environment can generate pressure impulses in the Sun. The knowledge gleaned from these solar results could be useful in identifying the asteroseismic signatures of such transients in solar-like pulsating stars. The study of these acoustic oscillations in the sunspots during major flares have shown that abrupt changes in solar magnetic fields can lead to impulsive changes in Lorentz force acting on the sunspots, which results into inducing acoustic emission in the sunspots. These acoustic emissions could be helpful in better understanding of physical dynamics beneath the sunspots. Additionally, such magnetically driven acoustic emissions can travel upward into the solar atmosphere as magnetoacoustic waves and thereby can heat the active region atmospheres. It is also believed that acoustic waves intermittently interact with the background solar magnetic fields. Application of wavelet technique to the velocity signals shows leakage of photospheric oscillations into the chromosphere. Gravity waves in the solar atmosphere are now increasingly recognised as an important contributor to the dynamics and energetics of the lower solar atmosphere. The study of two-height velocity-velocity cross-spectra and phase and coherence signals in the wavenumber-frequency dispersion diagrams and their association with background magnetic fields would be quite useful in understanding the propagation characteristics of these gravity waves. Further, the results and understanding obtained from the global seismology of the Sun are now being utilized in the study of global properties of sun-like pulsating stars exploiting the stellar pulsations. This has led to the evolution of a new field, namely, helio- and asteroseismology. The study of magnetic activity in such stars can improve our understanding of the stellar activity cycles and the stellar flares. The studies of oscillations observed in the Sun and other sun-like stars also allow us to test the physics in extreme conditions of stellar interiors as well as help us refine models of internal structure and evolution of stars.	
E2	**Sub Area**	**Flux emergence and the coupling of the solar atmosphere (PRL)**
E2.1	The emergence of magnetic fields on the solar photosphere occurs on a wide range of spatial and temporal scales. Investigating the processes of flux emergence is essential for understanding how the magnetic field couples the solar atmosphere and in determining i) The heating of the transition region and corona. ii) The production ofsmall-scale transients. iii) The instabilities driving mass ejections from the Sun. This field of solar physics requires multi-wavelength andmulti-resolution observations which will provide an unprecedented view of the Sun and its magnetic field with the next-generation ground-based telescopes and space missions becoming operational within 2-3 years.	

E3	**Sub Area**	**Magnetic field and velocity mapping for prediction of solar eruptions (PRL)**
E3.1	Solar surface magnetic field is measured to monitor magnetic energy storage and evolution of the stresses leading up to these eruptions combined with the velocity measurements on the surface. Above the surface, physical parameters of the chromospheric and coronal phenomena are being used to predict the geoeffectiveness of these eruptions.	
E4	**Sub Area**	**Solar cycle variation, prediction of activity cycle (PRL)**
E4.1	The 11-year activity cycle is a dominant characteristic of the Sun and also the solar dynamo that generates the solar magnetic field. The discovery of solar magnetic fields introduced a 22-year periodicity, as the magnetic polarities of the polar regions change sign every 11 years. Correlations have been identified and quantified among all the measured parameters, but in most cases such correlations remain empirical rather than grounded in physical processes. For a better physical understanding of solar physics a systematic reassessment of solar activity indices and their usefulness in describing and predicting the solar activity cycle is required.	
E5	**Sub Area**	**Study of solar rotation (PRL)**
E5.1	The differential rotation of the Sun plays a key role in the formation of sunspots and thereby governs the solar activity cycle. Recently it is shown that the solar corona also shows differential rotation with increasing height (or, temperature). Furthermore, the study of North-South asymmetry in the rotation of the Sun has indicated that this asymmetry leads the solar activity cycle. The study of chromospheric rotation with height and its variation over the solar activity cycle can improve our understanding about the differential nature of the solar rotation.	
E6	**Sub Area**	**The heating of solar corona and transition region (PRL)**
E6.1	The tenuous outer atmosphere of the Sun commonly known as 'corona', is orders of magnitude hotter (> 1 MK) than the solar surface (< 6000 K). It is now widely accepted that magnetic field plays an important role in the heating of solar corona. Magnetohydrodynamic (MHD) waves and small-scale transients (e.g., microflare, nano-flare, spicules) are proposed to provide sufficient energy to maintain the hot corona and transition region. Although there exist ample observations of wave propagation and small-scale transients in the solar atmosphere, the exact physical processes/mechanisms behind their dissipation and contribution to the heating of coronal plasmas are still unclear and not fully quantified. Therefore, a thorough assessment of the role of each of these proposed mechanisms is required.	

E7	Sub Area	Transient Phenomena: Flares, Eruptive Filaments/Prominences, Coronal Mass Ejections (PRL)
E7.1		CMEs inject large amounts of mass and magnetic fields into the heliosphere, causing major geomagnetic storms and interplanetary shocks, which are a key source of solar energetic particles. CMEs are often associated with erupting prominences and flares but our physical understanding of how and why CMEs are initiated is poor. It is important to carry out long term and high resolution studies of source regions of CMEs and also monitor their manifestations in the solar wind. Further, study of halo-like CMEs, which suggest the launch of a geoeffective disturbance toward Earth is also very important for space weather forecasting purpose. The fast and wide CMEs produce coronal and interplanetary shocks which are observed as type II radio bursts in meter and Decameter-hectometer(DH) wavelengths. The investigation of solar radio bursts in metric and DH wavelengths is also extremely important in view of probing the origin and propagation of CMEs. During the transients, the Sun releases large amounts of plasma and magnetic fields into interplanetary space. These events often generate bursts of radiation across the electromagnetic spectrum, including radio wavelengths, driven by fast electrons. Identifying and tracking moving radio sources within solar storms is essential to investigate their origin, emission mechanisms, and internal magnetic fields. Combining solar radio images with spacecraft data will help uncover the connection between radio bursts, CMEs, and multi-wavelength signatures to understand space weather disturbances better.
E8	**Sub Area**	**Multi-wavelength studies of the Sun (PRL)**
E8.1		Our understanding of the solar interior, the visible outer layers, and the "invisible" corona are not complete. New developments in the observational techniques from ground and space in optical, X-ray, ultra-violet and radio regimes of the electromagnetic spectrum are expected to continuously extend the frontiers of knowledge of the Sun in particular the eruptive phenomena such as flares and CMEs. Further, the HXR spectroscopy of solar flares is of particular importance to explore the basic physics of particle acceleration and explosive energy release in solar flares. Combination of imaging and spectroscopic observations in X-ray regime would reveal the location and strength of accelerated electrons and ions besides that of the hottest plasma.
E9	**Sub Area**	**Numerical simulation for solar atmosphere (PRL)**
E9.1		The solar corona is intriguing because of its million degree Kelvin temperature and hosting eruptive processes which releases energy and mass which influence the space weather. In absence of any reliable measurement of the coronal magnetic field, it becomes important to numerically construct it using photospheric observations from ground and space based observatories. Additionally, state-of-the-art computer simulations are employed to explore the coronal dynamics.

E10	Sub Area	Heliospheric evolution of CMEs and their space weather impact (PRL)
E10.1	When coronal mass ejections or CMEs are launched from the Sun, they arrive at Earth within 1-4 days depending upon their initial speeds and their level of interaction with the ambient solar wind through which they travel. Research is being carried out for a better understanding of the expansion and propagation of CMEs in the inner heliosphere, thereby improving the forecasting of CME arrival and their impact on the Earth's atmosphere. Such knowledge is crucial, as energetic and high speed CMEs are known to be the major cause of severe disturbances of the Earth's space weather.	
E11	Sub Area	Solar Wind Turbulence (PRL)
E11.1	Even after 60 years since its discovery, the physics of solar wind remains elusive. Multiple spacecrafts continuously sample various solar wind parameters at different heliospheric distances. These data reveal that the magnetic plasma of the solar wind is turbulent in nature. However, the generation and dissipation mechanisms of this turbulence remains an unsolved problem. In-situ data further reveal that the collisionless nature of the magnetic plasma gives rise to several waves and instabilities in the heliosphere, which in turn interact with the solar wind plasma. Elemental abundances of the solar wind also change in a non-trivial way. Many of these problems are thought to be interlinked. They are also supposed to be connected to the lower corona. A thorough understanding of turbulence, wave-particle interaction, and elemental abundances of the heliosphere may unfold many important questions about it. Such can be done either through sophisticated numerical simulations or through existing spacecraft data analysis. Data analysis from the Parker Solar Probe (PSP), the Advanced Composition Explorer (ACE), WIND, STEREO, etc., gives a detailed understanding of the heliosphere. Through such analyses, one also gains experience in tackling data from the in-situ instruments (e.g., ASPEX, PAPA, Magnetometer) onboard Aditya-L1.	
F	Area	Astronomy & Astrophysics (PRL)
F1	Sub Area	Minor Bodies of the Solar system (PRL)
F1.1	**Comets and Asteroids (PRL)** Comets and asteroids form the major part of the population of small bodies of the Solar System. These objects were scattered into different directions during the proto-solar nebula phase as the planets formed. This has given rise to many reservoirs of comets and asteroids. As they come closer to the Sun, the material constituting the comet starts to sublimate and is thrown out. The ejected material develops into a coma and tail. The characteristics of the dust in the coma can be studied by measuring the polarization induced by scattering of solar light by the dust. The dust properties and the chemical composition of the coma allow to infer the basic building blocks of the Solar system. We have a long running program to study the dust properties and the composition of the comets and asteroids. For this we make use of optical polarimetry, imaging as well as spectroscopy with the observing facilities operated by PRL at Mt Abu.	

F1.2	**Near Earth Objects (NEOs) (PRL)** Near Earth Objects and Potentially Hazardous Objects Most of the asteroid population in the Solar system is confined to a belt between Mars and Jupiter. However, some of the asteroids do have orbits that bring them closer into the inner Solar system. Asteroids that have perihelion distances less than the 1 AU are known as Near Earth Objects (NEO). During some part of their orbit, they may approach close to the Earth. Asteroids are typically quite faint objects (mag fainter than 17) but when they come close to the Earth, they can brighten up substantially allowing for detailed observations with even smaller telescopes. A small fraction of the NEOs with the minimum orbit intersection distance with Earth of less than 0.05 AU are called Potentially Hazardous Objects. Close approach by the Near-Earth-Objects (NEOs) provides a unique opportunity to study these very numerous, but normally very faint population of minor bodies in the solar system.	
F2	**Sub Area**	**Extra-Solar Planets (PRL)**
F2.1	A new program for detection and characterization of exoplanets using optical fiber-fed stabilized high-resolution spectroscopy was initiated at the Mt. Abu Gurushikar Observatory of PRL. The project is called PRL Advanced Radial-velocity Abu-sky Search (PARAS). PARAS have the capability to a level of sub-2m/s precision on bright stars (< 6.5 mag) and 5 to 10m/s on fainter stars up to 10th mag. PARAS was involved in the first detection of an exoplanet from the Country (India) which has a mass of a 27 Earth mass. In the near future we will have 2.5m telescope and PARAS-2 for sub-1m/s precision, which will able to detect super Earths in close orbits around G and K dwarfs. We also have a 43cm wide field telescope for doing exoplanet transit observations. Apart from Exoplanet detections, research work on exoplanet atmospheres are also conducted through global collaborations and modelling of exoplanet atmospheres.	
F3	**Sub Area**	**Galactic Astronomy (PRL)**
F3.1	**Star Formation (PRL)** To explain the origin of massive stars (> 8 Msun) and young stellar clusters, a cloud-cloud collision process has been proposed in recent years as an interesting alternative against the existing competing theories of massive star formation. Multi-wavelength studies are being done from Radio to optical wavelengths to model and understand the physical processes inside the star forming molecular clouds.	
F3.2	**Studies on Asymptotic Giant Branch (AGB) stars (PRL)** Post-Asymptotic Giant Branch (PAGB) stars are rapidly evolving low and intermediate-mass stars (1-8 Solar mass) in the transition phase from the mass-losing AGB stars to the Planetary Nebulae (PNe) and are enshrouded by optically thick circumstellar matter that generally consists of molecular gas and dust. There exist a number of unresolved issues as to the physical processes that govern the evolution at these late stages. The chemistry of the circumstellar environment of these stars is highly dynamical due to the enrichment of the surface layers by the convective dredge-up process; initially oxygen-rich envelopes turning to carbon-rich.	

F3.3	**Novae and Super Novae (PRL)** Cataclysmic events in the sky called Novae where a white dwarf accretes mass from a Giant star in a binary system and when the total mass of the white dwarf exceeds the Chandrashekar limit of 1.4 Solar Mass, hydrogen fusion flash happens on the surface of the white dwarf. Such astrophysical are extensively observed from Mount Abu facility using the PRL Near-IR camera and spectrograph and are studied in detail. Several interesting results were derived from these studies like detections of Dust, evolution of atomic and molecular species to understand the evolution and time scale of such astrophysical systems. NIR study of supernovae were initiated from early 2014 from Mt. Abu in the near infrared wavelengths with the outburst of Supernova 2014J which was the brightest and closest supernova Type 1a in the last four decades. Three bright supernovae namely SN2014J, SN2016adj and SN2017eaw are extensively observed from Mt. Abu facility both spectroscopically and photometrically and studied in detail.
F3.4	**X-ray Binaries and Pulsars (PRL)** Galactic X-ray binaries are among the brightest X-ray sources in the sky and are known to be variable over time scales ranging from milliseconds to years. However, over the intermediate time scale of few minutes to hours these sources, particularly the black hole binaries, are not known to vary significantly. We employed an innovative method of phased resolved spectroscopy with constrained system parameters which showed that, it is the high mass accretion rate that is responsible for the observed 'heartbeat' type variability. For this space-based X-ray telescopes are used like RXTE and XMM-Newton. Astrosat was used to measure the first polarization measurements in the CRAB pulsar in the X-ray wavelengths. The Crab pulsar is a typical example of a young, rapidly spinning, strongly magnetized neutron star that generates broadband electromagnetic radiation by accelerating charged particles to near light speeds in its magnetosphere. Despite of the spectroscopic and timing observations over decades, the mechanism of the emission in pulsars remains poorly understood. Polarization analysis only within the off-pulse region of the pulse profile showed that the emission has slightly higher polarization with fraction of polarization 39.0 +/-10%. The high significance of polarization detection enables to examine the dependence of polarization characteristics with pulse phase.
F3.5	**Structure of the Milky Way Galaxy (PRL)** We know that the Milky Way is a spiral Galaxy. However, the detailed structure of the Milky Way is not yet clear since we are in the disk of the Galaxy. Dust in the Galactic plane prevents a clear view of the distant regions of the Galaxy in the optical wavelengths. One can probe the structure of the Milky Way in a relatively better way by observing in the infrared domain where the effects of the dust are much reduced. We make use of large scale archival data from various optical and near infrared surveys to understand the details of the structure of the Milky Way. We make use of various tracers such as the Red Clump stars, the open clusters, Variable stars etc to study the structure of the distant

	regions of the Milky Way Galaxy. We have also initiated a program using PRL telescopes to study the polarization properties in different lines of sight towards distant regions of the Milky Way. This allows to understand the properties of the dust distribution in various directions and also to understand the large scale material distribution in various components of the Milky Way.
F3.6	**Exploring the atmospheric properties of most abundant stars (M dwarfs) in the Milky Way galaxy (PRL)** M dwarfs, because of their small mass, small size, and low luminosity, are the ideal targets for detecting and characterising rocky exoplanets planets. Also, a highly active and flaring nature of M dwarfs may impact the atmosphere of orbiting planets and various biological processes, thus impacting their potential habitability. The atmosphere of M dwarfs is dominated by complex molecules, which complicates the determination of their stellar properties and chemical composition. This also introduces significant uncertainties in their derived stellar parameters that propagate directly into the properties of orbiting planets and affect the understanding of their interior and atmosphere. Using PRL observing facilities (1.m and 2.5m telescopes) we are attempting to characterise the atmospheric properties of M dwarfs.
F4	**Sub Area** — **Extra-Galactic Astronomy (PRL)**
F4.1	**Active Galactic Nuclei (PRL)** In a long-term program, active galactic nuclei (AGN) have been studied to understand their structure and energy processes which lead to huge energy output from a very compact region. Blazars, a subclass of AGN, are used as tool in this study. Optical brightness and polarization variability studies enables us to make studies on the size of the inner region from where the central engine that is the black hole is located and indirectly infer the mass of the black hole.
F4.2	**Studies of High-redshift radio galaxies (PRL)** Deep radio surveys combined with auxiliary multi-wavelength surveys have helped the discovery of a new population of distant and dusty galaxies. These galaxies termed as Infrared-Faint Radio Sources (IFRSs) are detected at radio wavelengths but they are very faint or undetected in the optical, IR wavelengths. Notably, the surface density of IFRSs is found to be higher than that of radio galaxies. It was found that the IFRSs are high-redshift radio-loud active galactic nuclei at the redshifts $z = 1.7 - 4.3$, and a limit of $z \geq 2.0$ is placed on the IFRSs with no or faint optical counterparts. The discovery of this new population of galaxies is crucial to understand the galaxy evolution in the early Universe. Such observations are being carried out using the national facility of GMRT in the radio wavelengths, and then look for their optical counterparts. They also help us to understand the Universe at an epoch time of redshift of $z > 2.0$.

F5	Sub Area	Astrochemistry, Astrobiology (PRL)
F5.1		Conditions commensurate to the ISM and Solar System icy bodies can be recreated in the laboratory in order to understand the physico-chemical nature of molecules that are largely frozen on to the cold ISM dust grains. A combination of closed cycle helium cryostat and UltraHigh Vacuum (UHV) condition is used to bring temperatures down to 4 K and pressures of the order of 10-10 mbar. An optical window, mimics the dust grain in these experiments. The nature of the optical windows depends on the wavelength that is used to probe the molecular ices, for example, Zinc Selenide (ZnSe) and Lithium Fluoride (LiF) is used for infraRed (IR) and Vacuum UltraViolet (VUV) probing / Spectroscopy, respectively. To simulate shock processing either shock in the ISM or impact induced shock, an 8-meter-long, high intensity shock tube is used. Samples processed in our shock tube can reach temperatures up to ~ 10000 K. Various facilities are used in order to mimic the condition experienced by astrochemical ices and astromaterials; (i) electron from a commercial electron gun, (ii) for ion irradiation we use the ECR facilities, (iii) for the precious VUV photons from Synchrotron beamlines and (iv) the shock processing from a gas gun driven shock tube. Thus, the astrochemical icy conditions are recreated and the physico-chemical nature of astrochemical ices are probed by spectroscopy. Proposals are invited in order to use these unique facilities mimicking (i) ISM cold dust and solar system icy surface conditions and (ii) shock processing of dust in the ISM and impact induced shock on planetary bodies. These facilities can be used to understand the survivability of biomolecules (and even microbes) under the extreme conditions that can be recreated in the laboratory, so proposal related to astrobiology are also invited.
G	Area	Space Instrumentation (PRL)
G1	Sub Area	Upper Atmosphere (Ionosphere/Thermosphere) (PRL)
G1.1		**Optical techniques (PRL)** 1. MISE (Multiwavelength Imaging Spectrograph using Echelle Grating): MISE is a high spectral resolution, large field-of-view (FOV; 140 degrees) instrument that is capable of retrieving faint dayglow emissions at multiwavelengths (OI 557.7, 630.0, and 777.4 nm) that are buried in the strong solar scattered background continuum. 2. NIRIS (Near Infrared Imaging Spectrograph): NIRIS is a large FOV (80 degrees) grating spectrograph that yields spectra in the 823 - 894 nm region. NIRIS is used for deriving nighttime Mesospheric OH and O_2 emission intensities and their corresponding temperatures.

	3. HiTIES (High Throughput Imaging Echelle Spectrograph: HiTIES yields nighttime spectra at multiple wavelengths of thermospheric interest are OI 557.7nm and OI 630.0nm. 4. CMAP (CCD-based Multi-wavelength Airglow Photometer): CMAP is a narrow field of view photometer that provides nightglow emission intensities at multiple wavelengths spanning mesosphere to thermosphere. The emissions being Na 589.0nm, OI 557.7 nm, OI 630.0nm, OI 777.4 nm. 5. CPMT (CCD-based Photometer for Mesospheric Temperature): CCD-based photometer for Mesospheric Temperatures (CPMT) is a 5-filter photometer for focussed study of mesospheric temperatures corresponding to OH and O2 emissions. 6. PAIRS (PRL Airglow InfraRed Spectrograph): PAIRS yields nighttime spectra at multiple wavelengths. 7. ADIC (Automated Digital Imaging Cameras) have been developed to carry out simultaneous photography from 4 locations of rocket vapour cloud released from Thumba, India. 8. UVIS (Ultraviolet Imaging Spectrograph): UVIS was designed to obtain emission intensities at MgII 280.0 nm and OI 297.2 nm wavelength which originate in the height range of 85-110 km. It has a FOV of 80 deg with spectral resolution 0.2 nm at 297.2 nm. 9. Narrow Spectral Band, Narrow Field-of-view airglow photometer: This instrument is capable of enhancing the signal to noise ratio (SNR) of nighttime airglow emissions in the wavelengths of OI 630.0 nm and 777.4 nm by limiting the spectral bandwidth and brings out the small variations in the airglow intensity buried in the background by limiting the field of view. This philosophy is now being adopted for space-borne measurements on-board Indian satellites.
G1.2	**Radio Techniques (PRL)** 1. DPS (Digisonde Portable Sounder): For ionospheric studies we use a digisonde wherein radio waves of different frequencies (0.5 - 20 MHz) are sent upwards and their return echo is monitored which yields information on the height of the ionosphere and the plasma densities therein. 2. GPS/GNSS/IRNSS receiver based Total Electron Content (TEC) measurements: Three receivers measure TEC over this region using GPS, GNSS and IRNSS satellite transmissions at multiple frequencies (L1, L5, S band etc.) and are operational in the lab round-the-clock. 3. Langmuir Probe: The lab is also engaged in the design and fabrication of Langmuir probes for space plasma measurements on-board rocket and satellites. The speciality of this class Langmuir Probe is its capability to capture small changes in the electron density perturbations enabling the group to address various plasma irregularity processes in the ionosphere.

G2	Sub Area	Earth's Lower/Middle Atmosphere (PRL)
G2.1		1. Aerosol Chemical Speciation Monitor (ACSM) 2. Ceilometer 3. Disdrometer 4. Dual wavelength dual Polarization LIDAR 5. Flame Ionization Detector (FID) 6. Gas Chromatographs 7. Greenhouse Gas Analysers 8. Hygroscopic Tandem Differential Mobility Analyzer (HTDMA) 9. LIDAR 10. Multiwavelength Radiometer 11. Single Particle Soot Photometer (SP-2) 12. Surface Trace Gas Analysers 13. Dual wavelength dual polarization Lidar 14. Multi wavelength sun photometer 15. Pyranometer 16. Pyrgeometer 17. Pyrheliometer 18. **Proton Transfer Reaction- Time of Flight- Mass Spectrometry (PTR-TOF-MS)**- The PTR-TOF-MS technique is used for the measurements of different VOC compounds present in atmosphere. The time of flight (TOF) mass spectrometer separates the ions according to their mass to charge ratio (m/z). The PTR-TOF-MS provides the mass spectra of many VOCs in a short time (<1 s). PTR-TOF is used for measurements of trace gases (ppt-ppb levels) in air and provides a high time resolution data. This is India's first Proton Transfer Reaction Time of Flight Mass Spectrometer (PTR-TOF-MS) system. 19. **Thermal Desorption-Gas Chromatography-Flame Ionization Detector/Mass Spectrometer Detector (TD-GC-FID/MSD)**- The GC-FID/MSD system which is coupled with a Thermal Desorption-gas is used for the analysis of a class of VOCs known as non-methane hydrocarbons (NMHCs) for which PTR-TOF-MS based measurement is not possible. 20. **VOC Analyzers**-The VOC analyzer provides online gas chromatograph for the analysis and monitoring of trace amounts of C2-C12 hydrocarbons. VOC analyzers are portable and have been used in field experiments at remote places. This setup has been operated during ship-borne campaigns to study the remote atmosphere.

G3	Sub Area	Planetary Exploration (PRL)
G3.1	**Atmosphere experiments (PRL)** 1. Charge particle measurements 2. Ion and Neutral Composition (Mass Spectrometer) 3. Vertical distribution of Electron Density 4. Vertical distribution of Species 5. Planetary Lightning experiment: To understand lightning on other planets like Venus and Mars. Research work can involve modelling, data analysis and instrumentation related to cloud charging, EM wave propagation in ionosphere, plasma waves, ground based experiment. 6. Radio Occultation Experiment to observe profiles of atmospheric parameters like temperature, density etc.	
G4	**Sub Area**	**Planetary Atmosphere (PRL)**
G4.1	**Surface measurements (Elemental composition) experiments (PRL)** 1. X ray Spectrometer. 2. Laser induced breakdown spectros copy. 3. Surface & Subsurface Thermophysical properties of planets. 4. Dust and surface charging – The objective is to study lunar surface charging, dusty plasma, laboratory experiments, dust levitation, dust impact, escape study, instrumentation. 5. Microwave probing of surface and subsurface. 6. Planetary Geophysical Studies – Experiments and Numerical Modeling.	
G5	**Sub Area**	**Astronomy (PRL)**
G5.1	**Instrumentation for ground-based and space-based facilities (PRL)** 1. Visible and IR imaging with precision photometry, polarimetry, low resolution spectroscopy in IR and optical wavelength and high resolution optical fibre based spectroscopy for ground based 1.2 m and upcoming 2.5 m telescope. 2. X-ray instrumentation for space-based facilities (Imaging and Spectra and Polarization) 3. Gamma Ray Spectrometer for space-borne platforms. 4. Active optics for upcoming 2.5 m telescope. 5. Detector arrays for Visible, IR and X-ray regions.	

G6	Sub Area	Solar Studies (PRL)
G6.1		**Instrumentation for future solar and heliospheric missions (PRL)** Aditya-L1 mission is India's first dedicated science mission for the study of the Sun which has been placed at the first Lagrangian point (L1) of the Sun-Earth System. ASPEX payload on-board Aditya-L1 developed by PRL is dedicated for the investigation of the characteristics of solar wind ions (H+, He++ and few other ions) from low to high energies with directional information. ASPEX also records the arrival of interplanetary transient events (e.g. ICME) at the L1 point which are flagged by the enhancements in ion counts in 3 channels beyond a pre-defined threshold. Success of the ASPEX payload and observations paves the way for development of future solar and heliospheric missions. Complementing the observations made by Aditya-L1 mission with other measurements from radio and optical telescopes at USO/PRL, holds potential for solar physics research and also for space weather forecasting applications.
G6.2		**Optical instrumentation for Solar observations (PRL)** A 50 cm telescope for solar observations. Specialised back-end instruments, namely a Narrow–band Imager to record simultaneous images of the photosphere and chromosphere, a Polarimeter to measure the magnetic fields in sunspots and an Adaptive Optics system for image stabilisation and to achieve diffraction-limited performance.
G6.3		**Active and adaptive optics for diffraction limited imaging (PRL)** To achieve high-resolution observations with ground-based telescopes, Udaipur solar observatory (USO) is engaged in the research and development of active and adaptive optics systems for compensation of atmospheric turbulence in real-time. A low-order adaptive optics system is already developed; to achieve the maximum possible resolution with existing telescopes at USO, the development of a high-order AO system is in progress. In this regard, different mechanisms/techniques are being explored for wavefront sensing and wavefront reconstruction. Besides, off-line image restoration techniques such as blind-deconvolution and speckle masking techniques are being explored.
G6.4		**Radio instrumentation for solar transient studies (PRL)** Transient solar phenomena are accompanied by energy releases in the radio wavelengths predominantly arising from the solar atmosphere (chromosphere to corona). They provide valuable information on solar energetics, plasma and magneto-hydrodynamics and space weather. This motivates the requirement for synoptic monitoring of the Sun at multiple frequencies with instruments that can provide high angular, spectral, and temporal resolutions.

	However, such monitoring is done only at a few places worldwide in narrow-band widths in different frequency ranges. Therefore, there is an urgent need to develop solar-dedicated radio instrumentation to fill this gap. To complement India's maiden space-based solar mission, Aditya-L1, developing space-based radio instruments is also the need of the hour.	
G7	**Sub Area**	**Moon (PRL/ SAC)**
G7.1	**Chemical, mineralogical and morphological studies (PRL)** We tend to use various proxies like chemical, mineralogical, morphological, chronological etc. studies, typically in combination, to understand the processes involved in shaping (physical and chemical differentiation of) the terrestrial planets throughout geologic time. Various approaches, e.g., orbital, in - situ experiments and sample (including meteorite)studies in labs, should be considered comprehensively to work on the fundamental science problems (or part of them) for any planetary missions.	
G7.2	**Lunar surface sciences (SAC)** The main research themes for research includes Lunar Surface composition, Lunar morphology, Hyper spectral data analysis for Lunar Surface, Thermal Remote Sensing of the Moon, Spectral characterization of Lunar analogues, Lunar surface dating and lunar volcanism. Multi-frequency microwave SAR studies for H_2O / Ice detection on Lunar surface. **Moon** • Characterizing the mineralogical diversity of the lunar crust and understanding the nature of lunar water cycle: a) Constraining lunar crustal composition through high-resolution hyperspectral data of the Moon obtained from recent, ongoing and upcoming lunar missions. b) Comparative compositional studies of lunar near and far side mare and their implications in thermal and chemical evolution of the Moon. c) Lunar hydration mapping of polar regions (molecular water/hydroxyl ions) and characterizing their nature using hyperspectral data. • Investigation of lunar volatiles at polar regions: Development of new techniques and radar-based models for detection and quantitative estimation of water-ice deposits inside the permanently shadowed regions at lunar poles. • Lunar morphological studies: a) Morphometric and rheological study of lunar domes. b) Analysis of spatial and statistical distribution of boulders from high-resolution optical datasets.	

	• Characterization of physical properties of lunar regolith: a) Inversion of global regolith thickness and physical properties of the lunar near surface using multi-wavelength radar studies. b) Development of physical models for dielectric constant and surface roughness estimation over lunar surface. c) Development of empirical and semi-empirical radio-wave scattering models to address scattering from surface and subsurface heterogeneities. • Understanding the lunar tectonics through modelling and analysis of lobate scarps of the Moon. • VNIR and thermal remote sensing simulation Studies: a) Visible-Near Infrared (VNIR) reflectance studies using physics-based models and studying the effects of optical properties, viewing geometry, grain size, etc. b) Modelling and estimation of thermal conduction in lunar regolith.	
G7.3	**Lunar surface science (Impact Catering, Volcanism, Space weathering) (PRL)** The main research themes includes Lunar Morphology, Surface composition via Hyper spectral data analysis, Thermal Remote Sensing of the Moon, Lunar surface dating using crater chronology, Spectral characterization of Lunar analogues, and Multi-frequency microwave SAR studies for H_2O / Ice detection.	
G7.4	**Estimation of water abundance on the Moon (PRL)** A combined approach of study using remote sensing observations from Chandrayaan missions and modelling is required to investigate variations and abundances of hydration on the lunar surface. Such an approach of looking at global scale variations using the multi wave length data of Chandrayaan missions will help to understand associated transport processes and their origin.	
G8	**Sub Area**	**Mars/Venus (PRL/SAC)**
G8.1	**Morphology, mineralogy, chronology and topography studies (PRL)** This topic research aims to analyze the morphology of glacial and fluvial landforms on Mars to infer the potential role of water and ice in their formation, examine the role of topography to in the consequences of photographic control on the emplacement of the land forms, infer the presence of primary and secondary minerals in the deposits to examine role of aqueous processes, and to establish chronological history of land forms to deduce their period of formation in the past geological history of Mars. Morphological studies from major geological processes will provide major pathways to explore these rocky planetary bodies.	

G8.2	**Studies on Martian analogue (PRL)** To study the potential planetary analogues sites on the Earth to understand the intricacies of planetary processes such as the connection between impact -fluvial processes on Earth and Mars, impact fragmentation on Earth and Moon, gully formation on Earth and Mars, debris covered glaciations on Earth and Mars. The reflect copy measurement from the laboratory based instruments will provide more in sight sin understanding the mineralogical composition. Boulder falls on the Earth, Moon and Mars provide an opportunity to do comparable planetology. The basaltic crusts comprising the surfaces of the Mars of ten resemble the terrestrial basalts and many volcanic and sediment logical features appear similar to be existed on Mars. Therefore, planetary analogues studies are essential to understand the geologic context and validate the orbital data for ongoing and future space missions to Mars. To study the potential planetary analogues sites on the Earth to understand the intricacies of planetary processes such as the connection between impact -fluvial processes on Earth and Mars, impact fragmentation on Earth and Moon, gully formation on Earth and Mars, debris covered glaciations on Earth and Mars. The reflect copy measurement from the laboratory based instruments will provide more in sight sin understanding the mineralogical composition. Boulder falls on the Earth, Moon and Mars provide an opportunity to do comparable planetology. The basaltic crusts comprising the surfaces of the Mars of ten resemble the terrestrial basalts and many volcanic and sediment logical features appear similar to be existed on Mars. Therefore, planetary analogues studies are essential to understand the geologic context and validate the orbital data for ongoing and future space missions to Mars. **Mars (SAC)** • Martian geological studies: Mineralogical and morphological studies of volcanic provinces, and monitoring of Polar Ice caps on Mars using optical and hyperspectral remote sensing data. • Modelling studies of Martian landforms and their implications. • Modelling and simulation studies for Martian subsurface geology. **Venus (SAC)** • Venus geological studies using microwave remote sensing data: a) Scattering properties of Venusian geologic features, i.e., volcanic landforms and highland regions using ground-based and orbital-based radar data and development of radar scattering models. b) Characterization of large-scale Venusian volcano-tectonic structures by integrating observations from Magellan SAR, Radiometer and Altimeter observations.

	• Fast radiative transfer model development for retrieval and assimilation applications. • Retrieval of Venus surface temperature and emissivity parameters. **Planetary Atmospheres** • Understanding the atmospheric circulation dynamics of the Venusian atmosphere: Retrieval of atmospheric winds from UV channels. • Synergistic measurements from instruments aboard upcoming Venus mission of ISRO are targeted to probe unambiguous detection of Venus lightning in a more decisive manner. • Measurements of Venus cloud top brightness temperature statistics at different locations, emission angles, and times, and generation of cloud top temperature maps. **Planetary Analogues** • Spectral characterization of Venus analogues under simulated Venusian surface temperature conditions with respect to the near-infrared filters proposed in the Venus Surface Emissivity and Atmospheric Mapping (VSEAM) instrument on-board Venus Orbiter Mission. • Characterizing terrestrial Venusian analogues using polarimetric radar based and field based Ground Penetrating Radar (GPR) studies. • Wide spectral range characterization of Moon and Mars analogues from different geological settings across India.	
H	**Area**	**Laboratory Study of Astro Materials (PRL)**
H1	**Sub Area**	**Meteorites from Asteroids (PRL)**
H1.1	**Early solar system processes and time scales (PRL)** Solar system formation scenarios have been debated for along time now. Various processes that took place 4.56B yrs ago are recorded in some of the early forming solids preserved in few of the primitive meteorites/asteroids. Study of these important meteorites and samples from sample return mission provide clues in to origin and evolution of the Solar system. **Asteroids (SAC)** • Investigation of Visible and Near Infrared spectra of Near-Earth Asteroids obtained from spacecraft-based observations. • Polarimetric radar studies of Near-Earth Asteroids to characterize their near-surface physical properties.	
H2	**Sub Area**	**Moon and Mars Meteorites (PRL)**
H2.1	**Composition, evolution and chronology (PRL)** Planetary bodies formed at different locations of the protoplanetary disk and are a	

	tell- tale of the original composition of the protoplanetary disk along with information on how & when the bodies formed. Stable and radioactive isotopes from the various bodies (mars, moon, asteroids, comets) provide the compositional as well as chronological information of the different phases of planetary evolution.	
I	**Area**	**Study of terrestrial analogues of Moon and Mars (PRL)**
I1	**Sub Area**	**To understand surface properties and aqueous processes on Mars (PRL)**
I1.1	Geochemical, Spectroscopic, X-ray & astro-biological studies of the terrestrial analogues of Moon and Mars.	
I2	**Sub Area**	**Planetary Environmental Simulation and Experimental Studies on Analogues (PRL)**
J	**Area**	**Payloads for upcoming planetary missions (PRL)**
J1.1	Experiments based on EM radiation, particle irradiation and nuclear reactions can be devised to understand surface and subsurface composition and the equipment can be realized in a miniaturized space qualified form.	
J1.2	**Radio Occultation Experiment (PRL)** This is to observe profiles of neutral density, temperature, ion densities in the atmospheres of Mars and Venus for future ISRO missions.	
J1.3	Development of In-situ technologies for planetary surface and sub-surface science.	
J1.4	**Experiments related to hypervelocity dust impact, micrometeorite detection, modelling and data analysis, study of space debris (PRL)** Payloads are being developed to dust Interplanetary Dust Particles. The Inter planetary Dust Particles (IDPs) or micro meteorites or spaced ebrisare originated from asteroid belt and the resources. The IDP shave velocity greater than 1km / s (i.e., hypervelocity) and may enter planet. They are some times trapped between two planet sand creatures once dustring. The properties of the dust at planet may be understood using a hypervelocity dust, impact experiment using an instrument on future planetary missions/ modelling. The project can cover such aspects related to the interplanetary /planetary dust detection / modelling.	
J1.5	**Langmuir Probe (PRL)** The knowledge of the local plasma environment and its variability with time and space is essential in determining the plasma dynamics and transport properties within the Martian ionosphere. In this context, the Langmuir probe is probably the simplest technique to measure the plasma configuration in terms of particle density, temperature, electric potential, and particle distribution within a plasma environment–moreover, tweaking with an additional probe to the instrument could also measure the local electric fields. The instrument primarily works on the principle of measuring currents under varying applied voltages and subsequent variations in V-I characteristics.	

J1.6	**Miniaturised Neutral Ion Mass Spectrometer (PRL)** To observe ions in the exosphere of Mars and Venus in ISRO's future missions.	
J1.7	**Energetic Ion Spectrometer (PRL)** Energetic Ion spectrometer (EIS) is the instrument aimed at measuring the energetic particles in the energy range of 100keV to 100MeV in the space/planetary environment.	
J1.8	**Lightning Experiment (PRL)** Payload to detect and study lightning on Venus is being developed for future ISRO mission.	
K	**Area**	**Geosciences (PRL)**
K1	**Sub Area**	**Biogeochemistry (PRL)**
K1.1	**Biological N_2 fixation in oxygen minimum zones (OMZs) of the Indian Ocean (PRL)** Nitrogen and oxygen are important elements for life and their cycling in ocean is interconnected. The distribution of oxygen in the ocean interior is controlled by an intimate interplay of physics and biology. Oxygen is transported by circulation and mixing processes into the ocean interior from near-surface waters, where it is produced by photosynthesis and exchanged with the atmosphere. Oxygen consumption by bacterial respiration of organic matter occurs throughout the ocean but most intense in oxygen minimum zones (OMZs). Recent observations suggest that the biological N_2 fixation (major source of bioavailable nitrogen in open ocean) occurs in such OMZs. Both the supply and consumption of oxygen and bioavailable nitrogen are sensitive to physical parameters in ways that are not fully understood. Research carried out at PRL has led to substantial improvement in our understanding of the various transport and biogeochemical processes responsible for regulating N_2 fixation in the Indian Ocean.	
K1.2	**Carbon: Nitrogen: Phosphorous stoichiometry in the Indian Ocean (PRL)** Availability of nitrogen (N) and phosphorus (P) determine the strength of the ocean's carbon (C) uptake, and variation in the N:P ratio in inorganic nutrients is key to phytoplankton growth. A similarity between C:N:P ratios in the plankton and deep-water inorganic nutrients was established in the last century. However, recent studies have suggested a variation in nutrients N:P ratio as well as cell species dependent phytoplankton C:N:P ratio. At present, our understanding of the (environmental) factors governing C:N:P stoichiometry remains poor. The northern Indian ocean due to its geographic setting and monsoonal wind forcing provides a natural biogeochemical laboratory to explore the effect of environmental and physical factors on C:N:P stoichiometry. Research carried out at PRL under the ISRO-GBP program has improved our understanding to some extent on the C:N:P ratio in bulk organic matter pools and nutrients. However, knowledge at the cellular level is still fragmentary, yet critical to identify the variation in the ratio.	

K1.3	**Trace element biogeochemistry in ocean (PRL)** PRL played a lead role and initiated studies on trace elements and their isotopes for the Indian Ocean region under the aegis of International GEOTRCAES programme. As part of the Indian GEOTRACES and related programs, high-resolution sampling was performed in the Arabian Sea, the Bay of Bengal, and the Indian Ocean along with some major estuaries and rivers of India to understand biogeochemical cycling and distribution of trace elements. Trace elements in ocean are essential micronutrients and their abundances influence overall productivity of the ecosystem. Distribution of trace elements and their isotopes in oceans also provide information on physical and chemical processes such as water mass movement, redox condition, and sources and sinks of these elements. PRL intends to continue these studies in the northern Indian Ocean as this region is not well constrained vis-à-vis their geochemical cycling.
K1.4	**Nitrogen and carbon cycling in a tropical estuary and adjacent coastal region (PRL)** Estuaries and adjacent coastal regions are vulnerable ecosystems due to increased nutrient loading from anthropogenic activities. Excess nutrients enter the system as organic and inorganic N and P compounds through rivers and the atmosphere, and threaten coastal ecosystems. Anthropogenic inputs cause many estuarine-coastal systems to shift drastically from N limitation to an N surplus leading to eutrophication, a major threat to most of the estuaries and coastal waters around the world. At present, our knowledge of N and C cycling, particularly N uptake dynamics and its dependence on N and P distribution in tropical estuaries and the adjacent coastal waters remains rudimentary. Information about the rates of transformation of N and C in such systems is needed to develop mitigation strategies to restore and save the estuarine-coastal coupled systems from eutrophication. The research carried out in PRL in recent years at different estuarine-coastal coupled systems of India has added significantly to this knowledge.
K1.5	**Carbon and nitrogen fluxes in river systems of India(PRL)** Human activities are drastically altering water and material flows in river systems across India. These anthropogenic perturbations have rarely been linked to the carbon (C) fluxes of Indian rivers that may account for considerable percentage of the global fluxes. In this regard, a conceptual framework for assessing human impacts on Indian river C and N fluxes is needed. Lower reaches and tributaries of rivers, such as the Ganges, which drains highly populated urban centers, tend to exhibit higher levels of organic C and the partial pressure of CO_2 (pCO_2) than less impacted upstream reaches. Also, proper quantification of impacts of river impoundment on CO_2 outgassing from the rivers of India is still lacking. Within this context, PRL has initiated a program to study C and N cycling in rivers of India, where movement of these important elements throughout the river continuum will be studied.

K1.6	**Nitrogen and carbon cycling in a terrestrial ecosystems of India (PRL)** In past few decades, human activities have altered many terrestrial ecosystems by increasing human derived N inputs which has caused shift in natural cycling of elements. This has eventually affected C fluxes and its storage capacity of soils, providing positive feedbacks to climate change. As N acts as an important growth limiting nutrient for plants and the biogeochemical cycles of N and C are coupled, it is important to understand N cycling in forest ecosystems in order to develop proper forest management practices. Production of NH4+ in soils can be studied by determining either net rates which shows the amount of nutrient remaining after consumption; or gross rates which allows quantification of total mineralized N. So far, many studies have been conducted on net rates of mineralization as it is considered to be the principal step which determines plant productivity but few studies exists vis-à-vis gross mineralization rates worldwide. For the first time in the southeastern Asian region, research carried at PRL using isotope dilution technqiue to quantify rates of gross mineralization and nitrification in the Himalayas, Western Ghats, Rann of Kutch, and Kerala has added significantly to our knowledge regarding natural pathways of nutrient production and consumption in different ecosystems of India.	
K2	**Sub Area**	**Paleoclimate (PRL)**
K2.1	**Coral as a Proxy for Sea Surface Properties (PRL)** Coral are organisms growing in shallow marine conditions and are sensitive to sea surface temperature (SST). They form annual bands and record properties of sea surface conditions at very high-resolution and could prove to be a good calibration for paleoclimatic studies. Based on corals from the Andaman region, reservoir age correction was provided as applicable to radiocarbon dates of marine samples. Paired measurements of Sr/Ca and stable isotopes in corals from Andaman region have shown that these can be effectively used for calibration of SST and show signatures of Indian summer monsoon. Coral radiocarbon measurements for the period 1949-2013 have yielded air-sea exchange rates of CO_2 for the Indian Ocean and shows relation with wind speed and alkalinity.	
K2.2	**Paleoclimatic Reconstructions from Marine Sediments of the Indian Ocean (PRL)** PRL has been at the forefront of research in paleoclimate reconstruction. Towards this, several marine cores from the northern Indian Ocean have been investigated. Based on studies of a sediment core from the western Arabian Sea, it was observed that variations in the Somali upwelling has relationship with southwest monsoon rainfall. Evidence of poor bottom water ventilation during LGM in the equatorial Indian Ocean was found from studies in the equatorial Indian Ocean. Recently, signatures of global climatic events and forcing factors for the last two millennia from the active mudflats of Saurashtra has been found. Similarly, cores from other regions of the Indian Ocean are under investigation.	

K2.3	**Past climate using speleothems (PRL)** Past monsoon conditions can be assessed from variations in oxygen isotope ratios and trace element compositionsin cave carbonate deposits (stalagmites). Exploring new caves covering different geographical sites and monitoring variability in isotopic and geochemical compositions of modern cave seepage water canadd to a very limited data set available on past monsoon from terrestrial records. Also, trapped water in the carbonate matrix represents the past water. Its isotopic composition can be utilized to interpret past hydrological conditions. Work is being carried out on the development of vacuum technique to extract trapped water from the carbonate matrix along with dating technique utilizing U-Th decay series, which is presently unavailable in India. Overall, PRL has contributed significantly to paleomonsoon reconstruction using speleothems.	
K2.4	**Paleoglaciation records from the central and western Himalaya (PRL)** The mountain glaciers are active geomorphic agents to shape the landforms and are responsible for producing some of the most spectacular landscapes on the surface of the earth. Timing and amplitude of paleoglaciations represent important cornerstones of terrestrial paleoclimatic research as glaciers are arguably the most sensitive recorders of climate changes as they respond to the combined effect of snow fall and temperature. To reconstruct the history of glaciations, large scale field mapping of glacial deposits (moraines) along with geochronology using different techniques like optical chronology and cosmogenic radionuclides dating is being carried out at PRL.	
K3	**Sub Area**	**Atmospheric chemistry(PRL)**
K3.1	**Non-conventional stable isotopes in atmospheric carbon cycle research (PRL)** Precise quantifications of the sources and sinks of CO_2 in the atmosphere are very important for modelling future climate. The existing studies, mainly based on the conventional stable isotope ratios and CO_2 concentration are not enough to precisely quantify the CO_2 budget because of their complex interactions with various reservoirs and contribution from multiple components with overlapping range of isotopic ratios. Clumped and triple oxygen isotopes in CO_2 are two recently developed isotopic proxies and are found to be applicable to address many of the carbon cycle issues. Clumped isotopes in CO_2 are molecules in which more than one isotopes are replaced by their rare counterparts and are mostly used as a proxy of CO_2 formation/exchange temperature. The triple oxygen isotopes or 17O excess in CO_2 is the excess abundance of 17O compared to that expected from mass dependent fractionation processes and is mostly acquired from the interaction of CO_2 with ozone in the stratosphere. These two isotope proxies basically measure anomalies and are free from many terrestrial complex processes. With modern mass spectrometry techniques, very precise measurements of these isotope ratios are possible and hence can be used to estimate the contribution of CO_2 from different sources and estimate the gross primary productivity,	

	the total CO_2 assimilated by plants. Geosciences division of PRL recently started developing techniques for measuring these nonconventional isotope ratios, along with the existing conventional isotope measurement facilities to precisely constrain the atmospheric carbon budget in India.	
K3.2	**Research on Aerosol Chemistry and Characteristics (PRL)** Aerosols are known to affect the Earth's climate (radiation budget, hydrological cycle), aquatic ecosystem (biogeochemistry of oceans and lakes), and air quality (visibility and human health). After emission and/or formation, aerosols react with other species during atmospheric transport that further lead to transformations in their chemical and physical properties. These processes not only affect their optical and hygroscopic properties but also the bioavailability of nutrients present in aerosols. However, the characteristics and composition of aerosols remains poorly understood. Aerosol research at PRL focusses on understanding the physicochemical characteristics of ambient aerosols over different regions of India, and how they relate to atmospheric chemistry, clouds, climate, ecosystem, air quality, and human health. Chemical and isotopic compositions of aerosols as well as their characteristics using state-of-the-art online and offline measurements techniques over different parts of India and surrounding oceans are being studied. In addition, focus is specifically on studying emerging research areas such as secondary organic aerosols, brown carbon aerosols, and oxidative potential of aerosols. Such studies are not only important in understanding and assessing the effects of aerosols on air quality and climate, but also in validating/modifying regional and global climate models.	
K4	**Sub Area**	**Earth Surface Processes (PRL)**
K4.1	**Application of non-traditional stable isotopes to study Earth system processes (PRL)** It is important to understand the origin and temporal evolution of the Earth and its various systems. Recently, non-traditional stable isotopes have been used as a new tool to study various earth system processes. Some of the important aspects that can be explored using non-traditional stable isotopic systems are redox evolution of Earth's oceans and atmosphere (Fe, Mo and U isotopes), reconstruction of silicate weathering history and understanding the weathering regime (Li isotopes), reconstruction of seawater paleo-pH (B isotopes), paleo-volcanism (Hg isotopes), biomineralization of foraminiferal tests (Ca isotopes). The initial step to study these problems in Earth Sciences by suitable non-traditional isotopic proxies involve intensive field work for collection of appropriate samples (e.g., recent marine sediments and black shales for understanding recent and past ocean redox using Mo isotopes, river water and suspended sediments to understand	

	weathering regime using Li isotopes) followed by sample preparation in laboratory for extraction and purification of element(s) of interest, their mass spectrometric analyses, and modelling of data. PRL has been involved in such studies and wishes to continue using emerging techniques as they are indispensable for understanding the Earth as a system.
K4.2	**Catastrophic events across the Indian geological records (PRL)** At PRL, we aim to understand 'catastrophic events' such as mass extinction events across major boundaries (Permian-Triassic -250 Million Years ago, Cretaceous-Palaeocene – 65 Million year etc.) from the Indian geological records. Also, works on impact craters (Lonar, Dhala, and Ramgarh etc.) are underway, where the major objectives are to understand the processes responsible for such global events using the geochemical anomalies and chronological information along with proxies to pin point the factors responsible for such type of events.
K4.3	**Present and past extreme events (PRL)** The extreme precipitation events, like of June 2013 in Uttarakhand, create flash floods in monsoon dominated Central Himalayan valleys. The fluvial deposits in the associated river basins are being studied at PRL to understand the past processes from the central to western Himalayas during the late Quaternary period. Generally, sediment bulking in the monsoon dominated Himalayan rivers is caused due to (i) landslide dammed lake out bursting, (ii) the glacial lake out bursting, and (iii) recession of valley glacier deglaciation. In this program, we intend to quantify the spatial and temporal changes in the sediment provenance in order to ascertain the role of climate and tectonics in valley-fill deposits.
K4.4	**Accelerator Mass Spectrometer: Application of Cosmogenic Radionuclides in Geosciences (PRL)** The Accelerator Mass Spectrometer Facility at PRL has been installed to measure ^{14}C, ^{10}Be and ^{26}Al. Radiocarbon (^{14}C) has been extensively used in application of earth, ocean, planetary and atmospheric sciences. Several samples from archaeological sites have been dated using ^{14}C. Radiocarbon has been used as a tracer to understand various ocean processes. One of the major oceanic climatic process which governs the Earth's climate is ocean circulation. Based on radiocarbon dates of planktonic and benthic foraminifera in marine sediments, ventilation rates of the Indian Ocean have been established for the last 50 kyr. Radiocarbon dates of groundwater provide estimate of climatic conditions at the time of recharge. Meteoric ^{10}Be has been used as chronological tool for dating marine sediments up to 10 million years. In-situ10Be is being used for deriving the exposure age of glacier and gives understanding of glacier retreat or advance rates.

K5	Sub Area	Earth Surface Landforms and Processes (PRL)
K5.1	**Fluvial depositional environment and facies (PRL)** Rivers are one of the dominant agents of landscape modification as the flowing waters are continually eroding, transporting, and depositing sediments (Fluvial Processes) in the course of time. Fluvial geomorphology deals with the form and function of streams and the interaction between streams and the landscape around them. It depends on fluvial dynamics, sediment load, slope / slope stability, vegetation, surface runoff, climate, tectonics, etc. An architectural element may be a component of a depositional system, characterized by a distinctive facies assemblage, internal geometry, external form etc. Stream morphology is dynamic and constantly changing in both space and time. River based flooding is among one of the most frequent and widespread natural hazards of our country. Apart from studying palaeo-climates, studying fluvial deposits are important in economic aspects as they are characterized by good porosity and permeability, thus constitute excellent aquifers, placer deposits, coal, oil and gas reservoirs are hosted in fluvial units. The understanding of system dynamics will help us for planning for climate change. Thus, proposal is invited to understand fluvial processes and palaeoclimate changes.	
K5.2	**Coastal configuration changes and interaction with sea level and tectonics (PRL)** The long coastline of India makes it a suitable area to study the past surface, internal and climatic processes that shaped the present day coastline. Understanding the past response to various forcing are important to understand and model the present coastal dynamics in the view of ongoing threat of global warming, climate, sea-level changing scenarios. In view of this, it is important to understand the process taking place along the coast in past and present. The study of such processes will enable us to design the strategies for probable future issues and provide us the parameters which should be monitored via ground or satellite based observations. Sedimentary archives along the coast provide excellent proxies to study such processes in past. Such archives are need to be studied in order to develop understanding of coastal sedimentary processes. The proposals are thus invited for coastal sediment studies.	
K6	**Sub Area**	**Hydrology (PRL)**
K6.1	**Application of Oxygen and Hydrogen Isotopes to Understand Hydrological Processes (PRL)** There are complex hydrological processes which cannot be discerned by measuring volumes and fluxes of water across hydrological boundaries. Such processes are, for example, variation in vapour source for rainfall, evaporation from falling raindrop, continental recycling of water, surface water - groundwater interaction and exchange.	

	These processes can be discerned by monitoring oxygen and hydrogen isotopic composition of water in different hydrological reservoirs such as groundwater, river water, rainwater, oceanwater and atmospheric water vapour. Spatio-temporal variation in isotopic composition of water in these hydrological reservoirs in conjunction with various geohydrological and hydrometeorological parameters can provide new insights in the hydrological processes. A Stable Isotope Ratio Mass Spectrometer laboratory set up under the National Programme on Isotope Fingerprinting of Waters of India (IWIN National Programme) is leading this long-term programme of isotopically characterizing water sources of India with a view to obtain new insights into hydrological processes. Some of the important scientific results from this research pertains to interaction between rain and vapour, relative contribution of vapour from the Arabian Sea and the Bay of Bengal, extent of evaporation from falling raindrops, identification of regions in which groundwaters do not seem to be recharged by freshwater during an annual cycle of groundwater hydrology.	
L	**Area**	**Atomic, Molecular and Optical Physics (PRL)**
L1	**Sub Area**	**Laboratory Instrumentations (PRL)**
L1.1	• Development of electron and ion imaging spectrometer • Coincidence momentum imaging spectrometer, reaction microscope • Development of ions source/Ion gun • Laser produced plasma: Plume dynamics and plasma spectroscopy • Laser Induced Breakdown Spectroscopy: Fundamentals and applications • Development of Magnetic Bottle electron Spectrometer • Development of large area position sensitive detectors for charged particles imaging • Development of Piezo pulse valve (0 to 1 KHz rep rate) and plunger-based pulse valve (0 to 1KHz rep rate) for supersonic atomic/molecular beam generation	
L2	**Sub Area**	**Spectroscopy (PRL)**
L2.1	**Ultrafast Science and Technology (PRL)** The electron dynamics in atomic and molecular system is in attosecond (10^{-18} s) and the nuclear dynamics is ranging from picosecond (10^{-12} s) to femtosecond (10^{-15} s) time scale. Science at this time scale is named as ultrafast science. At atomic level, most of dynamical processes are in this time scale. Modern experimental techniques are needed to understand the ultrafast science. • Femtosecond stimulated Raman spectroscopy • Femtosecond transient absorption spectroscopy	

	• Femtosecond-Laser Induced Breakdown Spectroscopy: nanosecond-LIBS, Nanoparticles Enhanced LIBS, Femtosecond-LIBS • Femtosecond micromachining
L2.2	**Development of XUV/EUV light source using femtosecond laser (PRL)** • Development of XUV/EUV source based on Higher Harmonic Generation method • Higher Harmonic Generation from gas, solid, liquid and plasma • XUV-IR pump probe experiment • Photoionization of atoms and molecules using XUV/X-ray • Photoelectron Spectroscopy • Intense TW femtolaser light interaction with matter: Extreme photonics
L2.3	**Attosecond science and technology (PRL)** • Attosecond Streaking • Attosecond transient absorption spectroscopy • Attosecond physics at nanometric tips • Attosecond Angle-Resolved Photoelectron Spectroscopy
L2.4	**Atomic collisions (PRL)** • Electron and ion impact processes in molecules • Study of atomic and molecular clusters
L2.5	**Gas phase astrochemistry (PRL)** • Gas-phase Chemistry in the Interstellar Medium • Chiral molecules in space: study of light induced processes in chiral molecules)
L3	**Sub Area** — **Ultrafast laser application (PRL)**
L3.1	**Femtosecond Laser Precision Engineering (PRL)** • Micro and nano structure development using femtosecond laser • Diamond, silicon, and ceramic cutting using ultrafast laser • Micromilling using ultrafast laser • High Harmonic generation based EUV lithography
L3.2	**Optical fiber and application (PRL)** • Fabrication of optical fiber • Development of Hollow Core Fiber for femtosecond pulse compression • Fibre optics-based tools development for medical, defence, and aerospace
L3.3	**Ultrafast science and technology (PRL)** • Attosecond physics phenomena at nanometric tips • Femtosecond filamentation and plasma chemistry

L3.4	**Technology development in laser and photonics (PRL)** • Development of Femtosecond oscillator, Femtosecond amplifier, Femto-optics (grating, mirrors, polarizer, etc.) • Development of XUV/EUV optical components • Development of Nd: YAG laser, Yb: YAG, and Tm: YAG lasers • Development of femtosecond fiber laser • Development of LIDAR (Light Detection and Ranging) • Development of photon/electron detector, and power meter	
M	**Area**	**Emerging Areas In Theoretical Physics (PRL)**
M1	**Sub Area**	**Ameliorating the Theoretical Frameworks of Fundamental Physics (PRL)**
M1.1	**Scrutinising the validity of the standard models of particle physics and cosmology and their extensions by computing various observables and comparing them with the experimental data (PRL)** Some of the experimental evidence in the areas of particle physics and cosmology indicate that the known and established theoretical frameworks in these areas are not complete and adequate. Quantifying these inadequacies, modifying theoretical frameworks and testing their viabilities constitute a core of the theoretical physics programme emerging in the next couple of decades.	
M1.2	**Probing physics beyond Standard Model in Neutrino Experiments (PRL)** Exploring signatures of physics beyond the Standard Model of particle physics in experiments to detect neutrinos from Astrophysical and laboratory sources constitutes a very important current research area presenting many new opportunities. Next generation neutrino experiments offer particular advantages over existing experiments, including large volumes and high intensity beams. These detectors also open up the possibilities of detecting low mass dark matter candidates, new neutrino interactions etc.	
M1.3	**Probing nature of neutrinos in rare processes (PRL)** Neutrinos being particles with zero charge can be their own antiparticles i.e can have Majorana nature. This violates lepton number and allows the rare process of neutrino less double beta decay. There are many experiments which are searching for these processes. Neutrino less double beta decay can help in probing the neutrino mass along with beta decay experiments and cosmological constraints. One can also look for predictions of physics beyond the Standard Model in such processes. In addition an analogous lepton number violating process can take place in colliders and complementarity of these with neutrinoless double beta decay experiments can constrain the parameters of the beyond Standard Model physics.	

M1.4	**Charge-Parity (CP) violation in the neutrino sector and origin of matter-antimatter asymmetry (PRL)** Several neutrino oscillation experiments are in the process of determining the amount of CP violation in the lepton sector and it is expected to be measured within the next 10 years. Whether the observed amount is enough to explain dominance of matter seen in our universe is a question of fundamental interest.
M1.5	**Testing grand unification through Proton decay (PRL)** Hypothetical theories which unify the fundamental interactions predict unstable protons. Several ongoing experiments are searching for the proton decay and they are expected to give decisive results on some of the simplest frameworks of unification. Activities in this area are therefore going to increase in the coming years.
M1.6	**Precision physics at the LHC (PRL)** Due to the tremendous improvement of the Large Hadron Collider (LHC) experimental results, theoretical predictions of the Standard Model and beyond the Standard model processes need to be extremely accurate. This necessitates inclusion of higher order terms in the perturbative calculations and that, in practice, invokes non-trivial complexity due to the increasing number of loops and legs. To compute such theoretical estimations and to build machinery in order to attain such precise results are of utmost importance, as the present and future success of the LHC crucially depends on these theoretical inputs.
M1.7	**Search for the theory of unconventional superconductivity (PRL)** Several superconducting materials have been discovered in the last couple of years which do not follow the known theory of superconductivity. It is one of the active areas where a radically new theoretical framework might be needed to describe the observations.
M1.8	**Topological Quantum Matter, Superconducting Junctions, and their Functionalities (PRL)** Superconducting interfaces, in combination with non-superconducting quantum matter, have been found as excellent platforms to host emergent phases, which are not possible to find in bulk superconductors. Exploring new quantum matter with topological properties and forming their interfaces with superconductors to find new functionalities are of fundamental interest and extremely needed for future applications.
M1.9	**Physics of the quantum Hall effect and topological order (PRL)** The quantum Hall effect occurs in two-dimensional electron systems in the presence of a perpendicular magnetic field. Integer and fractional quantum Hall states exhibit many fascinating phenomena, such as quasiparticles with fractional charge and anyonic statistics, as well as nontrivial topological order. Ongoing experiments on novel quantum

	materials continue to yield surprising discoveries which are challenging to explain within the conventional framework of theoretical condensed matter physics. One example is the recent observations of quantum Hall physics even in the absence of magnetic fields. Understanding the dynamics that promotes these phases, determining the nature of the ground states, characterising the low-lying excitations and proposing concrete experiments to test the predictions presents a rich set of directions and questions for theoretical research. The potential applications of such phases in the field of quantum technologies provides an extra impetus to this line of research work.	
M2	**Sub Area**	**Fundamental Physics using Space-borne Experiments (PRL)**
M2.1	**Searching for Dark Matter through Balloon/Satellite/Space-station based Detectors for multi-messenger insight (PRL)** The existence of a non-luminous and non-baryonic form of matter, popularly known as dark matter (DM), is already well established and measured at different length scales of the Universe by observations like galaxy rotation curves, gravitational lensing, bullet clusters, etc. Besides that, the current relic density of DM has been measured quite precisely in satellite-borne experiments like Planck and WMAP. A dominant part of the matter in the present Universe is in the form of DM. However, the nature and production mechanism of the same remains a mystery and still an open question. This proposed research wishes to look into the properties and interactions of possible candidates of DM, be it weakly or feebly interacting fundamental particles originated through particle interactions in the early Universe. It is essential to look into such models and study the possible signature of such new physics in the present and upcoming experiments that comprise direct, indirect and collider searches of dark matter. Such a study also requires an extensive overlap within the broad areas of astrophysics, cosmology, and particle physics. Through different ground-based and space-borne experiments, direct and indirect searches of Dark Matter can reveal helpful information. With multi-messenger signatures from the multi-wavelength capabilities of X-ray, gamma-ray and ultraviolet telescopes, the neutrino detector and the detection of gravitational waves, along with the constraints from direct detection and collider production, provide us with a robust framework for a deeper insight.	
M3	**Sub Area**	**Data Science and Machine Learning (PRL)**
M3.1	Modern Machine Learning (ML) frameworks aim to utilise different deep neural networks over large data sets to find hidden features in data and solve diverse problems. Although its impact is now overwhelmingly evident in our everyday life, from a simple Google search to the autonomous car, it is still in an evolving phase with fundamental research (especially in India). In the last few years, such techniques have demonstrated their exceptional capability in theoretical and experimental research. For instance, remarkable progress is achieved in developing different algorithms in classification, identification,	

	characterisation and estimation, various applications in experimental measurements in theoretical physics and experiments. With these in mind, it is high time to prioritise and invest in capacity building for this critical component of future capability. Deep neural networks are incredibly versatile and applicable in diverse areas of research. It is envisaged that the techniques developed in this project would generate the opportunity and zeal to explore them further in different fields, including space physics.	
M3.2	**Developing Algorithms towards Explainability with Deep Machine Learning(PRL)** The true power of deep learning comes from "learning from data," more often than not, a deep neural network's performance improves as we feed in more data from a more extensive statistical sampling. Lately, the importance of explainability in machine learning has been realised in research and development and in all other scopes of applications, too. This effort is worth making the "black box" of complex ML models more transparent by understanding which features or inputs are most influential in the model's output, how those features interact to produce a specific result, or why the model made a particular prediction in a given instance. Explainability promotes accountability by allowing us to identify and correct errors or biases in ML models, thus building trust in why a model made a particular decision. Understanding the deeper perspective can also help identify weaknesses, refine features, and improve overall performance.	
M3.3	**Applying Deep Machine Learning Techniques in the Areas of Fundamental and Space Physics (PRL)** With advanced implementation, the application of machine learning (ML) techniques is revolutionising almost all scientific disciplines. Typically, research domains are characterised by vast datasets, complex phenomena, and the need for sophisticated analysis, making them ideal candidates for Machine Learning applications, giving the unique opportunity to explore complex phenomena in nature, and it is now widely used in different streams of research. In this project, we test and develop advanced deep machine learning applications to improve the detection of new physics searches, especially in theoretical physics, and try to develop physics-intuitive neural networks that follow specific requirements. Our group at PRL has been actively working in this field for the last several years.	
N	**Area**	**Weather and Climate (NARL/SAC/IIRS/NESAC/PRL)**
N1	**Sub Area**	**Radiation, Aerosols, and Trace Gases (NARL/IIRS/NRSC/PRL)**
N1.1	**Modelling of Atmospheric Chemistry and Dynamics (PRL)** Atmospheric chemistry and dynamics play key roles in impacting the air quality and climate. In this regard, modelling over varying scales (local, regional, and global) and complexities (box, chemical transport, general circulation) are being performed at PRL supported by Vikram HPC. In particular, the focus is on the modelling of atmospheric trace gases and aerosols over the South Asian region. A variety of natural and man-made emissions, together	

	with improved representation of complex topography and detailed chemistry are included in complex earth system models. The simulations assist in interpreting observations and in predicting effects of possible scenarios. Feedbacks between atmospheric chemistry and regional climate, also through biogenic processes, are to be studied.
N1.2	**Research Areas in the field of Space Sciences (SAC)** Multi-wavelength astronomy is the major thrust area of research with special emphasis on terahertz (THz) or sub mm astronomy. THz astronomy has potential to answer some of the most profound questions related to the cold components of the Universe on scales of galaxies, molecular clouds, star and planets. Multi-wavelength observations along with theoretical models and simulations are used to understand various astronomical phenomenon. Apart from these studies research related to exoplanets and solar physics are also quite important themes being explored at SAC. Important research areas and challenges involved in ongoing program is as follows. • Understanding temporal evolution of elemental abundances in solar flares X-ray observations through theoretical modelling and satellite observations. • Sub-mm astronomy can answer some of the most profound questions related to the cold components of the Universe on scales of galaxies, molecular clouds, star and planets. Precursor studies using multi-wavelength studies using observations from global sub-mm telescopes. • Radiative transfer simulations and modelling for Terahertz site characterization studies. • Research studies related to transit light curves and atmospheric characterization of exoplanets. • Experiments and modelling of various physical, chemical and biological phenomena in microgravity conditions. • Magnetohydrodynamic simulations and modelling studies for protoplanetary disc and filament formation in ISM. • Ionospheric properties of Earth with modelling and satellite observations for understanding the space weather.
O	**Area** — **Astronomy & Astrophysics (URSC)**
O1	**Sub Area** — **Compact Object Astrophysics (URSC)**
O1.1	**Magneto-Hydrodynamic Effects on Accretion Disks in Strong Gravity (URSC)** Magneto-hydrodynamic (MHD) simulations are crucial for understanding the behavior of accretion disks, especially in environments with intense gravitational fields, such as those around black holes or neutron stars. MHD combines magnetism and fluid dynamics to model the dynamics of electrically conductive fluids in the presence of magnetic fields.

	These simulations are vital for exploring how magnetic fields influence the structure and evolution of accretion disks, impacting phenomena such as jets/outflows and energy release. Aim of the proposal is to address how strong gravitational fields affect the MHD dynamics of accretion disks. Specifically, it is important to investigate how the interplay between strong gravity and magnetic fields influences the disk's stability, turbulence, and the generation of Quasi-periodic Oscillations (QPOs). Understanding these effects is essential for interpreting observational data from Galactic and extra-Galactic compact objects.	
O2	**Sub Area**	**Galactic Astronomy (URSC)**
O2.1	**Impact of AGN and Star-formation Feedback on Evolution of Galaxies (URSC)** The study of local galaxies is crucial for understanding the formation and evolution of galaxies on a broader scale. In star-forming galaxies, we can examine the conditions that lead to the birth of new stars, including the role of gas dynamics, feedback from supernovae, and the impact of magnetic fields. Active Galactic Nuclei (AGN) in local galaxies provides a unique perspective on the impact of super-massive black holes on their host galaxies. Gas dynamics around AGN are critical for understanding how these black holes influence their environment. The study of AGN involves examining the movement of gas in the accretion disks, the outflows driven by jets and radiation, and how these processes affect star formation and galactic evolution. This includes analyzing how AGN feedback mechanisms, such as the kinetic and thermal energy released by jets, can regulate gas inflows and outflows, thereby influencing the rate of star formation and the growth of the galaxy. By studying these local systems in detail using space based observations in synergy with ground based observations, we need to develop models and test theories about feedback that is fundamental to galaxy evolution.	
P	**Area**	**Space Instrumentation (URSC)**
P1	**Sub Area**	**UV/EUV Instrumentation (URSC)**
P1.1	**Development of an UV Polarimeter (URSC)** UV polarimetry is a crucial tool in astrophysics, providing insights into the magnetic fields, dust properties, and scattering mechanisms in various cosmic environments. By capturing medium and star-forming areas, which are crucial for our understanding of cosmic evolution. However, its success heavily depends on the capabilities of the instruments used. UV polarimeters require exceptionally sensitive detectors (preferably in the range of 150 nm – 300 nm) to capture the faint signals along with an optimized optical design with minimal number of optical elements to minimize the loss of signal. The design of these instruments must also minimize instrumental polarization, which can distort the results, requiring meticulous calibration and engineering precision.	

P1.2	**Development of a Detector System for EUV Imaging/Spectroscopy of Cosmic Sources (URSC)** EUV (Extreme Ultraviolet) imaging and spectroscopy are essential tools in astrophysics, offering unique insights into the high-energy processes occurring in a variety of cosmic environments, such as the solar corona, supernova remnants, and active galactic nuclei. These wavelengths can reveal information about hot plasmas, magnetic field structures, and energetic events that are not accessible at other wavelengths. However, the detectors required for EUV observations of Galactic/Extra-galactic sources (excluding the Sun) present significant challenges. EUV photons are scarce and require highly sensitive detectors with high spatial and spectral resolution to capture meaningful data. The materials used in this must be carefully selected for their ability to work with weaker fluxes that are more challenging to measure than those in other wavelengths. Together with the high sensitivity, solutions to maintain long-term performance with minimal degradation should be explored.	
P2	**Sub Area**	**Detector Technology (URSC)**
P2.1	**Study of Superconducting Materials for Future Low Temperature Radiation Detector Development (URSC)** The future in space science detector technology is towards fabrication of multi-wavelength and large array superconductor detector technology. Study of specific superconductor materials and its characterization, which requires sub-Kelvin cooling, to minimize the noise in the measurement of photons is the prime objective of the proposed research area. Microwave Kinetic Inductance Detector (MKID) is one such detector technology which has been studied in first decade of 21st century and is still a subject of intense interest for multi-wavelength and noise-free detector technology. MKID can detect a large part of the electromagnetic spectrum starting from X-rays to Millimeter as well as it is capable of particle detection. This particular benefit makes MKID as one of the most powerful detectors in the modern era of Astronomy. Work envisaged: • Study of specific superconductor materials catering for detection of large part of the electromagnetic spectrum. • Modeling and simulation of bulk material for characterization of critical temperature and sensitivity to detection of electromagnetic radiation. • Design of patterned detector to act as a resonator and characterization of responsivity for change in material kinetic inductance with incidence energy.	

P2.2	**Development of X-ray CMOS Detector for X-ray Imaging and Spectroscopy Application (URSC)** CMOS detector technology for optical imaging is being used very widely nowadays. The CMOS detector made with Silicon can be used for soft X-ray detection and spectroscopy application. The major technological requirement for soft X-ray application is the device should have Back- illuminated architecture and higher depletion depth for higher efficiency in soft X-ray band. Preliminary specifications for the X-ray CMOS sensor are ➢ 1K x 1K sensor for soft X-ray Imager with ~40 µm pixel, may be a High-Rho device. ➢ Low read noise [for spectral resolution; energy dispersive]. ➢ Depletion depth > 35 µm [for higher QE at medium energy X-ray ~8 keV]. ➢ Full well ~ 10000 [sufficient for X-ray photon counting mode operation]. ➢ Back illuminated preferred [for having higher QE at low energy X-rays < 1000 eV]. ➢ Digital output; LVDS SPI with 12/ 14 bits ADC. Work envisaged: ➢ Modeling and pixel design of the sensor for the suitable fab-lab having Rad-Hard high-Rho fabrication process. ➢ Design of full array sensor along with Analog to digital converter and digital interface; LVDS-SPI. ➢ Fabrication of proto devices and preliminary characterization of the sensor.
P2.3	**Development of Readout Electronics for Microwave Kinetic Inductance Detector (MKID) (URSC)** MKIDs work on the principle that incident photons change the surface impedance of a superconductor through the kinetic inductance effect. The kinetic inductance effect occurs because energy can be stored in the super-current of a superconductor. Reversing the direction of the super-current requires extracting the kinetic energy stored in the super-current, which yields an extra inductance. This change can be accurately measured by placing this superconducting inductor in a lithographed resonator. A microwave probe signal is tuned to the resonant frequency of the resonator, and any photons which are absorbed in the inductor will imprint their signature as changes in phase and amplitude of the probe signal. Work Envisaged: 1. Read-out electronics technology to be designed to excite the resonator and detect the change in phase on absorption of electromagnetic radiation. 2. Finally, the design to be extended for large array device.

P3	Sub Area	Exoplanet Imaging (URSC)
P3.1		**Direct Imaging of Exoplanets (URSC)** The field of exoplanet science is one of the most rapidly emerging and important areas for answering key questions about planet formation and finding other habitable worlds. More than 5,000 exoplanets have been discovered, with the majority of discoveries made using indirect methods. Direct imaging and characterization of rocky exoplanets is one of the key scientific goals of current and upcoming large telescopes. To directly image planets around a star, it is necessary first to resolve the planet from the star and then suppress the starlight to extremely high contrast levels so that the planets become visible. For an Earth-like planet around a Sun-like star, this requires a contrast of 10 billion at a small angular separation of 0.1 arc-seconds. Such high contrast is possible only from space, where atmospheric turbulence is absent. This is usually achieved with the help of a stellar coronagraph or an interferometer. Ground-based telescopes have demonstrated this technology in detecting larger planets at high orbital distances, but it has never been demonstrated for habitable zone planets, which require an optimized space-based telescope. NASA's Nancy Grace Roman Telescope plans to demonstrate the coronagraph and active wave front control technology in space by 2027. The European mission LIFE (Large Interferometer for Exoplanets), utilizing stellar interferometry, plans to characterize Earth-like planets. Developing this technology for a space-based platform is of paramount importance toward the long-term vision of exoplanet exploration. For demonstrating the technology on ground, it is required to demonstrate the hardware in the space environment conditions, preferably in the visible / near infrared region of the spectrum.
Q	Area	Emerging Areas in Theoretical Physics (URSC)
Q1	Sub Area	Strong Gravity (URSC)
Q1.1		**Imaging of Black Holes (URSC)** A black hole's shadow, credit to the phenomenal image of the BH by the EHT collaboration, represents the projection of its unstable-photon region onto the observer's sky. While significant progress has been made in black hole imaging, numerous intriguing opportunities for further study remain. Compact objects are surrounded in an intricate environments that include accreting plasma and electromagnetic fields, both of which significantly affect their imaging properties. While the impact of non-magnetized plasma on the shadow of a static,

	spherically symmetric black hole (BH) is well-understood and can be calculated with an unstable photon sphere, the scenario becomes more complex in stationary axisymmetric space times. Despite this, there is limited research on general plasma models and rotating BHs beyond the Kerr solution. This gap underscores the need for a detailed investigation into how these factors influence black hole imaging. This project aims to address this need by exploring the effects of various plasma models and magnetic fields on the imaging of rotating black holes, advancing our understanding of their observational signatures in the electromagnetic band (radio to X-rays). Upon modeling of magnetized relativistic accreting plasma around central sources, polarimetric properties of the compact emission can be measured, providing insights into black hole spin information.	
R	**Area**	**Space weather (VSSC)**
R1	**Sub Area**	**Space Weather Modeling and Forecasting (VSSC)**
R1.1	**Forecasting Solar Flares, Coronal Mass Ejections, and their geo-effectiveness using Physics Informed AI/ML (VSSC)** Space weather forecasting using AI/ML involves the development of machine learning/ deep learning (ML/DL) algorithms to analyze large datasets of background Solar wind parameters, solar flares and Coronal Mass Ejections (CMEs) to forecast when these events will reach Earth and what will be its geo-effectiveness with sufficient lead time. Though flares and CMEs are understood as triggered by the common physical process of magnetic reconnection, their association is challenging to predict. Once the CMEs have erupted from the Sun, we also need to predict their magnetic signatures near Earth (Sun-Earth Lagrange-1 point). In this project, instead of using a purely ML-based approach, we expect to develop **Physics-Informed ML/DL** models that aim to predict the space weather conditions. For instance, the Helioseismic Magnetic Imager (HMI) dataset can be used to identify active regions, and using this as a knowledge-informed deep learning, a solar flare forecast model can be developed. Furthermore, the output of this data-driven model can be used to classify whether a solar flare will be accompanied by a CME using deep learning algorithms. This information, along with other datasets, needs to be used to forecast the geo-effectiveness of the CME in terms of the magnetic field magnitude and direction at the Sun-Earth L1 point. Through this project, we expect to have validated and tested software for predicting Solar flares (M class or greater) associated CMEs, and their geo-effectiveness in terms of IMF at L1.	

S	Area	Satellite Remote Sensing of Earth and Planetary Atmosphere (VSSC)
S1	Sub Area	Satellite based retrieval of aerosol properties (VSSC)
S1.1	**Development of an algorithm for satellite-based retrieval of aerosol properties over land through the synergy of radiative transfer computations and surrogate modelling (VSSC)** Satellite based retrieval of aerosol properties is essential to unveil the large spatial and temporal heterogeneity in aerosol distribution and characteristics, which is vital for the accurate estimation of aerosol impacts. However, retrieval of aerosol properties from satellite-based measurements is challenging due to multiple factors, including the intricacies in delineating the aerosol signal from satellite measured radiance which includes contribution of both atmosphere and underlying surface. This becomes more challenging over land regions where the surface reflectance shows large heterogeny. However, retrieval of aerosol properties over land is inevitable as most of the anthropogenic aerosol sources are located in land regions. Satellite based polarisation measurements enable better delineation of surface contribution and thereby better retrieval of aerosol properties over land. There are different types of sensors and algorithms which uses different techniques for the retrieval of aerosol properties over land. Look up table approach, based onradiative transfer computations, is one of the methods, which has been widely used for the global retrieval of aerosol properties. However, these algorithms are computationally too intense. In view of these, the proposed research aims at the development of inversion algorithms by combining the potential of radiative transfer computations and surrogate modelling. Major objectives of the proposal are (i) development of an algorithm using radiative transfer computations and surrogate modelling, for the retrieval of aerosol properties over land and ocean from satellite-basedmeasurements of total and polarised radiation, (ii) implementation of the algorithm on satellite-based measurements and retrieval of aerosol parameters and (iii) validation of retrieved aerosol parameters using ground-based measurements.	
S2	Sub Area	Satellite based retrieval of green-house/trace gases (VSSC)
S2.1	**Development of inversion algorithms for satellite-based retrieval of green-house/ trace gases using radiative transfer computations and surrogate modelling approaches (VSSC)** Rapid increase in concentration of green-house gases in the atmosphere and its adverse effects in climate and air-quality are of major concern. Trapping of more radiation in the Earth-atmosphere system due to the enhancement in green-house gases alters the global energy balance and hence affects the climate. In addition, increase in pollutant	

	gases due to various anthropogenic activities deteriorates the air quality in many of the major cities and affects human health. Hence, continuous measurements of green-house and trace gas concentrations is inevitable to address the global climate change and monitor air quality. Satellite-based measurements of spectral radiance at suitable wavelengths can be used for the retrieval of these gases on a global scale. In view of these, the major objectives of the proposed research activity are (i) development of inversion algorithms for the retrieval of green-house/trace gases (CO_2, CH_4, H_2O, O_3 and CO) concentration using line-by-line radiative transfer computations and surrogate modelling approaches, (ii)implementation of the algorithm on existing satellite measurements and retrieval of gas concentrations and (iii) validation and Inter-comparison of the retrieved gas concentrations using ground based and satellite-based measurements. Radiative transfer simulations need to be carried out to compute top of the atmosphere spectral radiance, for different combinations of atmospheric, surface and sun-satellite geometry conditions. These simulated radiance data forms the trading data set for the model.	
T	**Area**	**Design and Development of Quadrupole Mass Spectrometer (LEOS)**
T1.1	**MEMS based Quadrupole Mass Spectrometer (LEOS)** Development of lightweight, low-power mass spectrometers can be a very useful space science instrument for earth observation and planetary missions. Mass spectrometry (MS) is an advanced scientific tool to detect and quantify atomic or molecular samples. This has been the instrument of choice for space exploration to analyze the composition of gaseous samples right from upper atmospheric studies using balloon flight to deep space planetary missions. It is also used in extensive ground applications such as environmental monitoring, forensic detection, electronics, and biomedical applications, etc. There is a lot of interest and demand in developing high-performance mass spectrometer with low weight, form factor, and power consumption. One of the enabling technologies to achieve this goal is silicon micromachining, also called Micro Electro Mechanical Systems (MEMS) technology. In such missions, mass spectrometers can be used to perform the chemical analysis of atmospheric composition or evolved gases from rock samples. Besides small size and low weight, common requirements include low cost, low power consumption, field portability, reliability, and redundancy for long period operations. The prime objective is to develop a miniature Quadrupole Mass Spectrometer (QMS) for space applications with a mass range of up to 300 amu and a resolution of 1 amu, comprising MEMS-based quadrupole mass filter at its core. Quadrupole Mass Filter (QMF) employs RF and DC electric fields applied across quadrupole electrodes for temporal separation of ions. The novelty proposed is the usage of MEMS technology to physically shrink the mass filter element without compromising much on its scientific capabilities.	

U	Area	Development of CNT based nonwoven fabric sheet (LEOS)
U1.1		**Synthesis and study on carbon nanotube-based nonwoven fabric sheet for dust repellent space applications (LEOS)** In the lunar/Martian environment, dust accumulates on opto-electro-mechanical surfaces and causes friction and wear. It can adhere to surfaces, causing coating contamination, false instrument readings, clogging, thermal and optical control problems, abrasion, equipment failure, and loss of traction. In recent times, research carried out on the CNT-based nonwoven fabric sheet is shown to reduce friction and wear on surfaces of equipment. Such a sheet can become a promising dust repellent tool for space equipment and instruments aboard landers/rovers that are destined to work in lunar and Martian environments. The prime objectives of proposal interest are: a) fabrication of a carbon nanotube-based nonwoven fabric sheet by a suitable process (floating catalyst CVD); b) study the electrical conductivity, and flame resistance; and c) address problems regarding lunar dust, namely, dust adhesion and abrasion and surface electric fields, and dust transport using, lunar regolith simulant and potential use of CNT sheet as a surface textile material to withstand extreme lunar/Martian dust conditions.

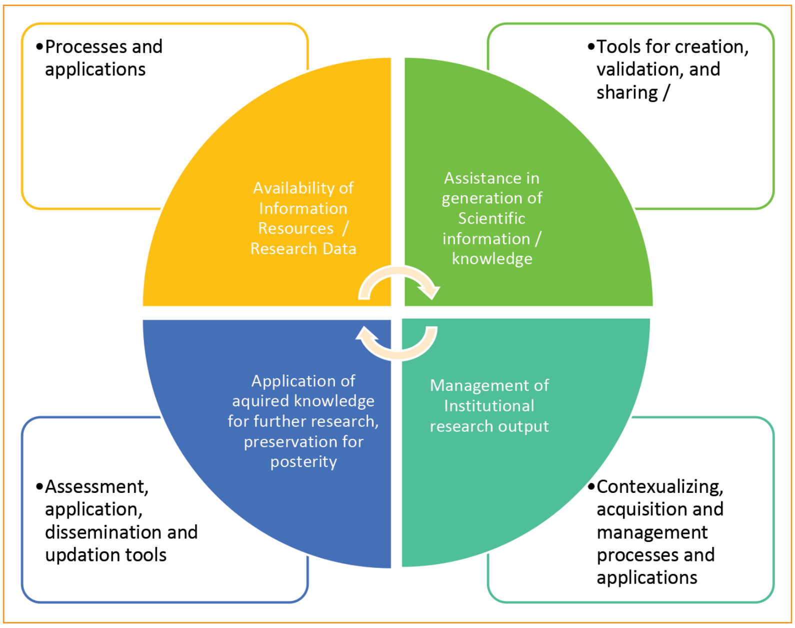
SPACE POLICY & MANAGEMENT

A	Area	Space Policy and Economy (ISRO-HQ)
A1	Sub Area	Evolving Space Governance and Global Policy (ISRO-HQ)
A1.1	**Development of National Space Policies for Emerging Spacefaring Nations (ISRO-HQ)** As more nations step into outer space activities, the need for national space policies becomes urgent. This research will explore model frameworks for emerging space actors, balancing international obligations with national interests. Develop a case studies, policy drafts, and strategic roadmaps tailored to the capacities and ambitions of developing countries. Analyzing nations like non-space firing nations at the core.	
A1.2	**Space Traffic Management: Creating a Unified Global Policy (ISRO-HQ)** Space is congested. Satellites, debris, and mega-constellations create collision risks. A comprehensive space traffic management (STM) policy remains elusive. This research will assess existing initiatives (e.g., U.S. STM proposals, UN COPUOS work), identify regulatory gaps, and propose a scalable international STM framework adaptable for future traffic scenarios, including AI-managed spacecraft.	
A1.3	**The Politics of Lunar Governance: Evaluating Current Proposals and Future Needs (ISRO-HQ)** With Artemis Accords, China-Russia Lunar Initiatives, and others pushing lunar agendas, governance of the Moon is becoming critical. This research will analyze competing visions for lunar governance, focusing on resource rights, security zones, environmental preservation, and legal precedents under the Outer Space Treaty. The research will develop model legal-political agreements for future lunar activities.	
A1.4	**International Responsibility for AI-Operated Satellites (ISRO-HQ)** AI is increasingly managing satellite constellations and autonomous missions. But when AI-driven decisions cause accidents or treaty violations, who is responsible? This research explores liability attribution, treaty interpretations, and policy recommendations for AI-managed space systems under the Outer Space Treaty and Liability Convention.	
A2	Sub Area	Space Economy (ISRO-HQ)
A2.1	**Direct and Indirect impacts of space sector in India (ISRO-HQ)** India's space sector has undergone remarkable growth, evolving from its early beginnings with the Indian Space Research Organisation (ISRO) to becoming a global player in space technology and exploration. With ambitious missions like Chandrayaan, Mangalyaan, and Gaganyaan, India has demonstrated its technological prowess while contributing to scientific advancement. Beyond its achievements in space, the sector plays a crucial role in driving economic growth and societal progress.	

	This research study aims to analyze the direct and indirect impacts of the Indian space sector on the nation's economy and society, exploring its multidimensional influence. Key Focus Areas of the Study: 1.Economic Contributions a. Assessing the space sector's role in GDP growth, employment generation, and industrial expansion. b. Evaluating the rise of private space startups and their contribution to innovation and investment. 2.Technological Advancements & Spin-off Benefits a. Examining how space research has led to advancements in telecommunications, agriculture, weather forecasting, and disaster management. b. Analyzing the commercialization of space-derived technologies in other industries. 3.Societal Impact & Inclusive Development a. Investigating how satellite-based services (e.g., telemedicine, education, and rural connectivity) have improved quality of life. b. Studying the role of space technology in bridging urban-rural disparities. 4.Global Competitiveness & Strategic Influence a. Understanding India's position in the global space economy and its potential for international collaborations. b. Assessing how space diplomacy strengthens India's geopolitical standing. 5.Policy & Future Prospects a. Reviewing government initiatives like space sector reforms, privatization, and foreign direct investment (FDI) policies. b. Identifying challenges and opportunities for sustainable growth in the space industry. This study will provide valuable insights for policymakers, industry stakeholders, and researchers, highlighting how India's space ambitions translate into broader economic and societal benefits. By understanding these impacts, India can further harness its space potential for inclusive and sustainable development.	
B	**Area**	**Space Insurance (ISRO-HQ)**
B1	**Sub Area**	**Innovative Space Risk and Insurance Models (ISRO-HQ)**
B1.1	**New Risk Models for Mega-Constellations: Insurance Challenges and Solutions (ISRO-HQ)** Satellite mega-constellations like Starlink and Kuiper change the risk landscape. Collisions, cyber-attacks, and orbital debris risks multiply with thousands of interconnected satellites. This research investigates how insurance companies and governments must innovate underwriting practices, loss models, and liability assumptions to keep up with these large-scale deployments.	

B1.2	**Developing Insurance Models for Space Tourism (ISRO-HQ)** The rise of companies like Blue Origin, Virgin Galactic, and SpaceX signals the birth of space tourism. However, insuring non-astronauts in a highly risky environment demands new approaches. This research will study the current legal liability regimes, health coverage requirements, and possibilities for customized space tourist insurance models, aiming to frame an industry-ready insurance product proposal.	
B1.3	**Space Debris and Third-Party Liability: Insurance Gaps and Innovations (ISRO-HQ)** No clear private sector insurance fully covers the risks posed by space debris-induced damages. This research will review the current gaps in space debris liability insurance, assess the need for compulsory third-party insurance regimes, and propose novel hybrid models combining public and private insurance mechanisms.	
B1.4	**Building an International Space Risk Pool: Combining Space Insurance, Law, and Policy (ISRO-HQ)** Given the enormous financial and human risks in space activities, an international space risk pool could offer a collective insurance model against catastrophic failures. This research will draw from terrestrial models (like terrorism insurance pools) and design a cooperative global insurance framework involving public and private stakeholders, embedded within space policy and legal systems.	
C	**Area**	**Management (SAC)**
C1.1	**Research Proposal Evaluations for Sponsored Research with (SAC)** A number of sponsored research avenues are currently undertaken under SAC such as RESPOND, Space Technology Cell (STC), Space Technology-Incubation Cell (STI-C), RAC-S (Regional academic Centres of Space), to name a few. Several project proposals in various subjects related to Space applications are received from academia across India under these avenues. In order to screen-in proposals , especially with regard to expertise and publications of the proposer (PI: Principle investigator), it is proposed to design an automatic screen-in procedure, combining AI/ML techniques to identify and match the PI/CO-PIs expertise and bibliometric information (publication, grant funding received, patents etc) with that of the expertise required in project proposals by SAC. Suitable analytics such as cluster analysis techniques may be employed to identify subject experts and match it with expertise required for SAC's sponsored research activities. Offline/Intranet use of this facility may also be employed to gather details about previous projects, support in the monitoring and will help to identify duplication, gaps and additional opportunities in future research activities.	

C1.2	**Experimental Social Research studies including Randomised Control trials to execute Impact assessment studies of ISRO's educational outreach activities (ISRO-HQ/SAC)** As a leading space agency in the country, SAC/ISRO has actively promoted STEAM (Science, Technology, Engineering, Arts and Mathematics) education, facilitated research collaborations, and contributed to the dissemination of advanced space technologies. SAC's initiatives, including student outreach programs, satellite-based educational services, and academic partnerships, have directly influenced students, researchers, and educational institutions. With India's growing emphasis on space science, innovation, and technological advancements, it is essential to evaluate ISRO's role in shaping the country's scientific progress and the broader implications of its educational and research-driven initiatives. It is proposed to conduct social experimental studies such as Randomised Control Trials (RCTs), Cohort studies or Case Control studies or other types of pre and post taest studies to understand the ways in which SAC/ISRO's educational outreach programmes such as GujSAC BHAvi VaIgnank KAryakram (GujSAC BHAVIKA), YUVIKA, UNNATI, has supported to pursue students to select careers in STEM subjects. Such studies can support in providing data-driven insights in understanding long-term engagement and knowledge retention of the participants, identify best practices and areas for improvement in program structure and delivery, quantify the return on investment (ROI) from educational outreach programs and support in identifying high-impact strategies to improving the reach and effectiveness of future initiatives.
C1.3	**Analysing Public Sentiment on ISRO's Major Space Missions through Social Media Analysis (ISRO-HQ/SAC)** The Indian Space Research Organisation (ISRO) has garnered significant global attention through its ambitious space missions, including Chandrayaan, Mangalyaan, Aditya-L1, and the forthcoming Gaganyaan project. Public perception of these missions is instrumental in shaping both national and international support, influencing funding allocations, and informing policy decisions. In the contemporary digital era, social media platforms serve as critical spaces for public discourse, facilitating real-time expression of sentiment, engagement, and opinion formation. This proposed research area include sentiment analysis of social media data to systematically examine public emotions, concerns, and enthusiasm surrounding ISRO's major space missions. By analyzing sentiment fluctuations before, during, and after key mission events, this research seeks to provide a comprehensive assessment of the impact of ISRO's achievements on its global reputation. The findings will contribute to a

	deeper understanding of how public discourse evolves in response to space exploration milestones and will offer insights into the broader implications for public engagement, policy formulation, and scientific communication strategies.
C1.4	**Space education for differently abled students (SAC)** A study conducted in SAC highlighted the importance of designing engaging learning modules related to Space Science & Technology for differently abled students which may be inBraille, audio content or in sign language. Studies indicates that such learning modules, especially in local languages, are limited in scope. Options may be explored to design 3D tactile models of space systems, tactile books, audio books, immersive modelsbased on ISRO's space journey, developing space Science based lexicon for Indian Sign Languagefor supporting SAC's Space exhibition centre at Ahmedabad.
C1.5	**Knowledge Management Practices in Research and Development (SAC)**  Libraries represent an indispensable link in the scientific research and knowledge generation system chain. Knowledge management (KM) has rapidly moved beyond the stage of a trend and has established itself as a key part of many libraries knowledge strategy. Consumed and produced knowledge and information are key resources and is prime indicator for assessment of growth of any organization.Due to increasingly dynamic environment, organizations are realizing that there is a vast and largely untapped knowledge asset floating around the organization, which may be tapped and utilized by an effective KM strategy and implementation plan. Major areas of Knowledge Management includes development of processes and applications for transforming research data into scientific information; tools for creation, validation, standardization and dissemination or sharing of knowledge; the acquisition, contextualizing, and management processes; and assessment and applications tools using information and knowledge.The core of the process is how to make implicit or tacit knowledge, explicit.

	It involves a multi-disciplinary approach to achieve organisational objectives by making the best use of the explicit and tacit knowledge of researchers. The suggested research topics are: • Exploring various Knowledge Management Systems (KMS) programs in different R&D organisations. Investigating missing interactions in present knowledge management system. Designing suitable framework for effective Knowledge Management System. • Development and designing of processes and applications for access management; resource management, validation, contextualizing, and standardization. • Development and designing of processes and applications for effective information retrieval and dissemination tools, integrated search and other applications for meaningful utilization of knowledge pool. • Delivery of organized knowledge resources through innovative information services. • Preservation of Institutional Intellectual output.
C1.6	**Artificial Intelligence (AI)and Libraries (SAC)** Application of AI in libraries, digital preservation, information literacy, and knowledge management gaining momentum day-by -day. Feasibility studies and subsequent application developments may be undertaken in some key areas, like in Library Operations-enhancing search and discovery, and improve user experience; Information Literacy for librarians and researchers; AI-powered Information Retrieval and Management like metadata extraction, content analysis, and personalized information delivery, etc. Libraries can use AI powered recommendation systems to suggest books, articles, or other resources to users based on their reading history and preferences. Machine learning algorithms can analyse borrowing patterns and predict future trends, helping library professionals make informed decisions about which material to acquire, retain or discard.
C1.7	**Research Information Network System (SAC)** In the present age of networking and immensely potent tools for communication, scientific communication is no longer limited to scholarly and traditional modes of research communication. Many research network for collaboration are already in place and being utilized for advancement of scientific research. Indian research Information Network System (IRINS) is one such web-based Research Information Management (RIM) service developed by the Information and Library Network (INFLIBNET) Centre. The portal facilitates the academic, R&D organisations and faculty members, scientists to collect, curate and showcase the scholarly communication activities and provide an

	opportunity to create the scholarly network. The IRINS is available as free software-as-service to the academic and R&D organisations in India. The IRINS supports to integrate the existing research management system such as HR system, course management, grant management system, institutional repository, open and commercial citation databases, scholarly publishers, etc. It has integrated with academic identity such as ORCID ID, Scopus ID, Research ID, Microsoft Academic ID, Google Scholar ID for ingesting the scholarly publication from various sources. Studies may be taken up regarding pros and cons of designing and deployment of a dedicated or joining an existing such networks for better synergy between academia and research institution.	
C1.8	**Data Analytics and Predictive Modelling in Library Services (SAC)** Library can use cutting edge technologies like data analytics and predictive modelling to enhance their services and meet the evolving needs of patrons. By leveraging the power of data, libraries can gain valuable insights into patron behaviour, usage patterns and collection trends, ultimately leading to more efficient and personalized services.	
C1.9	**Other topics related to capacity building (ISRO-HQ/SAC)** • Impact assessment of deployed space-based services such as Vessel Monitoring System and developing associated science and technology narratives. • SWOT analysis of the Indian space ecosystem in line with projected Indian space economy. • Assessing and Benchmarking Project Management practices at ISRO besides developing a case study. • Understanding the influence of psychological variables on the scientific productivity or performance of scientific and technical personnel. • Study and development of assessment centre for Training Need Identification of various cadres. • Assessing the technology/economic dividends of technology transfer in promoting private players and enumerating actionable items for improving Indian space economy. • Content generation for a specific eLearning modules embedding learning analytics.	
D	**Area**	**Artificial Intelligence for Education (IIRS)**
D1.1	**Artificial Intelligence for space science education (IIRS)** Artificial Intelligence to enhance digital learning in field of space science for school and college students. AI is transforming digital education by personalizing learning,	

	automating tasks, and improving efficiency, ultimately creating more engaging and effective learning environments. AI in education can improve efficiency, engagement, and equity. AI affects schooling beyond its technological capabilities. AI improves tailored learning experiences, motivating and retaining students. AI's capacity to process large information helps educators understand student performance and provide customized guidance. Gamified learning and interactive components make learning fun and engaging. The study aims to enhance learning space science using AI based innovative methods. This study will explore utilisation of AI tools and their capabilities like speech recognition to increase the support available to students with disabilities, multilingual learners, and others who could benefit from greater adaptability and personalization in digital tools for learning.

Annexure-1

Application for Grant of Funds

1.	Title of the Research Proposal	
2.	Name of the Principal Investigator (Address/Phone/E-mail)	
3.	Name(s) of other investigator(s) with the name(s) of their Institution	
4.	Name of the Institution with Full Address	
5.	Whether the Institution/University is a Government Institution or Non-Government Institution?	
6.	Is the Institution/University/Society managed by an NGO/Trust/Society If yes, provide the details	
7.	If the Institution/society is Non-Government: NGO Darpan Unique ID of the Institution* : PAN Number* : *(It is mandatory for all institutions/ professional societies other than Central/ State Govt. Institutions/Departments)	
8.	Proposed duration of Research Project	
9.	Relevant ISRO Centres for this proposal as per latest RA Document	
10.	Amount of grant requested (in Rs.) 1^{st} Year, 2^{nd} Year, 3^{rd} Year & Total	
	Manpower	
	Equipment	
	Satellite Data/Data	
	Consumables & Supplies	
	Internal Travel	
	Miscellaneous (3% of the total project cost)	
	Others	
	Overheads	
	Total	

11.	a) Bio-data of all the Investigators (Format-A). b) Brief description of the Research Proposal with details of budget (Format-B). c) Declaration (Format-C).
12.	I/We have carefully read the terms and conditions for ISRO Research Grants and agree to abide by them. It is certified that if the research proposal is approved for financial is approved for financial support by ISRO, all basic facilities including administrative support available at our Institution and needed to execute the project will be extended to the Principal Investigator and other Investigators.

Name	**Institution**	**Designation**
Principal Investigator		
Co-Investigator(s)		
Head of the Department/Area		
Head of the Institution		

#College Seal is Required

Form A

Bio-data of the Investigator(s)

(Bio-data for **all the investigators** should be given, each on a separate sheet)

1.	Name	
2.	Date of Birth (dd/mm/yyyy)	
3.	Designation	
4.	Degrees conferred (begin with Bachelor's degree)	

Degree	Institution conferring the degree	Field(s)	Year

5.	Research/training experience (in chronological order)

Duration	Institution	Name of work done

6.	Major scientific fields of Interest	
7.	List of publications	
8.	Email id and Telephone number of PI with STD Code	
9.	Email id of the Head of the academic institution	

Form B

1.	**Title of the Research Proposal** • Area (Specify as per RA document) • Sub Area	
2.	**Summary of the proposed research** A Simple concise statement about the investigation, its conduct and the anticipated results in no more than 200 words	
3.	**Objectives** A brief definition of the objectives and their scientific, technical and techno-economic importance.	
4.	**Approach** A clear description of the concepts to be used in the investigation should be given. All supporting studies necessary for the investigation should be identified. The necessary information of any collaborative arrangement, if existing with other investigators for such studies, should be furnished. The principal Investigator is expected to have worked out his collaborative arrangement himself. For the development of balloon, rocket and satellite-borne payloads it will be necessary to provide relevant details of their design. ISRO should also be informed whether the Institution has adequate facilities for such payload development or will be dependent on ISRO or some other Institution for this purpose.	
5.	**Methodology** Details of the method and procedures for carrying out the investigation with necessary instrumentation and expected time schedules should be included.	
6.	**Major Scientific fields of Interest** A brief history and basis for the proposal and a demonstration of the need for such an investigation preferably with reference to the possible application of the results to ISRO's activities. A reference should also be made to the latest work being carried out in the field and the present state-of-art of the subject.	
7.	**Linkages to Space Programme**	
8.	**Deliverables to ISRO on successful completion of the project**.	
9.	**Data base and analysis** A brief description of the data base and analysis plan should be included. If any assistance is required from ISRO for data analysis purposes, it should be indicated clearly.	

10.	**Available Institutional facilities** Facilities such as equipments, etc, available at the parent Institution for the proposed investigation should be listed.	
11.	**Fund Requirement** Detailed year wise break-up for the Project budget should be given as follows:	

Fellowships*	**Ist Yr**	**2nd Yr**	**3rd Yr**	
Research Fellows				
Total				
*Note: please specify the designation, qualification and rate of salary per month for each category				
	Ist Yr	**2nd Yr**	**3rd Yr**	**Total**
Equipment**				
Total				
Please specify the various individual items of equipment and indicate foreign exchange requirement, if any				
	Ist Yr	**2nd Yr**	**3rd Yr**	**Total**
Satellite data/data				
Total				
	Ist Yr	**2nd Yr**	**3rd Yr**	**Total**
Consumables & Supplies *(Justification needed)				
Total				
	Ist Yr	**2nd Yr**	**3rd Yr**	**Total**
Internal Travel				
Total				
	Ist Yr	**2nd Yr**	**3rd Yr**	**Total**
Miscellaneous (3% of the total project cost)				
Total				
	Ist Yr	**2nd Yr**	**3rd Yr**	**Total**
Any Others *(Justification needed)				
Total				
	Ist Yr	**2nd Yr**	**3rd Yr**	**Total**
Overheads(Overhead Expenses of 20% of Total Project Cost not exceeding ₹3.00 lakhs)				
Total				

10.	Whether the same or similar proposal has been submitted to other funding agencies of Government of India. If Yes please provide details of the institution & status of the proposal.	Yes/No

**Justify each equipment. If computer is proposed, only desktop has to be purchased but not laptop.

Annexure-2

Form –C

Terms and Conditions of ISRO Research Grants

1. The approved funds should be utilized solely for the purpose for which they have been granted unless ISRO agrees otherwise. A Certification that the funds have been so used should be produced by the grantee Institution after the end of each year of the support.

2. Due acknowledgement to ISRO should be made in all reports and publications arising out of the part of the work supported by ISRO. The grantee will take prior permission of ISRO before publishing any work based on the ISRO supported project.

3. Two copies of all the publications resulting from the research conducted with the aid of the grant should be submitted to ISRO.

4. Any intellectual property rights or such information/knowledge being able to sustain or create or any such right arising out of the projects sponsored by ISRO will be held jointly by the Academic Institution/R & D institution and ISRO as per RESPOND norms. Academic Institute/R & D institution and ISRO shall inform each other before filing for any protection of any Intellectual Property Rights resulting from any of the project sponsored by ISRO. Academic institute/R & D institution and ISRO will ensure appropriate protection of Intellectual Property Rights generated from cooperation, consistent with laws, rules and regulations of India. The expenses for filling the Patent protection in India and abroad shall be borne equally between Institute and ISRO. Any/all financial accruals due to any commercial exploitation, of this patent shall be shared equally between them, on 50:50 basis. However any of the parties is free to utilize the IPR for their own use on non commercial basis.

5. The principal Investigator is required to submit two copies of yearly reports indicating the progress of the work accomplished. He is also required to submit two copies of a detailed technical report on the results of the research/development after the completion of the project. The reports will become the property of ISRO.

6. In addition, ISRO may designate Scientists/specialists to visit the Institution periodically for reviewing the progress of the work.

7. An inventory of items purchased from ISRO funds should be sent to ISRO, giving the description of equipment, cost in rupees, date of purchase and name of the supplier along with a purchase certificate from the Administration of the Institution. All items of equipments and unconsumable items costing more than Rs. 5,000/- shall remain the property of ISRO and ISRO reserves the right to transfer them or dispose of them on the termination of the project as ISRO may deem fit.

8. The accounts of the expenses incurred out of ISRO funds should be properly maintained and should be authenticated by an approved auditor. The final accounts statement in duplicate duly audit should be sent to the pay & Accounts Officer, DOS/Senior Accounts Officer, ISRO Headquarters, as the case may be, at the end of each financial year of support.

9. If the total amount sanctioned is not spent during the period of support, the remainder amount should be surrendered to the Pay & Accounts Officer, ISRO Headquarters, as the case may be, within one month after the completion of the project.

10. The assets acquired wholly or substantially out of the ISRO grant should not, without its prior sanction, be disposed off, encumbered or utilized for purposes other than that for which the grant is sanctioned.

11. A register of assets permanent and semi-permanent should be maintained by the grantee Institution, which should be available for scrutiny by Audit.

12. The grantee institution should not divert the grants-in-aid for utilization of the same for similar objects of another institution if it is not in a position to execute or complete the assignment. The entire amount of the grant should then be immediately refunded to ISRO by the institution.

13. The terms and condition of ISRO research grants are subject to change from time to time, but the funding of any project will be governed by the terms and conditions existing on the date of starting of the project with ISRO funds.

Declaration

I / We have clearly read the above terms and conditions and hereby agree to abide by the rules and regulations of ISRO research grants and accept to be governed by all the terms and conditions laid down for this purpose.

I / We certify that I / We have not received any grant-in-aid for the same purpose from any other Department of the Central Government / State Government / Public Sector Enterprise during the period to which the grant relates.

	Signature & Name	**Designation**
Principal Investigator		
Head of the Department / Area (college seal is mandatory)		

Annexure-3

RESPOND COORDINATORS OF ISRO/DOS CENTRES

Sl. No	ISRO/ DOS Centre	Name & Designation	Contact details
1.	SAC	Dr. Abha Chabra Scientist/Engineer-SG RESPOND and Research Management Division Research, Outreach and Training Management Group Space Applications Centre, ISRO Ahmedabad-380015, Gujarat	Tel Phone No: 079- 26913333 Email: research_sac@sac.isro.gov.in
2.	VSSC	Shri Santhosh Kumar S Scientist/Engineer-SF Deputy Division Head RESPOND Coordinator Academic & Sponsored Research Coordination Division, PPEG Vikram Sarabhai Space Centre VSSC, Thiruvananthapuram-695 022, Kerala	Tel Phone No: 0471-2564620 Email: s_santhoshkumar@vssc.gov.in
3.	LPSC	Shri TV Shreejith Scientist/Engineer-SF RESPOND Coordinator, PPEG, MSA Entity Liquid Propulsion Systems Centre (LPSC-V) Valiamala Thiruvananthapuram-695 547	Tel Phone No: 0471-2567562 Email: tvshreejith@lpsc.gov.in, respond@lpsc.gov.in
4.	PRL	Dr. Nandita Srivastava Senior Professor, Udaipur Solar Observatory Physical Research Laboratory (PRL) Badi Road, Dewali Udaipur-313001, Rajasthan	Tel Phone No: 0294-2457211 (office) Email: nandita@prl.res.in; respond@prl.res.in
5.	URSC	Dr. J Krishna Kishore Scientist/Engineer-G, GD, ATDG RESPOND Coordinator, URSC U R Rao Satellite Centre HAL Airport Road Vimanapura PO, Bengaluru-560 017, Karnataka	Tel Phone No: 080-25084480/81 080-25084391 Email: jkk@ursc.gov.in

6.	NRSC	Dr. Chandrasekar K Scientist/Engineer-G & Group Director PPEG, MSA National Remote Sensing Centre NRSC, Balanagar Hyderabad-500 037	Tel Phone No: 040-23884017 040-23884012 Email: Chandrasekar_k@nrsc.gov.in
7.	NARL	Dr. S. Sridharan Scientist/Engineer-SG National Atmospheric Research Laboratory Gadanki-517 112, Pakala Mandal Chittoor District, Andhra Pradesh	Tel Phone No: +91-8585-272124 +91-8585- 272024 (1006) Email: susridharan@narl.gov.in
8.	SDSC-SHAR	Shri Bala Narayanan N R, Scientist/Engineer-SE, PPEG / MSA SDSC-SHAR, Sriharikota Andhra Pradesh-524 124	Tel Phone No: 08623 22 6173 Email: nrbala@shar.gov.in
9.	IPRC	Shri S. Krishna Diwakar Scientist/Engineer-SF DDH, PPED, MSA RESPOND Coordinator IPRC Mahendragiri-627 133	Tel Phone No: 04637 281745 Email: diwakar@iprc.gov.in
10.	IIRS	Dr. Ashutosh Bhardwaj Scientist/Engineer-SG RESPOND Coordinator & Head, RPMD Research Project Monitoring Department (RPMD), Programme Planning and Evaluation Group (PPEG) Indian Institute of Remote Sensing (IIRS) 4 Kalidas Road Dehradun–248001	Tel Phone No: 0135-2524350/4351 Email: respond@iirs.gov.in; ashutosh@iirs.gov.in
11.	NESAC	Dr. K K Sharma RESPOND Committee Chairman Scientist/Engineer-G North Eastern Space Applications Centre Govt. of India Umiam-793 103, Meghalaya	Tel Phone No: 0364 2570138 Email: kk.sarma@nesac.gov.in
12.	IISU	Shri K S Nandhakumar Scientist/Engineer-SG Head, PPEG, PPED ISRO Inertial Systems Unit (IISU) Vattiyoorkavu PO Thiruvananthapuram-695 013, Kerala	Tel Phone No : 0471 2569357 Email: ks_nandhakumar@vssc.gov.in

13.	ISTRAC	Shri Pradeep Kumar C Scientist/Engineer-G Group Head, Signal Processing & Software Development Group Radar Development Area, ISTRAC/ISRO Plot No 12 & 13, 3rd Main, Phase II Peenya Industrial Area Bangalore-560058, Karnataka	Tel Phone No : 08028094489 / 08028094499 Email: pradeepkc@istrac.gov.in
14.	MCF	Shri S.N. Jagannath, Scientist/Engineer-SE Master Control Facility Hassan-573201, Karnataka	Tel Phone No : 08172-273112 Email: jagannath@mcf.gov.in
15.	HSFC	Shri Ravinthar S Scientist/Engineer-SG Group Head Programme Planning and Evaluation Group Management systems Area, Human Space Flight Centre (HSFC), ISRO HQ Bengaluru-560094, Karnataka	Tel Phone No : 080-2217 2620 Email: ravinthar-hsfc@isro.gov.in
16	LEOS	Shri Raja VLN Sridhar Scientist/Engineer-SF Laboratory for Electro-Optics Systems (LEOS) Peenya, Bengaluru-560058, Karnataka	Tel Phone No : 080 2268 5270/5180 Email: rvlnsridhar@leos.gov.in

REGIONAL ACADEMIC CENTRES FOR SPACE (RAC-S)

Sl. No	RACS Name	States/UTs covered under the RAC-S	Zone	Name of the Coordinator & Address	Email ID
1	RACS - MNIT Jaipur, Jaipur	Dadar& Nagar Haveli, Goa, Daman& Diu, Gujarat, Maharashtra and Rajasthan	Western Zone	Dr. Namita Mittal Malaviya National Institute of Technology Jaipur: 302 017 Rajasthan	Email: coord.racs@mnit.ac.in
2	RACS - Gauhati University, Guwahati	Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland and Tripura	North –Eastern Zone	Dr. Madhurya P Bora Professor of Physics Physics Department Gauhati University Guwahati: 781 014 Assam	Email: mpbora@gauhati.ac.in
3	RACS - NIT Kurukshetra, Kurukshetra	Delhi, Haryana, Himachal Pradesh, Jammu & Kashmir, Punjab, Ladakh, Chandigarh and Uttarakhand	Northern Zone	Prof. Brahmajit Singh, Dean, Research & Consultancy, National Institute of Technology Kurukshetra: 136 119	E-mail: brahmajit@nitkkr.ac.in
4	RACS - NITK Surathkal, Mangalore	Andhra Pradesh, Karnataka, Kerala, Lakshadweep, Pondicherry, Tamil Nadu and Telangana	Southern Zone	Prof. S. M Kulkarni (Research & Consultancy) National Institute of Technology Karnataka, Surathkal, Mangalore, Pin 575 025, Karnataka	Email: dean.rc@nitk.edu.in
5	RACS - IIT (BHU), Varanasi	Chhattisgarh, Madhya Pradesh, Uttar Pradesh	Central Zone	Dr. Shishir Gaur, PhD Assistant Professor Department of Civil Engineering Indian Institute of Technology (BHU) Varanasi-221005	Email: shishirg.civ@iitbhu.ac.in
6	RACS - NIT Patna, Patna	A&N Islands, Bihar, Jharkhand, Odisha, Sikkim, West Bengal	Eastern	Dr. Manpuran Mahto Assistant Professor Department of Electronics & Communication Engineering National Institute of Technology (NIT) Patna	Email: mmahto@nitp.ac.in

Annexure-5

SPACE TECHNOLOGY INCUBATION CENTRE (STIC)

S-TIC	Region	State & UTs	S-TIC Academia Coordinator
National Institute of Technology, Agartala	North Eastern	Assam, Tripura, Meghalaya, Mizoram, Arunachal Pradesh, Nagaland, Sikkim	Dr. MITRA BARUN SARKAR Co-ordinator, S-TIC NITA National Institute of Technology Agartala Barjala, Jirania, West Tripura-799046 Email: stic.nita@nita.ac.in
Dr. B. R. Ambedkar National Institute of Technology, Jalandhar	Northern	Punjab, Haryana, Himanchal Pradesh, Uttarakhand, Jammu and Kashmir, Ladakh, Chandigarh, Delhi	Dr. Joseph Anand VAZ Professor, Department of Mechanical Engineering Dr. B. R. Ambedkar National Institute of Technology G. T. Road Bye Pass, Jalandhar Punjab 144 011, India Email: coordinatorstic@nitj.ac.in
National Institute of Technology, Tiruchirappalli	Southern	Tamil Nadu, Kerala, Karnataka, Andhra Pradesh, Telangana, Lakshadweep, Puducherry	Dr. S.S.Karthikeyan Associate Professor Department of ECE National Institute of Technology Tiruchirappalli-620 015 INDIA Email: isrostic@nitt.edu
Visvesvaraya National Institute of Technology, Nagpur	Western	Gujarat, Maharashtra, Rajasthan, Daman & Diu and Dadar & Nagar Haveli.	Prof. Sunil Bhat Department of Electrical Engineering, Visvesvaraya National Institute of Technology, Nagpur, India -440010 Email: coordinator-stic@vnit.ac.in
Maulana Azad National Institute of Technology, Bhopal	Central	Uttar Pradesh, Madhya Pradesh, Chhattisgarh	Dr. Savita Nema Professor, Electrical Engineering Department M.A.N.I.T. Bhopal PIN 462 003 Email: coordinator.stic@manit.ac.in
National Institute of Technology, Rourkela	Eastern	Bihar, Jharkhand, West Bengal, Odisha, Andaman and Nicobar Island	Dr. Ananta C. Pradhan Associate Professor Department of Physics & Astronomy National Institute of Technology Rourkela, Odisha - 769008, India Email: coordinator-stic@nitrkl.ac.in

RESPOND

CAPACITY BUILDING & PUBLIC OUTREACH (CBPO)

Indian Space Research Organisation

Headquarters, Bengaluru