Wall friction in confined flows of anisotropic particles: a unified scaling law

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Introduction

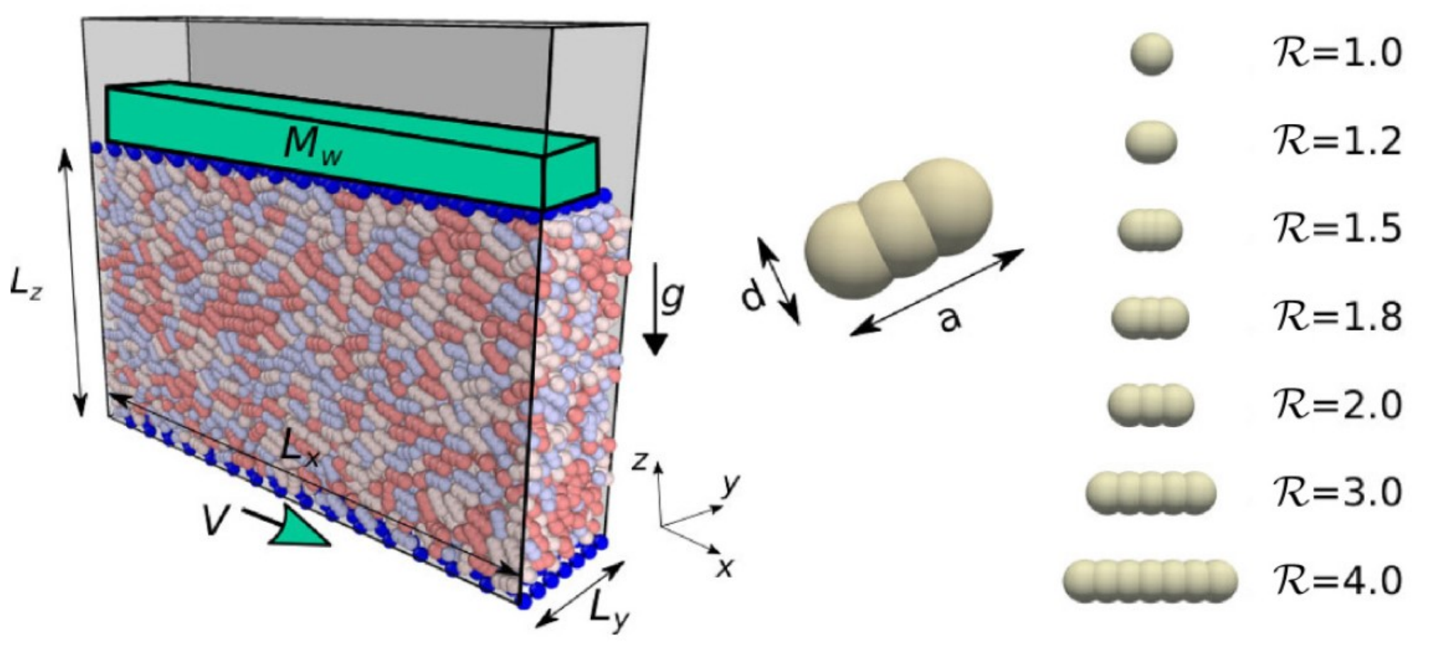
Interactions of flowing granular media with flat and frictional boundaries is frequent

- Nonlocal effects
- Possible heterogeneity (static, creeplike, and shear localization regions)

understanding the behavior at interfaces is fundamental for a full 3D rheological model of granular flows.

Here, we study the effective friction at lateral flat frictional walls in a confined and shear-driven dense granular flow composed of shape anisotropic particles.

Numerical setup



- Rectangular cuboid (L_x = 20a and L_y = 10d, L_z variable with a and d the max. and the min. axis of a particle)
- PBC in flow (x-) direction, gravity
- Two flat but frictional sidewalls
- Top and a bottom : bumpy walls (regular triangular mesh of spheres of diameter d with a spacing of 1.5d)
  - ✓ The bottom wall moves at a fixed velocity V
  - ✓ The top wall is fixed in the x- and y-directions but can freely move in the z-direction
- Normal forces : spring dashpot
- Tangential forces : spring, the displacement is limited a Coulomb plastic condition with a friction coefficient μ_{pp}
- Particle/sidewall contact treated in the same manner but with a friction coefficient μ_{pw}

Kinematics

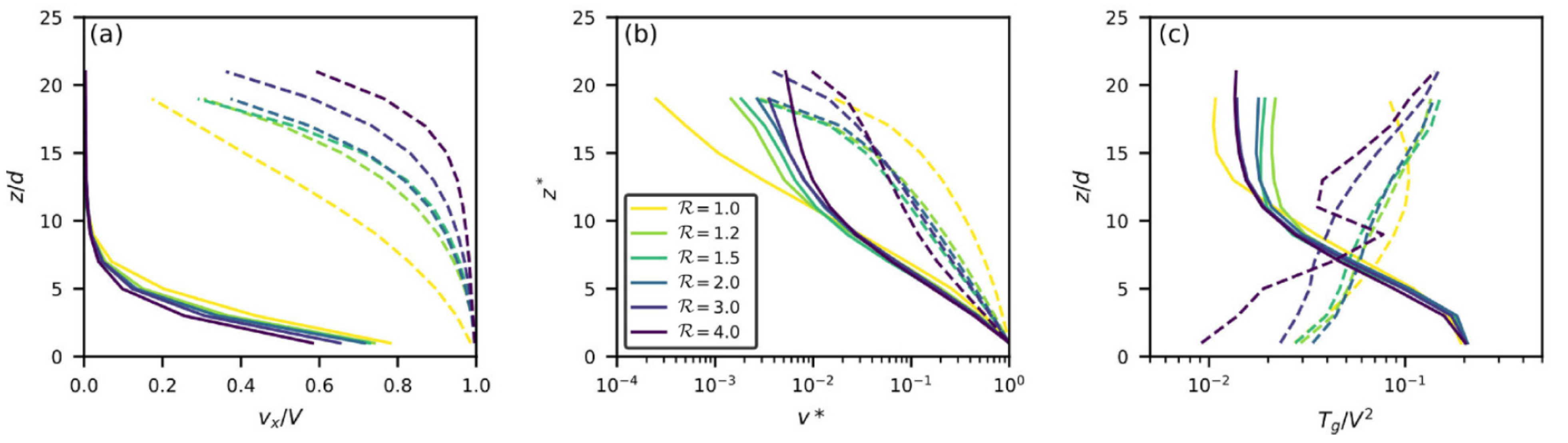
- Shear localization at the top(bottom) for low (high) sidewall friction
- Rescaled velocity profile (by considering top or bottom localization)

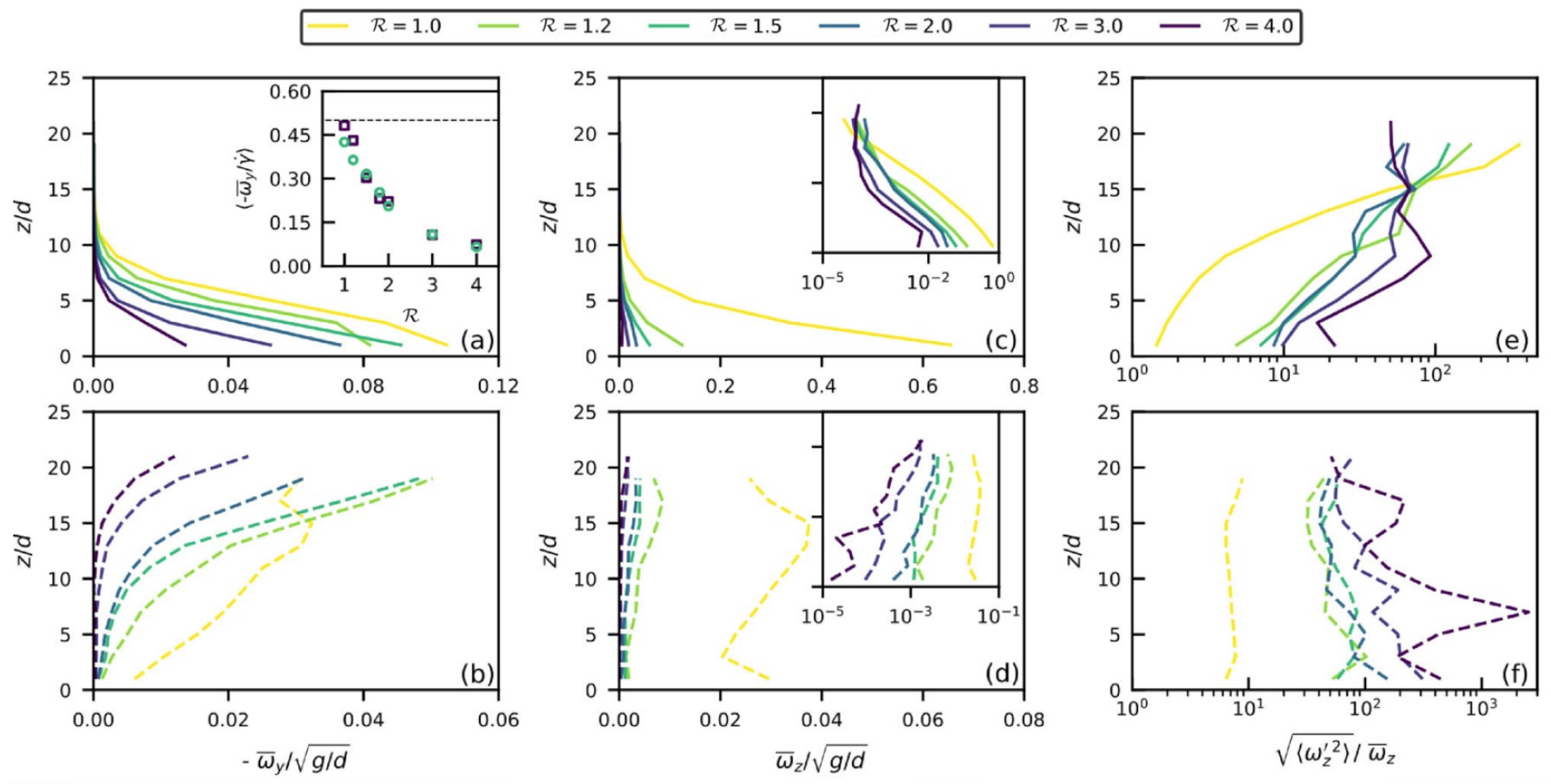
Top $z^* = z/d$
$v^* = v_x/(V - v_w)$
Bottom $z^* = (L_z - z)/d$
$v^* = (V - v_x)/(V - v_w)$
v_w: slip velocity at the wall

Velocity decay length almost unaffected by particles' shape

- Higher granular temperature, T , in the region where the shear localizes, independently of the flow pattern and the particle shape
- Particle shape: a negligible impact on the granular temp. esp. for zone of shear localization. Some differences far from the latter.

μ_{pw} = 0.3 (solid lines) μ_{pw} = 0.05 (dashed lines)





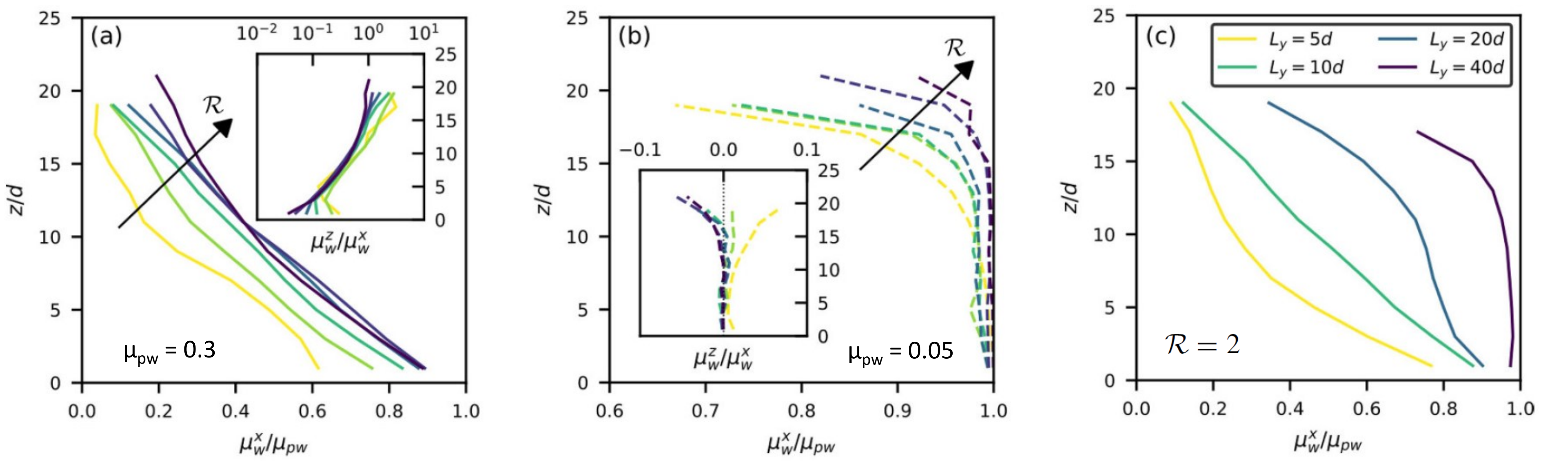
- Mean angular velocity $\overline{\omega}_y$ systematically ↘ with ↗ particle elongation
- Rotations' frustrations by particle shape is even stronger for $\overline{\omega}_z$ (rolling comp. with respect to the wall) $\rightarrow$ shape anisotropy hinders rolling
- The ratio of the angular velocity fluctuations to the mean angular velocity :

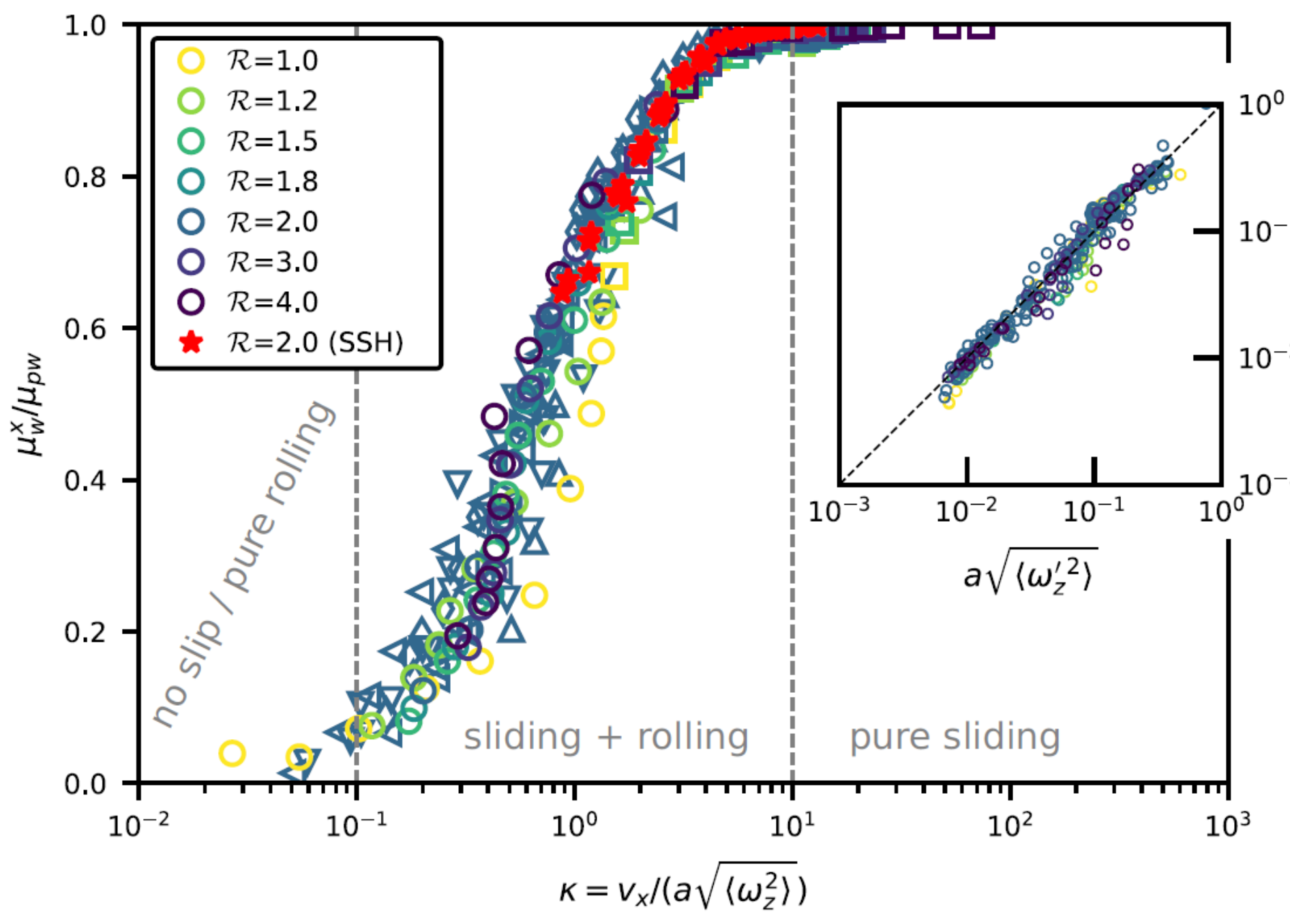
$$\sqrt{\langle \omega_z'^2\rangle} = \sqrt{\langle (\omega_z - \langle \omega_z\rangle)^2\rangle} \ / \ \overline{\omega}_z$$

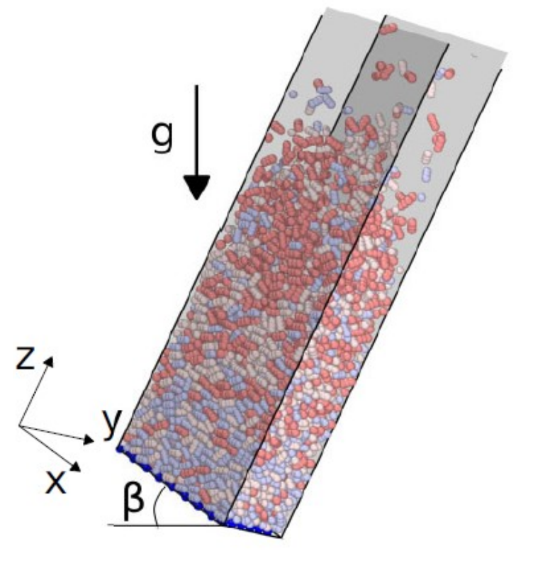
strongly depends on particles' shape

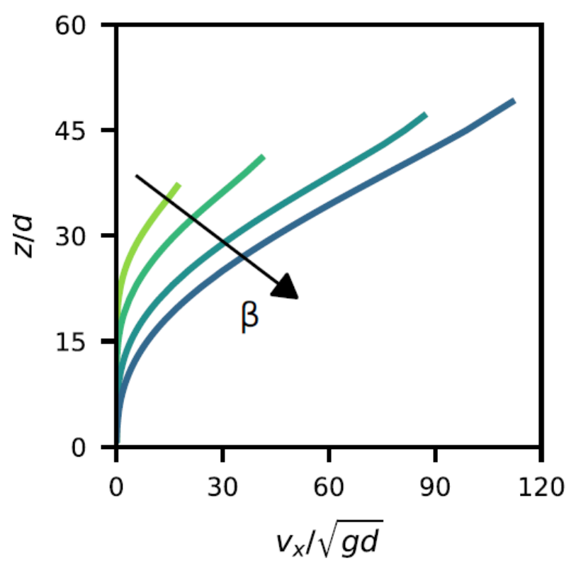
Effective wall friction $\mu_w^x = \langle F_x\rangle/\langle F_y\rangle$ $\mu_w^z = \langle F_z\rangle/\langle F_y\rangle$

- Shear localizes at the bottom → the wall friction is partially mobilized in the flow direction
- Shear localizes at the top → μ_w^x is minimum in the shear region
- Increasing Ly → higher mobilization of the effective sidewall friction
- The ↗ of friction mobilization with Ly is evidently related to the progressive reduction of the slowly (creeplike) moving zone









Particle shape $\rightarrow$ frustration of particle rotations
$\rightarrow$ Effective wall friction

Tempting to associate the mobilization of wall friction with a balance between slip velocity and rolling motion.
$\kappa = v_x/a\sqrt{\langle \omega_z^2\rangle}$

The scaling seems very robust: independent of the driving velocity, the applied pressure, the width of the channel, and the wall-particle and particle-particle frictional properties.
Also, it remains valid for confined free surface flows

Conclusions

- Particle shape mainly affects the angular velocity profiles both spinning and rolling motions being frustrated.
- Particle elongation also affects effective wall friction $\rightarrow$ elongated particles show less friction weakening at the wall than more isotropic particles.
- In dense granular flows the effective friction at flat interfaces scales according to a balance between sliding and angular motion of the particles.
- Three regimes have been identified: pure sliding, no-slip–pure rolling, sliding and rolling coupling
- This description is relevant both for shape isotropic and elongated particles and in different flow configurations (i.e., shear driven and gravity driven).

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