GRANULAR FLOW ON A ROTATING AND GRAVITATING ELLIPSE

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ABSTRACT

Granular avalanches on small bodies are particularly interesting because of their **faint gravitational field**, **rotation** and **undulating topographies**. We wish to study the flow of grains over a **rotating** and **gravitating ellipse**. using **Discrete Element(DE)** simulations in LAMMPS.

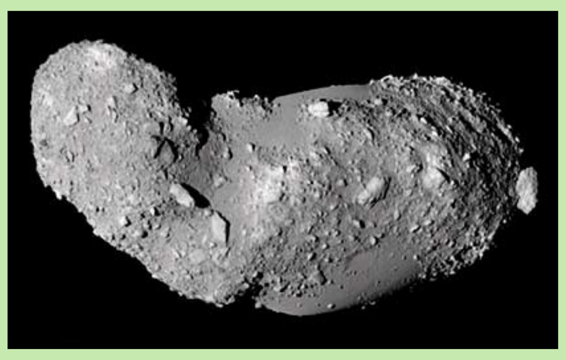


Fig.1. Asteroid Itokawa

Schematic

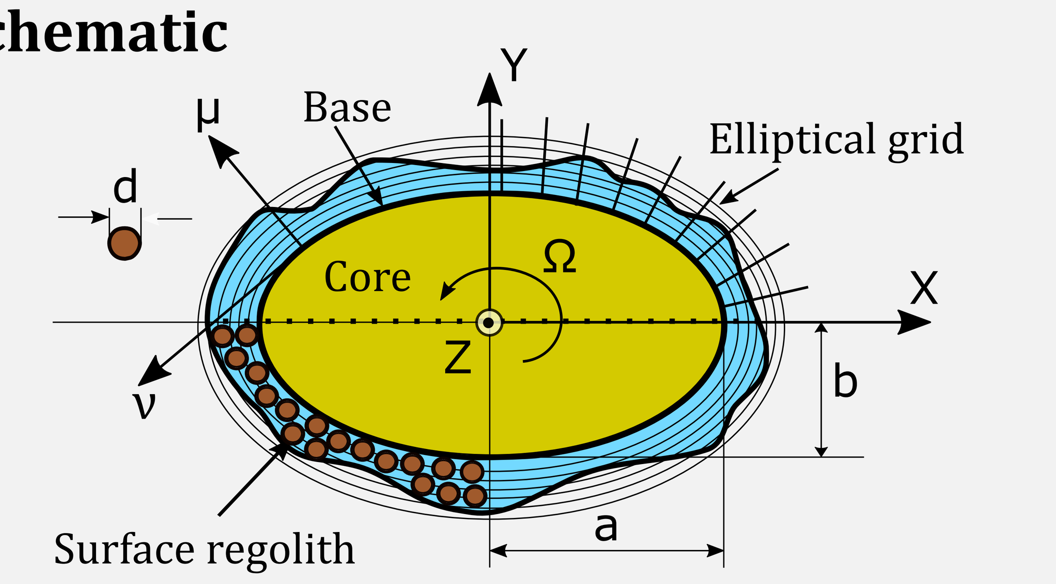


Fig.2. Schematic for the problem

Assumptions & parameters

- Grains are **spherical**.
- Flow is **shallow***.
- Collisions are **elastic**.

d = 1m
b/a = 0.379
$^*\rho_{core} = 2 \times 10^5 kgm^{-3}$
$\rho_{grain} = 1.5 \times 10^2 kgm^{-3}$
# of grains = 24248

Quantity	Non-dimensionalisation parameter
Rotation rate	Ω_{sh} for axis ratio 0.38 (our case)
Effective gravity	Effective gravity at $\nu=\pi/4$, for zero rotation rate
Height	Initial height i.e. 5m

Equation of motion:

$$\mathbf{a} = \underbrace{\frac{\mathbf{F}}{m}}_{\text{Gravity}} - \underbrace{2(\boldsymbol{\Omega}\times\mathbf{v})}_{\text{Coriolis}} - \underbrace{\overset{0}{\dot{\boldsymbol{\Omega}}}\times\mathbf{r}}_{\text{Euler}} - \underbrace{\boldsymbol{\Omega}\times(\boldsymbol{\Omega}\times\mathbf{r})}_{\text{Centrifugal}}$$

Migration

The sign of the **effective tangential gravity** changes **simultaneously at all points** on the ellipse (Fig.3).

Ω_{th} ⟶ threshold rotation rate for change in direction of migration

Mass shedding(Fig.9(d))

The reversal in the direction of the **effective normal gravity** happens at **different rotation rates for different angular locations** (ν).

Ω_{sh} ⟶ shedding from major axis happens before anywhere else (Fig.4)

Effective gravity = |$a_{centrifugal}$ - $a_{gravity}$|

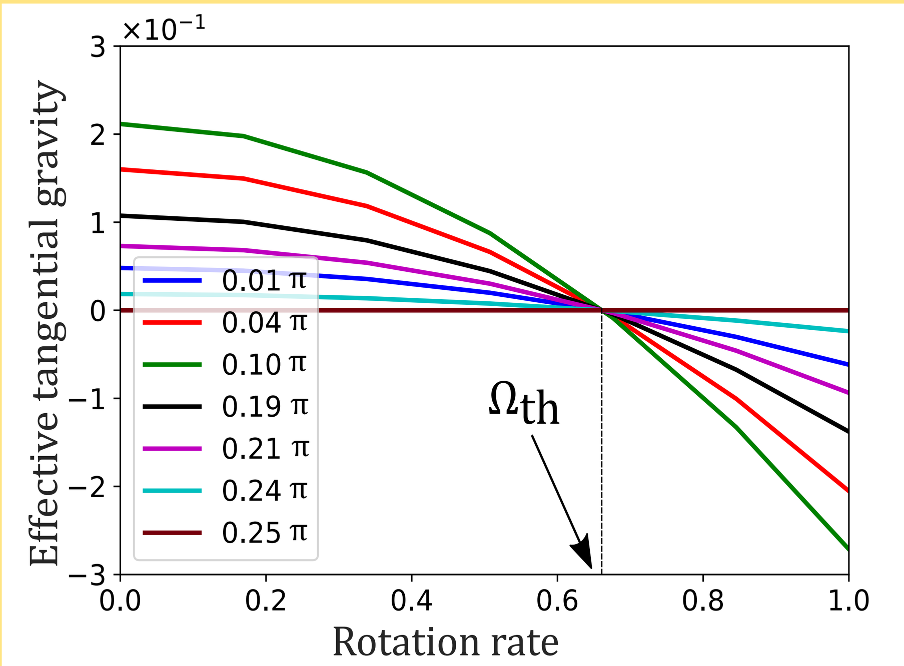


Fig.3. Threshold rotation rate for switch in direction of migration

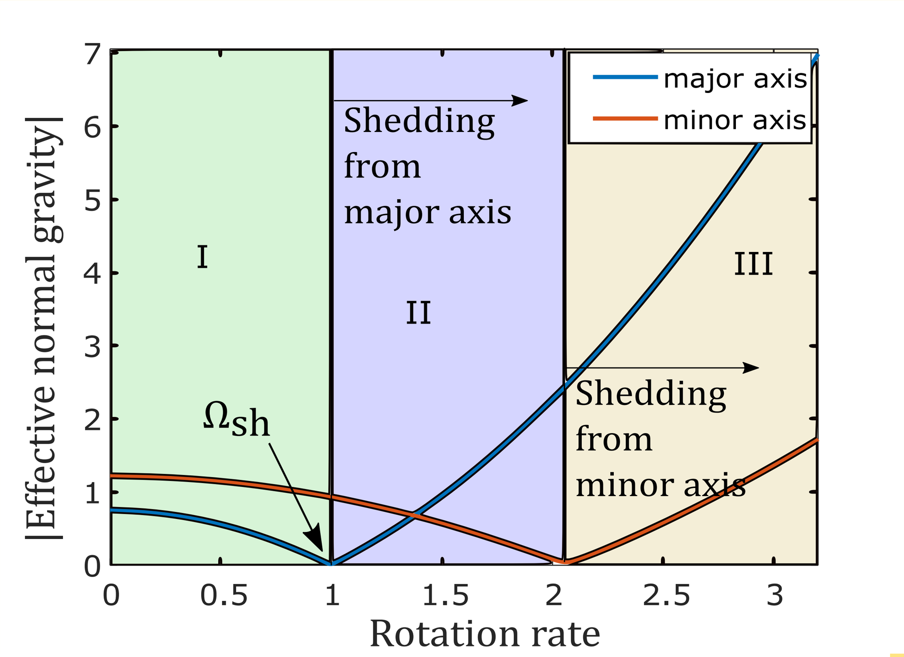


Fig.4. Critical rotation rate for shedding

Axis ratio and friction

Higher axis ratios result in a **convergence** of shedding rotation rates at the **major and minor axes**. Friction (δ=4°) causes **region I** to be split into **three** divisions.

A : Pre-critical (towards minor axis)
B : Critical (no regolith motion, Ω th lies here)
C : Post-critical (towards major axis)

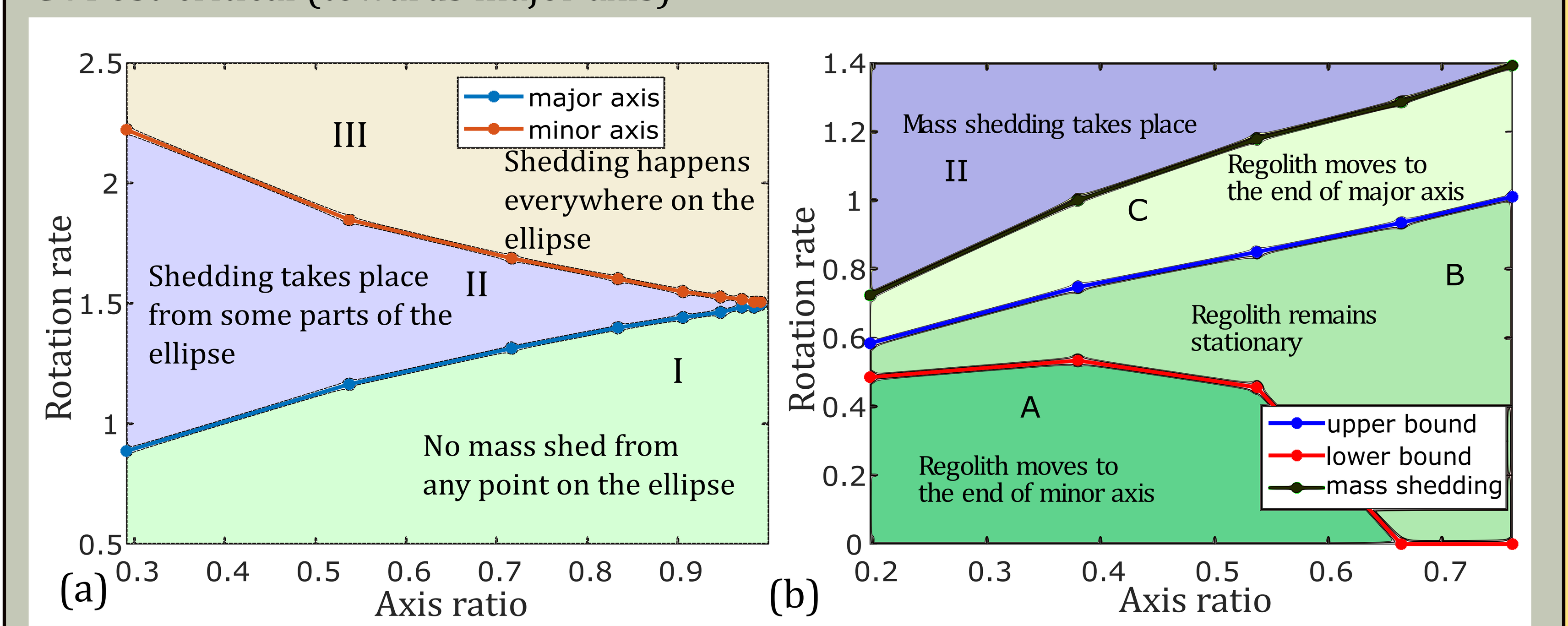


Fig.5. Variation of rotation rates for **(a)** shedding and **(b)** migration with axis ratio

Post-processing

- Coordinates of grains are mapped onto a fine **elliptical grid**.
- Zero multiplicity of grains at the first grid point along μ denotes the height at a particular ν.

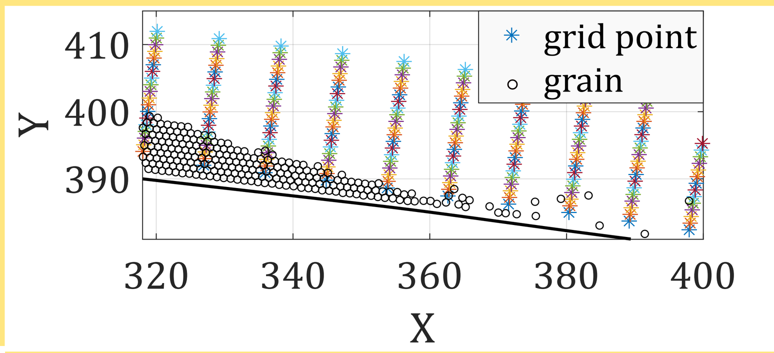


Fig.6. Elliptical grid

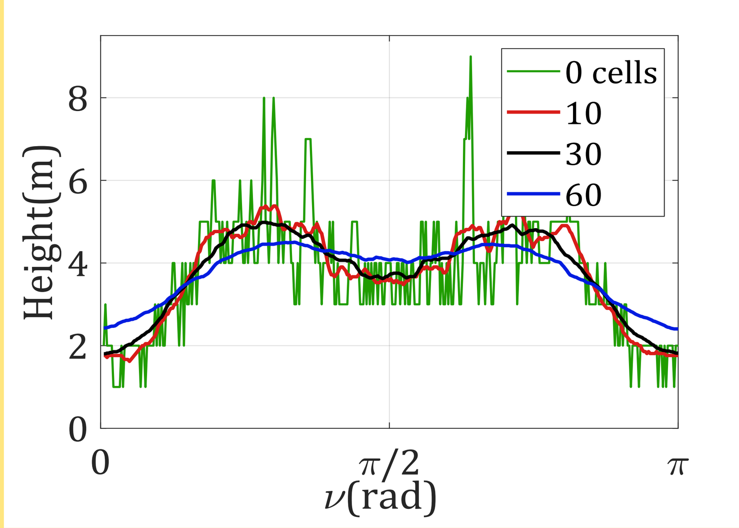
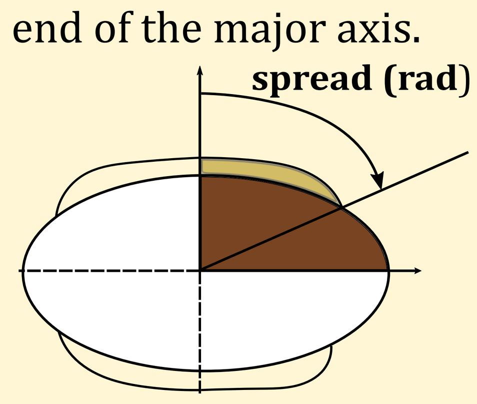


Fig.7. Cell averaging

- To convert discrete data to continuous form we apply **averaging** over adjacent cells along ν.
- More cells give smoother curves but their behaviour significantly differs from the discrete data.

Spread

Spread is defined as the **surface cover of regolith** from the end of the minor axis along the surface towards the end of the major axis.



Initial conditions

We start with a layer of **uniform height** throughtout, where height is measured normal to the surface of the ellipse i.e. along μ.

DEM (LAMMPS) results

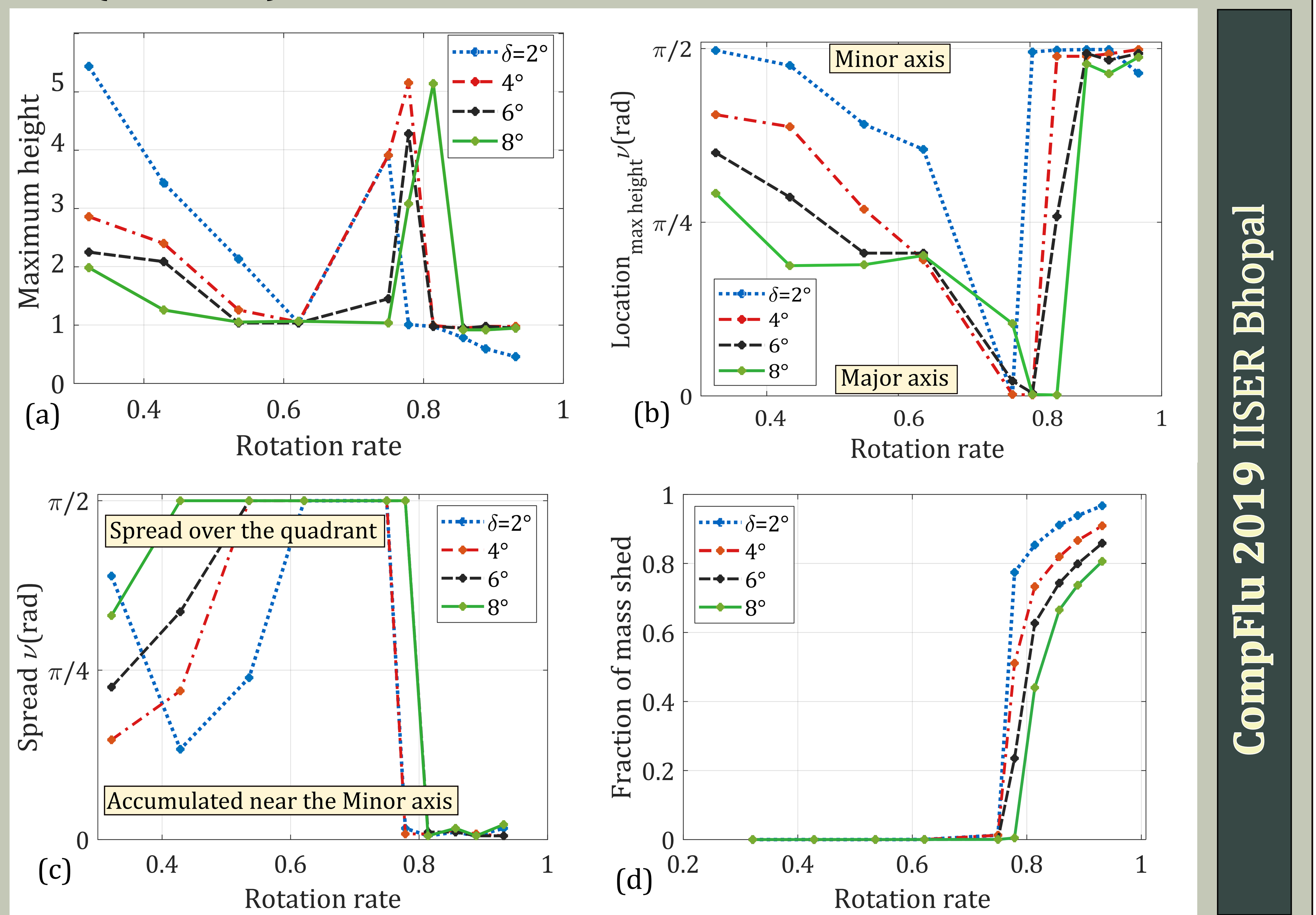


Fig.8. Variation of regolith layer properties with rotation rate

Pre-critical regime

- Grains accumulate at the minor axis.
- The maximum height decreases.
- Regolith tends to be more spread out.

Post-critical regime

- Grains accumulate at the major axis.
- The maximum height increases.

Friction angle(δ)

- Maximum height reduces.
- Lesser mass is shed.

NOTE: **Location of the maximum height** moves **towards the major axis** with rotation rate. Once **shedding starts**, it reduces and **shifts back** to the minor axis.

Coriolis acceleration and asymmetries

- Shedding may be **aided or hindered** (Fig. 9(d)) at different positions on the ellipse.
- The **max. heights** on either side of both the axes are **different** (Fig.10).
- The magnitude of **friction** depends on the **normal force** which is augmented by the Coriolis term (-2[**Ωxv**]) on the **retrograde side**(motion against the direction of rotation) **contrary to the prograde side**.

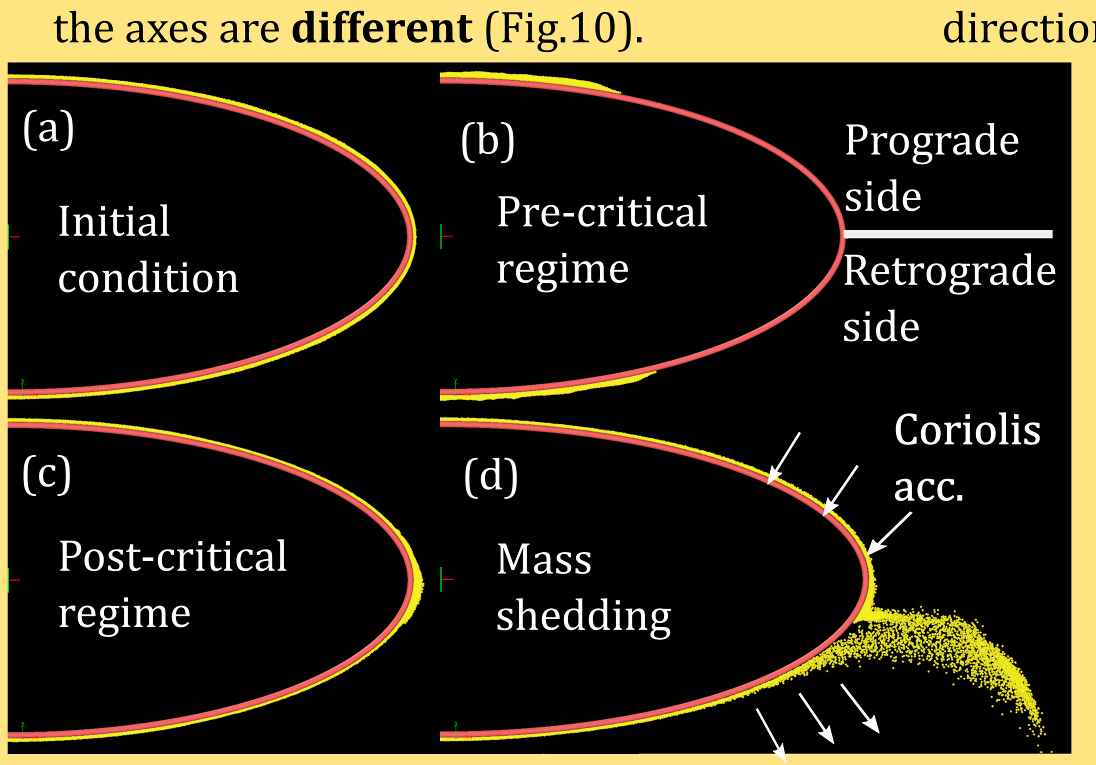


Fig.9. LAMMPS simulations

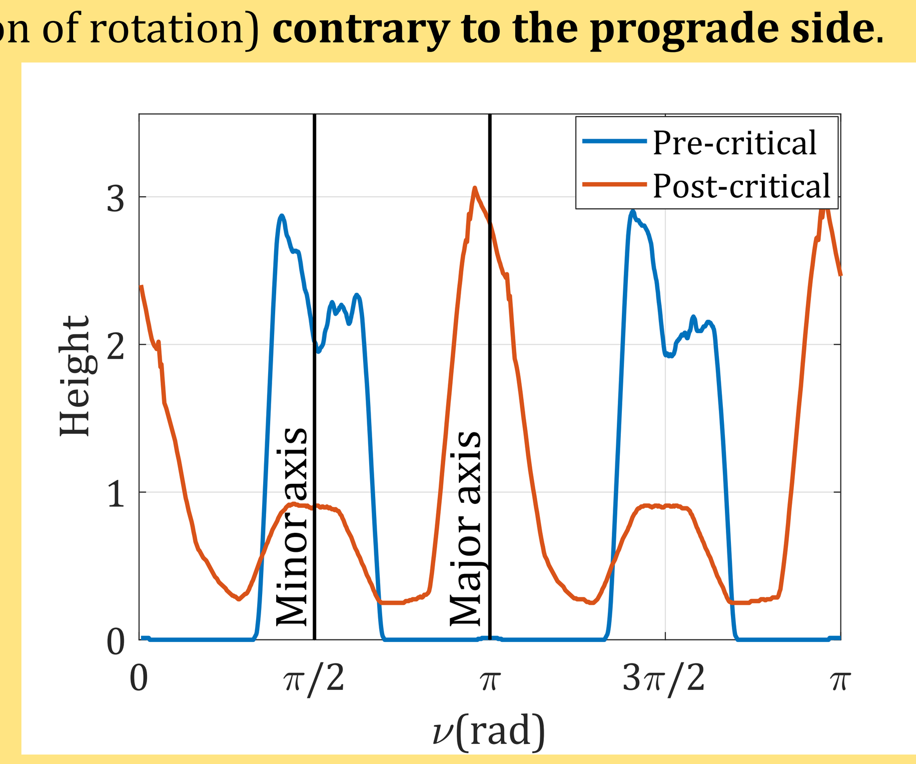
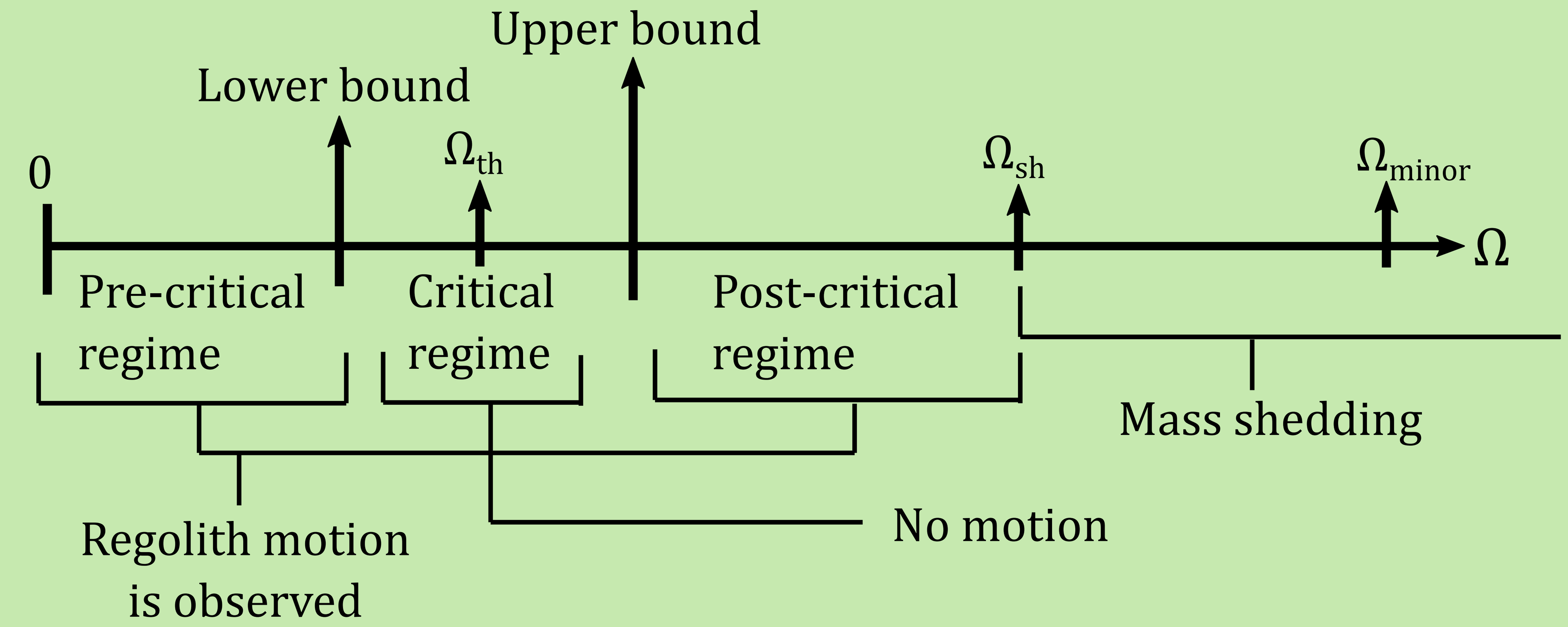


Fig.10. Typical height profiles

CONCLUSIONS



- We **indentify different regimes** of rotation rates that represent various phenomena like migration and shedding.
- **Friction** acts to **abate motion** resulting in a bigger Critical regime.
- **Coriolis acceleration** gives rise to **asymmetries** in the flow which gets pronounced with rotation.

Acknowledgements

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References

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