University of Colorado
Boulder

Celestial and Spaceflight
Mechanics Laboratory

Effects of probe shape and surface topography in deployment to small bodies

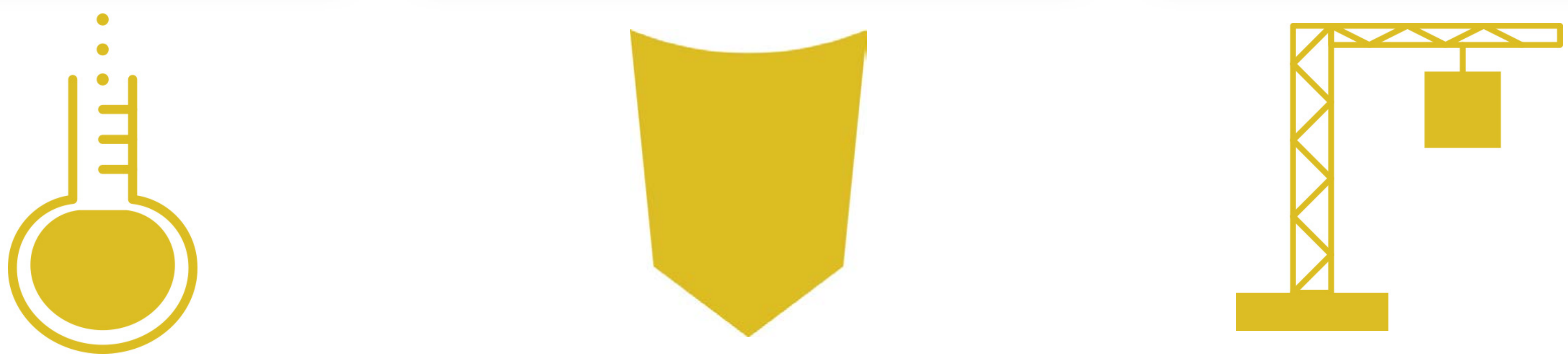
Stefaan Van wal
Daniel Scheeres

15th International Planetary Probe Workshop
June 14th, 2018
Boulder, Colorado

Small-body exploration

Small-body exploration

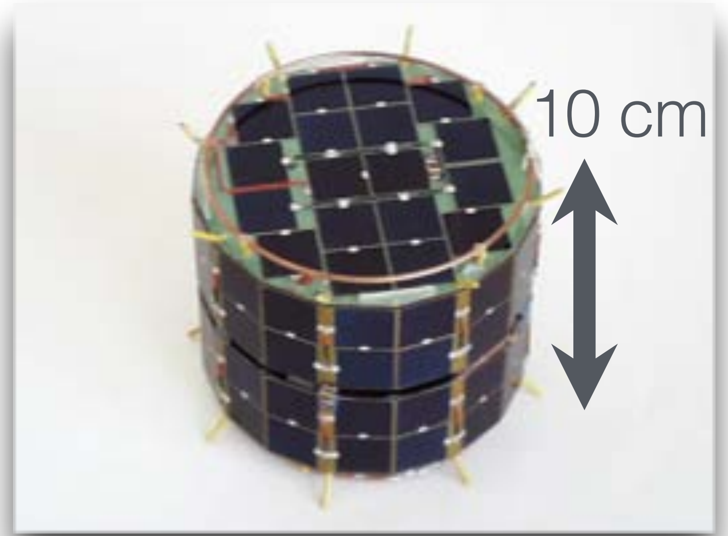
Science | Planetary defense | Resources

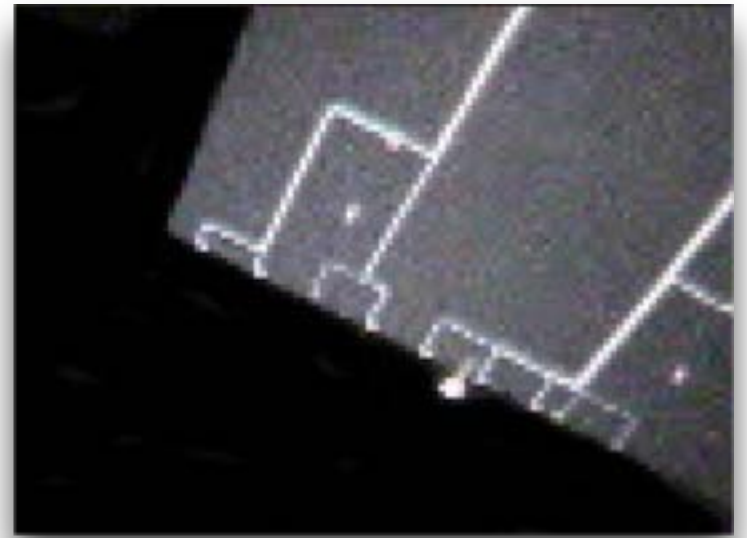


- Current baseline: remote sensing operations
- Increased return: **surface exploration**

Surface exploration: Past

- Minerva-I (Hayabusa-1)

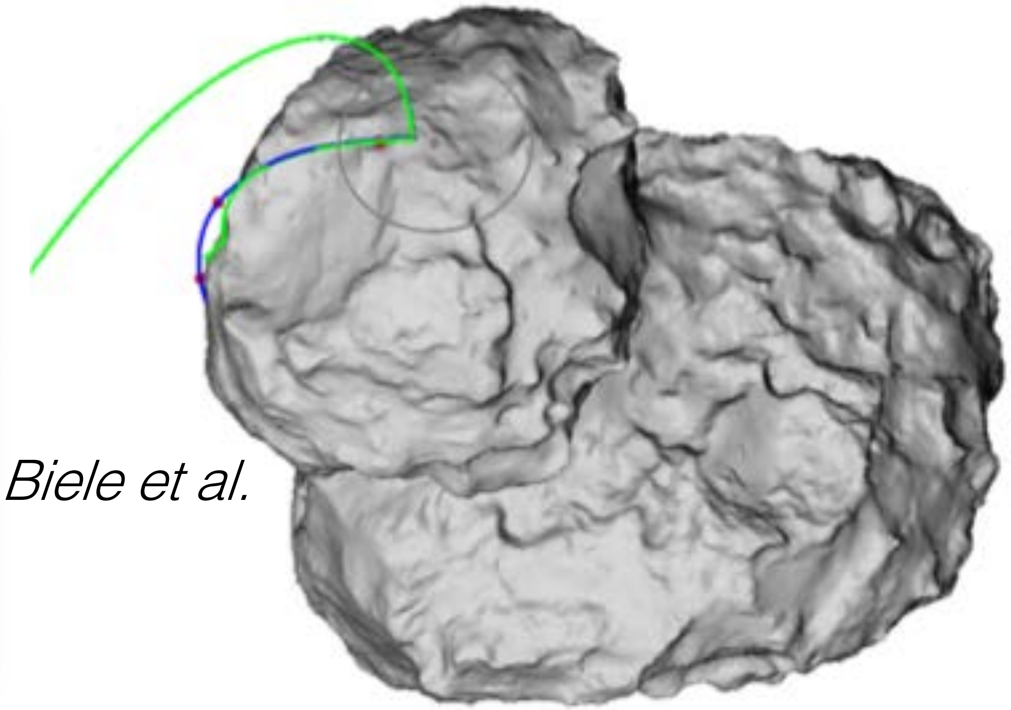




Yoshimitsu et al.

- Philae (Rosetta)

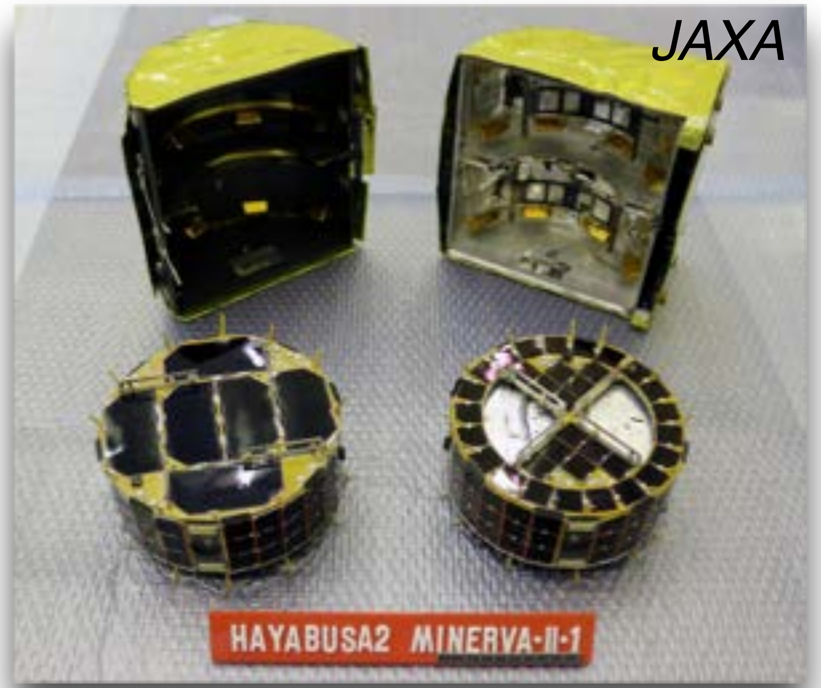
Biele et al.



☞ **Lander deployment is challenging!**

Surface exploration: Future

- Hayabusa-2:
  - Minerva-II and Mascot rovers

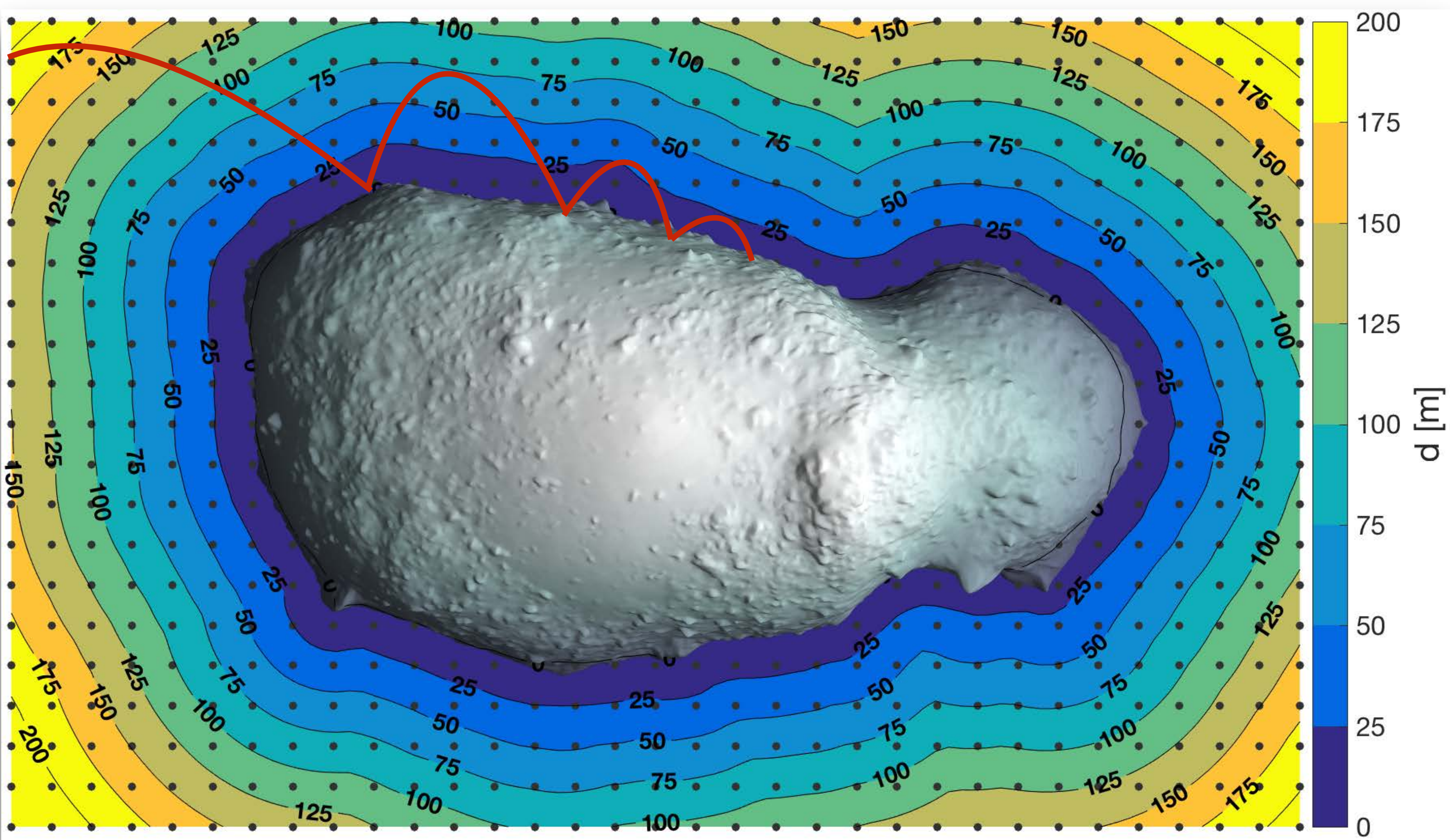


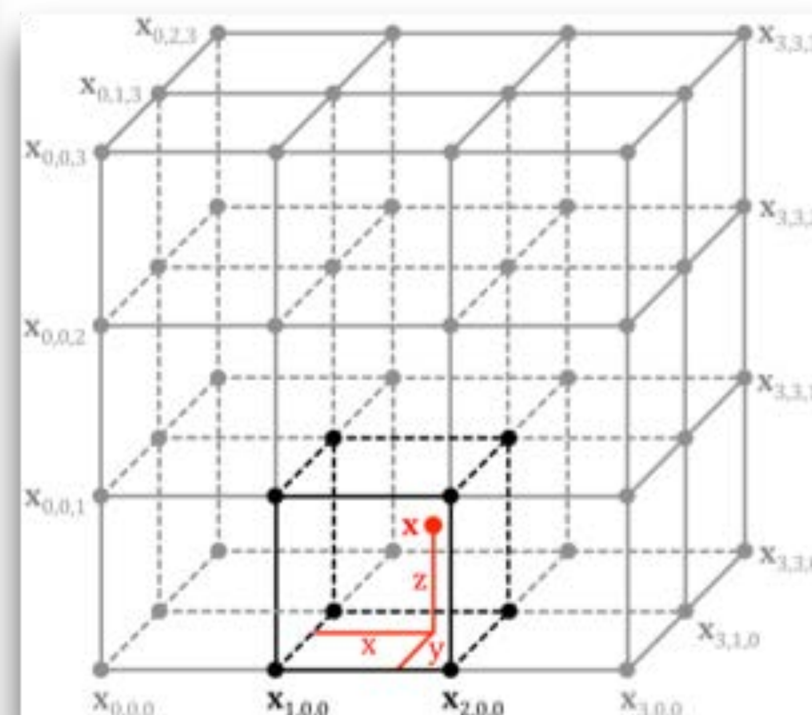
  - Deployed <u>before</u> Hayabusa-2 sample acquisition
  - Rovers must avoid sampling site exclusion zone

☞ **Planning of rover deployment requires simulation of bouncing trajectories**

Modeling: Shape

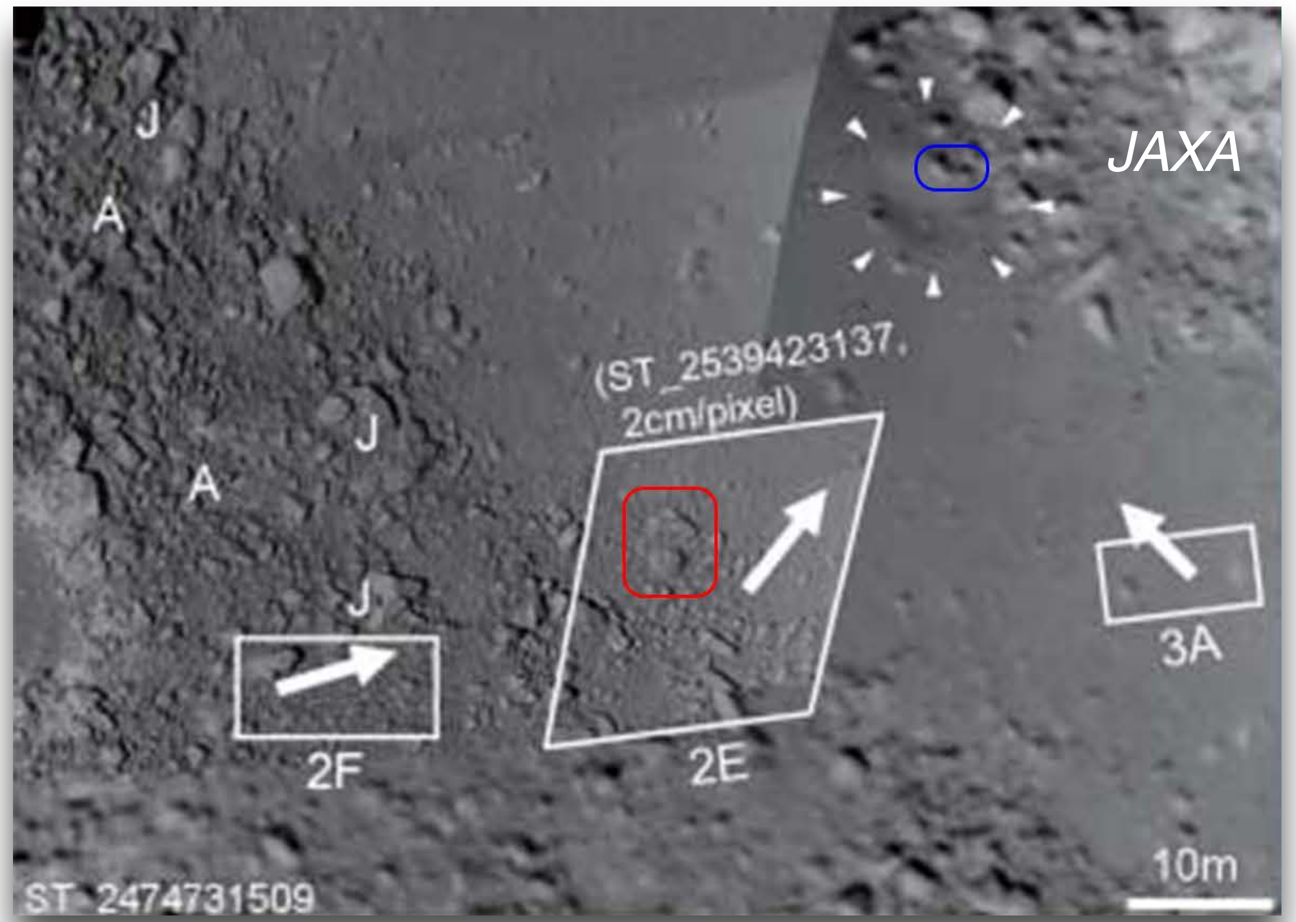
- Signed distance field (SDF):
  - Implicit shape model
  - Gridded 3D sampling of distance function d(**x**)
  - Linearly interpolated to yield d(**x**) and **N**(**x**) = ∇d(**x**)
  - Inexpensive collision detection *vs*. classical polyhedron model

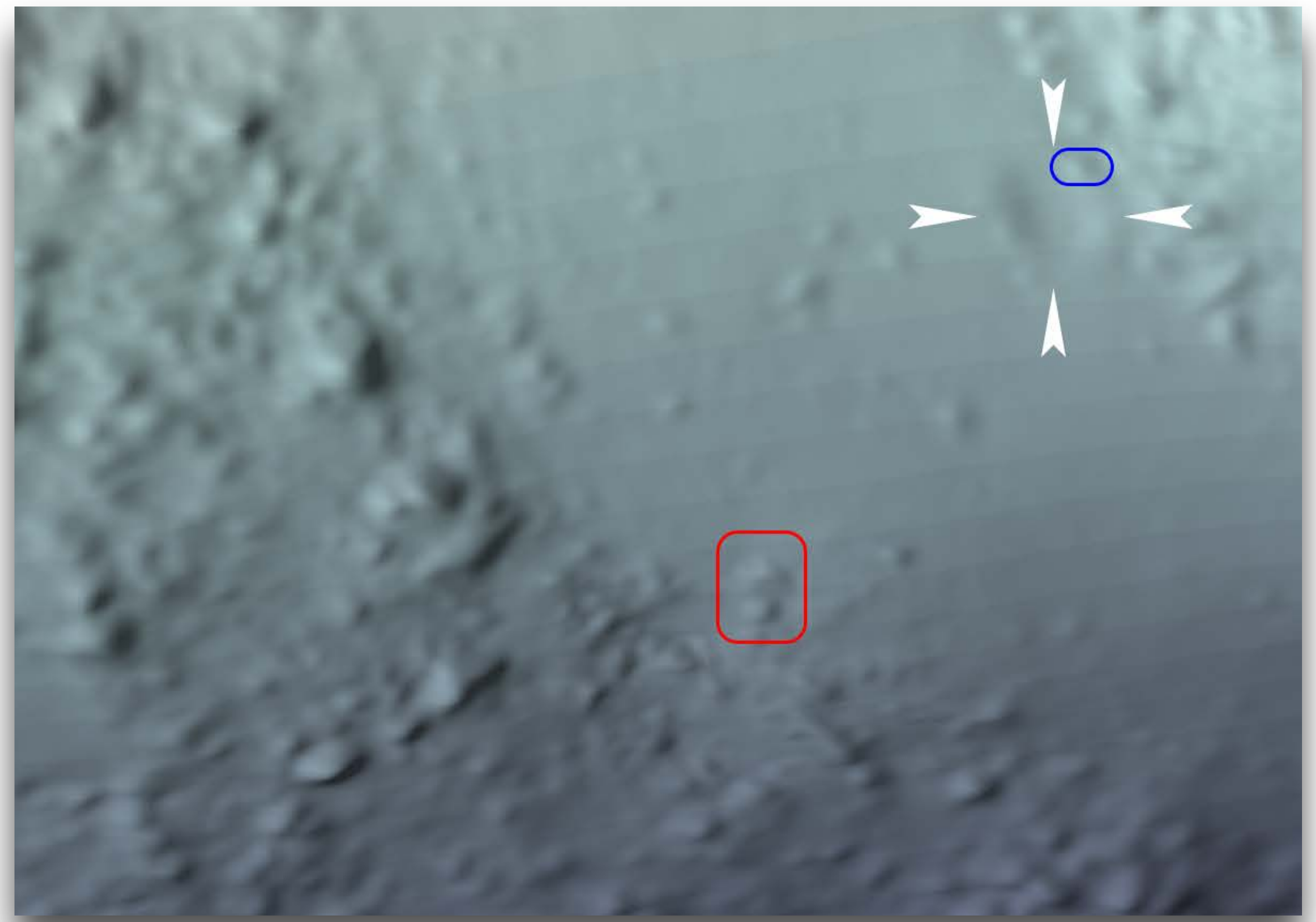




Modeling: Surface features

- Asteroids and comets are covered with rocks of various sizes
- Global shape models are smooth with only large features
- Example: Itokawa

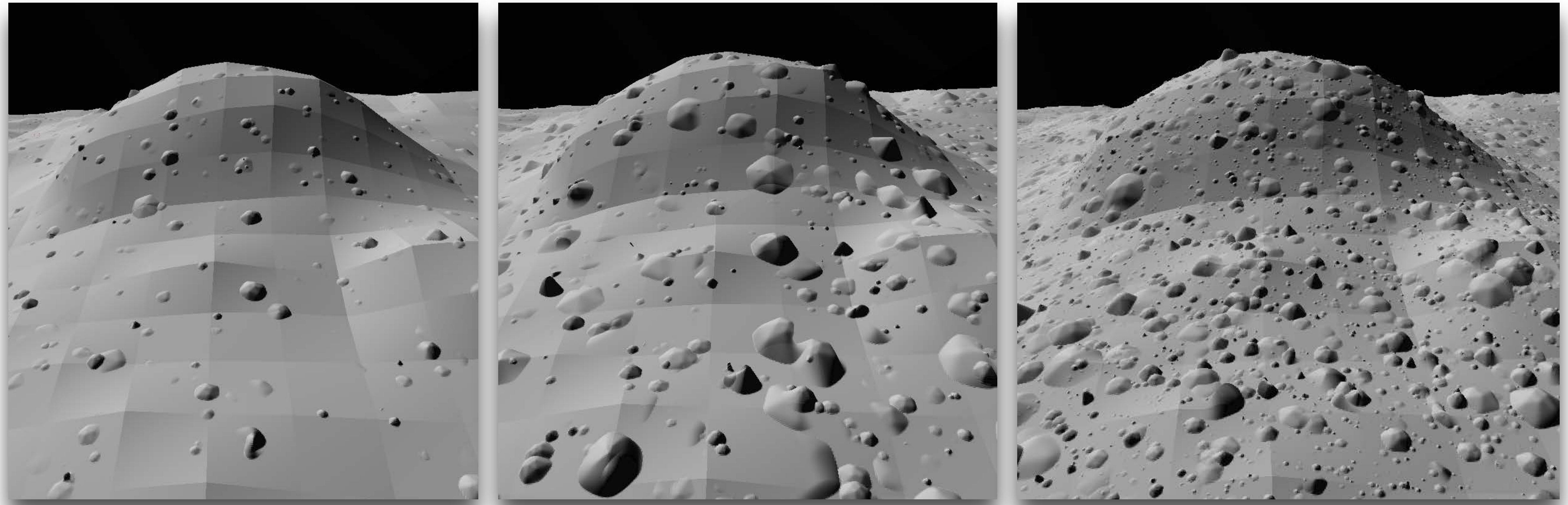




- Presence can affect motion of a probe
- How to account for millions/billions of rocks?

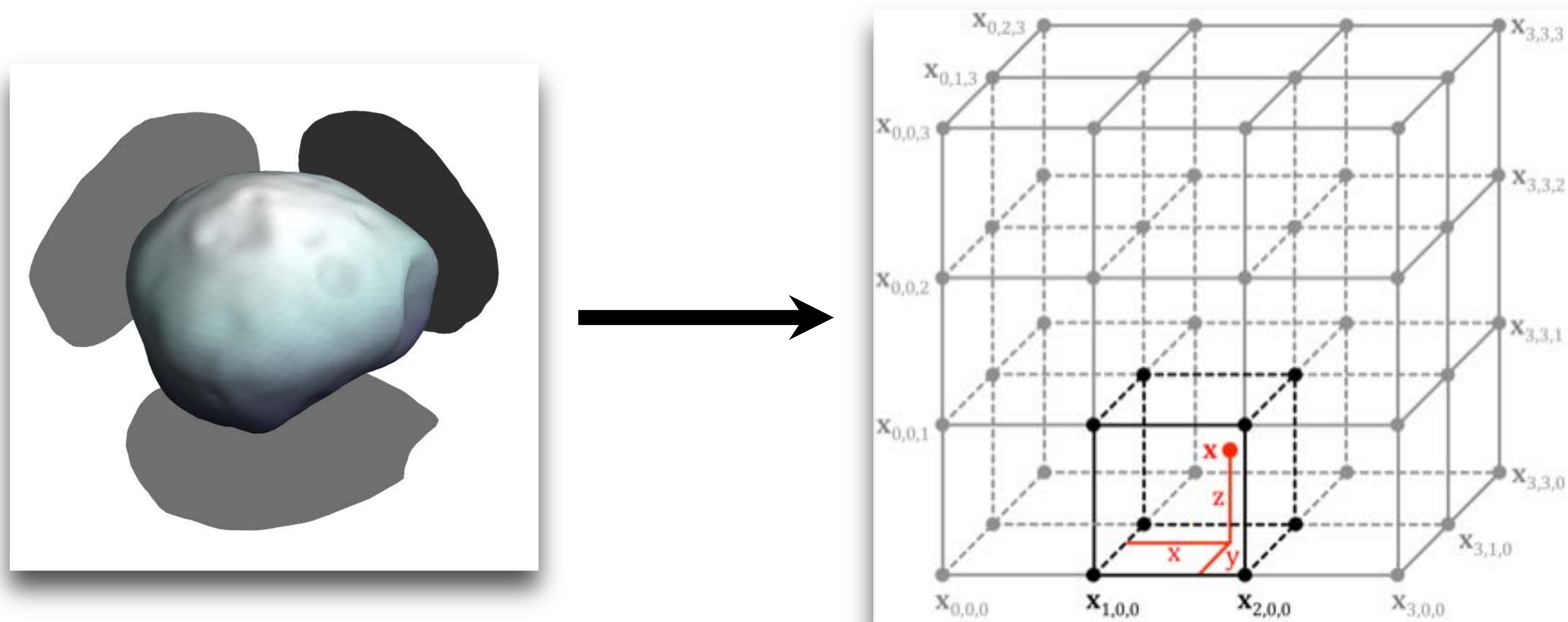
Modeling: Surface features

- Procedurally seeded rocks:
  - Aperiodic tiling of seeding texture
  - Texture can be tuned to match observations
  - Numerical cost is two additional SDF samplings
  - Example of different rock populations:



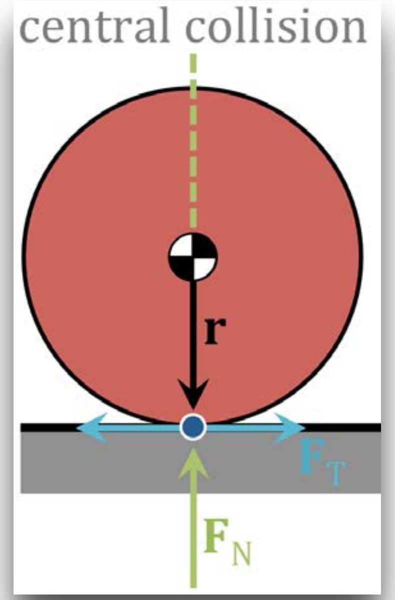
Modeling: Gravity

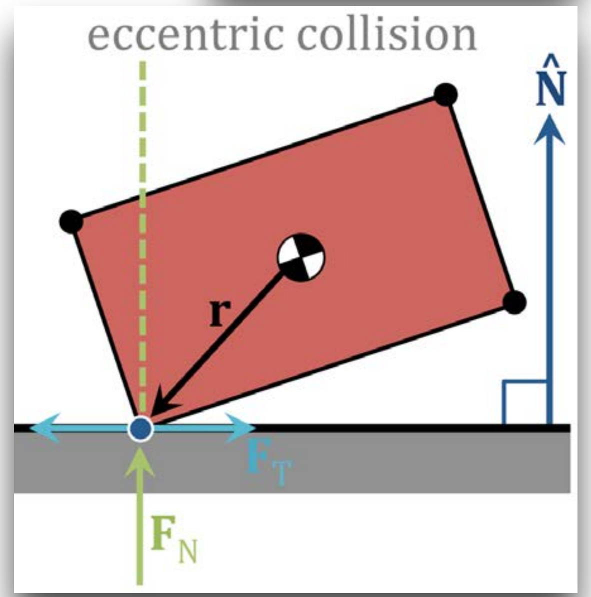
- Voxelized gravity field:
  - Pre-compute polyhedron gravity $\mathbf{g}(\mathbf{x})$ at 3D mesh points
  - Interpolate gravitational perturbation $\Delta\mathbf{g}(\mathbf{x}) = \mathbf{g}(\mathbf{x}) - (\mu/r^3)\mathbf{x}$ at field point $\mathbf{x}$
  - Inexpensive evaluation of complex gravity field

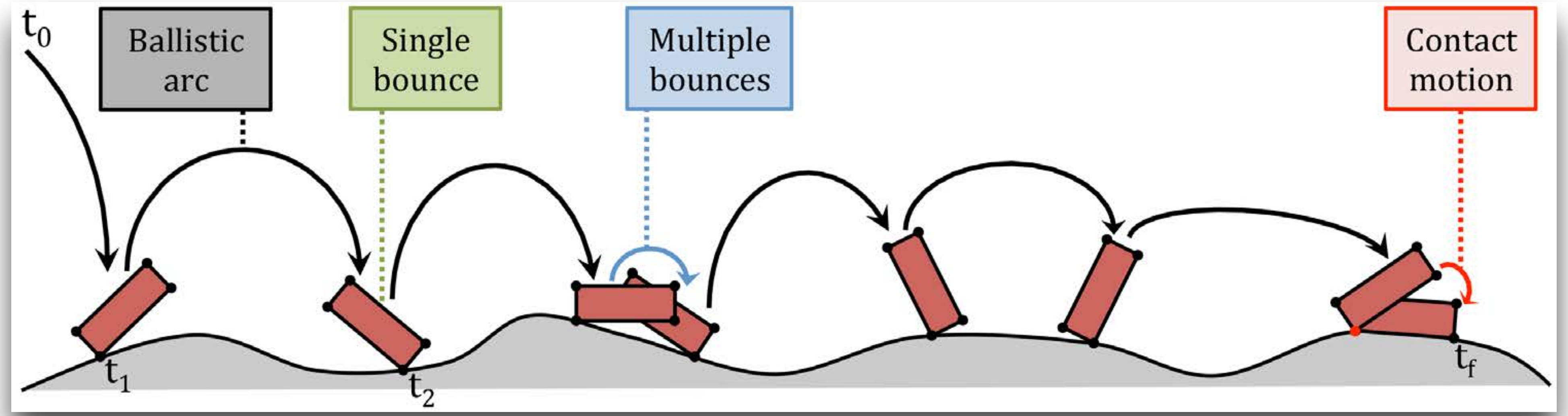


Modeling: Contact

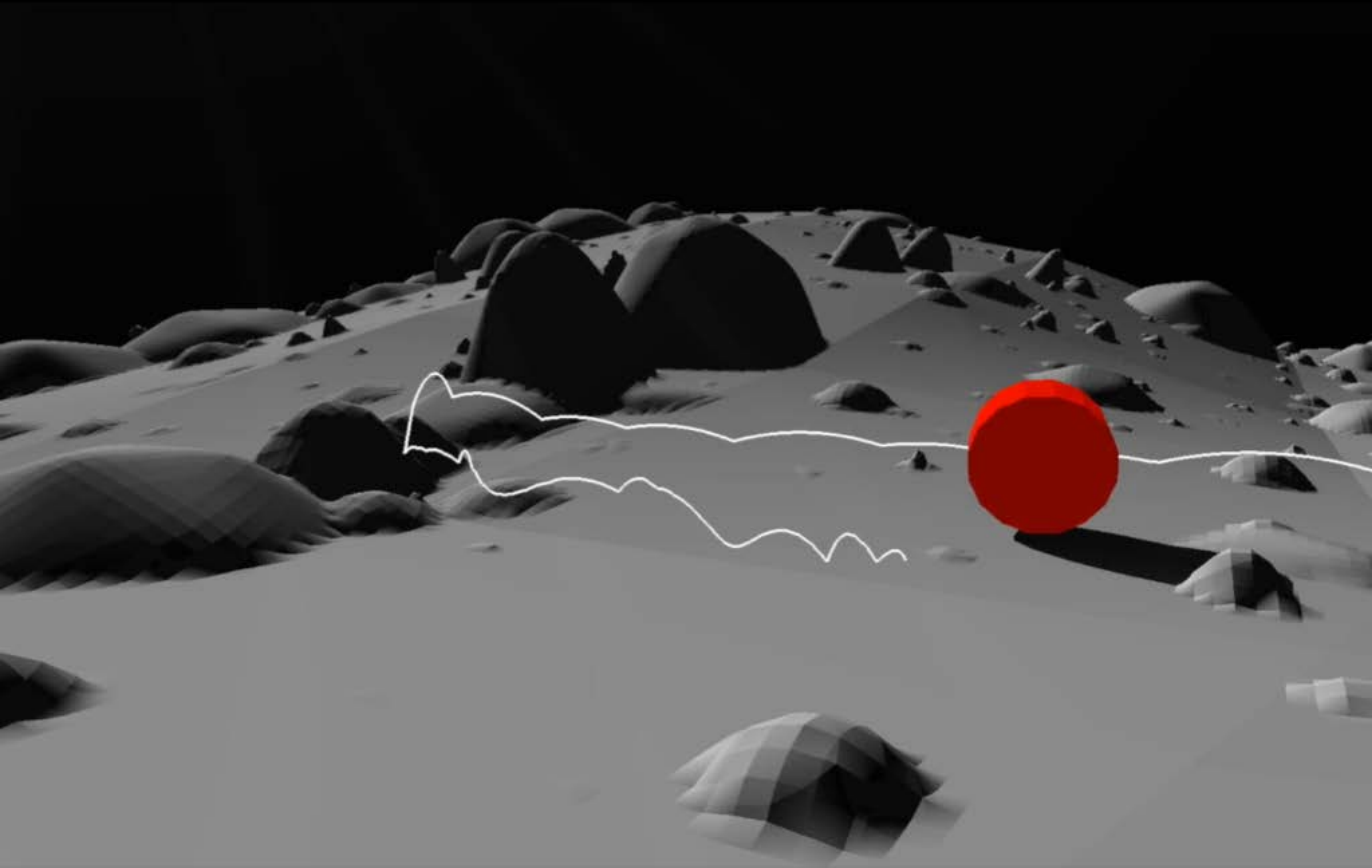
- Hard contact model with normal and friction forces:
  - The forces are coupled for *eccentric* collisions!
  - Numerical integration is required to evaluate effect
  - Based on model by Stronge
- Model is governed by:
  - Coefficient of restitution *e* and friction *f*
  - <u>Assumed independent of velocity and attitude</u>
- Distinguish between slip and stick of contact point
- Impulsive collision *vs.* continued contact motion





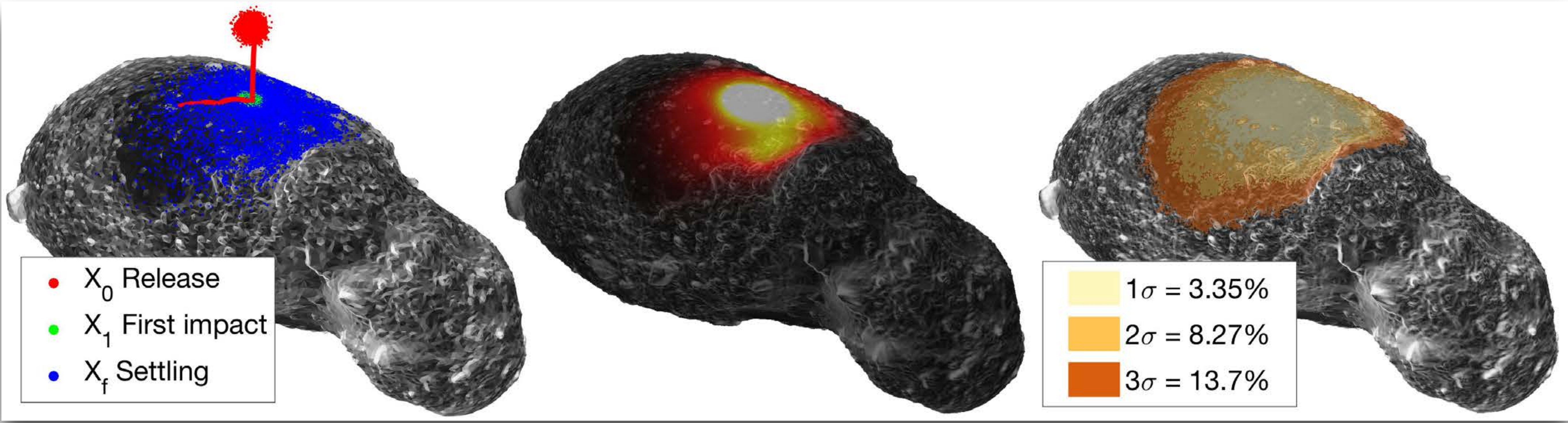


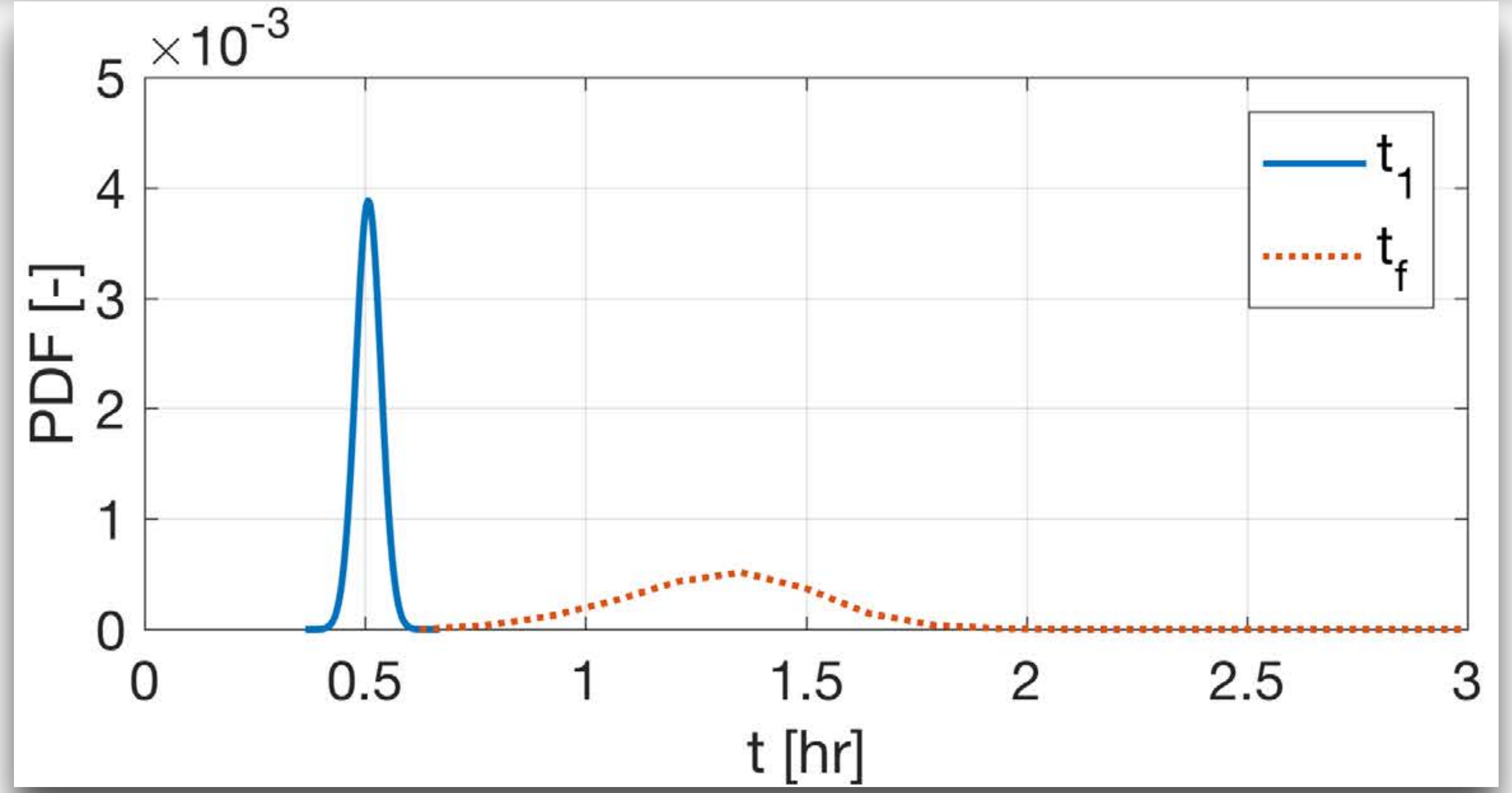
A single simulation



A batch of simulations

- Parallel implementation on GPU enables broad studies



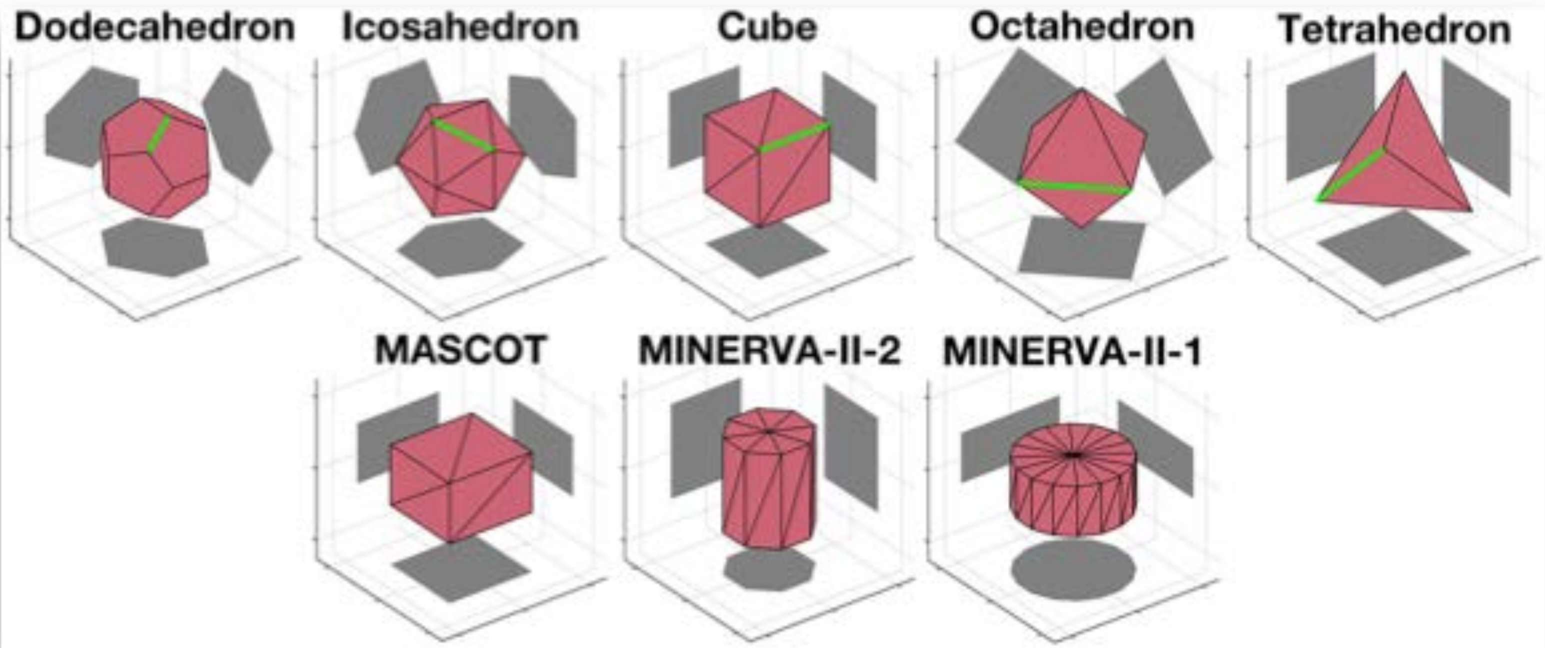


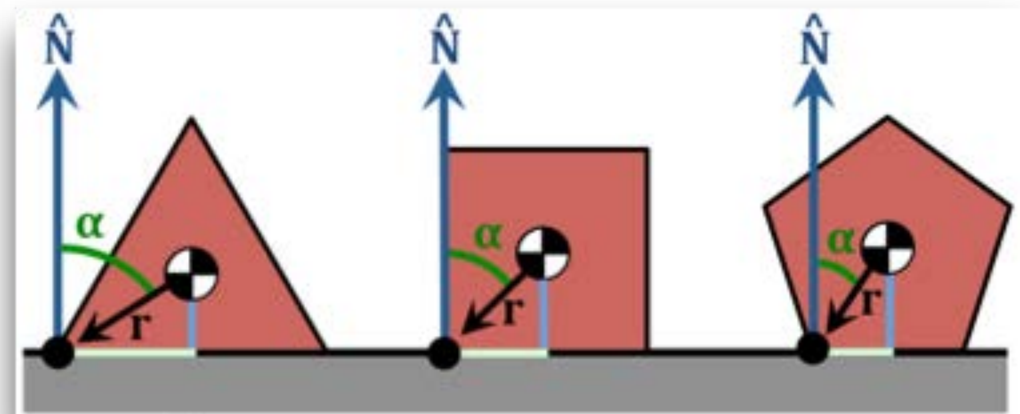
surface dispersion

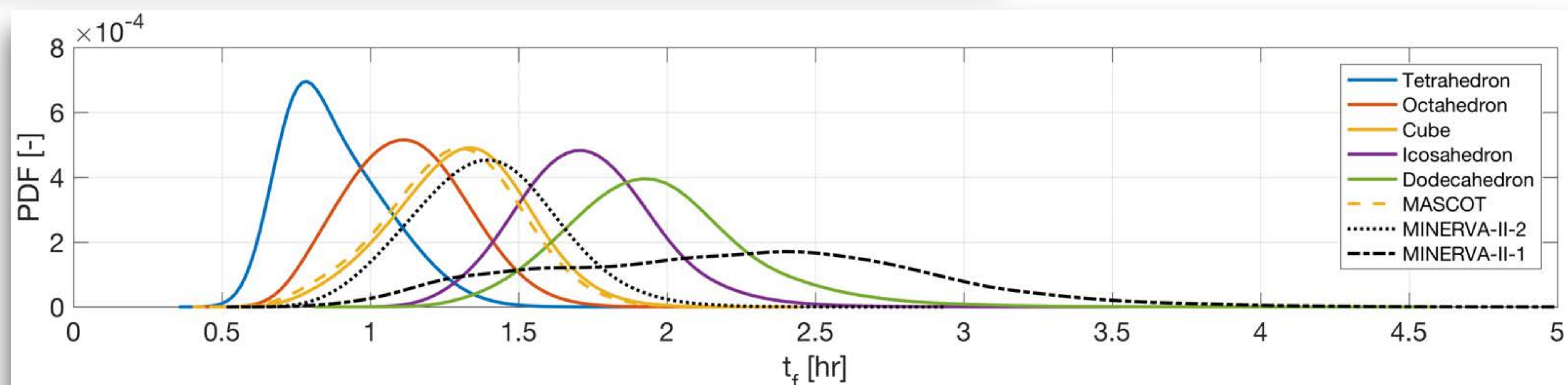
settling time

Effect of lander shape

- Repeat nominal scenario for different shapes:



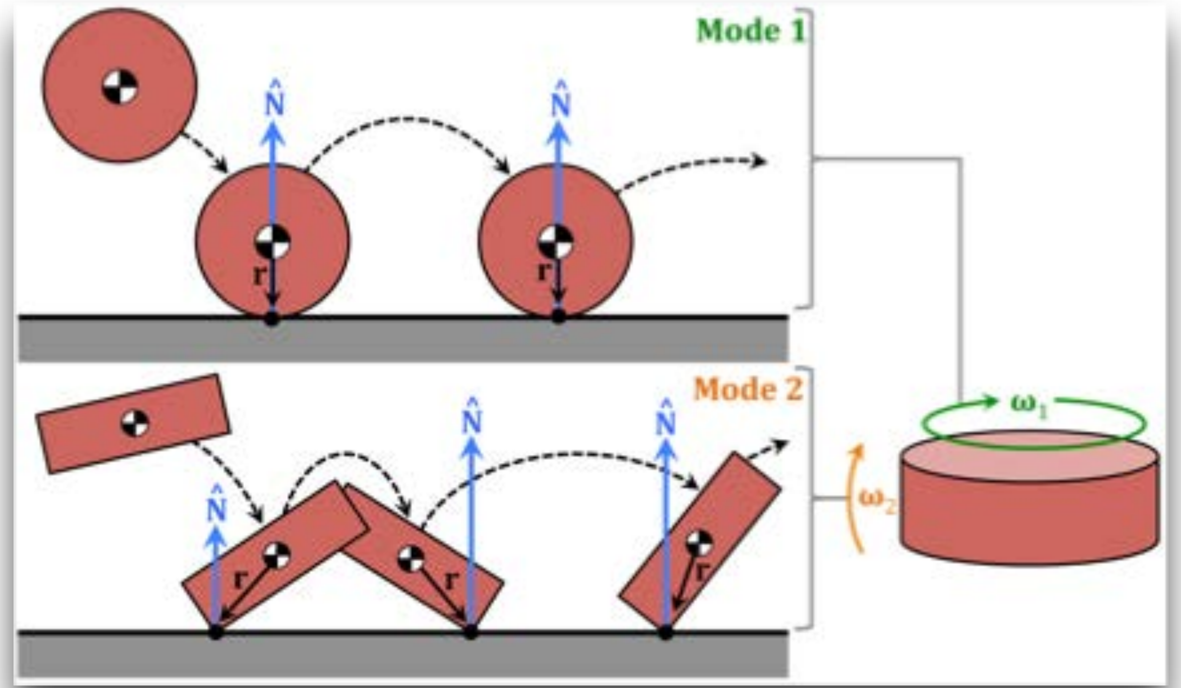


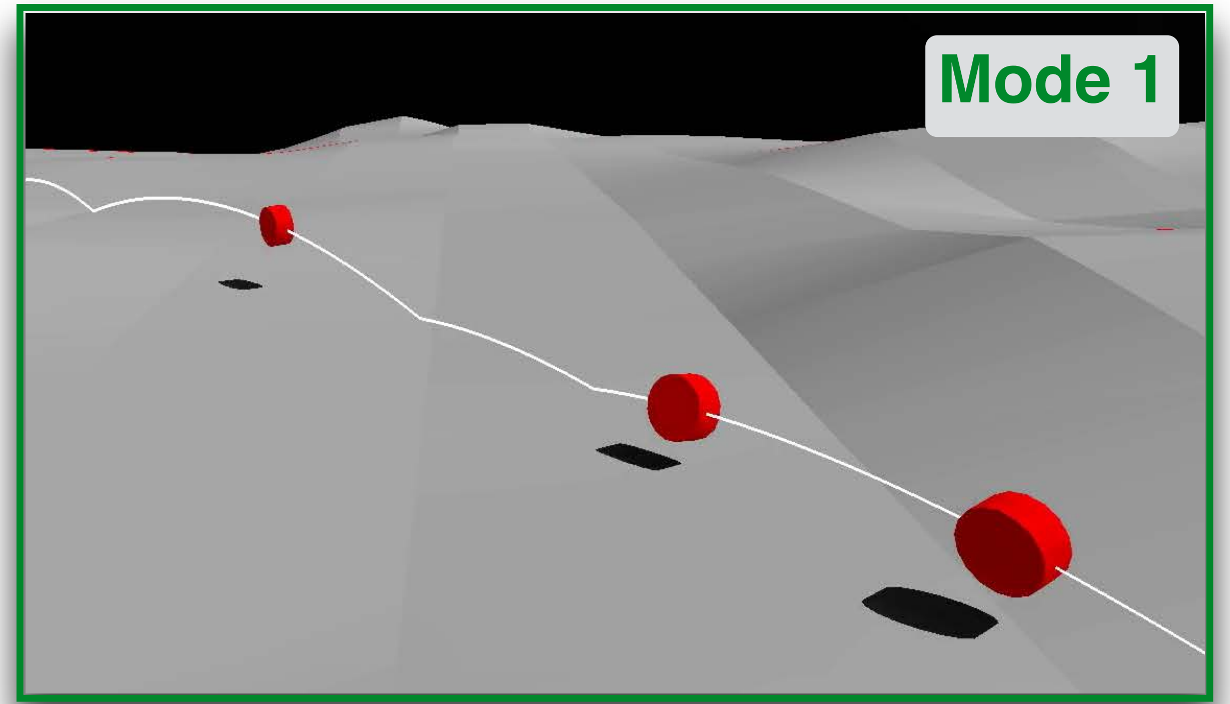


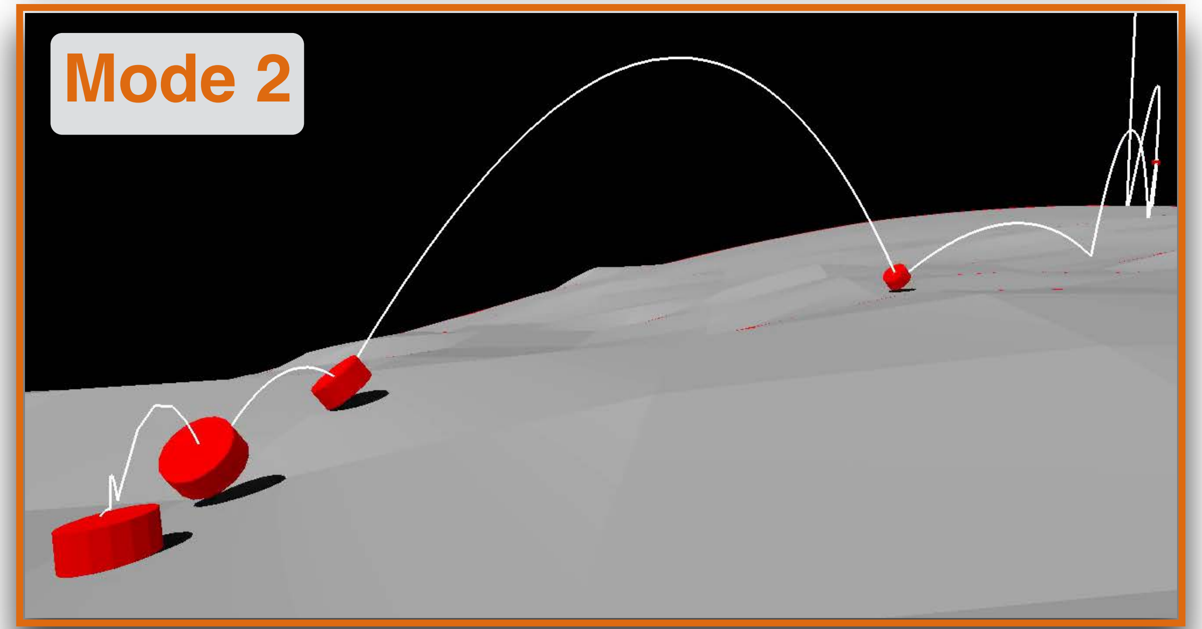
  - Different shapes experience notably different dynamics!
  - Implications for lander design

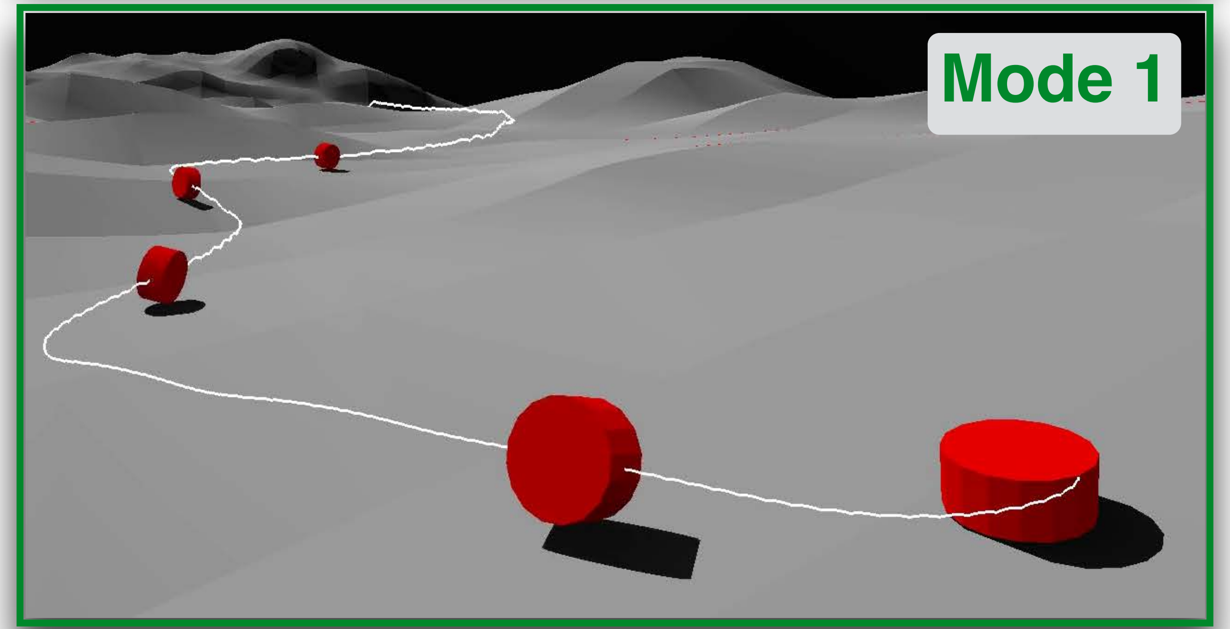
Effect of lander shape

✤ Behavior of Minerva-II-1:





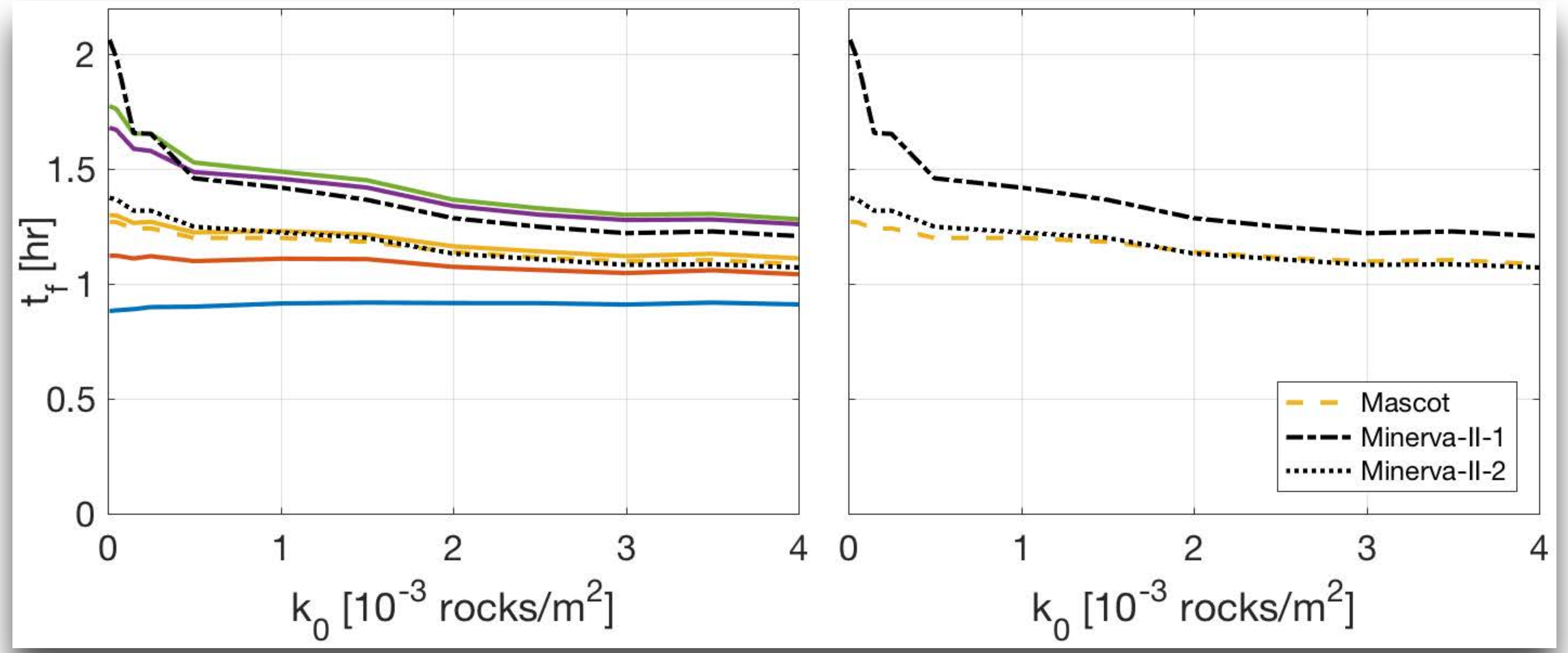


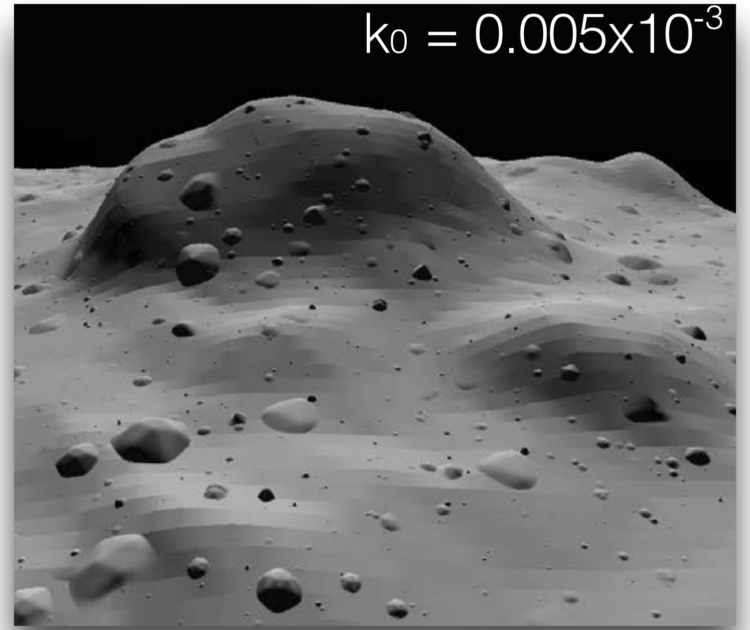


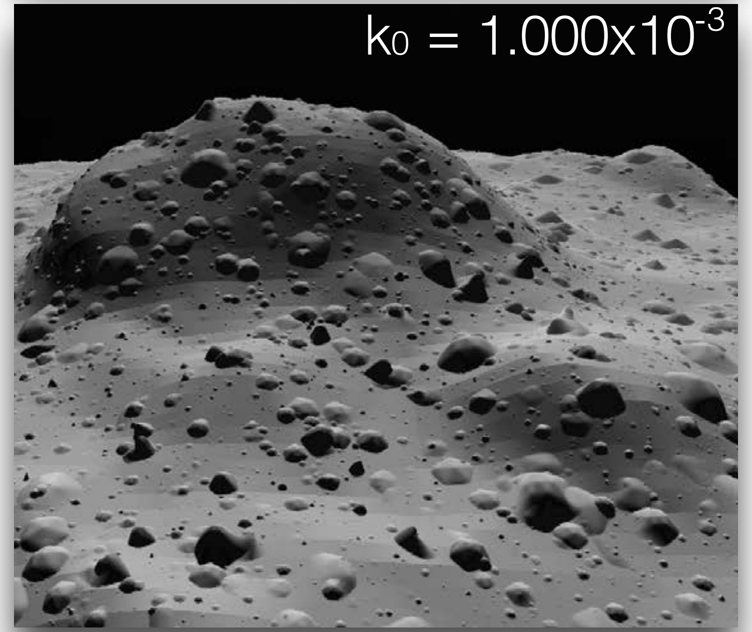
➢ Presence of rocks?

Effect of rocks

- Using procedurally seeded rocks, varying spatial density k_0:
  - Settling time statistics:



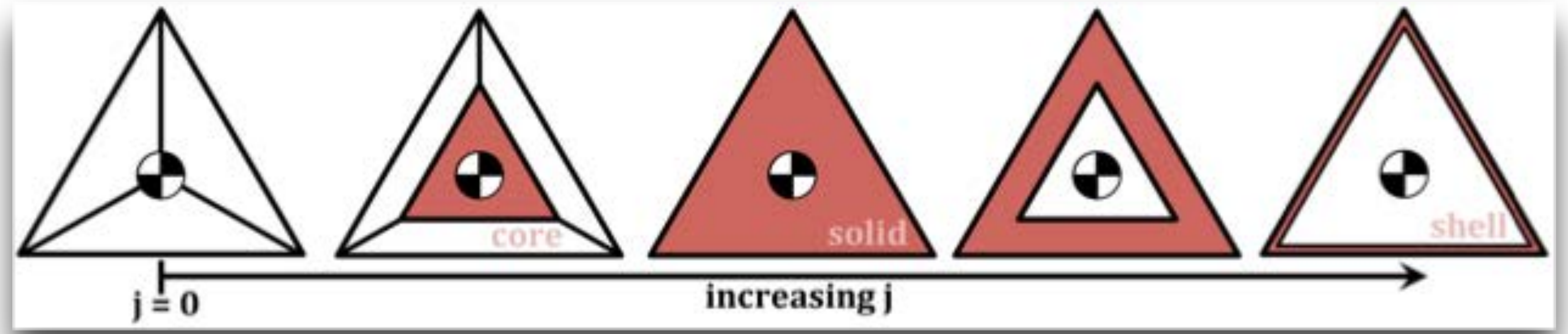


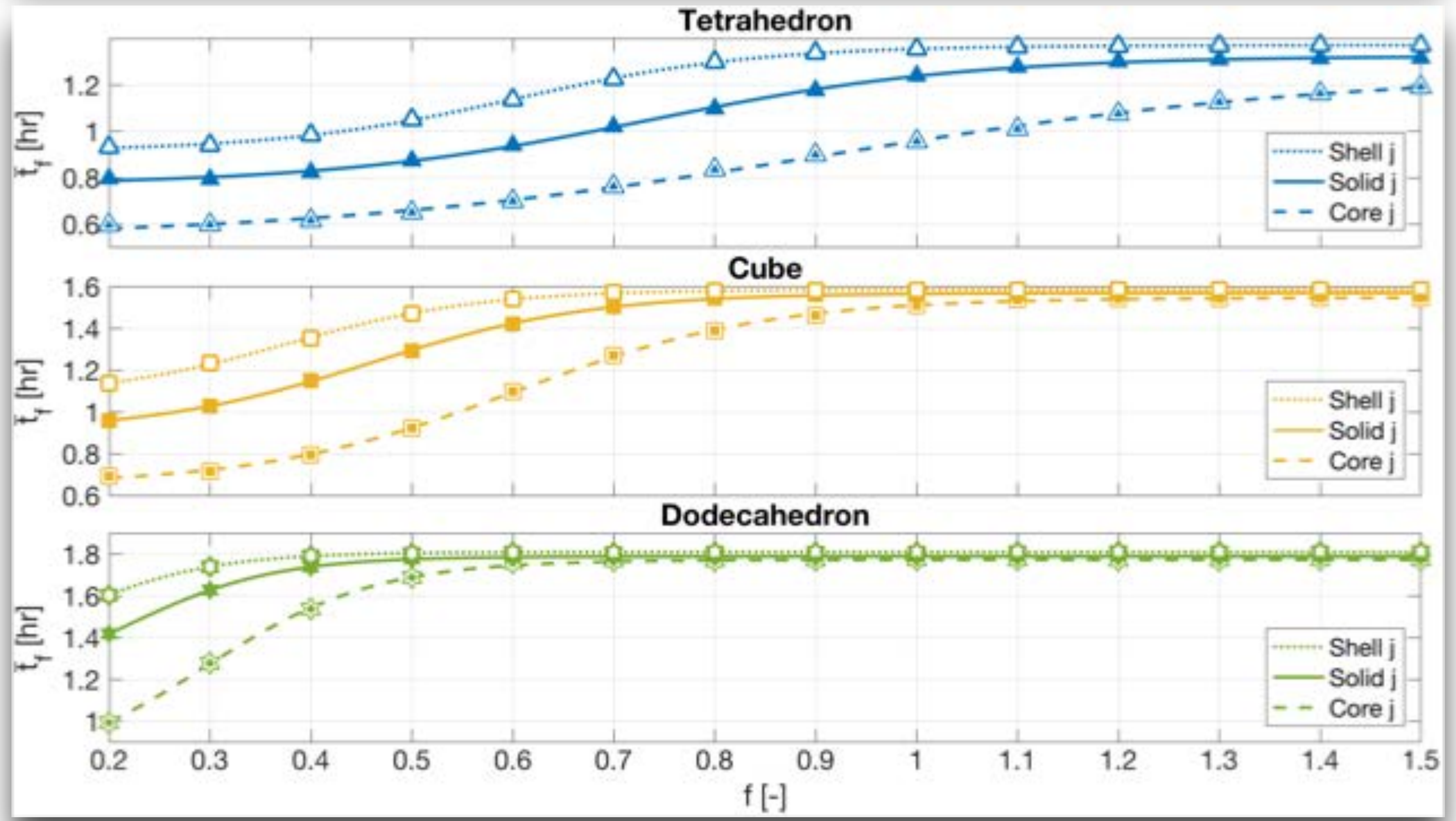


  - Rocks resist the 'rolling' motion of a probe
  - They are important to model!
  - Results hold for normal & grazing impacts
  - Implications for Minerva-II-1 rover

Effect of mass distribution

- Repeat nominal scenarios for varying *j*:





- Further implications for lander design

Questions?

stefaan.vanwal@colorado.edu