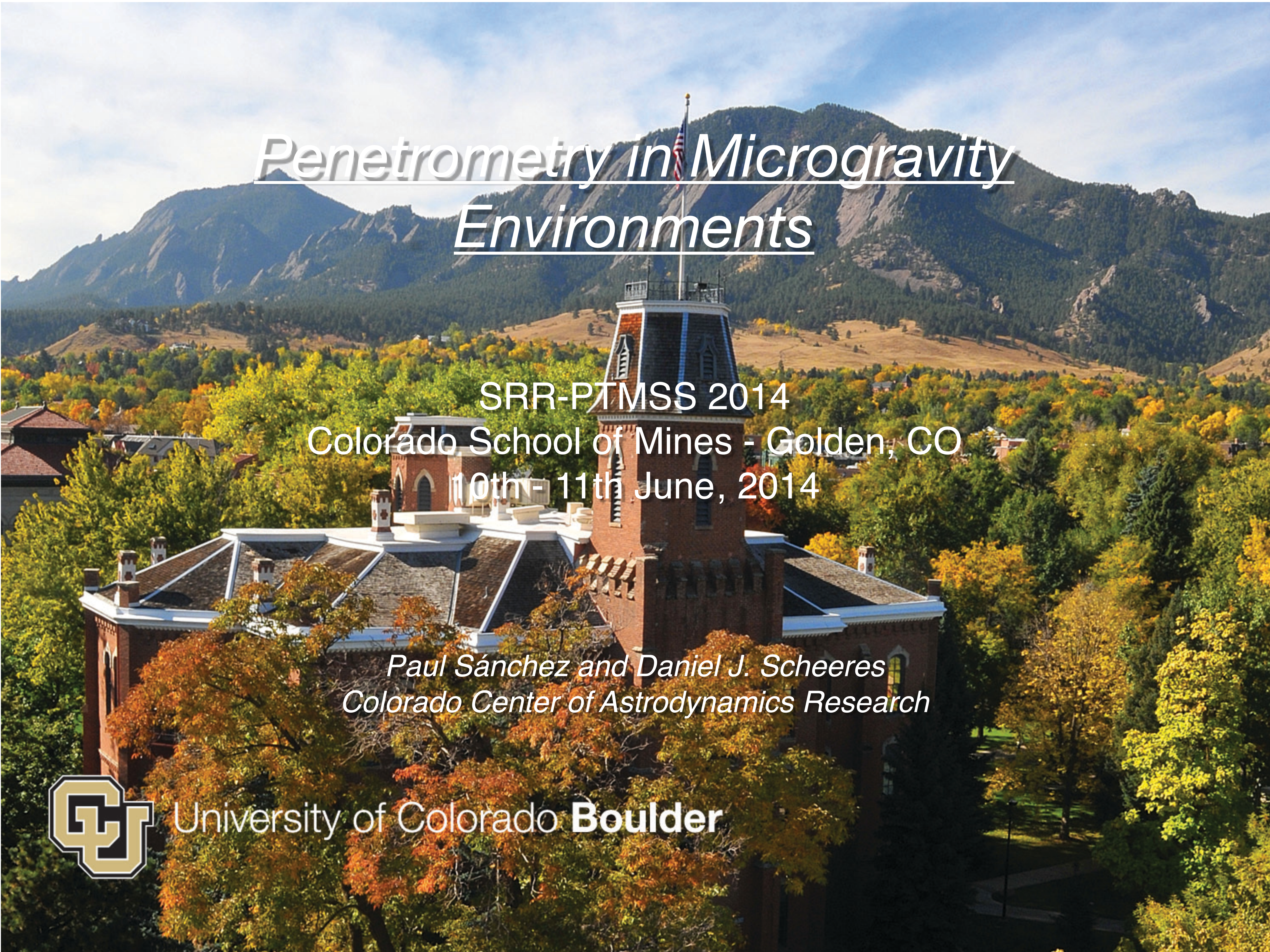

Penetrometry in Microgravity Environments

SRR-PTMSS 2014
Colorado School of Mines - Golden, CO
10th - 11th June, 2014

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Colorado Center of Astrodynamics Research

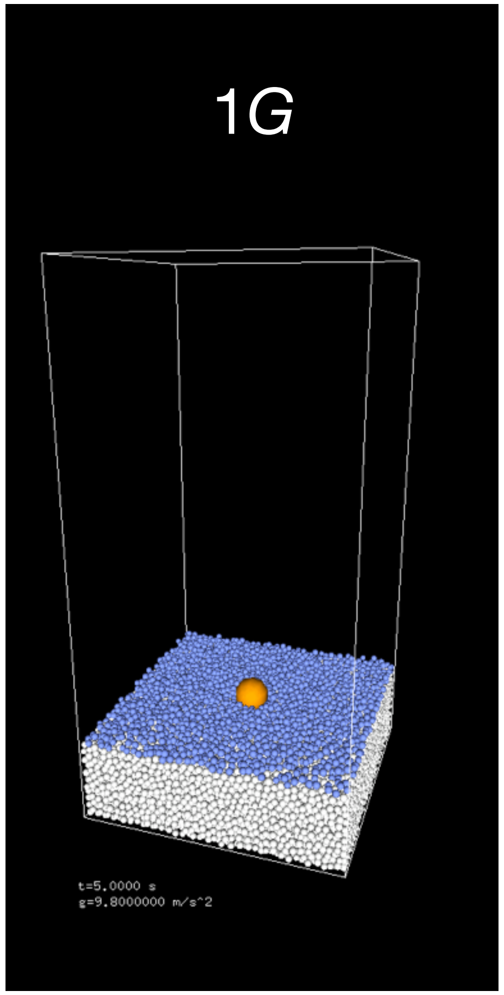
University of Colorado **Boulder**

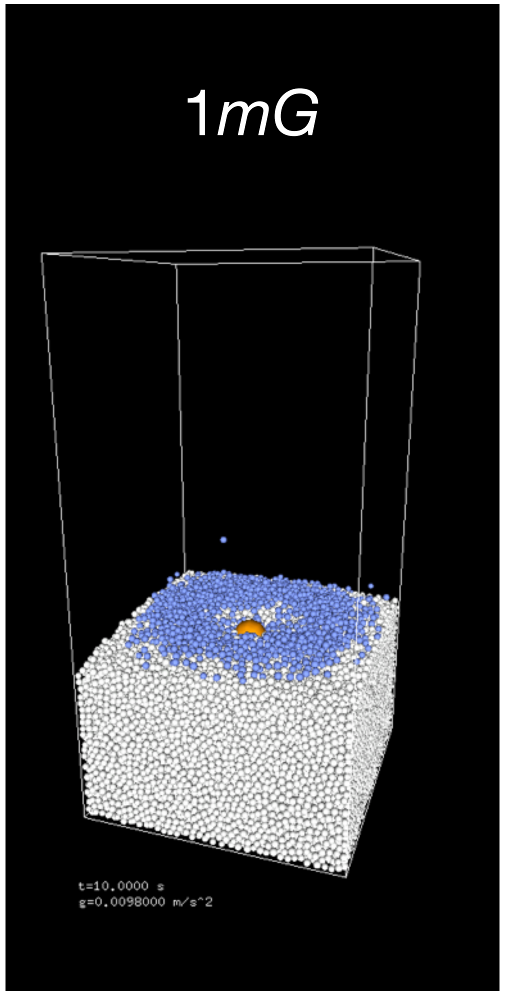
Motivation

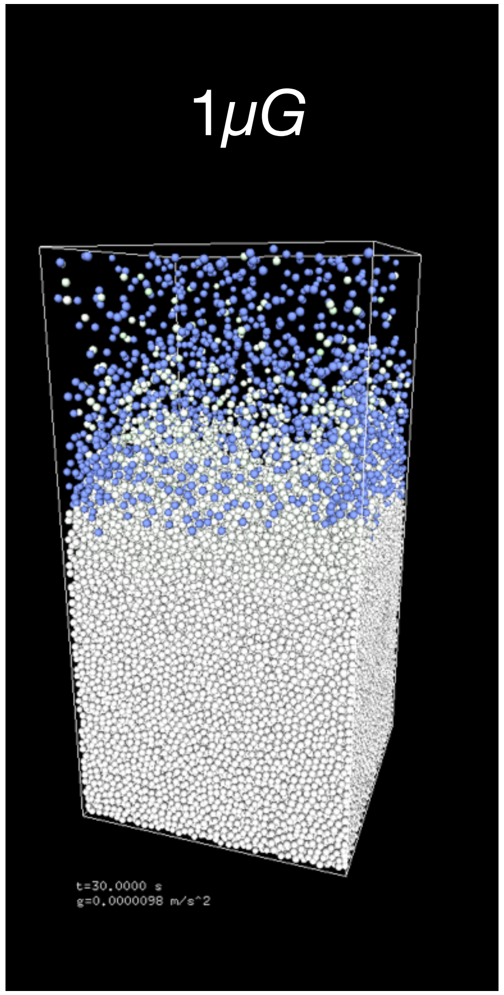
- The Hayabusa mission to Itokawa and future sample-return missions (OSIRIS-REx and Hayabusa 2) will have to interact with asteroid surfaces to accomplish their objectives.
- Though much is known about the dynamics of granular aggregates on Earth, micro-gravity environments are largely unknown.
- The mechanisms need to be tested before they are used, but the right gravitational conditions cannot be readily obtained experimentally on Earth.

First Impact

- The same experiment with 3 different gravitational fields.
- Impact velocity ~10cm/s.







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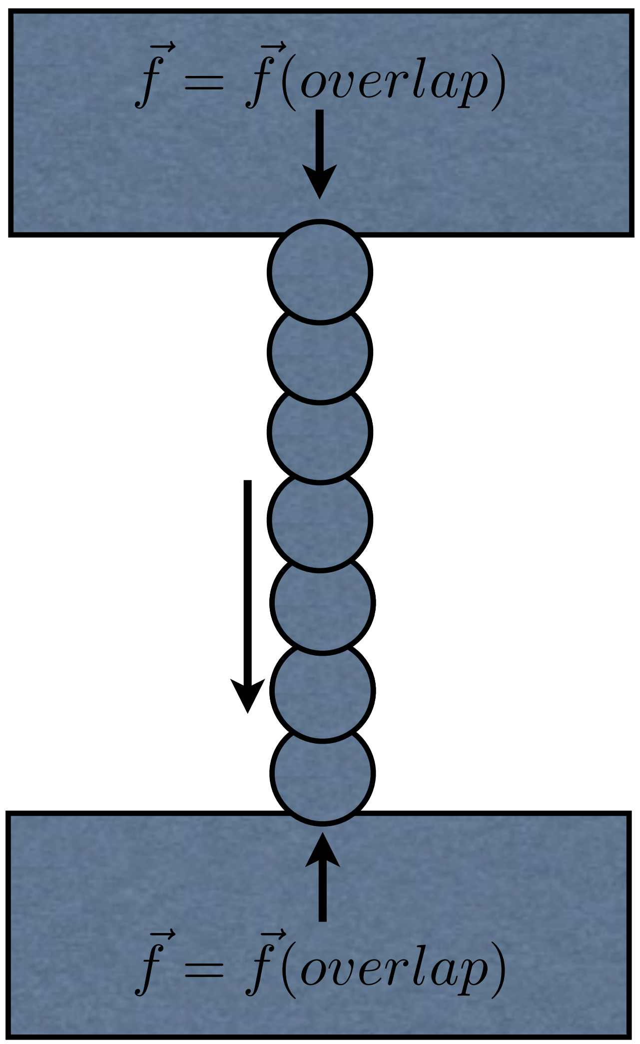
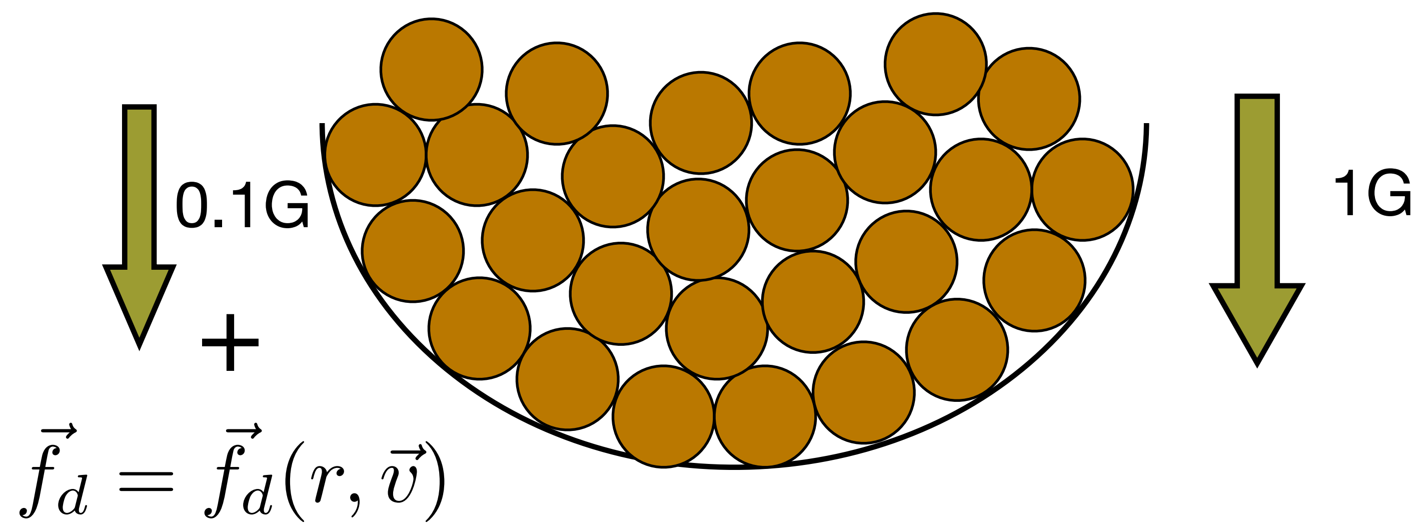
Soft-Sphere DEM



Settling process



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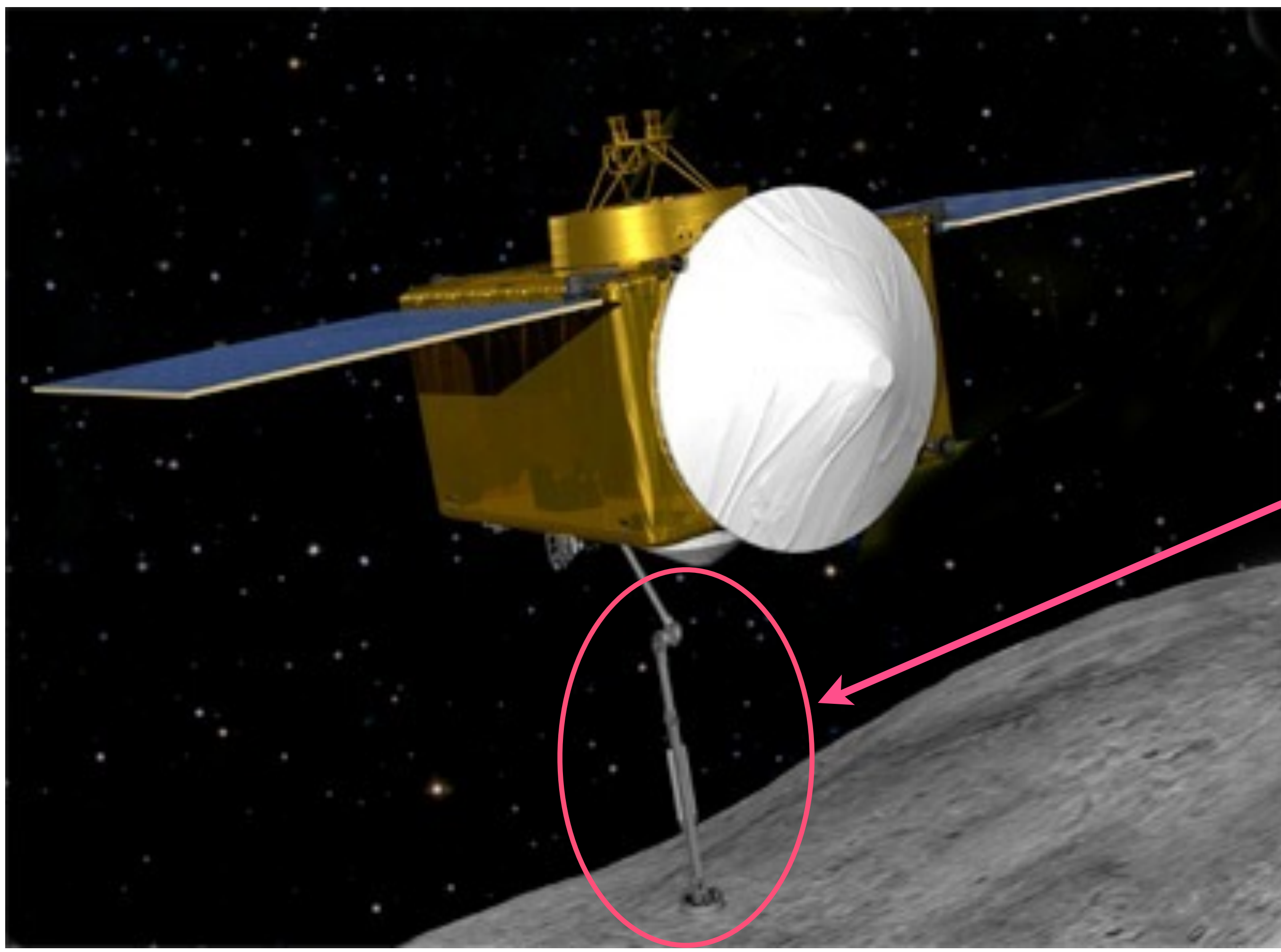
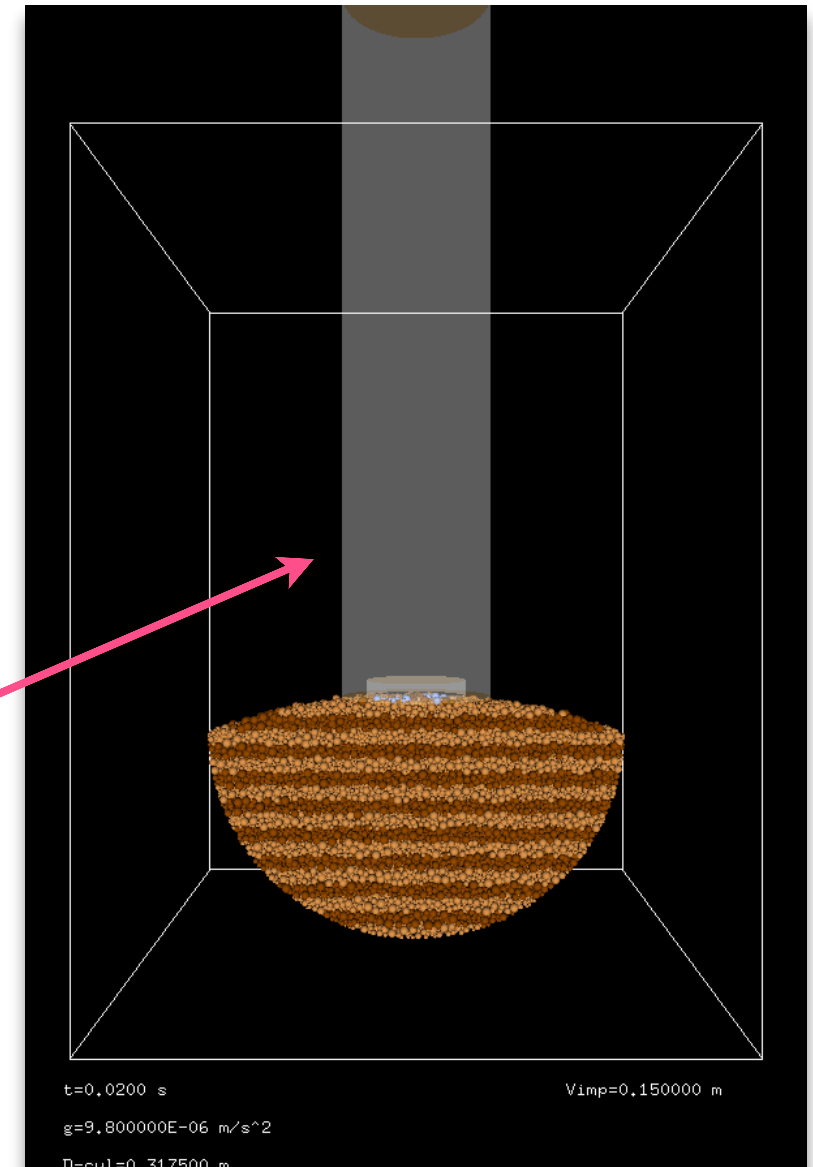
Mechanics Laboratory

TAGSAM-OSIRIS-REx





Will the geometry of the sampler chamber capture or not the regolith upon impact?

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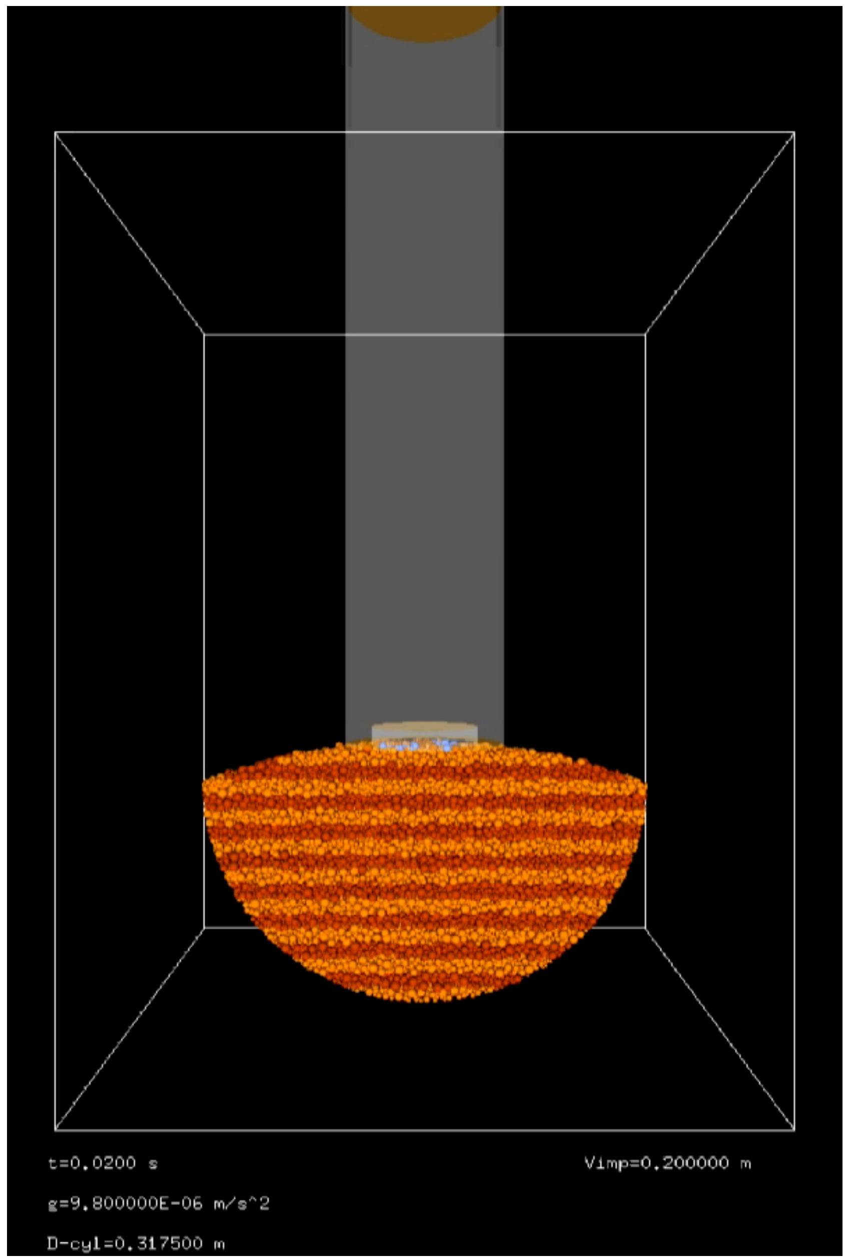
Typical Simulation



Polydisperse regolith: 0.5-2.5 cm
Hemiphere radius: 0.45 m
Impact speed: 0.2 m/s

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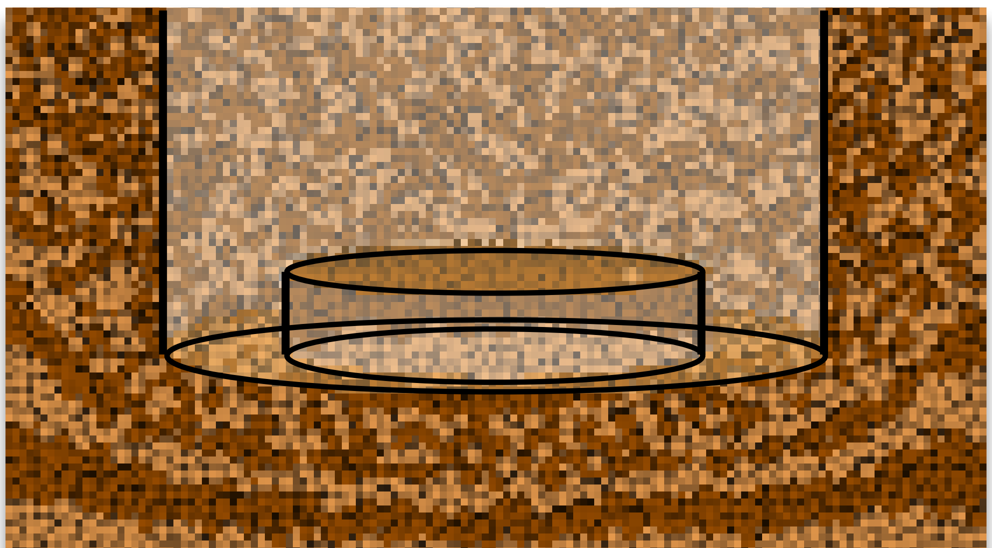
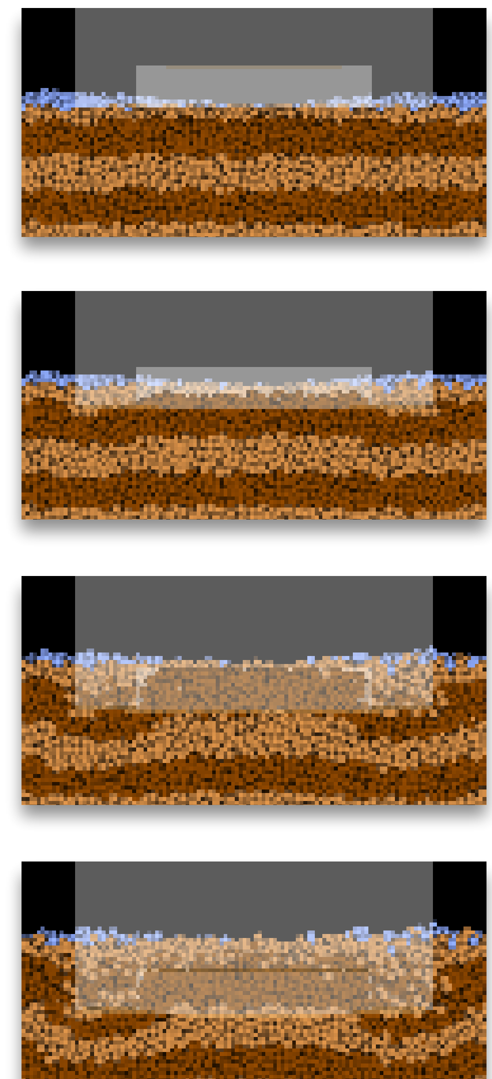
Sampler Head and Chamber



v_i=15cm/s



t=0.1s

t=0.2s

t=0.3s

t=0.4s

- Detail of the sampler head as it was implemented for simulations.
- The snapshots show the particles getting into the sampler chamber at the beginning of the simulation.
- The rest of the simulations shows them staying inside it.

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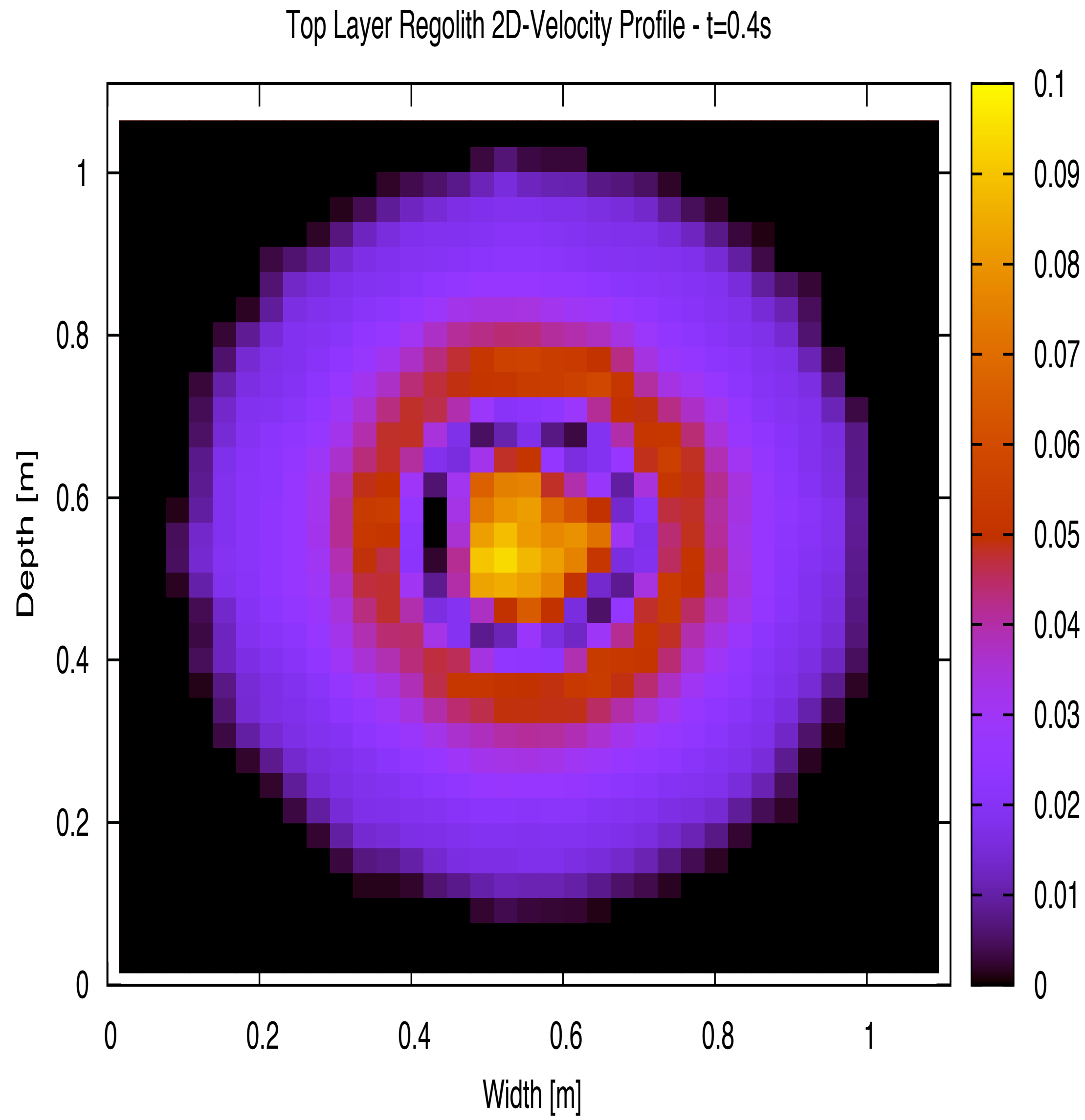
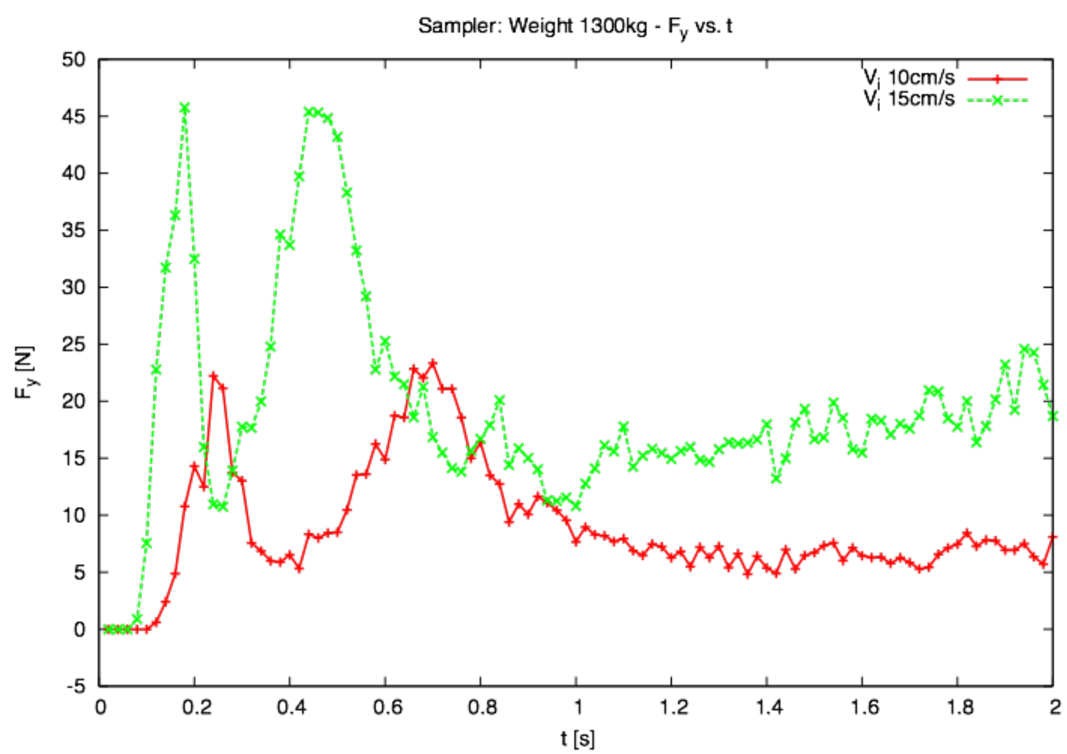
Velocity Profile (upper layer)



10 cm/s

- There will always be regolith coming up towards the space-craft, but its velocity depends on the mass of the impactor.
- The upward velocity of the regolith is close to the impact velocity of the cylinder.

Sampler Head and Chamber: Remarks



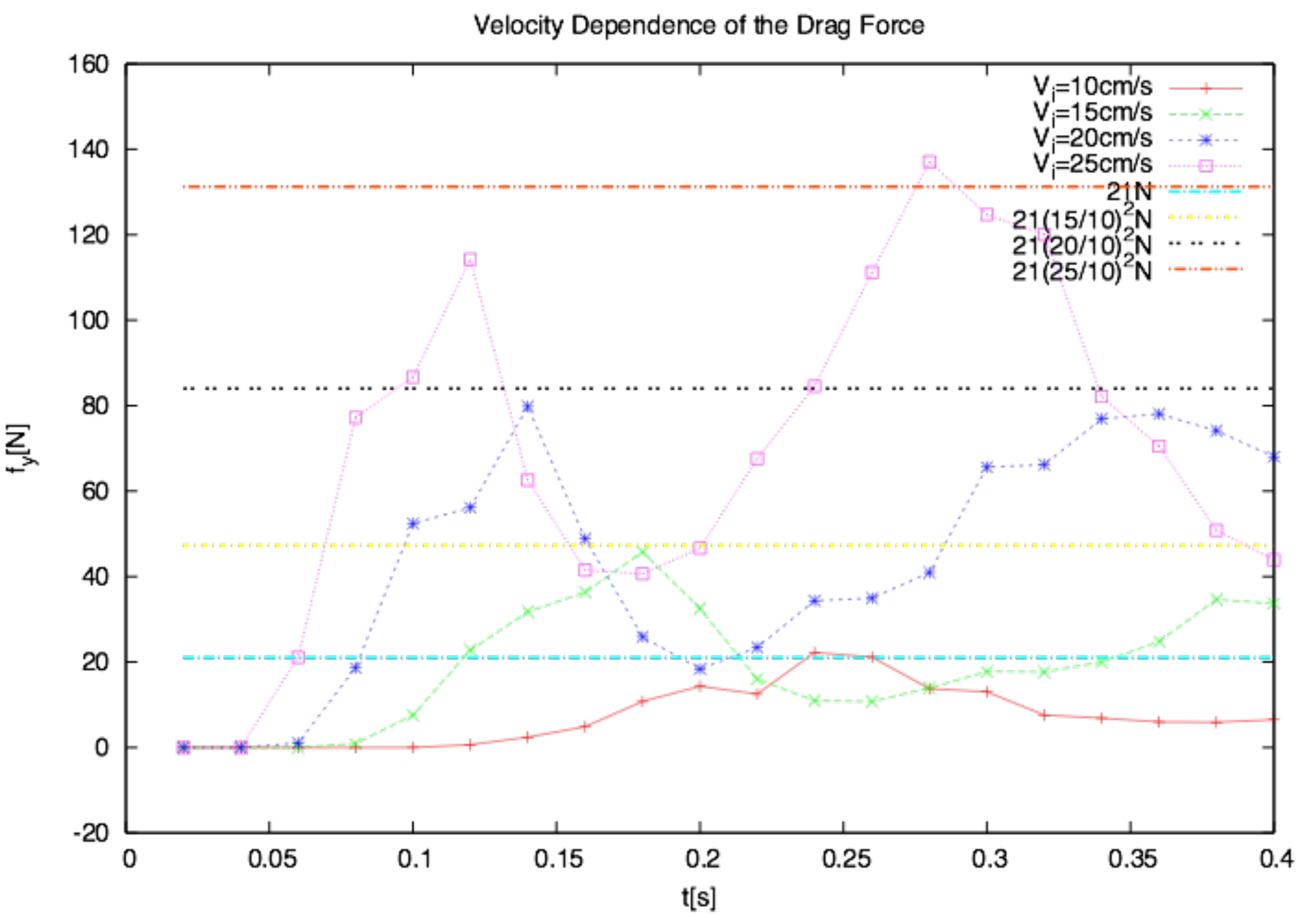
- The peaks in the force “felt” by the sampler head corresponds to the instants of contact between the flat a surface and the regolith.
- The height of the peaks depends directly on the impact velocity. This was also confirmed for higher impact velocities.

Drag Force at 1μg

- The plot shows the force that the sampler would "feel" during the first impact with the regolith without the influence of the spring.
- The gravity field has been adjusted to 1μg.
- The horizontal lines show a V_i^2 proportionality of this force.
- This finding could point to a liquid-like behaviour of the regolith under these low-gravity conditions.
- Proportionality indicates high Reynolds number drag:

$$\frac{1}{2}\rho V_i^2 C_D A$$

- Physically this makes sense as the regolith "fluid" reacts in turbulent-like fashion.



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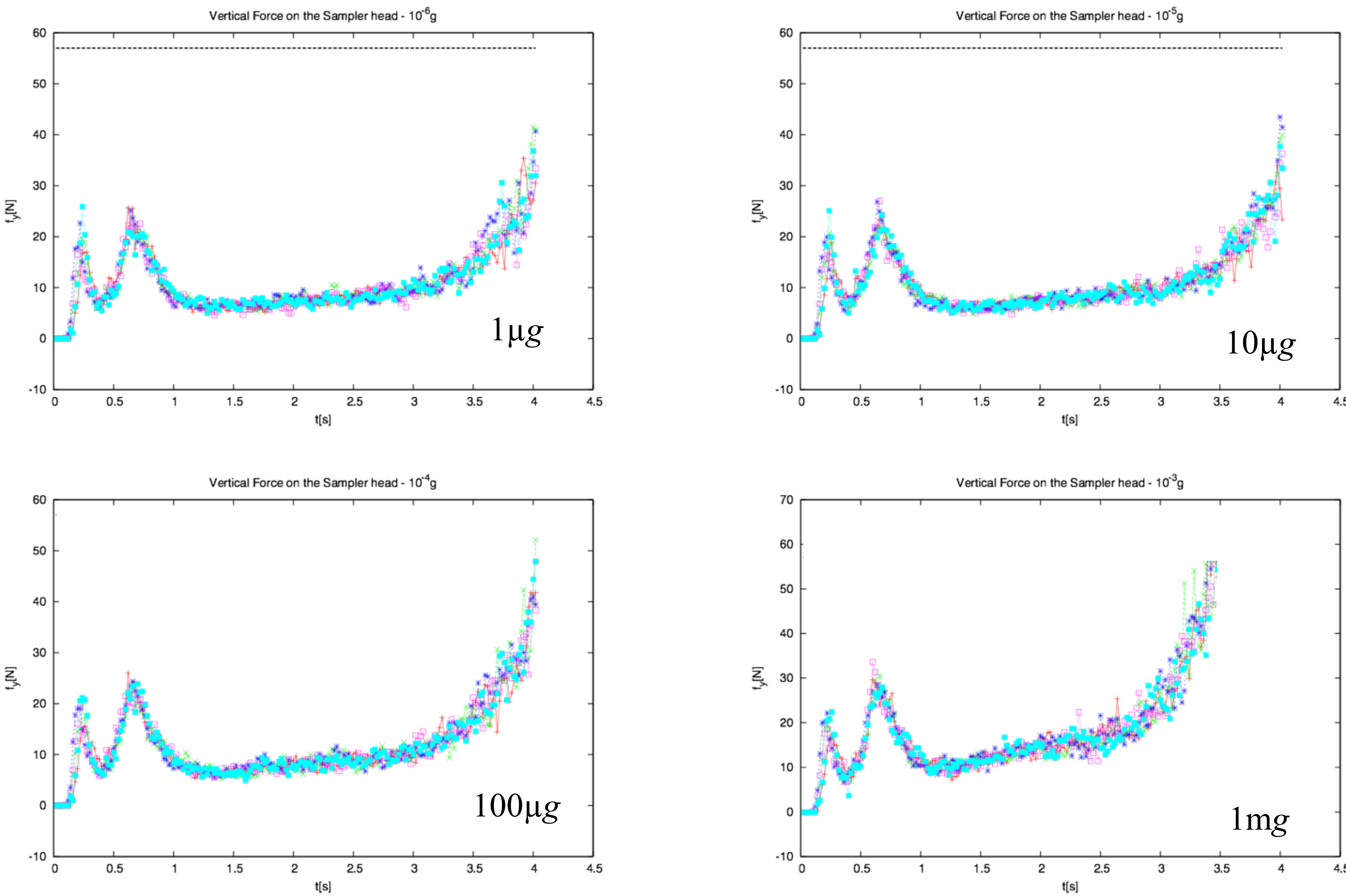
Other Gravitational Fields (v_i=10 cm/s)



The force that the mechanism feels remains independent of the gravitational field up until 100 μg and then it begins to change.

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Cohesive Regolith

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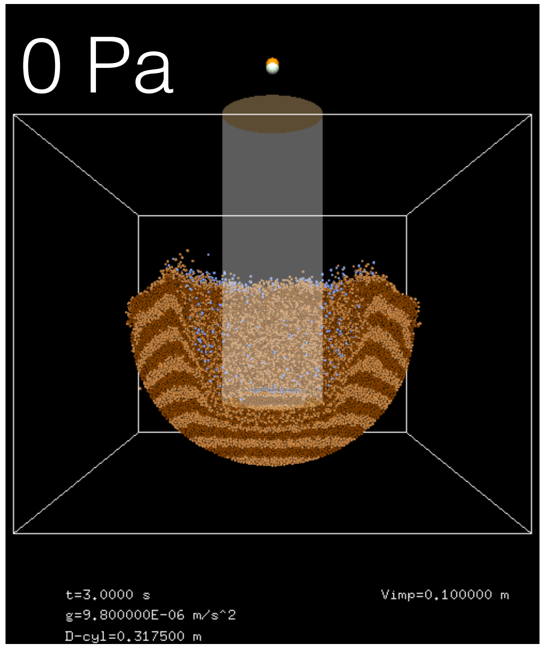
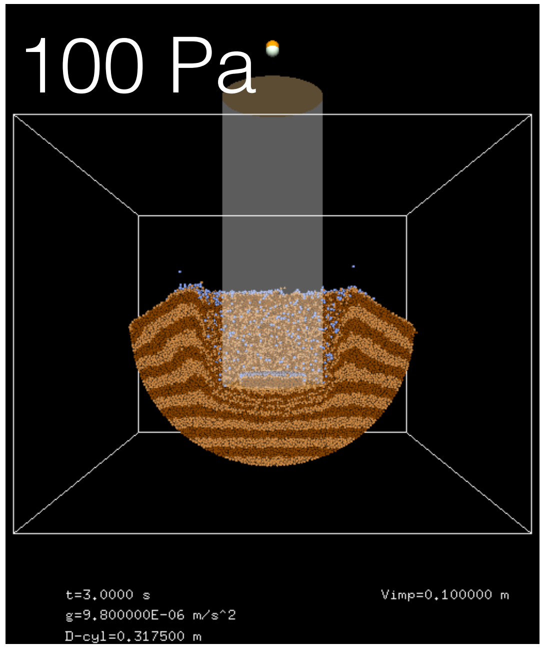
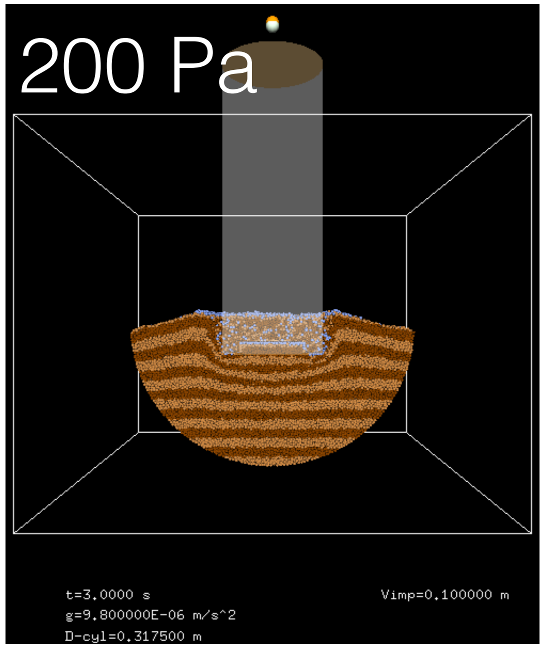
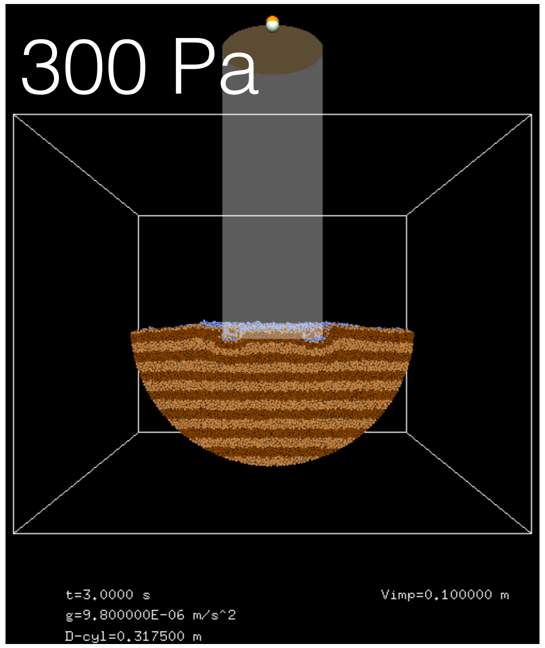
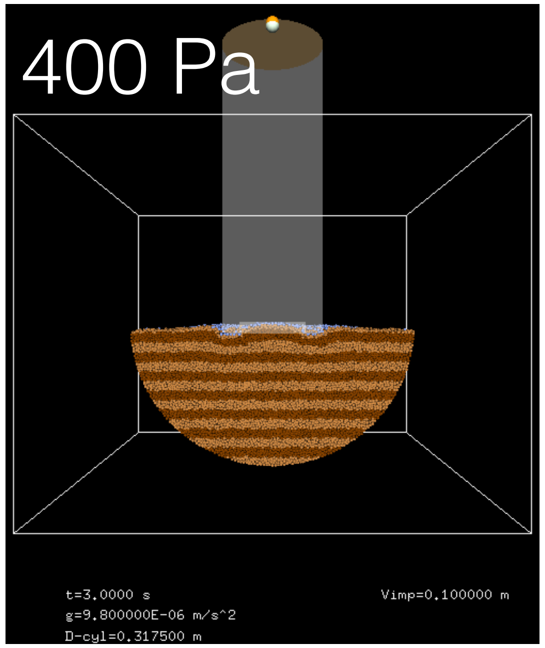
Lowest point of penetration











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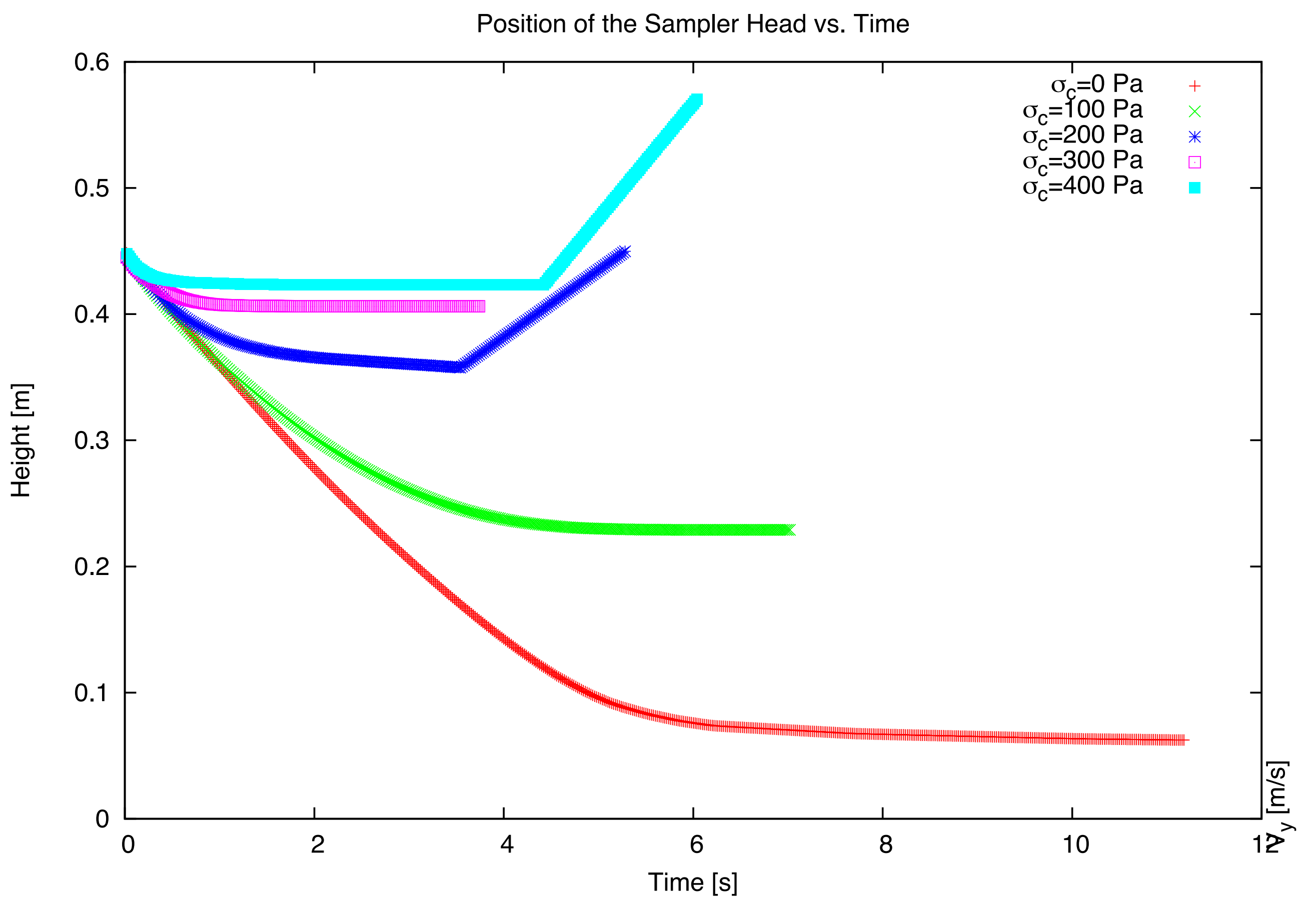
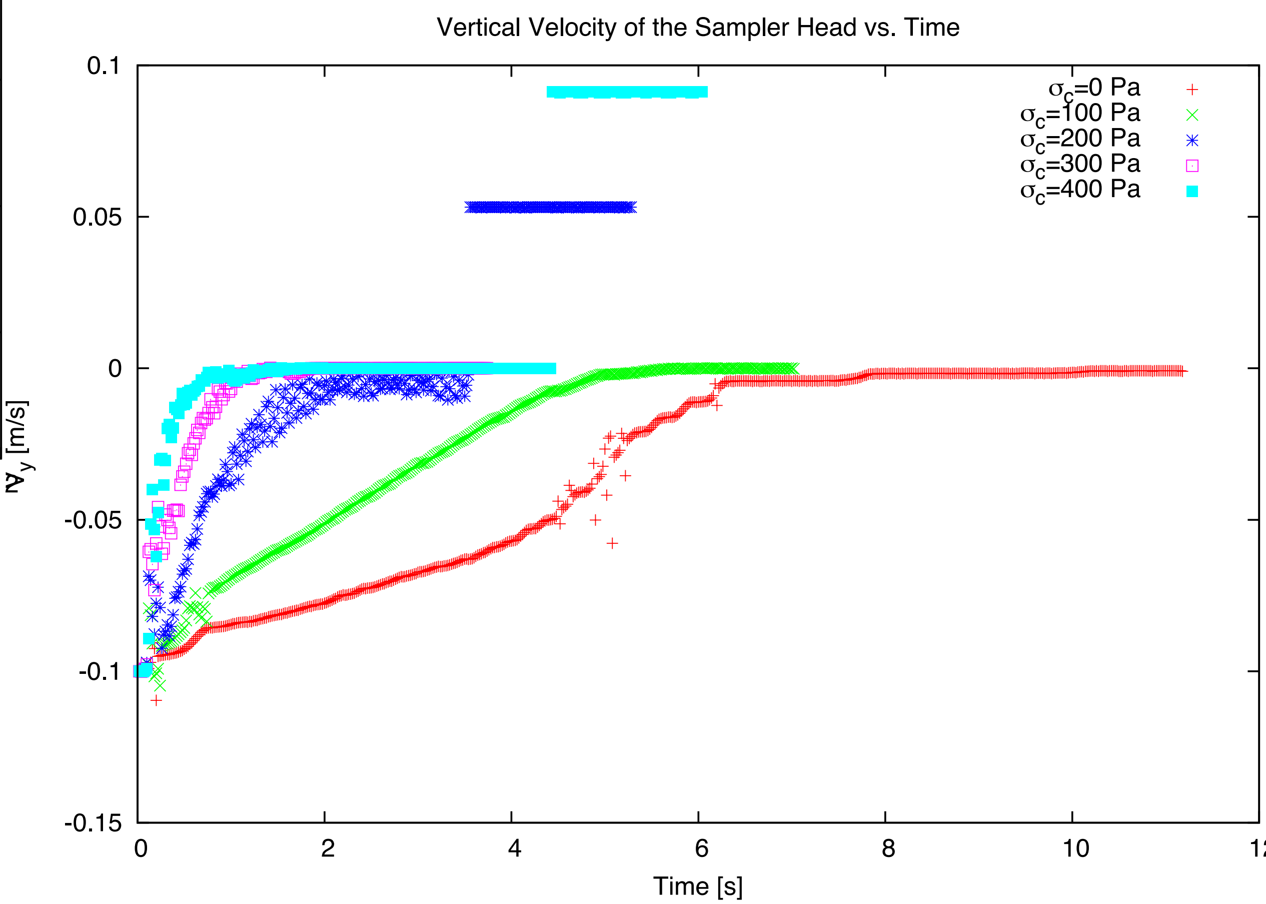
Position and Velocity





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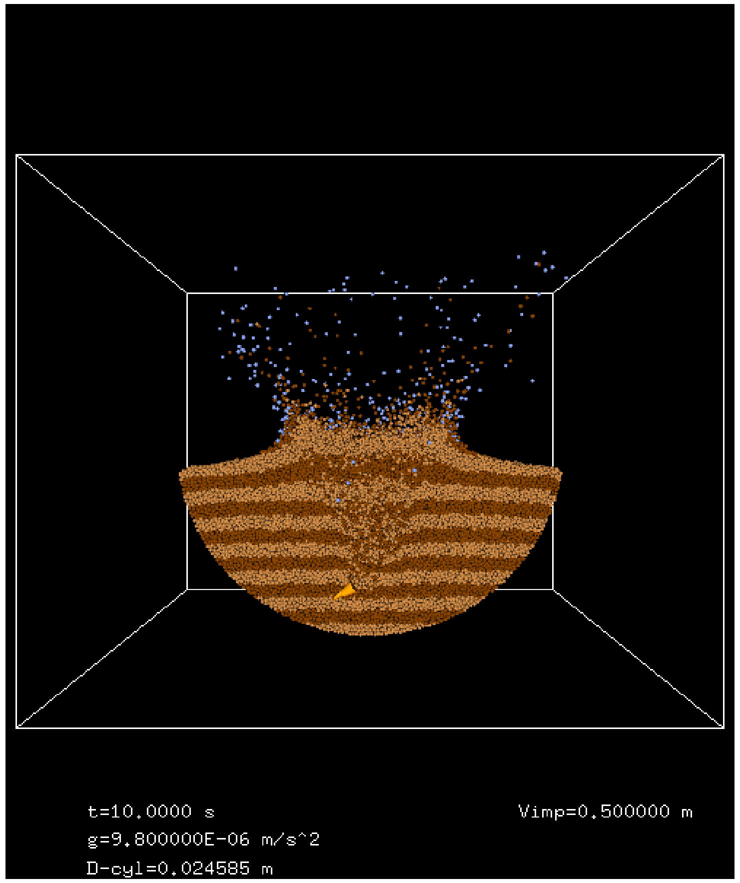
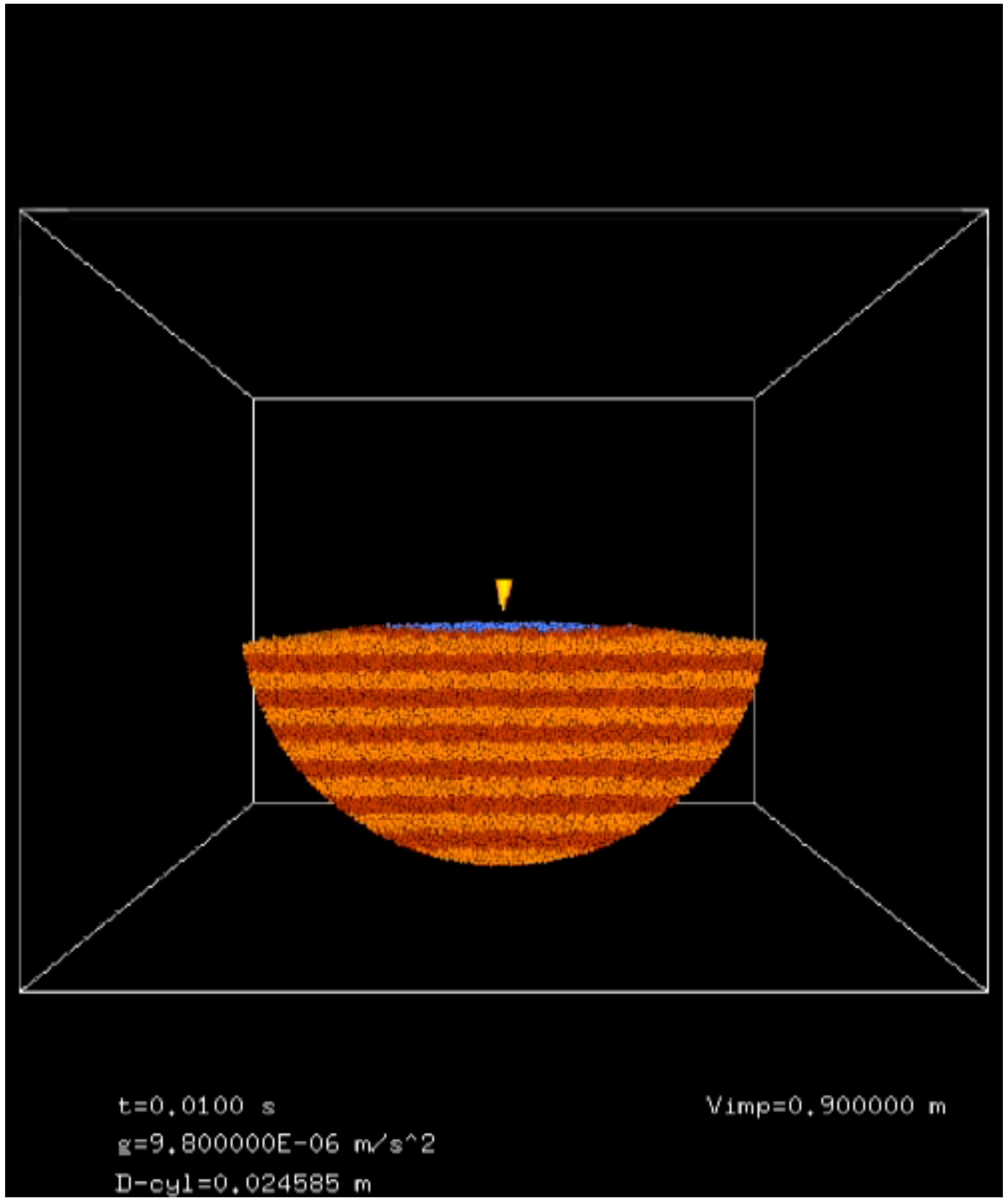
A different projectile

Non-spherical projectile (Cone)

- For the following simulations we are using a Soft-sphere DEM code.
- This code simulates the dynamics of 180.000 spherical grains as they are impacted with a right circular cone.
- ***Gravity field***: external gravitational field of 1μG
- ***Grains***:
  - Size distribution: **a.** 0.9 - 1.1 cm; **b.** 0.5-2.5 (1/d).
  - Static and dynamic friction are implemented.
  - Material density: 2500 kg/m^3.
  - Packing fraction: **a.** 0.62; **b.** 0.64.
- ***Cone***:
  - Material density: 8000 kg/m^3.
  - Height: 6 cm.
  - Radius: 1.6 cm.
  - Impact speed: 10, 30, 50, 70 and 90 cm/s
- ***Container***: hemisphere, 45 cm radius.
- ***Simulation time***: 10 s.



Typical Simulation



Monodisperse material: ~1cm
Impact velocity: 90cm/s
Total time:10 s

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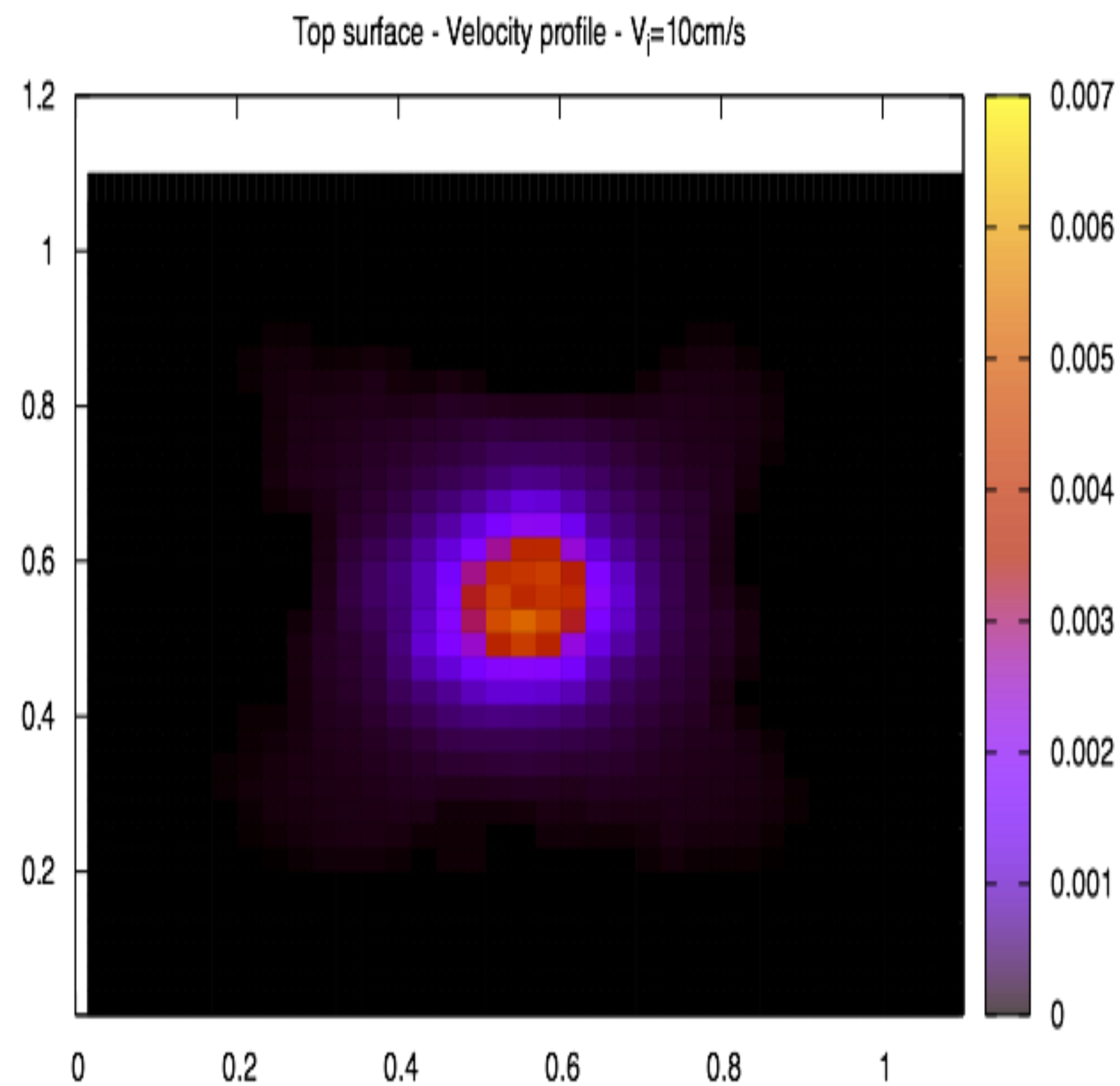
Velocity Profile (upper layer)



10 cm/s

- There will always be regolith coming up towards the space-craft, but its velocity depends on the mass of the impactor.
- The upward velocity of the regolith is about one order of magnitude smaller.

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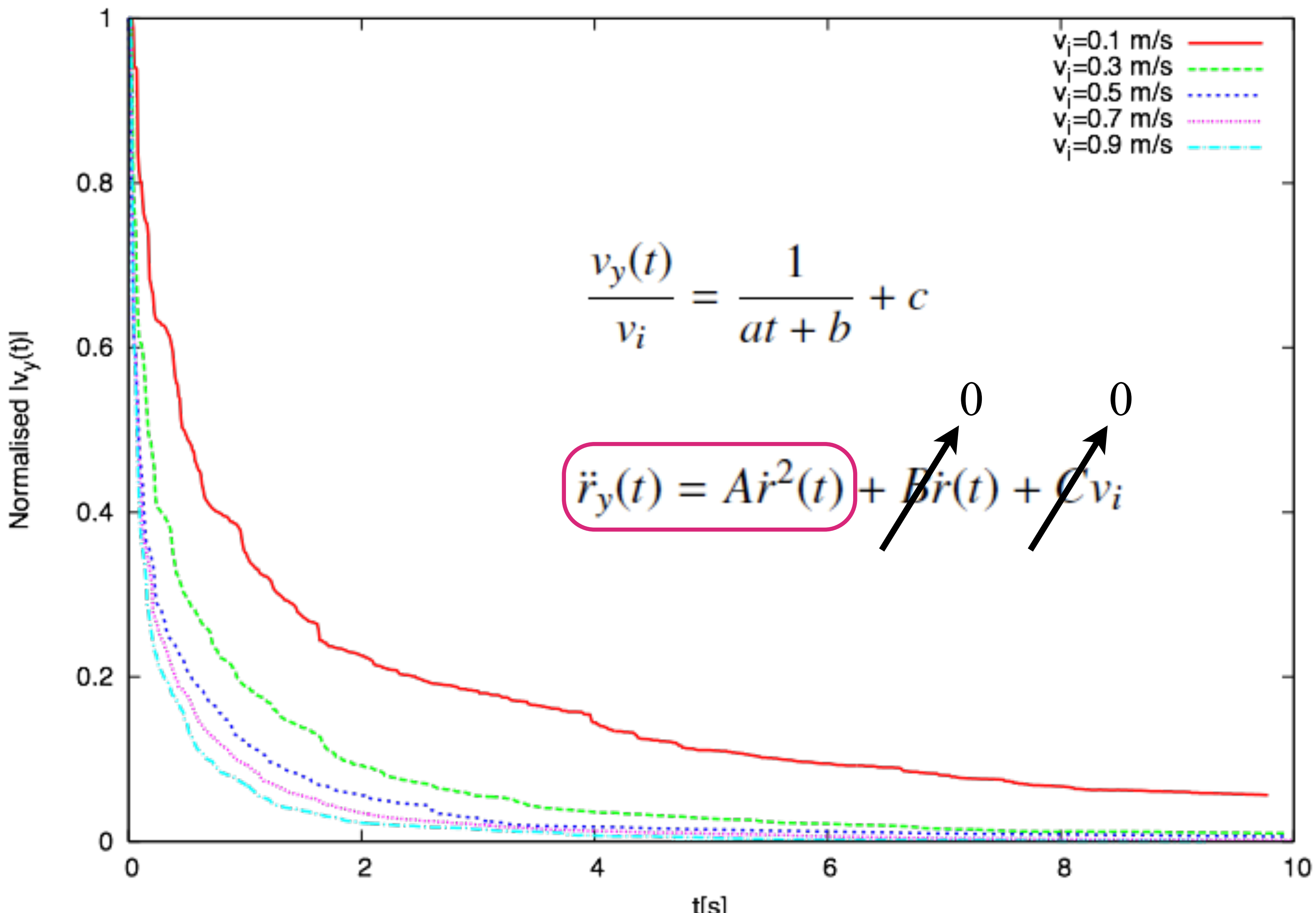
Normalized Speed



$$\frac{v_y(t)}{v_i} = \frac{1}{at + b} + c$$

$$\boxed{\ddot{r}_y(t) = A\dot{r}^2(t)} + \cancelto{0}{B}\dot{r}(t) + \cancelto{0}{C}v_i$$

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Conclusions

- For values of the gravitational field in the micro-gravity regimen, the resistance force on the TAGSAM is independent of its impact velocity.
- Both impactors always produce regolith that moves "upwards" and that could potentially impact the space-craft.
- The upwards velocity of this regolith depends on the mass of the impacting body and its shape.
- The size range of the regolith did not produce a noticeable change in the dynamics of the TAGSAM; however, this was not the case for the cone where its displacement was shortened.
- The drag force on the cone and the sampler head upon impact show a dependence on v^2.

Thanks, any questions?