A Thermal Origin to the Asymmetry of the Permanent Dust Cloud at the Moon

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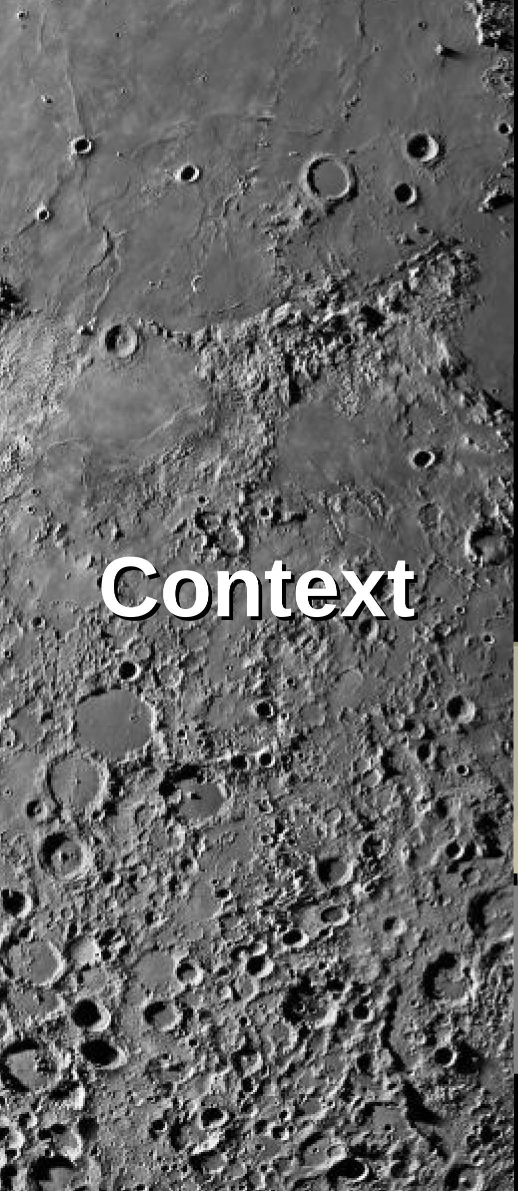
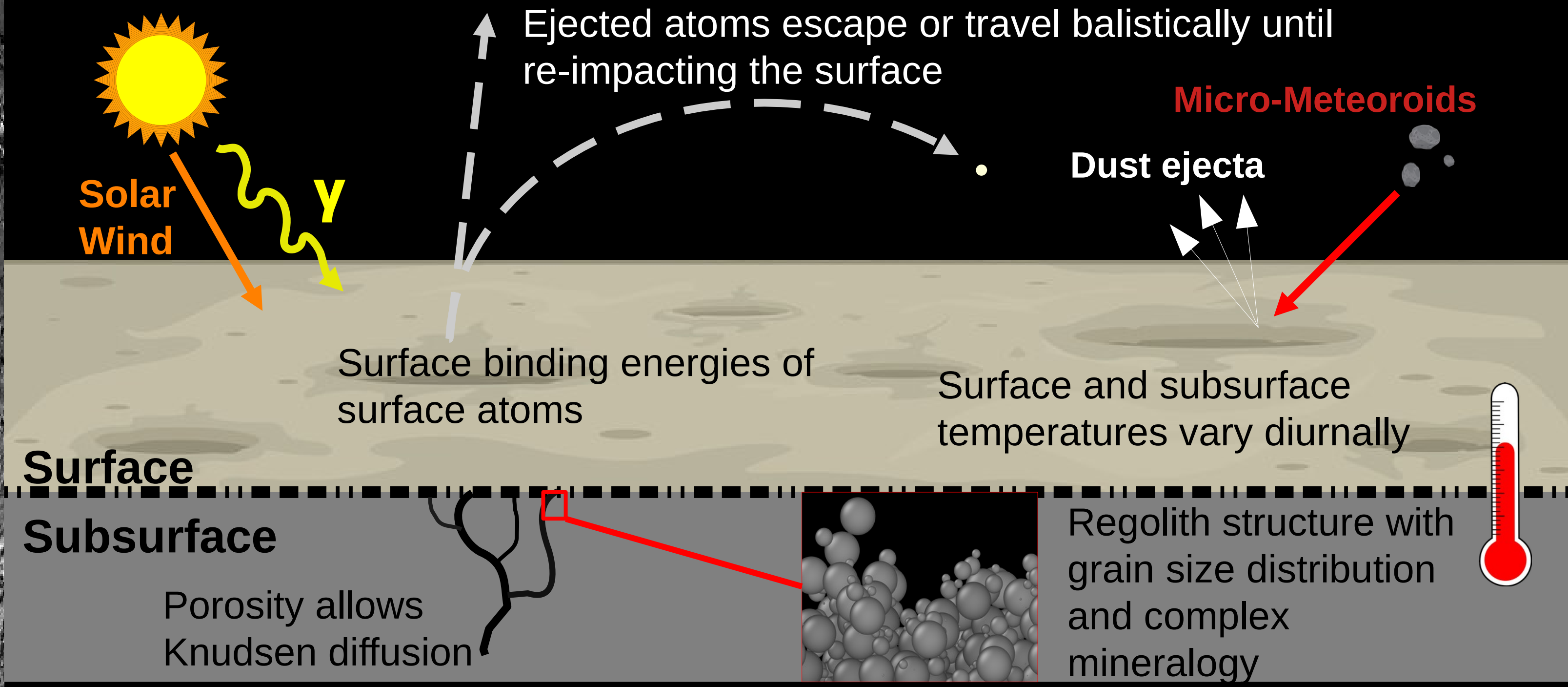
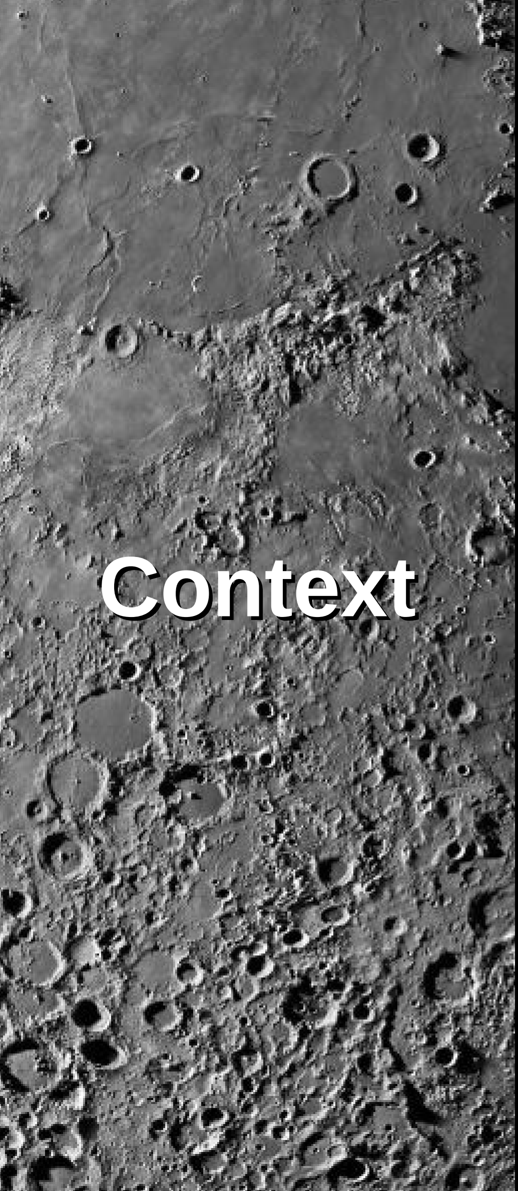
Astronomical Institute of the Romanian Academy, 17th of June 2026



The lunar surface is exposed to space weathering, including **micro-meteoroid impacts**



Context

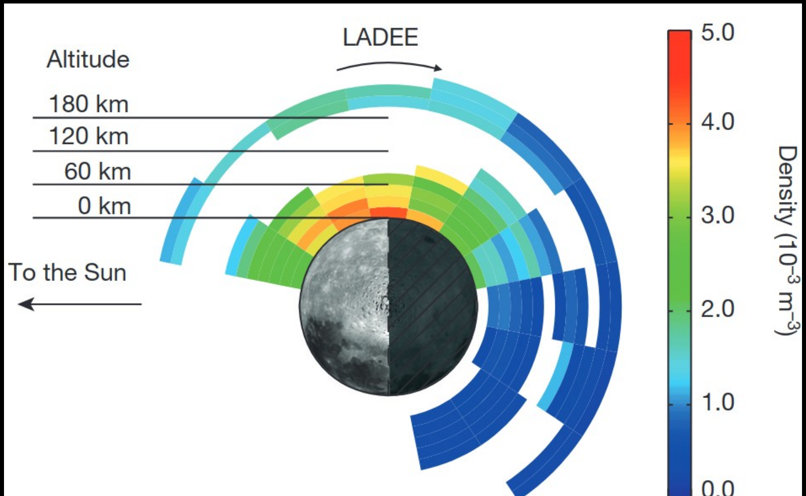


Lunar Atmosphere and Dust Environment Explorer (LADEE) orbited the Moon taking data with the Lunar Dust Experiment (LDEX)

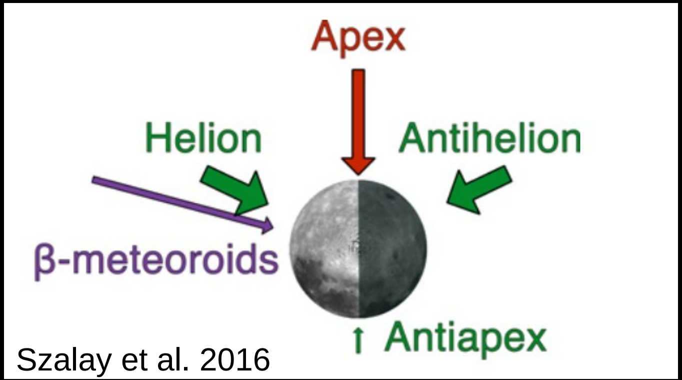
LDEX measured a permanent dust cloud at dawn, **tilted** towards the day-side (~15-20% difference)

Total yield of **~10**

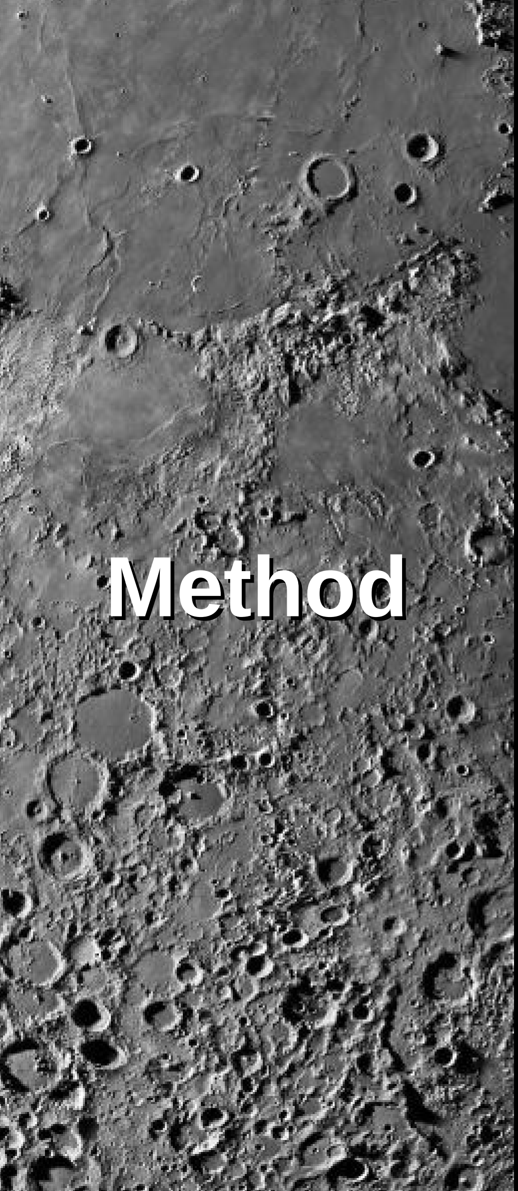
Current explanation : beta-meteoroids
No influence from the surface temperature ?



Horanyi et al. 2015



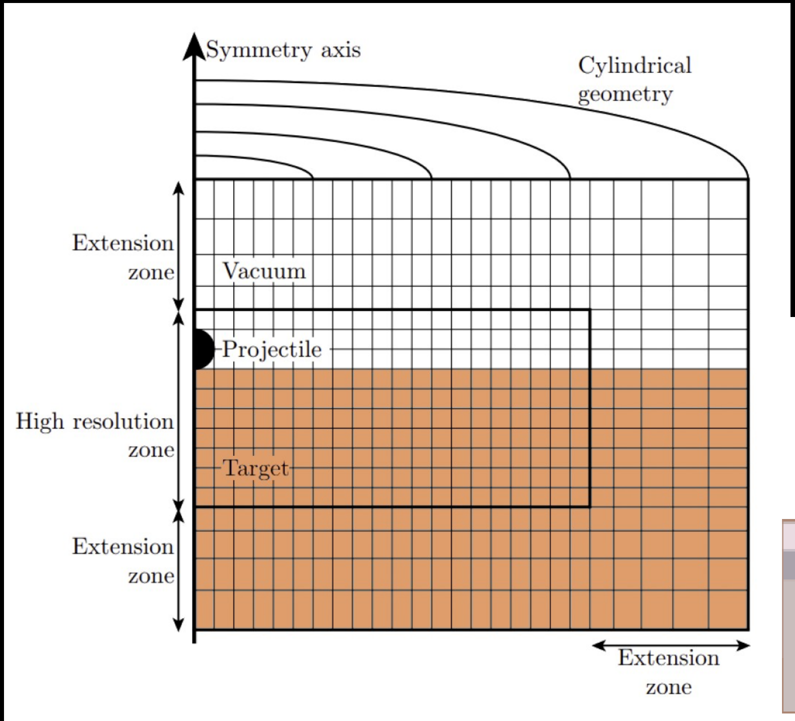
Szalay et al. 2016

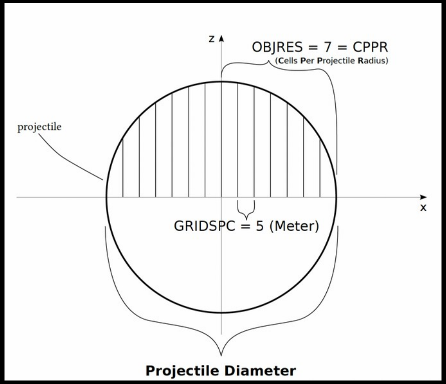


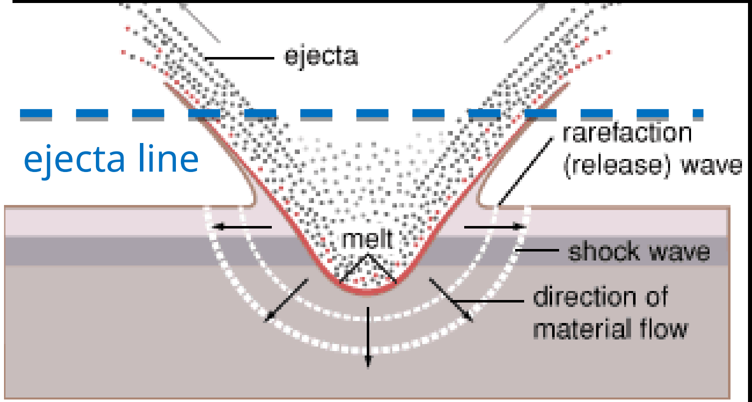
Method

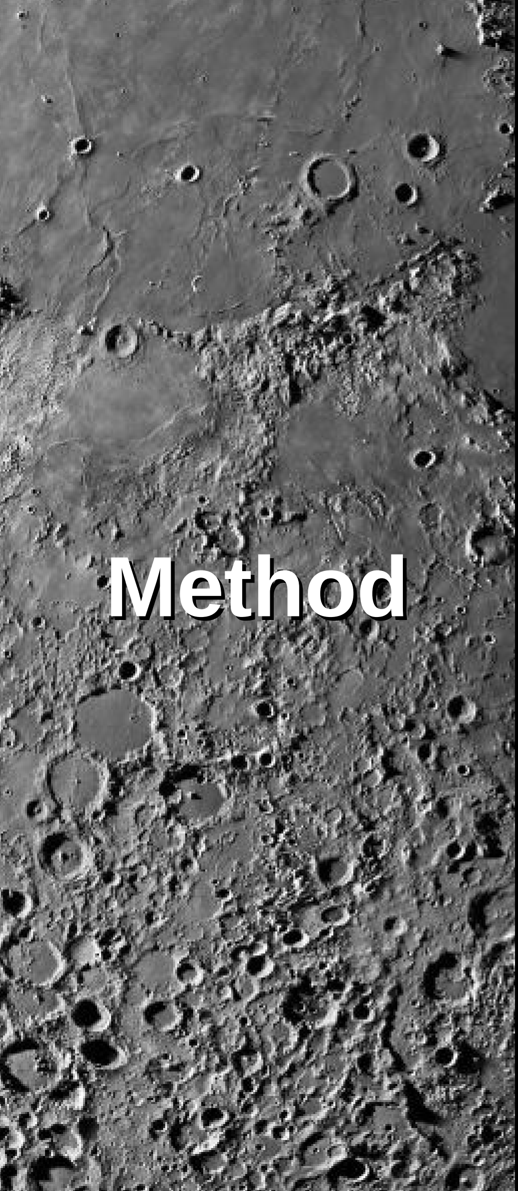
shock physics code*

* Amsden+1980; Collins+2004; Wünnemann+2006





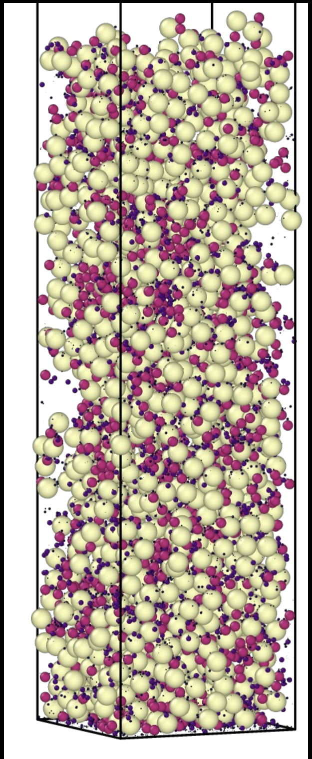


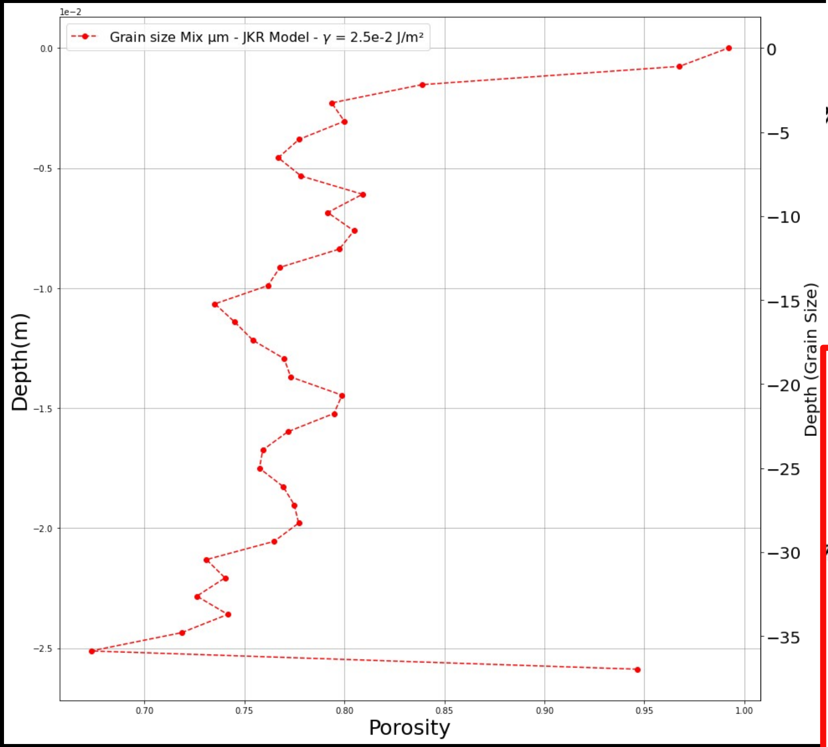


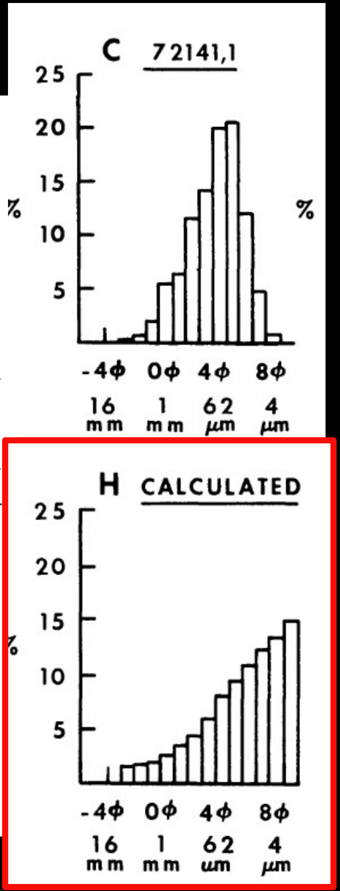
Method

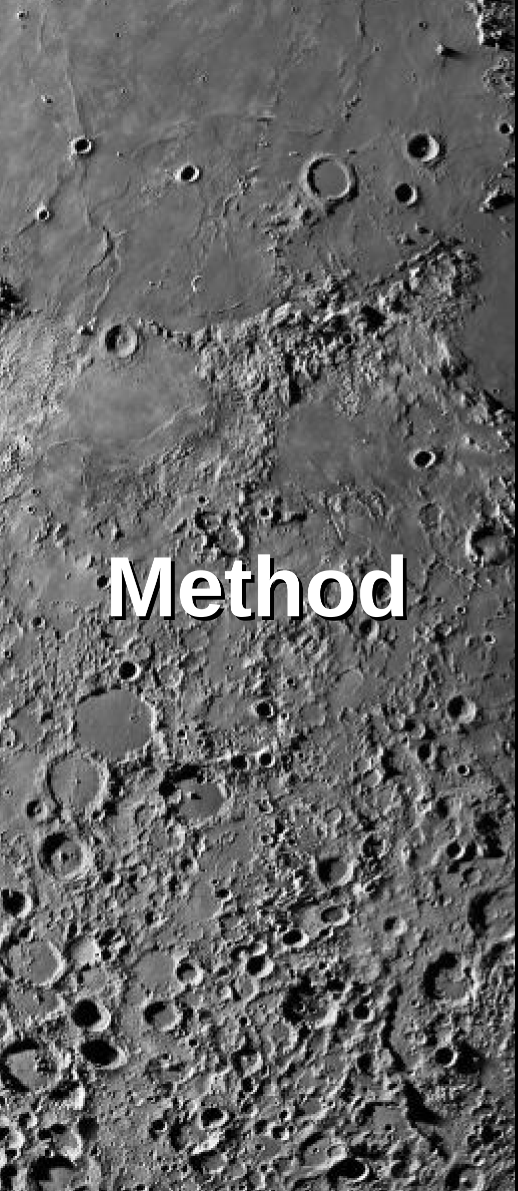
Some constraints :

- Regolith model formed with granular simulations





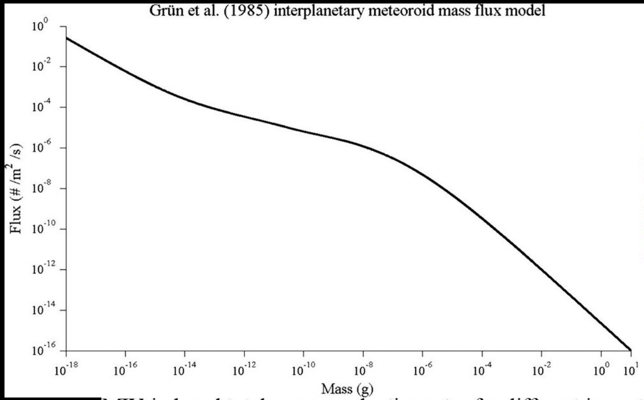


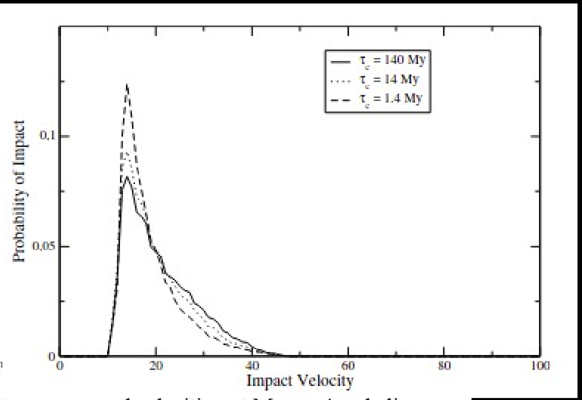


Method

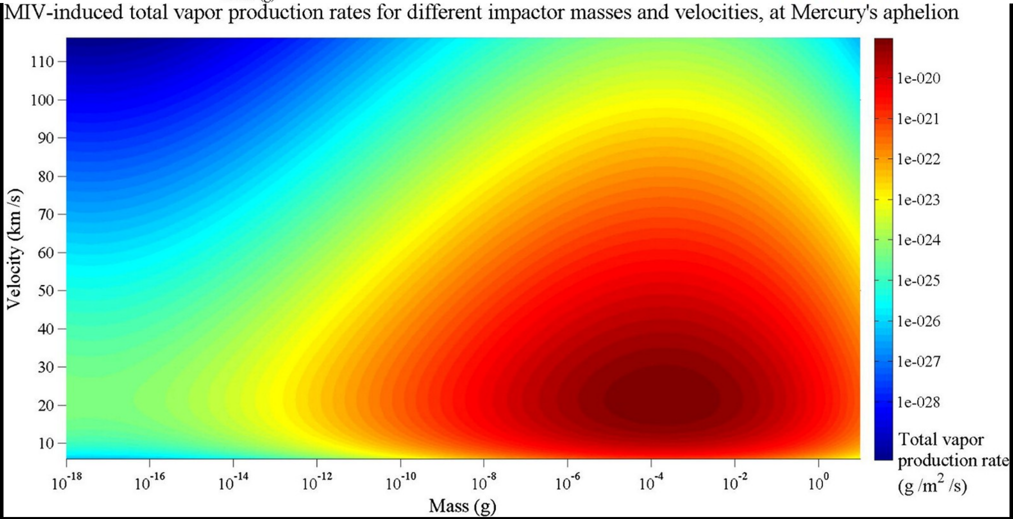
Some constraints :

- Impactor most efficient if: frequent, large, high velocity

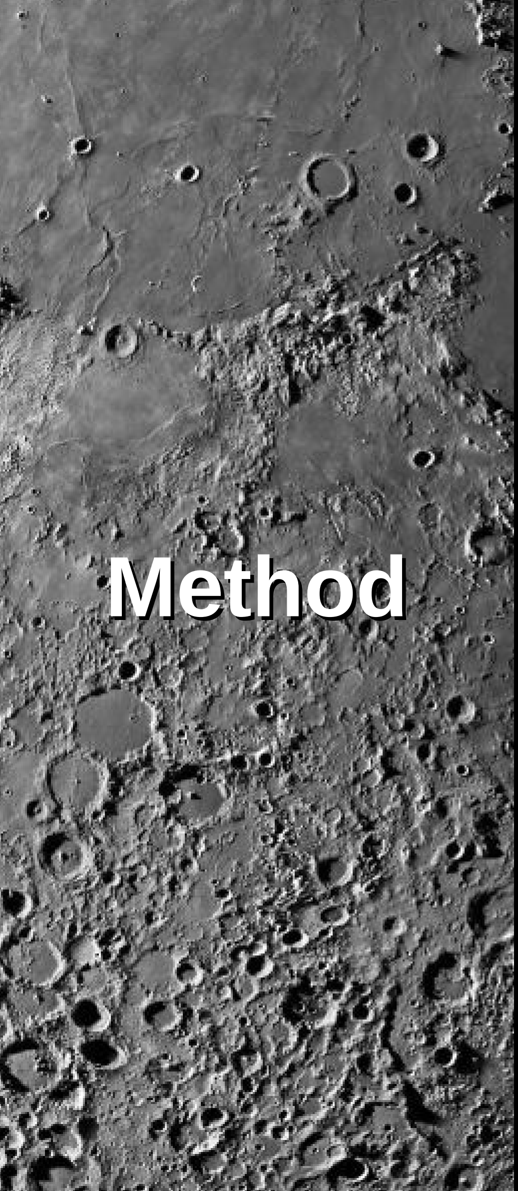




Marchi et al. 2005



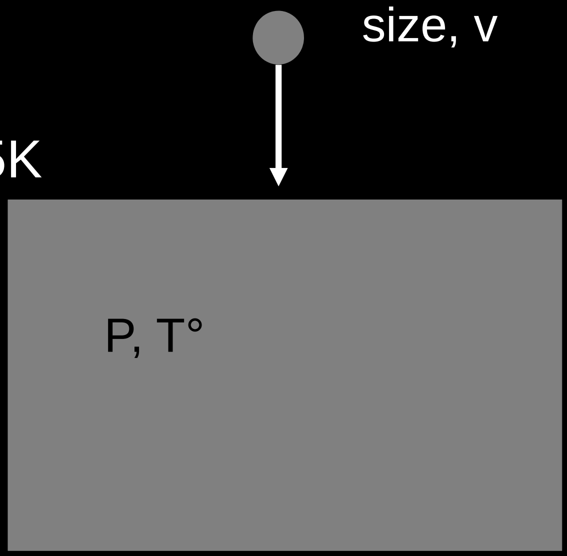
Grotheer & Livi 2013



Method

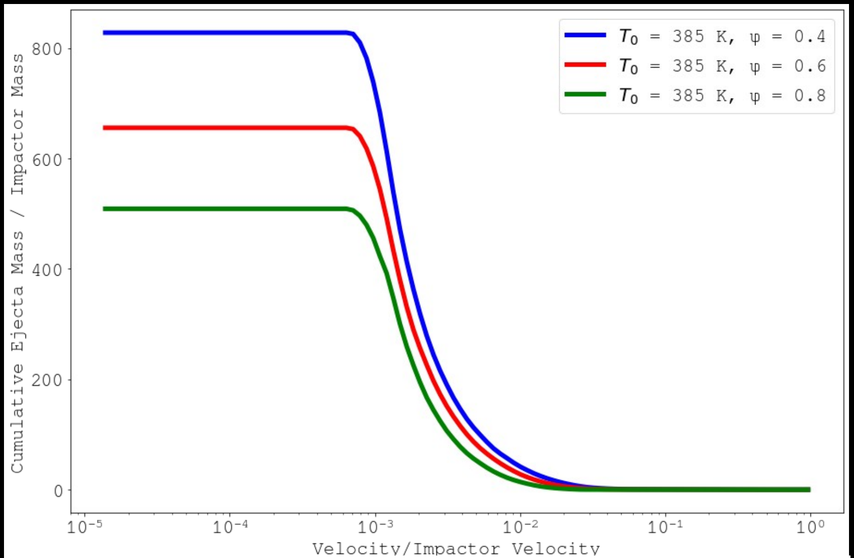
Parameters :

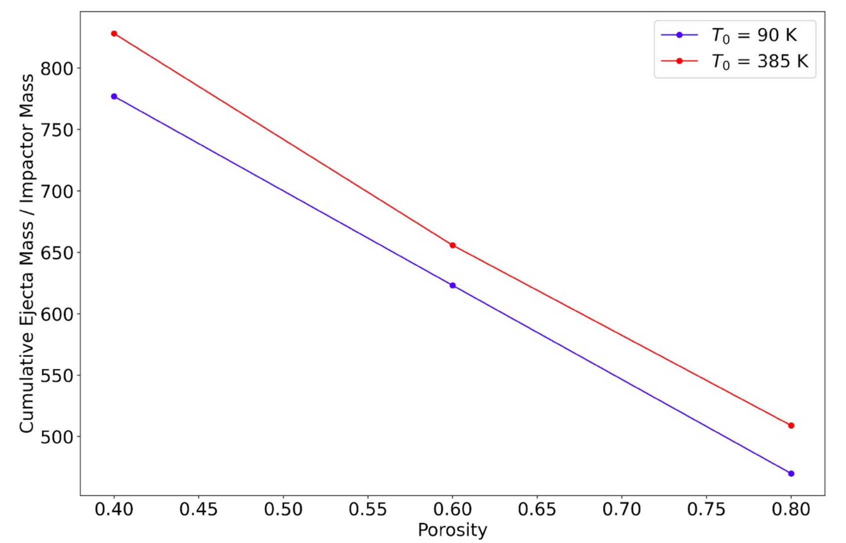
- Basaltic porous regolith (Porosity = 40% ; 60 %, 80%)
- Cohesion ~ 8.37 kPa
- Surface temperature : 90 K or 385K
- Projectile speed : 40 km/s
- Projectile size : 100 µm



Results

- Porosity affects the total ejecta (cushioning)
- Yield is much higher than what LDEX measured (factor 40 to 80)
- Higher temperatures favor larger ejecta (5-8%)
- Yield remains too high compared to LDEX





Verkercke et al. 2025

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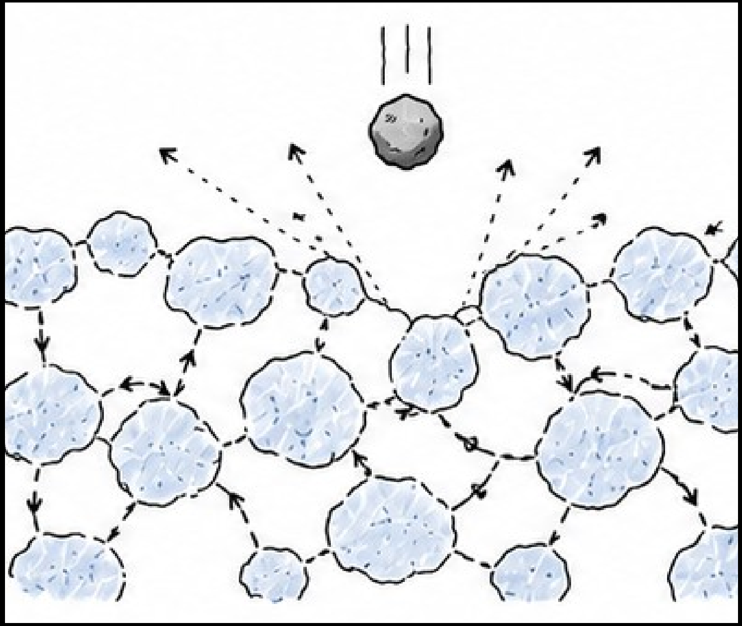
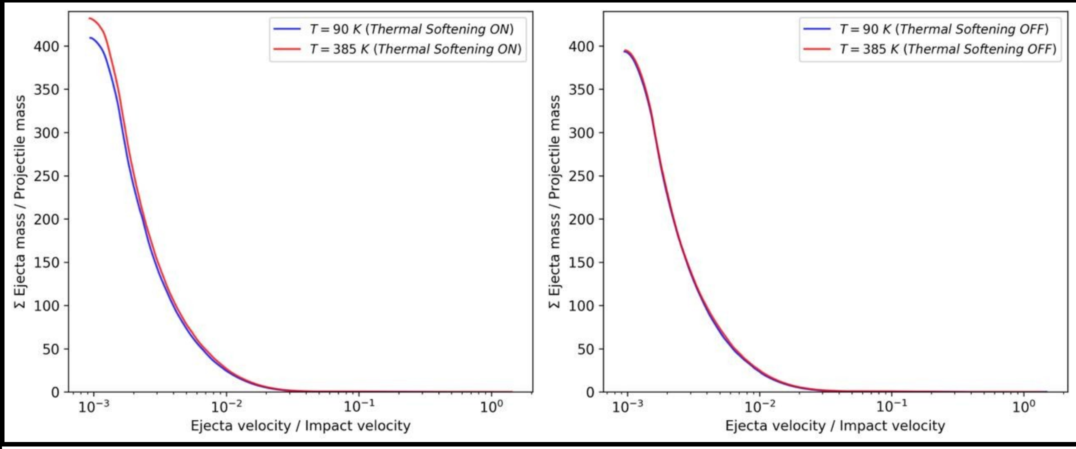


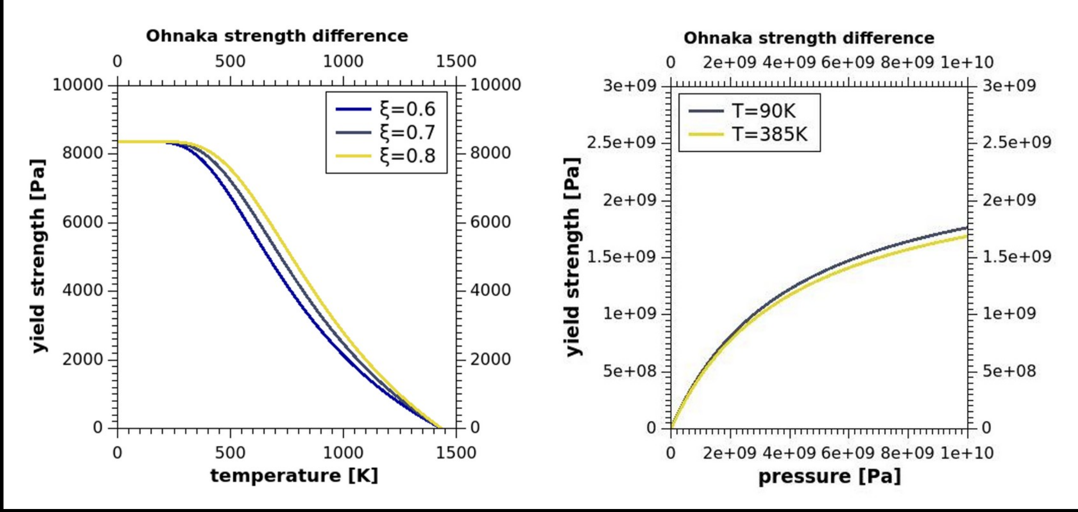
Senel et al. 2026

Results

- Thermal softening responsible for the yield difference with temperature

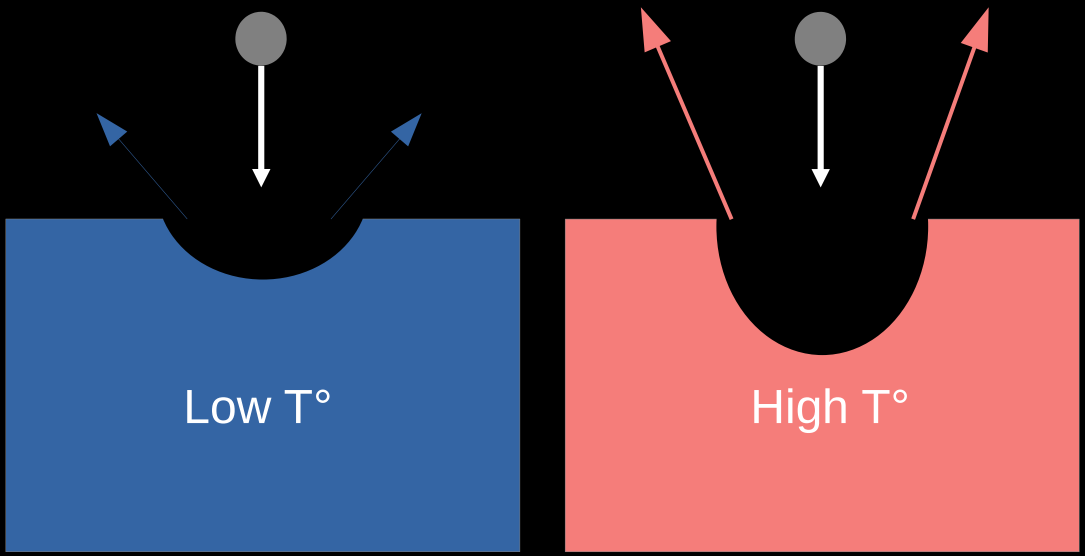
- Higher temperatures decrease the yield strength

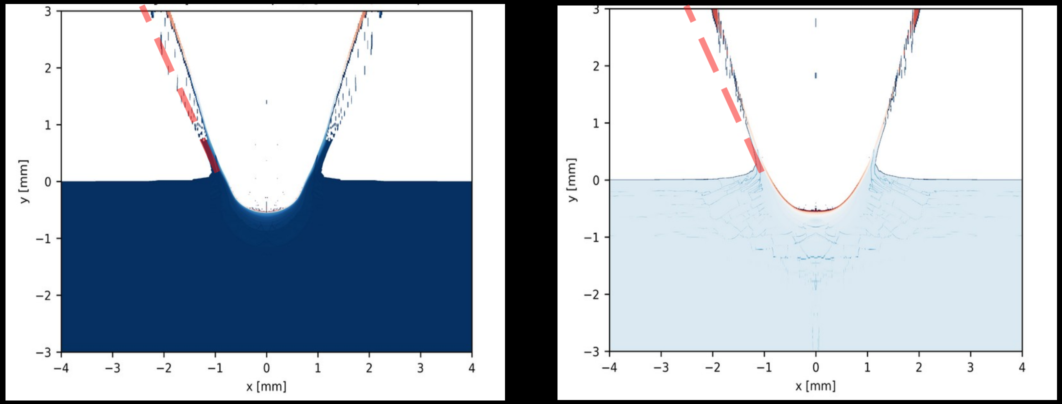




Results

- Porosity slightly affects the velocity and angular distributions of the ejecta
- Higher temperatures favor ejecta closer to the surface normal





Senel et al. 2025

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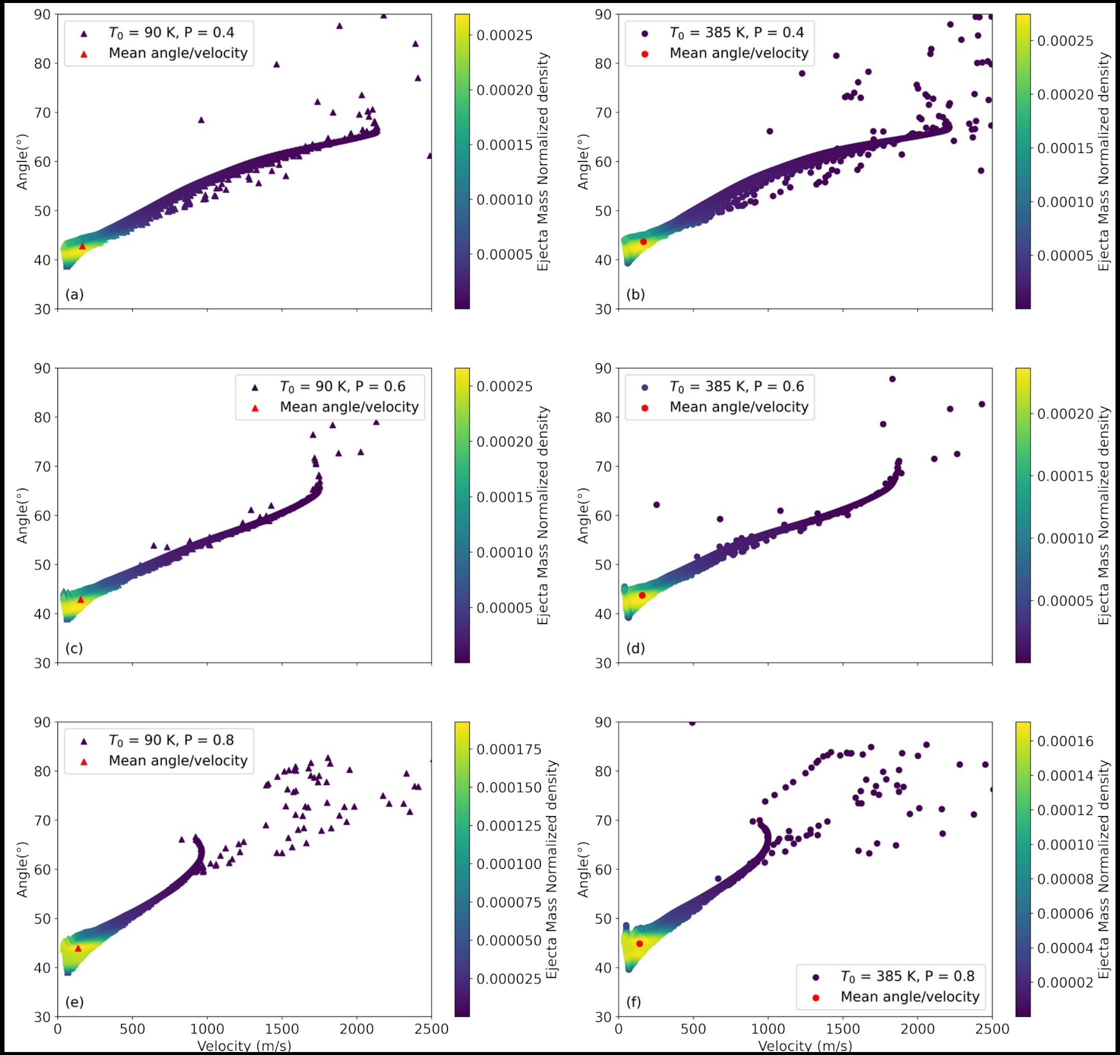
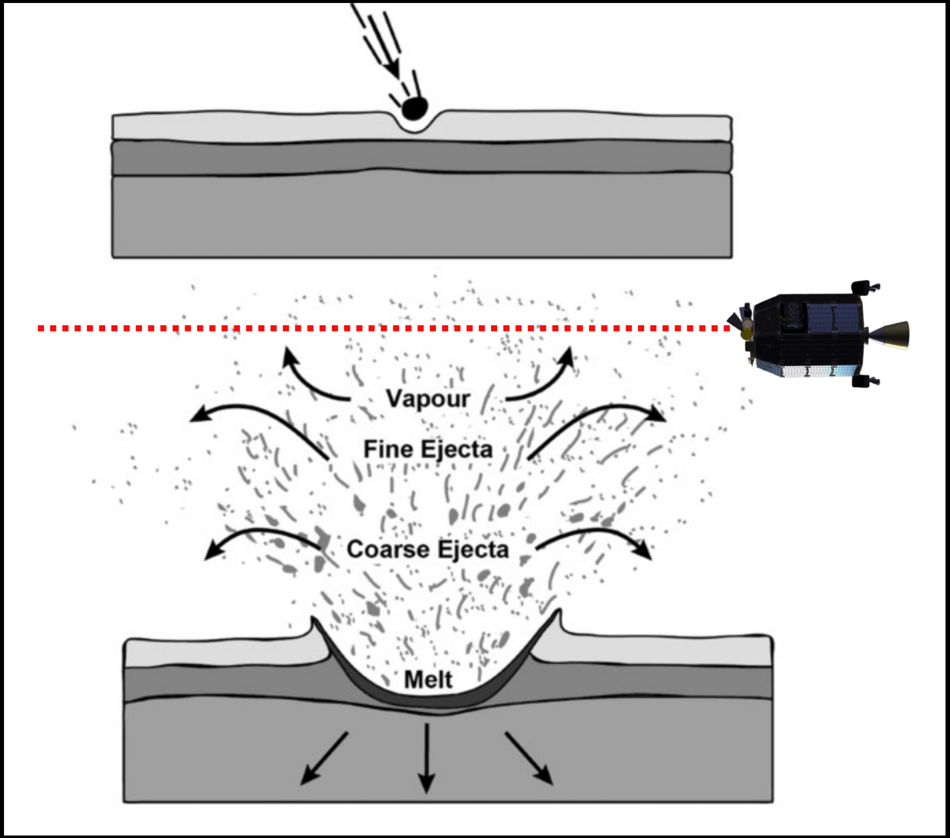
Cold | Hot



Verkercke et al. 2025

Results

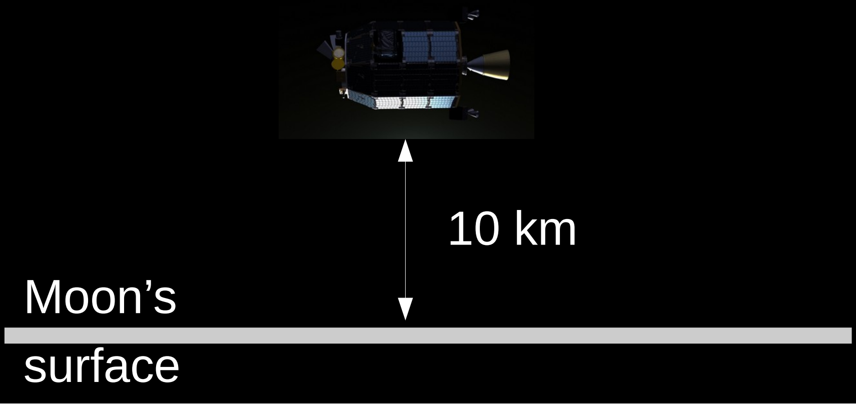
- Filtering of the ejecta by the gravity
- Fine and energetic dust goes higher
- Most of the dust is coarse and has a low velocity
- Need to account for LADEE altitude

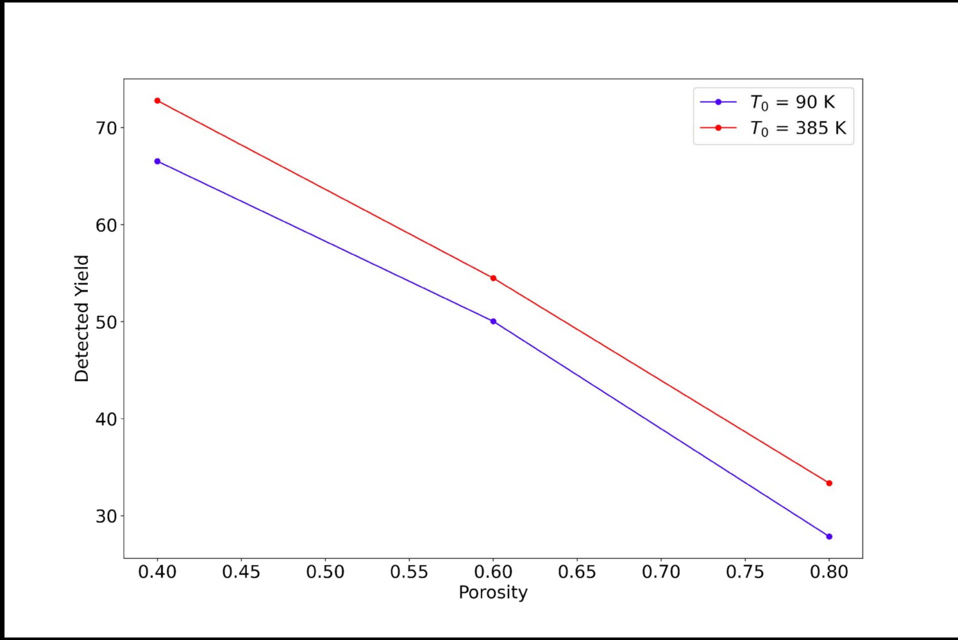


Carling et al. 2024

Results

- Most of the ejecta does not reach LADEE's orbit (95%)
- Accounting for this reconcile the model and the observation
- Difference of ~15 % between hot and cold regolith, as observed

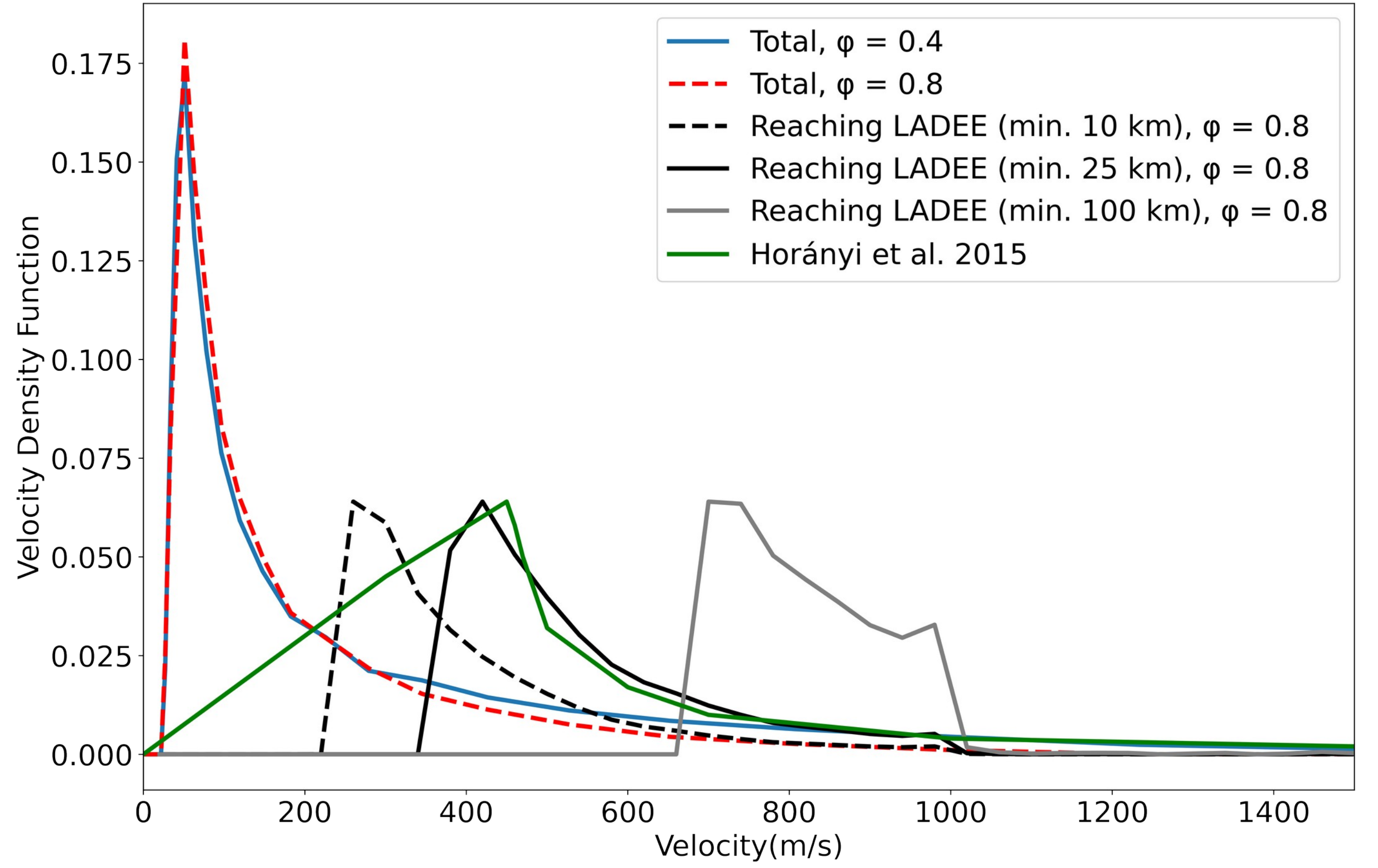




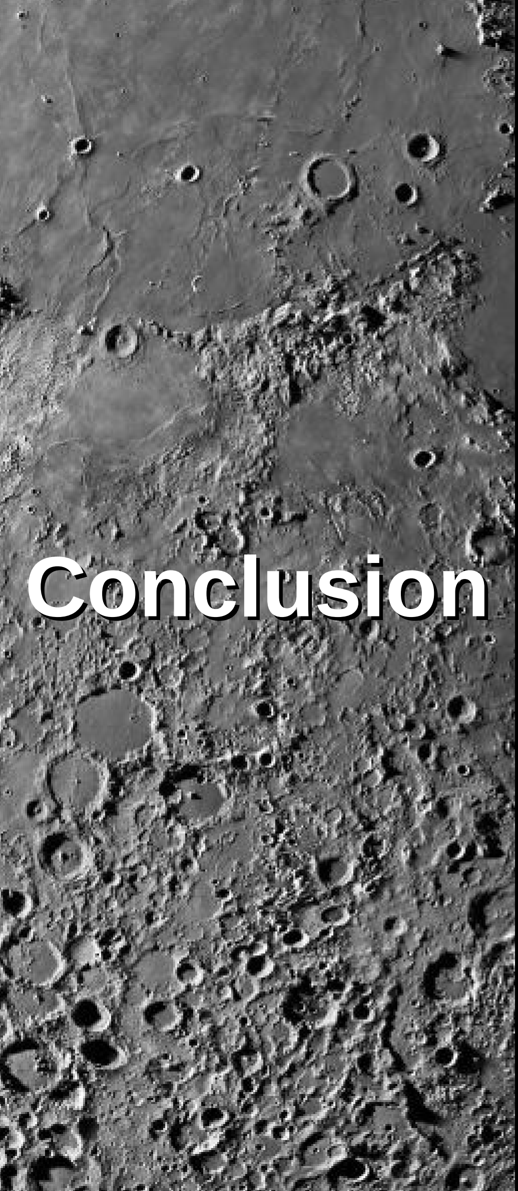
Verkercke et al. 2025

Results

Accounting for LDEX altitude also reconciles the simulated velocity distribution and the one derived from observations

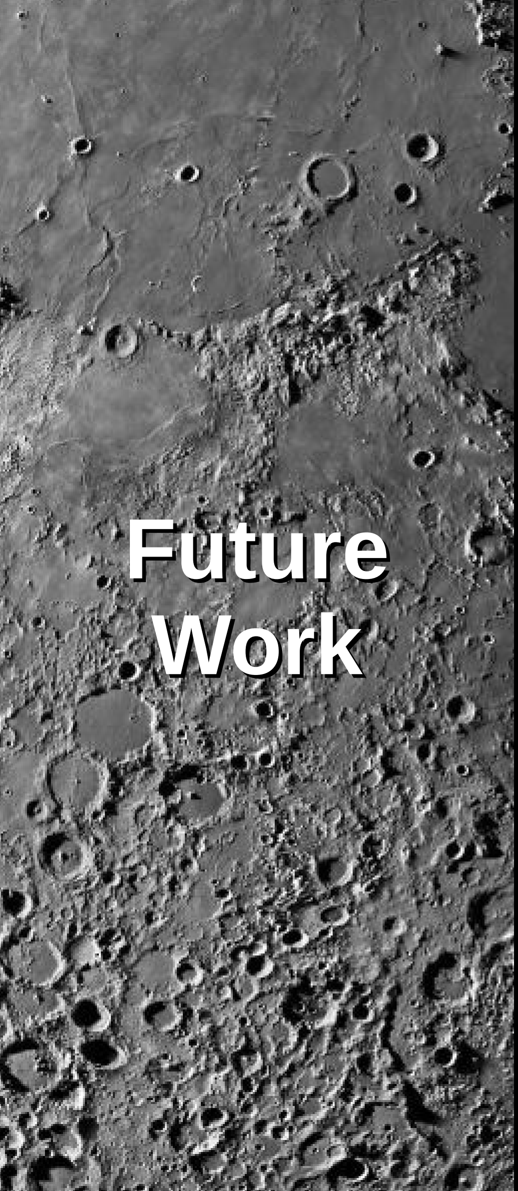


Verkercke et al. 2025



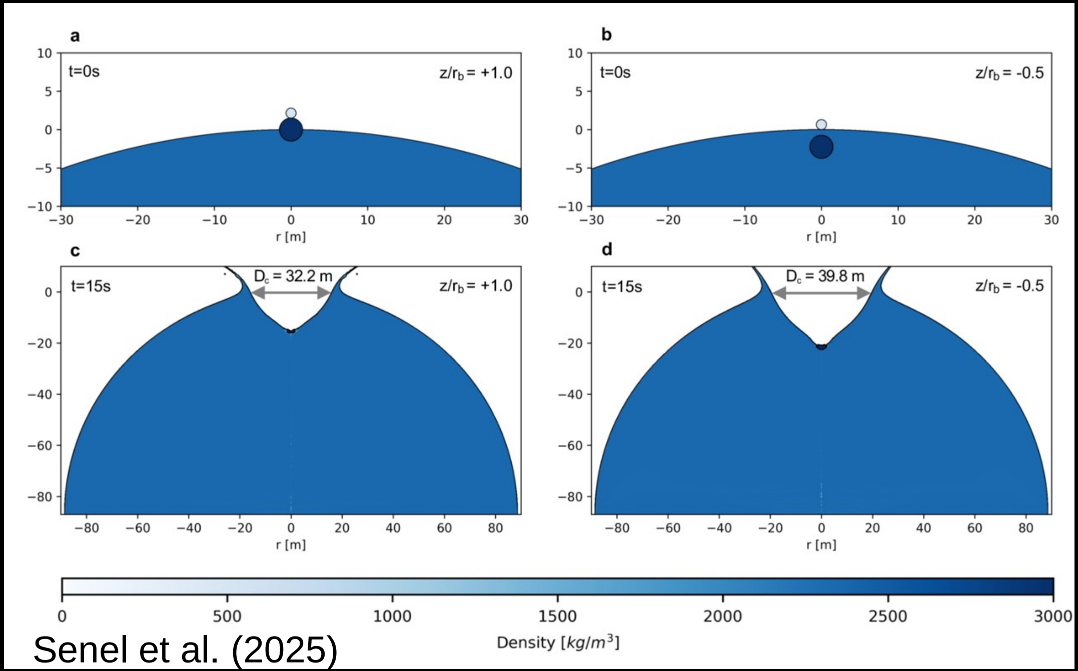
Conclusion

- Regolith’s **temperature and porosity** affect the total ejecta mass
- **Thermal softening** is the mechanism responsible for the influence of temperature on the ejecta
- Accounting for LADEE’s altitude, our model **reproduces the yield and the velocity** distribution derived from LDEX
- Measuring the ejecta can be used for an **indirect observation** of the regolith properties

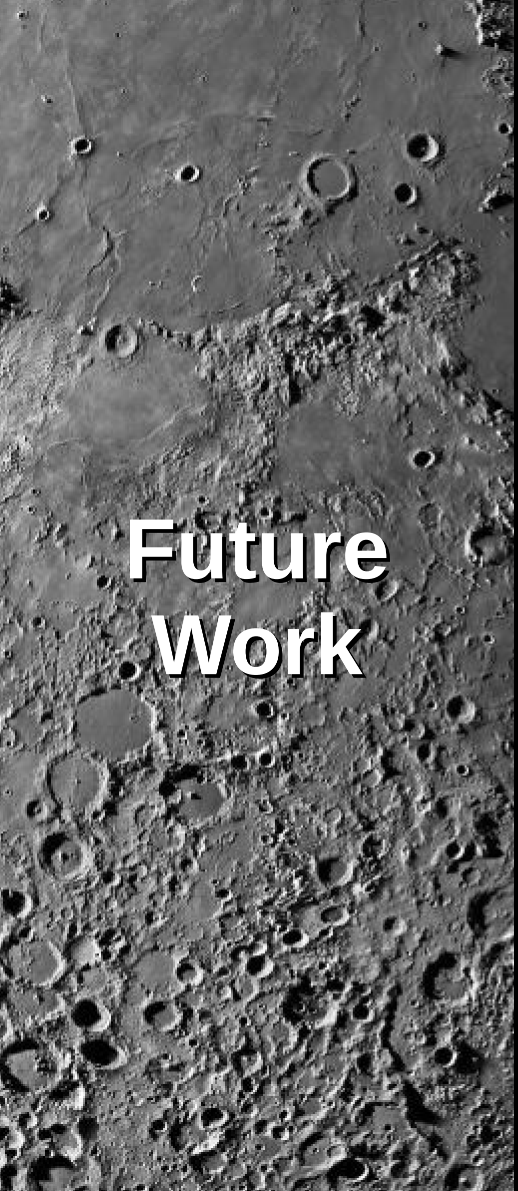


Future Work

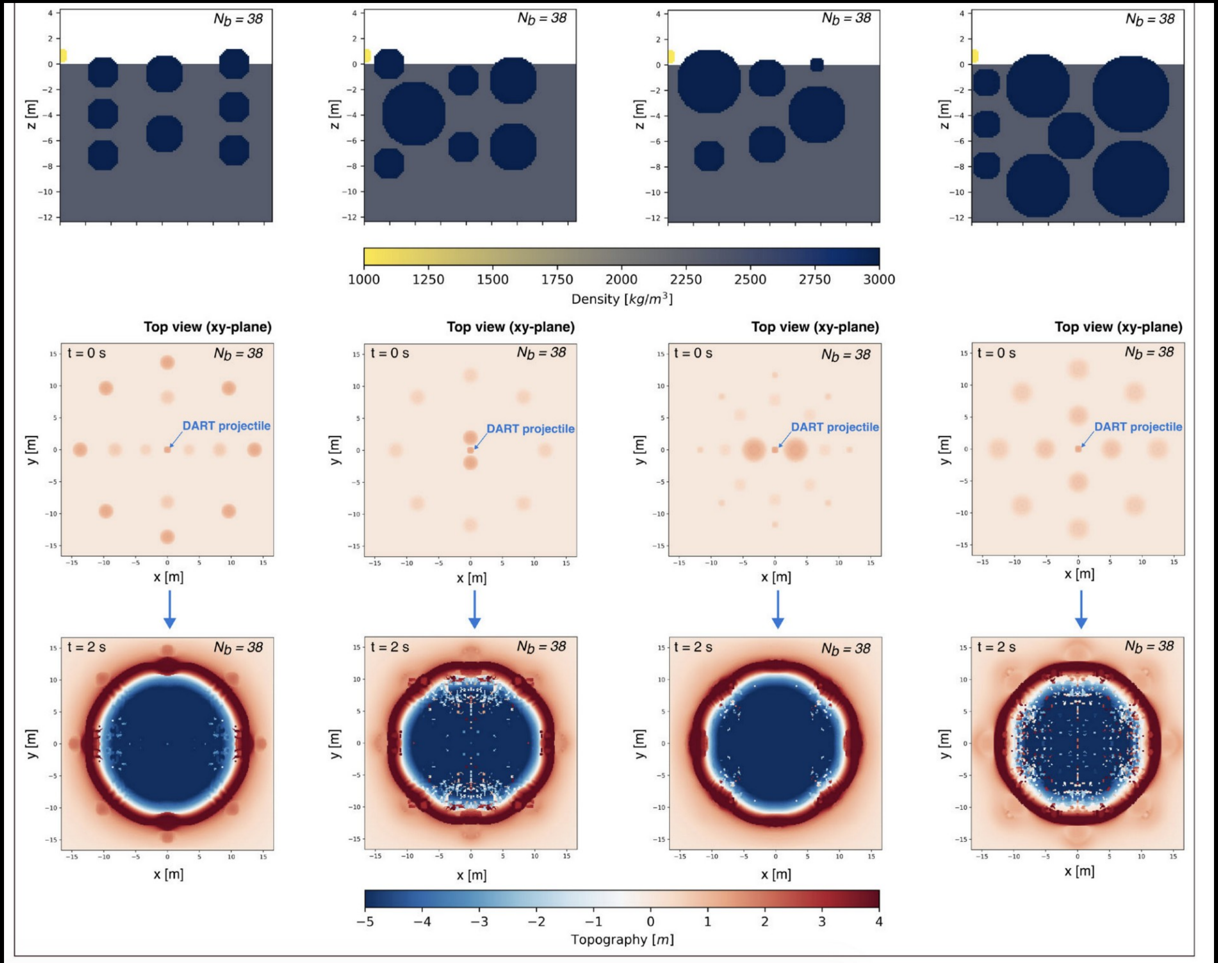
- Investigate the surface composition on the ejecta; consider topography, granular structure of the regolith, porosity profile
- Influence of impactor velocity, porosity, size, etc…
- 3D simulations for heterogeneous surface and oblique impacts



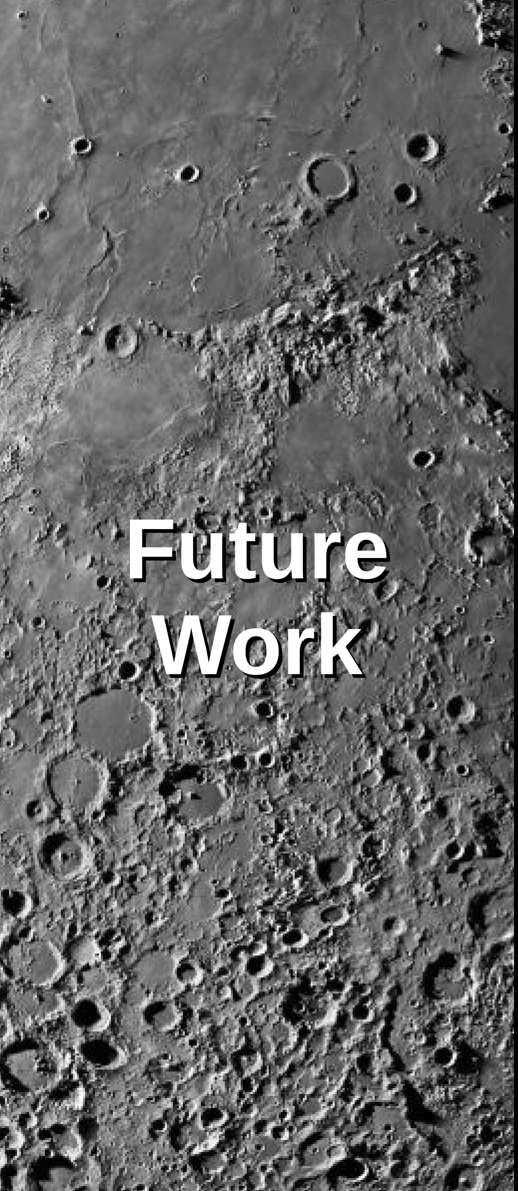
Senel et al. (2025)



- 3D simulations for heterogeneous surface



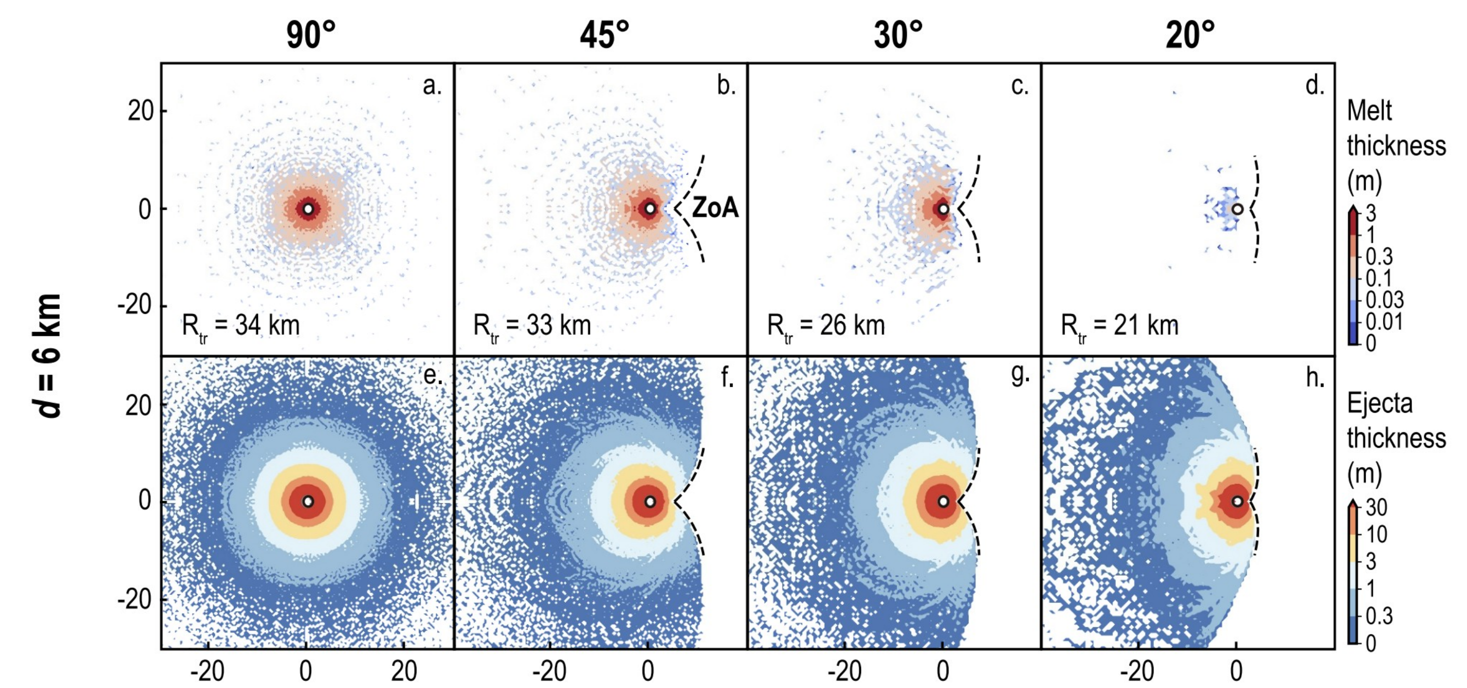
Senel et al., 2026)



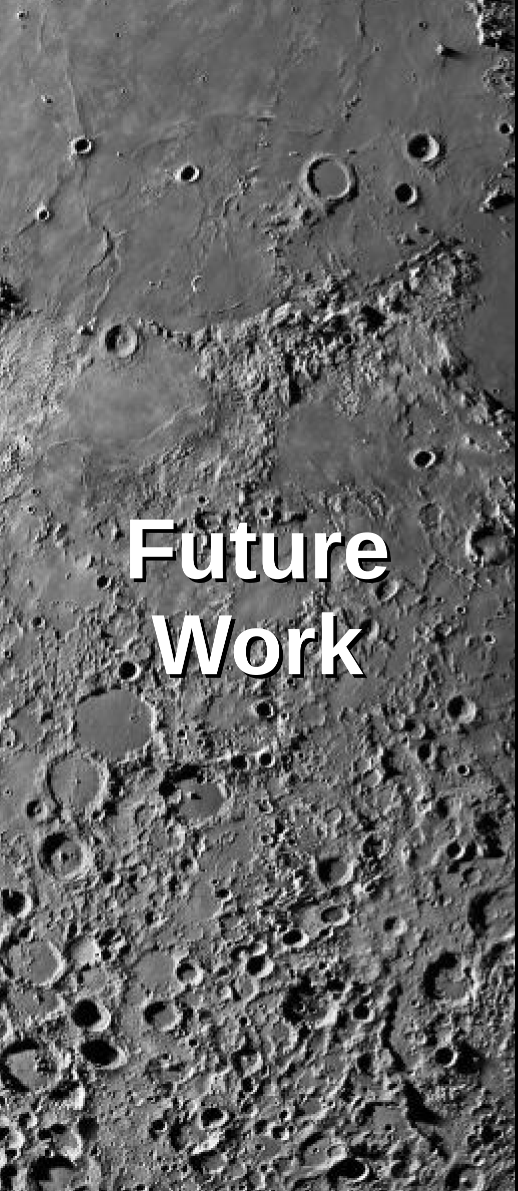
Future Work

- 3D simulations for oblique impacts

  Needs to be considered as most impacts are not normal



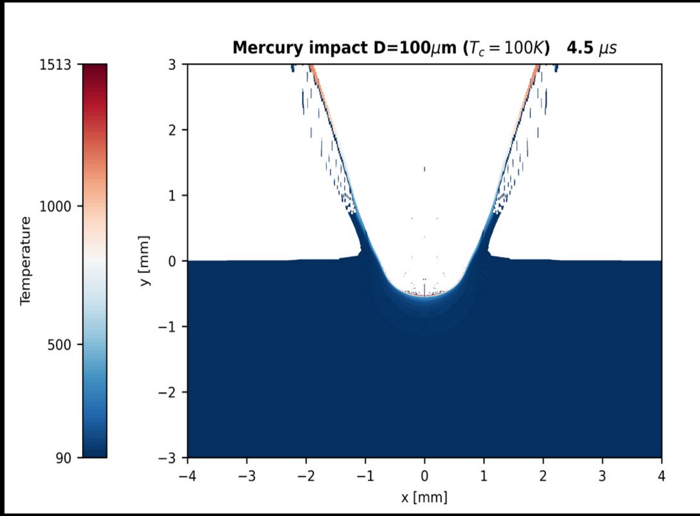
(Luo et al., 2025)



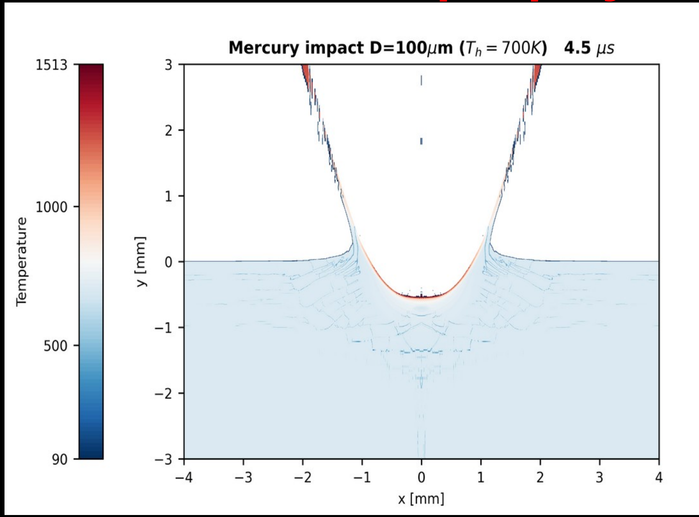
Future Work

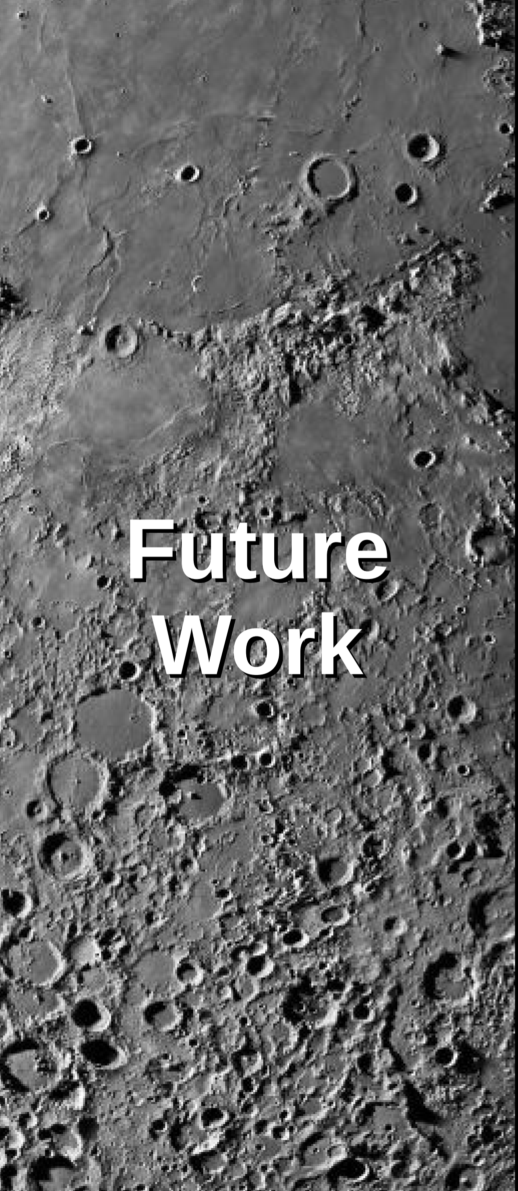
- Crater's size changes depending on the surface T°
- Affects the local microstructure of the regolith
- Contributes to the overturn of the regolith
- Higher excavation can lead to higher vaporization for the exosphere
- Limits the surface alteration caused by the SW

COLD surface – 100 μm projectile



HOT surface – 100 μm projectile

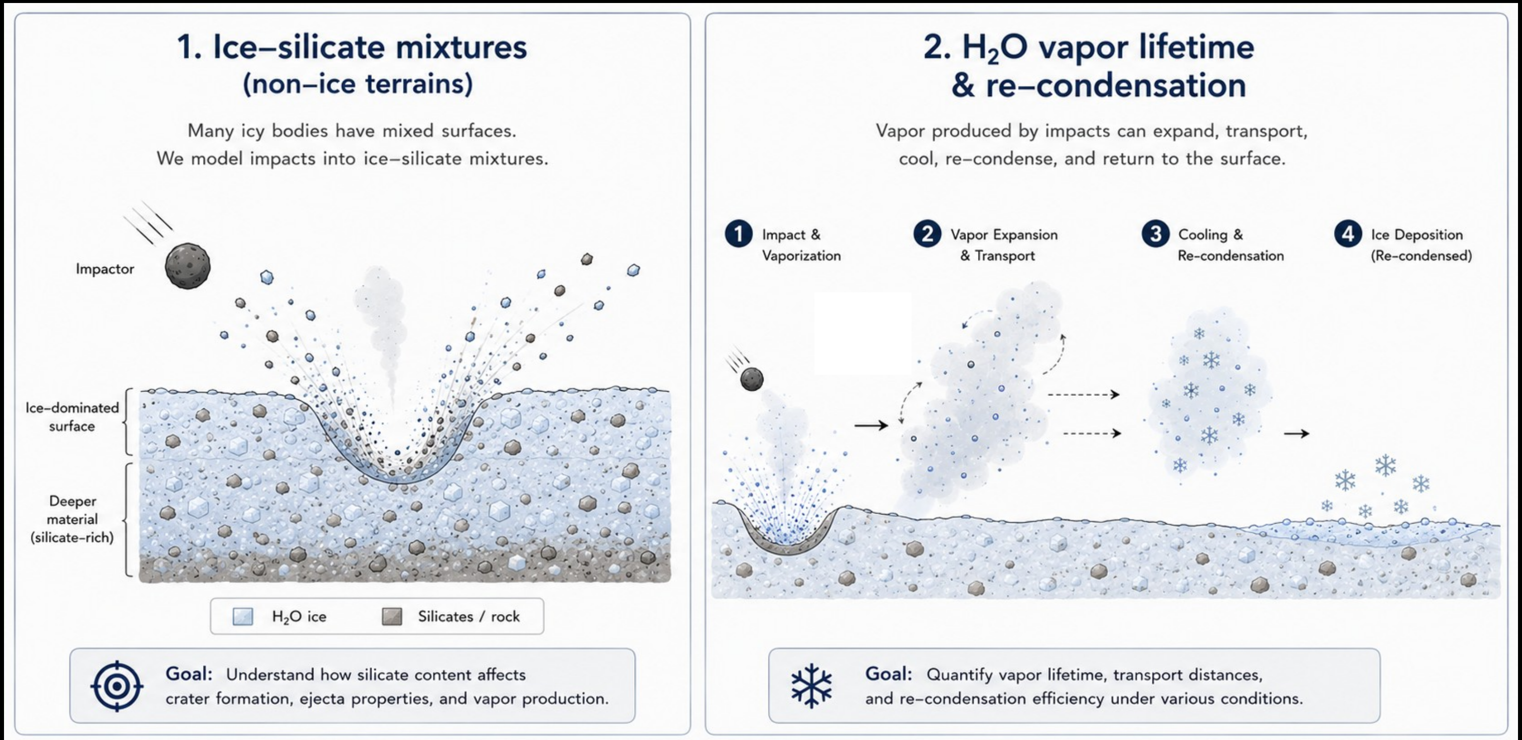


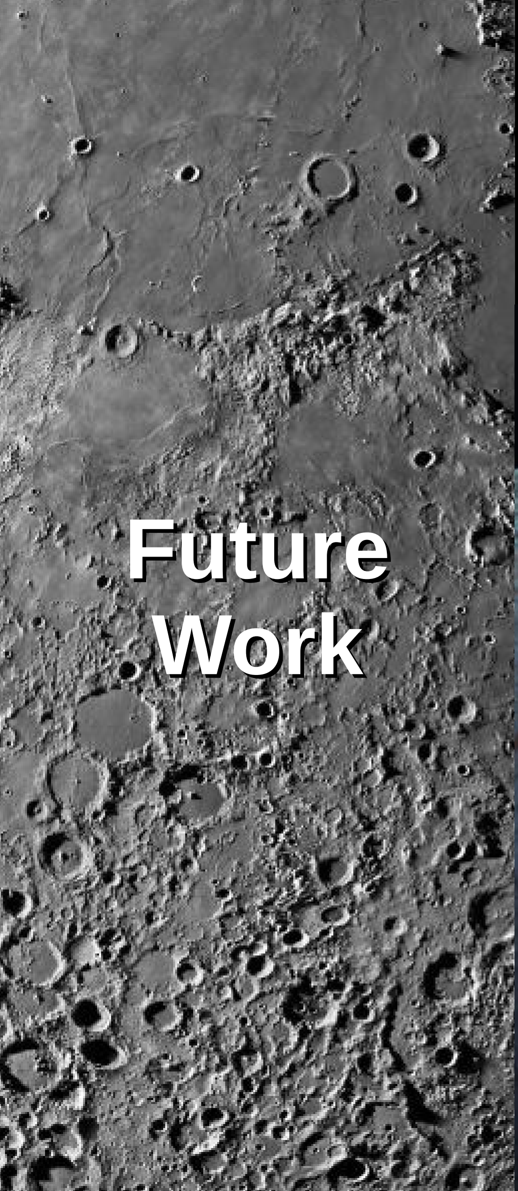


Future Work

- Heterogeneity in the surface composition (ice - silicate)

  Present at Moon (craters) and on Jovians moons

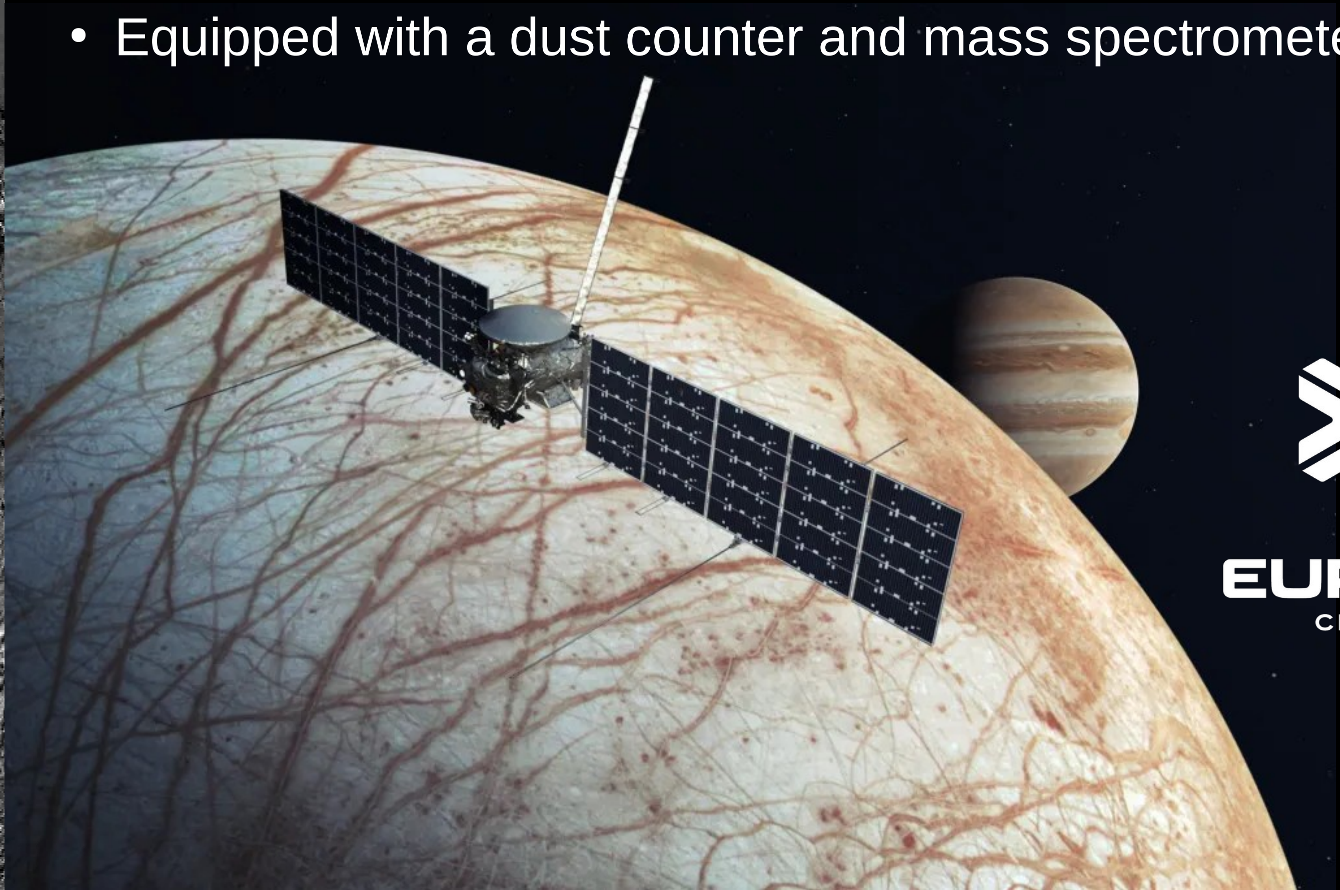




Future Work

- Needed for the preparation of the Europa Clipper NASA mission

- Equipped with a dust counter and mass spectrometer !



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Thank you