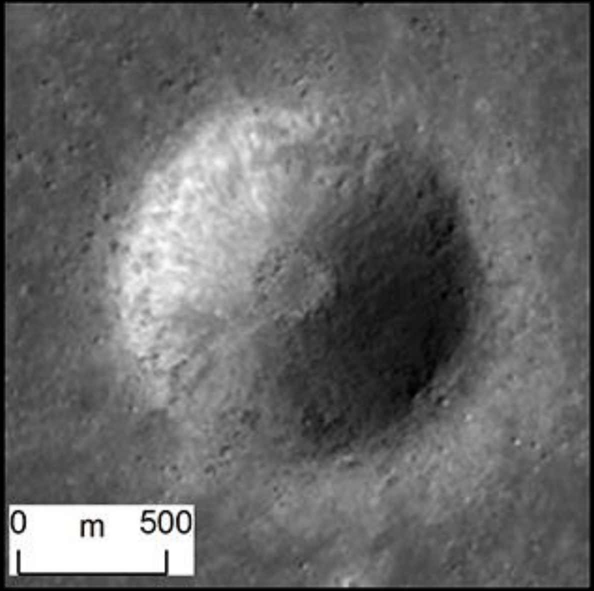
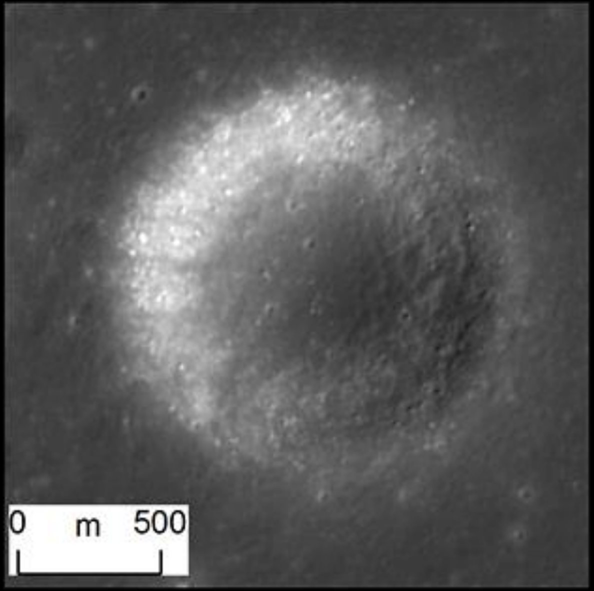
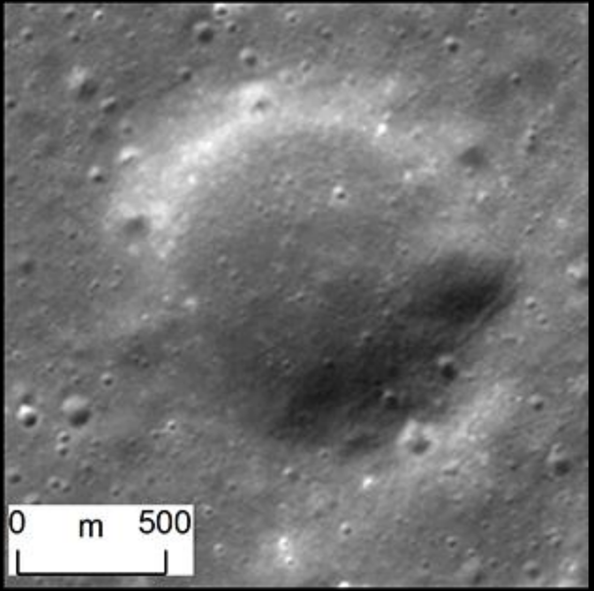
Using Measurements of Topography to Infer Rates of Crater Degradation and Surface Evolution on the Moon and Mercury



Fresh Crater
T~0.01 Ga



Moderately Degraded
T~3 Ga



Very Degraded
T~3.7 Ga

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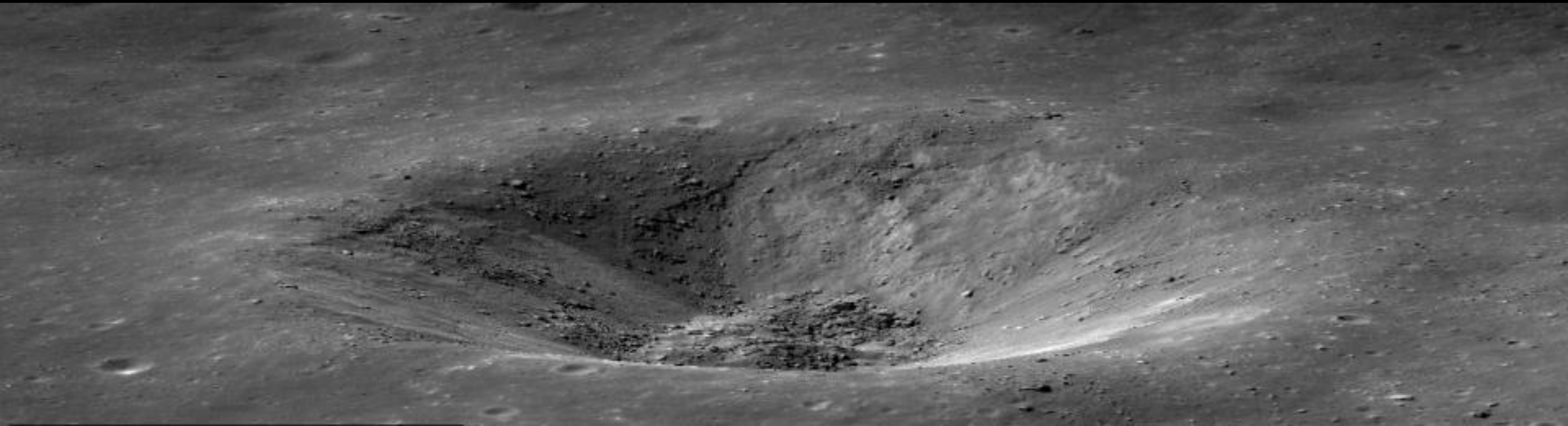
December 12, 2017

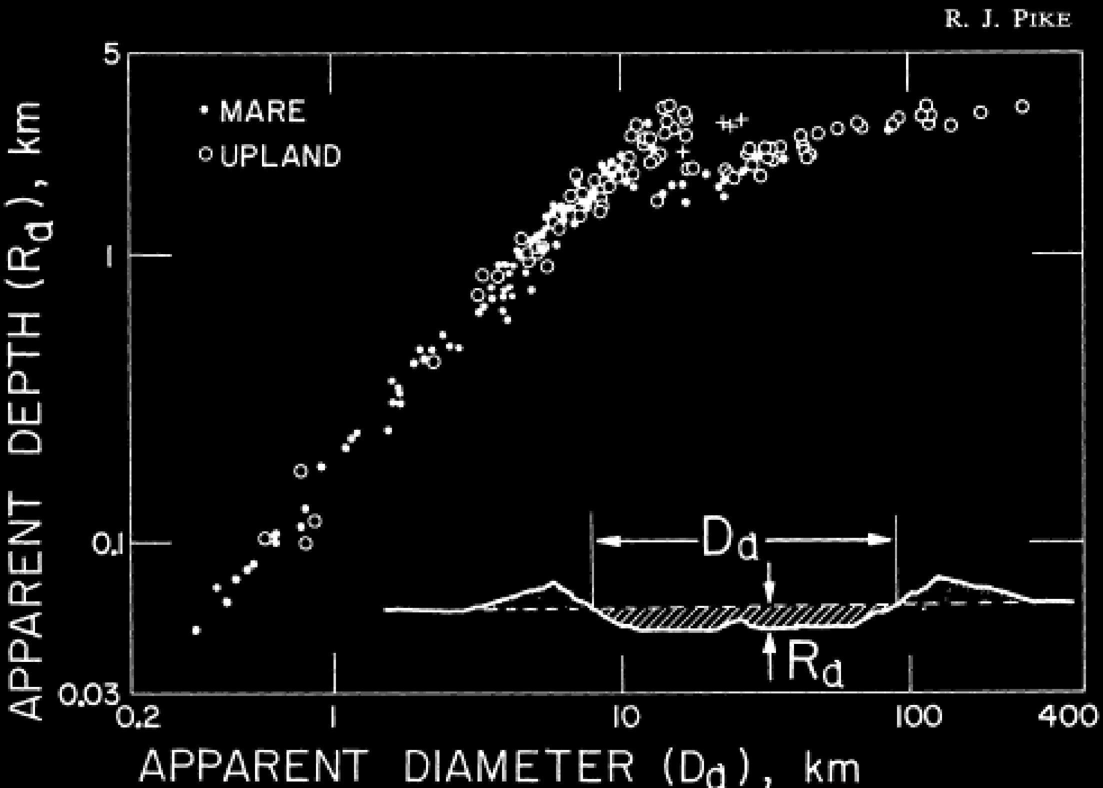
Motivating questions

1. How does the topography of airless bodies evolve?
2. What is the relative rate on the Moon and Mercury?
3. Can we constrain the age of features and units from their topography?

LROC NAC Synthetic Perspective of North Ray Crater (50 My old)

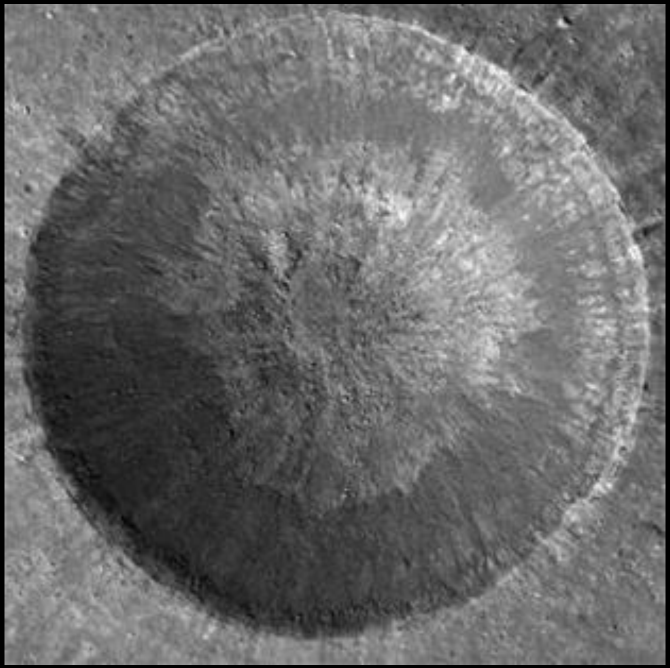


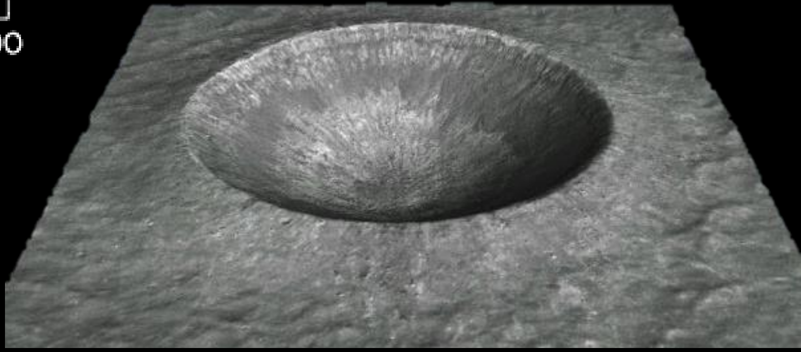
Background: Simple craters have a known and self-similar initial form



Pike 1977: d/D of fresh craters is ~0.2.

Note: New LROC papers (Daubar, Mahanti, Stopar) have updated d/D for craters <200-400 m.



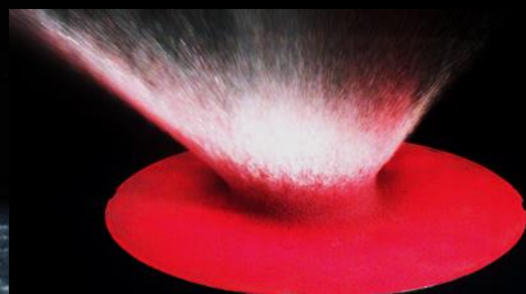


Linné Crater, 2.2 km diameter (LROC; Garvin et al., 2011)

Background: Diffusion and Cratering

"…[impact cratering] is analogous, but generally at a larger scale, to the effect of a raindrop …"

Alan Howard, 2007 (Geomorphology)



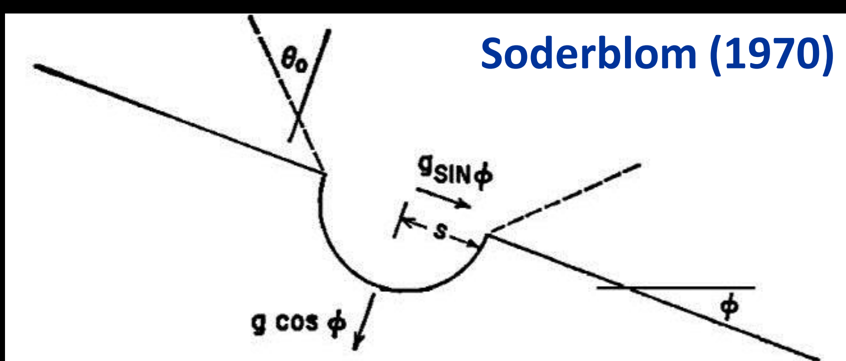
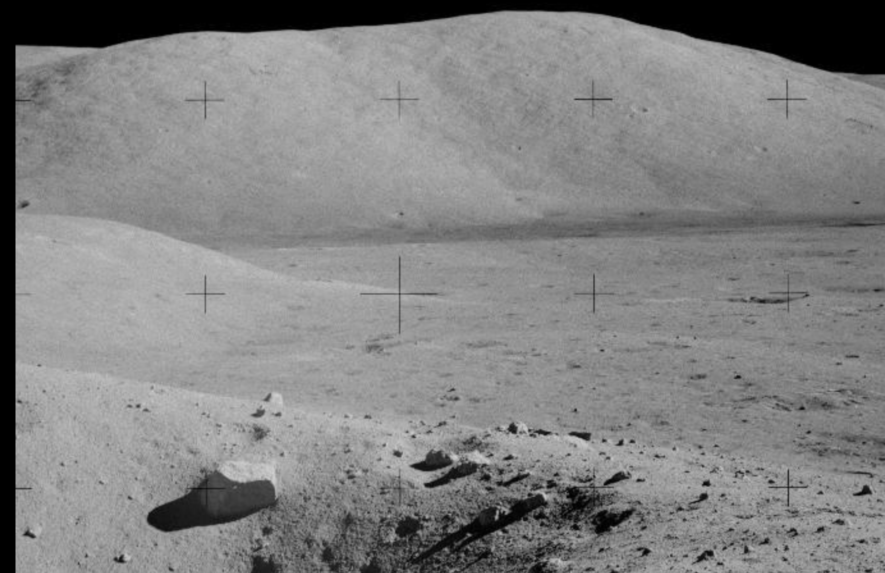


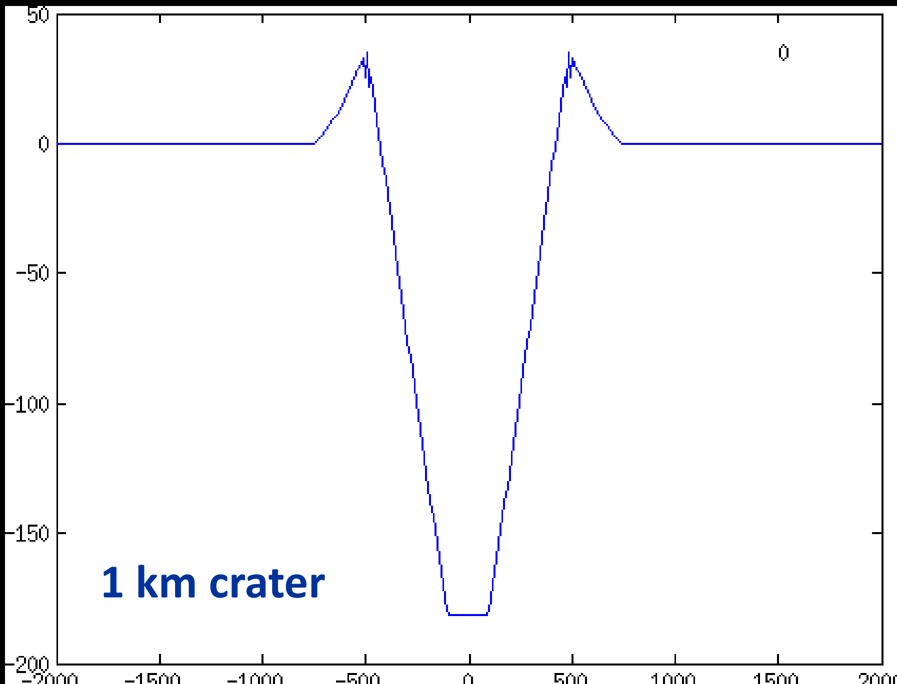
Fig. 2. The geometry of the ejecta trajectories of a crater eroding a surface with slope Φ.



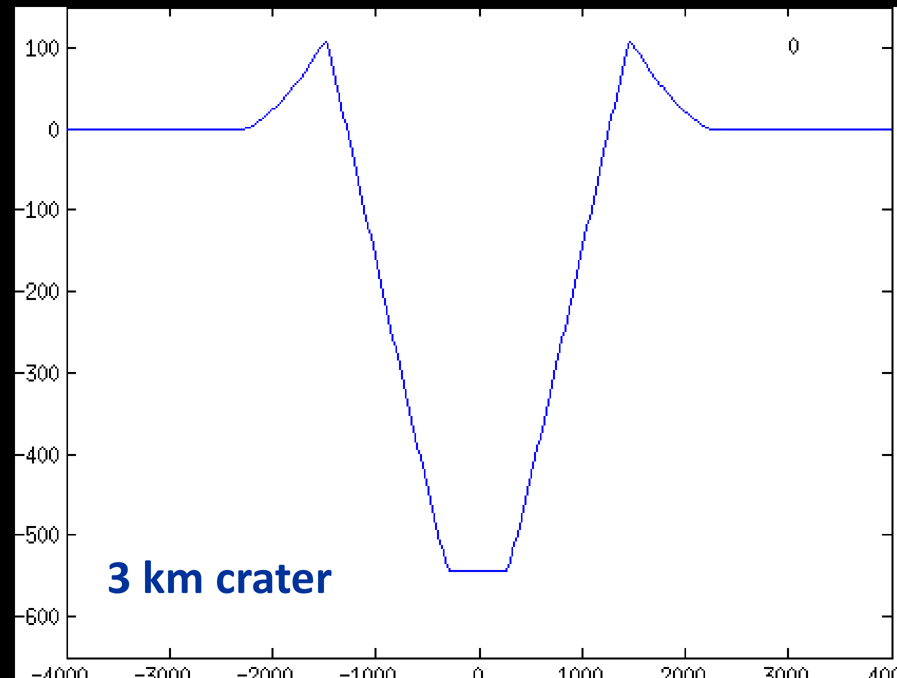
North Massif, Apollo 17

Topographic Diffusion & Crater Degradation

Elevation (m)



Distance (m)



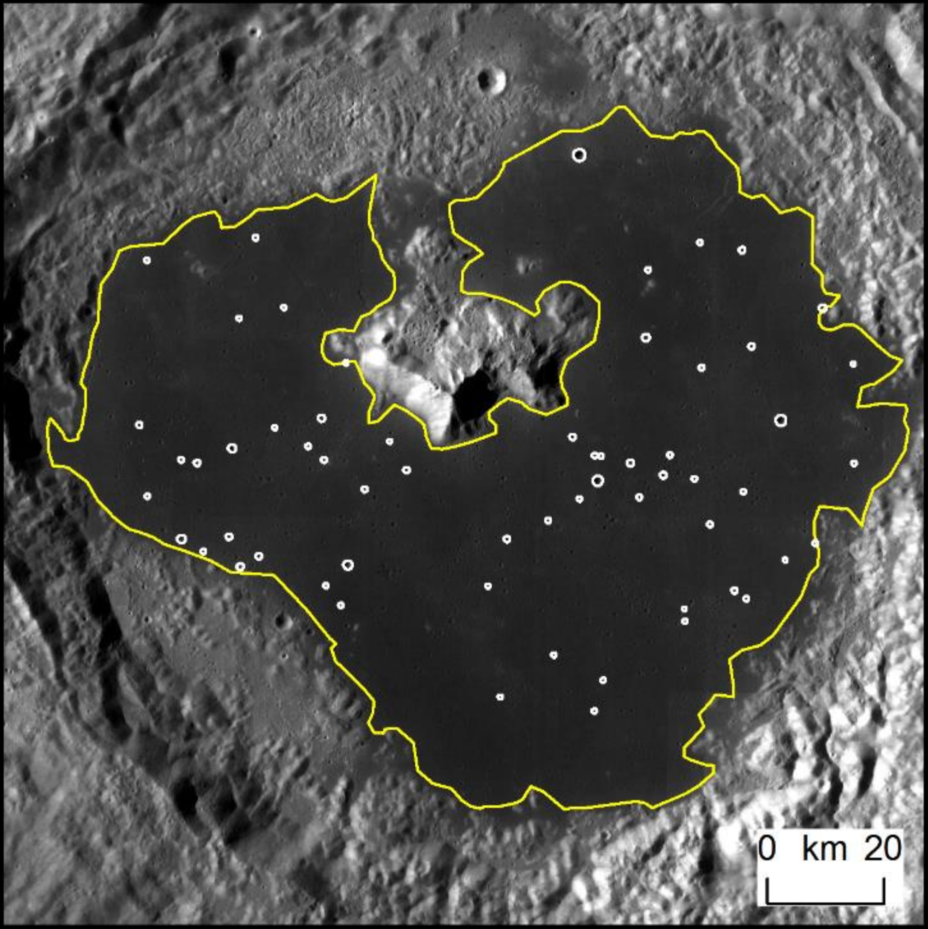
Distance (m)

Topographic evolution of elevation field *h*, with diffusivity *κ*:

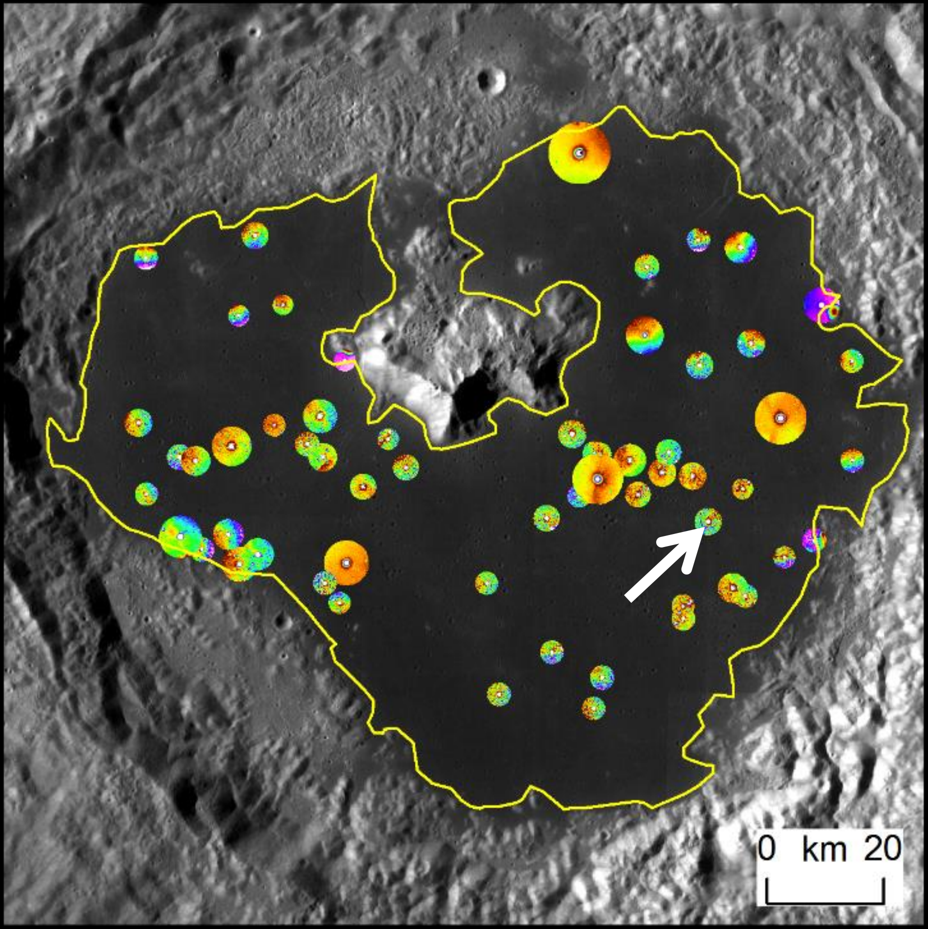
$$\frac{\partial h}{\partial t} = \kappa \nabla^2 h$$

Methodology and Data Analysis

Map all craters *D*=800m to 5 km

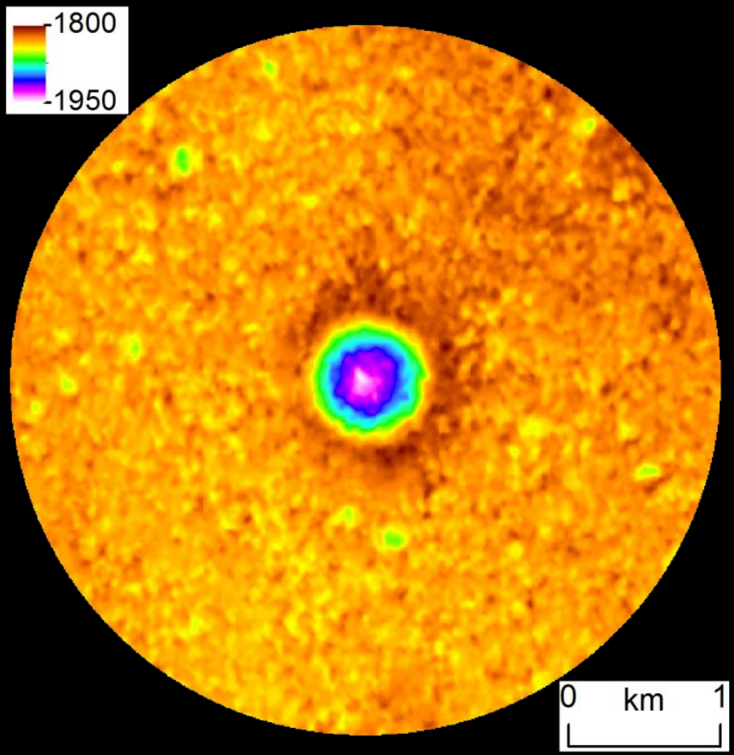


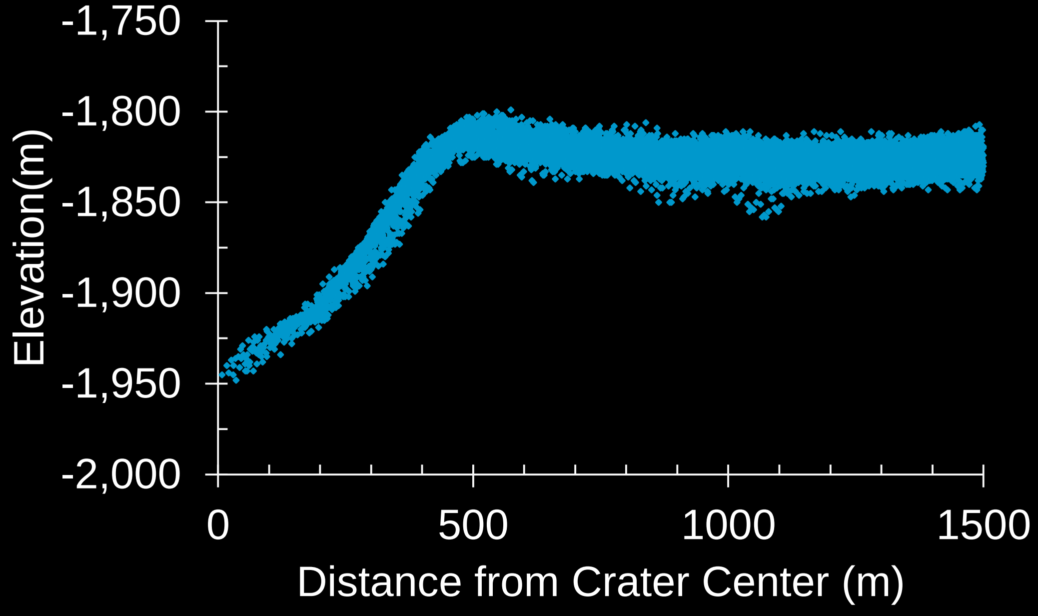
Extract topography for each crater



Mare inside Tsiolkovsky Crater

Methodology and Data Analysis

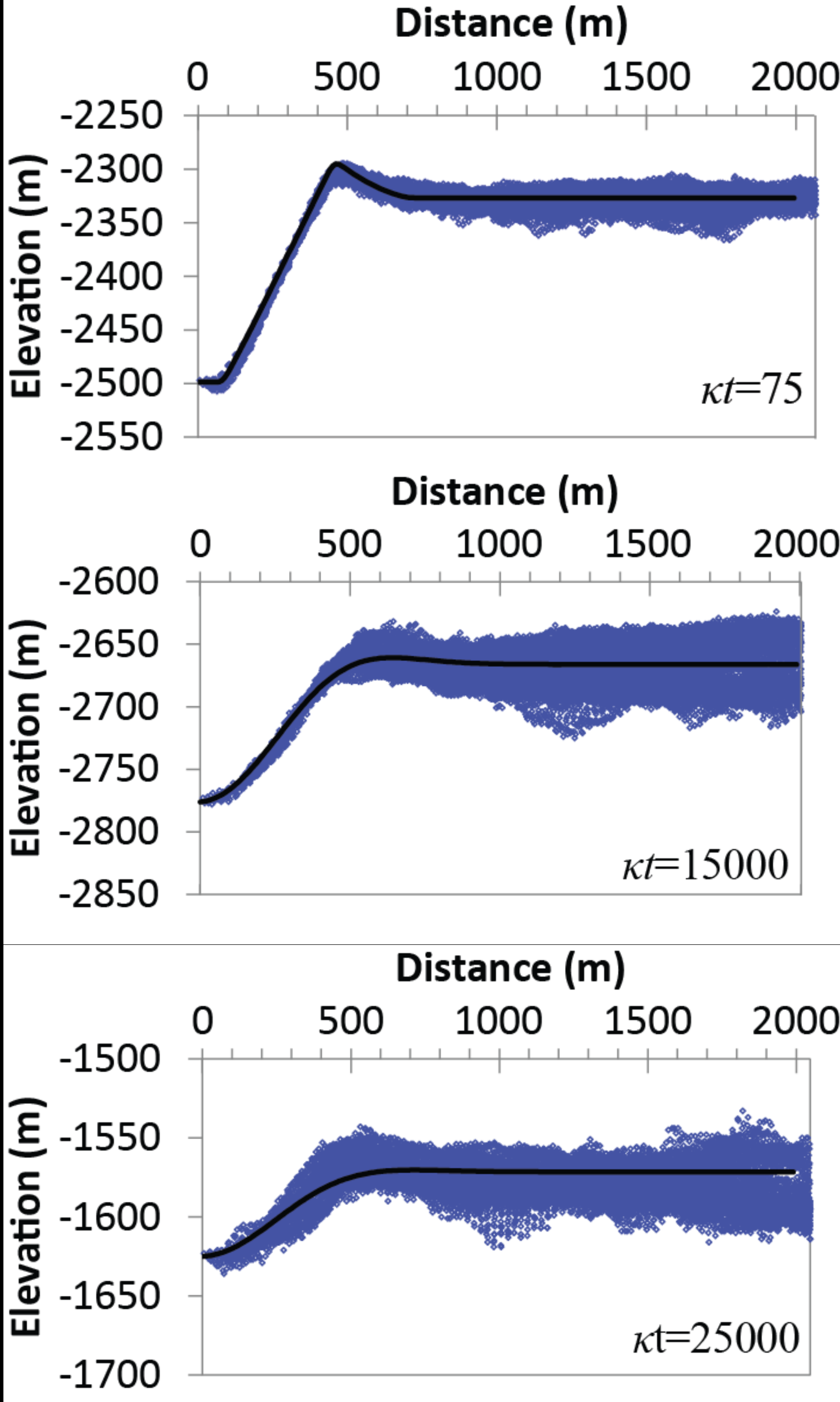




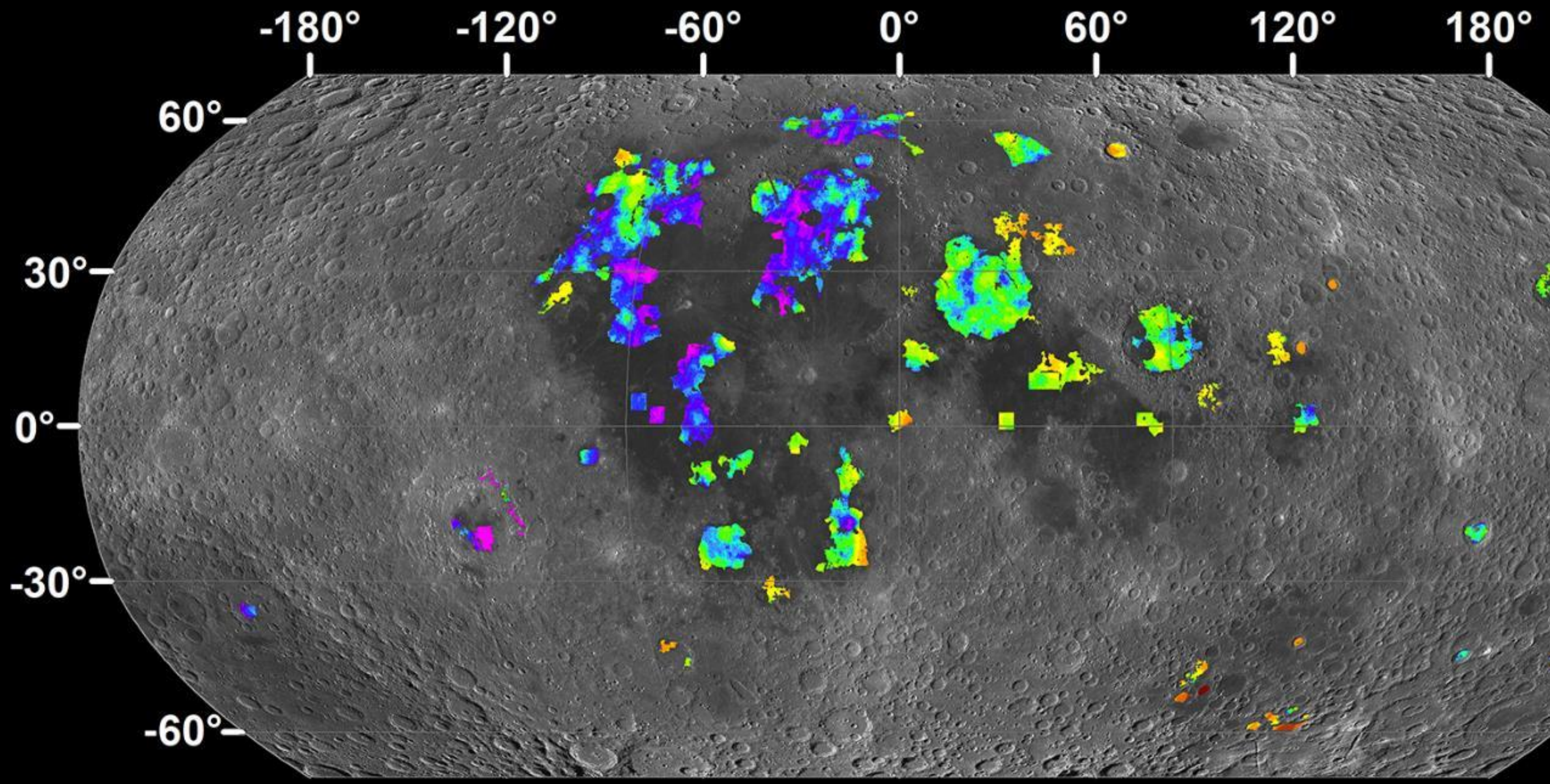
Data extracted with Terrain Camera (TC) stereo dtm (~7 m/px).
Results from LOLA are agree, though sparse sampling is a challenge.

Fitting Diffusion Profiles

- Mapped, extracted topography, and fit diffusion profiles (in 2D) for 13514 craters on the Moon.
- Solve for three parameters:
  - H_0: "zero value" for surrounding elevation
  - D_0: initial diameter
  - κt: Degradation state
- Typical fitting uncertainties:
  - κt is ~2.5%
  - D_0 is ~0.5%



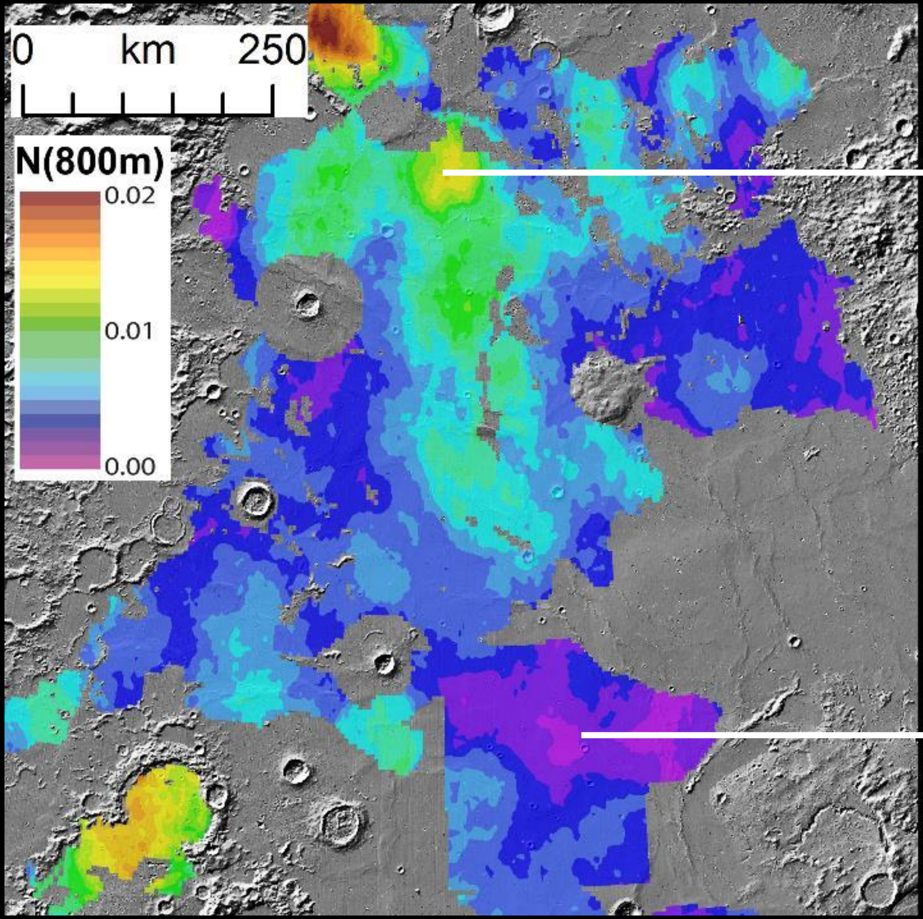
Crater Density on the Lunar Maria



N(800m): Crater density number of
D≥800 m craters per 10^3 km^2

Neukum Model Age (Ga) from Crater Density

Crater Density (Detail)

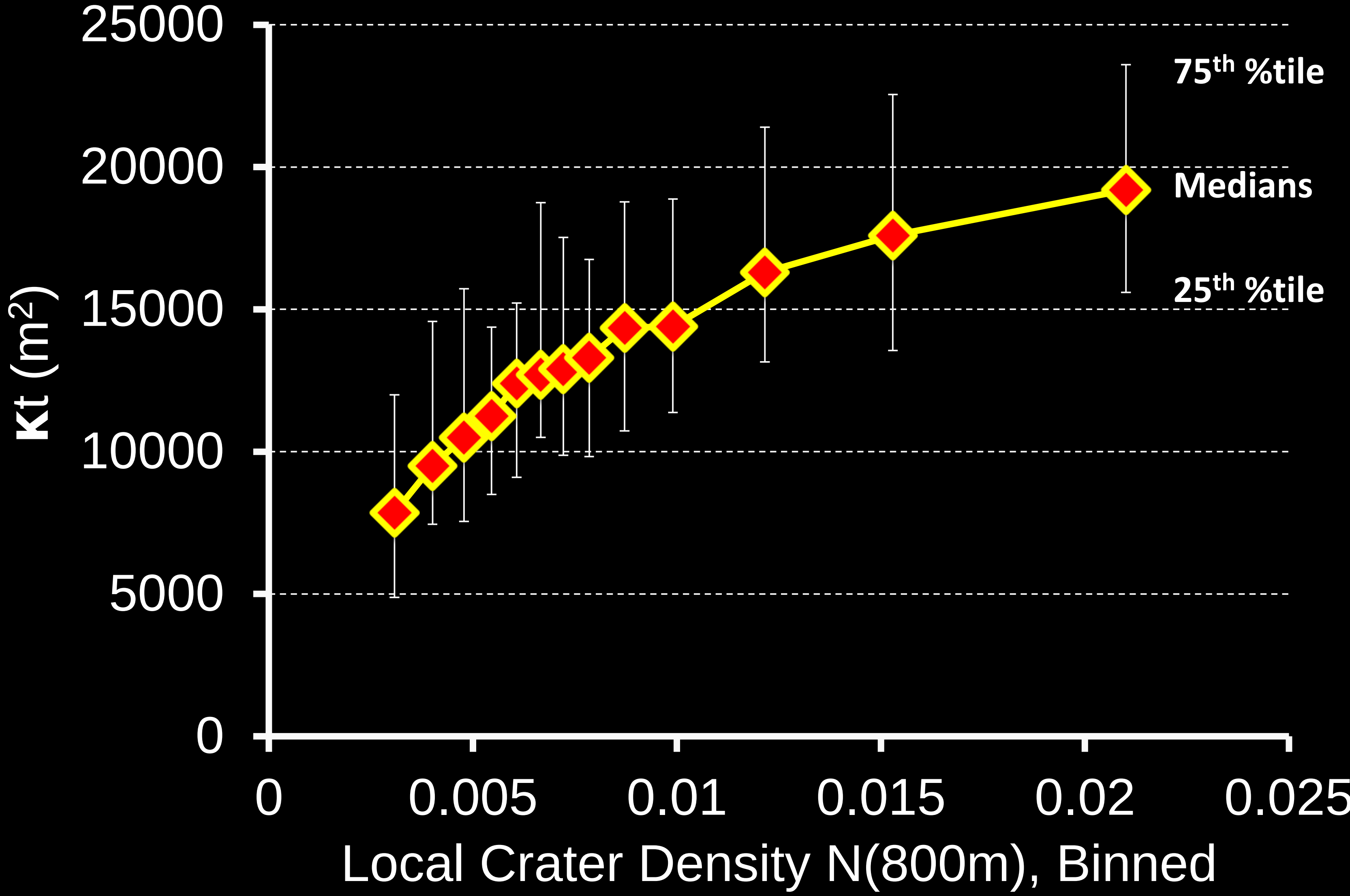


Factor of 10 × difference in crater density

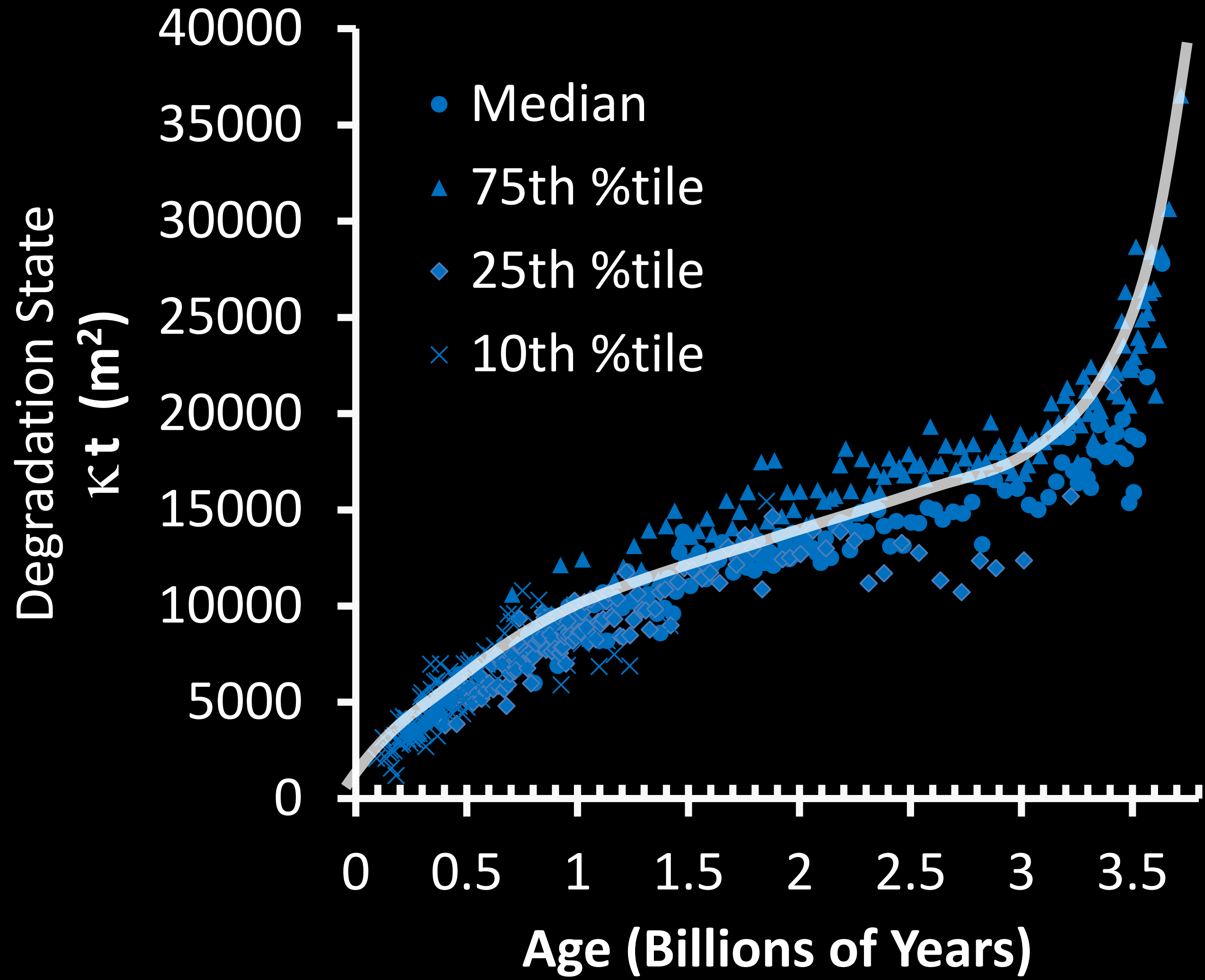
N(800m): Crater density number of D≥800 m craters per 10^3 km^2

Computed in 50 km radius moving neighborhoods

Degradation State versus Crater Density

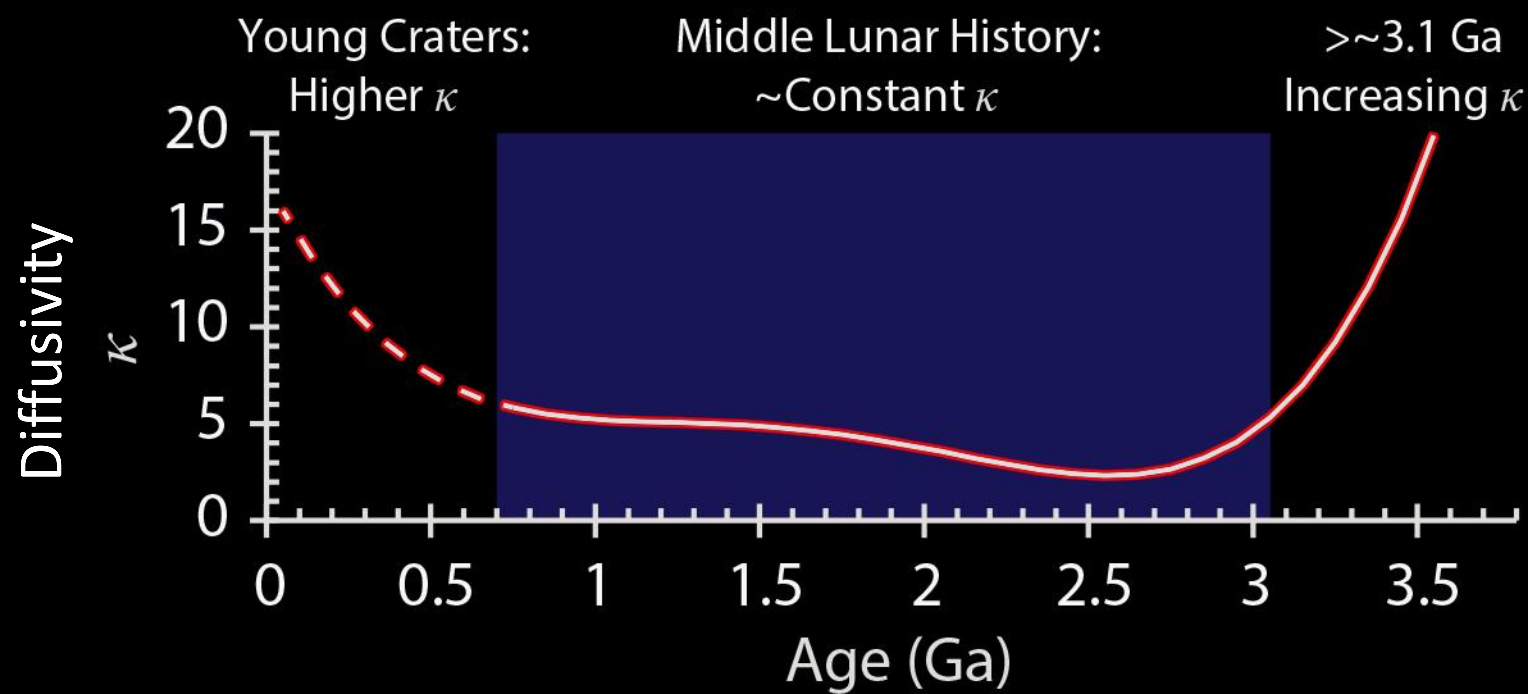


Degradation State versus Age



Fassett and Thomson, 2014

Diffusivity and Erosion History



- Typical diffusivity (at km-scale) over last ~3 Gyr is κ~5 m^2/Myr.
- Diffusivity is ~200× less than what is measured in the western US (e.g. κ~1 m^2/Kyr; *Colman and Watson* 1983).
- Reminder: Erosion Rate, $dh/dt = \kappa\nabla^2 h$.
- Median erosion/gradation rate ($|\kappa\nabla^2 h|$) = 0.3 mm/Myr.

New insights into diffusive forcing

- Crater ejecta alone is insufficient to explain observed diffusion rate.
  - Rate is too slow; equivalently, crater densities too high in saturation equilibrium.
- Indirect mobilization of materials by secondary effects, rather than just volume of ejecta alone.
- Effective diffusivity is size-dependent (anomalous diffusion).

Soderblom (1970)

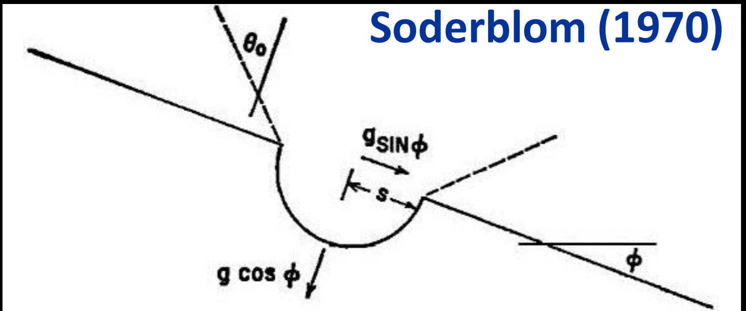


Fig. 2. The geometry of the ejecta trajectories of a crater eroding a surface with slope Φ.

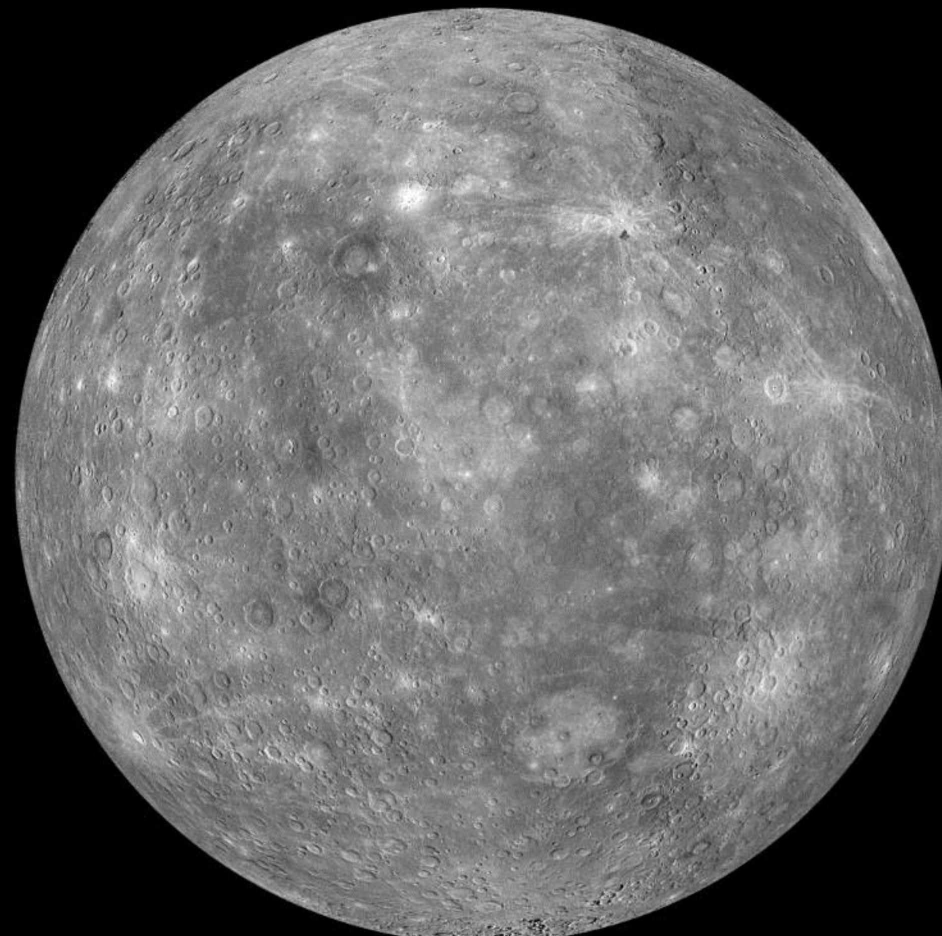
NASA/GSFC/ASU/LROC team

March 17, 2013 impact crater, before and after

See Speyerer et al., 2016

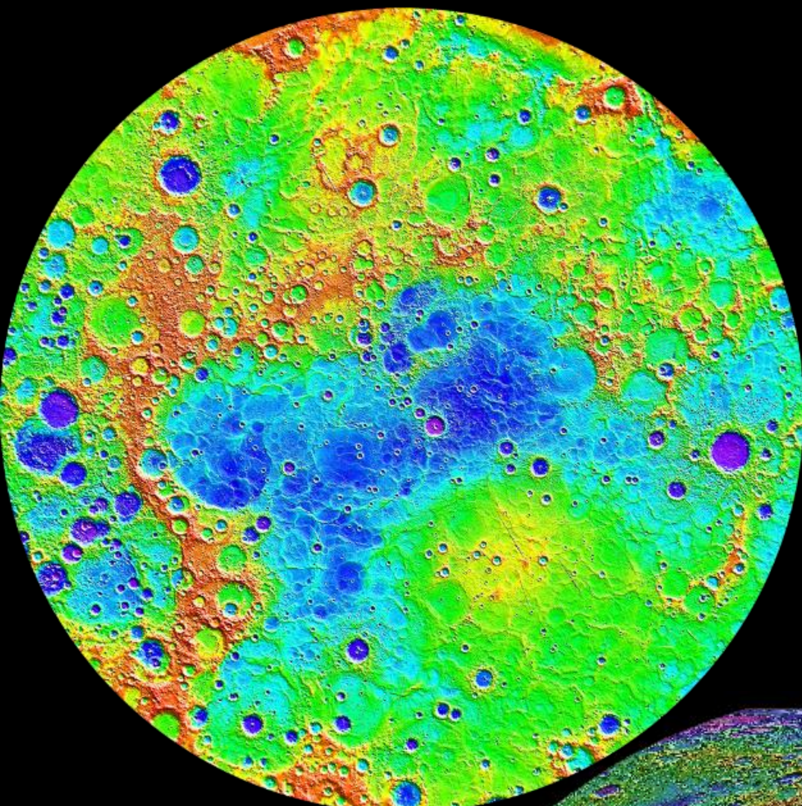
How does Mercury compare to the Moon?

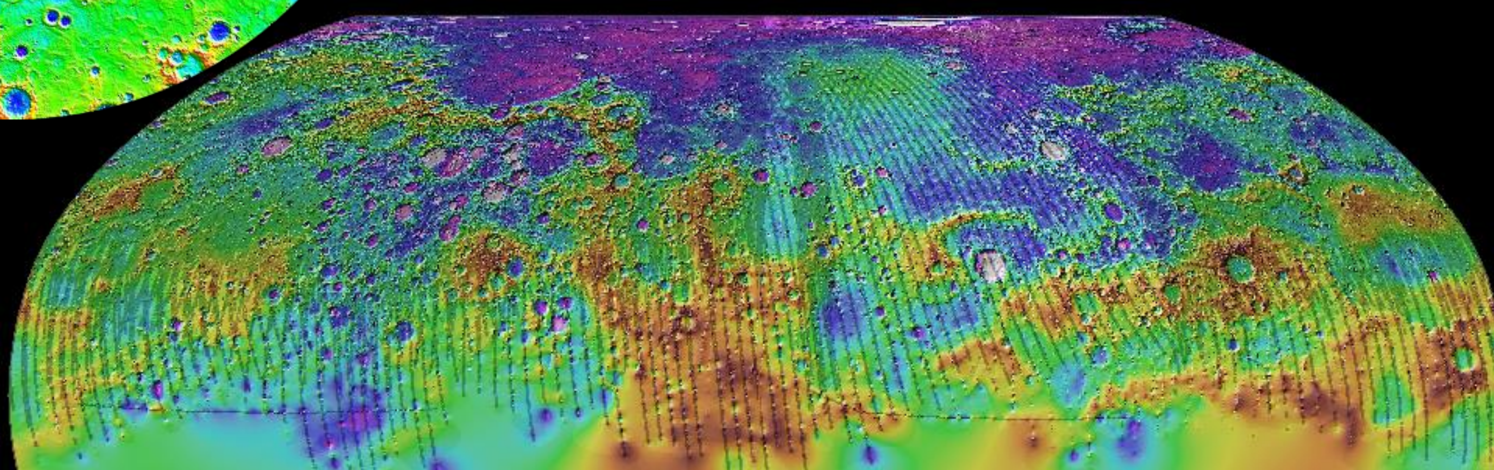
Moon (LROC)



Mercury (MDIS mosaic)

Two Sources of Mercury Topography: Mercury Laser Altimeter (MLA)

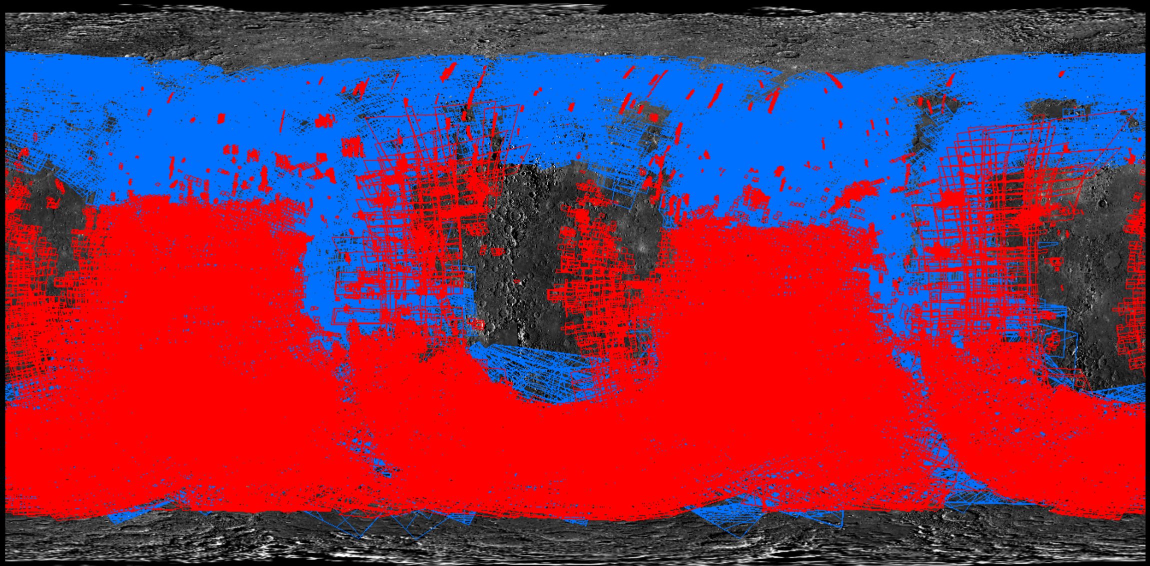




Two Sources of Mercury Topography: MDIS Stereo Topography

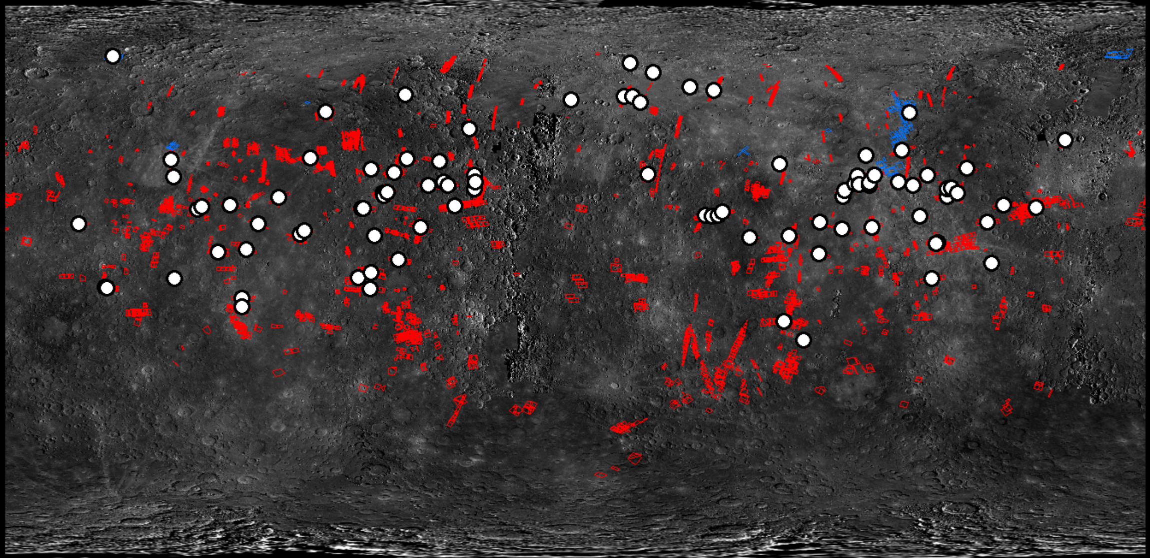
All Stereo Pairs
Wide Angle Camera, blue;

Narrow Angle Camera, red

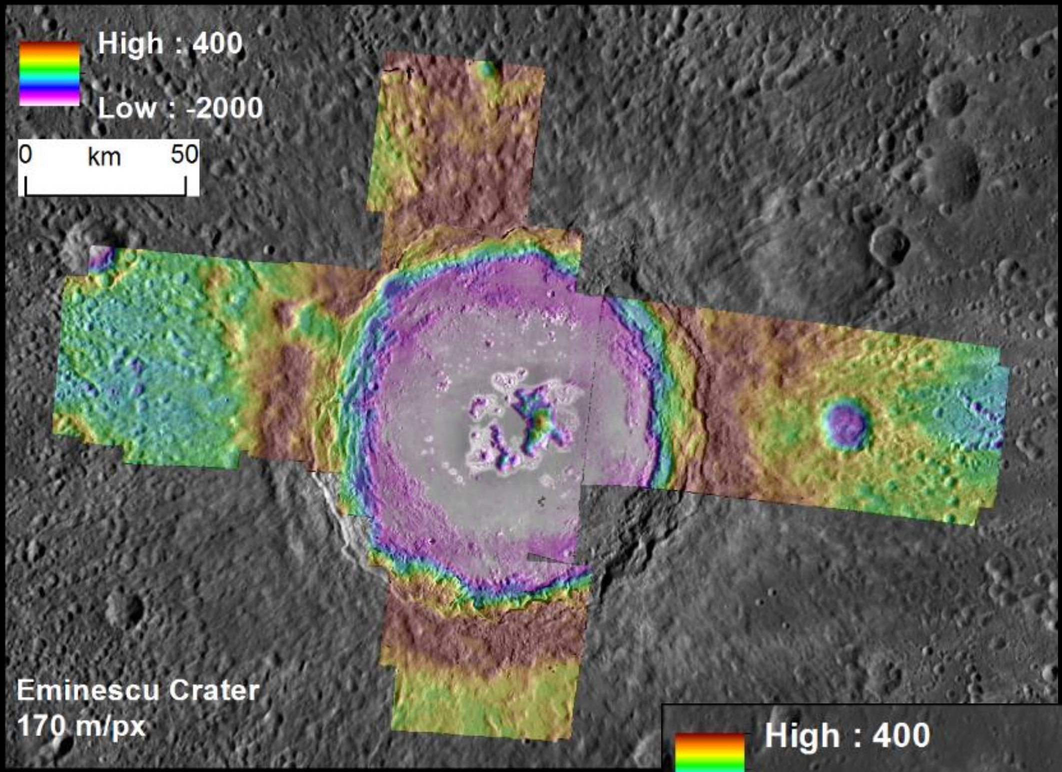


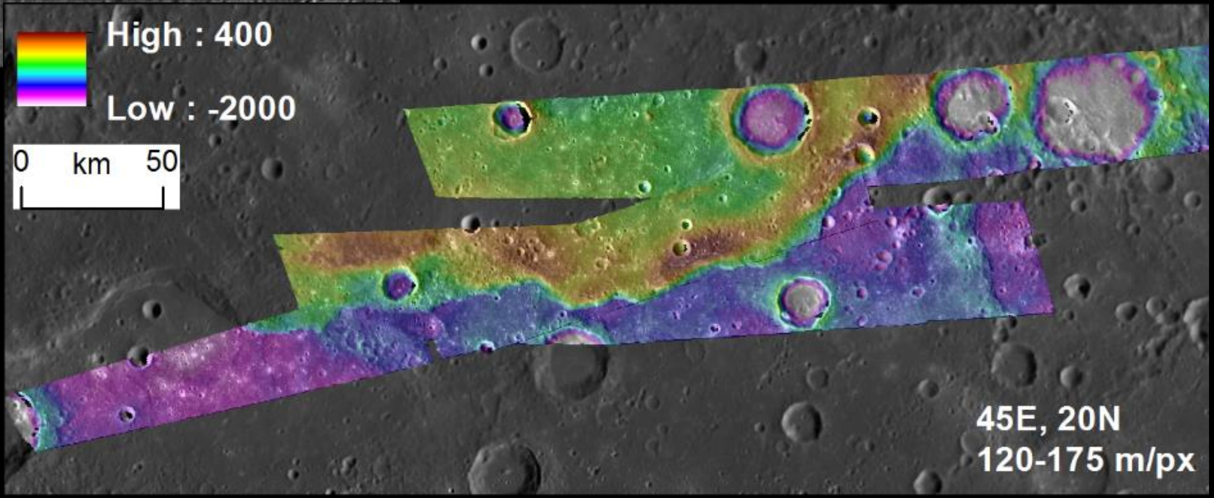
All Stereo Pairs
Source images <100 m/px

Dots are processed Digital Terrain Models (DTMs)



Stereo Topography Examples

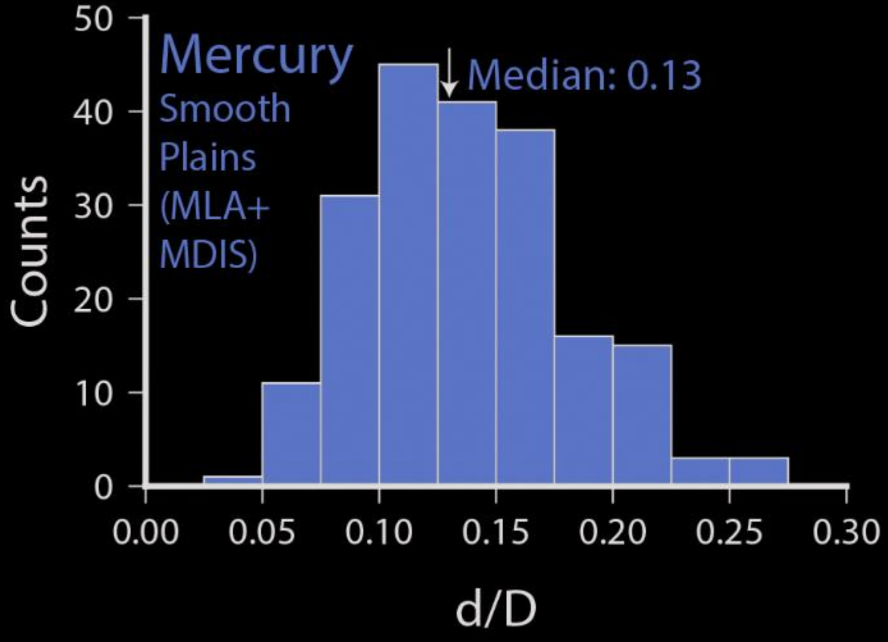


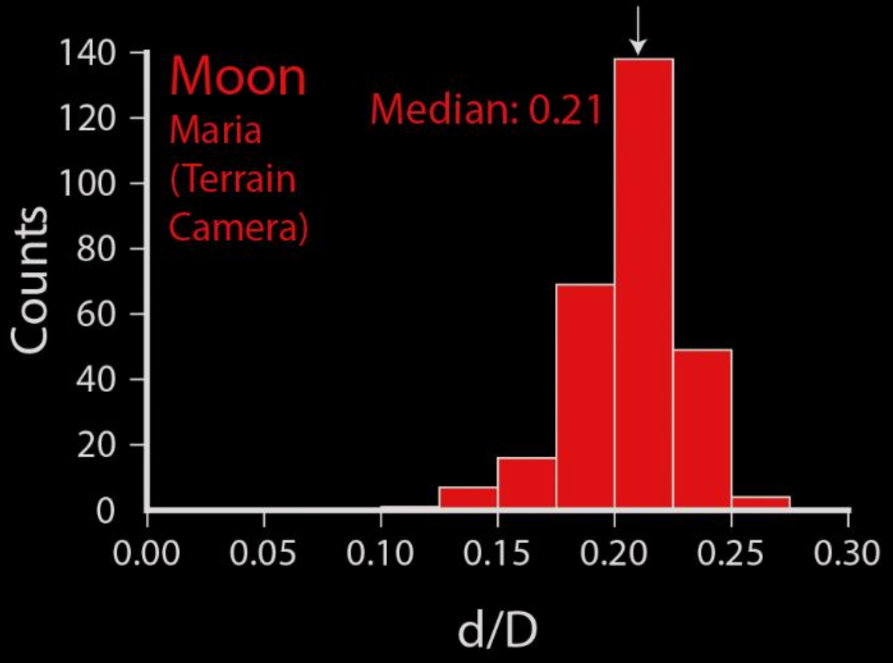


Get data or manuscript (Fassett, 2016): http://www.calebfassett.com/mercurydtms

Mercury Craters

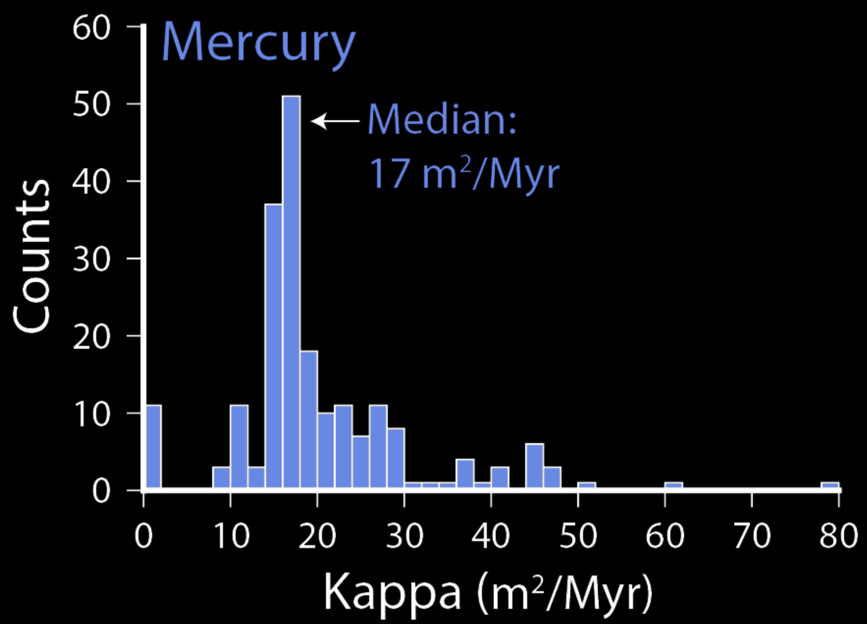
- Measured d/D of 117 craters with MLA & 87 with MDIS stereo.
  - Limited analysis to the *smooth plains* to provide consistent comparison to lunar maria data.
  - Limited to craters 2.5 to 5 km because of resolution.

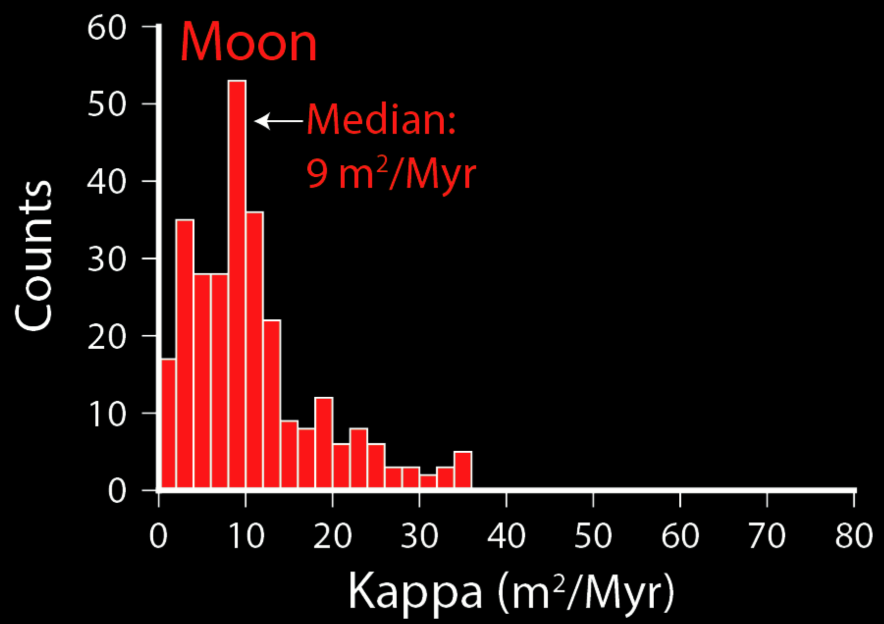




Mercury landforms degrade faster

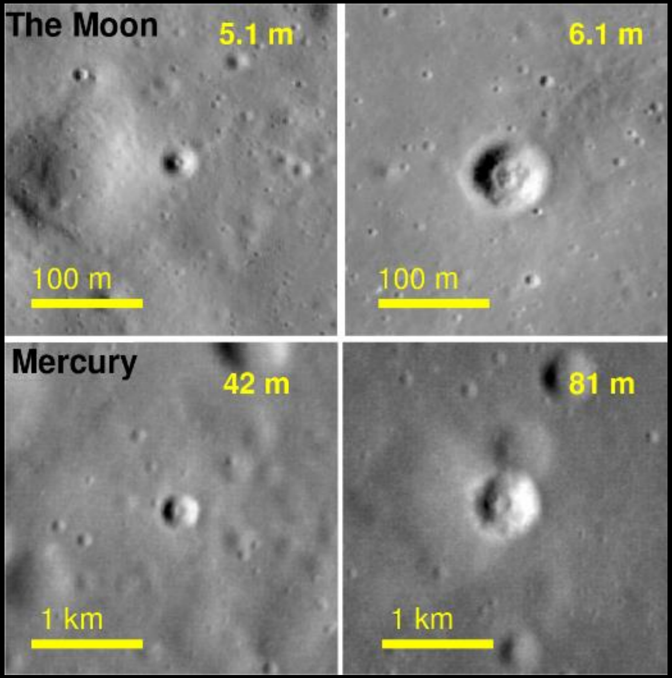
- Diffusivity (Kappa) required to reach observed *d/D* is much higher on Mercury than the Moon.
  - κt for Mercury craters was calculated as the value required to match the observed *d/D.* Plot below assumes that Mercury plains are ~3.7 Ga.
  - Effective kappa is for craters in 2.5 to 5 km size range. Recall diffusivity is size-dependent and faster at larger sizes.





Mercury landforms degrade faster

- Crater degradation consistent with:
  - Faster destruction of crater rays (*Braden et al., 2013*).
  - Faster growth of regolith (*Kreslavsky et al., 2014*).



Kreslavsky and Head, 2015

- Likely underlying cause for all of these phenomena is the much higher impact velocities at Mercury.

- Implications for understanding broader geology?

Conclusions

- We are converging on a model for how the topography of airless bodies evolves, including *process* and *rate.*
- This understanding provides a framework for constraining the *age of individual craters, features, and surfaces.*
- Landform evolution was much faster on Mercury than the Moon. *This may have important consequences for understanding early Mercury history.*