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Determination of Macroscopic Roughness of Dimorphos Using a Disk-Resolved DART Image

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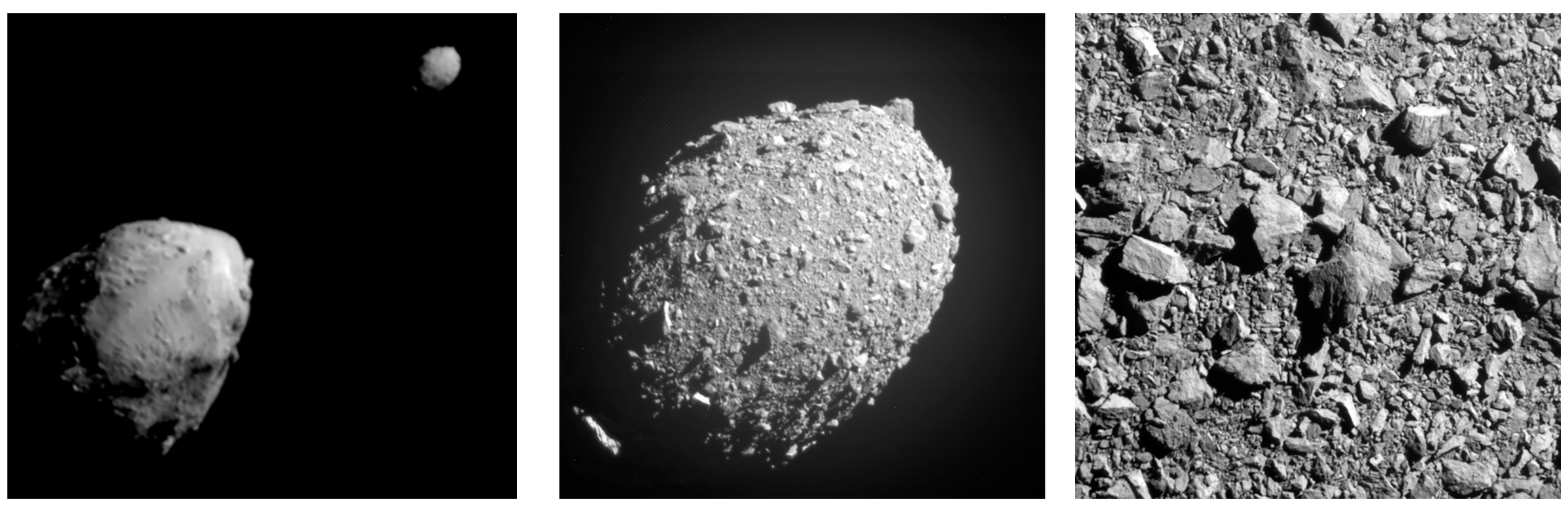
DART provided valuable close-up images of Dimorphos

- DART crashed into Dimorphos, companion of asteroid (65083) Didymos, on 26 September 2022 [1].
- Right before the crash, the camera DRACO took close-up images of Didymos.
- These images provide us a unique opportunity to study the scattering properties of the asteroid via photometry.
- Particularly, the surface roughness of an planetary body can be uniquely constrained from disk-resolved images [2], which is presented here.
- For full photometric analysis, see Dr. Buratti's talk on Friday (506.02)



Credits: NASA/Johns Hopkins APL

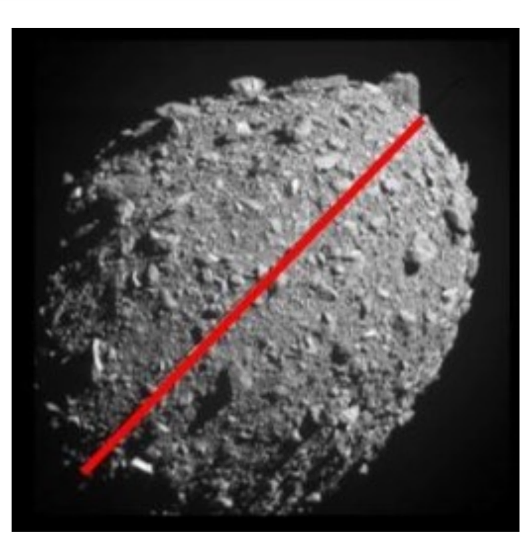
Macroscopic roughness of planetary surfaces

- Macroscopic roughness encompasses facets ranging in size from aggregates of particles to mountains, craters and ridges
- These features alter the reflected light from a planetary surface in two ways: the local incidence and emission angles are changed by alteration of the surface profile from that of a smooth sphere, and they remove radiation from the scene by casting shadows [3, 4]
- For low albedo objects, like asteroids, the roughness at sub-millimeter scale dominates, and hence enables us to peer *below the resolution limit of the camera* [5].

Research question: What is the macroscopic roughness of Dimorphos?

Data

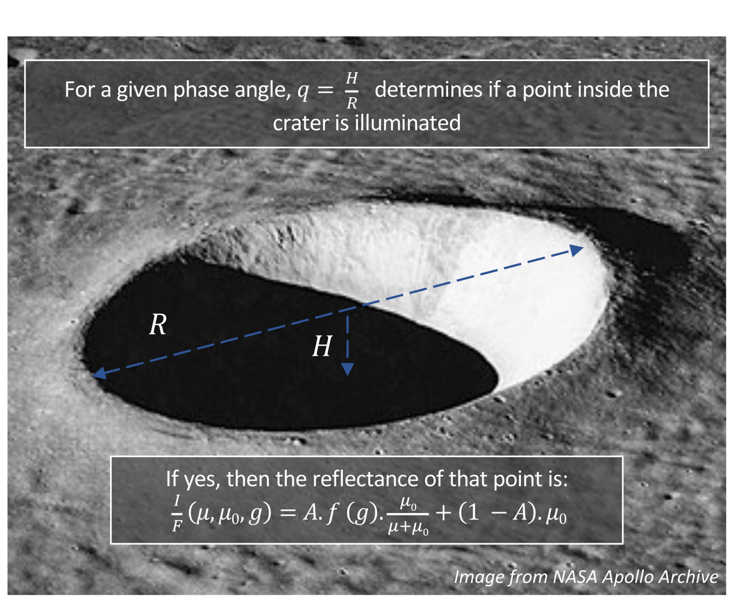
- We use an image obtained right before the crash from the camera DRACO, at a phase angle of 59°.
- Reflectance values along the long axis of this image were extracted to get maximum coverage in incidence or emission angle.

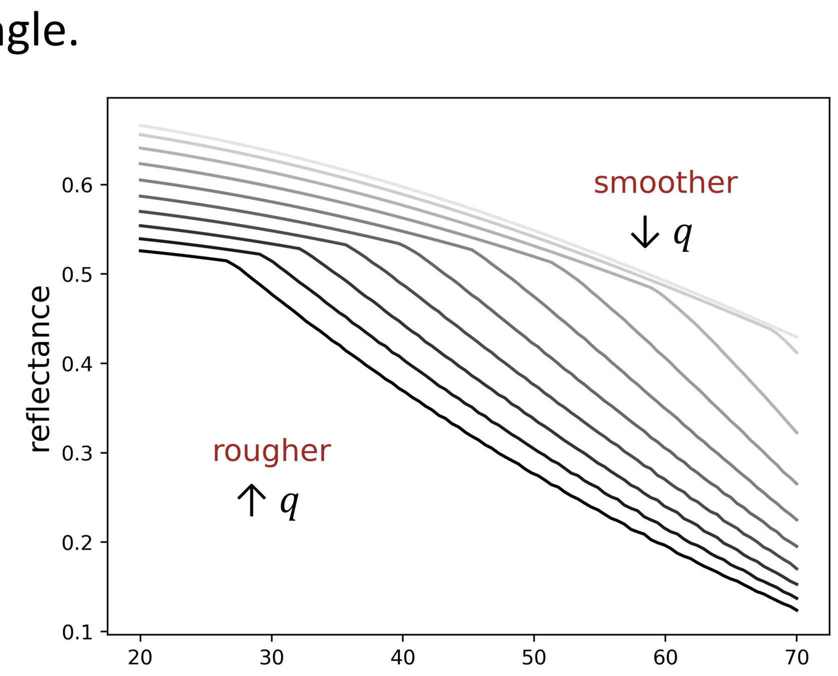


- Disk-integrated phase curve observations of the system from the Table Mountain Observatory were also used to constrain the solar phase function of the surface (f), needed in our roughness model described below.

Model

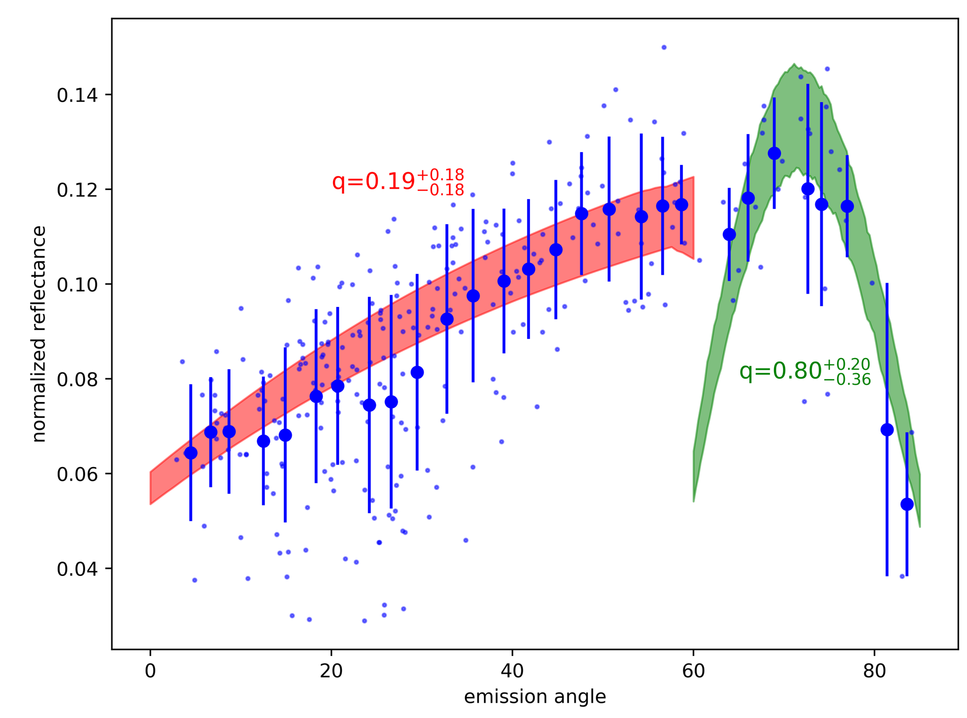
- We use the crater roughness model [4] that calculates reflectance of a surface full of idealized craters. The roughness of this surface is characterized by the depth-to-radius (q) ratio for these craters.
- Higher q → higher roughness
- The effect of roughness is a characteristic inflection in reflectance with increasing emission or incidence angle.

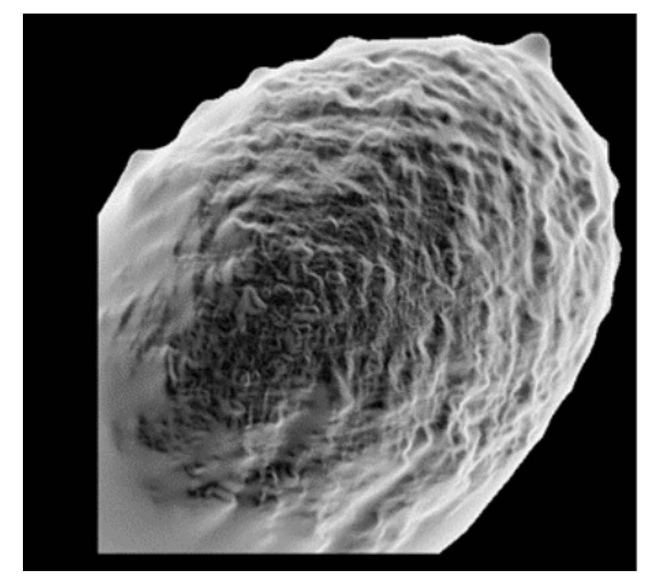




Roughness fit results

- We employ Bayesian inference to constrain uncertainty on the q parameter and account for its degeneracies with other model parameters [6].
- The reflectance data seems to be divided into two populations with distinct roughness: a low roughness ($q = 0.19^{+0.18}_{-0.18}$) terrain at smaller emission angles, and a high roughness ($q = 0.80^{+0.20}_{-0.36}$) terrain at larger emission angles.

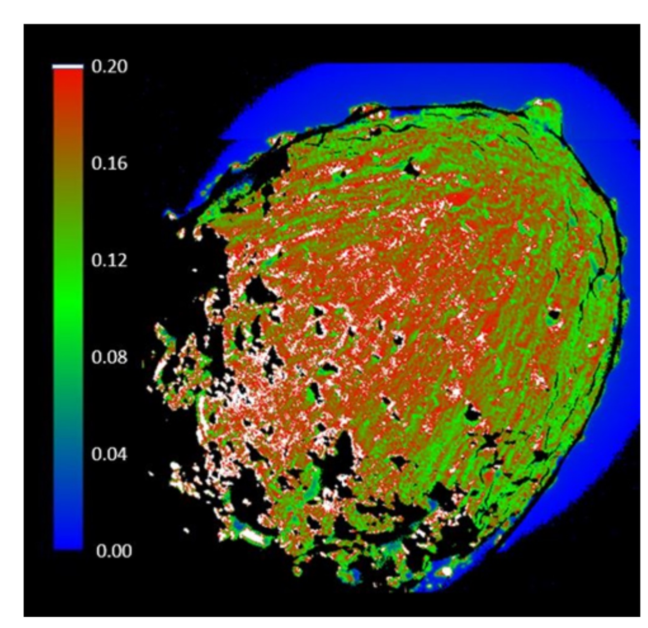




Emission angle map

Interpretation

- The albedo map of Dimorphos shows high albedo striations, which could have been formed from an impact.
- The surface appears to be substantially smoother towards the ends of the radiating striations, perhaps due to infilling of dust from the impact that formed the striations.
- These smooth areas mixed with boulders could be causing two different populations of roughness to appear in the reflectance data.
- The average roughness of Dimorphos from our study (mean slope angle $\bar{\theta} \sim 18°$) is typical of asteroids ($\bar{\theta} \sim$ 20-30°) [7].



Normal Reflectance map

Future Work

- Our study highlights that a through analysis of disk-resolved images of asteroids can reveal the complexity of macroscopic roughness across the surface, which a value derived from disk-integrated data (most commonly found in literature) does not convey.
- This work is part of a larger project of quantifying macroscopic roughness from disk-resolved images of asteroids with the following goals:
  1. Extend analysis to all asteroids with disk-resolved images (taken by spacecrafts), such as Bennu, Ryugu, Itokawa, etc.
  2. Estimate roughness along multiple longitudes and latitudes of each asteroid.
  3. Compare roughness estimates of different asteroids and identify potential trends.
  4. Compare roughness estimates from this study to previous estimates derived using disk-integrated observations, where available.

Acknowledgements:

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References:

[1] Daly et al., *Nature,* 2023, 616 [2] Helfenstein et al., *Icarus*, 1988, 74 [3] Helfenstein, *Icarus*, 1988, 73 [4] Buratti & Veverka, *Icarus*, 1985, 64 [5] Helfenstein & Shepard, *Icarus*, 1999, 141 [6] Mishra et al., *PSJ*, 2021, 2, 5 [7] Tatsumi et al., *A&A*, 2020, 639

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