Didymos and Dimorphos surface characterization through boulders' cracks and mass movements analysis

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Introduction: On 26 September 2022, the Double Asteroid Redirection Test (DART) spacecraft impacted the surface of Dimorphos, the ~150 m-size moonlet of the binary system (65803) Didymos (~780 m-size, [1]), allowing detailed surface characterization. Both DART and the Light Italian Cubesat for Imaging of Asteroids (LICIACube, [2]) provided direct observations of geological features, including lineaments, rocks' fractures and/or cracks, boulders, craters and signs of mass movements. Here we study both boulders' fractures and mass movements in order to constrain their formation processes and to investigate the formation and evolution of the Didymos system. Specifically, boulders cracks analysis is pivotal to constrain the internal structure and history of the body and the occurrence of mass movements provide crucial insights on the mechanical behavior of the binary system's constitutive material.

Dataset: DRACO, the scientific camera onboard DART [3], imaged the surface of Dimorphos with a spatial resolution from few meters to a maximum of 5.5 cm. Didymos was instead observed by both DRACO camera with a resolution up to 3.9 m and LICIAcube LUKE camera with a resolution up to 4.5 m. Here we use the DRACO image taken 1 s before impact with a resolution of 5.5 cm to map and analyze Dimorphos boulders cracks, as shown in Fig. 1, and multiple DRACO and LICIACube images to investigate mass movements on Didymos (Fig. 2).

Boulders cracks: We mapped approximately 50 fractures with a length ranging from 1 to 10 m. The length size distribution is shown in Fig. 1b. We also investigated the orientation of such fractures, deriving a rose diagram showing an E-W preferred orientation, which may point to a thermal mechanism formation for the boulder cracks [4]. Hence, to understand the mechanism triggering the formation of such boulders cracks, we plan to use two approaches: (i) test thermal cracking as possible mechanism using a 3D thermal model and thermal-fatigue models for explaining the disintegrating process of surface rocks and cracks propagation in the E-W orientation, and (ii) test meteoroids impact as possible mechanism for boulders cracks with other directions, comparing them with rock samples too. We also plan to investigate if the distribution is better fit by either a power law or an

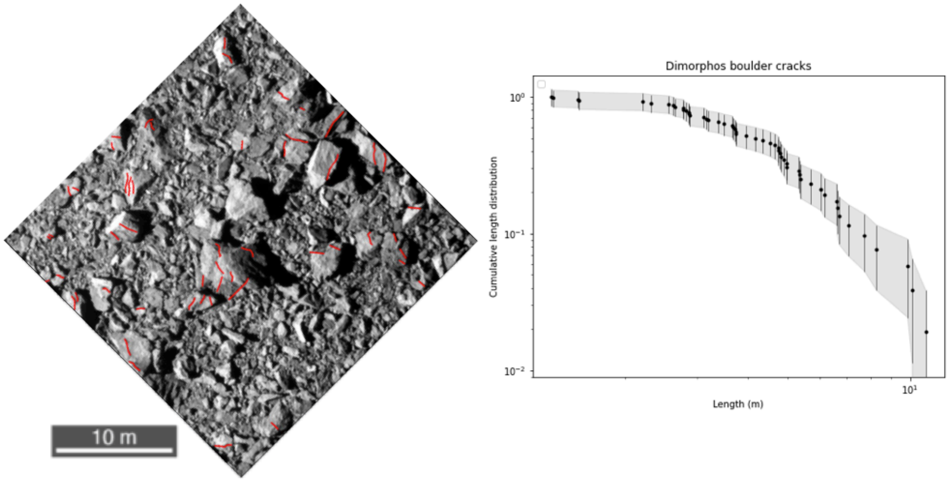

Figure 1 Left: a DRACO image showing Dimorphos at 6 cm spatial resolution where boulders' cracks are highlighted. Right: Cumulative length distribution of cracks on the boulders of Dimorphos.

exponential distribution, which may help discern which formation processes occurred

Mass movements: In Fig. 2a, the shaded area is characterized by a smoother-than-the-surroundings texture. The smooth terrains are mainly located along the equatorial ridge of the asteroid and seem to be correlated with mass movements signatures, suggesting that the smooth terrains are probably due to landslides forming on the slopes (arrows). In addition, there could be the presence of rockfalls identified as single boulders movements from visible tracks on the surfaces. Lineaments perhaps produced by the action of the movement of boulders across the surface (rolling stones) are also observed. Future investigation will be carried on LICIACube images (Fig. 2b) to properly characterize the mass movements orientation and volumes and understand their triggering mechanism.

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References: [1] Rivkin, A.S., et al. 2021. PSJ, 2, 173; [2] Dotto, E. et al. 2021, PSS, 199, 105185; [3] Fletcher, Z. J., et al. 2018. SPIE 10698; [4] Delbo, M. et al., 2022, Nature Geoscience, 15, 453–457; [5] Delbo M. et al., 2014, Nature, 508(7495), 233-236.

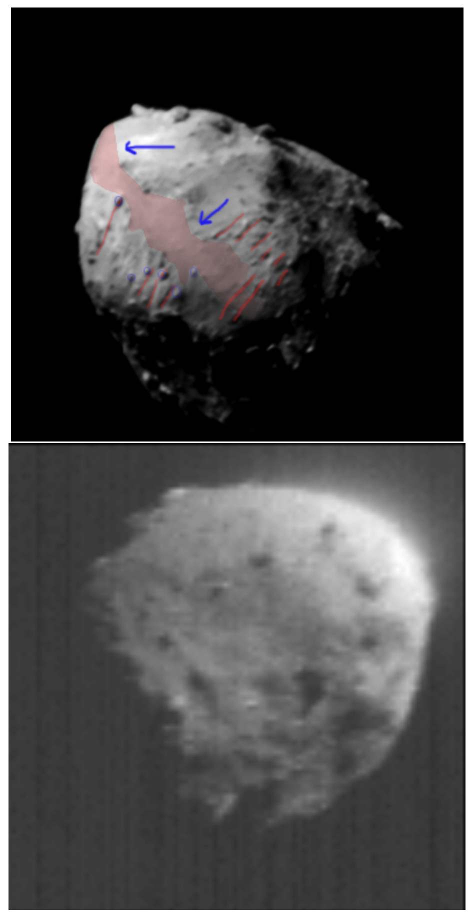

Figure 2 DRACO and LICIACube LUKE images (panels a and b, respectively) of Didymos taken at a resolution of 5.0 and 4.7 m, respectively. The shaded area in the top panel corresponds to the equatorial ridge characterized by the presence of terrains smoother than the surroundings.