THE SHAPE OF DIMORPHOS WITH RELEVANCE TO BINARY ASTEROID FORMATION. R. T. Daly[1], C. M. Ernst[1], O. S. Barnouin[1], H. F. Agrusa[2], R.-L. Ballouz[1], T. L. Farnham[2], R. W. Gaskell[3], M. Hirabayashi[4], S. Jacobsen[5], J. McMahon[6], A. J. Meyer[6], P. Michel[7], H. Nair[1], M. C. Nolan[8], P. Pravec[9], S. D. Raducan[10], D. P. Sanchez[6], D. J. Scheeres[6], Y. Zhang[2], A. Zinzi[11,12] and the DART Team, [1]Johns Hopkins Applied Physics Laboratory, Laurel, MD, USA (terik.daly@jhuapl.edu) [2]University of Maryland, College Park, MD, USA [3]Planetary Science Institute, Tucson, AZ, USA [4]Auburn University, Auburn, AL, USA [5]Michigan State University, East Lansing, MI, USA [6]University of Colorado, Boulder, CO, USA [7]Université Côte d'Azur, Observatoire de la Côte d'Azur, CNRS, Laboratoire Lagrange, Nice, France [8]University of Arizona, Tucson, AZ, USA [9]Astronomical Institute AS CR, Ondrejov, Czech Republic, [10]University of Bern, Bern, Switzerland [11]Agenzia Spaziale Italiana, Via del Politecnico, Roma, Italy, [12]ASI Space Science Data Center.

Introduction: On 26 Sept. 2022, the Double Asteroid Redirection Test (DART) spacecraft slammed itself into asteroid Dimorphos to demonstrate kinetic impact for asteroid deflection. Prior to DART's arrival, little was known about the shape of Dimorphos. Radar and lightcurve observations found the diameter of Dimorphos to be 150 ± 30 m [1] and 171 ± 11 m [2,3], respectively. Neither method robustly measured the detailed shape or elongation of Dimorphos.

The shape of Dimorphos, like those of all asteroids (e.g., [4]), is a clue to the object's material properties, origin, and evolution. Here we summarize the initial understanding of Dimorphos' shape as seen by DART and describe aspects of the shape that must be explained by models of the asteroid's formation and evolution.

Methods: We built a global digital terrain model (DTM) of Dimorphos using stereophotoclinometry (SPC) [5–7] and images from the onboard camera taken in the mission's final 74 seconds (e.g., Fig. 1). Despite the limited imaging, SPC is robust enough to produce a reasonable global DTM [8].

In DART images, Dimorphos looks similar to a rock-covered egg (Fig. 1a). We therefore used a triaxial ellipsoid as the starting point for the DTM. Triaxial dimensions were determined by fitting an ellipsoid to the limbs lit by the sun and by Didymos (Fig. 1b), and position of the terminator. The axis extents were determined by minimizing errors from metrics [9] developed as part of the OSIRIS-REx mission. The terminator varies systematically with the ratio of the long axis (X, which is known from the sunlit and Didymos-lit limbs) and the intermediate axis (Y, which is largely into and out of the image plane in Fig. 1).

Detailed topography was added to the starter model in areas imaged by the DART spacecraft by tiling the surface with a grid of local DTMs with ground-sample distances of 60, 25, 10, 5, and 3 cm. Topography was computed via two-dimensional photoclinometry, with geometric stereo at the center [5–8]. Other maplets conditioned solely by limb points were added to better represent boulders on the sunlit limb. Local DTMs were united with the starting shape to create the global DTM.

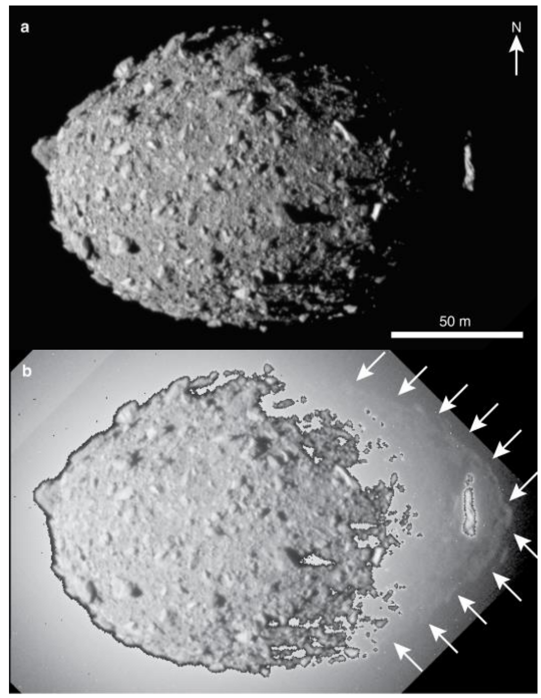

Fig. 1. Dimorphos as seen by DART. (a) The overall shape appears ellipsoidal with boulders along the sunlit limb but no notable concavities. (b) The same image with an extreme stretch. Arrows indicate the dark limb illuminated by scattered light from Didymos. The arrow in (a) points to Dimorphos' north.

Results: The global DTM indicates that Dimorphos is oblate (Fig. 2), rather than prolate as had been assumed [10]. The global DTM has the highest fidelity where maplets exist (gray). Areas along the limb (blue and magenta points) are well constrained. The side opposite from the maplets was not imaged by DART. Uncertainties are ±2 m in the extents of the X (long) and Z (short) axes and ±4 m in the Y (intermediate) axis.

Discussion: DART imaged only one side of Dimorphos, but several factors are consistent with an oblate shape, including the non-detection, to date, of a reliable elongation in lightcurves [2,3], comparisons with LICIACube images [11], the lack of obvious concavities such as those on Eros or Itokawa, and the

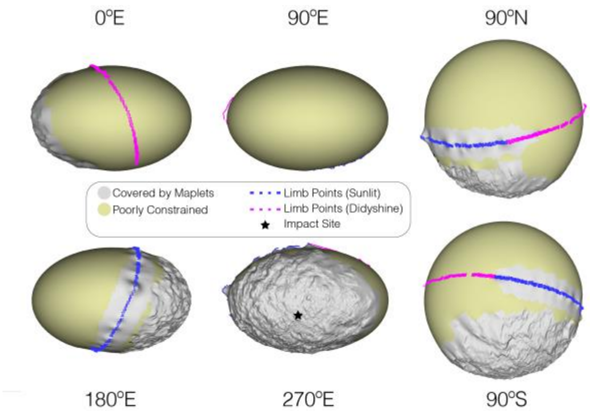

Fig. 2. Global DTM of Dimorphos viewed along its principal axes. The prime meridian points toward Didymos. A black star marks the DART impact site.

ellipsoidal outline, in contrast to the diamond-shaped Bennu or Ryugu. Dimorphos is likely tidally locked [12–14] so DART most likely imaged Dimorphos while the asteroid's X axis was oriented toward Didymos.

Models of Dimorphos' formation must explain both the asteroid's oblateness and its remarkably uniform, ellipsoidal outline. No other asteroid studied by spacecraft has such a limb (e.g., compare Fig. 1 against compilations of asteroid and comets by the Planetary Society [15]). Dimorphos' shape is unusually uniform compared to NEA secondaries with radar-based shapes (Fig. 3). The lack of obvious craters distinguishes Dimorphos from Dactyl, the moon of the main-belt asteroid Ida [16], but Dimorphos is ~1000x smaller.

The asteroid's ellipsoidal outline is reminiscent of Saturn's moons Methone (Fig. 4), Aegaeon, Anthe, Pallene, and Polydeuces (e.g., [17]). However, these moons are notably elongated [18]. Do these ellipsoidal profiles signal analogies between processes operating in Saturn's rings and during Dimorphos formation? Does Dimorphos' bulk shape approximate an equipotential surface? If so, then the body in aggregate may be extremely weak. Or does the ellipsoidal outline without notable visible concavities indicate that the body has reached the end state of some evolutionary process? If so, then what process and over what timescale? Future work will answer such questions and clarify what the shape of Dimorphos is telling us about the origin and evolution of the Didymos system.

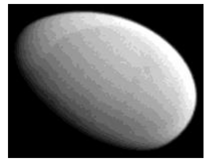

Fig. 4. Methone (~3 km across) as seen by Cassini at 63° phase, similar to the 60° phase at which DART imaged Dimorphos. Note the ellipsoidal outline.

Conclusions: The initial global DTM of Dimorphos produced from DART data indicates that the asteroid is an oblate body free from substantial concavities, a state that models for the formation of Dimorphos must explain. A final global DTM built from both DART and LICIACube images will be produced in Spring 2023 and refine the shape parameters reported here.

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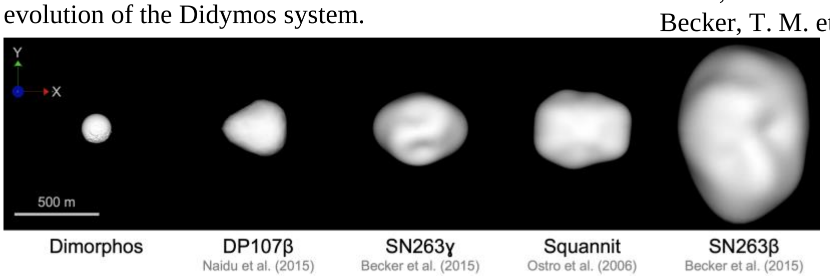

Fig. 3. Global DTM of Dimorphos compared to radar shape models of moons in the DP107 [19], KW4 [20], and SN263 [21] near-Earth asteroid systems as viewed from above their North poles. Asteroid size increases from left to right.