The Science Proximity Operations of the Double Asteroid Redirection Test Mission. O.S. Barnouin[1], N.L. Chabot[1], C.M. Ernst[1], I. Carnelli[2], A. Cheng[1], M. Kueppers[3], P. Michel[4], and A.S. Rivkin[1], [1]The Johns Hopkins University Applied Physics Laboratory, Laurel, MD, USA (olivier.barnouin@jhuapl.edu); [2]ESA-HQ, France; [3]SRE-OOR, ESA/ESAC, Spain; [4]Lagrange Laboratory, CNRS, Côte d'Azur Observatory, Nice, France

Introduction: The moon of the near-Earth binary asteroid 65803 Didymos is the target of the Double Asteroid Redirection Test (DART) mission. This mission makes up the US contribution to a joint NASA and ESA effort to investigate the effectiveness of a kinetic impactor in deflecting an asteroid. In the proposed plan, DART would impact the Didymos moon (henceforth Didymos B), while the ESA-led Hera mission would survey the Didymos system, to investigate changes in the geophysical and dynamical properties of the target binary asteroid after the DART impact.

We focus here on the proximity operations undertaken by the DART spacecraft before impact that address three main objectives: (1) to refine pre-encounter estimates of the Didymos A rotation rate and Didymos B orbit and search for additional system members; (2) to characterize the global shape and surface geology of Didymos A and B; and (3) to characterize the local surface properties and slope of the DART impact site. The results from all three objectives affect how the deflection of Didymos B is interpreted from ground-based and Hera observations.

Imaging timeline: The DART imaging campaign can be split into three phases (Figure 1):

(1) *Long-range phase***:** The long-range phase begins when the Didymos system is first acquired by DART's narrow-angle visible imager DRACO (Didymos Reconnaissance and Asteroid Camera for OpNav). This occurs ~30 days before impact and extends until the terminal phase begins. During this phase, DRACO acquires a long-range suite of observations, most of which cannot separately resolve the two bodies. Approximately 7 days before impact, 2x2 binned images can be obtained at a cadence up to one per second.

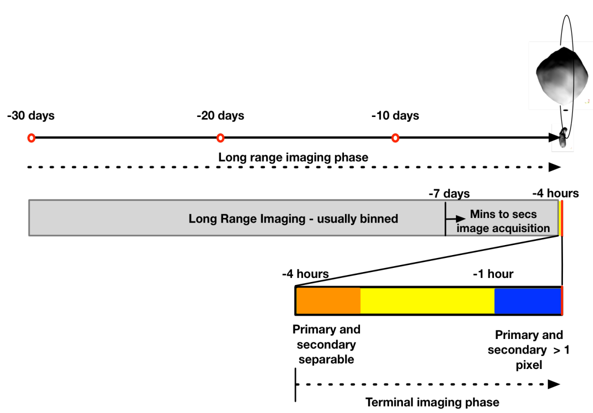

Figure 1. The DART imaging timeline.

(2) *Terminal phase***:** The terminal phase begins with the initiation of DART's autonomous navigation, ~4 hours prior to impact, and extends until the final phase begins. During this phase, the separation between Didymos A and B can be resolved and DRACO images support both autonomous navigation and characterization of Didymos A and B. By the end of this phase, images will be obtained of Didymos B that have a 2x2 binned ground sample distance of ~3.5 m.

(3) *Final phase***:** The final phase comprises the last ~2 minutes of the DART mission. During this phase, all DRACO images will be devoted to characterization of Didymos B, as autonomous navigation will have been completed. In the current operational plans, at ~17 s prior to impact, DRACO images will have a ground sample distance ≤50 cm. Higher-resolution data will continue to be acquired in the final seconds of the mission. Planned real-time DSN coverage enables downlink of these images to Earth, including all images acquired 5 s before impact (down to ~15 cm pixel scale with 2x2 binned pixels) and earlier, and possibly including images acquired during the final 5 seconds.

Pre-encounter refinements: The long-range phase DRACO images of the Didymos system provide lightcurves at viewing geometries complementary to those obtainable by ground-based telescopes. Using approaches employed in previous efforts [1–3], these lightcurves will tighten constraints on the rotation rate and shape of Didymos A, and the orbital period and shape of Didymos B. The long-range images also will be used to search for any additional satellites.

Global shape and surface geology: In the current imaging plans, about 80 min before the DART impact, Didymos B becomes a resolved object in DRACO images. Images containing both Didymos A and B will be collected until ~4 min prior to impact, when the planned DRACO pixel scale is 7 m (Figure 2). After this time, portions of Didymos A will extend beyond the DRACO field of view as the DART spacecraft continues to advance toward Didymos B. The final planned images containing small portions of Didymos A will be acquired ~2 min prior to impact, with a pixel scale of 3.5 m.

These images will be used to enhance the lightcurve-based shape models of Didymos A and B. We will use stereophotoclinometry (SPC; [4]), which combines traditional stereo techniques with photoclinometry, to estimate the heights across small patches of the surface (called maplets) from multiple images acquired during approach. The impact trajectory limits stereo information for the high-resolution images, but limbs will be incorporated to constrain maplet positions. The DART team will further constrain the shapes of both Didymos A and B, in particular the portions not observed by DRACO in high-resolution images, by incorporating lightcurve data collected both during the long-range phase and by ground-based observations. The lightcurve data from DRACO are obtained at a different geometry than what is possible from Earth and enhance ground-based observations to help improve the shape. The shape modeling effort will also take advantage of changes in surface illumination observed as Didymos A rotates and Didymos B orbits for the ~1 hour of resolved imaging when the pixel scale is too large to contribute to maplet topography. SPC has been successfully used to construct shape models from small body flybys (e.g., Steins, Lutetia, Phoebe), and Sierks et al. [5] demonstrate that for Lutetia, the combination of constraints on rotation axis, ground-based lightcurves, and an SPC-derived shape model produced a derived volume with less than 10% error.

Resolved images that contain both Didymos A and B will allow characterization of the shapes and large-scale geological properties of both bodies, and will be sufficient to map and measure features such as craters and large blocks, and to assess the distribution of smooth versus rough terrain and albedo variations. The images will enable comparisons between the two bodies, which will be important to interpret the origin and evolution of the binary system. In addition, the images will allow comparisons to similarly sized asteroids that have been (or will have been) visited by spacecraft. Itokawa (visited by Hayabusa) is between Didymos A and B in size; Ryugu and Bennu (the targets of Hayabusa 2 and OSIRIS-REx, respectively) are similar in size and shape to Didymos A. Comparisons to these bodies will not only help to understand the nature of objects of this size and shape, but also may shed light into differences between binary and single asteroids.

Characterize the local surface properties: The DRACO images acquired during the final minutes of the DART mission provide high-resolution views of Didymos B and the DART impact site. Experience from prior asteroid missions such as NEAR-Shoemaker and Hayabusa show DRACO's images at ≤50 cm/pix are sufficient to characterize the target surface and resolve features at the scale of the DART spacecraft, including surface roughness, blocks, craters, lineaments and regions covered in regolith. Assessments of roughness and surface structures, particularly blocks, will be key for assessing the initial impact conditions. If the impact occurs into terrain covered in blocks at the scale of the spacecraft, the coupling of the spacecraft to the target will be affected and lead to a different momentum transfer than if the impact occurs onto relatively smooth regolith.

The high-resolution images, in conjunction with the shape model, are also important for estimating the regional surface tilts at the impact site. The precision of a regional tilt estimate depends on the local phase angles of the images. The tilt estimate from DRACO imaging should be better than 10° for the current 60° phase angle envisaged. The relationship of mapped regolith regions with regional tilt, and slope relative to gravity, once Didymos B mass is estimated, will provide insights on the origin of any mapped surface regolith, and near surface structural nature of the asteroid at DART's impact site.

Conclusion: The shapes, geologic features, and internal properties of the Didymos system are key information to interpret the DART impact and associated momentum transfer. The final DRACO images and the assessments undertaken with them will provide much of this needed information. These data help to constrain the momentum transfer values from the impact, to inform numerical simulations of the event, and to gauge the generic effectiveness of a kinetic impactor for hazard mitigation.

References: [1] Pravec, P. et al. (2006). *Icarus*, 181:63–93. [2] Viikinkoski, M. et al. (2015). *A&A*, 576, A8–11. [3] Weaver, H.A. et al. (2016). *Science*, 351(6), aae0030. [4] Gaskell, R.W. et al. (2008). *MAPS* 43, 1049–1061. [5] Sierks, H. et al. (2011). *Science*, 334, 487–490.

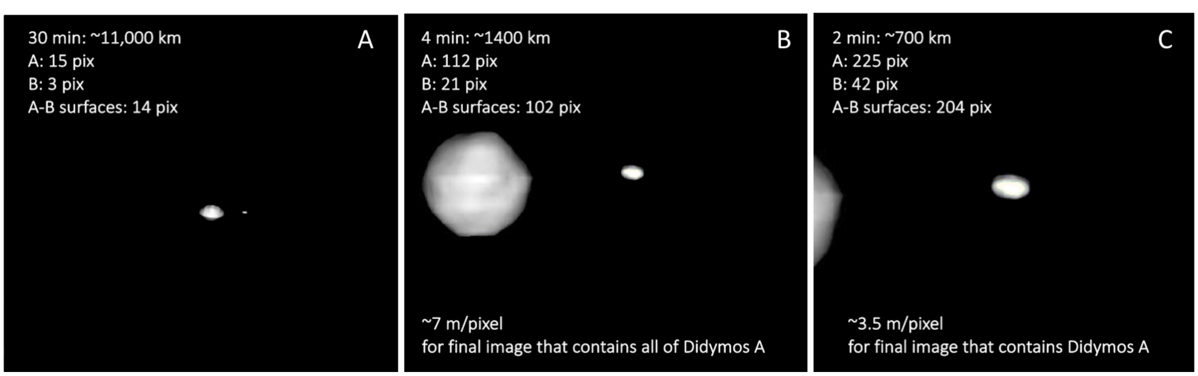

Figure 2. Simulated DRACO images: 30 min (A), 4 min (B) and 2 min (C) before impact.