REAL-TIME MONITORING OF ONBOARD IMAGE PROCESSING PERFORMANCE DURING DART TERMINAL APPROACH.

D. L. Bekker[1], R. T. Daly[1], C. M. Ernst[1], Z. J. Fletcher[1], L. M. Rodriguez[1], C. A. Sawyer[1], [1] Johns Hopkins University Applied Physics Laboratory, Laurel, MD (dmitriy.bekker@jhuapl.edu)

Introduction: On 26 September 2022, the world watched a live image feed from the Double Asteroid Redirection Test (DART) spacecraft as it headed to impact with its target – the asteroid moonlet Dimorphos of the (65803) Didymos binary asteroid system [1]. This successful demonstration of kinetic impactor technology enabled the collection of crucial observational data [2, 3] needed for the design of future planetary defense missions to protect Earth from hazardous asteroids – if such a threat is ever identified.

In the final four hours of the DART mission, termed *Terminal Approach*, the spacecraft navigated autonomously to impact using the onboard Small-body Maneuvering Autonomous Real Time Navigation (SMART Nav) system [4]. SMART Nav processed a list of candidate objects in the field of view that was supplied by the onboard processing component [5] of the Didymos Reconnaissance and Asteroid Camera for OpNav (DRACO) – the sole instrument onboard [6].

DRACO images were captured at 1.04 Hz and streamed in real-time to Earth, with all data passing through the DRACO Image Processing Pipeline (DRIP) onboard [5]. This live image feed was provided to the public to follow DART's progress during terminal approach. At the Johns Hopkins Applied Physics Lab Mission Operations Center (MOC), operators used enhanced telemetry and image displays to monitor image quality and the status of onboard processing. Visualizing these data was important to ensure DRIP and SMART Nav were operating properly and did not require any parameter adjustments that had been prepared as part of pre-planned mission contingencies and practiced in rehearsals. We present an overview of the displays used to monitor DART onboard image processing performance, shown at the T- 20min mark prior to impact.

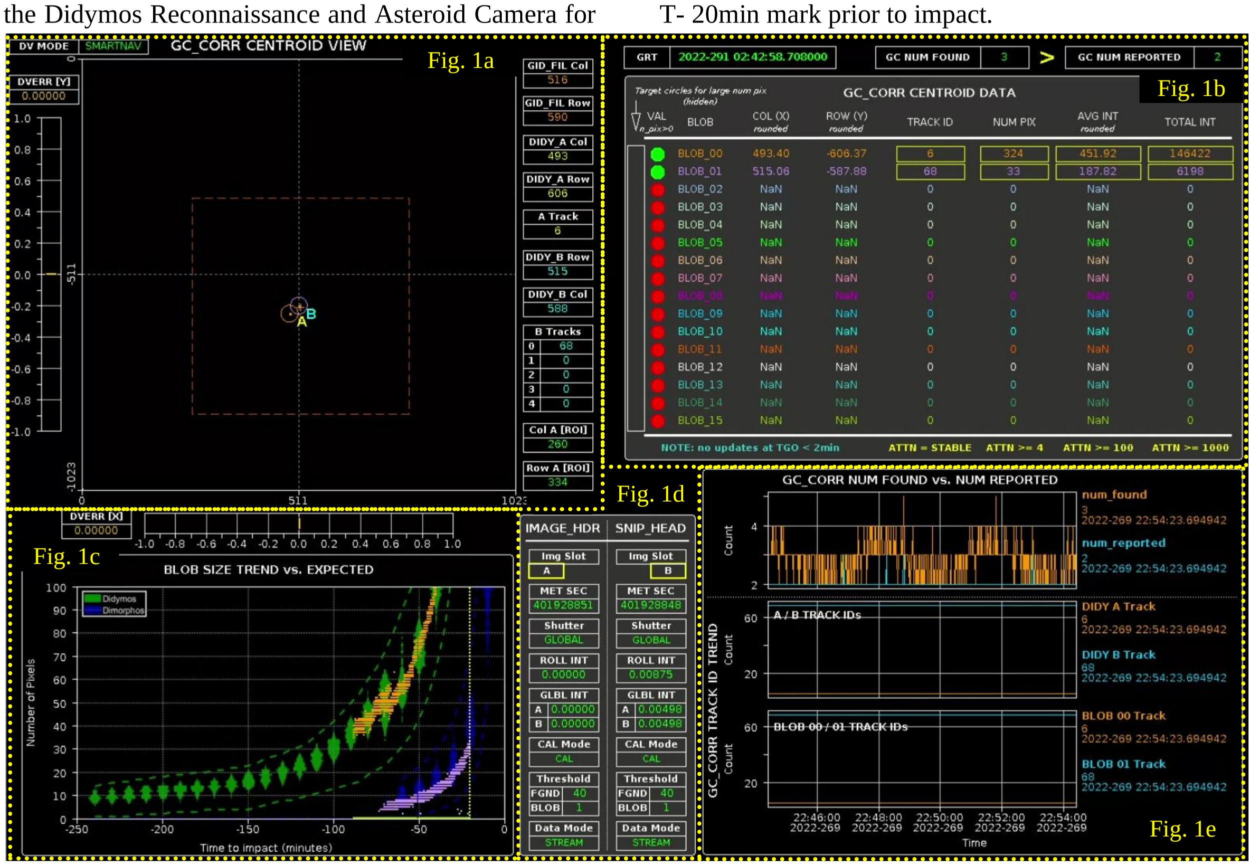

Figure 1. Blob and Centroid Display (T- 20min), updated at a 1 sec cadence. **a)** Geometric view of the location of centroids from DRIP, annotated with SMART Nav-reported identification as Didymos (obj. A) and Dimorphos (obj. B). Red dotted square denotes active 512x512 window used for live image streaming. **b)** Listing of up to 16 blobs reported by DRIP along with their coordinates, characteristics, and SMART Nav assigned track IDs – all computed onboard. **c)** Sizes of largest two blobs, as compared to expected results from models. **d)** DRIP image processing state telemetry. **e)** Number of all blobs found vs. blobs reported to SMART Nav for processing (after reduction by filtering), track IDs of largest two blobs, and IDs assigned as Didymos (obj. A) and Dimorphos (obj. B).

Blob and Centroid Display: During terminal approach, DRIP was configured to capture images for streaming and provide connected-component analysis (CCA) results to SMART Nav. The CCA algorithm was used to generate a list of contiguous objects above a threshold (blobs), compute their center coordinates (centroids), and report statistics such as blob number of pixels and blob intensity. These data were then used by SMART Nav to build tracks and ultimately determine which object was Didymos and which was Dimorphos. In the MOC, operators monitored blob statistics to understand where they were located in view (Figure 1a), how many, how big, and how bright these were calculated to be by DRIP (Figure 1b), and how the largest two blobs tracked expected model performance (Figure 1c). DRIP included onboard filtering functions to discard small blobs that otherwise would put unnecessary pressure on downstream SMART Nav processing. This functionality was monitored as well (Figure 1e), and used to monitor how Dimorphos came in and out of view when first being resolved by DRACO.

Engineering Image Display: While the blob and centroid display was useful for monitoring onboard processing performance, a big picture view was needed to put this information in context with actual image data as received from the spacecraft. The engineering image display (Figure 2) showed this concisely, with key summary data displayed alongside and overlaid with the image. Focusing more on the image processing performance and telemetry in-context, this view differed from the web-based display broadcast live during the impact event, intended for a broader audience and with a different set of overlays. The engineering image display let the MOC team confirm that DRIP and SMART Nav were tracking the correct objects, and that the blob ID'd as Dimorphos was indeed the smaller, dimmer object. Automatic zoom-ins of both Didymos and Dimorphos provided first-look basic shape and size characteristics, and an ability to visually track the DRACO image detector maximum pixel value to monitor and inform if there is saturation. Immediately after impact, the scripts used to generate this display were reused for quickly generating an impact sequence movie and impact image mosaic for broadcast to the public.

Conclusion: The DART mission terminal approach was a four-hour dynamic event that required real-time monitoring of onboard image processing performance. Unlike many flyby missions, relying solely on static telemetry view data and analyzing post-event imagery was not an option. A carefully overlaid live-view of both telemetry and image data was necessary to quickly visualize spacecraft performance, health, image quality, and targeting state. Future missions with dynamic events can benefit from a similar approach, joining telemetry data and instrument observational data in real-time for mission operations use.

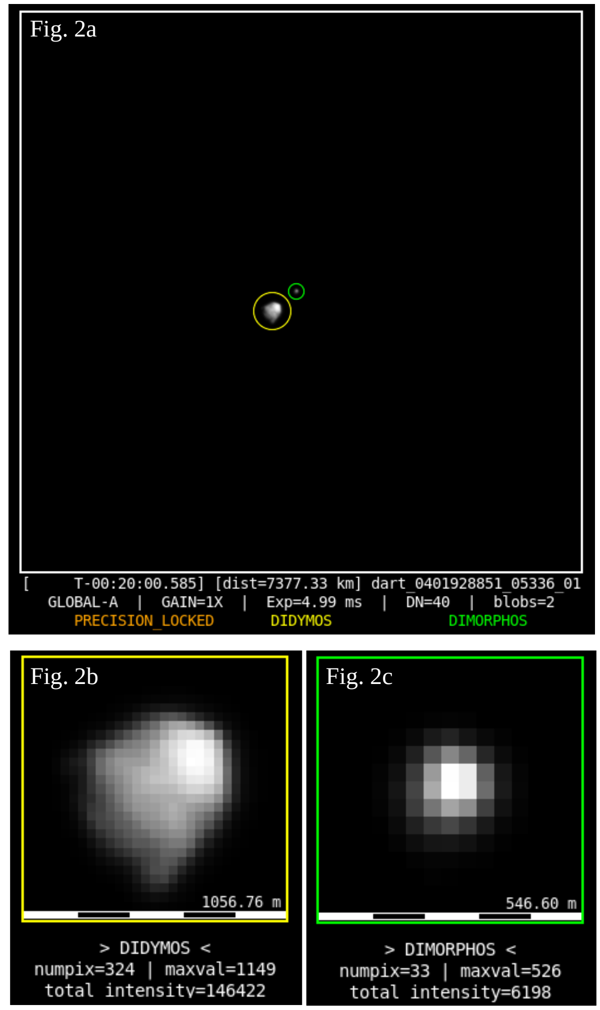

Figure 2. Engineering Image Display (T- 20min, at same time instance as display in Figure 1), updated at a ~30 sec cadence as live image data became available for analysis in the MOC. Contrast stretching applied on the ground to enhance visual. **a)** Overlay view, showing blobs identified as Didymos and Dimorphos together with the real image as computed onboard the spacecraft. Time to impact (T-), distance to-go, number of blobs detected, and other engineering state data are also shown. **b)** Zoom-in of blob identified as Didymos. **c)** Zoom-in of blob identified as Dimorphos. In both **b)** and **c)**, number of pixels in blob, total blob intensity, value of maximum pixel, and scale bars are also shown.

References: [1] Daly, R. T. et al. (2023) *Nature*, in revision. [2] Thomas, C. et al. (2023) *Nature*, in revision. [3] Cheng, A. F. et al. (2023) *Nature*, submitted. [4] Chen, M. H. et al. (2018) *AAS GNC*, 18-063. [5] Bekker, D. et al. (2021) *IEEE SCC*, 122-133. [6] Fletcher, Z. J. et al. (2022) *SPIE*, 121800E.