# NASA's Double Asteroid Redirection Test (DART) DRACO – Testing and Preparation for Impact

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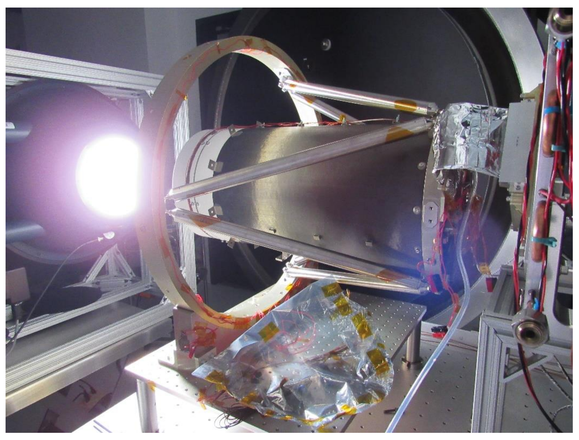
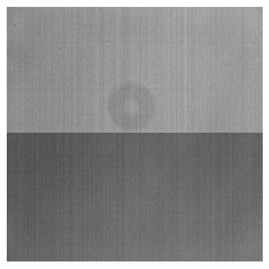
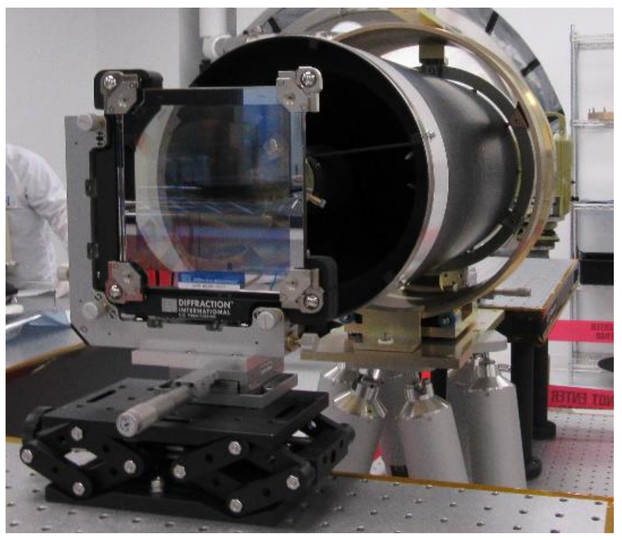
## Ground Testing

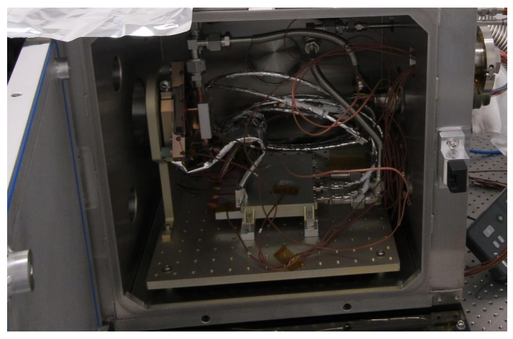


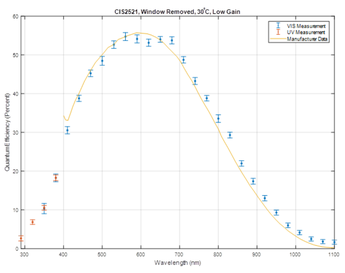


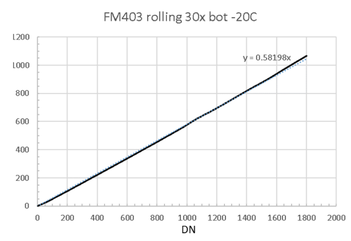
Once full assembled and aligned, DRACO went through an extensive ground characterization campaign at the operational temperature range of the instrument in a thermal vacuum chamber. Flat field, image quality, geometric and radiometric ground calibration was performed. (Top: DRACO positioned for throughput testing with an integrating sphere. Bot left: Ronchi ruling used for measuring Modular Transfer Function (MTF) of 0.12 @ 40cyc/mm. Bot right: flat-field showing both detector halves and a faint ghost




DRACO was aligned using a Computer Generated Hologram (CGH), which allowed aligning M1 to the test optical axis. M2 was then brought into position using interferometry and ground adjustments of M2. Final interferometric measurements of the aligned telescope prior to detector integration showed less than 0.09 waves RMS of wavefront error over the entire field.



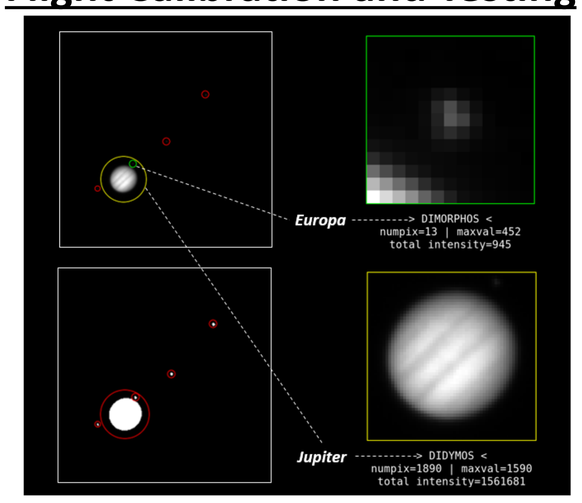


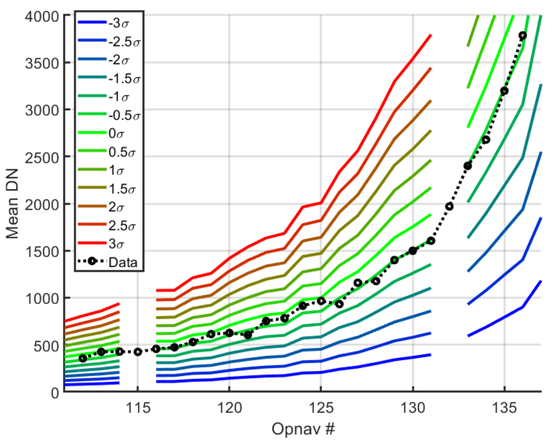

DRACO's detector was the BAE CIS2521F. Detector level characterization was performed, which measured dark current, gain, quantum efficiency, full well and read noise. Dark current was negligible at the -20C operating temperature and read noise was <2e- for 30x gain mode. Additional radiation testing was performed to qualify the detector and readout electronics to the space environment. (Top: detector and readout electronics in vacuum chamber for detector level thermal testing. Bot left: measured detector quantum efficiency. Bot rigt: measured gain, 30x rolling shutter data shown)

## Flight Calibration and Testing


DRACO's performance was calibrated in-flight primarily through use of star calibrations. Geometric, radiometric and straylight calibrations were performed to assess performance of DRACO. Furthermore, the point spread function (PSF) of stars were used to characterize the image quality of DRACO, which showed no degradation post-launch. (above: M38 Starfish cluster, taken with DRACO and used for in-flight calibration)

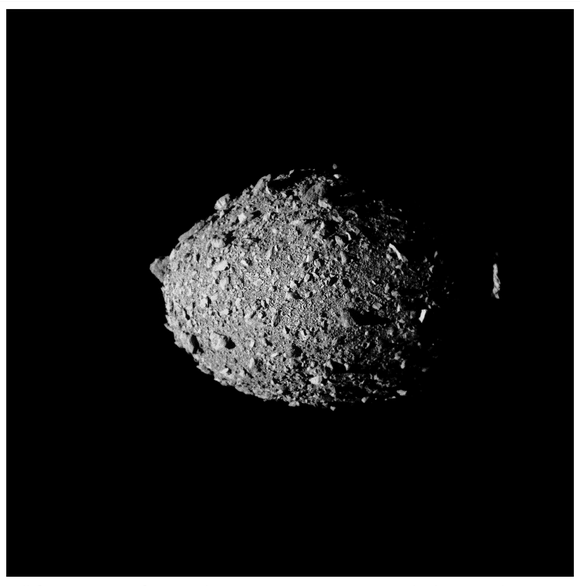



A key test to prepare for terminal was a series of Jovian moon tests. In these tests, DRACO was pointed at the Jovian system when a moon was about to transit behind of or in front of Jupiter. SMARTNav was enabled during these tests and used to track the moons and Jupiter as a imitation of Didymos/Dimorphos (Top: Europa is in process of emerging from Jupiter, with very similar geometry to terminal. Bottom left: thresholded image of same scene used for SMARTNav)

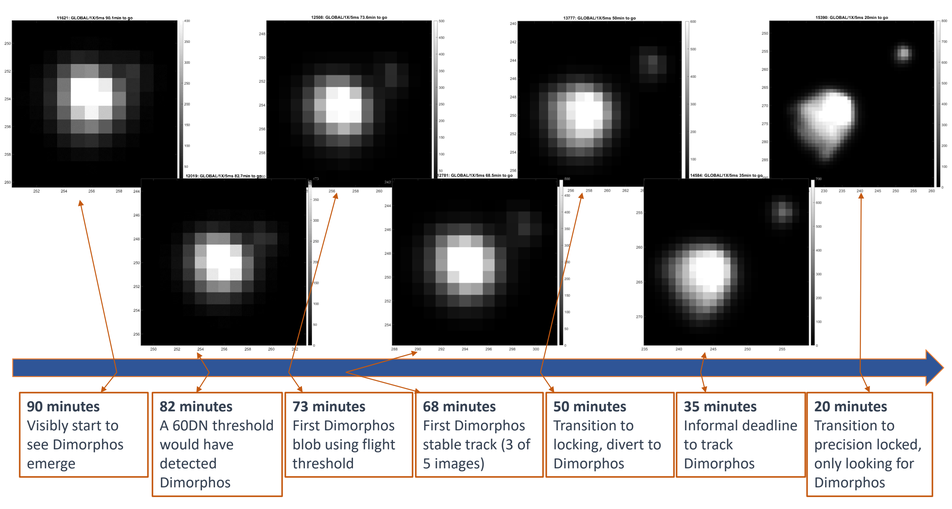



Starting at 30 days prior to impact, Optical Navigation (OpNav) images were taken of Didymos every 5 hours. These images were used to perform trajectory correction maneuvers on approach to Didymos prior to changing over to autonomous on-board targeting with SMARTNav. (Above: time sequence of Didymos brightness in DRACO images over a series of OpNav images, showing the system matching the expected brightening well)

## Terminal



Full-frame image of Dimorphos. Composite image using highest resolution image taken for each region of on Dimorphos. Impact location is shown near the center of the illuminated region and highlighted in the image on the right. Shadowed regions of Dimorphos contain enough signal from reflected light off Didymos that the full shape of Dimorphos can be determined.




Final complete image taken of Dimorphos, taken at 1.818 seconds prior to impact with a pixel scale of 5.5cm showing an area of ~784 m$^2$.Final images of Dimoprhos were used to characterize the impact site

*"SMART Nav Guidance: Ensuring Asteroid Impact for the DART Mission," Jensenius, M.A. et al. 45th Annual American Astronautical Society Guidance and Control Conference, AAS-23-135.*
*"On-orbit DRACO Calibration for DART SMART Nav," Sawyer, C.A. et al. 45th Annual American Astronautical Society Guidance and Control Conference, AAS-23-111.*
*"SMART Nav Targeting: In-flight testing and DART terminal phase performance,", Ericksen, P.S. et al. 45th Annual American Astronautical Society Guidance and Control Conference, AAS-23-154.*
*"Real-time Monitoring of Onboard Image Processing Performance during DART terminal approach," Bekker. D.L. et al. 54th Lunar and Planetary Science Conference, 13-17 March 2023.*
*"Successful Kinetic Impact into an Asteroid for Planetary Defense," Daly, R.T., Ernst, C.M., Barnouin, O.S. et al. Nature (2023)*

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DART
Double Asteroid Redirection Test

Goddard Space Flight Center
Johnson Space Center
Langley Research Center
Glenn Research Center
Marshall Space Flight Center
Planetary Defense Coordination Office

Johns Hopkins Applied Physics Laboratory
Jet Propulsion Laboratory, California Institute of Technology
Aerojet Rocketdyne
Lawrence Livermore National Laboratory
Auburn University
University of Colorado Boulder
University of Maryland
Northern Arizona University
Planetary Science Institute