

DART GUIDANCE & CONTROL, SYSTEM PERFORMANCE, AND CHALLENGES



Joshua Richman, Daniel O'Shaughnessy, Sarah Hefter, Emil Superfin, Ian Murphy
Johns Hopkins University Applied Physics Laboratory, Laurel MD, 20723, USA

Mission Concept

- The NASA Double Asteroid Redirection Test (DART) is a technology demonstration for the kinetic impactor method of planetary defense against asteroids. The DART spacecraft was launched in November 2021 and successfully impacted the asteroid Dimorphos, the smaller of two bodies in the Didymos binary system, on September 26th, 2022.
- This impact marks the first time humanity has altered the course of a celestial body, and ongoing science investigations will reveal the asteroid's composition and determine how effectively the kinetic impactor transferred momentum to the system.

Guidance and Control Subsystem

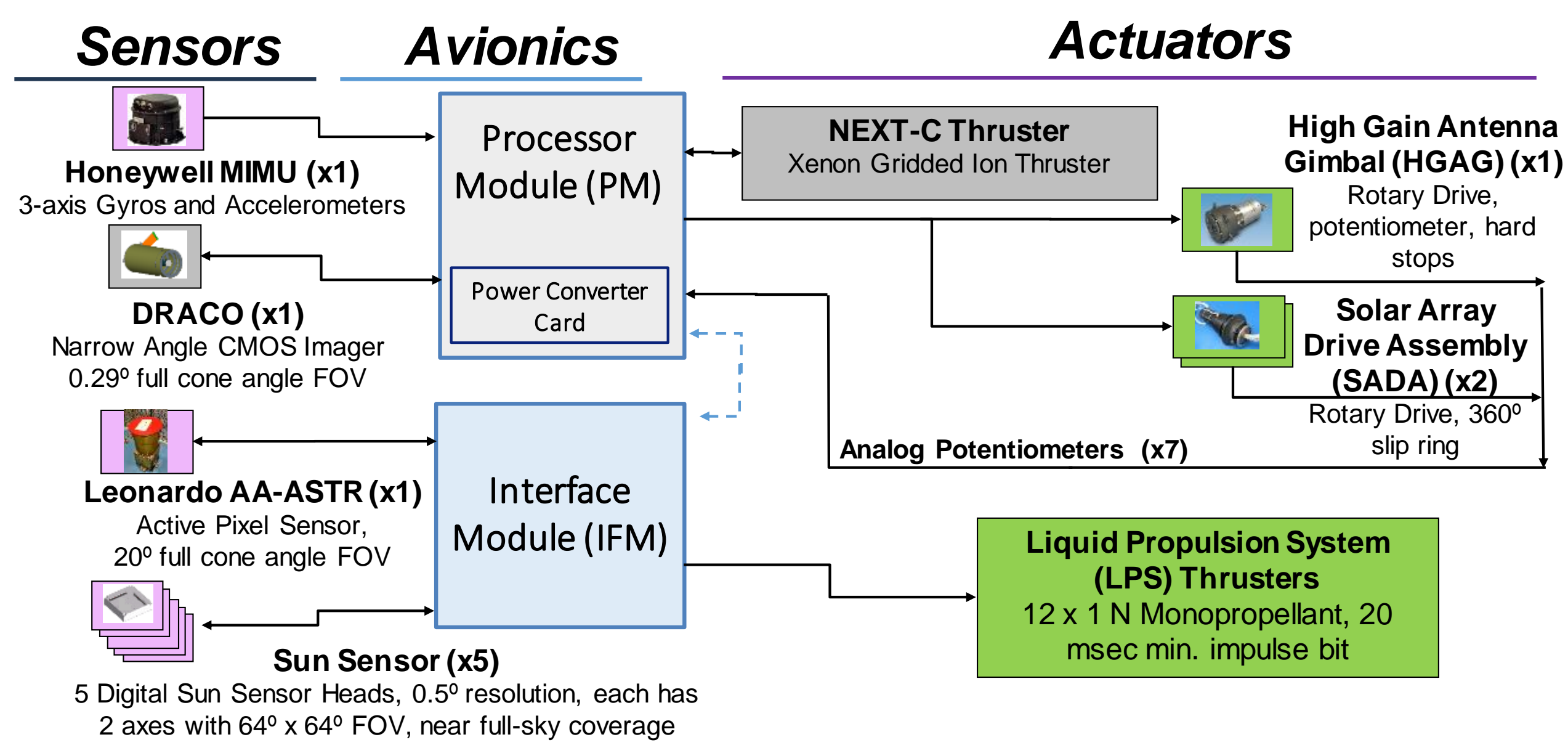


Figure 1: Guidance and Control hardware block diagram with sensors, avionics, and actuators

Terminal Guidance / SMART Nav

- The Didymos Reconnaissance and Asteroid Camera for Optical Navigation (DRACO) camera captured images of the asteroid system at 1 Hz
- Images were processed by the Small-body Maneuvering Autonomous Real-Time Navigation (SMART Nav) system, which used thresholding, blobbing, and centroiding techniques to calculate an inertial Line of Sight (LOS) estimate. Delta V commands were generated based on the projected miss distance, miss distance uncertainty, remaining propellant, and time to impact.
- A simple switch feeds SMART Nav commands into the Delta V control block, and they are executed identically to ground-commanded burns

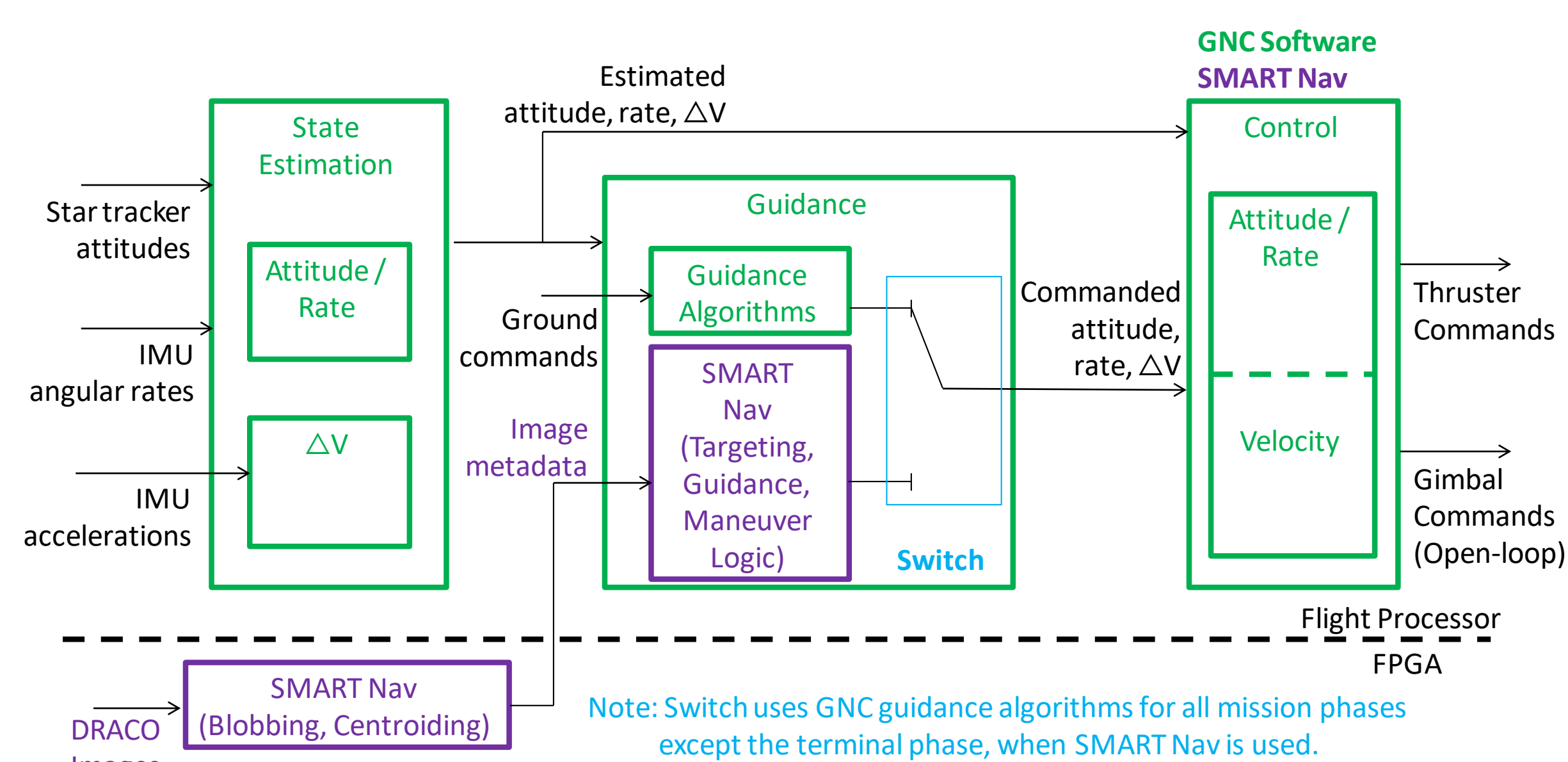
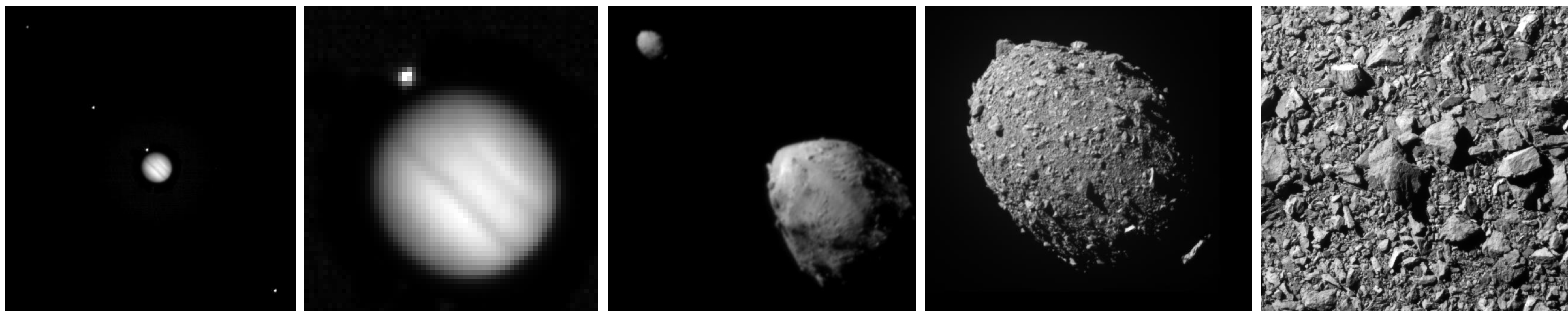


Figure 2: Guidance and Control software block diagram. Ground commands or autonomous SMART Nav commands can be sent from the Guidance block to the Control block depending on the mission phase (normal operations vs. terminal phase)

Photos

Credit: NASA/Johns Hopkins APL



The Jovian System (left) was observed during a series of DRACO Calibration tests which collected over 5000 images. SMART Nav algorithms were exercised as Europa emerged from behind Jupiter (right) similar to Dimorphos emerging during the terminal phase

Didymos and Dimorphos 2.5 minutes before impact

Final full image of Dimorphos 11 seconds before impact

Final full image 1.82 seconds before to impact

Thermal Alignment Issues

- Star tracker characterization tests in flight revealed secular drifts in the alignment between the star tracker and the DRACO imager. The drifts were believed to be caused by transient thermal environments caused by spacecraft slews (changing the incident sun angle) in preparation for imaging tests.
- Subsequent thermal tests conducted after reaching thermal equilibrium revealed a secondary effect: heater cycling on a component near the star tracker and DRACO resulted in cyclical changes in the sensor alignment
- Over 100,000 images were captured and processed across 7 different characterization tests

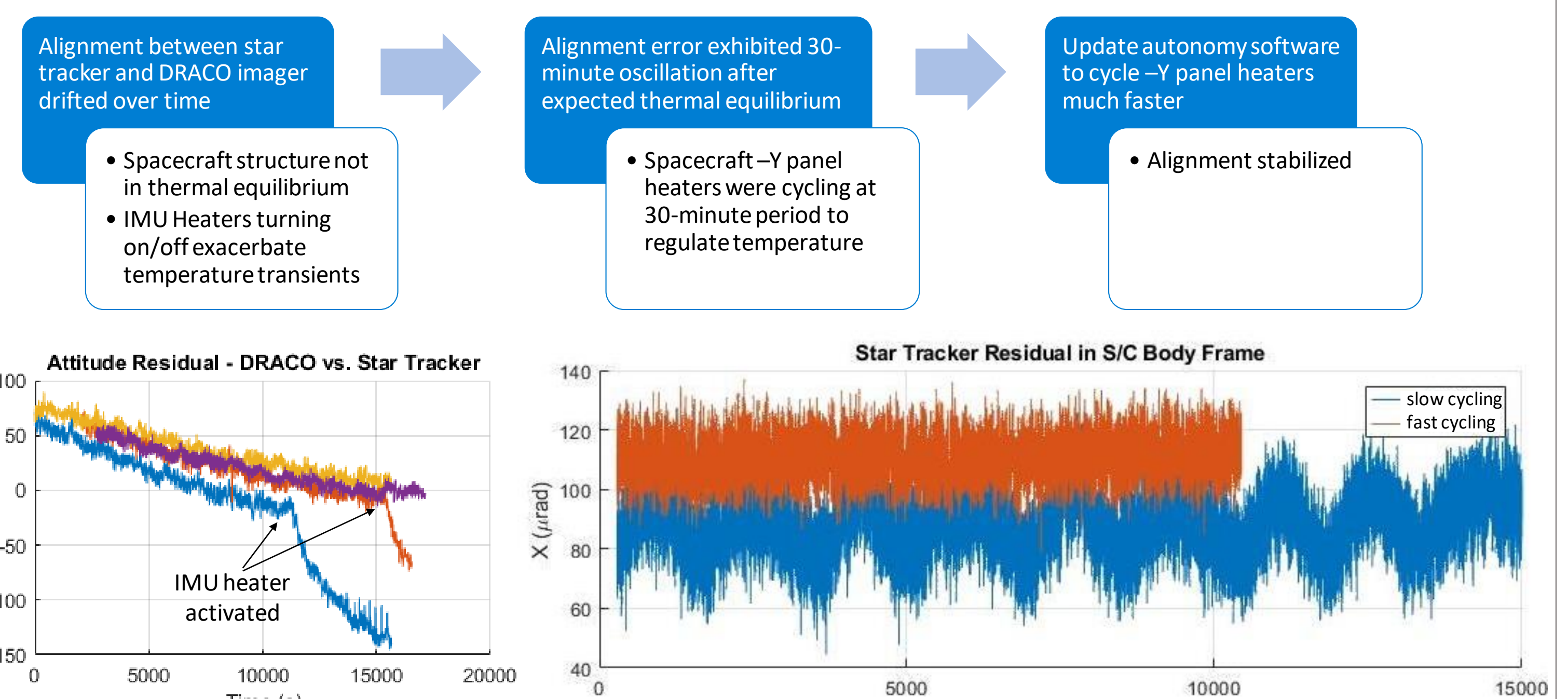


Figure 3 (above): Calculated angle error between star tracker attitude measurement and from DRACO image processing. The left plot shows a secular drift produced by thermal transients after slews and the effect of the IMU heater activating. The right plot shows the alignment oscillation with two different -Y panel heater cycle settings

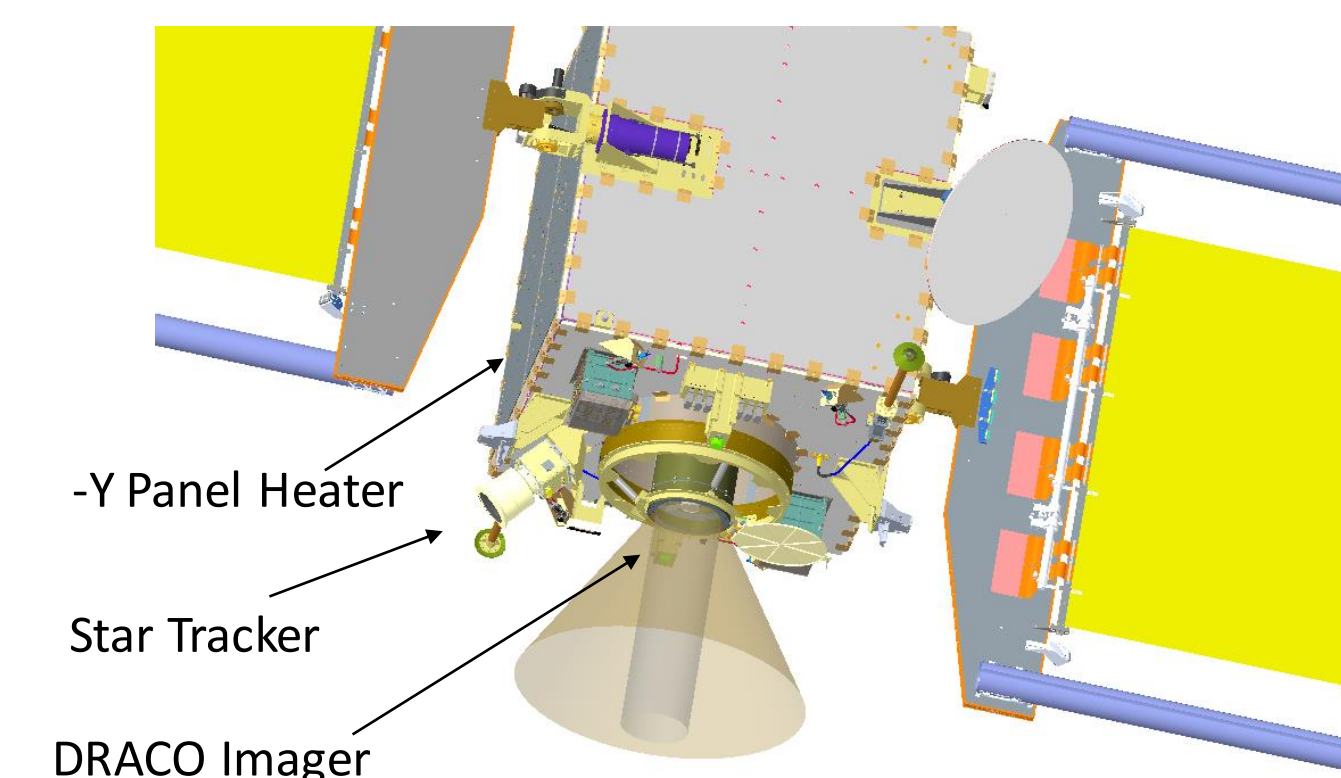


Figure 4 (left): Locations of the Star Tracker, DRACO, and -Y Panel heater on DART. Thermal expansion of the panel heater causes thermal expansion of the structure, slightly warping the Star Tracker and DRACO panel

Expected Impact Performance

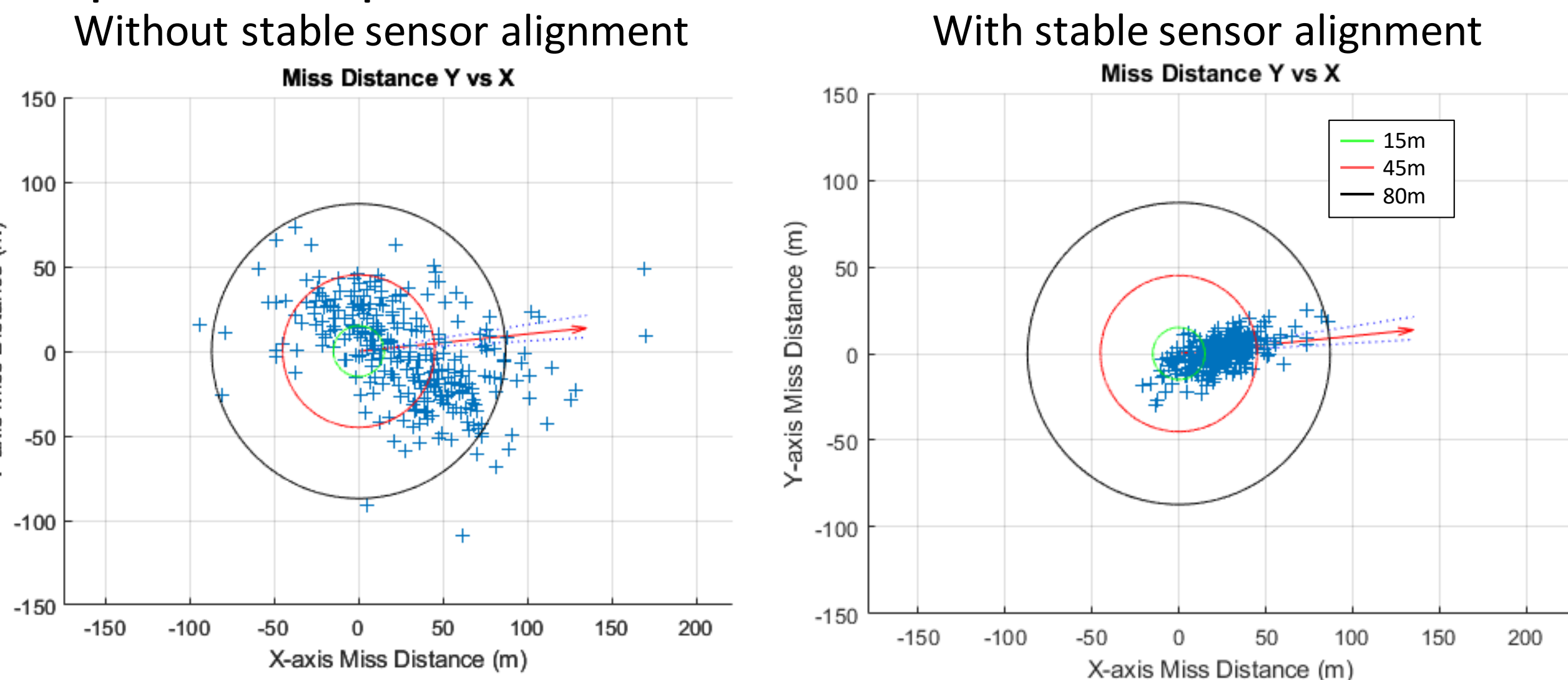


Figure 5: Monte Carlo Simulation results showing the distribution of miss distance from the center of Dimorphos at impact, with (right) and without (left) stabilized sensor alignment

- Accurate and stable alignment between star tracker and DRACO was critical for LOS estimation, dramatically increasing the performance of the SMART Nav terminal guidance system.
- DART impacted Didymos within 25m of the geometric center, and within 2m of the center of the illuminated figure

