DAWN

A Journey to the Beginning of the Solar System

Dawn Lessons

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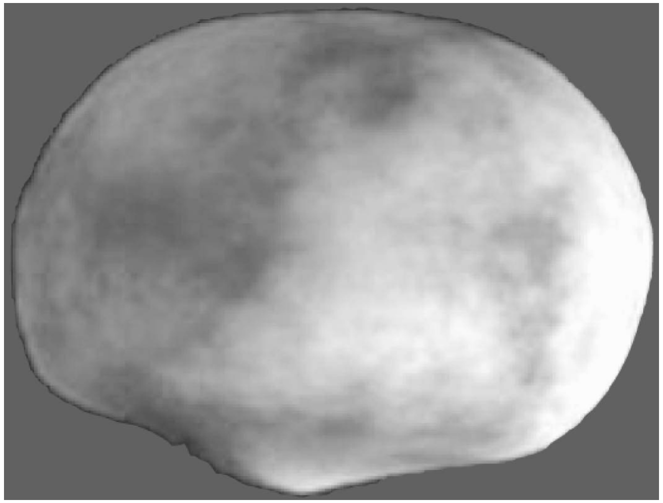
(Inputs From Many)

Project Highlights

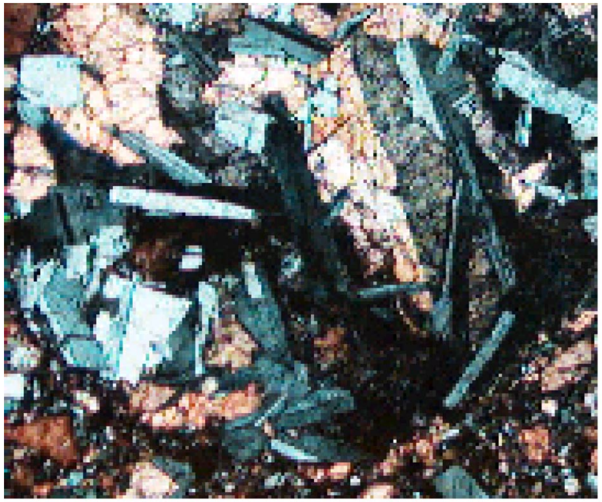
- Dawn is the 9th project in NASA's Discovery Program
- The Dawn PI is Professor Chris Russell from UCLA
- The day to day management of Dawn is performed by JPL with Orbital Sciences Corporation as the system contractor
- Objective is to examine the geophysical properties of the two most massive objects in the main asteroid, Vesta and Ceres, to yield insights into important questions about the evolution of the solar system
- Dawn is enabled by Ion Propulsion

Scientific Motivation

- By comparing Vesta and Ceres, Dawn will yield insights into conditions and processes acting at the formation of the solar system.
  - Although they are at similar distances from the Sun, Vesta was melted and is dry, while Ceres did not melt and retained water.
- Vesta and Ceres are unlike any bodies that have been visited by a spacecraft.
  - They are the two most massive objects in the asteroid belt.
  - Vesta is the source of many meteorites.

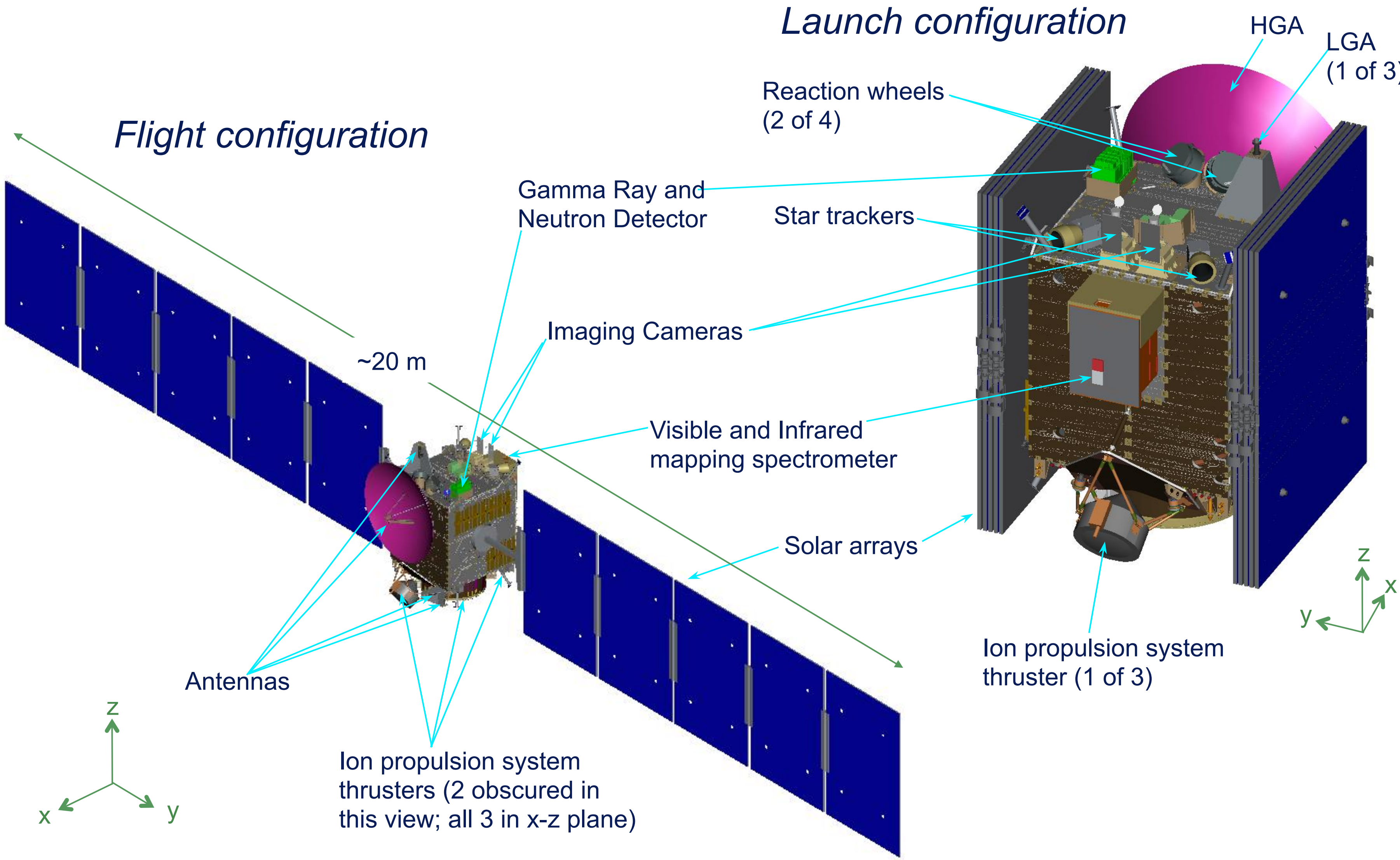


Hubble image of Vesta



Crystals in meteorite

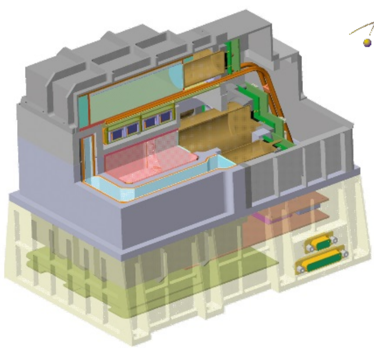
Spacecraft Configuration



Scientific Payload

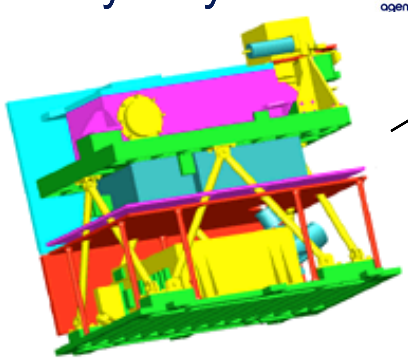
Gamma-ray and neutron spectrometer

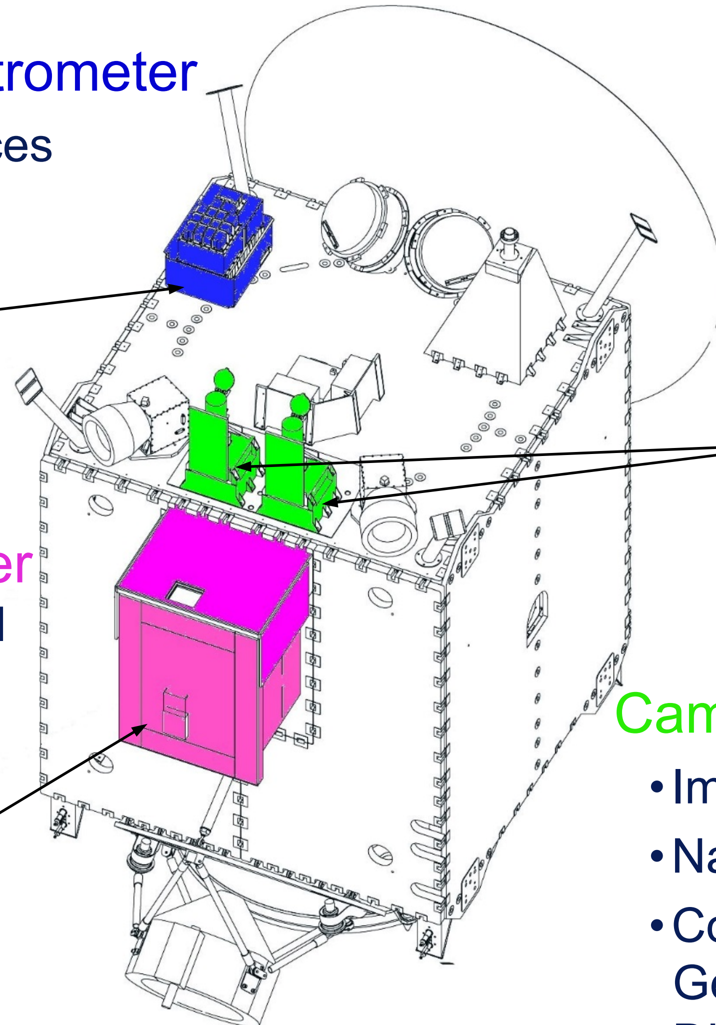
Mapping of elemental abundances



Visible/IR mapping spectrometer

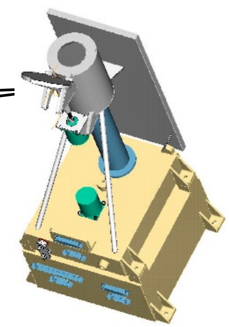
- High resolution mineralogical and temperature mapping
- Contributed by Italy's ASI



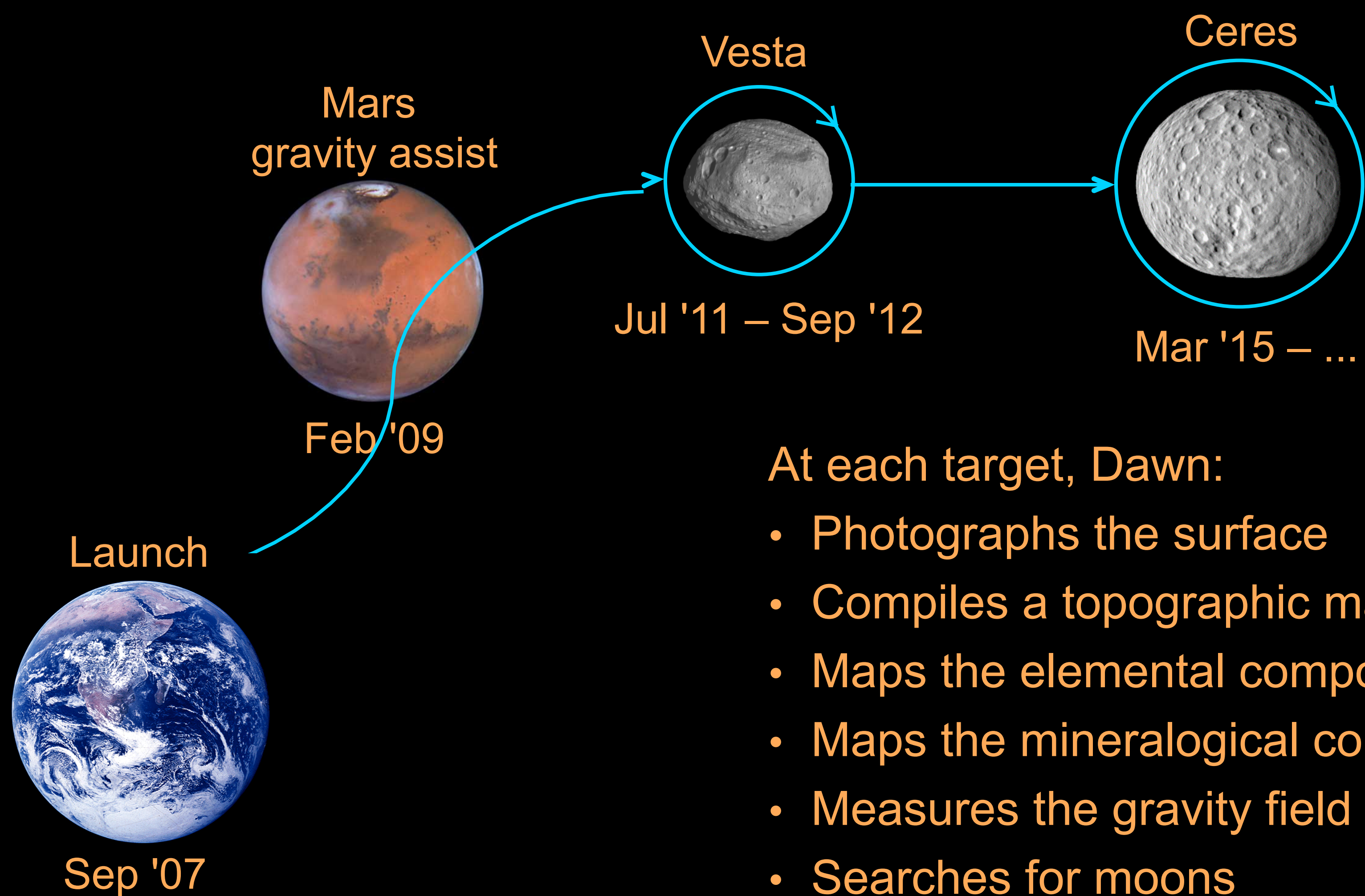


Cameras (2)

- Imaging science
- Navigation
- Contributed by Germany's MPS & DLR



Mission Itinerary



At each target, Dawn:

- Photographs the surface
- Compiles a topographic map
- Maps the elemental composition
- Maps the mineralogical composition
- Measures the gravity field
- Searches for moons

Lessons Learned – Fault Protection

Lesson Learned

•Fault protection (FP) is a very tricky product to specify, implement, and verify. JPL has significant cultural differences with many of our contractors in the fault protection realm. Inexperienced contractors will have difficulty meeting commitments on fault protection performance and/or schedule, even when they have strong consistent staffing.

Experience

•Orbital was fully aware that FP development would be challenging and assigned one of their best fault protection engineers to Dawn and JPL did the same.

•Dawn FP development effort was consistently behind schedule, and consistently struggled to demonstrate compliance with requirements. As development proceeded, it became clear that JPL was having difficulty expressing the desired FP behavior via the traditional requirements process and difficulty communicating the degree of analysis and testing that would be required to certify the flight readiness of the FP.

•It became clear that additional resources (both people and testbeds) would be required to complete the fault protection development effort.

Recommendation

•Carefully consider the costs, risks, and benefits of asking an inexperienced contractor to deliver the Flight System fault protection. You may get a higher-quality, lower-cost product by taking over FP delivery responsibility.

Lessons Learned – Software Simulators

Lesson Learned

•Software simulators are a good investment for any development effort that will require significant fault protection testing and/or mission scenario testing. Software simulators are relatively cheap and easy to replicate, and they enable a lot of parallel testing by multiple testers or test teams.

Experience

•The FP collaboration would not have been possible without the introduction of additional testbeds, specifically a suite of software simulators. Each simulator was a single UNIX workstation that hosted the flight code, the appropriate flight hardware simulations (sensors, actuators, I/O delays, etc), as well as the dynamics simulation.

•The Dawn software simulators did not replace the hardware-in-the-loop Flight System Testbeds, but they were an outstanding complement to the Flight System Testbeds. They were relatively cheap and easy to replicate, they could be located and operated in a normal office environment, and they were more amenable to running the types of tests that are common in the fault protection test program (e.g. "batch" tests, long duration tests, etc).

Recommendation

•Software simulators should be included in the baseline set of test assets, for any mission that anticipates either a significant fault protection test campaign, or a significant mission scenario test campaign.

Lessons Learned – Closed Loop AACS 1

Lesson Learned

•Lack of a closed-loop ACS test capability in the ATLO environment can be a significant, high-risk TAYF exception. It can lead to testability gaps at the ACS level, the Flight System level, and even the project-level mission scenario tests.

Experience

•Orbital's heritage approach to the ACS V&V was to exercise the ACS algorithms in concert with a flight system dynamics simulation, using the Flight System Testbed. The baseline plan for the ACS V&V included some basic phasing tests on the Flight System in ATLO, but it did not include any closed-loop algorithm tests with the Flight System in ATLO. Without a closed-loop test capability in ATLO, the project was unable to operate the flight ACS outside of idle mode; this was quickly identified as a significant TAYF exception for both the Flight System V&V campaign, as well as the project-level mission scenario tests.

•A high fidelity testbed would have addressed the ATLO TAYF and could be used as a workhorse for formal closed-loop verification and sequence validation. The Dawn testbed was not a high fidelity testbed. The testbed hosted an engineering model C&DH, but all subsystems were modeled with varying levels of fidelity. Many of the models had clear "heritage" from past missions, there was no clear paper trail linking the parameters in these models with flight or ground test data.

Lessons Learned – Closed Loop AACS 2

Experience

•Clearly, there was a significant gap between the V&V capabilities of the testbed (which was hardware-poor) and the V&V capabilities of the Flight System (in which the ACS sensors could not be properly stimulated). This gap was captured on the project's significant risk list, early in Phase C.

•Project systems engineering led a risk reduction campaign throughout Phase C/D. The primary objective was to improve the likelihood that a significant, mission-threatening ACS algorithm error would remain undetected during closed-loop testing. One of the pillars of this risk reduction campaign was the addition of a closed-loop testing capability to the ATLO environment. The ATLO closed-loop simulation interacted with the flight sensors and actuators that were used in safe mode. The ATLO simulation was also able to mimic an acceptable star tracker output in ATLO; although this capability did nothing to certify the flight readiness of the star tracker, it permitted flight-like operation of the ACS estimation and control algorithms during mission scenario testing.

Recommendation

•During Phase A/B, carefully review the Flight System provider's capabilities and plans for closed-loop ACS testing. These closed-loop test plans should address both the Flight System Testbed, and the Flight System itself. Identify any associated gaps in ACS testability, risk rate these gaps, and suggest appropriate mitigations.

Lessons Learned – Launch

Lesson Learned

•Flight Systems should be required to autonomously achieve and maintain a fully safe state after launch vehicle separation, even in the presence of credible faults. A fully safe state is one that is power-positive, thermally safe, and commandable.

Experience

•The Dawn Flight System has two very large solar array wings. During launch, each of these wings was held in the stowed position and deployed autonomously to maximize power and simplify AACS design. Full deployment of these solar array wings was crucial to mission success and a mission-critical event.

•In retrospect, the Project did not provide the Flight System with appropriate FP requirements for solar array deployment failures, and the Flight System failed to satisfy some of those requirements. There were two major shortcomings in the eventual Flight System design:

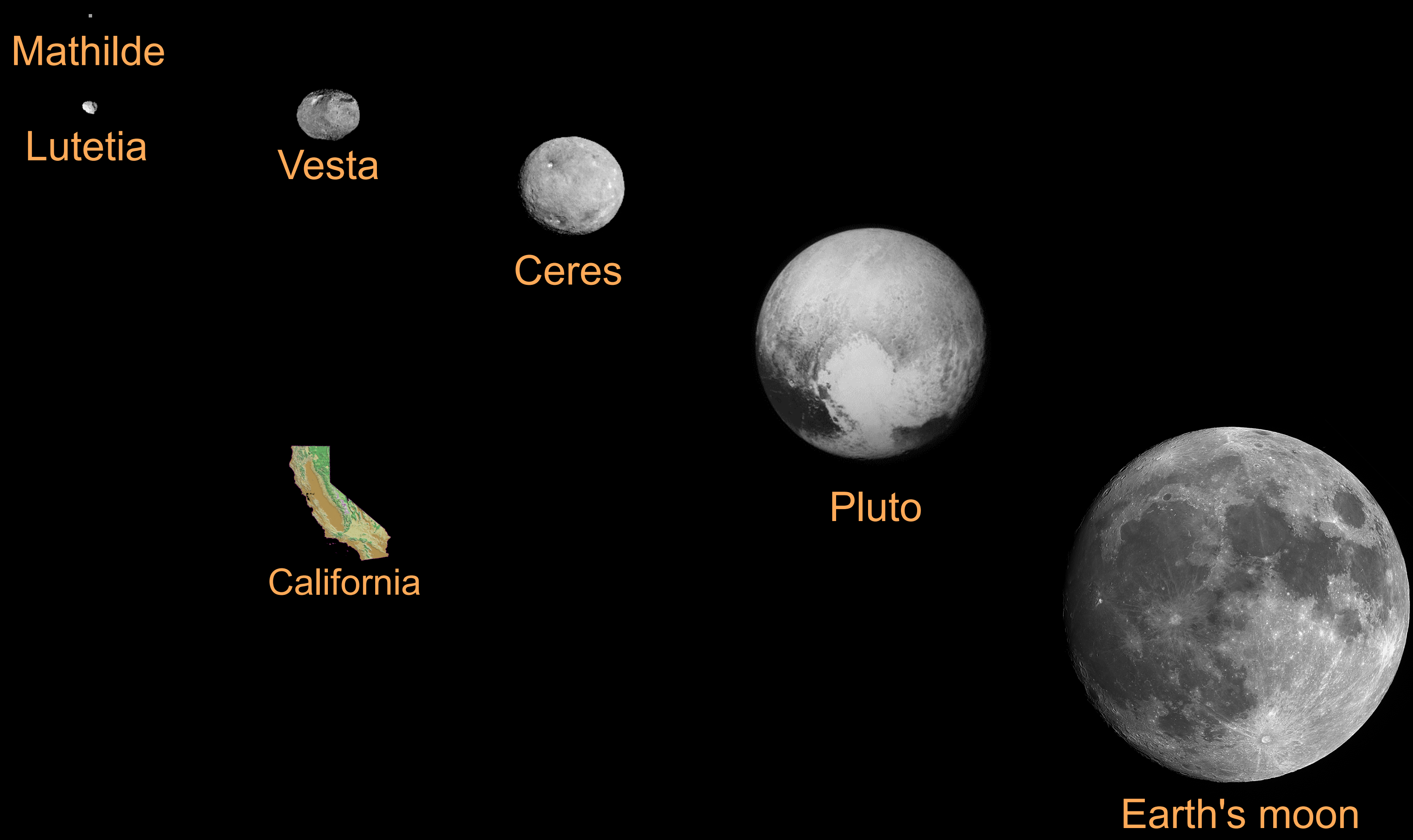
- 1) The Flight System was unable to autonomously achieve a power-positive attitude with two stowed solar array wings.
- 2) The Flight System was unable to maintain a thermally safe state with a stowed +Y solar array wing, because the thermal design for the +Y spacecraft panel relied upon louvers and radiators that were blocked by the stowed +Y solar array wing.

Recommendation

•Projects with critical deployments after launch vehicle separation should carefully identify and mitigate any credible faults that could prevent successful completion of those critical deployments. For those faults where the mitigation includes ground-in-the-loop interaction, the Flight System must be able to autonomously achieve and maintain a fully safe state, even in the presence of those faults.

BACKUP

Ceres and Vesta Size in Context



Coupling of Mass, Power, and Thrust Time

- For a mission using an ion propulsion system (IPS), mass and power are tightly coupled.
  - Power to the IPS translates directly to thrust.
  - Greater power yields both greater thrust and greater specific impulse.
- Because the IPS thrust is low, thrusting is required during ~ 80% of Dawn's interplanetary cruise and ~ 40% of the time orbiting the protoplanets.
  - Mass and power are important throughout the mission.
  - Deterministic thrusting periods typically last for years.
- Positive mass and power margins are necessary but not sufficient, because there also must be enough time to accomplish the required thrusting.
  - Missed-thrust margin ≡ the duration of unexpected missed thrusting that can be accommodated at a specified time.
- Because of their coupling, the margins for mass, power, and missed thrust cannot be assessed without careful attention to the others.

Ion Propulsion Is Essential for Dawn

- It would not be possible to rendezvous with either one of Dawn's targets using a conventional propulsion system within NASA's constraints.
- Without ion propulsion, a mission only to Vesta (the easier target to reach) would require:
  - 5500 lbs. of chemical propellants instead of 650 lbs. of xenon.
  - A new spacecraft structural design.
  - A high energy version of the Delta IV, instead of the Delta II.
  - One year longer flight time.

Responsibility Breakdown

UCLA

- Principal Investigator (Dr. Chris Russell)
- Science Data Center
- Education / Public Outreach Oversight

JPL

- Project management & implementation
- Mission & project system engineering
- Project safety & mission assurance
- Launch vehicle interface
- Payload systems
- Mission operations, including S/C
- Navigation
- Ion Propulsion System (IPS)
- High Voltage Electronics (HVE)
- Small Deep Space Transponders (SDSTs)
- Traveling Wave Tube Amplifiers
- JPL IV&V

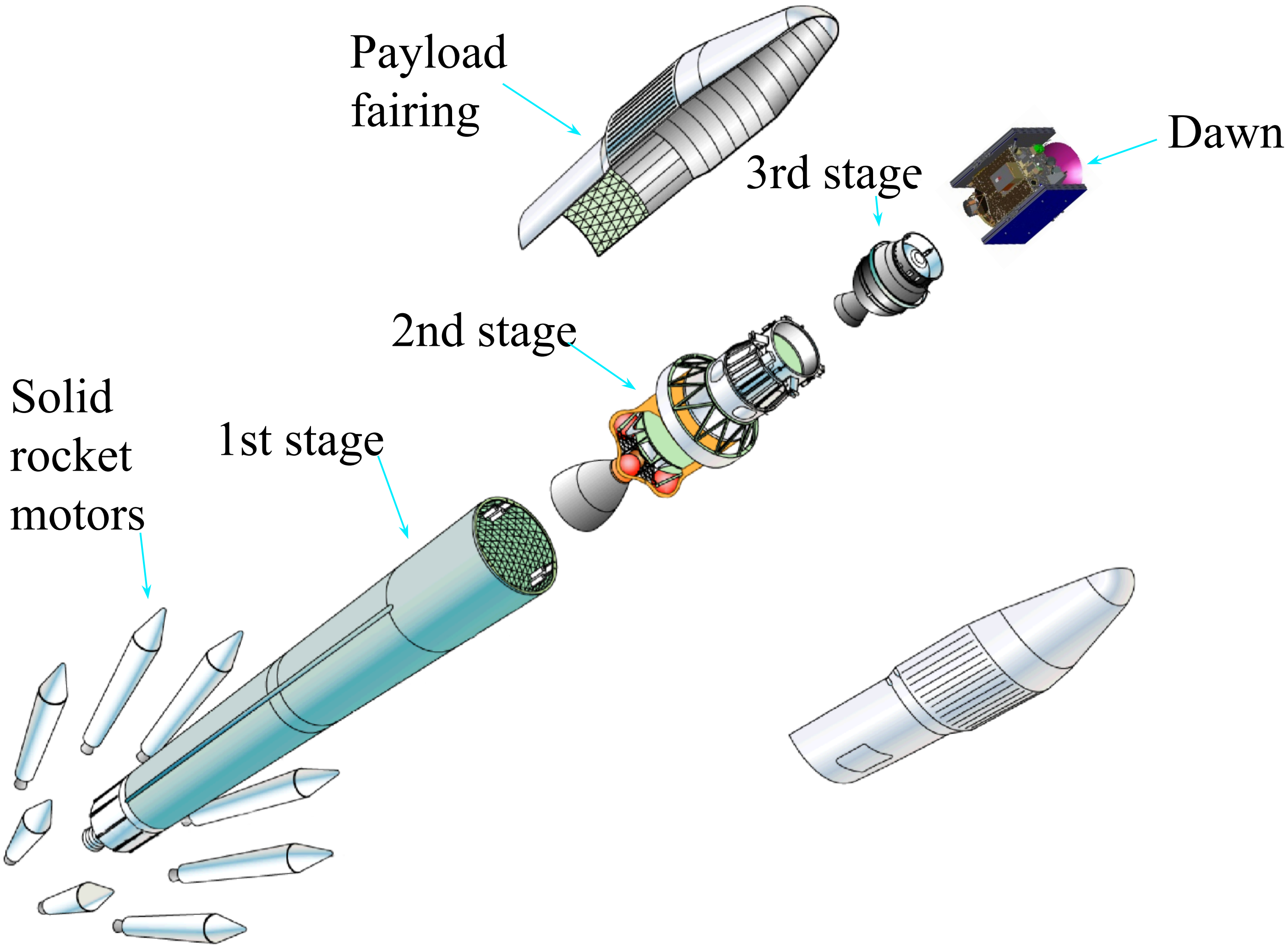
ORBITAL

- Spacecraft bus (hardware & software)
- Integration & test of flight system (hardware & software)
- Flight system transport
- Lead project KSC operations

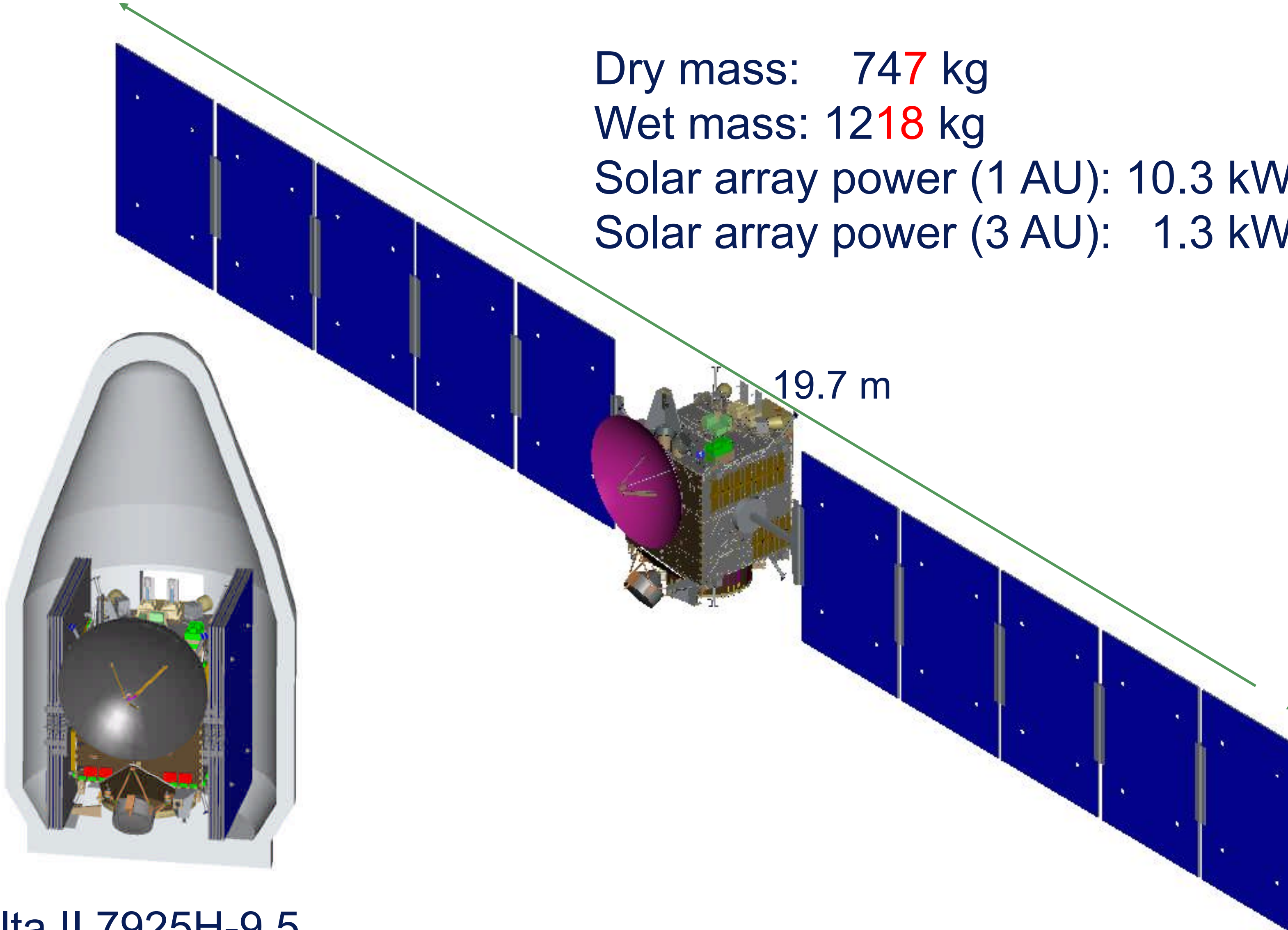
OTHER

- MPAe [It's now MPS, and DLR remained a contributor] - Framing Camera
- ASI - Mapping Spectrometer
- LANL - Gamma Ray and Neutron Detector (GRaND)
- KSC - Launch vehicle & Services
- NASA IV&V Center – NASA IV&V
- Univ of Maryland - E/PO Management
- McREL - E/PO contractor
- GSFC [Thermal vac ended up being at NRL, not GSFC, and spin balance ended up at Orbital] -

Delta 7925H-9.5 Launch Vehicle



Spacecraft



Dry mass: 747 kg
Wet mass: 1218 kg
Solar array power (1 AU): 10.3 kW
Solar array power (3 AU): 1.3 kW

Delta II 7925H-9.5

Dawn Trajectory