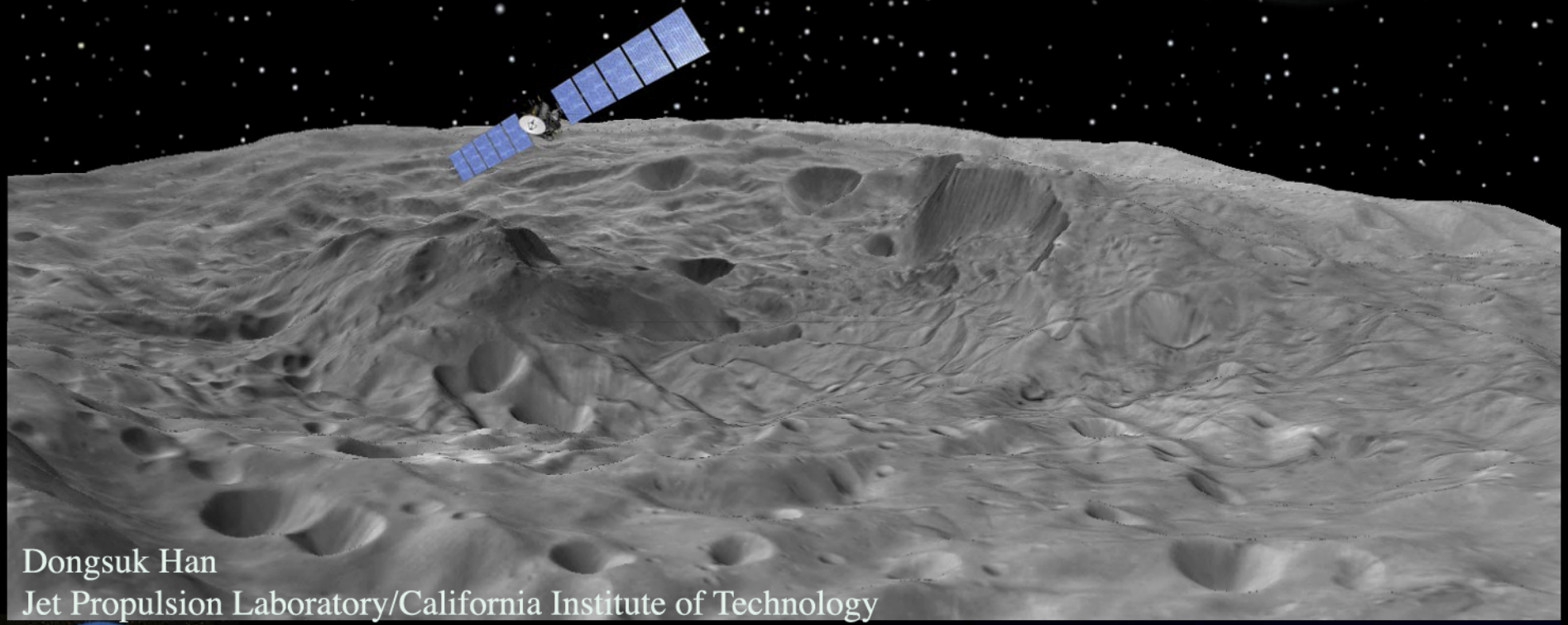
23rd ISSFD

Orbit Transfers for Dawn's Vesta Operations Navigation & Mission Design Experience



Dongsuk Han
Jet Propulsion Laboratory/California Institute of Technology

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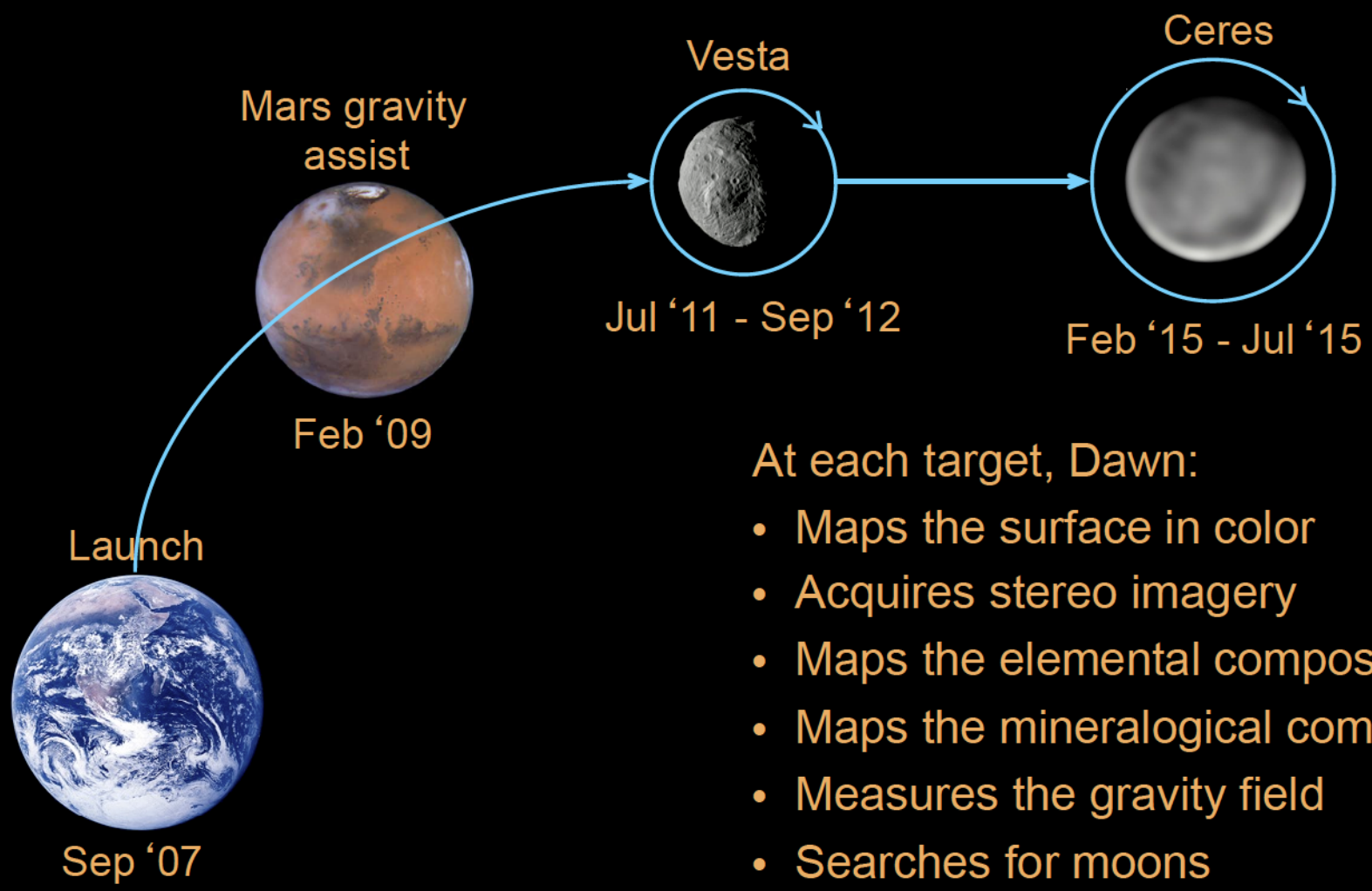
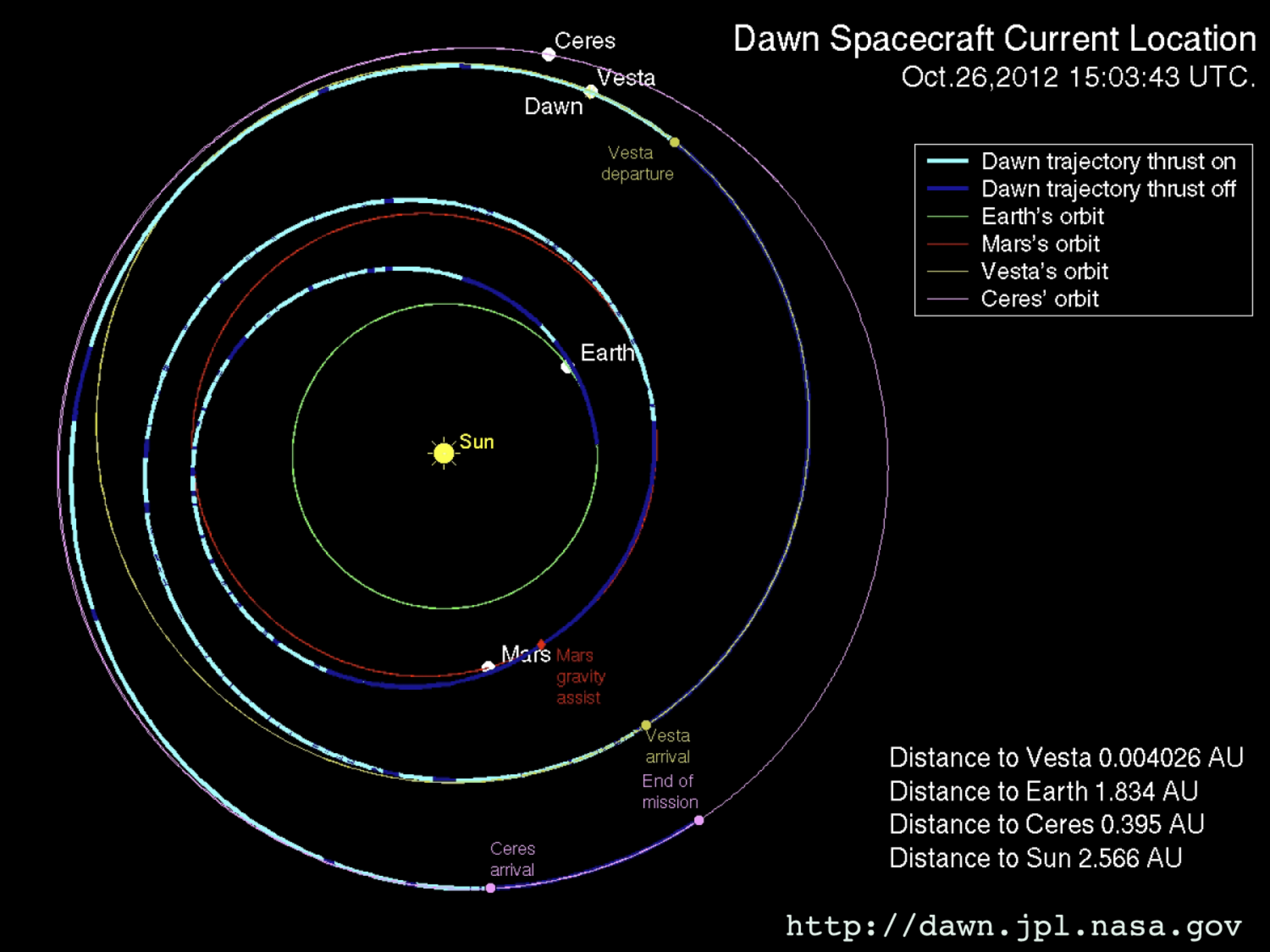
Mission Itinerary

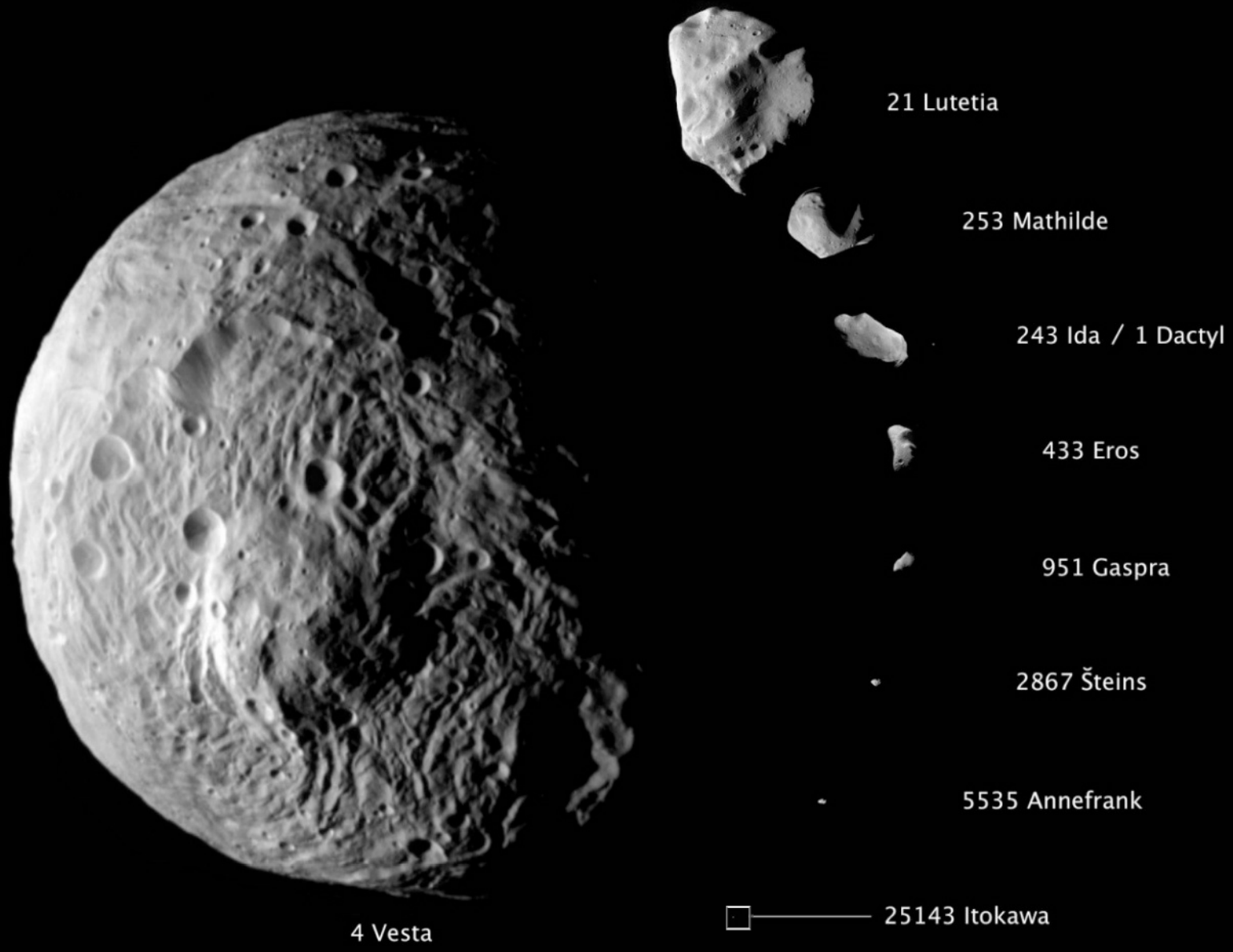


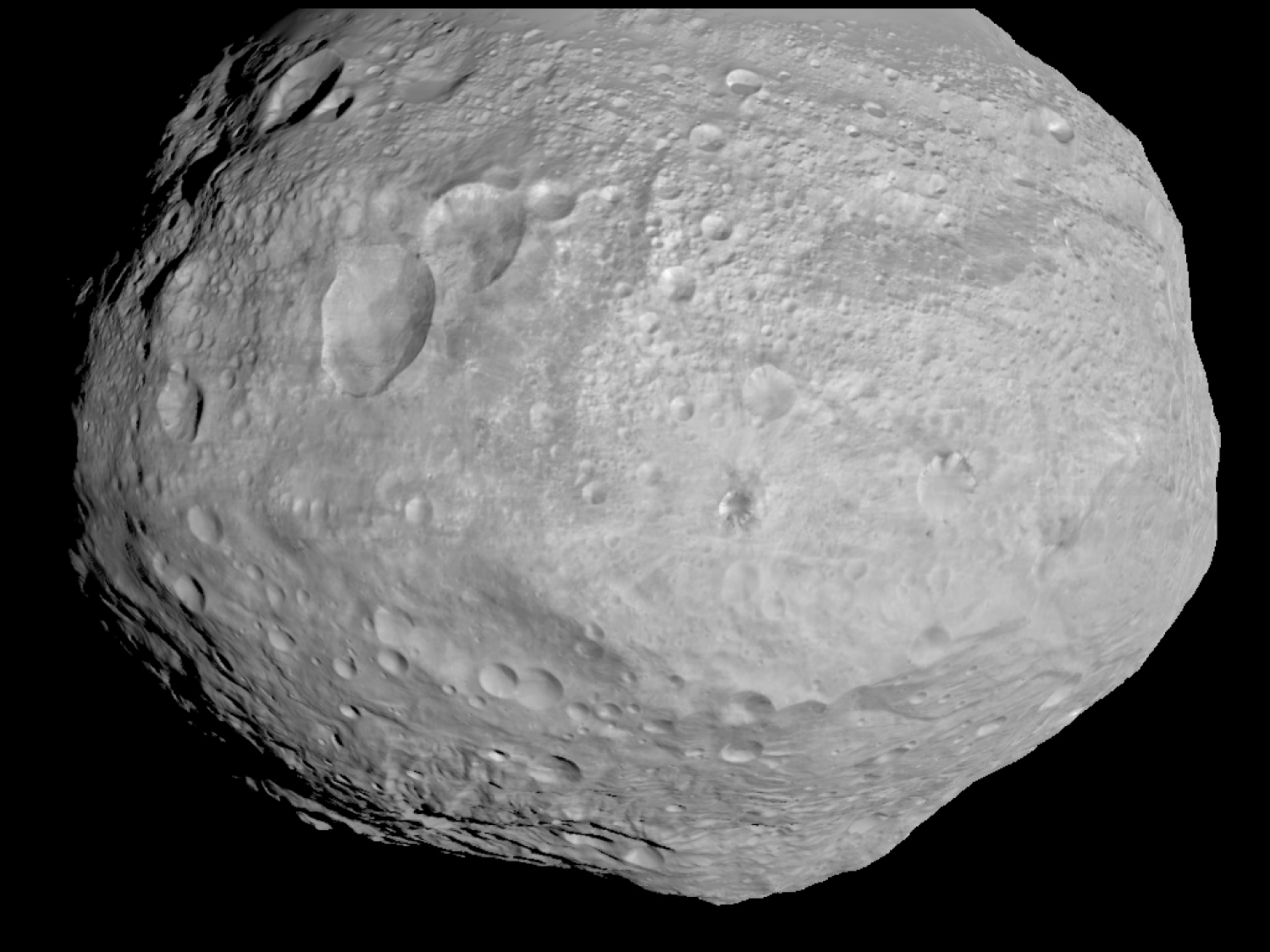
At each target, Dawn:

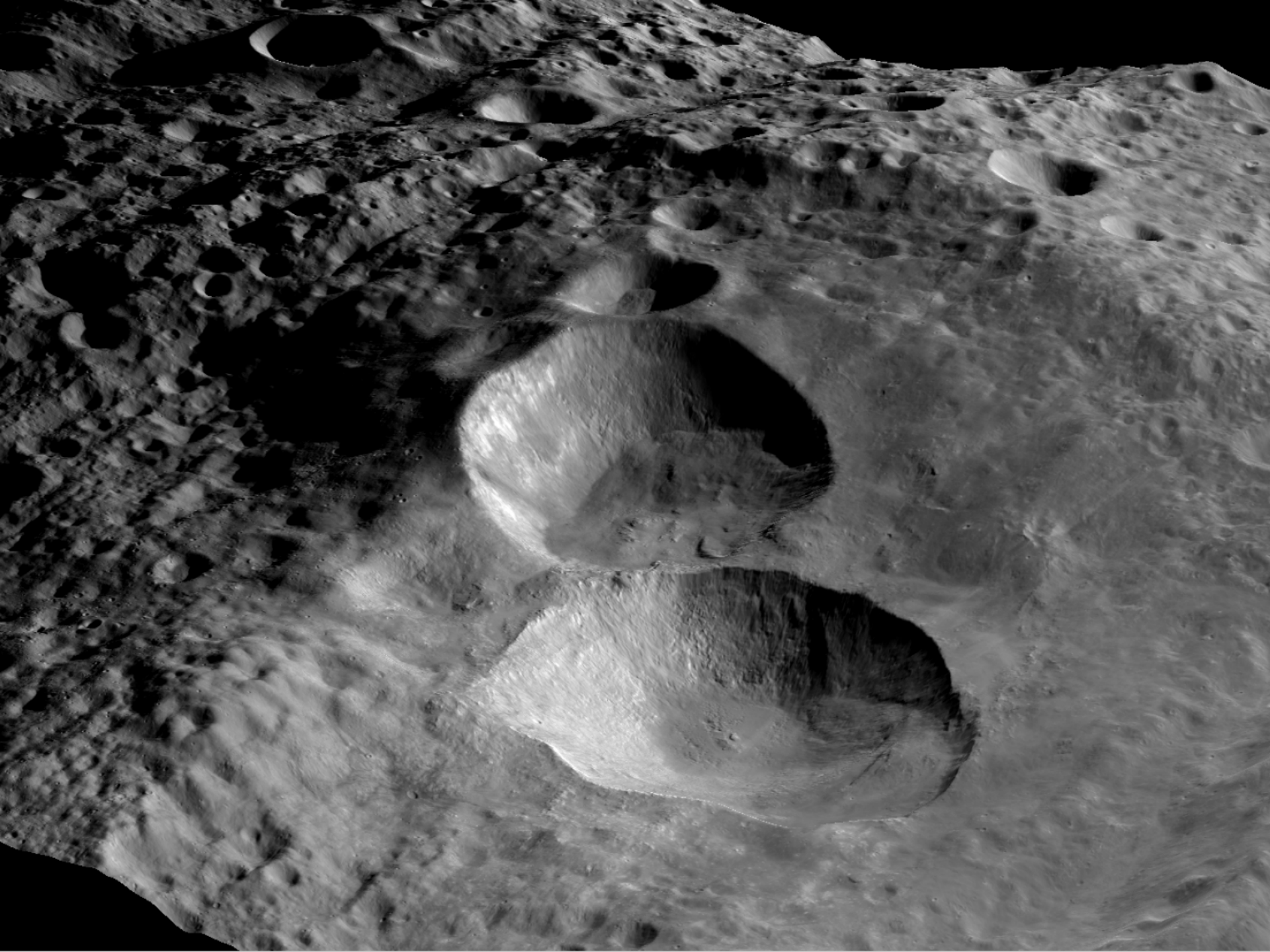
- Maps the surface in color
- Acquires stereo imagery
- Maps the elemental composition
- Maps the mineralogical composition
- Measures the gravity field
- Searches for moons


Dawn Spacecraft Current Location
Oct.26,2012 15:03:43 UTC.
Ceres
Vesta
Dawn
Vesta departure
Earth
Sun
Mars
Mars gravity assist
Vesta arrival
End of mission
Ceres arrival
Dawn trajectory thrust on
Dawn trajectory thrust off
Earth's orbit
Mars's orbit
Vesta's orbit
Ceres' orbit
Distance to Vesta 0.004026 AU
Distance to Earth 1.834 AU
Distance to Ceres 0.395 AU
Distance to Sun 2.566 AU
http://dawn.jpl.nasa.gov

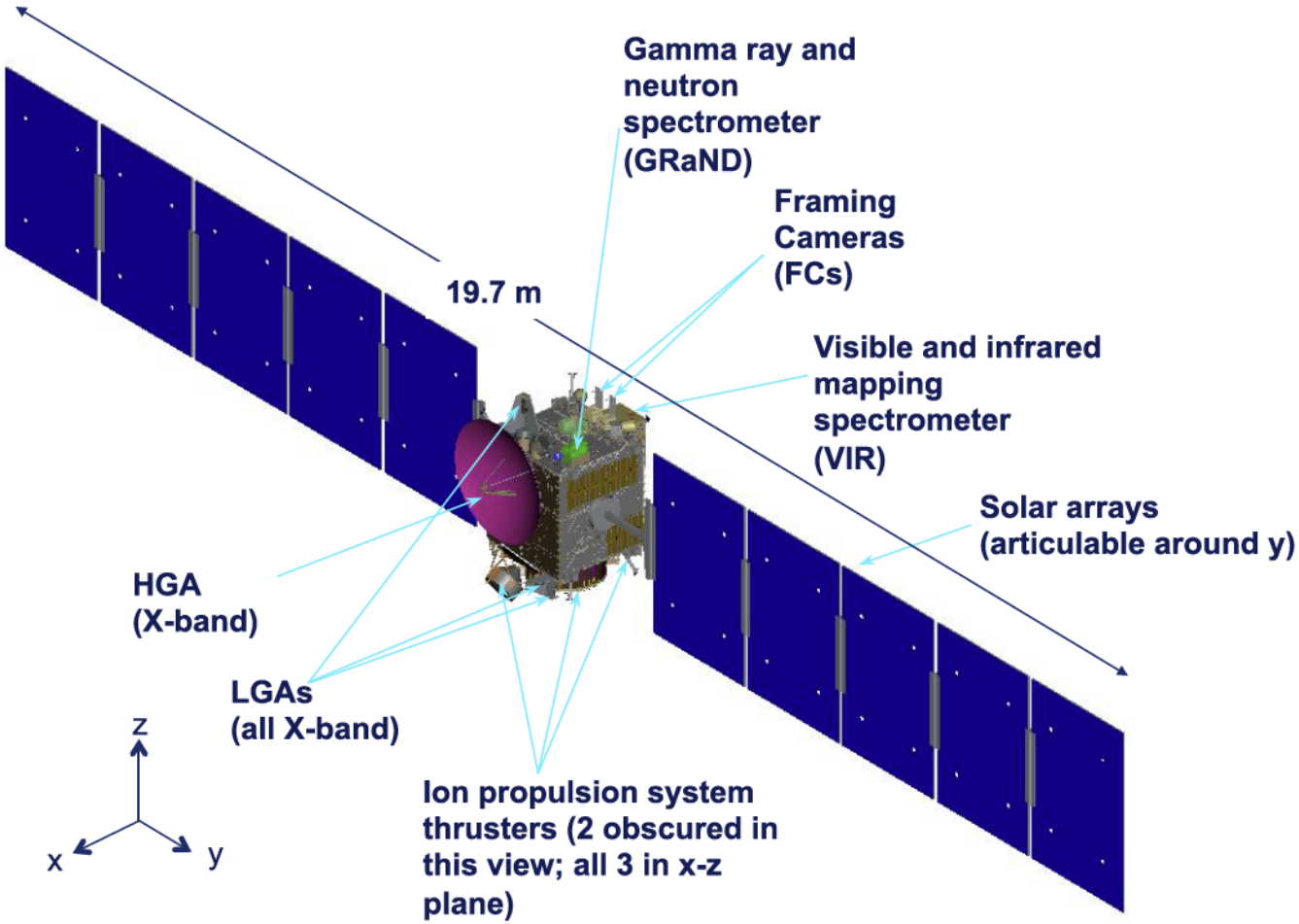
Vesta Size in Context







Dawn Flight System Configuration



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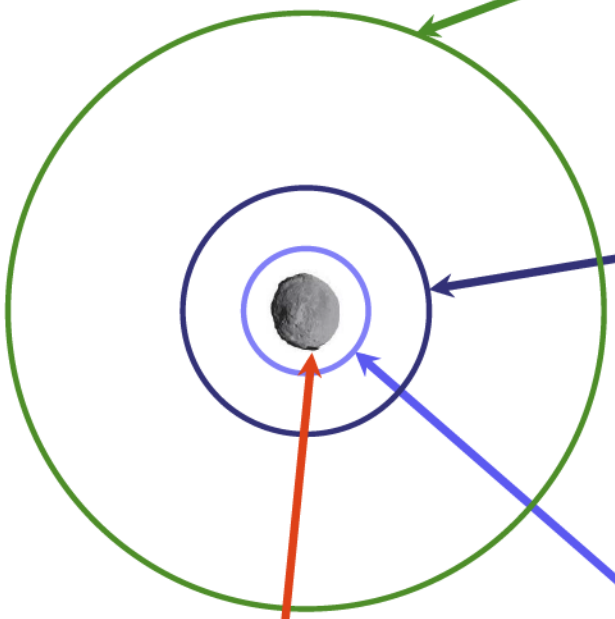
Vesta Science Orbits

Dawn



Vesta
282 km mean equatorial radius,
Rotation period 5.3 hrs

Survey

- 3000 km radius, 69 hrs, 7 orbits
- Global spectral mapping with VIR

HAMO, HAMO-2

- 950 km radius, 12.3 hrs, 6 x 10 orbits
- Global imaging with FC
- Requires ground track spacing (full body coverage in 10 orbits)

LAMO

- 475 km radius, 4.3 hrs, 6 months
- Mapping gravity field & elemental composition (GRaND)
- Requires ground track spacing, minimal orbit maintenance maneuvers

Navigational Challenges

- Low thrust using IPS (76mN – 46mN at Vesta)
  - IPS thrusts were on more than half of the time
  - Infrequent tracking data between long maneuvers
  - Need to pass through 1:1 resonance to reach LAMO
- Largely unknown pole, GM, gravity field of Vesta
  - Mission design must be robust to late findings
- Navigation team is heavily involved in ground operational timeline building
  - Thrusting events define operational timeline during transfer
- Spacecraft dynamic constraint
  - Maneuver team needs to deliver “flyable” thrust profile in short time

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Constraints

- Programmatic constraint on total lifecycle cost of the mission
  - Dictates the end date of Vesta operation
- Dawn spacecraft shall not enter eclipses
  - Flight system must remain safe from eclipses even if control is lost for 28 days
- ACS agility constraints
  - ACS system limits attitude rate and angular acceleration
  - Spacecraft attitude is dictated by thrust direction while thrusting
  - Avoid attitude singularity when thrust vector goes near Sun point

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Orbit Determination

- For each sequence build:
  - Estimate Vesta physical parameters
    - GM
    - Pole (using optical images)
    - Gravity (Survey: 4th, HAMO: 8th: LAMO: 15th)
  - Estimate spacecraft state for each sequence build
  - Estimate IPS performance (magnitude, pointing)
  - Complete this process in 4 hours

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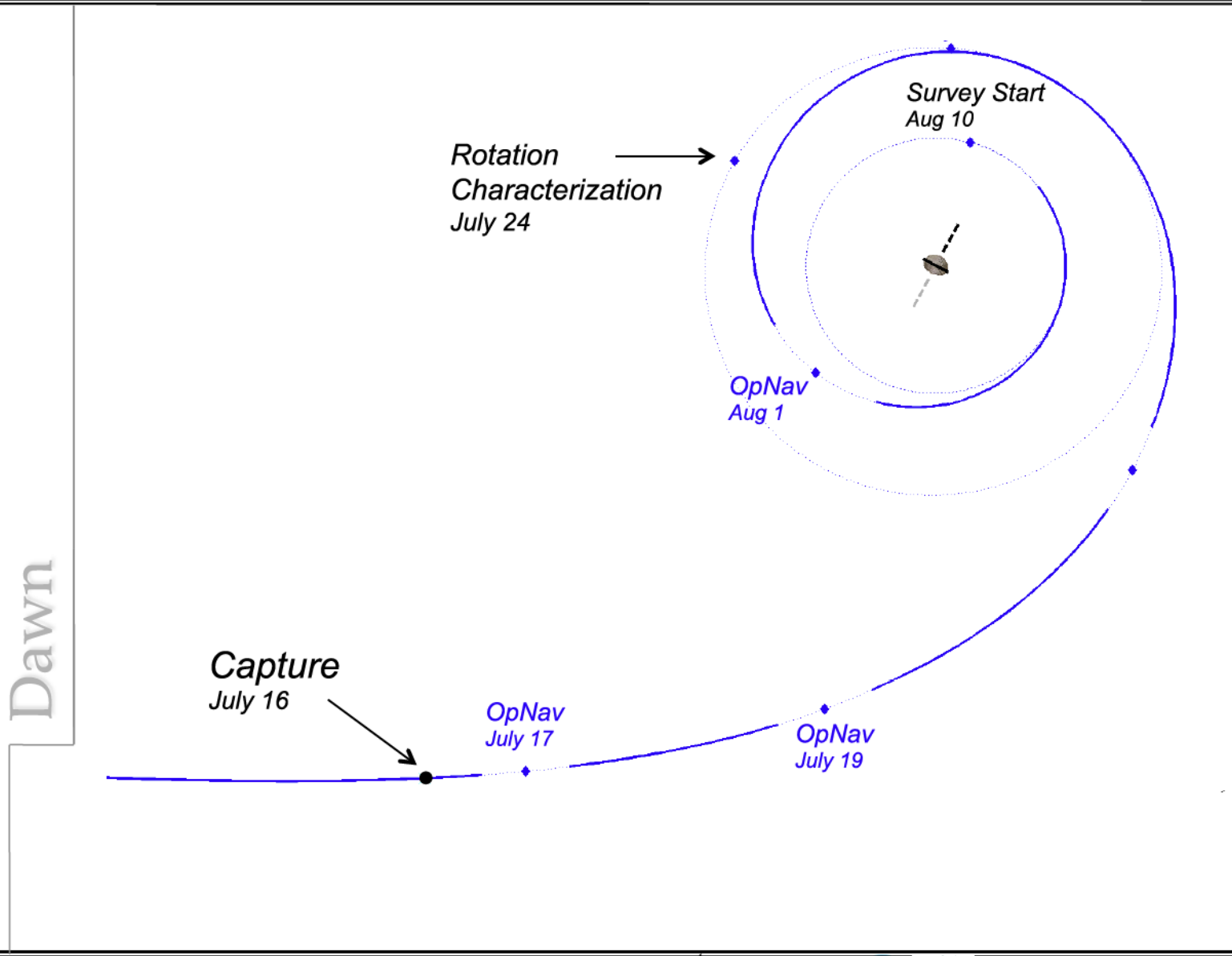
Approach Phase



Mission Planning & Design

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Define begin & end date of Vesta operation

Design science orbits

Design transfer orbit architecture

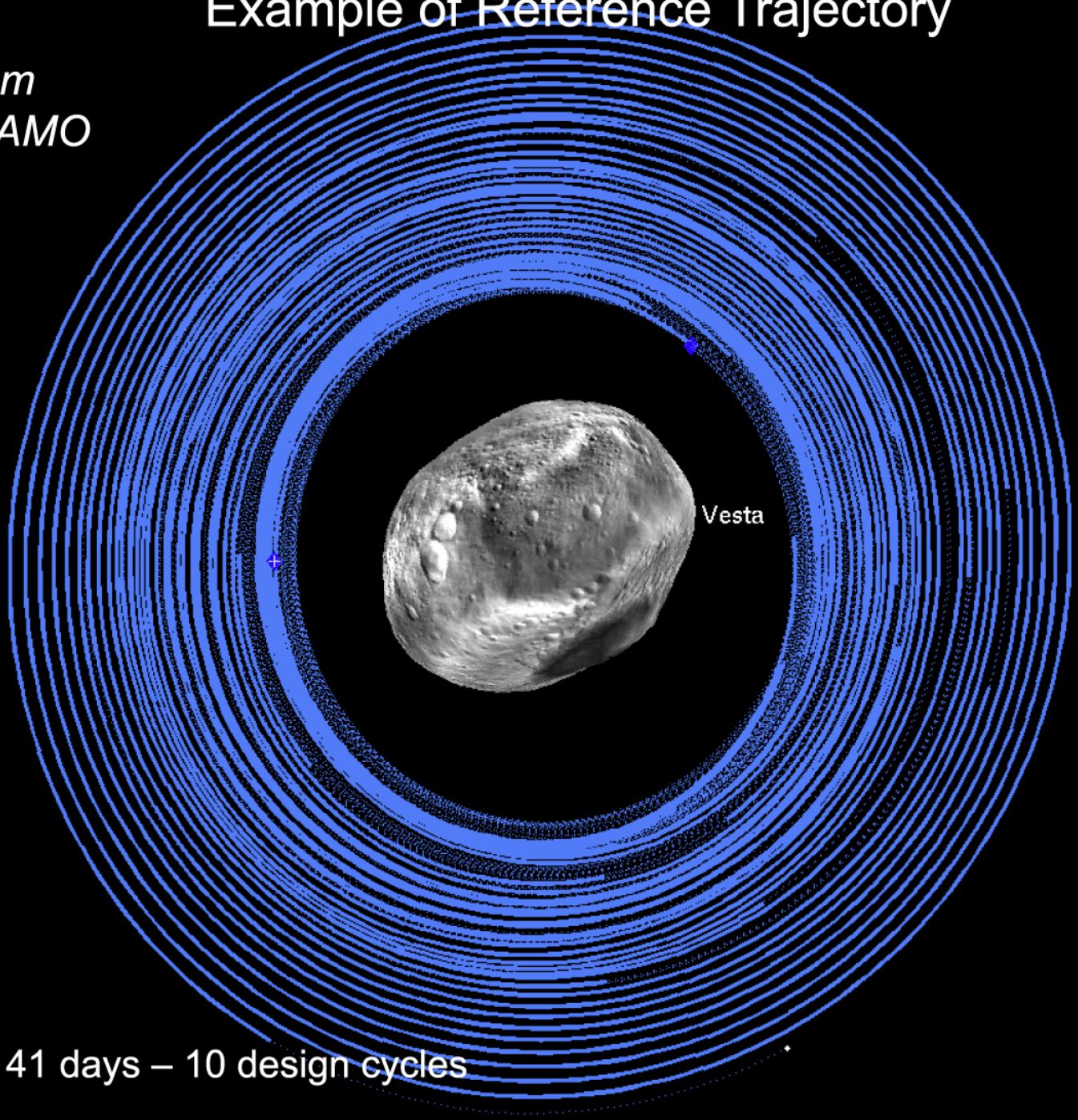
- Find ~~an optimal~~ a "working" set of transfer architecture
- Each transfer is broken into several thrust sequences
- Strategically placed coasting blocks

Build Thrust Sequence

- Deliver flyable thrust profile

Example of Reference Trajectory

Transfer from HAMO to LAMO



175 orbits – 41 days – 10 design cycles

Orbit Transfer Architecture Design

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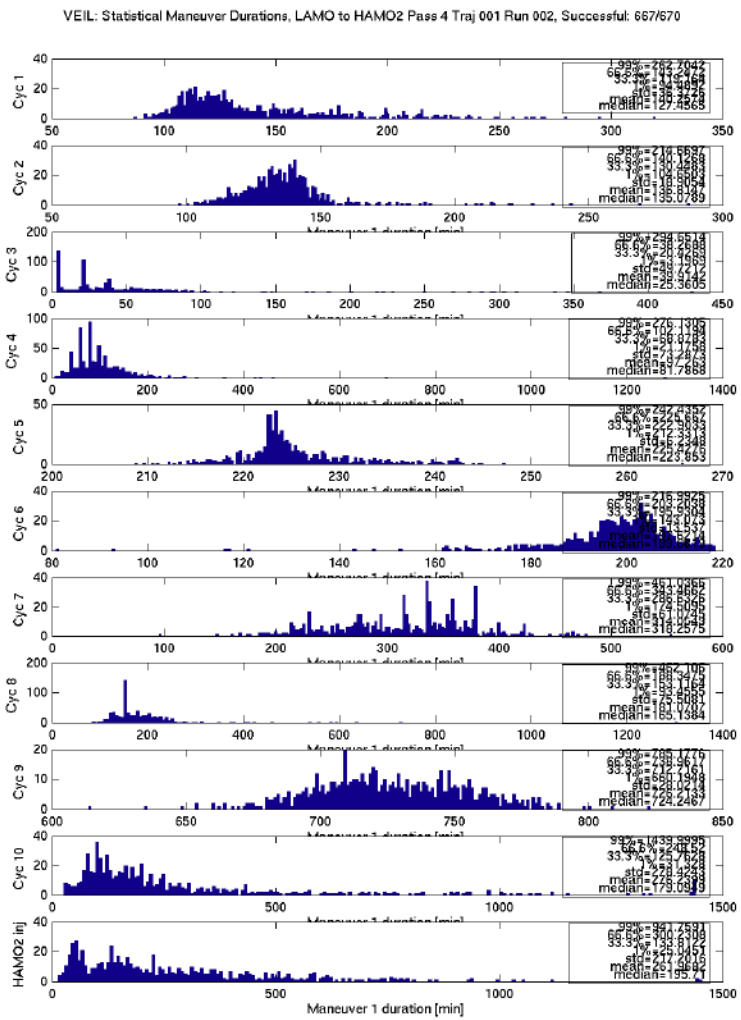
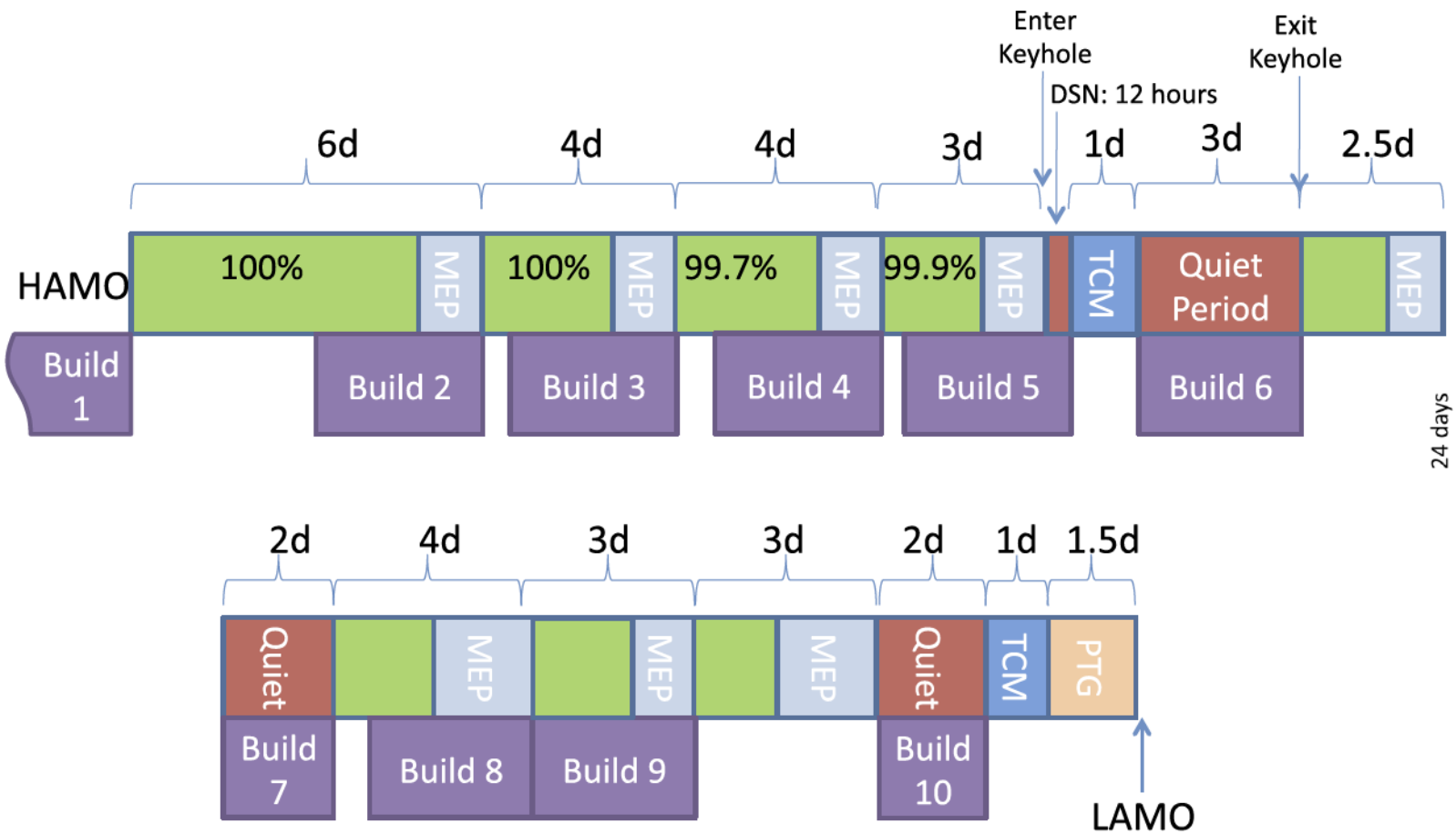
- Veil: Monte-Carlo low-thrust trajectory statistical analysis tool
- Takes random samples from input covariances: state, spacecraft dynamics, Vesta physical parameters
- Runs Mystic (JPL's low thrust trajectory optimization tool) for each sample case to find optimal trajectory to target



Statistical maneuver durations: LAMO to HAMO-2 case

Sample Transfer Architecture



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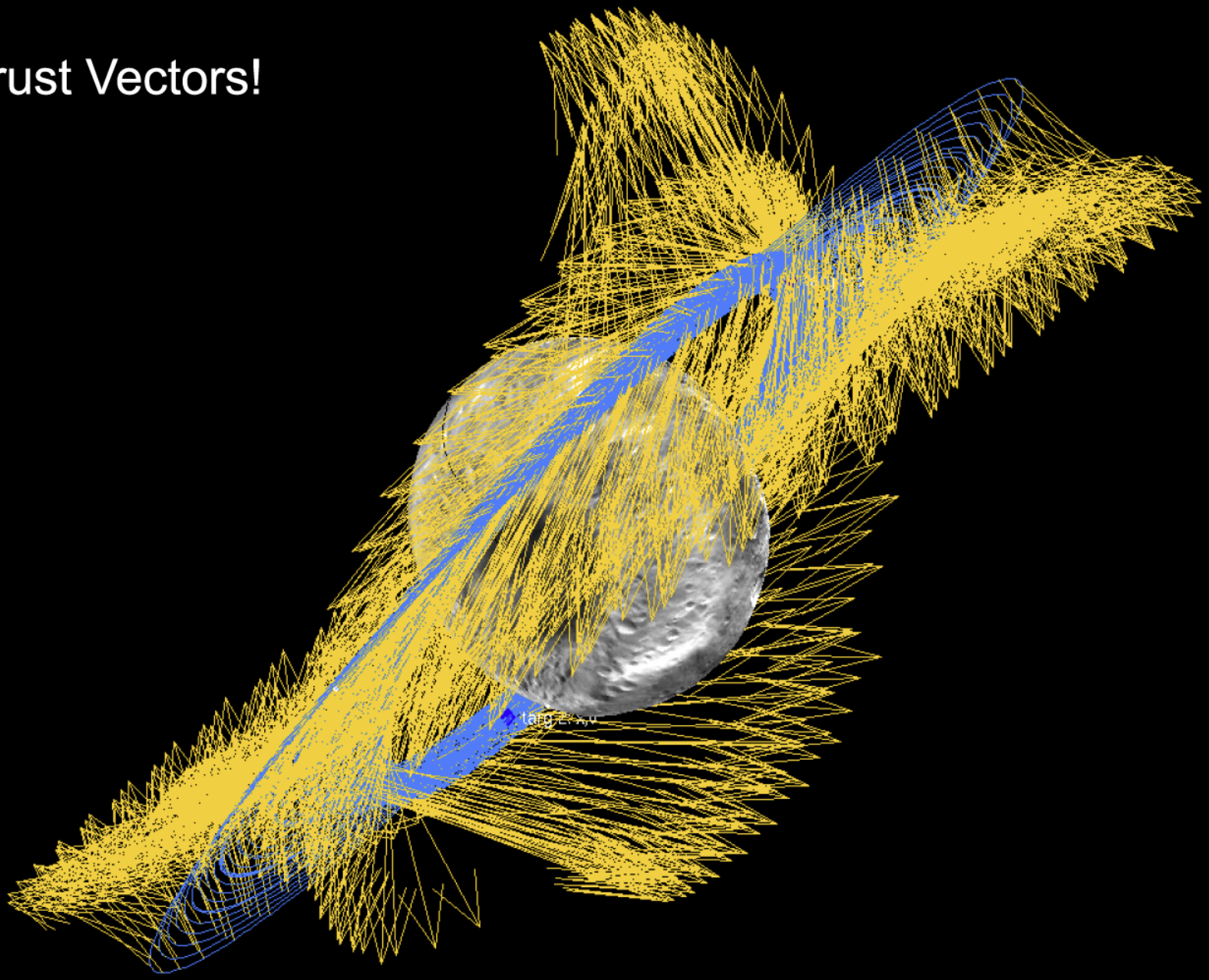
Thrust Vectors!



Summary

- Dawn's orbit transfers at Vesta posed many technical challenges for navigation team
- New techniques were developed and applied for design and operations for Vesta orbit transfers.
- Successful navigation during Vesta operations enabled the operations team to exceed all requirements at Vesta

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Acknowledgement

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Dawn Navigation team during Vesta Operations

Orbit Determination

Brian Kennedy

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(* from INAF)

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Brian Rush
Andrew Vaughan

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Greg Whiffen

Daniel Parcher
John Smith