Optical Navigation for the Dawn Mission at Vesta

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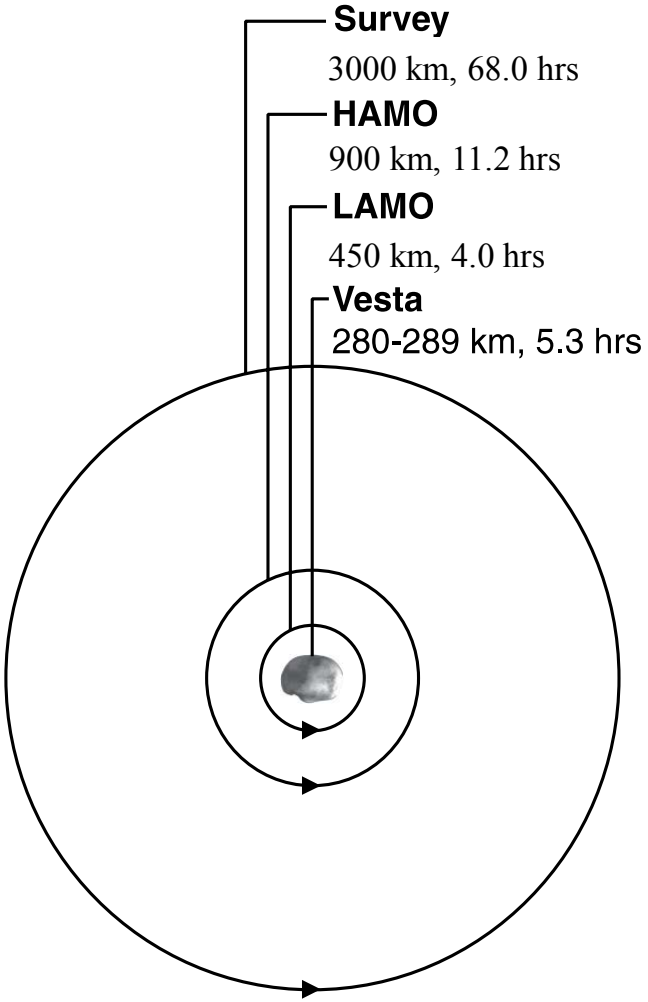
Vesta Mission Phases

- **Approach**
  - Began ~100 days before orbit insertion
  - Mostly nav phase; Pole and phase function determination
  - Radius decreases from 160,000 to 3000 km
- **Survey Orbit**
  - Duration 7 orbits (~20 days);
  - Altitude; 10 Vesta radii. 2 x FOV across
  - IR mapping & Spectroscopy
- **High Altitude Mapping Orbit (HAMO-1 & 2)**
  - Beta angle = 30º and 35 º, Incl. = 90º. Duration 62 orbits (30 days) for each
  - Topography investigation
  - Altitude; 2.4 Vesta radii. 8 x FOV across
- **Low Altitude Mapping Orbit (LAMO)**
  - Beta angle = 45º, Incl. = 90º. Duration ~ 4 months
  - Mineral composition, elemental abundances & gravity, crater distribution
  - Altitude; < 1 Vesta radius; 26 x FOV across



OpNav Overview

- Main OpNav operations tasks
  - Image planning & sequencing
  - In-flight Framing Cameras Calibration
  - Navigation Studies, Simulation & testing
  - Orbit Determination support
  - Vesta parameters estimation; pole, rotation rate, shape, gravity terms

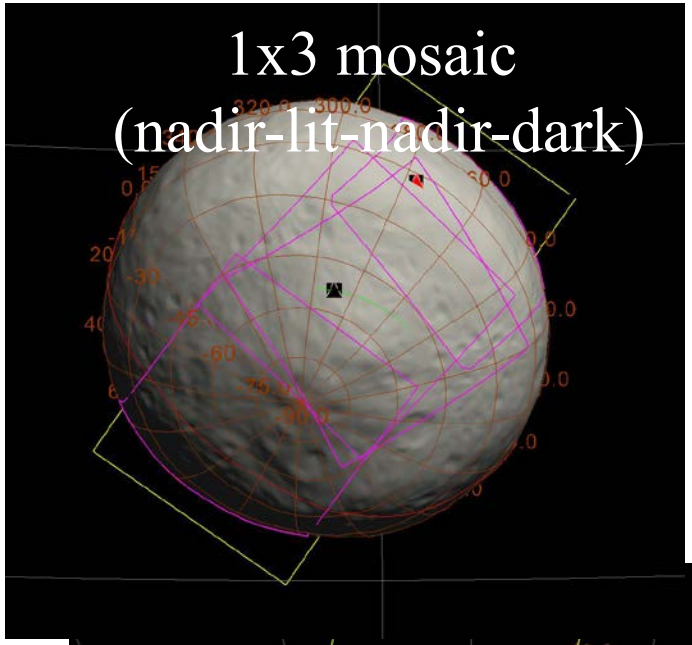
- Large range in Vesta resolution from 5 pixels across to 26 x FOV
  - Large body processing techniques
- Star-relative for most of approach until stray-light of extended Vesta too bright
- While in science orbits nominal camera pointing from attitude control

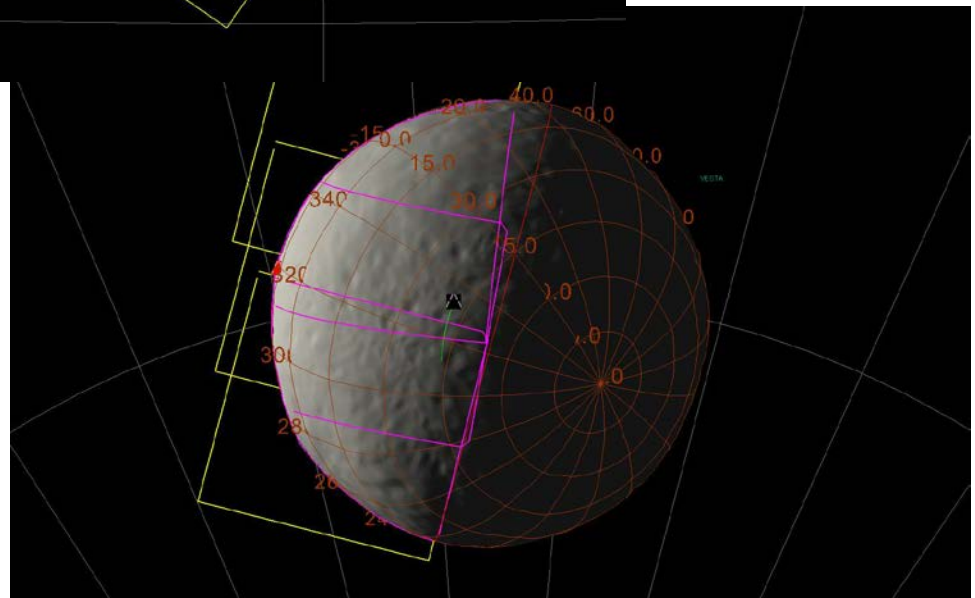
Limb scans
When Vesta is 5-700 pixels
Observables; pixel, line of CoF
useful for ~ 3 months in mission

Landmarks
When Vesta ≥ 40 pixels
Observables; landmark pixel, line location and landmark vector
Used for most of the mission

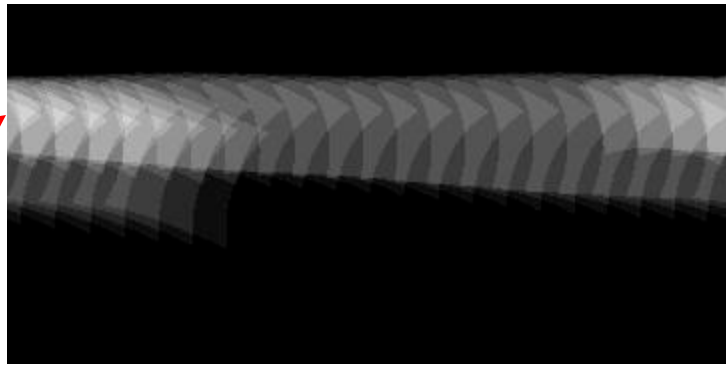
Planning for Images in orbit

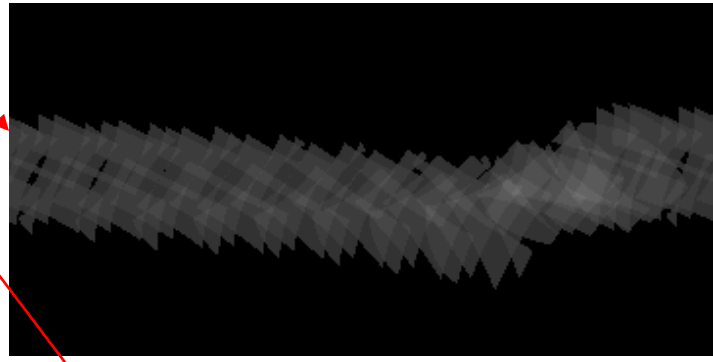
Multi-mission tools such as the Science Opportunity Analyzer greatly aid design of Vesta-relative observations

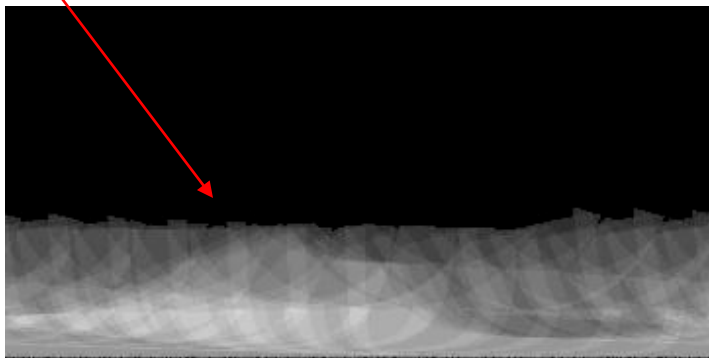




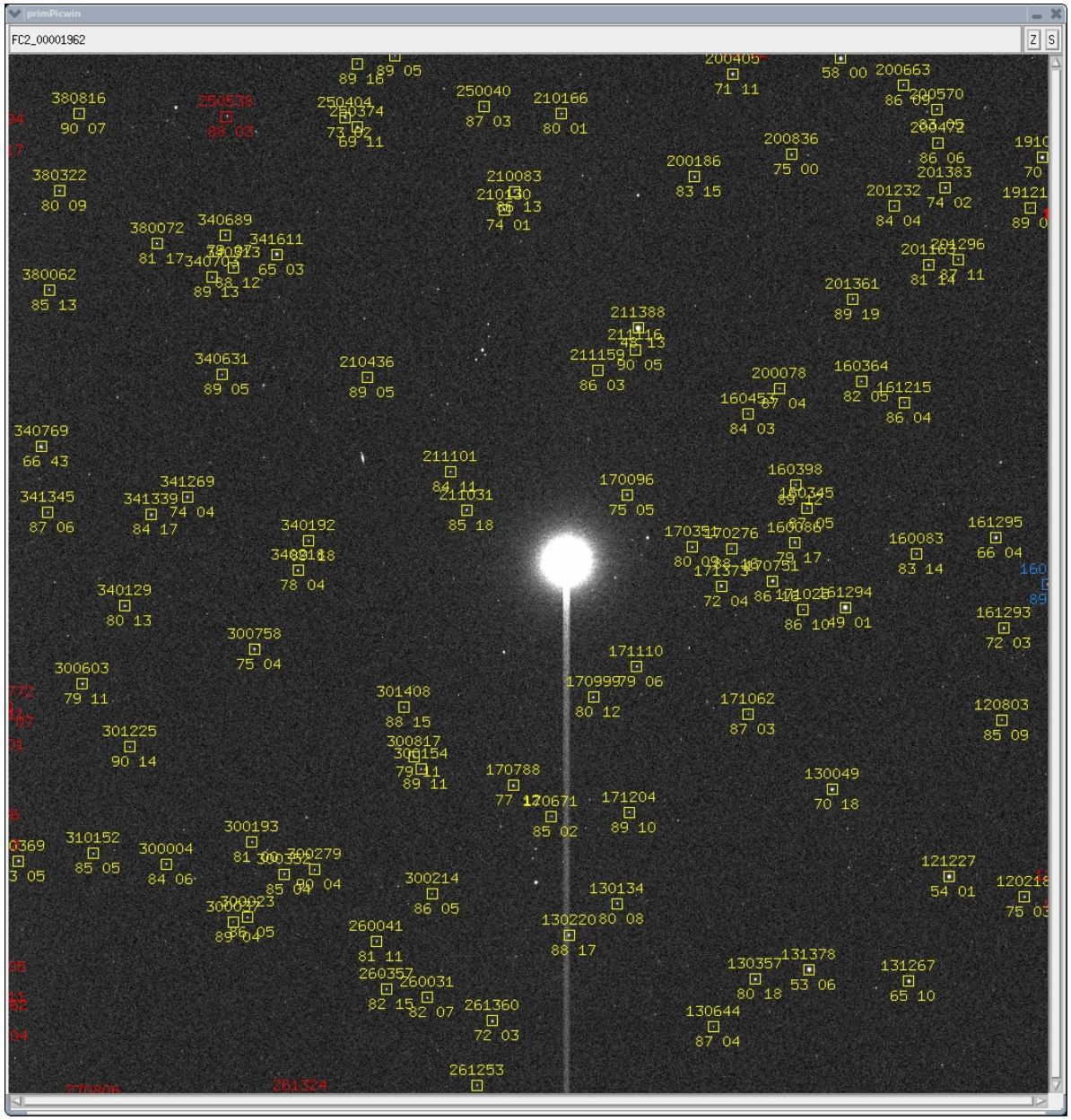
Use of coverage tools allow efficient Planning. Example from survey North Equatorial South Pole mosaics







Early approach Star Image-long exposures

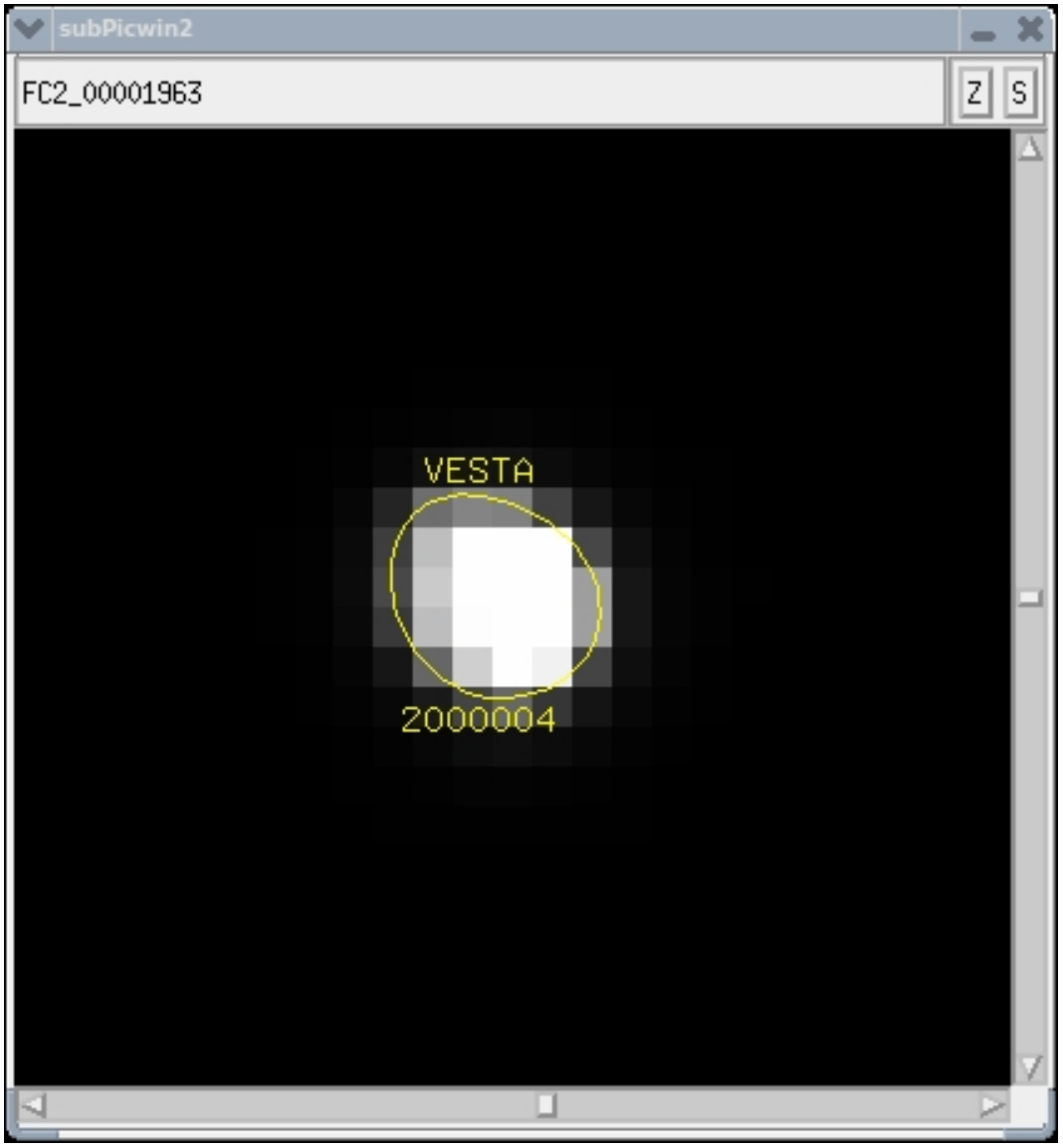


First 16 OpNav sessions were star-relative, alternating long-short exposures

Typical long exposure, 1.5 sec with saturated Vesta to bring the background stars

Stars down to 9 Vmag are usable

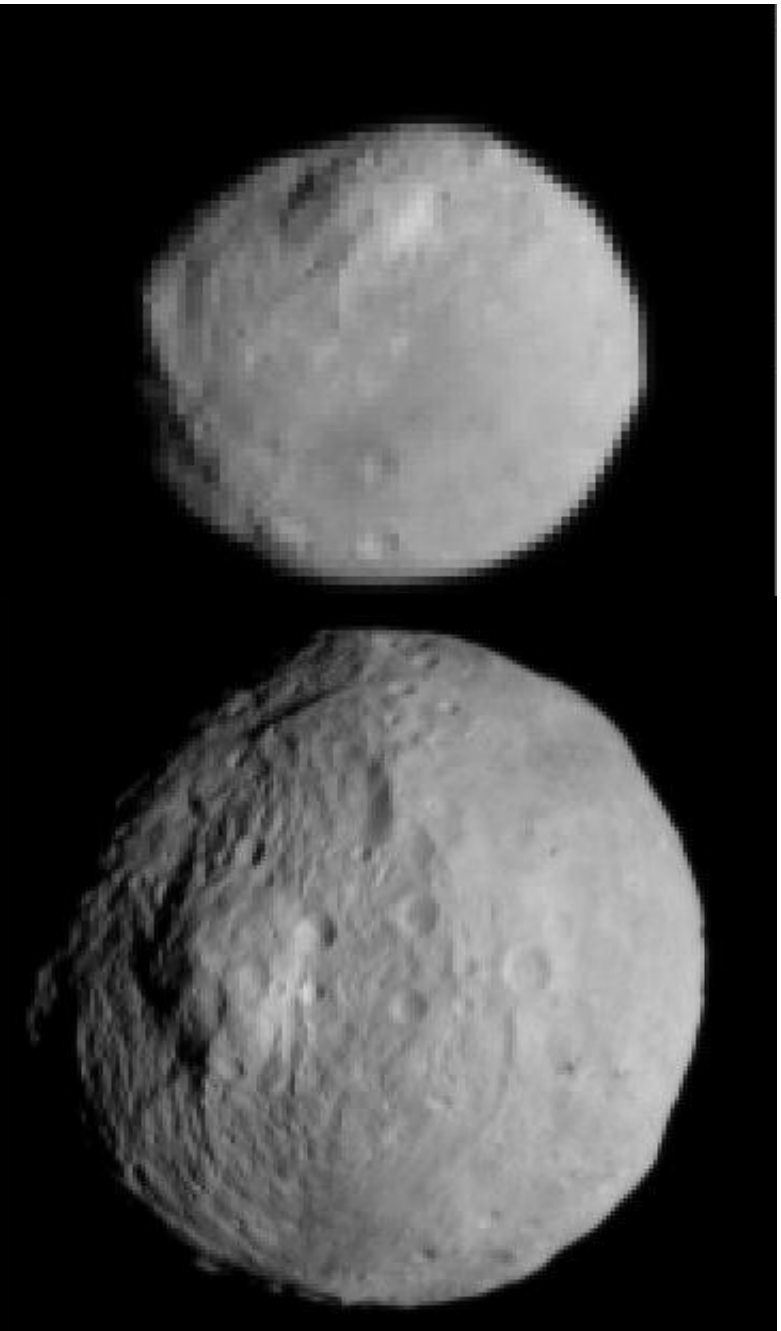
Early approach Vesta image short-exposures



Vesta from OpNav2 with
a-priori shape overlay

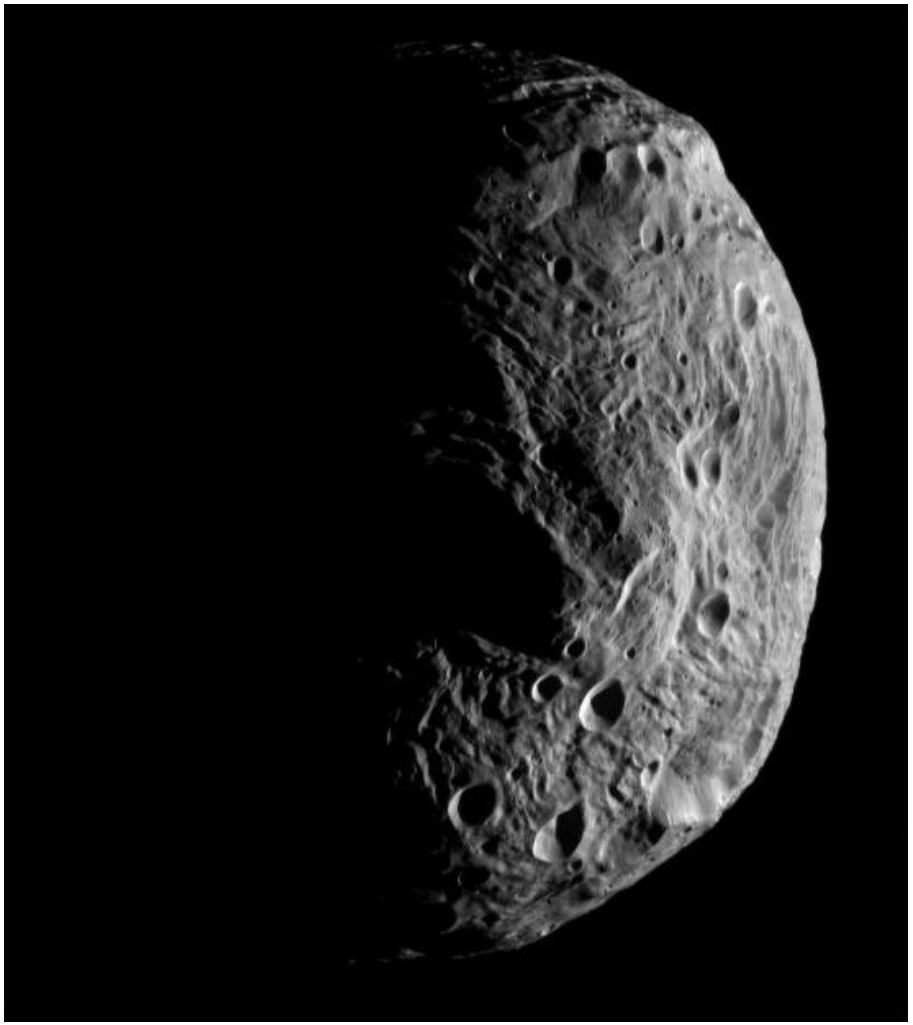
Approx size 6x5 FC pixels
@ 94 km/pix

Some Characteristic Images: Mid Approach



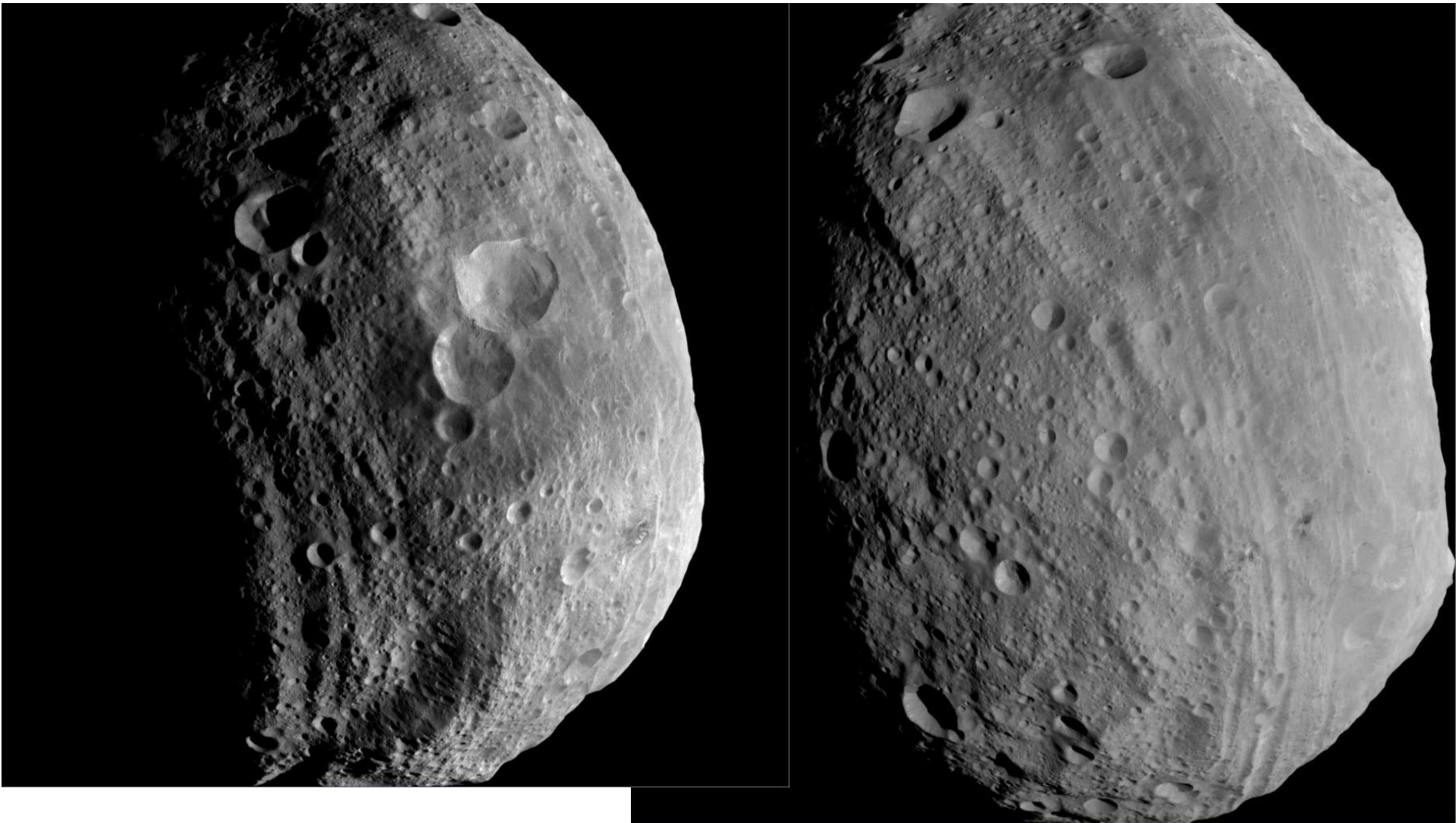
Rotational Characterization (RC)1 upper left

RC2 lower left, OpNav 18 lower right

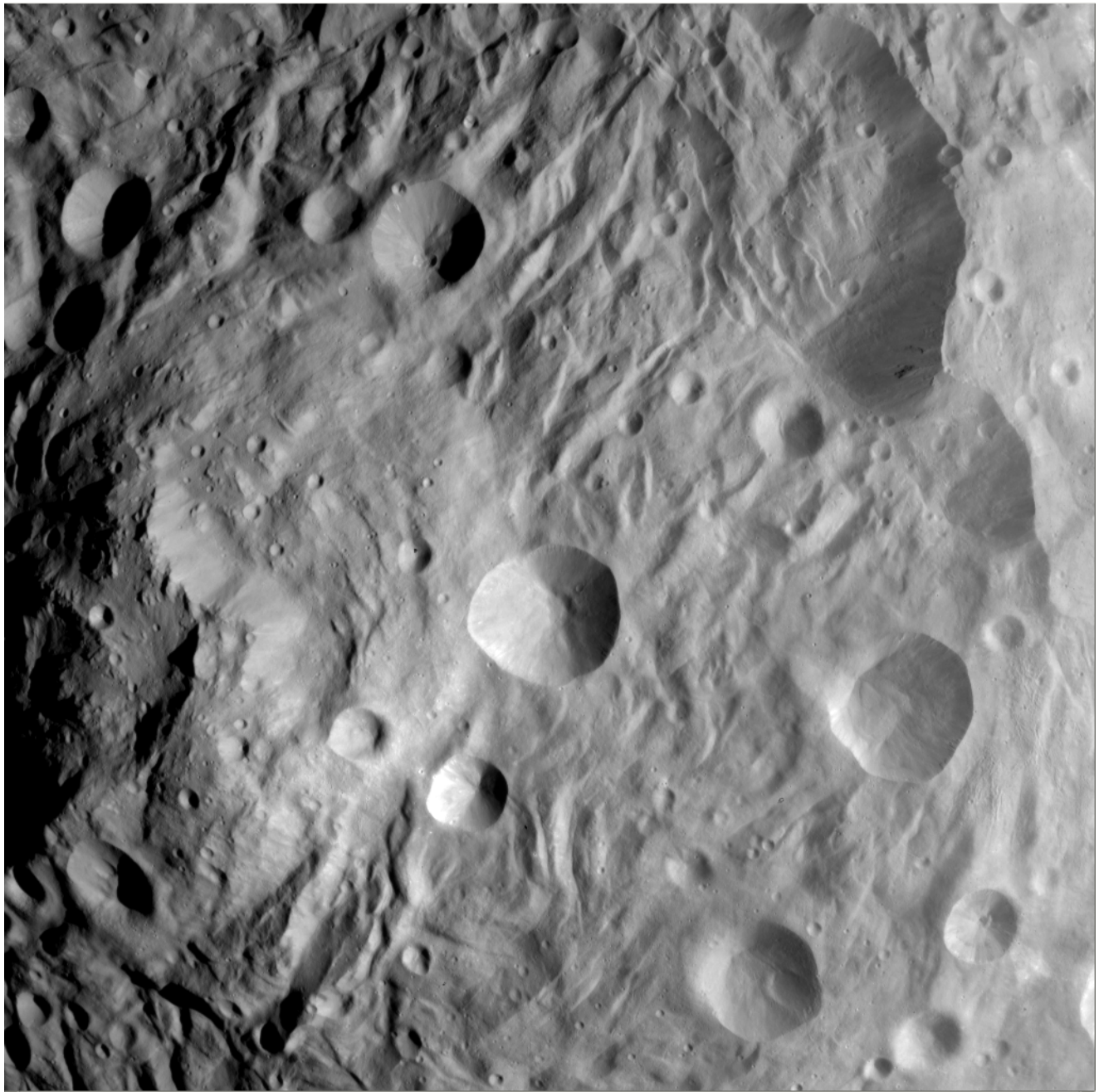


Late Approach

OpNav 19 left (North latitudes) and RC3 right (Equatorial)

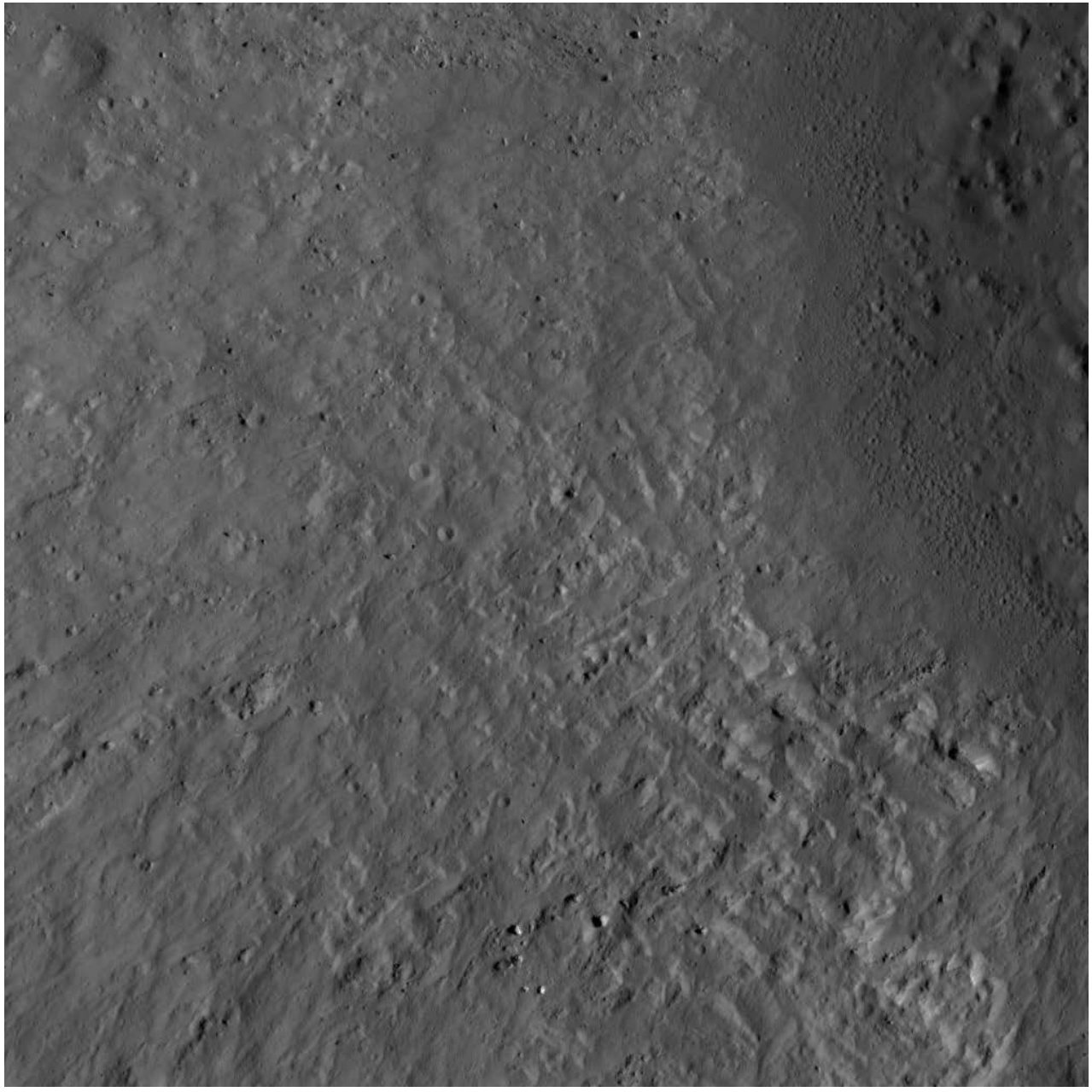


Survey South Pole View



South Crater Rim from Hamo

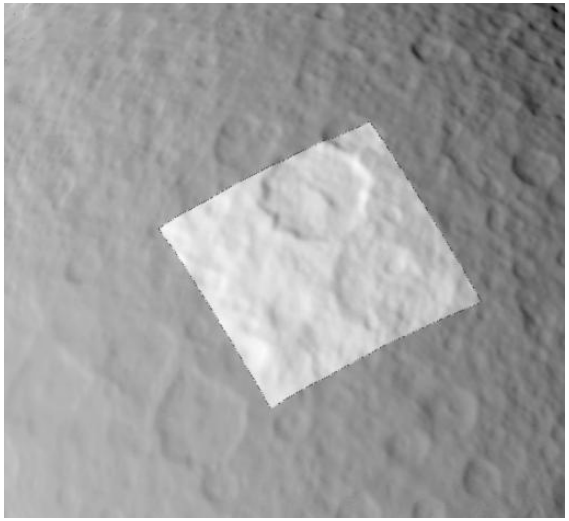
Boulders in Marcia Crater from Lamo

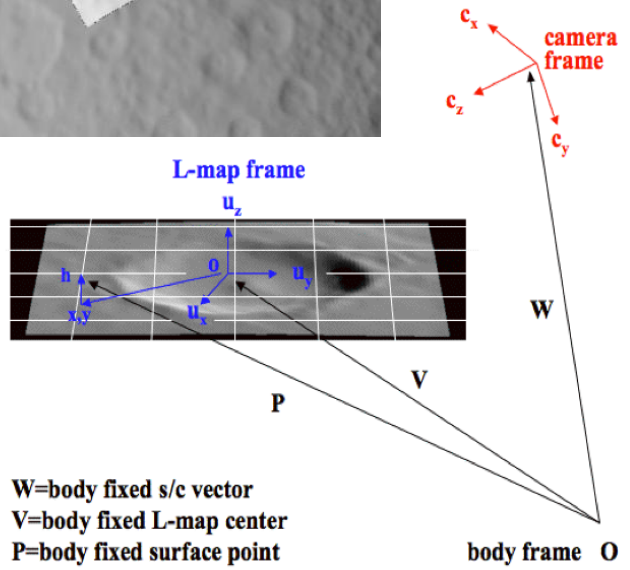


Landmark Definition

Landmark is a control point at the center of a 3-d topography & albedo map of a patch of surface; not tied to specific feature

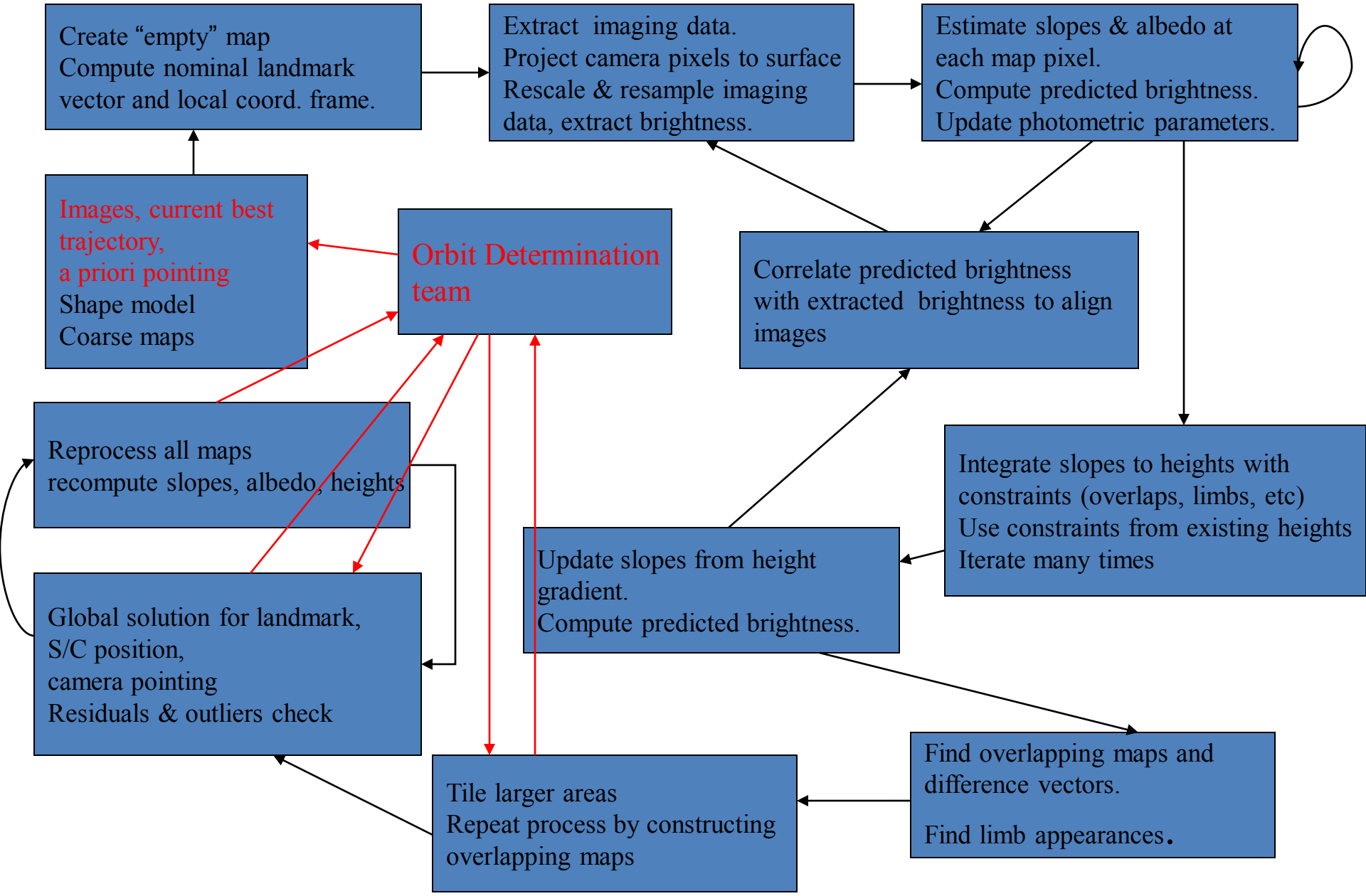
- any surface patch will do
- Allows for systematic surface landmark coverage
- Automated search & identification of landmarks in images
- Precision center-finding by cross-correlation between images & map
- Improved accuracy in landmark estimation by use of constraints such a limb appearances of maps and correlation between overlapping maps



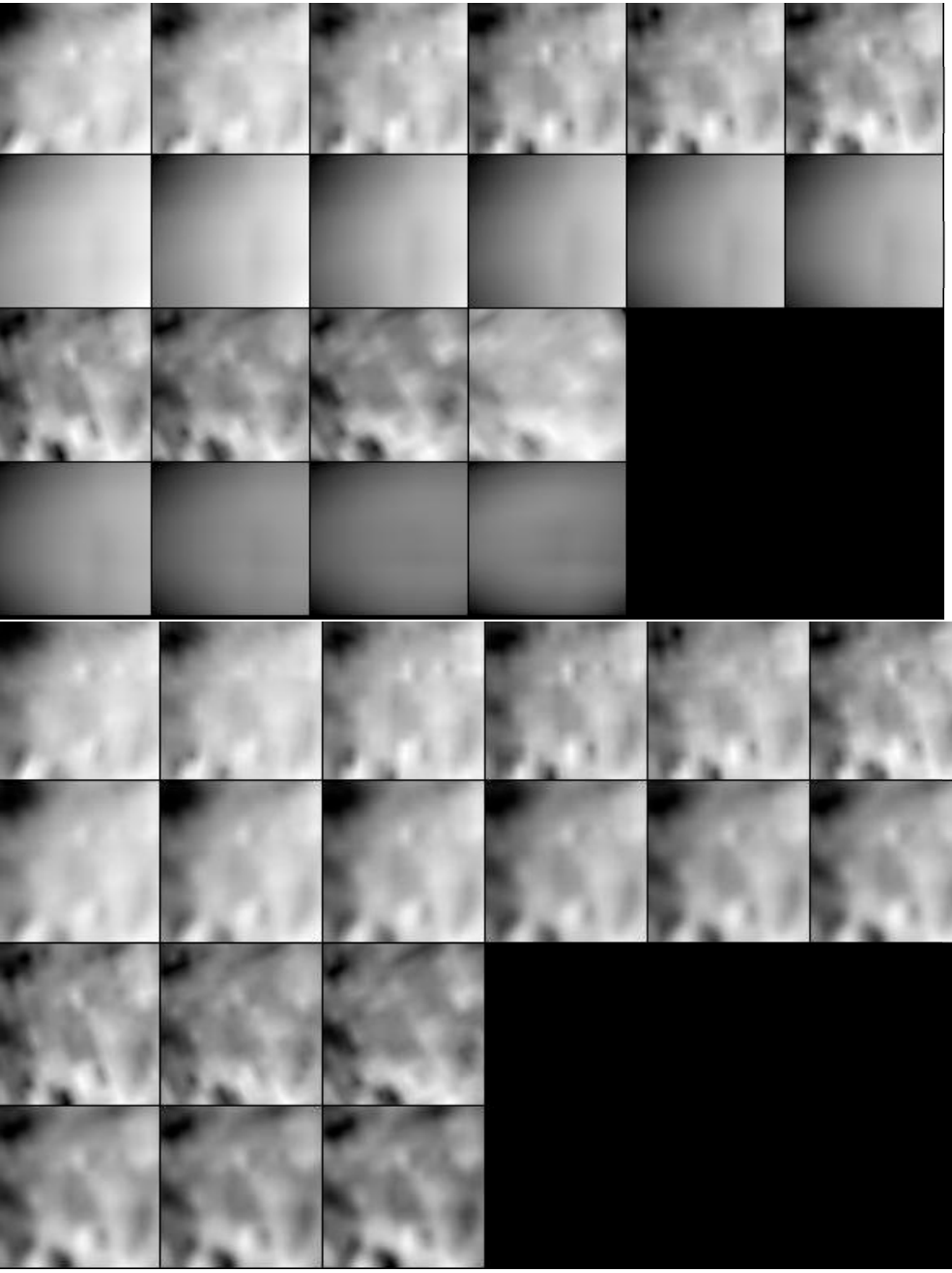


- Map of 99x99 pixels with relative heights & albedo assigned to each pixel
- Local coord. system relates map pixels to an absolute surface position

Landmark Processing Overview



Very first landmarks



Initial stage

Extracted images projected against

a priori shape

Images are misaligned due to pointing, position and projection errors

Image resolution: 9 km/pix

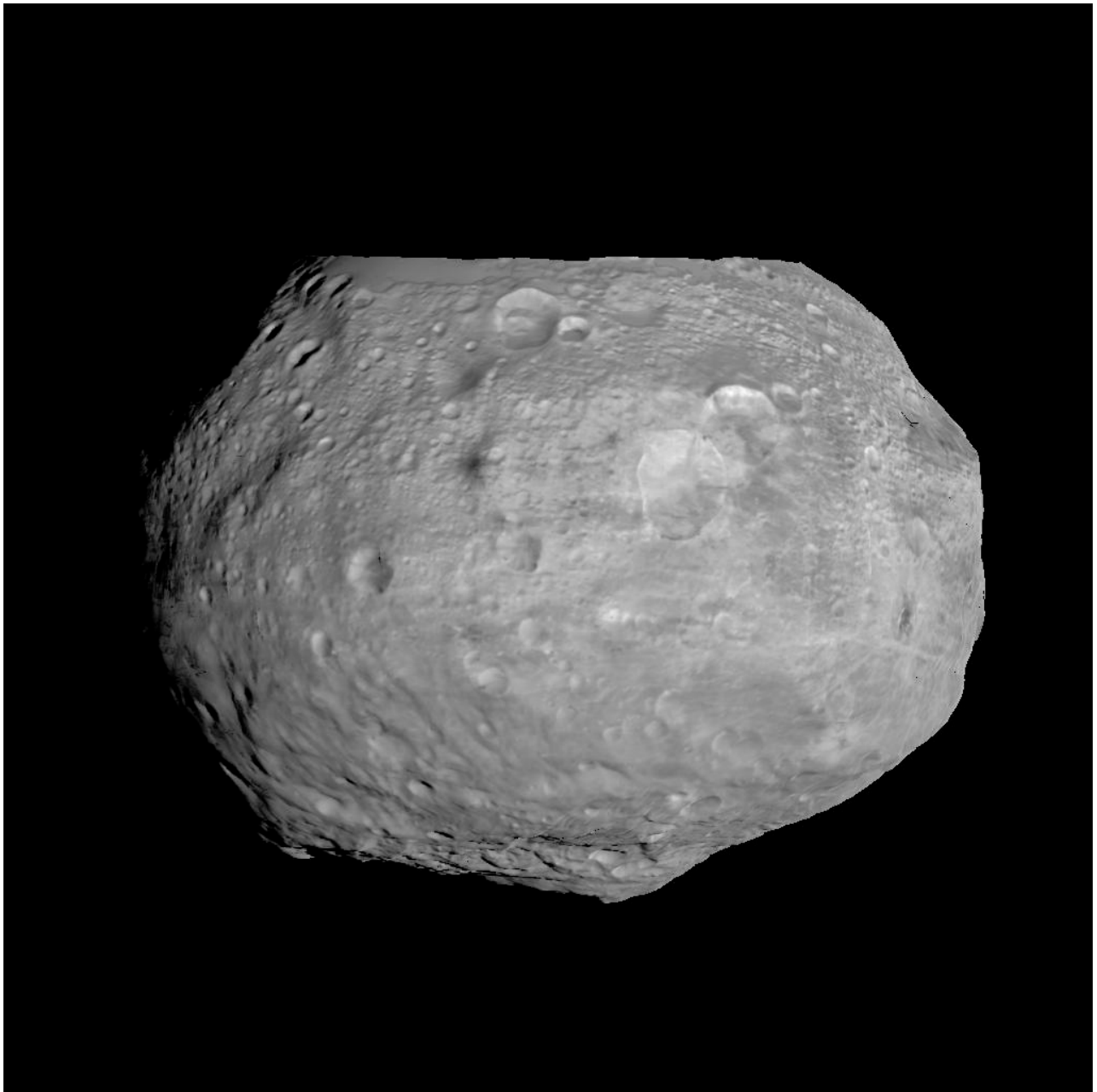
Map resolution: 1.5 km/pix

Final stage

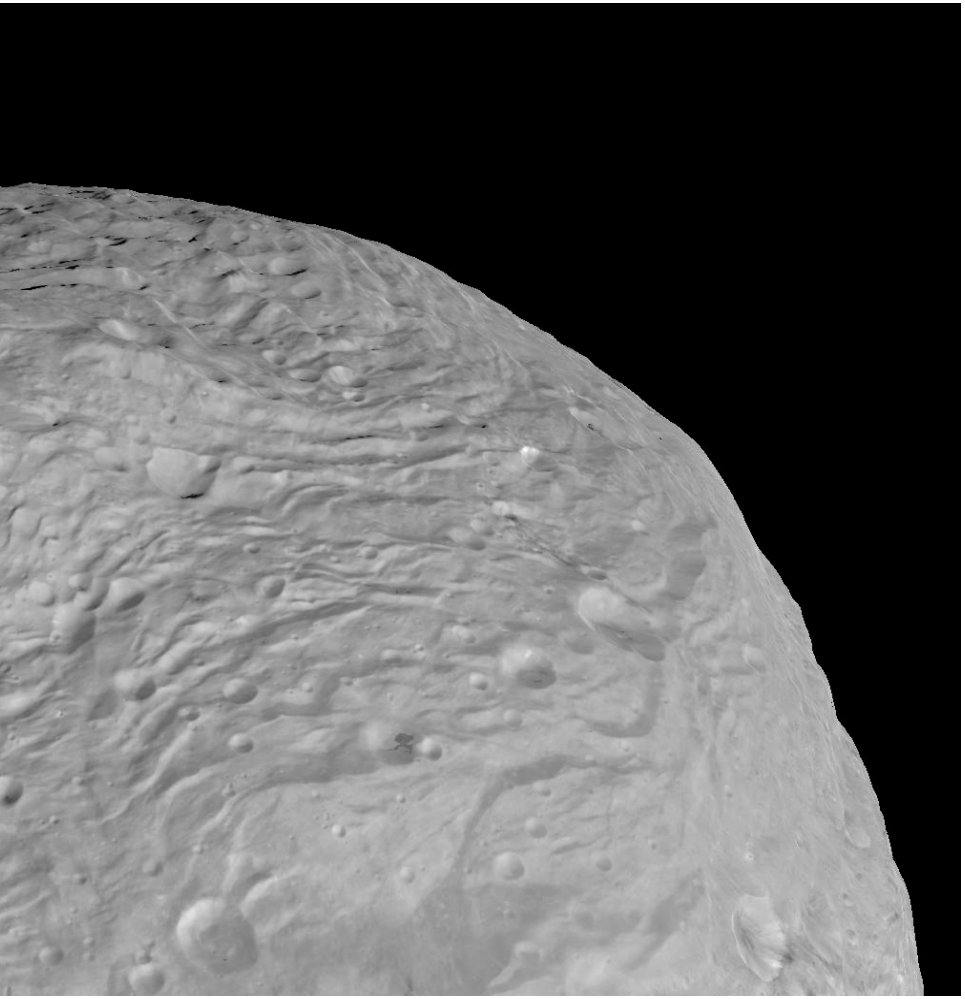
Images aligned and projected against landmark map rendered at each image geometry

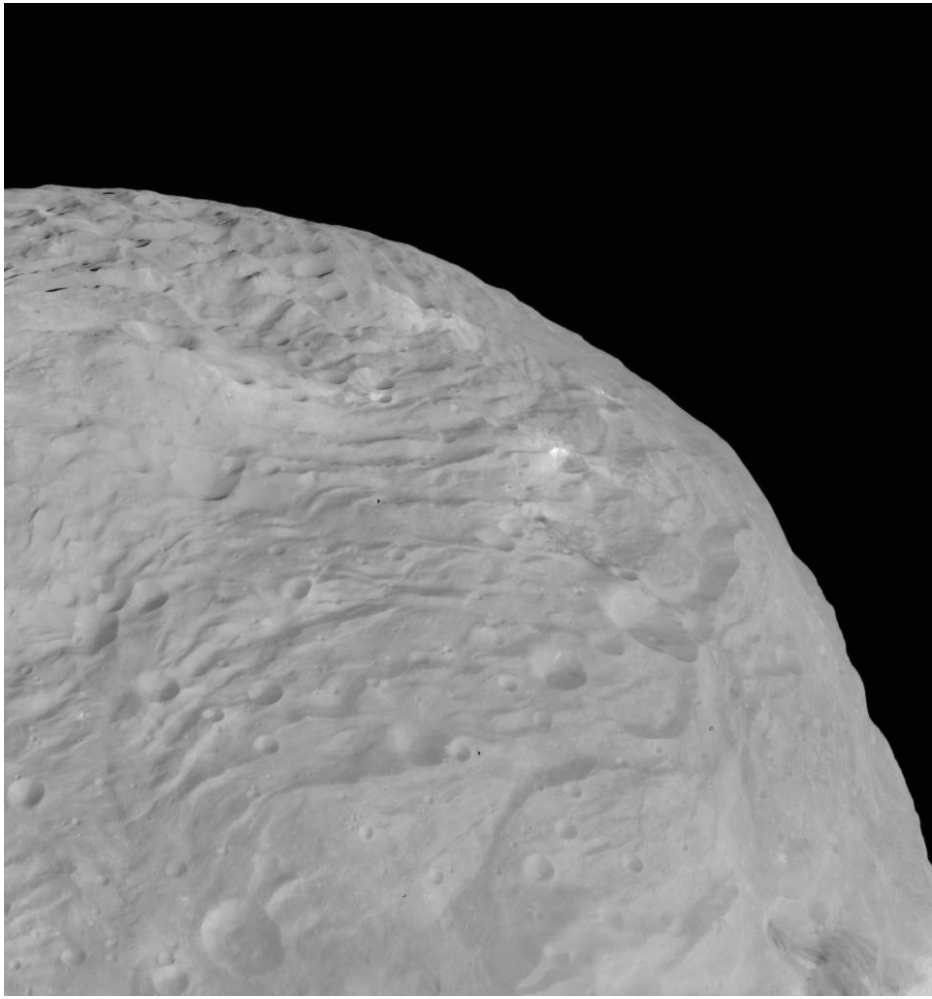
Vesta Late Approach Landmarks

Equatorial view from late approach after tiling the surface with landmarks at 750 m/pix



Landmark maps from Survey

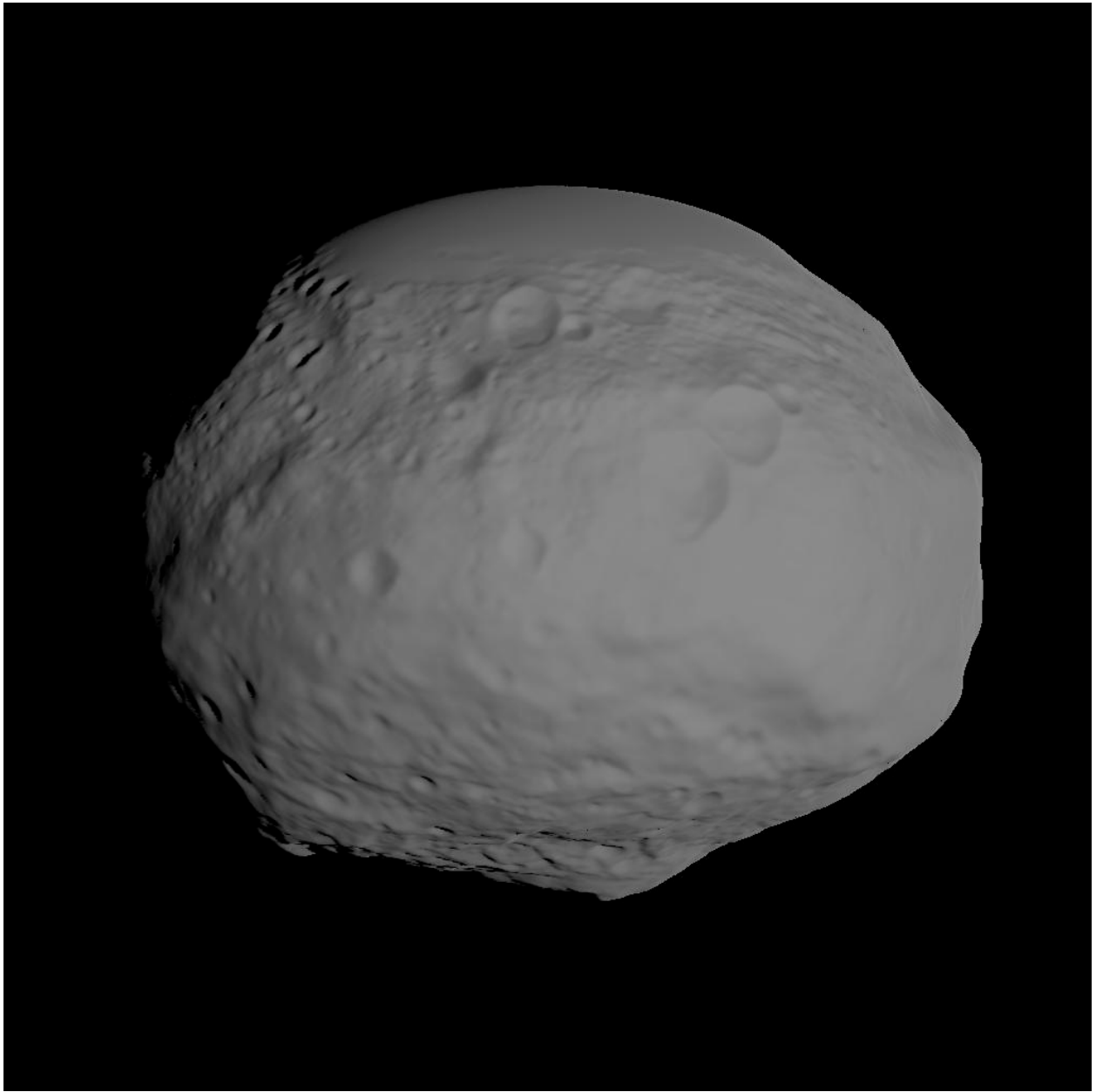




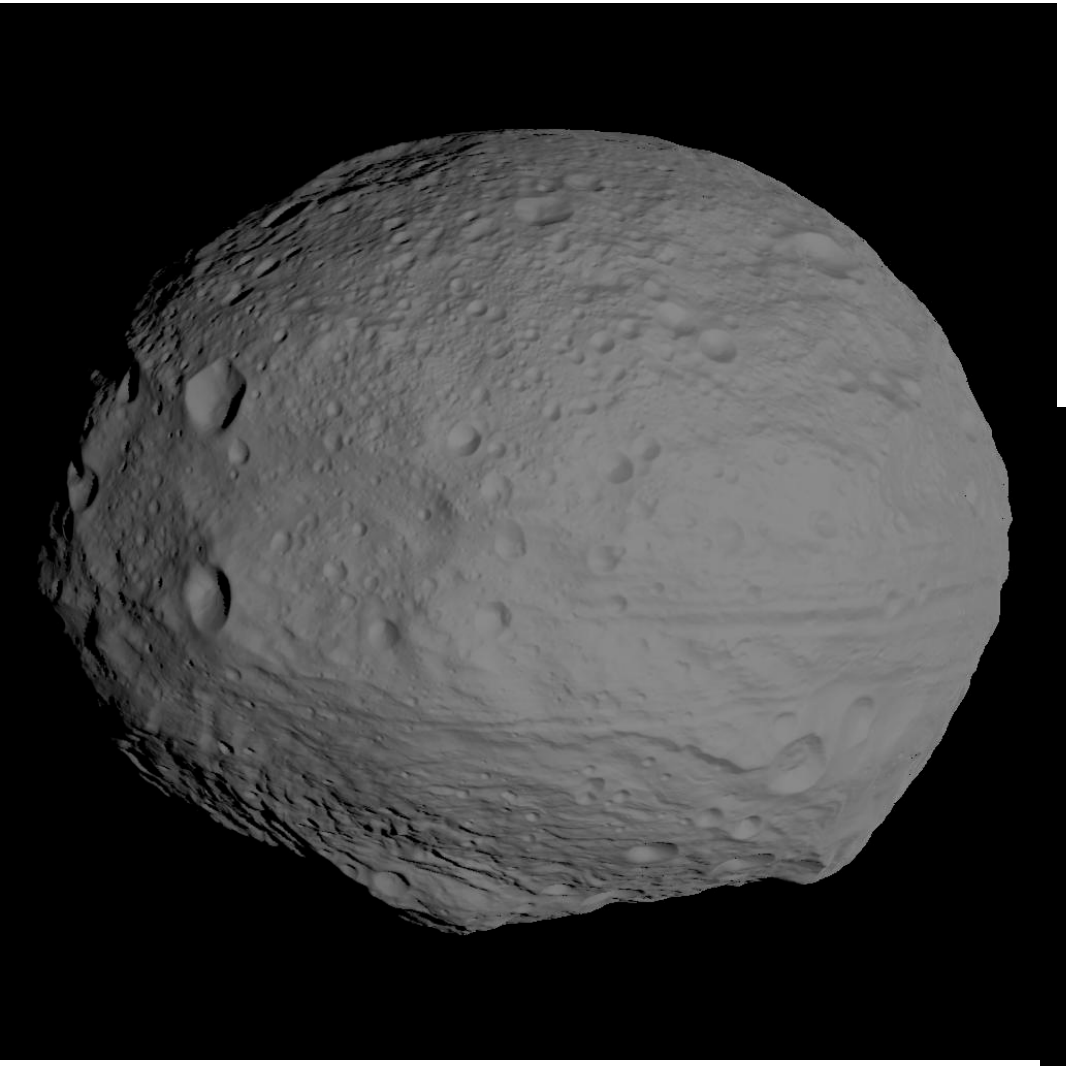
Left: survey image. Right: view of the landmark maps at the same geometry as the image

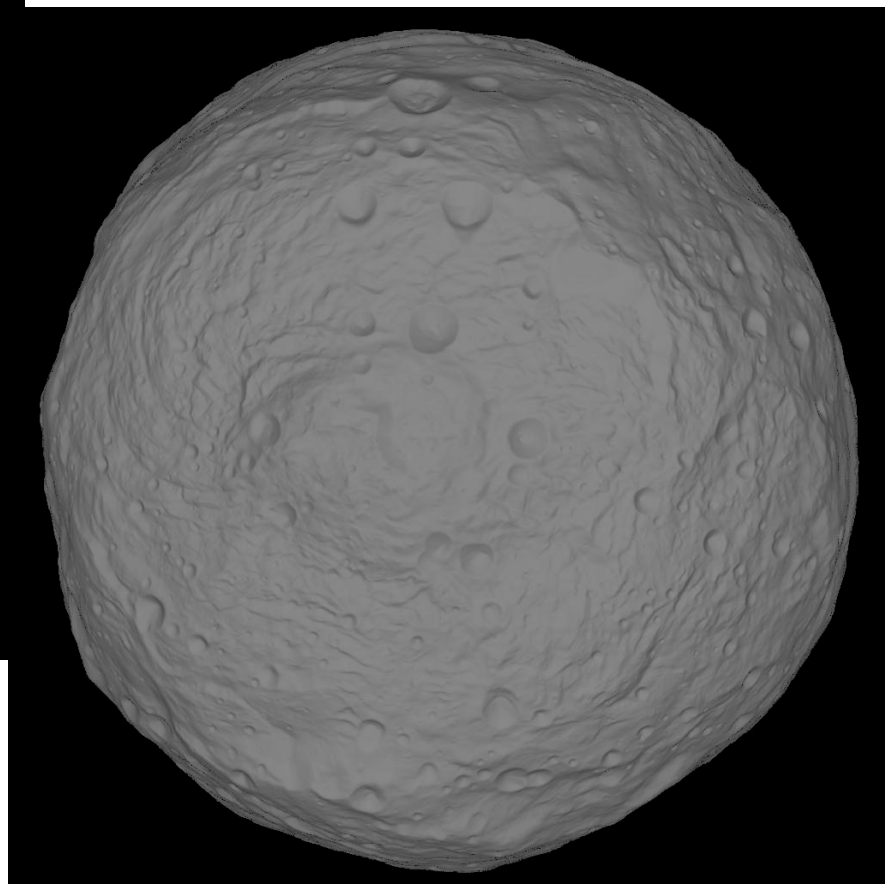
Shape Model Evolution - Late approach Landmarks

After tiling the surface with landmarks at 750 m/pix



Shape Model Evolution – End of Mission





Equatorial view (upper) and south polar view (right)

Hierarchical Landmark Development

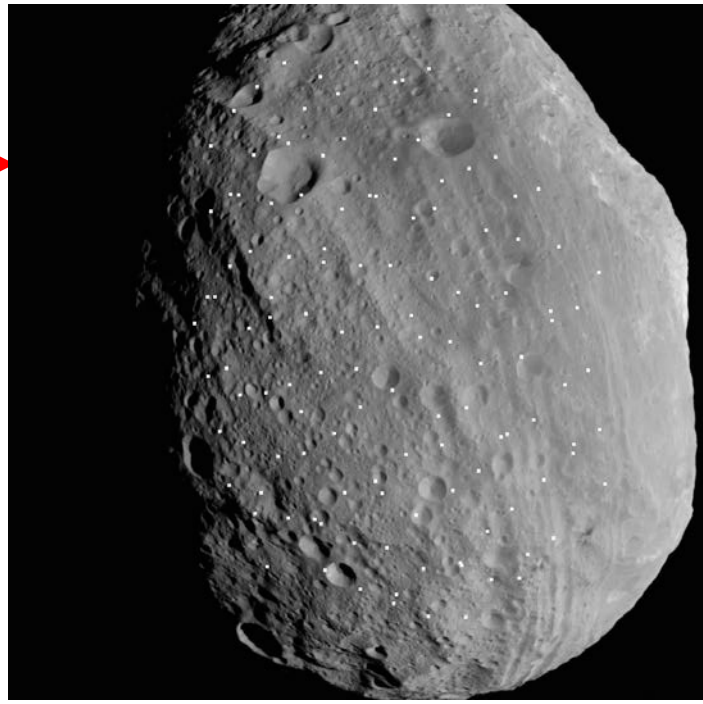
Method proceeds by building overlapping landmarks of increasing resolution

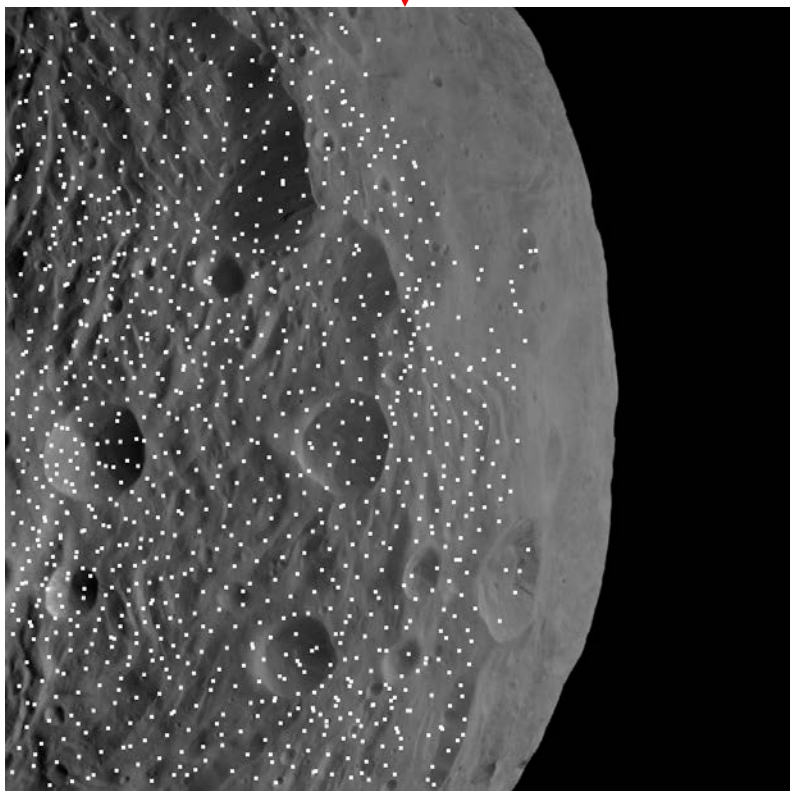
Coarse maps with sparsely located landmarks tie the whole surface together and provide context topography

New higher resolution images register on existing maps

Current maps are rebuilt

A denser landmark set is constructed overlapping the existing ones





Landmarks from one phase forms the basis for image processing in the next phase:

On approach we build the landmarks for Survey

On Survey we build landmarks for HAMO-1 etc.

Ratio of 2-3 in map resolution between successive orbits

Summary of Landmarks to date

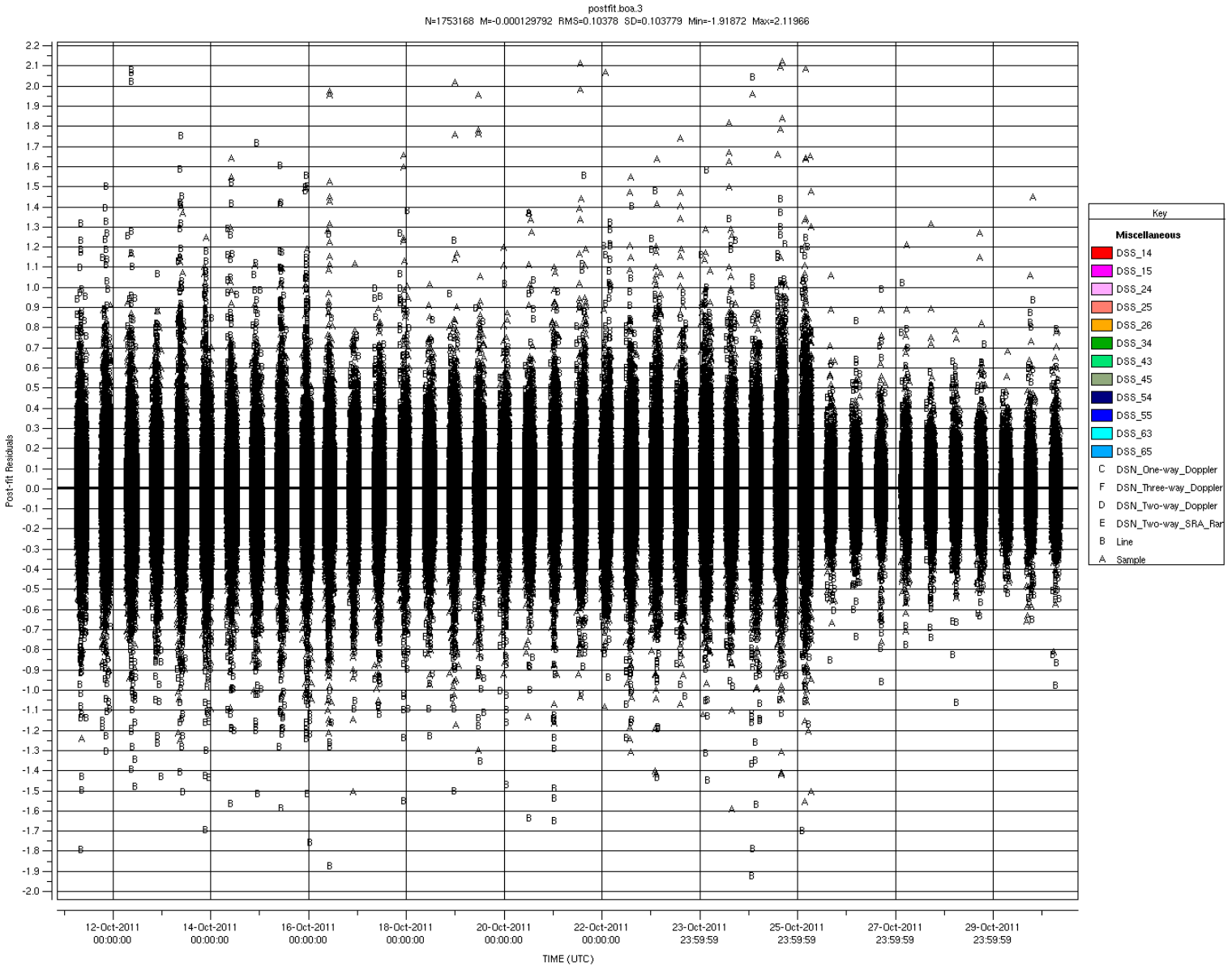
HAMO-2 reconstruction is still underway

Mission Phase	Approximate number of landmarks and surface coverage	Landmark map pixel resolution	1-σ post-fit RMS landmark-image residuals Total landmark residuals in parentheses	1-σ post-fit covariance for landmark vectors/DOF
Mid approach, RC1 - OpNav18	220 90º S to 10º N	1.5 km	0.3 pixels (1.3 km)	710 m
Late approach OpNav19 - 23	816 90º S to 47º N	1.5 km, 1 km, 750 m	0.38 pixels (0.55 km)	225 m
End of Survey, round 1	2817 90º S to 47º N	750 m, 300 m	0.15 pixels (88 m)	97 m
End of Survey, round 2	17630 90º S to 47º N	300 m 125 m	0.14 pixels (62 m)	65 m
End of HAMO-1	69242 90º S to 47º N	300 m, 125 m, 60 m	0.14 pixels (33 m)	43 m
End of HAMO-2, round 1	69242 90° S to 47° N	300 m, 125 m, 60 m	0.22 pixels (24 m)	29 m

Post-Fit Optical Residuals from Orbit Determination

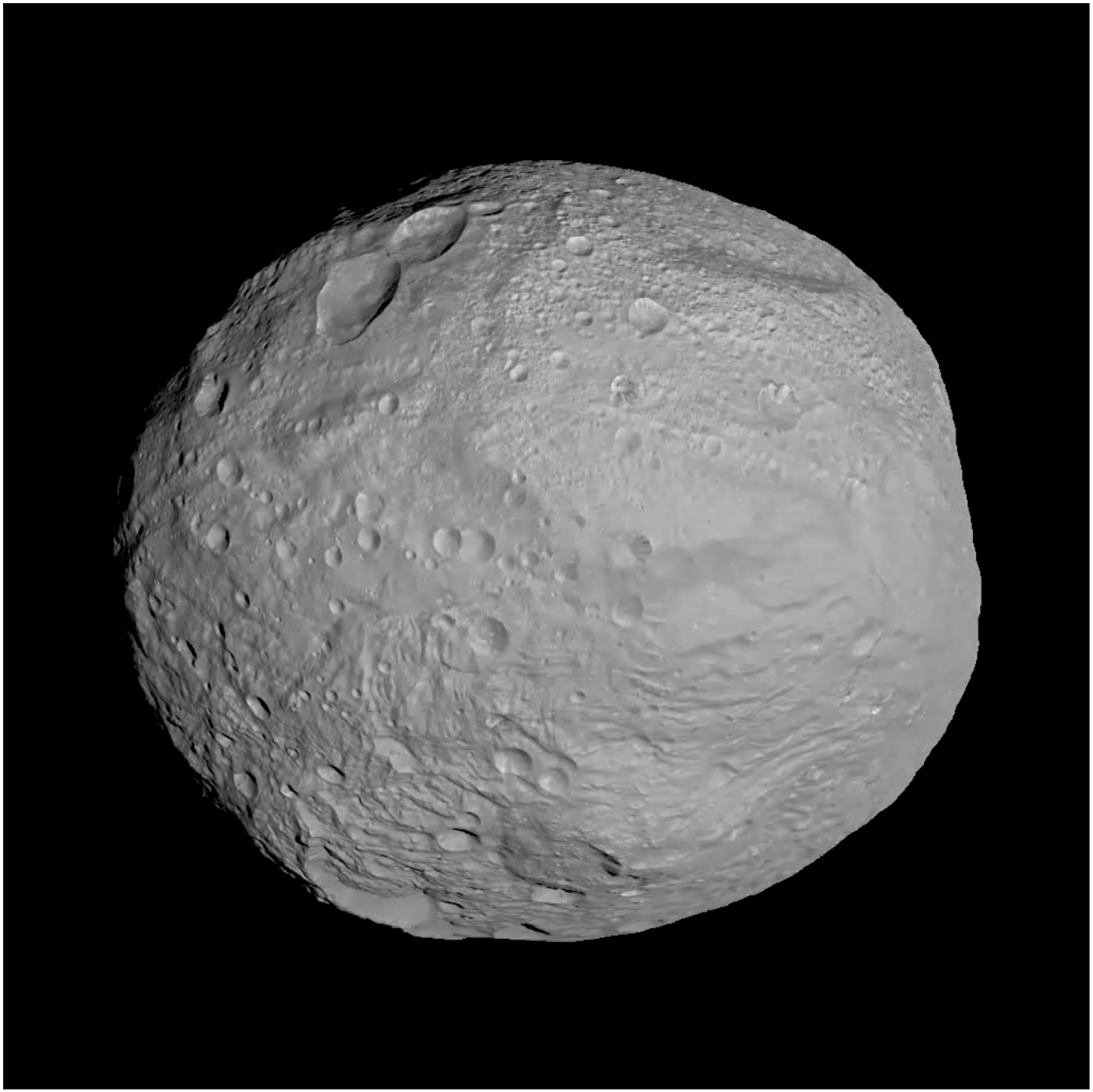
Residuals from HAMO-1 reconstruction in FC pixels

Imaging cycles presented different signatures depending on the off-nadir view angles



Conclusions

- Optical Navigation operations were successfully planned and executed at Vesta over a 15-month period

- Optical Navigation has contributed to meeting science requirements at all mission phases without incurring any delays that could result in loss of science

- In the process we have acquired a number of valuable lessons-learned that range from planning and sequence building to image processing and estimating asteroid parameters, that are under study for the upcoming encounter with Ceres