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The Gravity Field of Vesta from Dawn

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Abstract

The Dawn mission to Vesta has completed the bulk of the gravity measurements and a global solution is available. When correlated with a shape model derived from the framing camera data, these data can constrain the interior structure from the core to the crust. The investigation [1] utilizes the precision Doppler tracking of the spacecraft and landmark tracking from framing camera images to measure the gravity field of Vesta. The solution also yields the spin-pole location and rotation. The second-degree harmonics together with assumptions on obliquity or hydrostatic equilibrium determine the moments of inertia and constrain the core size and density. The determination of GM is highly accurate for a gravity field of degree 8 with 140-km resolution. The result shows that J_2 is not consistent with a homogeneous density body.

1. Introduction

An 8th degree and order map of the gravitational field from HAMO is shown in Figure 1; the spectrum is shown in Figure 2. With uncertainties three times the formal errors, the *normalized* gravity coefficients are: GM (km^3/s^2) = 17.28867 ± 0.00003 (0.0002%), J_2 = 0.0317799 ± 0.0000002 (0.0005%), C_{22} = 0.0043513 ± 0.0000003 (0.007%), S_{22} = 0.0003641 ± 0.0000005 (0.1%), C_{21} = 0.00000000 ± 0.00000003, S_{21} = 0.00000001 ± 0.00000003.

2. Three-Layer Model

Three-layer mass-balance models were calculated and compared to the measured second-degree gravitational moment J_2. Core density was fixed at an average value for iron meteorites, i.e., 7400 kg/m^3. For an assumed core flattening of 0.1, and a mean crustal thickness of 22.5 km, a mantle density of 3170 kg/m^3 corresponded to a crustal density of 2990 kg/m^3. An expected value from hydrostatic equilibrium for a core flattening is 0.1; however, Vesta is not hydrostatically equilibrated at present. An average core size of ~105-120 km is needed to match the observed J_2 [2].

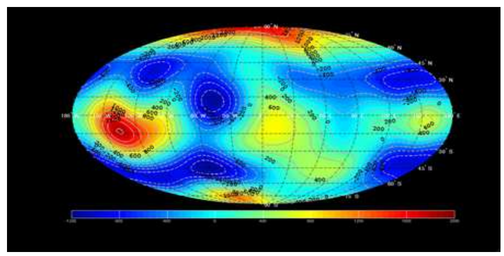

Figure 1: Radial Acceleration (mGal) on a 290 km × 265 km ellipsoid used for spherical harmonic expansion without diverging at the poles.

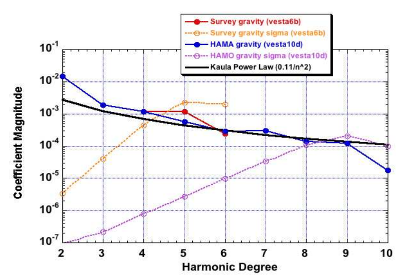

Figure 2: Spectrum of the gravity field harmonic expansion where degree 8=104 km at half-wavelength.

3. Bouguer Maps

Figure 3 shows a representative Bouguer map: observed gravity minus gravity from a 3-layer model. Contours show the surface acceleration difference in mGal and background plot represents the topography. The shape volume is 7.497×10^7 km^3, crust volume is 1.771×10^7 km^3, mantle volume is 5.216×10^7 km^3, core volume is 5.094×10^6 km^3, core size is 115.6 km × 104.0 km, core average size is 111.6 km, and core flattening is 0.1.

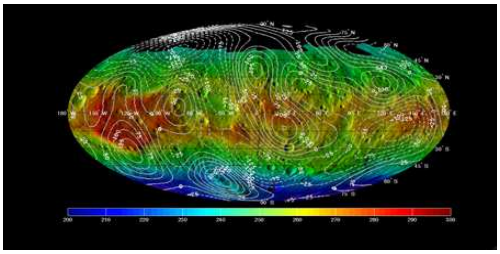

Figure 3: Representative Bouguer map based on the nominal three-layer model.

4. Hydrostatic Equilibrium

The shape of Vesta is reasonably well approximated by a triaxial ellipsoid, which departs from an oblate spheroid in that the two equatorial axes differ by 8 km. For slowly rotating fluid bodies, the expected shape is that of a MacLaurin spheroid, with a short axis aligned with the spin axis, and two equatorial axes equal to each other and longer than the polar axis. The angular momentum of Vesta, assuming a homogeneous density distribution, is only 44% of that at the bifurcation into two stable fluid configurations. As a result, if Vesta were hydrostatic, it would have an axisymmetric shape. Our gravity analysis has confirmed that Vesta is not currently in hydrostatic equilibrium. There are three separate components to this confirmation. First, for a hydrostatic body, far removed from tidal influences, rotation is the only source of non-spherical perturbations. We have measured high-degree gravity coefficients that have a variance spectrum similar to what is expected for solid bodies. Second, the non-zero values of C_{22} and S_{22} attest to non-hydrostatic structure, even at harmonic degree 2. Finally, the second-degree zonal coefficient J_2 is too large for Vesta to be in hydrostatic equilibrium. If we compare the observed J_2 value to that imposed by the rotational potential, the apparent fluid Love number k_2 is 1.85, whereas the largest possible value is 1.5. This suggests that the gravitational field of Vesta is at present dominantly that of a solid body, which is rather far from hydrostatic equilibrium.

5. Vesta Physical Parameters

In addition to the gravity field estimate, other determined parameters include the Vesta pole position and rotation rate and body-fixed locations of the landmarks from the optical data. The landmark locations are given in a coordinate system with the center-of-mass at the origin and thus can be used to find the offset between the shape model and gravity field. Current estimates show the frame tie offset of the Gaskell shape model is constrained to be less than several hundred meters.

The solution of the pole location from the Vesta10d solution is RA=309.031 ± 0.003 and Dec = 42.2264 ± 0.0002. More recent Doppler data have sufficient quality to solve for Vesta's rotation rate and the spin pole precession rate, which will constrain the moment of inertia, and thus help resolve internal structure.

Acknowledgements

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References

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