THE DYNAMICS OF DAWN AT VESTA. P. Tricarico and M. V. Sykes, Planetary Science Institute, 1700 East Fort Lowell, Suite 106, Tucson, Arizona 85719, tricaric@psi.edu, sykes@psi.edu.

Introduction: The NASA Dawn Discovery mission will be arriving at its first rendezvous target, Vesta, in mid-2011, using a low-thrust solar electric propulsion (EP) system. After approximately one year at Vesta, Dawn will leave orbit and depart for its second target, Ceres, arriving in 2015. The efficiency of electric propulsion makes this mission possible within Discovery program cost limits.

Vesta is one of the most massive asteroids in the main belt between Mars and Jupiter. It fits within the envelope of a triaxial ellipsoid of dimensions 577, 563, and 478 km, but deviates from that shape as a consequence of a nearly hemispheric impact crater covering its southern pole [1]. Its surface is covered with basalt, and it is thought to be the source object of HED meteorites on the Earth. From those meteorites it is inferred that Vesta has a substantial metallic core [2].

Vesta's mass and irregular shape is expected to be manifested in higher-order gravitational terms that will effect the orbital motion of Dawn as it executes its mission.

Dawn will initially enter into a survey orbit at around 2700 km radius to obtain a preliminary shape model and specrtrally map the illuminated surface. Using its EP thrusters, it will then descend to its High Altitude Mapping Orbit (HAMO) around 950 km radius at which it will obtain observations for the stereo-photoclinometric determination of its surface topography. Dawn will then descend to its Low Altitude Mapping Orbit (LAMO) of approximately 460 km to map Vesta's elemental composition using the Gamma-Ray Neutron Detector (GRaND) [3,4]. The transition between these orbits will be relatively slow, about 30 days [5]. Consequently, while descending from HAMO to LAMO, Dawn will experience significant perturbations as it slowly passes through commensurabilities between its orbital period and Vesta's 5.3 hour rotational period.

A minimum LAMO is of significant science value. It provides maximum spatial resolution for Dawn's Framing Camera (FC) and Visible InfrRed mapping spectrometer (VIR), but is of particular value for GRaND instrument, where both sensitivity and spatial resolution are improved with decreasing altitude [6]. A better gravity model is also obtained.

Vesta Gravity Model: A simple model of Vesta's gravitational field is derived using the shape model derived from observations by the Hubble Space Telescope [7], a recent determination of its total mass [8], and assuming uniform mass density throughout the body. This maximizes the power in the higher order gravity terms compared with a model assuming a metallic core, and provides a "worst case scenario" for Dawn operations.

A Monte Carlo method is used to sample 10^8 points inside the Vesta shape, corresponding to one sampling point per km of resolution. The gravitational potential to the 8^{th} degree is then calculated.

Simulating Dawn Motion: This work makes use of the open-source tool for celestial mechanics investigations, ORSA, developed by P. Tricarico [9]. ORSA implements the interaction between bodies with arbitrary shapes and mass distributions [10], and the code has been validated with data from the NEAR mission to Eros [11].

We assume Dawn descends from HAMO in a polar orbit using 20 mN of thrust, at the low end of Dawn's thrust range [12], but effecting transfer to LAMO in about the 30 days nominally planned. Dawn mass is assumed to be about 1000 kg and the total surface area 39.2 m^2 [12] . The effect of radiation pressure is estimated using the formalism of Scheeres [13].

The Effects of Vesta's Gravity: Figure 1 shows that in the absence of thrusting at non-resonant orbital radii, the Dawn spacecraft radial range will oscillate around 50 km in the course of 50 days as gravitational perturbations affect its semimajor axis and eccentricity. Below a 400 km radius, this oscillation quickly blooms in amplitude and threatens to come within Vesta's maximum radius of 289 km at its equator. It would appear that 400 km is the minimum safe radius for LAMO against loss of thrust. Near commensurabilities between Dawn's orbital period and Vesta's rotational period, the effect of Vesta's gravity are enhanced.

Running a number of simulations with thrusting from HAMO to LAMO, and stepping through different initial phases of Dawn's orbit and Vesta's rotation, we find that there are cases in which the Dawn spacecraft can be trapped in the 1:1 resonance. This is observed at higher thrusts as well. This is illustrated in Figure 2. When trapped, Dawn's orbit librates about the longitude corresponding to the shortest equatorial diameter. In the meantime, it appears that the spacecraft motion remains within a well-defined envelope that appears to be safe against sudden loss over the time scales studied. Escape from the resonant trap was achieved by increased thrust (35 mN) at the right phase of libration. The full range of circumstances for trapping and escape from the 1:1 resonance is to be explored. The combination of Vesta's mass and complex gravity with

Dawn's low-thrust propulsion results in interesting operational challenges whose understanding will be of value to future missions to large irregular asteroids.

References:

[1] Thomas P. C. et al. (1997) Science 277, 1492-1495. [2] Ghosh A. and McSween H. Y. (1996) LPS XXVII, 185. [3] Russell C. T. et al. (2004) Plan. & Sp. Sci. 52, 465-489. [4] Russell C. T. et al. (2007) Adv. Sp. Res. 40, 193-201. [5] Russell C. T. et al. (2007) Earth, Moon, Plan. 101, 65-91. [6] Prettyman T. H. et al. (2003) IEEE Trans Nucl. Sci. 50, 1190-1197. [7] Thomas P. C. et al. (1997) Icarus 128, 88-94. [8] Pitjeva, E. V. and Standish E. M. (2009) Celest. Mech. Dyn. Astron. 103, 365. [9] http://orsa.sourceforge.net [10] Tricarico P. (2008) Celest. Mech. Dyn. Astron. 100, 319-330. [11] Tricarico P. and Sykes M. V., in preparation. [12] Rayman M. D. et al. (2007) Acta Astron. 60, 930-938. [13] Scheeres D. J. (1999) J. Astronaut. Sci. 47, 25-46.

Figure 1. Radial range as a function of the initial radius of a circular orbit, computed over a period of 50 days. The central mark in each bar represents the median of the range. Five spin-orbit resonances have been identified and are clearly marked. The 1:1 resonance affects the largest interval in initial radius, but the strongest perturbations come from the 2:3 resonance.

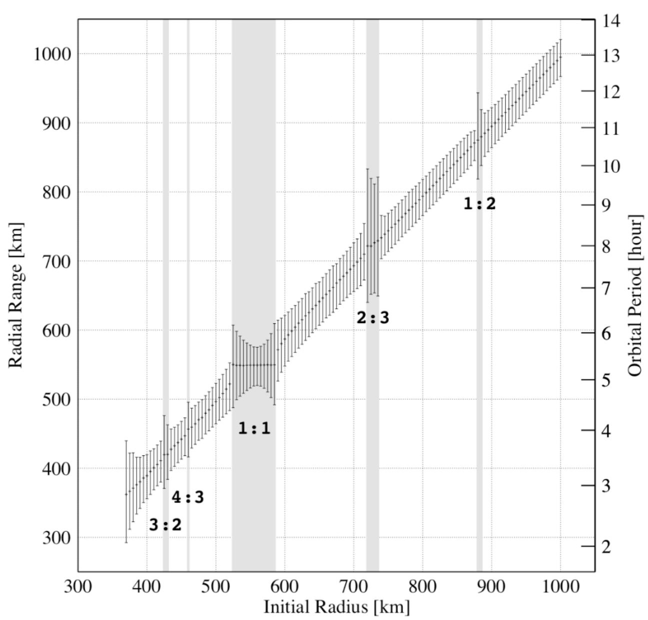

Figure 2. Dynamics of the Dawn spacecraft spiraling in from HAMO under 20 mN thrust, becoming trapped in the 1:1 resonance between Dawn's orbital period and Vesta' rotational period. Trapping is sensitive to the equatorial longitude at which Dawn crosses the resonance.