DERIVING THE DYNAMICS OF EROS FROM GRAVITY VARIATIONS; *David E. Smith*[1], *Maria T. Zuber*[2,1], and *David D. Rowlands*[1], [1]Laboratory for Terrestrial Physics, NASA/Goddard Space Flight Center, Greenbelt, MD 20771, [2]Department of Earth and Planetary Sciences, Johns Hopkins University, Baltimore, MD 21218.

One of the objectives of the Near Earth Asteroid Rendezvous (NEAR) mission is to improve our understanding of the dynamics and interior of Eros. One source of information about the interior is the gravity field, and both the gravity field and the dynamics are information that can be extracted from the very precise data that is used to track the spacecraft. Because Eros has an irregular shape its gravity field is non-symmetric and this causes perturbations of the motion of the NEAR spacecraft that can be detected in the tracking data. These perturbations can be used to map the gravity field of the body but they can also be used to determine the orientation of the gravity field and its rate of rotation. It is the irregularity of Eros' s gravity field that permits the estimation of its rotation from the time and spatially varying gravity signal.

Background. The current best estimate of the synodic period of Eros has an uncertainty of 720 msec [1]. The pole orientation of this asteroid has been estimated to an accuracy of ~2° [1, 2, 3, 4, 5]. For comparison, the position of the north pole of Gaspra was calculated in two independent determinations from Galileo imaging [6, 7], and these studies obtained uncertainties of about 1° and 2-3°, respectively. We estimate that it will be possible to resolve the Eros rotation rate to about 1 millisecond and the spin axis direction to about 0.01° from one to two months of Doppler tracking of the NEAR spacecraft under the approximate current mission scenario [8].

The Simulation. We have performed a simulation of the motion of a spacecraft around the asteroid 433 Eros in order to understand how the geophysics and rotational dynamics of a highly elliptical body, such as an asteroid, can be determined solely from the Doppler tracking data of the spacecraft. We have created simulated tracking data for the asteroid approach and several orbital stages and determined the precision with which the rotational state of the asteroid can be derived, as well as the size and quality of the gravity field, and the precision of the orbit.

We first simulated the shape and size of Eros from which we derived a mass and gravity field. A tri-axial ellipsoid with the "known" physical dimensions, 36 km x 13 km x 15 km, was "filled" with approximately 20 million small cubes, 50 meters on a side and density 3500 kg m^{-3}. This value of density corresponds to a silicate rich body. The mass of Eros and the gravity field out to degree 10 were then computed in a reference frame in which the z-axis is coincident with the rotation axis through the center of mass and parallel to the axis of maximum moment of inertia. Because of the simplicity of the assumed shape and the coordinate system chosen, many terms in the Legendre polynomial expansion of the gravity potential are zero. This simplification of the model does not limit the effectiveness of the simulation since all terms will be estimated in the analysis. It only implies that these terms will have zero value in the simulated data.

Using the density and the calculated volume we derived a mass for Eros of 1.299×10^{16} kg from which we calculated the GM (product of the mass and gravitational constant) as $GM_{Eros} = 8.57 \times 10^5\ m^3\ sec^{-2}$. For comparison, Phobos, the natural satellite of Mars has a $GM_{Phobos} = 5.86 \times 10^5\ m^3\ sec^{-2}$ [9] .

Using the model of Eros' gravity field we then simulated the hyperbolic approach of NEAR to Eros and four orbital configurations with altitudes ranging from 1000 km to 35 km. During each orbital phase we simulated the acquisition of X-band Doppler tracking data by the Deep Space Network (DSN) with an accuracy of 0.1 mm s^{-1} at a ten second rate. We did not make any attempt to simulate maneuvers or momentum dumps in the simulation although we presume these will occur. Our orbital arcs were 5 to 6 days in length and therefore we have assumed that the orbital maneuvers do not occur more frequently than this or that they are fully characterized and therefore modelable. Both the data simulation and the subsequent analysis were performed using NASA/GSFC's GEODYN program system [10].

Analysis of Simulated Data. We analyzed the simulated tracking data with a "clone" gravity model of Eros developed in the same manner as before but using dimensions of Eros 1 km wider, *i.e.,* 36 km x 16 km x 13 km. This "clone" gravity model was used in the orbit determination of NEAR and to compute the partial derivatives of the parameters to be adjusted, including the gravity field. The data were analyzed in various orbital arc lengths depending on the phase of the mission, ranging from 5 days during the close in orbital phases to a single 18 day arc on approach to Eros. The orbital fit to the simulated data using this clone gravity model ranged from a high of 2 mm s^{-1} on the 35 km radius orbit to 0.1 mm s^{-1}, the noise level, on the 200 km orbits after adjusting for the orbit but before estimating the new gravity field coefficients or Eros's rotational state. These results indicate the weakness of the Eros gravity field at 200 km distance on the orbit of NEAR over a 6 day period, the orbital arc length.

Normal equations were developed for each orbital arc. These equations relate the observations to the parameters describing the orbit, the gravity field, the rotation, and all other parameters to be adjusted. The normal equations were then solved to provide the values for the adjusted parameters and their variances. Table 1 summarizes the results obtained for each of the orbital phases for the precision of GM, the gravity field, the rotation period and spin axis direction, and then orbit.

Table 1. NEAR Simulation results

Phase/ Altitude	Data Span	sGM/GM	Approx. Gravity field size	Eros Rotation s (pd)	s (dir.)	Orbit Precision
Flyby, 500 km	18 days	0.6×10^{-3}	-	~1000 sec	1.5^{o}	~10 km
1000 km	14 days	1.2×10^{-2}	-	~400 sec	4^{o}	~10 km
200 km	18 days	0.6×10^{-3}	3 x 3	0.5 sec	0.5^{o}	~300 m
50 km	60 days	0.7×10^{-6}	10 x 10	1.0 msec	0.01^{o}	5 m
35 km	42 days	3.4×10^{-6}	15 x 15	0.4 msec	0.01^{o}	1 m

Summary. From the table it is evident that a gravity field of the order 15x15 should be recoverable from the tracking data, but of equal interest is the expected quality with which the rotation of Eros can be estimated. At a distance of 35 km it is estimated that the rotation can be determined to better than a millisecond in period and about 0.01^{o} in spin axis direction. This result assumes that all maneuvers, spacecraft momentum dumps and other disturbances can be fully modeled and that the tracking of the spacecraft is continuous over the period. None of these assumptions will be completely true but the results suggest a very robust capability is potentially available if these effects can be minimized.

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