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Spacecraft Discoveries Enabled by Photometric Observations of the Dynamics of 1996 FG_3

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Abstract

We have observationally confirmed [1] a theoretically predicted [2] equilibrium between tidal and BYORP torques acting within the synchronous binary asteroid system 1996 FG_3. For the first time, we can solve for asteroid tidal parameters given this torque balance and a BYORP coefficient for the synchronous secondary. While the "rubble pile" interior structure hypothesis explains large inferred porosities, the surface of Itokawa, the observed spin limit amongst the asteroid population, and evidence that asteroid pairs form from rotational fission, the implications for asteroid geophysics are not well understood. These material properties are set by the asteroid's strength (rigidity) and internal energy dissipation, which determine tidal synchronization timescales and are related to phenomena such as seismic shaking of asteroids. Current theory and observations degenerately determine geophysical parameters of the primary and the BYORP coefficient of the secondary. A detailed shape model of the secondary is necessary to remove this degeneracy. This is added incentive for spacecraft missions to visit synchronous binary asteroids such as 1996 FG_3 over other asteroid system morphologies.

1. Theory

Mutual body tides are due to deformations caused by the changing gravitational field of orbiting bodies. These tides dissipate energy and exchange angular momentum between spin and orbit. To first order, these tidal interactions can be parameterized by two factors. The tidal Love number k is the ratio of the additional gravitational potential produced by the redistribution of mass relative to the deforming potential and is related to the strength (rigidity) of the body. The tidal dissipation number Q describes how effective the body dissipates mechanical energy. Both parameters are not well-known for "rubble pile" structures, and are constrained by dynamical evolution arguments (e.g. [3]). The BYORP torque is the summation of radiative torques from the surface of a synchronous binary member onto the barycenter of the system. McMahon & Scheeres [4] showed that showed that to first order in eccentricity the evolution of the semi-major axis and eccentricity depends only upon a single constant coefficient determined by the shape of the secondary (size-independent). The BYORP coefficient of the secondary of 1999 KW_4 is modeled to be $B \sim 10^{-3}$ [4]. When the BYORP torque is contractive, it balances the expansive tidal torque and the system evolves to an equilibrium semi-major axis that is stable in eccentricity due to tidal decay [2]. We can therefore solve for the unknown parameters B, k, and Q assuming that the observed systems occupy this equilibrium:

$$\frac{BQ}{k_p} = \frac{2\pi\omega_d^2 \rho R_p^2 q^{4/3}}{H_\odot a^7} \tag{1}$$

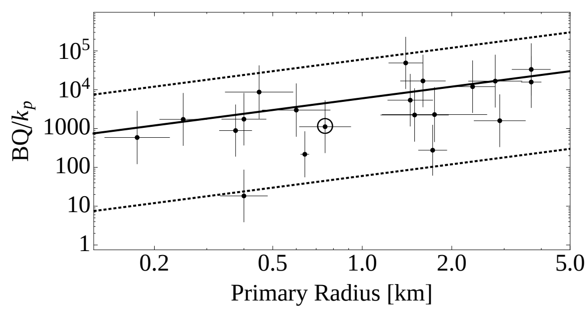

Figure 1: Points represent the calculated BQ/k_p with derived 1-σ uncertainties as a function of radius assuming these synchronous binaries are in the tidal-BYORP equilibrium (updated from [2]). 1996 FG_3 is encircled as the only confirmed equilibrium binary. The solid line is a simple fit to the data: $BQ/k_p = 6 \times 10^3 R_p$. The upper and lower dashed lines represent possible uncertainties in the BYORP coefficient ranging between 10^{-2} and 10^{-5}, respectively.

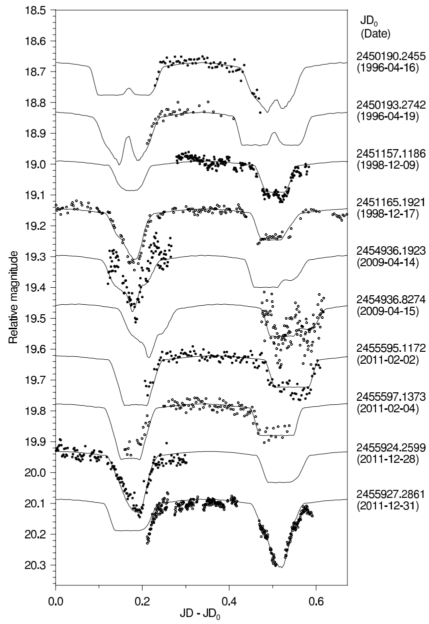

Figure 2: Points are photometric lightcurve observations of 1996 FG_3 spanning over fifteen years. The line is the best fit model to the data with the quadratic drift of the mean anomaly ΔM_d as a free parameter allowing for the possibility for evolution of the mean motion. The best fit has $\Delta M_d = 0.00^{+0.18}_{-0.10}$. Timing of mutual events determined the value of the quadratic drift ΔM_d. Magnitude scale is relative for each date.

This was done and is shown in Figure 1.

2. Observations

Changes to the semi-major axis reveal themselves most radically in the evolution of the mean anomaly, detected via mutual events (i.e. occultations and eclipses) [4, 5]. The mean anomaly M of a Keplerian orbit evolves as: $M = n(t-t_0)+\Delta M_d(t-t_0)^2$ where t and t_0 are the observation and periapse passage reference times, and $\Delta M_d = \dot{n}/2$ is the quadratic drift in the mean anomaly due to evolution of the mean motion. At the Asteroids, Comets and Meteorites meeting in May [1], Scheirich et al. determined basic parameters for 1996 FG_3 including sizes and shapes (ellipsoidal approximations) of both components, the mutual orbit (Keplerian approximation), and the quadratic drift in the mean anomaly ΔM_d, as an independent parameter, using data from over 15 years and a numerical model as described in [6]. Results are shown in Figure 2.

3. Consequences for Spacecraft

We have determined that 1996 FG_3 and possibly all synchronous binary asteroids occupy an equilibrium between tidal and BYORP torques. For the first time, the tidal parameters k and Q may be directly assessed, however without appropriately detailed shape models of the synchronous secondary member these parameters are degenerate with the BYORP coefficient of the secondary. These shape models will be a challenge to construct from ground observations because these synchronous satellites are small and very close to their companions. Spacecraft missions would be able to provide the necessary shape models to assess the system's BYORP coefficients, from which the tidal parameters could be directly calculated. This is an added incentive for spacecraft missions targeting asteroids for other goals (e.g. sample return) to consider low Delta-V synchronous binary asteroids such as 1996 FG_3 over other system morphologies. The tidal parameters k and Q constrain bulk asteroid geophysics providing insight into the strength (rigidity) and the energy dissipation mechanisms of these bodies.

References

[1] Scheirich P. et al.: Zero drift in the mean anomaly of the satellite of 1996 FG_3 and its implications for the BYORP Theory, ACM 2012, May 2012, Niigata, Japan, 2012.

[2] Jacobson S. A. and Scheeres D.: Long-term Stable Equilibria for Synchronous Binary Asteroids, Astrophysical Journal Letters, Vol. 736(1) pp. L19

[3] Taylor, P. A. and Margot, J-L.: Binary asteroid systems: Tidal end states and estimates of material properties, Icarus, Vol. 212, pp. 661-676, 2011.

[4] McMahon J. and Scheeres D.: Detailed prediction for the BYORP effect on binary near-Earth Asteroid (66391) 1999 KW4 and implications for the binary population, Icarus, Vol. 209, pp. 494-509, 2010.

[5] Pravec P. and Scheirich P.: Binary System Candidates for Detection of BYORP,42nd DPS, October 2010, Pasadena, CA, USA, 2010.

[6] Scheirich P. and Pravec P.: Modeling of lightcurves of binary asteroids, Icarus, Vol. 200, pp. 531-547, 2009.