Asteroids: New Observations, New Models
Proceedings IAU Symposium No. 318, 2015
S. R. Chesley, A. Morbidelli, R. Jedicke & D. Farnocchia, eds.

doi:10.1017/S1743921315009618

Spin-orbit coupling in binary asteroids

Jean-Luc Margot[1] and Shantanu P. Naidu[2]

[1]University of California, Los Angeles,
595 Charles Young Drive East, Los Angeles, CA 90095, USA
email: `jlm@astro.ucla.edu`

[2]Jet Propulsion Laboratory,
4800 Oak Grove Drive, Pasadena, CA 91109, USA
email: `shantanu.p.naidu@jpl.nasa.gov`

Abstract. We use radar images with decameter resolution to measure the sizes, shapes, spin states, mutual orbits, masses, and densities of components of asteroid binaries and triples. We simulate the spin-orbit dynamics of these systems and map the possible spin configurations of the satellites on surface of section plots. The presence of chaotic regions in the phase space has important consequences for the evolution of binary asteroids. It may substantially increase spin synchronization timescales, delay BYORP-type evolution, and extend the lifetime of binaries.

Keywords. minor planets, asteroids, solar system: general, planets and satellites: formation

---

The YORP-induced rotational fission hypothesis is the leading candidate for explaining the formation of binaries, triples, and pairs among small (<20 km) asteroids (e.g., Margot *et al.* 2015). Various evolutionary paths following rotational fission have been suggested, but many important questions remain about the evolutionary mechanisms and timescales. We test hypotheses about the evolution of binary asteroids by obtaining precise descriptions of the orbits and components of binary systems with radar and by examining the system dynamics with detailed numerical simulations. Predictions for component spin states and orbital precession rates can then be compared to observables in our data sets or in other data sets to elucidate the states of various systems and their likely evolutionary paths.

Accurate simulations require knowledge of the masses, shapes, and spin states of individual binary components. Because radar observations can provide exquisite data sets spanning days with spatial resolutions at the decameter level (Figure 1), we can invert for the component shapes and measure spin states. We can also solve for the mutual orbit by fitting the observed separations between components. In addition, the superb ($10^{-7} - 10^{-8}$) fractional uncertainties in range allow us to measure the reflex motions directly, allowing masses of individual components to be determined.

We use recently published observations of the binary 2000 DP107 (Naidu *et al.* 2015) and that of other systems to simulate the dynamics of components in well-characterized binary systems (Naidu and Margot 2015). We model the coupled spin and orbital motions of two rigid, ellipsoidal bodies under the influence of their mutual gravitational potential. We use surface of section plots to map the possible spin configurations of the satellites (Figure 2). For asynchronous satellites, the analysis reveals large regions of phase space where the spin state of the satellite is chaotic. The presence of chaotic regions may substantially increase spin synchronization timescales, delay BYORP-type evolution, extend the lifetime of binaries, and explain the observed fraction of asynchronous binaries.

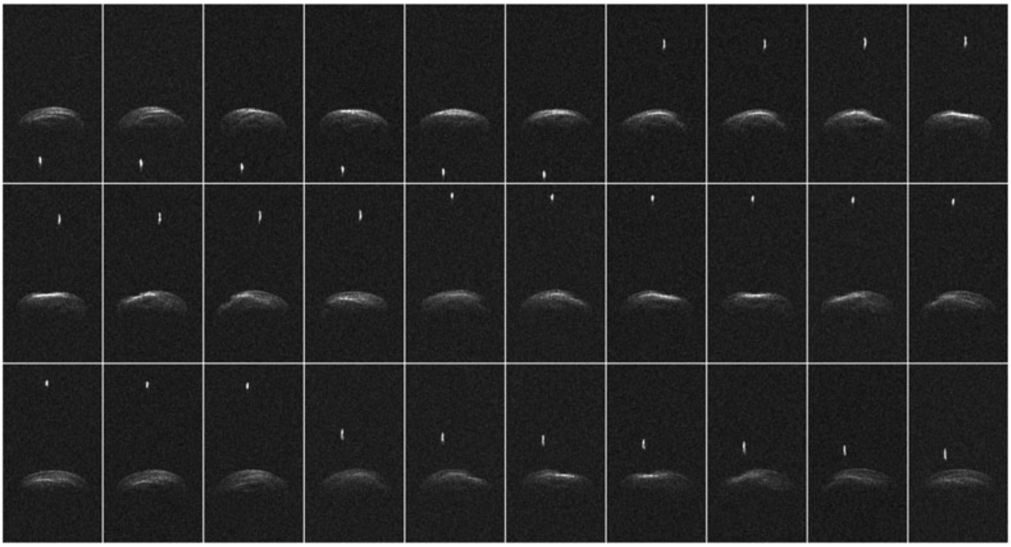

Figure 1. Range-Doppler images of binary asteroid 2000 DP107 obtained with the Arecibo planetary radar. Range increases down and Doppler shift increases to the right. The binary was first characterized with observations in 2000 (Margot *et al.* 2002). Additional observations in 2008 considerably improved our knowledge of the system (Naidu *et al.* 2015). This collage incorporates 4 separate days of observations in 2008. The images reveal a fast-spinning primary component (with 2.77 h spin period and ∼860 m equivalent diameter) and a smaller, slowly-rotating secondary component (with a 1.77 d spin period synchronized to the orbital period).

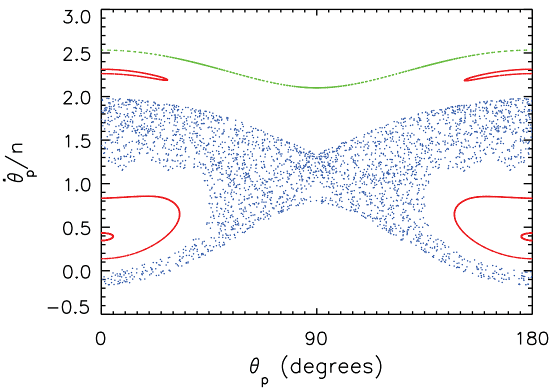

Figure 2. Surface of section plot showing the possible rotational regimes of the ∼200 m secondary of 1991 VH (secondary elongation $a/b = 1.5$ and mutual orbit eccentricity $e = 0.05$). The plot shows the angle between the long axis and the line of apsides of the mutual orbit, θ_p, against its time derivative, $\dot{\theta}_p$, normalized by the mean motion, n, at each pericenter passage. Five trajectories are illustrated (from top to bottom: non-resonant quasi-periodic, periodic, chaotic, periodic, periodic). While trapped in the sea of chaos, the secondary experiences torques on its permanent deformation that result in a highly variable spin rate, preventing BYORP-type evolution. Figure from Naidu and Margot (2015).

References

Margot, J. L., Nolan, M. C., Benner, L. A. M., Ostro, S. J., Jurgens, R. F., Giorgini, J. D., Slade, M. A., & Campbell, D. B. 2002, *Science*, 296, 1445

https://doi.org/10.1017/S1743921315009618 Published online by Cambridge University Press

Margot, J. L., Pravec, P., Taylor, P., Carry, B., & Jacobson, S. 2015, *in Asteroids IV*, arXiv:1504.00034

Naidu, S. P. & Margot, J. L. 2015, *The Astronomical Journal*, 149, 80

Naidu, S. P., Margot, J. L., Taylor, P. A., Nolan, M. C., Busch, M. W., Benner, L. A. M., Brozovic, M., Giorgini, J. D., Jao, J. S., & Magri, C. 2015, *The Astronomical Journal*, 150, 54