Libration-eccentricity evolution of expansive binary asteroids in the presence of tidal dissipation

J. McMahon[1]

[1]University of Colorado at Boulder

Singly-synchronous binary-asteroid systems have several evolutionary end-states, which depend heavily on the BYORP effect [1,2]. If BYORP is contractive, the primary and secondary could re-impact to form a contact binary, or they could end in a tidal-BYORP equilibrium [3]. Alternatively, if BYORP is expansive, they binary system could evolve to a wide asynchronous binary system [4,5], or the system could expand all the way to the Hill radius and form a heliocentric pair [3,6]. The distinction between these two expansive outcomes depends on whether the secondary asteroid stays synchronized, which keeps the BYORP effect active and the orbit expanding.

The early analysis of the expansive case [1,2] showed that BYORP will act to maintain a near-circular binary orbit as the semi-major axis increases, however this was based on the assumption that the secondary is tidally locked at all distances. In reality, the secondary will be librating around the tidally locked orientation to some degree, and this libration will grow as the orbit expands. The libration also causes variations in the osculating binary orbit eccentricity due to the elongation of the secondary body. This coupling is key to determining the fate of the expanding system [7]. If the eccentricity grows large enough, the secondary will begin circulating and BYORP will be shut off; conversely, if the eccentricity is bound to small enough values the libration will also be bounded and thus the system will be free to keep expanding. As the system expands the eccentricity variations will shrink as the gravitational perturbations from the elongated secondary fall off. Making matters more complicated is the fact that as the orbit grows, the 3rd body perturbations from the Sun can have a larger effect on the binary orbit. This combination of coupled dynamics and perturbations whose magnitude varies greatly over the range of binary orbit semi-major axes requires exploration through high-fidelity numerical simulation.

In this work, we attempt to quantify under what conditions a singly synchronous binary system can evolve to become an asteroid pair. This requires a detailed investigation of the stability of the secondary asteroid's librational motion [8] as BYORP adds energy to the orbit while tides simultaneously remove energy from the librational motion. In particular we investigate how various levels of tidal strengths change the stability of the librational motion, which has not been explored in the literature to date. This analysis will help to inform the expected production rates of heliocentric pairs and wide asynchronous binary systems from singly synchronous systems.

References: [1] M. Cuk and J. A. Burns, ICARUS 176, 418 (2005). [2] J. W. McMahon and D. J. Scheeres, Celestial Mechanics and Dynamical Astronomy 106, 261 (2010). [3] S. A. Jacobson and D. J. Scheeres, The Astrophysical Journal Letters 736, L19 (2011). [4] S. A. Jacobson, D. J. Scheeres and J. W. McMahon, The Astrophysical Journal, in preparation. [5] M. Cuk and D. Nesvorny, ICARUS 207, 732 (2010). [6] J. W. McMahon and D. J. Scheeres, ICARUS 209, 494 (2010). [7] J. Fang and J. L. Margot, The Astronomical Journal, 143, 24, (2012). [8] J. W. McMahon and D. J. Scheeres, Celestial Mechanics and Dynamical Astronomy 115, 4, (2013).