Spin-induced mass loss from rubble piles and the formation of asteroid satellites and pairs

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Non-gravitational effects may change the angular momentum of asteroids up to a few tens of km in size to the point that rotational stability is lost at high spin rates. Once instability is initiated, mass loss may happen and potentially create satellites or dynamically detached components (pairs). We have studied this problem by means of numerical simulations and investigated the production of secondary objects of different sizes by direct splitting of the parent body under the assumption of a low internal angle of friction.

We focused our attention on the effect of progressive spin-up of objects as a consequence of the YORP effect. Since asteroids are clearly not fluid but rocky bodies, one can assume that equilibrium theories — also describing bifurcations (e.g., [1]) — do not directly apply [2]. The equilibrium shapes of non-fluid bodies have been studied in the recent past by several authors, assuming that rubble-pile asteroids can be modeled as cohesionless granular systems in the frame of continuum theories [2–5]. [6] shows that a small amount of tensile strength could be sufficient for the survival of some fast rotators, even if they are internally fragmented. More relevant to this work are the results obtained by [7,8] by the same N-body approach that we use, i.e., by simulating the dynamics and the collisions of mono-dispersed hard spheres utilizing the PKDGRAV code [9,10]. The YORP effect is modeled by increasing rigid rotation by small increments with enough time to relax between subsequent spin-ups. In this work, our approach is based again on the same simulation code; however, our new exploration of the parameter space is broader than the previous study in the near-fluid regime, which is achieved by randomizing the initial particle positions somewhat to break the otherwise crystalline structure of monodisperse particle packing.

We find that the transformation of objects into prolate ellipsoids is an efficient process when the internal angle of friction is low, which can result either in single-particle ejection from the ellipsoid "tips" or in splitting, with the formation of satellites of different size ratios. As we use random particle packing, the global internal strength of our objects is generally smaller than the one used in the simulations by [7,8]. This permits the study of a greater range of low-strength cases than was achieved in [8]. Our main conclusions: (1) The formation and size of a secondary are not strongly related to the initial shape of the parent body. However, a well-defined sequence of intermediate re-shaping processes — eventually producing binary systems — is identified. (2) The pattern of shapes that is found reproduces rather well the transition from prolate objects to binaries, passing through intermediate phases described in the literature [1,11]. (3) We show that the creation of binary systems with mass ratios >10 %, corresponding to minor component sizes of the order of one half of the primary, is possible. (4) We find that the outcome of the process (mass shedding/fission) is essentially chaotic, therefore unpredictable. We argue that this may be driven by the amount of crystal packing occurring inside the evolving body as it randomly re-adjusts itself when responding to spin up. Finally, we stress that we do not follow the long-term evolution of the resulting binary systems, a task that is beyond the aim of this work. A fraction of the secondary objects that form are not dynamically bound to their primaries. Further investigations should elucidate these behaviors and link them to the observed sample of binaries and decoupled pairs.

References: [1] N.R. Lebovitz, Int. J. Eng. Sci. 36 (1998) 1407–1420. [2] P. Tanga, C. Comito, P. Paolicchi, D. Hestroffer, A. Cellino, A. Dell'Oro, et al., Astrophys. J. 706 (2009) L197–L202. [3] K.J. Walsh, D.C. Richardson, P. Michel, Nature. 454 (2008) 188–191. [4] K.J. Walsh, D.C. Richardson, P. Michel, Icarus. 220 (2012) 514–529. [5] K.A. Holsapple, Icarus. 154 (2001) 432–448. [6] K.A. Holsapple, Icarus. 172 (2004) 272–303. [7] I. Sharma, J.T. Jenkins, J.A. Burns, Icarus. 200 (2009) 304–322. [8] K.A. Holsapple, Icarus. 187 (2007) 500–509. [9] Richardson et al., (2000) Icarus 143, 45–59. [10] Stadel (2001) Cosmological N-body simulations and their analysis (PhD thesis) U. Washington. [11] Y. Eriguchi, I. Hachisu, D. Sugimoto, Dumb-Bell-Prog. Theor. Phys. 67 (1982) 1068–1075.