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Possible routes to spin up fission for the formation of asteroid binaries and pairs

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Abstract

Non-gravitational effects (such as the "YORP" acceleration by thermal emission) may change their angular momentum of asteroids up to a few tens of km to the point to prevent any kind of rotational stability. Once instability is enforced mass loss may happen in more or less abrupt ways and potentially create satellites. We are studying this problem by means of numerical simulations, which extend previous results. We show that under certain conditions the production of secondary objects of different sizes by direct splitting can be a rather common event.

1. Introduction

Our goal is to infer more details on the evolution of the shapes of gravitational aggregates having achieved large angular momenta. In particular, we focus our attention on the effect of progressive spin-up of the objects as a consequence of physical processes like the YORP effect.

By analyzing the behavior of gravitational aggregates close to the bifurcation points predicted by theory, we also check if the predictions on the transition from prolate objects to binaries are valid.

Since asteroids are clearly not fluid, but rocky bodies, one can assume that equilibrium theories – also describing bifurcations (see e.g. [1]) - do not directly apply. However, the effective potential for ellipsoidal shapes (resulting from gravity and rotation) is extremely flat around the minima corresponding to the Maclaurin and Jacobi sequences, in such a way that a wide range of shapes can be considered to be very close to fluid equilibrium [2]. We also showed that the theoretical sequences still represent important attractors for the evolution of shapes, under a perspective that is evolutionary and fully dynamical, not quasi-stationary.

In this work, our approach is based on a numerical method already successfully applied by several authors, using essentially the same simulation code. However, our new exploration of the space of parameters is extensive and includes also some differences in some important assumptions concerning the initial conditions of the simulated systems. Some of the most recent papers published in the literature, which are taken into account in what follows, in order to compare and interpret the results obtained in our analysis, are [2–4].

2. Context and approach

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 cohesion-less granular systems in the frame of continuum theories [5–7]. [8] demonstrates 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 [3,4] by the same N-body approach that we use, i.e. by simulating the dynamics and the collisions of mono-dispersed hard-spheres (*pkdgrav* code). The YORP effect is modeled by increasing the rigid rotation by small increments (1% of the tangential velocity). Between each "kick" the body is left to relax during several time steps.

The general pattern of shape evolution found by [3,4] exhibits first a polar flattening of the body and, at higher spins, the gradual shedding of particles from the equator. A fraction of these particles re-accumulates in orbit to form a satellite. Shedding from the equator seems to be more efficient for oblate bodies. Direct formation of secondaries by ejection of several particles does not appear as an efficient mechanism.

[9] employs continuum theory to study the deformation of a body whose angular momentum is increasing. Some major differences relative to the results of [3] are stressed, in particular the absence of efficient mass shedding and the tendency of rapid rotators to evolve toward prolate shapes.

[10] by using a "soft particles" approach and including friction, suggest that – in fact – friction is a key element of the process, their results being closer to the predictions by [9].

3. Results

We ran our spin-up simulations with a time resolution improved by a factor 10X relative to [3,4], and by following the evolution of all bodies for a long time. We find that the transformation of objects in prolate ellipsoids is an efficient process, 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 internal strength of our objects is smaller than the one used in the so-called "nominal" simulations of [3,4]. Our results should be compared to the "fluid" cases of [4], which, conversely, fail to show the formation of large secondaries. As tentative explanation, this discrepancy can be ascribed to subtle differences in the simulations (such as their total duration and the time step). We conclude therefore that our results represent a correct generalization of the results obtained by [4].

Also:

- We find that the final issue of the process (i.e. the size of the secondary) is poorly related to the initial shape. However a well-defined sequence of intermediate re-shaping processes - eventually producing binary systems - is identified.
- This patter of shapes reproduces rather well the transition from prolate to binaries, passing through intermediate phases described in literature [1,11]
- We systematically 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.
- Our results show that friction is not strictly needed for producing large satellites, although soft-particle codes incorporate more realistic physics.

Eventually, we stress that we don't follow the long-term evolution of the binary systems we form, a task that is beyond the aim of this work. A fraction of the secondary objects that we form are not dynamically bound to the primaries. Further investigations should elucidate these behaviors and link them to the observed sample of binaries and decoupled pairs.

References

[1] N.R. Lebovitz, The mathematical development of the classical ellipsoids, Int. J. Eng. Sci. 36 (1998) 1407–1420.

[2] P. Tanga, C. Comito, P. Paolicchi, D. Hestroffer, A. Cellino, A. Dell'Oro, et al., RUBBLE-PILE RESHAPING REPRODUCES OVERALL ASTEROID SHAPES, Astrophys. J. 706 (2009) L197–L202.

[3] K.J. Walsh, D.C. Richardson, P. Michel, Rotational breakup as the origin of small binary asteroids, Nature. 454 (2008) 188–191.

[4] K.J. Walsh, D.C. Richardson, P. Michel, Spin-up of rubble-pile asteroids: Disruption, satellite formation, and equilibrium shapes, Icarus. 220 (2012) 514–529.

[5] K.A. Holsapple, Equilibrium Configurations of Solid Cohesionless Bodies, Icarus. 154 (2001) 432–448.

[6] K.A. Holsapple, Equilibrium figures of spinning bodies with self-gravity, Icarus. 172 (2004) 272–303.

[7] I. Sharma, J.T. Jenkins, J.A. Burns, Dynamical passage to approximate equilibrium shapes for spinning, gravitating rubble asteroids, Icarus. 200 (2009) 304–322.

[8] K.A. Holsapple, Spin limits of Solar System bodies: From the small fast-rotators to 2003 EL61, Icarus. 187 (2007) 500–509.

[9] K.A. Holsapple, On YORP-induced spin deformations of asteroids, Icarus. 205 (2010) 430–442.

[10] D.P. Sánchez, D.J. Scheeres, DEM simulation of rotation-induced reshaping and disruption of rubble-pile asteroids, Icarus. 218 (2012) 876–894.

[11] Y. Eriguchi, I. Hachisu, D. Sugimoto, Dumb-Bell-Shape Equilibria and Mass-Shedding Pear-Shape of Selfgravitating Incompressible Fluid, Prog. Theor. Phys. 67 (1982) 1068–1075.