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SPIN UP FISSION AND THE FORMATION OF ASTEROID BINARIES AND PAIRS. A. Campo Bagatin[1,2,3], P. Tanga[4], A. Thirouin[5], A. Cellino[6], C. Comito[4], J. L. Ortiz[5], D. Hestroffer[7] and D.C. Richardson[8]. [1]Departamento de Física, ISTS, Universidad de Alicante, Spain, [2]IUFACyT, Universidad de Alicante, Spain (acb@ua.es. P.O. BOX 99, 03080 Alicante, Spain), [3]Southwest Research Institute, Boulder, CO, U.S.A., [4]Laboratoire Lagrange, UMR7293, Université de Nice Sophia-Antipolis, CNRS, Observatoire de la Côte d'Azur, Nice, France, [5]Instituto de Astrofísica de Andalucía, CSIC, Granada, Spain, [6]INAF/Osservatorio Astronomico di Torino, Italy, [7]IMCCE, Observatoire de Paris, France, [8]Department of Astronomy, University of Maryland, U.S.A.

Abstract: Non-gravitational effects (such as YORP acceleration by thermal emission) may change the 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 can potentially create satellites. We are studying this problem by means of numerical simulations, extending previous results and showing that -under certain conditions- the production of secondary objects of different sizes by direct splitting can be a rather common event.

Introduction: Our goal is to infer 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.

We analyze the behavior of gravitational aggregates close to the bifurcation points predicted by theory and check if the predictions on the transition from prolate objects to binaries are valid.

Asteroids are clearly not fluid, they are rather rocky bodies with a likey gravitational aggregate structure, at least in the range from a few hundred meters to a few tens of km [1]. Therefore one can assume that equilibrium theories – also describing bifurcations (see e.g. [2]) - 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. A wide range of shapes can then be considered to be very close to fluid equilibrium and the theoretical sequences still represent important attractors for the evolution of shapes, under a perspective that is evolutionary and fully dynamical, not quasi-stationary [3].

Our approach is based on a numerical method already successfully applied by several authors, using essentially the same N-body simulation code (PKDGRAV). 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.

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 [4–6]. [7] 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 [8,9] using our same N-body approach, i.e. by simulating the dynamics and the collisions of mono-dispersed hard-spheres (pkdgrav code). The YORP effect is modeled by increasing rigid rotation by small increments. Between each "kick" the body is allowed to relax during several time steps.

The general pattern of shape evolution found by [8,9] 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.

[10] employs continuum theory to study the deformation of a body whose angular momentum is increasing. Some major differences relative to the results of [8] are stressed, in particular the absence of efficient mass shedding and the trend of rapid rotators to evolve toward prolate shapes.

[11], by using a "soft particles" approach and including friction, suggest that friction is a key element of the process and obtain results close to the predictions by [10].

Finally, using the same numerical methods, [12] showed, at a different scale, in the case of the formation of the system of the dwarf planet Haumea, how a fission -induced by a low energetic collision on a born fast rotating parent body- may explain its main features.

Results. We ran our spin-up simulations with a time resolution ten times larger than [8,9], and we follow 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 ellipsoid "tips" or in splitting, with the formation of satellites of different size ratios with respect to primaries.

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 [8,9]. Our results should be compared to the "fluid" cases of [9], which, conversely, fail to show the formation of large secondaries. As a tentative explanation, this discrepancy can be ascribed to subtle differences in the simulations (such as the total duration and time step). We therefore conclude that our results represent a correct generalization of the results obtained by [9].

We also find that:

- A well-defined sequence of intermediate reshaping processes - eventually producing binary systems - is identified.
- This pattern of shapes reproduces rather well the transition from prolate to binaries, passing through intermediate phases described in literature ([2] to [11], and [13])
- The final issue of the process (i.e. the size of the secondary) is poorly related to the initial shape of the parent body.
- 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 behavior and link it to the observed sample of binaries and decoupled pairs.

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