Radiation Recoil Effects on the Dynamical Evolution of Asteroids.
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Introduction: The thermal reemission from irregularly shaped bodies results in a torque that can change the rotation rate and the orientation of the spin axis [1]. Extensive analyses of the basic behavior of the YORP effect have been previously conducted leading to the idea of the "YORP cycle". In the classical YORP cycle, an asteroid would spin up while increasing its obliquity until a certain point. Then it would start to slow down until it changes its spin again or it would rotate so slowly that it will end up tumbling until it reestablishes its principal axis of rotation and starts to spin up again.

The rotation rate of asteroids obtained from optical light curves has given strong evidence to support the idea that most asteroids are aggregates. The YORP effect has an extreme sensitivity to the topography of the asteroids and a minor change in the surface of an aggregate can stochastically change the YORP torques [2]. Therefore, applying a constant YORP torque to continuously spin up an aggregate object past the point where mass shedding and possible re-accumulations of the shedded mas occur, as previous numerical simulations of dynamically evolved aggregates have done, is not realistic.

Here we present the results of the first simulations that self-consistently model the YORP effect on the spin states of dynamically evolving aggregates. We follow the evolution of aggregate objects, computing the sequence of spin states and YORP torques through which they evolve as the changing spin alters their shape, which subsequently chages the YORP torques

Methods: To self-consistently model the YORP effect on the spin states of dynamically evolving aggregates we combined two codes: 1.TACO, which models the surface of an asteroid using a triangular facet representation and can self-consitently compute the torques from the YORP effect [2]; and 2. pkdgrav, a cosmological N-body code modified to simulate the dynamical evolution of asteroids represented as aggregates of spheres using gravity and collisions [3]. Each code uses the most appropiate representation of an asteroid to do the calculations. Spheres are convenient to simulate the dynamical evolution of aggregates but the triangular tiling is the method of choice for calculating the YORP torques due to its geometrical simplicity. We have developed several algorithms in order to interact correctly between the two codes. One of the algorithms fits a triangular tiling over an object created for pkdgrav, composed of spheres, in order to be used with TACO to compute the YORP torques. Figure 1 shows the tiling obtained for one of the objects.

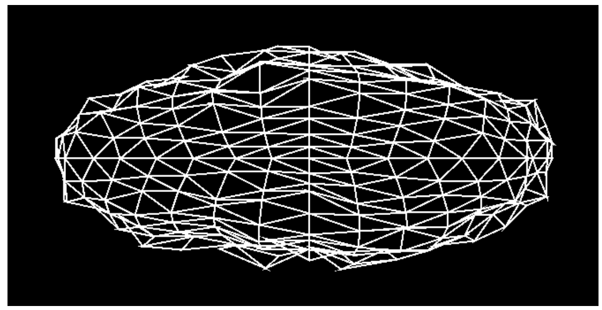

Figure 1. The tiling obtained for the original object in one of the simulations. The line of sight is the middle axis and the spin axis points up.

For our simulations we use the end states objects from [4], who created ellipsoidal aggregates with arbitrary values of the semi-axis ratios, normalized spin and angular momemtum and let them evolve dynamically allowing reshaping until they reach a stable configuration. The objects have a natural disordered packing, are composed of ~1500 spheres and range from 3 to 6 km in diameter. We use the hard-sphere discrete element method in pkdgrav and set the normal and tangential coefficients of restitution to 0.2 and 0.5, respectively, for all simulations.

After obtaining the tiling and YORP torques for the original aggregate object, we evolve the obliquity and spin in time. Objects are evolved incrementally in spin rate with increments no larger than 0.5% and without exceeding the maximun and minimum allowed spin rates given by the obtained YORP torques. The object is run dynamically with pkdgrav at each new spin rate for several rotations and if there is a movement of spheres we let it evolve until it settles down. Then we transform the object to the orientation of the original object and obtain a new tiling and YORP torques. The spin and obliquity are evolved in time using the new torques obtained and the whole process is repeated until a subsequent tiling and respective torques are obtained after a movement of spheres. Simulations are run until the time reaches 15 Myrs, the spin reaches 0 cycles/day or until there are isolated spheres. Part of the spin and obliquity evolutions of the object in Figure 1 along with the respective torques are shown in Figures 2 and 3.

Results and Conclusions: We will be presenting an statistical analysis of the results obtained for at least one hundred simulations. A change in the shape of an aggregate can speed up or slow down their spin-up or spin down evolution but also even the slight shape change could reverse the sign of the YORP torques preventing the objects to continuously spin up or down. The continuous changes in the shape of an aggregate can cause a different evolution of the YORP torques and therefore the object may not necessarily evolve through the YORP cycle as a rigid-body would.

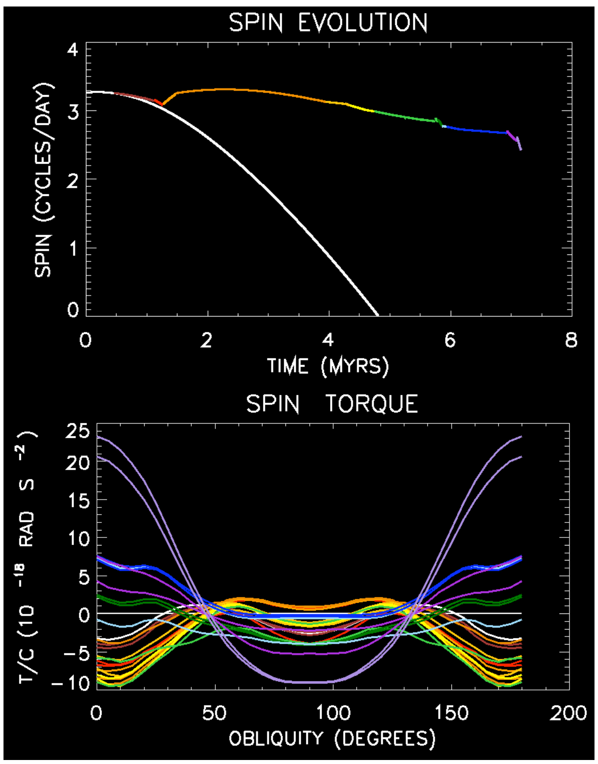

Figure 2. The spin evolution (top) of the aggregate object in Figure 1 shown in a sequence of colors along with the YORP torques (bottom) through which it evolves. The torque of the original object and the evolution that it will follow if it was a rigid-body are shown in white.

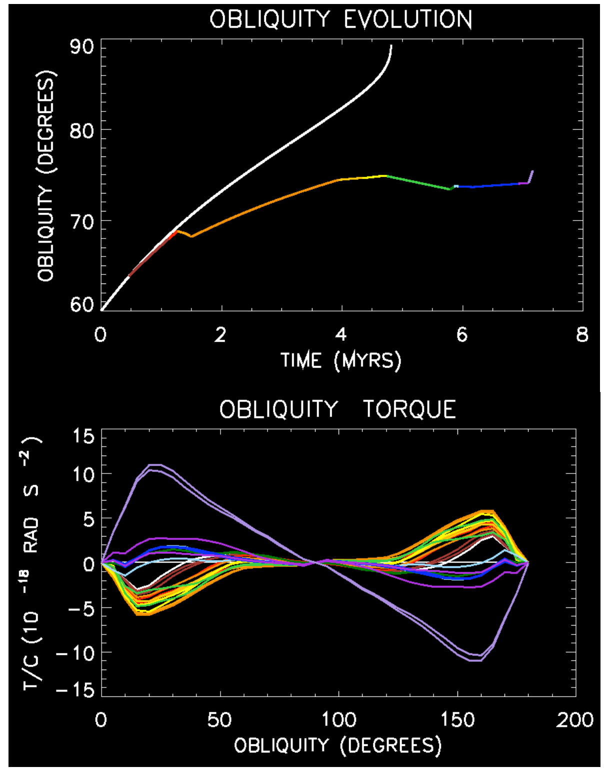

Figure 3. The obliquity evolution (top) of the aggregate object in Figure 1 shown in a sequence of colors along with the YORP torques (bottom) through which it evolves. The torque of the original object and the evolution that it will follow if it was a rigid-body are shown in white.

References:

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