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Asteroid fission, binaries and the small main belt population

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Abstract

Using a Monte Carlo method we model the spin evolution of small Main Belt asteroids under the joint effects of YORP and collisions. Our simulations allow us to estimate the fraction of asteroids undergoing rotational fission in different size ranges. When an asteroid reaches its disruption spin limit we determine the outcome of its subsequent evolution based on accumulated statistics on their evolution based on numerical integrations (i.e., binary or ternary formation, binary disruption, etc..). Our aim is to predict the percentage of binary asteroids and their properties in the Belt, the number of objects like P/2010 A2 per year and the effects of YORP-induced fission on the overall asteroid size distribution at the small size end.

1. Introduction

The rotation rates of small asteroids in the Main belt are controlled by mutual collisions and YORP, i.e. the torque from the absorption and re-radiation of solar energy. The YORP effect gradually spins up asteroids until they undergo reshaping or fission. In contrast, during a collision between a small projectile and the target asteroid, angular momentum is impulsively transferred from the orbital motion of the projectile to the spin of the target. In addition, these impulsive variations in the rotation rate, which constantly occur in the Main Belt because of the dense population of bodies, may significantly interfere with YORP by changing the rotation parameters, the phase of the YORP cycle, and the torque itself. According to [6], alterations to the small-scale topography may even reverse the sign of the YORP torque.

We describe the Monte Carlo method used to predict the number of asteroids spun up to fission by YORP and collisions and we outline the post–fission evolutionary tracks followed by these asteroids which include asteroid reshaping and erosion and binary (or triple) formation. Our goal is to produce a numerical algorithm able to predict 1) the amount of binary asteroids produced by the fission process and their stability properties, 2) how many objects like P/2010 A2 we may expect per year and 3) the effects of the loss of asteroids by fission on the overall size distribution of asteroids at the small size end.

2. The Monte Carlo method for YORP and collisions

To model the evolution of the spin of a single asteroid due to repeated collisions with other asteroids of the Main Belt we use Poisson statistics based on the the intrinsic probability of collision for the Main Belt $< P_i >$. The projectile's size and their impact velocity is randomly drawn from the distribution given in [1]. After each impact, we add the angular momentum vector of the projectile to that of the target selecting a random geometry for the impact compatible with the orbital distribution of the asteroid belt. In between two collisions the spin rate of an asteroid evolves under YORP. We follow the approach outlined in [5] and also adopted in [4]. A non-dimensional YORP coefficient C_Y is defined which depends on both the asteroid's shape and moment of inertia. After any collision we update the YORP coefficient to account for both the change in obliquity and possible modifications of the surface properties of the asteroid caused by the cratering (the formation of a new crater, moving boulders, shifting the barycenter etc., see [1]).

According to our model, the rotational fission of small asteroids occurs frequently and might explain the population of binary asteroids, objects like P/2010 A2 and its associated tail of millimeter-sized dust particles, as well as the slope at the small size end of the asteroid size distribution. Fission is an additional erosion mechanism, besides cratering and fragmentation, acting only at small diameters.

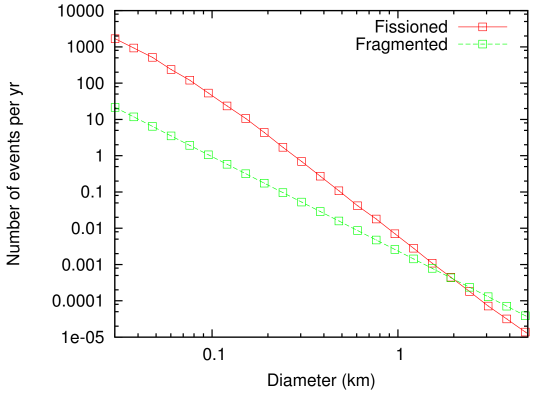

Figure 1: Number per year of expected small asteroids which will be spun up to fission in the asteroid belt as a function of their diameter. These asteroids will follow the evolutionary paths outlined in Sec. 3. For comparison, the number of breakup events is also shown.

3. The outcome of asteroid fission

The YORP effect can rotationally accelerate small bodies in the inner Solar System. Small asteroids are "rubble piles" that when spun fast enough can fission into two components orbiting each other. After fission these components chaotically orbit each other transferring energy and angular momentum via spin-orbit coupling through the components' non-spherical gravitational potential terms. These exchanges rapidly change the mutual orbit and spin states of the components. The spin rate necessary for rotational fission depends on the component mass ratio (smaller component mass divided by larger), and so the mass ratio q determines the initial energy of the system and its subsequent evolution. Figure 1 shows the detailed evolutionary paths for high $q > 0.2$ and low $q < 0.2$ mass ratio systems. Using a numerical model of the post-fission dynamics, [2] determined the relative frequency of each evolutionary path as well as the relative timescales for evolution along these paths. It is important to note that the eventual outcomes of this evolution are single asteroids (re-shaped asteroids, contact binaries, each member of asteroid pairs). This evolutionary process represents a cycle that asteroids may evolve through more than one time.

4 Conclusions

We will present the predicted outcomes of our simulations and compare them with the measured binary population and small size distributions in the main belt.

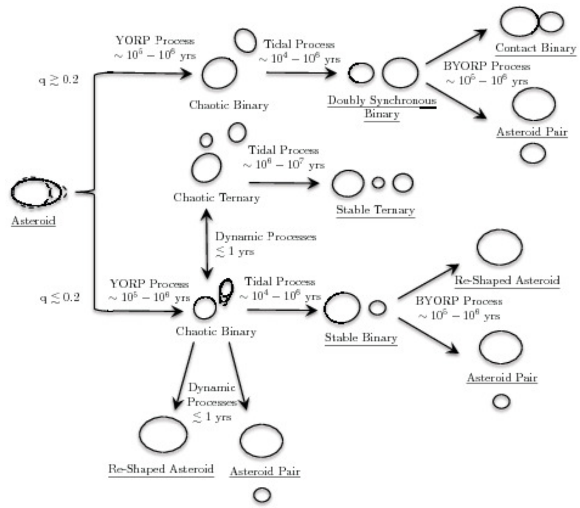

Figure 2: Evolutionary tracks for a small asteroid. q is the rotational fission component mass ratio. Arrows indicate the direction of evolution along with the process propelling the evolution and a typical timescale. Simple schematics show evolutionary states, an underline indicates an observed asteroid class.

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