Effects of YORP-induced rotational fission on the asteroid size distribution at the small size end.

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The asteroid belt size distribution has been shaped by collisions slowly grinding the population away into smaller bodies via cratering or fragmentation. However, at the small size end YORP may contribute to the erosion process by accelerating the rotation rate of small asteroids beyond their disruption spin limit causing mass shedding and fission. This can explain why, according to NEOWISE [6], the slope of NEOs is about -1.32, significantly less steep than previous estimates which accounted for the Yarkovsky steepening effect [1].

Introduction

The asteroid belt is a collisionally–evolved population [2] and the wavy shape of its size distribution has been attributed to the dependence of the strength of the bodies on their size and to dynamical processes capable of removing bodies from the belt like PR drag or the Yarkovsky effect. These last drag forces can interrupt the collisional cascade process affecting the whole size distribution. Recently, the survey SKADS [3] found that the slope of the size distribution of main belt asteroids at small sizes is shallower than previous estimates. Moreover, the NEOWISE survey [6] capable of acquiring an ubiased sample of Near Earth Objects (NEO) claims that their cumulative size distribution is best represented by a power law with a slope of 1.32$\pm$0.14 below 1.5 km. This value is much lower than previous estimates and might imply that small asteroids are eroded at a rate faster than that expected from collisions only.

A mechanism which potentially may explain why small asteroids are eroded at a faster rate than that predicted by collisions is rotational fission. The spinning up by YORP beyond the limit of cohesion can cause either material at the surface of the body to reach ejection speeds separating from the body or lead to the fission of the asteroid followed by mutual interactions between the leftovers [4]. The former mechanism can explain objects like P/2010 A2, a small body with a diameter of approximately 120 m orbiting in the inner asteroid belt which revealed an extended tail of dust particles [5]. Fissioning can account for the formation of asteroid binaries [4] even if in most cases they will be unstable on a short timescale. In either case, the original body is eroded by a mechanism independent of collisions, causing a reduction in the number of small asteroids. We expect to see this reduction at the small size end of the asteroid size distribution, in particular in the inner regions of the solar system since YORP is more efficient closer to the sun.

We developed a Monte Carlo model to predict the depletion rate of small asteroids, due to YORP–induced rotational breakup, as a function of their size. Our final goal is to include this additional erosion process in models of the collisional evolution of main belt asteroids to evaluate its impact on the slope of the size distribution.

The model

To model the evolution of the spin of a single asteroid due to YORP we follow the approach outlined in [10] and also adopted in [9] and [7]. A non-dimensional YORP coefficient C_Y is defined which depends on the asteroid's shape and moment of inertia. 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. Using a numerical model of the post-fission dynamics, [4] determined the relative frequency of different evolutionary path (such as re-shaped asteroids, contact binaries, asteroid pairs, binary systems) as well as the relative timescales for evolution along these paths. In our model these evolutionary paths are all implemented and the outcomes of the steady state population are then compared with the measured binary population and small size distributions in the main belt. The effects of repeated collisions on the rotational rate of each asteroid are also accounted for by using an algorithm based on the Poisson statistics tuned on the intrinsic probability of collision for the Main Belt $< P_i >$. 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. After any collision we update the YORP coefficient to account for both the change in obliquity and possible modifications of the surface prop-

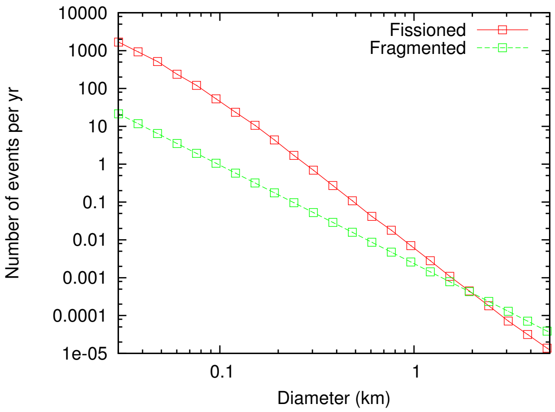

Figure 1: Number per year of expected small asteroids spun up to fission in the asteroid belt as a function of their diameter. For comparison, the number of breakup events is also shown.

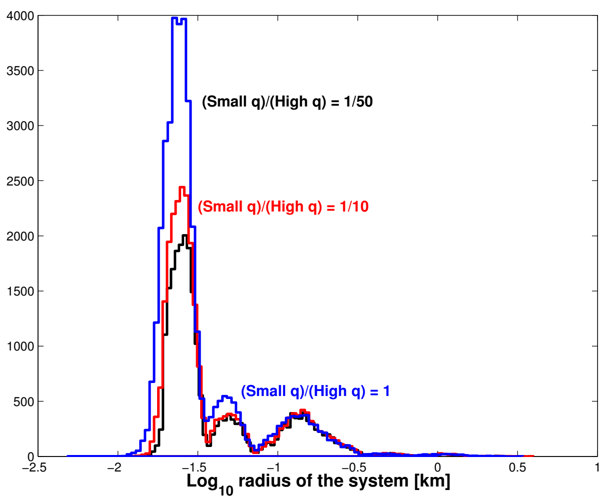

Figure 2: Distribution of the radius of the binary systems in the steady state population.

erties of the asteroid caused by the cratering (the formation of a new crater, moving boulders, etc.). In between two collisions the spin rate of an asteroid evolves only under YORP.

Results and Conclusions

An interesting outcome of the model, in addition to the erosion rate of asteroids due to rotational breakup, is the estimate of the fraction of binay asteroid systems. An example is shown in Fig. 2 illustrating the orbital radius distribution of binary asteroids for three different scenarios characterized by different statistical distributions of the mass ratio q between the primary and secondary body of the binary system. According to [4], the probability of producing a binary is approximately 50 times higher if the system has a high mass ratio ($q > 0.2$). However, such initial mass distributions may not be that common so we consider different statistical distributions for q which are shown in different colors in Fig. 2. Our model gives about 24 % of asteroids which are binaries in the asteroid belt adopting the nominal distribution for q, while the fraction rises to 38 % when the probability of having a high mass ratio binary is set to 1. These values are similar to those observed and currently recorded in the databases of binary asteroids [8] making us confident that the model is robust.

In the evolution model we are also able to estimate and track the flux of bodies in different size bins, flux due to the erosion of the bodies due to mass shedding, or binary formation. Preliminary simulations show that fission due to YORP induced spin-up is relevant for bodies with diameters below about 1 km. In this size regime the fission rate due to spin-up is comparable to the collision induced fragmentations. This effect is therefore statistically significant and should show up in the cumulative size distributions. We will compare the fraction of fissional events with those due to cratering and fragmentation giving a statement about the relevance of the rotational fission process.

The dependence of the results concerning binary formation and fissional erosion from the various model assumptions and parameteres will be explored in detail.

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