YORP-Yarkovsky evolution of asteroid families: the effects of collisions

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The depletion of objects in the central part of an asteroid family, which can be observed in the absolute magnitude (H) vs. semimajor axis (a), can be explained in terms of a coupling of the YORP and Yarkovsky effects (Paolicchi and Knezevic, Icarus, 2016). In particular, it can be ascribed to the obliquity evolution caused by YORP and on how it influences the Yarkovsky drift.
With this work we intend to improve the modeling of YORP-Yarkovsky evolution of asteroid families exploiting a model which tracks the evolution of the spin vector of small asteroids, including also the effects of collisions on the YORP induced obliquity evolution. This allows a better modeling of the asteroid spin evolution.
In these preliminary steps, we consider a few model families simulating their time evolution in the magnitude vs. semimajor axis plots.
The obtained results should then be compared with observed families to determine and tune the intensity of the effect.

The YORP-eye

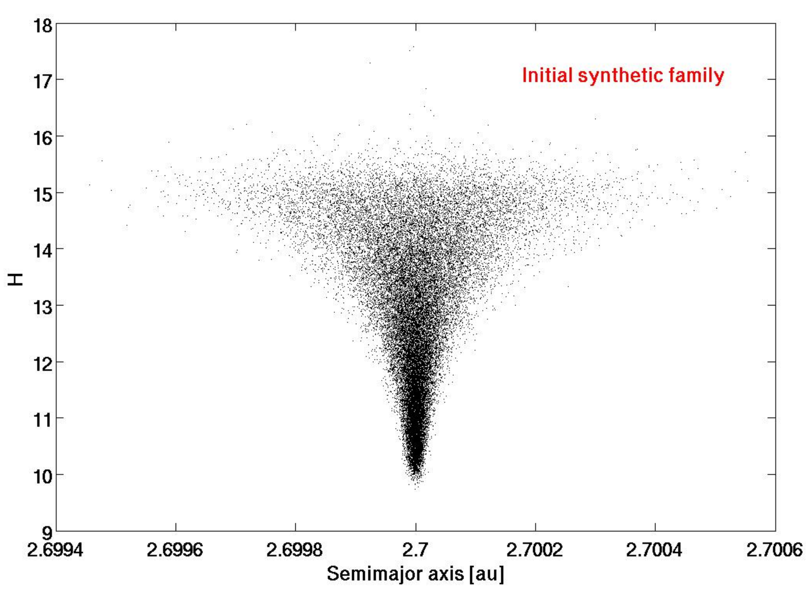
The typical timescale for the YORP driven evolution scales with the size *r* of a body as $1/r^2$. In a family the sizes of the bodies range usually by more than one order of magnitude: thus in the same family, with a given age, it may happen (and usually happens) that the largest bodies had not the time to undergo a complete YORP cycle, while the smallest bodies passed many cycles. The spin vectors of bodies are clustered (essentially up and down) during a YORP cycle; in turn, a body with spin up (or down) maximizes its semimajor axis mobility due to Yarkovsky effect. A depletion in the central regions of the family (in *a*) is expected. This depletion cannot be effective for the largest bodies, becomes more and more effective going to smaller bodies (which passed one or a few cycles). It is not clear what happens when a body has passed many cycles, but it is reasonable to guess some mixing effect, and a less effective depletion. Thus the depletion should be maximum in a range of sizes (or magnitudes); in the plane *a-H* it may appear as a hole in the distribution: the YORP-eye.

The simulation procedure

A synthetic family is generated with the procedure described in the following box.
The semimajor axis of the individual asteroids is evolved under the Yarkovsky effect.
The drifting rate in semimajor axis due to the Yarkovsky effect is of the same order of magnitude of that adopted by Bottke et al. (2001) for the Koronis family. The drift rate is properly scaled for the size and semimajor axis of the fictitious fragments considered in our model.
The YORP effect on the evolution of the magnitude and direction of the spin vector is computed following the method described in Marzari et al. (2011).
The YORP-driven obliquity evolution is computed according to a simple model, based on the above theory, tracking the spin axis displacement along the YORP cycles from 0 to π.
The change in the angular momentum and obliquity due to impacts, against a population of potential impactors (derived from the SDSS size distribution of asteroids and distributed over logarithmic size bins), is finally computed, again using the model described in Marzari et al. (2011).
The whole system is evolved for 1.5 By.

Generation of the synthetic families

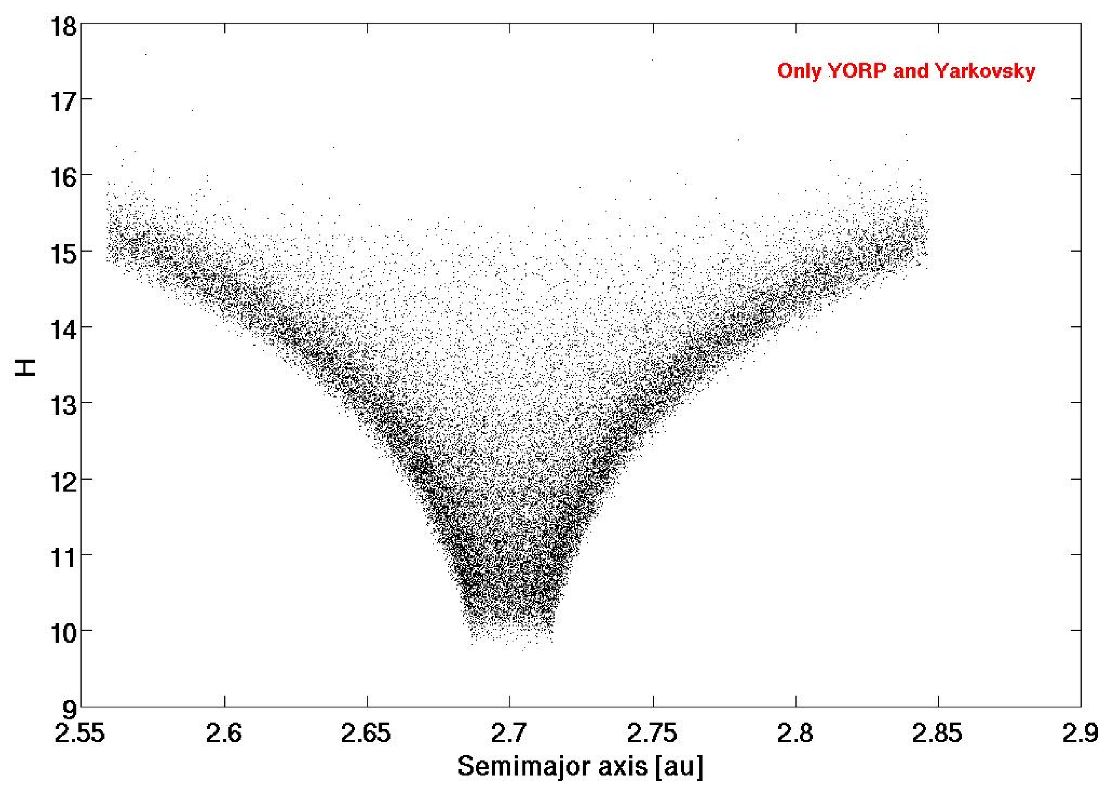
The semi-major axis (a) – diameter (D) diagram of an asteroid family is expected to evolve in time under the complex interplay between Yarkovsky-YORP effect and collisions. In order to simulate the evolution of the D versus a diagram we built up a simple model of the initial status of the family. The major requirement of the model is to be able to highlight the different evolution of bodies belonging to different intervals of diameter. From this point of view the choice of the size distribution is not important, so we generate the list of the family members so that the distributions of their diameter is uniform in a log D scale. An ejection velocity vector **V** and a spin vector **S** are assigned at each member in the following way. The direction of **V** is chosen at random, assuming an isotropic symmetry of the ejection velocity field. The modulus V is randomly generated according to a Maxwellian distribution, the mean value of which is related to the diameter. If D_0 is a reference diameter (usually one km), the mean value of the distribution of V is $V_m(D) = V_0(D_0/D)b$, where b > 0 and D is the diameter of the asteroid. Also the direction of **S** is assumed isotropically distributed. Its modulus S = 2p/P, where P is the rotation period of the asteroid, is generated according to another Maxwellian distribution, the mean value of which is $S_m(D) = S_0(D_0/D)g$, where g > 0. In this way, velocities and spin rates tend to increase while the size of the bodies decrease, at a pace depending on the values of the exponents b and g. In conclusion, our basic fragmentation model depends on the four parameters V_0, b, S_0 and g. Important values of the exponents are b = 3/2 and g = 5, corresponding respectively to an equipartition of the total kinetic energy and the total angular momentum among all the members of the family. The values of V_0 and S_0 have been explored in the ranges 0.1-1.0 km/s and 1-10 rev/day respectively (D_0 = 1 km).
Finally the initial orbital elements of the members have been computed from the corresponding ejection velocities and the orbital element of the parent body at the moment of the break-up. In general, the resulting distribution of the members' semi-major axes depends mainly on the semi-major axis of the parent body and the transversal components of the ejection velocities, while it is much less affected by the other orbital elements, in particular the true anomaly of the parent body.
The family parent body is located at 2.7 au. Note that for the current tests we are considering objects between 5 and 50 km of diameter.

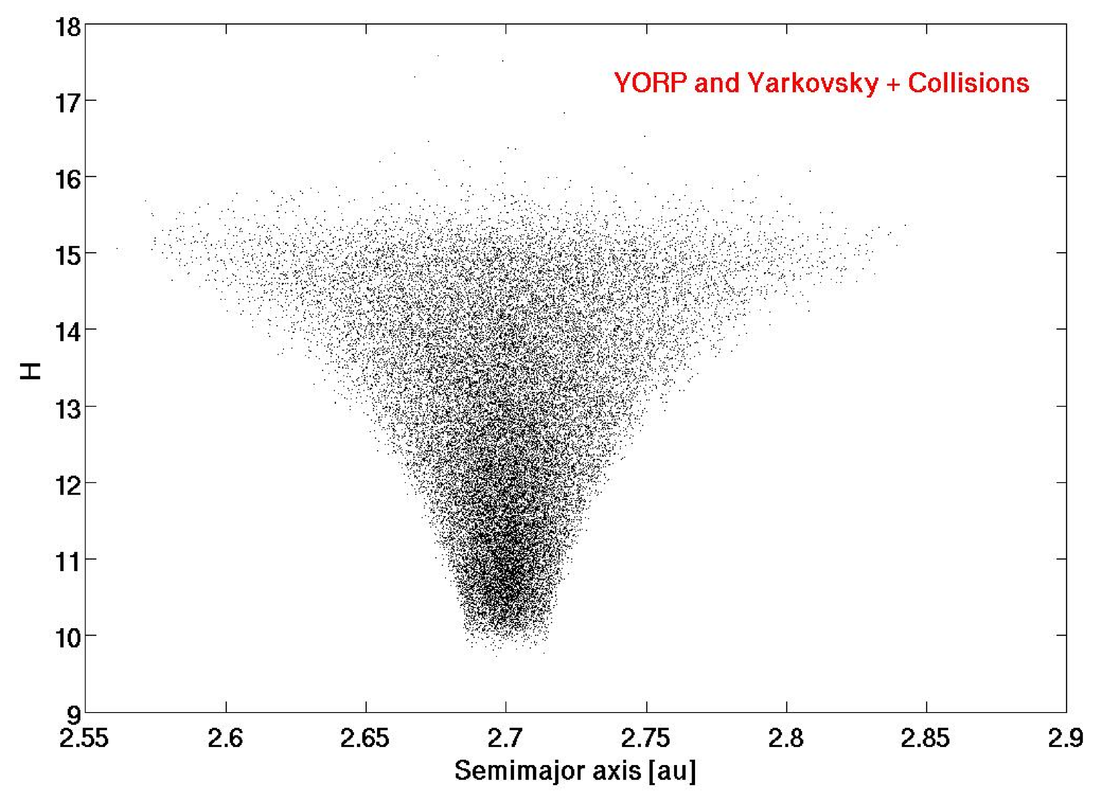


Distribution of the objects of the synthetic family in the semimajor axis (a) vs absolute magnitude (H) space.

Conclusions and future work

A preliminary set of tests with the above model was performed on a few synthetic families.
First the model was ran considering the effect of Yarkovsky and YORP on the evolution of the family. The left figure below shows the distribution of the asteroids in the usual V-plot , absolute magnitude (*H*) vs. semimajor axis (*a*). A migration of the smaller objects towards to "wings" of the V-shaped plot is apparent, with a depletion of the central core of the family.
On the other hand, the bottom figure shows the evolution of the same family where also collisions are taken into account. Whereas the spreading of the family due to Yarkovsky is still evident, now apparently the effect of the collisions tends to randomize the distribution of the obliquities, hence preventing the accumulation of objects in the extremes paths in the wings of the V shaped plot. In particular, in this case the depletion in the central part of the family disappears.
We stress again that the results shown here are at a very preliminary stage and that the model deserves further testing.
In particular we shall improve the YORP obliquity evolution model and the relative weight between this effect and the change in obliquity due to collisions, especially for the smaller objects.
Once the model will be fully validated, further testing will include the sensitivity analysis of the influence of other model parameters such as the initial family ejection velocity, the initial orbit of the parent body, the initial distribution of masses and spins within the family members, …..





References:

- Paolicchi P. and Knežević Z., Footprints of the YORP effect in asteroid families, *Icarus*, 274, 314-326 (2016)
- Marzari F., Rossi A. And Scheeres D. J., Combined effect of YORP and collisions on the rotation rate of small Main Belt asteroids, *Icarus*, 214, 622-631 (2011)
- Bottke W., Vokrouhlický D., Broz M., Nesvorný D., Morbidelli A., Dynamical Spreading of Asteroid Families by the Yarkovsky Effect, *Science*, 294, 1693-1696 (2001)