Origin of Dimorphos from a fast spinning Didymos: accretion scenario and constraints on dissipation

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Introduction:

Didymos is a binary near-Earth asteroid. It is the target of the DART and HERA space missions. The primary body, Didymos, rotates in 2.25h, close to the centrifugal breakup limit. The secondary body, Dimorphos, is a 140 meters moon orbiting in about 12 h. The origin of this asteroidal pair is still unknown.

Here we investigate the possible origin of Dimorphos in a scenario where Dimorphos is formed from debris centrifugally extracted from Didymos, and forming a ring of debris.

Method

In order to do so, we use a models of ring/satellite interactions, to track the evolution of material lost from Didymos’ surface and deposited as a ring at its equator. This kind of model has been used in the past to study the origin of giant planet’s moons from planetary rings [1].

In particular we investigate the effect of material flux from Didymos, the effect of tides on long term accretion, and the mass of Dimorphos Vs. Time.

Results

We find that due to viscous spreading, the ring of material lost from Didymos spreads outside the Didymos’ Roche limit. At the Roche limit, material acquires and starts to form moonlets, while majority of the ring’s mass falls back to Didymos’ surface because of viscous spreading (this is indeed an accretion disk). A fraction of the mass crossing the Roche limit will form a population of moonlets, while most of the ring’s mass falls back on Didymos. Due to the ring’s torque, moonlets then migrate outward close to the 2:1 mean motion resonance with Didymos Roche Limit (at about 1km from Didymos’ center), and at this location, material accumulates to form a proto-Dimorphos.

Accretion history of Dimorphos

The rate at which Dimorphos forms is controlled by the flux and masses of moonlets. This flux is controlled by the debris ring’s mass as well as the k2/Q of the primary (where k2 is the Love number and Q the tidal dissipation rate of Didymos).

To match the properties of today’s Dimorphos, the total mass that must be deposited in the ring is about 25% of Didymos’ mass. It is possible that a fraction of the material travelled several times between the ring and the surface of Didymos. The models produce an orbit similar to that observed for a Didymos tidal parameter k2/Q about 10⁻⁵. If the ring deposition timescale is long (>10² yr) (so the material flux is small) Dimorphos could be assembled through a finite number of two bodies collisions with objects of constant mass, resulting in an irregularly shaped object as it forms from the collision of similar-sized satellitesimals.

However, the top-shape of Didymos is expected to be achieved due to a fast spin-up of the asteroid, which would result in a short deposition timescale (<yr). In that case, Dimorphos would form from progressively accreting material at the Roche Limit, where the material is accreted in the form of small particles (<< Dimorphos size). This would result in an ellipsoidal Dimorphos constructed of small pieces with sizes of the order of meters, which seems in agreement with the recent images of Dimorphos obtained by DART mission[2].

We conclude that Dimorphos may be the natural result of material loss from a fast spinning Didymos, that have reaccreted at the primary Roche limit. This suggest also that Didymos’ tidal dissipation factor, Q, should be > 10⁴ which can be potentially tested with the upcoming HERA missions.

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References: