CAN PARTICLES EJECTED BY THE FAST SPINNING PRIMARY OF THE (65803) DIDYMOS NEA BINARY SYSTEM FORM A DISK?

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Introduction: (65803) Didymos is the binary Near Earth Asteroid target of the DART (NASA)/LICIA (ASI) and Hera (ESA) missions. It orbits the Sun with a semi-major axis of 1.64 AU, and it is made of a 780 m diameter primary body (Didymos) and a 160 m satellite (Dimorphos), orbiting the primary with a semi-major axis of 1180 m and an orbital period of 11.9 h [1]. The primary has a rotation period of 2.26 h, very close to the limit of structural stability [2] [3]. The low density estimated for Didymos, 2170 kg / m^3, shows that it is not a monolithic body, will have high macro-porosity, typical of gravitational aggregates (or "rubble-piles"). Numerical simulations show that they can be generated naturally in the aftermath of a catastrophic collision between asteroids, as a result of the gravitational interaction between the irregular fragments resulting from the collision [4], or by in-orbit aggregation of ejecta due to primary fast spin [5]. The evolution under YORP spin-up may lead to oblate spheroidal shape asteroids with an equatorial bulge, commonly called “top-shapes” (e.g.: (162173) Ryugu [6], (101955) Bennu [7], (65803) Didymos, etc.). Such bodies may rotate close to the limit of structural stability, kept together by the shear forces generated by friction between their components. Local acceleration near the equatorial region may be directed outwards in those asteroids, allowing regolith to leave the surface [8] [9]. When this happens, particles evolve under the action of the gravitational field of the asteroid, the gravitational force of the Sun, the pressure of solar radiation, and in the case of binary asteroids, the secondary’s gravitational force also comes into play.

Methodology: Under the frame of the EC H2020 NEO-MAPP project, we are studying the dynamics of particles that are ejected from the surface of Didymos when the centrifugal acceleration is large enough to overcome local gravity. The analysis is carried out with a numerical code that integrates the particles’ equation of motion in a non-inertial rotating frame of reference, centered on the primary asteroid. A polyhedral shape model for Didymos is considered, formed by 1000 vertices and 1996 triangular faces, at which center, sample particles are placed. Particle size distribution follows a power law $n(r) = kr^{\alpha}$ with $\alpha = -3.5$. The environment of the asteroid is studied by computing the radial density of particles. To do this, a 3D grid is built, the surface of the asteroid is divided into latitude and longitude bins, and it is propagated into space as 3D radial cells. During integration, we track the trajectories of particles and -at the end of the simulation- we compute the total mass density in each cell, assuming -as an arbitrary reference- an ejection mass rate of 1 kg/s.

Results: A process of detachment and re-entry of particles to the primary is found to happen for most of values around the nominal Didymos physical parameter space. That could enforce the formation of a dust band around asteroid equatorial latitudes. The corresponding mass density depends on the physical parameters of the asteroid, the size of particles considered, and the very position of the asteroid in the heliocentric orbit. For instance, Figure 1 shows the radial mass density of particles with sizes (radius) in the 5 μm - 2 mm range in the nominal case. The x-axis represents the radial distance -outside the asteroid ($r > \sim 430$ m) - from the center of the Didymos to the center of any 3D cell. Note that the y-axis represents the mass density integrated over all latitudes and longitudes. The two curves represent the result of simulations performed for 30 days around perihelion and aphelion epoch. The figure shows a particle cloud up to 600 m approximately, with a decrease as we move away from the asteroid surface. Besides, we observe less mass density in the moment that the asteroid passes by the perihelion, with respect to aphelion. This is due to more efficient radiation pressure of the sun sweeping away small particles from the system.

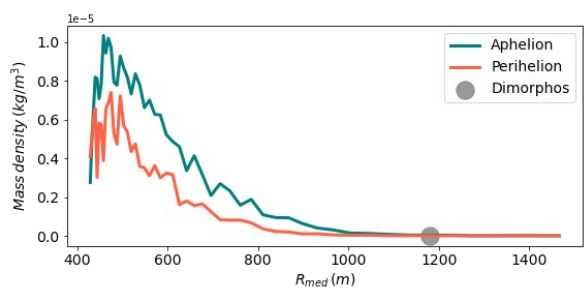

Figure 1: Mass density around Didymos with respect

radial distance from the center of the body. Density is integrated over all latitude and longitude.

Figure 2 shows mass density with respect to co-latitude, integrated over radius and longitude. The cloud is concentrated near the equatorial plane, and we do not find particles at high latitudes. The irregular shape of Didymos prevents the particle disk from being symmetrical with respect to the equatorial plane. We find a disk mass ratio of 4/9 between perihelion and aphelion.

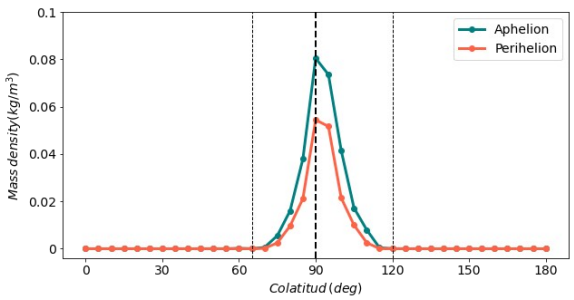

Figure 2: Total mass density with respect to co-latitude (0° correspond to north pole, 90° to the equator and 180° to the south pole). Density is integrated over radius and longitude.

Figures 1 and 2 represent the nominal case, in which the bulk density of the asteroid is ρ=2103 kg/m3 and its volume $V=2.48\times10^9$ m^3. Such parameters have uncertainties, namely, $\rho_D = 2170 \pm 350$ kg/m^3 and $V_D = 2.48\times10^9 \pm 3\%$ m^3. In this work, we explore such parameter space in order to obtain a global idea about the possibility to have a stable disk of particles around the primary asteroid.

We also investigate the end state of particles, establishing four different possibilities: ES1) particles that can take off and land again on the primary surface; ES2) particles remaining in orbit at the end of the simulation; ES3) particles re-accumulating on the secondary; ES4) particles that can escape from the system, mainly due to solar radiation pressure (SRP). The percentages of particles that reach the different end states are computed in each simulation, as well as the mean lifetime of the particles with respect to their size. In our nominal case (Fig. 1 and 2), around perihelion, more than 90% of particles end up in ES1, between 0.03 and 1.55% of particles end up in ES2, about 0.22% ended in ES3, and ∼8% escape from the system (ES4). Around aphelion, more than 95% come back to the primary surface (ES1), between 0.04 and 3.17% of particles end up in orbit (ES2), about 0.45% end up in ES3, and ∼0.5% can escape from the system (ES4). These values depend strongly on the size of particles in the considered range.

The disk of particles is made of those that are in the end state ES2: in the aforementioned case, the mean orbit lifetime is 52 h around perihelion, and 125 h around aphelion. Such differences are related to the different intensity of SRP at different heliocentric positions of the binary system, affecting small particles to a greater extent during perihelion, ejecting them from the system.

In summary, in this work the possible existence of a disk of particles around Didymos is studied, exploring different physical parameters for the asteroid system.

Acknowledgments: NT, ACB and MPM acknowledge funding from the NEO-MAPP project (H2020-EU-2-1-6/870377).

References: [1] Benner, L. A. et al. (2010) Bull. Am. Astron. Soc. 42, 1056. [2] Pravec, P. et al. (2008) Icarus 197, 497–504. [3] Margot, J.-L. et al. (2015) Asteroids IV 355–374. [4] Campo Bagatin, A. et al. (2018) Icarus 302, 343–359. [5] Walsh, K. J. Et al. (2008) Nature 454, no. 7201, pp. 188–191. [6] Watanabe, S. et al. (2019) Science 364, 268–272. [7] Lauretta, D. S. et al. (2019) Nature 568, 55–60. [8] Campo Bagatin, A. (2013) LPSC. [9] Yu, Y., et al. (2019) MNRAS 484, 1057–1071.