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INFLUENCE OF THE BODY COMPOSITION ON THE EVOLUTION OF EJECTA IN THE DIDYMOS-DIMORPHOS BINARY SYSTEM

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The DART spacecraft will impact Dimorphos (the secondary body of the Didymos binary asteroid) to test the kinetic impactor deflection method against possibly hazardous Near Earth Asteroids. The impact crater will be first imaged by the LICIACube spacecraft [1], hosted as a piggyback and released by DART just before the impact, and then, several years later, by the HERA probe. To fully exploit the wealth of data obtained and to understand the physics of the whole impact experiment it is of paramount importance to properly model the dynamics of the binary system pre- and post-impact and the dynamics of the particles ejected from the impact crater.

In this context a comprehensive model was developed to simulate the outcome of the impact experiment.

The final goal is to study the short (within the DART-LICIACube framework) and medium (the HERA framework) term dynamics of the system and of the ejecta particles with a comprehensive model described in the following section. The expected final output shall be useful to better understand the initial crater evolution and the characterization of the dust environment within the binary system at the time of HERA arrival, exploring also the possibility of the formation of long term stable particles.

The model: The dynamics of the system and the ejecta particles will be studied by means of the following model.

Starting from different cratering simulations of the DART impact (e.g. [2,3]), the initial conditions of the ejecta particles (such as velocity, launch angle, launch position) are defined producing a 3D representation of the crater (Cartesian coordinates and velocities of the vectors of each particle) in a topocentric frame.

The particles are then propagated with the *Radau* integrator [4] using the following default dynamical model:

- Dimorphos is considered the primary body, with Didymos rotating in an apparent circular (or elliptic, induced by DART impact) orbit around it;
- the gravity field of the primary can be computed either by means of the polyhedral approach [5] for an ad-hoc shape or with an analytical expression for a triaxial ellipsoid [e.g., 6,7,8];
- the direct and indirect perturbations of the secondary body, modeled as a rotating ellipsoidal body, are considered;
- the Solar Radiation Pressure (SRP) is computed, including shadows effects;
- for the computation of the area over mass ratio in the SRP effect, the ejecta particles are assumed to be ellipsoids whose axis ratio are extracted from a Gaussian distribution [9] and with a distribution of rotation rates extracted from a Maxwellian distribution. The possibility to assign a random value to the area (extracted between the maximum and the minimum ellipse area) at each time step (i.e., a tumbling particle) is also foreseen.

The impact against the primary and secondary ellipsoidal bodies are recorded and the integration is carried out until a distance of twice the Hill radius of Didymos is achieved. After that distance the particle is considered escaped and is not followed further.

The simulation campaign: A large set of simulation was performed and is under analysis. The main purpose of the campaign is to validate the model and the software and to assess the most relevant effects. The simulated cases include:

- Polyhedron vs analytical gravity
- Solar radiation pressure models (eg. Spherical vs. ellipsoidal particles, different rotation,...)
- Different particles sizes and distributions
- Different target composition
- Different ejection velocities
- Different impact location

The analysis is performed on different time scales, ranging from a few minutes (the formation of the crater as imaged by LICIACube) to a few years to explore the possibility of the existence of stable particles left in the binary system at the arrival epoch of HERA.

Selected results: as mentioned before, the model can simulate both the short and long term evolution of the ejecta dynamics. In this section a few images are included to highlight some of the model features and the main results obtained so far are recalled.

Figs. 1 and 2 show two snapshots of a short movie of the ejecta plume evolution in the first few minutes after the impact. The two plots refer to a simulation evolving a batch of 500 identical ellipsoidal particles, randomly rotating, ejected with velocities between ~5 and ~20 cm/sec.

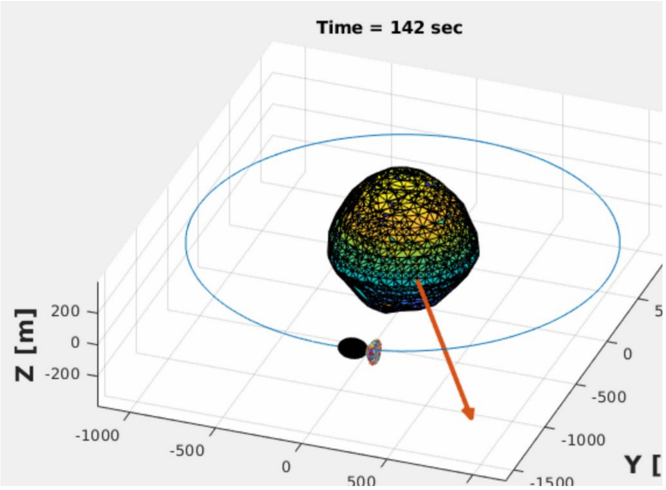

Figure 1. Snapshot of a simulation showing the initial evolution (142 seconds after the impact) of a group of 500 particles (~ 5 cm in size) with the full dynamical system described above. The arrow shows the direction away from the Sun.

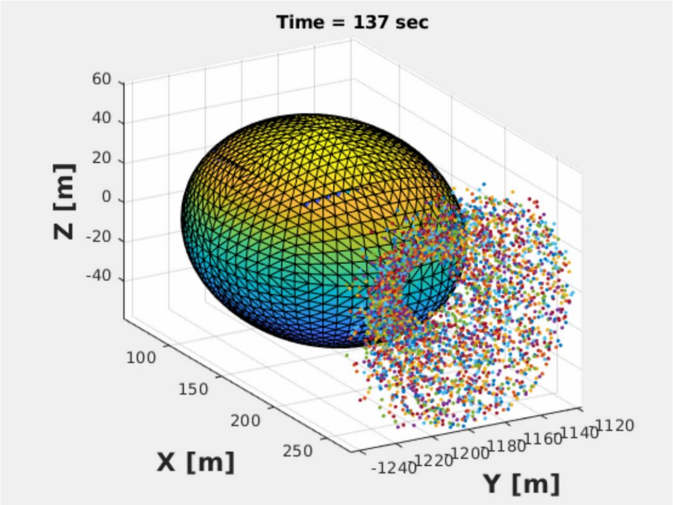

Figure 2. Detail, centered on Dimorphos, from the same simulation as in Fig. 1.

Going to longer evolution time spans, Fig. 3 shows the evolution over about 1 month, of a batch of 48 ellipsoidal particles (~ 5 cm) with regular rotation around the principal axis. More than 80 % of the particles re-impact against Didymos. The rest mostly impact against Dimorphos, while a few of them escape from the system after a number of close encounters with either one of the asteroids. The bottom panel shows a detail of the evolution, excluding the escaping orbits. All the particles either impact or escape within last at most ~ 40 days.

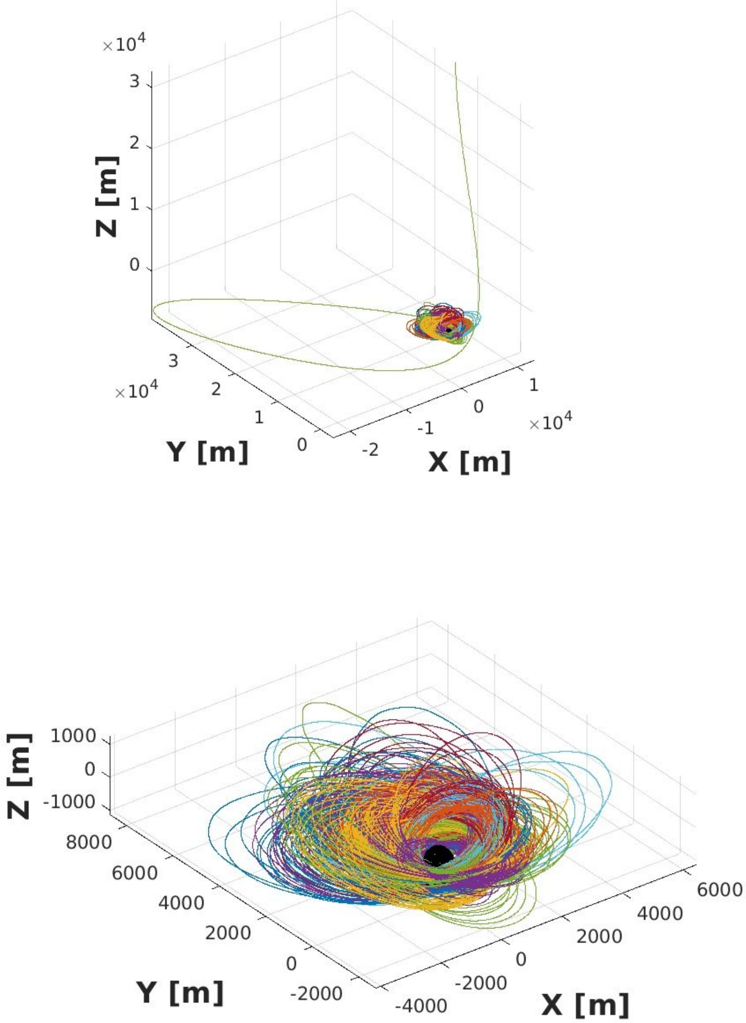

Figure 3. Evolution over about 1 month of a group of 48 particles (~ 5 cm in size). See text for details.

Note that the repeated close encounter make the ejecta dynamics extremely chaotic. Slight changes in the pre-encounter conditions can lead to a completely different post-encounter evolution for a given particle.

Main conclusions: from the set of simulation performed so far the following conclusions can be summarized:

- The gravity potential computed with the polyhedron can be effectively substituted with the analytical formulation for nearly ellipsoidal bodies or when the distance from the central body is large enough to minimize the shape effects.
- In order to explore the influence of the asteroid composition in the ejecta evolution, different impact simulations (w.r.t. the ones originally foreseen for this work) for less cohesive bodies (leading to smaller ejection velocities) shall be adopted.
- Different models for the rotating particles in the SRP effect computation were tested. The three models give comparable results when looking at the global behavior over long time spans.
- The dynamics of the particles appears extremely cahotic due to the repeated close encounters with either one of the asteroids.
- Impact locations in the vicinity (around 10 degrees in latitude and longitude) lead to quite similar ejecta evolutions. Impacts in the Northern and Southern region appear to lead to more long lived particles (perhaps related to higher inclination orbits).
- Particles below 1 mm are quickly (~ 1 day) swept away by SRP.
- Particles larger ≥ 1 mm show a growing percentage of longer living orbits. Nonetheless, in the analyzed simulations, no particle survived in the system for more than ~ 45 days.

Future work will analyze:

- Different impact simulations
- Significantly longer time spans, looking also at the characterization of the observed chaotic behavior.
- Orbital elements analysis of the surviving orbits to identify potential regions of stability (also in relation to the existing literature on the subject)

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