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LOW-SPEED EJECTION MECHANISMS IN THE DART EXPERIMENT

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Extended Abstract

Following the impact of the NASA-DART space probe against the asteroid Dimorphos, several thousand tons of material were ejected at a wide range of velocities. Several groups have used close observations of LICIACube, as well as long-range long-range tracking from HST and the ground, to infer the spatial and velocity distribution of ejecta (Li et. al. 2022). From images taken by LICIACube's camera LUKE during the fly-by with a wide range of viewing angles (see Fig. 1), it was concluded that the ejecta cone had a wide angle of $\sim 145^\circ$.

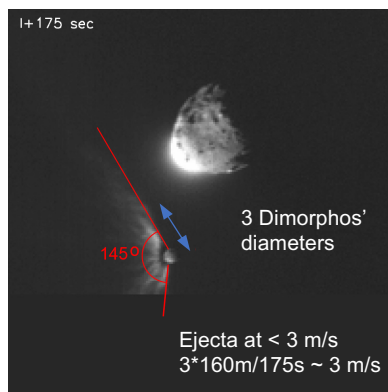


Fig. 1 – View from LICIACube 175s after impact.

The ejected material can be broadly classified into three different regimes: the very-high-speed ejecta (with speeds tens m/s); the high-speed ejecta (a few m/s); and the low-speed ejecta (below 1 m/s).

The radial extension of the cone and the darkened ring just above the surface observed in a side view are in correspondence with the fact that most of the material

was ejected at very low velocities. After 175s, an optically thick ejecta cone is still concentrated within 3 Dimorphos' diameter (160m). Therefore, the ejection velocity is $\sim 3\text{m/s}$ ($3 \cdot 160\text{m}/175\text{s}$).

In addition, the tip of the ejecta cone does not appear to have been located at the surface, as would be expected from a point source cratering event. The ejecta was released from a wide area covering almost the entire impacted hemisphere (half of the Dimorphos surface centered on the impact point).

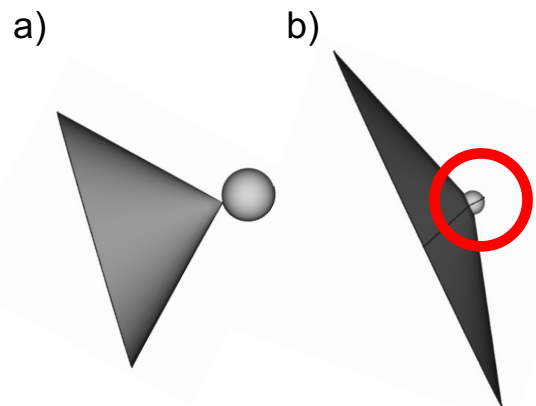


Fig. 2 – Drawings of the ejecta cone: a) with the tip of ejecta cone on Dimorphos' surface; b) with the tip of the cone inside the body. Note that drawing a) is not compatible with LICIACube images. The ejection area should occupy an area comparable to the entire impacted hemisphere.

What are the physical mechanisms that could explain the wide ejecta cone, the large ejection zone (~one hemisphere) and low velocities of the material?

Moreno et al. (2022) and Tancredi et al. (2022) presented models similar to those used to study the evolution of Active Asteroids to predict coma brightness and the formation of a long-lived tail after impact. They dubbed the DART experiment as the creation of the first artificial Active Asteroid. The inversion of this model is used by Moreno et al. (this conference) to infer the ejecta distribution in mass and velocities, concluding that most of the material was released at velocities comparable to the escape velocity from Dimorphos' surface (i.e. 0.09 m/s). This is in correspondence with LICIACube's observations that a lot of material has moved very little, even over 100s after impact. The extend of the dark ring of optically thick material at T+175s is less than 1 Dimorphos' radius; therefore, this material is moving at less than 0.5 m/s, just above the escape speed from Dimorphos' surface.

Tancredi et al. (2022) proposed that the mechanism to produce a large amount of material being lofted of material at low speed is the consequence of the generation of seismic waves during impact, and the propagation of these waves to distances far from the impact point. To simulate this process, we divide it into the following steps:

- i) generation of impact-induced seismic waves and propagation into the interior of the body;
- ii) arrival of these waves at points located far from the impact point, producing a shaking effect on the ground;
- iii) lofting of particles due to shaking and ejection at low speed (comparable to the escape velocity);

We performed numerical simulations of these steps using the DEM code ESyS-Particle (<https://launchpad.net/esys-particle>), and later improvements that include self-gravity (ESyS-Gravity, Rocchetti et al. 2021).

To simulate the first two steps, we impacted a rubble pile Dimorphos with a projectile with a fraction of the kinetic energy ($f_{KE}=0.25\%$) of the real experiment, and the same linear momentum. We let the system run for a few seconds and we compute the velocity of the particles projected in the radial direction.

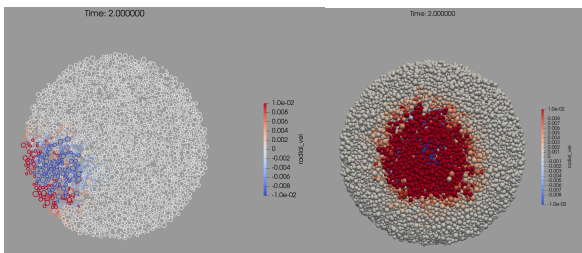


Fig. 3 – Snapshots of the propagation of the impact induced seismic wave to the interior of the body, and to a region far from the impact point. a) Slice view passing through impact point and center. b) Downward view of the impacted hemisphere. The particles are colored by the radial velocity.

If the seismic waves arrives at distances over 30° from the impact point, it could induce ground shaking at distal locations.

Floor shaking with a small displacement could induce lofting of small particles, with velocities larger than the escape speed. We named it the “cocoa effect”. It is the lofting of small particles from the top of a dust layer when shaking the ground.

To simulate this third step, we have done laboratory and numerical experiments. In the numerical experiments we used a box filled with small particles, and the box is shaken from the bottom. The shaking produces lofting of the particles, with larger velocities of the particles at the top of the later. The experiments were done with acceleration of gravity like the one at Dimorphos' surface. We observed that depending on the strength of the shaking, particles can reach ejection velocities larger than the escape speed.

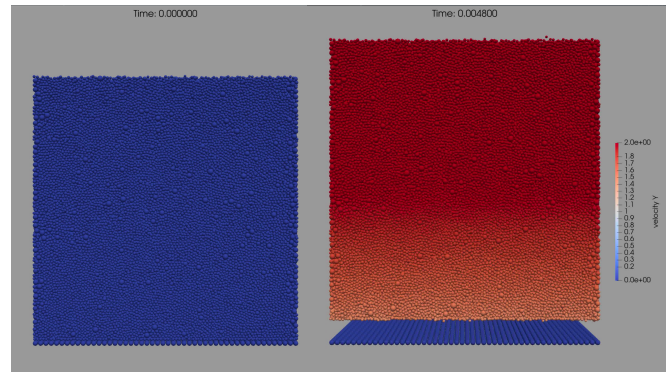


Fig. 4 – Snapshots of the simulations of the “cocoa effect”.

Conclusions

- The cone has a very wide open angle of $\sim 145^\circ$.
- Large amount of the dust particles in the ejecta cone have speeds $< 3\text{m/s}$, and in the densest part of $< 0.5\text{m/s}$
- A cone with a tip on the surface looks incompatible with the observations.
- A broad outflow cone coming from a large surface area is required.
- Cratering experiments and SPH models produce ejecta plume with a conical shape with a tip on the surface, in contradiction with observations.
- Other models are required to explain a broad outflow cone, e.g. seismic shaking + “cocoa effect”

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