Dimorphos ejecta plume dynamics by means of non-spherical dust simulations and DART/ LICIACube data

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On the 26th of September 2022, NASA's Double Asteroid Redirection Test (DART) mission [Rivkin et al 2021] was the first space mission demonstrating the kinetic impactor method for planetary defence and ASI's Light Italian Cubesat for Imaging of Asteroids (LICIACube) [Dotto et al. 2021] was the first to image it. To gain maximal scientific return from the DART and LICIACube operations and describe the physical conditions for future asteroid impact or post-impact flyby missions proper modelling must be timely provided.

We developed a 3D+t model (LIMARDE) for simulating the dust plume evolution of asteroid impact ejecta aimed at: 1) describing the near- and far- field dust environment after the impact; 2) interpreting ejecta plume observations such as the forthcoming LICIACube images, and 3) predicting complex dust environment near active asteroids. The model can cover a large range of dust dynamical parameters at different time scales and allows input from different impact modelling approaches (e.g., analytical scaling laws, SPH (Smoothed Particle Hydrodynamics) and HD (Hydrocodes) simulations).

Here, we focus on the interpretation of the first data obtained after the DART impact. Derived dust dynamical observations with LICIACube images[Dotto et al. 2023] will be interpreted with respect to dust non-sphericity, temperature, initial velocity, and rotational energy in the propagation of the ejecta. Our results will focus on the scientific return from the mission, and which dynamical parameters governed the motion and led to the post-impact morphology of the near -field ejecta. In addition, the non-sphericity of the particles has a direct influence on the optical thickness of the plume. LIMARDE can compute single trajectories of the dust propagating in the plume and can give the rotational frequency and particle orientation for a given time and distance. The latter will be used for supporting studies on the optical thickness derived from the obtained LICIACube images.

Dust dynamics of the Dimorphos plume evolution and LICIACUBE data

LIMARDE code- LICIACube Model for Aspherical Rotating Dust Ejecta

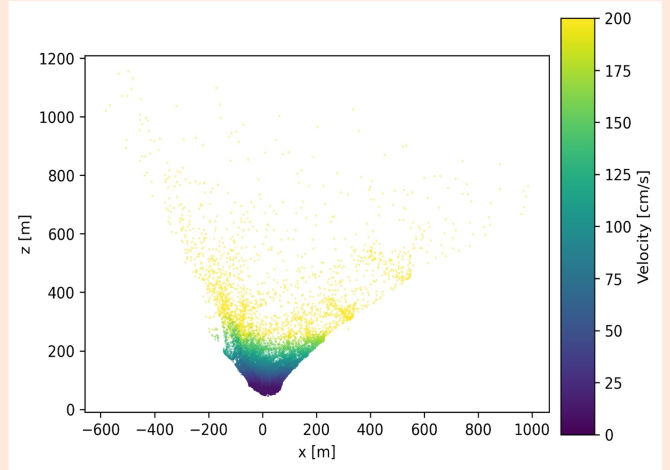
(LIMARDE; Ivanovski et al. 2023, u. rev.)

- a 3D+t nonspherical dust model that solves the Euler dynamical and kinetic equations.
- different shapes, initial particle orientations, and velocities, as well as torque, are considered.
- the particles are assumed to be homogeneous, isothermal convex bodies having the same physical properties of Dimorphos's surface where applicable.
- the dust motion starting from the initial dynamical parameters (speed, orientation, and torque) is governed by SRP and Didymos and Dimorphos gravity
- collisions are approximated by the interaction between the ejected particles assuming only one family of particles with different velocity that expands spherically as a result of the impact.

Plume characteristics

- wide opened cone of the ejecta
- filamentary structure
- Different dust velocity and particle size distribution in the plume
- Deviation or supraposition of the internal fluxes («streamers») during the plume evolution
- Different plume morphology

Input Impact data



Raducan et al.

T = 150 seconds
Beta ~ 3.82
V_min = 7 cm/s
V_max = 3.95 km/s
Total ejecta mass at T => M = 1.665e7 kg
Number of the ejecta particles at T =>
N = 35863, Resolution ~6x 10^6

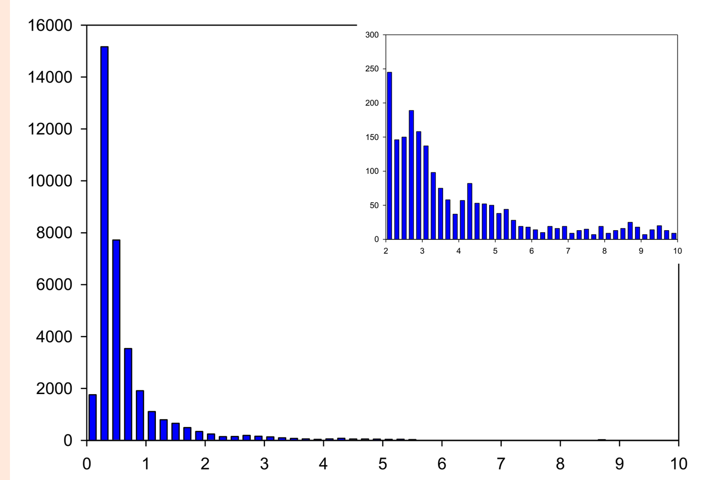
Projectile	
Mass	~580 kg
Impact velocity	~6.149 km/s
Density	1000 kg/m3
Radius	~ 0.52 m

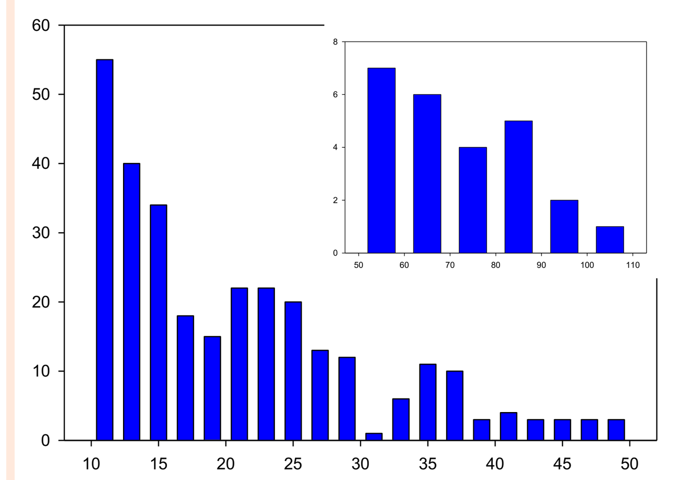
Top : velocity distribution

Bottom left: velocity distribution in bins with size of 0,2 m/s for the range from 0 to 10 m/s

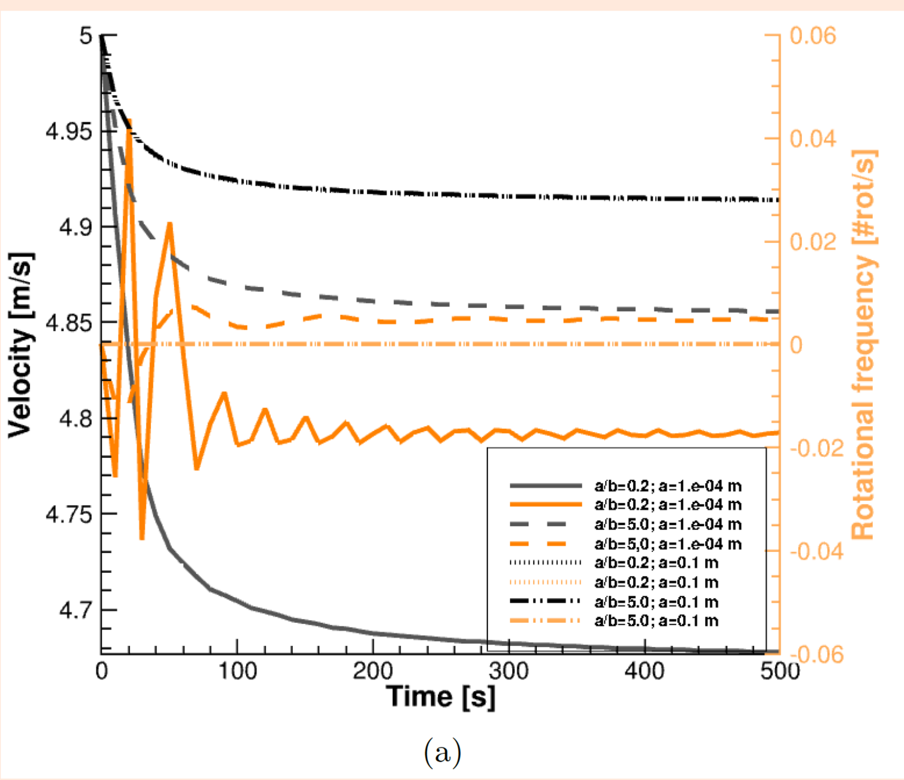
Bottom right: velocity distribution in bins with size of 0,2 m/s for the range between 10m/s and 50 m/s

26 particles of 35863 are with higher speeds.

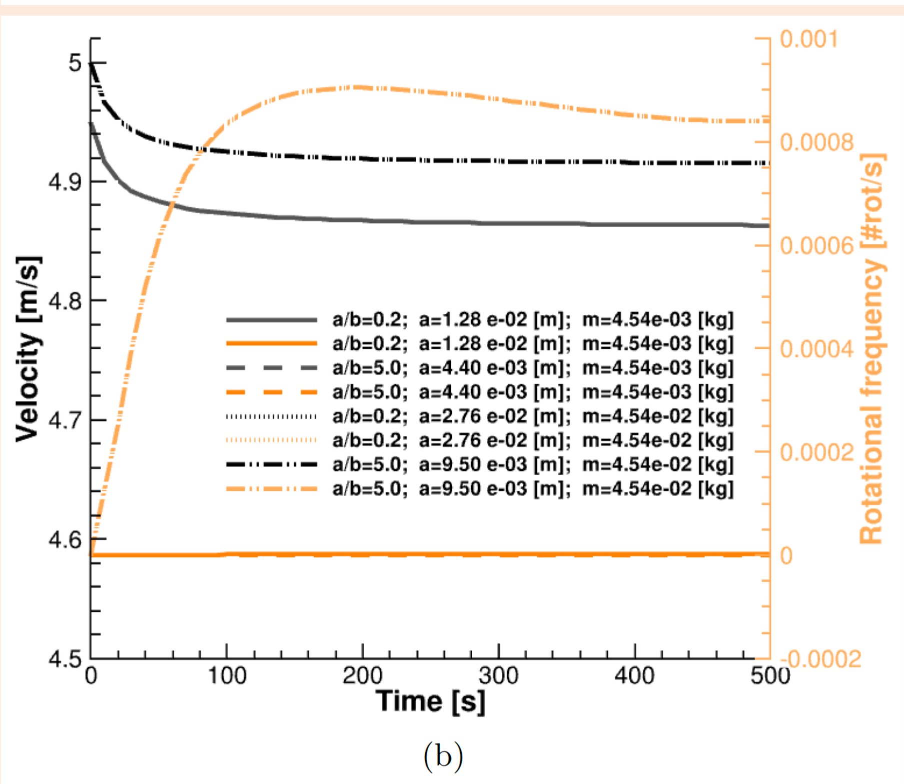




The Model



(a)

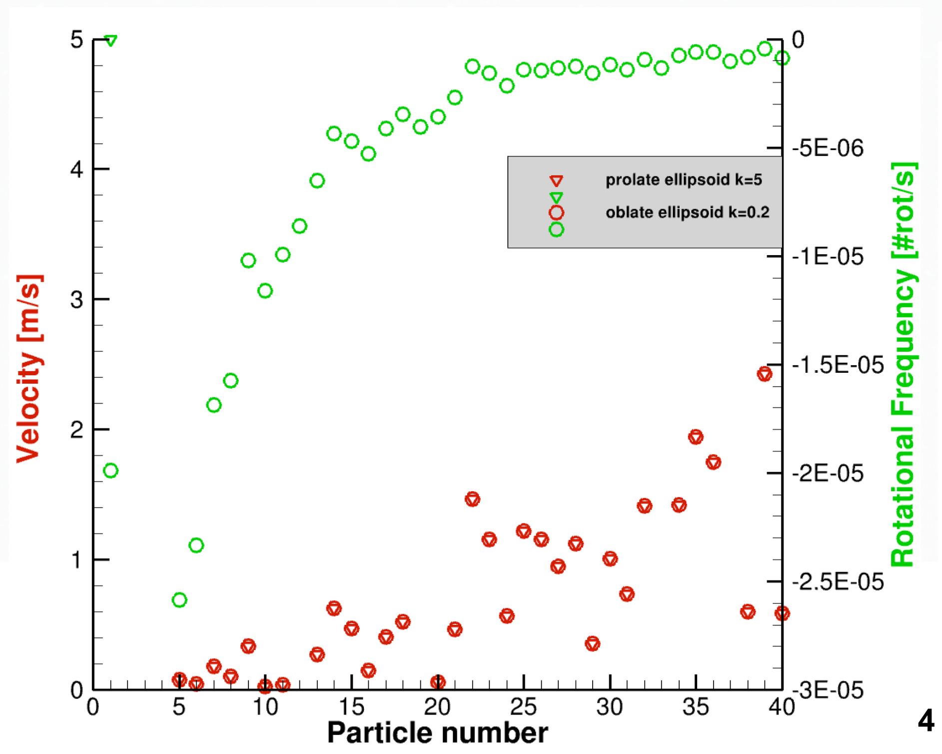


(b)

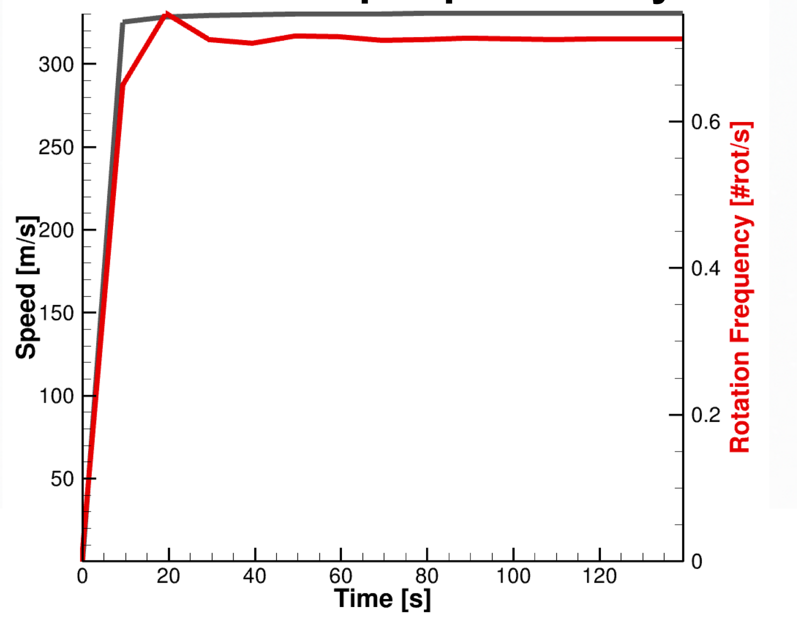
(a) Dust velocity and rotation frequency with no initial rotational energy of the dust for prolate and oblate particles for two sizes 10^{-4} and 0.1 m;
(b) Dust velocity and the rotational frequency for four particle cases- different shapes and mass shows identical dynamical behaviour governed by the gravity.

LIMARDE simulations

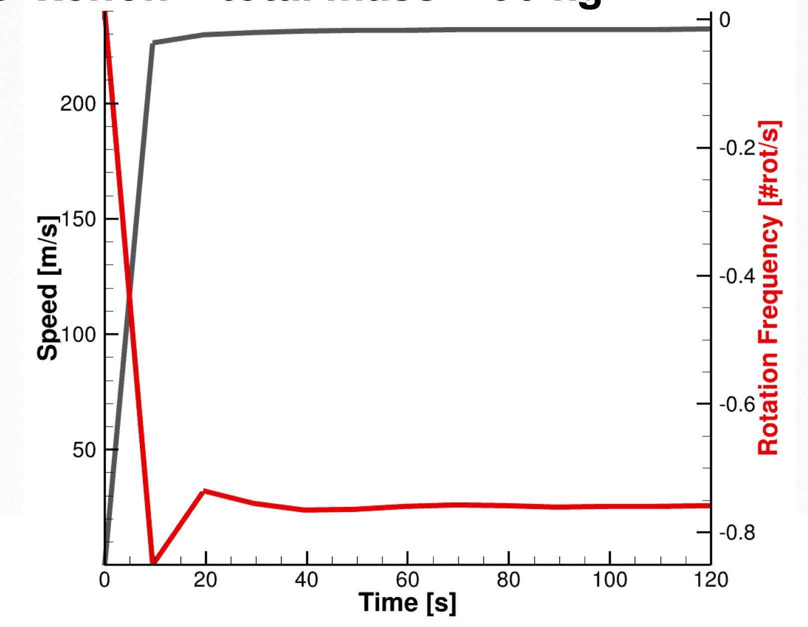
- to compute the dust velocity distribution based on the physical properties: size, mass and shape derived from LICIACube obs.
- to reconstruct the dust distribution of the plume with its filaments, spikes and large aperture
- to determine the contribution of the rotation of the dust in the optical thickness of the plume
- to check what is the role of the fragmentation of the particles
- to constrain the physical properties based on the dynamical properties of the ejected dust in the near- mid- and far- environment.



Vapor plume – hydrazine+xenon – total mass ~ 90 kg



4 kg particle ejected instantaneously with the vapor plume



1-cm particle with rho = 2.600 kg/m³ (0.01kg)

Particle velocity and rotation frequency for 50 velocity averaged velocities bins – velocities from 0.1 to 10 m/s. In all velocity bins we took the averaged velocity taking into account the velocity distributions and mass distribution within the bins at 150s by the impact simulations. Results show no influence on the shape for chunks with mas of hundreds kg.

Conclusions

We present preliminary results with LIMARDE using a test set of calibrated impact simulations. For big particles (greater than hundreds of kilograms in mass) and velocities in the range 0.1 to 10 m/s no influence of the shape on the motion of the particles within the plume. The dynamical behaviour of the particles do not change in the next 300 s. Currently, we are investigating the dynamical behaviour of smaller particles with velocities from 10 to 100 m/s.

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References and Acknowledgements

Dotto, E., et al. 2023, Nature (*in preparation*). Fahnestock et al. 2022,PSJ; Ivanovski et al. 2017, Icarus ; Ivanovski et al. 2022(PSJ, under review); Rivkin, A.S. et al. 2021,PSJ, Dotto, E. et al. 2021, PSS 199, 105185

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