NON-SPHERICAL DUST DYNAMICS OF THE EJECTA PLUME IN SUPPORT OF DART/LICIACUBE MISSION

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Dust dynamics of the plume evolution (close and far-field) after the DART impact

Ojectives:

To study the dust dynamics of/in the plume:

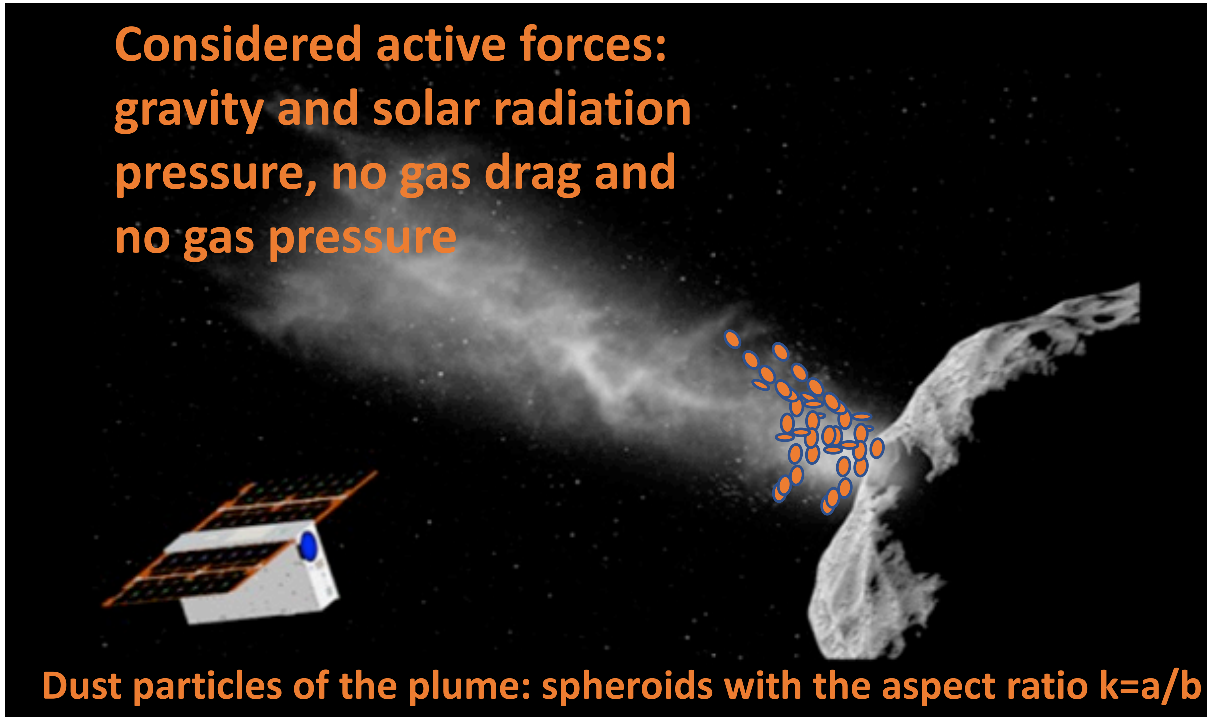
- **to compute the dust velocity of the particles based on their physical properties: size, mass and shape.**

- **to compute the distance and time at which the dust particles reach the upper limit of 5 m/s (a scientific constraint for LICIACube measurements) as a function of their physical properties.**

- **to determine the size of the acceleration region after the impact and the time needed to reach its boundary when particle rotates.**

- **to study the initial dynamical conditions that constrain the further dynamical evolution of the plume and therefore the plume density structure.**

Plume evolution setup



Method: non spherical dust dynamical model that solves the Euler dynamical and kinetic equations (updated from Ivanovski+2017) and analytical model for single dust particle expansion without dust collisions

Model setup: three body problem - solar radiation pressure, initial velocity of the ejecta, gravity field

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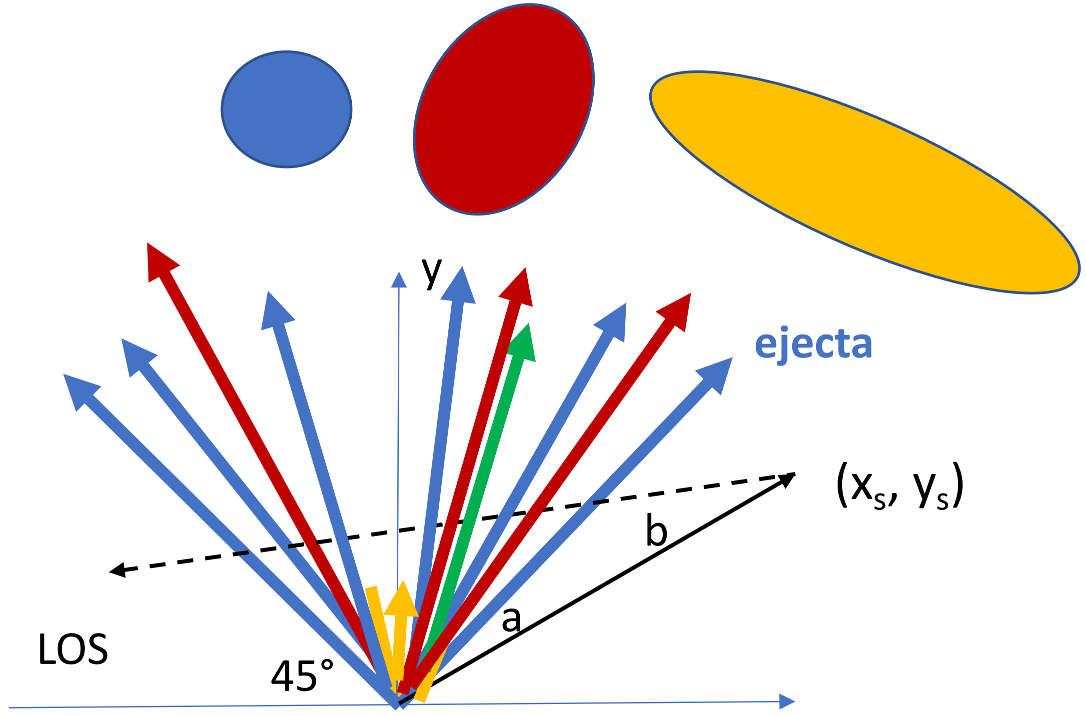
Geometry of the plume evolution and model setup of rotating particles

- ✓ Single particle motion ejected from the surface with different initail orienation 45- 135 degrees

- ✓ **The different particle cross section will change the optical thickness of the plume. It is not only the size distrubution but the particle shapes and their orientation.**

- ✓ In case of relatively strong solar radiation pressure, if the particle has initial torque will rotate during the plume evolution and its speed will be different than the non-rotating one of the same mass, shape and size.

- ✓ Solar radiation pressure will affect its motion at large distances – far-field simulations. At what distance the particles achieve their terminal velocities or eventually stop acceleration/deceleration?



Courtesy A. Cheng

$x_s > y_s$ with a<0 and b<0; LOS through ejecta cone twice

Consider x-y plane defined as plane containing axis of 45° ejecta cone and vector (x_s, y_s) to LICIACube; origin is DART impact site. Line-of-sight LOS is also considered within x-y plane. Calculate optical depth of ejecta along LOS. Three geometries are illustrated, defining angle b between LOS and direction to DART impact.

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Non-spherical dust dynamics using scaling laws input

Ejecta model non-spherical simulations

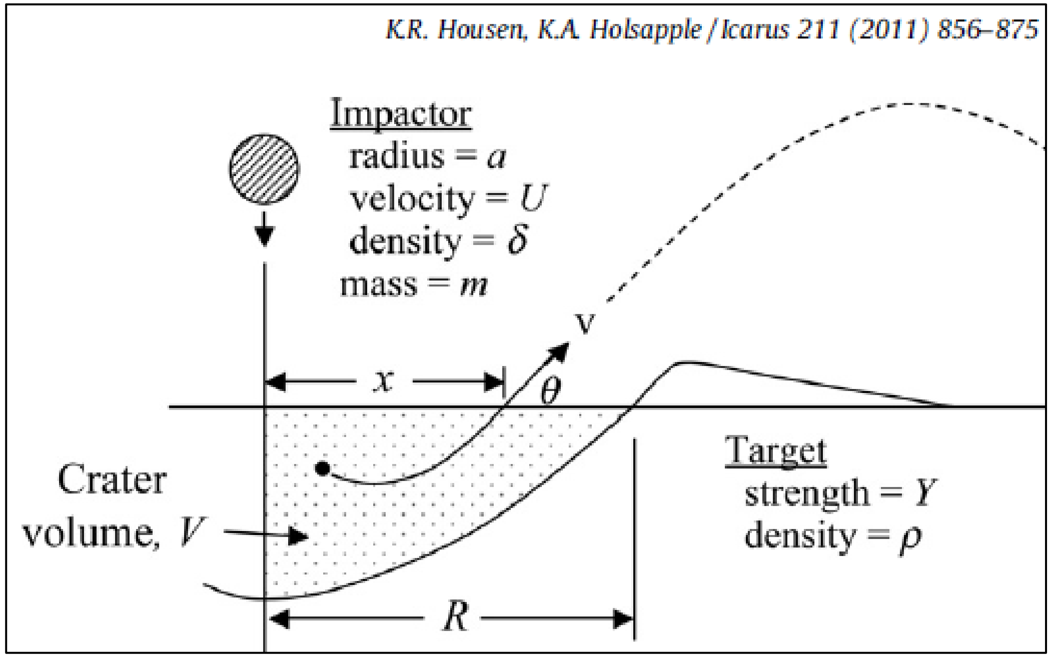


Table 1: Impact ejecta scaling parameters of Weakly Cemented Basalt material (see Housen & Holsapple 2011 for the parameter definitions).

a (m)	R (m)	δ (g/cc)	ρ (g/cc)	μ	C_1	k	p	ν	n_1	n_2
0.5	10	0.57	2.6	0.46	0.18	0.3	0.3	0.4	1.2	1

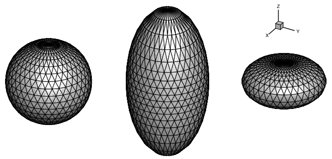
AIM: Didymos and ejecta Reference model V5

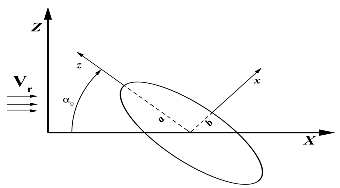
0.02 m/s < V_{ini} ≦ 59.0 m/s

0.6 ≦ χ < 10

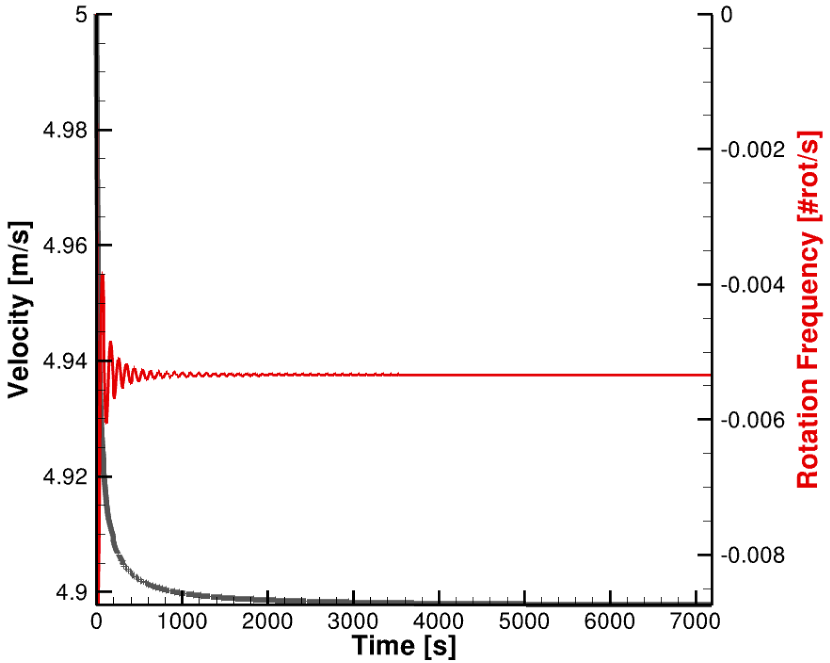
Input -> Scaling laws Housen and Holsapple 2011

Parameters	Case A	Case B
Particle size [m]	1.0x10^{-4}	1.0x10^{-4}
Initial orientation[degrees]	45	45
Particle density [kg/m^3]	2600	2600
Initial angular velocity [#rot/s]	0	50% E_kin
Initial velocity [m/s]	5.0	5.0
Aspect ratio	0.2;5.0	0.2; 5.0





Increase the initial rotational energy up to 50% of the kinetic energy leads to less than few precent difference in the velocity under considered initial conditions.



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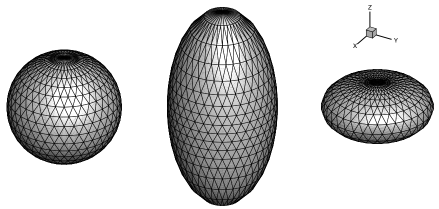
Dust dynamics using scaling laws with different T_{dust} 1/3

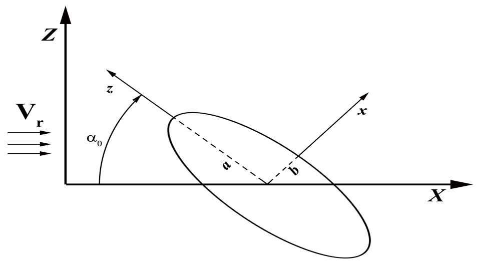
Parameters of the current case studies

Parameters	Case A	Case B
Particle size [m]	1.0×10^{-4}	1.0×10^{-4}
Initial orientation [degrees]	45	45
Particle density [kg/m^3]	2600	2600
Initial angular velocity [#rot/s]	0	10% E_kin
Initial velocity [m/s]	2.5; 5.0	2.5; 5.0
Aspect ratio	0.2;5.0	0.2; 5.0
Distance [km]	55.25	55.25
Dust temperature [K]	280; 360	280;360

Table 1: Impact ejecta scaling parameters of Weakly Cemented Basalt material (see Housen & Holsapple 2011 for the parameter definitions).

a (m)	R (m)	δ (g/cc)	ρ (g/cc)	μ	C_1	k	p	ν	n_1	n_2
0.5	10	0.57	2.6	0.46	0.18	0.3	0.3	0.4	1.2	1





WCB C3
Cheng et al. 2016

Cheng et al. 2016
Eq. 4:

The speed of ejecta v, non-dimensionalized by the incident velocity U, that are released at radial distance x from the central point of impact is

$$\frac{v}{U} = C_1 \left[\frac{x}{a} \left(\frac{\rho}{\delta} \right)^{\nu} \right]^{-\frac{1}{\mu}} \left(1 - \frac{x}{n_2 R} \right)^{p} \quad (4)$$

0.02 m/s < V_{ini} ≦ 59.0 m/s
0.6 ≦ χ < 10

AIM: Didymos and ejecta Reference model V5

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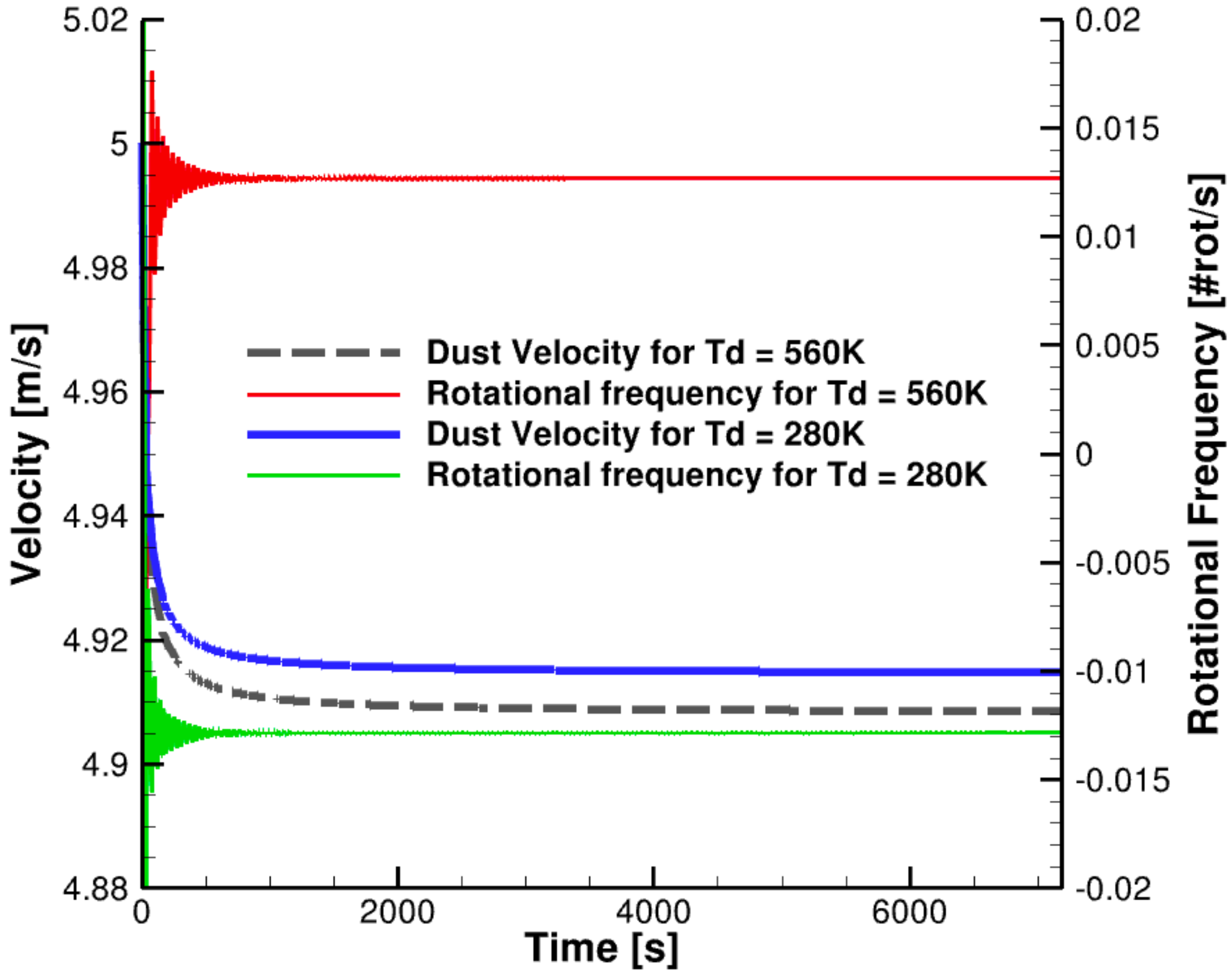
Dust dynamics using scaling laws with different T_{dust} 2/3

Cases A

Spheroid (**a/b = 0.2**, 100 µm) in the considered cases with initial velocity **5 m/s** or higher decelerate with less than few % at 55.25 km from Dimorphos. Therefore, the initial velocity is the key initial parameter. The increase of dust temperature of 100% does not decrease the rotational frequency.



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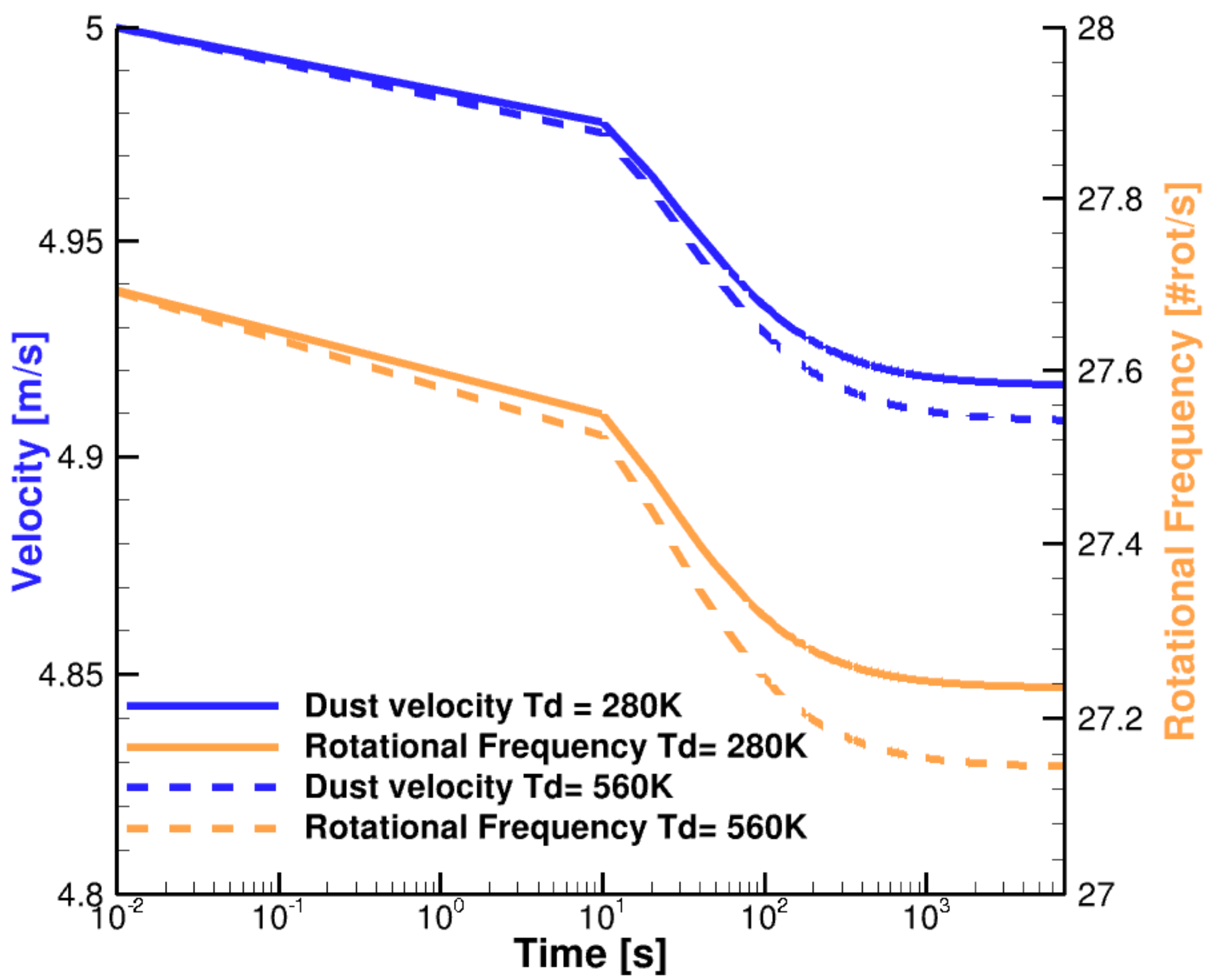
Dust dynamics using scaling laws with different T_{dust} 3/3

Case B

Spheroid (**a/b = 0.2**, 100 μm) in the considered cases with initial velocity **5 m/s** or higher decelerate with less than few % at 55.25 km from Dimorphos. Therefore, the initial velocity is the key initial parameter. The increase of dust temperature with 100% decreases the initial rotational frequency of few precents.



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Chained modelling of ejecta dynamics using impact iSALE

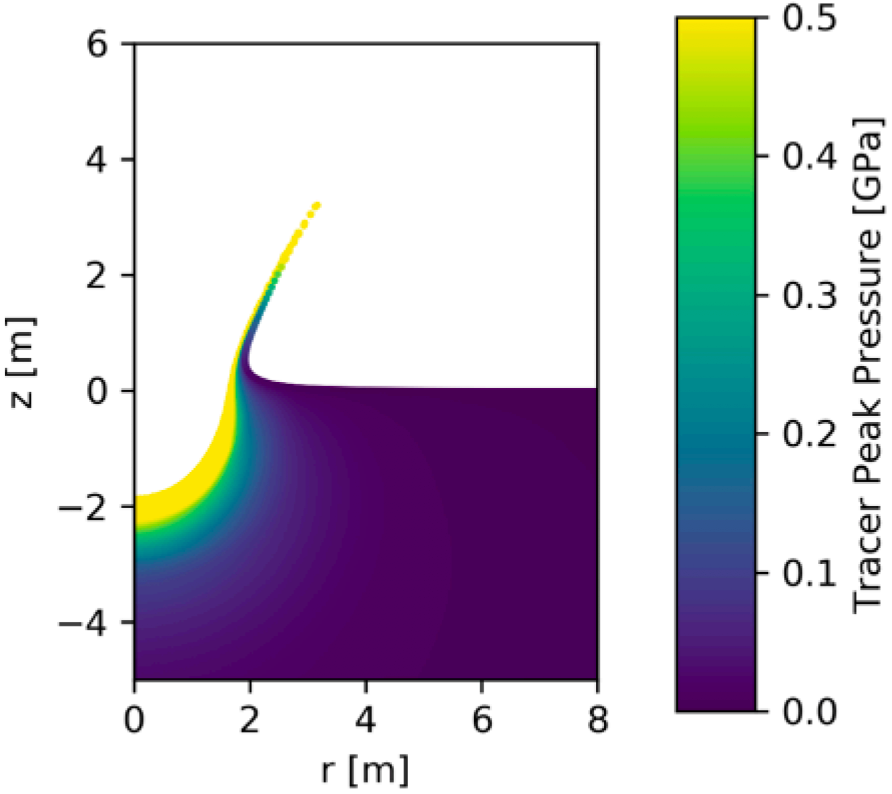


Fig. 1: A snapshot of the formation of the crater resulting from the iSALE modelling performed with parameters reported in Table 1. The colorbar represent the peak pressure of the ejecta tracer particles.

Tracer velocity
Launch angle (35°-49°)
Launch position
Mass

Description	Symbol	Target
Strength model		ROCK/LUND
Poisson ratio	ν	0.25
Strength at zero pressure (intact; MPa)	Y_0	0.1
Strength at inf. pressure (intact; MPa)	Y_∞	1000
Friction coefficient (damaged)	μ_d	0.60
Initial porosity	ϕ_0	30%
Initial distension	α_0	1.30

Input -> iSALE simulations

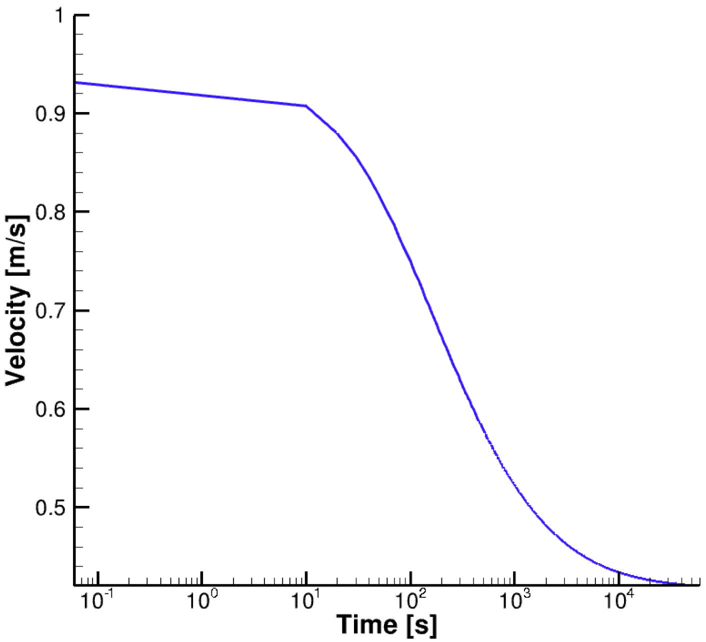
Ejecta model non-spherical simulations

Table 1. The dust model initial parameters.

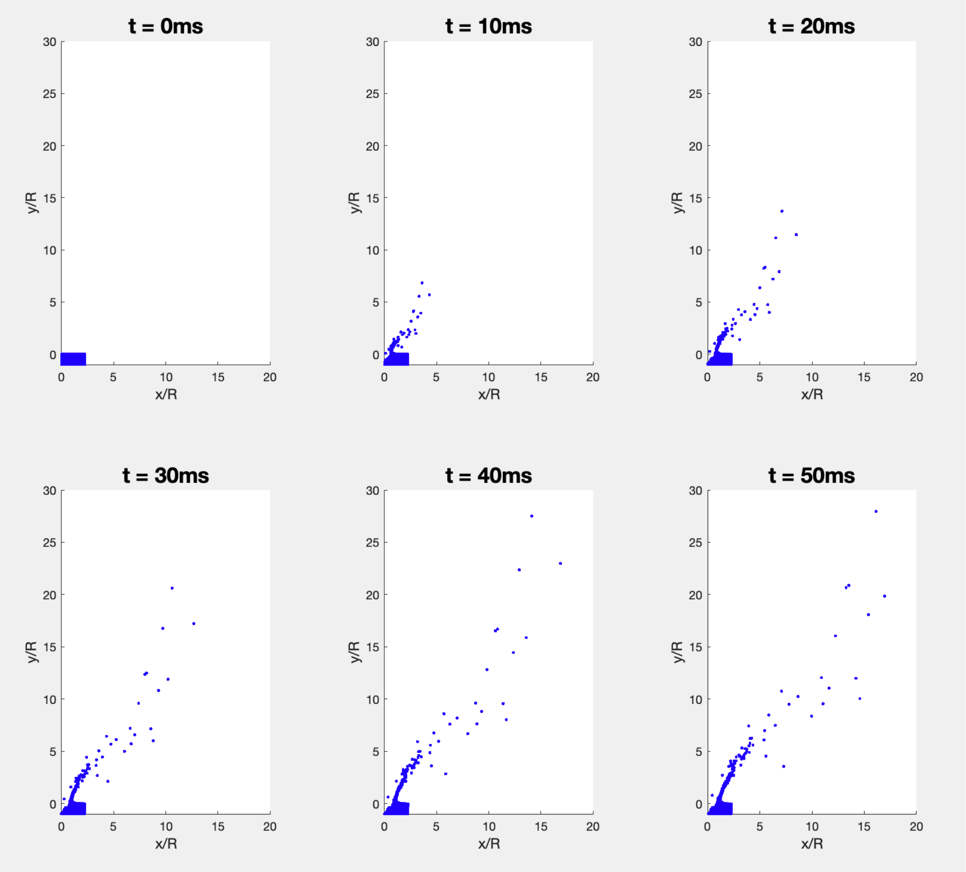
Input parameter	Parameter value	Comments
Particle parameters		
Particle size [m]	$1.0 \times 10^{-3} - 1.0 \times 10^{0}$	Cheng et al. 2016
Particle density [kg/m^3]	1200 – 3000	Cheng et al. 2016
Spheroid aspect ratio, a/b	5;0.2	Assumed aspect ratios, Ivanovski et al. 2017
Initial particle orientation [deg]	45 – 135°	Compatible with Cheng et al. 2017
Particle temperature, T_d [K]:	280	Yu et al. 2017
Initial ejecta speed, v_{ie} [m/s]:	200	Yu et al. 2017
6583 Didymos system parameters		
Mean diameter of the primary-didymos, D_p [m]	775 ± 10%	Yu et al. 2017
Mean diameter of the secondary-didymoon, D_s [m]	163 ± 18	Yu et al. 2017
Total system mass, M [kg]	$(5.278 \pm 0.54) \times 10^{11}$	Yu et al. 2017
Solar distance on the impact date Oct 5 2022, r_h [AU]	0.97 – 1.03	Yu et al. 2017
Surface temperature of the secondary, $T_{didymoon}$ [K]	280	Yu et al. 2017

Parameters	Case
Particle size of a.r. 0.2 [m]	4.75×10^{-2}
Initial orientation [degrees]	46
Launch position [m]	11
Particle mass [kg]	7.45×10^{-2}
Initial velocity [m/s]	0.94
Aspect ratio (a.r.)	0.2
Dust Temperature	280

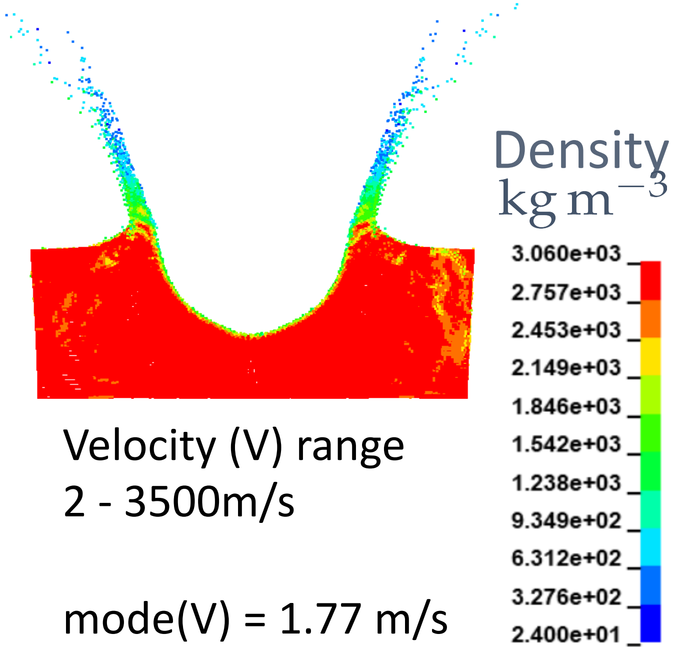
Velocity of an oblate particle (a. r. a/b =0.2). The complete set of parameters is given in the tables above. The gravity of the whole binary was considered (binary was approximated as a mass point).



Chained modelling with SPH impact output



Input -> G. Zanotti's master thesis - SPH simulations



Velocity (V) range
2 - 3500m/s

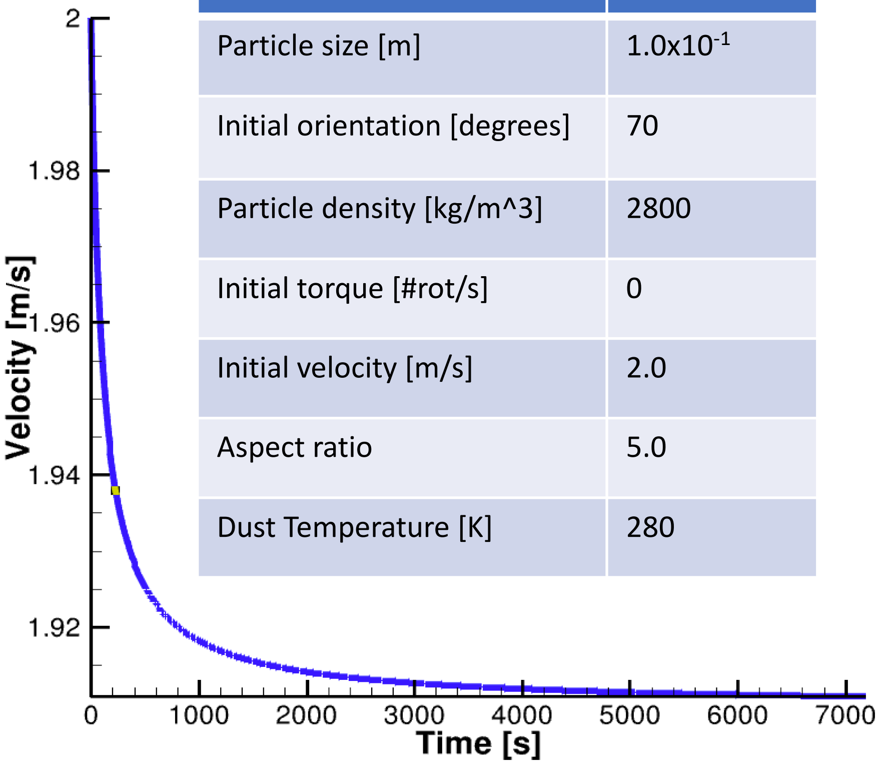
mode(V) = 1.77 m/s

Wider angle spectrum
up to 70 degrees

Study case A: Ejecta model non-spherical simulations

Density 2800 kg/m^{-3}
Assumed size 0.1m -> 1.03x10^{5} kg
Consistent with Scaling Laws Estimation

Parameters	Case A
Particle size [m]	1.0x10^{-1}
Initial orientation [degrees]	70
Particle density [kg/m^3]	2800
Initial torque [#rot/s]	0
Initial velocity [m/s]	2.0
Aspect ratio	5.0
Dust Temperature [K]	280



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Main research objectives and ongoing work

- To investigate how much different particle shapes and sizes could change the optical depth (because of the dust scattering, geometry and dynamics)

- By varying the initial angular velocity of the ejected particles, provided with the obtained dependence on the assumed particles' temperature, we study what amount of dust particles' rotational energy after the thermal shock due to the impact is necessary to intrude the rapidly expanding plume.

Ongoing work

- What minimum initial threshold speed for a given type of dust (in terms of size, density and launch angle) is sufficient to govern the plume evolution independently from the intensity of the thermal shock and rotation state of the ejected dust particles.

- Validity of collision-free ejecta evolution assumption

- Constrain the momentum transfer enhancement parameter (β)

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