Cratering processes on rubble-pile asteroids: insights from laboratory experiments and numerical models

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DART is a kinetic impactor test

DART = Double Asteroid Redirection Test

- S-type double asteroid system
- YORP asteroids $\implies$ low cohesion and high porosity
- Diameter of the secondary: 150–180 m

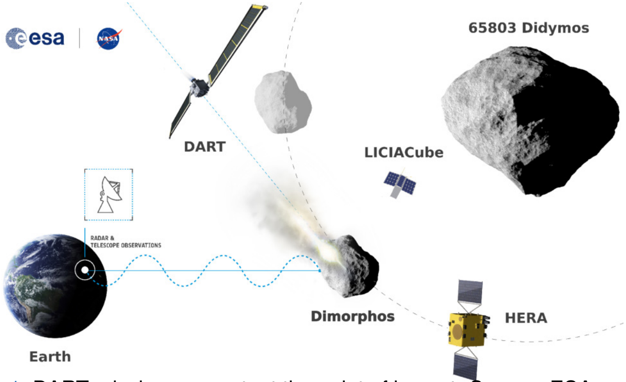


Figure 1: DART mission concept, at the point of impact. Source: ESA.

What do we know about the impact conditions and what is the main driver for β?

Target properties

Figure 2: Dimorphos. Source: ESA.

- Cohesive strength – not known
- Bulk density/porosity – not known
- Internal structure – not known

Impact conditions

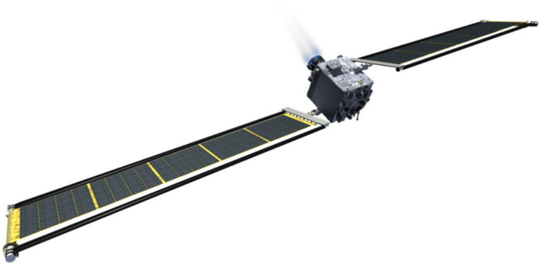


Figure 3: DART spacecraft. Source: NASA.

- Impact velocity – known
- Impact angle – not known
- Impactor mass/shape – known

Previous work quantifies the effects of various target properties and simple structures ($Y_0 > 100$ Pa)

The DART impact into different targets can produce the same β, but different craters. Both β and crater size/morphology together can be diagnostic of target properties (Raducan et al., 2020).

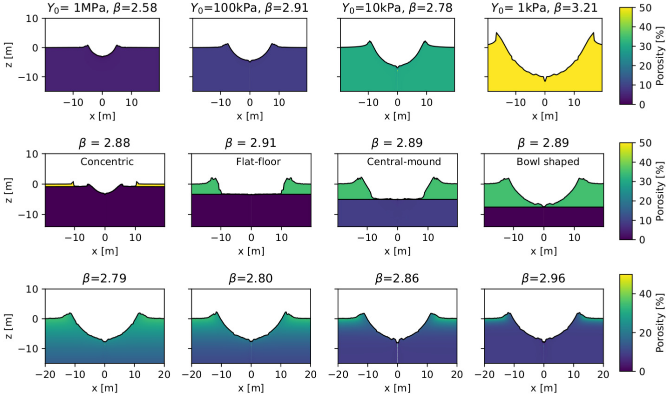
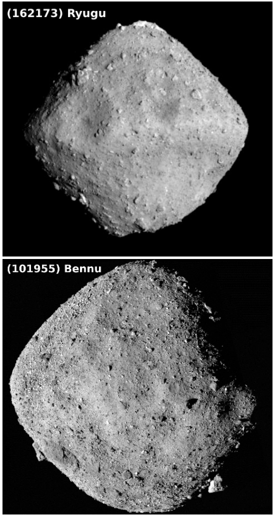


Figure 4: Crater profiles from iSALE-2D simulations of various targets.

Ryugu, Bennu – both rubble-pile asteroids. Dimorphos also a rubble-pile?



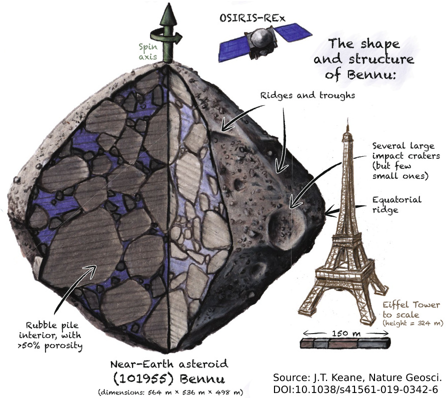
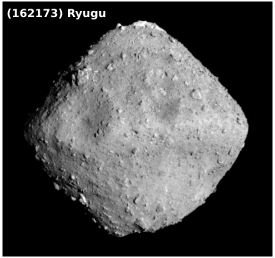
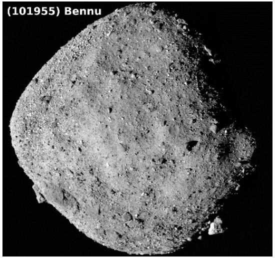


Figure 5: Sketch of asteroid Bennu interior. Source: James Tuttle Keane, Nat. Geosci. vol. 12 (226).

Ryugu, Bennu – both rubble-pile asteroids. Dimorphos also a rubble-pile?





We need to validate our numerical models against laboratory experiments!
We need laboratory experiments purposely designed to mimic asteroid surfaces!

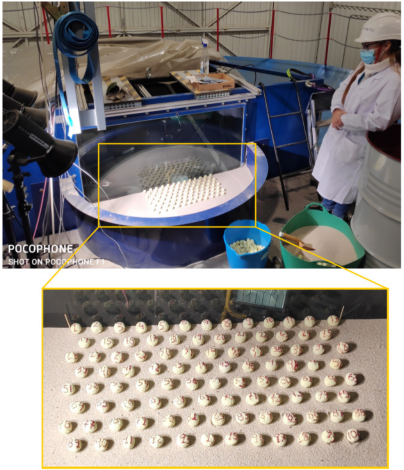
Experimental Projectile Impact Chamber (EPIC) - Quarter space experiments into heterogeneous targets

Projectile:

- Delrin (disrupts upon impact), 2 cm diameter, m_p = 5.7 g
- Velocity: $\approx$ 400 m/s

Target:

- 4 layers of porous ceramic balls embedded in dry beach sand matrix;
- Sand: ρ = 1.8 g/cm^3;
- Ball: d = 2.25 cm, m = 5.7 g, $\approx$50% porosity.

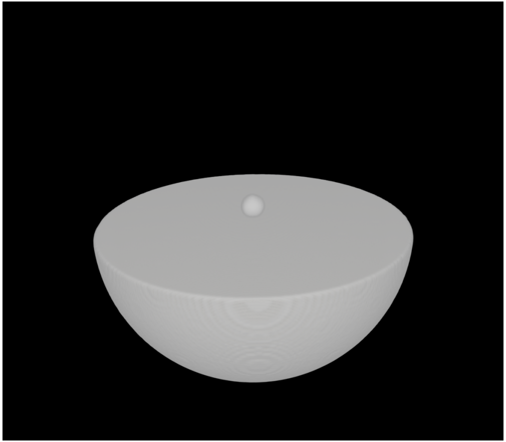


We used SPH to model the EPIC experiment

T = 0 ms

EPIC experiment

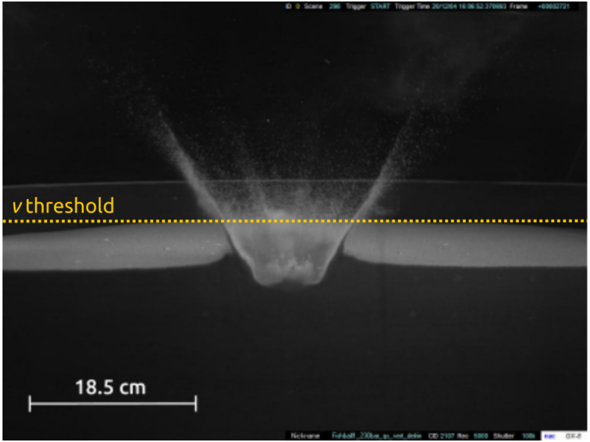
SPH simulation (only slow ejecta)



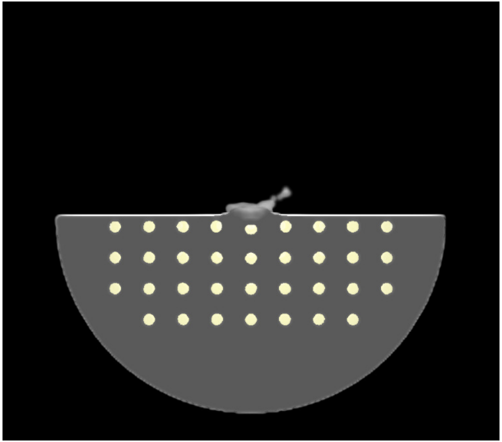
We used SPH to model the EPIC experiment

T = 4 ms

EPIC experiment



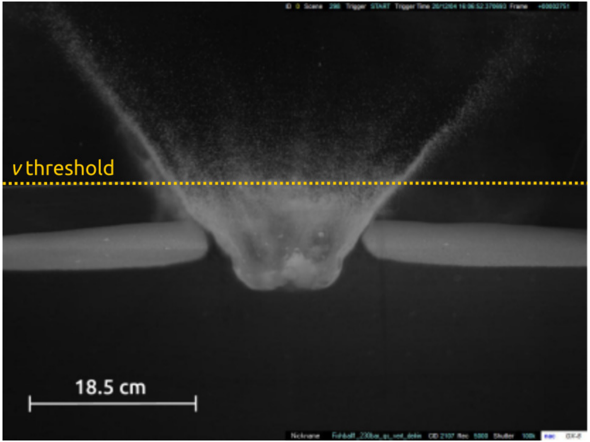
SPH simulation (only slow ejecta)



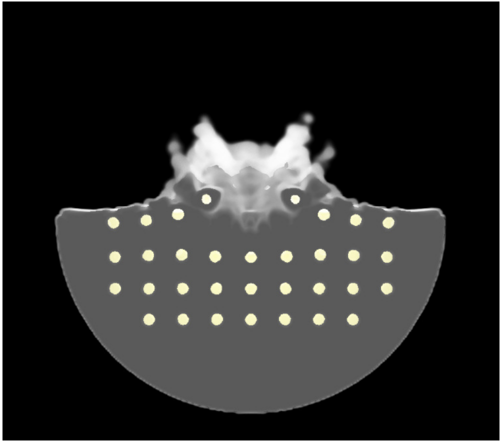
We used SPH to model the EPIC experiment

T = 10 ms

EPIC experiment



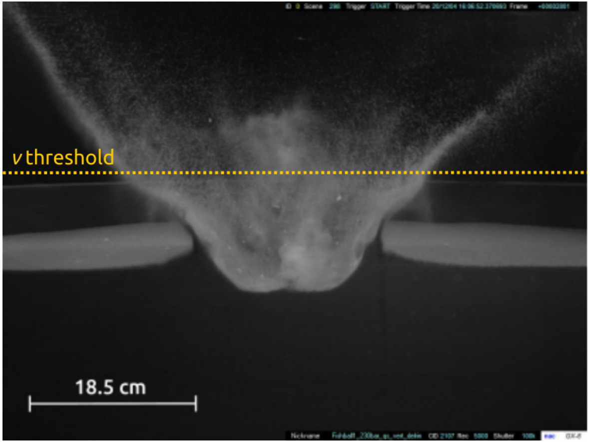
SPH simulation (only slow ejecta)



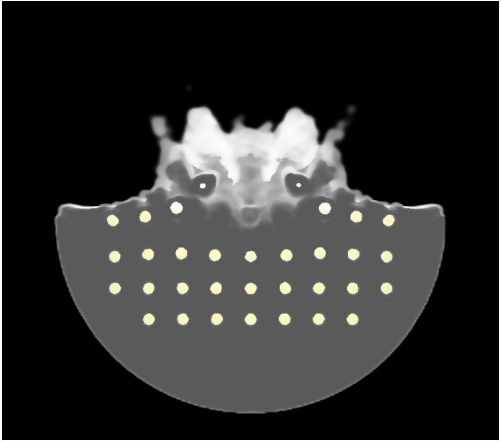
We used SPH to model the EPIC experiment

T = 20 ms

EPIC experiment



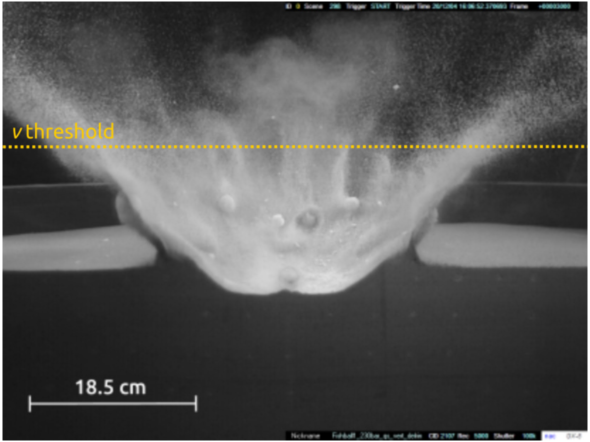
SPH simulation (only slow ejecta)



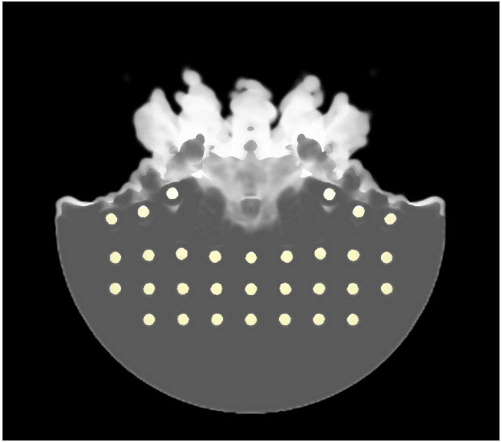
We used SPH to model the EPIC experiment

T = 35 ms

EPIC experiment



SPH simulation (only slow ejecta)



We used SPH to model the EPIC experiment

Final crater - good match with the experiment

Crater dimensions
Pre-impact level diameter: 20.2 cm
Rim diameter: 28.2 cm
Depth: 2.9 cm

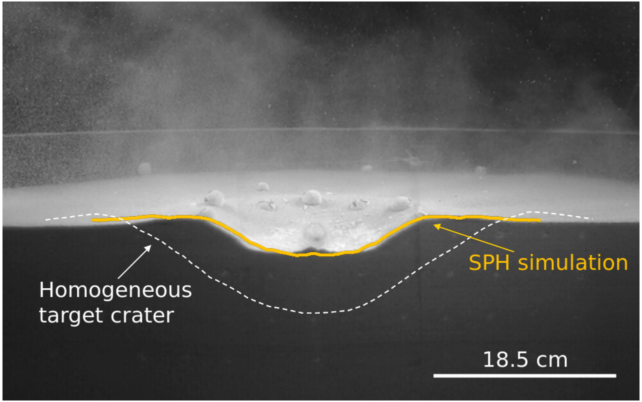


Figure 6: Final crater morphology ($T \approx 0.8$ s).

We used SPH to model the EPIC experiment

Boulder distribution - good match with the experiment

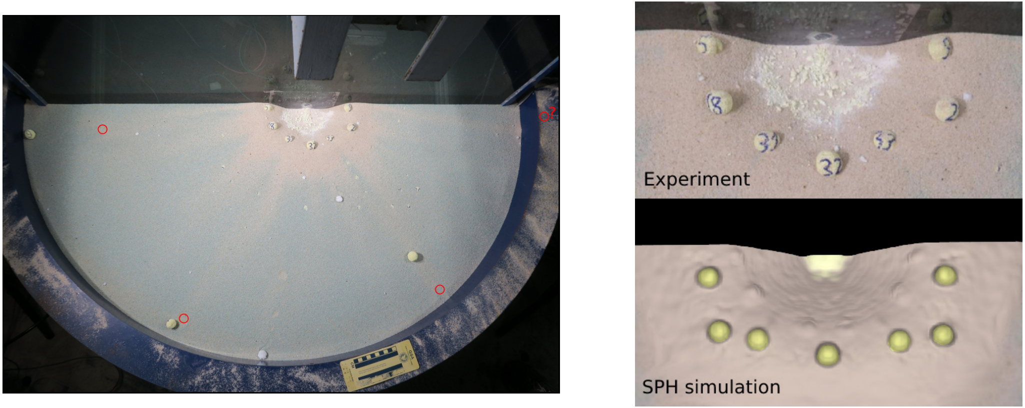
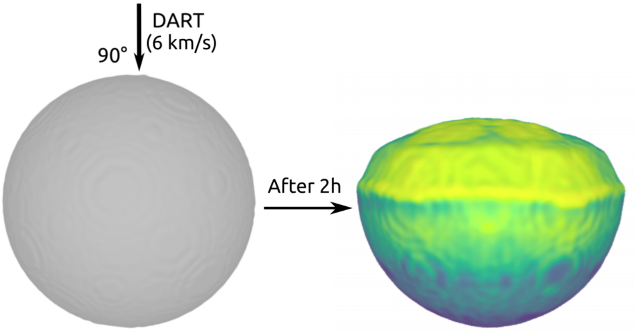


Figure 7: Boulder distribution.

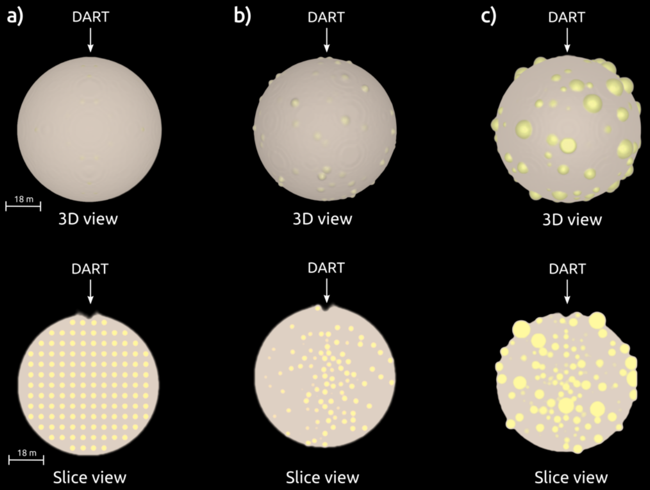
We used SPH to model DART-like impacts on spherical homogeneous asteroid



	Impactor			Target	
radius	mass	velocity	strength	friction	density
a	m	U	Y_0	f	ρ
(m)	(kg)	(km/s)	(Pa)		(kg/m^3)
0.5	500	6.0	0	0.6	1620

We modelled DART-like impacts on spherical rubble-pile asteroids - initial

a) Grid-like distribution of 2.5 m boulders;
b) Random distribution of 2.5 m boulders;
c) Random distribution of boulders between 2 and 10 m.



DART-like impacts on spherical rubble-pile asteroids – after ≈ 2 h

a) Grid-like distribution of 2.5 m boulders;
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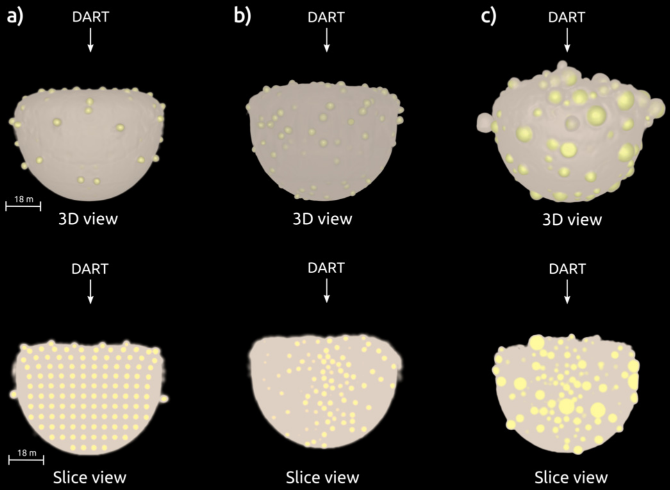
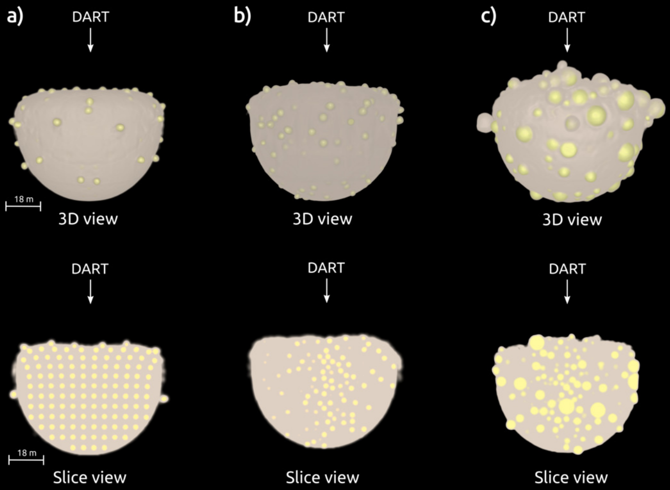
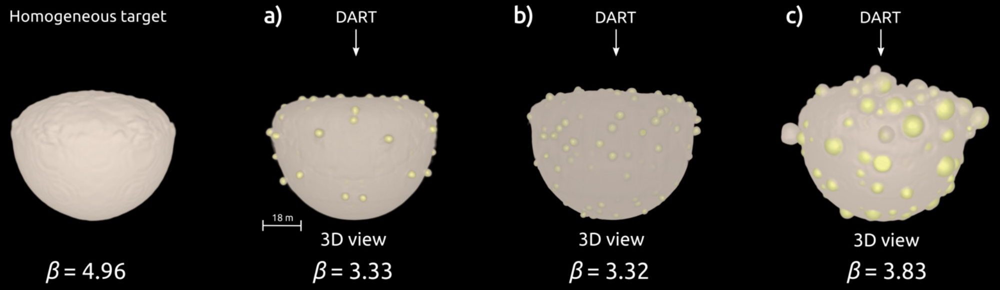


DART-like impacts on spherical rubble-pile asteroids – after ≈ 2 h

Homogeneous target



The boulder size-distribution influences the deflection efficiency, β



Conclusions

- The DART mission may impact a rubble-pile asteroid. We need laboratory experiments purposely designed to mimic asteroid surfaces;
- SPH simulations of impacts into heterogeneous targets show great agreement with laboratory experiment results;
- The DART impact on cohesionless spherical bodies is likely to produce morphologies that are dissimilar to cratering and change the global morphology of the asteroid;
- DART-like impact simulations on rubble-pile asteroids show that both the target morphology and the momentum transfer are affected by the distribution of surface boulders.

Acknowledgements

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