Deflecting rubble-pile asteroids: Lessons learned from the DART impact on Dimorphos

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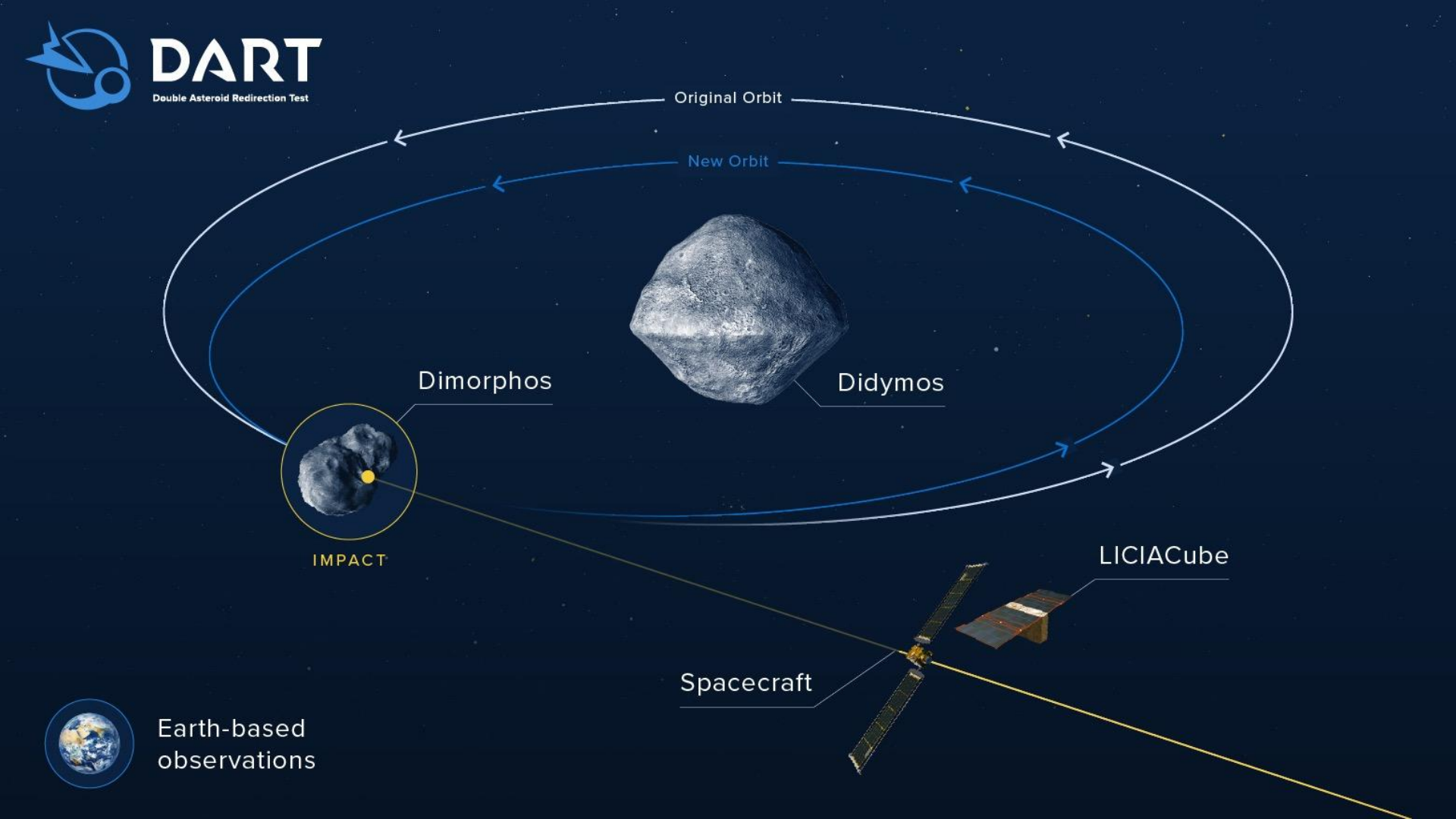
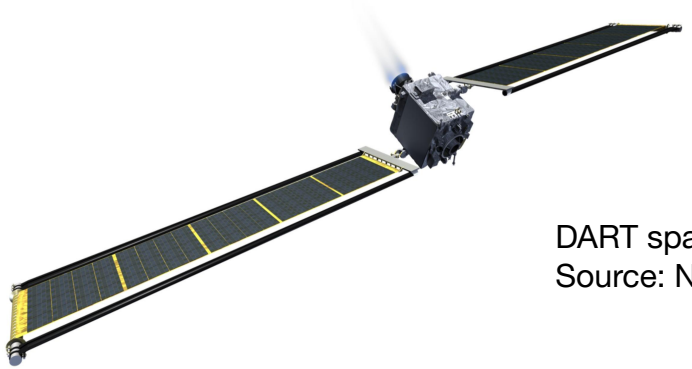

DART
Double Asteroid Redirection Test
Original Orbit
New Orbit
Dimorphos
Didymos
IMPACT
LICIACube
Spacecraft
Earth-based
observations

We didn’t know Dimorphos’s material properties

Target properties

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

Impact conditions



DART spacecraft.
Source: NASA.

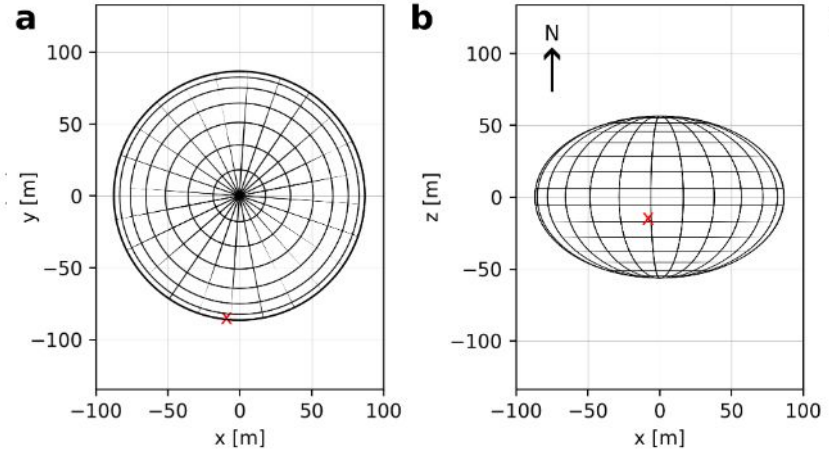
- Impact velocity – known
- Impact angle – known
- Impactor mass/shape – known

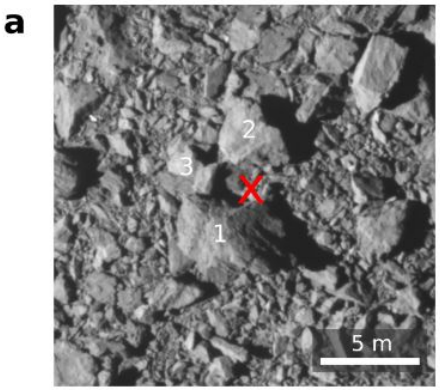
We used Bern SPH to simulate the DART impact on rubble-pile targets

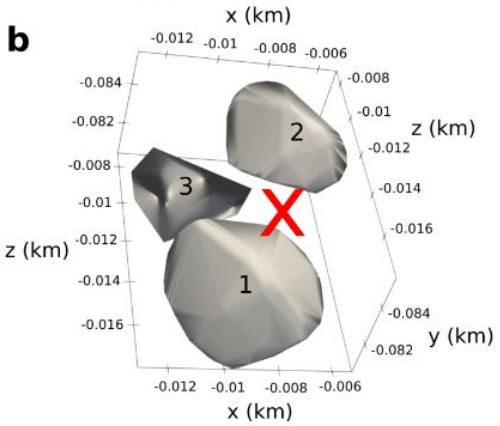
We used Dimorphos's shape and the impact site characterisation

Projectile: 579.4 kg, at 6.1449 km/s

1 - Atabaque Saxum
2 - Bodhran Saxum
3 - Caccavella Saxum

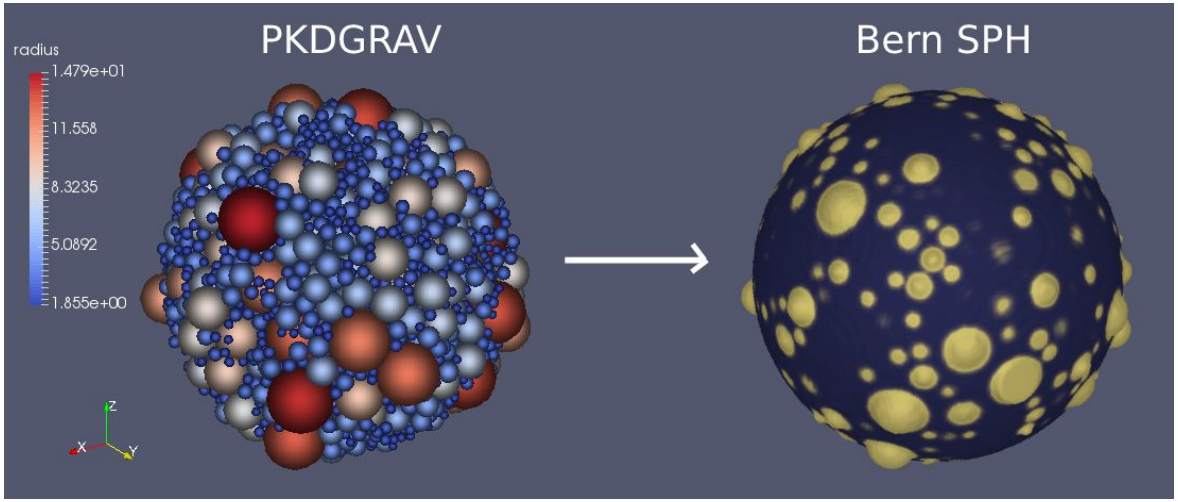


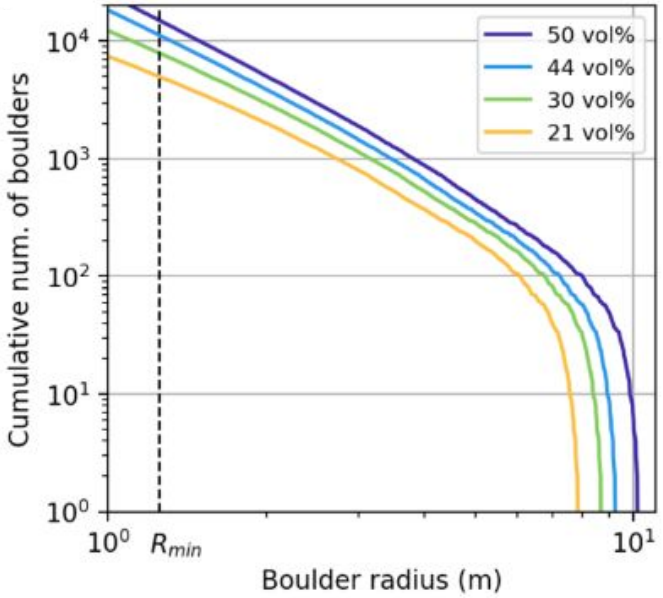




Daly et al., 2023 (Nature)

We used pkdgrav to generate rubble-pile shapes as inputs for Bern SPH



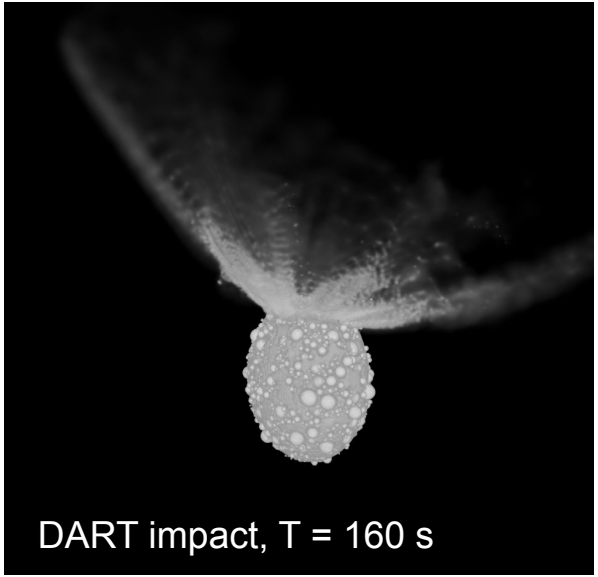


We used Bern SPH to simulate the DART impact

Boulder tensile strength, Y_T = 10 MPa
Boulder porosity, 10%

We systematically varied target material properties:

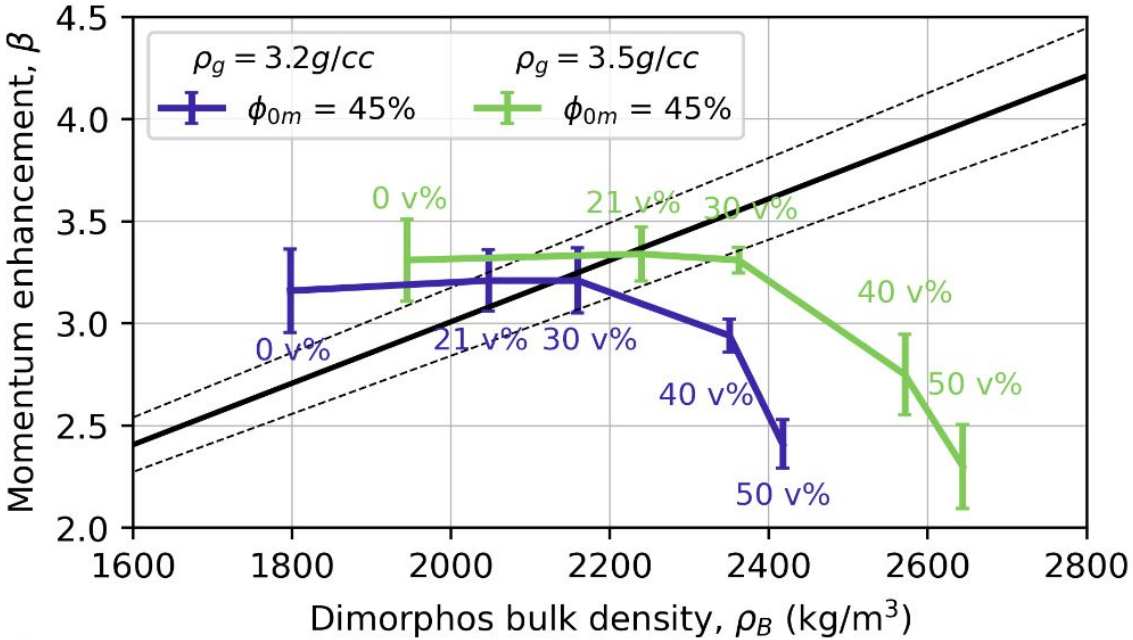
Boulder volume fraction, 0 – 50 vol%
Matrix cohesion, Y_0 = 0 – 50 Pa
Matrix porosity, 45%



We track the impact outcome to up to 2 hours after the impact and compare the outcome with the observations.

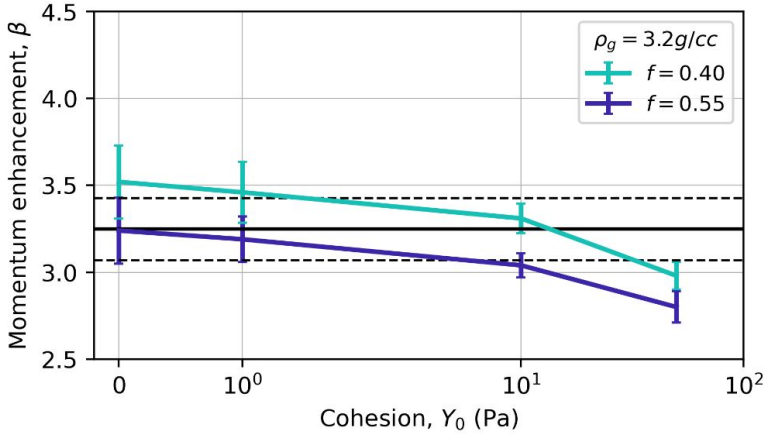
Finding 1: The surface boulder packing is low (<40 vol%)

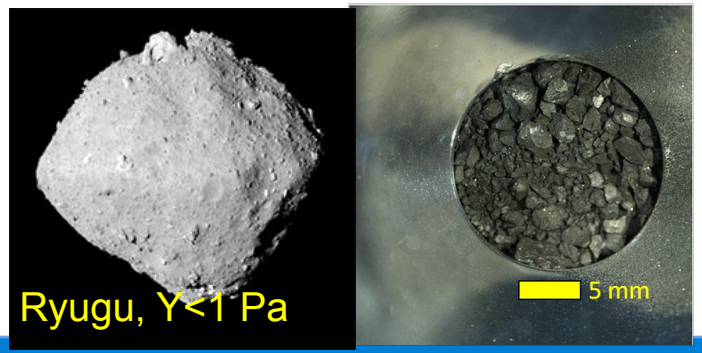
(of boulders larger than 2.5 m)

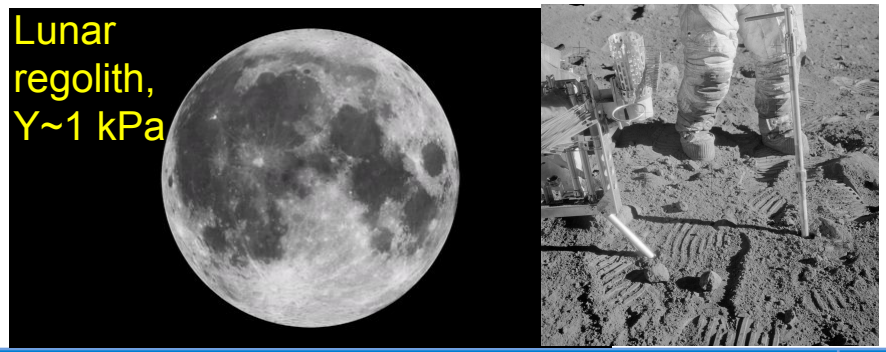


Constant volume ~ 0.00181 km^3

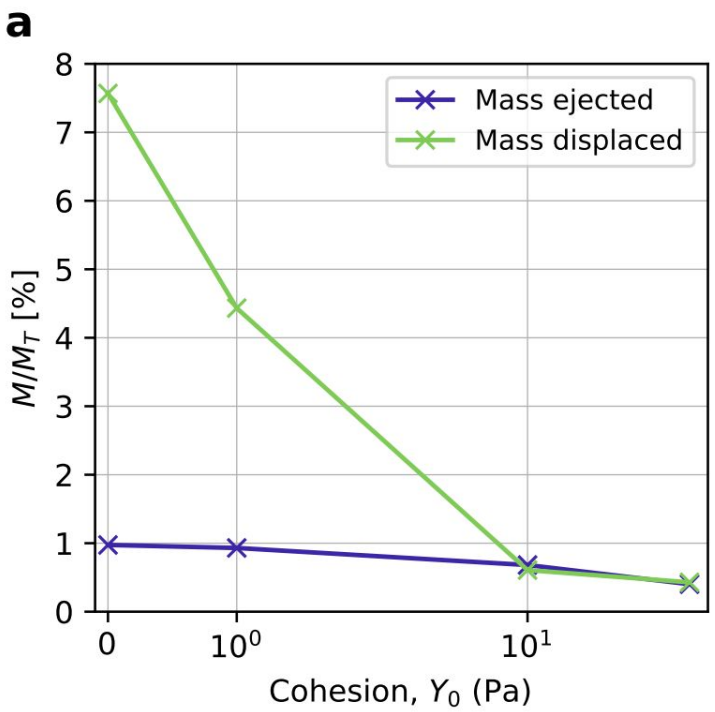
Finding 2: The surface/shallow sub-surface cohesion is less than 50 Pa. Best fit, Y < 1Pa







Finding 3: More than 0.3% and up to 1% of Dimorphos's mass was ejected – consistent with early observations



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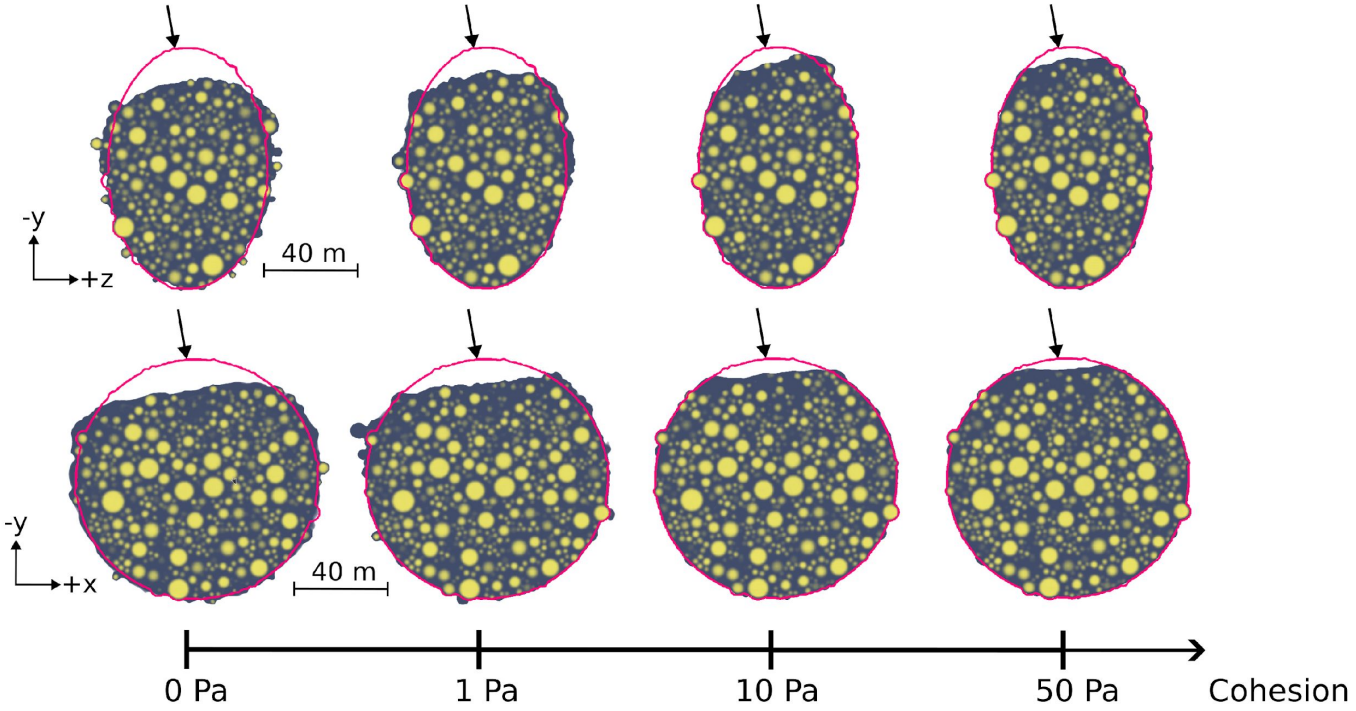
Article | Published: 01 March 2023

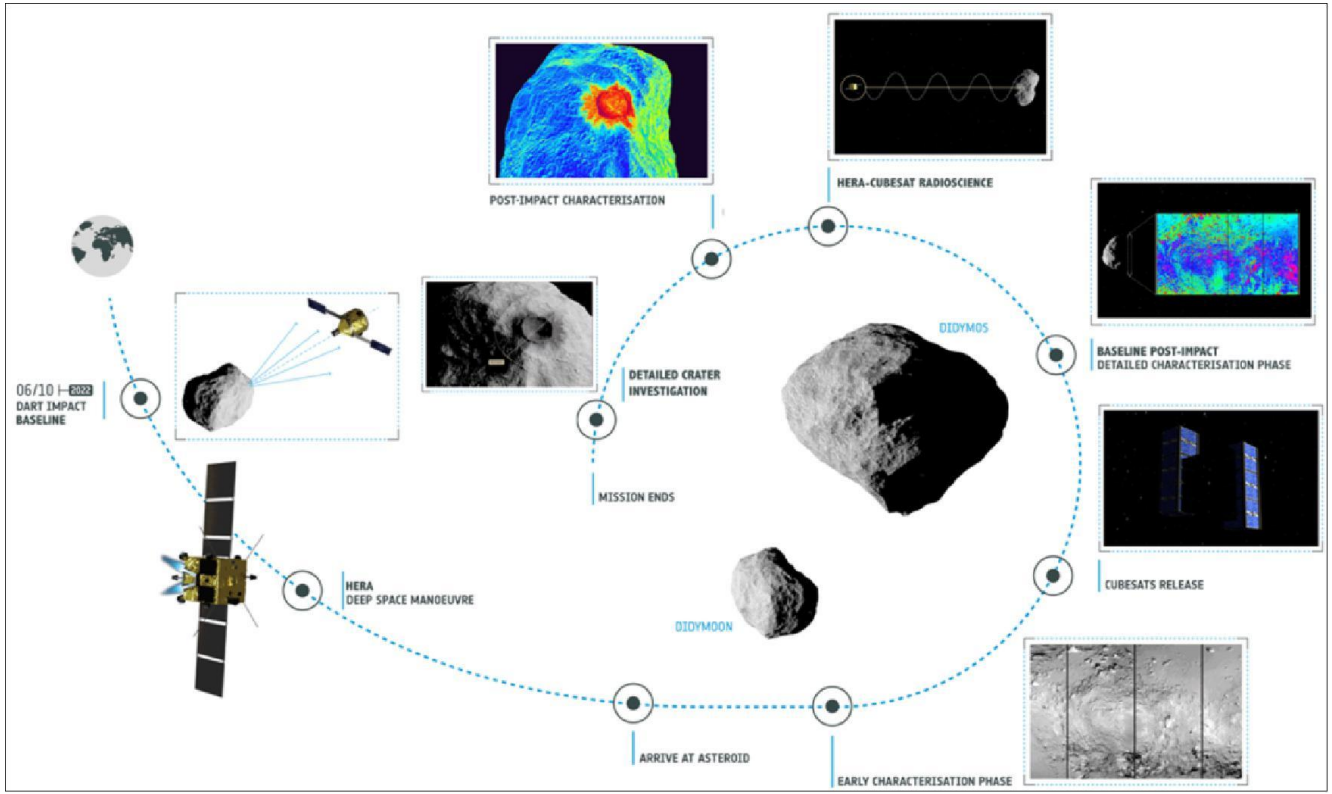
Light Curves and Colors of the Ejecta from Dimorphos after the DART Impact

Ariel Graykowski, Ryan A. Lambert, Franck Marchis, Dorian Cazeneuve, Paul A. Dalba, Thomas M. Esposito, Daniel O'Conner Peluso, Lauren A. Sgro, Guillaume Blaclard, Antonin Borot, Arnaud Malvache, Laurent Marfisi, Tyler M. Powell, Patrice Huet, Matthieu Limagne, Bruno Payet, Colin Clarke, Susan Murabana, Daniel Chu Owen, Ronald Wasilwa, Keiichi Fukui, Tateki Goto, Bruno Guillet, Patrick Huth, … Ian M. Transom + Show authors

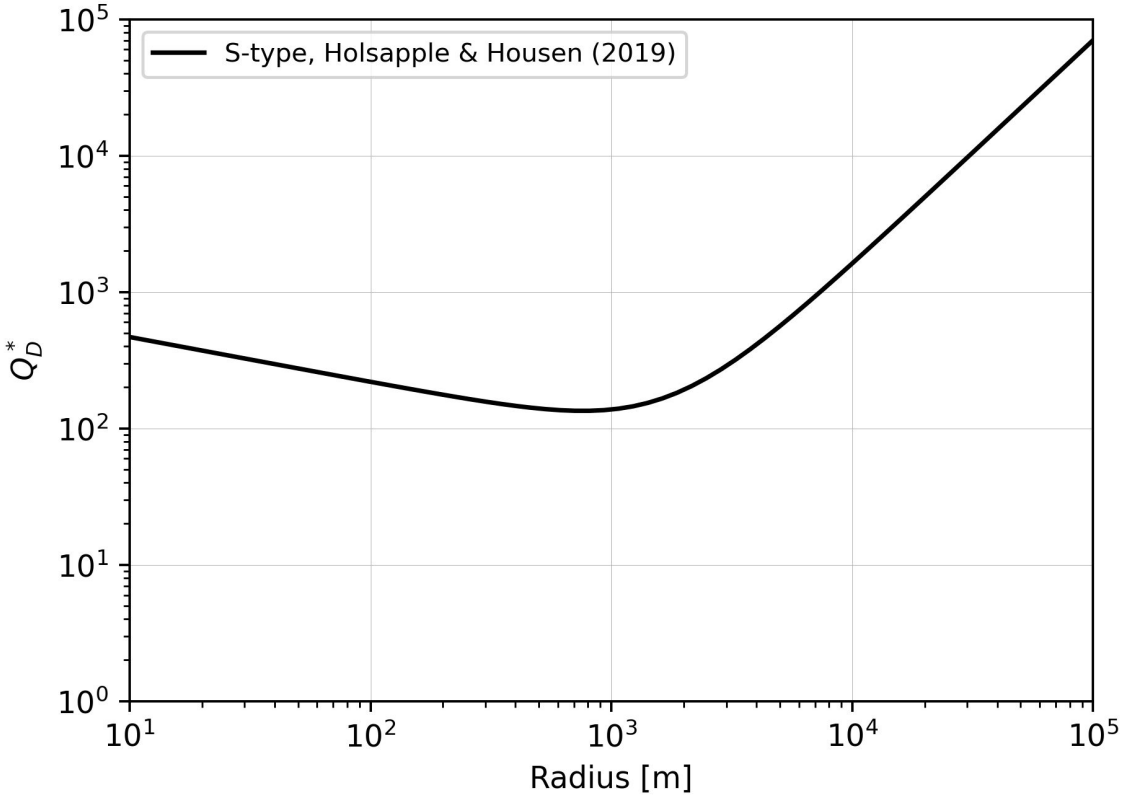
DART impact occurred in the sub-catastrophic regime and may have caused the global deformation of Dimorphos



Our models provide testable predictions that will be studied by ESA's Hera mission

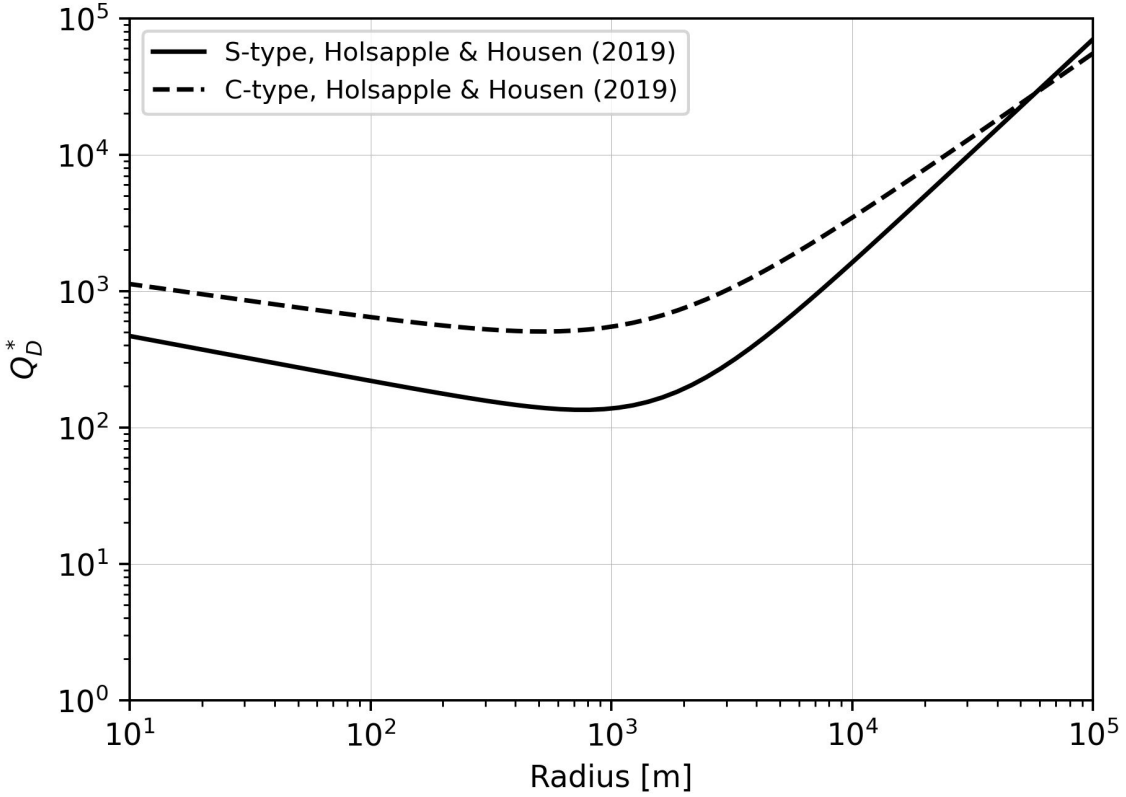


Catastrophic catastrophic disruption threshold for asteroids



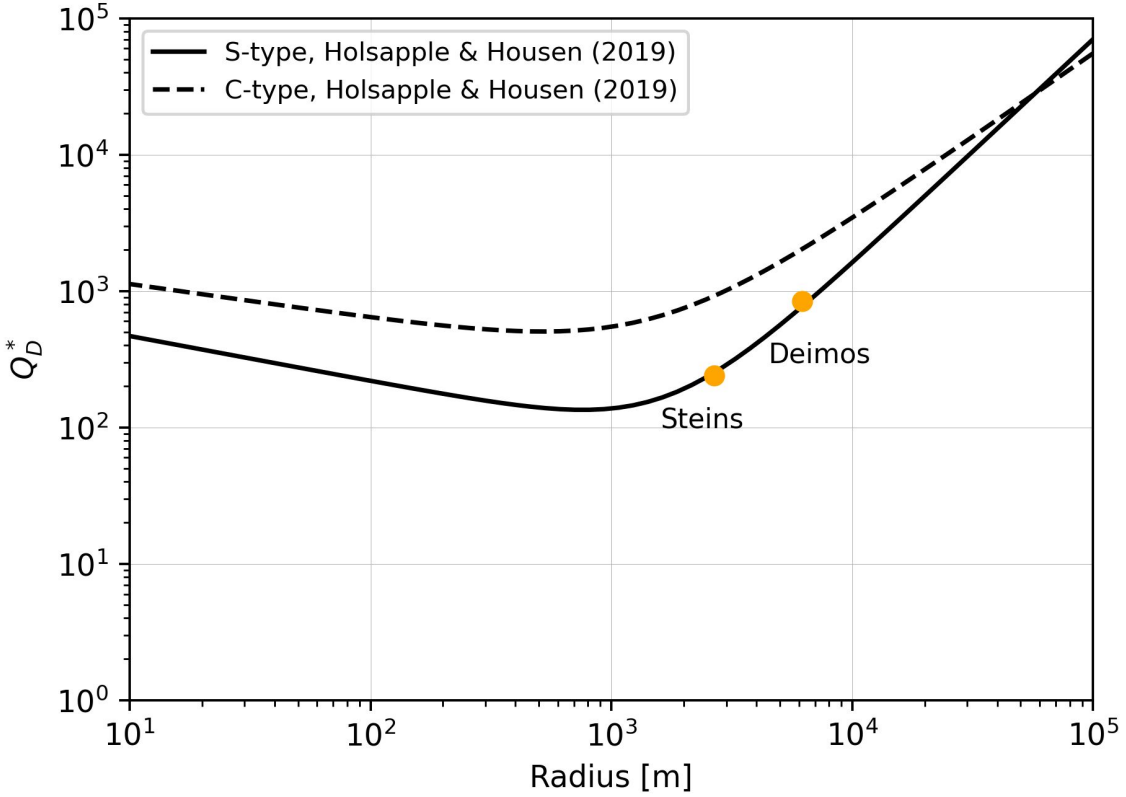
- Q^*_D curve for rocky S-type asteroids, at 5.5 km/s and 45º

Catastrophic catastrophic disruption threshold for asteroids



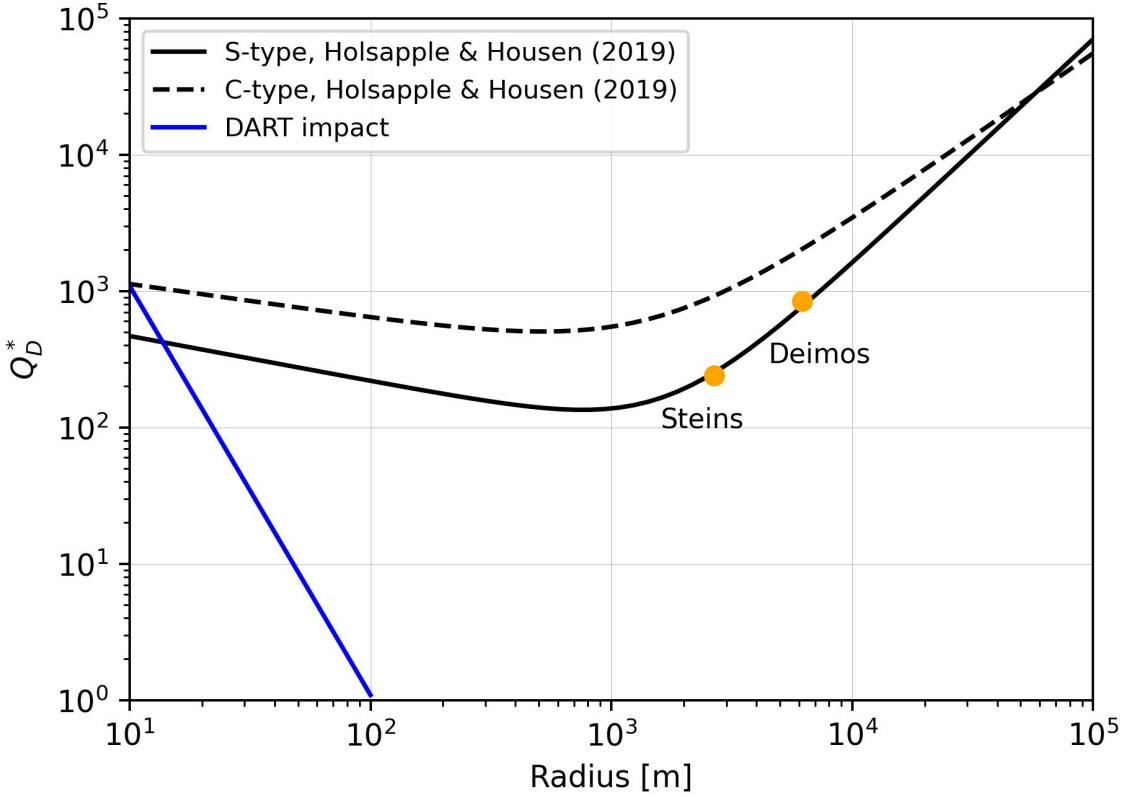
- Q^*_D curve for rocky S-type asteroids, at 5.5 km/s and 45º
- Q^*_D curve for porous C-type asteroids, at 5.5 km/s and 45º

Catastrophic catastrophic disruption threshold for asteroids



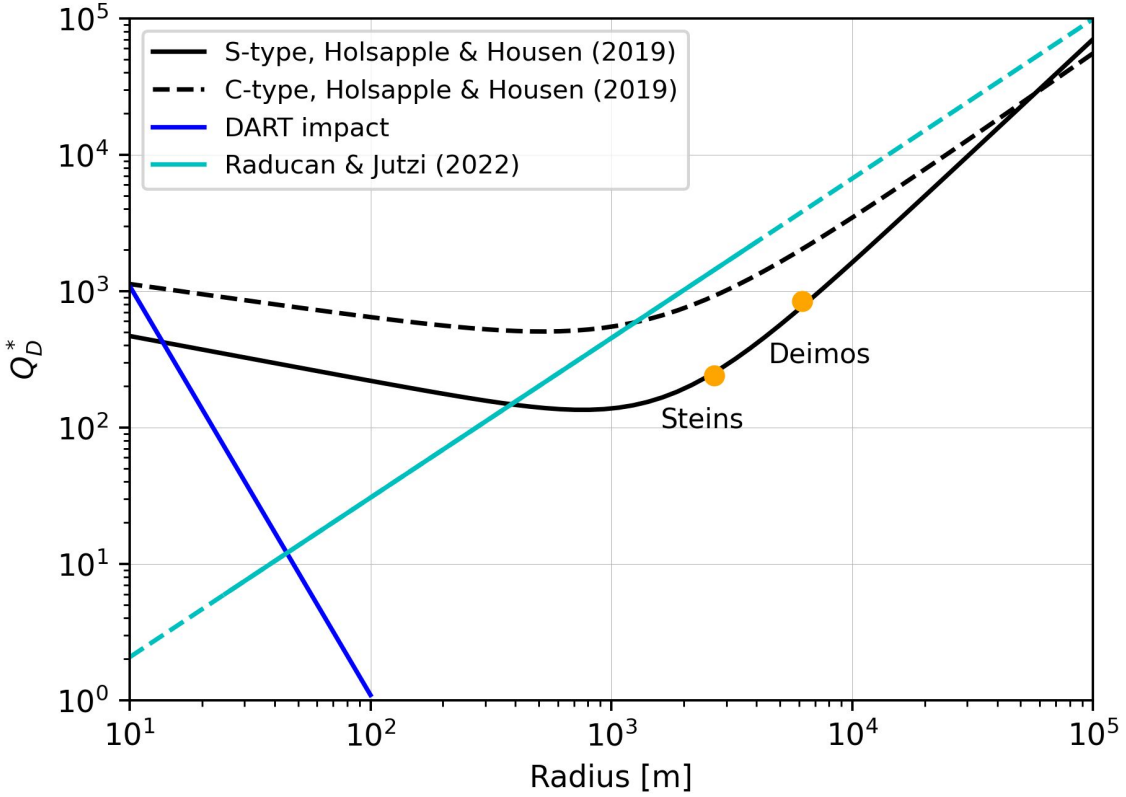
- Q^*_D curve for rocky S-type asteroids, at 5.5 km/s and 45º
- Q^*_D curve for porous C-type asteroids, at 5.5 km/s and 45º

Catastrophic catastrophic disruption threshold for asteroids



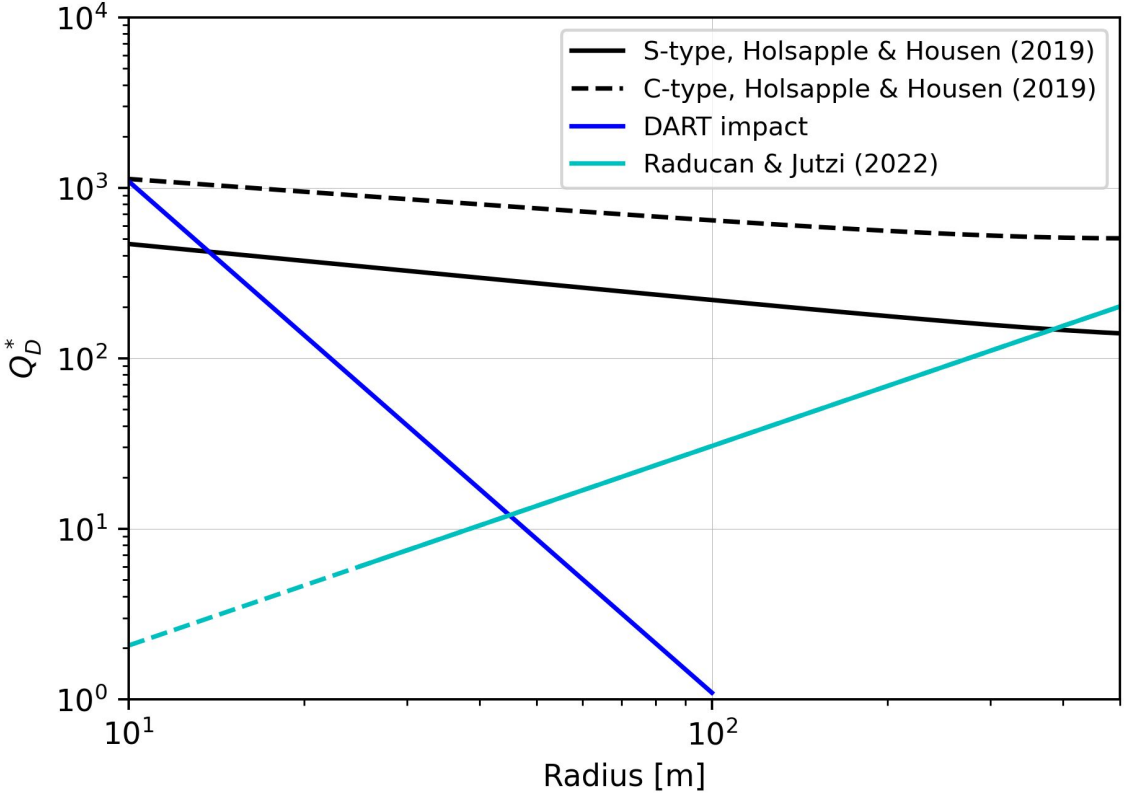
- Q^*_D curve for rocky S-type asteroids, at 5.5 km/s and 45º
- Q^*_D curve for porous C-type asteroids, at 5.5 km/s and 45º
- Specific impact energy for DART

Catastrophic catastrophic disruption threshold for asteroids

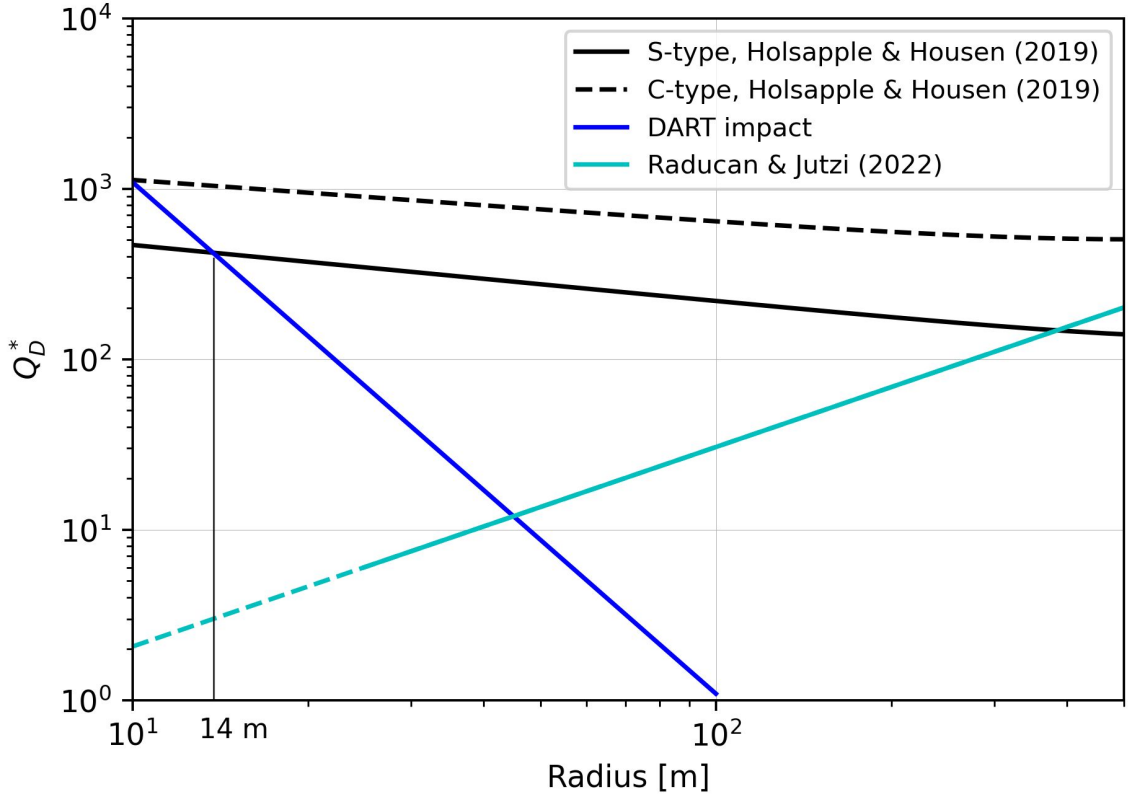


- Q^*_D curve for rocky S-type asteroids, at 5.5 km/s and 45º
- Q^*_D curve for porous C-type asteroids, at 5.5 km/s and 45º
- Specific impact energy for DART
- Q^*_D curve for homogeneous, cohesionless asteroids

Catastrophic catastrophic disruption threshold for asteroids

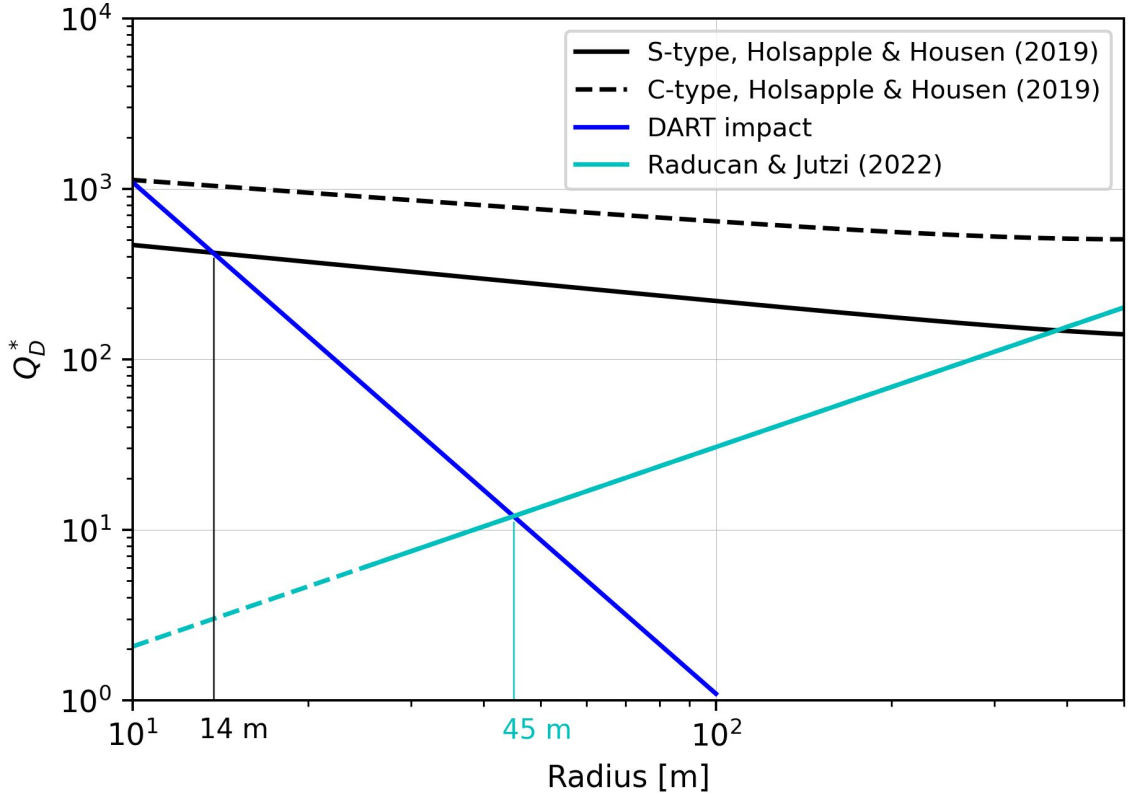


Catastrophic catastrophic disruption threshold for asteroids



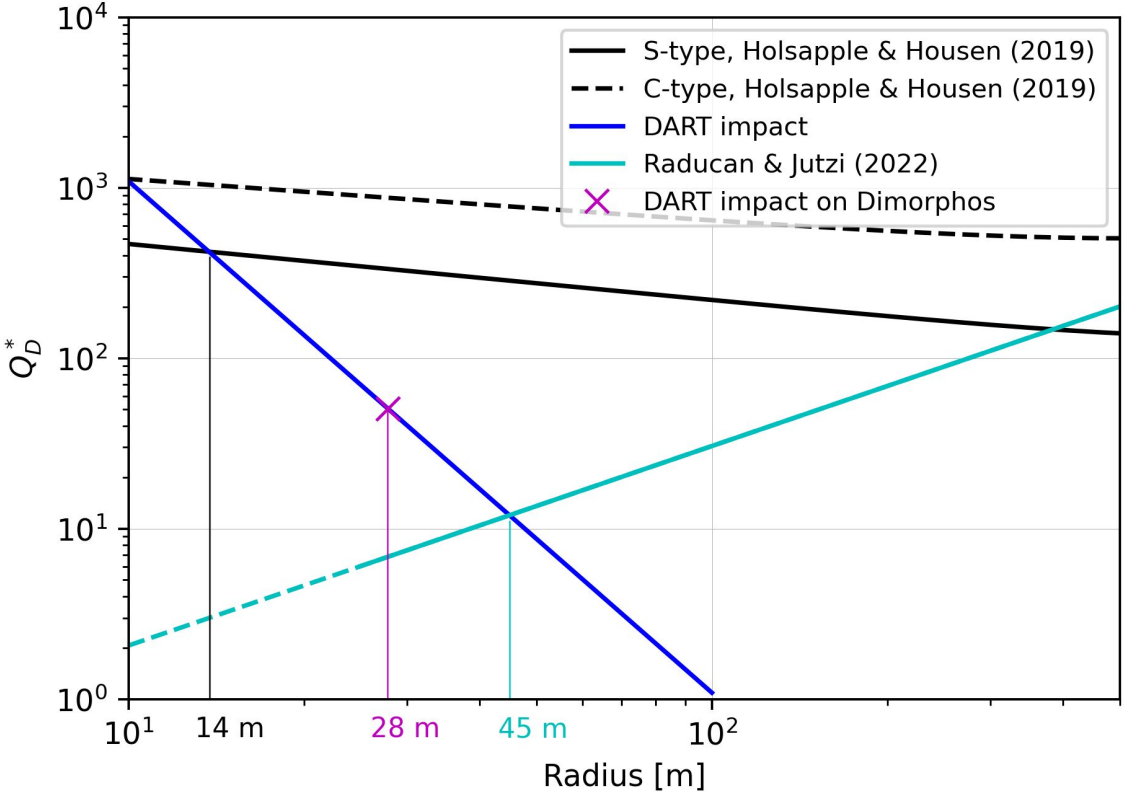
- A DART-like spacecraft would disrupt a <28 m (diameter) S-type monolith

Catastrophic catastrophic disruption threshold for asteroids



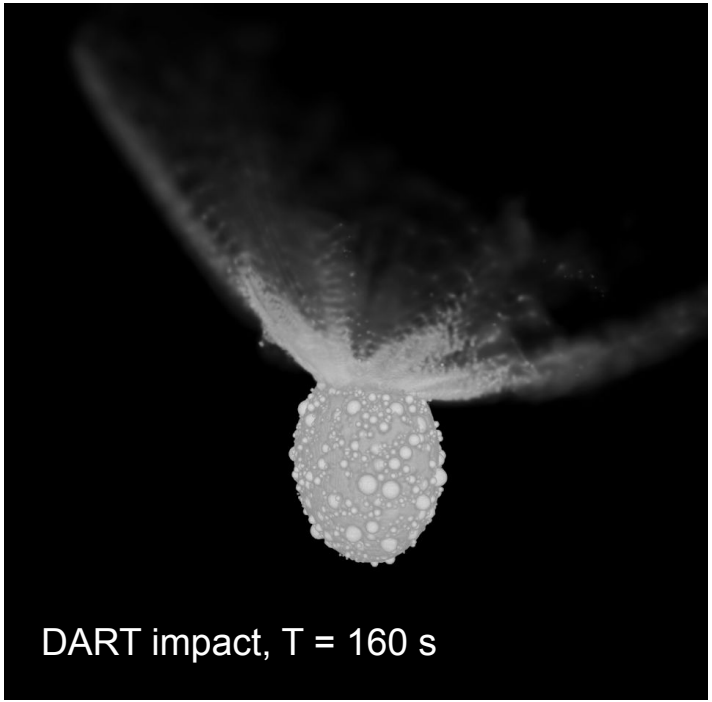
- A DART-like spacecraft would disrupt a <28 m (diameter) S-type monolith
- A DART-like spacecraft would disrupt a <90 m cohesionless, homogeneous target

A DART spacecraft would catastrophically disrupt a rubble-pile asteroid smaller than ~56 m across

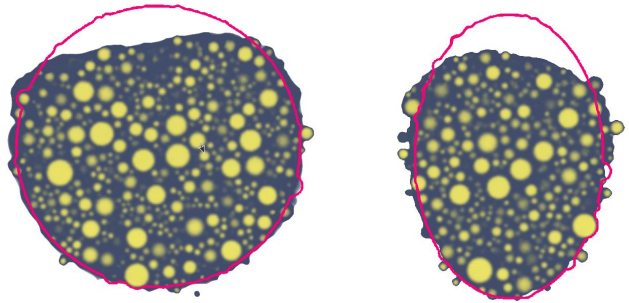


- A DART-like spacecraft would disrupt a 28 m (diameter) S-type monolith
- A DART-like spacecraft would disrupt a <90 m cohesionless, homogeneous target
- A DART-like spacecraft would disrupt a <56 m Dimorphos

Conclusions



- Dimorphos is a rubble-pile, with a low surface cohesion and a low boulder packing (less than ~40%)
- DART likely caused the deformation and resurfacing of Dimorphos, as opposed to a well defined impact crater
- Our models provide testable predictions that will be studied by ESA's Hera mission in late 2026.
- DO NOT send a DART-sized spacecraft to an asteroid smaller than ~56 m across



Dimorphos,
T = 2 hours