SPH simulations for space defense

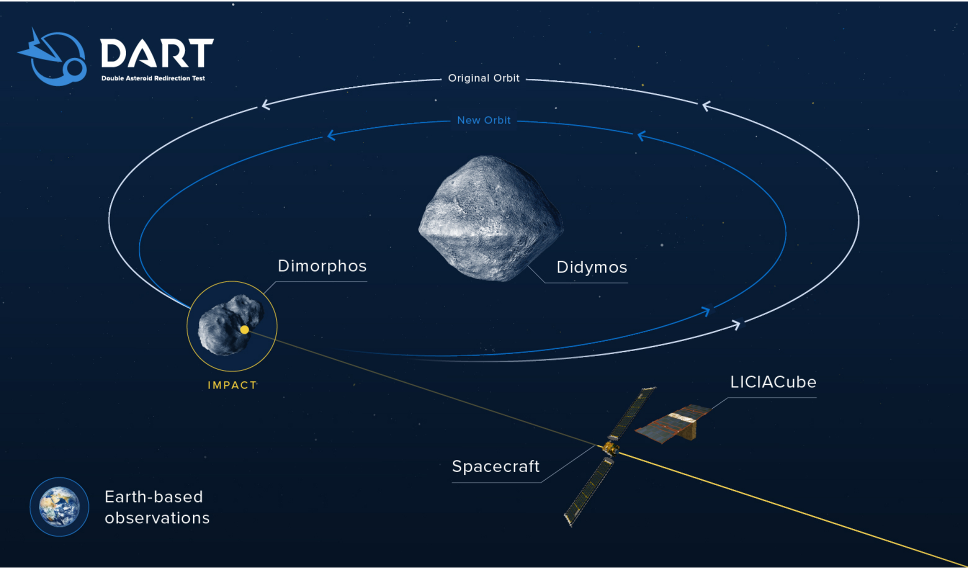
Maximilian Rutz

July 18, 2020

Roadmap

1. Dart and Hera missions
2. SPH setup
3. SPH results

Dart and Hera missions


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

Dart Mission

- Launch in July 2021 on a SpaceX Falcon 9
- Impact in fall 2022
- Impact at 0.04 au to Earth, 15x Earth-Moon, 1/10x Earth-Mars
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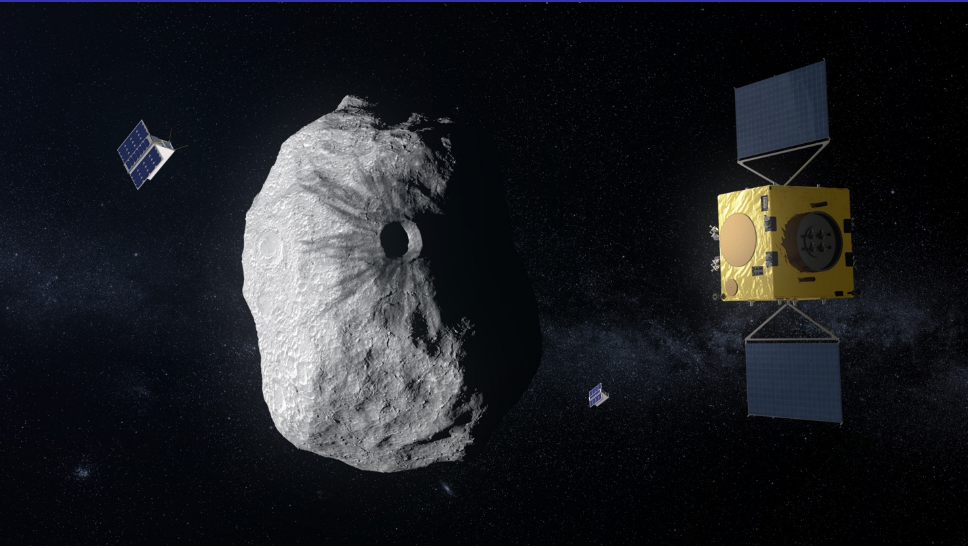

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- Arrival in 2026
- Why a second mission?
  - Dust cloud after impact
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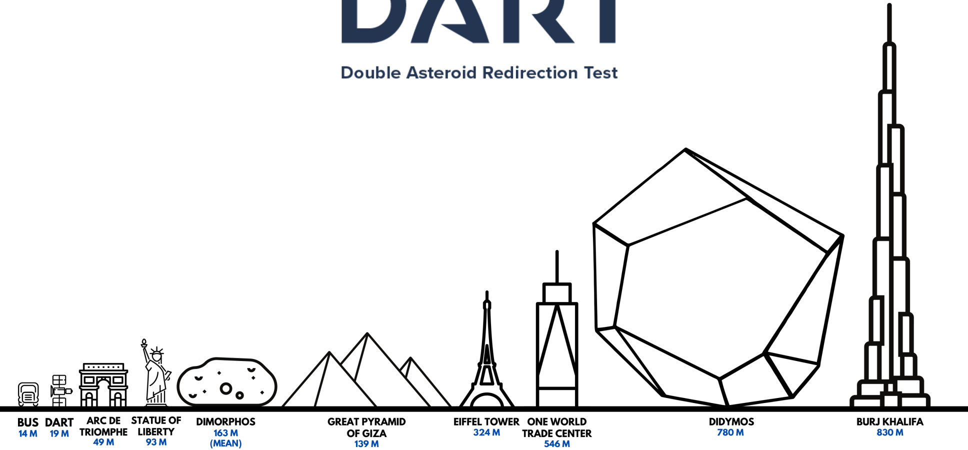
DART

Double Asteroid Redirection Test



SPH setup

Simulation goals

Compare numerical results with observations to:

1. test numerical codes
2. identify target properties through parameter studies

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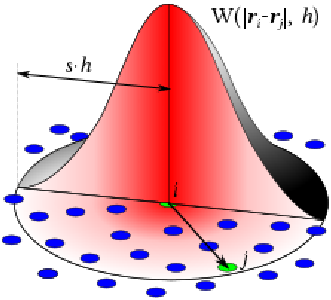
Smoothed Particle Hydrodynamics

- gridfree method
- particles move through space with a velocity
- particles carry physical quantities like density, pressure or energy
- hydrodynamic/continuum mechanics equations can be solved for every particle
- spatial resolution



Simulation scenario

Target:

- 160 meter diameter
- important parameters such as porosity and strength unknown

Impactor:

- 500 kg mass
- 6 km/s impact velocity
- main body 1.3 x 1.2 x 1.2 meter

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Miluphcuda solid models

- fragmentation for brittle materials
- p-α porosity model
- shear strength
- no self gravity

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Initial conditions

IMAGE 1st frame

Initial conditions

Target:

- basalt
- 20 meter diameter halfsphere
- constant smoothing length in center

Impactor:

- aluminum
- 0.75 meter diameter sphere
- 6 km/s impact velocity
- 500 kg mass
- same smoothing length as center of target

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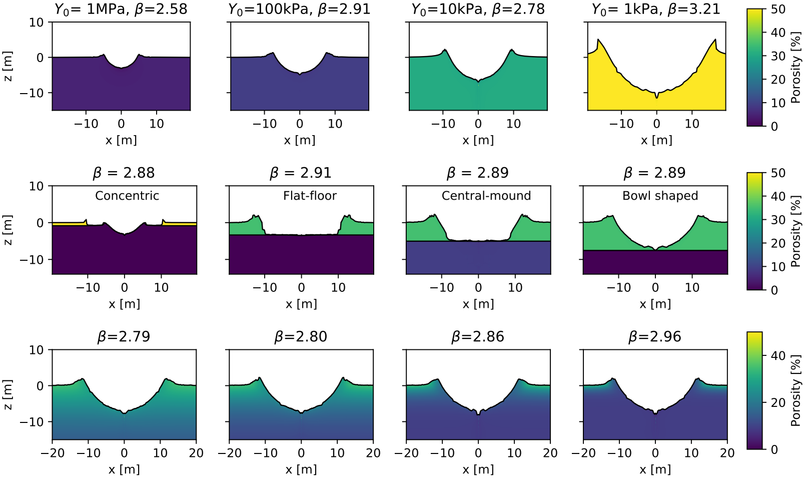
SPH results

Beta factor

Momentum change because of ejecta: $\beta = 1 + \frac{p_{ejecta}}{p_{impactor}}$

The DART impact into different targets can produce the same β, but different craters.

Measurements of **both** β and crater size/morphology **together** can be diagnostic of target properties.



Raducan et al. (2020), PSS

Beta factor other literature Stickle

Table 1. Results from Spheral calculations for material with various compositions

Material	Porosity	Strength	Density g/cm^3	Δv (cm/s)	β
Granite	0.2	1 MPa	2.16	0.099	1.353
Basalt	0.2	1 MPa	2.16	0.102	1.391
Pumice	0.2	1 MPa	2.16	0.093	1.277
Granite	0.4	1 MPa	1.62	0.126	1.288

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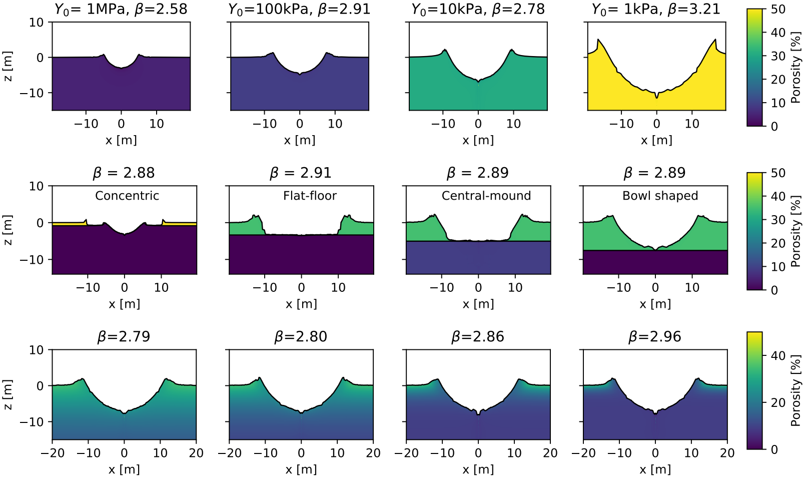

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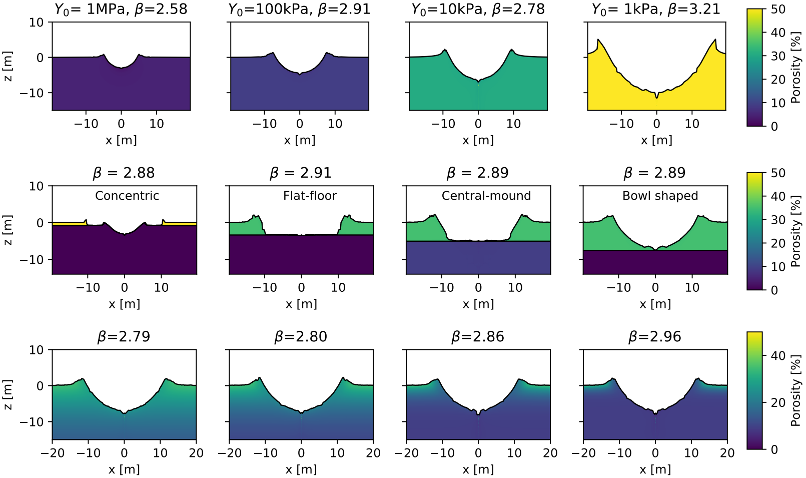

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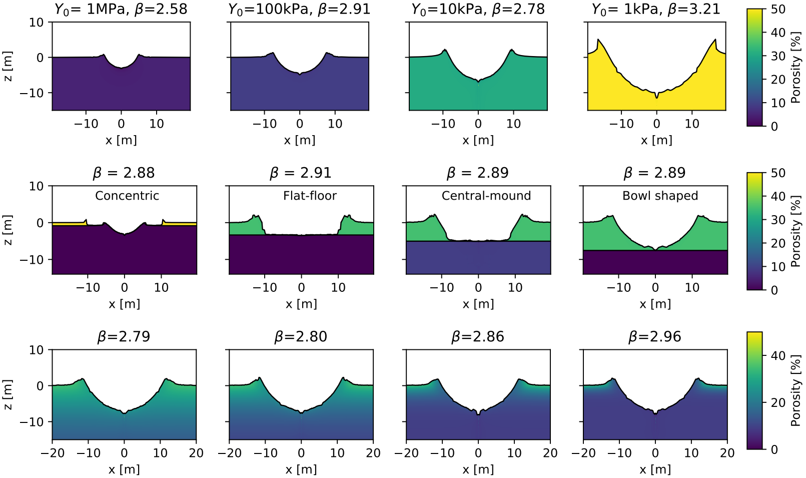

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Personal observations about SPH

- A lot of individual physics implementable
- interaction between physical models within a code can get complex
- Many different codes available
- Difficult to reproduce and compare results between different codes
- Dart setup could be useful as benchmark for solid models

Sources and additional information

Illustrations taken from Dart and Hera websites:

- https://dart.jhuapl.edu/
- https://www.nasa.gov/planetarydefense/dart
- https://www.esa.int/Safety_Security/Hera

Papers:

- "Modeling impact outcomes for the Double Asteroid Redirection Test (DART) mission", Stickle et al., Procedia Engineering 2017
- "The role of asteroid strength, porosity and internal friction in impact momentum transfer", Raducan et al., Icarus 2019