Numerical modelling of the DART impact and the importance of the Hera mission

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IARC Impacts & Astromaterials Research Centre

Science & Technology Facilities Council

Imperial College London

DART is a kinetic impactor test

DART = Double Asteroid Redirection Test

- S-type double asteroid system
- YORP asteroids $\Longrightarrow$ low cohesion and high porosity
- Diameter of the secondary $\approx$160 m

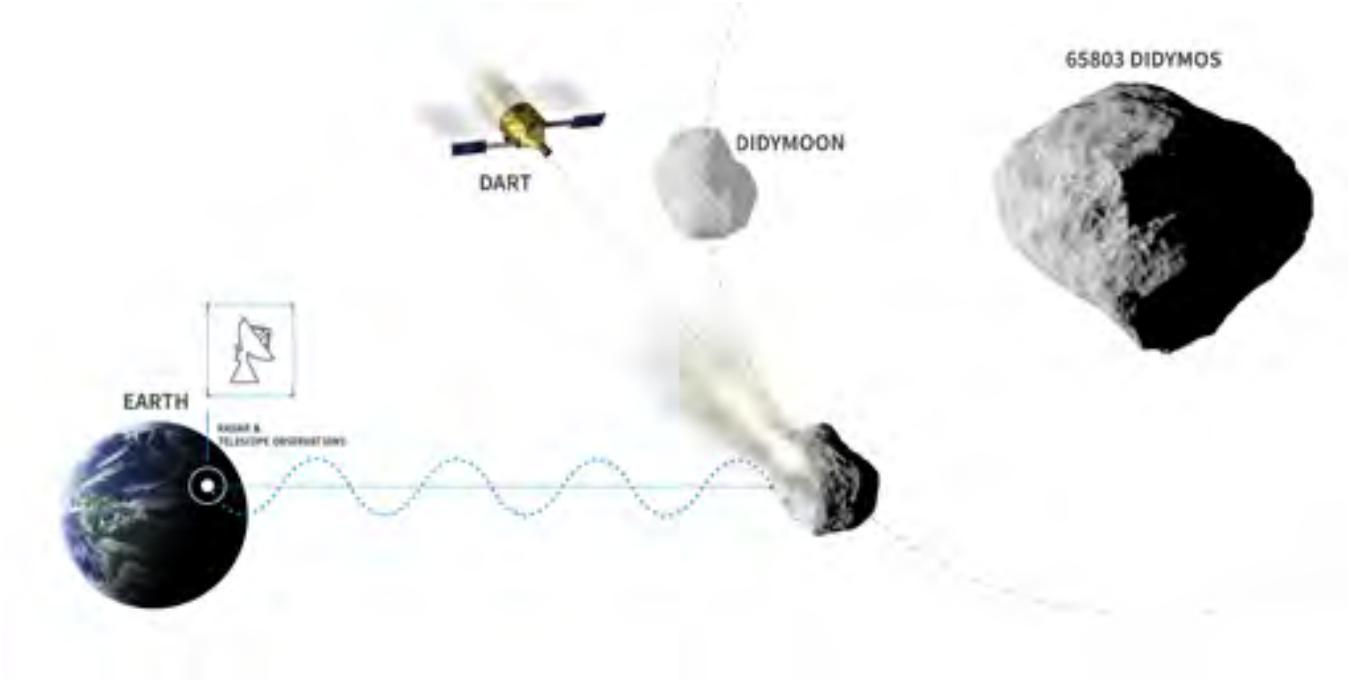

Figure 1: DART mission concept, at the point of impact. Source: ESA.

Crater ejecta provides the momentum enhancement, β

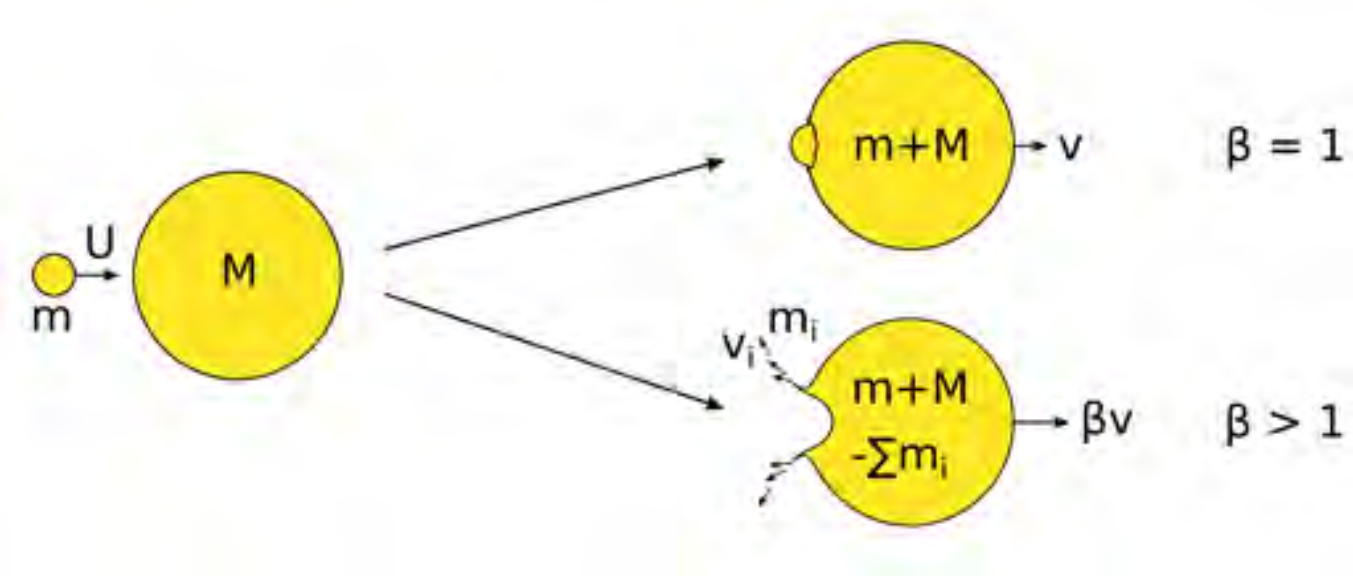

Figure 2: Momentum transfer and two possible outcomes for the β value.

Change in velocity of the asteroid in terms of β (Holsapple and Housen, 2012):

$$\Delta \mathbf{v} = \frac{P_{proj}}{M} \times \beta \tag{1}$$

$$\beta - 1 = \frac{P_{ejecta}}{P_{proj}} \tag{2}$$

Crater ejecta provides the momentum enhancement, β

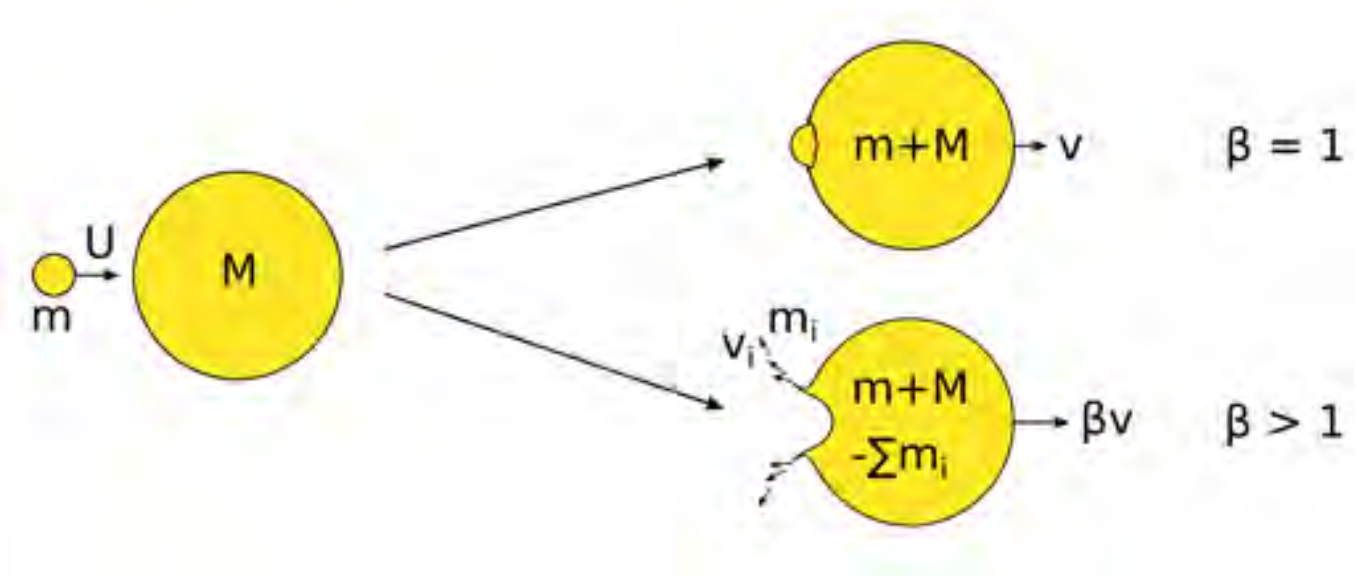

Figure 2: Momentum transfer and two possible outcomes for the β value.

Larger β $\implies$ more deflection!

Change in velocity of the asteroid in terms of β (Holsapple and Housen, 2012):

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iSALE 2D and 3D to simulate the DART impact

Table 1: iSALE input parameters

<——— Projectile parameters ———>				<——- Target parameters ———>		
radius a (m)	mass m (kg)	velocity U (km/s)	density δ (kg/m^3)	strength Y_0 (kPa)	density ρ (kg/m^3)	friction f
0.42	310	7.0	1000	10	2120	0.6

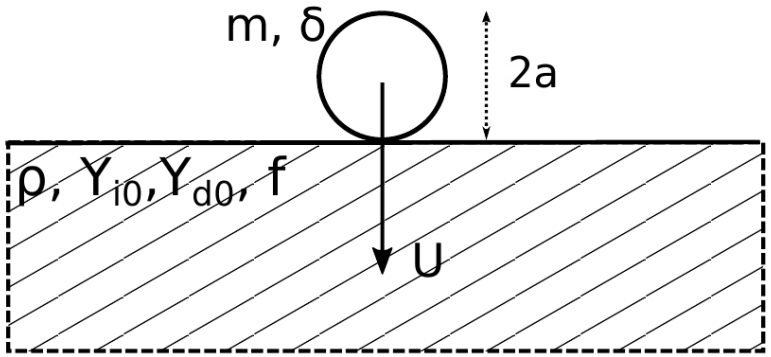

Figure 3: Diagram of the simulation set-up.

The vertical DART crater in 2D vs 3D

$\beta - 1$ = Cumulative ejecta momentum

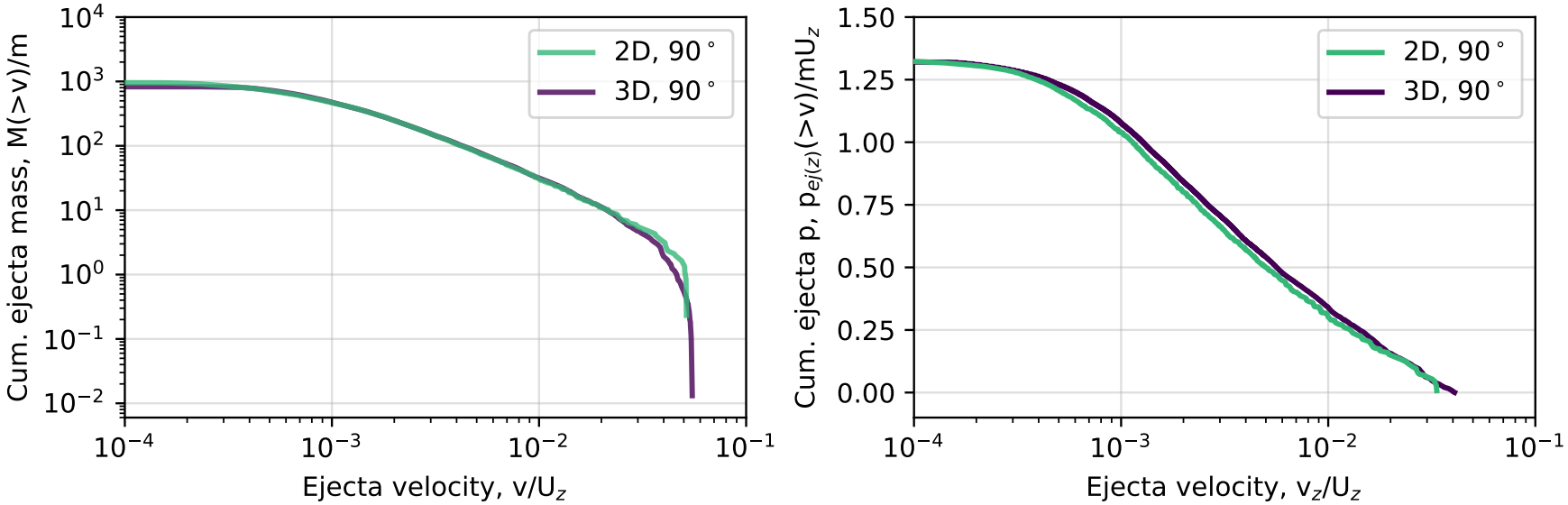

Figure 4: Ejecta distribution of a vertical DART impact modelled in 2D and in 3D.

The 3D DART impact at 90° and 45°

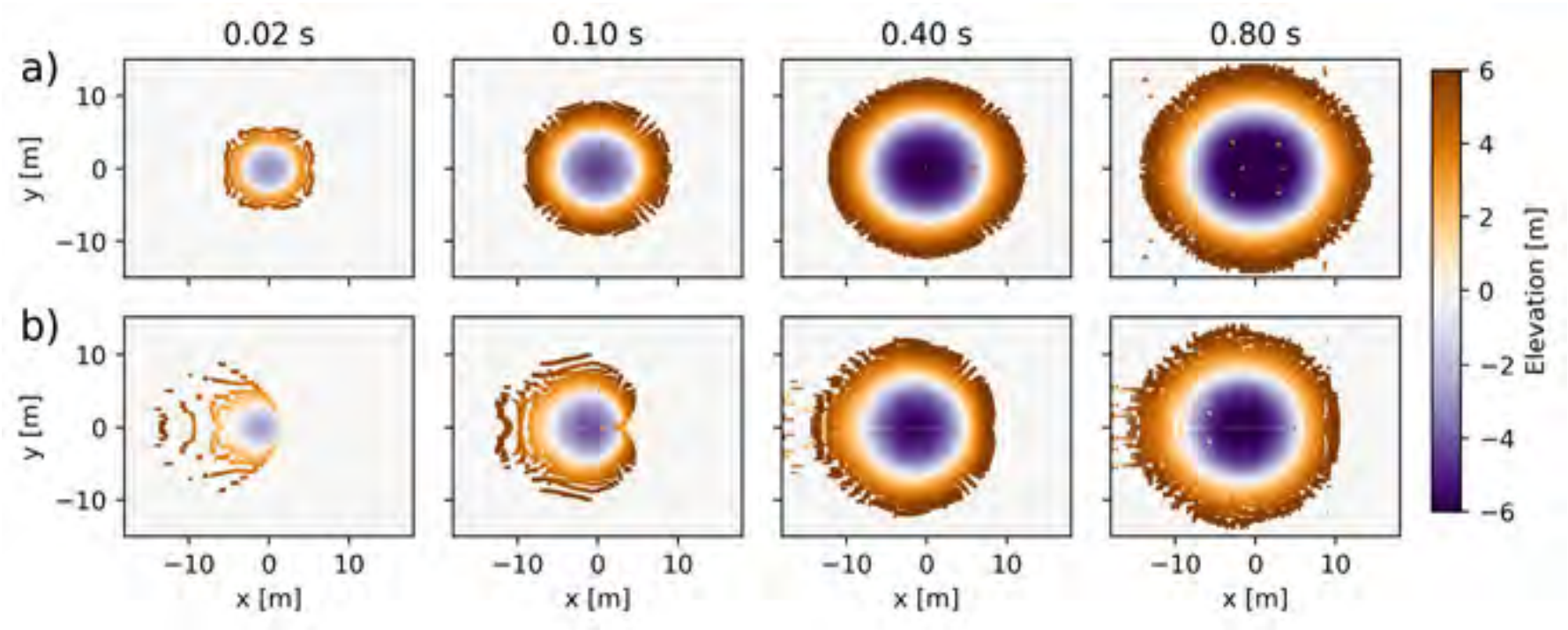

Figure 5: Surface topography of the DART impact at four different times: 0.02 s, 0.10 s, 0.40 s and 0.80 s. 90° and 45° (impact direction is right to left).

$\beta - 1$ from the 90° and the 45° impacts converge

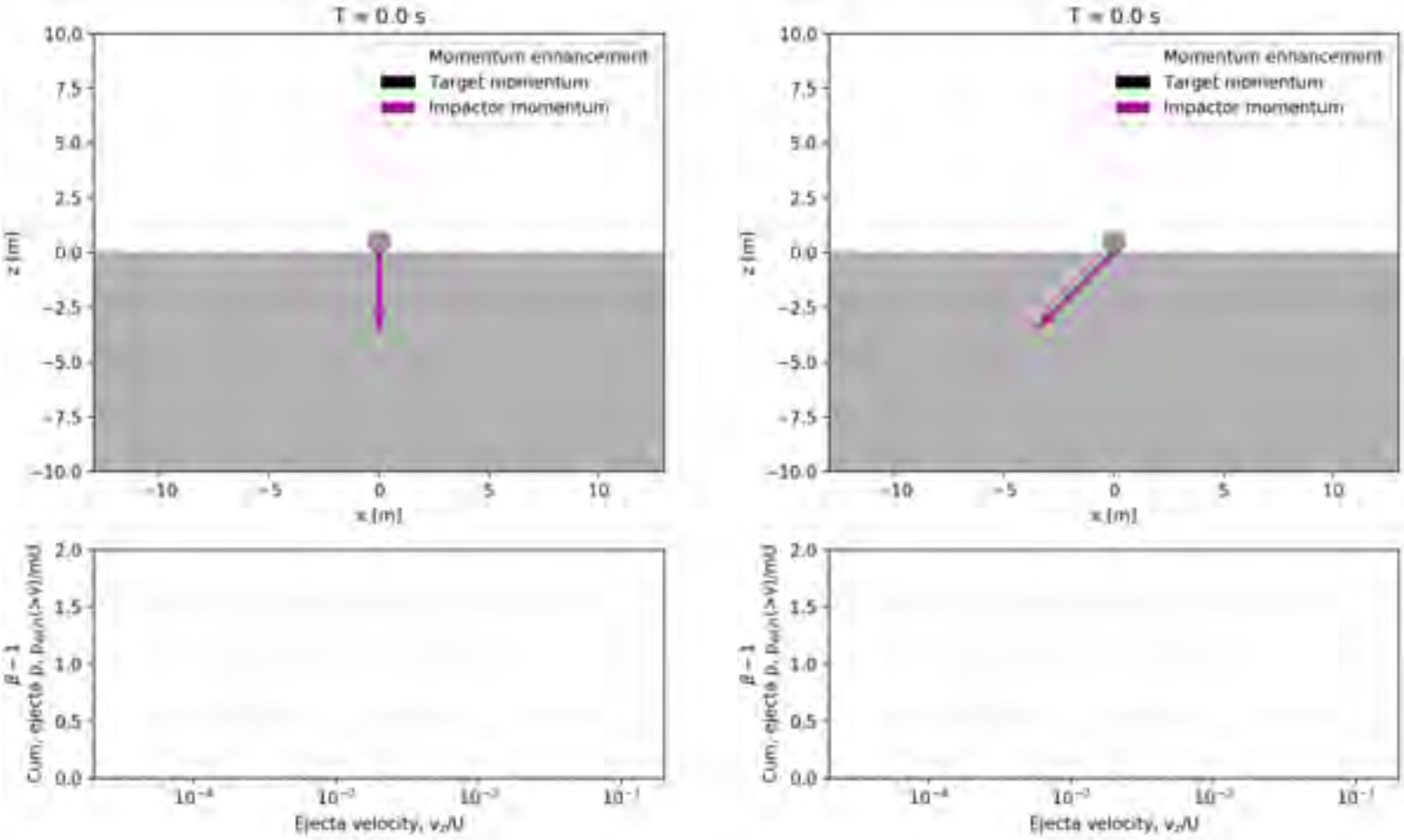

Figure 6: Momentum enhancement, impactor momentum and target momentum vectors.

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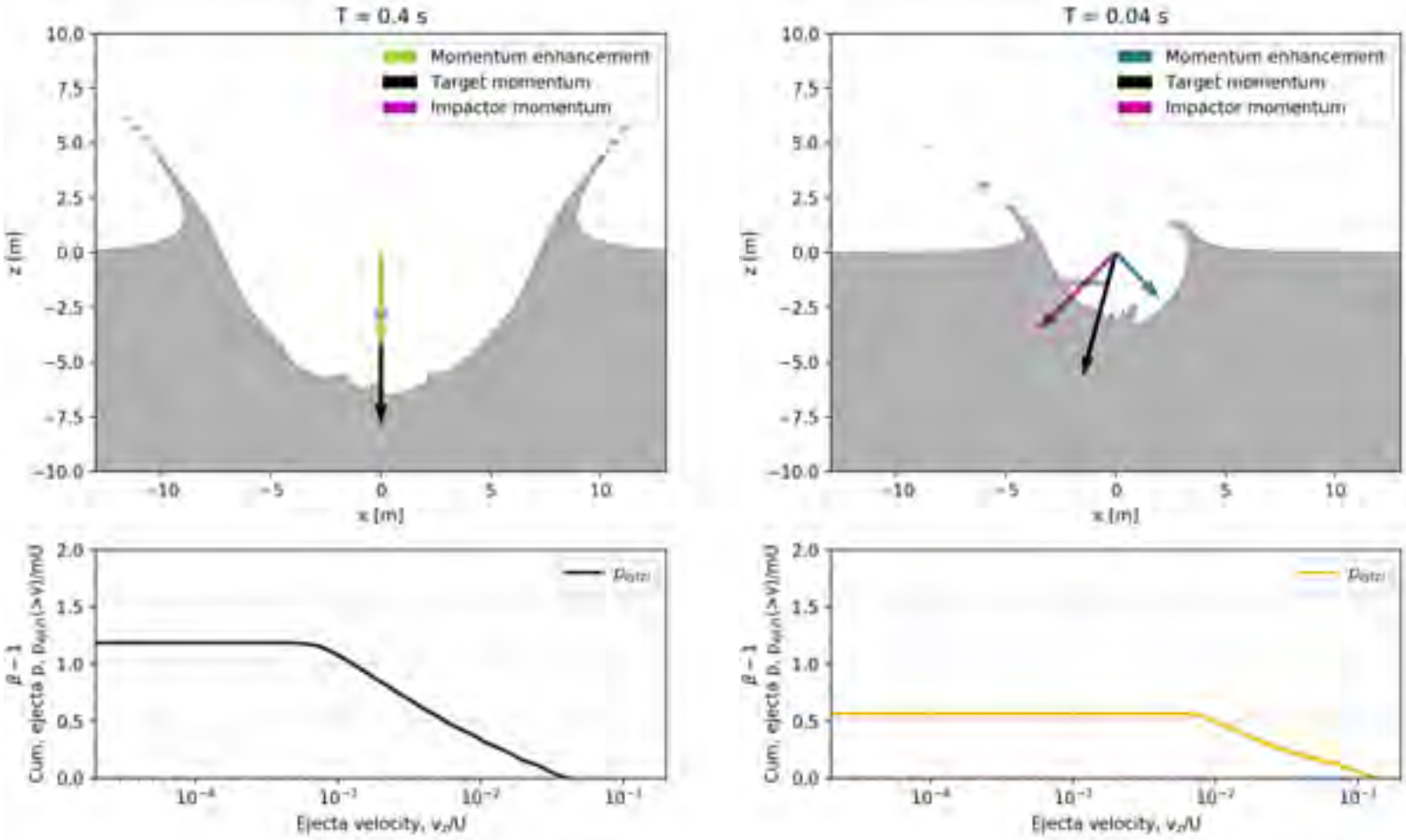

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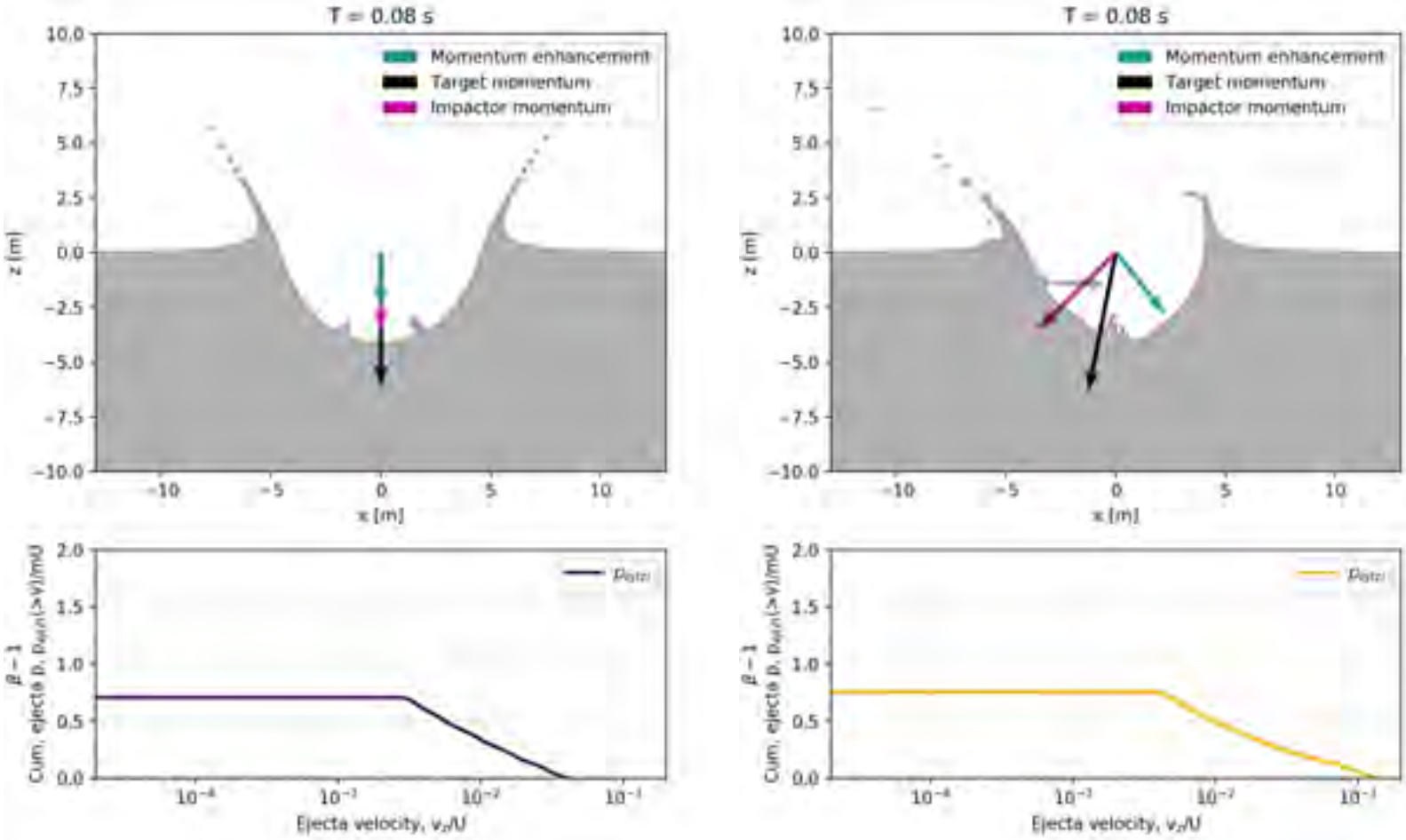

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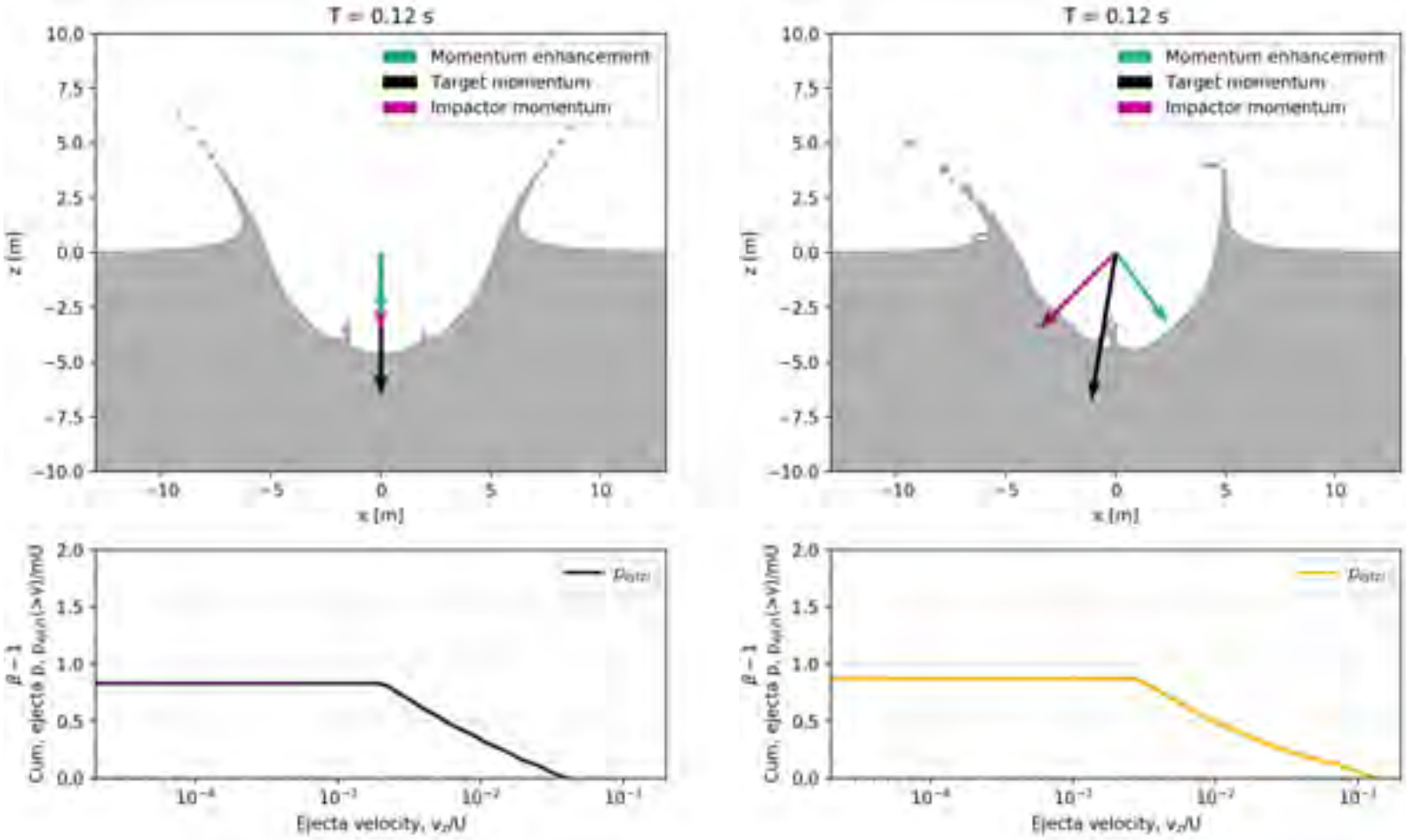

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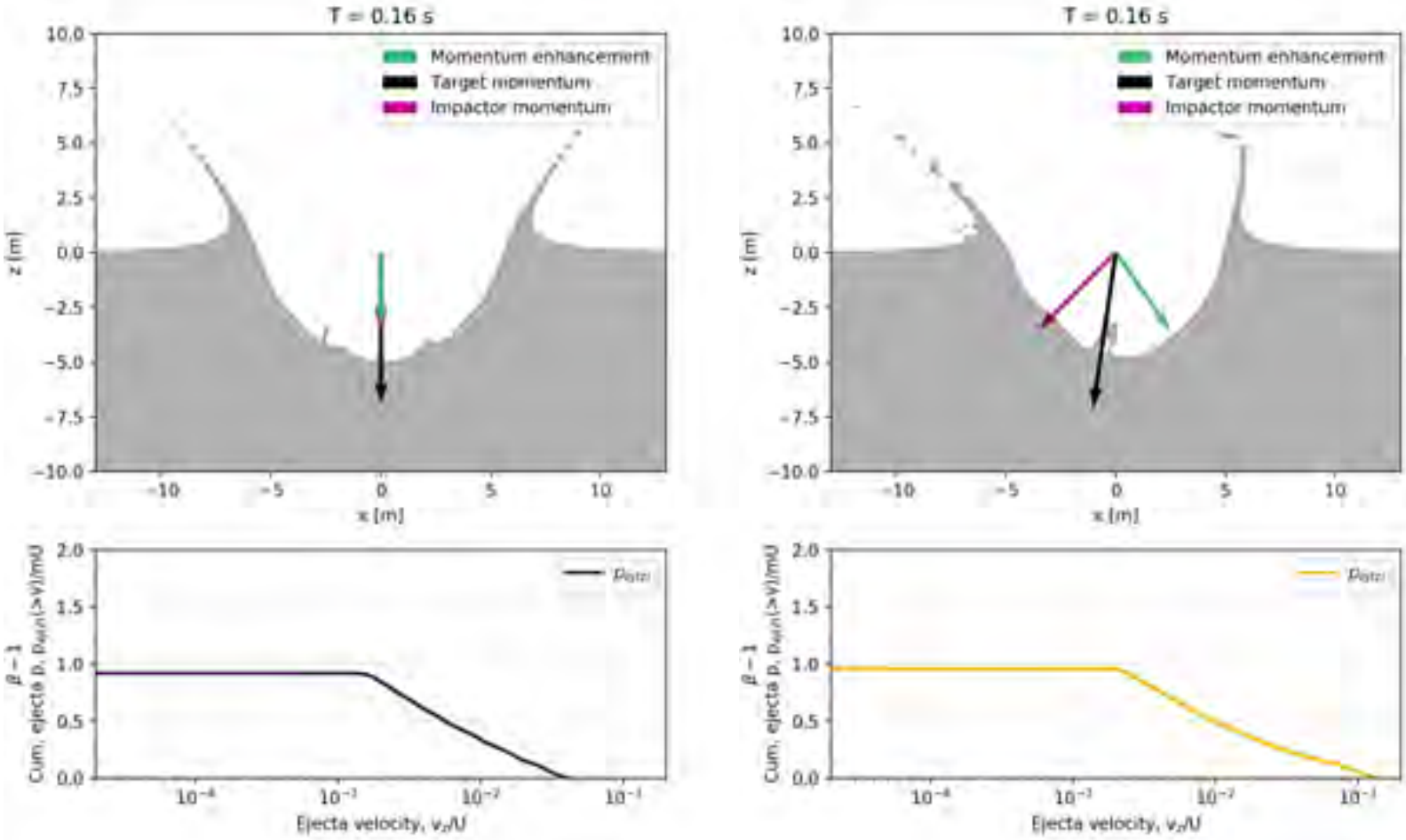

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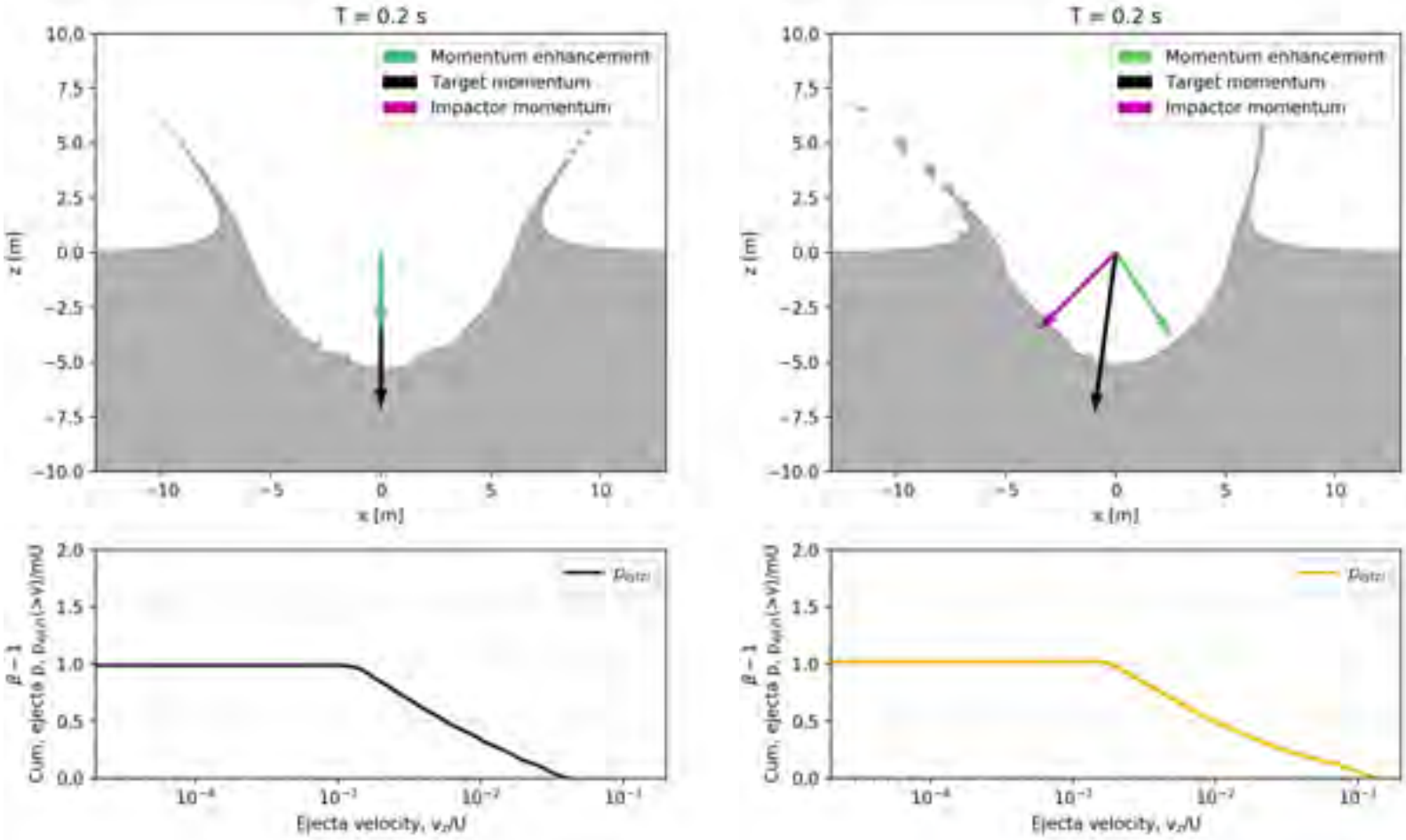

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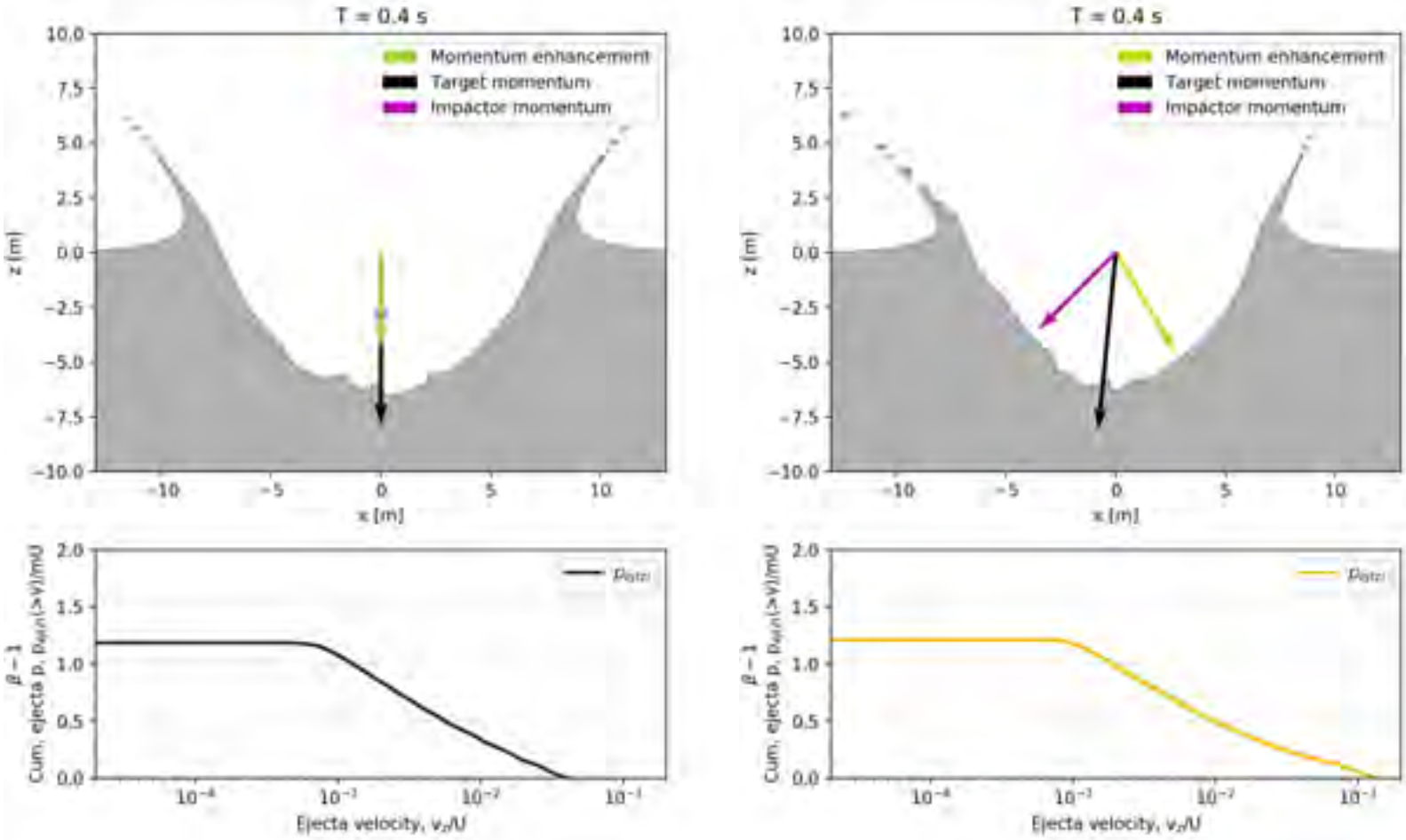

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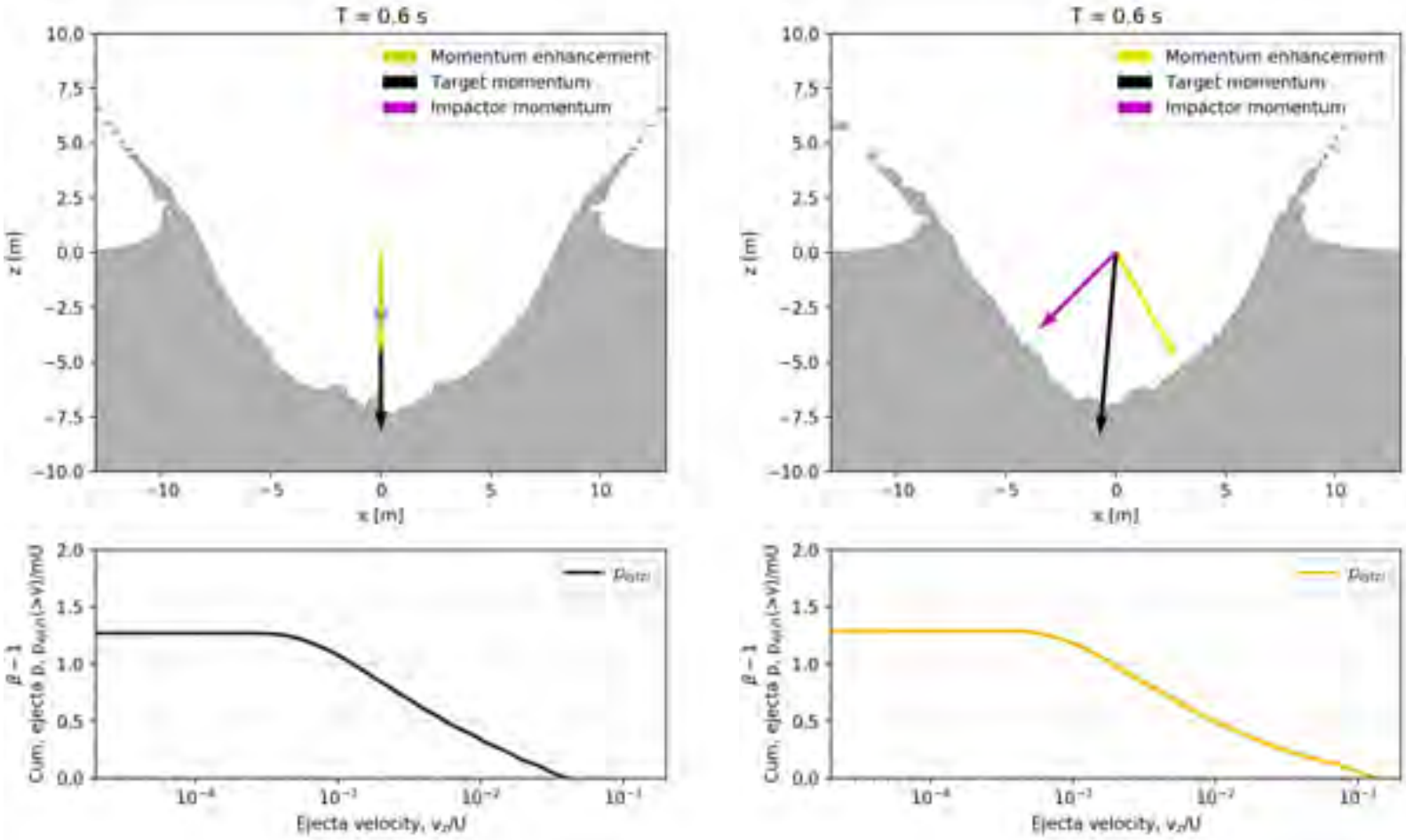

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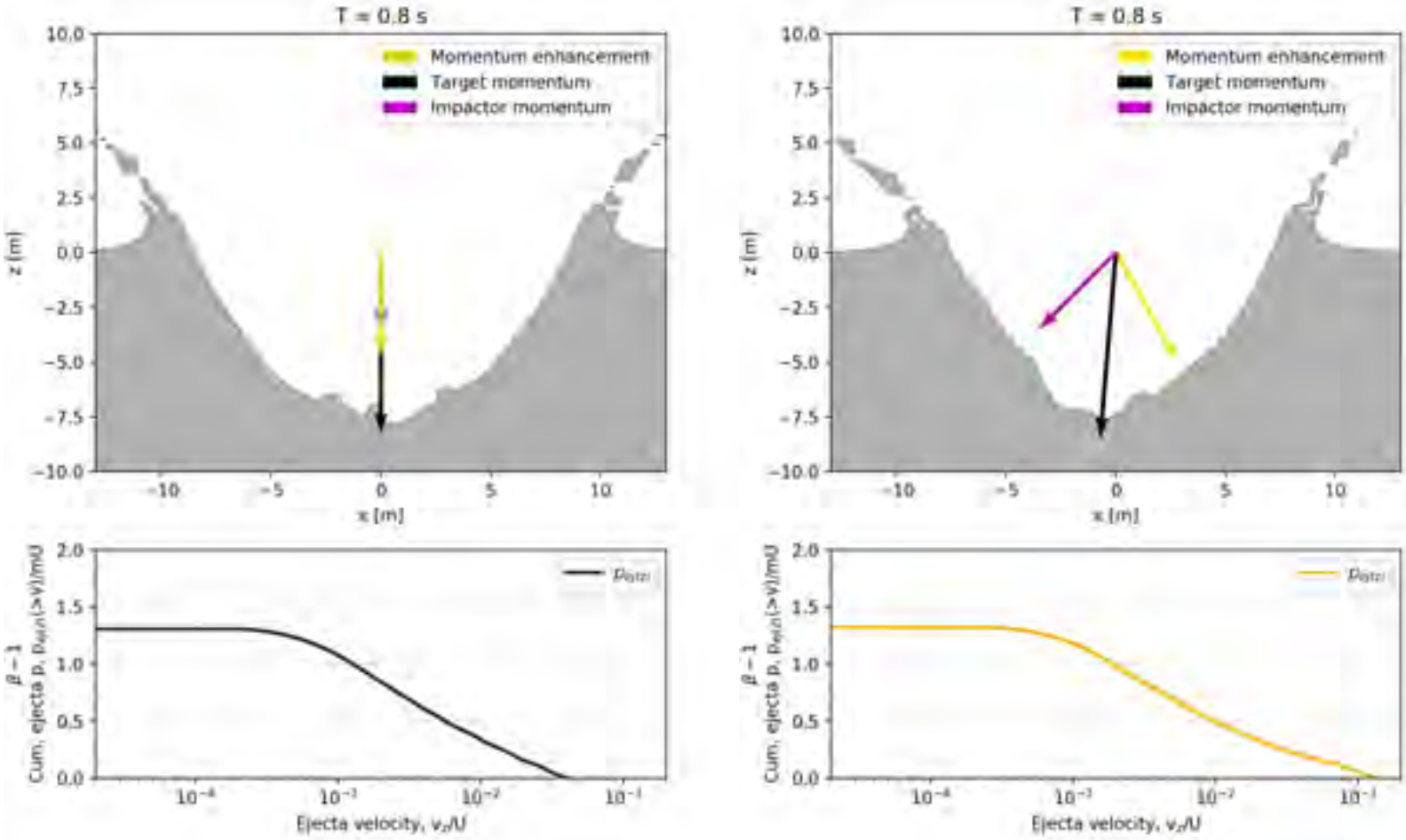

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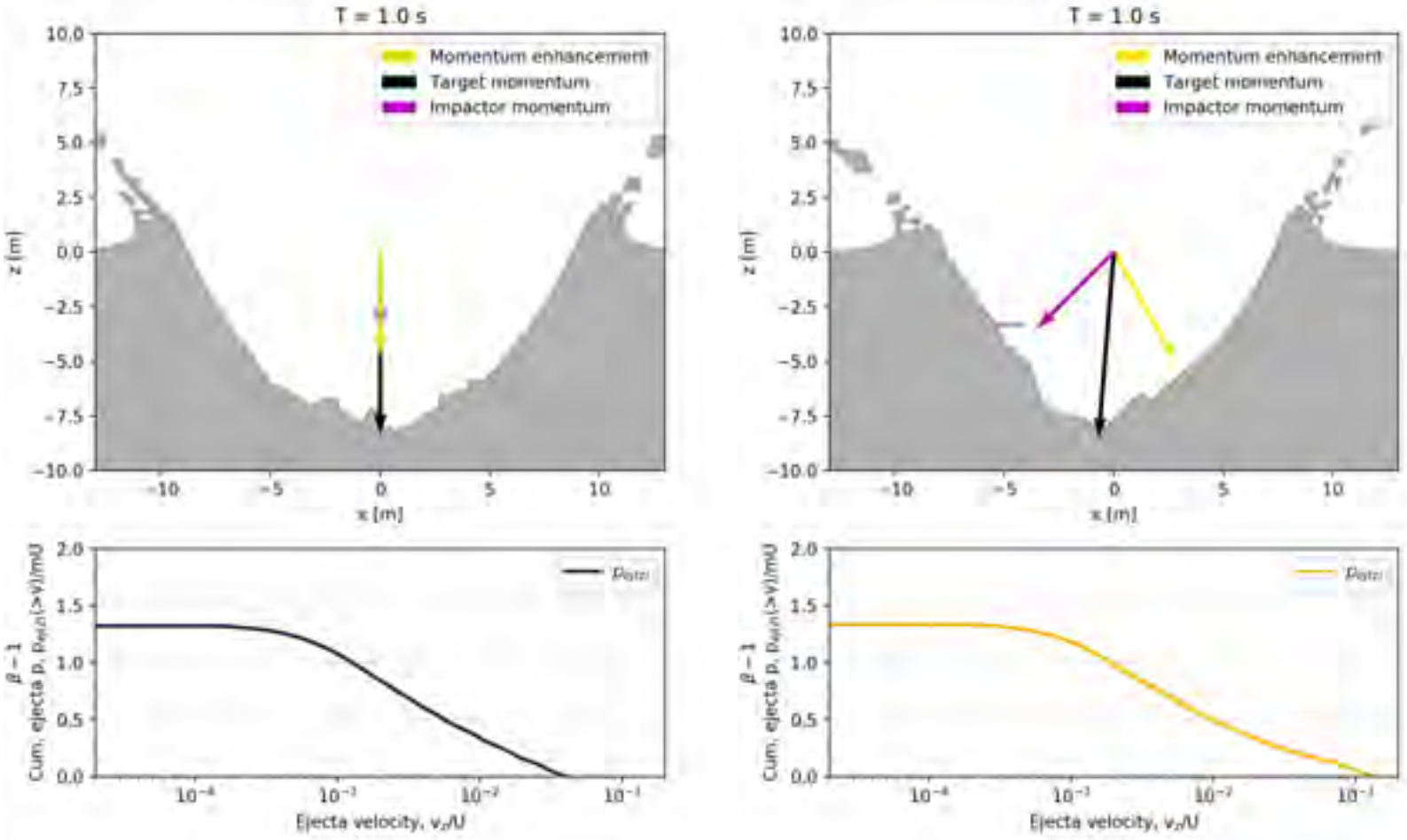


Figure 6: Momentum enhancement, impactor momentum and target momentum vectors.

iSALE 2D simulations of the DART impact

a) homogeneous porous internal structure;
b) layered targets;
c) targets in which porosity exponentially decreases with depth.

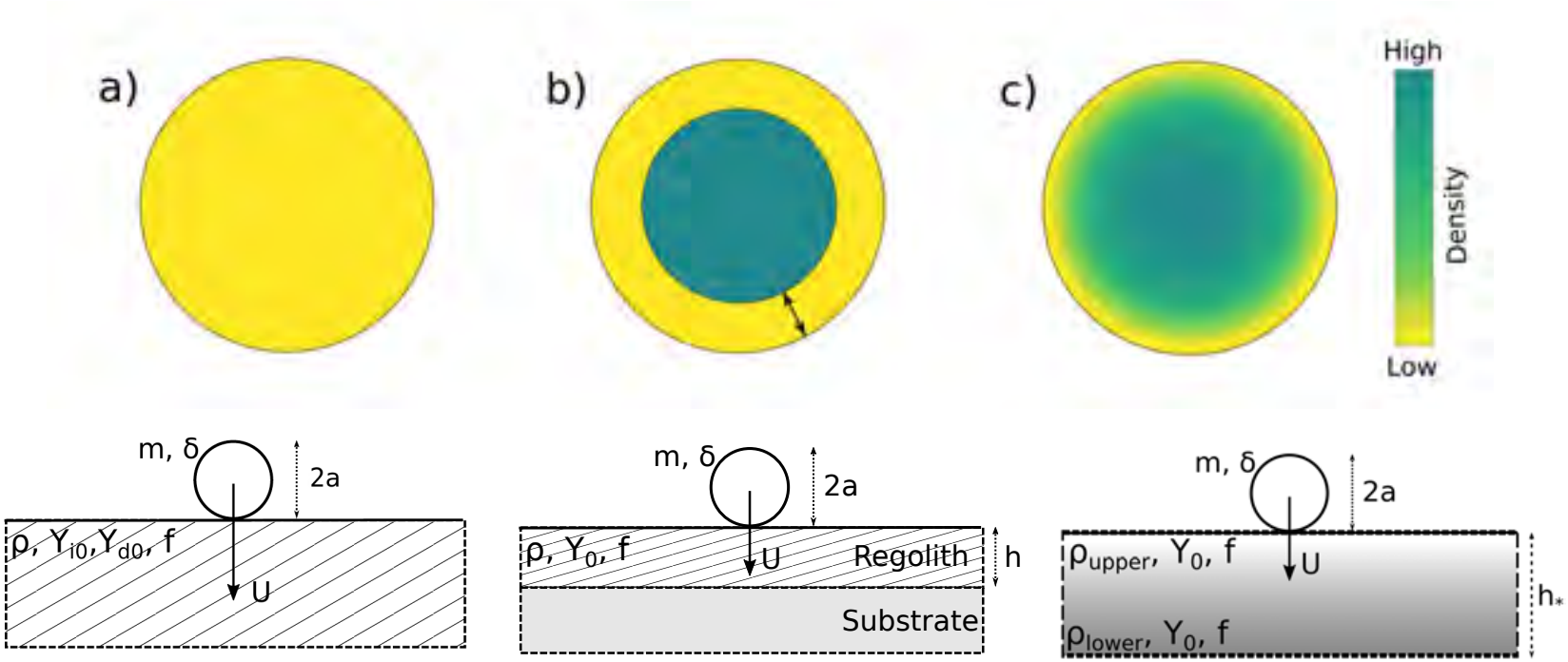


Figure 7: Schematic representation of the Didymoon internal structure models.

For more details check out Raducan et al., 2019 (Icarus), Raducan et al. 2019 (PSS, in review)

iSALE 2D to simulate the DART impact - a) Homogeneous structure

Table 2: iSALE input parameters, homogeneous target, case a).

<——— Projectile parameters ———>				<——- Target parameters ———>		
radius	mass	velocity	density	strength	porosity	friction
a	m	U	δ	Y_0	ρ	f
(m)	(kg)	(km/s)	(kg/m^3)	(kPa)	(%)	
0.42	310	7.0	1000	0.1–100	0–50	0.6

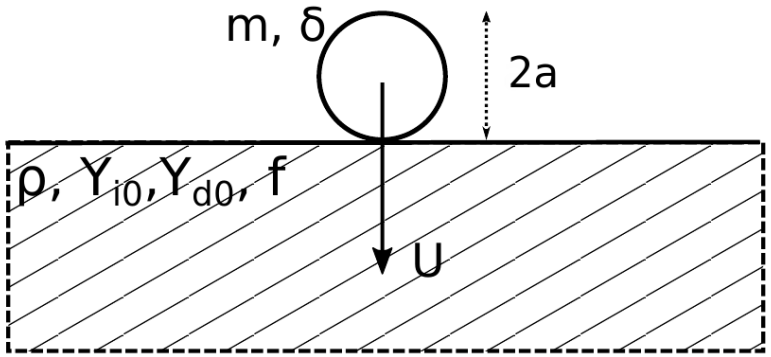


Figure 8: Diagram of the simulation set-up.

iSALE 2D to simulate the DART impact - b) Layered structure

Table 3: iSALE input parameters, layered target, case b).

	<—— Regolith parameters ——>		<—— Substrate parameters ——>	
No.	strength, Y_{r0} (kPa)	porosity, ϕ_{r0} (%)	strength, Y_{s0} (kPa)	porosity, ϕ_{s0} (%)
1.	1	35	100	0
2.	1	50	100	0
3.	1	35	100	10
4.	1	50	100	10

* h between 0.5a and 20a, a = impactor radius

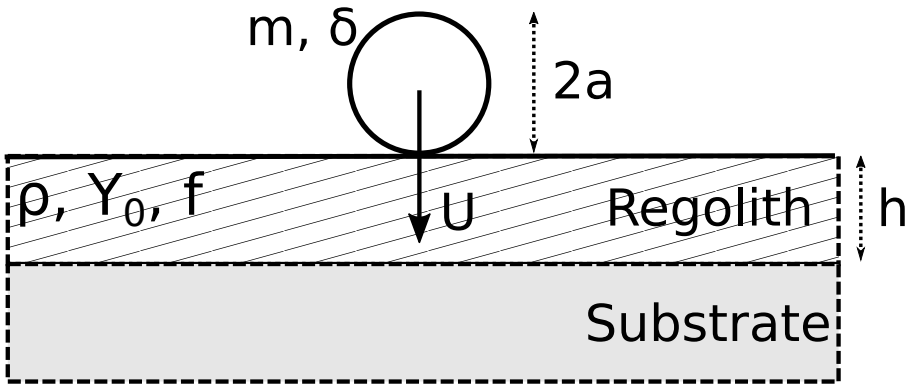


Figure 9: Diagram of the simulation set-up.

iSALE 2D to simulate the DART impact - c) Porosity gradient

Table 4: iSALE input parameters, exponential porosity gradient , case c).

	<—— Surface parameters ——>	<– Minimum porosity parameters –>
No.	porosity, ϕ_{upper} (%)	porosity, ϕ_{lower} (%)
1.	50	0
2.	35	10

* E-folding depth, h_*/a, between ≈2.5 and ≈20, a = impactor radius

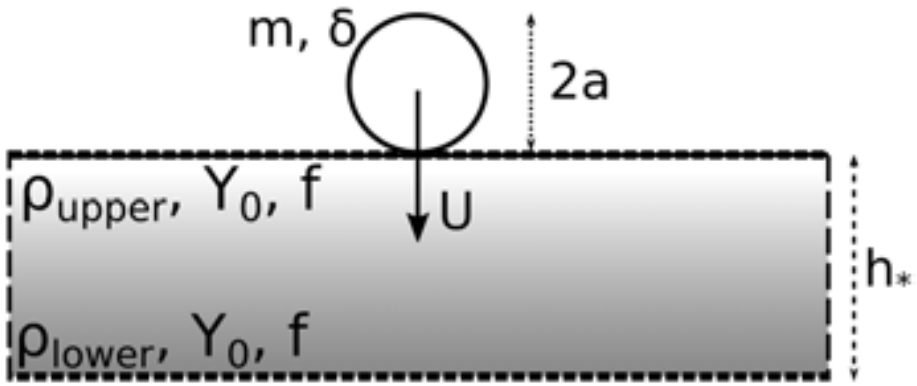
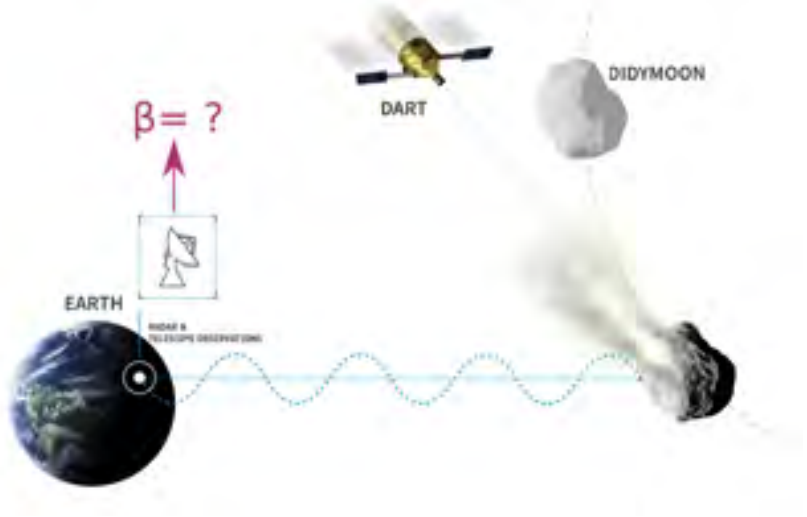


Figure 10: Diagram of the simulation set-up.

β will be measured by Earth-based telescopes



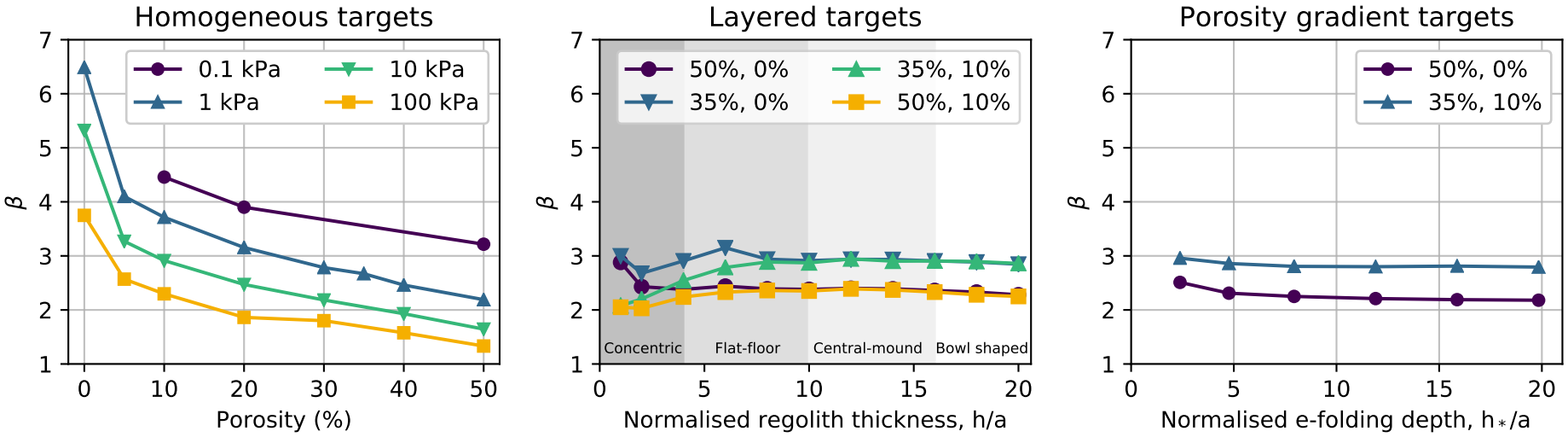
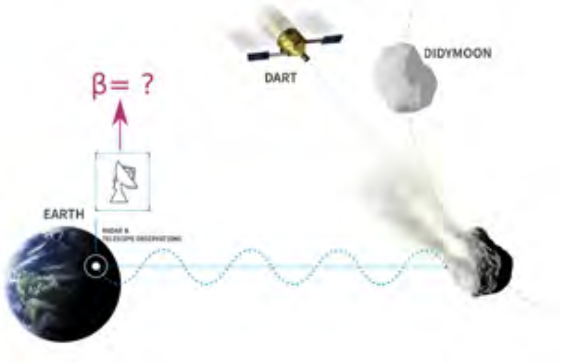


Figure 11: Momentum transfer efficiency, β, for different target structures.

Same β predicted for different target structures

Assume β = 2.9. What are the target properties?



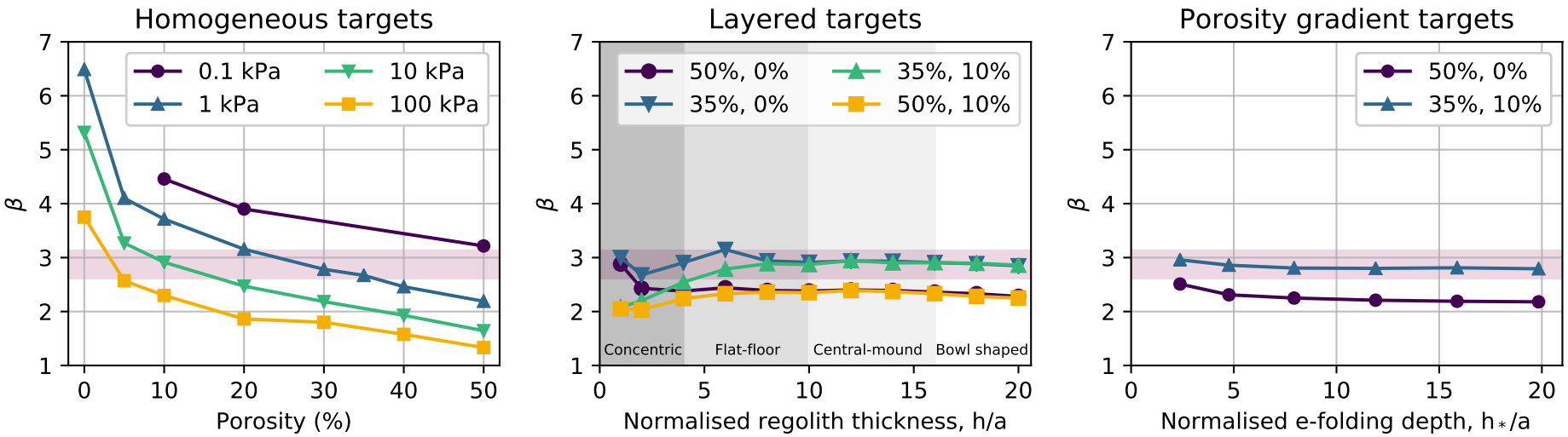


Figure 12: Momentum transfer efficiency, β, for different target structures.

Same β predicted - homogeneous targets

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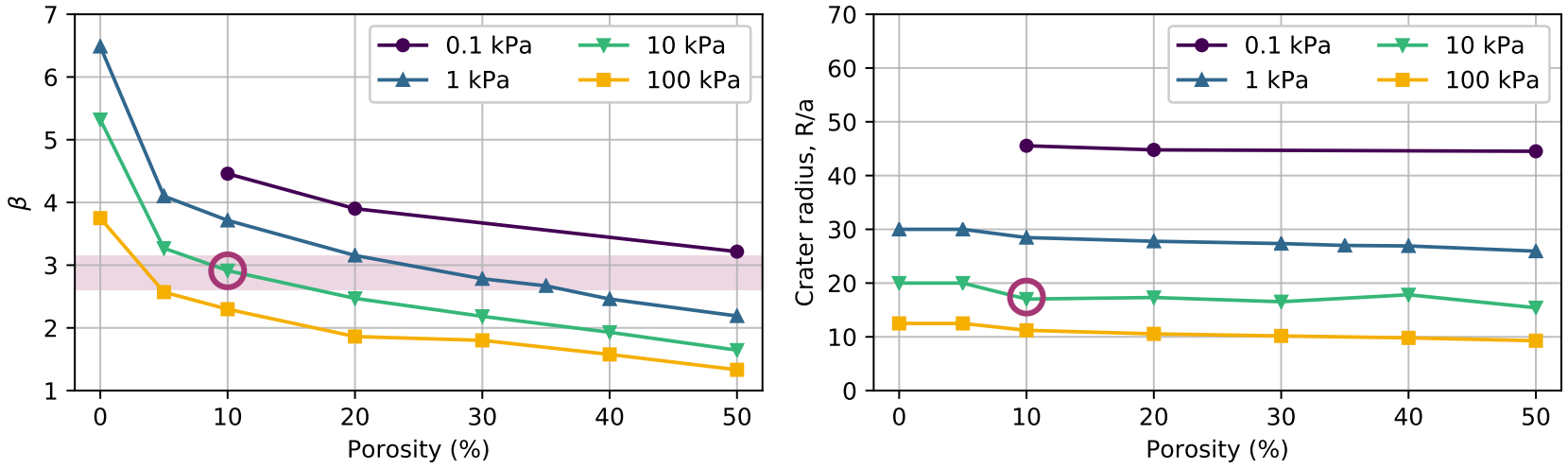
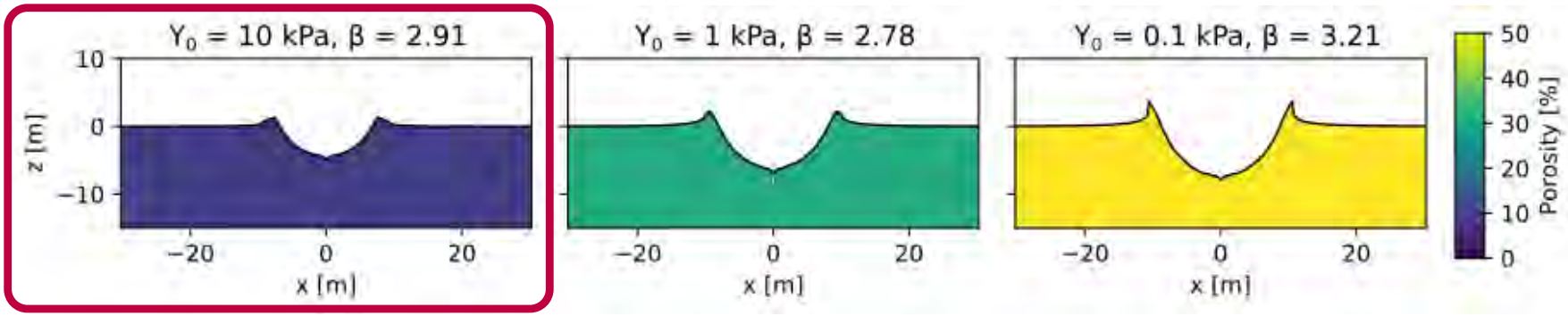


Figure 13: Momentum transfer efficiency, β, and crater radius, R/a for impacts into homogeneous targets.



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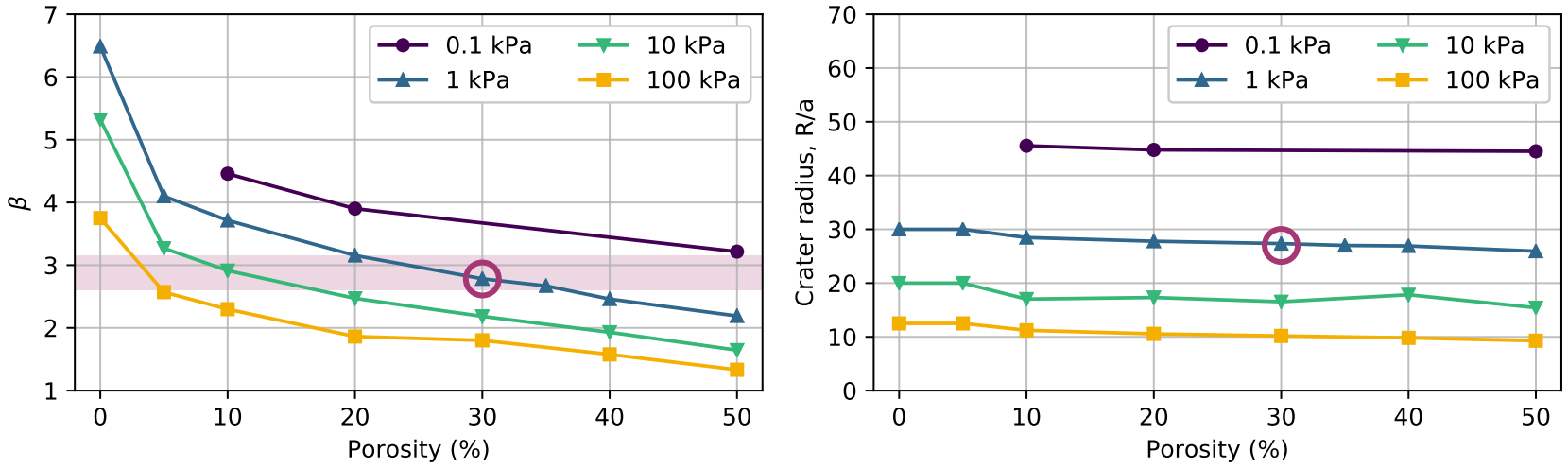

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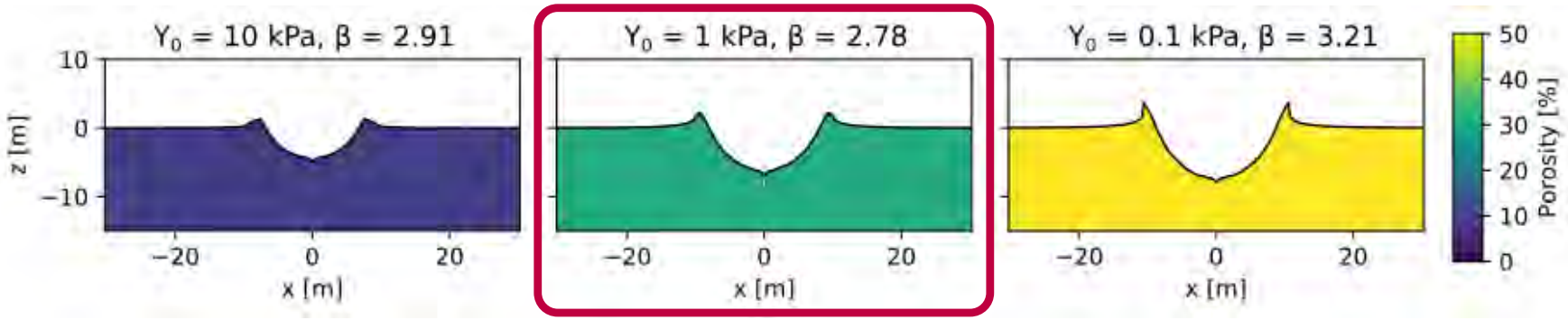

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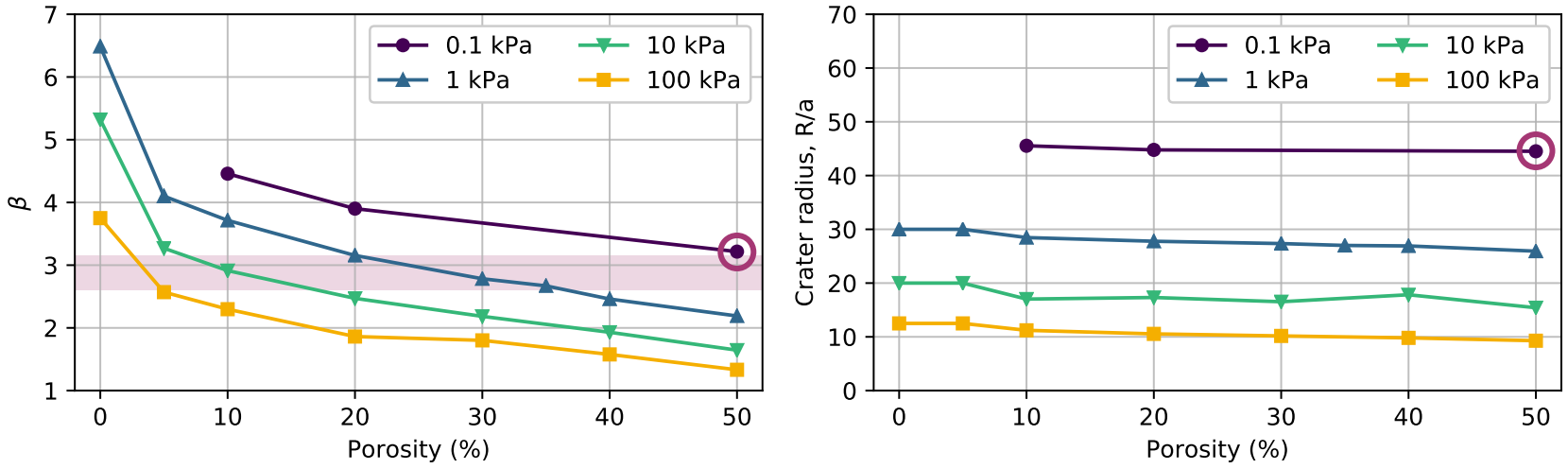

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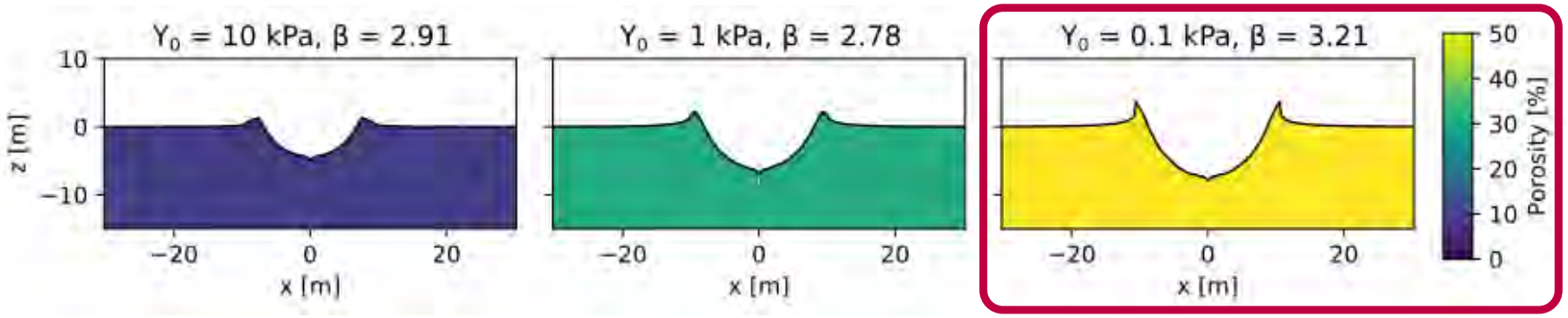

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a) homogeneous porous internal structure;
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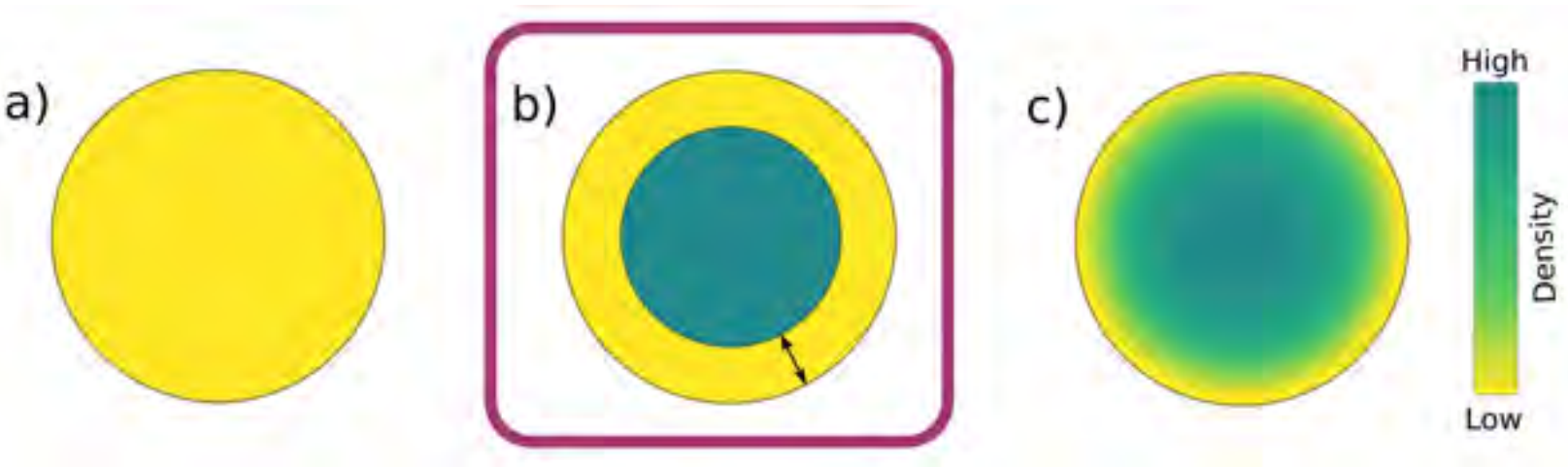

Figure 14: Schematic representation of the Didymoon internal structure models.

Crater profiles differ with regolith thickness

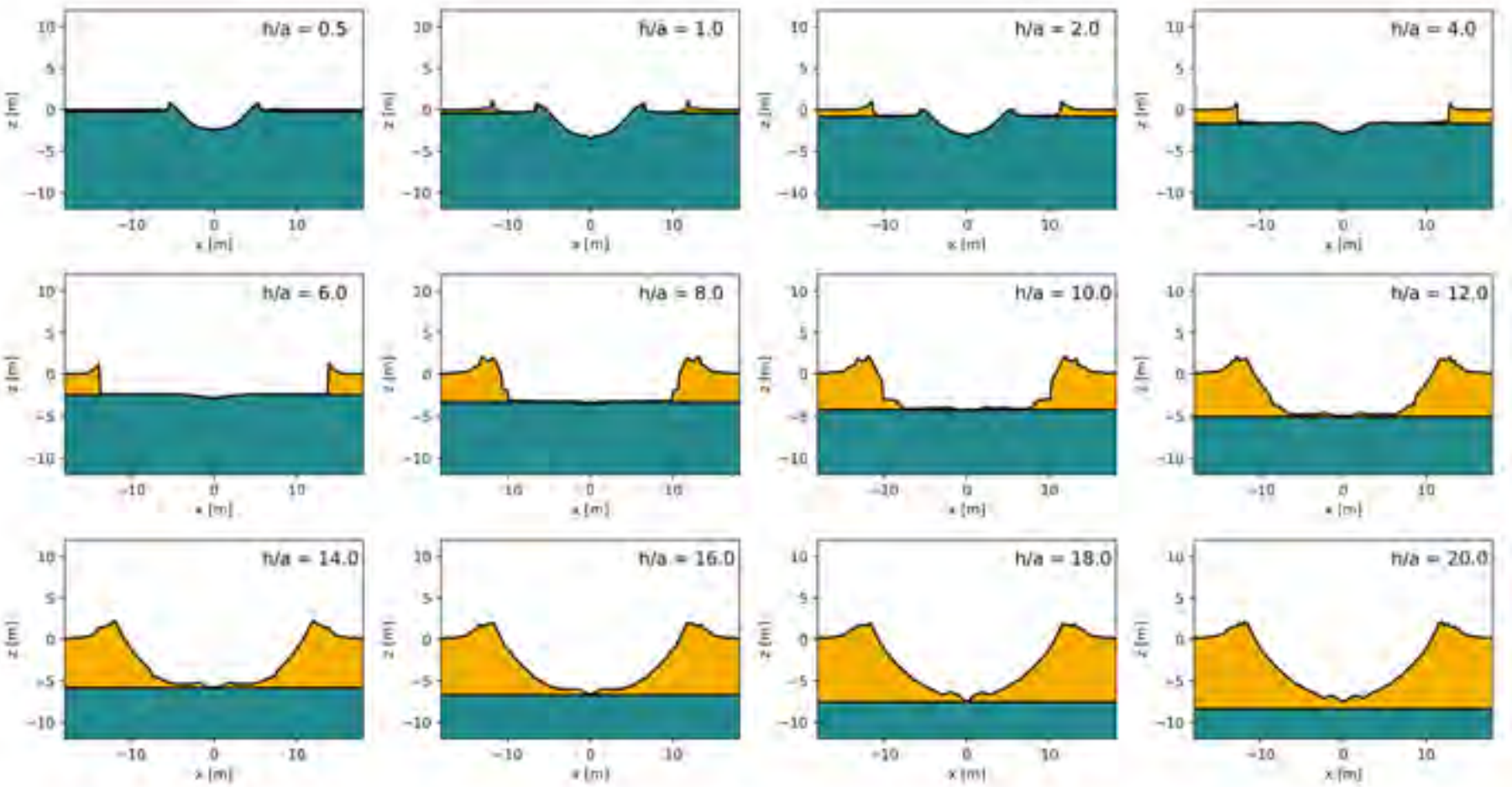

Figure 15: iSALE crater profiles for h/a between 1 and 20.

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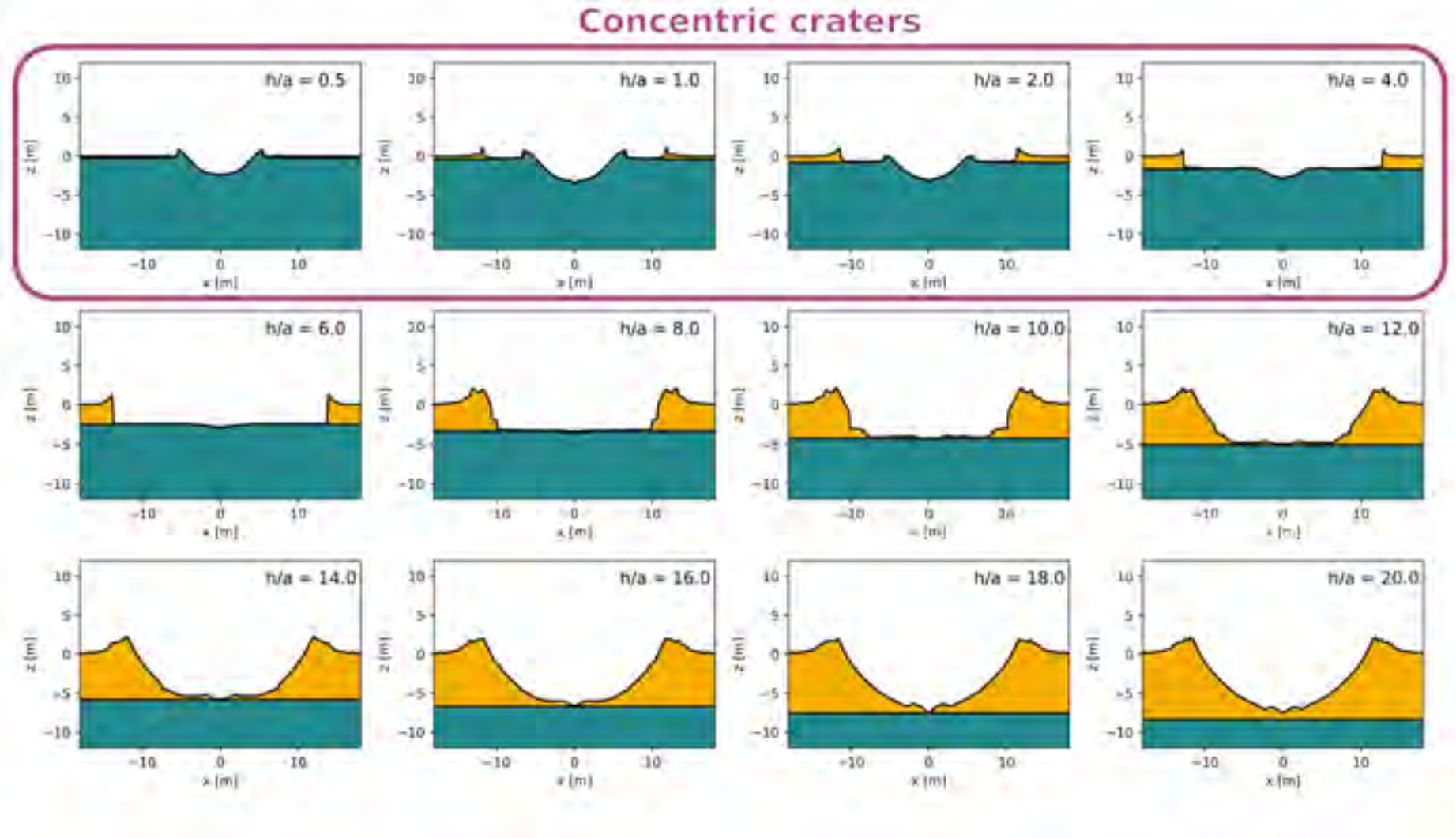

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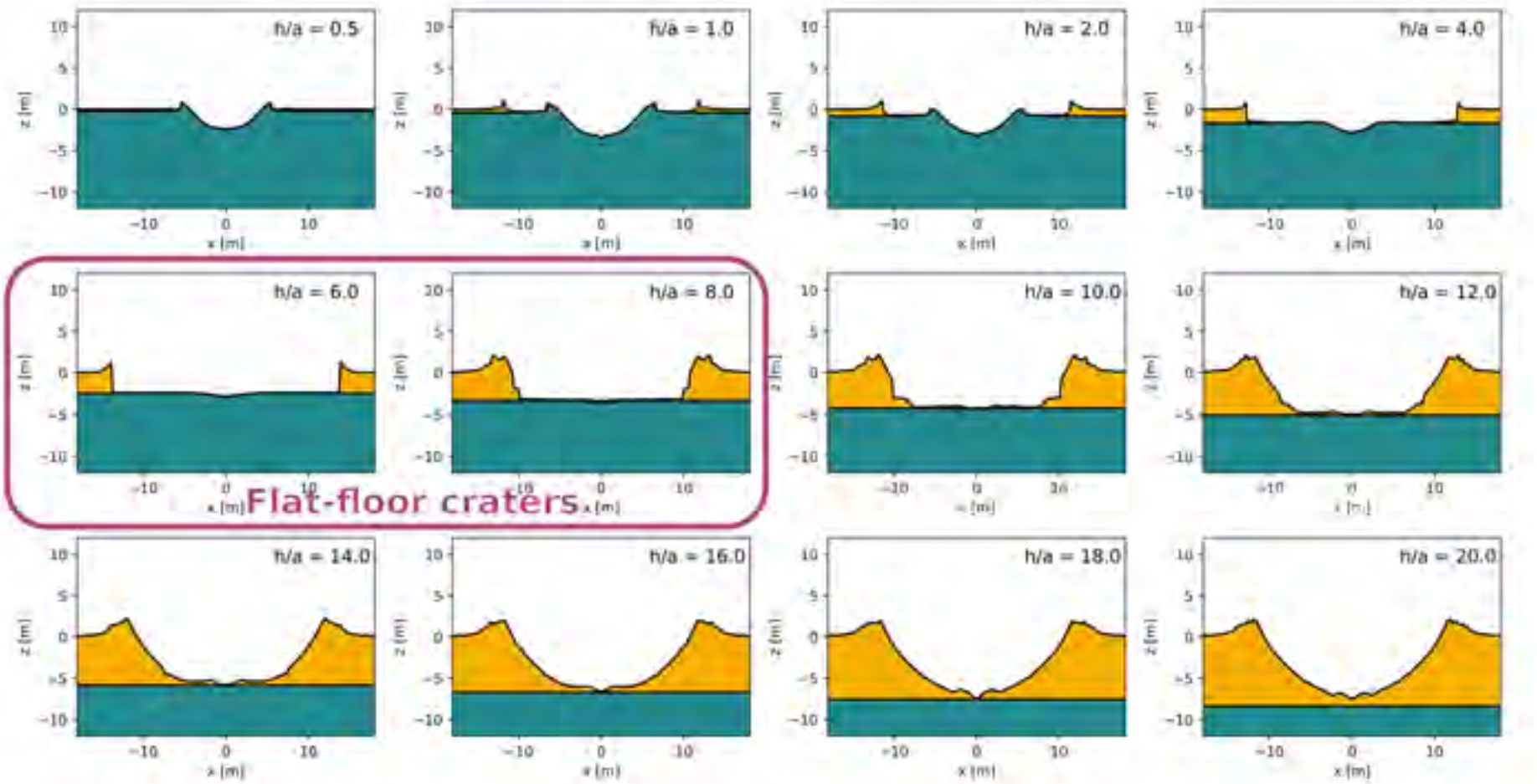

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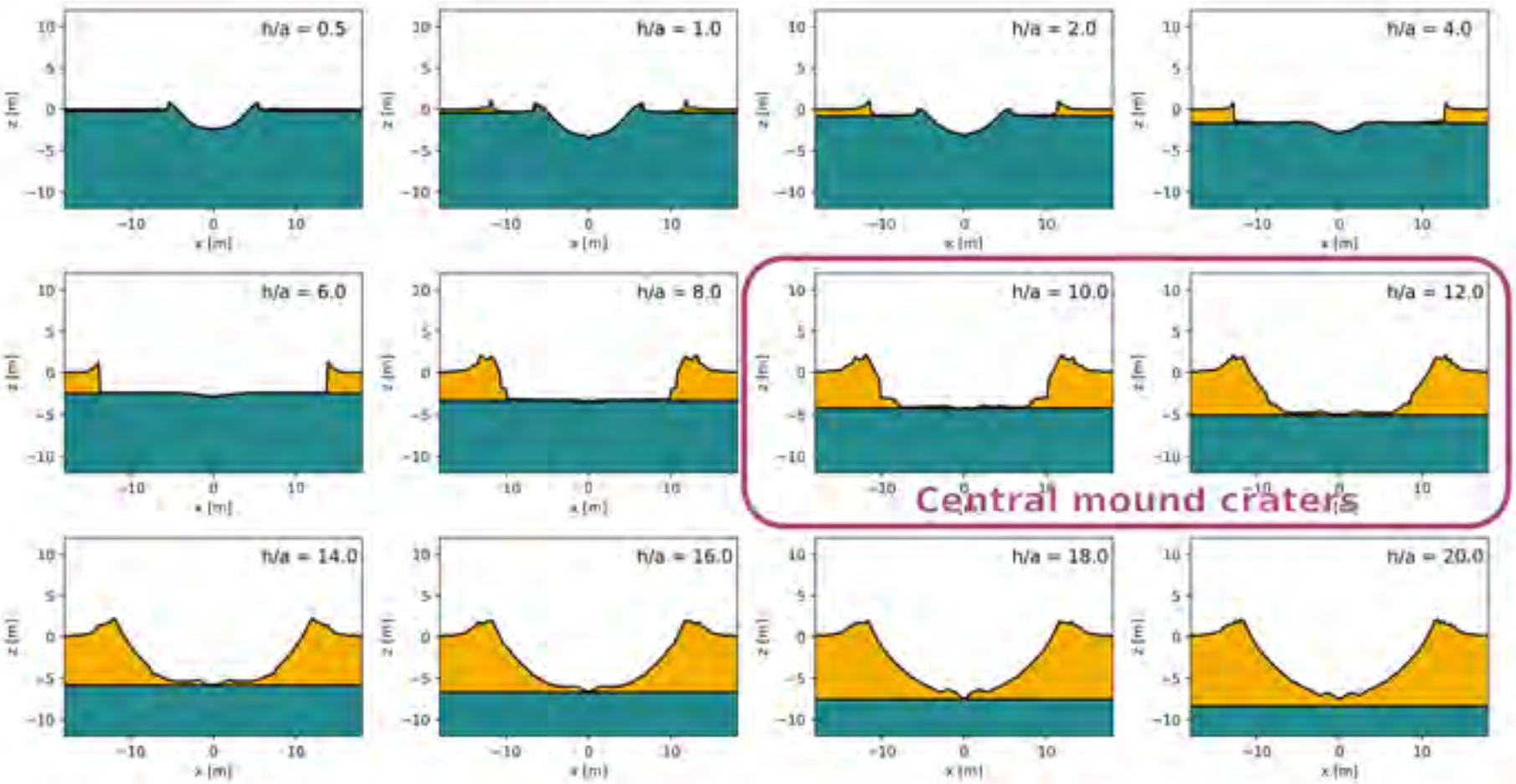

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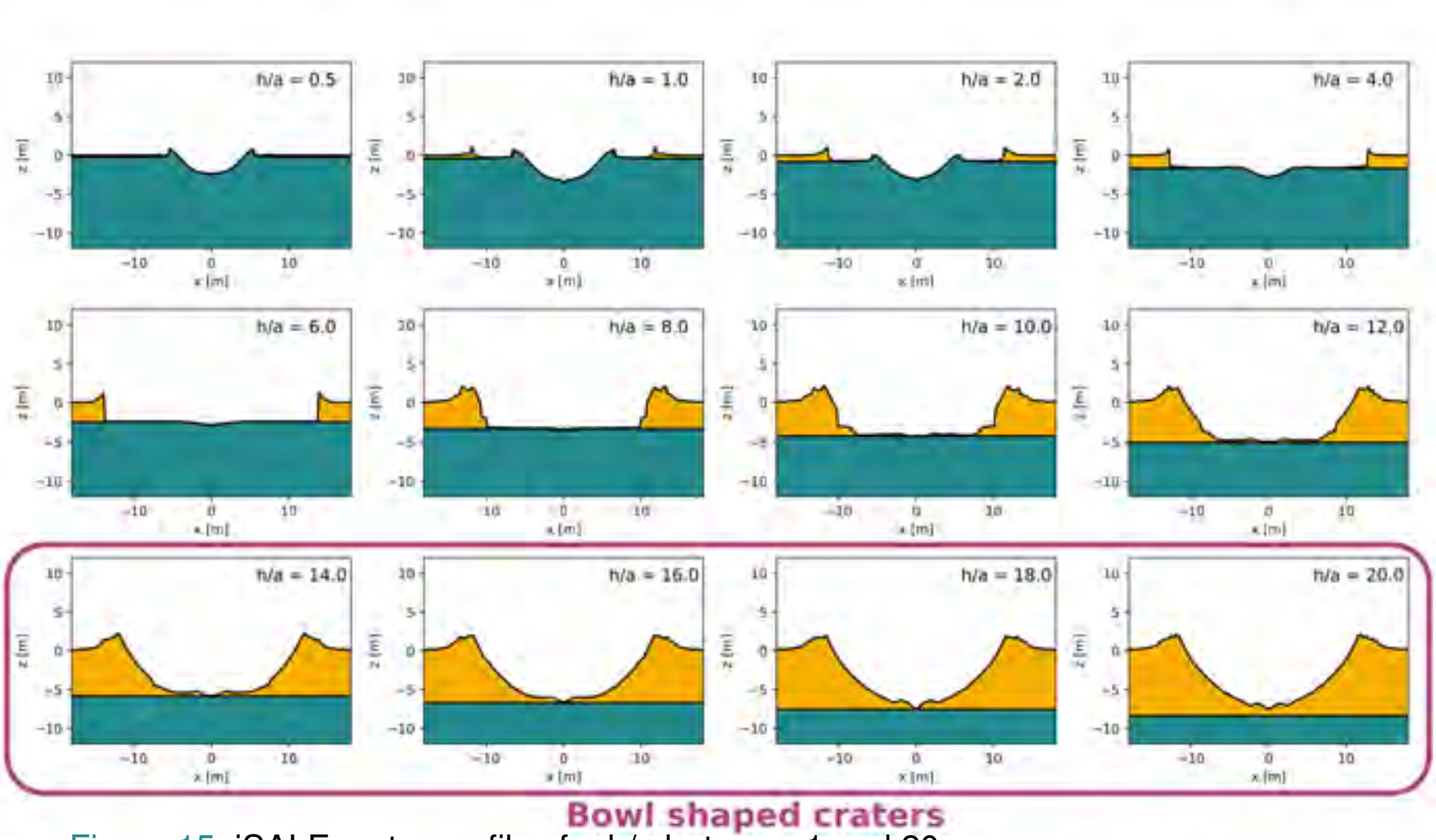

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Same β predicted - layered targets

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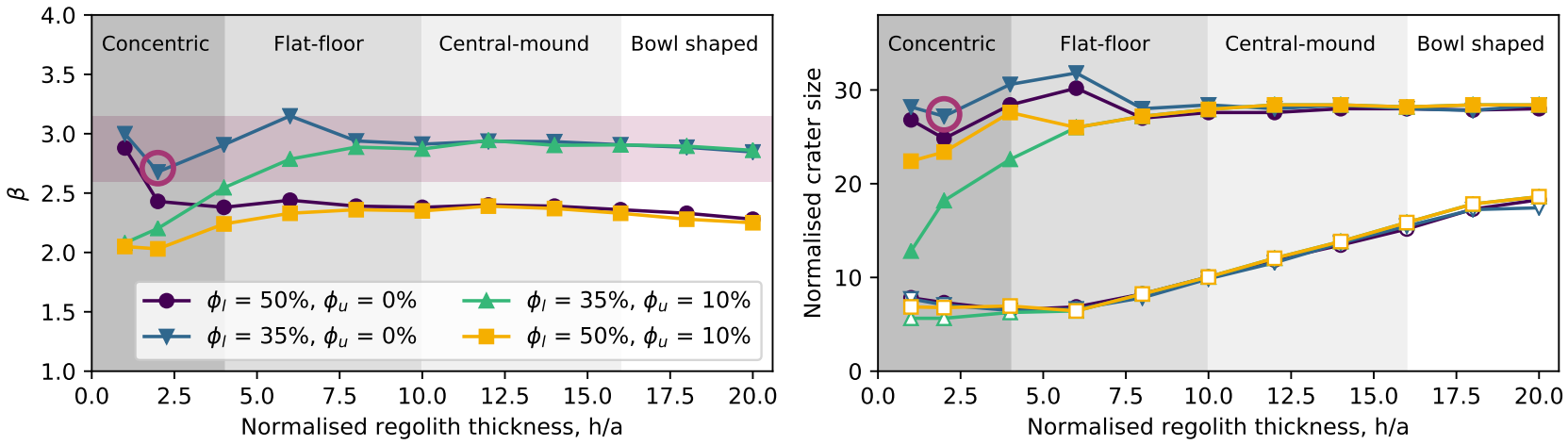
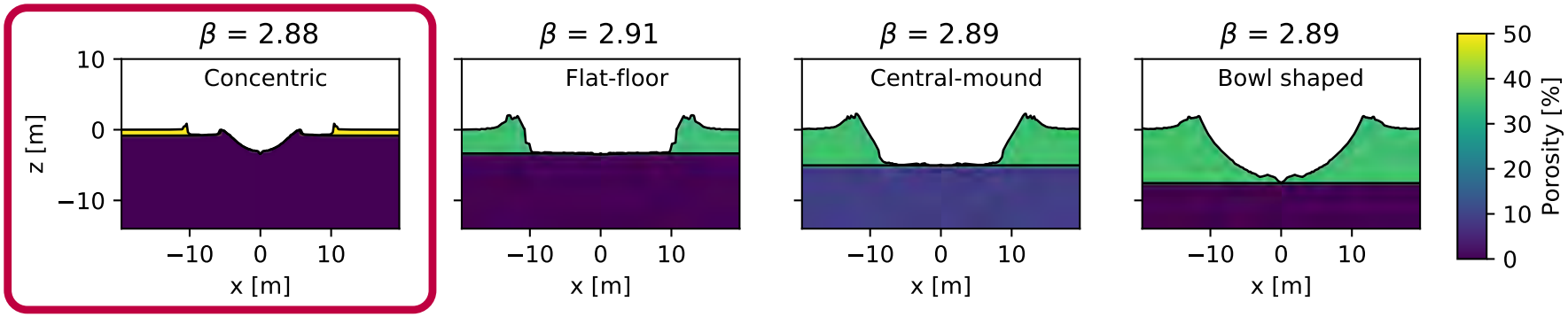


Figure 16: Momentum transfer efficiency, β, crater radius, R/a and crater depth, d/a for impacts into layered targets.



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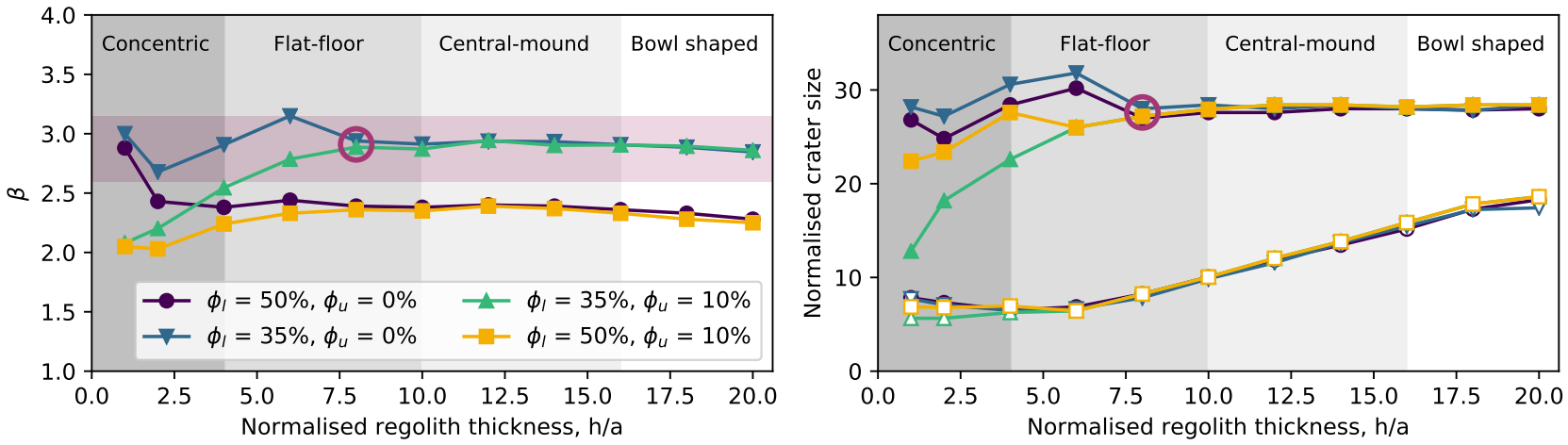

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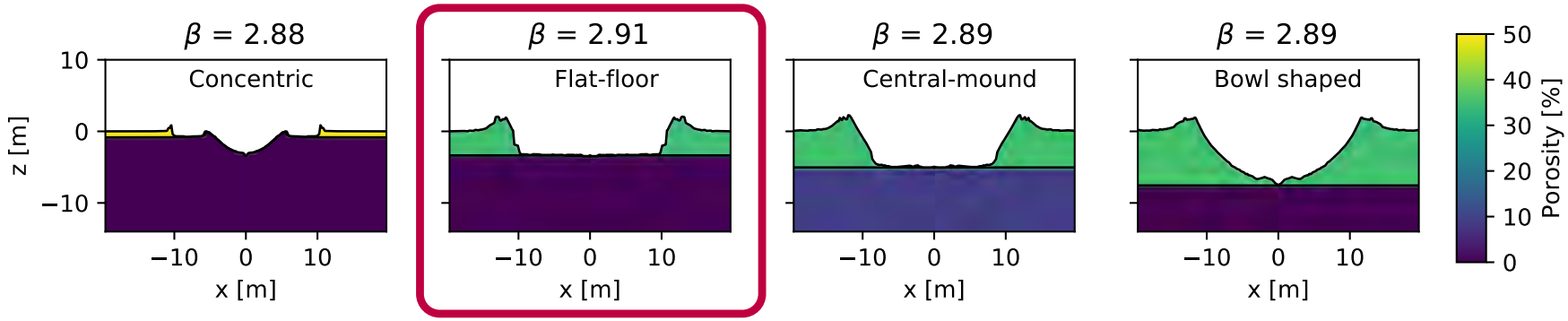

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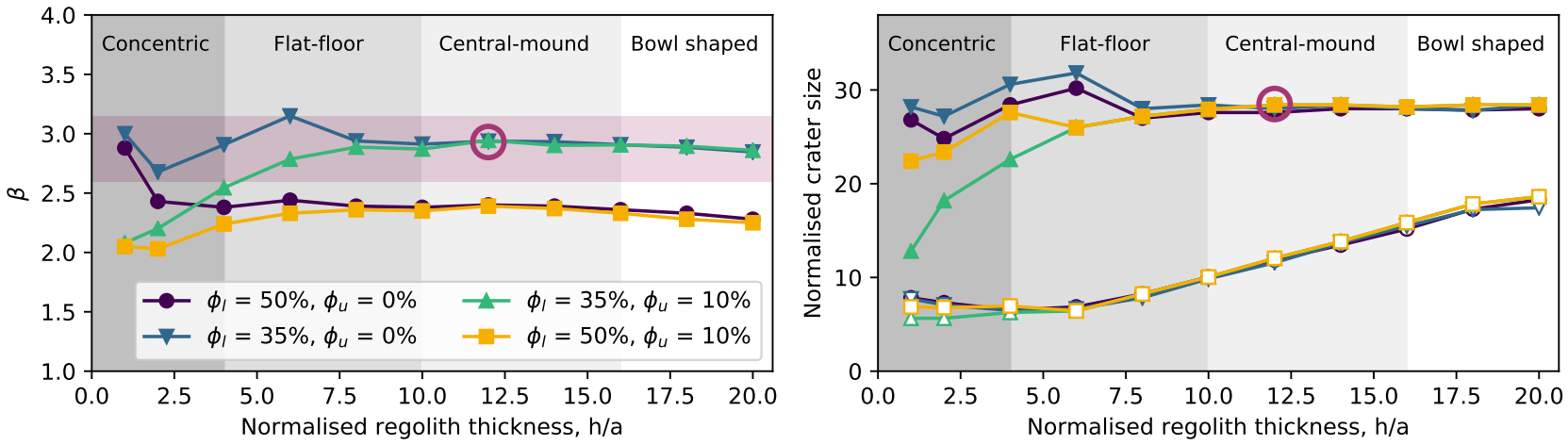

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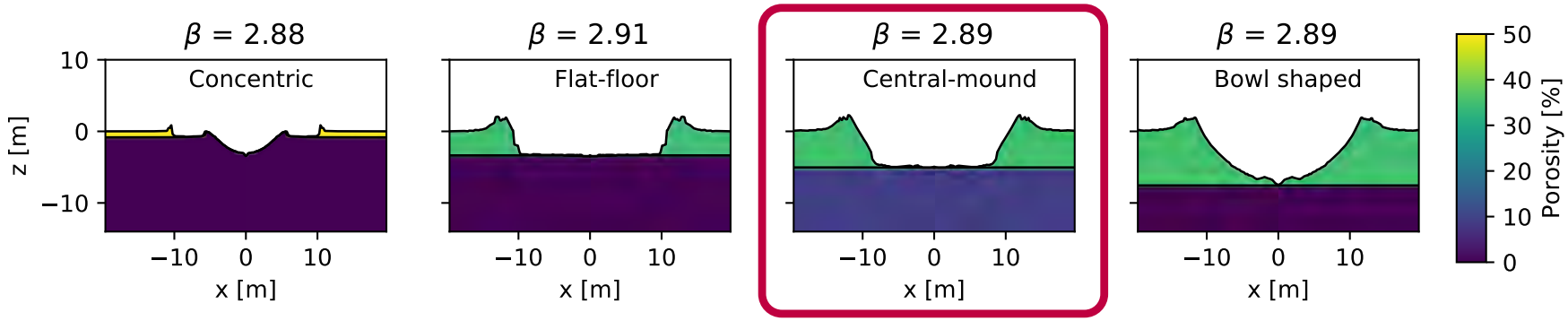

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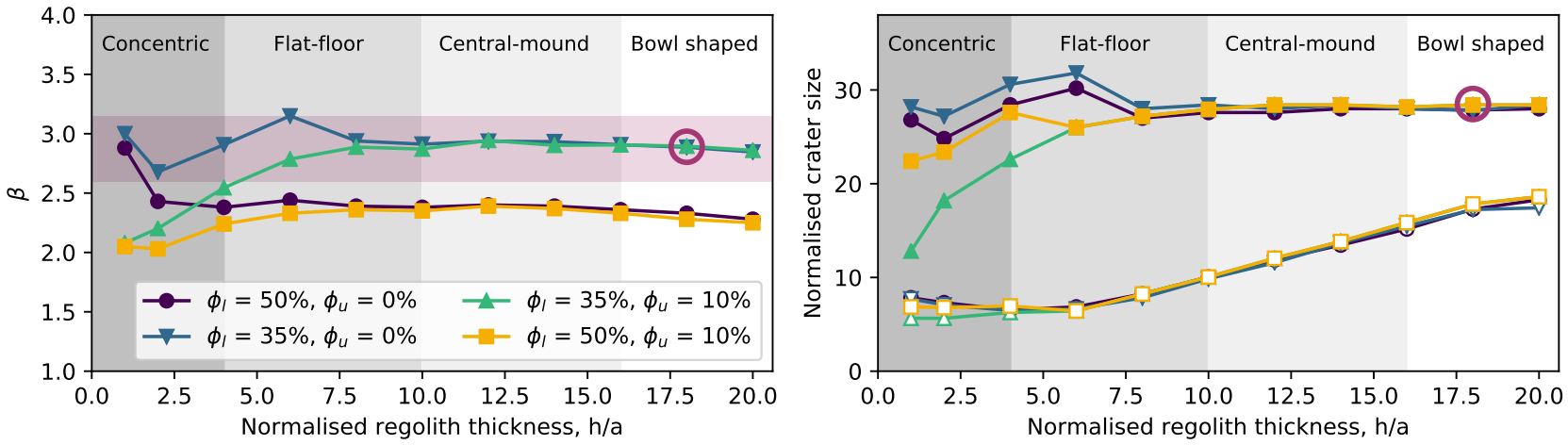

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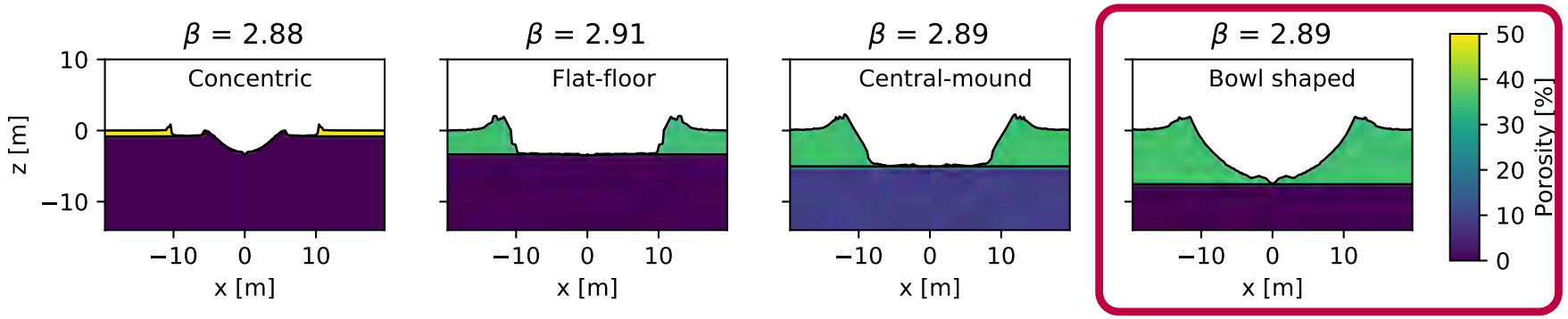

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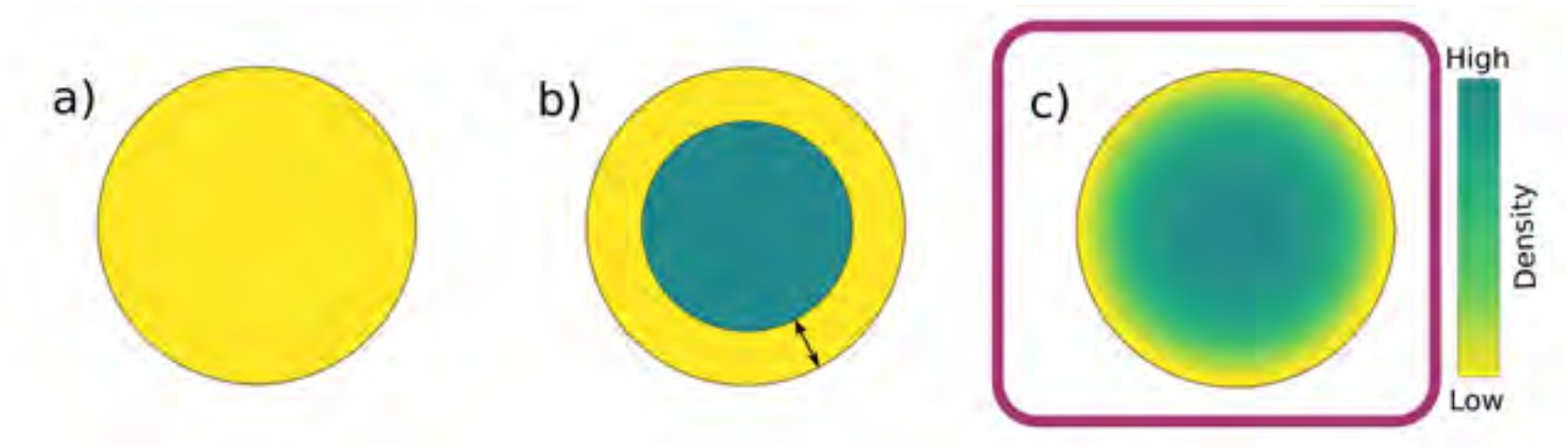


Figure 17: Schematic representation of the Didymoon internal structure models.

Same β predicted - porosity gradient targets

Assume β = 2.9. What are the target properties?

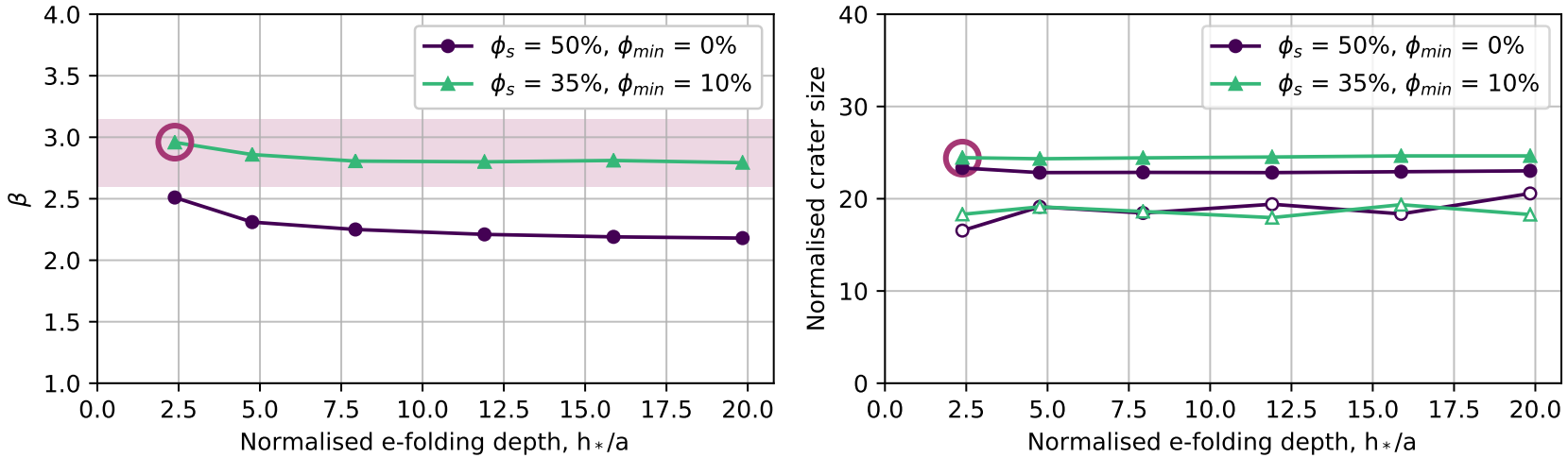
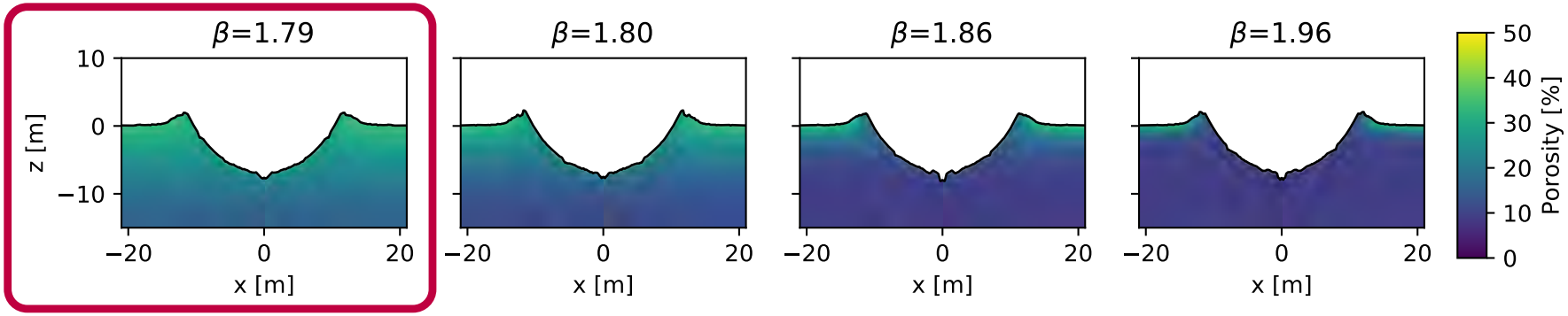


Figure 18: Momentum transfer efficiency, β, crater radius, R/a and crater depth, d/a for impacts into targets with an exponential porosity gradient.



Same β predicted - porosity gradient targets

Assume β = 2.9. What are the target properties?

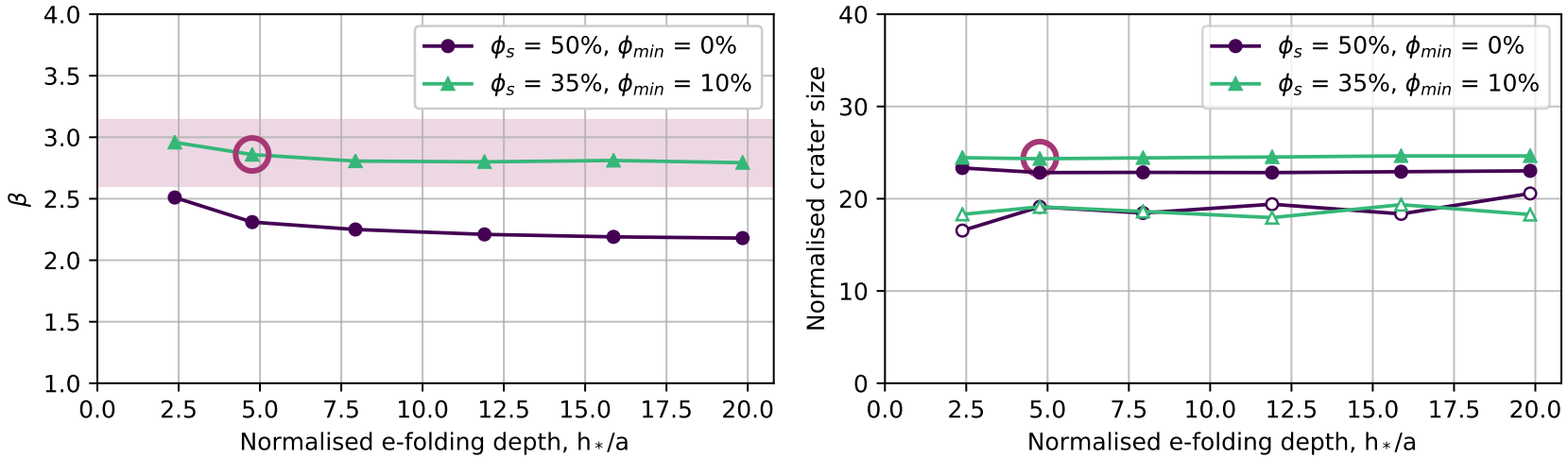
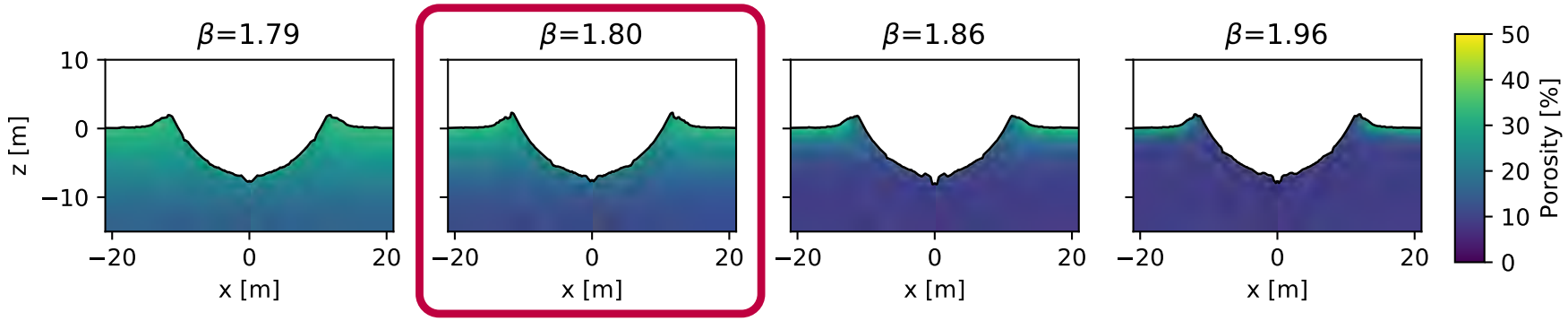


Figure 18: Momentum transfer efficiency, β, crater radius, R/a and crater depth, d/a for impacts into targets with an exponential porosity gradient.



Same β predicted - porosity gradient targets

Assume β = 2.9. What are the target properties?

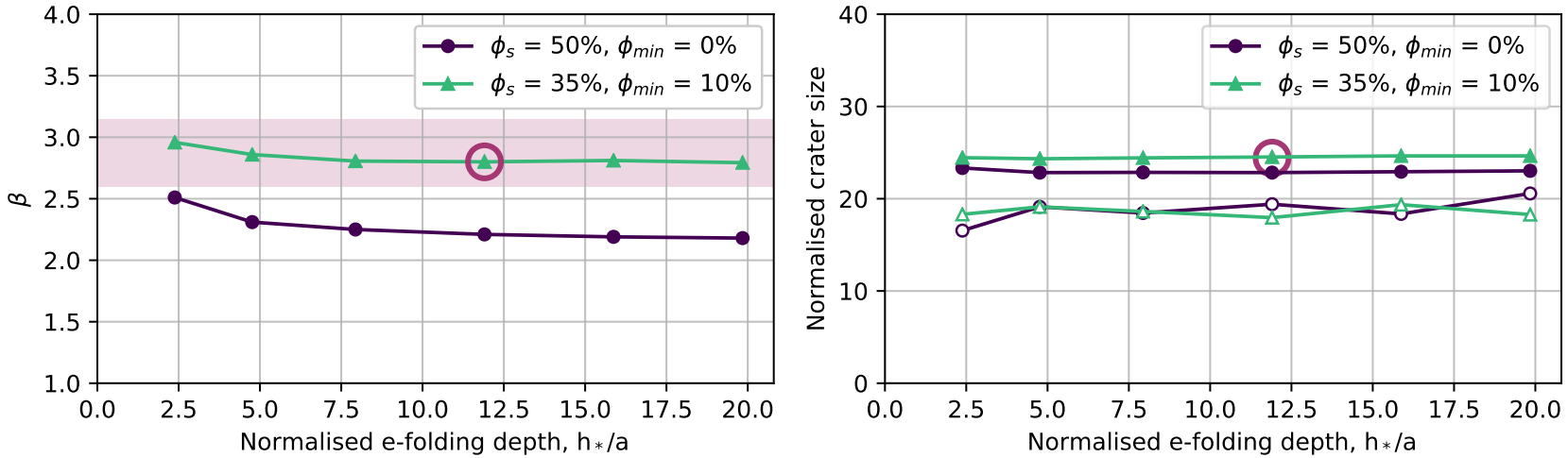
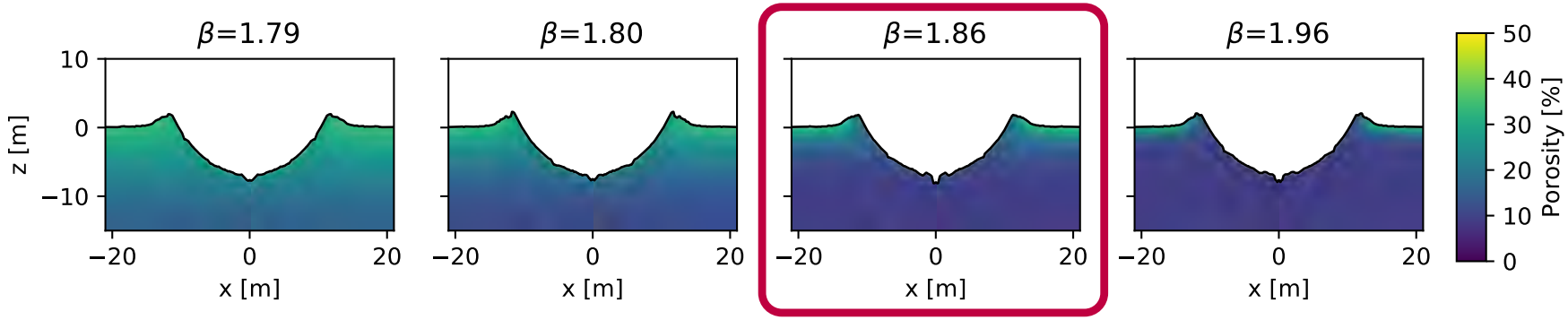


Figure 18: Momentum transfer efficiency, β, crater radius, R/a and crater depth, d/a for impacts into targets with an exponential porosity gradient.



Same β predicted - porosity gradient targets

Assume β = 2.9. What are the target properties?

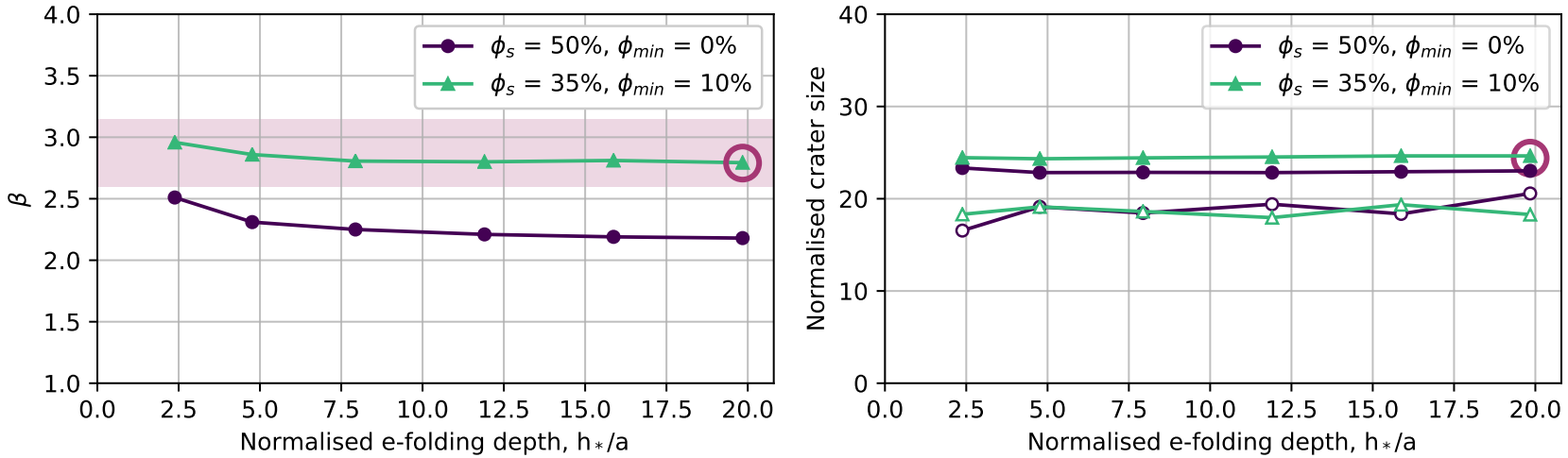
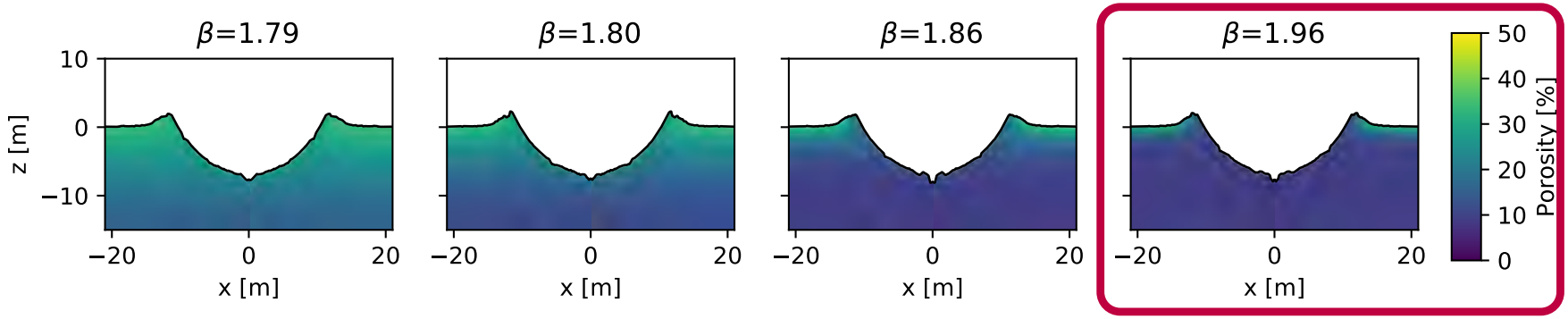


Figure 18: Momentum transfer efficiency, β, crater radius, R/a and crater depth, d/a for impacts into targets with an exponential porosity gradient.



Same β predicted for different target structures

To validate our numerical models, we need:

- Morphology and size of the DART crater
- Bulk density measurements
- Asteroid surface survey
- Surface cohesion estimate

We need Hera to validate our numerical models

ESA's Hera mission will arrive at Didymoon several years after the DART impact and will perform detailed measurements that will enable us to validate our numerical models:

- Morphology and size of the DART crater
- Bulk density measurements
- Asteroid surface survey
- Surface cohesion estimate

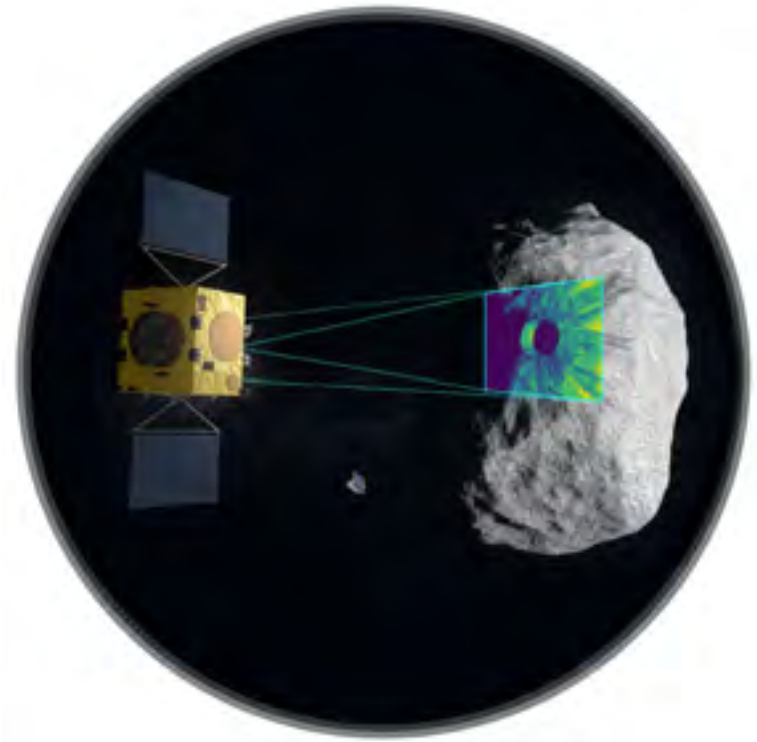


Figure 19: Hera at Didymoon. Source: ESA.

Conclusions

- 2D numerical simulations can be used to estimate the deflection caused by a vertical impact, but further testing is required to find if they can also estimate the vertical component of the ejecta momentum in an oblique impact;
- β greatly influenced by the cohesion, porosity and the target structure, expecting values between 2 and 4 (maybe even higher if the cohesion $\approx$ few Pa);
- Same β values were observed for impacts into a variety of targets;
- Hera measurements are vital for validation purposes.

Thank you

We gratefully acknowledge the developers of iSALE (www.isale-code.de) and STFC for funding (Grant ST/N000803/1).