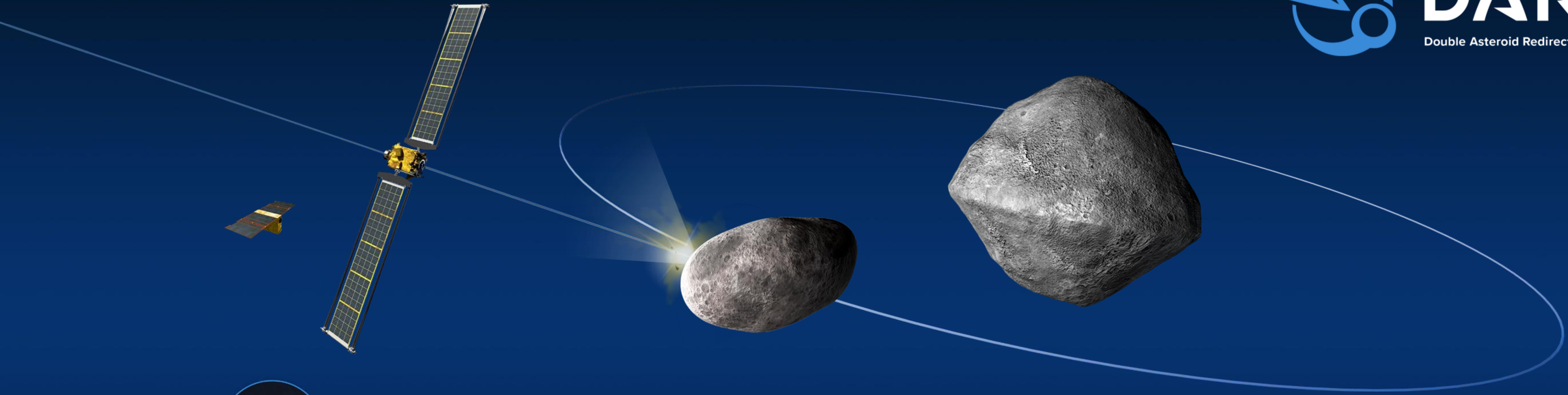
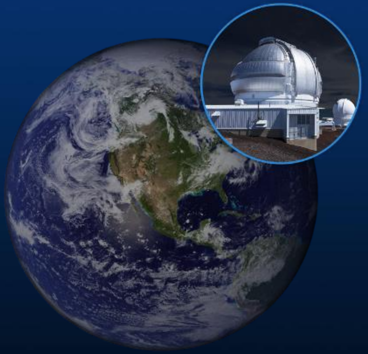
DART
Double Asteroid Redirection Test





Projectile Geometry Effects on Momentum Enhancement of Hypervelocity Impact Simulations

Mallory E. DeCoster,[1] Dawn Graninger,[1] Emma Rainey,[1] Michael Owen,[2] Angela Stickle, [1]

[1]Johns Hopkins University/Applied Physics Laboratory
[2]Lawrence Livermore National Laboratory

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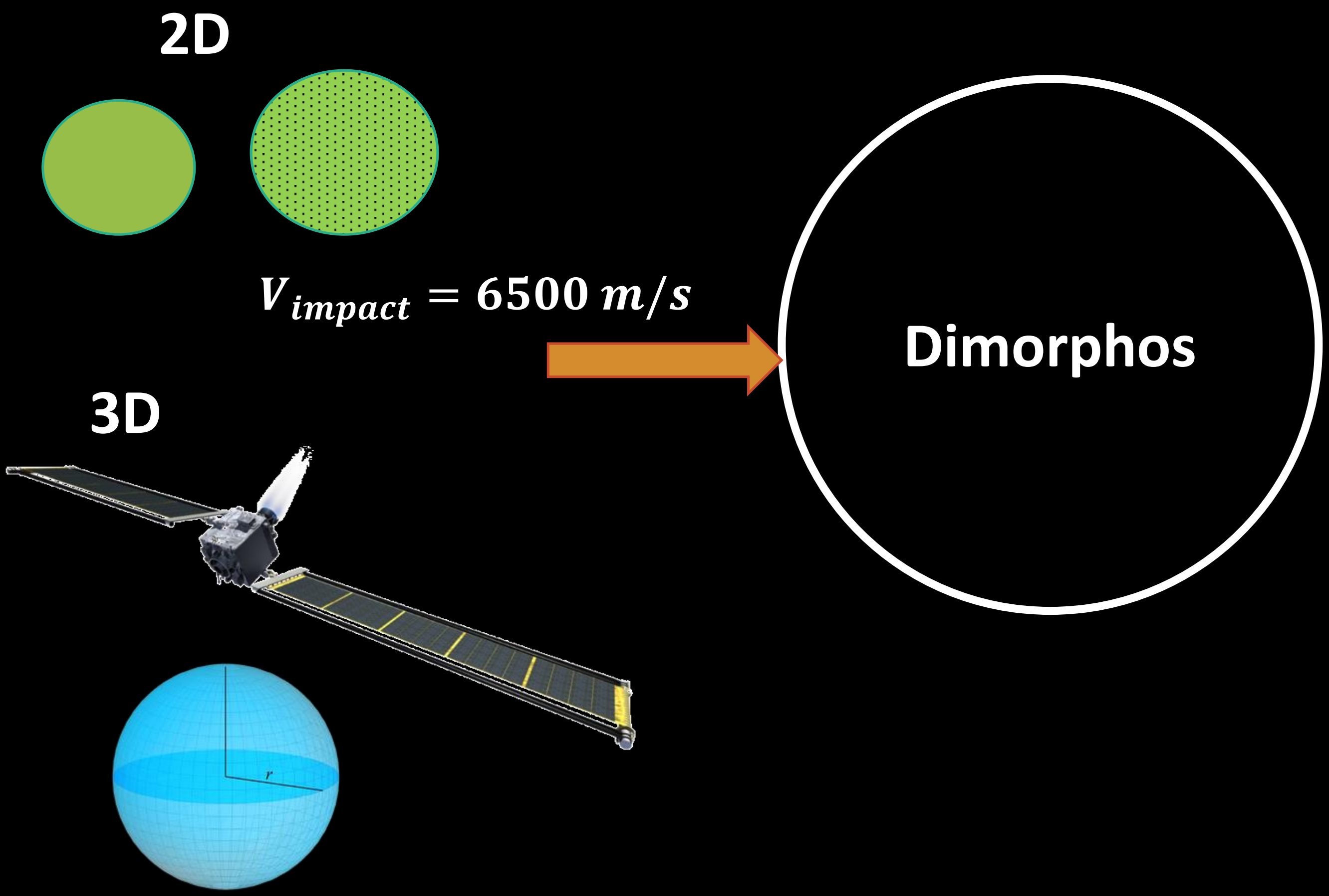
Is momentum enhancement (β) tied to the efficiency of the projectile to generate ejecta during crater formation? If so, is a simplified point source solution accurate for efficiently modeling the DART intercept?

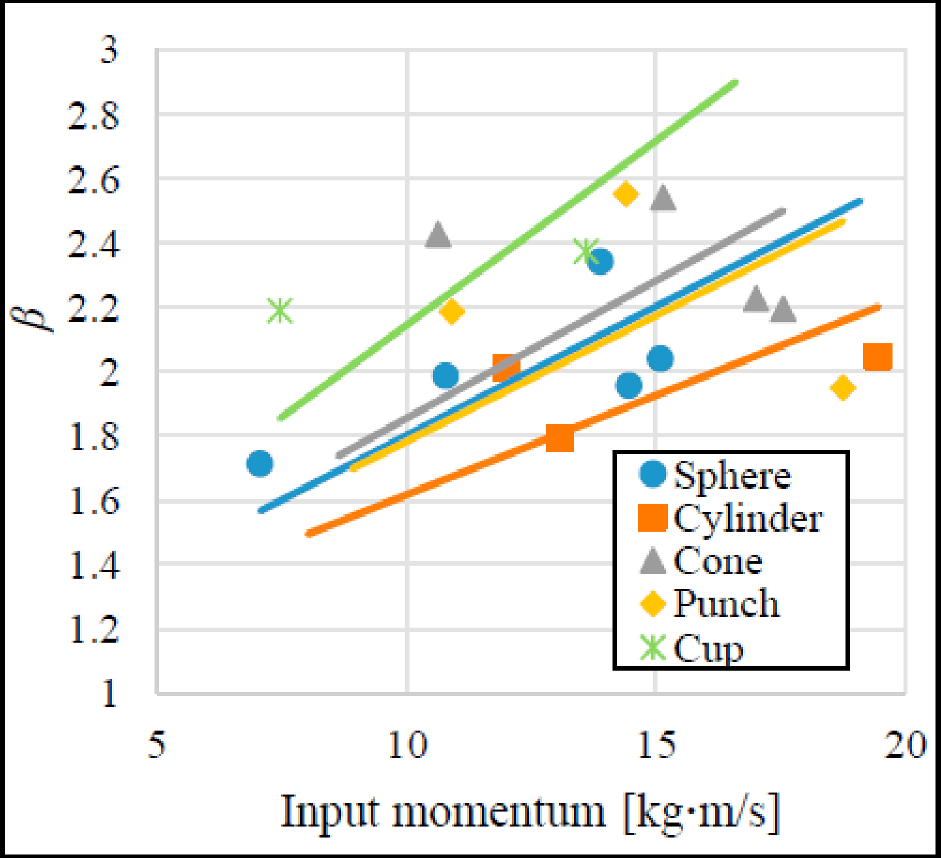


2D

$V_{impact} = 6500\ m/s$

Dimorphos

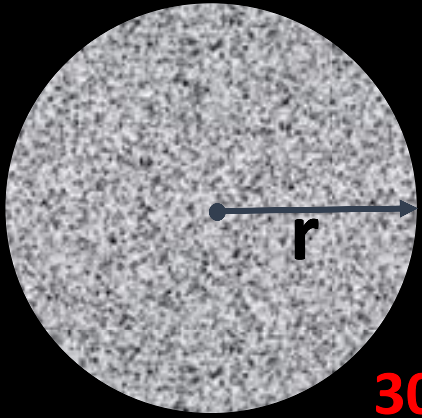
3D



Ikeda *et al.*, Procedia Engineering 204 (2017) 138-145

The simulation parameters defined for the 3D CTH tests were adapted from the benchmarking study and standardized across the different codes. This time we used a more realistic target material of 30% porous basalt.

Dimorphos (Target) Shape



Sphere

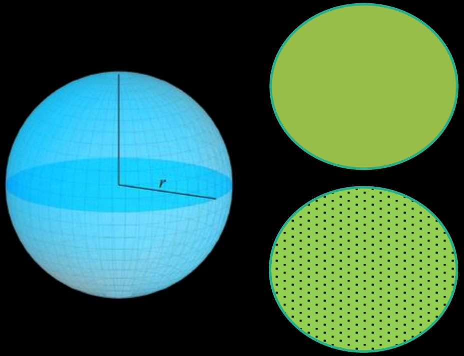
Radius (r) = 80 m

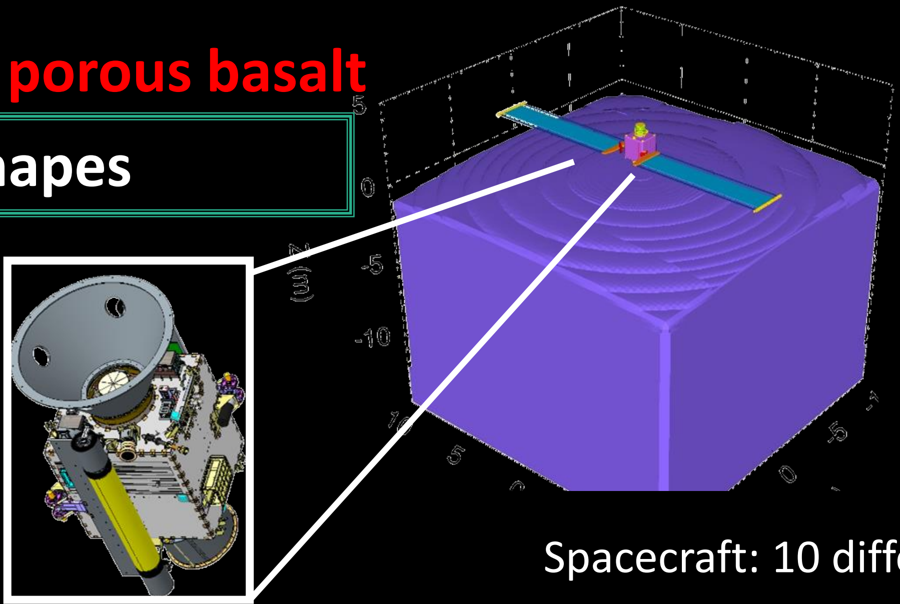
Mass = 1.3x10^9 kg

Material

30% porous basalt

2D/3D Impactor Shapes





Asteroid Equation of State: Sesame

Bulk density = 2.65 g/cc

Porous density = 1.8536 g/cc (30% porosity)

Pore compaction pressure = 280 MPa

P-alpha describes pore crushing process

Base Asteroid Strength

Model: Brittle Damage with Localized Thermal Softening (BDL-Basalt)

Cohesion of intact material: 90 MPa

Limiting strength: 3.5 GPa

Tensile/spall strength: -10 MPa

Impactor Properties

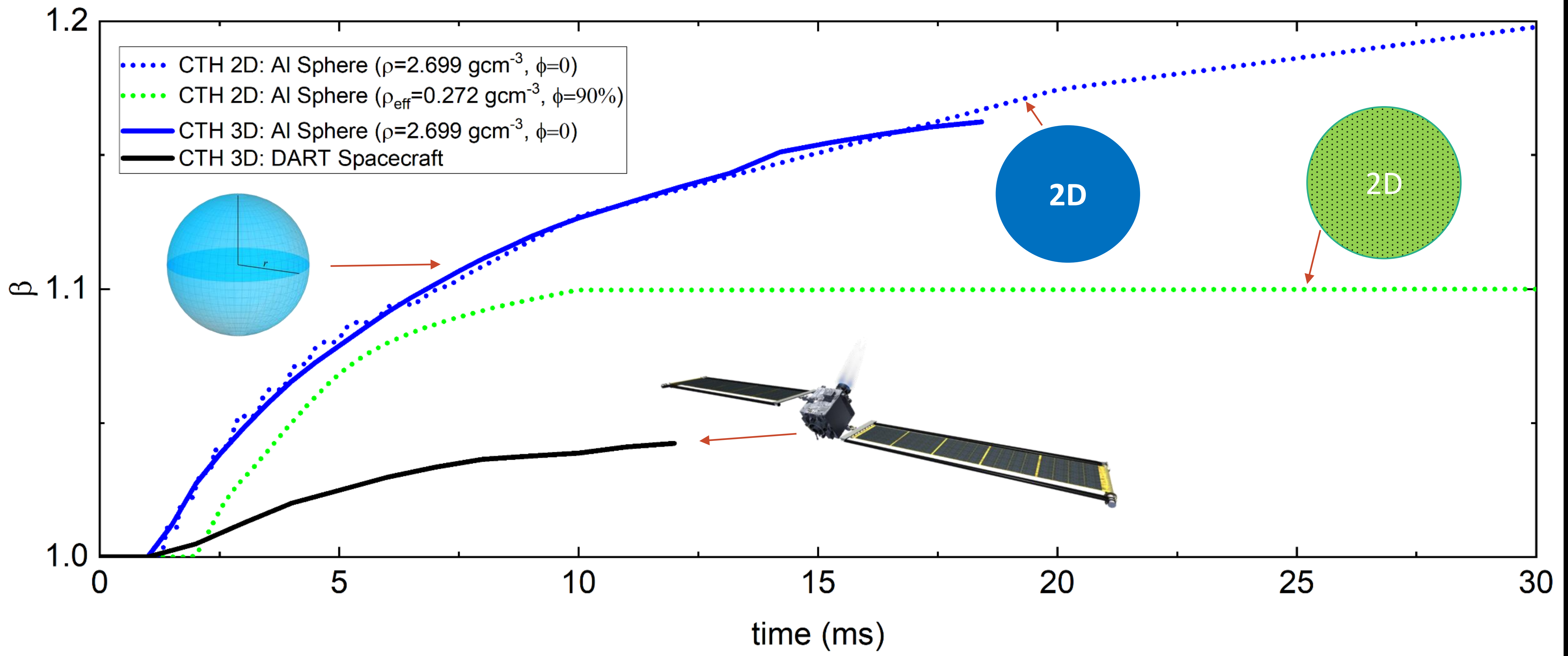
Mass = 550 kg

Velocity = 6.65 km/s

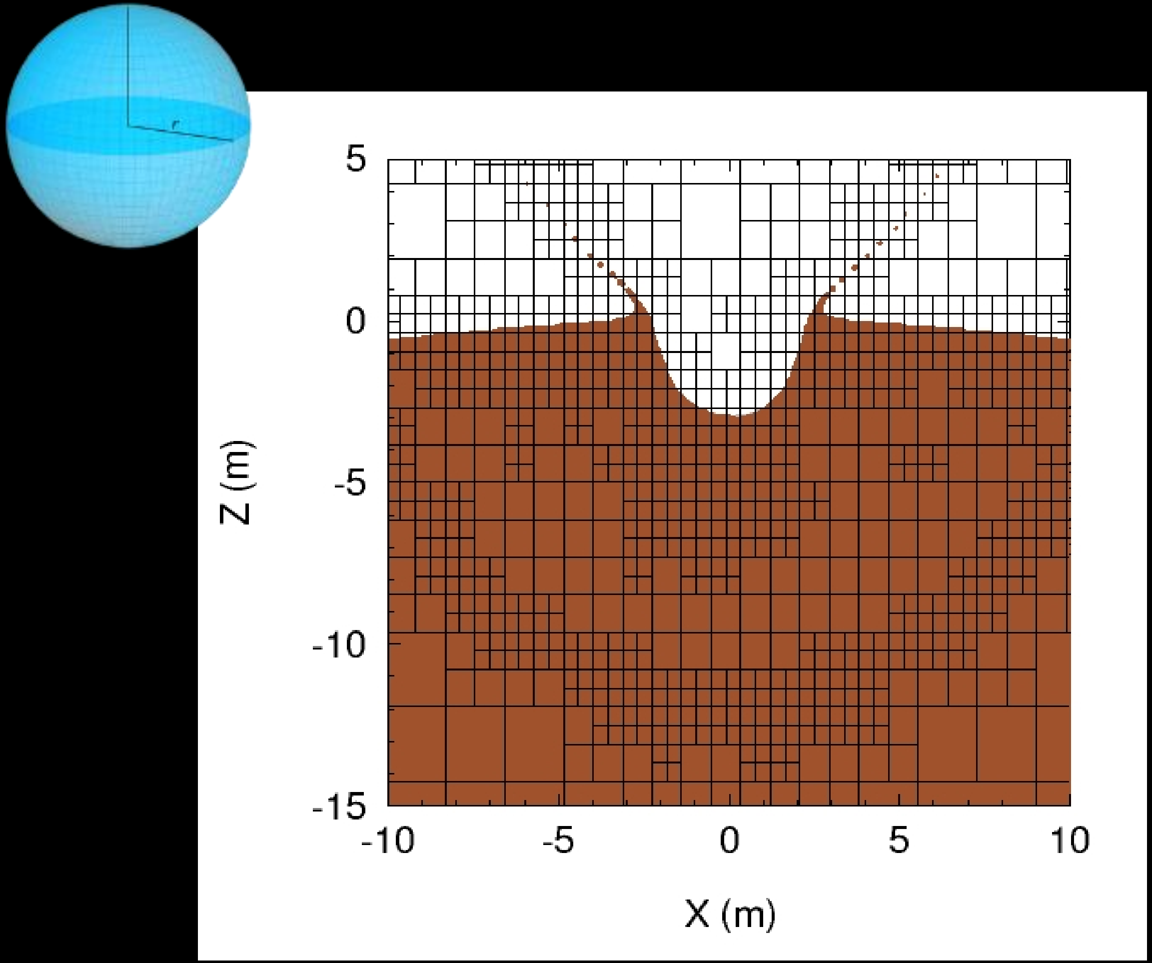
Simple shapes: Fully dense Aluminum

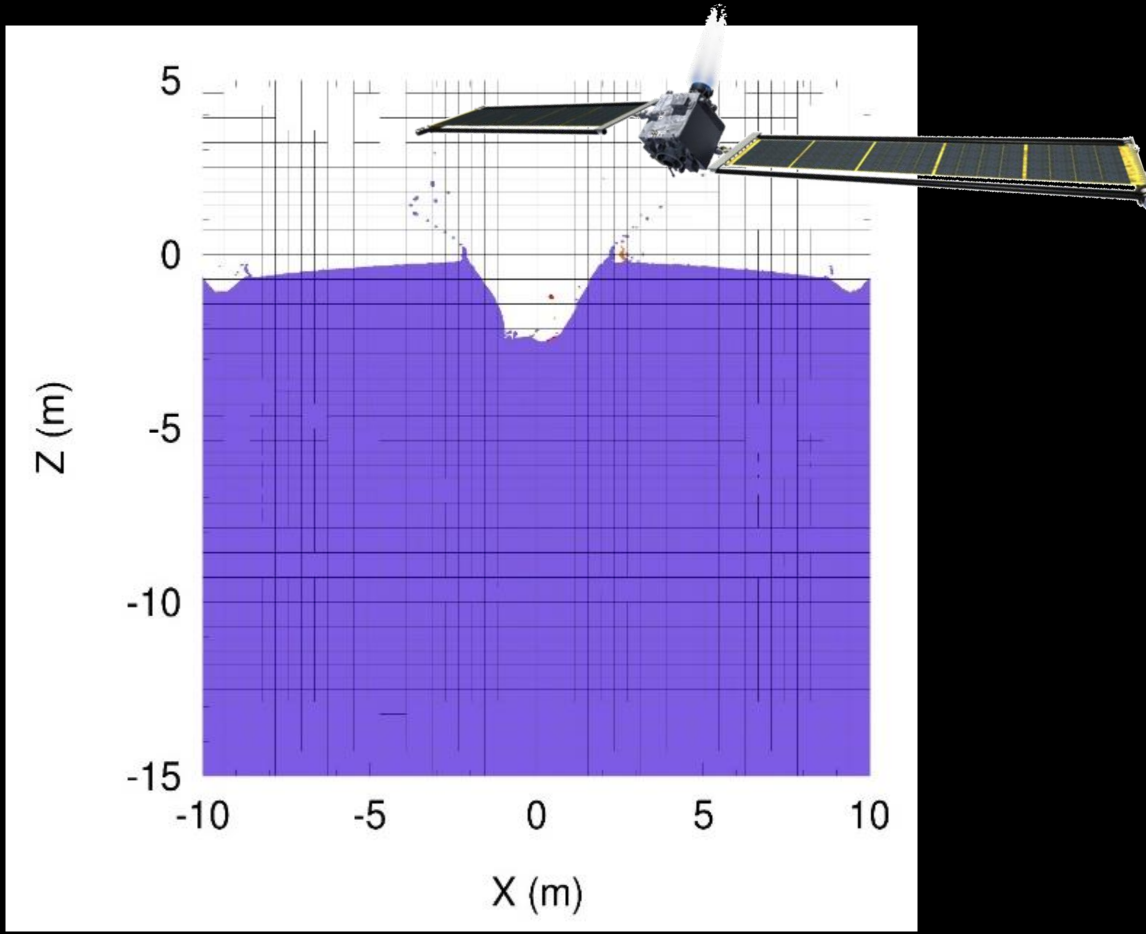
Spacecraft: 10 different materials (Al, Al alloys, steel, oxides, water, xenon)

The temporal evolution of β for the 2D and 3D spheres are very similar. The momentum enhancement for the 3D sphere over predicts the spacecraft β by ~10%.

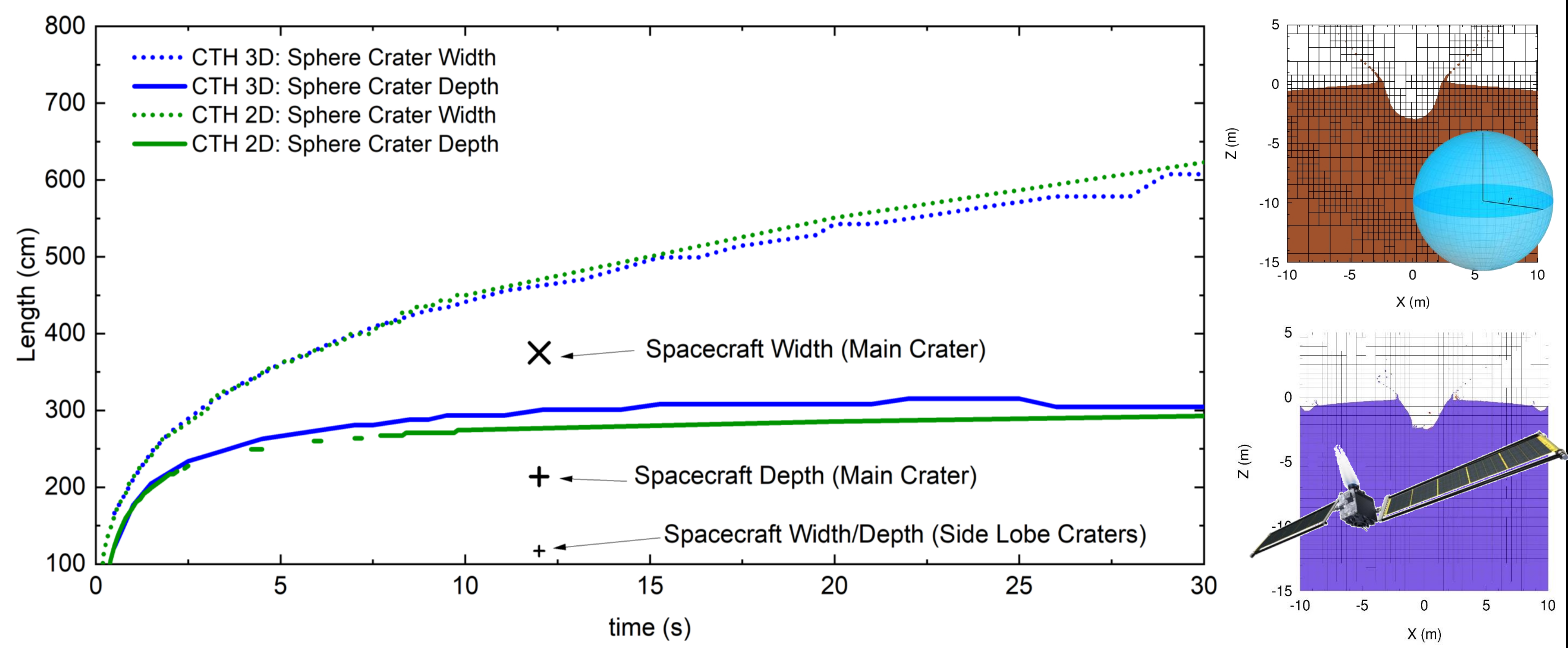


The temporal crater evolution of the 3D spacecraft is much different than the 3D sphere. In contrast to a singular transient crater that is wider than it is deep, the spacecraft produces a very complex-looking crater shape with side lobes.

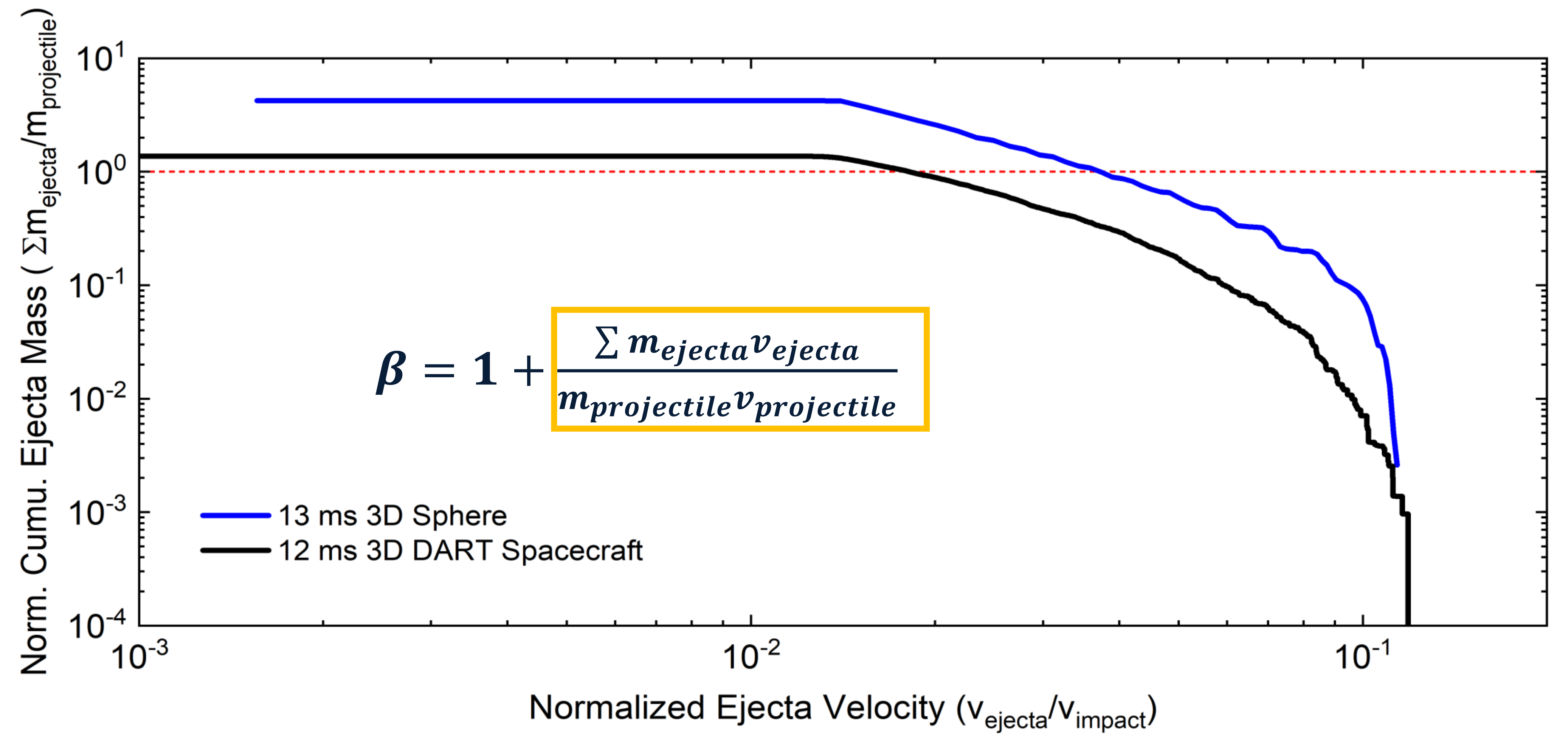




All impactors produce craters that are wider than they are deep. The sphere's crater is symmetrical while the spacecraft results in a more complex crater that is not as deep or wide as the sphere.

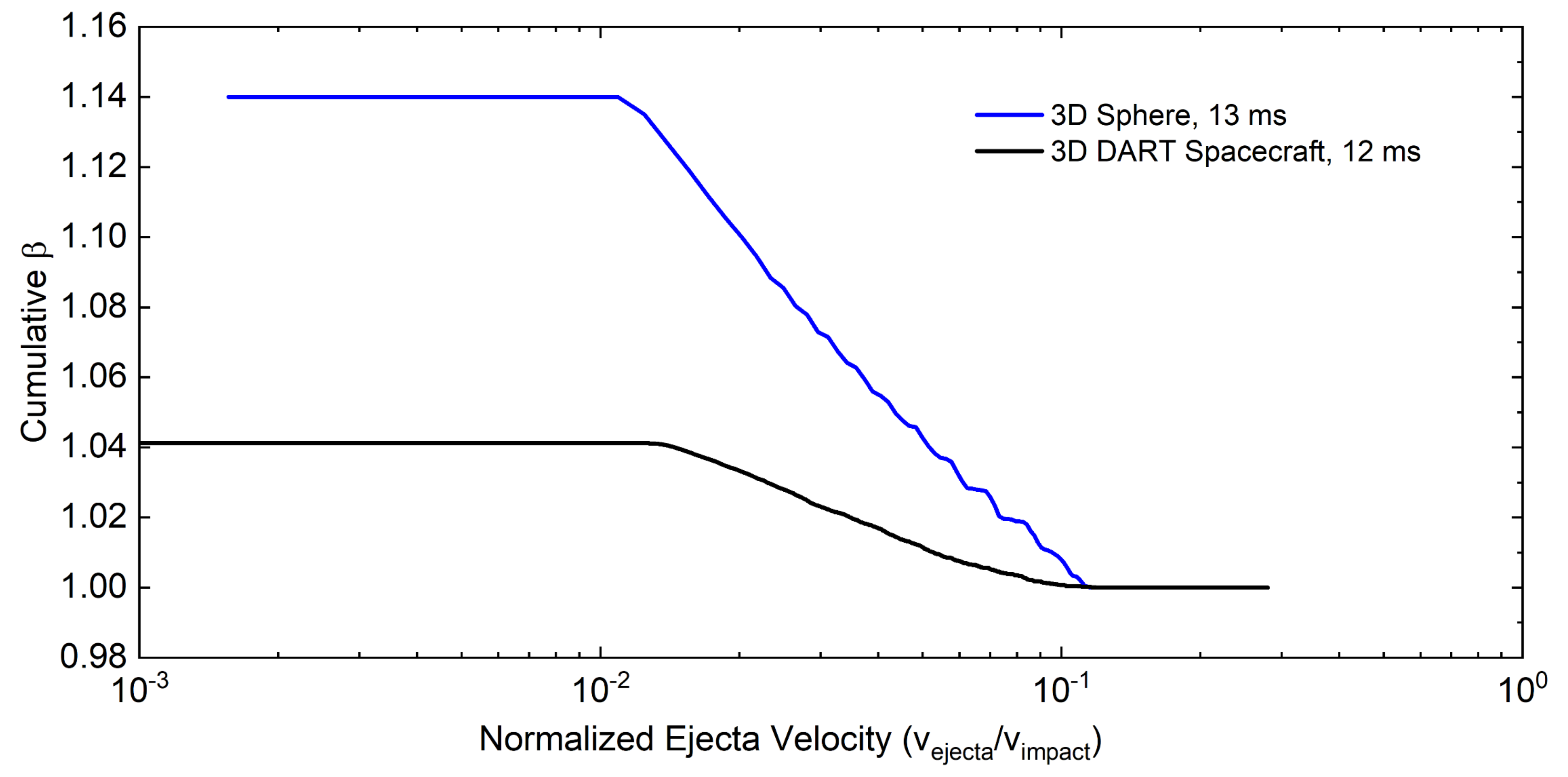


The 3D DART spacecraft produces ~3x less ejecta mass than the sphere, which is responsible for the smaller β. Our results suggest a fully dense Al sphere projectile excessively over predicts β for the DART intercept event.

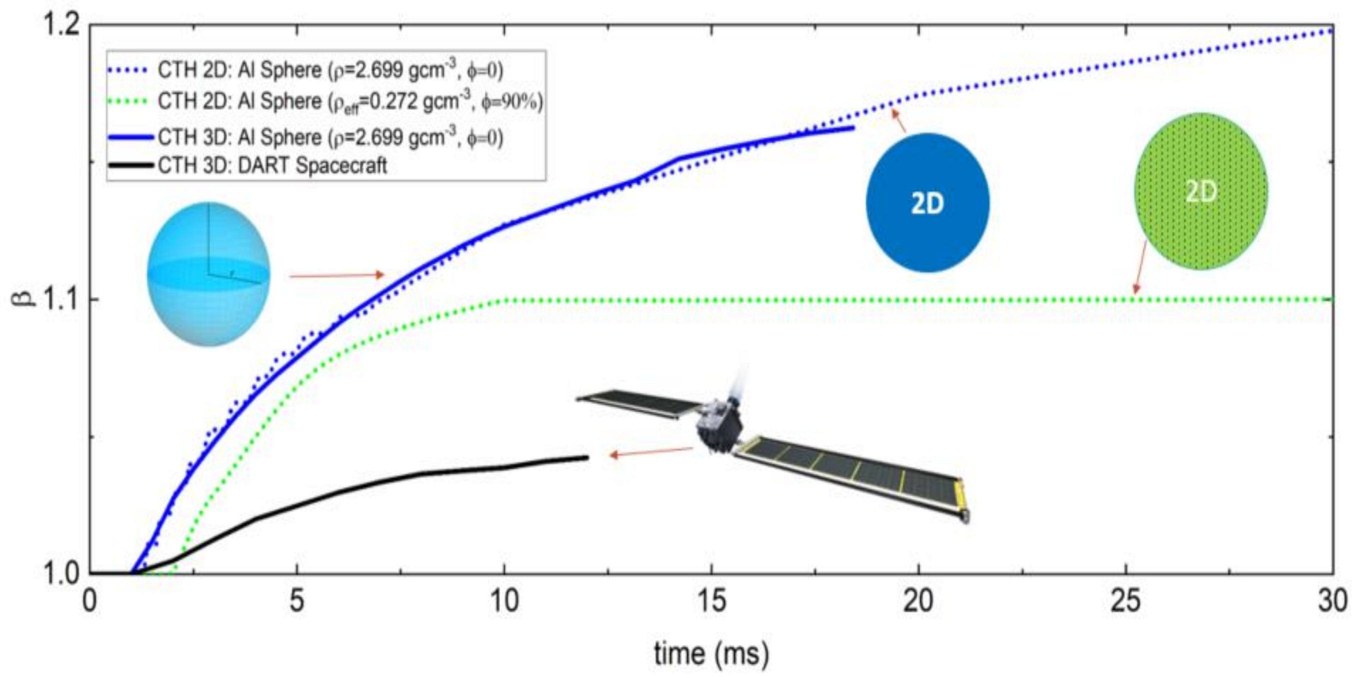


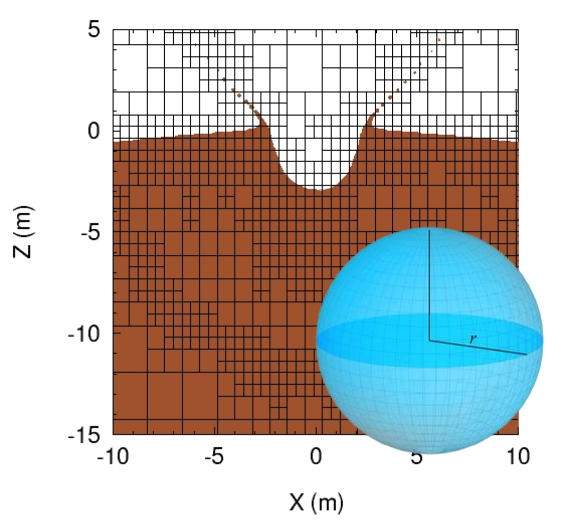
$$\beta = 1 + \boxed{\frac{\sum m_{ejecta} v_{ejecta}}{m_{projectile} v_{projectile}}}$$

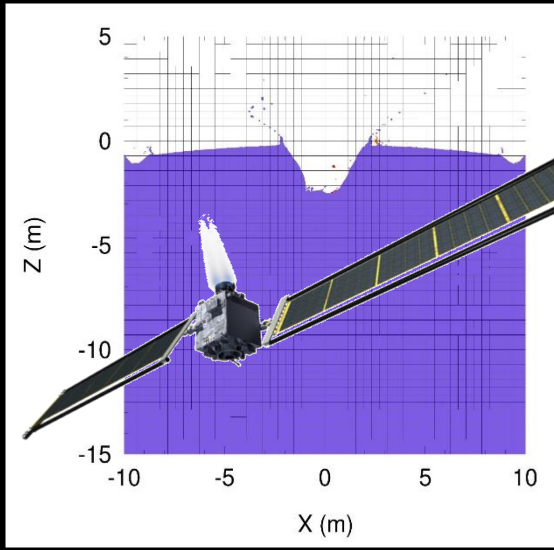
The sphere projectile creates a very different ejecta cloud compared to the spacecraft. While the range of ejecta velocities are similar, the ejecta formed from the sphere has a higher population of fast moving material.



Conclusion: The results show that a simplified model of the projectile over predicts β by ~ 10%. The sphere is a more efficient projectile resulting in more total ejecta mass and a larger population of fast moving material.







This study investigates the effects of projectile geometry on the momentum enhancement factor (β) for efficiently simulating the DART hypervelocity impact.

Contact Information:

Mallory E. DeCoster
Space and Missile Defense Applications Group
Johns Hopkins University Applied Physics Lab
11100 Johns Hopkins Rd.
Laurel, MD 20723-6099
Office: 240-228-2351
e-mail: Mallory.decoster@jhuapl.edu

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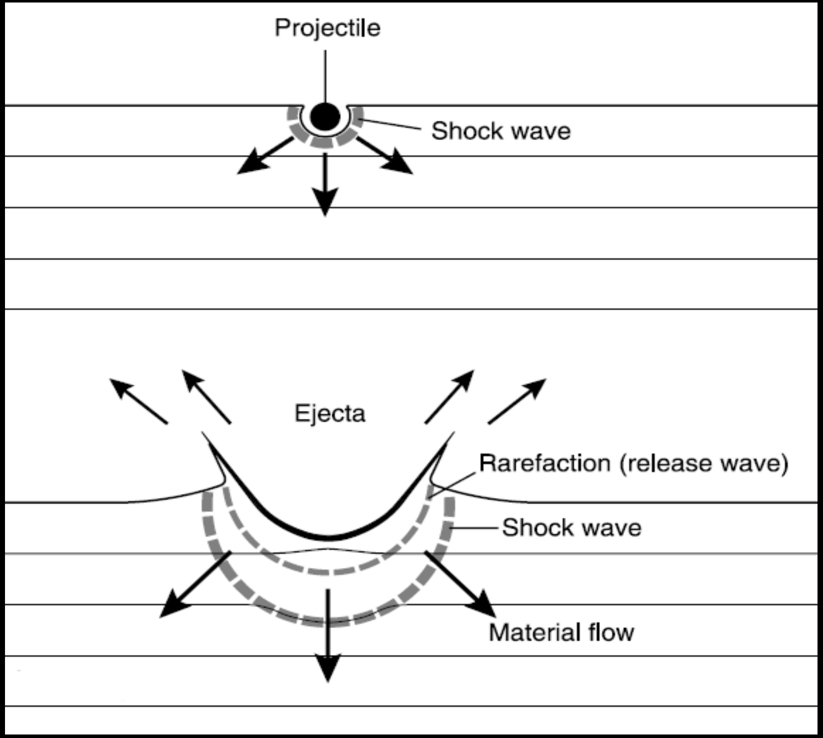
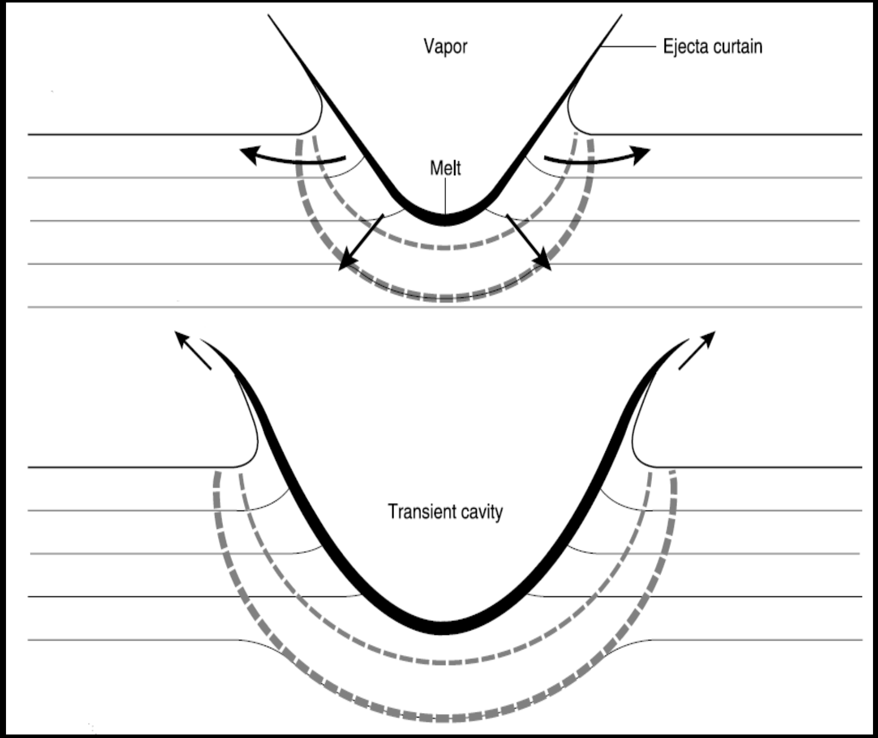
Backups

The processes which form large impact craters resulting from hypervelocity impacts are not fully known. We'd like to understand if the projectile can be represented as a simplified point source to make modeling more efficient.

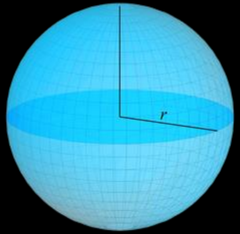


Contact/Compression Stage



Excavation Stage

is



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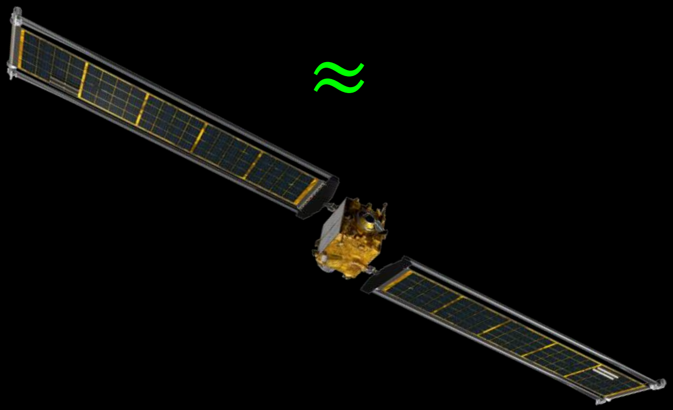

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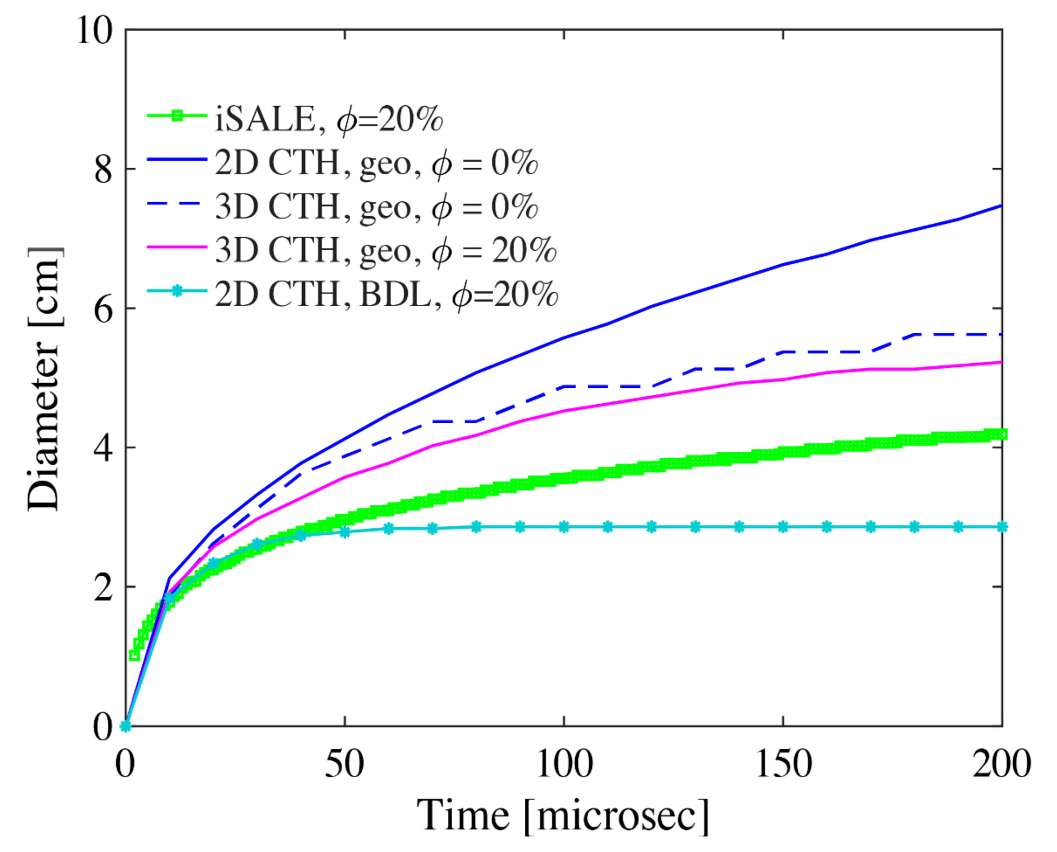
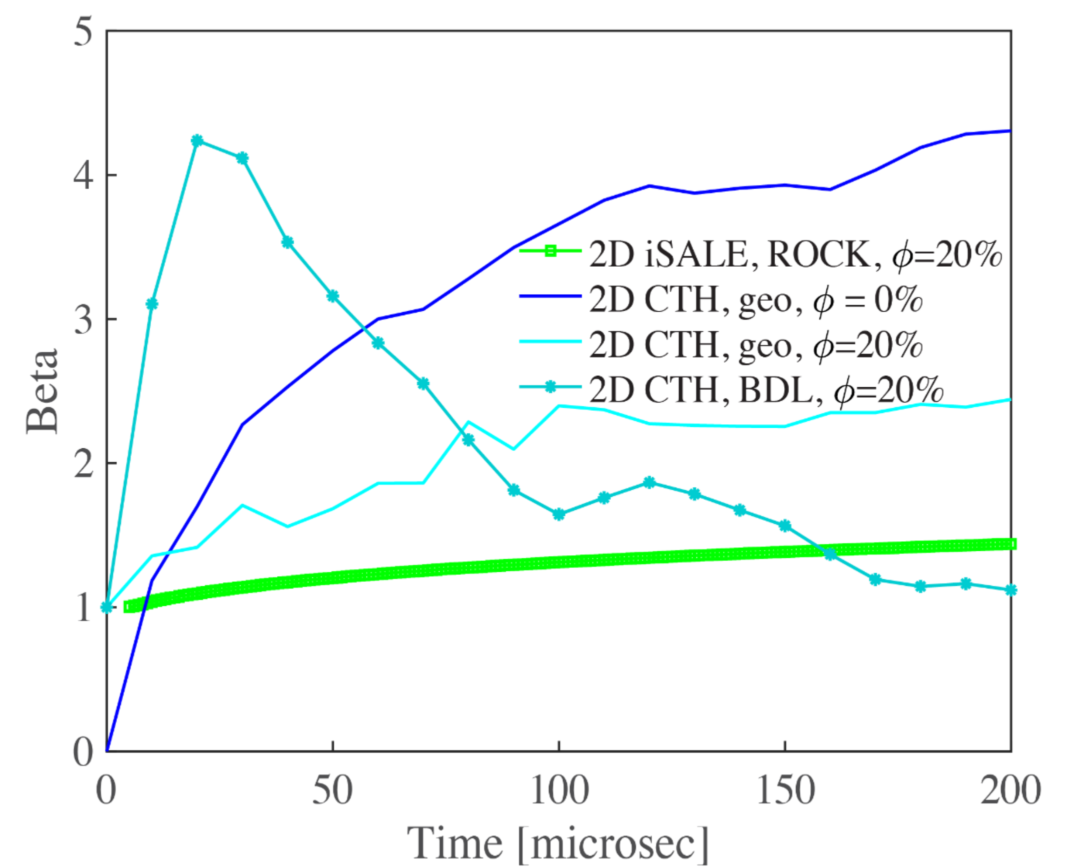
French, *Traces of Catastrophe*, Lunar and Planetary Institute (2003).

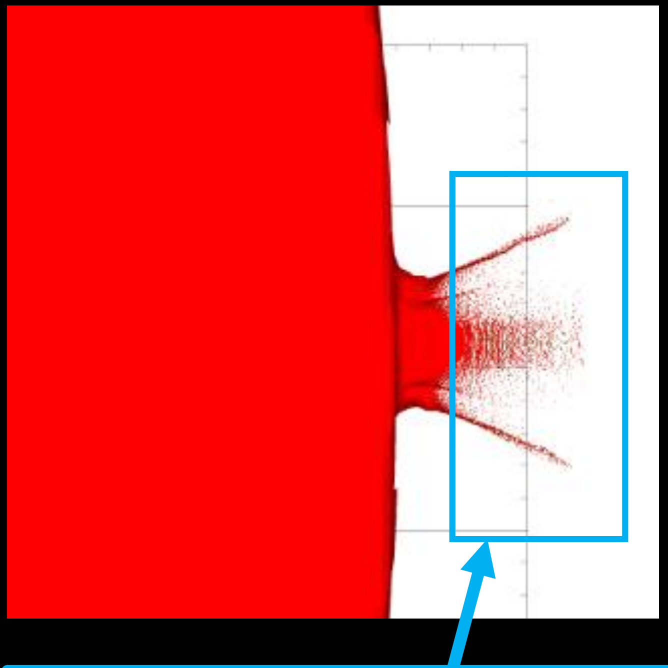
DART benchmarking studies show the propagation of error associated with variables in the phase space. The strength model and material parameters produce the largest uncertainty (~ 20%) in the prediction of crater size and momentum enhancement.



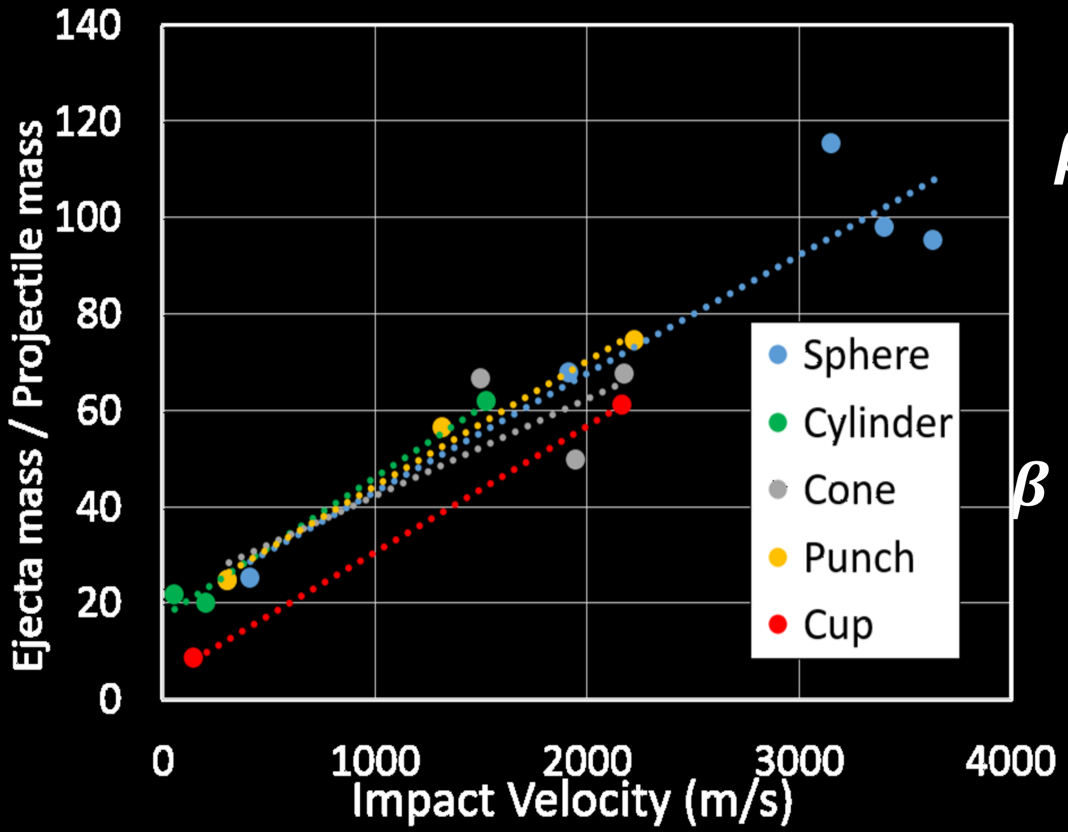


Stickle *et al.*, Icarus 338 (2020) 113446

While it has been shown that β is directly linked to the target material properties, the effects of the projectile geometry on momentum enhancement are relatively unknown. Due to the extra boost provided to β by escaping crater ejecta, it has been suggested that projectile configurations that promote large amounts of ejecta excavation will be more efficient impactors.



Ejecta = any material with mass above 80 cm of impact plane (1% target radius) with positive velocity normal to the impact plane, and a volume fraction < 1.



Ikeda *et al.*, Procedia Engineering 204 (2017) 138-145

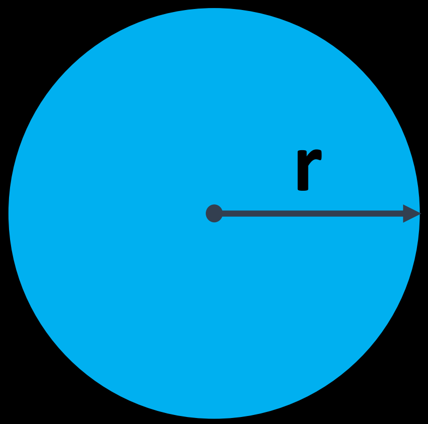
$$\beta = \frac{\Delta P_{Dimorphos}}{m_{projectile} v_{projectile}}$$

$$\beta = 1 + \frac{Total\ Ejecta\ Momentum}{m_{projectile} v_{projectile}}$$

β > 1, maybe >> 1

The simulation parameters defined for the initial 2D CTH tests were adapted from the benchmarking study and performed with no porosity in the basalt target.

Dimorphos (Target) Shape



Sphere

Radius (r) = 80 m

Mass = 1.3×10^9 Kg

Material

Fully dense basalt

Cohesion=90 MPa (strong target)

Asteroid Equation of State: Sesame

$$F(V,T) = \phi_0(V) + F_{ion}(V,T) + F_{el}(V,T)$$

Bulk density = 2.648 g/cc

Base Asteroid Strength

Model: Brittle Damage with Localized Thermal Softening (BDL)

Damage is evolved in Asteroid

2D Impactor Shapes

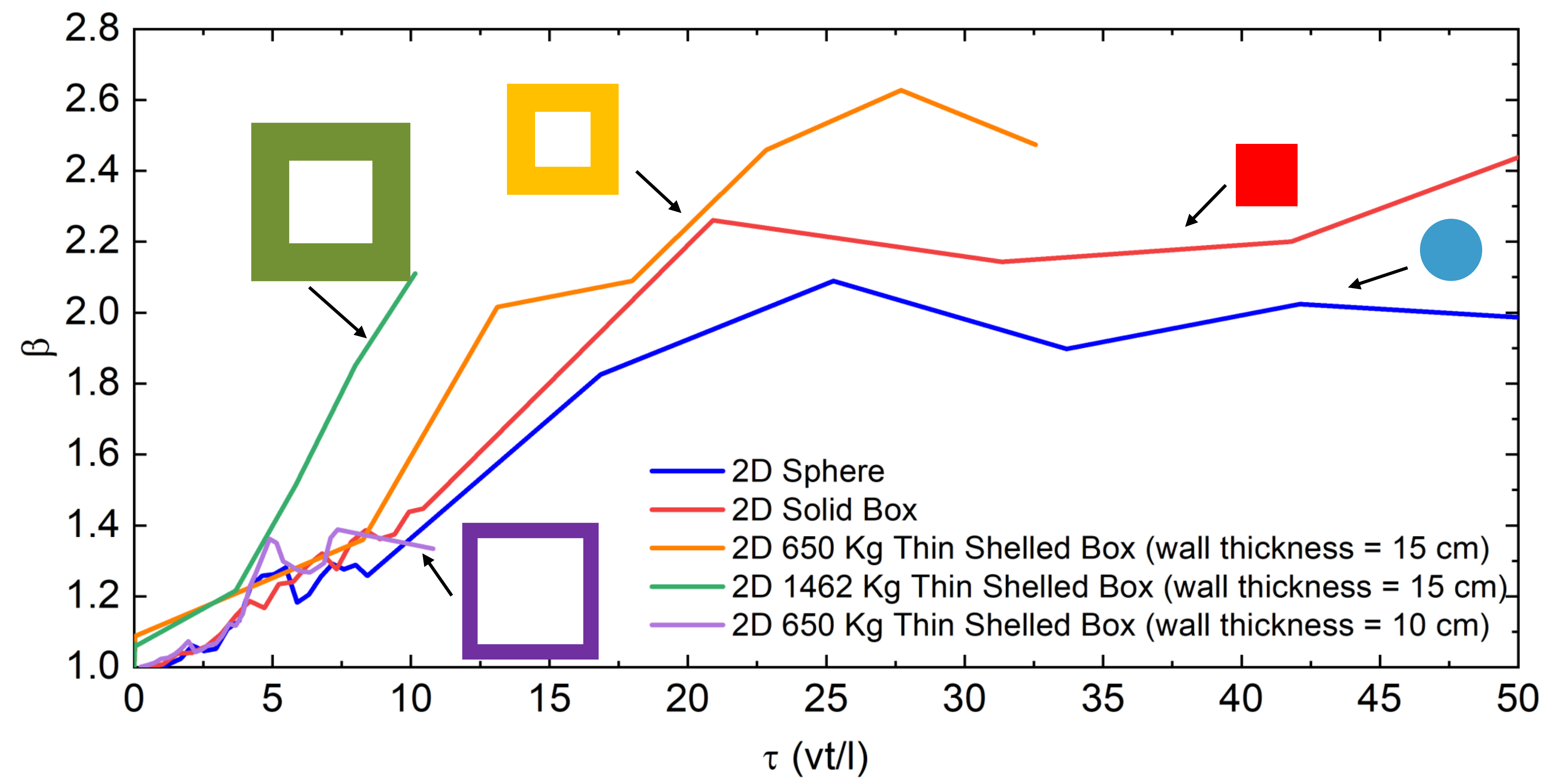
Impactor Properties

Composition: Fully dense Aluminum

Mass = 650 - 1462 Kg

Velocity = 6.65 km/s

The 2D results show that there is not a strong dependence between β and projectile shape when the projectile mass is evenly distributed during impact. A natural question to ask is how does this translate to a more complex projectile shape, like the full spacecraft model with deployed solar panel wings?



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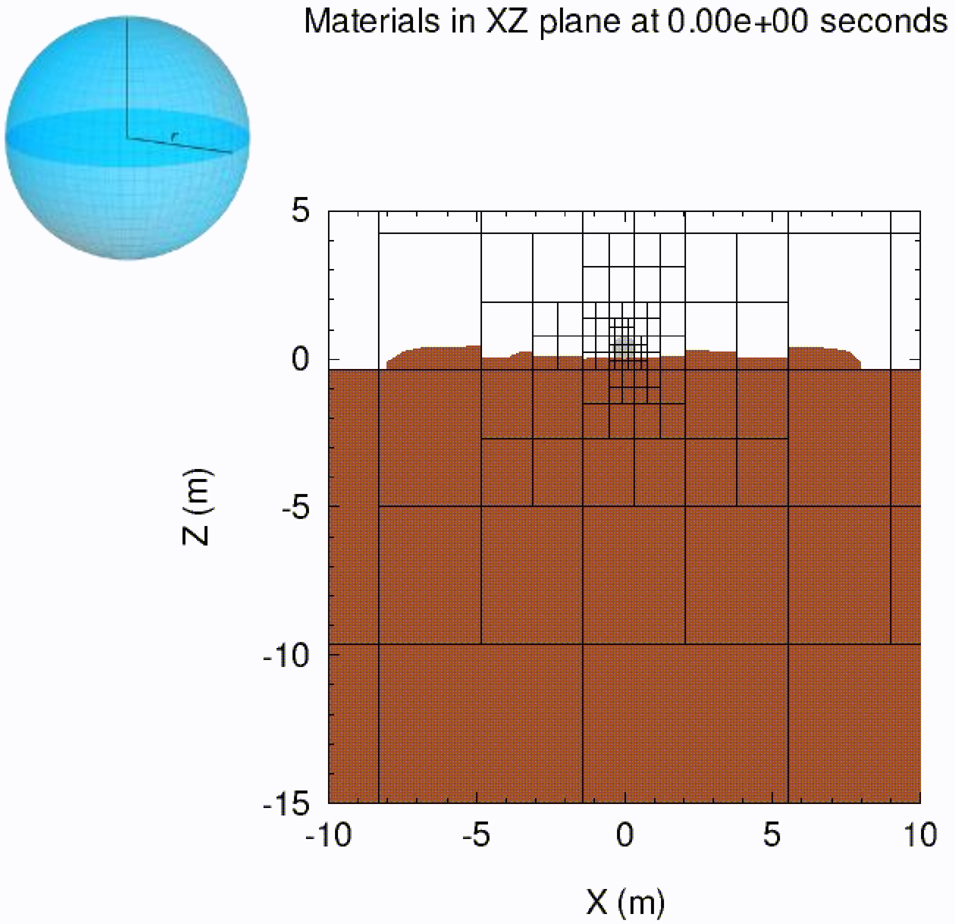

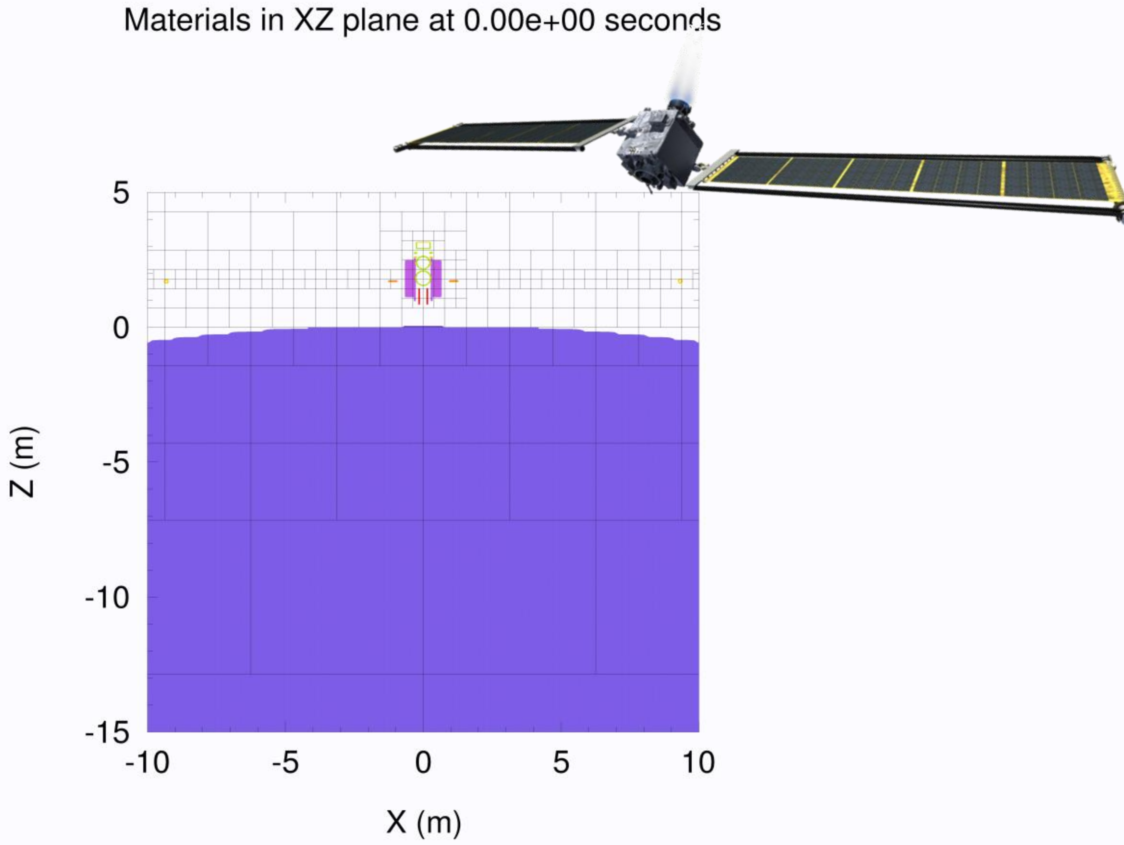

A much more complex crater is created by the spacecraft, as the solar panels contribute to the coupling of the spacecraft to the target .