The Double Asteroid Redirection Test (DART) Impact Modeling Working Group Inverse Test

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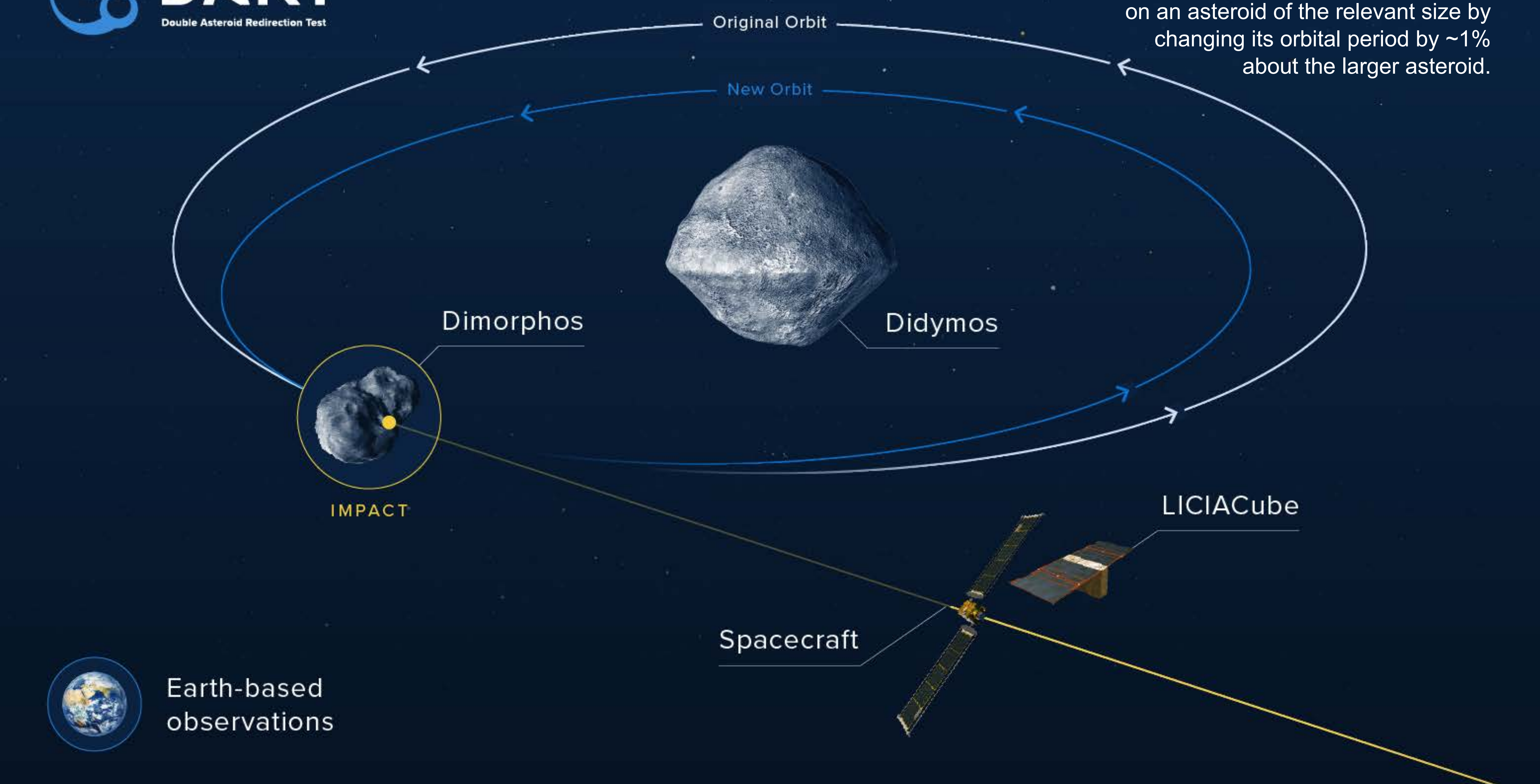
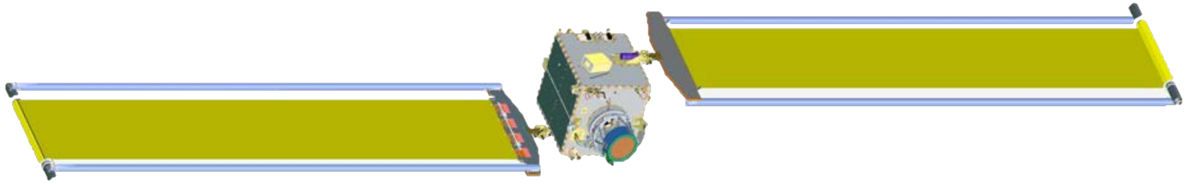
The Ideal Target

It allows a deflection demonstration on an asteroid of the relevant size by changing its orbital period by ~1% about the larger asteroid.

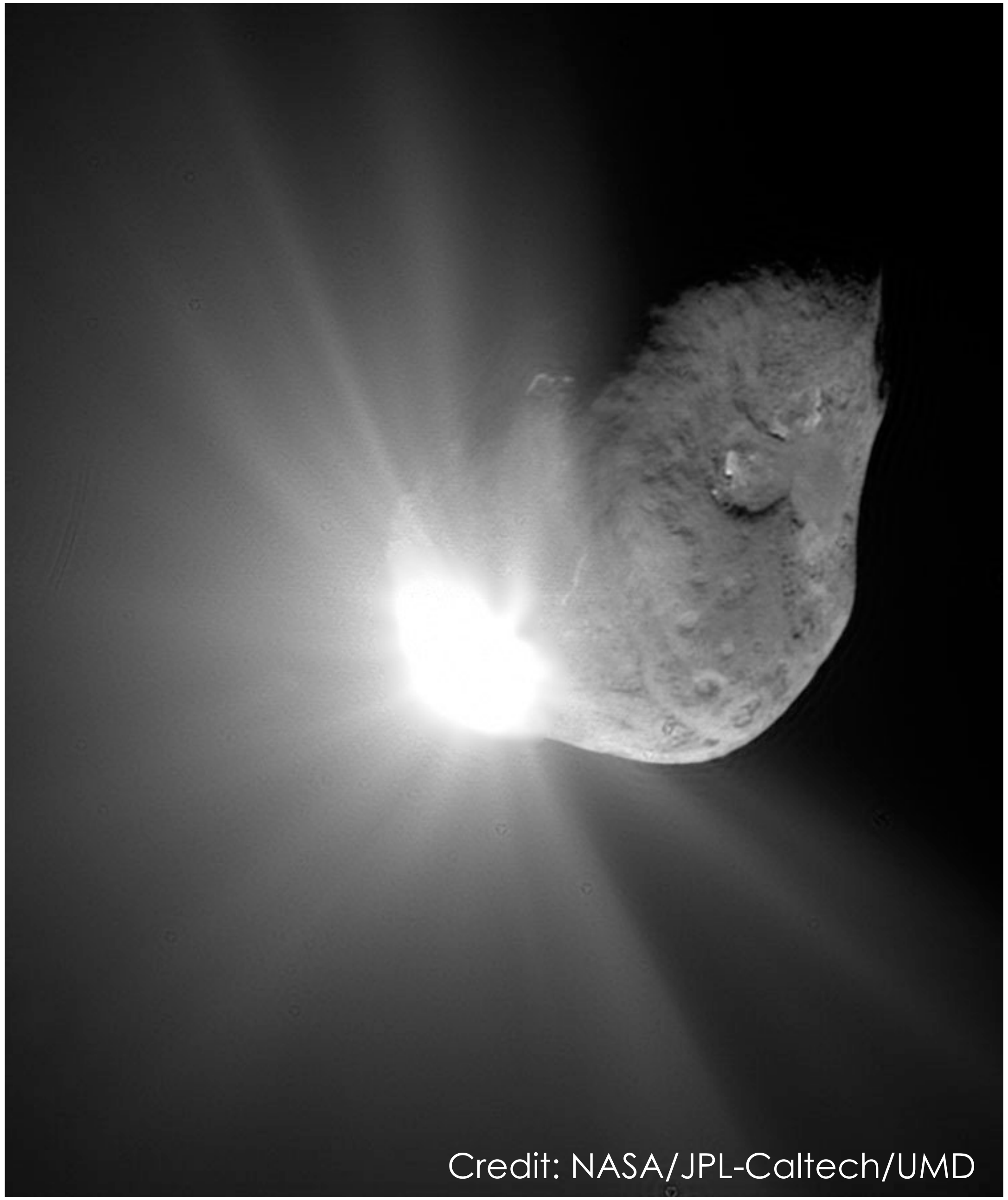


Planetary-scale Impacts Provide Partially Well-controlled Experiments

- The DART impact will join Deep Impact and LCROSS as planetary-scale impact experiments
  - Initial impactor parameters are well known



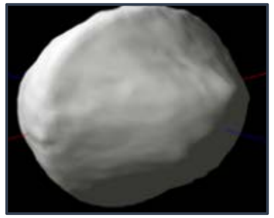
  - Physical properties of Dimorphos are not well constrained



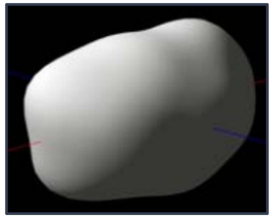
We know little about the object we are going to hit

Dimorphos

?



ID1: kw4a



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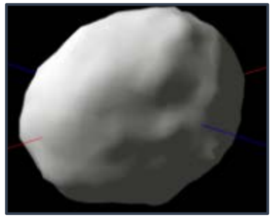
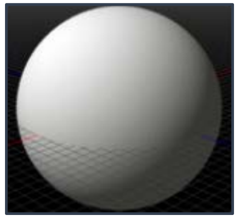
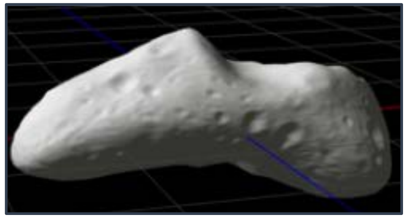


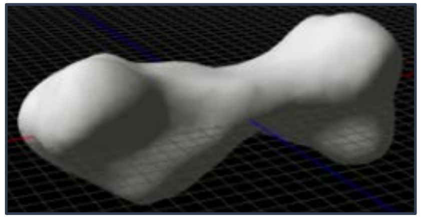
ID6: Rashalom



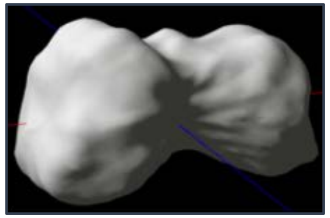
ID7: sphere 1



ID4: Eros



ID5: Kleo



ID3: Mithra

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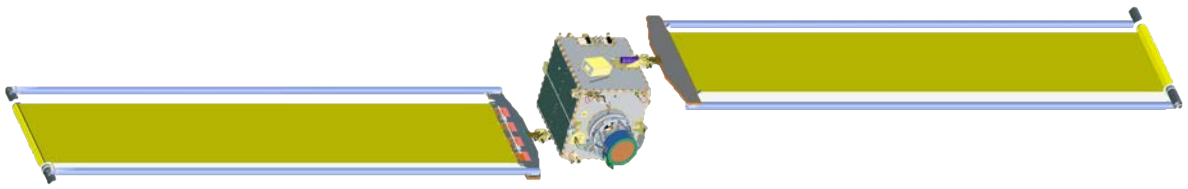
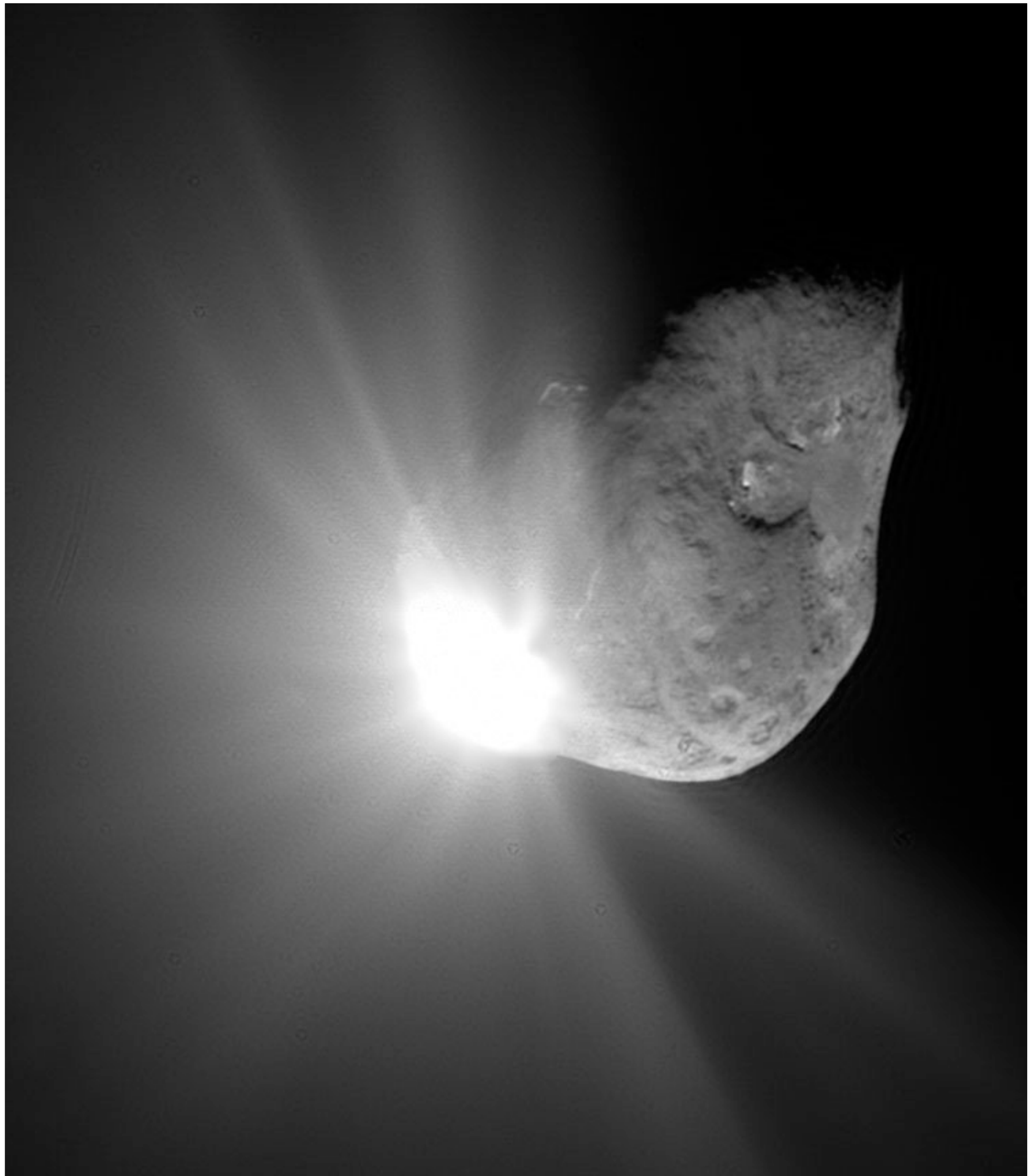
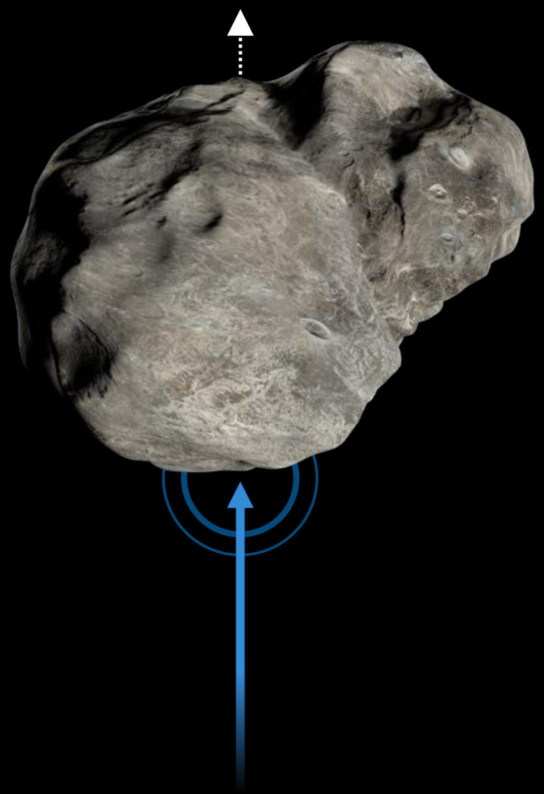


  - Physical properties of Dimorphos are not well constrained
- Understanding the conditions of the DART impact is essential for interpreting the ability of the kinetic impactor to deflect an asteroid (estimating β)



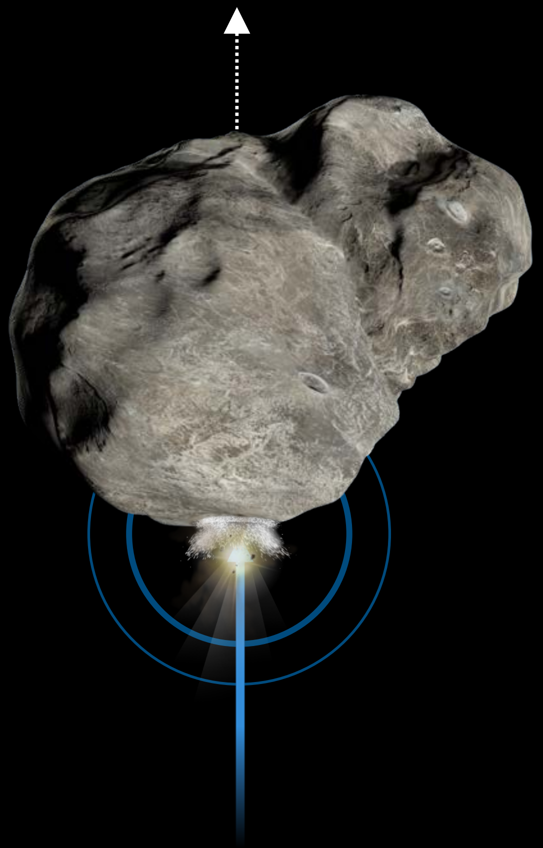
Credit: NASA/JPL-Caltech/UMD

What Is Beta?



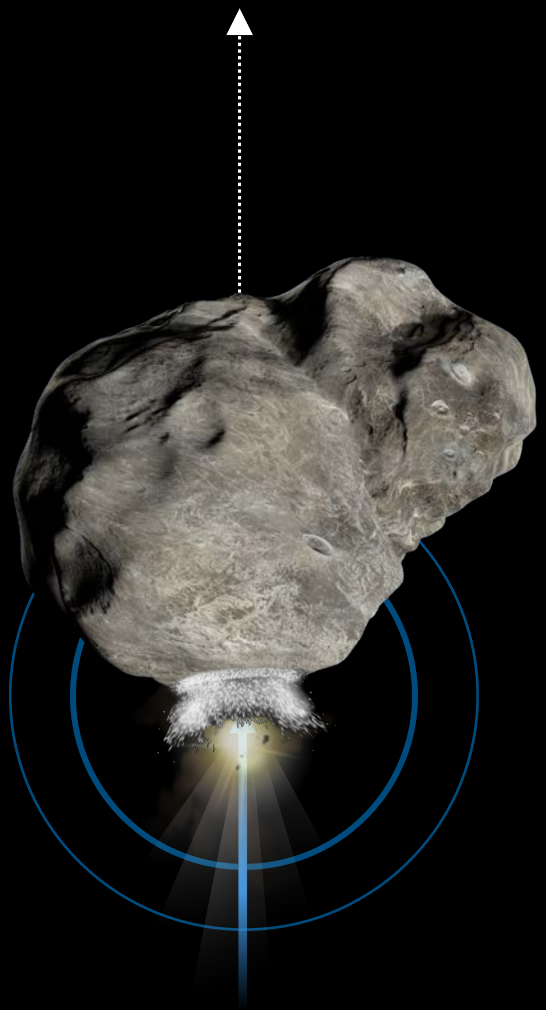
Beta = 1

No ejecta and small momentum increase



Beta = 2

Moderate ejecta and momentum increase



Beta = 4

Heavy ejecta and large momentum increase

The DART Impact Modeling Inverse Test

- Inverse problems tell us about parameters that we cannot directly observe
- Goal: determine the model parameters that best fit a given deflection observation
  - Trial and Error Method
  - Optimization algorithms (see Cody Raskin's talk, next)

Questions we want answered:

- What is the expected uncertainty on β estimates following the DART impact from simulations? How do target property choices affect the predicted values?
- How well can the impact scenario be recreated from limited information?
- Are current data analysis procedure and handoffs adequate or do new tools need to be developed?
- How long do these simulations take to provide answers and how many different simulations need to be run?

DART "Inverse Test" provides a different controlled experiment

Step 1: Set up "observations" → "The Game Masters"/Truth team

Test shape model and impact scene generated by ProxOps team

→ Pass to impact team →

Impact models generate a Δv from a DART impact

→ Work with other working groups →

Turn Δv into an "observed" Δp and period change

Step 2: Simulate post-impact modeling activities → "The Adventurers"

Receive shape model, mass estimate, period change, impact angle, simulated impact site image

→

Use prediction simulations to identify range of possible material parameters

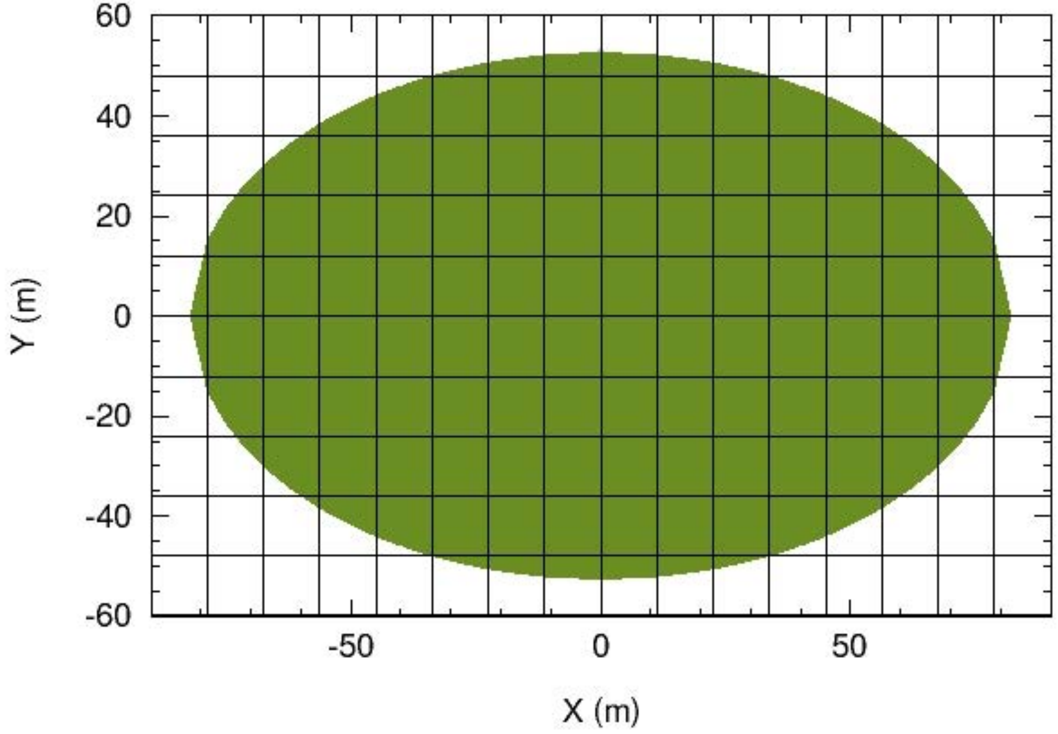
→

Turn Δv into a β with assumed material properties

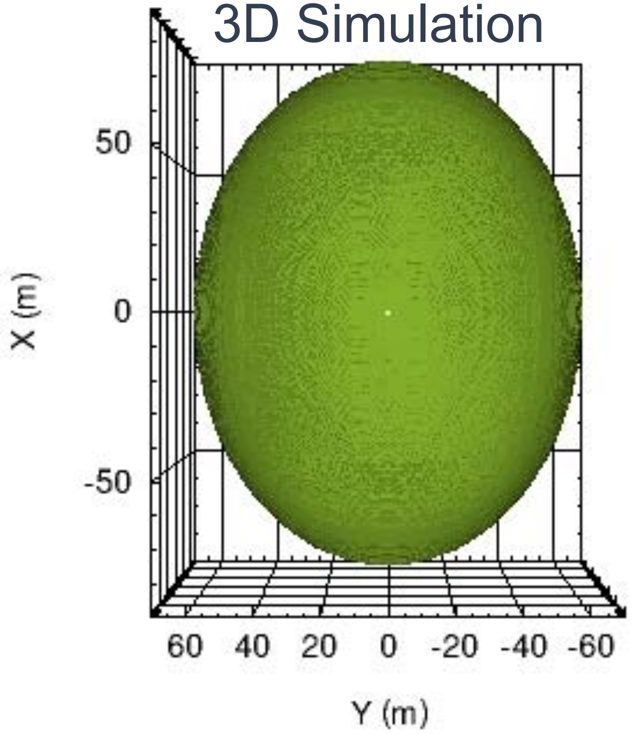
DART Truth Model #1 – simple case

CTH Simulations run by Emma Rainey

2D Simulation



3D Simulation

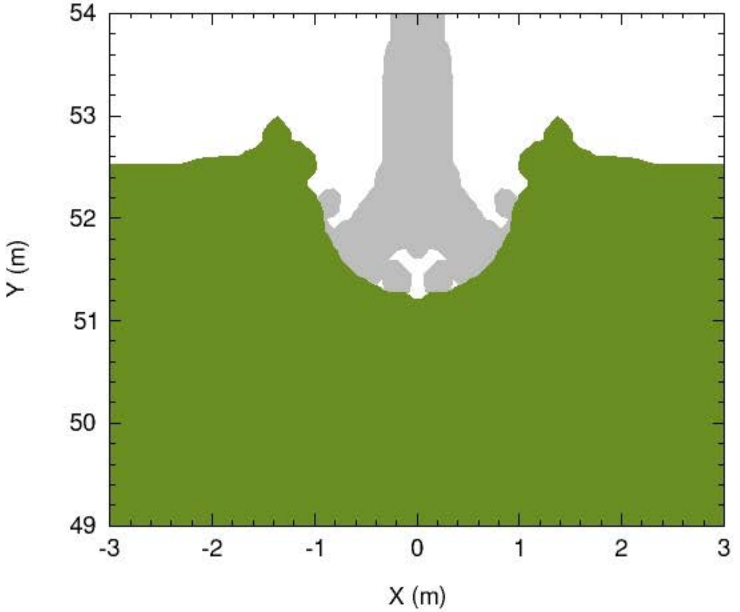


Impactor properties, limited target properties, impact geometry, and deflection velocity were provided to team

DART Truth Model #1 – simple case

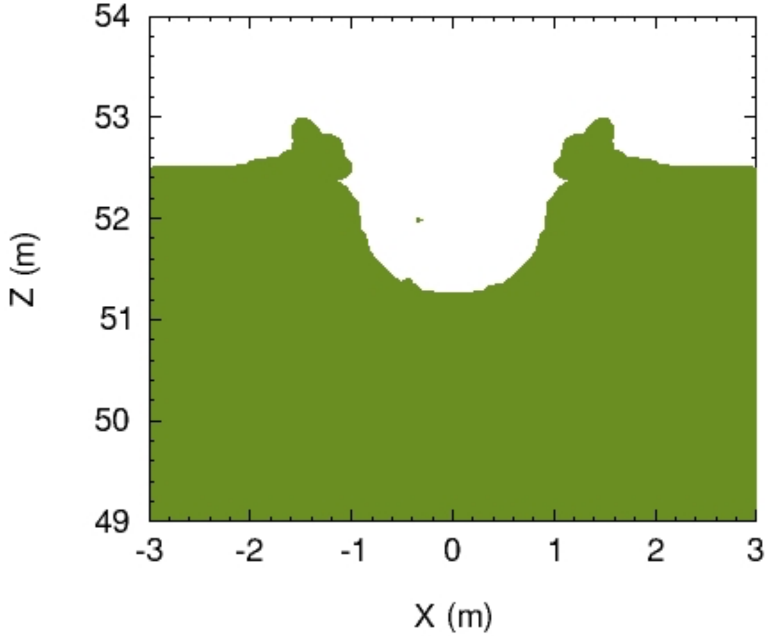
CTH Simulations run by Emma Rainey

2D Simulation



$\Delta v = 0.096 \pm 0.0029$ cm/s

3D Simulation

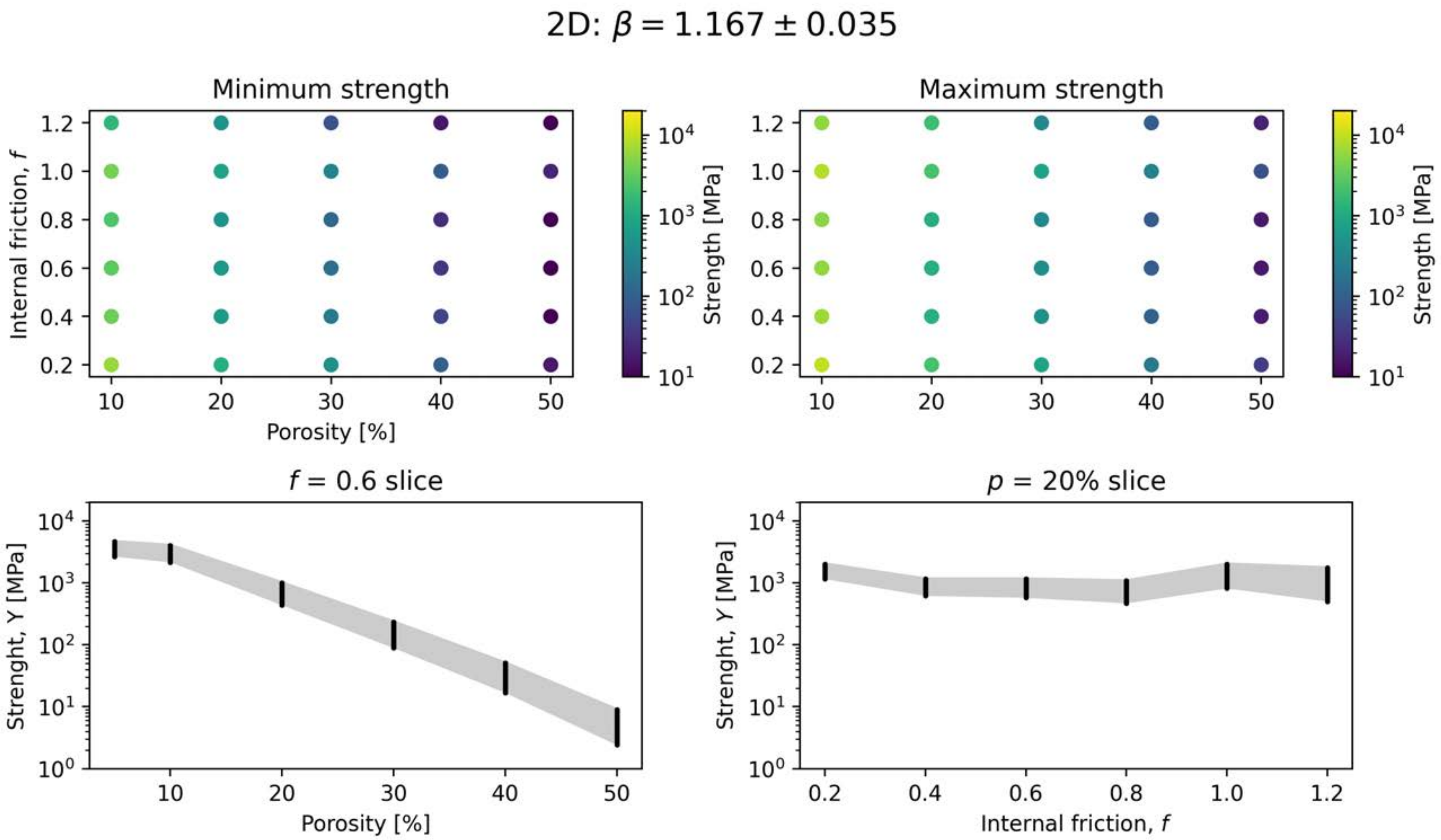


Width = 2.11 m
Depth = 1.20 m

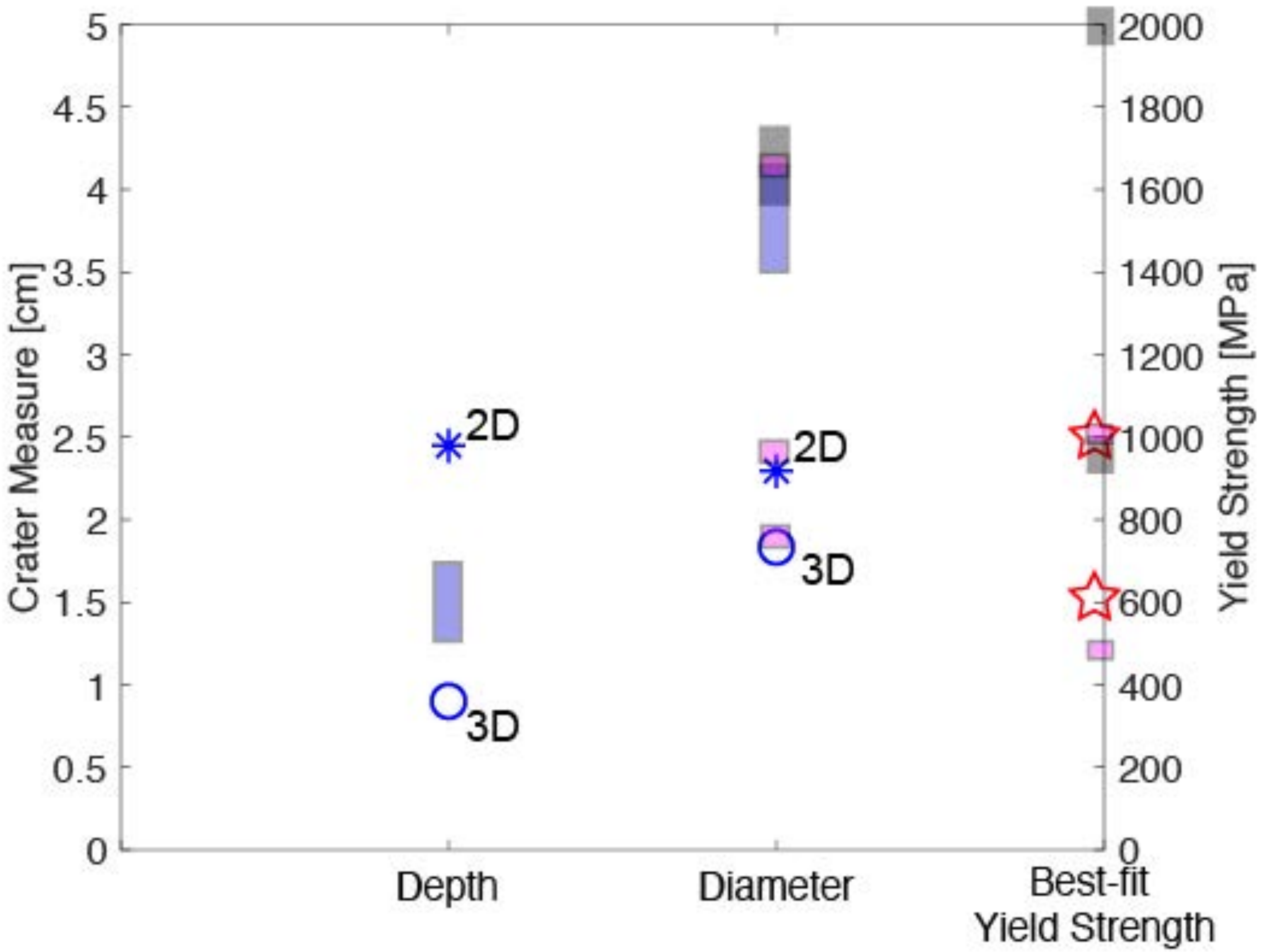
$\Delta v = 0.115 \pm 0.017$ cm/s

Analytic model illustrates that a range of strength/porosity values can give you the same momentum enhancement

Model by Sabina Raducan



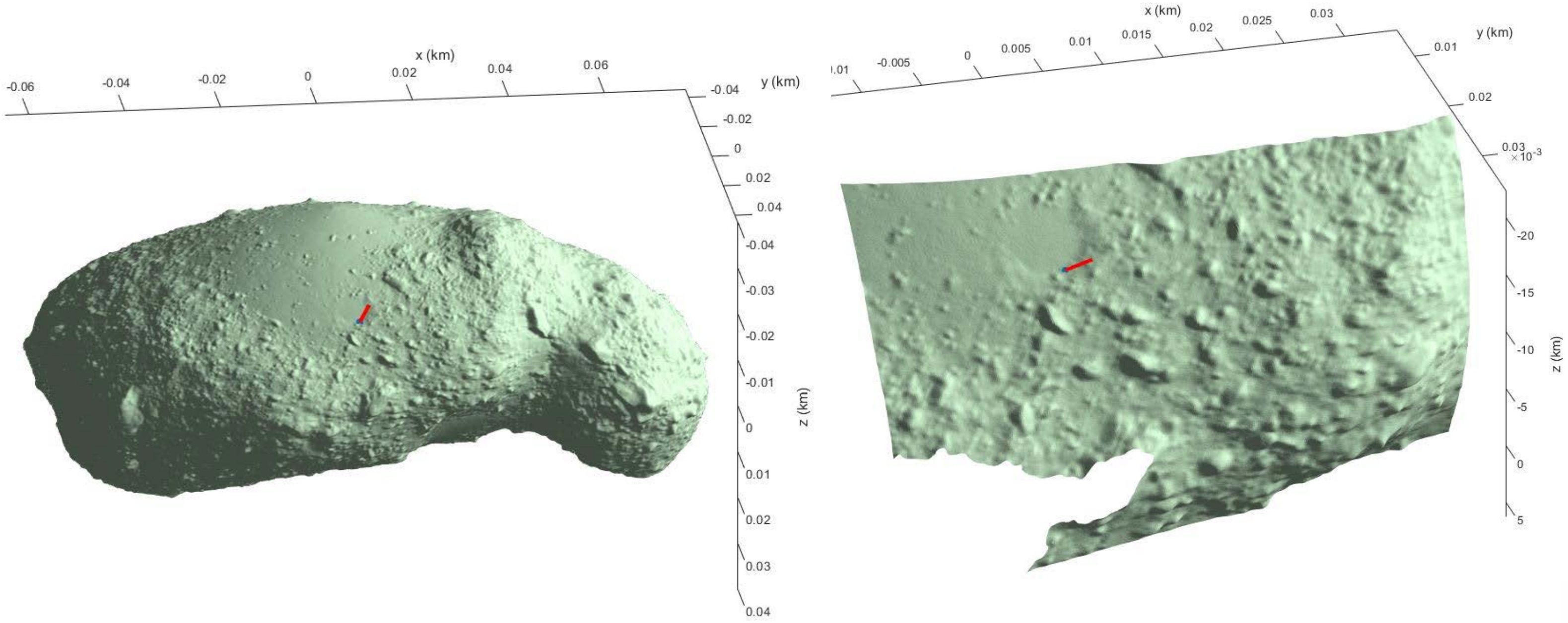
SL WCB diameter ~ 7.5 m



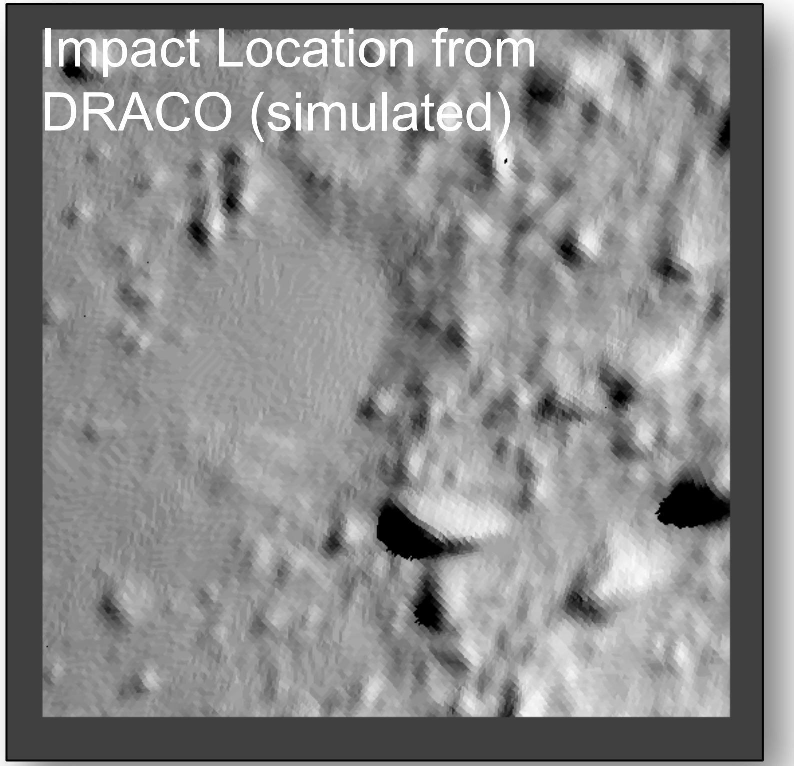
Models by Andy Cheng, Mallory DeCoster, Dawn Graninger, Robert Luther, Mike Owen, Jason Pearl Cody Raskin, Tane Remington

The second exercise provides a more stressing case

Beta will be estimated using procedure determined by DART team



Impact Location Plotted on STL



Truth models still in construction. Stay tuned!

Implications for DART

- Values provided to the team and specific hand-off procedures are vital to test before impact
- We know that β is not uniquely tied to one set of material parameters
  - Other information (e.g., crater size) is vital to limit range of possible values
  - Modeling work group simulation library provides important limits and starting points for parameters
- Given a deflection velocity, the adventurers were able to reproduce β values within ~10-15% of the "truth" value
  - This is comparable or better than variability due to different codes and/or users [Stickle et al. 2020]
  - Crater size has a larger range, depending on values chosen for strength
- In simple case, all adventurers were able to determine parameters similar to truth
- "Trial and error" methods can reproduce β in this simple case
  - More complex optimization methods could provide more robust answers if more complicated simulations are required? → See Cody Raskin's talk for descriptions of these types of simulations from LLNL
- Inverse test #2 will require more complicated models and provide better constraints on expected uncertainty in post-impact β calculations

DART

Double Asteroid Redirection Test