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APPLIED PHYSICS LABORATORY

Assessing the Capabilities and Limitations of Flyby Missions for Planetary Defense Characterization

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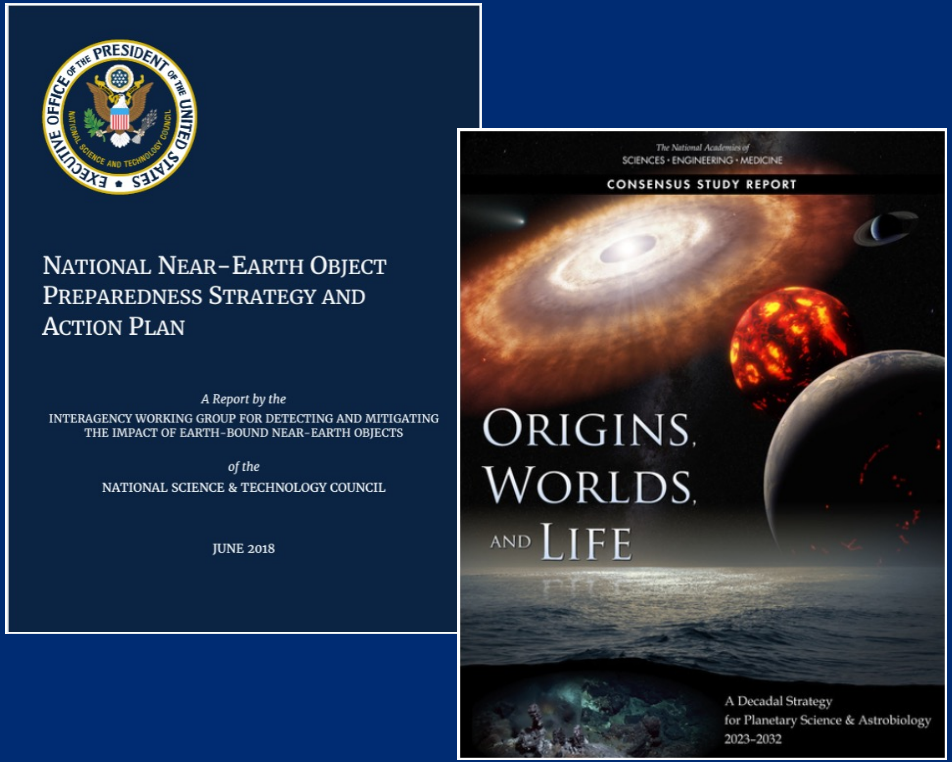
Jodi Berdis, PhD
Hari Nair, Anna Martin, Terik Daly, Carolyn Ernst, Olivier Barnouin,
Justin Atchison, Ry Bull, Angela Stickle, Andy Rivkin

Johns Hopkins University Applied Physics Laboratory, Laurel, MD, USA

Jodi.Berdis@jhuapl.edu

Motivation



	NEO Properties (in ascending order of notional priority for planetary defense analysis)	Measureable via Remote Observations	Measureable During Flyby	Measureable During Rendezvous
1	Heliocentric Orbit State	Y-	Y	Y
2	Mass	N	p	Y
3	Binarity	p	Y	Y
4	Body bounding sphere	p-	p	Y
5	Best-fit triaxial ellipsoid	p-	p	Y
6	Target point on asteroid surface	N	p	Y
7	Topography	N	p	Y
8	Surface roughness within 2-sigma targeting error around surface target point	N	N	Y
9	Rotational State	Y-	p	Y
10	Bulk cohesion	Y-	p	Y
11	Compressive strength	N	N	Y
12	Tensile strength	N	N	Y
13	Shear strength	N	N	Y
14	Bulk porosity	N	N	Y
15	Gravity field (mascons)	N	N	Y
16	Composition	p-	p	Y
17	Volatile inventory and location	N	N	Y

Legend	Y: Yes, usually best quality, usually sufficient.	Y-: Yes, but not necessarily best quality / sufficient	p: partial, may be incomplete / inaccurate / uncertain.	p-: partial, of less quality than "p".	N: No; asteroid property cannot be characterized.

Barbee et al. (2020)

Study Objectives

- Generate real and simulated **imaging datasets that are representative of what an asteroid flyby mission would return** under various encounter conditions.

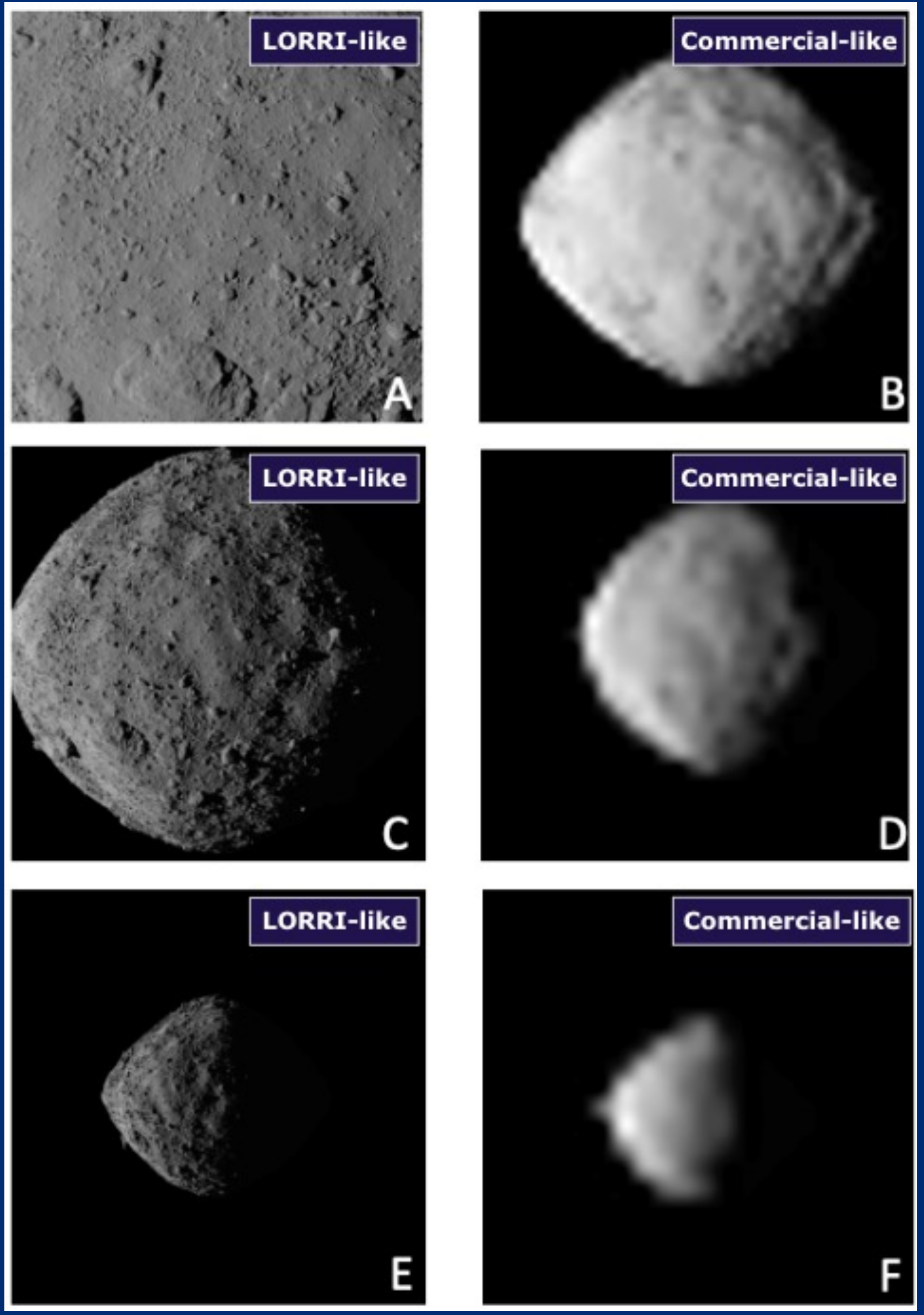
- Analyze the datasets using the tools and methods that would be used in a real-life situation.

- Assess **how well the analyses constrain asteroid properties relevant to planetary defense**, and whether they are sufficient to inform mitigation strategies.

Technique

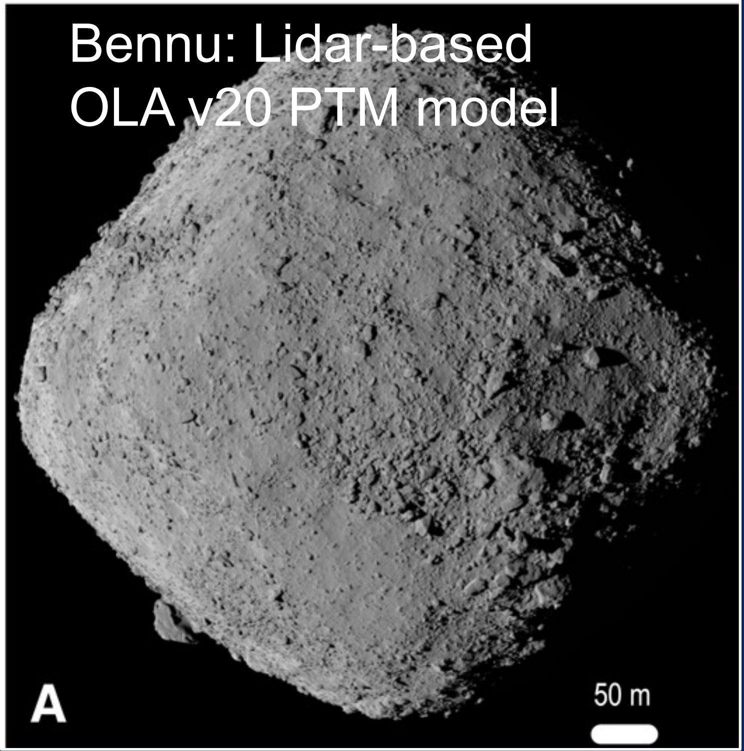
- Encounters
  - Flyby speeds: 5, 10, 15, 20 km/s
  - Closest approach distances: 25, 50, 100 km
  - Phase angles **at closest approach**: 0°, 30°, 60°, 90°, 120°
- Camera types
  - LORRI-like (iFOV = 5 μrad)
  - COTS-like (iFOV = 174.6 μrad)
- Images were simulated at ±128, ±64, ±32, ±16, ±8, ±4, ±2, ±1, ±0 seconds from closest approach

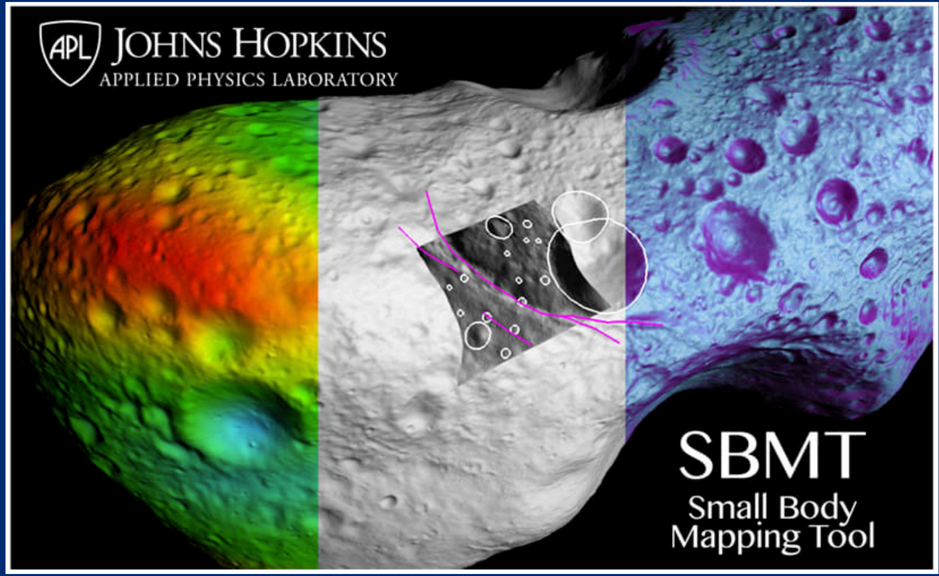
	Closest Approach Distance [km]	Flyby Speed [km/s]	Phase Angle at Closest Approach [°]
Panels A + B	25	15	30
Panels C + D	50	10	60
Panels E + F	100	20	90



Technique

- Stereophotoclinometry (SPC) shape modeling (Gaskell et al. 2008; Barnouin et al. 2020; Palmer et al. 2022; Daly et al. 2022)
  - **Midlatitude Fit** starter model: initial triaxial ellipsoid scaled to match the images near mid-latitudes
  - **Circumscribed** starter model: initial triaxial ellipsoid scaled to encapsulate the body at the equator and the poles
  - **Volume error** calculated: Error of reconstructed shape model compared to truth shape model
  - **Volume improvement** calculated: how much the volume of the reconstructed shape model improved compared to the starter shape model
- Small Bodies Mapping Tool
  - Map craters and boulders

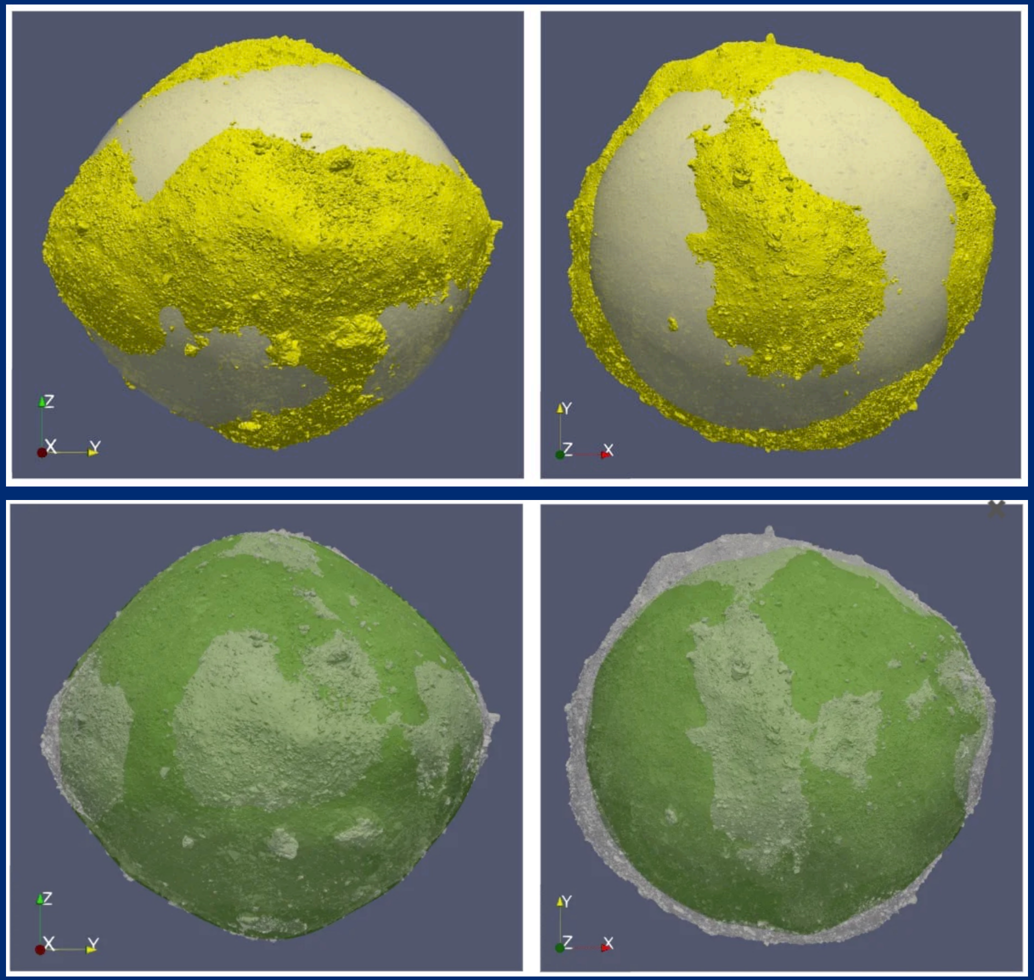




Volume Improvements

<u>Flyby trajectory:</u>
LORRI-like camera
10 km/s speed
50 km closest approach distance
30° phase angle at closest approach

Midlatitude Fit Starter Shape Model



White: Starter triaxial shape

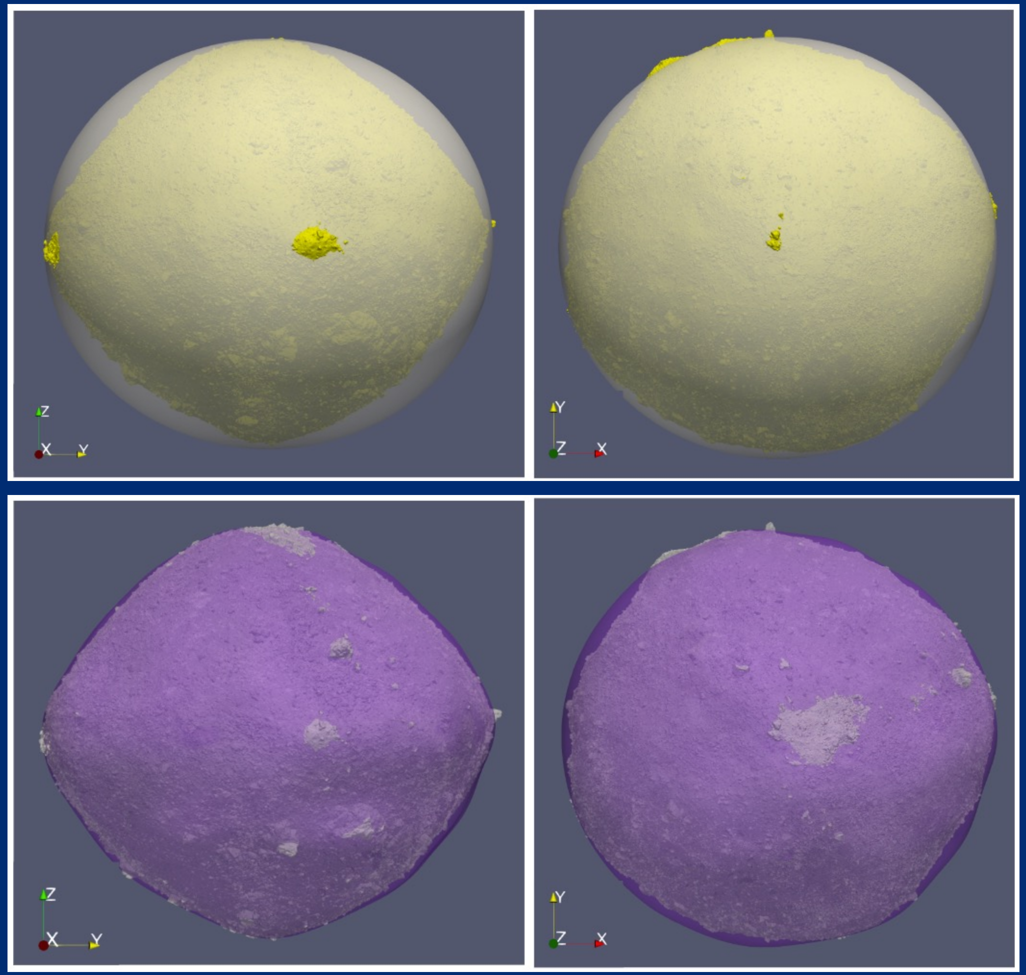
Yellow: True model

Green: Reconstructed shape model (from **Midlatitude Fit**)

Purple: Reconstructed shape model (from **Circumscribed**)

Gray: True model

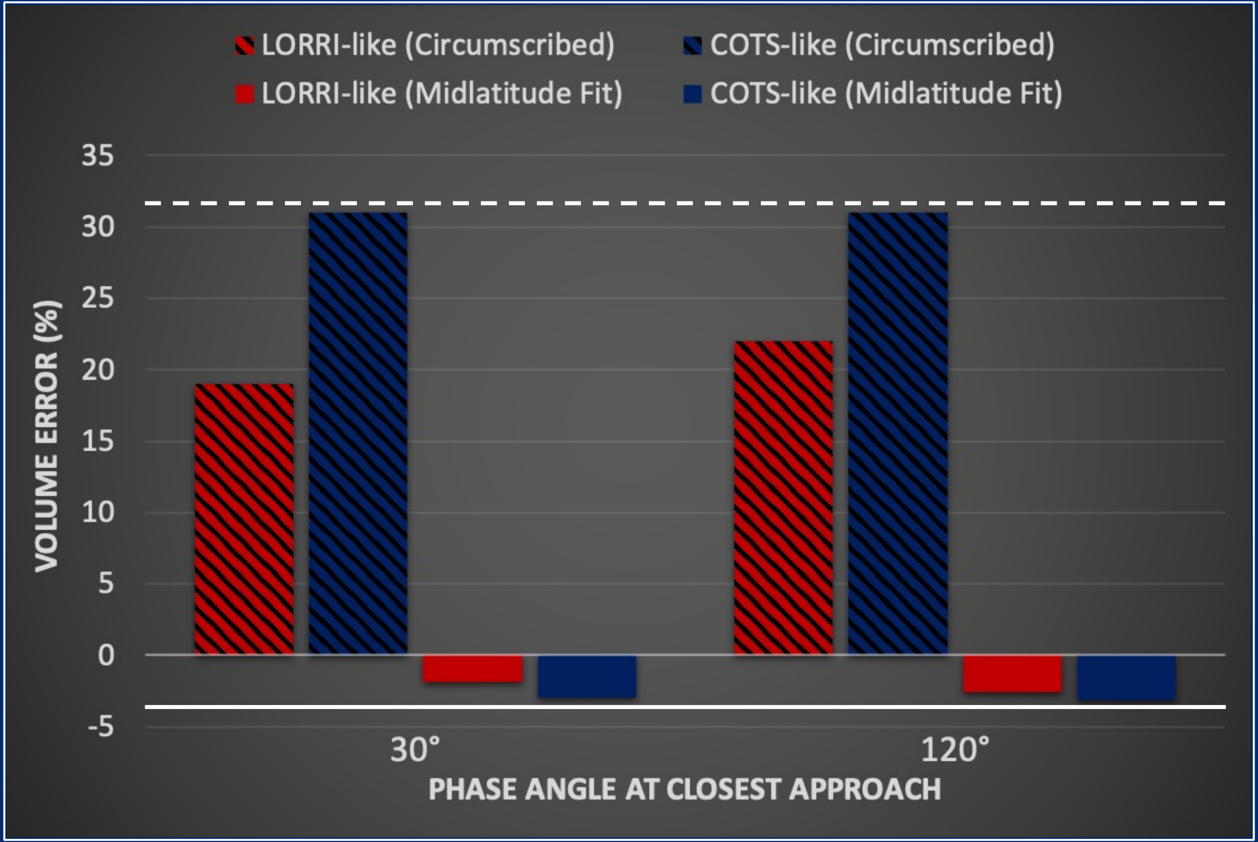
Circumscribed Starter Shape Model

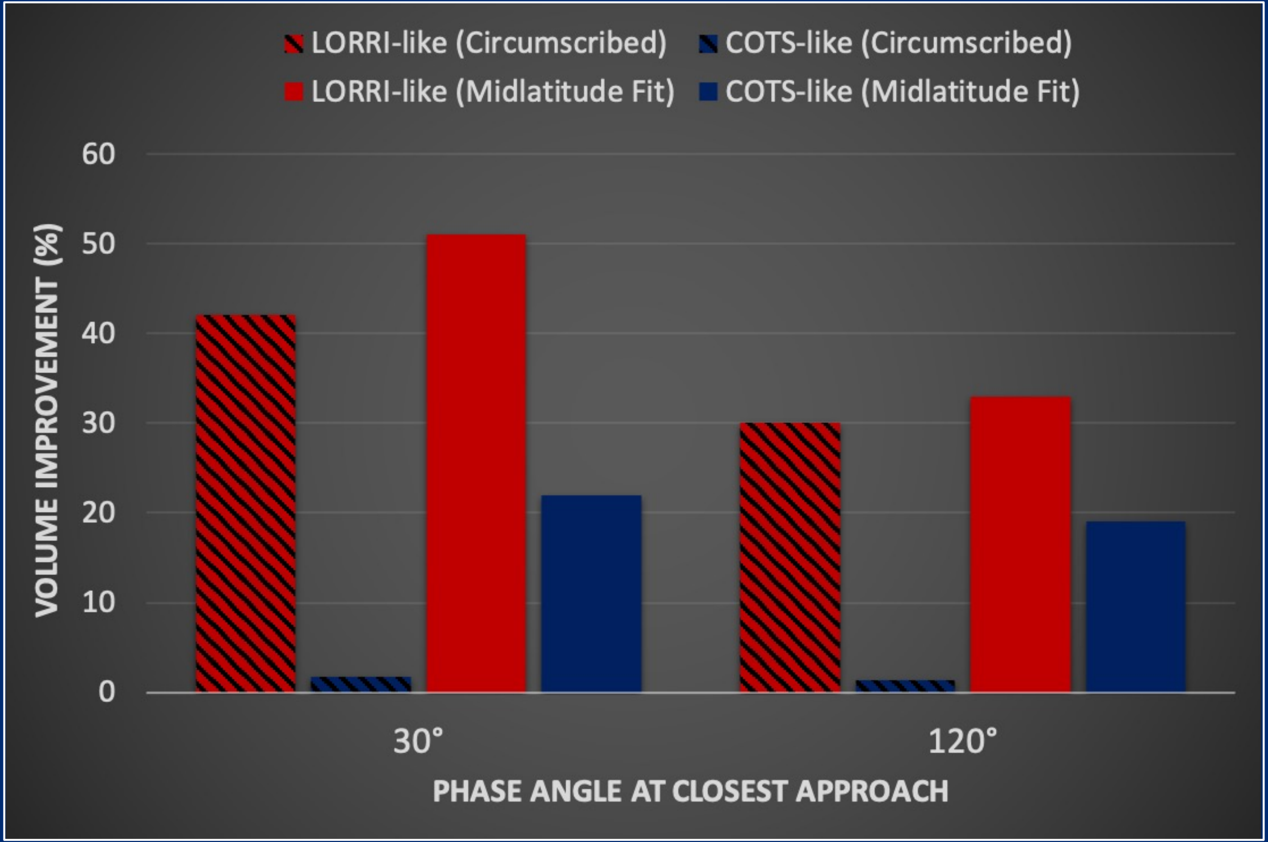


Volume Improvements

Encounter Parameter	LORRI-like	COTS-like
Flyby Speed	10 km/s	10 km/s
Distance @ Closest Approach	50 km	25 km
Phase Angle @ Closest Approach	30° and 120°	30° and 120°

-- Circumscribed starter shape volume error
— Midlatitude Fit starter shape volume error

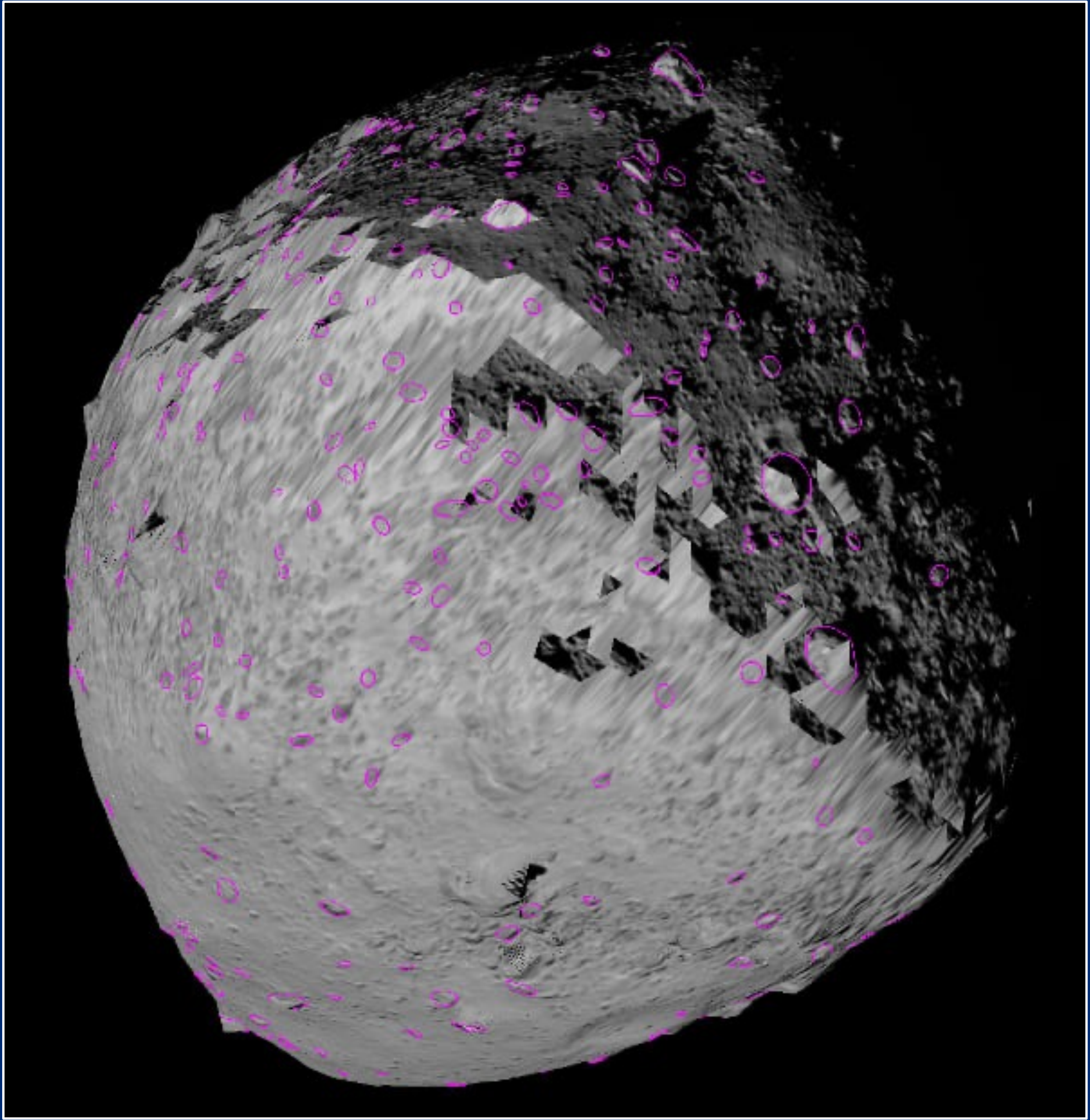




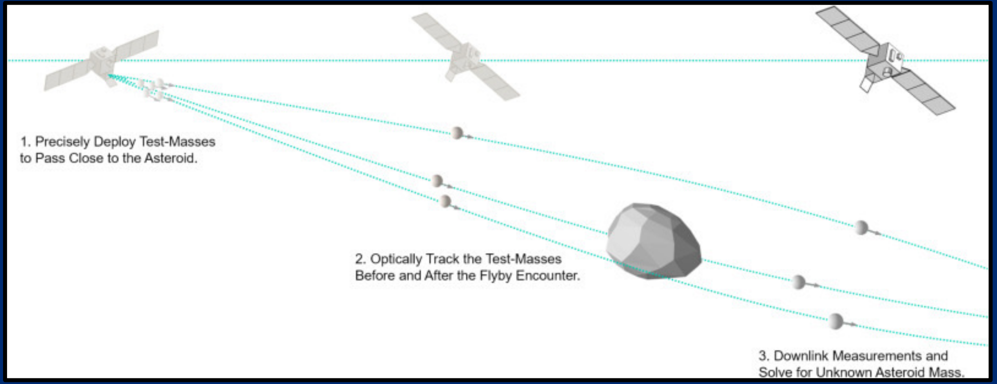
Surface Structure

Inferences on internal properties from images: rubble pile vs. monolith?

- 30° phase angle at closest approach trajectories have the most useable image coverage.
- Coarse image overlap: acquire more images at closest approach to smooth image transitions.



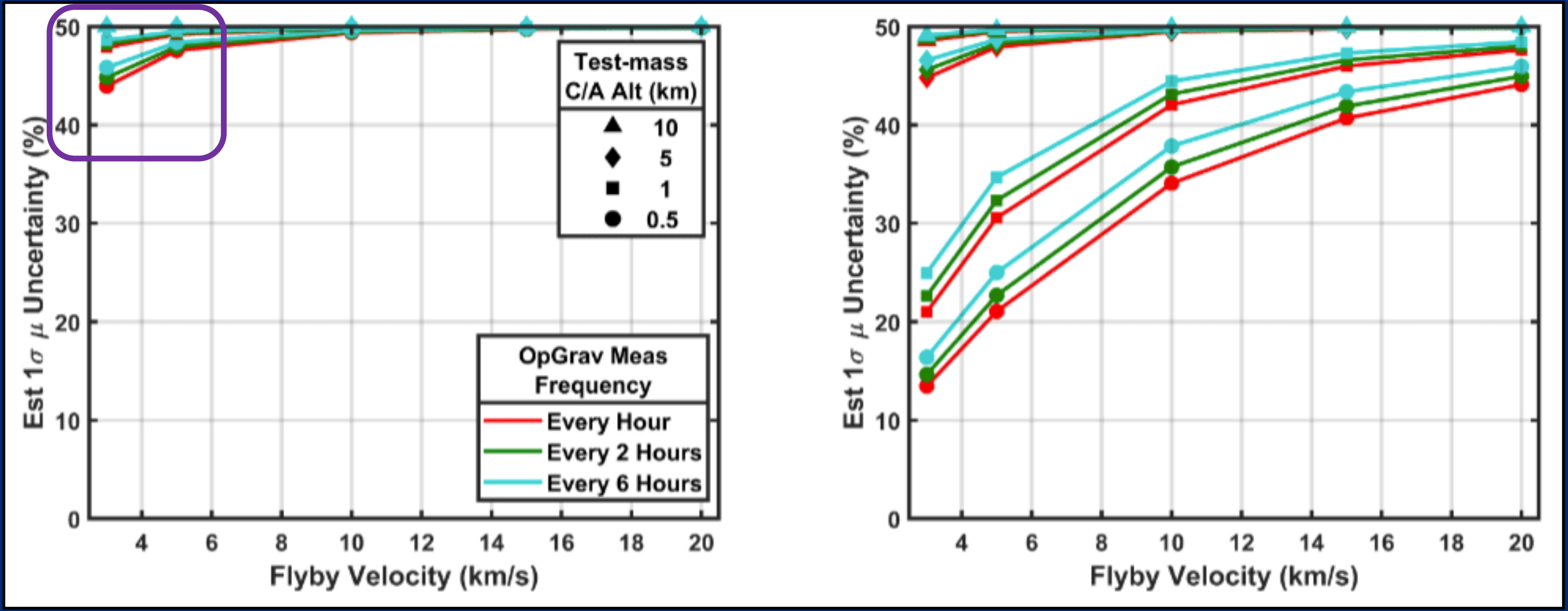
Mass?



Bull et al. (2021)

250 m Diameter Asteroid

500 m Diameter Asteroid



Take-Aways

1. The ability to view well-resolved asteroid limbs across the entire encounter minimizes the volume error.
2. Faster imaging cadence during closest approach will improve volume estimate (more limbs) and crater/boulder mapping.
3. Phase angles of 0° or 30° at closest approach minimize volume error and maximizes the number of useable images for crater/boulder mapping.
4. Volume error does not change significantly with flyby speed for these cases.
5. Imaging from the COTS-like camera led to shape models with large volume errors because the images were so coarse that limbs were not very helpful.
6. It is challenging to measure the mass of 50- to 250-m diameter asteroids, requiring more advanced technologies than OpGrav.

NEO WARP 2

Near-Earth Object Workshops to Assess Reconnaissance for Planetary defense

June 28-30, 2023

Laurel, Maryland, and Virtual

Organizing Committee:
Brent Barbee (NASA/GSFC), Jodi Berdis (JHU/APL), Lorraine Fesq (JPL), Dawn Graninger (JHU/APL), Josh Lyzhoft (NASA/GSFC), Carol Raymond (JPL)

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BACK-UP

$$\varepsilon_S = \frac{S - T}{S}$$

$$\varepsilon_R = \frac{R - T}{T}$$

$$V = \frac{\varepsilon_S - \varepsilon_R}{\varepsilon_S}$$

V	Volume improvement
S	Starter shape model volume
T	True shape model volume
R	Reconstructed shape model volume
ε_S	Starter shape model volume error
ε_R	Reconstructed shape model volume error