National Aeronautics and Space Administration

FY24 Strategic University Research Partnership (SURP)

Measuring Mass Shifts in Apophis during its 2029 Close Approach

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Background: On April 13, 2029, the asteroid (99942) Apophis will approach within 4.9 Earth radii from the Earth's surface, closer than the geosynchronous belt. The 2029 Apophis flyby will be viewed around the globe by scientists and amateur astronomers and will be a key and continuing story for mass media. This encounter represents an opportunity to probe the internal mass distribution and strength of a potentially hazardous asteroid.

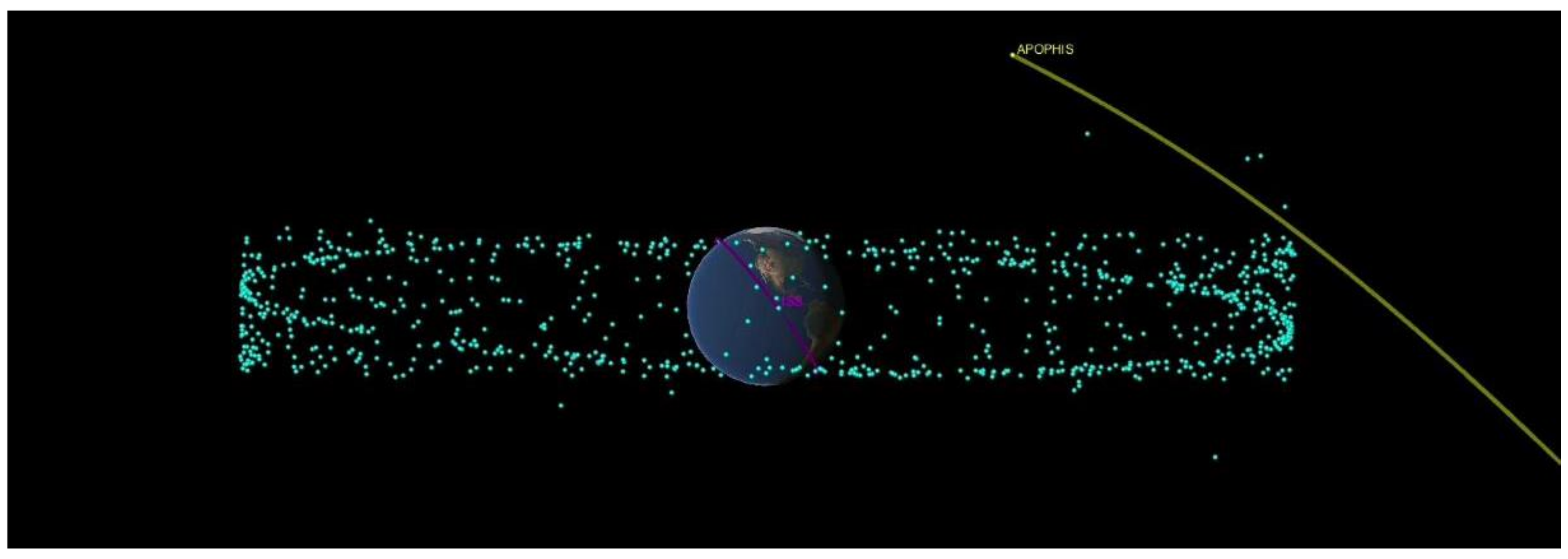

Figure 1. 2029 Close approach of Apophis to Earth, with geosynchronous satellites for context.

Objectives:

1. Update and refine tools to determine the Apophis inertia tensor and center of mass offset before, during and after the flyby using planned DSN Goldstone radar observations.
2. Develop algorithms determine the degree of density heterogeneity within a multi-component asteroid and constrain its distribution, leveraging the asteroid shape and estimated moments of inertia.
3. Understand the sensitivity to which we can detect or constrain internal shifts and deformations within the asteroid due to its interaction with the Earth.

Approach and Results: The study is divided into two main parts: (1) simulating the close approach using numerical simulations, and (2) estimating the feasibility of observing these effects using ground-based delay-Doppler radar. The simulations model possible mass shifts during the flyby, while the observational analysis evaluates whether these shifts can be detected.

Based on radar data, we have created eight distinct shape models of Apophis (Fig. 2). Mass shifts are quantified by two primary factors: the relative angular deviation between the two massive cores, and surface boulder displacements at the neck region.

Key Findings. In all eight shape models, we examined the relationship between friction, cohesion, and structural resistance. Our results indicate that both friction and cohesion significantly influence boulder interactions, especially for the spherical models. For the irregular polyhedron models, the shapes dominated the internal resistance more than friction, cohesion, or orientation. These models produced the most realistic results, with internal angular shifts ranging from 0.01 to 0.1 degrees (Fig.3) and maximum boulder displacements in the neck region remaining at the centimeter scale (Fig.4). Based on earlier work on estimating the shifts in Apophis' spin state using radar observations, *these results suggest that the changes may not be clearly detectable using radar alone, suggesting the necessity of in-situ observations to confirm surface and internal changes during the close approach.*

Significance/Benefits to JPL and NASA: The product of this study will be used to seek support for a "ground-based mission" combining the planned observation campaign and the supporting analysis. The successful execution of this work will produce unprecedented insight into the internal properties of a small asteroid, with a similar impact as a space-based mission. The activities, combined with the large media and public interest, will also highlight JPL's role as the premiere space research center for primitive body science and planetary defense.

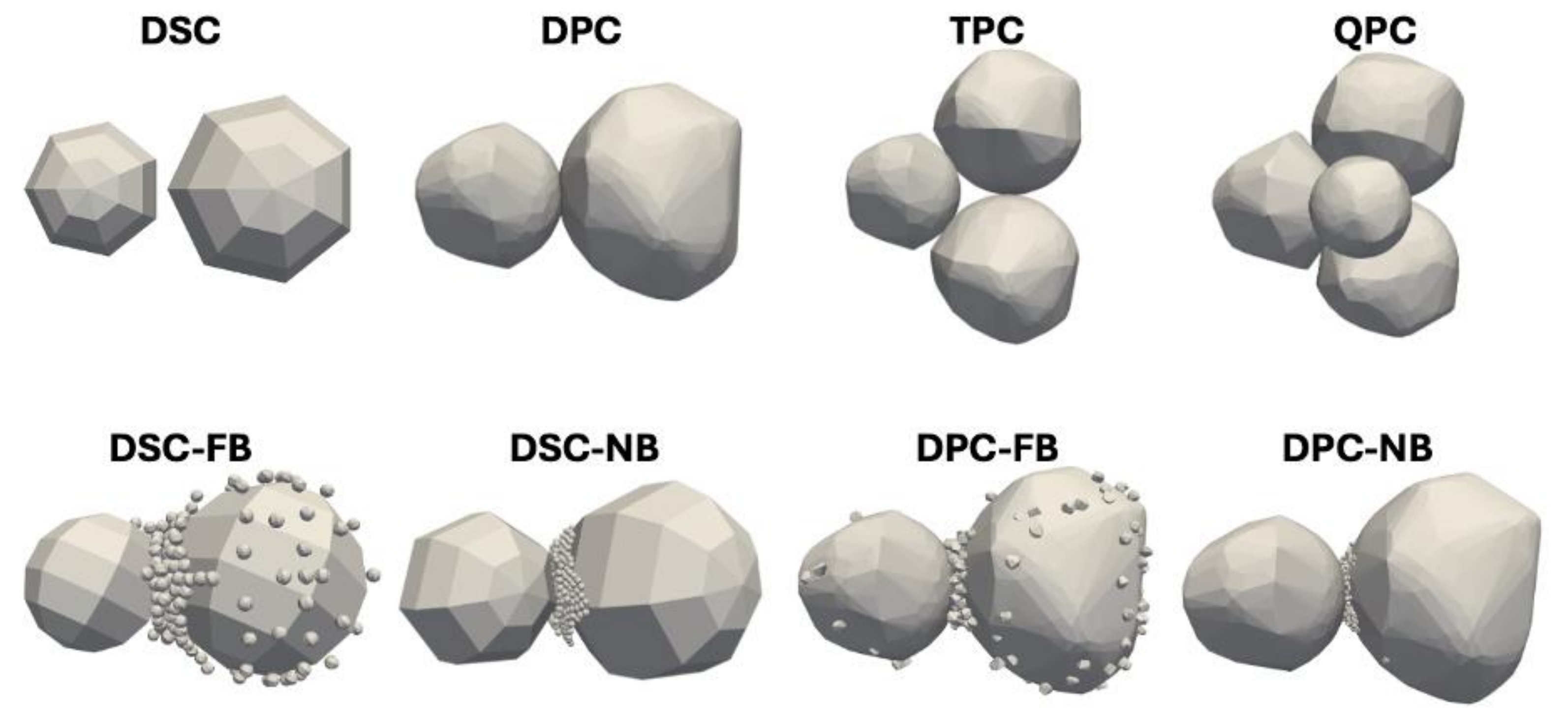

Figure 2. Eight Shape Models for Apophis.

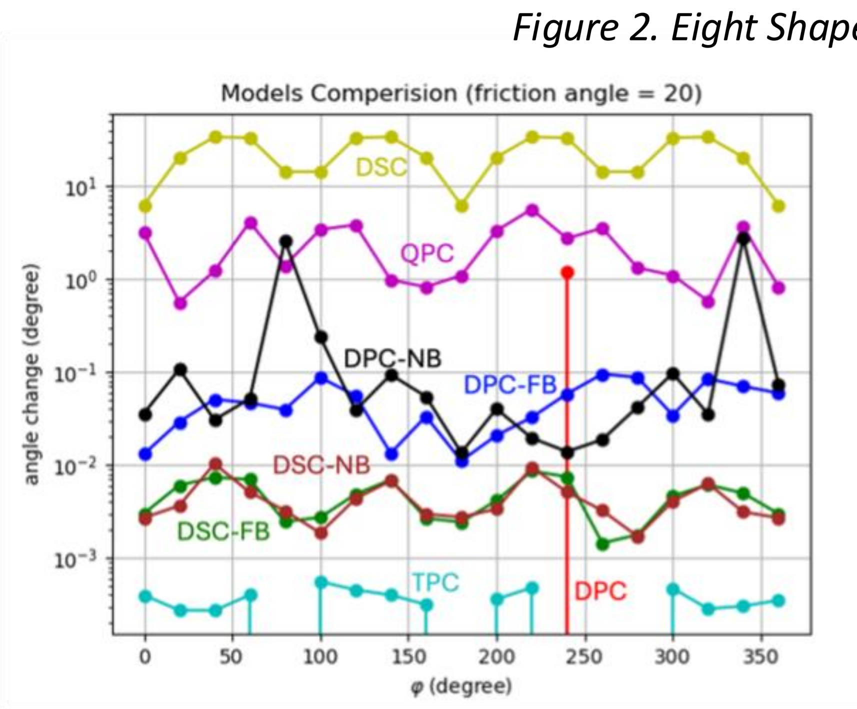

Figure 3. Internal mass shift in different models.

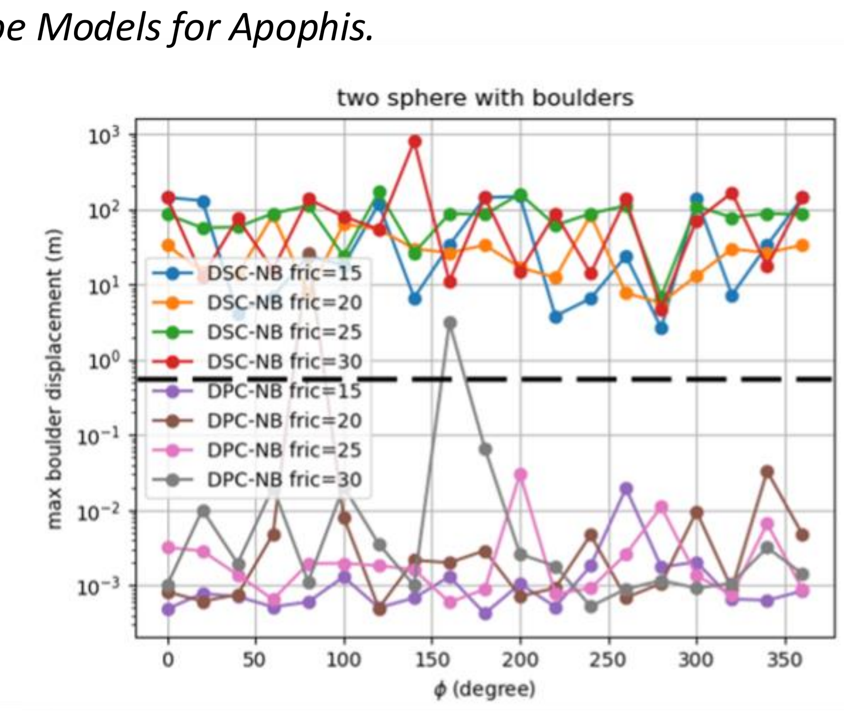

Figure 4. Displacement of surface boulder at neck region.

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www.nasa.gov

RPD-143 Clearance Number: CL#00-0000

Publications:

- Hai-Shuo Wang, D. J. Scheeres "Uncertainty Estimation of Apophis Mass Distribution Across its Flyby." Apophis T-5 Workshop, April 22-23, 2024, ESTEC, The Netherlands.
- Hai-Shuo Wang, D. J. Scheeres "Uncertainty Estimation of Apophis Mass Distribution Across its Flyby." LPSC 2024, March 11-15, 2024, The Woodlands, Texas.
- Hai-Shuo Wang, D.J. Scheeres, P. Sanchez, "Modeling the response of a multi-component model of Apophis to its close Earth Approach." 2023 Division for Planetary Sciences, October 1-6, 2023, San Antonio, Texas.

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