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☑ **Apophis: T-4 Years**

Apophis 2029: Synergy between Numerical Models and Radar Tomography Data from the Caltech Mission

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Coordinated use of modeling and in-situ radar data can advance our understanding of the internal structure of rubble pile asteroids, essential for planetary defense and planetary science. On April 13, 2029, asteroid 99942 Apophis will pass within 32,000 km of Earth, closer than geostationary orbit. A potential Caltech-led mission could escort Apophis through this encounter, observe its response to Earth's gravity, and use bistatic radar to map its interior. The mission aims to reveal Apophis' shape, density, internal block and void distribution, and spin state changes. It would perform bistatic radar, mapping the asteroid's internal structure at tens-of-meter scales and producing 3D backscatter and dielectric constant maps. These observations would offer groundbreaking insights into rubble-pile interiors, though methods for interpreting such data remain an open challenge.

To effectively simulate potential radar observations, realistic asteroid models are necessary. Previous work using the Discrete Element Method (DEM) has modeled Apophis as a lattice arrangement of uniform-sized spheres or a collection of large aggregates of spheres. We have developed an improved DEM model of Apophis using level sets to represent realistic block shapes and with size-frequency distributions of blocks ranging from meters to tens of meters in diameter, similar to those observed on the surfaces of analogous asteroids (e.g. Itokawa) by previous missions. Simulated scenarios explore several internal configurations, such as uniform block spatial distributions, larger blocks near the core or surface, and contact binaries. These models are currently being used to predict Apophis' response to its Earth flyby and can also be used to generate simulated bistatic radar images to help define radar specifications and data volume requirements needed to determine whether the interior is homogeneous or heterogeneous at large scales and constrain the size-frequency distribution and spatial arrangement of interior boulders in greater detail.

This work underscores the synergy between modeling and radar tomography. We discuss how modeling can help define mission requirements and refine data interpretation methods, ensuring high scientific return from radar missions to Apophis or similar asteroids. In turn, radar tomography data can validate and improve models, advancing planetary defense strategies, including asteroid risk assessment and deflection planning.