# Reconnaissance of Apophis (RA):

## A Mission Concept for Exploring the Potentially Hazardous Asteroid Apophis During Its 2029 Earth Encounter

**Presented to the Apophis T-9 Years: Knowledge Opportunities for the Science of Planetary Defense Workshop**

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# RA Mission Concept Overview

**RA addresses both science and planetary defense objectives while taking advantage of the historic opportunity presented by Apophis' incredibly close approach to Earth.**

| 2026 | | | | 2027 | | | | 2028 | | | | 2029 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1st Q | 2nd Q | 3rd Q | 4th Q | 1st Q | 2nd Q | 3rd Q | 4th Q | 1st Q | 2nd Q | 3rd Q | 4th Q | 1st Q | 2nd Q | 3rd Q | 4th Q |

Apophis-Earth close approach

**Launch Period (latest; launching earlier is better)** | **Interplanetary Cruise** | **Apophis Proximity Operations**

↑ **Rendezvous**

- RA is a small (<180 kg) spacecraft employing solar electric low-thrust propulsion to rendezvous with Apophis ~6—8 months before the April 2029 Earth close approach.
- RA remains in close proximity to Apophis throughout, gathering data before, during, and after the Earth close approach.
- RA performs science at Apophis and simultaneously demonstrates a prototype rapid response in situ reconnaissance capability for potentially hazardous NEOs.

Thanks to additional team members who have joined since the start of the concept development.

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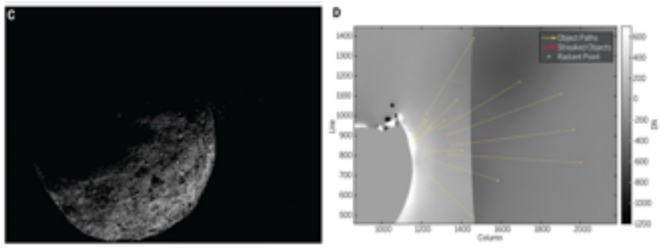
# Towards a ”Rapid Response” Demonstration

- Small spacecraft, minimal (but sufficient) instrumentation
- Can devise and attempt a “rapid” development process, i.e., propose and test changes in the process that result in earlier launch readiness
  - May require accepting elevated risk of failure
- <u>Or</u>, can follow a traditional development timeline (with a traditional risk / reliability posture) <u>but</u>:
  - Keep the spacecraft small / simple
  - Identify options that *could* have been used to shorten development time and document those options (for demonstration on a follow-on mission for which the stakes are lower, i.e., not to Apophis)
  - All of that still gets us much closer to a rapid response capability, but without putting the mission to Apophis at undue risk of failure due to testing rapid development protocols for the first time

# RA Science Overview

- **Science Gaps:**
  - How will the shape and rotation state of Apophis be affected by a very close planetary encounter?
  - How does minor planet regolith material respond to gravitational effects during a close planetary encounter?
  - Does the OH that has been observed on the Moon also occur on S-type asteroids such as Apophis? Dominant hypothesis is implantation of hydrogen by solar wind.
  - How coherent are boulders on S-complex asteroids? A major finding of Hayabusa2 and OSIRIS-REx is that the Ryugu and Bennu boulders exhibit much lower thermal inertias than any known meteorites, suggesting a difference in material properties with scale. Is the same true of S-type asteroids?
  - Surface particle ejection events have been observed on Bennu by OSIRIS-REx. How common is this behavior for minor planets? Can it occur on a largely anhydrous object? Does Apophis exhibit similar processes?
- **Our mission will:**
  - Measure the detailed shape and rotation state of Apophis before and after the Earth encounter, thus enabling characterization of the effects of the encounter
  - Map Apophis' thermal emission, providing a key parameter input to Yarkovsky acceleration models necessary for understanding Apophis' dynamical evolution and future motion
  - Multispectral mapping of Apophis before and after Earth encounter, characterizing any "refreshing" of the optically active surface due to resurfacing
  - Characterize the natural satellites, mass, density, gravity field, and crater and boulder populations of Apophis.




Particle Ejections from Bennu. From Lauretta, et al., "Episodes of particle ejection from the surface of the active asteroid (101955) Bennu," *Science* 06 Dec 2019: Vol. 366, Issue 6470, eaay3544 DOI: 10.1126/science.aay3544

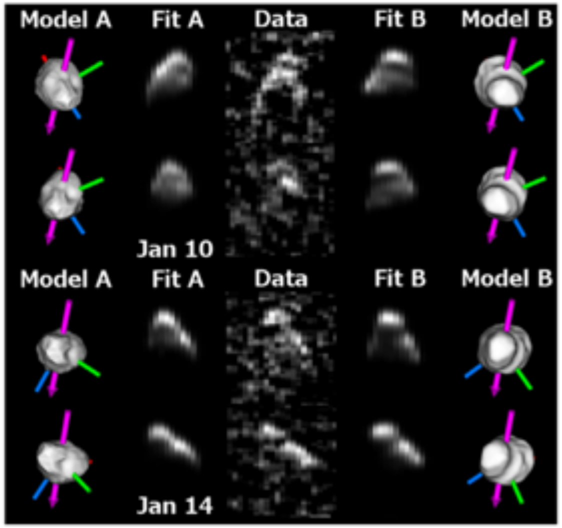



**Fig. 6.** Data, fits, and 3D models for two vertex models that are bifurcated. Collage of, from left to right: plane-of-sky renderings of Model A and its corresponding fits, delay-Doppler radar images, fits and plane-of-sky views of Model B. For additional description, see caption of Fig. 5. Fits to other radar images not shown here appear in Supplementary Fig. 4.

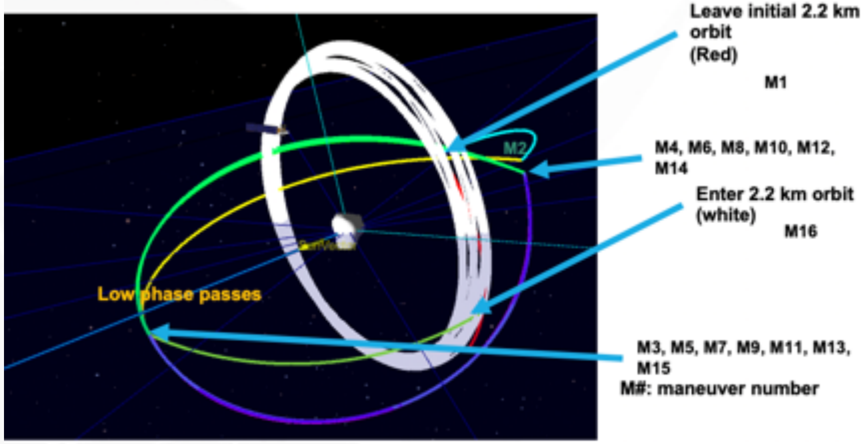
Radar shape of Apophis (Brozovic, et al. 2018)

# Scientific Implementation

- Apophis proximity operations begin well before Earth close approach and continue after
- Asteroid-wide mapping campaigns with RGB color imaging and spectroscopy before and after Earth approach
- Apophis will be the smallest natural object ever to have been orbited by a spacecraft
- Main spectral and color imaging data sets to be acquired from low-phase-angle flybys at $\lesssim$ 5 km range
  - Combination of hyperbolic flyby and orbital observations (informed by successful OSIRIS-REx and Hayabusa2 asteroid observing strategies)

**Summary of Primary Science Deliverables:**

- VIS (medium-angle + wide-angle) color imaging of Apophis before/after Earth encounter, < 1 m/pixel, near-complete coverage
- Spatially resolved IR spectroscopy of Apophis
- Thermal emission imaging of Apophis before/after Earth encounter
- Rotation state of Apophis before/after Earth encounter.
- Bulk density of Apophis
- Shape model of Apophis before/after Earth encounter.
- Ejected particle populations and trajectories, if any.



# Proximity Operations

**Preliminary Survey**

- Slow hyperbolic flybys
- Estimate GM (mass of Apophis)

**Orbital Phase**

- Global surface imagery/mapping

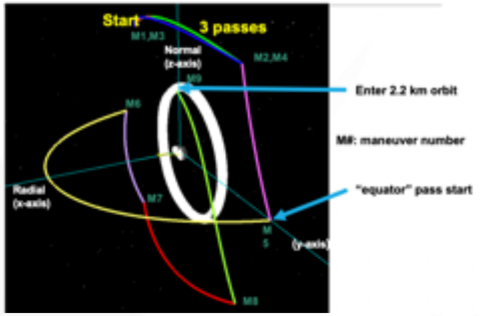
**Low-Phase Trajectories**

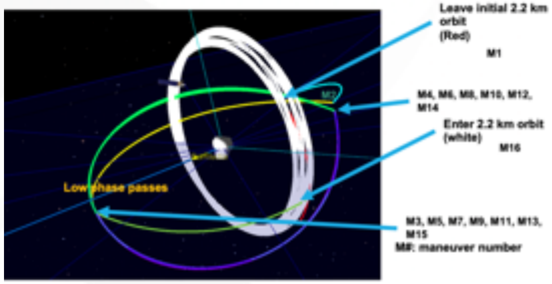
- Spectral, albedo, and color imaging observations

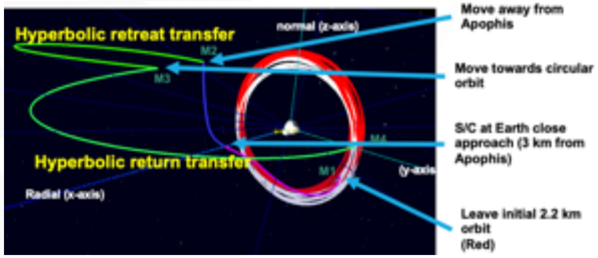
**Earth flyby: Safe Observations**

- Observe Apophis during Earth close approach from safe vantage point

**Repeat observations after Earth close approach; generate post-Earth-encounter data products for comparison to pre-encounter data**



# Questions?

# APPENDICES

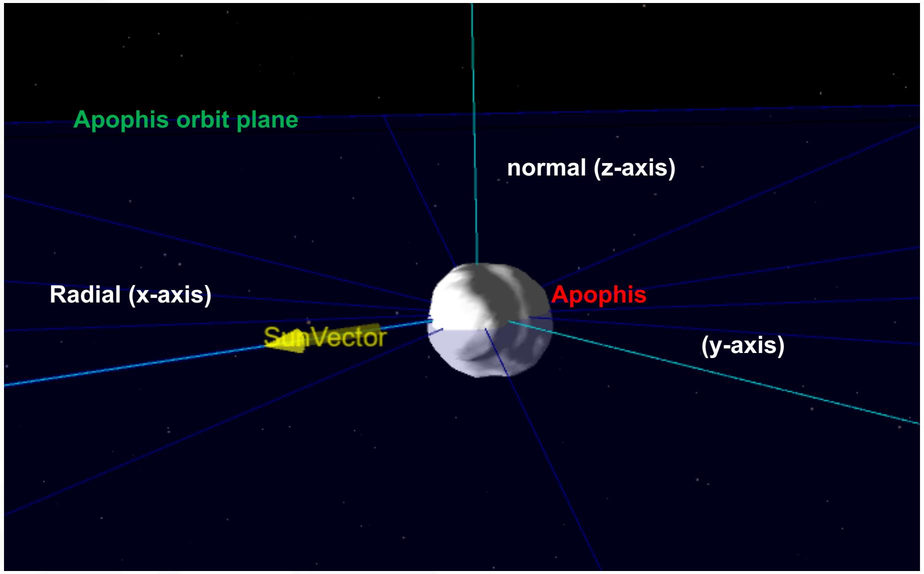
# SAM (Sun / Anti-Momentum) Frame

Radial: toward Sun from Apophis (x-axis)

Normal: radial x velocity (z-axis)

Complete right hand coordinate system (y-axis)

Radial and y-axis are in the orbit plane of Apophis



# Preliminary Survey

Hyperbolic flyby trajectories
- 4.3 – 5 km distance from Apophis center
- Start: 03 Sep 2028 00:00:37.034
- End: 18 Sep 2028 22:05:25.034

~2 month orbit after flybys
- Start: 18 Sep 2028 22:05:25.034
- End: 17 Nov 2028 07:41:25.034
- Approx. distance: 2.2 km
- Approx. eccentricity: 0.0001
- Phase angle ~ 97 degrees

Point mass gravity

Xenon gas propellant

Number of maneuvers: 9