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Jet Propulsion Laboratory
California Institute of Technology

Physical characterization of 99942 Apophis from ground-based radar assets in 2029

[1]Marina Brozović, [1]Lance A.M. Benner, [1]Shantanu P. Naidu, [2]Michael W. Busch, [1]Jon D. Giorgini, [3]Patrick A. Taylor, [1]Steven R. Chesley, [1]Davide Farnocchia, [4]Daniel J. Scheeres, [1]Mark S. Haynes, [1]Joseph Lazio, [5]Timothy Hall, and [6]Shinji Horiuchi

[1]Jet Propulsion Laboratory, California Institute of Technology; [2]SETI Institute; [3]National Radio Astronomy Observatory, Green Bank Observatory; [4]University of Colorado; [5]Lincoln Laboratory, MIT; [6]Canberra Deep Space Communication Complex, CSIRO

Apophis will be an exceptional radar target before, during, and after the <5 Earth radii from the surface encounter on April 13, 2029. Observations at Goldstone could start as early as mid-March and last until mid-May. Goldstone imaging at a resolution of 3.75 m/pixel, the finest resolution available at the 70 m DSS-14 antenna, will likely occur between April 6–21. We also plan to use the 34 m DSS-13 antenna at Goldstone that can achieve up to 1.875 m resolution, which should place thousands of pixels on the asteroid for at least two days centered on the closest approach. Apophis will be observable at Goldstone twice on April 13: first from 0.9-0.7 lunar distances ~14 hours prior to the flyby and again for several hours starting just a few minutes before the closest distance. Apophis will also be observed at Canberra Deep Space Network complex in Australia. DSS-43 antenna has 80 kW C-band transmitter (7190 kW, C-band), and 34-m antennas such as DSS-34, 35,and 36 have 20 kW transmitters. Apophis is likely to be observed from other radar facilities that are currently used for ionospheric or space debris studies (e.g. HUSIR and MISA radars at Haystack Observatory in Massachusetts and EISCAT-3D in Norway). It is also possible that the 100-m Green Bank Telescope will have a radar transmitter by 2029 and could observe Apophis.

The principal goals for radar will be full characterization of the spin state change and high-resolution imaging. Because Apophis is a non-principal axis rotator, estimation of the shape and spin state will provide precise estimates of the moment of inertia ratios that will constrain the internal structure pre- and post- flyby. Modeling of the spin change will provide additional insight into the interior. The images might reveal surface feature changes if localized events occur (e.g., if a boulder moves or if there are landslides). Dual-polarization radar imaging will enable polarimetric investigation of the surface roughness, regolith distributions, and changes that may occur during the flyby. Ground-based long-wavelength radar (wavelengths of decimeters to meters) could map the depth of regolith, reveal features not visible on the surface, and image the interior. The ionospheric HAARP radar in Alaska could be used as a transmitter and the Owens Valley Radio Observatory Long Wavelength Array used as the receiving antennas for a radar tomography experiment (PI. M. Haynes).

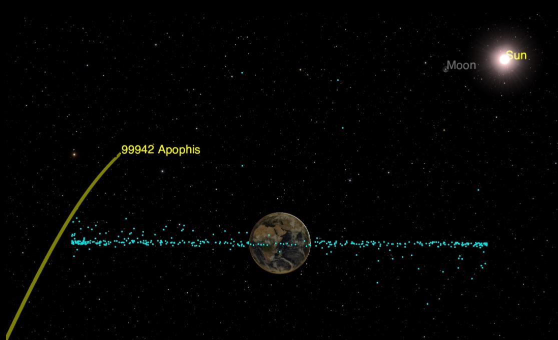


Figure 1. Apophis trajectory with respect to Earth viewed from the equatorial plane. The blue dots visualize orbits of geosynchronous satellites. Apophis will approach from the south at a declination of about -30 deg, rapidly move past Earth, and then recede at a declination of +17 deg. After the closest approach, Apophis will become a daytime object for several weeks but will gradually move away from the Sun until it reaches 17th magnitude near opposition in late November, 2029.

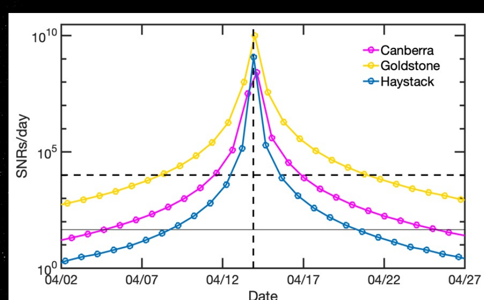


Figure 2. Estimated SNRs for Goldstone (DSS-14), Canberra (DSS-43), and Haystack (HUSIR 37-m antenna). The SNRs assume an average diameter D=0.34 km, simplified rotational period of 30.5, and OC radar albedo of 0.2. Loss of Arecibo will not affect radar imaging opportunity because Goldstone has finer range resolution and can track Apophis inbound for weeks at declinations that were too far south for Arecibo.

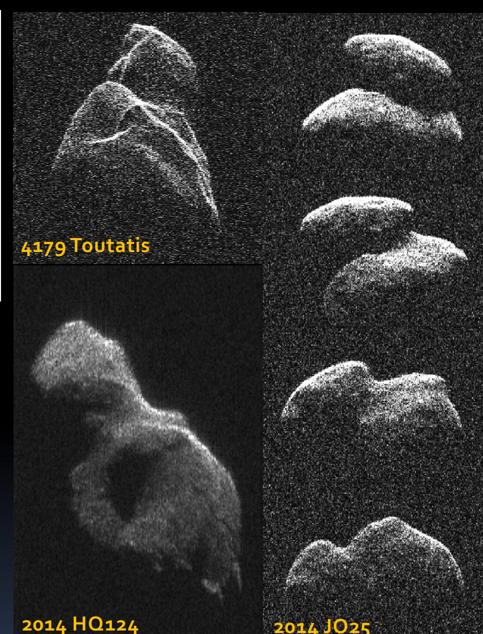
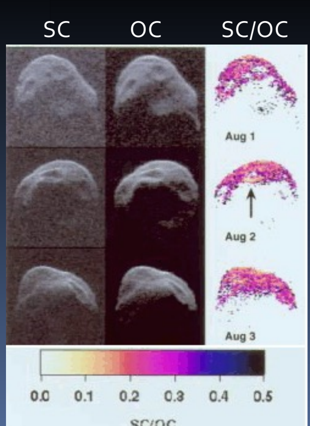


Figure 3. Expected quality of 3.75 m/px resolution delay-Doppler images during Apophis flyby in 2029. 4179 Toutatis was imaged on December 13, 2012 at ~19 LD with DSS-14. 2014 HQ124 was imaged on June 8, 2014 at ~3 lunar distances (LD) with DSS-13 and Arecibo. 2014 JO25 was imaged on April 20, 2017 at ~7 LD with DSS-14 and the Green Bank Telescope (GBT). The radar images show fine surface details such as concavities, ridges, and surface boulders. We can expect twice the resolution (1.875 m) in range at Goldstone and possibly higher with Haystack HUSIR radar.



1999 JM8: Benner et al., 2006

Figure 4. Radar signal is circularly polarized, and the reflection from an object results in an echo polarized in the same sense (SC), or the opposite sense (OC) as the transmitted signal. The echo power ratio in the SC or OC provides a measure of the surface roughness, and can reveal the presence of regolith on the surface. The comparison of the polarization ratios pre- and post- flyby could also reveal changes due to tidal resurfacing.

Busch et al., 2010

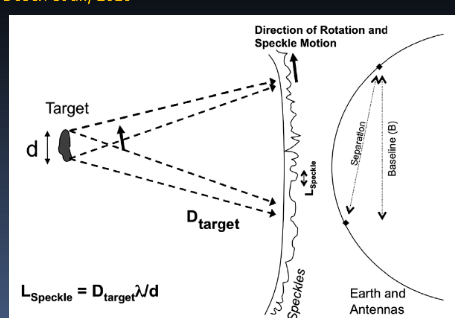


Figure 5. An asteroid's instantaneous spin vector direction can be determined by tracking the motion of the radar speckle pattern from multiple receiving stations on Earth. Radar speckle observations will be possible pre- and post- flyby allowing to detect any spin state changes for Apophis.