

OSIRIS-REx at Apophis: Opportunity for an Extended Mission. D. S. Lauretta¹, E. B. Bierhaus², R. P. Binzel³, B. J. Bos⁴, P. R. Christensen⁵, S. R. Chesley⁶, M. G. Daly⁷, D. N. DellaGiustina¹, C. Drouet d’Aubigny¹, D. Farnocchia⁶, V. E. Hamilton⁸, D. C. Reuter⁴, B. Rizk¹, A. A. Simon⁴, and B. M. Sutter², ¹Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ, USA. ²Lockheed Martin, Littleton, CO, USA. ³Massachusetts Institute of Technology, Cambridge, MA, USA. ⁴NASA Goddard Space Flight Center, Greenbelt, MD, USA. ⁵Arizona State University, Tempe, AZ, USA. ⁶Jet Propulsion Laboratory, Pasadena, CA, USA. ⁷York University, Toronto, Canada. ⁸Southwest Research Institute, Boulder, CO, USA.

Introduction: NASA’s Origins, Spectral Interpretation, Resource Identification, and Security–Regolith Explorer (OSIRIS-REx) mission has the primary objective of returning samples of pristine carbonaceous regolith from asteroid (101955) Bennu to Earth [1]. Additional mission objectives include:

1. Understanding the interaction between asteroid thermal properties and orbital dynamics by measuring the Yarkovsky effect on a potentially hazardous asteroid and constraining the asteroid properties that contribute to this effect.
2. Improving asteroid astronomy by characterizing the astronomical properties of a primitive carbonaceous asteroid to allow for direct comparison with ground-based telescopic data of the broader asteroid population.

The mission achieved Objective #1 using astronomical techniques pre-launch [2] and spacecraft tracking data since encounter [3]. Objective #2 was completed with Approach-phase point-source observations of Bennu [4].

We have developed a mission design that allows us to put the OSIRIS-REx spacecraft into orbit around asteroid (99942) Apophis in 2029. Such an extended mission (EM) is in direct support of the Security (#1) and Spectral Interpretation (#2) objectives of OSIRIS-REx. This low-cost opportunity allows for the OSIRIS-REx payload [1] to perform a detailed characterization of this potentially hazardous asteroid, comparable to that achieved at Bennu [4-11]. Apophis’ size and gravitational field are comparable in magnitude to those of Bennu, and much of OSIRIS-REx’s concept of operations will be relevant.

In addition to enhancing the OSIRIS-REx mission objectives, there are specific aspects of scientific interest for Apophis. In particular, the ability to measure a non-carbonaceous S-type target with the same suite of instruments that we used at Bennu enables a direct comparison between two very different small bodies. This EM also provides the opportunity to study a rubble-pile asteroid right after a close approach to Earth, when planetary tidal forces could produce significant surface and internal structural changes.

Mission Profile: OSIRIS-REx is on track to obtain a sample from Bennu on August 25, 2020. This date is subject to change, based on the results of a series of low-altitude flyovers of the primary sample site, Nightingale, and the backup sample site, Osprey [12], and subsequent sample collection rehearsals. The project has sufficient margin to sample any time in 2020. The departure window for the return cruise extends from March through May 2021. In all cases, the sample returns to Earth in September 2023.

At Earth return, the spacecraft will have a substantial amount of delta-V available for an EM opportunity. Our EM trajectory design allows for the optical acquisition of Apophis on April 8, 2029, when we cross the threshold of 2 million km range that defined the start of the mission’s approach to Bennu. This trajectory is different from the Bennu approach in that the major delta-V to approach Apophis is an Earth gravity assist (EGA) concurrent with the Apophis close approach on April 14, 2029. At this time, the OSIRIS-REx spacecraft will be 30,000 km from the asteroid. The approach velocity after the EGA is ~50 m/s. Thus, the approach maneuver would happen between April 13 and 21, with a velocity of 50 m/s. This maneuver places the spacecraft on a rendezvous trajectory that arrives at Apophis on April 21, 2029.

Proximity Operations: After Apophis’ close approach to Earth, its semimajor axis will increase from 0.9 to 1.1 AU. The post-encounter perihelion is 0.9 AU, and the aphelion is 1.3 AU. These orbital parameters are similar to Bennu’s, so the instrument and spacecraft operational environment is well within the fight system capabilities.

Once in the vicinity of Apophis, the science payload of cameras, a laser altimeter, and spectrometers—OCAMS MapCam and PolyCam [13], TAGCAMS [14], OLA [15], OVIRS [16], OTES [17], and REXIS [18]—is capable of characterizing the surface. Also, the Guidance, Navigation, and Control Flash LIDAR [1], which saw little action at Bennu when the primary guidance system changed to Natural Feature Tracking, is available for range measurements and topography.

The starting point for the Apophis mission profile is the successful campaign at Bennu. During the Approach

phase, OCAMS will survey the asteroid operational environment for potential spacecraft hazards. To provide ground-truth data for telescopic characterization, the team will obtain disk-integrated photometric and spectral data of Apophis.

We will follow the very successful step-by-step process used during the OSIRIS-REx mission [1] to reduce mission risks by characterizing the asteroid's shape, and determining its gravity field. We will likely repeat the Preliminary Survey, Detailed Survey, and Orbital B phases from the OSIRIS-REx mission profile [1]. These high-fidelity observations have produced global imaging mosaics at 5-cm resolution. OVIRS and OTES have collected data that provide global chemical and mineralogical maps of Benu's surface. TAGCAMS has contributed to mission science, even though it was designed as a navigational aid and engineering camera system only. In particular, the NavCam1 imager is ideal for characterizing particle ejection events [11]. TAGCAMS observations of Apophis will help determine whether such particle ejections are a ubiquitous phenomenon on small near-Earth asteroids (as would be the case if they are caused by meteoroid impacts, a leading hypothesis [11]) or are specific to Benu's hydrated mineralogy [8].

A critical difference between the two targets is the much higher global albedo of Apophis (4.4% versus 33% [9, 19]). Benu has several bright boulders (>26% normal albedo) which have been well exposed by the OSIRIS-REx instruments [20, 21]. The performance of the instrument complement at Apophis will be at least as good as at Benu. Higher albedo increases the signal-to-noise ratio, which is especially relevant for OVIRS and the OCAMS MapCam. The higher albedo allows for imaging that is even more tolerant to the raster-scan acquisition strategy used during OSIRIS-REx operations at Benu. This strategy maximized coverage while allowing exposure times that did not lead to motion blur even at the highest resolutions.

Observations of Apophis after its close approach to Earth permit measurement of spin state changes relative to the spin state measured from the ground before the encounter. Spacecraft tracking and OTES data would yield unprecedented insights into Yarkovsky drift. In essence, the Yarkovsky drift vector would be simultaneously measured in real-time along with the thermal re-radiation causing the drift. The post-encounter ephemeris update would tightly constrain the impact likelihood. This characterization would almost certainly eliminate any residual impact likelihood assessed from ground-based measurements.

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