

# INITIAL CONCEPT OF OPERATIONS FOR OSIRIS-APEX OPTICAL NAVIGATION AND ASTROMETRY SCIENCE AT APOPHIS

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**Abstract.** *OSIRIS-APEX will have a dynamical close encounter with Earth on 13 April 2029 where tidal forces will perturb it’s trajectory, spin state, and may even liberate regolith. OSIRIS-APEX will perform an Earth gravity assist on the same day, targeting a slow approach and rendezvous with Apophis by June 2029. A post-encounter search for mass shedding, natural satellites, and ejected particles are key science objectives. Early characterization of the spin state and shape of the target is critical to achieving mission navigation and science objectives. Here we present analyses and constraints that culminate in the initial concept of operations for optical navigation and astrometry science.*

**Introduction.** The OSIRIS-Apophis Explorer (OSIRIS-APEX, or APEX) mission will rendezvous with and study asteroid Apophis in 2029, weeks after Apophis’ close encounter with Earth on 13 April 2029. Apophis will be optically acquired by the PolyCam instrument<sup>1</sup> no later than 2 April 2029, initiating optical navigation (OpNav) operations and astrometry science. We will present the OpNav and astrometry science objectives and initial plans for the first several mission phases, shown in context with the full mission timeline in Figure 1, which focus on navigation and asteroid geophysical characterization. The range and phase angles for the Acquisition through Terminator Orbit (TO) phases are plotted in Figure 2.

**Acquisition.** As Apophis enters cis-lunar space with a closest altitude to Earth of one-tenth the lunar distance, tidal forces will significantly affect its trajectory and spin state and may even liberate dust and rocks from its surface.<sup>2-4</sup> An hour after Apophis’ dynamical Earth encounter, APEX will perform an Earth Gravity Assist (EGA) at an altitude of 1153 km to enable arrival at Apophis in July 2029.<sup>5</sup> APEX has three primary photometric and astrometric investigations planned in the weeks surrounding the Apophis-Earth encounter: Apophis-relative OpNav, initial unresolved spin state characterization, and search for evidence of natural satellites and mass shedding. OpNav imaging will utilize PolyCam on a daily cadence to support early ephemeris estimation prior to approach targeting. Pre- and post-EGA light curves will be captured with PolyCam, over 11-day campaigns, with an ideal imaging cadence of 2 hours, when feasible within mission constraints. After EGA, there will not be sufficient dynamic range in PolyCam to image background stars without overexposing Apophis, so additional imaging will be required to obtain long- and short-exposure imaging pairs, like in the OSIRIS-REx concept of operations (ConOps).<sup>6</sup> In the weeks following EGA, the OCAMS instrument suite<sup>1</sup> will search for evidence of mass shedding by looking for scattered light from dust and individual particles near Apophis and its wake. The search will begin with PolyCam around 14 April 2029, after EGA-related spacecraft constraints are lifted. This observation campaign should be capable of detecting large natural satellites and roughly meter-sized blocks within the 34-km Hill Sphere, but it is unlikely that any individual particles smaller than 10 cm will be detectable before 26 April 2029.

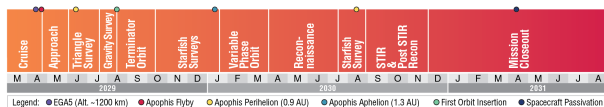


Figure 1. OSIRIS-APEX Mission Timeline

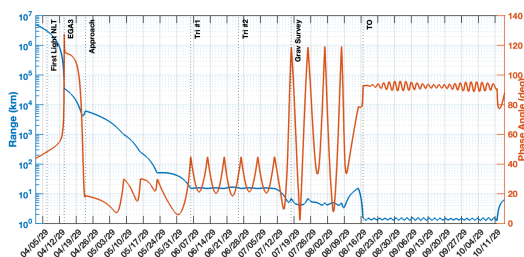


Figure 2. APEX Range and Phase Angles from Acquisition through Terminator Orbit.

**Approach.** This mission phase will begin with the first of four Apophis Asteroid Approach maneuvers (AAAs) on 22 April 2029; these maneuvers target a slow approach at relatively low phase angles. The search for natural satellites in the 34-km Hill Sphere will be possible using a single PolyCam image until 26 April 2029, after which a mosaic or use of the wider field-of-view (FOV) MapCam<sup>1</sup> will be required. Eventually, due to resource constraints, the natural satellite search will narrow to a 10 km orbit radius. Daily OpNav imaging with PolyCam will continue until after AAA-4 on 23 May 2029, at which point MapCam will become the primary OpNav imager through the remainder of the Approach phase. Apophis will subtend more than 10 PolyCam pixels on 3 May 2029

and will fill the FOV by the end of the Approach phase on 5 June 2029. During this time, the navigation team will begin developing coarse limb-based shape models and estimating the spin state. Plans and techniques for initial, resolved spin state estimation are currently in development. Additionally, in the final weeks of Approach, low-phase imagery at  $<2$  m/px ground sample distance (GSD) will be collected for stereophotoclinometry (SPC).<sup>7</sup>

**Triangle Survey.** On 5 June 2029, the spacecraft will begin a weekly maneuver cadence, maintaining on the order of 10–15 km range while varying phase angles between 45 and 75 degrees. This trajectory design allows for the required SPC coverage at specific geometries to build up over time. Initial analysis of coverage is underway and expected to be reported in the manuscript. OpNav imaging with NavCam 1<sup>8</sup> and MapCam is planned for this phase, at a cadence driven by a variety of analyses that will be presented.

**Gravity Survey.** Beginning 17 July 2029, three 4–5 km hyperbolic flybys are designed to enable estimation of Apophis’s gravitational parameter to within 0.1% uncertainty. This information will feed into the design of subsequent orbital phases. OpNav imaging with NavCam 1 is planned for this phase. During this phase, the OpNav team will be generating digital terrain models (DTMs) with SPC using the data collected during Triangle Survey.

**Terminator Orbit.** On 8 August 2029, the mission will begin an operational sequence to insert APEX into a terminator orbit around Apophis on 16 August 2029. During this phase, the navigation team will focus on transitioning to landmark (DTM)-based OpNav measurements,<sup>9</sup> which involves estimating and iterating on the asteroid’s geophysical parameters, similar to the techniques performed at Bennu.<sup>10</sup> A search for previously undetectable centimeter-scale ejecting particles<sup>11</sup> is also planned for the Terminator Orbit phase, and if there is positive detection of this phenomenon, additional observations will be planned in subsequent mission phases. Dust on the NavCam 1 lens collected during the Bennu sample collection event<sup>12</sup> will increase the stray light from Apophis, limiting the region of the usable FOV and distance from the asteroid where particles will be detectable. Further characterization and analysis is planned to determine the feasibility and ConOps.

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