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TRAJECTORY CONCEPTS FOR AN APOPHIS RENDEZVOUS MISSION

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ABSTRACT

Asteroid 99942 Apophis is of significant planetary defense interest due to the April 2029 encounter with Earth where the asteroid will pass within geosynchronous orbit (GEO belt). A rendezvous mission to Apophis will increase our understanding of hazardous Near Earth Asteroid (NEO) interior structure, surface properties, rotational dynamics, and topography among other compelling science objectives. Of particular interest is the effect of the tidal interaction with Earth during the 2029 encounter and the potential effects on the asteroid's regolith configuration. In order to sufficiently understand this phenomenon, a baseline measurement of the interior and surface properties is required. This paper examines various trajectory concepts to rendezvous with Apophis prior to the Earth encounter to enable pre and post encounter data collection. Several transfer trajectories are explored to satisfy arrival months before Earth encounter, including chemical and low thrust dedicated launches. Alternatively, Apophis rendezvous concepts made possible by launching as a ride-share with low energy Lunar or Lagrange Point missions is also explored.

For high thrust (chemical) transfers, several gravity assist sequences including Earth, Mars, and Venus gravity assists were explored to reach Apophis – with an imposed constraint limiting the total mission deterministic Delta-V (DV) to 800 m/s – consistent with low cost ESPA class mission concepts. Arrival dates closer to Earth close approach are not feasible from a DV standpoint, launch must occur by early 2022 and rendezvous with Apophis by early 2025.

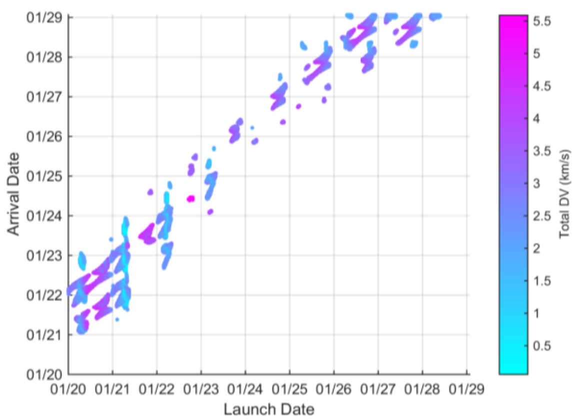

Figure 1. Launch Date vs Arrival Date for Apophis Rendezvous

Broad searches were complete for low thrust transfers as well. Maintaining the ESPA class concept constraint, search parameters consisted of a 180 kg initial wet mass, 280 W of power for the SEP system, and a single Busek BHT-200 thruster capable of delivering 12 mN thrust. Gravity assist sequences including up to three Earth gravity assists (EGA) were explored. Launch C3 for all low thrust trajectories were capped at 1 km^2/s^2, equivalent to the launch energy achievable from a lunar gravity assist.

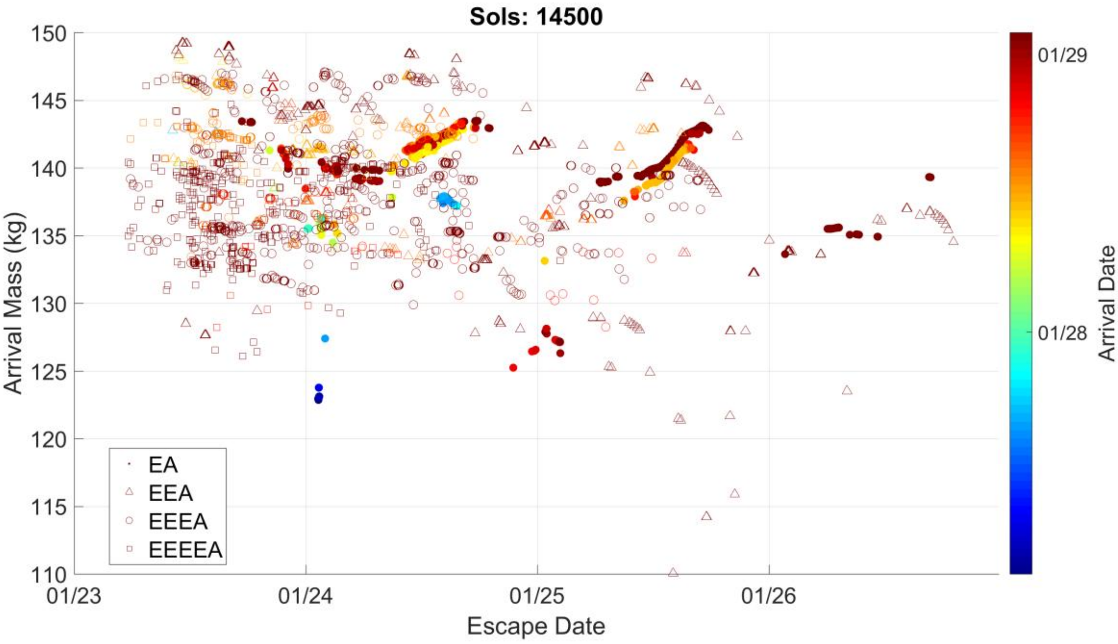

Figure 2. Low Thrust Broad Search Results

A low energy ride-share concepts was also investigated. The NASA Interstellar Mapping and Acceleration Probe (IMAP) will launch in 2024 and go to the Sun-Earth L1 Lagrange Point. A low thrust transfer achieving Apophis rendezvous was constructed from the IMAP separation vector.

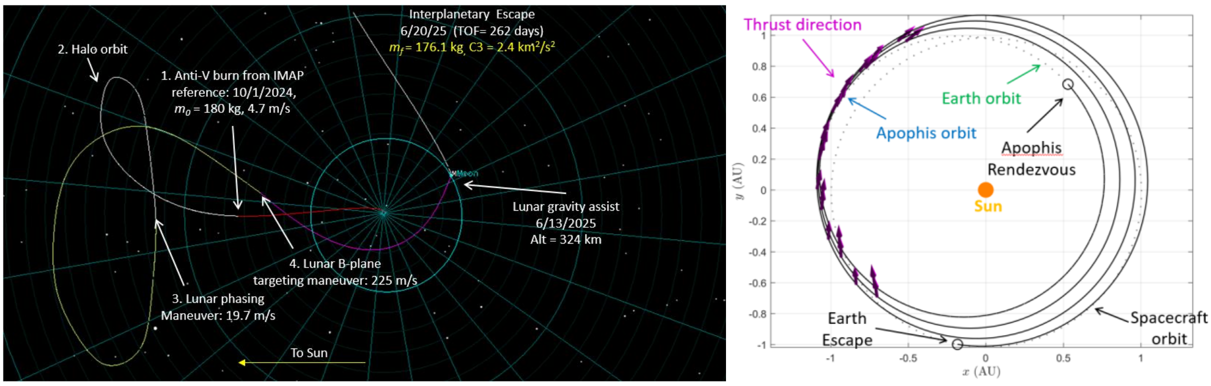

Figure 3. Low Energy Transfer from IMAP Separation Vector

The Apophis encounter with Earth in April 2029 provides a unique opportunity to study a potentially hazardous asteroid (PHA). In order to understand the effects of tidal interaction with the Earth on the physical properties of PHAs, it is critical to establish a baseline model of the interior and surface composition of Apophis months before the Earth encounter. High thrust options require rendezvous many years before the encounter in order to be DV viable. For concepts to rendezvous closer to the encounter, low thrust transfers must be utilized. Feasible trajectories for launches using lunar gravity assists or ride-share with Lagrange point missions have been demonstrated and can fit within ESPA class satellite constraints.