Is the technology ready for a CubeSat Apophis 2029 mission?

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Introduction

Apophis' 2029 Earth fly-by represents a unique opportunity to observe any possible tidal effects on its surface or interior. To obtain a detailed overview of the resulting changes on Apophis, a dedicated rendezvous mission is required. In this study, we will evaluate the feasibility of designing a low-cost mission utilizing current or forthcoming CubeSat technology.

Mission requirements

Based on the ESA CDF 178(A) report, the minimum required Δv for an Apophis transfer prior 2029 is in the range of 4 and 6.5 km/s with multiple departure windows in the second half of 2020's. In order to keep the mass budget and operational costs of the mission low, a high level of autonomous execution is desired. This requirement is further driven by the fact that no detailed shape / surface model of Apophis will be available prior the spacecraft encounter. High-level requirements for a low-cost Apophis missions include:

- Δv at least 4.5 km/s
- Interplanetary multi-sensor ADCS (Attitude Determination and Control System).
- Autonomous cruise and rendezvous navigation.
- Deep-space communication
- On-board generation of asteroid reference feature-set for mapping / proximity observations
- Autonomous execution of a pre-loaded scientific observation sequence
- Advanced on-board data processing and compression for efficient download

Current deep-space CubeSat mission status

Several completed or forthcoming CubeSat deep space missions demonstrated or will demonstrate relevant technology. These include:

MarCO (Mars Cube One – 6U CubeSats which already demonstrated extended (> 6 months) deep space operations including autonomous cruise to Mars and ADCS/power/thermal/communication management beyond 1.5 au. Status: Completed (2018).

Hera CubeSats – the 6U CubeSats *Juventas* and *APEX* will demonstrate several weeks long proximity operations in the vicinity of the binary asteroid Didymos, including precise GNC (Guidance, Navigation and Control) and advanced payloads. The cruise and communication relay will be provided by the Hera

mothercraft. For local operation, a Δv of ~10 m/s is envisioned. Status: Hera is an approved ESA mission and will arrive at Didymos in 2026.

M-ARGO – 12U stand-alone CubeSat study. M-ARGO will demonstrate most of key components required by the Apophis 2029 mission as autonomous Earth departure, interplanetary cruise, and small NEO rendezvous. Currently envisioned Δv is ~3.5 km/s and payload allocation of ~1U. Status: M-ARGO is an ESA mission proposal, currently in a Phase-A study.

Artemis 1 (Orion EM-1) – forthcoming mission compromising of 13 6U CubeSats as Artemis 1 secondary payloads, testing operations in the Earth-Moon space including formation flying, proximity operations, or advanced payloads and propulsion technologies. Status: CubeSats delivered. Artemis 1 launch planned for 2021-22.

LICIA – 6U CubeSat deployed by DART spacecraft prior its impact on Didymos. LICIA will demonstrate deep-space communication together with formation flying and target pointing / imaging during high-velocity fly-by of Didymos. Status: DART is an approved NASA mission which will arrive at Didymos in October 2022.

Technology readiness

Requirement	Mission demonstrator
Δv of 4.5 km/s	To be developed M-ARGO up to 3.5 km/s
Interplanetary ADCS	MarCO Artemis-1 LICIA Hera M-ARGO
Interplanetary cruise	MarCO M-ARGO
Proximity operations	Artemis-1 LICIA Hera, M-ARGO
Deep space communication	MarCO LICIA M-ARGO
Autonomous rendezvous	M-ARGO
Autonomous navigation reference generation	To be developed
Autonomous observations	To be developed
Advanced on-board data handling	To be developed Partly tested on Hera/APEX

Mission / technology status legend: Accomplished, approved, under study, to be developed.

Outlook

The current or forthcoming technology is mostly ready to enable an Apophis 2029 mission. Specific areas requiring further development include a higher Δv propulsion or advanced autonomous navigation / operations and compact payloads.