



DROID: A mission concept to accompany and characterize Apophis through its 2029 Earth closest approach

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Introduction: The close approach of asteroid (99942) Apophis on April 13, 2029 presents a unique opportunity to achieve breakthrough science and strengthen planetary defense goals.

As discussed in [1], low-frequency (VHF) radar observations can probe the interior structure of small bodies, as demonstrated by CONSERT at comet 67P [2, 3], and the planned JuRa low frequency radar on Hera/Juventas at the Didymos system—target of the DART mission. Radar measurements can determine the distribution of monolithic objects and voids within the body at 10's of meter scale, which are critical for potential deflection and disruption attempts. This is best accomplished by multi-static, low frequency radar [4].

A mission concept to exploit the Apophis opportunity has been developed in a collaboration between NASA/JPL and CNES. The Distributed Radar Observations of Interior Distributions (DROID) mission would rendezvous with Apophis in late Summer 2028, seven months prior to Earth closest approach (ECA) and escort it through the encounter. A possible asteroid flyby on the way would delay arrival to late 2028 but still provide ample time for pre-ECA characterization. DROID's measurements would determine the interior structure and properties, the body's shape, morphology and rotation and observe any resolvable changes. DROID provides unique high fidelity in situ data that complements and enhances Earth-based optical and radar observations of Apophis, as well as data collected by OSIRIS-APEX which is due to rendezvous with Apophis 8 days after ECA.

As illustrated in Figure 1, DROID's architecture calls for three spacecraft: an ESPA Grande-class Mothership and two 6U CubeSats. The Mothership carries the CubeSats to Apophis, achieves the rendezvous cruise trajectory, performs high resolution imaging, and acts as a Direct-to-Earth (DTE) node for the constellation. Once Apophis's physical characteristics (shape, spin, gravity field) are sufficiently characterized, the Mothership deploys both CubeSats, which then insert themselves into coordinated low orbits to perform monostatic and bistatic radar observations.

Mission Goals: The DROID mission has two primary goals. The first goal is to understand the interior structure of a rubble pile asteroid and implications for its formation, evolution and response

to a deflection attempt. Objectives include determining shape and density, and determining the internal size, distribution, and arrangement of blocks and voids within Apophis. \

DROID's second goal is to understand how close planetary encounters affect asteroids. DROID will provide critical pre-ECA imagery of Apophis that are necessary for change detection. Objectives include determining if material moves on the surface of Apophis during the Earth flyby, and determining how the spin state of Apophis changes during ECA.

Payload: Given the goals above, DROID employs four types of payloads distributed over three spacecraft (Figure 1). Objectives requiring surface imaging are to be met with a narrow-angle camera (NAC) on-board the Mothership spacecraft, whose focal plane is to be based on the Advanced CASPEX detector [5]. Additional wide-angle cameras (WACs) are carried on the two CubeSats for optical navigation.

The objective to map internal structure is achieved using the Low Frequency Radar (LFR) on the CubeSats. The LFR is baselined as a version of JuRa (60 MHz), [6], modified to operate in a bistatic mode [1]. Inter-Spacecraft Link (ISL) S-band transponders on all three spacecraft perform data transfer between CubeSats and Mothership, and synchronize the CubeSat clocks for accurate bistatic radar measurement. ISLs are also used with the Mothership's DTE link to map the gravity field.

Mission Architecture: The DROID mission architecture is compatible with either direct launch or rideshare and will utilize heritage bus designs that can achieve the required propulsion performance. DROID's 3.54 km/s ΔV requirement is similar to that of ESCAPADE, which uses bipropellant propulsion [7], DROID's reference mission is constrained by a cruise trajectory insertion (CTI) window of about October-November 2027. Details of launch, CTI and cruise are provided in [8].

Operations: DROID arrives at Apophis around August-September 2028 (~December if it performs a precursor asteroid flyby) and executes a 0.30 km/s burn to reduce its relative velocity. During this phase, the Mothership NAC begins preliminary characterization of Apophis's shape and spin. Approach imaging is then followed-up by several flyby maneuvers used to characterize the gravity field with DTE communication.

The Mothership then deploys the CubeSats, which maneuver into 2-5 body radii altitude, sun-synchronous terminator orbits using their own cold gas propulsion. Following CubeSat deployment, the Mothership positions itself in a 9 body radii altitude orbit where it continues its imaging investigations using the NAC. The CubeSats are positioned antipodally with $\pm 15^\circ$ margin in their relative position and continuously collect both monostatic and bistatic echoes. A 2-body radii altitude orbit will enable mapping of 20% of the 3D monostatic Doppler sampling at 60 MHz [9], within 40 days. Radar data products include: (1) 3D volumetric backscatter via monostatic/bistatic tomographic SAR, (2) average dielectric constant along interior bistatic ray paths with assessment of internal heterogeneity [10].

The configuration of the DROID constellation during ECA and Post-ECA operations is the subject of on-going studies. Major ECA drivers include positioning of cameras to maximize the likelihood of capturing surface changes and mitigating the risk of collisions with potential ejected debris. The major Post-ECA driver is escaping from Apophis orbit to a safe heliocentric orbit prior to depleting propellant in order to avoid any possibility of impacting the asteroid and perturbing its orbit.

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