APOPHIS 2029, ATENA Concept: Mission Design and Satellite Architecture

G. Saita[1*], V. Di Tana[1], C. Burattini[1], P. Amabili[1], M. Pereira[1], E. Ammannito[2], M. Amato[3], B. Barbee[3], T. Haas[3], B. Hsu[3], T. Hurford[3], L. Lim[3], J. Lyzhoft[3], A. Nicoletti[3], J. Nuth[3], J. Panek[3], B. Sarli[3], M. Vavrina[3]
[1]Argotec Srl, Via Luigi Burgo,8, 10099, San Mauro Torinese, Turin, Italy
[2]ASI,Via del Politecnico snc, 00133, Rome, Italy
[3]NASA/GSFC, 8800 Greenbelt Road, Greenbelt, MD, 20771, USA
*giorgio.saita@argotecgroup.com

Introduction: In April 2029, the Apophis asteroid will perform a history-making Earth flyby, passing as close as ~31300 km from the planet. This unique scenario offers the opportunity to characterize the asteroid in terms of mass, density, shape, rotation state, composition and thermal inertia. Furthermore, mapping Apophis during its approach to our planet, and also after the Earth close flyby, will enable us to acquire and compare pre- and post-encounter data, increasing our understanding of gravitational remote interactions between the celestial bodies. This mission will demonstrate, with just five years left before the encounter, a SmallSat-enabled rapid-response to a potentially hazardous NEO (Near Earth Object). The mission falls within the Planetary Defense Program identified as a priority in the latest NASA's Planetary Science Decadal Survey. The mission, named ATENA (Advanced Technology Exploration of NEA Apophis), presented in this abstract was born out of international collaboration between ASI (Agenzia Spaziale Italiana) ARGOTEC, and NASA/GSFC (Goddard Space Flight Center). Within this context, ASI will coordinate the international consortium and manage the scientific investigation. GSFC will perform the trajectory and mission analysis, support the scientific investigation, provide the spectrometer BIRCHES, and manage the support of the Deep Space Network (DSN). ARGOTEC will develop the spacecraft, lead the integration of all payloads, and manage the mission execution and operations. This Italian-led mission, ATENA, will aim to optimize data production with that of OSIRIS-APEX, operated by GSFC, which will observe Apophis only after its planetary closest approach.

Mission ConOps: The current mission ConOps targets a launch in Q4 2027. A direct launch or kick-stage will be exploited to inject the satellite into an escape trajectory. After separation from the kick-stage, the spacecraft will begin an interplanetary transfer using its electric propulsion system to reach Apophis and, finally, rendezvous with the asteroid. During proximity operations and as close as about 2-10 km from Apophis, ATENA will perform its scientific activities mapping the asteroid surface features, shape, rotation state, albedo, color and thermal properties. The spacecraft will follow Apophis' trajectory until Earth closest approach, characterizing the influence of Earth's presence on the asteroid behavior. After the Earth encounter, the spacecraft will continue the observations until its end of life. Classical radiometric measurements and optical navigation are envisioned for spacecraft navigation.

Mission Analysis: ATENA departs Earth no later than Q4 2027, using some combination of kick-stage and launch vehicle upper stage to achieve the required Earth departure characteristic energy (C_3). ATENA then rendezvouses with Apophis mid-February of 2029 (2 months prior to Earth encounter). The mission's nominal heliocentric cruise trajectory is shown in Figure 1.

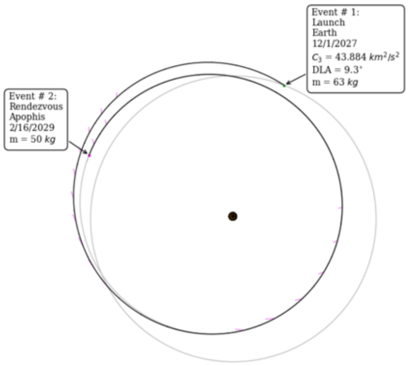

Figure 1: ATENA's Nominal Heliocentric Cruise Trajectory for Apophis Rendezvous.

Post-launch maneuvering is performed by the onboard electric propulsion system, which employs a Hall thruster with 220 W power (by end of life). The nominal design for the proximity operations trajectories is shown in Figure 2. ATENA's proximity operations design builds on OSIRIS-REx heritage and directly utilizes expertise from that mission. In Figure 2, the low-phase approach with particle search trajectory is rendered in green. The preliminary survey trajectories are rendered in red and include slow hyperbolic flybys to estimate Apophis's *GM*. These are followed by low-phase trajectories (rendered in cyan) for spectral, albedo, and color imaging. Safe observations trajectories during closest approach to Earth are rendered in white and provide observations of Apophis during Earth close approach from a safe vantage point. The post-Earth flyby survey trajectories are rendered in purple and include 2-tier slow hyperbolic flybys at both high and low altitudes. All proximity operations trajectories are designed to be passively safe (all drift away from the asteroid if the next maneuver is not performed) and none require capturing into orbit around the asteroid.

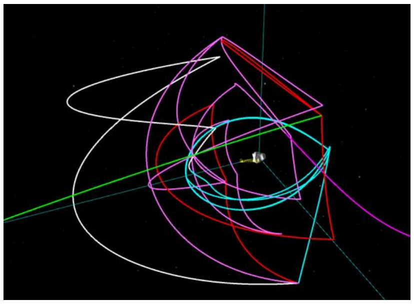

Figure 2: Nominal Proximity Operations Trajectories Relative to Apophis.

Payload Suite: The instrument suite consists of both optical imaging and spectral capabilities. The visible instrument suite includes a wide-FoV (Field of View) and a narrow-FoV camera, named LUKE and LEIA respectively. The cameras are the same as those used on LICIACube [1], the microsatellite that monitored NASA's DART spacecraft impact of the asteroid Dimorphos [2]. These cameras on LICIACube were able to collect more than 600 pictures of the impact [3], proving themselves capable of operating in the deep space environment and in proximity to an asteroid. The InfraRed (IR) observations will be carried out with BIRCHES, an IR Spectrometer developed by NASA/GSFC. Designed to be compact, versatile, and low-cost, BIRCHES will provide spectral measurements of volatiles and features affected by space weathering in the 1-to-4-micron spectral region. This instrument has already flown on-board the Lunar IceCube mission [4]. Thus, the entire payload suite proposed for ATENA has flight heritage and high TRL (Technology Readiness Level), improving hardware reliability.

Table 1-1 Key Payload Features.

	LUKE	LEIA	BIRCHES
Mass [kg]	0.40	0.89	3.5
FoV [deg]	± 5	± 2.06	< 6
Sensor Array [px]	2048x1088	2048x2048	1024x1024
Pixel Size [µm]	5.5	5.5	18
Broadband	450-700 nm	450-900 nm	1-4 µm

Satellite Architecture: The spacecraft is based on ARGOTEC's Hawk Platform, originally designed for deep space missions such as LICIACube and ArgoMoon, leveraging ARGOTEC's expertise on deep space missions. The satellite has a total mass below 70 kg (including margins at system and subsystem levels) and is composed of:

- Two deployable solar wings oriented, by means of a SADA (Solar Array Driving Mechanism), towards the Sun, maximizing power generation during the interplanetary transfer. The EPS (Electrical Power Subsystem) is completed by two battery packages and two PCDUs (Power Control Distribution Unit), both developed in-house by ARGOTEC.
- The propulsion relies on a Hall-effect thruster head. A Reaction Control System (RCS) is included in the propulsion suite for attitude control maneuvers and momentum management.
- The TMTC (TeleMetry and TeleCommands) subsystem is based on the X-band transponder (UST-Lite) currently under development by ARGOTEC. It is a Software-Defined Radio (SDR) capable of operating in multiple frequency bands (S, X, K, and Ka-bands) and enabling simultaneous transmission and reception across various radio frequency links while providing radiometric functionality. These capabilities allow performing radio science in the proximity of the asteroid. Four low-gain patch antennas, positioned to maximize the spacecraft reachability, and a high-gain reflect array antenna to download both scientific and navigation data in real-time, are included in the TMTC.
- The baseline ADCS (Attitude Determination and Control System), with flight heritage in deep space missions, includes a dedicated electronic control board, gyroscopes, two star trackers, four sun sensors and four reaction wheels.
- The OBC (On-Board Computer) is a rad-hard device developed in-house by ARGOTEC and already used for both LICIACube and ArgoMoon. Furthermore, it can include an on-board GNC algorithm already developed for LICIACube.

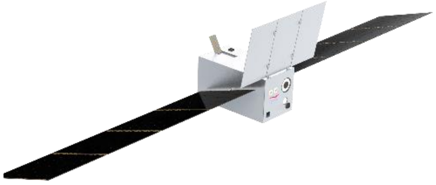

Figure 3: ATENA Spacecraft Rendering

References:

[1] G. Gutierrez, D. Riccobono et al., (2024) *LICIACube: Mission Outcomes of Historic Asteroid Fly-By Performed by a CubeSat*, IEEE2024.

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