ANIME: THE "ASTEROID NODAL INTERSECTION MULTIPLE ENCOUNTERS" CUBESAT MISSION TO EXPLORE NEAR-EARTH ASTEROID DIVERSITY. D. Perna[1], M. Pajola[2], L. Casalino[3], S. Ivanovski[4], M. Lavagna[5], M. Zannoni[6], M. Bechini[5], A. Capannolo[5], A. Colagrossi[5], G. Cremonese[2], E. Dotto[1], A. Lucchetti[2], E. Mazzotta Epifani[1], J. Prinetto[5], E. Simioni[2], P. Tortora[6] and G. Zanotti[5]
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ANIME in a nutshell: The "Asteroid Nodal Intersection Multiple Encounters" (ANIME) mission concept has been proposed in response to the 2020 Italian Space Agency (ASI) call for ideas for future CubeSat missions. ANIME aims to explore three near-Earth asteroids (NEAs), selected by virtue of their peculiar and yet unexplored size and physical regimes, as well as their relevance in terms of planetary protection. Thanks to an optimized trajectory, the targets are encountered during their passages through their orbital nodes. With a nominal launch in late 2026, the 12U ANIME spacecraft will flyby (391211) 2006 HZ51 and (450300) 2004 QD14 in June 2027 and December 2027, respectively, and then rendezvous with asteroid 2000 SG344 in September 2028. Both 2006 HZ51, with an equivalent diameter of 410±90 m and an albedo of 0.42±0.23 [1], and 2004 QD14, with an equivalent diameter of 143(-24/+49) m and an albedo of 0.37(-0.18/+0.20) [2], are classified as Potentially Hazardous Asteroids (PHAs). The ~40-m-sized 2000 SG344 is an order of magnitude smaller than previously visited asteroids, and its study will allow us to constrain the latest theories about planetary system formation scenarios, addressing questions about the monolithic vs. cohesive vs. rubble pile aggregation structure of small asteroids. Moreover, 2000 SG344 presents a very high impact risk, with multiple potential collision solutions with our planet during the course of the next century[1]. It is also considered an excellent target for future human exploration thanks to its accessibility[2]. The strategic relevance of the ANIME mission also lies in the step forwards that will be taken in validating critical small spacecraft technologies for deep space exploration.

Propulsion and Interplanetary Trajectory: The considered propulsion system consists in a single Busek BIT-3 radiofrequency ion thruster, producing a thrust of 1 mN with a specific impulse Isp equal to 2100 s. The overall rationale behind the ANIME target selection and interplanetary trajectory design lies in encountering asteroids that have a nodal passage in the proximity of the Earth, considering their relative positions and velocities. Asteroids 2000 SG344, 2006 HZ51 and 2004 QD14 are selected as ANIME targets due to their pivotal scientific and strategic relevance, over a rather large number of suitable alternatives. The reference solution (Figure 1) has a total ΔV of 1.05 km/s and a propellant consumption of 1.04 kg (out of the available 1.5 kg). The ample propellant margin guarantees flexibility in terms of: i) departure date changes, ii) strategies for escape from Earth sphere of influence (depending on the launch opportunities and orbit provided by the launcher), iii) further stage target changes, iv) maneuver capabilities after rendezvous with the final target.

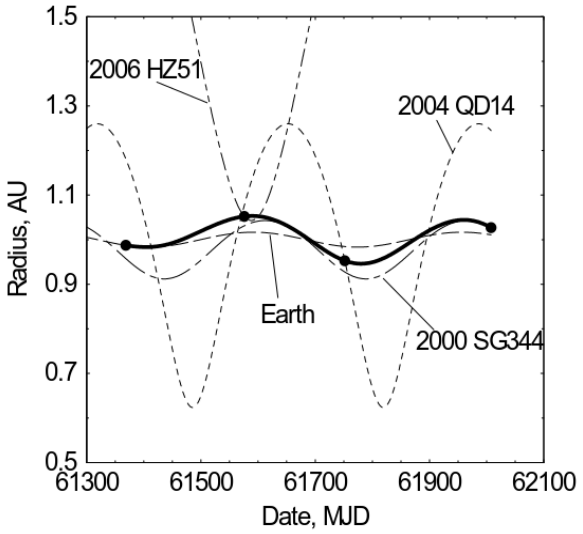

Figure 1: Reference ANIME trajectory.

Imaging Payload and Science: NEMOCAM (Near Earth Multiple Objects CAMera), the main scientific instrument onboard ANIME, is an off-the-shelf modified Ritchey-Chrétien telescope derived from the Simera Sense Ltd TriScape 100 camera, covering the 400-670 nm spectral range with an RGB Bayer filter. With NEMOCAM, it will be possible to get decimeter-scale images of both PHA targets during flybys, while closer-range acquisitions (down to a distance of 10 km) for 2000 SG344 will return a large number of centimeter-scale images. Such data will be fundamental to study the morphology and surface features (craters, boulders, regolith deposits) of the 3

[1] https://cneos.jpl.nasa.gov/sentry/
[2] https://cneos.jpl.nasa.gov/nhats/

target NEAs, unveiling their formation mechanisms and evolutionary processes in the near-Earth environment.

PHAROS (Potentially Hazardous Asteroids and Rendezvous ObServer), the secondary payload onboard ANIME, is the off-the-shelf GECKO catadioptric camera from SCS Space (Pty) Ltd. PHAROS, with an RGB pattern similar to that of NEMOCAM, will be used for proximity navigation (down to a distance of 400 m) to support both radio science investigation and surface characterization at higher resolution (3×) than NEMOCAM during the close-range campaign around 2000 SG344.

Navigation and Radio Science: Multiple low-altitude, low-velocity flybys will be performed during proximity operations at 2000 SG344, to estimate its mass as well as possible density anomalies, thus helping to constrain its composition and formation processes. Range and range-rate measurements are carried out using the onboard radio tracking system, for which we consider JPL's IRIS CubeSat Deep Space Transponder. By knowing the spacecraft's state relative to the asteroid, ranging measurements with the Earth are also useful to better determine the heliocentric orbit of 2000 SG344, hence to accurately assess its future impact solutions with our planet. Methods and tools adopted in the radio science experiment can be also used to perform operational navigation during the entire ANIME mission.

Theoretical Modelling: Optical and radio science measurements (e.g., bulk density, boulder size distribution, etc.) obtained by ANIME will constrain the input parameters for numerical simulations that we will perform following two approaches: (i) streaming instability [3] as a mechanism to form planetesimals overcoming the so-called "meter-size barrier", and (ii) N-body simulations of gravitational collisions of km-sized boulders [4]. Through such simulations, the ANIME theoretical modelling efforts will allow us to constrain the formation scenario and internal structure of 2000 SG344 and similar, still unexplored, asteroids in the tens-of-meters size range.

Spacecraft and Operations Design: Both flybys will take place at minimum distances of ~50-60 km from the target PHAs, with relative velocities of ~10 km/s. The rendezvous operations around 2000 SG344 (nominal duration: 2 months) will foresee maneuvered transfers (e.g., slow flyby branches connected through holding points) to allow a first far-range (10 km) global characterization of the target, followed by a close-range phase for higher resolution imaging and radio science. The descent on the target's surface is foreseen at the end of the mission.

The 12U ANIME spacecraft (Figure 2) has an initial wet mass of ~20 kg. We highlight that most of the components that have been selected have successfully flown on multiple missions in the Earth orbital environment (TRL 9), and the configuration design takes into account a proper shielding of the most critical components against radiation issues. Moreover, the ANIME mission will offer the opportunity to technological solutions currently under development to fill the gap to face a deep space environment.

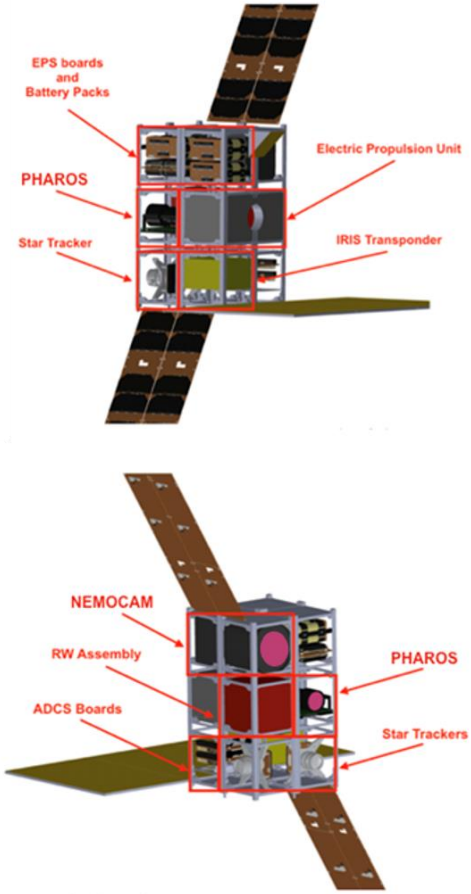

Figure 2: Detail of the ANIME CubeSat components.

References: [1] Nugent C. R., et al. (2015) The Astrophysical Journal, 814, 117. [2] Trilling D.E., et al. (2016) The Astronomical Journal, 152, 172. [3] Johansen A., et al. (2007) Nature, 448, 1022. [4] Michel P., et al. (2001) Science, 294, 1696.