RADAR TO APOPHIS: PROBING THE INTERIOR OF 99942 APOPHIS WITH CUBESATS. A. Herique[1], D. Plettemeier[2], P. Michel[3], W. Kofman[1], Y. Rogez[1], the JuRa team, The DROID team and the RAMSES Team, [1]Univ. Grenoble Alpes, CNRS, CNES, IPAG, F-38000 Grenoble, France alain.herique@univ-grenoble-alpes.fr, [2]TU Dresden, Germany, [3]OCA CNRS, Nice, France.

Introduction: Knowledge of Apophis' internal structure is crucial to better understand its accretion and dynamical evolution, to improve our ability to study its stability conditions and to model its response to the gravitational constraints induced by Earth close approach. This is also crucial for planning any interaction of a spacecraft with Apophis, especially for Planetary Defense purposes.

Is Apophis a rubble-pile, as expected, or a monolithic rock, and how high is the porosity? What is the typical size of the constituent blocks? Are these blocks homogeneous or heterogeneous? If Apophis is bilobed, how does the material differ between each lobe? Direct measurements of Apophis deep interior are needed while our present knowledge entirely relies on inferences from remote sensing observations of the surface combined with theoretical modeling [1].

Radars sounding is the most mature instrument capable of achieving the objective of characterizing the internal structure and heterogeneity, for the benefit of science as well as for planetary defense or exploration.

The characterization of the internal structure of an asteroid is the goal of JuRa, the Juventas radar, onboard the ESA Hera mission. JuRa is a monostatic radar, BPSK coded at 60MHz carrier frequency and 20MHz bandwidth, inherited from CONSERT/Rosetta. The instrument is integrated on Juventas cubesat for the ESA Hera mission [2,3]. Hera will be launched this autumn to deeply investigate the Didymos binary system and especially its moonlet Dimorphos, five years after the DART/NASA impact.

The Radar to Apophis, RA, is a modified version of JuRa able to operate in both monostatic and bistatic modes between orbiting or landed CubeSats. This radar is proposed to probe Apophis in 2029, on the DROID proposed mission understudy by JPL/CNES [4] and the RAMSES proposed mission understudy by ESA [5].

In monostatic mode, the radar instrument on one CubeSat is operating on its own. The center frequency at 60 MHz provides the capacity to probe up to 100 meters or more with a limited resolution (≈20 m). Multipass processing allows us to build a 3D tomographic image of the interior to identify internal structure like layers, voids and sub-aggregates, to bring out the aggregate structure and to characterize its constituent blocks in terms of size distribution and heterogeneity at different scales from submeter to global.

In bistatic mode, the two satellites are maintained opposite from each other around Apophis, using semi-autonomous navigation based on an optical camera. Electronics on the two platforms measure the signal transmitted throughout Apophis, as CONSERT on Rosetta/ESA [6]. Using the synchronization provided by the ISL, the radar provides then an absolute measurement of the propagation delay between the platforms through the asteroid allowing us to achieve a direct measurement of the dielectric permittivity, which is related to composition and microporosity. Partial coverage will provide slices of the body with average characterization and its spatial variability to characterize large scale structures. Dense coverage will provide a larger diversity of observation angles, the bistatic mode will then allow a complete 3D tomography [7] to recover the permittivity contrast throughout the volume.

Implementaion: The Radar to Apophis is close to a carbon copy of JuRa on Juventas/Hera.

For the electronics (1U, 1kg), minor optimizations are proposed based on experience (mainly thermal optimization, adjustment of the network position and the software). The interfaces could be revised depending on the carrier platform. The implementation of the bistatic mode only requires a revisit of the software and firmware, if the ISL takes over the frequency and time control.

For the antenna a crossed dipole is proposed, as for Juventas providing full polarization. It is consists of 4 booms of 65g each. An optimization of the boom length and matching network will be required depending on the platform and the solar array geometry.

On DROID-JPL/CNES, the two radars are carried by two 12U CubeSats orbiting Apophis. The mothercraft and its payload are proposed to be developed and operated by JPL while the two CubeSats are proposed to be developed and operated by CNES.

On RAMSES ESA, the bistatic geometry is under consolidation depending on the daughtercraft and the instrument selection. The configuration under consideration consists of a radar on the mother ship and a second radar on a Cubsat. A solution with a lander and the mother ship is also being considered.

Conclusion: The Radar to Apophis is proposed to deeply investigate Apophis in 2029 and provide the first survey of the internal structure of Apophis while cameras will monitor Apophis changes induced by the Earth encounter. It is a unique opportunity to better understand and model the stability condition of this PHA.

The proposed instrument is almost a carbon copy of JuRa on Juventas/Hera, with mainly software changes. This approach warranties the readiness of the instrument and the compliance with an instrument delivery end 2026 for a launch early 2028. The consortium under consideration is therefore as close as possible to the JuRa/Hera consortium.

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References: [1] A. Herique A. et al (2018), ASR 62, [2] P. Michel et al (2022) PSS 3:160, [3] A. Herique et al (2022) EPSC2022-487, [4] C. Raymond et al, (2023) Apophis T-6 [5] , M. Kueppers et al., this conference, [6] W. Kofman et al (2015) Science aab0639 [7] M. Haynes (2021) ASR 68.