DROID: Bistatic Low-frequency Radar Sounding Of 99942 Apophis In 2029

A. Herique [1], P. Adell[2], P. Bousquet[3], B. J. R. Davidsson[2], C. Elachi[4], Y. Gregoire[3], M. S. Haynes[2], A. P. Michel[5], D. Plettemeier[6], C. Raymond[2], Y. Rogez[1], and N. Verdier[3]

[1] Univ. Grenoble Alpes, CNRS, CNES, IPAG, F-38000 Grenoble, France alain.herique@univ-grenoble-alpes.fr,
[2] Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA
[3] Centre National d'Etudes Spatiales.
[4] California Institute of Technology, Pasadena, CA
[5] OCA CNRS, Nice, France
[6] TUD, Dresden, Germany

Apophis' internal structure :

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 to plan any interaction of a spacecraft with Apophis especially for Planetary Defense purposes (Herique et al. ASR 2018).

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? Is it fine dust, sand, pebbles or larger 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.

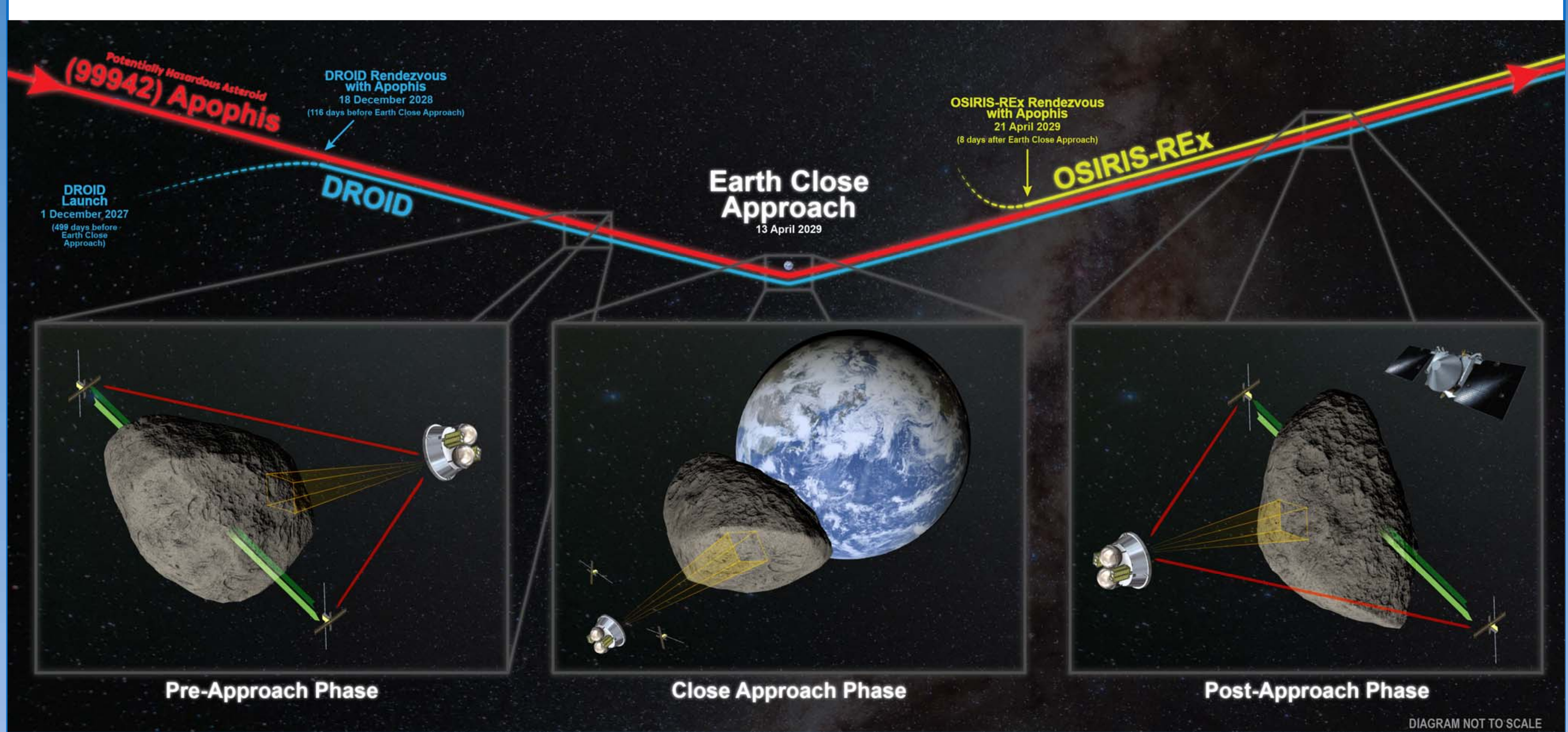
A radar operating at distance from a spacecraft is the most mature instrument capable of achieving this science objective of characterizing the internal structure and heterogeneity from sub-metric to global scale, for the benefit of science as well as for planetary defense or exploration.

DROID: a mission concept to accompany and characterize Apophis through its 2029 earth closest approach (C. A. Raymond at al. – PDC poster #83)

The **DROID** mission is proposed to rendez-vous Apophis before closed approach offering a unique opportunity to survey this PHA. The mission concept has been developed in collaboration between NASA/JPL and CNES: the DROID mothership will arrive months prior to Earth closest approach (ECA) providing crucial optical observations before and after closest approach to monitor any induced response.

After ECA, the mothership will release two CubeSats which will orbit Apophis for several weeks. These two 6 or 8 U CubeSats will offer a unique opportunity to directly observe Apophis internal structure with the a Bistatic Low Frequency Radar associated to the gravity field from the Inter Satellite Link (ISL).

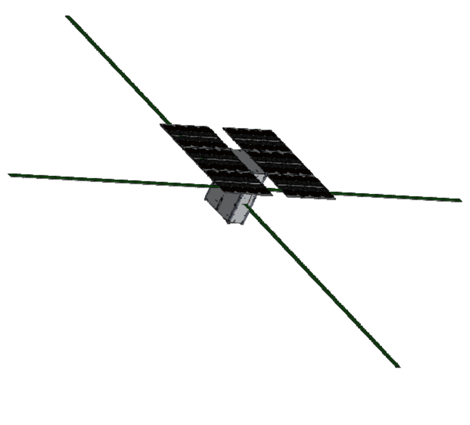
The inter satellite link between mothercraft and daughtercrafts provides, in addition to the TMTC channel, the synchronization of the two radar electronics. This allows absolute timing of the radar operation in bistatic mode as well as mothercraft-CubeSat ranging for the orbit a-posterior reconstruction. Timing and orbit restitution are required by the bistatic radar to measure the propagation delay and to analyze it in terms of dielectric permittivity. Accurate knowledge of the CubeSats orbit is also an opportunity for radio science to retrieve the first orders of the gravity field which are related to the larger scales of the interior heterogeneity (P. Michel et al PSS 2022).



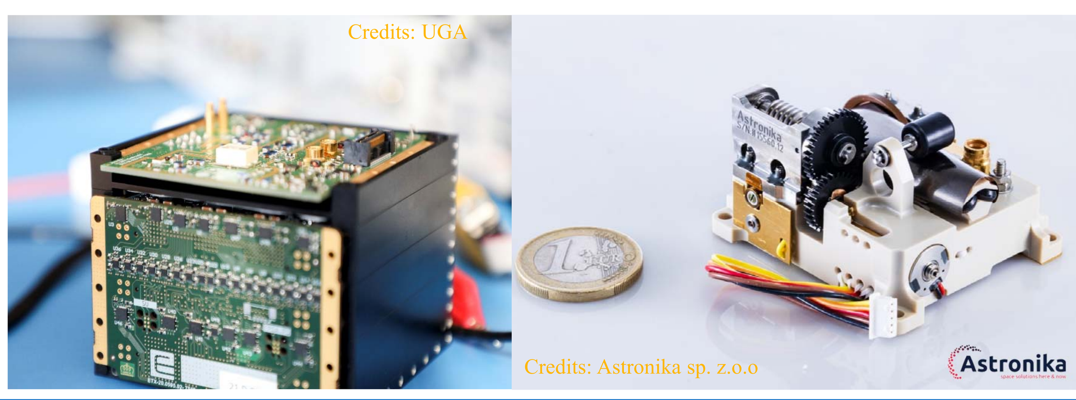
JuRa/HERA Heritage and Readiness

The proposed Radar to Apophis is close to be a carbon-copy of JuRa (A. Herique et al. PDC Poster) developed for the Hera/ESA mission:

- The JuRa is under test to be delivered in June 2023 for integration on Juventas Cubesat. JuRa electronics has been developed in newspace approach with tailored radiation, thermal vacuum, shock and EMC test. Hera launch is planned autumn 2024
- The antennas are expected to be carbon copy Jura antennas
- The main evolution concerns the implementation of the bistatic mode which requires a synchronization process between the two electronics: Inter Satellite Link (ISL) would provide the reference frequency and a common timing (under study). Limited evolution of interface board and SW are expected. The monostatic capabilities will be preserved.



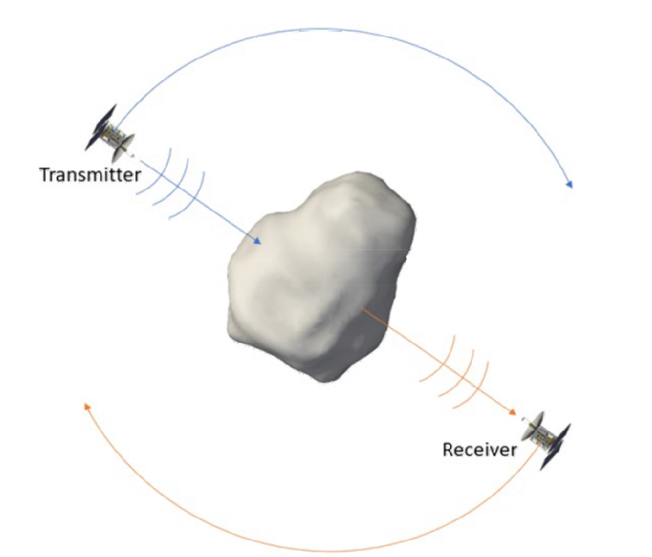
JuRa Electronics box and antenna boom



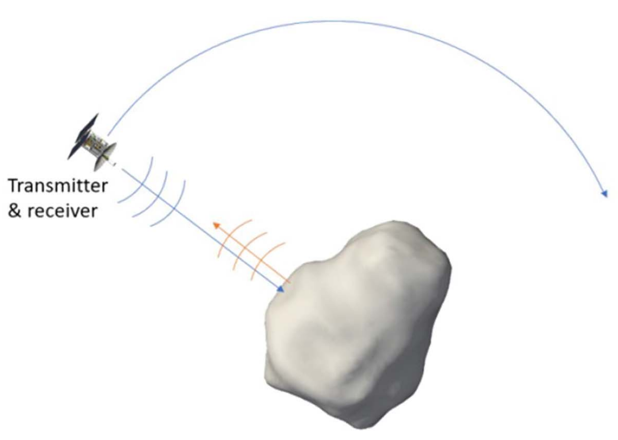
RA : a Radar to Apophis

RA The Low Frequency Radar operating in both monostatic and bistatic modes (Herique et al. ASR 2018).

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 (Kofman et al, science 2015).



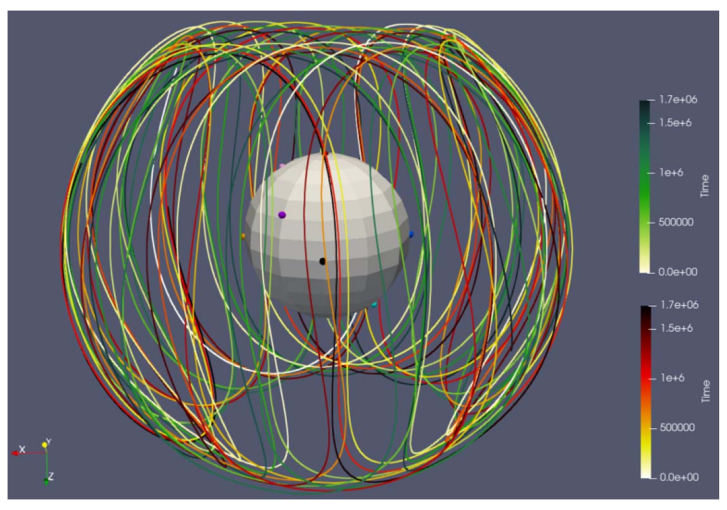
Using the synchronization provided by the ISL, the radar provides an absolute measurement of the propagation delay between the platforms through the asteroid allowing us to achieve a direct measurement of the dielectric permittivity, which is related to composition and microporosity. Partial coverage will provide slices of the body with an 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 to recover the permittivity contrast throughout the volume.



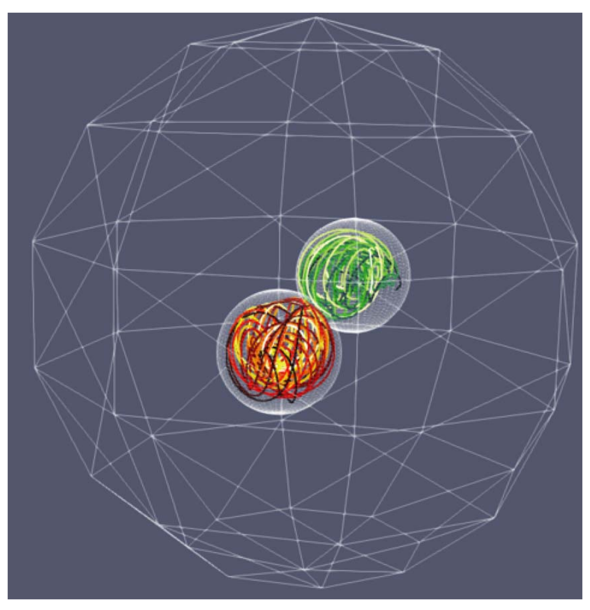
In monostatic mode, the radar instrument on one CubeSat is operating on its own. The wave frequency at 60 MHz provides the capacity to probe up to 100 meters or more with a limited resolution (≈20 m). It corresponds to the radar under implementation for the Juventas CubeSat on Hera/ESA mission. Multipass 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 sub-meter to global.

Orbits and operations : The proposed operation scenario consists in an alternation of monostatic and bistatic acquisition sequences.

The two CubeSats will orbit Apophis at a distance of the surface lower than one kilometer, in relative position close to opposition in order to limit the instrument blinding by the direct propagation path during bistatic acquisition.



Orbits of the 2 CubeSats in the body fixed frame



Ewald Sphere : final coverage for 2 points on Apophis

The implementation of two polarizations on board each instrument and the large antenna beam will limit attitude control constraints. Beneficing of the low rotation speed of Apophis, radar measurement and ISL synchronization sequences would be interlaced to provide the required time synchronization during the bistatic measurement phases.

The resolution of the bistatic resolution will be limited by the "in-opposition" orbit constraint and of course also by the volume. The resolution as evaluated on the Ewald sphere is better than 10m 3D.

Acknowledgement

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Jet Propulsion Laboratory
cnes
Université Grenoble Alpes
IPAG Institut de Planétologie et d'Astrophysique de Grenoble