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A Low Frequency Radar to Fathom Asteroids from Juventas Cubesat on HERA

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Abstract

After several asteroid-orbiting missions, an asteroid's internal structure has never been observed directly, even though this question is crucial for science, planetary defense and exploration. With the HERA mission, the LFR on the Juventas Cubesat will fathom Didymos's moonlet in 2026. This paper presents the scientific rationale, the mission and the radar planned for exploring the interior.

Rationale

Our knowledge of the internal structure of asteroids relies entirely on inferences from remote sensing observations of the surface and theoretical modeling [1]. Is the body a monolithic piece of rock or a rubble-pile, and how high is the porosity? What is the typical size distribution of the constituent blocks? Are these blocks homogeneous or heterogeneous? If the body is covered by a regolith whose properties remain largely unknown in terms of depth, size distribution and spatial variability, does it result from the re-accretion of fine particles or from thermal fracturing? After several asteroid-orbiting missions, these crucial and yet basic questions remain open. Direct measurements of an asteroid's deep interior and regolith structure are needed to better understand asteroid accretion and their dynamic evolution and to provide answers that will directly improve our ability to understand structures and dynamic processes.

Probing the interior is also crucial for determining material composition and mineralogy. Space weathering alters the uppermost few microns of asteroid surface materials, while thermal cycling affects greater depths. Therefore, surface properties as observed by optical remote sensing may not be representative of the interior mineralogy and chemical composition. Direct observations of the asteroid subsurface are also required to better model mechanics of such kinds of granular materials in low gravity. This is crucial for planning any interaction of a spacecraft with an asteroid, for exploration or sample-return purposes, and for any mining activity in the future.

Radars operating at a distance from a spacecraft are the most mature instruments 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.

Juventas and HERA

HERA is a candidate for ESA mission to be launched to the Didymos binary asteroid system, an S-type asteroid system orbiting the sun with a semi-major axis of 1.64 AU. The primary body has a diameter of 800 m and the secondary (Didymoon), which is the main target of the mission, a diameter of about 150 m. Didymoon orbits the primary body at a distance of 1.1 km. HERA will be launched in 2023 (backup 2024) and will arrive at Didymos in 2026.

Juventas is a 6U CubeSat designed as part of the HERA mission to complement its science and in-orbit demonstration objectives. The HERA spacecraft will carry two CubeSats to be deployed after a preliminary characterization phase has completed. The Juventas mission's main scientific objective is to assess the physical and dynamic properties of Didymoon such as the interior structure and surface strength. Knowledge of these properties is necessary to characterize the DART (DART is NASA's impact mission to the same asteroid) impact and assess the outcome of the deflection test, and crucial for our understanding of the evolution of asteroids. Juventas therefore complements the HERA planetary defense demonstration mission to a binary asteroid and helps meet its scientific and technological goals. The CubeSat payload consists of a low-frequency radar (LFR), a 3-axis gravimeter, an inter-satellite radio link (ISL), a visible-spectrum camera, and an IMU (accelerometers and gyros).

LFR to fathom asteroid

The Low Frequency Radar (LFR) has been developed and optimized to fathom the asteroid from a small platform. This instrument is inherited from CONSERT/Rosetta [2], [3] and has been redesigned in the frame of the AIDA/AIM phase A/B [4], [5] and for the HERA/ESA mission. LFR is under development, instrumenting JUVENTAS CubeSat for the HERA/ESA mission.

- With one CubeSat, LFR will operate in monostatic mode to probe down to the first hundreds of meters of the subsurface and will obtain the full tomography of a body like the Didymos' moonlet.
- With the same instrument architecture, two platforms would allow bistatic modes in transmission to fathom larger bodies like CONSERT on board Rosetta and Philae and bistatic modes in reflection offering a larger diversity in terms of geometry to resolve permittivity and roughness.

LFR monostatic on Juventas maps the backscatter coefficient (sigma zero - σ_0) of the surface or subsurface, which quantifies the returned power per surface or volume unit. It is related to the degree of heterogeneity at the scale of the wavelength and to the dielectric contrast of heterogeneities, giving access to both the sub-meter texture of the constituent material and larger scale structure.

- The first objective of LFR is to characterize the moonlet's interior, to identify internal structure like layers, voids, sub-aggregate, to bring out the aggregate structure and to characterize its constituent blocks in terms of size distribution and heterogeneity at different scales (from sub metric to global)
- The second objective is to estimate the average permittivity and to monitor its spatial variation in order to retrieve information on its composition and porosity, especially in the area of the impact crater.
- The same characterization applied to the main asteroid of the binary system is among the secondary objectives, to detect differences in texture and composition and to support the modeling of the binary system's formation.
- Supporting shape modeling and the determination of the dynamic state through radar ranging is another one of the secondary objectives.

Measurements: With one sequence of operations, SAR processing integrates several thousand measurements along an acquisition orbit to provide a 2D image, mixing in the same resolution cell (pixel) features from surface and subsurface.

If radar waves penetrate the whole moonlet, the signal returned from the opposite side jointly with the shape model gives direct access to the average dielectric permittivity which is related to the composition and to the propagation regime (heterogeneity scales) as with a bistatic radar [3], [6], [7]. Multi-pass acquisitions with different geometries allow 3D-tomography processing to access the vertical distribution of materials. Tomography performance is mainly limited by the number of acquisition sequences and therefore by the overall data volume as well as orbit constraints. With full penetration, the tomography would benefit from an absolute measurement of the propagation delay [8], [9].

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