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The Radio Science Experiment on Hera, Juventas and Milani

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1. Introduction

Hera is ESA's first planetary defense mission, launched on 7 October 2024 as part of the joint ESA-NASA AIDA collaboration. It will reach the Didymos binary asteroid system in October 2026 [1].

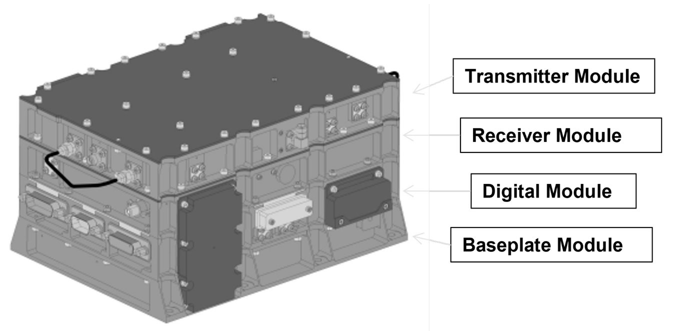
Following NASA's DART impact on Dimorphos [2,3], Hera will perform a detailed post-impact survey to assess the kinetic impactor technique as a viable asteroid deflection strategy. It will also characterize the physical and compositional properties of Dimorphos, informing future planetary defense missions.

This poster presents the Hera Radio Science Experiment (RSE) [4,5], which will operate during both cruise and proximity phases. The RSE will enable precise estimation of key parameters such as mass, mass distribution, rotational states, and orbital dynamics, crucial to quantifying the momentum transfer from the DART impact.

2. Hera RSE Science Goals

1. Accurately reconstruct the trajectories of Hera, Juventas, and Milani.
2. Estimate the masses and higher-order gravity fields of Didymos and Dimorphos.
3. Characterize the post-impact mutual orbit, heliocentric orbit, rotational states, and dynamical evolution of the binary system.
4. Determine the rotational state of Dimorphos, including its librations, which is key to assessing energy dissipation, post-impact dynamics, and placing tighter constraints on its internal structure.

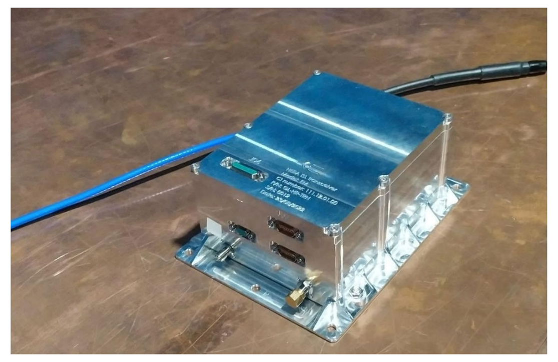
3. Hera Radio System



Hera's X-DST

Earth-based two-way radiometric Doppler and range measurements: Hera's X-Band link Deep Space Transponder (X-DST) developed by Thales Alenia Space Italia (TAS-I).

Hera's ISL



Inter-Satellite Link (ISL): Hera to Juventas and Milani communication, data/commands/telemetry relay, and navigation through ISL ranging. Developed by Tekever (Portugal).

Ground system

Earth-based radio science radiometric measurements are generated at ground stations part of the ESA ESTRACK and NASA DSN.

4. Methods

Deep space Orbit Determination (OD) aims to obtain the position and velocity of a spacecraft traveling through the solar system, thanks to a variety of observables. In addition, the OD process can be exploited to obtain a deep understanding of the solar system dynamics and scientific information on celestial bodies (gravity science) [6].

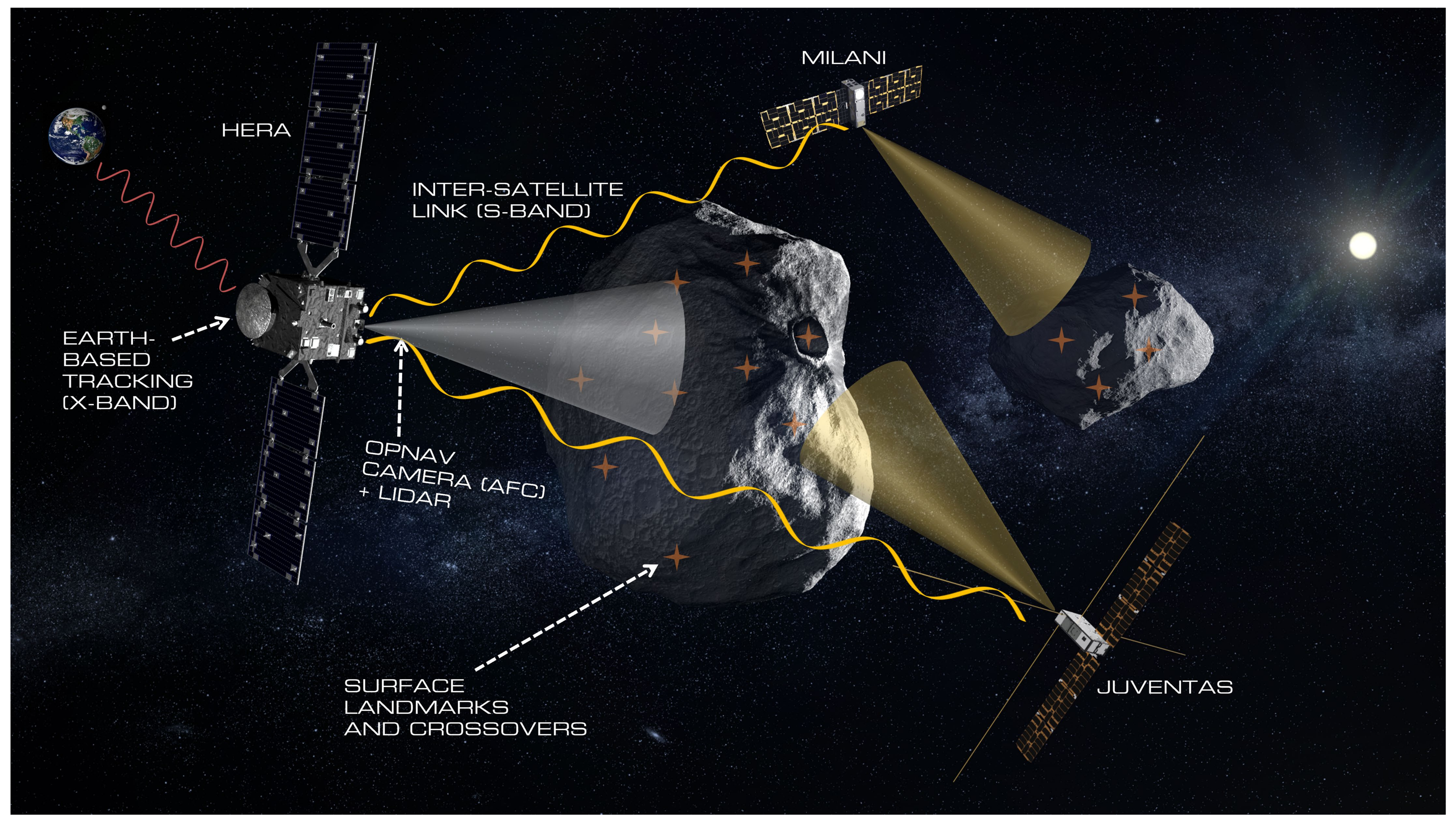


Figure 1: Hera radio science experiment measurement model. The measurements included within the Hera RSE are ground-based radiometric data, Hera optical images, Hera to CubeSats Inter-Satellite Link radiometric measurements, and Hera PALT LIDAR measurements to surface landmarks and crossovers on Didymos and Dimorphos.

The radio science data of Hera, Juventas, and Milani is processed using NASA-JPL's orbit determination program MONTE (Mission Analysis, Operations, and Navigation Toolkit Environment) [7,8].

5. RSE Cruise Phase and Mars Flyby

Main objectives:

1. Radio link performance and spacecraft characterization.
2. Tracking data processing and OD tests
3. Test of WBDDOR.
4. Constrain Deimos ephemeris during the Mars flyby (adding optical data)

Figure 2: Artistic impression of ESA's Hera spacecraft during its Mars flyby last 12 March 2025, with Mars and its moons Phobos and Deimos in view. The maneuver provided a crucial gravity assist on Hera's journey to the Didymos-Dimorphos system.

6. Results: Cruise Phase – Mars Flyby

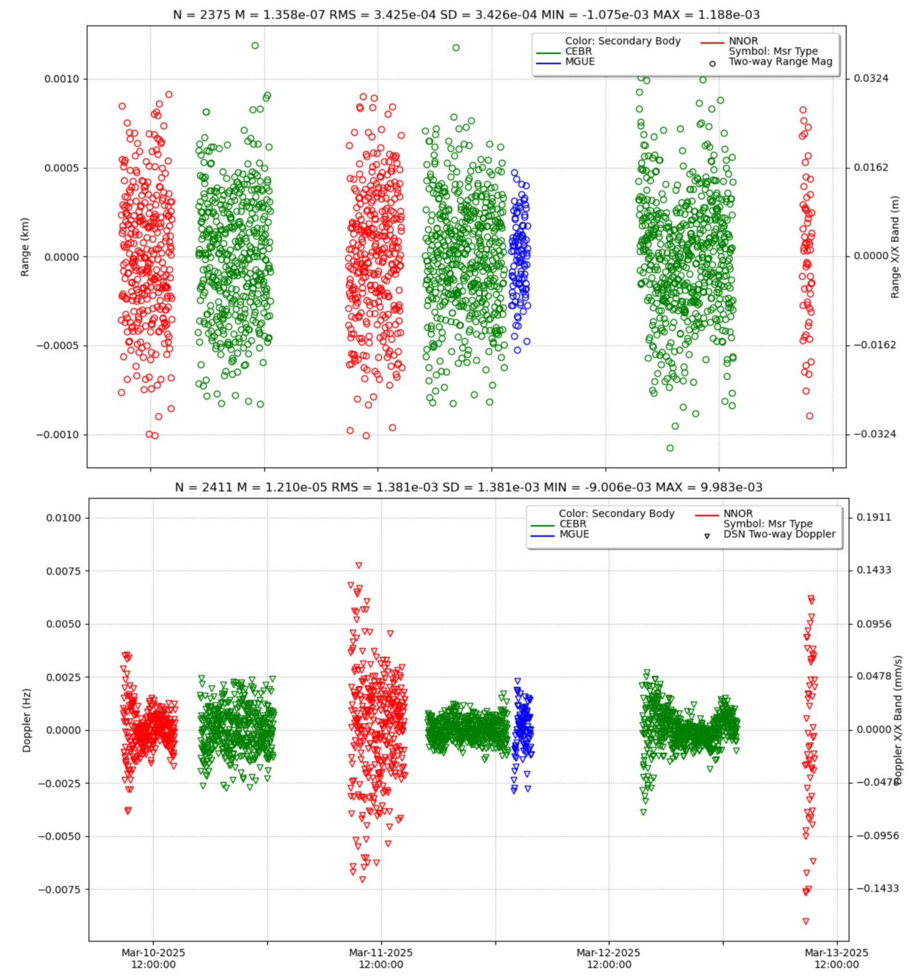


Figure 3: Hera Range (top) and Doppler (bottom) residuals from the Mars flyby OD. The analysis included also 6 DDOR measurements, not reported here.

OD Setup

- Mars Gravity Field: JGMRO120_F [9]
- Mars Rotational: IAU 2015 [10]
- Ephemerides: DE440, MAR097, SB441 (asteroids) [11,12]
- Hera a priori state + attitude: latest kernels [13]

Residuals RMS

- Range = 0.3 m
- Doppler = 0.03 mm/s

Hera-Mars B-Plane (EMO2000)

- BT/BR Error ellipse (3σ) = 13 x 120 m
- T_CA uncertainty (3σ) = ± 0.01 sec

Current work

- Inclusion of optical navigation images from the Asteroid Framing Cameras (AFC)
- Generation of range normal points for Deimos ephemeris reconstruction

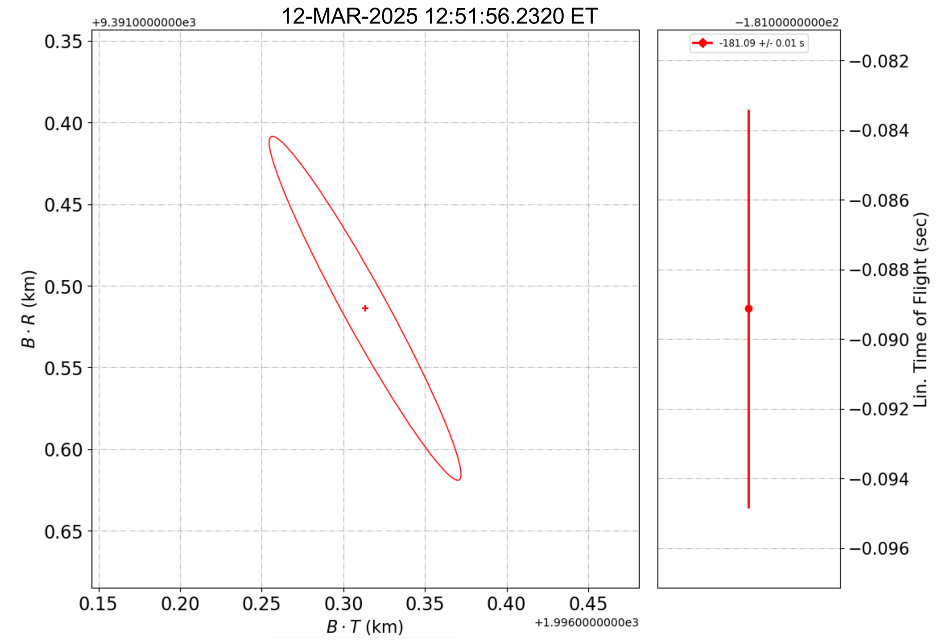


Figure 4: Hera-Mars B-Plane (EMO2000)

7. Expected Accuracies: Asteroid Phase

Expected uncertainties (1σ) [5]:

- Didymos GM: < 0.01 %
- Dimorphos GM: < 0.1%
- Didymos J_2: < 0.1%
- Dimorphos J_2: < 1%
- Asteroids frames: degree-level
- Dimorphos relative orbit: sub-meter level
- Didymos extended gravity field up to degree 3-4

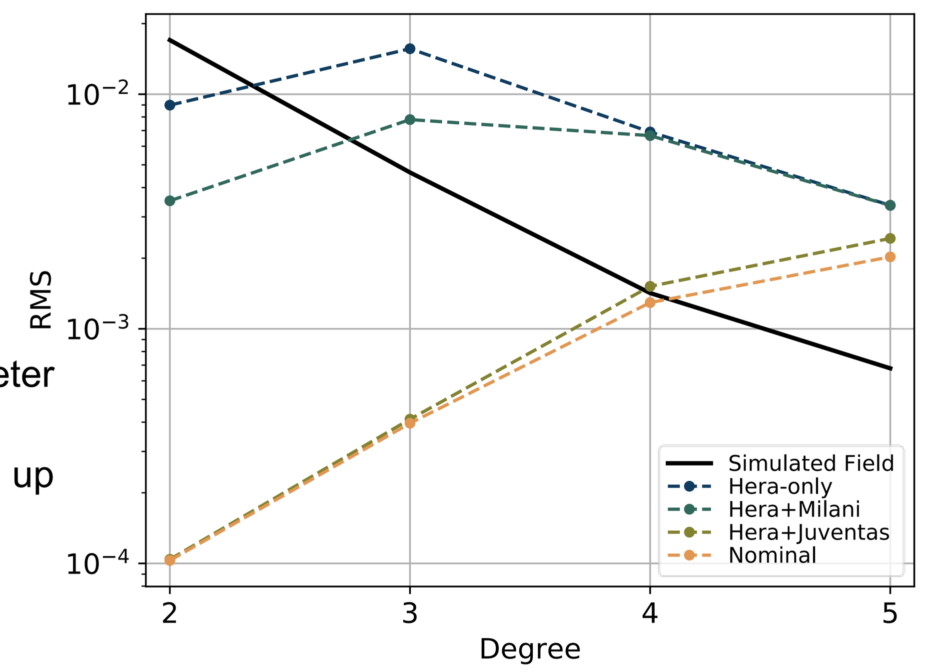


Figure 5: Power spectra of the simulated Didymos gravity field (black) and of the recovered gravity field uncertainty at the end of the nominal mission, showing the contribution of each spacecraft.

Acknowledgements

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References

[1] Michel, et al., The Planetary Science Journal, Vol. 3, No. 7, 2022, p. 160.
[2] Cheng, et al., 2023, Nature, 616(7957), 457-460.
[3] Dotto, et al., 2023, Nature.
[4] Tortora et al., 2024, Space Science Reviews.
[5] Gramigna et al., 2024, Planetary and Space Science 246, 105906
[6] Milani and Gronchi, 2010, Cambridge University Press.
[7] Evans, et al, CEAS Space Journal, Vol. 10, No. 1, 2018, pp. 79–86.
[8] Moyer, John Wiley & Sons, 2005.
[9] Konopliv et al., Geophysical Research Letters, 2020.
[10] Archinal et al., 2018, Celestial Mechanics and Dynamical Astronomy, 130, 1-46.
[11] Park et al., 2021, The Astronomical Journal, 161(3), 105.
[12] Jacobson and Lainey, 2014, Planetary and space science, 102, 35-44.
[13] https://spiftp.esac.esa.int/data/SPICE/HERA/kernels/

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