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Didymos Gravity Science Investigations with the Hera mission

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Abstract

The Asteroid Impact and Deflection Assessment (AIDA) is an international collaboration supported by ESA and NASA to assess the feasibility of the kinetic impactor technique to deflect an asteroid, combining data obtained from NASA's DART and ESA's Hera missions [1, 2]. In 2022, DART will perform a kinetic impact on the secondary of the binary near-Earth asteroid (65,803) Didymos, recently named Dimorphos. After 2 years, Hera will follow-up with a detailed post-impact survey of Didymos, to fully characterize this planetary defense technique. Additionally, Hera will deploy two CubeSats around Didymos once the Early Characterization Phase has completed, to complement the observations of the mother spacecraft and increase the scientific return of the mission. The first Cubesat, called Juventas, will complete a low-frequency radar survey of the secondary, to unveil its interior, while the second one has not yet been selected.

One of the main objectives of Hera is to characterize the mass and mass distribution of both Didymos primary and secondary by means of radio science investigations. This paper describes the concept of the gravity science investigations to be jointly carried out by the three mission elements, i.e. Hera, Juventas and CubeSat-2. The experiment will combine classical ground-based radiometric measurements, spacecraft-based optical images of Didymos, and Satellite-to-Satellite radiometric tracking between Hera and the Cubesats. Finally, our results and achievable accuracy for the estimation of the mass and gravity field of Didymos and Dimorphos are presented.

1. Introduction

Most of the information about the formation processes of an asteroid lies in its interior structure. One of the very few constraints of the internal mass distribution of a celestial body is given by its gravity field, even if the inversion process is not unique. First, the bulk density can be inferred by measuring the mass of the body, combined to the volume estimated from optical images. In addition, the higher degrees of the gravity field provide information about the internal distribution of mass, such as the moments of inertia.

The main scientific goals of the Hera radio science investigations are:

- Determine the mass and gravity field of Didymos and Dimorphos;
- Reconstruct the motion of Dimorphos around Didymos;
- Contribute to the characterization of the energy transfer between DART and Dimorphos.

Such objectives are a valuable contribution to the Hera mission objectives, leading to a better understanding of the formation and evolution processes of the Didymos system.

2. Technique

The determination of the gravity field of a celestial body is an application of the orbit determination process of deep space spacecraft. In particular, the gravity of Didymos can be estimated precisely reconstructing the trajectory of Hera during a selected number of close encounters (about 10 km at closest approach). The classical observables used in the orbit determination are obtained from the X-band radio link between the spacecraft and the Earth. The microwave signal is sent to spacecraft from a ground antenna and coherently retransmitted back to Earth, where Doppler and range measurements are obtained. A previous study performed for the AIM proposed mission [4] demonstrated that gravity science at Didymos is feasible using radio tracking data only, under realistic assumptions on the technological capabilities of the space and ground segment. Shorter pericenter distances increase the attainable accuracy. However, a significant improvement can be obtained even at relatively large distances processing also optical images of Didymos and Dimorphos taken by the spacecraft.

In addition, Hera may track Juventas and CubeSat-2 by means of a space-to-space inter-satellite link (ISL), capable of determining the relative distance (ranging) and the relative line-of-sight velocity (Doppler) between the two bodies. In particular, the latter is expected to represent a very nice add-on to the gravity investigation carried out by the Hera mission, as the Doppler shift that affects the inter-satellite link contains the information on the dynamics of the system, i.e. masses and gravity field of Didymos and Dimorphos.

The expected accuracy in the estimation of Didymos gravity fields were obtained through numerical simulations of the orbit determination of Hera and the two Cubesats. Conservative assumptions were made in terms of both radiometric and optical measurement noises, and large a-priori uncertainties for the estimated parameters were used.

3. Results

As a result of the numerical simulations, the masses of Didymos and Dimorphos are expected to be estimated with relative uncertainties less than 10^{-4} and 10^{-3}, respectively. The addition of the ISL measurements improves the achievable accuracies but it is not required to estimate the masses. However, given the relatively large distance of Hera from the system, the higher degree gravity of Didymos and Dimorphos can be estimated only adding the ISL Doppler measurements between the Cubesats and the mother spacecraft. In this case, the gravity field of Didymos can be estimated to at least degree 3, depending on the assumptions about the ISL operations and performance. Similarly, ISL Doppler measurements allows to estimate the extended gravity field of Dimorphos up to degree 2, with an uncertainty of about 10%.

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