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# Didymos Gravity Science through Juventas Satellite-to-Satellite Doppler Tracking

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## Abstract

Juventas is a 6U CubeSat designed as part of ESA's Hera mission [1] to provide bonus science. Hera – named after the Greek goddess of marriage – is a candidate ESA mission that will be humankind's first probe to rendezvous with a binary asteroid system. Hera is ESA's contribution to an international collaboration project named Asteroid Impact and Deflection Assessment (AIDA). NASA will first perform a kinetic impact on Didymos secondary, nicknamed Didymoon, then Hera will follow-up with a detailed post-impact survey, to fully characterize this planetary defense technique. The CubeSats will be deployed by the Hera spacecraft once the Early Characterization Phase has completed. In close orbit within the Didymos system, Juventas will carry out satellite-to-satellite Doppler tracking to measure the asteroid gravity field and will complete a low-frequency radar survey, to unveil Didymoon interior.

This paper describes the mission scenario for the gravity science experiments to be carried out by Juventas, together with the techniques building on the optical combination of previous radio science studies carried out in the context of ESA's AIM (Asteroid Impact Mission) studies. Finally our results and achievable accuracy for the estimation of the mass and gravity field of Didymos primary and secondary are presented.

## 1. Introduction

Among the other scientific objectives, Juventas will contribute to Didymos gravity science. Most of the information about the formation processes of an asteroid lie in its interior structure. The bulk density can be inferred by measuring the mass and volume, both of them accessible with a spacecraft orbiting the asteroid or performing a flyby, equipped with a camera and a tracking system. This is a suitable way to set constraints on the chemical composition of the interior and on the formation processes of the body. The best solution is of course provided by a spacecraft orbiting the body, since it allows a much comprehensive determination of both the shape and the gravity field.

## 2. Technique

The determination of the gravity fields requires an orbit determination process. The Juventas team optimally combines all significant heritage and previous studies on Didymos system dynamics and gravity science experiments [2], [3], [4]. The approaches followed in these parallel studies were complementary. On one side in the CUBATA study [3], focus was given to using one or two CubeSat(s) to establish a space-to-space inter-satellite link (between the main S/C and one CubeSat, or between the two CubeSats) capable of determining the Doppler shift due to the relative line-of-sight velocity between the two bodies. On the other hand in the AIM Radio Science study [4] the main S/C was considered to operate as a standalone mission and to carry out a classical gravity field determination by means of ground-based S/C tracking and the use of the on-board camera for optical navigation. In both cases, however, the main scientific goals of the investigation(s) where:

- Determine the mass and gravity field (at least up to degree 2, or even higher) of Didymos;
- Determine the mass of Didymoon;
- Reconstruct the motion of Didymoon around Didymos;

- Contribute to the characterization of the energy transfer between DART and Didymoon.

Such objectives are a valuable complement to the Hera mission objectives, leading to a better understanding of the formation and evolution processes of the Didymos system, made possible, for example, by the optimal combination of the independent measurements provided by the on-board camera and the gravity field reconstruction enabled by tracking the Hera S/C and/or Juventas.

By taking advantage of the main outcomes of both studies [2] and [3], the Juventas gravity science experiment was devised as the synergetic work of Hera and the CubeSat(s).

The Hera spacecraft communicates with the ground station on the Earth by means of a standard two-way X-band system. The microwave signal is sent to S/C from a ground antenna and coherently retransmitted back to Earth, where Doppler and range measurements are obtained. As shown in [3] the main result of the numerical simulations using the main S/C radio tracking data only is that gravity science at Didymos proved feasible, using realistic assumptions on the technological capabilities of the space and ground segment. Shorter pericenter distances increase the attainable accuracy, but good results can be obtained at large distances using optical navigation images.

On the other hand, Hera may track Juventas (and possibly also APEX [5], the second 6U CubeSat deployed by Hera in the proximity of the Didymos system) by means of a space-to-space inter-satellite link (ISL). This represents a very nice add-on to the gravity investigation carried out by means of Hera tracking observables as the Doppler effect that affects the inter-satellite link contains the information on the dynamics of the system, i.e. masses and gravity field of Didymos primary and secondary. The definition of such additional radio science capability requires ISL system to be carried on-board both Hera and Juventas (and possibly APEX). Given the currently on-going development (at high TRL) of an S-band ISL system, we have confidence in the capability of the system to being able to provide range-rate measurements with an accuracy in the range 50-100 microns/s @ 60s integration time. With these accuracies for the Doppler measurements in the satellite-to-satellite tracking, the following conclusions can be drawn from our numerical simulations: even though the gravity field accuracies are slightly better in the Cubesat-to-Cubesat scenario, the tracking option from the main S/C (Hera) to Juventas provides the best results for both the GMs (mass of Didymain and Didymoon), gravity field estimation and CubeSat positioning. In both options, the degree 2 gravity field can be retrieved with an uncertainty < 10%.

## 3. Summary and Conclusions

Building on previous results, we show how Juventas gravity science benefits from the optimal combination of the ground-based Hera radio tracking observables (Doppler and ranging) and the Hera-Juventas satellite-to-satellite Doppler observables. In particular, we show how this combination can provide the highest flexibility in terms CONOPS for the radio tracking (either ground-based or intersatellite) and image acquisition (for Optical Navigation) schedule.

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