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

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## 1. Hera-Juventas mission

Juventas is a 6U CubeSat designed as part of ESA's Hera mission [1] to accomplish additional science objectives. Hera 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), together with NASA's DART mission. DART will first perform a kinetic impact on Didymos secondary (Didymoon), then Hera will follow-up with a detailed post-impact survey, to fully characterize this planetary defense technique. After the Early Characterization Phase, Hera will deploy two CubeSats, called Juventas and APEX. The CubeSats will communicate with the Earth only through an S-band (2.2-2.4 GHz) Inter-Satellite Link (ISL) with Hera.

## 2. Orbits

Once the cubesats have been released by Hera, Detailed Characterization Phase (DCP) will begin. During DCP Hera will orbit Didymos system at an altitude between 10 km and 23 km (Figure 1) forming a sort of *hourglass* orbit. This orbit is formed by repeated arcs of 3 and 4 days. Each arc is separated from the previous one by an orbital maneuver.

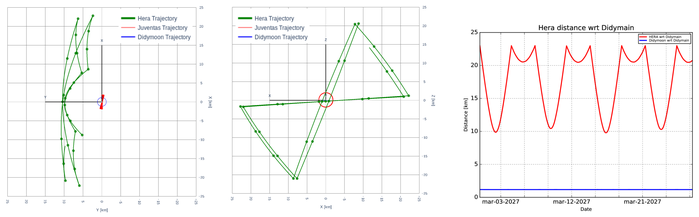


**Figure 1:** Hera trajectory during DCP-1. Z-axis is Didymoon-orbit normal, X-axis is toward Vernal Equinox.

One the other hand, Juventas - in close orbit within the Didymos system - will carry out satellite-to-satellite tracking to measure the asteroid gravity field and will complete a low-frequency radar survey, to unveil Didymoon's interior. Juventas will stay in a Sun Syncrhonous Terminator Orbit (SSTO) at low altitude (2-3 km) around the Didymos system (Figure 2).

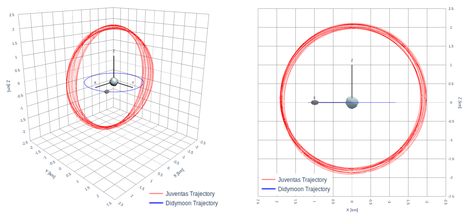


**Figure 2:** Juventas trajectory during DCP-1. Z-axis is Didymoon-orbit normal, X-axis is toward Vernal Equinox.

## 2. Juventas radio science investigation

During DCP Hera will perform radio science investigations of the Didymos system [2] through standard range and Doppler tracking at X-band (7.2-8.4 GHz). During a single Hera arc, it is assumed to perform 3 tracking passes, where Doppler and ranging observable are acquired, as scheduled in Figure 3. Moreover, optical observables are acquired outside tracking periods, every 2 hours, if Sun-Didymos-Hera phase angle is less than 60 deg.

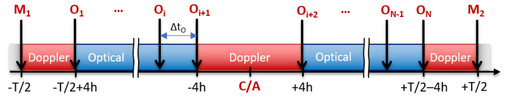


**Figure 3:** Hera-G/S observation schedule for a single Hera arc.

In addition, the ISL between Hera and Juventas can be exploited to perform satellite-to-satellite tracking. Juventas, while in orbit around the binary system on Sun Syncronous Terminator Orbits (SSTO), will be continuously in touch with the main S/C using the Inter-Satellite Link (ISL). The link will be established to acquire either Doppler or ranging, according to a preset duty cycle. The ISL schedule used for this preliminary simulations is reported in Figure 4. The baseline case is assumed to be 20% of tracking duty cycle (1min/5min), which represents a good compromise between tracking and operation requirements, keeping most of the time allocated for other scientific purposes (4min/5min).

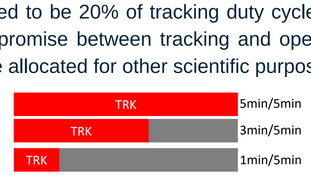


**Figure 4:** Hera-Juventas tracking (ISL) duty cycles considered. From top to bottom: 100%, 60% and 20% (nominal).

## 3. Simulation scenario

The ability to meet the radio science requirements has been assessed by means of numerical simulations using MONTE (NASA/JPL).

**Simulated Scenarios**

The cases considered during this investigation are the following:

1. Hera only: Earth-based range+Doppler + optical (SPA<60deg)
2. Hera+Juventas (ranging):
   case 1 + Hera/Juventas ISL ranging, duty cycle: 100%, 60%, 20%
   ISL range noise: 50 cm
3. Hera+Juventas (Doppler):
   case 2 + Hera/Juventas ISL Doppler, duty cycle: 100%, 60%, 20%
   ISL Doppler noise: 0.05 mm/s at 60 s integration times (constant)

**Dynamical model**

The dynamical model [3] used for the analysis includes:

- Gravitational accelerations of all the Solar System planets and satellites, and Didymos asteroid.
- Non-gravitational perturbations (Solar Radiation Pressure).

## 4. Preliminary results

Figure 5 and 6 show the estimated formal uncertainty for GM of Didymain and Didymoon, respectively. In both cases the analysis carried out provide feasibility of gravity estimation for Hera mission, which is greatly improved using Juventas ISL data. In particular, Juventas using Doppler only in addition to Hera observables provides much better results than using ranging only.

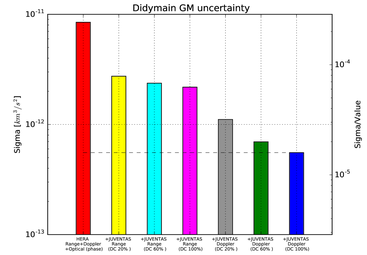


**Figure 5:** Determination of Didymain mass.

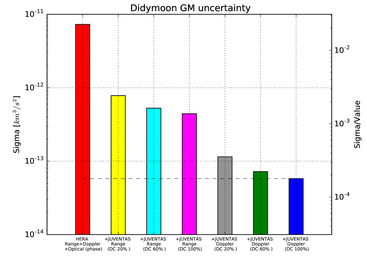


**Figure 6:** Determination of Didymoon mass.

In Figure 7 the results of Didymain gravity field estimation are presented. It worth noting that neither Hera only nor Hera+Juventas (range) cases are accurate enough to reach the aim. Thus Hera+Juventas (Doppler) is the only option which allow to observe Didymain gravity field up to degree 3 for any of the selected Doppler tracking duty cycle. The estimation of degree 4 is possible only for a continuous ISL Doppler tracking, thus represents a theoretical limit for the assumption made in this analysis.

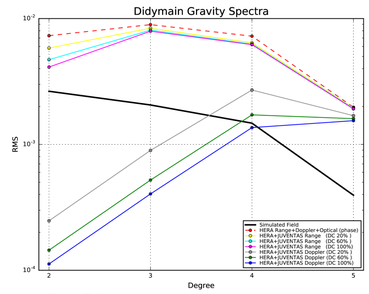


**Figure 7:** Didymain gravity field estimation performance.

## 5. Conclusions

The proposed analysis proved that the gravity science experiment for Hera-Juventas mission is feasible. Although through Hera only is possible to observe Didymain and Didymoon masses, this case does not carry enough information to estimate the Didymain extende gravity field. The application of a second cubesat orbiting the binary system at low altitude is required to provide significant results about Didymain gravity field. It also worth noting that Juventas range tracking is not required as the Doppler tracking provides better results in all the studied cases.

**References**

[1] Michel, P., et al. "European component of the AIDA mission to a binary asteroid: Characterization and interpretation of the impact of the DART mission". Adv. Space Res. (2018), Volume 62, Issue 8, pp. 2261-2272.

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