ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

RADIO SCIENCE AND PLANETARY EXPLORATION - LABORATORY -

Didymos Gravity Science through Ground-based and Satellite-to-Satellite Doppler Tracking

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Summary

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   - Didymain extended gravity
   - Didymoon J_2
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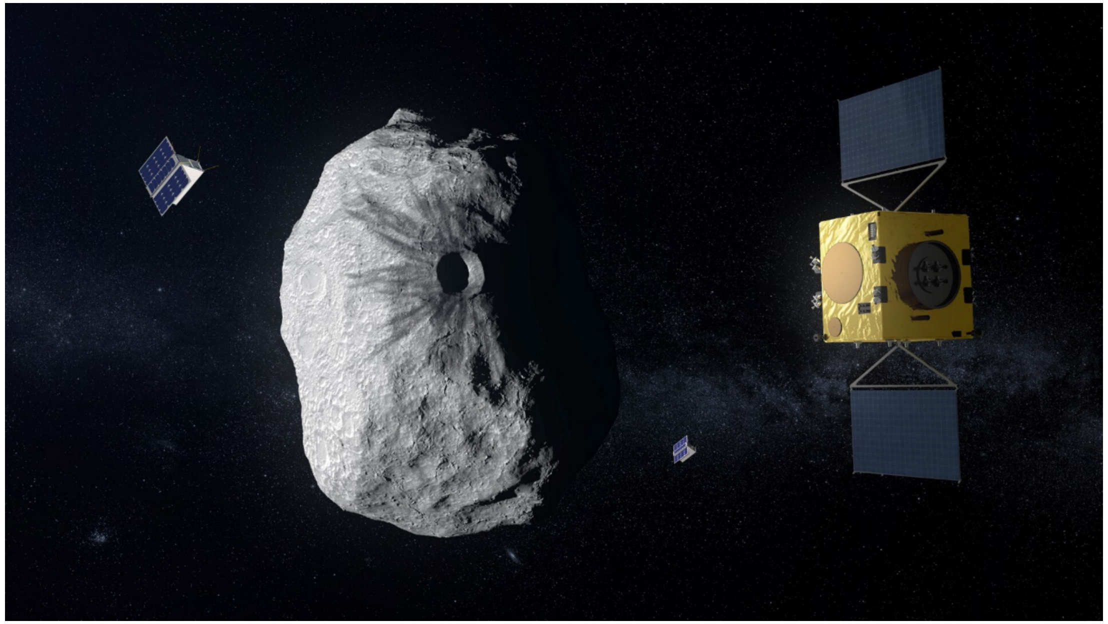
Hera mission to the Didymos system (ESA)



Near Earth Object Modelling And Payloads for Protection

NEO-MAPP

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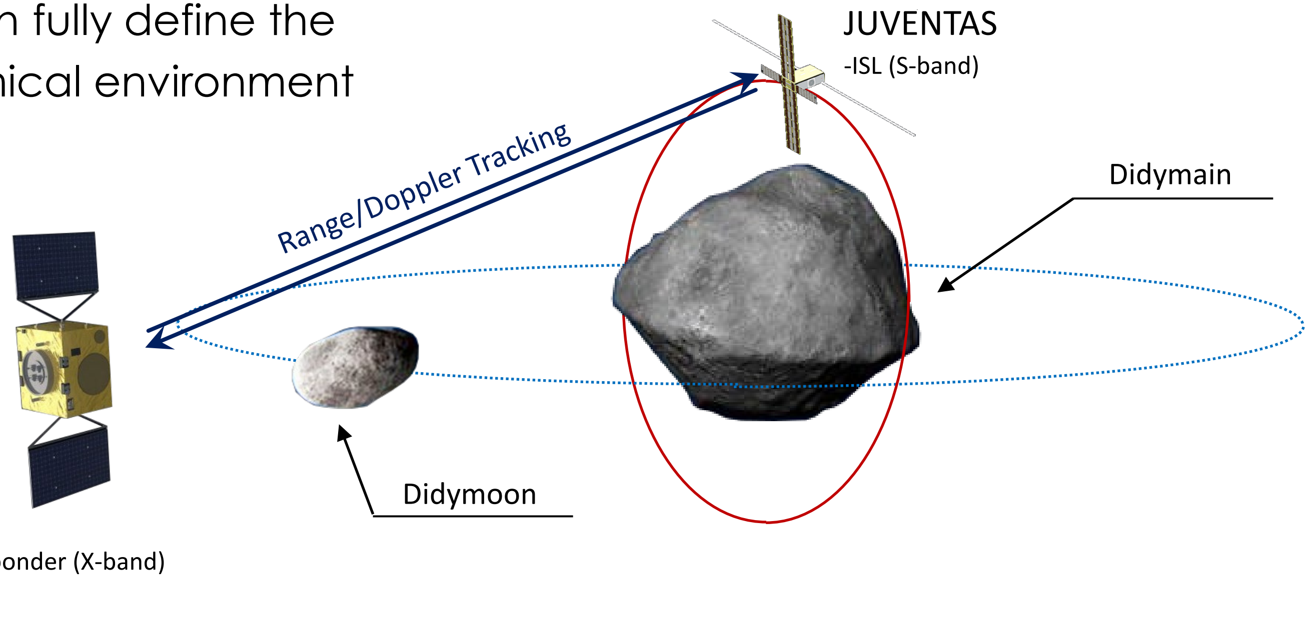
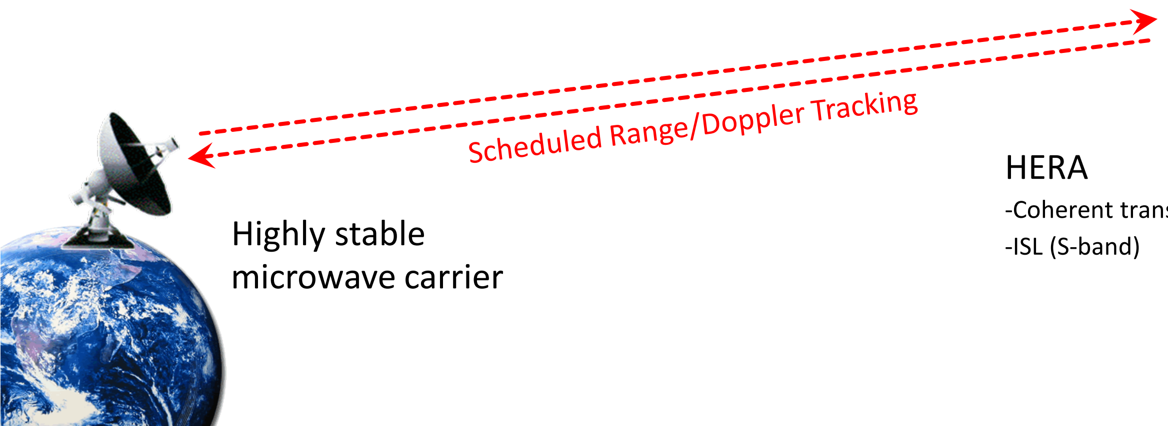
HERA / JUVENTAS Radio Science Concept

- **Radio science experiments** on space missions usually exploit the information carried by radio link between the S/C and the Earth to infer data of scientific interest
- If multiple spacecraft are present, the **Inter-Satellite Link (ISL)** can be also exploited to increase the sensitivity to the parameters of interest
- Gravity science experiments:
  – Application of the orbit determination technique
  – Purpose: estimate a set of parameters which fully define the trajectory of the spacecraft and the dynamical environment
  – Hardware required: coherent transponder (not necessarily dedicated to science)
  – ISL already used for TT&C of the SmallSat (with the addition of Doppler feature)



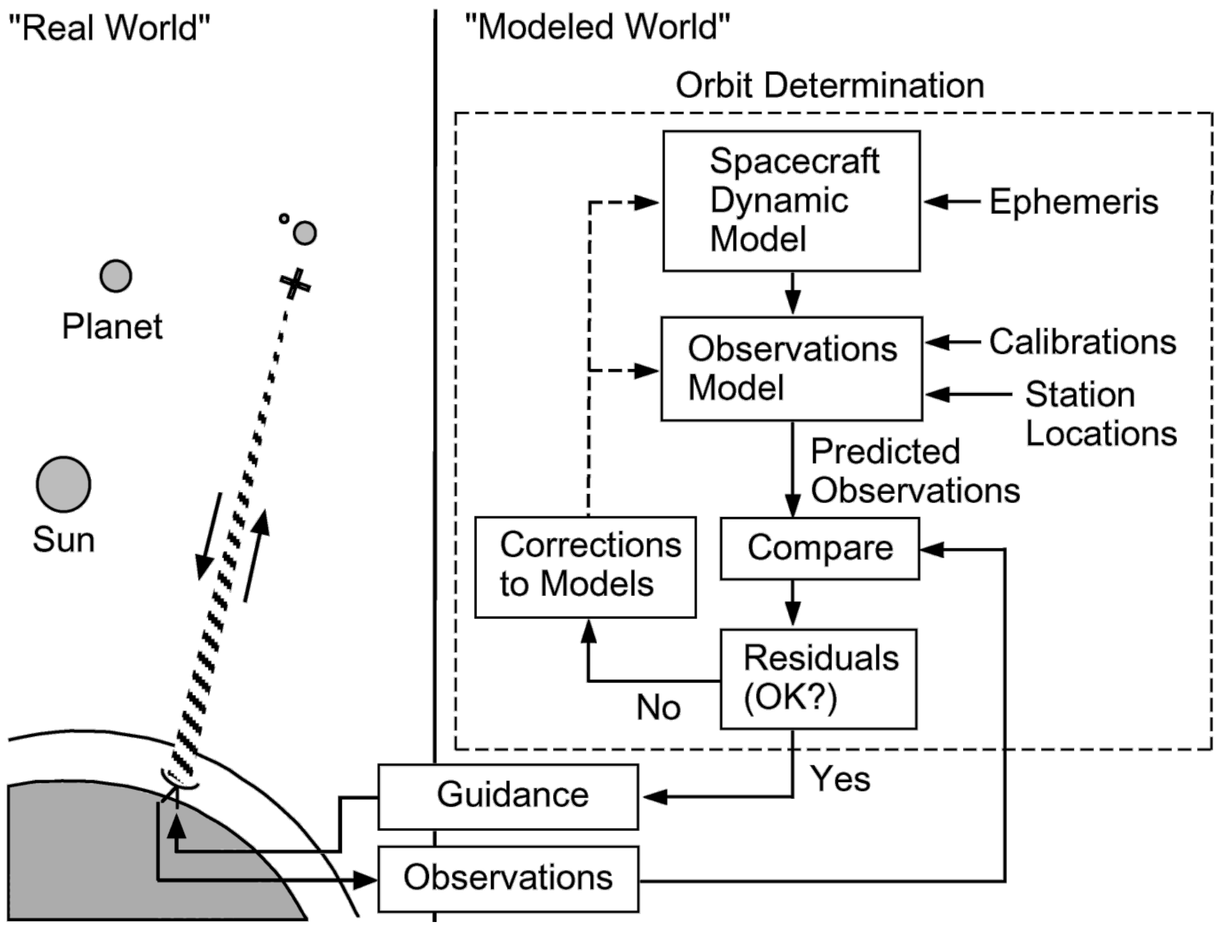


Science Objectives

Measurements	Estimated Parameters	Science objectives
• Earth/Hera Range Tracking	• Didymos ephemerides in the Solar System	• Improved heliocentric orbit • Refinement of models of the non-gravitational accelerations acting on small bodies (Yarkovsky effect)
• Earth/Hera Doppler Tracking. • Hera Optical Observables	• Didymoon ephemerides relative to Didymain	• Improved Didymoon orbit • Dissipation and tidal evolution of asteroid binary system • Balance between tides and YORP effect
• Earth/Hera Doppler Tracking. • Hera Optical Observables. • Hera/Juventas Doppler Tracking.	• GM of Didymain and Didymoon • Degree 2 gravity of both • Higher degree gravity of Didymain	• Bulk density • Moments of inertia • Gravity anomalies and density distribution
	• Pole orientation • Rotational dynamics	• Moments of inertia • YORP effect • Coupling between orbital and rotational dynamics

Numerical Simulations

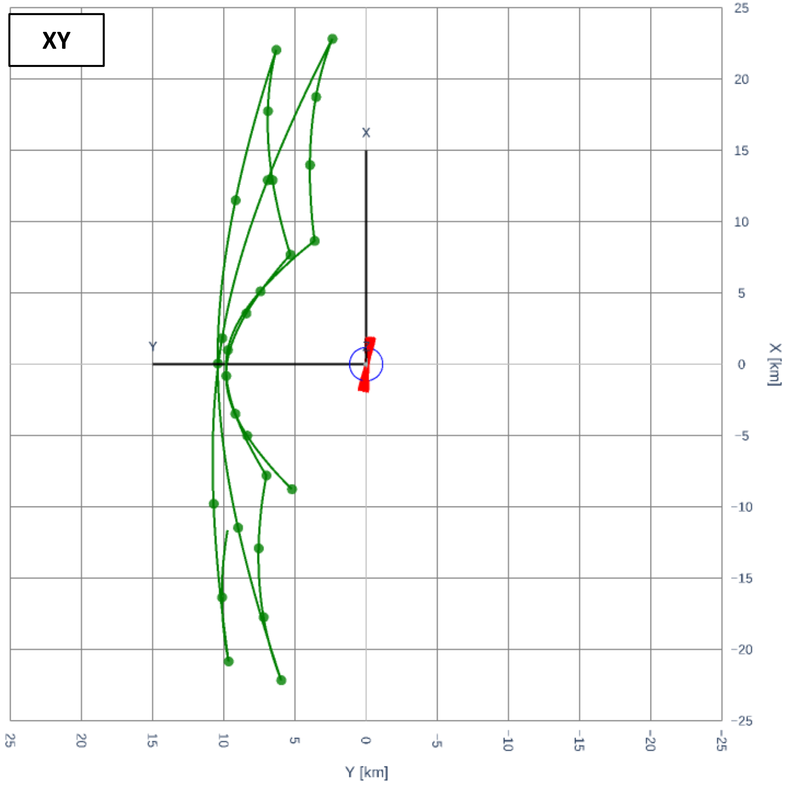
- Numerical simulations of HERA Radio Science Experiment:
  - Assess the feasibility of Radio Science investigations of the Didymos system
  - Provide a preliminary evaluation of the experiment performances
  - Identify the main driving parameters which affect the performances, providing reference values which maximize the scientific return of the mission
- Gravity science experiment: particular application of spacecraft orbit determination

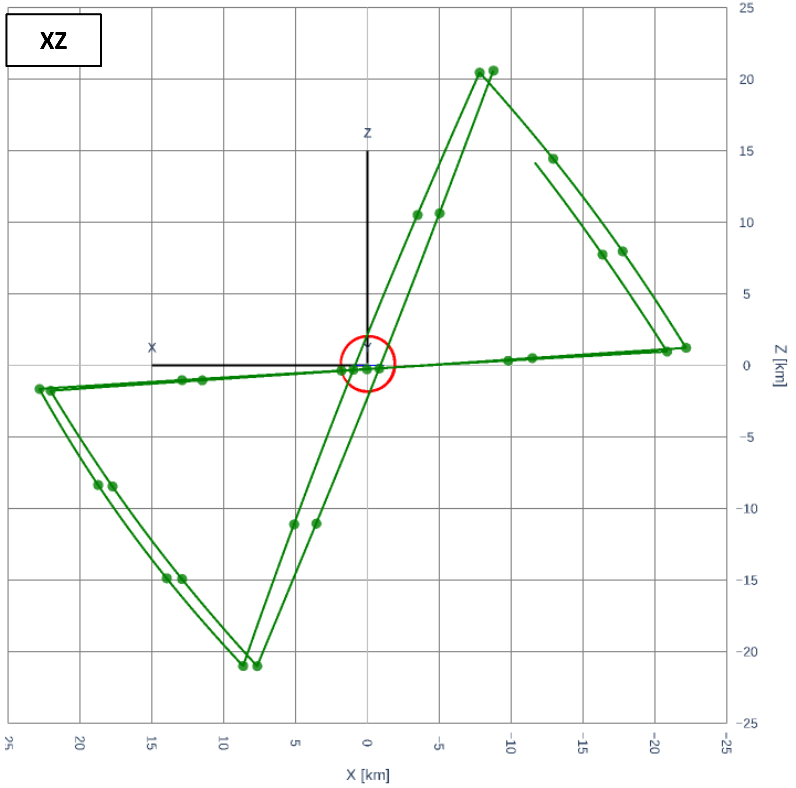


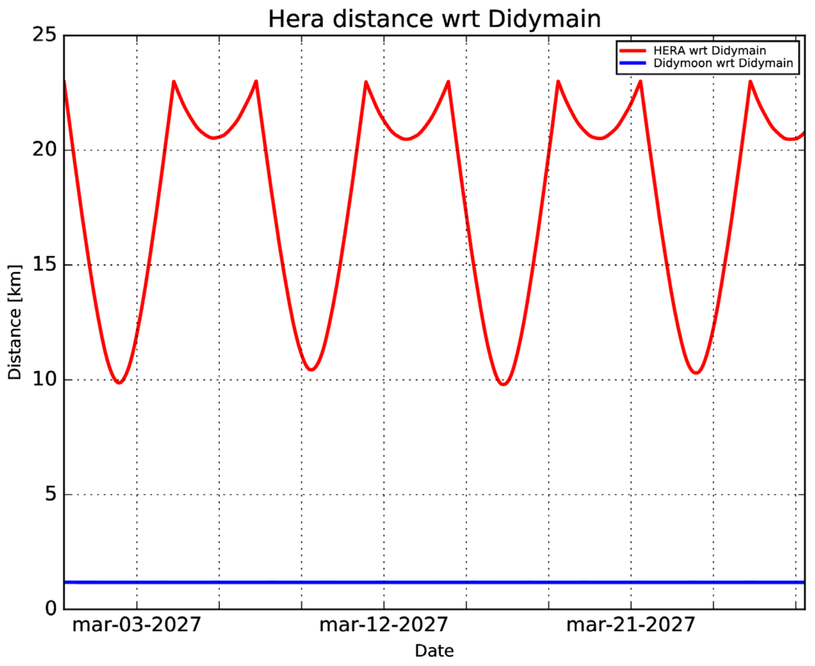
HERA Trajectory and Observables Assumptions

- Mission concept similar to Rosetta: HERA-Didymos orbit consists of a series of hyperbolic arcs connected by impulsive maneuvers
- This strategy is much more flexible and offers the following operational advantages:
  - Lower sensitivity to errors in gravity potential
  - Lower sensitivity to errors in the maneuvers
  - More favorable illumination conditions, both for science and optical navigation
  - Safe escape trajectory in case of S/C problems
- During this study, **the same strategy was adopted for the radio science investigations**, which should be performed during a limited number of hyperbolic arcs connected to a pyramid-like trajectory
- The following **constraints on Hera** during radio science arcs apply:
  - No optical measurements can be acquired during tracking periods (HGA to Earth)
  - Maximum Sun phase angle to acquire pictures of Didymos: 60 deg
  - No thruster maneuvers during arcs

HERA Trajectory (Didymoon Orbit-Normal Equinox)







Hera Trajectory
Juventas Trajectory
Didymoon Trajectory

Z=Didymoon Orbit-Normal
Y=Vernal Equinox

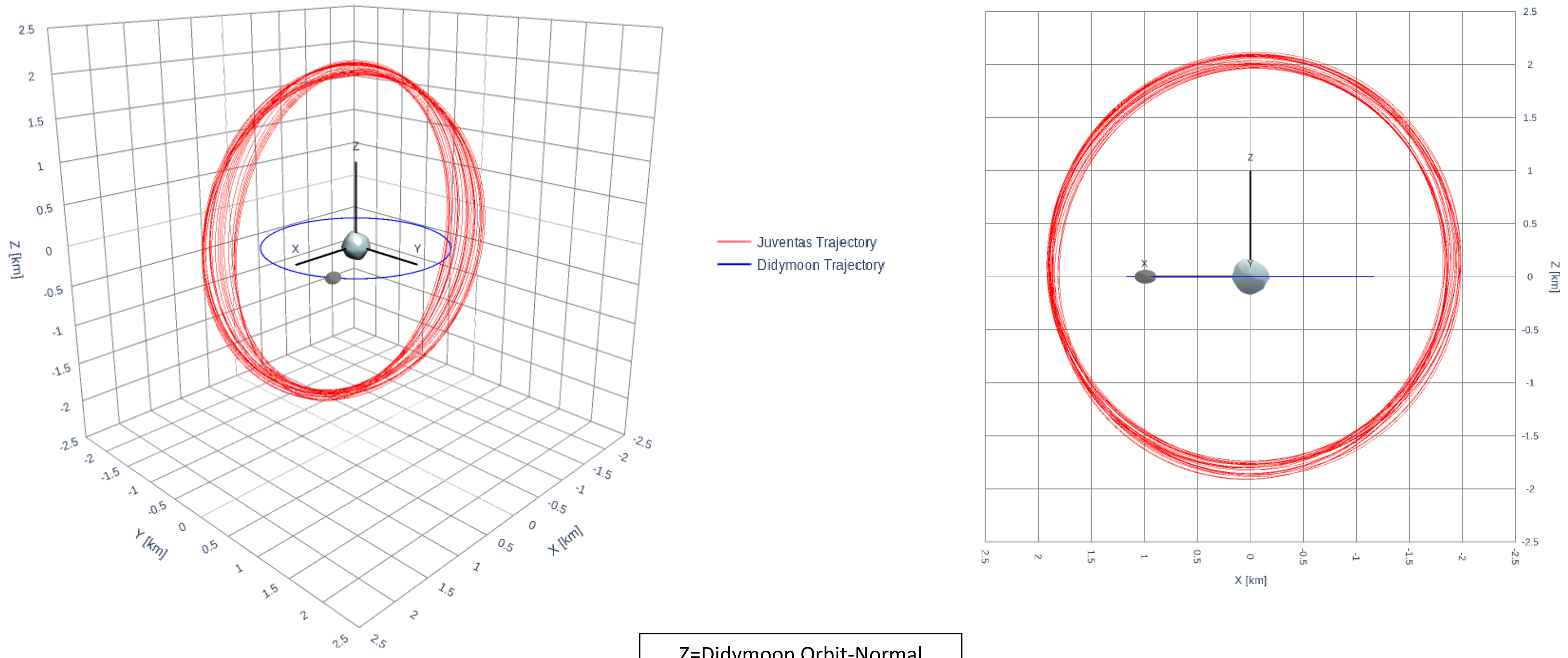
Ticks: 1 day

HERA distance from Didymain:
Min. : ~10 km
Max. : ~23 km

JUVENTAS Trajectory and Observables Assumptions

- **Sun Syncronous Terminator Orbits (SSTO)** at 2 km altitude from Didymain
- The following **constraints on Juventas** during radio science arcs apply:
  - Continuous **HERA-JUVENTAS ISL (Inter-Satellite Link)** with scheduled Duty Cycle
    - If ISL from HERA is done using quasi-omnidirectional S-band patch antennas, then there is **no need for fixed attitude during dedicated tracking time.**
  - No thruster maneuvers.
  - **ISL Ranging noise**: 50 cm.
  - **ISL Doppler noise**: 50 microns/s @60 s integration time.
    (Fully feasible by the existing system produced for PROBA-3 by TEKEVER – PT)
- **Juventas data volume negligible**: the Doppler data would be acquired and generated on-board HERA.
  - The only data generated onboard Juventas are a few HK parameters.

JUVENTAS Trajectory (Didymoon Orbit-Normal)



Z=Didymoon Orbit-Normal
Y=Vernal Equinox

Simulated Scenarios

Scenarios:

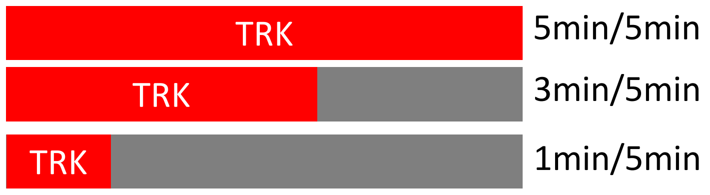
a) Hera only:
  - Range+Doppler (Earth/Hera) and Optical (max Sun phase angle: 60 deg)

b) Hera + Juventas (Range):
  - Hera Range+Doppler (Earth/Hera) and Optical (max Sun phase angle: 60 deg)
  - Hera/Juventas ISL Range only

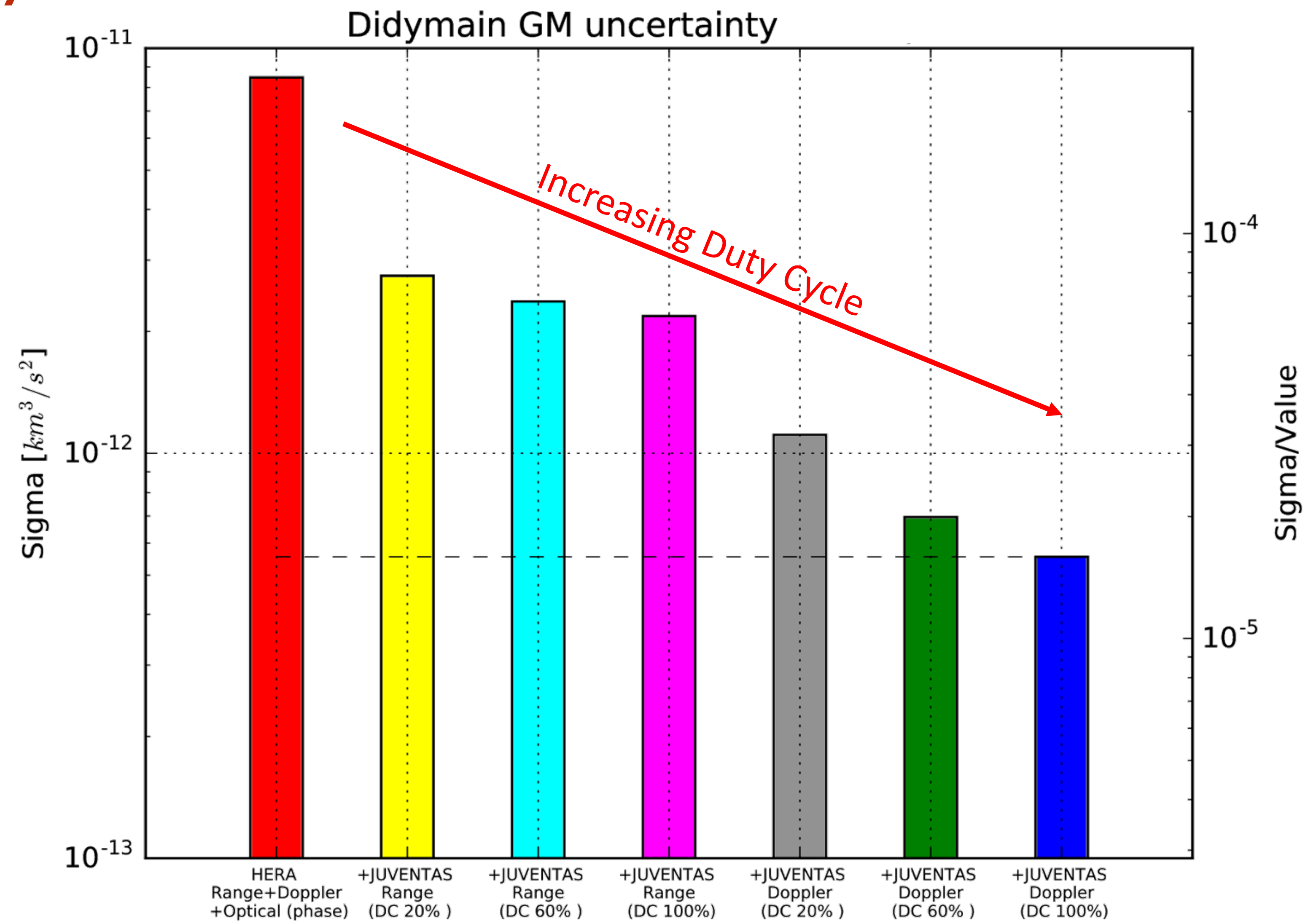
c) Hera + Juventas (Doppler):
  - Hera Range+Doppler (Earth/Hera) and Optical (max Sun phase angle: 60 deg)
  - Hera/Juventas ISL Range+Doppler:

ISL Duty Cycles:

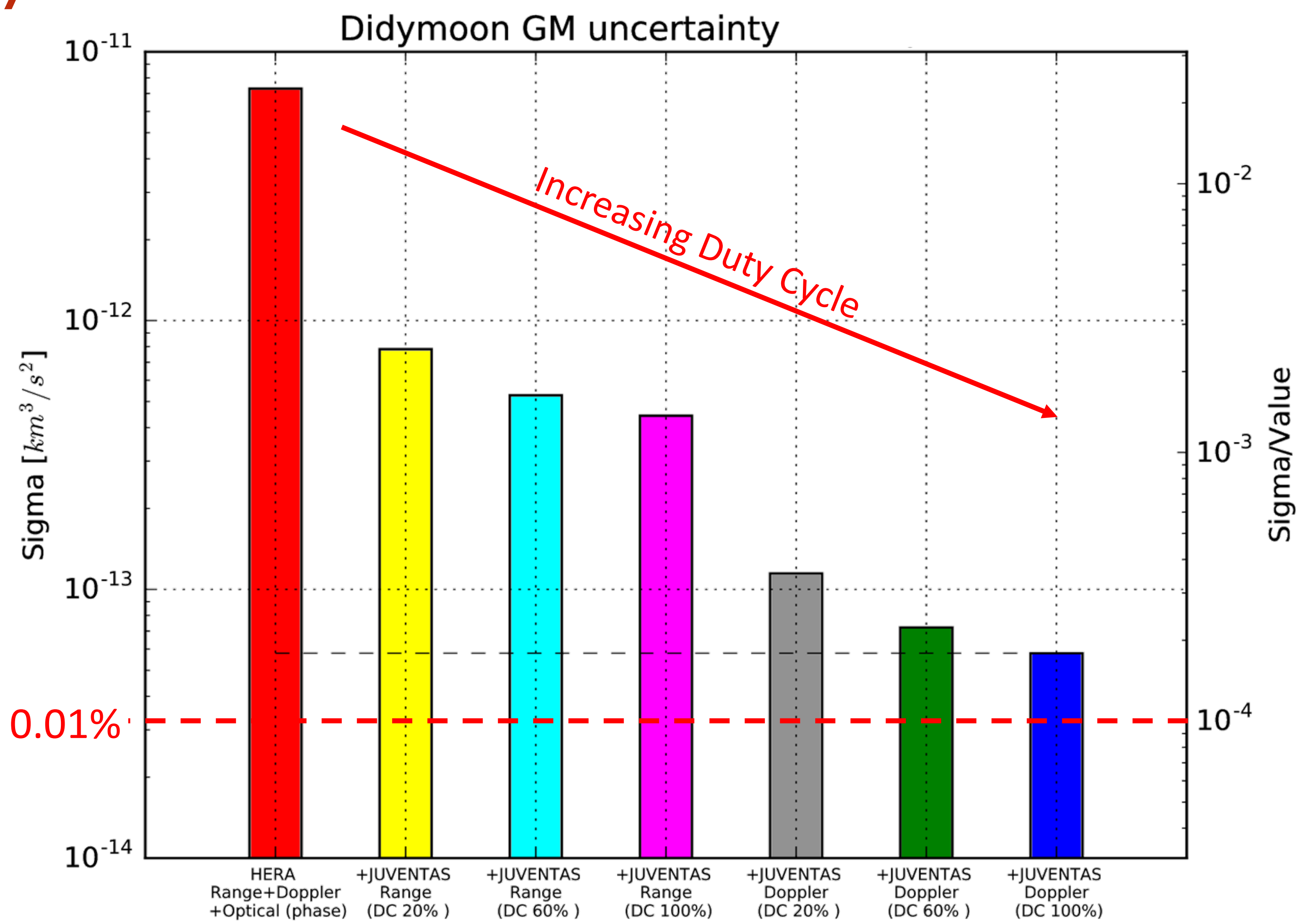
- 100%: Duty cycle 5min/5min
- 60%: Duty cycle 3min/5min
- 20%: Duty cycle 1min/5min



Results: Didymain mass



Results: Didymoon mass



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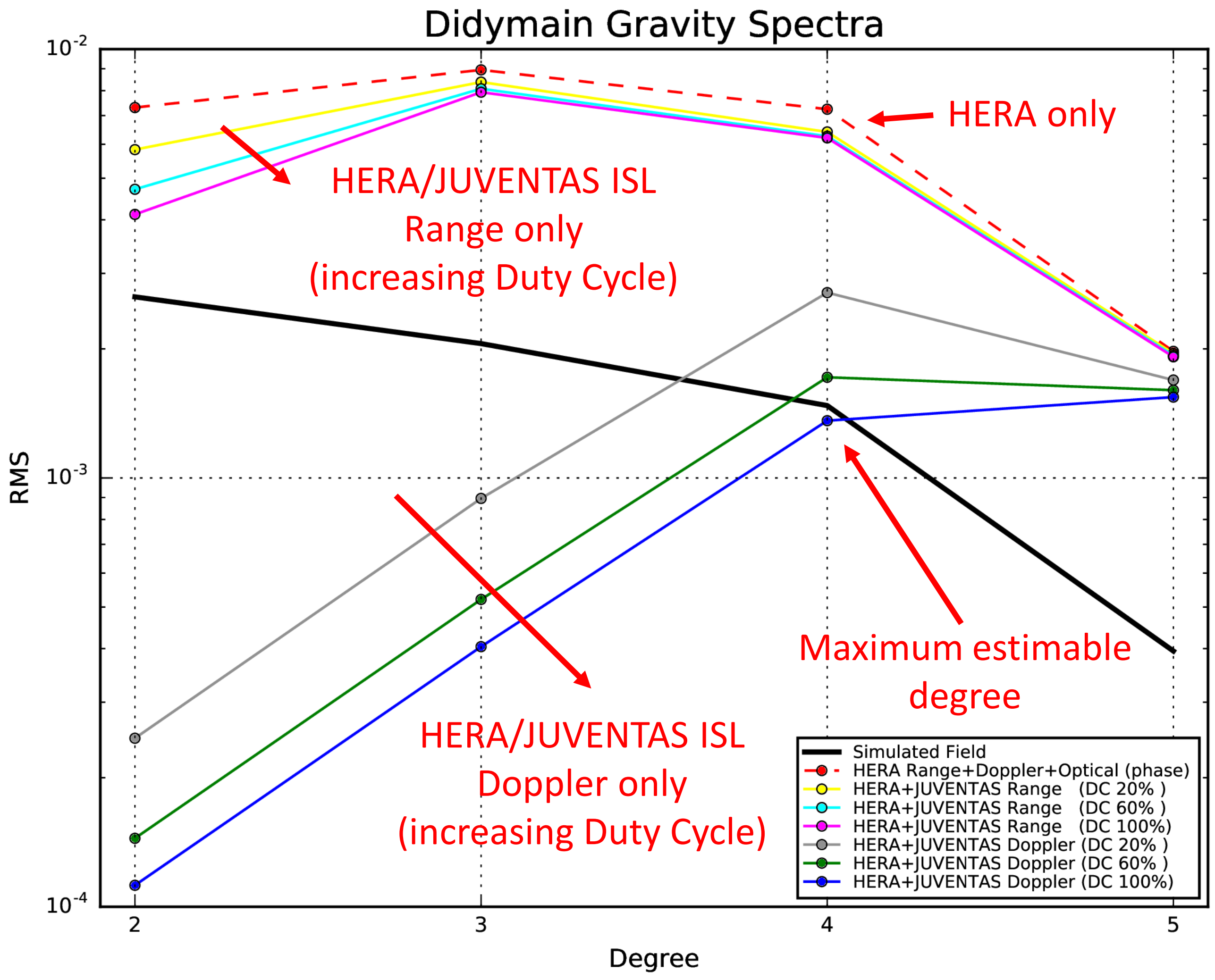
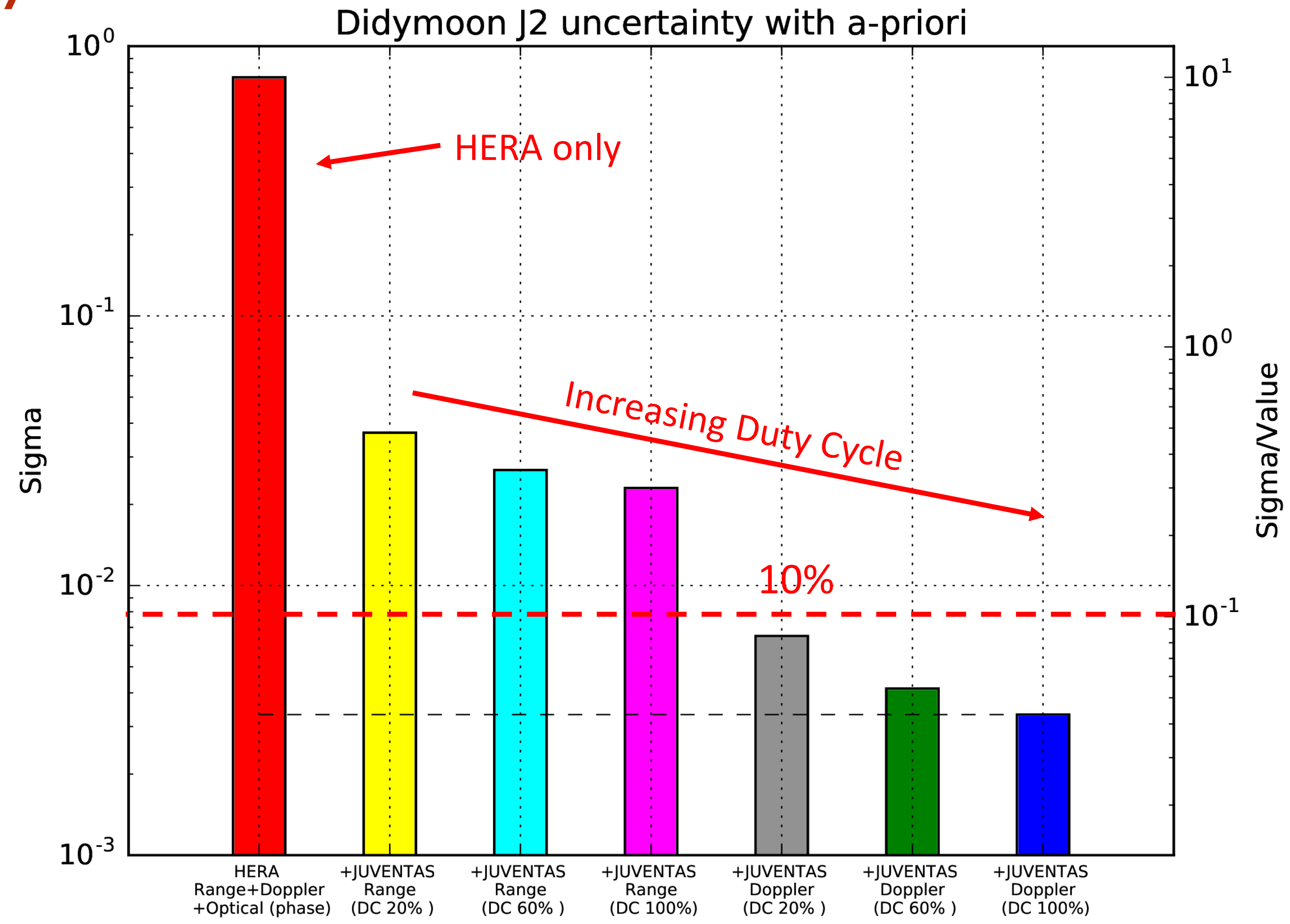
Results: Didymain gravity field

- HERA only does not allow to estimate Didymain's gravity field
- The addition of ISL Ranging improves (negligibly) the attainable uncertainties
- ISL Doppler allows to estimate degree 2 and 3
- With 100% of Duty Cycle degree 4 becomes observable



Results: Didymoon J2



Radio Science and Planetary Exploration Laboratory

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Conclusions

- The HERA gravity science experiment at Didymos **proves feasible**, using realistic assumptions on the technological capabilities of the space and ground segment
- **Optical Navigation** (OPNAV) images are essential to estimate Hera's trajectory
- **The addition of Juventas in orbit in the binary system** increases the overall accuracies, and gives access to the degree 3-4 gravity field of Didymain and degree 2 of Didymoon (at least)
- **Hera-Juventas ISL Doppler** enables to estimate the extended gravity field of Didymain and (marginally) Didymoon:
    - Didymain max observable degree: 3-4 (20%-100% DC)
    - Didymoon: J2 uncertainty 3-9% (20%-100% DC)

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Thank you!

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