Radio Science Investigations at Didymos

HERA Community Workshop

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Summary

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- Radio
- Radio Science Experiment numerical simulations
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  - S/C Simulated Tracking Timeline
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  - HERA S/C tracked from Earth
  - HERA S/C tracked from Earth + 1 Cubesat tracked from HERA
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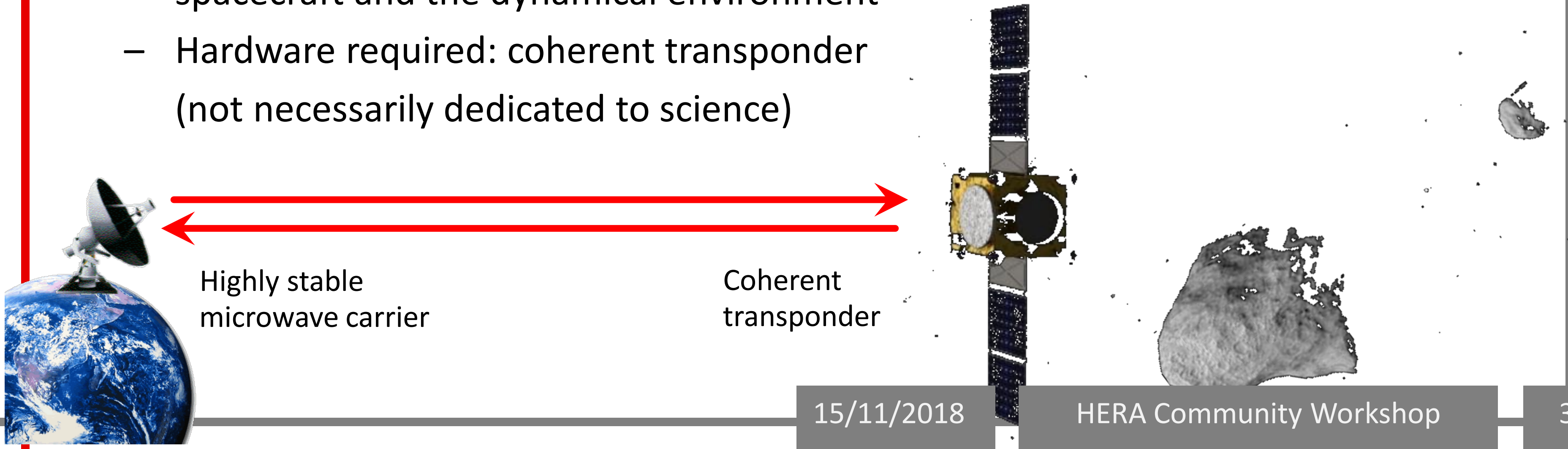
HERA Radio Science: Concept

- Radio science experiments on space missions exploit the information carried by radio link between the S/C and the Earth to infer data of scientific interest.
- Measured quantities: properties of received signal like frequency, phase, amplitude, polarization.
- Gravity science experiments:
  - Application of the orbit determination techniques
  - 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)

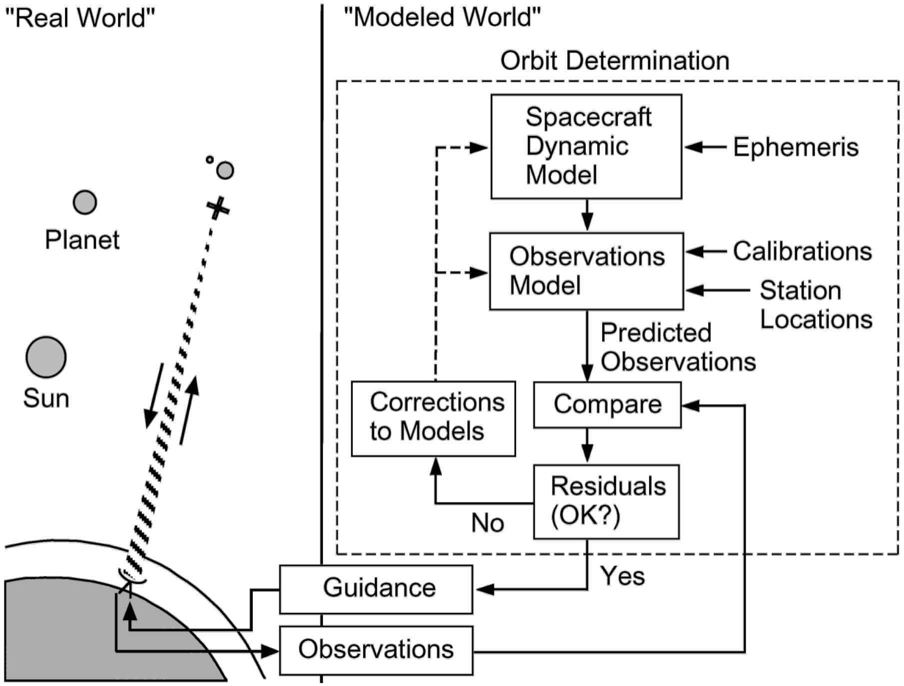


HERA Radio Science: Science Objectives

Measurements	Estimated Parameters	Science objectives
Range tracking	Didymos barycenter ephemerides in the Solar System	Improved heliocentric orbit. Refinement of models of the non-gravitational accelerations acting on small bodies (Yarkovsky effect).
Doppler tracking and optical observables	Didymoon ephemerides relative to Didymain	Improved Didymoon orbit. Dissipation and tidal evolution of asteroid binary system. Balance between tides and YORP effect.
Doppler tracking Combine with shape derived from camera.	GM Degree 2 gravity Higher degree gravity	Bulk density. Moments of inertia. Gravity anomalies and density distribution.
Doppler tracking and optical observables	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.



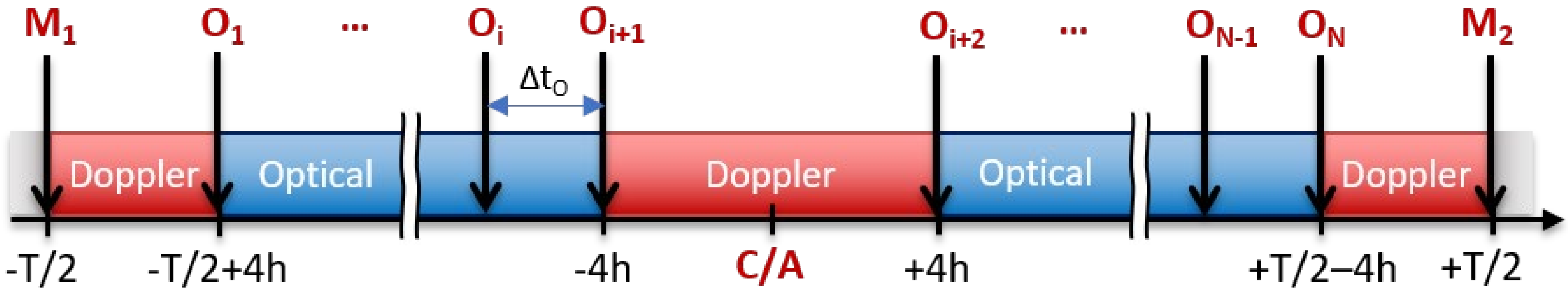
HERA Trajectory Assumptions

- Mission concept similar to Rosetta: HERA-Didymos orbit consists of a series of hyperbolic arcs connected by impulsive maneuvers to form **pyramid-like trajectories**
- 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 pyramid-like reference trajectory.
- The following **constraints on the S/C trajectory** 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 (90 deg)
  - No thruster maneuvers

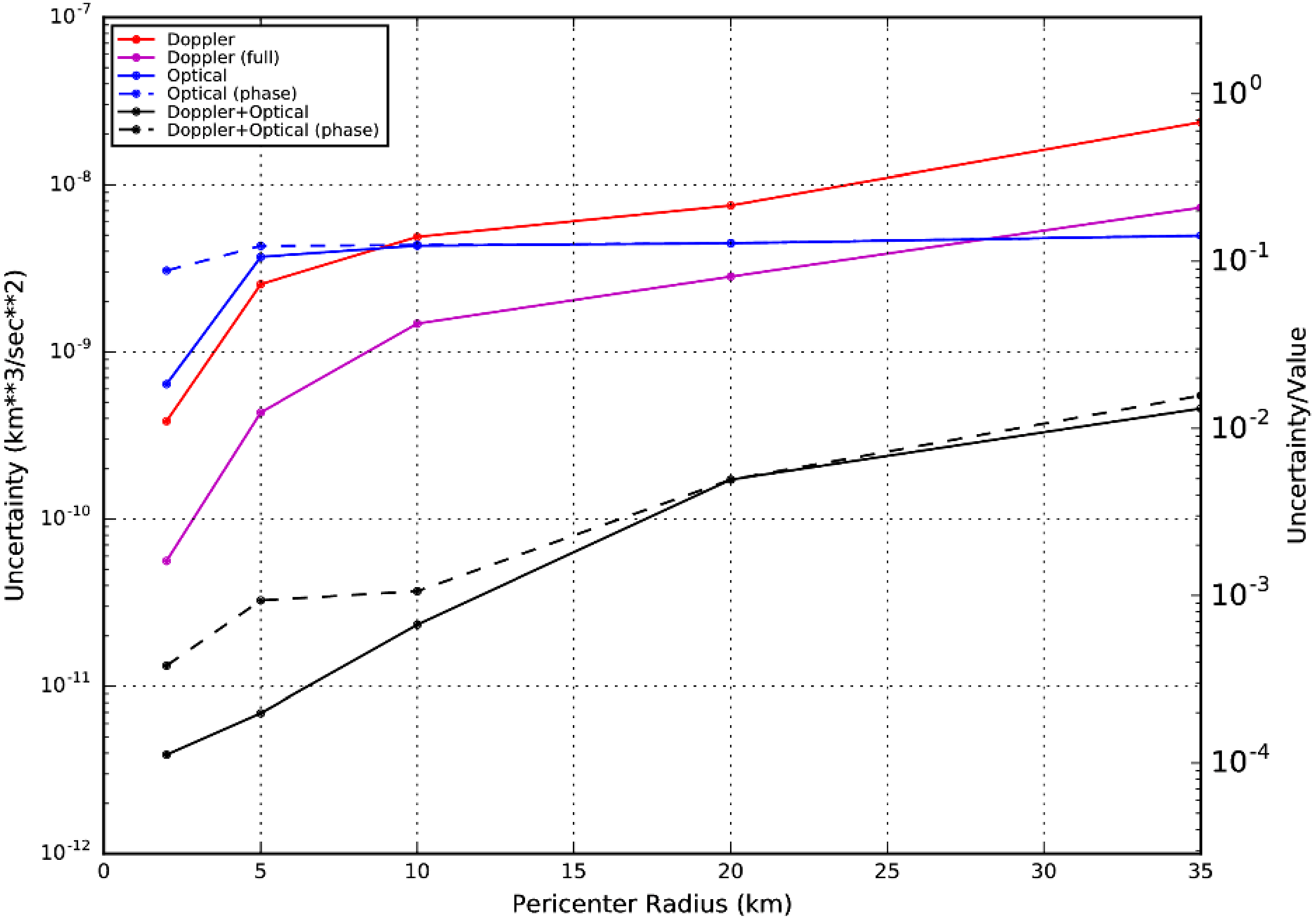
Radio Science Operations Timeline

- Each arc has a duration T, symmetric around the flyby C/A, with the following timeline:
  - C/A – T/2: arc start. Typically an orbital maneuver (M1) is executed just before the arc start, to insert the spacecraft into the desired trajectory.
  - C/A: closest approach to Didymain. The initial conditions of the spacecraft are referred to this epoch. The trajectory is integrated from this state both backward and forward.
  - C/A + T/2: arc end. An orbital maneuver (M2) is performed just after the arc end, to insert the S/C into a new arc of the pyramid-like nominal trajectory.

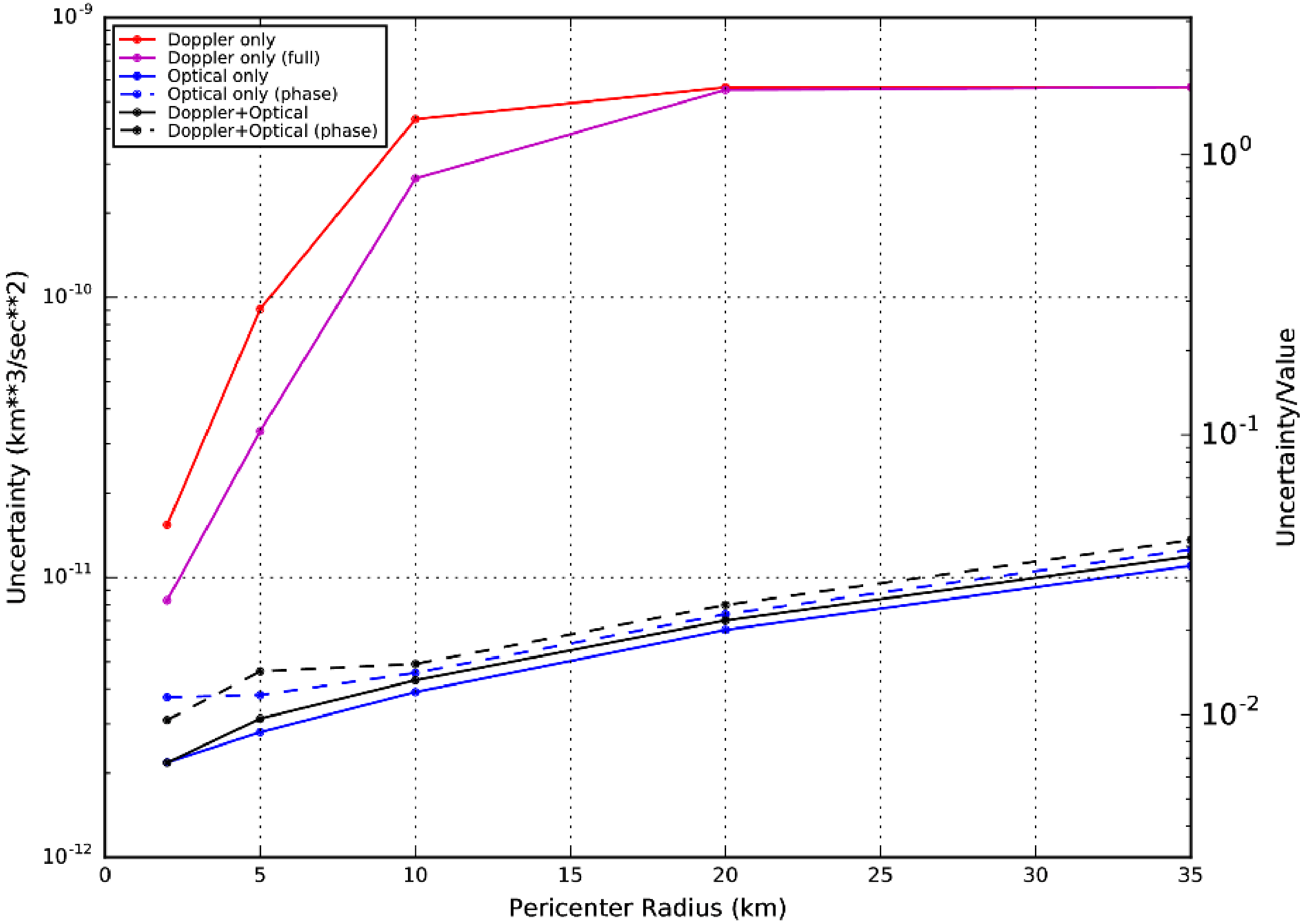
Single Arc Timeline



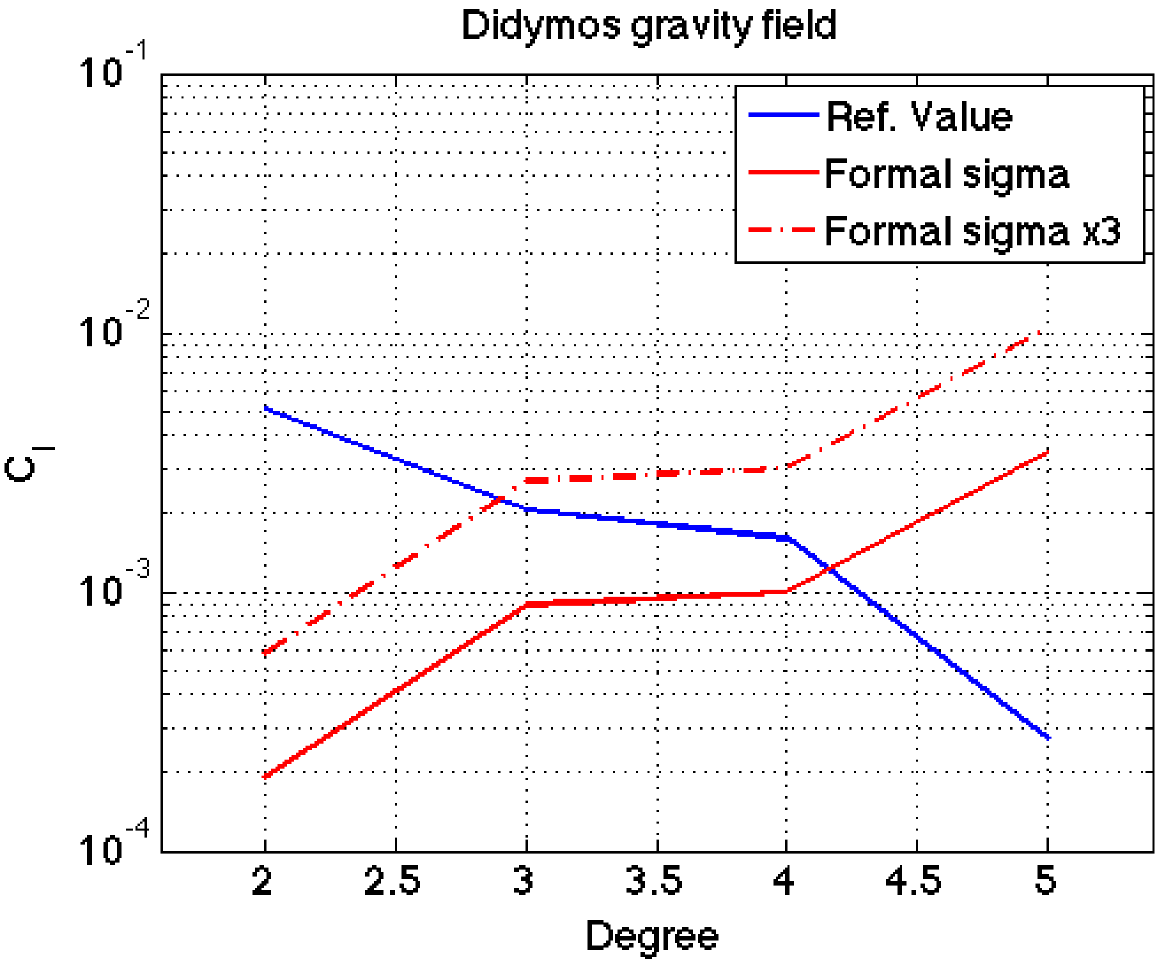
Determination of Didymos mass



Determination of Didymoon mass



Determination of Didymos gravity field (by adding a Cubesat in orbit around Didymos)



Results from the COPINS “CUBATA” study led by GMV in 2015-16

Conclusions

- The HERA gravity science experiment at Didymos **proved feasible**, using realistic assumptions on the technological capabilities of the space and ground segment
- **Optical Navigation** (OPNAV) images are crucial to improve the estimation accuracy of the scientific parameters of interest (GM Primary, GM Secondary)
- Shorter pericentre distances increase the attainable accuracy, but **good results are already obtained at large distances** using OPNAV images
- Implementation of the phase angle constraint on the acquisition of OPNAV images does not prevent reaching the required level of accuracy
- **The addition of a Cubesat in orbit to the binary system** increases the accuracies, and gives access to the degree 3 gravity field.