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AIDA: Measuring Asteroid Binary System Parameters and DART-Imparted Deflection using the AIM Spacecraft

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Overview

Radio Science at small bodies

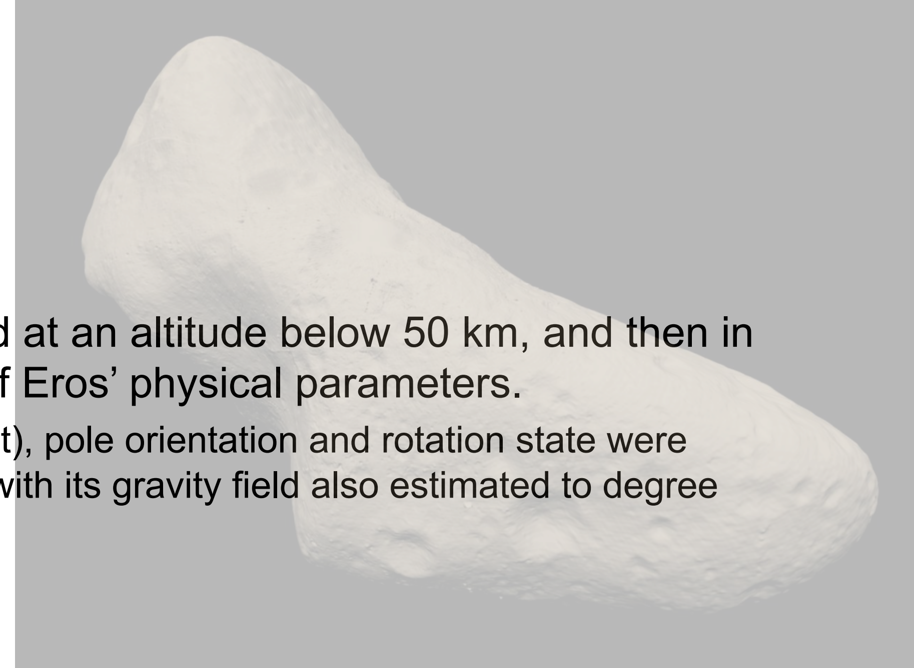
- Past missions: NEAR (NASA), Hayabusa (JAXA), Rosetta (ESA)
- Results from the B612 study on asteroid impact and tractoring deflection techniques
  - D.K. Yeomans et al. "Near-Earth Object (NEO) Analysis of Transponder Tracking and Gravity Tractor Performance", final report to B612 Foundation, JPL Task Plan No. 82-120022, 2008

Binary Asteroid Case: AIDA / AIM study

- **AIDA mission concept objectives and study goals**
- **AIM trajectory**
  - 2km and 5km terminator orbits
  - Flyby approaches (300 m from Didymoon, 1500 m from Didymain)
  - GM uncertainty as function of orbit altitude
- **DART impact observation**
  - 100 km and 50 km standoff orbits for DV impact observation
  - Didymos ephemeris uncertainty improvement

Concluding remarks

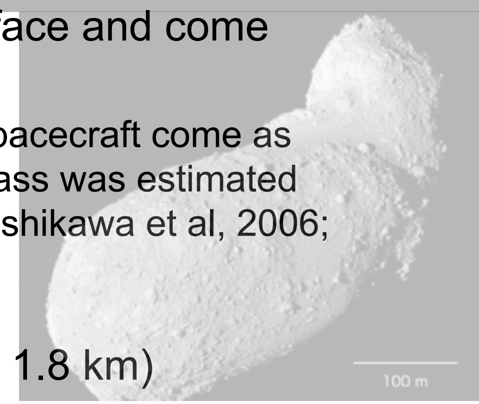
Past Missions



NEAR (Eros, 33 km x 13 km)

In the last 6 months of the mission: orbited at an altitude below 50 km, and then in a 35- km circular orbit for precise estimations of Eros' physical parameters.

- Its GM (mass times gravitational constant), pole orientation and rotation state were determined to less than 0.1% accuracy, with its gravity field also estimated to degree and order 24 (Miller et al, 2002).



Hayabusa (Itokawa**,** 535 m x 294 m x 209 m)

Visited for a few months in 2005, first spacecraft to touch the surface and come back with samples.

- A refined estimate of Itokawa's mass was obtained by having the spacecraft come as close to 5 km from the surface without using thrusters. Itokawa's mass was estimated with an error of 5-6%, and its gravity field to degree and order 4 (Yoshikawa et al, 2006; Scheeres et al, 2006).

Rosetta (Churyumov – Gerasimenko, 4.1 x 3.3 x 1.8 km, & 2.6 x 2.3 x 1.8 km)

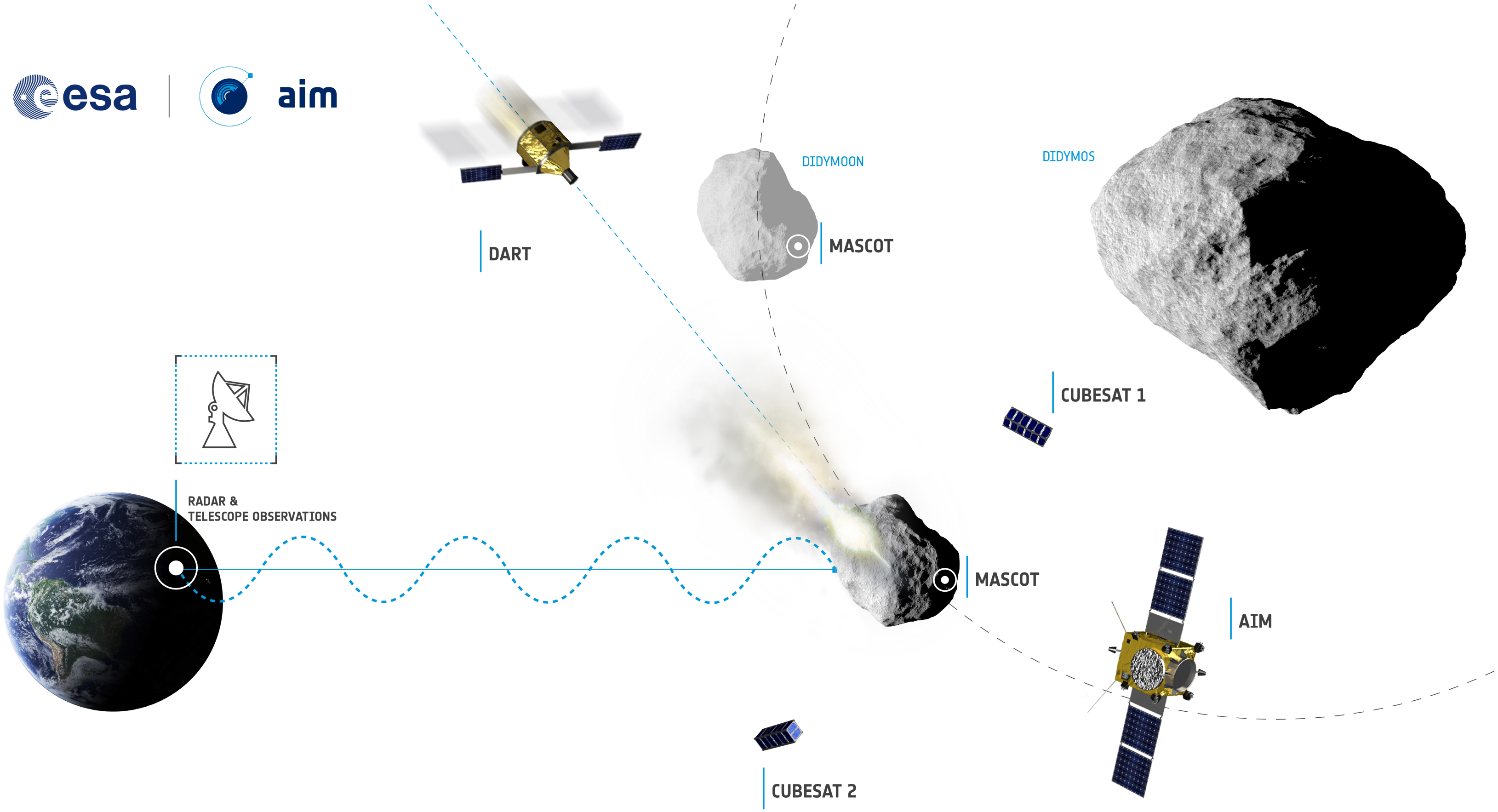
After rendezvous'ing with C-G in 2014 and releasing its lander, Philae, the spacecraft orbited the comet for 2 years.

- In the summer 2016, from lowering the spacecraft orbiting altitudes, C- G's mass, pole orientation, and ephemeris were estimated with errors less than 0.1% (Patzold et al, 2016; Broschart et al, 2016)

Credits: NASA, JAXA, ESA

AIDA Mission Concept Objectives

ESA-led AIM would launch in October 2020, arrive in Spring 2022.
NASA-led DART would arrive at Didymos in late 2022 and impact the moon at ~6 km/s.
AIM would perform detailed characterization, and before-and-after impact comparisons.



Credits: ESA

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Radio Science Analysis

Terminator Orbits

Binary Component Flybys

AIDA Target: Binary Asteroid (65803) Didymos

Didymos asteroid system:

- 775 m (+/-10%) diameter primary body
- 163 m (+/-0.018 m) diameter secondary body
- 1.18 km +/- 0.04 km distance between secondary and system barycenter.

Assumed density: 2146 kg/m^3 for both bodies

Other parameters and 1-sigma uncertainties assumptions:

Parameters	**Values**	**1-sigma**
Didymain states	Defined at Epoch	0.5km; 0.01km/s
moon states	Defined at Epoch	0.5km; 0.01km/s
AIM spacecraft	Approach specific	0.05km; 0.005km/s
SRP factor	1	100%
Harmonics factor	1	100%
Pole (RA and DEC)	310 deg, -84 deg	20 deg; 5 deg
Spin state	2.26 hrs	0.0001 hr

Radio Science Study Goals

Determine measurability of Didymos parameters and impact DV

Uncertainty Assumptions

- Didymos system parameters and a priori uncertainties from AIDA reference document.
- Didymos ephemeris and a priori covariance from JPL SSD Alain Chamberlain.
- Didymoon/Didymain orbits integrated using initial conditions from Didymos system ephemerides simulated by JPL SSD Eugene Fahnestock.
- Harmonics a priori uncertainty from technique by McMahon (LPSC 2016)
- Accounting for uncertainties on planetary ephemeris, DSN locations, media

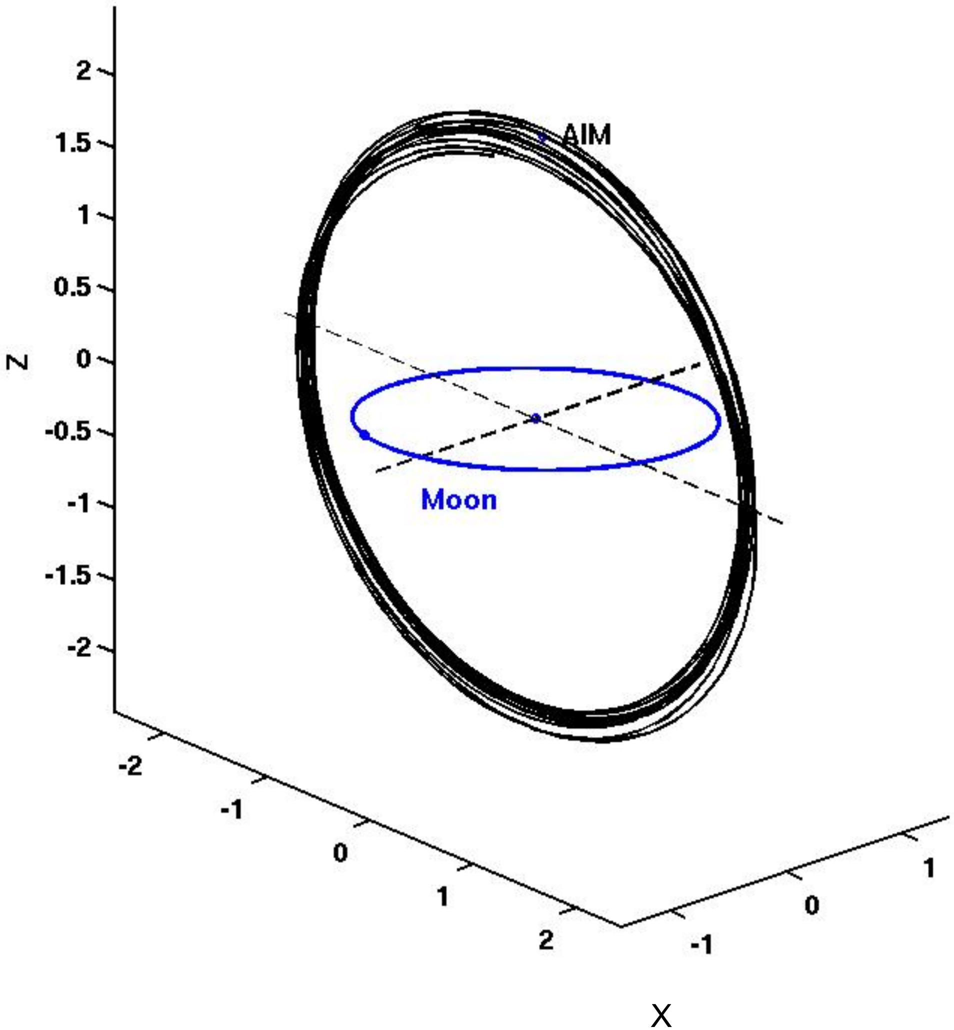
Spacecraft desaturations

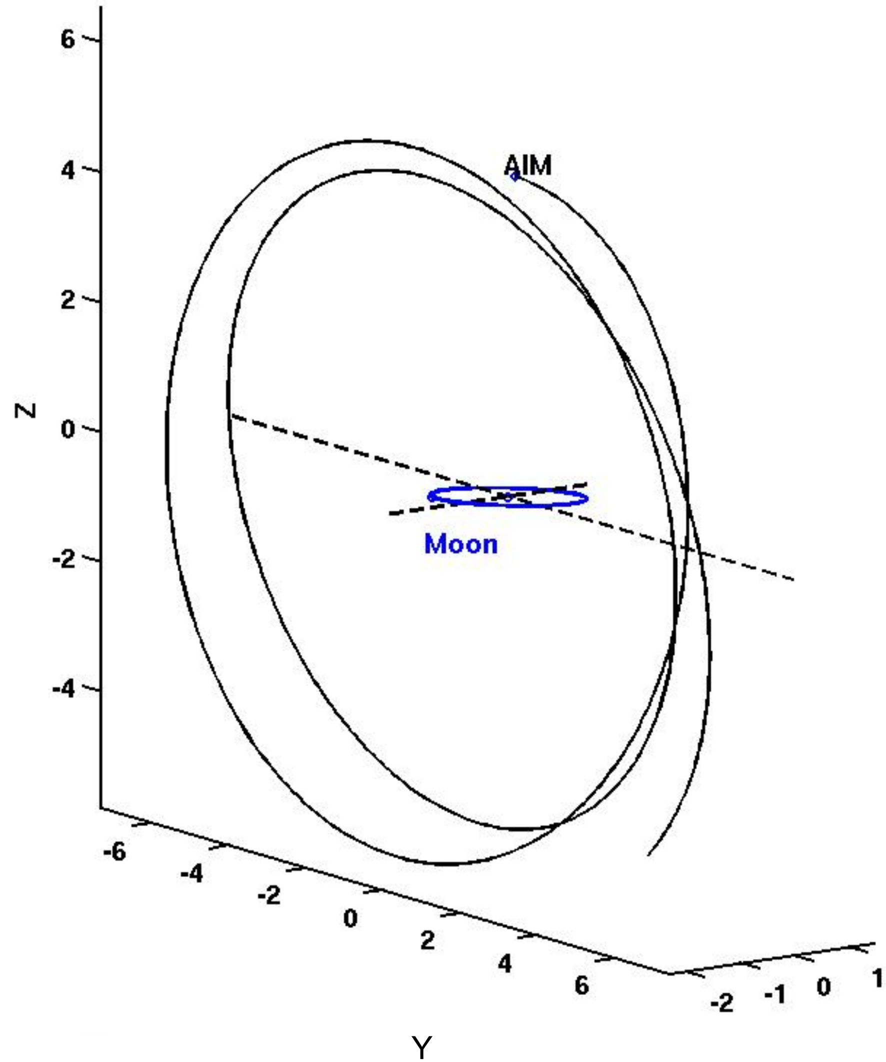
- Modeling spacecraft using desaturations (1x / 2 days) (assume use of reaction wheels for turns, balanced thrusters), and compared with a “clean” spacecraft.

Simulated Data

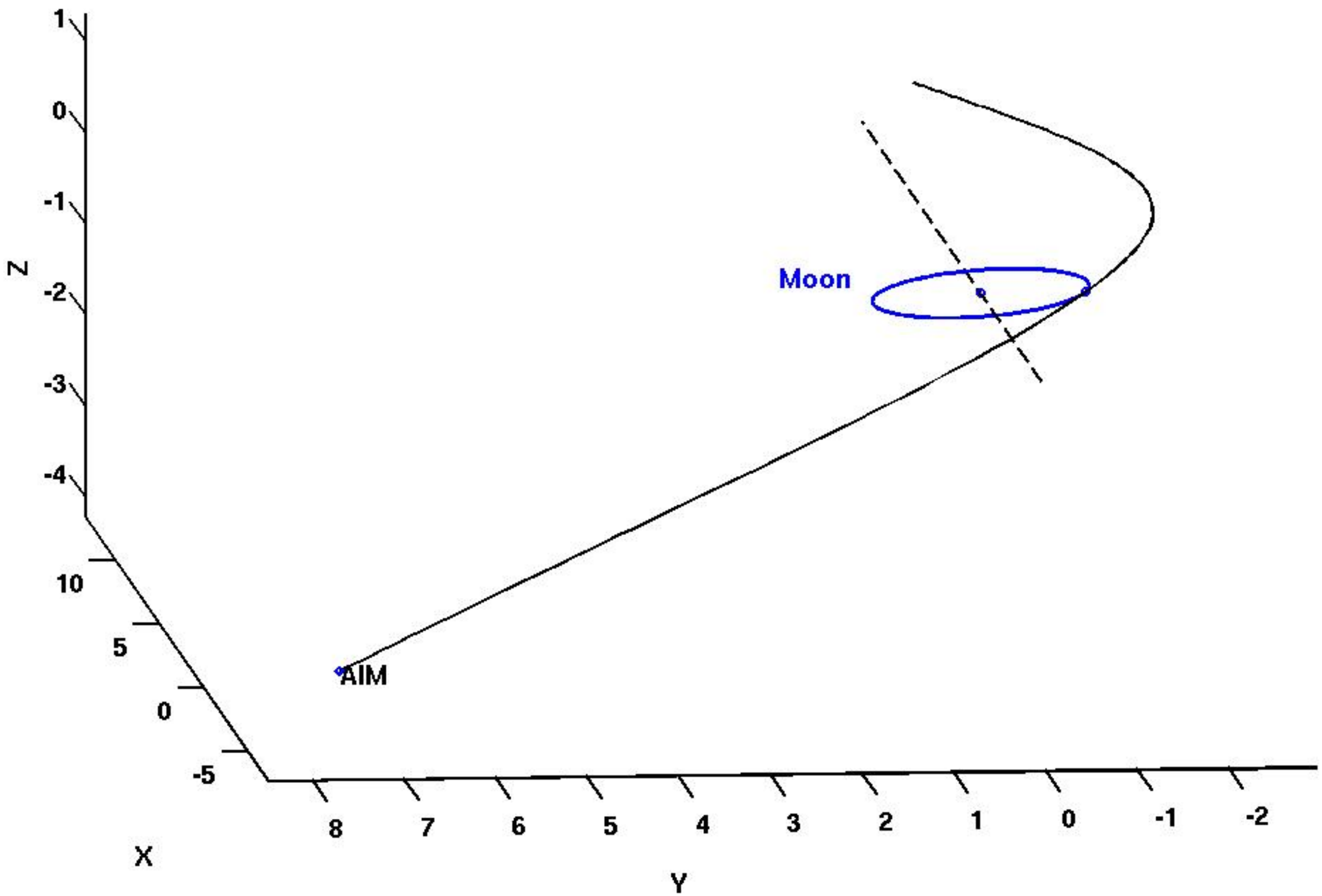
- Simulated radiometric measurements: 7 per week, 8 hr tracks
- Simulated optical measurements (13 deg field of view, 1 pic/12 hrs, alternating between main and moon every 6 hrs, equally generated landmarks)
- Pointing uncertainty not included

2km & 5km Terminator Orbits

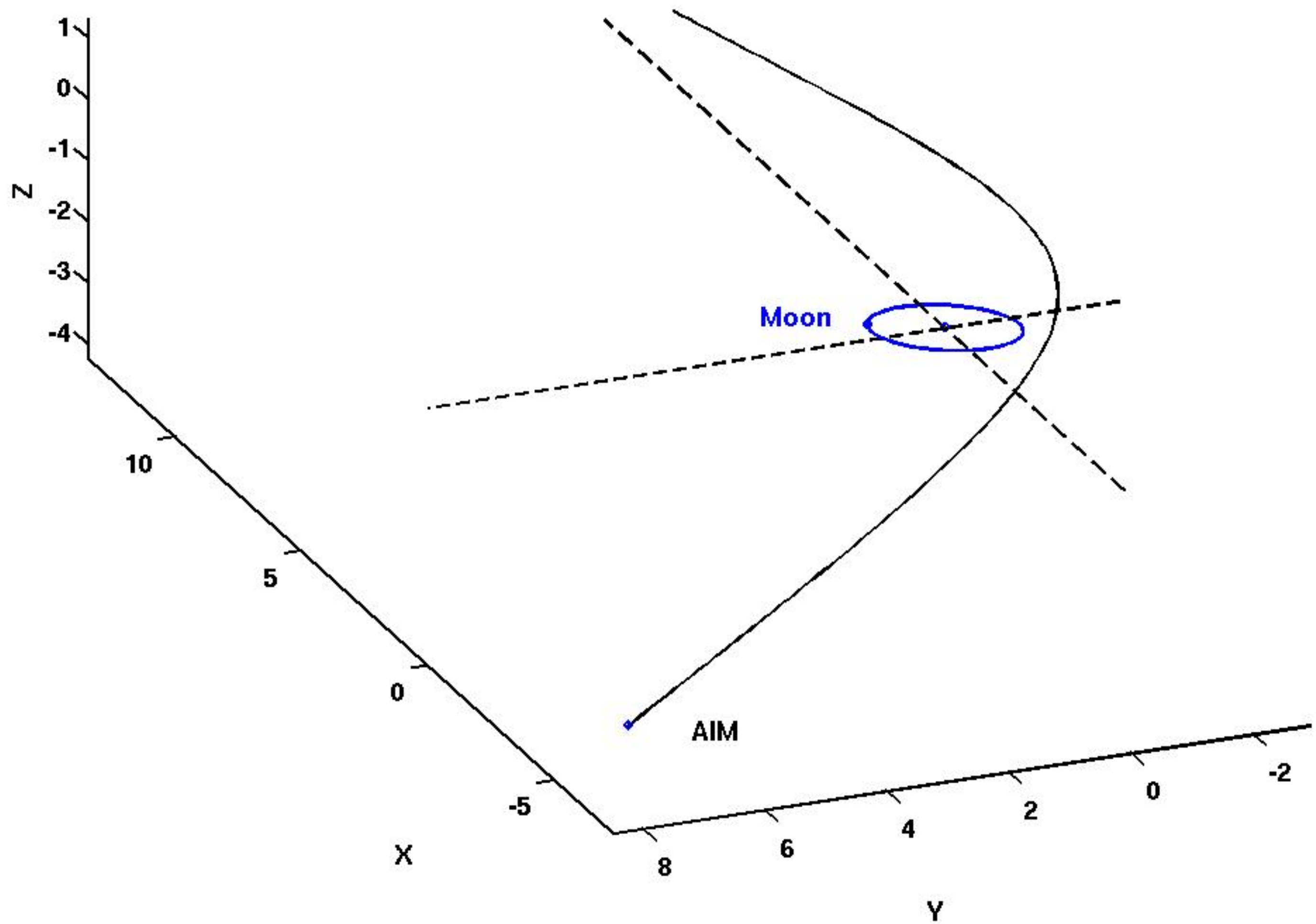




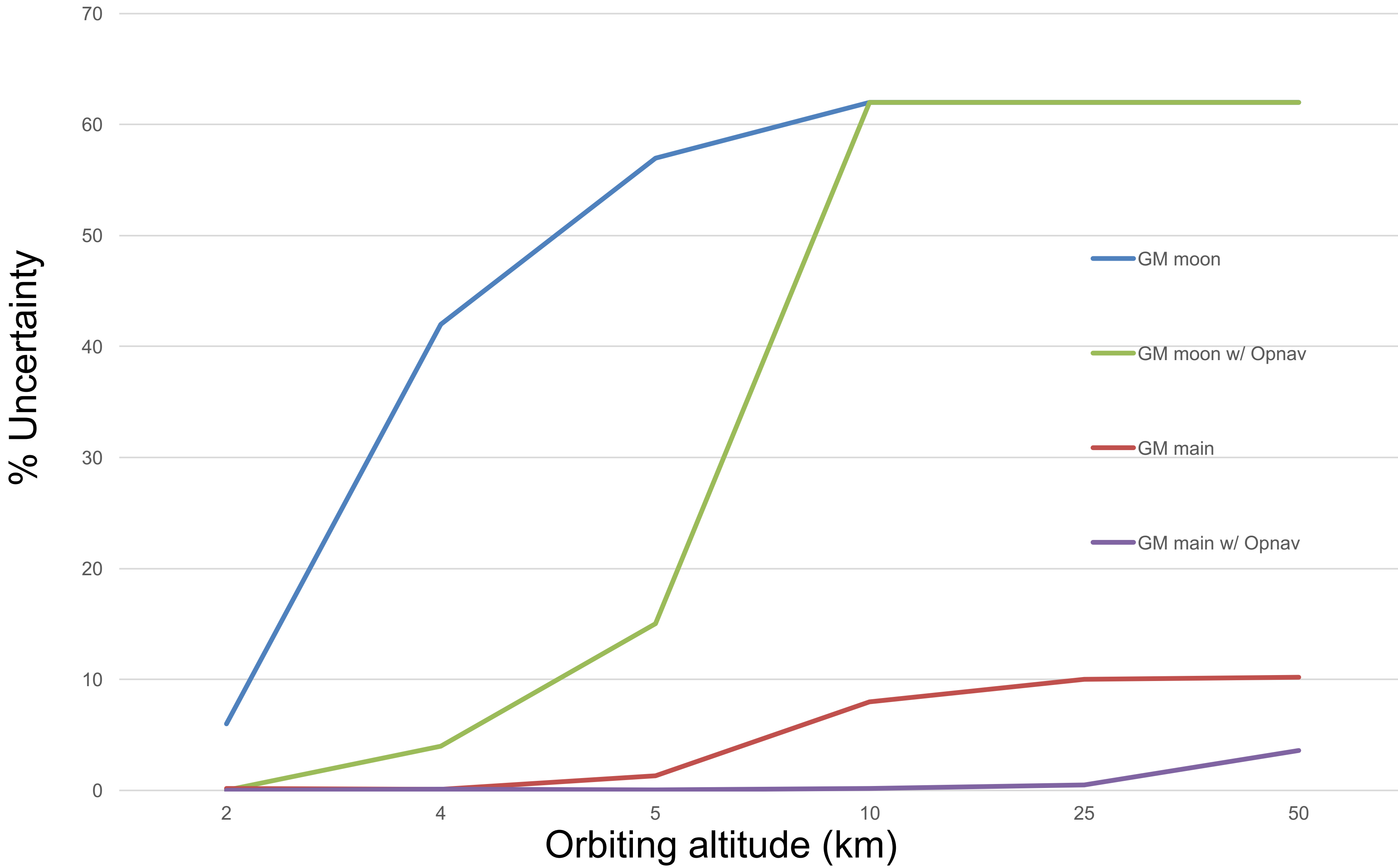
Didymoon Flyby at 300 m altitude



Didymain Flyby at 1500 m altitude



Asteroid GM Uncertainties vs Orbiting Altitudes, with/without Optical navigation



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Impact Observation from 50 km and 100 km orbit platforms

Spacecraft Observation Platform

Uncertainty Assumptions – already refined from pre-impact operations

- A priori covariance on states, GMs, pole data using 2km terminator orbit case
- Accounting for uncertainties from planetary ephemeris, DSN locations, media

Spacecraft orbit maintenance

- From 50km and 100km orbiting platform, over 4, 12, and 31 days
- Impulse maneuver every 4 days to stay within "box" for > 4 days cases
- Uncertainty on DART-induced DV and orbit maintenance impulses is 1 mm/s

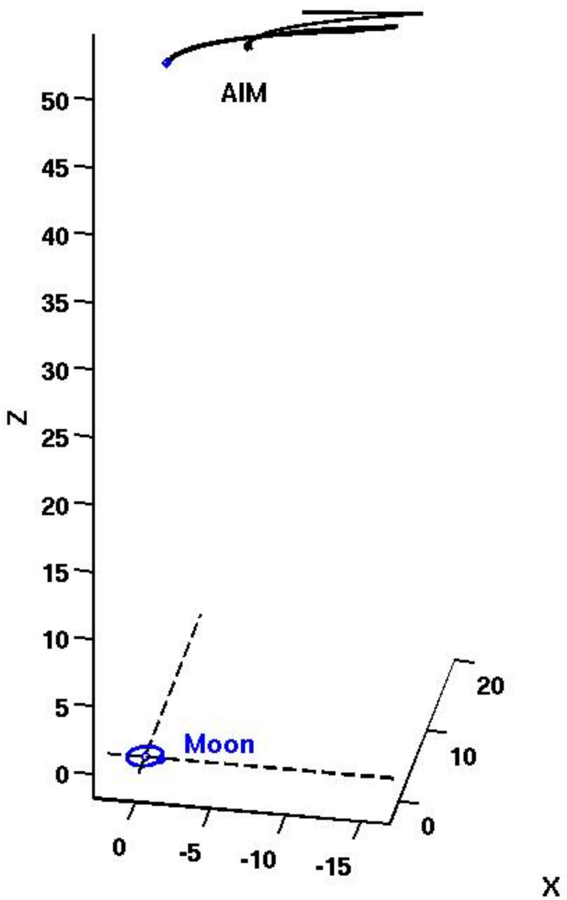
Simulated Data

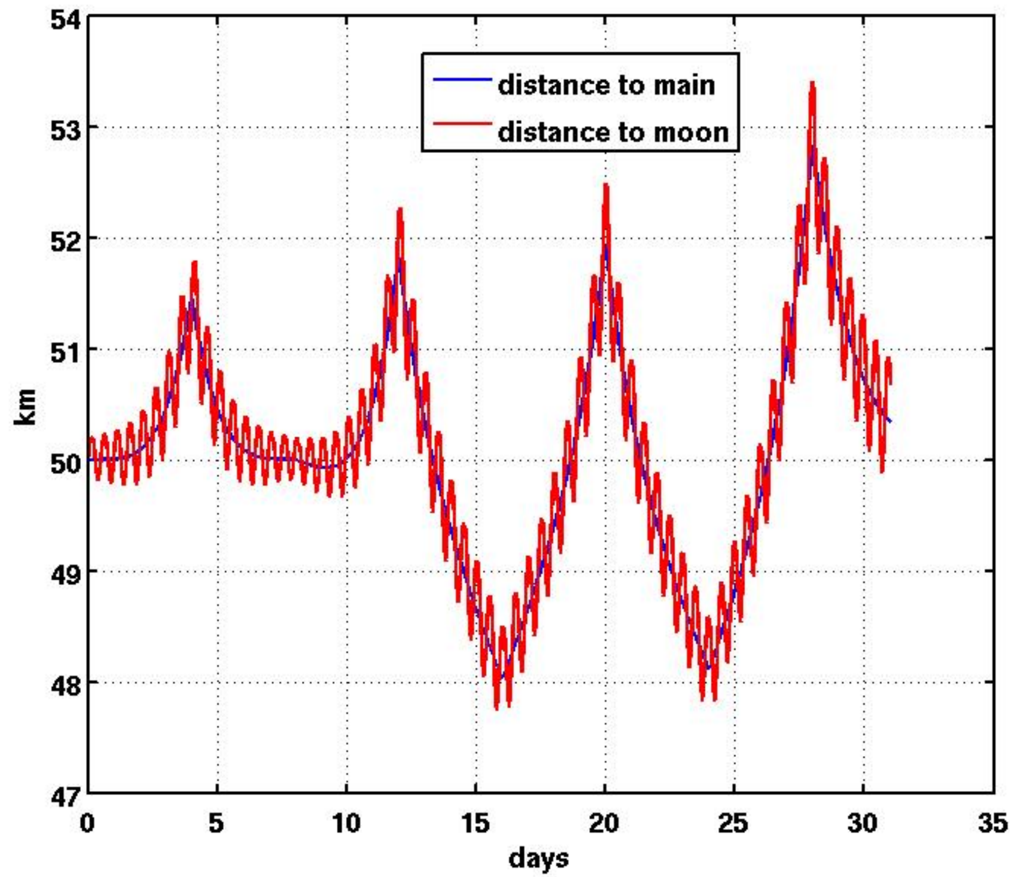
- Simulated radiometric measurements: 7 per week, 8 hr tracks
- Simulated optical measurements: Didymain landmarks and component centroids
- Pointing uncertainty is not included

Parameters of Interest

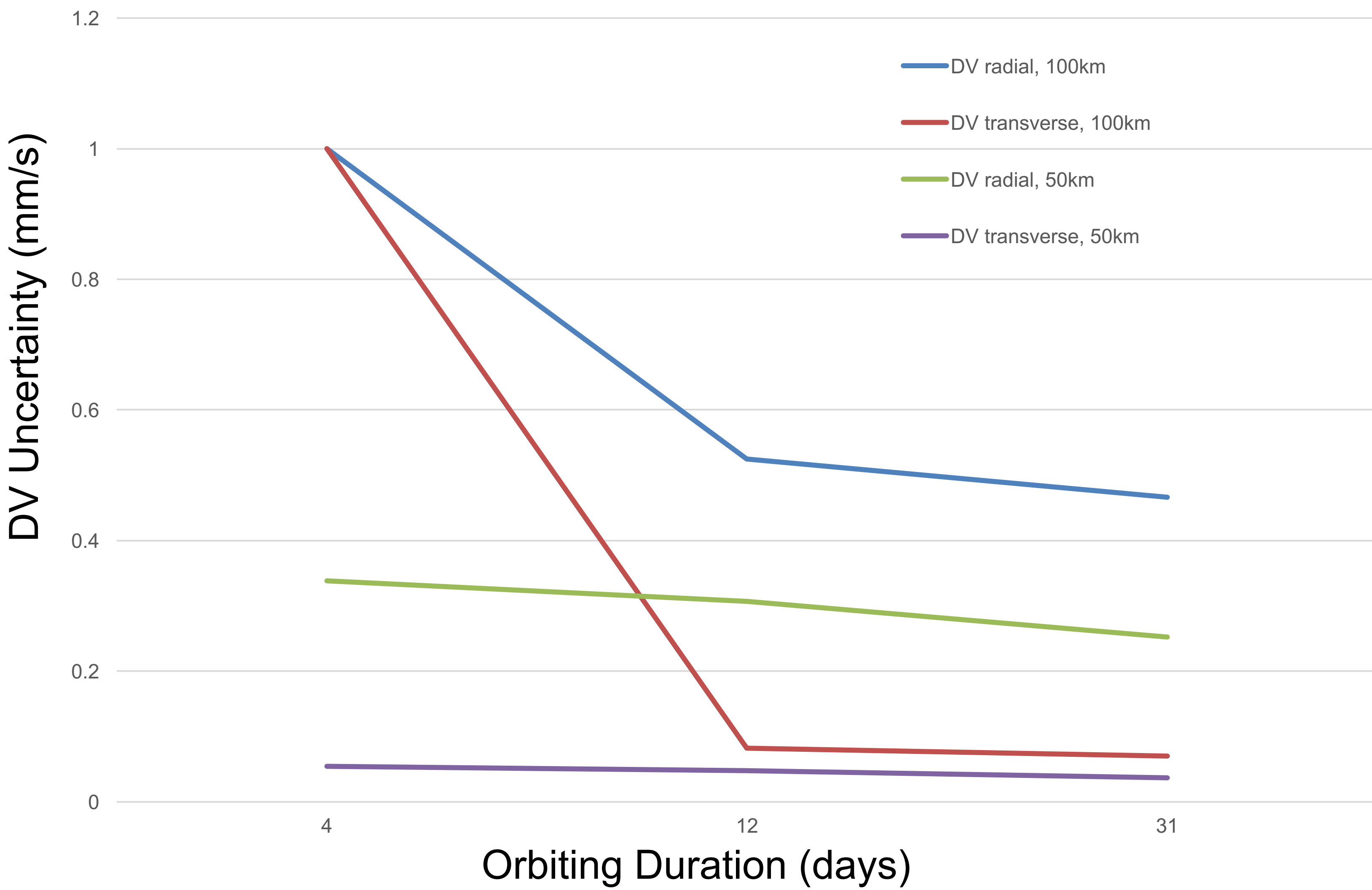
- DV uncertainty in RTN frame: radial and transverse visible from pole observation platform
- Beta uncertainty: take DV uncertainty projected along surface normal at impact location, normalize by impact DV magnitude.

50 km Standoff Orbit

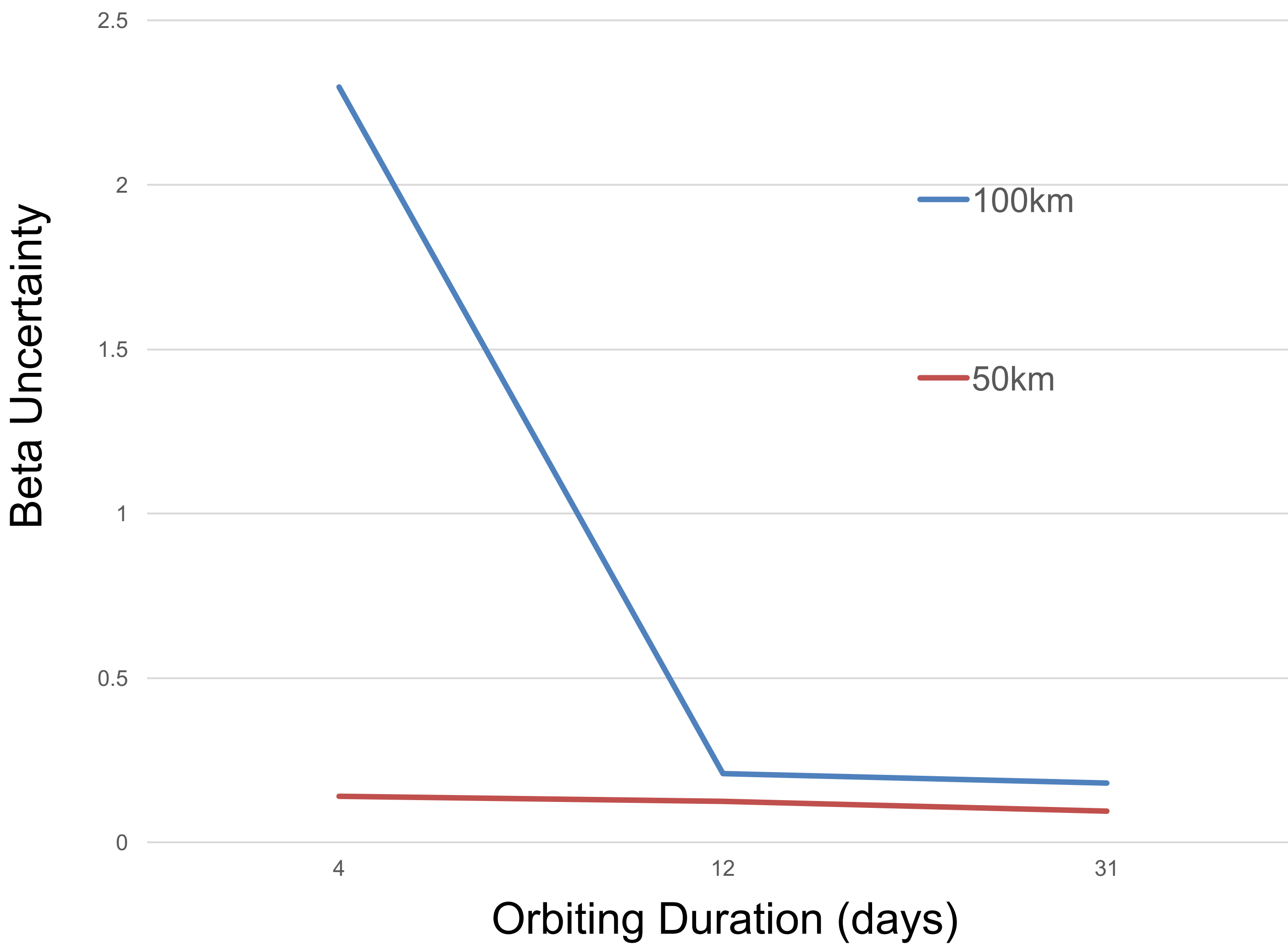




DV Uncertainties vs Time for 100km and 50km Orbiting Platforms, with Optical Navigation



Corresponding Beta Uncertainties for Low, Moderate (Beta = 1.2), and High (Beta = 2) Excitation Impact Study Cases (0.43 mm/s impact), for both 100km and 50km Platforms



Conclusions

Pre-impact:

→ The GM of the main and moon asteroid can be determined to less than 1% for the main with orbit altitudes below 10 km, and to less than 5% for the moon with orbit altitudes below 4 km.

Post-impact:

→ After the DART impact, ΔV uncertainty < 0.05 mm/s can be obtained (in transverse direction from a pole observation) with orbiting platform at 50 km over a week.

→ ΔV uncertainty < 0.1 mm/s with orbiting platform at 100 km over 30 days.

→ The uncertainty in the transfer of momentum is directly linked to the body physical properties.

After 12 days of observation, Delta-Beta, drops below 0.25 (1-sigma)

→ Recommendation would be to bring the spacecraft lower, say 25 km, for Delta-V and Delta-Beta measurements.

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Thank you!

Questions?