Radio Science Experiment for Marco Polo

Asteroid mass, density, gravity field, orbit

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Radio-Science Method

- Two-way radio link between the spacecraft and Earth using the spacecraft´s radio subsystem and radio carriers at two frequencies: X/X and X/Ka
- Observables:
  - Carrier frequency shift due to relative motion between spacecraft and ground station on Earth (Doppler => relative velocity)
  - Propagation time of coded (ranging) signal => distance between spacecraft and ground station

Space Segment

- Instrumentation onboard the Marco Polo spacecraft:

  X/X transponder

  X/Ka transponder

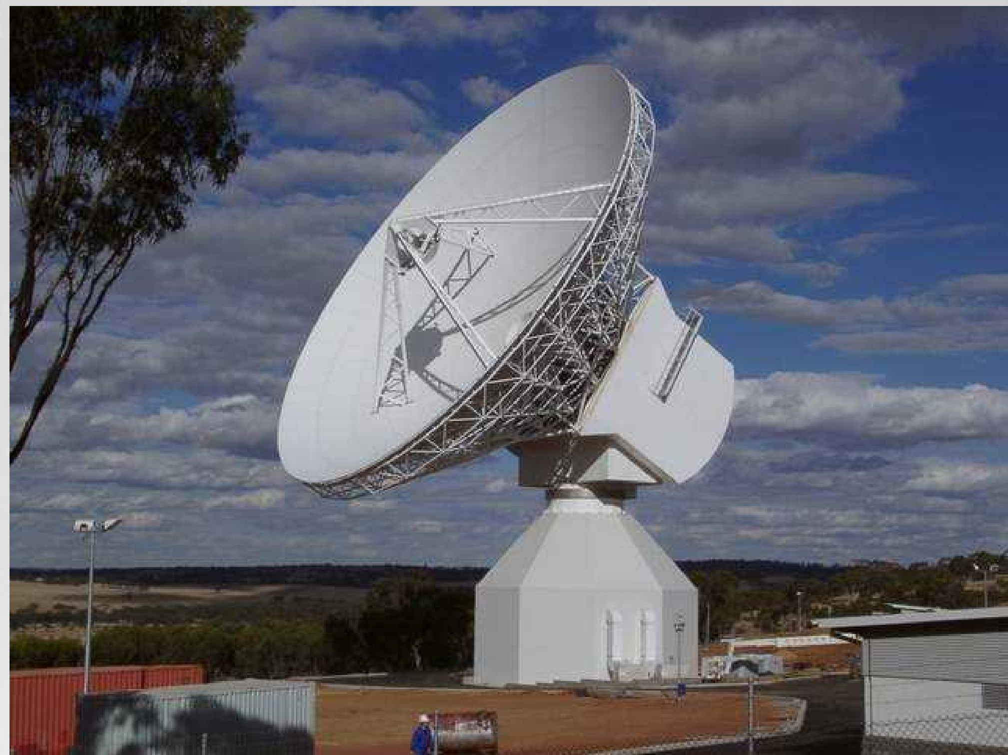
  Reception/transmission via High Gain Antenna (HGA)

  RF power: X-band xx Watt; Ka-band 2.5 Watt

- Spacecraft will be configured and operated in the two-way radio link mode

Ground Segment

- 35-m antenna structure; (New Norcia) and Cebreros
- Cebreros is equipped with Ka-band receivers/transmitters
- up/down-link converter chains
- Intermediate Frequency Modem System (IFMS) to transmit, receive and record radio signals parameters:
  - Doppler
  - Ranging
  - Signal Power (AGC)
  - Meteo data



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Science Objectives

- Geophysical characterization of the asteroid
  - mass, bulk density
  - for a close orbiter:
    - gravity field; low degree and order
    - Comparison with computed gravity coefficients
    - => first idea of internal structure
- Precise determination of heliocentric orbit
  - By orbiting or escorting
  - By beacon on the surface

strategy

- Pre-arrival determination of shape and first order rotational state by optical instruments required
- => first estimate of the volume, assume density

  => first mass estimate; required for approach navigation

- Have some close and/or slow flybys (drift-bys) for a mass determination in the 10%....1% accuracy range
- Depends on v_0*d , noise, initial mass estimate, asteroid ephemeris and geometry
- Good mass determination required for going into bound orbit

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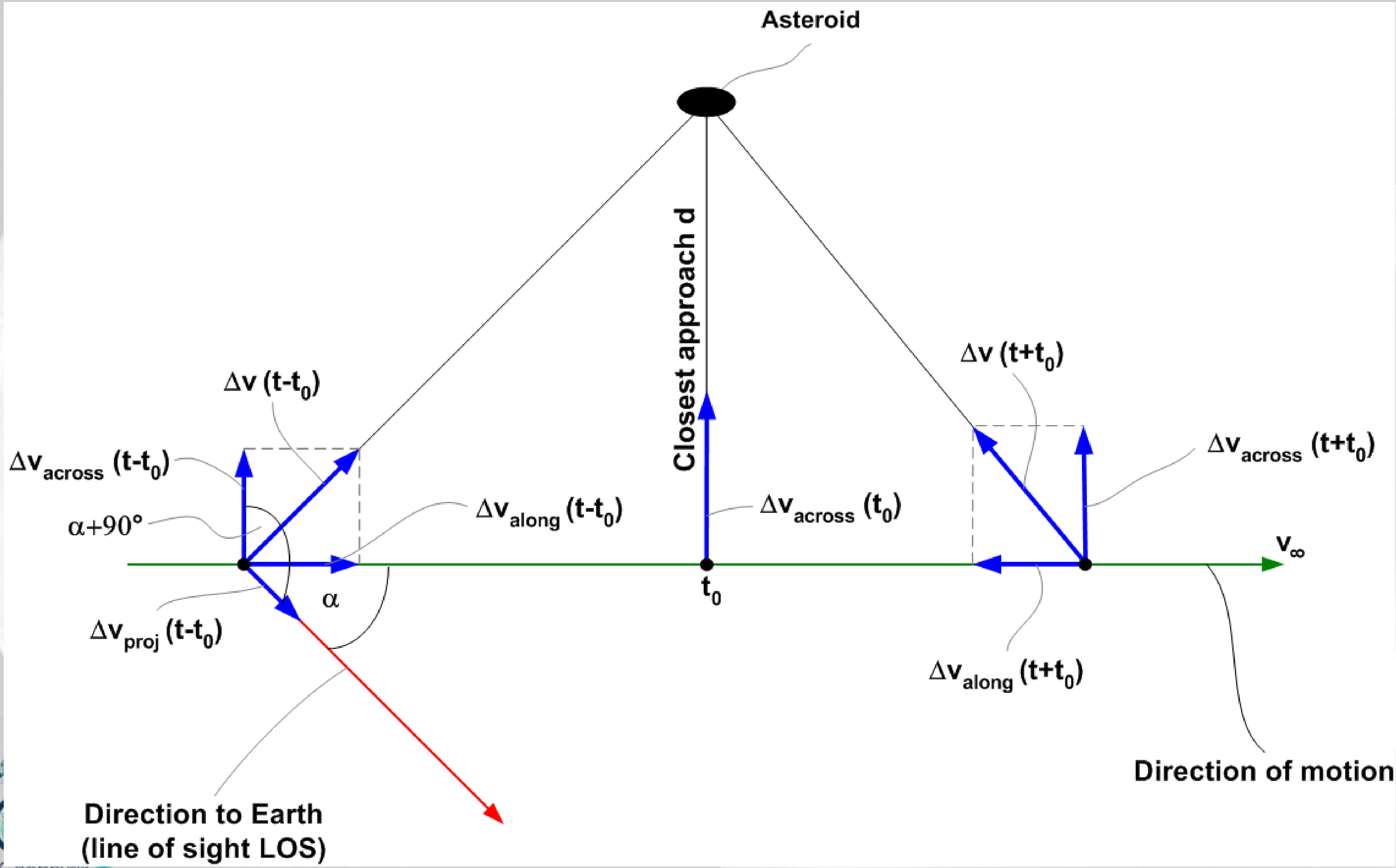
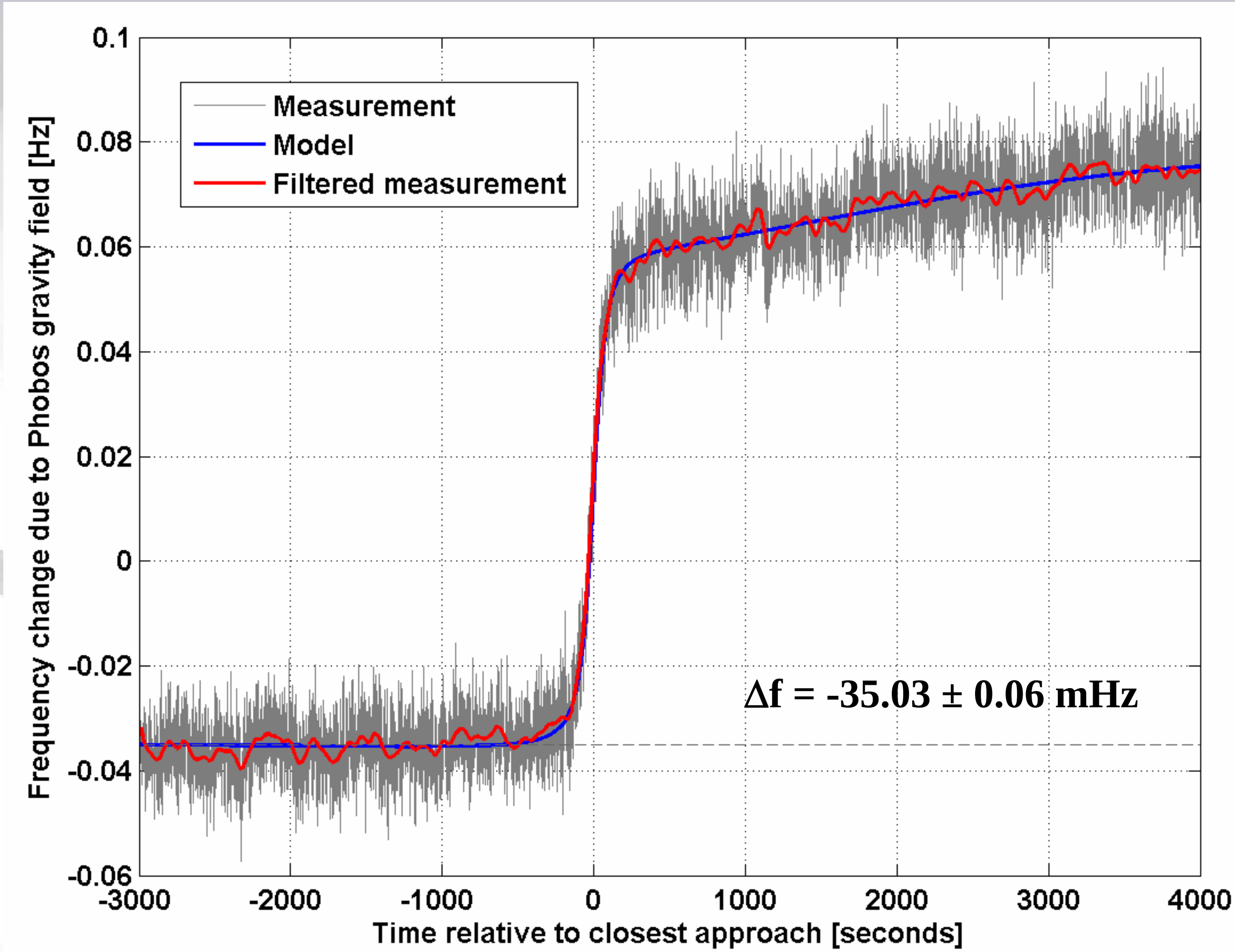
Asteroid flybys - geometry



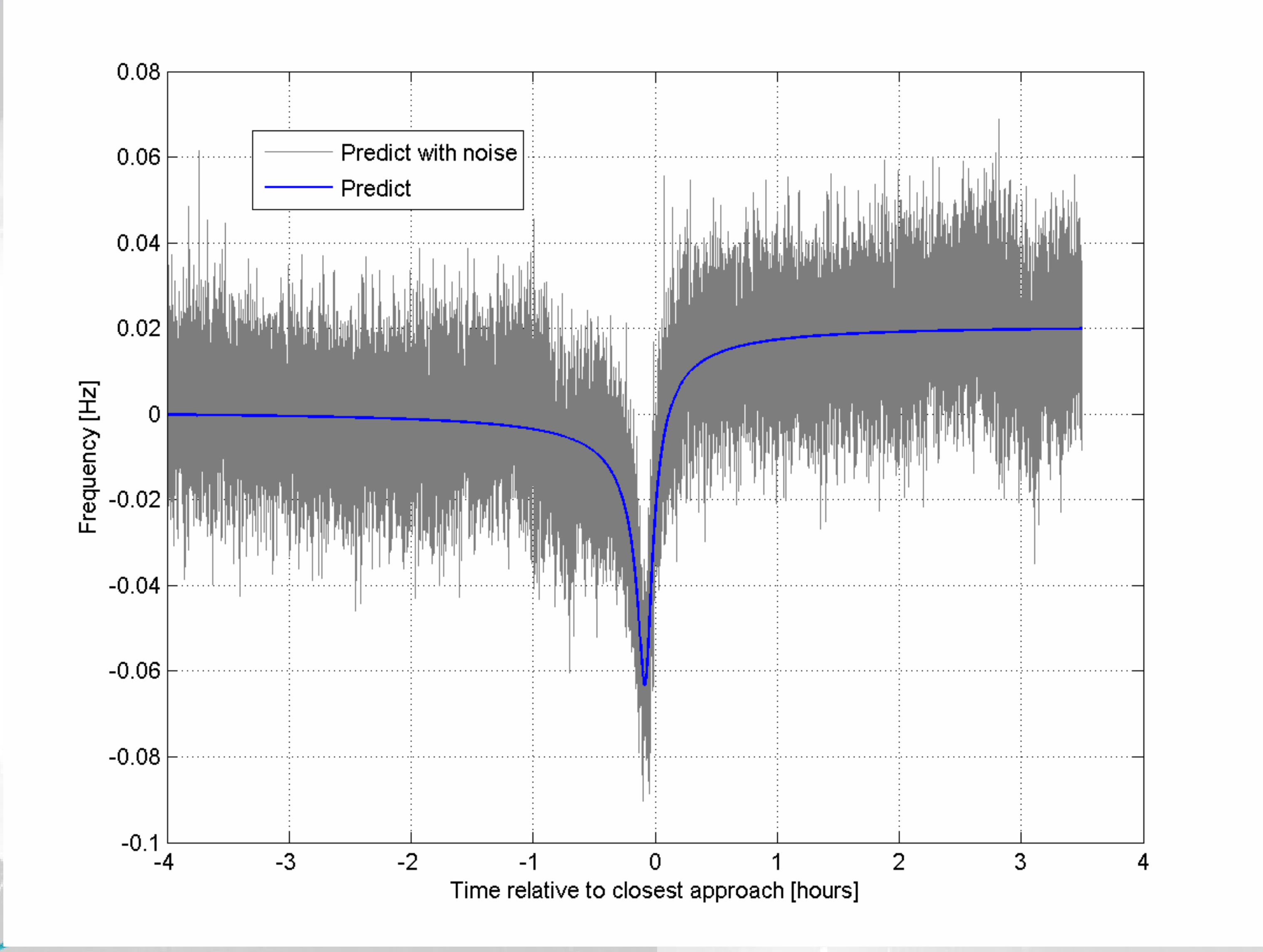
MEX/Phobos flyby, 17th July 2008



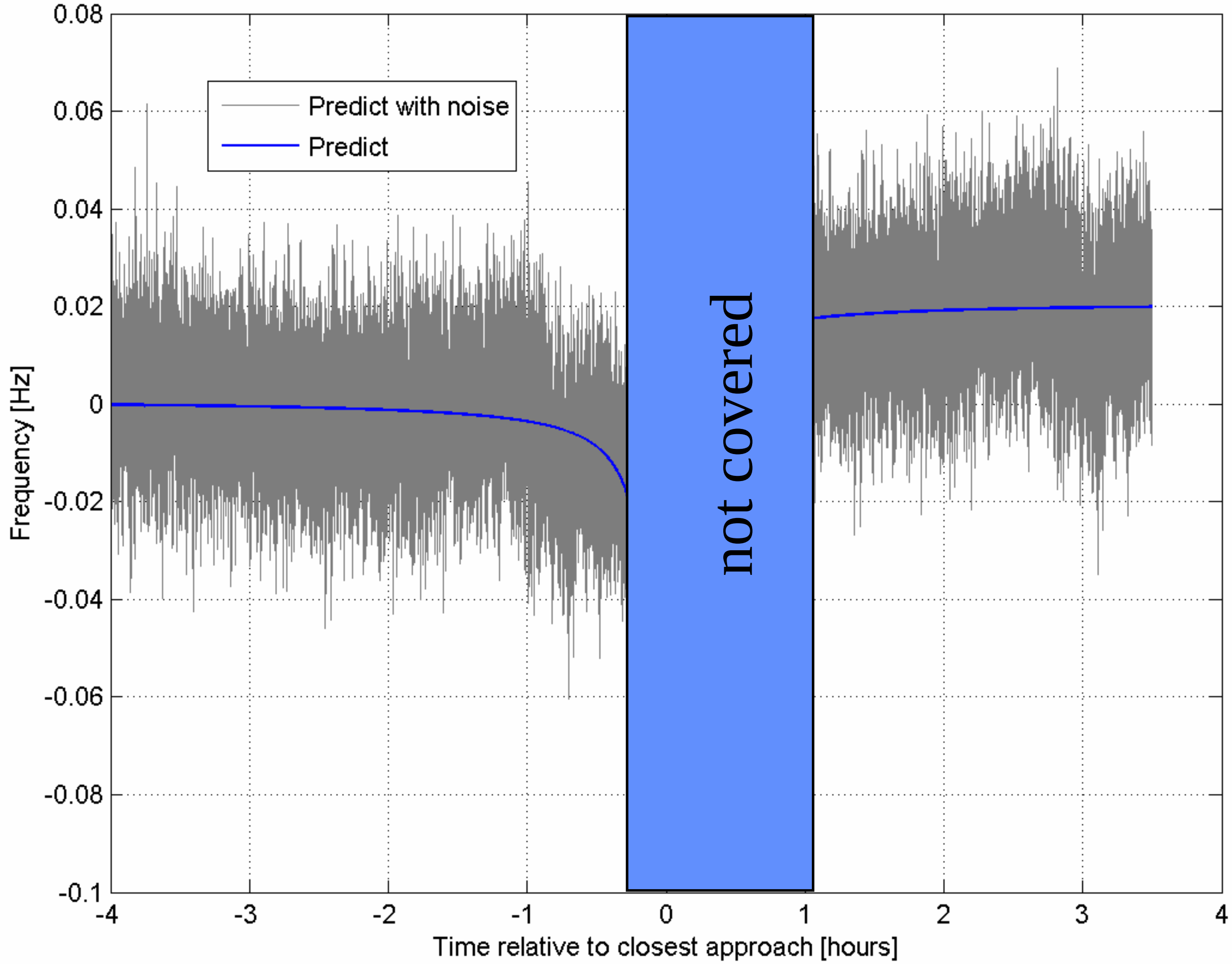
GM = 0.7120 ± 0.0006 x10^{-3} km^3/sec^2 (error 0.08%) (1σ)

Based on JPL Phobos ephemeris from *Jacobson, 2008*

Rosetta/Lutetia Flyby 2010 - simulation



Rosetta/Lutetia Flyby 2010 - simulation



estimated mass error 4%

Drift-bys at very small bodies: GM accuracy

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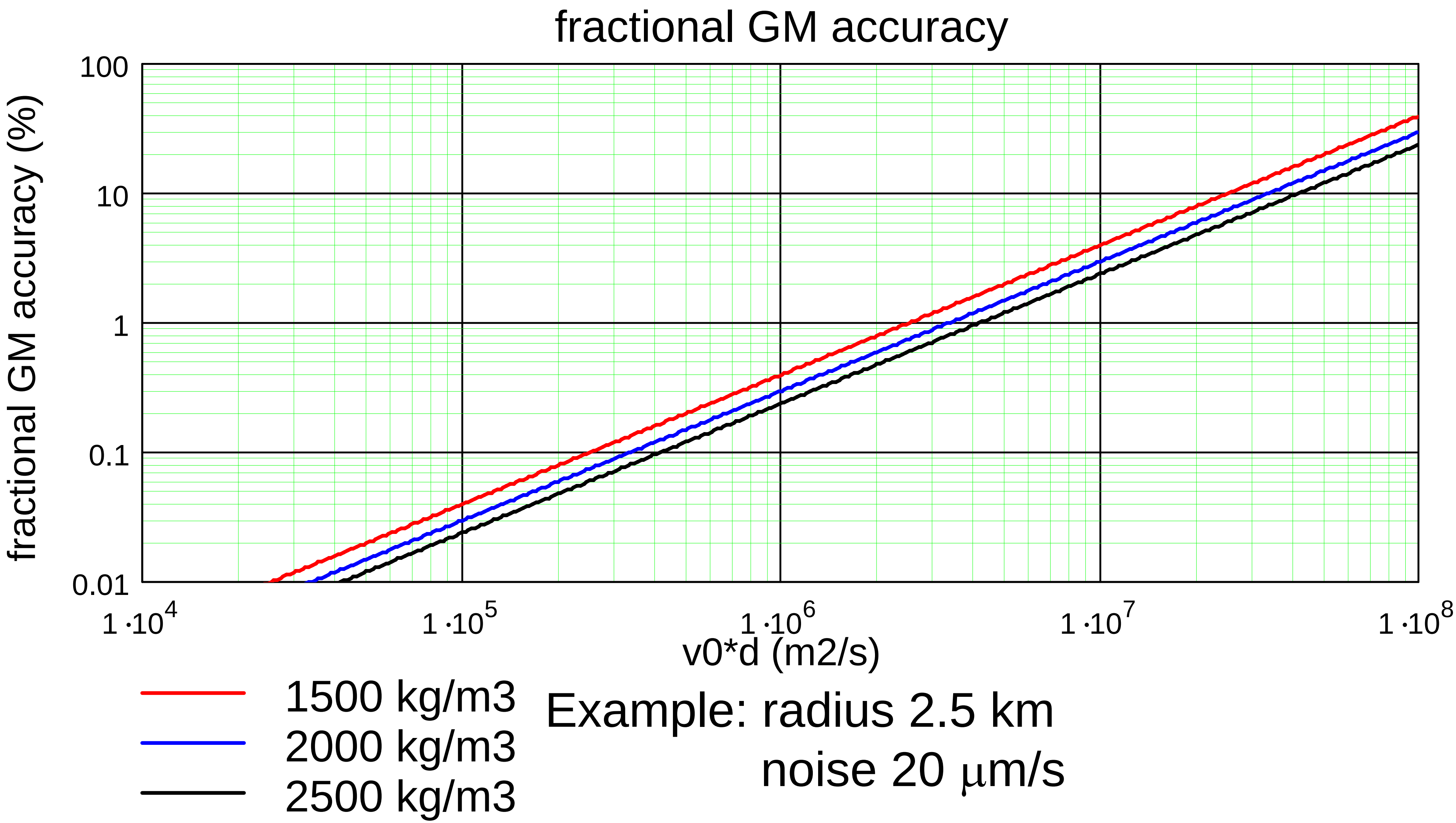

Example: radius 2.5 km
noise 20 μm/s

Drift-bys at very small bodies: GM accuracy

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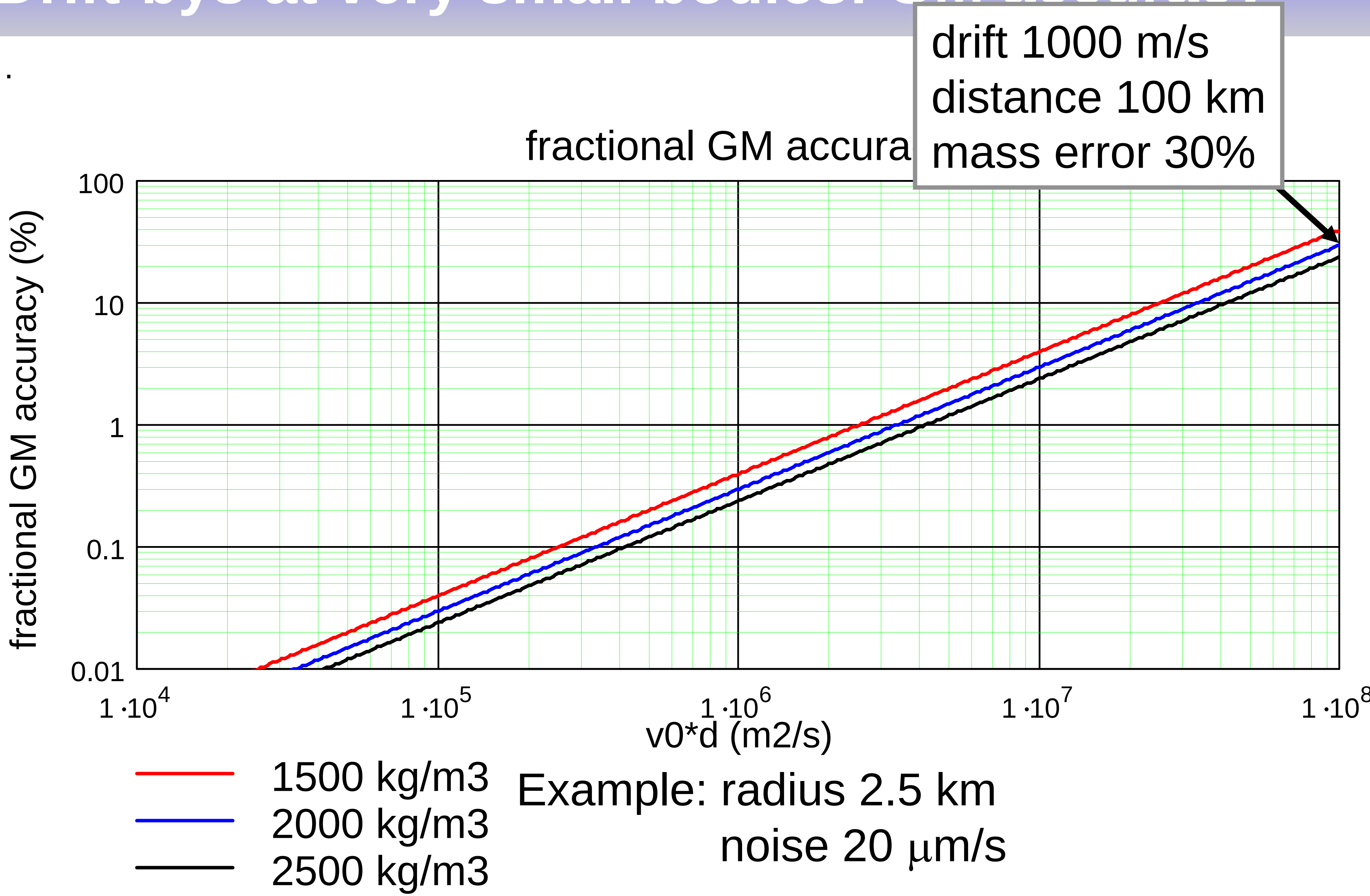

Example: radius 2.5 km

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Drift-bys at very small bodies: GM accuracy

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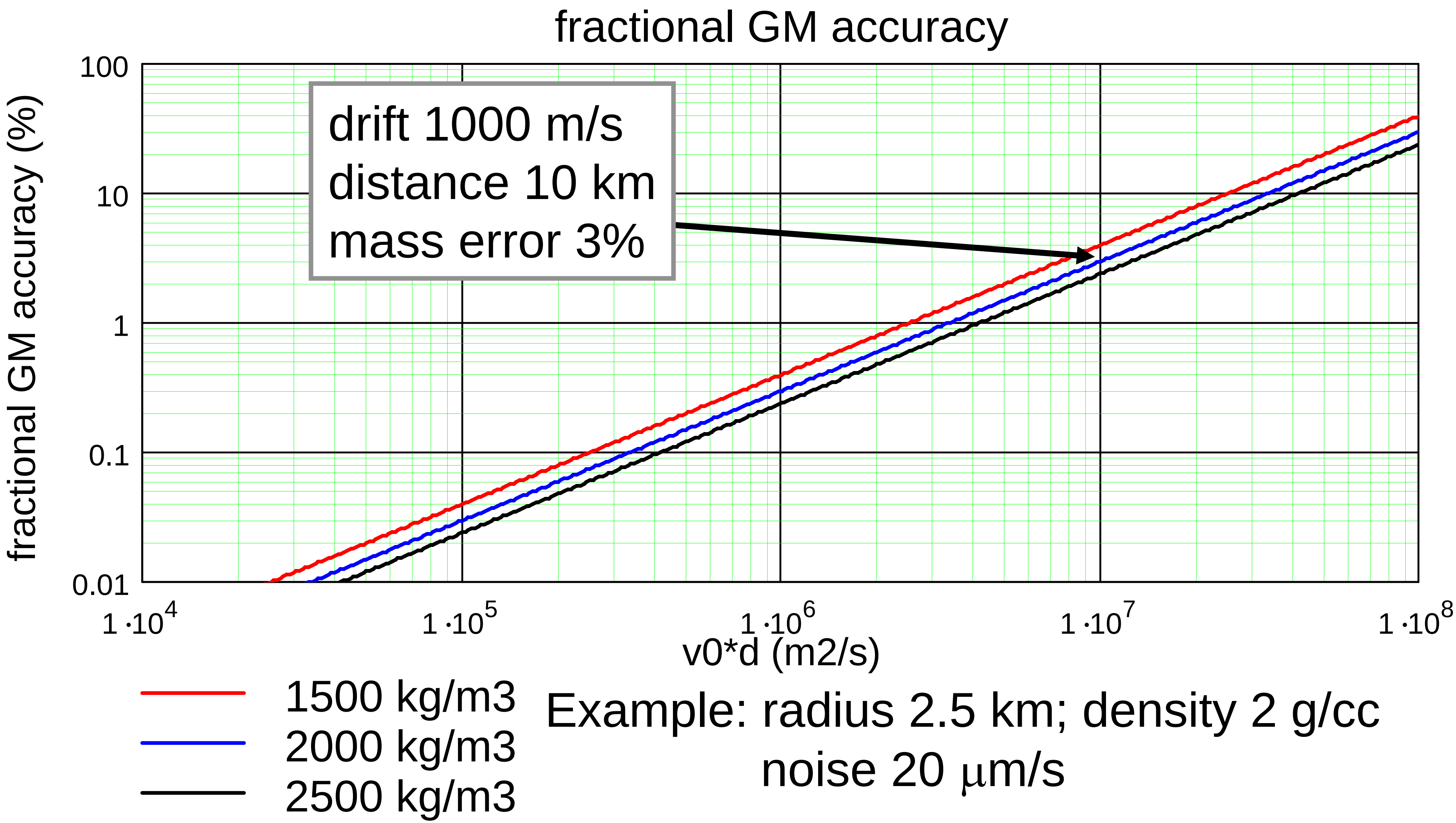

Example: radius 2.5 km; density 2 g/cc
noise 20 μm/s

Drift-bys at very small bodies: GM accuracy

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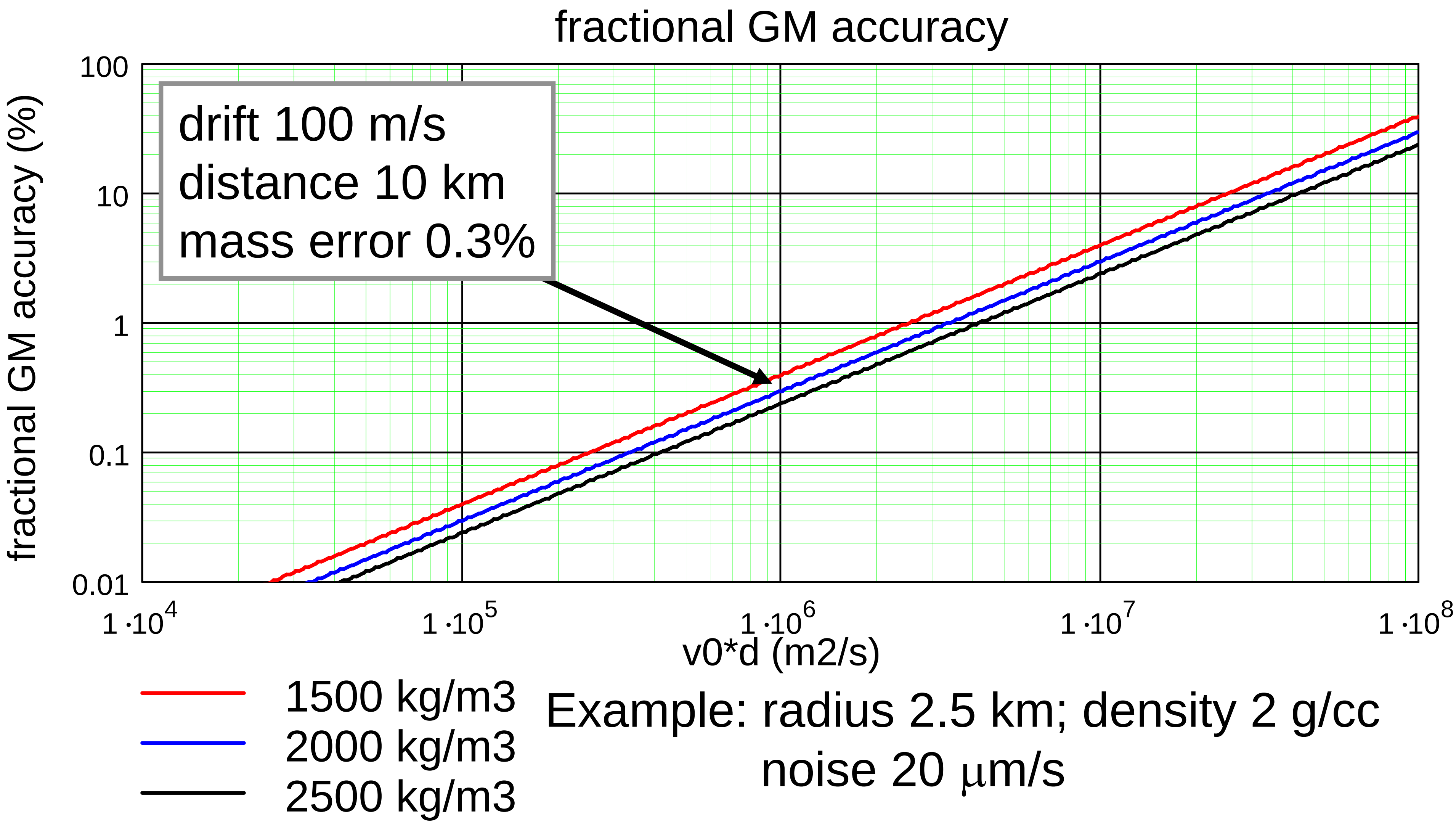


Example: radius 2.5 km; density 2 g/cc

noise 20 μm/s

Initial Mass Determination

- The mass accuracy is iteratively improved by more and closer flybys (drift-bys)
- Once the mass is sufficiently well known, the spacecraft may be injected into a bound orbit; the mass may now be determined with even higher accuracy
- The bulk density follows from the volume and mass determination
- The driver for the density accuracy is the volume determination which is from experience less precise than the mass determination
- Low degree and order gravity field may be determined from orbiting, but is challenging for small bodies

Radio Science Simulator (RSS)

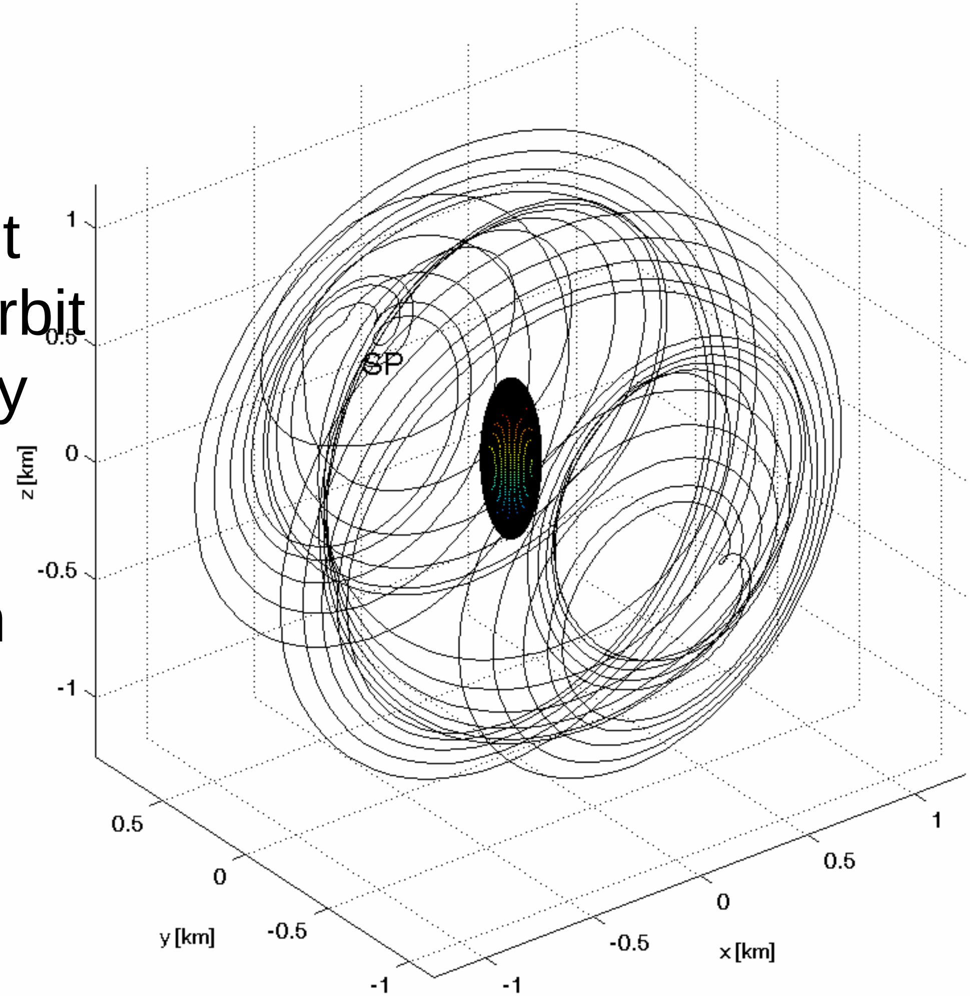
- Developed by Universität der Bundeswehr München
- Software based on MATLAB / SIMULINK; User friendly graphical interfaces
- Planning and analysis of Radio Science observations
- Main computation tasks:
  - State vectors of spacecrafts
  - Planetary ephemeries
  - Ground station visibilities
  - Occultations (planetary, solar)
  - Spacecraft attitude control maneuver for Bistatic Radar and occultation measurements
  - Doppler und Ranging predicts based on planning or reconstructed orbits
  - Simulation of orbits about planetary bodies assuming models of the planetary body and of gravitational and non-gravitational forces acting on the spacecraft

Simulation of orbits about small bodies

Simulation study for Don Quichote; terminator orbit of a 400 m size body

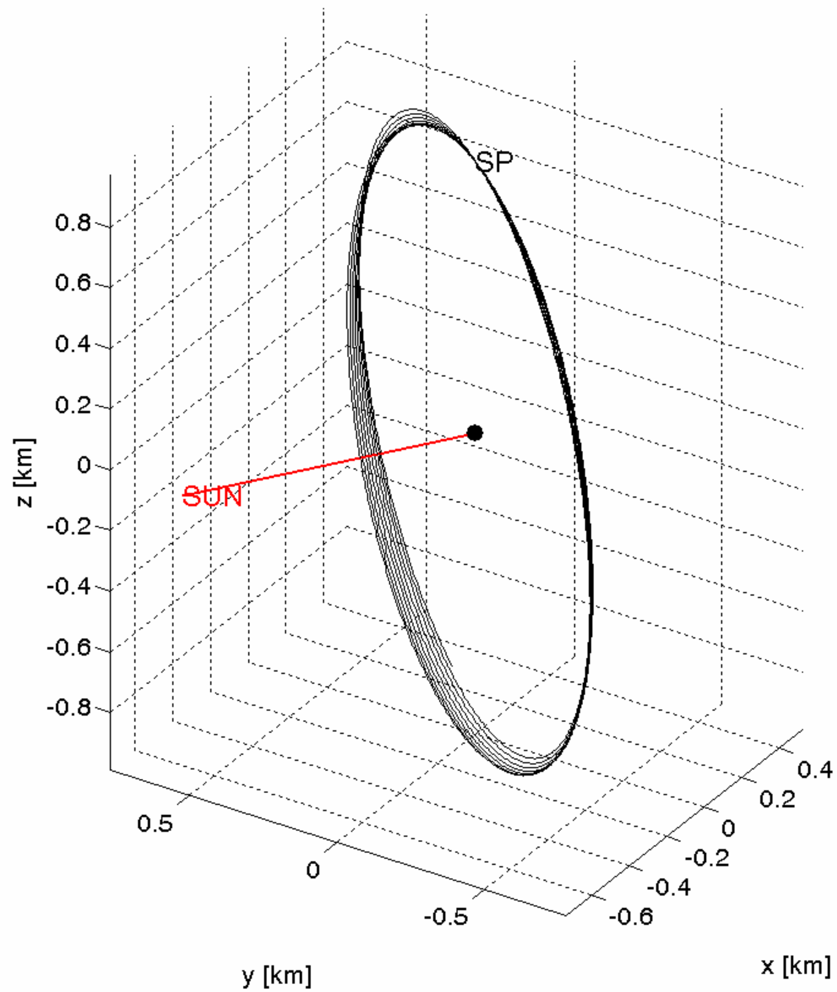
Example of simulated s/c orbit considering the heliocentric orbit of small body, potential gravity field, non-gravitational forces

Body-fixed coordinate system
body rotates about small axis
s/c terminator orbit



Simulation study for Don Quichote; terminator orbit of a 400 m size body

same orbit as seen from
inertial reference frame



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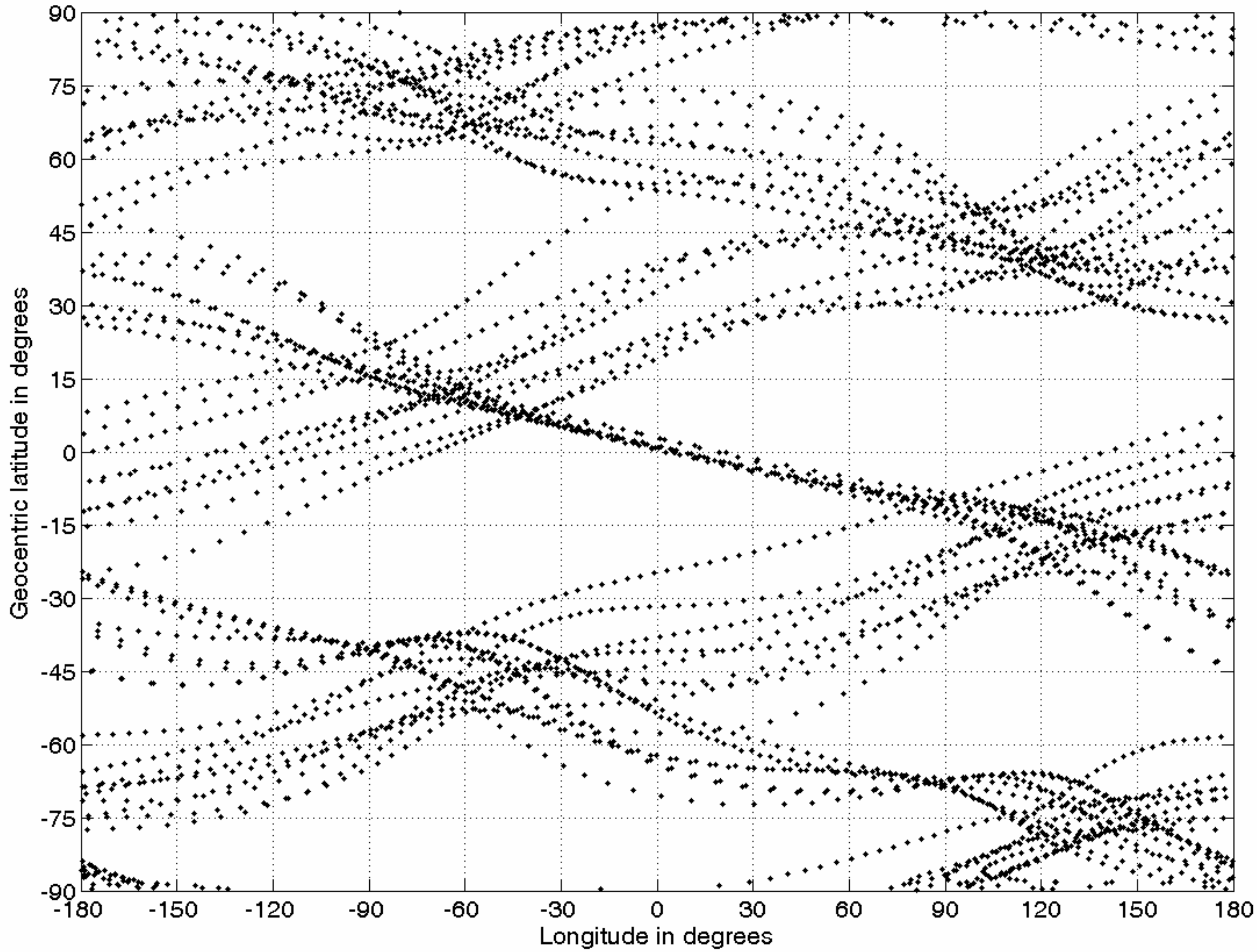
simulation study for Don Quichote; terminator orbit of a 400 m size body

surface coverage over a time range of 14 days



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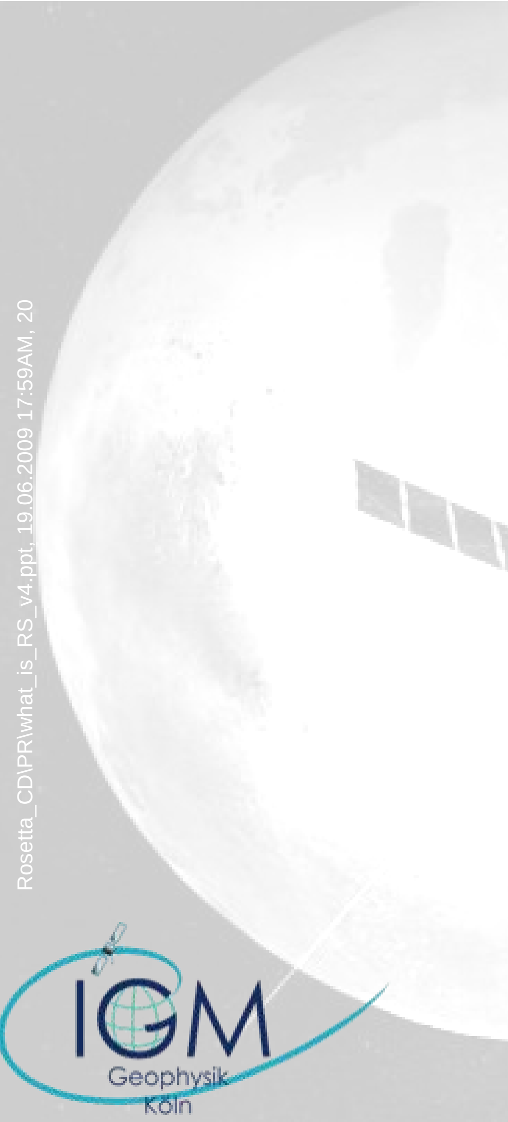
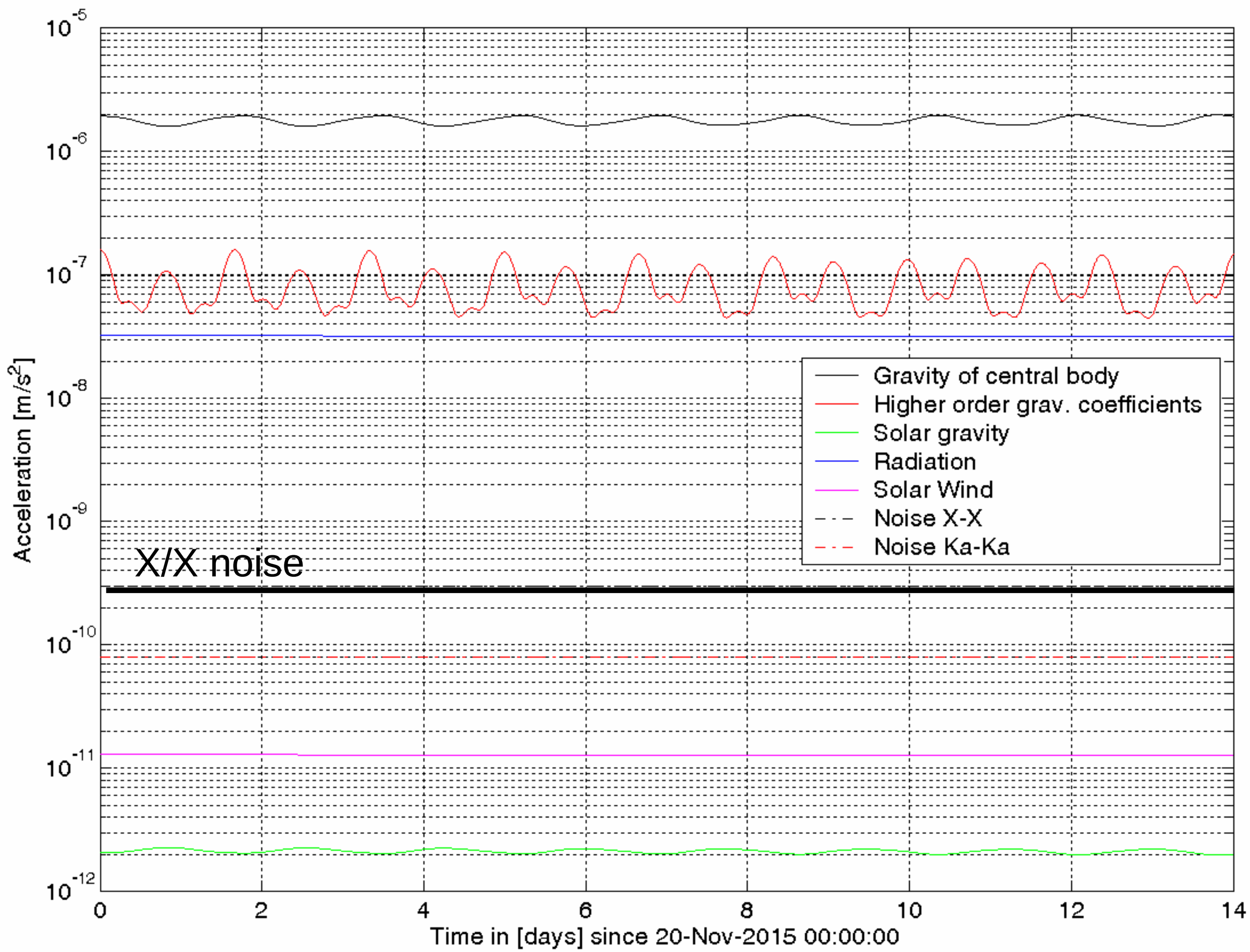
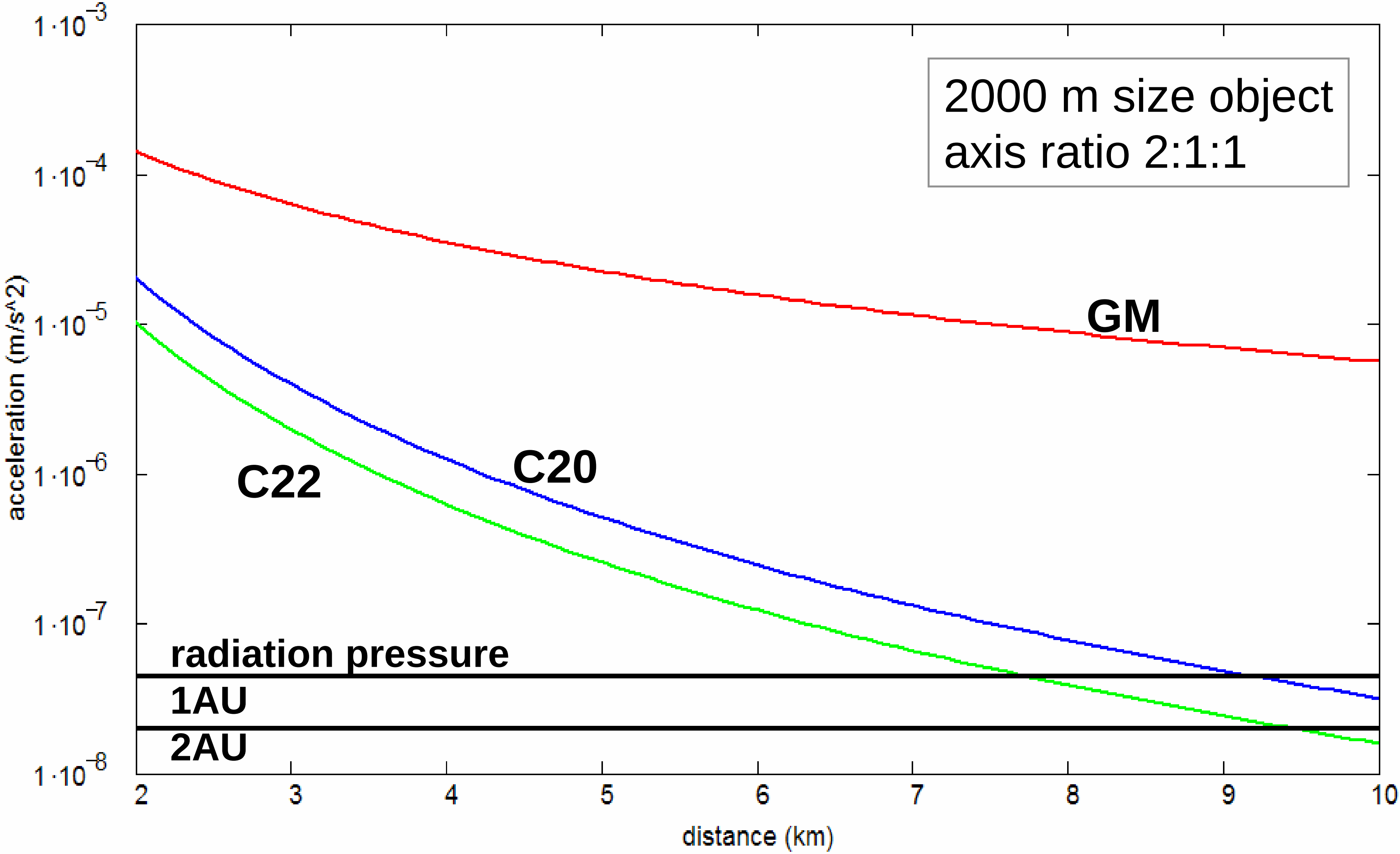
Simulation study for Don Quichote; terminator orbit of a 400 m size body





Gravity field acceleration



asteroid orbit

- Spacecraft tracking during prime mission
  - improved ephemeris; important for improved spacecraft orbit
  - improved received frequency prediction and residuals; extracted gravity field

- Radio beacon on the asteroid surface
  - radio tracking of asteroid
  - precise orbit determination
  - rotational states => hints on internal structure
  - orbit perturbations

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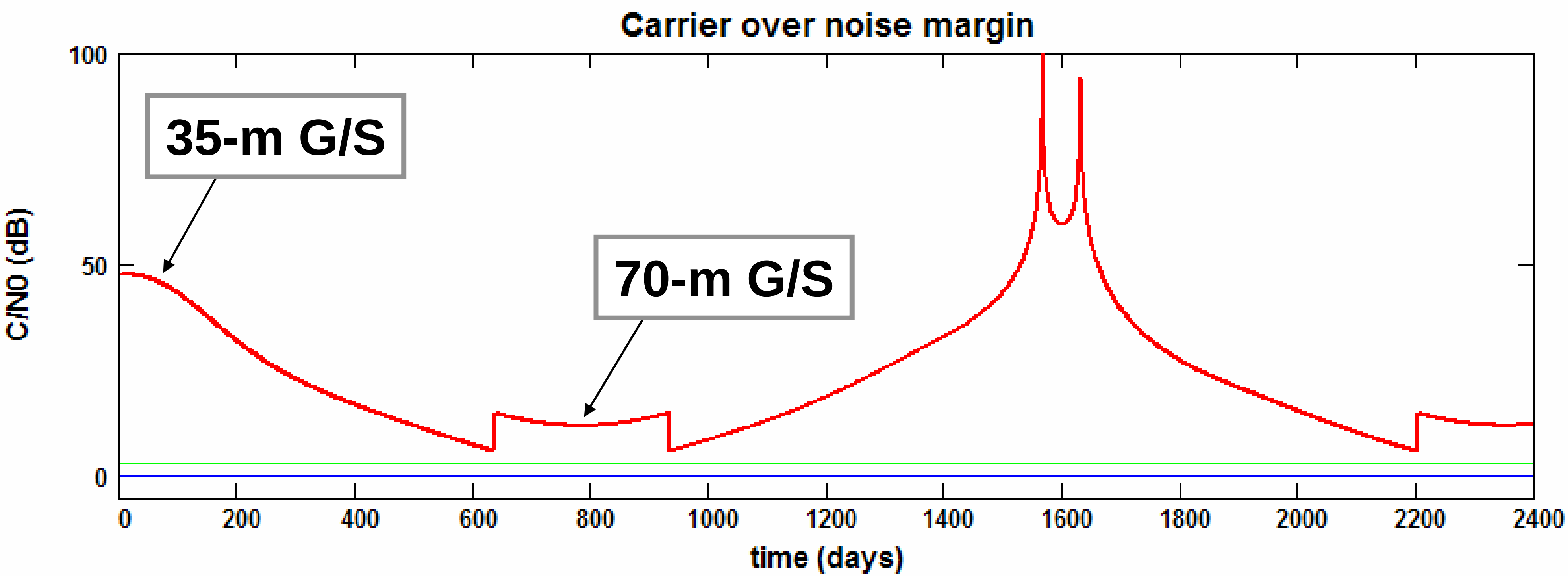
method

- Two-way X/X transponder on the surface (LaRa type)
- Transmission RF power: 1 – 3 watts
- Beacon antenna: omni-directional dipole with 0.7 dBi gain
- Ground stations: 35-m dish (NNO-type); 70 m dish (DSN)
- Example: Asteroid Wilson-Harrington, a = 2.64AU, e = 0.62
- Geocentric distances: very close Earth distances to 3 AU

received signal power



Conclusions

- Radio Science Group Cologne/Munich may provide support for planning and feasibility assessments of potential Marco Polo orbit scenarios

- Radio Science experiment on Marco Polo may characterize physical parameters of the asteroid: mass, bulk density, rotation, interior....

=> important for further study of surface material

- Long duration orbiter or surface beacon may be used for precise determination of heliocentric orbit => potential hazard?