COSPAR 2022
44th SCIENTIFIC ASSEMBLY
16-24 July 2022, Athens, Greece
a**MUSE**d by the Athenian **URANIA**

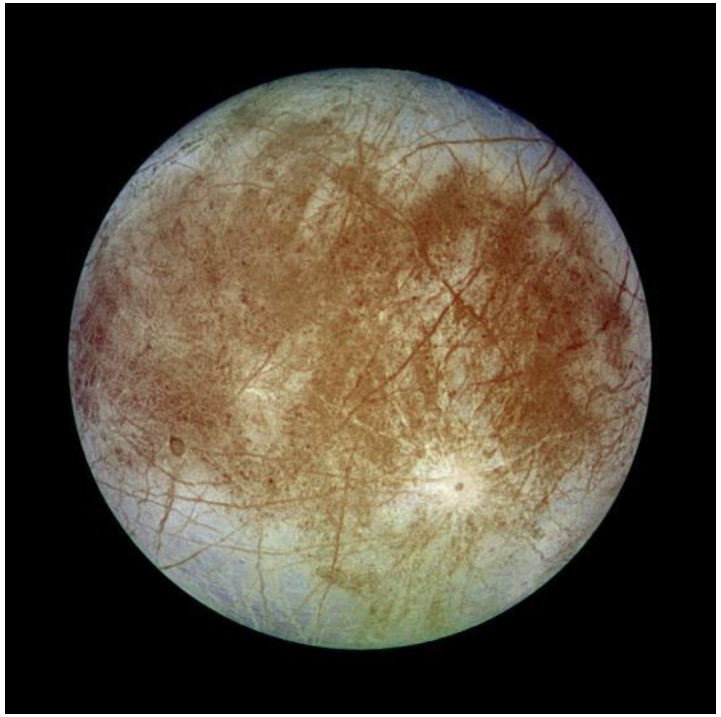
Callisto and Europa: a simulation study for gravity field determination from orbit tracking data

W. Desprats (1), D. Arnold (1), S. Bertone (2,3), M. Blanc (4),
A. Jäggi (1), M. Li (5), L. Lei (5), and O. Witasse (6)
(william.desprats@aiub.unibe.ch)

PSD.1: Satellite dynamics: new developments and challenged for Earth and solar system sciences

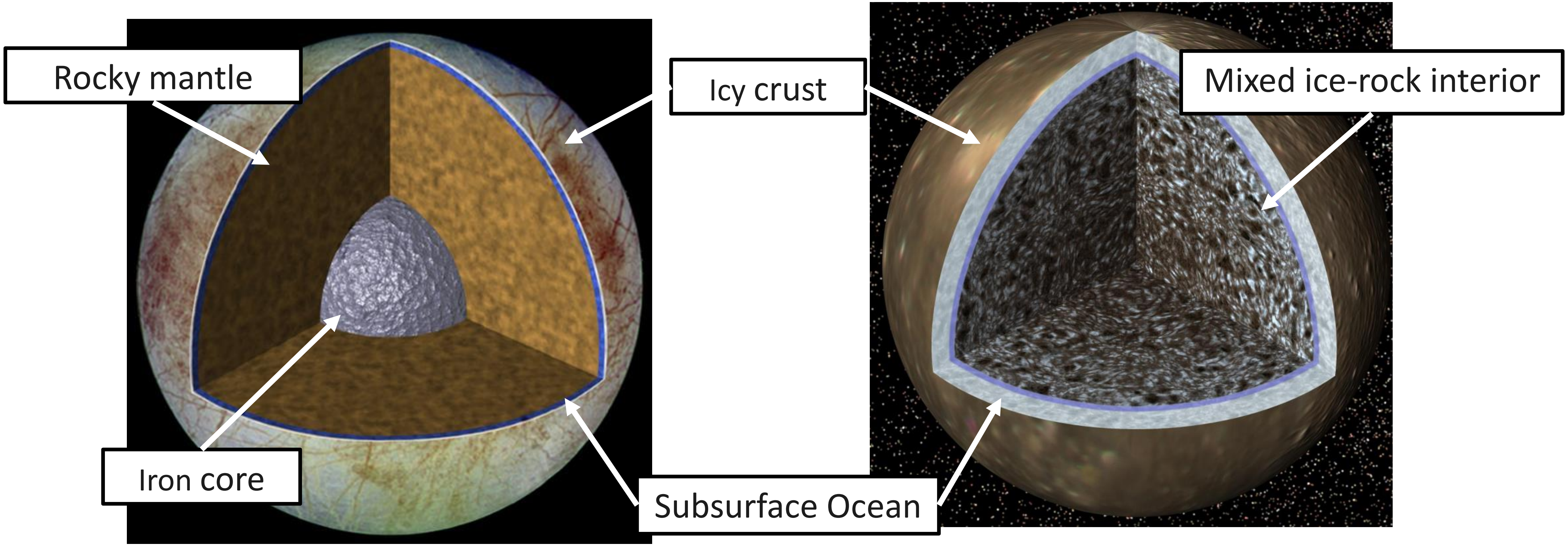
(1) Astronomical Institute, University of Bern, Switzerland, (2) University of Maryland, Baltimore County, USA,
(3) NASA Goddard Space Flight Center, (4) IRAP, CNRS-Université Paul Sabatier, Toulouse, France,
(5) NSSC, Beijing, China, (6), European Space Agency

Europa & Callisto



Radius	1561 km	2410 km
Mass	0,008 M_{Earth}	0,018 M_{Earth}
Distance to Jupiter	670 900 km	1 882 700 km
Orbital period	3,551 days	16,689 days
Surface	Cracks and streaks	Heavily cratered

Europa & Callisto: internal structure



Rocky mantle

Icy crust

Mixed ice-rock interior

Iron core

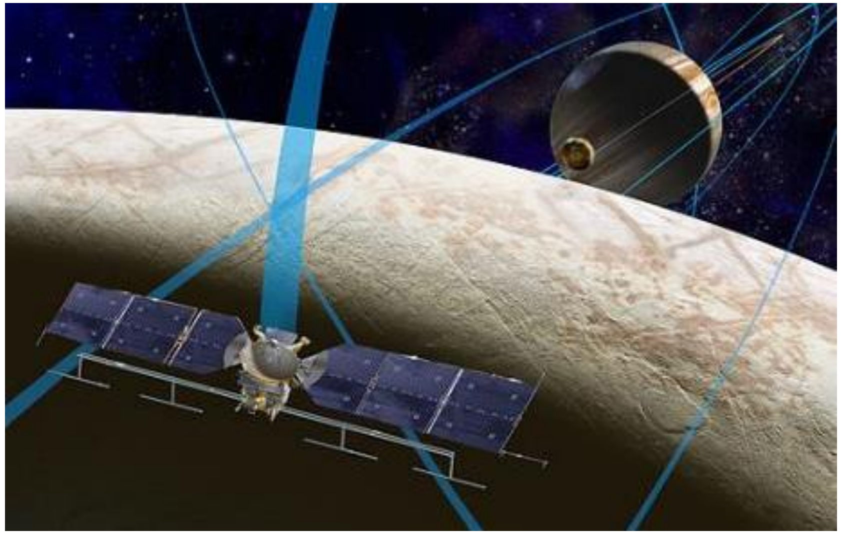
Subsurface Ocean

Evidence of water plumes on Europa

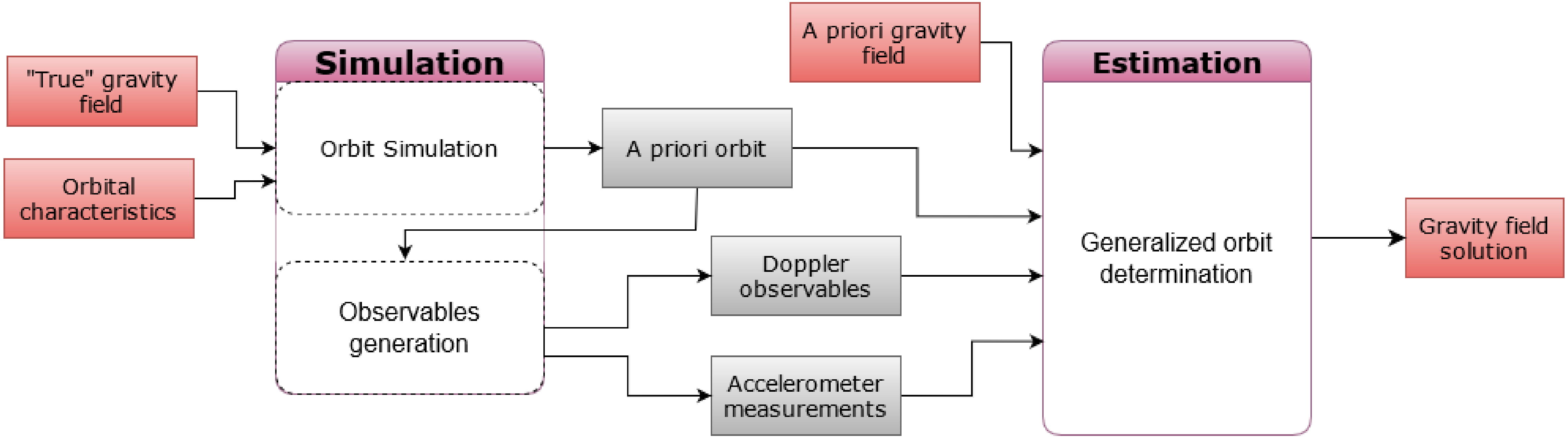
Planned missions to the Jovian moons

- **JUICE (ESA):**
  - Launch: 2023
  - Jupiter arrival: 2031
  - 2 Europa flybys
  - 21 Callisto flybys
  - Orbit around Ganymede

- **Europa Clipper (NASA):**
  - Launch: 2024
  - Jupiter arrival: 2030
  - 45 flybys of Europa



Our simulation pipeline

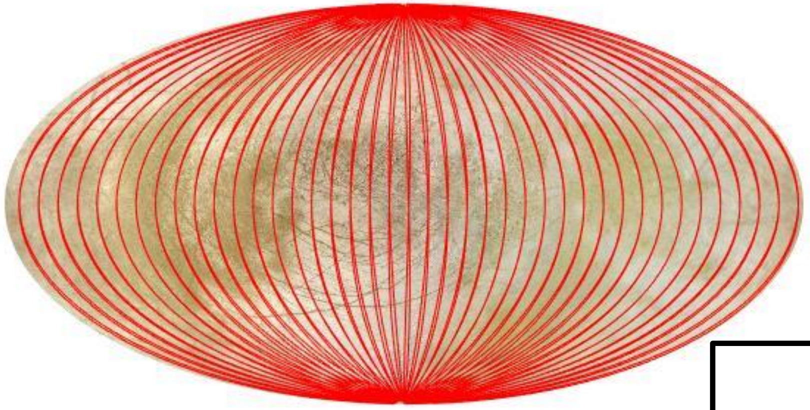


- Orbit propagations and the whole gravity field recovery process were based on a development version of the Bernese GNSS Software.

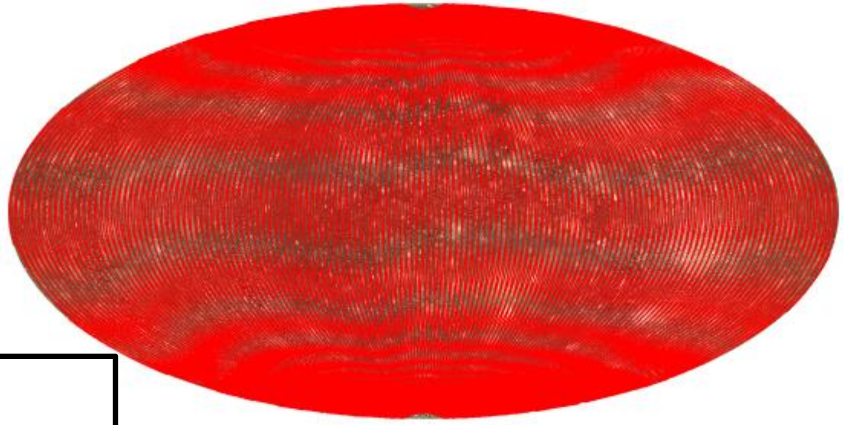
- 3 months mission
- 2-way Doppler:
  - Fixed noise: σ (τ=60s) = 0.1 mm/s
  - Detailed noise model (incl. solar plasma)

Repetitive Ground Track Orbits (RGTO)

1:41 Europa RGTO

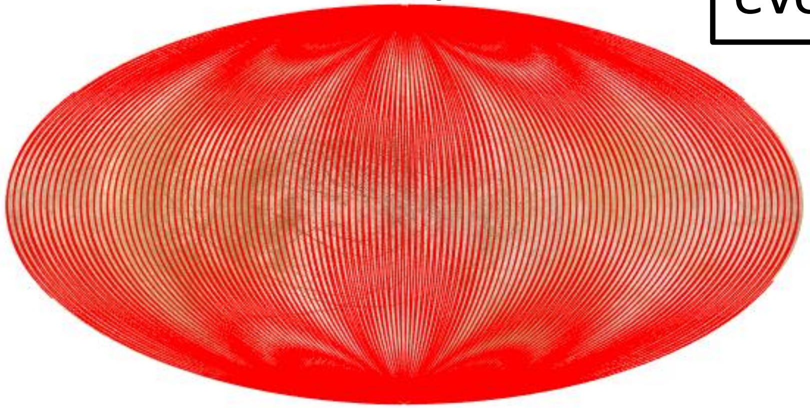


1:146 Callisto RGTO

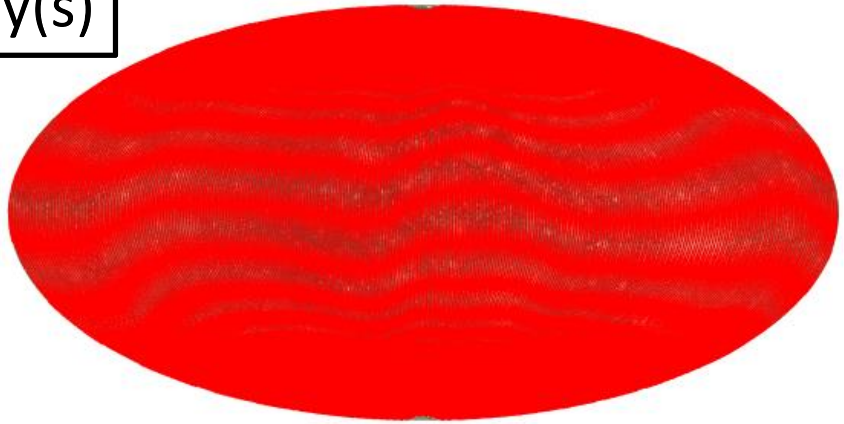


m:R RGTO:
R orbit ground tracks repeat
every **m** Europa/Callisto day(s)

3:119 Europa RGTO



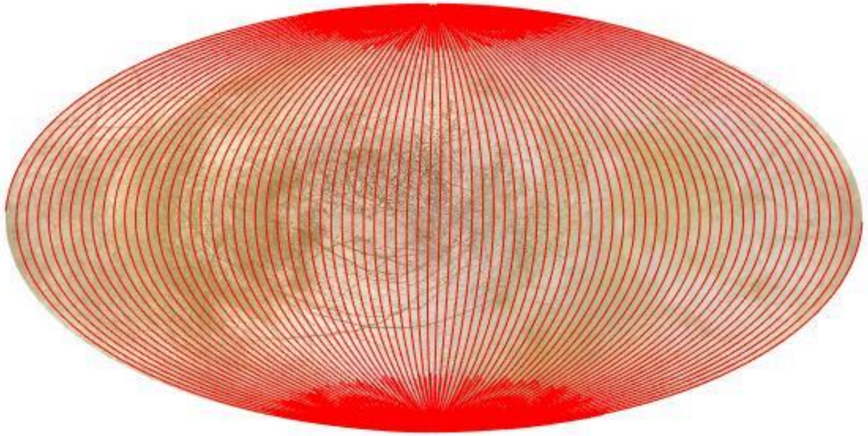
2:293 Callisto RGTO



β_{Earth} angle

Edge-on orbit

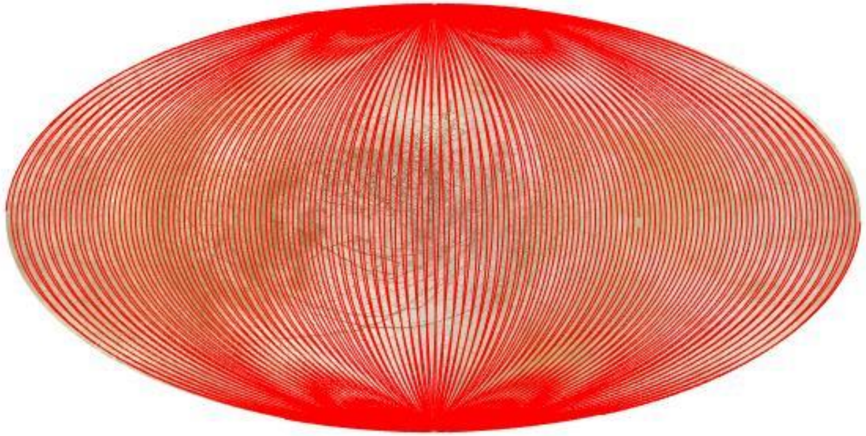
$\beta_{Earth}=0°$



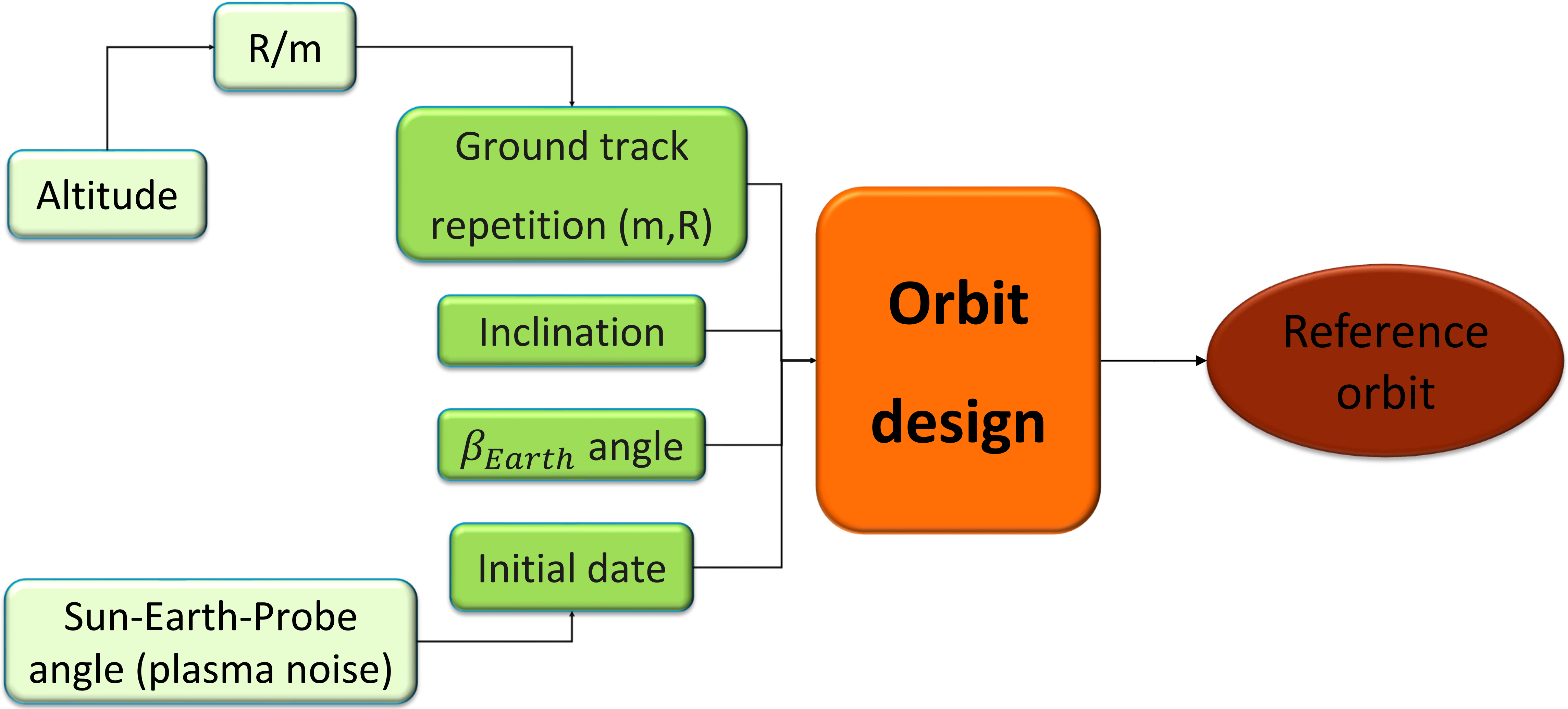
⊙ Earth direction

Face-on orbit

$\beta_{Earth}=90°$



Orbit design toolbox



Force model and synthetic gravity field

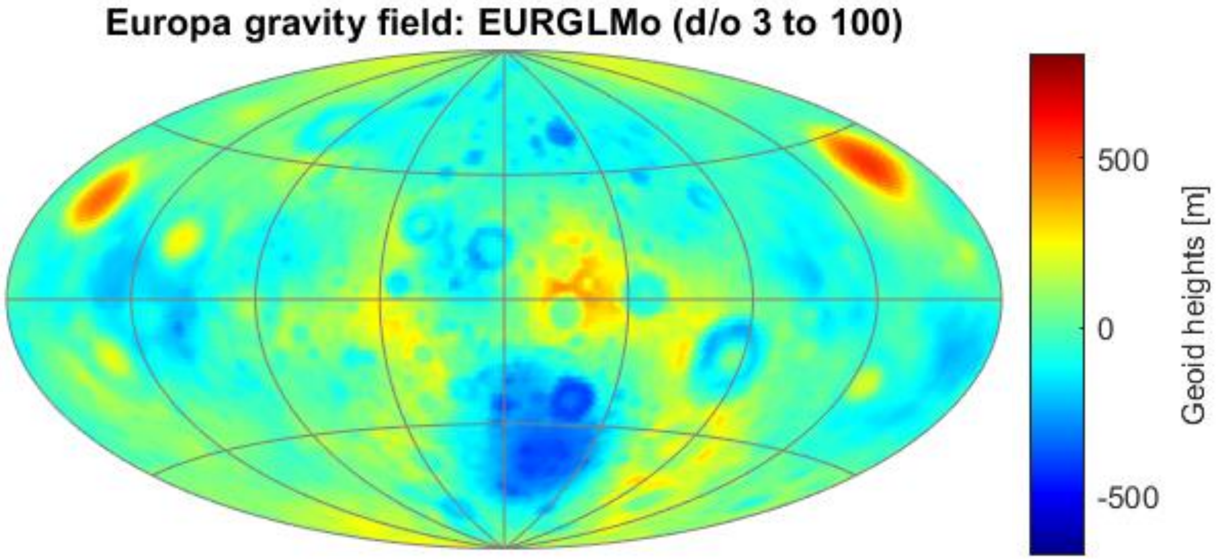
Force model:

- **Callisto/Europa:**
  - Synthetic gravity field
  - Tides (k_2=0.3/0.257)
- **Jupiter:**
  - Point mass
  - Zonal coefficient (J2 to J6)
- **Other 3rd body:**
  - Other Galilean moons
  - Sun
  - Other planets
- **Non gravitational acc. (NGA)**:
  - Direct Solar radiation pressure (SRP)
  - Planetary radiation pressure (PRP)

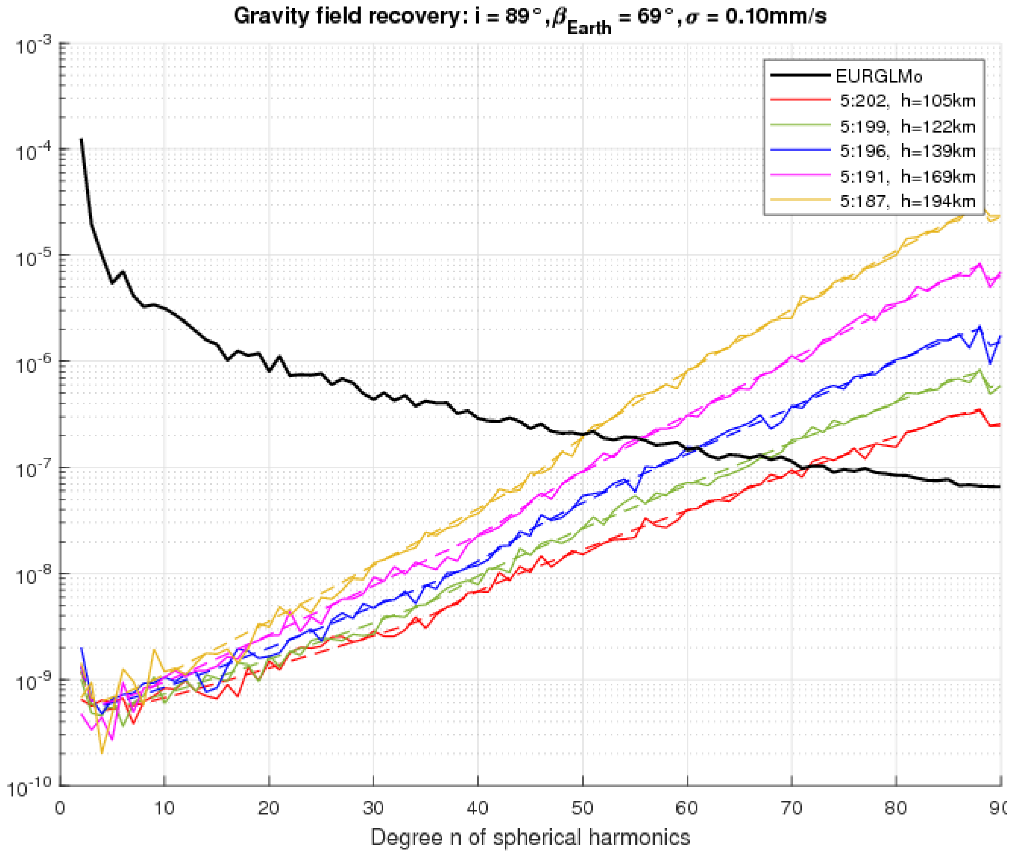
Synthetic gravity field:

$$V(r,\lambda,\phi) = \frac{GM}{r}\sum_{n=2}^{n_{max}}\sum_{m=0}^{n}\left(\frac{R_e}{r}\right)^n P_{nm}(sin\phi)(C_{nm}cosm\lambda + S_{nm}sinm\lambda)$$

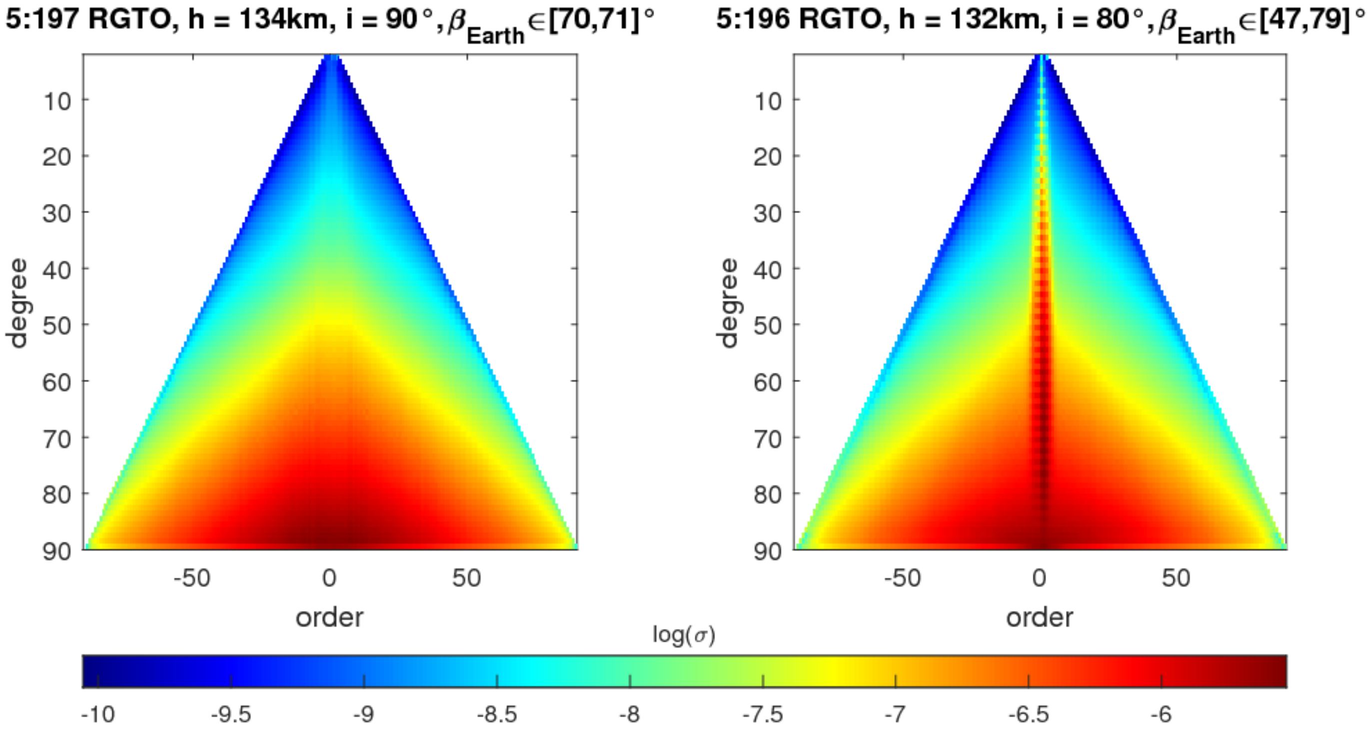
- Up to degree and order 2: from Galileo mission
- From d/o 3 to 100: Scaled Moon's gravity field



Influence of the altitude and inclination



90 d/o gravity field recovery: 3 months, σ = 0.10mm/s

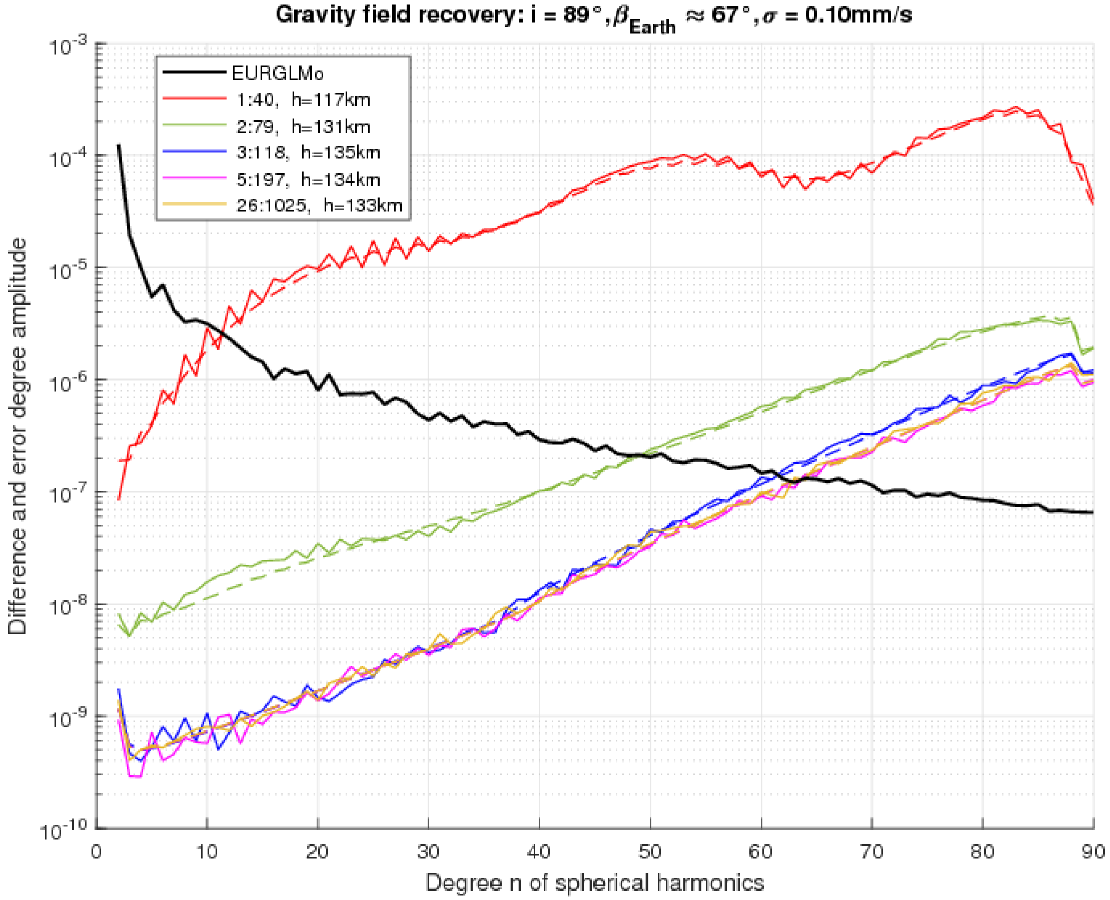


$$\Delta_n = \sqrt{\frac{1}{2n+1}\sum_{m=2}^{n}\left(\Delta\bar{C}_{nm}^2 + \Delta\bar{S}_{nm}^2\right)}$$

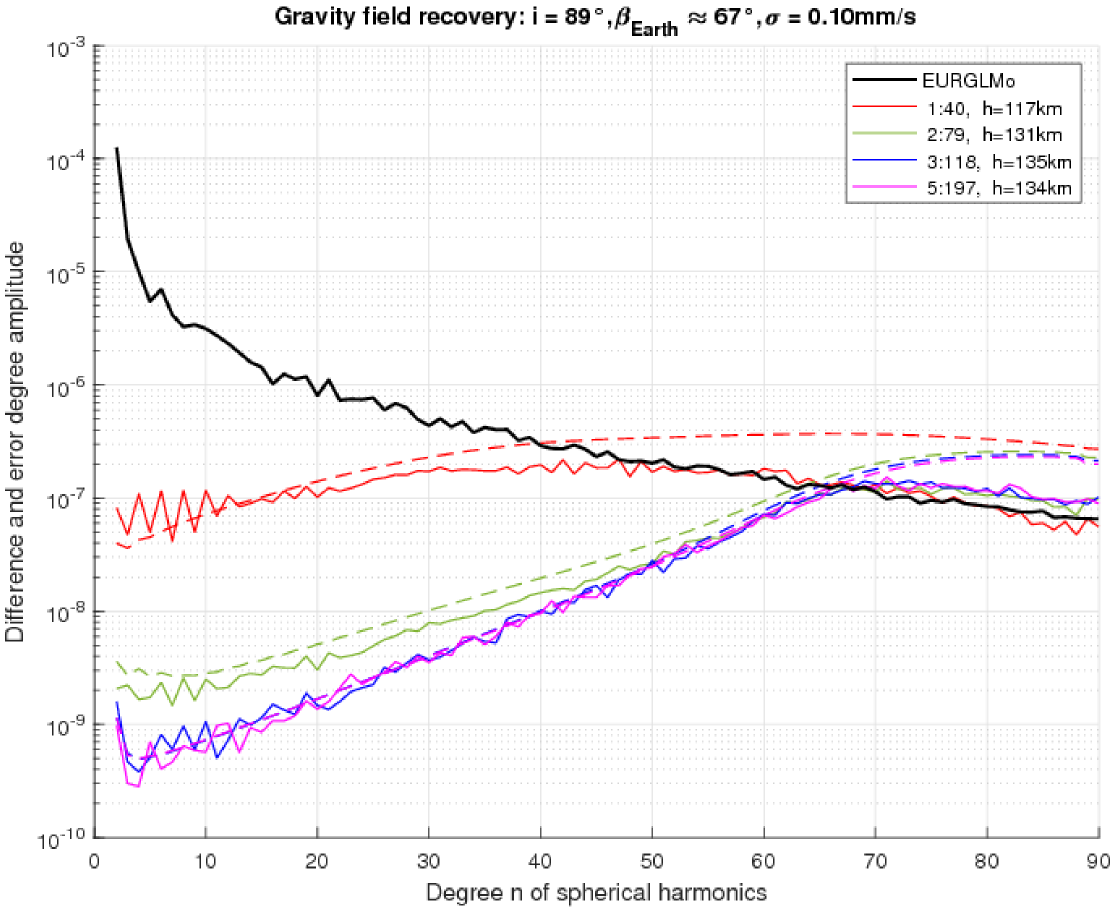
Influence of ground track repetition

$h \simeq 140\text{km},\ i = 89°,\ \beta_{\text{Earth}} = 66°$

Free solution



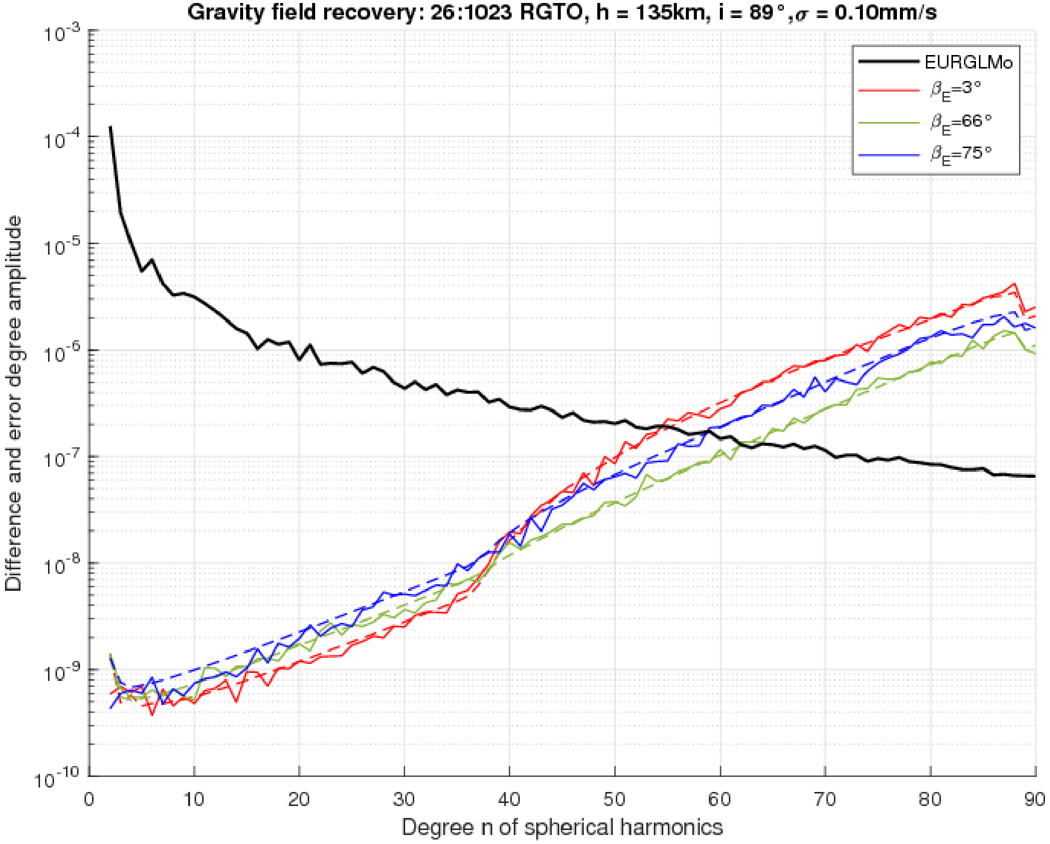
Kaula regularisation

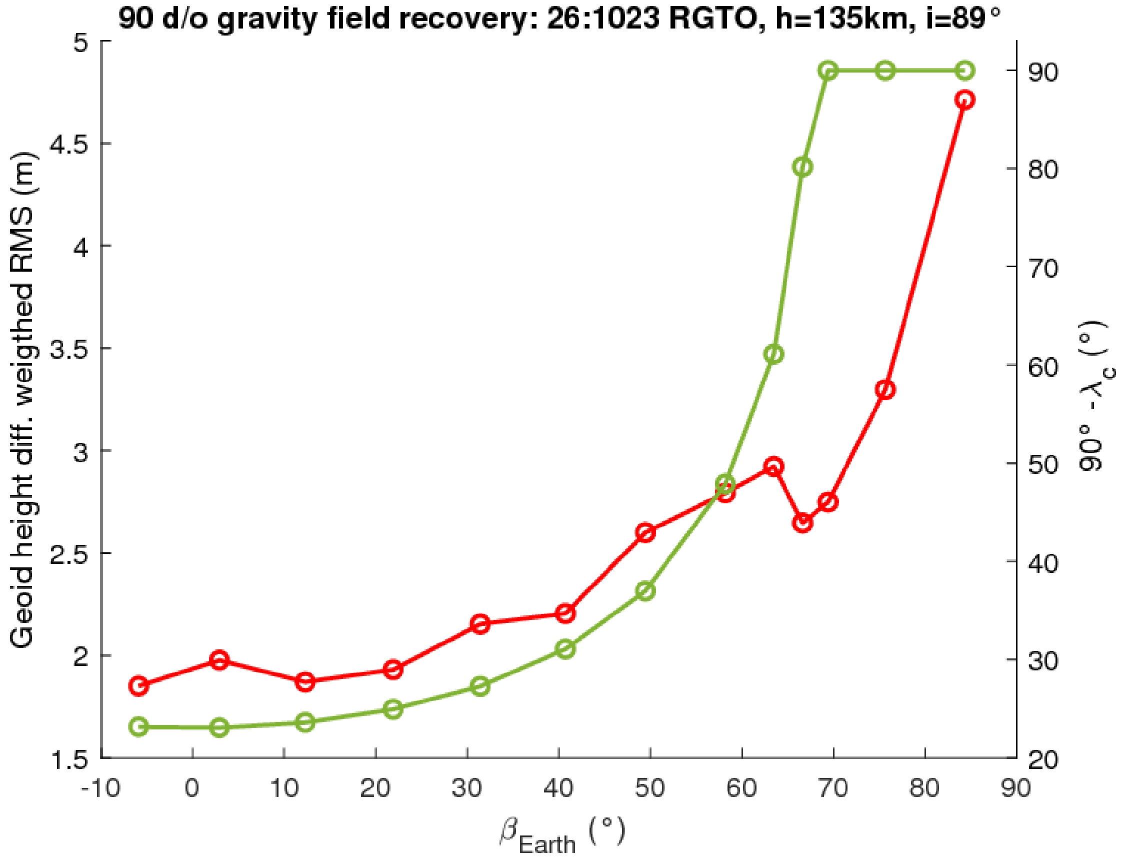


Influence of Earth beta angle

$$\Delta_n = \sqrt{\frac{1}{2n+1}\sum_{m=2}^{n}\left(\Delta\bar{C}_{nm}^2 + \Delta\bar{S}_{nm}^2\right)}$$

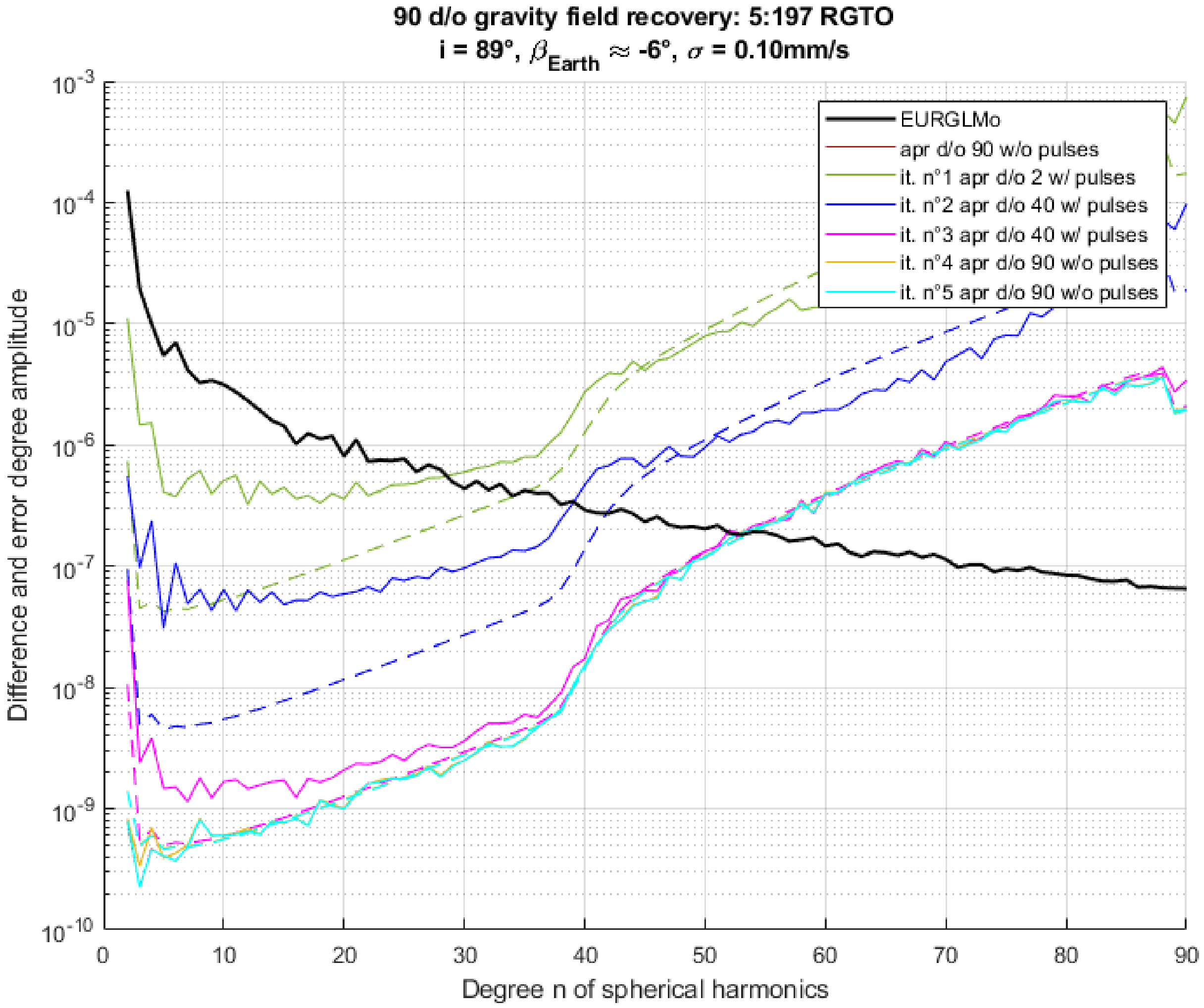
$$(\Delta g)_{WRMS} = \sqrt{\frac{\sum_{\theta,\phi} cos(\theta)\, \Delta g_{\theta,\phi}^2}{\sum_{\theta,\phi} cos(\theta)}}$$


Gravity field recovery: 26:1023 RGTO, h = 135km, i = 89°, σ = 0.10mm/s


90 d/o gravity field recovery: 26:1023 RGTO, h=135km, i=89°

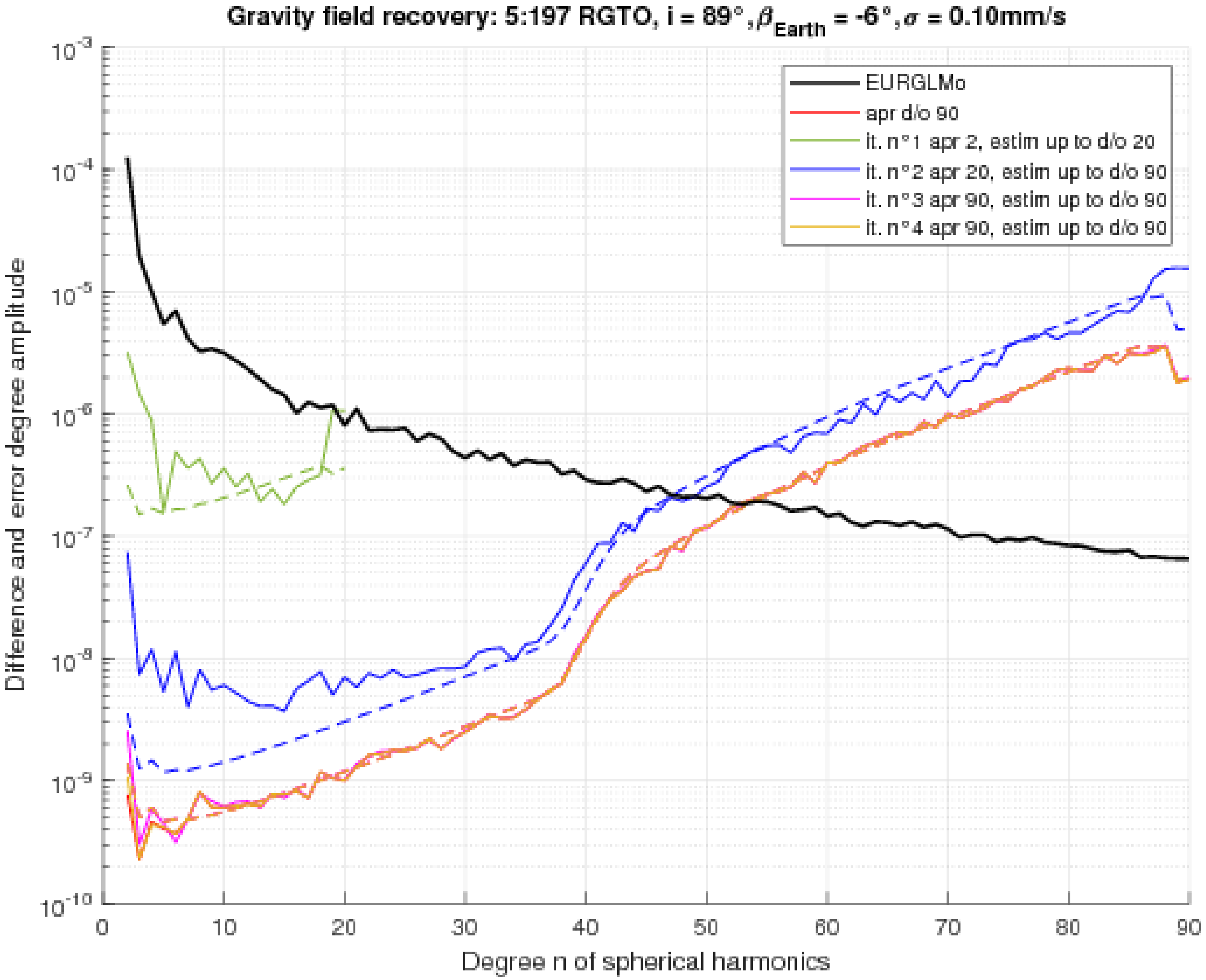
Using a degree-2 a priori gravity field: making use of pulses

- Starting from the truth, truncated d/o 2
- Pseudo-stochastic pulses (instantaneous velocity change) every 60min to help orbit convergence
- 1 m/s constraints in all direction (Radial, Along-track, Cross-track)
- Affects the low degree
- Last iteration w/o pulses



Using a degree-2 a priori gravity field: co-estimation of the low degrees

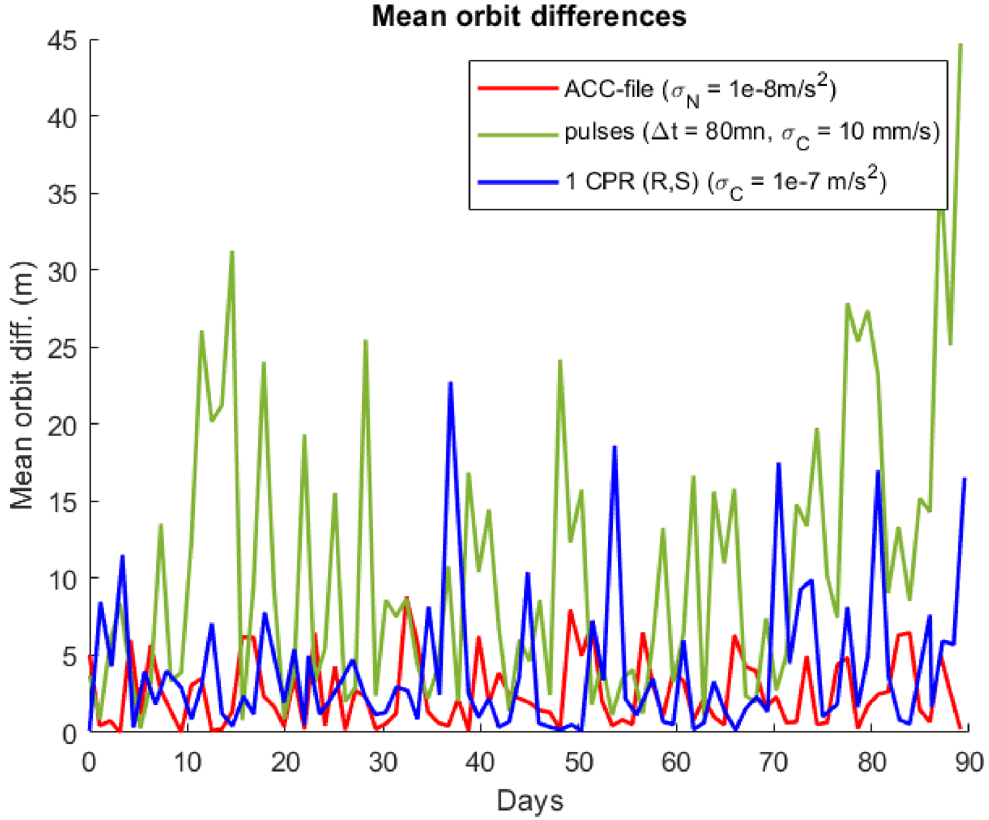
- Starting from the truth, truncated d/o 2
- Co-estimation of the low-degree gravity field coefficients with the orbit parameters in the first iteration
- Free solution
- No additional parameters needed

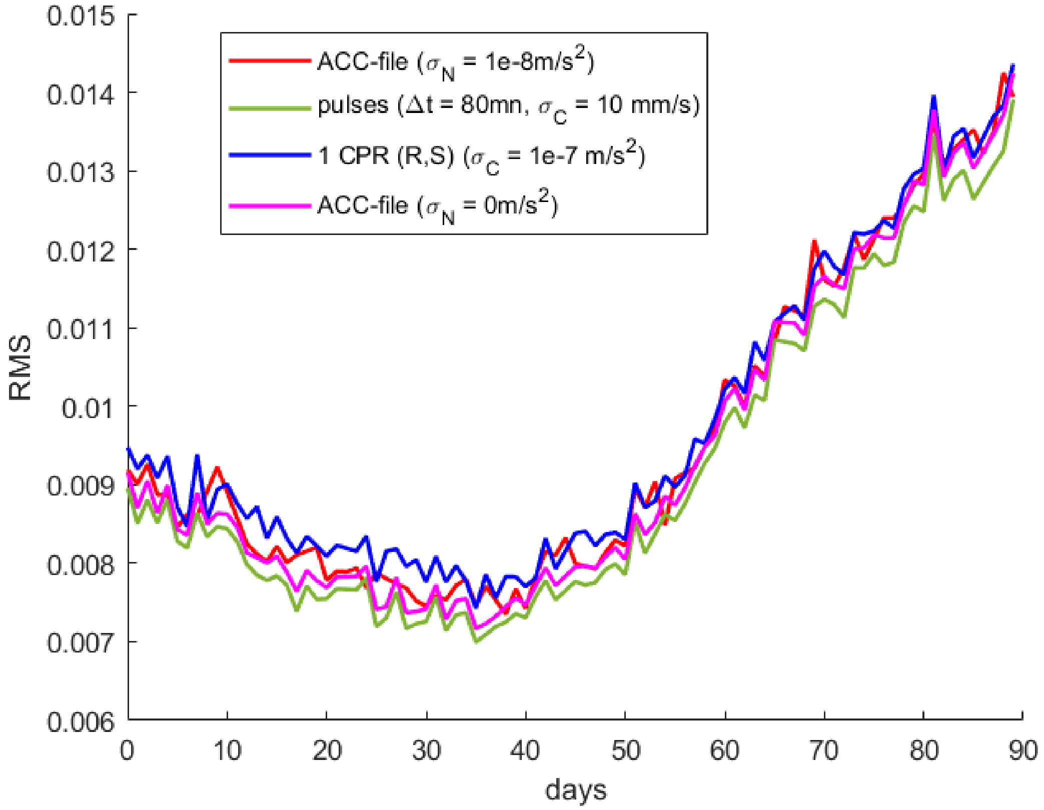


NGA mitigation strategies around Callisto: orbit fit

- Different strategies to handle NGA:
  - On-board accelerometer (10^{-8} m/s^2 white noise)
  - Pseudo-stochastic pulses (every 80mn = ½ orbital period)
  - 1 Cycle Per Revolution acceleration in radial and along-track directions

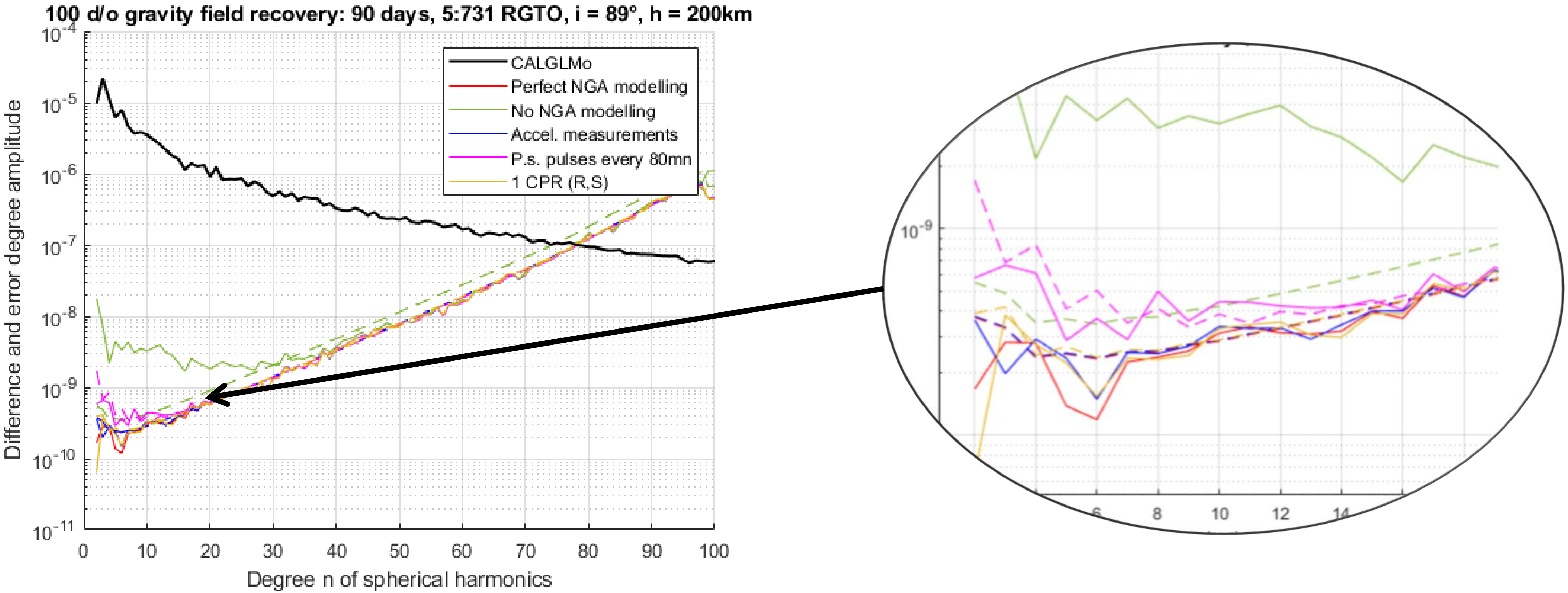
Average orbit distance between the simulated reference orbit, and the final estimated orbit for each 25h arcs.





NGA mitigation strategies around Callisto: gravity field recovery

- Different strategies to handle NGA:
  - On-board accelerometer (10^{-8} m/s^2 white noise)
  - Pseudo-stochastic pulses (every 80mn = ½ orbital period)
  - 1 Cycle Per Revolution acceleration in radial and along-track directions



Summary & Outlook

Summary

- Influence of several orbital characteristic on gravity field recovery
- Comparison of several strategies using a very poor knowledge a priori gravity field
- Non-gravitational acceleration mitigation

Outlook

- Estimation of rotation parameters
- Simulation of altimetry measurements
- Altimetry crossover analysis to constrain orbit and geodetic parameters

Thank you for your attention!