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

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

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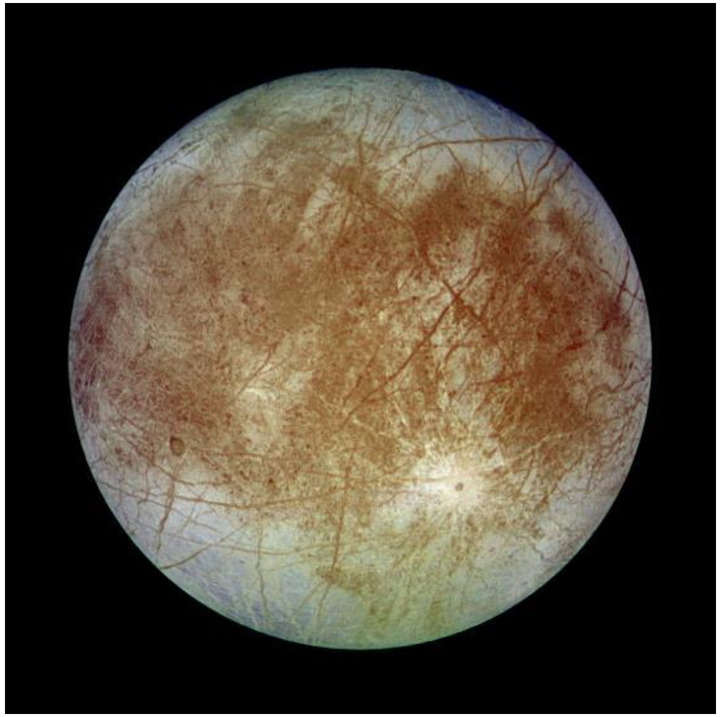
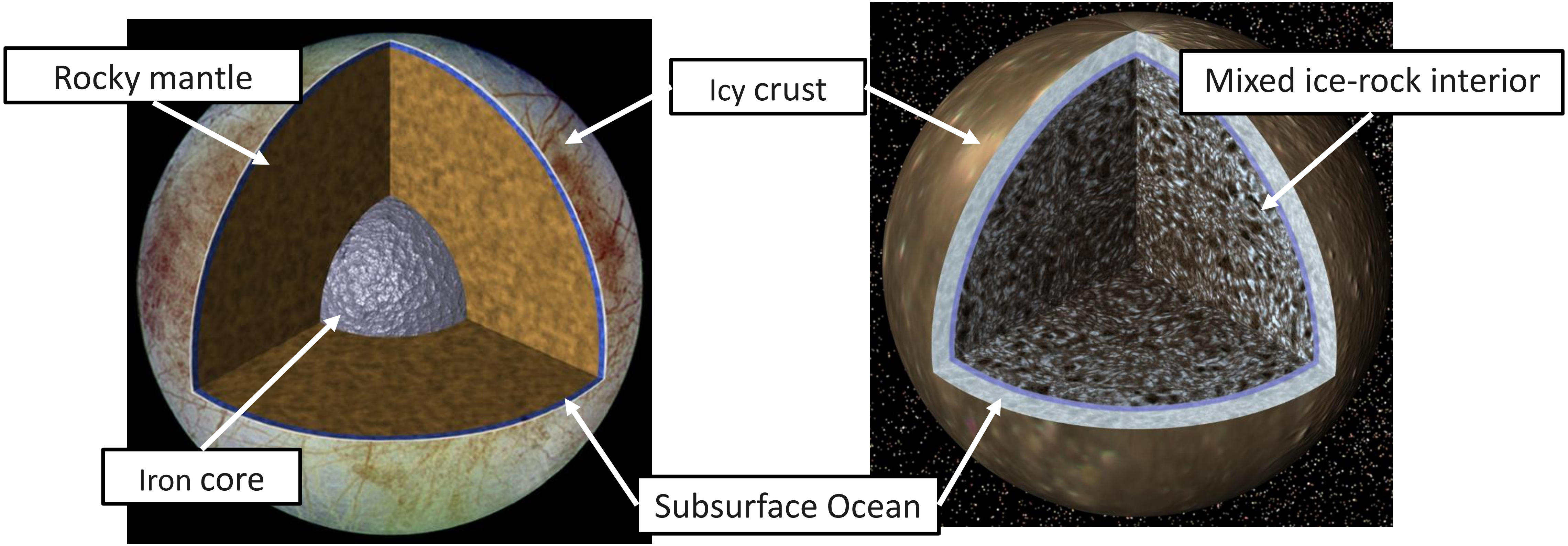
Europa & Callisto



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

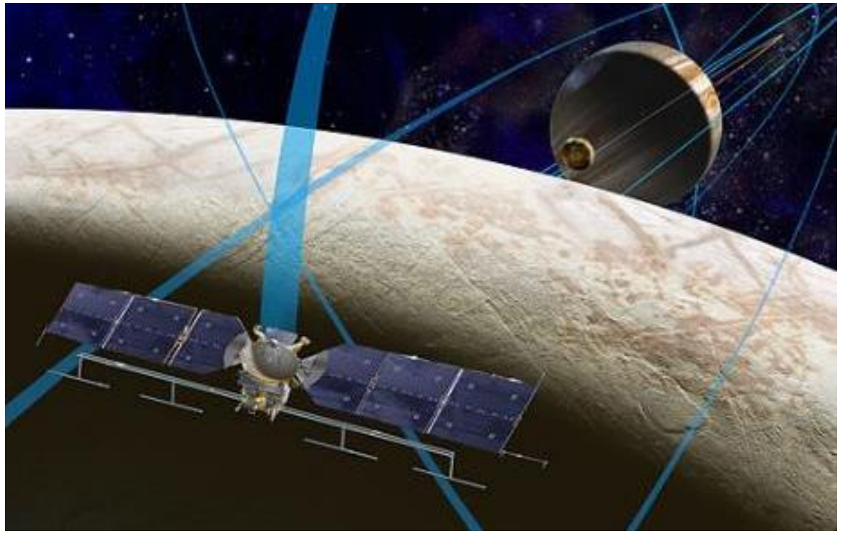


Evidence of water plumes on Europa

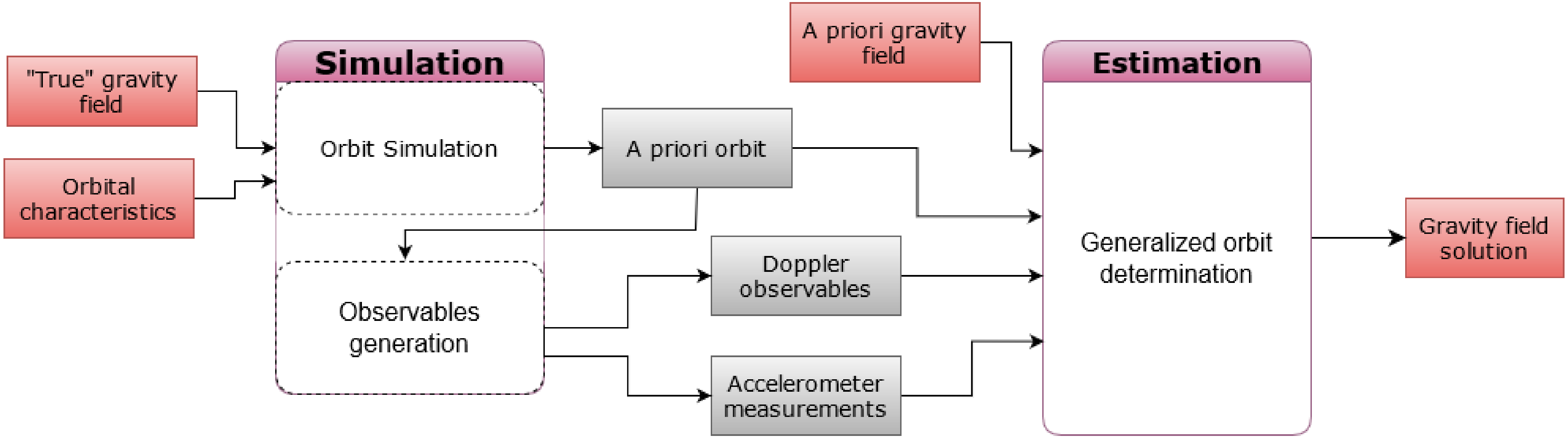
Planned missions to the Jovian moons

- **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

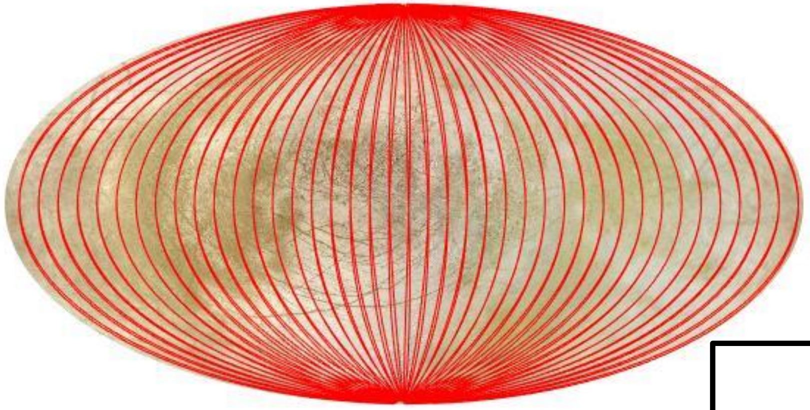


- Orbit propagations and the whole gravity field recovery process were based on a development version of the Bernese GNSS Software.

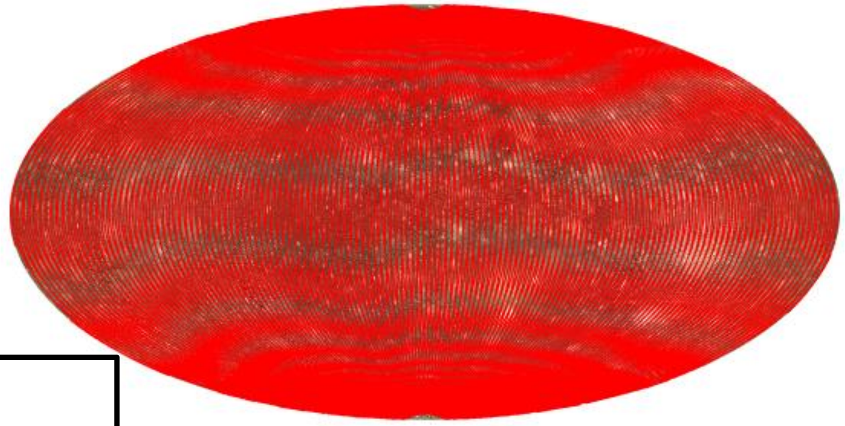
- 3 months mission
- 2-way Doppler:
  - Fixed noise: σ (τ=60s) = 0.1 mm/s
  - Detailed noise model (incl. solar plasma)

Repetitive Ground Track Orbits (RGTO)

1:41 Europa RGTO

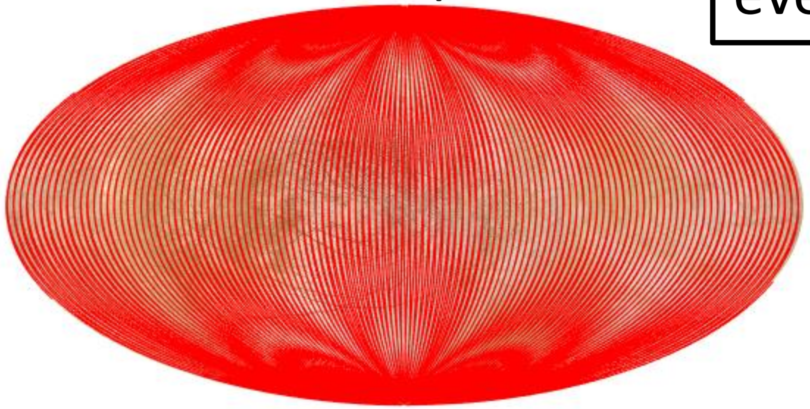


1:146 Callisto RGTO

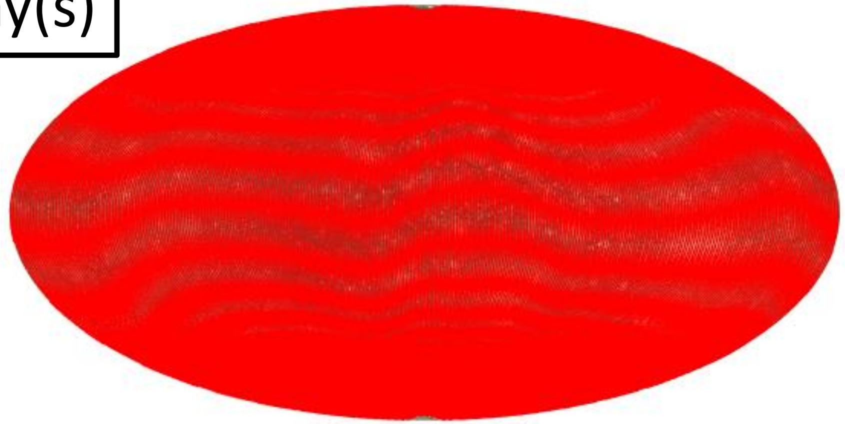


m:R RGTO:
R orbit ground tracks repeat every **m** Europa/Callisto day(s)

3:119 Europa RGTO

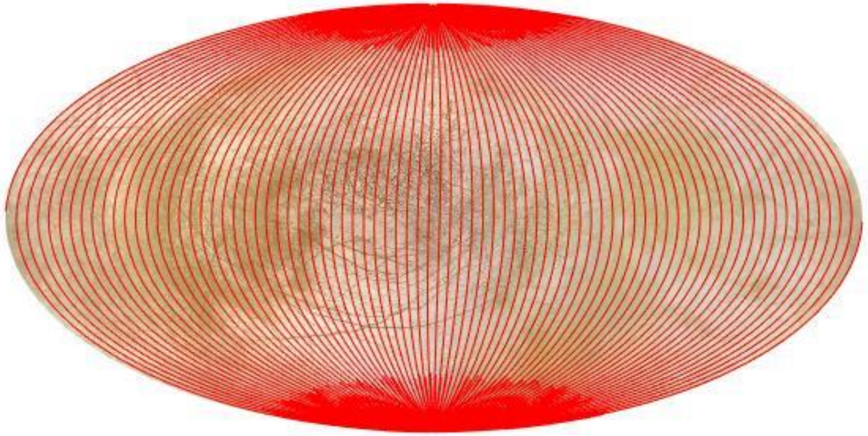


2:293 Callisto RGTO



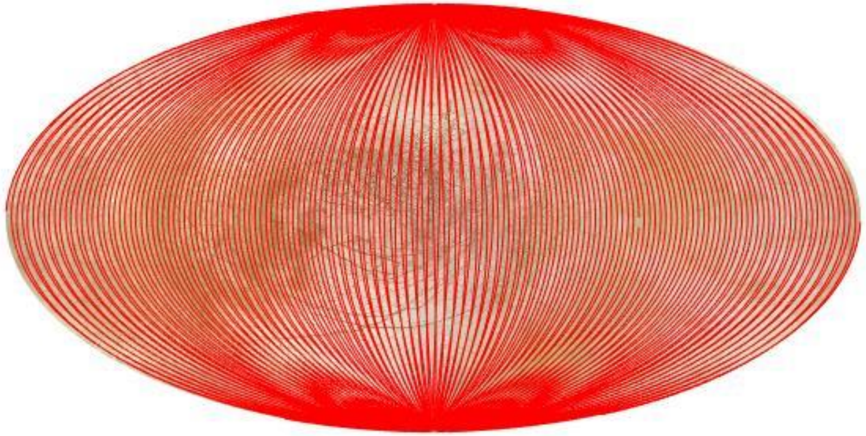
β_{Earth} angle

Edge-on orbit
β_{Earth} =0°

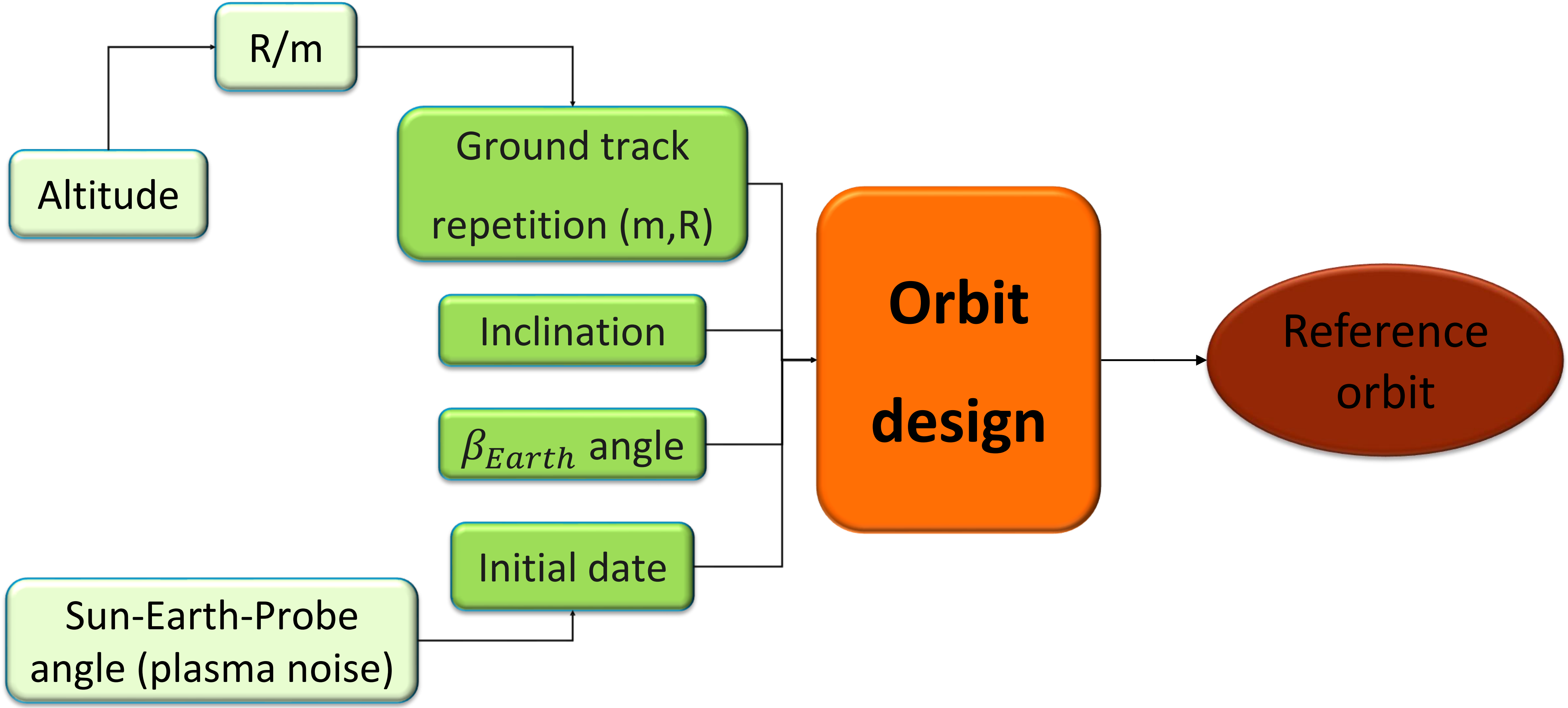


⊙ Earth direction

Face-on orbit
β_{Earth} =90°



Orbit design toolbox



Force model and synthetic gravity field

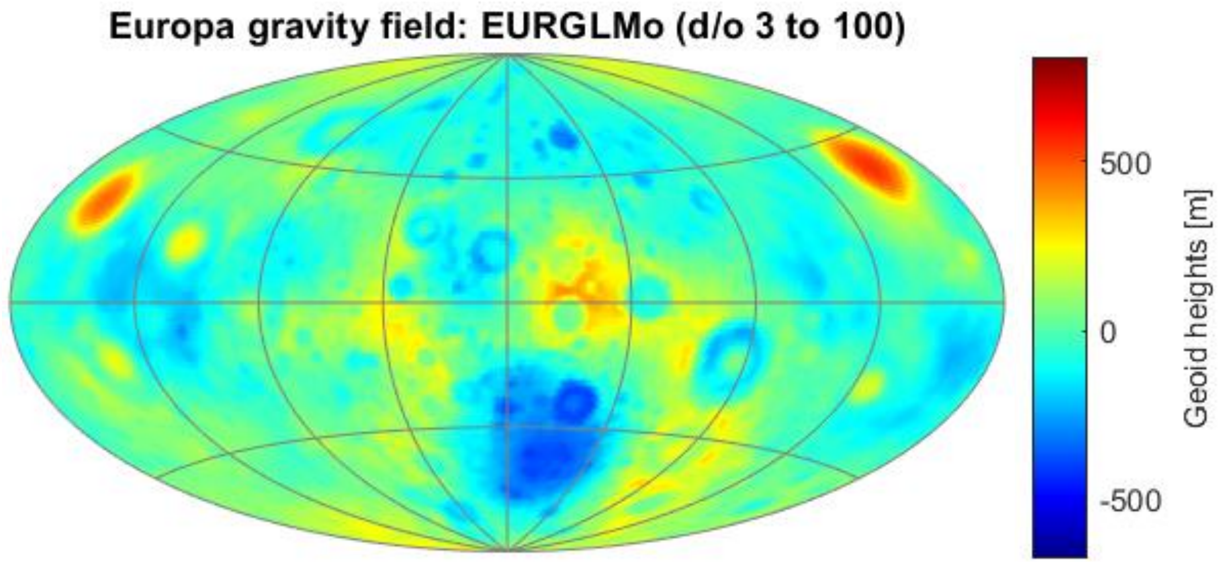
Force model:

- **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)

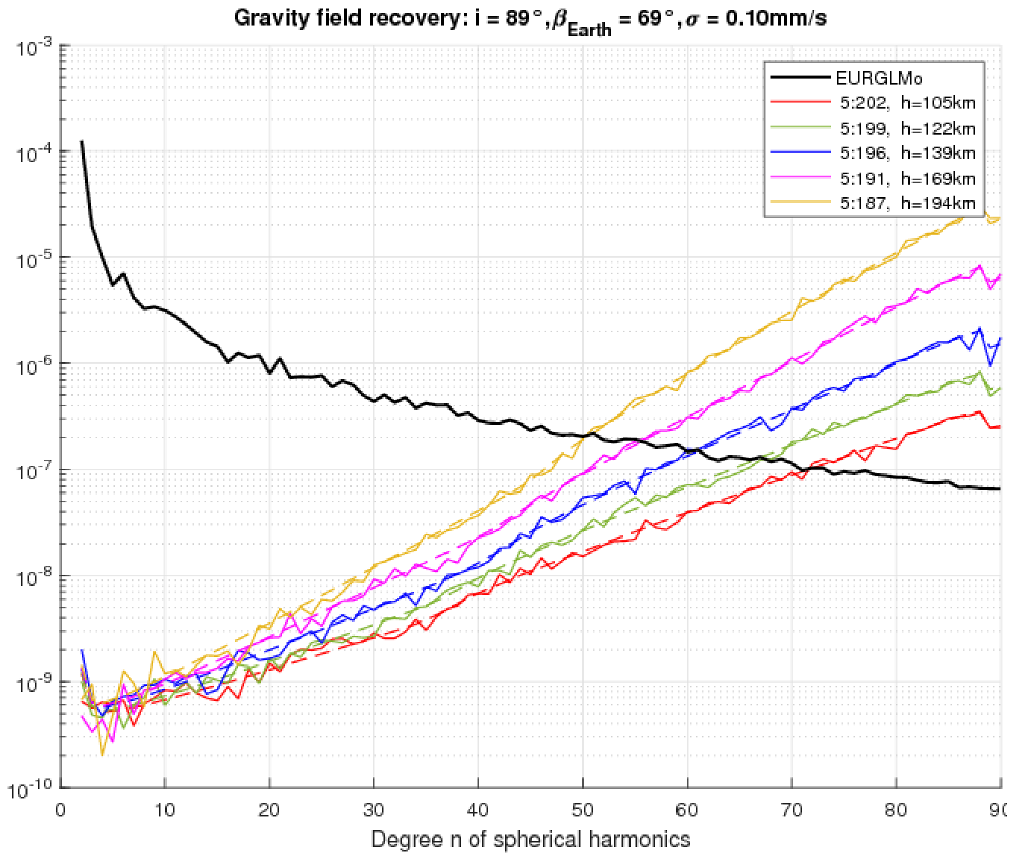
Synthetic gravity field:

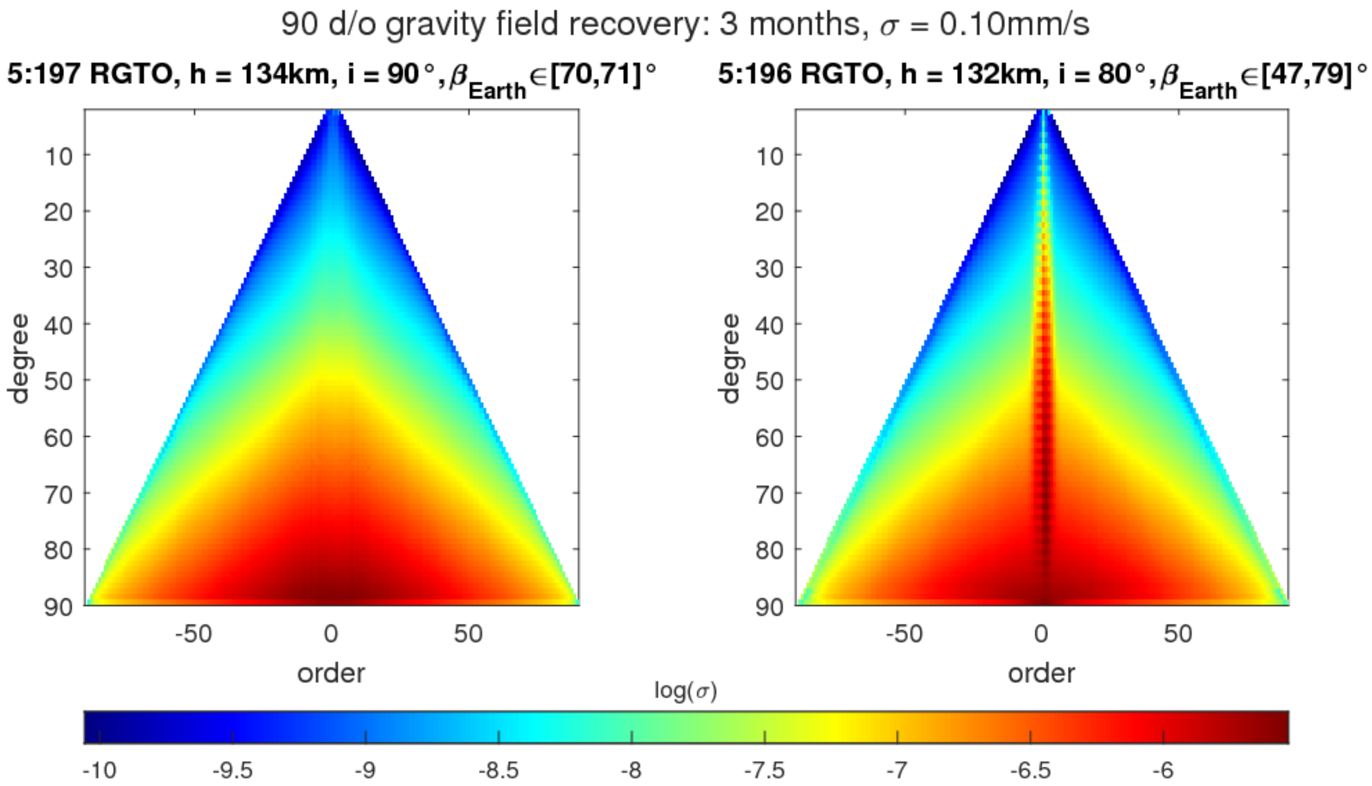
$$V(r,\lambda,\phi) = \frac{GM}{r}\sum_{n=2}^{n_{max}}\sum_{m=0}^{n}\left(\frac{R_e}{r}\right)^n P_{nm}(sin\phi)(C_{nm}cosm\lambda + S_{nm}sinm\lambda)$$

- 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



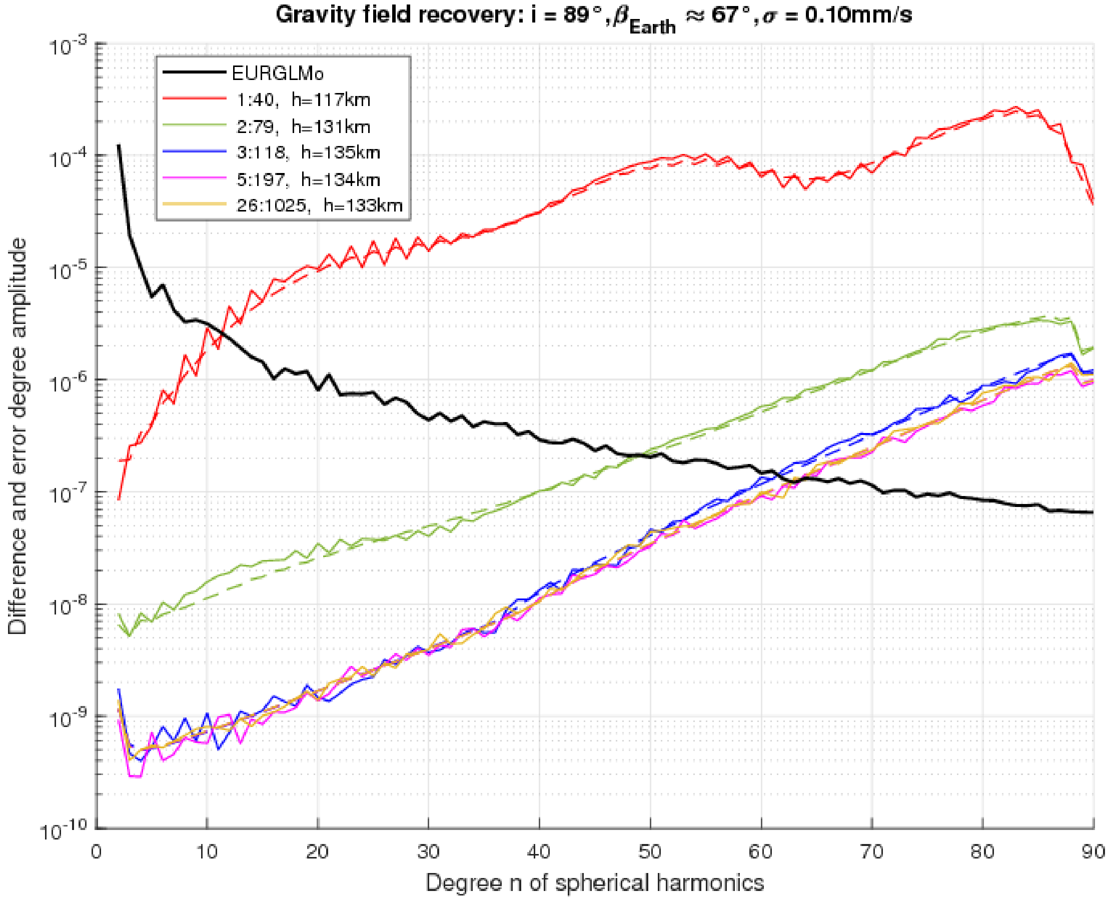


$$\Delta_n = \sqrt{\frac{1}{2n+1}\sum_{m=2}^{n}\left(\Delta\bar{C}_{nm}^2 + \Delta\bar{S}_{nm}^2\right)}$$

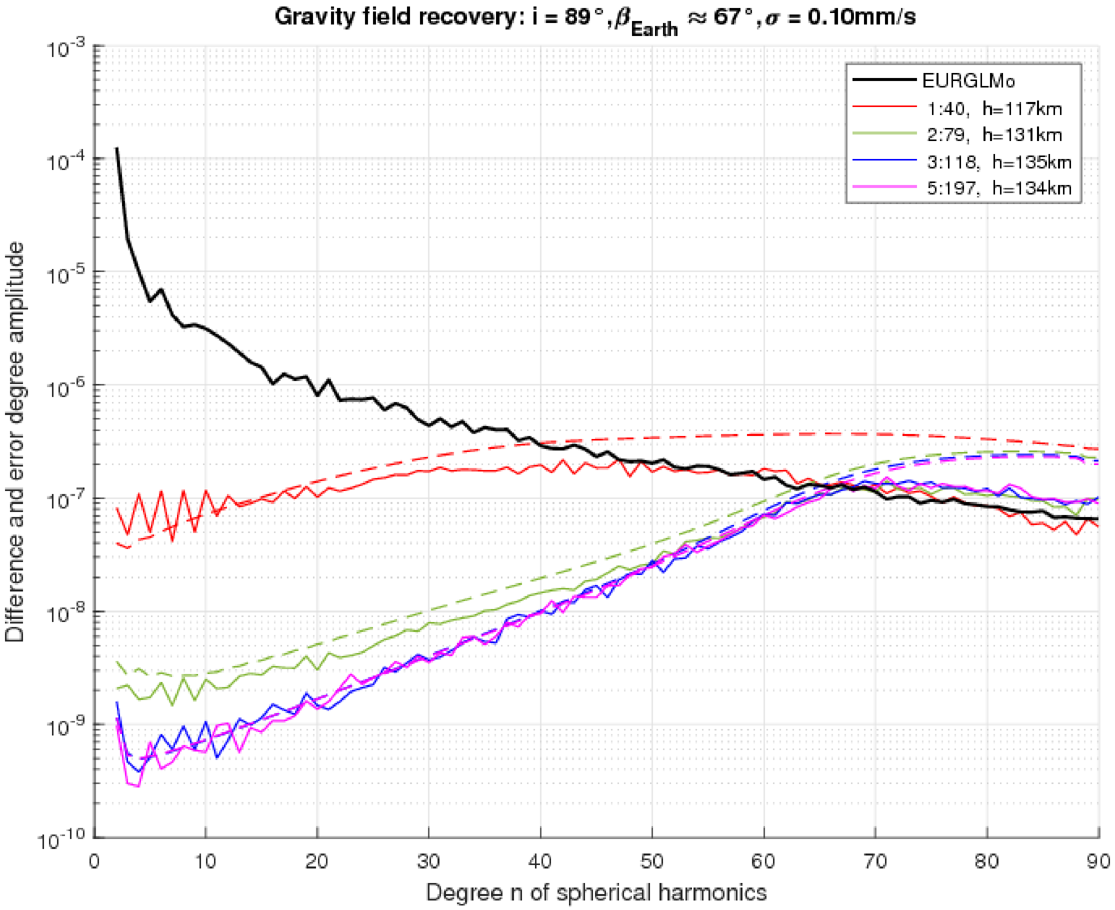
Influence of ground track repetition

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

Free solution



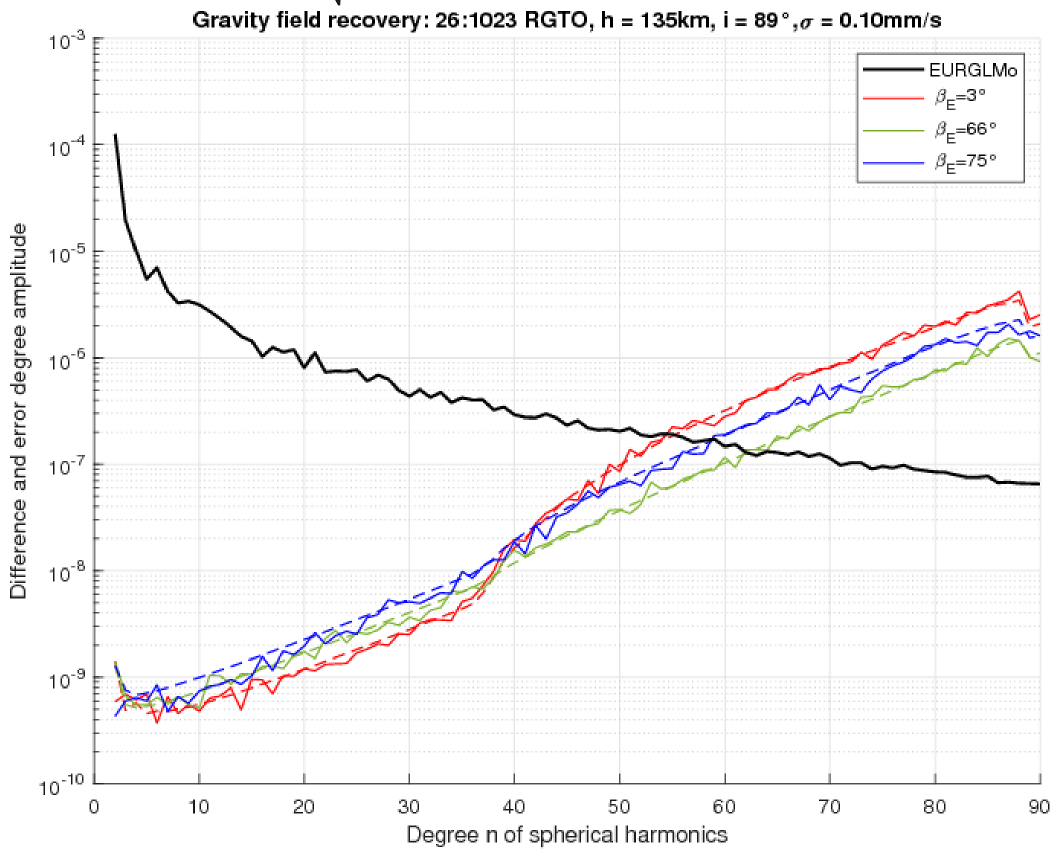
Kaula regularisation

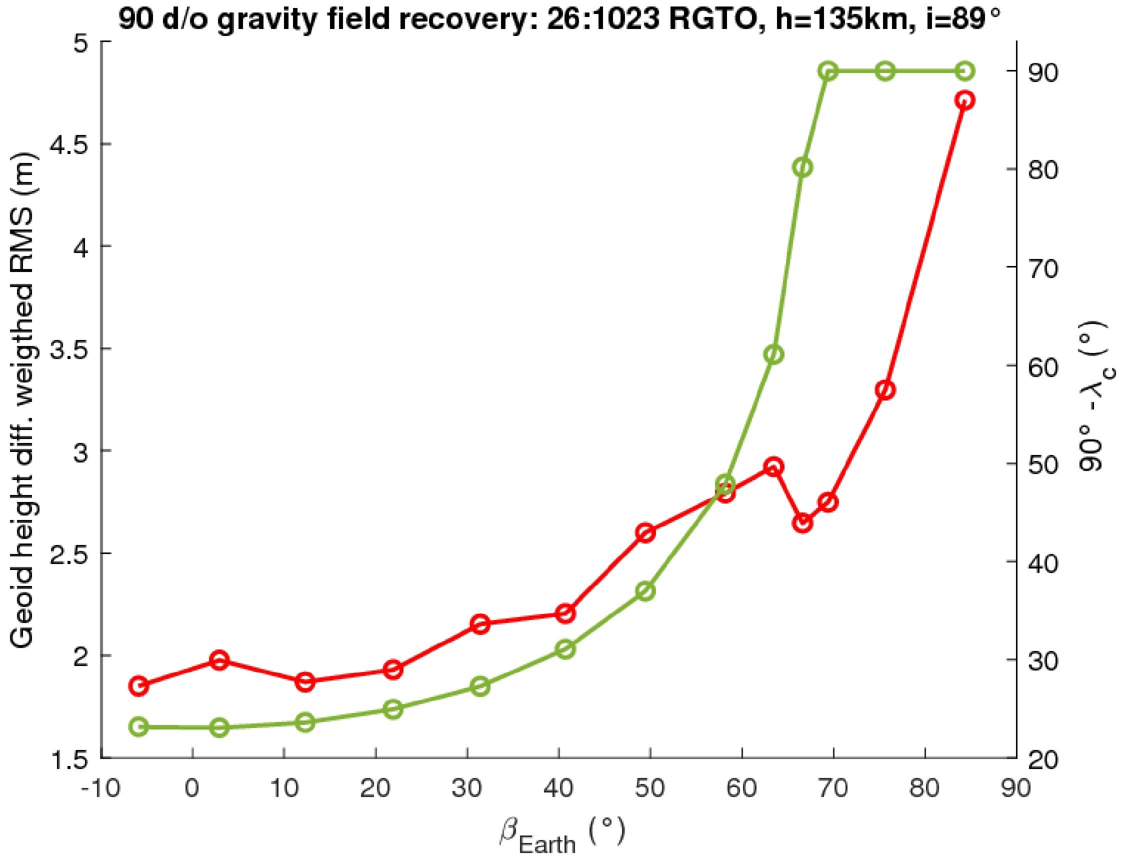


Influence of Earth beta angle

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

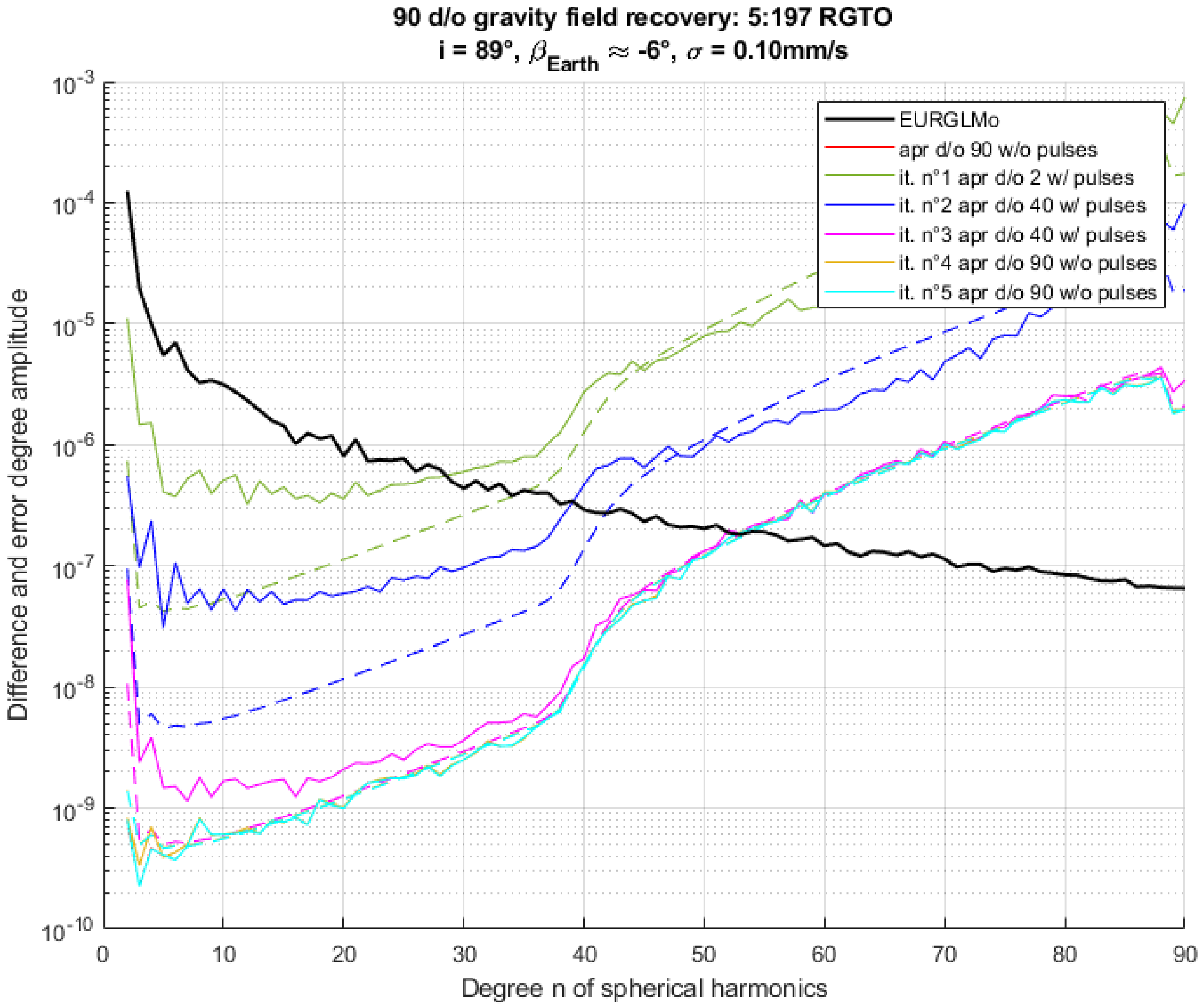
$$(\Delta g)_{WRMS} = \sqrt{\frac{\sum_{\theta,\phi} cos(\theta)\,\Delta g_{\theta,\phi}^2}{\sum_{\theta,\phi} cos(\theta)}}$$





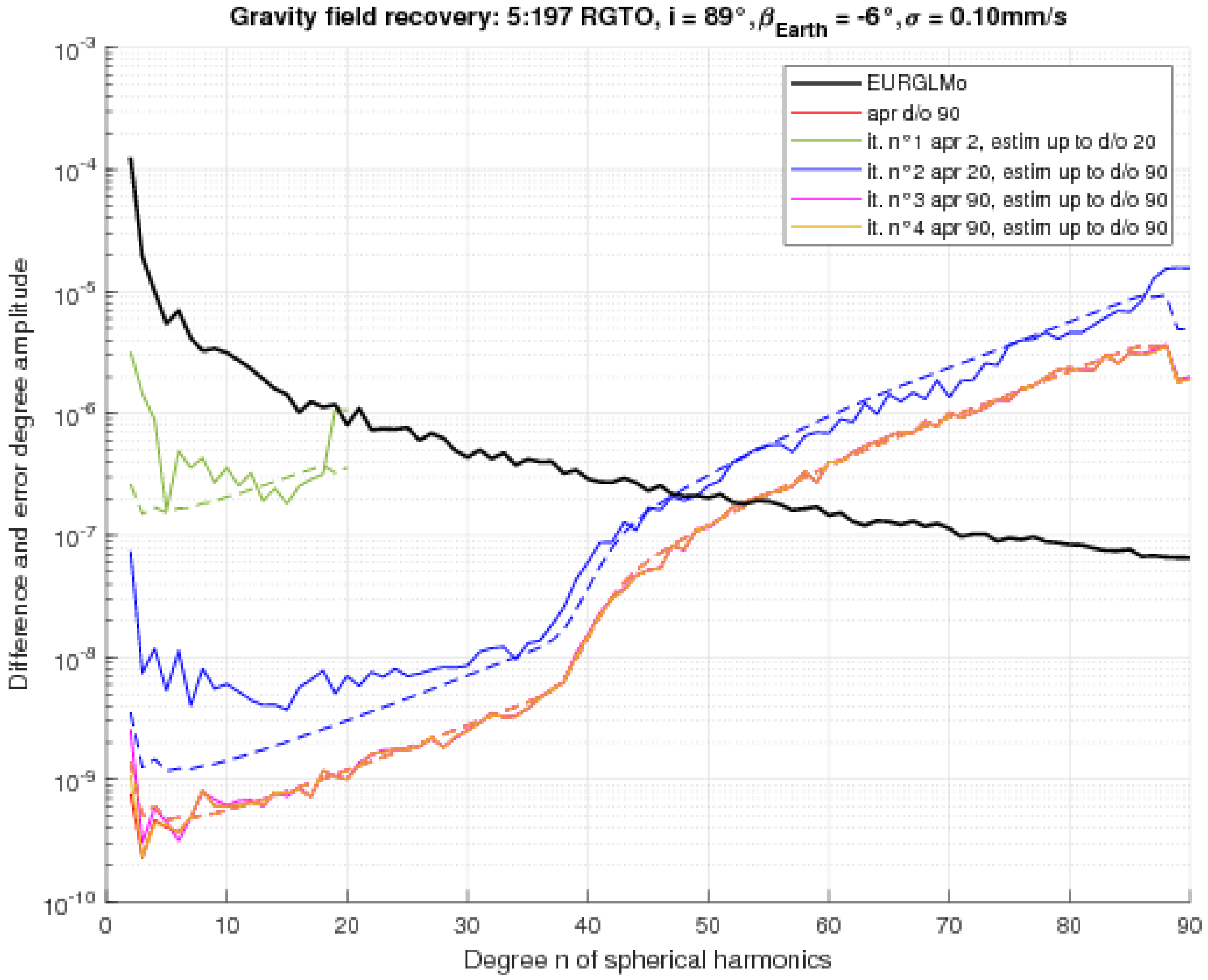
Using a degree-2 a priori gravity field: making use of pulses

- 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

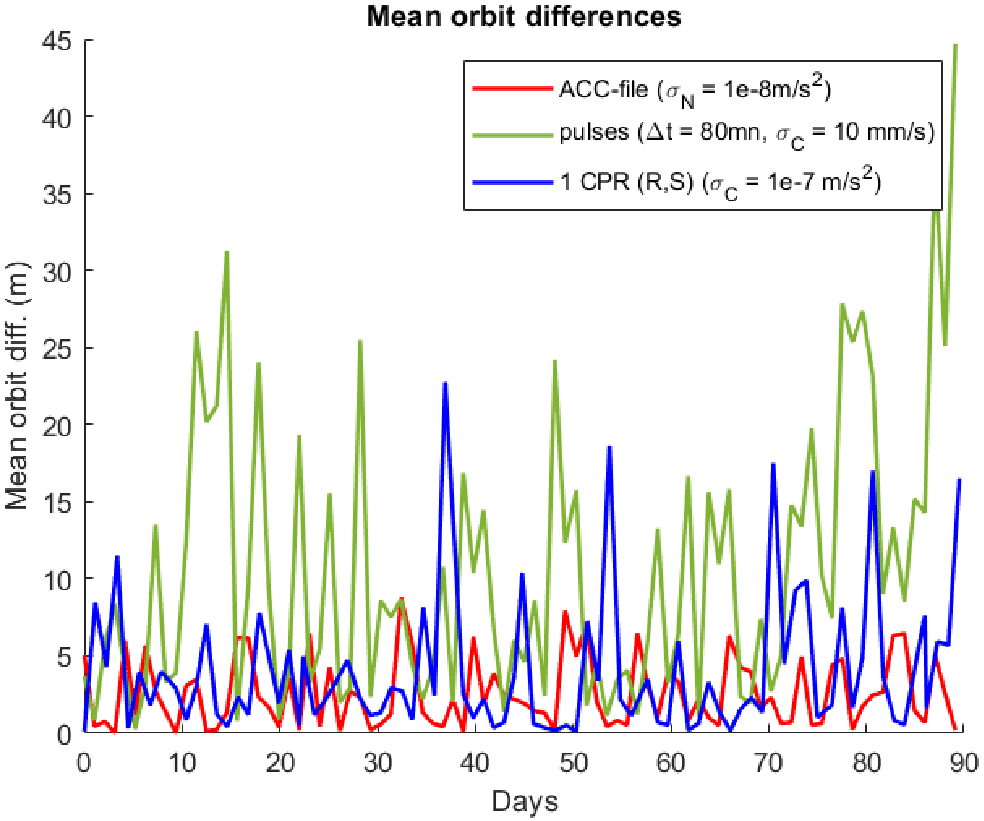
- Starting from the truth, truncated d/o 2
- Co-estimation of the low-degree gravity field coefficients with the orbit parameters in the first iteration
- Free solution
- No additional parameters needed

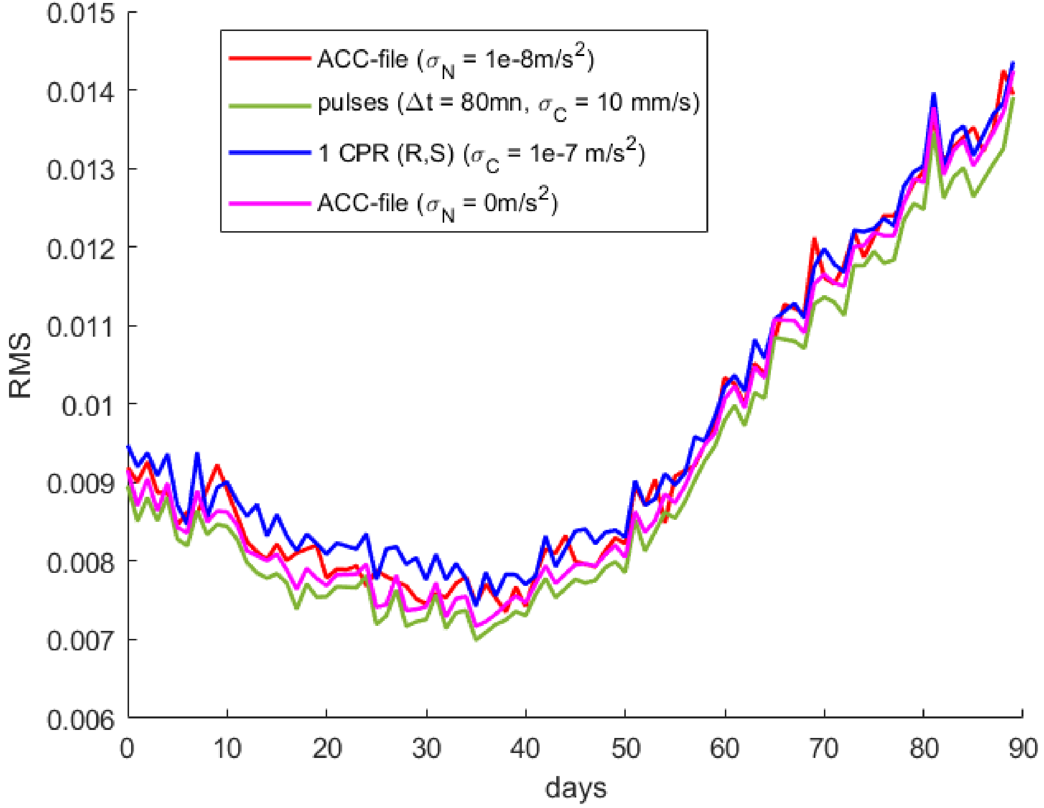


NGA mitigation strategies around Callisto: orbit fit

- 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

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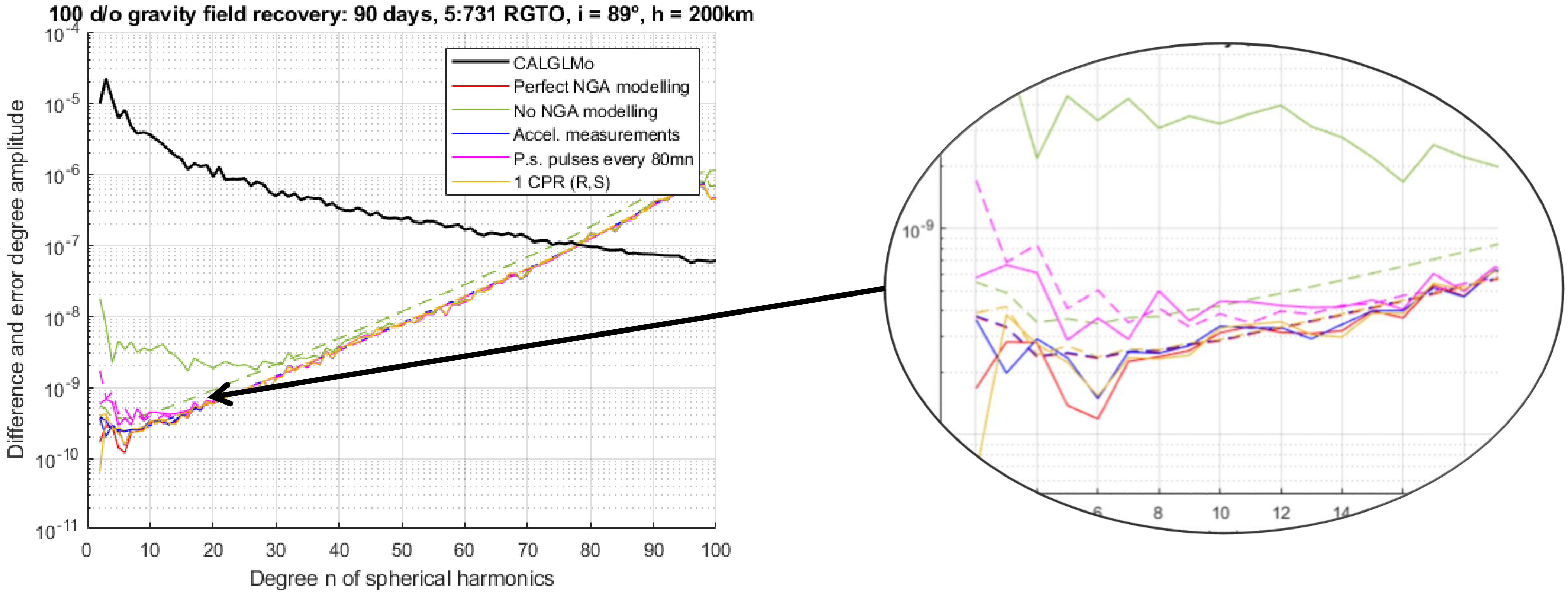

Summary & Outlook

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!