Recoverability of Callisto gravity field influenced by orbiter mission characteristics

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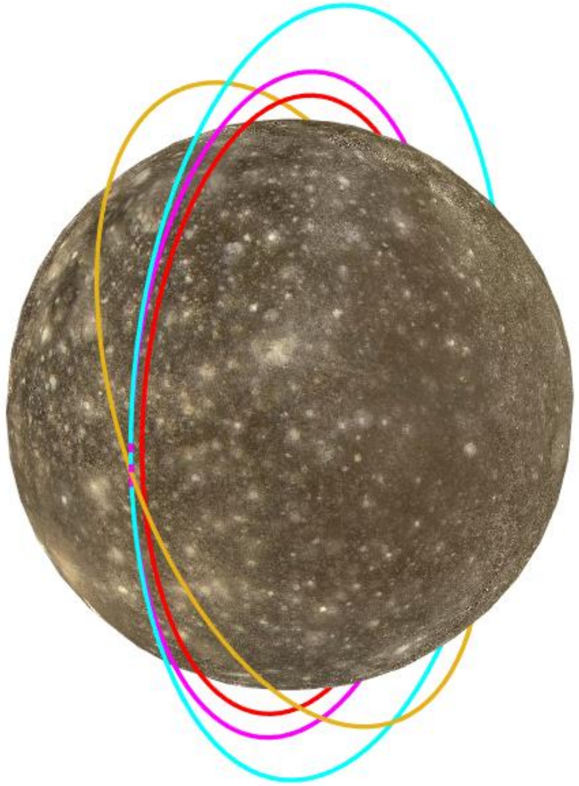
Introduction and Background

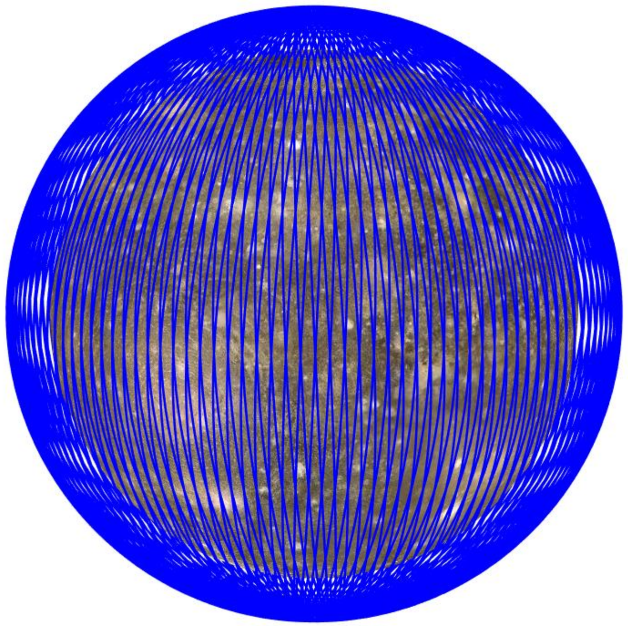
- Gan De is a Chinese exploration mission currently under study by the National Space Science Center (NSSC), Chinese Academy of Science (CAS). The mission would fly to Jupiter in the 2030's. An orbiter would be injected into a Low Callisto Orbit to perform an extensive characterization of its surface and interior, investigate its degree of differentiation and search for the possible existence of an internal ocean.

- Potential orbits are under study:
  - After an extended tour of the Jupiter system, a first polar elliptic orbit is foreseen for capture around Callisto. Then two polar circular orbits could be used for science investigation. A first one for at least 6 months, and a second one with lower altitude, with the possibility of regular manoeuvres to counteract orbit decay.
  - Sun synchronous orbits (SSO) are also a possibility. The angle between Sun and orbital plane would be constant, but with an important polar gap and highly dependent on the gravity field knowledge at low altitude.



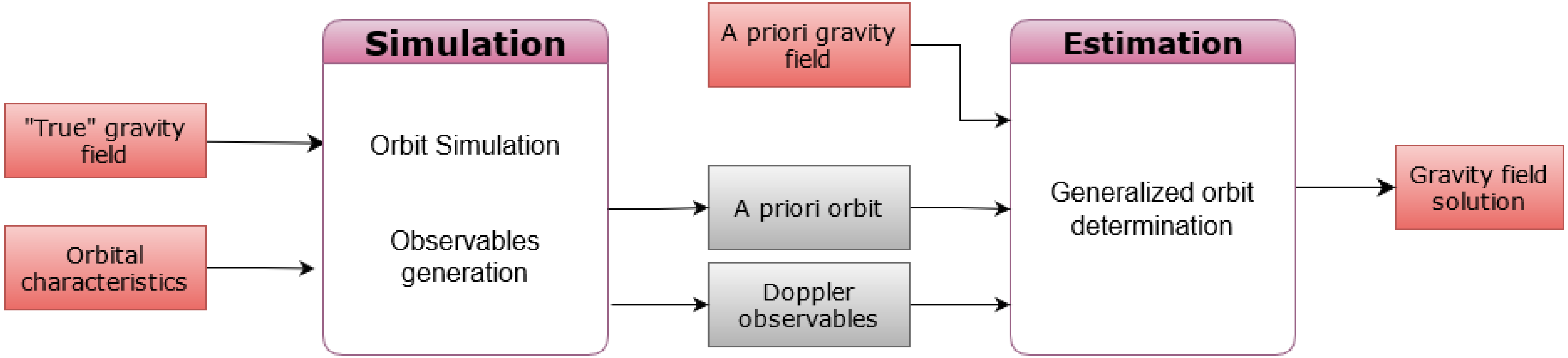
- Using simulated radio tracking data from the orbiter, we analysed the recoverability of Callisto gravity field, based on several orbit configurations.

Repetitive Ground Track Orbits



- In this study, we made use of Repetitive Ground Track Orbits (RGTO)
- The ground tracks of a m:R RGTO repeat after m Callisto days (16.67 days), and within this period, the probe would have completed R orbit revolutions around Callisto.
- Repetitive ground tracks are beneficial for the observation of time varying phenomena on the ground surface, as repeated observations of a given point of the surface are ensured.
- We can define RGTO with ground tracks which won’t repeat within the duration of the mission. For m = 6, the repetition cycle is 100 days, thus for 90 days, the ground tracks will not overlap.
- With these reference orbits, we were also able to take into account regular manoeuvres to counteract the natural decay of the probe when needed.

Simulation study flowchart



- Orbit propagations in a full force model, as well as the whole gravity field recovery process were done using a development version of the Bernese GNSS Software.

Force model and synthetic gravity field

Force model:

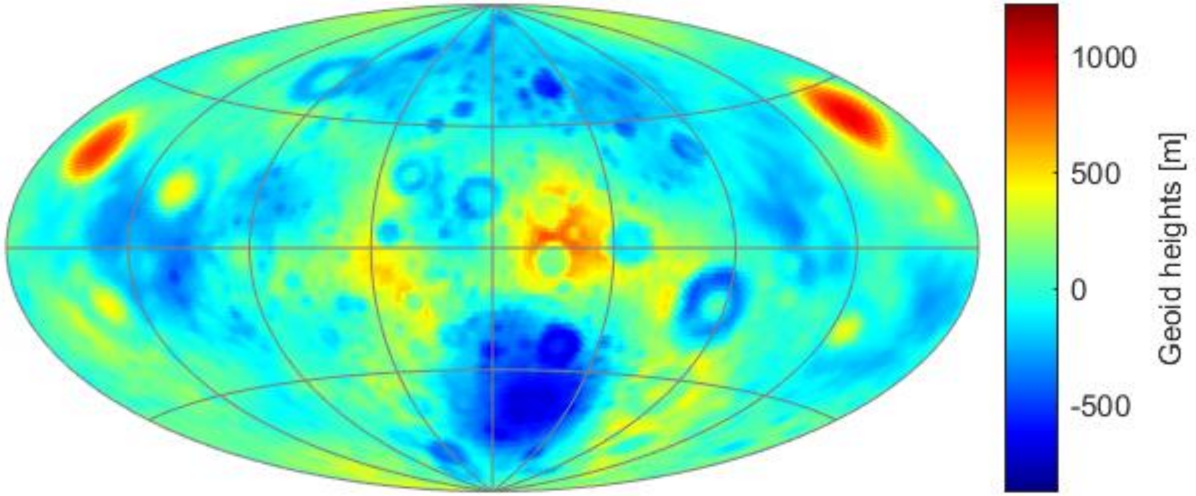
- **Callisto:**
  - Synthetic gravity field
  - Tides (k_2=0.3)
- **Jupiter:**
  - Point mass
  - Zonal coefficient (J2 to J6)
- **Other 3rd body:**
  - Other Galilean moons
  - Sun
  - Other planets
- **Non conservative forces** (not considered yet):
  - Direct Solar radiation pressure
  - Planetary radiation pressure

Synthetic gravity field:

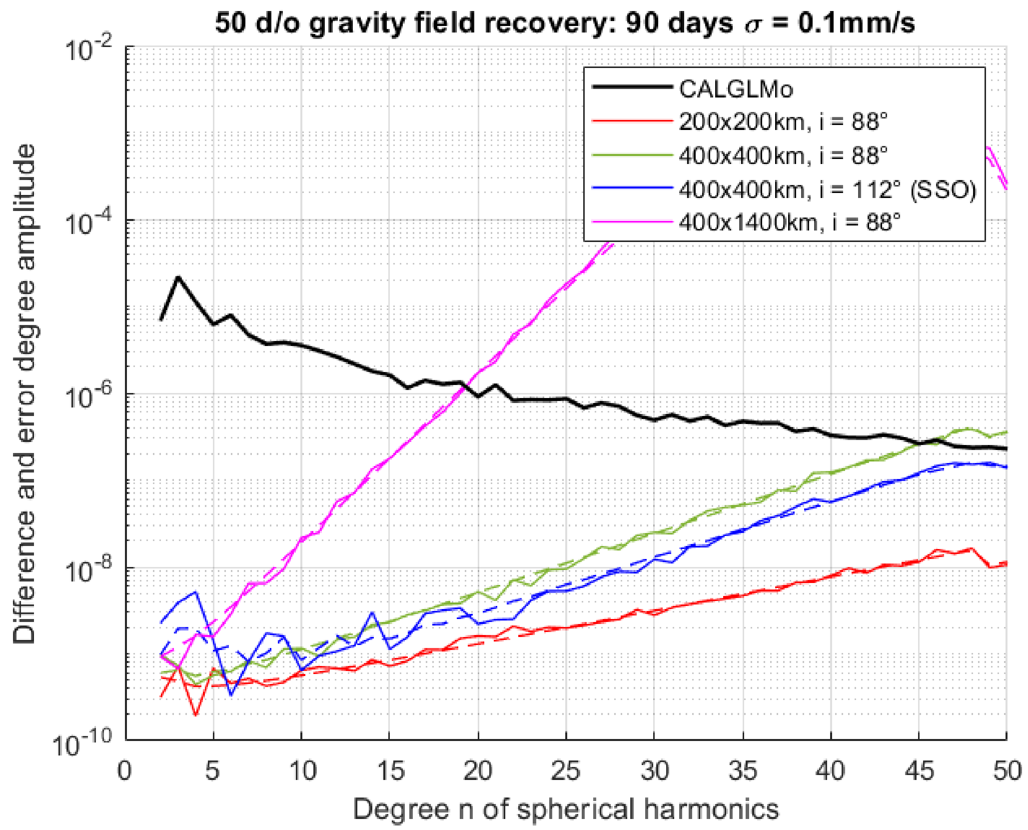
$$V(r,\lambda,\phi) = \frac{GM}{r}\sum_{n=2}^{n_{max}}\sum_{m=0}^{n}\left(\frac{R_e}{r}\right)^n P_{nm}(sin\phi)(C_{nm}cosm\lambda + S_{nm}sinm\lambda)$$

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

Callisto gravity field: CALGLMo (d/o 100)



Gravity field and k2 Love number recovery influenced by altitude and inclination



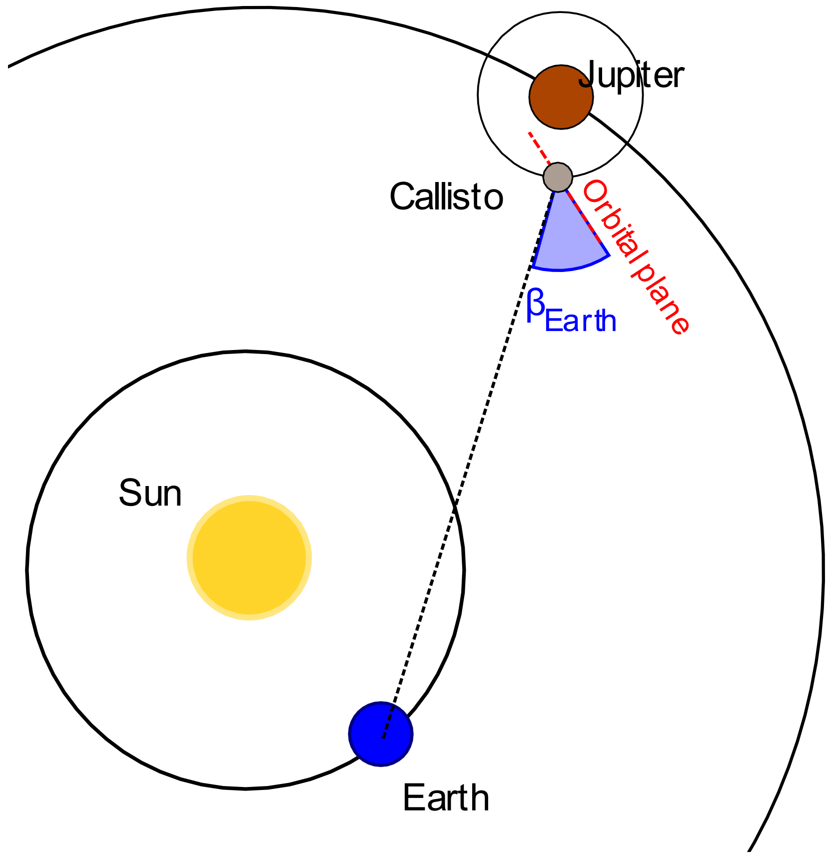
Difference (solid) and error(dashed) degree amplitudes ($M_n = \sqrt{\frac{\sum_{m=2}^{n}(\Delta\bar{C}_{nm}^2+\Delta\bar{S}_{nm}^2)}{2n+1}}$). 22° polar gap omitted for the Sun Synchronous Orbit (SSO) according to van Gelderen and Koop rule of thumb

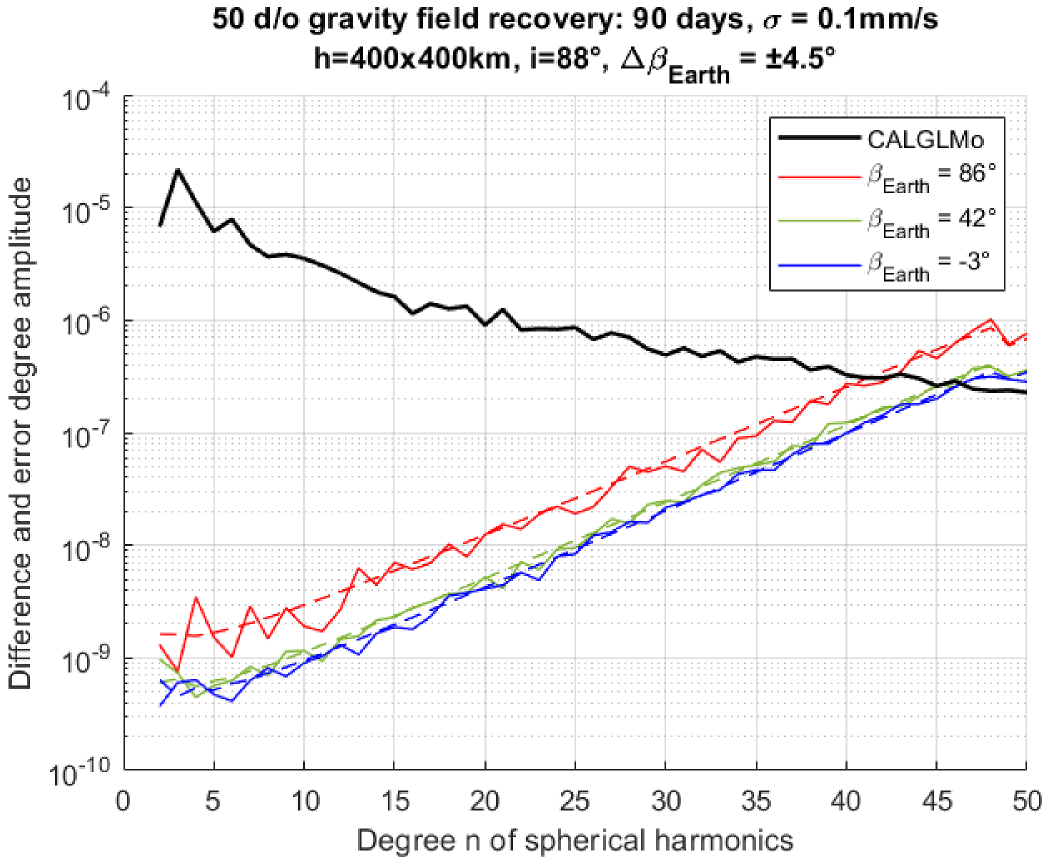
- Starting date : 01-05-2031
- β_{Earth} = 45°
- 2-way X-band Doppler noise: σ (τ=60s) = 0.1mm/s
- Freely estimated gravity field coefficients in one iteration using true gravity field as a priori
- [Not presented here] Starting from a low-degree gravity field, pseudo-stochastic pulses are considered, and within a few iterations, the gravity field can be recovered to the same level of accuracy.

Altitude	Inc.	k_2 formal error
200x200km	88°	2.1×10^{-6}
400x400km	88°	2.2×10^{-6}
400x400km	112°	4.9×10^{-6}
400x1400km	88°	2.2×10^{-6}

The influence of the Beta Earth angle

- β_{Earth} : Angle between the orbital plane of the probe and the Earth



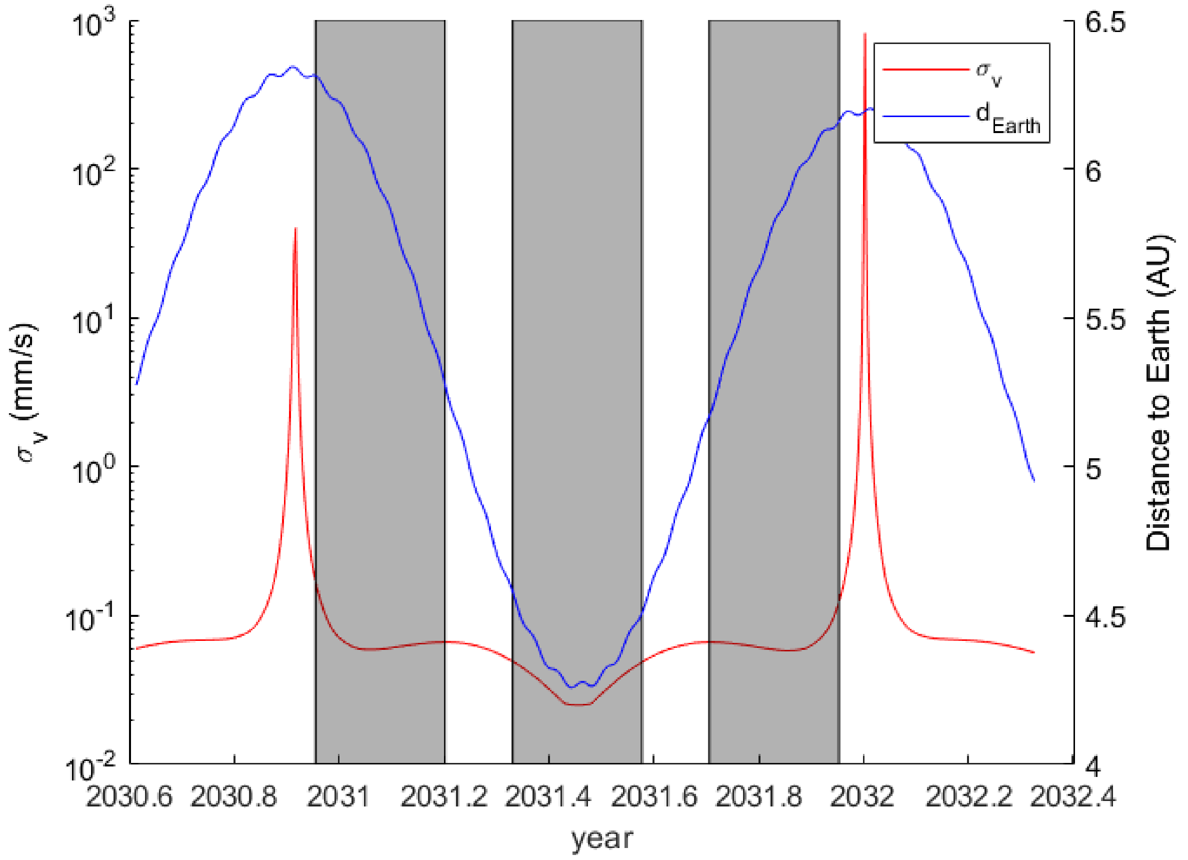


- Despite increasing occultations of the probe by Callisto, an edge-on orbit (β_{Earth}=0°) is more beneficial for gravity field recovery

A detailed Doppler noise budget

Source	Noise (μm/s)
Interplanetary plasma	3,8 – 132
Troposphere	9,0 – 30
Transponder	5,4
Ground station	4,8
Numerical noise	2,4 – 4,1

Noise model based on Iess et al (2012): Improved Doppler tracking system for deep space navigation.. Interplanetary plasma is the main contributor, and is a function of the Sun-Earth-Probe angle (SEP).

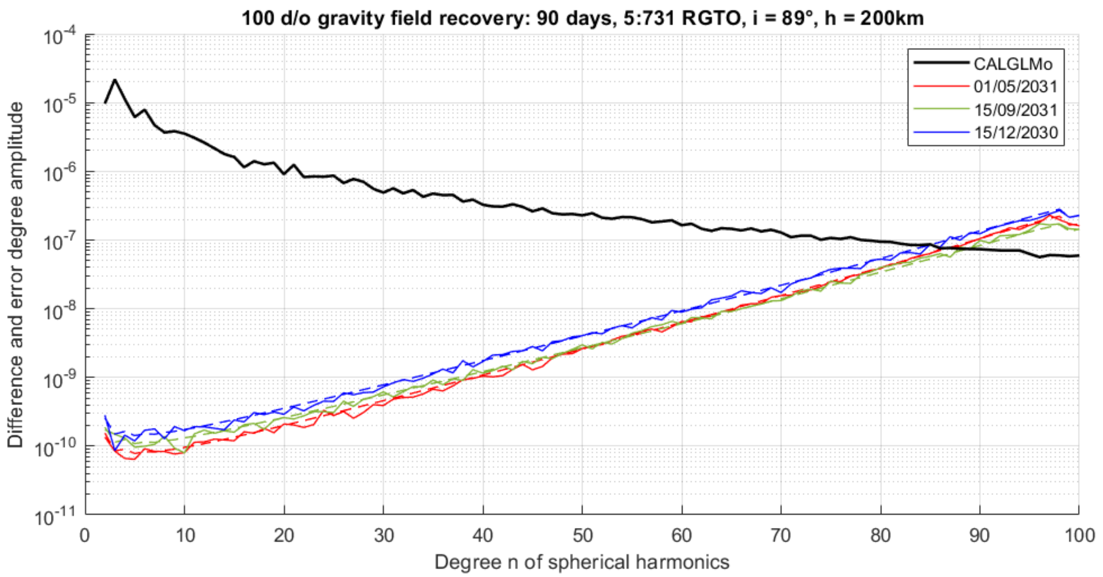


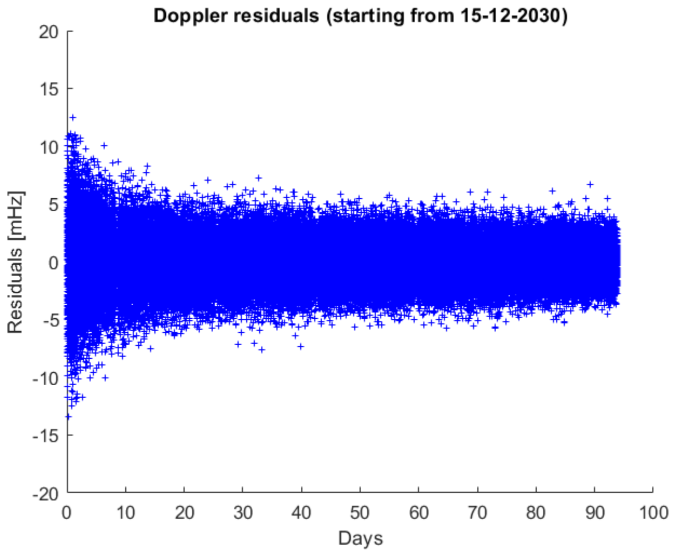
We selected 3 different starting dates:

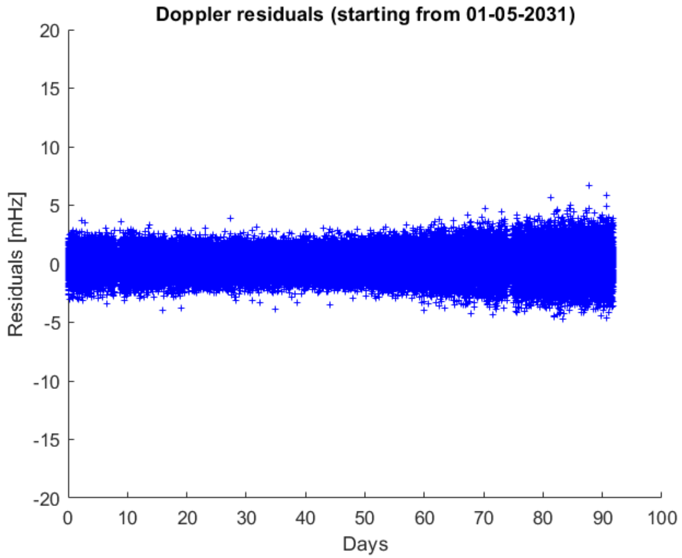
- 2 worst cases SEP $\in [12°; 90°]$
  - 15/12/2030
  - 15/09/2031
- 1 best case SEP $\in [130°; 180°]$
  - 01/05/2031

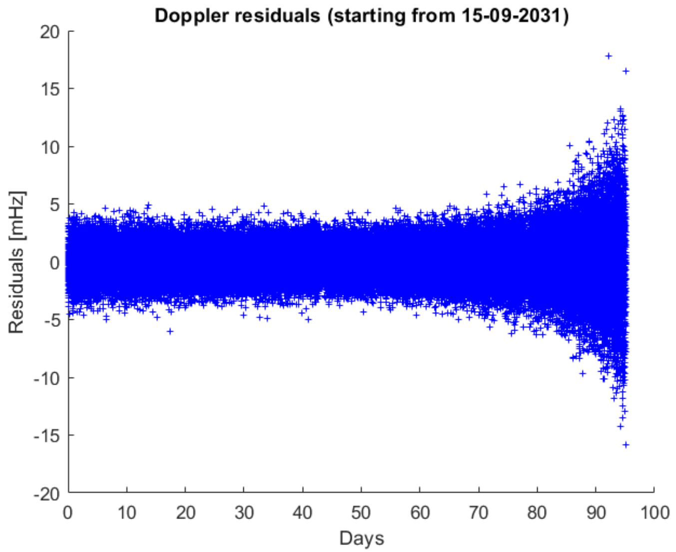
3 different Sun-Earth-Jupiter configurations

- For these tests, regular manoeuvres approx. every Callisto day (≃6 m/s) were taken into account to counteract the natural decay of the probe.
- The influence of a larger Doppler noise is visible:
  - In the Doppler residuals
  - At the lower degrees of the gravity field solution
- The differences in the higher degrees might be caused by a different ground coverage



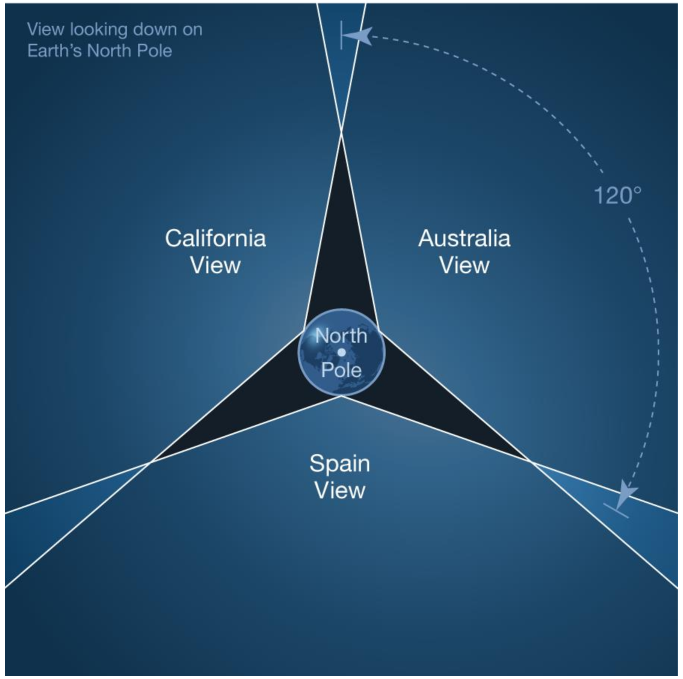




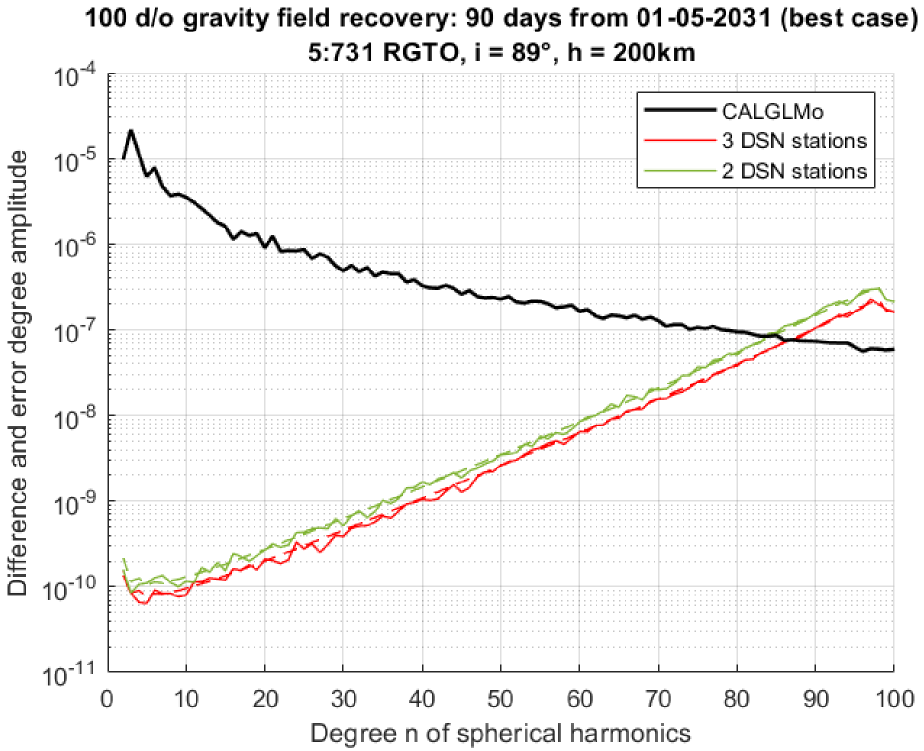


Limited availability of Ground Stations

Location od Deep Space Network (DSN) stations



- Complete availability of the 3 DSN Stations was assumed in the previous results
- The use of only 2 DSN stations slightly deteriorate the gravity field solution (no impact of the choice of the remaining stations)



Conclusions / Outlook

- A highly eccentric orbit over a time span of 90 days can already improve the knowledge of Callisto's gravity field (up to d/o 19 for a 400x1400km orbit). However, as the eccentricity increases significantly with time, such an orbit is not stable for more than 3 months.
- Sun synchronous orbits suffer from a large polar gap, the recovery of zonal coefficient is then largely impacted, just as Love number k2 recoverability.
- For all non-Sun synchronous orbits, β_{Sun} does not vary much (max. 1.2°/month). A SSO for maximum illumination might then not be compulsory.
- Low altitude polar orbits are the best suited for gravity field recovery. At 400km altitude, one can expect to recover the gravity field up to d/o 45 after 90 days.
- Lower orbits are even more beneficial, with a gravity field which can be estimated to a d/o of 80 after 90 days. But will require manoeuvres to increase the orbit lifetime. Repetitive Ground Track Orbits are well suited to efficiently plan station keeping manoeuvres.
- In the near future, we aim to investigate a more realistic observation scheduling.