# GRAIL Gravity Field Determination Using the Celestial Mechanics Approach – First Results

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# Celestial Mechanics Approach (CMA)

**Celestial Mechanics Approach:**
**Gravity field recovery is rigorously treated as an extended orbit determination problem, i.e., all available measurements contribute to one and the same set of parameters**

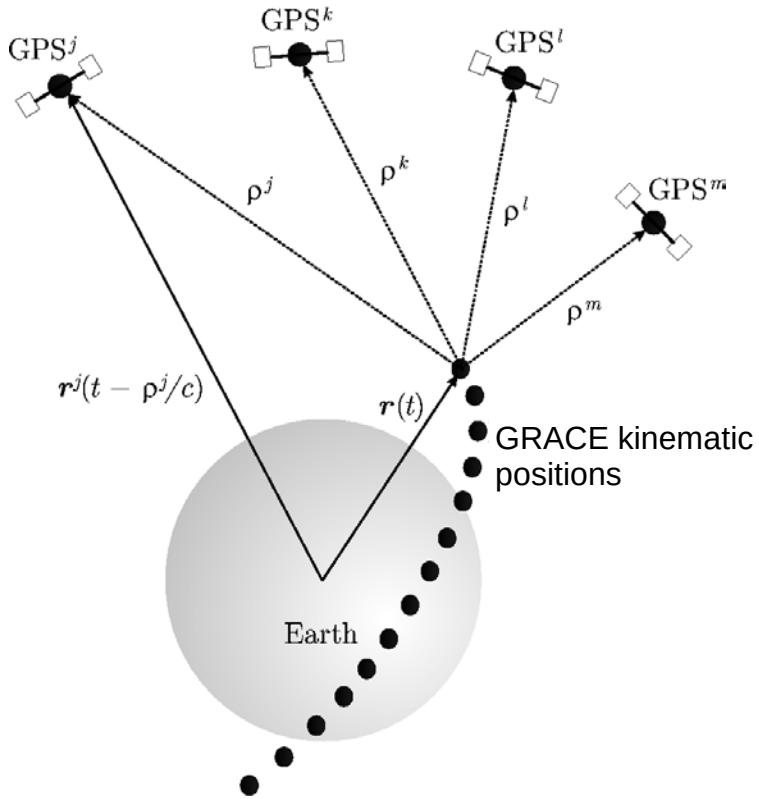
**The approach is flexible with respect to**

- **Parameter set-up**
- **Normal equation modifications**

**→ Generation of ensembles of solutions**

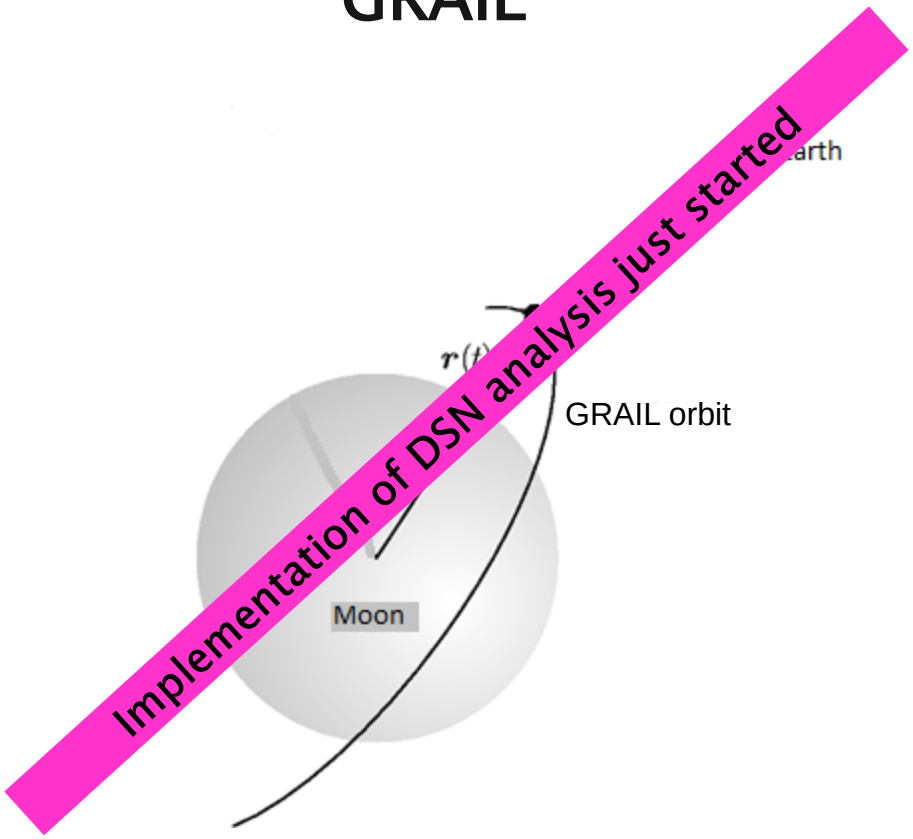
# Celestial Mechanics Approach (CMA)

## GRACE




The GRACE satellites may be geo-located with cm-accuracy at any time, e.g., by a kinematic precise point positioning.

## GRAIL

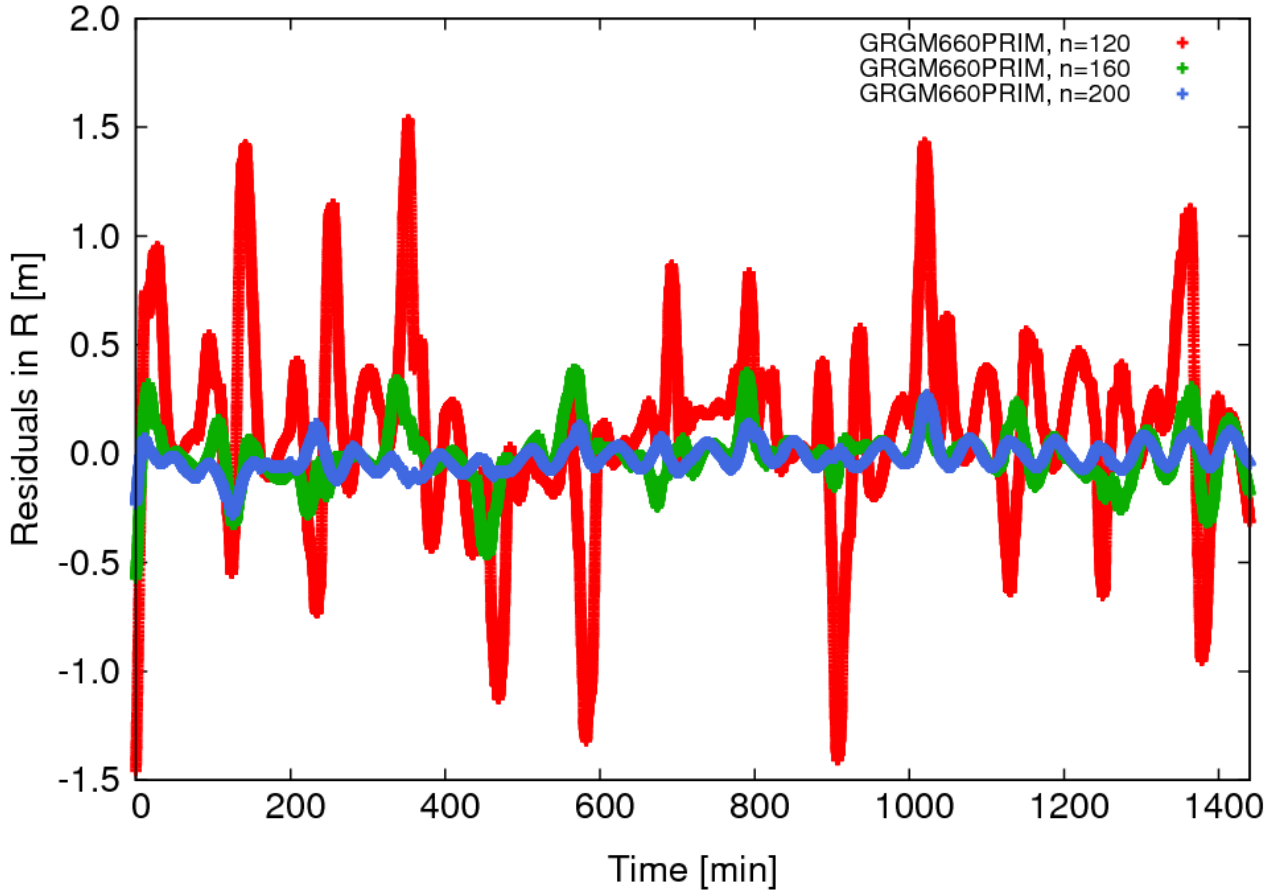



The orbits of the GRAIL satellites may be constrained by Doppler measurements.

# CMA – Current Status

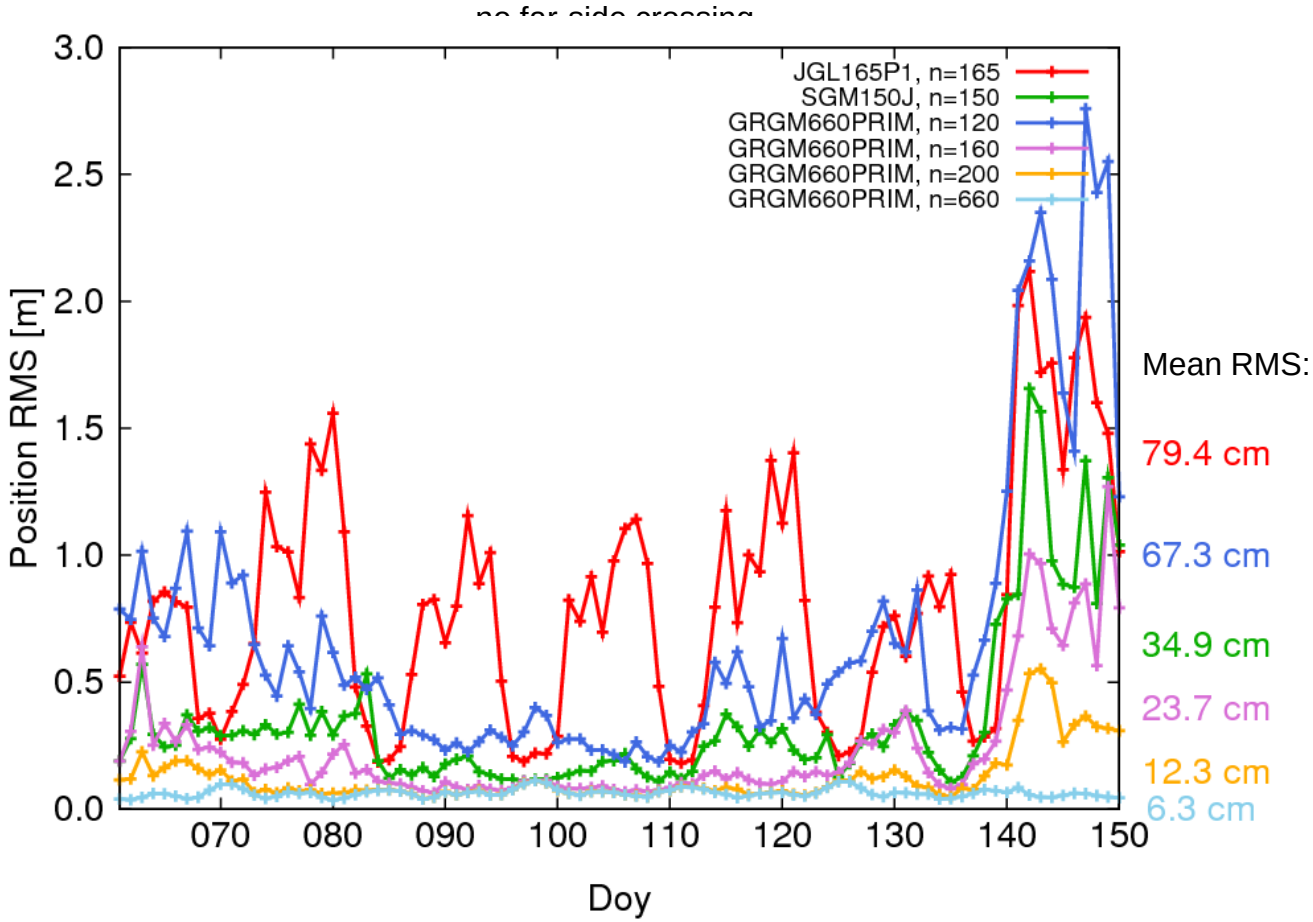
| | |
|---|---|
| Static field | • SH expansion up to d/o 120, 160, 200 |
| Data | • GNI1B positions, DOYs 062–150, (243–333)<br>• KBR1B range-rates, " , " |
| Orbits | • Initial conditions every 24h<br>• Pulses every 40 min |
| K-band | • Time bias every 24h |
| A priori | • JGL165P1, SGM150J, GRGM660PRIM |
| RPR | • No parametric model implemented yet |
| Background | • Reference frame trafo (DE-405)<br>• 3rd body-perturbations<br>• No tide model implemented yet |
| Weighting | • Position : K-Band = 1 : $10^8$ |

# GNI1B Pseudo-Observation Fits



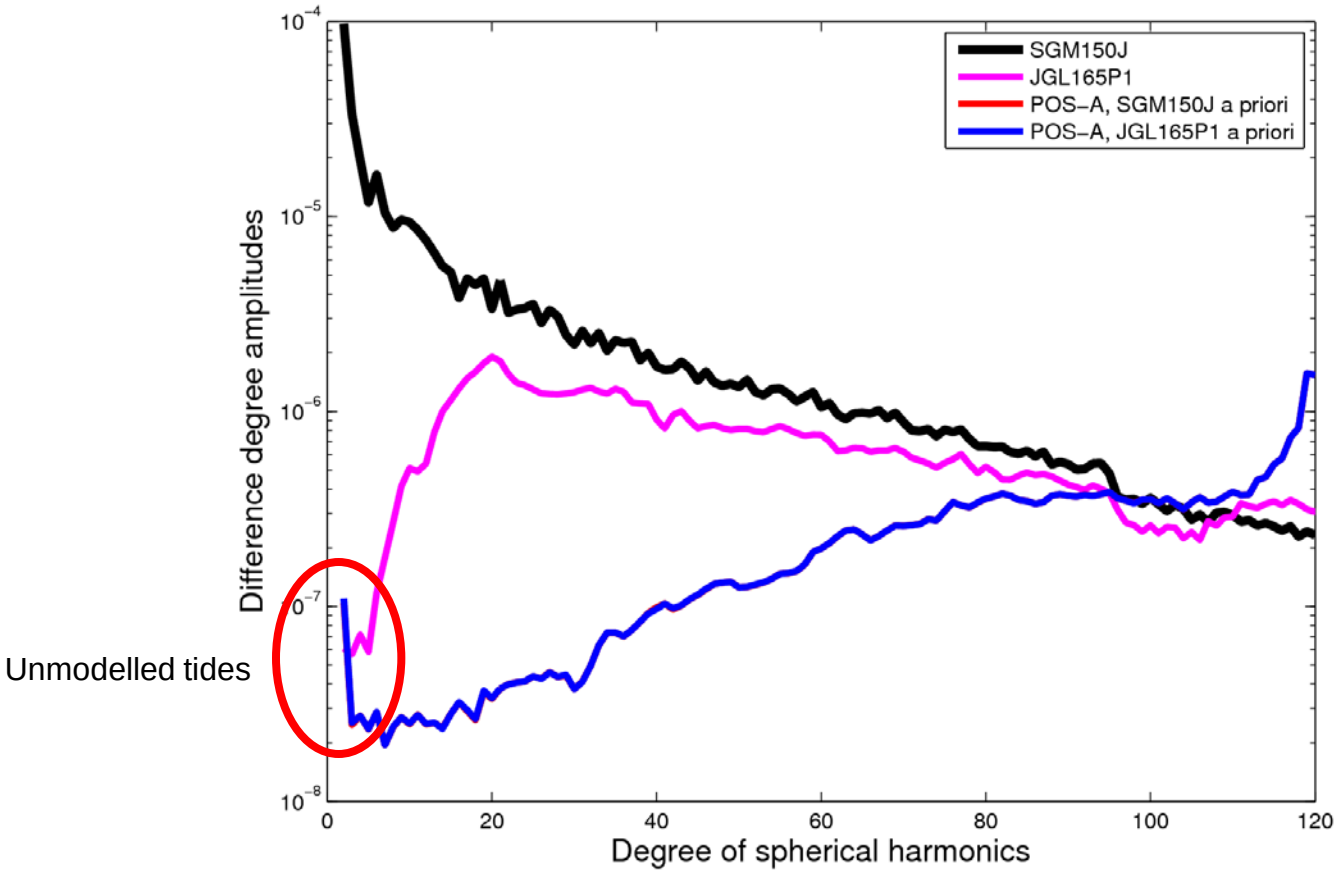

Radial position residuals for GRAIL-A from an orbit determination using position pseudo-observations. Larger residuals on the far-side are clearly visible for the “old” gravity field models JGL165P1 and SGM150J. Significantly improved representation when using the GRAIL gravity field models up to d/o 120, 160, 200 (no far-side effect).

# GNI1B Pseudo-Observation Fits



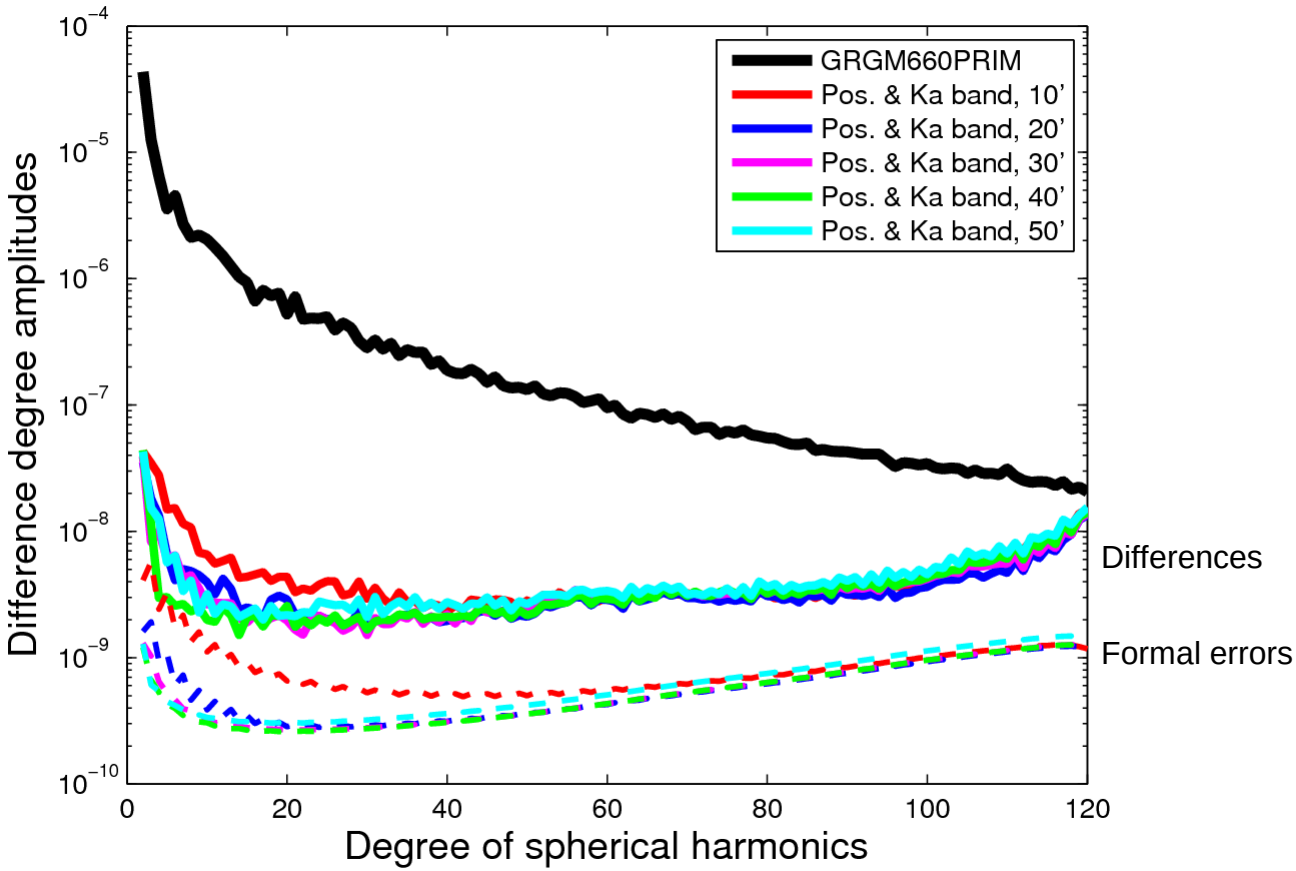

Daily RMS values for GRAIL-A from an orbit determination using position pseudo-observations. Slightly worse fits are still obtained for the beginning and end of the mission when using the GRGM660PRIM just to d/o 200.

# Position Solutions – Linearization Issues?



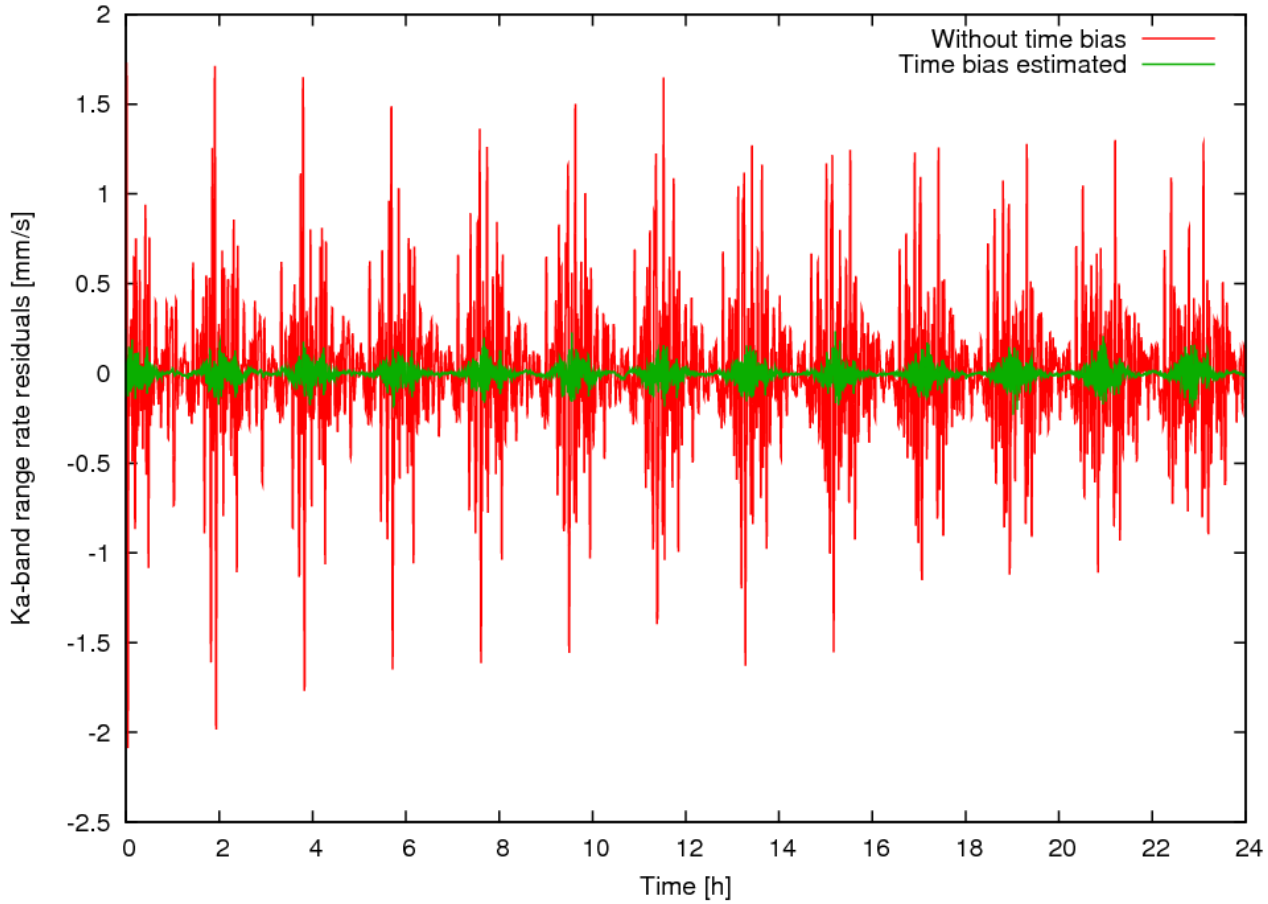

Differences between the JGL165P1 and the **SGM150J** a priori gravity field model are huge. Independently of the used a priori gravity model, the CMA solutions based on GRAIL-A position pseudo-observations agree equally well with SGM150J within one iteration.

# Combined Solutions – Impact of Pulses



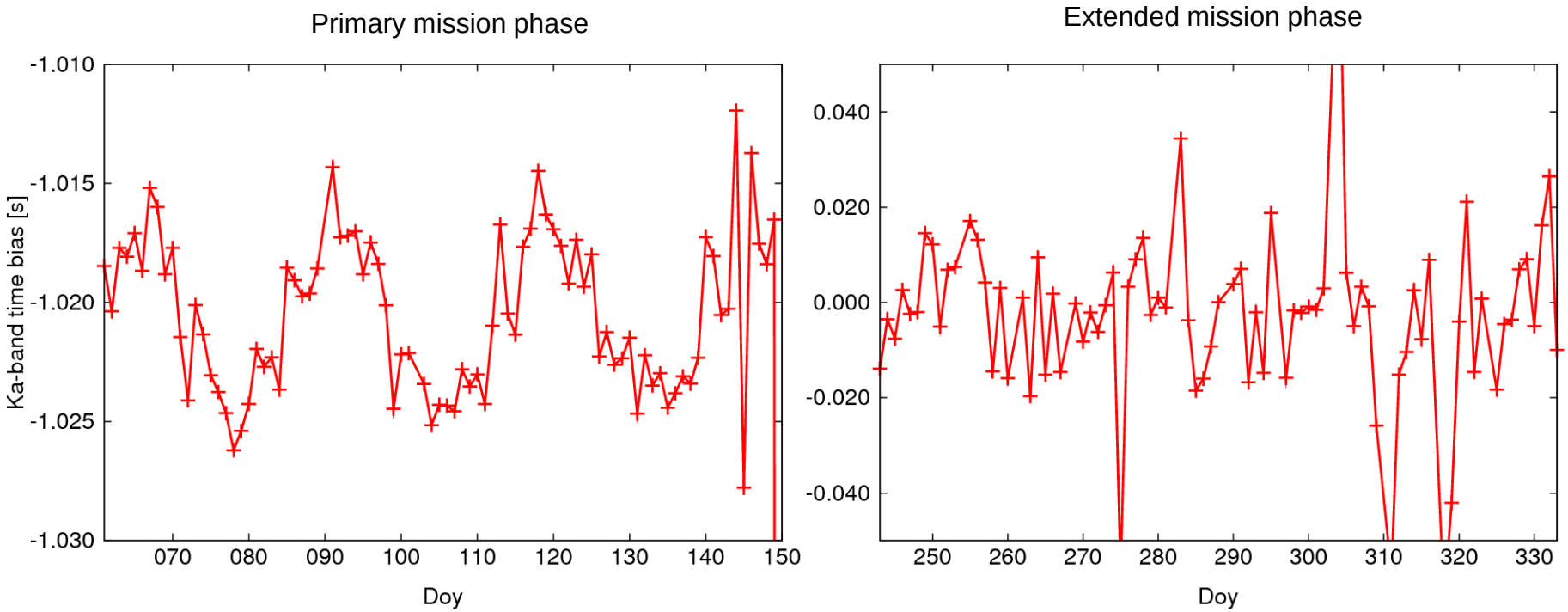

Pulses are set up to compensate for not yet explicitly modelled forces, e.g., radiation pressure. The "optimal" pulse spacing of 40 min for solutions up to d/o 120 follows from both the formal errors of the CMA solutions and the differences wrt **GRGM660PRIM**.

# KBR1B Range-Rate Observation Fits



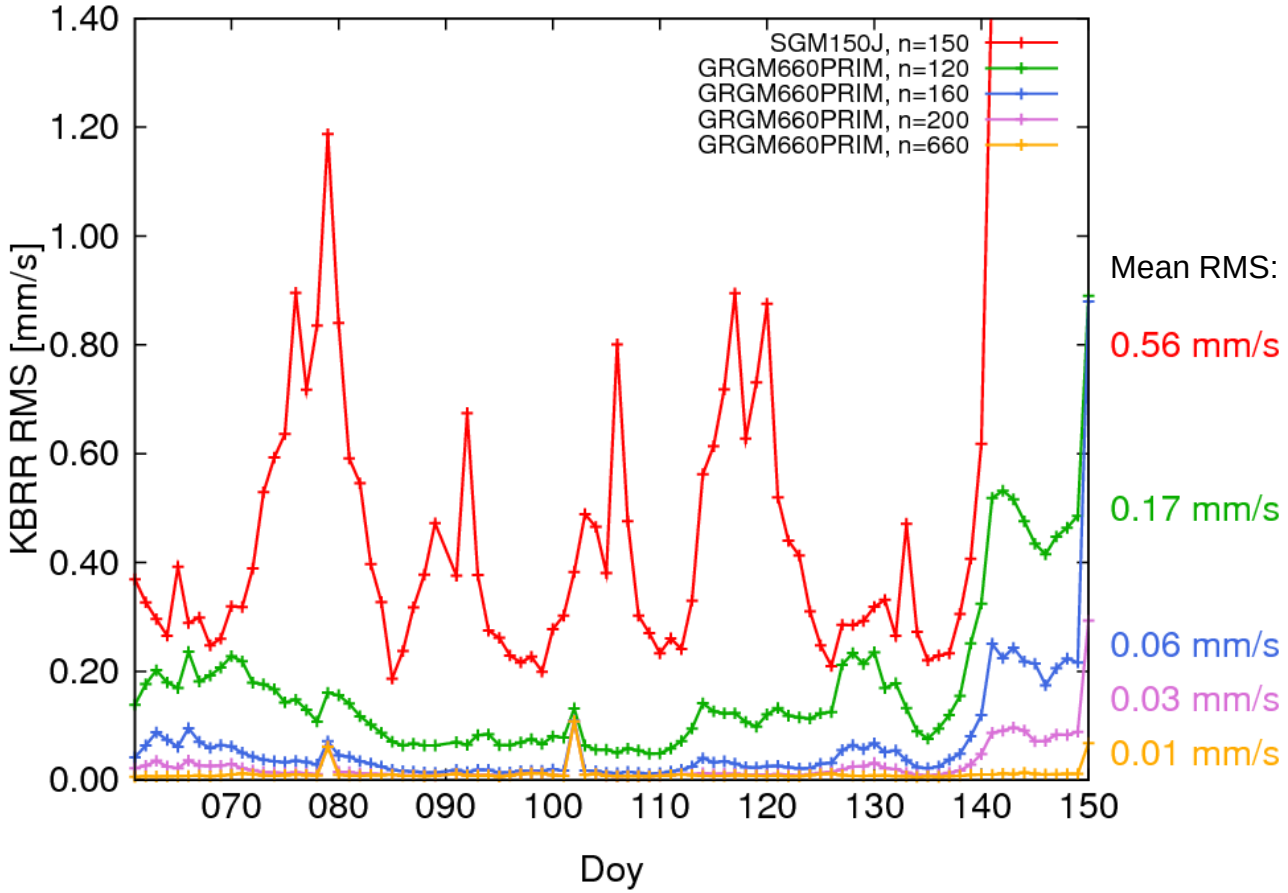

K-Band residuals when using the GRGM660PRIM gravity field model up to d/o 160. Significant reductions are achieved by estimating one K-Band time-tag offset per daily arc.

# KBR1B Time Biases



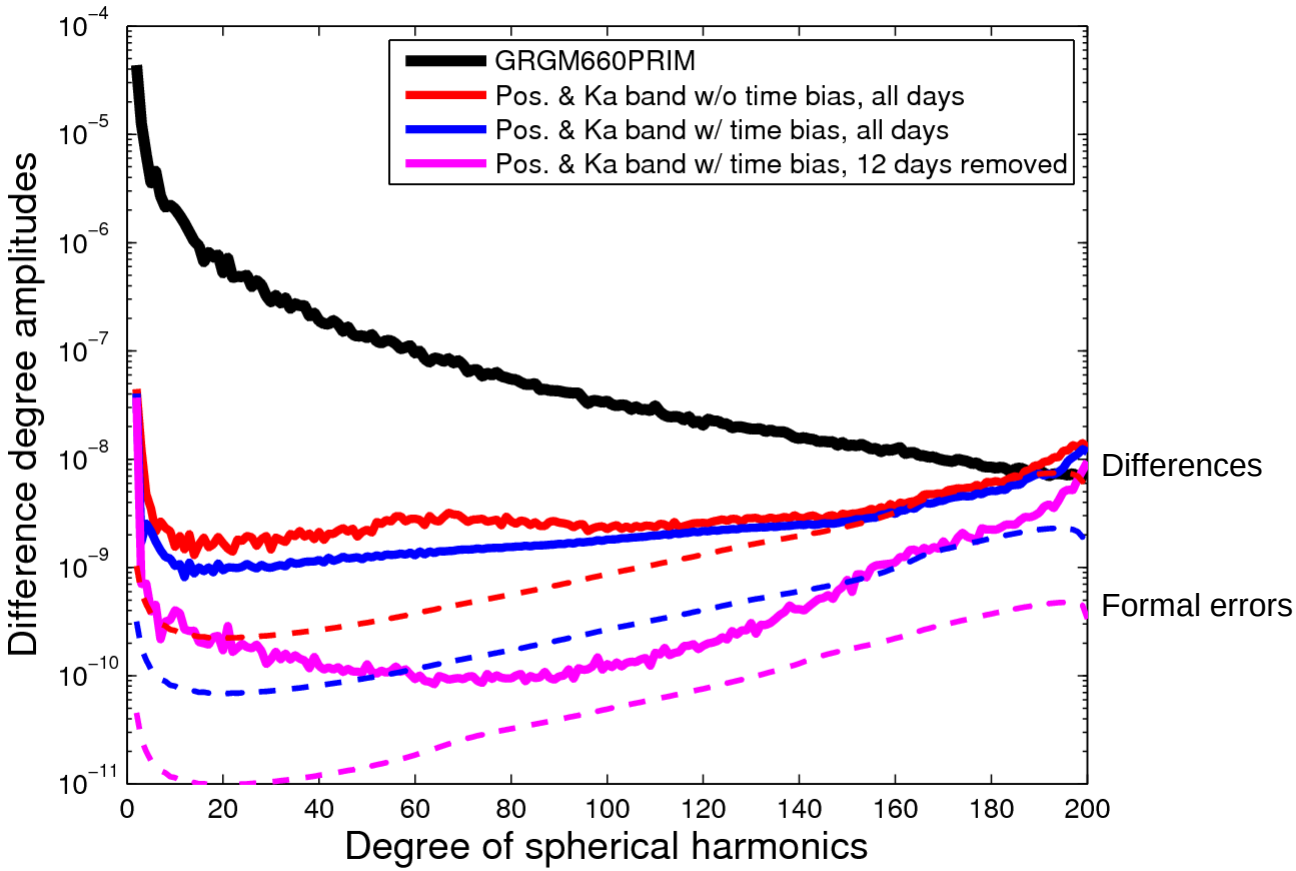

A significantly different behavior of the time biases is observed for the primary mission phase (-1.026 sec) and the extended mission phase (-0.002 sec).

# KBR1B Range-Rate Observation Fits



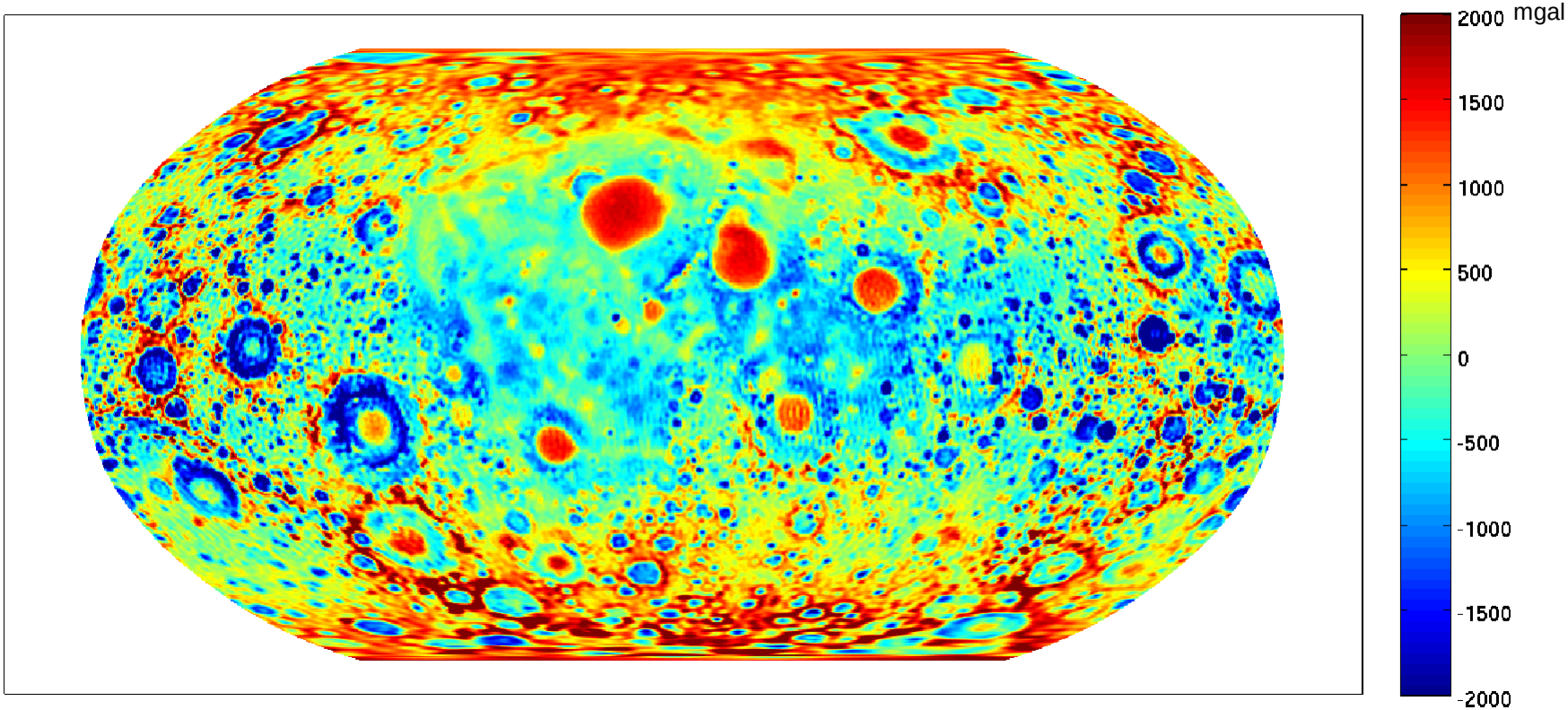

Daily K-Band RMS values from a combined orbit determination using position pseudo-observations and K-Band range-rate data with a weighting ratio of 1:$10^8$. Obviously there is still a long way to go to reach the K-Band residual level …

# First Combined Solutions up to d/o 200



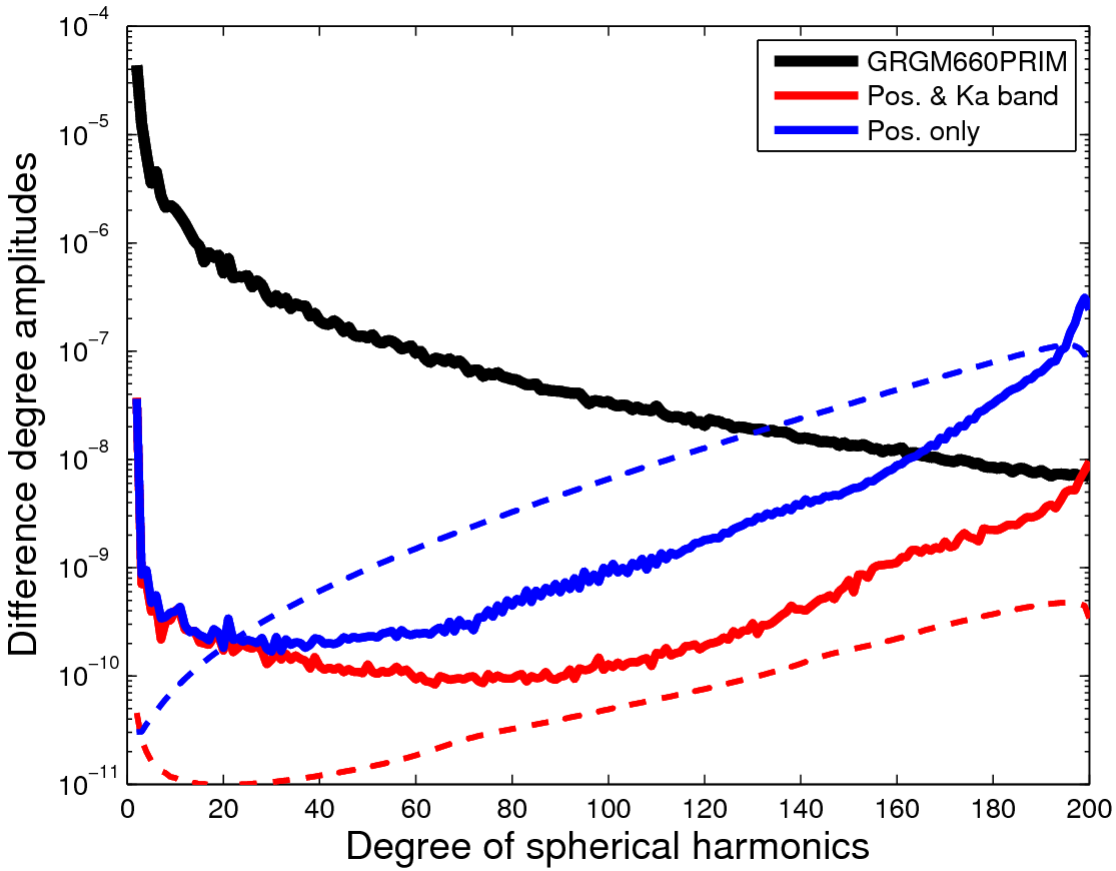

Co-estimation of K-Band time-tag offsets seems to be important when processing the data of the primary mission phase. Further improvements are achieved when skipping a few problematic days (12 days show larger residuals, needs to be further investigated).

# First Combined Solutions up to d/o 200




Gravity anomalies from the combined gravity field solutions up to $n_{max}$ = 160 and 200, resp. For the higher resolution solution some artifacts (stripes) are visible ...

# First Combined Solutions up to d/o 200




The solution is currently dominated up to d/o 30 by the GNI1B position pseudo-observations and represents thus not yet a fully independent recovery. According to the formal errors this should change when further exploiting the KBR1B data, but the implementation of DSN data analysis is a **must** to obtain fully independent results also for the long wavelengths.

# Conclusions

- Availability of GNI1B data allowed for an "easy start" to extend the CMA to GRAIL gravity field recovery
- Empirical orbit parameters allowed to generate first "Bernese" lunar gravity field solutions without using sophisticated background models
  - Efforts are needed to improve the background models
- Basic understanding of the observables is achieved
  - Large effort is still needed to "see" the KBR residual level
- Low degrees are biased towards GRGM660PRIM due to the use of GNI1B data as pseudo-observation
  - DSN data analysis capability is a must (efforts have started)

=> Still a long way to go, but the prospect to provide an independent solution might justify the effort