Advances in MLA and BELA altimetry crossover analyses for Mercury geodesy

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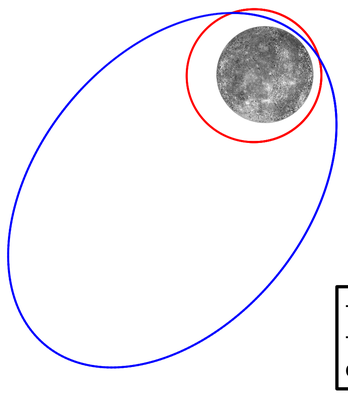
MESSENGER and BepiColombo mission

Our work focuses on **Mercury's geodetic parameters**, which have implications for our understanding of Mercury's interior structure (Goossens et al., 2022), and on the role of **on-board laser altimeters** in their determination.

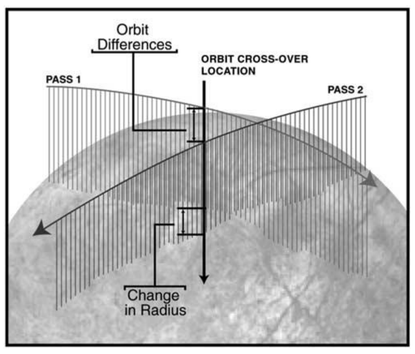


MESSENGER (2011 – 2015):
- highly eccentric orbit and high latitude periapsis
- Mercury Laser Altimeter (MLA)

Mercury Planetary Orbiter (MPO) (2026 - ?) component of BepiColombo:
- Lower altitude apoapsis and lower latitude periapsis
- BepiColombo Laser Altimeter (BELA)

→ We use crossovers to assess the quality of OD solutions, in view of a future re-analysis
→ We investigate the added value of BELA in the framework of crossovers-based solutions of orbit and geodetic parameters.

Laser altimetry crossover analysis



Neumann et al., 2001

Crossover analysis is performed within the Pyxover software package (Bertone et al. 2020).

We solve for **kinematic corrections** of each ground tracks in Along-track (A), Cross-track (C) and Radial (R) direction, as well as for **geodetic parameters** in a least-square improvement of crossovers generated by (past and future) probes in orbit around Mercury.

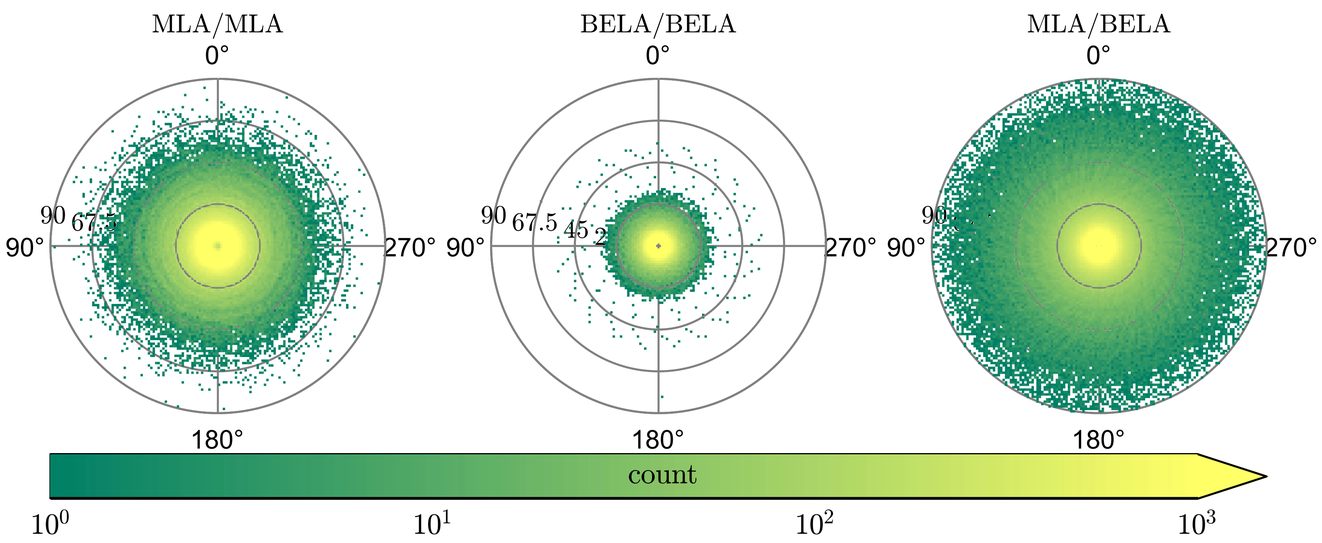
We estimate orientation parameters (right ascension RA and declination DEC of the North pole, rotation rate PM, libration amplitudes L) and the Love number h_2.

Combined MLA/BELA crossover analysis

MLA observations are collected in the northern hemisphere (mainly above latitude 60°-70°), thus limiting Mercury's ground surface coverage.

BELA has a more uniform altimetry mapping of Mercury's surface, but the polar orbiter limits the crossovers at even higher latitude, yet in both hemisphere.

We also search for crossovers between the ground tracks of two altimeters, which results in a higher density of lower latitude crossovers in the Northern hemisphere.

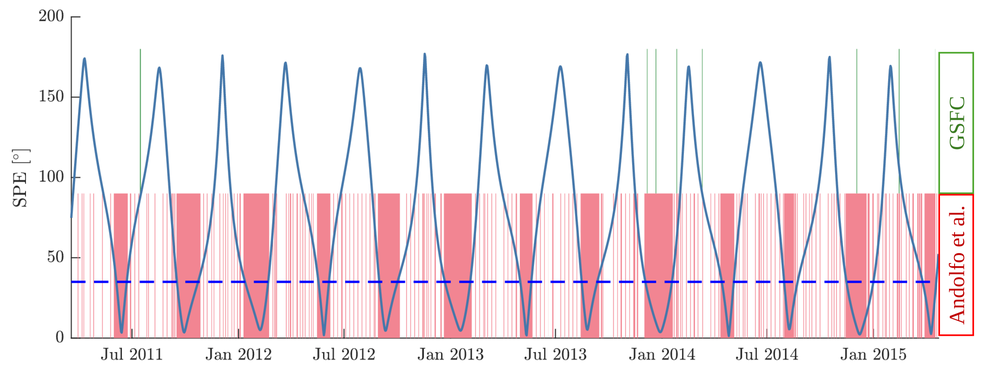


Distribution of the different crossover datasets in the Northern hemisphere (BELA/BELA crossover distribution is similar in the Northern and the Southern hemisphere)

MPO OD is expected to result in an orbit quality significantly better than MESSENGER's (Iess et al., 2021).
→ BELA tracks could serve as reference to improve MLA georeferencing in the combined analysis.

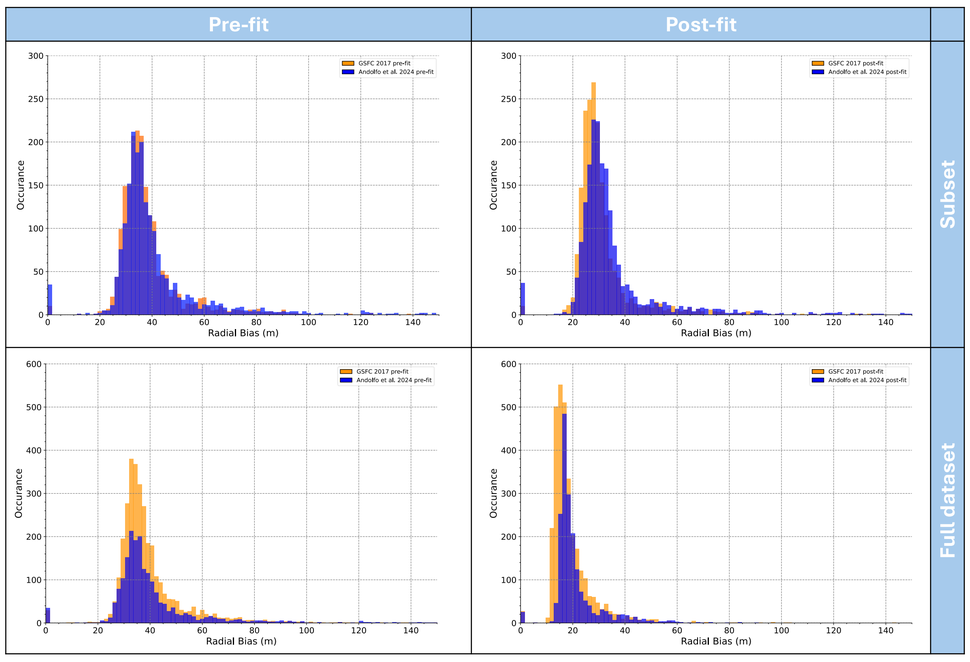
Update on MLA crossover analysis: orbit quality

- Recent orbit solutions (Andolfo et al., 2024) include an advanced modeling of non-gravitational forces (NGF).
- However, the orbit coverage is sparser (1907 tracks) than for NASA GSFC's latest orbit solution from 2017 (3222 tracks), notably at low SPE < 35°, where Doppler noise is large.



Orbit data gaps and Sun-Probe-Earth (SPE) angle

- The orbits of Andolfo et al. (2024) agree better with altimetry in terms of crossover discrepancies in the time span common to both orbit datasets.
- The quality of the 1902 tracks within this subset, in terms of radial biases (i.e., crossover discrepancies RMS), is nevertheless not largely improved.
- Large outliers are more frequent than in GSFC orbit dataset.

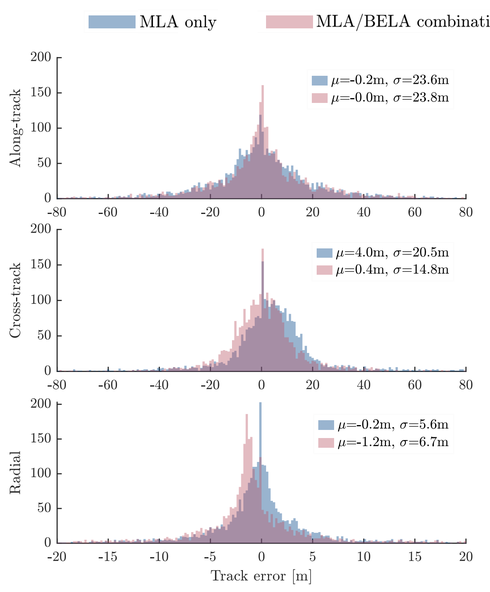


Histograms of MLA tracks radial biases

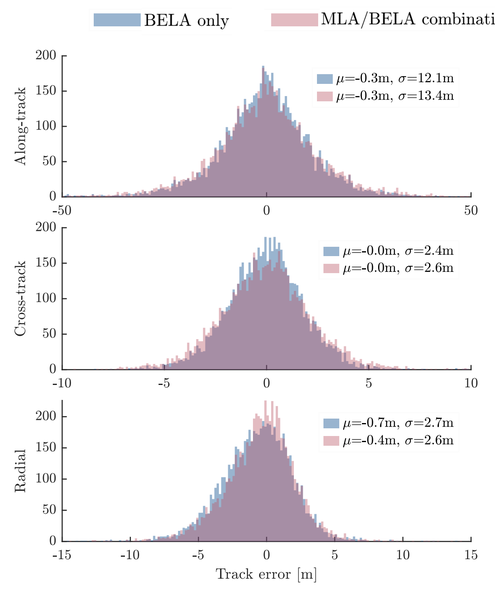
Improved modeling of NGF can be beneficial, but future analyses need a more extended OD coverage; using direct altimetry as constraint is also helpful.

Future work:
- Update of the solutions for geodetic parameters from Bertone et al. (2021).
- Investigate the impact of the input rotation models.

Initial closed loop simulation results for geodetic parameter improvement



Histograms of MLA tracks radial biases



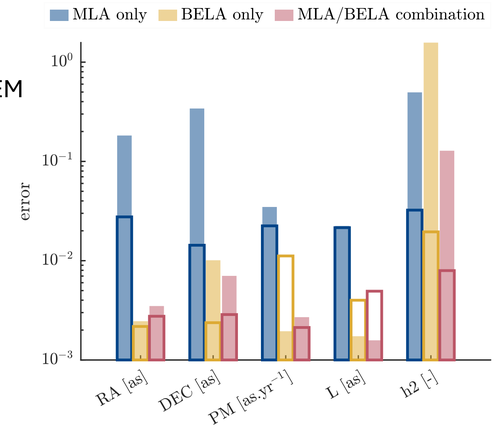
Histograms of BELA tracks radial biases

Hypotheses:
- 0.2 m white noise on the altimetric ranges
- Simulated small scale topography on top of Mercury large scale DEM
- 20 arcsec pointing error in roll and pitch

Unaccounted pointing errors lead to significant errors in A and C directions for MLA, and in A direction for BELA.

Combining MLA with BELA crossovers significantly improves the error in C direction.

A combination of BELA and MLA altimetry would ensure extended crossovers coverage at lower latitudes (helpful for most geodetic parameters), while also help improve MLA orbit solutions.



True (filled) and formal (empty) errors of geodetic parameters

Future work:
- Mitigate the imbalance between crossovers at high latitude, and crossovers at lower latitude.
- Make use of higher accuracy expected from MPO OD (e.g., constraining the MPO orbits, downweighting MLA/MLA crossovers…).

References

Andolfo et al. (2024). *Precise Orbit Determination of the MESSENGER Spacecraft.* Journal of Guidance, Control, and Dynamics.
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