AGU24
Washington, D.C. | 9–13 December 2024

P43A-3003

MLA and BELA altimetry synergies for Mercury geodesy and interior studies

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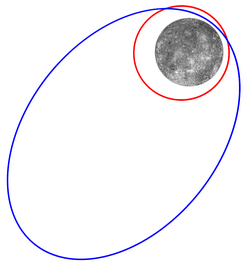
MESSENGER and BepiColombo mission

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.

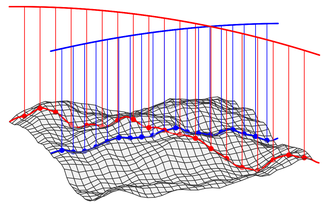


MESSENGER (2011 – 2015):
- highly eccentric orbit and high latitude periapsis
- Mercury Laser Altimeter (MLA)

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

→ We investigate the added value of BELA in the framework of crossovers-based solutions of orbit and geodetic parameters.

Laser altimetry crossover analysis



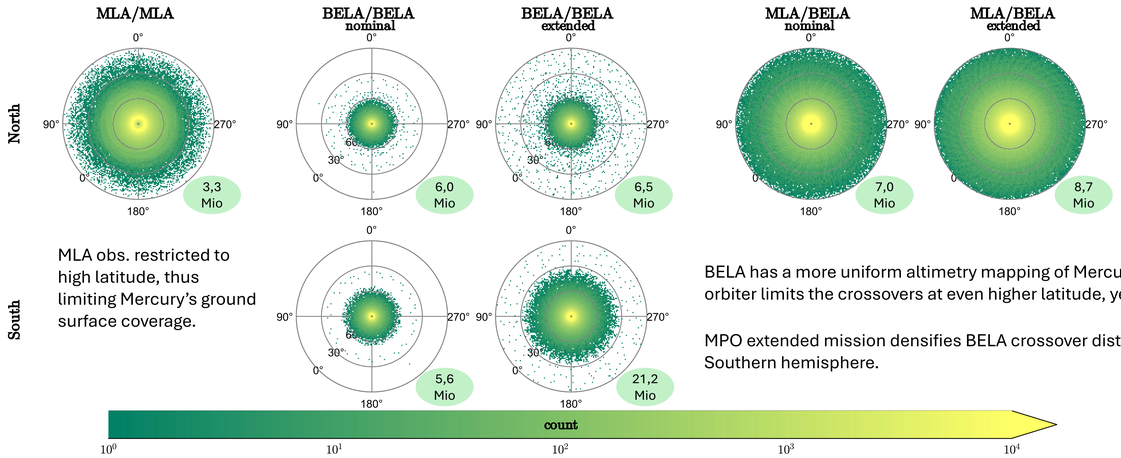
At each crossover between two altimeter tracks, the difference in elevation is 0, as the topography cancels out.

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



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.

MLA obs. restricted to high latitude, 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.

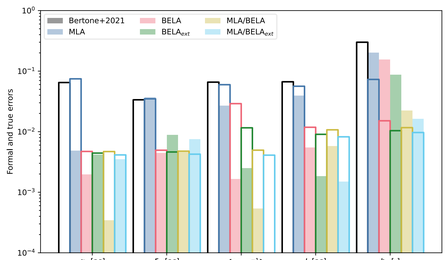
MPO extended mission densifies BELA crossover distribution, especially in the Southern hemisphere.

Distribution of the different crossover datasets

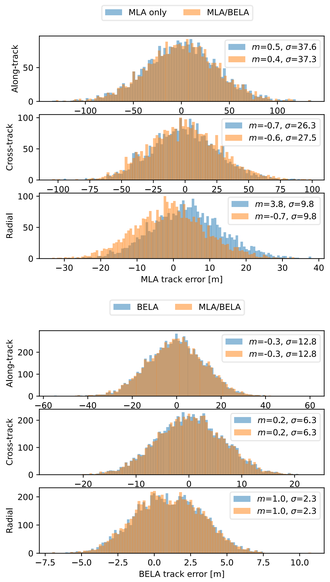
Closed loop simulation results for orbit and geodetic parameter improvement

Hypotheses:
- Simulated small scale topography on top of Mercury large scale DEM
- MLA
  - 0.2 m white noise on the altimetric ranges
  - (20, 20, 5) m in Along-track, Cross-track, Radial
  - Altitude threshold: 1050 km
- BELA:
  - Error model function of altitude and slope
  - (10, 5, 0.2) m in Along-track, Cross-track, Radial
  - Altitude threshold: 1050 km

- Combining MLA with BELA crossovers reduce orbit biases in radial direction.
- Toward the end of the extended mission, BELA tracks are not well constrained by altimetry crossovers in the Northen hemisphere.



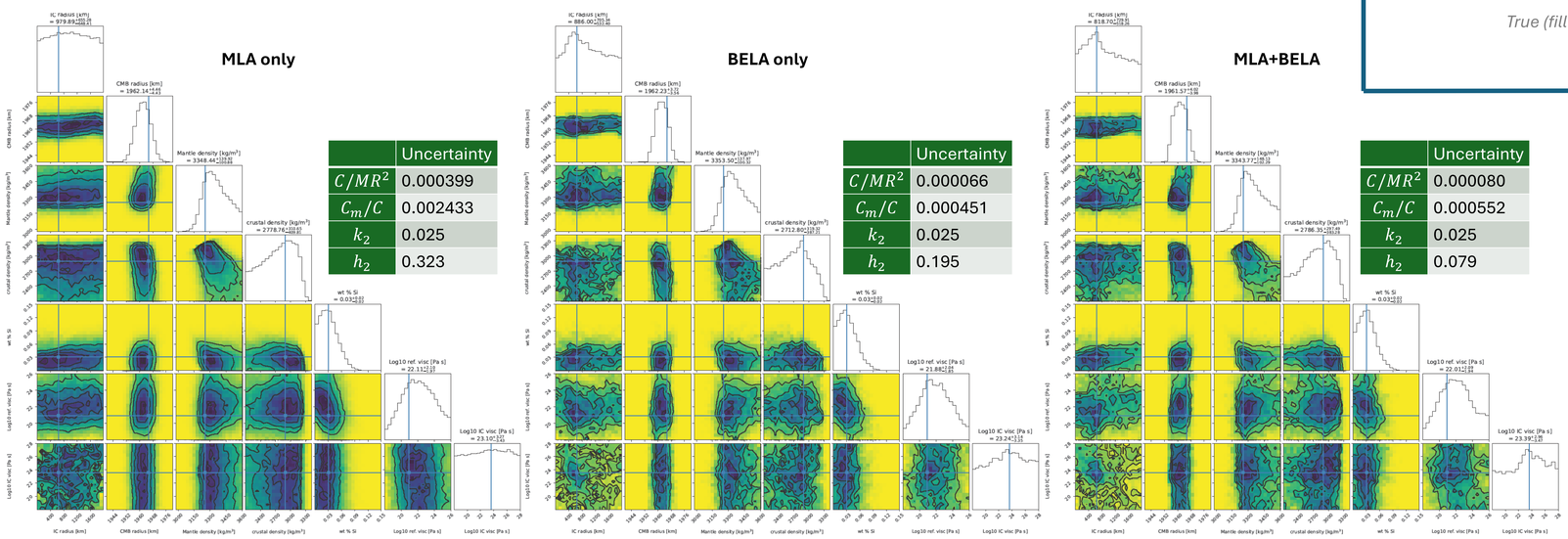
True (filled) and formal (empty) errors of geodetic parameters



Histograms of tracks errors

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.

Impact on internal structure models via MCMC analysis



	Uncertainty
C/MR^2	0.000399
C_m/C	0.002433
k_2	0.025
h_2	0.323

	Uncertainty
C/MR^2	0.000066
C_m/C	0.000451
k_2	0.025
h_2	0.195

	Uncertainty
C/MR^2	0.000080
C_m/C	0.000552
k_2	0.025
h_2	0.079

	Model value
C/MR^2	0.345741
C_m/C	0.426608
k_2	0.613
h_2	1.129

We derived moments of inertia and tidal Love numbers based on a realistic interior model, and perform a Markov Chain Monte Carlo (MCMC) approach (see Goossens et al., 2020), using uncertainties derived from the closed-loop simulation.

Reduced uncertainties on geodetic parameters lead to a better determination of Mercury's internal structure, as shown by comparing MCMC results based on each individual and combined datasets.

References

Bertone et al. (2020). *Pyxover - a python suite of altimetry analysis tools for planetary geodesy.*
Bertone et al. (2021). *Deriving Mercury geodetic parameters with altimetric crossovers from the Mercury Laser Altimeter (MLA).* Journal of Geophysical Research: Planets.
Goossens et al. (2022). *Evaluation of recent measurements of Mercury's moments of inertia and tides using a comprehensive Markov chain Monte Carlo method.* The Planetary Science Journal.