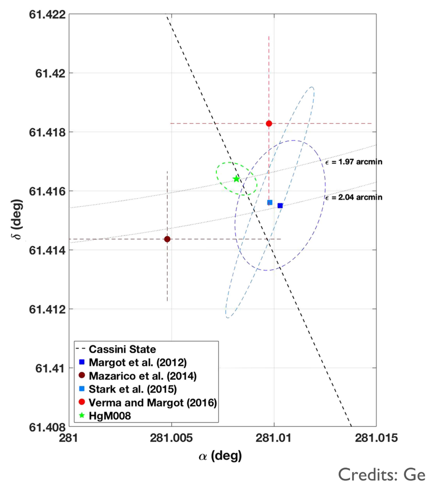
AGU19#P13C-3524: New analysis of Mercury Laser Altimeter crossovers to improve geodetic constraints by MESSENGER

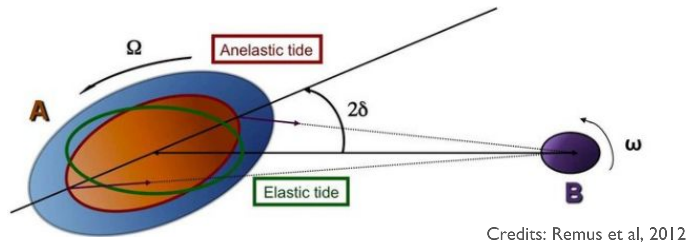
S. Bertone (GSFC/UMBC), E. Mazarico (GSFC), M.K. Barker (GSFC), S. Goossens (GSFC/UMBC), T.J. Sabaka (GSFC), G.A. Neumann (GSFC), D.E. Smith (MIT), A. Genova (La Sapienza, IT)

A. Open questions in Mercury geodesy



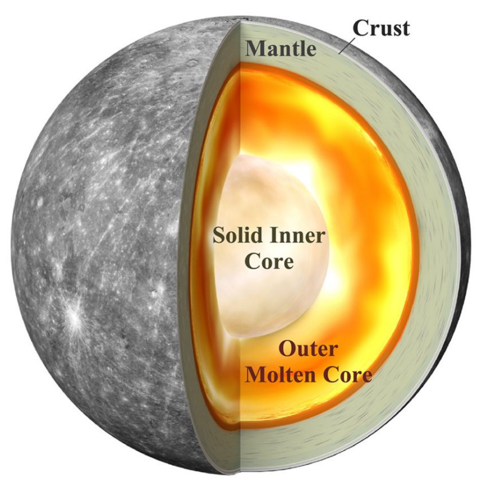
Credits: Genova et al, 2019

Uncertainties on rotational parameters



Credits: Remus et al, 2012

Difficult determination of body tides

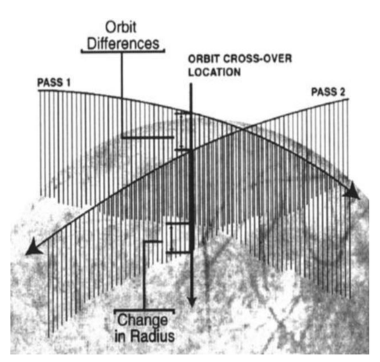


Additional constraints on geophysical parameters support analysis of Mercury internal structure (e.g., core size) and evolution

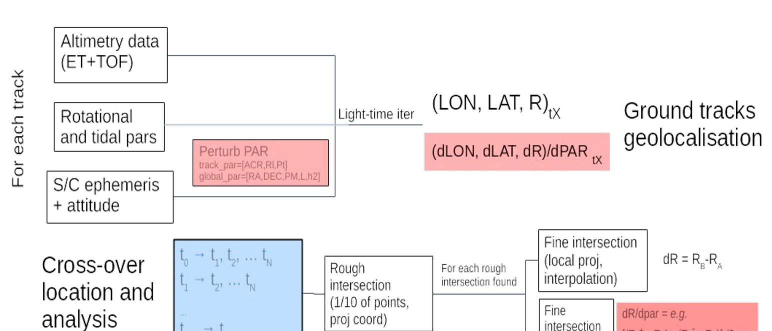
B. Overview of MLA crossovers analysis

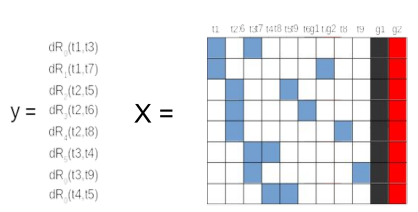
- Based on MESSENGER's Mercury Laser Altimetry (MLA) dataset, we improve Mercury geodetic parameters via least squares minimization of crossover discrepancies;
- Simulation and analysis of synthetic MLA data (see C): validation, find an appropriate orbit parametrization and error assessment;
- Solution of Mercury pole RA, DEC coordinates, prime meridian (PM) rate and librations (L) using the full MLA dataset (3.7 millions of crossovers, 2011-2015);
- Verification by: comparing solutions from different a-priori orbits (KinetX, Genova 2018) and parameter solutions (IAU, Genova 2019).

i. Overview of crossovers analysis workflow

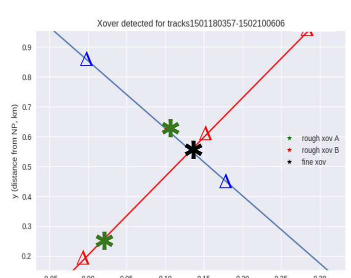


Crossover point and discrepancies dR (Rowlands, 1999)

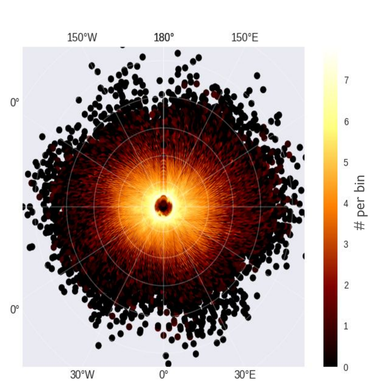




$$p = (X^TWX + \lambda_{avg}M_{avg} + \lambda_{ACR}M_{ACR} + \lambda_{RIPt}M_{RIPt})^{-1}(X^TWy)$$



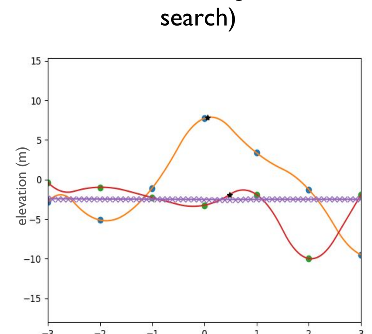
Intersection of two MLA ground-tracks (Δ: MLA observations, crossover locations: ✱ rough, ✱ fine search)



Crossovers density (Mercury North-polar projection)

Setup:

- Modular Python code, fully parallelized
- Fit of orbital and pointing corrections (ACR biases and polynomes)
- Huber weighting of observations based on residuals values, separation from MLA data, off-nadir pointing
- Regularization of ACR(+Roll, Pitch) corrections and their average variations to maximum expected values and from simulations



Terrain elevation at crossover point (spline interpolation of MLA geolocalised data)

C. Simulation: data weighting and error assessment

Error source	Value [m]
Instrument	0.2
Pointing & alignment	9.5
Radial orbit errors	1.8
Rotational state	2.0
Interpolation errors	7.7

Table : Main errors affecting altimetry crossover analysis (Steinbrugge, 2018)

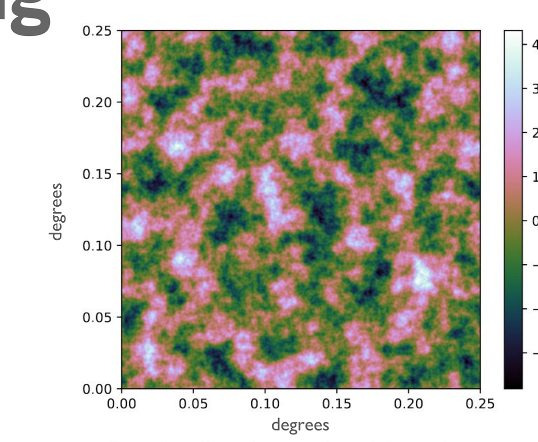


Fig : Small scale simulated fractal noise (periodic) to be added to Mercury topography.

- We test the impact of most error sources on crossovers discrepancies in our simulation environment
- Unperturbed tests with small scale roughness provide measurement sensitivity to interpolation error
- Option to perturb orbit, pointing and geodetic parameters and test different constrainings for recovery

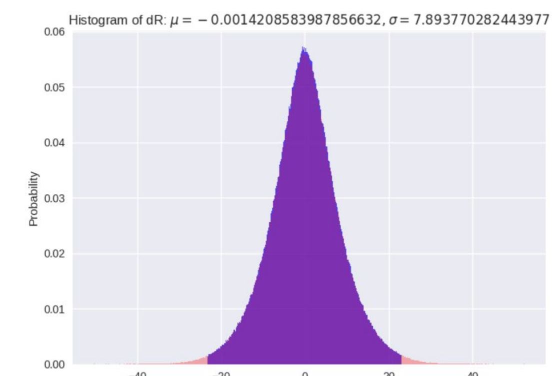
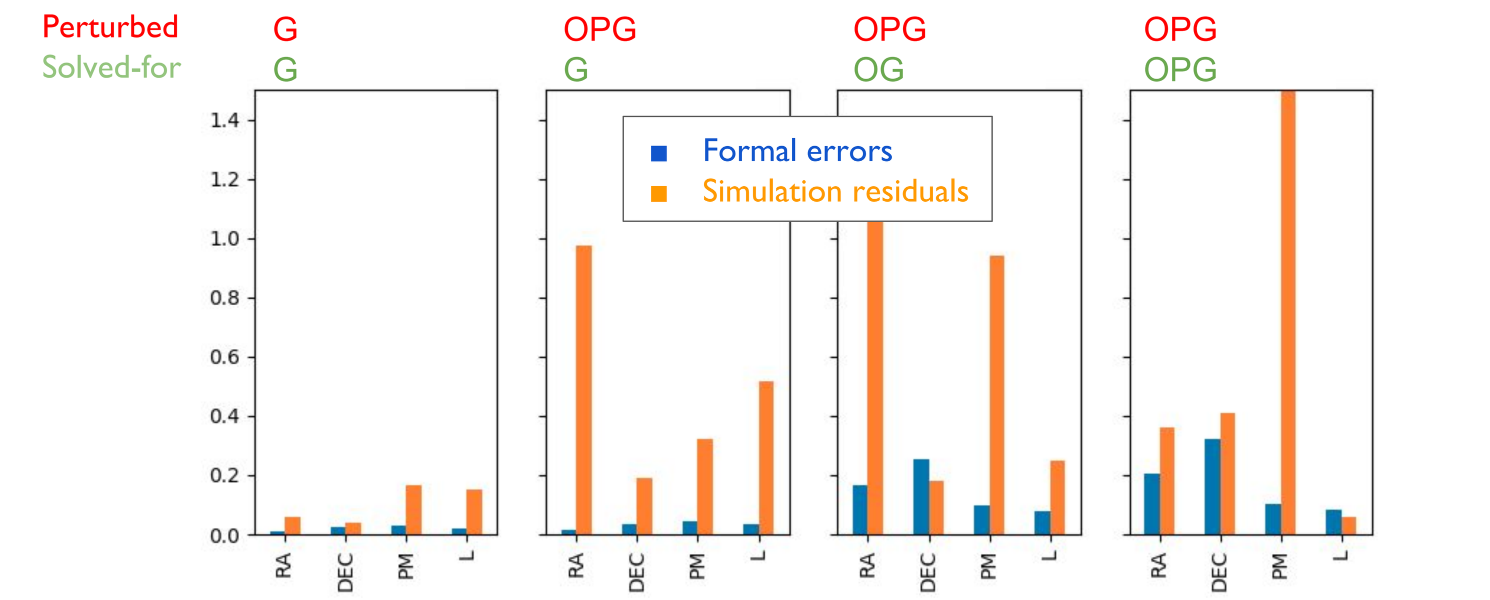


Figure : altimetry crossover residuals distribution resulting from 0-test (no observation noise or parameter errors)

i. Tests on 500 tracks of synthetic MLA data with different error sources and parametrizations

- GG : RA (as), DEC (as), PM (as/y), L (as)
- OO : Orbit corrections (ACR bias, linear, quadratic)
- PP : Pointing corrections (roll, pitch)



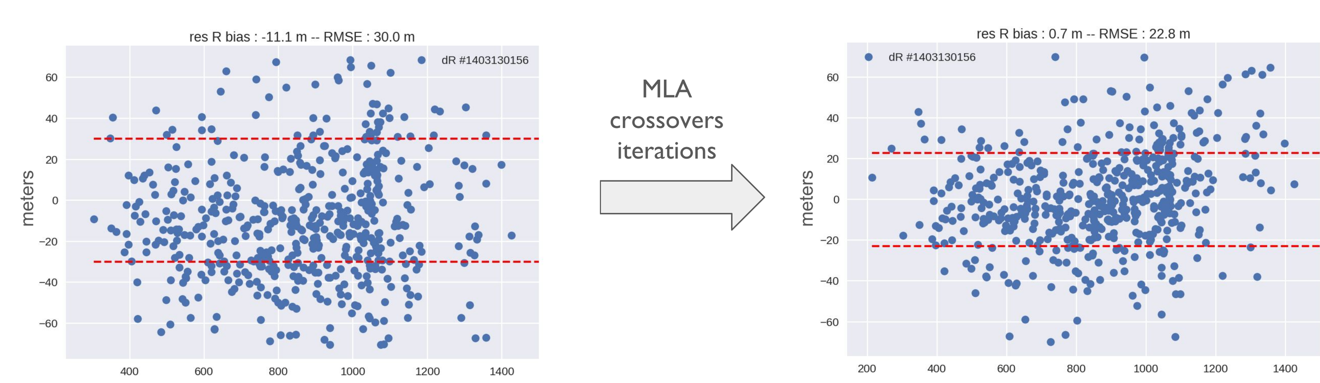
Result:	Interpolation error is the main source of error	Unmodeled errors impact geodetic recovery	Formal errors increase by estimating orbital corrections	Consistent parametrization gives realistic formal errors

Reliability and rescaling of formal errors from closed-loop simulations

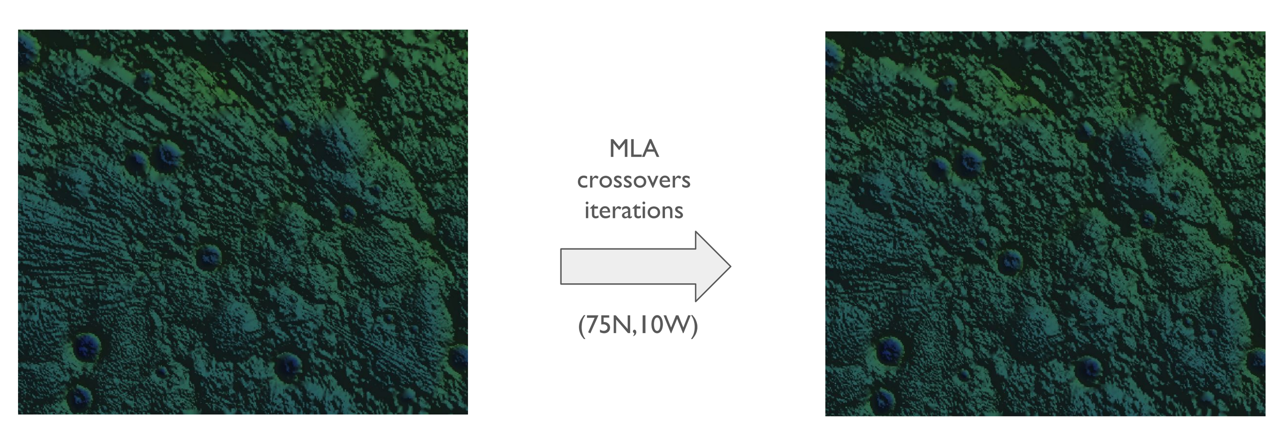
D. Processing of MLA crossovers

i. Improvement of orbital and geophysical parameters

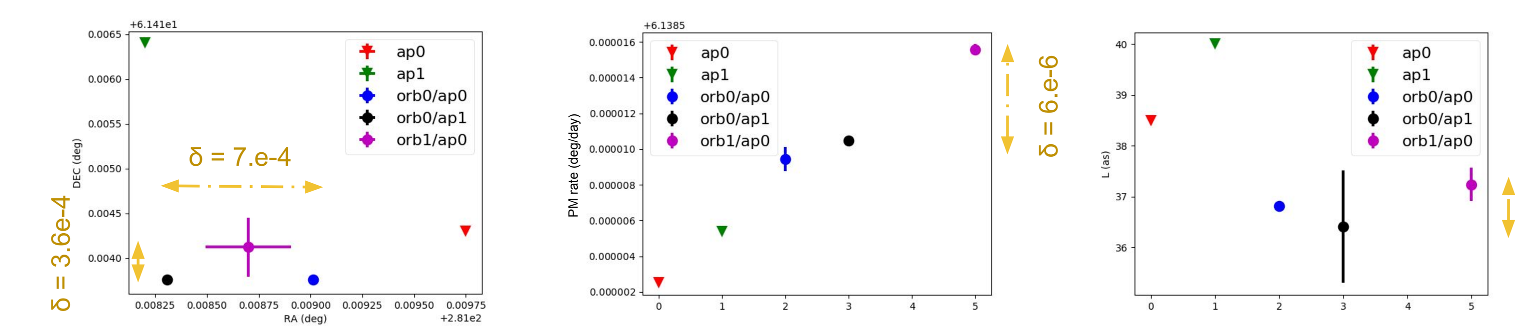
- Iterative solution, convergence on parameters changes below formal errors (10-20 iterations)
- Complex pattern in orbital errors, regularisation of ACR biases
- Checking quality of pre-fit and post-fit orbit residuals by:
  1. Pseudo-time series including dR of all crossovers for a single MLA track: RMSE of post-fit residuals (by ACR bias + rotational pars fit to dR) reduced from 30 m to 22.8 m, trends still visible



  2. Reconstructed topography from geolocalised MLA residuals; interpolation and shadowing highlight inconsistencies due to orbital and orientation errors; comparison shows crossovers fit contribution



ii. Check independence from a priori orbits and parameters

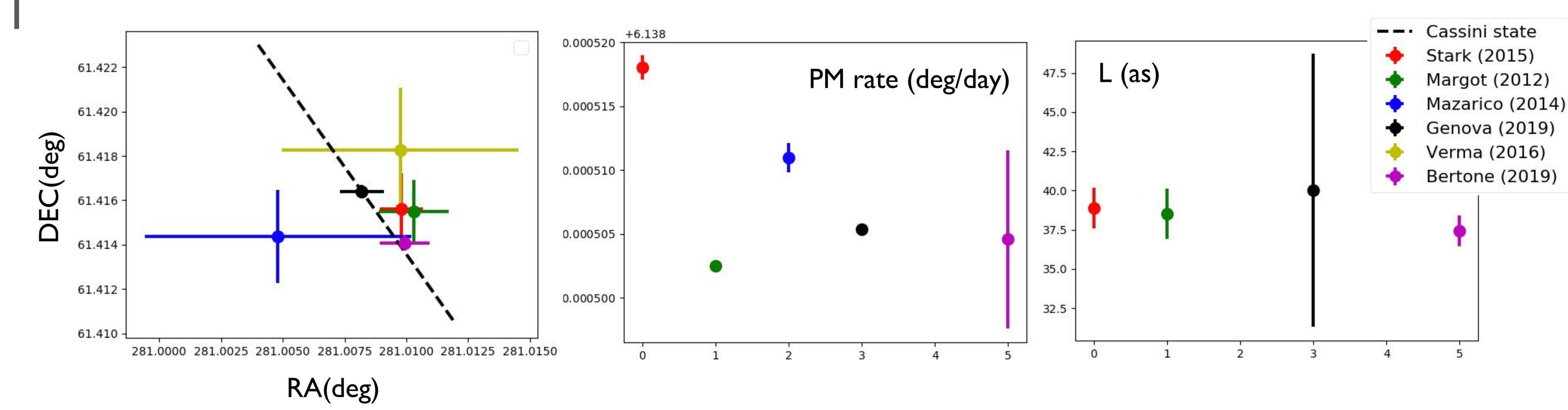


- Dataset: crossovers among 500 chosen MLA tracks (homogeneously distributed in spacetime)
- Consistent parametrization with ACR biases (constraint: 100 m) and [RA, DEC, PM rate, L]
- Comparison of multiple solutions based on: KinetX (orb0) and Genova 2018 (orb1) Doppler orbit reconstruction and IAU (ap0, Archinal, 2017) and Genova 2019 (ap1) apriori values.

Dispersion at convergence contributes to realistic error assessment

iii. Comparison with previous solutions by other groups/techniques

- Weighted least square solution based on full MLA dataset
- Solutions from Earth radar, MESSENGER (camera and altimetry, Doppler, crossovers)



Acknowledgments: SB acknowledges support by the Swiss National Science Foundation within the Advanced Postdoc Mobility program and by NASA's Planetary Science Division Research Program through the CRESST II cooperative agreement. The MLA data were processed on the GSFC NCCS ADAPT cluster.