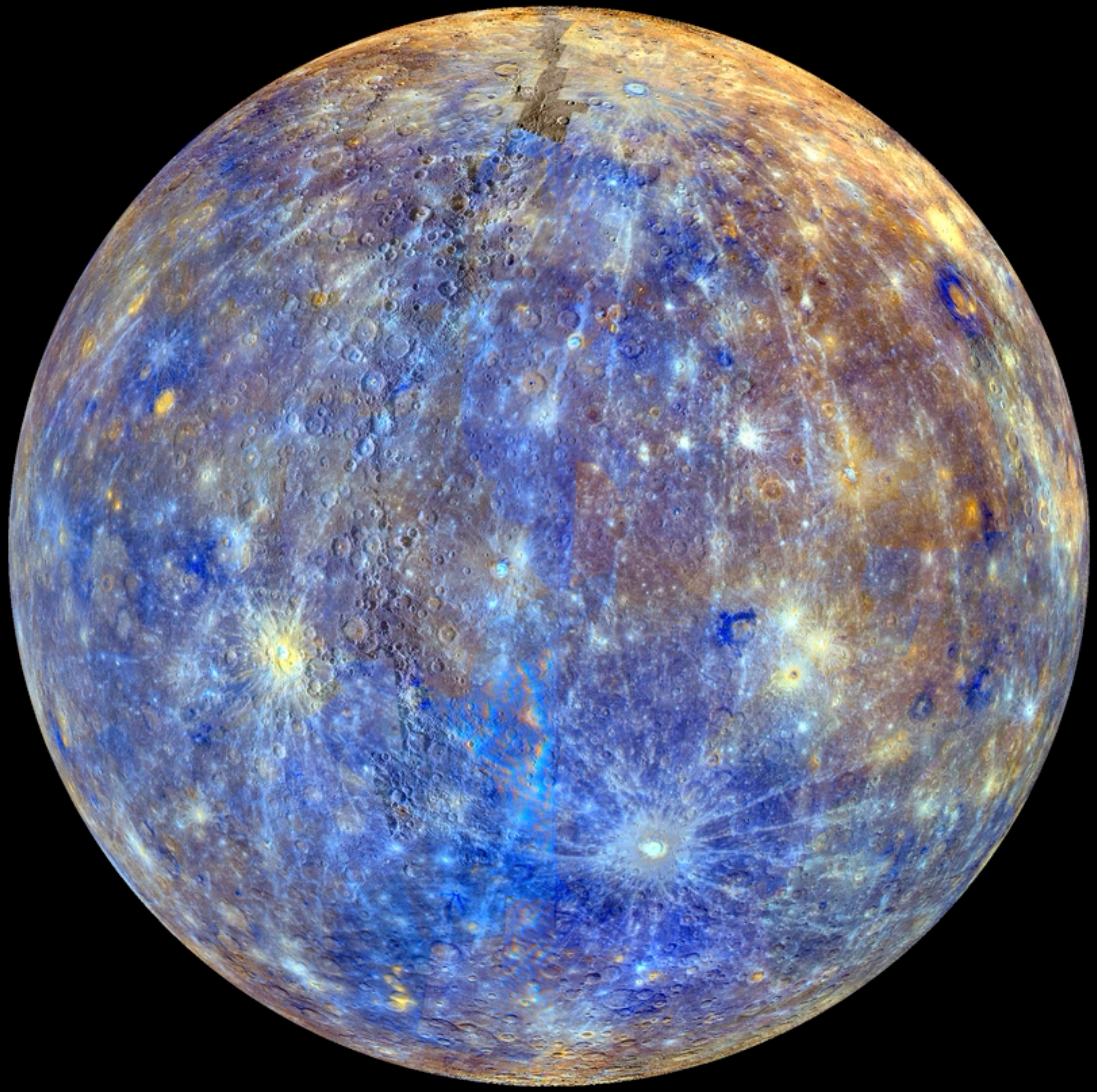
Constraining Mercury's interior structure from geodesy data and thermal state



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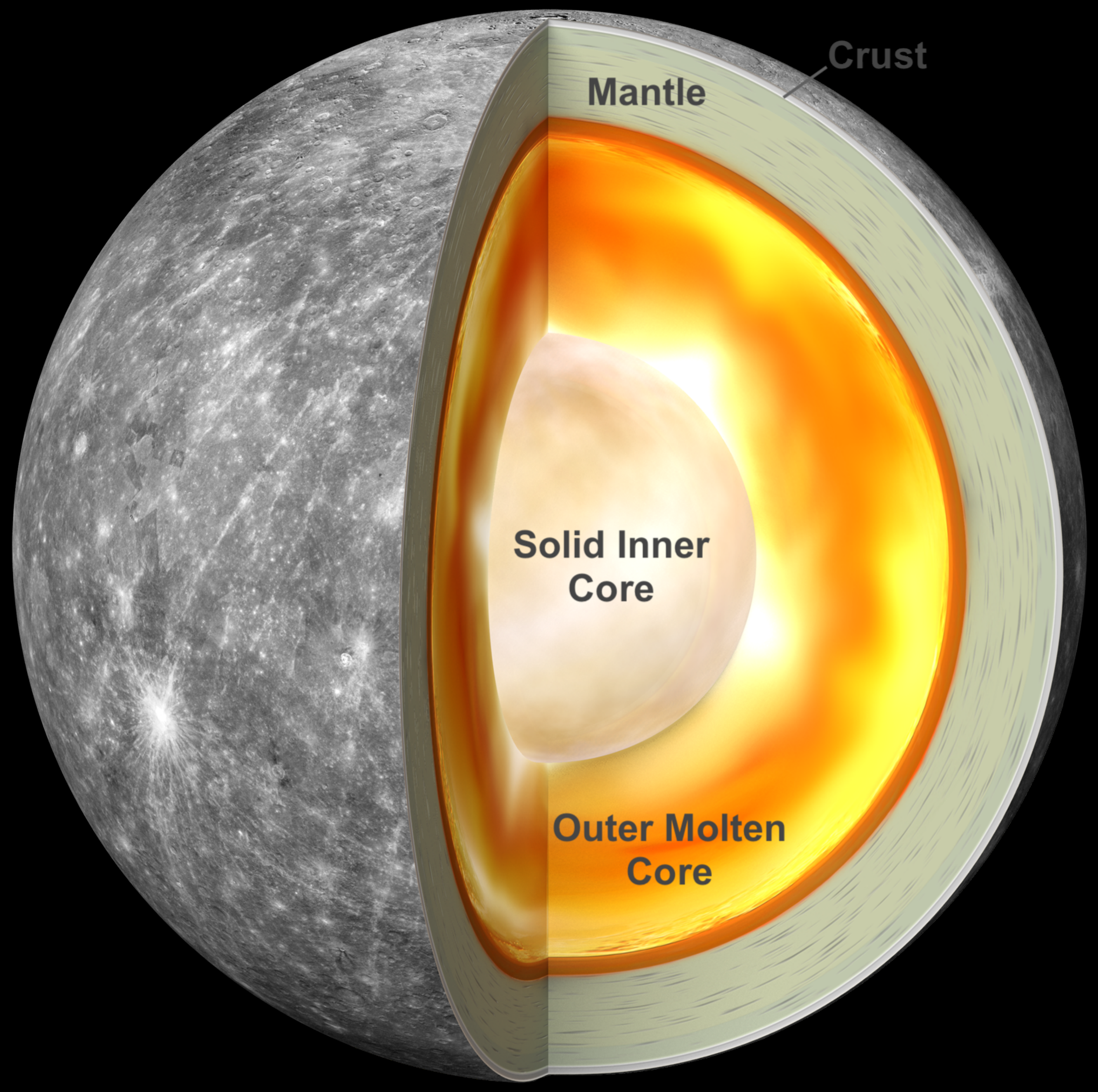
Scope

- Extremely reducing formation conditions (e.g. McCubbin+ 2012; Zolotov+2013):
  - Si main light element in the core (e.g. Chabot+2014, Malavergne+ 2014, Namur+ 2016)
    →~equipartition between solid and liquid Fe, small effect on core liquidus
  - mantle FeO depleted (Malavergne+2014), ~20wt% sulphides, pyroxene rich (Boujibar+2025)
    →low density, stiff
- Geodesy observations (average density, moment of inertia MOI, annual libration amplitude, tidal Love number k_2):
  (e.g. Rivoldini+2019, Knibbe+2020, Rivoldini+ 2025)
  - liquid core, radius: 2005±30 km
  - average mantle density: ~3.1 g/cm^3
- Inner core: not yet detected
  - Geodesy observations can be explained without an i.c., large uncertainties on radius estimates
  - Observational support: past and present dynamo, radial contraction
  - Theoretical modelling: thermal evolution (e.g.Davies+2024, Knibbe+2025), dynamo simulations (e.g. Kolhey+2025)
  - Geodesy: effect on annual libration amplitude (Dumberry+2013) of the order of current precision (Xiao+2025) if i.c. has large radius

This study

- use most recent estimates about geodesy observations as well as the up to date material properties to inform about the interior structure and in particular on the inner core
- show how results from whole planet thermal evolution studies and self-consistent structure modelling further improve our knowledge about Mercury’s interior

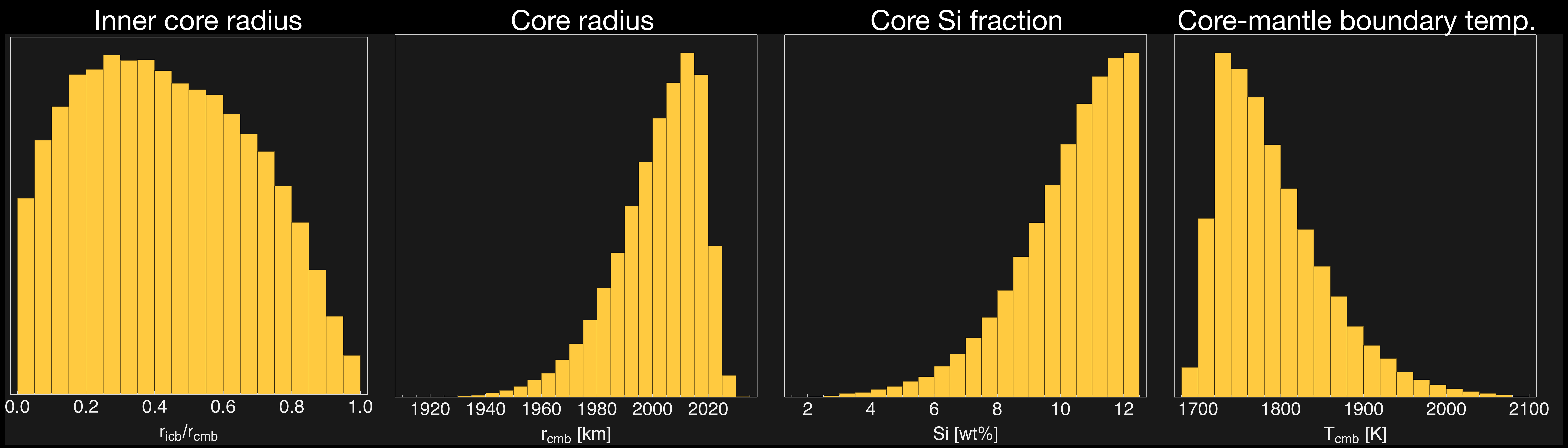
Interior structure model (present-day)



- **model parameters**:
  - inner core radius, core temperature (CMB), core flattening
  - mantle composition (fo, opx, odi)
  - crust: thickness and density
- **priors**:
  - Fe-Si core
  - CMB temperature allows for liquid core and below mantle solidus (Namur+2016)
  - Si≤eutectic (12.5 wt%) in Fe-FeSi (Edmund+2022)
  - Moho density contrast in agreement with topography and gravity field constraints
  - conductive mantle
- equations of state for core alloy (Edmund+2022, Terasaki+2019) and mantle (Stixrude+2024)
- core liquidus parameterisation (Edmund+2022)
- composition dependent mantle rheology (Qu+2021)
- includes effect of mantle-core coupling on libration amplitude (Dumberry+2013)

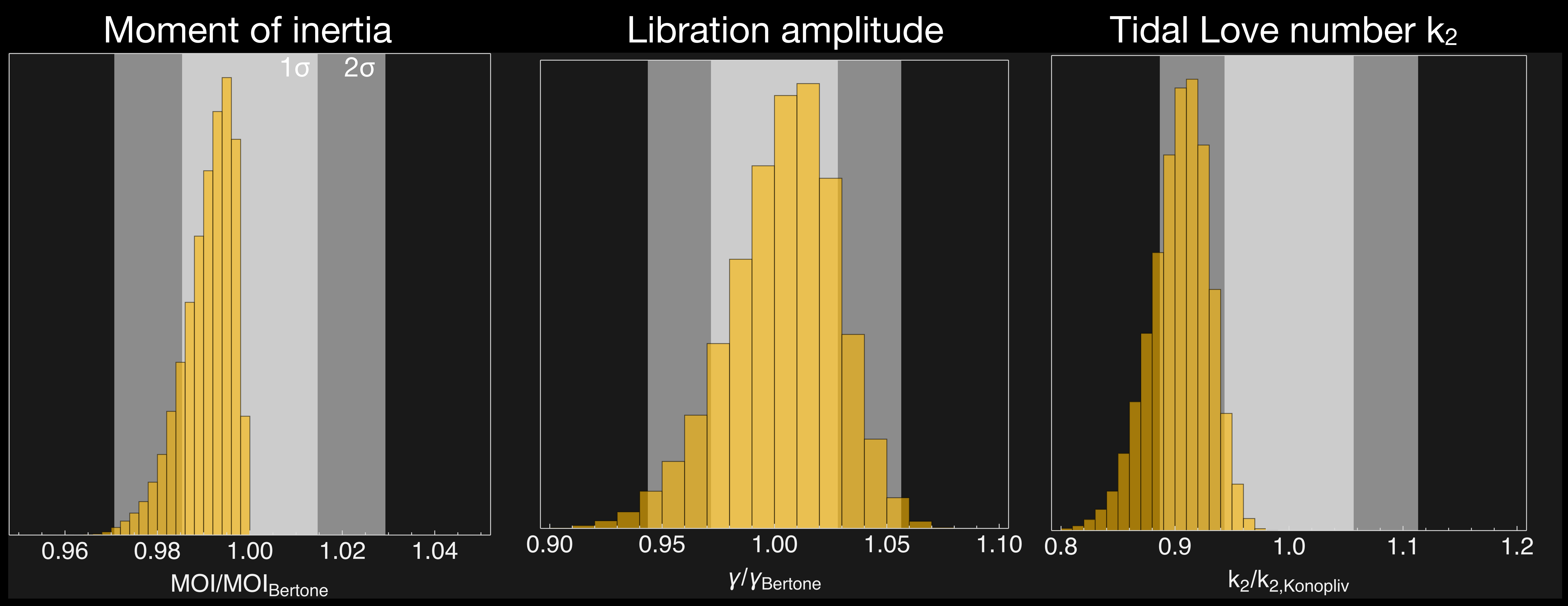
Interior structure inference from Geodesy data

data: mass, moment of inertia+ libration amplitude (Bertone+ 2021), tidal Love number (Konopliv+ 2020)



- constrained: core radius (2005± 20km), mantle density (~3.1 g/cm^3), 8-12 wt%Si, CMB temperature (1790±70 K)
- weakly constrained: inner core radius (870±490 km), mantle composition (fo favoured over opx), grain size (< 1mm !!)
- not constrained (~prior): crust thickness and density

Data compatibility

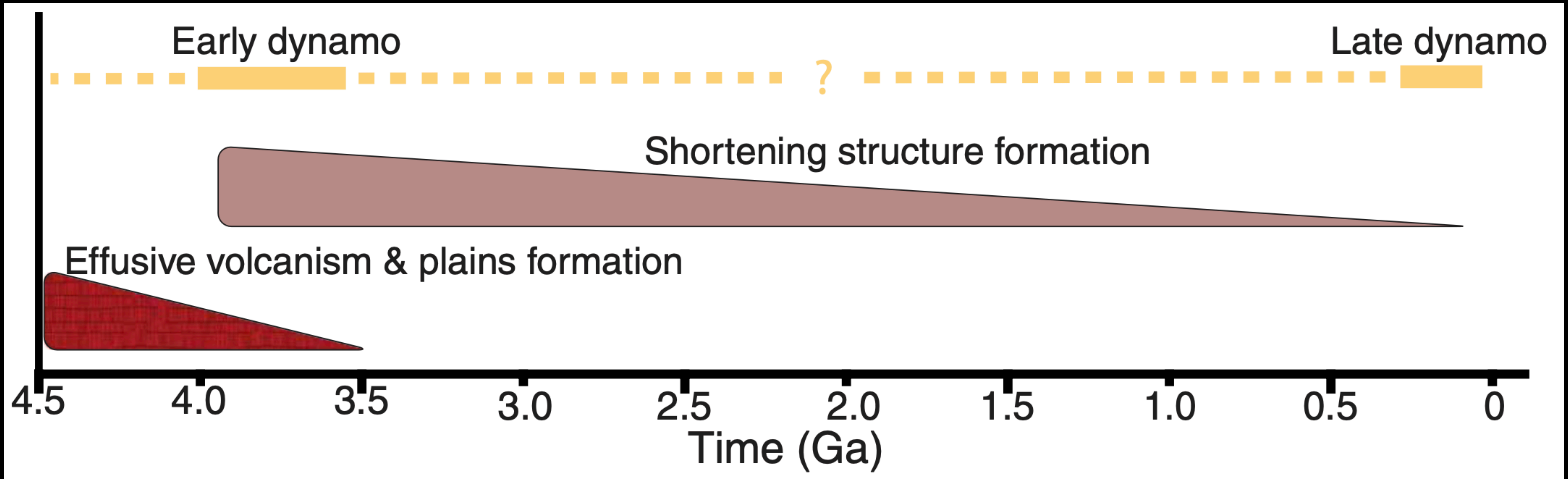


- best fitting models agree well with MOI and libration amplitude
- predicted k_2 values are only marginally compatible with observations
  - k_2 estimate unreliable? (large variation in published values k_2~0.45-0.56, e.g. Mazarico+2014, Genova+2019, Konopliv+2020)
  - opx-rich mantle rheology is too stiff and not representative for Mercury's mantle
    →~25% reduction in rigidity is required to match observations

Thermal evolution modelling (i.e. M. Lécaille)

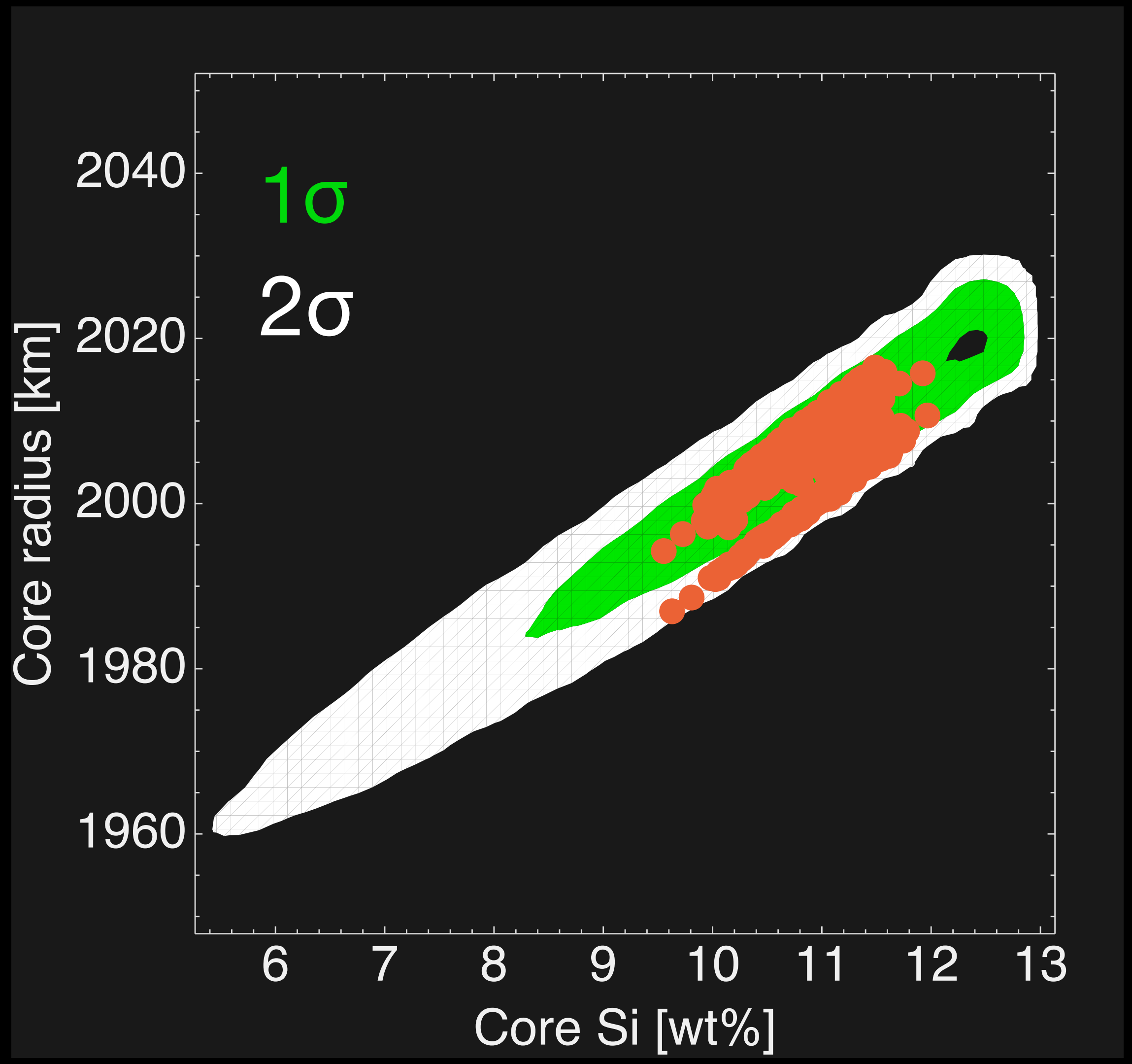
- Initial models are self consistent (agree with mass) depending on mantle and core composition and assumed starting thermal state
- Same equations of state for mantle, core, and core liquidus as in part one
- **Updates** compared to part one:
  - composition dependent partitioning of Si between solid and liquid core
  - upper core thermal boundary layer and core thermal structure
  - self-consistent mantle temperature
- **Downgrades** compared to part one:
  - no constraint on emplaced crust density

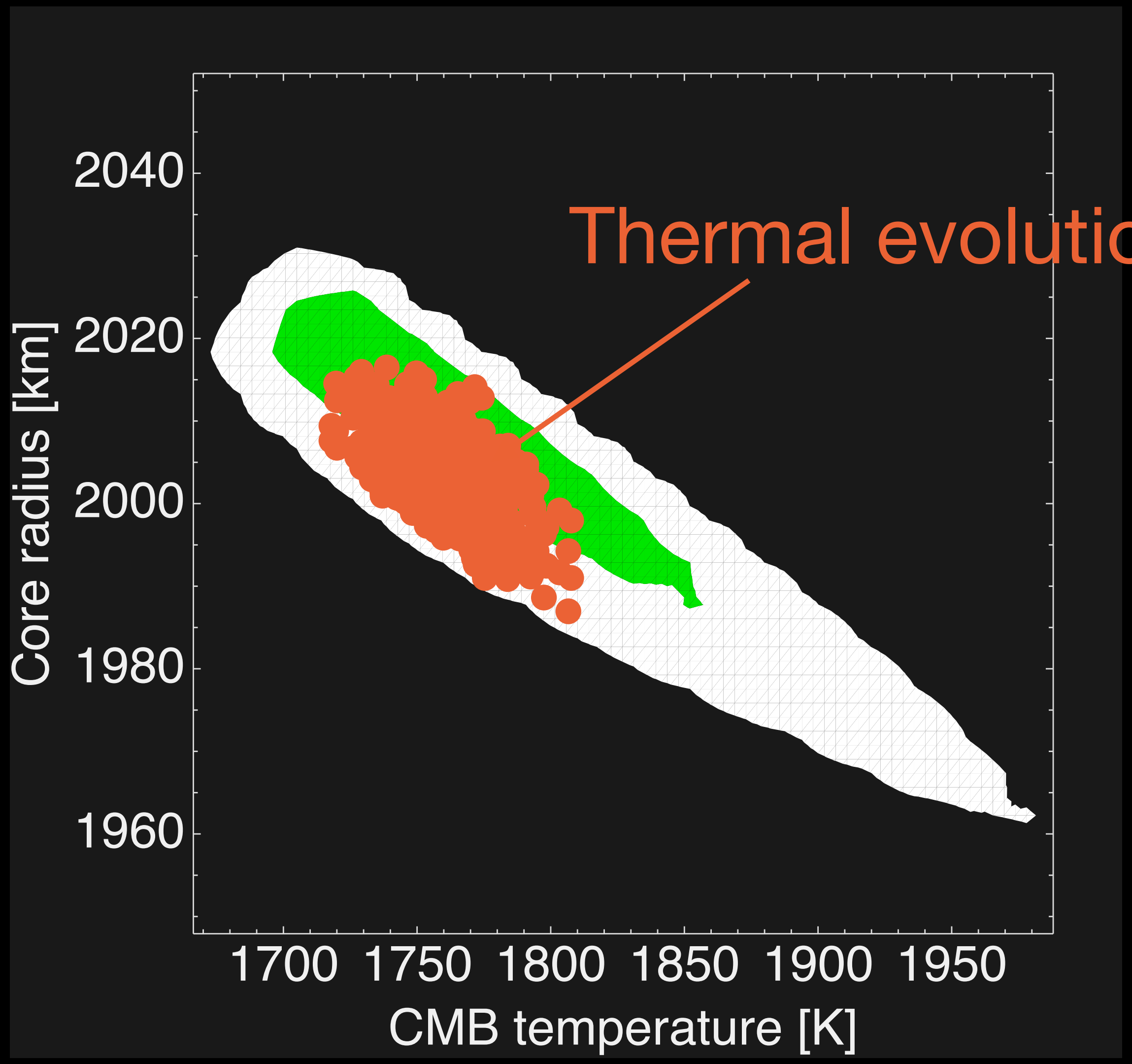
Thermal evolution constraints (i.e. M. Lécaille)

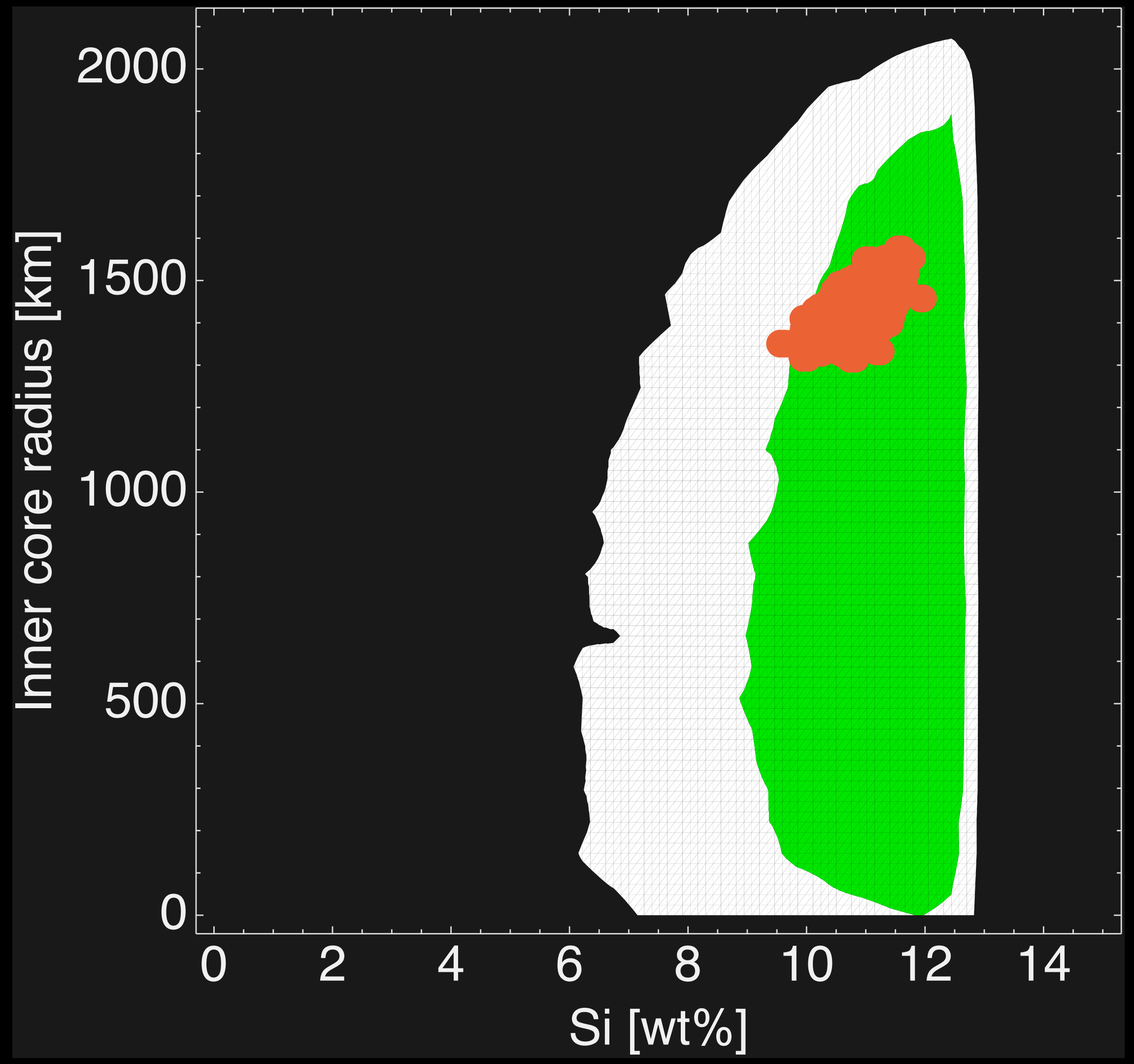


- Crust formation timing and thickness (15-60 km)
- Radial contraction
- Present-day upper core thermal boundary layer and inner core
- Past and present-day dynamo

Final state thermal evolution models



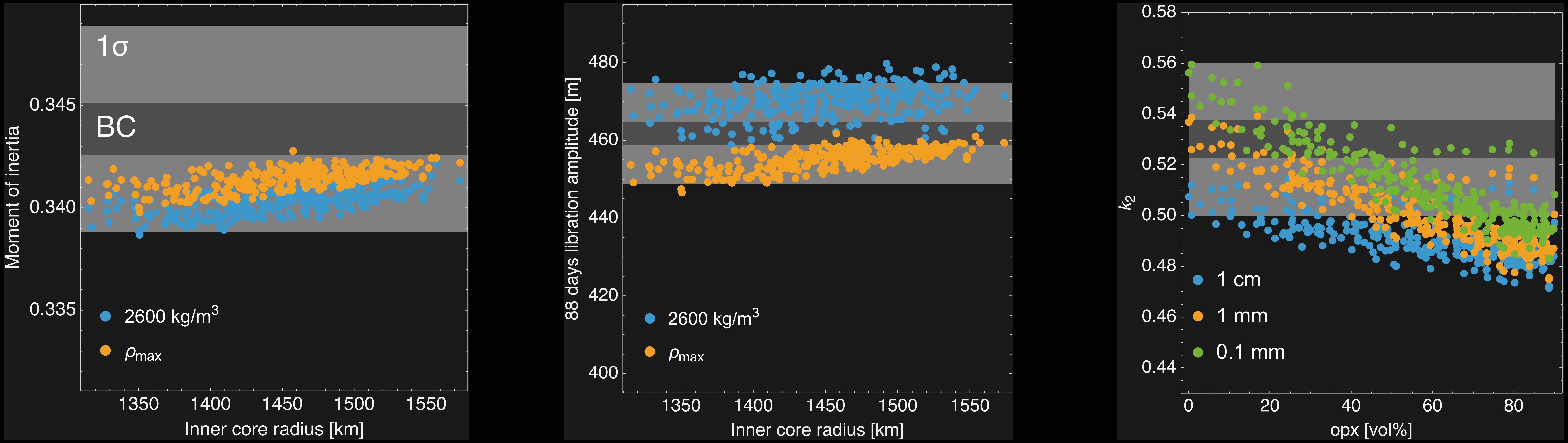




Compared to geodesy compatible models final state thermal evolution models

- have a significant reduced parameter space
- agree well (~1σ) with CMB temperature, core radii, and composition
- have a inner core of ~1500 km (~600 km larger)
- favour opx over fo

Thermal evolution models and geodesy data



- models agree well with moment of inertia and liberation amplitude
- only models with a low fractions of opx agree with k_2

Summary

- Challenging to obtain precise estimates about the detailed core structure from MESSENGER geodesy data alone
- More precise determination of geodesy data from BepiColombo will improve those inferences
- Significant parameter space reduction and information about the detailed core structure can be achieved if geodesy data and results from whole-planet thermal evolution simulations are combined
- experimental rheology model for fo-opx aggregates is at odds with tidal Love numbers
- inferences rely heavily on thermodynamic and transport properties that are not all well known and therefore are also a limiting factor