Mercury's interior: New views from MESSENGER

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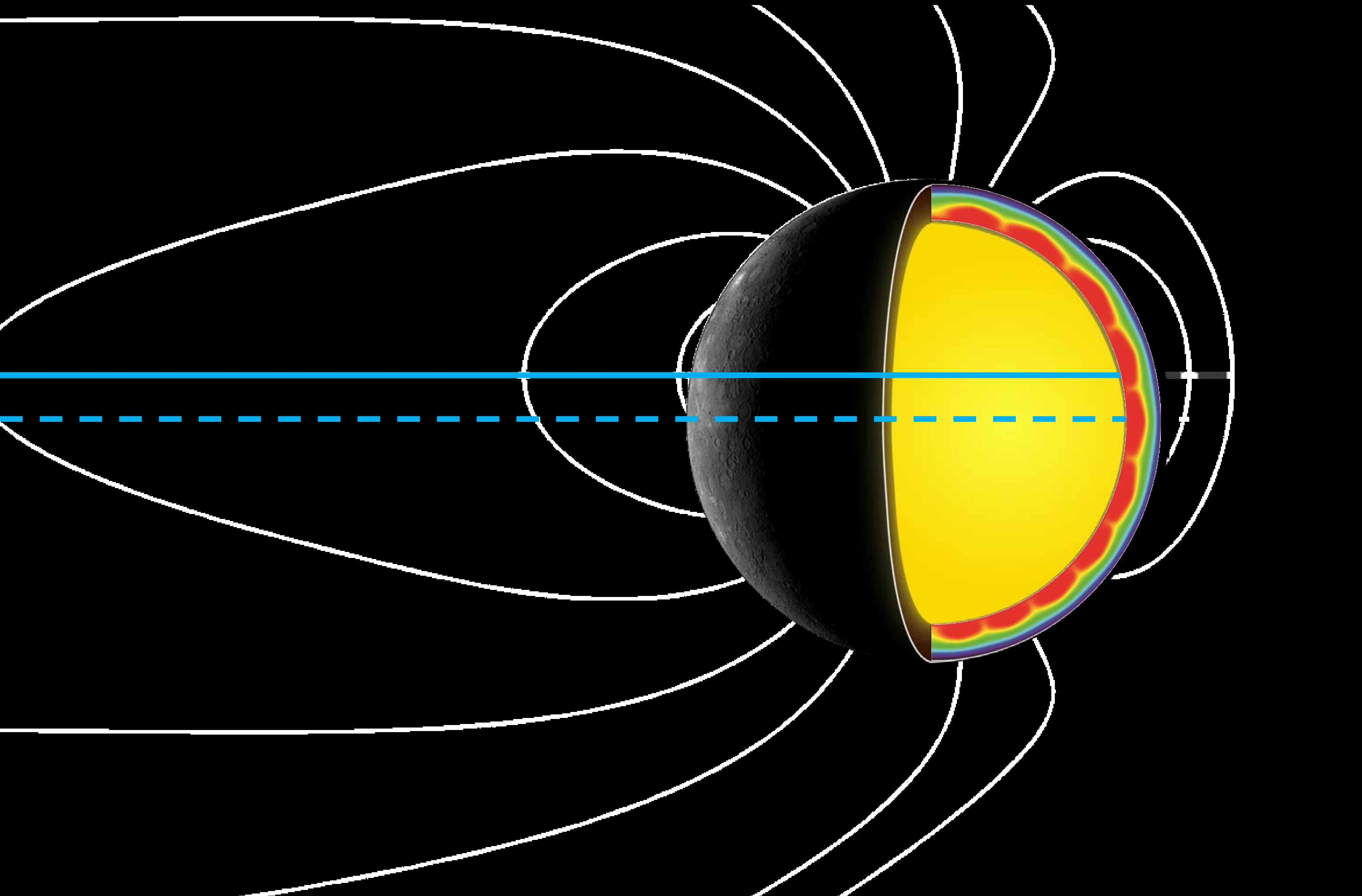
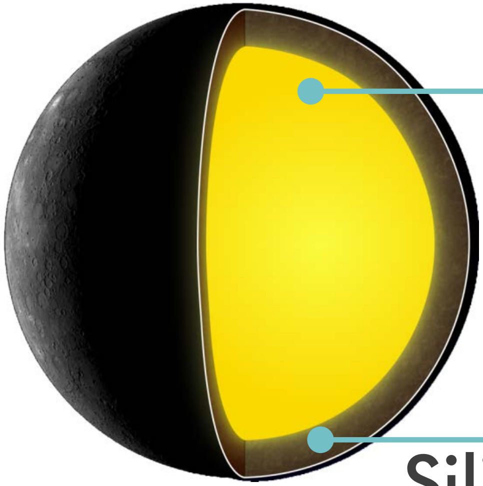
Mercury system science

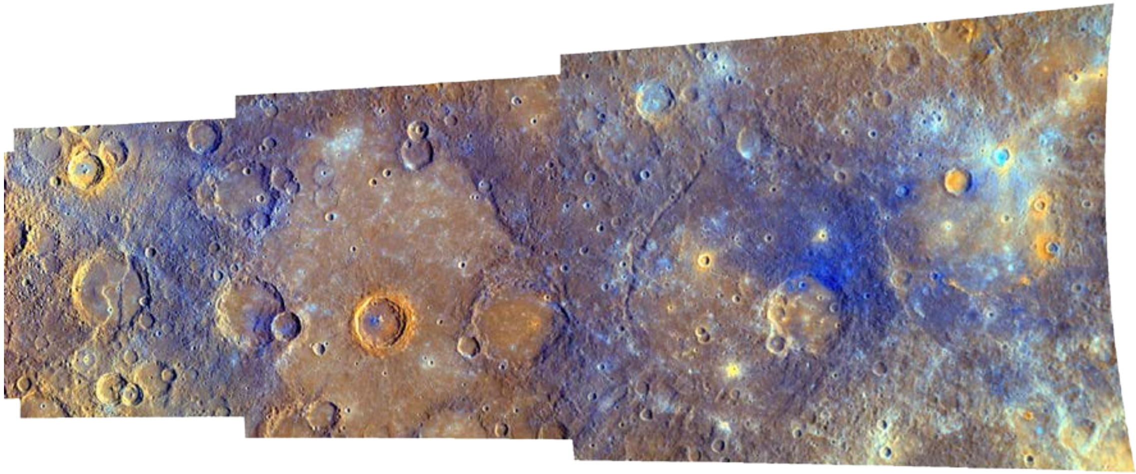


Driving questions

What is Mercury made of?



How did Mercury evolve?



MESSENGER happened, and now we know…

- **Global shape, topography, and gravity**
- **Internal magnetic field geometry & timing**
- **Much more contraction than once thought**
- **Strongly chemically reduced planet**
- **Heat production, with lots of potassium**
- **Volcanism**
- **So what is our picture of Mercury's interior now?**

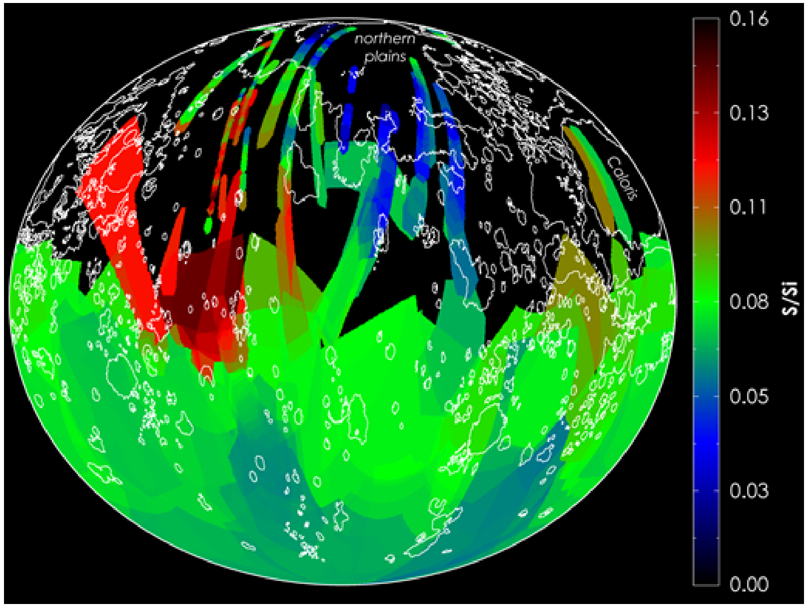
Direct observations: Geochemistry

Heat production

	Mercury	Chondritic
K (ppm)	1288 ± 234	544
U (ppb)	106 ± 11	7.8
Th (ppb)	155 ± 54	30
Th/U	1.5 ± 0.5	3.8

Chemically reduced

Fe	S
~ 1.5 wt %	~2 wt %



Weider and Nittler et al (2013)

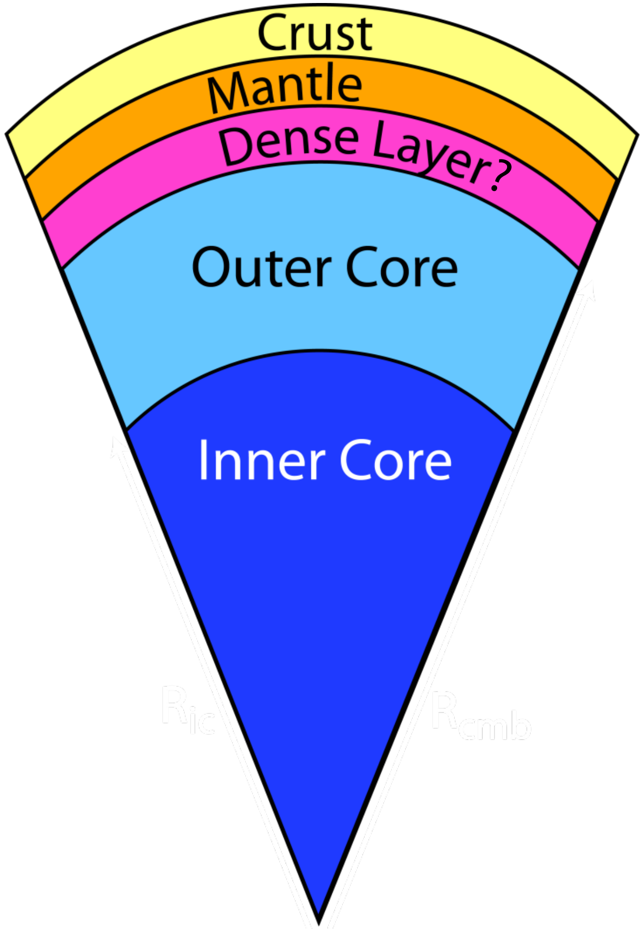
- **Much more heat production than once thought.**
- **Sub-chondritic Th/U**
- **Highly chemically reduced surface rocks → reduced core**

Peale Experiment

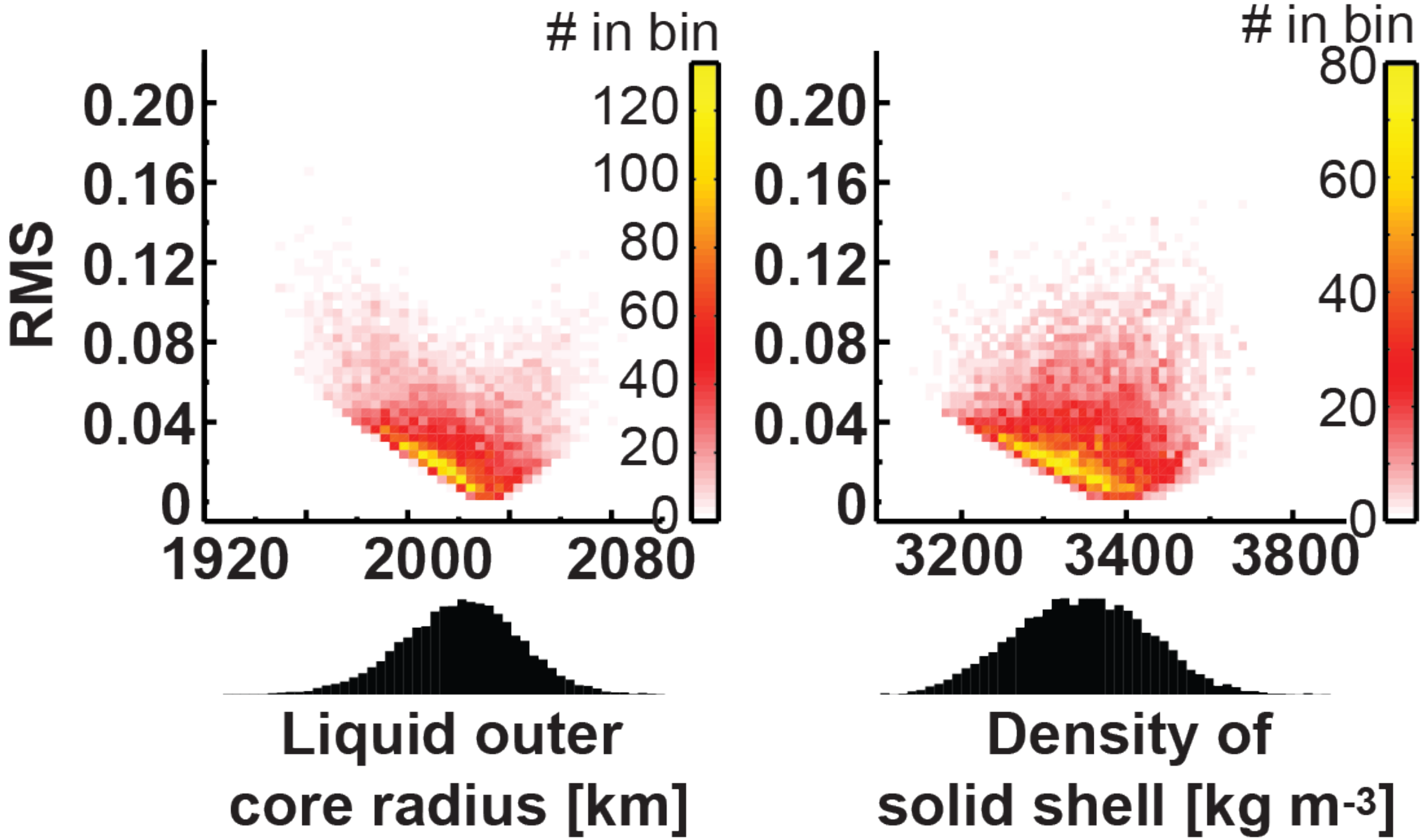
- **Gravity + spin state**
- **Normalized polar moment of inertia**
  - $C/MR^2 = 0.349 \pm 0.014$
- **Solid, librating shell fraction of MOI**
  - $C_m/C = 0.424 \pm 0.024$

Modeling Interior Layering

- **Range of layer thicknesses**
- **Plausible ranges of rock and metal densities are known**
  - **Density is a function of temperature, pressure and composition**
  - **Self-gravity and self-compression**
- **Search for models that satisfy:**
  - **Bulk density and mean radius.**
  - **Non unique = we look at millions of models**
- **Calculate moments of inertia to compare with measured values**

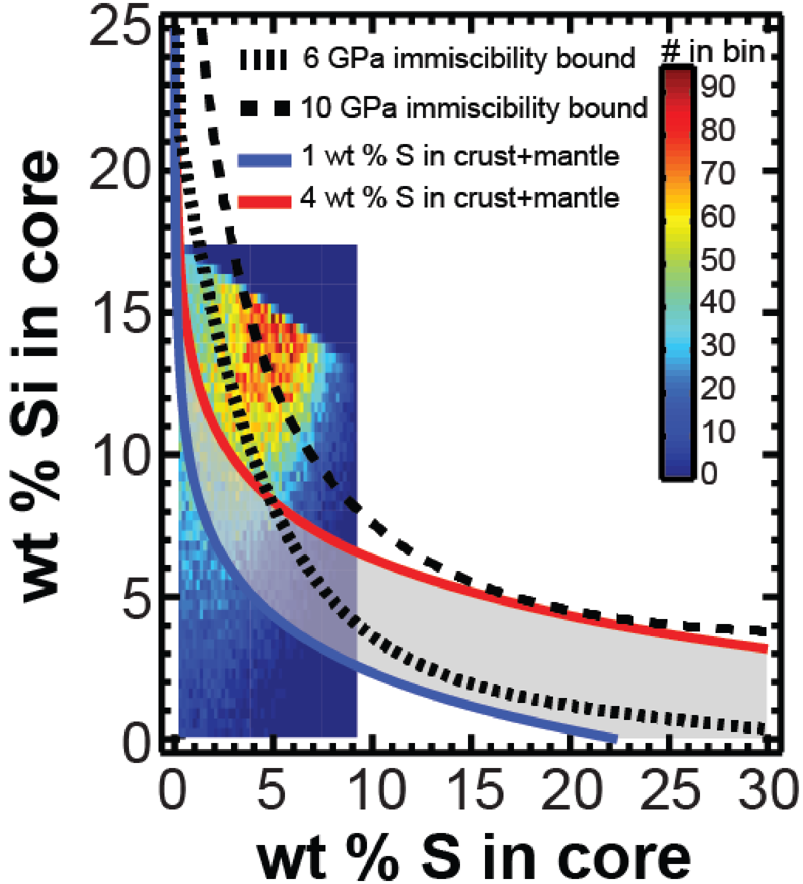


Internal structure

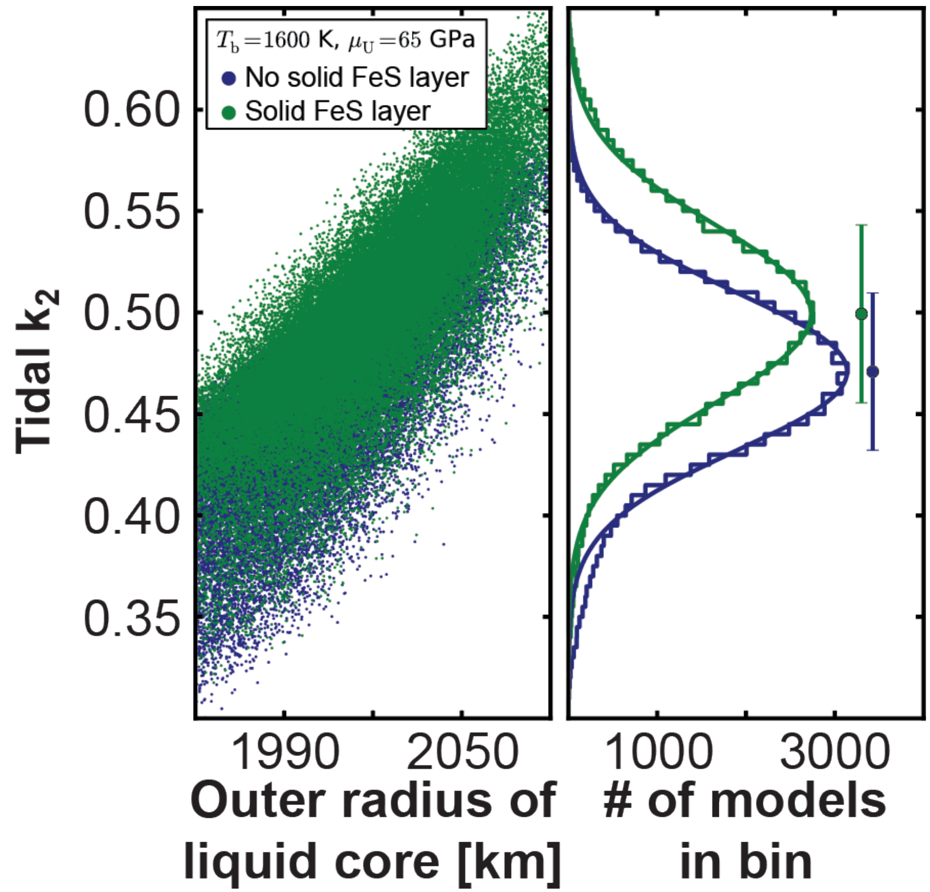


Models with additional constraints from metal:silicate partitioning of S and Si (Chabot et al., 2014)

Is there a solid FeS layer in the core?

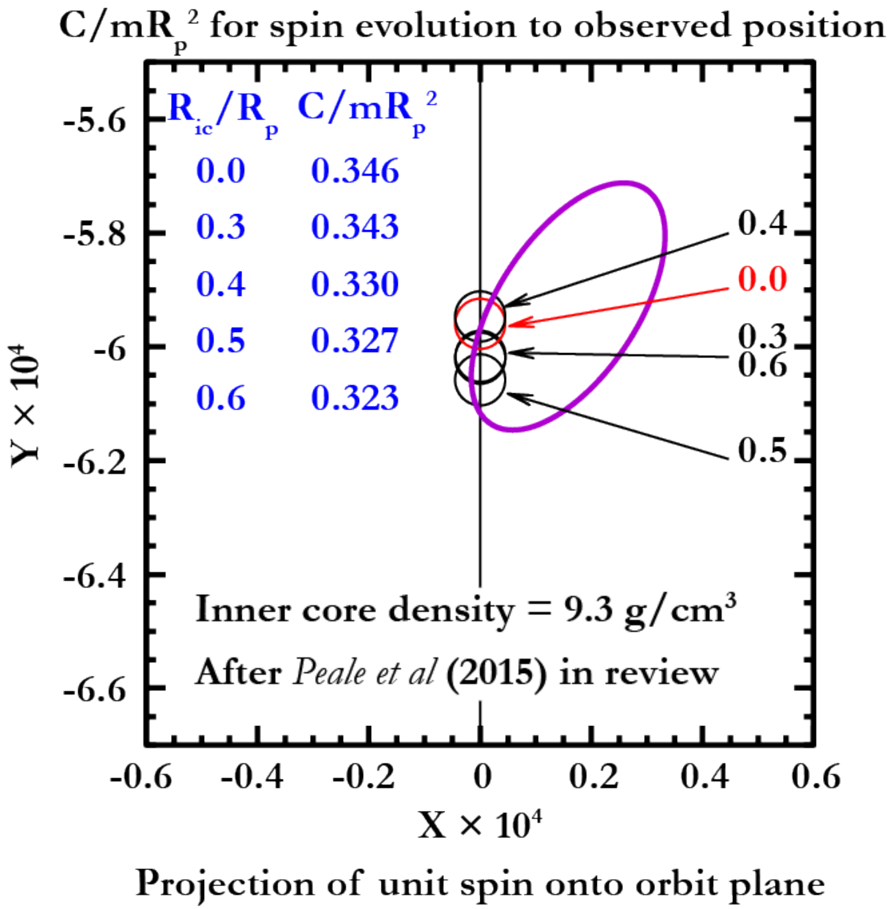


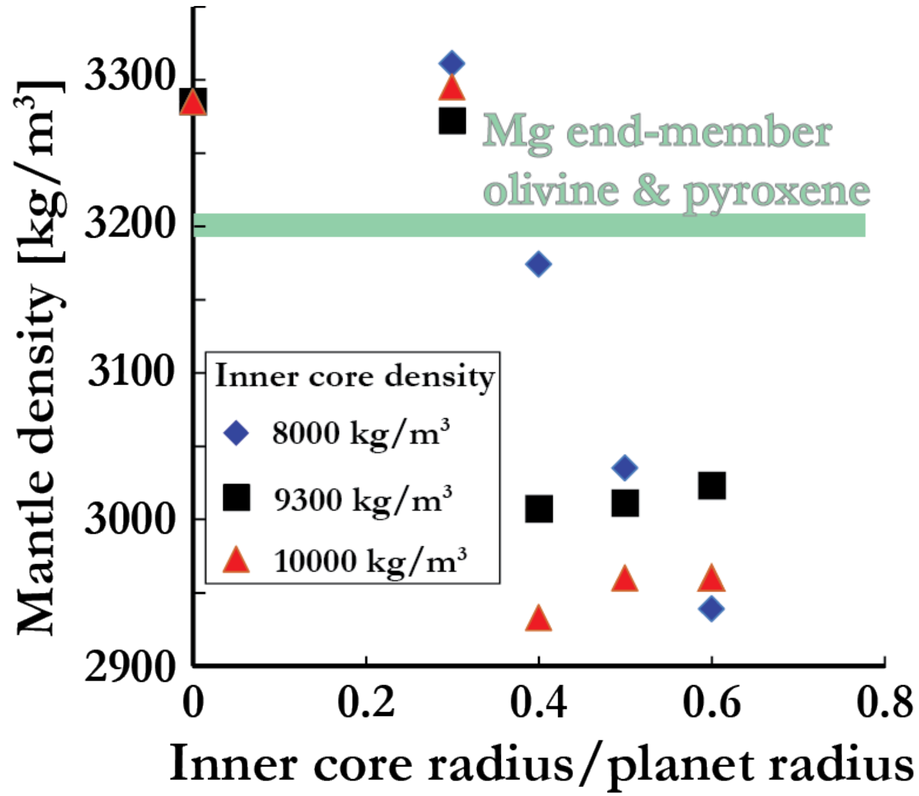
Hauck et al (2013) + Chabot et al (2014)

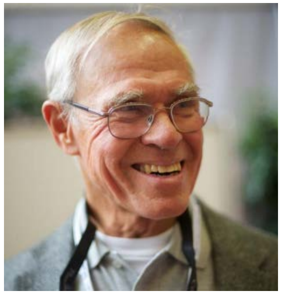


Padovan et al (2014)

Role of inner core size

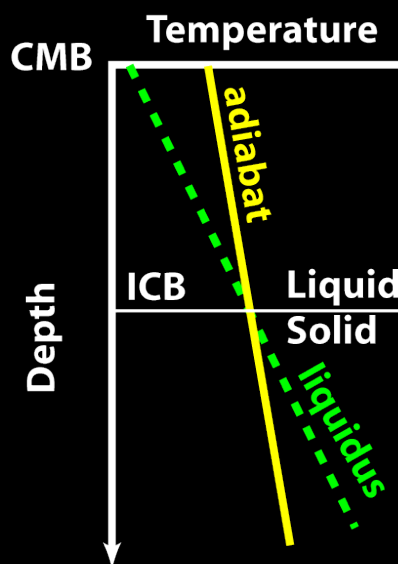






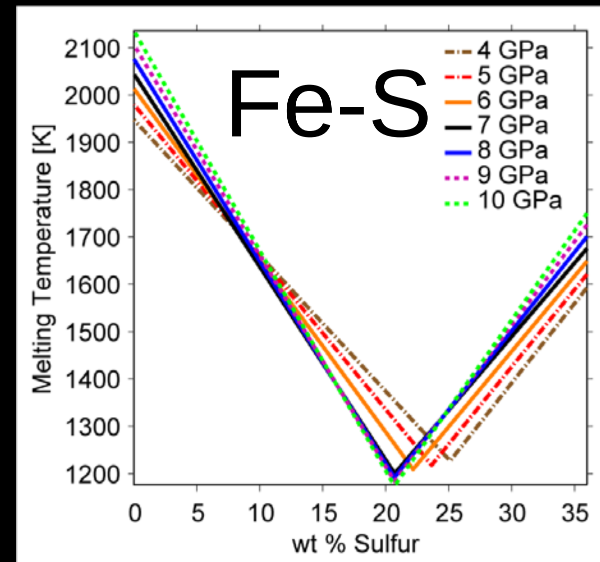
Stan Peale (1937-2015)

Core crystallization

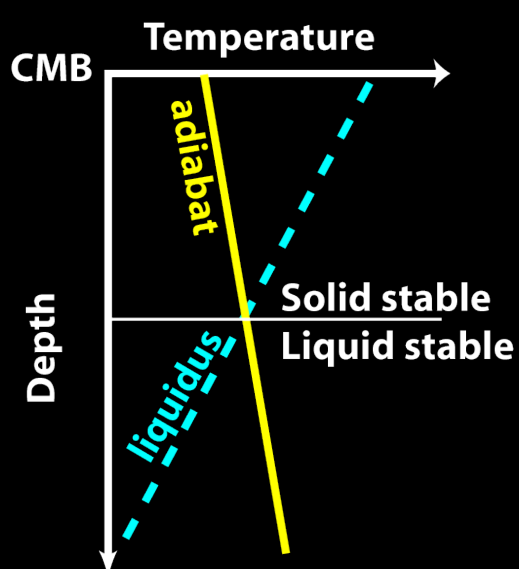


$dT_{liquidus}/dP > dT_{adiabat}/dP$

- Deep precipitation
- **Earth-like**

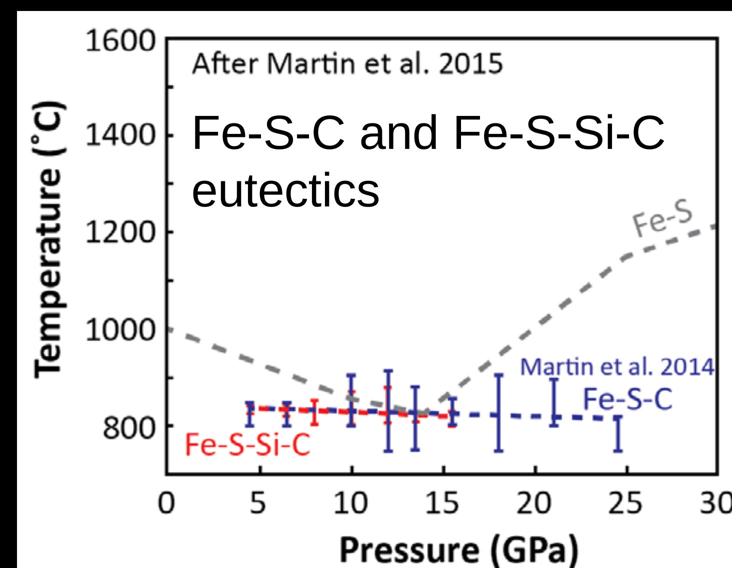


End member and eutectic data from *Boehler* [1992, 1996] & *Fei et al.* [1995, 1997, 2000]



$dT_{liquidus}/dP < dT_{adiabat}/dP$

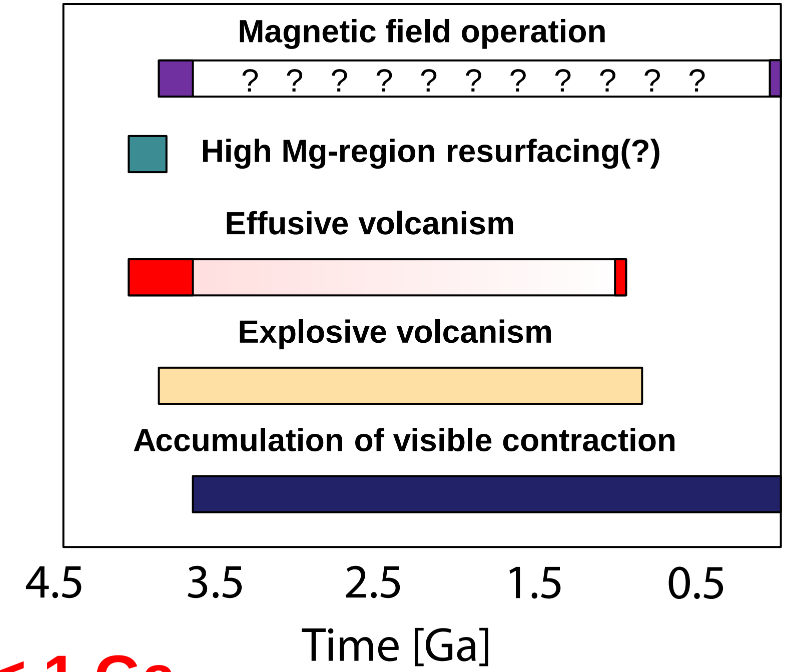
- Shallow precipitation
- **Ganymede?**
- **Moon?**
- **Mercury?**
- **Mars?**



But what does it all mean?

Constraints on internal activity

- **Radial contraction since LHB: ~5-7(+) km**
- **Mag field timing: 3.7-3.9 Ga & today.**
- **Resurfacing: HCT ~4.1-4.0 Ga , NVP/Caloris ~3.8-3.55 Ga, some limited younger stuff (e.g., Rachmaninoff ~1 Ga)**

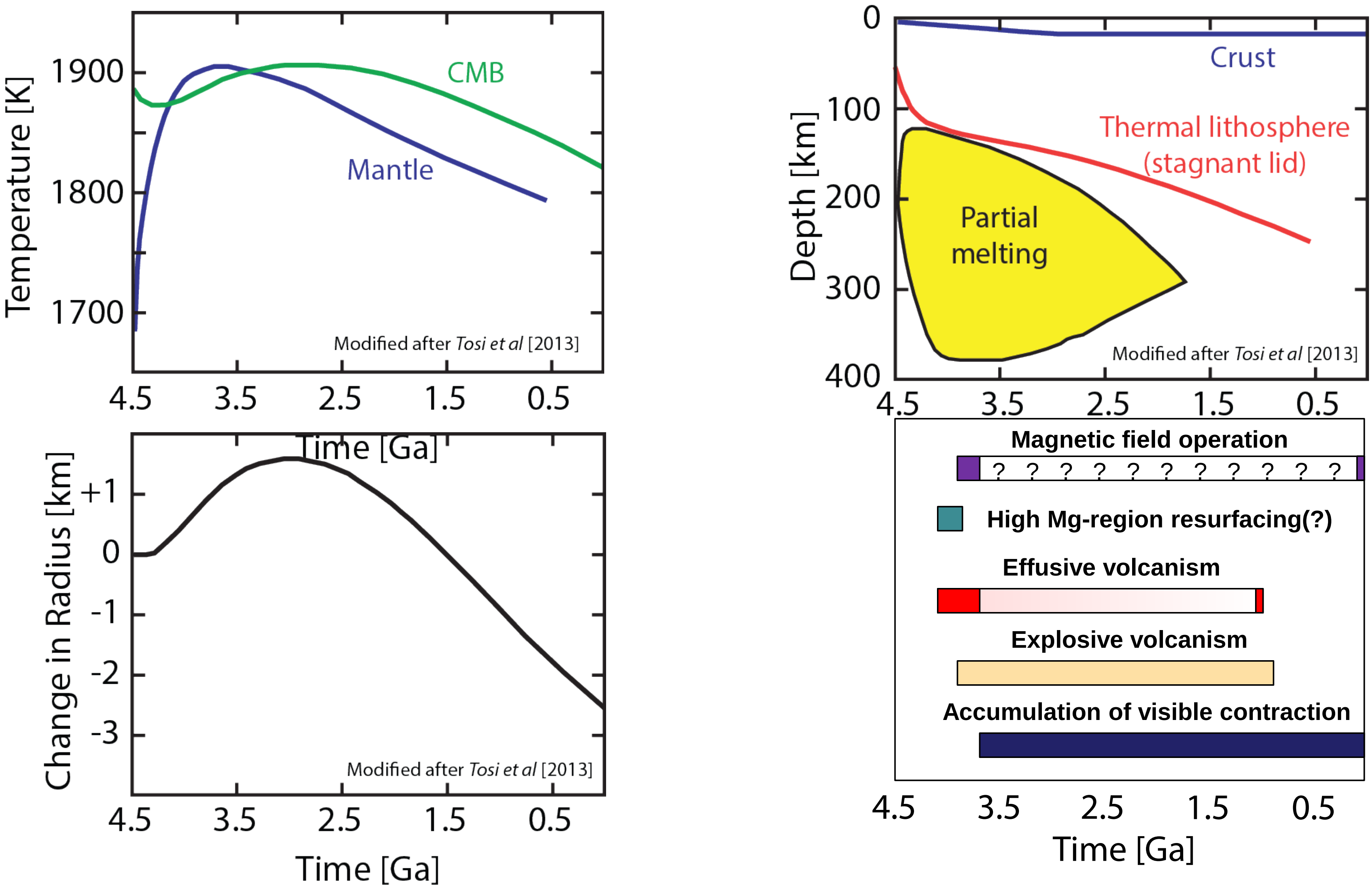


- **Explosive volcanism: 3.9 Ga → < 1 Ga**
- **Surface compositions: suggest lava liquidus temperatures (@ 1 bar – higher at depth) of ~1723 K for HCT and probably high degrees of melting.**
  - **Several distinct lava compositions, including Caloris interior and NVP, and distinct older compositions, e.g., HMR, southern hemisphere heavily cratered terrains, etc.**

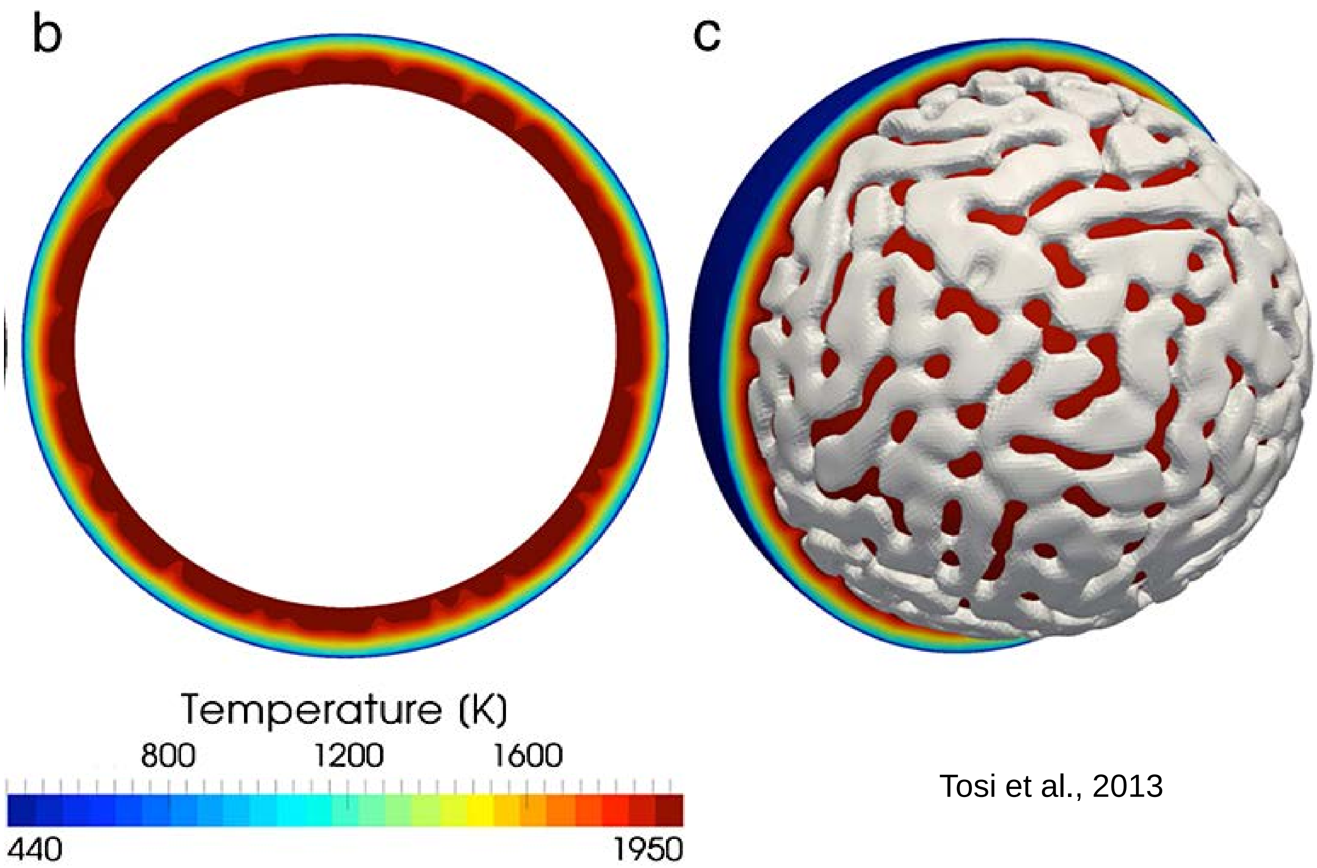
Thermal evolution

- Temperature drives most things
- Through temperatures and rate of heat loss the thermal evolution is intimately connected to:
  - Major tectonic activity
  - Major volcanic activity
  - History of magnetic field

Generic thermal evolution



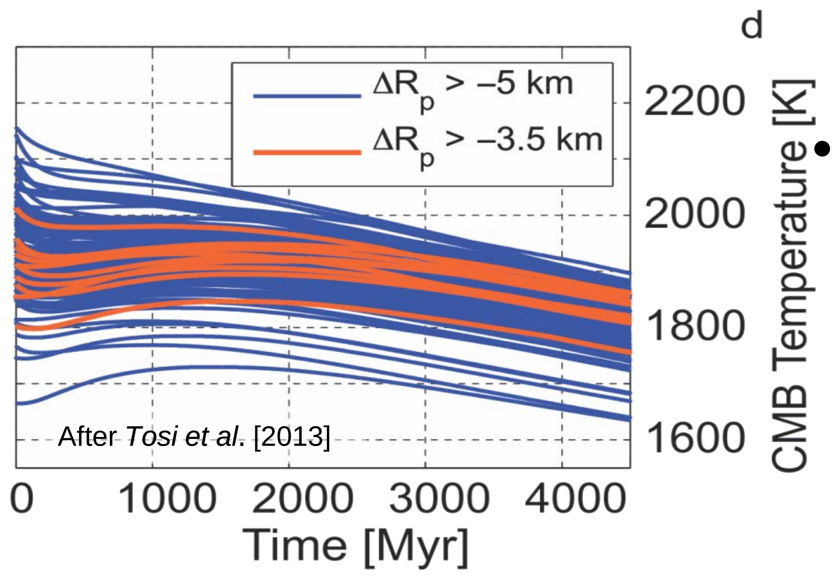
3-D Picture



Tosi et al., 2013

- **Note the small scale of upwellings and thick lithosphere – melt production could be widely distributed, though perhaps not typically voluminous**
- **Questionable mixing efficiency due to small scale of cells and the low convection velocities**

Magnetic field results…

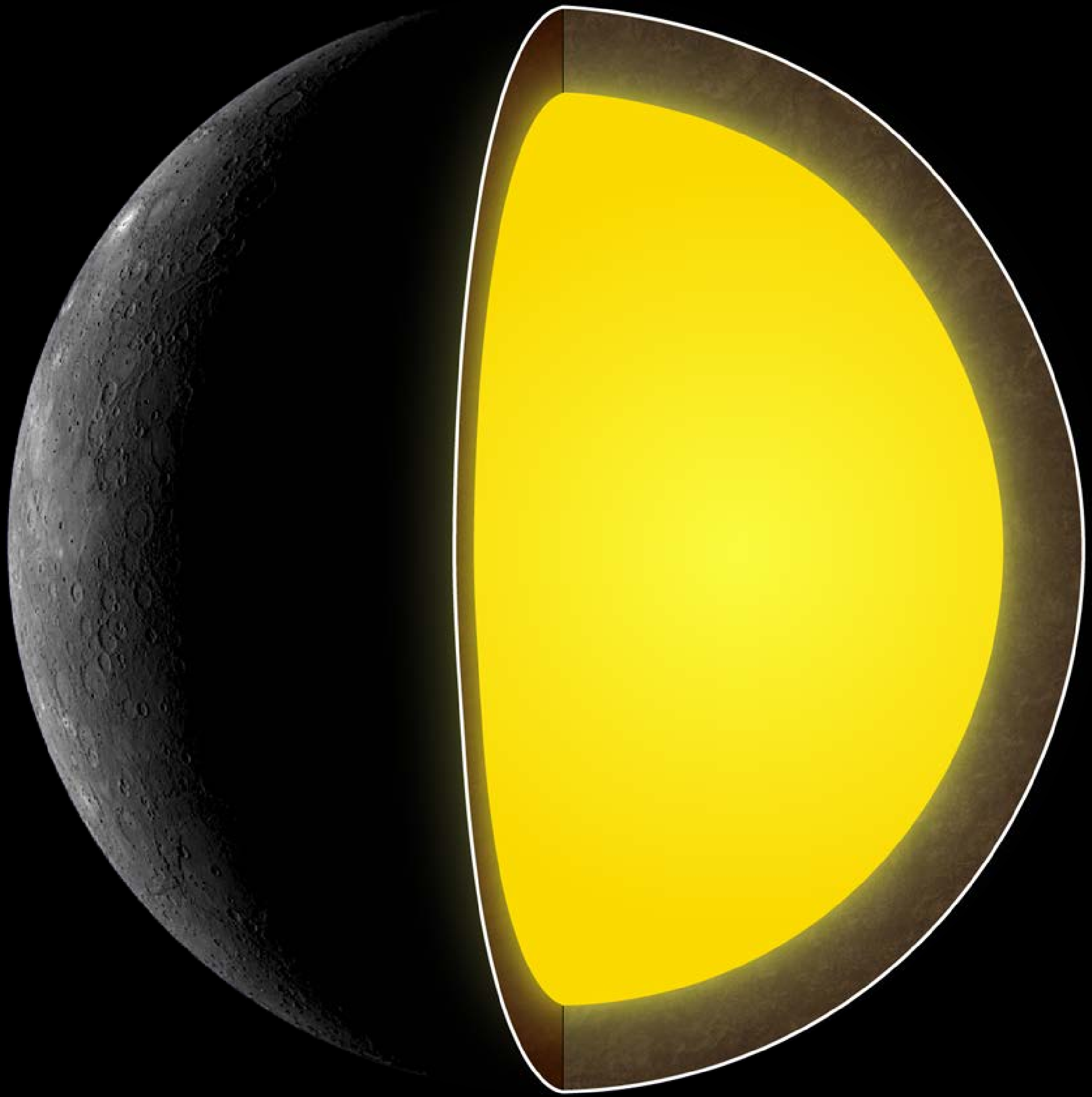


- **Core cooling is slow, sustained thermal dynamo is very unlikely.**
- **Early and present day magnetic field is challenge. Requires one of the following:**
  - **Core solidification for ~3.7 Gyr**
  - **Transient early dynamo and more recent core restart due to solidification.**
  - **Lots of core heat generation**

- **Regardless, may rule out models with slow early mantle convection leading to core warming – ruling out at least some global expansion models**

Future opportunities

- Mercury’s obliquity
- Global Fe, Mg, S, Ca, etc inventory at geological scales
- Global gravity
- Global fine-scale topography
- Laboratory geochemistry and petrology to interior compositions
- Refining understanding of both
  - Age of magnetic field
  - Mechanism(s) of dynamo generation



Graphic courtesy P. Byrne