Mercury Science 2010-2020

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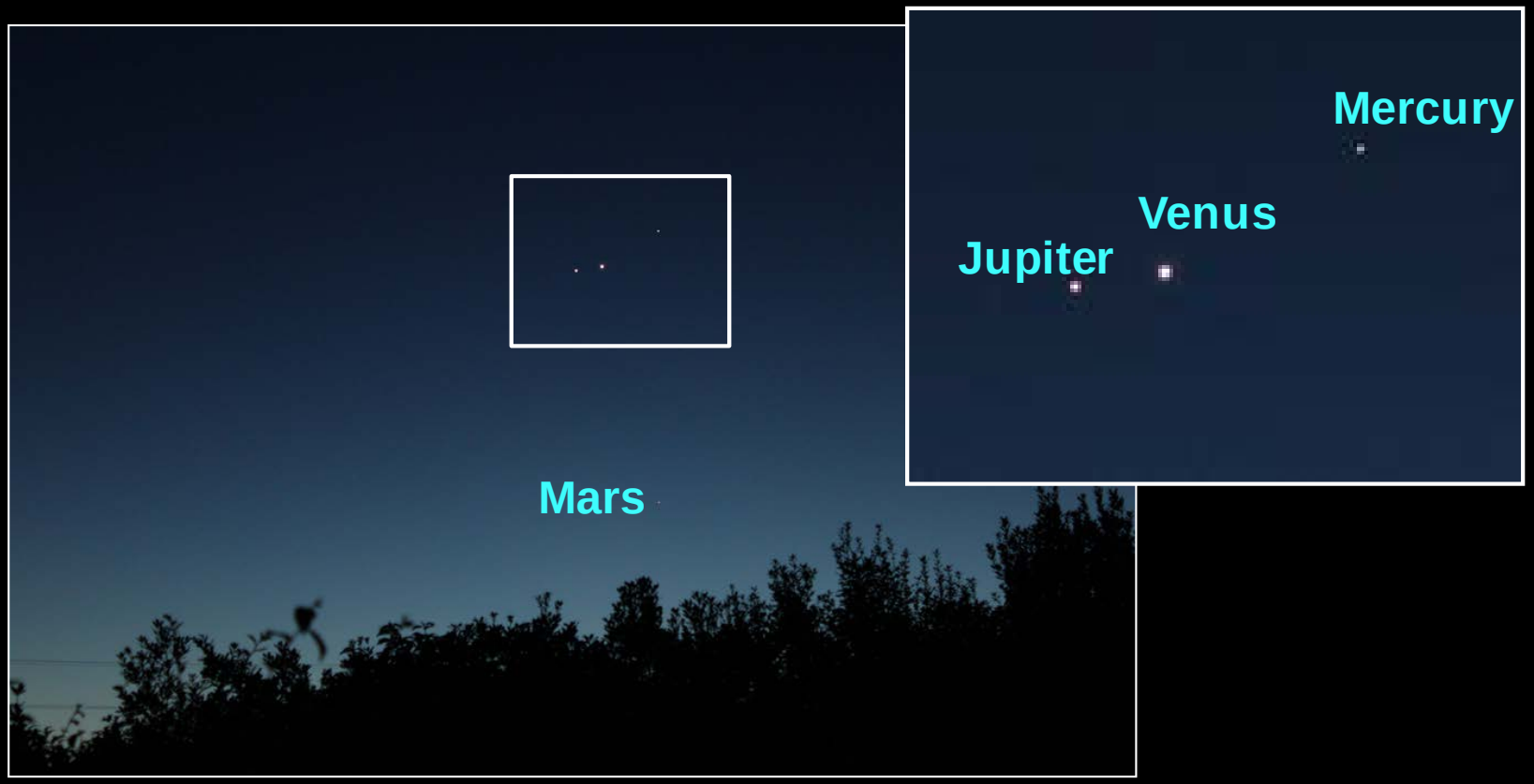
Presentation to PSDS Panel on Mercury and the Moon Jan 29, 2021

Mercury

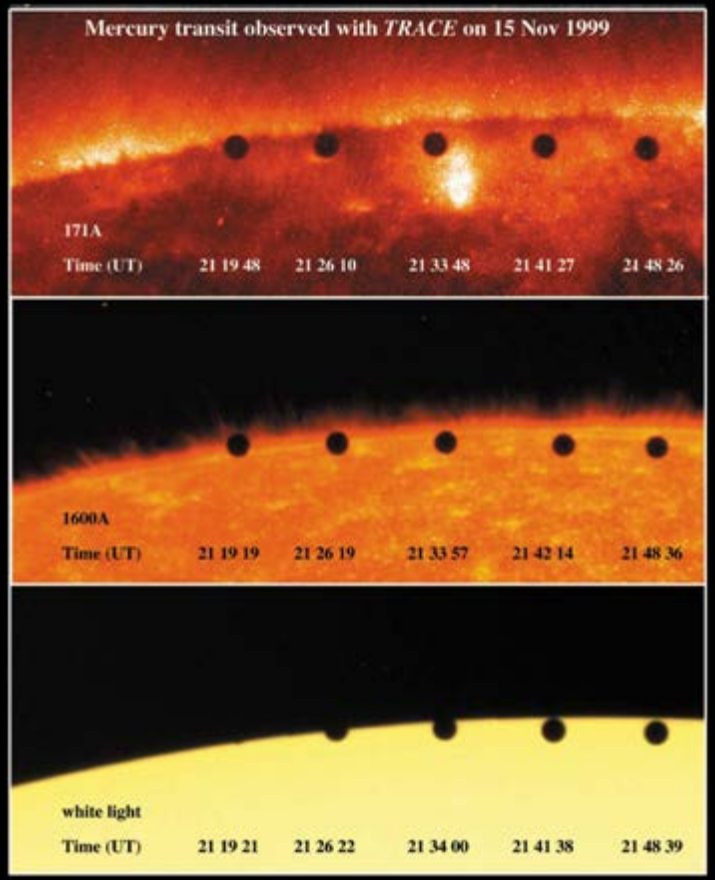


May 12, 2011, from NZ (M. White, Flickr)

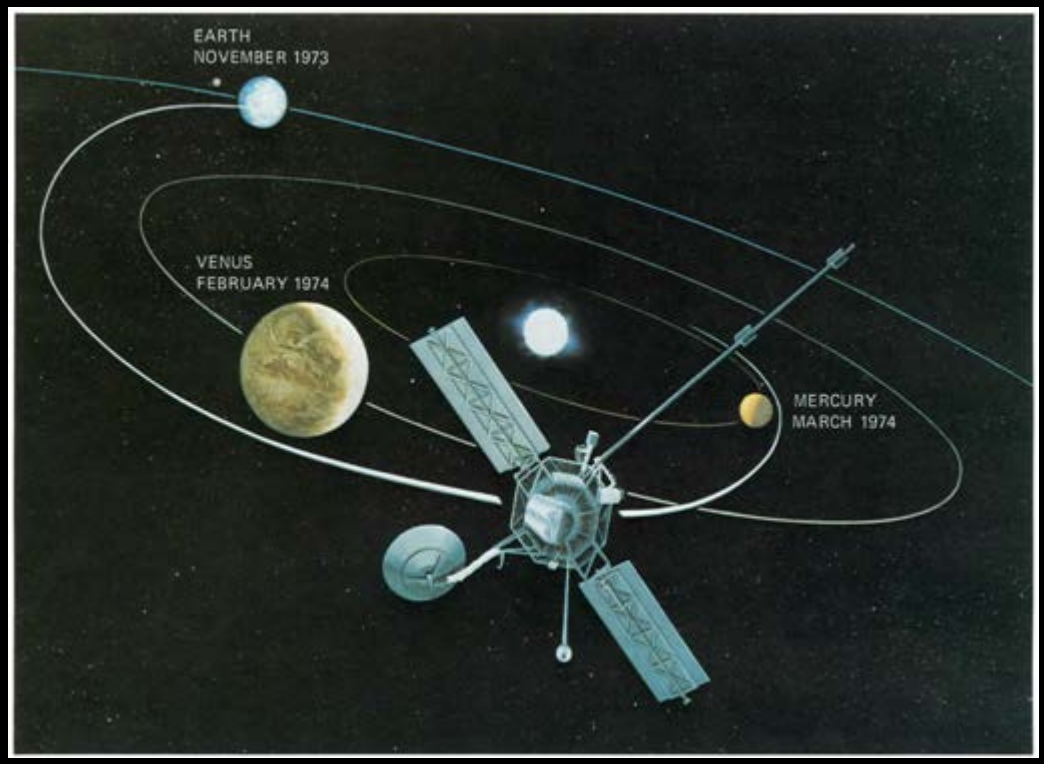
- Naked-eye planet, but very difficult to observe due to proximity to Sun

Mercury Is Difficult to Study

…by telescope …



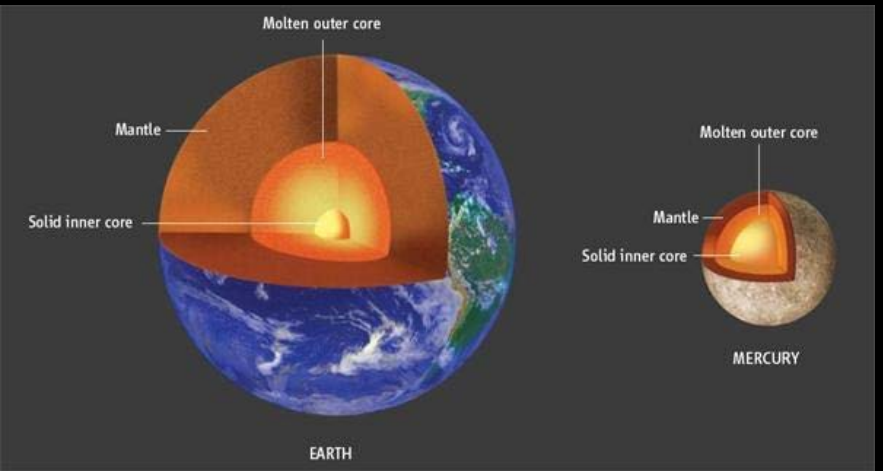
…or spacecraft.



Only visit prior to 2008 was by Mariner 10, 1974-1975

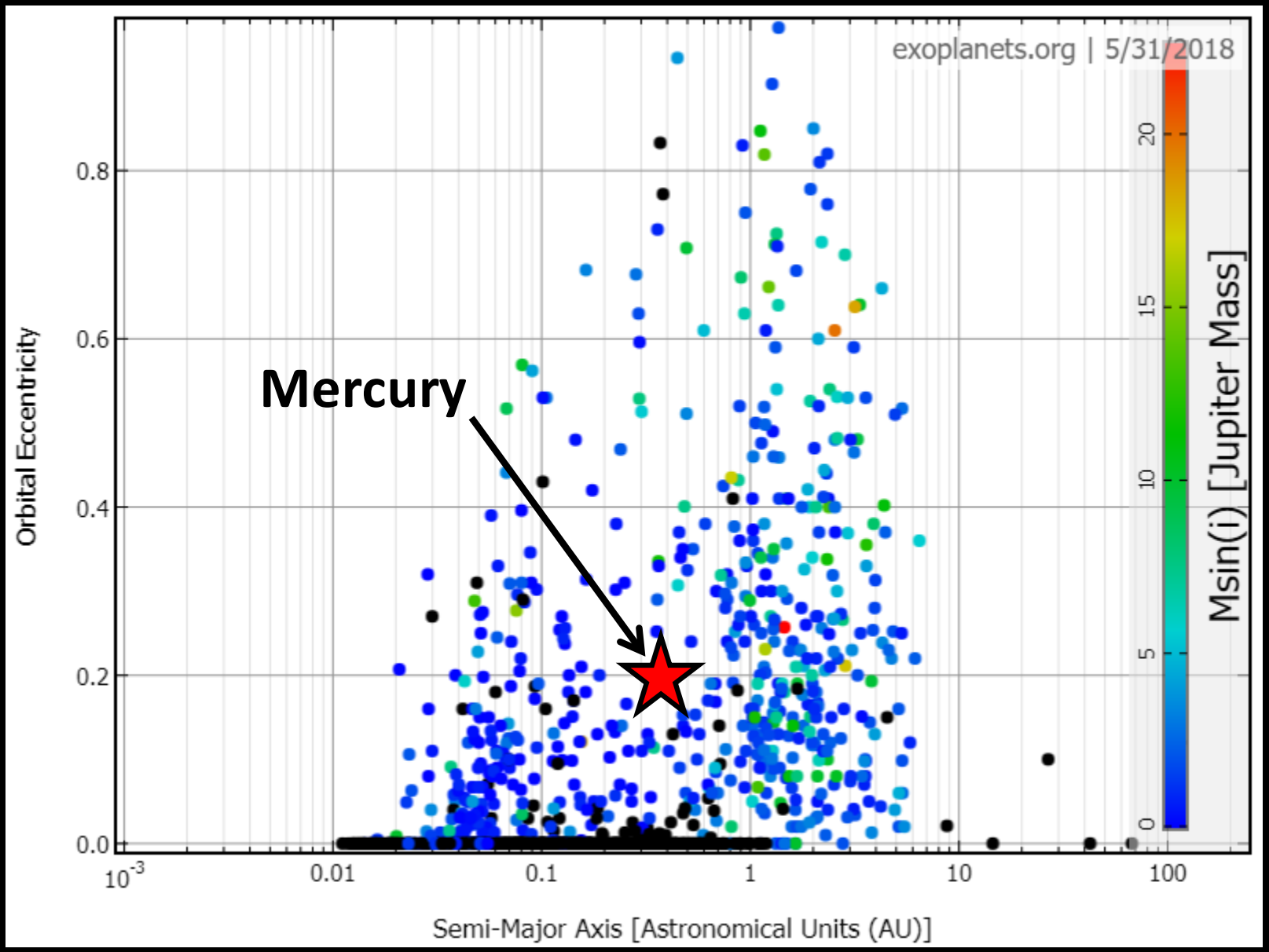
Mercury: planet of extremes

- Smallest, densest planet
- Closest to Sun
- Highest diurnal variation in temperature
  - −170 ºC to +430 ºC
- Very high Fe:silicate ratio
  - Core ~70% of mass, 80% radius
- Magnetic field: dynamic magnetosphere
- Exosphere (Na, K, Ca, H, He, O)
- Low FeO in surface silicates
- Evidence for water ice in polar craters

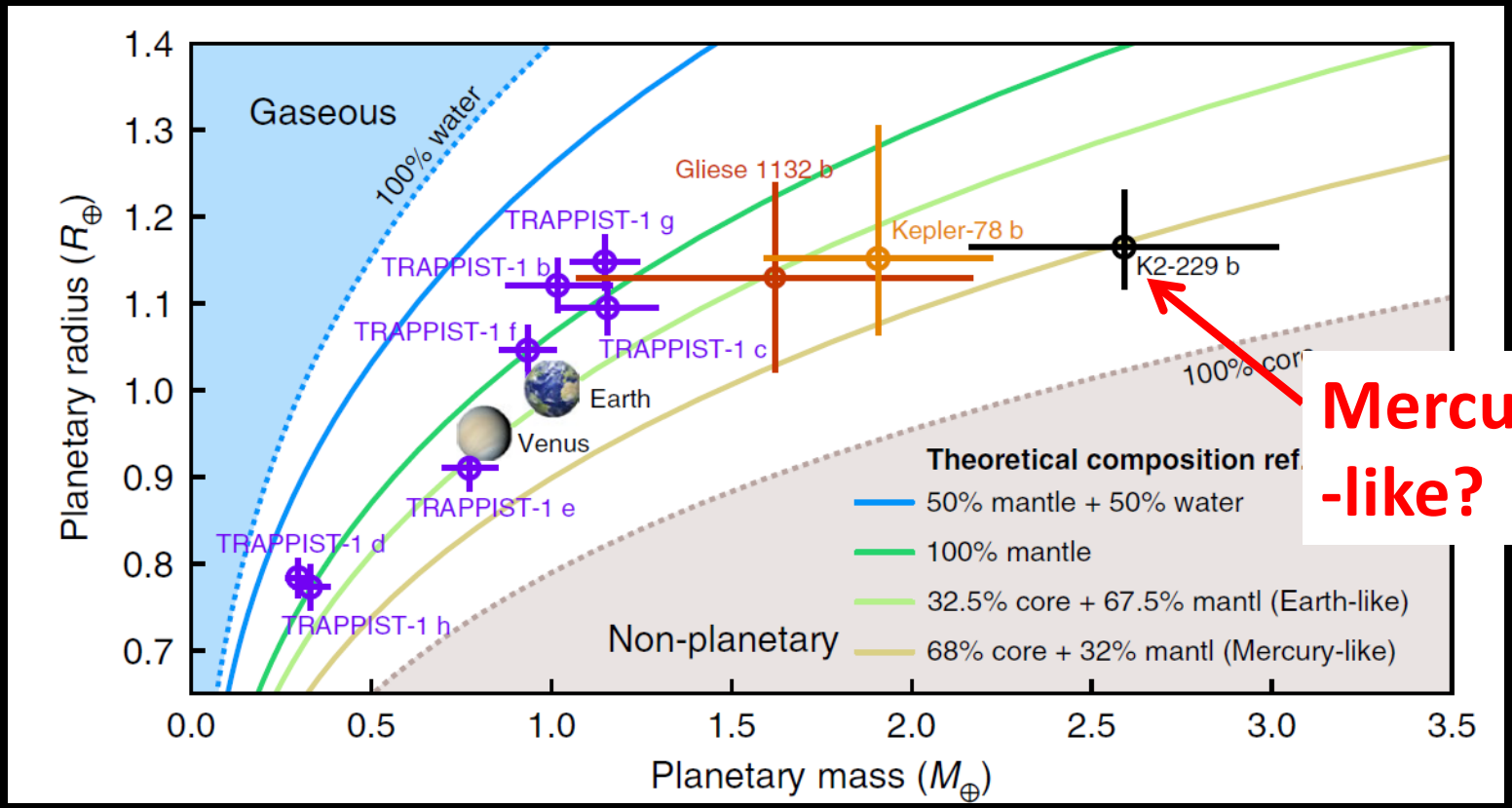


"end-member of planet formation"

Extrasolar Planetary Context

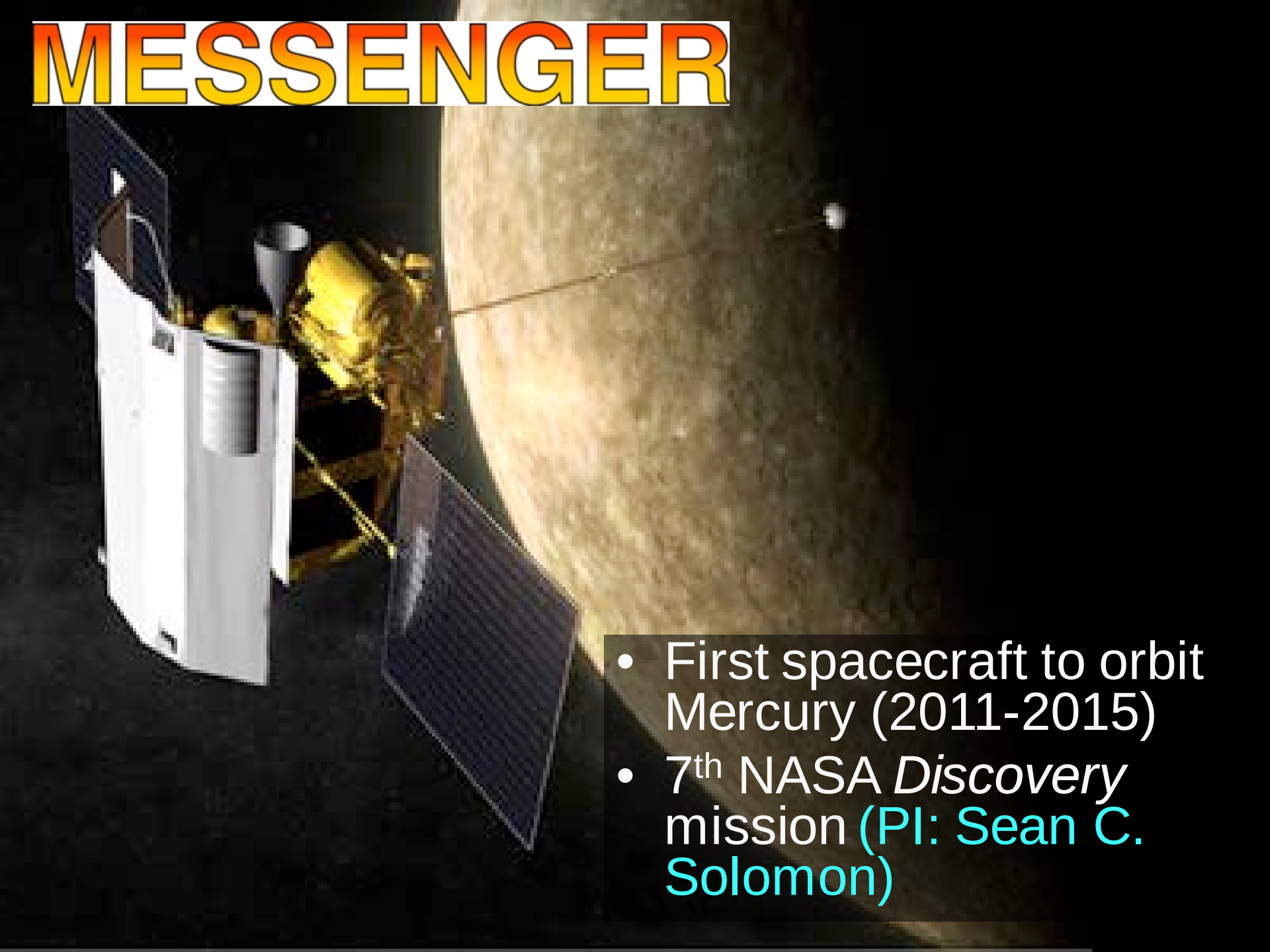


Extrasolar Planetary Context



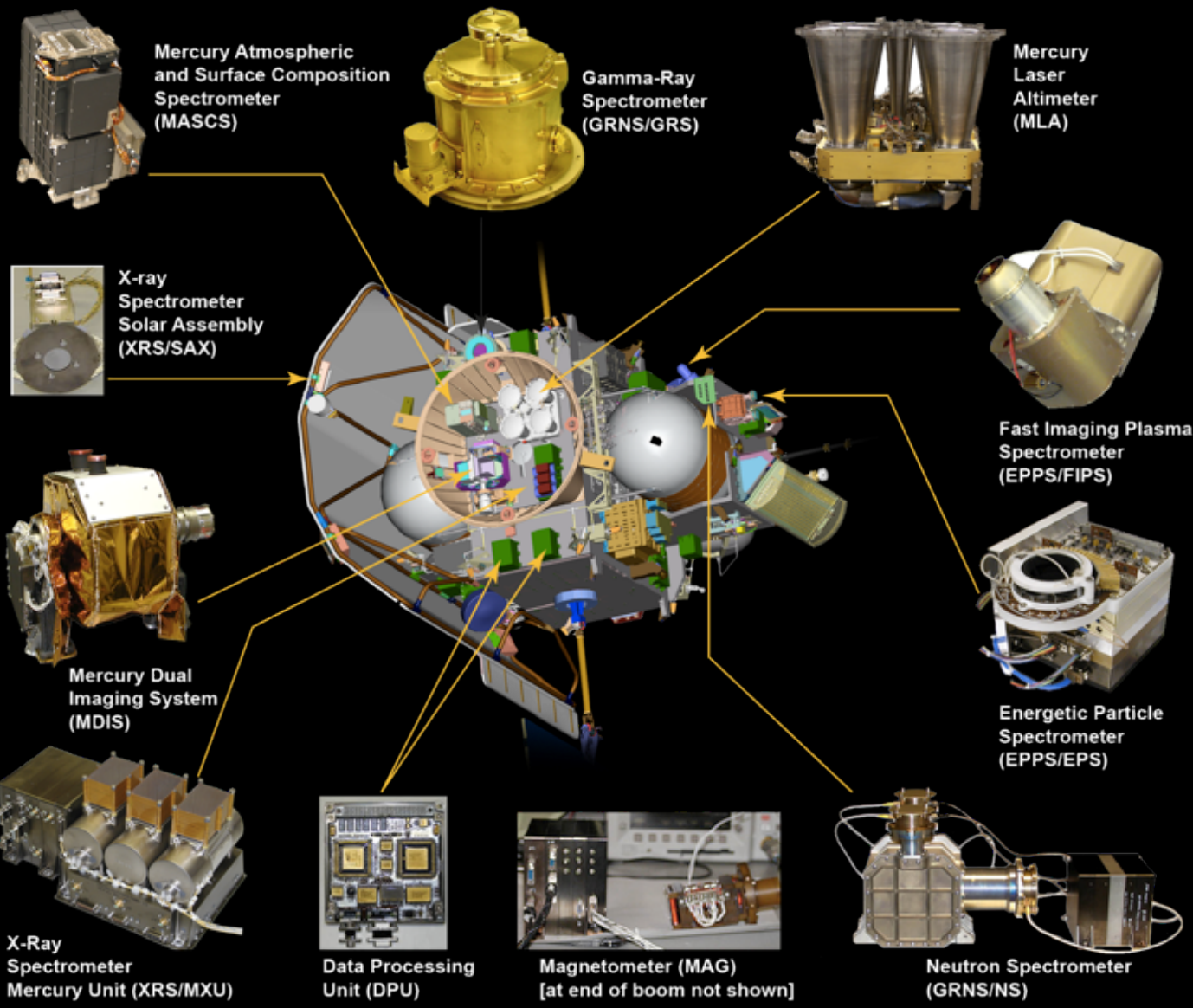
Saterne et al. 2018

MESSENGER

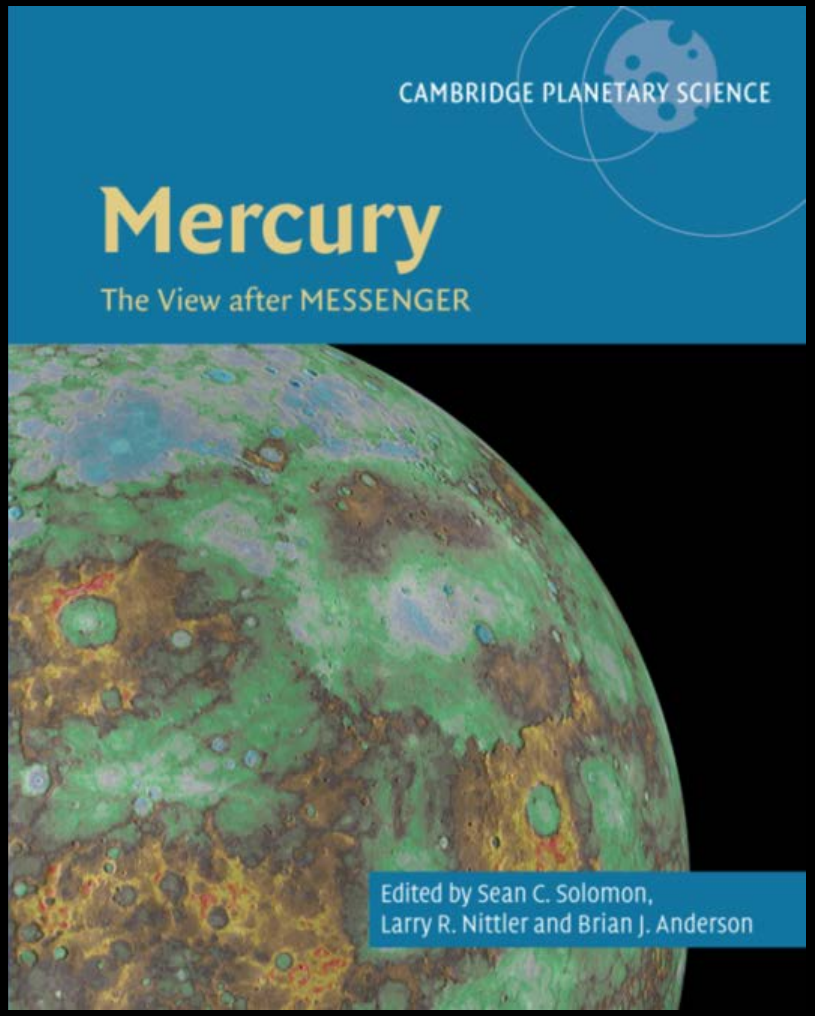


- First spacecraft to orbit Mercury (2011-2015)
- 7th NASA *Discovery* mission (PI: Sean C. Solomon)

MESSENGER's Scientific Payload

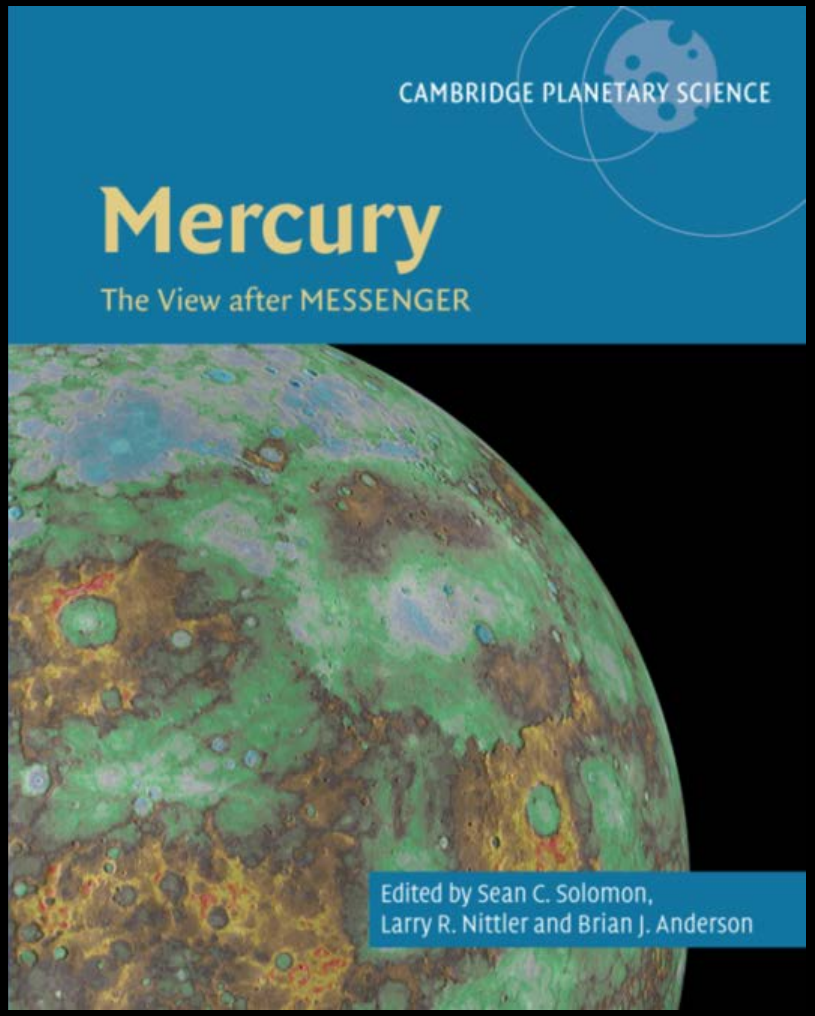


MESSENGER



- Orbited Mercury for 4 years
- Returned wealth of data from 9 instruments
- Revolutionized understanding of planet
  - Geochemistry
  - Geology
  - Geophysics
  - Exosphere
  - Magnetosphere

MESSENGER



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- Returned wealth of data from 9 instruments
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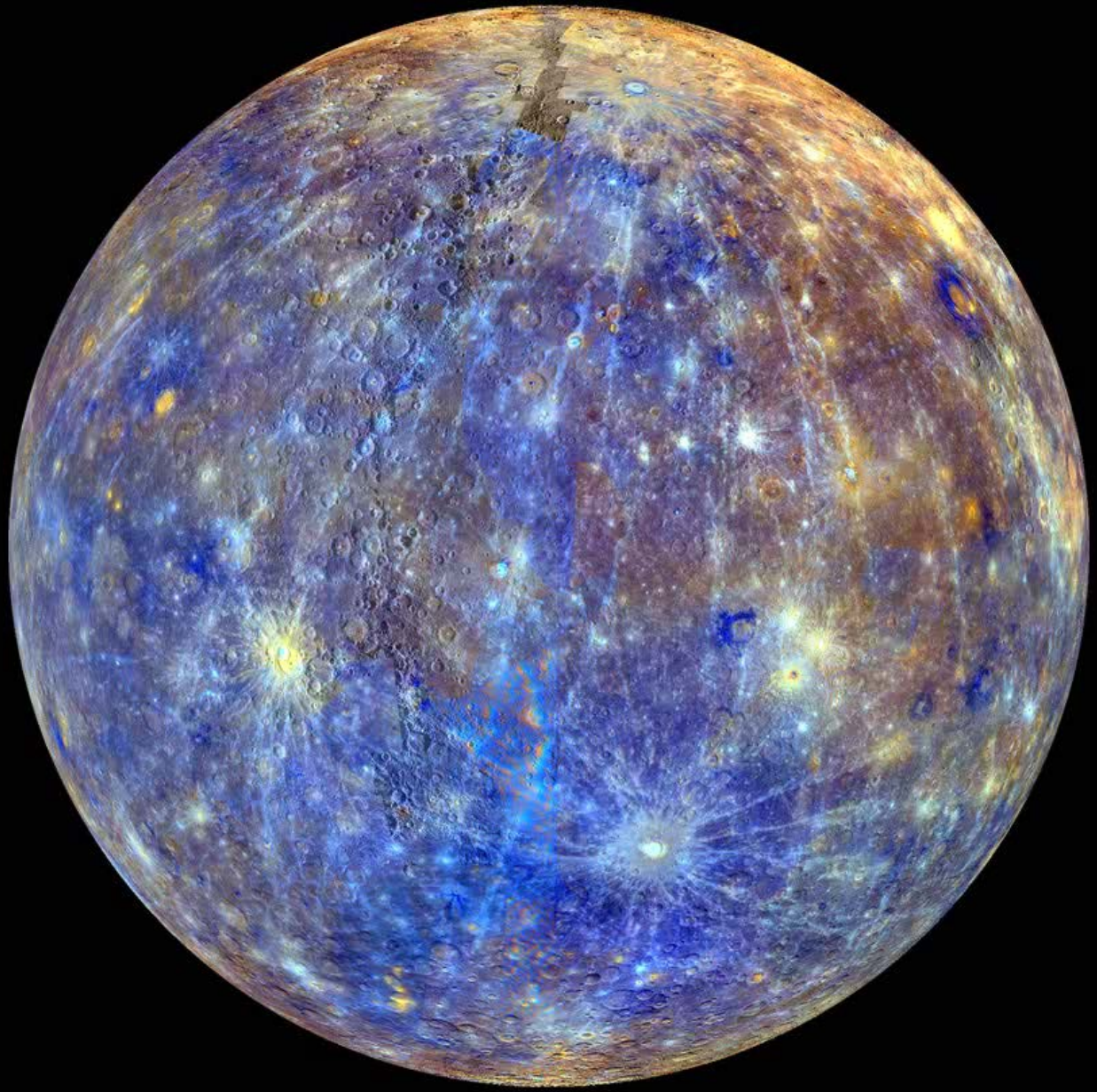
Most of our knowledge of Mercury was obtained in last decade, largely by MESSENGER investigations

Feb 2013: MESSENGER imaging coverage reached 100%

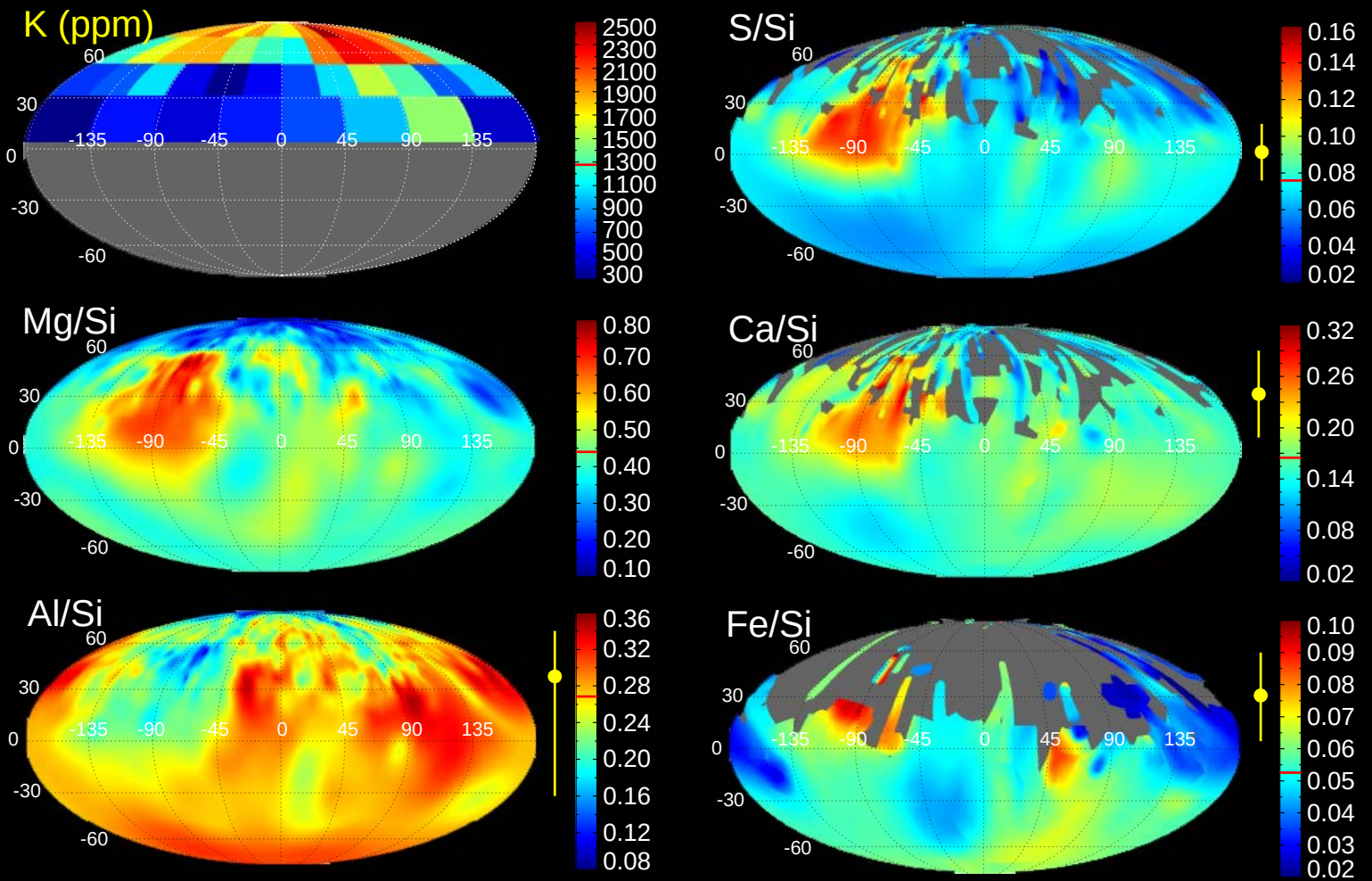
Mercury in “true” color – RGB: 630, 560, 480 nm



Mercury in "enhanced" color – RGB: PC2, PC1, 430/1000

Mercury has a heterogeneous surface composition

GRS XRS



Nittler et al., 2018

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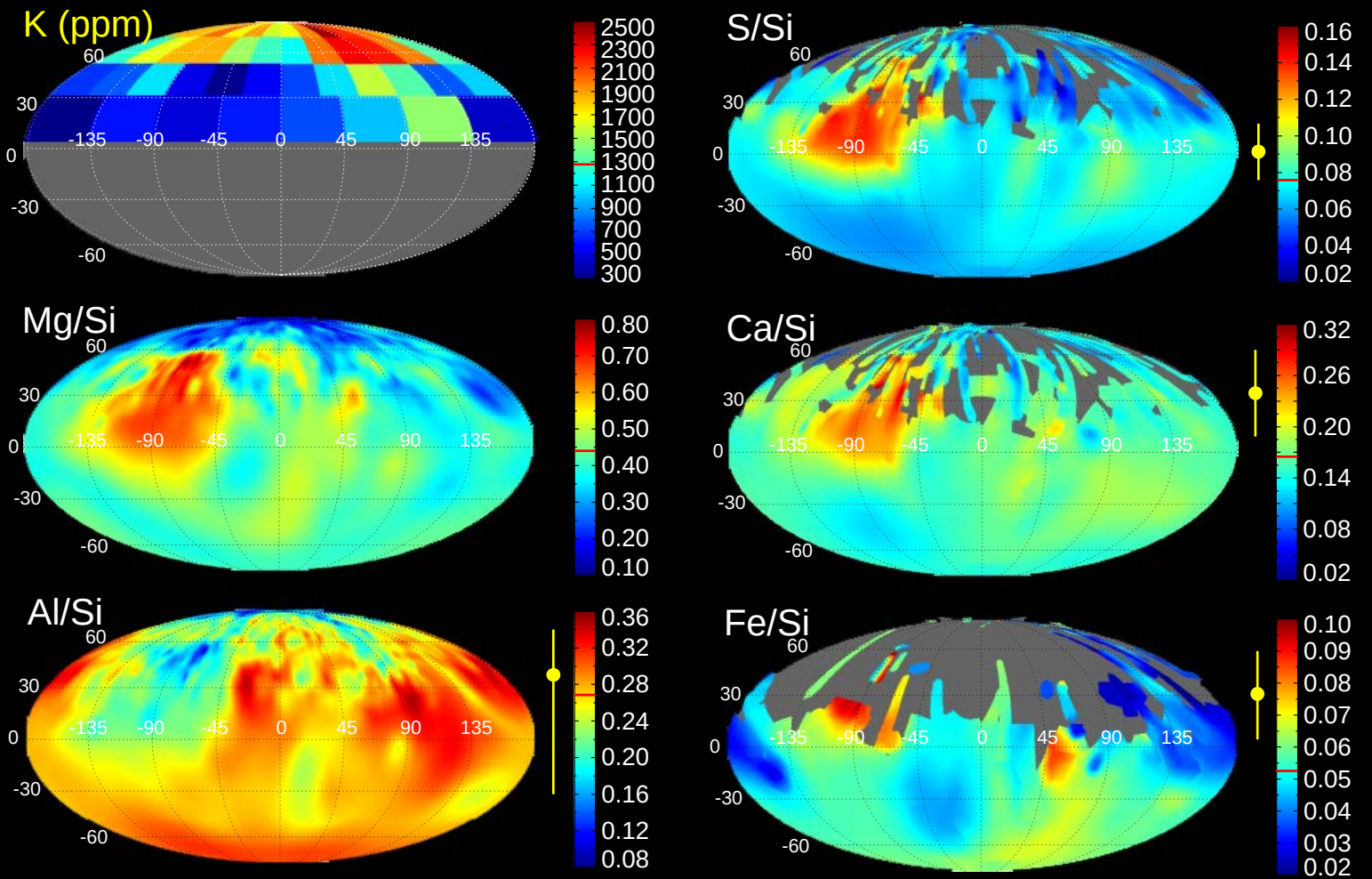
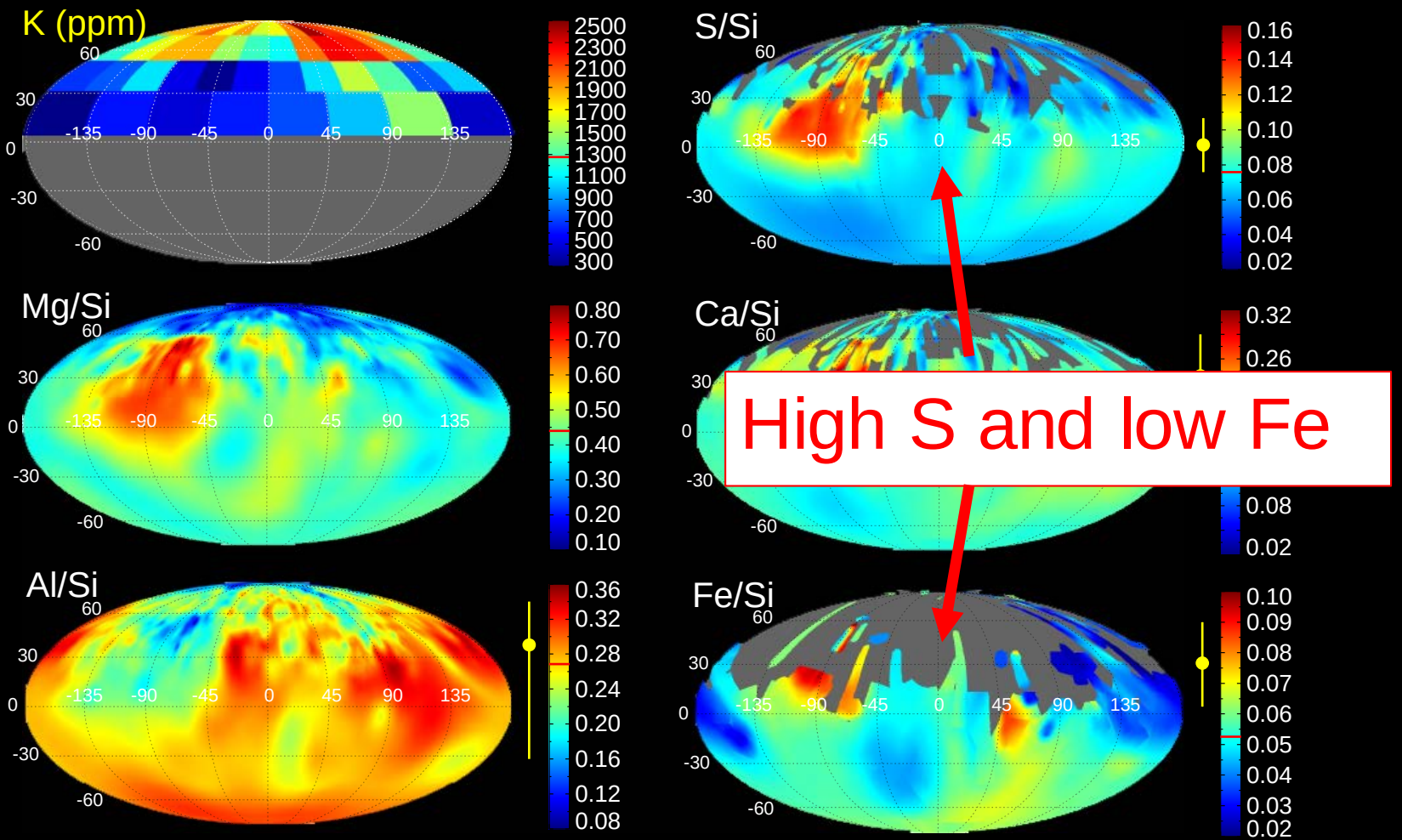


No lunar-like feldspar-rich flotation crust (Al/Si>0.6)

Nittler et al., 2018

Mercury has a heterogeneous surface composition

GRS XRS



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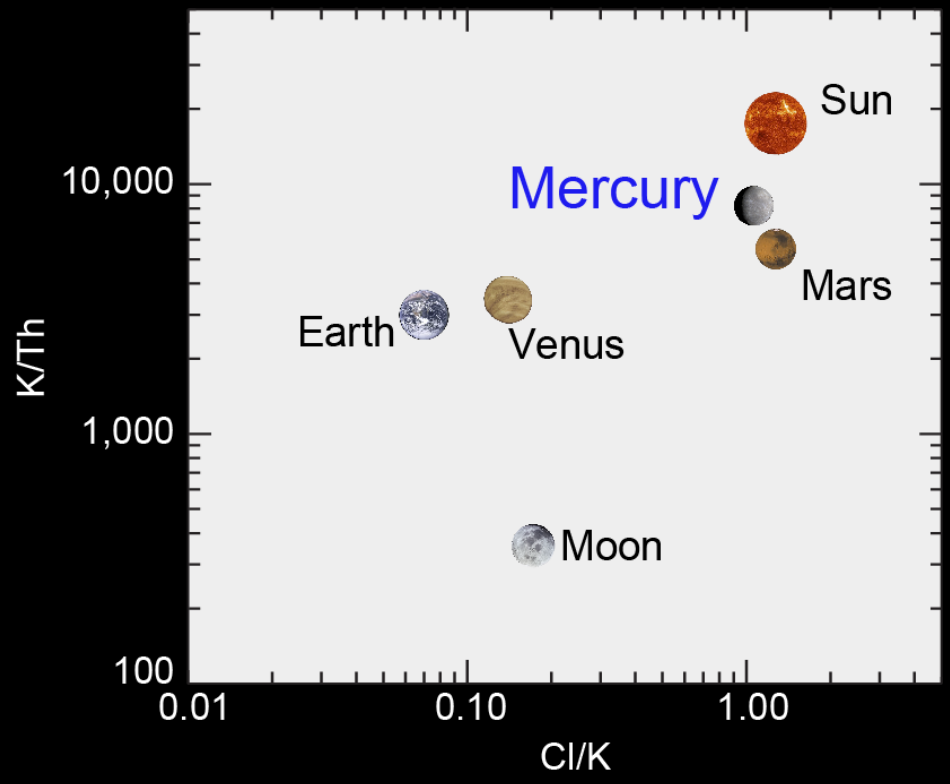
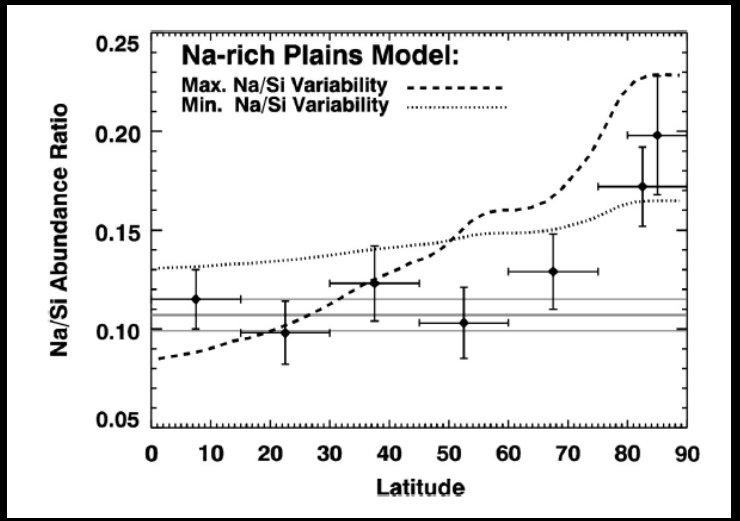
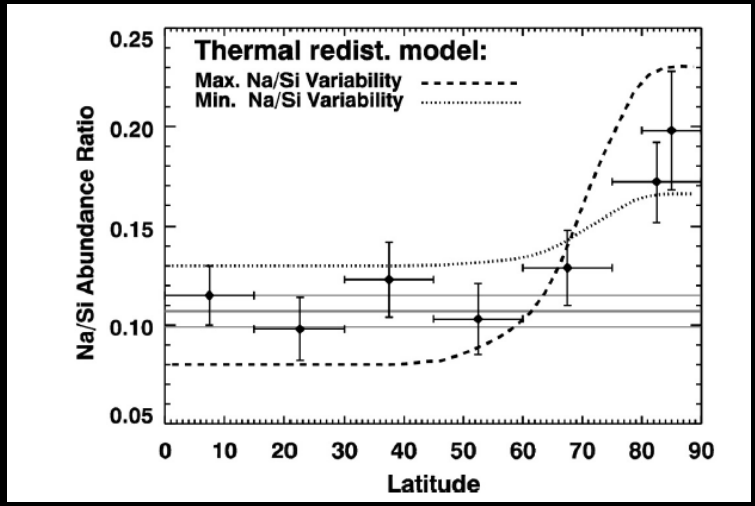
Nittler et al., 2018

Mercury is a volatile-rich world



(Peplowski et al.. 2011; Evans et al, 2015; Nittler & Weider 2019)





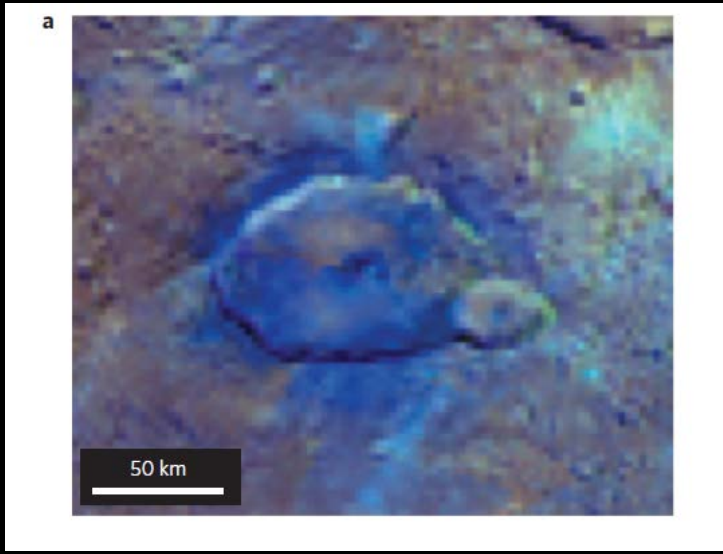
(3-5 wt% Na; Peplowski et al., Icarus, 2014)

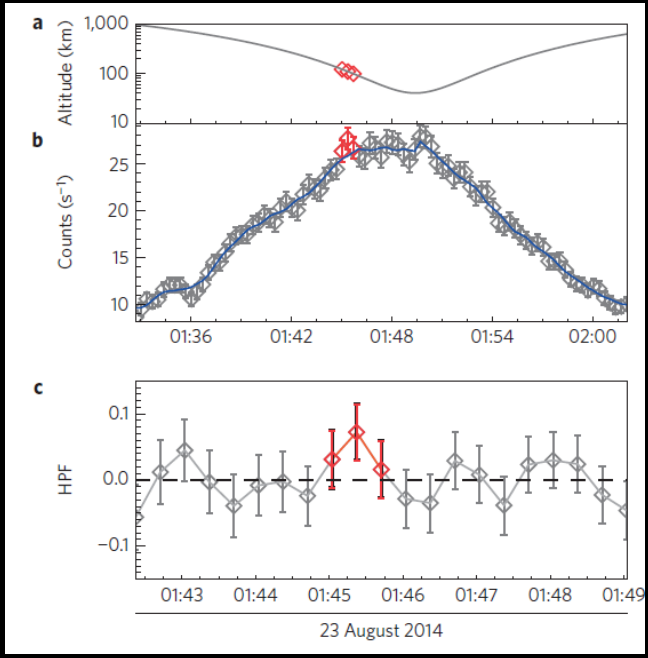
Mercury is a volatile-rich, chemically reduced world

- S,Fe contents indicates formation under much less oxidizing conditions than other planets
  - log fO_2=IW-2.6 to IW-7.3 (McCubbin+ 2012, 2017; Zolotov+ 2013; Namur+ 2016)
- Important constraints on still-mysterious origin of planet
  - Volatile-rich nature rules out many scenarios (e.g. Lewis 1972; Cameron 1988) involving very high temperatures
  - Distinct redox state indicates formation from different mix of building blocks than other terrestrial planets (role of water? Implications for accretion models?)

(Ebel and Stewart, 2018)

Carbon on Mercury

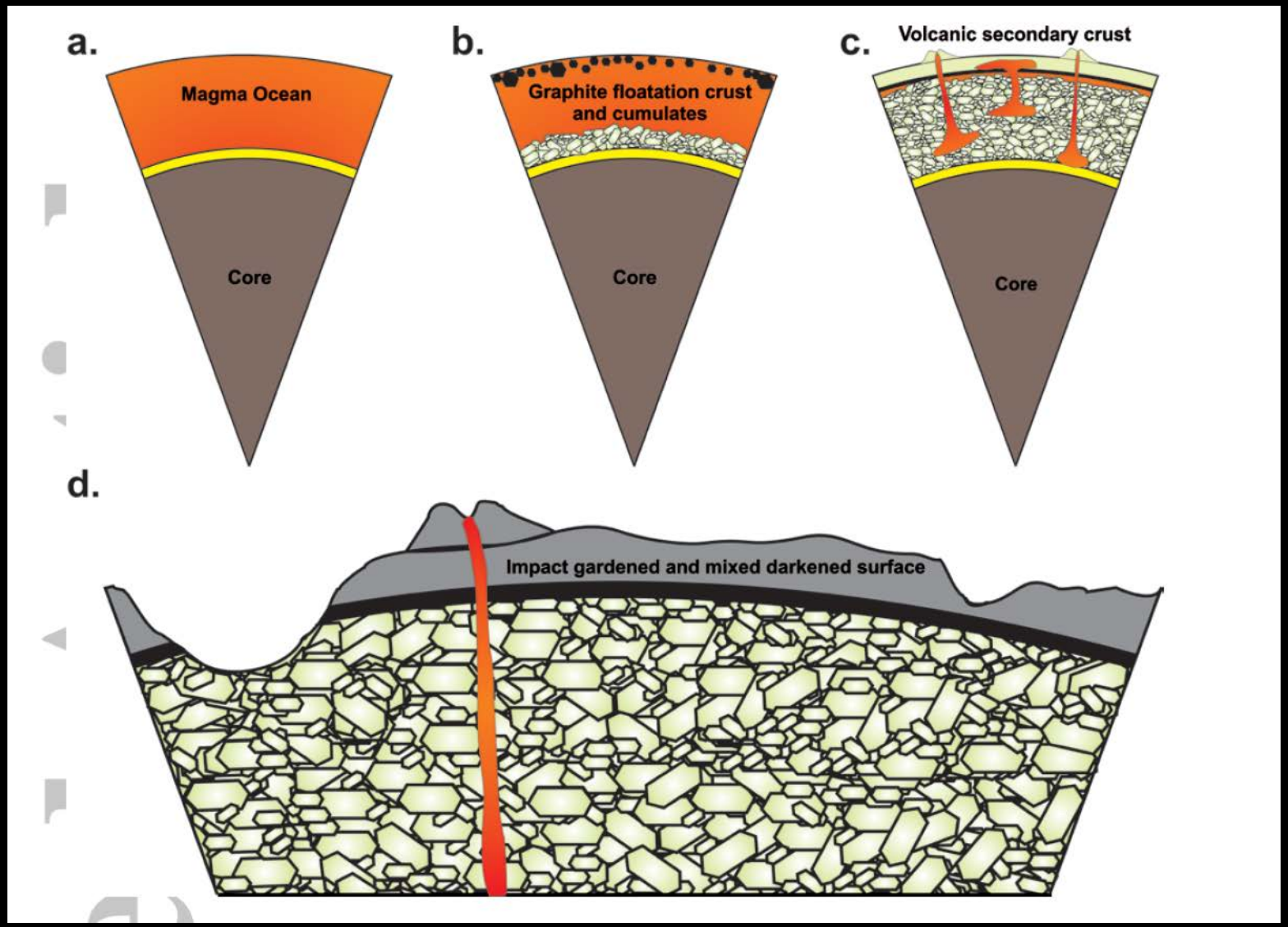




- Mercury very dark; darkest materials excavated from deep in crust
- Gamma-ray, VIR reflectance, and neutron data most consistent with graphite being “darkening agent,” with a few wt% C in crust

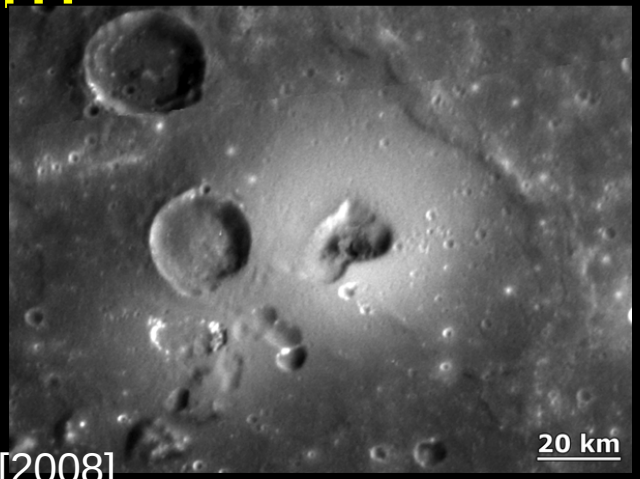
Murchie et al. 2015; Peplowski et al. 2015, 2016; Klima et al. 2018

Graphite magma ocean flotation crust?

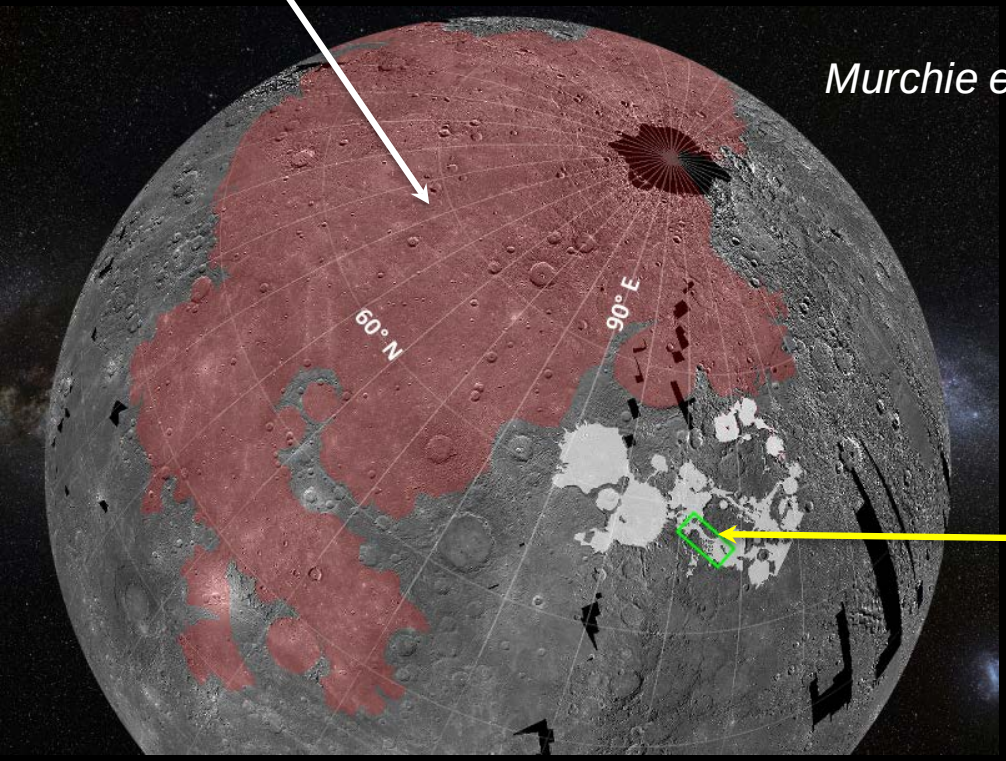


(Vander Kaaden et al. 2015)

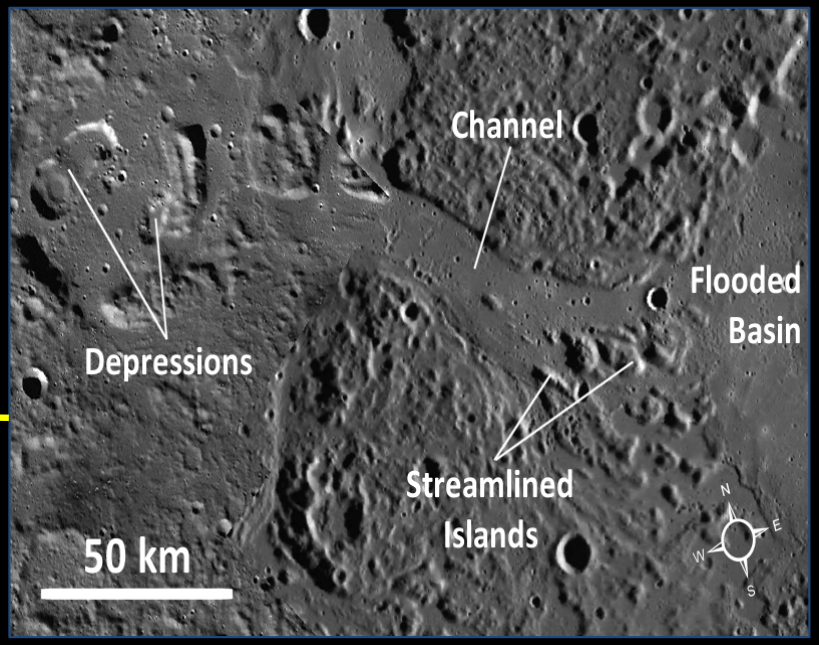
Mercury experienced widespread volcanism



Northern Plains

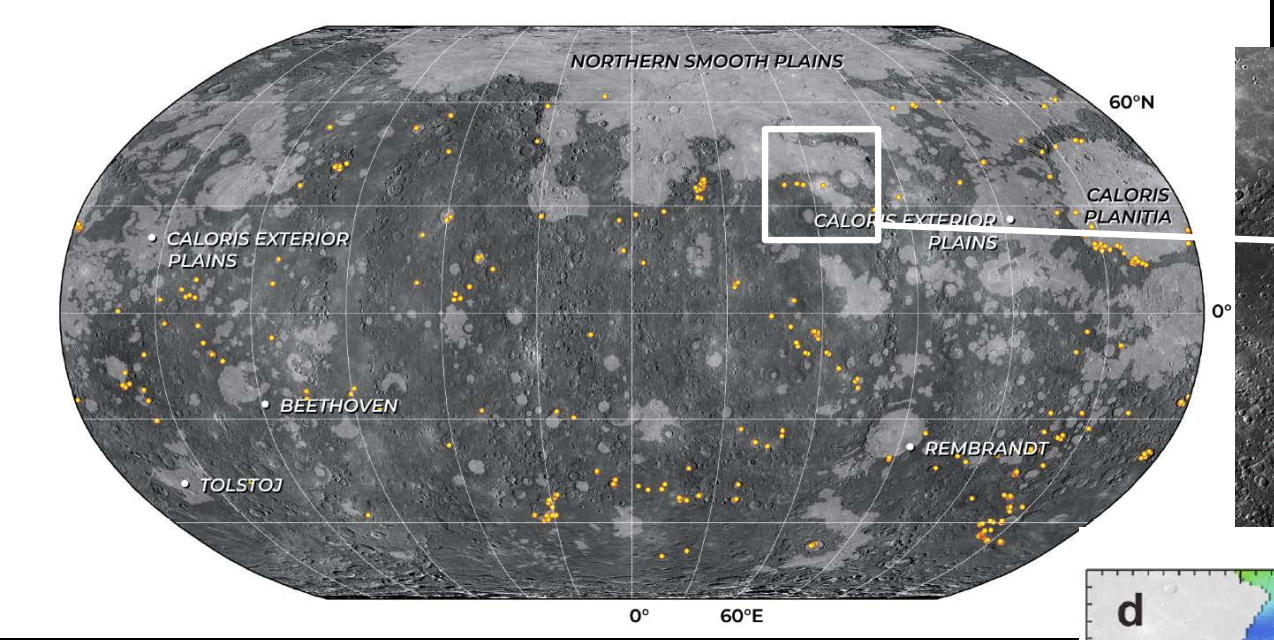


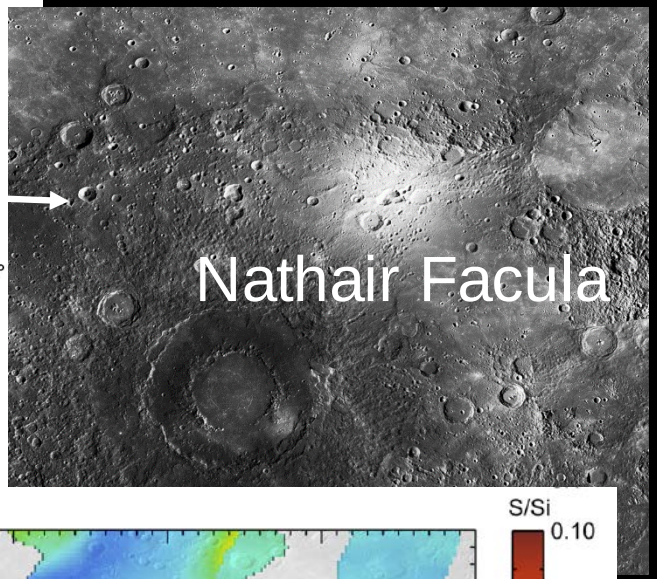
Murchie et al. [2008]



Head et al. [2011]

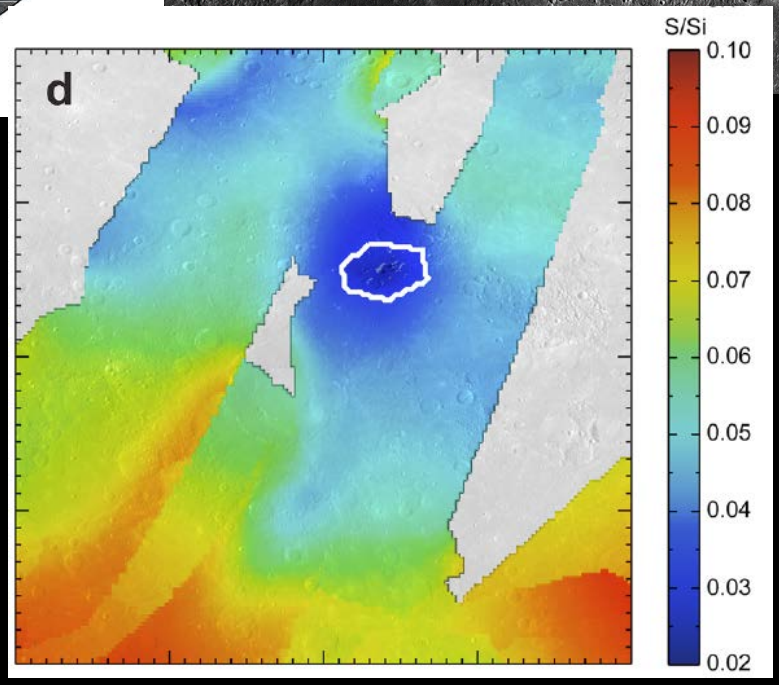
Mercury experienced explosive volcanism





Pyroclastic deposits across Mercury
(Thomas et al. 2014; Byrne et al. 2018)

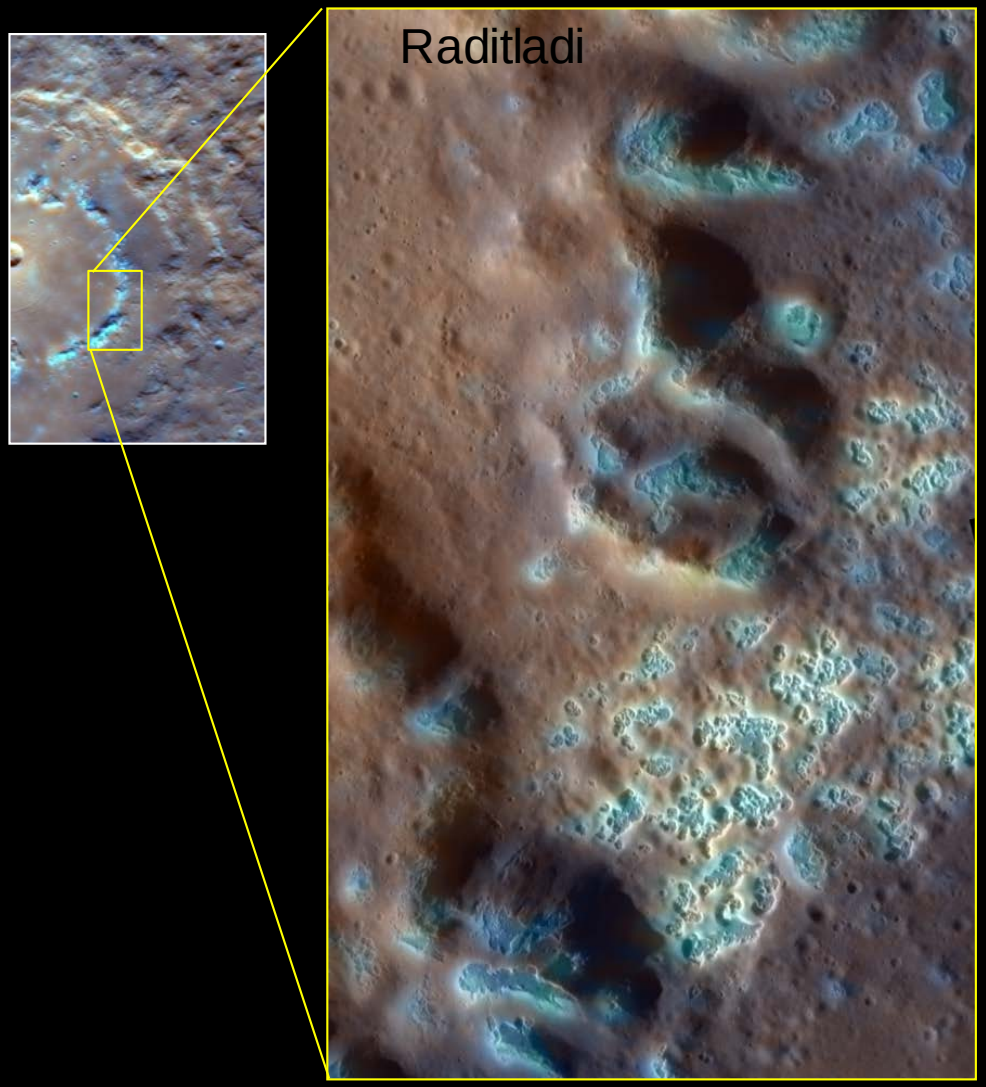
- Largest (75-km Nathair Facula) S and C depleted
- Explosive volcanism likely driven by S- and C-bearing volatiles



Weider et al. (2016)

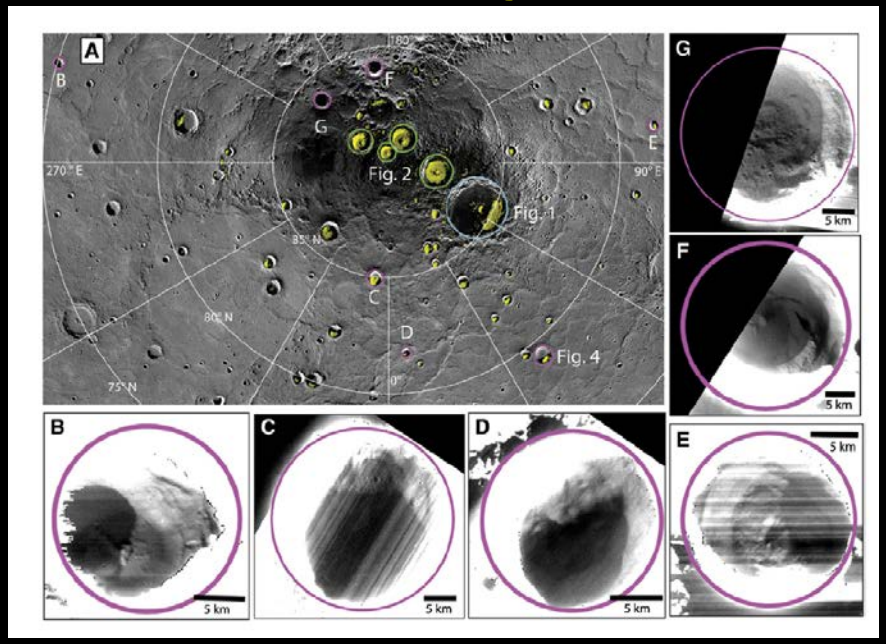
Mercury has “hollows”

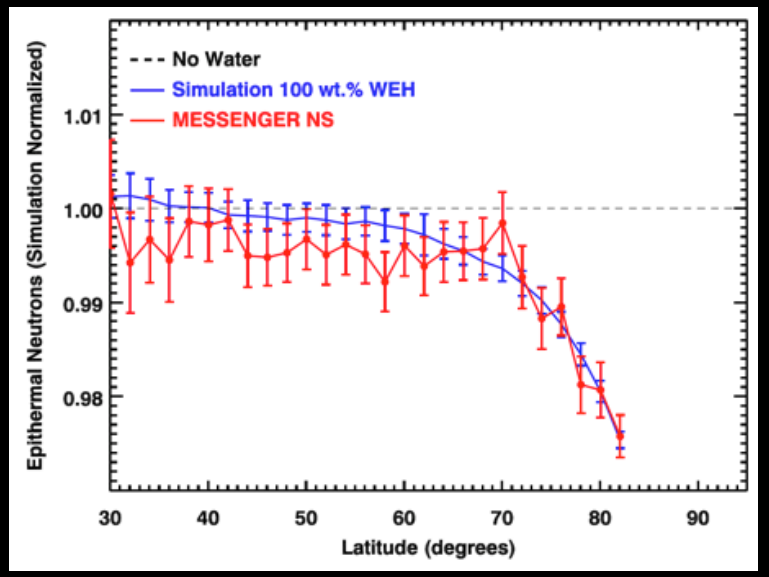
- New type of landform not seen elsewhere in solar system
- Rimless depressions, commonly with halos.
  - Associated with (C-rich) low-reflectance material in impact craters
  - Likely formed from volatile loss from sub-surface, weakening rocks and leading to collapse
  - Young! (Mercury is geologically active)



[Blewett et al., 2011; 2018]

Mercury's Polar Deposits

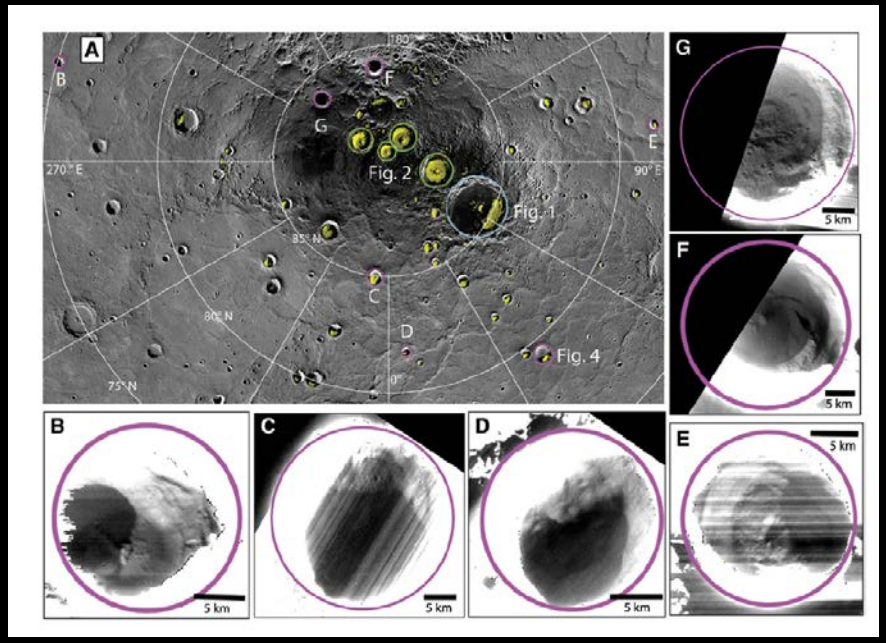


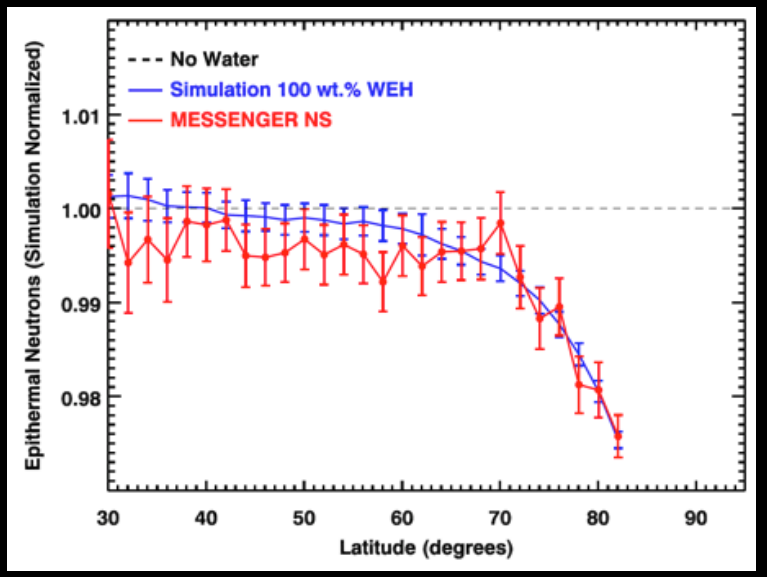


- Deposits with radar characteristics of water ice discovered in polar craters by ground-based astronomy in 1992.
- MESSENGER data (neutrons, imaging, laser altimeter reflectance) and thermal modeling confirm that radar-bright deposits are mainly water ice, but in some places likely covered in organics

(Lawrence et al., Neumann et al., Paige et al. 2013; Chabot et al. 2014, 2018)

Mercury's Polar Deposits





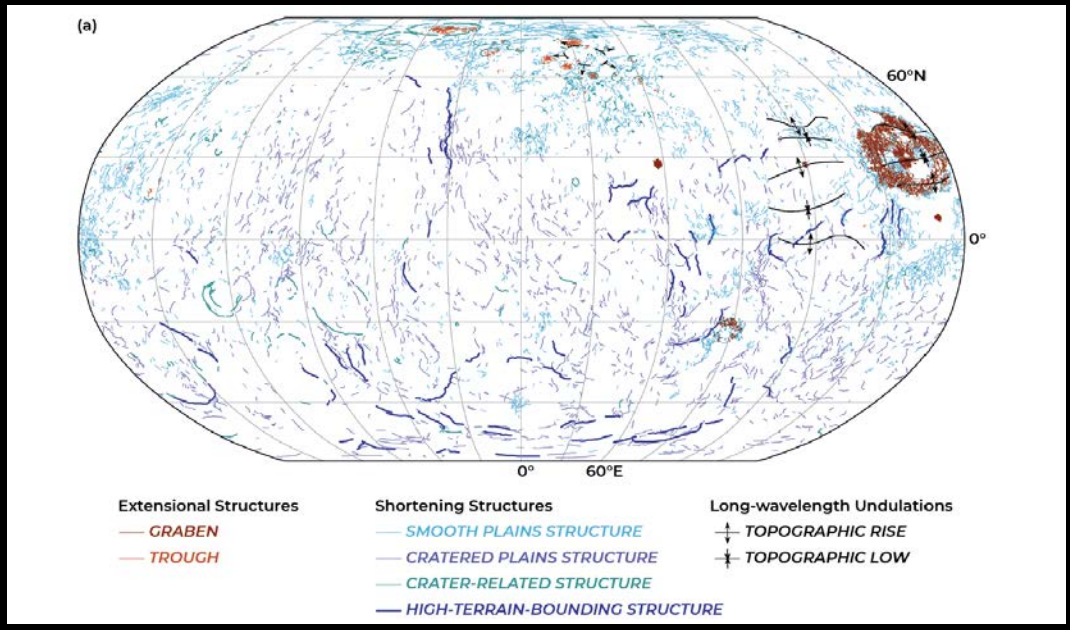
- Deposits with radar characteristics of water ice discovered in polar craters [illegible]2.
- MESSENGE[illegible]meter reflectance) a[illegible]dar-bright deposits are [illegible] likely covered in organics

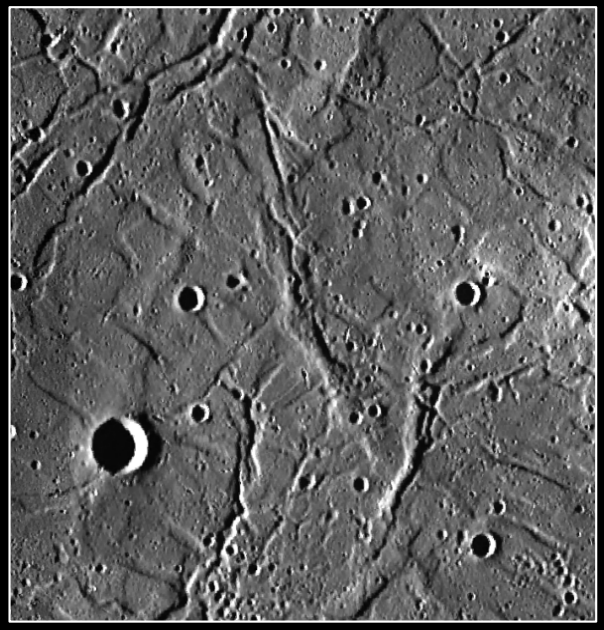
Likely from recent large cometary impact

(Lawrence et al., Neumann et al., Paige et al. 2013; Chabot et al. 2014, 2018)

Mercury has contracted a lot

- Mercury covered with lobate scarps and other tectonic shortening features due to contraction of planet as it cooled





- Detailed analysis of MESSENGER data indicates much more contraction than previous work, consistent with expectations from thermal modeling (Byrne et al. 2014, 2018)

Mercury's Internal Structure

- Model of interior based on gravity field
  - Based on millions of internal structure models (Smith et al. 2012, Hauck et al. 2013, Margot et al. 2018)
  - Top of liquid core at r=2015 ± 30 km [R_{planet}=2440 km)

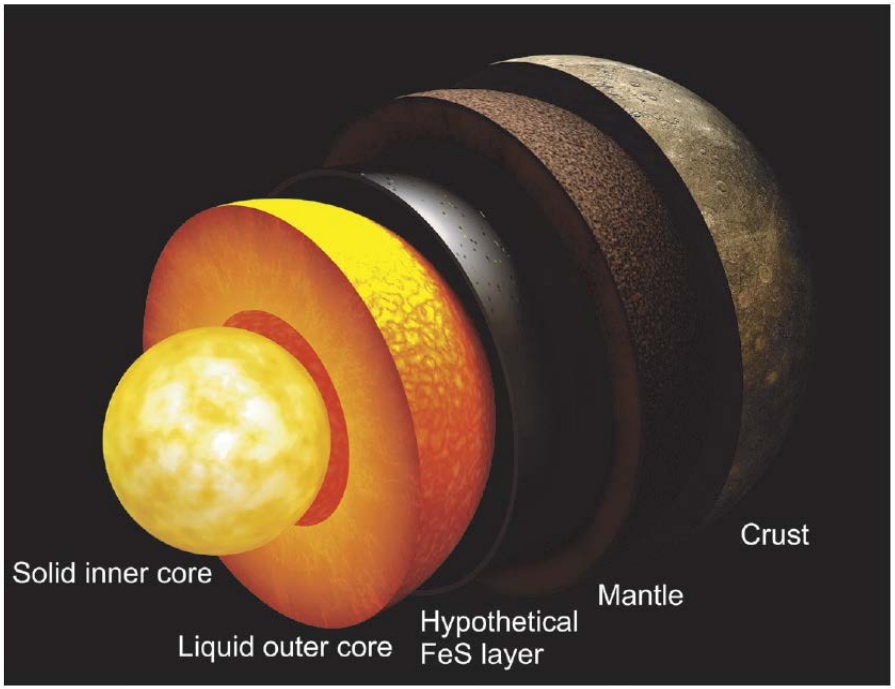
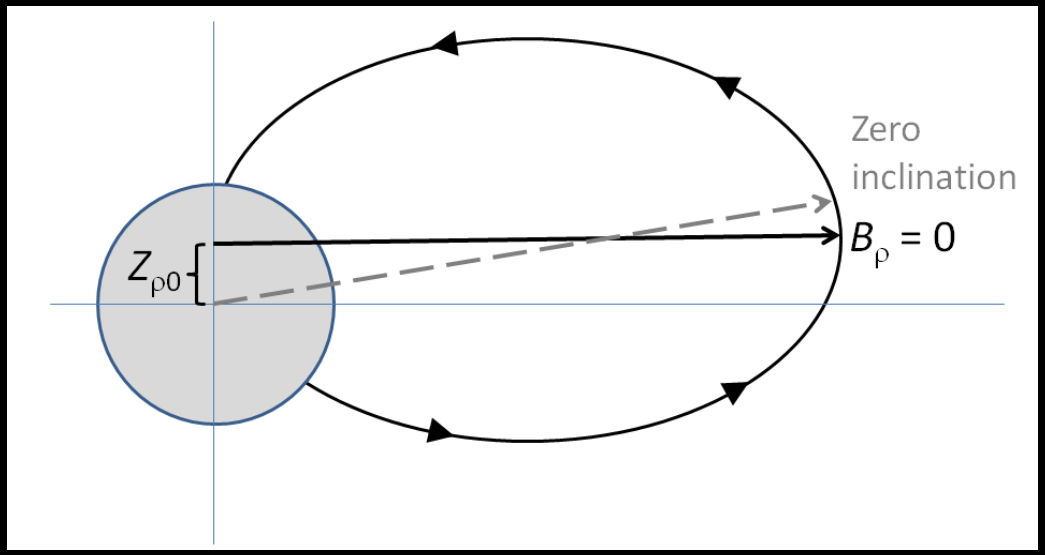


FIGURE 1 The interior structure of Mercury. The relatively thick crust (~40 km) overlies the comparatively thin mantle (~400 km). A hypothetical iron sulfide layer might occur at the core–mantle boundary, overlying the liquid outer core (radius of ~2,000 km). The innermost part of Mercury is probably a solid core having a radius of < 1,000 km. FIGURE COPYRIGHT © MARK A. GARLICK.

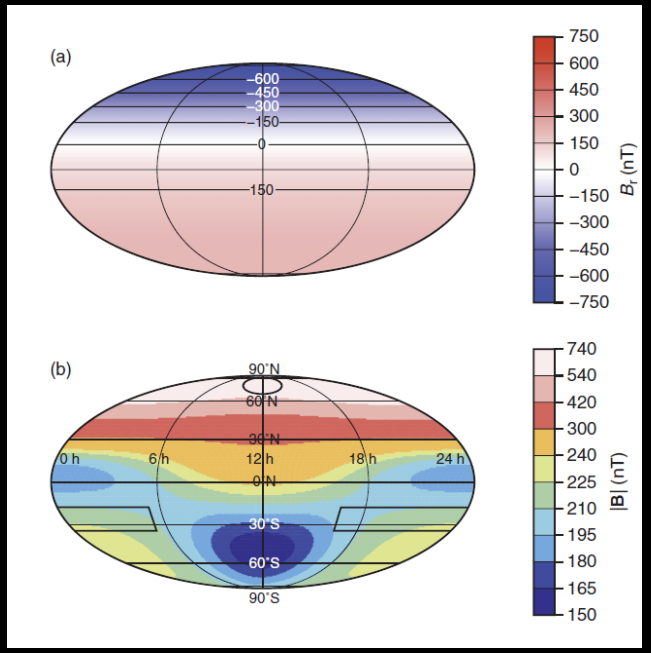
- High density (FeS) layer at base of mantle postulated but not favored

Charlier & Namur (2019)

Mercury has a strange magnetic field

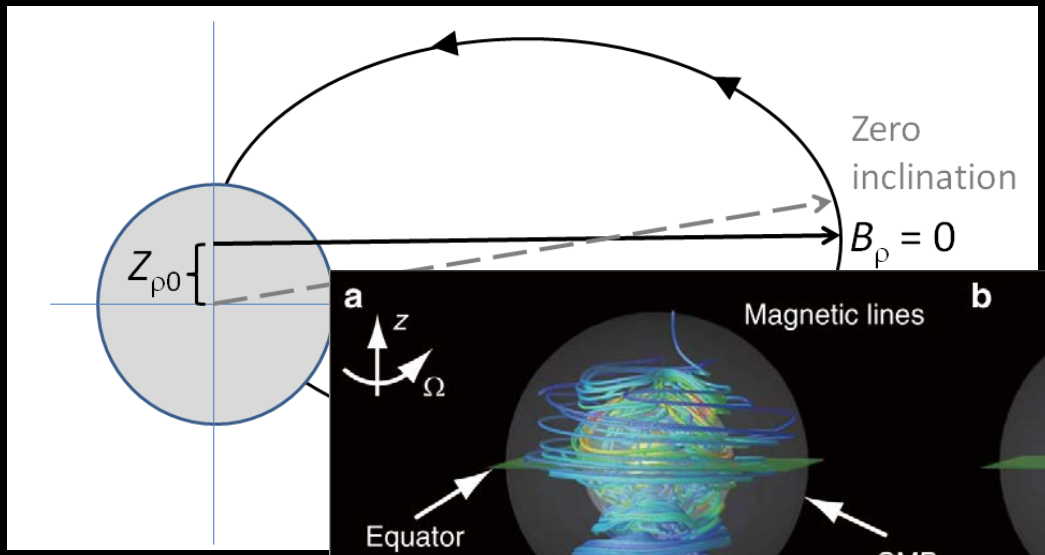


Anderson et al. (2011); Johnson et al. (2018)

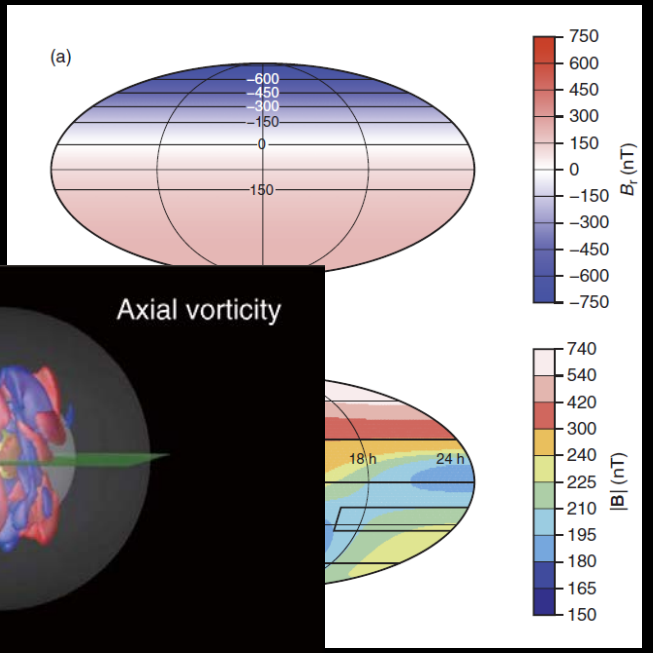


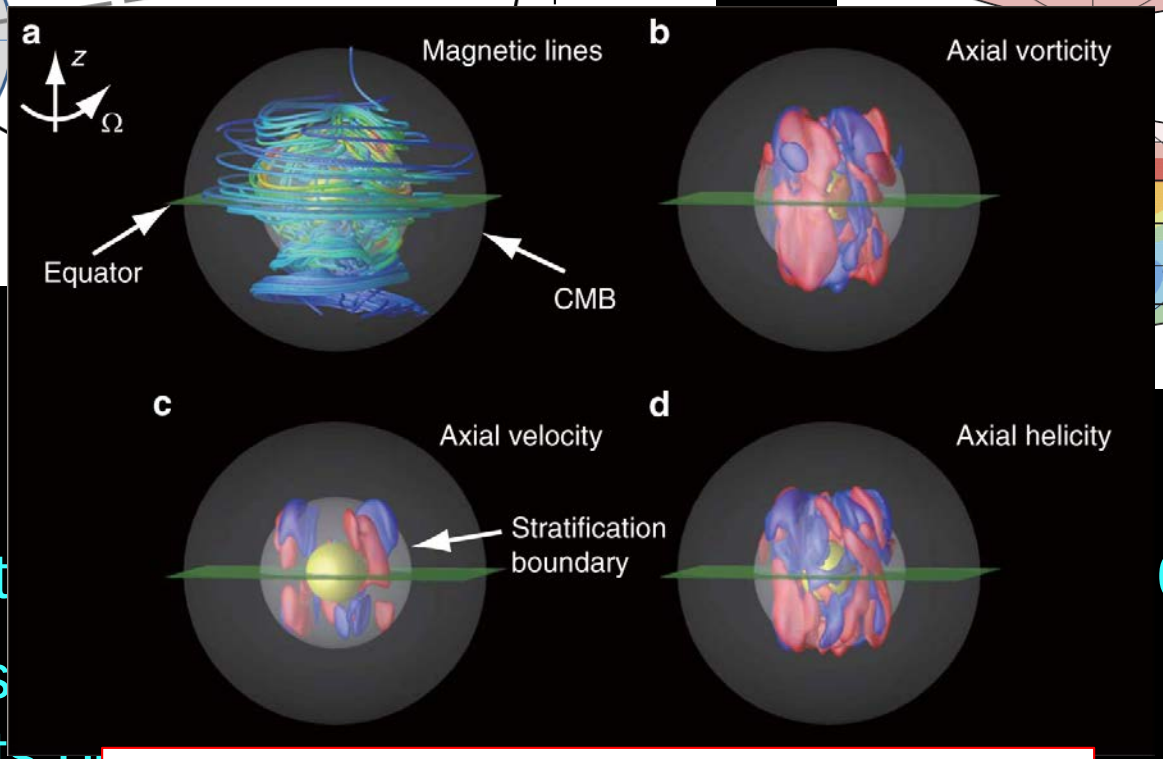
- Magnetic field is dipolar and of the same sense as that of the Earth, but displaced northward from equator by 480 km
- Large offset is unprecedented in the Solar System and puts constraints on the generation mechanism

Mercury has a strange magnetic field



Anderson et

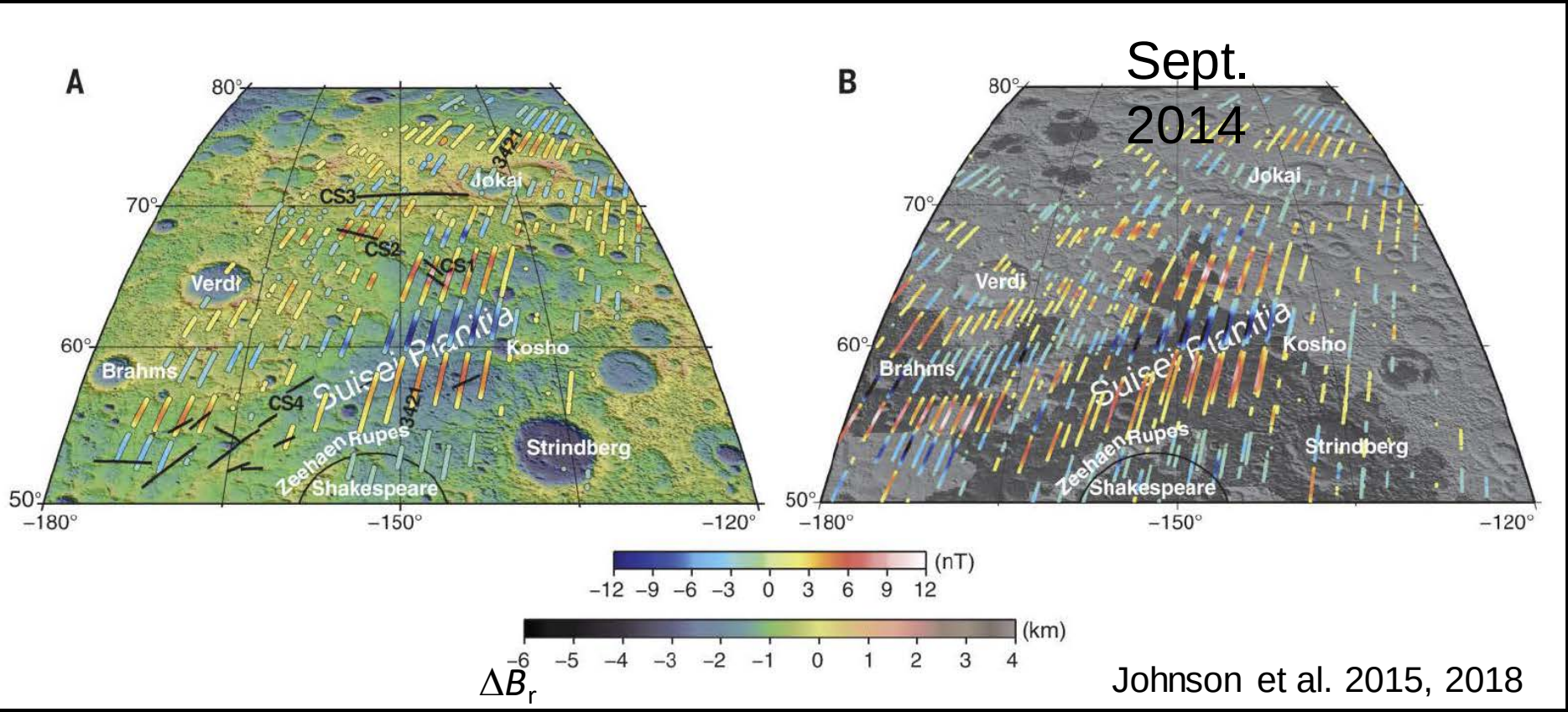




- Magnetic … that of the Earth, but … 0 km
- Large offs… and puts constraints o…
  - (lots of mod… mm., 2019)

(lots of models, ideas, e.g. Takahashi et al., Nature Comm., 2019)

Mercury has had magnetic field for 4Gyr



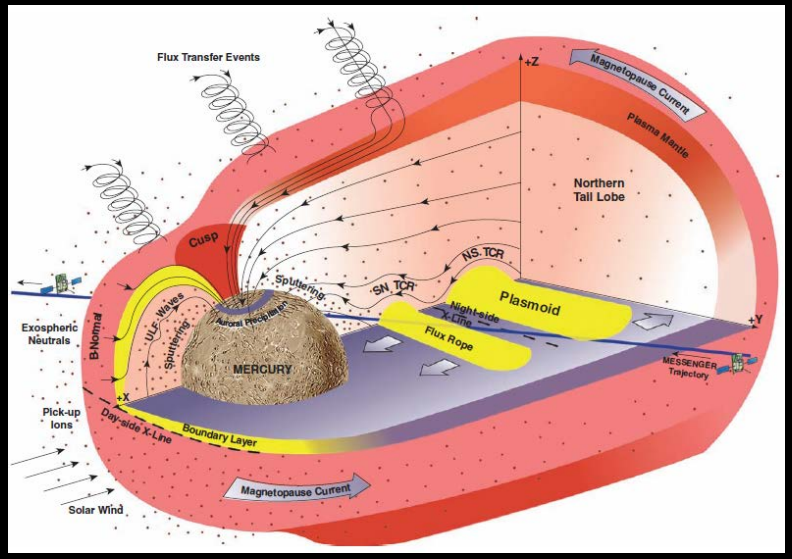
Johnson et al. 2015, 2018

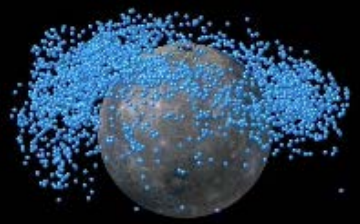
- Low-altitude (<60 km) measurements could resolve remanent crustal fields from internal field
- Thermal preservation of magnetization over ~4 Gyr!

Mercury's Magnetosphere

- Interaction of solar wind with planet's field leads to complex and highly dynamic magnetosphere

- Frequent highly energetic bursts of 30-300 keV electrons – origin unknown





Slavin et al. (2009, 2018)

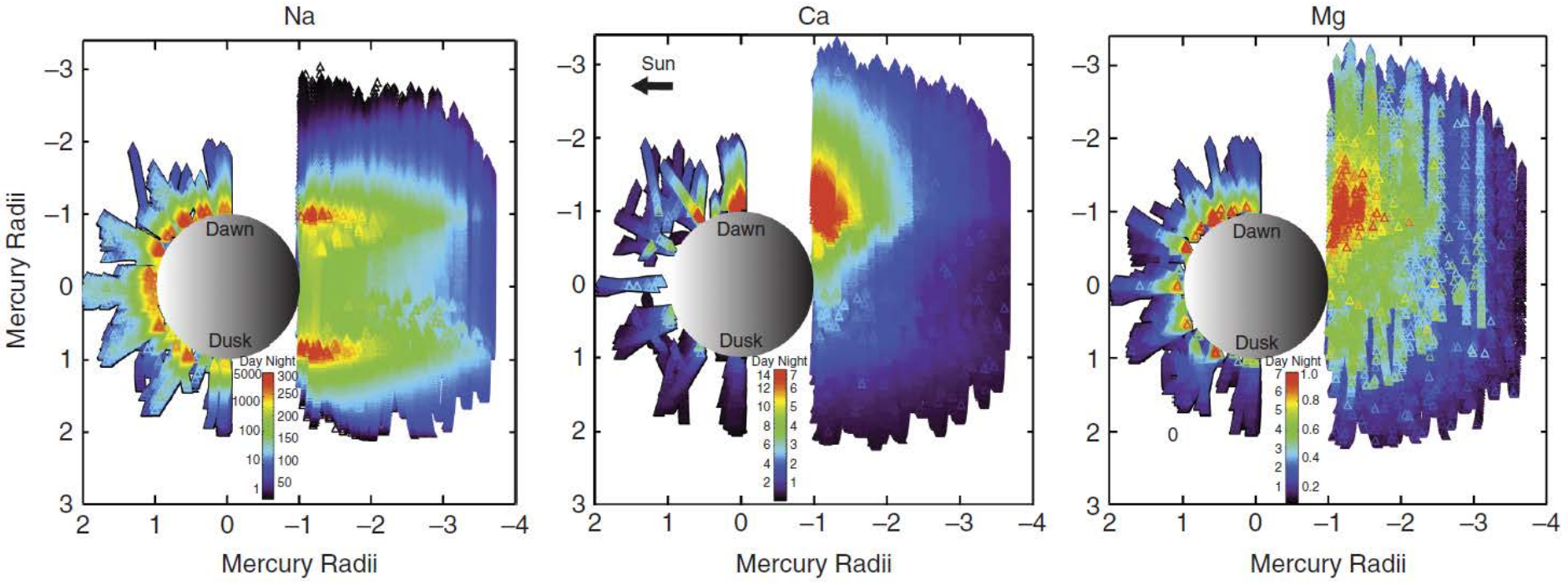
Simulation of ion density at equator (J. Paral)

Mercury's exosphere is complex and dynamic

McClintock et al (2018)

- Na exosphere over two years

Mercury's exosphere is complex and dynamic

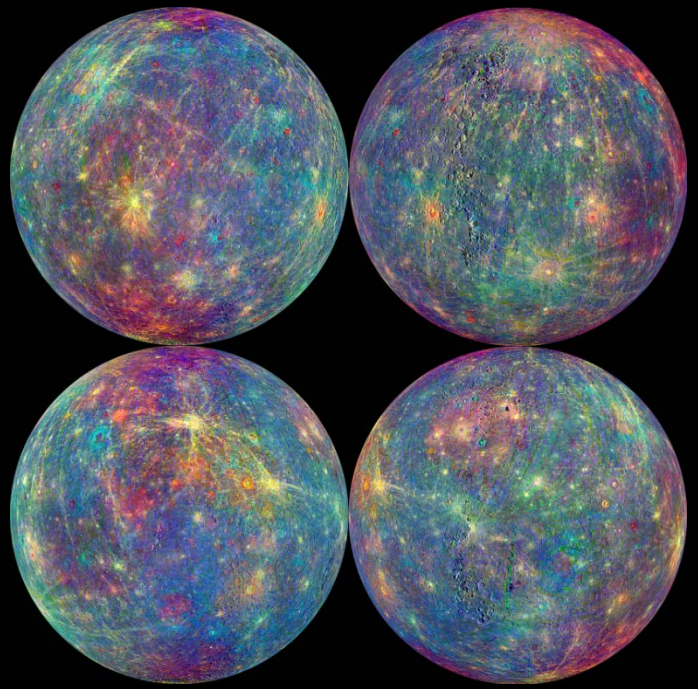


McClintock et al (2018)

- Each species has different region of enhanced brightness
  - Not fully understood but MG emission is correlated with surface composition (Merkel et al. 2018)

Mercury Science 2010-2020

- Despite its small size, Mercury is a weird and wonderful world.
- Different in fundamental ways from other terrestrial planets
  - Volatile-rich, chemically reduced
  - Has “hollows”, polar ice deposits
  - Offset magnetic field, and crustal remanant magnetism
  - Unique and dynamic exosphere and magnetosphere



- Many fundamental questions still unanswered

Acknowledgements

- MESSENGER Science Team, Engineers and Mission Controllers

NASA
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THE JOHNS HOPKINS UNIVERSITY APL