MESSENGER at Mercury: Scientific Highlights and End of Mission

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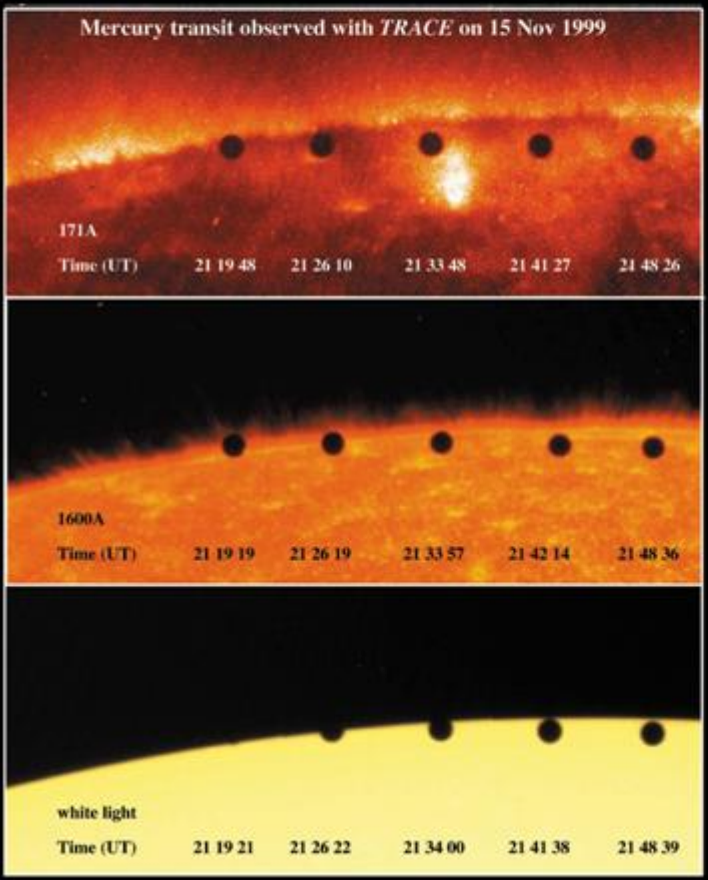
Carnegie Institution of Washington

Acknowledgments: The MESSENGER Science Team

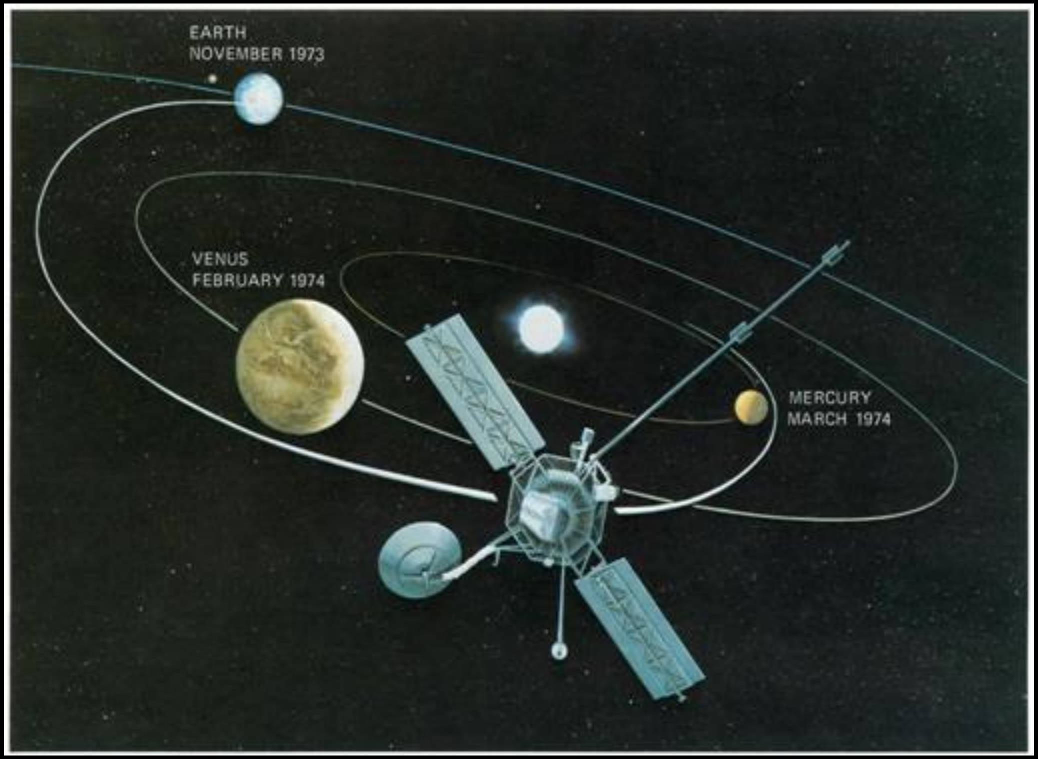
NAC Science Committee, April 6, 2015

Mercury Is Difficult to Study

…by telescope …



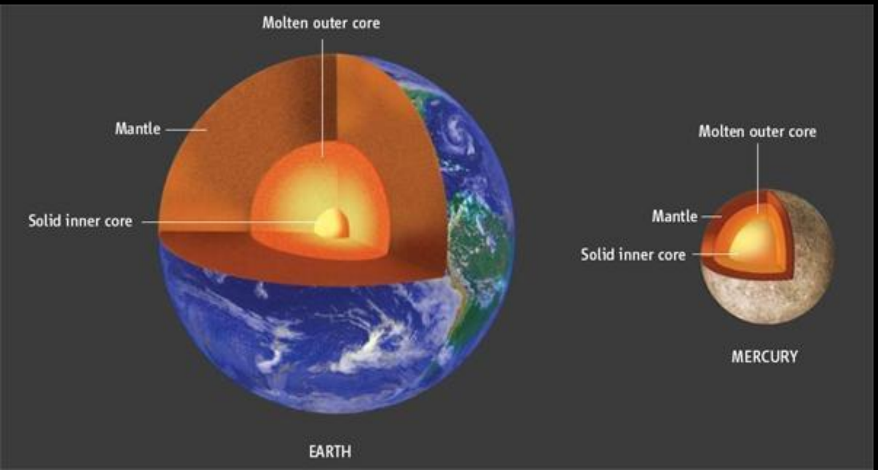
…or spacecraft.



Only prior visit was by

Mariner 10, 1974-1975

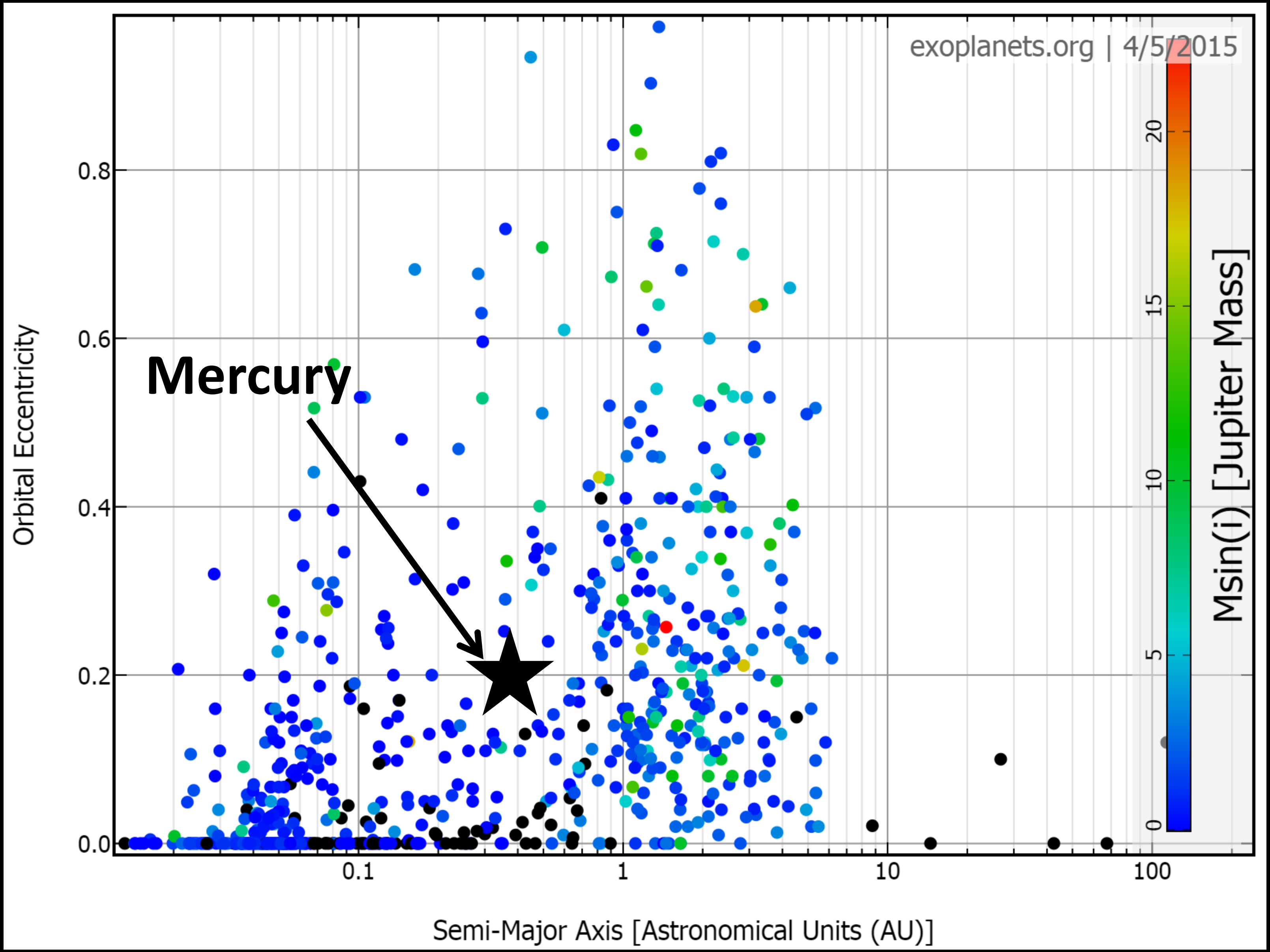
Mercury: planet of extremes



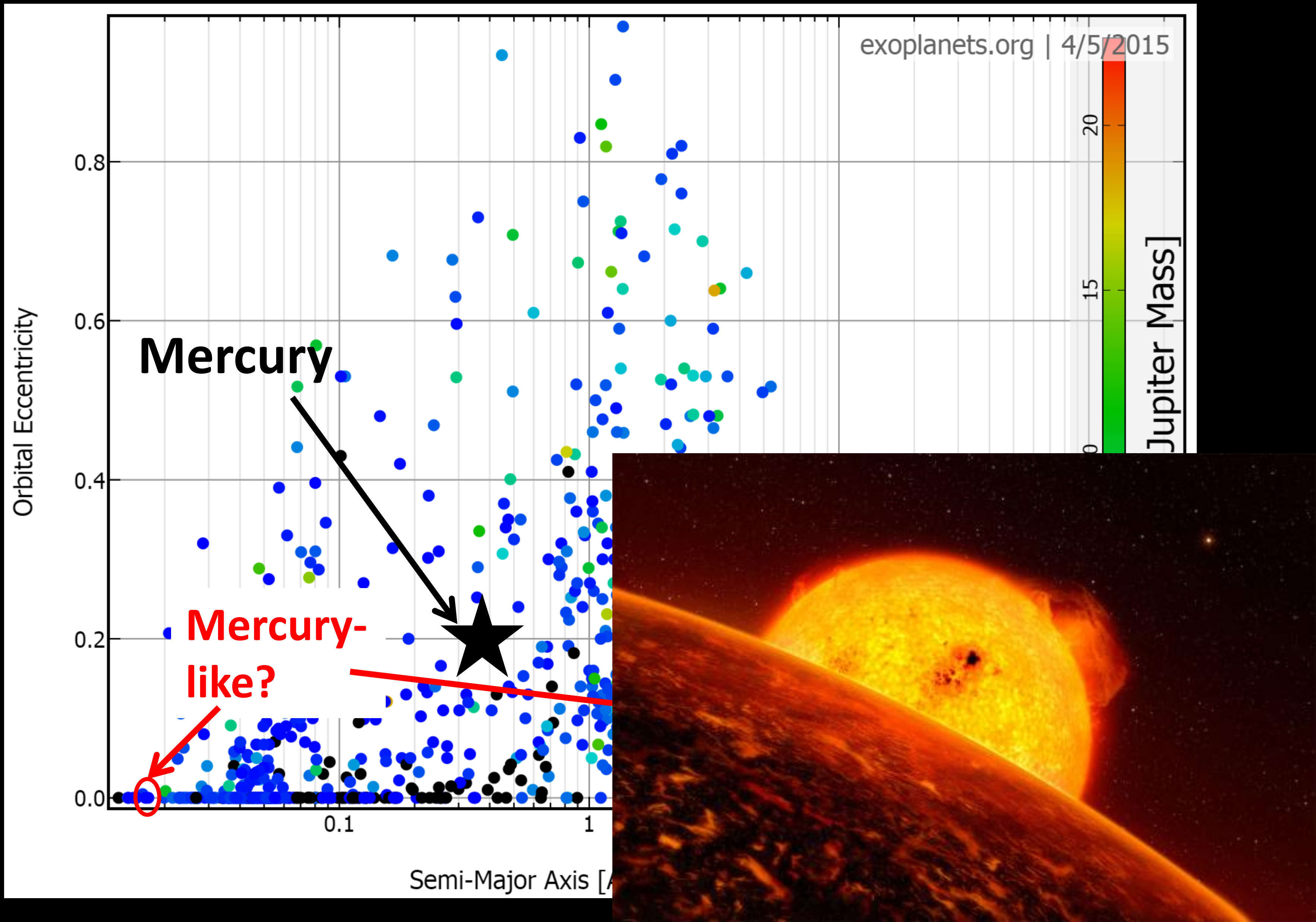
- Smallest, densest planet
- Closest to Sun
- Highest diurnal variation in temperature
  - −170 ºC to +430 ºC
- Very high Fe:silicate ratio
  - Core ~70% of mass, 80% radius
- Magnetic field: dynamic magnetosphere
- Low FeO in surface silicates
- Evidence for water ice in polar craters

"end-member of planet formation"

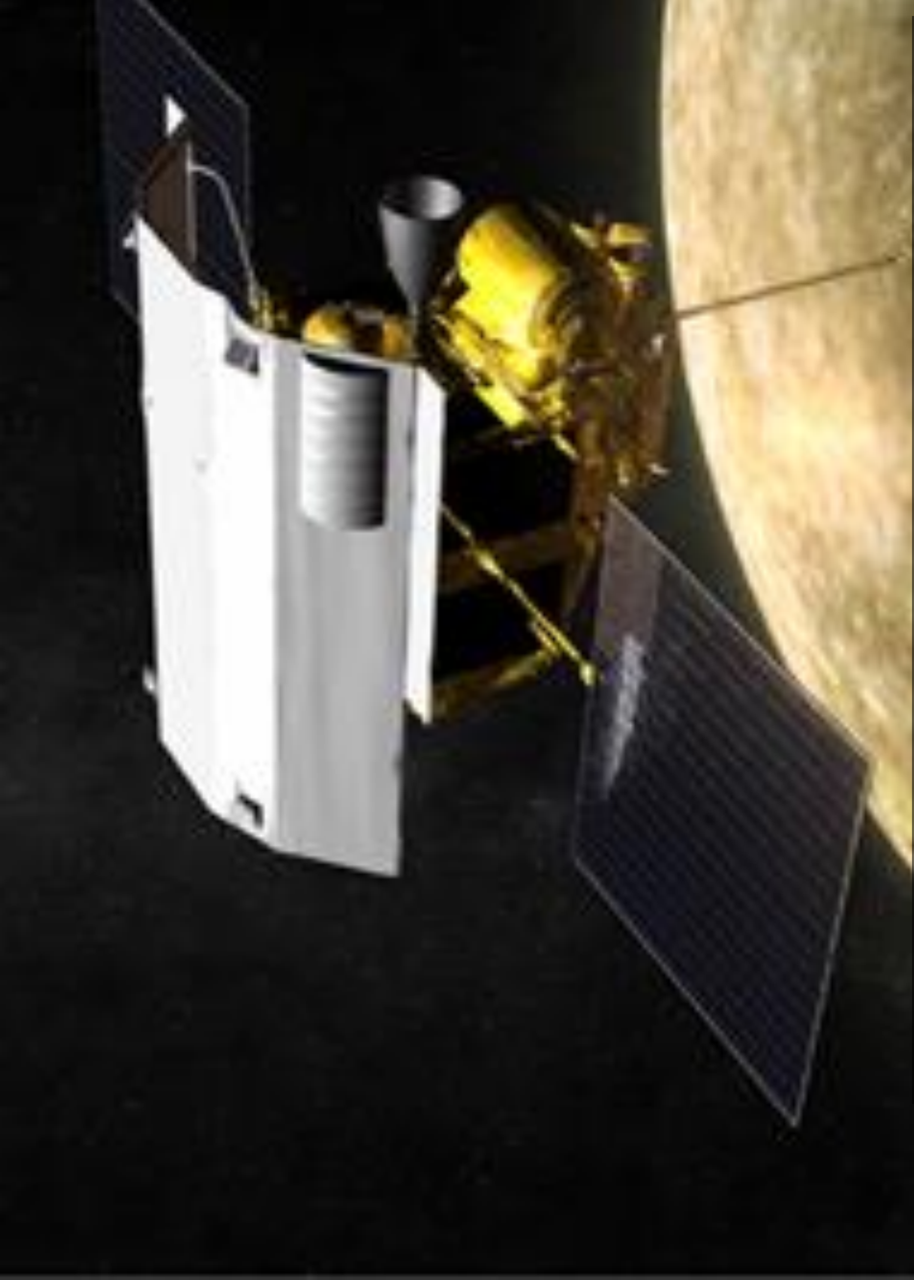
Extrasolar Planetary Context



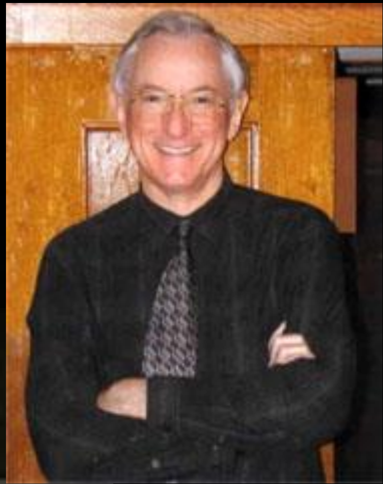
Extrasolar Planetary Context



MESSENGER

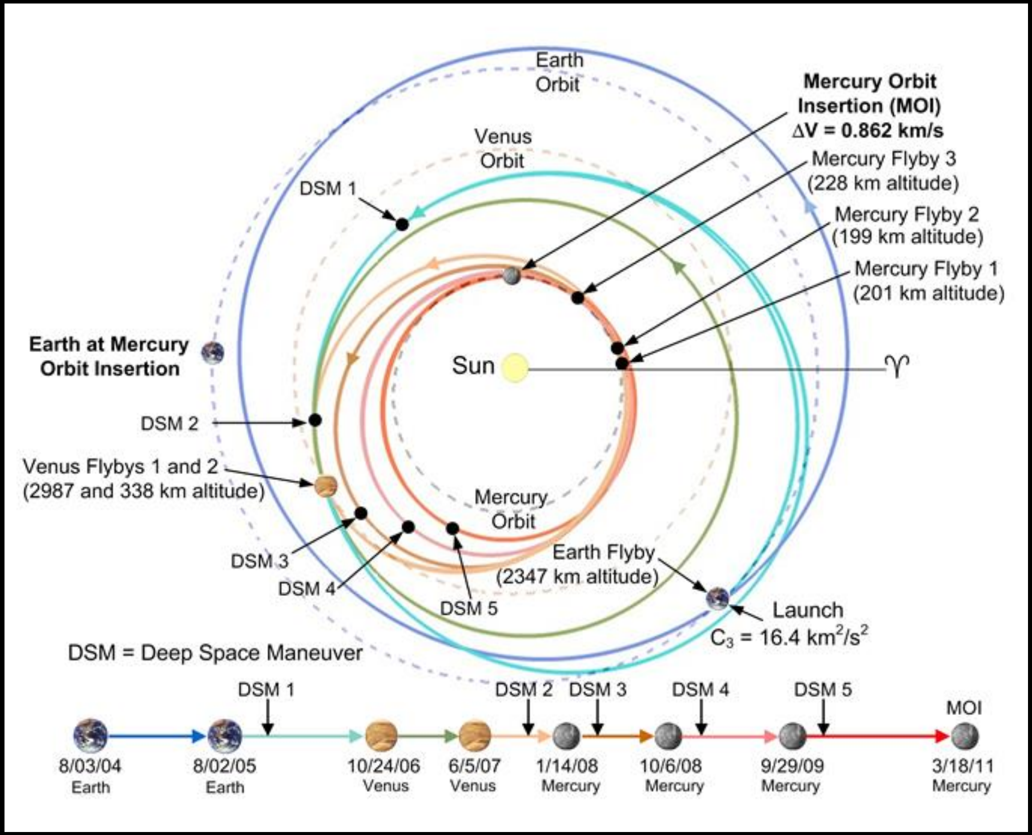


- First spacecraft to orbit Mercury
- 7th NASA *Discovery* mission
  - PI: Sean C. Solomon [formerly CIW, now Columbia University]



Start in 1999 – Launch 2004 – Orbit 2011

- **Six planetary gravity assists (1E, 2V, 3M) and 15 orbits around the Sun from launch to orbit insertion**



Getting to Mercury

Earth (August 2005)

Venus (October 2006)

Mercury Flybys (2008-2009)

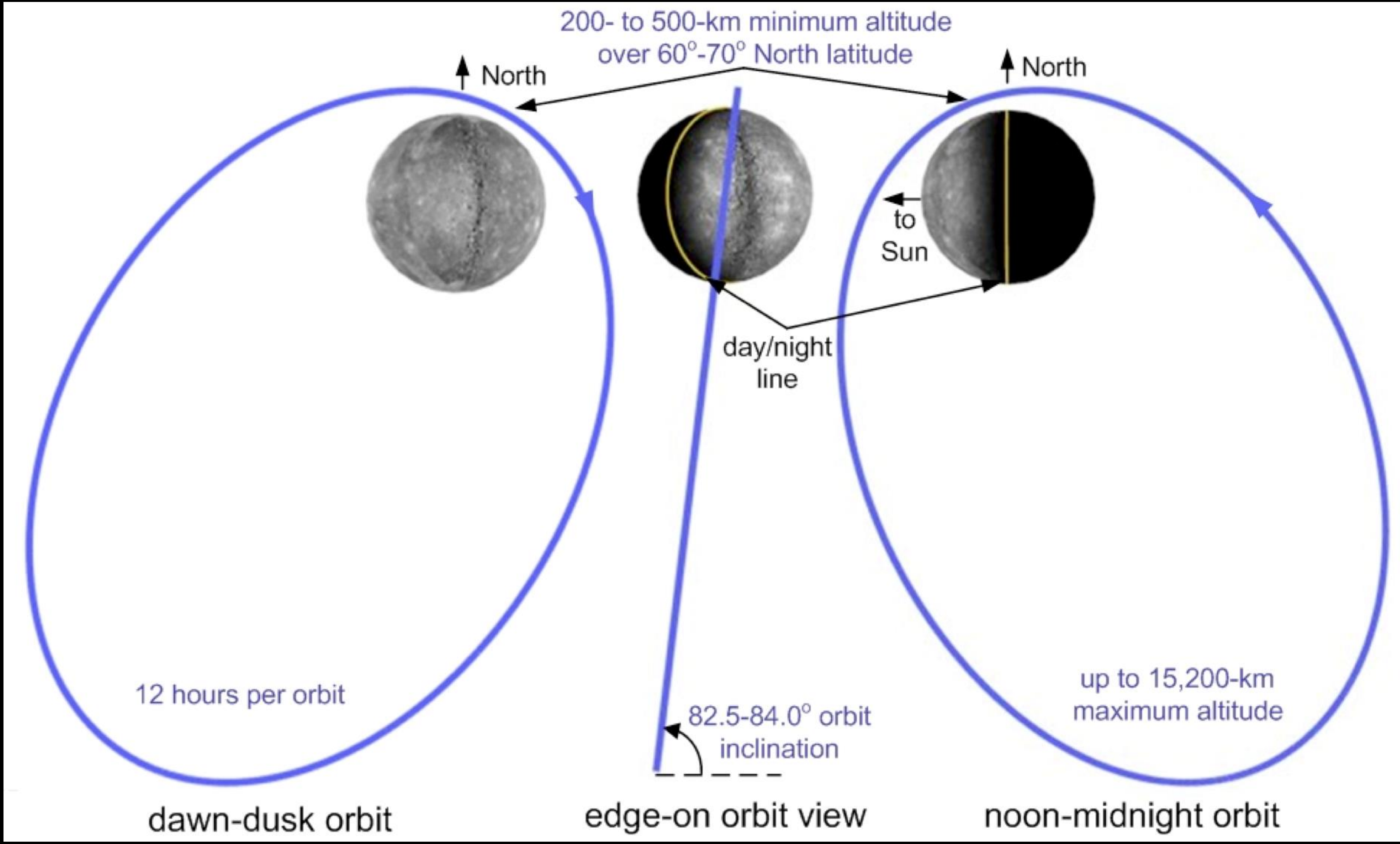

M1 (Jan 2008)


M2 (Oct 2008)

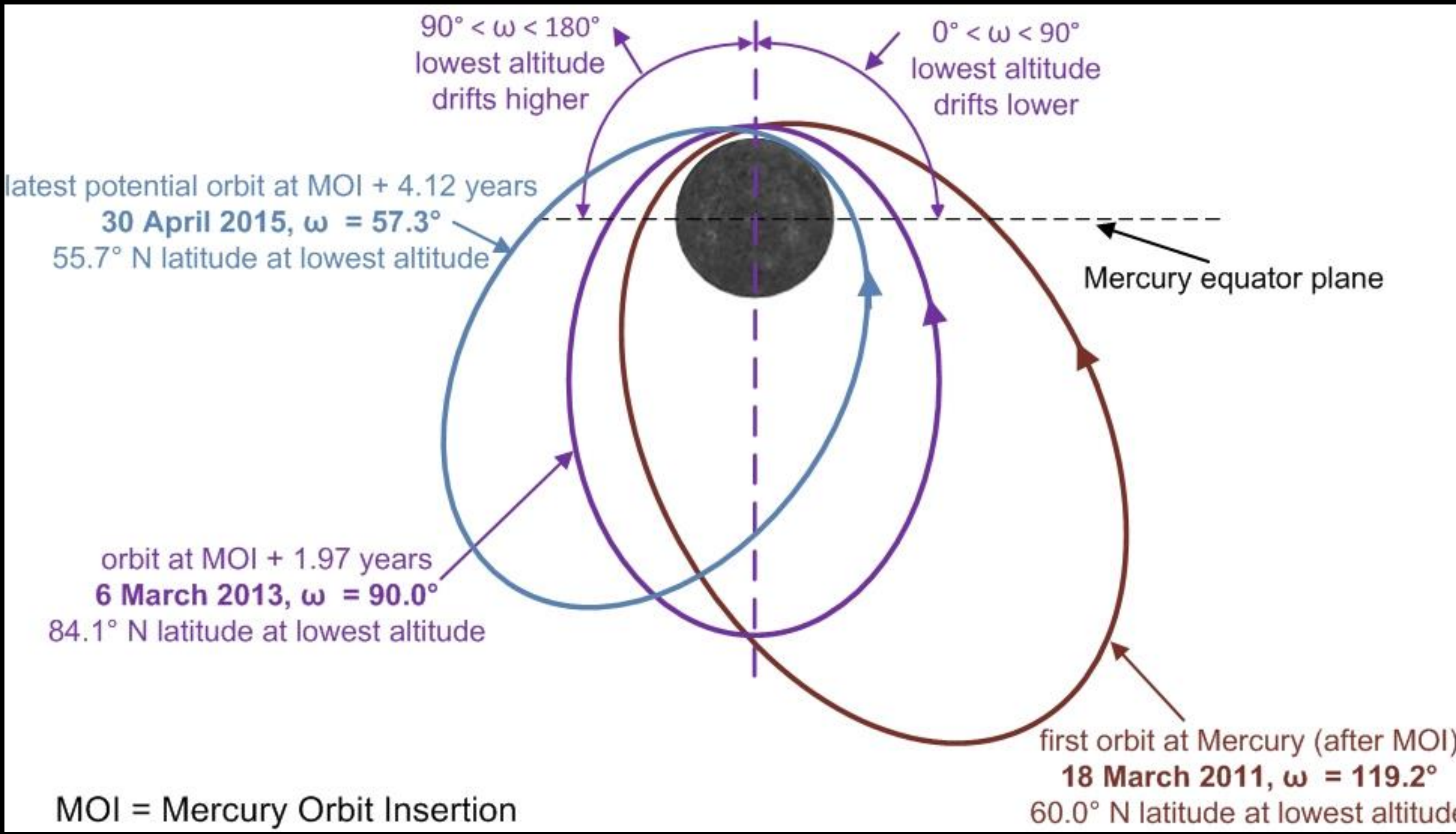
- >90% of surface imaged


M3 (Sep 2009)

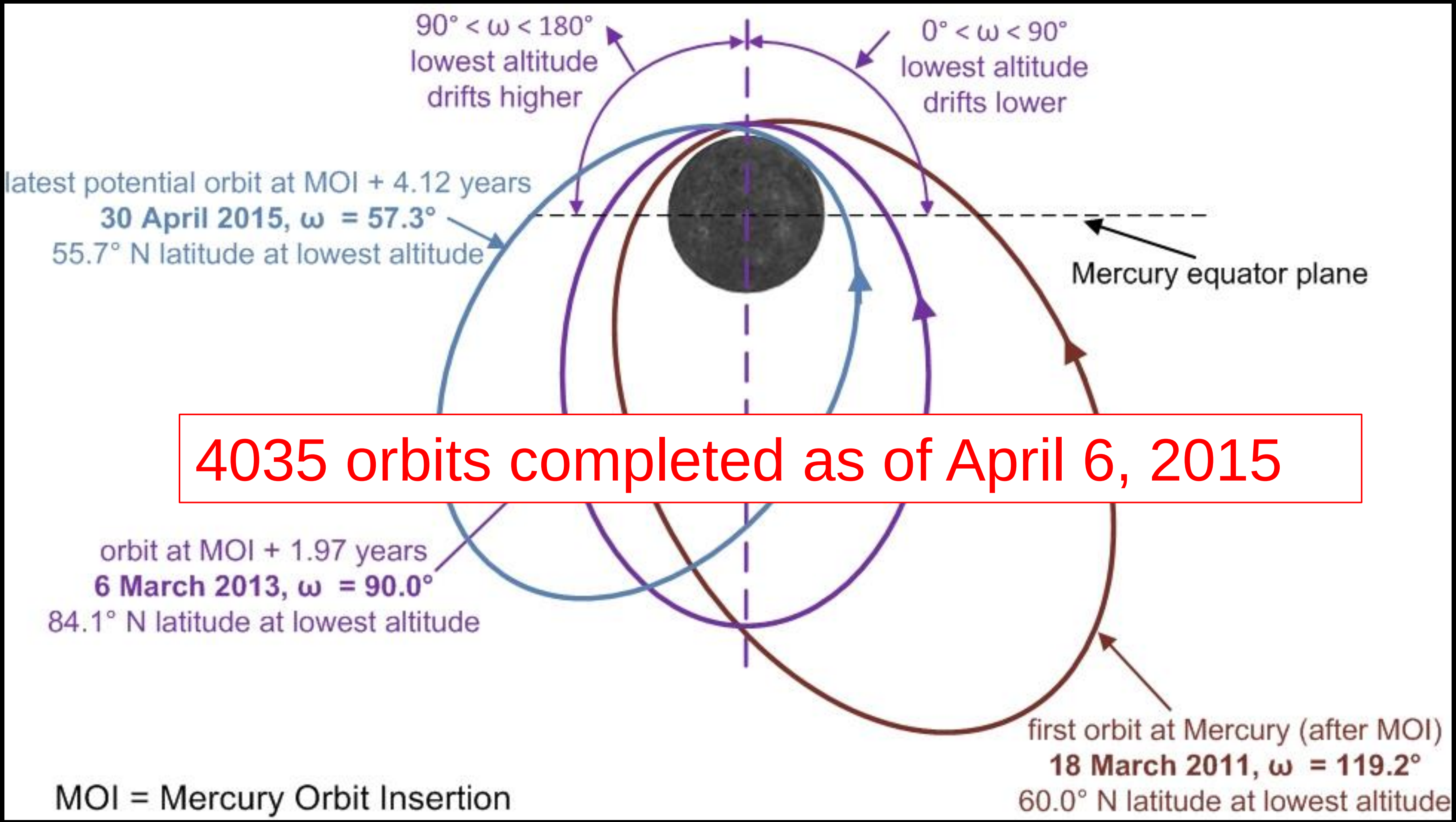
Mercury Orbit Insertion (March 18, 2011)



Evolution of MESSENGER's orbit



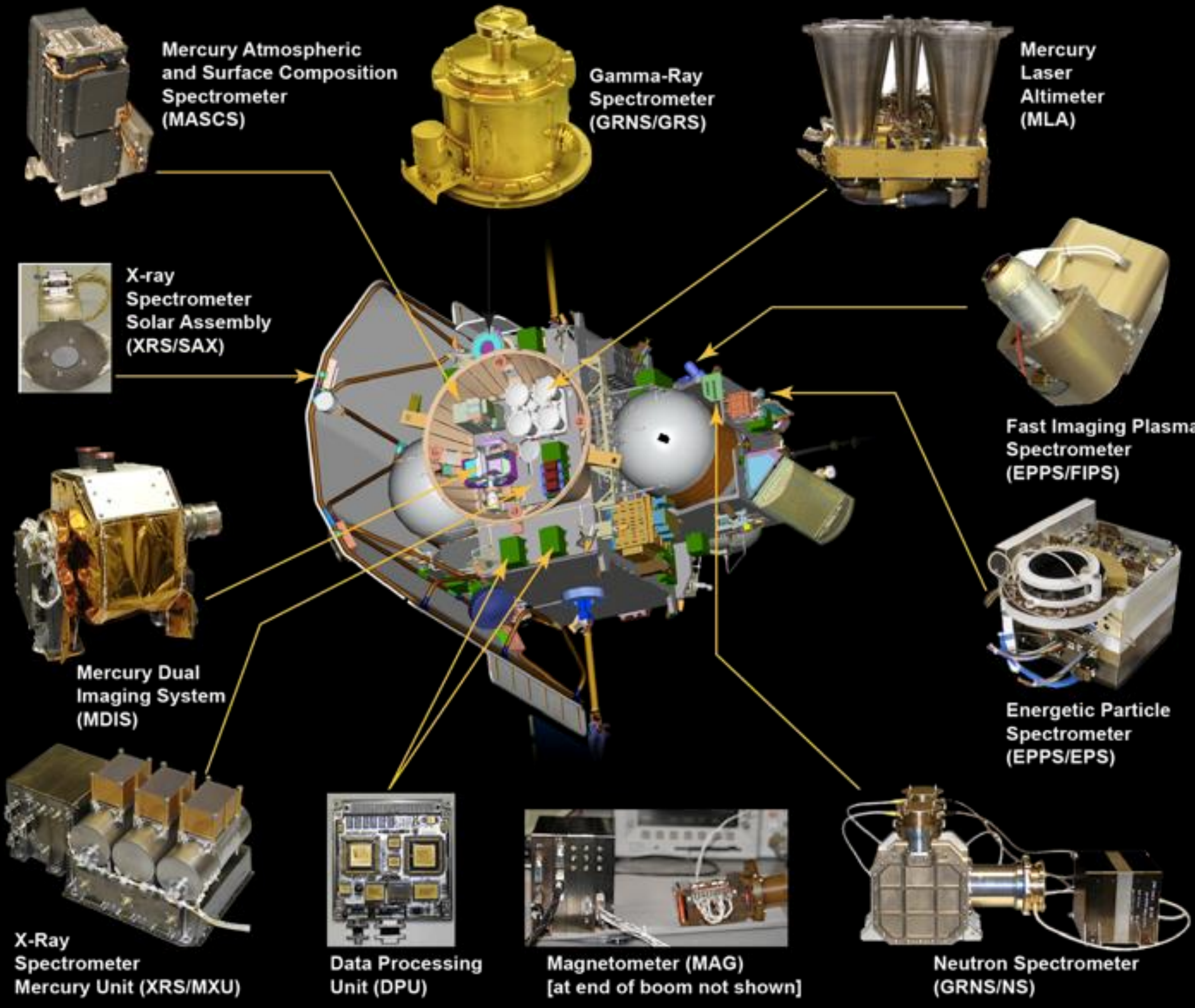
Evolution of MESSENGER's orbit



MESSENGER's Guiding Science Questions mapped to Measurement Objectives

Science Questions	MESSENGER Measurement Objectives
What planetary formational processes led to Mercury's high ratio of metal to silicate?	Map the elemental and mineralogical composition of Mercury's surface
What is the geological history of Mercury?	Globally image the surface at a resolution of hundreds of meters or better
What are the nature and origin of Mercury's magnetic field?	Determine the structure of the planet's magnetic field
What are the structure and state of Mercury's core?	Measure the libration amplitude and gravitational field structure
What are the radar-reflective materials at Mercury's poles?	Determine the composition of the radar-reflective materials at Mercury's poles
What are the important volatile species and their sources and sinks near Mercury?	Characterize exosphere neutrals and accelerated magnetosphere ions

MESSENGER's Scientific Payload



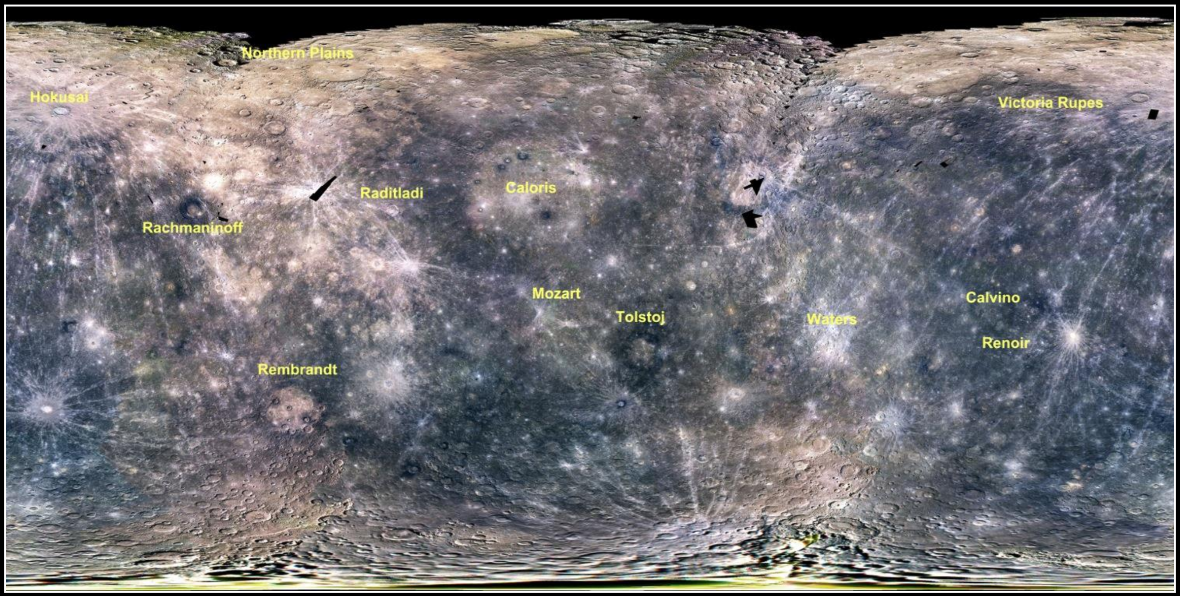
MESSENGER's Scientific Accomplishments

- Reports on Mercury results fill several special issues and sections of various journals
- A new book on Mercury is in the initial stages

Feb 2013: MESSENGER imaging coverage reached 100%

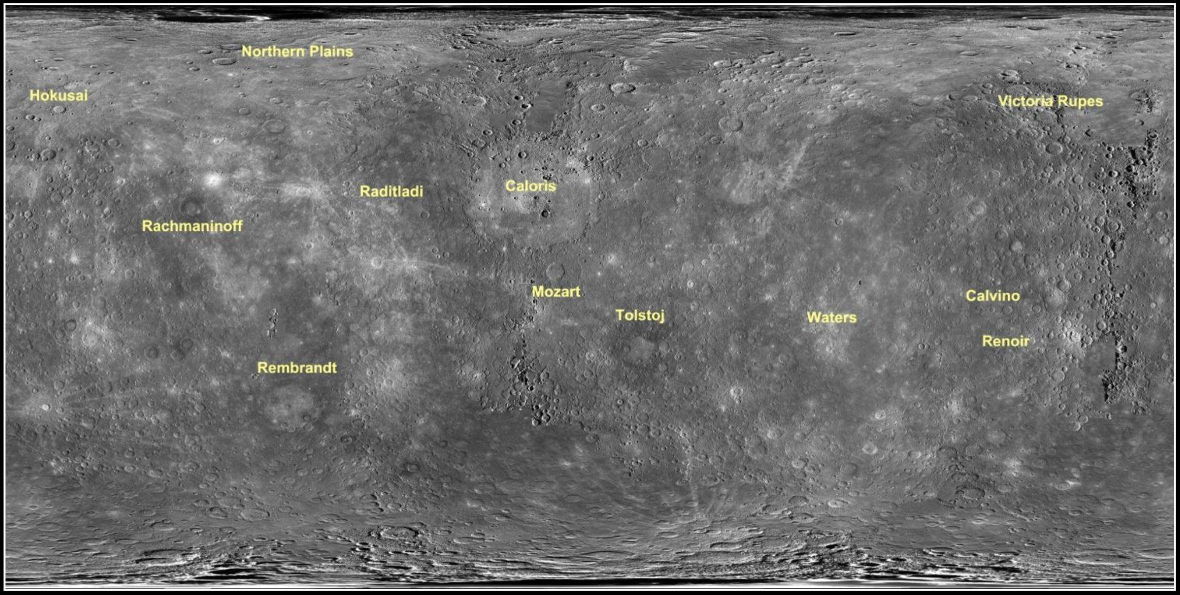
Mercury in "true" color – RGB: 630, 560, 480 nm

Global Maps (<~1km/px)



Multispectral map

Morphology map

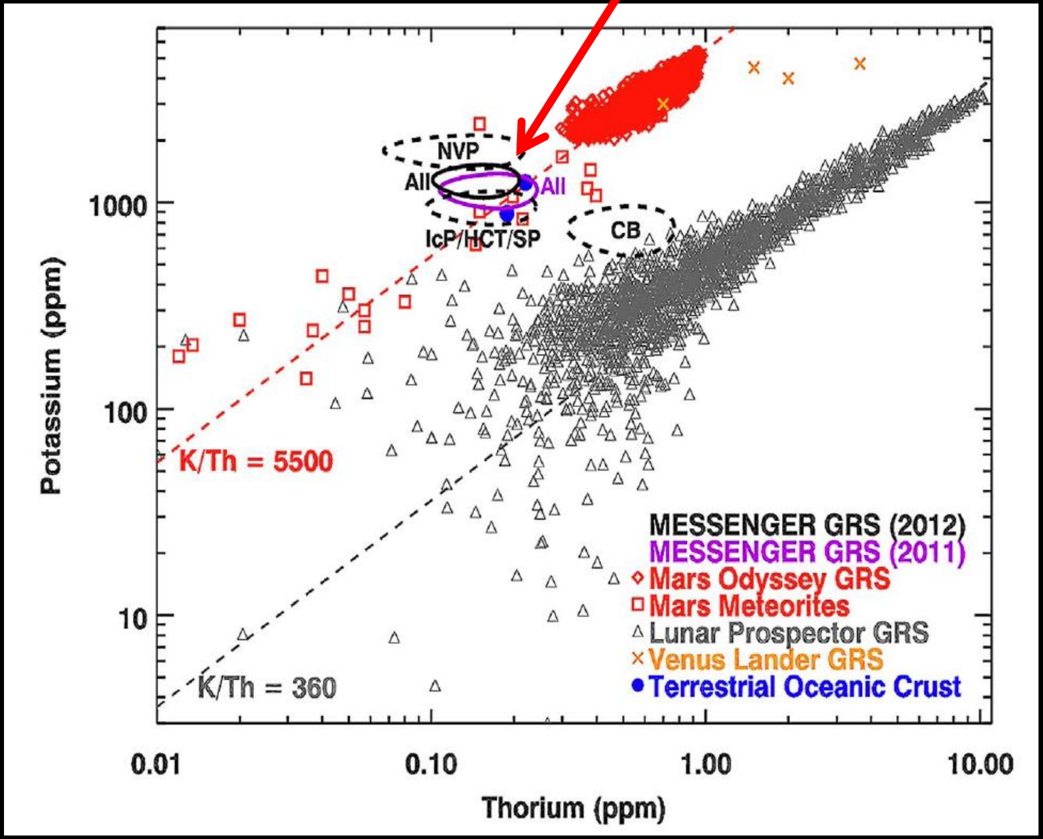


Composition of Mercury

- Measurements by x-ray, gamma-ray and neutron spectrometers reveal surface chemistry
- S- and volatile rich
- Fe-poor

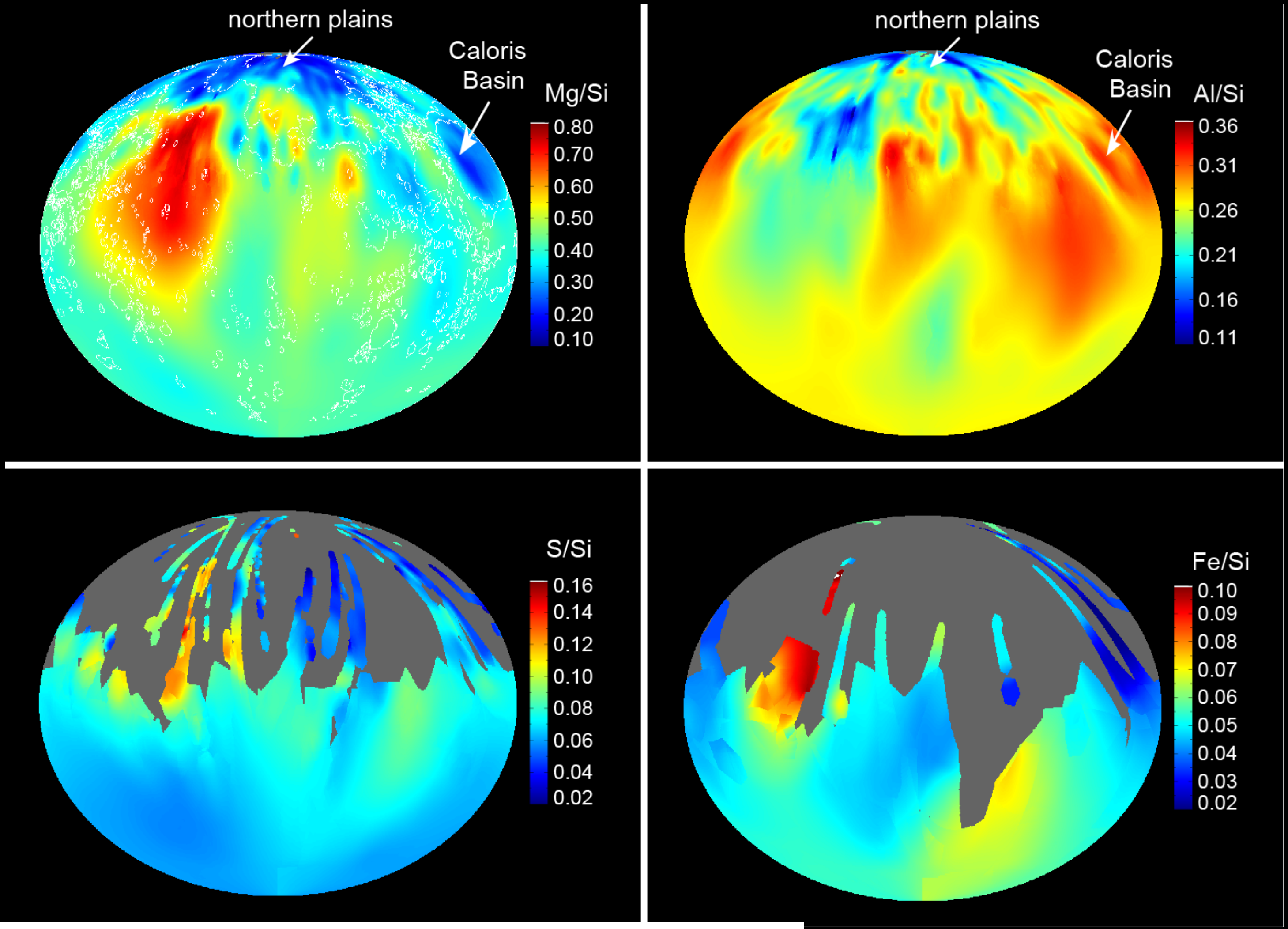
Rules out many pre-MESSENGER formation models and indicates starting materials highly chemically reduced

Mercury similar to Mars, Earth



(Peplowski et al., 2011,2012)

Composition of Mercury

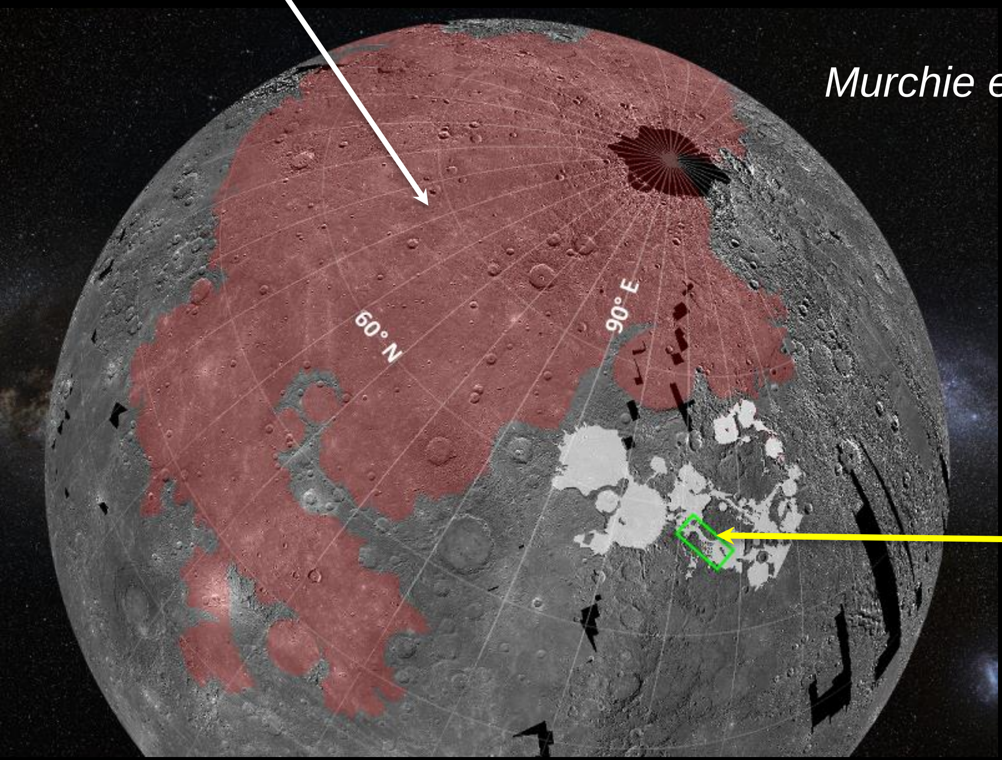


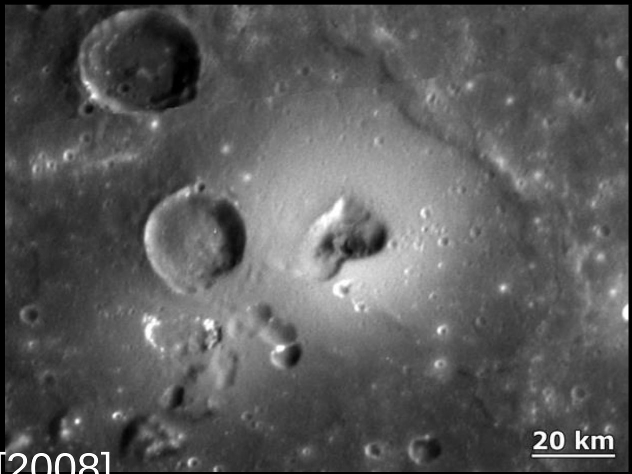
- Element maps reveal remarkable heterogeneity

Weider et al. 2015

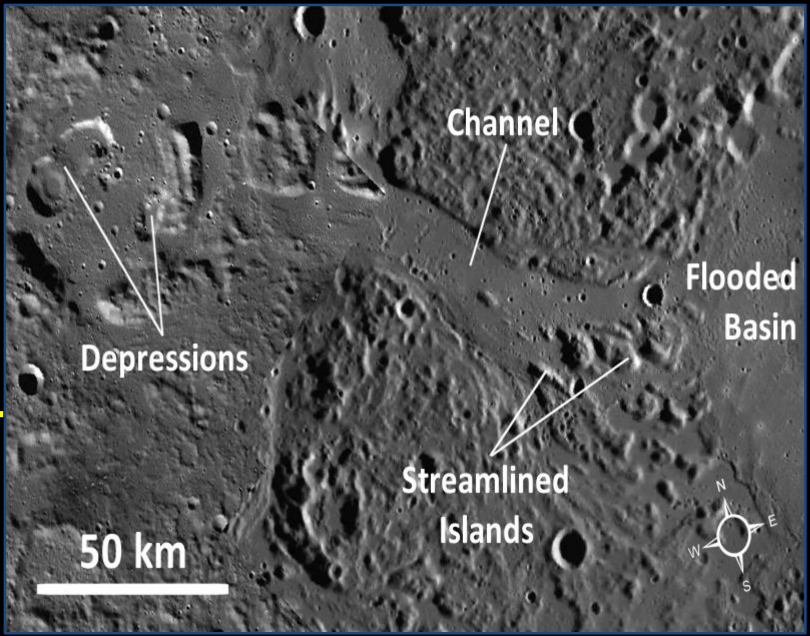
Geologic History: Widespread Volcanism

Northern Plains





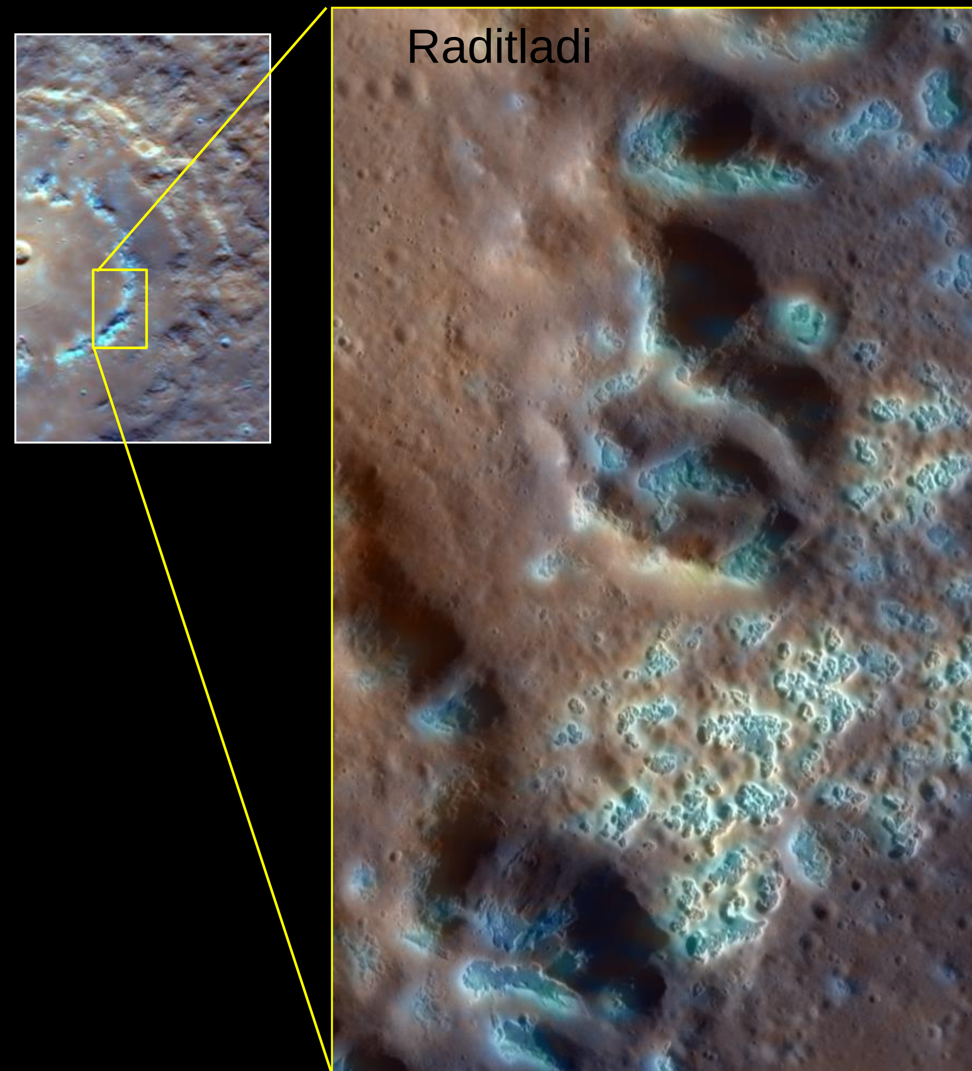
Murchie et al. [2008]



Head et al. [2011]

New Landform: “Hollows”

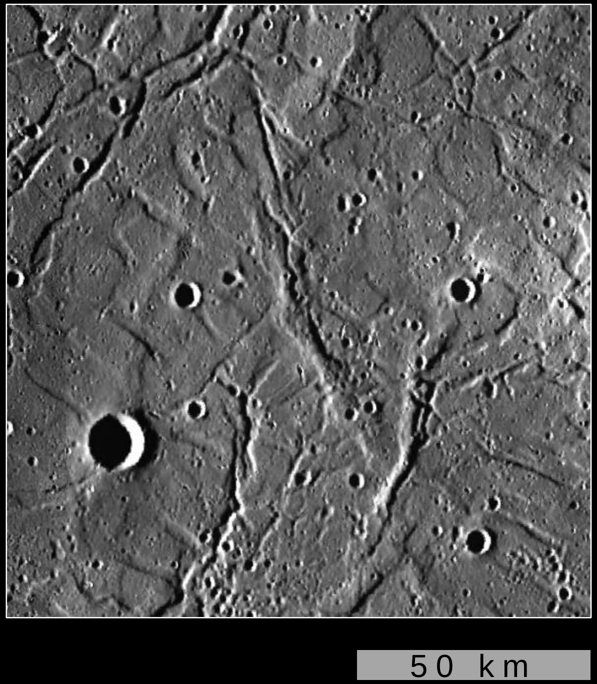
- Bright deposits within
  impact craters show fresh-appearing, rimless depressions, commonly with halos.
- Formation from recent volatile loss?

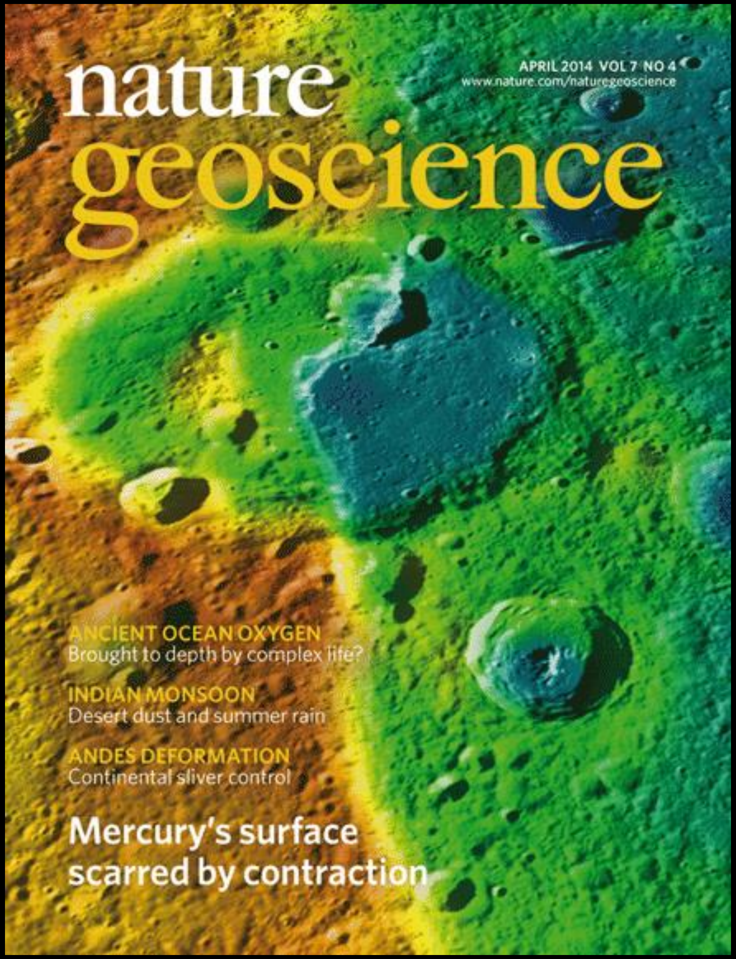


[Blewett et al., 2011]

Tectonics

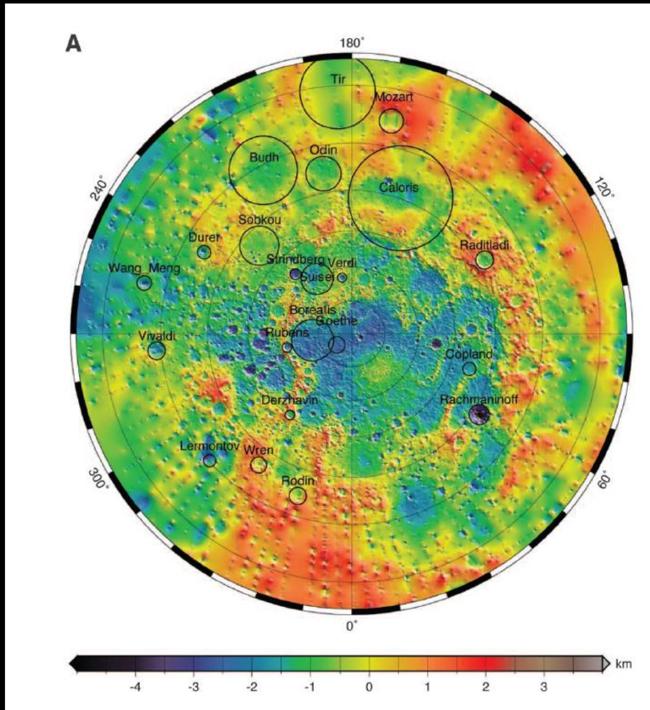
- Mercury covered with “lobate scarps” (cliffs)
- Due to contraction of planet as it cooled





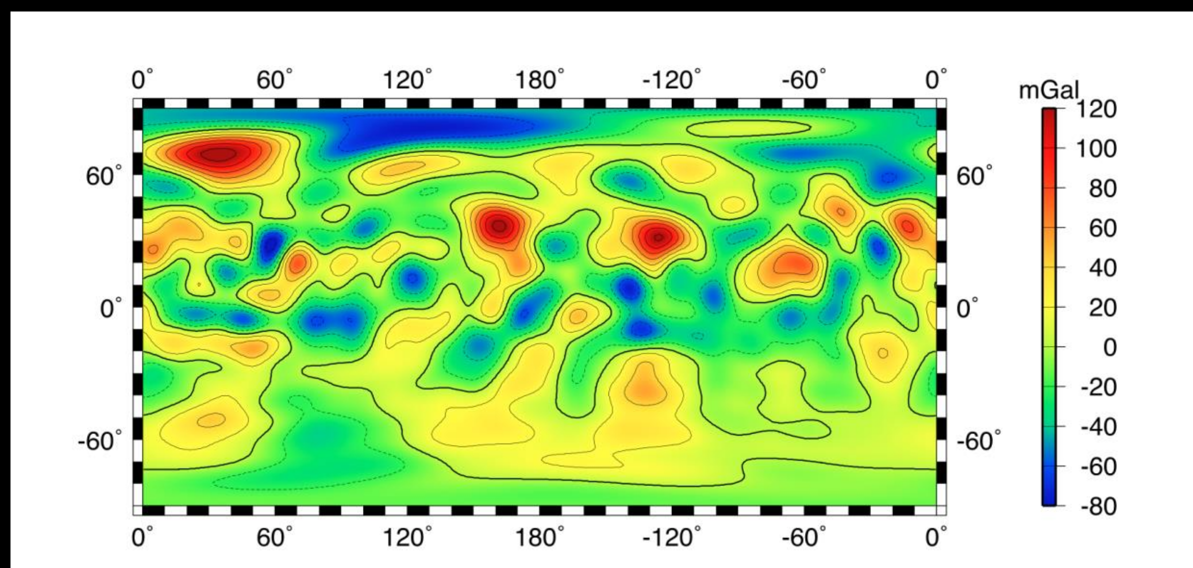
- Detailed analysis of MESSENGER data indicates much more contraction than previous work (Byrne et al. 2014)

Mercury Geophysics



Zuber et al. Science [2012]

- Radio Science combined with topography (left, from laser altimetry) to infer gravity map (below)
- Use to constrain interior structure

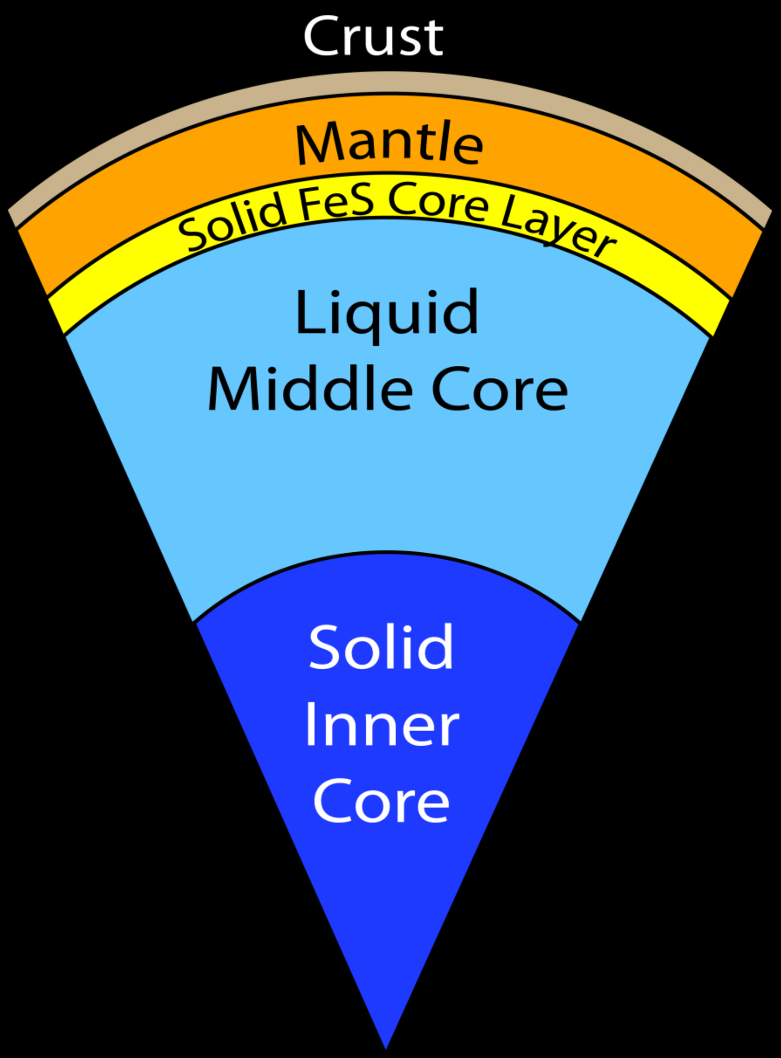


Smith et al. Science [2012]

Internal Structure

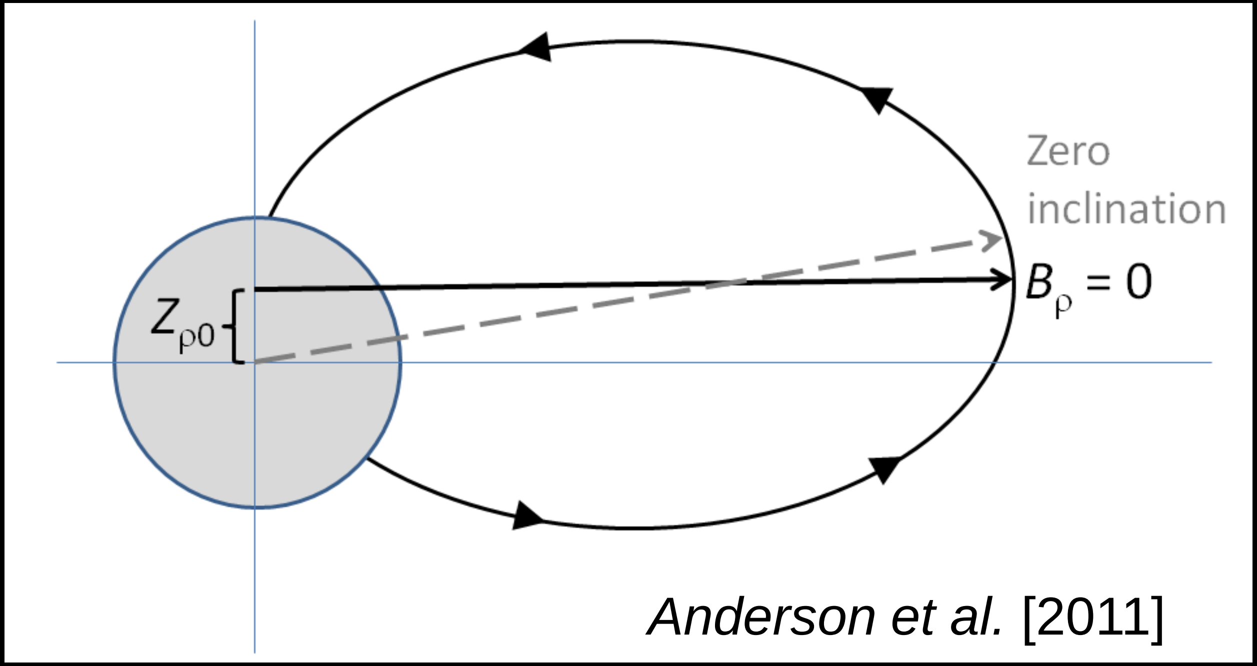
- Model of interior based on gravity field
  - Based on millions of internal structure models (Smith et al. 2012, Hauck et al. 2013)
  - Top of liquid core at r=2020 ± 30 km [R_{planet}=2440 km)

- High density (FeS) layer at base of mantle not required but consistent with data and may be expected for highly reduced planet



Hauck et al. [2012]

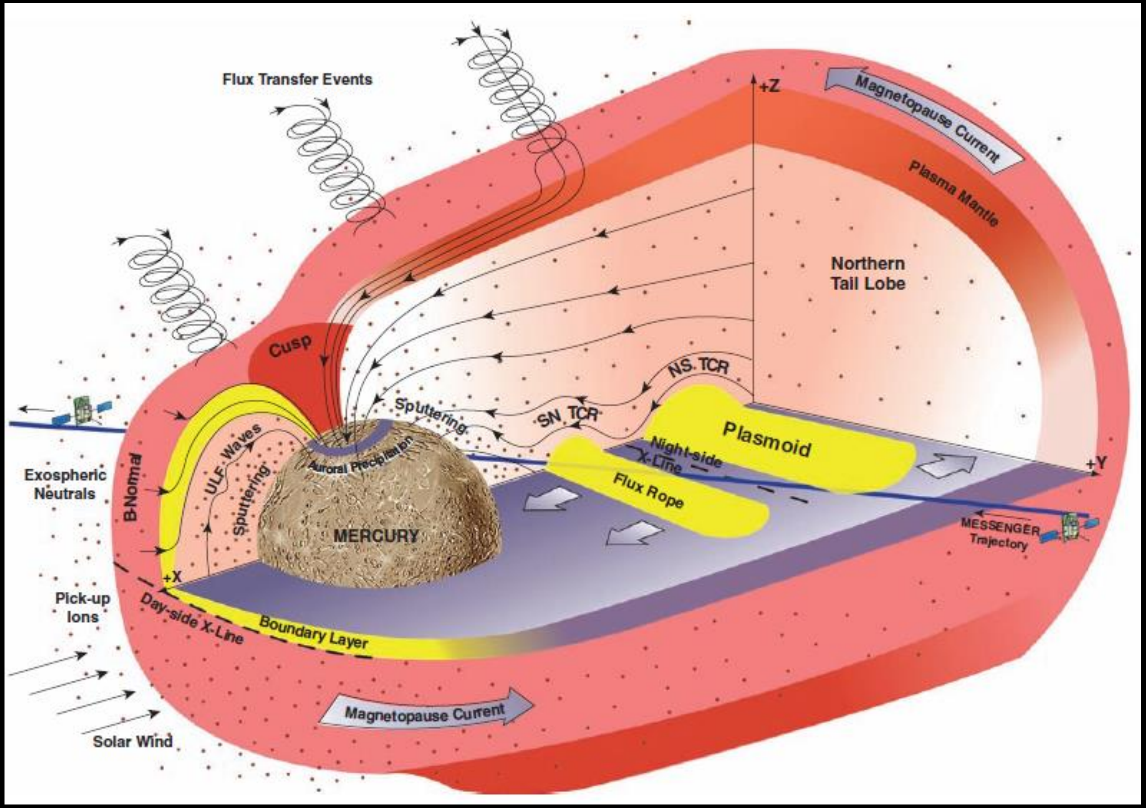
Magnetic Field: Dipole with Equator Offset



- Magnetic field is dipolar and of the same sense as that of the Earth, but displaced northward from the planet center by 480 km
- Large offset is unprecedented in the solar system and puts constraints of the generation mechanism

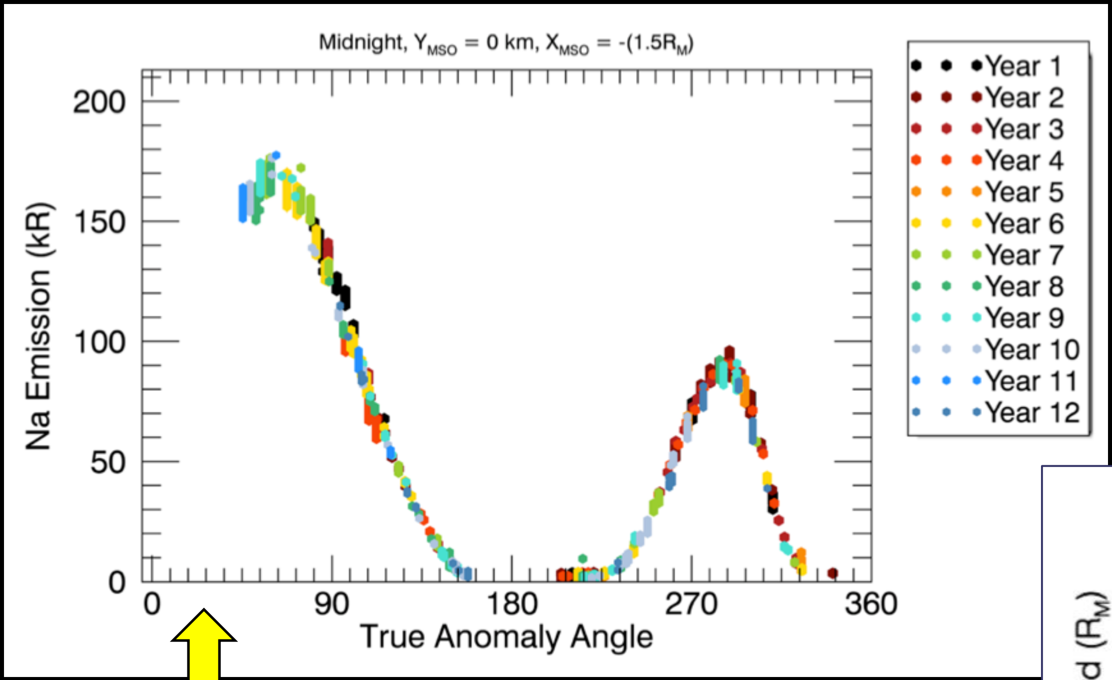
Mercury’s Magnetosphere

- Interaction with solar wind stretches Mercury’s magnetic is stretched into an elongated cavity referred to as the magnetosphere
- Highly dynamic
- Frequent highly energetic bursts of 30-300 keV electrons – but no steady-state radiation belts. (Ho et al. 2012)

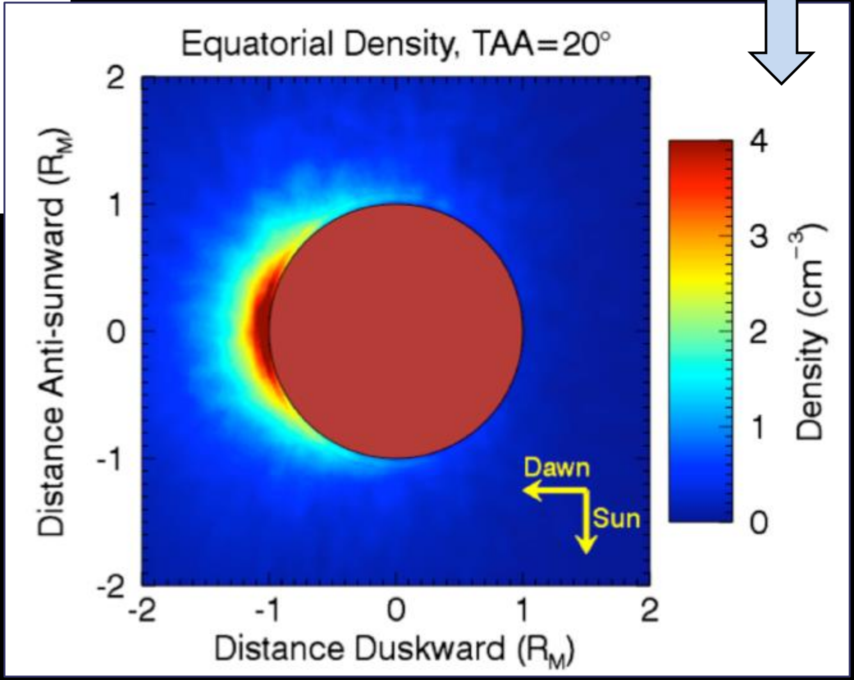


Slavin et al. [2009]

Mercury's Sodium and Calcium Exospheres Revealed

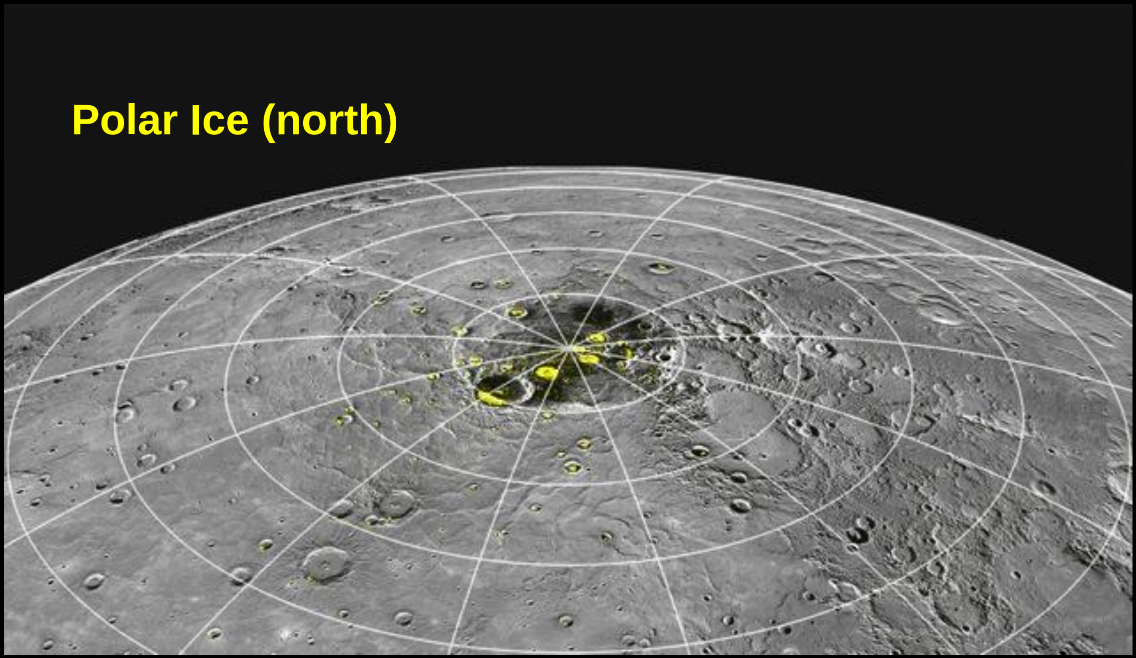


Calcium observations point to a persistent dawn source and suggest an origin associated with meteoroid impacts



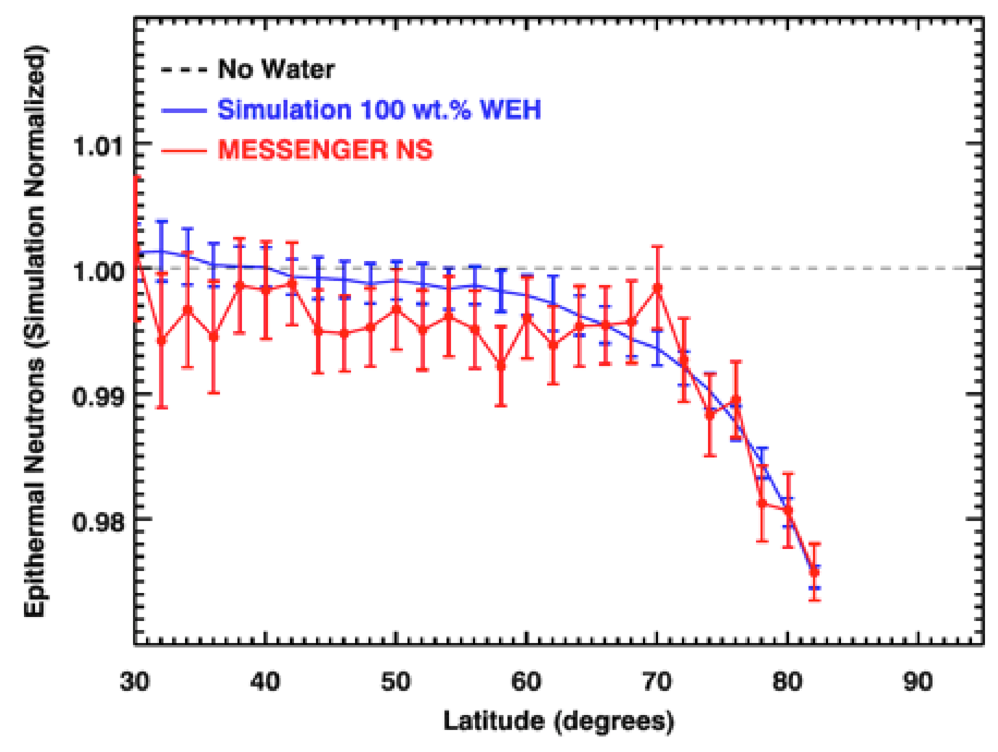
Sodium observations in the tail region are dominated by seasonal variability

Mercury's Polar Deposits



- Deposits with radar characteristics of water ice discovered in polar craters by ground-based astronomy in 1992.
- Imaging of polar regions confirms that radar-bright deposits occur in permanently shadowed regions
- Thermal modeling indicates ice/organic stability where deposits located

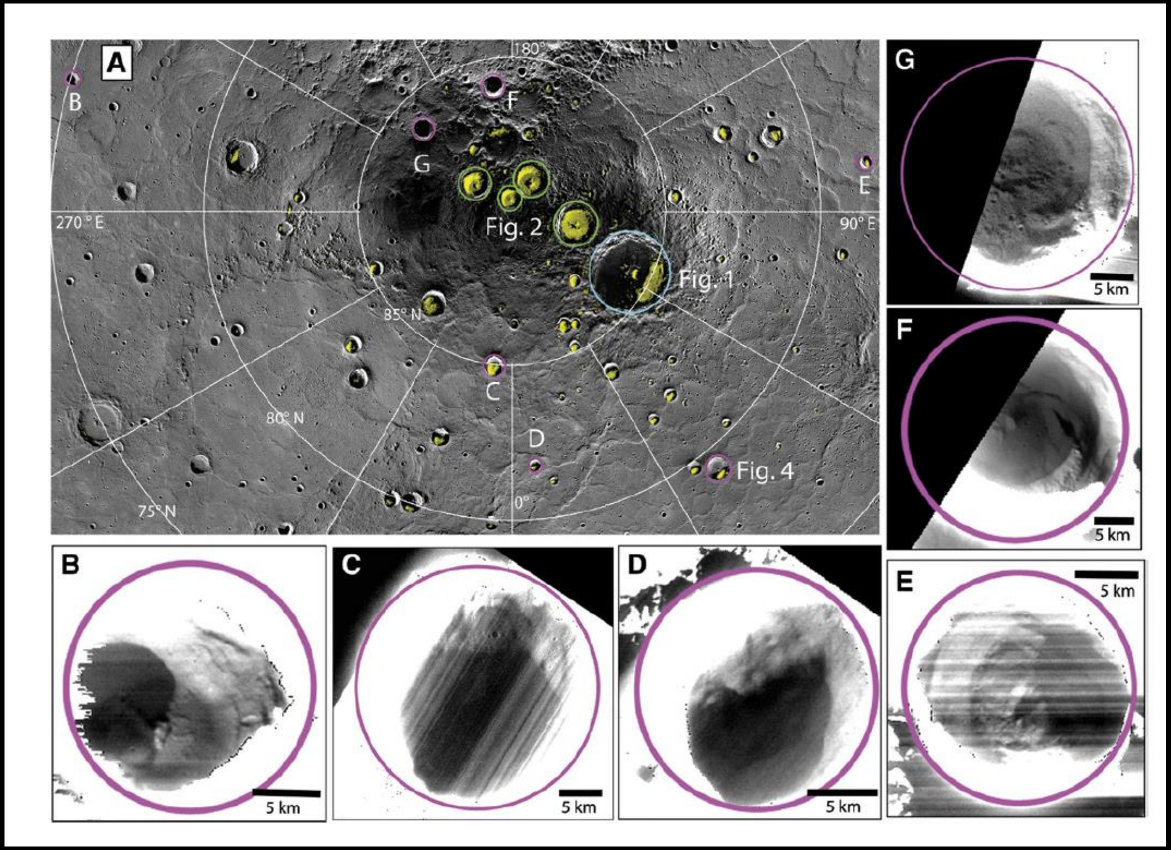
Mercury's Polar Deposits



- Neutron emissions sensitive to hydrogen
- Decrease at Mercury's North pole quantitatively matches expectation if deposits are water ice

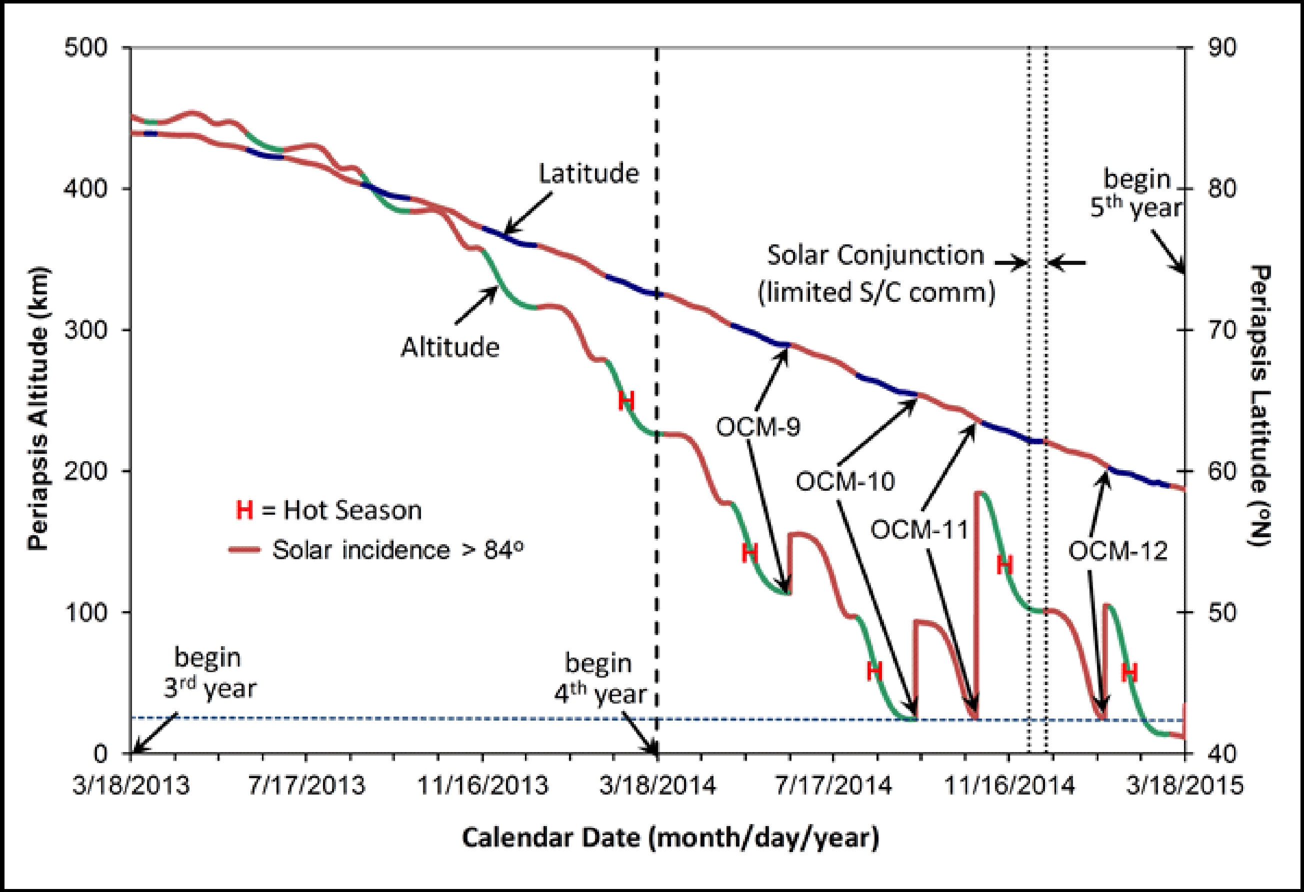
Lawrence et al., Neumann et al., Paige et al. Science [2013]

Mercury's Polar Deposits



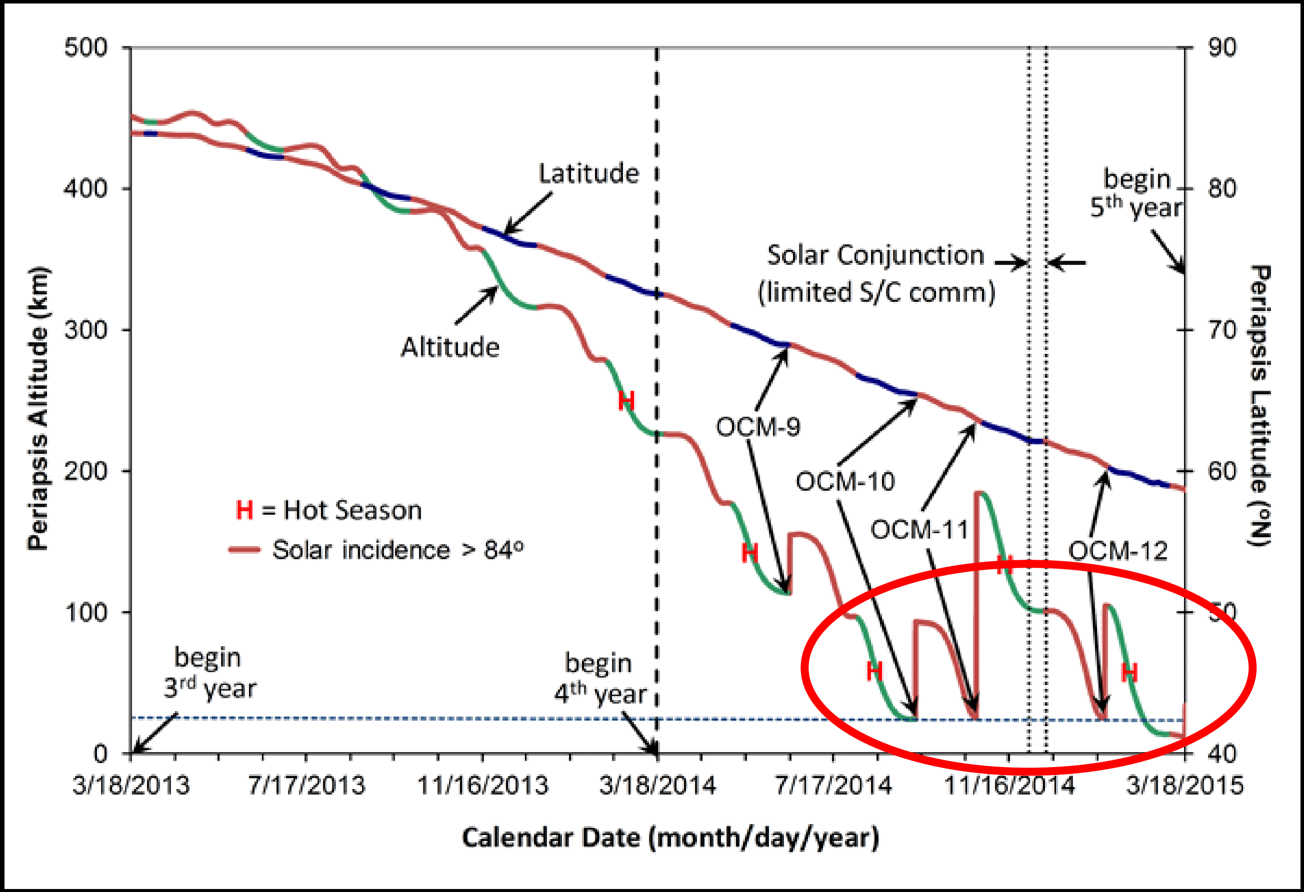
- Deep MESSENGER imaging also reveals brightness variations in deposits (Chabot et al , 2014)

XM2: Low-altitude Campaign



- Since April 2014, periapsis altitude <200km

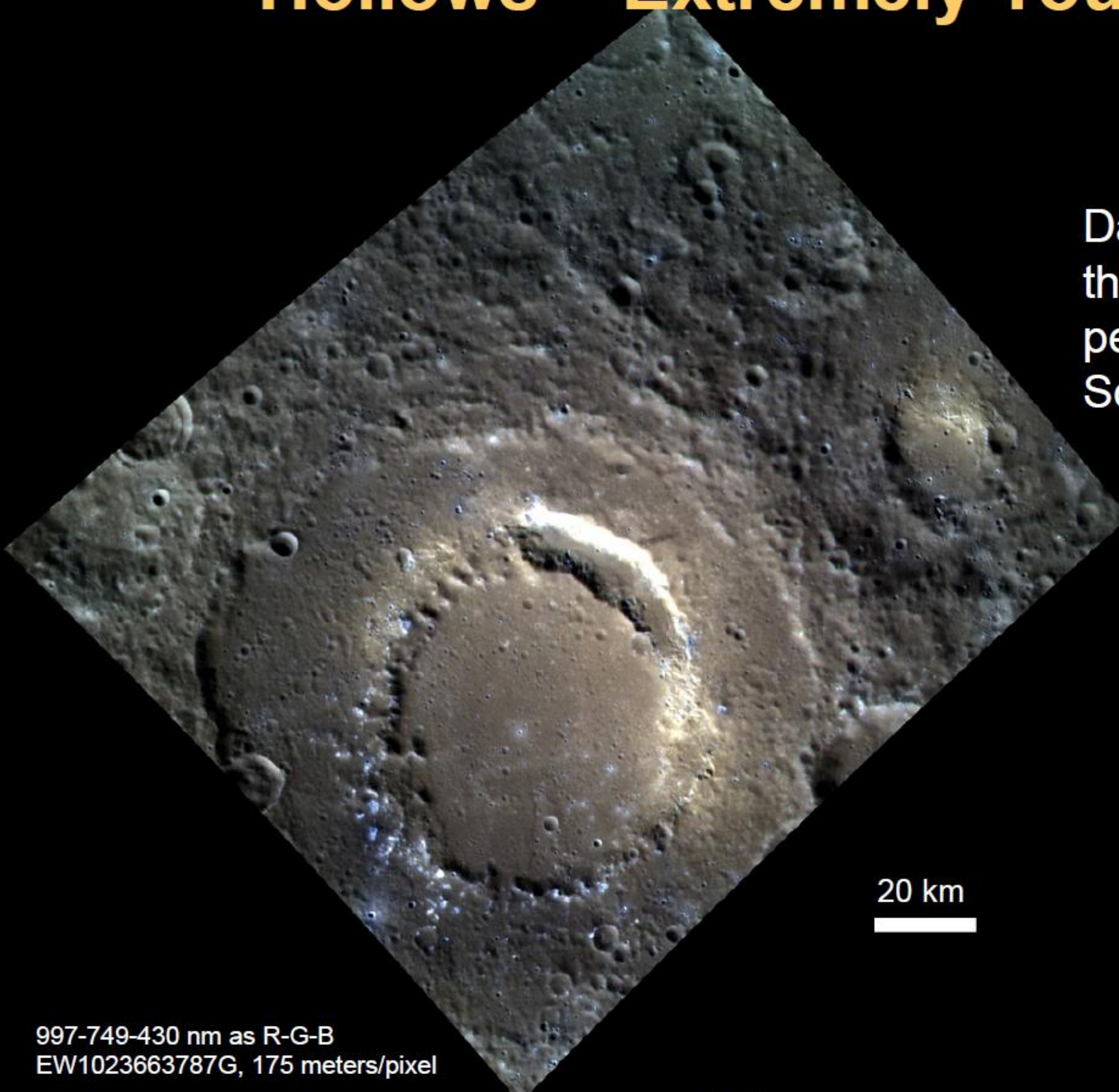
XM2: Low-altitude Campaign



- Since April 2014, periapsis altitude <200km
- Since August 2014, mostly 20-100km

Allows unprecedented resolution!

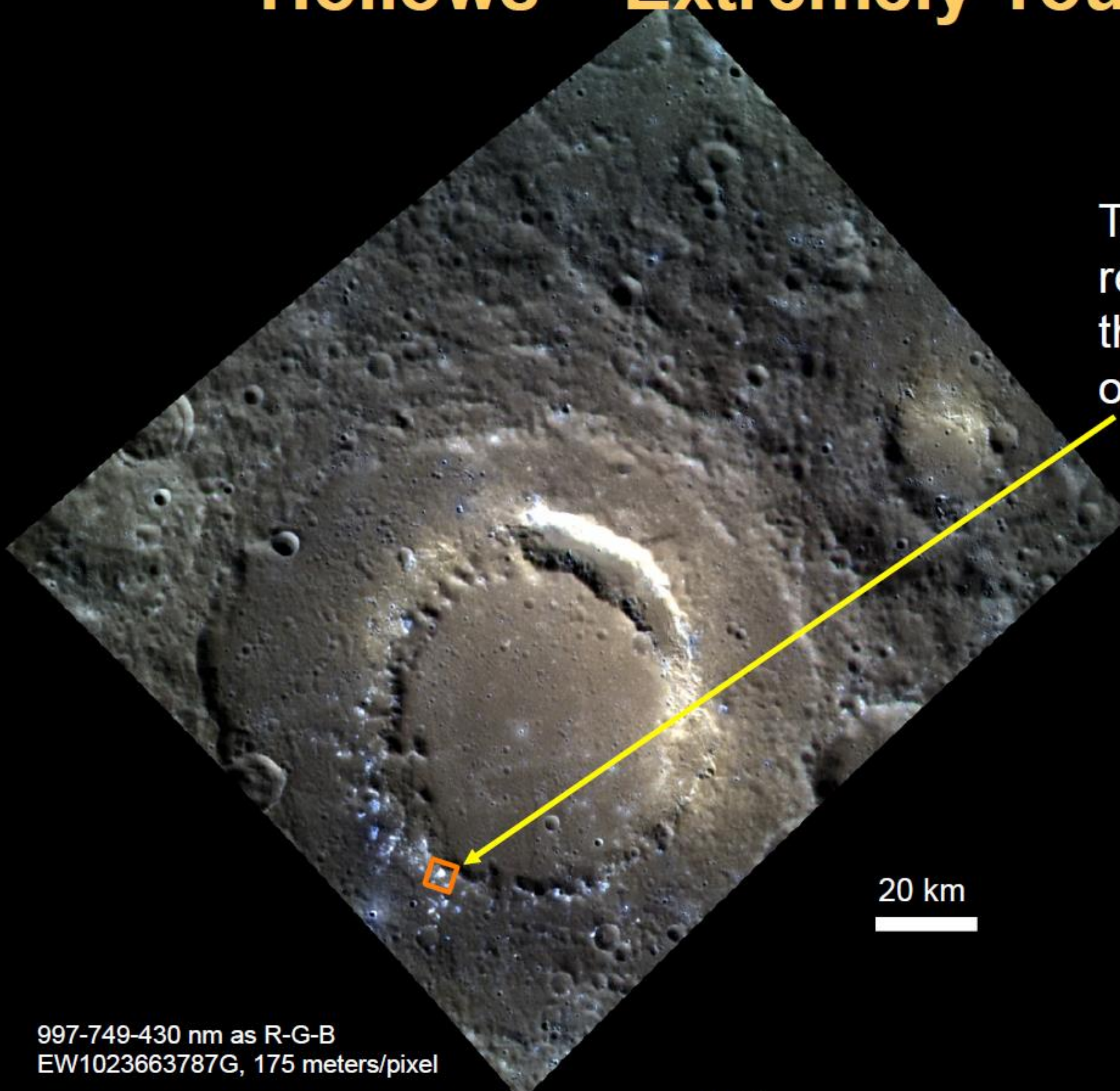
Hollows – Extremely Young



Dark material on the southwestern peak ring of the Scarlatti basin.

997-749-430 nm as R-G-B
EW1023663787G, 175 meters/pixel

Hollows – Extremely Young

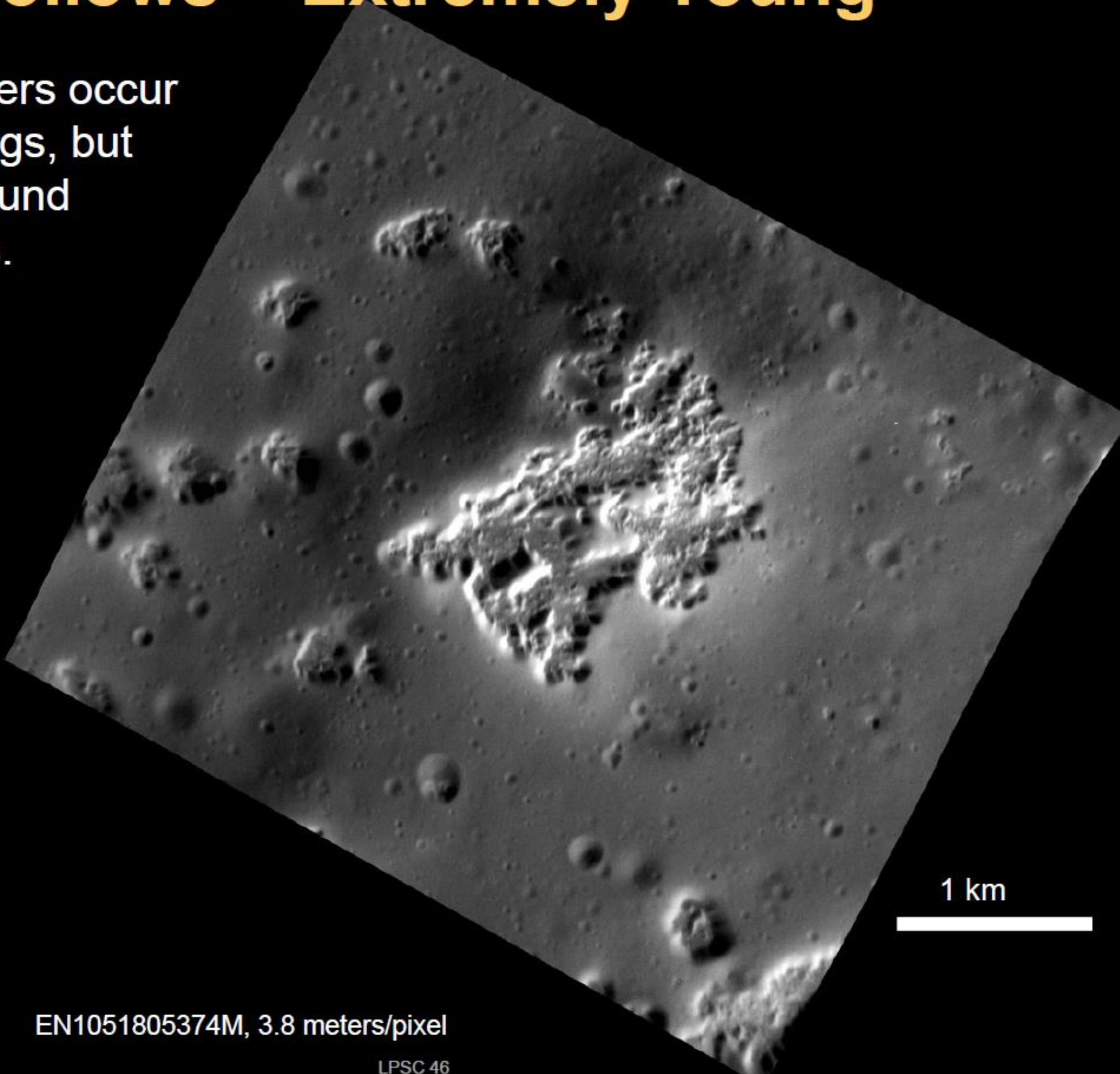


997-749-430 nm as R-G-B
EW1023663787G, 175 meters/pixel

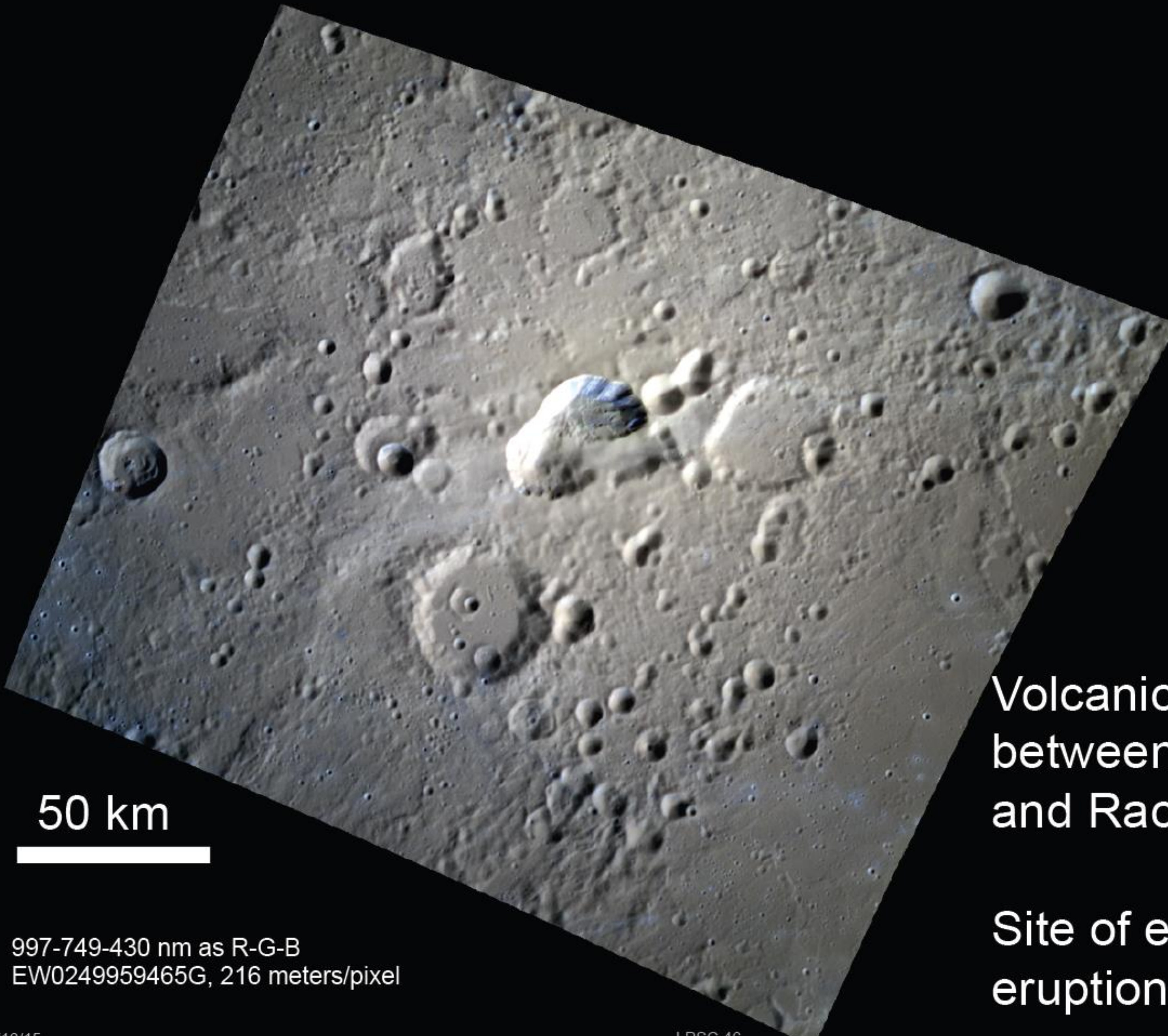
Hollows – Extremely Young

Small impact craters occur on the surroundings, but few (if any) are found within the hollows.

Hollows are very young relative to the rest of Mercury's surface.



EN1051805374M, 3.8 meters/pixel

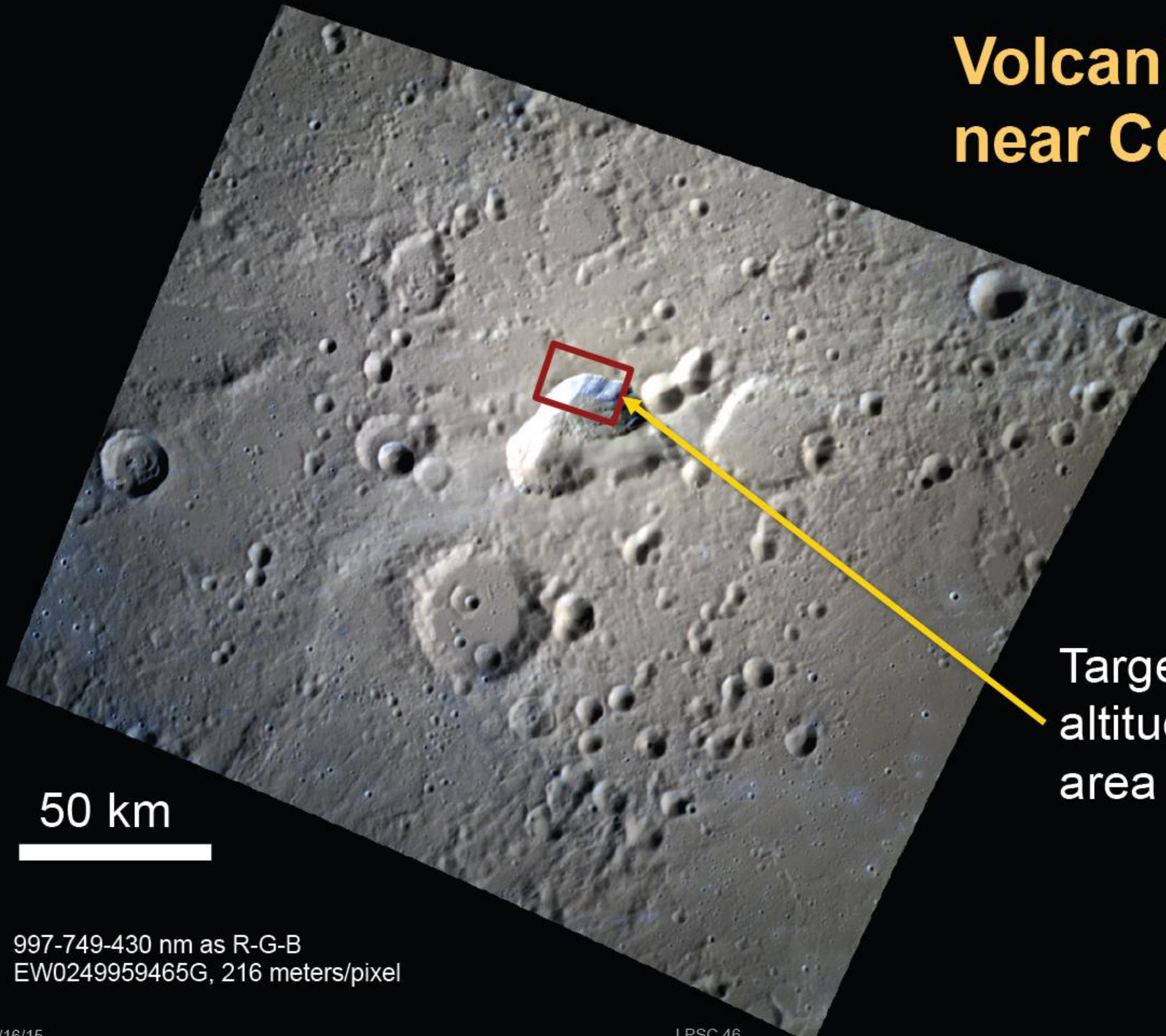


997-749-430 nm as R-G-B
EW0249959465G, 216 meters/pixel

Volcanic vent between Copland and Rachmaninoff

Site of explosive eruption(s)

Volcanic vent near Copland crater

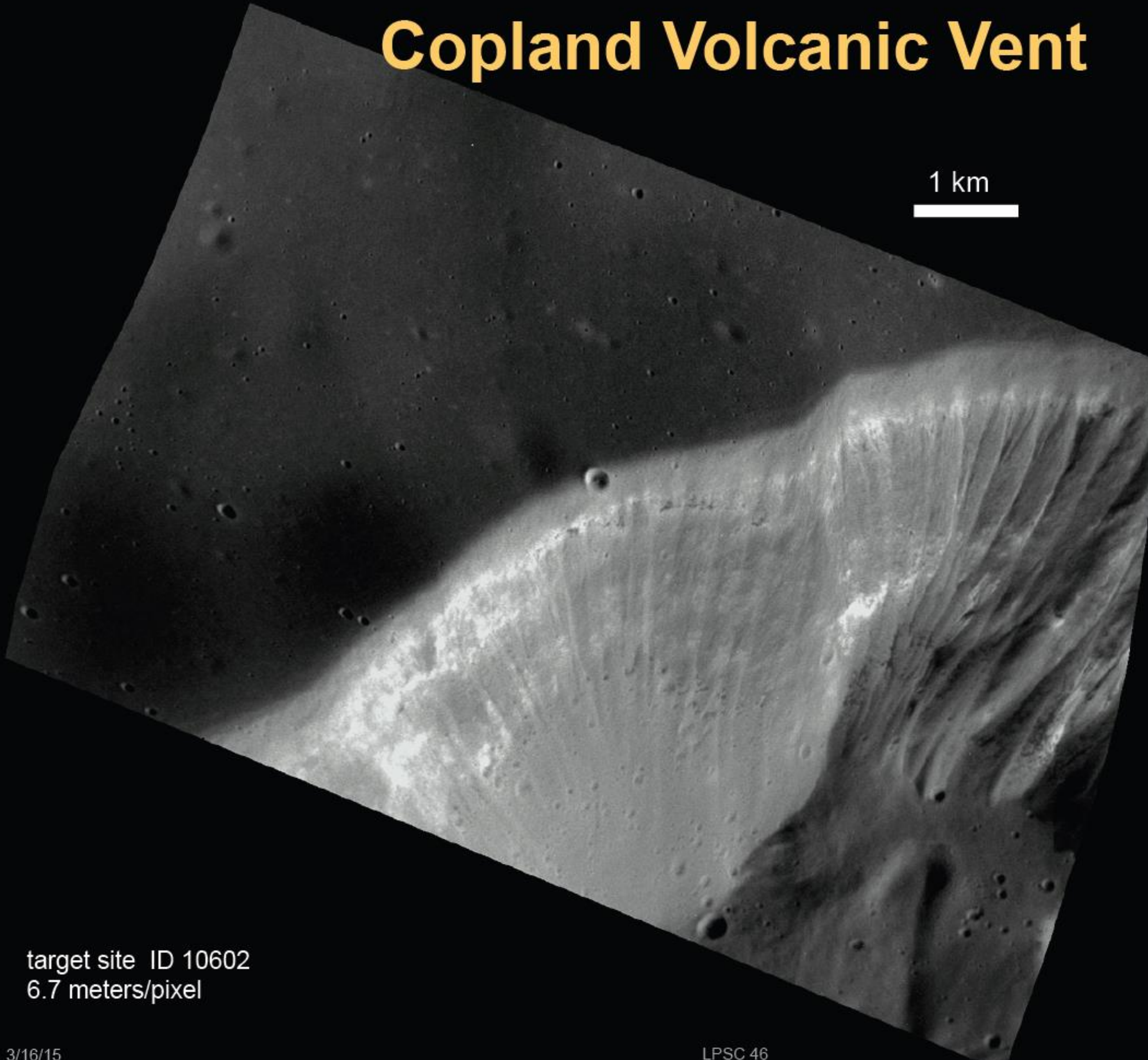


Targeted low-altitude image, area of red box

50 km

997-749-430 nm as R-G-B
EW0249959465G, 216 meters/pixel

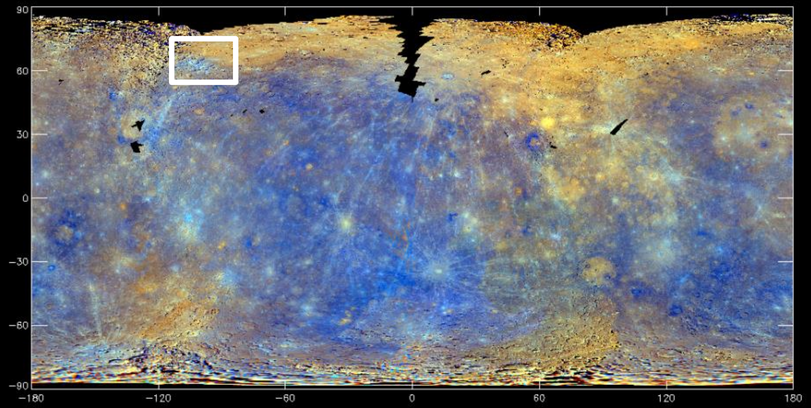
Copland Volcanic Vent



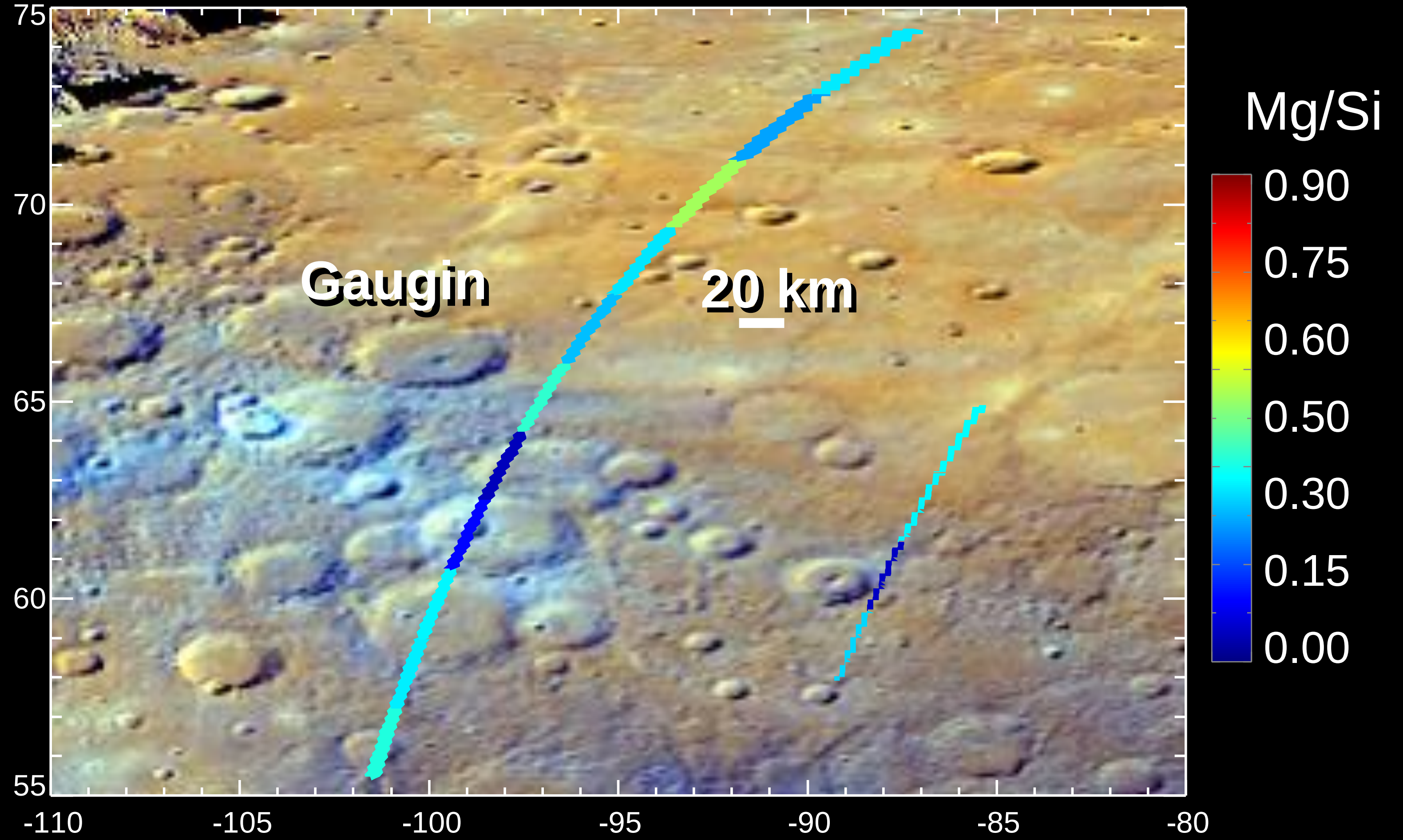
Bright layers and outcrops of hollows material on walls of the vent

Fluting/gullies on wall from landslides

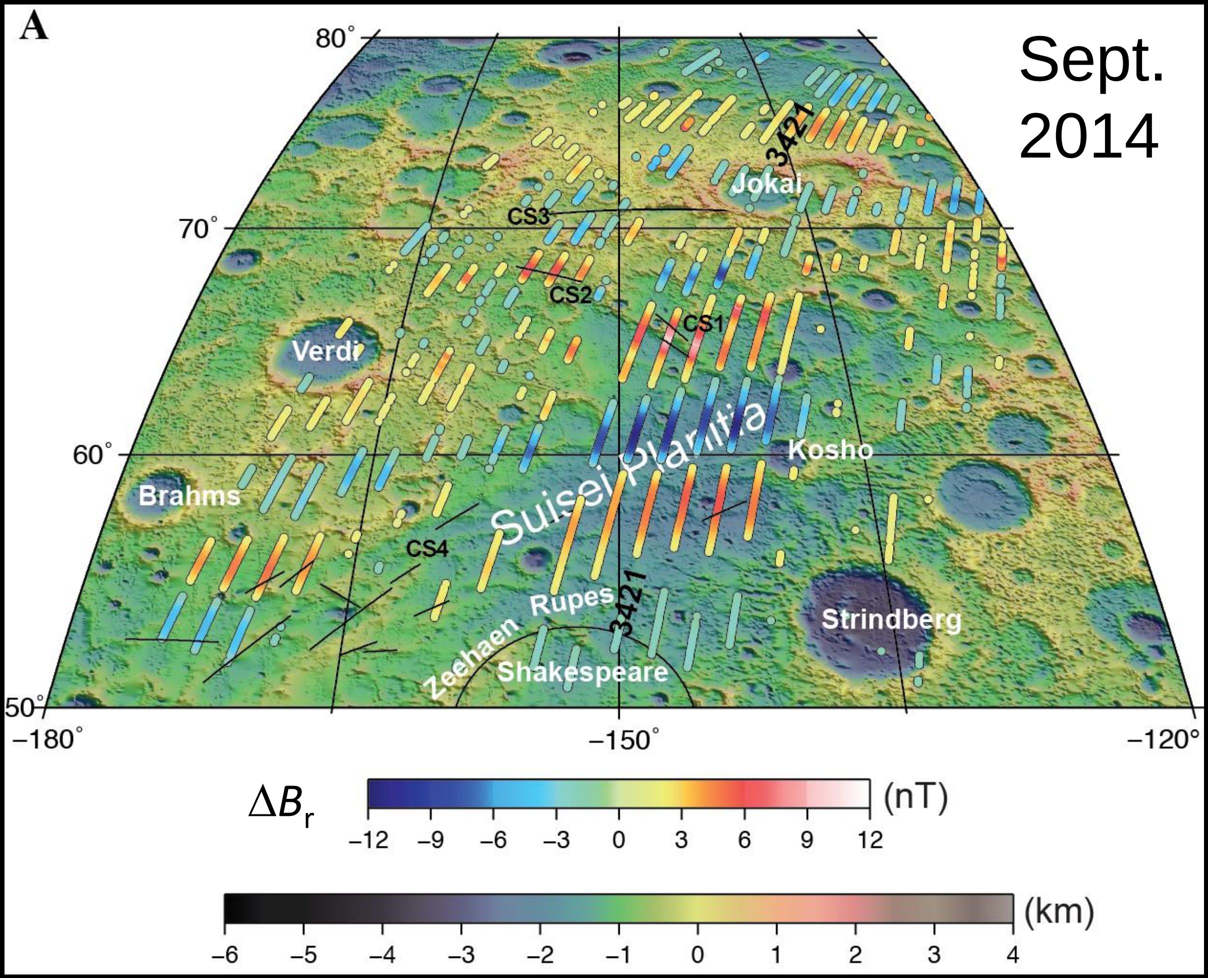
target site ID 10602
6.7 meters/pixel



Low-altitudes allowing chemical measurements with ~few km resolution



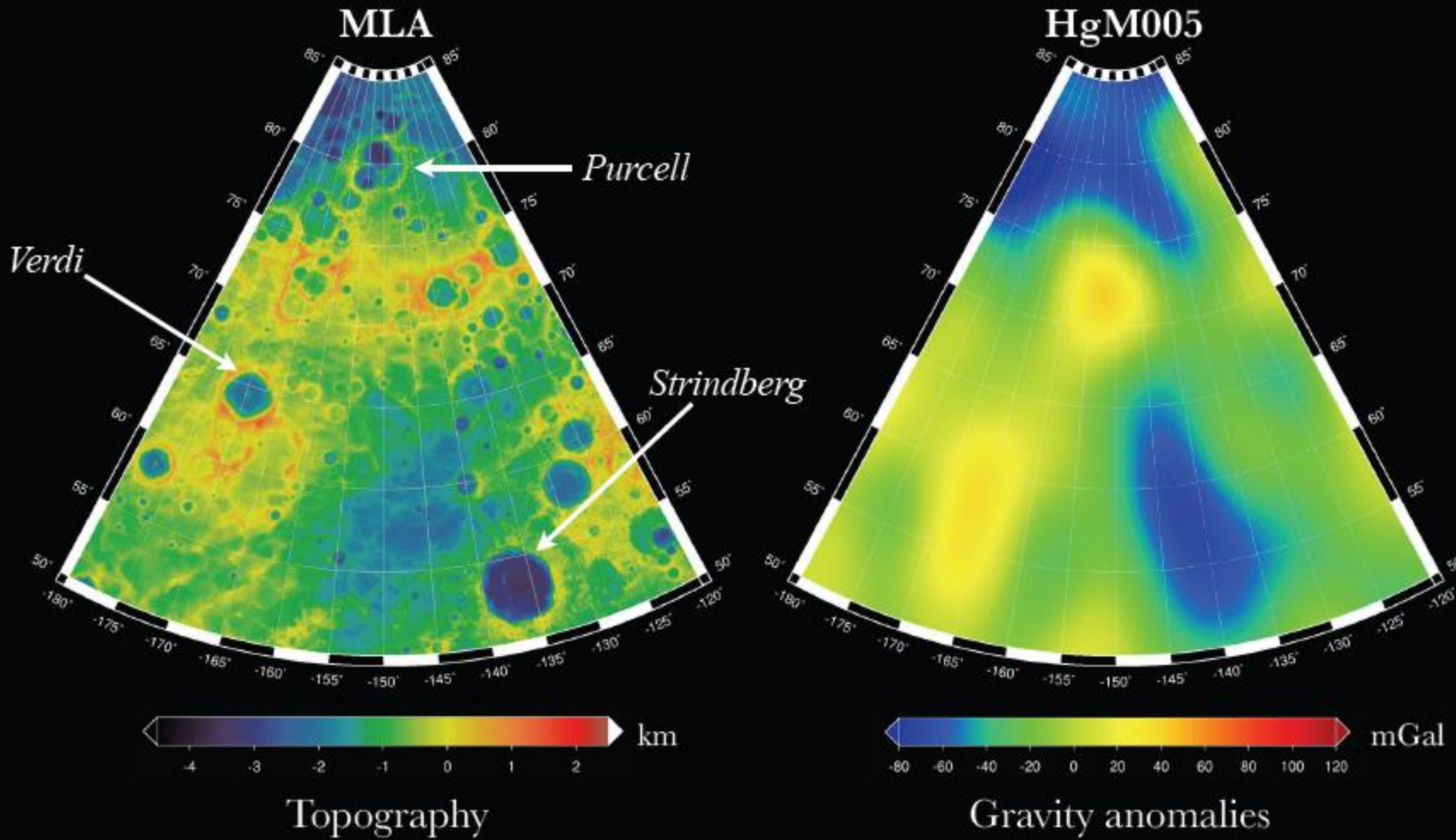
Remanent Crustal Magnetism



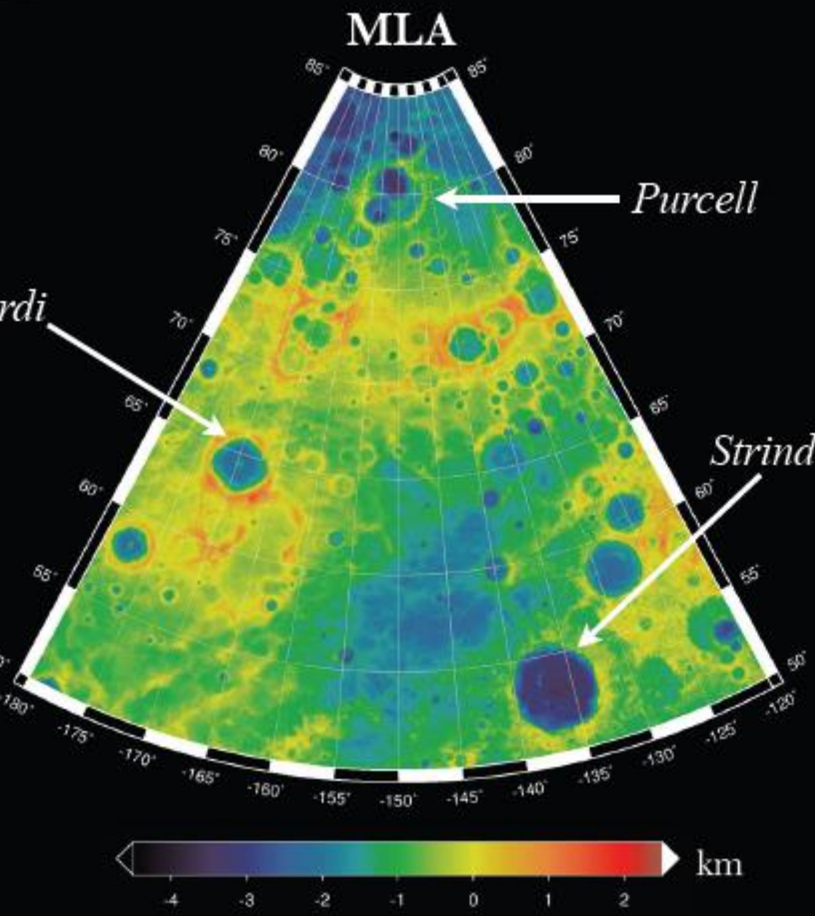
Johnson et al. LPSC 2015

- Altitudes 25 - 60 km
- Thermal preservation of magnetization over ~4 Gyr!

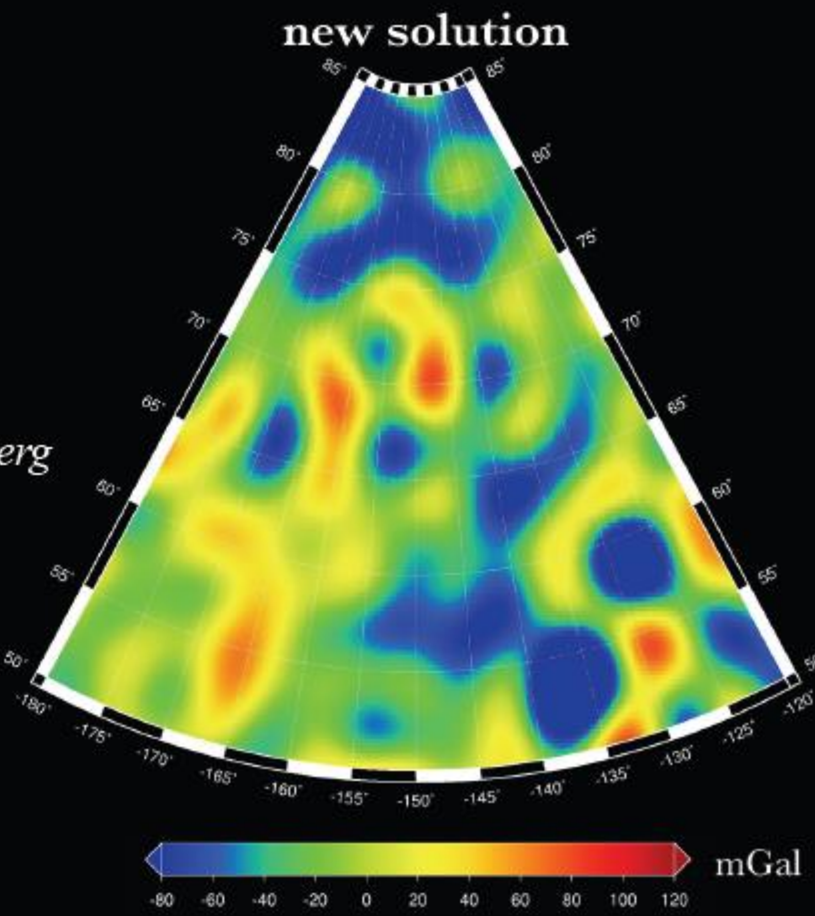
Gravity Anomalies



Gravity Anomalies

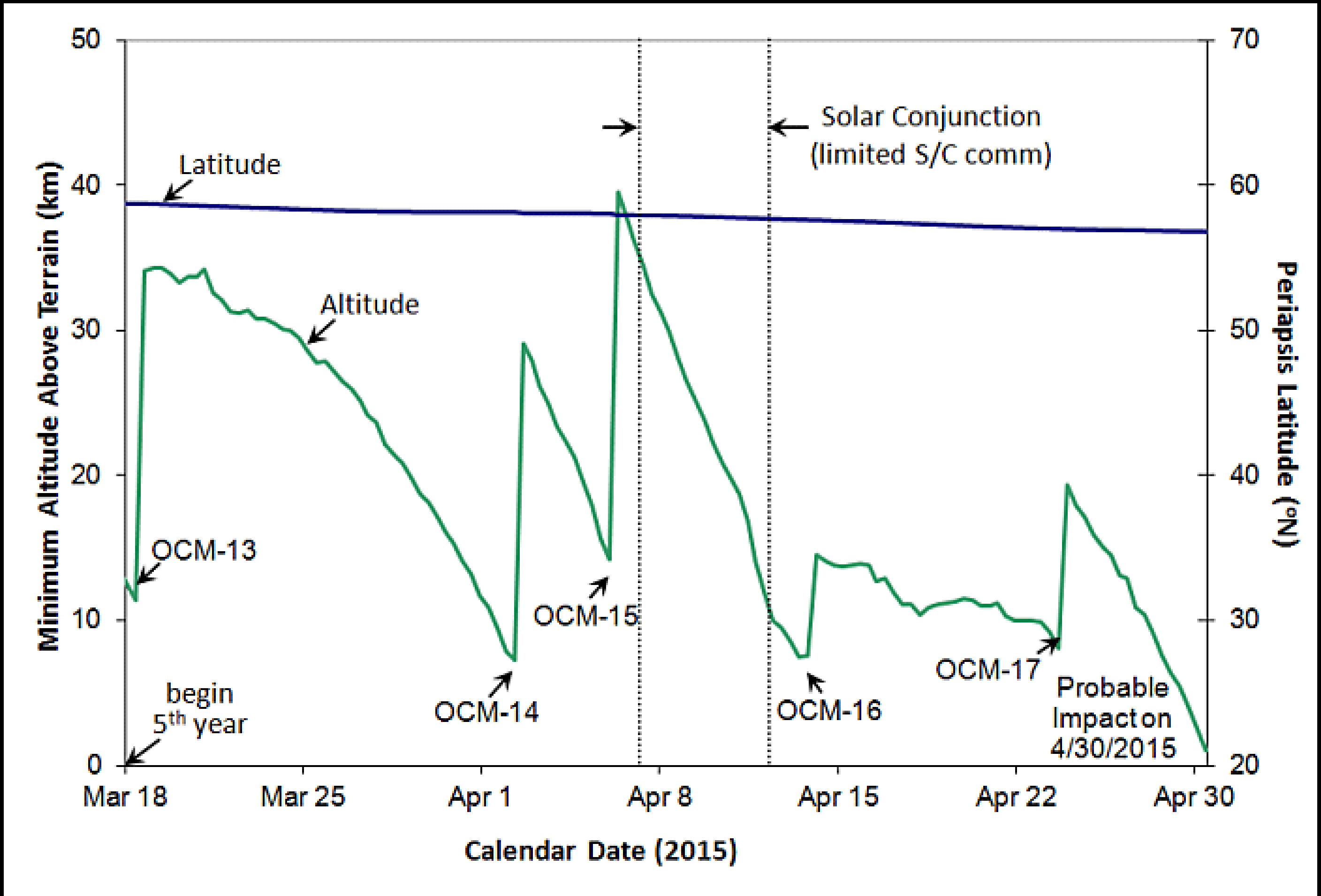


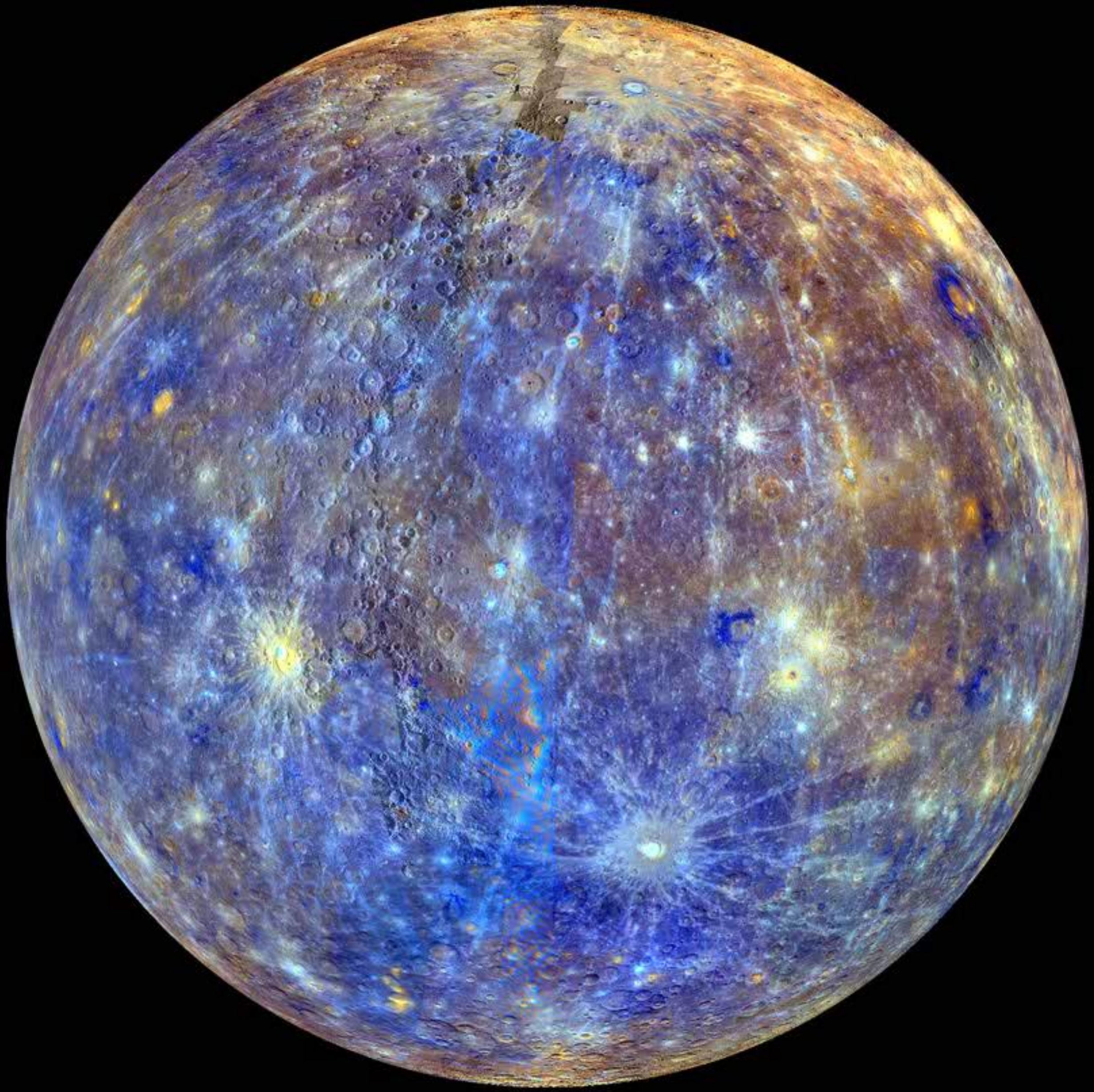
Topography



Gravity anomalies

XM2' - Endgame


Solar Conjunction
(limited S/C comm)
Latitude
Altitude
OCM-13
OCM-14
OCM-15
OCM-16
OCM-17
begin
5th year
Probable
Impact on
4/30/2015
Minimum Altitude Above Terrain (km)
Periapsis Latitude (°N)
Calendar Date (2015)
Mar 18
Mar 25
Apr 1
Apr 8
Apr 15
Apr 22
Apr 30
0
10
20
30
40
50
20
30
40
50
60
70



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