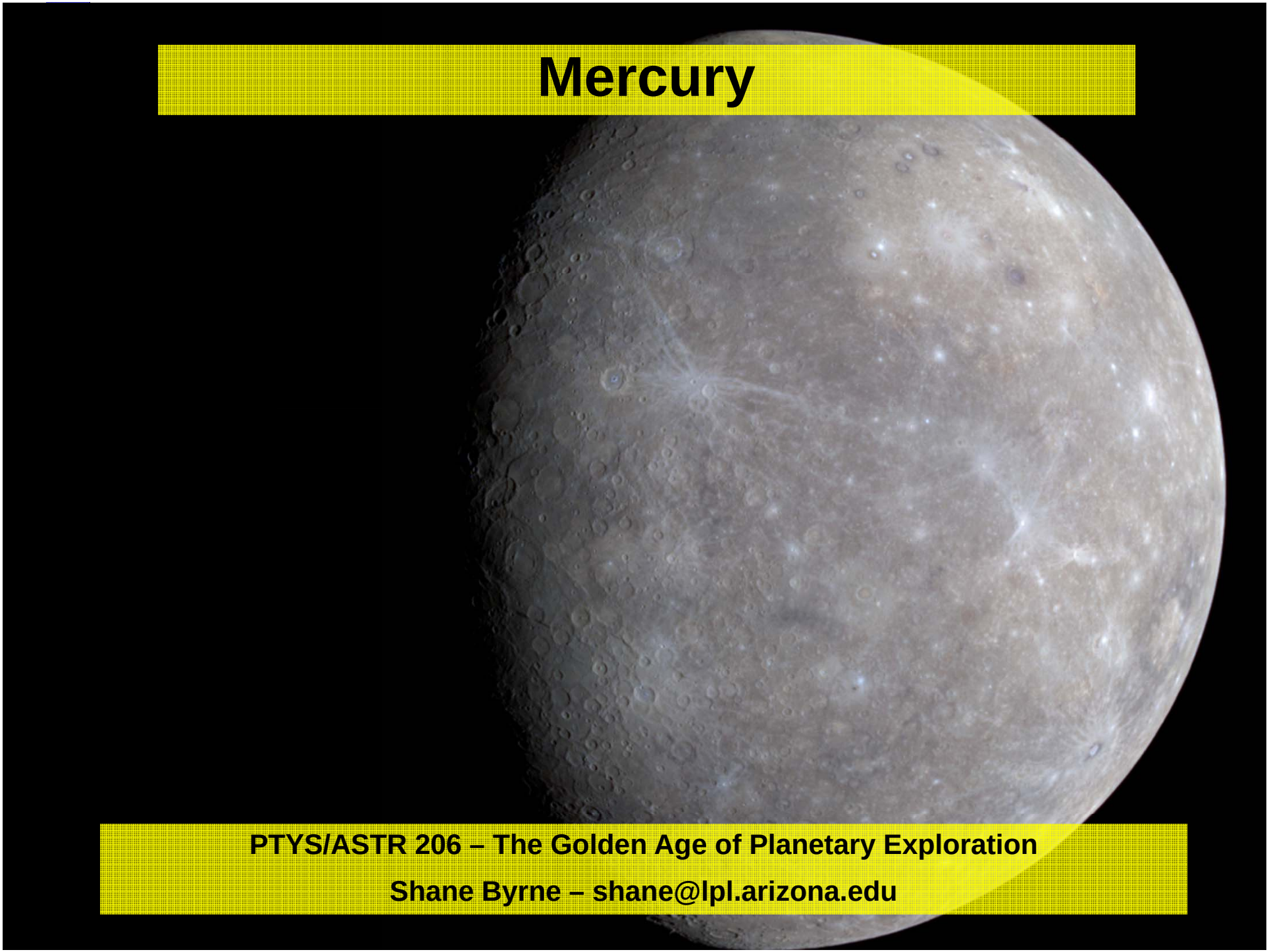
- **Announcements**
  - **Homework #2 late submissions due now**
    - **50% credit**
  - **Mid-term #1 on Thursday**
    - **Based on the first 10 lectures (incl. this one)**
    - **Multiple choice - bring #2 pencils**
    - **Lasts 1 hour and starts on time**
    - **You won't need a calculator**
    - **Any questions on formulas will include the formula**
    - **Practice exam available on class website**
    - **Don't memorize numbers…**
      - **…but understand quantities relative to each other**
      - **e.g. IR wavelength longer than UV wavelength**
      - **1AU much bigger than the Earth-Moon distance**

Mercury



PTYS/ASTR 206 – The Golden Age of Planetary Exploration

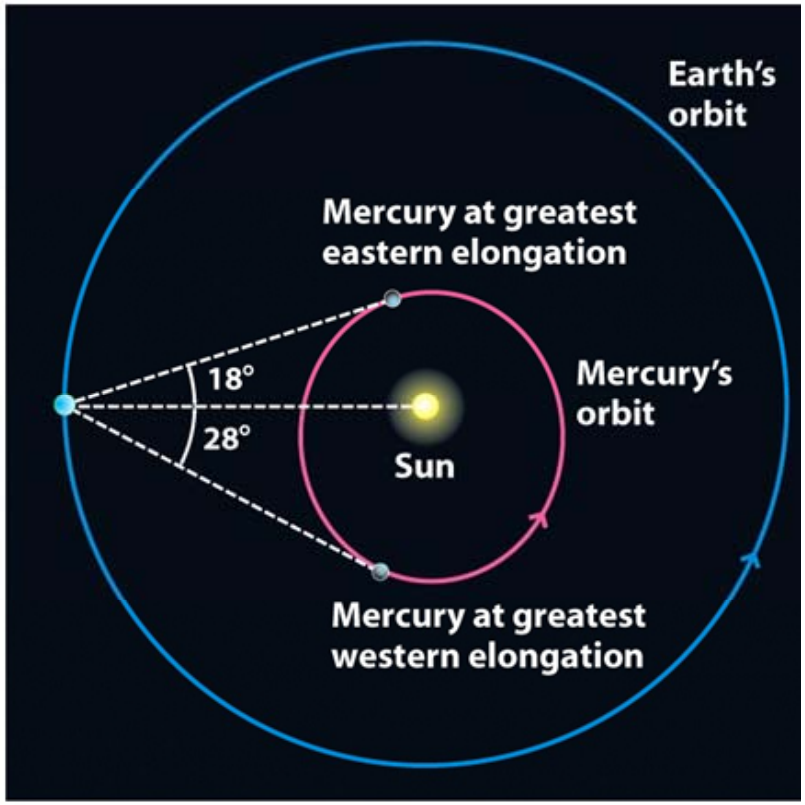
Shane Byrne – shane@lpl.arizona.edu

In this lecture…

- Mercury's strange orbit
  - Extreme temperatures
  - Hot and cold longitudes
- Mercury's even stranger interior
  - Giant core
  - Magnetic field
- Mercury's surface
  - Like the Moon – but not quite
  - A planet that shrunk
  - Newly found Volcanoes
  - Caloris basin and the 'weird' terrain

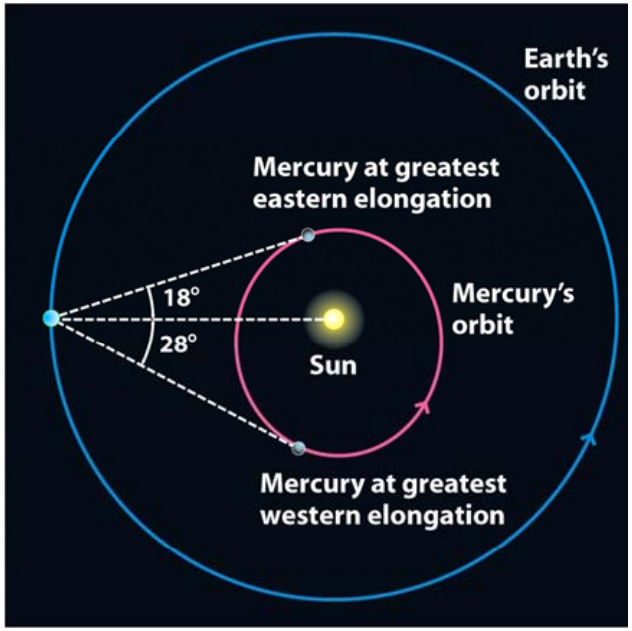
Mercury's Orbit

- **Closest to the Sun**
  - **Average distance 0.39 AU**
- **Mercury's orbit is odd compared to other planets**
  - **Both eccentric and inclined**



Planet	Inclination	Eccentricity
Mercury	**7°**	**0.21**
Venus	3.4°	0.01
Earth	0°	0.02
Mars	1.9°	0.09
Jupiter	1.3°	0.05
Saturn	2.5°	0.06
Uranus	0.8°	0.05
Neptune	1.8°	0.01

- Mercury's surface gets extremely hot
  - Perihelion - closest to the sun
  - Mercury is 0.31 AU from the sun
  - Aphelion – Furthest from the sun
  - Mercury is 0.47 AU from the sun

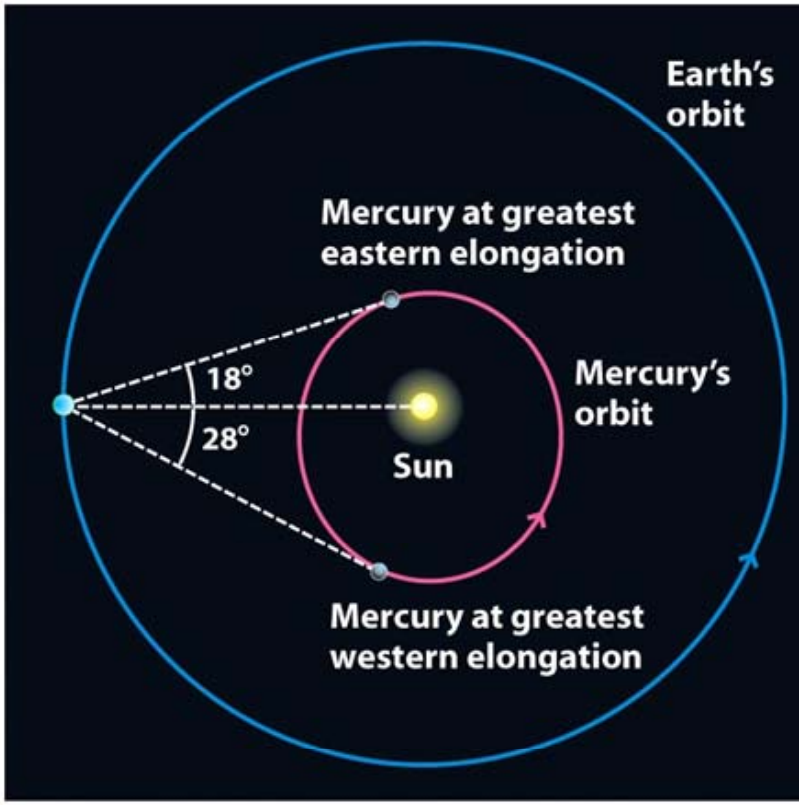


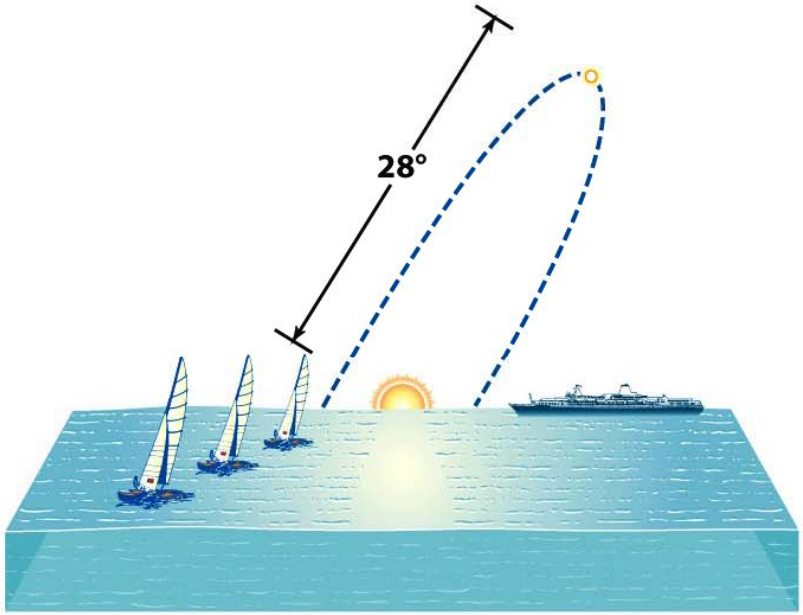
- Remember this?

Solar power = 1367 W m^{-2} / R^2

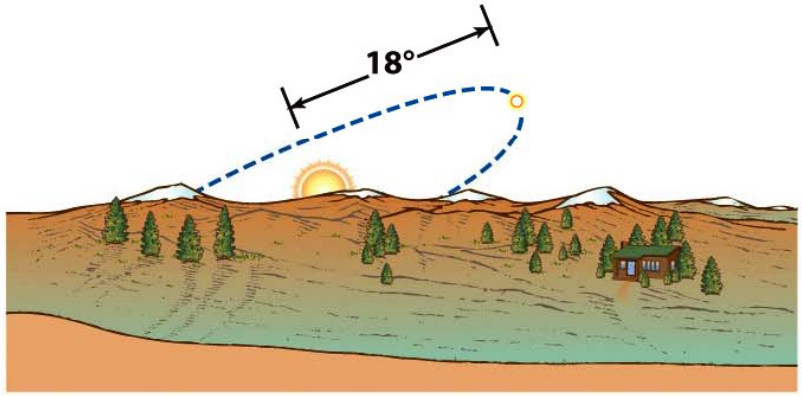
  - R is the solar distance in AU
  - Mercury at perihelion 14,225 W m^{-2}
    - Temperatures as high at 700K
  - Mercury at aphelion 6188 W m^{-2}
    - Temperatures as high as 570K
  - Night-time temperatures on Mercury as low as 100K

- **Mercury is hard to observe from the Earth with telescopes**
  - **Always visible for less than 2 hours**
  - **Either just before dawn or just after Sunset**
  - **Always close to the horizon**





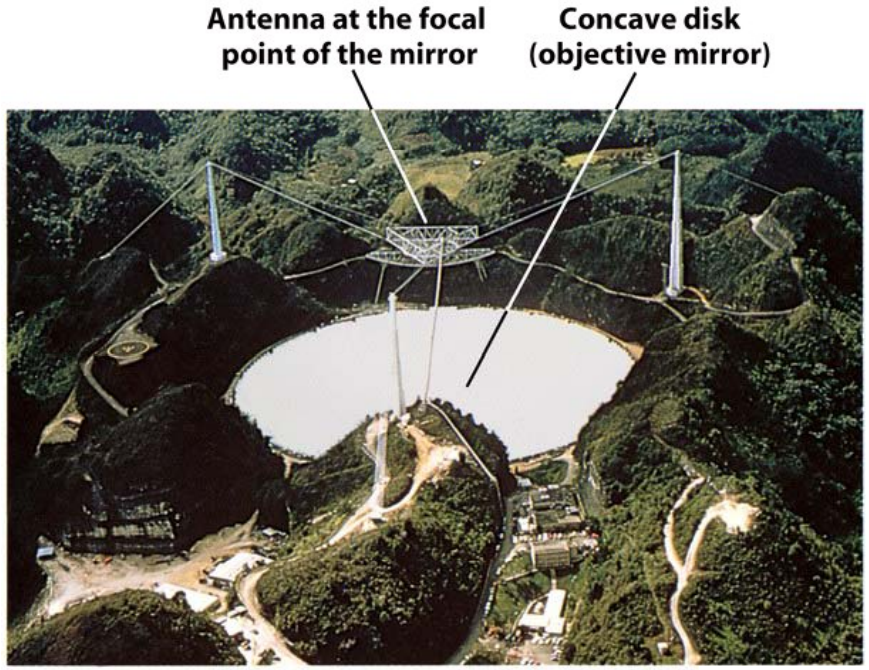
Favorable elongation



Unfavorable elongation

Figure 11-2
Universe, Eighth Edition

- **We have other tools available (I)**
  - **Radar observations - Arecibo**



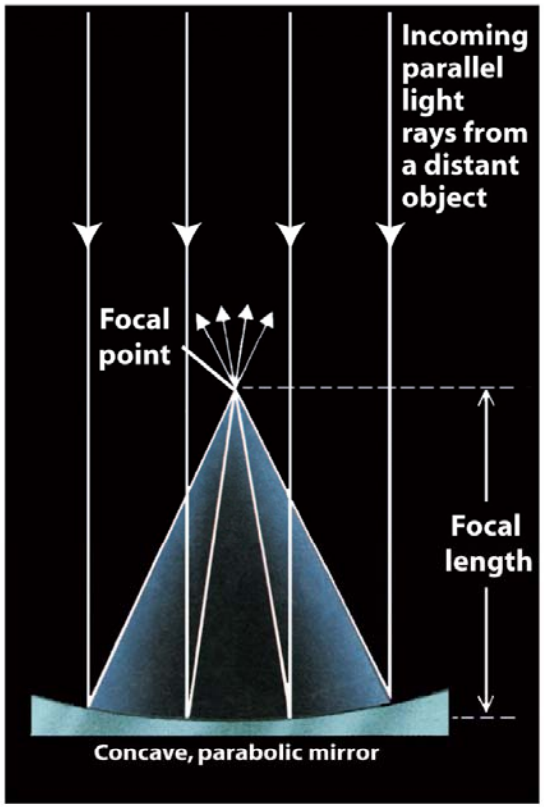
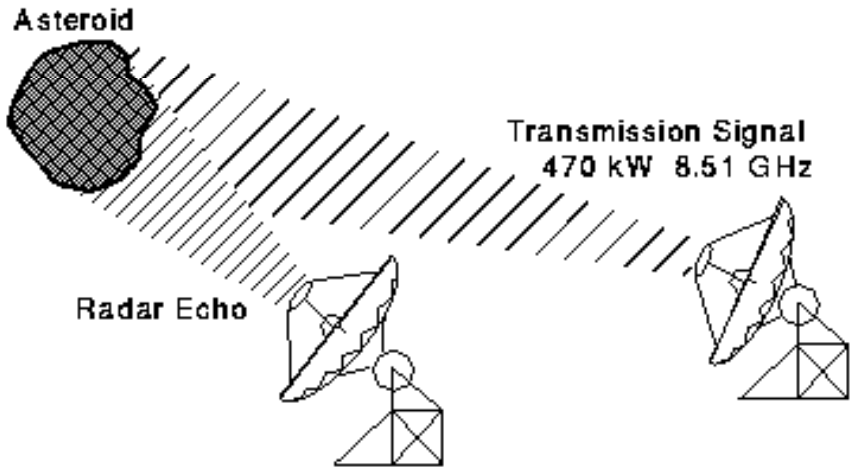
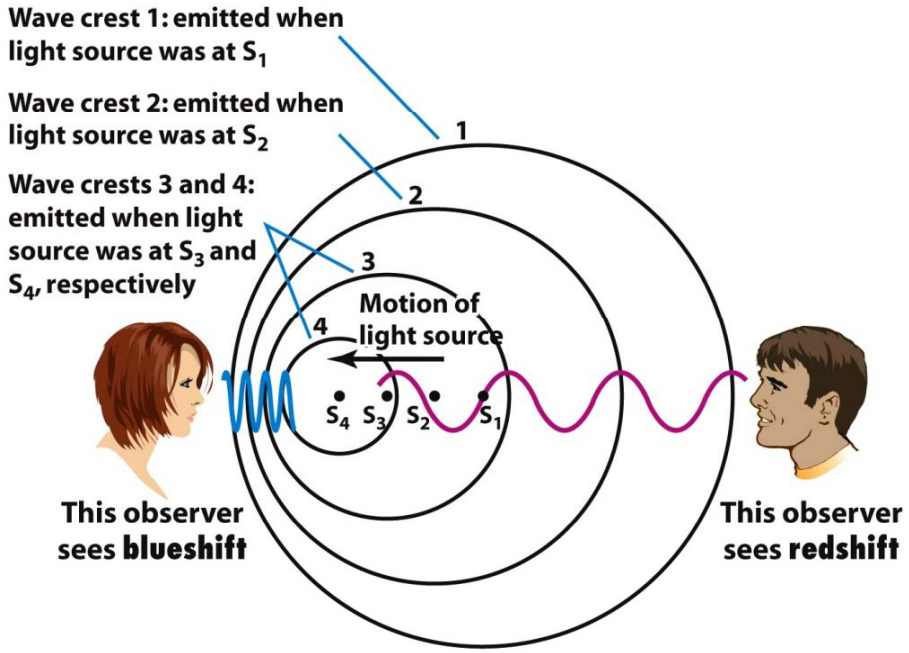


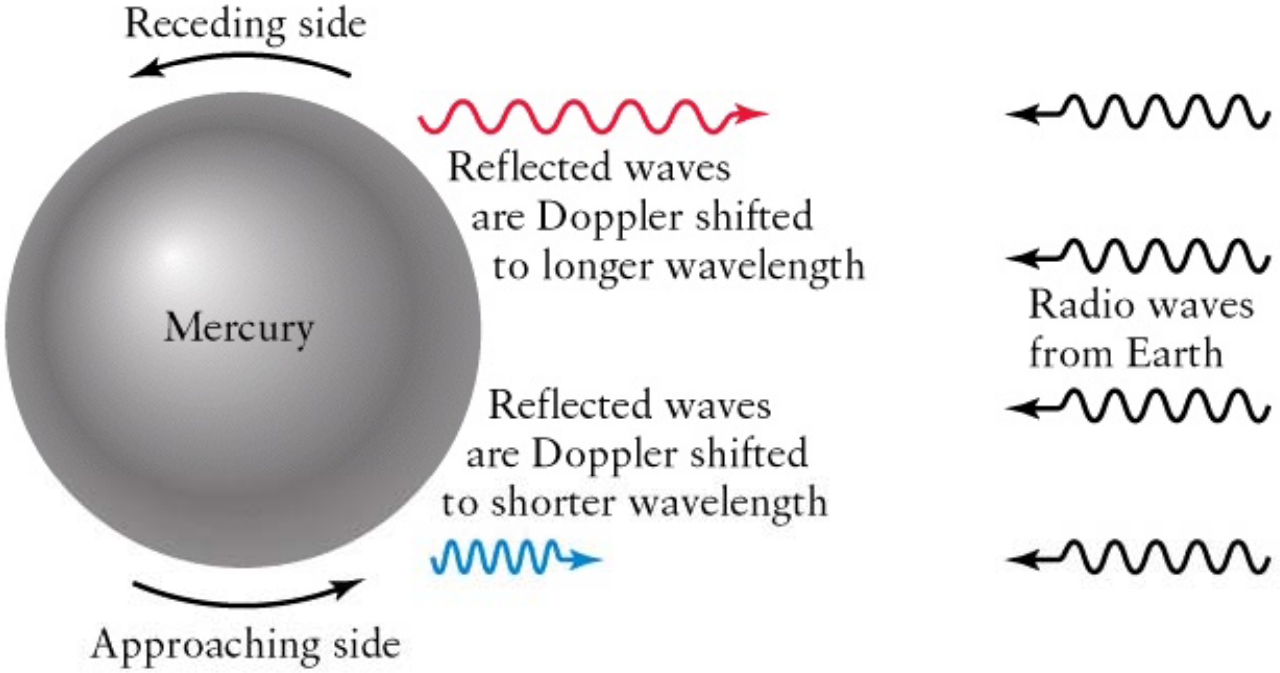
Figure 6-9b
Universe, Eighth Edition

  - **With radar we supply the 'light' and wait for the reflection**



- **Radar observations tell us about Mercury's spin period**
  - **Doppler shift in wavelength – caused by motion**
  - **Wavelength is shorter when source and observer approach**
  - **Wavelength is shorter when source and observer recede**
- **The amount of wavelength shift of the radar tells us the rotation speed**





- **Another example of the Doppler shift**
  - **Convection cells on the Sun have..**
    - **Portions that rise towards the surface – approach observers on the Earth**
    - **Portions that sink away from the surface – recede from observers on the Earth**
  - **Wavelength of the emitted radiation is shifted slightly**

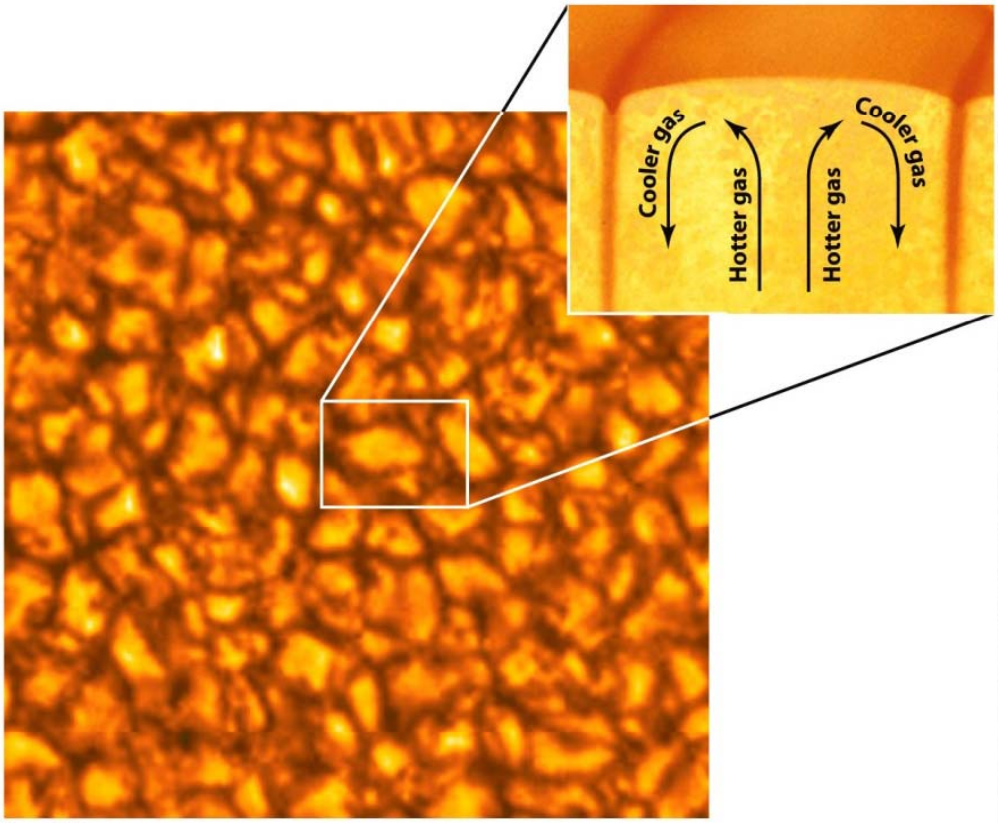


Figure 16-9
Universe, Eighth Edition

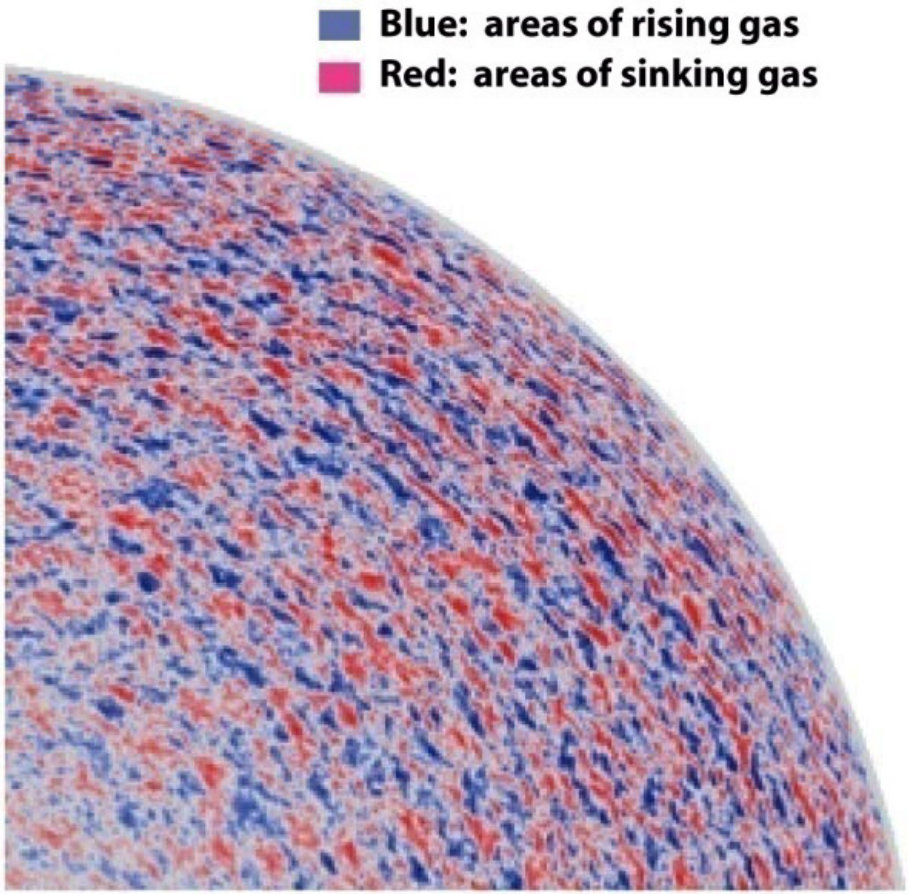
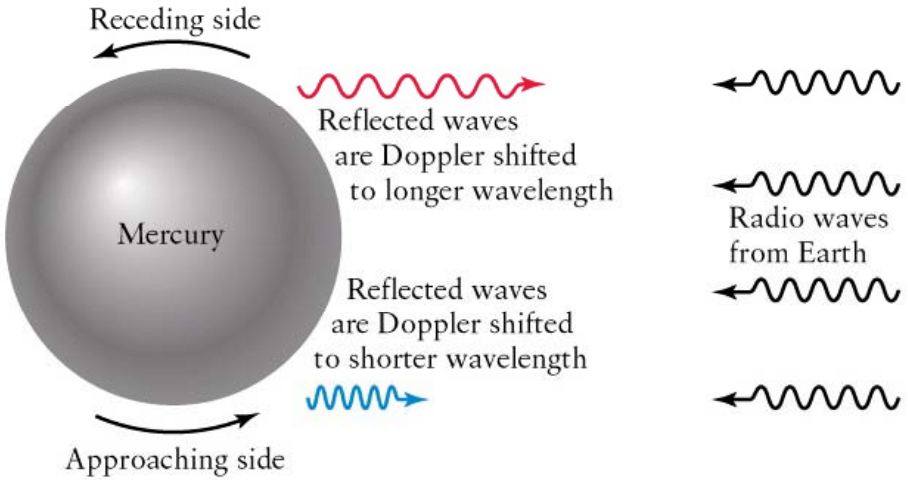
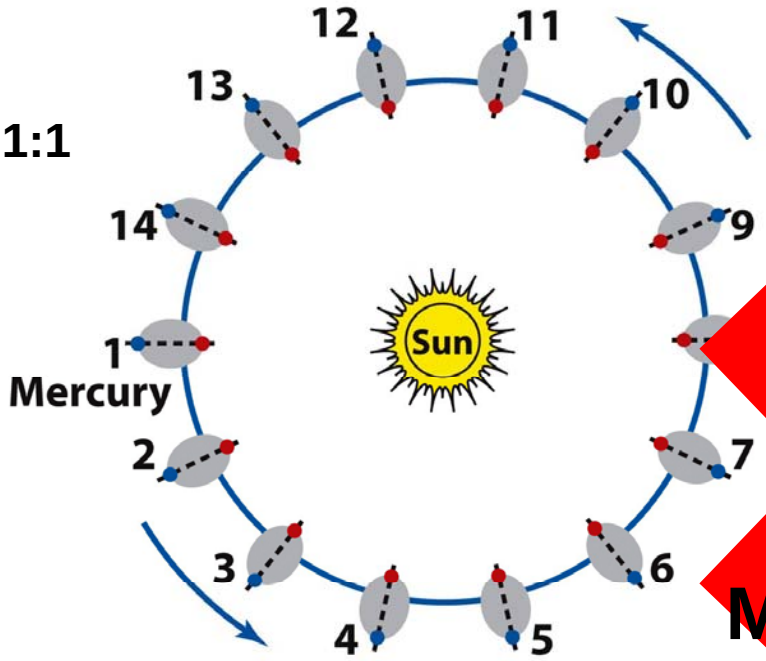


Figure 16-10
Universe, Eighth Edition

- **Back to Mercury…**
  - **Doppler shift of the radar reflections**
  - **Mercury rotates every 59 days**
  - **Orbital period was 88 days**
  - **Ratio is 3:2**
  - **i.e. three rotations every 2 orbits**



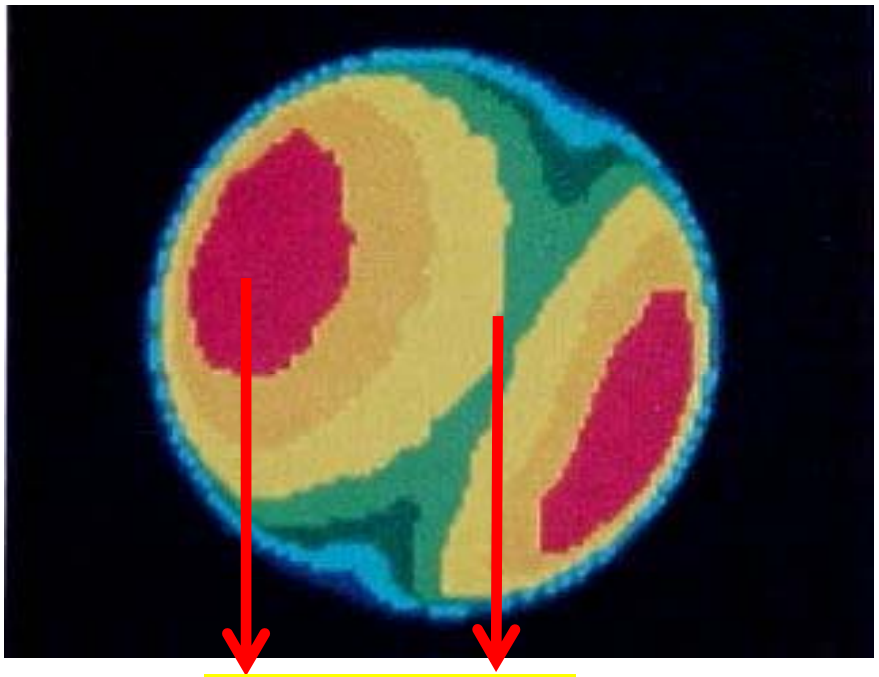
- **This was a surprise**
  - **People expected a ratio of 1:1**
    - **Synchronous rotation**
    - **Like Earth's Moon**



NOT THE CASE FOR MERCURY

Figure 11-6b
Universe, Eighth Edition

- Mercury does 1½ rotations every orbit
- At perihelion position
  - Sub-solar longitude is 0°, then 180°, then 0°, then 180° then 0° etc…
  - These are the 'hot' parts of Mercury
- At aphelion position
  - Sub-solar longitude is then 90°, then 270°, then 90°, then 270° then 90° etc…
  - These are the 'cold' parts of Mercury



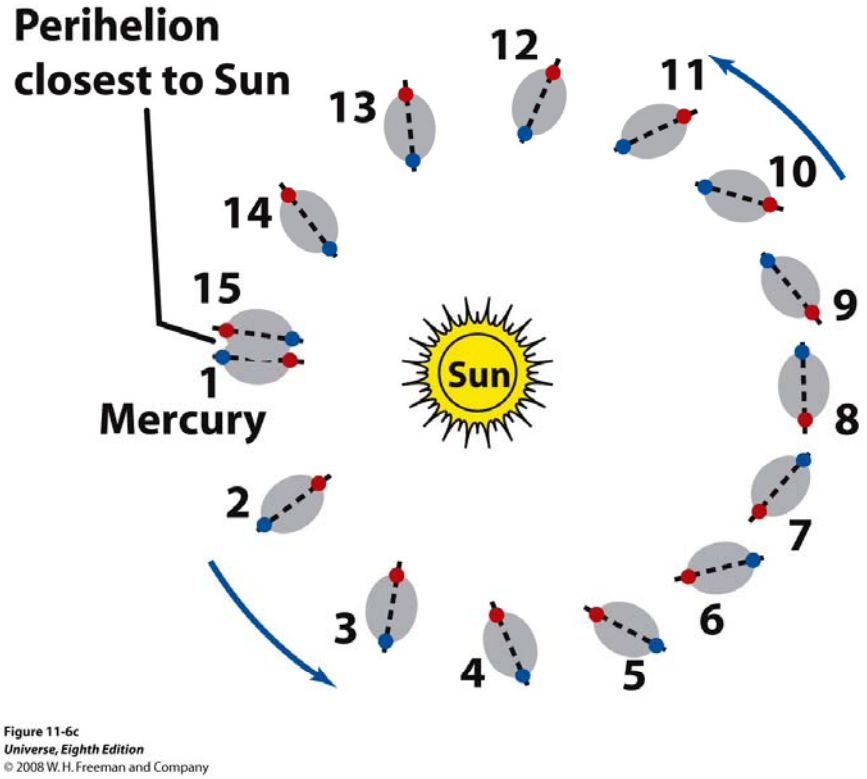


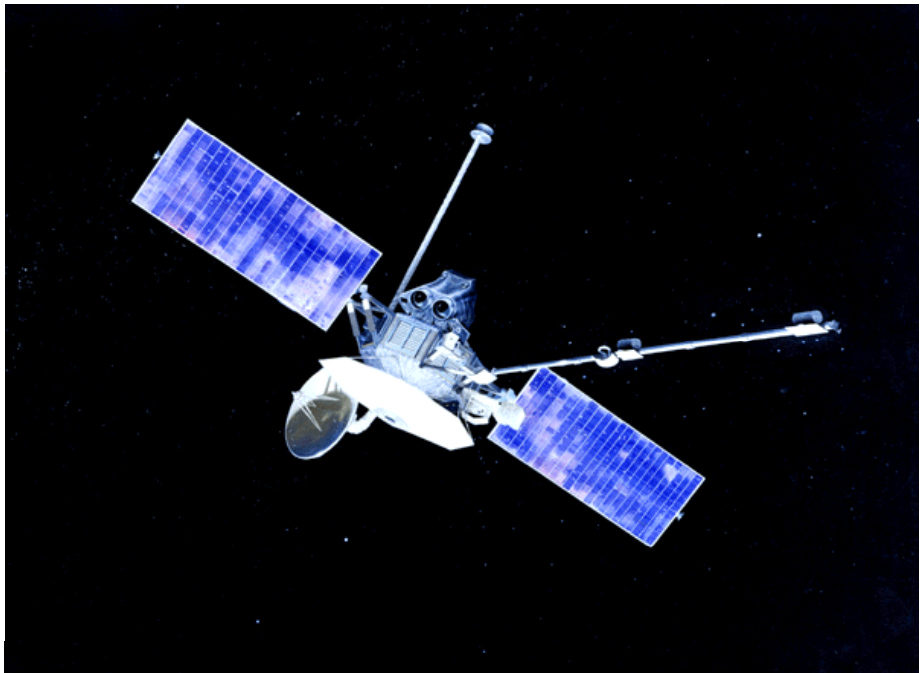
Figure 11-6c
Universe, Eighth Edition

Radio emission from Mercury

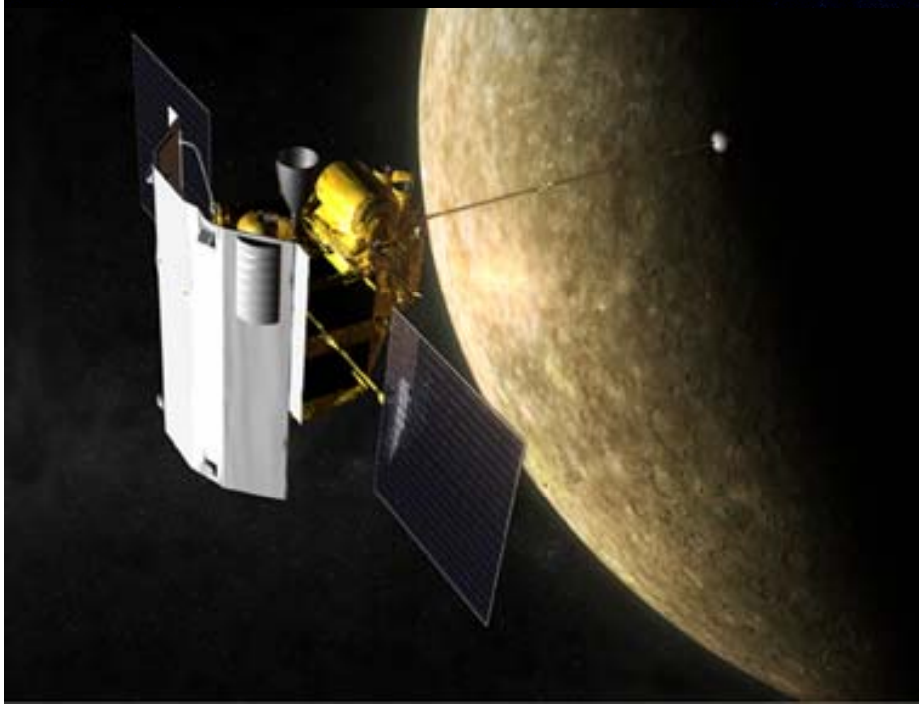
Senses temperature from the upper few meters of the surface

Shows the 'hot' longitudes 180° apart

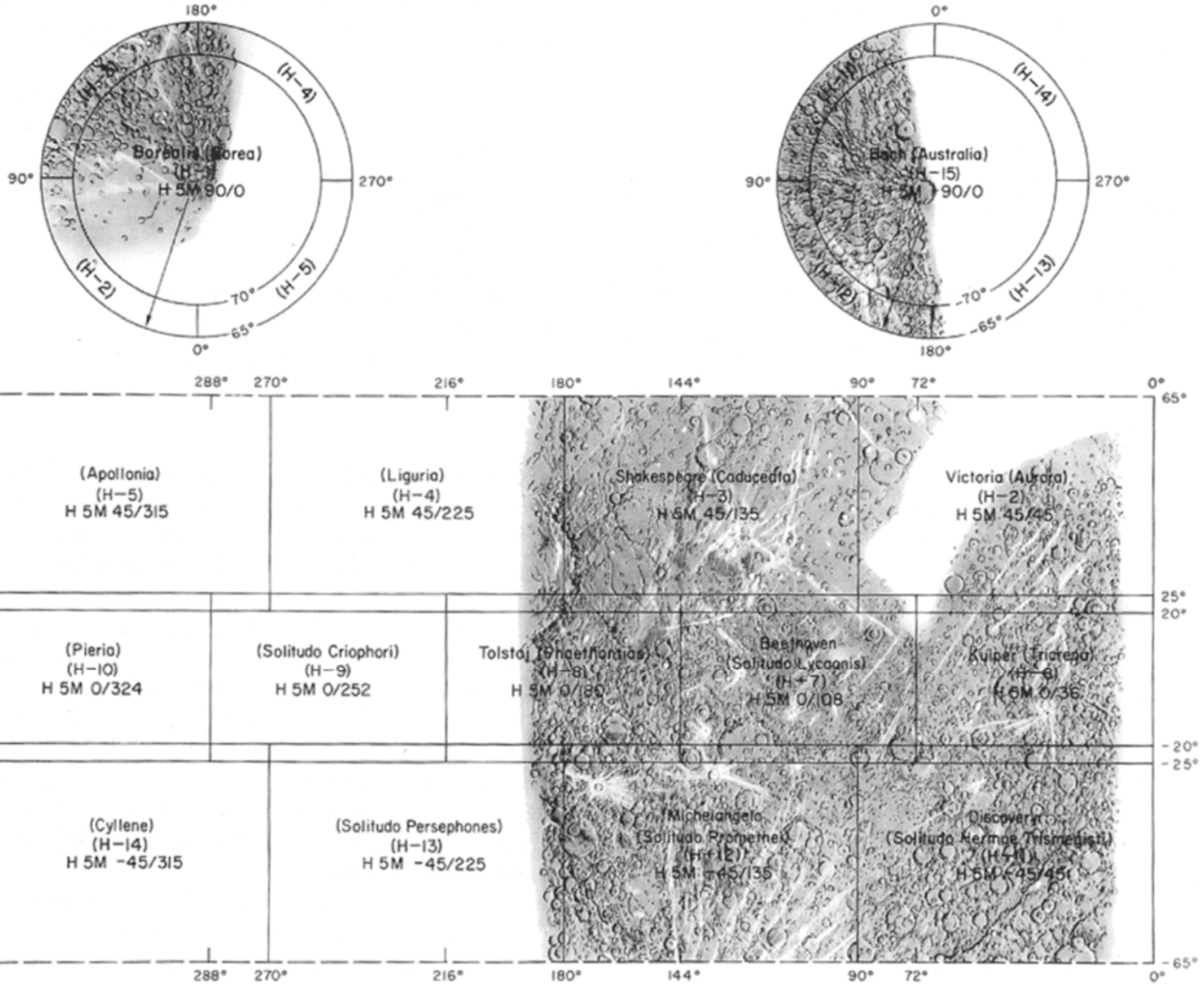
- **We have other tools available (II)**
  - **Spacecraft - Mariner 10**
    - **3 flybys in 1974 & 1975**
    - **Only mapped 50% of the planet**



  - **Messenger**
    - **3 flybys in 2008 & 2009**
    - **Enters orbit around Mercury - 2011**
    - **Already confirmed all the Mariner 10 results**
    - **Filled in the gaps in image coverage**

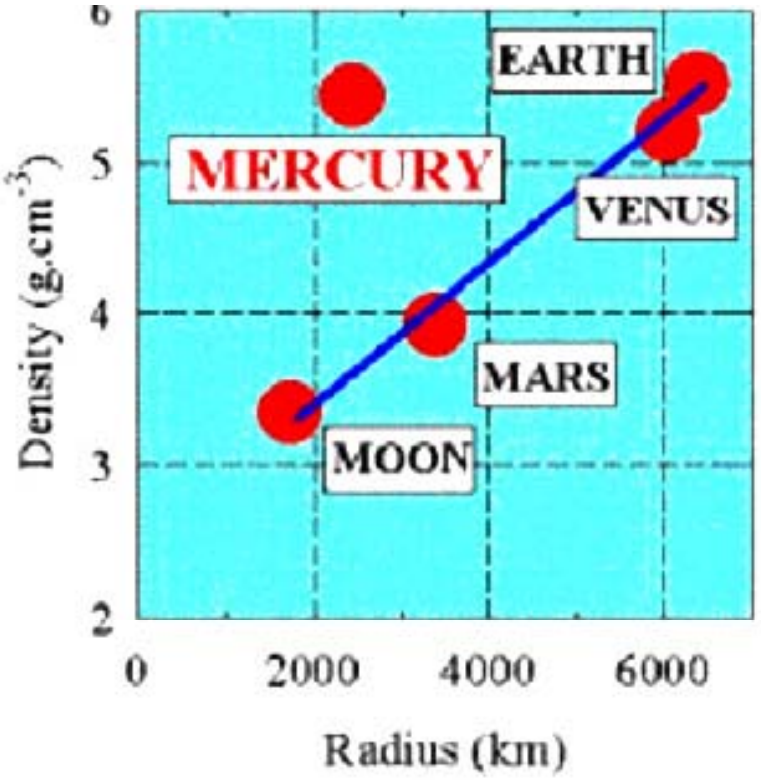


- **Mariner 10 imagery**
  - **Most of our Mercury results still come from this mission**

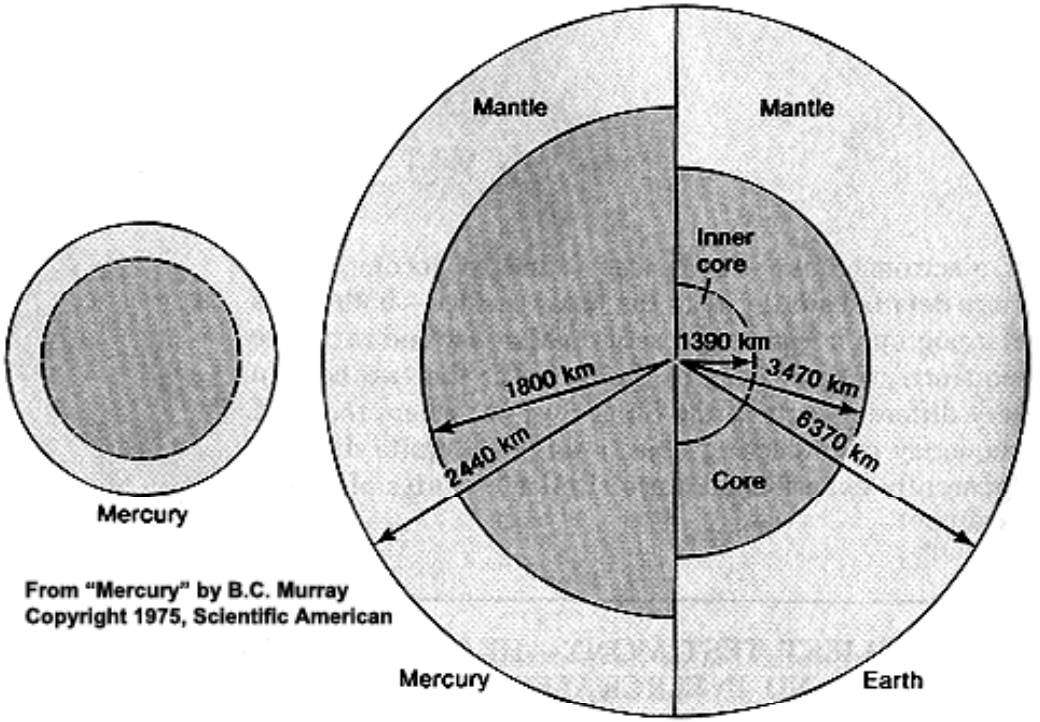


Mercury's Interior

- **Mercury is an anomaly among the terrestrial planets**
  - **Usually larger planets are denser**
  - **High gravity compresses material**
- **Mercury's density 5430 kg m^{-3}**
  - **Almost as dense as the Earth**
  - **Rock density ~3000 Kg m^{-3}**
- **Mercury's radius is 2440 km**
  - **Only 40% of Earth's radius**
  - **Only 6% of Earth's volume**



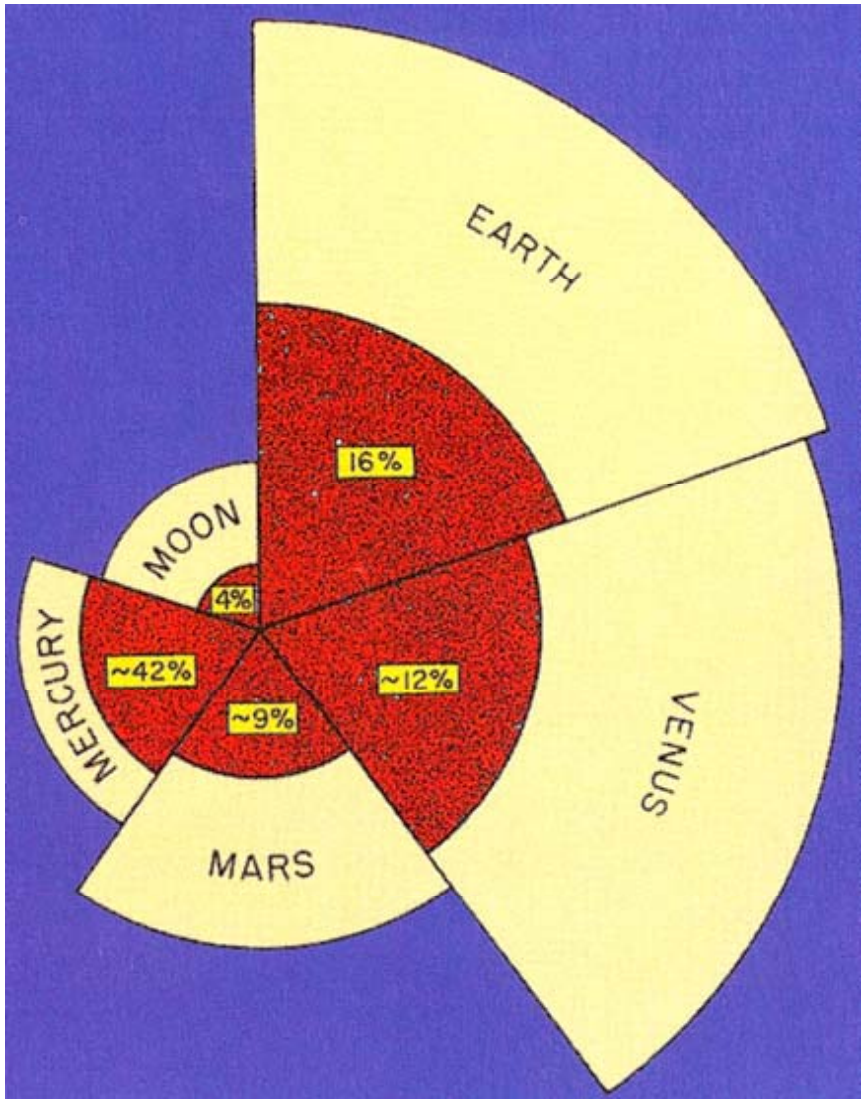
- **What's going on?**
  - **Mercury's iron core is enormous compared to the planet**
  - **Core radius**
    - **Earth 54% of planet**
    - **Mercury 75% of Planet**
  - **Core Volume**
    - **Earth 16% of the planet**
    - **Mercury 42% of the Planet**



From "Mercury" by B.C. Murray
Copyright 1975, Scientific American

  - **Mercury has a thin mantle**
  - **Probably a very thin (~100km) crust**

- **How did this happen?**
  - **Maybe Mercury formed that way**
  - **Maybe rock boils away in hot early phase**
  - **Maybe a giant impact occurred like on the Earth**
- **Giant impact theory is most popular**
  - **Large object hits an already differentiated Mercury**
  - **Iron core is protected**
  - **Mantle of rocks is stripped off**



- Another variation of the giant impact theory
  - Mercury is completely destroyed
  - Reforms from iron rich debris
  - Rocky debris lost

- Giant impacts in the very early solar system could be commonplace
  - Earth – large Moon
  - Mercury – large iron core
  - Venus – retrograde spin
  - Mars – topographic dichotomy
  - Uranus – spin axis in orbital plane

  - Probably not all of these were caused by giant impacts

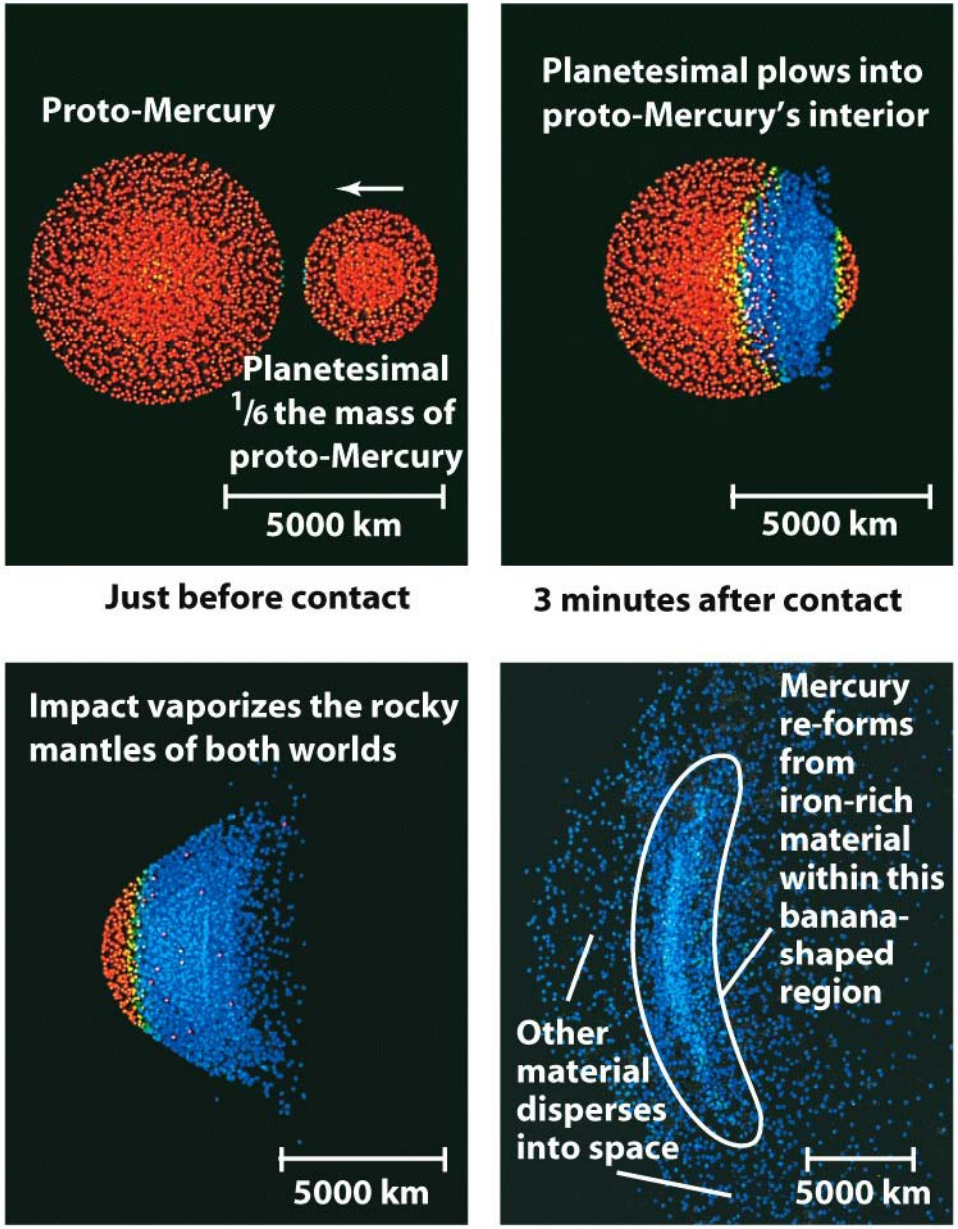


Figure 11-13
Universe, Eighth Edition

- **Mariner 10 also discovered a dipole magnetic field**
  - **Weaker version of Earth's field, ~1% as strong**
  - **Implies part of Mercury's core is still molten**
  - **A surprise considering that Mercury is small and so should cool off fast**
  - **Liquid core confirmed with terrestrial radar recently**

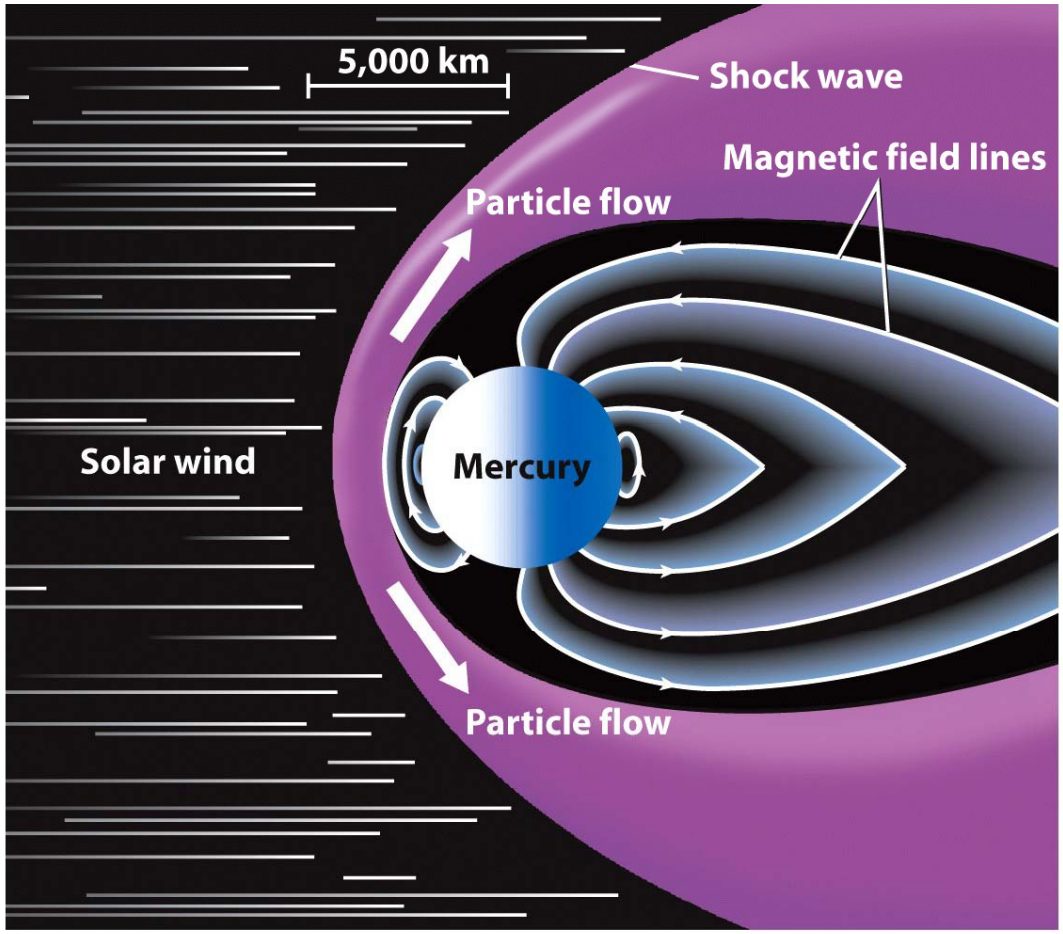


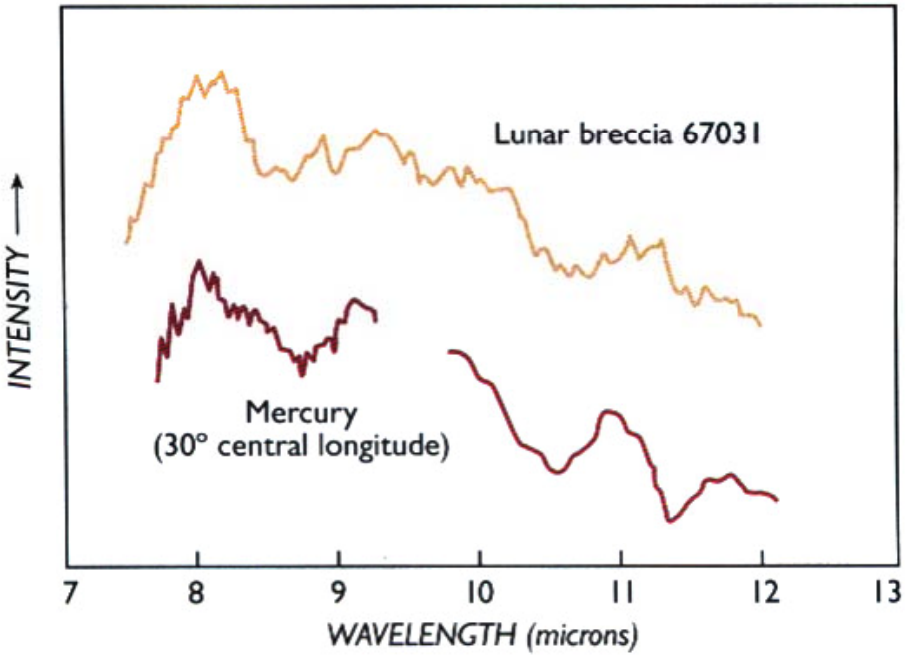
Figure 11-14
Universe, Eighth Edition

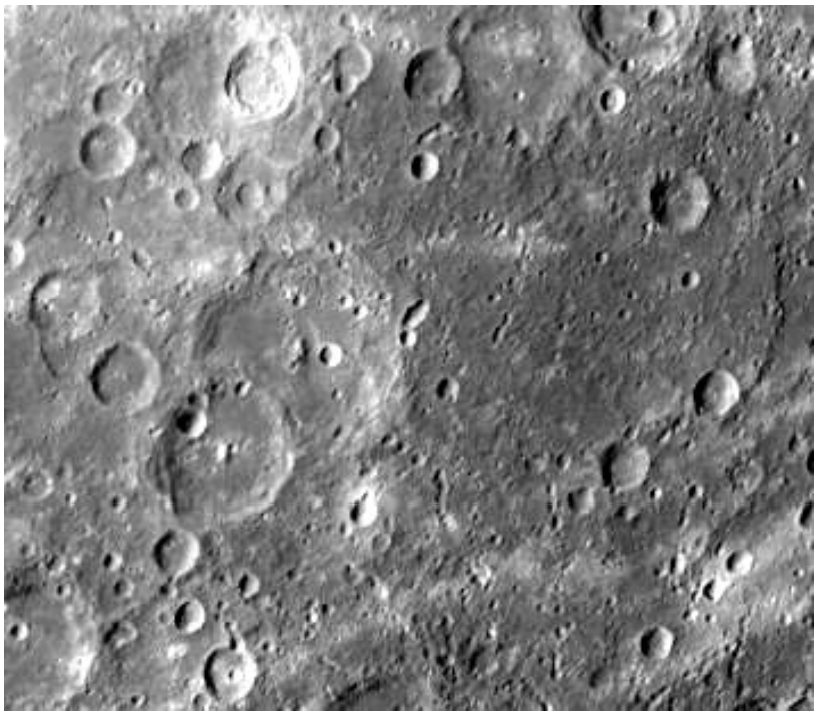
Mercury's Surface

- **Much like the Moon**
  - **Radar returns indicate regolith-like surface i.e. rough terrain composed of unconsolidated fragments**
  - **Spectrally very similar to the lunar highlands**
  - **Lots of craters**

…but…

  - **Smooth plains and cratered regions are mixed on Mercury**
  - **Smooth plains look volcanic but aren't dark like the lunar Maria**
    - **All the iron is in the core**





- **Intercrater plains**
  - **More cratered than lunar Maria**
  - **Not dark – no iron**
  - **Origin argued about for years:**
  - **They look volcanic**
  - **But ejecta from large impacts can also form plains**
    - **E.g. Cayley plains – Apollo 16**

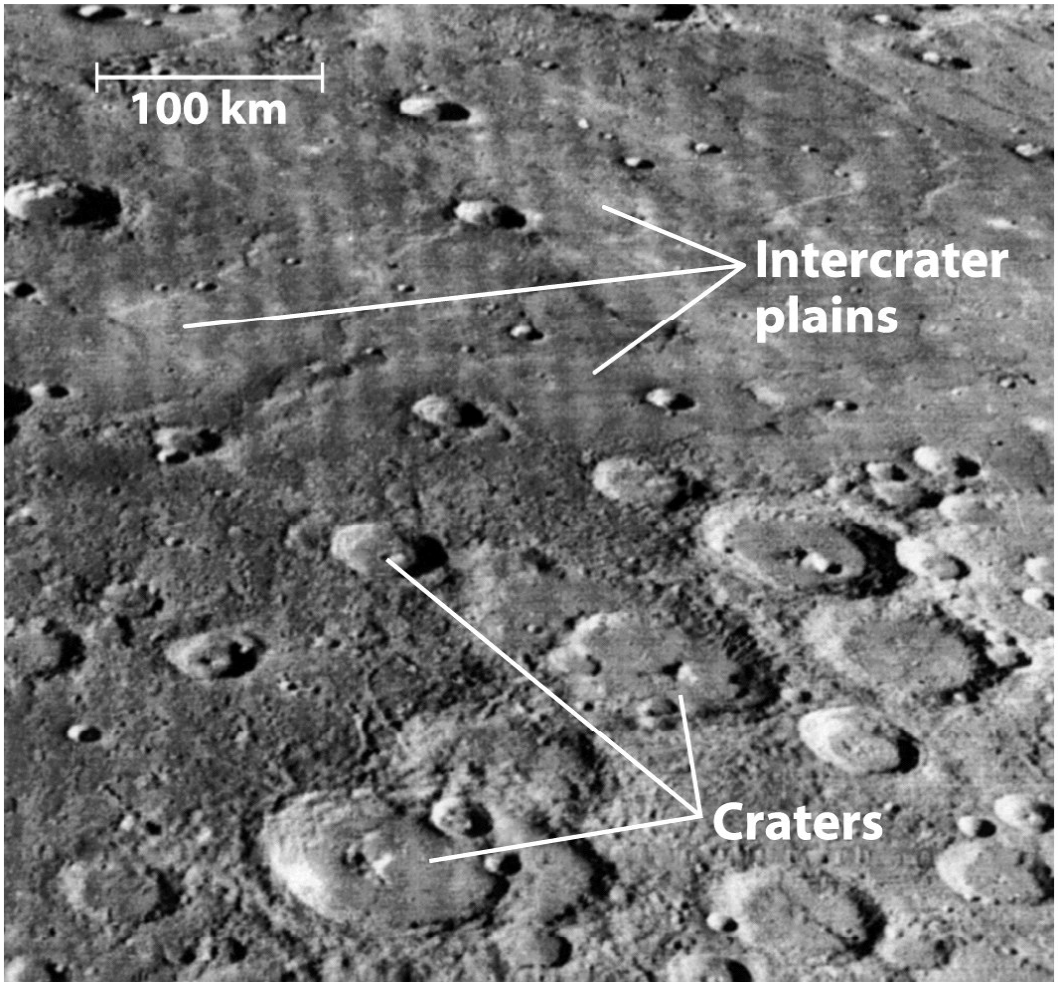
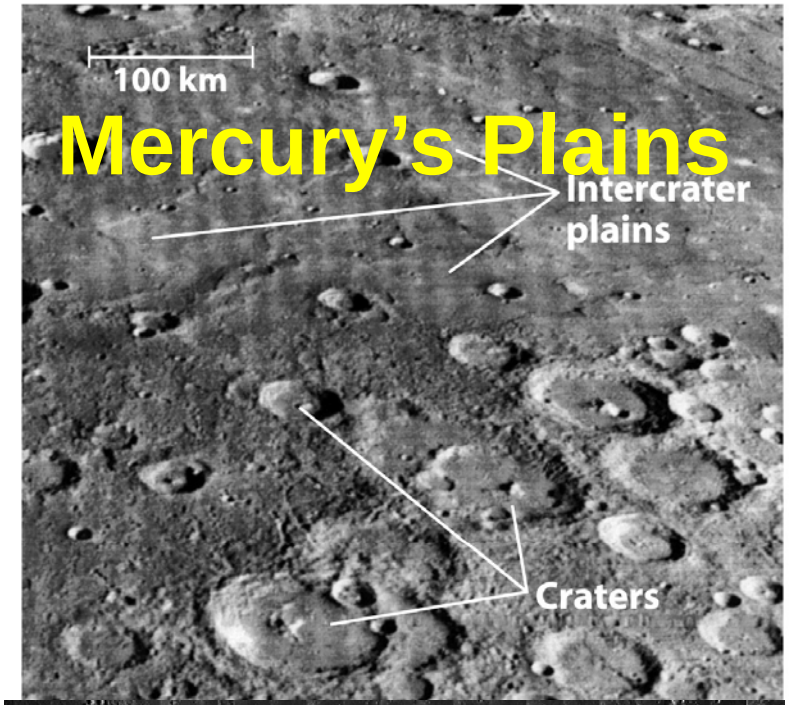
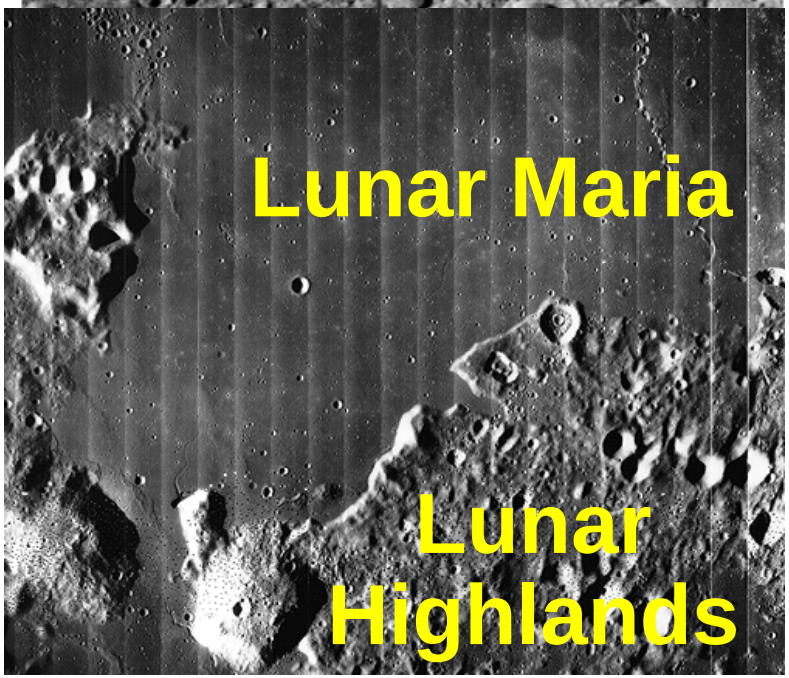


Figure 11-9
Universe, Eighth Edition





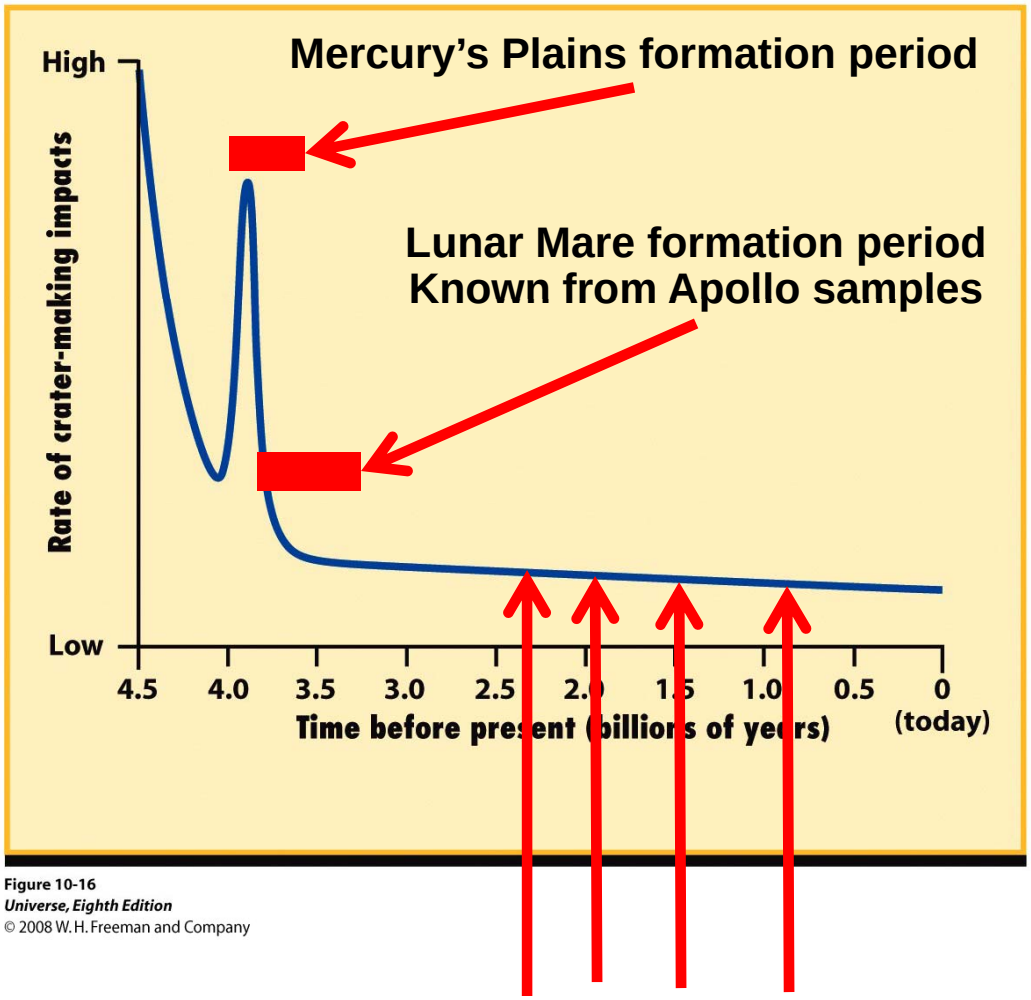
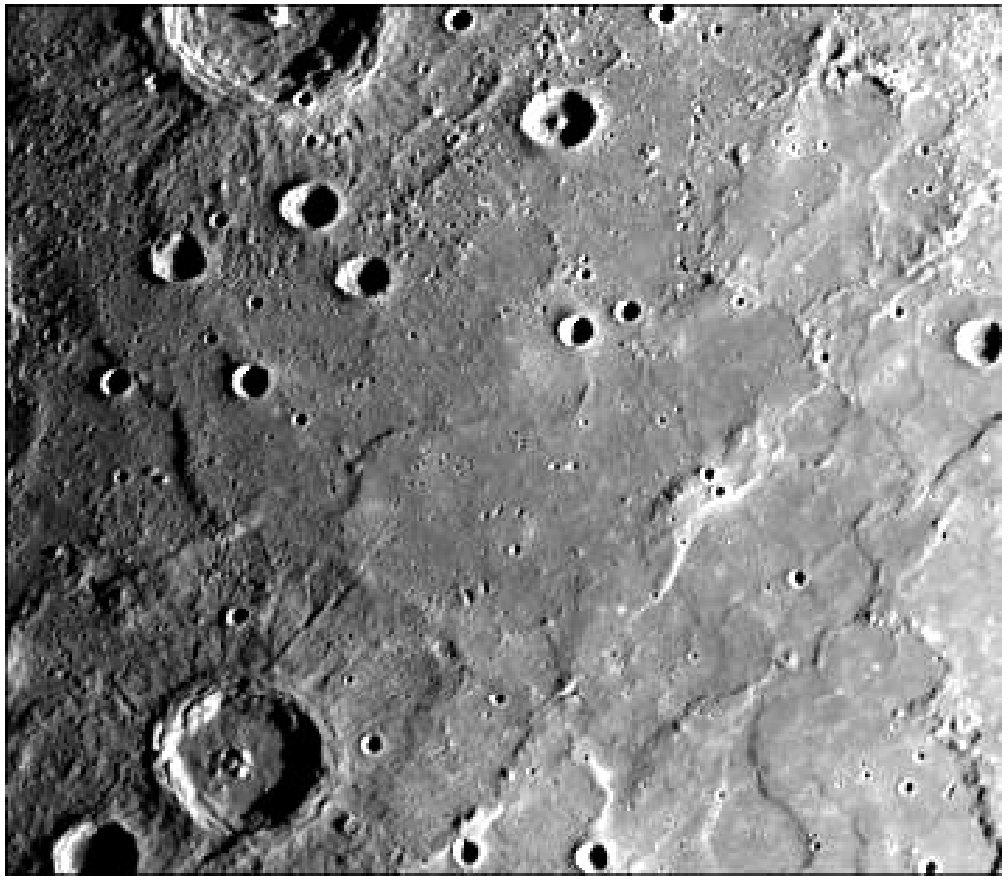


Figure 10-16
Universe, Eighth Edition

Cratering rate low after these lava flows form

- **Smooth plains**
  - **Erupted as flood volcanics**
  - **Lightly cratered**
  - **Still little iron**

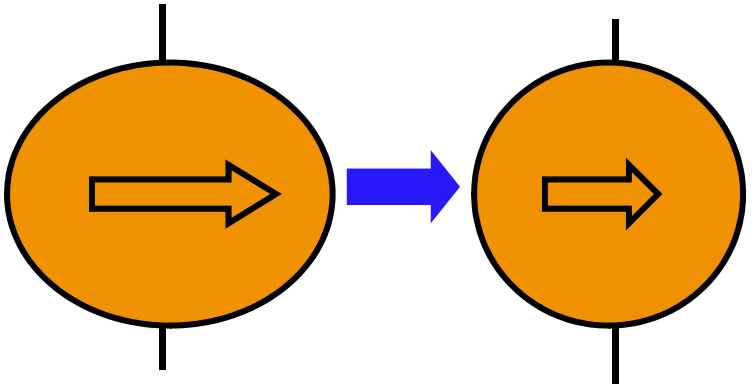


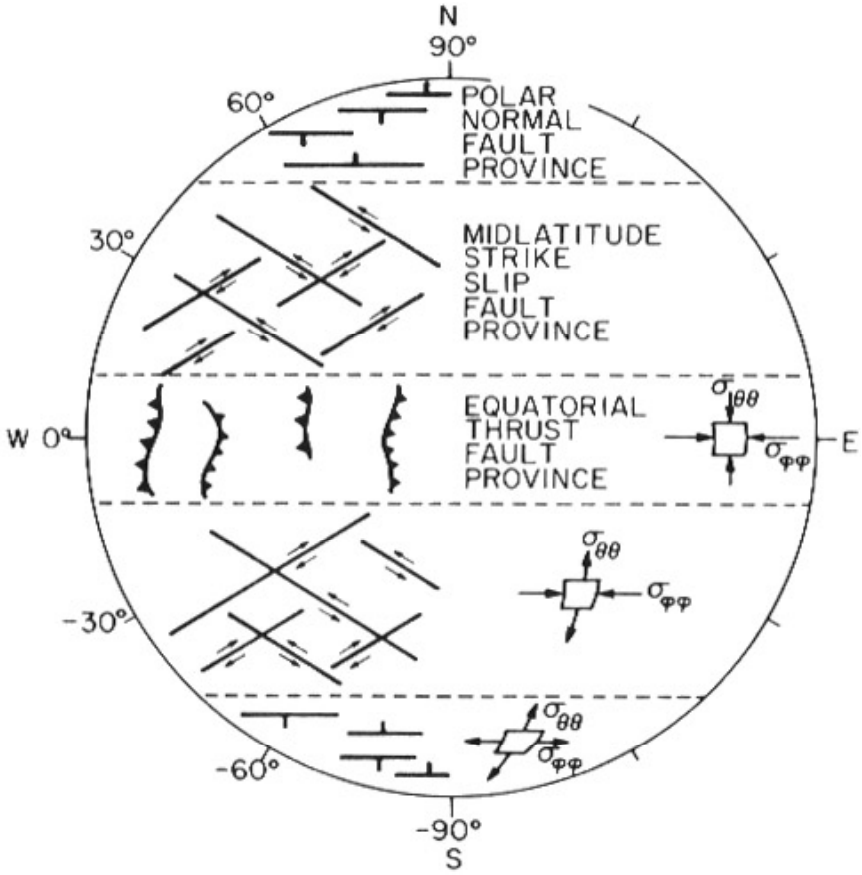
- **Messenger uncovers volcanic features**
  - **One mystery solved but many remain**

- **Tectonics on Mercury**

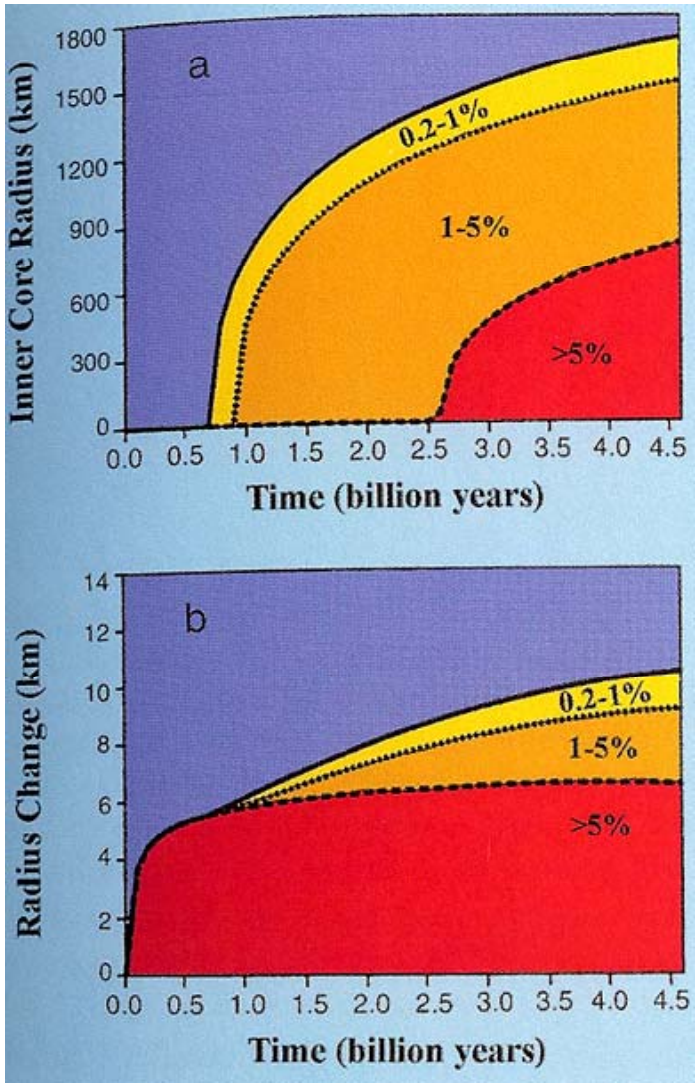
- **Mercury likely started with a faster spin.**
  - **Solar tides de-spun the planet to its current (59 days) spin rate**

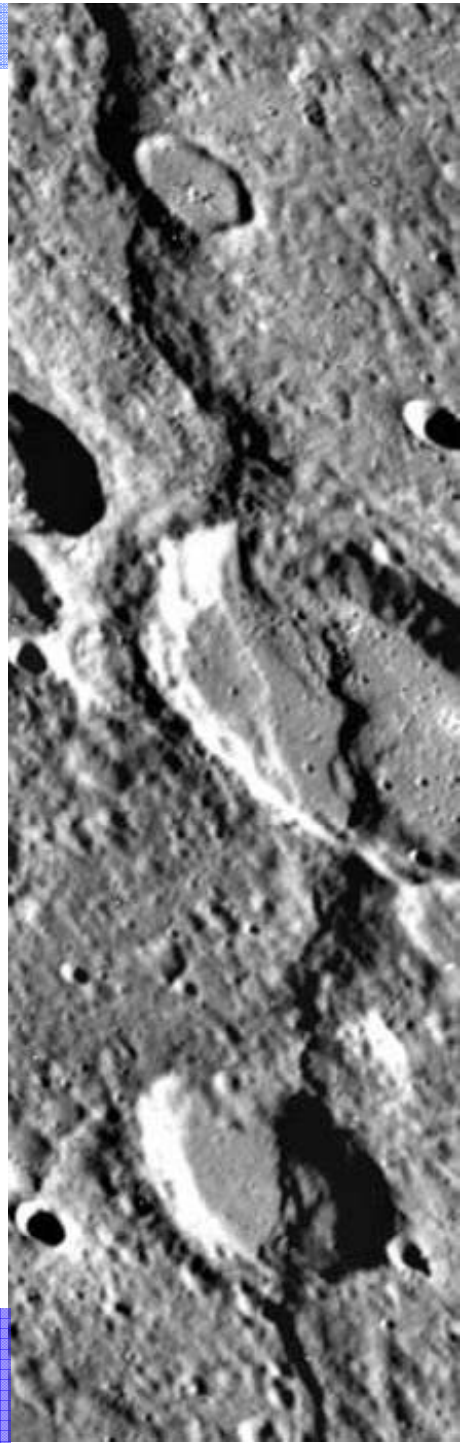
- **Ancient global lineament system observed**
  - **Planet bulges less at the equator when spinning slowly**
  - **Stresses created when rigid lithosphere readjusts to new shape**
  - **Orientations of lineaments are a good match to model predictions**





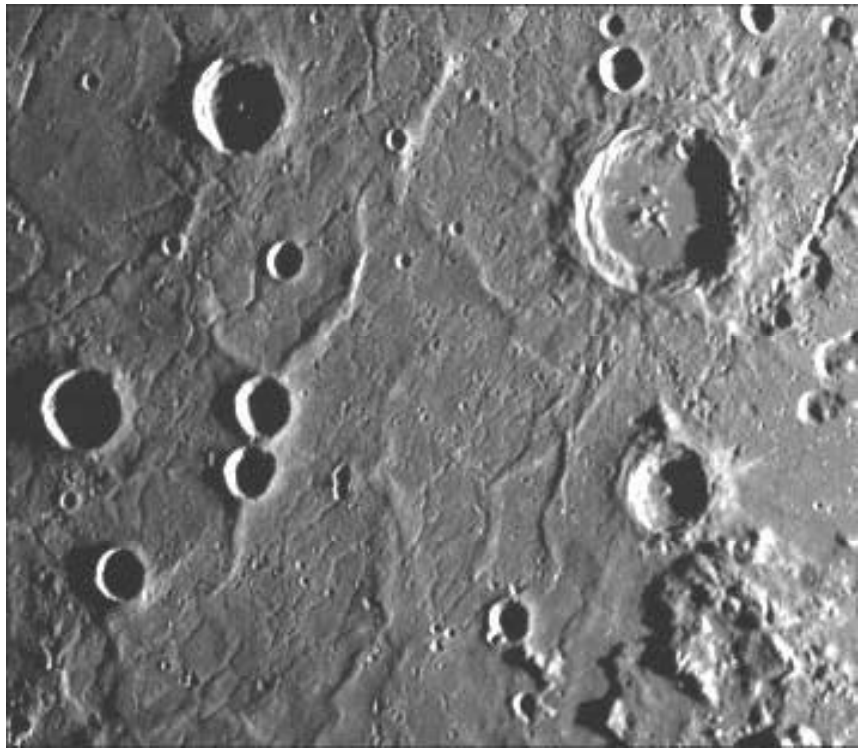
- **Core cools with time**
  - **Inner core of frozen iron grows**
  - **Planet shrinks a little**
  - **Usually not a problem…**
    - **…but Mercury has a huge core**
  - **Mercury shrunk several km in radius**
- **Shrinkage compresses the rigid lithosphere**
  - **Causes thrust faults to form**
  - **Extensive set of lobate scarps**
  - **No preferred azimuth**
  - **Global distribution**

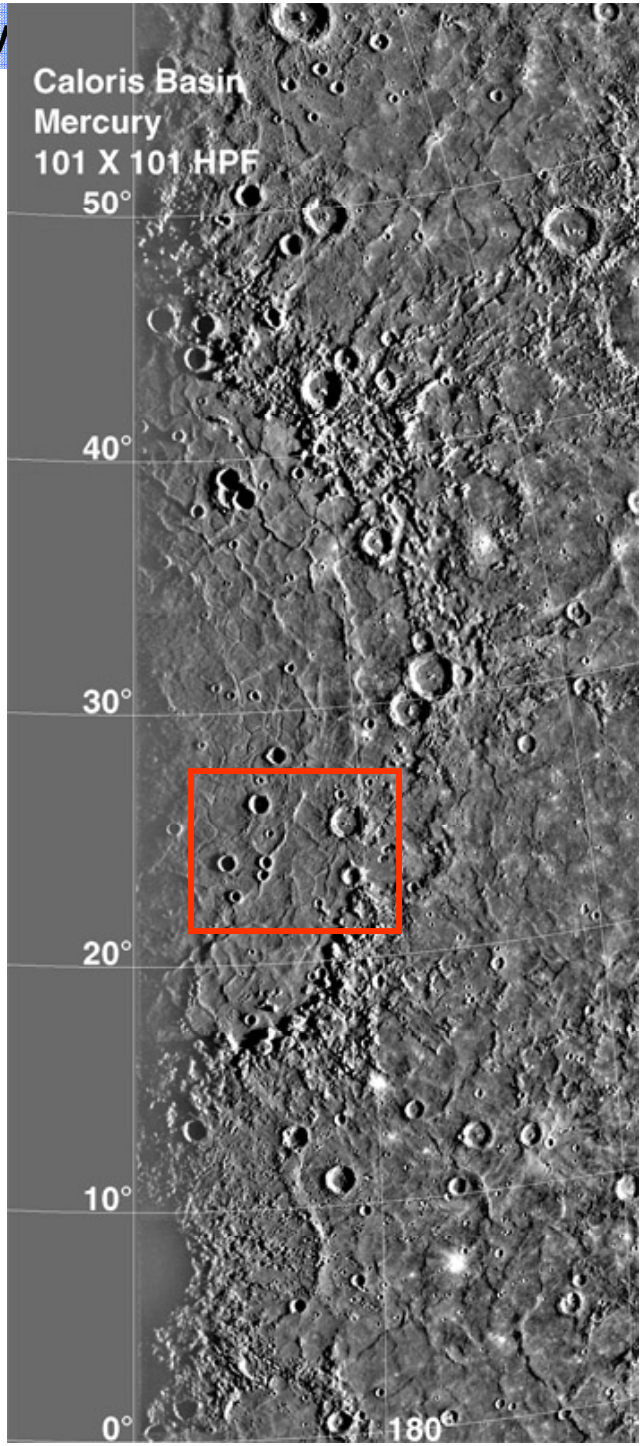




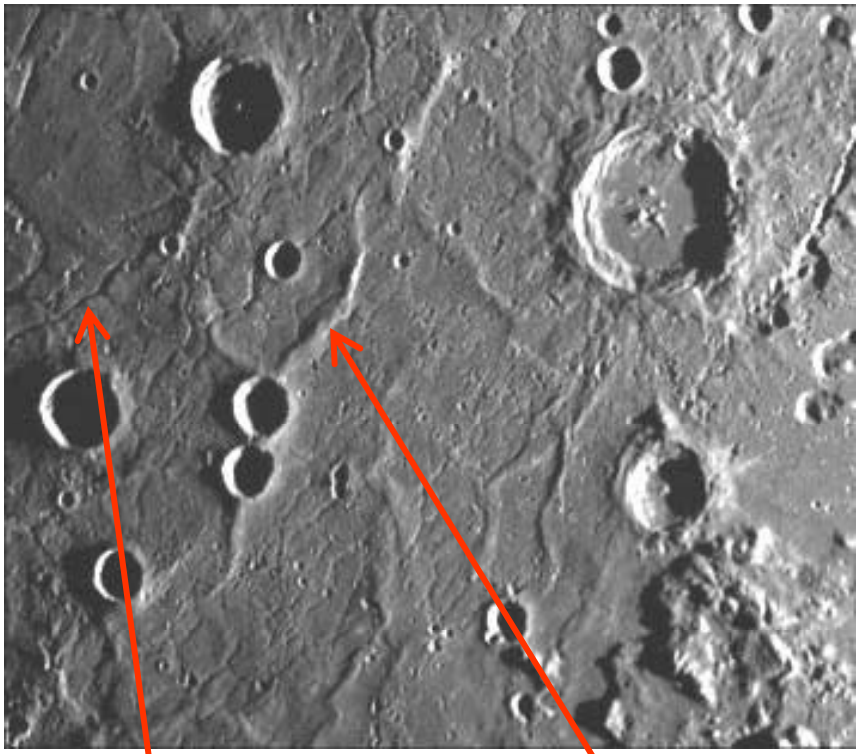
Discovery Rupes

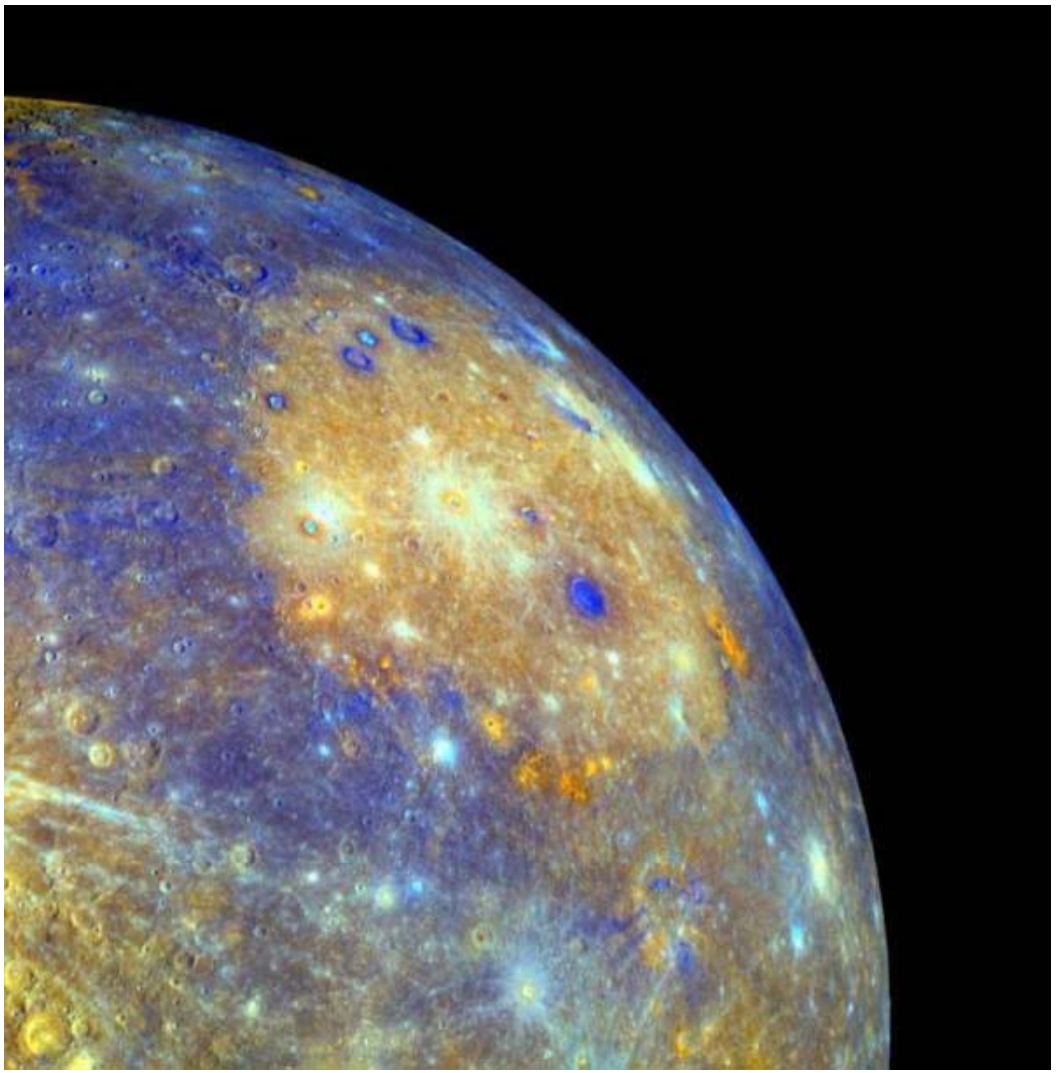
- Mercury has many impact basins
  - Much like the Moon
- One stands out – The Caloris impact
  - Impact structure is 1550 Km across
  - Six concentric rings 630-3700 Km across
    - Mountain chains up to 2km high
  - Dated at 3.8-3.8 Gyr ago
    - Late heavy bombardment



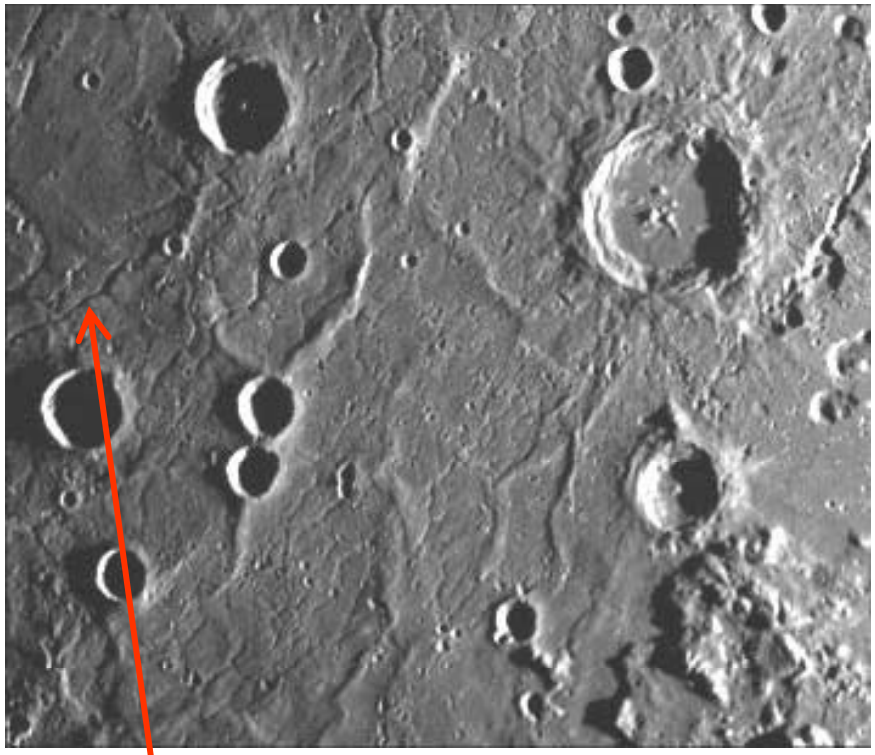


- **Caloris was flooded with volcanic material soon after forming**
  - **Causes subsidence of basin and compress features – wrinkle ridges**
- **Much later volcanism around the edges**

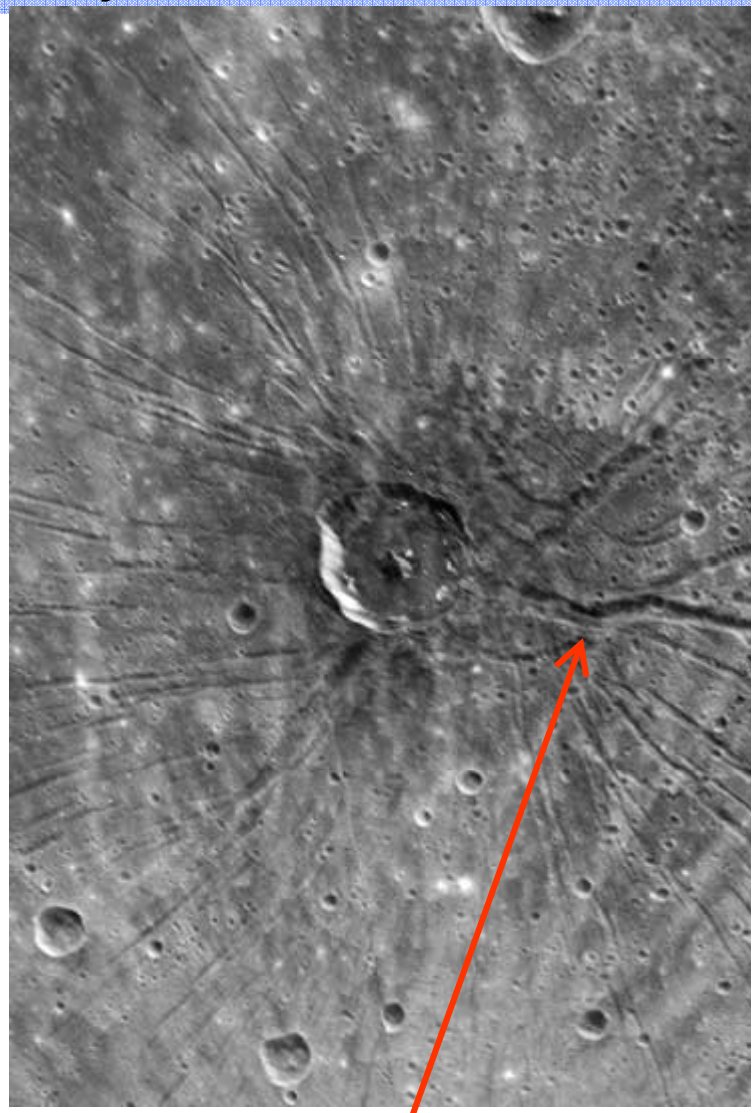




- **Rebound of the lithosphere comes later**
  - **Causes extensional cracks**



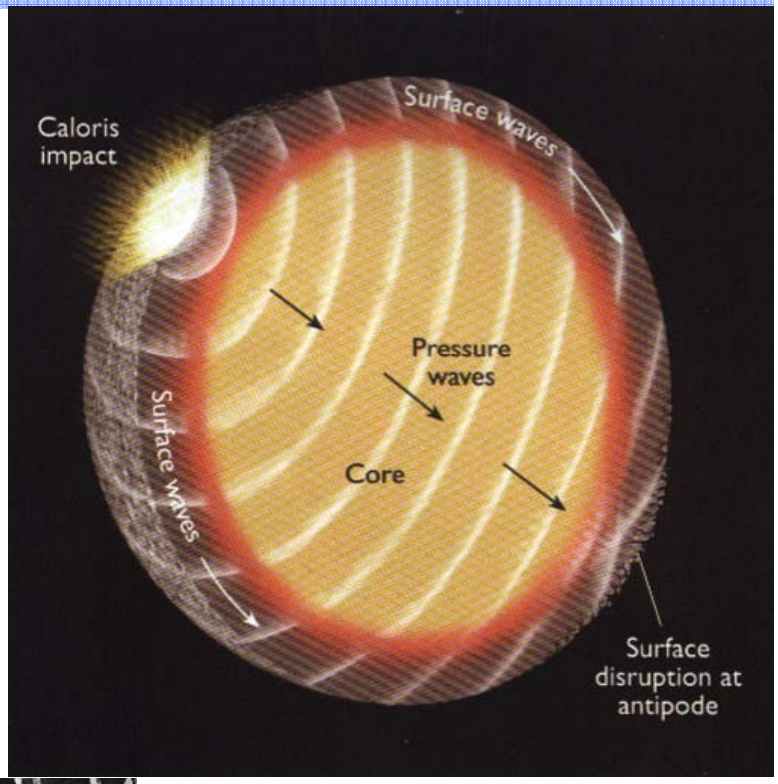
Extensional Fractures at basin edge

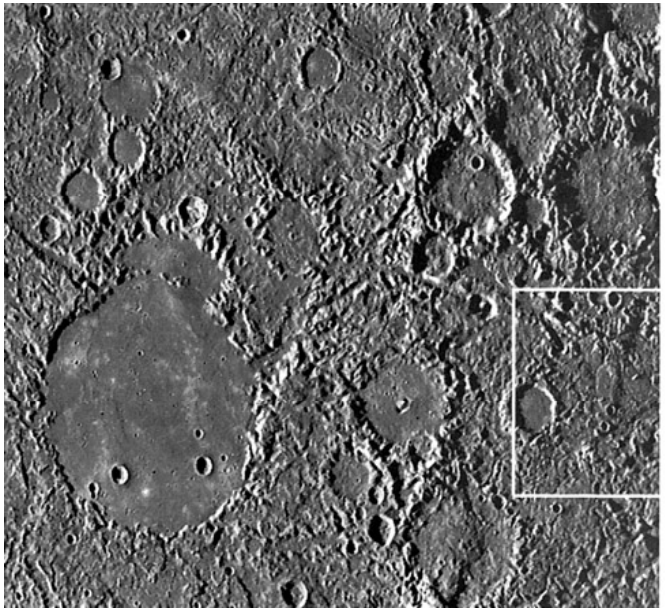


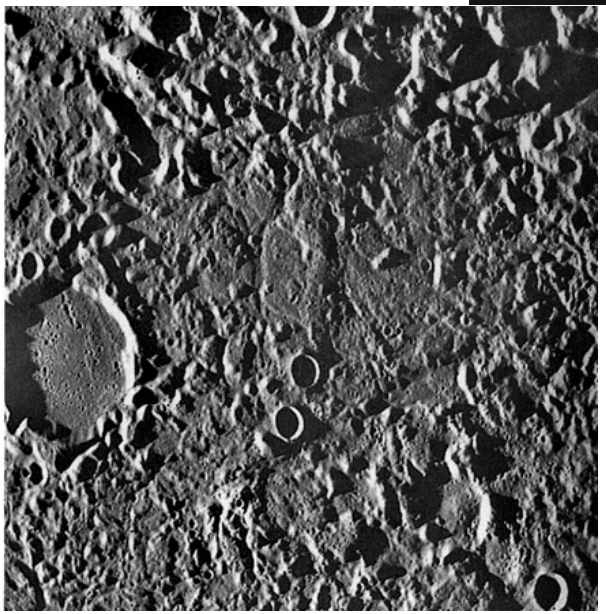
"The Spider"

Extensional Fractures at basin center

- **The "Weird" terrain**
  - **Properly "Hilly and Lineated" terrain**
  - **Seismic waves from the Caloris impact all meet at the antipode at the same time.**
    - **Modeling suggests <u>vertical motions of up to 1km</u>**
    - **Terrain broken up into 1km sized blocks**







Mercury's Timeline

- **Mercury forms, perhaps with a large core or suffers a giant impact**
- **Lithosphere forms**
- **De-spinning results in shape change and global tectonism**
- **Heavy bombardment**
  - Homogenizes regolith up to 20 km
  - Large basins form
  - Volcanic flooding – inter-crater plains
- **Core shrinks 1-2 km**
  - Global system of thrust faults forms lobate scarps
- **Caloris impact structure forms**
  - Antipodal 'weird' terrain
  - Smooth plains form
  - Subsidence and rebound in Caloris basin
- **Lighter cratering continues**
- **Bright rayed craters e.g. Kuiper**
  - **Named after our founder**

Pre-Tolstojan

Tolstojan

Calorian

Mansurian

Kuiperian

- **The Moon and Mercury have a lot in common**
  - **Both origins connected to giant impact**
  - **Dominated by impacts with regolith surfaces**
  - **Similar surface materials**
  - **Both in a some form of spin orbit resonance**
  - **Both have been partly resurfaced by flood volcanism**
  - **Both geologically dead for Gyr**

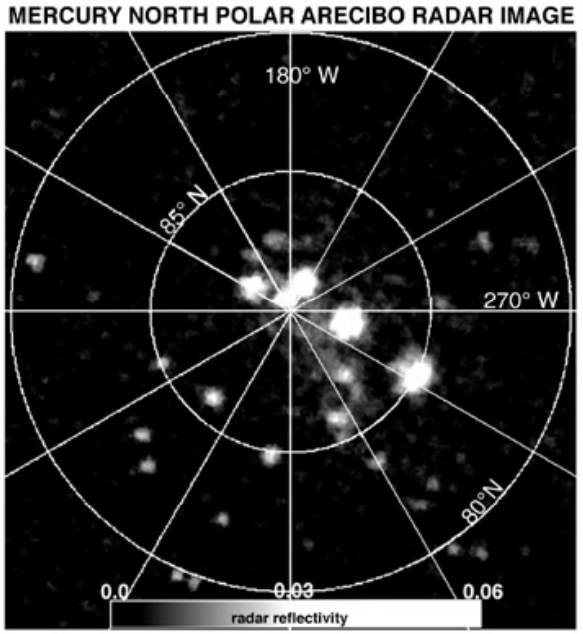
LRO

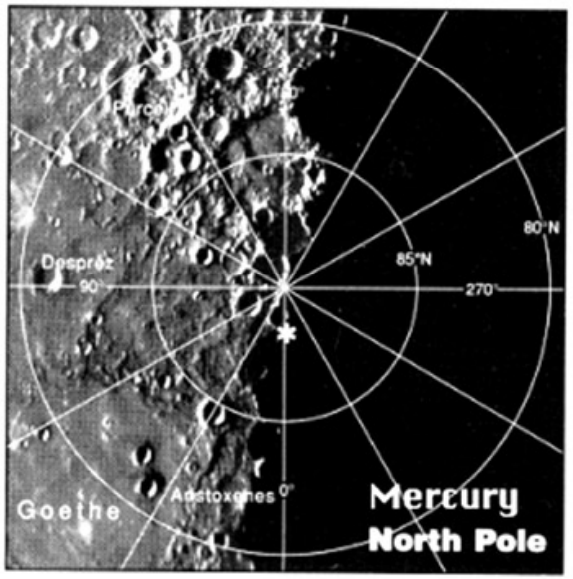
- **But their histories and internal structure are different**

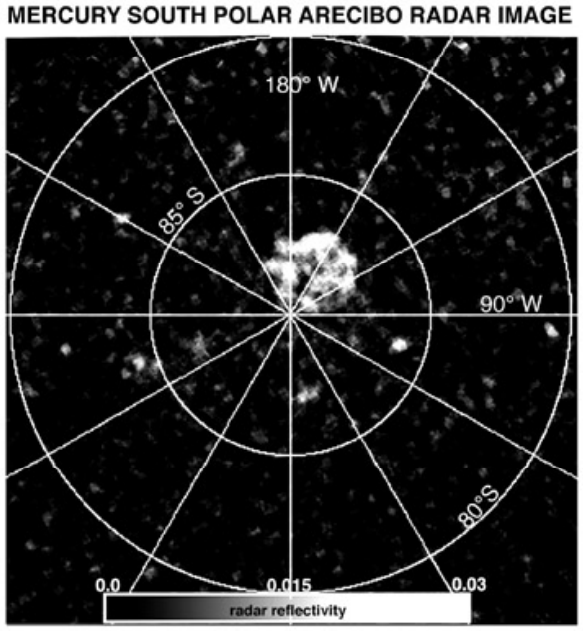
Moon	Mercury
Perhaps no core?	Dominated by a huge iron core
Basaltic volcanism	Plains volcanism not compositionally distinct
No significant tectonics	Global liniment system from spin-down Global thrust-fault system from contraction
Very iron poor	Most iron-rich planet
No current magnetism	Earth-like dipole field

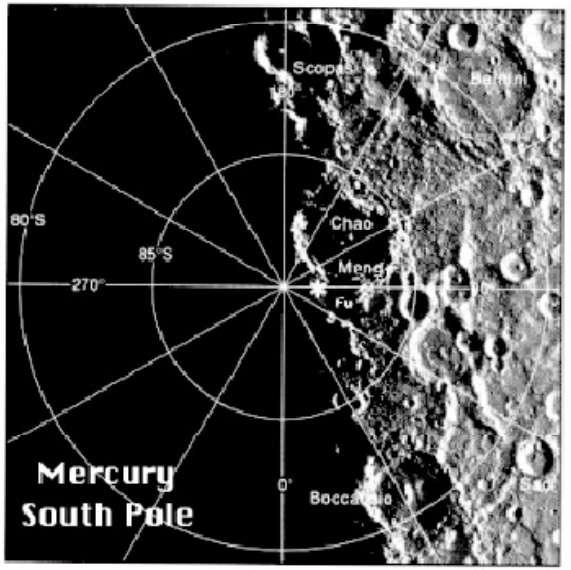
Messenger

- **Teaser for next lecture**
  - **Mercury has a thin atmosphere…**
  - **…and water ice deposits in its polar craters**









(Courtesy J. K. Harmon and M. A. Slade)

In this lecture…

- Mercury's strange orbit
  - Extreme temperatures
  - Hot and cold longitudes
- Mercury's even stranger interior
  - Giant core
  - Magnetic field
- Mercury's surface
  - Like the Moon – but not quite
  - A planet that shrunk
  - Newly found Volcanoes
  - Caloris basin and the 'weird' terrain

Next: Craters

- Reading
  - Chapter 11-1, 11-2, 11-3 to revise this lecture
  - Chapter 11-6 & 11-7 for next lecture