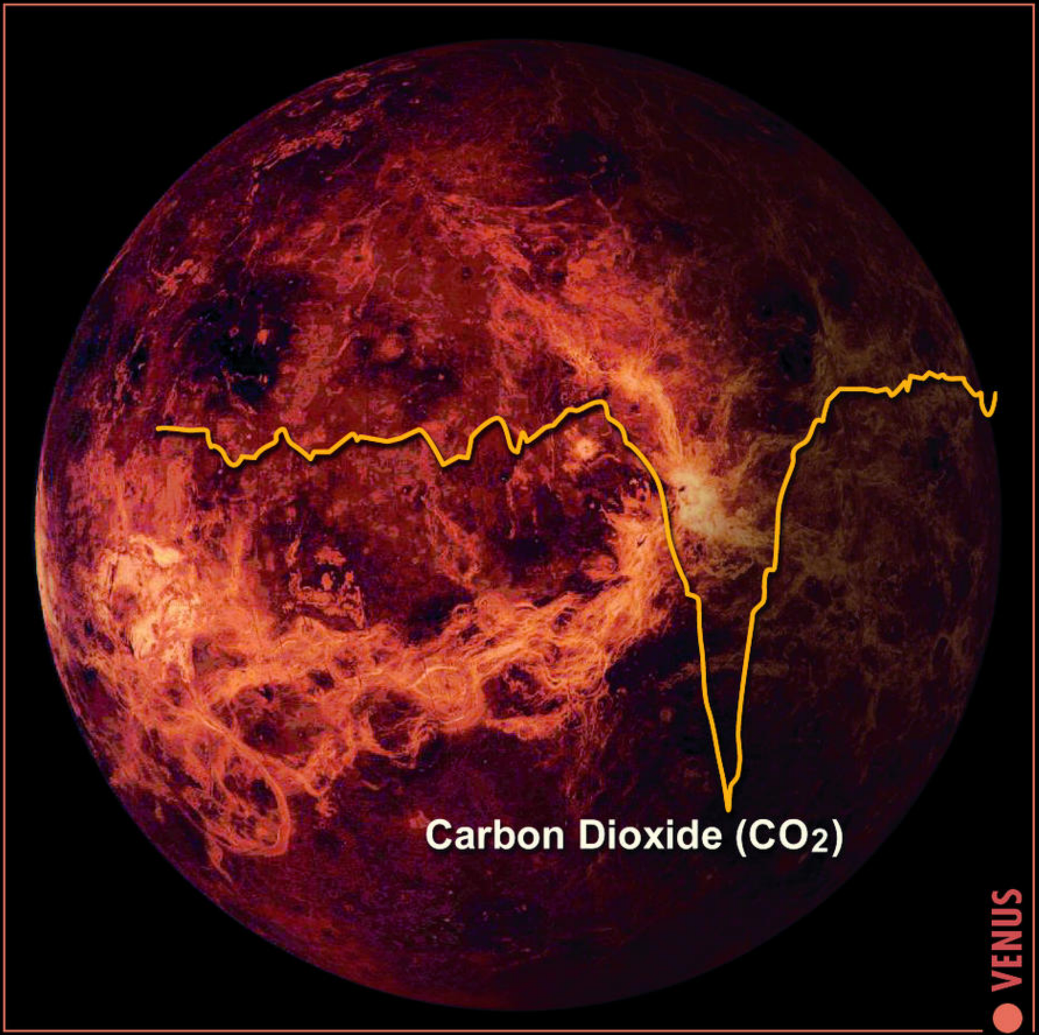
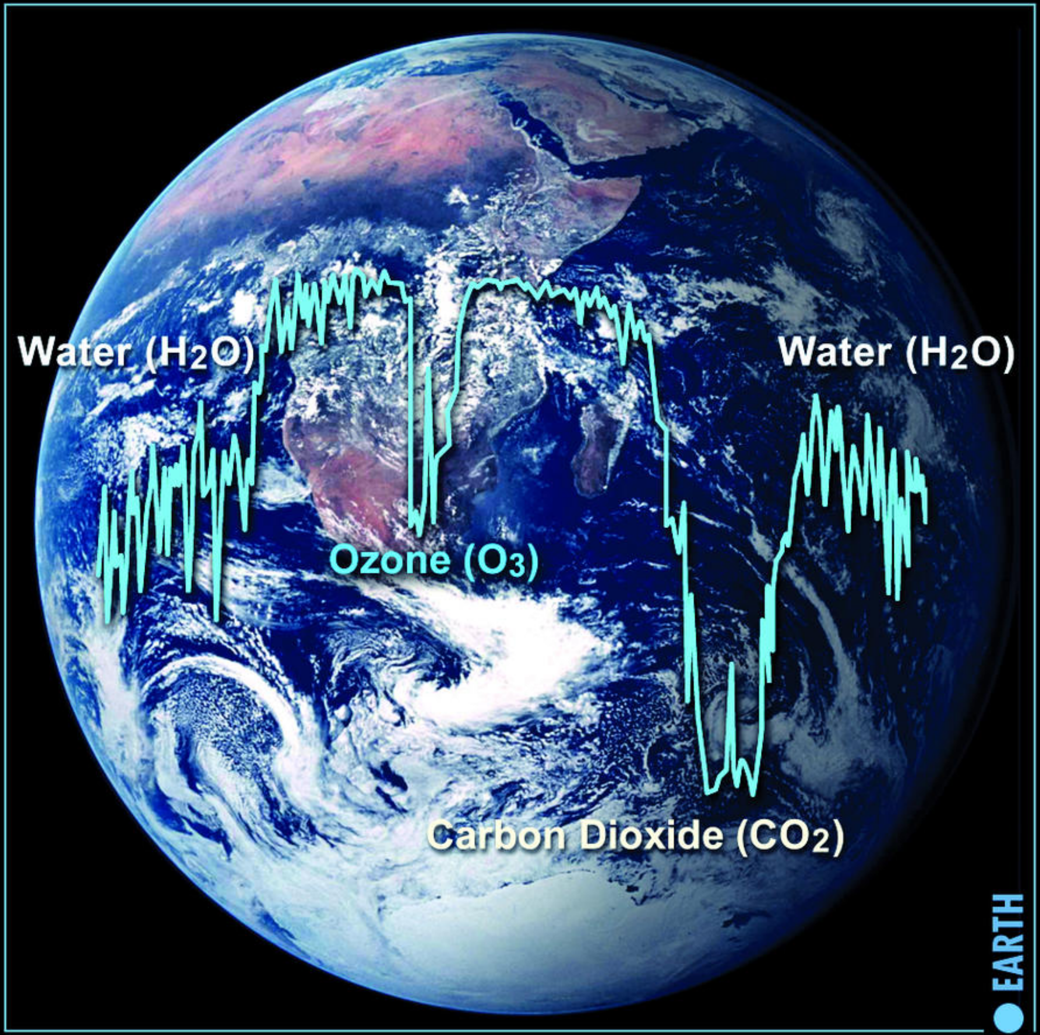
Planetary Habitability





Stephen Kane

UNIVERSITY OF CALIFORNIA
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Topics

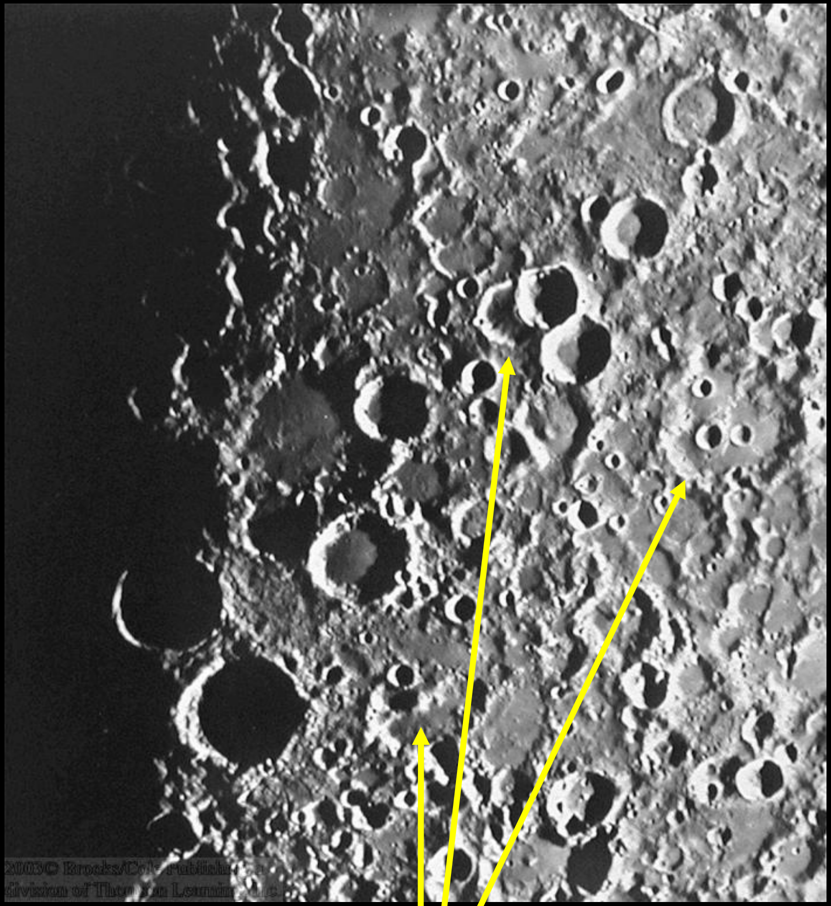
- Lecture 1 – Introduction
- Lecture 2 – Habitability Factors
- Lecture 3 - Stars
- Lecture 4 – Planetary Atmospheres
- Lecture 5 – Planetary Interiors
- Lecture 6 – Planetary Energy Balance
- Lecture 7 – Habitable Zone I
- Lecture 8 – Habitable Zone II
- Lecture 9 – Earth as a Living Planet
- Lecture 10 – Mars
- Lecture 11 – Icy Moons
- Lecture 12 – Venus
- Lecture 13 – Mercury & the Moon
- Lecture 14 – The Role of Giant Planets
- Lecture 15 – Stellar Influences
- Lecture 16 – Magnetic Fields
- Lecture 17 – Milankovitch Cycles
- Lecture 18 – Geological Cycles
- Lecture 19 – The Next Steps
- Lecture 20 – Summary/Discussion

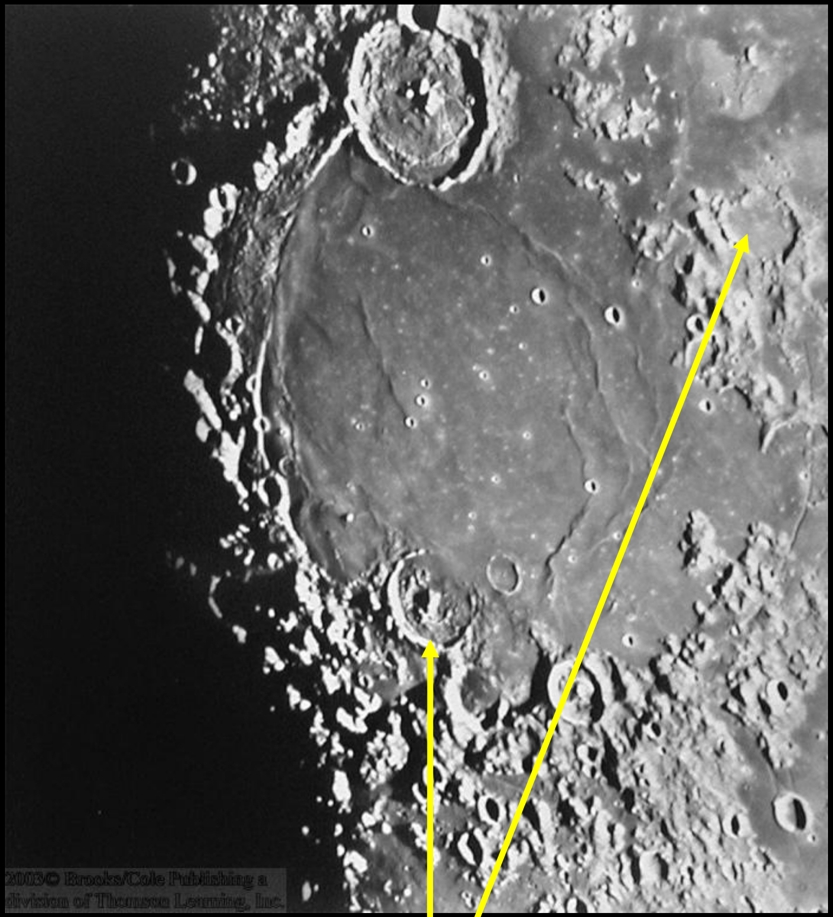
The Moon & Mercury

- Lunar impacts
- Formation of the moon
- Mercury properties
- Surface and interior
- Atmosphere and missions
- Importance of the Moon & Mercury

The Moon: Highlands

Saturated with craters





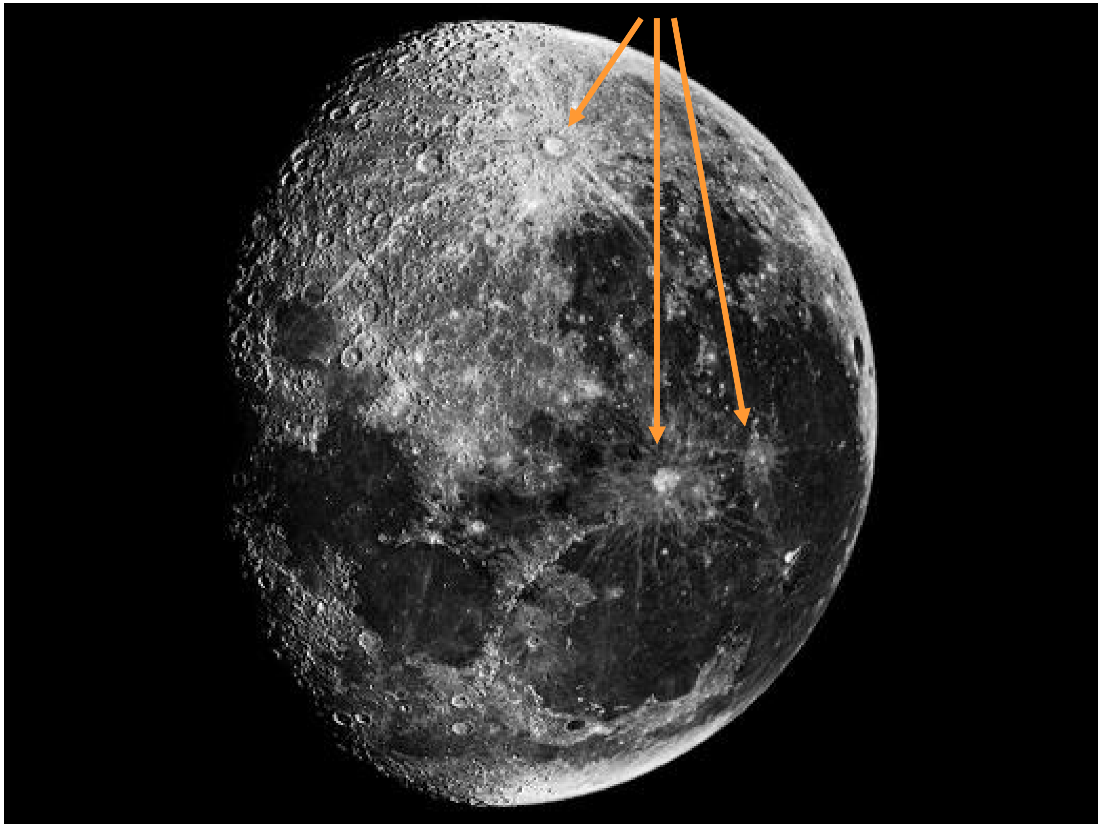
Older craters partially obliterated by more recent impacts

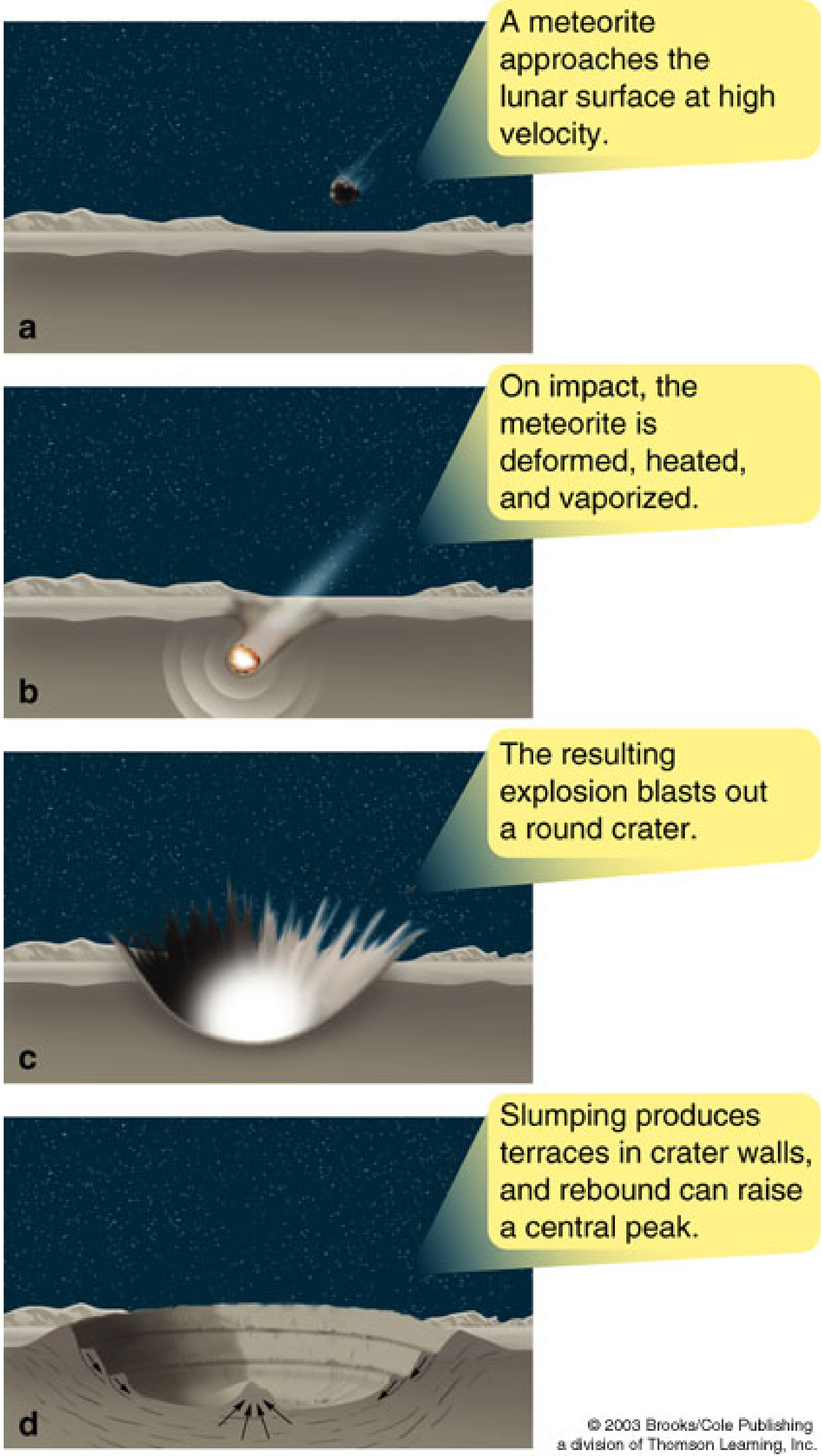
… or flooded by lava flows

Impact Cratering

Impact craters on the moon can be seen easily even with small telescopes.

Ejecta from the impact can be seen as bright rays originating from young craters

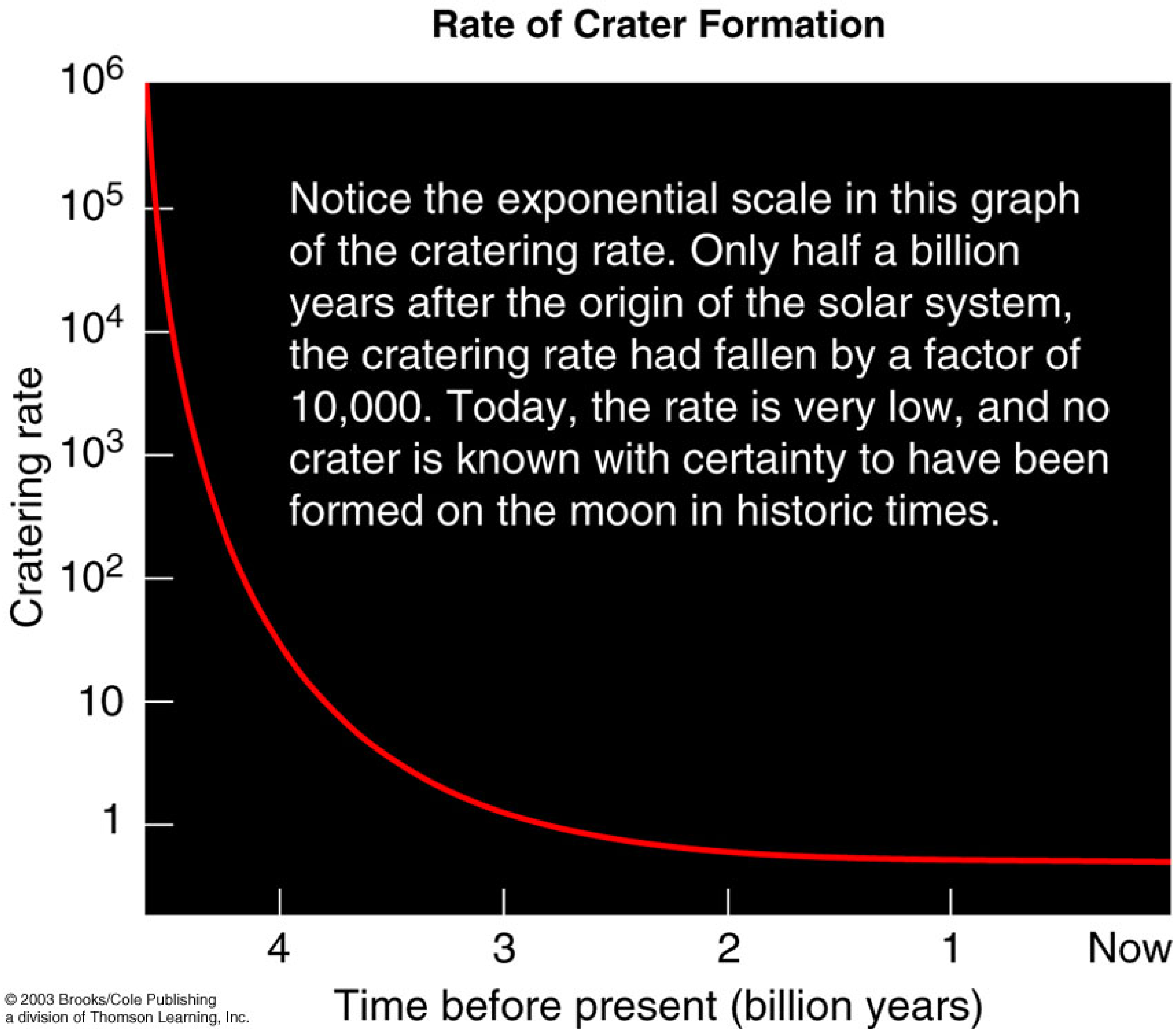




History of Impact Cratering

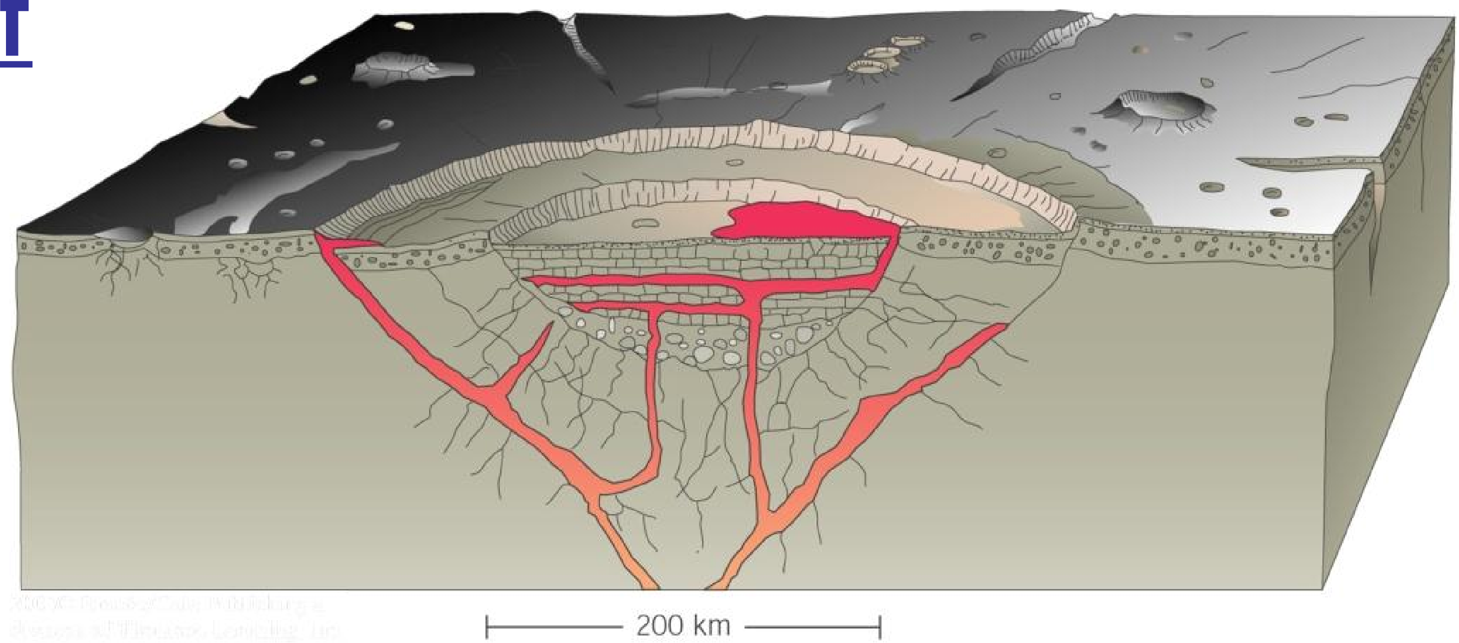
Rate of impacts due to interplanetary bombardment decreased rapidly after the formation of the solar system.

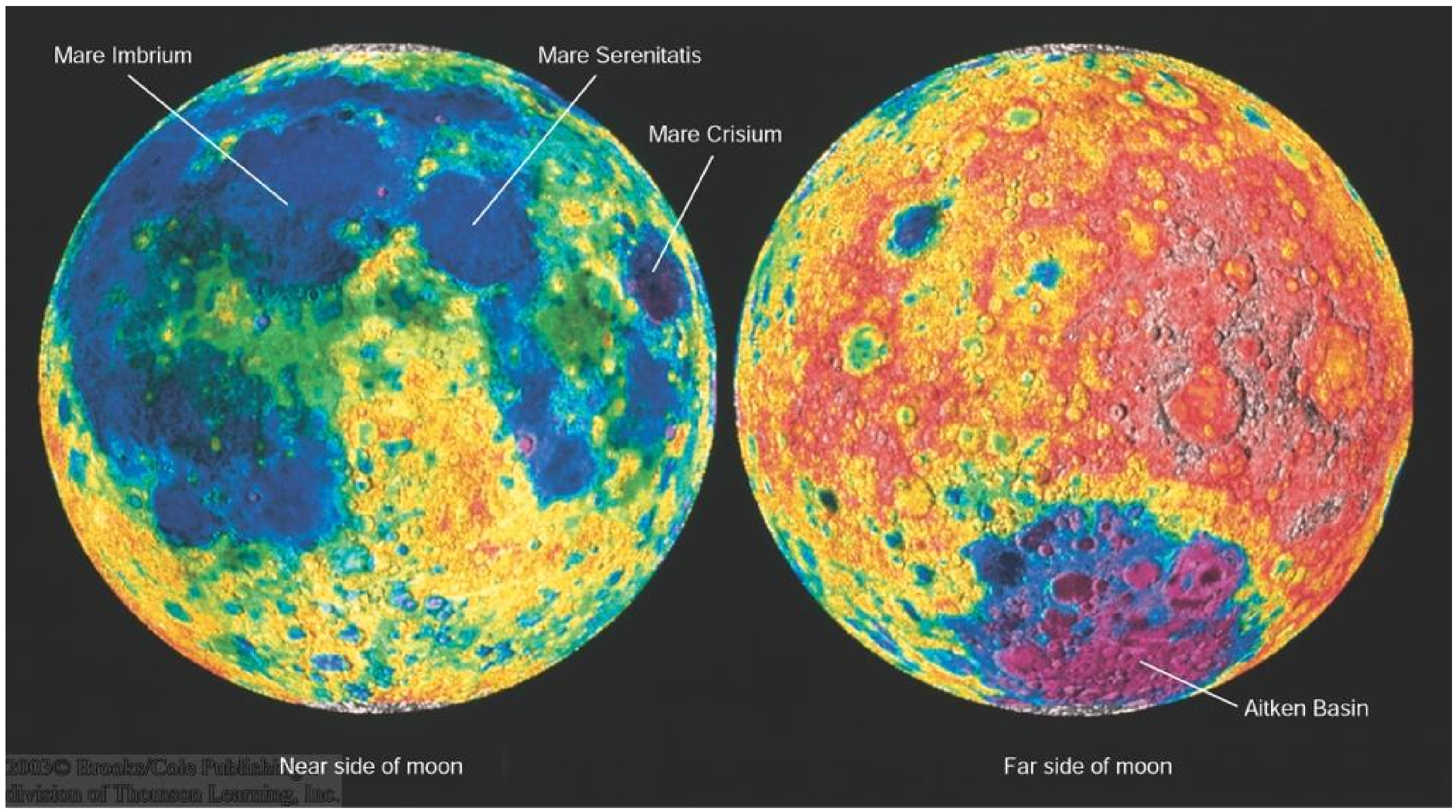
Most craters seen on the Moon's (and Mercury's) surface were formed within the first ~ ½ billion years.



Formation of Maria

Impacts of heavy meteorites broke the crust and produced large basins that were flooded with lava





Modern Theory of Formation of the Moon

The Large-Impact Hypothesis

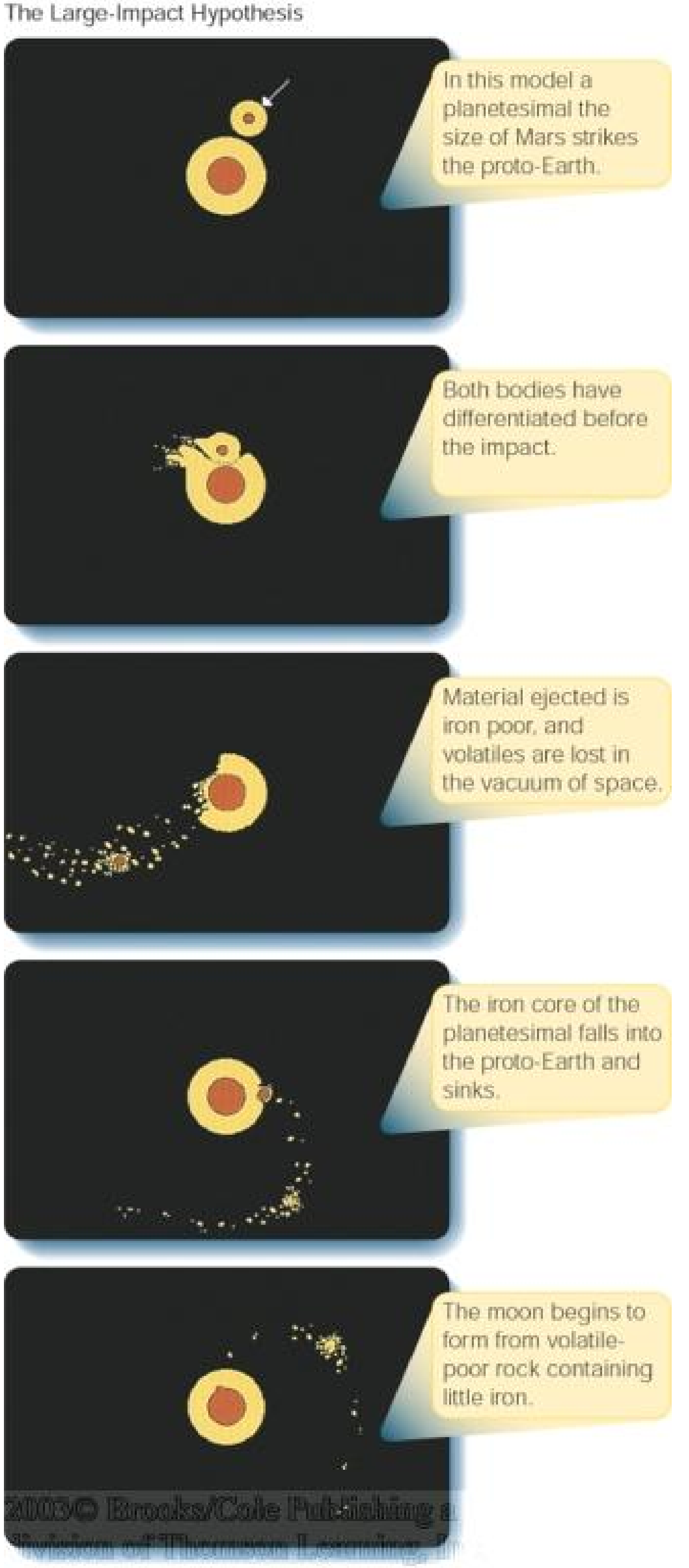
- Impact heated material enough to melt it

  → consistent with “sea of magma”

- Collision after differentiation of Earth’s interior

  → Different chemical compositions of Earth and moon

  (in particular: The moon does not have a large iron core.)



The History of the Moon

Moon is small; low mass → rapidly cooling off; small escape velocity → no atmosphere → unprotected against meteorite impacts.

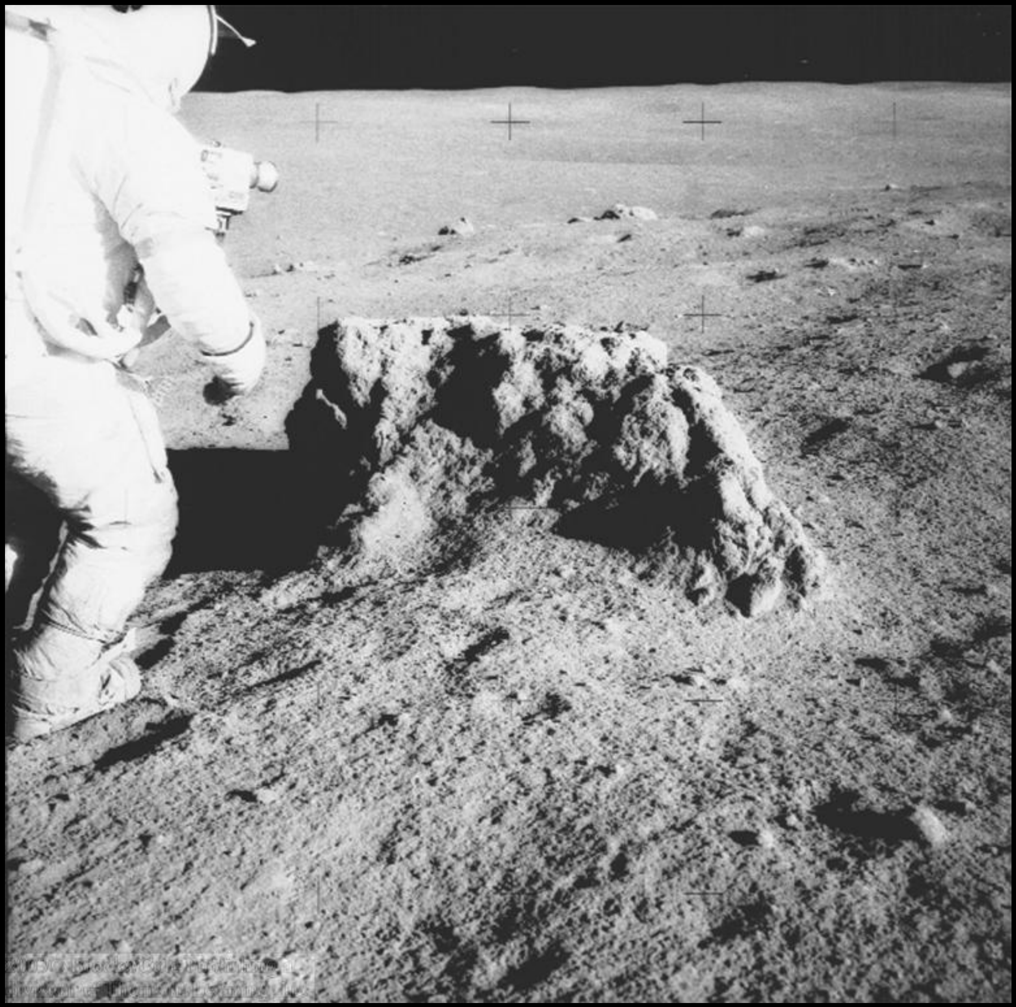
Moon must have formed in a molten state ("sea of lava");

Heavy rocks sink to bottom; lighter rocks at the surface

No magnetic field → small core with little metallic iron.

Surface solidified ~ 4.6 – 4.1 billion years ago.

Heavy meteorite bombardment for the next ~ ½ billion years.



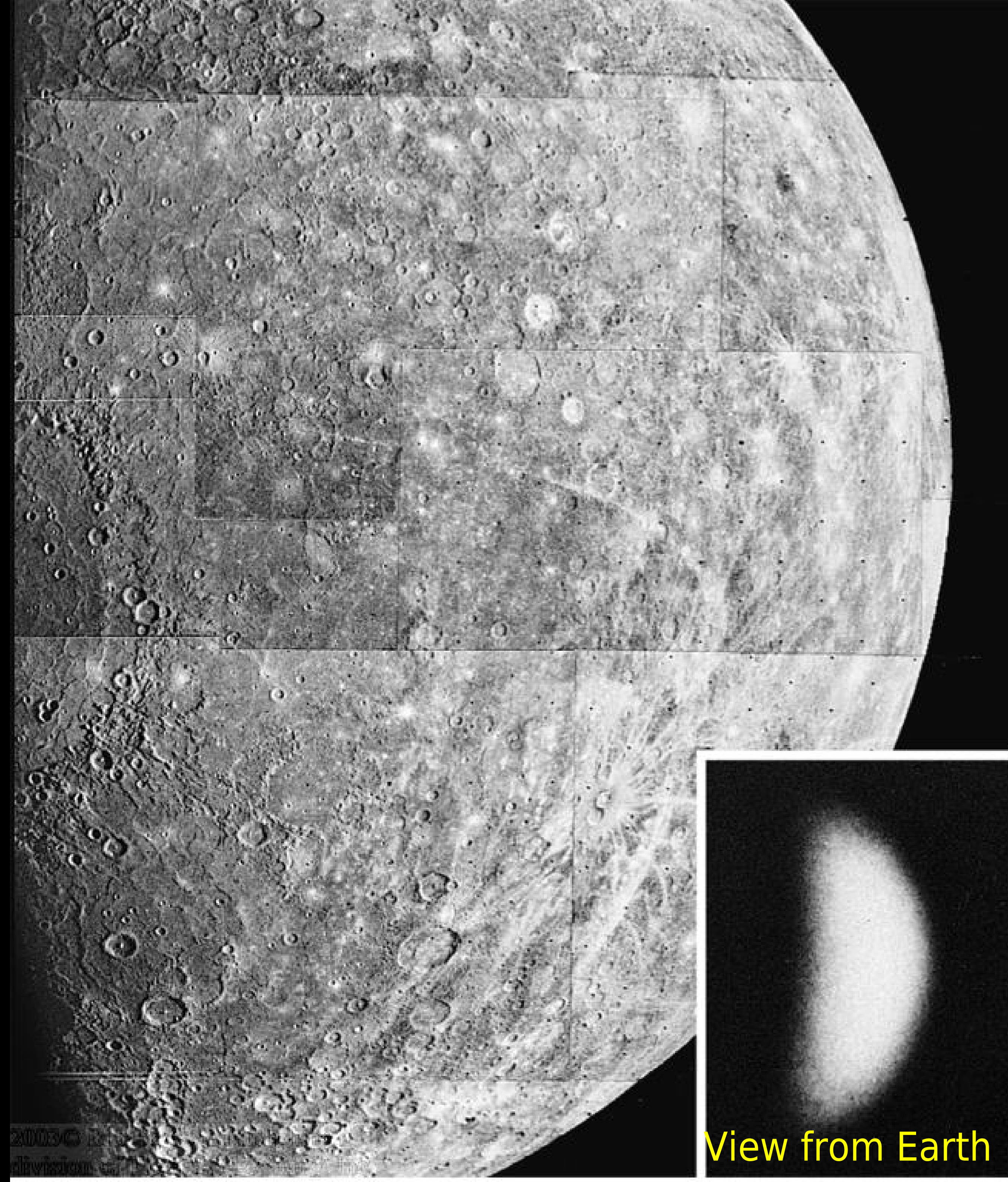
Alan Shepard (Apollo 14) analyzing a moon rock, probably ejected from a distant crater.

Mercury

Very similar to Earth's moon in several ways:

- Small; no atmosphere
- lowlands flooded by ancient lava flows
- heavily cratered surfaces

Most of our early knowledge based on measurements by Mariner 10 spacecraft (1974 - 1975)



View from Earth

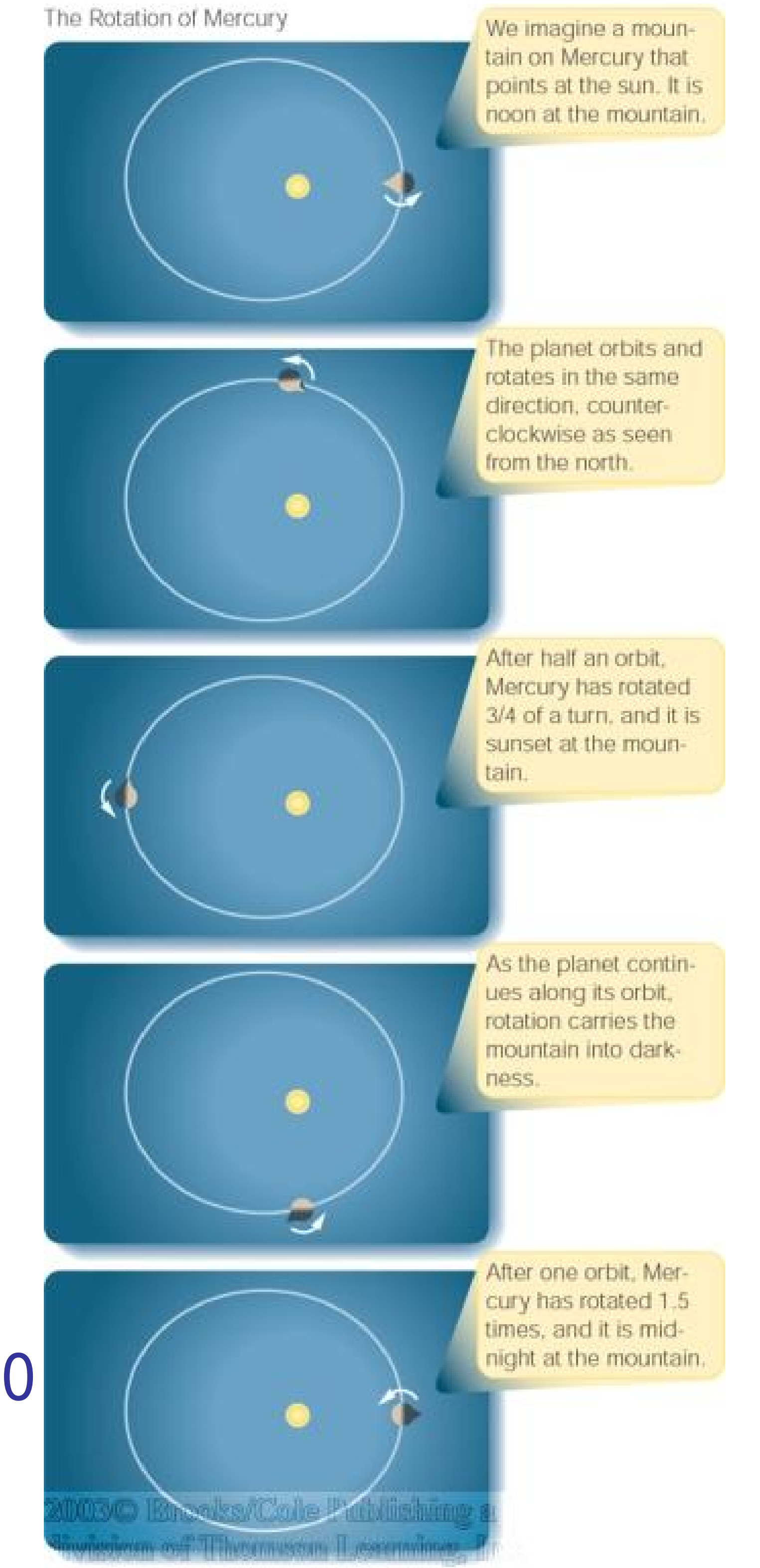
Rotation and Revolution

Like Earth's moon, Mercury's rotation has been altered by the sun's tidal forces.

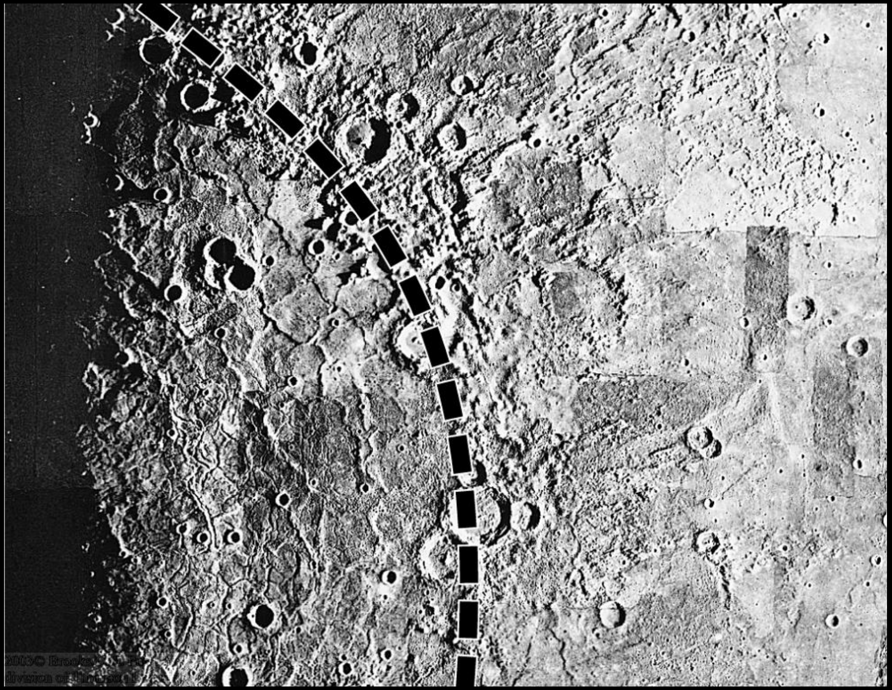
Revolution period = 3/2 times rotation period

Orbital period = 87.969 days
Rotation period = 58.646 days
Semi-major axis = 0.387 AU
Eccentricity = 0.205
Inclination to ecliptic = 7°
Mean radius = 2439.7 km (0.3829 Earth)

→ Extreme day-night temperature contrast: 100 K (-173 $^{\circ}$C) – 600 K (330 $^{\circ}$C)

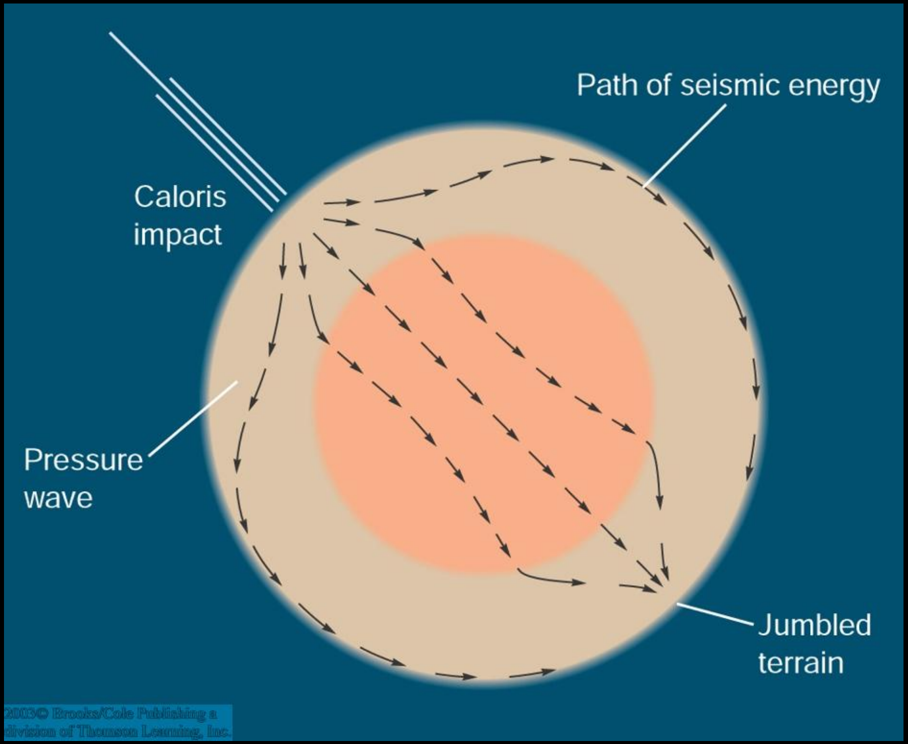


The Surface of Mercury

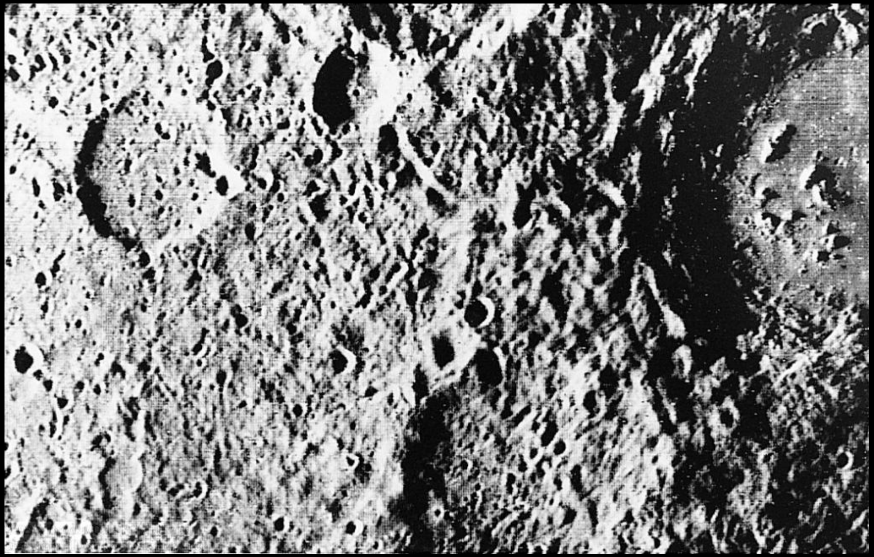


Very similar to Earth's moon:
Heavily battered with craters, including some large basins.

Largest basin: Caloris Basin



Terrain on the opposite side jumbled by seismic waves from the impact.



Lobate Scarps

Curved cliffs, probably formed when Mercury shrunk while cooling down

The Interior of Mercury

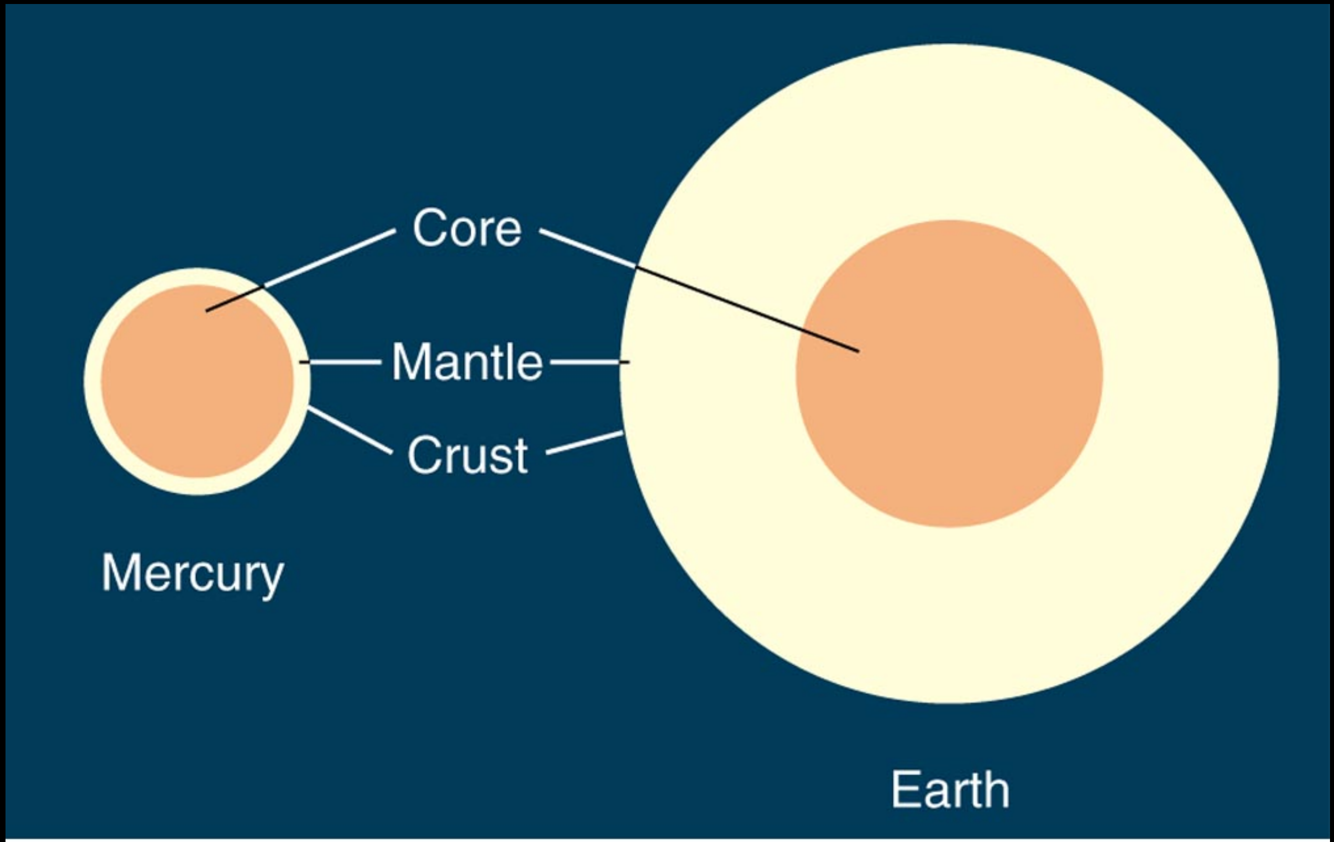
Large, metallic core.

Over 60 % denser than Earth's moon

Magnetic field only ~ 0.5 % of Earth's magnetic field.

Liquid metallic core should produce larger magnetic field.

Solid core should produce weaker field.



Mercury’s Atmosphere

Like the Earth’s Moon, Mercury has a very volatile atmosphere. What little atmosphere exists is made up of atoms or ions blasted off its surface by the solar wind and has less than a million-billionths the pressure of Earth's atmosphere at sea level. It is composed chiefly of oxygen, sodium, and helium.

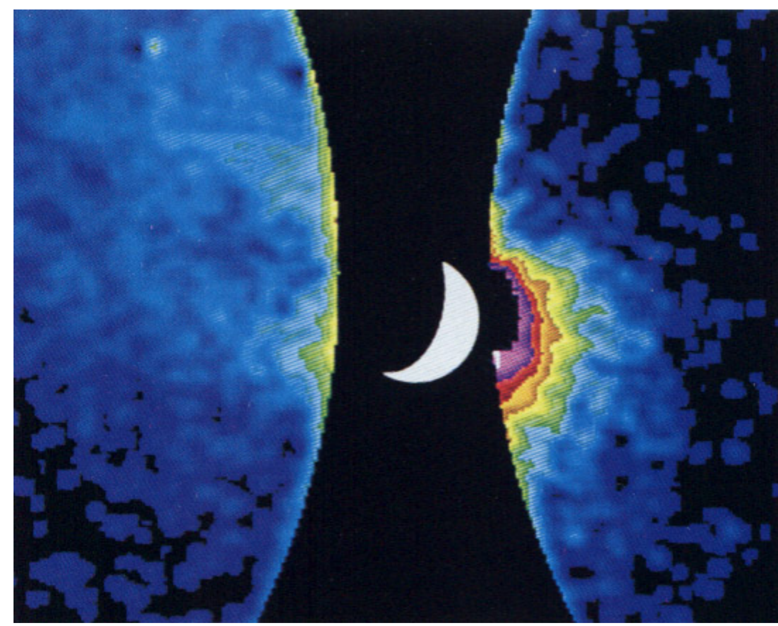
Mercury's extreme surface temperature enhances the escape of these volatile atoms into space.

With no atmosphere or hydrosphere, there has been no erosion from wind or water.

Mercury may have water ice at its north and south poles. The ice exists inside deep craters. The floors of these craters remain in perpetual shadow, so the Sun cannot melt the ice.

Two Tenuous Atmospheres

Species		*Mercury (atoms/cm³)*	*Moon (atoms/cm³)*
Hydrogen	(H)	200	< 17
Helium	(He)	6,000	2,000–4,000
Oxygen	(O)	< 40,000	< 500
Sodium	(Na)	20,000	70
Potassium	(K)	500	16
Argon	(Ar)	$< 3 \times 10^7$	4×10^4



MESSENGER

MErcury: Surface, Space ENvironment, GEochemistry and Ranging

Principal Investigator: Dr. Sean C. Solomon
Carnegie Inst. of Washington

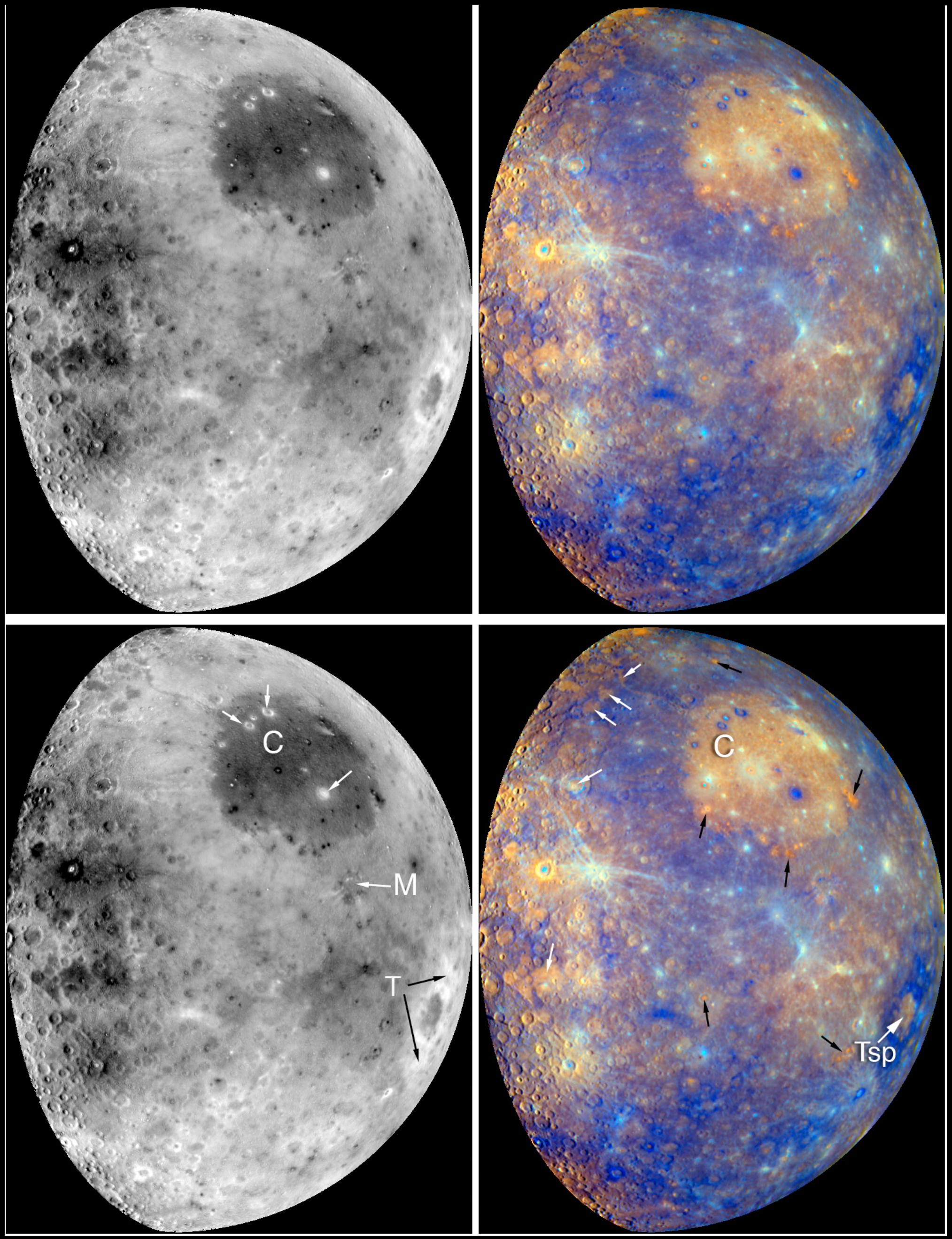
Project Management: Johns Hopkins University Applied Physics Laboratory

Instruments: JHU/APL, GSFC, Univ. Colorado, Univ. Michigan

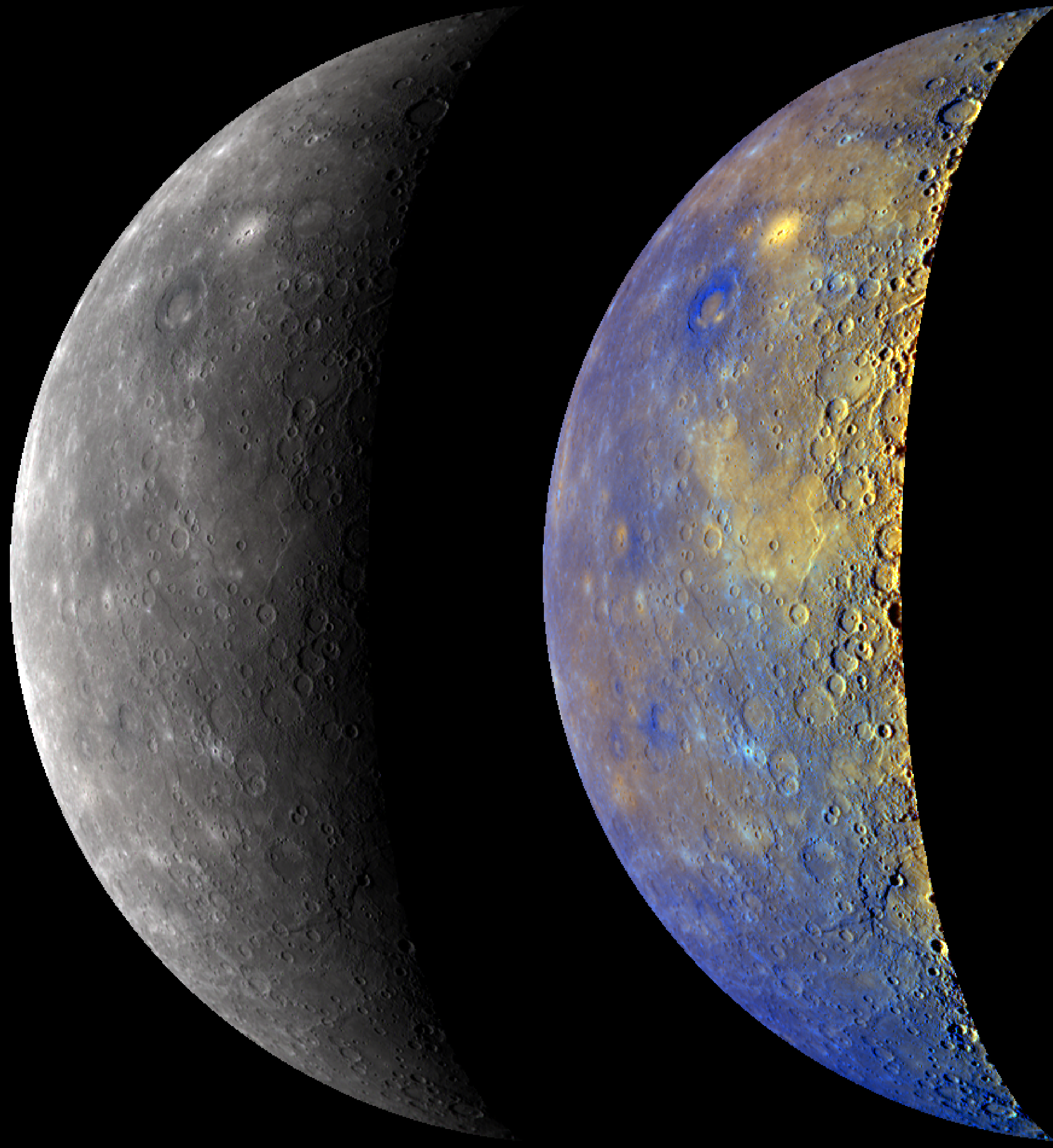
Structure: Composite Optics, Inc.

Propulsion: GenCorp Aerojet

Navigation: Jet Propulsion Laboratory



MESSENGER’s WAC multi-spectral images to study compositional variations across the surface of Mercury. The white arrows identify areas of Mercury’s surface that are interpreted to be relatively young volcanic plains, and the black arrows point to reddish areas interpreted to be volcanoes. Most of the color differences studied here are believed to indicate variations in the mineral composition and physical state of the rocks at different places on Mercury.



The moment of inertia factor is a dimensionless quantity that characterizes the radial distribution of mass inside a planet or satellite.

The moment of inertia of a homogenous sphere is

$$I = \frac{2}{5} MR^2 \ \mathrm{kg\,m^2}$$

$$\Rightarrow \quad \frac{I}{MR^2} = 0.4$$

For Earth, $\frac{I}{MR^2} = 0.331$, indicative of an iron core.

For the Moon, $\frac{I}{MR^2} = 0.3932$, suggesting an almost uniform density.

The mean density of the Moon is $3.4\ \mathrm{g\,cm^{-3}}$, compared to $5.5\ \mathrm{g\,cm^{-3}}$ for Earth.

Mercury: Has a tenuous atmosphere with a pressure of 10^{-12} bar. The average density of Mercury is $5.43\ \mathrm{g\,cm^{-3}}$ and the moment of inertia factor is

$\frac{I}{MR^2} = 0.353$, indicative of a liquid outer core.

Importance of the Moon and Mercury

- The surface history of most other terrestrial bodies has been “lost”.

- The Moon is a critical laboratory in the study of early Earth history and hence the formation of a habitable planet.

- The Moon and Mercury surfaces provide a history of early bombardment including timing, size distribution, and composition of impacting objects.

- Impacts and geology of Mercury provide constraints on volatile delivery.