Announcements

Homework #3 is due today 9/22

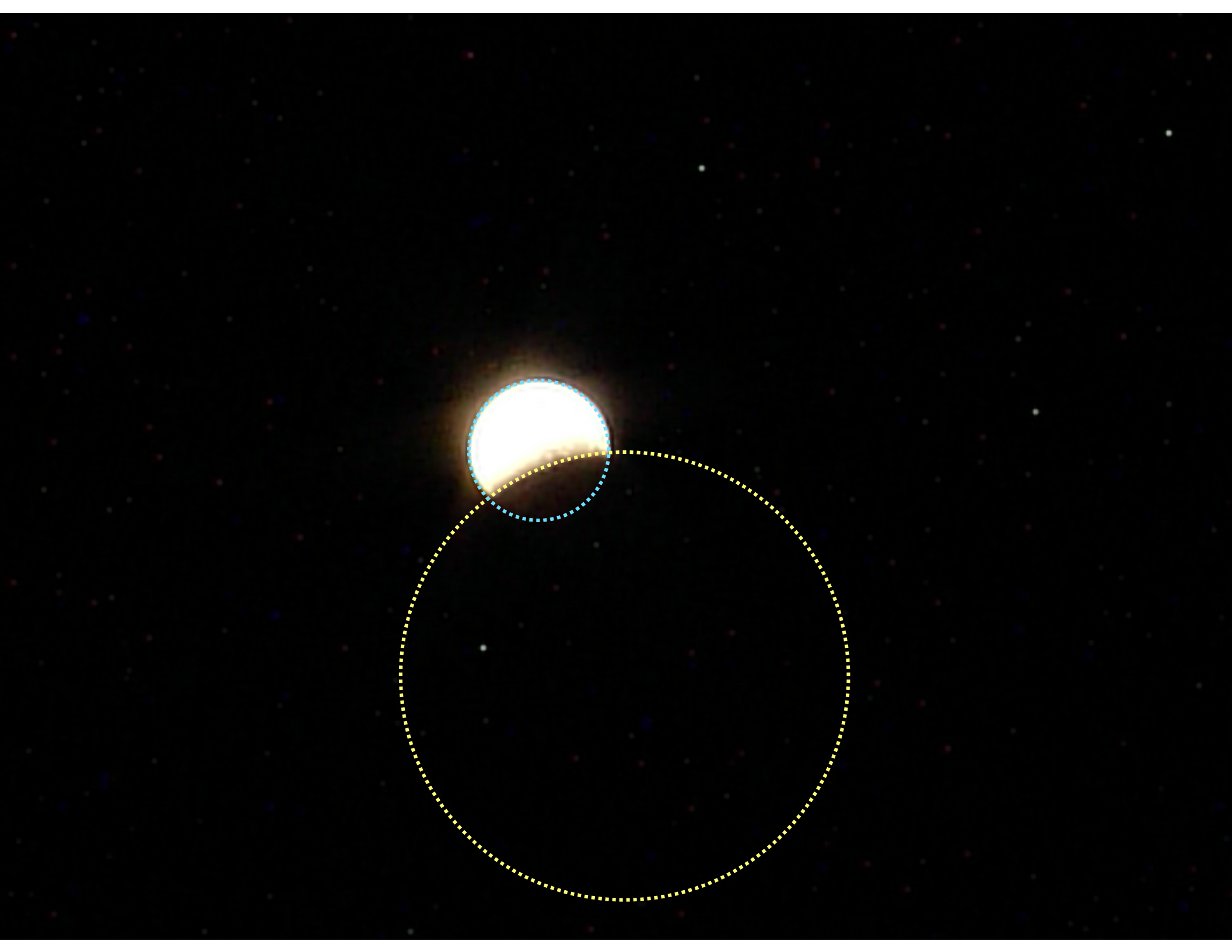
The Moon

Mass = 7.4×10^{25} g
= $0.012\ M_{Earth}$

Radius = 1738 km
= $0.27\ R_{Earth}$

Density = $3.3\ g/cm^3$
(Earth $5.5\ g/cm^3$)

Gravity = 1/6 that of Earth

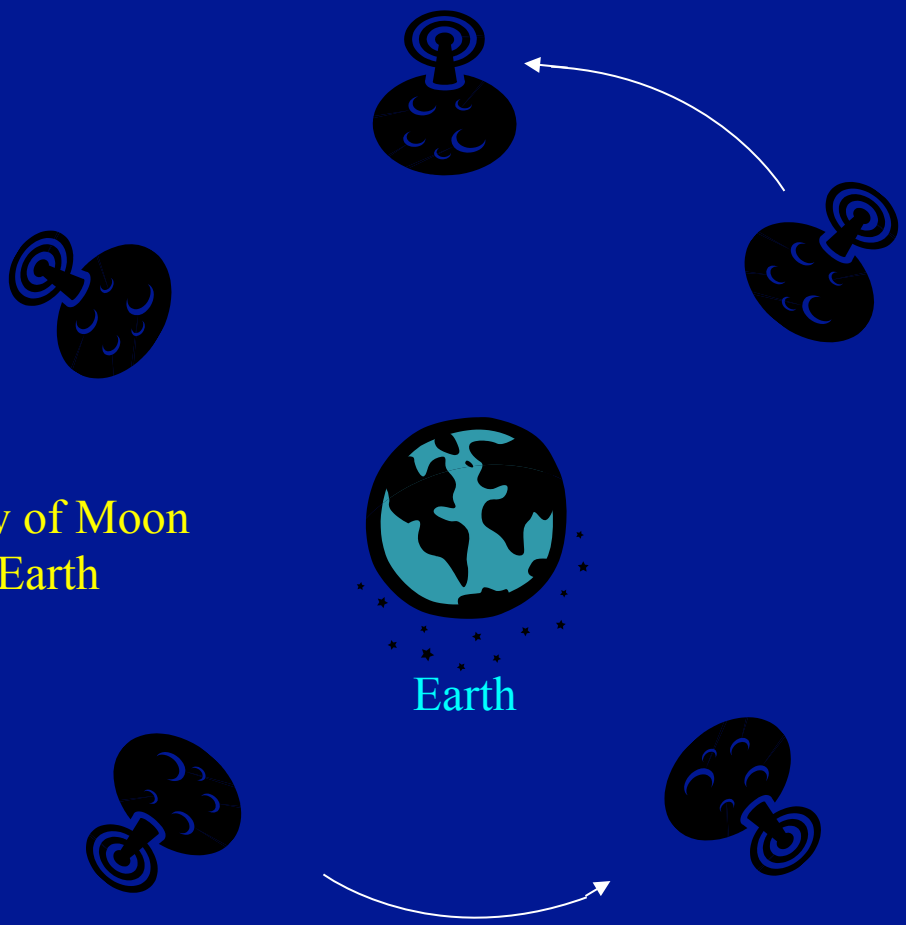


We always see the same face of the Moon.

This means: period of orbit = period of spin

Why?

Tidal Locking



The tidal bulge in the solid Moon elongates it slightly (2-3 km) along an axis pointing to Earth.

If orbit period faster than spin period, tidal bulge would have to move around surface of Moon, creating friction, which slows the Moon's spin down until tidal bulge no longer migrates around.

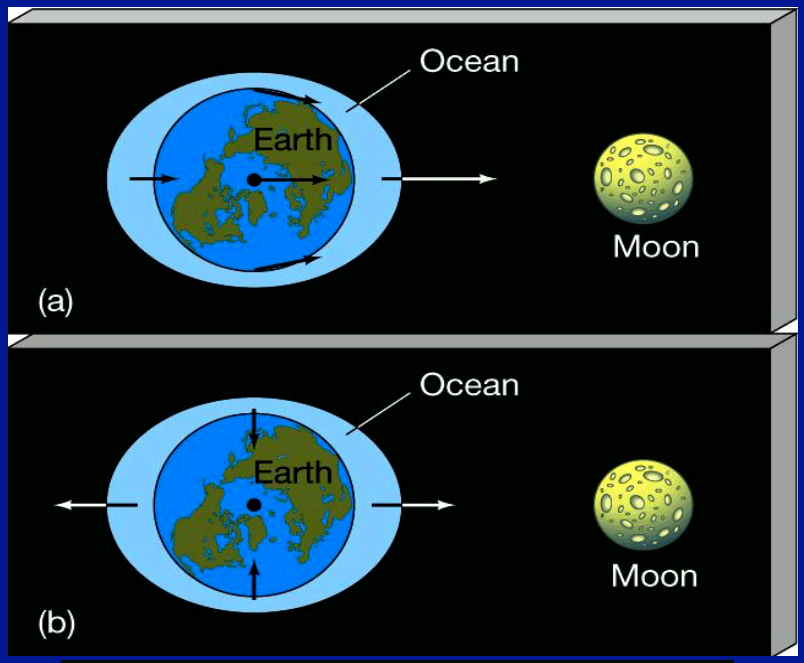
Dark side of the moon

Tides

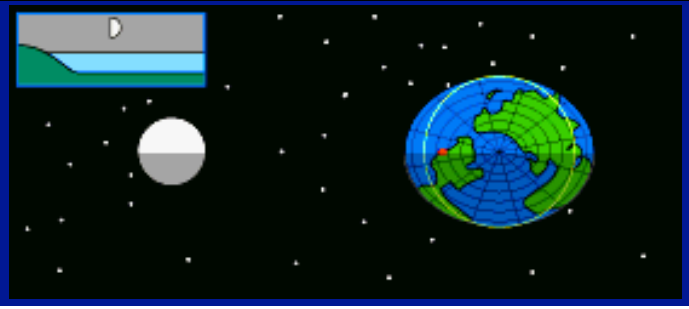
A feature of oceans (but solid material has small tides too).

Two high and two low tides per day.

Tides are due to Moon's gravitational pull being stronger on side of Earth closest to it (Sun causes smaller tides).

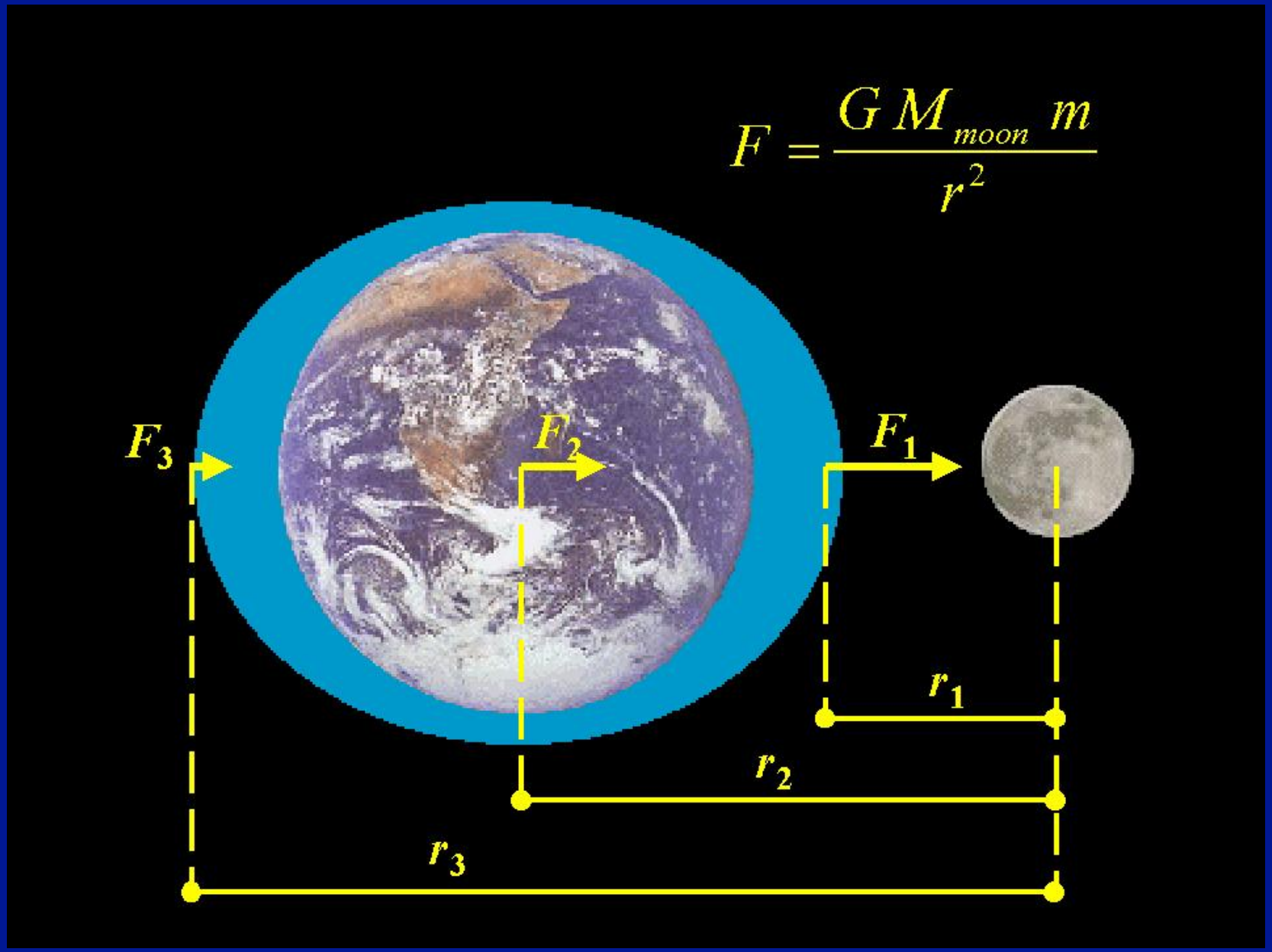


Earth-Moon gravity keeps them orbiting each other. But side of Earth closest to Moon has slightly stronger pull to Moon => bulges towards it. Other side has weaker pull => bulges away compared to rest of Earth.

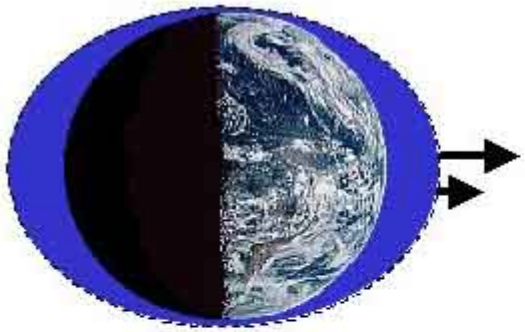


The Earth spins once a day while the bulge always points towards and away from the Moon => high and low tides.

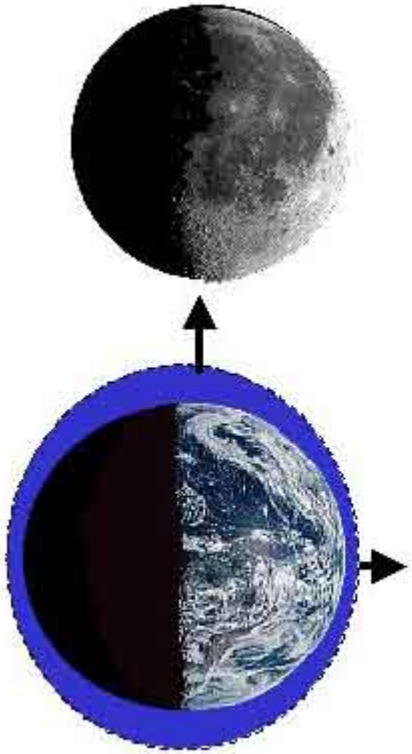
Tides



Tides



Spring tides at new and full phase are large because the gravity of the moon and sun pulls in the same direction.



Neap tides at first and third quarter phase are weak because the gravity of the sun pulls at right angles to that of the moon.

The Lunar Surface

- Large, dark featureless areas: "maria" or "seas".

- Lighter areas at higher elevation: "highlands".

- Loads of craters (due mostly to meteorite impacts). No winds to erode them away.

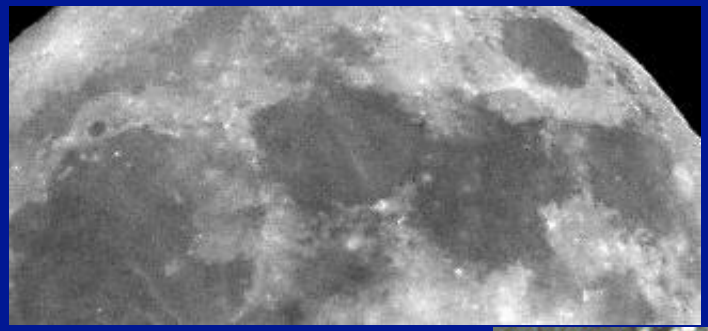
- Highlands have 10x the crater density of maria.

Lunar Volcanism (long ago)

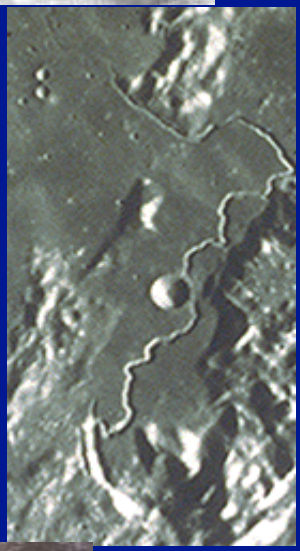
Remember: volcanism is a way of losing internal heat

Evidence:

- Maria: result of old, widespread lava flows (filled in largest, early impact craters)



- "Rilles": ditches indicating old lava flows



- Linear chains of craters (not formed by impacts), probably marks ancient fault, collapsed lava domes

Age of Lunar material

- Radioactive dating can give more accurate ages than crater rates.
- Samples from Mare 3.1 – 3.8 billion years old (as oldest rocks on Earth)
- Highland rocks typically 4-4.3 billion years, oldest rock dated to 4.46 billion years

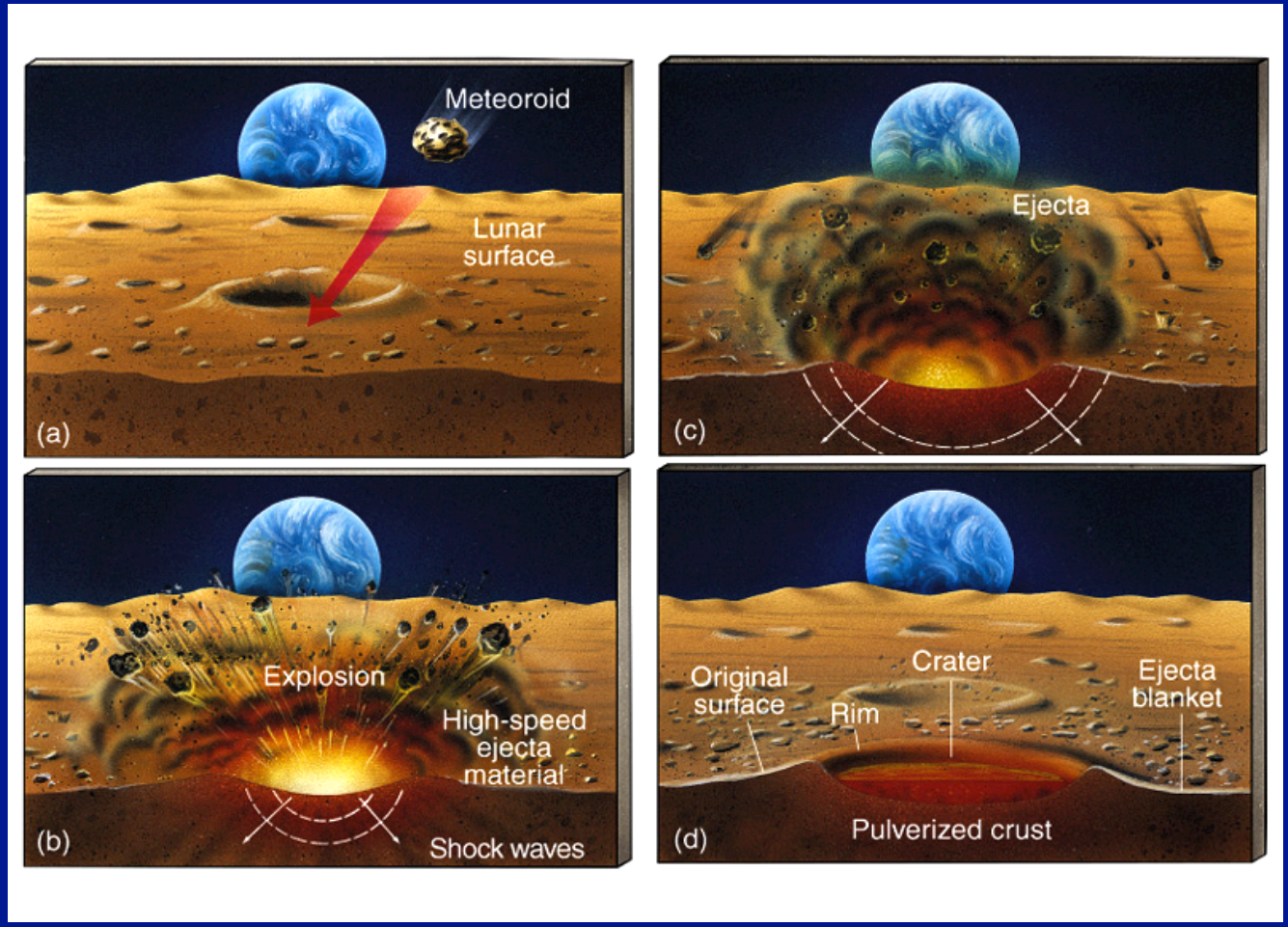
Oldest material on the Moon is almost as old as we believe the Solar System to be.

Cratering

- Impact speeds several km/sec

- "Ejecta blanket" of pulverized rock surrounds crater

- Impacts => "regolith": ~20 m thick layer of pulverized rock covering Moon.



Cratering Rates

Small meteroids common, large ones rare. So same true for craters:

Crater size	Occurrence
10 km	every 10 million years
1 m	every month

If no other processes (erosion, lava flows) change the surface, the number of craters in an area tells you the age of the surface.

Moon's History

Age: 4.5 billion years

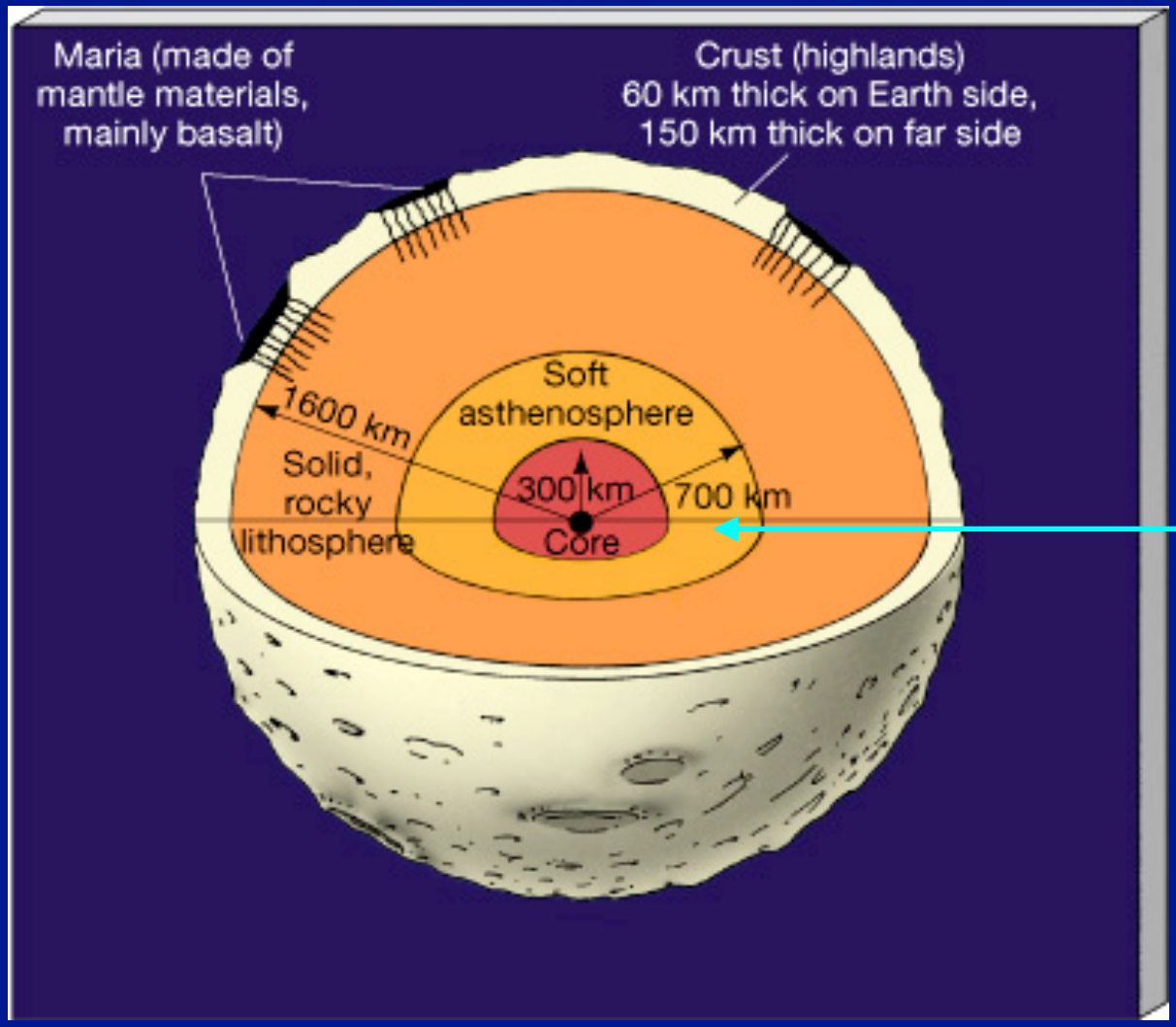
3.9 billion years ago:
heaviest meteoritic bombardment ended

3.9 - 3.2 billion years ago:
volcanism created maria. Maria are just the largest craters, filled in.

3.2 billion years -> present
no volcanism, cratering continued at lower rate, geologically dead!

Lunar Structure

(from Apollo seismic data and theoretical arguments)



Core and asthenosphere take up small fraction of volume compared to Earth case – the Moon is more rigid

And no atmosphere, so no wind or erosion.
Surface reflects geologic history well.

Chemical composition of rocks

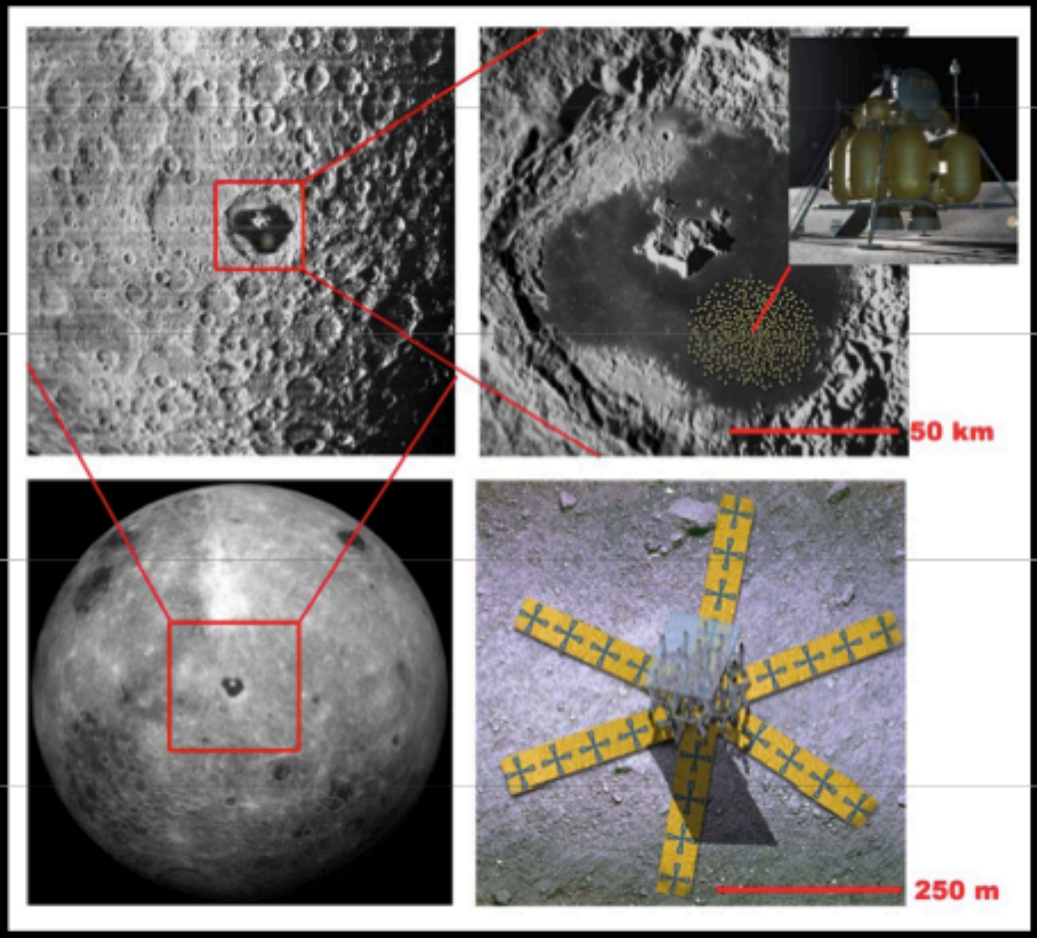
- Rich in refractory elements (Ca, Al, Ti that forms compounds, high melting points)
- Poor in light elements like H
- Abundant in Si, O

Mining on the Moon?

Telescopes on the Moon

Key subsystems

- Antennas
- Receivers/beamformers
  - No significant technology development (long heritage of HF/VHF receivers)
- Data storage
  - ~ 500 Tb per lunar night
- Rover deploys a station
- Data transmission
  - Lunar laser links
- Correlator
  - 1000 stations
  - *Small* bandwidth (~ MHz)
- Relay satellite downlink
  - ~ 2 Gb/s downlink
- Ground operations station



Clicker Question:

When do the largest high tides occur?

A: When the Moon is at first quarter

B: When the Moon is full.

C: When the Earth is at aphelion in its orbit.

D: When the Moon is at 3rd quarter.

Clicker Question:

The surface gravity of the moon is 1/6 that of Earth. If Matt weighs 120 lbs on Earth, how much does he weigh standing on the moon?

A: 120 lbs

B: 60 lbs

C: 30 lbs

D: 20 lbs

E: 10 lbs

Clicker Question:

Suppose the Moon was half as dense, but the same size. How much would Matt (120 lbs on Earth) weigh?

A: 120 lbs

B: 60 lbs

C: 30 lbs

D: 20 lbs

E: 10 lbs

How did the Moon form?

We're not quite sure! Three older theories:

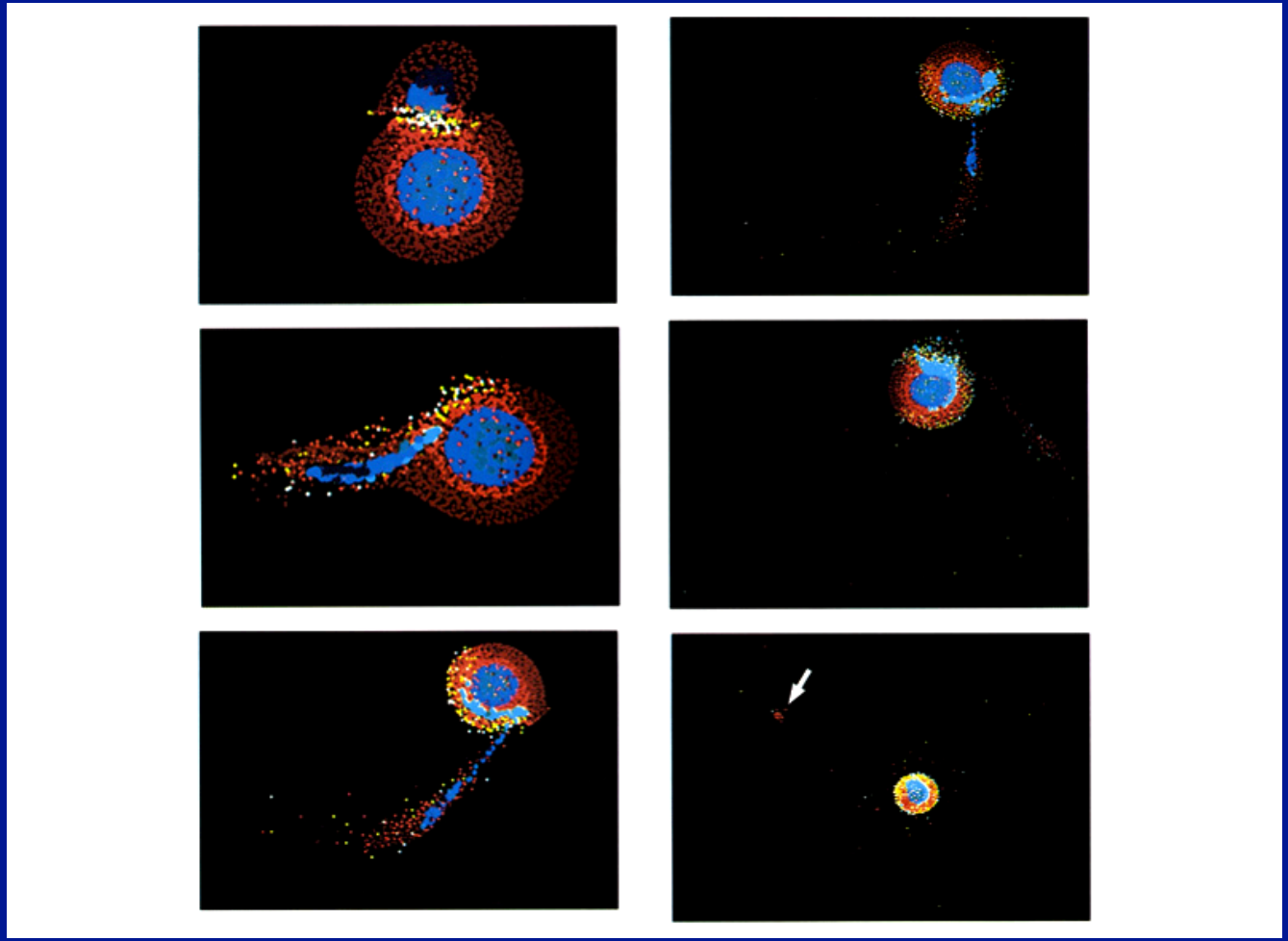
1) "Fission": The material that would be the Moon was thrown off the Earth and coalesced into a single body. Problem: Earth not spinning fast enough to eject large amount of material.

2) "Coformation": The Moon and Earth formed out of the same material at the beginning of the Solar System. Problem: Moon has different density and composition.

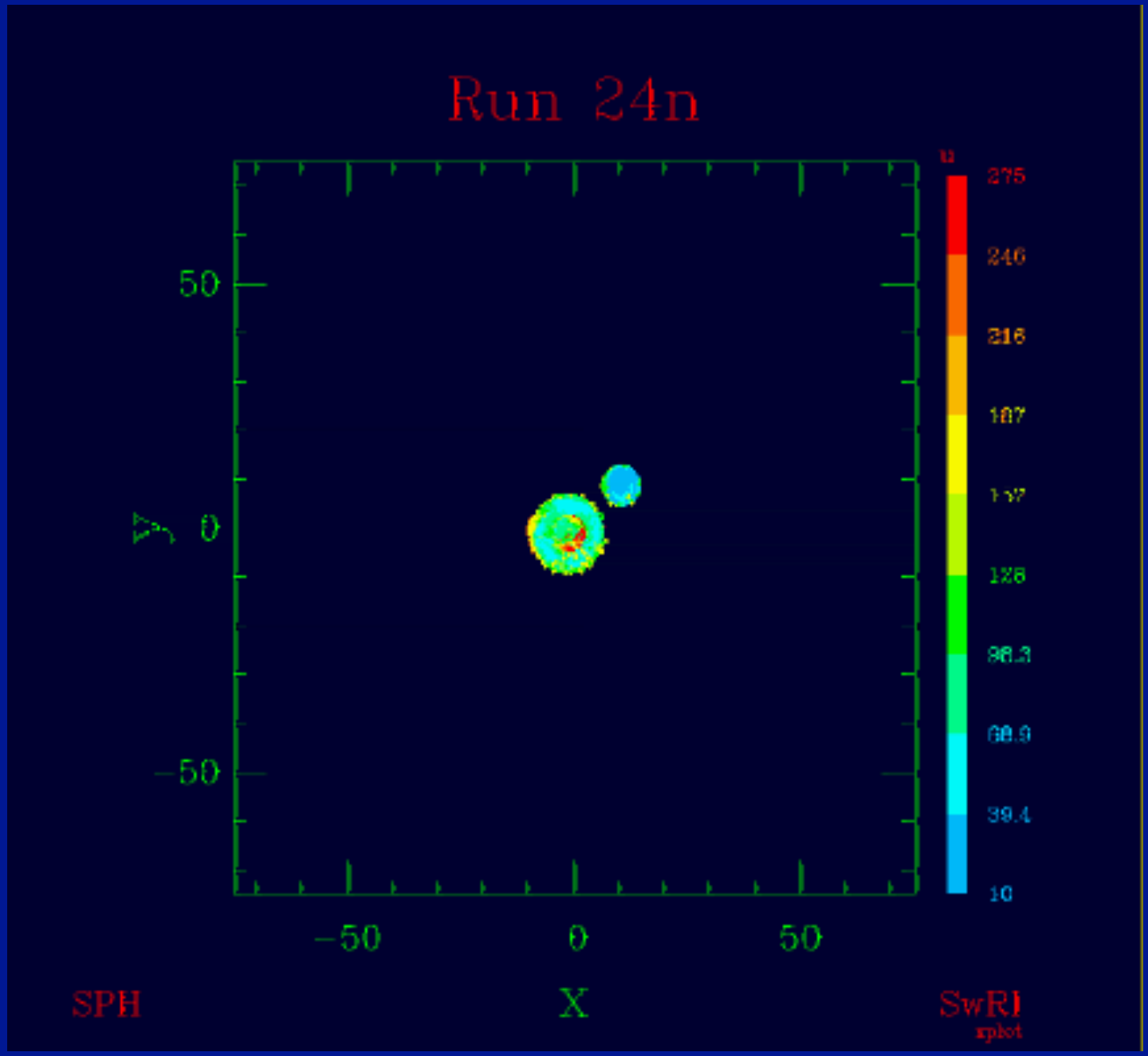
3) "Capture": The Moon was a stray body captured into orbit around Earth. Problem: an extremely unlikely event, given Moon's size is a substantial fraction of Earth's.

So now, Impact theory preferred:

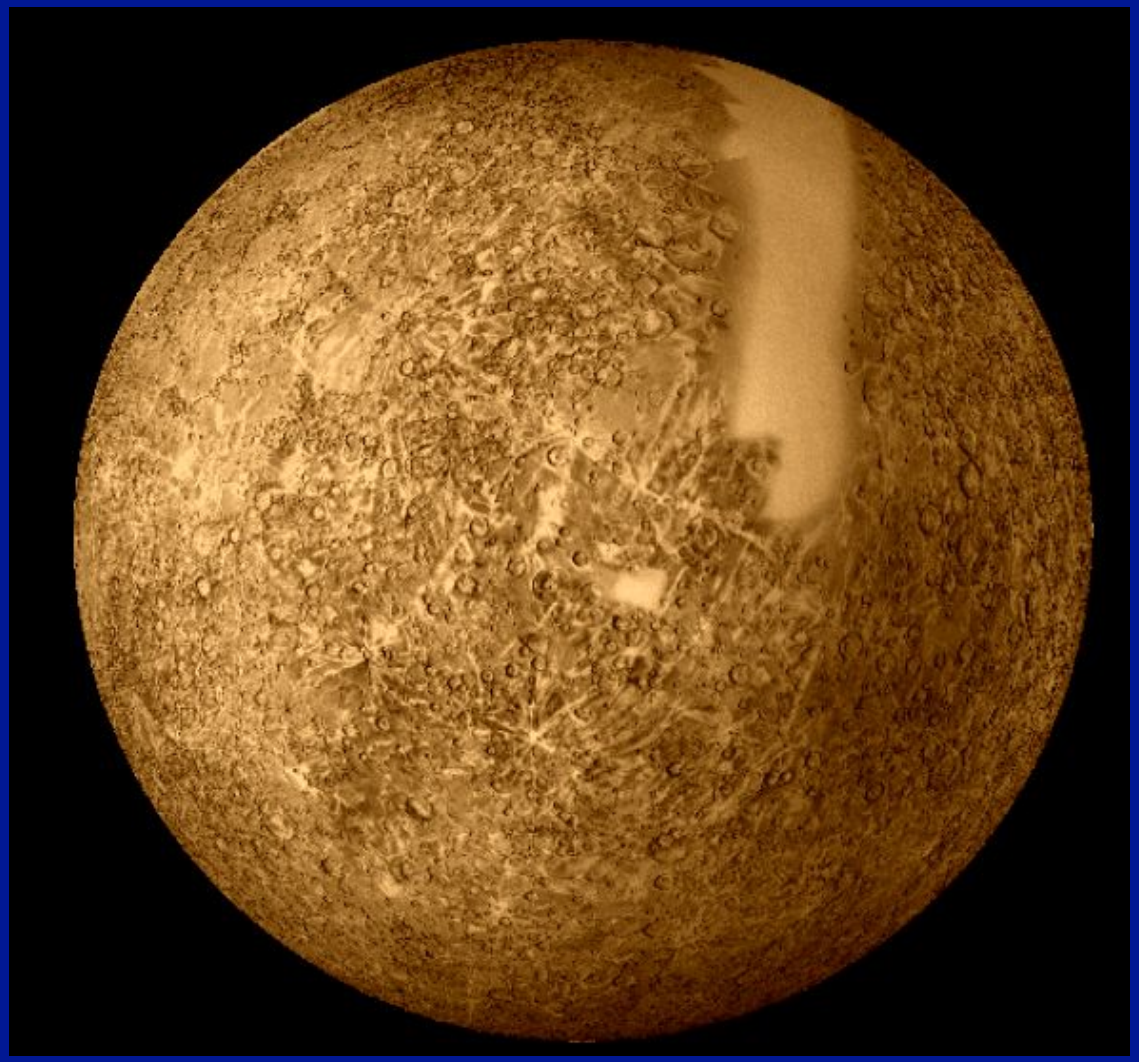
Early in Solar System, when many large planetesimals around, a Mars-sized object hit the forming Earth, ejecting material from the upper mantle which went into orbit around Earth and coalesced to form Moon. Computer simulations suggest this is plausible.



So now, Impact theory simulation:



Mercury



Mass = 3.3×10^{26} g
= $0.055\ M_{Earth}$

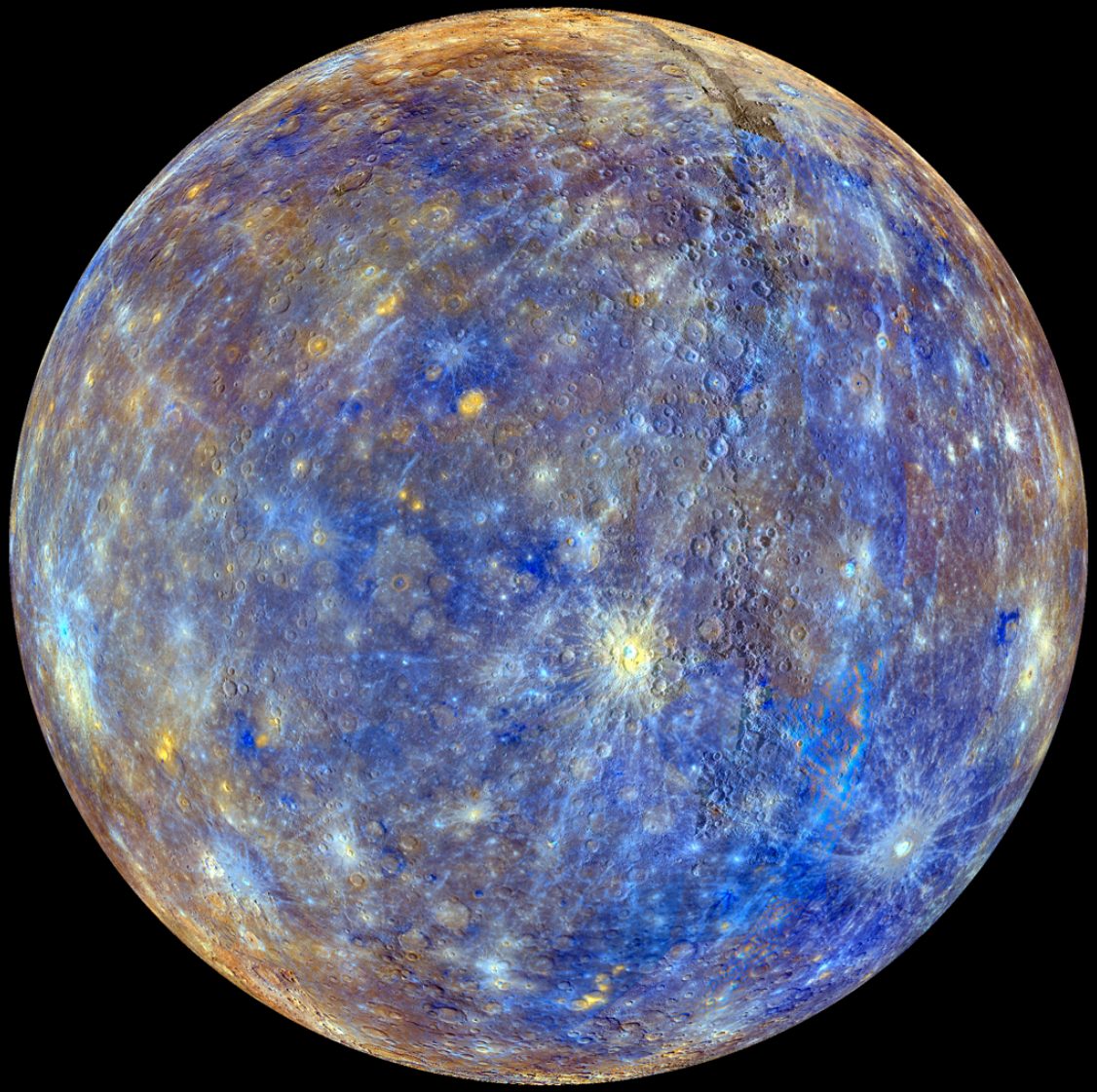
Radius = 2439 km
= $0.38\ R_{Earth}$

Density = $5.4\ g/cm^3$

Gravity = 0.38 that of Earth

Semimajor axis = 0.39 AU

Mercury's surface

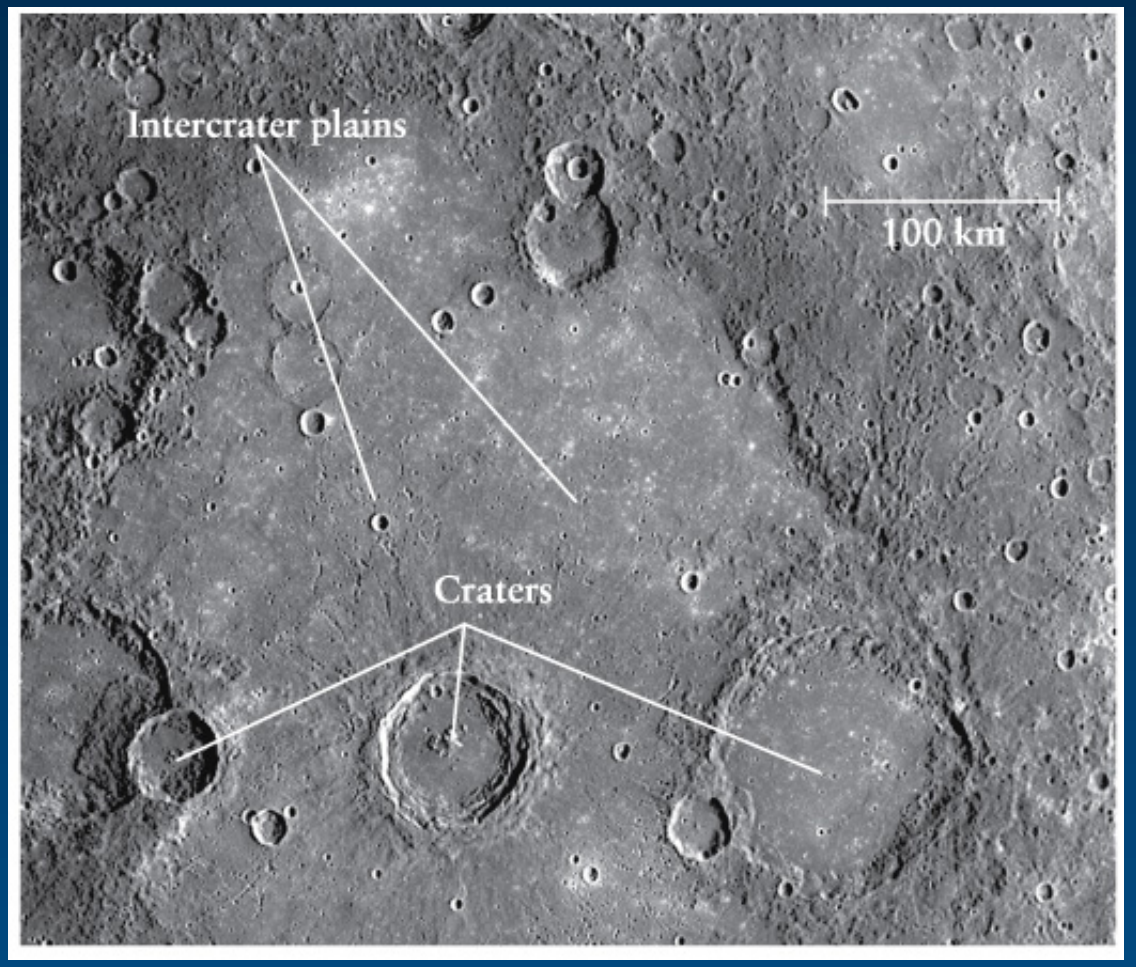


MESSENGER has imaged about 99% of surface, at 250-m resolution.

Mercury's surface compared to Moon

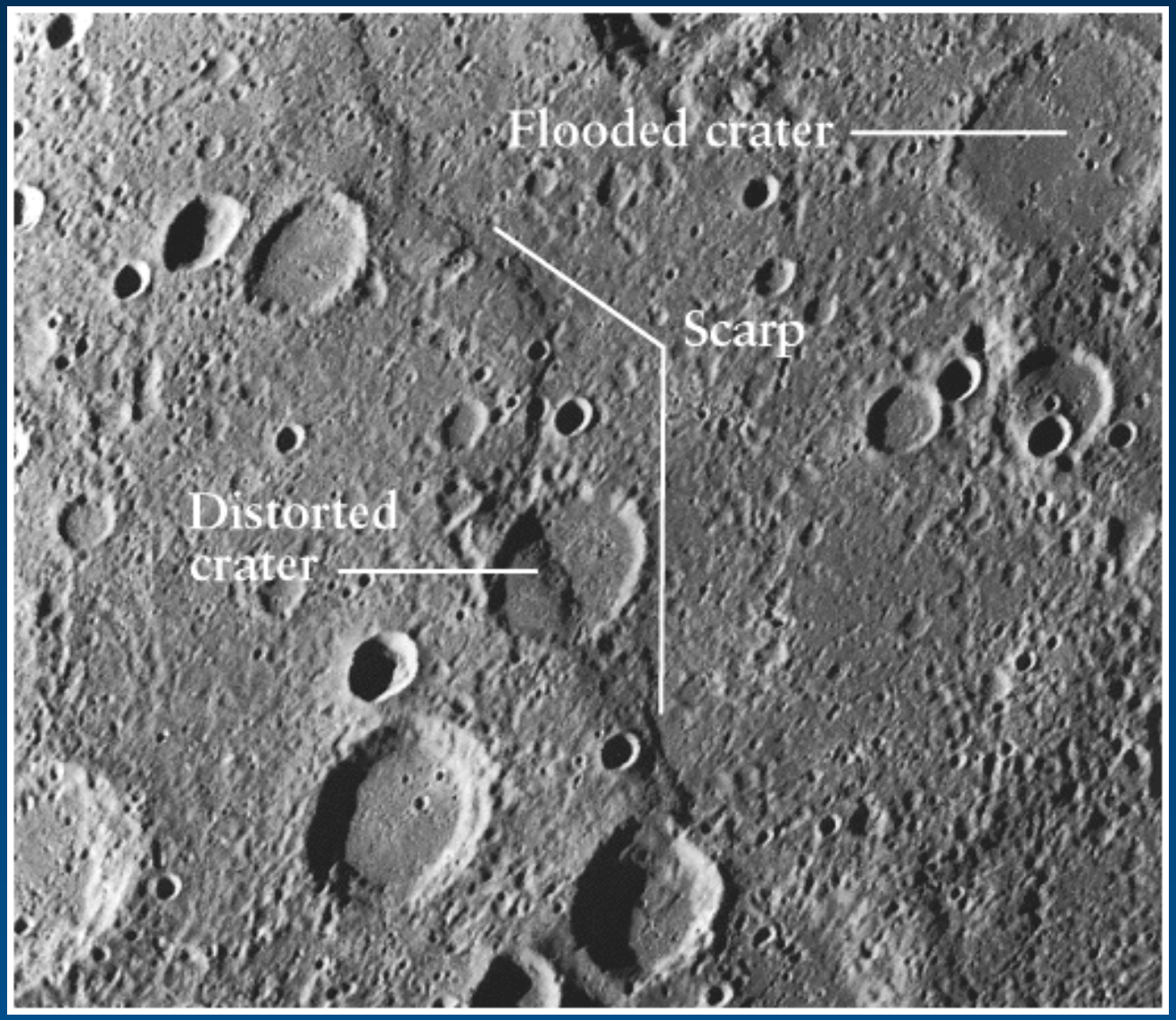
- No significant atmosphere (like the Moon) [but tenuous (pressure $<10^{-12}$ that of Earth's) *exosphere* of gas generated and maintained by the interaction of the solar wind with the planet's surface and magnetic field]
- Heavily cratered (like the Moon)
- 3.8 - 4 Gyrs old (similar to lunar highlands)
- No plate tectonics, water or wind erosion (like the Moon)
- Surface well preserved (like the Moon)

- "Intercrater plains" are 2 km lower than cratered terrain. Probably old lava flows - cratering rate indicates age of 3.8 Gyr.

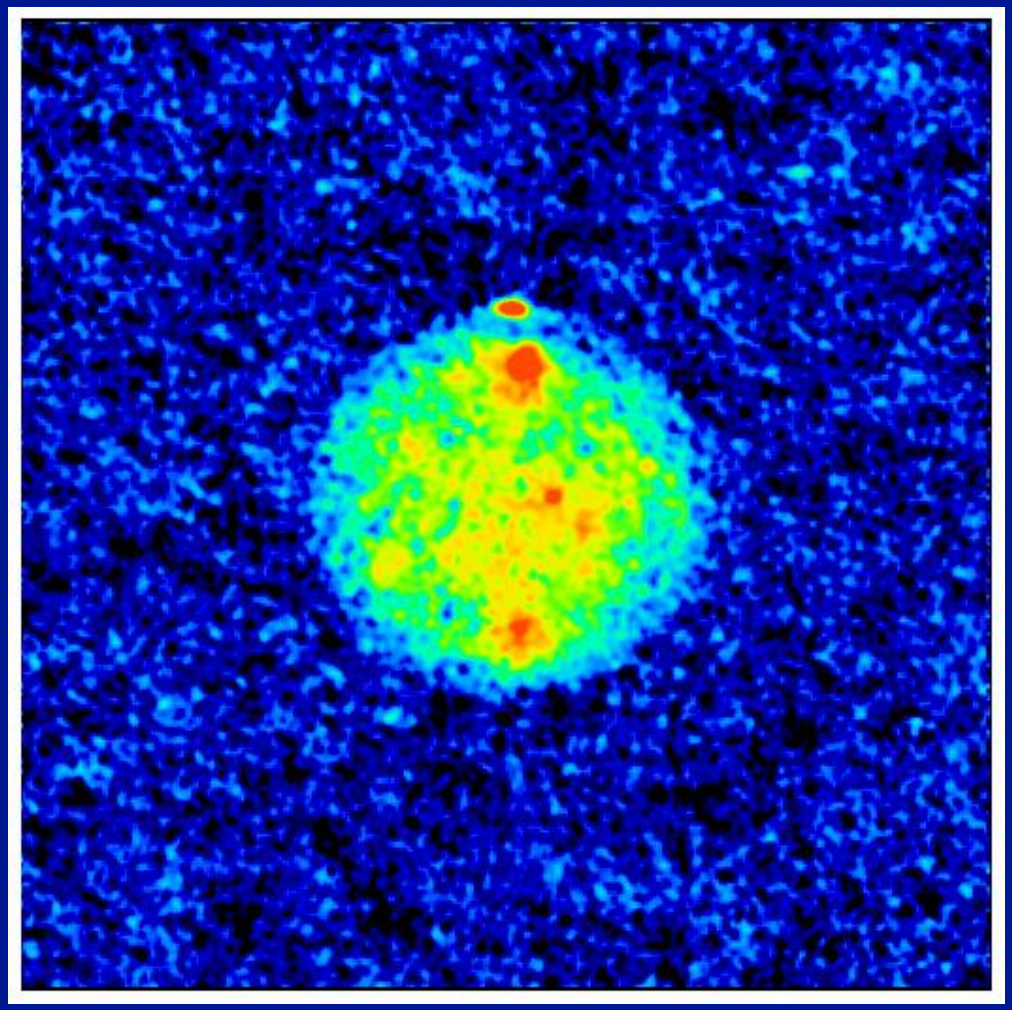


MESSENGER image

One unique feature: scarps. These are long cliffs, though to be caused by a cooling, contracting planet.



Discovery of Water Ice on Mercury

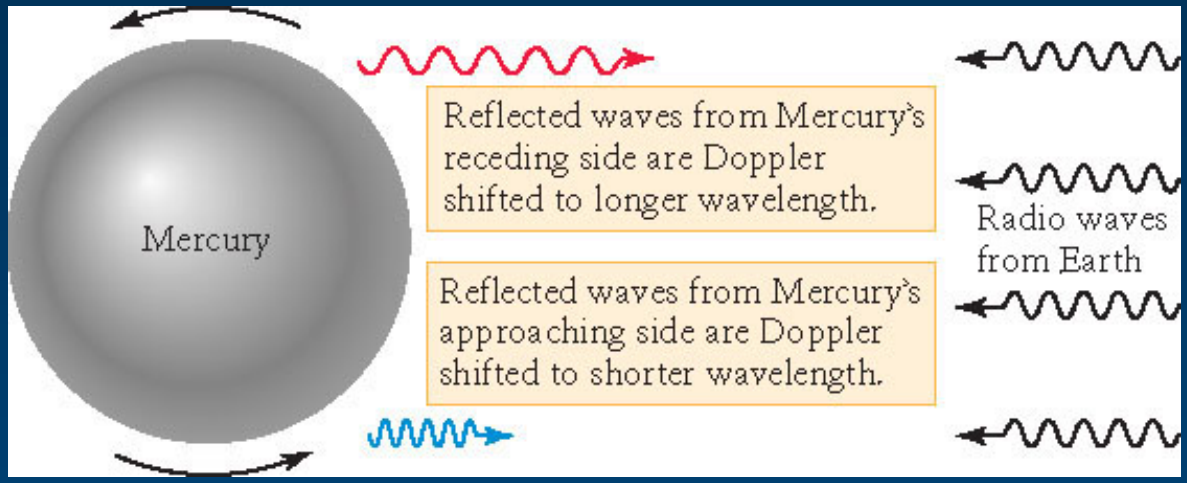


Goldstone 70m radar received by the VLA

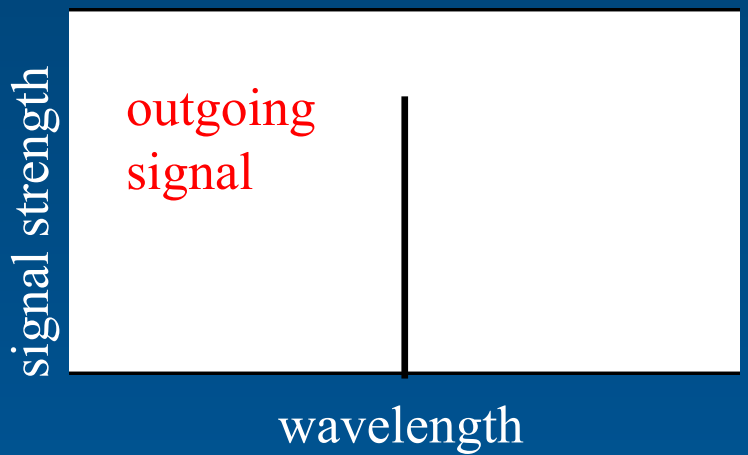
Polar regions could be 125 K and never warmed by the Sun

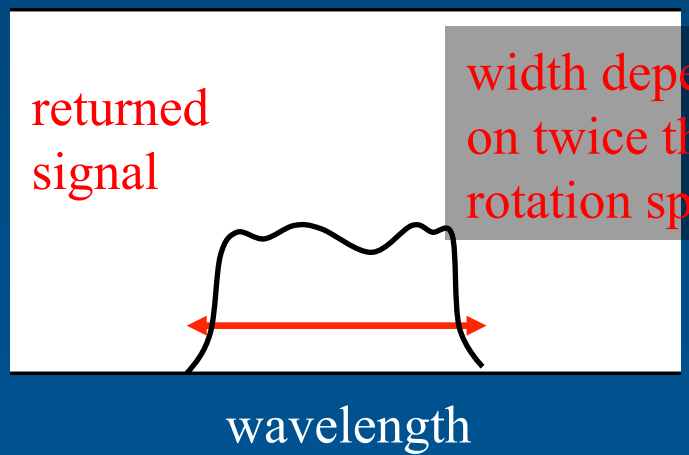
Mercury's orbit and rotation

How do we measure rotation of a planet?

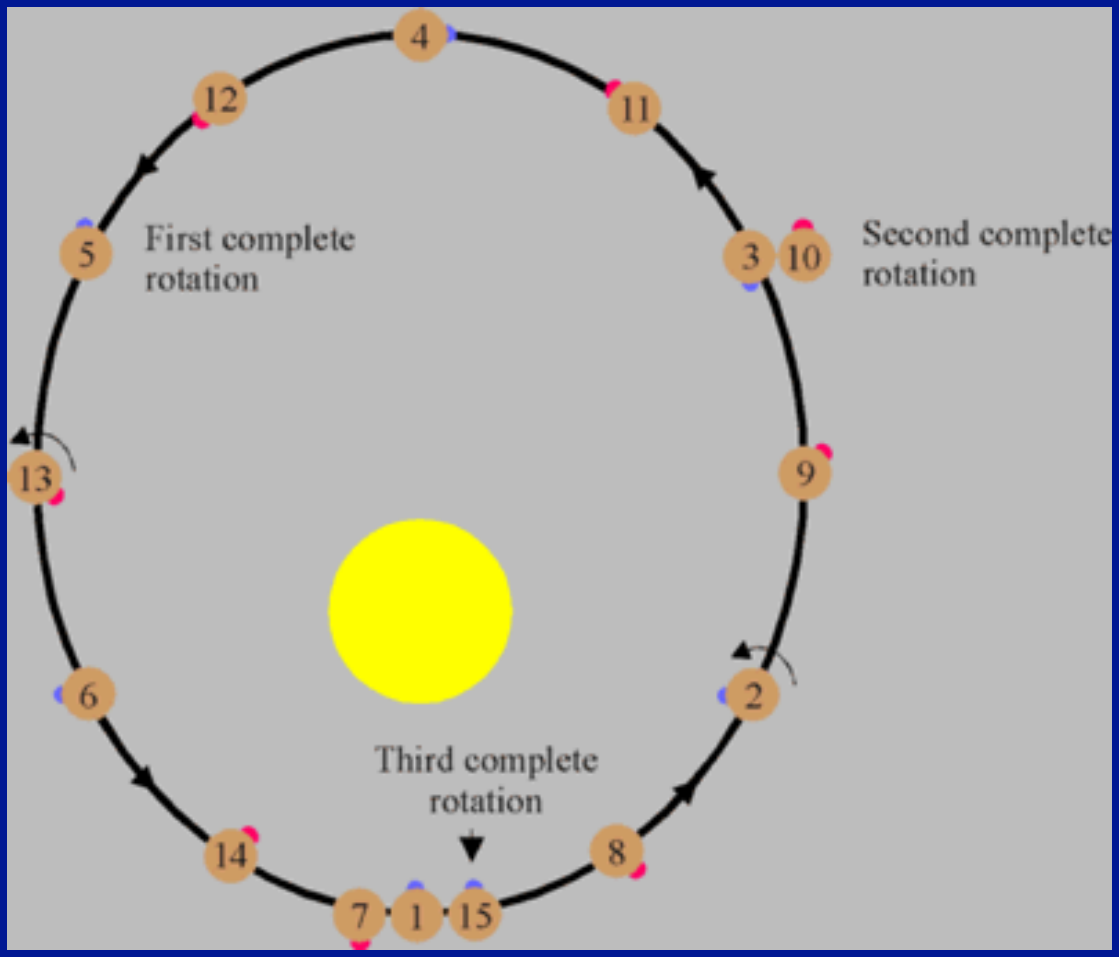


Even if angular resolution not high enough to resolve approaching and receding hemispheres, the returned signal will still have a width in frequency due to the outgoing signal bouncing off both hemispheres.





Orbit of Mercury



3:2 resonance with the sun

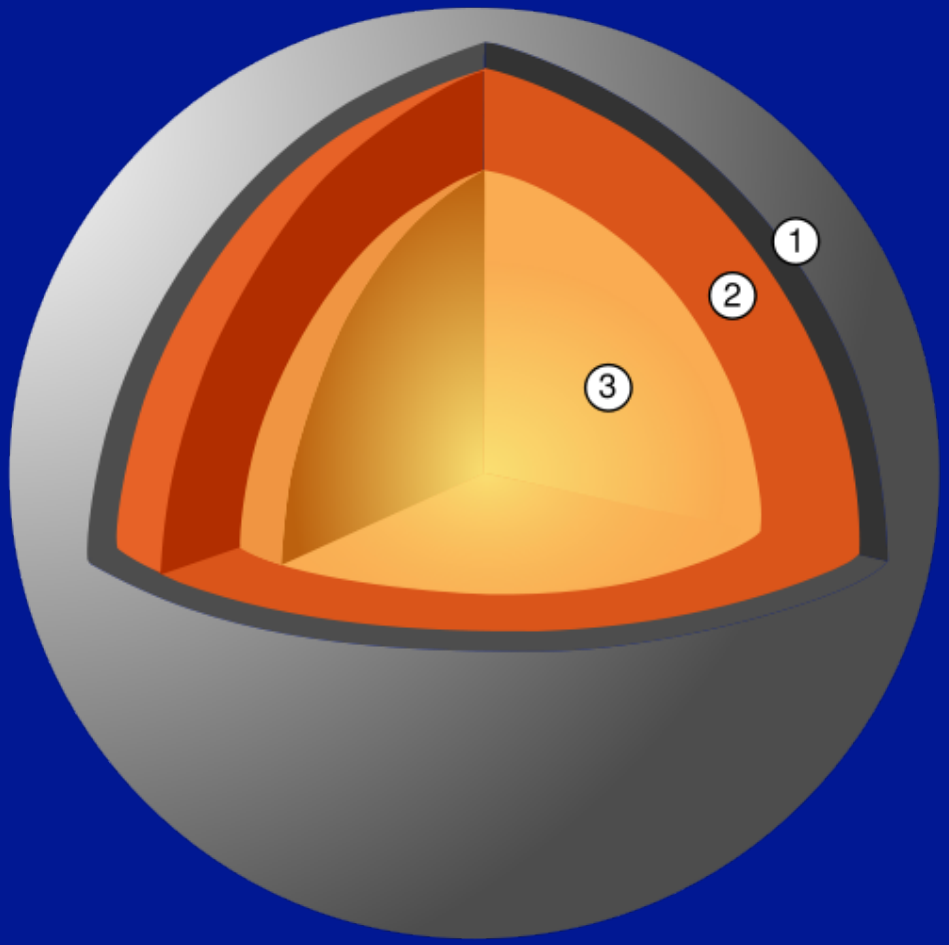
Orbital period of 88 days
Sidereal rotation of 59 days

1 “day” on mercury = 176 earth days

Daytime temp = 500 K
Nighttime temp = 100 K

Structure of Mercury

(from Mariner 10 and theoretical arguments)

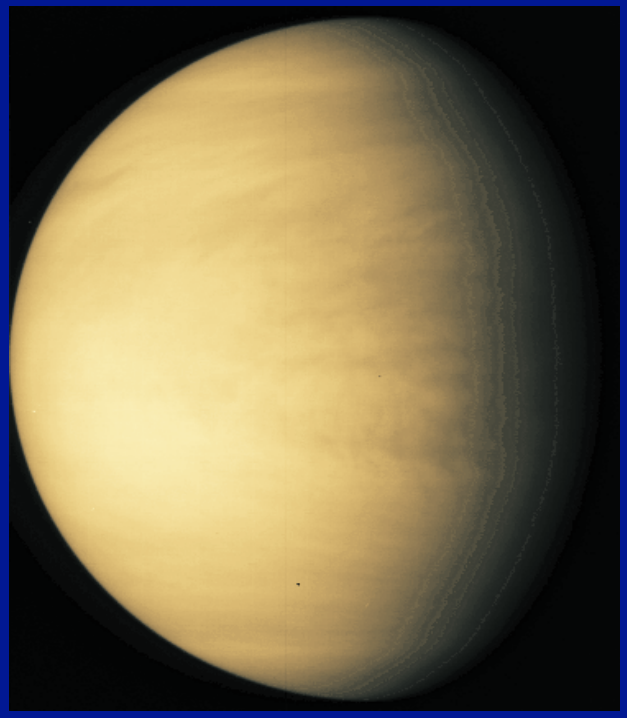


1.Crust 100-200 km thick

2. Mantle 600 km thick

3. Core, 1800 km in radius

And no atmosphere, so no wind or erosion.
Surface reflects geologic history well.



Venus

Mass = 0.82 M_{Earth}

Radius = 0.95 R_{Earth}

Density = 5.2 g/cm^3

Average distance from Sun = 0.72 AU

Orbital period = 225 days

Rotation period = 243 days (longer than orbital period, and retrograde!)

Venus' Atmosphere

- Pressure at surface is 90 x that of Earth's => much more gas in atmosphere. No oceans.

- Consequence - meteoroids burn up easily. No impact craters less than ~3 km. What's the composition of the atmosphere?

- 96.5% CO_2

- Yellowish color from sulfuric acid clouds and haze.

- Hot at surface - 730 K! Almost hot enough to melt rock

- Why so hot? Huge amount of CO_2 leads to strong greenhouse effect.

Early on, T may have been much lower (but still warmer than Earth). Oceans existed?

But if warm enough, T would start to rise because of...

Runaway Greenhouse Effect

1) Water and CO_2 evaporate from oceans into atmosphere.

2) Greenhouse effect more efficient.

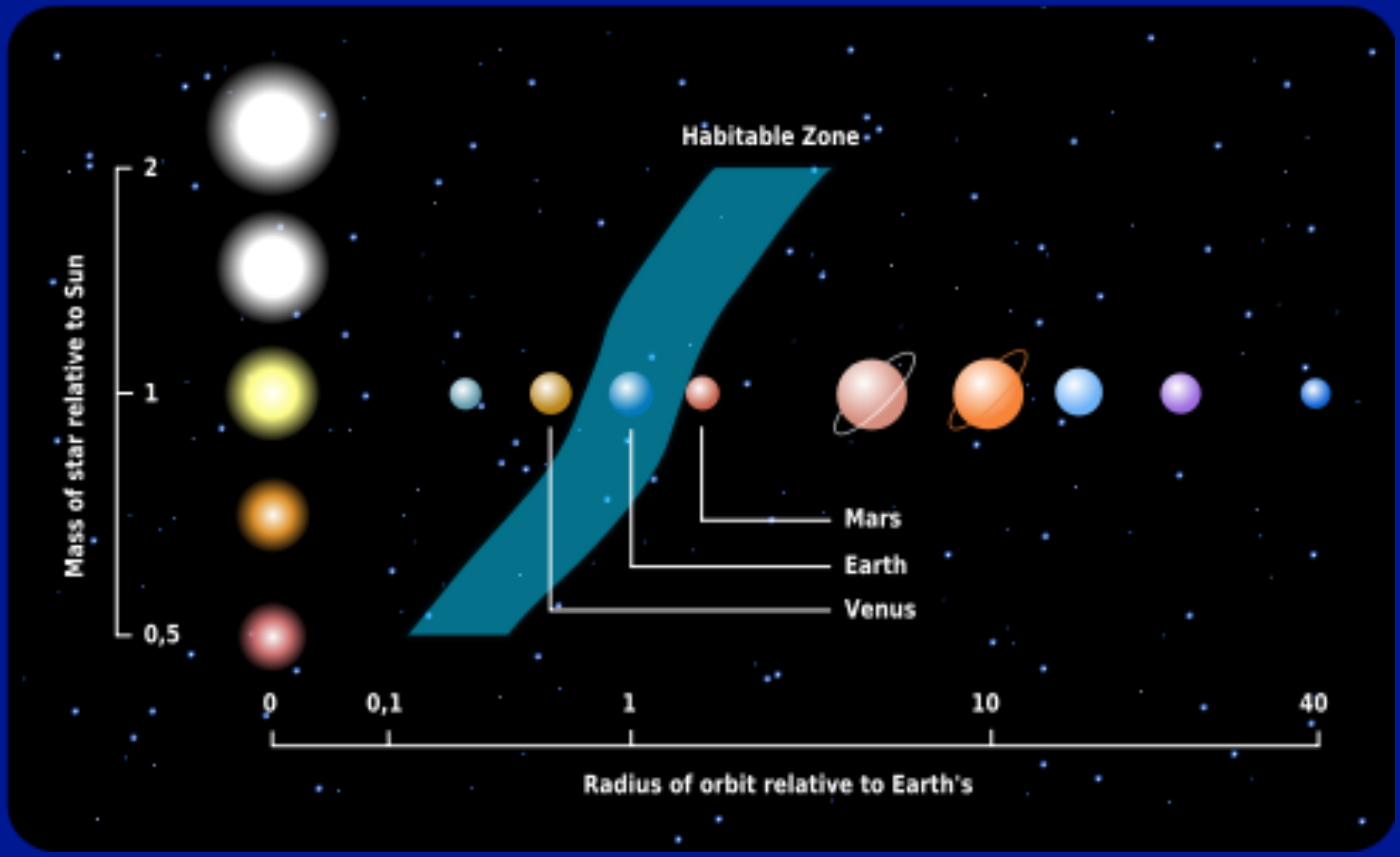
3) Temperature rises.

4) More evaporation (back to #1).

=> complete evaporation of oceans. Thick atmosphere.

The Habitable Zone or "The Goldilocks Problem"

In the zone …



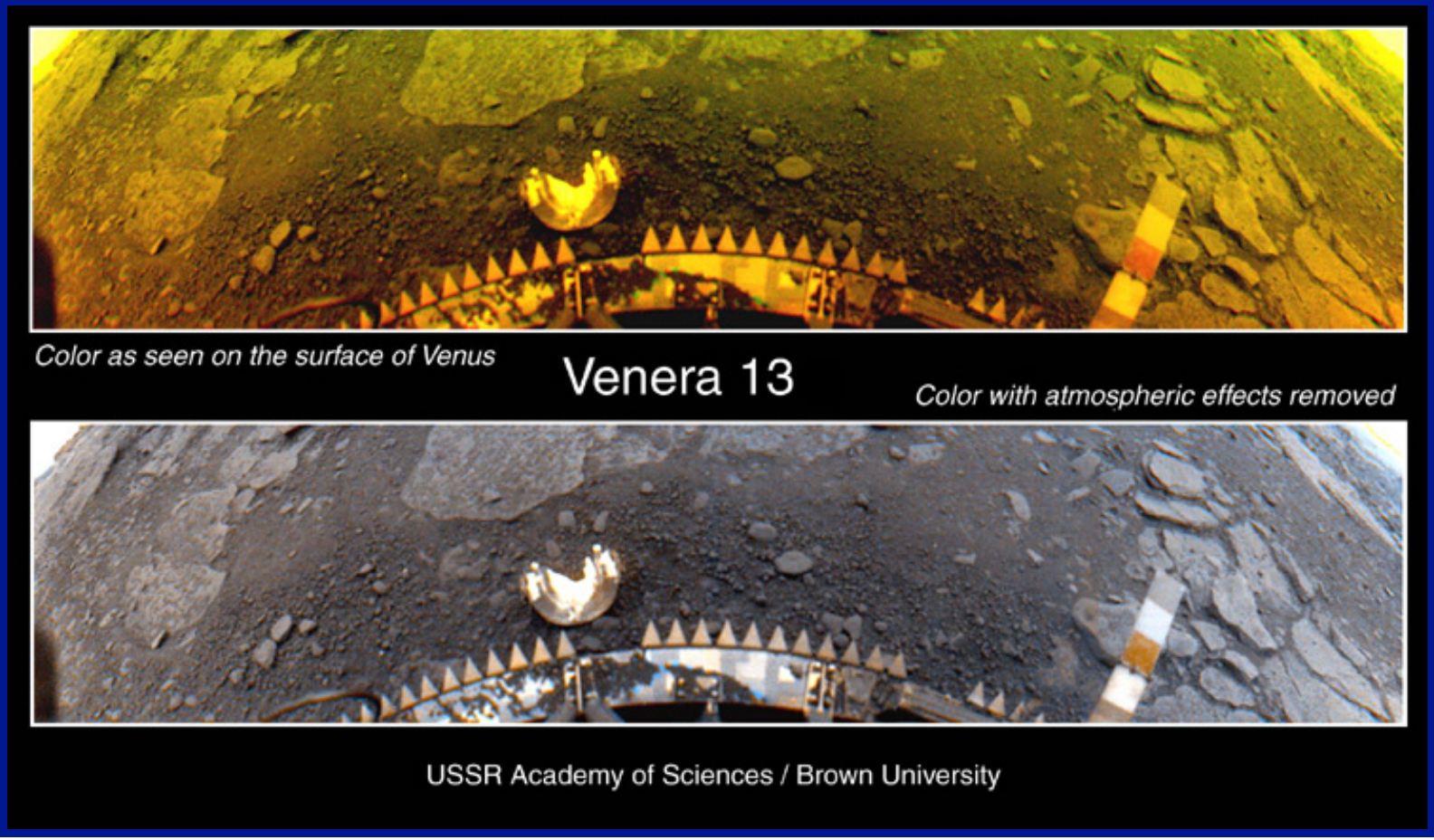
Missions to Venus

Soviet Venera 4 -18 (1967 - 1983)

Mariner 2, 5 and 10 (1962, 1967 and 1974)

Pioneer Venus (1978)

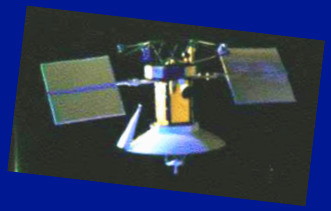
Magellan (1989)



Venera 13 photo of surface. Rocks are basalt and granite. Color is due to atmosphere.

Color corrected for atmosphere.

"Radar Echo" technique measures altitude

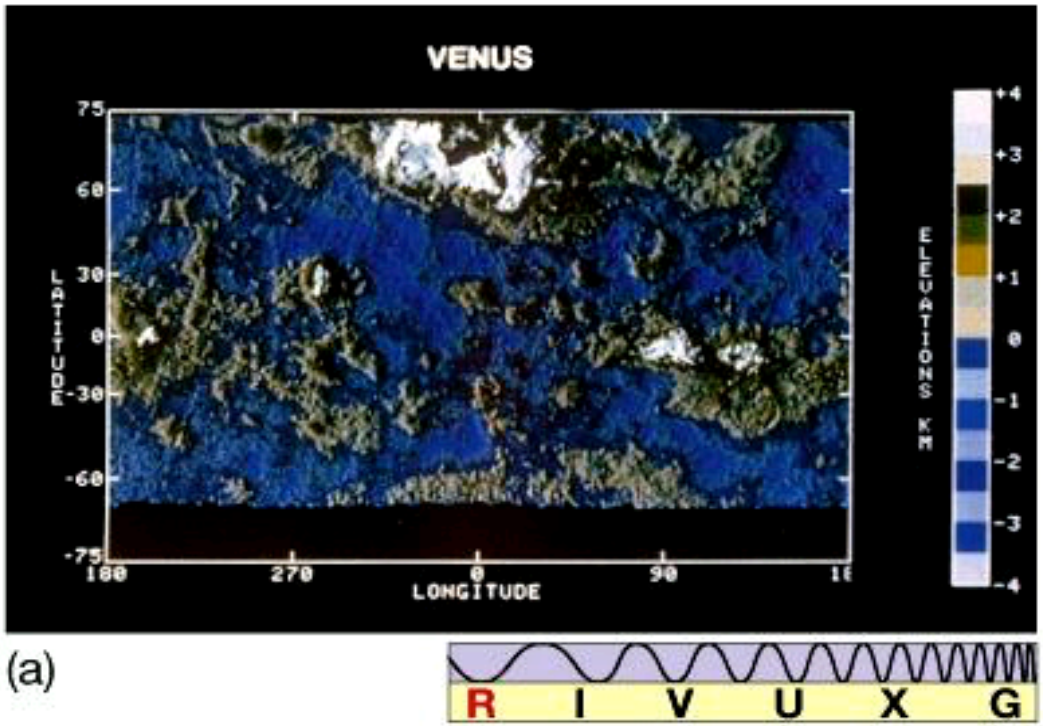


space probe

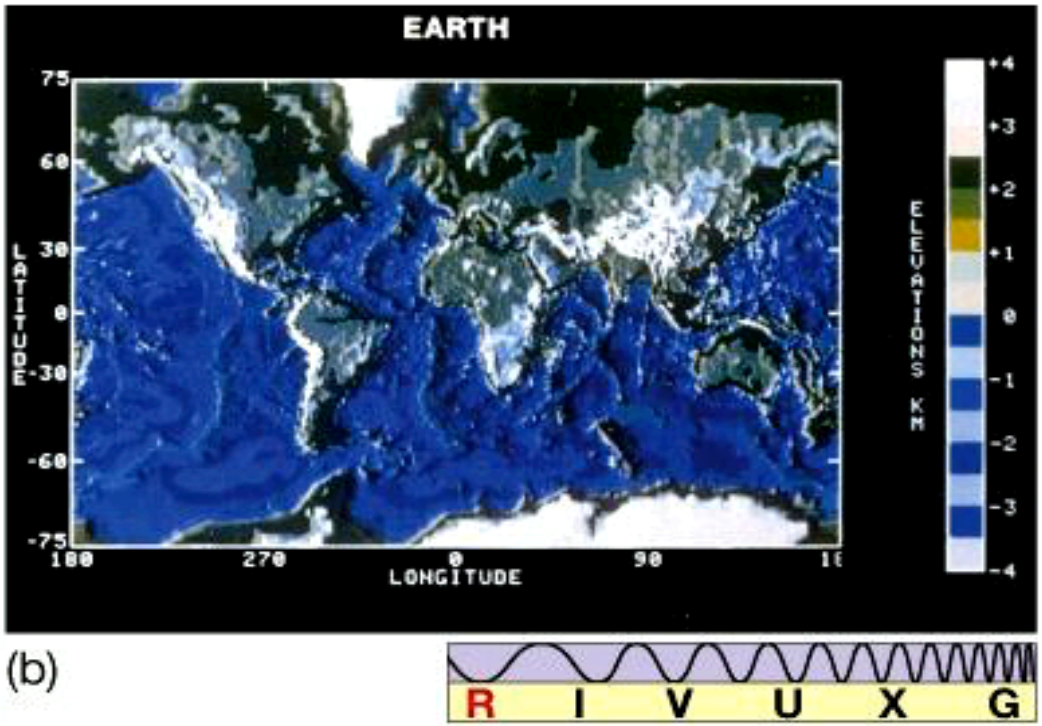
time for signal to return tells you the altitude of surface feature.

Planet Surface

Radar data (Pioneer Venus mission) reveal altitude variations on surface. Flatter than Earth, no evidence for plate boundaries => no large scale plate tectonics.

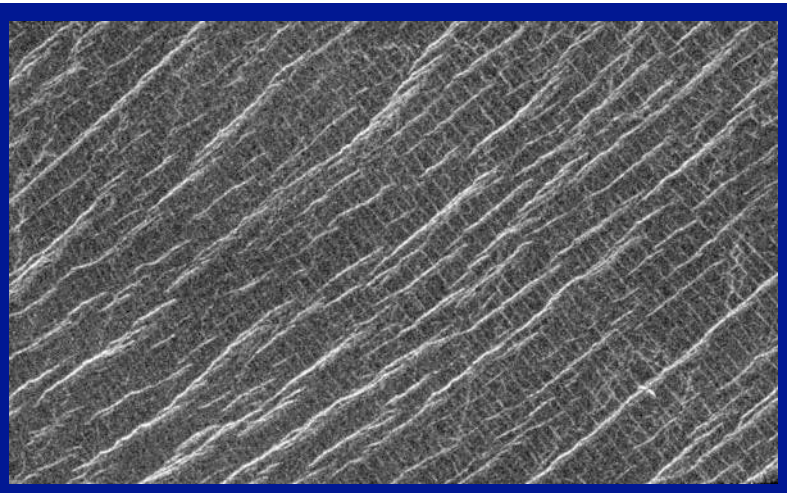


(a)



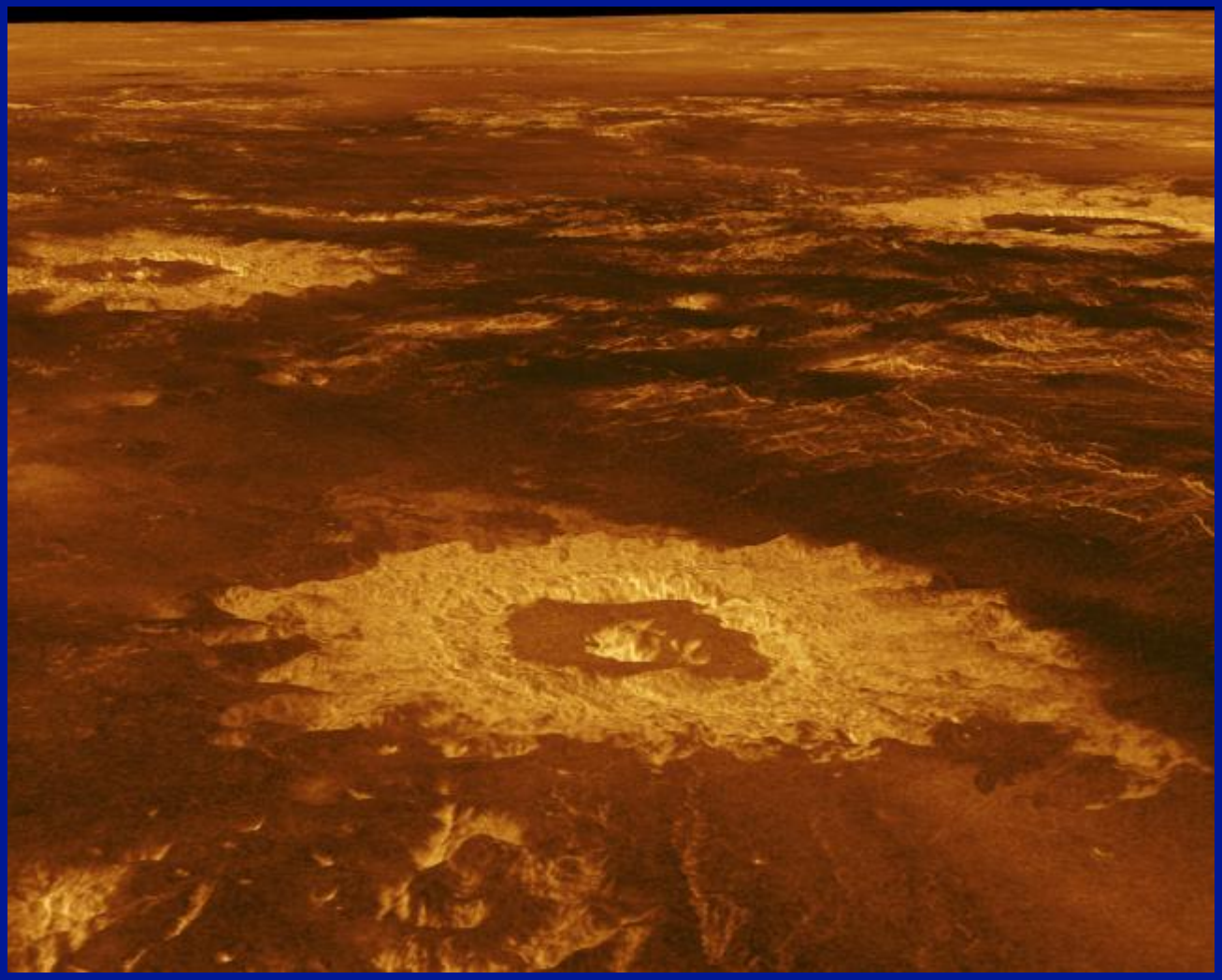
(b)

1 km



But plenty of evidence of stresses and fractures on smaller scales => much small-scale shifting of crust

Impact Craters



Unlike Moon, larger impact craters distributed randomly over surface => all parts of surface have about same age.

Paucity of large impact craters => surface is young, 200-500 million years?

Clicker Question:

The moon was most likely formed:

A: by fission as a large chunk of the Earth was thrown off.

B: by the same stuff that formed the Earth, “coformation”

C: by an impact of a proto-planet with the proto-Earth.

D: out of the proto-planetary nebula and later captured by the Earth.

Clicker Question:

We think Mercury could have ice at the poles because:

A: Mercury is so far from the Sun.

B: Optical images show white polar caps.

C: Radar images show high reflectivity at the poles.

D: Mercury is in a 3:2 spin:resonance orbit around the Sun.

Clicker Question:

Why is Venus the hottest planet in the Solar System?

A: It is the closest planet to the Sun.

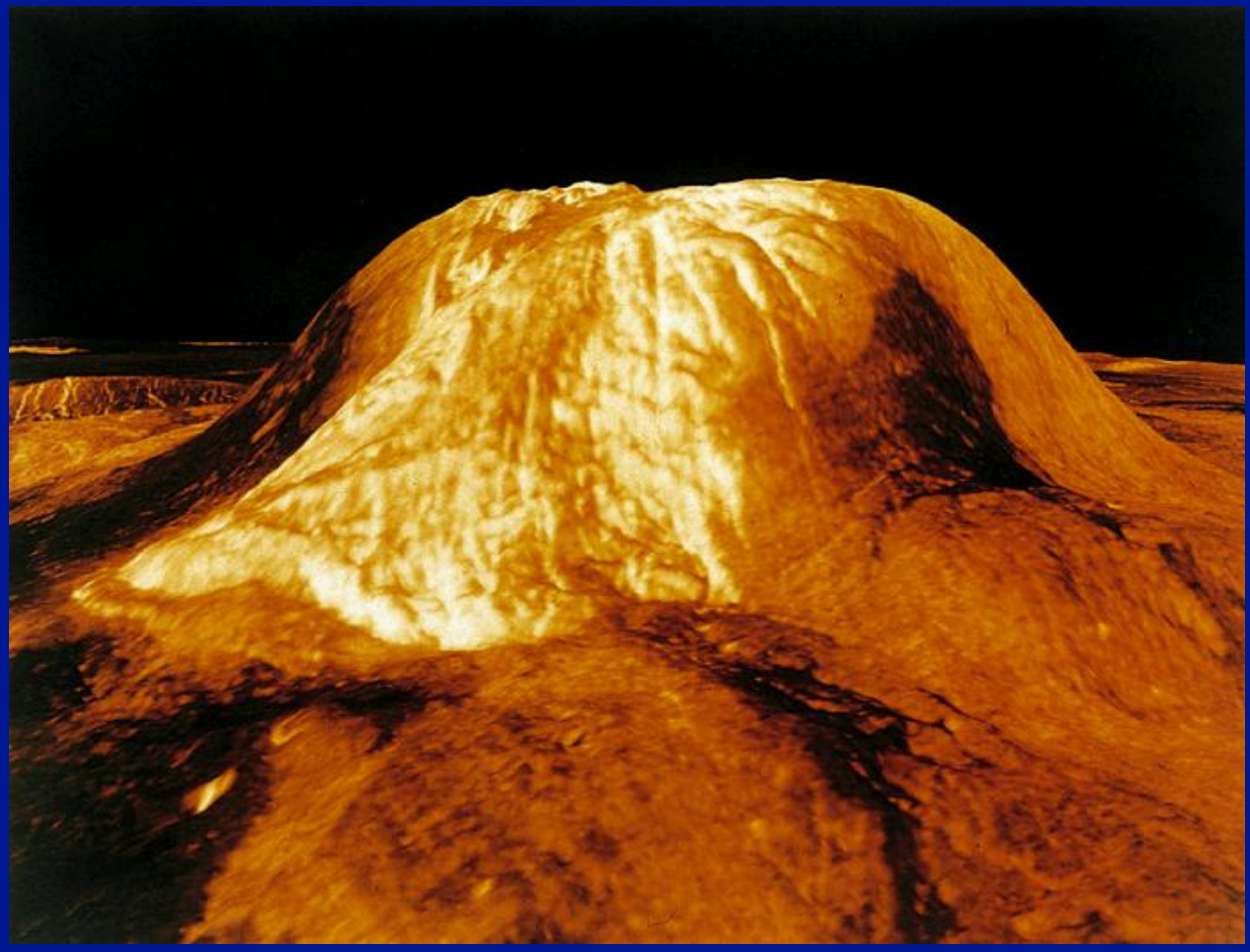
B: There is a lot of radioactive material in the crust.

C: There is a large concentration of carbon dioxide in the atmosphere.

D: The Russians left the lights on in the Venera 5 landing vehicle.

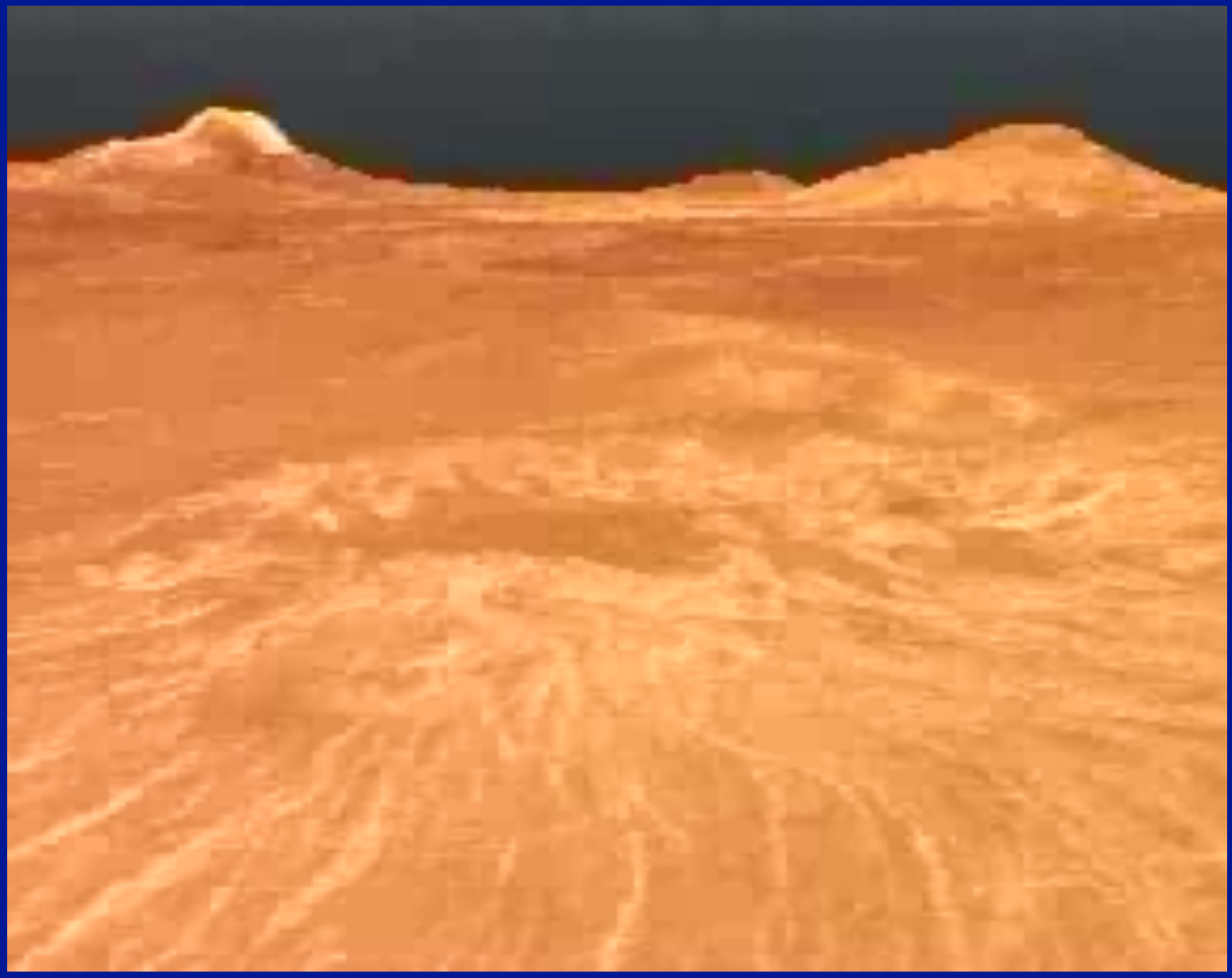
E. Taylor Swift lives there.

Volcanism



Shield volcano elevation map from Magellan radar data. About 100 km across.
Volcanism may be ongoing, based on sulfur dioxide variations in atmosphere.
But very little resurfacing in past 200-500 million years.

Volcanism



Venus surface flight simulation using data from Magellan.