

# THE MOON



Picture by T.A. Rector, &  
I.P. Dell'Antonio, NOAO

- About  $\frac{1}{4}$  the diameter of the Earth
  - 3475 km
- Only 1.2% the mass of the Earth
  - So avg. density is only  $3.34 \text{ g/cm}^3$
- Dark surface (asphalt-like)
- No atmosphere

# SURFACE OF MOON



- Craters galore!
  - No air to burn up incoming meteors
  - Very little erosion
    - Craters last a long time
- The older the terrain, the more craters it collects
- Note ejecta rays, central peaks

Picture by Steve Mandel,  
Hidden Valley Observatory

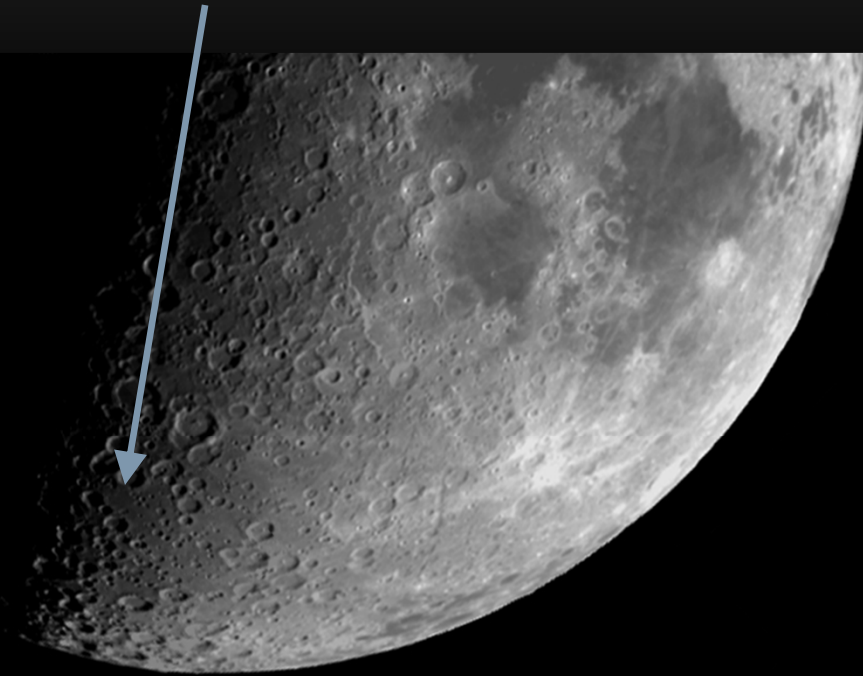
# CRATERS



- Caused by meteor impacts
  - From tiny to huge
  - Used to be many planetismals: but fewer are left floating around now
- Features:
  - Rim (circular)
  - Central peak
  - Low floor
  - Ejecta rays

The crater Copernicus,  
one of the Moon's larger craters

# HIGHLANDS

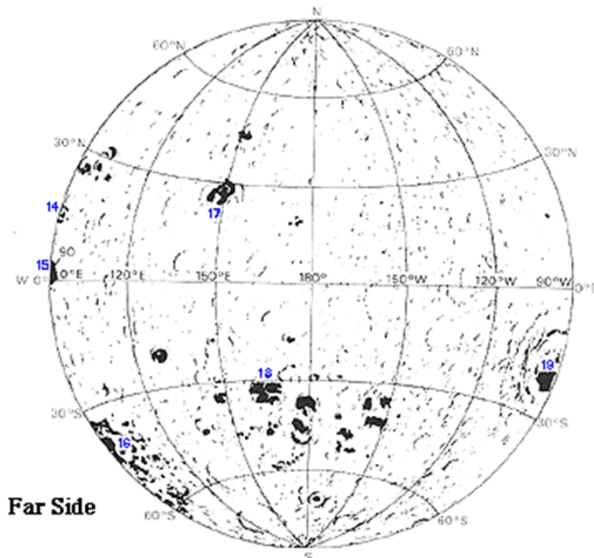
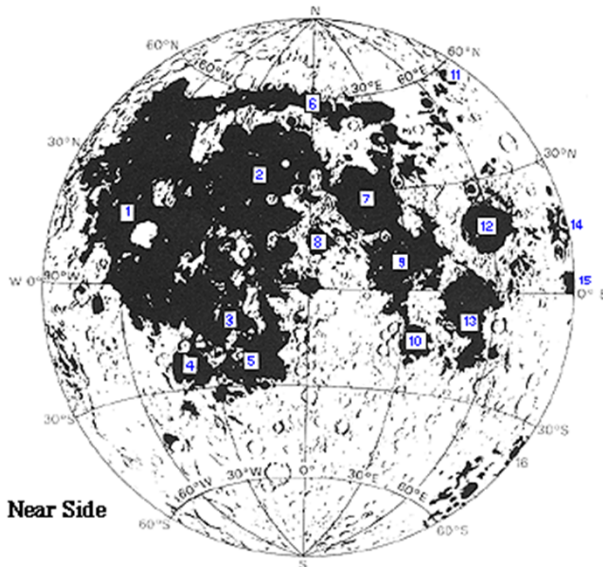


- Mountains formed
  - Not by tectonics or volcanoes
  - But by repeated cratering
- Old – 4.0-4.4 billion years
  - Bombarded by <10km chunks of leftover solar system crumbs
- Low density rock

Picture by  
Thomas L. Haynes,  
Rockford, MI

# MARIA

- Younger – 3.1-3.8 billion years
  - Formed by fewer, larger (>100 km) objects
- A Mare is formed by a big impact punching a hole in crust
  - still-liquid (at that point) mantle material oozed out
  - flooded large areas with lava
- Mostly on Near side
  - Gravitational focusing of meteors by Earth
  - Heavy maria also tidal lock towards Earth (*the Weeble effect*)



# REGOLITH



- The fine dust covering the lunar surface
- Pulverized moon rocks from impacts
- Lack of erosion will keep these prints around a long long time

MERCURY ♀

The innermost planet

# THE FASTEST PLANET

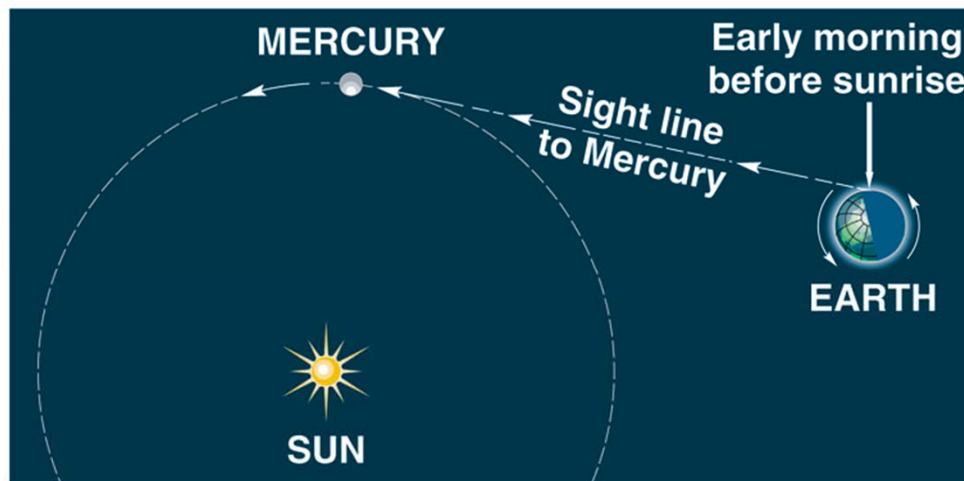


- Closest planet to Sun
  - Thus the fastest
  - 0.4AU "a" means  $\frac{1}{4}$  year "p" from Kepler's Laws
  - Named after the Greek/Roman god with the winged feet
- Small, hot
  - No atmosphere
  - so – many craters, like Moon

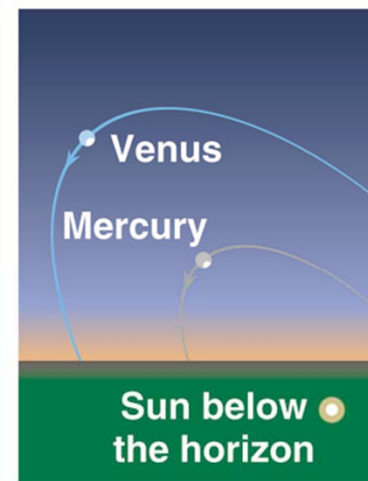


# THE VIEW FROM EARTH

- “Inferior” planet
  - Always close to Sun
  - so close it can be hard to see
  - Good telescopic observations hard due to steep angle through atmosphere

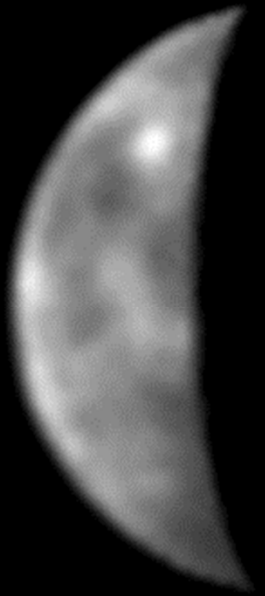


(a)



(b)

# WHAT WE SEE



- Not very much from Earth
- Two probes have visited
  - Mariner 10
    - 3 orbits in 1975
  - Messenger
    - 4104 orbits finished in 2015

Photo by  
Baumgardner et al (Boston U.)  
using Mt. Wilson

# SURFACE TEMPERATURES

- Long day, close to Sun –
  - 450 °C (lead melts at 330 °C)
- Long night, no atmosphere to insulate
  - -150 °C
- Almost no tilt of rotation axis to orbital plane
  - No seasons
  - Poles always see very oblique sunlight, also very cold
  - Radar reflections indicate polar ice caps?

# MOONLIKE

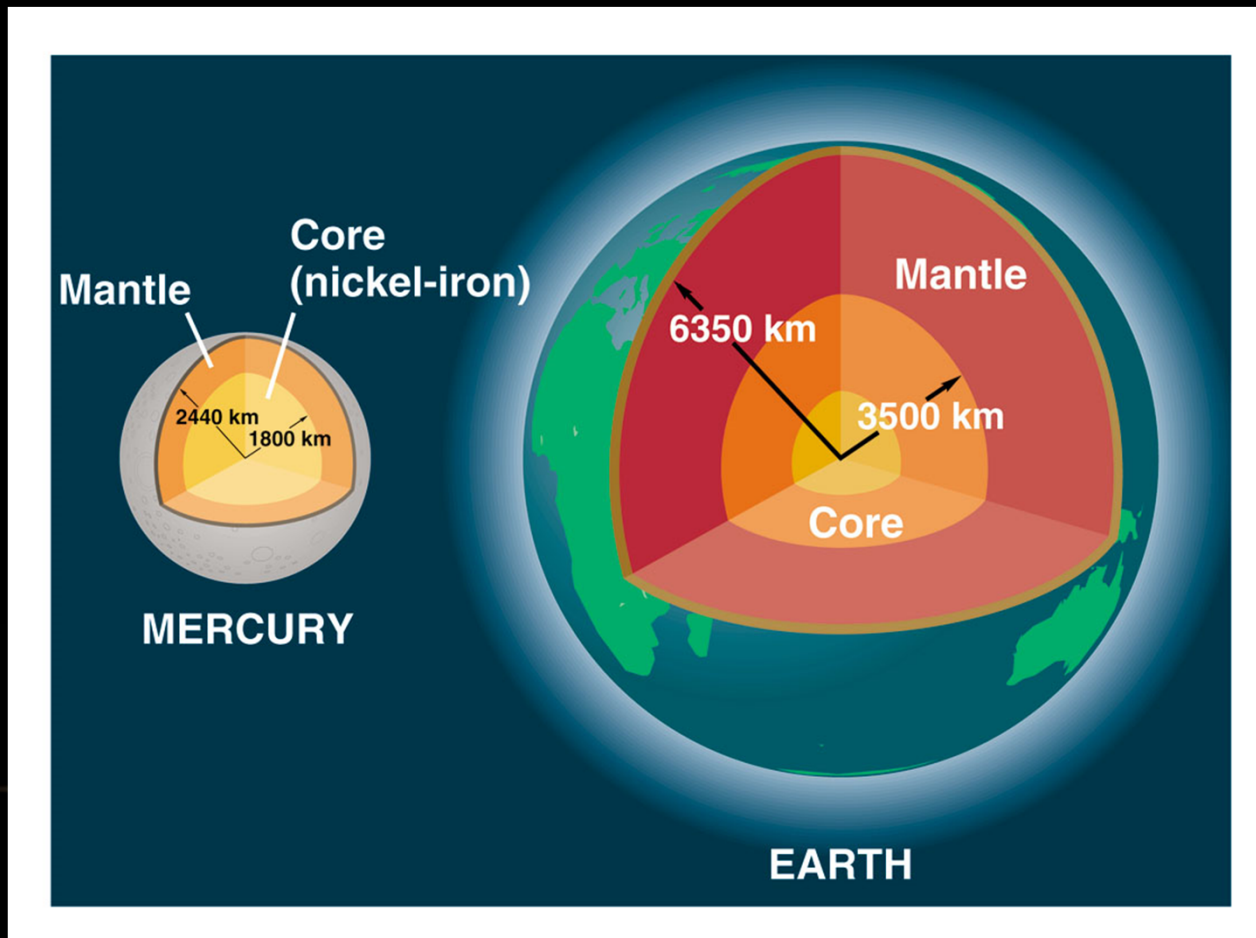
- Mercury is ~half again as big as Earth's moon (in diameter)
  - Similar to the large moons of Jupiter & Saturn (even smaller than Ganymede and Titan!)
- But as dense as Earth
  - 5.4 g/cm<sup>3</sup>
- No atmosphere
  - Small, hot in the day, and cold at night

# FROM GEOMETRY ALONE

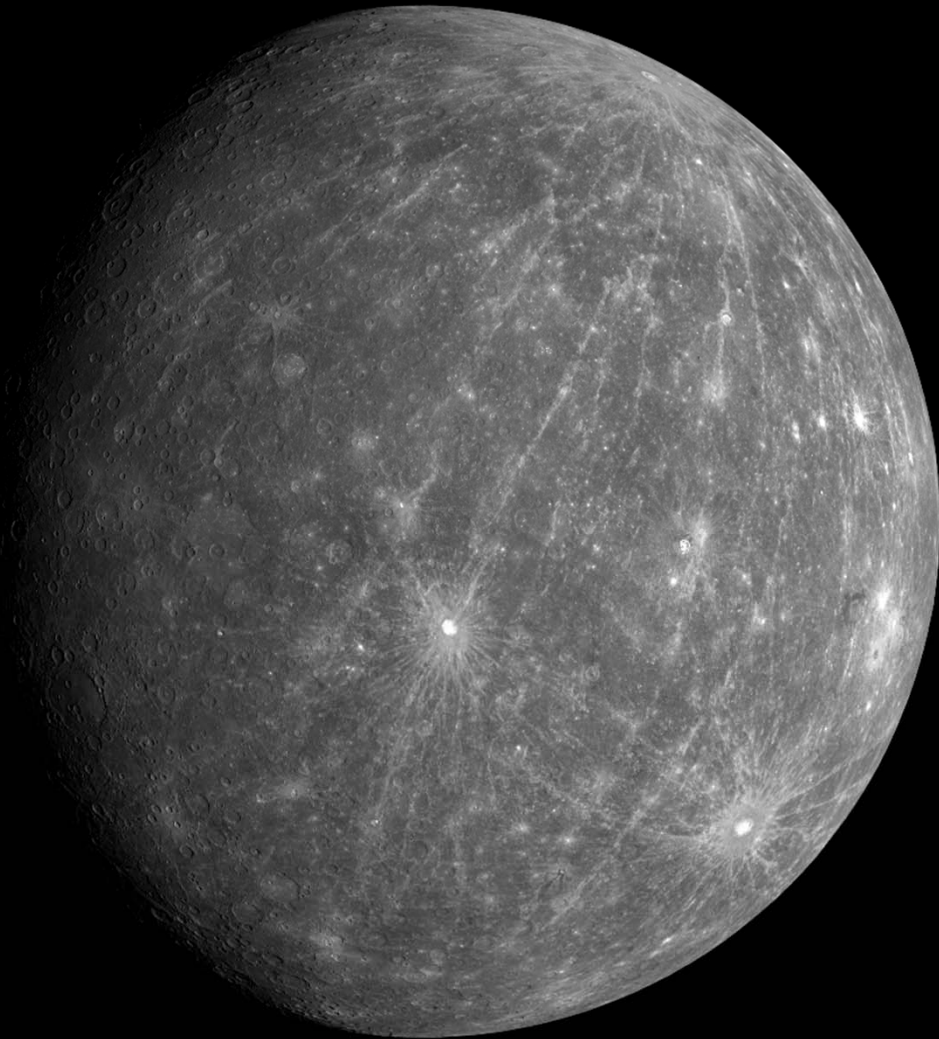
- Likely has large iron core
  - High average density
- Stronger gravity at surface than Moon
- Took longer to cool than Moon
  - Cooling time  $V/A \sim [(4/3)\pi R^3]/[4\pi R^2] \sim R$
- Iron core + long cooling means:
  - Maybe some magnetic field from still-molten iron core
    - Small field observed, but not well understood

# INTERNAL STRUCTURE

- Compared to Earth



# SURFACE FEATURES



- Three things apparently went on:
  - Cratering
  - Volcanism
  - Tectonic activity
- Names:
  - Craters after artists
  - Plains after mythological figures



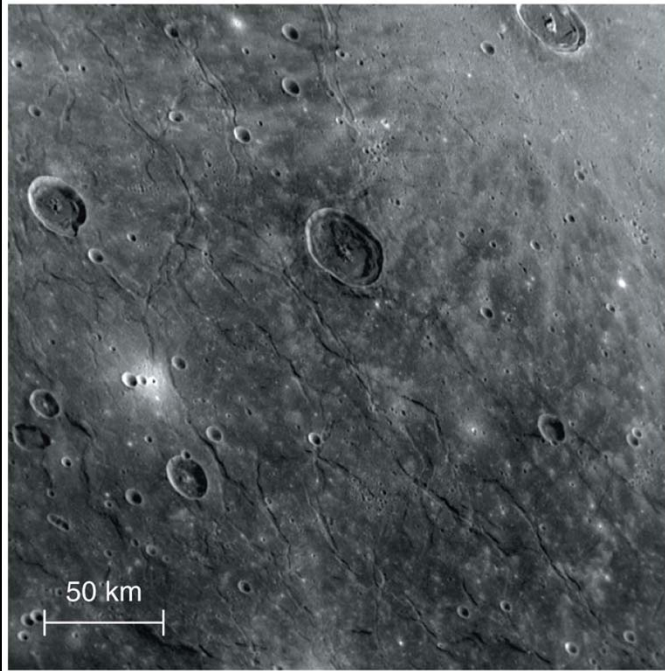
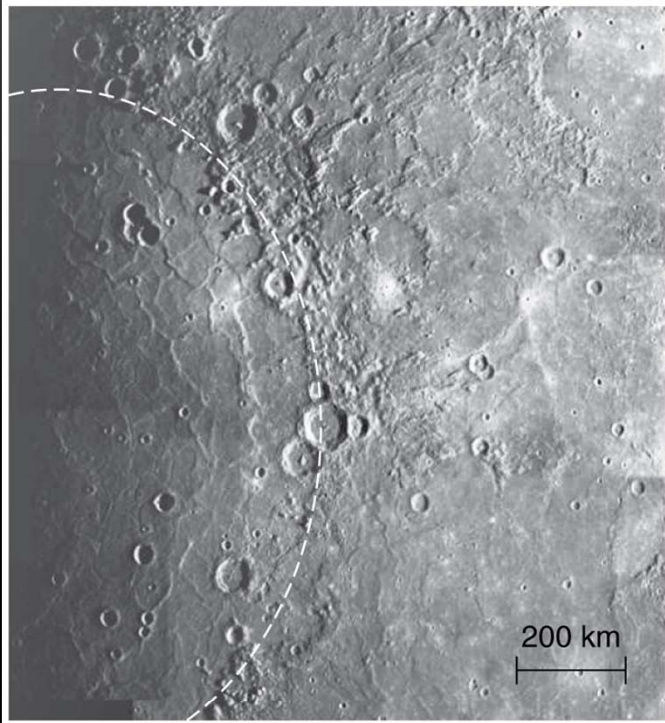
# CRATERING

- Highly cratered like Moon for same reasons:
  - No air to shield surface
  - No erosion to erase craters
- Higher gravity than Moon makes craters
  - Shallower
  - Ejecta sprays less far
- Note odd double craters

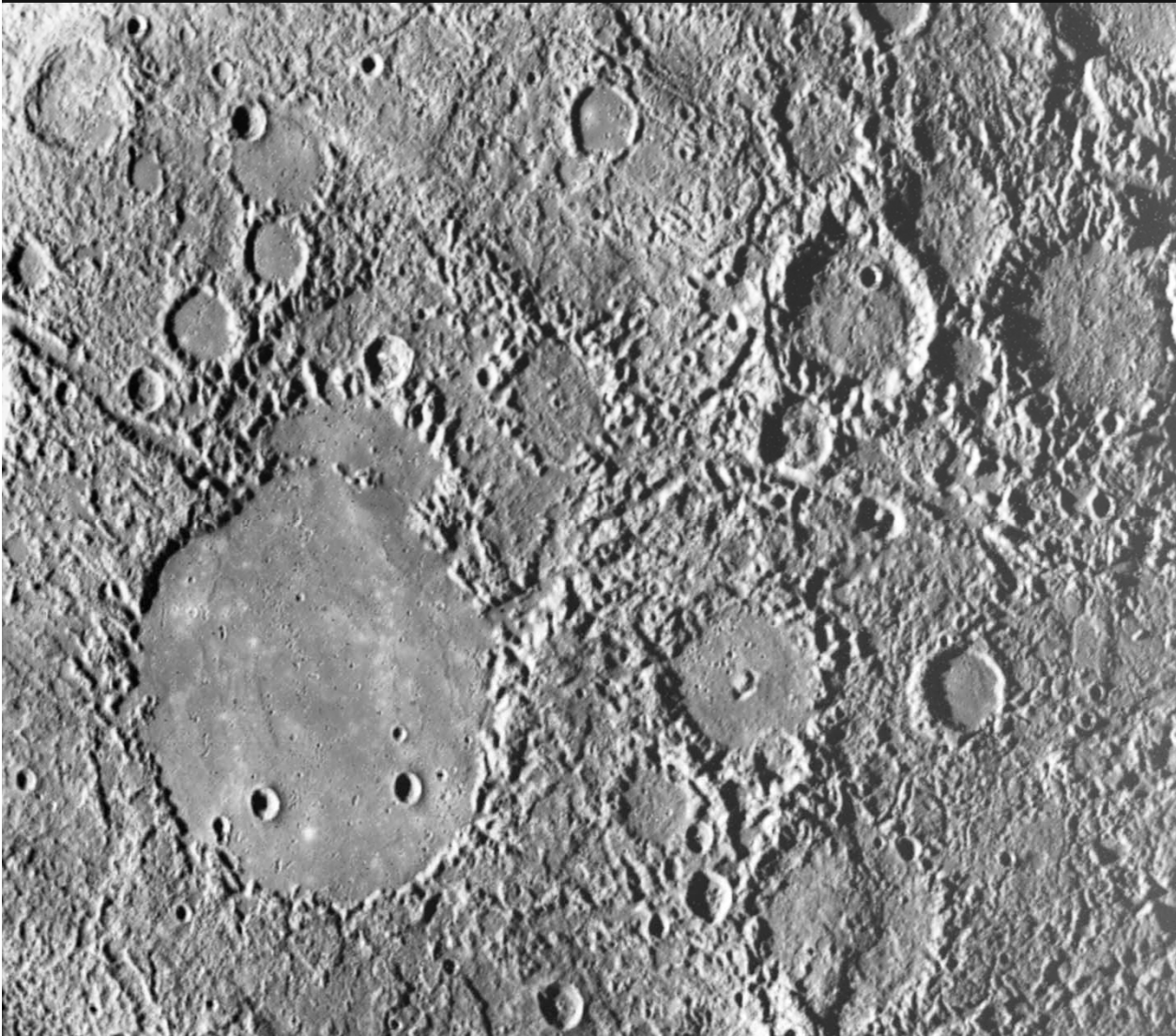


# CALORIS BASIN

- A Really Big Impact
- Filled back in by lava like maria on moon
- So big that...
  - shock waves hit other side of planet and mess up the surface there;
  - made Mercury lopsided!

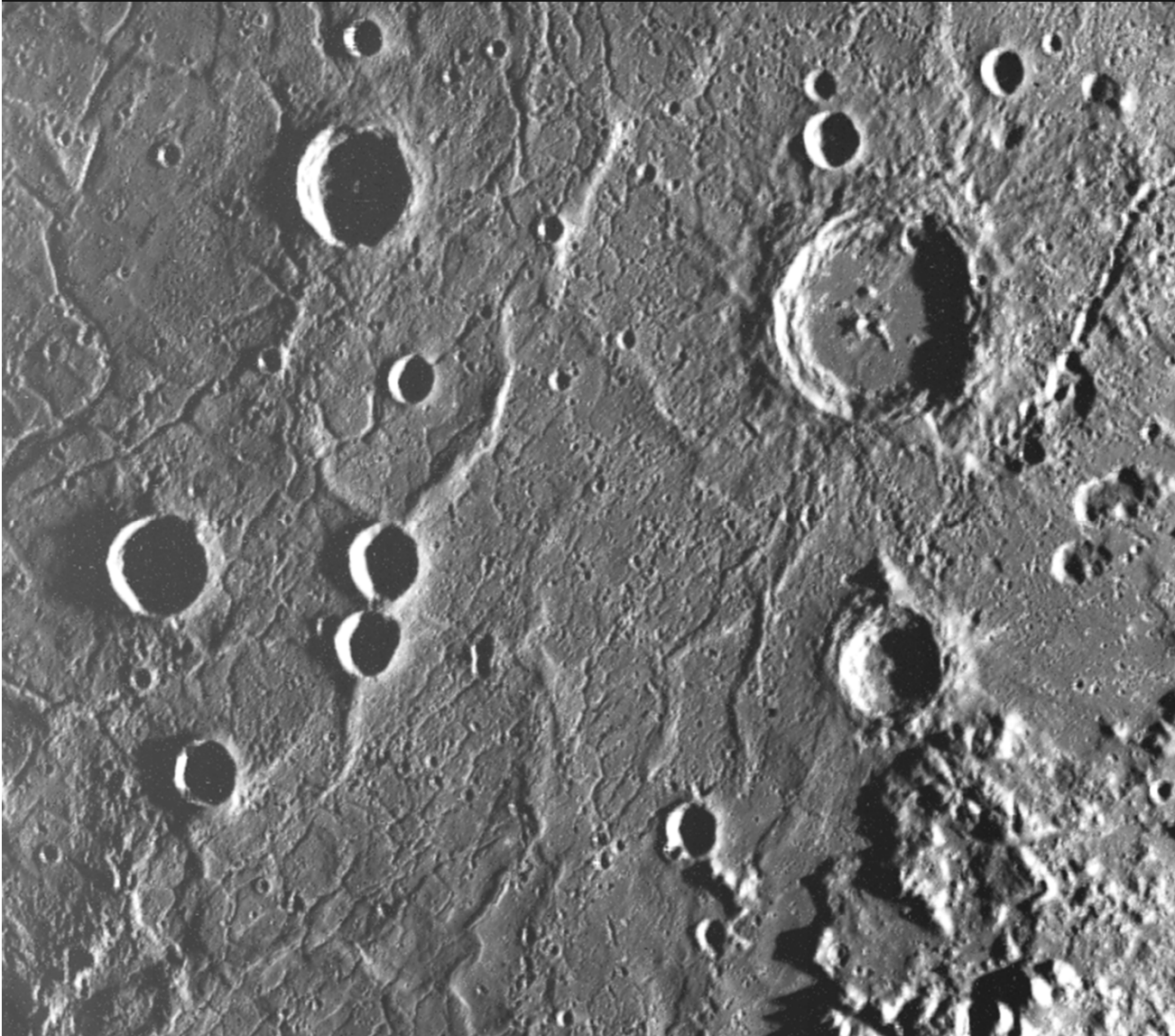


# VOLCANISM



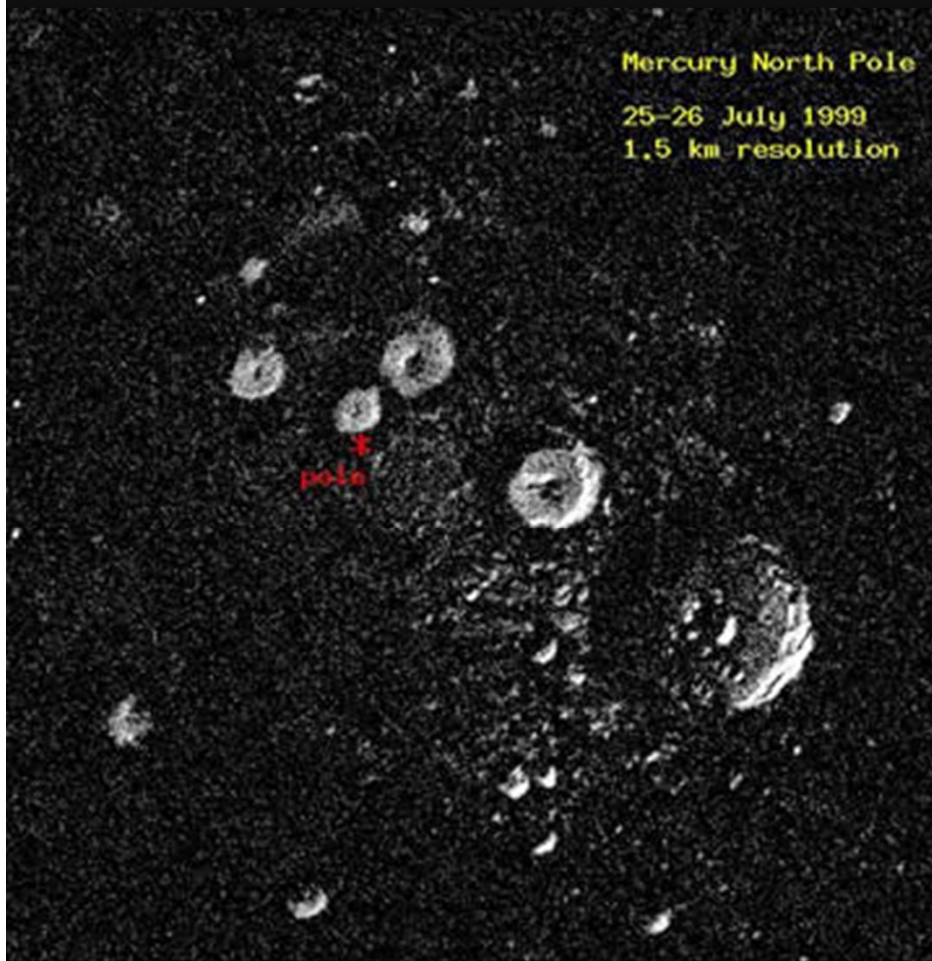
- Like maria on moon
  - Impacts punch holes in crust
  - Lava floods out and paves an area
- Mercury took longer to cool than the Moon
  - So more of the surface is paved
  - Has a much more "regular" surface
- "Rilles" seen
  - Squirmy lines probably lava tubes

# TECTONICS



- “Scarps” (long cliffs) are seen
- As planet cools, it shrinks
- Hard crust cracks and long cliffs form
- Wrinkled!
- Currently – no recent volcanism or tectonic action
  - All cooled off

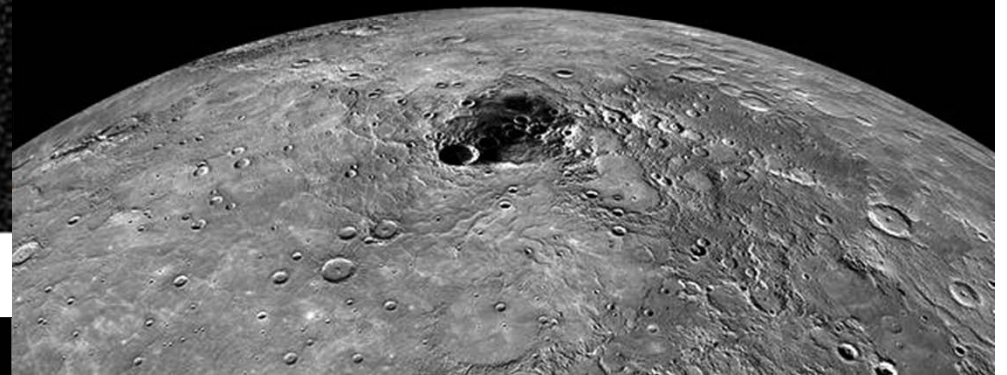
# WATER ICE???



Mercury North Pole  
25-26 July 1999  
1.5 km resolution

Arecibo Observatory S-band radar image of the north polar region of Mercury by J. Harmon, P. Perrilat, and M. Slade. The resolution is 1.5 kilometers (about 1 mile) and the image measures 450 kilometers on a side. The bright features are thought to be ice deposits on permanently shadowed crater floors.

- Brighter parts of this radar image might be ice
- In the shadows at the bottoms of craters at the north pole



MARS



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The Red Planet

# MARS



**Mars · February 1995**

**HST · WFPC2**

PR95-17 · ST Sci OPO · March 21, 1995 · P. James (U.Toledo), NASA

- 4<sup>th</sup> planet from the Sun
  - Next out from Earth
  - $a=1.52\text{AU}$ ,  $p=1.88\text{yrs}$
  - Orbit more eccentric than Earth's
- Reddish colored
  - From iron oxide
  - Associated with blood & fire, thus Mars the Roman War god

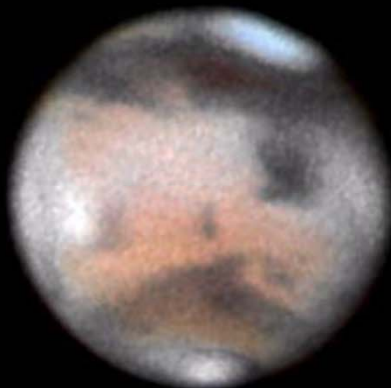
# VIEW FROM EARTH

- Mars is farther out than Earth
- Best view at Opposition
  - When it's on the opposite side of Earth from the Sun
- Only thing (other than the Moon) of which Earth-based telescopes can see the surface
  - Images by Don Parker, with 16" Newtonian scope

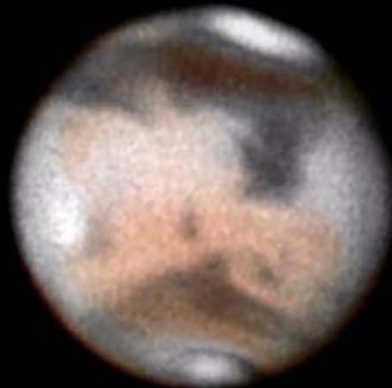
P  
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31 Mar 1997 Ls=264

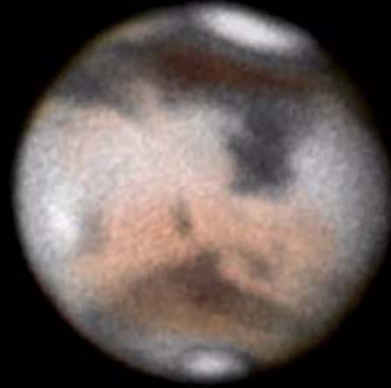
D. Parker



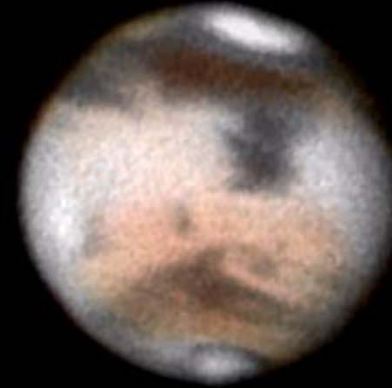
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03:57 UT CM=271

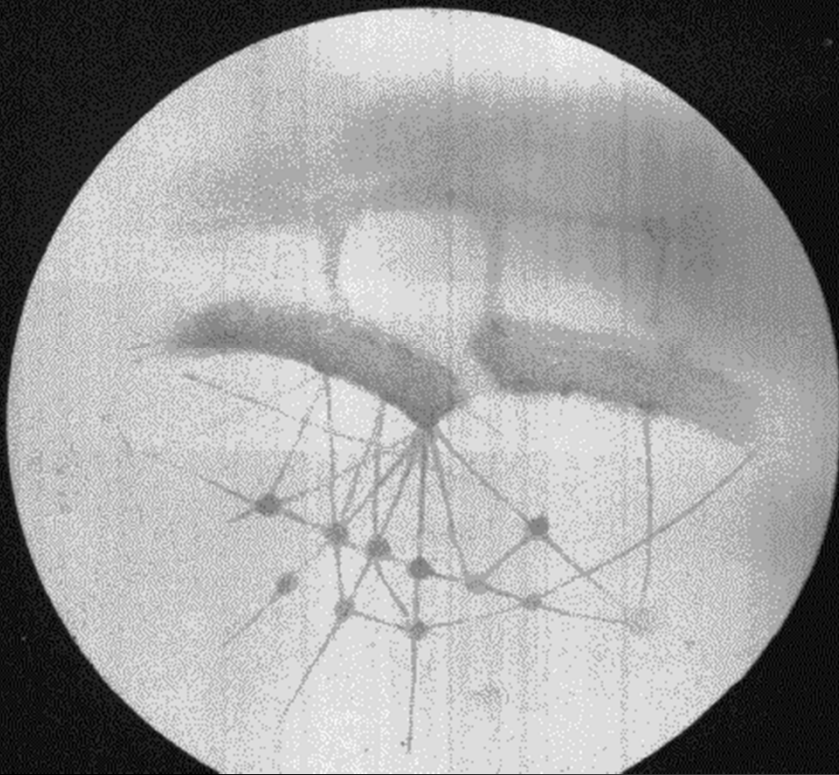


04:10 UT CM=274



04:22 UT CM=277

# CANALS OF MARS

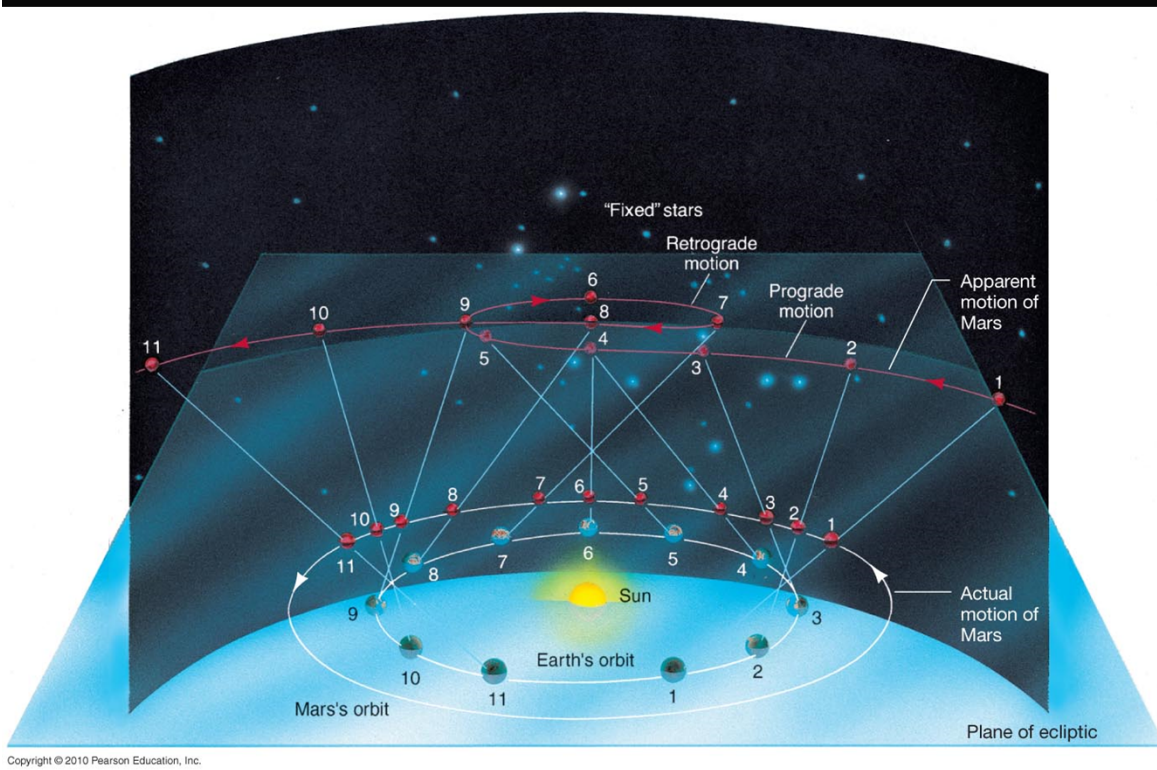


Mars drawing by Percival Lowell  
(1890's)

- Italian astronomers Secchi and Schiaparelli saw lines they called *canali*
  - Means "channels"
- People liked the idea of life on Mars building canals
- Observations get elaborate
  - But not everyone sees them
- Turns out to be optical illusions
  - Your eyes see points, then supply the lines themselves
  - Green is complementary color to red



# MARS' MOTIONS

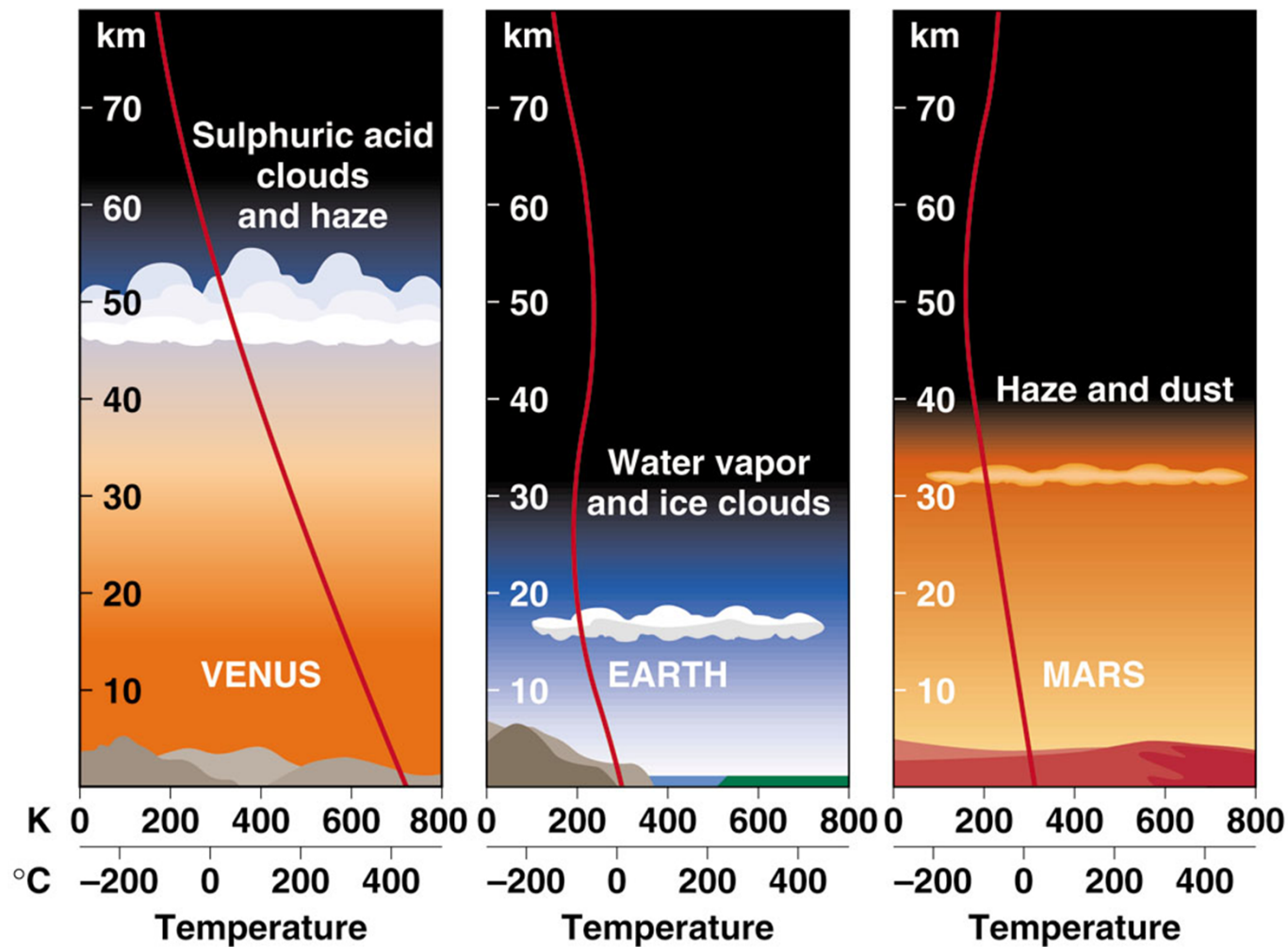


- At 1.5 AU it has a 1.88 year orbit
  - So Earth catches up to and passes Mars
  - Remember retrograde motion?
- Has 24.6 hour day
- Axis tilts at  $25.2^\circ$  – similar seasons to Earth
  - Although eccentricity of orbit magnifies them

# SIZE, DENSITY?

- Diameter is  $\frac{1}{2}$  Earth's
- Mass is 0.1 Earths
  - Surface gravity 38% of Earth's
- So density is  $3.93 \text{ gm/cm}^3$ 
  - Light - lack of a heavy iron core
  - Perhaps iron spread throughout planet
    - Certainly red surface color is from rust
  - No magnetic field seen, supports lack of iron core

# ATMOSPHERE



- Similar gases as Venus
  - Mostly CO<sub>2</sub>, some N<sub>2</sub>
- But very thin
  - 0.7% Earth's pressure

# TEMPERATURE, SEASONS

- Air temperature ranges
  - 30°C (noon)
  - -135°C (night!)
  - Thin atmosphere is poor blanket, even though it is CO<sub>2</sub>
- Polar ice caps made of water and CO<sub>2</sub> ice
  - CO<sub>2</sub> melts during summer
  - Winds caused by this make planetwide dust storms
  - Seasons more strongly affected by elliptical orbit than Earth's

# WHY DIFFERENT FROM EARTH?

- Similar to Earth to start
  - $\text{H}_2\text{O}$  condenses, washes  $\text{CO}_2$  into rocks
    - Will talk about evidence of water later
- But smaller planet cools off faster, no plate tectonics to recycle  $\text{CO}_2$  back into air
  - Thin air
  - Lack of ozone layer lets solar UV break up remaining  $\text{H}_2\text{O}$

# SUNSET ON MARS



Picture from Pathfinder lander

# MARS' MOONS

- Deimos
  - 9x8x6 miles
  - 1.3 day orbit
- Phobos
  - 17x14x11 miles
  - 0.3 day orbit



So close  
it will crash  
in 100  
mill yrs

# MARTIANS' VIEW OF THEIR MOONS

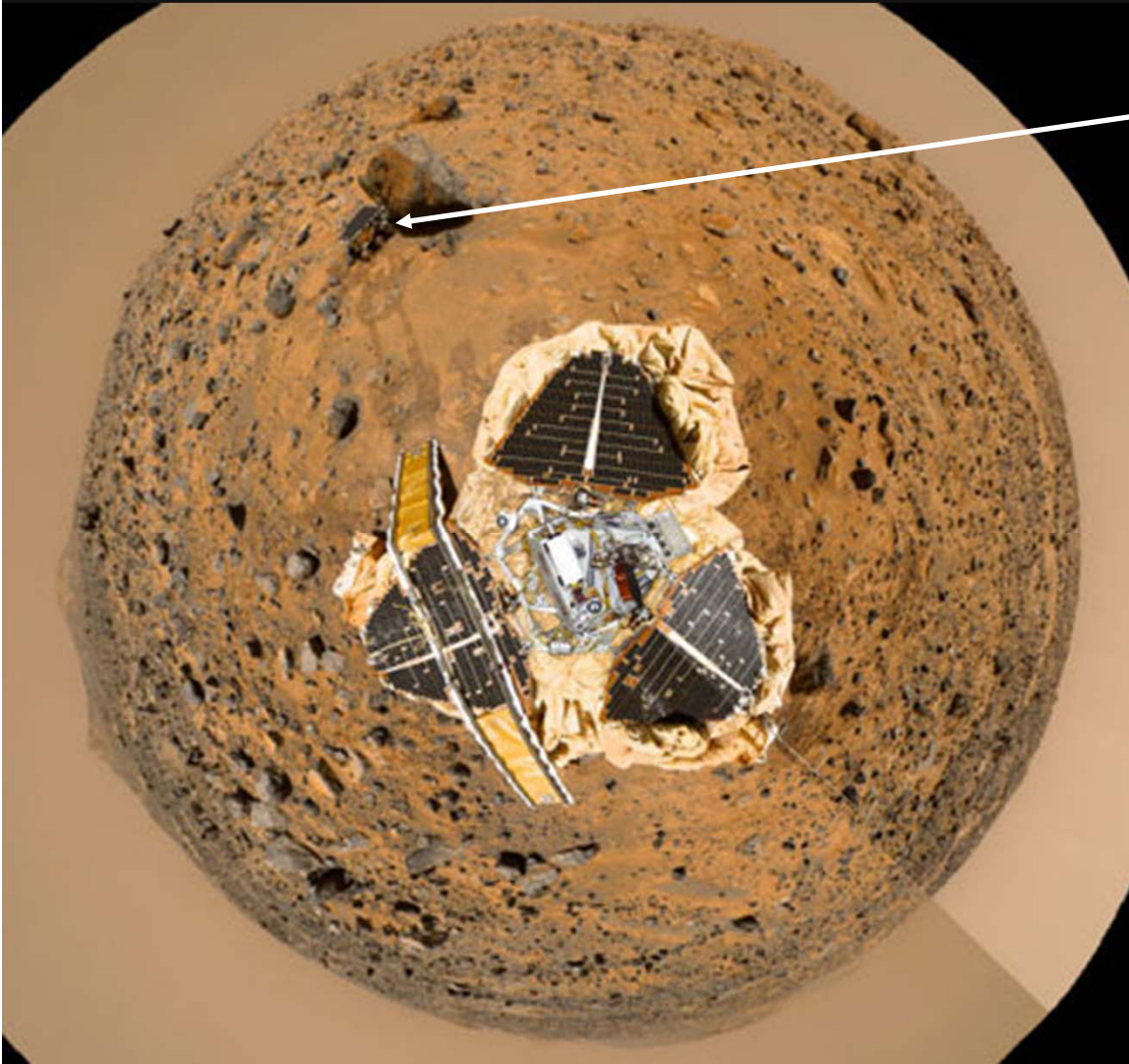
- Both moons orbit in the same ("prograde") motion as do most things in the solar system
- Mars has a sidereal day of 24.5 hours
- Phobos has an 7.7 hour orbit
  - Moves so quickly that it will rise in the east and set in the west!
- Deimos has a 30.3 hour orbit
  - Rises in east and sets in west, but this orbit is not that much longer than Mars' day – so it appears to move very slowly across the sky, swimming against the rising/setting stars



# MORE ON THE MOONS

- They are very non-spherical
  - So small, their gravity is so weak that it doesn't have the strength to squish them into spheres
- They have densities  $\sim 2 \text{ g/cm}^3$ 
  - Very different than Mars
  - Odds are these are asteroids, slowed down by an early, thicker atmosphere and captured into orbit
  - This also explains their close orbits

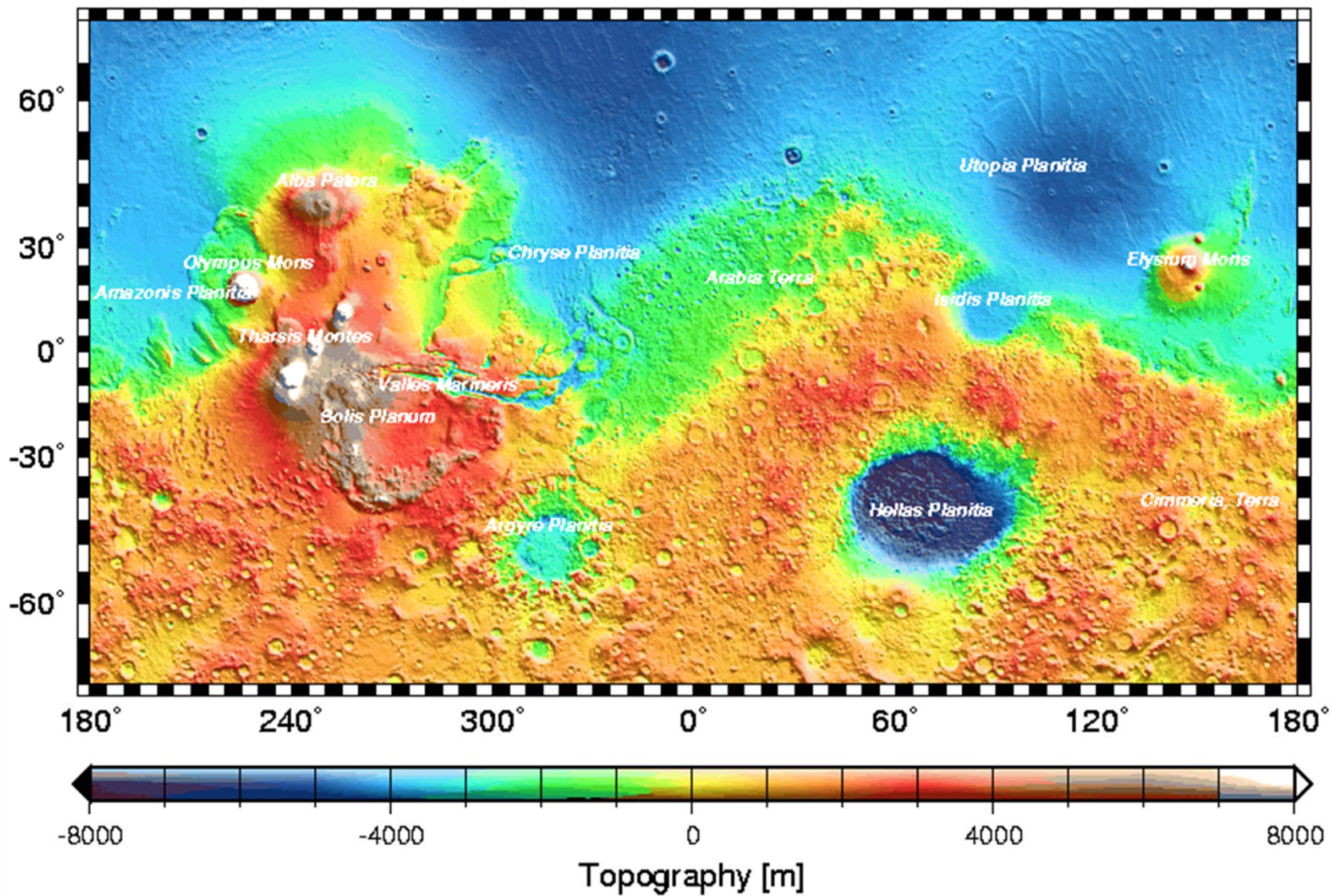
# PROBES



- Many probes notably –
  - 2 Viking orbiter/lander
  - Mars Global Surveyor orbiter
  - Pathfinder lander/Sojourner rover
  - Several probes failed to get there
  - Spirit, Opportunity, Curiosity more recently
- No humans yet, but Mars is otherwise well studied

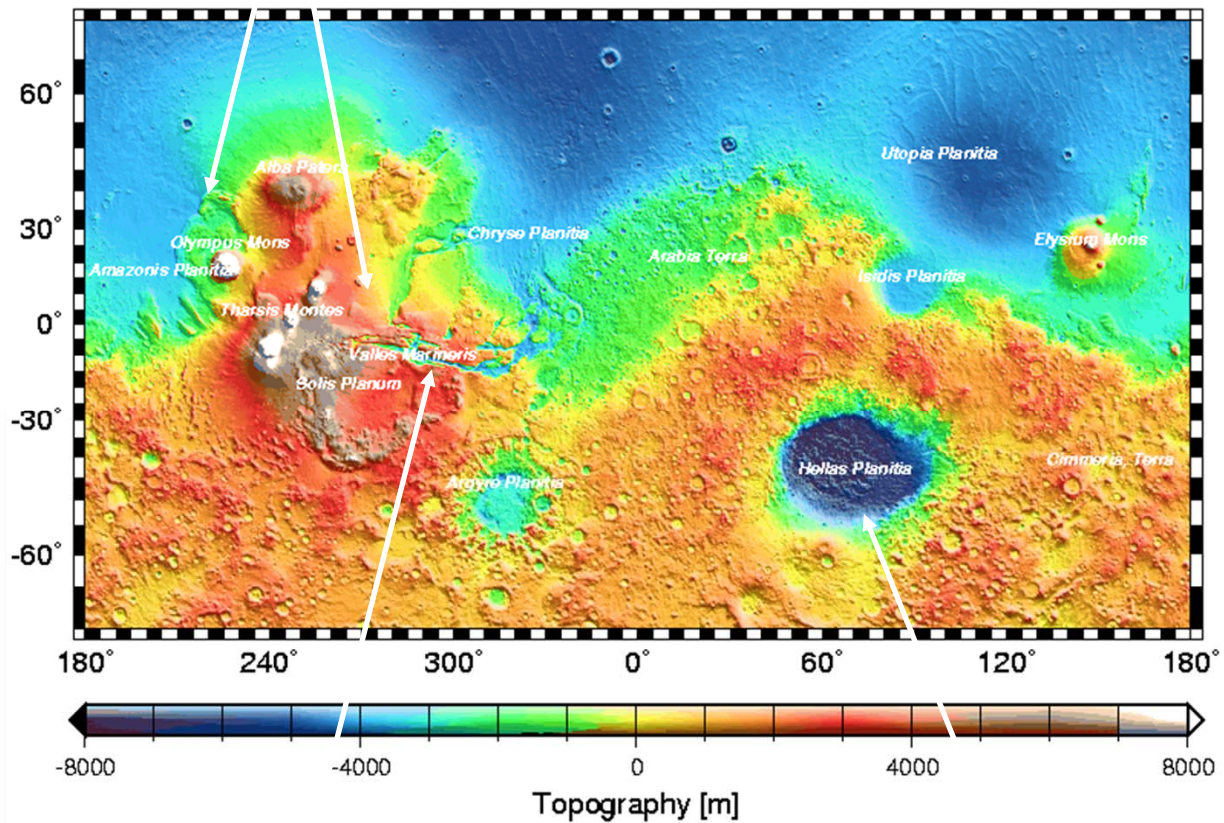
# MAP OF MARS

Mars Orbiter Laser Altimeter Map



# TOPOLOGY OF MARS

Tharsis Bulge



Northern hemisphere

- ~3by old
- Lava plains
- Lower terrain

Southern hemisphere

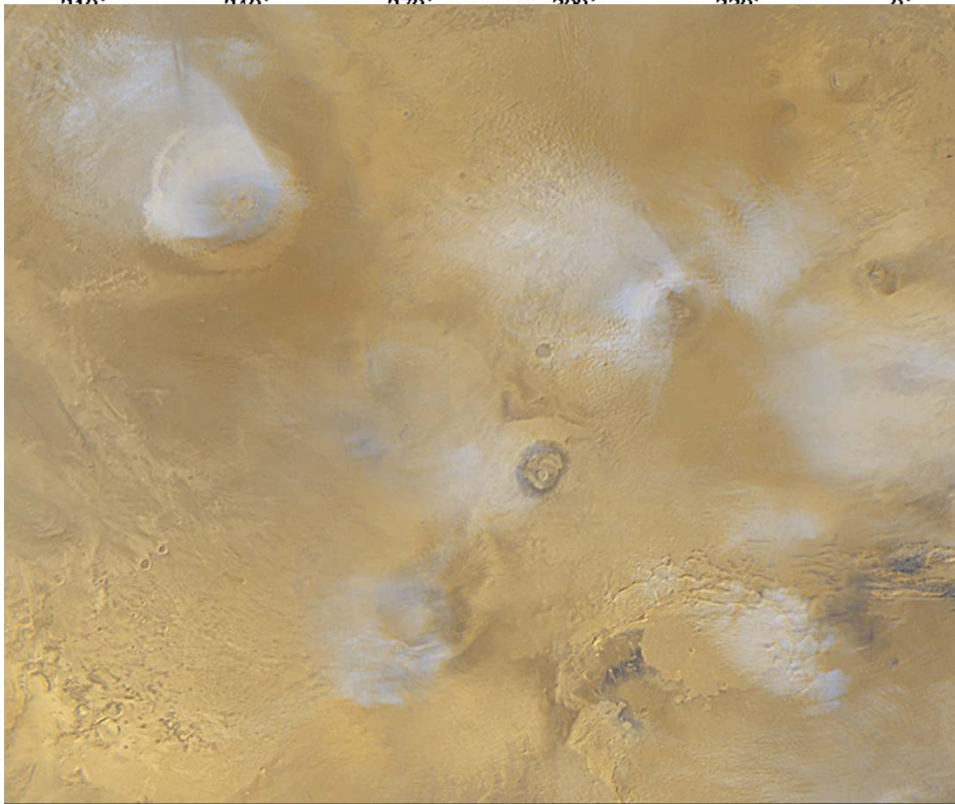
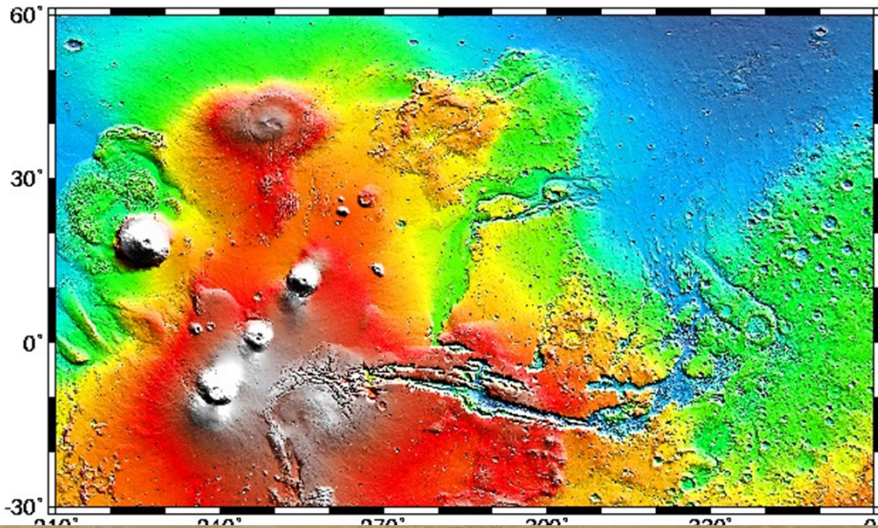
- ~4by old
- Cratered highlands

Valle Marineris

Hellas Basin

# THARSIS BULGE

- A huge bulge with 4 large extinct volcanoes
- The size of the western half of the US
- Shield volcanoes, which kept getting bigger since Mars' crust does not move like the Earth's



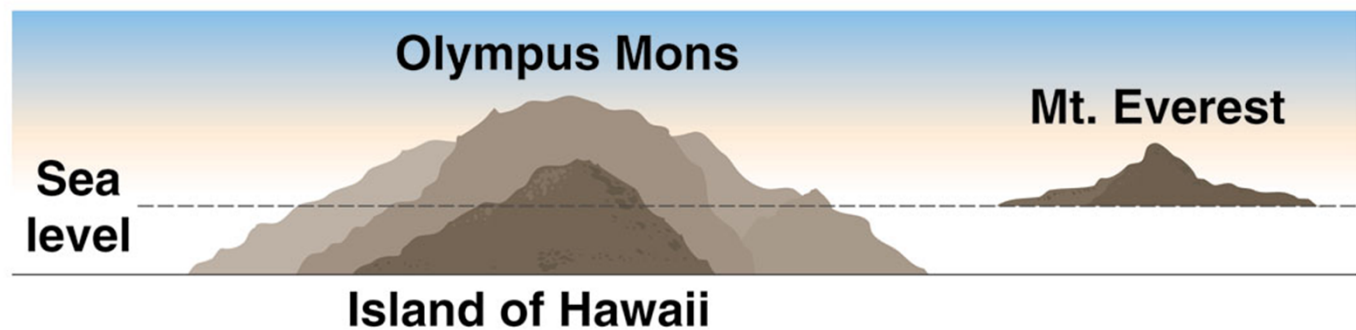
MOC2-134a Malin Space Science Systems/NASA

# OLYMPUS MONS

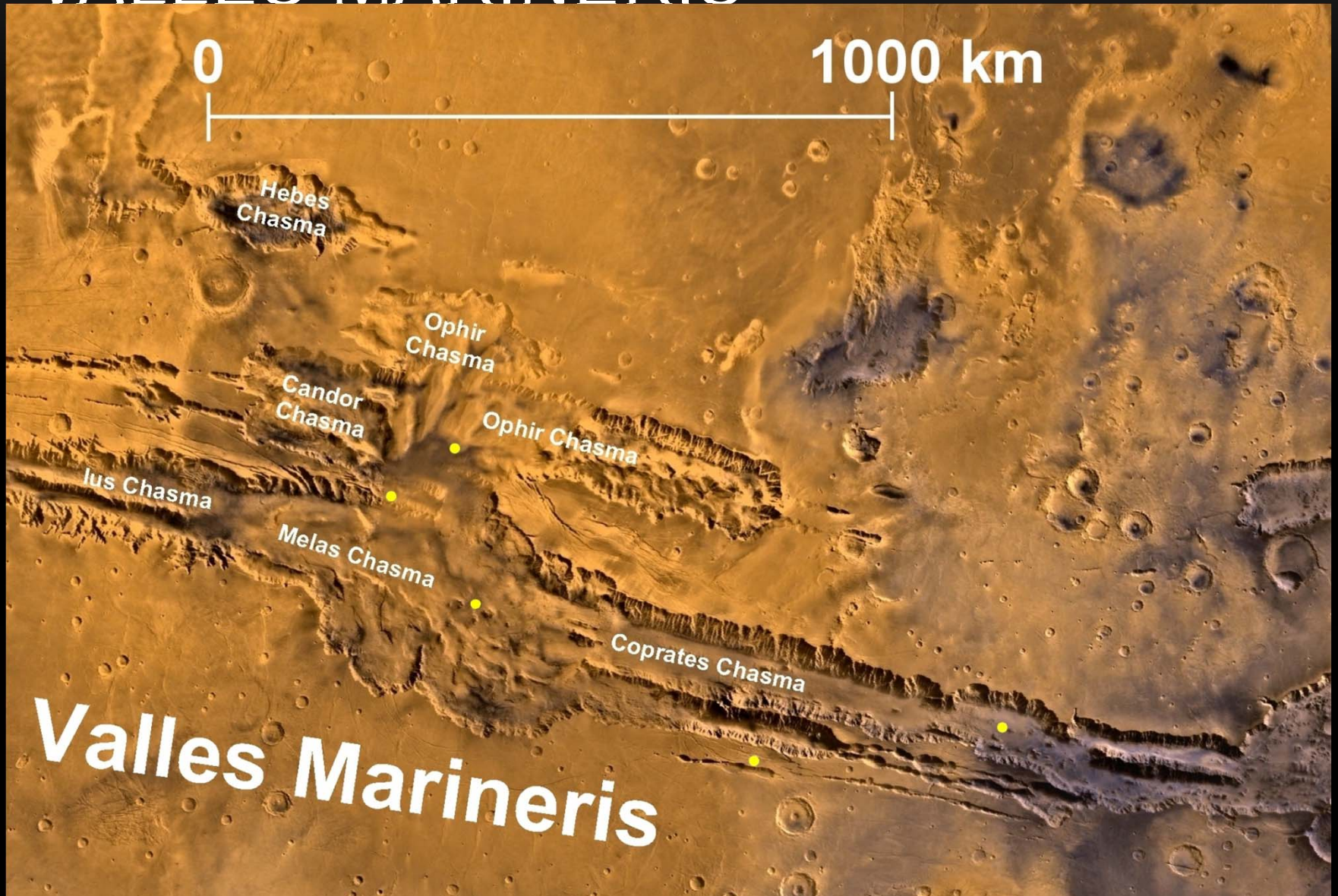


# OLYMPUS MONS

- Solar System's largest mountain
- Thick Martian crust (with low gravity) can support the weight
  - On Earth, it would sink

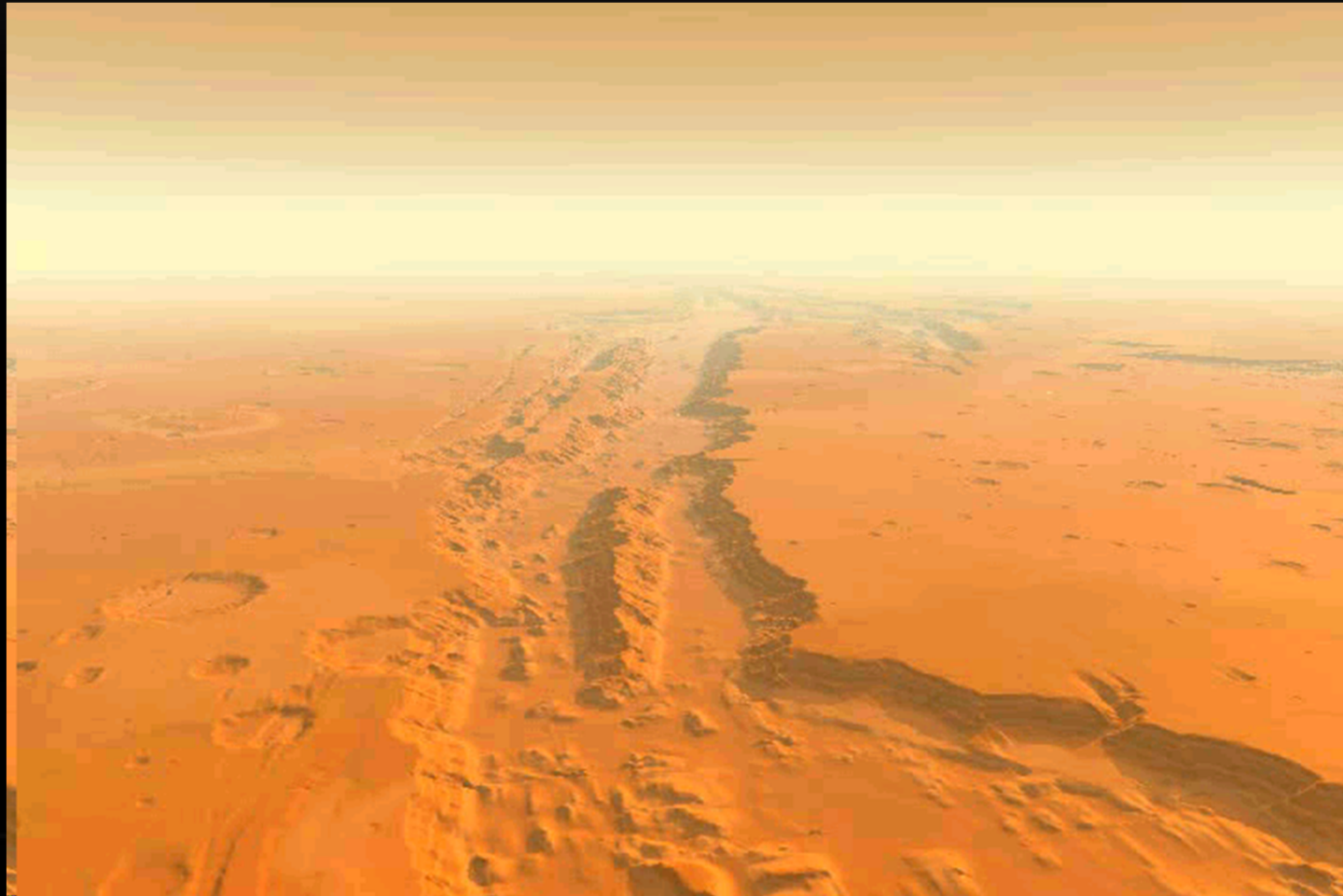


# VALLES MARINERIS



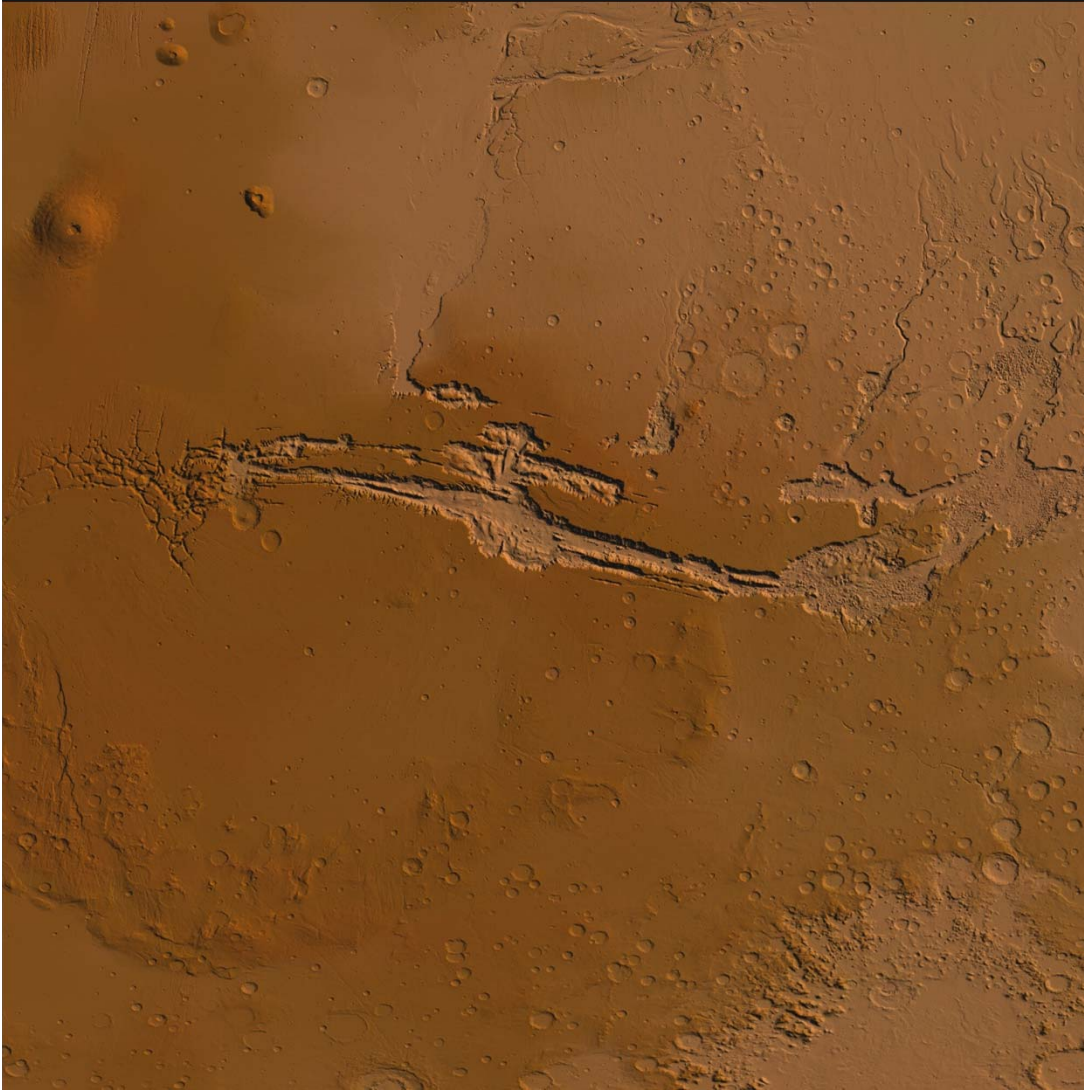


# VALLES MARINERIS



Animation by Adrian Lark from MOLA data ([link is on class website](#))

# VALLES MARINERIS



- A rift valley the size of the US

- Across Tharsis bulge

- Not a water-formed canyon

- Evidence of water erosion on edges though

- Is a big crack which formed as the bulge bulged

# CRATERING



• Many non-volcanic craters also exist

- Thin atmosphere
- old surface

• Cratering pattern lets us guess ages of terrain

- Also gives hints that early on, there might have been continental drift

• Also note the rivery-looking wiggles in this picture

# CRATERS WITH SPLASH?

- Some craters look like something splashing into mud
- Ejecta flows rather than flung like on Moon
- Evidence of impact melting permafrost?



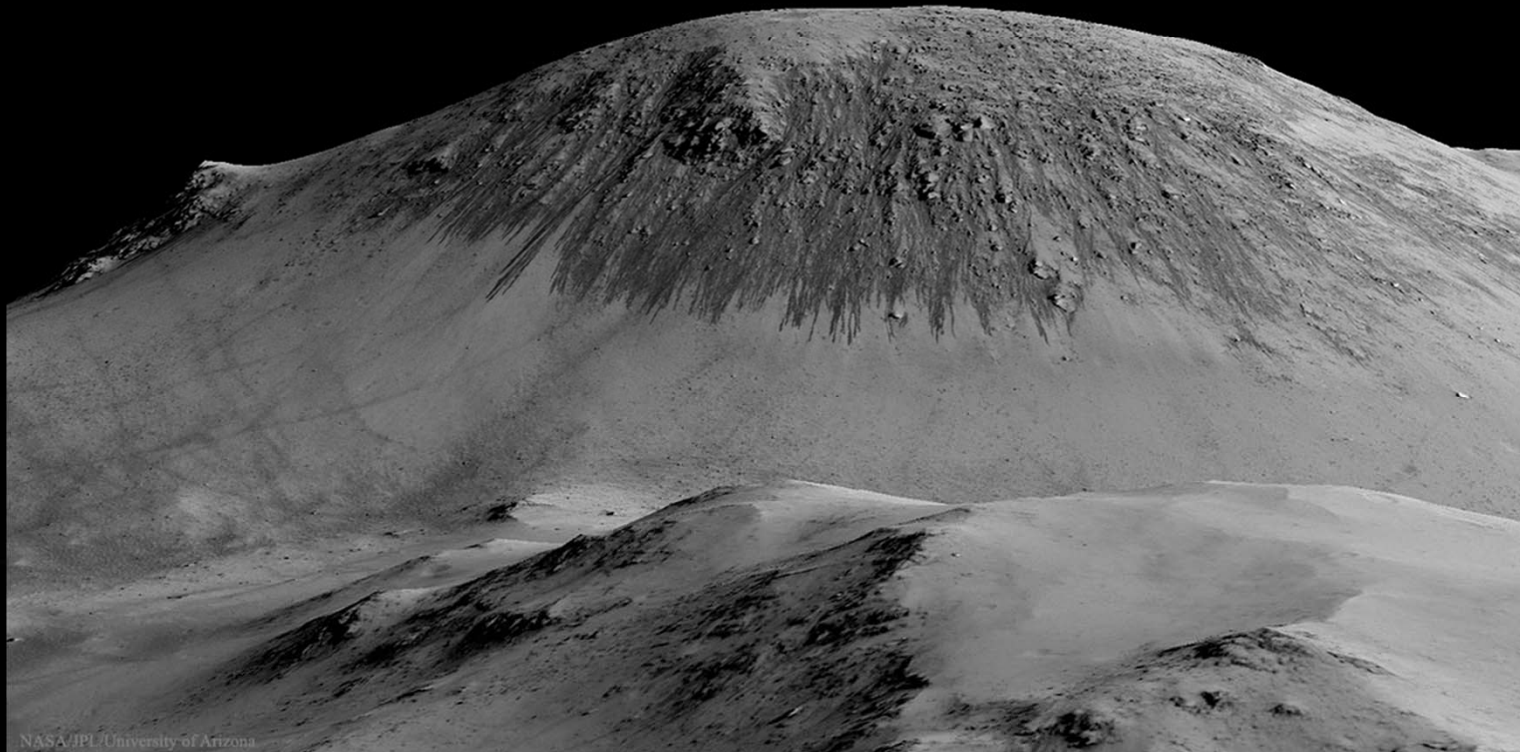


# LIQUID WATER?

- Dry riverbeds are present
- So liquid H<sub>2</sub>O did once exist
- Was it entirely due to cataclysmic events such as meteor impacts?
- Or was it once a nicer place, and the water is now all:
  - In the ice caps
  - In permafrost
  - Broken up by UV radiation?

# SEASONAL STREAKS

- 2015's news from the Mars Reconnaissance Orbiter shows water-formed streaks that change with the seasons: some water flows there still!

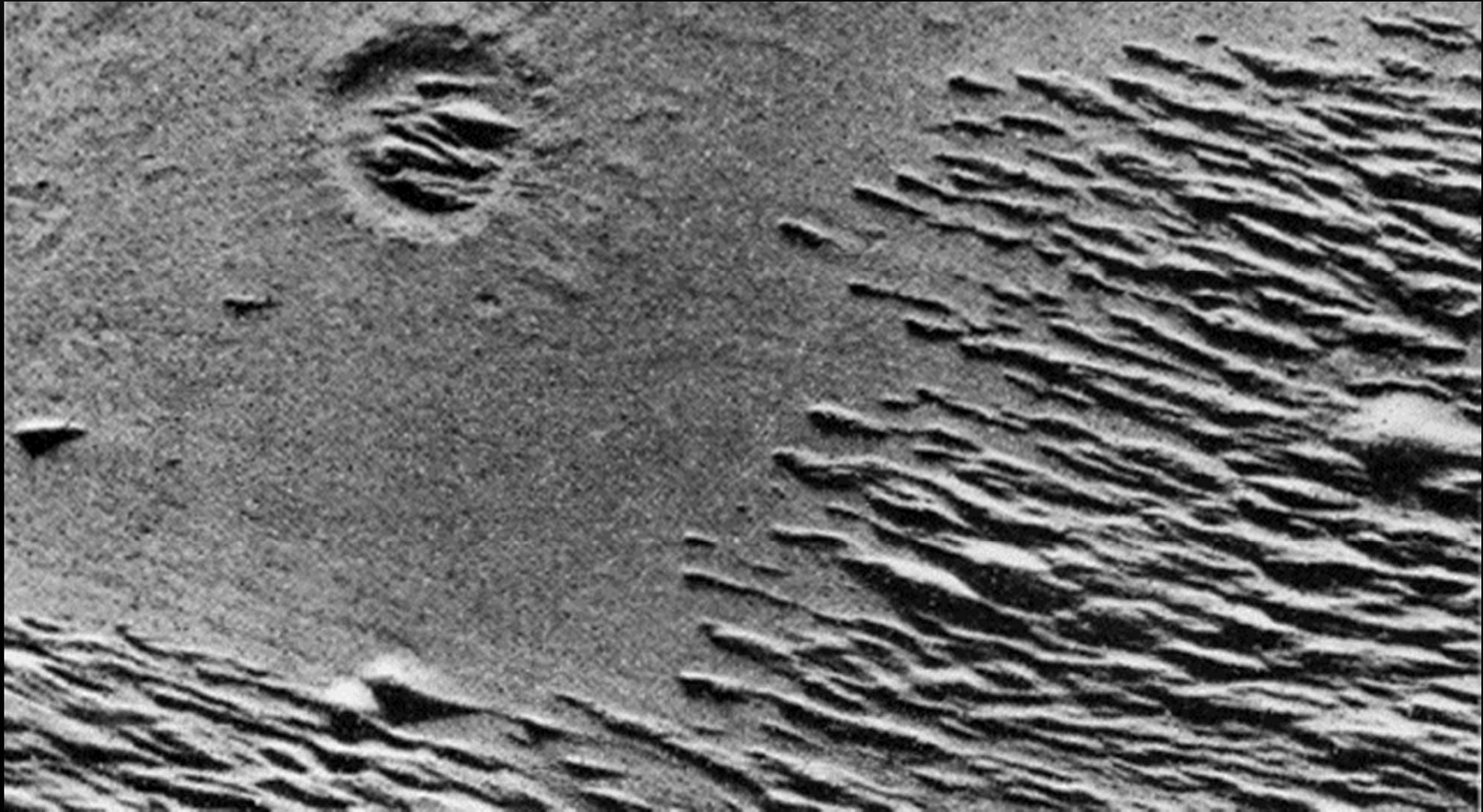


# WINDS AND DUST

- We see large seasonal dust storms
- Air is very thin, so dust must be pretty fine
- Even so, there are dunes
- Here are little ones seen by Pathfinder



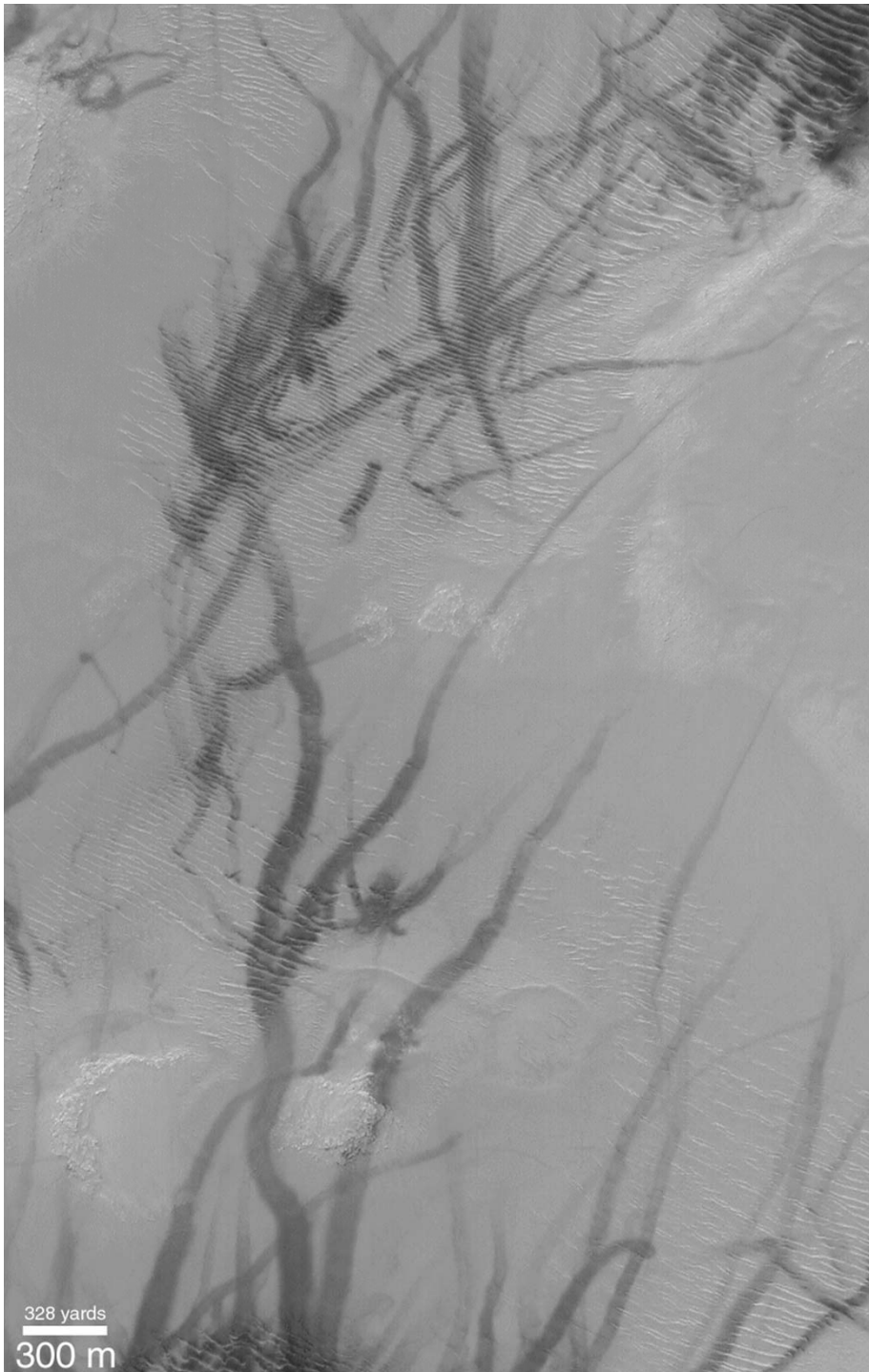
...AND BIG DUNES





# ...AND DUST DEVILS

- Trails of dust devils seen from orbit
- Landers have seen normal sized dust devils wander by



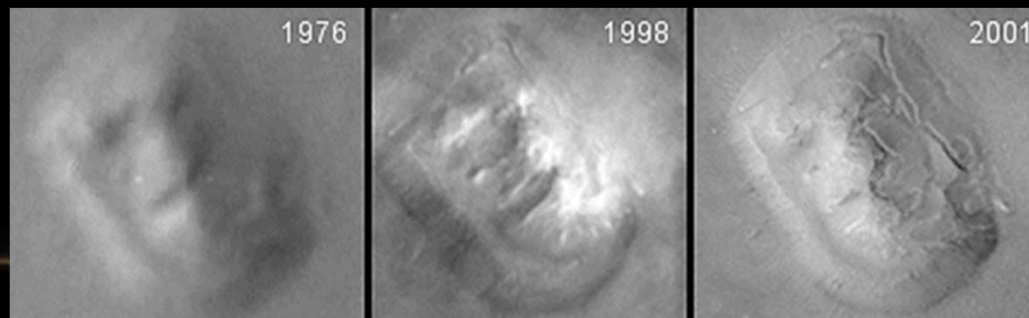
# FACE ON MARS?



- You've certainly seen this at the supermarket checkout line
- 1976 Viking I mission took a picture of an ordinary mesa with interesting shadows
- Mesa is about 2 miles long, many similar hills in this region of Mars ("Cydonia")

# BETTER QUALITY PICTURES

- In 1998 Mars Global Surveyor took a better picture, but a cloud was in the way
- 2001 MGS picture on a clear day
- Check out the class web site for a link to a web page all about it, including 3D views and a hiking map if you want to go to Mars and hike up the mesa



43m resolution

hazy day

1.6m resolution

# LIFE ON MARS?



- Mars is a not-so-bad place to live (if you could breath)
- Not until probes got there were Lowell's Canals fully ruled out
- Long a staple of SF writers
- Why not? What would it look like?

# LOOK FOR BACTERIA



Viking 2 Lander site

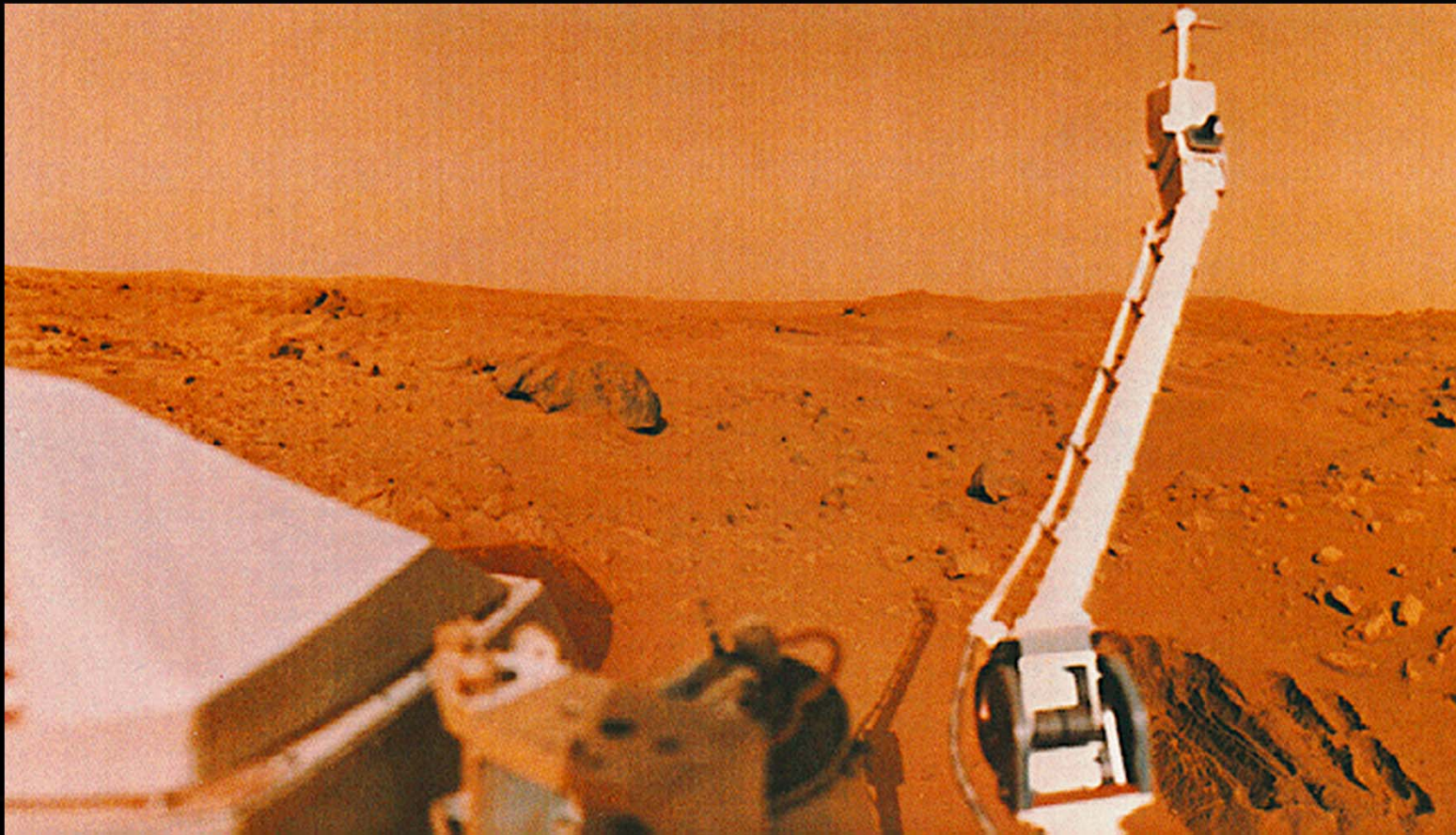
- Certainly no evidence of civilizations

- But on Earth, most life is actually bacteria

- Look for bacteria!
- They're everywhere here

- Maybe even leftover from long-ago watery days

GRAB SOME DIRT, ANALYZE IT



# RESULTS



Martian Sky from  
Pathfinder

- Viking took aboard soil
  - Sterilized some for a control sample
  - Added a little water
  - Watched for changes
- Also looked for organic materials with a mass spectrometer
- Everything seen was compatible with chemistry instead of biology

# LIFE SUMMARY

- Viking didn't find life
  - Neither have all following probes
- On Earth, there are really weird things living in really extreme places
  - Deep underground
  - In hot springs
- So we can't say that life doesn't exist on Mars – just that we haven't found it yet
  - Last week's current water discovery is optimistic!



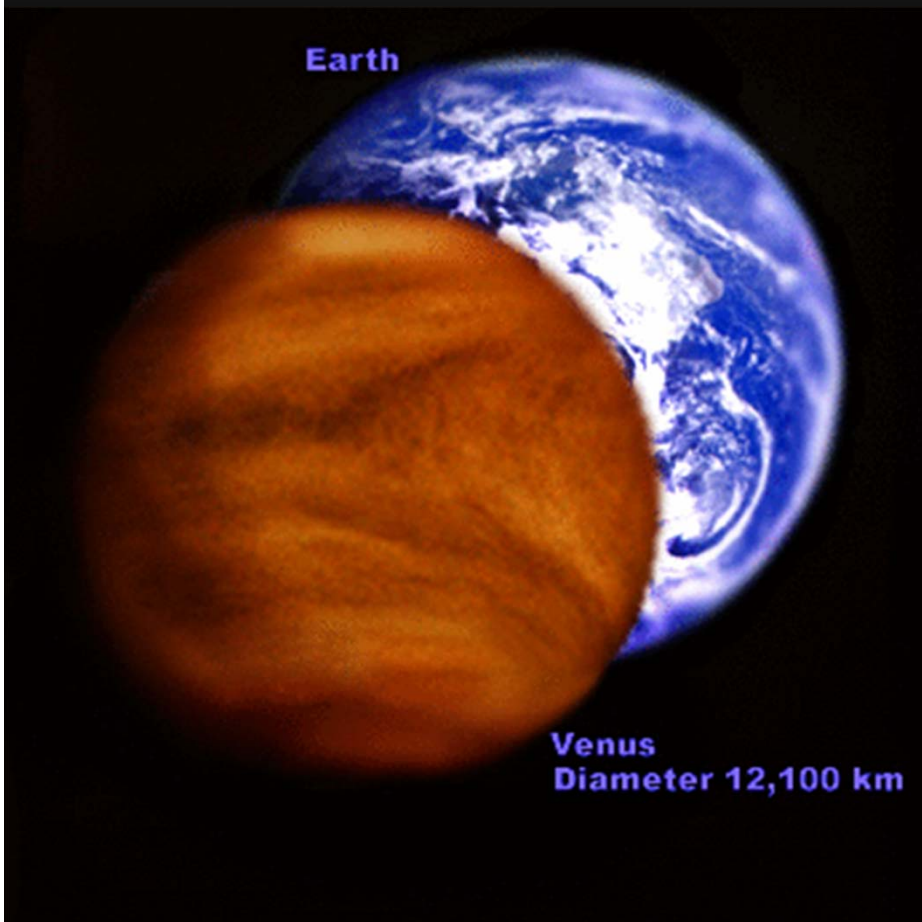
VENUS



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"Earth's twin"?

# "EARTH'S TWIN"



- Well, in size anyway –
  - 95% diameter
  - 82% mass
- Closest planet to Earth
- Thick atmosphere
- But nasty hot!
  - Runaway greenhouse effect

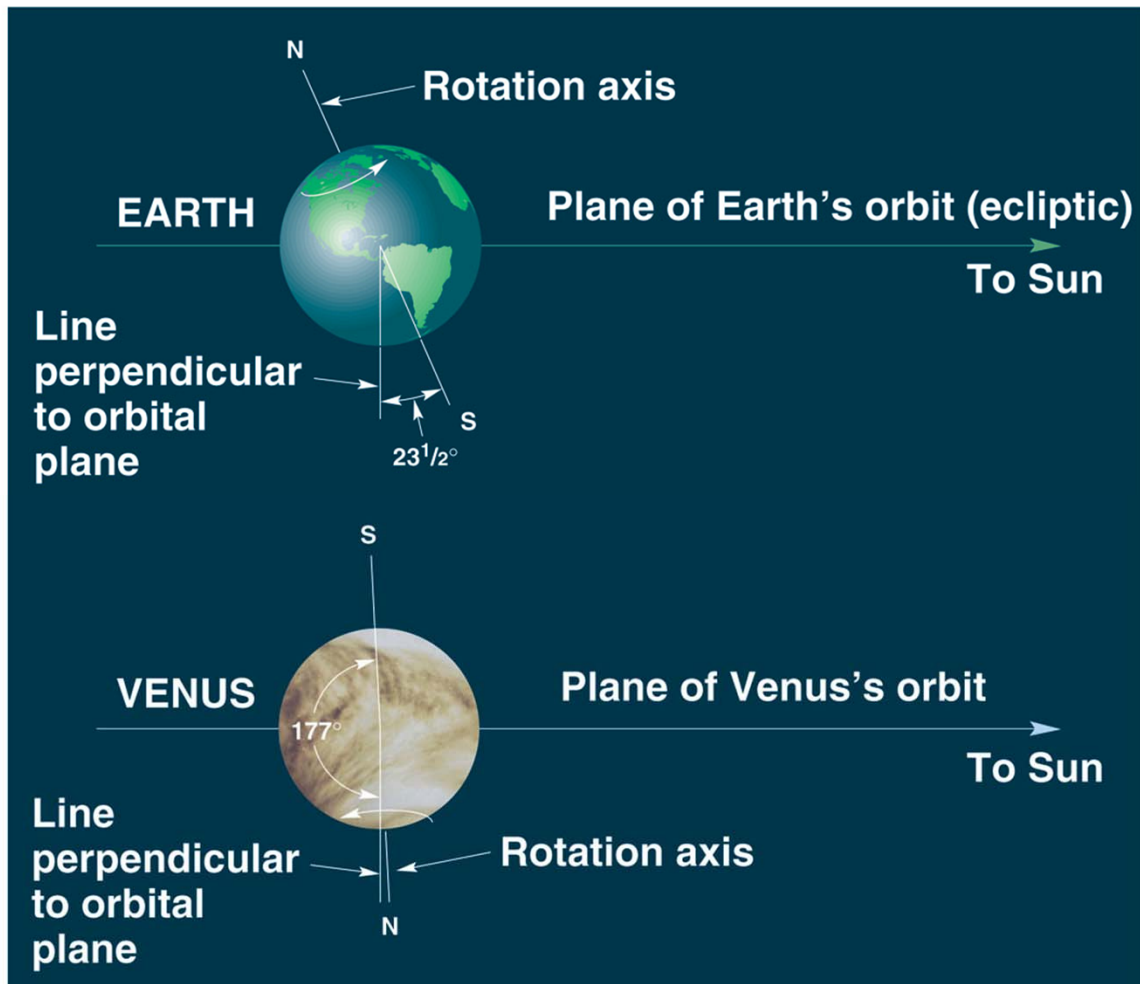
# VENUS' MOTIONS



- Inferior planet, so always hangs out near Sun in the sky
  - But further than Mercury
  - Very noticeable, bright
  - “Evening” or “Morning Star”
  - Popular UFO culprit
- Remember Galileo’s phases of Venus observation

Picture by Joe Orman  
Time-lapse of Moon and Venus setting

# ORBIT AND ROTATION

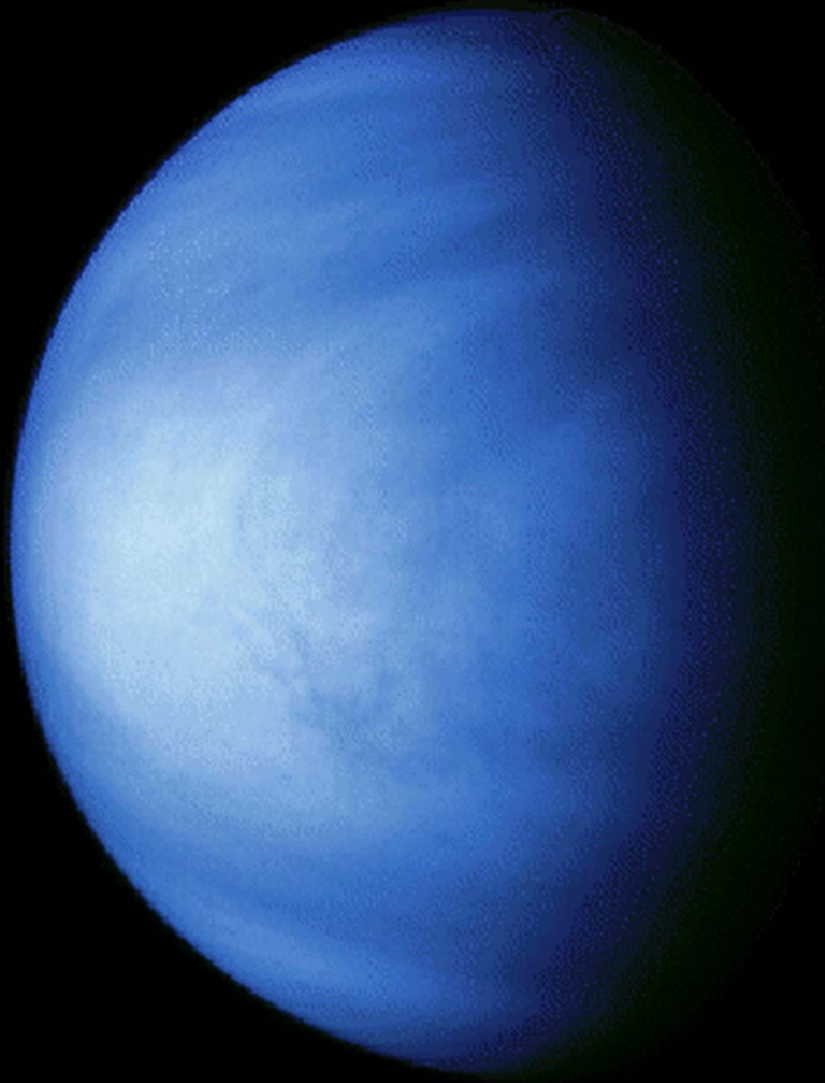


- Has most circular orbit in solar system
  - 225 day-long year
- Rotates once each 243 days
  - Backwards!
  - Results in 117 day solar day

# INTERNAL STRUCTURE

- Average Density similar to Earth –  $5.24 \text{ g/cm}^3$  vs.  $5.52 \text{ g/cm}^3$ 
  - Would be even closer if Venus had Earth's gravity compressing things
- Structure seems same as Earth
  - Crust, Mantle, iron core
  - No magnetic field
    - Rotates too slowly!
  - Somewhat less active
    - Cooled a bit faster than Earth due to smaller radius
- Surface rocks very similar

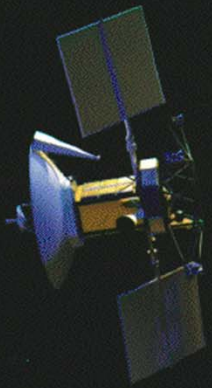
# WHAT WE SEE



- Simply the top cloud layer of a very dense atmosphere
- This picture is contrast-enhanced
  - In reality, Venus looks extremely bland!
- ...and false-color
  - Really looks just white

# SO HOW DO WE OBSERVE IT?

Magellan



- Radar
  - From Earth or Probes
- Many probes sent to Venus
  - US -
    - 3 Mariner flybys
    - 2 Pioneer orbiters
    - Magellan radar mapper
  - Russia -
    - many Venera orbiters, probes, landers
    - 2 Vega landers, orbiters, balloons

Venera 14

