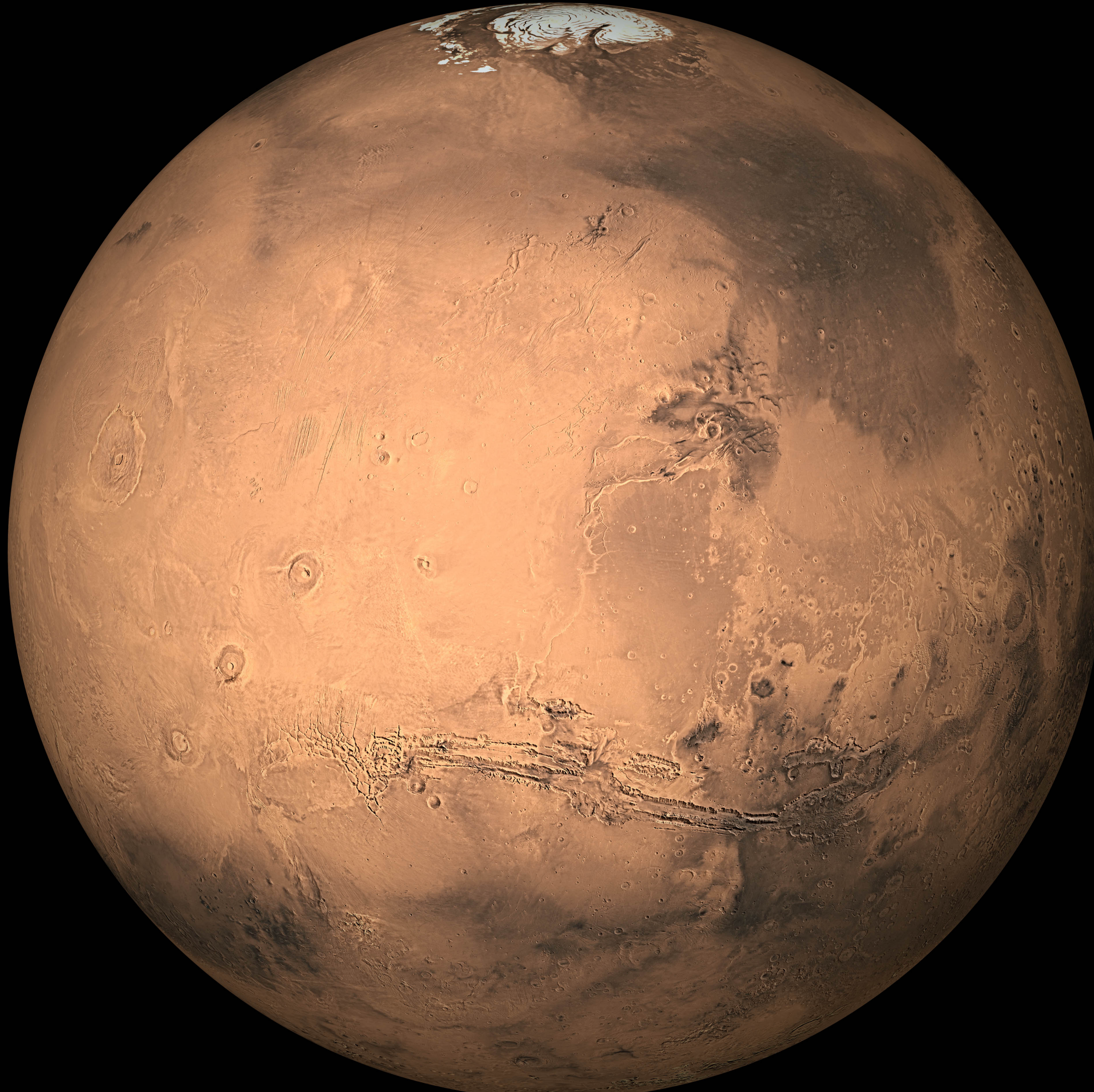
Lecture 12

Mercury



Mars

Guiding Questions

1. What makes Mercury a difficult planet to see? Why Venus is a bright morning and evening star? What are the best times to observe Mars?
2. What are special about orbital and rotation motions of Mercury and Venus?
3. How and why atmospheres of Venus and Mars are drastically different from Earth's? What effects do they have on the planets' temperatures?
4. What causes seasonal changes on Earth and Mars?
5. What is the evidence that there was once liquid water on Mars?

12.1 Overview

the terrestrial (inner) planet

	Mercury	Venus	Earth	Mars
Average distance from Sun (10^6 km)	57.9	108.2	149.6	227.9
Average distance from Sun (AU)	0.387	0.723	1.000	1.524
Orbital period (years)	0.241	0.615	1.000	1.88
Orbital eccentricity	0.206	0.007	0.017	0.093
Inclination of orbit to the ecliptic	7.00°	3.39°	0.00°	1.85°
Equatorial diameter (km)	4880	12,104	12,756	6794
Equatorial diameter (Earth = 1)	0.383	0.949	1.000	0.533
Mass (kg)	3.302×10^{23}	4.868×10^{24}	5.974×10^{24}	6.418×10^{23}
Mass (Earth = 1)	0.0553	0.8150	1.0000	0.1074
Average density (kg/m^3)	5430	5243	5515	3934

Mars's personality can be studied in comparison with other terrestrial planets.

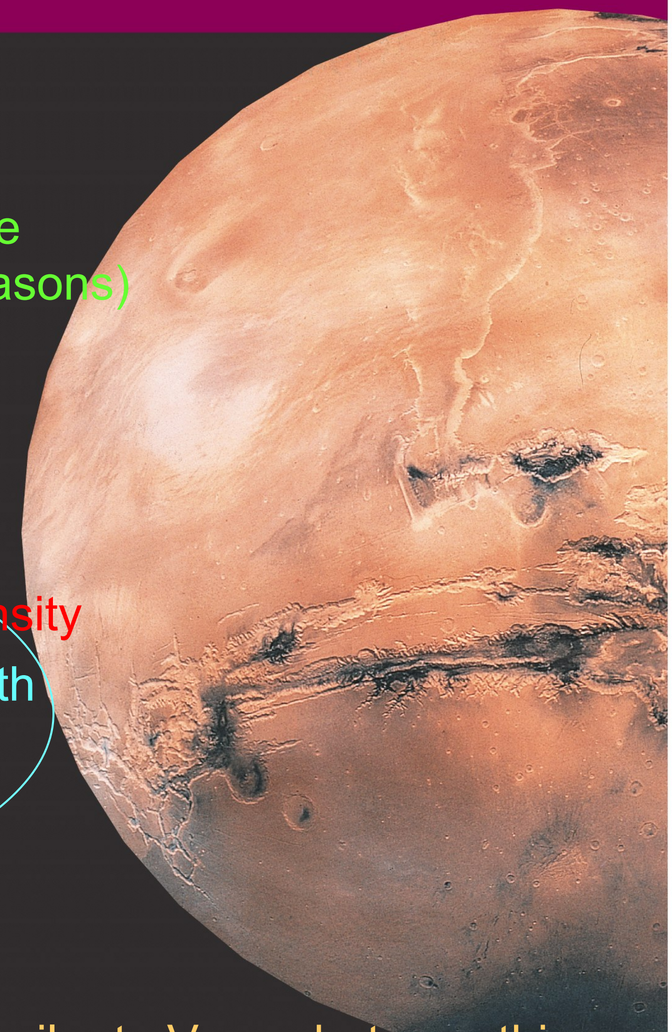
-1 Mars Data

Average distance from Sun:	1.524 AU = 2.279×10^8 km
Maximum distance from Sun:	1.666 AU = 2.492×10^8 km
Minimum distance from Sun:	1.381 AU = 2.067×10^8 km
Eccentricity of orbit:	0.093
Average orbital speed:	24.1 km/s
Orbital period:	686.98 days = 1.88 years
Rotation period:	$24^h\ 37^m\ 22^s$
Inclination of equator to orbit:	25.19°
Inclination of orbit to ecliptic:	1.85°
Diameter (equatorial):	6794 km = 0.533 Earth diameter
Mass:	6.418×10^{23} kg = 0.107 Earth mass
Average density:	3934 kg/m^3
Escape speed:	5.0 km/s
Surface gravity (Earth = 1):	0.38
Albedo:	0.15
Surface temperatures:	Maximum: 20°C = 70°F = 293 K Mean: −53°C = −63°F = 220 K Minimum: −140°C = −220°F = 133 K
Atmospheric composition (by number of molecules):	95.3% carbon dioxide (CO_2) 2.7% nitrogen (N_2) 0.03% water vapor (H_2O) 2% other gases

Earth-like
(Mars has seasons)

smallest density

Between Earth
and Mercury



similar to Venus but very thin

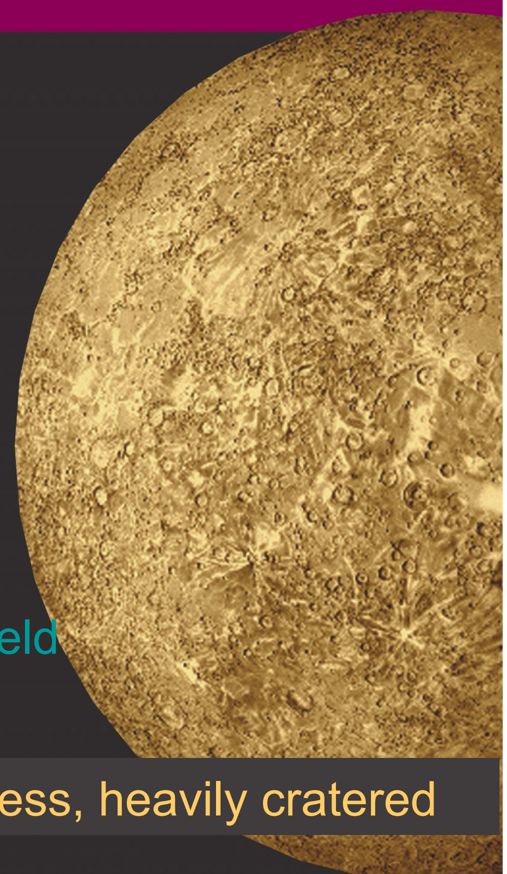
Mercury has a Moon-like surface but Earth-like interior. It also has its own unique properties.

Mercury Data

Average distance from Sun:	0.387 AU = 5.79×10^7 km
Maximum distance from Sun:	0.467 AU = 6.98×10^7 km
Minimum distance from Sun:	0.307 AU = 4.60×10^7 km
Eccentricity of orbit:	0.206
Average orbital speed:	47.9 km/s
Orbital period:	87.969 days
Rotation period:	58.646 days
Inclination of equator to orbit:	0.5°
Inclination of orbit to ecliptic:	7° 00′ 16′
Diameter (equatorial):	4880 km = 0.383 Earth diameter
Mass:	3.302×10^{23} kg = 0.0553 Earth mass
Average density:	5430 kg/m^3
Escape speed:	4.3 km/s
Surface gravity (Earth = 1):	0.38
Albedo:	0.12
Average surface temperatures:	Day: 350°C = 662°F = 623 K
	Night: −170°C = −274°F = 103 K
Atmosphere:	Essentially none

elliptical orbit
coupled spin-orbit

dense,
magnetic field



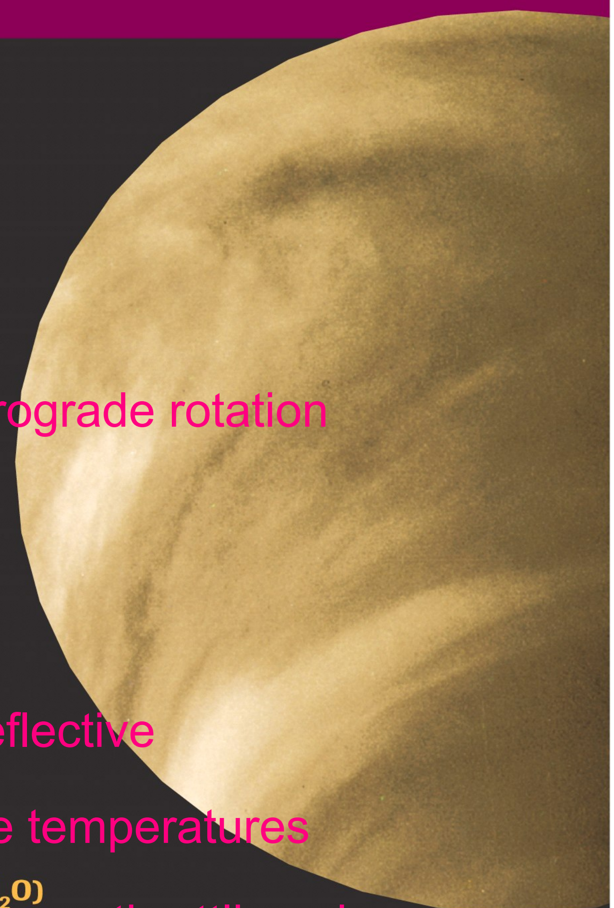
dry, airless, heavily cratered

Mercury is small and closest to the Sun.

Venus might be thought as the twin sister of the Earth with many similarities, yet differences abound.

Venus Data

Average distance from Sun:	0.723 AU = 1.082×10^8 km
Maximum distance from Sun:	0.728 AU = 1.089×10^8 km
Minimum distance from Sun:	0.718 AU = 1.075×10^8 km
Eccentricity of orbit:	0.0068
Average orbital speed:	35.0 km/s
Orbital period:	224.70 days
Rotation period:	243.01 days (retrograde)
Inclination of equator to orbit:	177.4°
Inclination of orbit to ecliptic:	3.39°
Diameter (equatorial):	12,104 km = 0.949 Earth diameter
Mass:	4.868×10^{24} kg = 0.815 Earth mass
Average density:	5243 kg/m^3
Escape speed:	10.4 km/s
Surface gravity (Earth = 1):	0.91
Albedo:	0.59
Average surface temperature:	460°C = 860°F = 733 K
Atmospheric composition (by number of molecules):	96.5% carbon dioxide (CO_2) 3.5% nitrogen (N_2), 0.003% water vapor (H_2O)



slow retrograde rotation

highly reflective

extreme temperatures

throttling air

Venus has a very thick atmosphere and is hotter than should.

- observation of terrestrial planets: their positions in the sky and their phases.
- orbital and rotation motions

  Kepler's third law: $a^3=P^2$

  spin-rotation coupling

role of gravitation

- atmospheres and energy balance

  greenhouse and icehouse effects

- surface, interior, geological activity, and magnetism

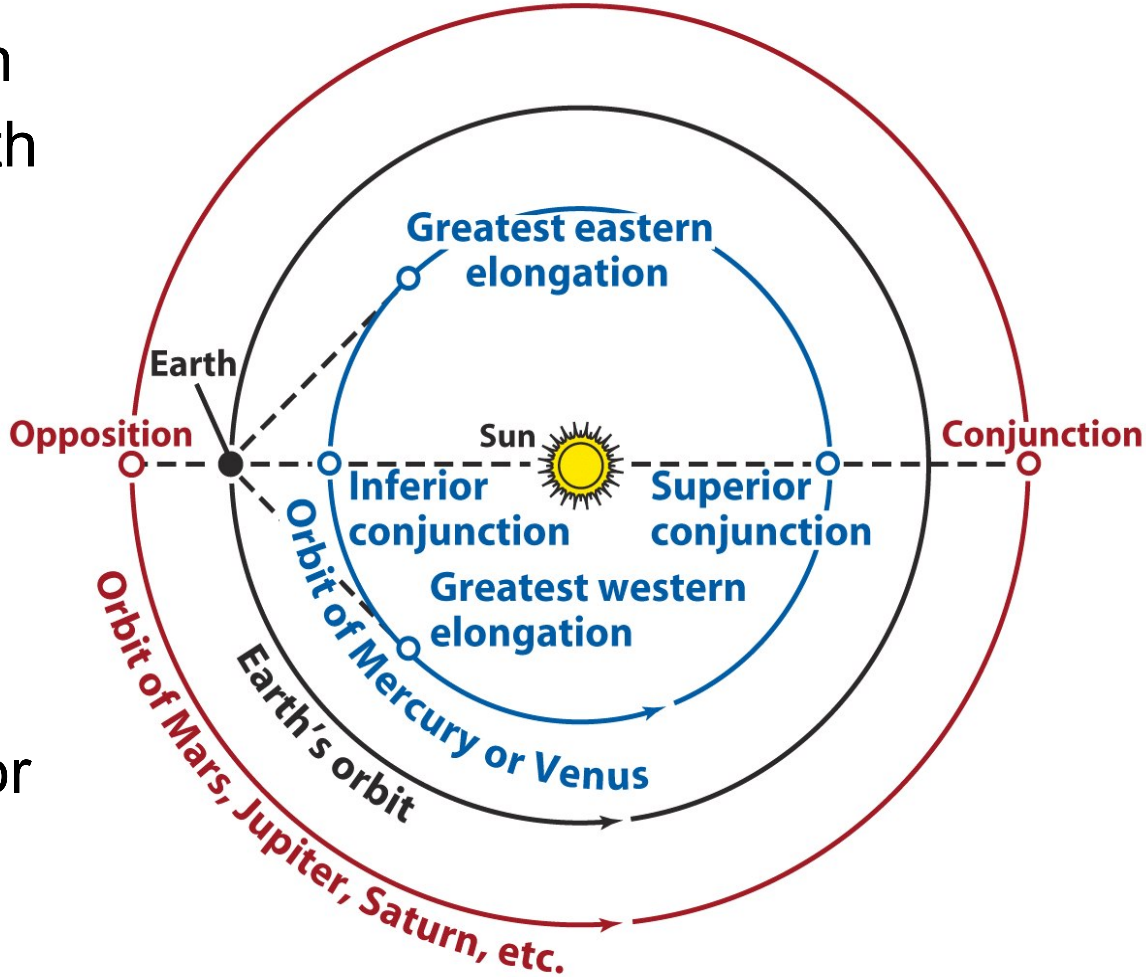
Gravity and distance to the Sun account for many important properties.

12.2 Position in the sky

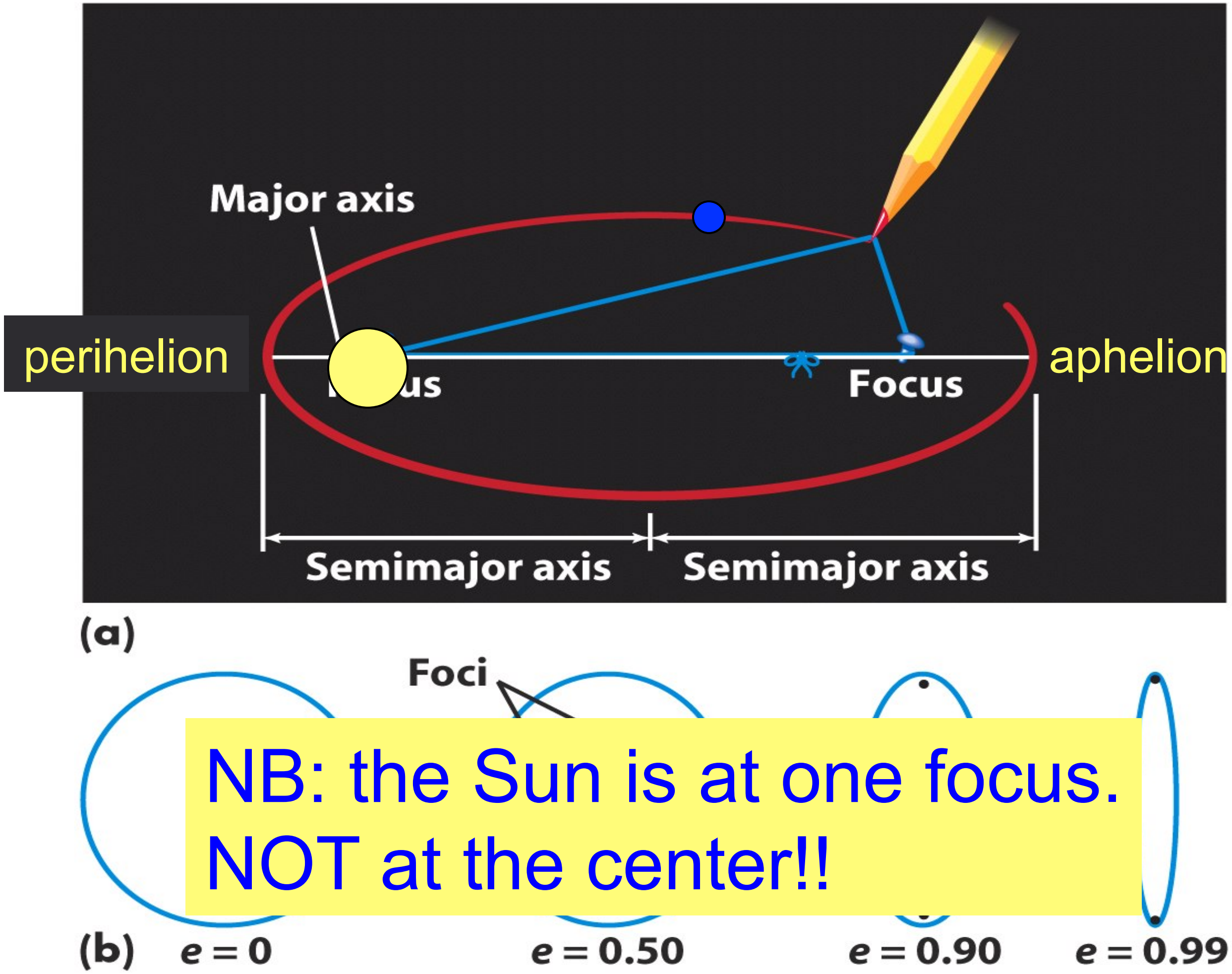
Mercury and Venus are **inferior planets** with smaller orbits than Earth's. They are always on the same side with the Sun and only seen in the daytime.

Mars, Jupiter, and Saturn are **superior planets** with larger orbits and may be observed both in the day and at night.

A planet is aligned with the Sun and the Earth at **conjunction** or **opposition** (only superior planets).



Kepler's First Law: the orbit of a planet is an ellipse with the Sun at one focus.



NB: the Sun is at one focus.
NOT at the center!!

Mercury: e = 0.206

Venus: e = 0.007

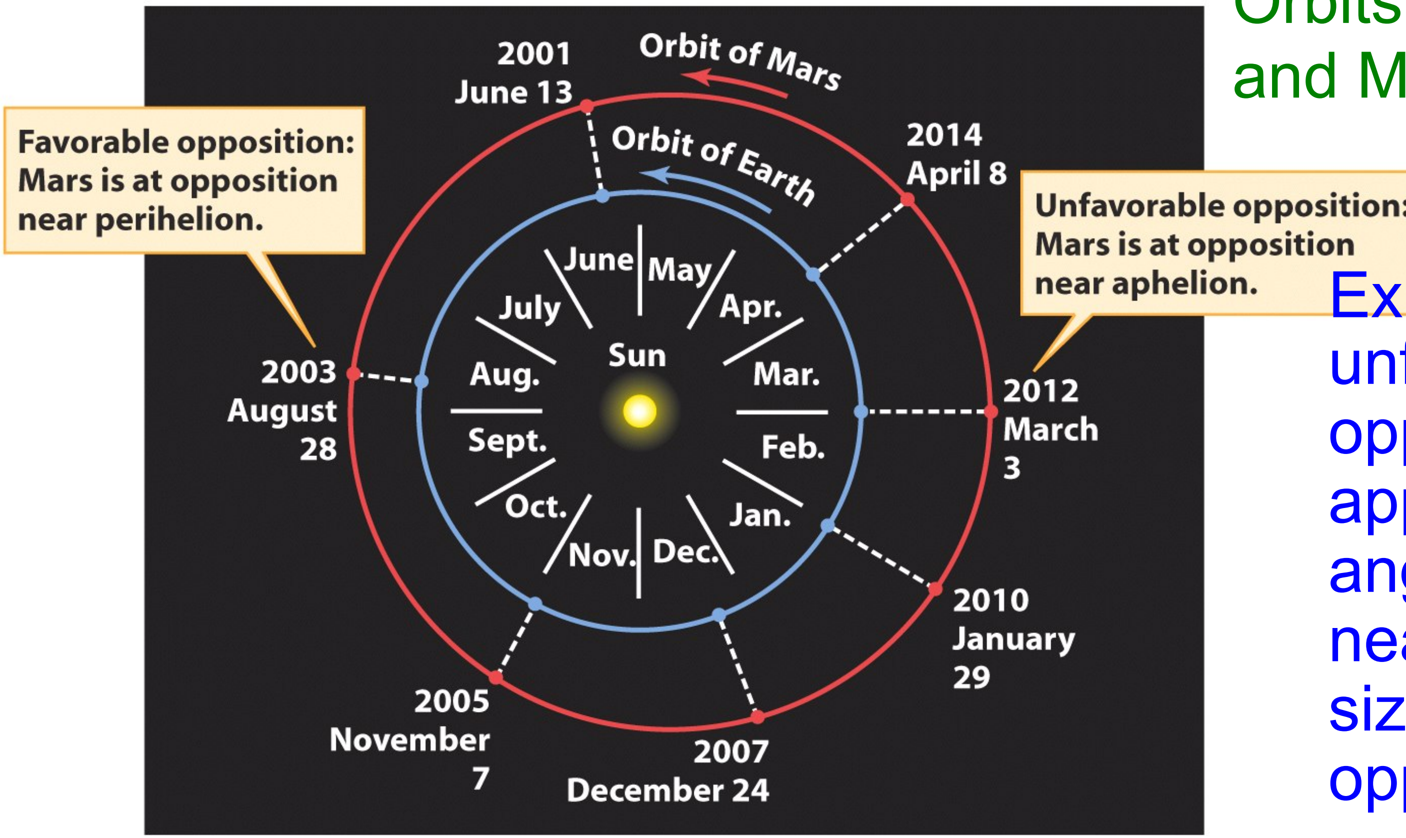
Earth: e = 0.017

Mars: e = 0.093

(Moon: e = 0.055)

The smaller eccentricity, the more circular is the orbit.

Earth-based observations of Mars are best made during favorable **oppositions**, when Mars is simultaneously at opposition and near perihelion.



Orbits of Earth and Mars

Ex.5: Mars at unfavorable oppositions appears (i.e., angular size) nearly half its size at favorable oppositions.

Q: Can we observe Mars at conjunctions? What's Mar's phase at oppositions? Can we see new Mars?

12.3 Orbit and Rotation

- Orbits of the planets in the solar system are described by **Kepler's three laws**.

  1st law: elliptical orbit with Sun at one focus -- Mercury's orbit has the largest eccentricity

  2nd law: planet moves faster at perihelion than at aphelion

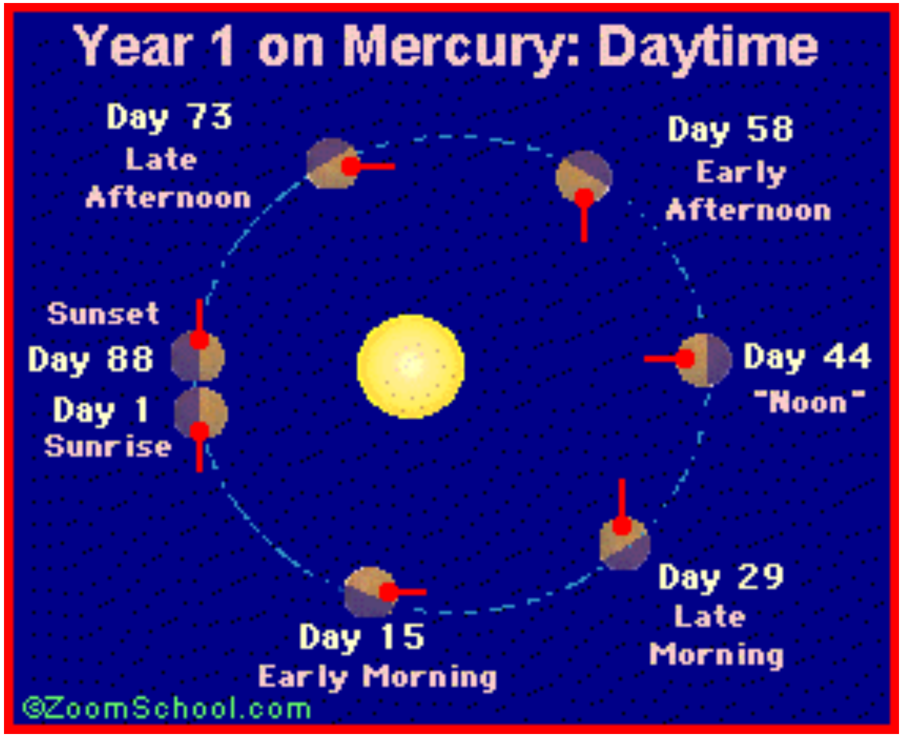
  3rd law: $a^3 = P^2$ a = 0.4, 0.7, 1, 1.5 AU
- small inclination of orbits to ecliptic by 7^0, 3^0, 2^0 for Mercury, Venus, and Mars.
- Inclination between equator and orbit plane:

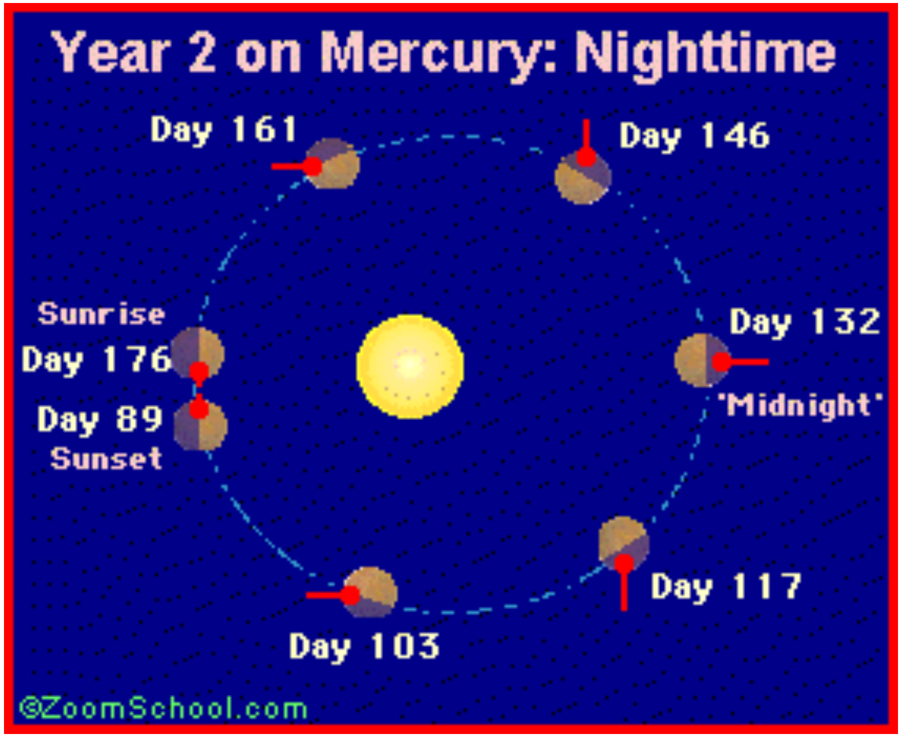
  Mercury: 0.5^0

  Venus: 177.4^0 retrograde rotation!

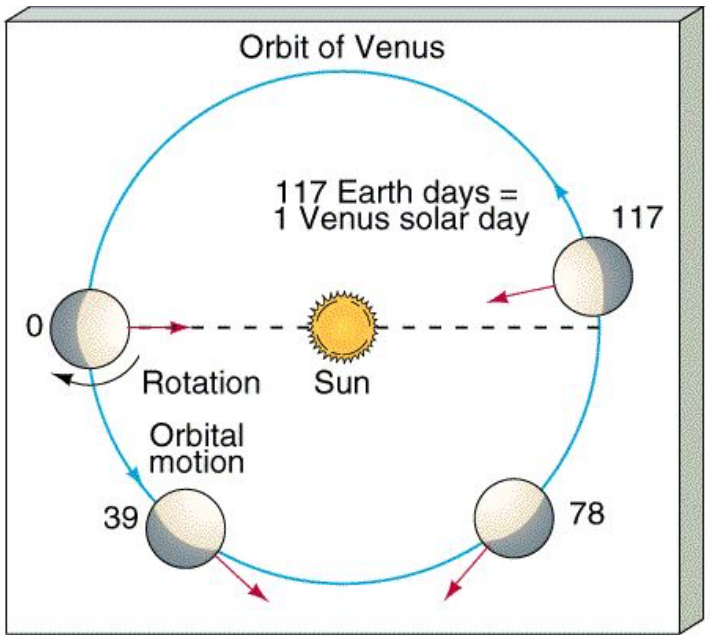
  Earth 23^0 and Mars 25^0 seasons!
- Mercury and Venus are slow rotators; Earth and Mars rotate fast. Magnetic fields?

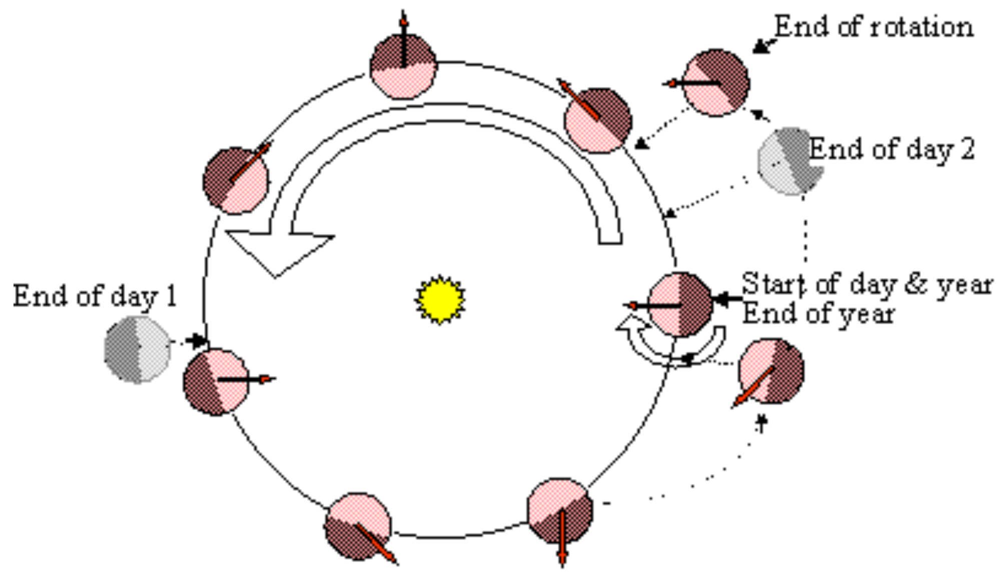
Q: we will send missions to land on Mercury. Instruments will use solar cells to provide power. If you are to design the capacity of the solar cells, for how long the solar cells should be able to provide energy in dark?





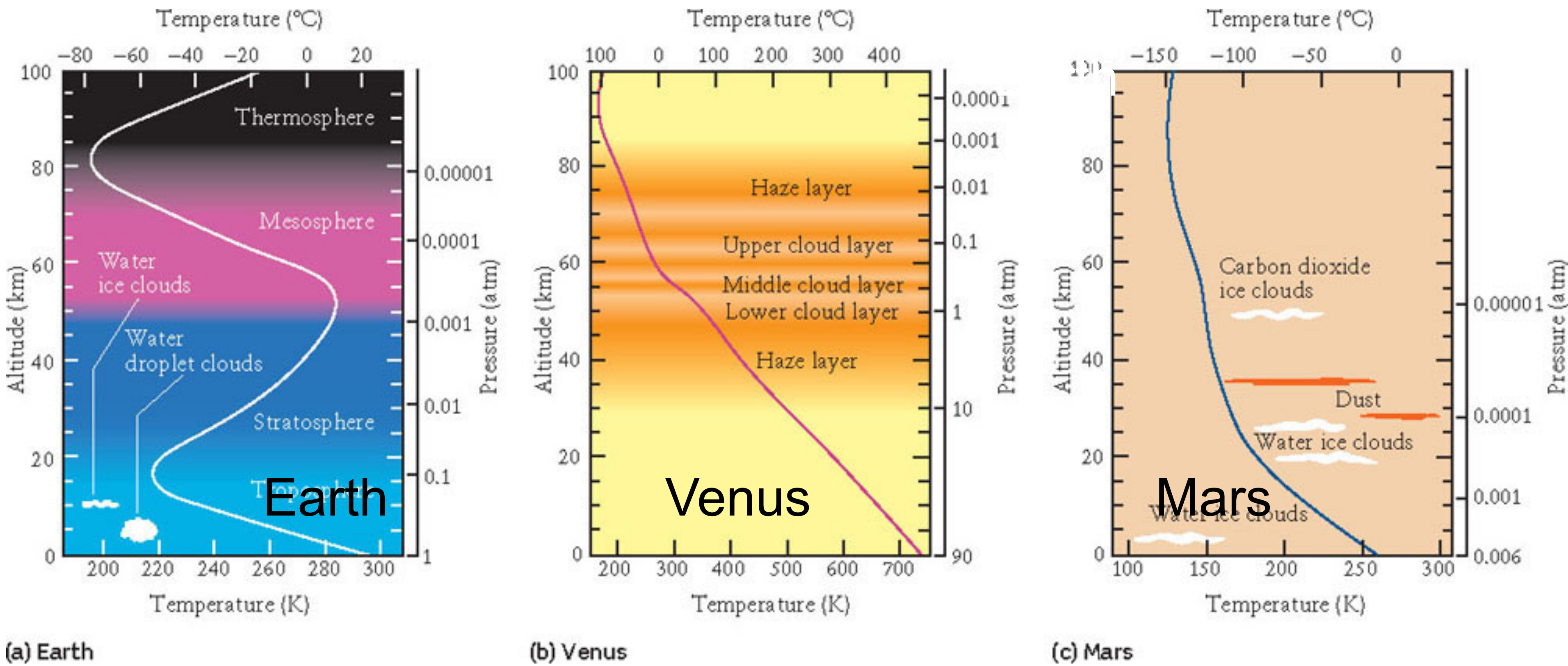
Q: we will send missions to land on Venus. Solar cells will face the sunlight during daytime to work most efficiently. How would you design to track the Sun in Venus' sky?





12.4 Atmosphere

- Venus: hot, dense; Mars: thin, cool. **Air pressure**: 0.01, 1, 90 *atmosphere* on Mars, Earth, and Venus.
- Venus and Mars: mostly made of CO_2; Earth: N_2 and O_2.



Temperature profiles in Venus, Mars, and Earth's atmospheres

Strong **greenhouse effect** raises Venus's temperature by over 400 K, and night is as warm as in daytime.

Ex.9: calculate the temperature of Mars if Mars's albedo is 0.15 and R_s = 6.96 × 10^8 m, d = 2.28 × 10^8 km

Using Stefan-Boltzman law to relate blackbody radiation and effective temperature, it can be shown that

$$T_p = \left(\frac{(1-a)R_s^{\,2}}{4d^2} \right)^{1/4} T_s$$

T_p = temperature of the planet (K degree)
T_s = temperature of the Sun (K degree)
R_s = radius of the Sun (m),
d = distance between the Sun and the planet (m)
a = albedo on the planet surface.

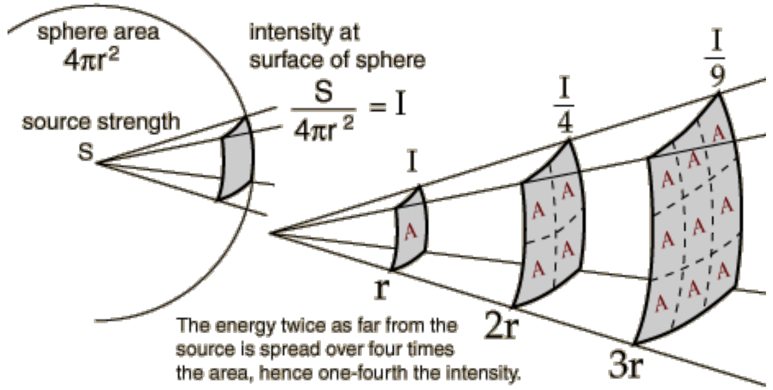
Without greenhouse effect, both Earth and Venus would have temperatures much lower than current values.

Brightness of a Star

- The **brightness** of a star is measured in terms of the **radiant flux** received from the star by observers.
- The radiant flux is the total amount of light energy of all wavelength that crosses a unit area oriented perpendicular to the direction of the light's travel per unit time.
- It is the number of joules of starlight energy per second received by on square meter of a detector aimed at the star.
- The **brightness** of a star depends on both its intrinsic luminosity and its distance from the observer.

- **Radiant flux** (**Apparent Brightness**) of the star drops off quickly with the distance *r* at which it is observed:

$$F_{obs} = \frac{L}{4\pi r^2} = \frac{\sigma T^4 R^2}{r^2} \quad (\mathrm{Jm^{-2}s^{-1}})$$



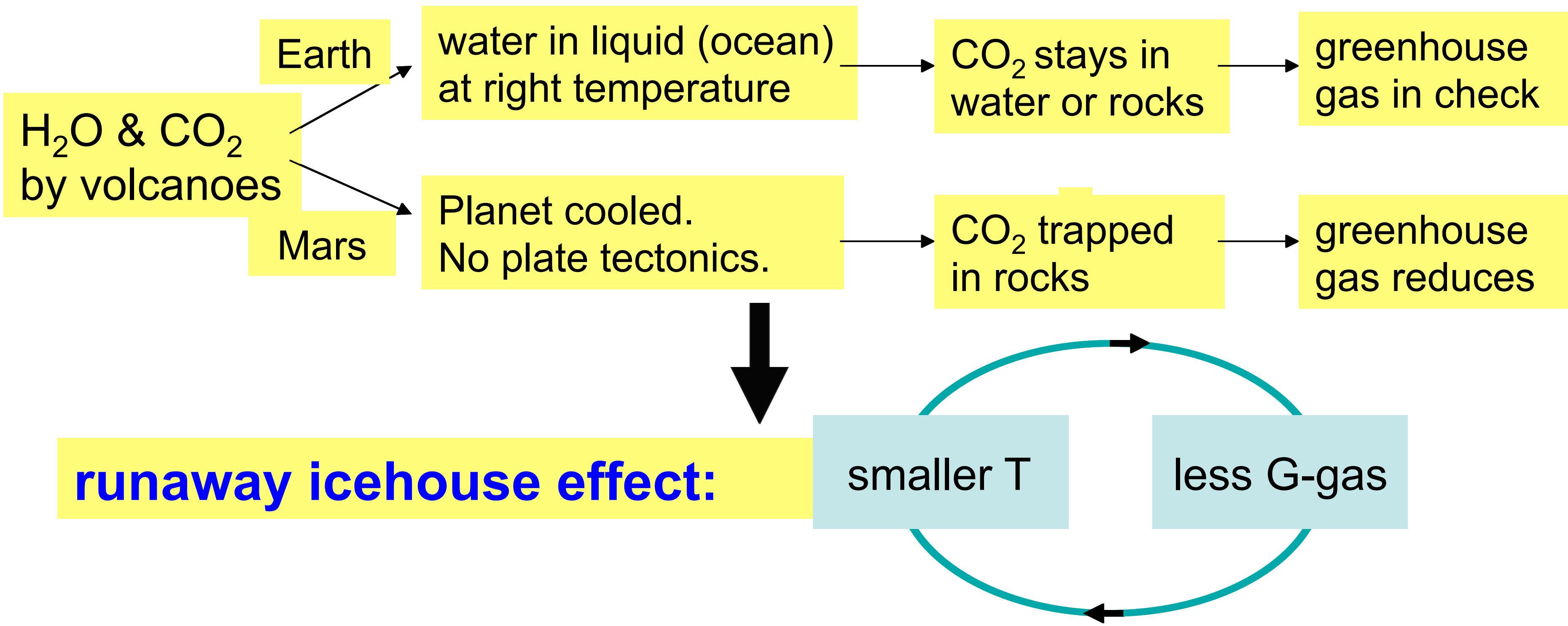
- **Albedo** is the fraction of sunlight reflected from the surface, relative to the amount striking the surface.

table 9-4 Chemical Compositions of Three Planetary Atmospheres	Venus	Earth	Mars
Nitrogen (N_2)	3.5%	78.08%	2.7%
Oxygen (O_2)	almost zero	20.95%	almost zero
Carbon dioxide (CO_2)	96.5%	0.035%	95.3%
Water vapor (H_2O)	0.003%	about 1%	0.03%
Other gases	almost zero	almost zero	2%

The chemical composition of the Earth's atmosphere is drastically different from that of other two terrestrial planets also possessing an atmosphere.

what leads to the difference in atmosphere composition if planets all formed from the same nebula?

They all started with the same composition, but the evolution took different paths as determined by the distance to the Sun and consequently the temperature (and mass as well).



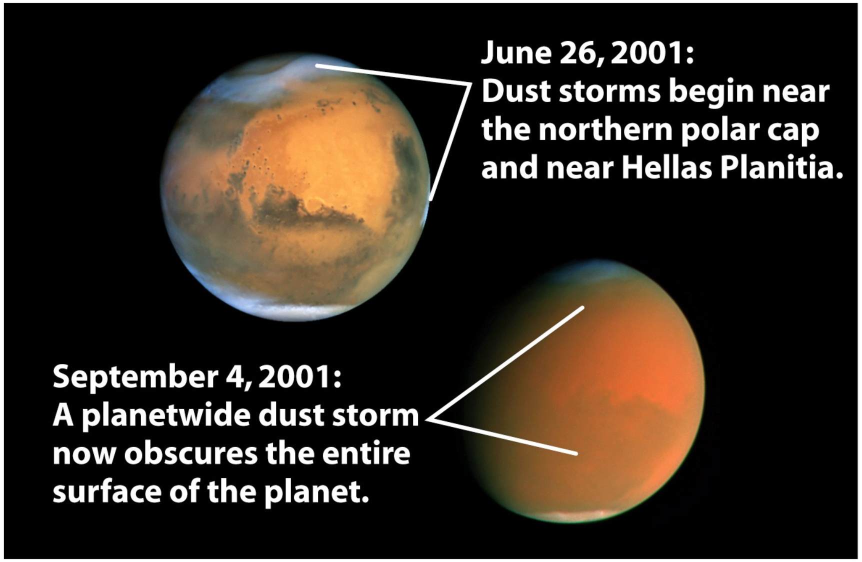
Earth: H_2O & CO_2 are **recycled** between air, ocean, and rocks.

Venus: runaway greenhouse effect ==> dense and hot

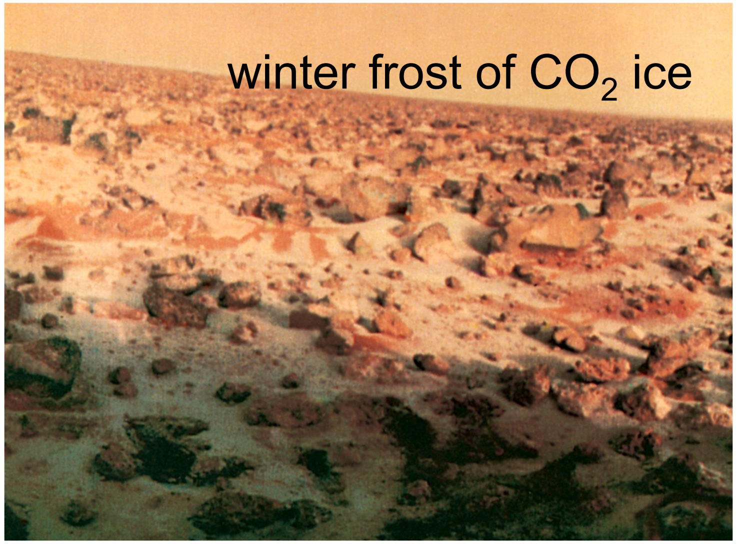
Mars: runaway icehouse effect ==> thin and cool

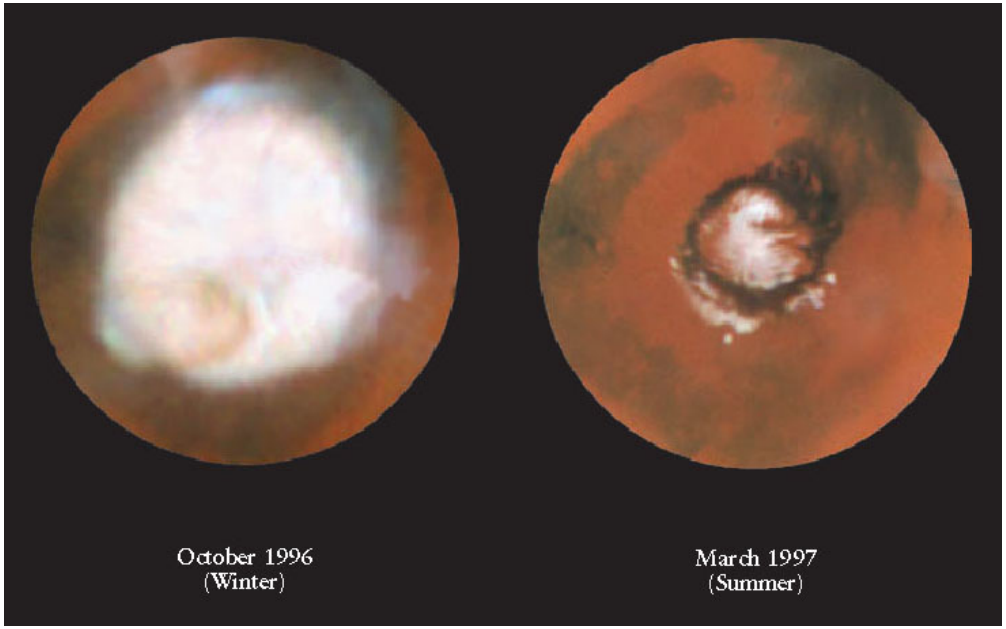
Q: what do you think is the key reason for these differences?

Like Earth, Mars exhibit **seasons** because of the **tilt of the planet's axis.** Both the **temperature** and **air pressure** change drastically with seasons.



Seasonal dust storms change Mars appearance.





seasonal variations of polar caps

Q: why are there large variations in the temperature?

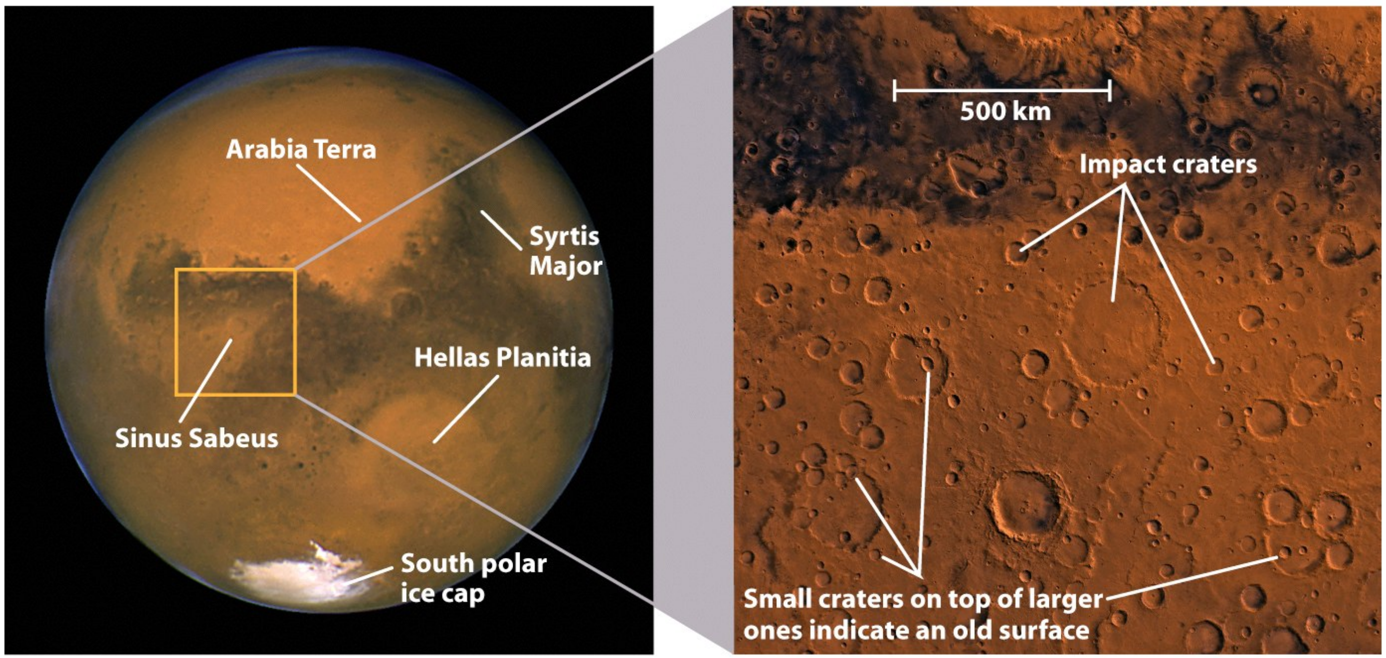
12.5 Surface and geological activities

Moon like Mercury. Volcanic Venus. Diverse Mars.
No plate tectonics

- **Cratering** is the telltale of the **age of a surface** (why?): Mercury is the most heavily cratered thus has an old surface, followed by Mars, Venus and Earth (note: in order of planet's size!).
- **Geological activities** empowered by **internal heat** (here comes the size dependence) renew the planet's surface.
  - -- **volcanoes**: still active on the Earth and perhaps Venus but not Mercury and Mars (why?)
  - -- **plate tectonics** are only found on the Earth: internal heat, molten interior, convection in aesthenosphere, thin and rigid crust, large body of water (ocean plates). How are all these not working on Mercury, Venus, and Mars?
  - -- **weathering** (wind & water erosion) and **life** activities: most evident on Earth, followed by Mars (in the past).

The diverse Mars surface

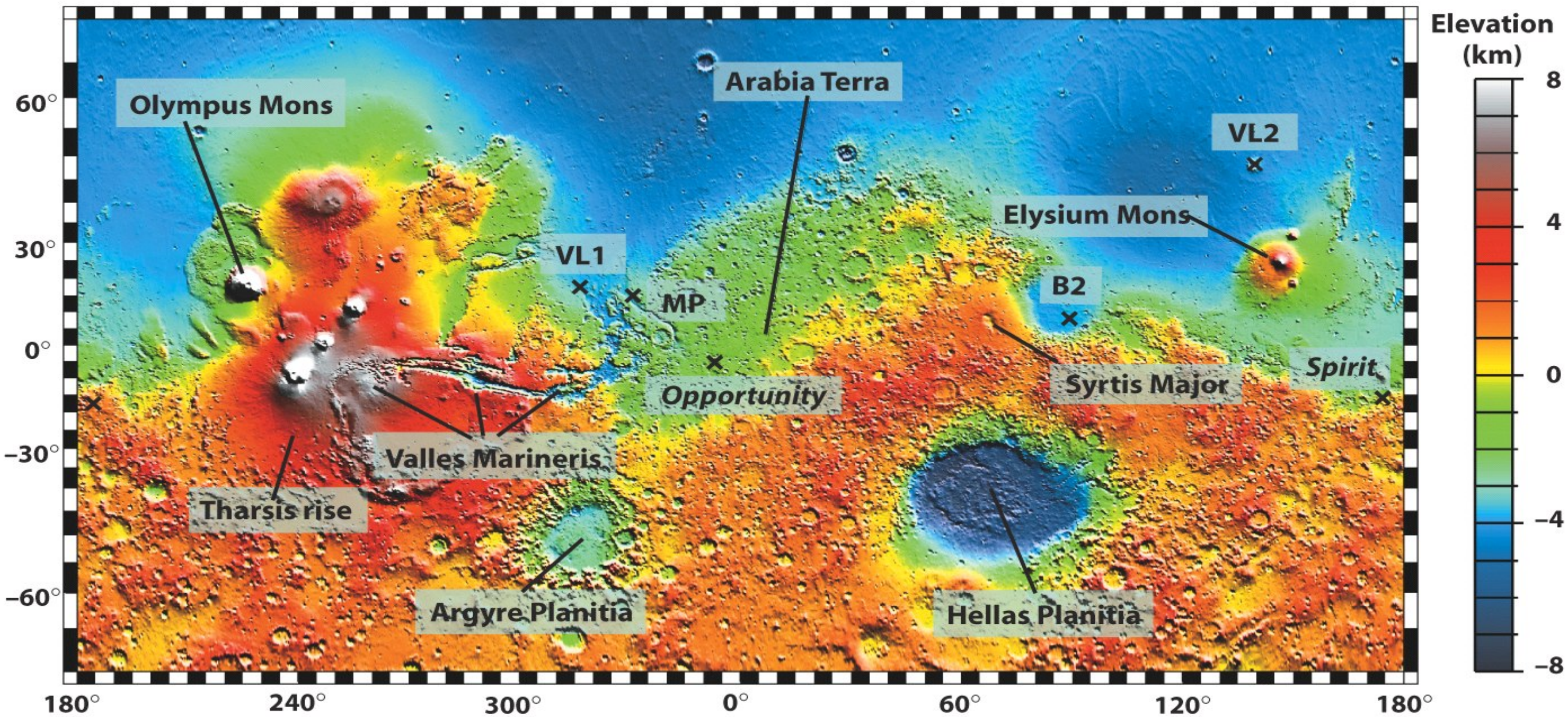
It was considered that Mars harbors water canals, vegetation, and intelligent life, which was found wrong by *Mariner* (1964-69) and followers (http://science.hq.nasa.gov/missions/solar_system).



(a) Mars from the Hubble Space Telescope (b) Closeup of Sinus Sabeus region

Mars is a remarkably diverse planet! Its surface is covered by **craters** (indication of what?), several huge **volcanoes** (driving mechanism?), a vast **rift valley**, and **dried-up riverbeds** (geological history?) --- but no canals.

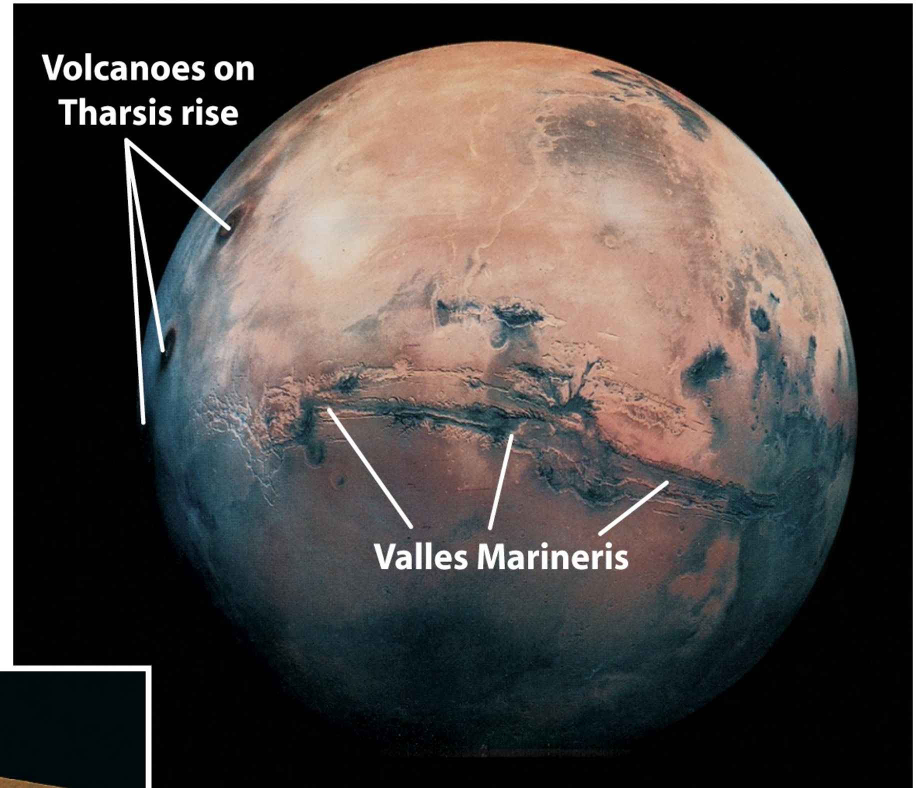
The topography of Mars - **crustal dichotomy**

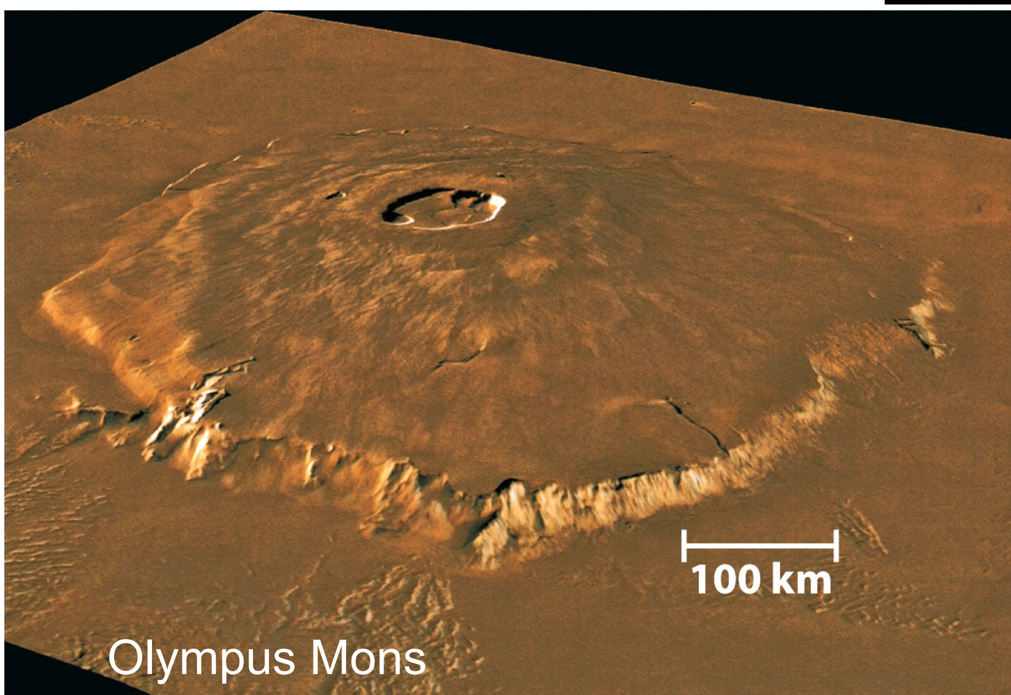


Southern highlands are heavily cratered, and higher and older than the smooth northern lowlands -- how does it compare with the Earth and Moon?

Cause of crustal dichotomy: a giant impact in the North (like how maria were generated on the Moon), or plate tectonics (southern crust was found thicker than northern crust)?

Olympus Mons is the largest Volcano in the solar system. It may be formed by hot-spot volcanism, like on Venus.





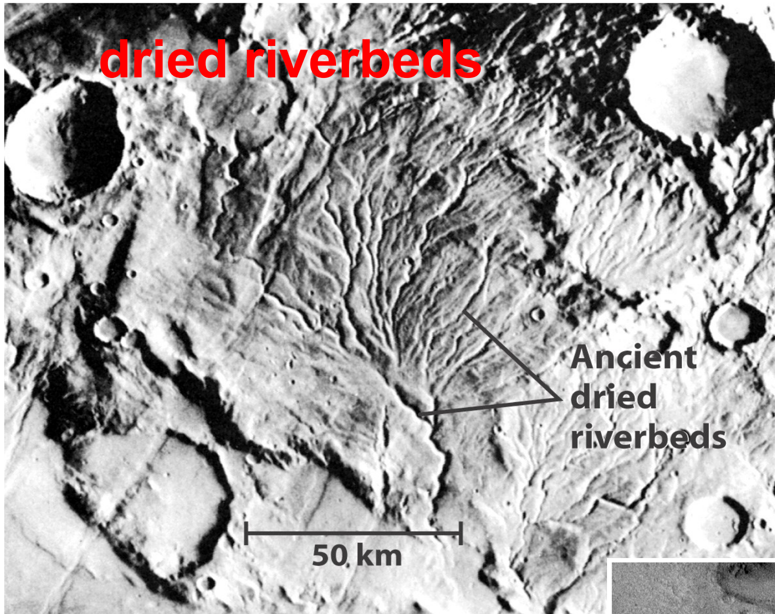
Martian **volcanoes** and the **Valles Marineris rift valley** were formed by upwelling plumes of magma in the mantle.

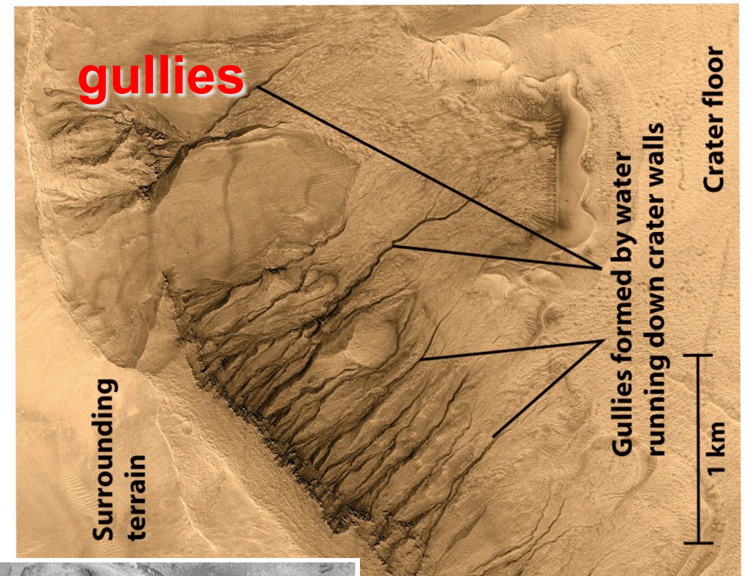
Q: No plate tectonics. Why?

Water on Mars

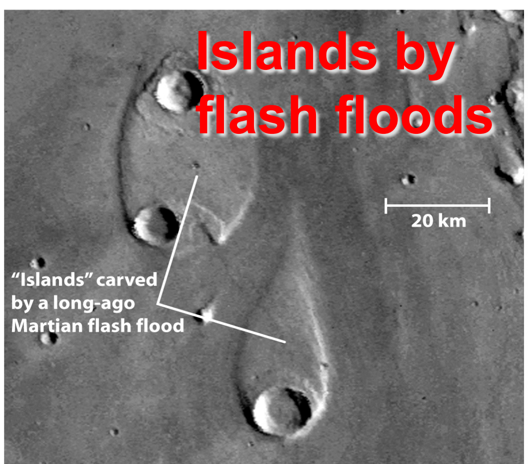
Many surface **erosion features** suggest that water once flowed.

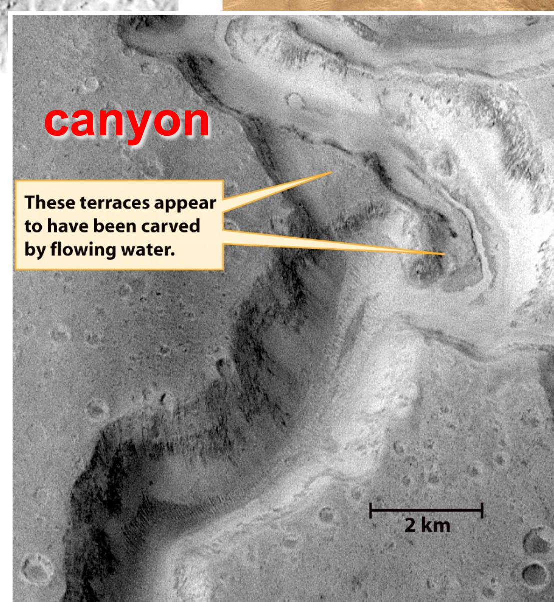
(http://marsprogram.jpl.nasa.gov/mgs/msss/camera/images/)

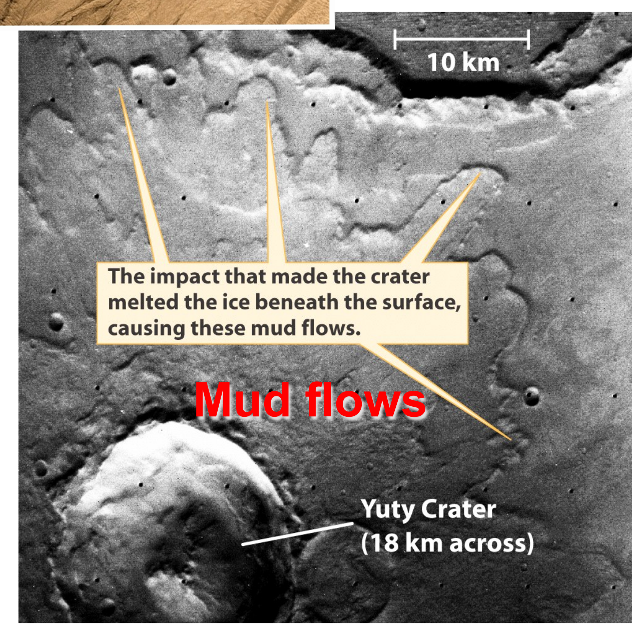




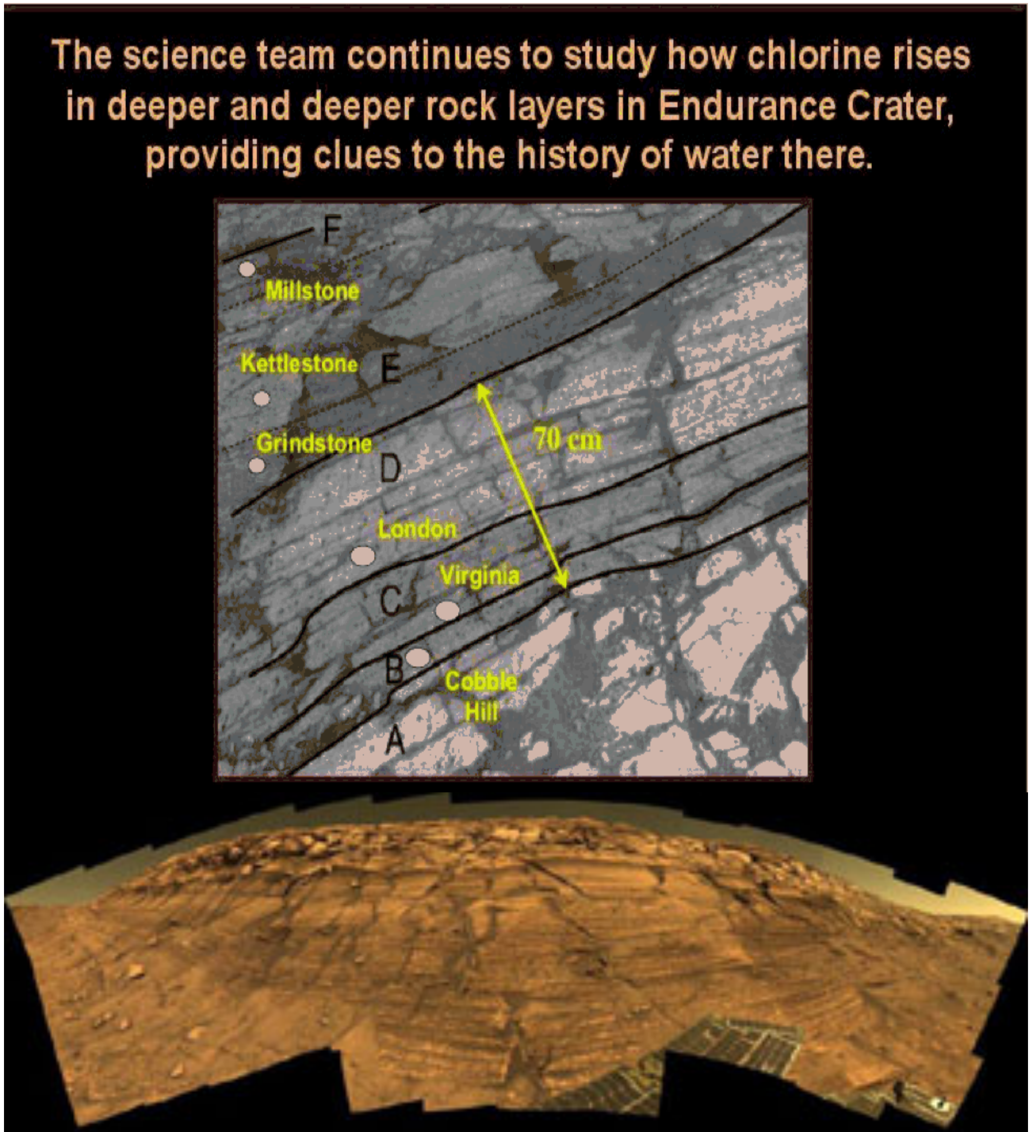
In the past, Mars could be warmer.







Opportunity's investigation on Meridiani Planum



Endurance Crater by Opportunity

Scientists identified three divisions within stacked sedimentary rock layers inside "Endurance Crater." Materials in all three divisions were wet both before and after the layers were deposited by either wind or water. Scientists analyzed how acidic water moving through the layers after they were in place caused changes such as the formation of hematite-rich spherules within the rocks.

Polar ice caps: Mars's water reservoir?

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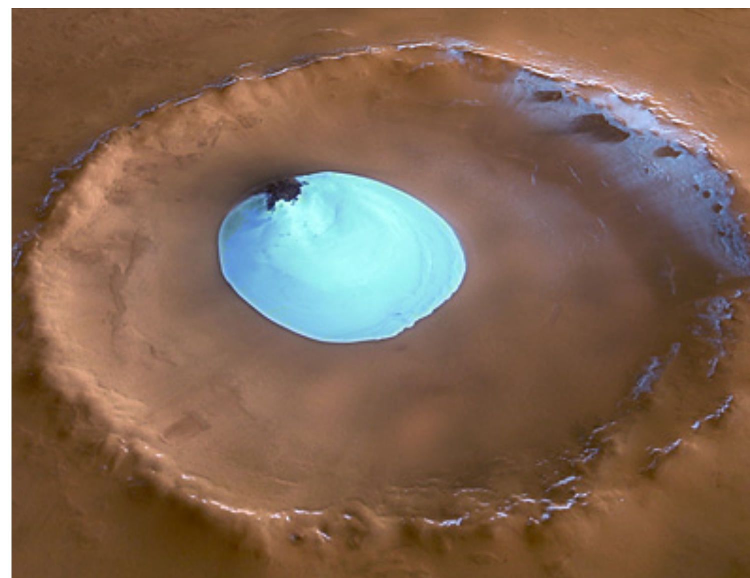
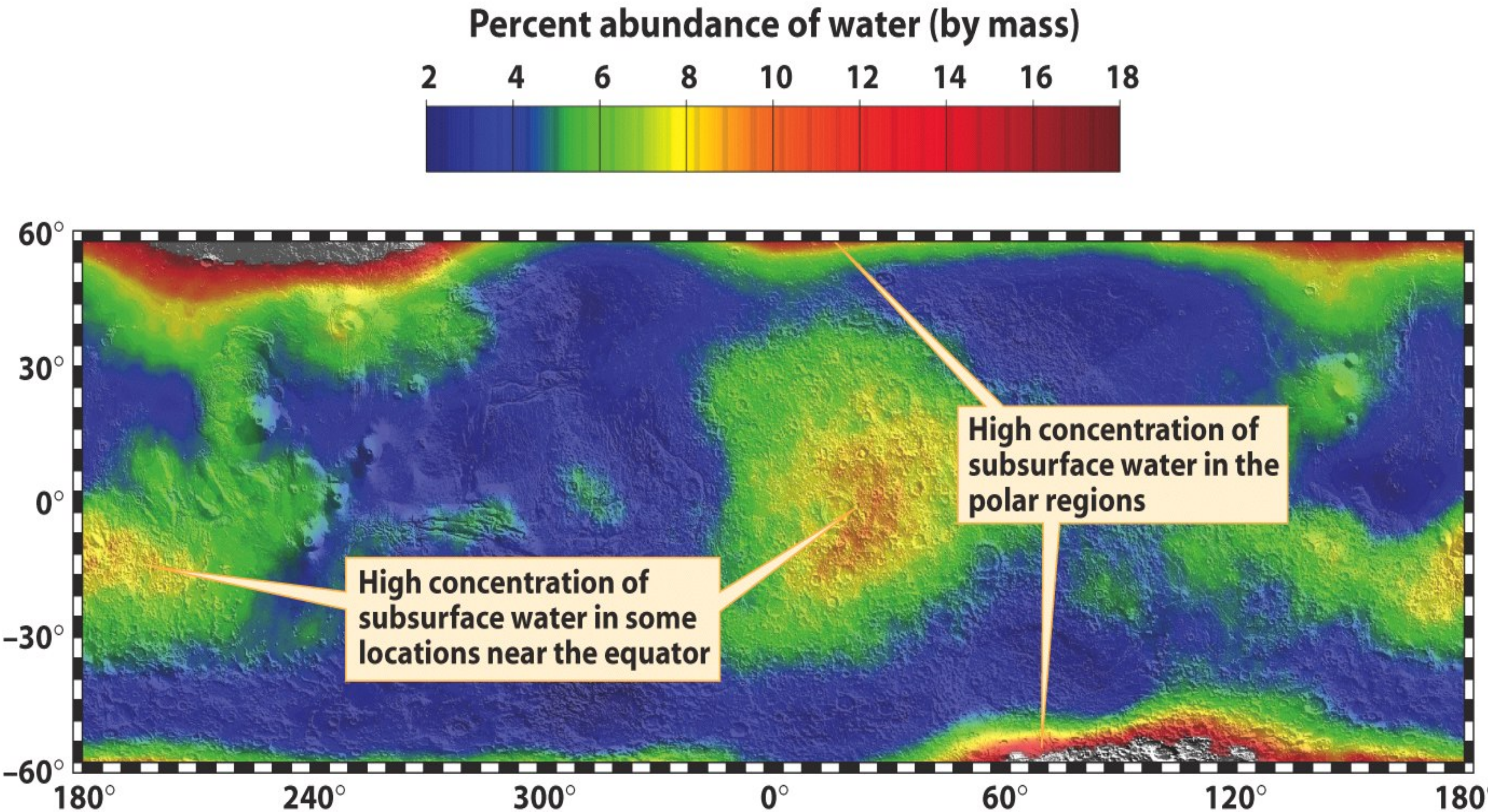
Infrared observations reveal ice water beneath frozen CO_2, by looking at **reflective** properties of the ice surface.

Visible and infrared spectrometers are used to detect ice water below the surface, finding abundant water ice in polar regions. The spectrometer on Mars Reconnaissance Orbiter also sees layers varying in soil composition and mixture with ice, suggesting geologically young layering near the Martian north pole.
Thick layers of possibly water-ice-rich materials are also found below impact structures.

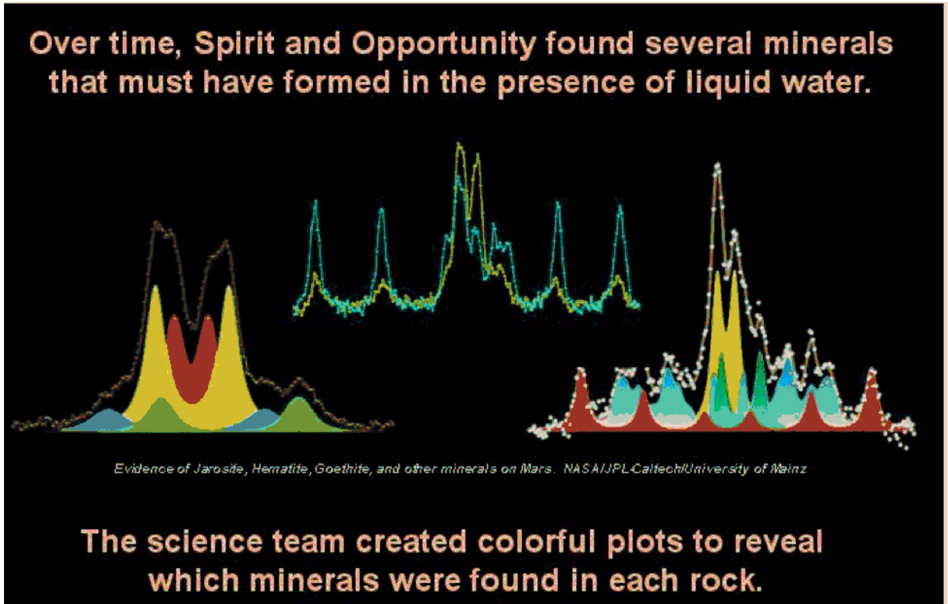

Polar cap by Mars Reconnaissance Orbiter

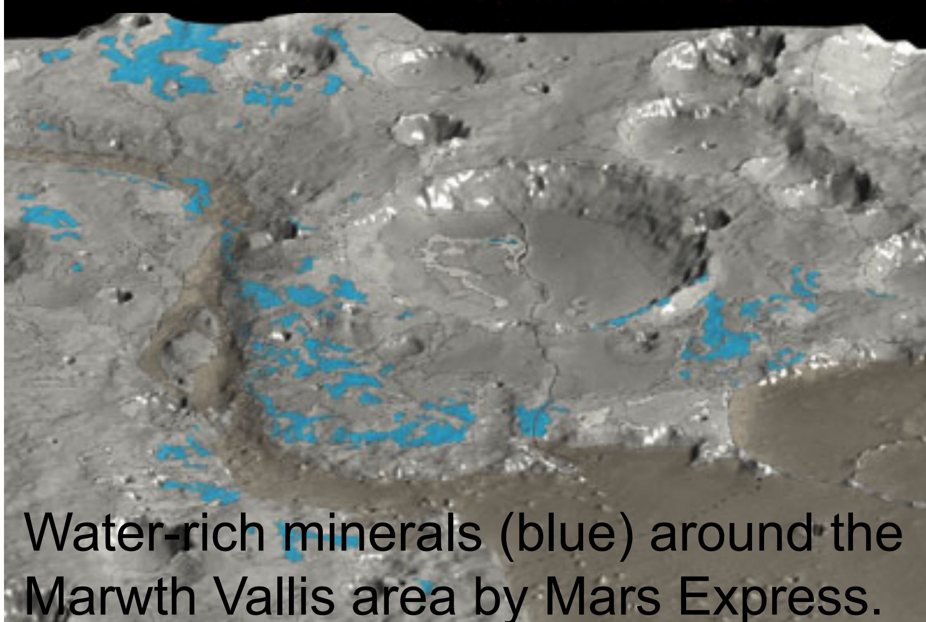

Residual water ice on the floor of Vastitas Borealis Crater (Mars Express).

Water (ice) beneath the Martian surface

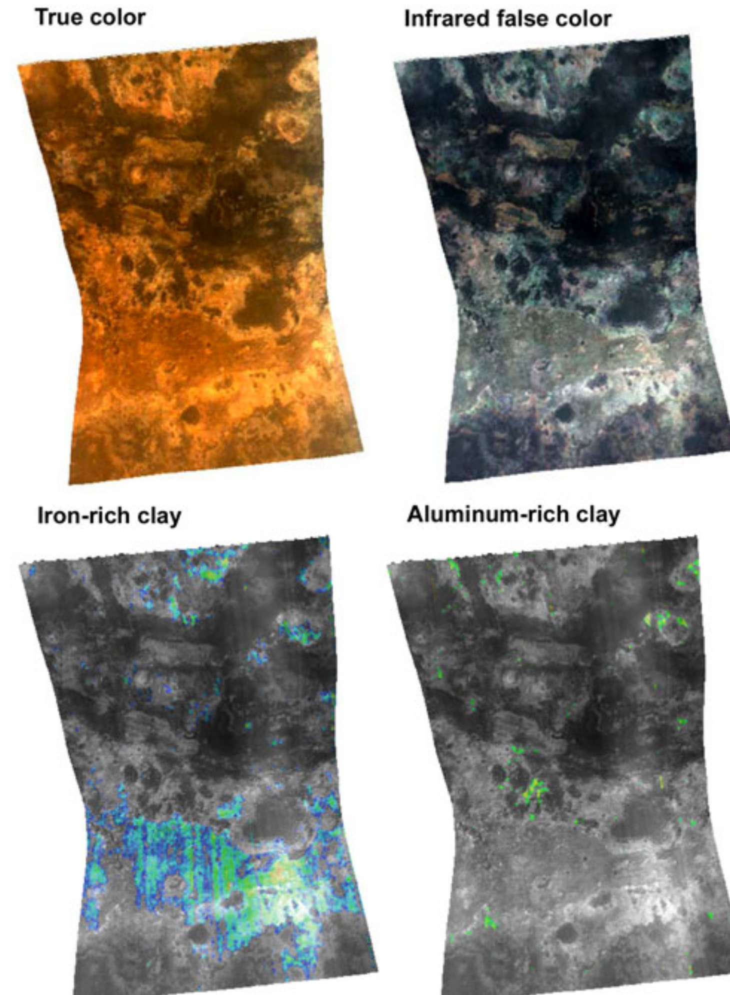


Seeking evidence for water and history of watery environment by studying **composition, erosion features,** and **mineralogy**.





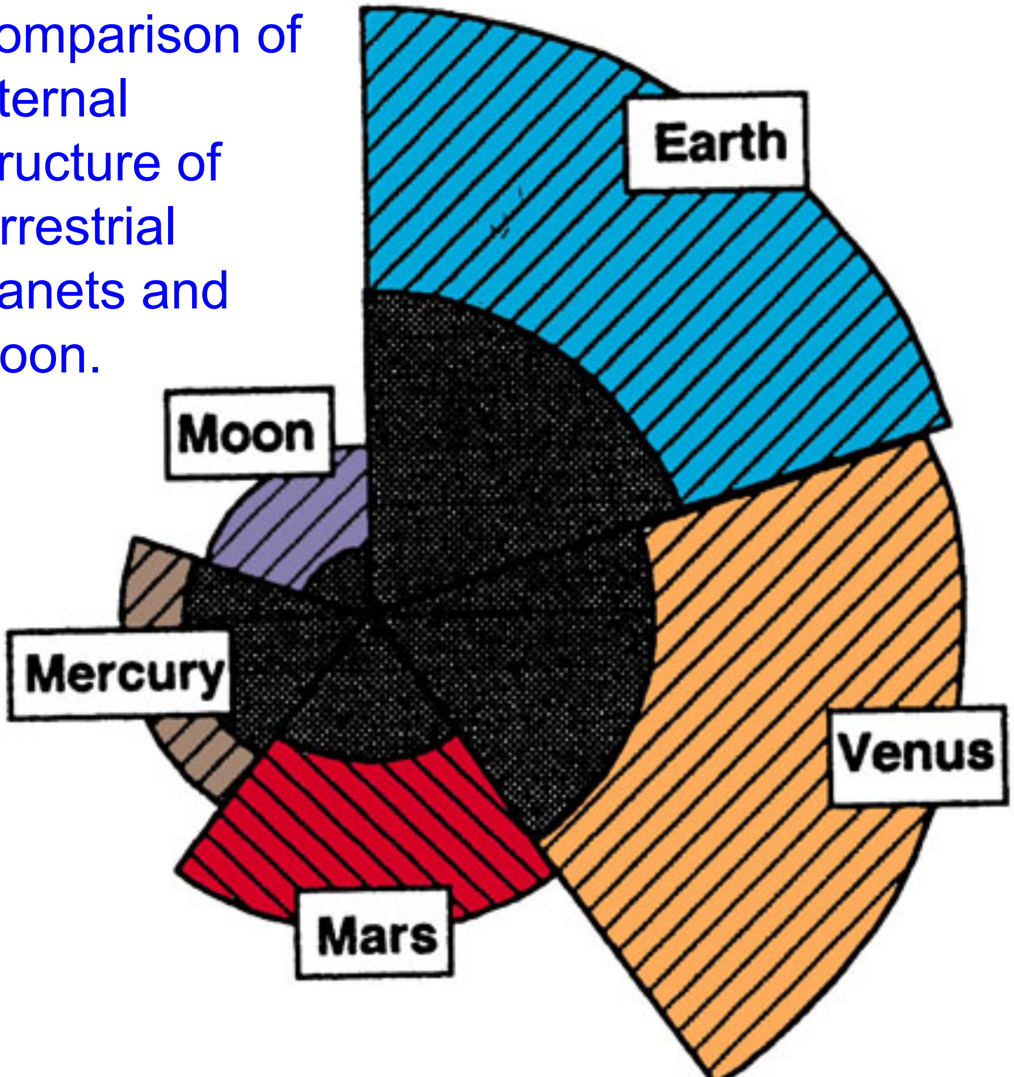
Water-rich minerals (blue) around the Marwth Vallis area by Mars Express.



Spectrometer observations of Mars clay near Mawrth Vallis by Mars Reconnaissance Orbiter

12.6 Interior and magnetic field

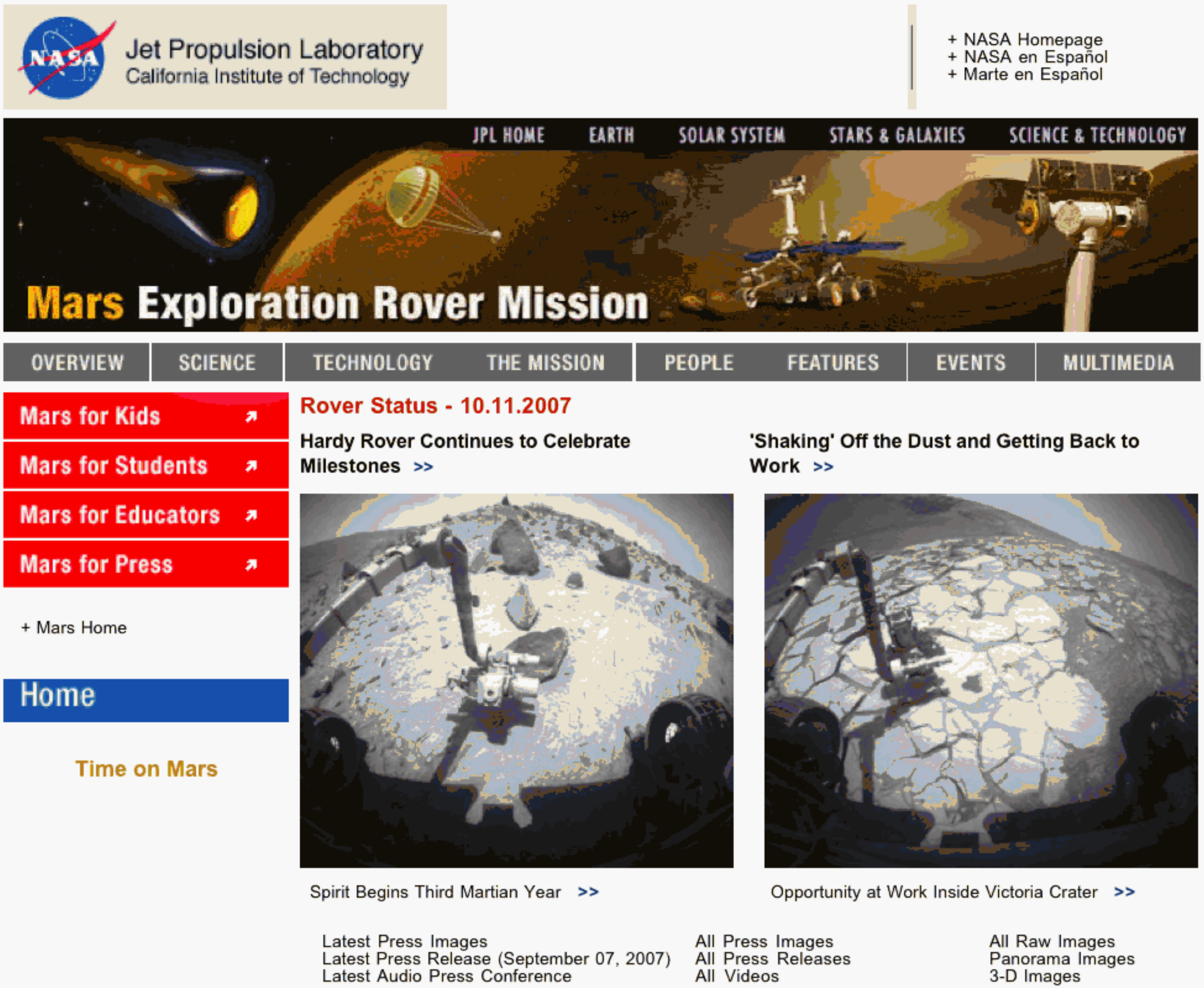
Comparison of internal structure of terrestrial planets and Moon.



- The size of the metal (iron) core largely determines the density: Mars and Moon is less dense than Earth, Mercury, and Venus.
- Earth and Mercury have global magnetic field due to partially liquid iron core.
- Mars and Moon have solid cores, and Venus rotates too slowly, thus no global magnetic field.

(from http://quartz.ucdavis.edu/~gel36/comparison.html)

12. 7 Exploration of Mars: Mars is the most visited.



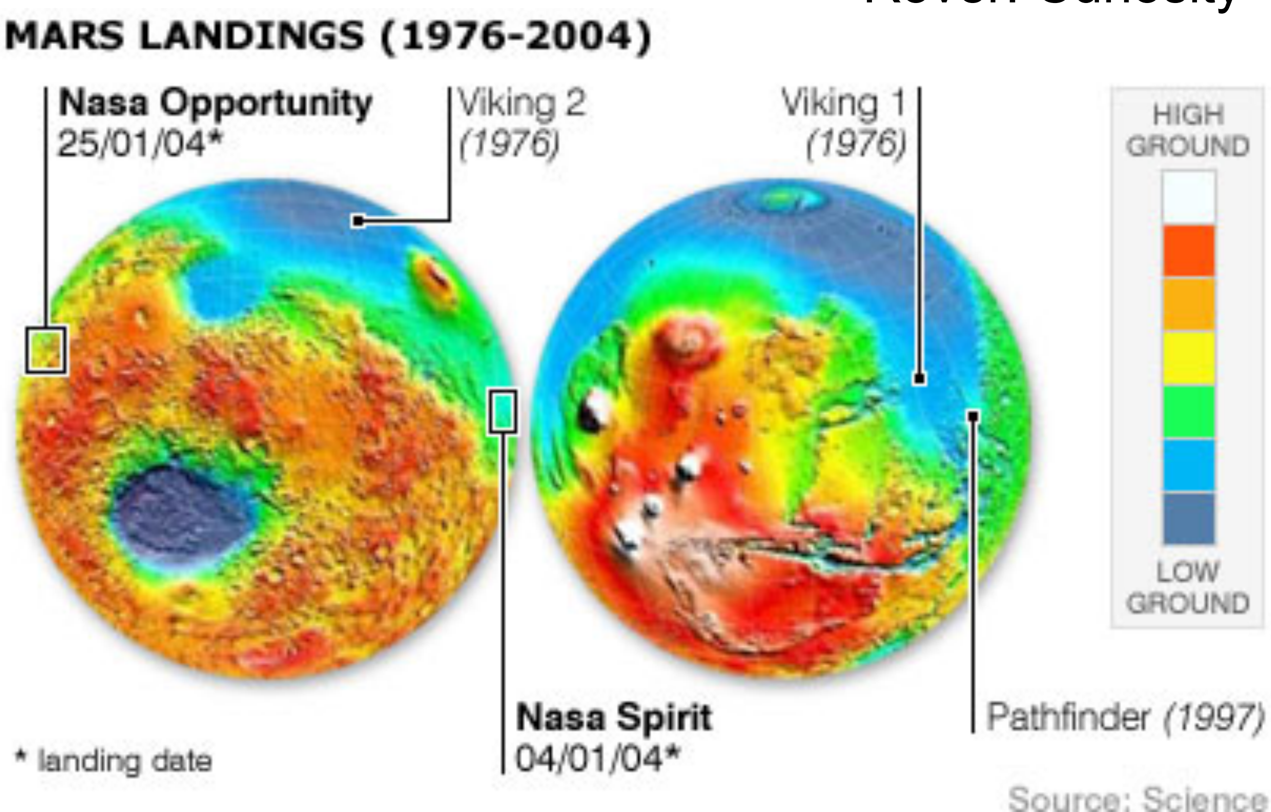
Missions to Mars

Past missions:

- Mariner 4,6,7,9 (1965-71)
- Mars 3,5 (1971-73)
- Viking Orbiters and Landers (1975)
- Pathfinder (1997)

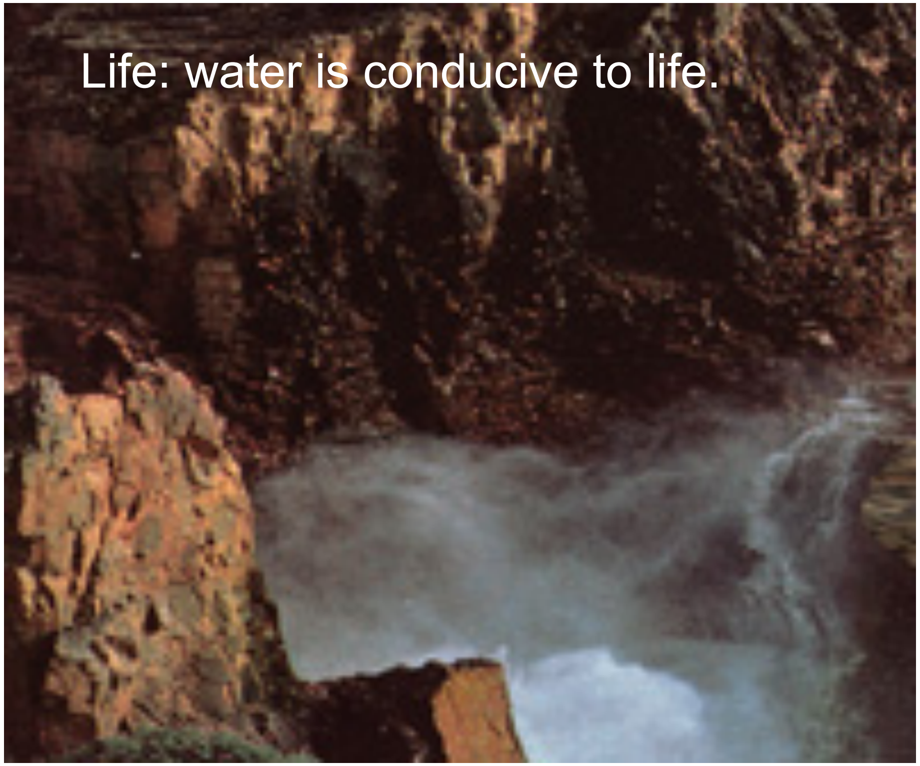
Current missions

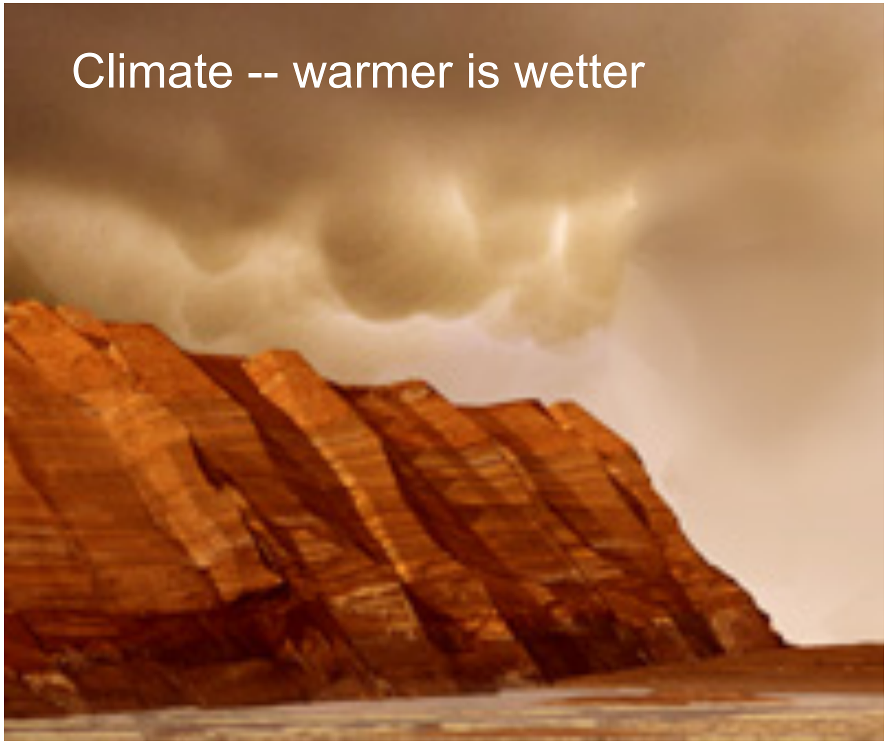
- Mars Global Surveyor
- Mars Odyssey
- Mars Express
- Mars Reconnaissance Orbiter
- Rovers: Spirit and Opportunity
- Rover: Curiosity



Looking for signs of past water on Mars

Understanding the history of water on Mars is important to meeting the four science goals of NASA's long-term Mars Exploration Program (http://mars.jpl.nasa.gov/msl/)





Q: what is the role of water in Earth's climate and geology?

Q: what do you think is to be prepared for human exploration?

Ex.13: science instruments used by the rovers to explore the Mars’s environment (http://marsrovers.jpl.nasa.gov/mission/spacecraft_surface_instru.html)

Key Words

- 1-to-1 spin-orbit coupling
- 3-to-2 spin-orbit coupling
- conjunction
- crustal dichotomy
- eccentricity of orbit
- favorable opposition
- greatest eastern elongation
- greatest western elongation
- gullies
- hot spot volcanism
- inferior planets
- Kepler's three laws
- pancake domes
- polar cap
- prograde rotation
- retrograde rotation
- radar technique
- rift valley
- runaway greenhouse effect
- runaway icehouse effect
- scarp
- solar transit
- superior planets