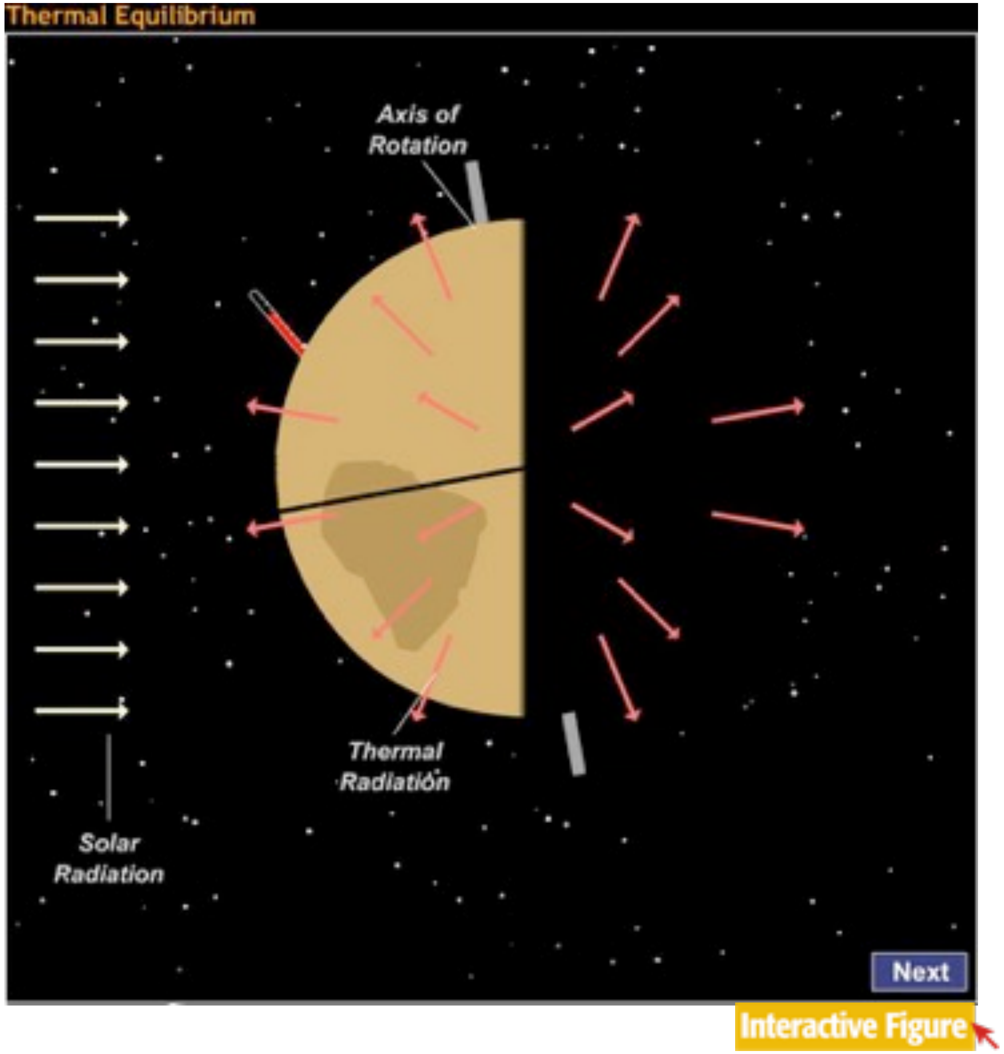
Today

- Terrestrial Planet Atmospheres (continued)

Events

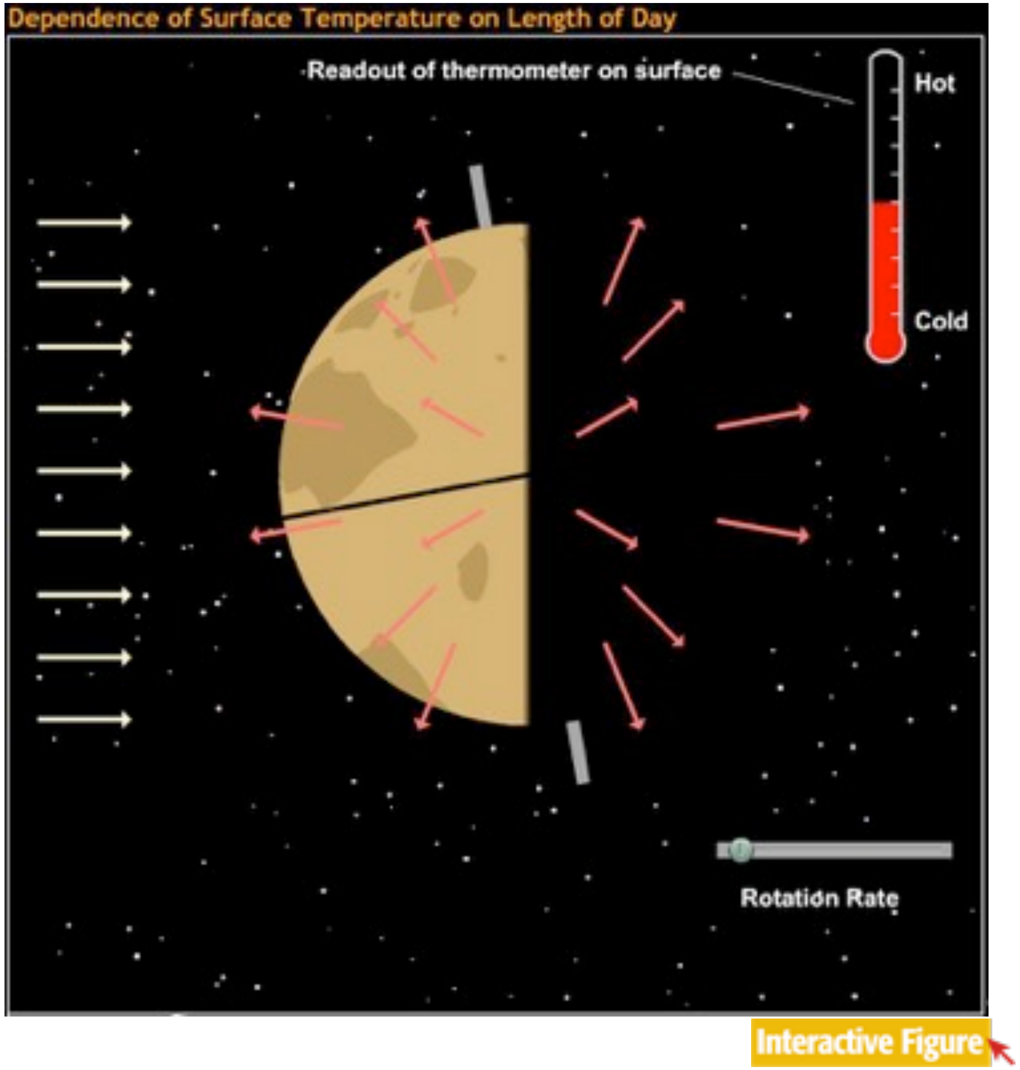
- Homework DUE
- Review next time?
- Exam next week

Planetary Temperature



- A planet's surface temperature is determined by the balance between energy from sunlight it absorbs and energy of outgoing thermal radiation.

Temperature and Rotation



- A planet's rotation rate affects the temperature differences between day and night.
- Rapid rotation evens out temperature variations
- Slow rotation exaggerates temperature variations

Temperature and Reflectivity

- A planet's reflectivity (or *albedo*) is the fraction of incoming sunlight it reflects.
- Planets with low albedo absorb more sunlight, leading to hotter temperatures.
- On planets without an atmosphere, like Mercury and the moon, that's it
  - the surface heats up during the day, and
  - cools off at night

"No Greenhouse" Temperatures

Atmospheres act like blankets, trapping heat.

TABLE 10.2 The Greenhouse Effect on the Terrestrial Worlds

World	Average Distance from Sun (AU)	Reflectivity	"No Greenhouse" Average Surface Temperature*	Actual Average Surface Temperature	Greenhouse Warming (actual temperature minus "no greenhouse" temperature)
Mercury	0.387	12%	163°C	day: 425°C night: –175°C	—
Venus	0.723	75%	–40°C	470°C	510°C
Earth	1.00	29%	–16°C	15°C	31°C
Moon	1.00	12%	–2°C	day: 125°C night: –175°C	—
Mars	1.524	16%	–56°C	–50°C	6°C

*The "no greenhouse" temperature is calculated by assuming no change to the atmosphere other than lack of greenhouse warming. For example, Venus has a lower "no greenhouse" temperature than Earth even though it is closer to the Sun, because the high reflectivity of its bright clouds means that it absorbs less sunlight than Earth.

- Venus would be 510°C colder without greenhouse effect.
- Earth would be 31°C colder (below freezing on average).

Planetary climates

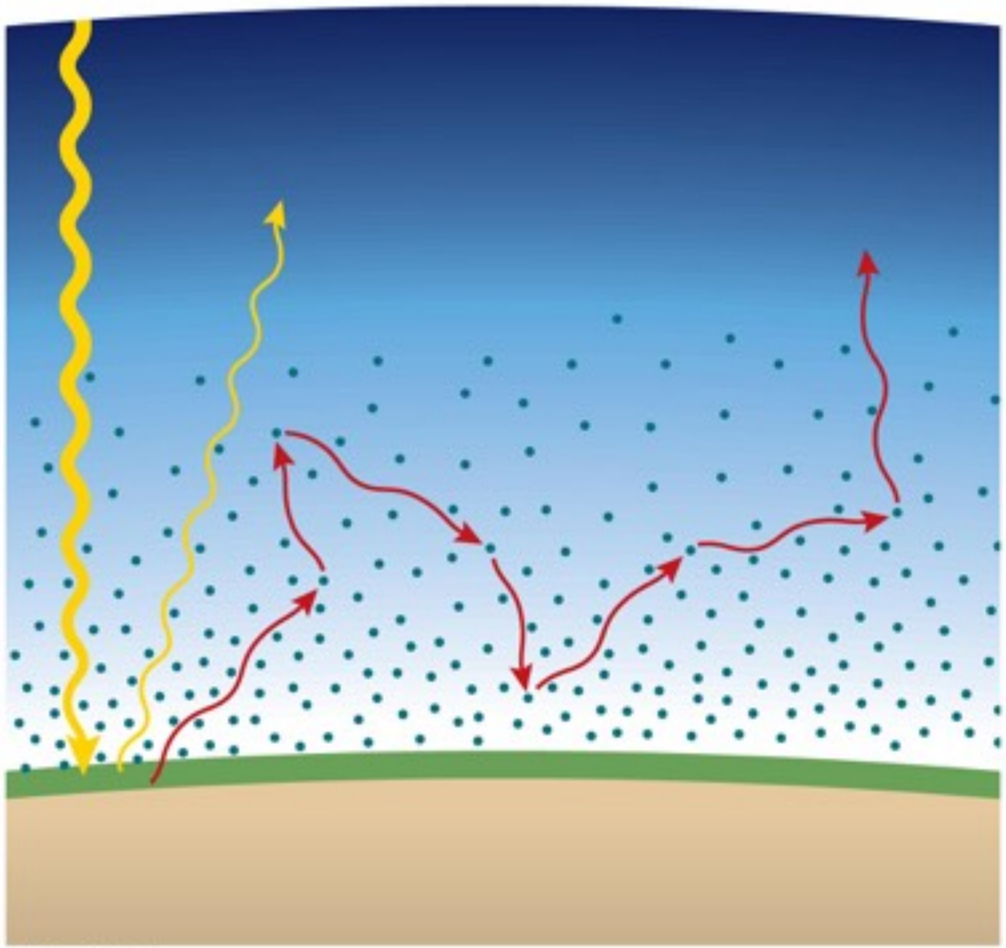
close to sun

- Mercury (no atmosphere)
  - Hot on day side, cold on night side
- Venus (thick atmosphere)
  - Hot all the time (hotter than Mercury!)
- Earth ("nice" atmosphere)
  - "just right"
- Moon (no atmosphere)
  - Hot on day side, cold on night side
- Mars (thin atmosphere)
  - colder now than in past

same distance from sun

far from sun

Greenhouse Effect



- Visible light passes through the atmosphere and warms a planet's surface.
- The atmosphere absorbs infrared light from the surface, trapping heat.

Greenhouse Gas

- Any gas that absorbs infrared
- Greenhouse gas: molecules with two different types of elements (H_2O, CO_2, CH_4)
  - though a minority of the atmosphere, they provide the bulk of the infrared opacity
- Not a greenhouse gas: diatomic molecules with two atoms of the same element (O_2, N_2)
  - Though oxygen and nitrogen compose the bulk of the atmosphere, they do not absorb in the infrared so don't contribute to the greenhouse effect

Main greenhouse gases
(on the Earth)

– all are < 1% of atmosphere, but provide

- Water (H_2O) ~60% of infrared opacity
- Carbon dioxide (CO_2) ~22%
- Methane (CH_4) ~7%
- Others (ozone, CFCs, nitrous oxide) ~11%

Note: water vapor absorbs more IR than CO_2!

Greenhouse Effect: Bad?

Just talking about the *natural* Greenhouse effect,
not any man-made addition to it.

The Earth is much warmer than it would be without an atmosphere because of the greenhouse effect. That's good!

(cf. the moon)

…the same can be said for Venus,
only more so...

Why is Venus so hot?

The greenhouse effect on Venus keeps its surface temperature at 470°C (878°F). That's higher than Mercury, even though it is farther from the sun.

The difference is the greenhouse effect.

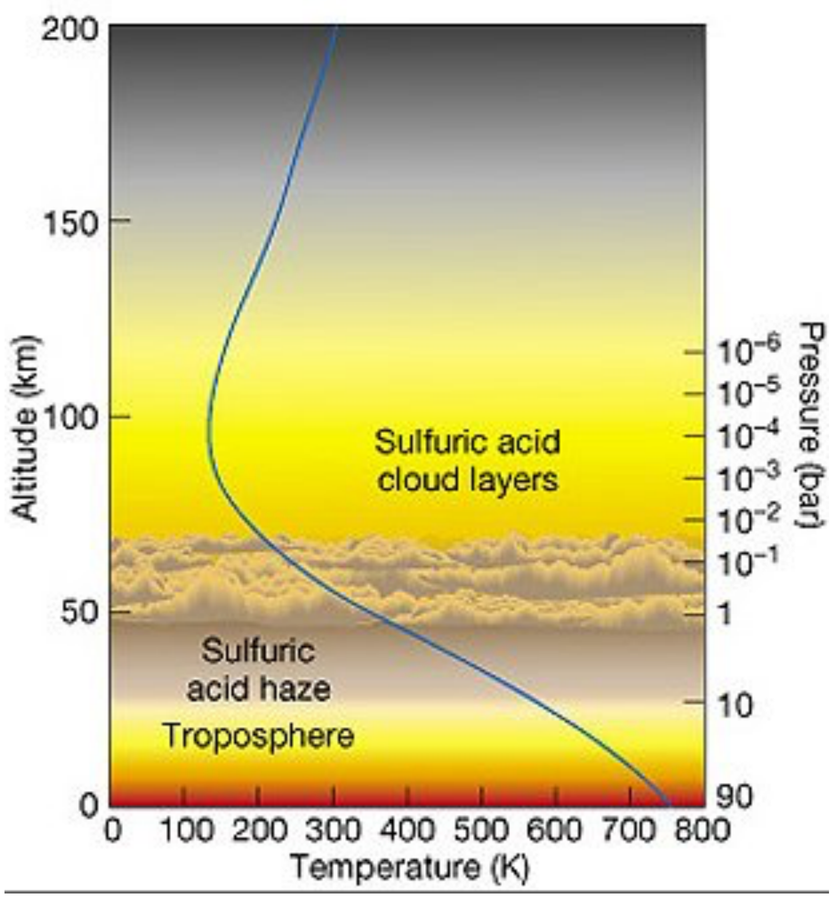
Why is the greenhouse effect on Venus so much stronger than on Earth?

Atmosphere of Venus

- Venus has a very thick carbon dioxide atmosphere with a surface pressure 90 times that of Earth.
- That's equivalent to nearly a kilometer beneath the surface of the ocean.

Venus

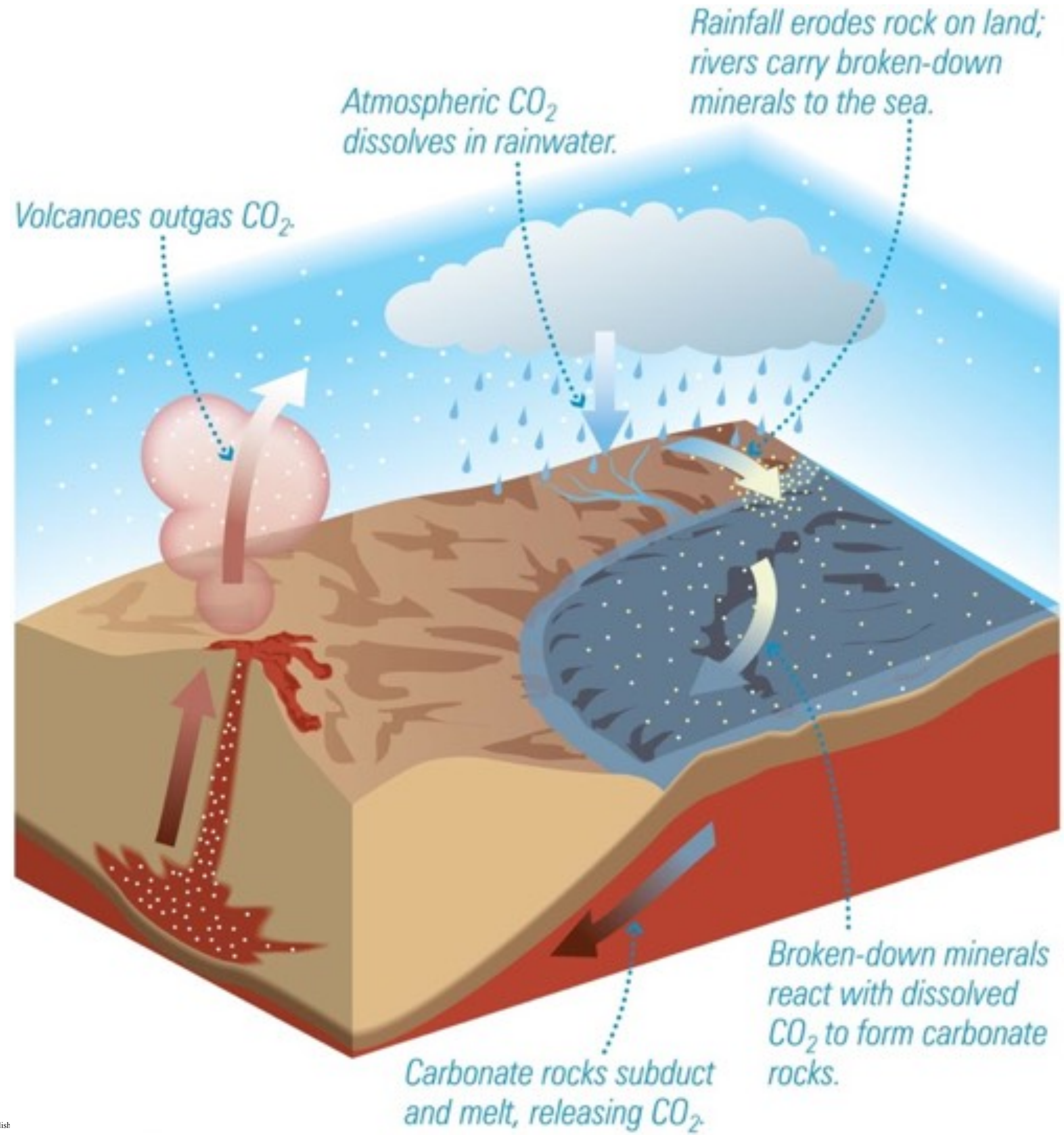
- Permanently shrouded in clouds of sulfuric acid
- Albedo of clouds high
  – little sunlight absorbed
  – yet temperature high
- Earth-like temperature and pressure about 50-60 km altitude



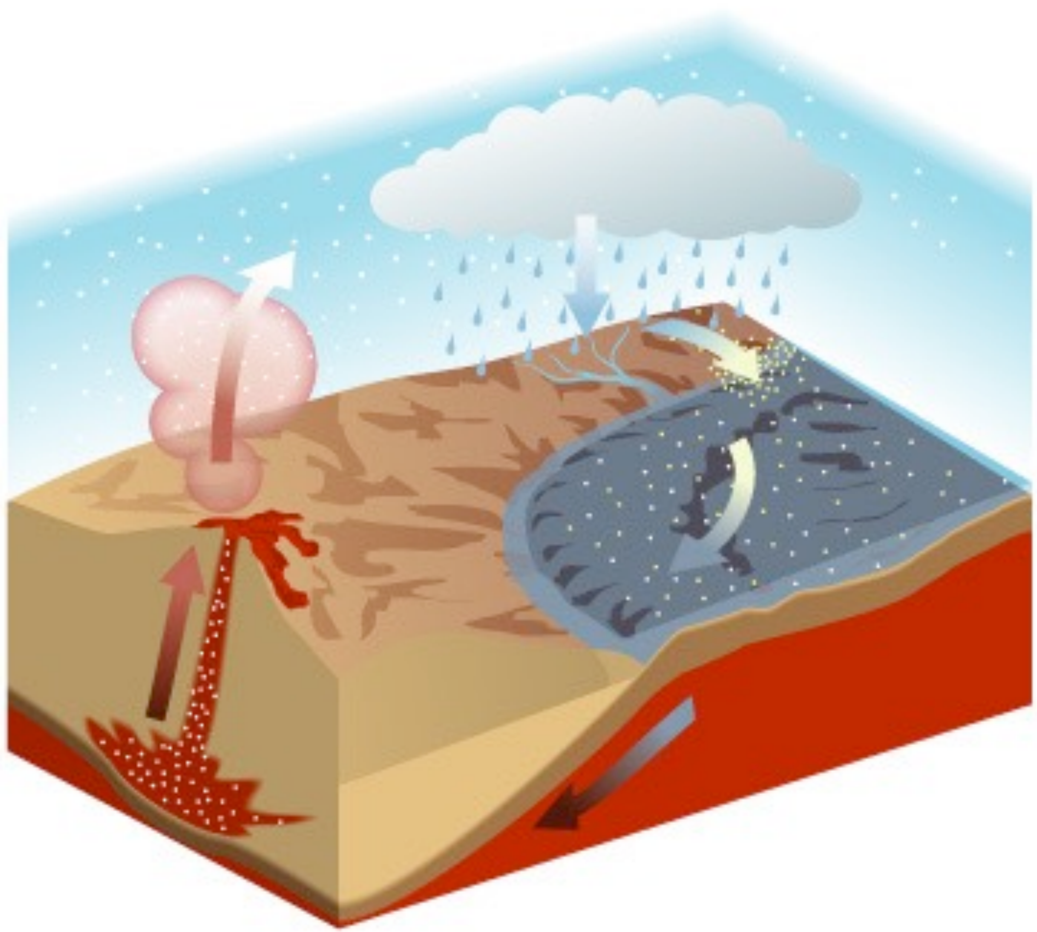
Greenhouse Effect on Venus

- Thick carbon dioxide atmosphere produces an extremely strong greenhouse effect.
- Earth escapes this fate because most of its carbon and water are in rocks and oceans.

Carbon cycle on Earth

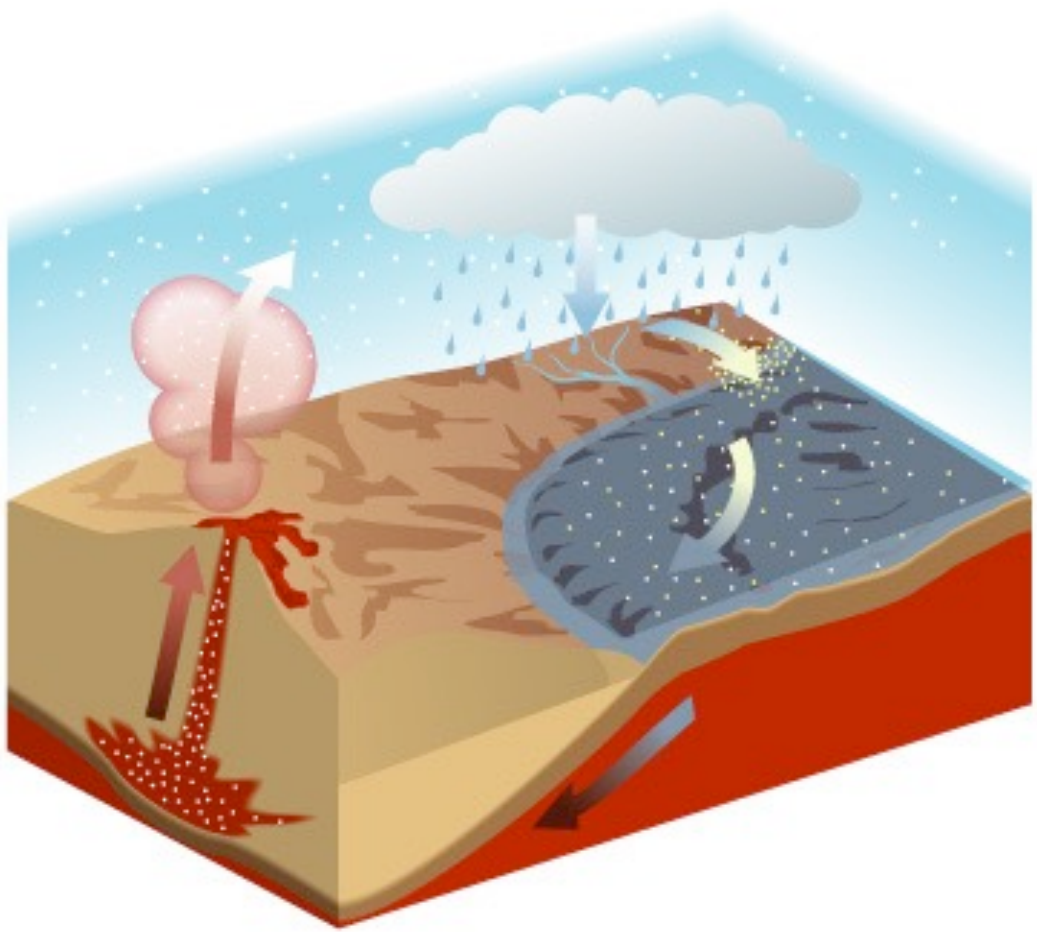


Carbon Dioxide Cycle



1. Atmospheric CO_2 dissolves in rainwater.
2. Rain erodes minerals that flow into the ocean.
3. Minerals combine with carbon to make rocks on ocean floor.

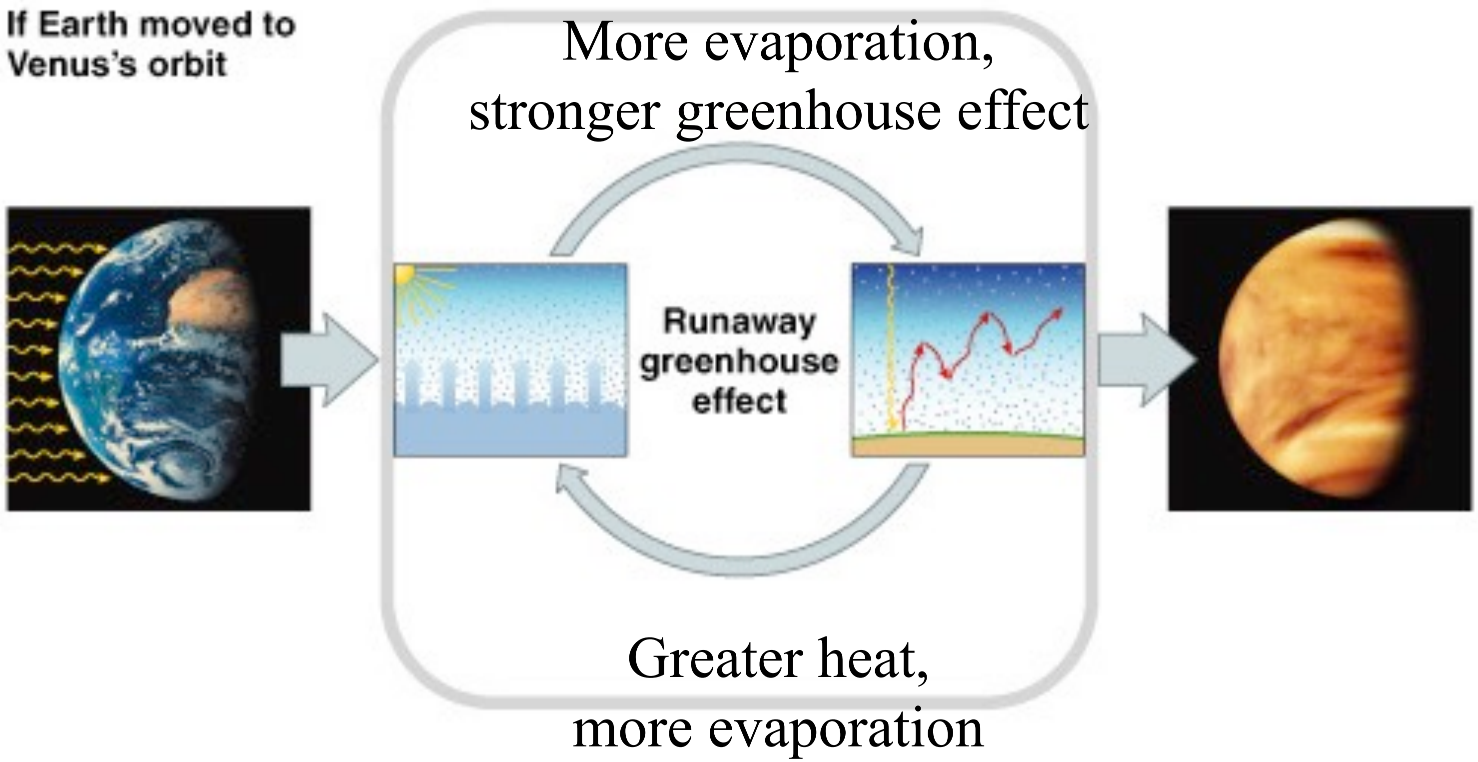
Carbon Dioxide Cycle



4. Subduction carries carbonate rocks down into the mantle.

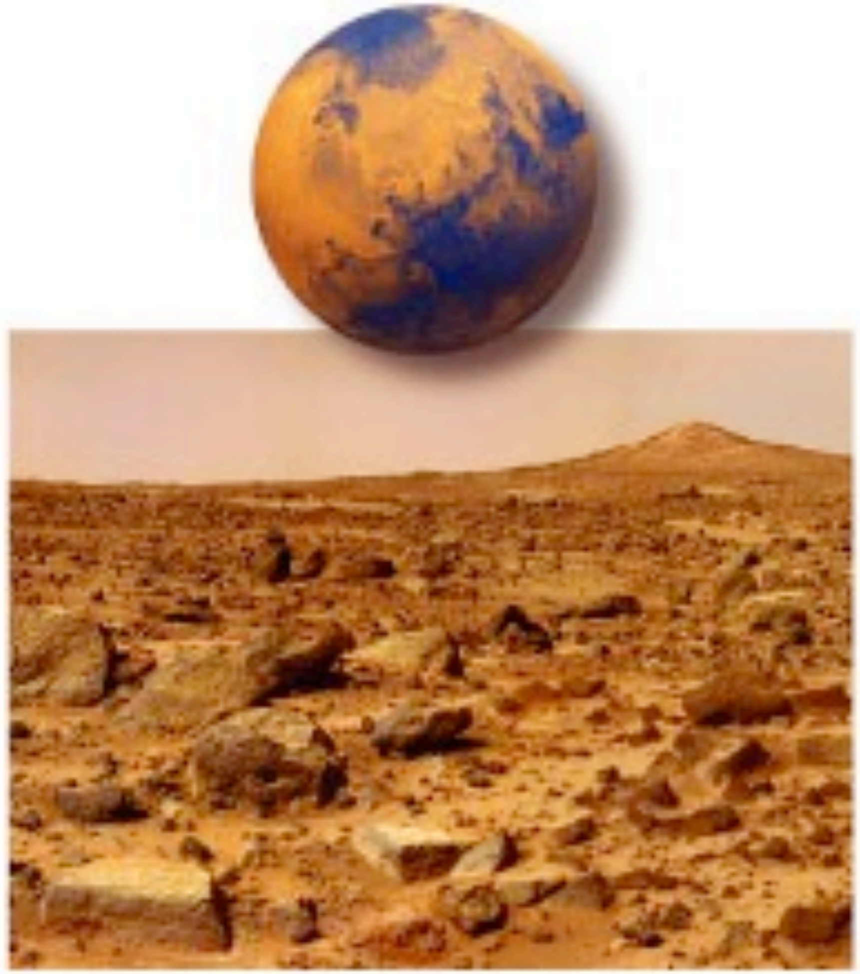
5. Rock melts in mantle and outgases CO_2 back into atmosphere through volcanoes.

Runaway Greenhouse Effect



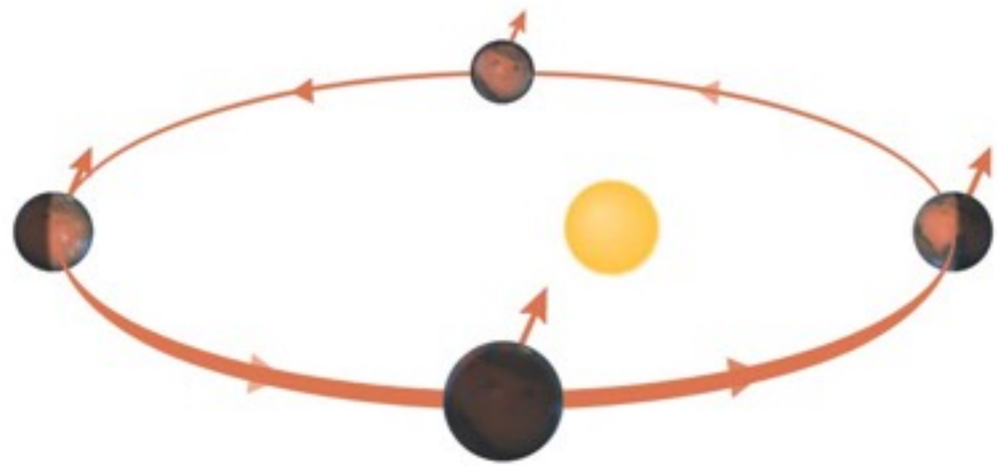
- Oceans evaporate; no longer absorb CO_2.
  - CO_2 builds up in atmosphere unchecked
  - "runaway greenhouse"

Mars: the opposite extreme



- Low gravity and a thinning atmosphere led to a runaway icehouse.
- Mars atmosphere currently ~1% as thick as Earth's

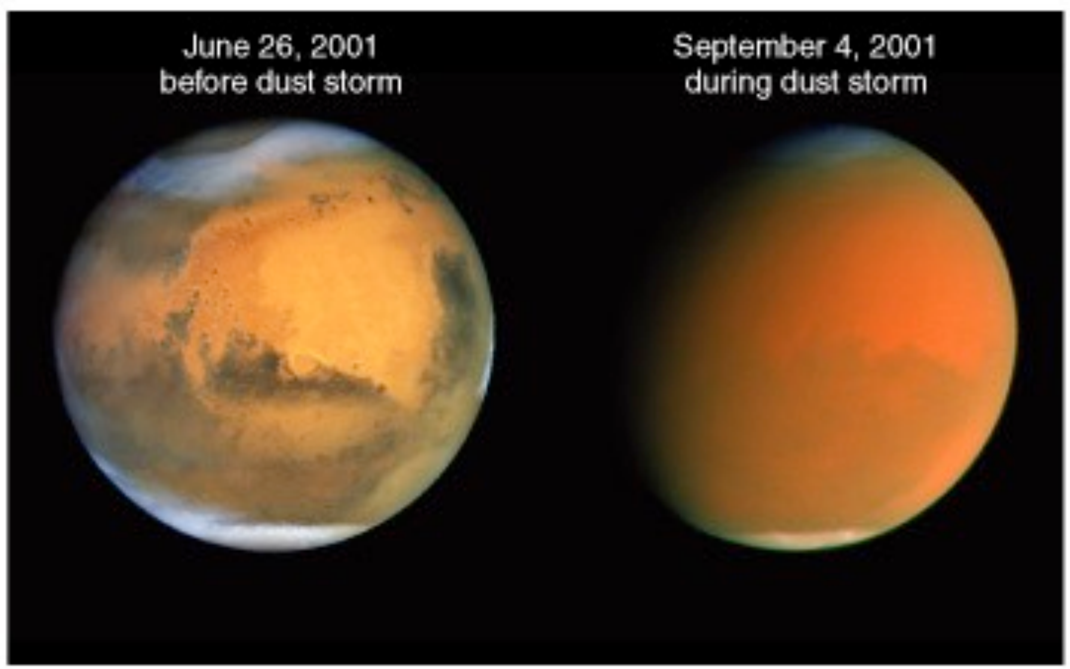
Seasons on Mars

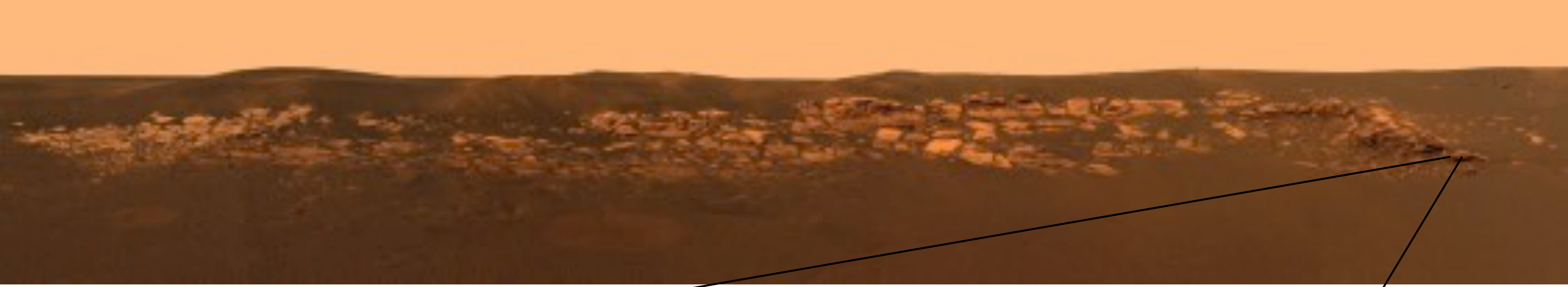


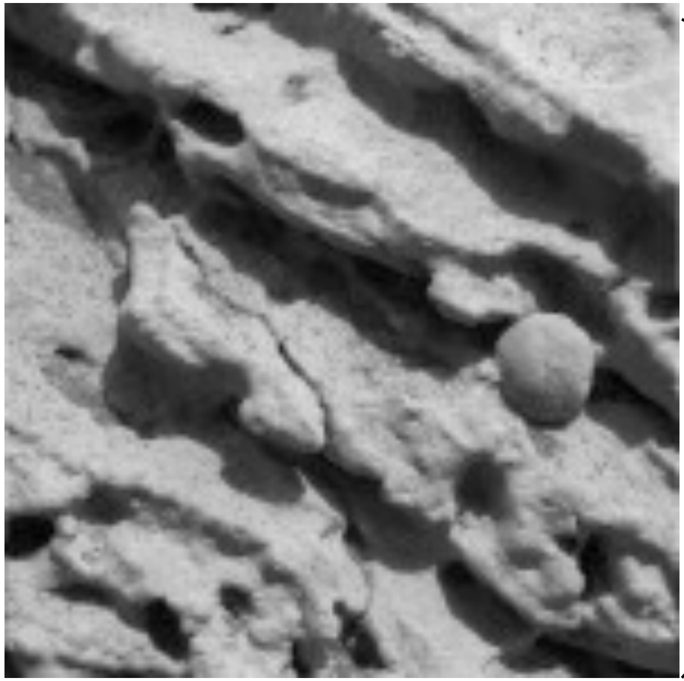
- Mars does have seasons; both axial tilt and distance from the sun matter.
- Seasons on Mars are more extreme in the southern hemisphere because of its elliptical orbit.

Storms on Mars

- Seasonal winds on Mars can drive huge dust storms.
- Drive ongoing wind erosion

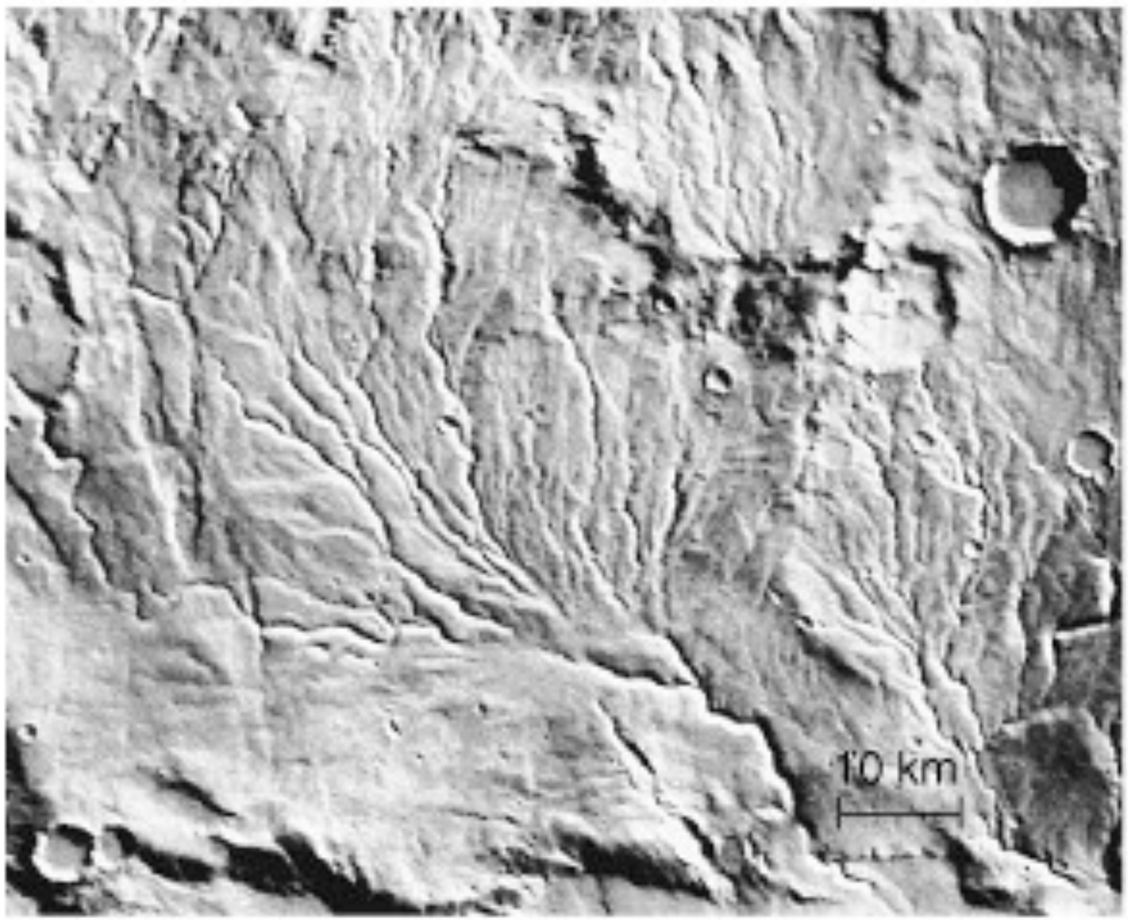






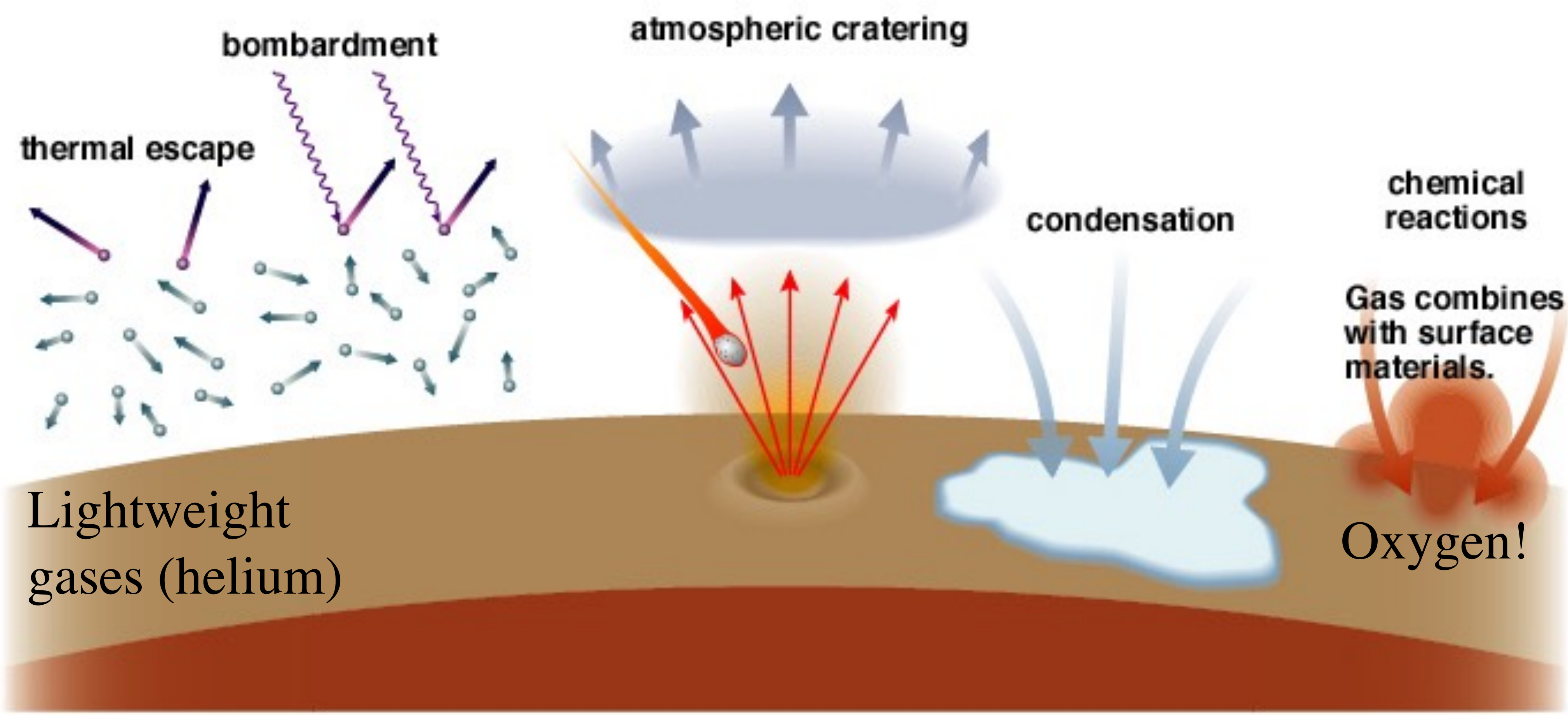
- 2004 *Opportunity* Rover provided strong evidence for abundant liquid water on Mars in the distant past.
- How could Mars have been warmer and wetter in the past?

Climate Change on Mars



- Mars has not had widespread surface water for 3 billion years.
- The greenhouse effect probably kept the surface warmer before that.
- Over time, Mars lost most of its atmosphere.

Factors affecting atmospheres

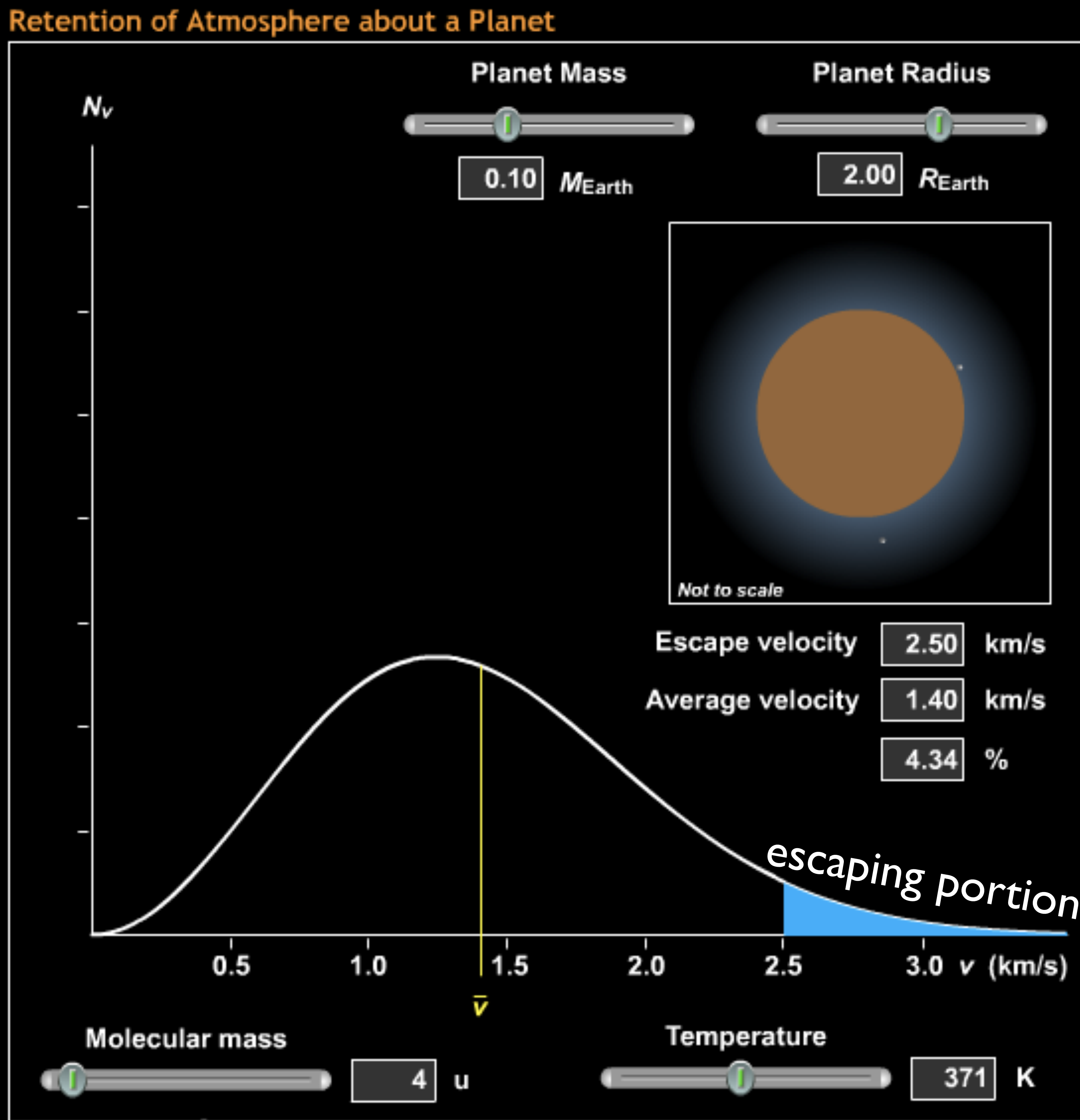


Can break up water vapor; hydrogen escapes

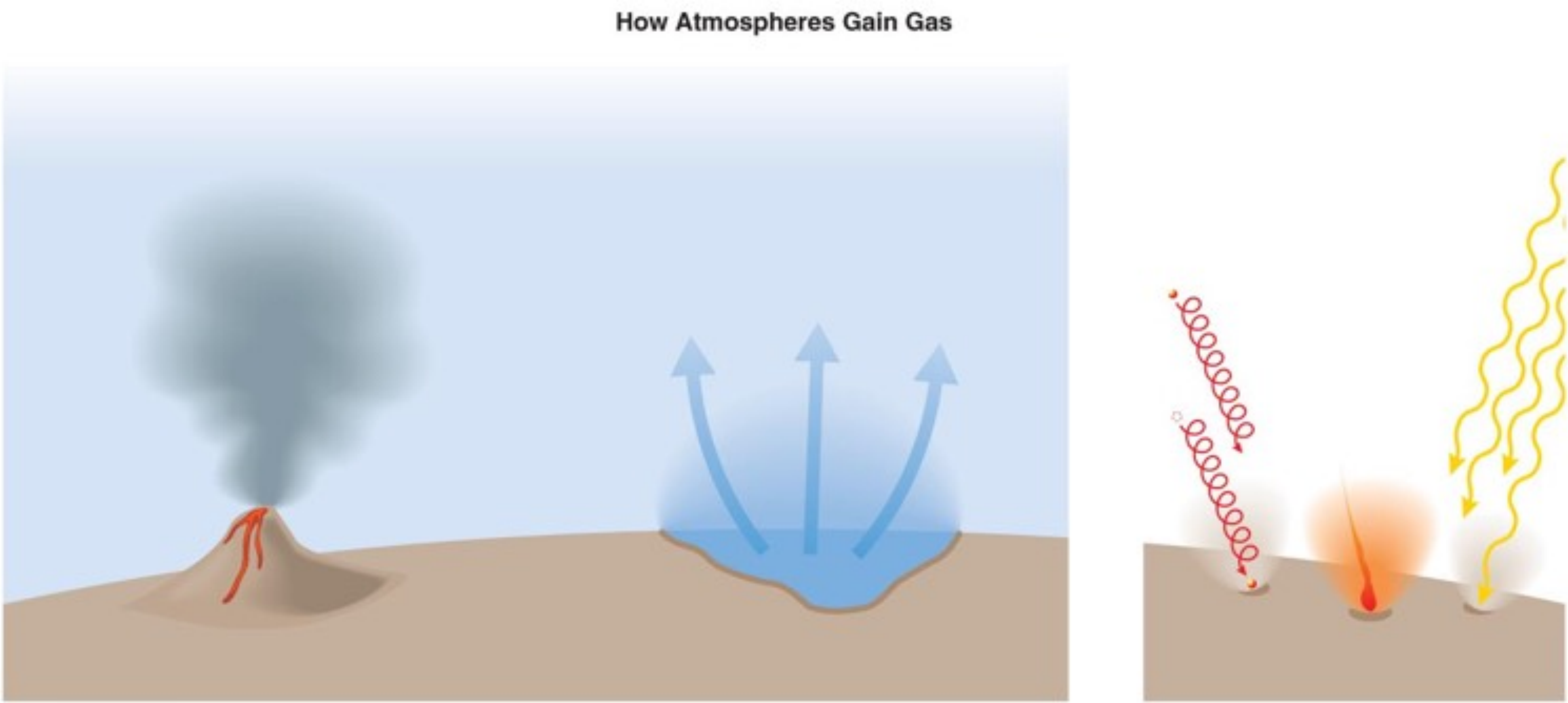
Water can freeze out

Thermal escape

If atmospheric gas is hot enough, some of it exceeds escape velocity and leaks into space.



Sources of Gas

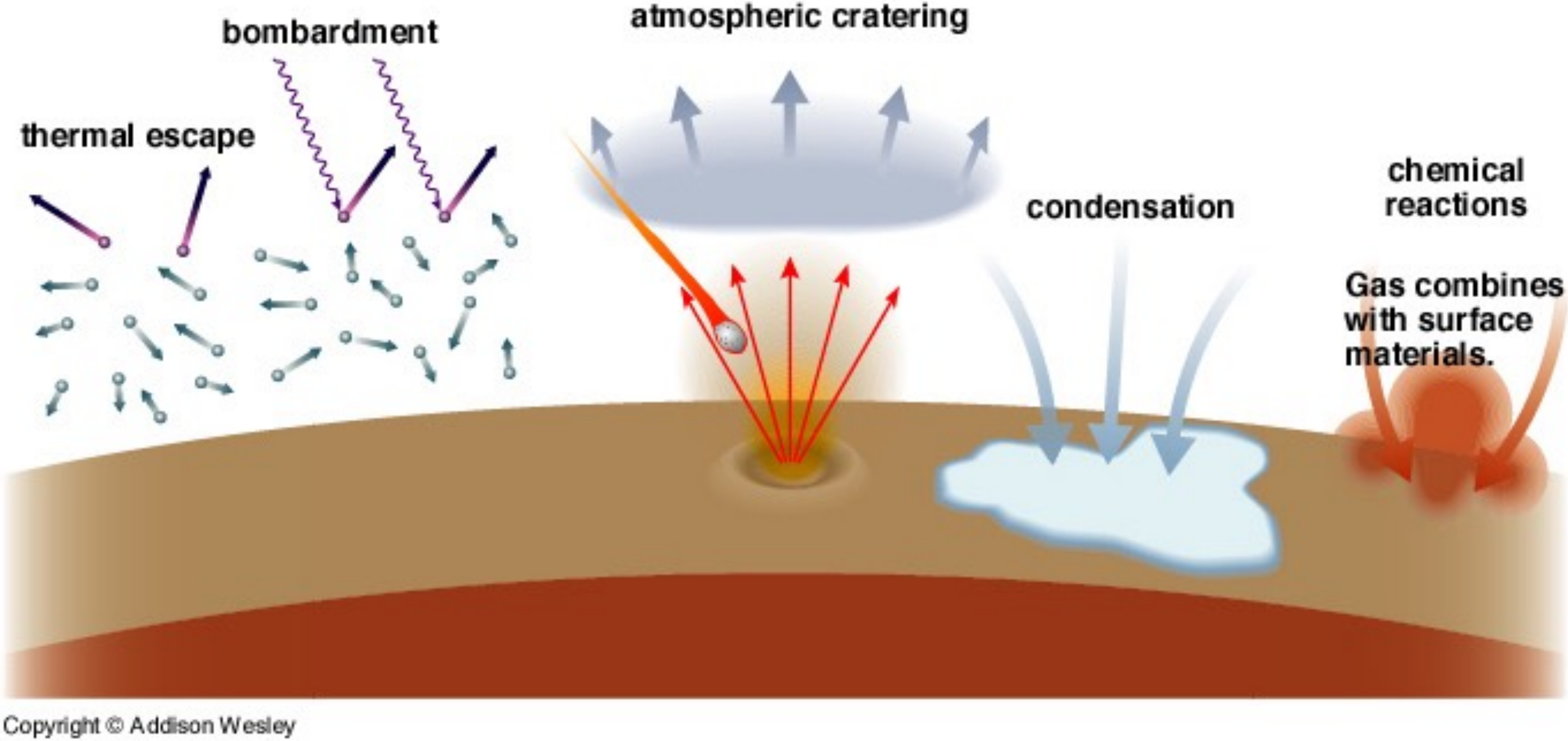


Outgassing from volcanoes

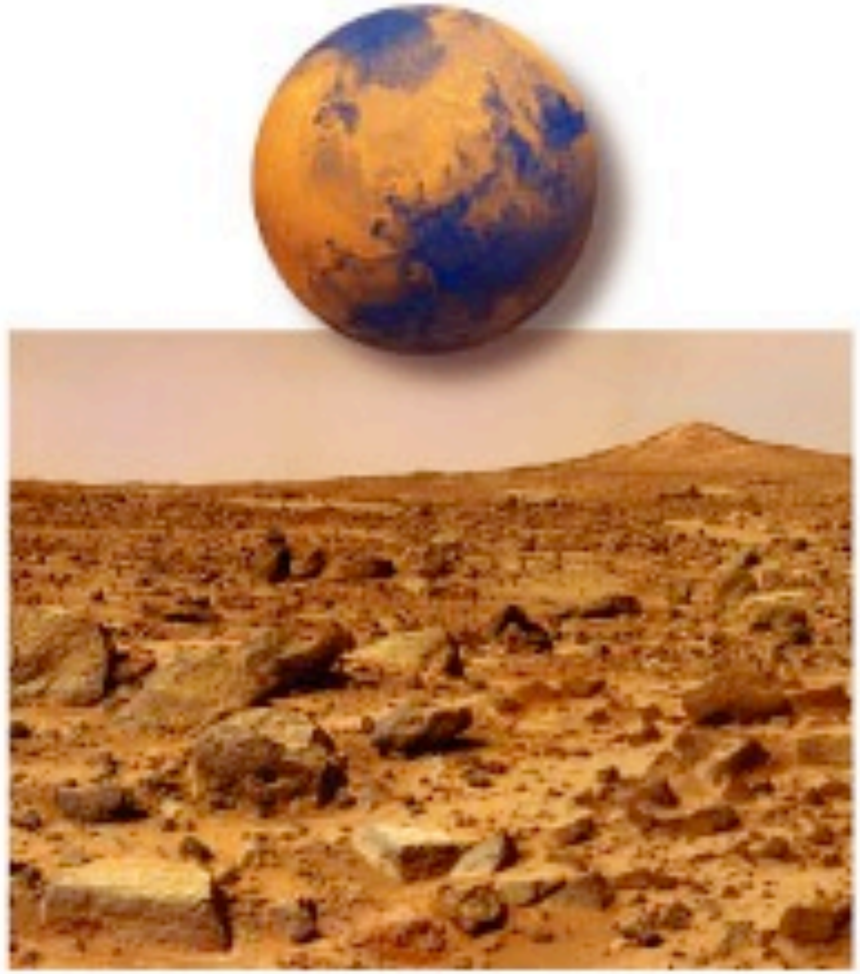
Evaporation of surface liquid; sublimation of surface ice (cometary coma)

Impacts of particles and photons e.g., comets

Loss of gas

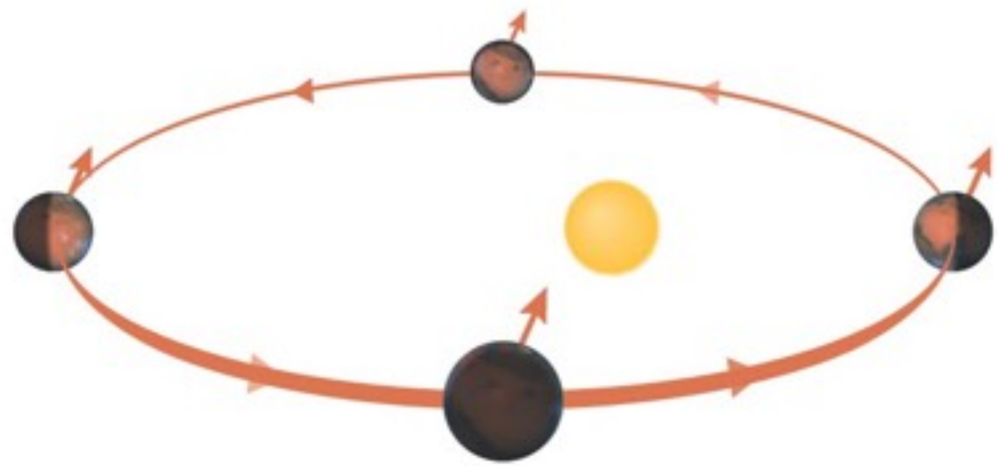

bombardment
atmospheric cratering
thermal escape
chemical reactions
condensation
Gas combines with surface materials.
Copyright © Addison Wesley

Mars: runaway icehouse



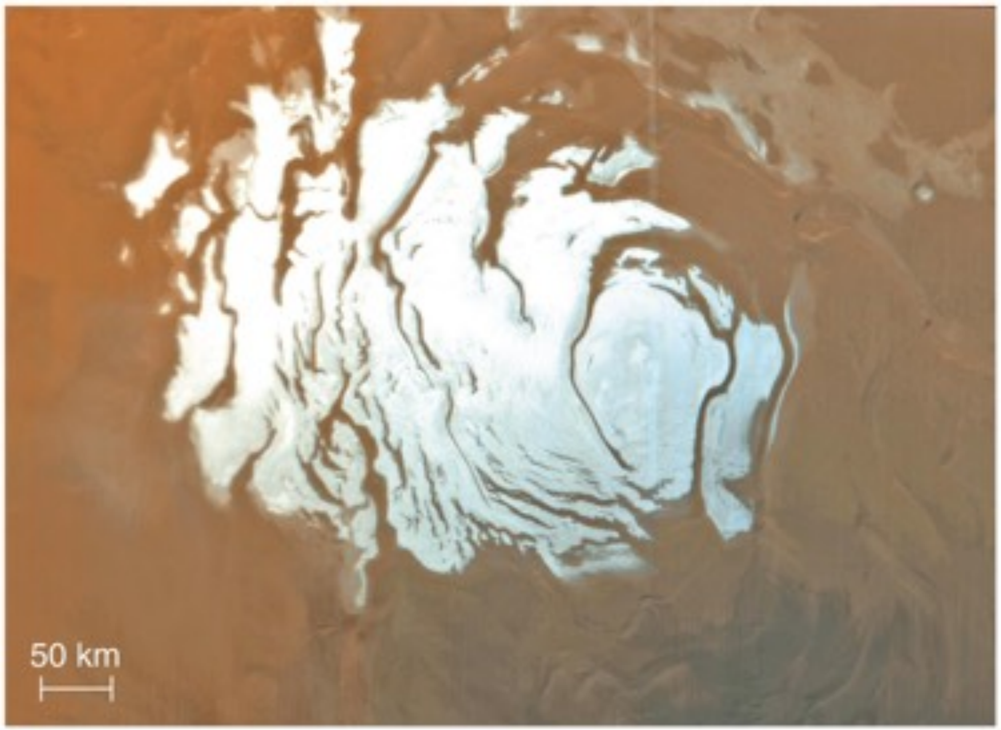
- Low gravity and a thinning atmosphere led to a runaway icehouse.
- Mars atmosphere currently ~1% as thick as Earth's

Seasons on Mars



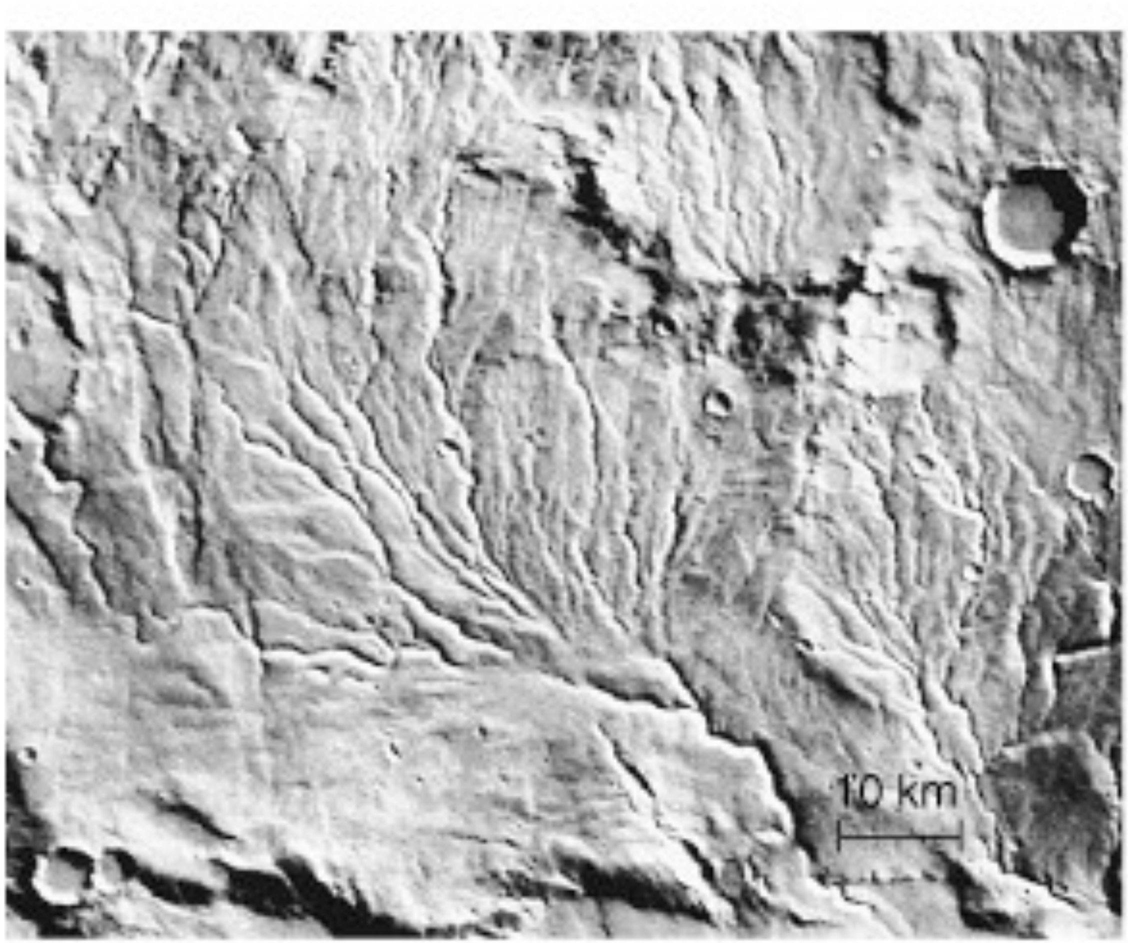
- Mars does have seasons; both axial tilt and distance from the sun matter.
- Seasons on Mars are more extreme in the southern hemisphere because of its elliptical orbit.

Polar Ice Caps of Mars



- Residual ice of the south polar cap remaining during summer is primarily water ice.
- Carbon dioxide ice of polar cap sublimates as summer approaches and condenses at opposite pole.

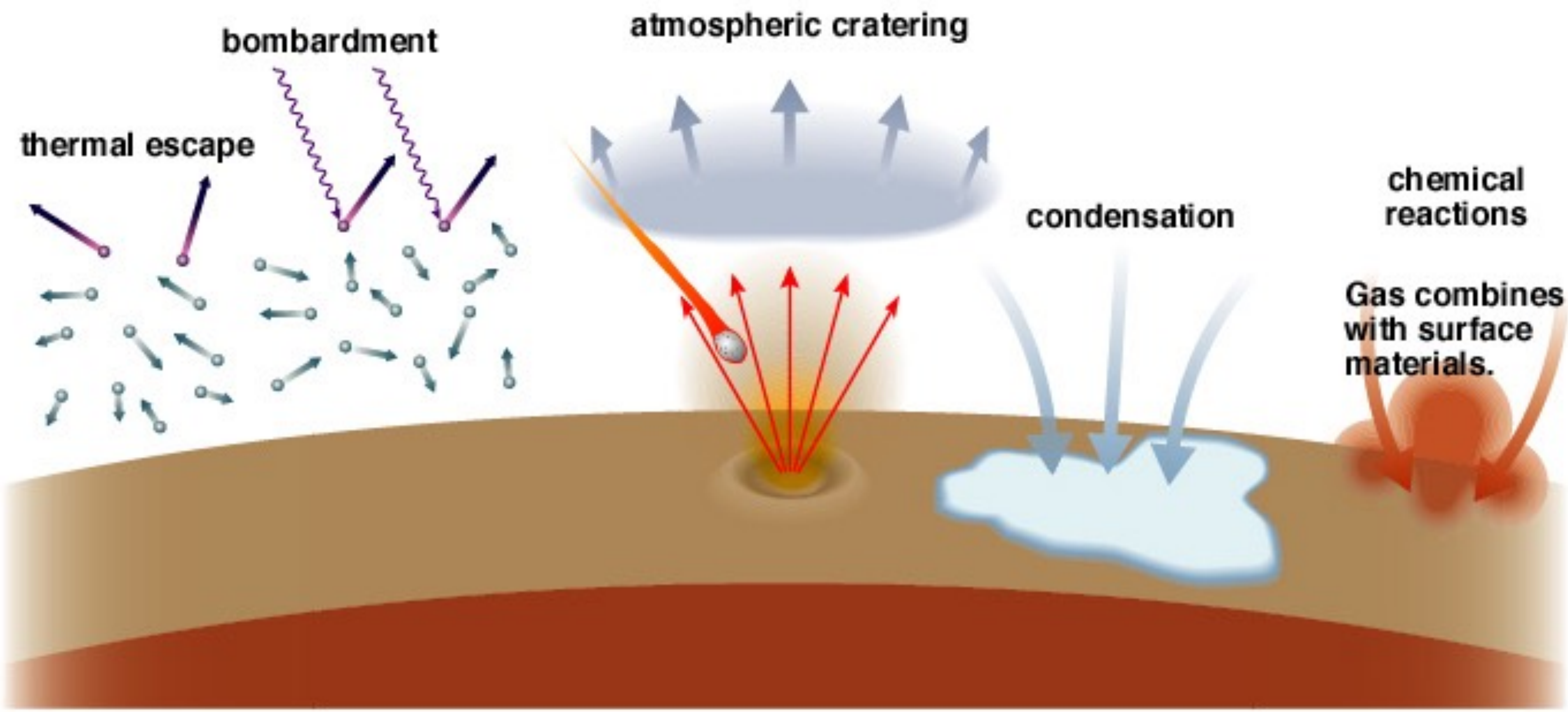
Climate Change on Mars



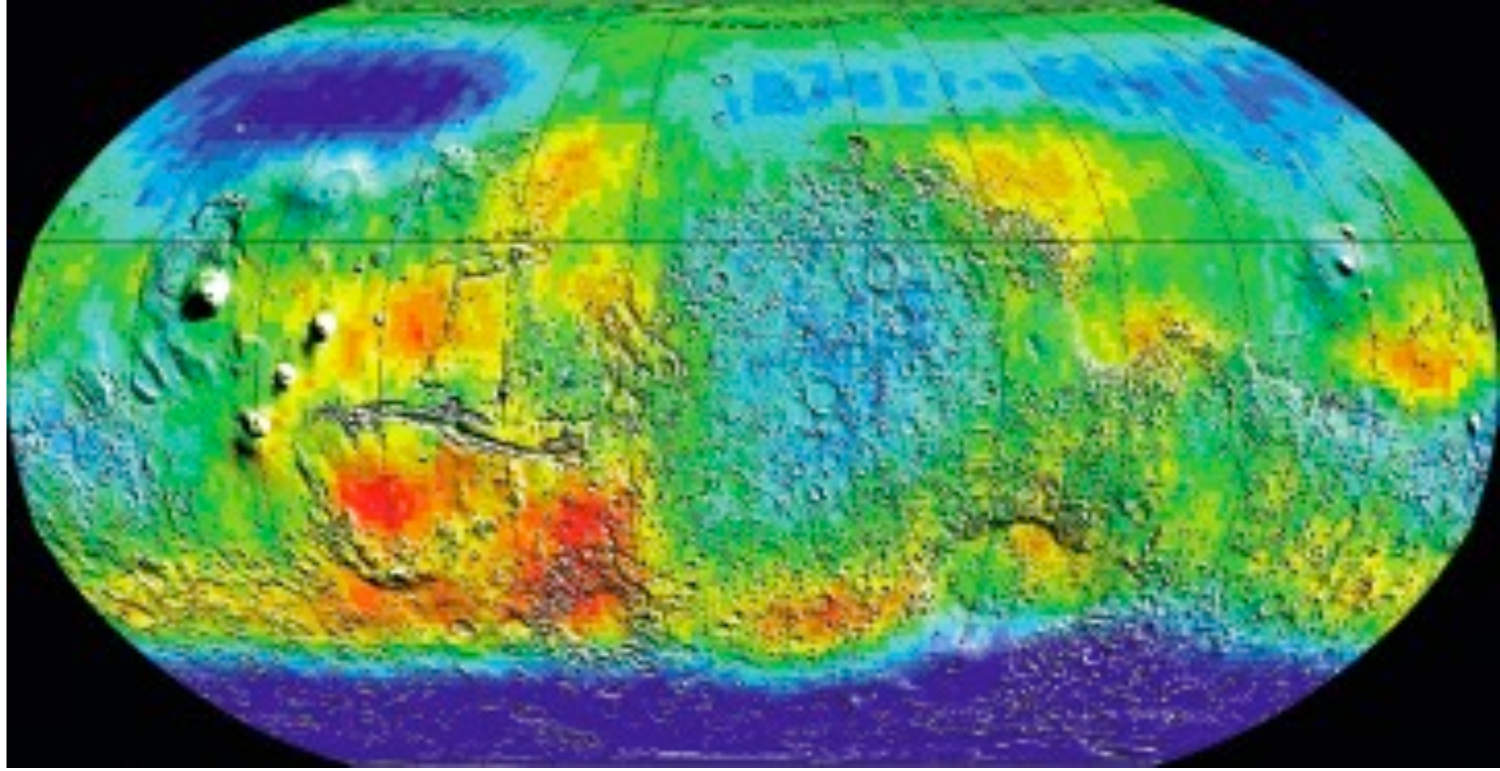
Erosion from water runoff on Mars
- an ancient riverbed!

- Mars has not had widespread surface water for 3 billion years.
- The greenhouse effect probably kept the surface warmer before that.
- Over time, Mars lost most of its atmosphere.

- Mars atmosphere was thicker in the past; its climate was warmer - liquid water!
- The atmosphere was gradually lost to space or frozen onto surface

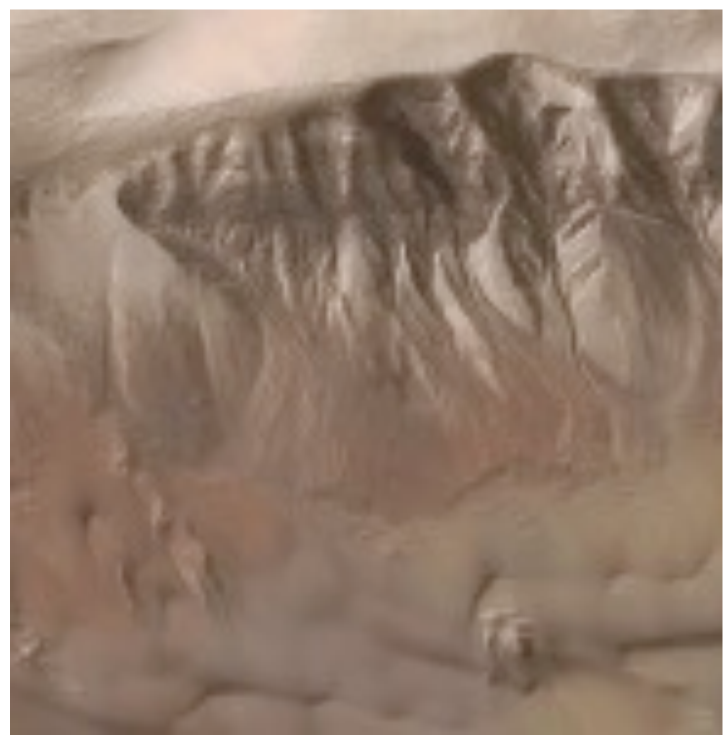


Today, most water lies frozen underground (blue regions) "permafrost"



Some scientists believe accumulated snowpack melts carve gullies even today.

Could see this happening in 2015!



Observed in 2015

https://cdn.theatlantic.com/assets/media/img/posts/2015/09/577359main_pia14472_946b/28ec00e1c.gif

Climate change on Mars

- Early Mars had thicker atmosphere
  - warmer climate
  - liquid water on surface (> 3 billion years ago!)

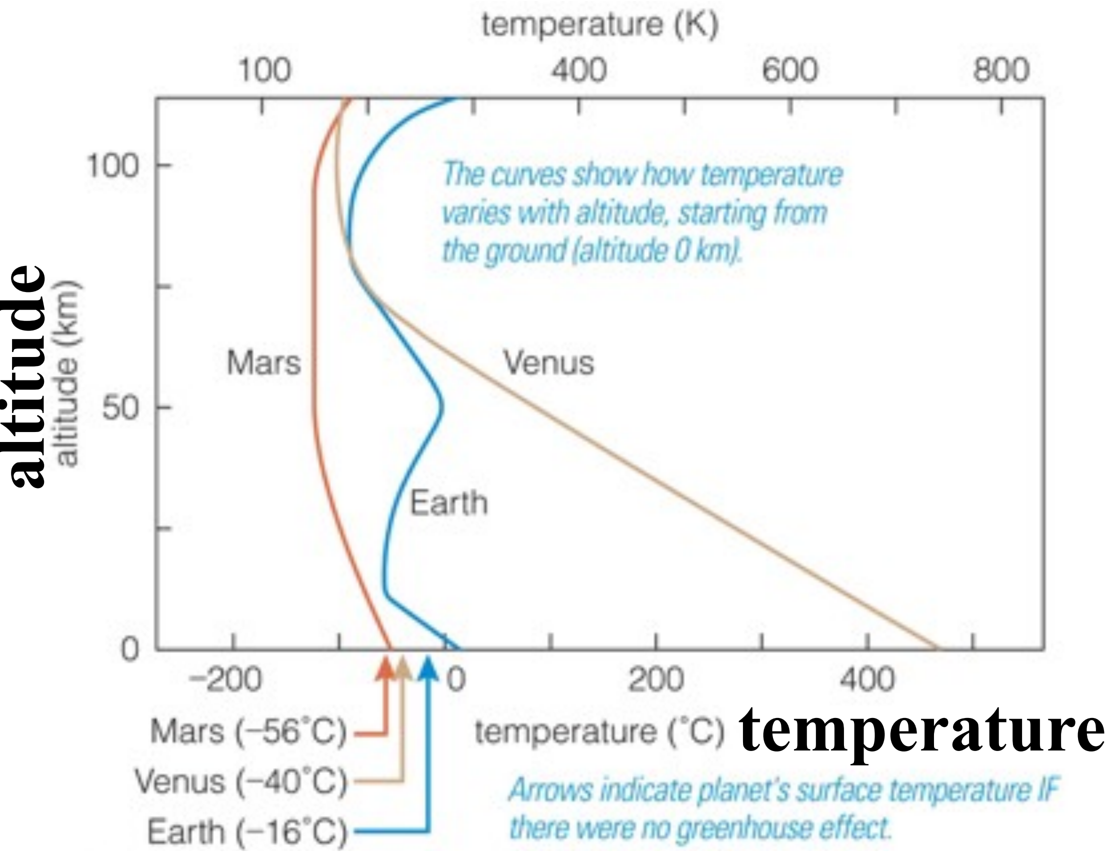
- Over time, most of Mars's atmosphere either
  - escaped into space
  - froze out onto surface

- Current atmosphere thin
  - Mostly CO_2, but not much of a greenhouse effect

"Normal" terrestrial atmosphere

- Atmospheric retention depends on
  - surface gravity
  - temperature
- Most common atmospheric composition
  - CO_2, N_2 (Venus, Mars)
  - or none at all (Mercury, Moon)
- Earth is the exception
  - H_2O plays crucial role in Carbon cycle
  - O_2 a biological byproduct

Atmospheres of Other Planets



"No greenhouse" temperatures

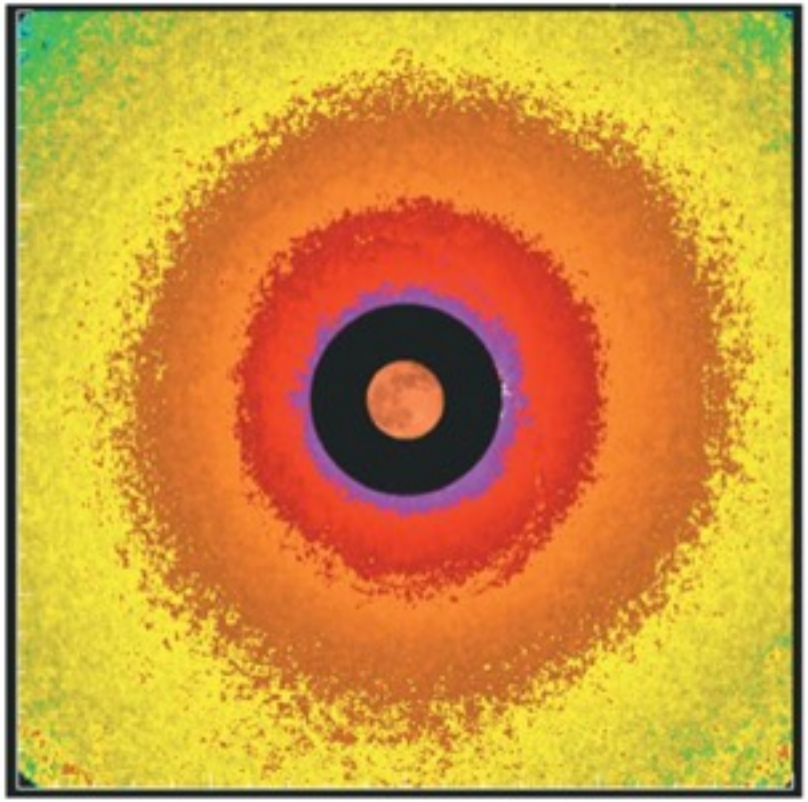
- Earth is only planet with a stratosphere because of UV-absorbing ozone molecules (O_3).
- Those same molecules protect us from Sun's UV light.

Do the Moon and Mercury have any atmosphere?

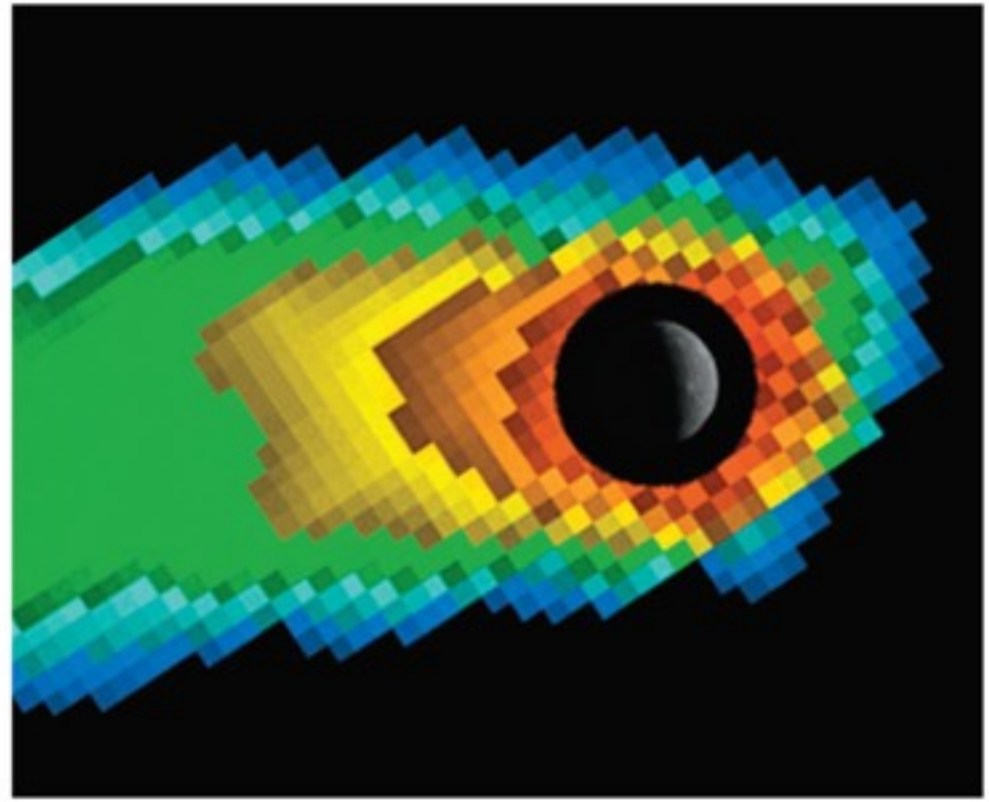
Moon

Mercury

Exospheres of the Moon and Mercury



a The Moon's exosphere, which extends high above the surface.

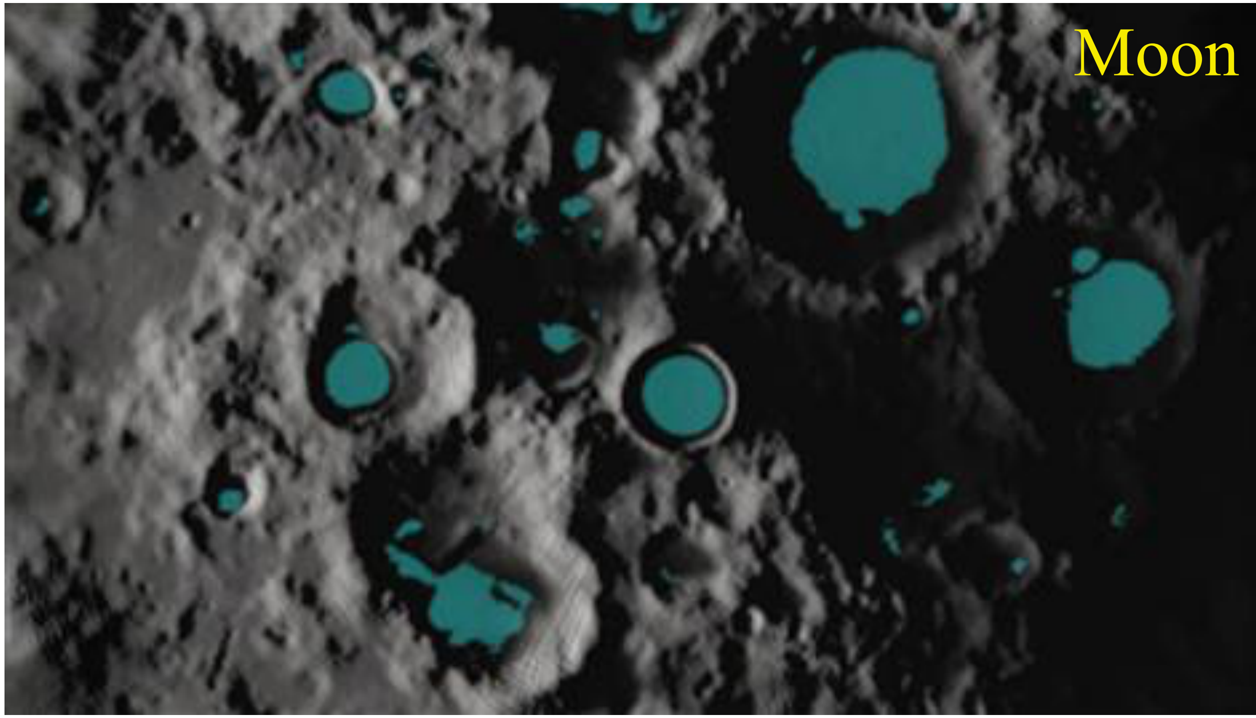


b Mercury's exosphere, much of which is escaping in this image.

- Sensitive measurements show that the Moon and Mercury have extremely thin atmospheres.
- Gas comes from impacts that eject surface atoms.

Ice in Polar Craters

- Radar reflectivity show evidence of water ice near the **poles** of the Moon and Mercury in **permanently shaded craters**



- May have been delivered by comets