Today

- Terrestrial Planets
  - Earth, Venus, Mars
- Atmospheres
- Climate
  - Greenhouse effect from planetary perspective
- Factors affecting atmospheres

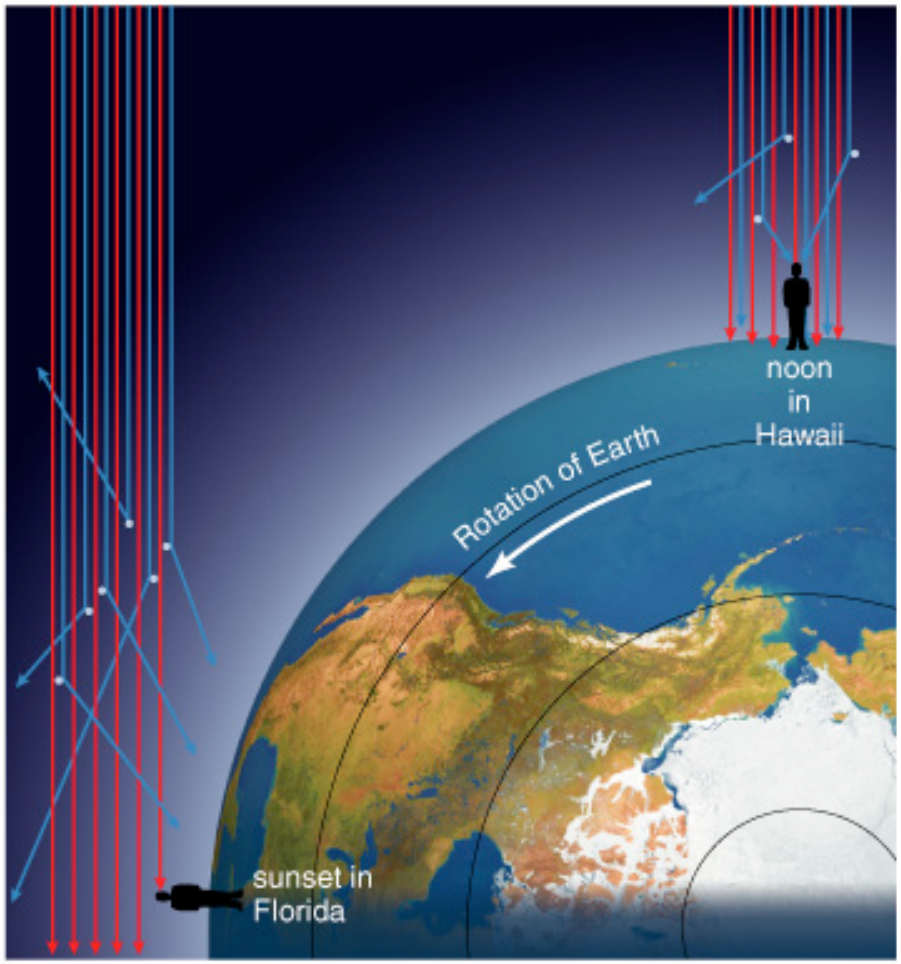
Reminders About First Exam

- Will be in this room, 9:30-10:45, Thursday
- Some multiple choice, some short answer
  Similar to homework, but you don't have to explain your multiple choice answers
- No calculators, no books, no notes, no phones
- Bring your student ID, put on desk
- Bring more than one #2 pencil!
- We will seat you
- Leave times at 10:15, 10:35 onwards
  Hand in to *your* TA at top of stairs

Astrobiology Seminar

- Friday, October 7, 2011, 12:30 PM
- “The Search for Life on Mars...A Search for the Origin of Life on Earth?” Andrew Steele
- Webcast
- See http://astrobiology.stsci.edu for details

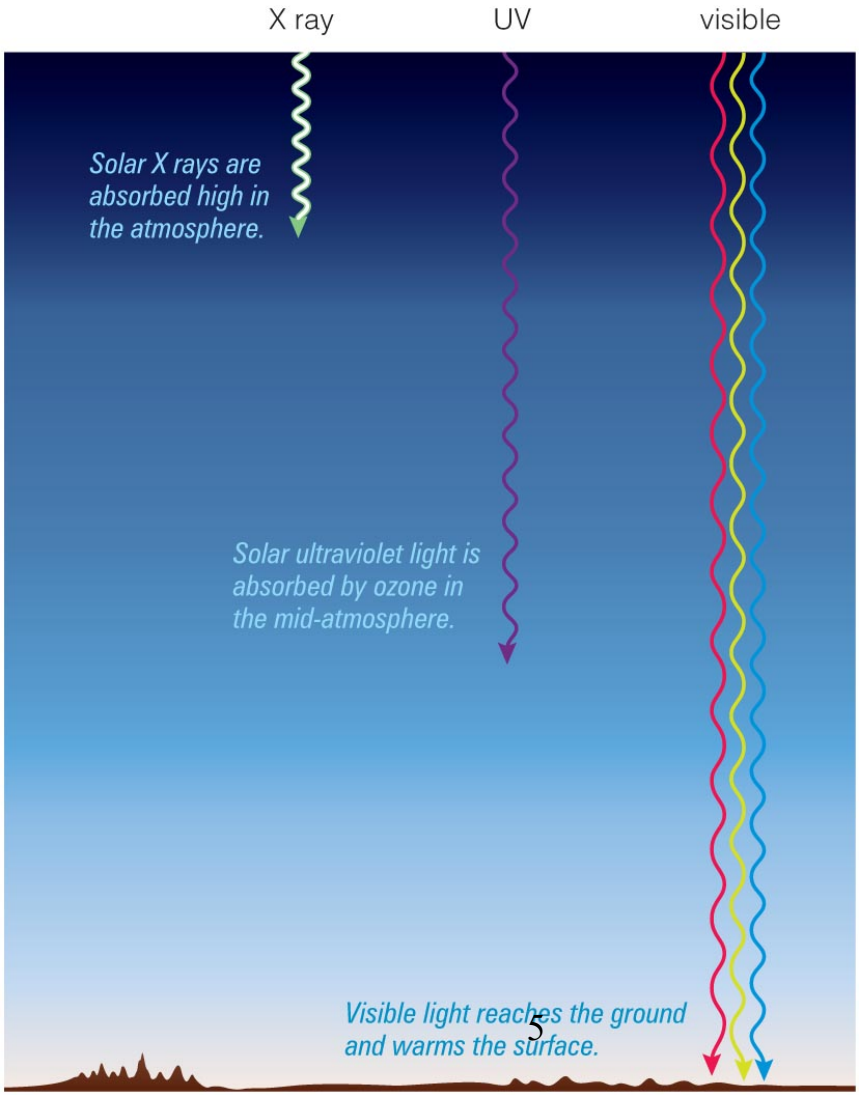
Why the sky is blue

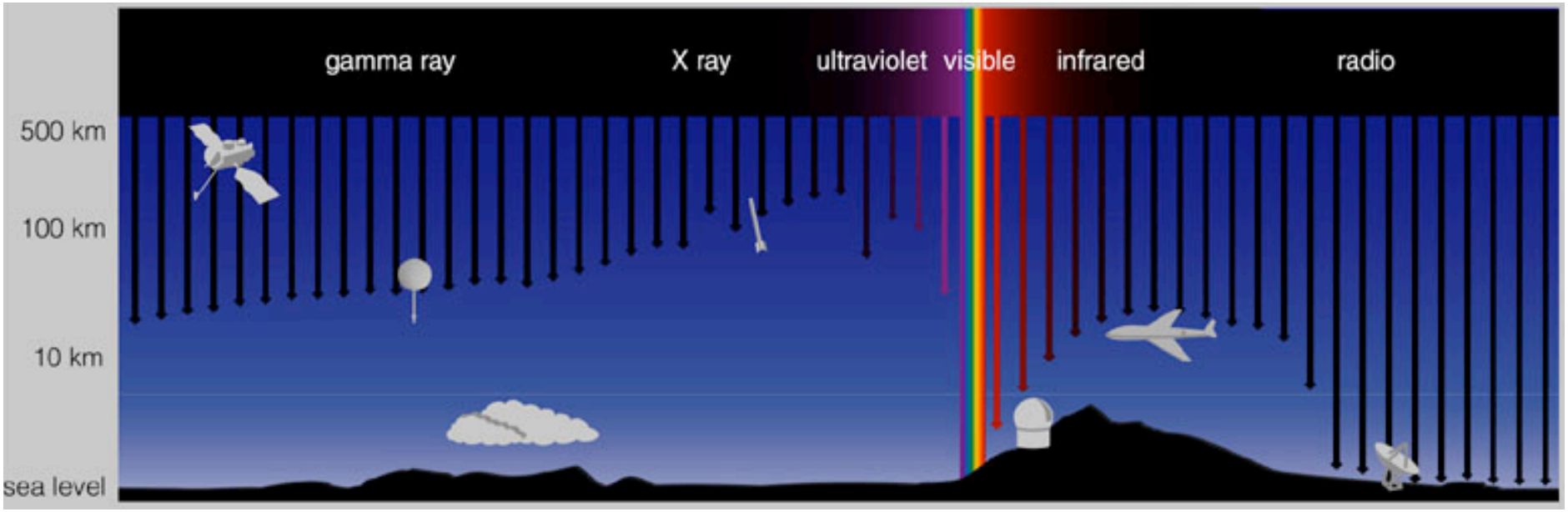


- Atmosphere scatters blue light from the Sun, making it appear to come from different directions.
- Sunsets are red because less of the red light from the Sun is scattered.

Radiation Protection

- All X-ray light is absorbed very high in the atmosphere.
- Ultraviolet light is absorbed by ozone (O_3).

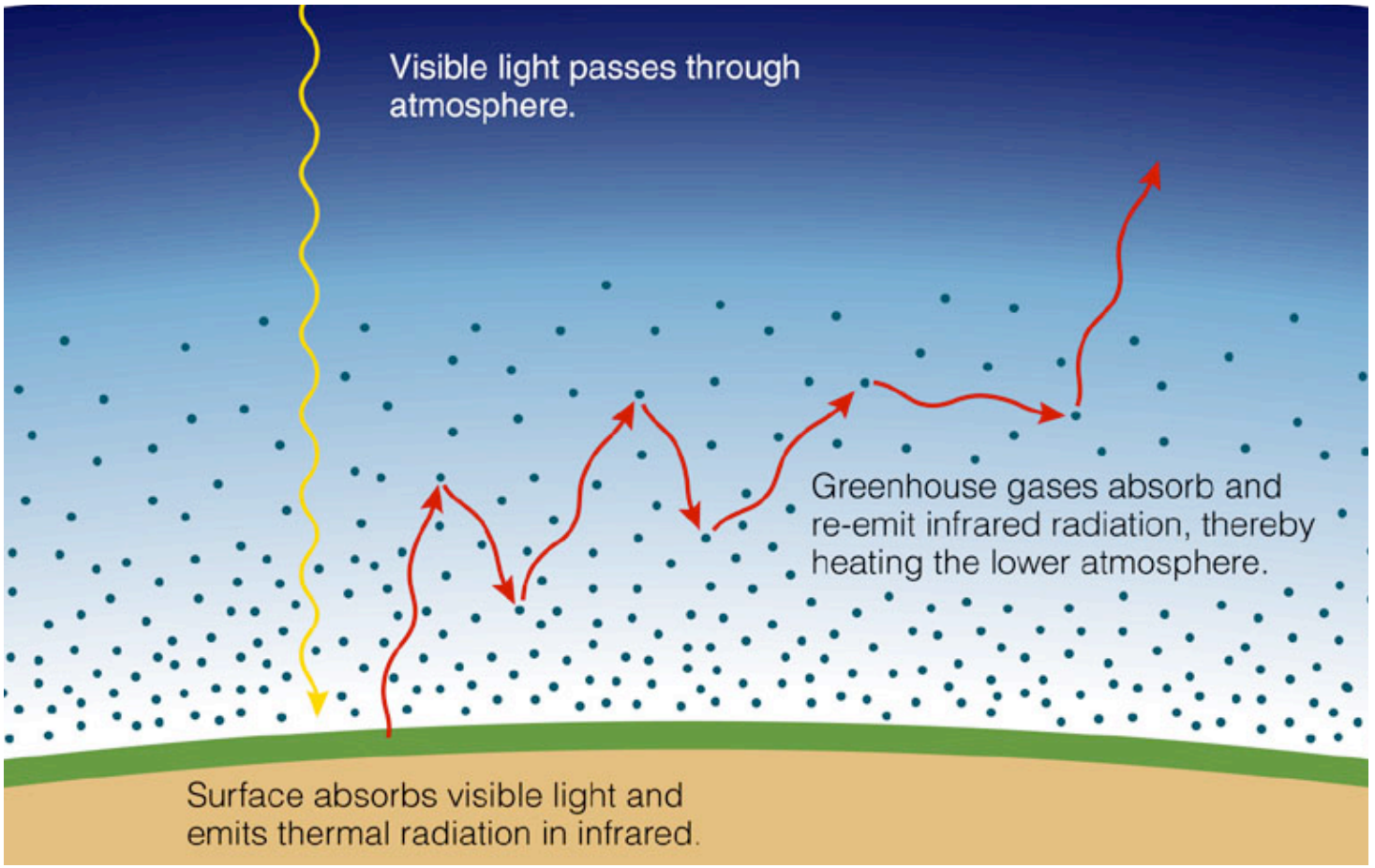




Earth's atmosphere absorbs light at most wavelengths.

The air looks clear to optical light & radio waves;
looks like a brick to X-rays and like a fog to the infrared.

The Greenhouse Effect



Greenhouse Gas

- Any gas that absorbs infrared
- Greenhouse gas: molecules with two different types of elements (CO_2, H_2O, CH_4)
- Not a greenhouse gas: molecules with one or 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)

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

Greenhouse Effect: Bad?

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?

Why is Venus so hot?

The greenhouse effect on Venus keeps its surface temperature at 470°C (878°F). This makes it the highest average temp of any planet; even higher than Mercury's average, even though Venus is farther from the sun.

The difference is the greenhouse effect.

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

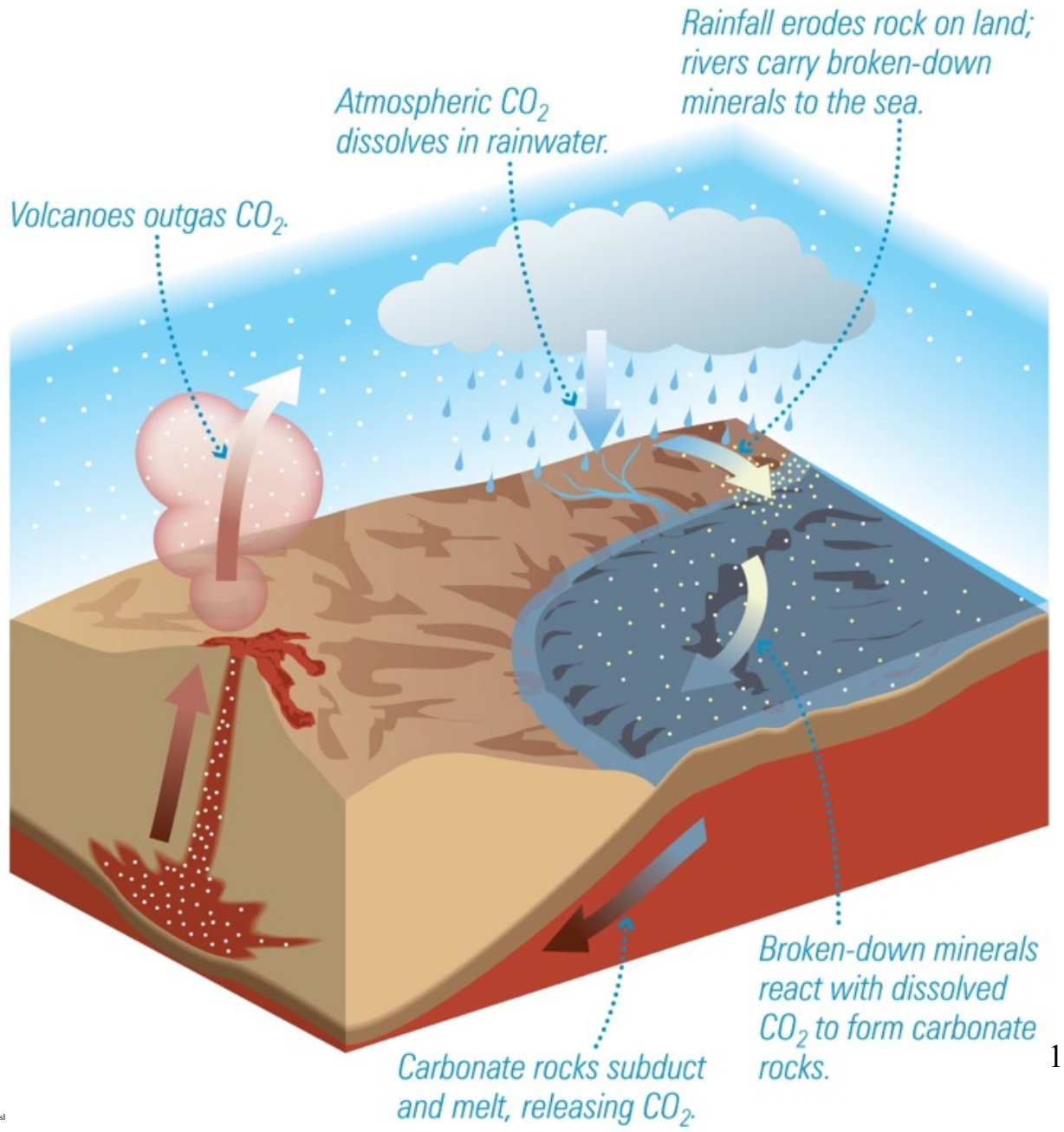
Atmosphere of Venus

- Venus has a very thick carbon dioxide atmosphere with a surface pressure 90 times that of Earth.

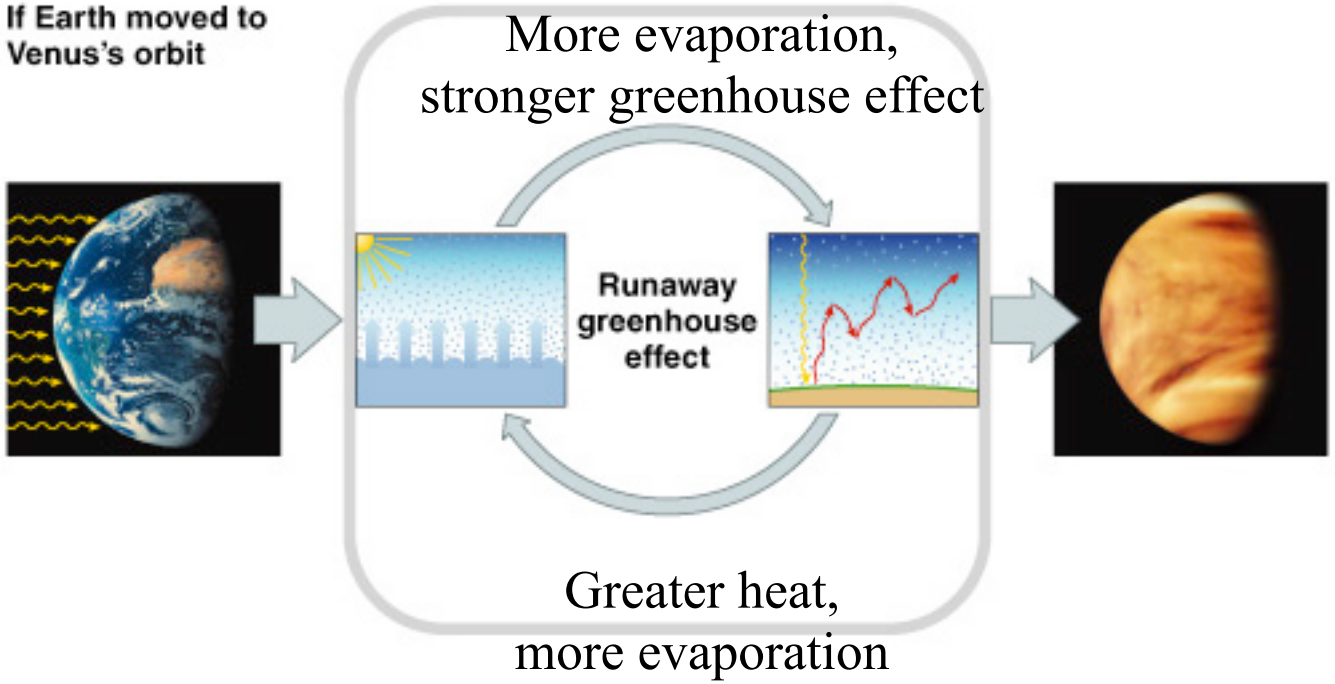
Greenhouse Effect on Venus

- 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

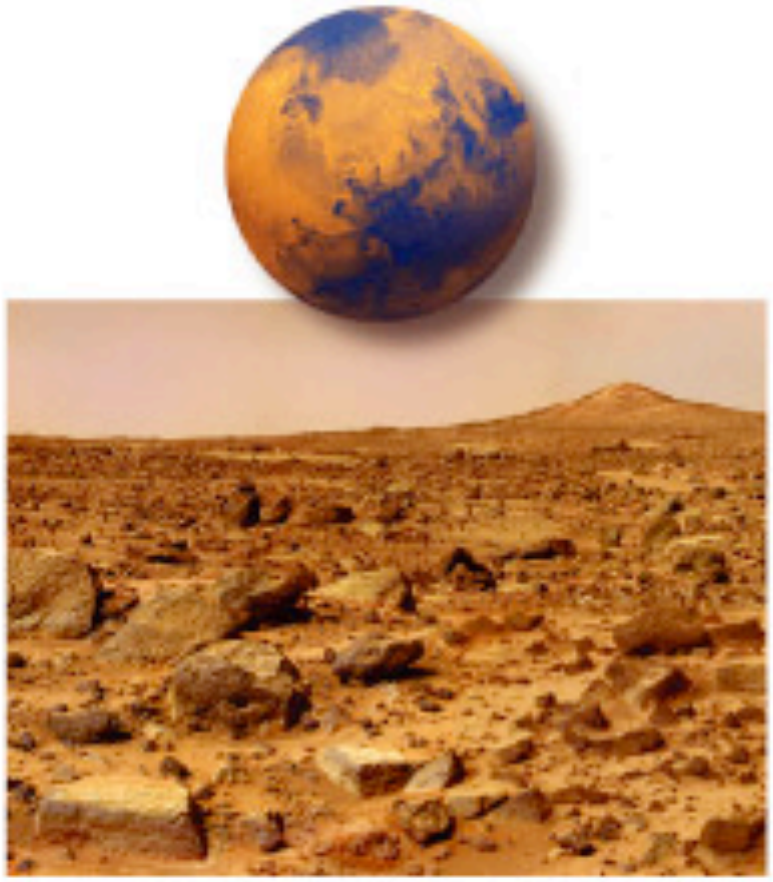


Runaway Greenhouse Effect



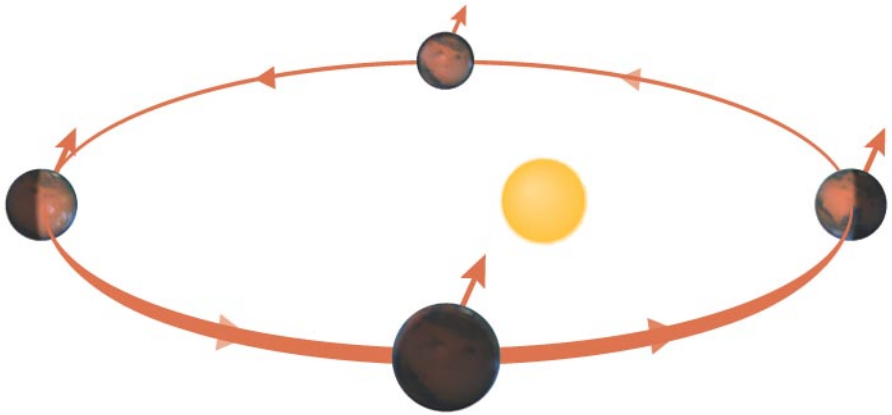
- Oceans evaporate; no longer absorb CO_2.
  - CO_2 builds up in atmosphere unchecked
  - "runaway greenhouse"

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.

Change of Mars' Seasons

Unlike Earth, Mars has no large moon to stabilize its axis. As a result, its axis wanders over tens of millions of years. What effect do you think this will have on the seasons on Mars?

A. No effect; seasons independent of axis

B. Seasons more extreme when axis points nearer to plane of Mars' orbit

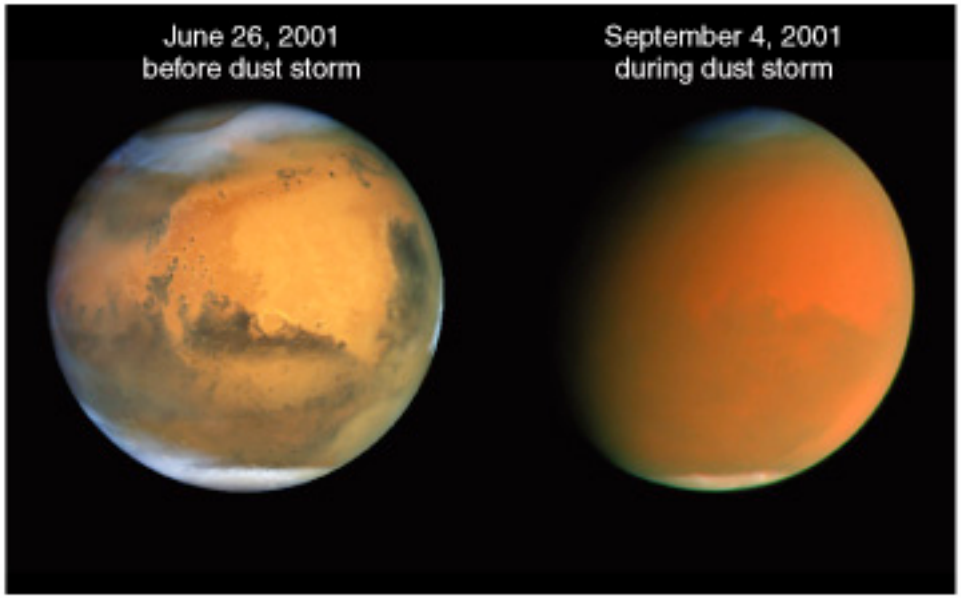
C. Seasons more extreme when axis points nearly perpendicular to orbit plane

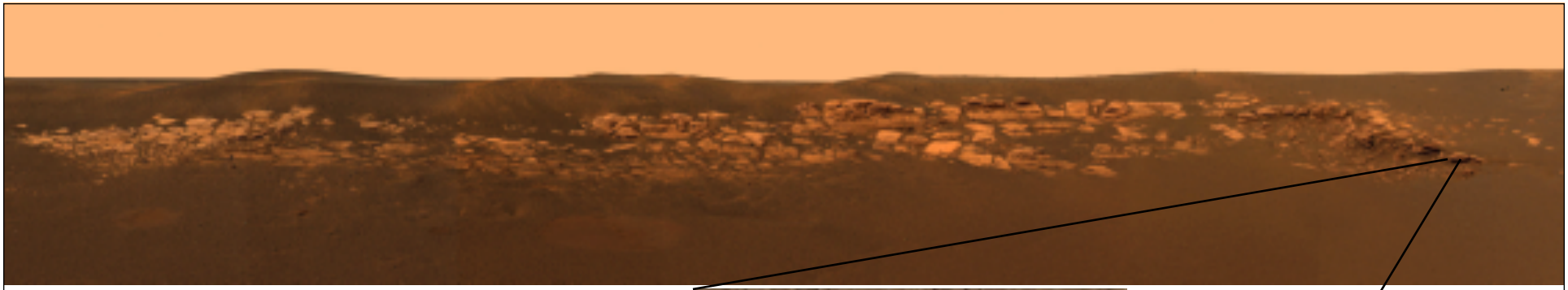
D. No effect: Martians have climate control

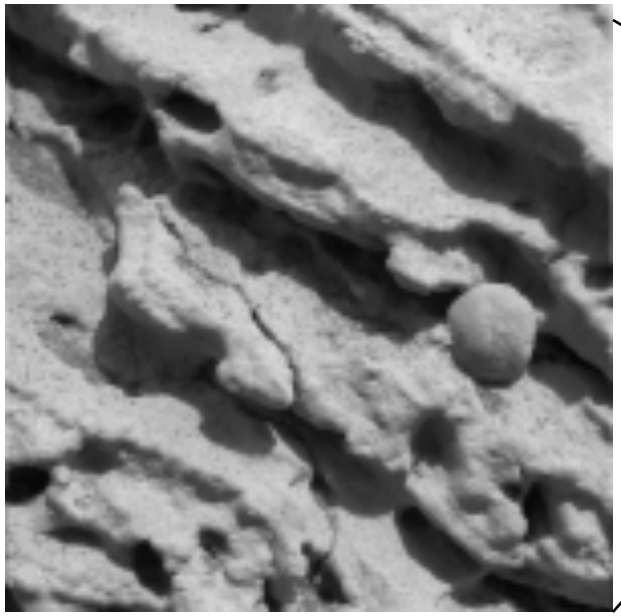
E. I don't know

Storms on Mars

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

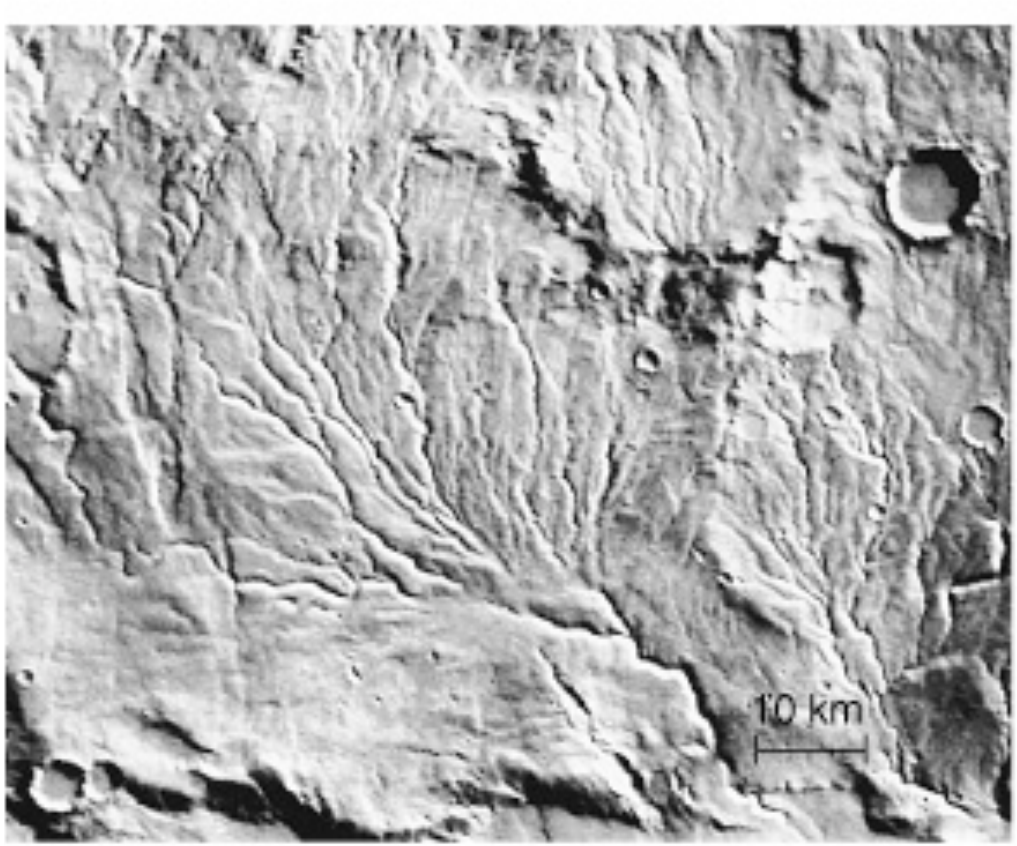






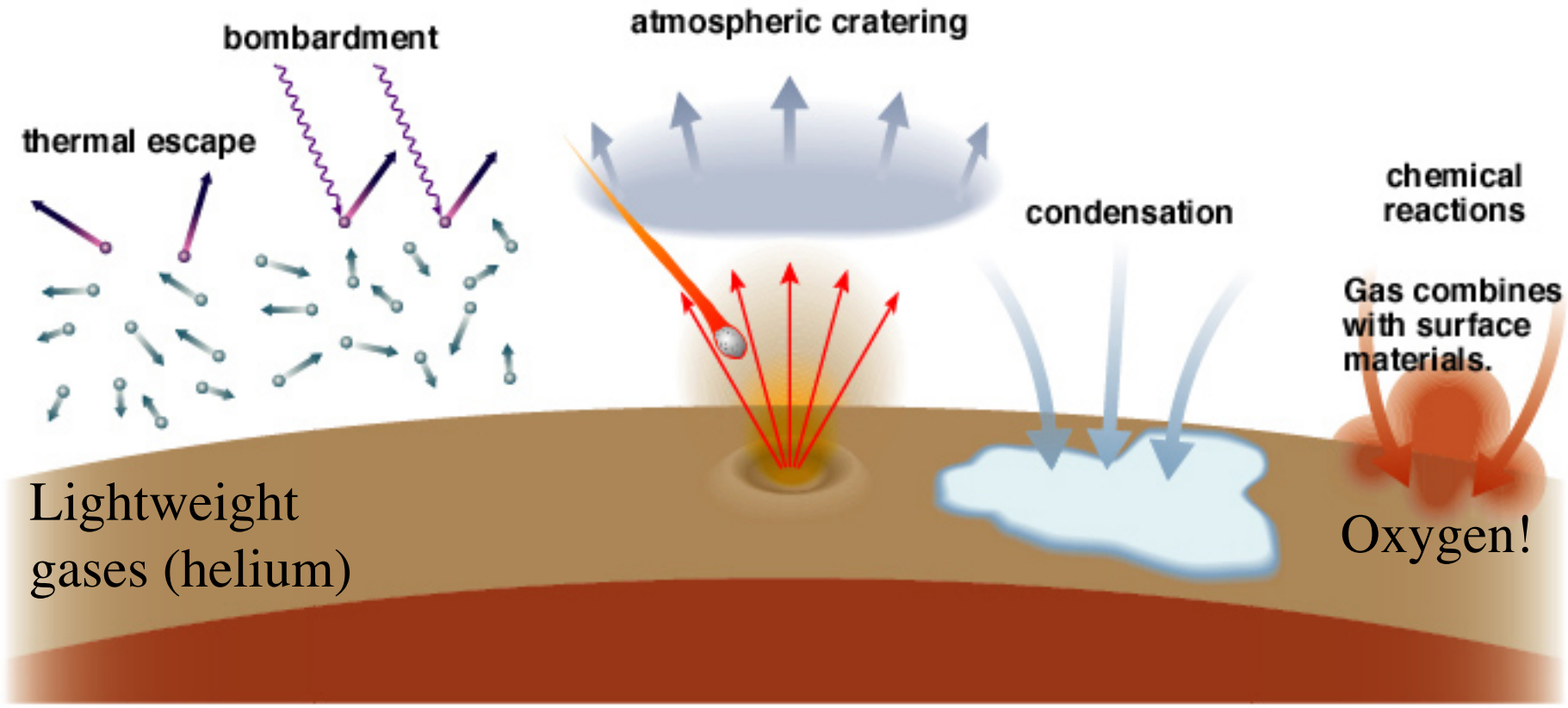
- 2004 *Opportunity* Rover provided strong evidence for abundant liquid water on Mars in the distant past.
- How could Mars have been warmer and wetter in the past?

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.

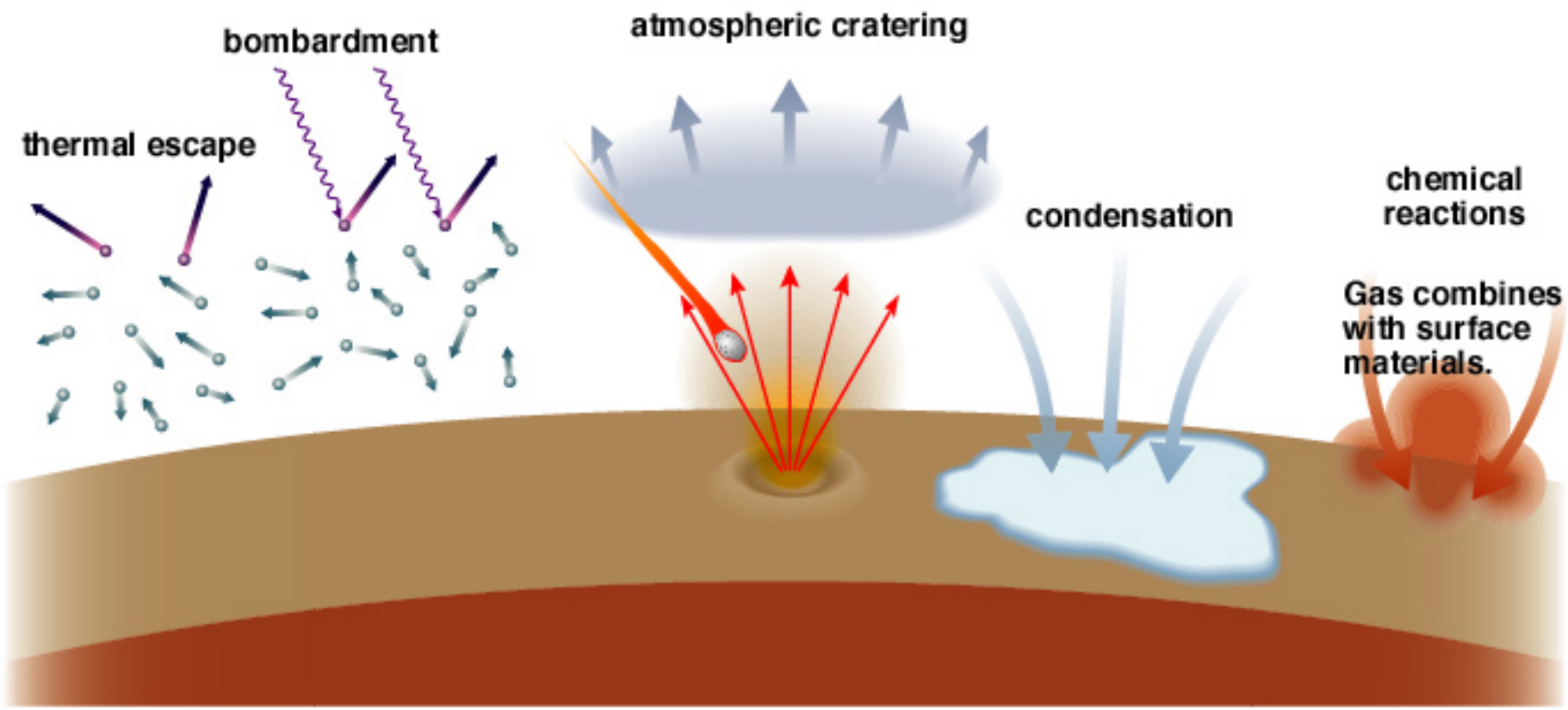
Factors affecting atmospheres



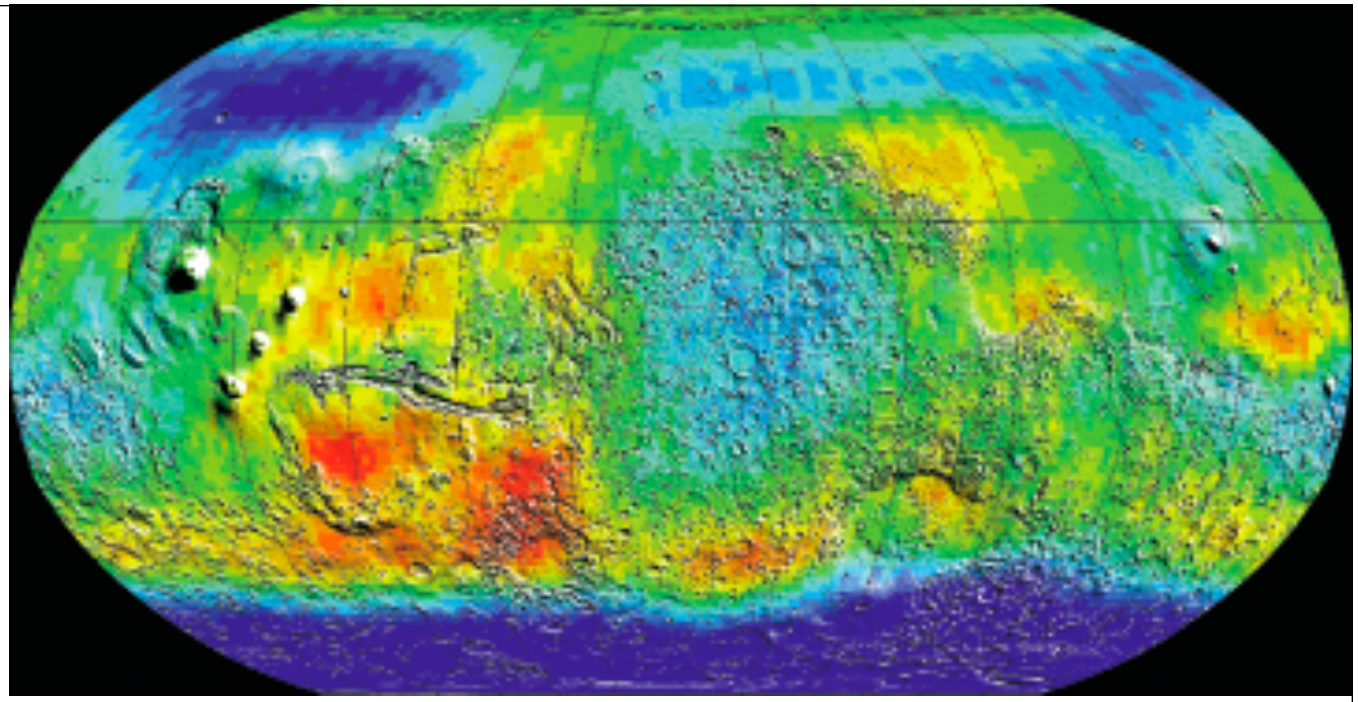
Can break up water vapor; hydrogen escapes

Water can freeze out

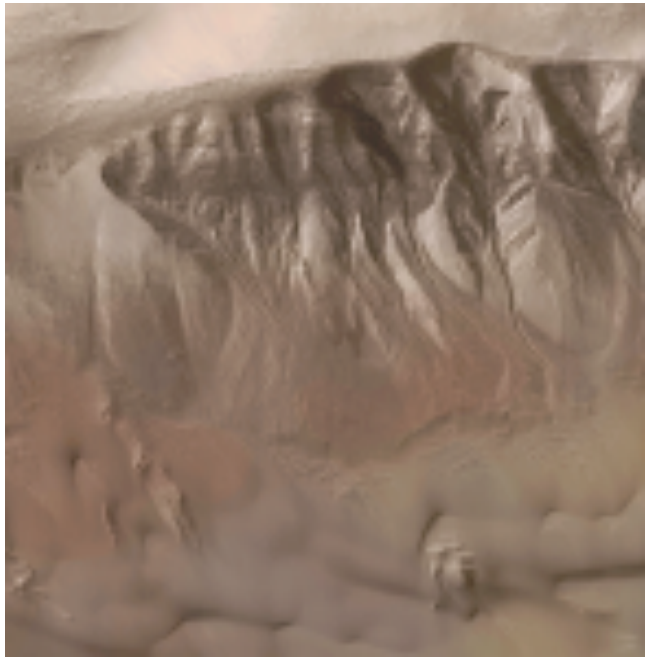
- Mars atmosphere was thicker in the past; its climate was warmer - liquid water!
- The atmosphere was gradually lost to space or frozen onto surface



Today, most water lies frozen underground (blue regions)



Some scientists believe accumulated snowpack melts carve gullies even today.



Unique features of Earth that are important for life:

1. Surface liquid water
2. Atmospheric oxygen
3. Plate tectonics
4. Climate stability

What unique features of Earth are important to human life?

1. Surface liquid water
2. Atmospheric oxygen
3. Plate tectonics
4. Climate stability

Earth's distance from the Sun and moderate greenhouse effect make liquid water possible.

What unique features of Earth are important to human life?

1. Surface liquid water
2. Atmospheric oxygen
3. Plate tectonics
4. Climate stability

PHOTOSYNTHESIS (plant life) is required to make high concentrations of O_2, which produces the protective layer of O_3.

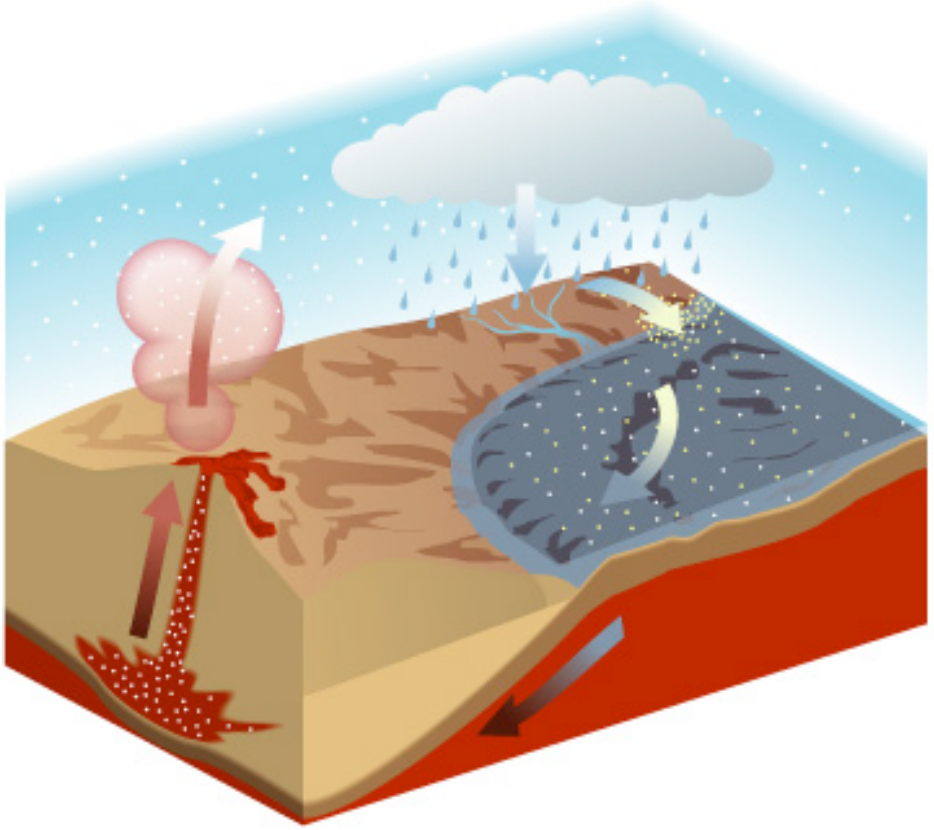
Oxygen is very reactive - would combine with rocks and disappear from the atmosphere if not continuously resupplied by plant life.

What unique features of Earth are important to human life?

1. Surface liquid water
2. Atmospheric oxygen
3. Plate tectonics
4. Climate stability

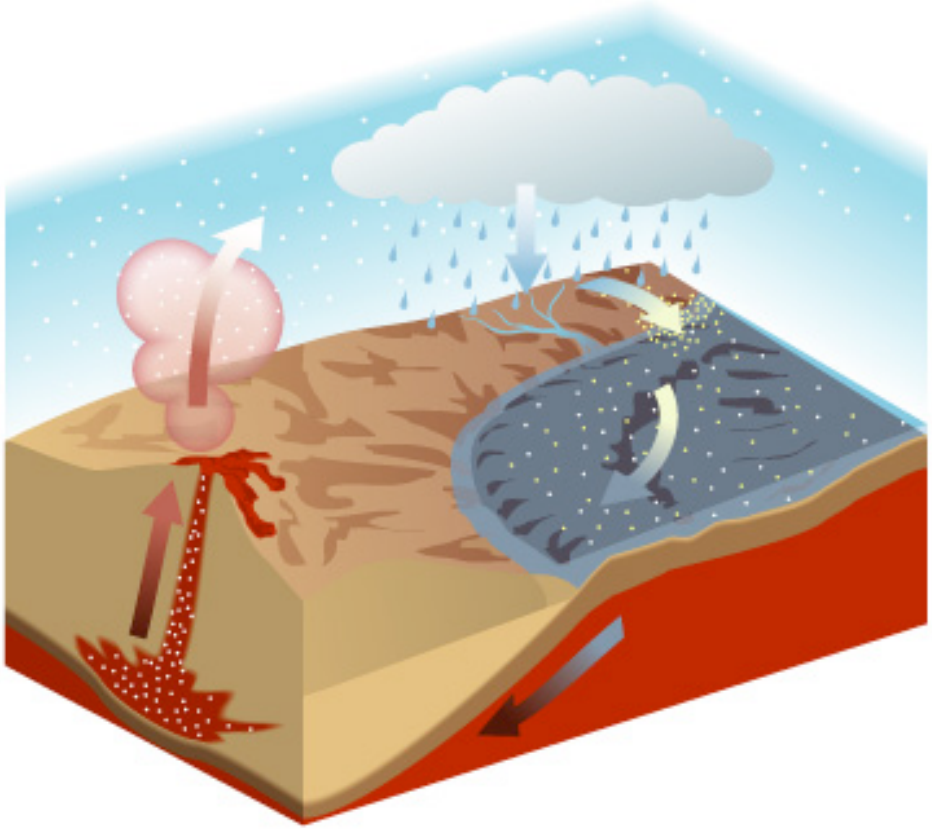
Plate tectonics are an important step in the carbon dioxide cycle.

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.

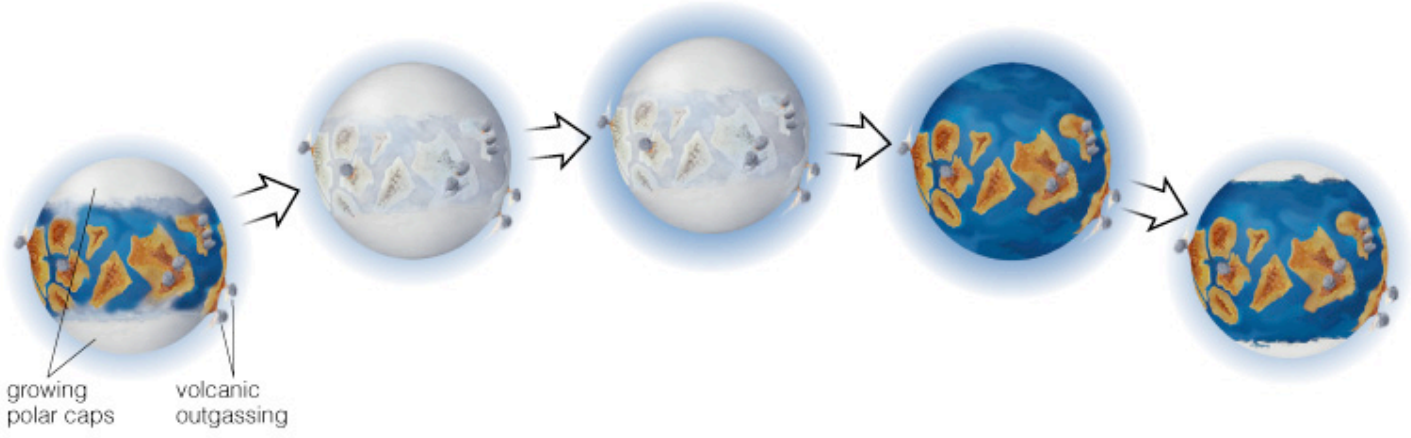
Carbon Dioxide Cycle



4. Subduction carries carbonate rocks down into the mantle.

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

Long-Term Climate Change



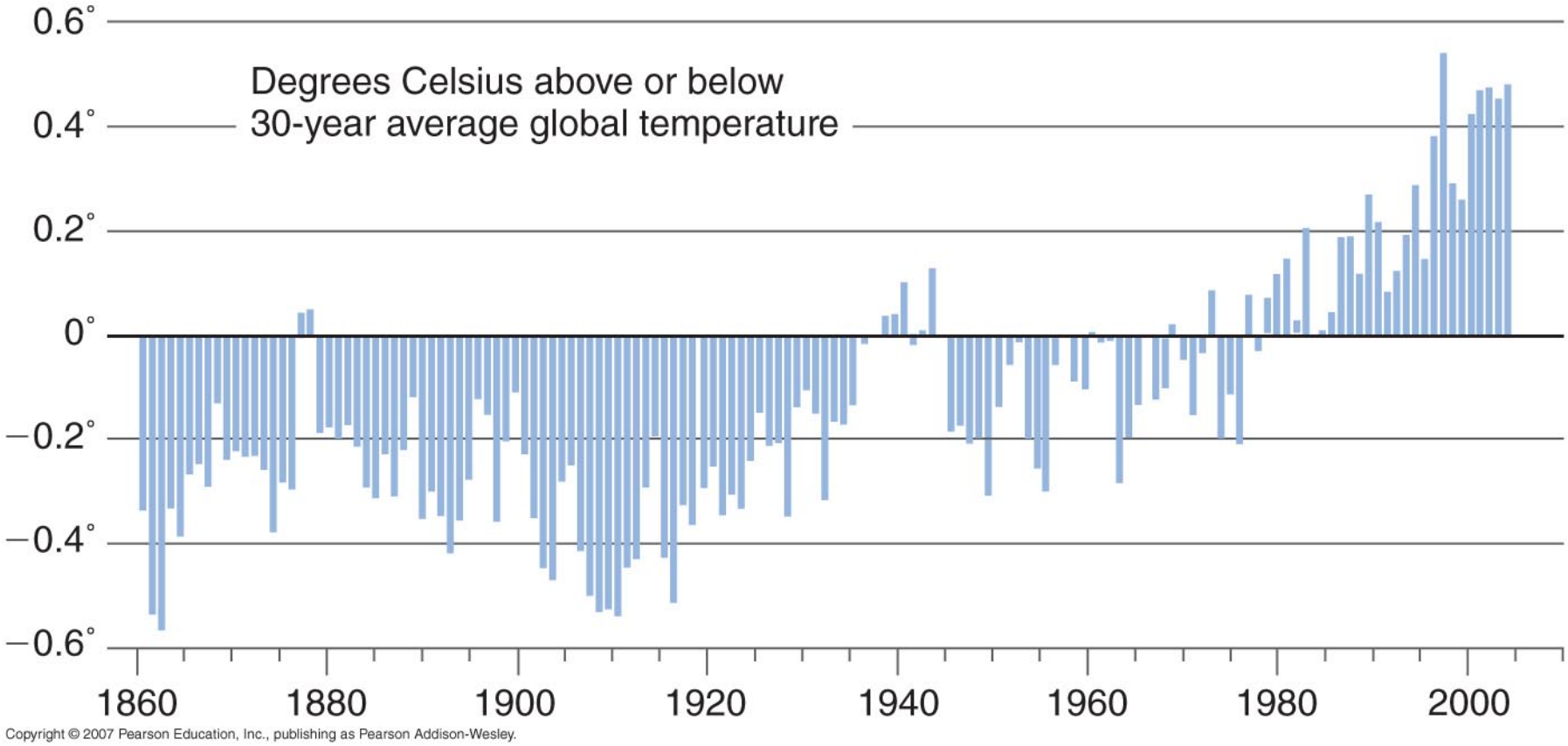
- Changes in Earth's axis tilt might lead to *ice ages*.
- Widespread ice tends to lower global temperatures by increasing Earth's reflectivity. Snowball Earth!
- CO_2 from outgassing will build up if oceans are frozen, ultimately raising global temperatures again.

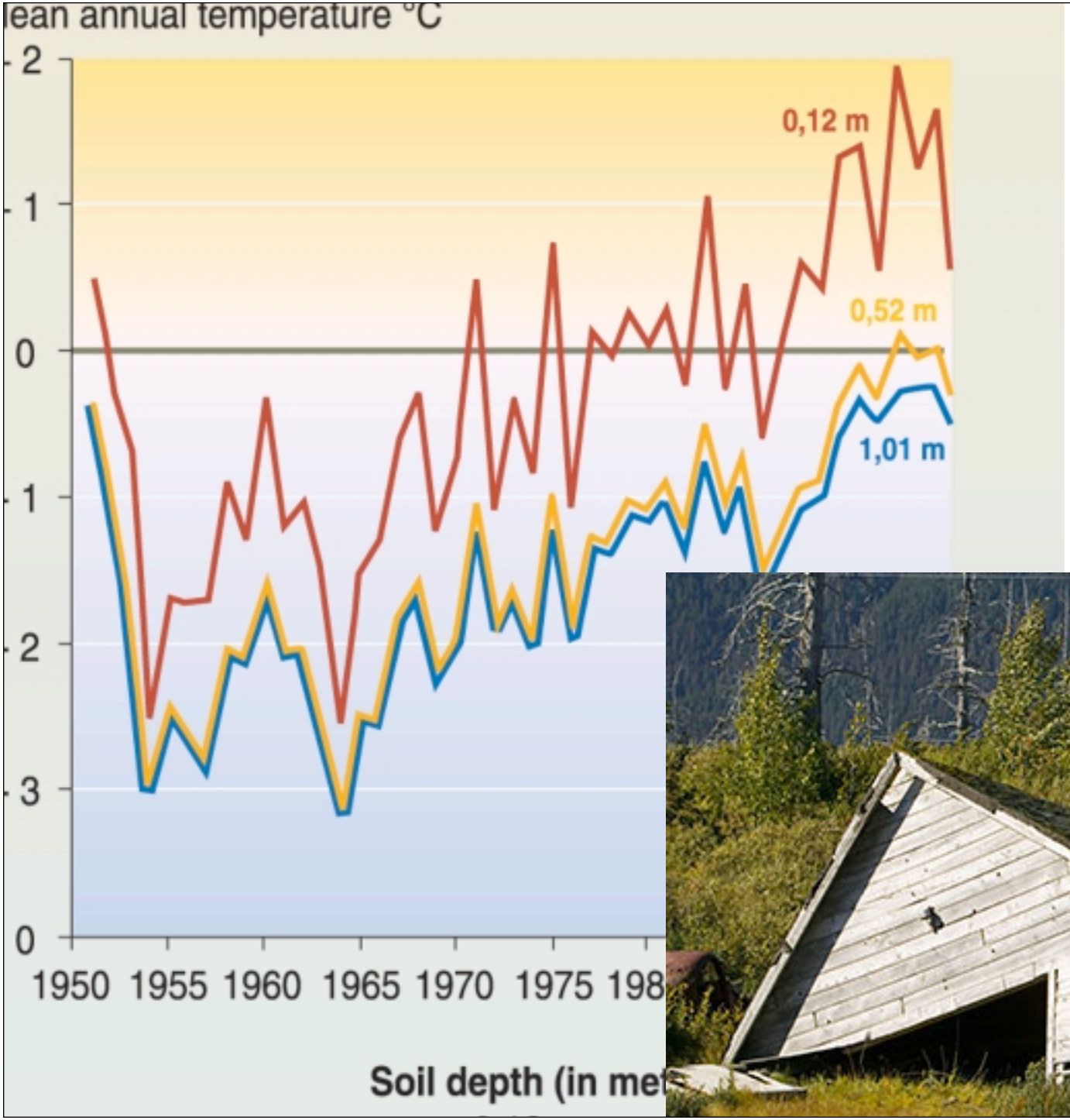
What unique features of Earth are important to human life?

1. Surface liquid water
2. Atmospheric oxygen
3. Plate tectonics
4. Climate stability

The CO_2 cycle acts like a thermostat for Earth's temperature.

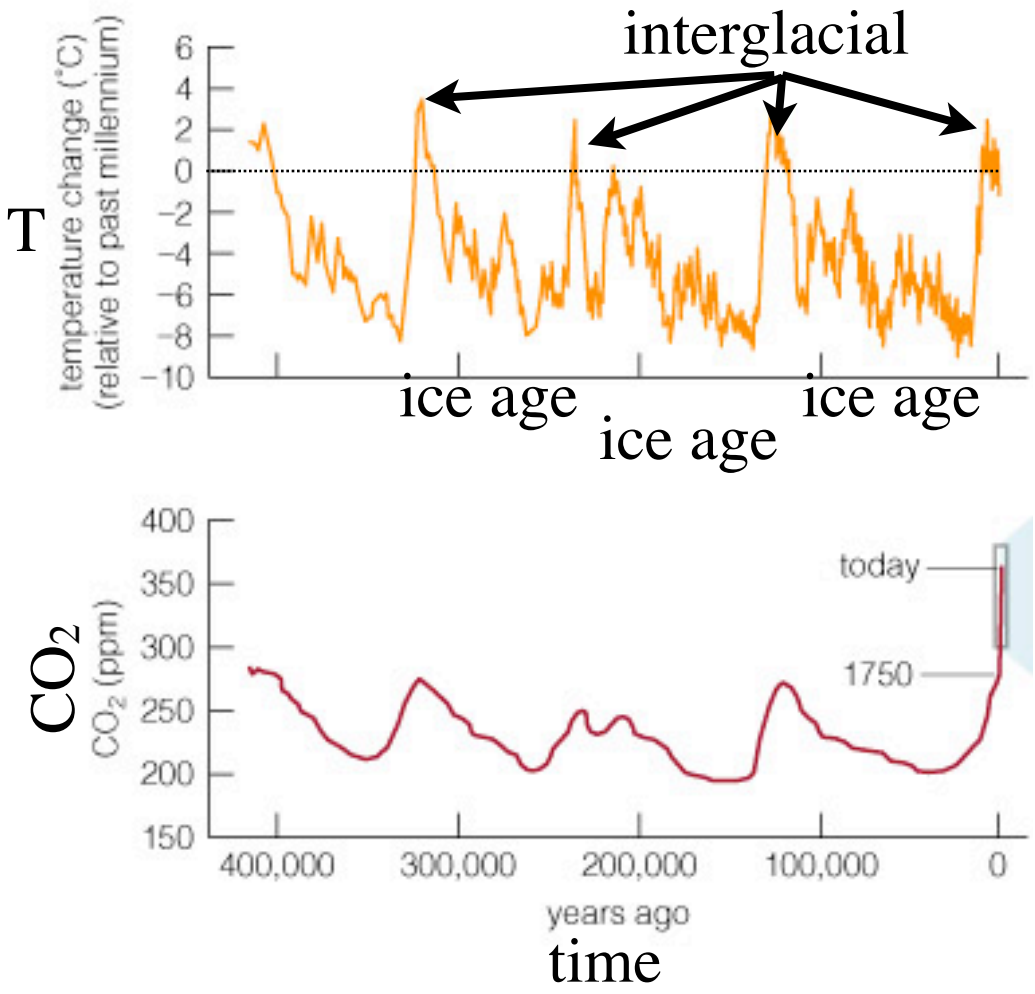
Some greenhouse effect is natural. Is it being enhanced by human activity?





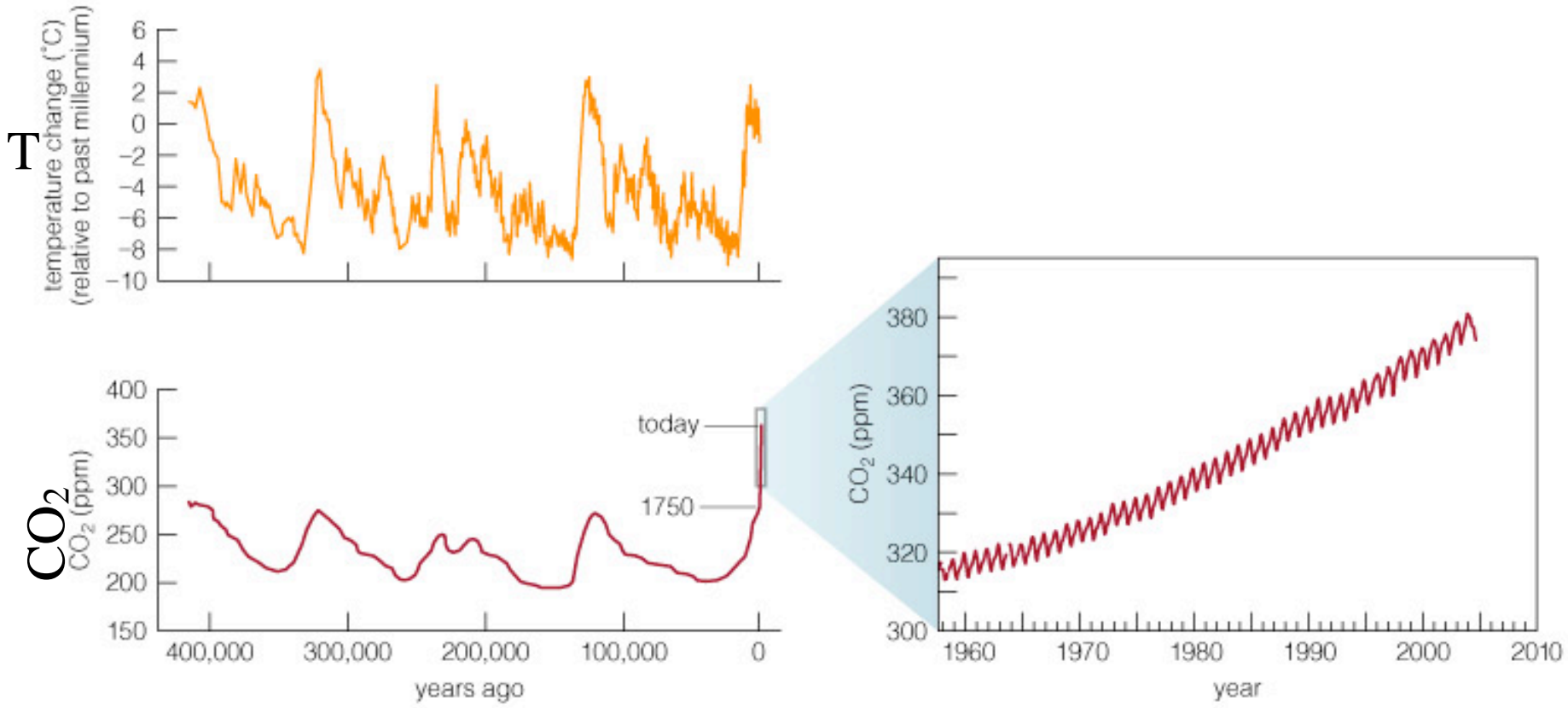
Arctic permafrost is melting

CO_2 Concentration

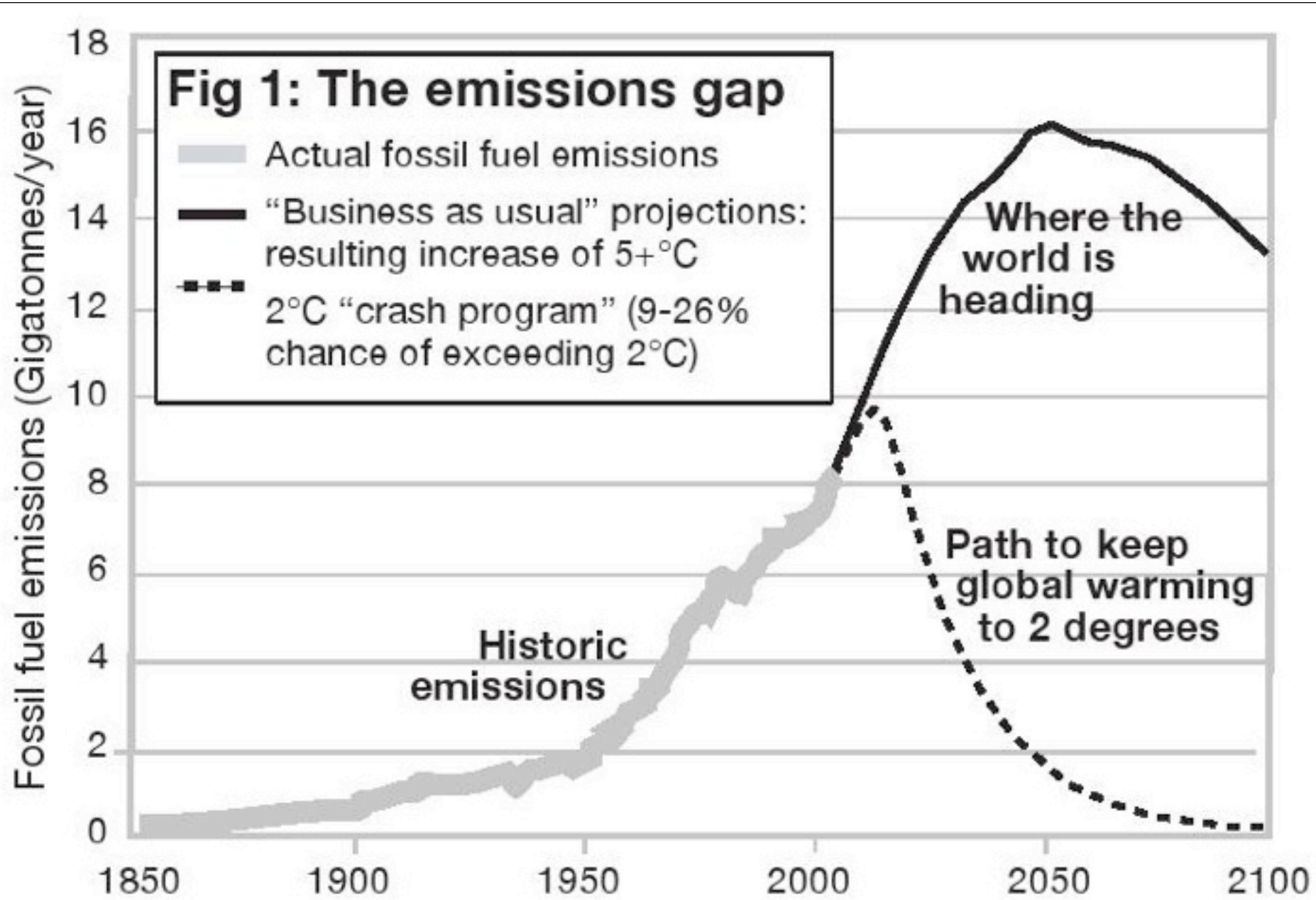


- Global temperatures have tracked CO_2 concentration for the last 500,000 years.
- Antarctic air bubbles indicate the current CO_2 concentration is at its highest level in at least 500,000 years.

CO_2 Concentration



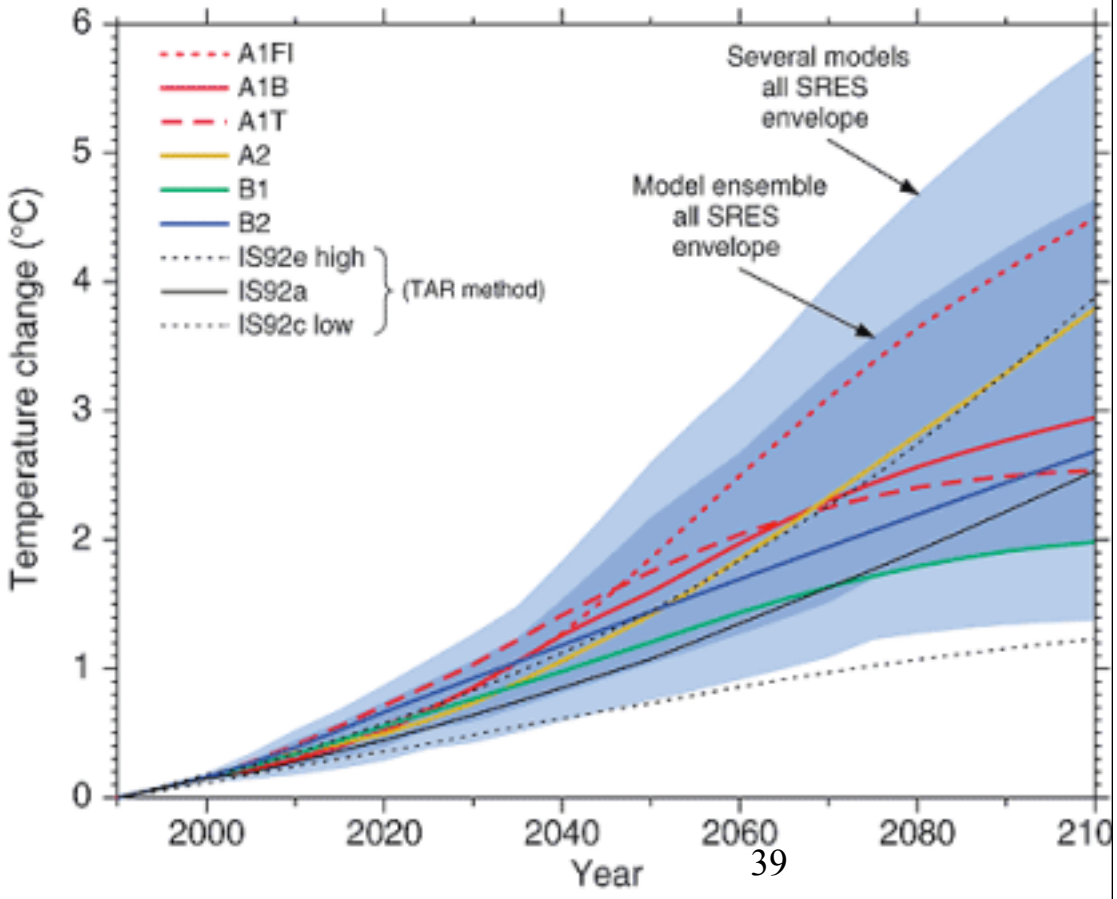
- Most of the CO_2 increase has happened in last 50 years. Amount consistent with the fuel burned.



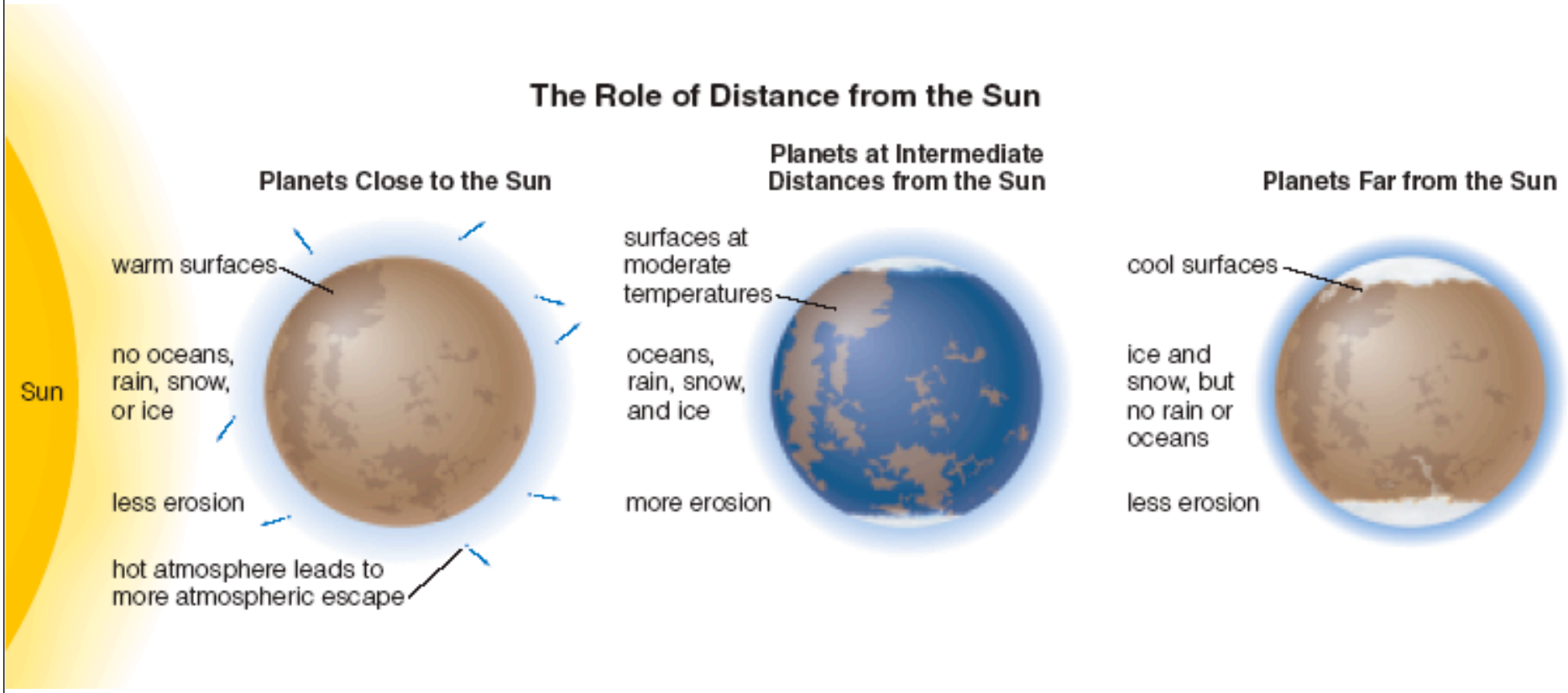
Source: *Historic emissions/BAU path:* GCP Report No 5/2006 www.globalcarbonproject.org. BAU based on 2001 IPCC report scenario. *2°C "crash program" path:* Athanasiou, T, S Kartha, P Baer, 2006. "Greenhouse Development Rights". EcoEquity/Christian Aid (www.ecoequity.org)

Modeling of Climate Change

- The recent temperature increase is consistent with human production of greenhouse gases.
- Basic physics simple; detailed predictions hard.
- We are changing the composition of the atmosphere we rely on.

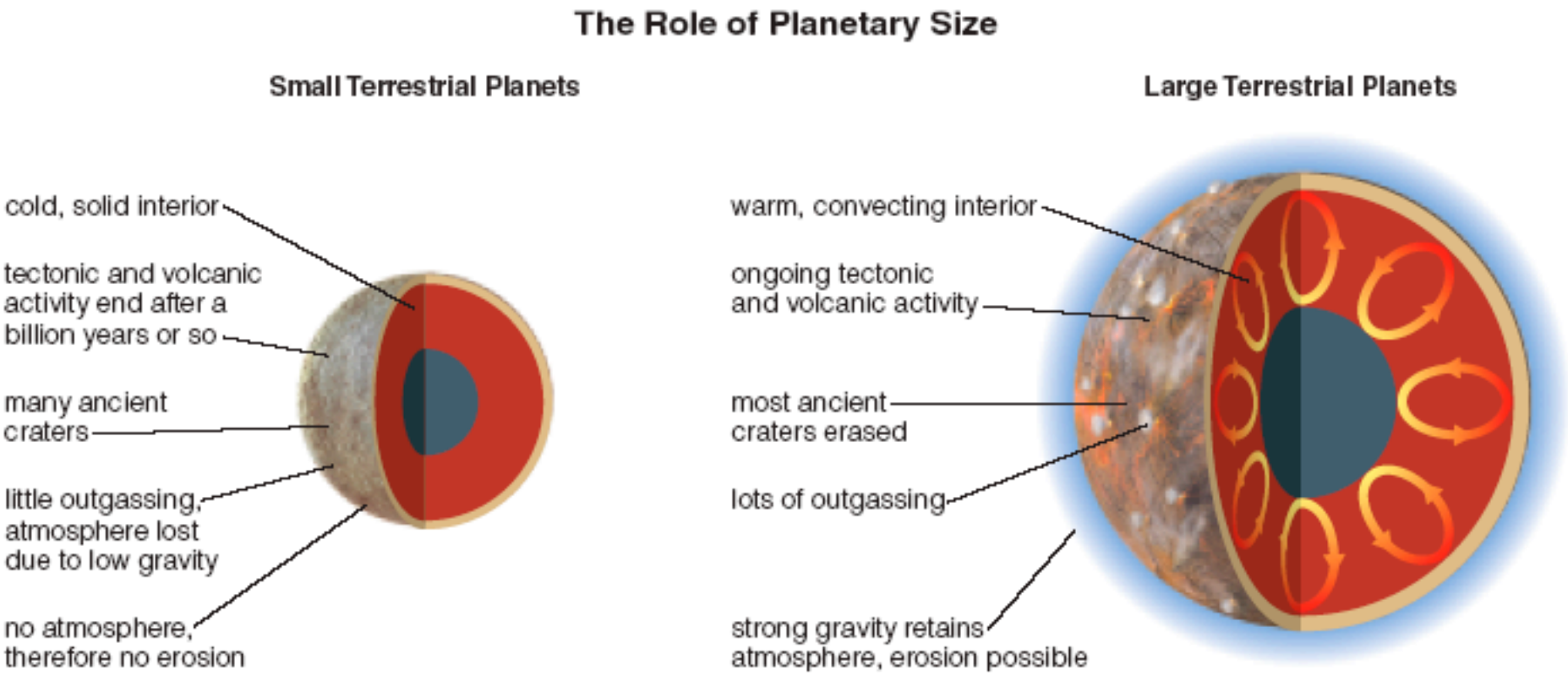


What makes a planet habitable?



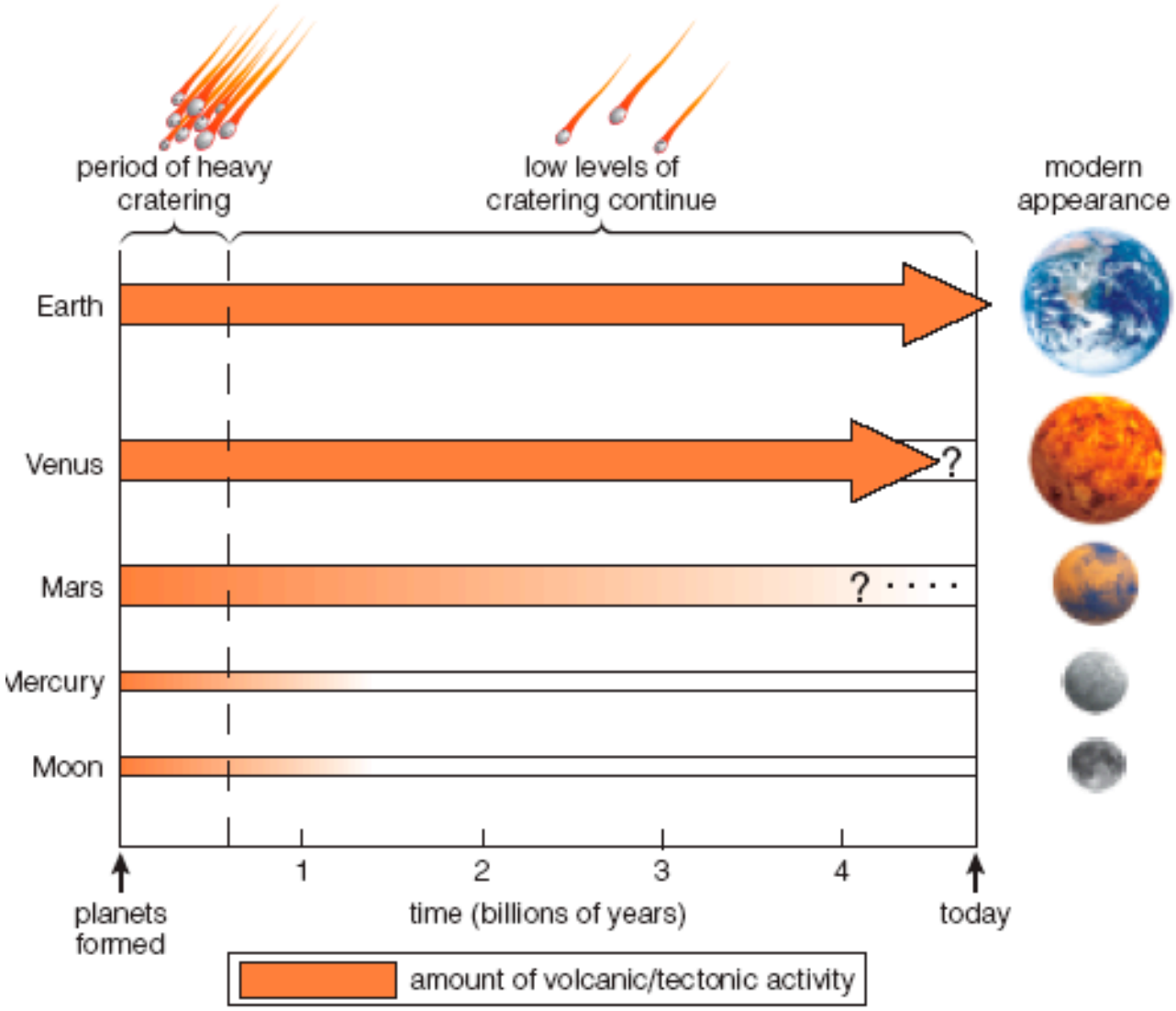
- Located at an optimal distance from the Sun for liquid water to exist

What makes a planet habitable?



- Large enough for geological activity to release and retain water and atmosphere

Planetary Destiny



Earth is habitable because it is large enough to remain geologically active, and it is at the right distance from the Sun so oceans could form.

What have we learned?

- What unique features of Earth are important for life?
  - Surface liquid water
  - Atmospheric oxygen
  - Plate tectonics
  - Climate stability

What have we learned?

- How is human activity changing our planet?
  - — Human activity is releasing additional carbon dioxide into Earth's atmosphere, presumably increasing the greenhouse effect.
- What makes a planet habitable?
  - — Earth's distance from the Sun allows for liquid water on Earth's surface.
  - — Earth's size allows it to retain an atmosphere and enough internal heat to drive geological activity.