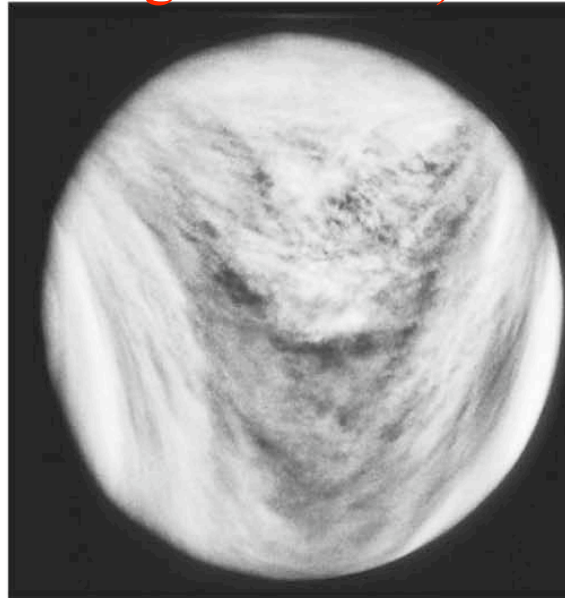


Lecture 21

1. Briefly finish off last time: fates of Venus & Mars
2. The effect of life on the early atmosphere.
3. The rise of atmospheric oxygen (first half of Chap. 11 of textbook, p.207-220)

What makes a good planet go bad?

Venus
(runaway
greenhouse)



- Oceans boiled away
 - No more weathering
 - Carbon partitions to atmosphere
 - CO₂ is ~245,000 times that on Earth
- T_s = 460 C

Earth
("just right")



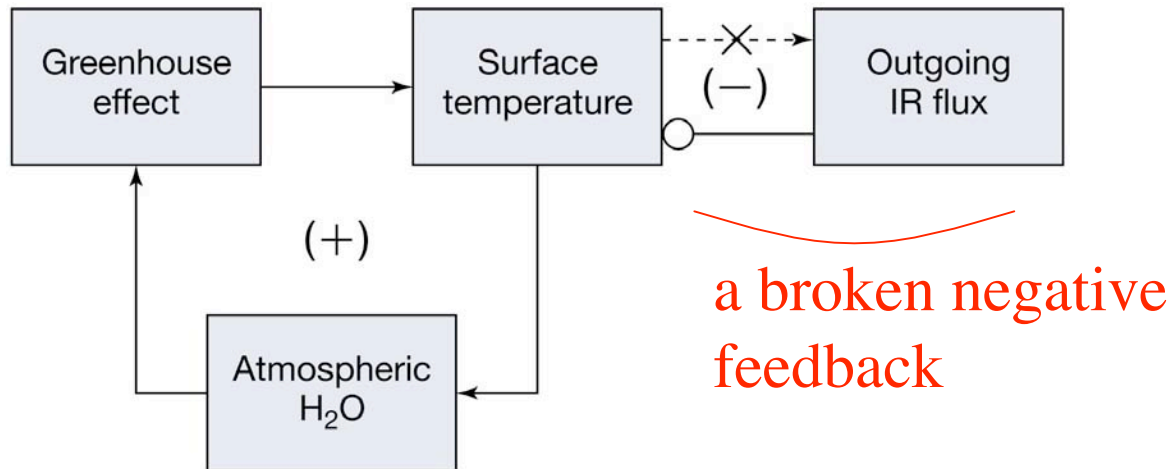
- has oceans
- hydrological cycle
- weathering returns CO₂ to lithosphere
- plate tectonics (volcanoes) return carbon to atmos.
- negative feedback

Mars
(virtually no
greenhouse)



- farther from Sun; too cold for liquid water
 - no water vapor greenhouse
 - too small for plate tectonics
 - no carbon cycle
 - CO₂ is ~16 times Earth
- T_s = -55C

Theory of runaway greenhouse on Venus



- Atmosphere became so warm and full of water vapor that almost no infrared radiation could escape from the surface
- Only infrared from the cold upper stratosphere escaped, which was not coupled to the surface temperature
- Surface became warmer and warmer, oceans evaporated
- No carbonate-silicate cycle => CO₂ built up in atmosphere
- No rain => sulfur also built up (sulfuric acid clouds on Venus)

LIVING and DEAD PLANETS

◀ Outgoing infrared spectra observed by satellites:

Which planet is the odd one out?

If photosynthesis ceased, O_2 would decrease exponentially to $<2\%$ of present levels in about 10 m.y.

NASA's *Terrestrial Planet Finder (TPF)* (2020 launch), will search the atmospheres of Earth-sized extrasolar planets for O_2 (via O_3)
=> life, possibility of complex life

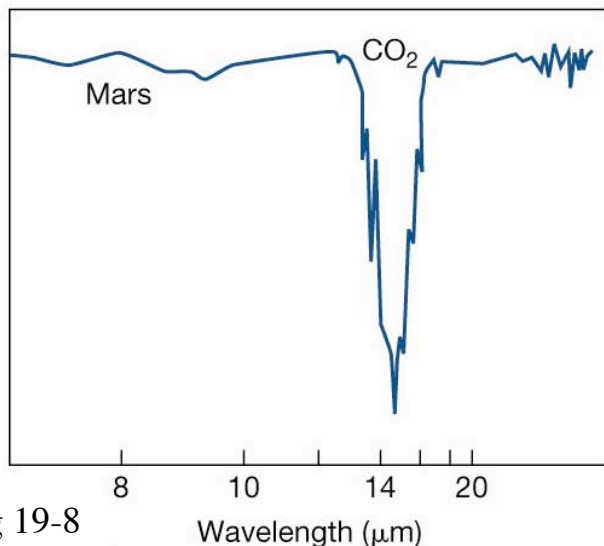
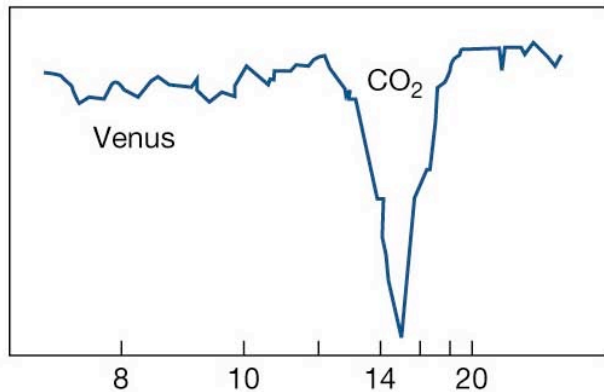
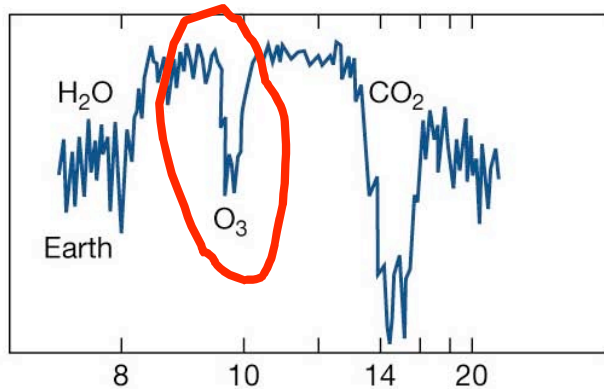


Fig 19-8

Wavelength (μm)

What we mean by a reducing vs. oxidizing atmosphere

Certain planetary atmospheres are said to be “reducing” (e.g. Jupiter, Titan)

Other planetary atmospheres are “oxidizing” (e.g. Earth)

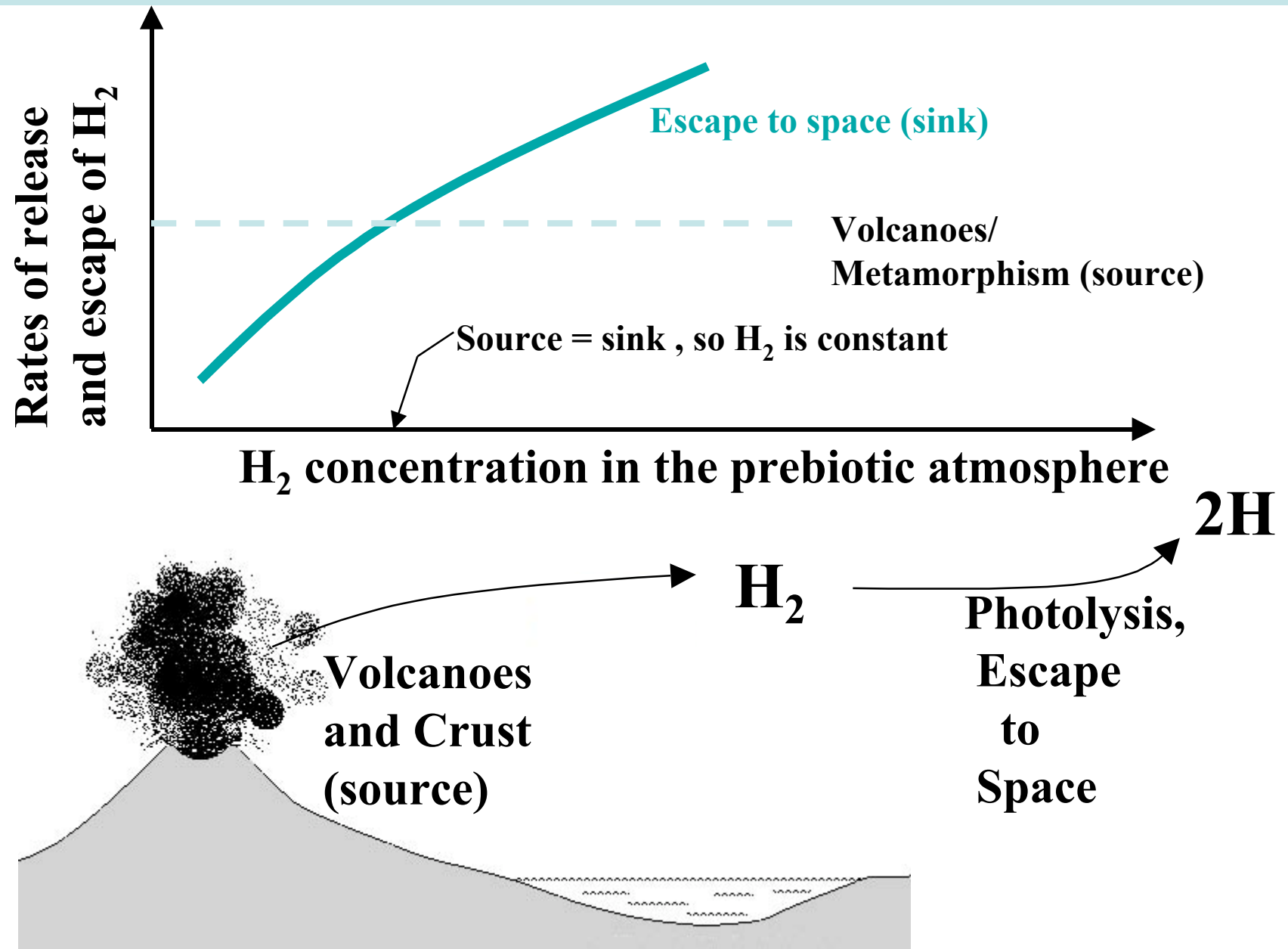
An oxidizing atmosphere is *hydrogen poor*.

A reducing atmosphere is *hydrogen rich*. Even a small excess of H₂ or hydrogen-bearing reducing gases (e.g. CH₄) tips the balance to an anoxic (i.e. virtually O₂-free) atmosphere.

What was the prebiotic
atmospheric
composition of our planet?

And then what happened after
life appeared?

THE PRINCIPLE BEHIND DEDUCING PREBIOTIC H₂ LEVELS



Prebiotic atmosphere was weakly reducing with almost no O₂

For reasonable values of outgassing on the early Earth (a few times the present rate of H₂ outgassing due to more tectonic activity), the calculated prebiotic H₂ level is ~1000 ppmv.

Prebiotic O₂ produced by photolysis of water vapor (and escape of hydrogen so that the photolysis products cannot recombine) would be consumed by photochemical reaction with hydrogen. Resulting O₂ levels are ~10⁻¹² bar, i.e. about 1 part per trillion.

Compare 0.55 ppmv H₂ in today's troposphere. Why low today?

H₂ reacts with the abundant O₂ through photochemical reactions. (Think of the troposphere as analogous to a slow combustion engine, with sunlight as the spark-plug.)

Some likely effects of early microbial life

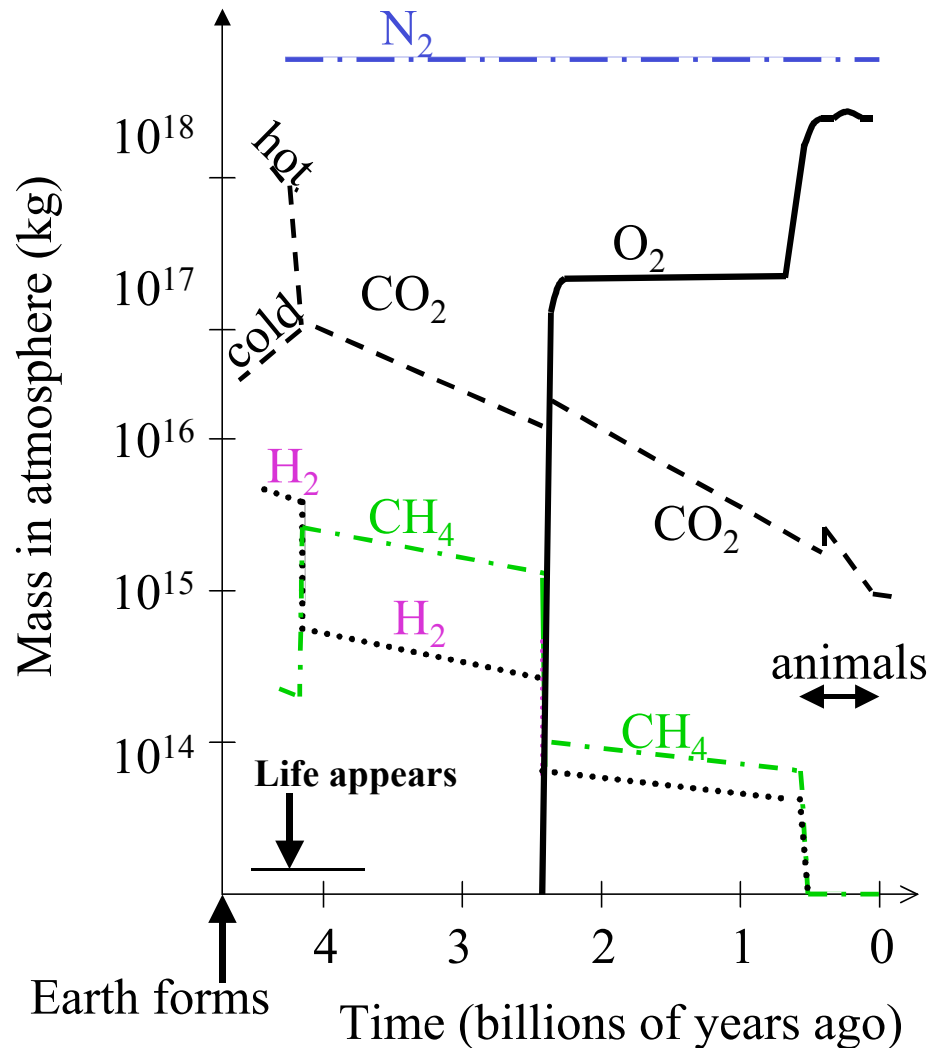
1. Making methane. Microbes eat H₂:
 $4\text{H}_2 + \text{CO}_2 = \text{CH}_4 + 2\text{H}_2\text{O}$

2. Microbes take C from CO₂ to make organic matter.

1 & 2 => pCO₂ probably drops (CH₄ control of greenhouse)

3. Microbes extract N from the air (*nitrogen fixation*). N is used in proteins. N would be returned to the air either as NH₃ which is decomposed by solar ultraviolet light to leave N₂, or released directly as N₂ after cycling by other microbes (*denitrification*).

History of Earth's atmospheric composition



This diagram is a composite from geochemical data and theoretical reasoning (Your instructor's best estimate)

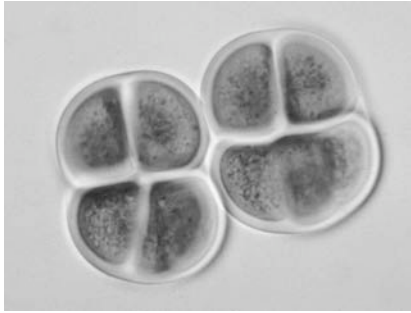
Rise of O₂

Broad reasons why important:

O₂ levels set the tempo for biological evolution.
O₂ allows complex life, here and on other Earth-like planets. Formation of O₃ layer screens out harmful UV for higher life.

Is the development of an O₂-rich atmosphere common on planets elsewhere in the galaxy / universe?

Are planets inhabited by complex life elsewhere in the Universe? Is the “Star Trek”/”Star Wars” picture wrong?
(Read *Rare Earth* popular book by UW’s
Peter Ward & Don Brownlee)



Where Earth's O₂ came from: The cyanobacteria.

O₂-producing photosynthetic bacteria, called **cyanobacteria**, inhabit all places on Earth where there is water and sunlight. There are about 10²⁷ cyanobacteria in the oceans.

One type of cyanobacterium, *Prochlorococcus*, is the most abundant organism on planet Earth. (Yet was only discovered in 1988!!)

When cyanobacteria die, their organic molecules are degraded but the basic structure of some of these molecules can be preserved.

Oils derived from cyanobacteria cell membranes are found in 2.7 Ga marine sedimentary rocks, i.e., cyanobacteria have been in the oceans since at least 2.7 Ga. Yet O₂ rose ~2.4-2.3 Ga. Why the delay?