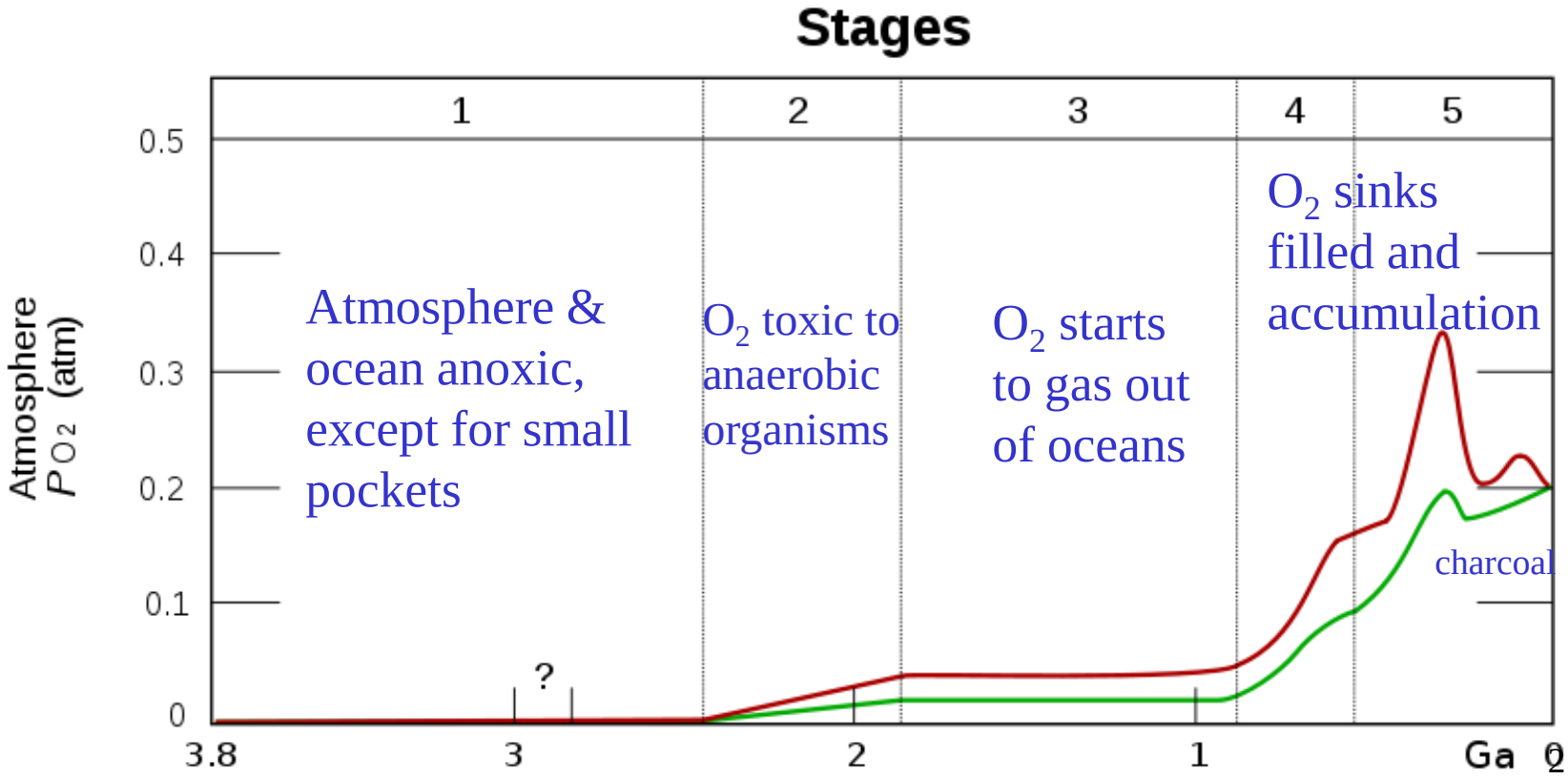
ASTR/GEOL-2040: Search for life in the Universe: Lecture 14

- HW4 due on Friday!
- Great oxidation
- Snowball Earth
  - Faculty Teaching Excellence program

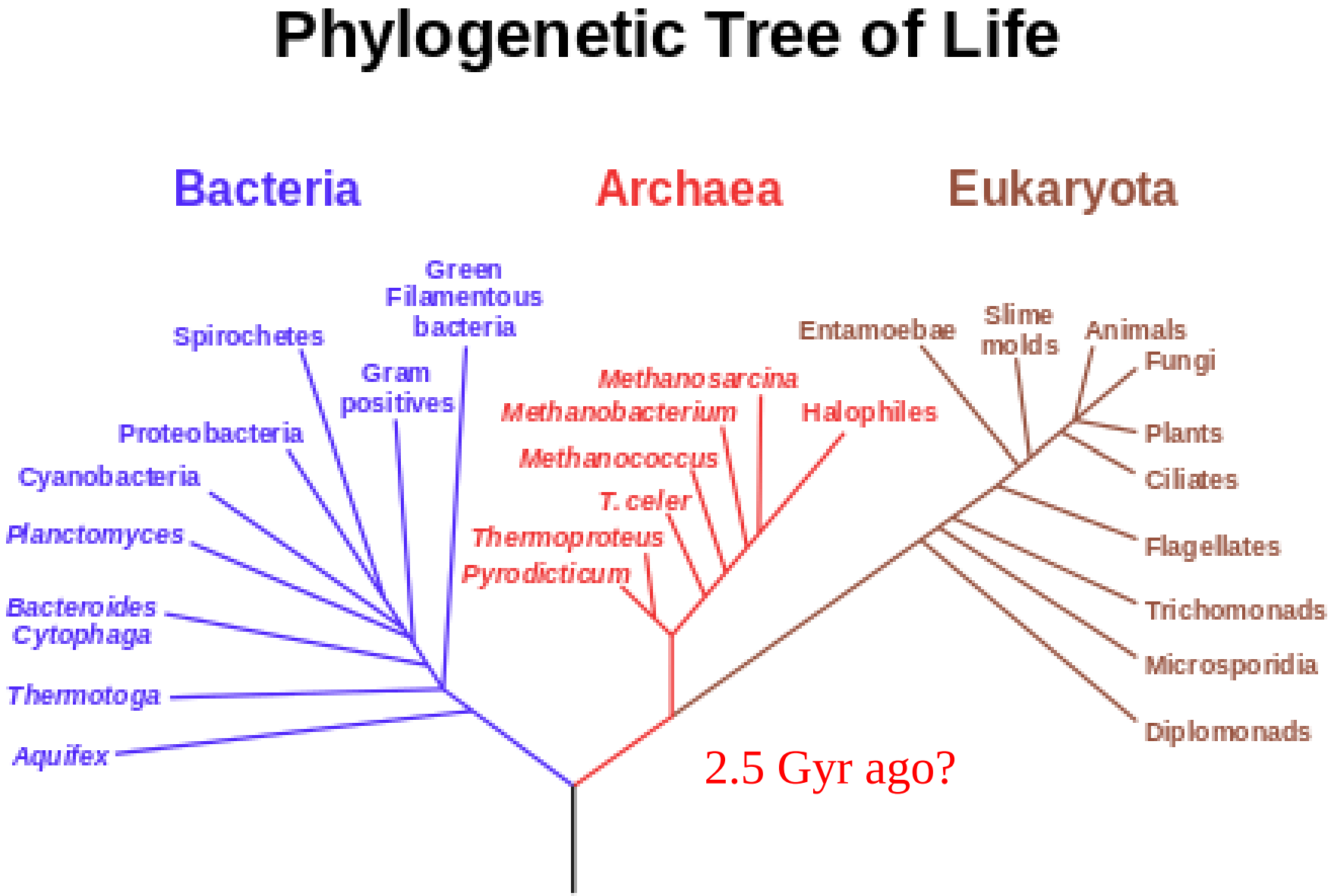
Axel Brandenburg
(Office hours: Mondays 2:30 – 3:30 in X590 and Wednesdays 11-12 in D230)

The great oxidation event (GOE)

- Oxygen catastrophe
- Mass extinctions



Rooted Tree

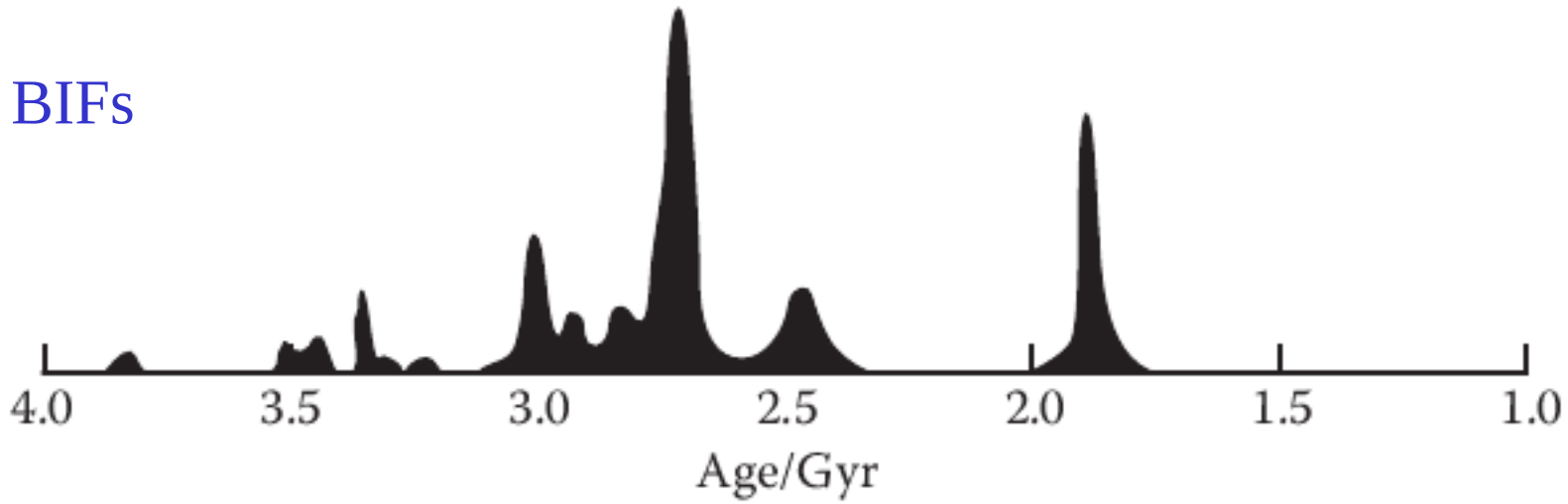

Phylogenetic Tree of Life
Bacteria
Archaea
Eukaryota
Green Filamentous bacteria
Spirochetes
Gram positives
Proteobacteria
Cyanobacteria
Planctomyces
Bacteroides
Cytophaga
Thermotoga
Aquifex
Methanosarcina
Methanobacterium
Halophiles
Methanococcus
T. celer
Thermoproteus
Pyrodicticum
Entamoebae
Slime molds
Animals
Fungi
Plants
Ciliates
Flagellates
Trichomonads
Microsporidia
Diplomonads
2.5 Gyr ago?

An anoxic environment

- Oceans dissolve iron
  - Comes from hydrothermal vents
  - In the form of ferrous iron (FeO)
- Early cyanobacteria (phytoplankton)
  - Gradual oxidation
  - Rust (hematite or Fe_2O_3) → insoluble
  - Banded Iron Formation (BIF)


BIFs: layers of Fe_2O_3 deposit

First BIFs 3.8 – 2.7 Gyr ago



- Earliest one: already 3.8 Gyr ago!
- Long lag time to 2.5 Gyr when O_2 levels rose. Why?

Why atmospheric O_2 much later?

A. No animal life available yet?
B. All used up by microbes
C. All used up by BIFs
D. Atmosphere still too warm
E. Not yet enough nutrients for phytoplankton

Why atmospheric O_2 much later?

A. No animal life available yet? — wrong logic

B. All used up by microbes — Possible, but too inefficient

C. All used up by BIFs — Possible, but big enough?

D. Atmosphere still too warm — not possible

E. Not yet enough nutrients for phytoplankton — Fe rich oeans → nutrient-rich

Why atmospheric O_2 much later?

A. No animal life available yet?

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C. All used up by BIFs

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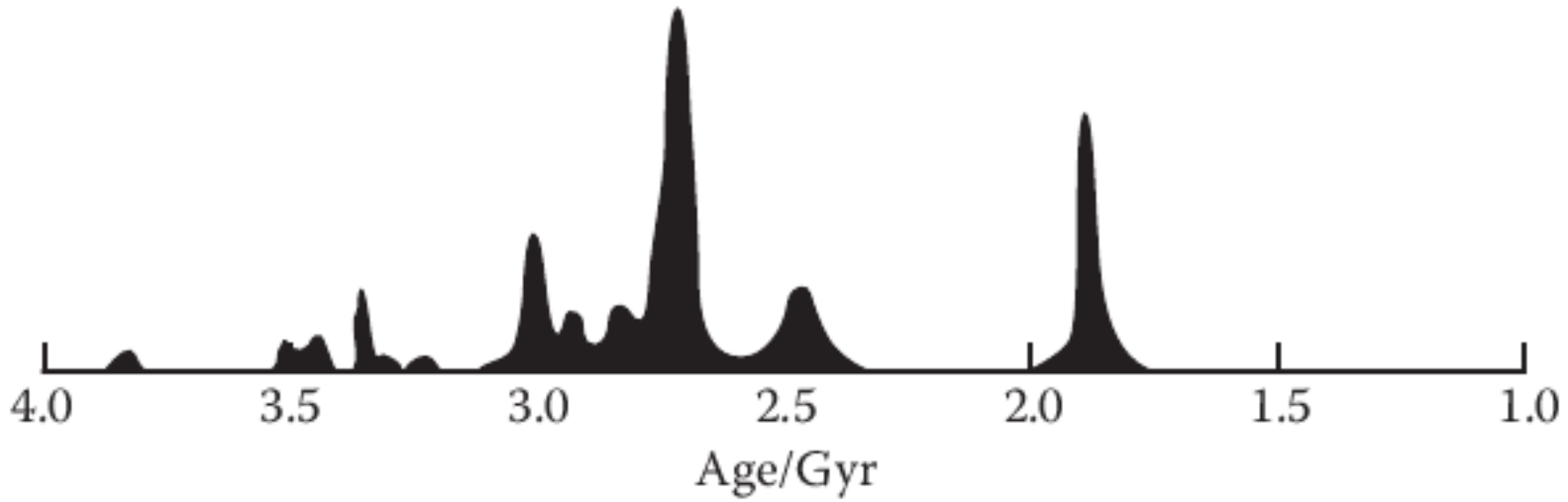
E. Not yet enough nutrients for phytoplankton

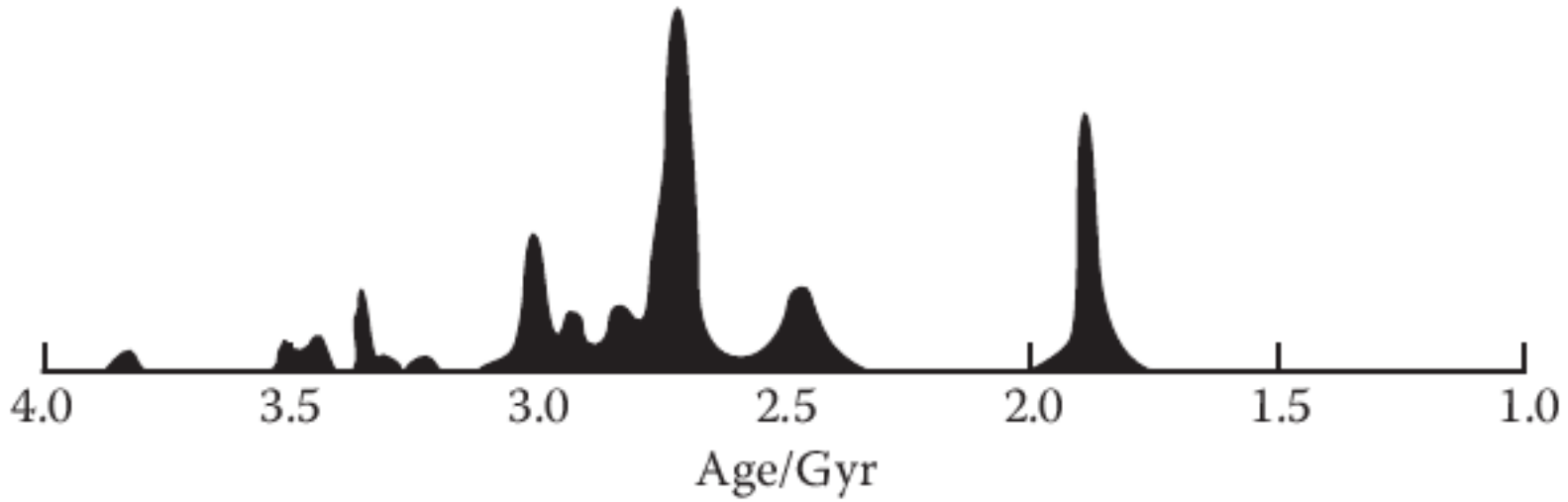
New feedback cycle

- Cyanobacteria + → O_2 + → less Fe
- Cyanobacteria – → O_2 + → more Fe



Another feedback cycle

- Cyanobacteria + → CO_2 – → cooler
- Cyanobacteria – → CO_2 + → warmer



Snowball Earth events

- Geological record → global events
  - Dramatic climate changes
- 2.45 Gyr ago (extreme event)
- 0.75 – 0.58 Gyr ago (up to 4)
  - Global glaciation (snowball Earth)
  - Mass extinction (CO_2 sinks cease)
  - Oceans become Fe-rich

Effects of snowball Earth on CO_2 sinks

- Photosynthetic life
- Acid rain: $H_2O+CO_2 = H_2CO_3$
- $CaSiO_3 + H_2CO_3 \rightarrow CaCO_3 + SiO_2$
- Snowball Earth would halt this process

Escaping Snowball Earth

- Volcanoes
- More O_2 production
  - BIFs
  - Explains Fe-rich betw glacial deposits
- Similar events earlier in history!

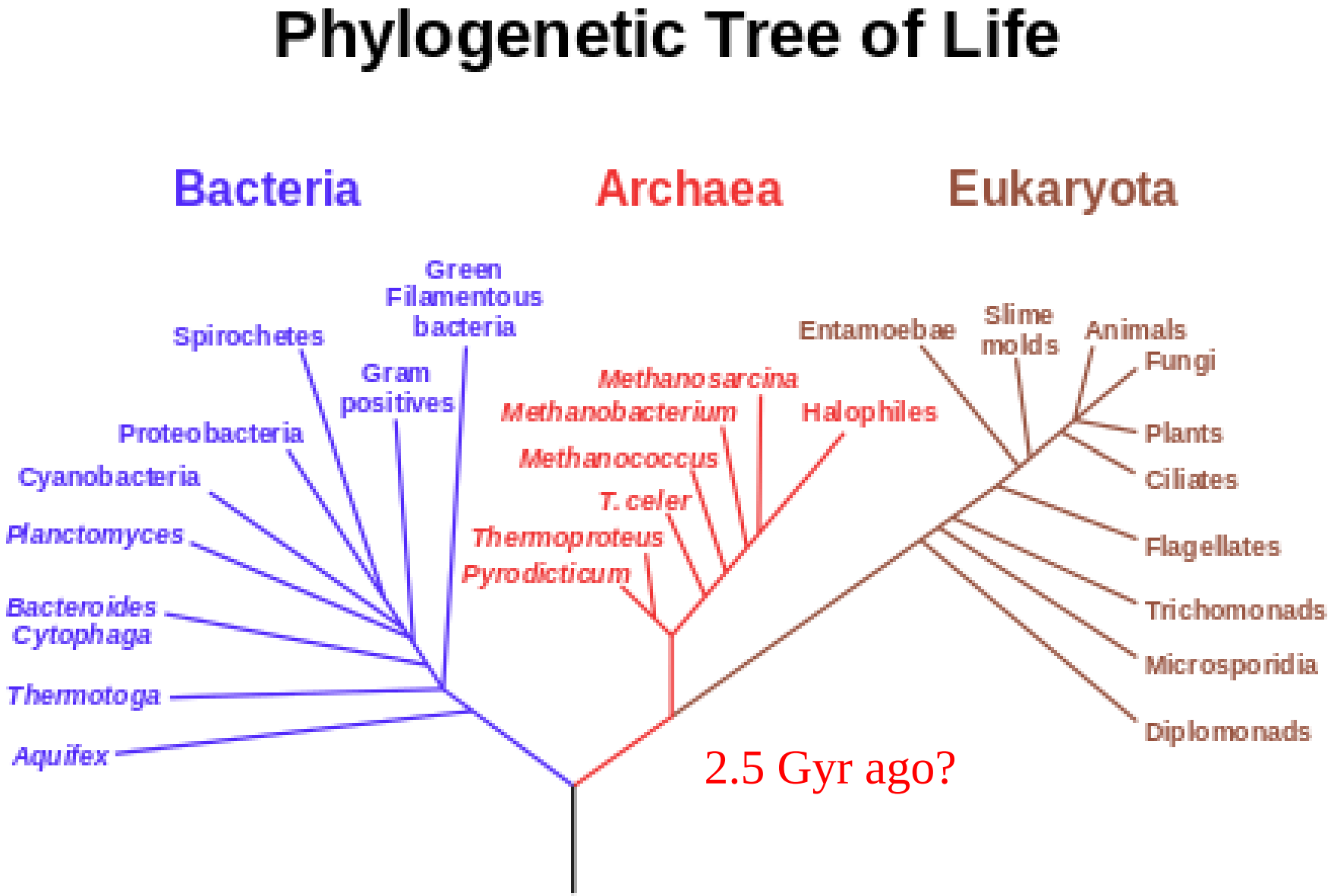
Snowball Earth & evolution

- Eukaria & Archea only after 2.5 Gyr
- Multicellular diverse life after 0.6 Gyr
- Coincidence?
- Greenhouse ← → Icehouse
- Evolutionary pressure
- Oxygen spikes could have sparked early animal evolution

Oxygen catastrophe

- Oxygen spikes
  - BIFs
  - Oceans Fe poor
- Phytoplanktons starve
  - Global disaster for most life
- Antioxidant enzymes (Vitamin E & C)
  - Reengineer life in iron-poor environments
  - Archea have such enzymes

Rooted Tree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2.5 Gyr ago?

Ice ages are different

- Temperature drops by a few degrees
  - More snowfall, down to low latitudes
  - Last one 10,000 yr ago
  - Duration: 35 Myr
- One contributor: cyclic changes in Earth rotation (tilt 22^{o}-25^{o}) & orbit
  - Milankovich cycles

Snowball Earth refers to

A. One in a series of deep ice ages that occurred >0.5 Gyr ago
B. The idea that Earth would be frozen without greenhouse effect
C. Any of the ice ages that occurred in the past few million years

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A. One in a series of deep ice ages that occurred >0.5 Gyr ago

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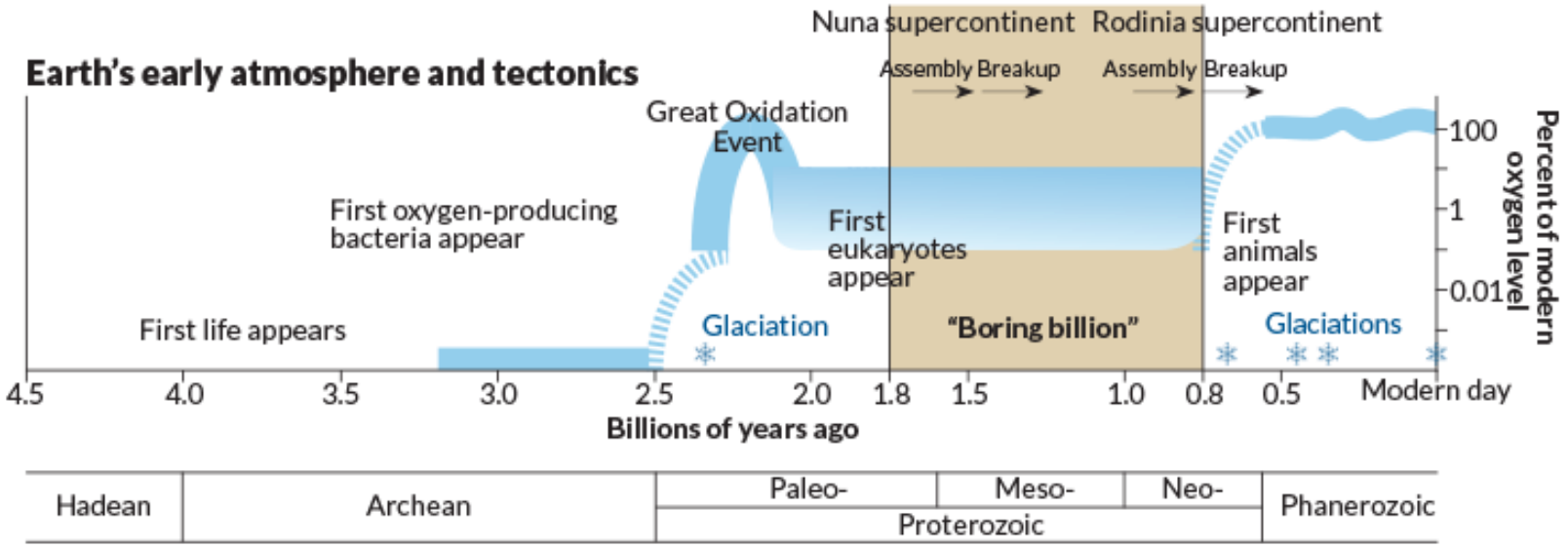
The boring billion: 1.8 – 0.8 Gyr

- After: atmos. O_2, glaciation, GOE, prokaryotic life, UV-blocking ozone
- O_2 remained at 1% PAL (present atmospheric level)



More evidence for early life
Accumulation of organics

- Photosynthesizing cyanobacteria
- Grow on top of each other
- Layered structure

Στρώμα λίθος

English Greek Spanish Detect language

Greek Finnish English

mattress

στρώμα

English Greek Spanish Detect language

Greek Finnish English

λίθος

stone

Modern stromatolites

Early Faint Sun Paradox

The Early Faint Sun Paradox: Organic Shielding of Ultraviolet-Labile Greenhouse Gases

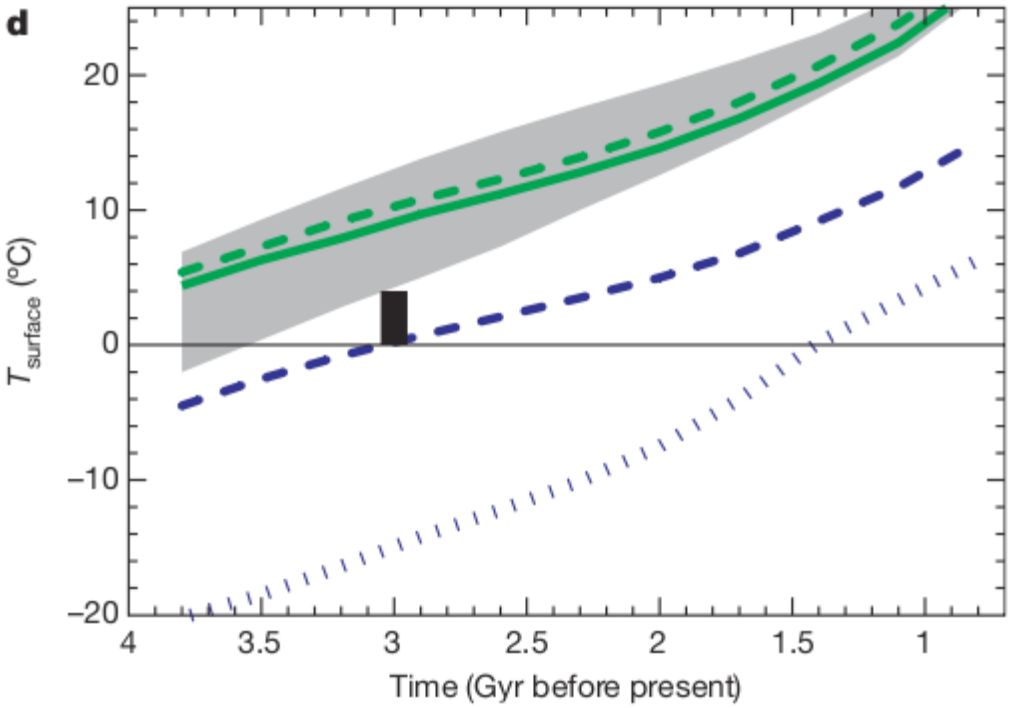
Carl Sagan and Christopher Chyba

www.sciencemag.org • SCIENCE • VOL. 276 • 23 MAY 1997

No climate paradox under the faint early Sun

Minik T. Rosing[1,2,4], Dennis K. Bird[1,4], Norman H. Sleep[5] & Christian J. Bjerrum[1,3]

Vol 464|1 April 2010|doi:10.1038/nature08955



- Early Sun 30% fainter
  - Yet liquid water!?
  - Greenhouse gases?
- Geol record: no!
  - Less continents
  - Less albedo

Next week

- Evidence for early life on Earth
- Oceans 4.4 Gyr ago
- Different rock types
- pp. 65 – 71 in RGS
  - After that
    - Significance of ^{13}C isotope
    - Cambrian explosion of life