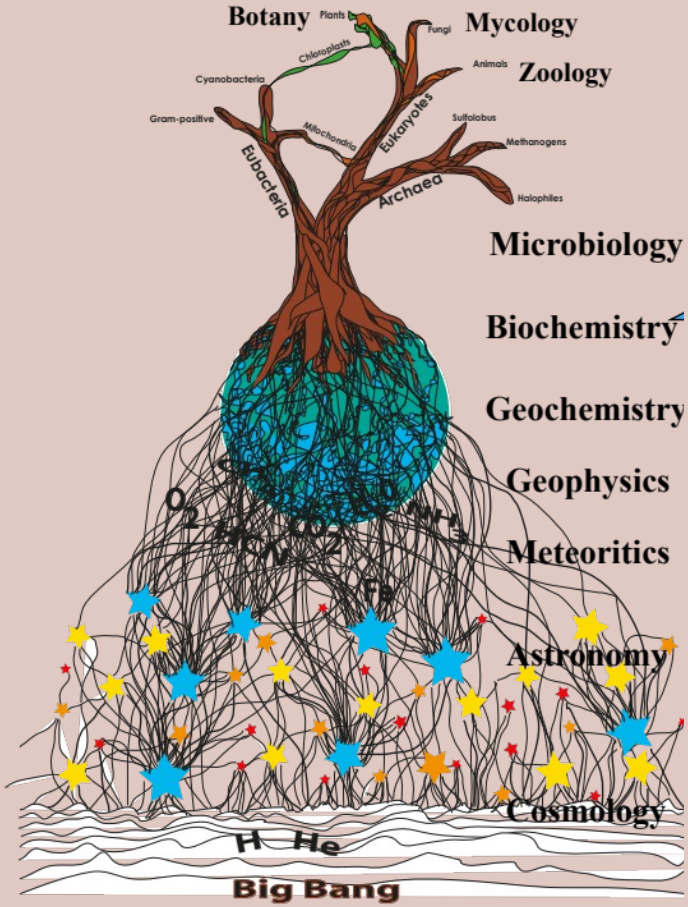
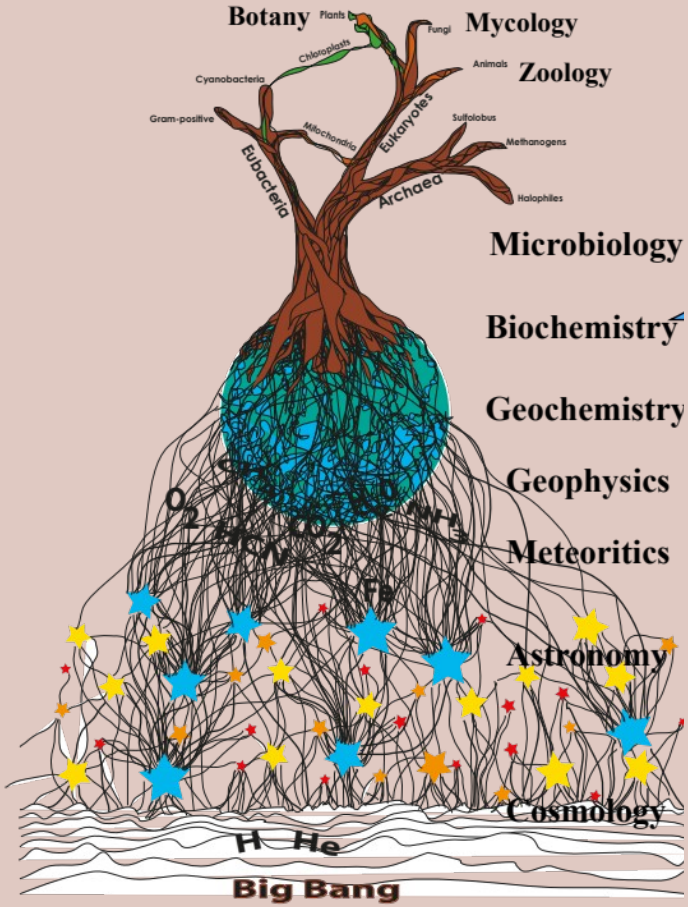


Habitability and the Search for Life Elsewhere



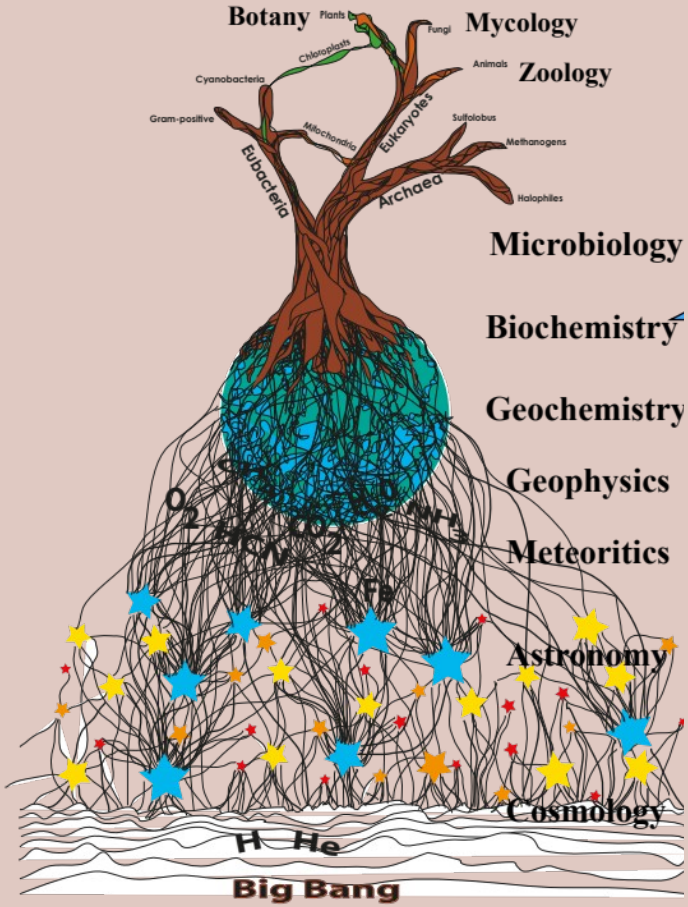
Habitability and the Search for Life Elsewhere

1) The origin of life: WHAT, WHEN, WHERE, HOW, WHY ?

2) What kind of planets are in the universe?

3) Habitable Zones: Terrestrial, Circumstellar, Galactic, Universal

4) Are we Alone? What can life on Earth tell us about life elsewhere?



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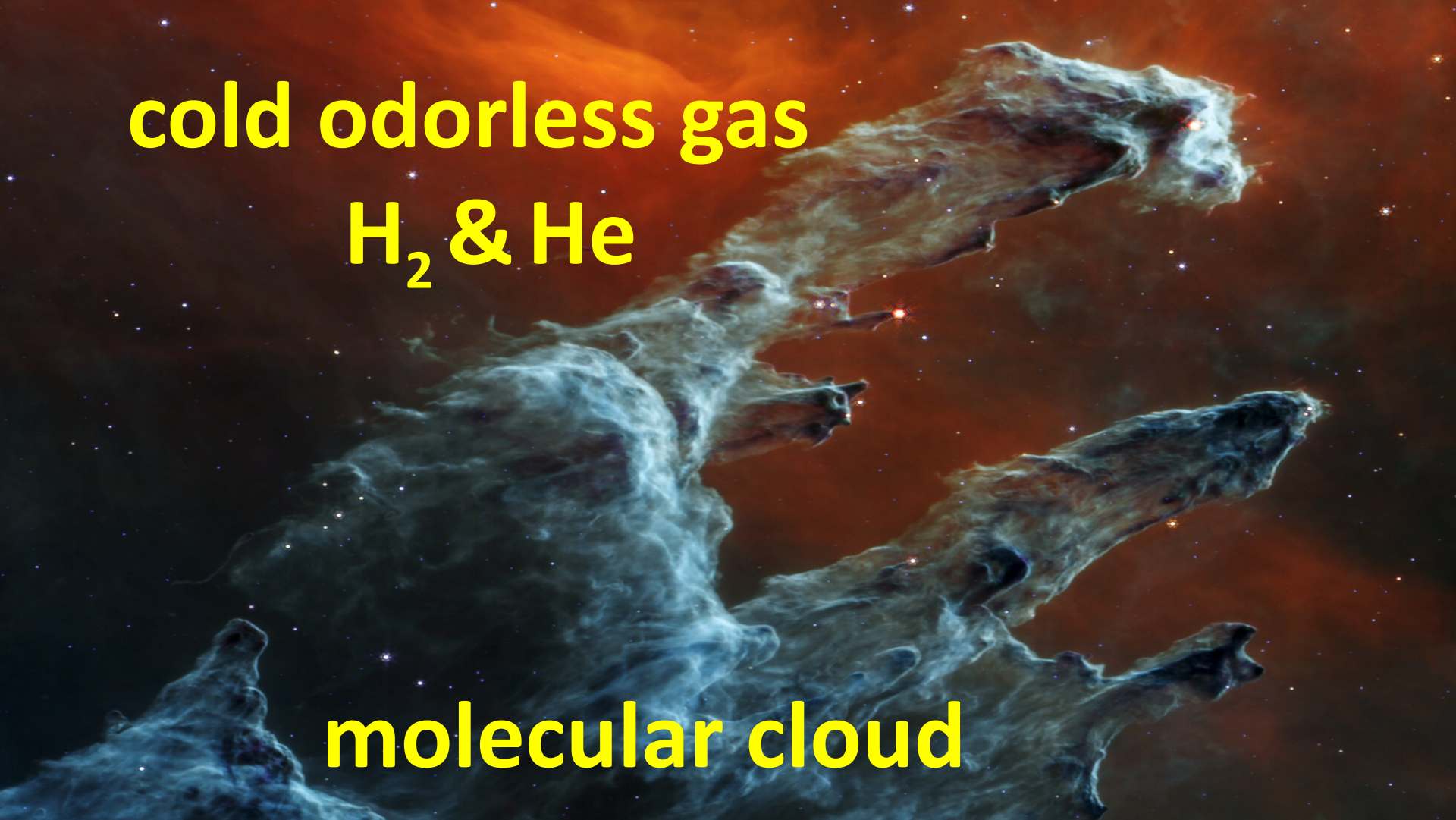
WHAT ?

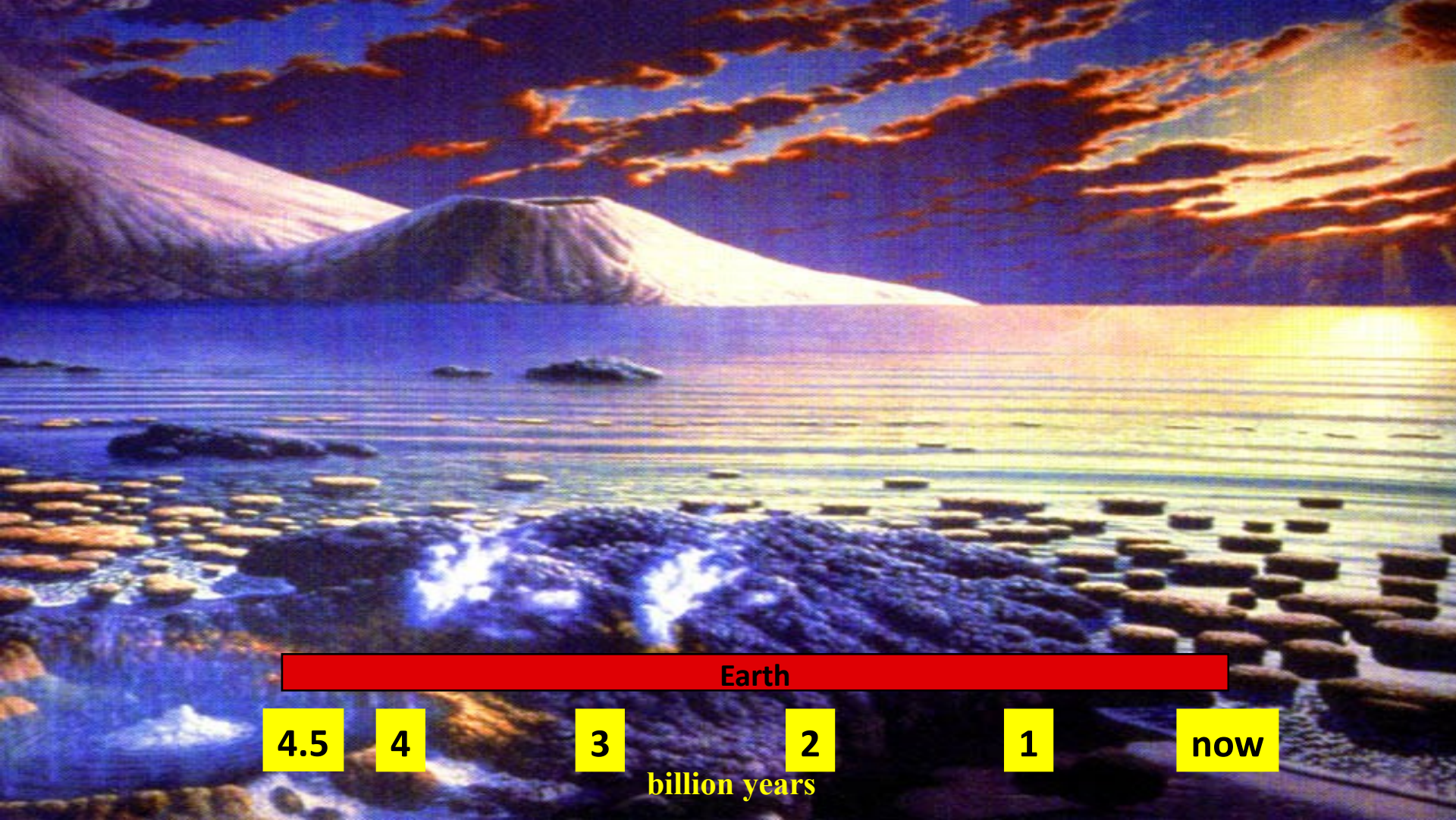

cold odorless gas
H_2 & He
molecular cloud

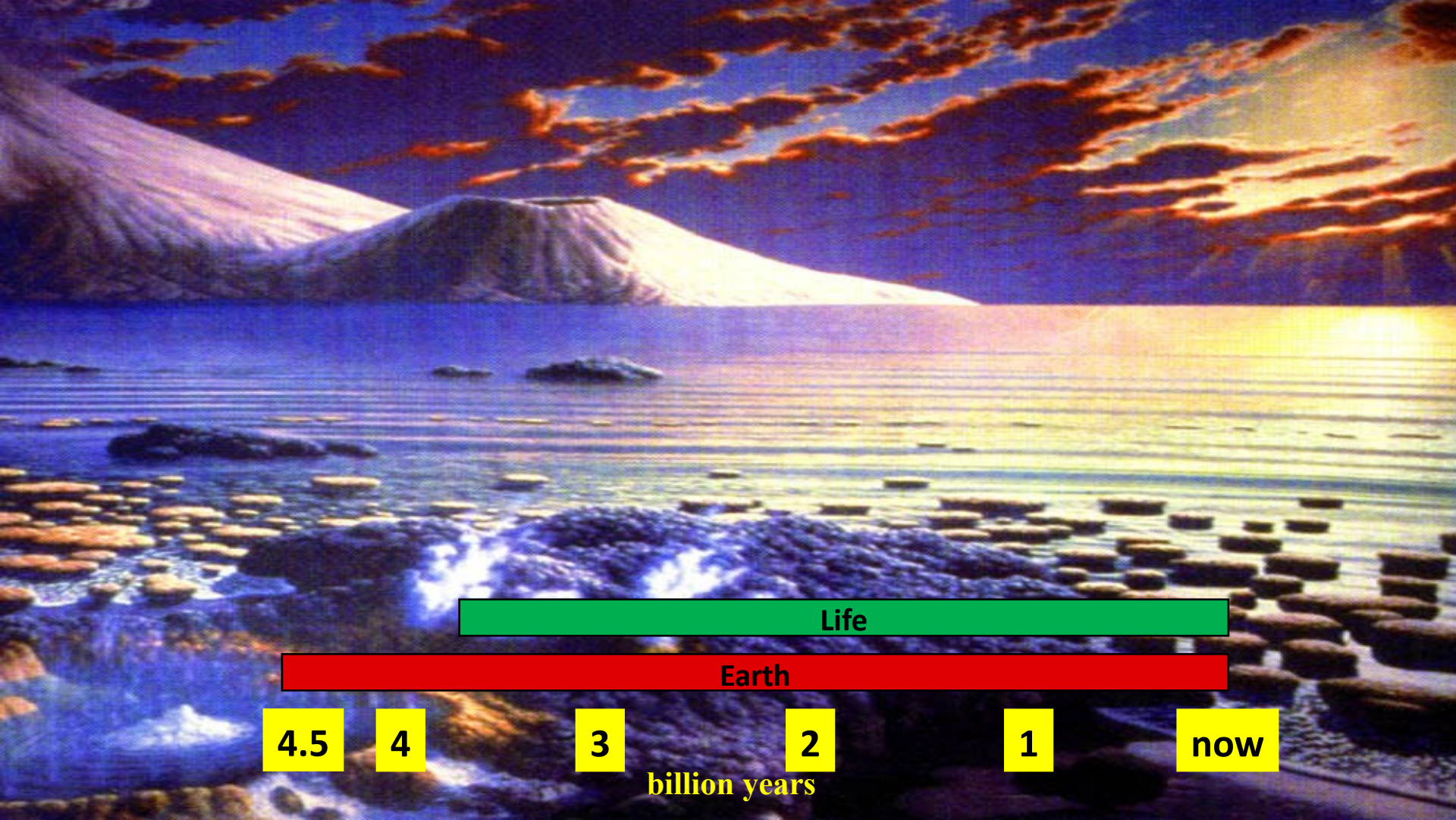

HOCNPS
life form

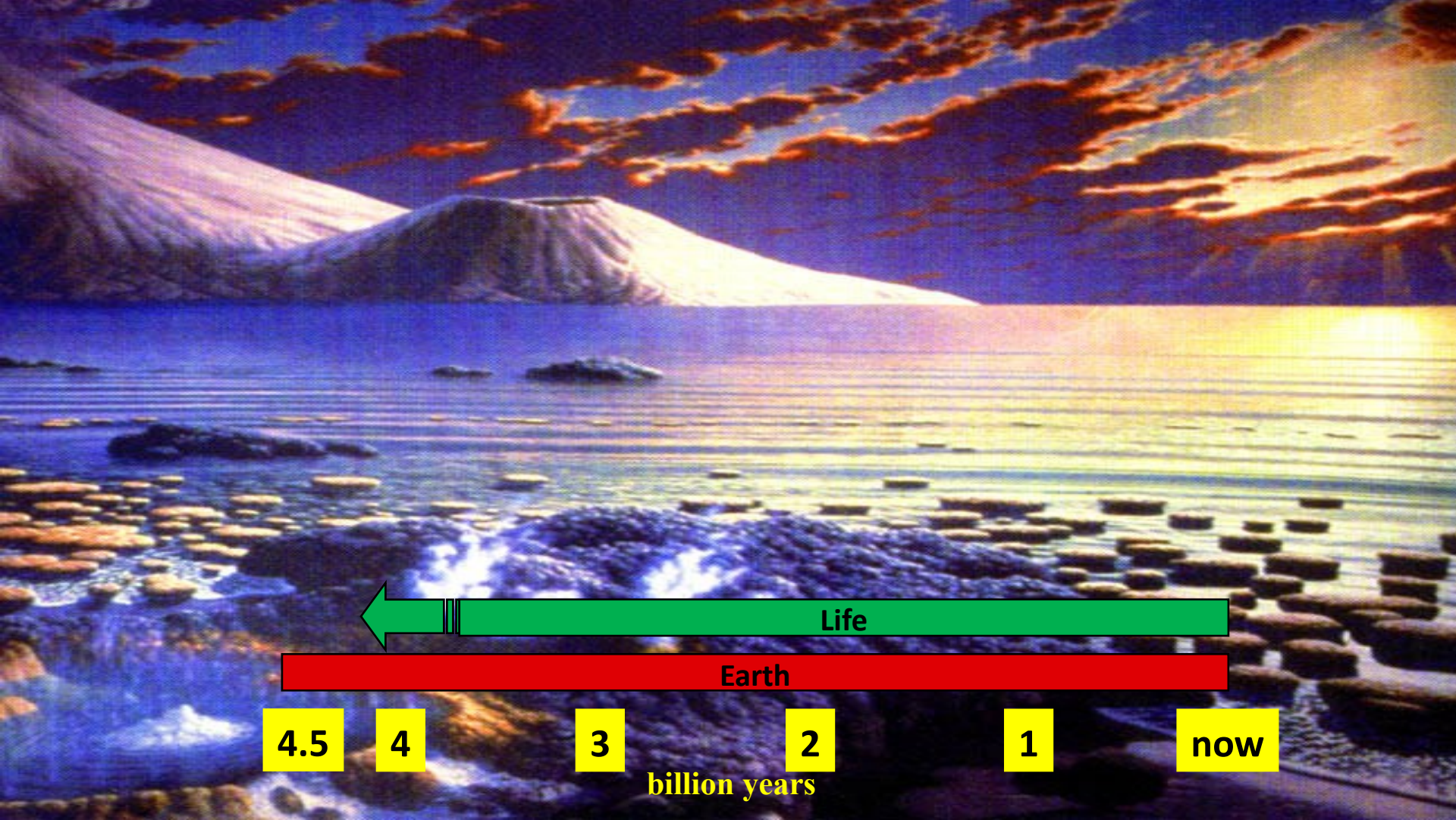
life

non-life

WHEN ?


Earth
4.5
4
3
2
1
now
billion years


Life
Earth
4.5
4
3
2
1
now
billion years


Life
Earth
4.5
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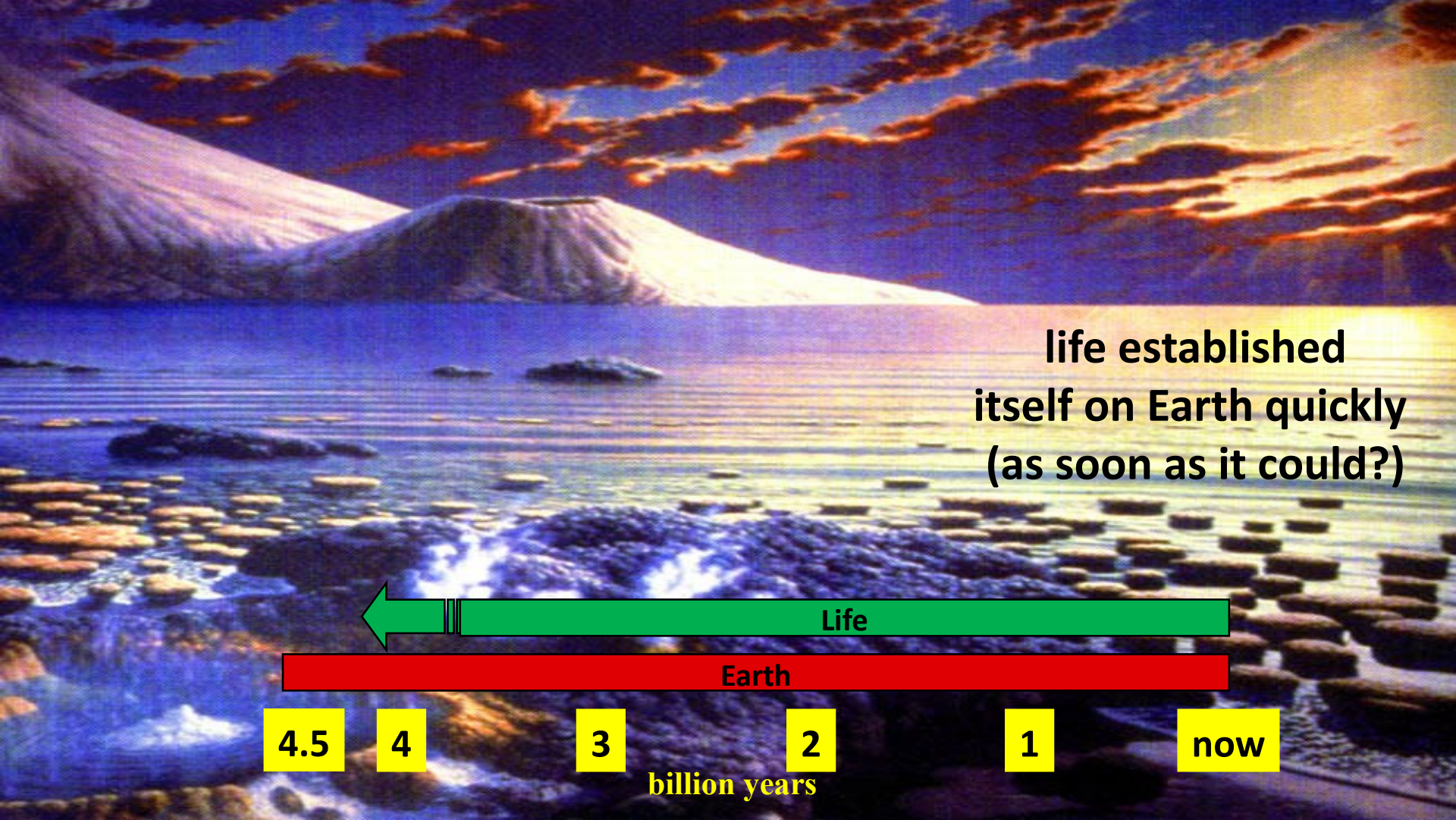
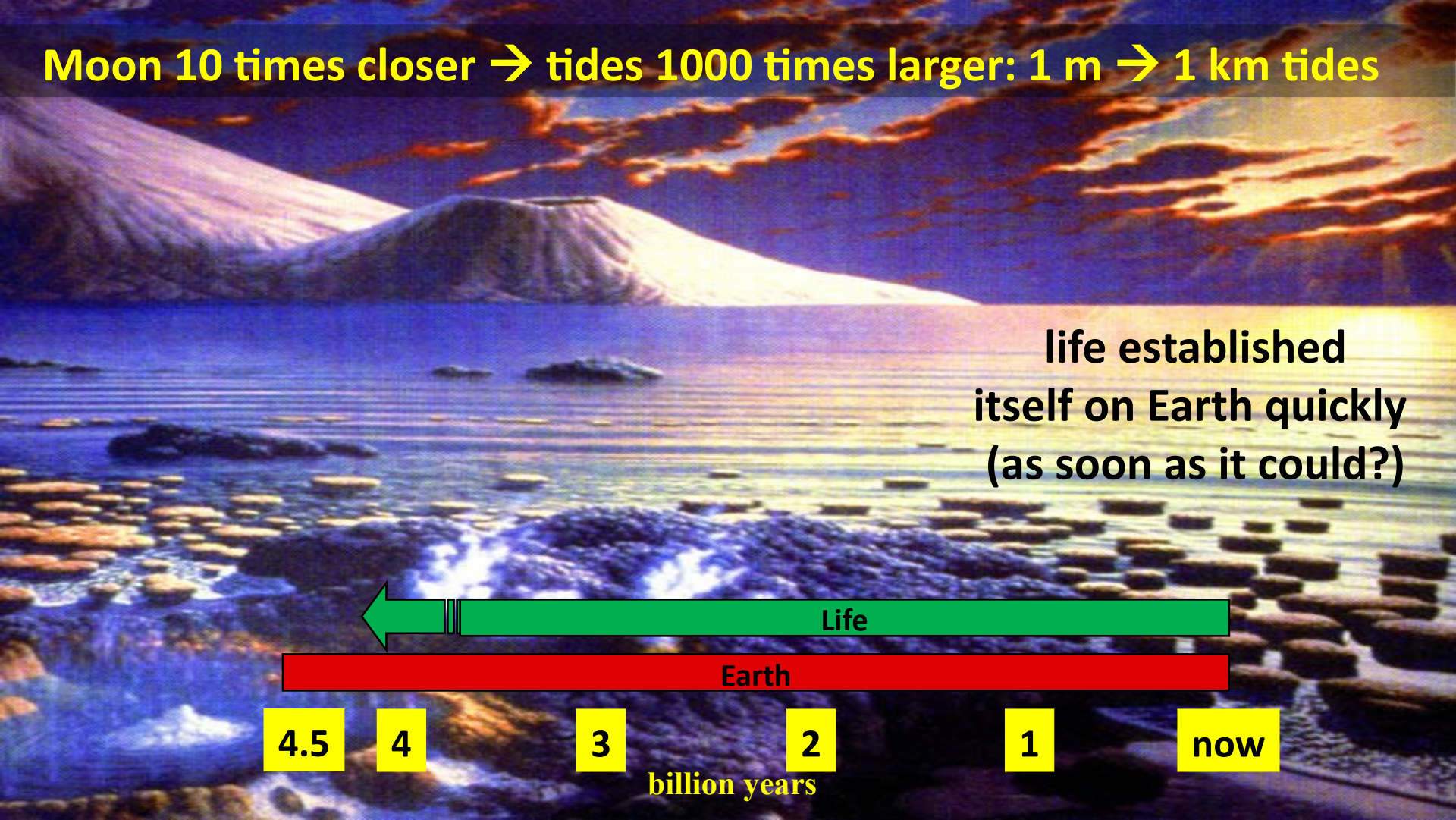
now
billion years


life established
itself on Earth quickly
(as soon as it could?)
Life
Earth
4.5
4
3
2
1
now
billion years

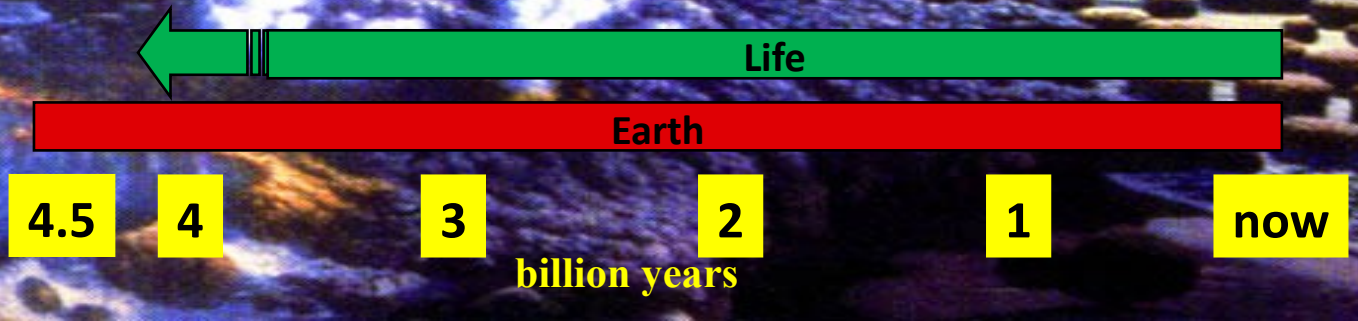
Moon 10 times closer → tides 1000 times larger: 1 m → 1 km tides



Moon 10 times closer → tides 1000 times larger: 1 m → 1 km tides

24 → 8 hour day: 2 x 1m tides → 6 x 1 km tides

life established itself on Earth quickly (as soon as it could?)



Moon 10 times closer → tides 1000 times larger: 1 m → 1 km tides

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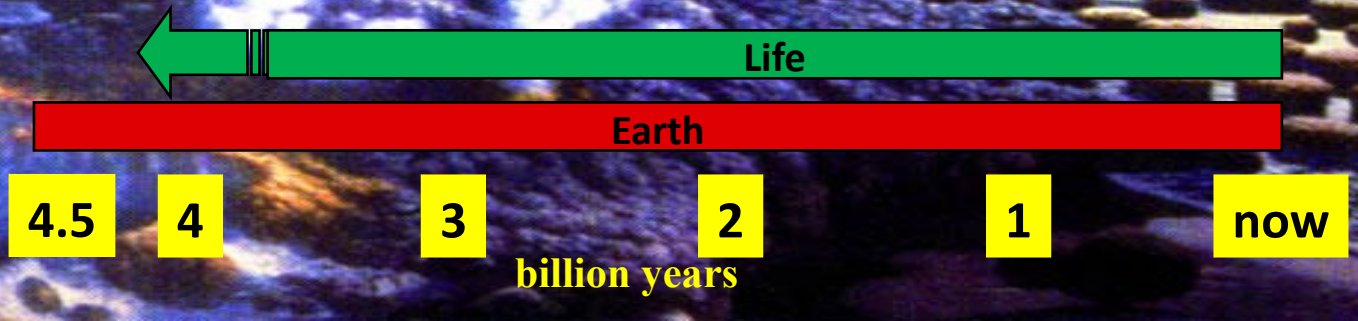
no quiet little tide pools but lots of wet/dry cycles

life established itself on Earth quickly (as soon as it could?)



Moon 10 times closer → tides 1000 times larger: 1 m → 1 km tides

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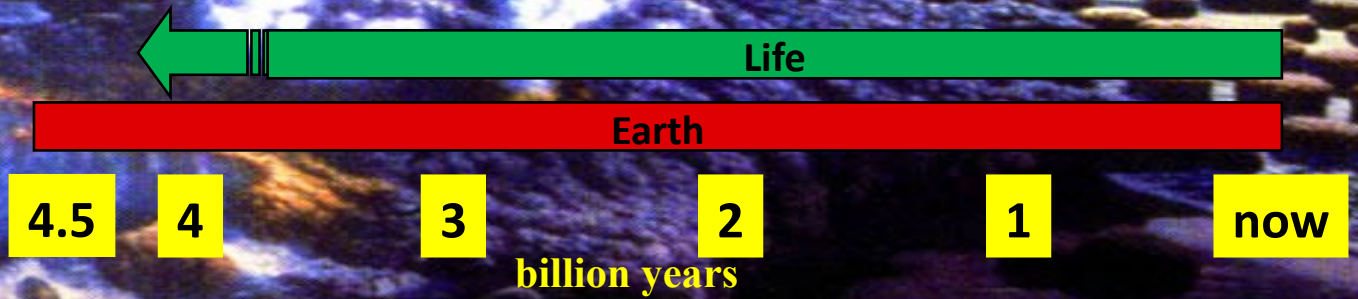
no quiet little tide pools but lots of wet/dry cycles

no oxygen, no ozone, lots of UV

life established itself on Earth quickly (as soon as it could?)

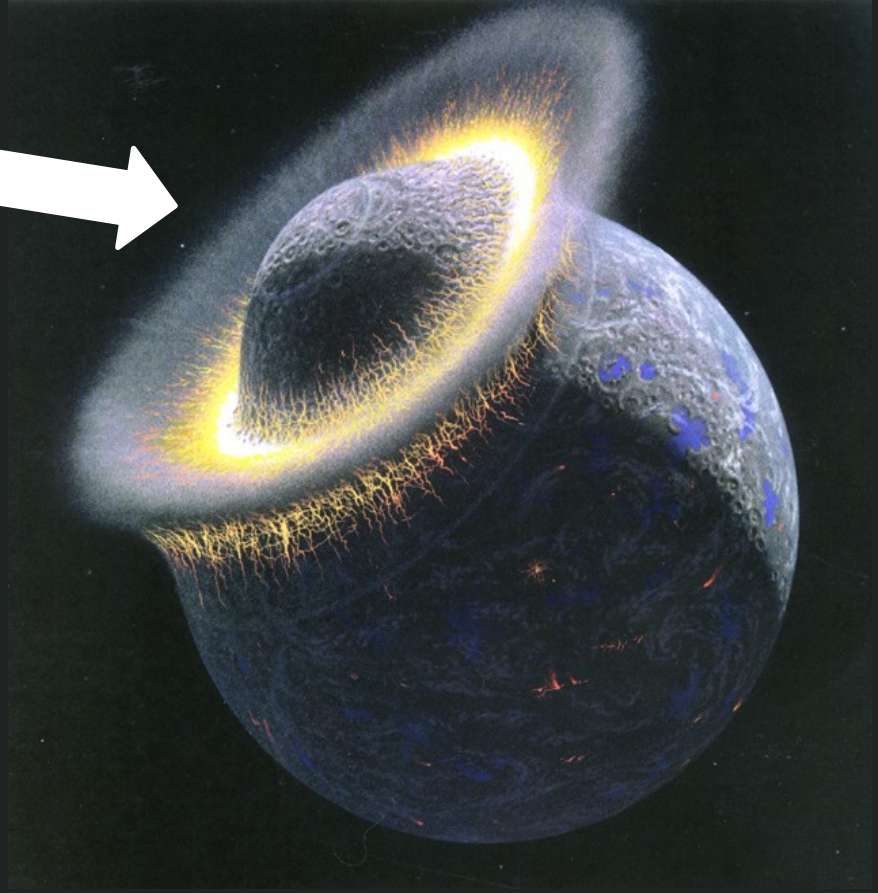


WHEN ?

history of accretion and bombardment

oldest rocks
oldest fossils
oldest isotopic fossils
oldest (= deepest) parts of phylogenetic tree

moon-forming impact
about 4.5 Gya
20-100 Myr after the
formation
of the Solar System



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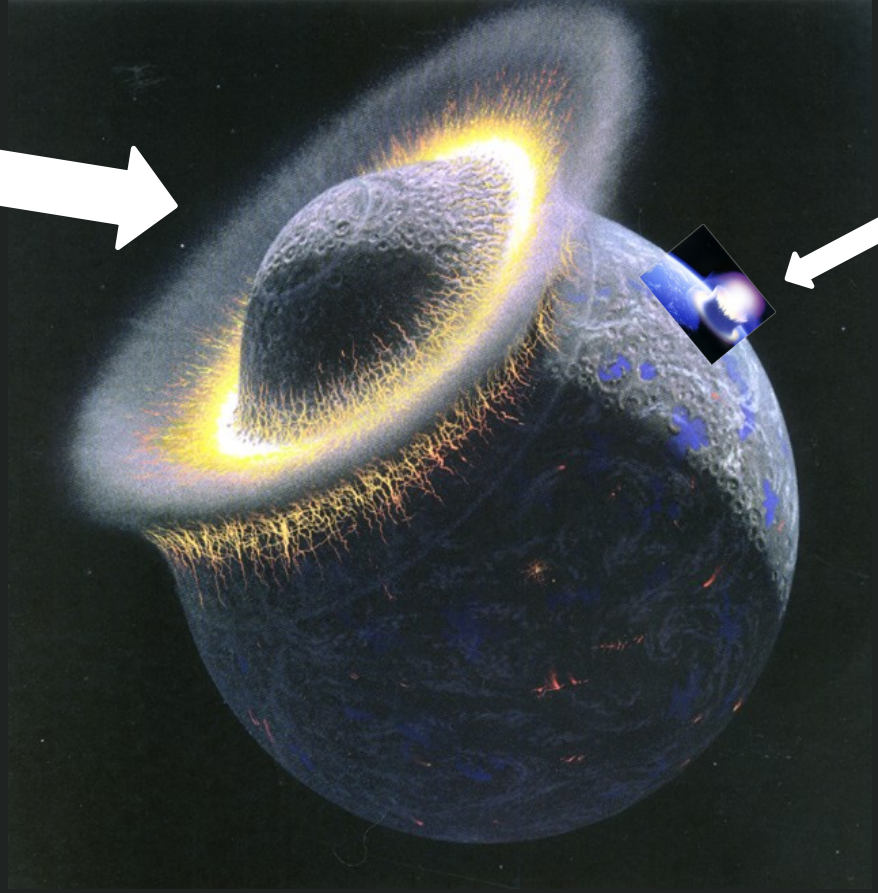
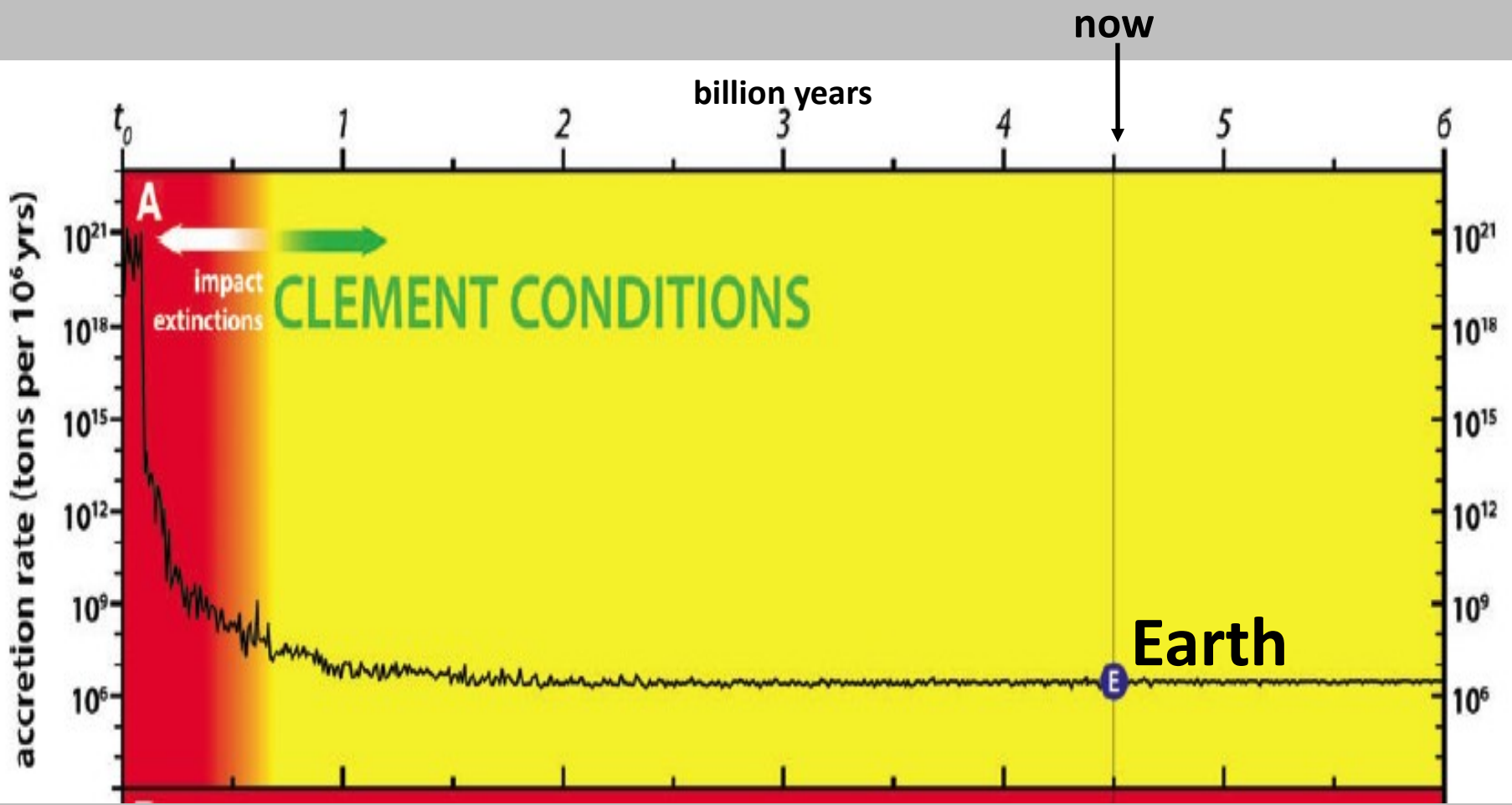
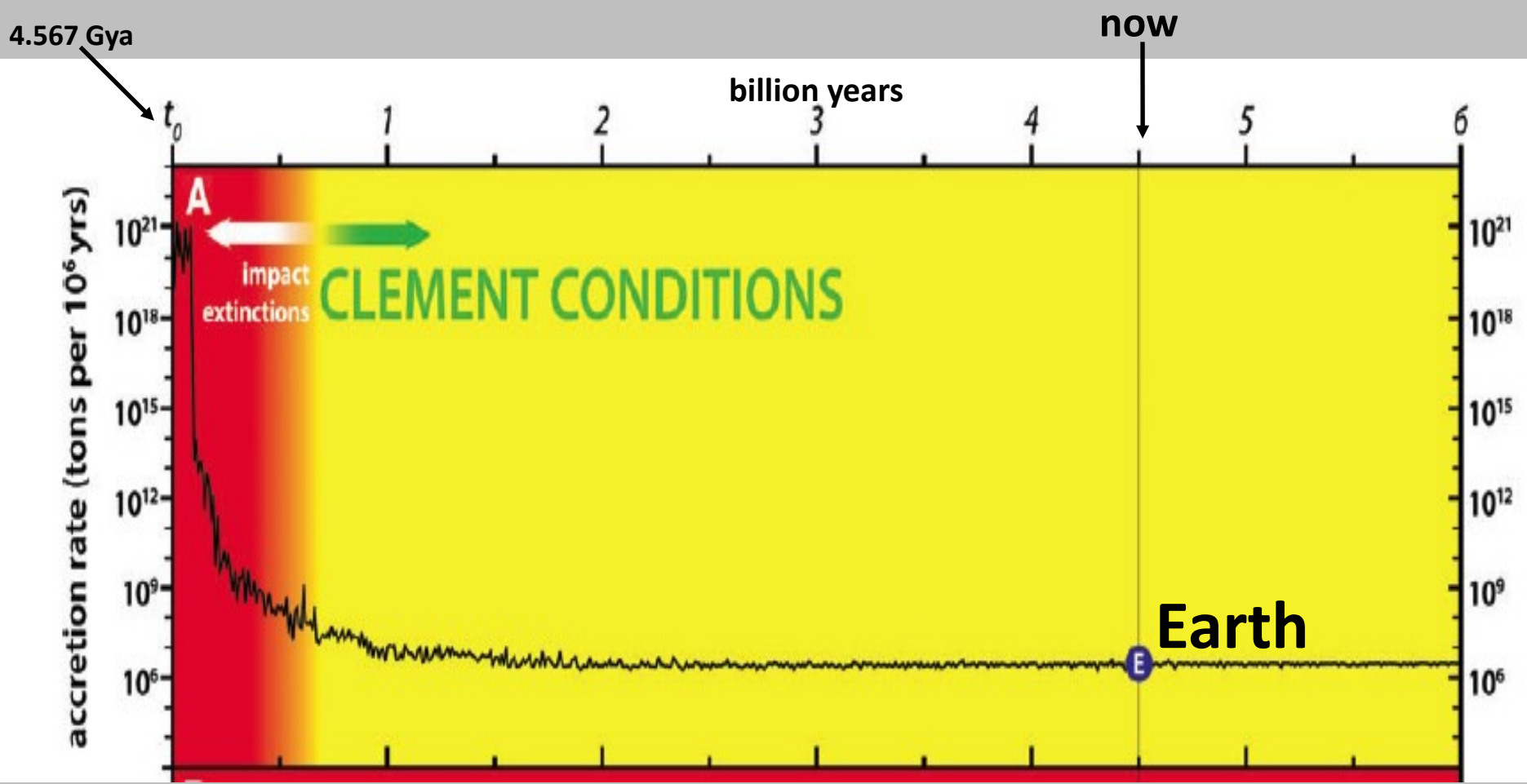


impact 65 Mya
that wiped out dinosaurs


now
billion years
t_0
1
2
3
4
5
6
A
impact extinctions
CLEMENT CONDITIONS
accretion rate (tons per 10^6 yrs)
10^{21}
10^{18}
10^{15}
10^{12}
10^{9}
10^{6}
E
Earth


4.567 Gya
now
billion years
t_0
1
2
3
4
5
6
A
impact extinctions
CLEMENT CONDITIONS
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10^{21}
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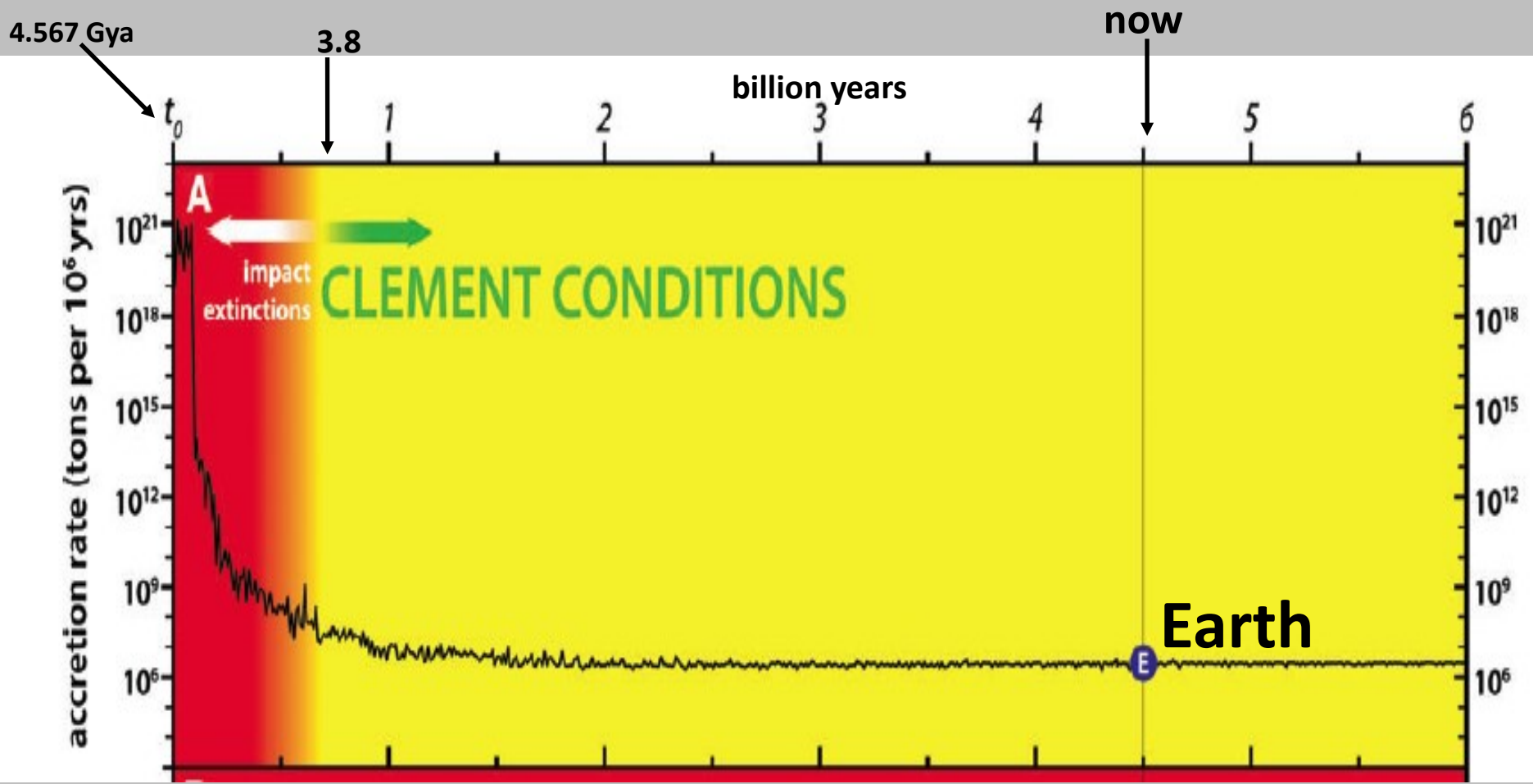
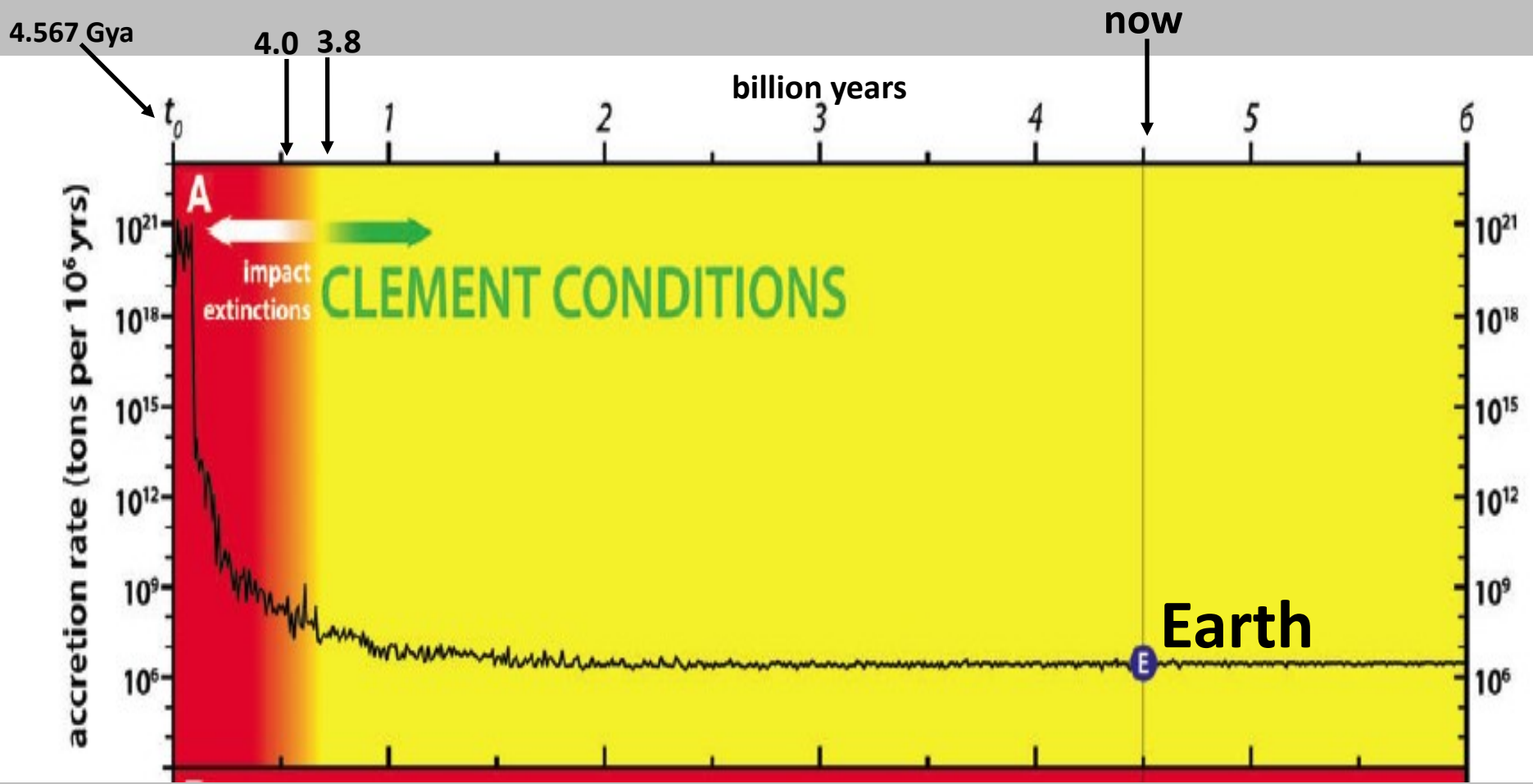
E
Earth


4.567 Gya
3.8
now
billion years
t_0
1
2
3
4
5
6
A
impact extinctions
CLEMENT CONDITIONS
accretion rate (tons per 10^6 yrs)
10^{21}
10^{18}
10^{15}
10^{12}
10^{9}
10^{6}
E
Earth


4.567 Gya
4.0
3.8
now
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t_0
1
2
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impact extinctions
CLEMENT CONDITIONS
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10^{21}
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10^{15}
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10^{9}
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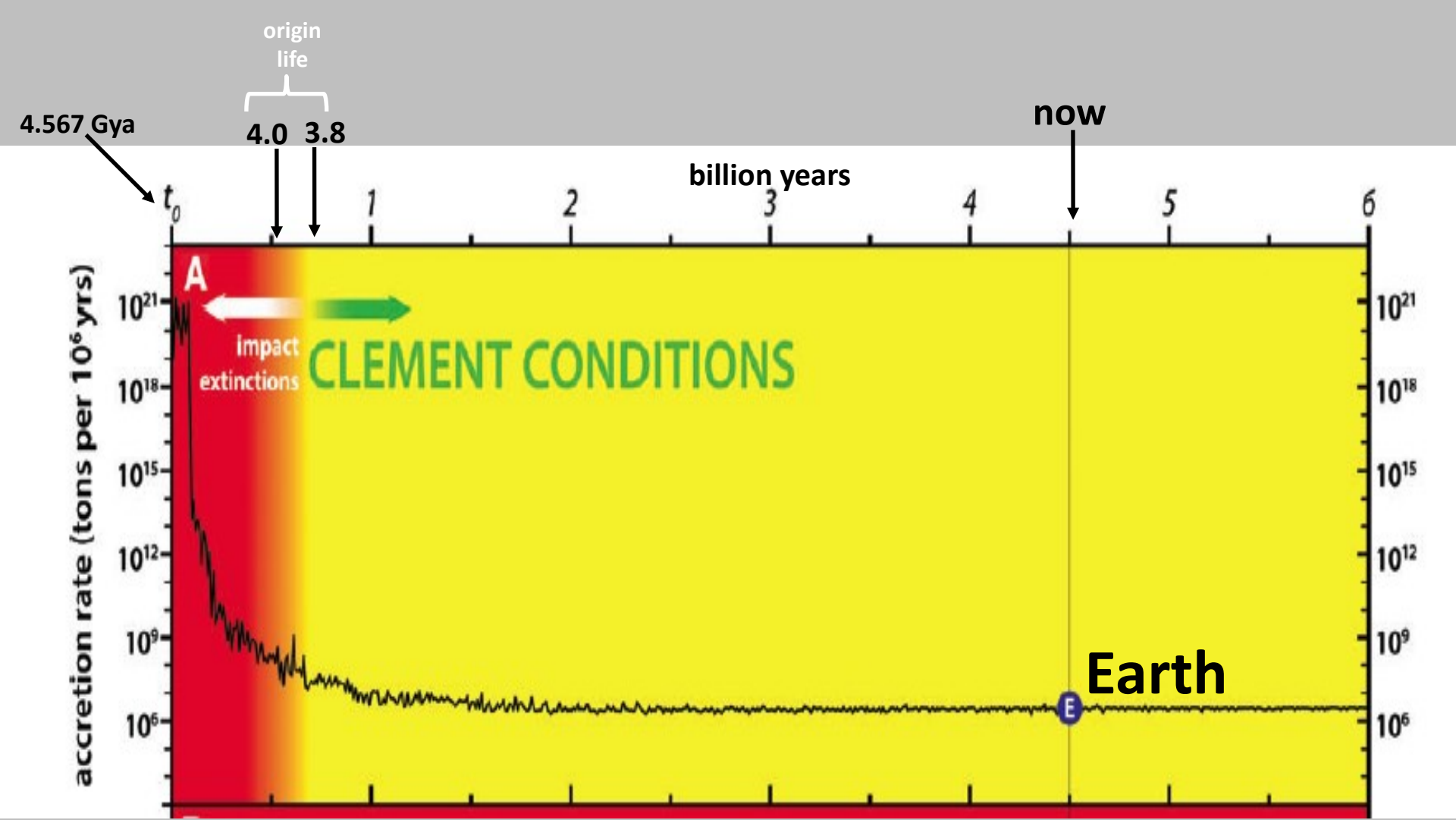
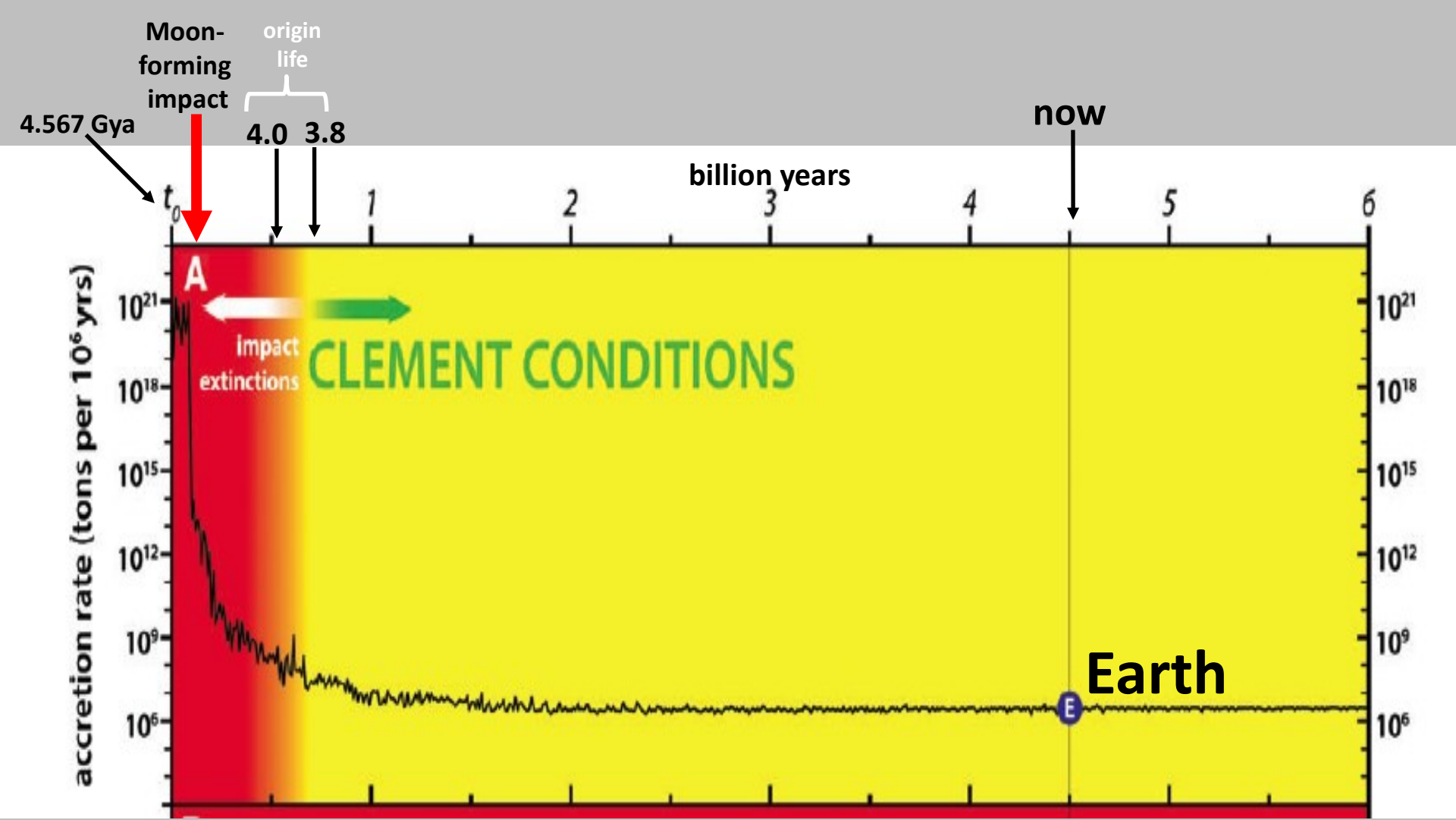
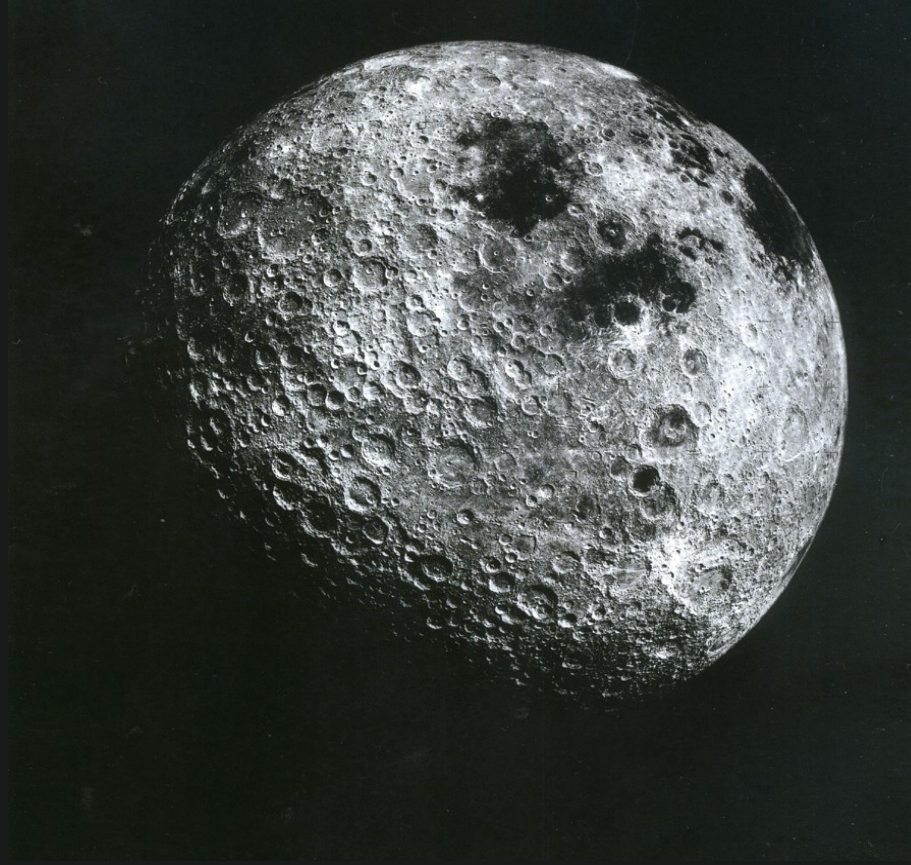
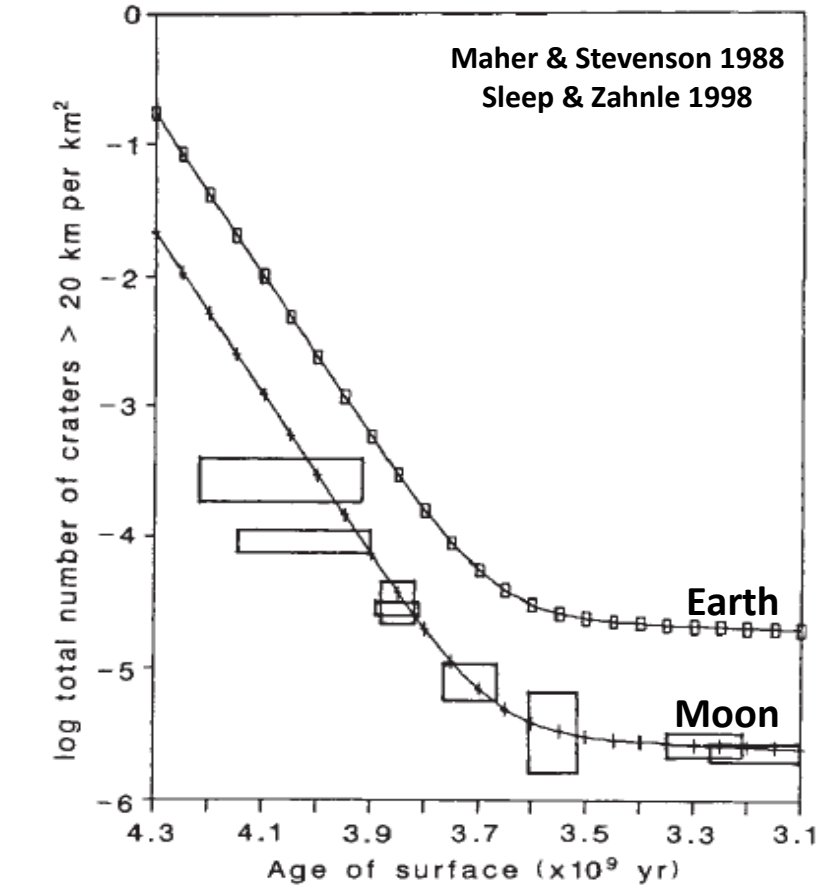
E
Earth

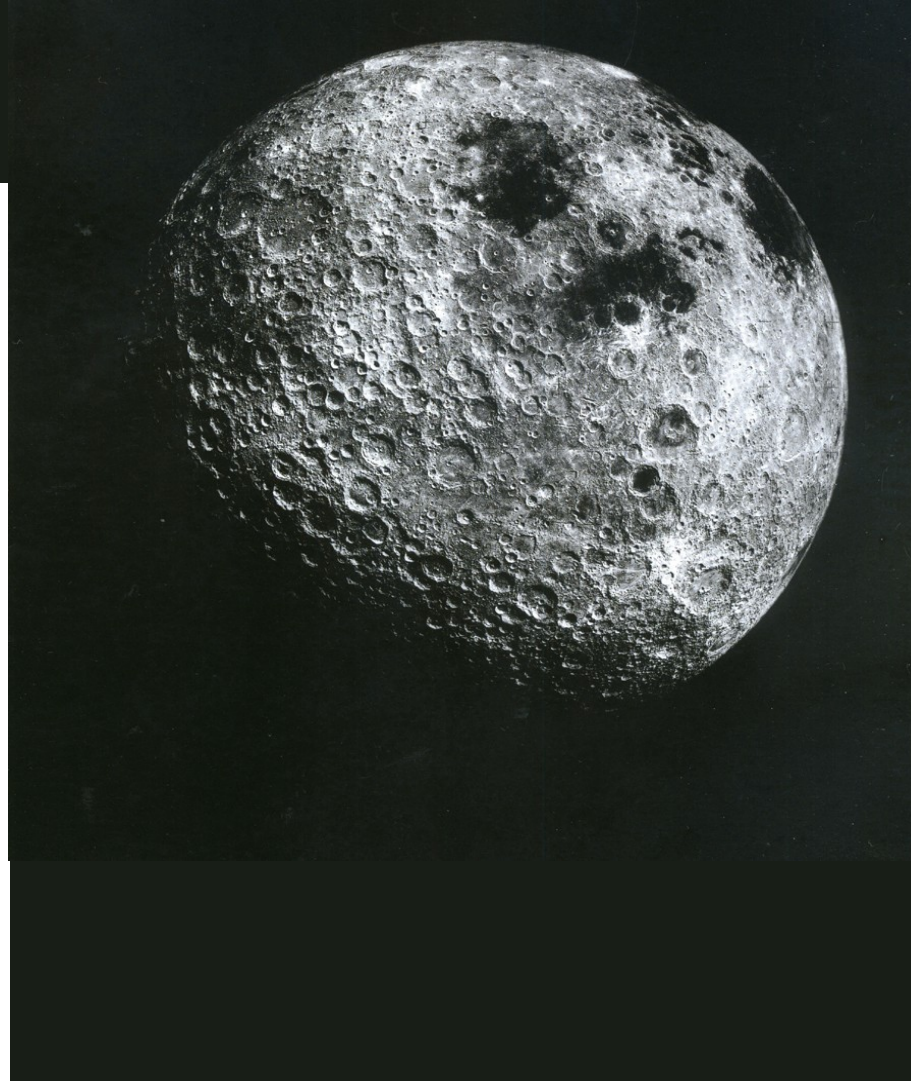

origin
life
4.567 Gya
4.0
3.8
now
billion years
t_0
1
2
3
4
5
6
A
impact
extinctions
CLEMENT CONDITIONS
accretion rate (tons per 10^6 yrs)
10^{21}
10^{18}
10^{15}
10^{12}
10^{9}
10^{6}
E
Earth


Moon-forming impact
origin life
4.567 Gya
4.0
3.8
now
billion years
t_0
1
2
3
4
5
6
A
impact extinctions
CLEMENT CONDITIONS
accretion rate (tons per 10^6 yrs)
10^{21}
10^{18}
10^{15}
10^{12}
10^{9}
10^{6}
E
Earth

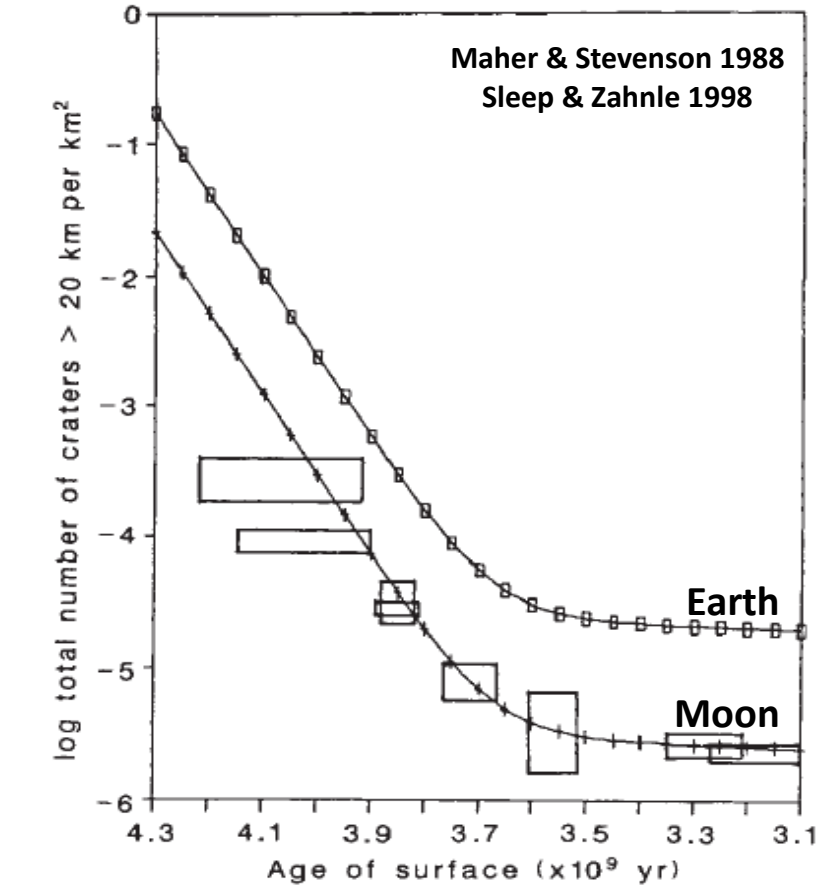
The Moon as a bombardometer

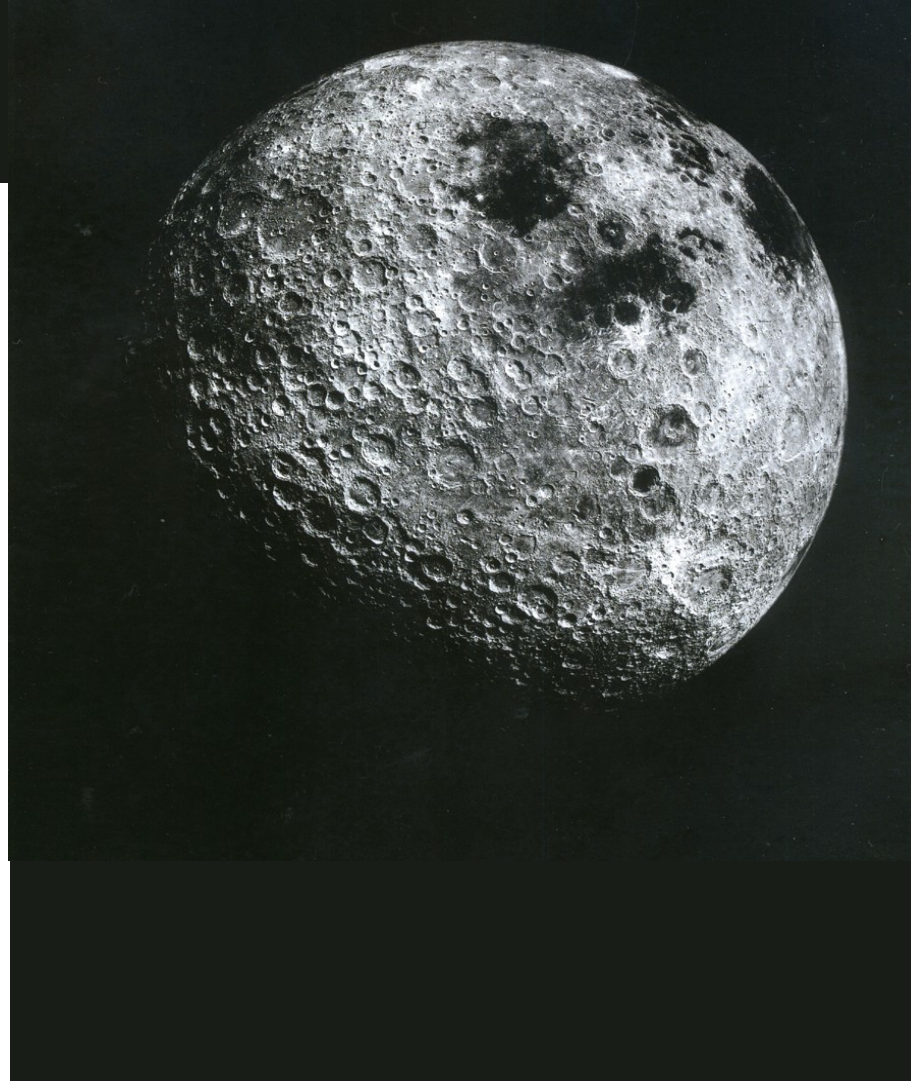



Maher & Stevenson 1988
Sleep & Zahnle 1998
log total number of craters > 20 km per km²
0
-1
-2
-3
-4
-5
-6
4.3
4.1
3.9
3.7
3.5
3.3
3.1
Age of surface (x10⁹ yr)
Earth
Moon



Did large impacts frustrate the origin of life?
Or were they needed for the origin of life?





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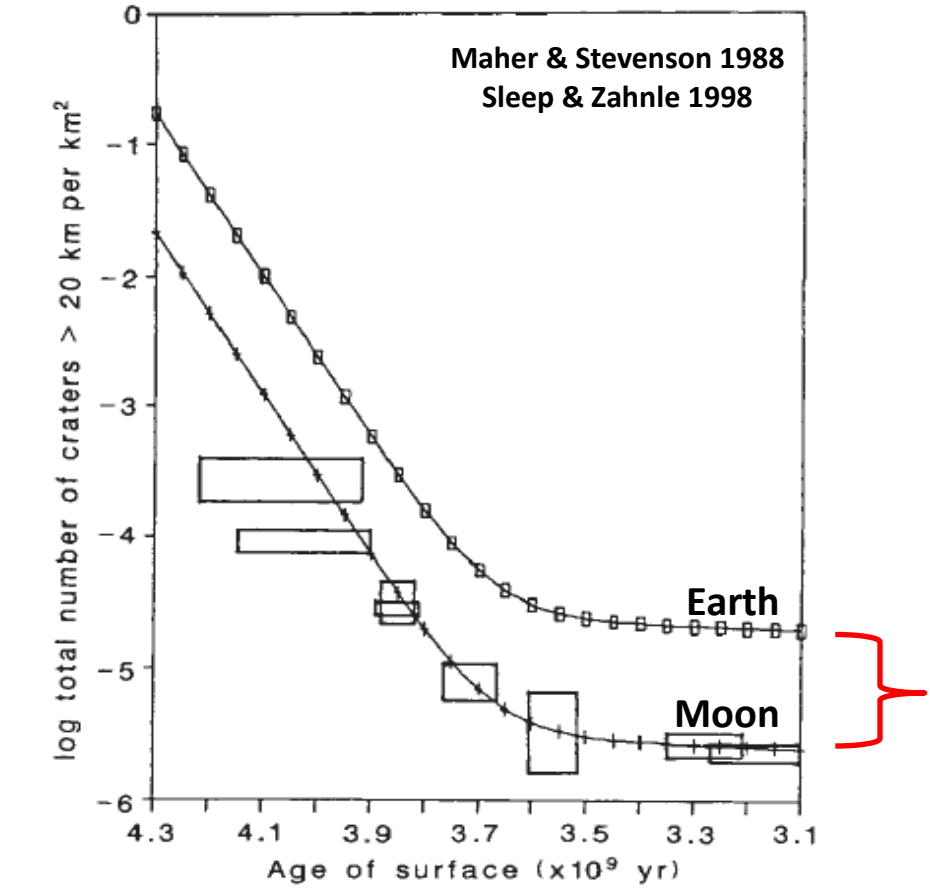
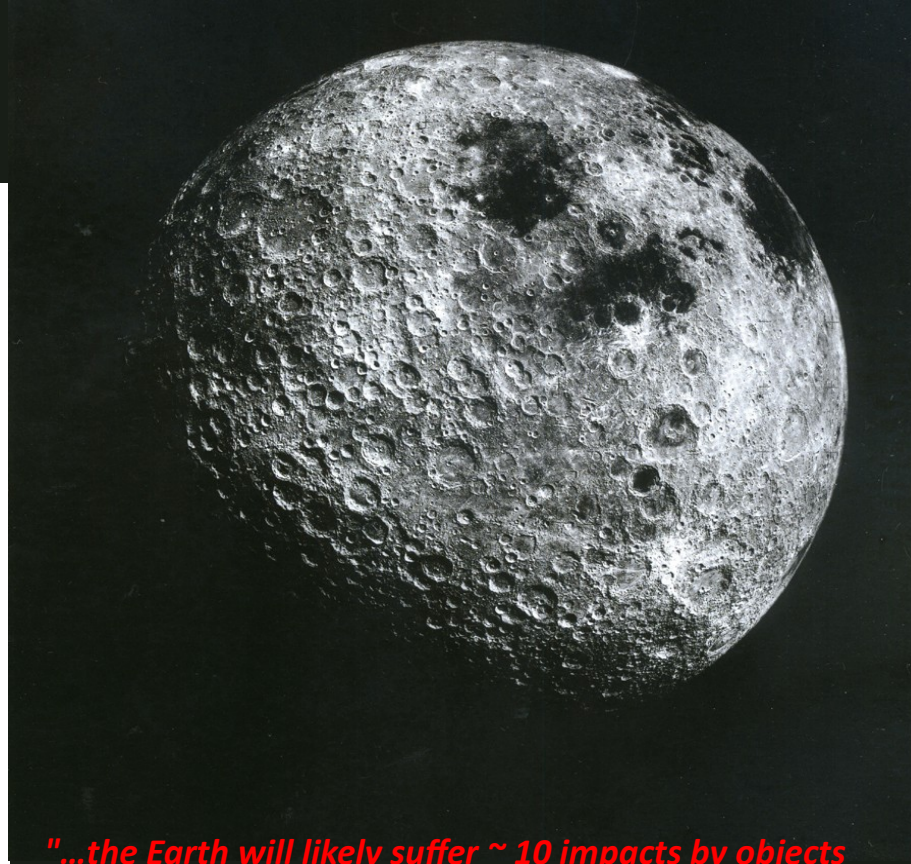
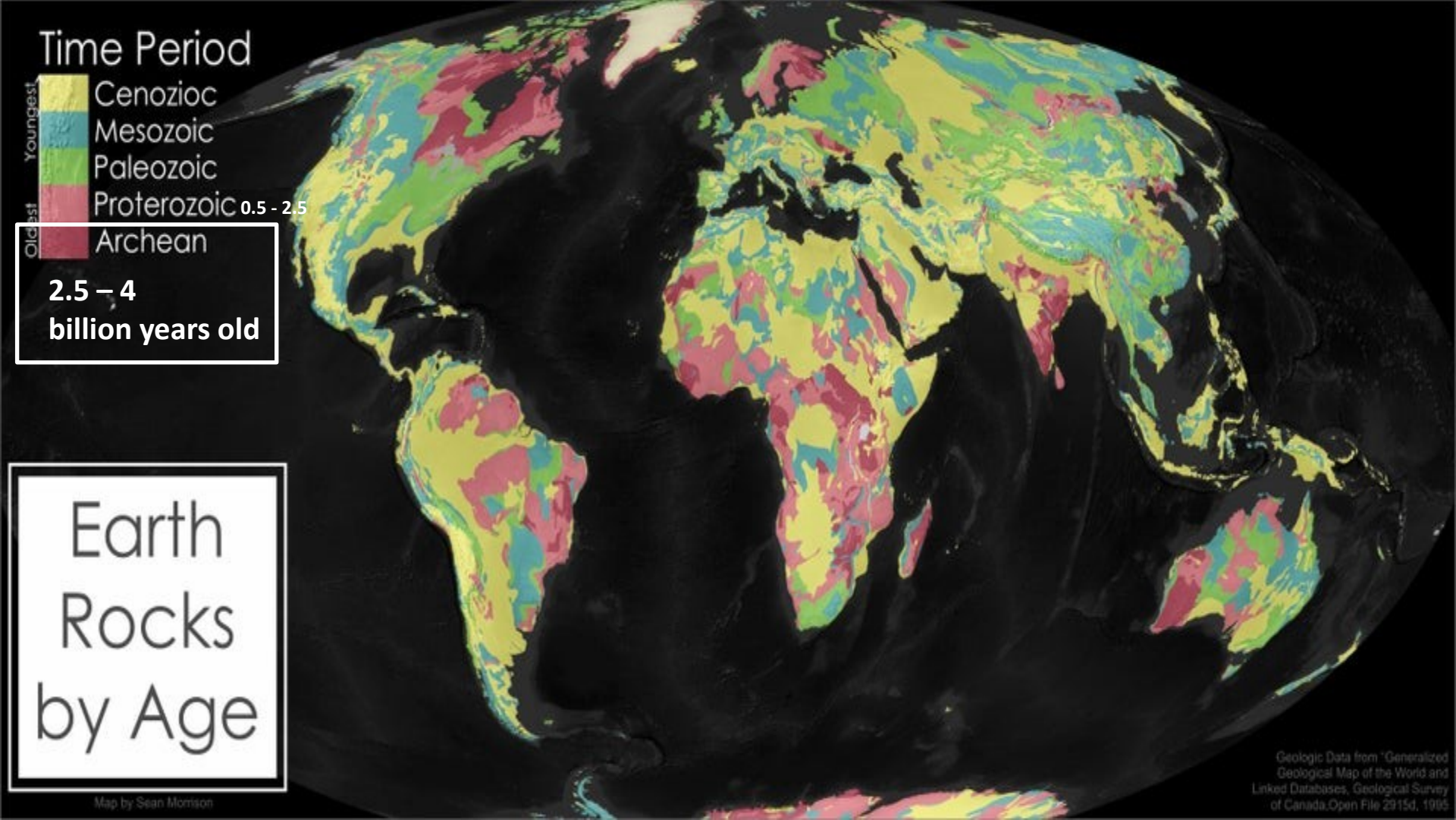
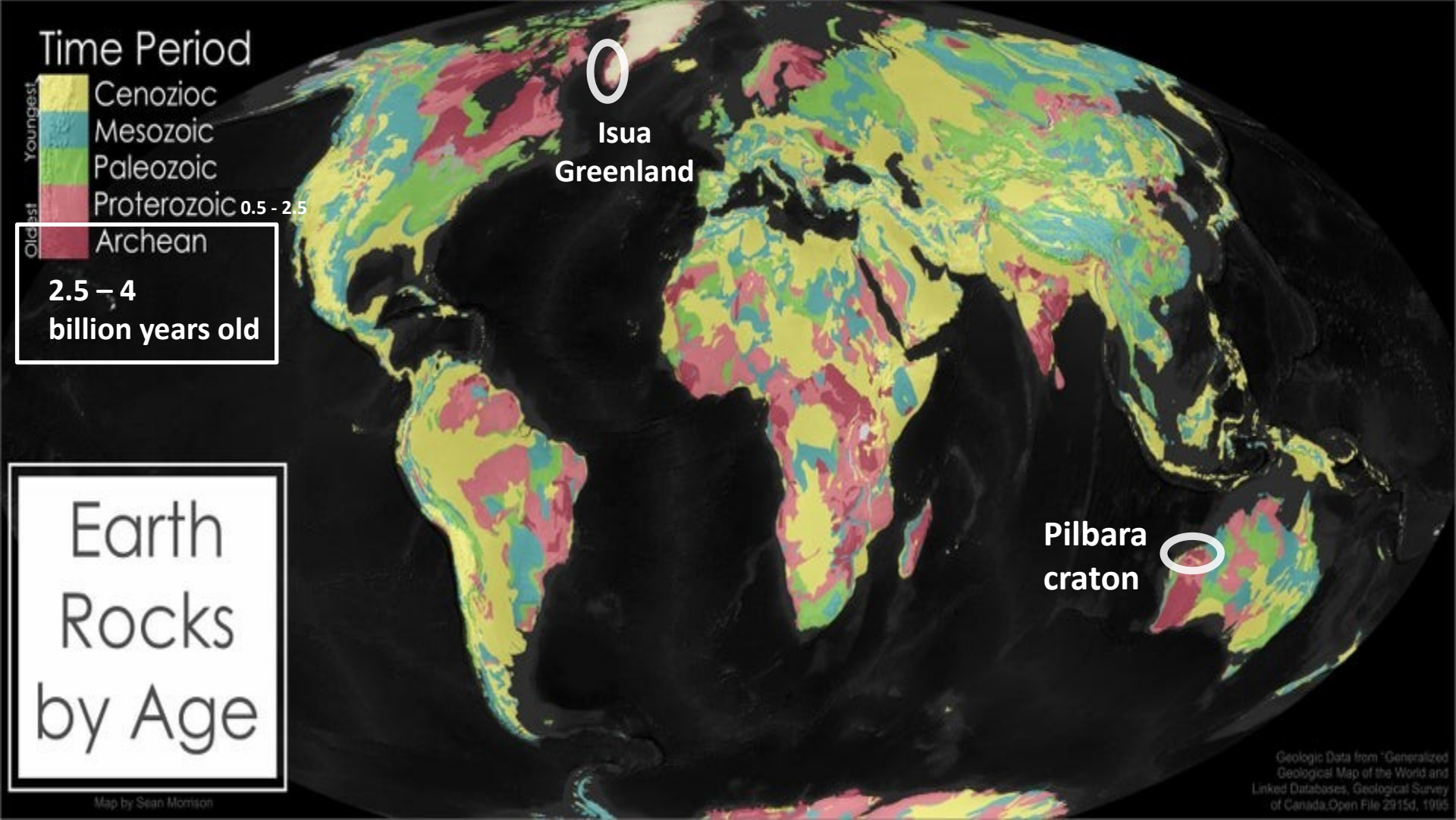




"...the Earth will likely suffer ~ 10 impacts by objects more massive than any that strike the Moon."

Hartman et al 2000


Time Period
Youngest
Oldest
Cenozioc
Mesozoic
Paleozoic
Proterozoic
Archean
0.5 - 2.5
2.5 – 4
billion years old
Earth
Rocks
by Age
Map by Sean Morrison
Geologic Data from "Generalized
Geological Map of the World and
Linked Databases, Geological Survey
of Canada.Open File 2915d, 1995


Time Period
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0.5 - 2.5
2.5 – 4
billion years old
Isua
Greenland
Pilbara
craton
Earth
Rocks
by Age
Map by Sean Morrison
Geologic Data from "Generalized
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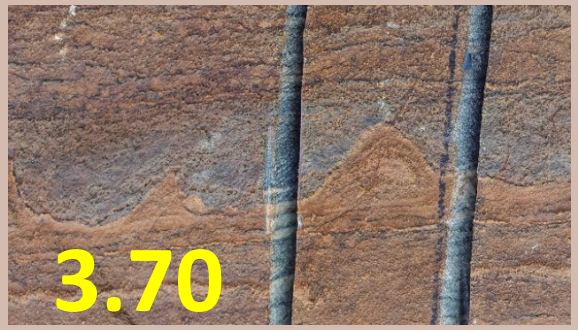
modern stromatolites
Shark Bay, Australia

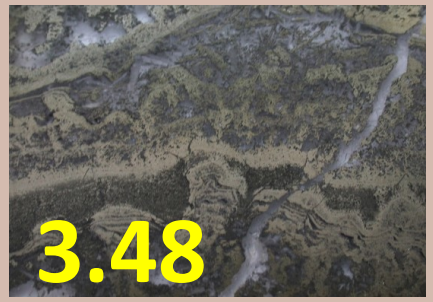
microbial mats

oldest macro-fossils: ~ 3.4 – 3.7 billion year old stromatolites

2016 Nutman et al
Isua Supracrustal Belt
Greenland

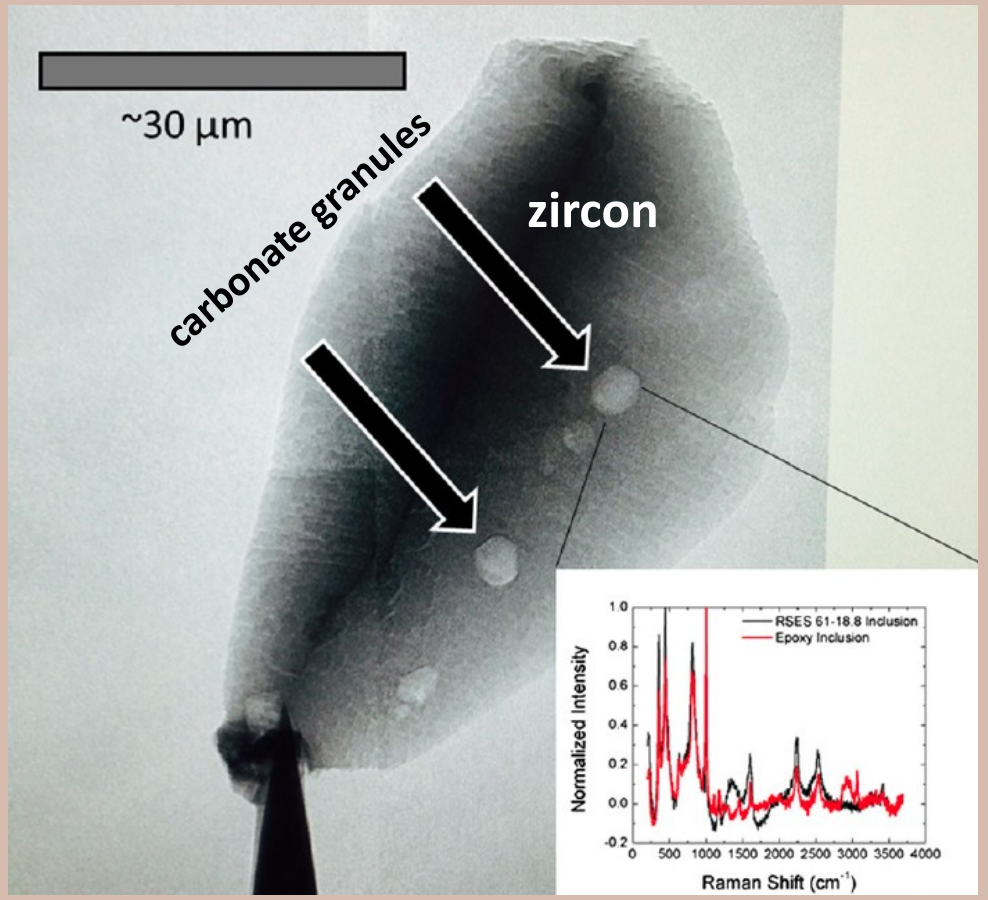


Dresser Formation
Pilbara Craton
Western Australia



2006 Allwood et al
Strelley Pool Chert
Pilbara Craton
Western Australia

oldest micro-fossils(?) : ~ 3.8 – 4.1 billion year old zircons



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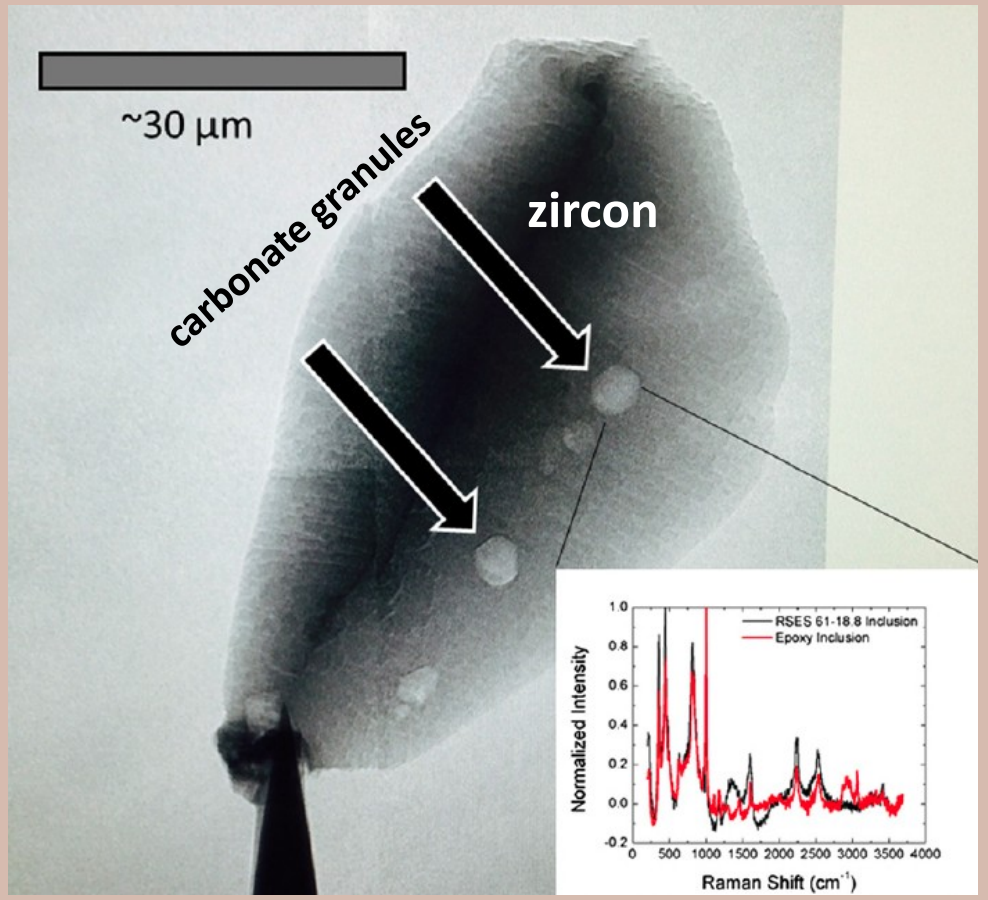
Life prefers ^{12}C to ^{13}C



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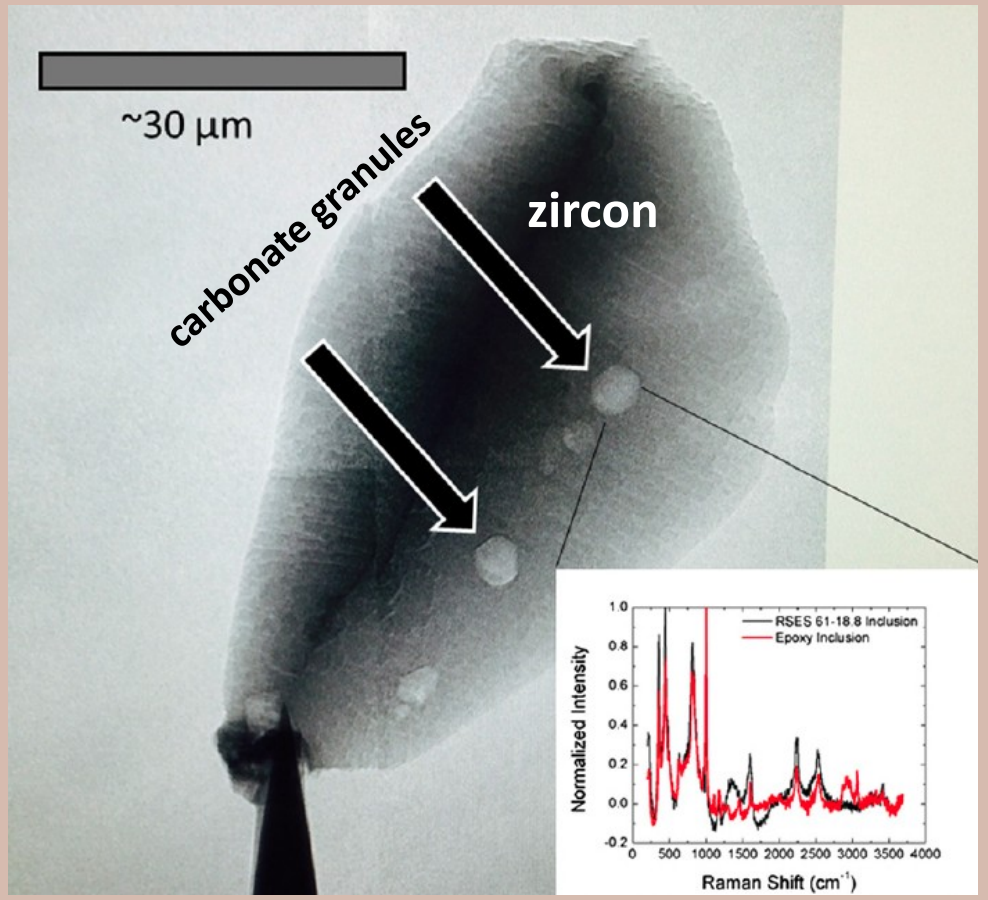
Therefore, organic carbon with a low 13/12 ratio can be evidence for life

3.8 Mojzsis et al 1996
Evidence for life on Earth before 3,800 million years ago



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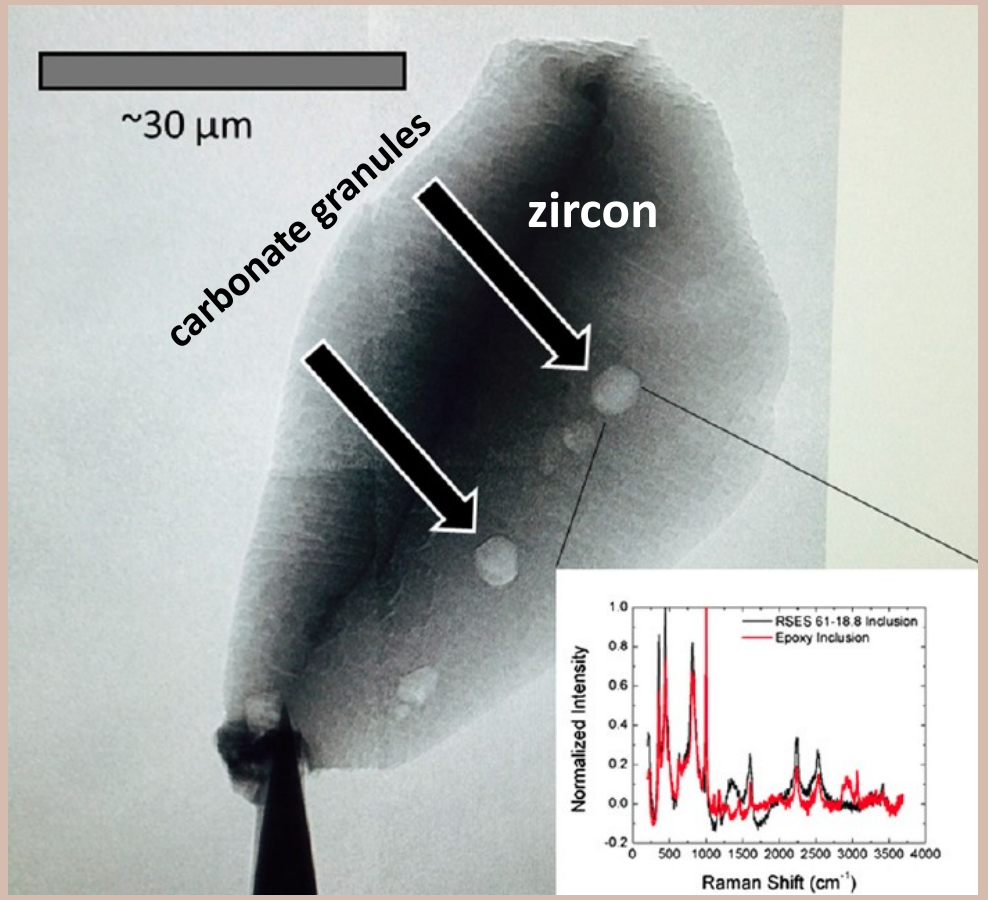
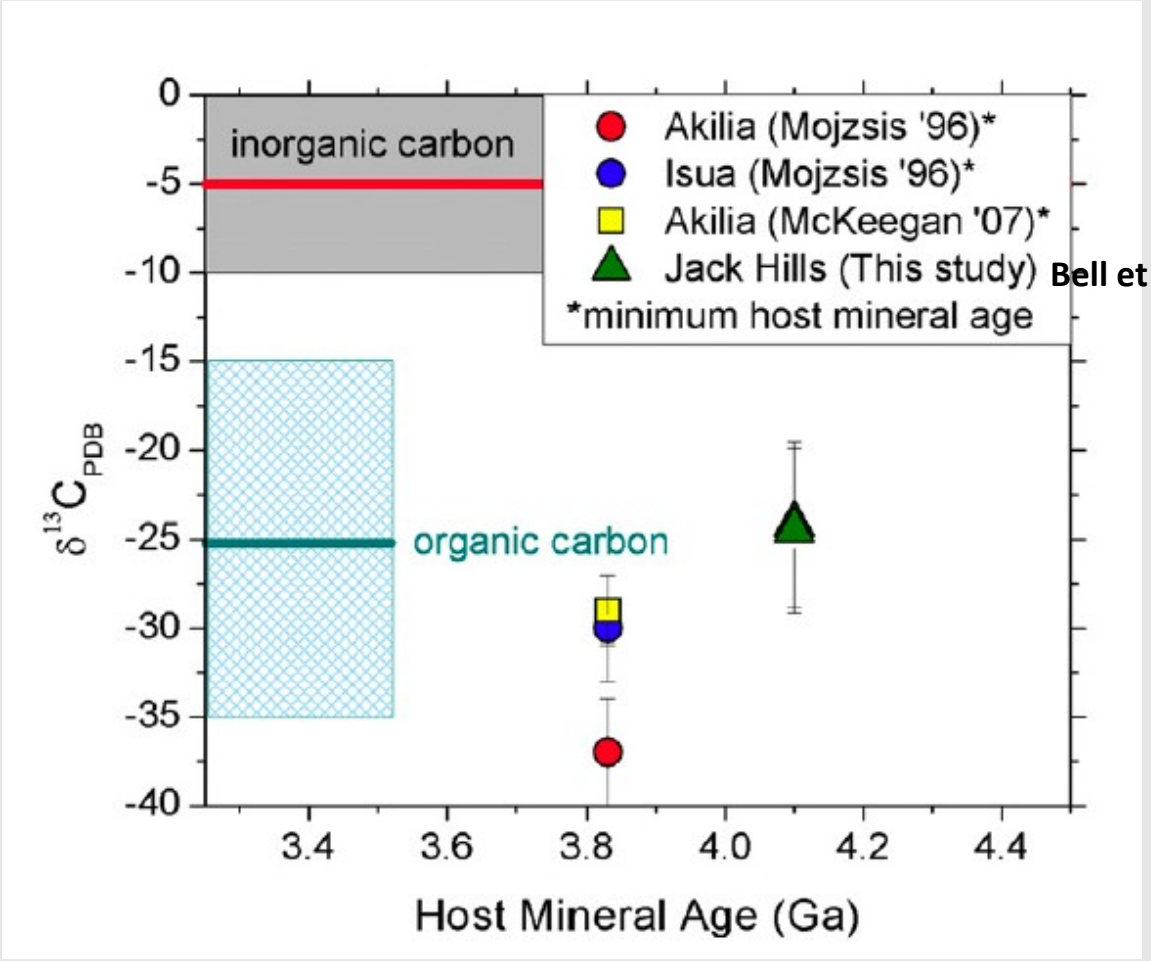
4.1 Bell et al 2015
Potentially biogenic carbon preserved in a 4.1 billion-year-old zircon



Life prefers ^{12}C to ^{13}C

high $^{13}C/^{12}C$

low $^{13}C/^{12}C$



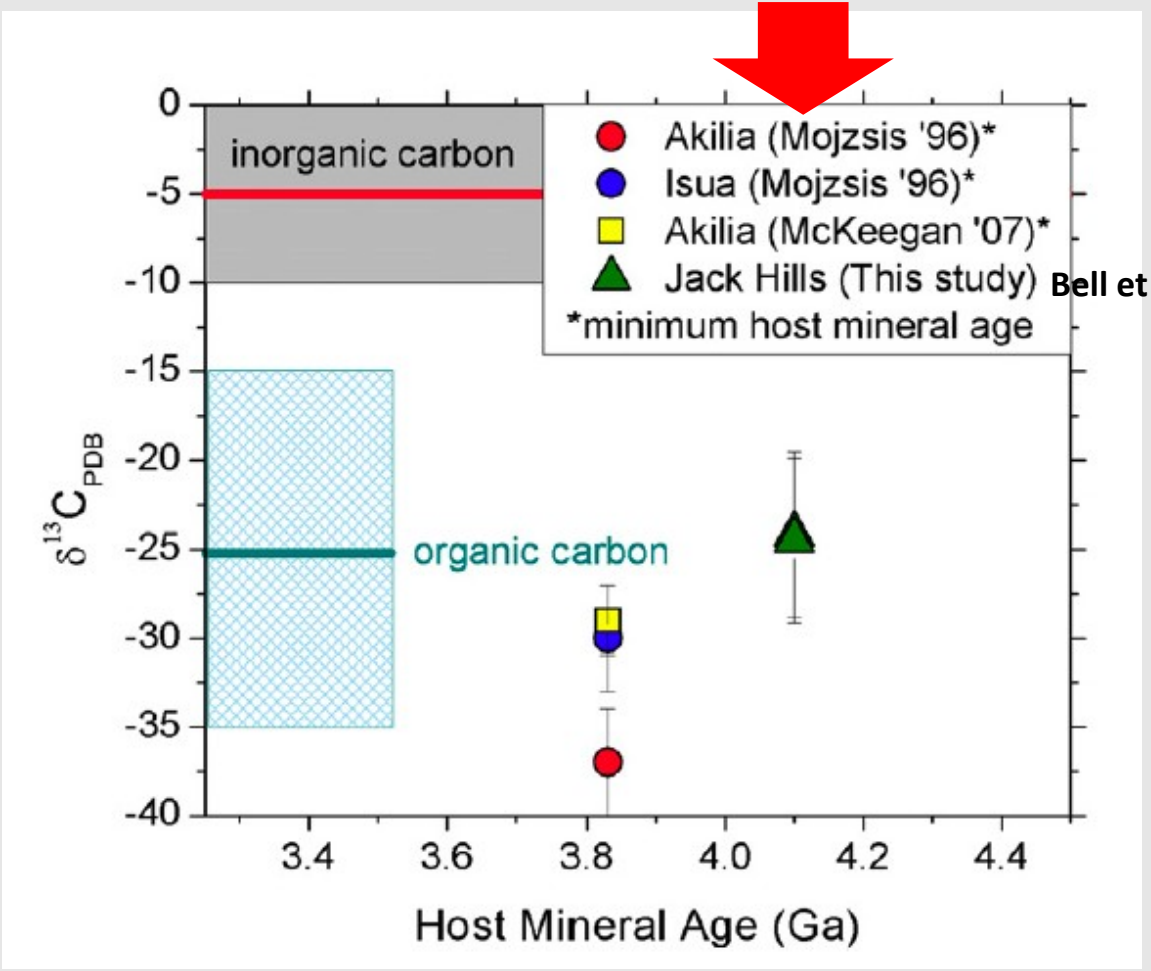
Bell et al 2015

Life prefers ^{12}C to ^{13}C

high $^{13}C/^{12}C$

low $^{13}C/^{12}C$

Hunters of low 13/12 ratios



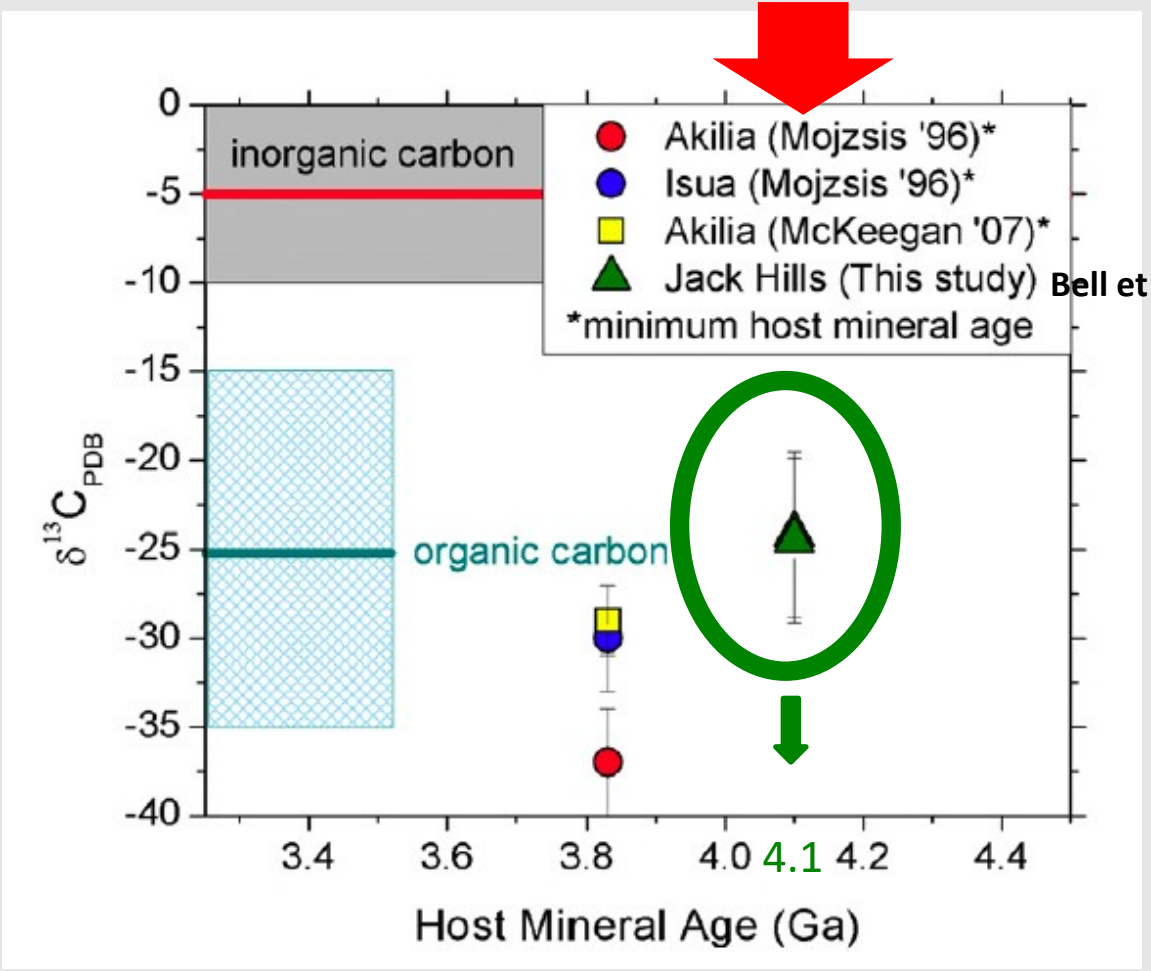
Bell et al 2015

Life prefers ^{12}C to ^{13}C

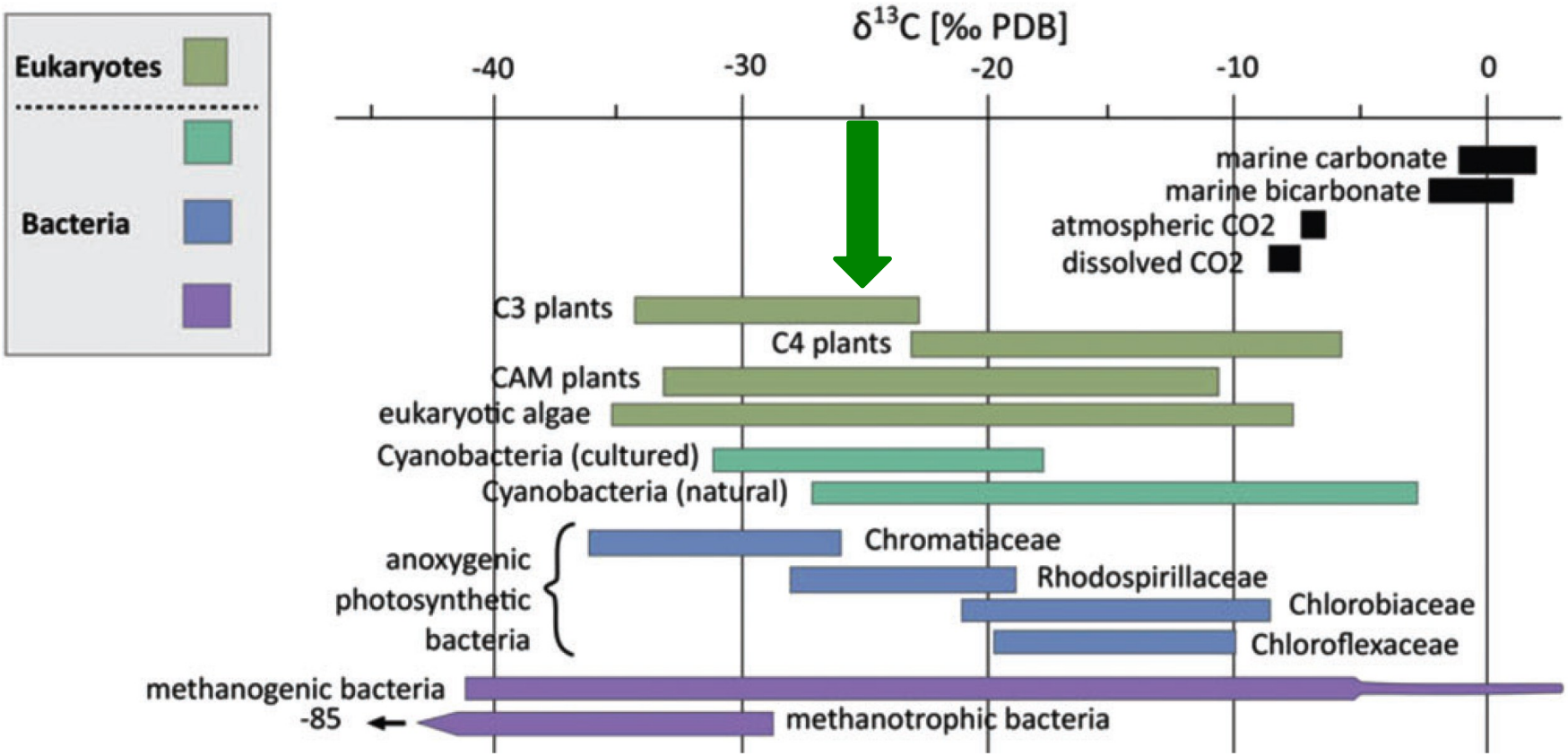
high $^{13}C/^{12}C$

low $^{13}C/^{12}C$

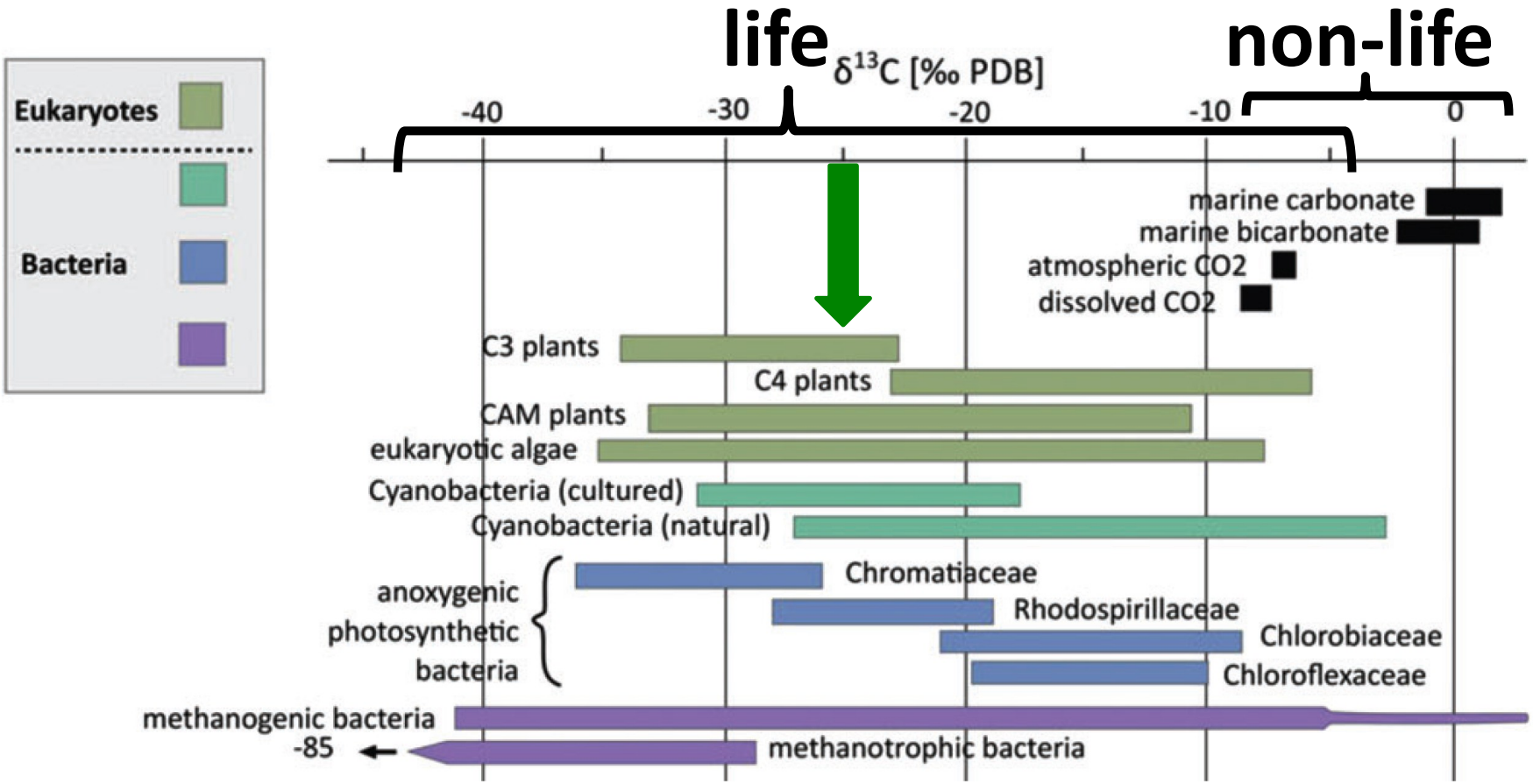
Hunters of low 13/12 ratios



Bell et al 2015



Pearce et al 2018

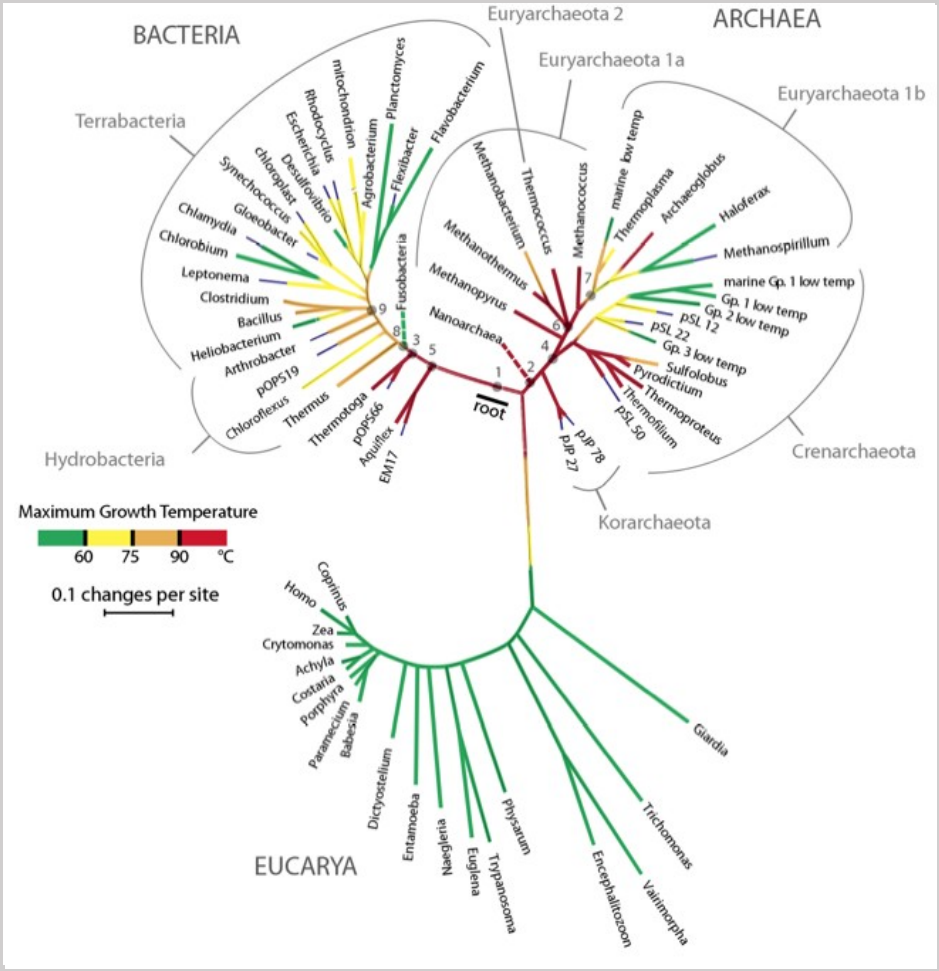


Pearce et al 2018

WHERE ?

Life started hot

(probably)

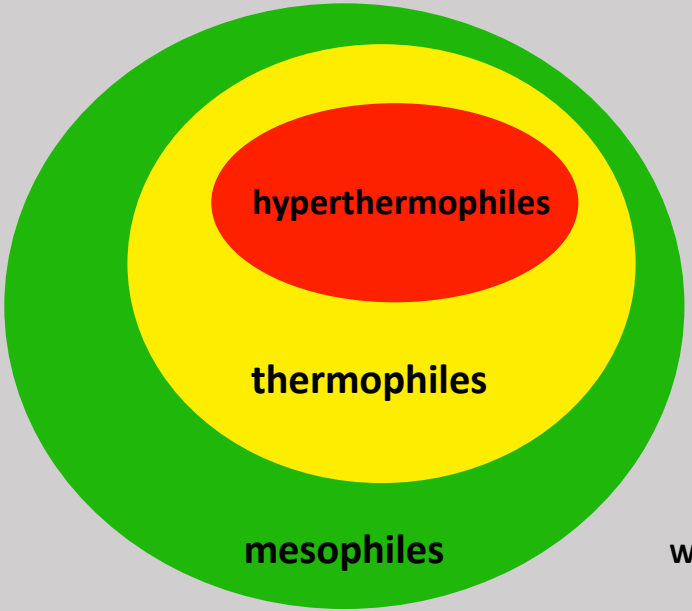


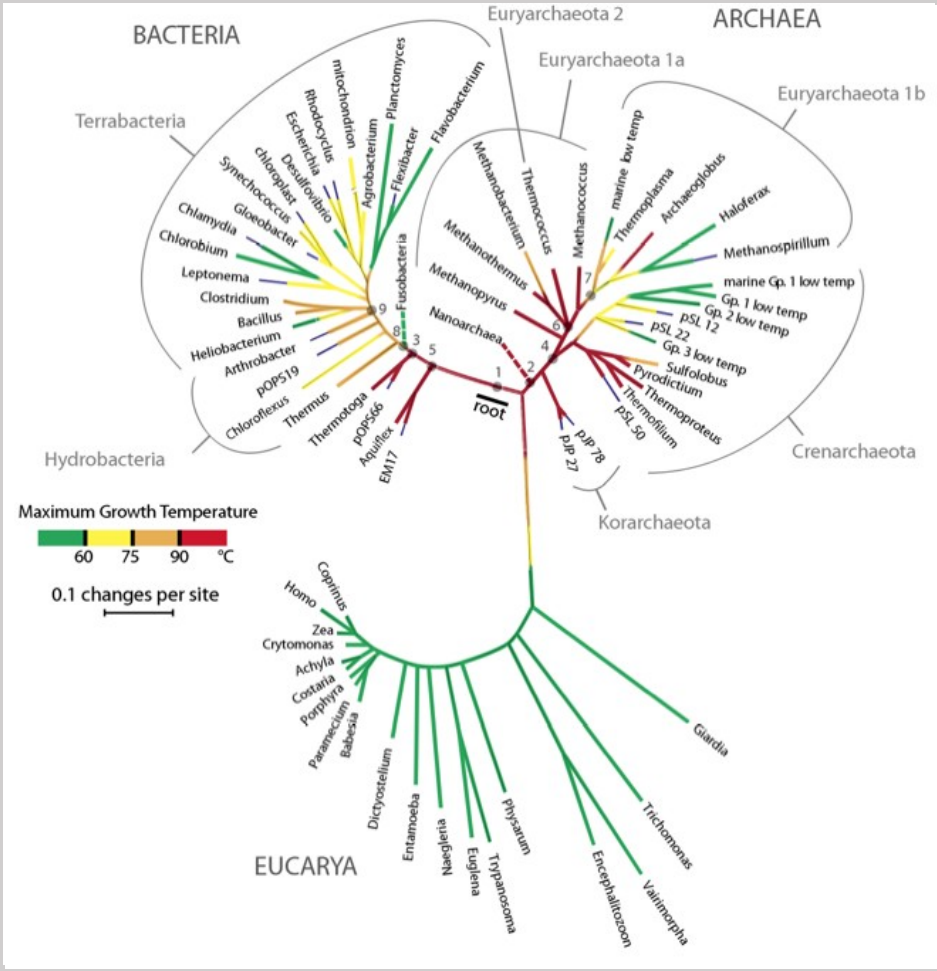
Woese et al 1990
Pace 1997
Lineweaver & Schwartzman 2003
Lineweaver & Chopra 2013

Life started hot

(probably)

mesophiles ← thermophiles ← hyperthermophiles





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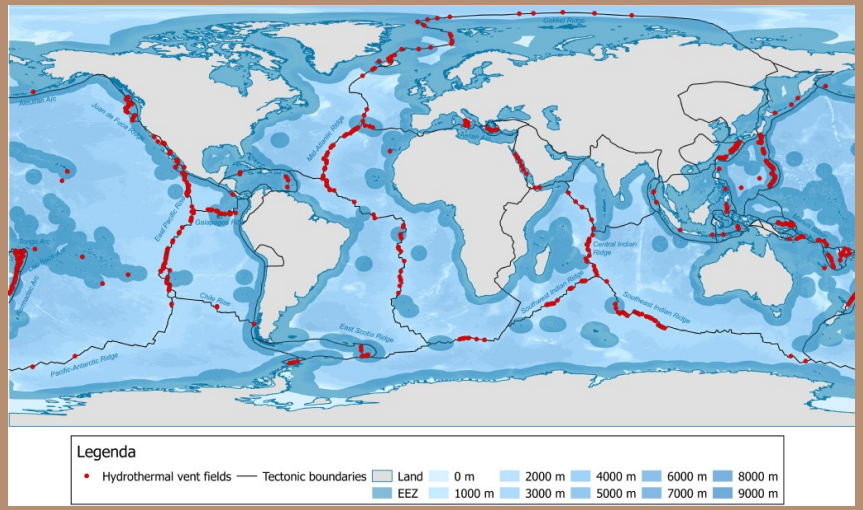
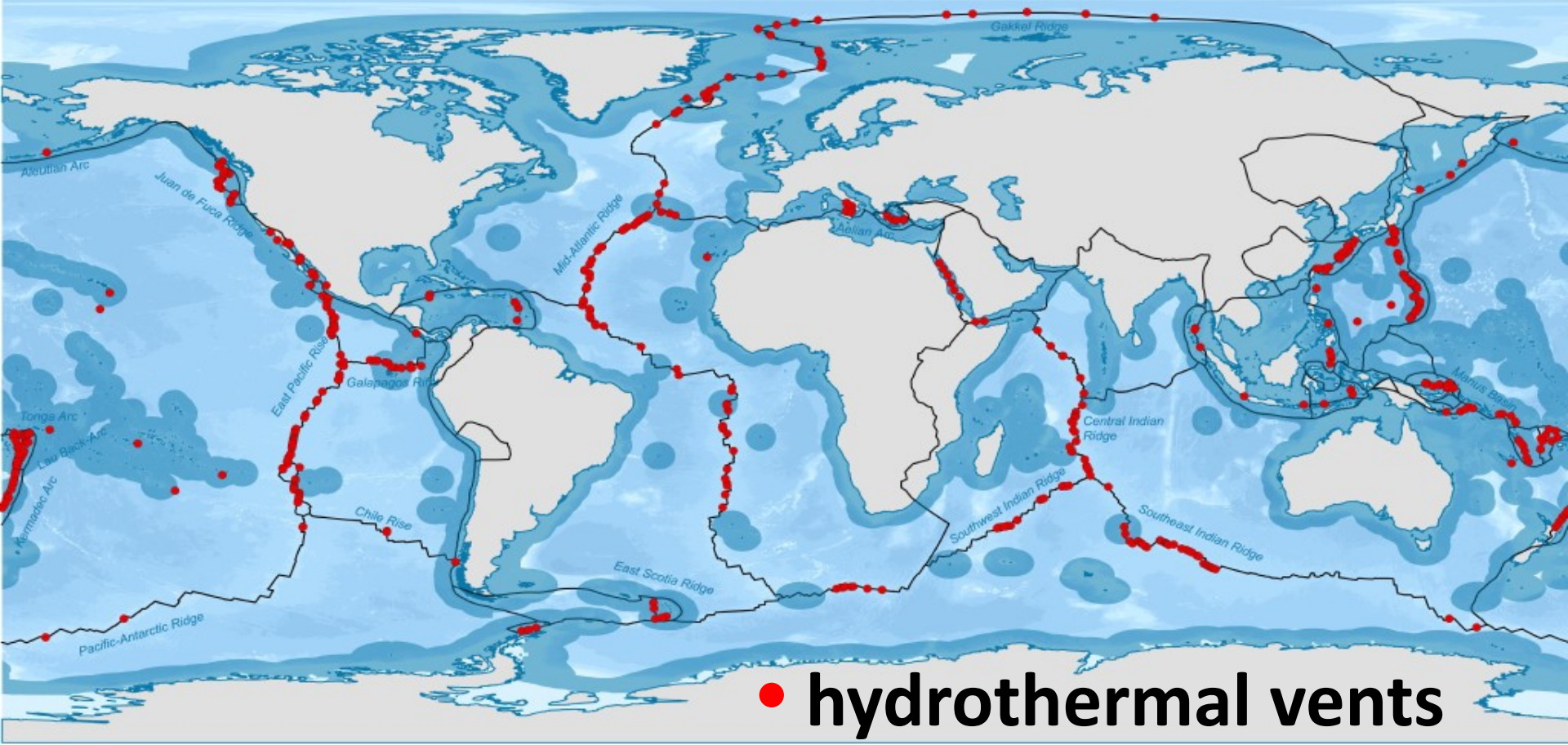
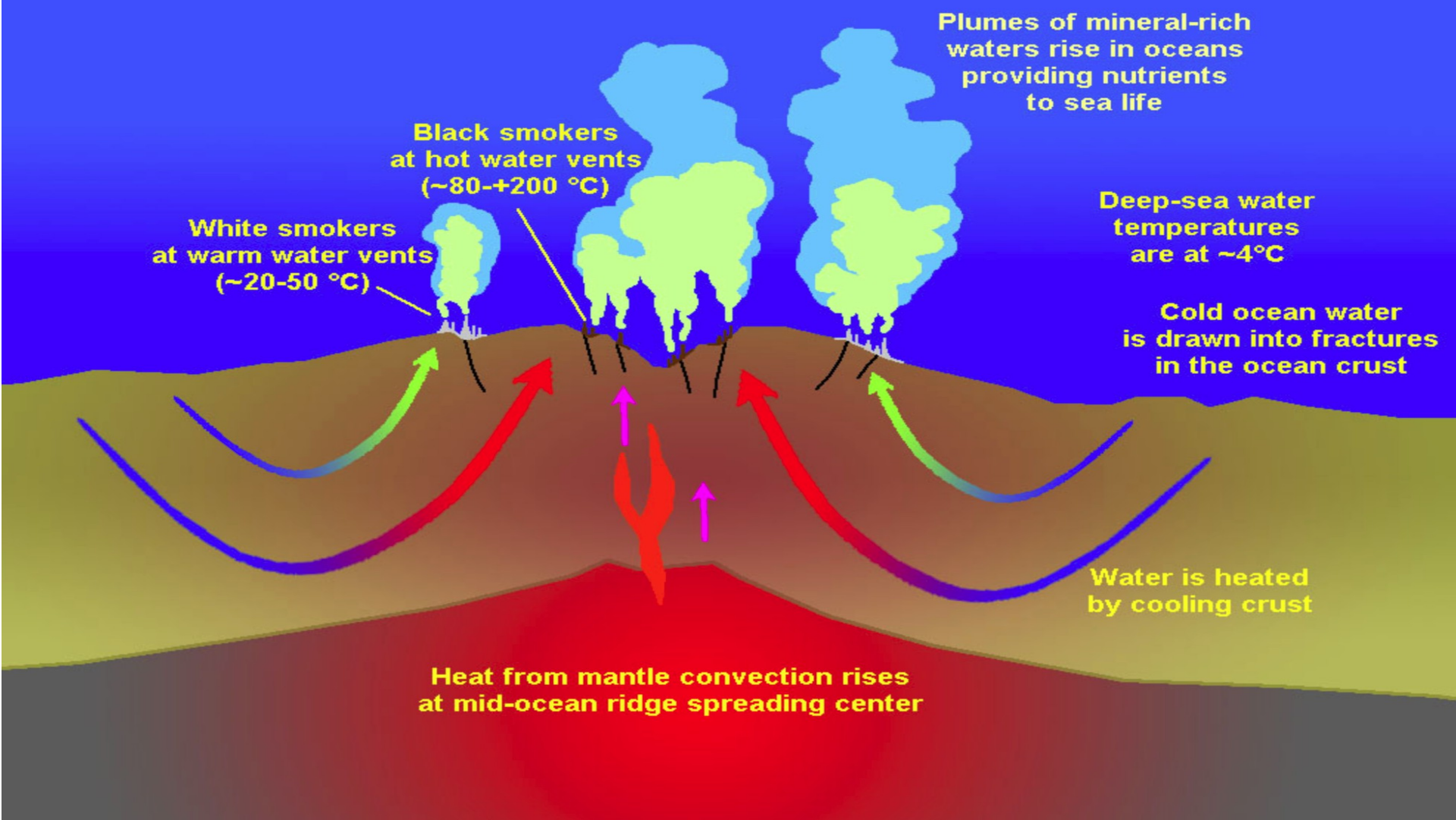
2 models for the origin of life

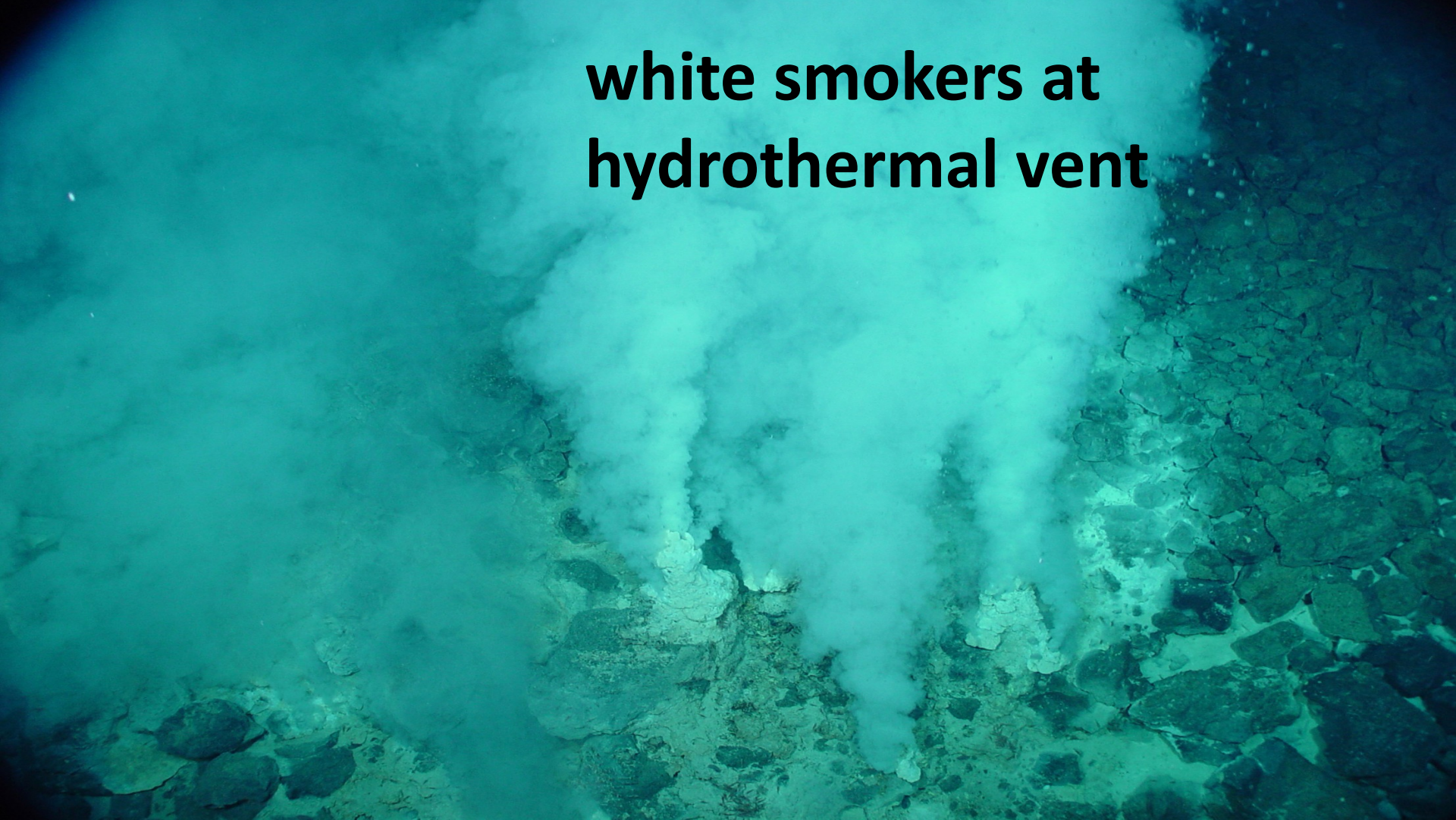
hot hydrothermal vents

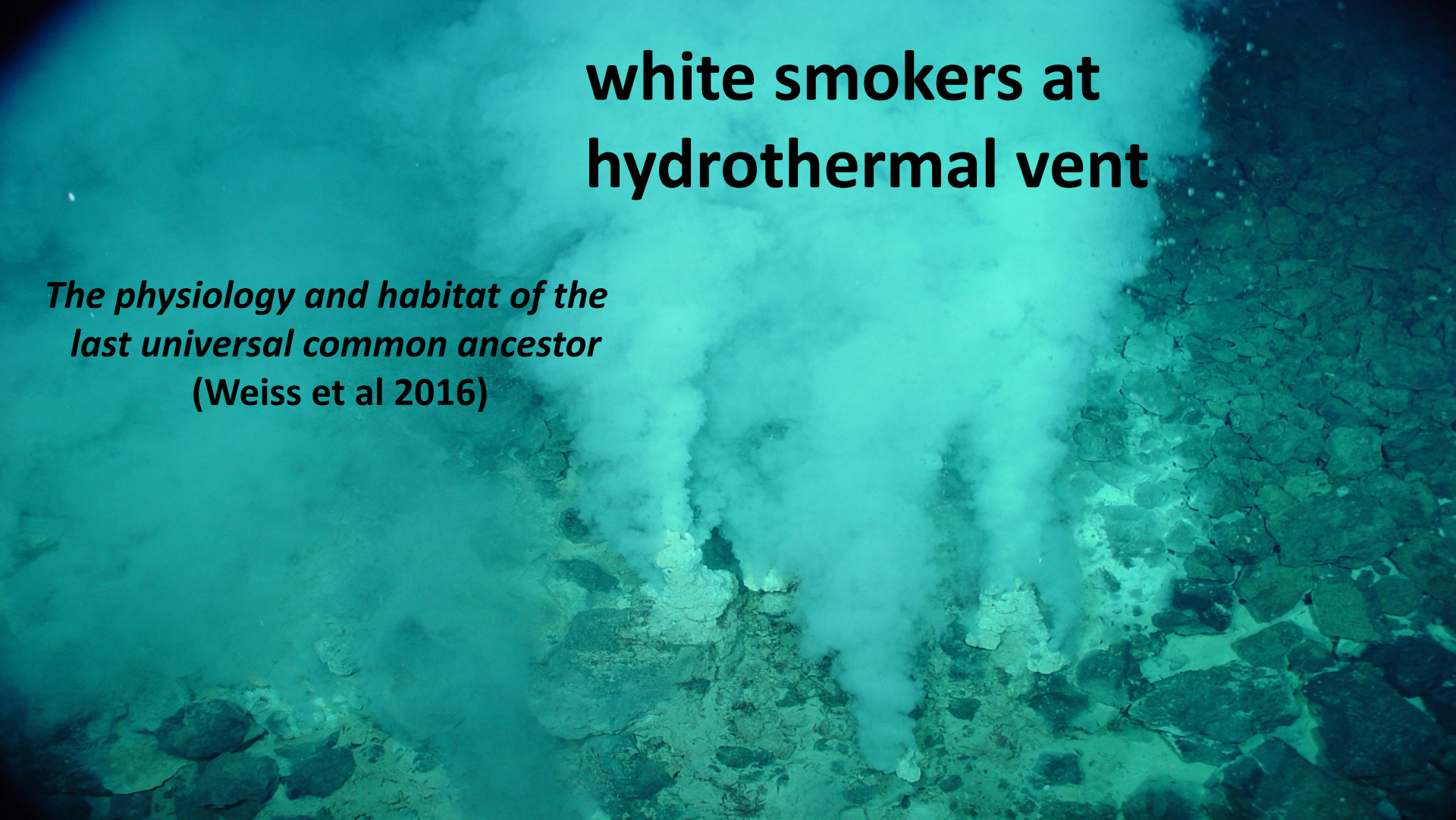


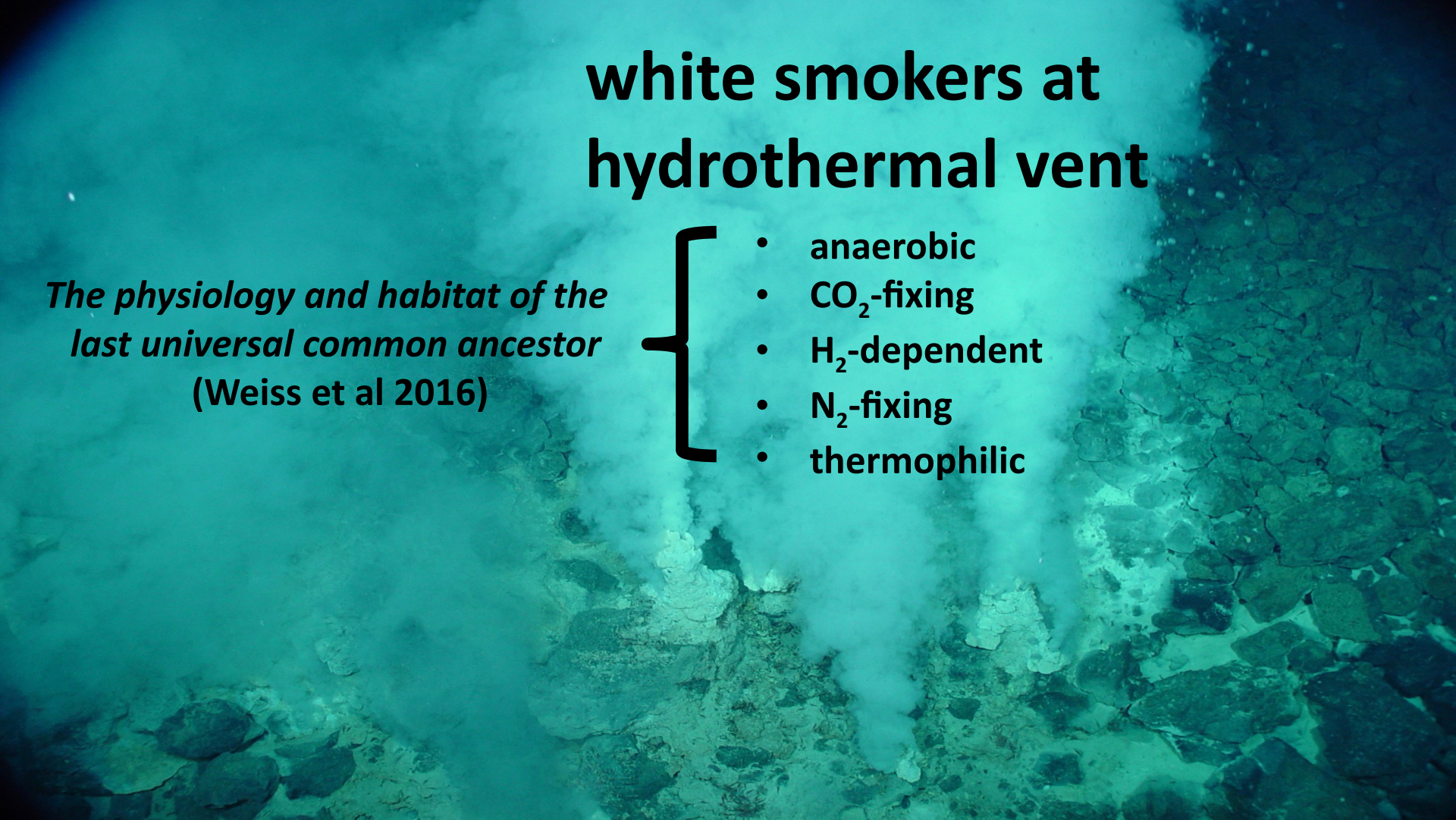
hot springs


Gakkel Ridge
Aleutian Arc
Juan de Fuca Ridge
Mid-Atlantic Ridge
Aeolian Arc
East Pacific Rise
Galapagos Rift
Tonga Arc
Lau Back-Arc
Kermadec Arc
Chile Rise
East Scotia Ridge
Pacific-Antarctic Ridge
Central Indian Ridge
Southwest Indian Ridge
Southeast Indian Ridge
Manus Basin
• hydrothermal vents
Legenda
Hydrothermal vent fields
Tectonic boundaries
Land
EEZ
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m

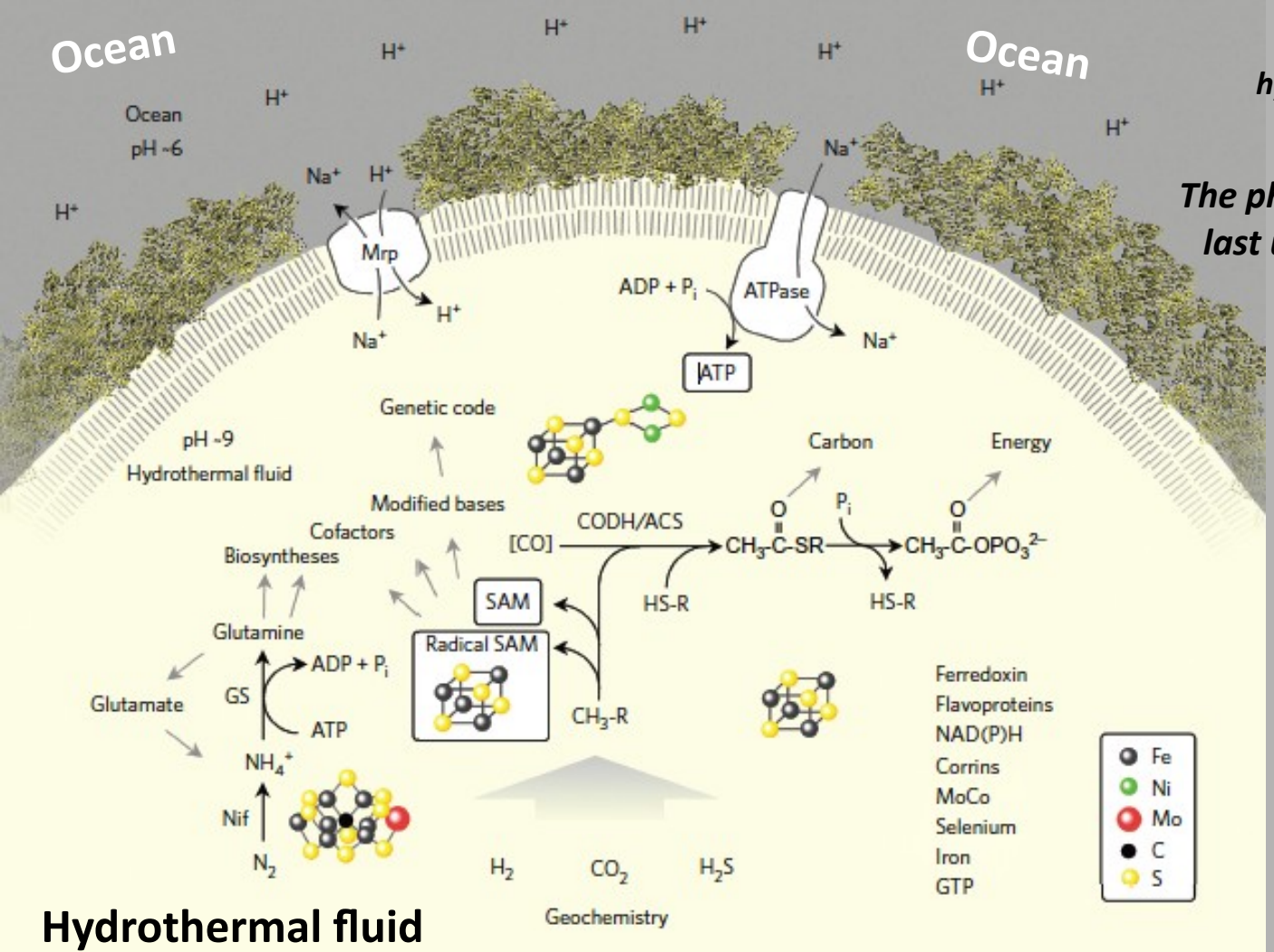

Plumes of mineral-rich waters rise in oceans providing nutrients to sea life
Black smokers at hot water vents (~80-+200 °C)
White smokers at warm water vents (~20-50 °C)
Deep-sea water temperatures are at ~4°C
Cold ocean water is drawn into fractures in the ocean crust
Water is heated by cooling crust
Heat from mantle convection rises at mid-ocean ridge spreading center


white smokers at
hydrothermal vent


white smokers at
hydrothermal vent
The physiology and habitat of the last universal common ancestor
(Weiss et al 2016)


white smokers at hydrothermal vent
The physiology and habitat of the last universal common ancestor (Weiss et al 2016)
anaerobic
CO_2-fixing
H_2-dependent
N_2-fixing
thermophilic

HOW ?



Hydrothermal fluid

white smoker hydrothermal vent chemistry

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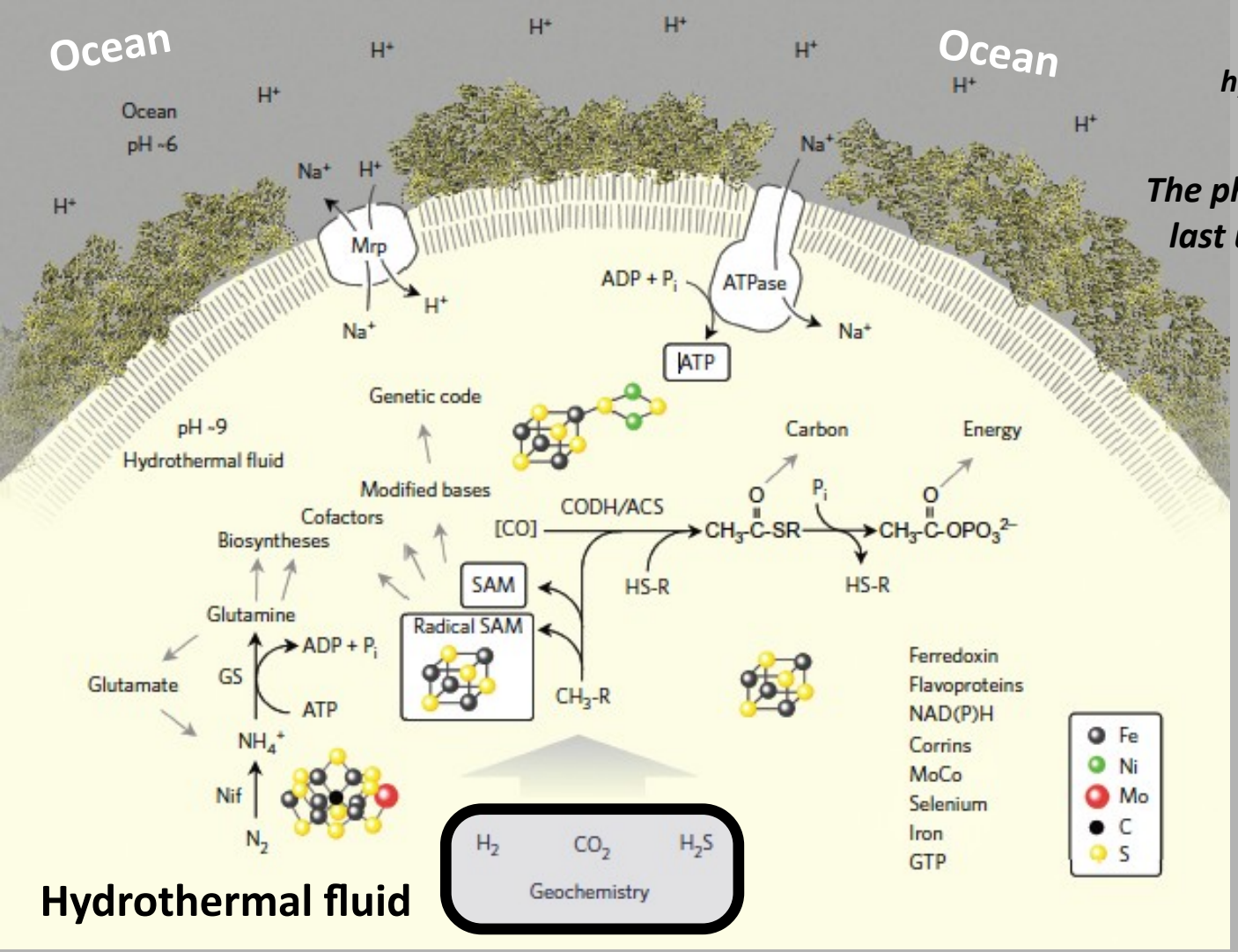

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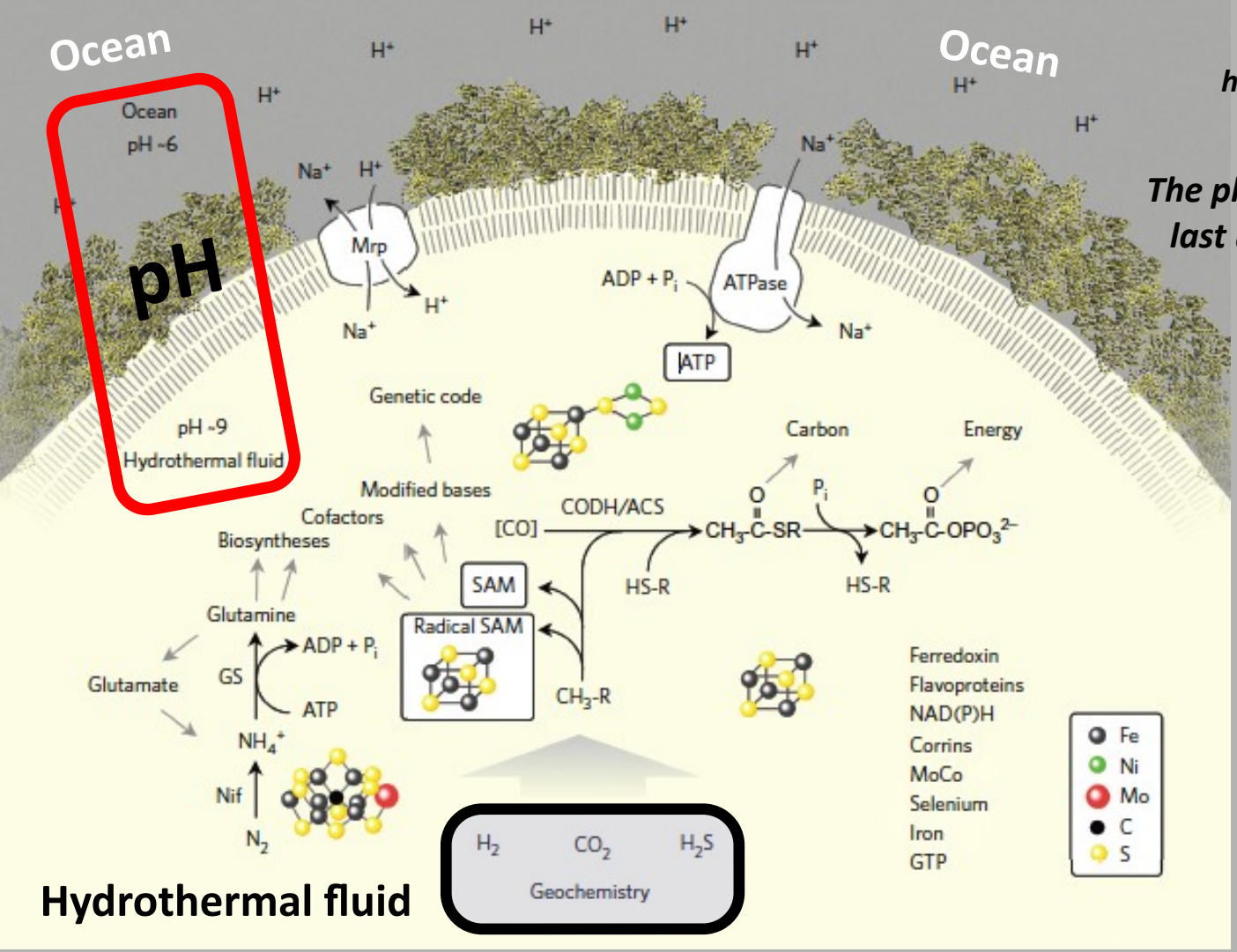

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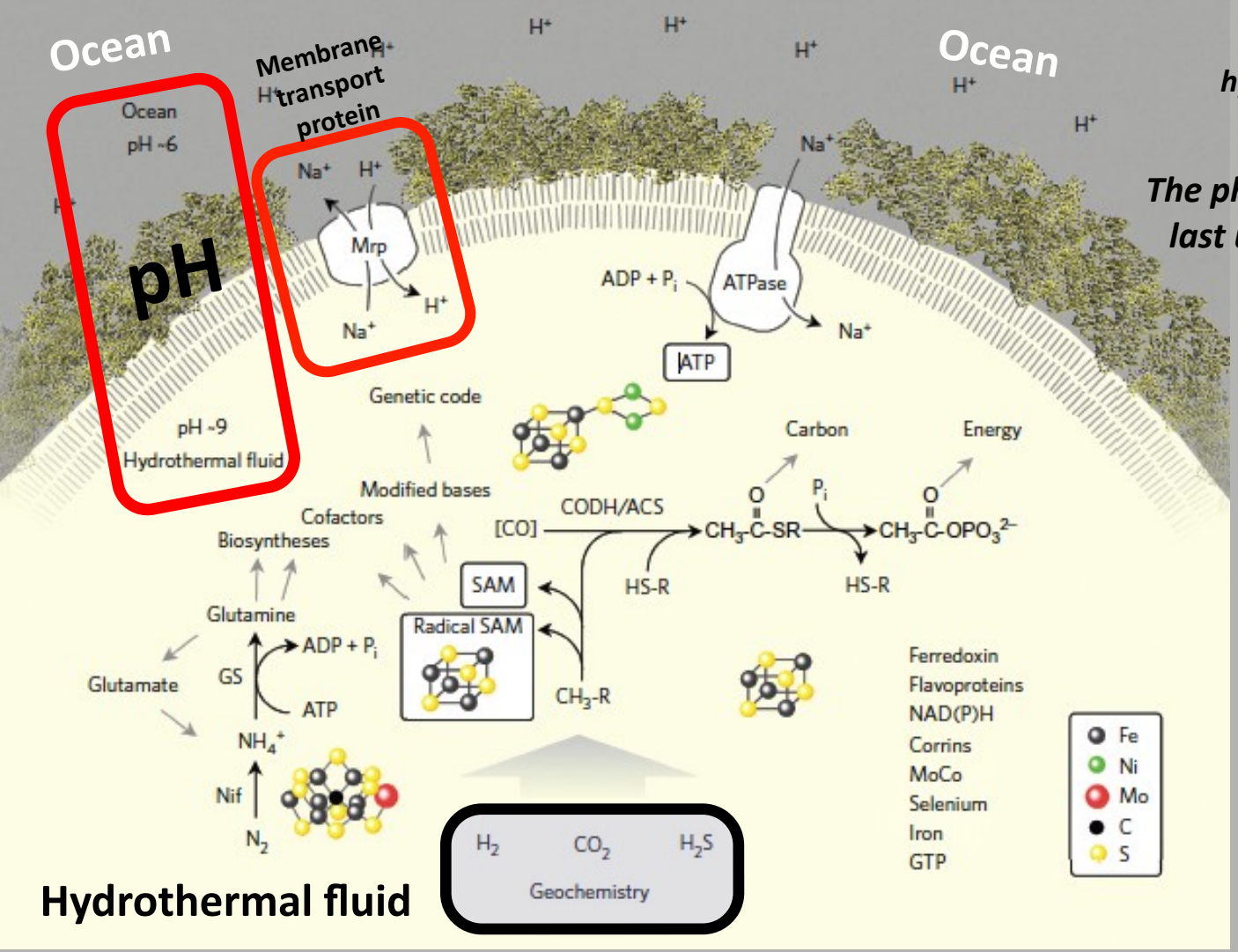

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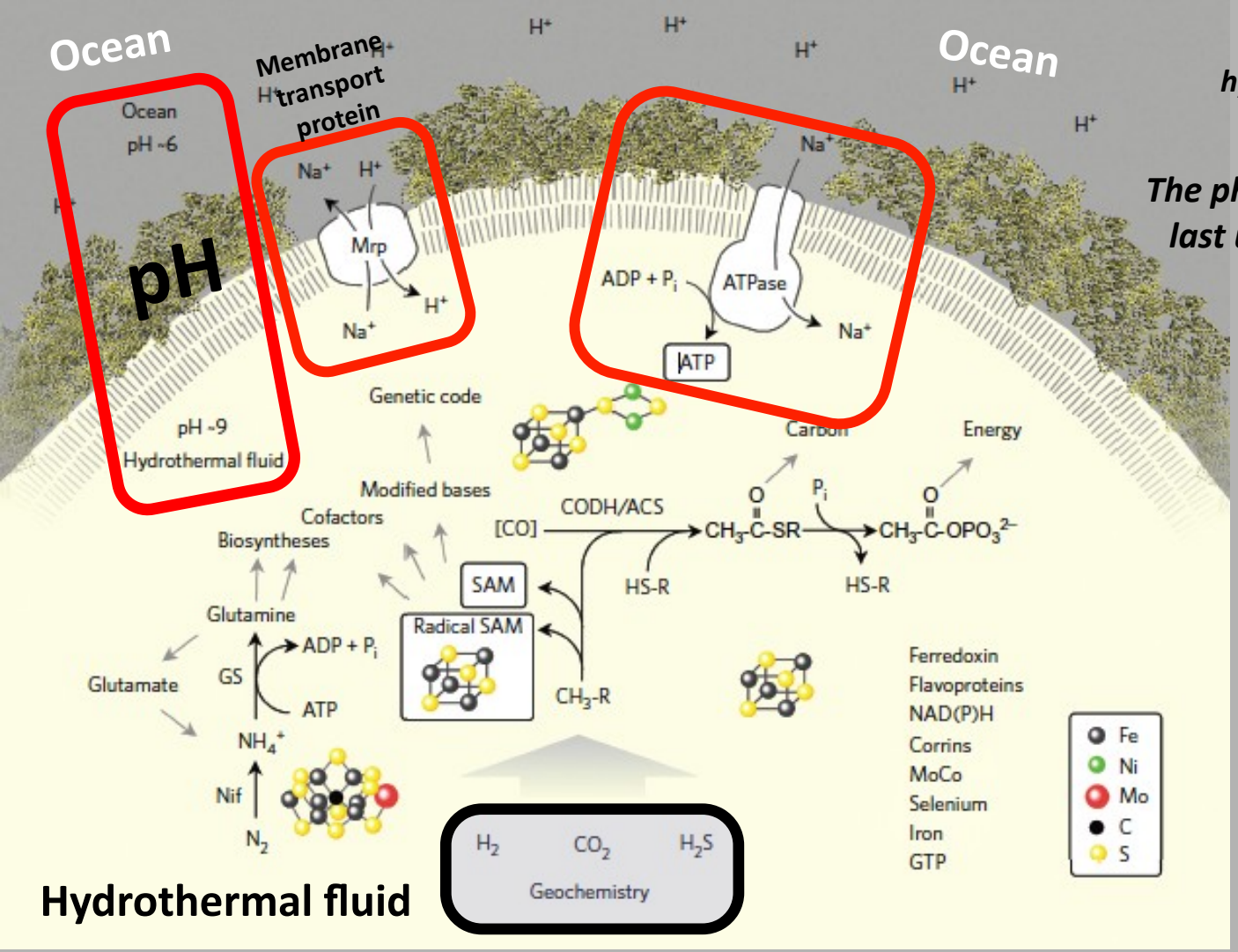

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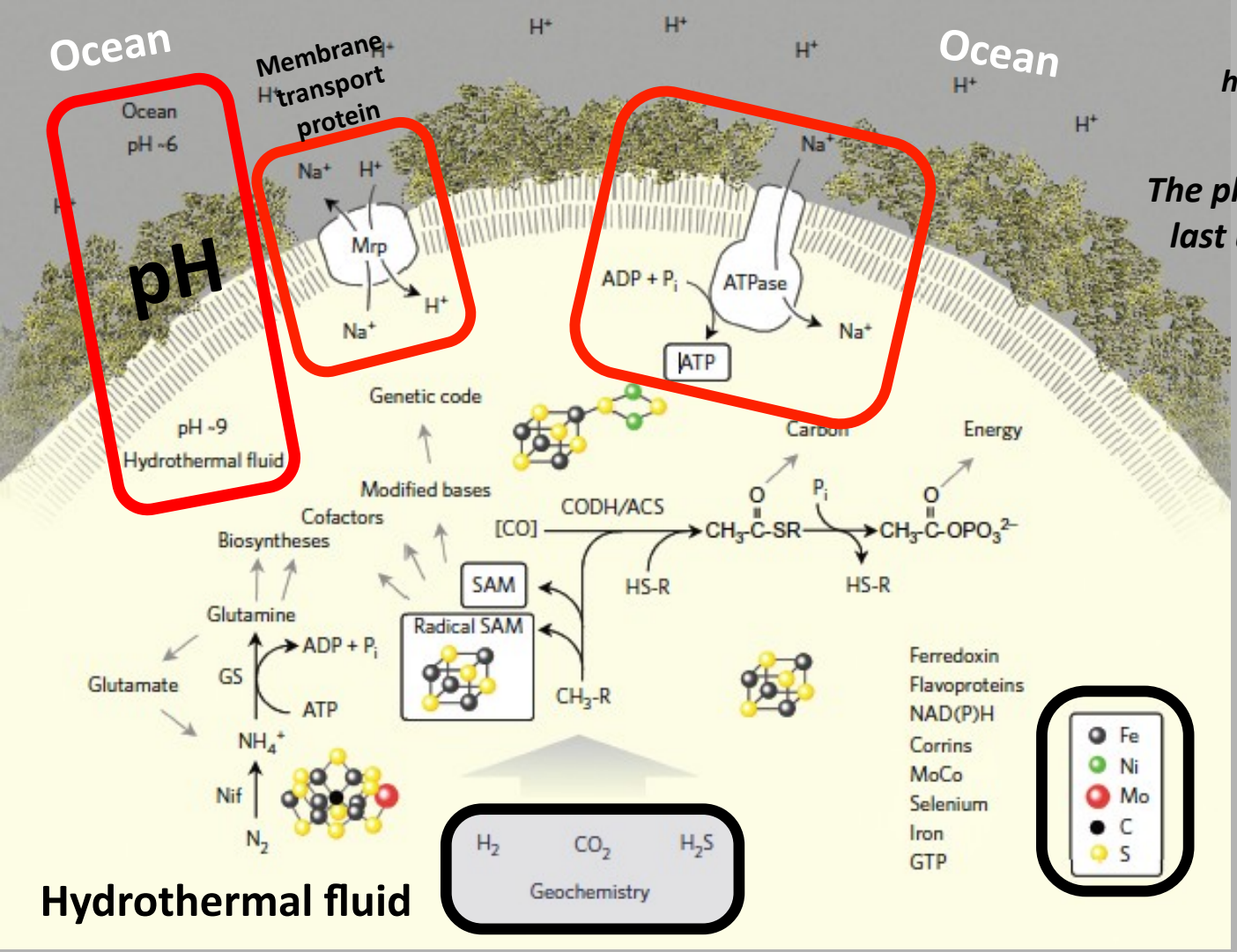

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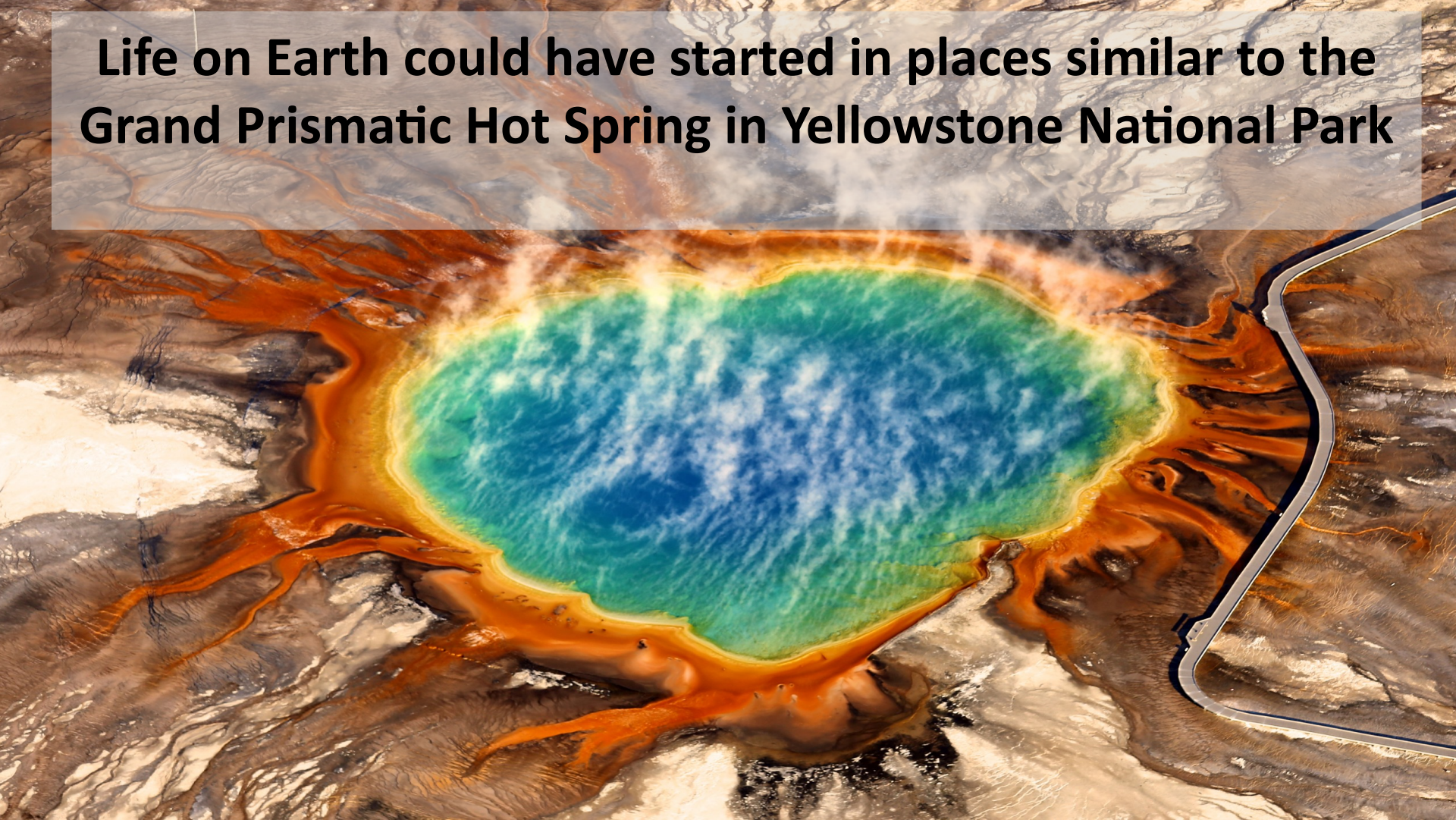
Life on Earth could have started in places similar to the Grand Prismatic Hot Spring in Yellowstone National Park




Life on Earth could have started in places similar to the Grand Prismatic Hot Spring in Yellowstone National Park
fresh water not salt water

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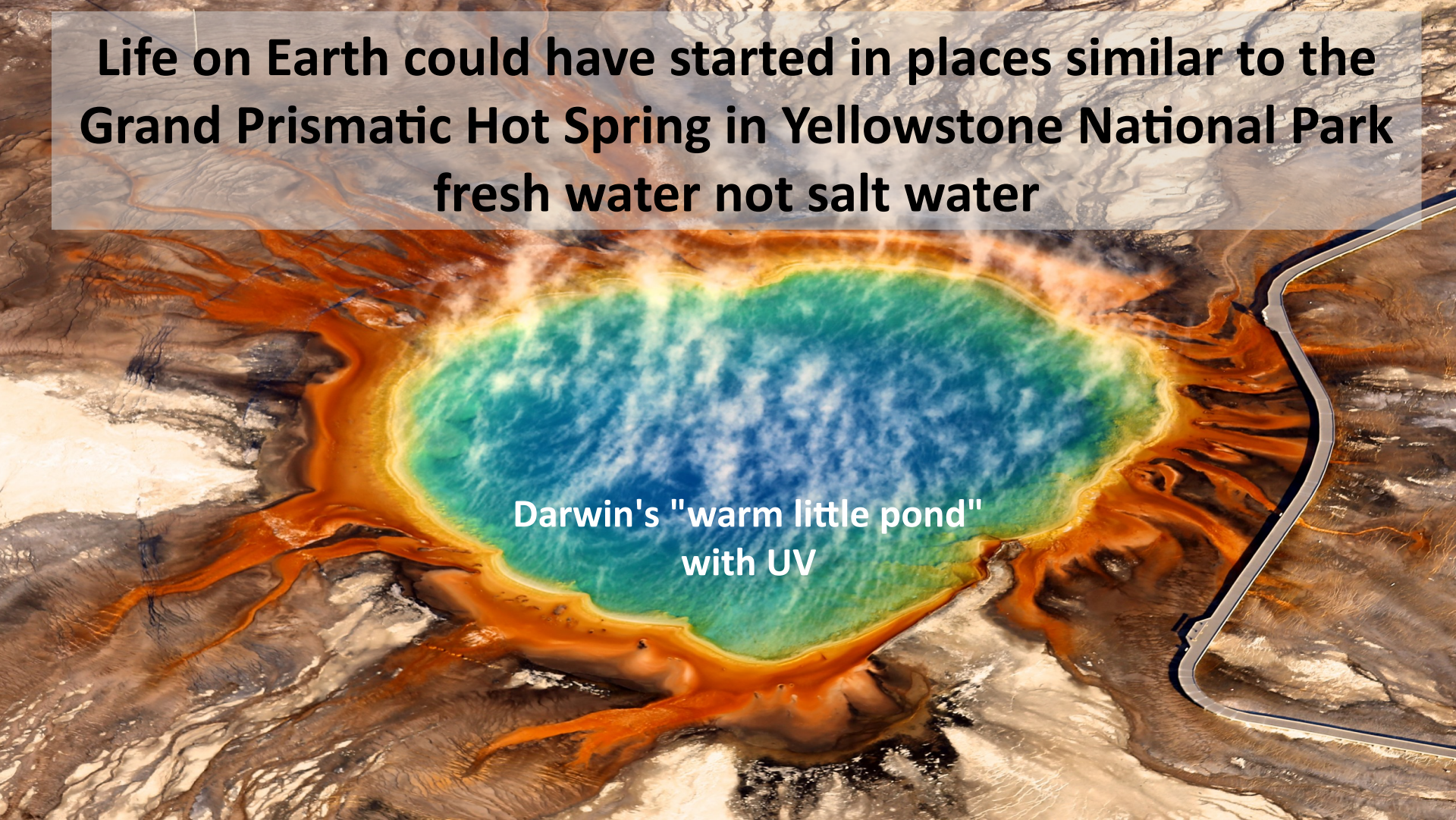


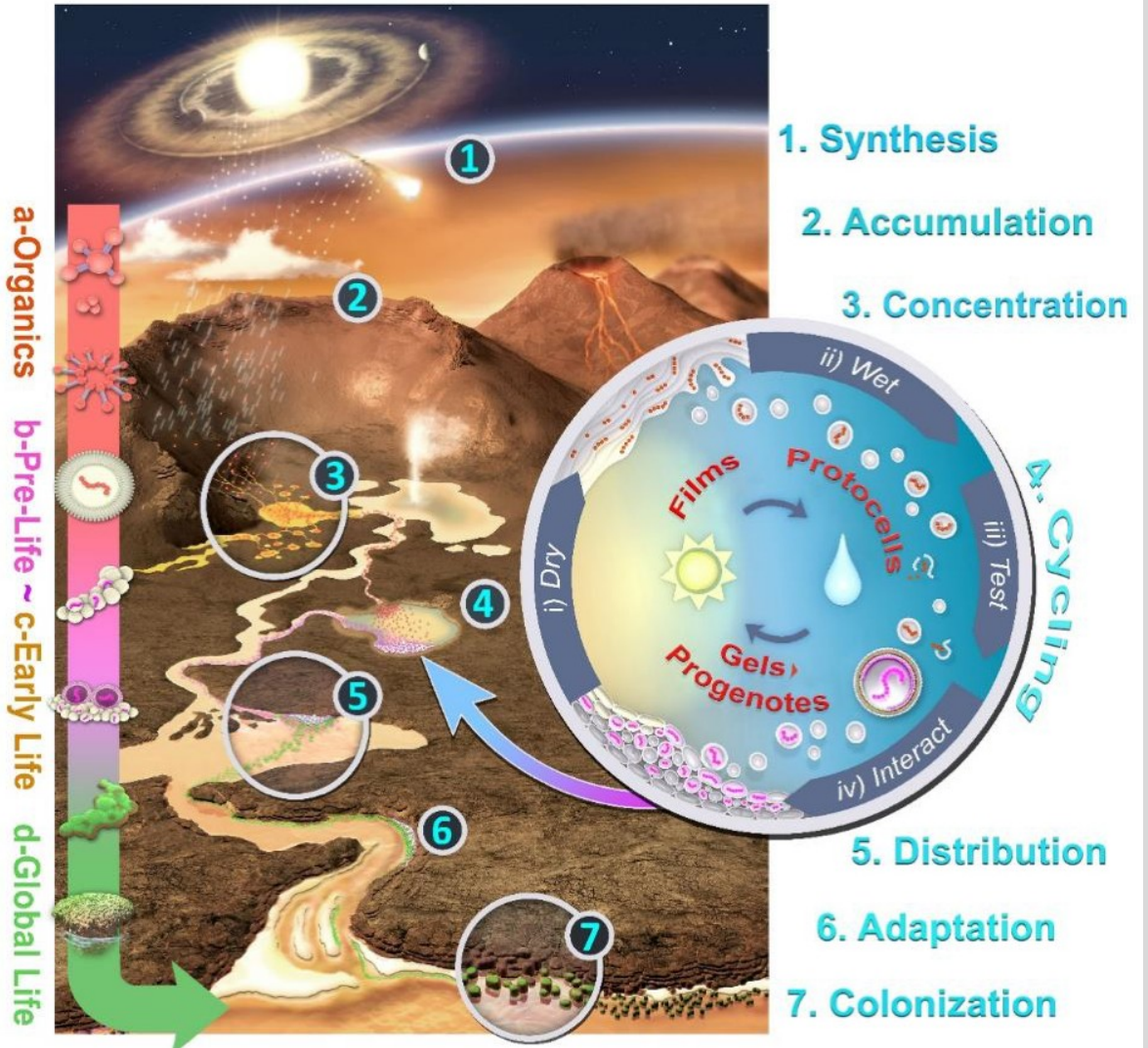
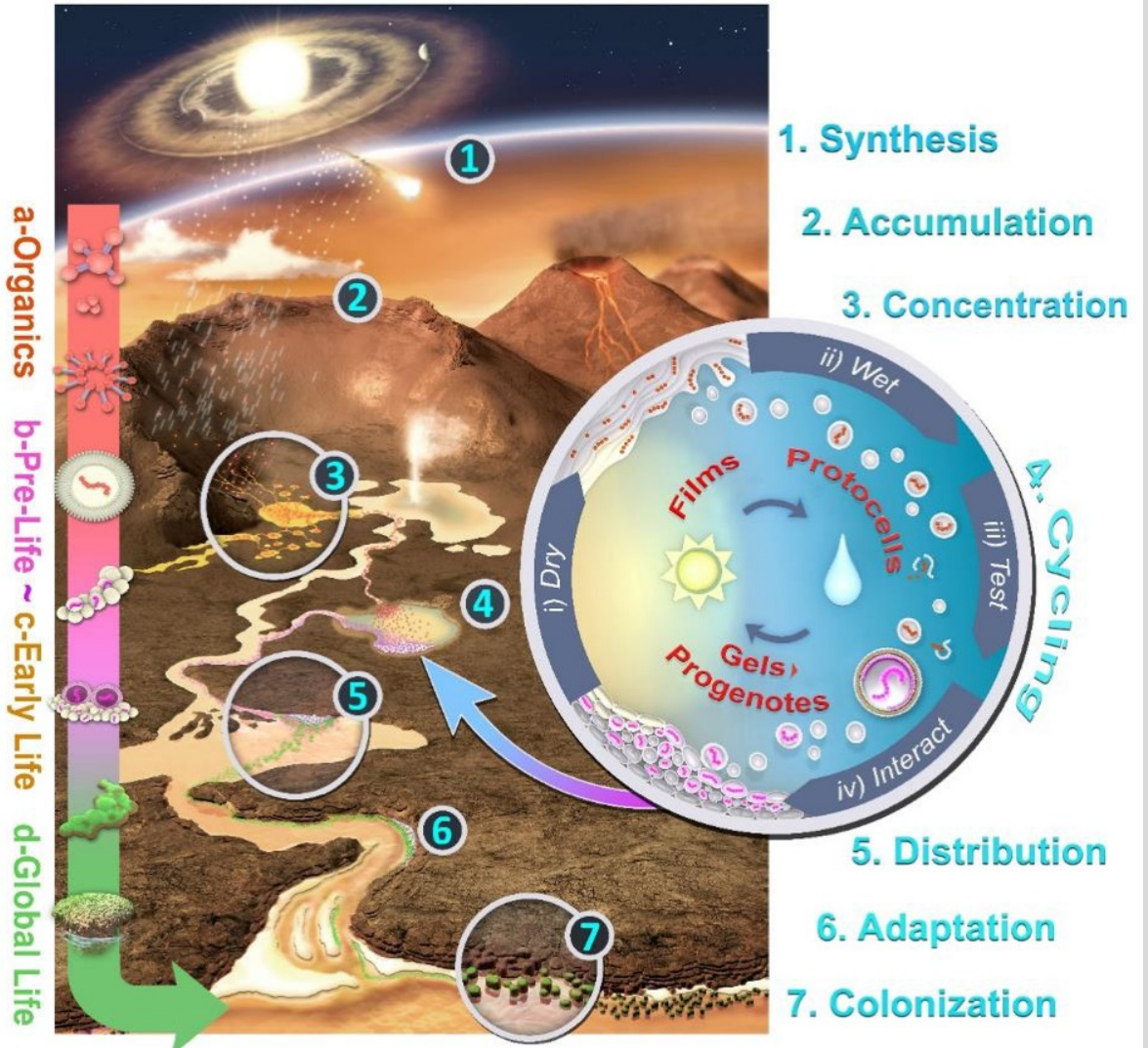


image: Bruce Damer and Deamer, Van Kranendonk, Sasselov



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not salt water

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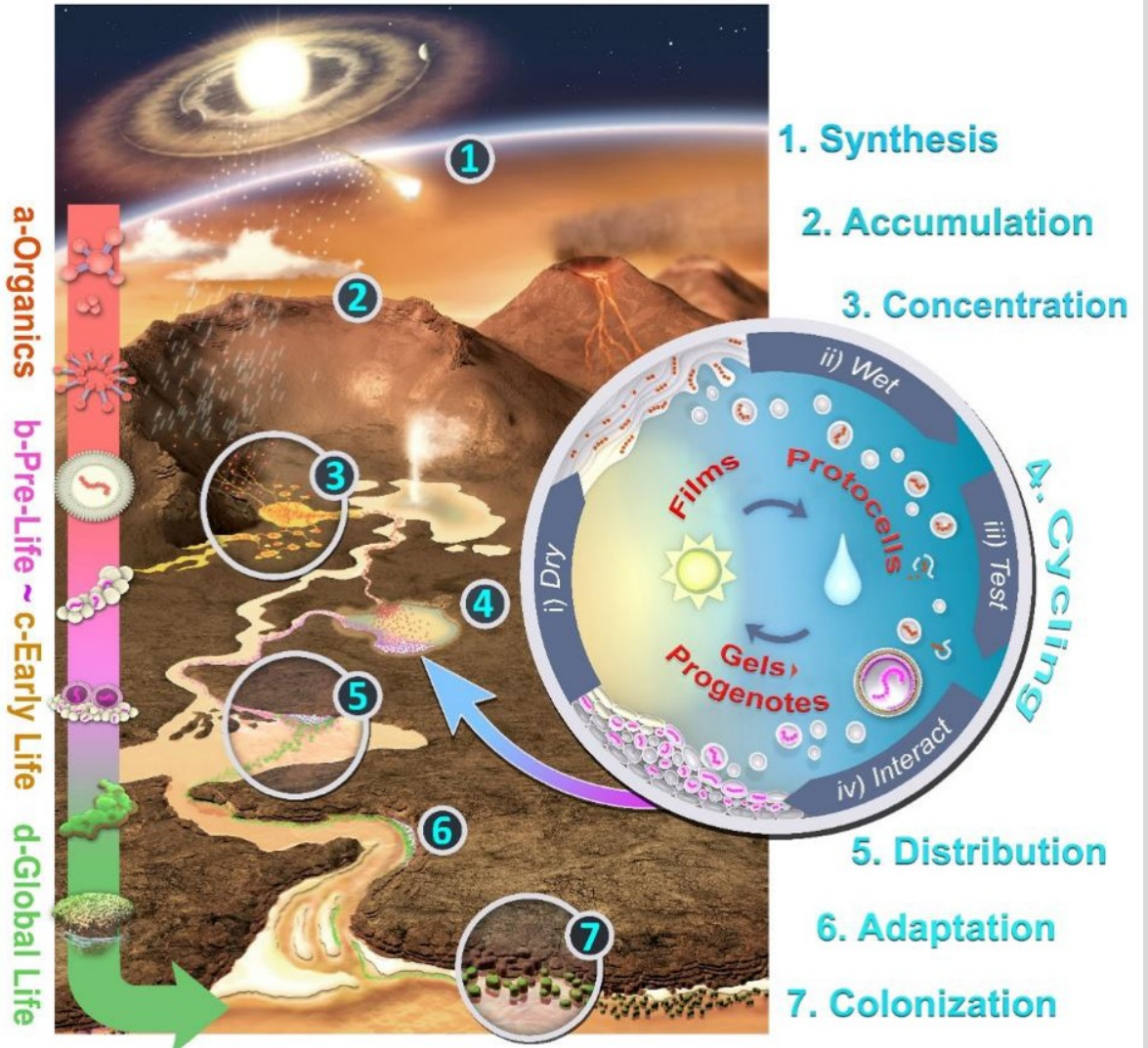
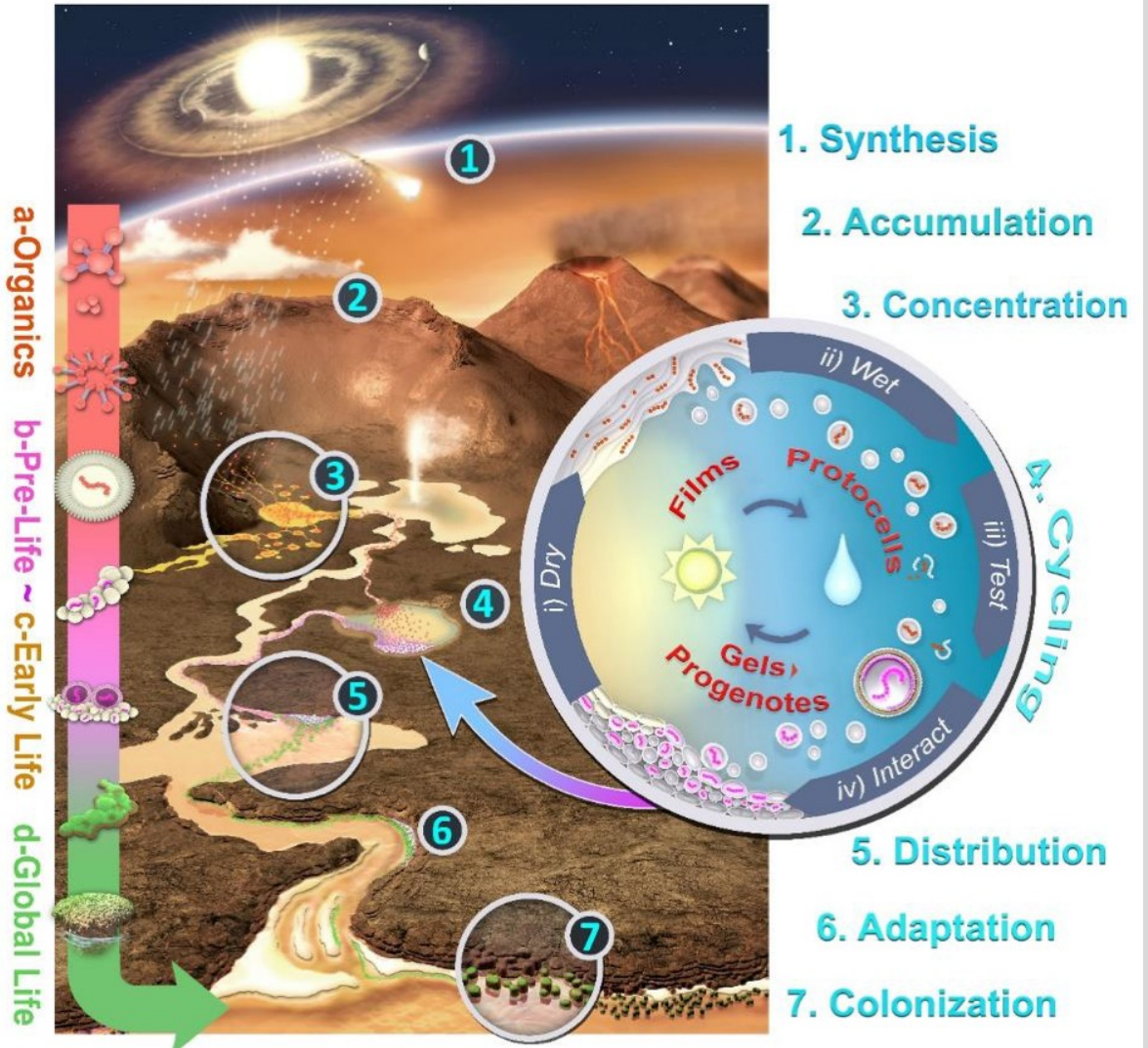


fresh water
not salt water

wet/dry by evaporation
not tides

Deamer, Van Kranendonk, Sasselov

image: Bruce Damer and



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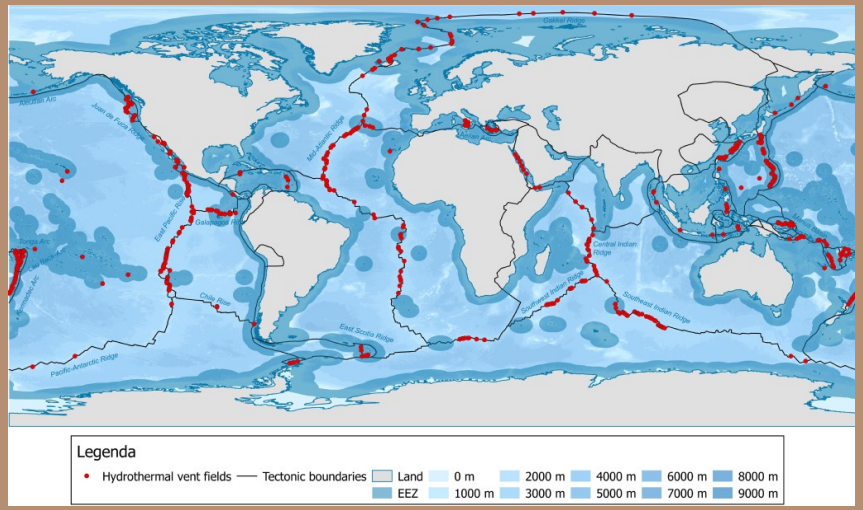
UV

image: Bruce Damer and Deamer, Van Kranendonk, Sasselov

2 models for the origin of life

hot hydrothermal vents



hot springs

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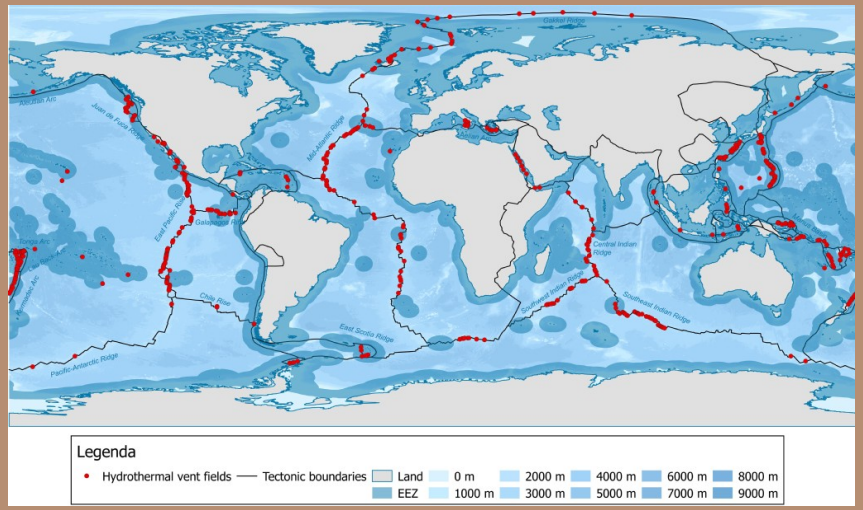

- salt water
- no UV
- no atmosphere

hot springs

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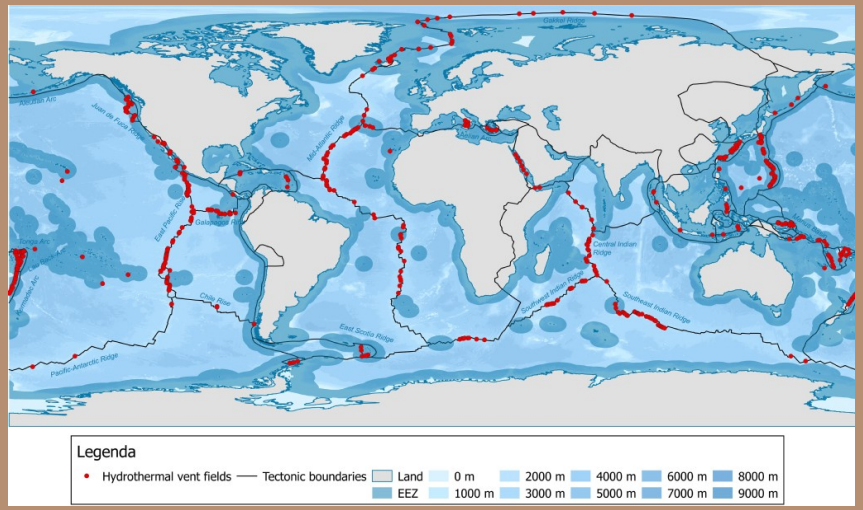

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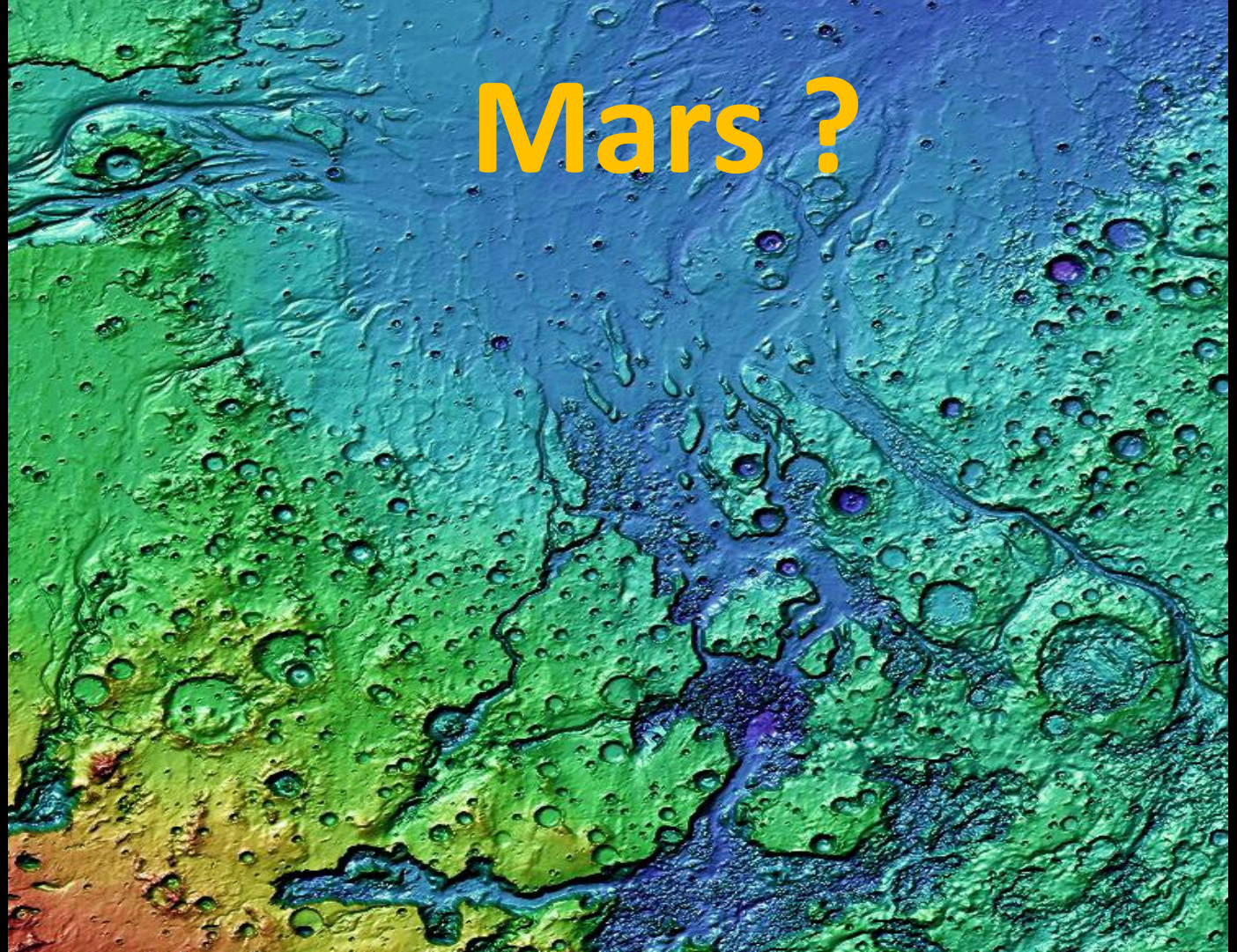
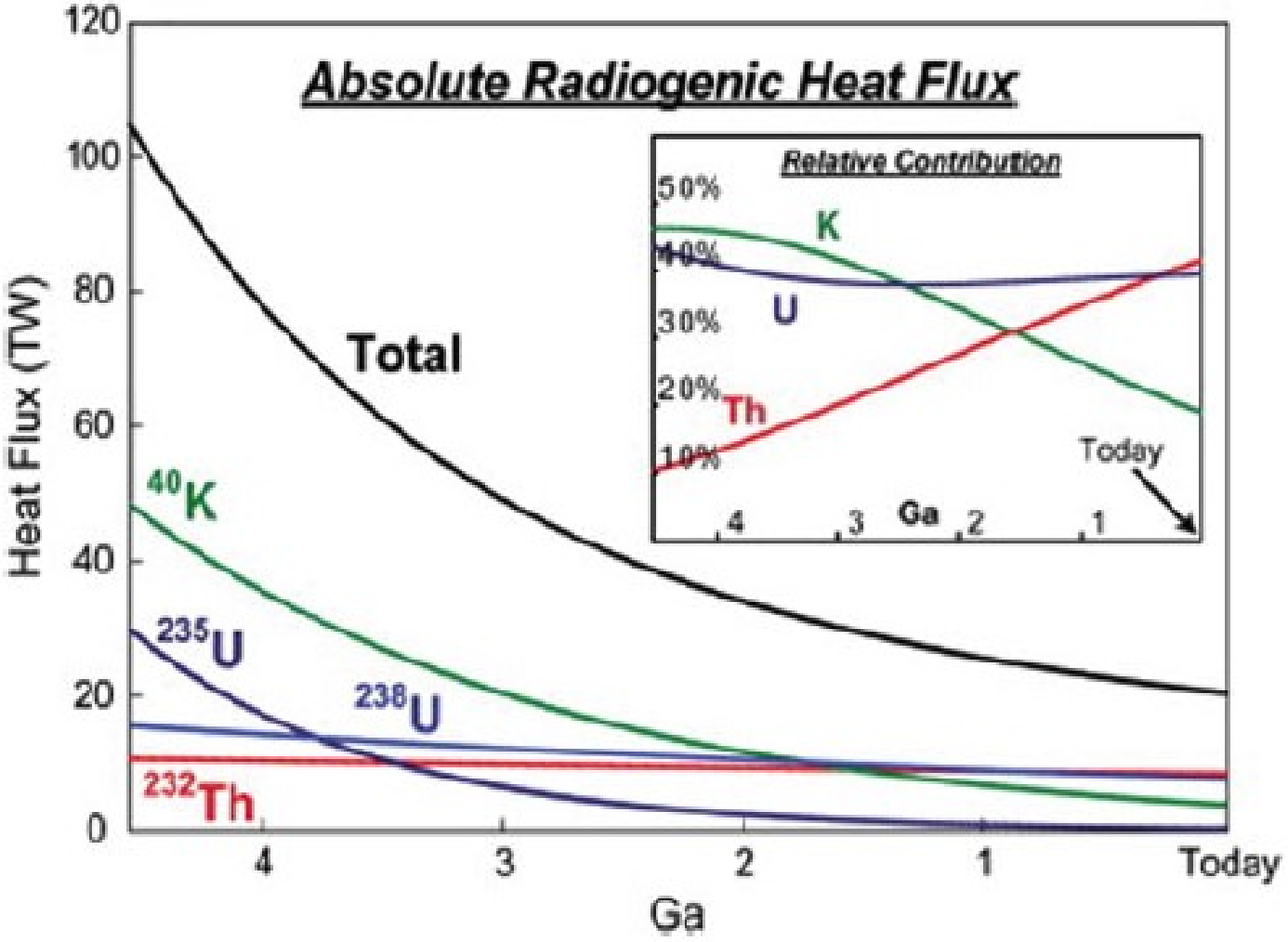
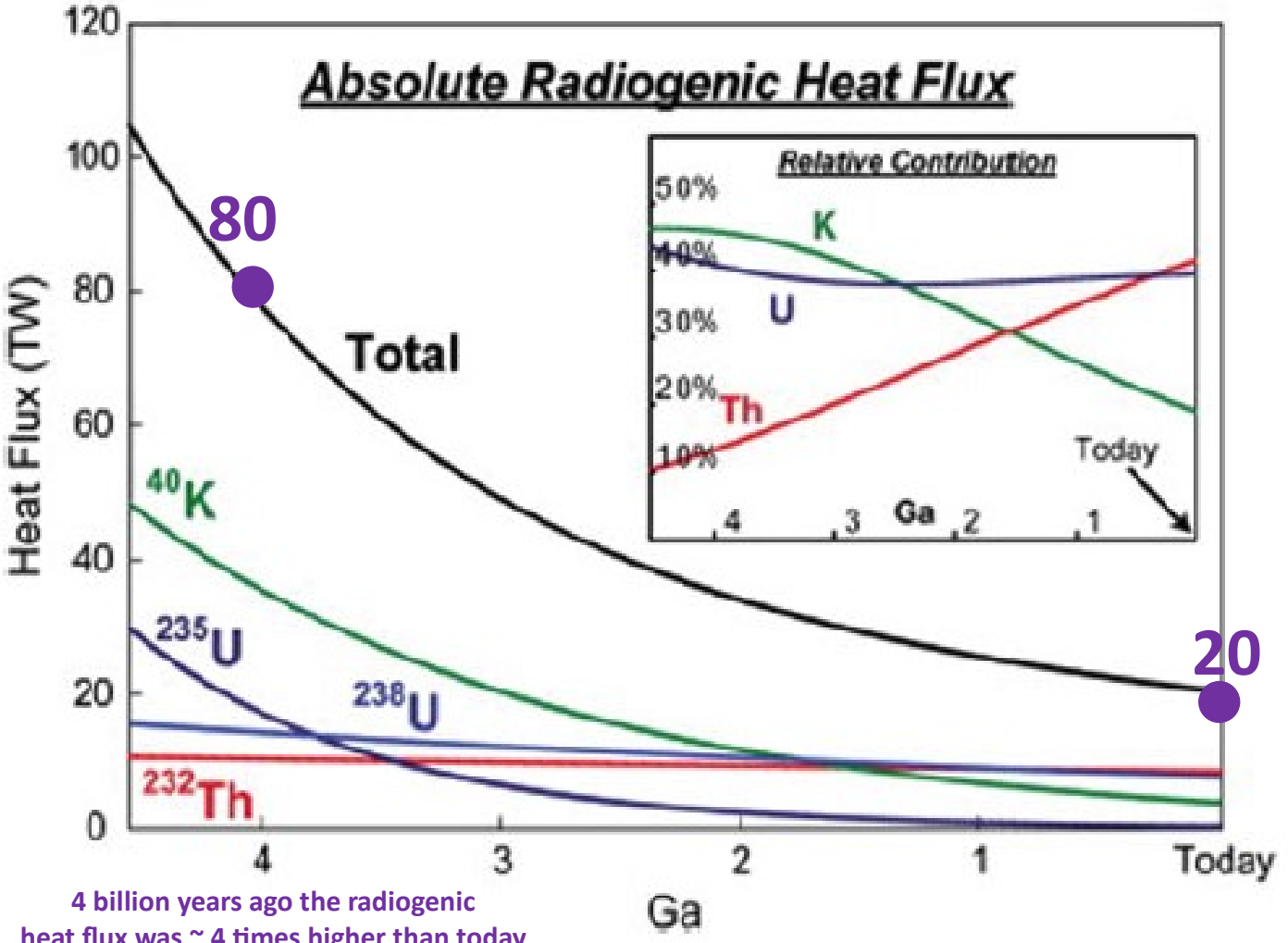

Mars ?

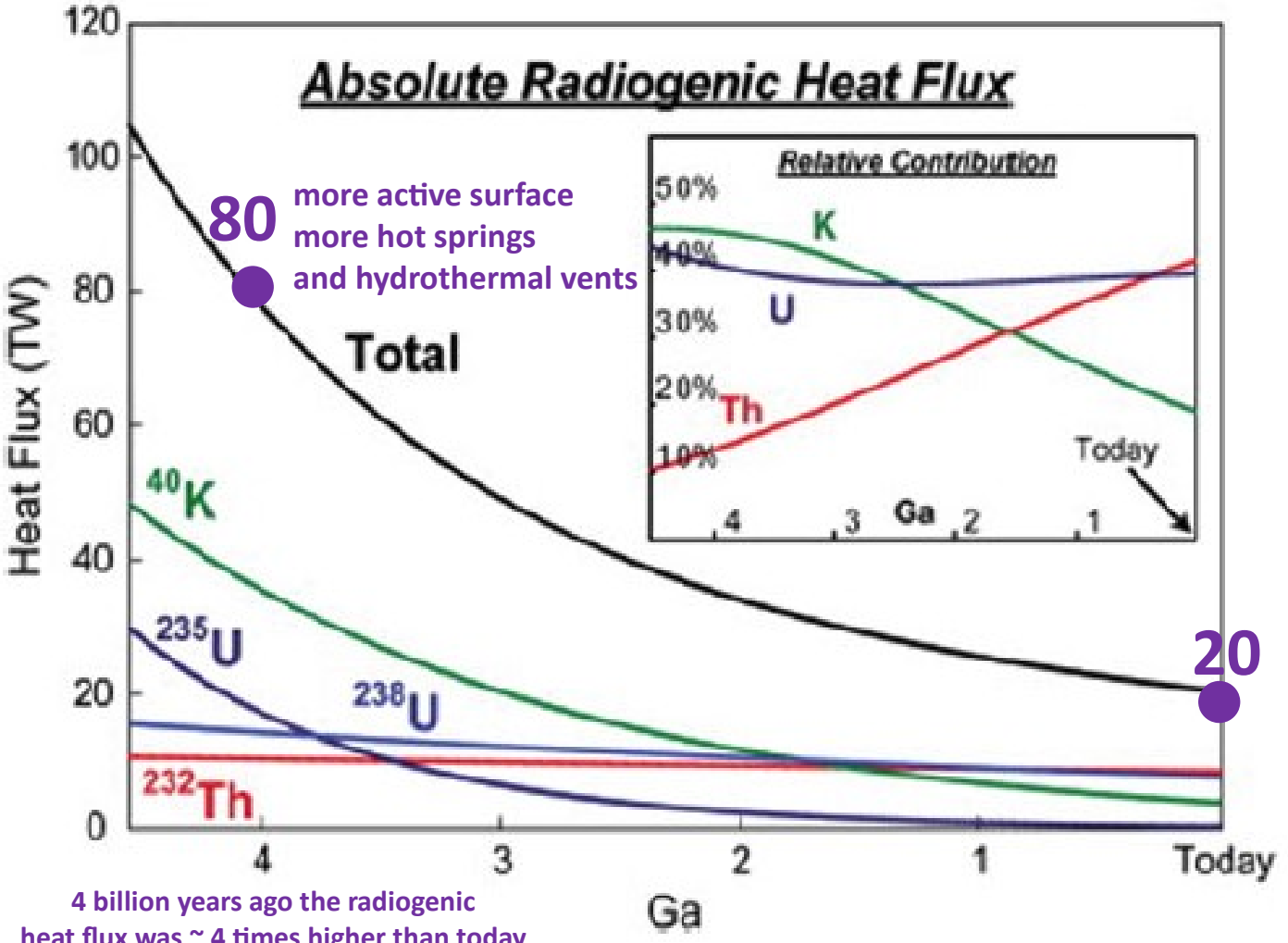


Arevalo et al 2009



4 billion years ago the radiogenic heat flux was ~ 4 times higher than today

Arevalo et al 2009



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Arevalo et al 2009

Origin of Life

WHEN

before 3.5 Gya
3.7, 3.8, 4.1 ?
after Moon-forming impact ~ 4.5
several times?

Origin of Life

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several times?

WHERE
2 models

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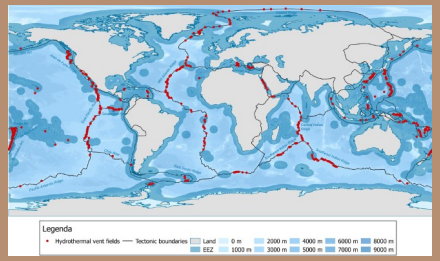

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hot springs

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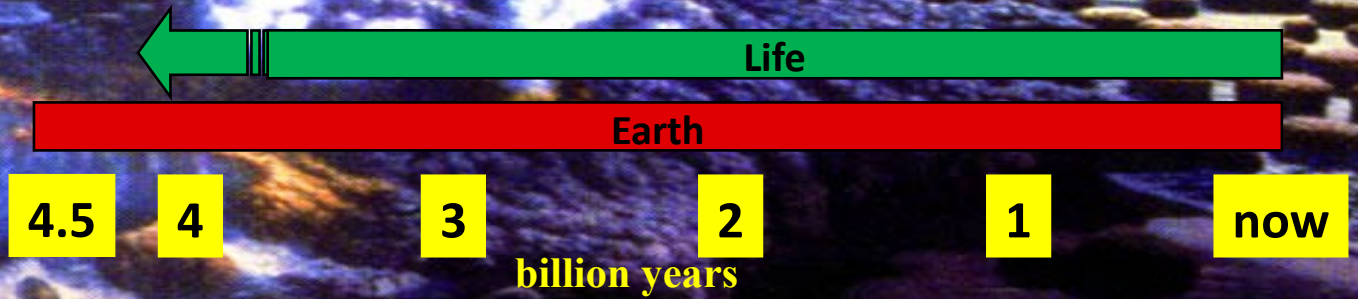
Why isn't it starting now?



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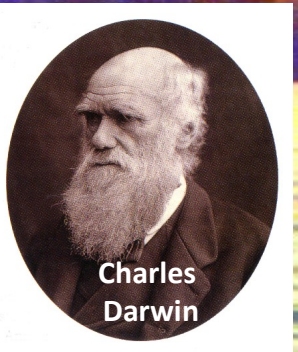
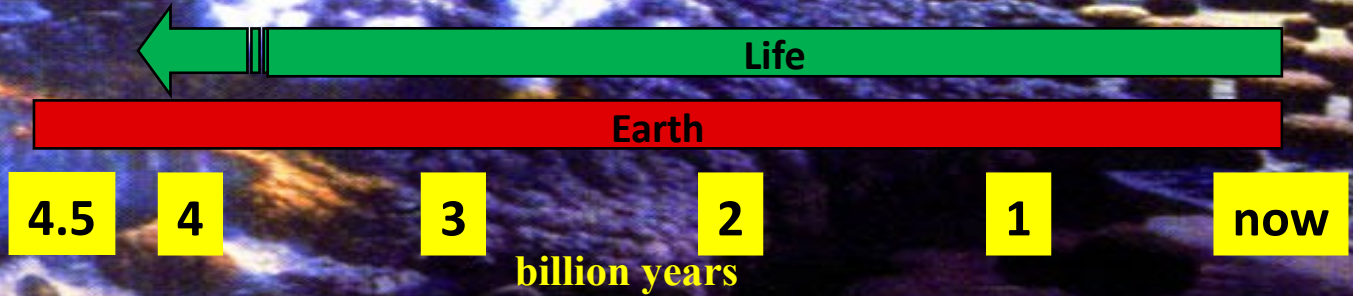
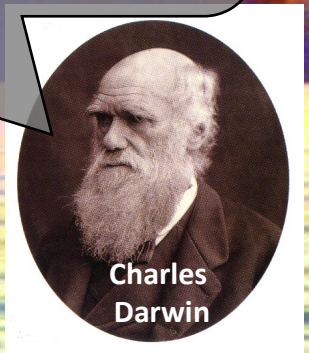




``It is often said that all the conditions for the first production of a living organism are now present, which could ever have been present. But if (and oh! what a big if!) we could conceive in some warm little pond, with all sorts of ammonia and phosphoric salts, light, heat, electricity, &c., present, that a protein compound was chemically formed ready to undergo still more complex changes, at the present day such matter would be instantly absorbed, which would not have been the case before living creatures were found."



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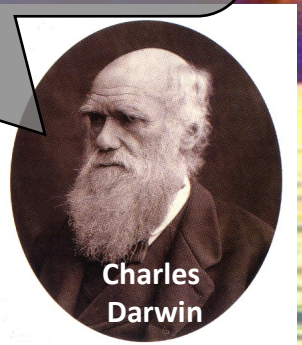
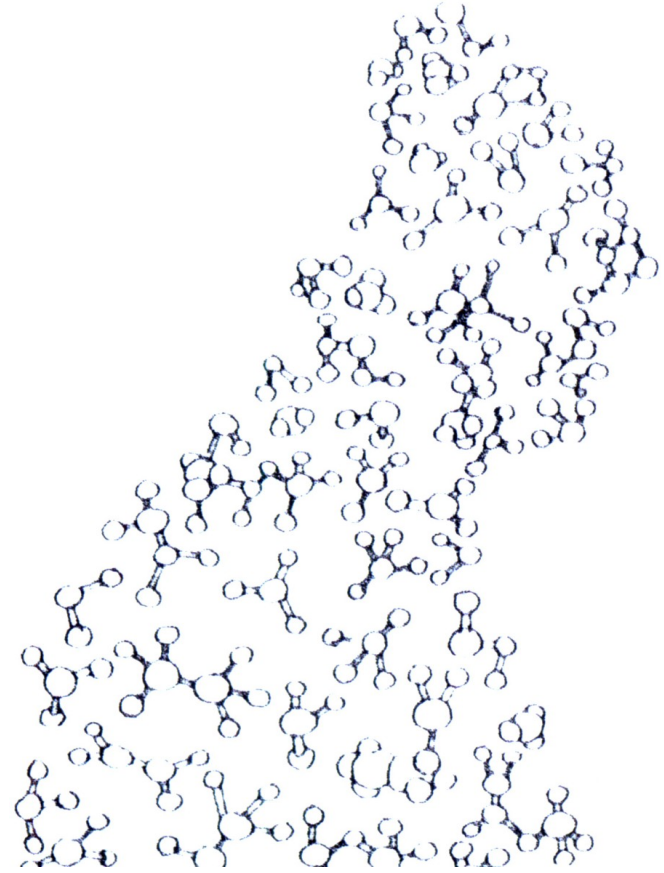
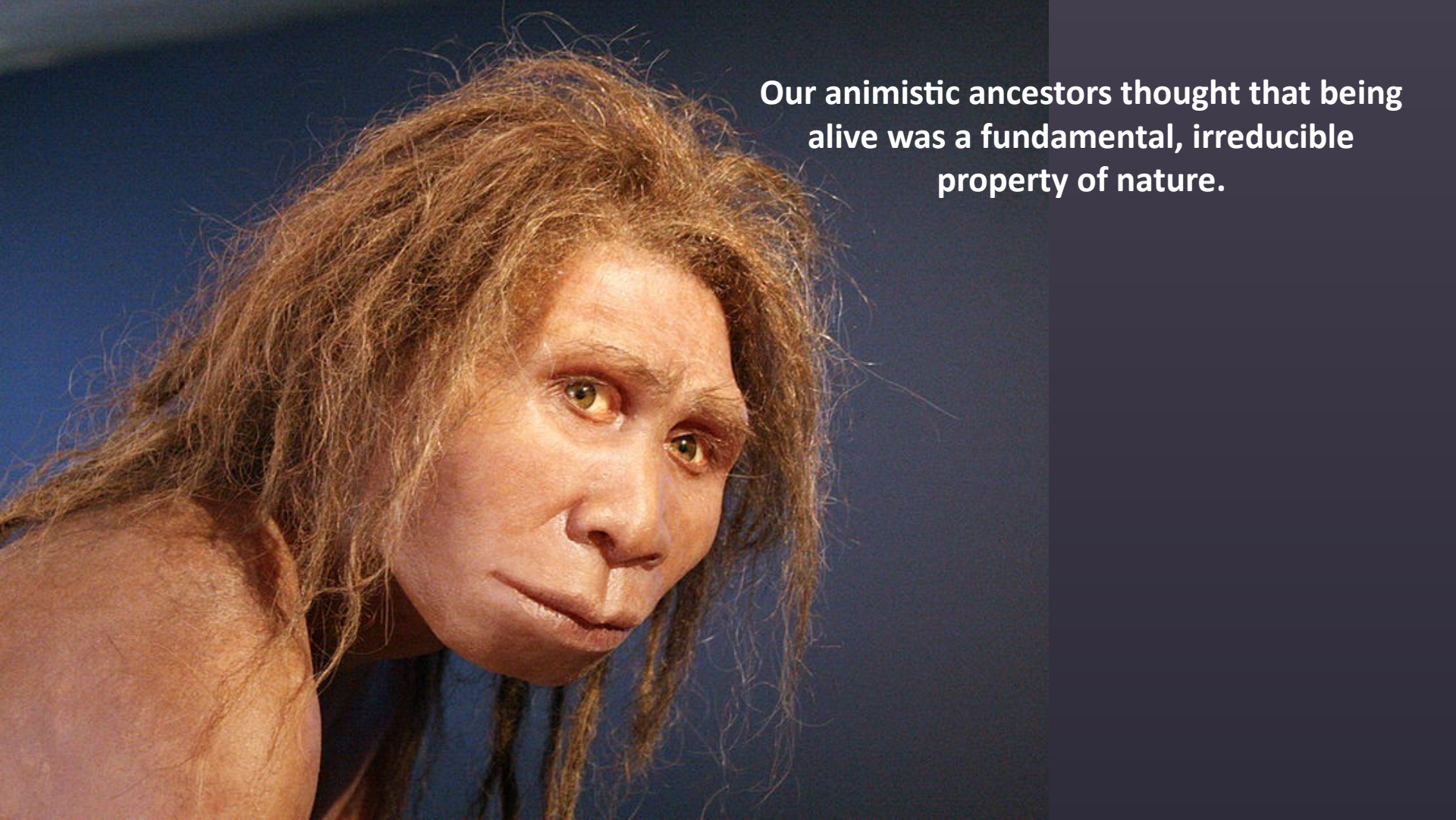


WHAT ?

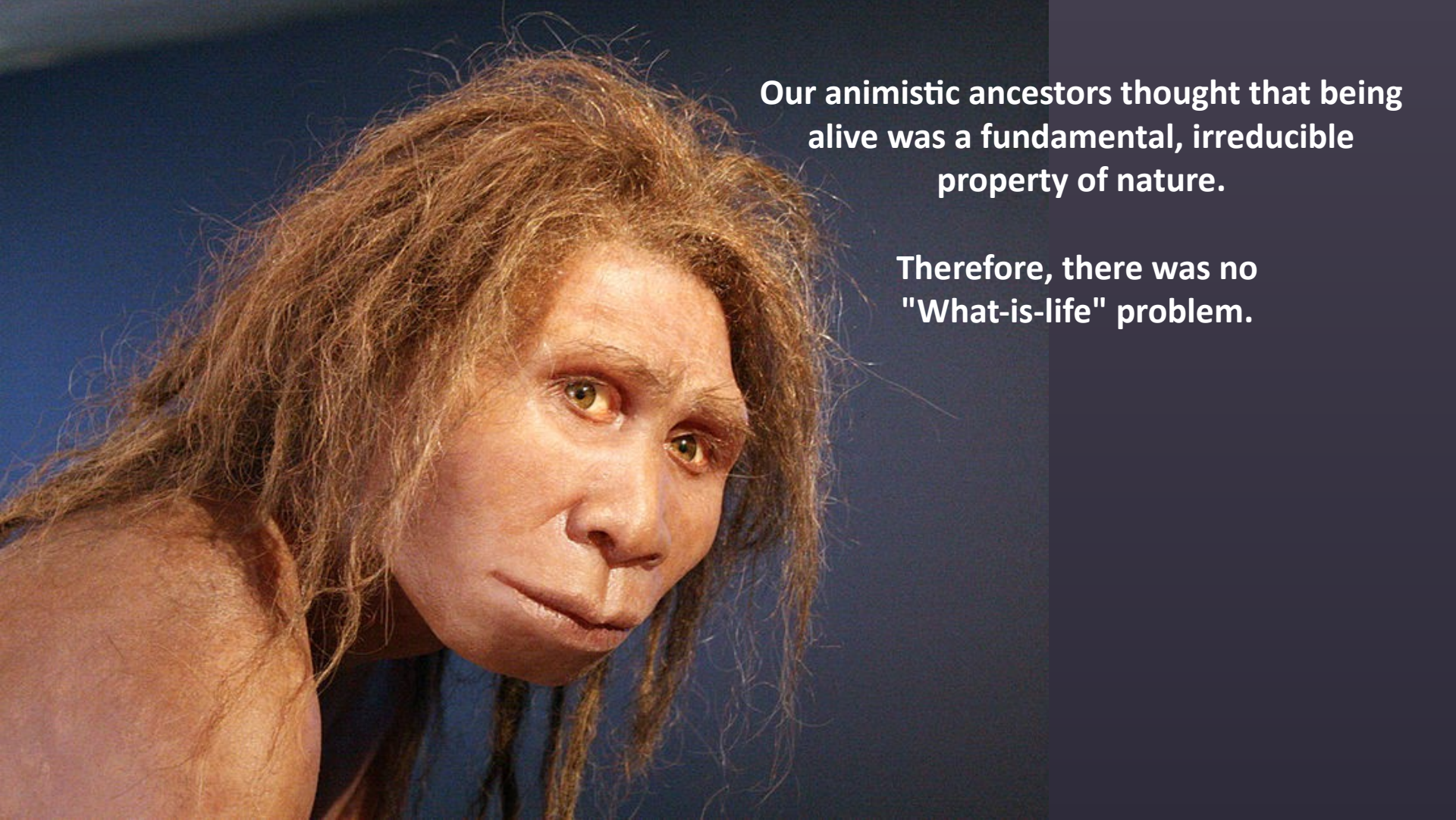
What is life?



Victor Juhasz



Our animistic ancestors thought that being alive was a fundamental, irreducible property of nature.



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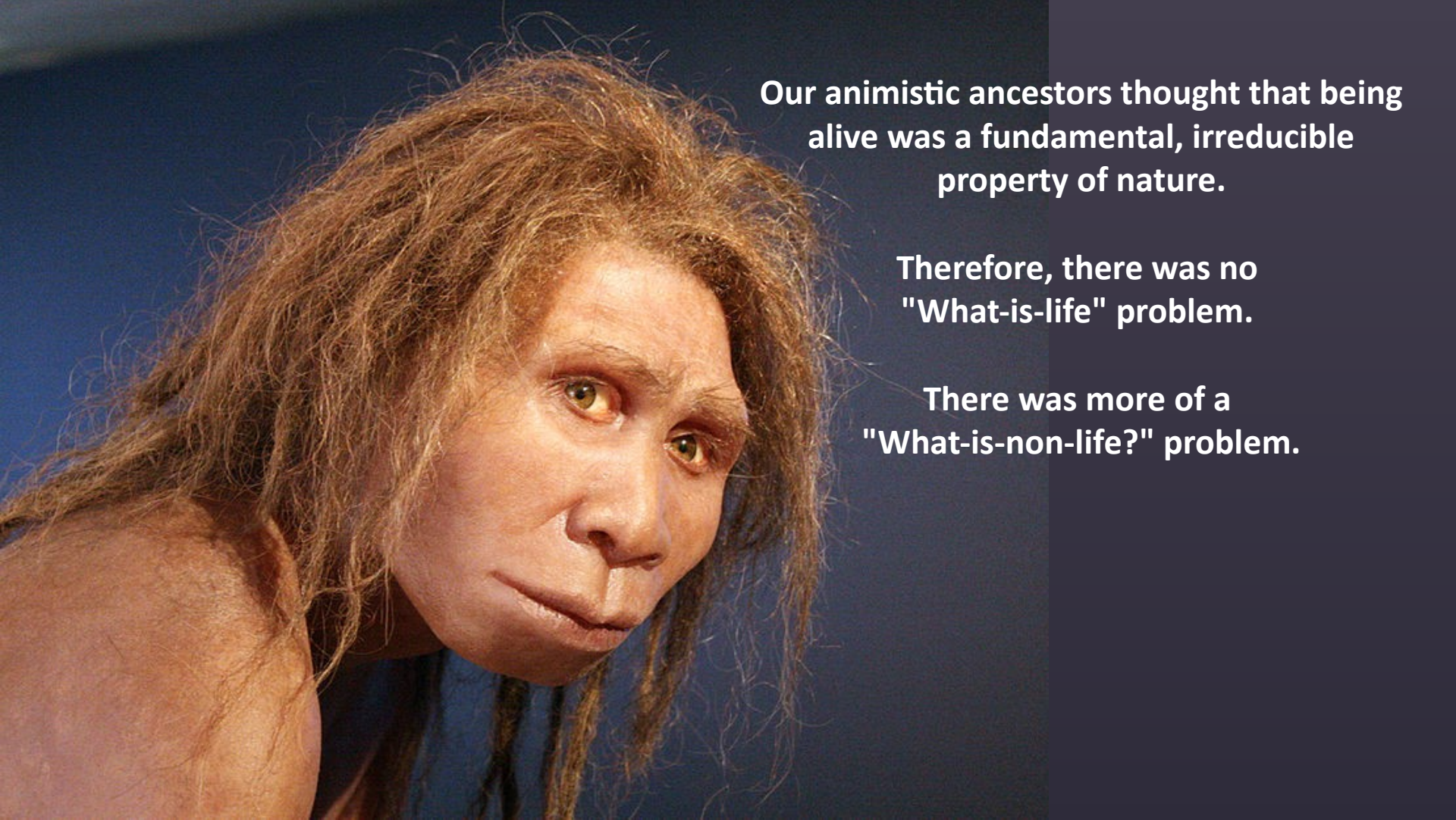

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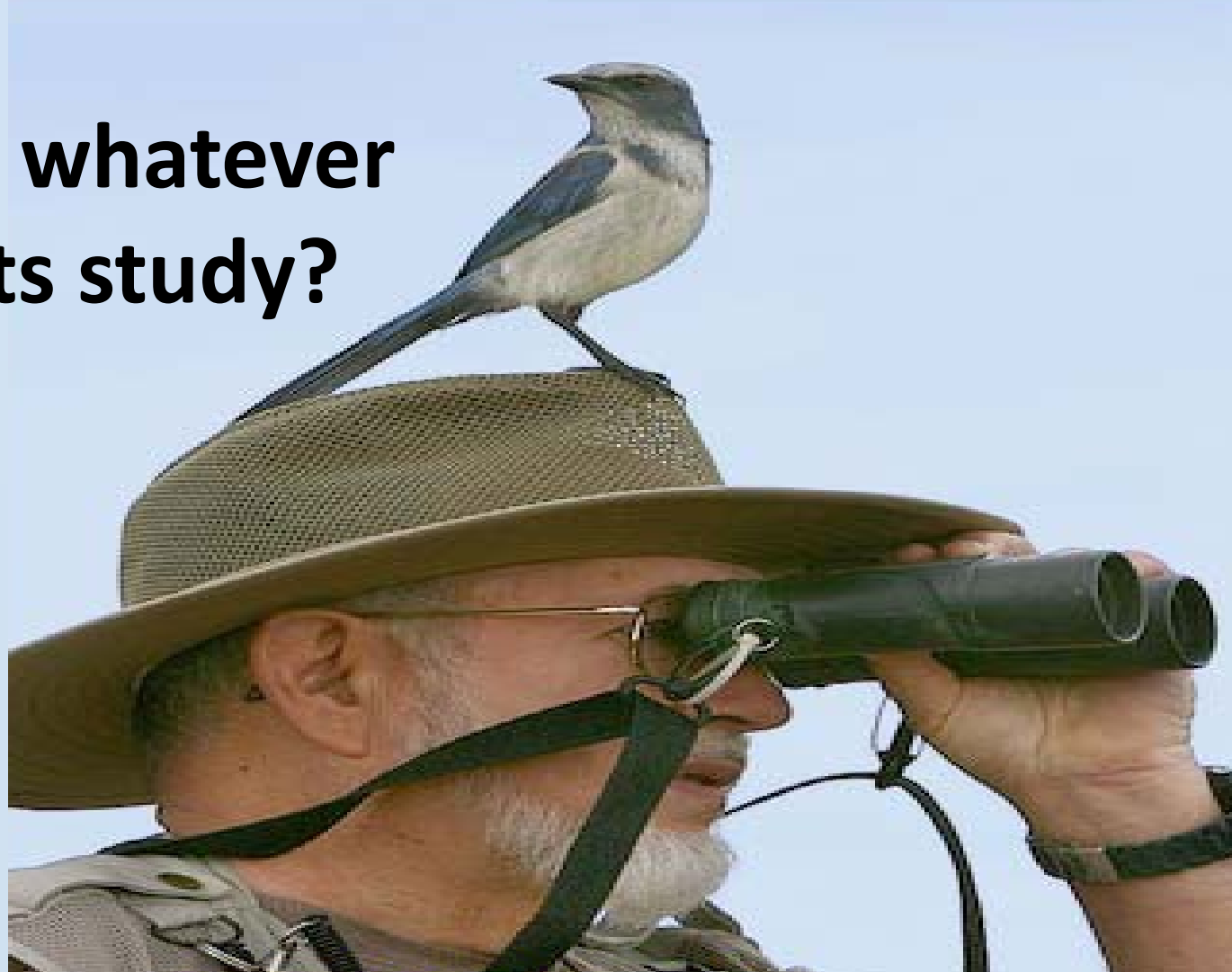
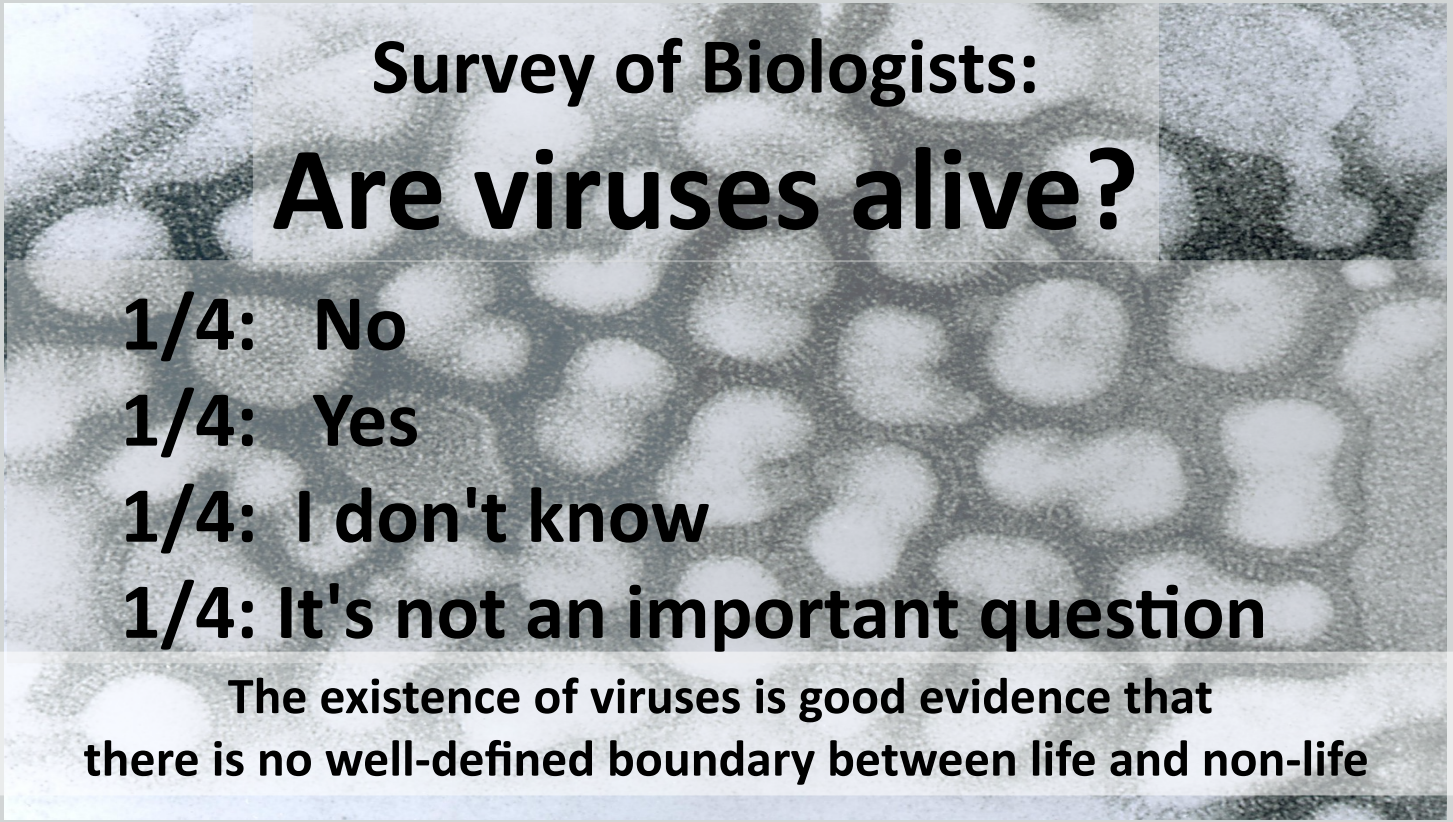
Therefore, there was no "What-is-life" problem.

There was more of a "What-is-non-life?" problem.

Is life just whatever biologists study?




Survey of Biologists:
Are viruses alive?
1/4: No
1/4: Yes
1/4: I don't know
1/4: It's not an important question
The existence of viruses is good evidence that
there is no well-defined boundary between life and non-life

Aristotle

De Anima

c. 350 BC

Of natural bodies some possess life and some do not: where by life we mean the power of self-nourishment and of independent growth and decay.

DEFINITIONS OF LIFE

"self-sustaining chemical system capable of Darwinian evolution" (Joyce et al 1994)

"a chemical system in which the flow and storage of energy are related to the flow and storage of information." Smith 2008

“a living organism is an organized unit, which can carry out metabolic reactions, defend itself against injury, respond to stimuli, and has the capacity to be at least a partner in reproduction.” Koshland 2002

"Life is one member of the class of phenomena which are open or continuous reaction systems able to decrease their entropy at the expense of substances or energy taken in from the environment and subsequently rejected in a degraded form". (Lovelock 1965)

An autopoietic machine is a machine organized (defined as a unity) as a network of processes of production (transformation and destruction) of components which: (i) through their interactions and transformations continuously regenerate and realize the network of processes (relations) that produced them; and (ii) constitute it (the machine) as a concrete unity in space in which they (the components) exist by specifying the topological domain of its realization as such a network (Maturana & Varela 1980)

Life is a property of an ensemble of units that share information coded in a physical substrate, and which, in the presence of noise, manages to keep its entropy significantly lower than the maximal entropy of the ensemble on timescales exceeding the "natural" timescale of the decay of the (information-bearing) substrate by many orders of magnitude." (Adami 1998).

an emergent property of particular kinds of complex systems (Weber 2010).

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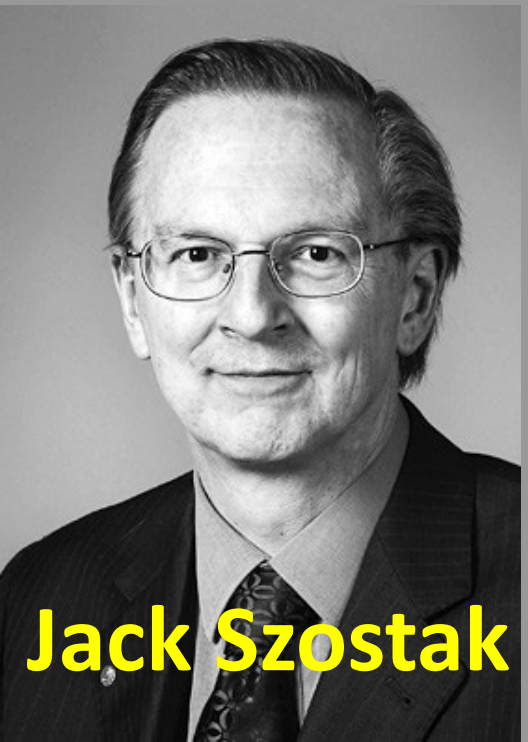
"Attempts to Define Life Do Not Help to Understand the Origin of Life"

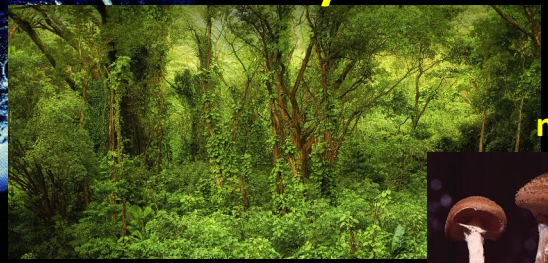


Journal of Biomolecular Structure and Dynamics

2012

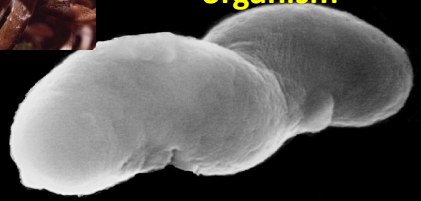
Gaia

ecosystem

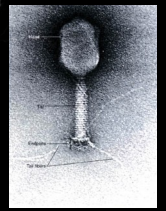


multicellular organism

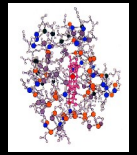
unicellular organism



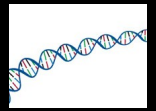
virus



prion



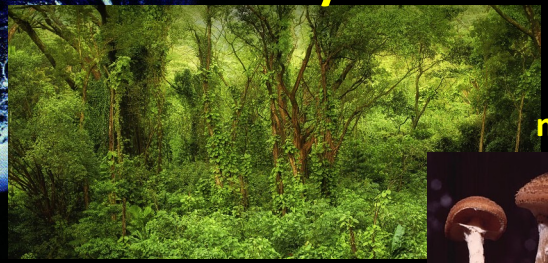
gene



Are there size boundaries to life ?

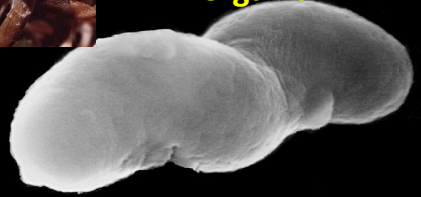
Gaia

ecosystem



multicellular organism

unicellular organism



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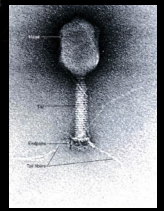
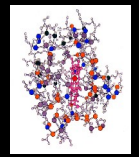


prion



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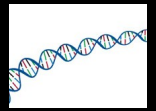

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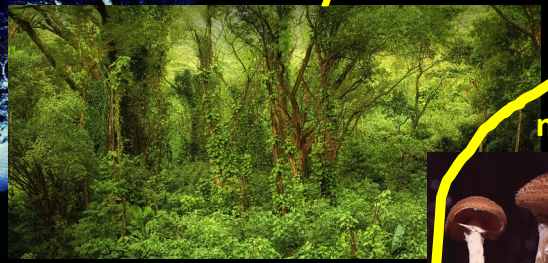
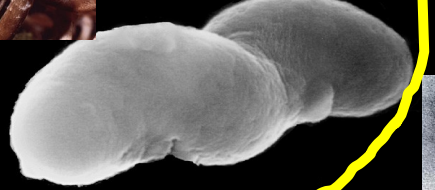
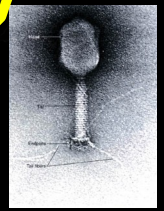


multicellular organism

unicellular organism



virus



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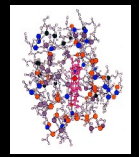

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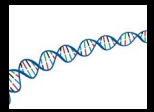

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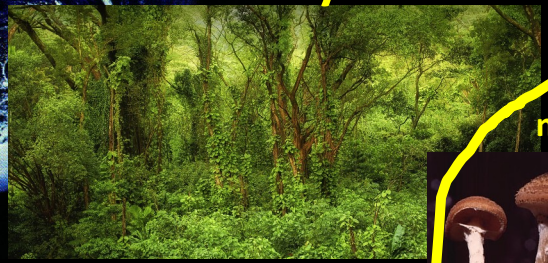
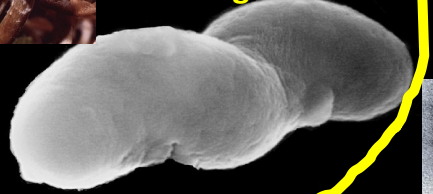


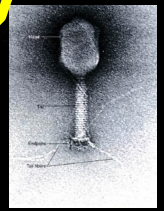
too big ?

multicellular organism

unicellular organism



virus



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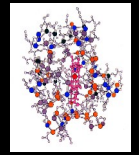

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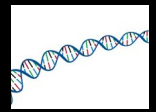

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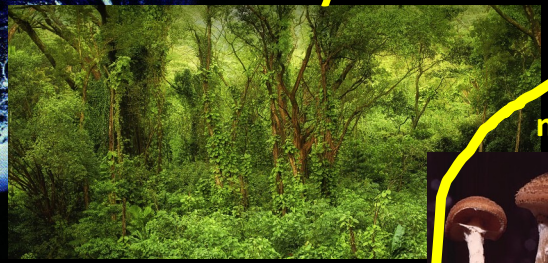

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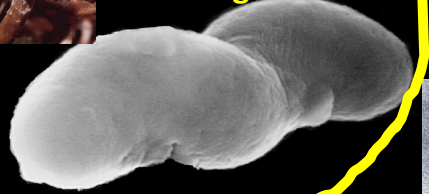

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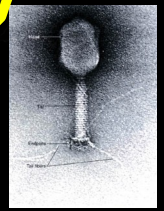

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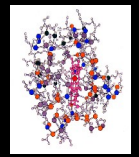

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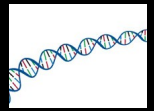



Plato
Aristotle

Is life an unchanging platonic form, like the number π ?

Is life an unchanging platonic form, like the number π ?

Does it have a stable unchanging definition?

Nein

Nein

only that which has no history can be defined

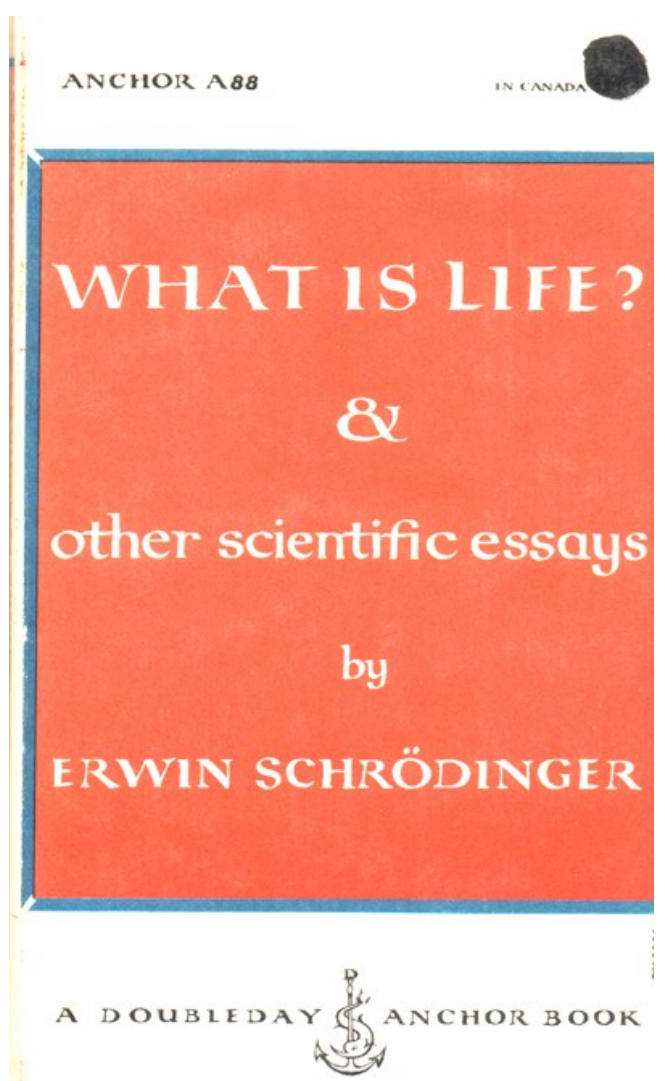
1887, Genealogy of Morality, II, 13

Nein

only that which has
no history can be defined

1887, Genealogy of Morality, II, 13

Life has a history...
therefore it cannot be defined



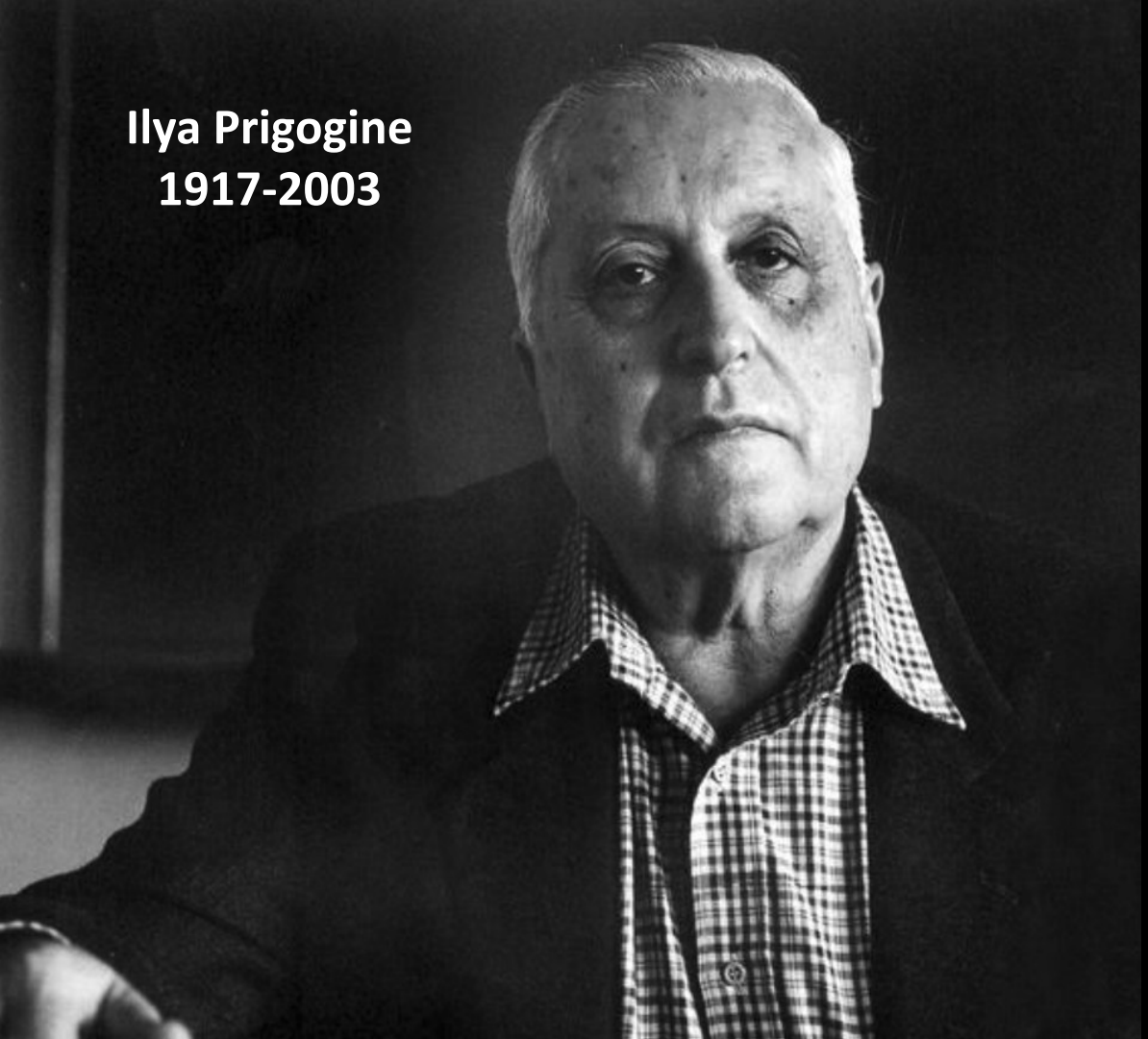
1943 lectures at the Dublin Institute of Advanced Studies
***What is Life?* (1944)**

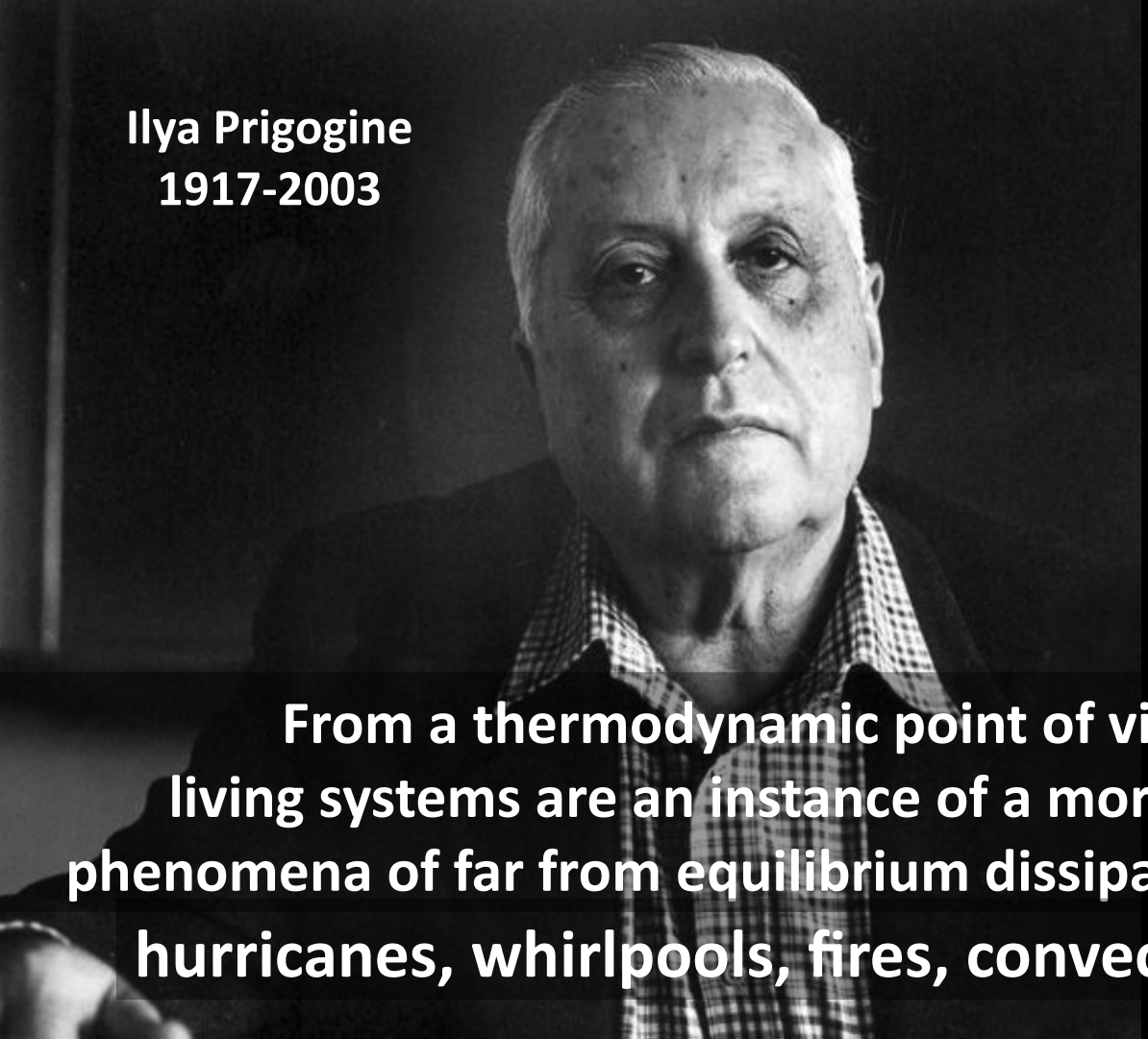
Erwin Schrödinger
1887–1961

1887-1961

Erwin Schroedinger

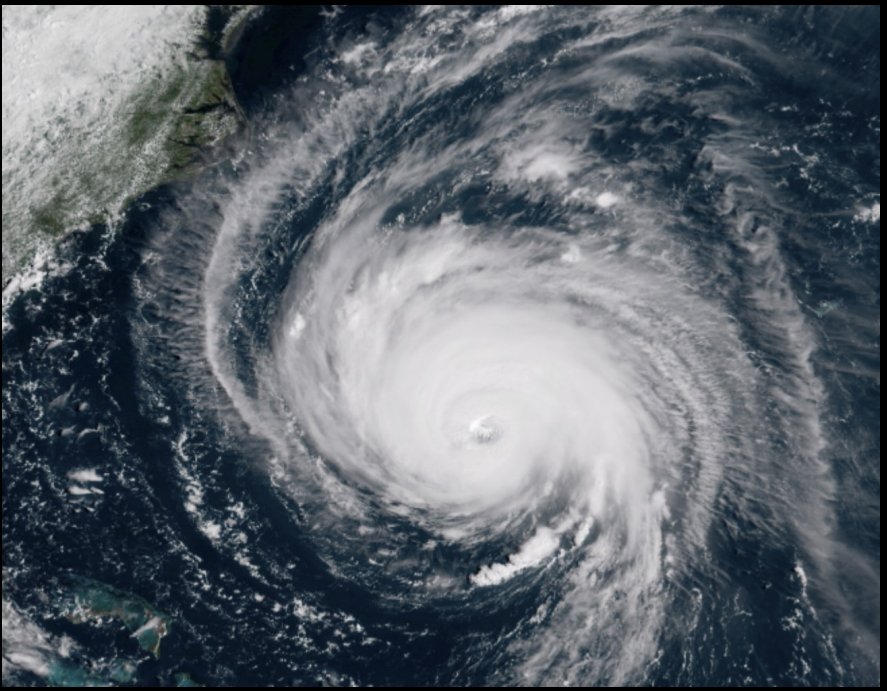
...everything that is going on in Nature means an increase of the entropy of the part of the world where it is going on. Thus a living organism continually increases its entropy... What an organism feeds on is negative entropy....the essential thing in metabolism is that the organism succeeds in freeing itself from all the entropy it cannot help producing while alive...
(What is Life? pp 71-72)

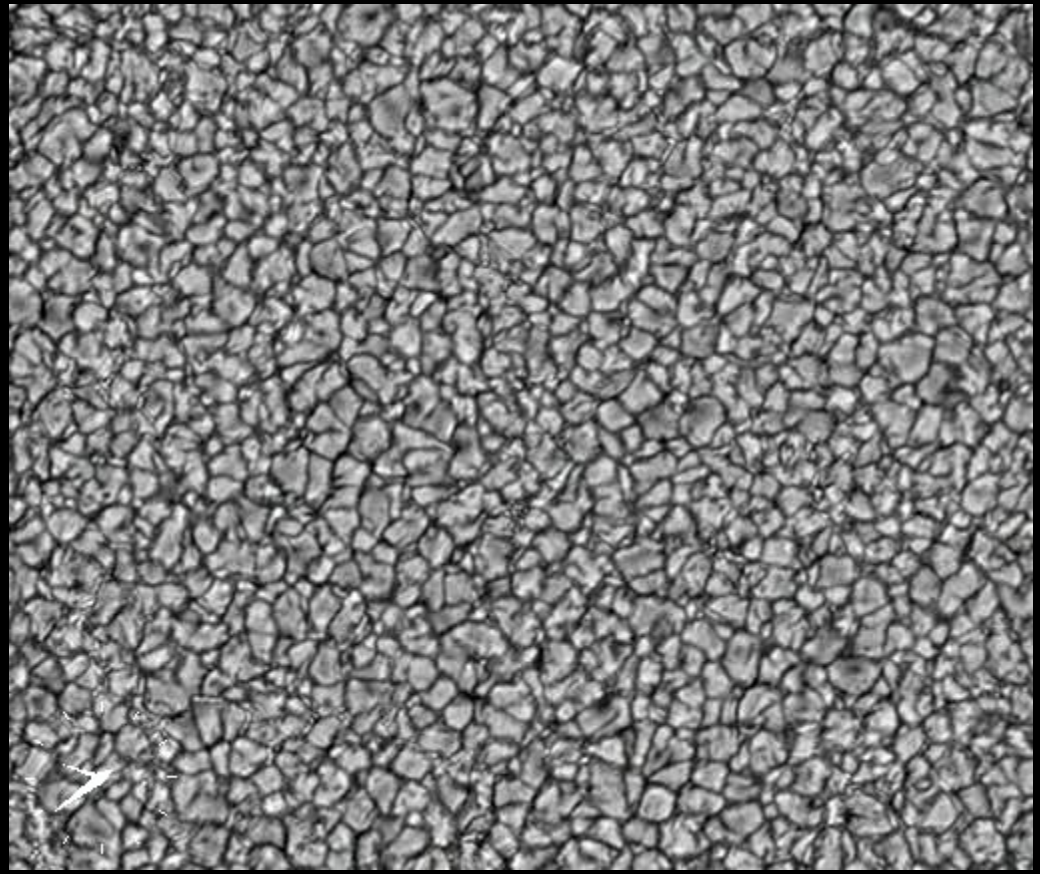

Ilya Prigogine
1917-2003

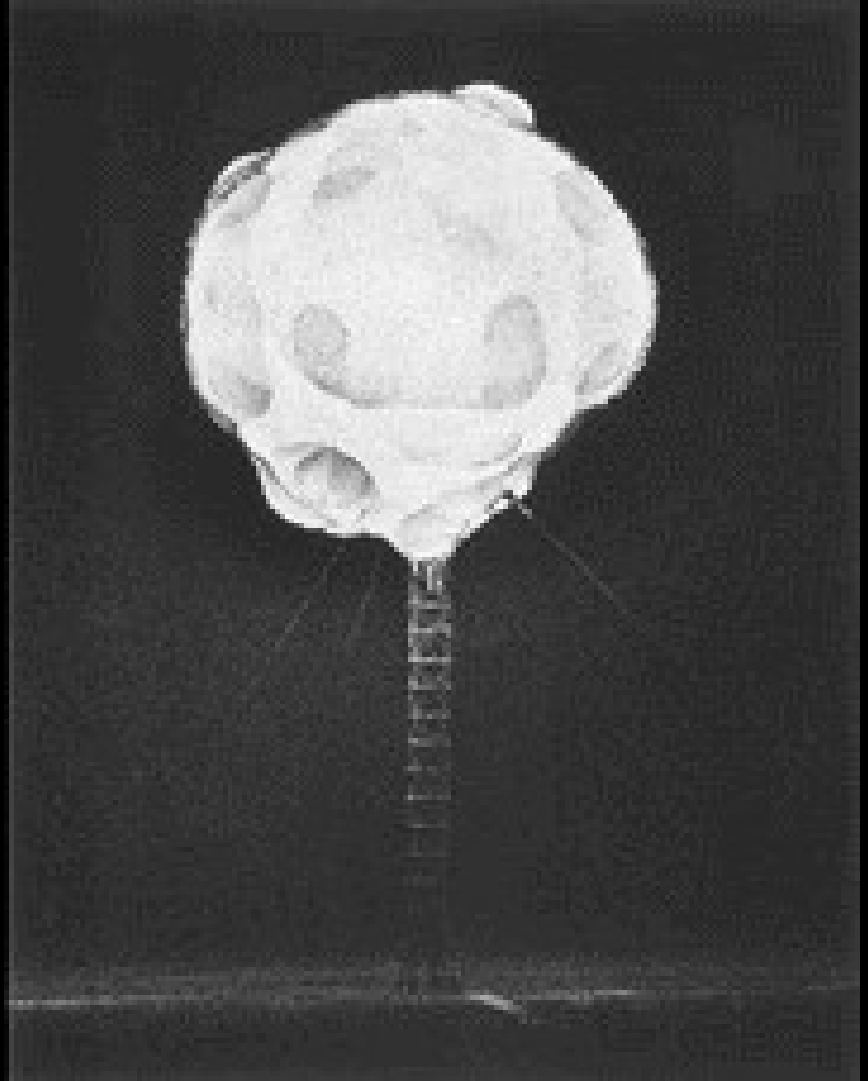


Ilya Prigogine
1917-2003

From a thermodynamic point of view…
living systems are an instance of a more general
phenomena of far from equilibrium dissipative systems:
hurricanes, whirlpools, fires, convection cells







Harold Edgerton

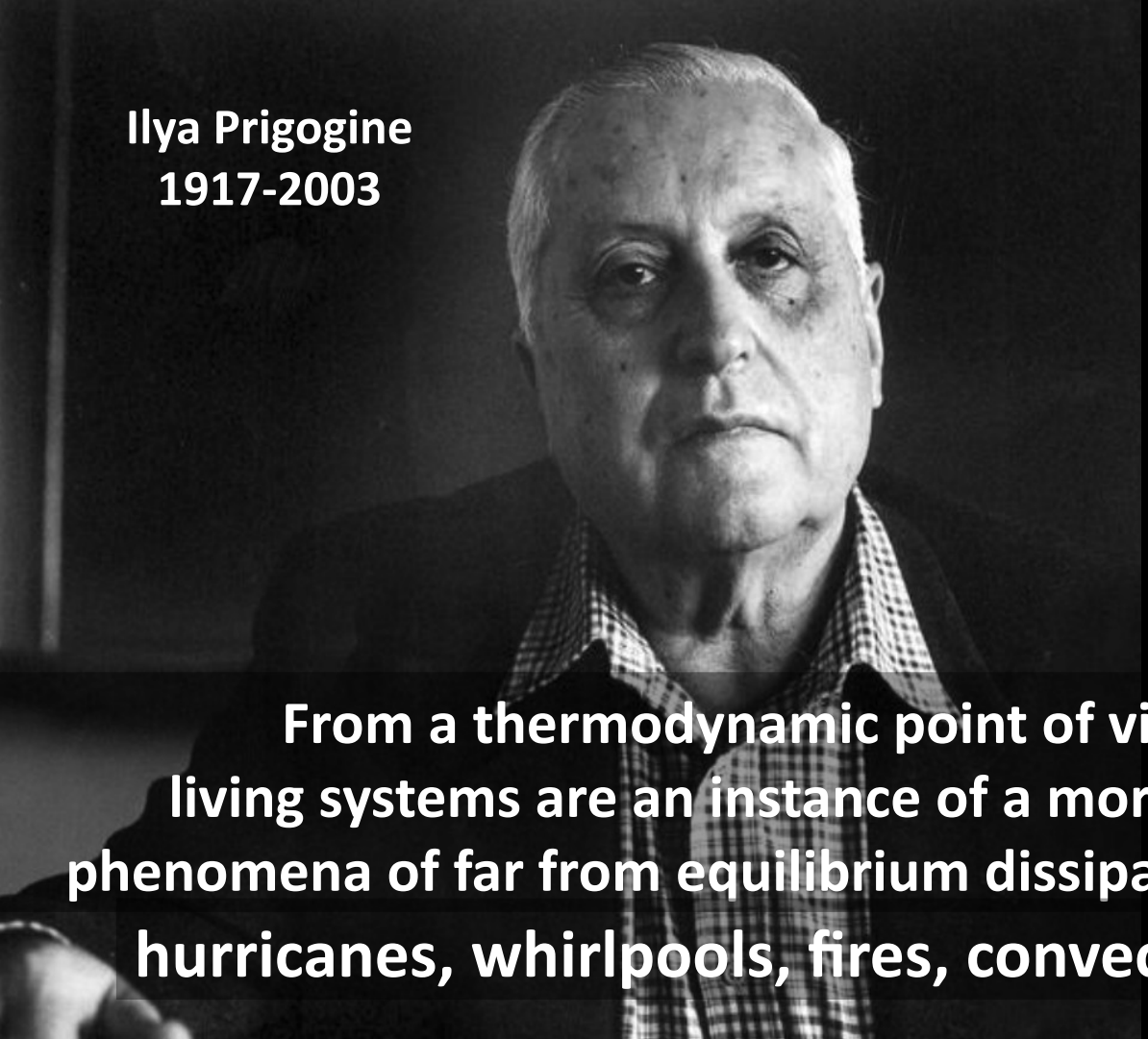

Rondeau

WHY ?

ENTROPY PRODUCTION

ENTROPY PRODUCTION

Far From Equilibrium Dissipative Systems exist in order to produce entropy



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Review

Life, gravity and the second law of thermodynamics

Charles H. Lineweaver [a,*], Chas A. Egan [a,b]

[a] *Planetary Science Institute, Research School of Astronomy and Astrophysics & Research School of Earth Sciences, Australian National University, Canberra, ACT Australia*

[b] *Department of Astrophysics, School of Physics, University of New South Wales, Sydney, NSW Australia*

Received 14 July 2008; received in revised form 7 August 2008; accepted 8 August 2008

Available online 22 August 2008

Communicated by J. Fontanari

Abstract

We review the cosmic evolution of entropy and the gravitational origin of the free energy required by life. All dissipative structures in the universe including all forms of life, owe their existence to the fact that the universe started in a low entropy state and has not yet reached equilibrium. The low initial entropy was due to the low gravitational entropy of the nearly homogeneously distributed matter and has, through gravitational collapse, evolved gradients in density, temperature, pressure and chemistry. These gradients, when steep enough, give rise to far from equilibrium dissipative structures (e.g., galaxies, stars, black holes, hurricanes and life) which emerge spontaneously to hasten the destruction of the gradients which spawned them. This represents a paradigm shift from "we eat food" to "food has produced us to eat it".

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Review

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arewealone.us
ARE WE ALONE?
...WELL...
HOW DID WE GET HERE?