Astrobiology
An Overview

Markus Kissler-Patig

IMPRS Graduate School 🙂

November 20-24, 2023

Daily: 10:00-12:00 & **12:45-13:30**

Astrobiology
An Overview

Day 5

🙂

Search for Extraterrestrial Intelligence; Alien Biochemistry

https://www.cosmos.esa.int/web/astrobio/imprs-2023

Monday November 20	Day 1: Definition of Life; Origin of Life; Evolution of Life; Limits of Life 10:00-12:00 & 13:00-14:00
Tuesday November 21	Day 2: Earth Climate History; Mars and Venus Climates 10:00-12:00 & 13:00-14:00 OLD SEMINAR ROOM
Wednesday November 22	Day 3: Habitable Places in the Solar System; Mars; Moons of Giant Planets 10:00-12:00 & 13:00-14:00
Thursday November 23	Day 4: Habitable Places beyond the Solar System; Exoplanets properties; Biosignatures 10:00-12:00 & 13:00-14:00
Friday November 24	Day 5: Search for Extraterrestrial Intelligence; Alien Biochemistry 10:00-12:00 & 12:45-13:30

Alien Biochemistries

Psychrolutes microporos AMS I.42771-001

What should we be looking for when we are looking for “Life” on exoplanets?

Let’s consider Life as:

Complex chemical reactions that allow

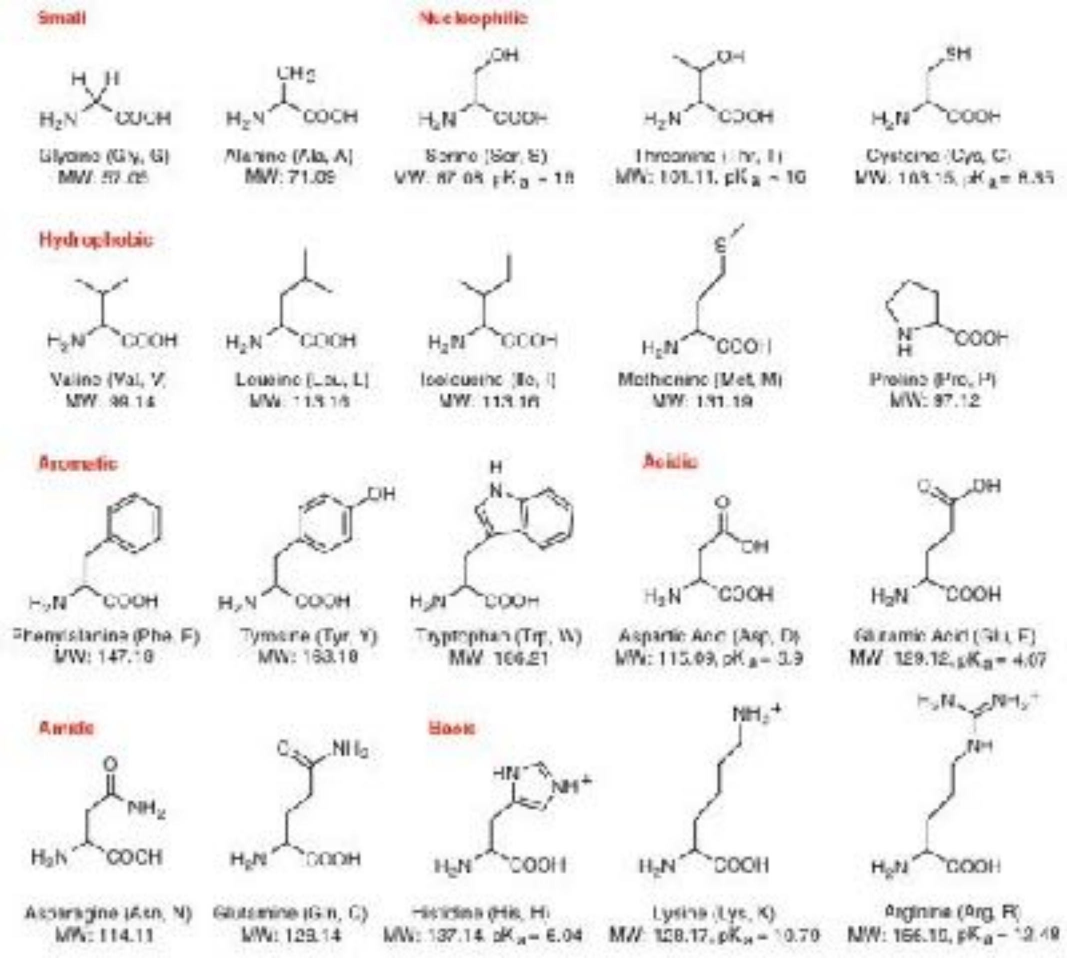
- Metabolism
- Reproduction
- Evolution

Different Biopolymers

Different Amino acids

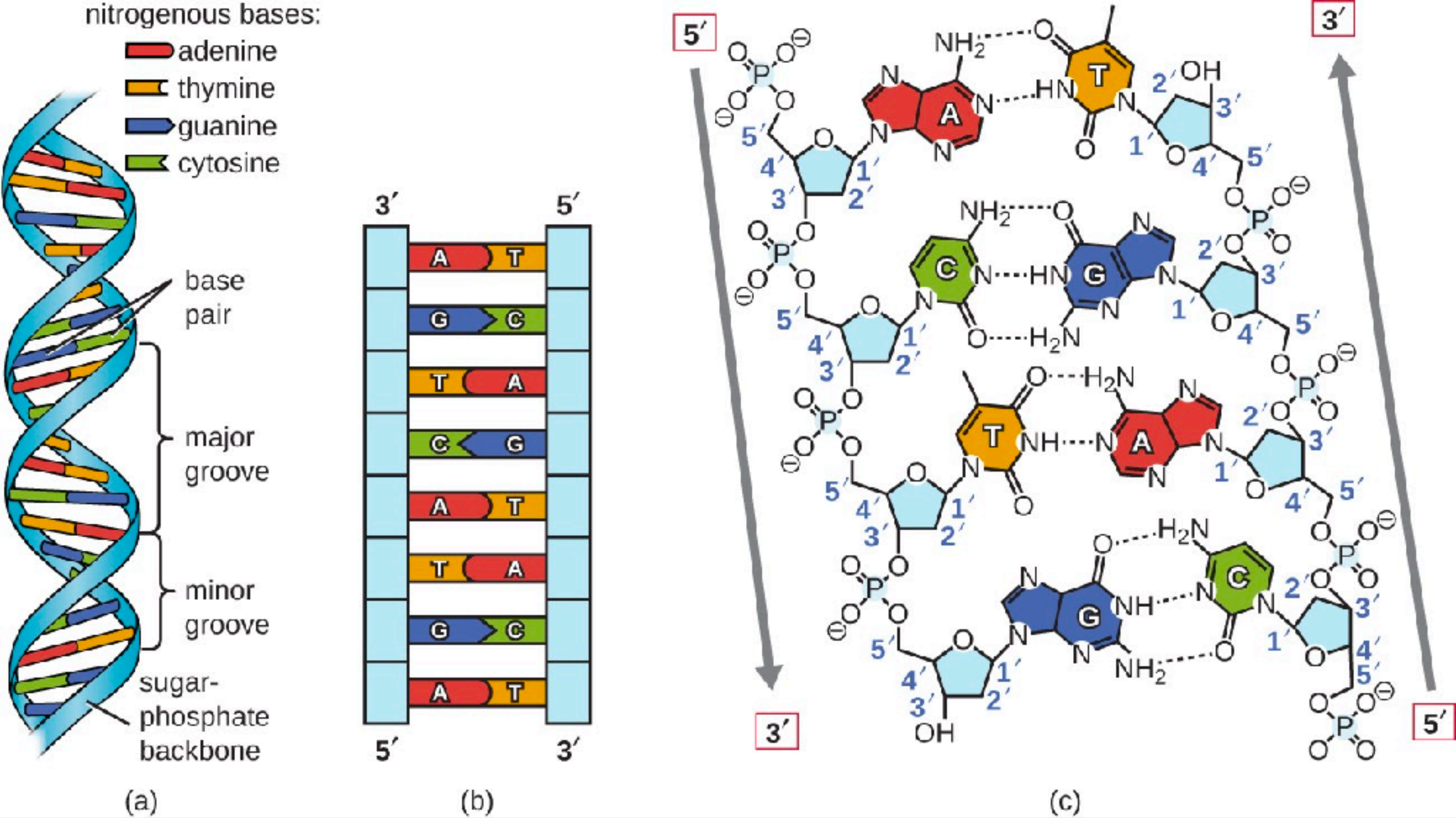
All life on Earth uses the standard 20 amino acids
(these are not the most abundant ones found in Meteorites)

Ribosomes are capable of using different amino acids to synthesise proteins



DNA-based life might exist, similar in all other respect to Earth life, but using different amino acids to synthesize proteins

Different "DNA"



Different "DNA"

Base-pairing is not unique!
Large purines (A,G) pair with small pyrimidine (C,T,U) - other combinations are possible...
(and have been synthesized in the lab)

The number of "letters" (3) to code an amino acid could be different (e.g $4^2=16$, $4^4=256$ AA be coded). Life could build on a different set of >20 'standard' amino acids

The Ribose backbone could be replaced (e.g. by glycerol). See the pre-RNA world research...

The Phosphor Group in the backbone could be modified. e.g. P replaced by Ar - claims for 'Arsenic life' were made (but refuted)

Periodic Table of the Elements

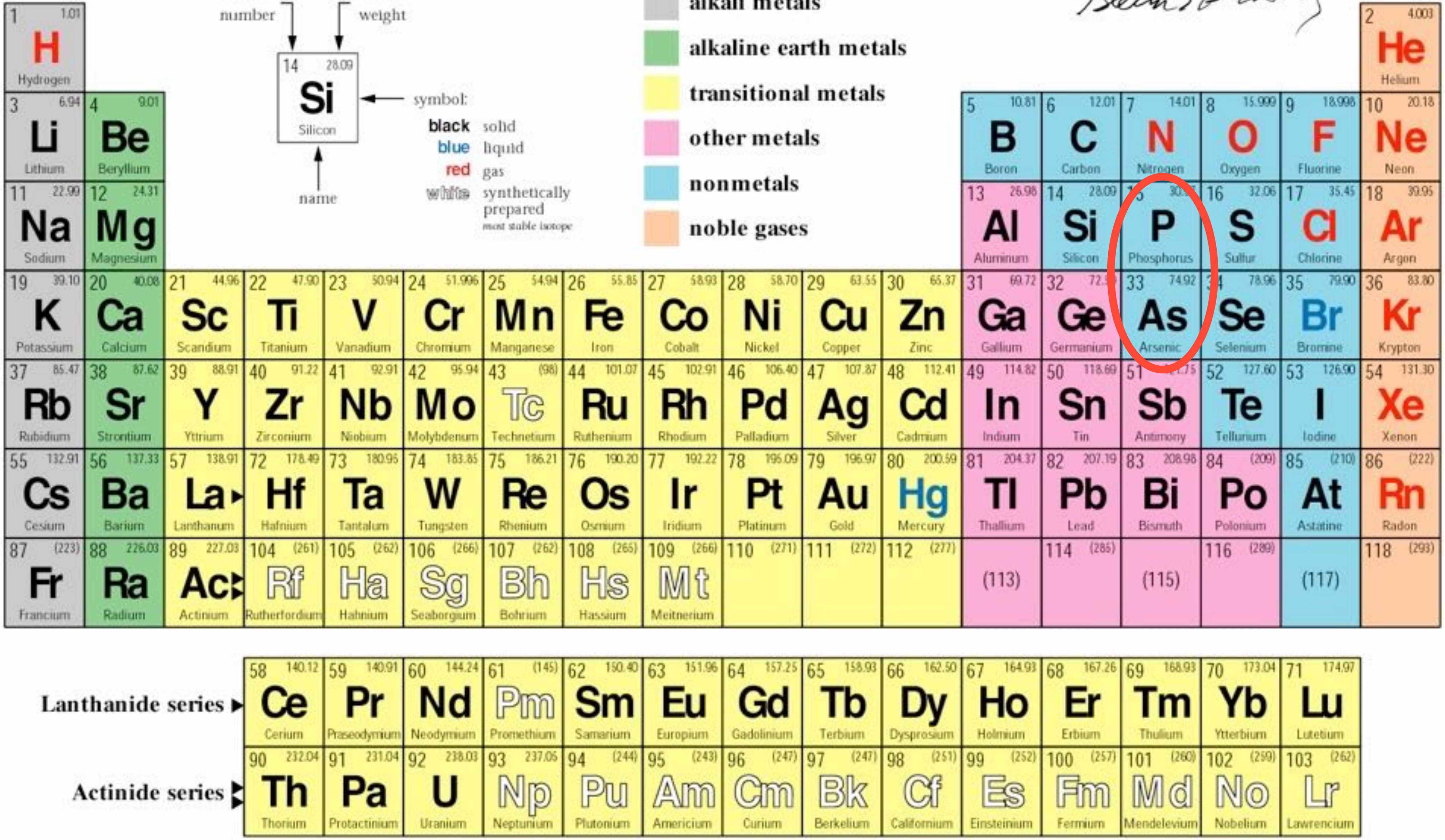
BERKELEY LAB
ERNEST ORLANDO LAWRENCE
BERKELEY NATIONAL LABORATORY

Glenn T Seaborg

atomic number → 14
atomic weight → 28.09
symbol: Si
name: Silicon

symbol:
black solid
blue liquid
red gas
white synthetically prepared
most stable isotope

⬜ alkali metals
🟩 alkaline earth metals
🟨 transitional metals
🟪 other metals
🟦 nonmetals
🟧 noble gases



1 1.01 H Hydrogen																	2 4.003 He Helium
3 6.94 Li Lithium	4 9.01 Be Beryllium											5 10.81 B Boron	6 12.01 C Carbon	7 14.01 N Nitrogen	8 15.999 O Oxygen	9 18.998 F Fluorine	10 20.18 Ne Neon
11 22.99 Na Sodium	12 24.31 Mg Magnesium											13 26.98 Al Aluminum	14 28.09 Si Silicon	15 30.97 P Phosphorus	16 32.06 S Sulfur	17 35.45 Cl Chlorine	18 39.95 Ar Argon
19 39.10 K Potassium	20 40.08 Ca Calcium	21 44.96 Sc Scandium	22 47.90 Ti Titanium	23 50.94 V Vanadium	24 51.996 Cr Chromium	25 54.94 Mn Manganese	26 55.85 Fe Iron	27 58.93 Co Cobalt	28 58.70 Ni Nickel	29 63.55 Cu Copper	30 65.37 Zn Zinc	31 69.72 Ga Gallium	32 72.59 Ge Germanium	33 74.92 As Arsenic	34 78.96 Se Selenium	35 79.90 Br Bromine	36 83.80 Kr Krypton
37 85.47 Rb Rubidium	38 87.62 Sr Strontium	39 88.91 Y Yttrium	40 91.22 Zr Zirconium	41 92.91 Nb Niobium	42 95.94 Mo Molybdenum	43 (98) Tc Technetium	44 101.07 Ru Ruthenium	45 102.91 Rh Rhodium	46 106.40 Pd Palladium	47 107.87 Ag Silver	48 112.41 Cd Cadmium	49 114.82 In Indium	50 118.69 Sn Tin	51 121.75 Sb Antimony	52 127.60 Te Tellurium	53 126.90 I Iodine	54 131.30 Xe Xenon
55 132.91 Cs Cesium	56 137.33 Ba Barium	57 138.91 La ▸ Lanthanum	72 178.49 Hf Hafnium	73 180.95 Ta Tantalum	74 183.85 W Tungsten	75 186.21 Re Rhenium	76 190.20 Os Osmium	77 192.22 Ir Iridium	78 195.09 Pt Platinum	79 196.97 Au Gold	80 200.59 Hg Mercury	81 204.37 Tl Thallium	82 207.19 Pb Lead	83 208.98 Bi Bismuth	84 (209) Po Polonium	85 (210) At Astatine	86 (222) Rn Radon
87 (223) Fr Francium	88 226.03 Ra Radium	89 227.03 Ac ▸ Actinium	104 (261) Rf Rutherfordium	105 (262) Ha Hahnium	106 (266) Sg Seaborgium	107 (262) Bh Bohrium	108 (265) Hs Hassium	109 (266) Mt Meitnerium	110 (271)	111 (272)	112 (277)	(113)	114 (285)	(115)	116 (289)	(117)	118 (293)

Lanthanide series ▸	58 140.12 Ce Cerium	59 140.91 Pr Praseodymium	60 144.24 Nd Neodymium	61 (145) Pm Promethium	62 150.40 Sm Samarium	63 151.96 Eu Europium	64 157.25 Gd Gadolinium	65 158.93 Tb Terbium	66 162.50 Dy Dysprosium	67 164.93 Ho Holmium	68 167.26 Er Erbium	69 168.93 Tm Thulium	70 173.04 Yb Ytterbium	71 174.97 Lu Lutetium
Actinide series ▸	90 232.04 Th Thorium	91 231.04 Pa Protactinium	92 238.03 U Uranium	93 237.05 Np Neptunium	94 (244) Pu Plutonium	95 (243) Am Americium	96 (247) Cm Curium	97 (247) Bk Berkelium	98 (251) Cf Californium	99 (252) Es Einsteinium	100 (257) Fm Fermium	101 (260) Md Mendelevium	102 (259) No Nobelium	103 (262) Lr Lawrencium

Different "DNA"

Arsenic Life: Wolfe-Simon et al. 2010

Really cool - but unfortunately **wrong**

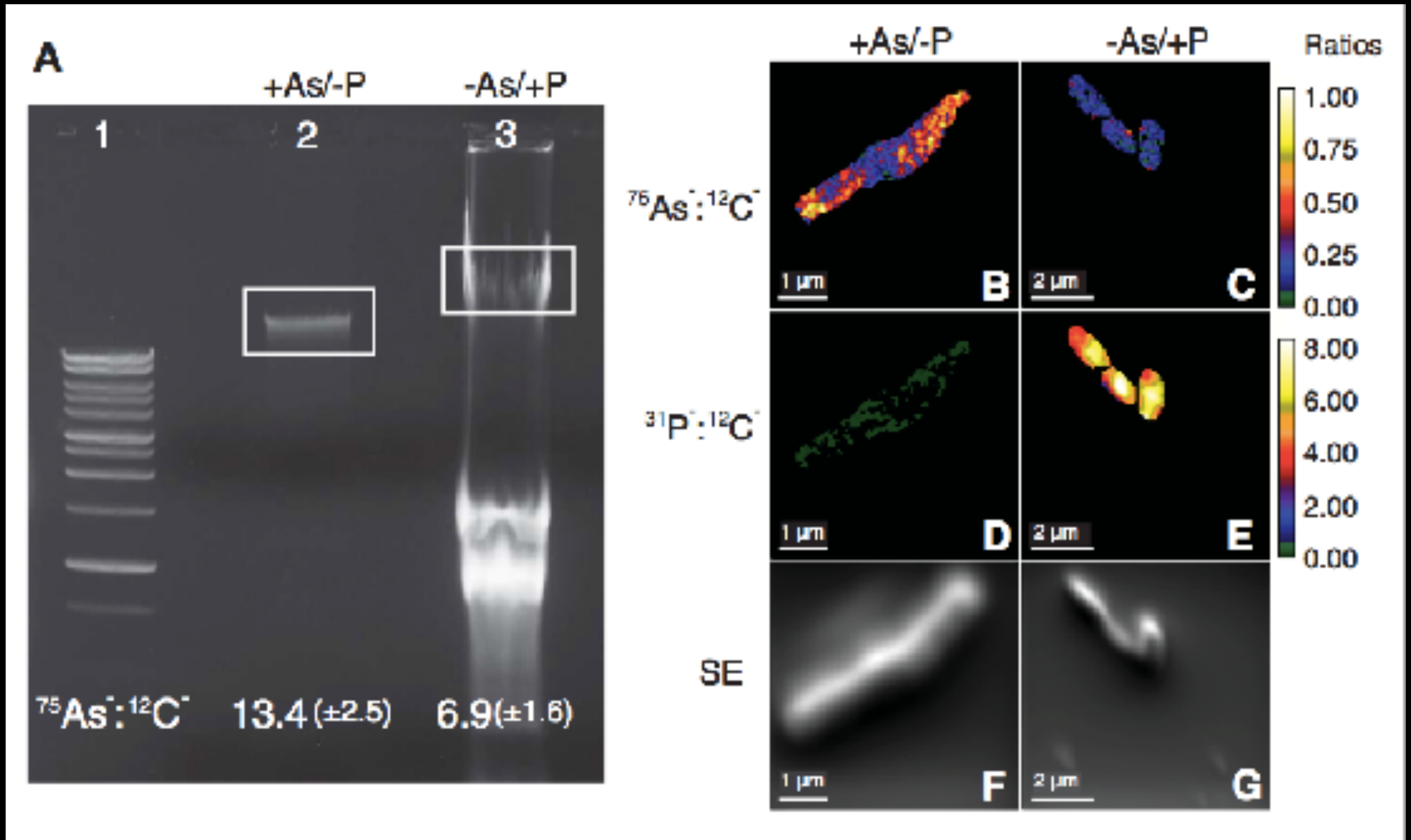
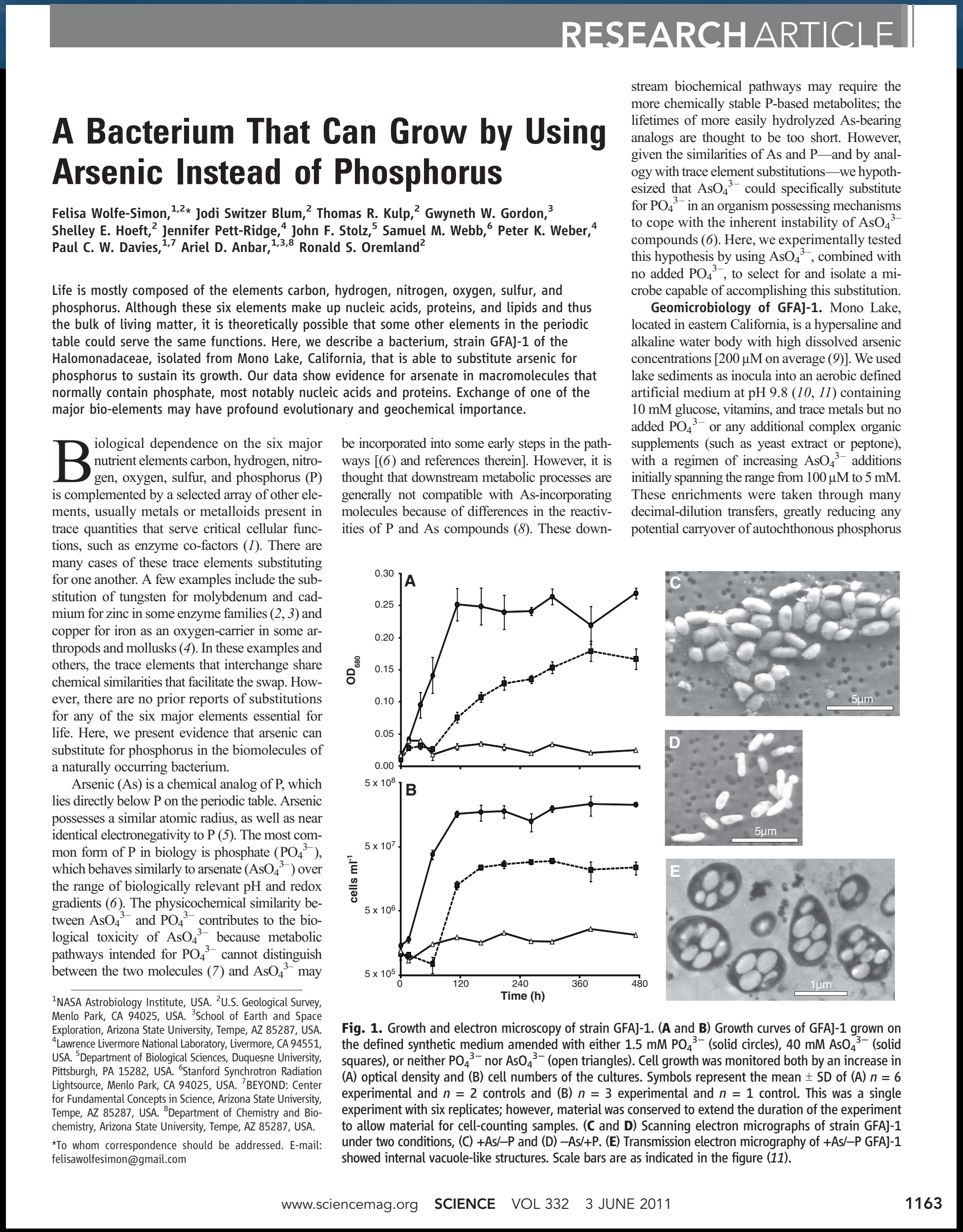


Fig. 2. NanoSIMS analyses of GFAJ-1: extracted DNA and whole-cells elemental ratio maps. (**A**) Agarose gel loaded with DNA/RNA extracted from GFAJ-1 grown (lane 2) +As/–P and (lane 3) –As/+P as compared with (lane 1) a DNA standard. Genomic bands were excised as indicated and analyzed with NanoSIMS. Ion ratios of $^{75}As^-:^{12}C^-$ of excised gel bands are indicated below with 2σ error shown (all values multiplied by 10^{-6}). (**B** to **G**) NanoSIMS images of whole GFAJ-1 cells grown either [(B), (D), and (F)] +As/–P or [(C), (E), and (G)] –As/+P. Shown are the ion ratios of [(B) and (C)] $^{75}As^-:^{12}C^-$, [(D) and (E)] $^{31}P^-:^{12}C^-$, and [(F) and (G)] secondary electron (SE). Ratios in (B) and (C) are multiplied by 10^{-4} and in (D) and (E) are multiplied by 10^{-3}. The color bars indicate measured elemental ratios on a log scale as indicated. Length scale is as indicated on images; images contain equivalent pixel density (*11*).



RESEARCH ARTICLE

A Bacterium That Can Grow by Using Arsenic Instead of Phosphorus

Felisa Wolfe-Simon,[1,2]* Jodi Switzer Blum,[2] Thomas R. Kulp,[2] Gwyneth W. Gordon,[3] Shelley E. Hoeft,[2] Jennifer Pett-Ridge,[4] John F. Stolz,[5] Samuel M. Webb,[6] Peter K. Weber,[4] Paul C. W. Davies,[1,7] Ariel D. Anbar,[1,3,8] Ronald S. Oremland[2]

Life is mostly composed of the elements carbon, hydrogen, nitrogen, oxygen, sulfur, and phosphorus. Although these six elements make up nucleic acids, proteins, and lipids and thus the bulk of living matter, it is theoretically possible that some other elements in the periodic table could serve the same functions. Here, we describe a bacterium, strain GFAJ-1 of the Halomonadaceae, isolated from Mono Lake, California, that is able to substitute arsenic for phosphorus to sustain its growth. Our data show evidence for arsenate in macromolecules that normally contain phosphate, most notably nucleic acids and proteins. Exchange of one of the major bio-elements may have profound evolutionary and geochemical importance.

Biological dependence on the six major nutrient elements carbon, hydrogen, nitrogen, oxygen, sulfur, and phosphorus (P) is complemented by a selected array of other elements, usually metals or metalloids present in trace quantities that serve critical cellular functions, such as enzyme co-factors (*1*). There are many cases of these trace elements substituting for one another. A few examples include the substitution of tungsten for molybdenum and cadmium for zinc in some enzyme families (*2*, *3*) and copper for iron as an oxygen-carrier in some arthropods and mollusks (*4*). In these examples and others, the trace elements that interchange share chemical similarities that facilitate the swap. However, there are no prior reports of substitutions for any of the six major elements essential for life. Here, we present evidence that arsenic can substitute for phosphorus in the biomolecules of a naturally occurring bacterium.

Arsenic (As) is a chemical analog of P, which lies directly below P on the periodic table. Arsenic possesses a similar atomic radius, as well as near identical electronegativity to P (*5*). The most common form of P in biology is phosphate (PO_4^{3-}), which behaves similarly to arsenate (AsO_4^{3-}) over the range of biologically relevant pH and redox gradients (*6*). The physicochemical similarity between AsO_4^{3-} and PO_4^{3-} contributes to the biological toxicity of AsO_4^{3-} because metabolic pathways intended for PO_4^{3-} cannot distinguish between the two molecules (*7*) and AsO_4^{3-} may be incorporated into some early steps in the pathways [(*6*) and references therein]. However, it is thought that downstream metabolic processes are generally not compatible with As-incorporating molecules because of differences in the reactivities of P and As compounds (*8*). These downstream biochemical pathways may require the more chemically stable P-based metabolites; the lifetimes of more easily hydrolyzed As-bearing analogs are thought to be too short. However, given the similarities of As and P—and by analogy with trace element substitutions—we hypothesized that AsO_4^{3-} could specifically substitute for PO_4^{3-} in an organism possessing mechanisms to cope with the inherent instability of AsO_4^{3-} compounds (*6*). Here, we experimentally tested this hypothesis by using AsO_4^{3-}, combined with no added PO_4^{3-}, to select for and isolate a microbe capable of accomplishing this substitution.

Geomicrobiology of GFAJ-1. Mono Lake, located in eastern California, is a hypersaline and alkaline water body with high dissolved arsenic concentrations [200 µM on average (*9*)]. We used lake sediments as inocula into an aerobic defined artificial medium at pH 9.8 (*10*, *11*) containing 10 mM glucose, vitamins, and trace metals but no added PO_4^{3-} or any additional complex organic supplements (such as yeast extract or peptone), with a regimen of increasing AsO_4^{3-} additions initially spanning the range from 100 µM to 5 mM. These enrichments were taken through many decimal-dilution transfers, greatly reducing any potential carryover of autochthonous phosphorus

Fig. 1. Growth and electron microscopy of strain GFAJ-1. (**A** and **B**) Growth curves of GFAJ-1 grown on the defined synthetic medium amended with either 1.5 mM PO_4^{3-} (solid circles), 40 mM AsO_4^{3-} (solid squares), or neither PO_4^{3-} nor AsO_4^{3-} (open triangles). Cell growth was monitored both by an increase in (A) optical density and (B) cell numbers of the cultures. Symbols represent the mean ± SD of (A) $n = 6$ experimental and $n = 2$ controls and (B) $n = 3$ experimental and $n = 1$ control. This was a single experiment with six replicates; however, material was conserved to extend the duration of the experiment to allow material for cell-counting samples. (**C** and **D**) Scanning electron micrographs of strain GFAJ-1 under two conditions, (C) +As/–P and (D) –As/+P. (**E**) Transmission electron micrography of +As/–P GFAJ-1 showed internal vacuole-like structures. Scale bars are as indicated in the figure (*11*).

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[1]NASA Astrobiology Institute, USA. [2]U.S. Geological Survey, Menlo Park, CA 94025, USA. [3]School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85287, USA. [4]Lawrence Livermore National Laboratory, Livermore, CA 94551, USA. [5]Department of Biological Sciences, Duquesne University, Pittsburgh, PA 15282, USA. [6]Stanford Synchrotron Radiation Lightsource, Menlo Park, CA 94025, USA. [7]BEYOND: Center for Fundamental Concepts in Science, Arizona State University, Tempe, AZ 85287, USA. [8]Department of Chemistry and Biochemistry, Arizona State University, Tempe, AZ 85287, USA.

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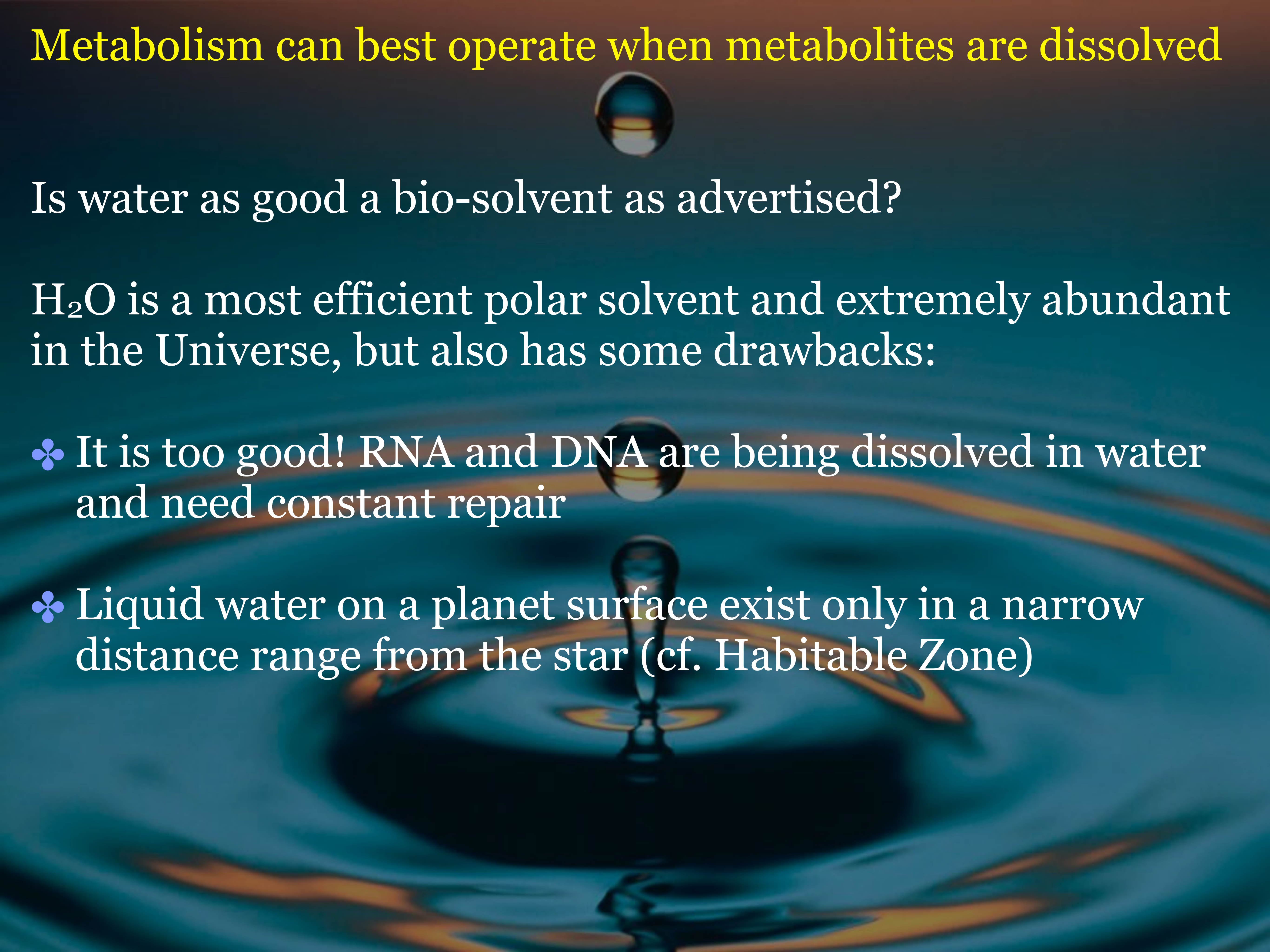
Different Solvent

Metabolism can best operate when metabolites are dissolved



Is water as good a bio-solvent as advertised?

H_2O is a most efficient polar solvent and extremely abundant in the Universe, but also has some drawbacks:

- It is too good! RNA and DNA are being dissolved in water and need constant repair
- Liquid water on a planet surface exist only in a narrow distance range from the star (cf. Habitable Zone)

Metabolism can best operate when metabolites are dissolved

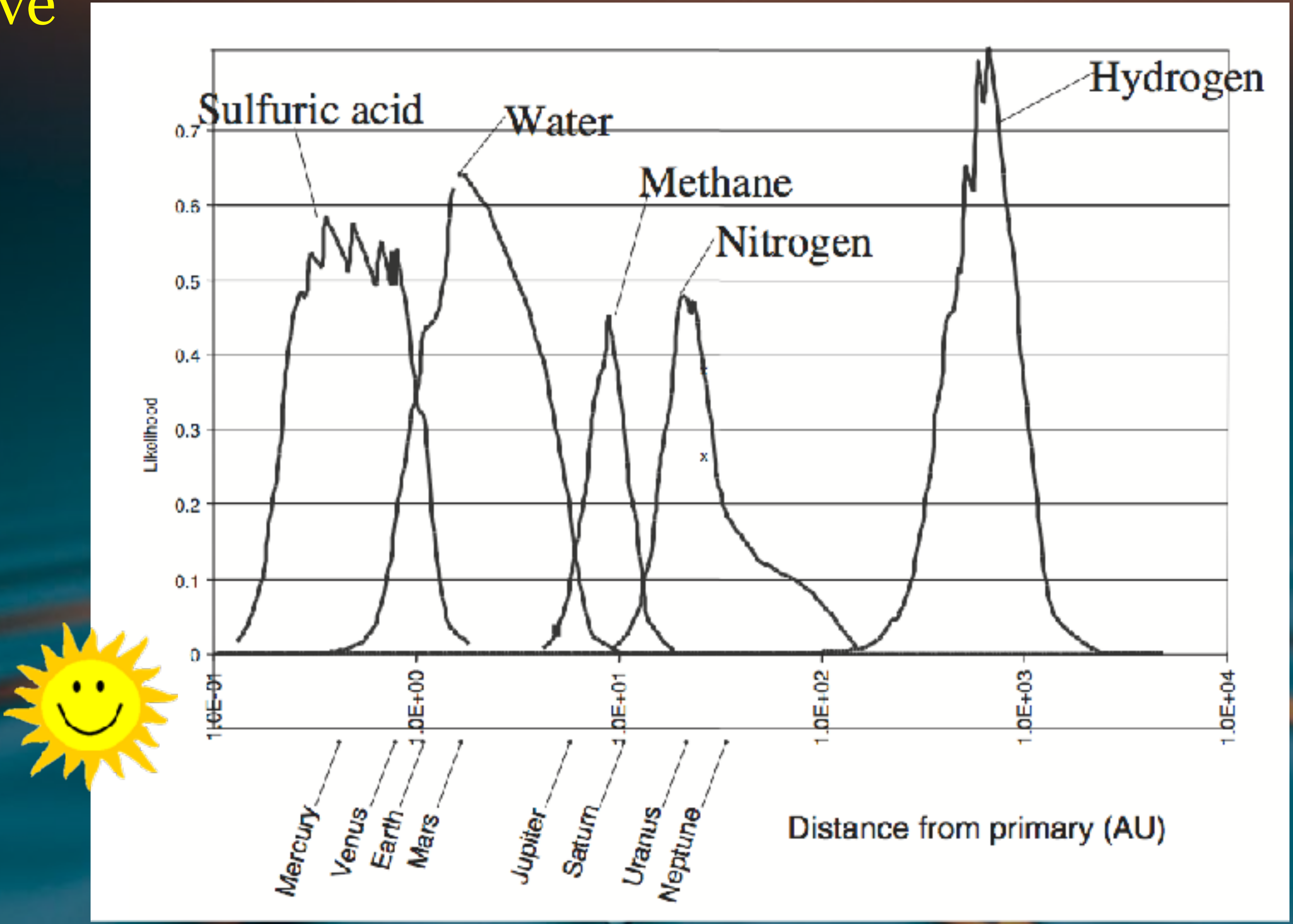
The solvent properties (solubility) are used for three tasks beyond dissolving metabolites:

1) for compartmentalization (insoluble membrane)

2) to build macroscopic structures (e.g. insoluble cellulose)

3) to achieve genetic regulation (e.g. selected solubility of steroids)

Alternative solvents



At high temperature, sulfuric acid might work
At low temperature, ammonia (NH_3), nitrogen might work

The alternatives have not extensively been studied in labs yet

Different Elements

Periodic Table of the Elements

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Ernest Orlando Lawrence
Berkeley National Laboratory

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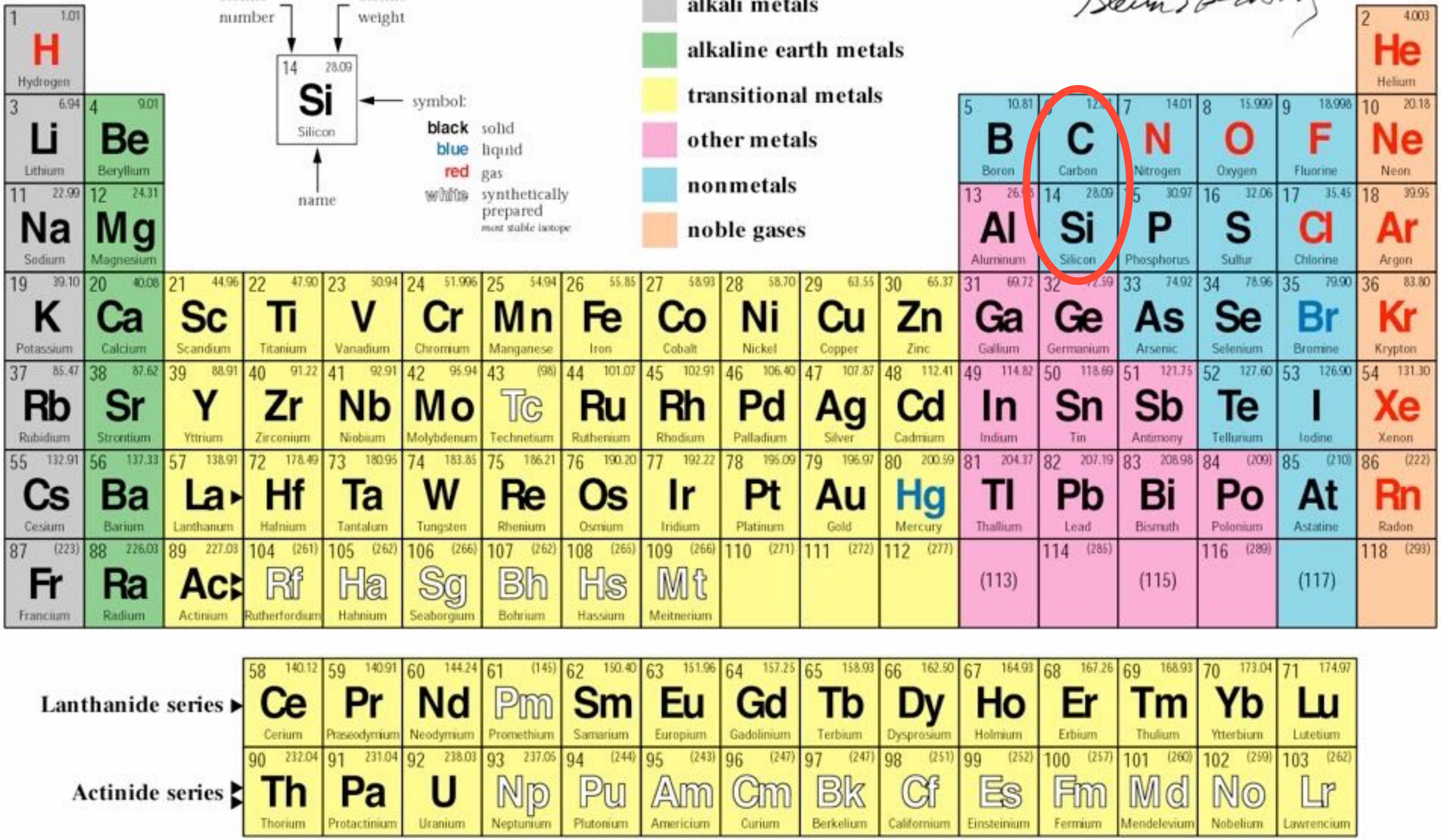

atomic number → 14 · atomic weight → 28.09
symbol: Si
name: Silicon

black solid
blue liquid
red gas
white synthetically prepared
most stable isotope

▨	**alkali metals**
🟩	**alkaline earth metals**
🟨	**transitional metals**
🟪	**other metals**
🟦	**nonmetals**
🟧	**noble gases**

1 1.01 H Hydrogen																	2 4.003 He Helium
3 6.94 Li Lithium	4 9.01 Be Beryllium											5 10.81 B Boron	6 12.01 C Carbon	7 14.01 N Nitrogen	8 15.999 O Oxygen	9 18.998 F Fluorine	10 20.18 Ne Neon
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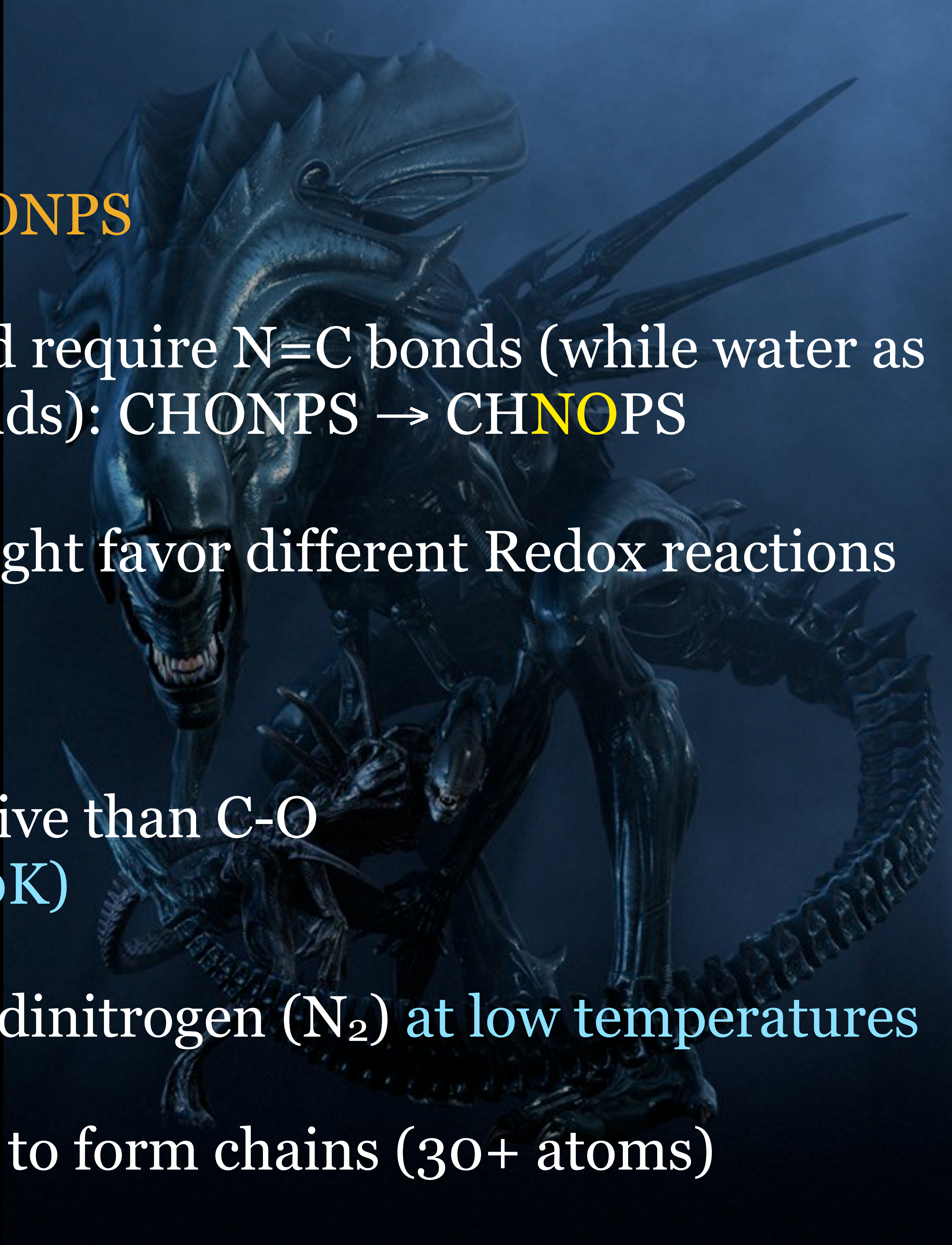
This is getting weird…



Terran life is build on CHONPS

Ammonia as solvent would require N=C bonds (while water as solvent builds on O=C bonds): CHONPS → CHNOPS

A different atmosphere might favor different Redox reactions

Silicon life:

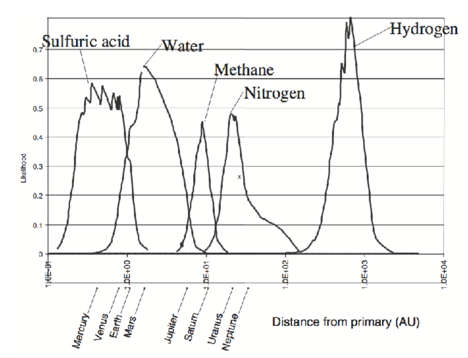
Si-O bonds are more reactive than C-O at low temperatures (<270K)

Si-O bonds are soluble in dinitrogen (N_2) at low temperatures

Si-Si double bonds known to form chains (30+ atoms)

M Dwarfs are the most common stars in the Milky Way

How far does their “N_2 Habitable Zone” extend?



Different Architecture

Life “Classic”
Life “RNA World”
Life “Weird”

Life “Classic”

Multiple biopolymers:

- DNA used for genetics
- Proteins used to solve structural and catalytic problems
- RNA is encoded to act as intermediate between the two

Life “RNA World”

Single biopolymer:

- Ribozymes does it all

A single biopolymer is a lot simpler - this type of life might be a lot more abundant in the Universe...

Life “Classic”
Life “RNA World”
Life “Weird”

Life “Weird”

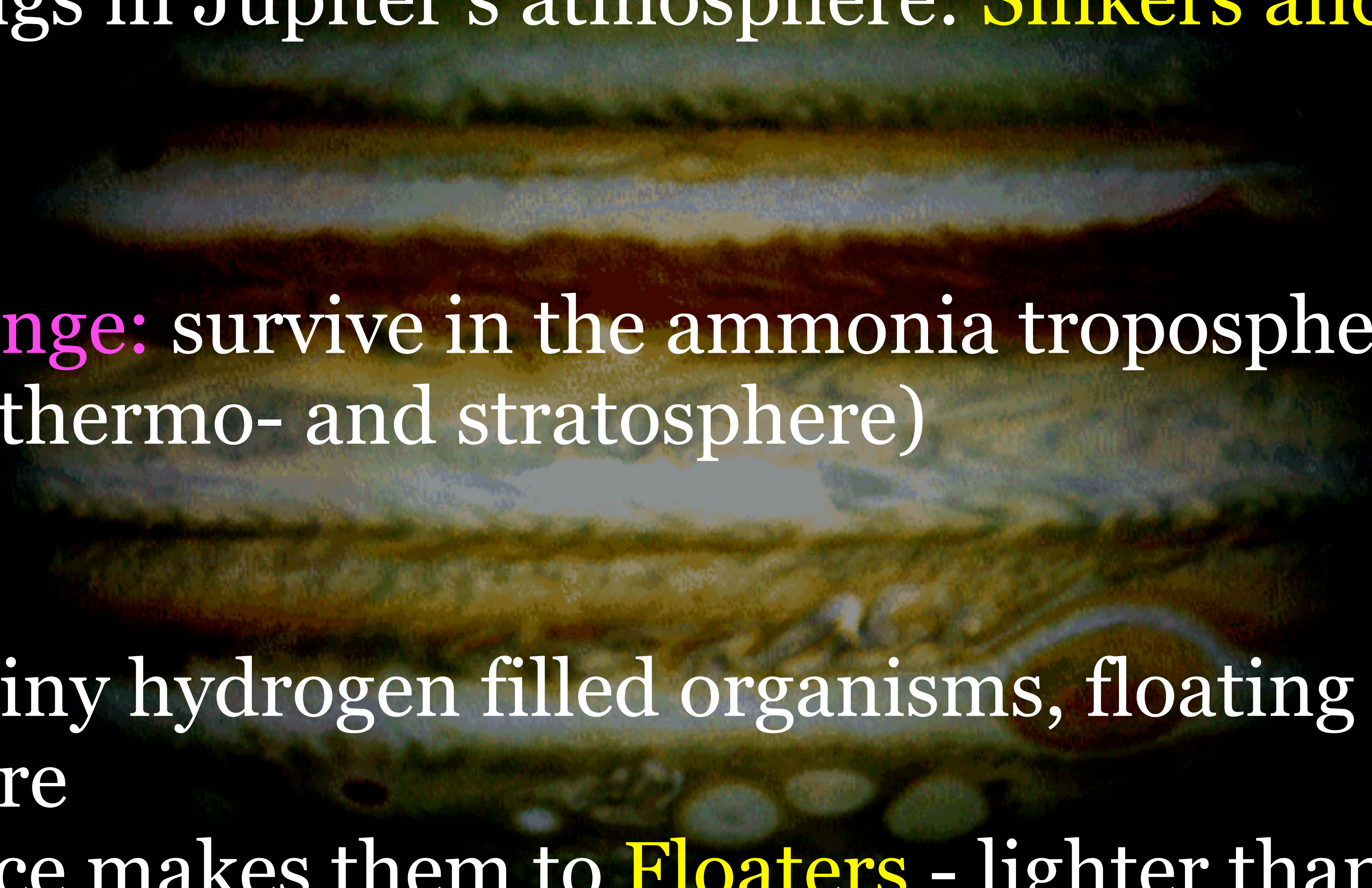
- Different single biopolymer
  perhaps driven by lack of space or scarce resources…

Arguments for at least two biopolymers would be:

- The catalyst should be optimized for many chemical reactions, i.e. easily change its physical properties
- The genetic molecule should be as simple as possible to allow accurate replication. It should be stable to allow Darwinian evolution

Very different Life

What would life look like on Jupiter?



Sagan & Salpeter 1976 imagined what it would take to have living beings in Jupiter’s atmosphere: Sinkers and Floaters

The challenge: survive in the ammonia troposphere (below the H/He thermo- and stratosphere)

The idea:
Sinkers - tiny hydrogen filled organisms, floating in the upper troposphere
Coalescence makes them to Floaters - lighter than environment, while evolution would add sense organs and directional flight, eventually making them hunters

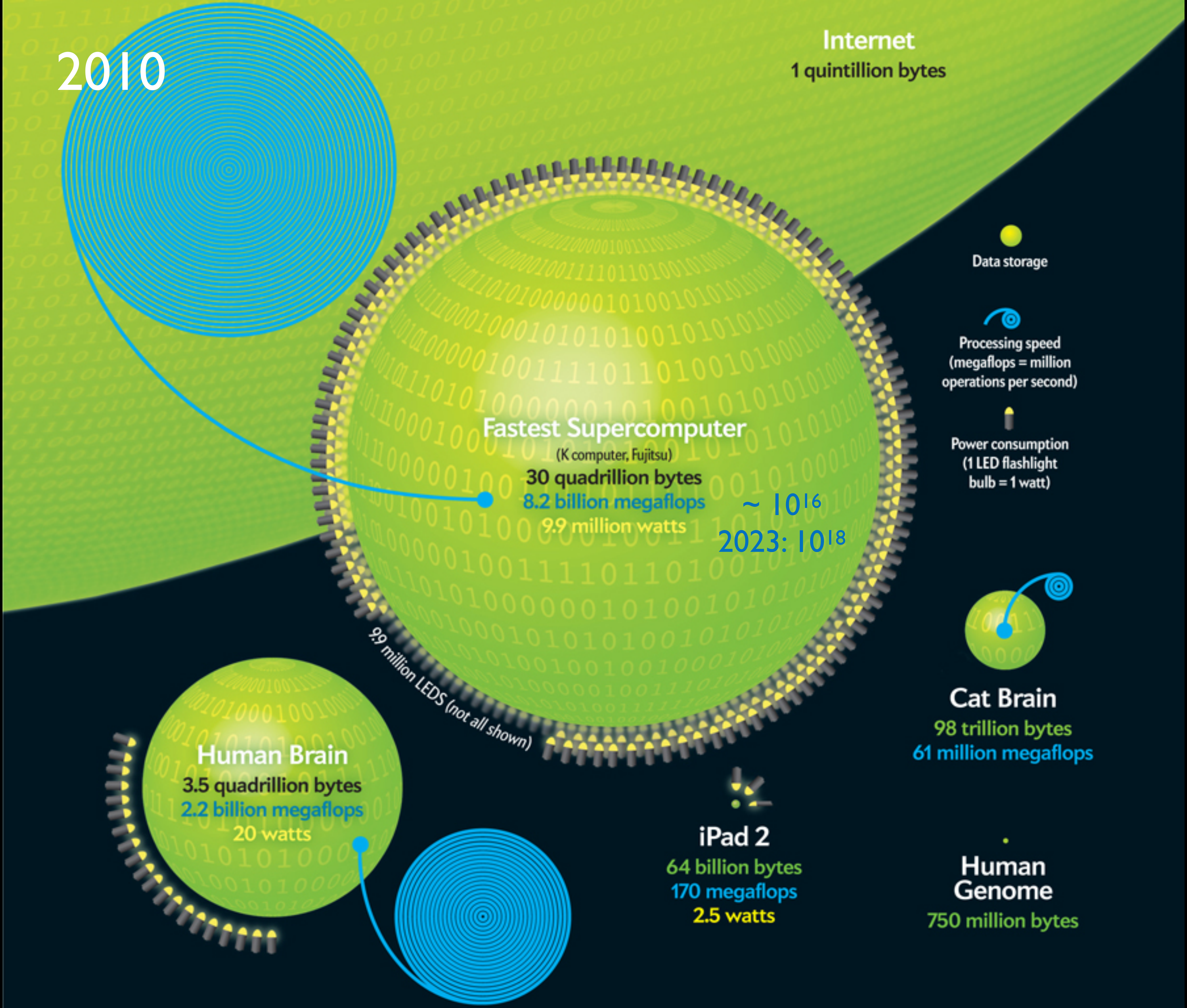
Could machines take over life?

Computers take over more and more tasks in our lives..

When will computer be so fast and complex, that we cannot differentiate them from being conscious?

Will computers program themselves to specialize, collect resources and build new, more complex generations?

What is the current “speed” of the brain compared to computers?



2010

~ 10^{16}

2023: 10^{18}

Life beyond our Universe

Multiverses are a possibility

Life would develop under different laws of physics

Deviations from the standard model of particles physics

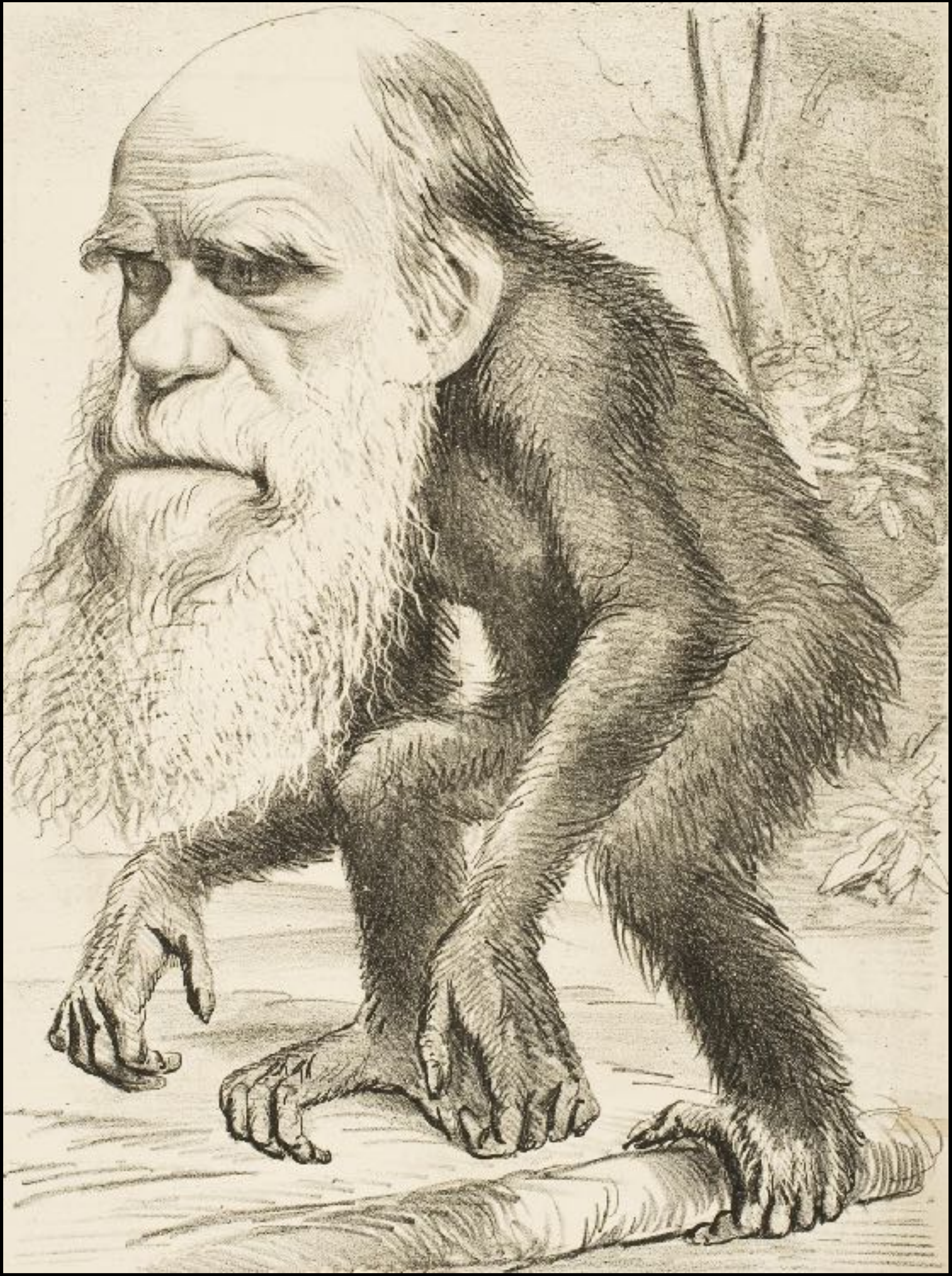
Changing Gravity: changes cosmology, structure formation, evolution of the Universe as a whole...

Changing the masses of Quarks: changes atomic physics and chemistry, star formation... does not exclude "life"

Removing the Weak Force: Big Bang nucleosynthesis would be overabundant in H and He - only massive, short lived stars... does not exclude "life"

More/less dimensions: e.g. *Flatland* by E.Abbott (1884)

The Evolution of Intelligence



It took us a while to get there…

Domain: Eukarya (nucleated cells, aerobic metabolism) [~2 Ga ago]

Kingdom: Animalia (locomotion, oxygen respiration, sexual reproduction, large number of different cells)

Phylum: Chordata (body plan, centralized nervous system)

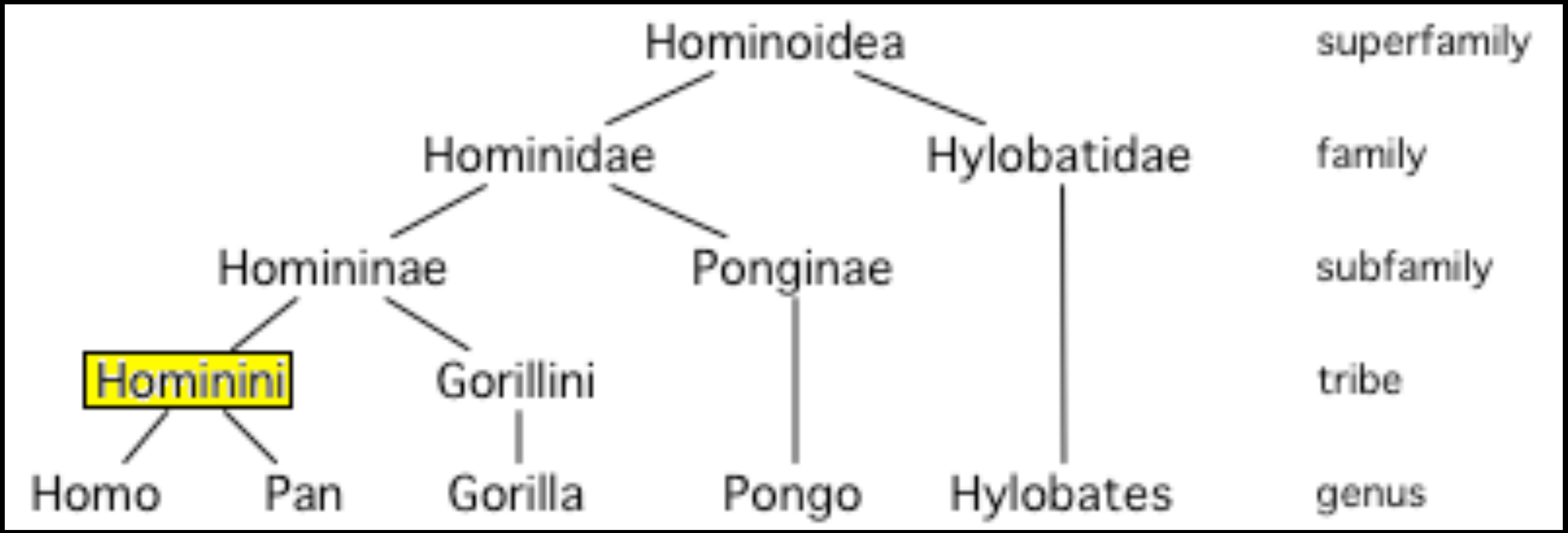
Class: Mammalia (hair, breast feeding) [~65 Ma ago]

Order: Primates (dexterity, acute vision, large brains)

Family: Hominidae (complex behaviour, large body size)

Genus: Homo [~2.5 Ma ago]

Species: Sapiens [~300.000 a ago]



Hominoidea superfamily

Hominidae Hylobatidae family

~14 Ma ago

Homininae Ponginae subfamily

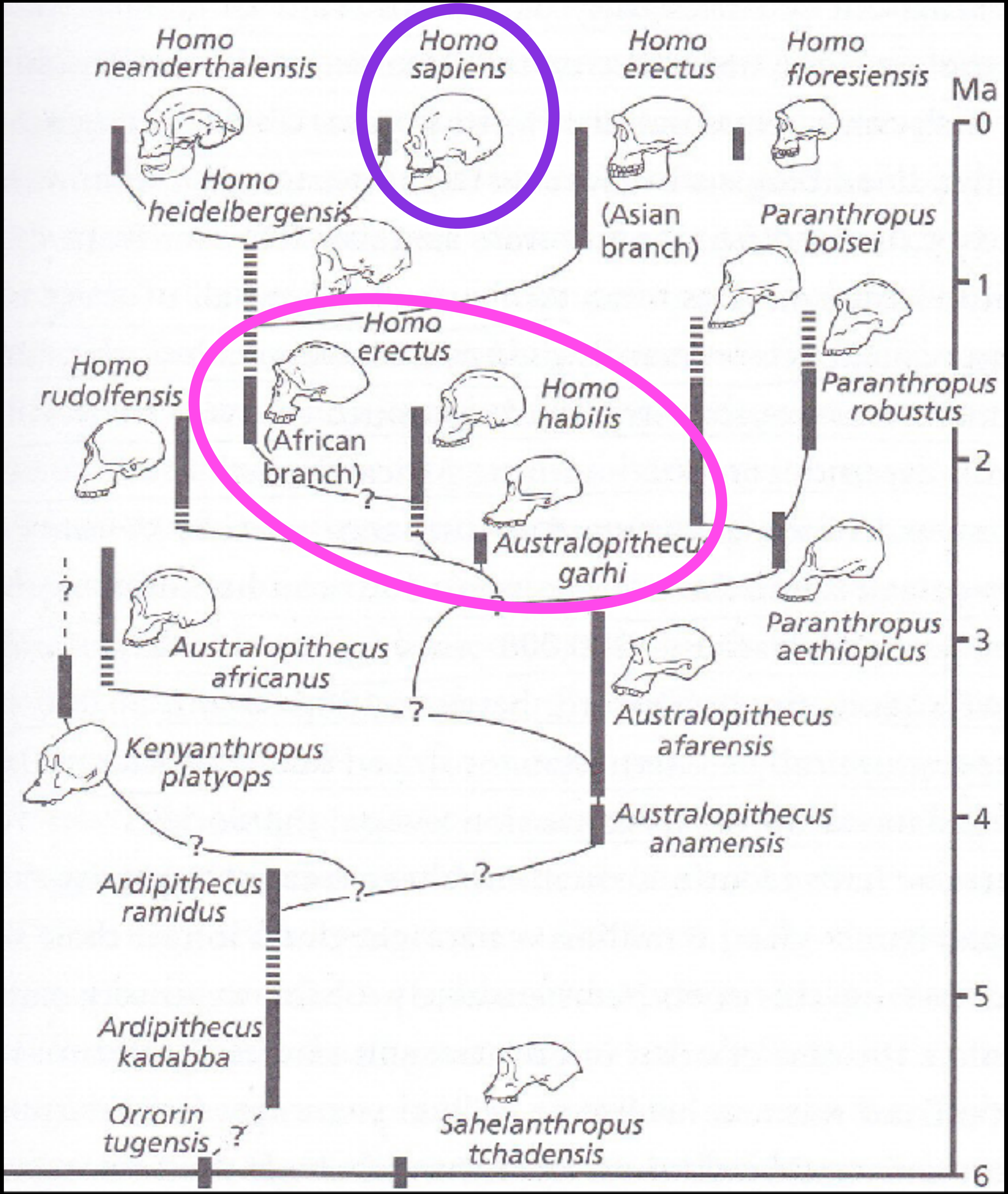
Hominini Gorillini tribe

~6 Ma ago

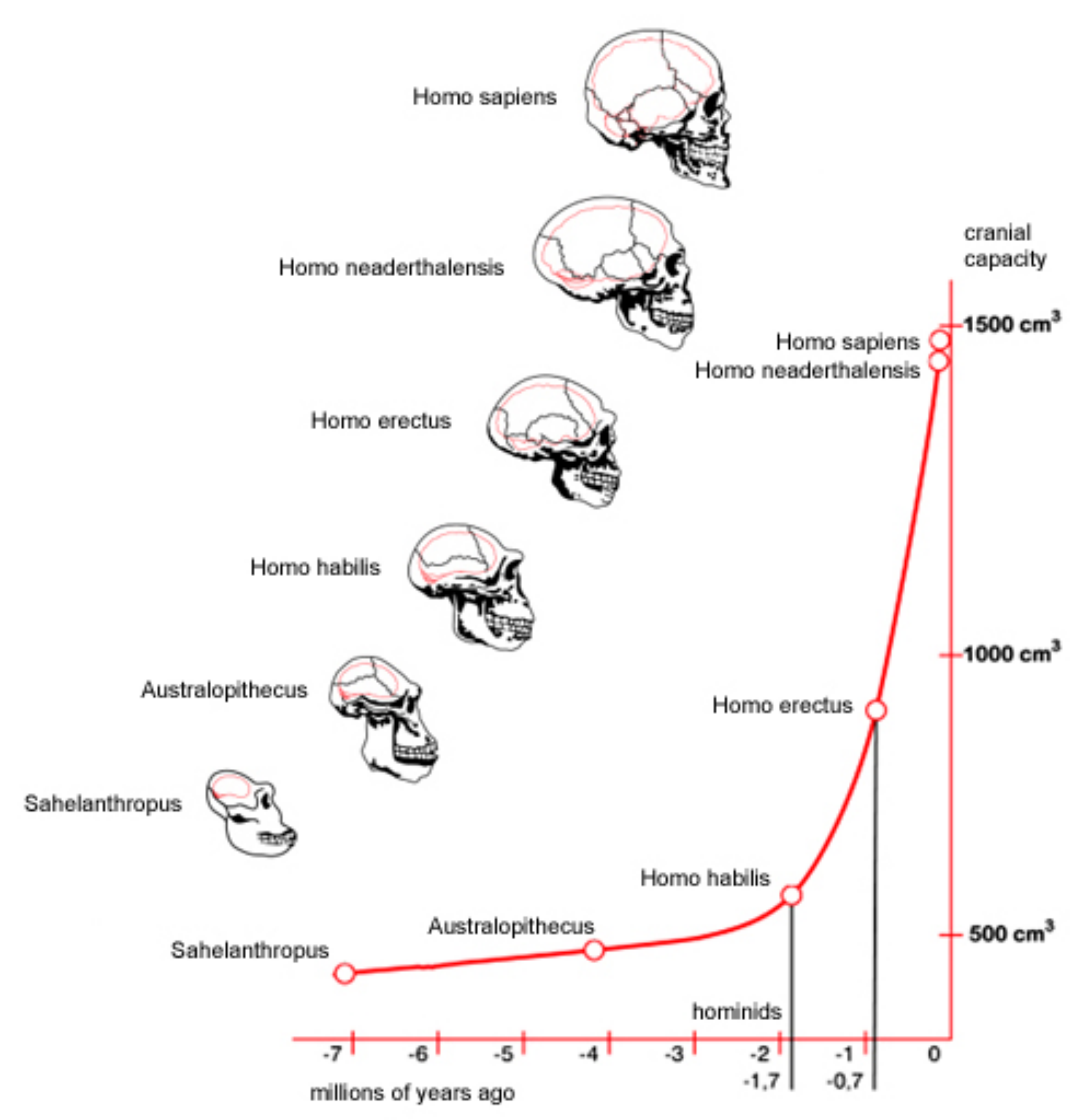
Homo Pan Gorilla Pongo Hylobates genus

Homo Sapiens appeared ~300.000 years ago (until recently believed ~150.000 years ago)

mtDNA pointed to single origin (East Africa); but oldest now found in Morocco…



The brain size evolved incredibly rapidly after the Australopithecus (in the last 1-2 million years)



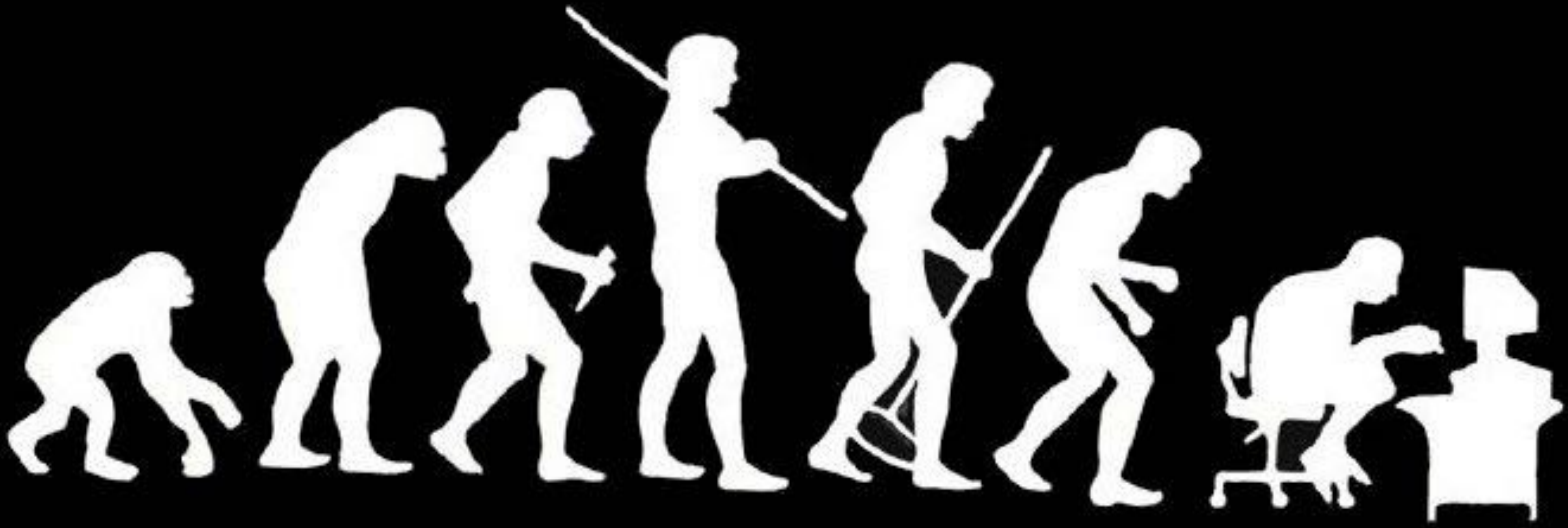
A series of pre-adaptations (each could have gone wrong...):

- Live on land - enables later use of tools and fire
- Body size - enable complex brain (of >1kg)
- Grasping hands (no claws) - manipulate objects, further develop the brain, not use for locomotion
- Mix/Meat diet - more energy, more proteins to develop the brain; hunting: group activity
  [homo erectus - 1 million years ago]
- Controlled use of fire - cooked meat, better tool; cooking as social activity promoted groups/camps/“nest”; self-organization of the group

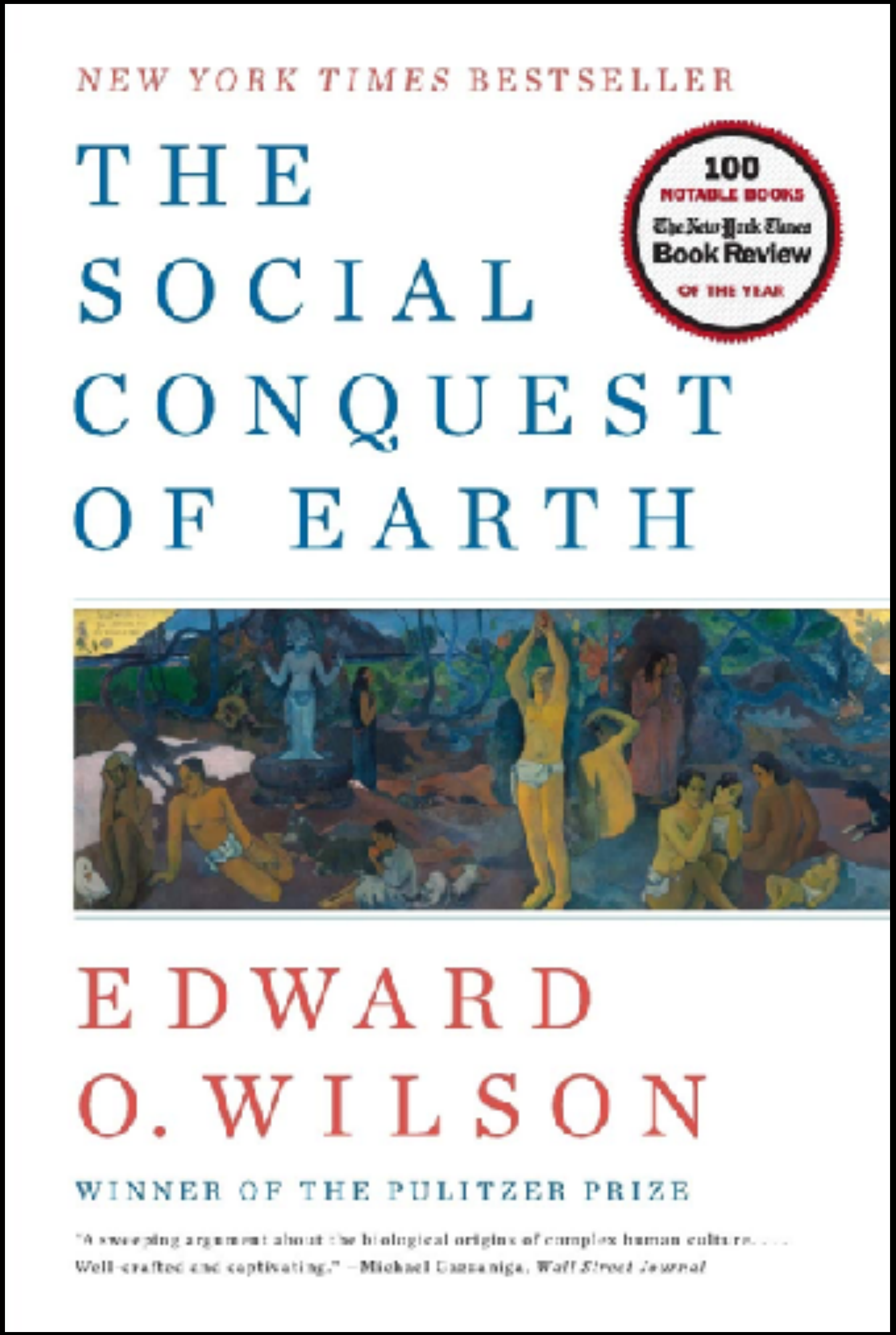
In such eusocial groups, social intelligence is a strong evolutionary advantage

The Evolution of the brain is most likely due to a step by step evolution of social behavior for survival and pressure on social intelligence.

See E.O.Wilson: “The Social Conquest of Earth”



Something, somewhere went terribly wrong



NEW YORK TIMES BESTSELLER

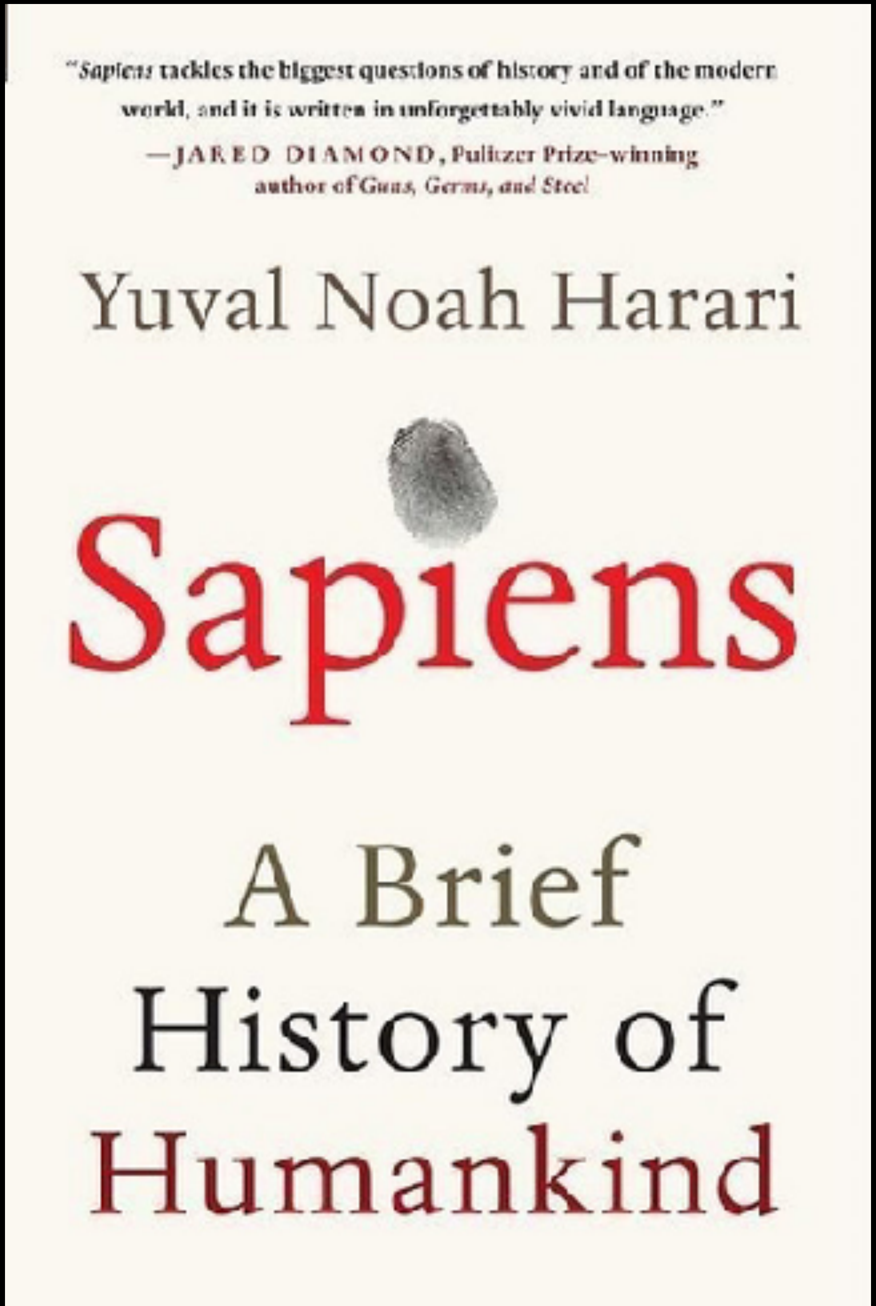
THE SOCIAL CONQUEST OF EARTH

100 NOTABLE BOOKS
The New York Times
Book Review
OF THE YEAR

EDWARD O. WILSON

WINNER OF THE PULITZER PRIZE

"A sweeping argument about the biological origins of complex human culture. . . . Well-crafted and captivating." —Michael Gazzaniga, *Wall Street Journal*

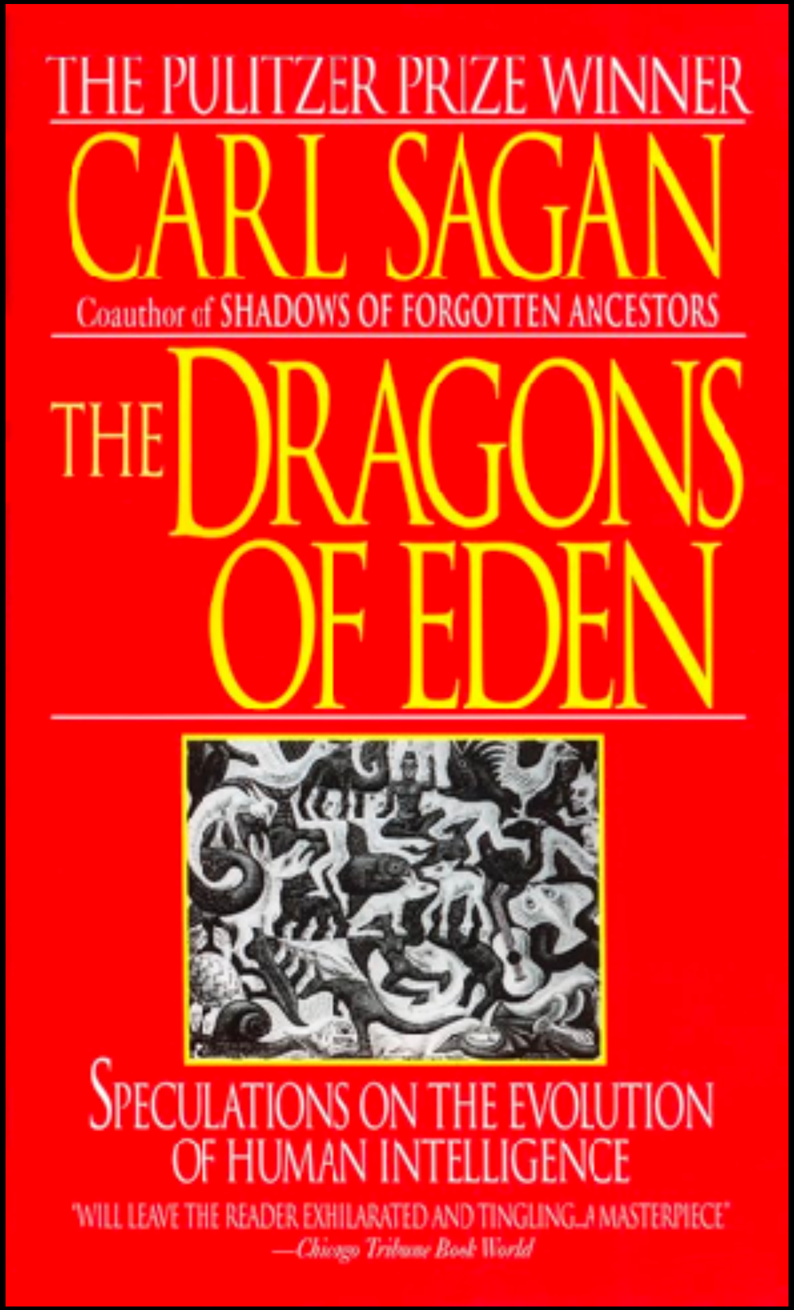


"*Sapiens* tackles the biggest questions of history and of the modern world, and it is written in unforgettably vivid language."
—JARED DIAMOND, Pulitzer Prize–winning author of *Guns, Germs, and Steel*

Yuval Noah Harari

Sapiens

A Brief History of Humankind



THE PULITZER PRIZE WINNER
CARL SAGAN
Coauthor of SHADOWS OF FORGOTTEN ANCESTORS

THE DRAGONS OF EDEN

SPECULATIONS ON THE EVOLUTION OF HUMAN INTELLIGENCE

"WILL LEAVE THE READER EXHILARATED AND TINGLING...A MASTERPIECE"
—*Chicago Tribune Book World*

Take a break…

Intelligence (planing complex actions, sophisticated operations, elaborate communication) is widespread and easy to explain by evolutionary pressure

Consciousness / Self-awareness (“theatre of the mind”) allows to consider alternatives and run multiple times situations in abstract form - eventually enabling even more complex behaviour

Astrobiology: consciousness allows to contemplate the Universe and to search for life elsewhere

Does consciousness always accompany intelligence?

How many intelligent species live on Earth?

Human intelligence forms:

https://www.bundesdruckerei.de/de/innovation-hub/was-ist-intelligenz

Climate changes - future prospectives

The emergence of civilisation (including leisure time for art and sciences) is related to the stability of the climate after the last glaciation (~15.000 to ~11.000 years ago)

The agricultural lifestyle (starting ~8.000 ago) was key to this development

Partly as a result, 8 millennia later, our species started to interact with its environment/climate

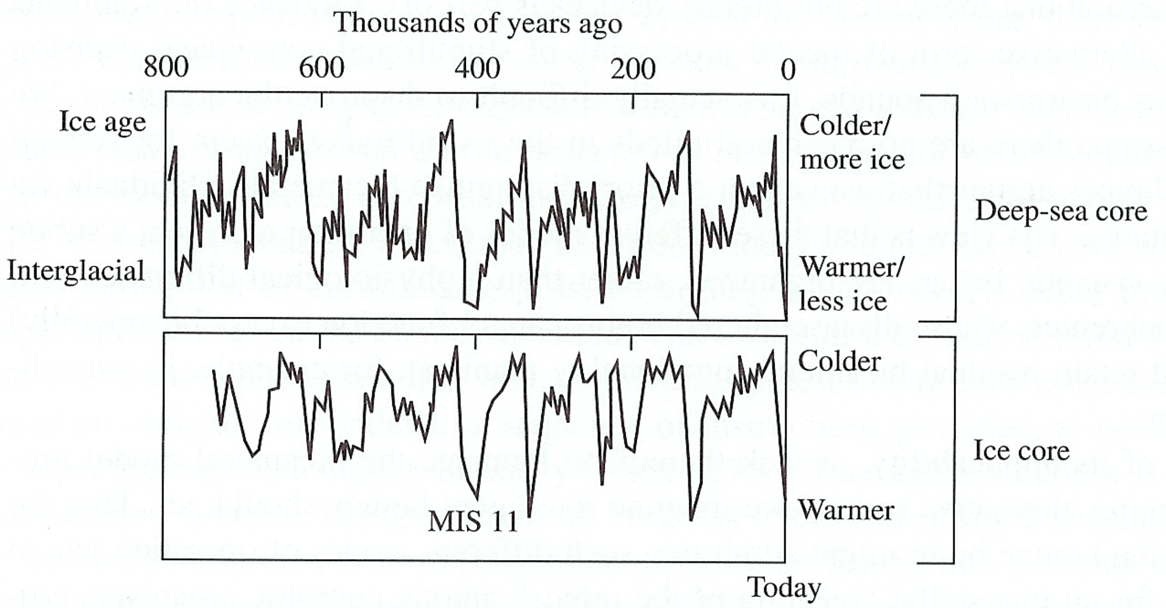


FIGURE 17.5 Pleistocene climate derived from the abundance of deuterium versus hydrogen in an Antarctic ice core, compared with the climate derived from oxygen isotopes in deep sea sediments. The record goes back 800,000 years, and shows among other features an interglacial at 400,000 years ("MIS-11") that lasted longer than the Holocene.

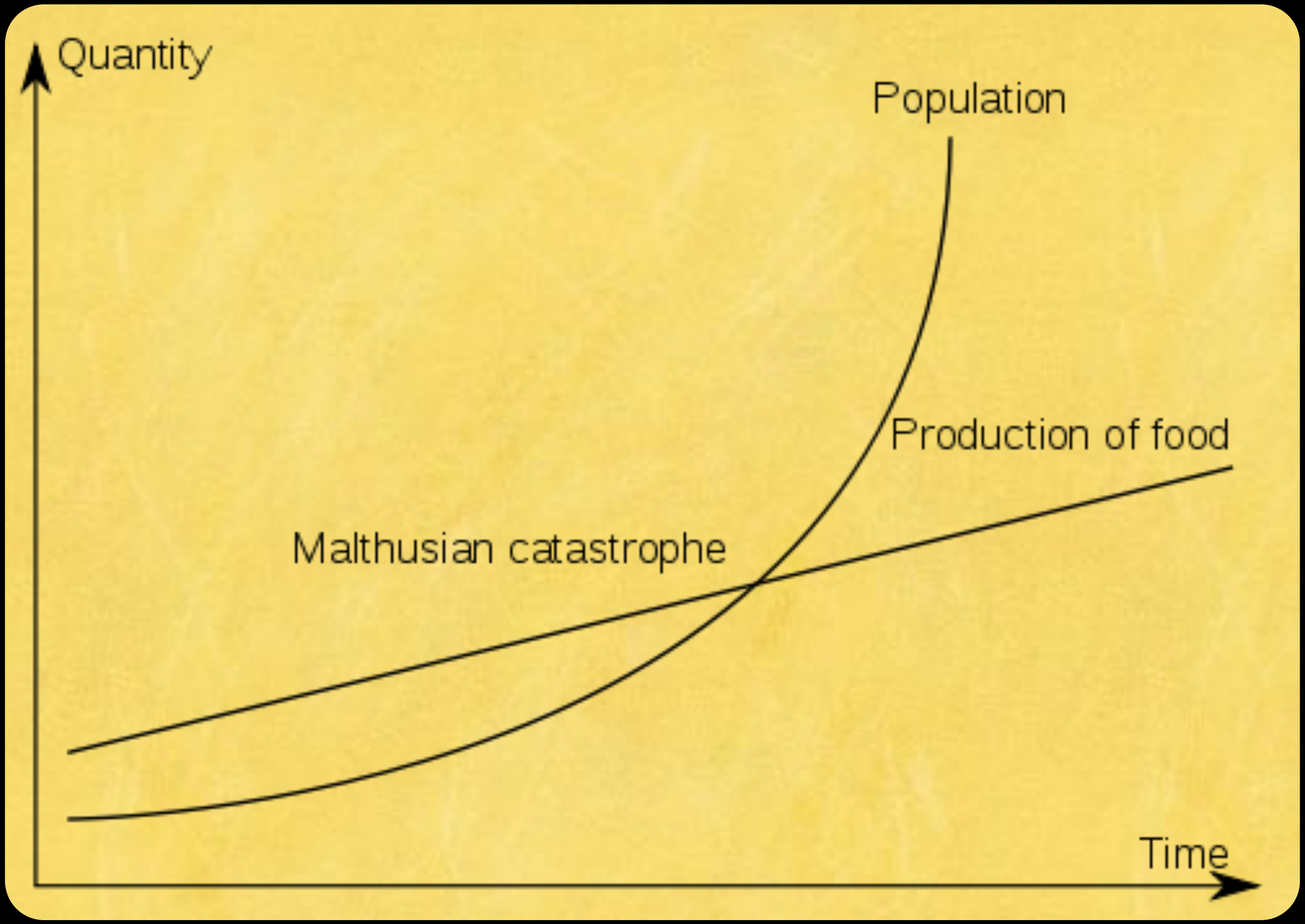
The typical lifetime of an animal species is 1 to 10 million years

The Homo exists since ~300.000 years…

Agricultures and cities since ~10.000 years…

The Challenge: make the last three centuries a prelude to a long-lasting civilization rather than to a Malthusian catastrophe

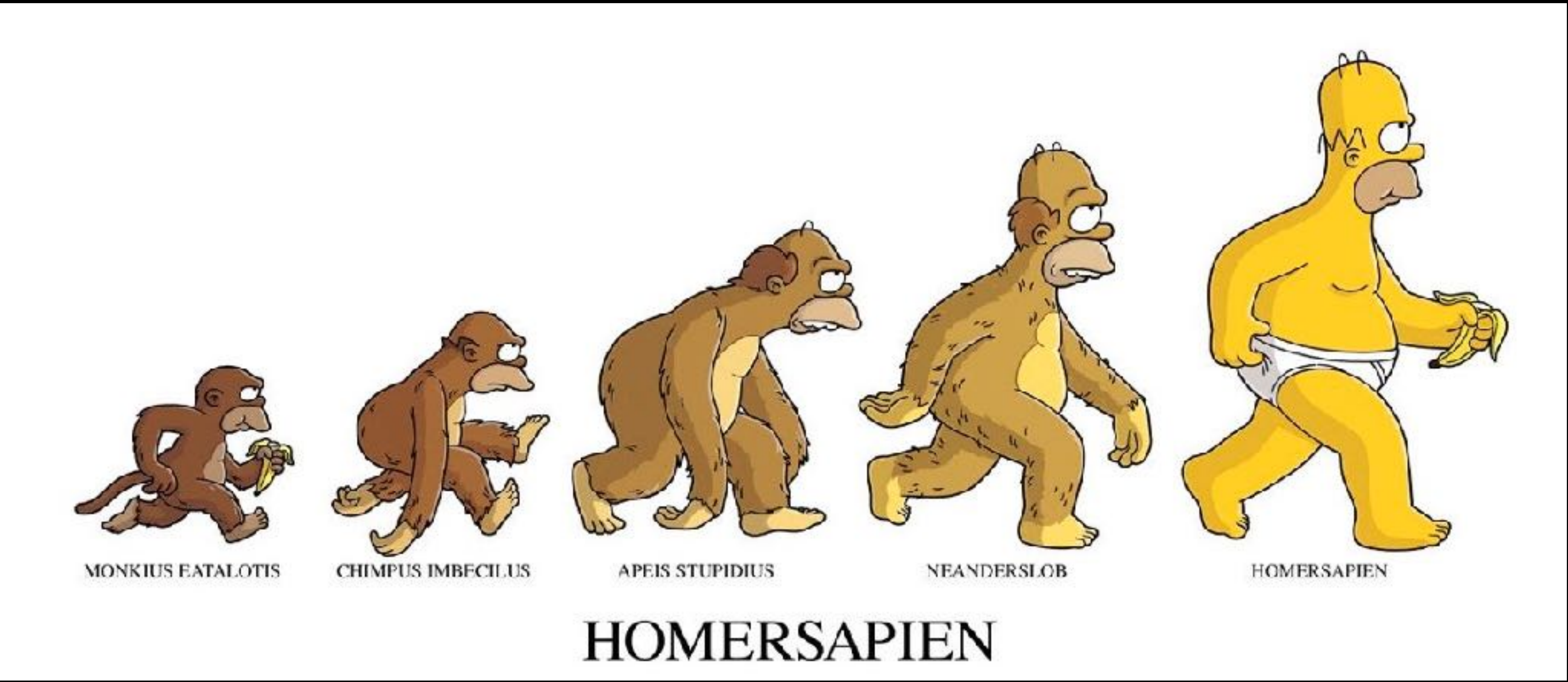
Sagan: we might become space farers not by choice but by necessity



And Humans?

We already think of ourselves as “post-Darwinian” organisms

What will happen once we star genome engineering?



What defined “Darwinian” evolution?

Will Humans still follow “Darwinian” evolution?

A network framework of cultural history – Schich et al. Science 1 August 2014: Vol. 345 no. 6196 pp. 558–562

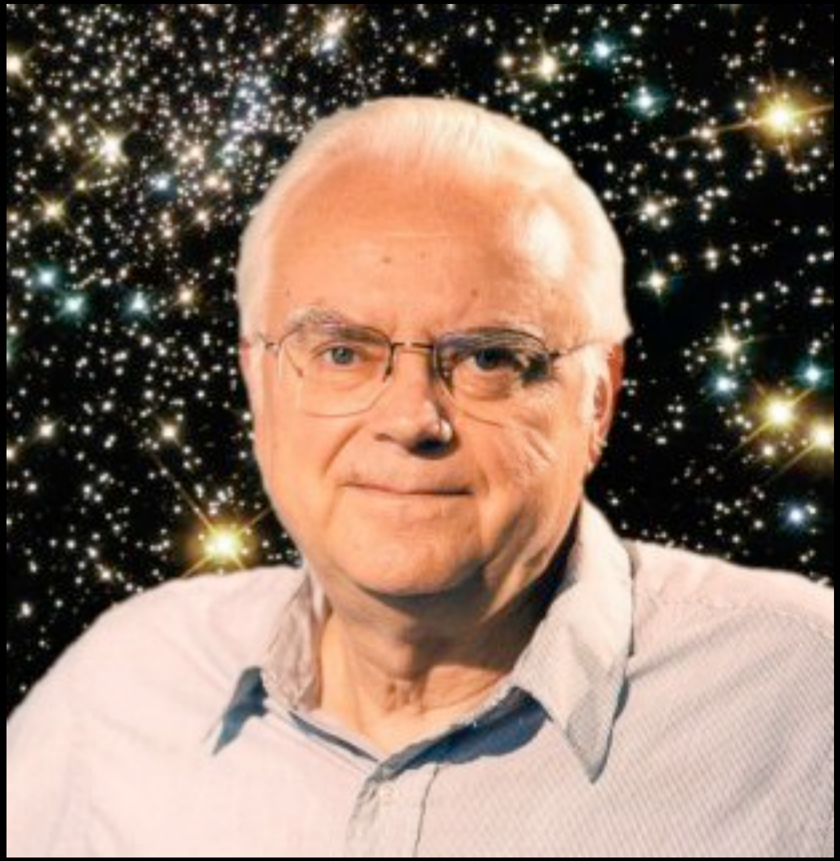
naturevideo

visualization by CultSci

[5:30min]

The Drake equation

The Drake Equation


Frank Drake (1930-)

1961, in preparation of the first meeting on detecting extraterrestrial intelligence…

SETI became a research field

N: the number of civilizations in our galaxy with which communication might be possible

$$\boxed{N = SFR \times f_{planets} \times f_{habitable} \times f_{habited} \times f_{intel} \times f_{tech} \times L}$$

The Drake Equation

$$N = SFR \times f_{planets} \times n_{habitable} \times f_{habited} \times f_{intel} \times f_{tech} \times L$$

Original estimates:

SFR=10/year, fp=50%, nh=2, fh=100%, fi=1%, ft=1%, L=10^4 years
N = 10

From this lecture, with optimism:

SFR=10/year, fp=50%, nh=2, fh=50%, fi=100%, ft=100%, L=10^4 years
N = 50.000 (statistically the closest is <100 pc away)

but N could be anywhere between 0 and 10^{6+}

Compute your favorite N from the Drake equation

$$N = SFR \times f_{planets} \times n_{habitable} \times f_{habited} \times f_{intel} \times f_{tech} \times L$$

⇒ *Fermi paradox*

but sufficient drive for SETI

Searching for Extraterrestrial Intelligence

SETI

Search for Extra-Terrestrial Intelligence

Intelligence in not well defined on Earth…

What are we searching for on other planets?

“Intelligence” = Technology?!

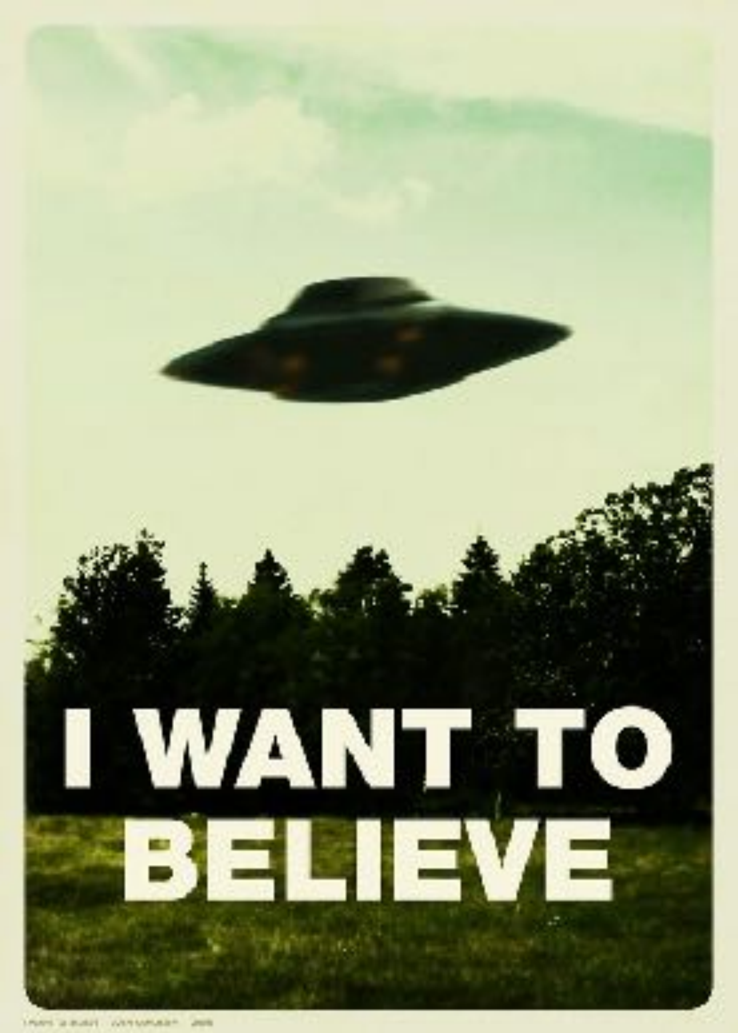
We assume that a civilization will develop:

- Energy production
- Transportation
- Information exchange
- (and Waging war)

Scenario 1: the civilisation is local

→ they do not try to communicate

⇒ look for unintentional manifestations



Scenario 2: they intend interstellar information exchange (travel?)

Fermi paradox ("Where is everybody?")

Solutions:

a) they are here (e.g. directed panspermia)

b) they exist but have no yet communicated (or we failed to understand the signal)

c) they do not exist

In all case, rules for **efficient communication** seem to be:

- have the maximum possible velocity
- be easy to generate, launch and capture
- not be absorbed by the interstellar medium
- require minimum energy per bit of information (?)
- go where aimed (?)

Consequently, communication focuses on electromagnetic radiation

Search Strategies

At which frequencies do we have a chance of detecting signal?

Astrophysical background: the sky is bright from the radio to γ-rays

In practice: spatial, spectral and temporal filters are used to reduce that background

The Earth atmosphere limits the accessible wavelength range

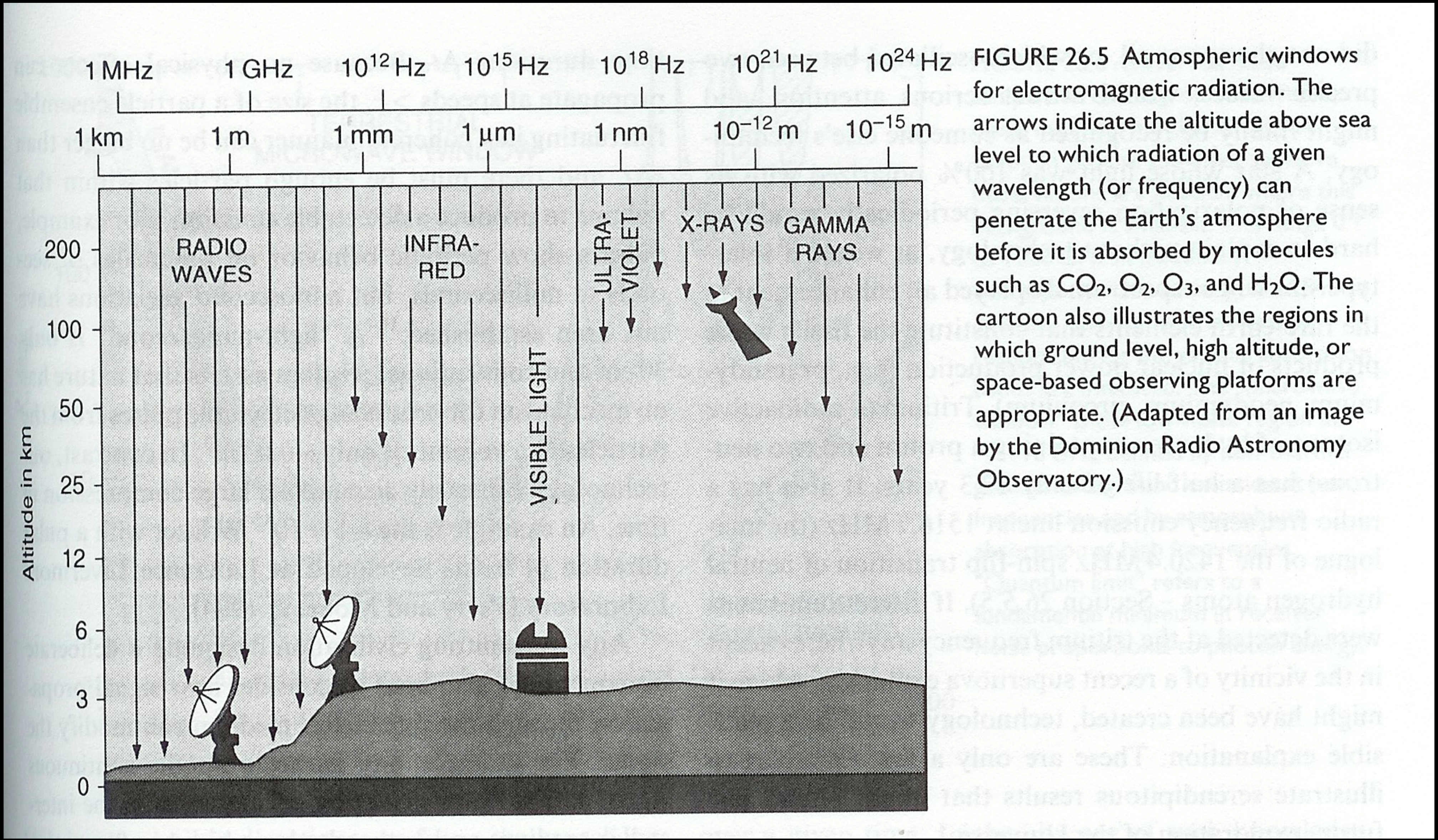


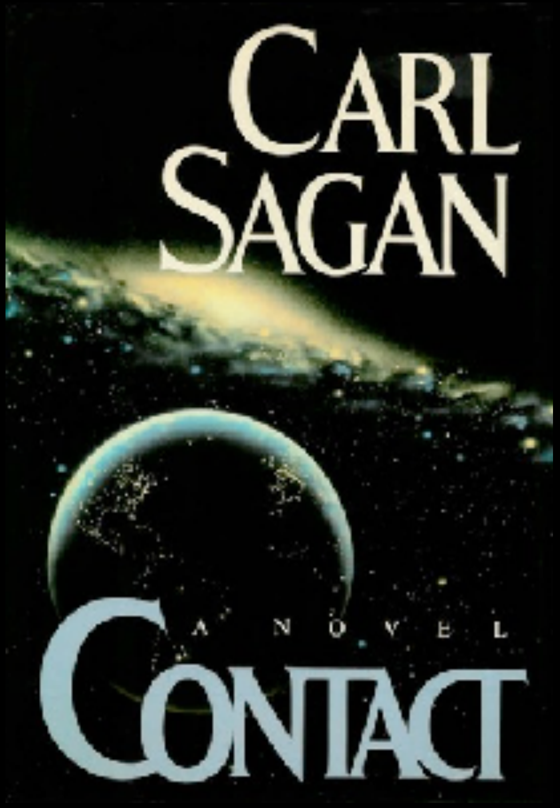
FIGURE 26.5 Atmospheric windows for electromagnetic radiation. The arrows indicate the altitude above sea level to which radiation of a given wavelength (or frequency) can penetrate the Earth's atmosphere before it is absorbed by molecules such as CO_2, O_2, O_3, and H_2O. The cartoon also illustrates the regions in which ground level, high altitude, or space-based observing platforms are appropriate. (Adapted from an image by the Dominion Radio Astronomy Observatory.)

Can we tell natural from artificial signals?

a) the signal could be unrecognisable for our (not very advanced) technology [tough luck...]

b) the signal would mimic an astrophysical signal (e.g. modulated pulsar, 100% polarised star, ...)

c) the signal cannot be produced by an astrophysical source (e.g. small $\Delta\nu$, or small Δt) [most SETI searches]

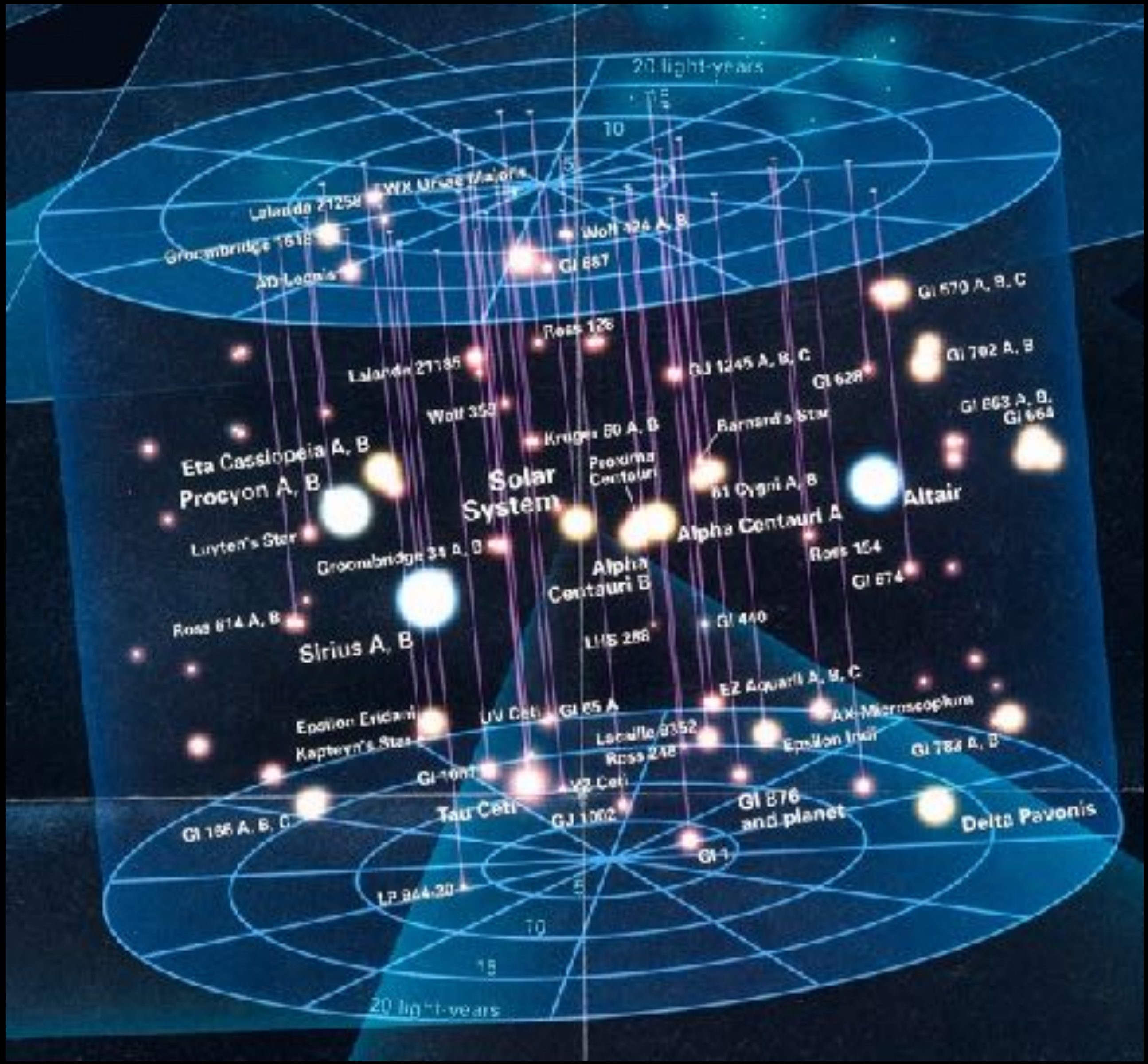


Targets or Sky sweeps?

Focused strategies usually target G2V stars (sun analogs)

Sky surveys suffer from lower sensitivity and irregular coverage

No strategy was successful so far ☺



The nearest 10 stars to Earth (excluding our sun, Sol)

1 parsec = 3.2616 light years

star	absolute visible magnitude	spectral class	luminosity	distance - parsecs
Proxima Centauri C	15.45	M5		1.31
Alpha Centauri A	4.3	G2	V	1.34
Alpha Centauri B	5.69	K5	V	1.34
Barnard's Star	13.25	M5	V	1.81
Wolf 359	16.68	M8		2.33
HD 95735	10.49	M2	V	2.49
Sirius A	1.41	A1	V	2.65
Sirius B	11.56	WD	VII	2.65
UV Ceti A	15.27	M5		2.72
UV Ceti B	15.8	M6		2.72

Which frequency range to probe?

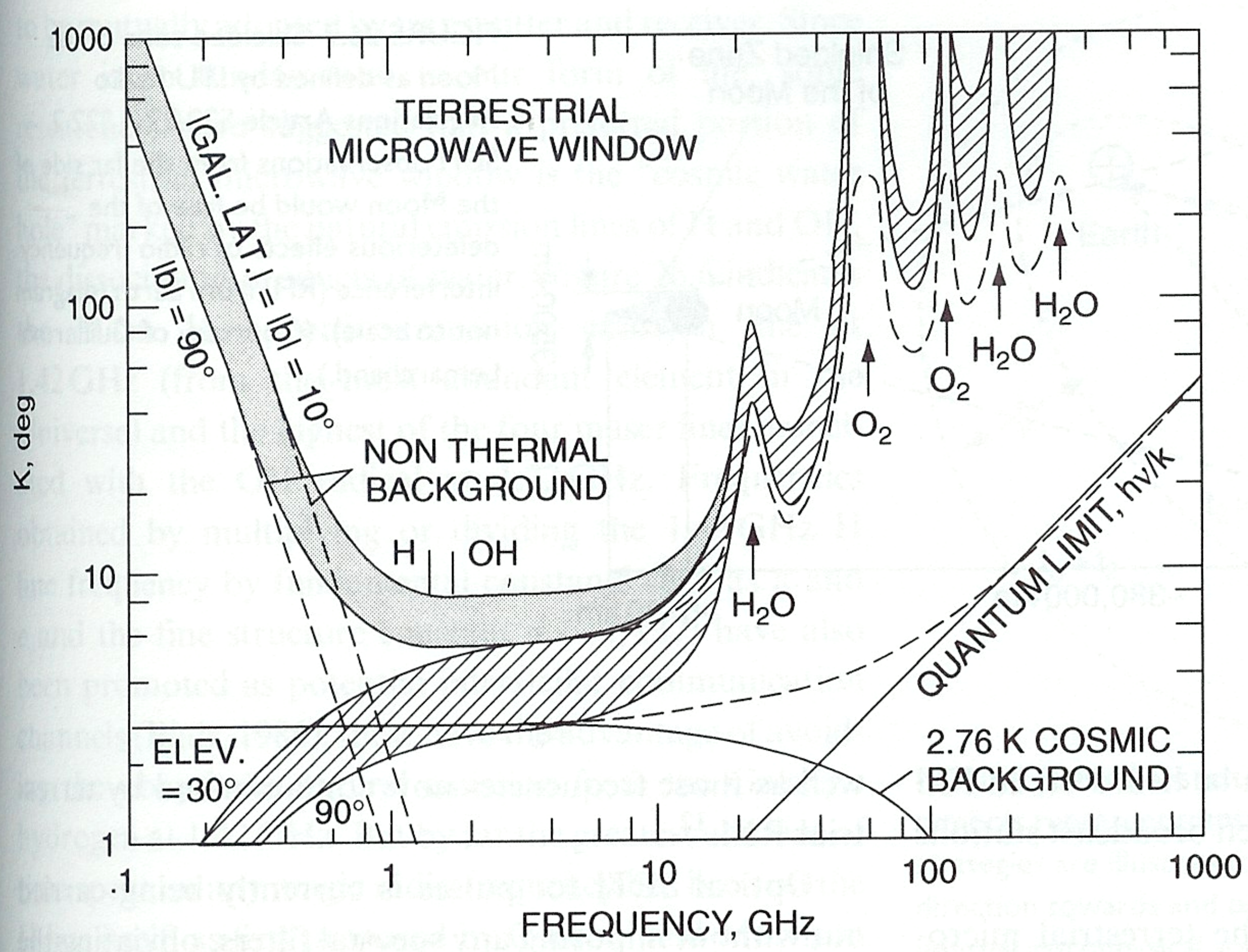


FIGURE 26.6 Observed noise temperature background for radio observations from the surface of Earth; in general the most sensitive observations are possible where this background is smallest. The range 0.1 to 1000 GHz in frequency corresponds to wavelengths of 3 m to 300 µm. Atmospheric molecules responsible for the various absorption bands are indicated. The "microwave window" is the low-noise region at ∼1–10 GHz defined by non-thermal galactic background emission at low frequencies and by atmospheric absorption at high frequencies. "Quantum limit" refers to a fundamental minimum in receiver noise proportional to photon energy.

From Earth, the best range is 1-10 GHz (λ=3-30cm)

If life is water based, communication will happen in the "water hole" (marked by H and OH, i.e. 1.42 GHz to 1.72 GHz)

Current searches

1896	Nicola Tesla suggested that radio could be used to contact extraterrestrial life (and thought to have found signals from Mars)
1924	“National Radio Silent Day” in the USA (August 21-23)
1959	Cocconi and Morrison, Nature - first SETI paper
1960	Frank Drake’s Project OZMA
1961	First SETI conference at the Green Bank observatory
1971	NASA funds Drake’s study for ‘Project Cyclops’ (10^{10} USD!)
1979	UC Berkley launches SERENDIP (in 1986 SERENDIP 2)
1992	NASA funds the MOP programme, Congress cancels it a year later
1995	The SETI institute is founded with private funds

The Allen Telescope Array
Since 2007 (with UC Berkeley)

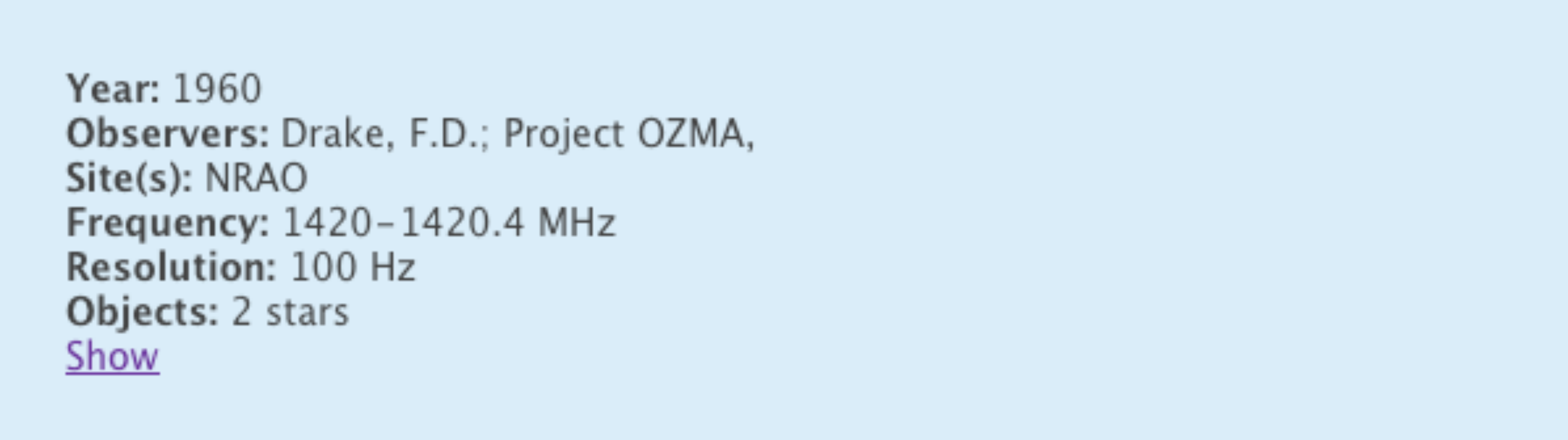
The Center for SETI Research

Carl Sagan Center for the Study of Life in the Universe

Center for Education and Public Outreach

https://observations.seti.org/ (deactivated?)

1960



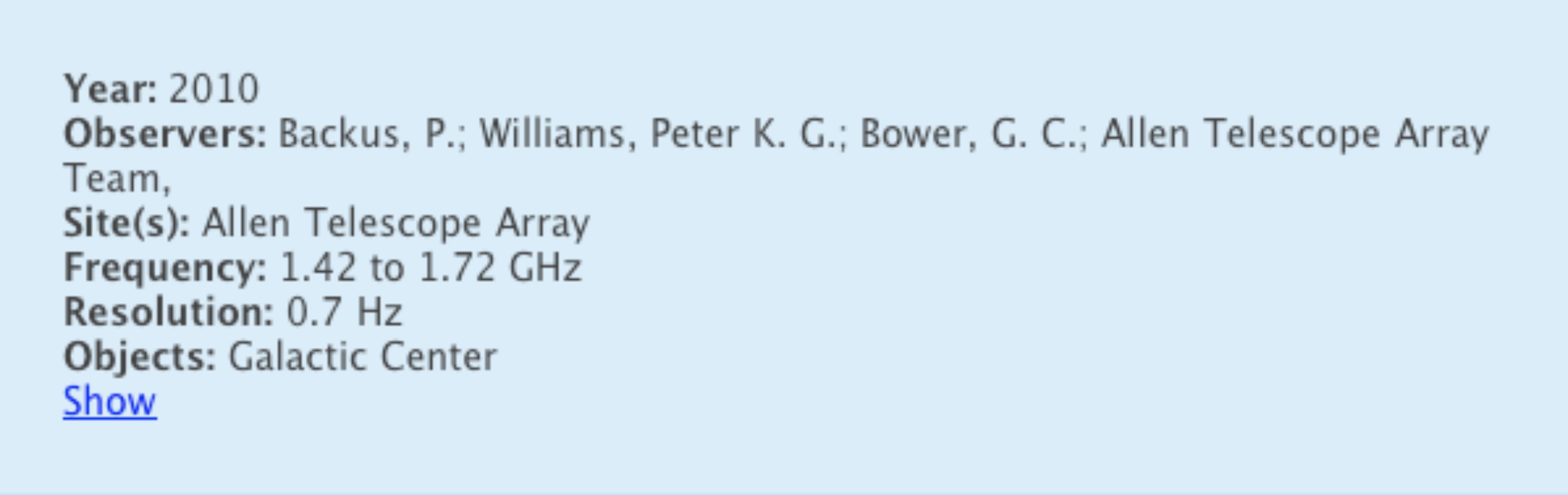
Year: 1960
Observers: Drake, F.D.; Project OZMA,
Site(s): NRAO
Frequency: 1420–1420.4 MHz
Resolution: 100 Hz
Objects: 2 stars
Show

…

~150 campaigns

…

2010



Year: 2010
Observers: Backus, P.; Williams, Peter K. G.; Bower, G. C.; Allen Telescope Array Team,
Site(s): Allen Telescope Array
Frequency: 1.42 to 1.72 GHz
Resolution: 0.7 Hz
Objects: Galactic Center
Show

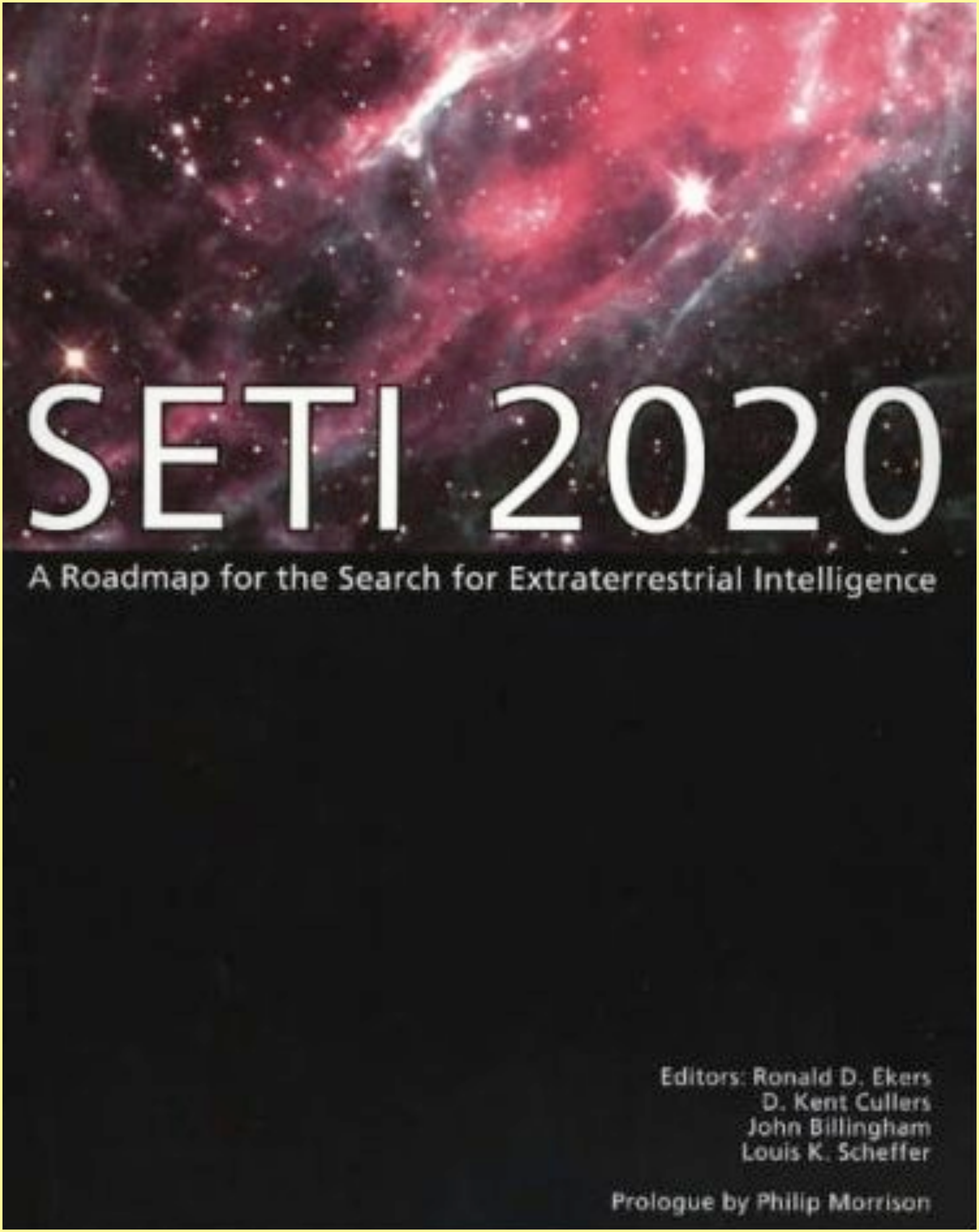
The future of SETI

Harvard: all-sky optical SETI survey (nanosecond pulses)

Berkeley + SETI: all-sky radio SETI survey with the Allen Telescope Array with new funding (100M$) from the *Breakthrough Listen Initiative*

SETI remains marginal science

Search strategies cover only a small fraction of possible signals…



SETI 2020

A Roadmap for the Search for Extraterrestrial Intelligence

Editors: Ronald D. Ekers
D. Kent Cullers
John Billingham
Louis K. Scheffer

Prologue by Philip Morrison

Lunch break…

Should we communicate?

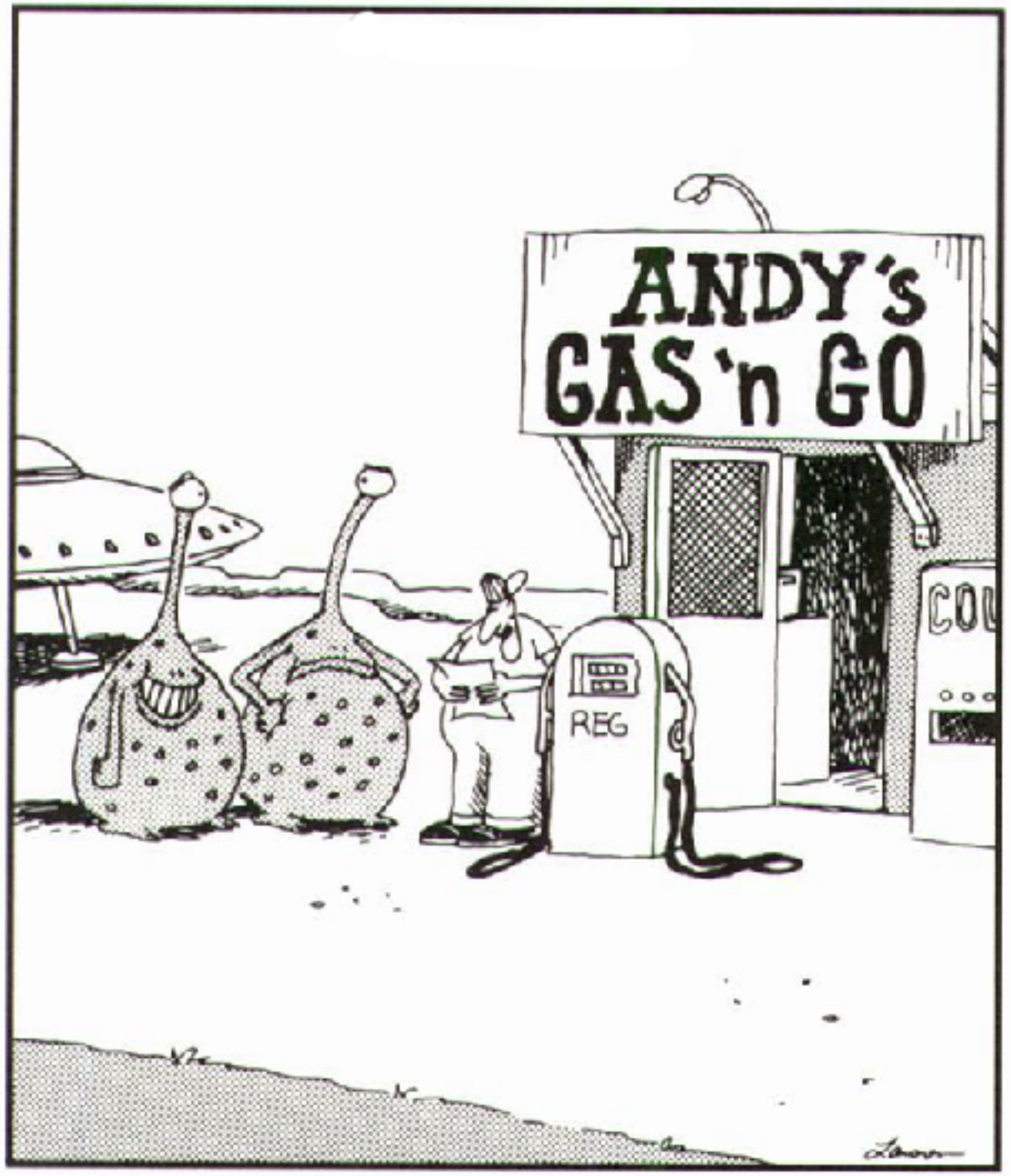
Since the mid 20th century, we are detectable

(Short) broadcast attempts are still taking place

A “Post-detection Protocol” has been adopted by most SETI groups

Current conclusion from a series of workshops (Ekers et al. 2002, ‘SETI 2020’): the strategy should not be to deliberately transmit

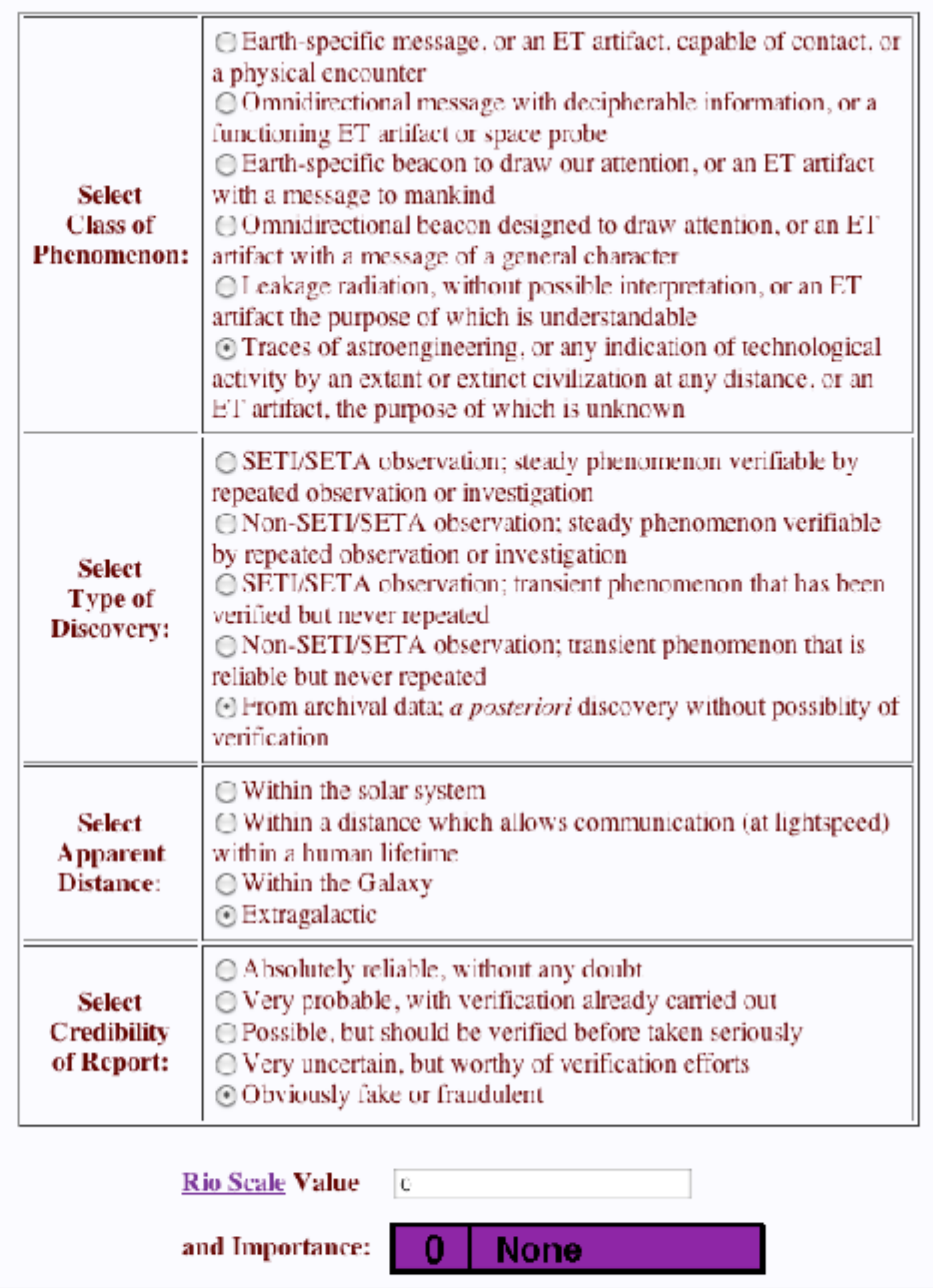
Given the Lifespan of a civilization, our transmission would need to last thousands to millions of years - which is beyond the capability of our civilization…



“Shoot! You not only got the wrong planet, you got the wrong *solar* system. ... I mean, a wrong planet I can understand—but a whole solar system?”

What if we succeed?

Assess the reliability: the Rio Scale (in analogy to the Torino Scale)



Select Class of Phenomenon:	○ Earth-specific message, or an ET artifact, capable of contact, or a physical encounter ○ Omnidirectional message with decipherable information, or a functioning ET artifact or space probe ○ Earth-specific beacon to draw our attention, or an ET artifact with a message to mankind ○ Omnidirectional beacon designed to draw attention, or an ET artifact with a message of a general character ○ Leakage radiation, without possible interpretation, or an ET artifact the purpose of which is understandable ● Traces of astroengineering, or any indication of technological activity by an extant or extinct civilization at any distance, or an ET artifact, the purpose of which is unknown
Select Type of Discovery:	○ SETI/SETA observation; steady phenomenon verifiable by repeated observation or investigation ○ Non-SETI/SETA observation; steady phenomenon verifiable by repeated observation or investigation ○ SETI/SETA observation; transient phenomenon that has been verified but never repeated ○ Non-SETI/SETA observation; transient phenomenon that is reliable but never repeated ● From archival data; *a posteriori* discovery without possiblity of verification
Select Apparent Distance:	○ Within the solar system ○ Within a distance which allows communication (at lightspeed) within a human lifetime ○ Within the Galaxy ● Extragalactic
Select Credibility of Report:	○ Absolutely reliable, without any doubt ○ Very probable, with verification already carried out ○ Possible, but should be verified before taken seriously ○ Very uncertain, but worthy of verification efforts ● Obviously fake or fraudulent

Rio Scale Value 0

and Importance: 0 None

Rio	Importance
10	Extraordinary
9	Outstanding
8	Far-reaching
7	High
6	Noteworthy
5	Intermediate
4	Moderate
3	Minor
2	Low
1	Insignificant
0	None

Interpreting Rio Scale Values

Studies show that the impact on world culture and religion will be minor....

Use the Rio Scale calculator to assess your latest UFO observation…

http://avsport.org/IAA/riocalc.htm

How to go on with Astrobiology?

Astrobiology

Fundamental questions:

- How does life begin and evolve?
- Does life exist elsewhere in the Universe?
- What is the future of life on Earth?

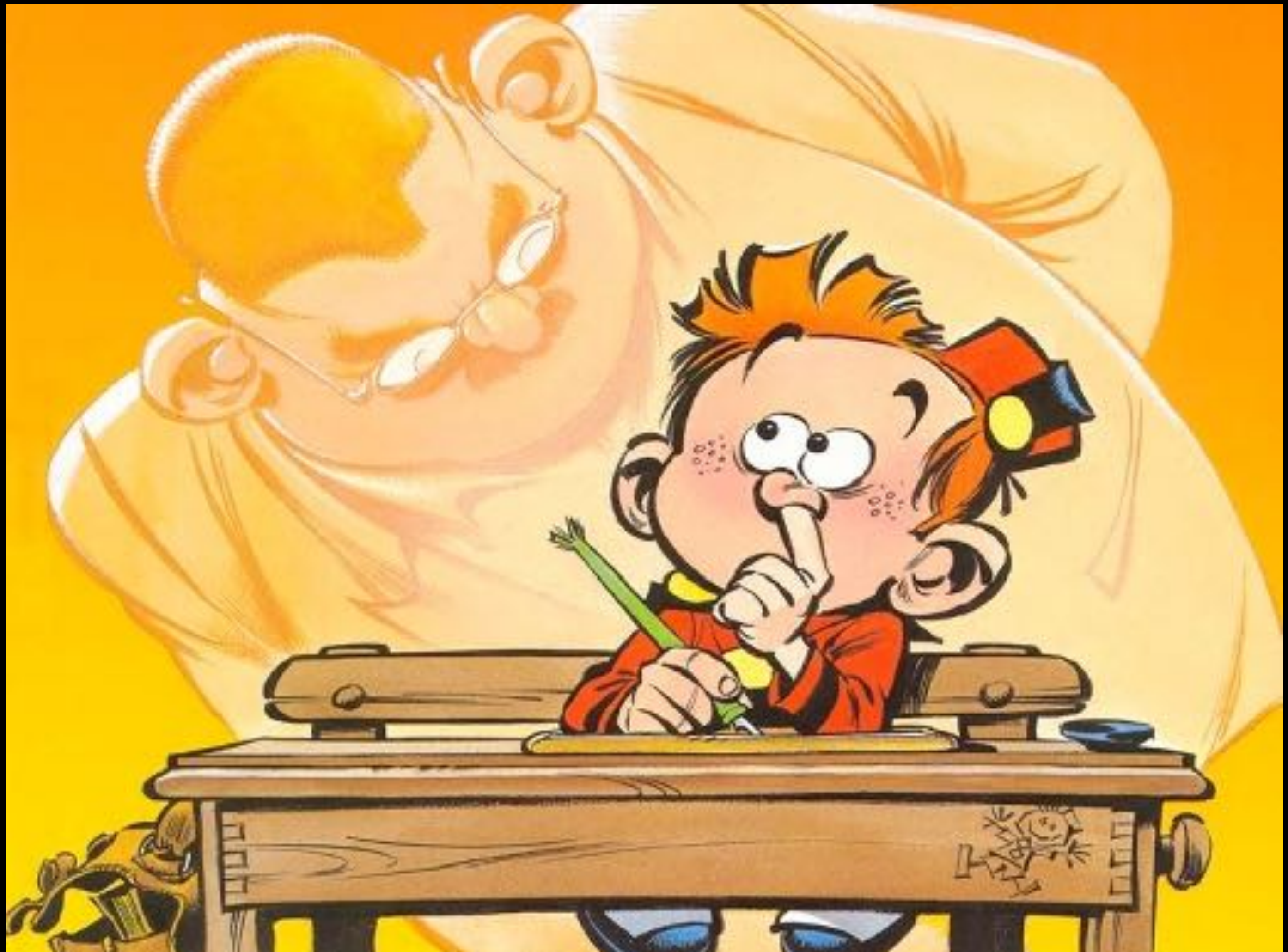
Each question relies on a complex list of multidisciplinary science questions

Why create a new *discipline*?

Until the 90s, astrobiological questions were answered in a collaborative framework

Today, the limit is not the scientific knowledge, but the limit of individual disciplines

Astrobiology attempts to break the traditional boundaries of individual disciplines



Societal and Ethical Concerns

- ★ Nuclear reactors and propulsion in space
- ★ Deliberate transportation of organisms between Earth and Mars
- ★ Commercial ventures into space
- ★ Engineering of new lifeforms adapted to live on other worlds
- ★ Terraforming
- ★ Space faring / Colonization

Some of these might not happen in decades or centuries, but it is unforeseeable how fast the field will progress

It is never too early to think about these issues

Scientists will remain the expert decision makers

How can **YOU** contribute to astrobiology?

Do **not** become an *Astrobiologist*

Attend classes in the other disciplines
(Biology, Astronomy, Geology, Chemistry, ...)

Do research on astrobiological questions
relevant to your field
(exoplanets, origin of life, socioeconomics, ...)

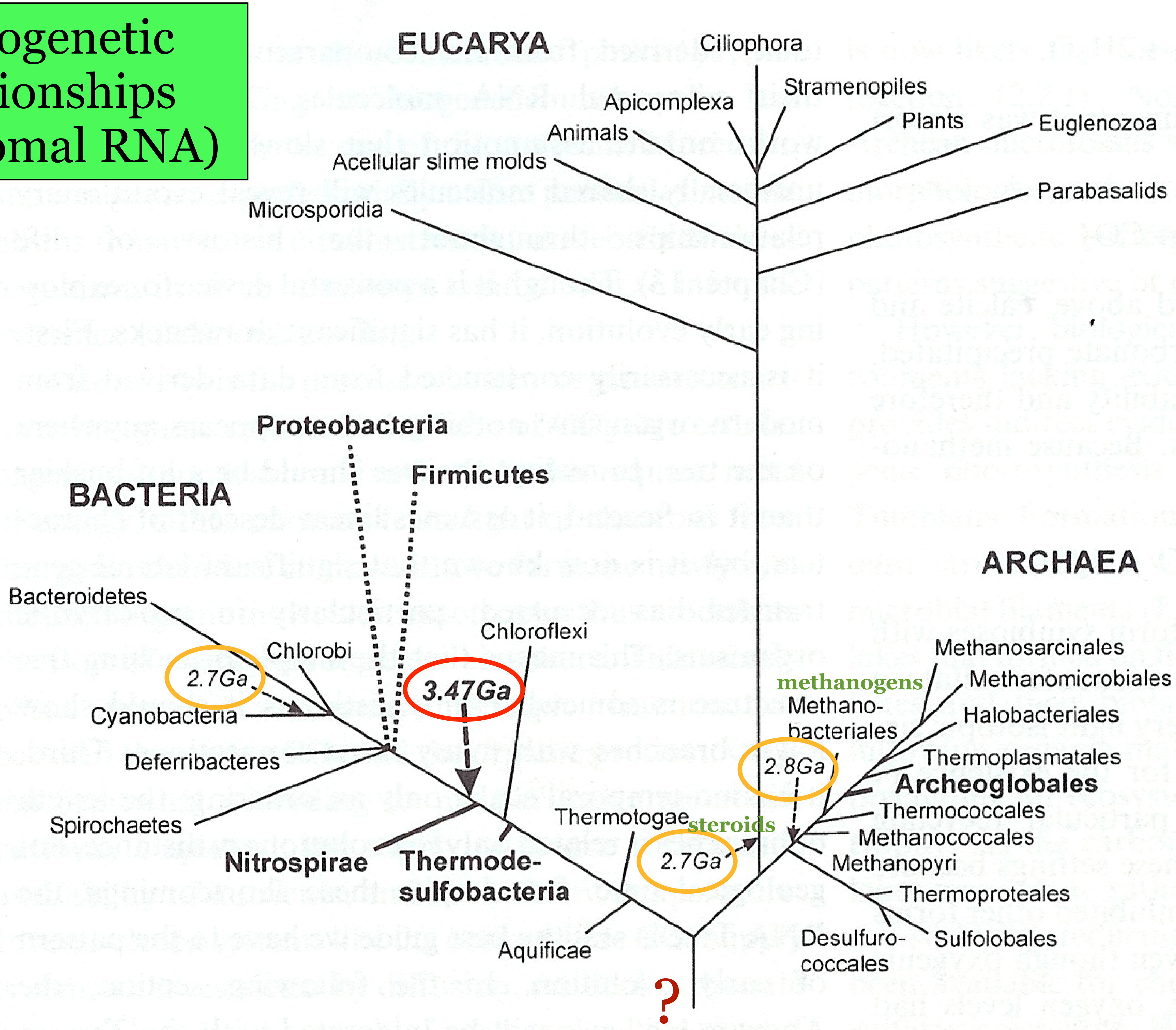
Monday November 20	Day 1: Definition of Life; Origin of Life; Evolution of Life; Limits of Life 10:00-12:00 & 13:00-14:00	✓
Tuesday November 21	Day 2: Earth Climate History; Mars and Venus Climates 10:00-12:00 & 13:00-14:00 OLD SEMINAR ROOM	✓
Wednesday November 22	Day 3: Habitable Places in the Solar System; Mars; Moons of Giant Planets 10:00-12:00 & 13:00-14:00	✓
Thursday November 23	Day 4: Habitable Places beyond the Solar System; Exoplanets properties; Biosignatures 10:00-12:00 & 13:00-14:00	✓
Friday November 24	Day 5: Search for Extraterrestrial Intelligence; Alien Biochemistry 10:00-12:00 & 12:45-13:30	✓

Overall Summary

Take home ideas from day 1

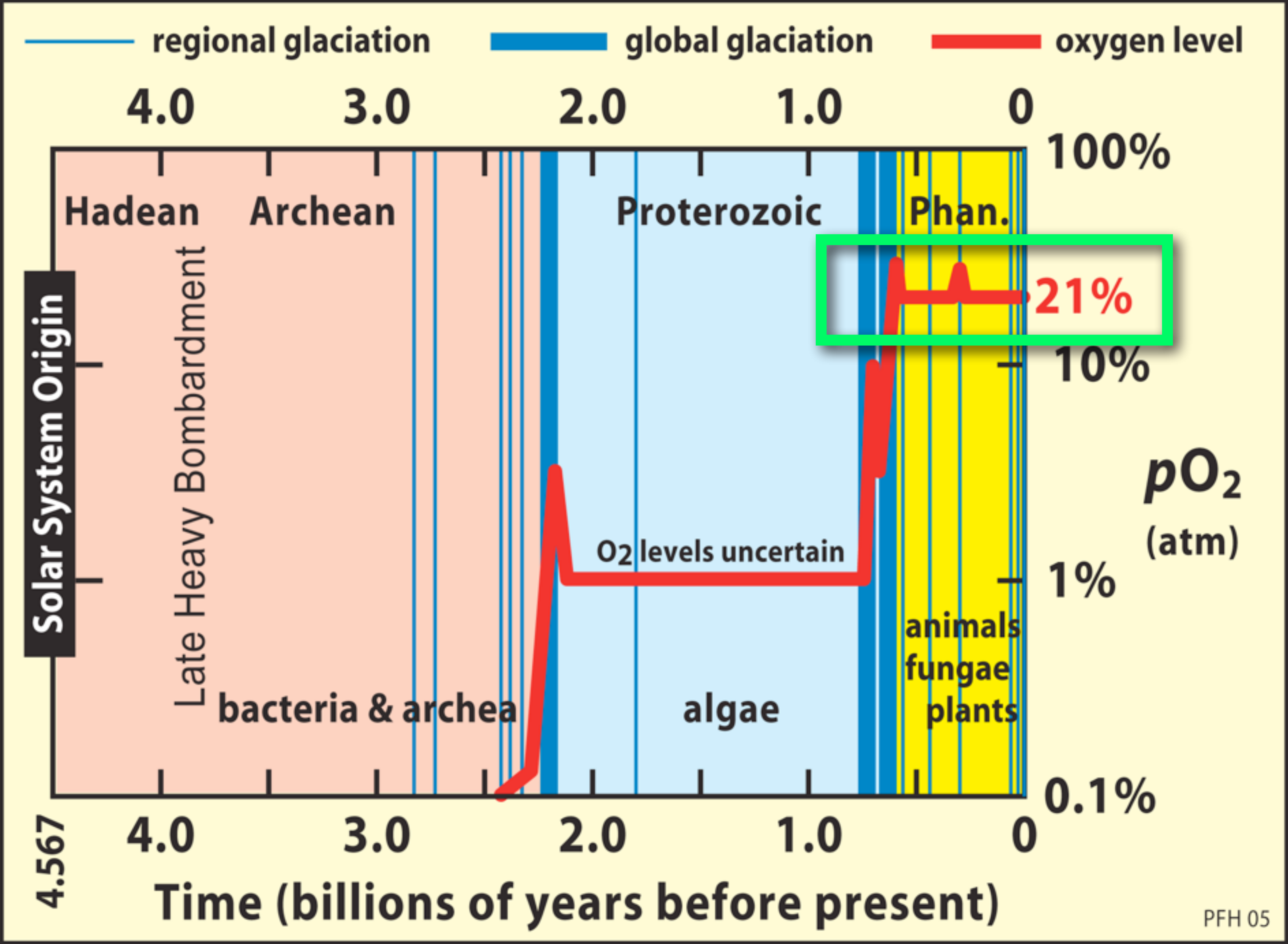
- Defining Life is difficult, as we know only one form of life to date
- Working definition: "A self-sustaining, replicating chemical system, capable of Darwinian evolution."
- Life builds on very common chemistry
- Life appeared on Earth as soon as water was liquid, 4 Gyr ago
- Life evolved and adapted to the most extreme environments

Phylogenetic relationships (ribosomal RNA)



Take home ideas from day 2

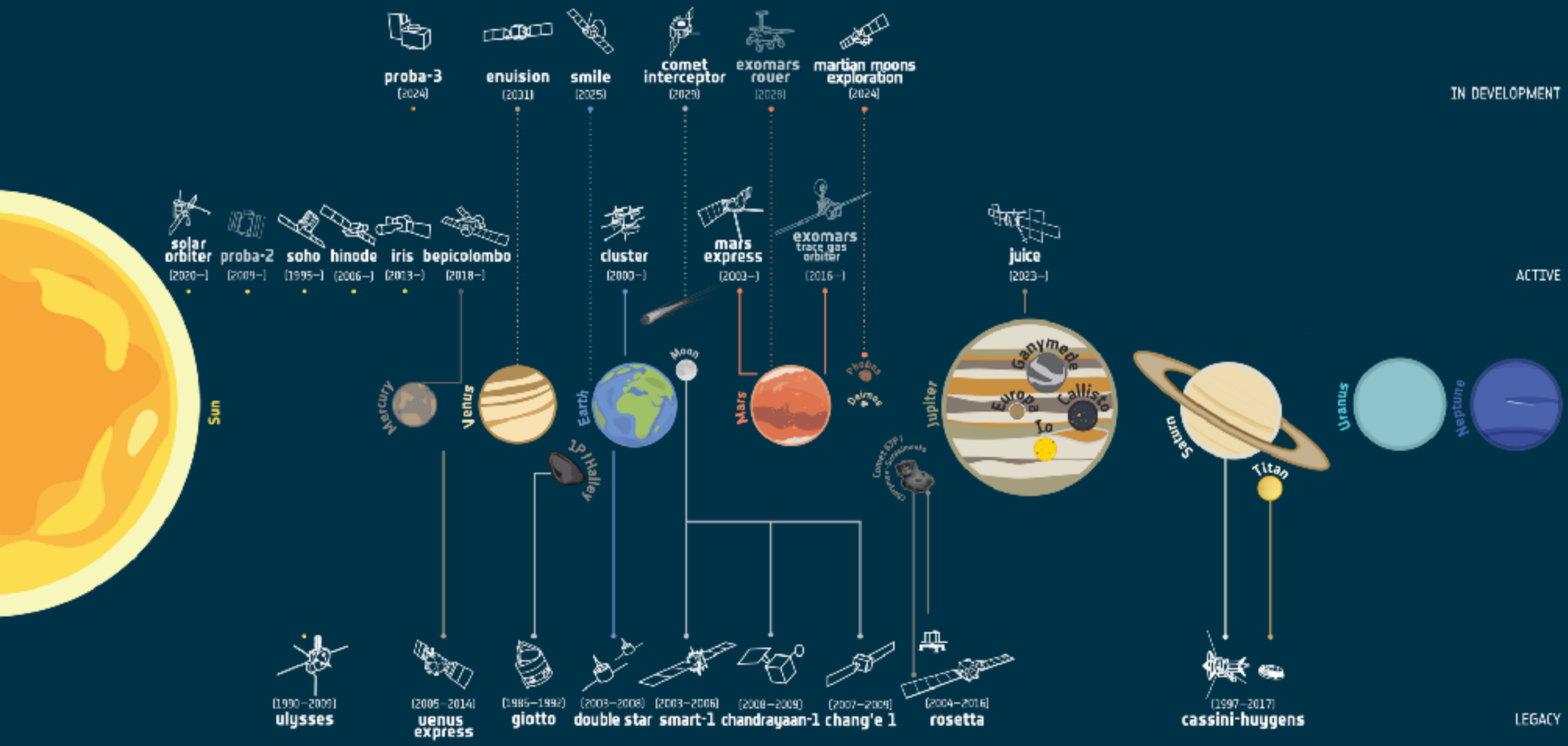
- Solar flux, albedo, greenhouse effect
- Feedback loops drive the climate
- Life modulates the most important volatiles in the atmosphere
- Oxygen appeared with photosynthesis
- Habitability is (currently) linked to liquid water
- Venus experienced a runaway greenhouse effect
- Mars never developed a greenhouse atm


regional glaciation
global glaciation
oxygen level
4.0
3.0
2.0
1.0
0
100%
Hadean
Archean
Proterozoic
Phan.
Solar System Origin
Late Heavy Bombardment
21%
10%
pO2
(atm)
O2 levels uncertain
1%
animals
fungae
plants
bacteria & archea
algae
0.1%
4.567
4.0
3.0
2.0
1.0
0
Time (billions of years before present)
PFH 05

Take home ideas from day 3

- The temperature gradient in the initial solar nebulae determines which elements condense where
- The origin of Earth's water is still speculative
- Mars remains the primary target to search for life in the Solar System
- Moons of Jupiter and Saturn host sub-surface liquid water
- Titan would host a weird life form

SOLAR SYSTEM EXPLORERS



IN DEVELOPMENT

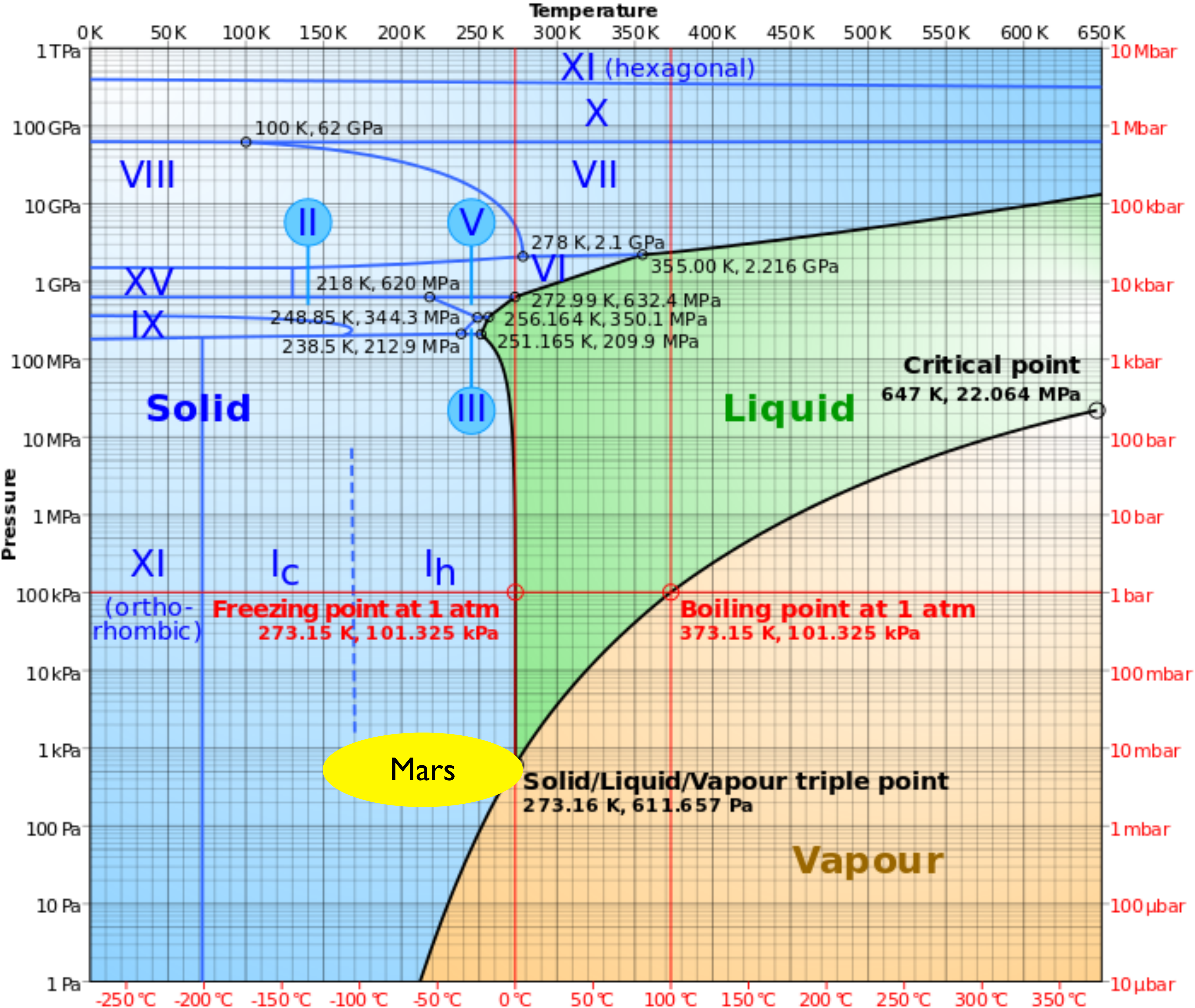
- **proba-3** (2024)
- **envision** (2031)
- **smile** (2025)
- **comet interceptor** (2029)
- **exomars rover** (2028)
- **martian moons exploration** (2024)

ACTIVE

- **solar orbiter** (2020–)
- **proba-2** (2009–)
- **soho** (1995–)
- **hinode** (2006–)
- **iris** (2013–)
- **bepicolombo** (2018–)
- **cluster** (2000–)
- **mars express** (2003–)
- **exomars** trace gas orbiter (2016–)
- **juice** (2023–)

LEGACY

- (1990–2009) **ulysses**
- (2005–2014) **venus express**
- (1985–1992) **giotto**
- (2003–2008) **double star**
- (2003–2006) **smart-1**
- (2008–2009) **chandrayaan-1**
- (2007–2009) **chang'e 1**
- (2004–2016) **rosetta**
- (1997–2017) **cassini-huygens**

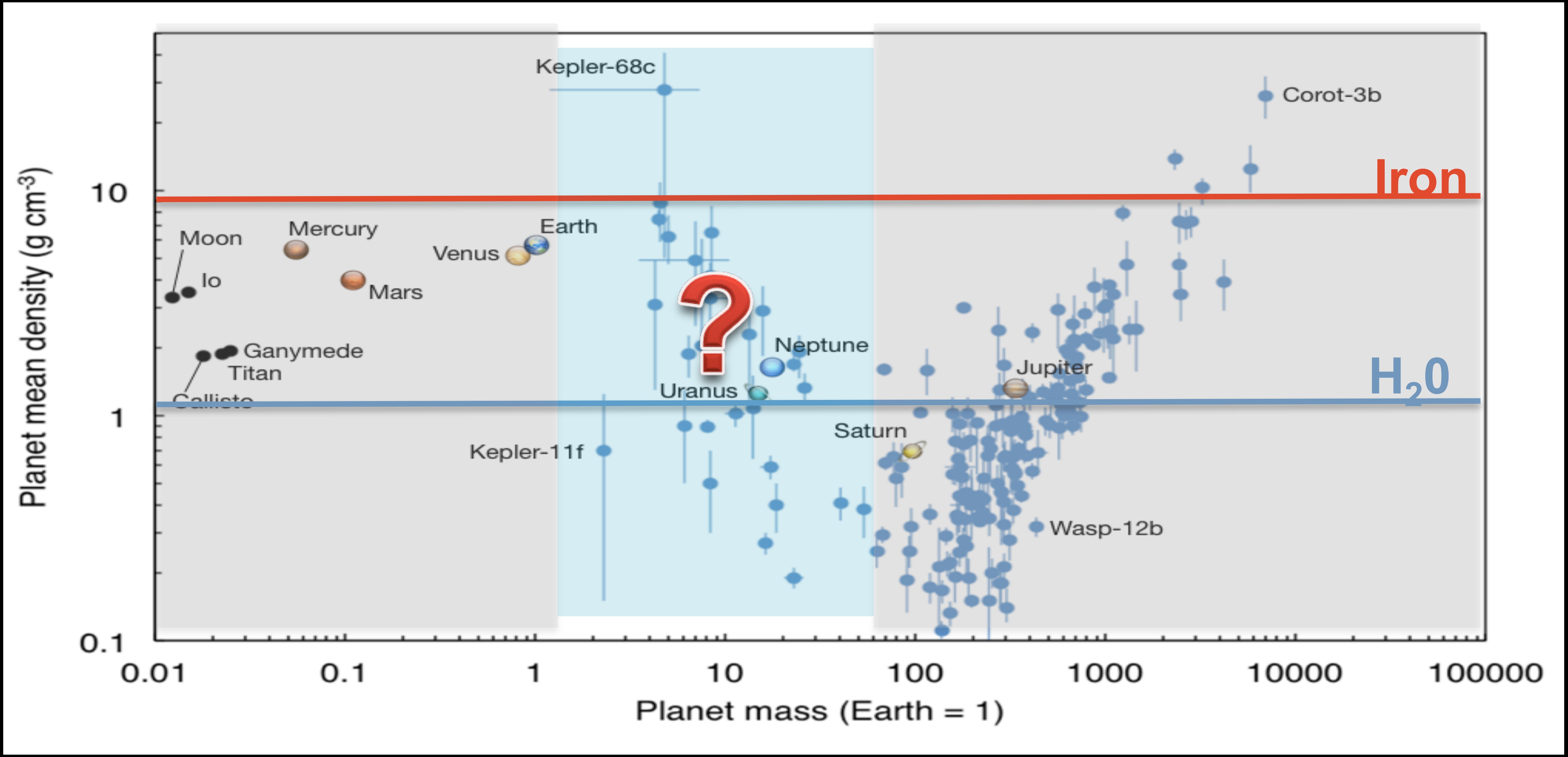

Temperature
0 K
50 K
100 K
150 K
200 K
250 K
300 K
350 K
400 K
450 K
500 K
550 K
600 K
650 K
Pressure
1 TPa
100 GPa
10 GPa
1 GPa
100 MPa
10 MPa
1 MPa
100 kPa
10 kPa
1 kPa
100 Pa
10 Pa
1 Pa
10 Mbar
1 Mbar
100 kbar
10 kbar
1 kbar
100 bar
10 bar
1 bar
100 mbar
10 mbar
1 mbar
100 µbar
10 µbar
-250 °C
-200 °C
-150 °C
-100 °C
-50 °C
0 °C
50 °C
100 °C
150 °C
200 °C
250 °C
300 °C
350 °C
XI (hexagonal)
X
100 K, 62 GPa
VIII
VII
II
V
278 K, 2.1 GPa
VI
355.00 K, 2.216 GPa
XV
218 K, 620 MPa
272.99 K, 632.4 MPa
IX
248.85 K, 344.3 MPa
256.164 K, 350.1 MPa
238.5 K, 212.9 MPa
251.165 K, 209.9 MPa
Critical point
647 K, 22.064 MPa
Solid
III
Liquid
XI
(ortho-
rhombic)
Ic
Ih
Freezing point at 1 atm
273.15 K, 101.325 kPa
Boiling point at 1 atm
373.15 K, 101.325 kPa
Mars
Solid/Liquid/Vapour triple point
273.16 K, 611.657 Pa
Vapour

Take home ideas from day 4

- Almost all stars host planets
- Stars $< 1M_\odot$ are better suited for life
- Over 5000 exoplanets are know to date, through transiting (radius) and radial velocity methods (mass)
- Hundreds of densities measured
- Spectroscopy of giant planet attempt atmospheres is possible
- Biosignatures in atmospheres are derived from metabolic redox reactions

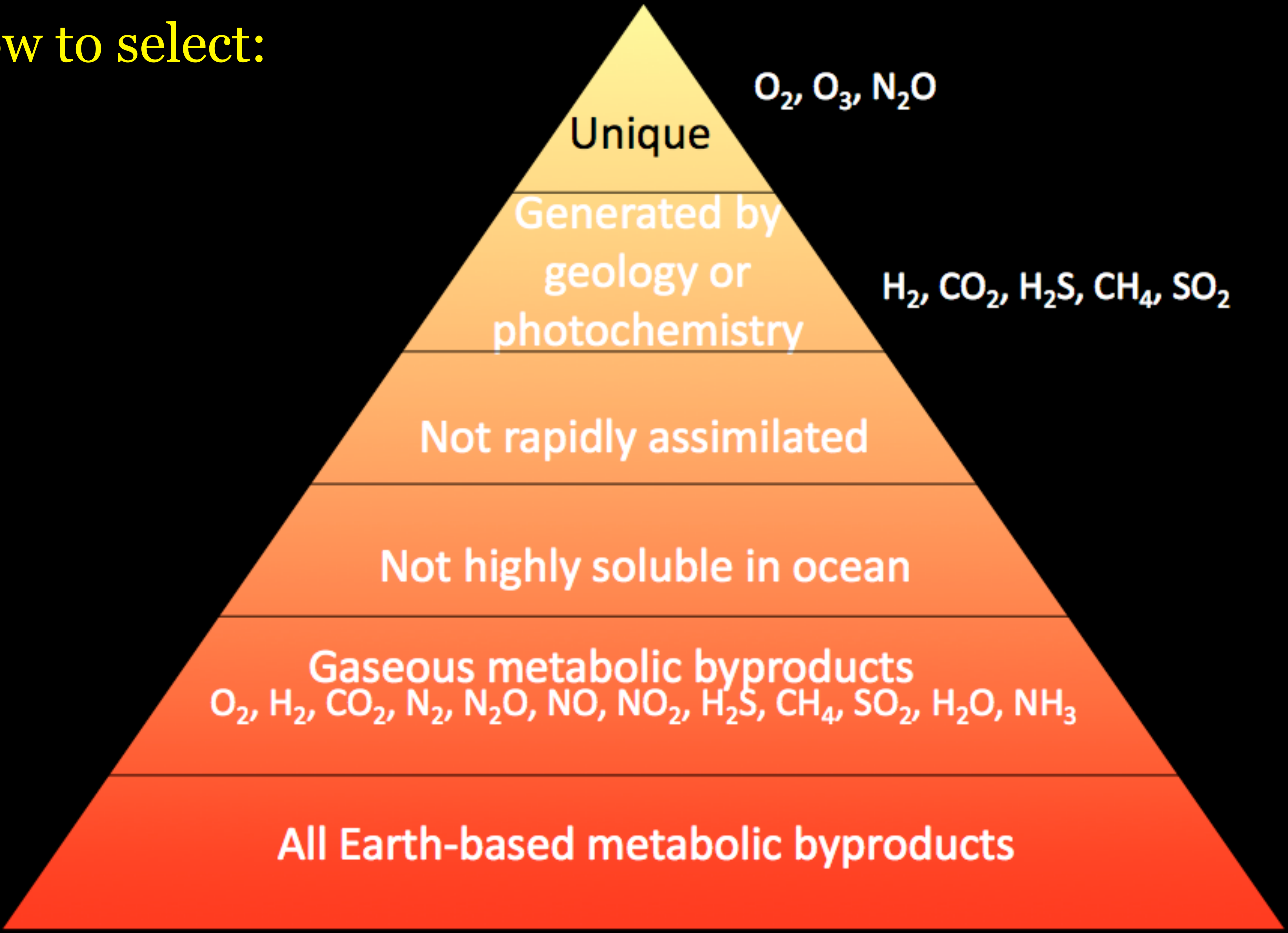
Mass - Radius relation

Mass and Radius allow to derive Density, i.e. Composition



Different atmospheres, different stellar fluxes could have different biosignatures…

How to select:



Unique

O_2, O_3, N_2O

Generated by geology or photochemistry

H_2, CO_2, H_2S, CH_4, SO_2

Not rapidly assimilated

Not highly soluble in ocean

Gaseous metabolic byproducts

O_2, H_2, CO_2, N_2, N_2O, NO, NO_2, H_2S, CH_4, SO_2, H_2O, NH_3

All Earth-based metabolic byproducts

Take home ideas from day 5

- Alien biochemistries can expand our idea of life (and habitats)
- Intelligence and consciousness developed with time as part of evolution
- SETI is in fact searching for technology (high risk, high return)
- Astrobiology:
  - How does life begin and evolve?
  - Does life exist elsewhere in the Universe?
  - What is the future of life on Earth?

Homework:

- Read some of the many good popular science books on astrobiology and related fields

- Stay curious and open minded

The End for Today

Astrobiology
An Overview

Markus Kissler-Patig

IMPRS Graduate School 🙂

Thank you!