Life on Earth and Elsewhere

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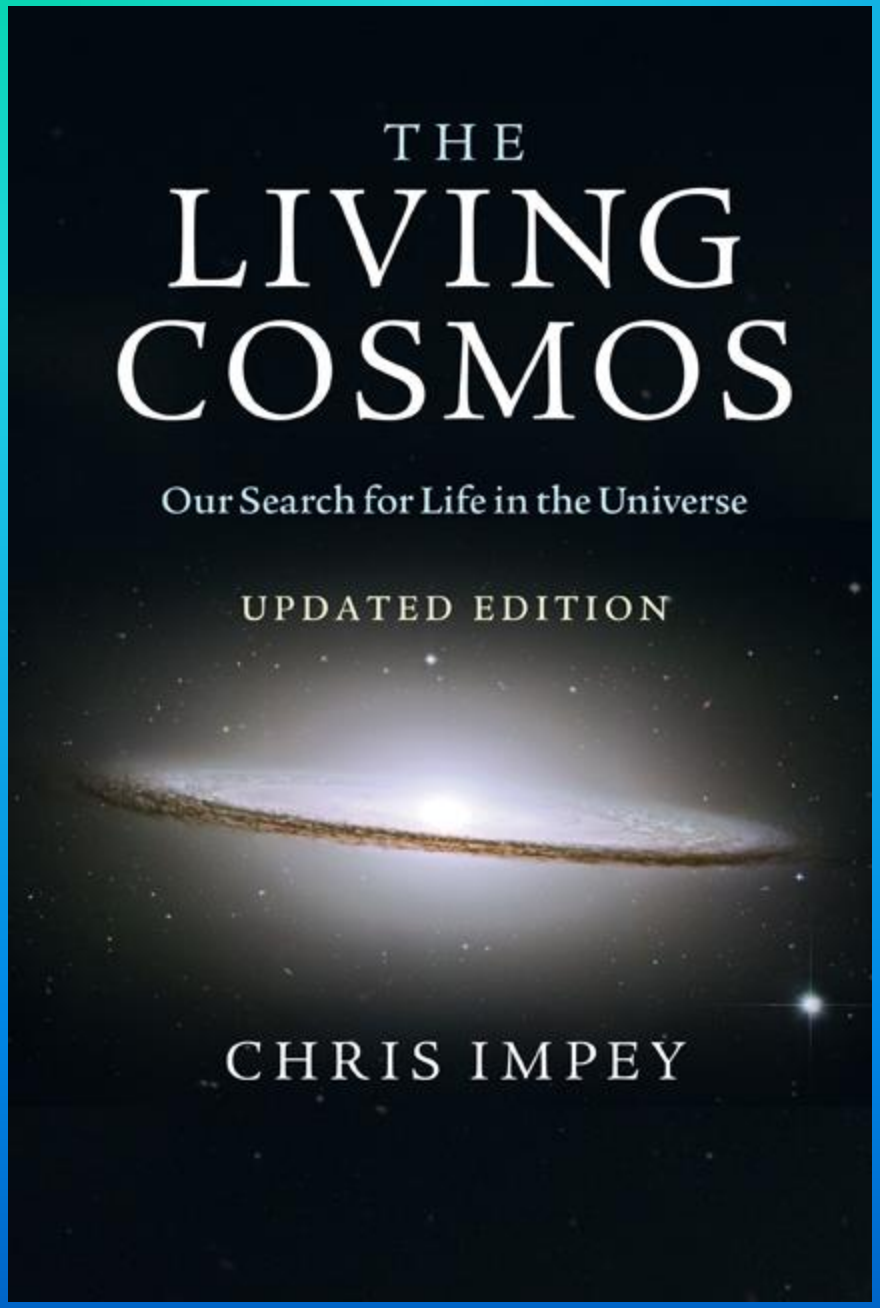
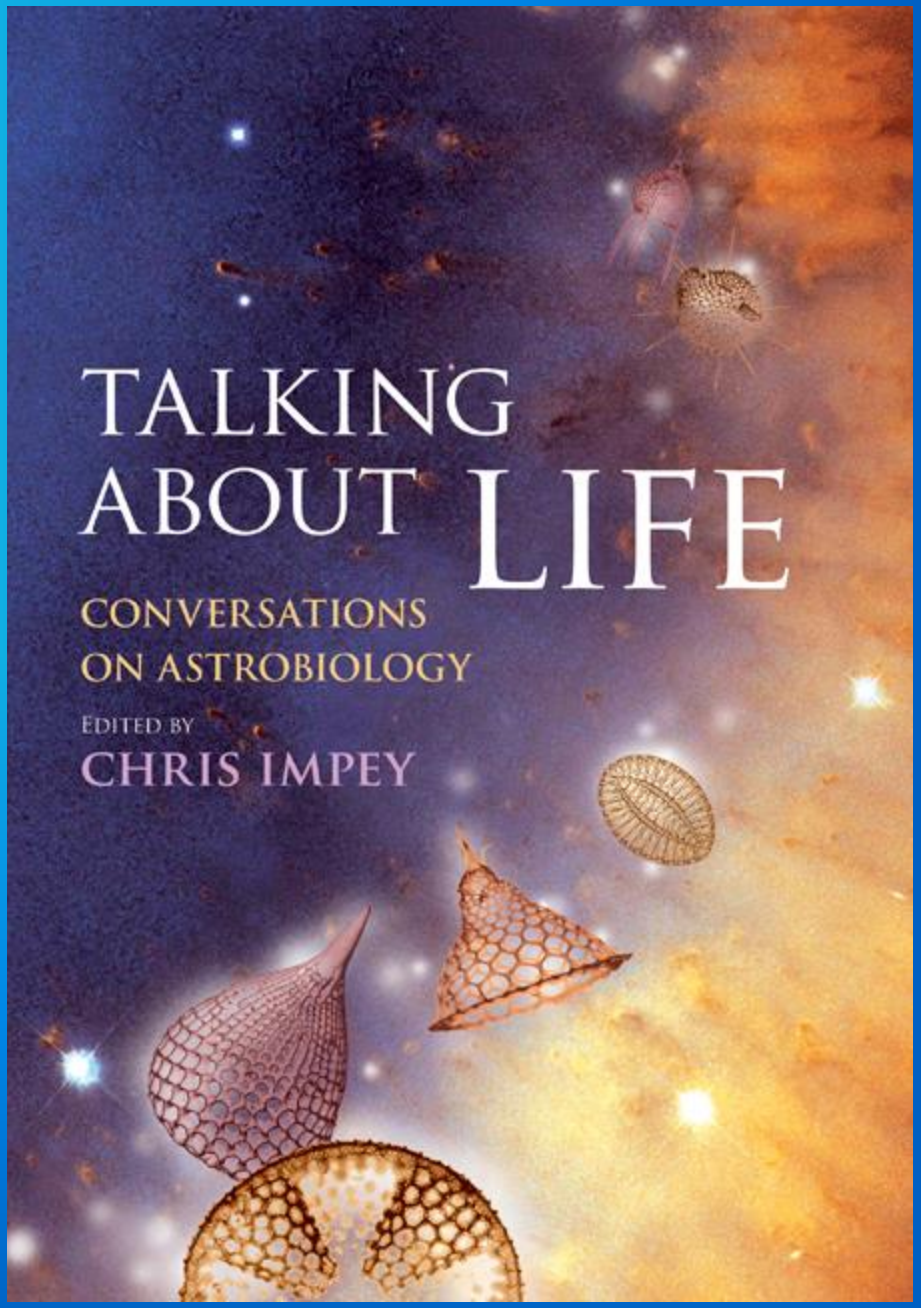
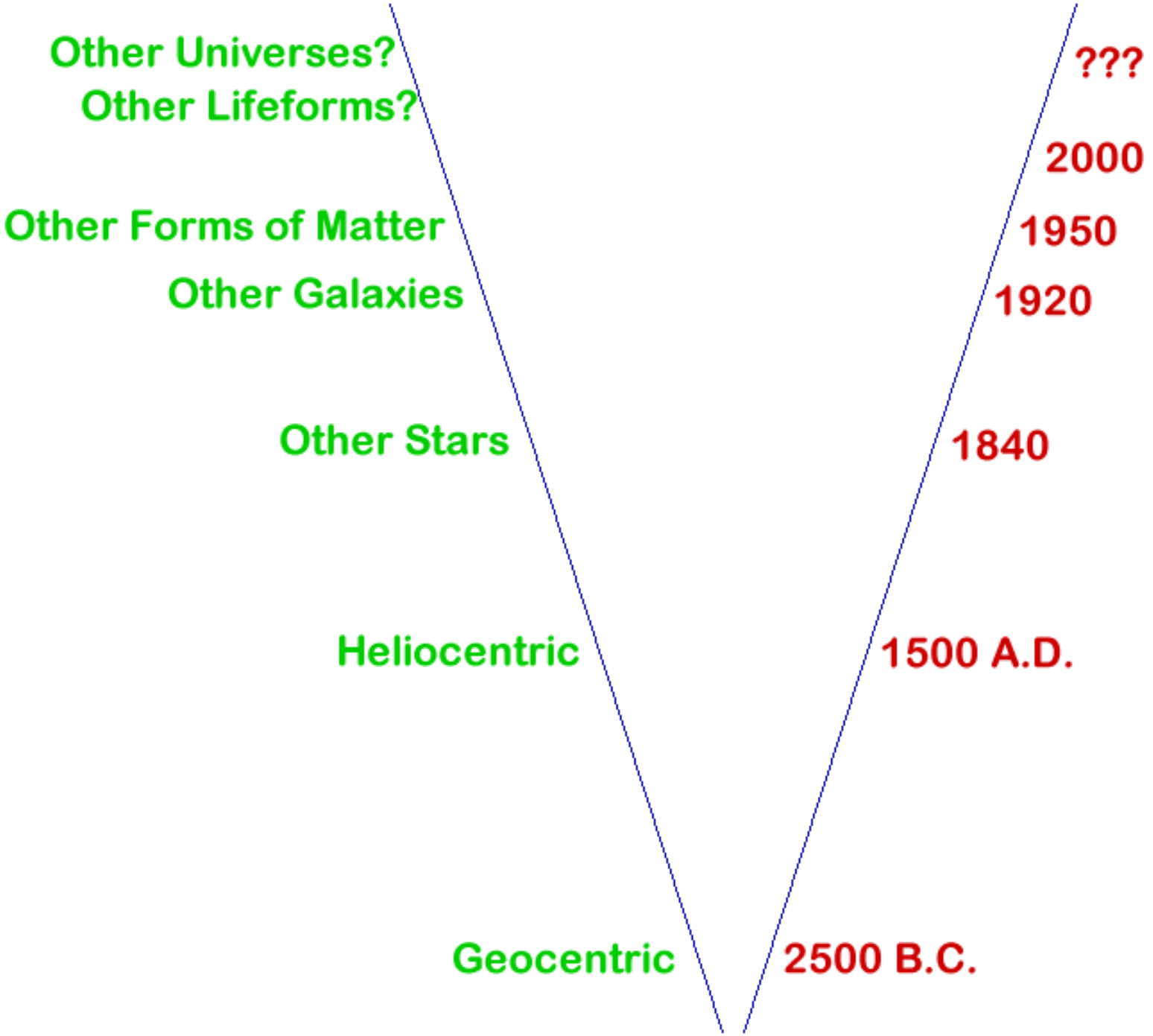
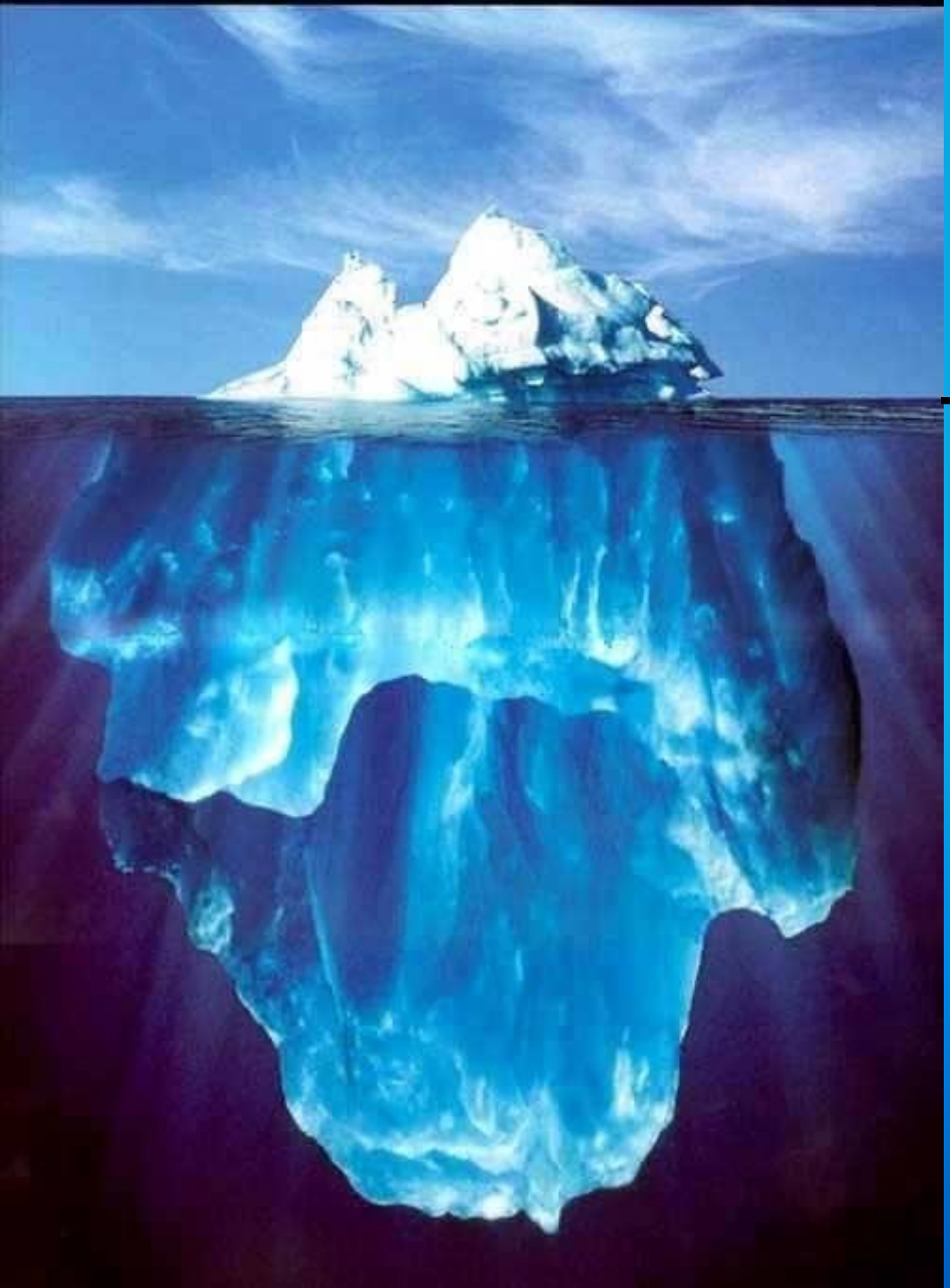

THE
LIVING
COSMOS
Our Search for Life in the Universe
UPDATED EDITION
CHRIS IMPEY


TALKING
ABOUT LIFE
CONVERSATIONS
ON ASTROBIOLOGY
EDITED BY
CHRIS IMPEY


Other Universes?
Other Lifeforms?
???
2000
Other Forms of Matter
1950
Other Galaxies
1920
Other Stars
1840
Heliocentric
1500 A.D.
Geocentric
2500 B.C.



What We Know (and don't…)

A majority of the biosphere is still unexplored.

Over 99% of microbes have not yet been cultured.

Only remote sensing through most of the Solar System.

A small fraction of habitable planets/moons discovered.

A tiny fraction of SETI search space explored.

"Cosmos Built for Life"

Human composition

Hydrogen
63%

Oxygen
26%

Carbon
9%

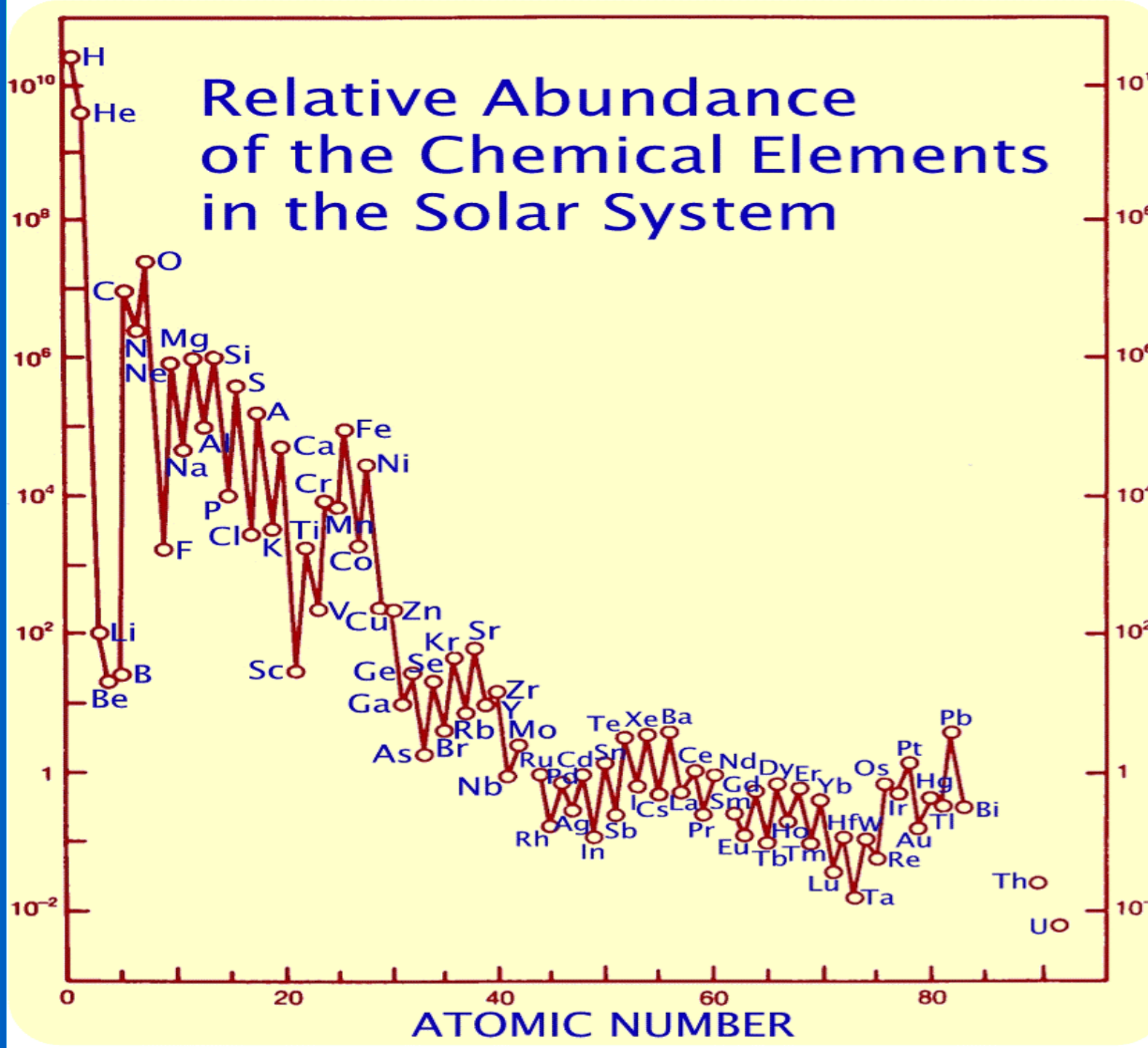
Nitrogen
1.25%

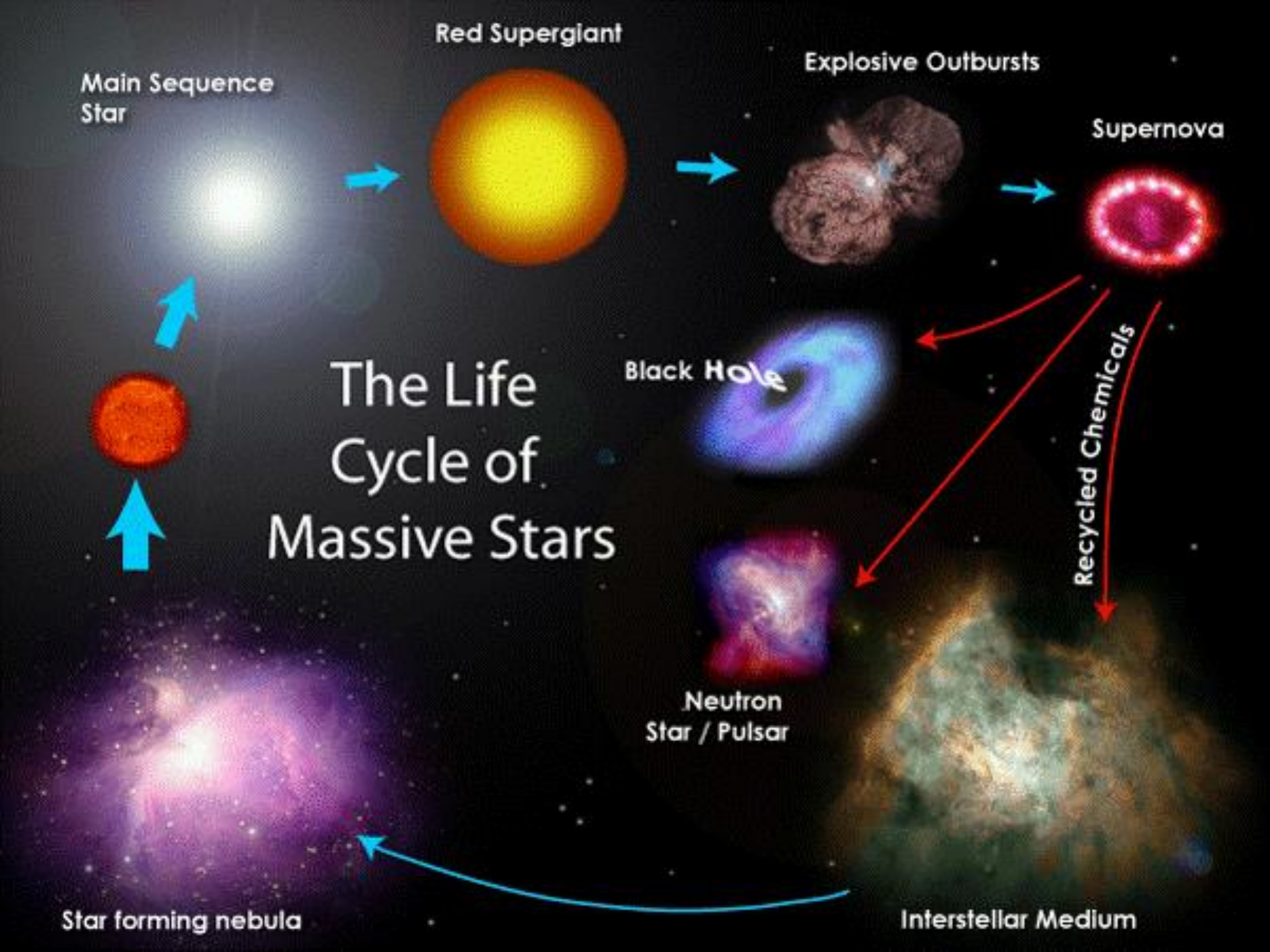
Calcium
0.25%

Phosphorus
0.19%

Potassium
0.06%

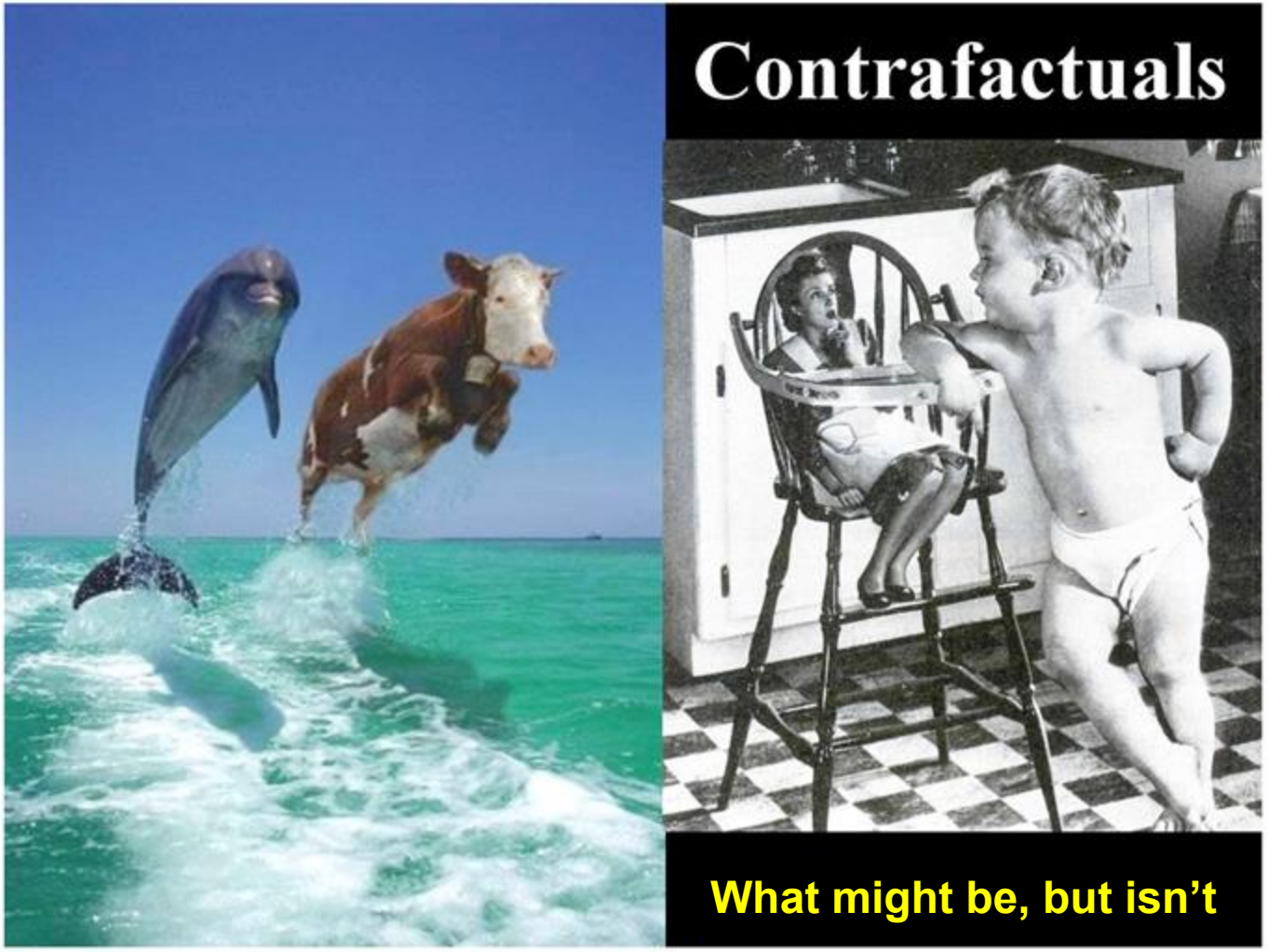
Sulfur
0.06%



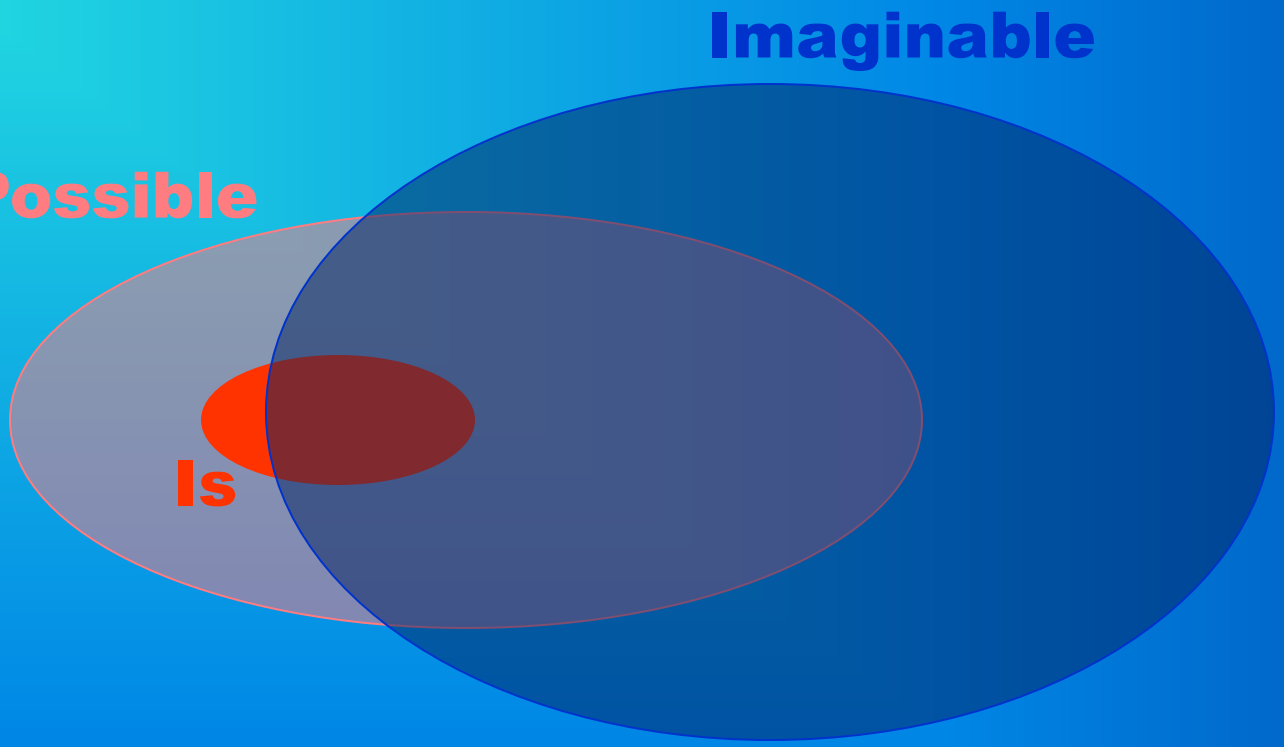

Red Supergiant
Explosive Outbursts
Main Sequence Star
Supernova
The Life Cycle of Massive Stars
Black Hole
Recycled Chemicals
Neutron Star / Pulsar
Star forming nebula
Interstellar Medium

"Defining Life is Hard"


DARWIN
MY COUSIN
THE BEAGLE
HOLY BIBLE


Contrafactuals
What might be, but isn't

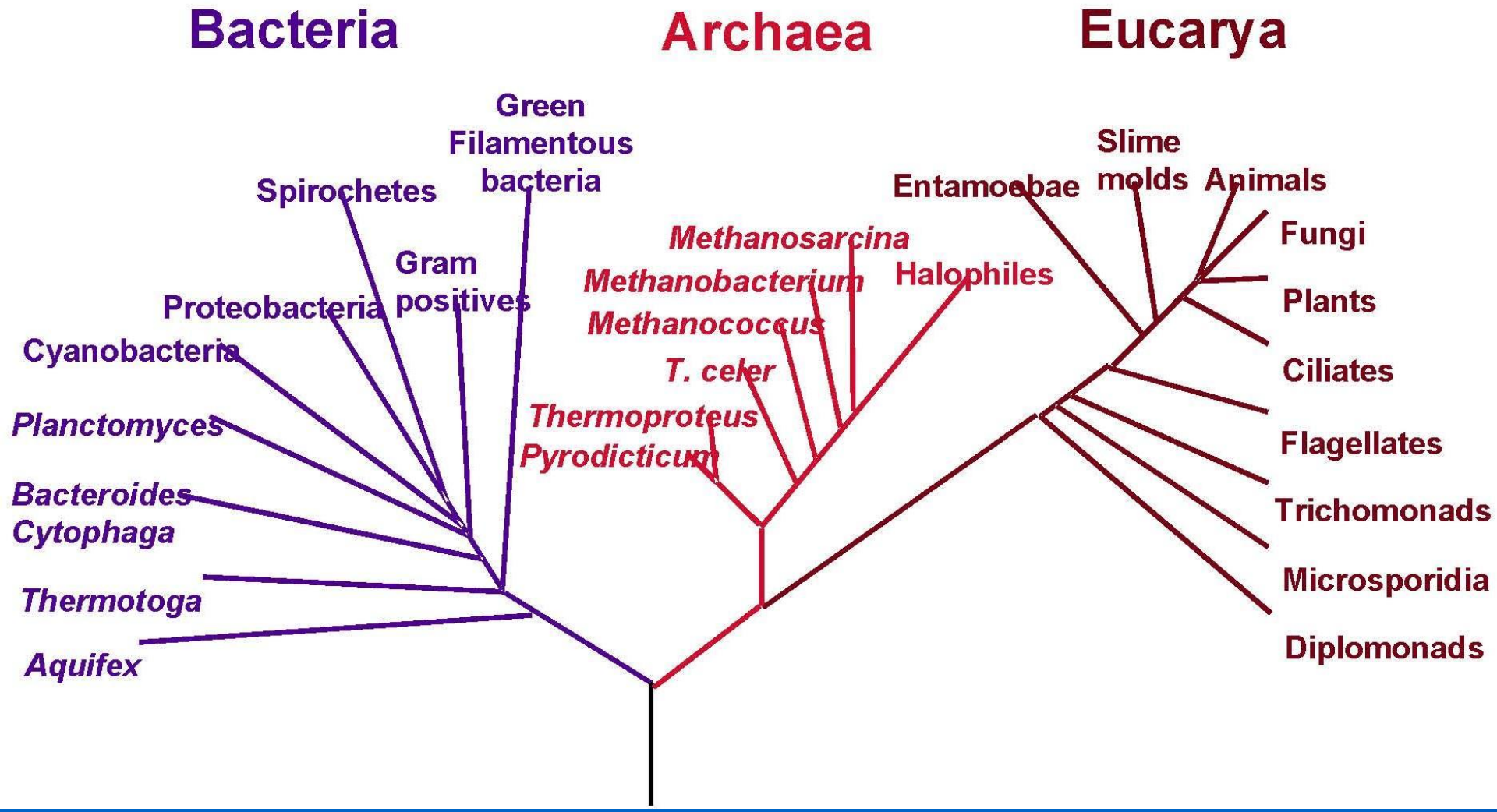
WHAT IS AND ISN'T



Isn't

"Life is One Thing"

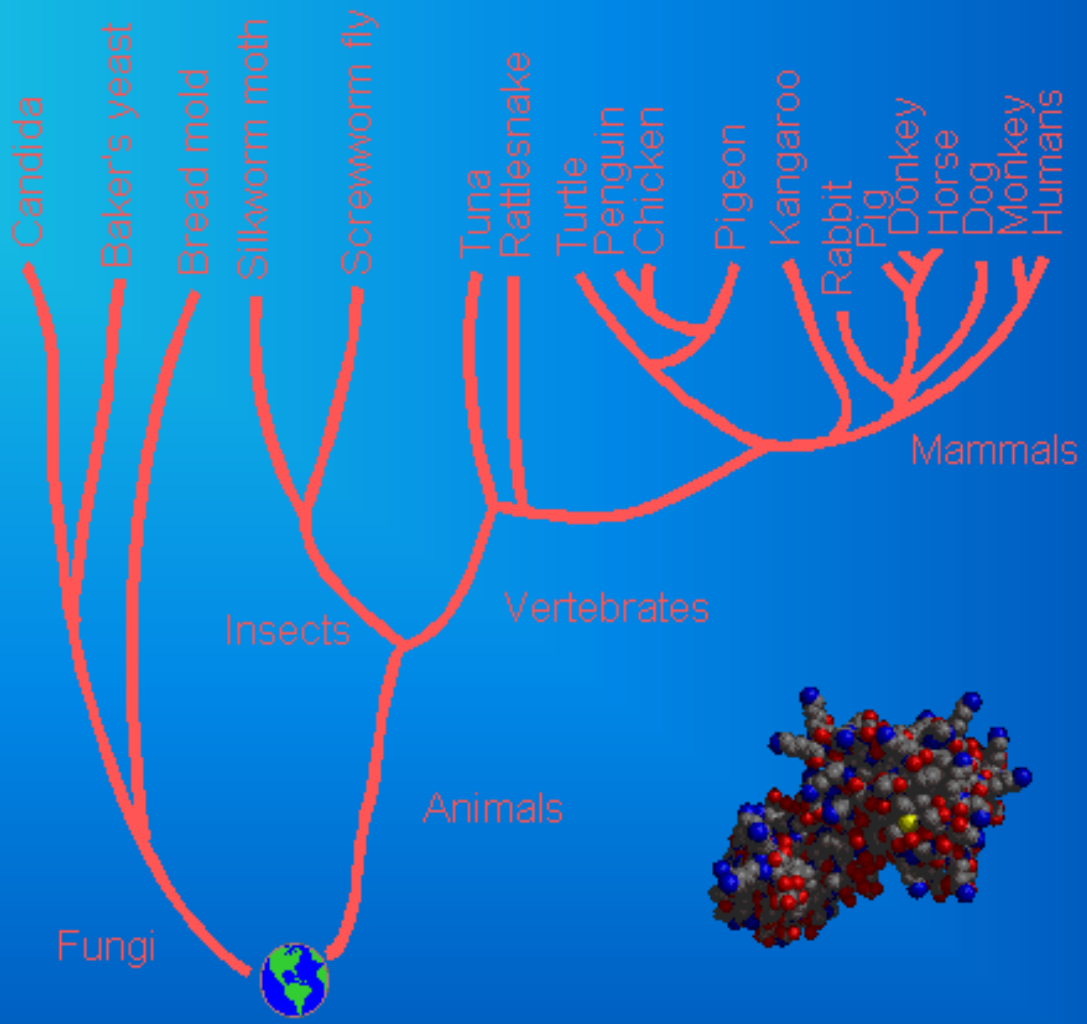
Phylogenetic Tree of Life



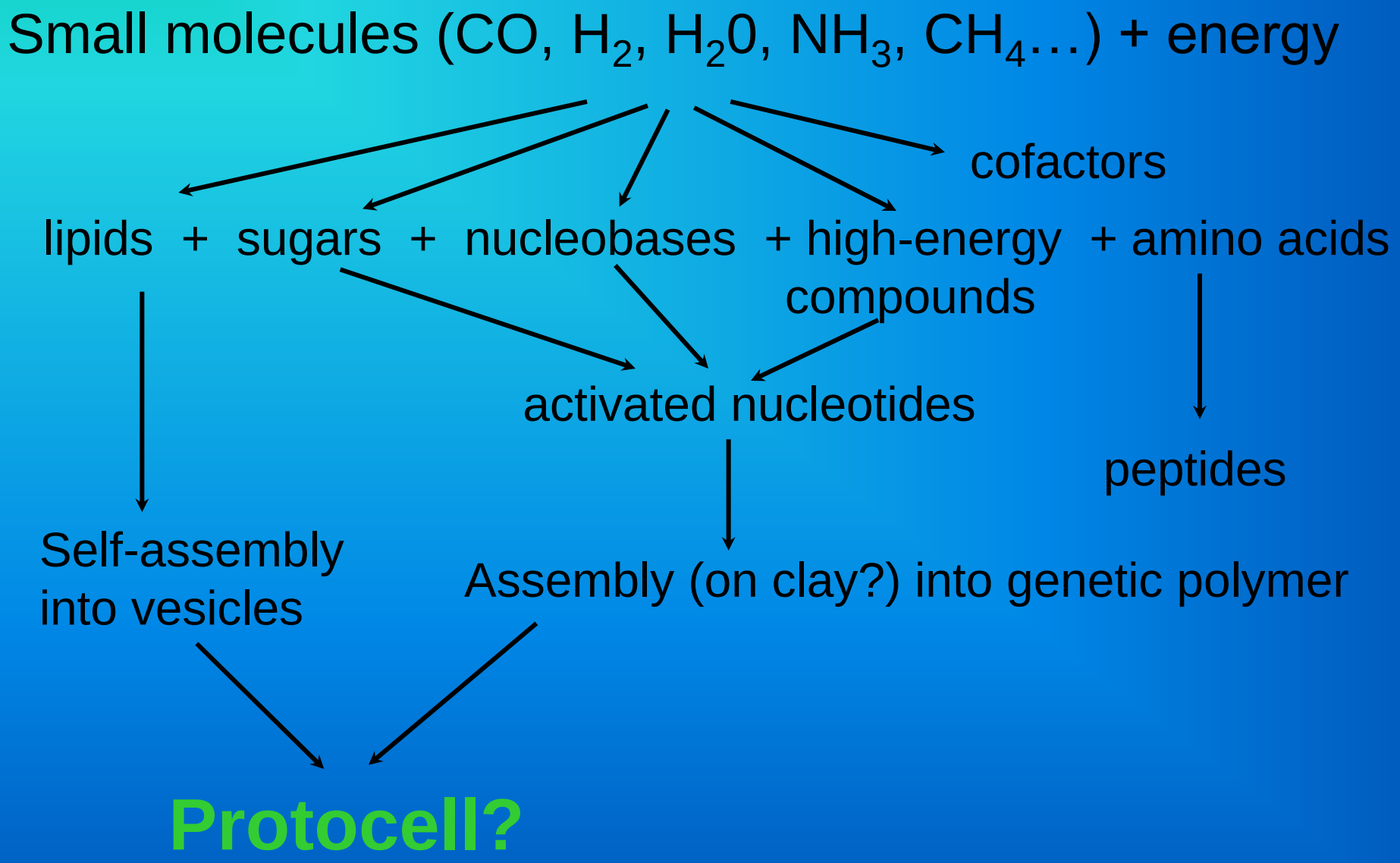
Evolutionary Linkage through Cytochrome C

Organism	# Deviant nuclic acids (in 110)
Human	0
Rhesus Monkey	1
Dog	13
Chicken	18
Rattlesnake	20
Tunafish	21
Moth	36
Wheat	43
Yeast	45

Next time you look into your glass of beer, acknowledge that there's kinship.

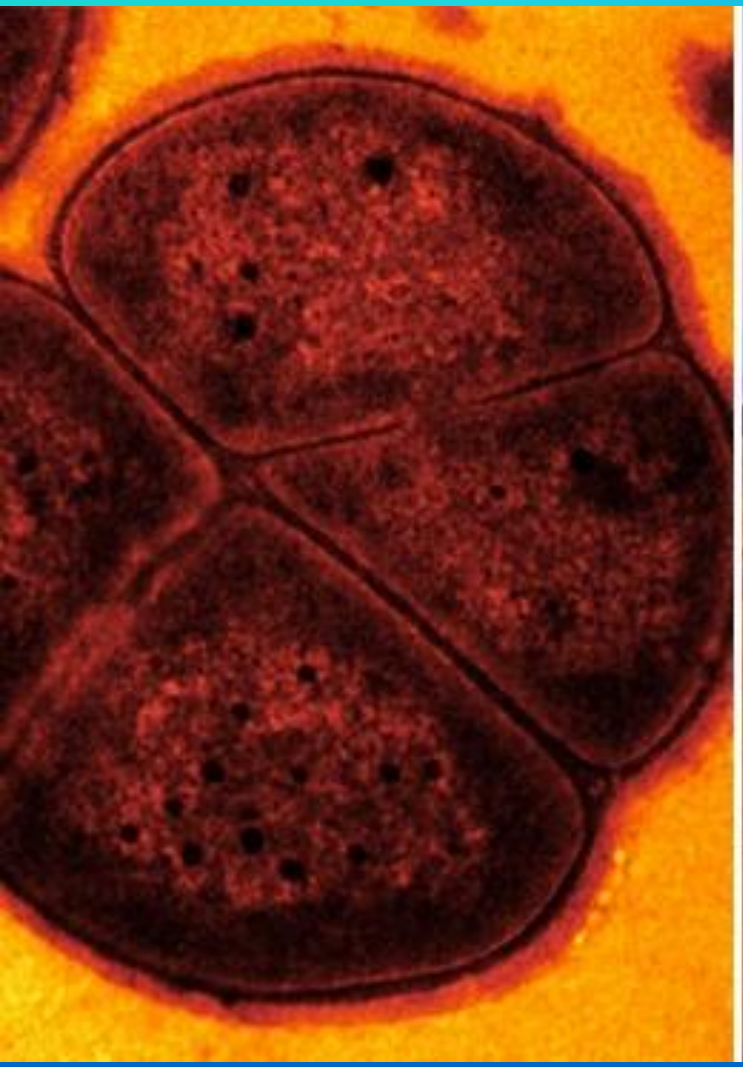


Steps Toward Life

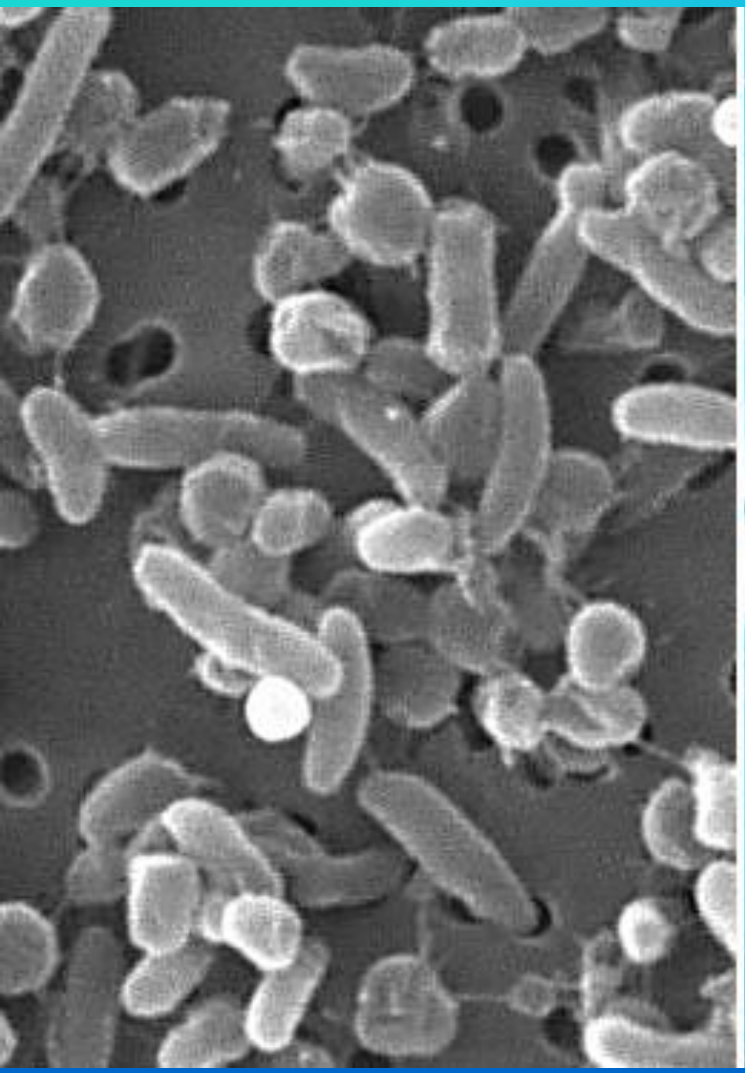


"Life on Earth is Hardy"

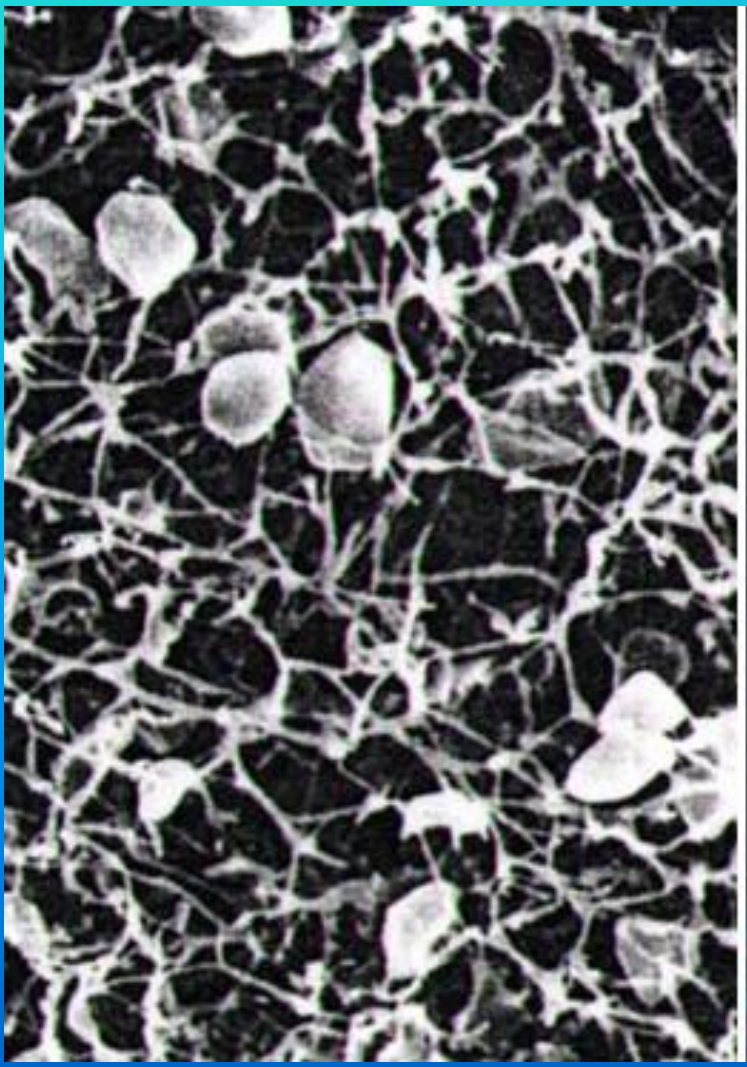
Extreme Dryness

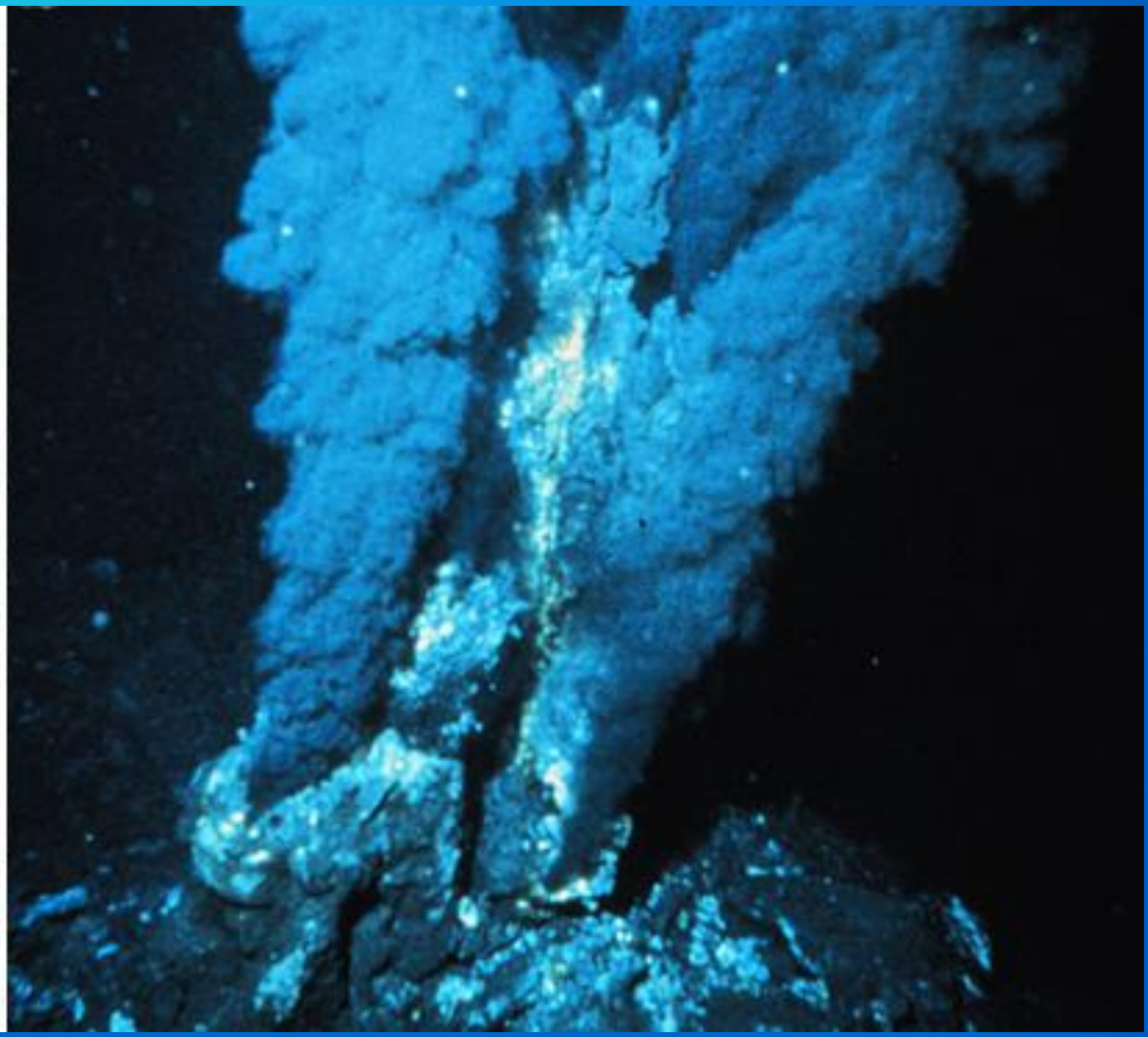


Extreme Cold

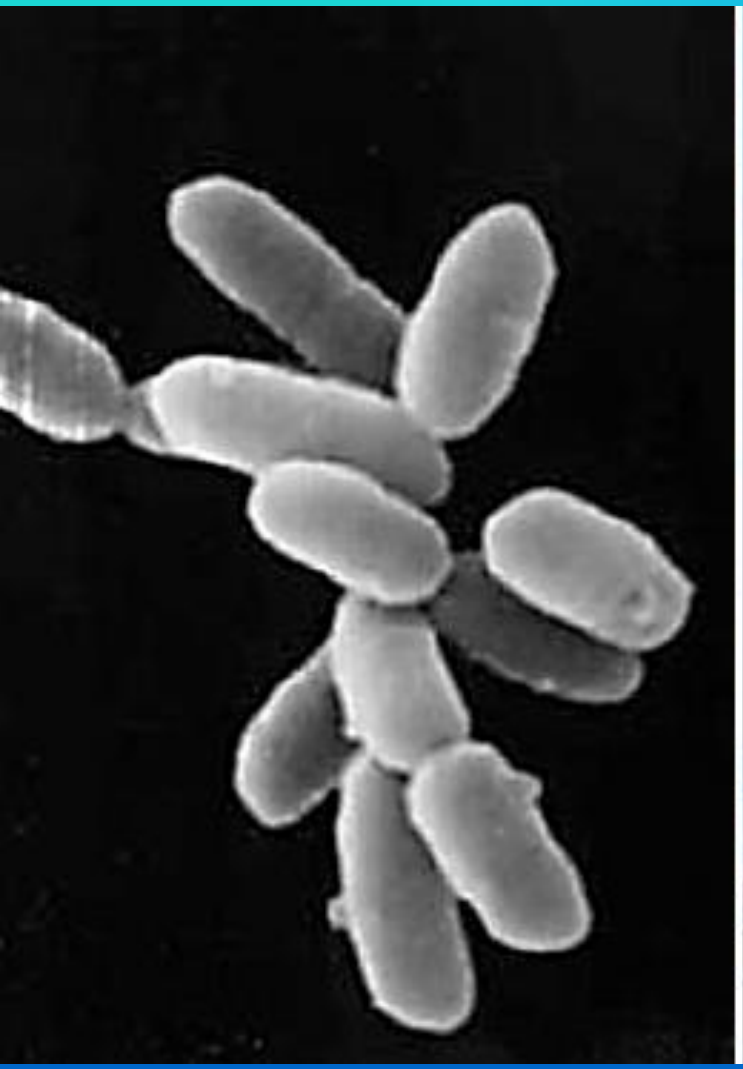


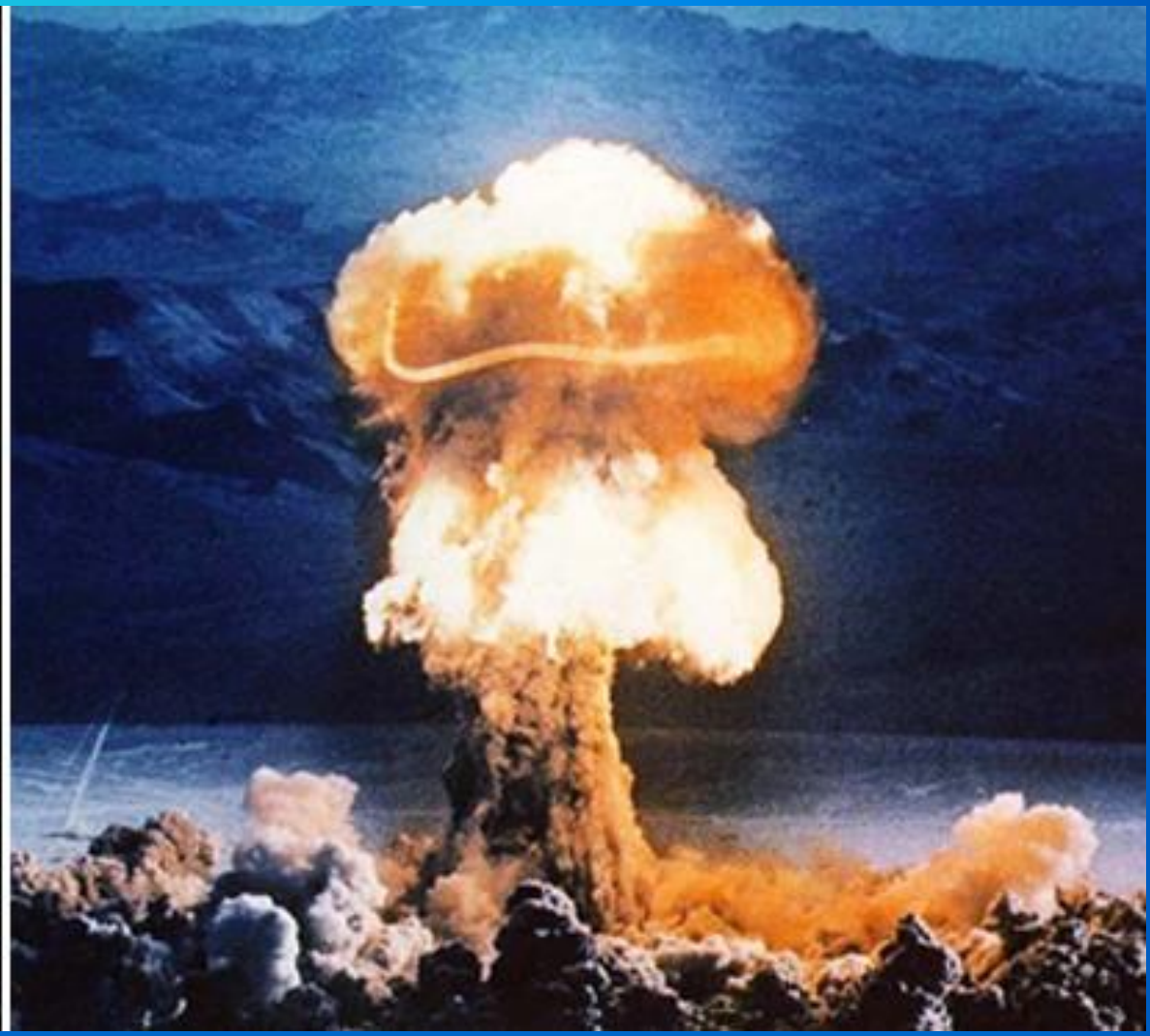
Extreme Heat



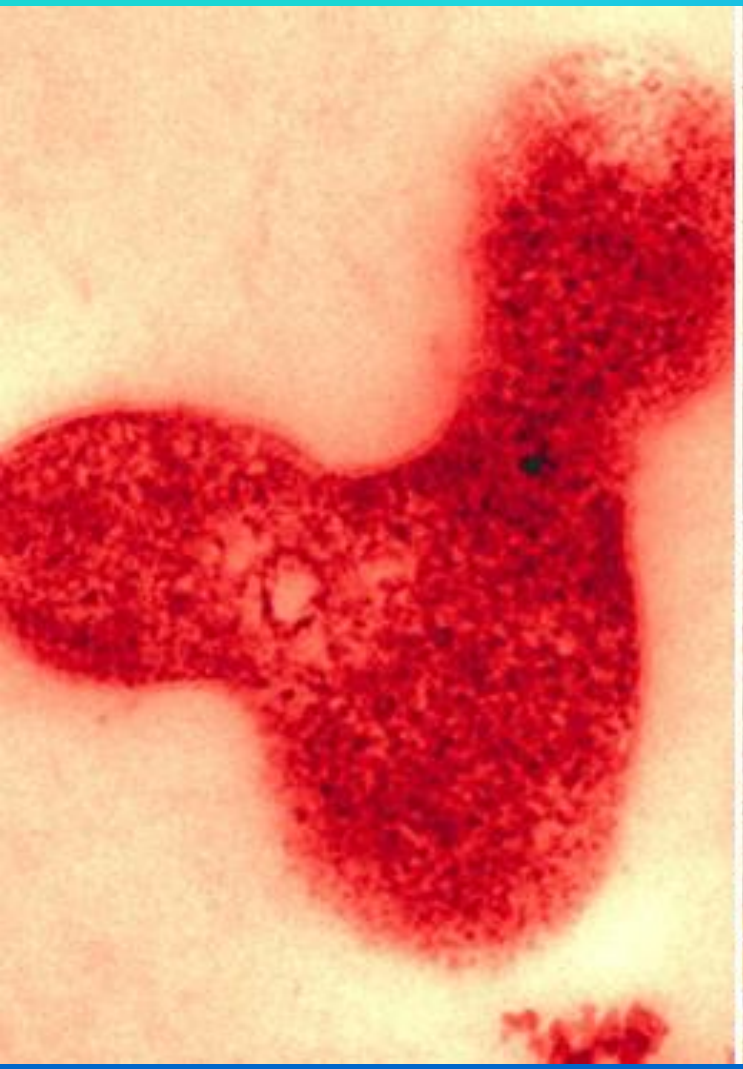


Extreme Radiation

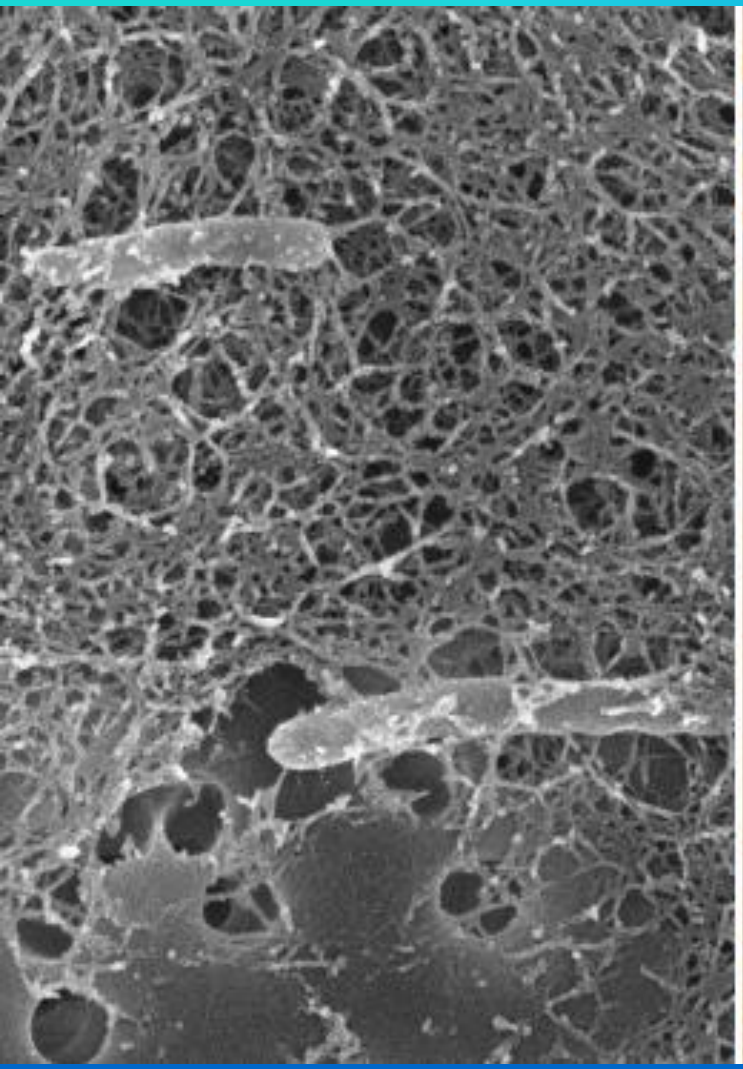


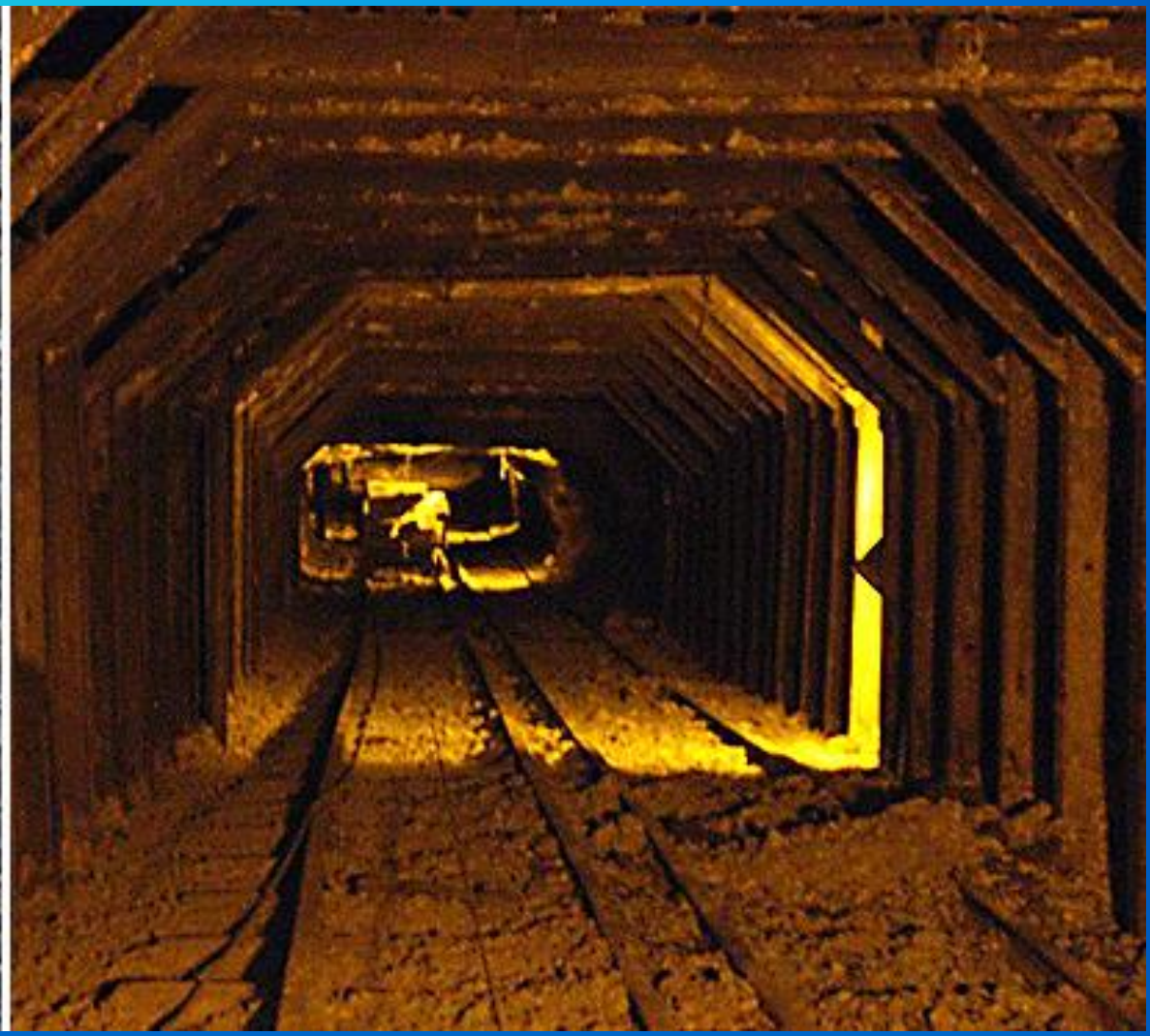


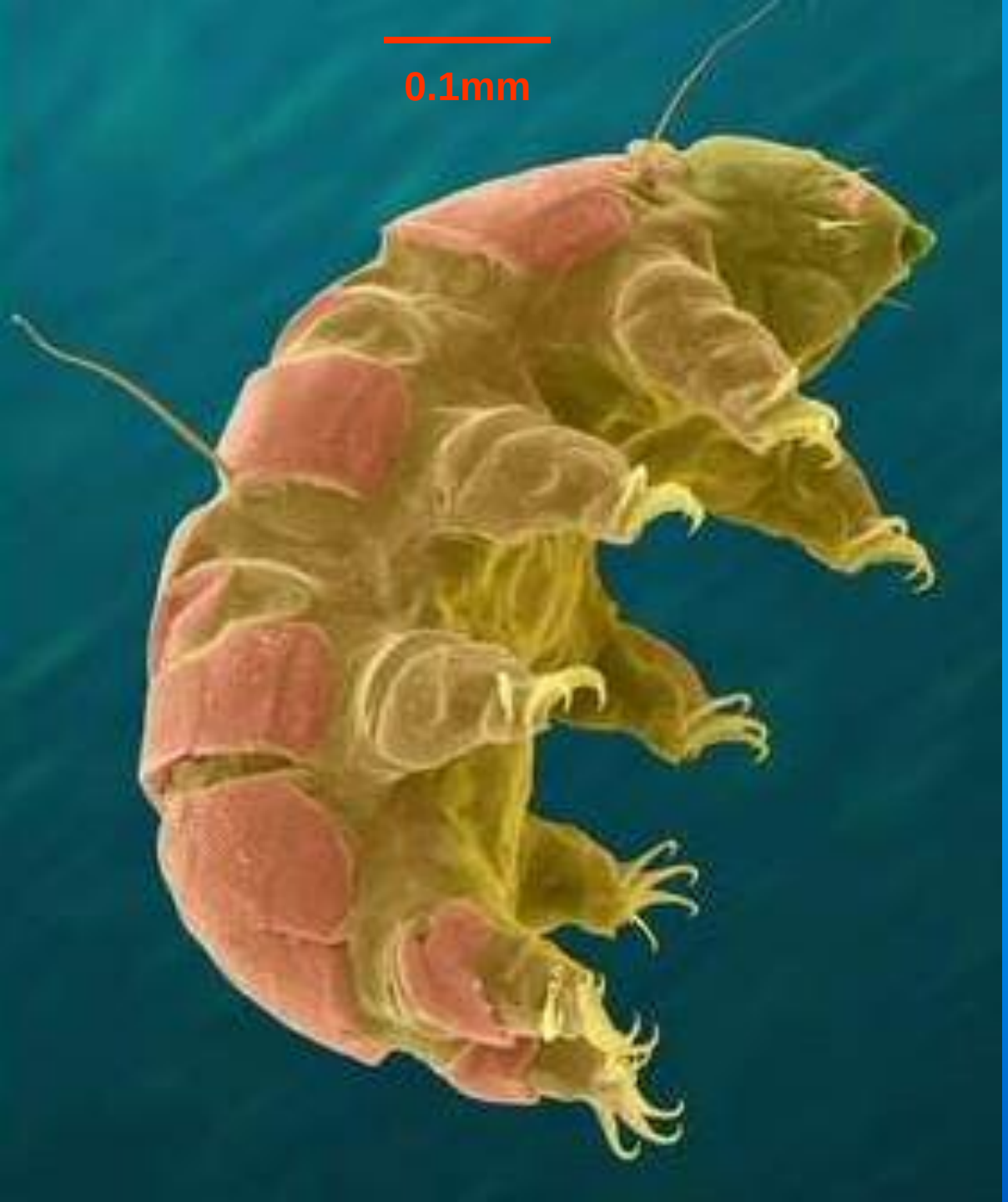
Extreme Toxicity



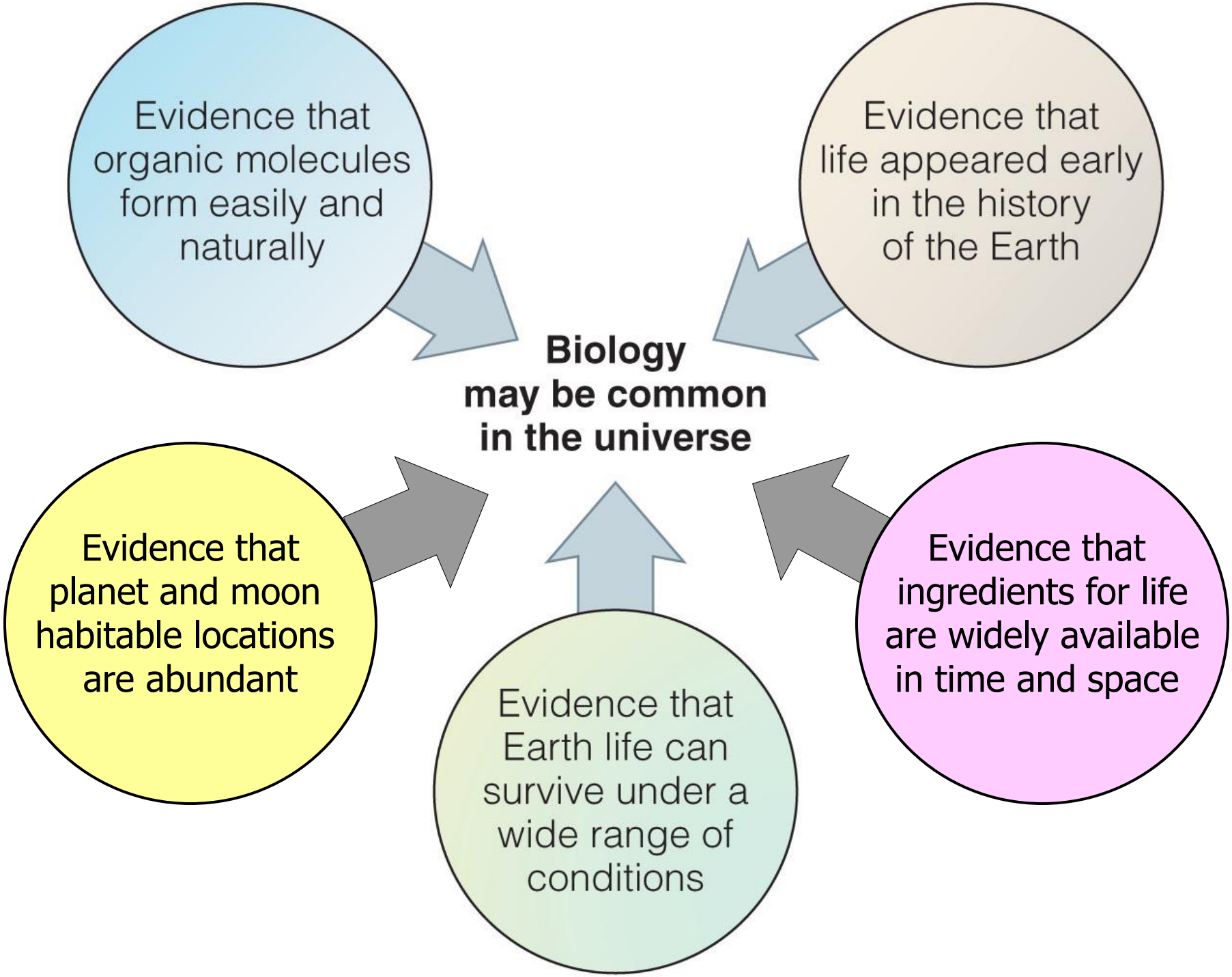
Extreme Isolation





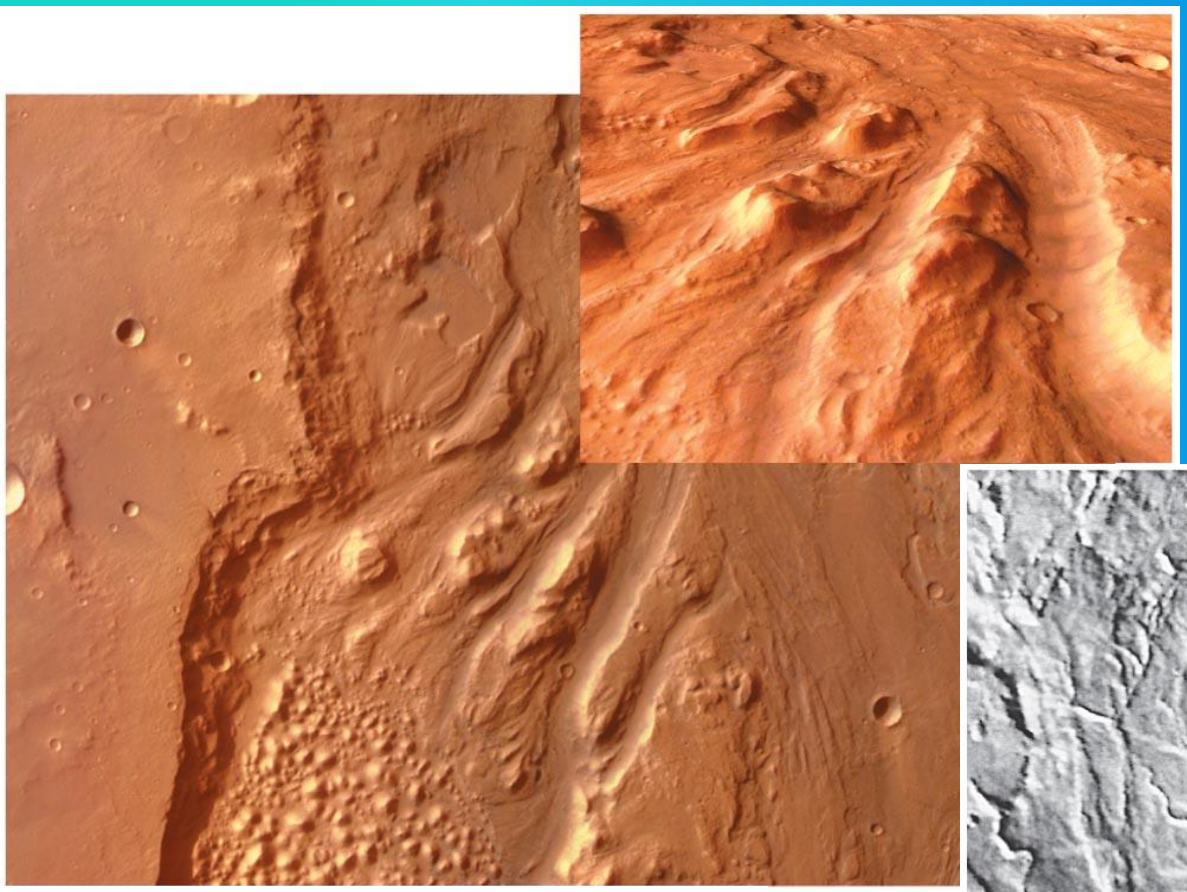


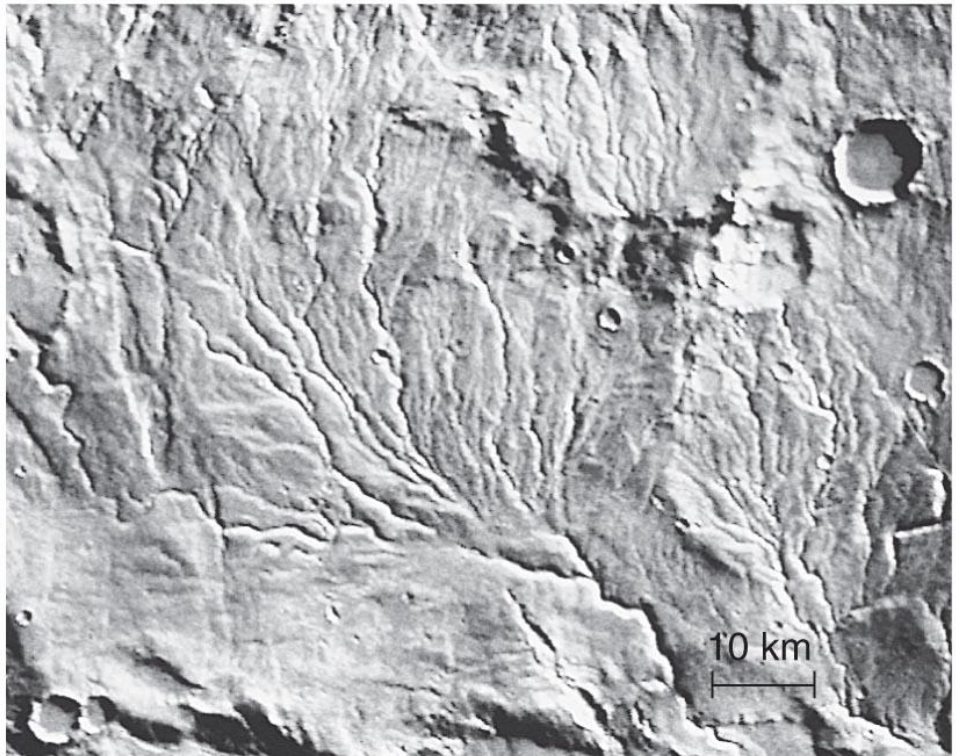
Meet the amazing tardigrade, with its own phylum and many species, it's got four pairs of legs, a digestive system, a single gonad, and it can go into a very dry suspended state (cryptobiosis) for over a thousand years, moving by being carried on the wind and also in fur of animals.

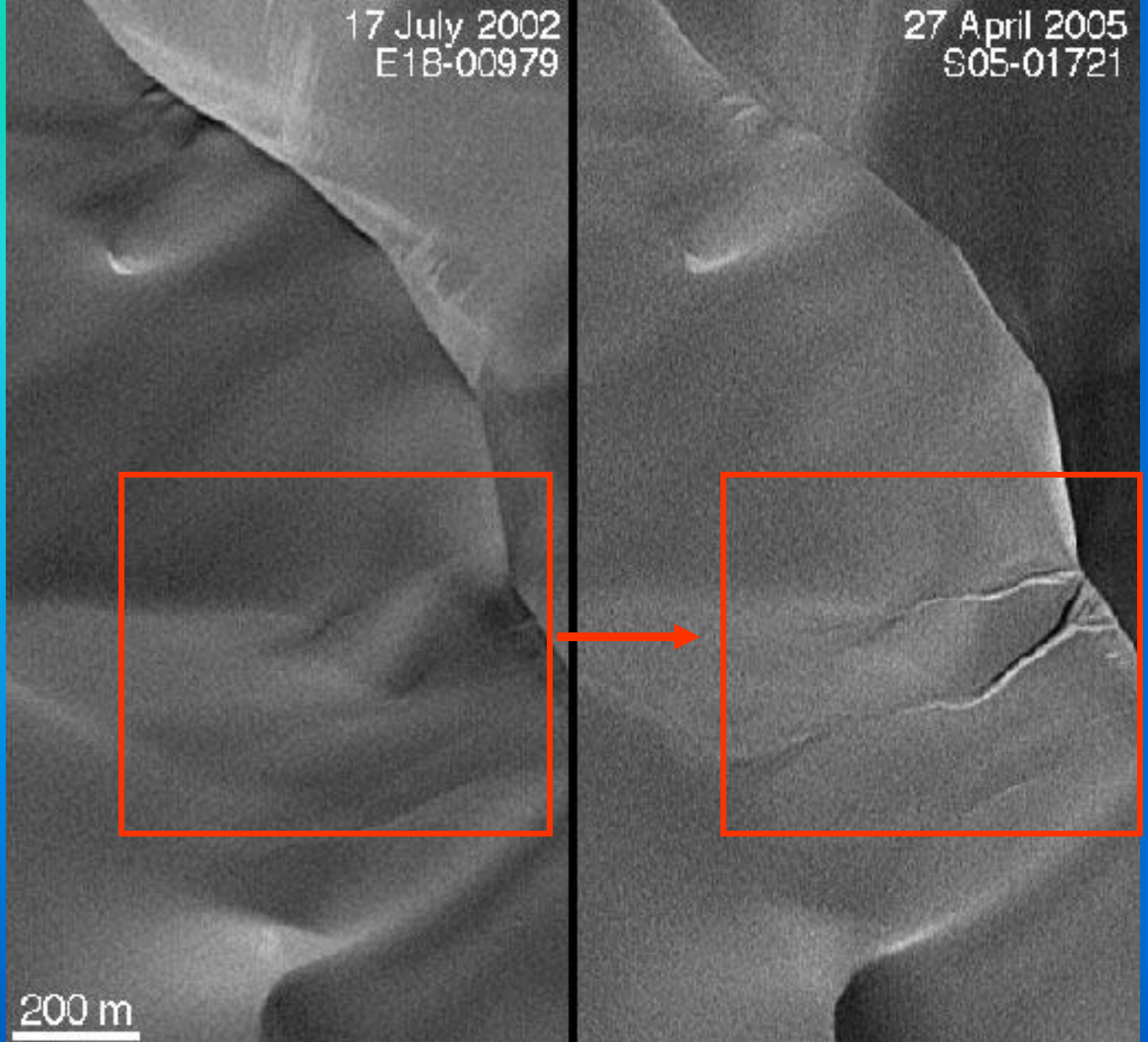

Evidence that organic molecules form easily and naturally
Evidence that life appeared early in the history of the Earth
Biology may be common in the universe
Evidence that planet and moon habitable locations are abundant
Evidence that Earth life can survive under a wide range of conditions
Evidence that ingredients for life are widely available in time and space

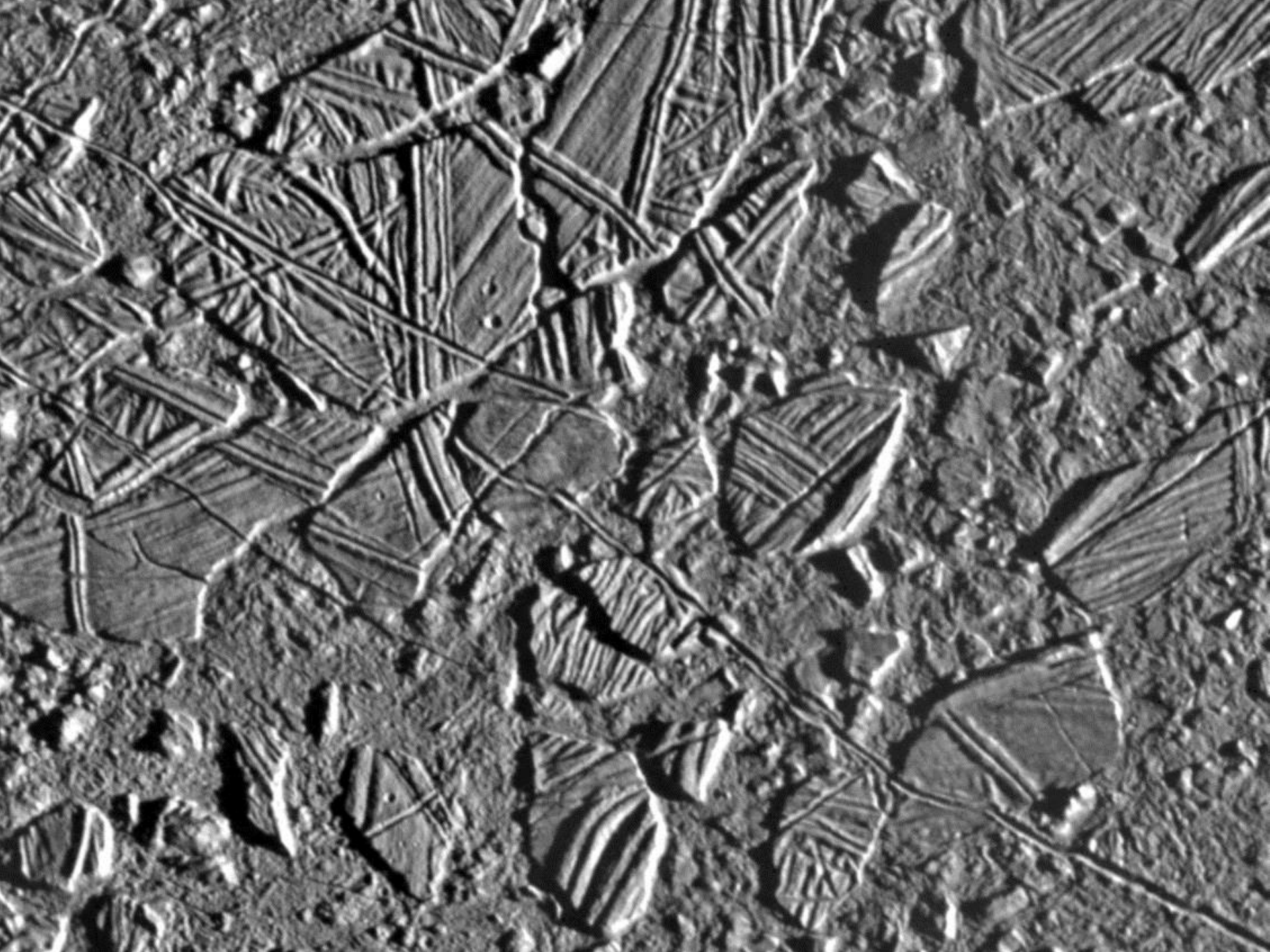
"Life in the Solar System"

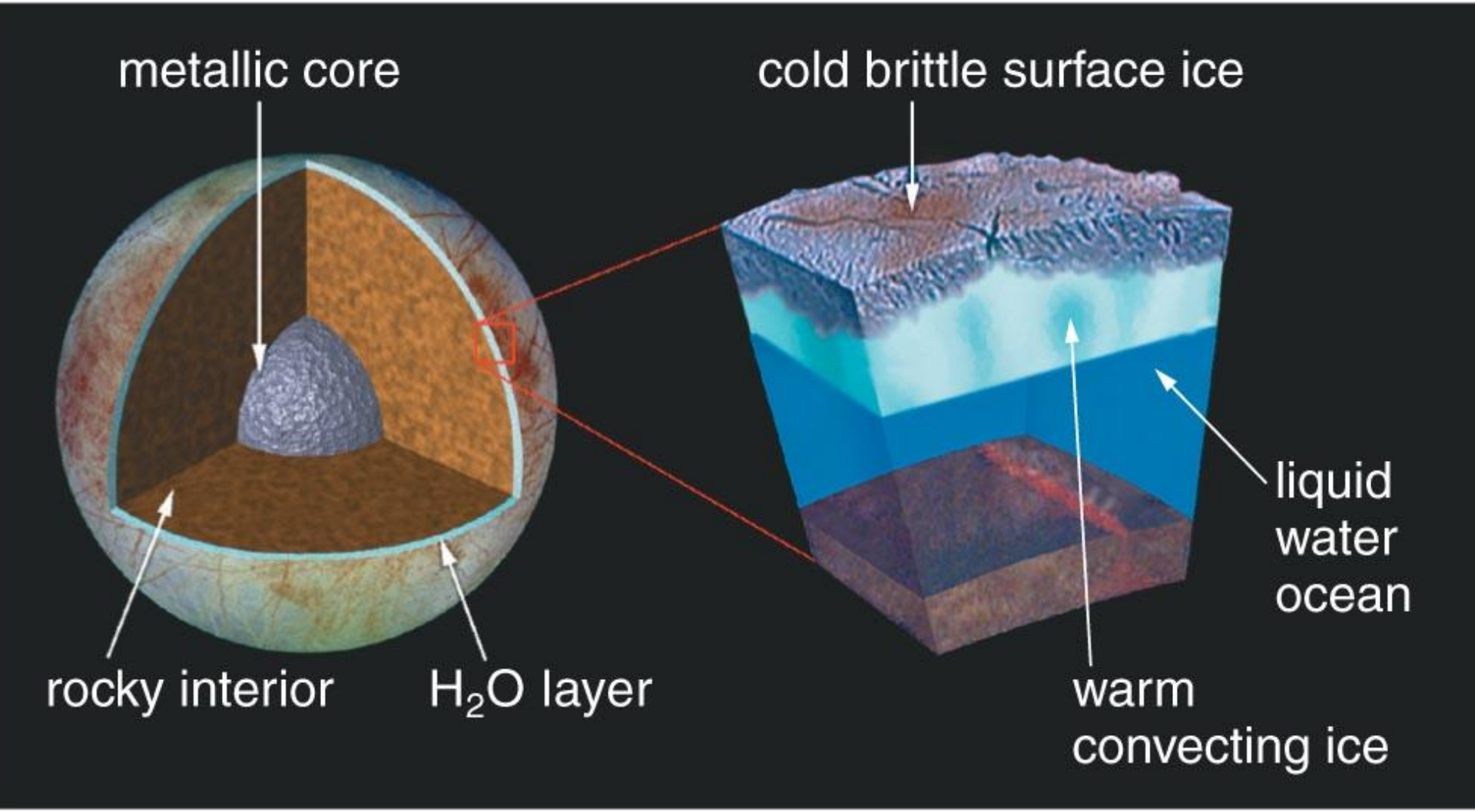
Evidence for Water

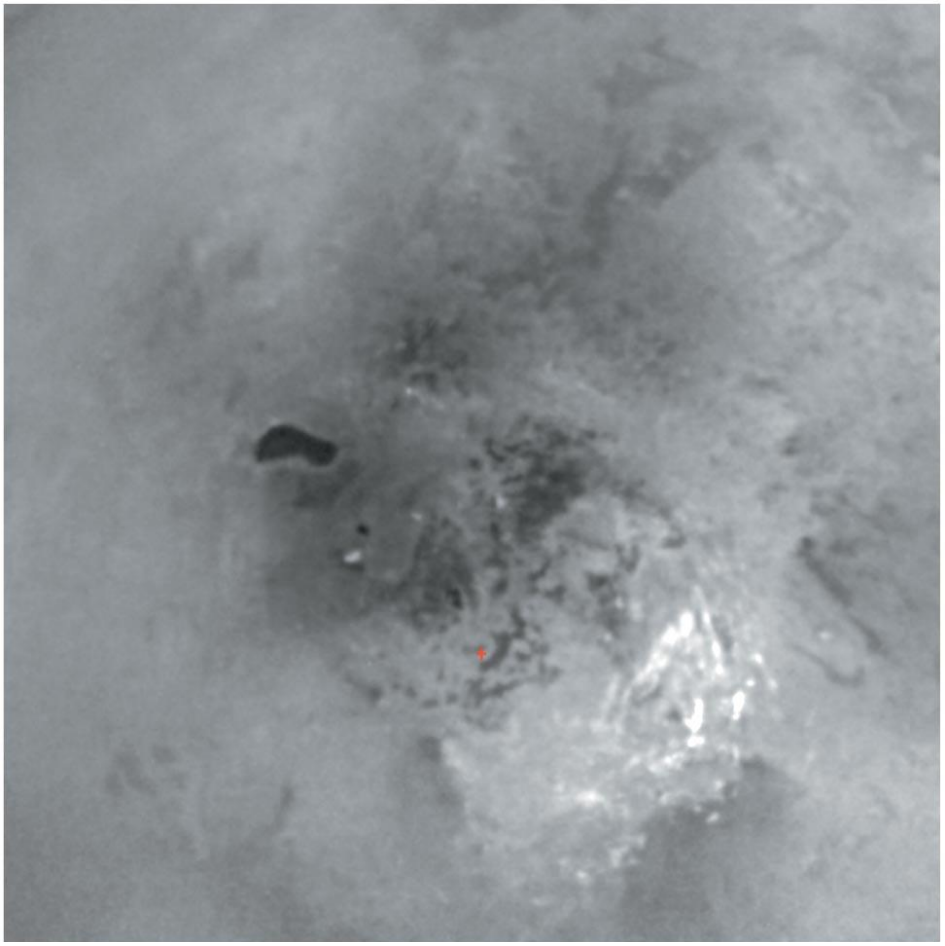





17 July 2002
E18-00979
27 April 2005
S05-01721
200 m

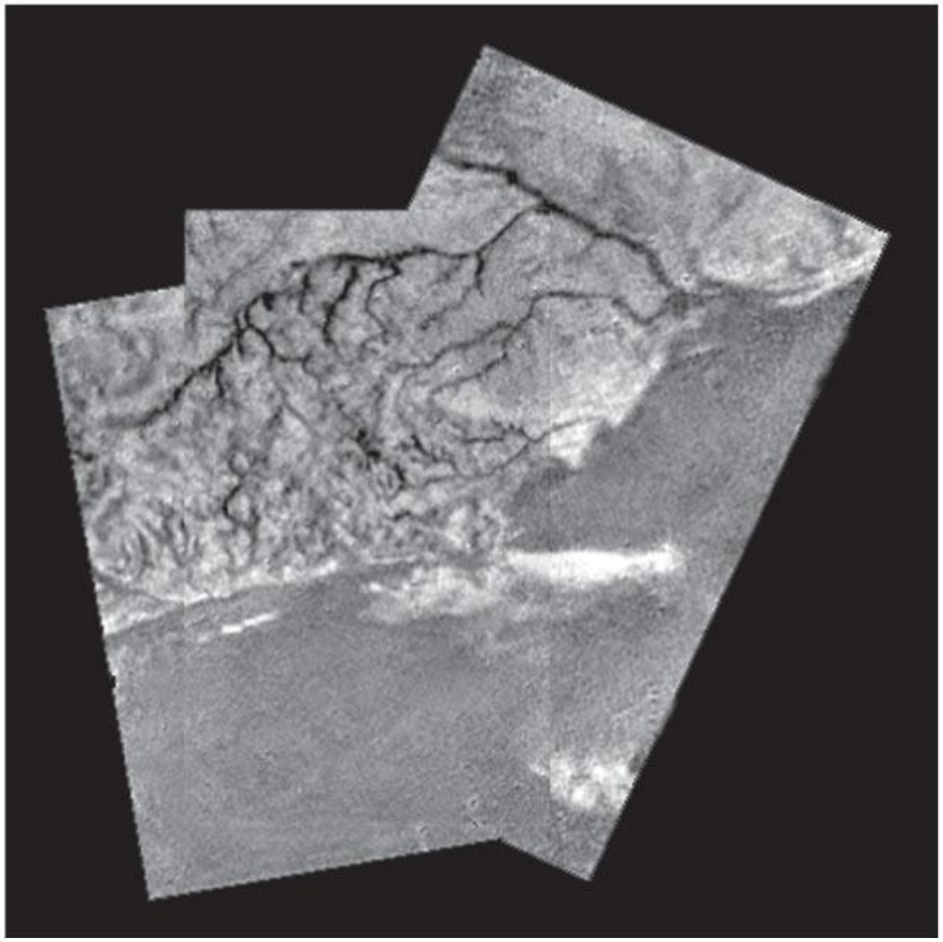



metallic core
cold brittle surface ice
liquid water ocean
rocky interior
H_2O layer
warm convecting ice

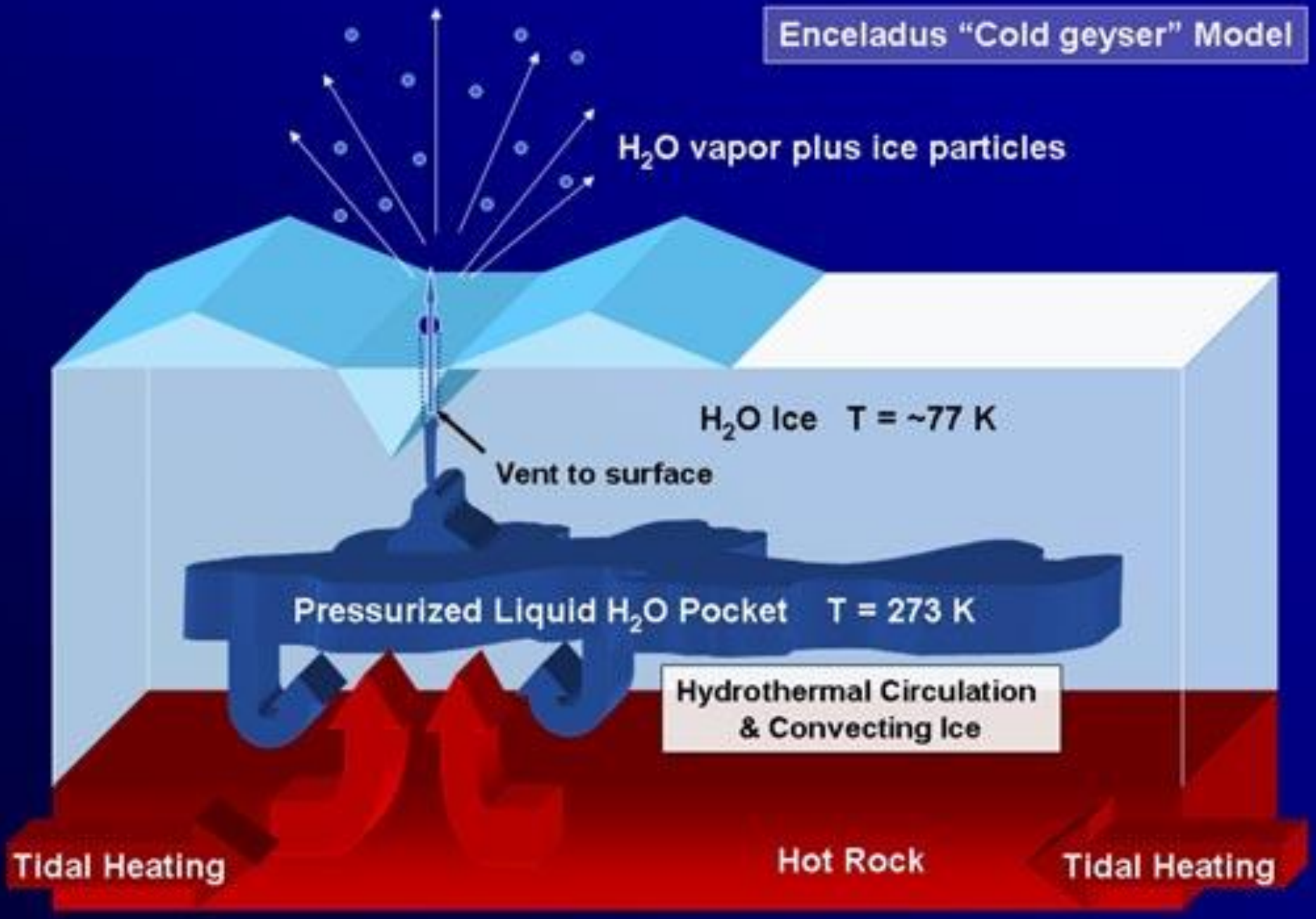


Ethane and methane lakes

Erosion and weathering




©1999 Walter Myers

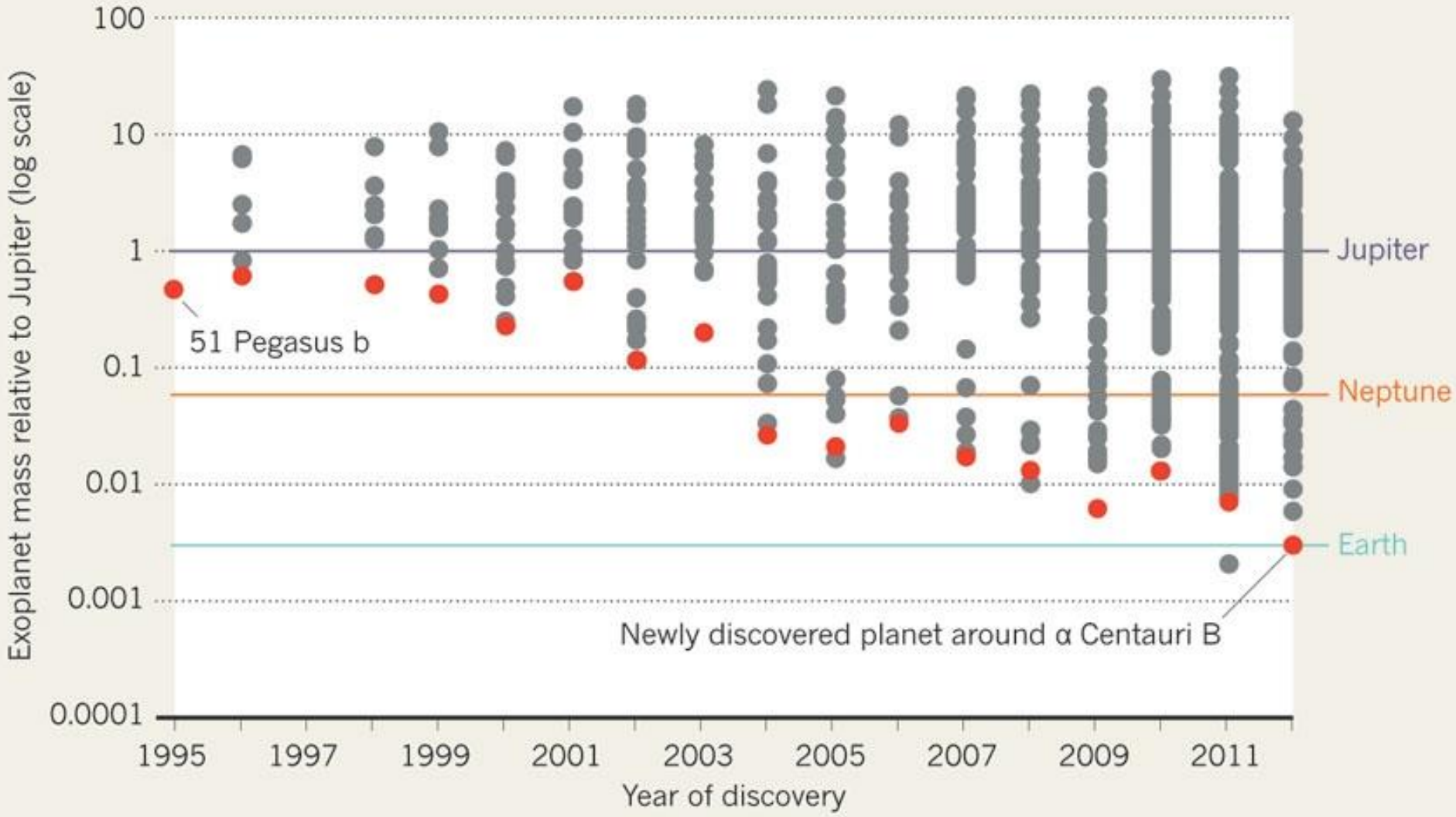

Enceladus "Cold geyser" Model
H_2O vapor plus ice particles
H_2O Ice T = ~77 K
Vent to surface
Pressurized Liquid H_2O Pocket T = 273 K
Hydrothermal Circulation & Convecting Ice
Tidal Heating
Hot Rock
Tidal Heating

"New Distant Worlds"

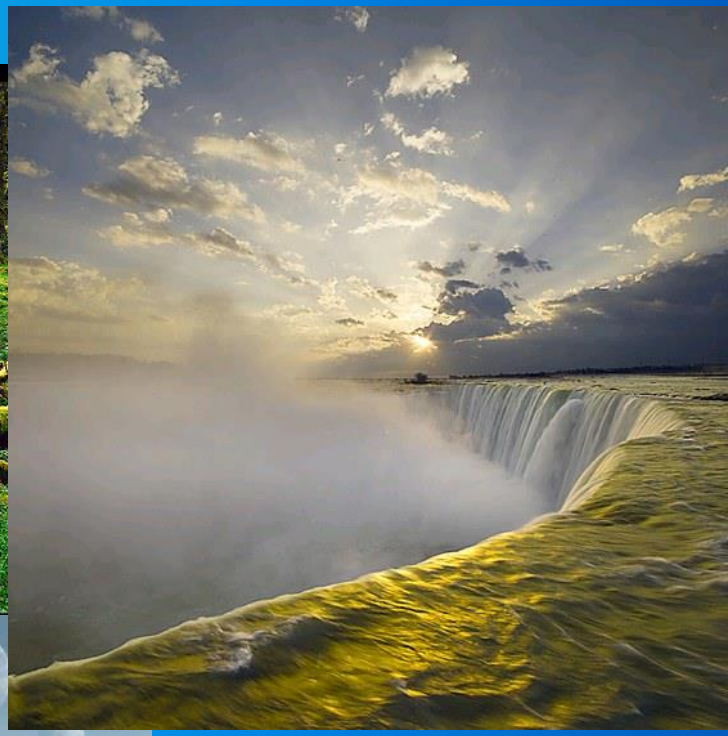
3000 Exoplanets

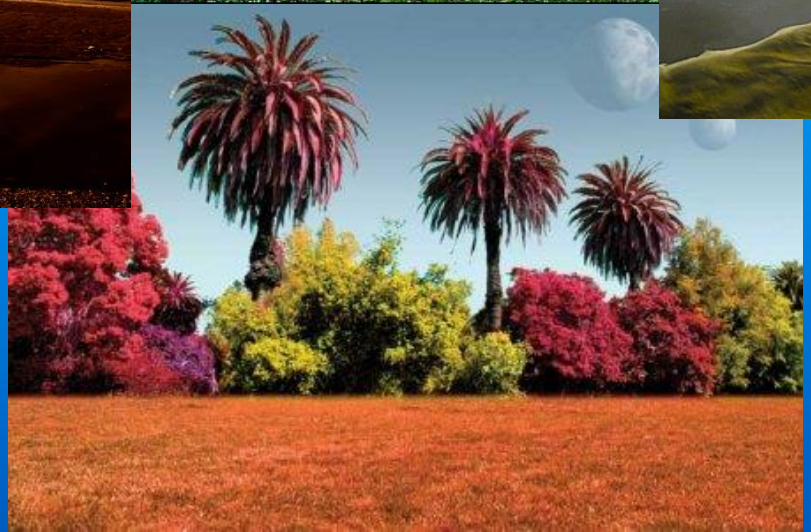
LOWEST OF THE LOW

With improving techniques for measuring exoplanets' mass through their gravitational influence on stars, the lightest exoplanets detected each year (red dots) have reached the range of Earth-mass planets.

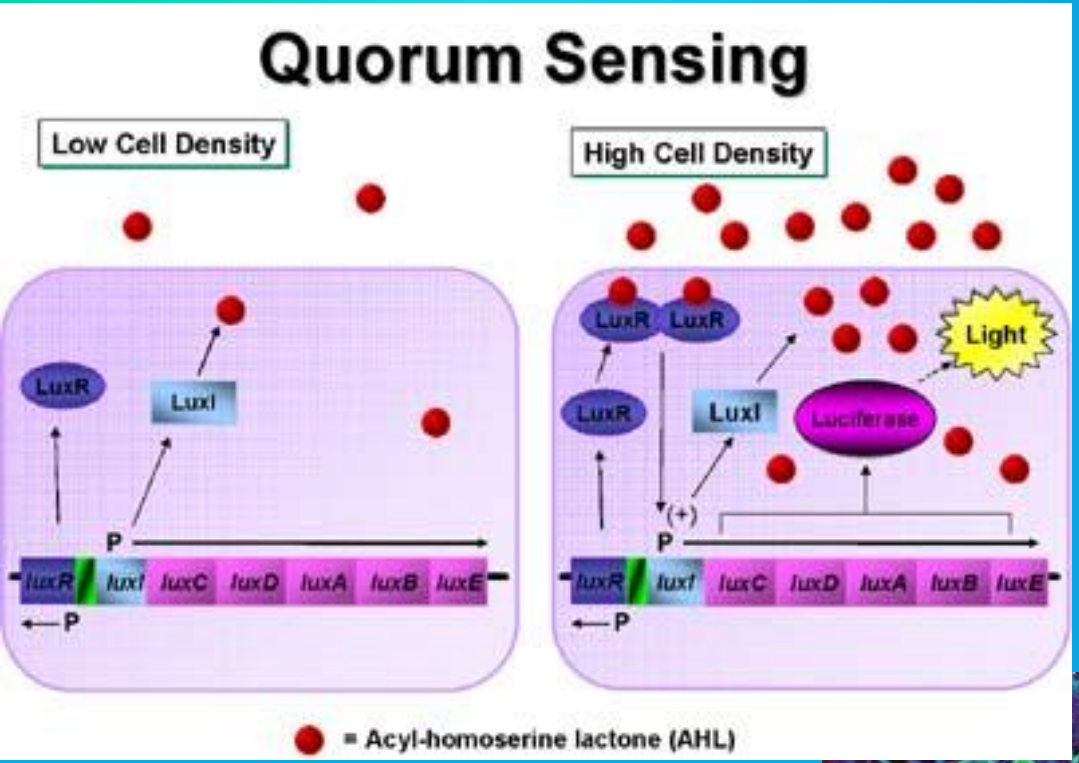


EARTH 2.0



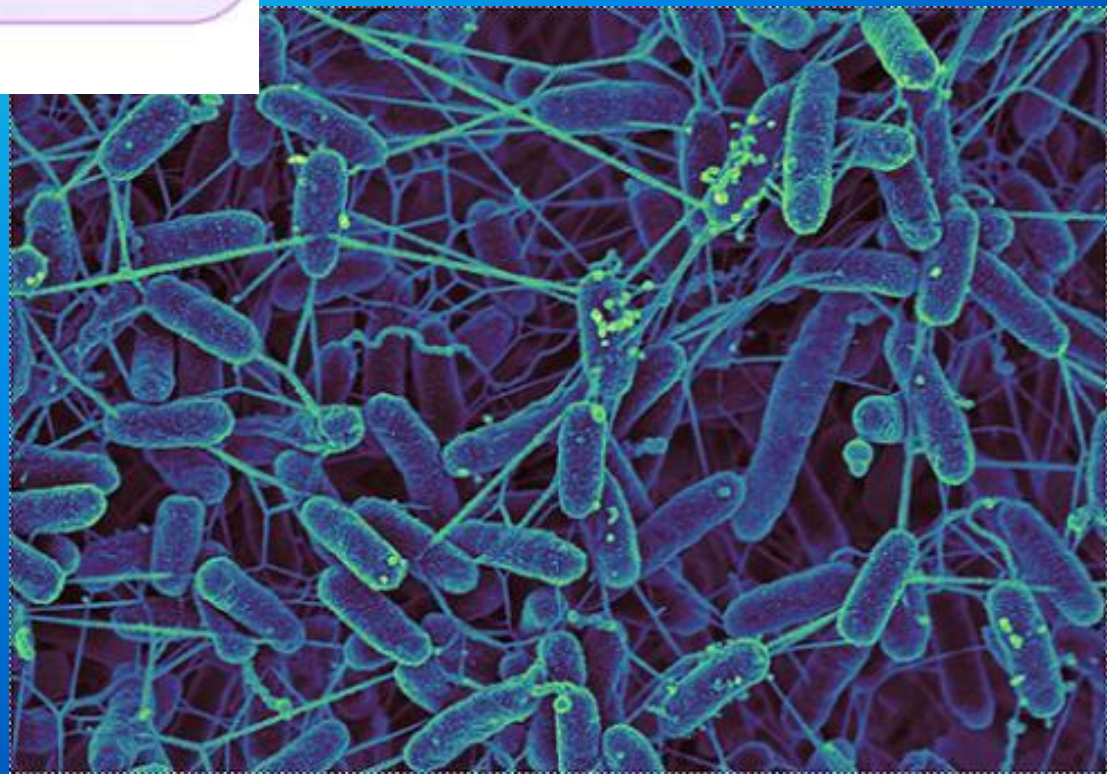


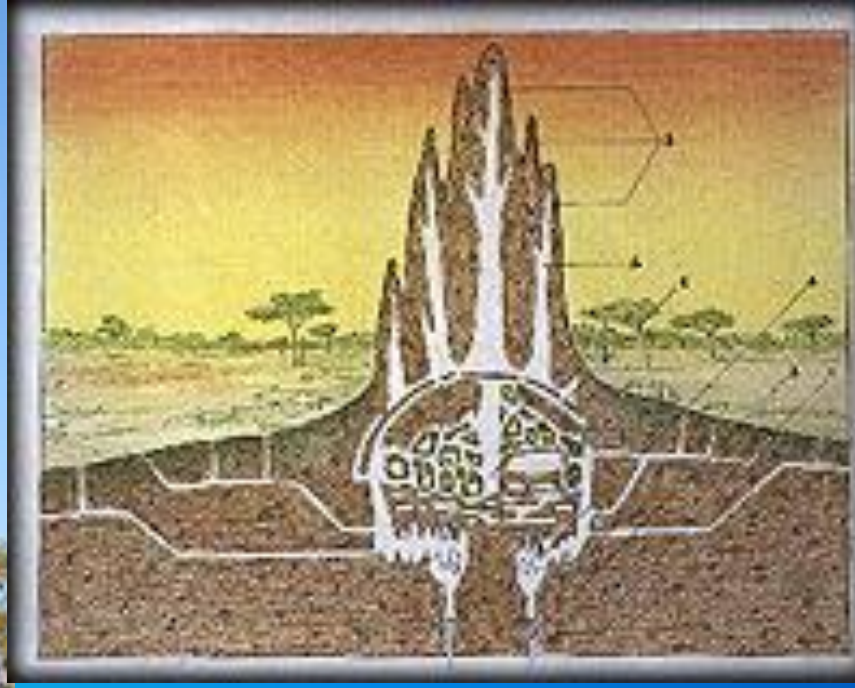
"The Aliens Among Us"



Bacteria use communal sensing of environment and adaptive signaling, also forming alliances with other species.

Apart from being very advanced biochemical factories, bacteria can sense magnetic fields and create nano-wires.



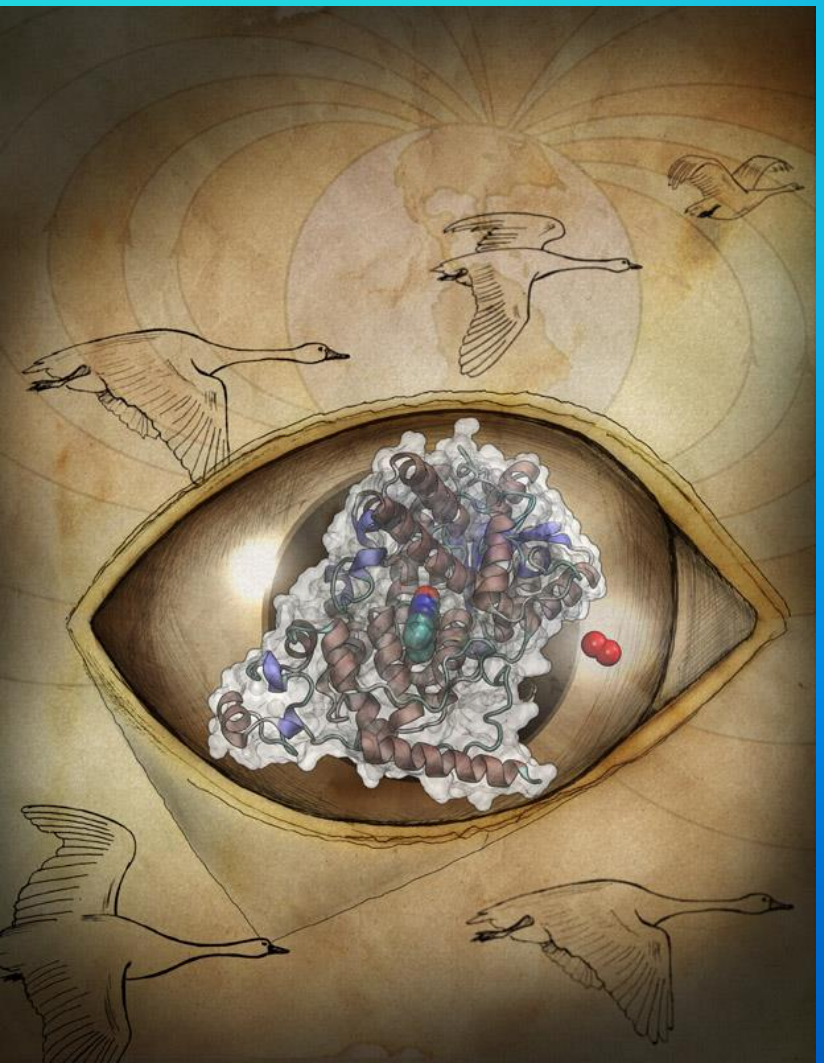


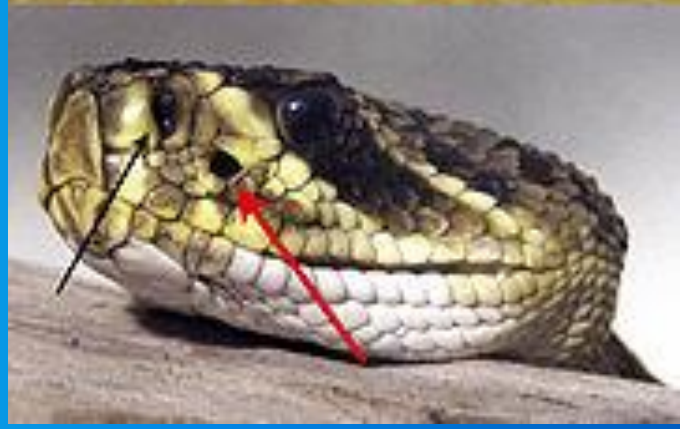
Termite mounds are engineering marvels, higher than our best skyscrapers, scaled to organism size. In construction, 5 temp control mechanisms.

Social insects have complex behavior, specialized function and communication by chemical means.

Intelligent function is distributed within the colony or hive, rather that individuals. How might this evolve?

Defining technology as tools or methods that allow a species to adapt to their environment…

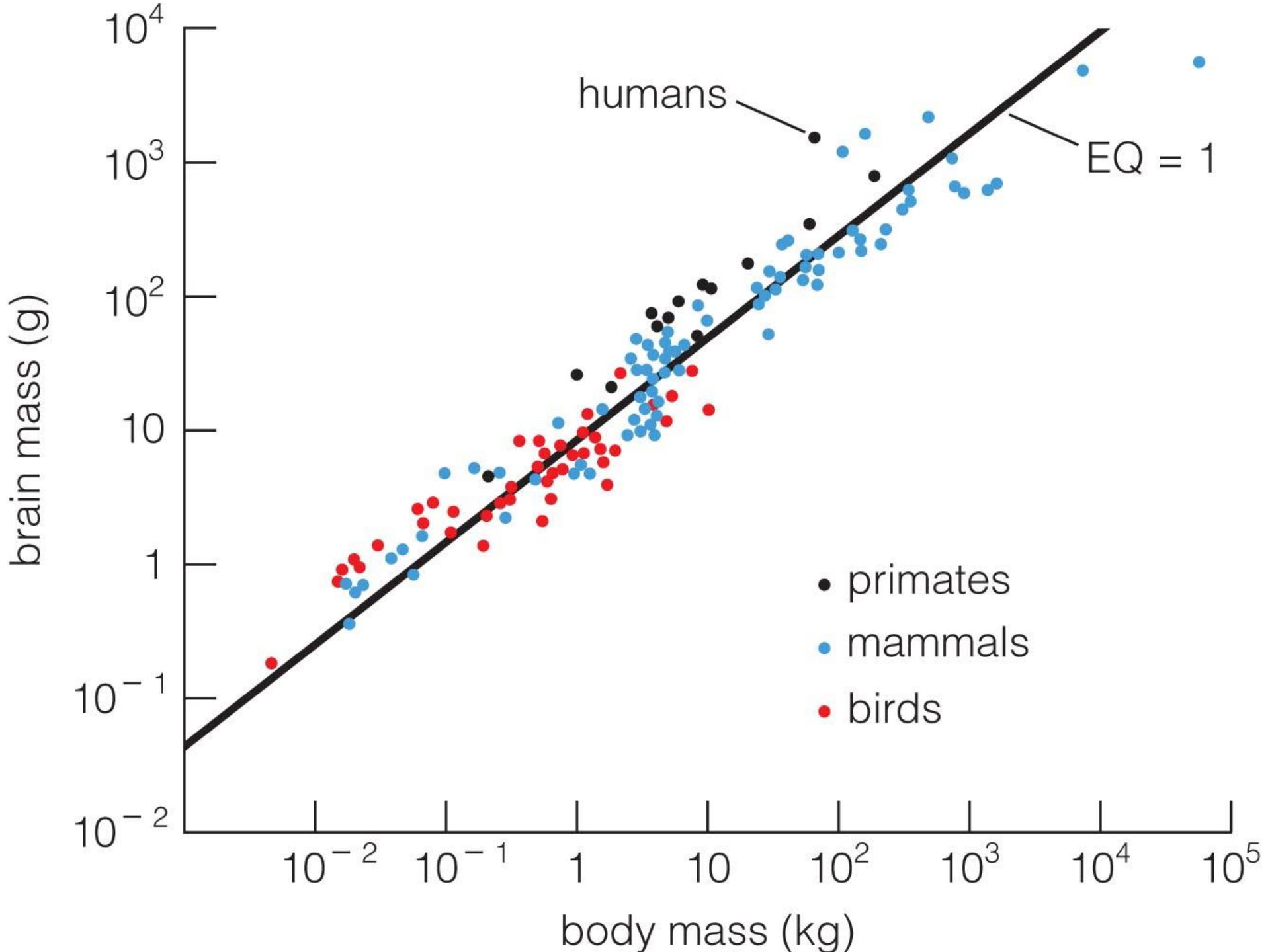




…it's not unique to humans. Animals have invented flight, sonar, IR/magnetic sensing, batteries, polarization sense, fiber optics, holography, etc.

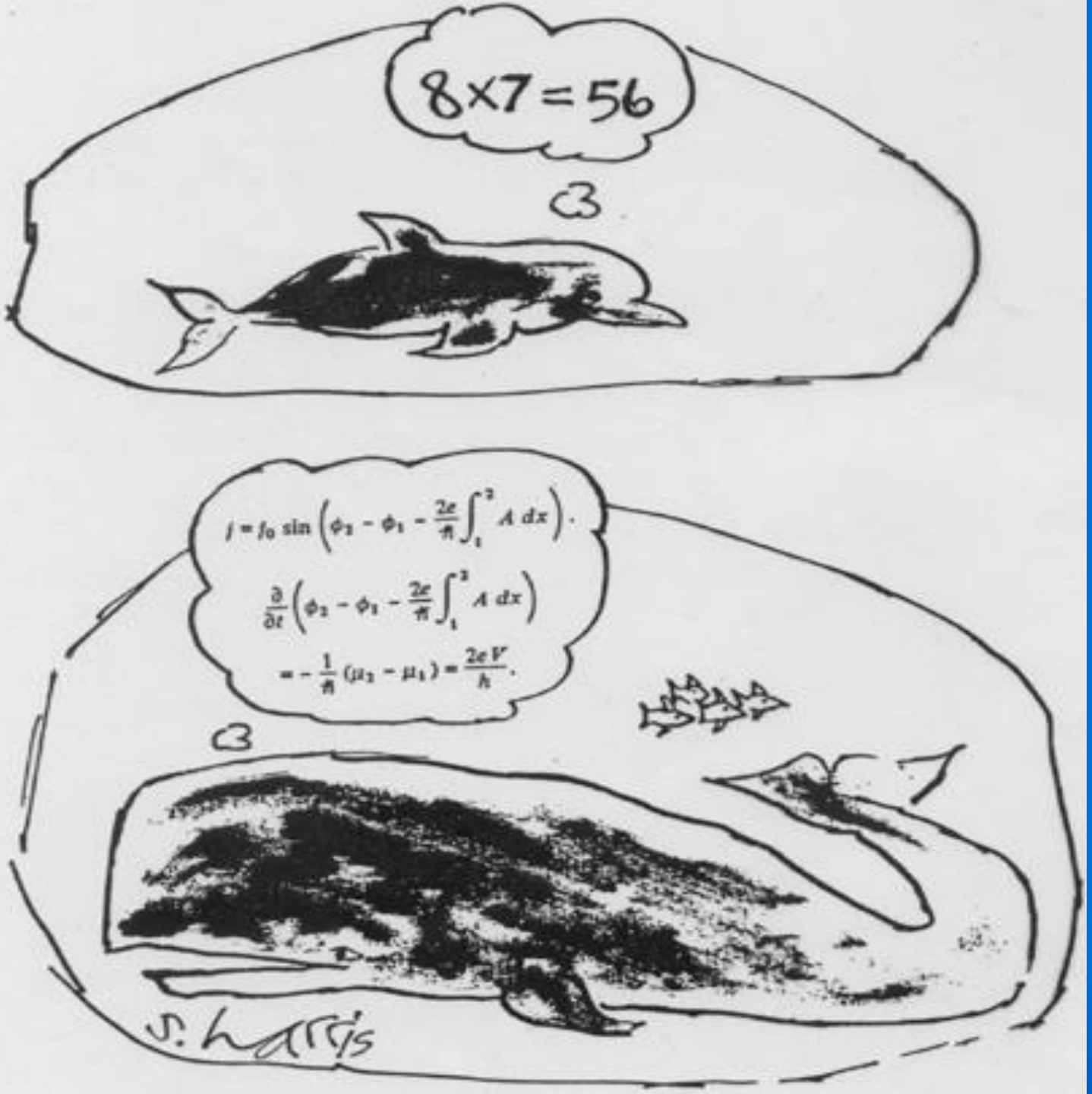
Alex the parrot was talkative and playful, defining new words and concept of zero.

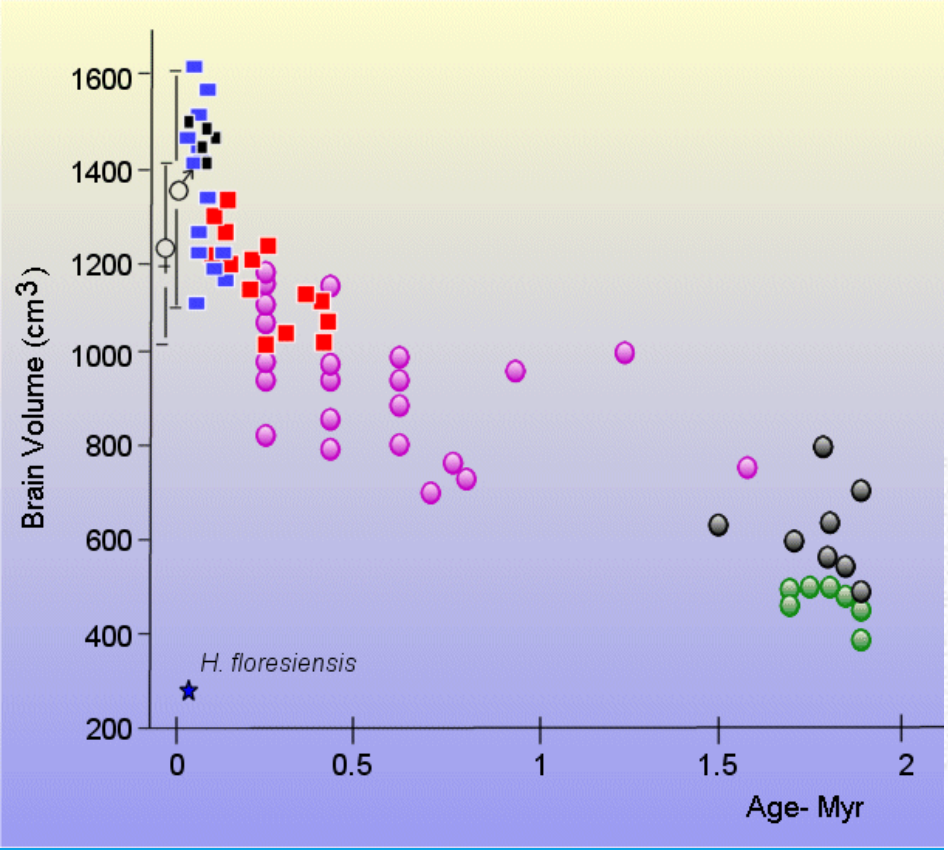
Rats are ticklish and curious, personality traits are seen, they can anticipate sex, and reflect on their thinking processes (meta-cognition).


humans
EQ = 1
primates
mammals
birds
brain mass (g)
body mass (kg)
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{-2}
10^{-1}
1
10
10^2
10^3
10^4
10^5

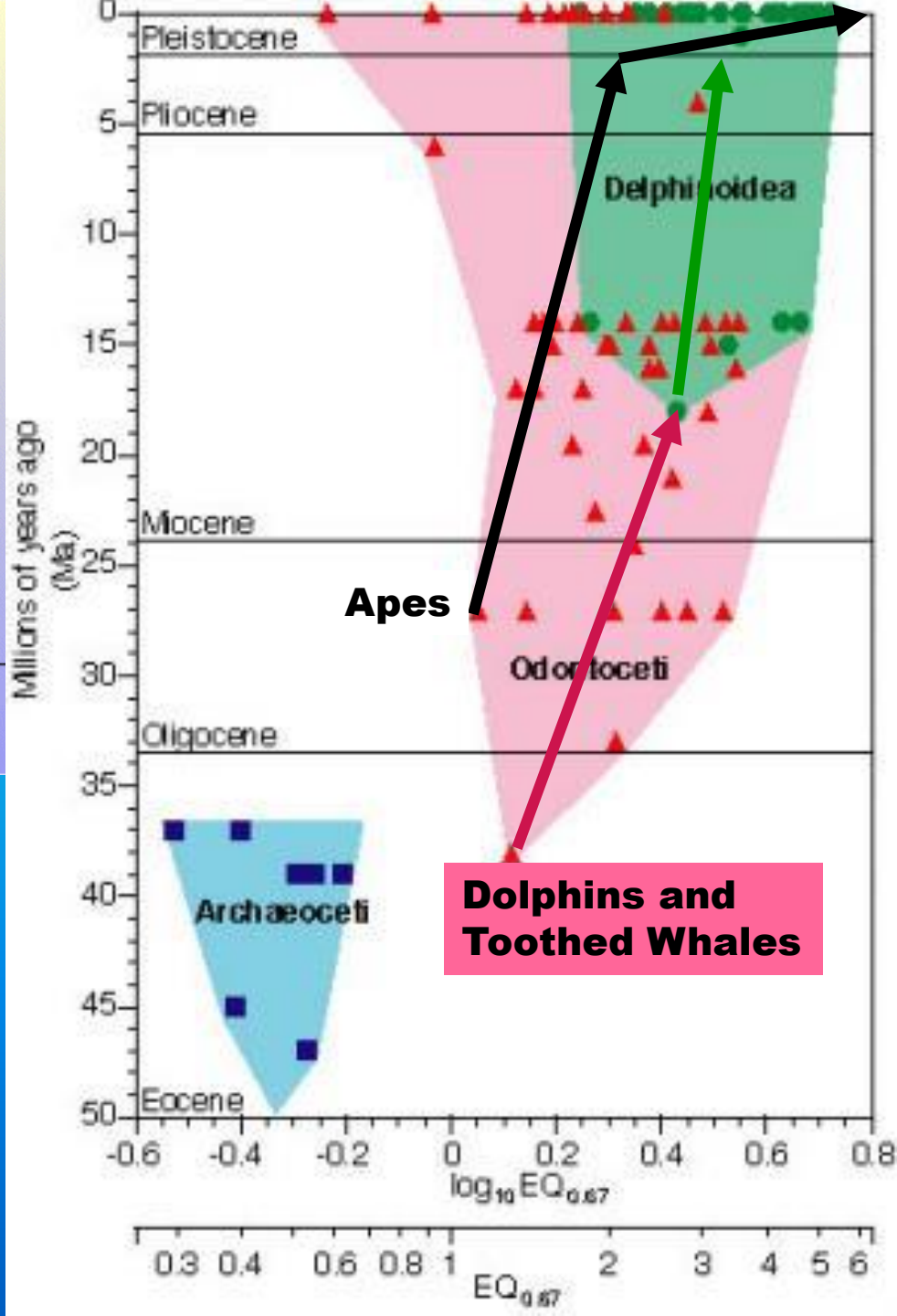
We're Better Than Orcas, Right?

	ORCAS	HUMANS
No natural enemies	√	√
Large brains	√	√
Complex language	√	√
Social animals	√	√
Mate for life	√	×
Bombs, Internet, Cars	×	√


8×7=56
$j = j_0 \sin\left(\phi_2 - \phi_1 - \frac{2e}{\hbar}\int_1^2 A\,dx\right).$
$\frac{\partial}{\partial t}\left(\phi_2 - \phi_1 - \frac{2e}{\hbar}\int_1^2 A\,dx\right)$
$= -\frac{1}{\hbar}(\mu_2 - \mu_1) = \frac{2eV}{h}.$
S. Harris



Evolution of intelligence: For most of the past fifty million years the largest brains were of creatures who lived in the oceans.



"Weird Life Possibilities"

Weird Life: Macro

A Bit Weird: Prokaryotes, eukaryotes, but different cell types

Fairly Weird: Novel symbiosis, gene and organism swapping

Mostly Weird: Non-cellular, networks as opposed to containers

Totally Weird: Planet-scale architecture, geo-engineering

Weird Life: Micro

A Bit Weird: Different amino acids, or bases for nucleic acids

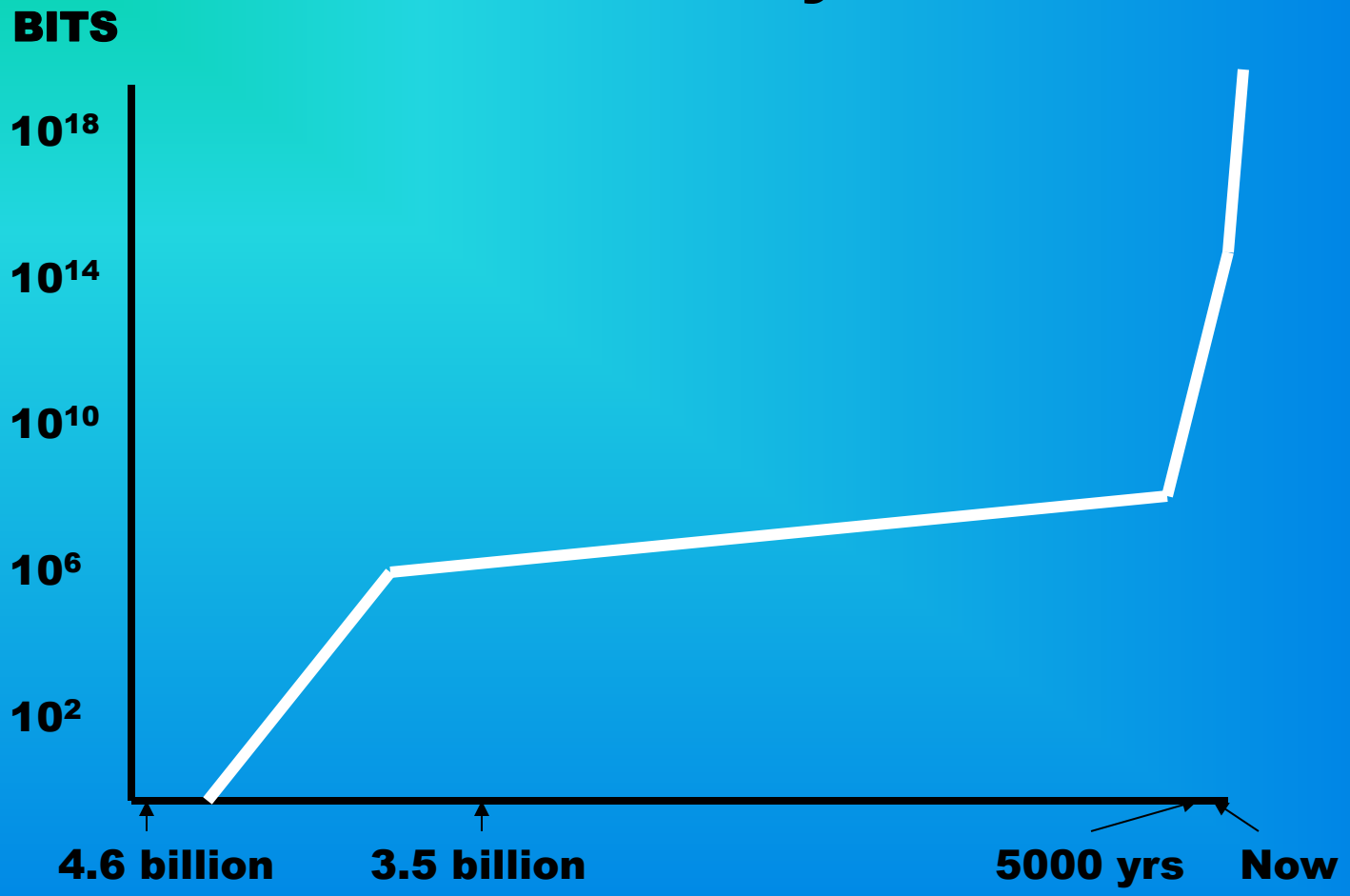
Fairly Weird: Not DNA-RNA-Proteins (the “Central Dogma”)

Mostly Weird: Non-carbon, non-water (silicate, ethane/methane)

Totally Weird: High density biochemistry, molecule-scale organisms

"Beyond the Singularity"

The History of Information



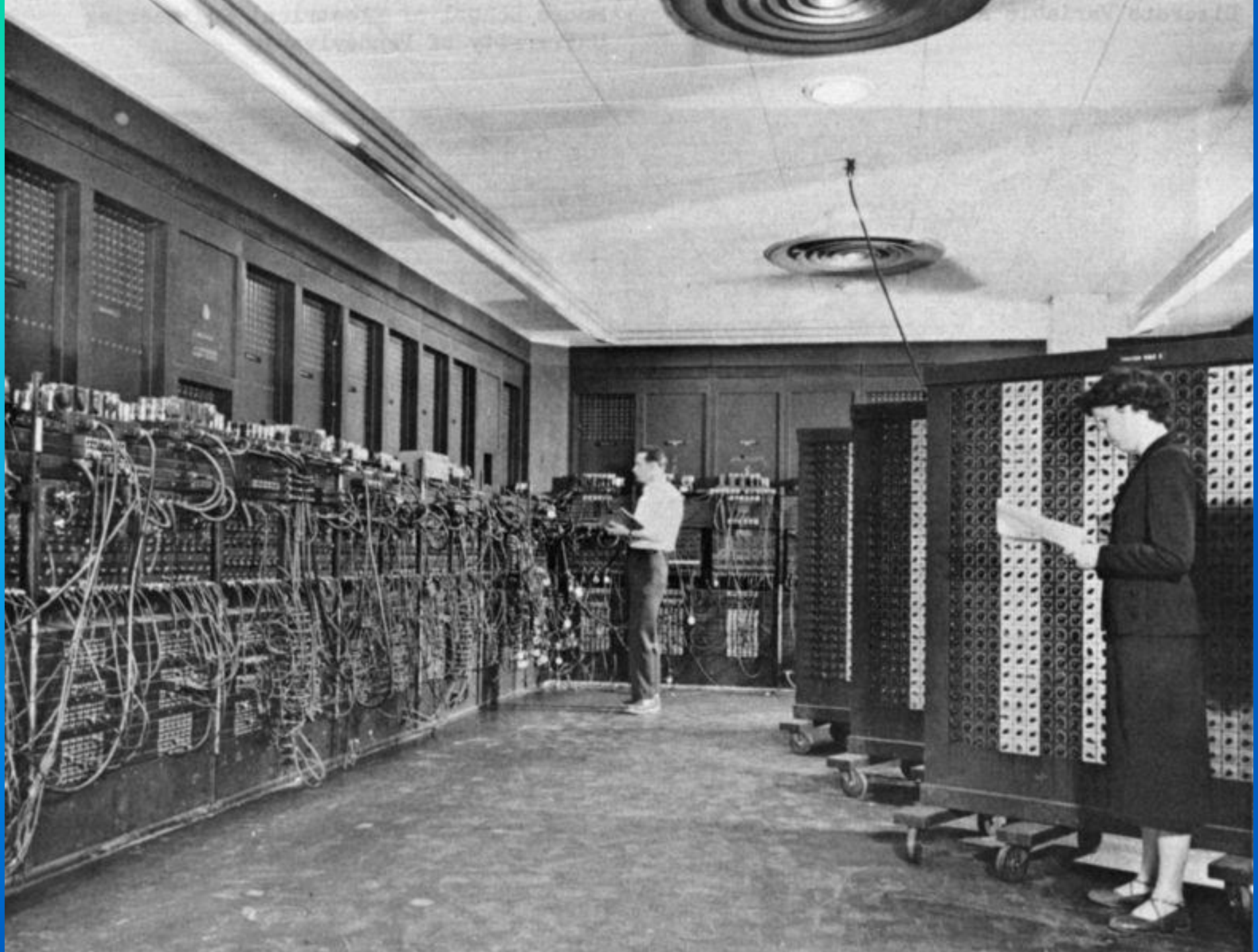
Early life:
0.01 bits/yr

Humans:
1 bit/yr

Books:
10^{13} bits/yr

Digital:
10^{19} bits/yr

Moore's law and its network bandwidth equivalent are at about 1 Gigabit (10^{9}) per second, but project to 1 Petabit (10^{15}) per second in 2020, the capacity of the human brain.



"Never make predictions, especially about the future."
Casey Stengel, Baseball Manager

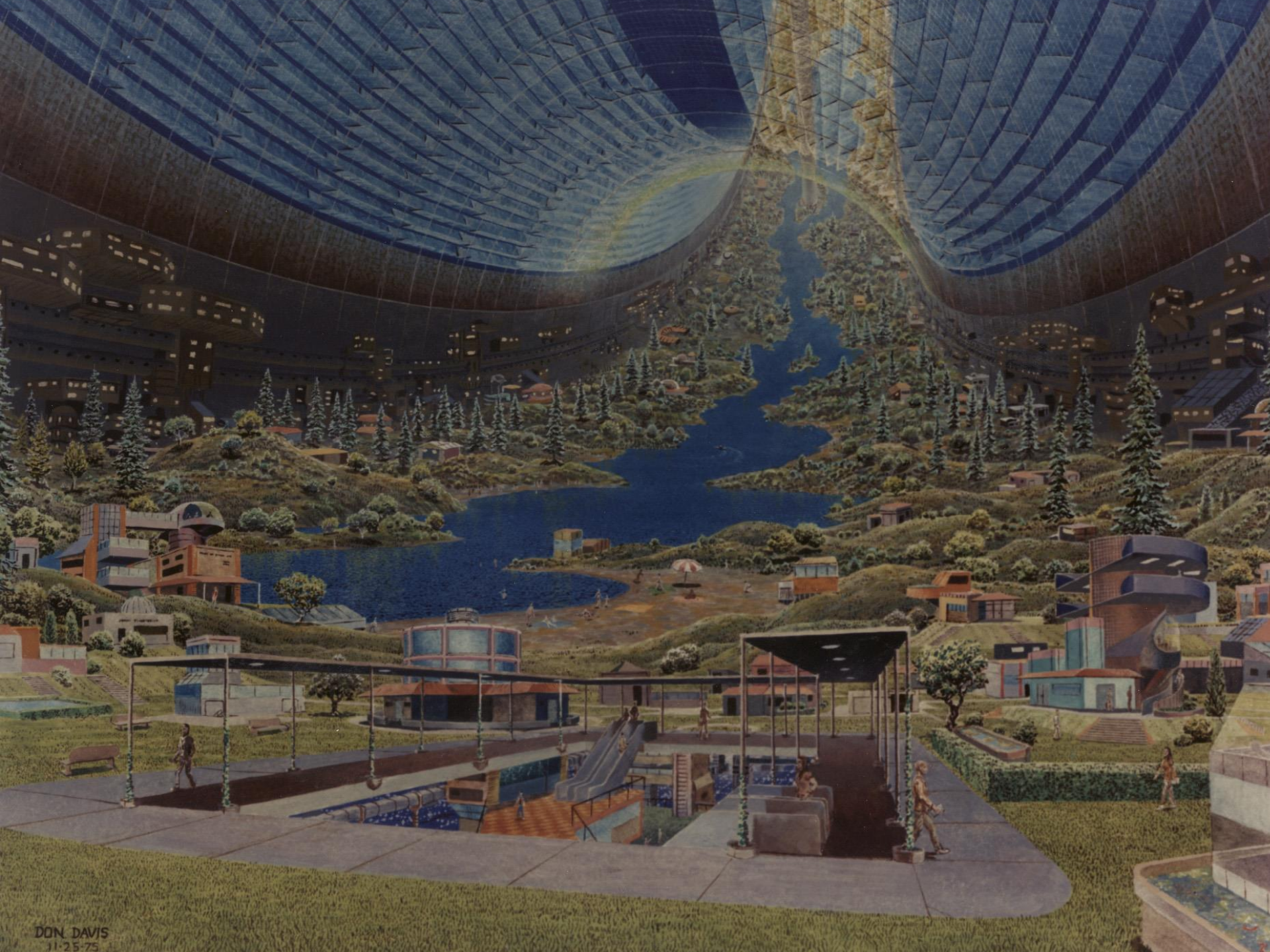
(ENIAC, from 1944, weighed 30 tons, dimmed Philly when it was running, and was a million times slower than a PC)

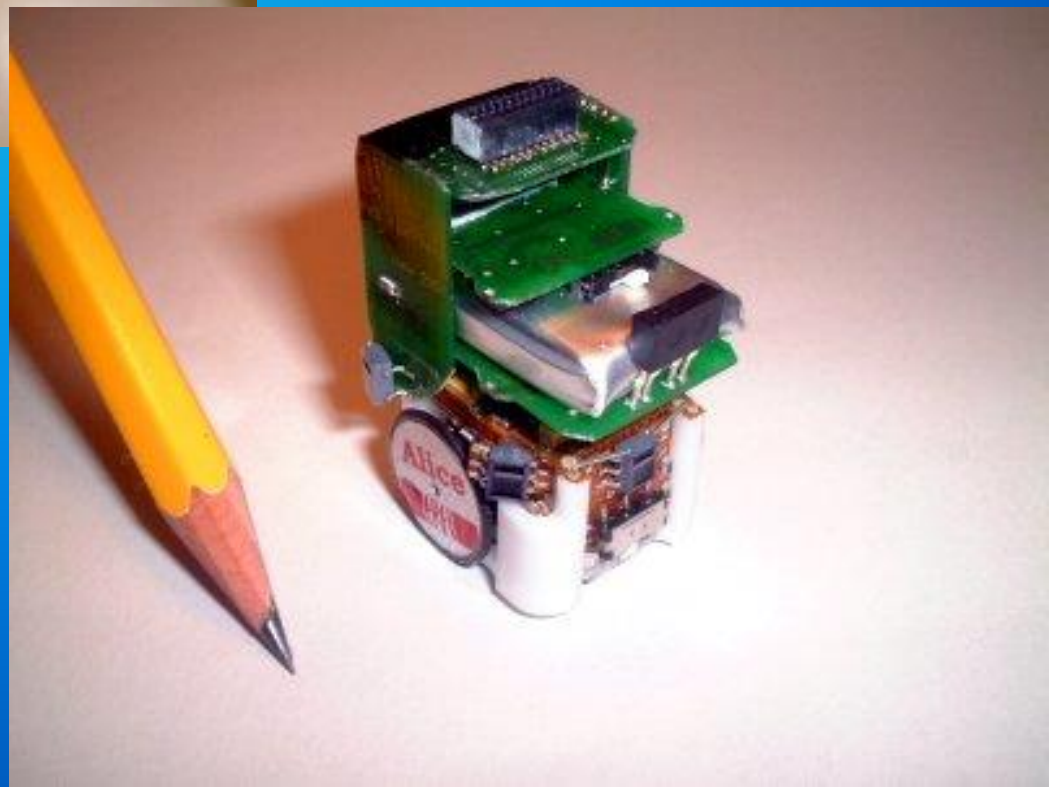
"I think there is a world market for maybe 5 computers"
Thomas Watson, IBM Chairman, 1943

"Computers in the future may weigh less than 1.5 tons"
Popular Mechanics Magazine, 1949

"There's no reason anyone would want a home computer"
Ken Olsen, CEO, Digital Equipment, 1977

"Life is digital information."
James Watson, on the significance of DNA

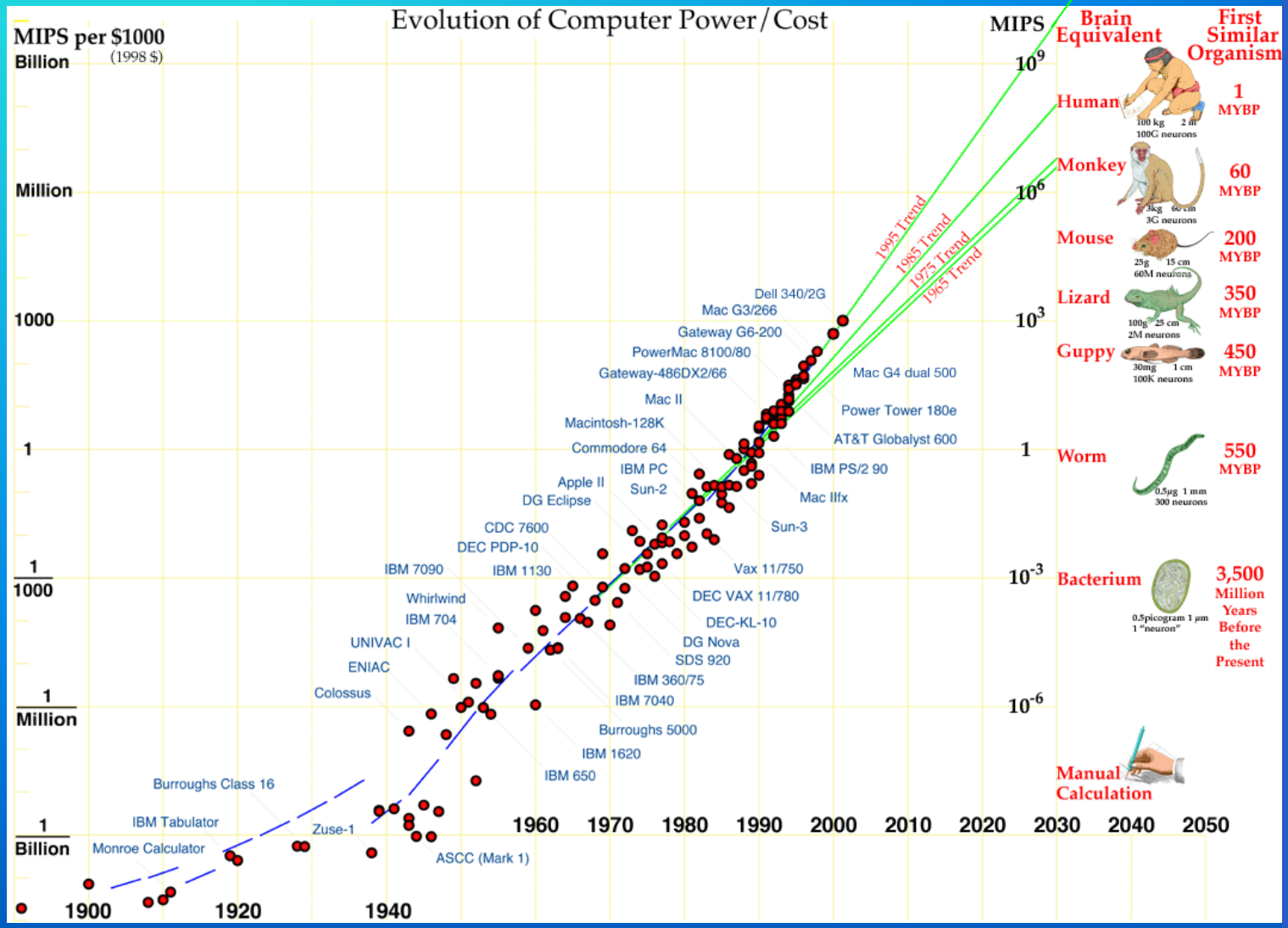

DON DAVIS
11-25-75


Alice

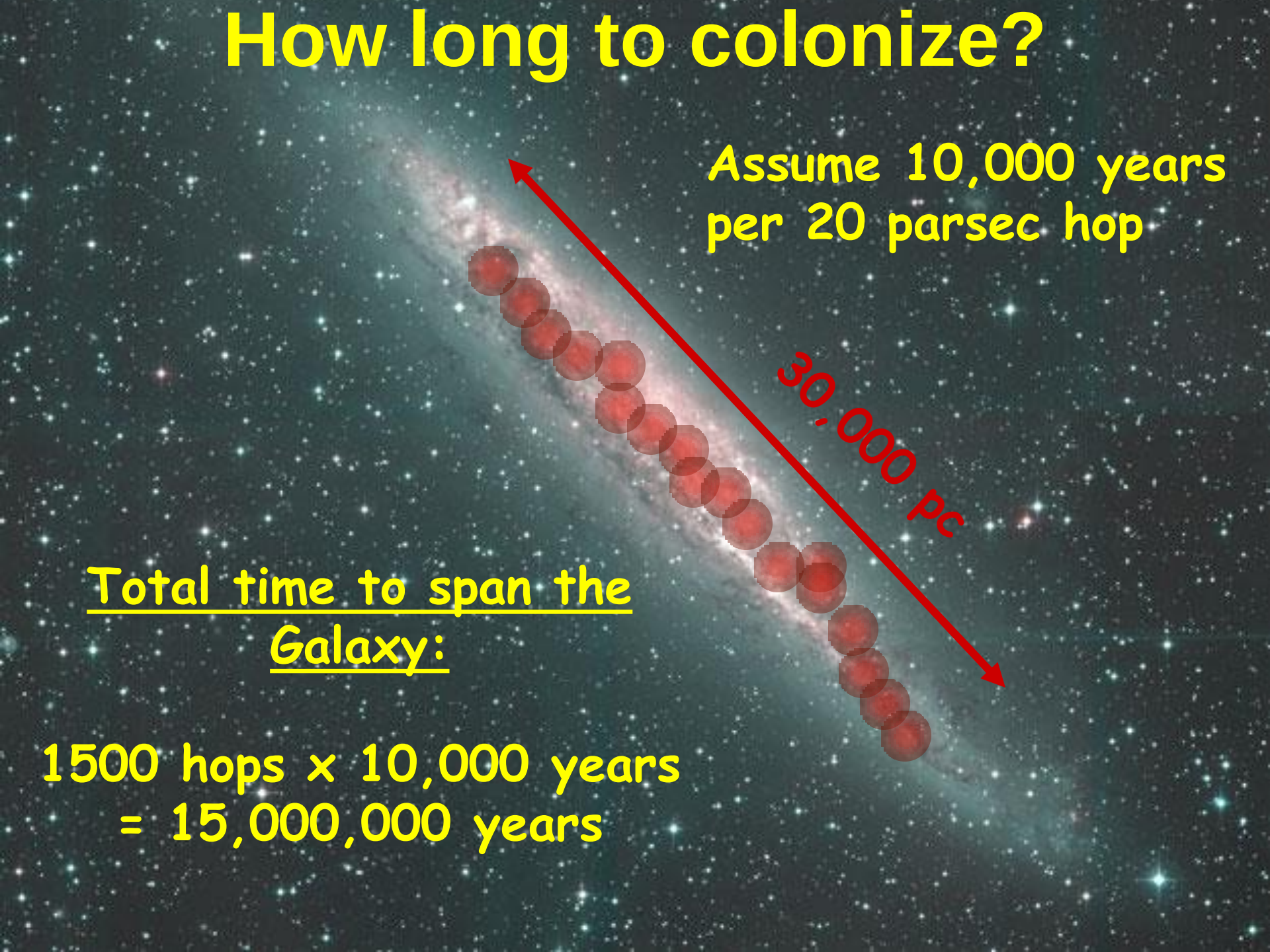
We're on the cusp of technological maturity: "ancestor" simulations of 10^{35} ops or 0.1c galactic exploration.

10,000 processors working for a year

Around 2050



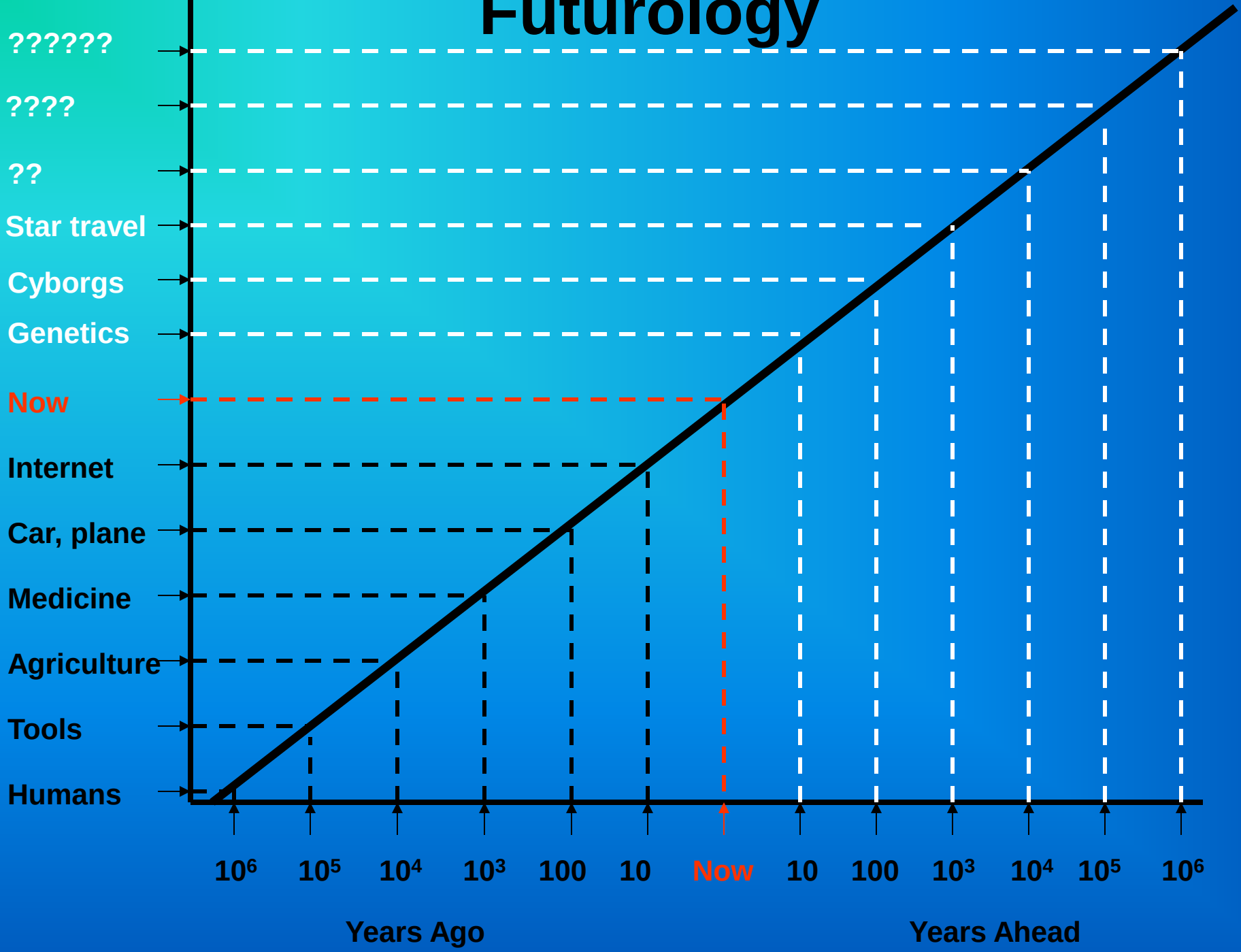
How long to colonize?



Total time to span the Galaxy:

1500 hops x 10,000 years
= 15,000,000 years

Futurology


??????
????
??
Star travel
Cyborgs
Genetics
Now
Internet
Car, plane
Medicine
Agriculture
Tools
Humans
10^6
10^5
10^4
10^3
100
10
Now
10
100
10^3
10^4
10^5
10^6
Years Ago
Years Ahead

Civilizations: Speculation

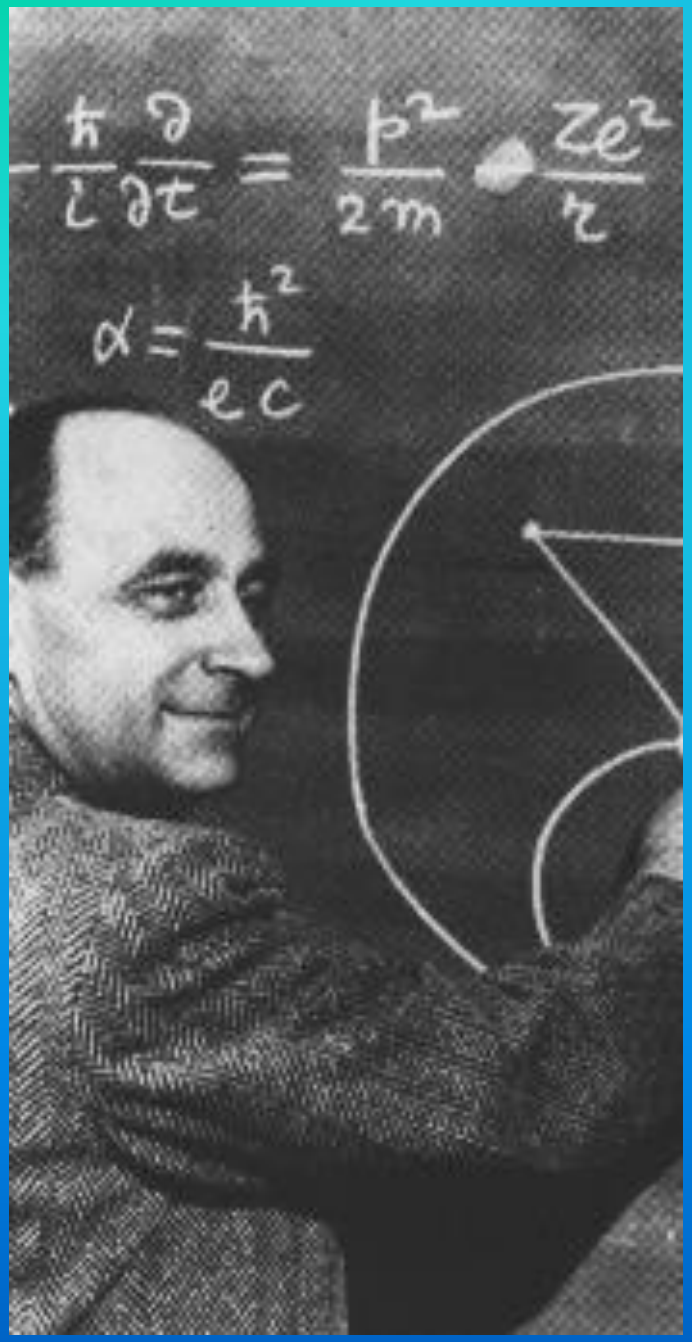
Nicolai Kardashev's classification of civilizations:

Type 0: not in complete control of planet's energy
Chemical propulsion, solar sails
Type I: harnesses energy output of an entire planet (10^{11} W)
Nuclear propulsion, laser sails
Type II: harnesses entire output of their host star (10^{26} W)
Antimatter drives
Type III: colonizes and harnesses output of entire galaxy (10^{37} W)
???

To which could be added (with implications for SETI):

Type Ib: non-electromagnetic signals with low opacity
Neutrino beams, dark matter beams
Type IIb: orchestrated stellar cataclysms (visible across universe)
Supernovae, gamma ray bursts
Type IIIb: signals from manipulation of space-time
gravity waves, baby universes

"Contemplating Aliens"



The Fermi Question

As originally phrased by Erico Fermi, it seems a reasonable proposition that:

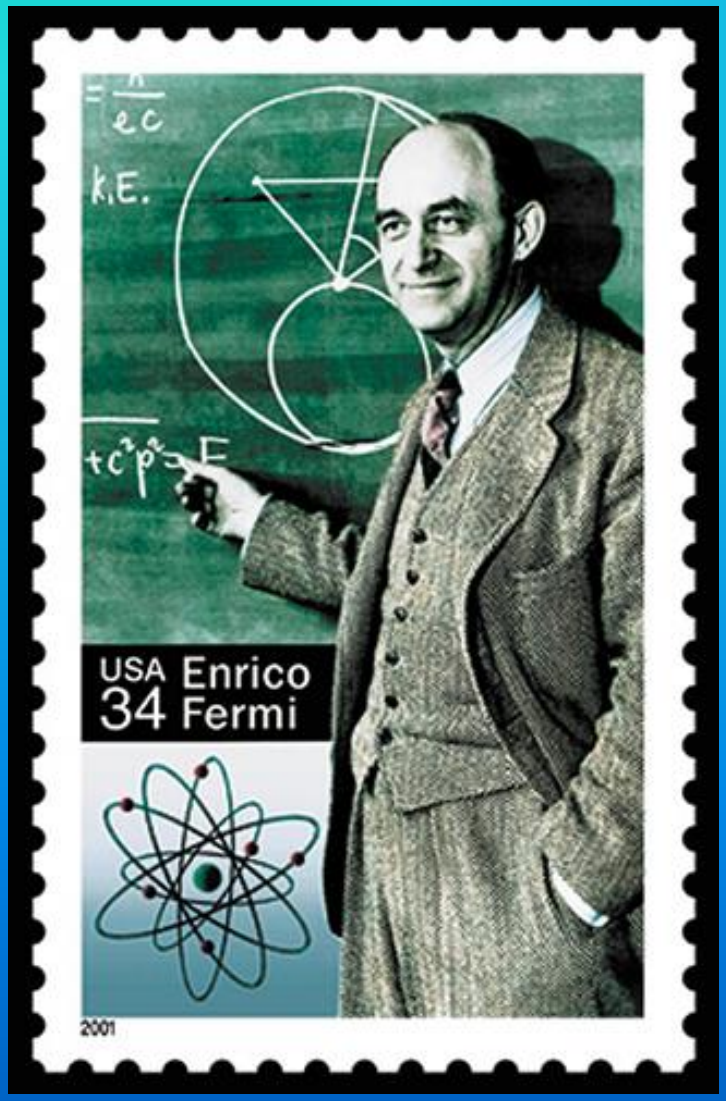
• Our civilization and technology is **very young**; life forms with much more advanced technology could have remarkable capabilities.

• A **modest extrapolation** of current technology allows us mine asteroids or moons, and create probes that could create replicas of themselves and propagate through the galaxy.

• There are **many likely sites** for complex life, and plenty of time for technology to develop, billions of years before Earth formed.

"Where Are They?"

Responses to Fermi



They don’t exist

They are very rare

They are unrecognizable

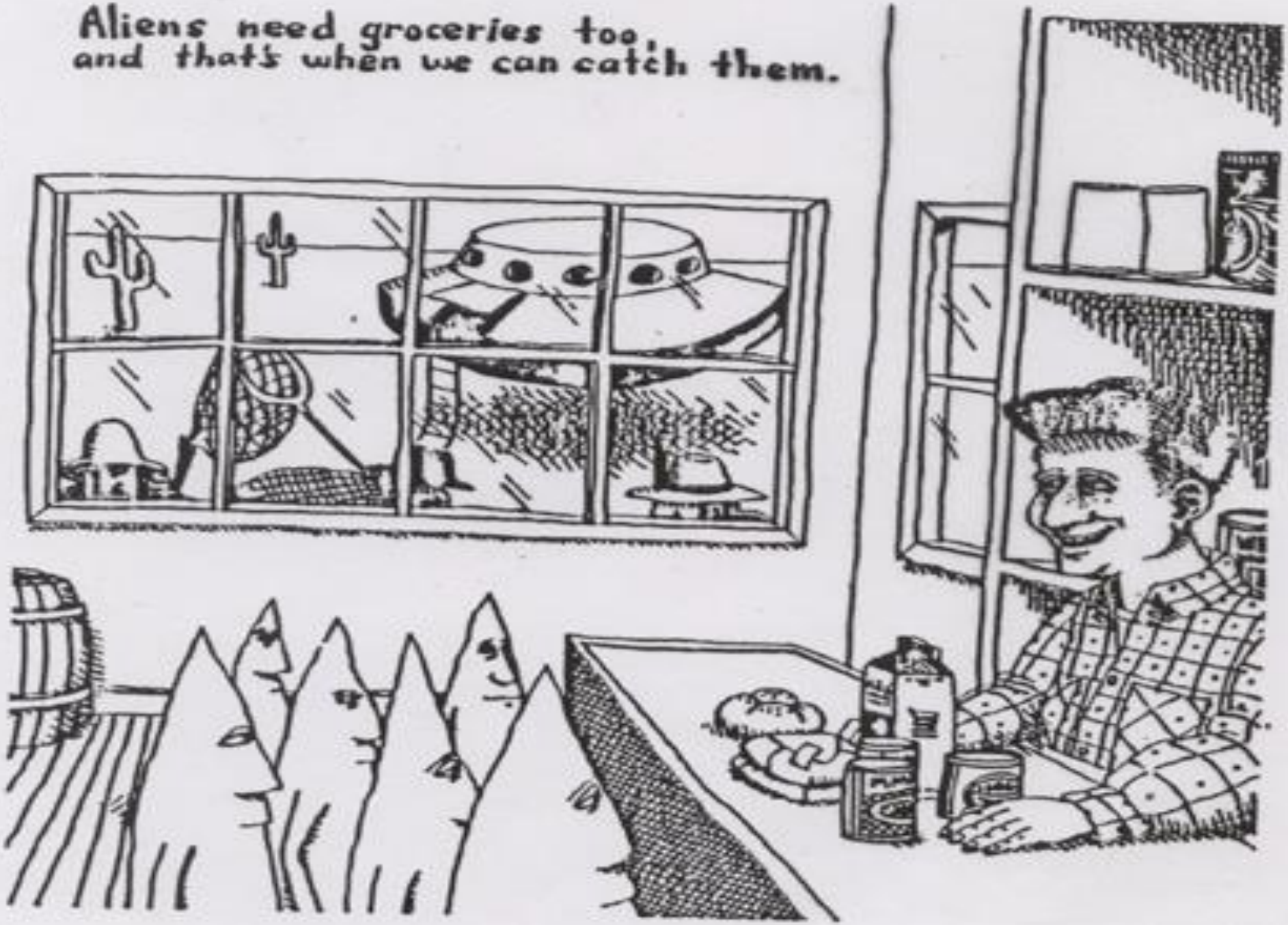
They are inscrutable

They don’t care

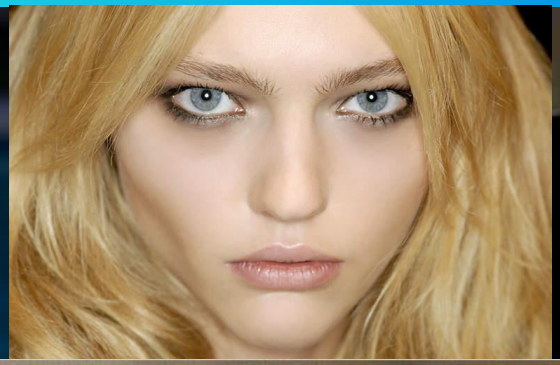
They created us

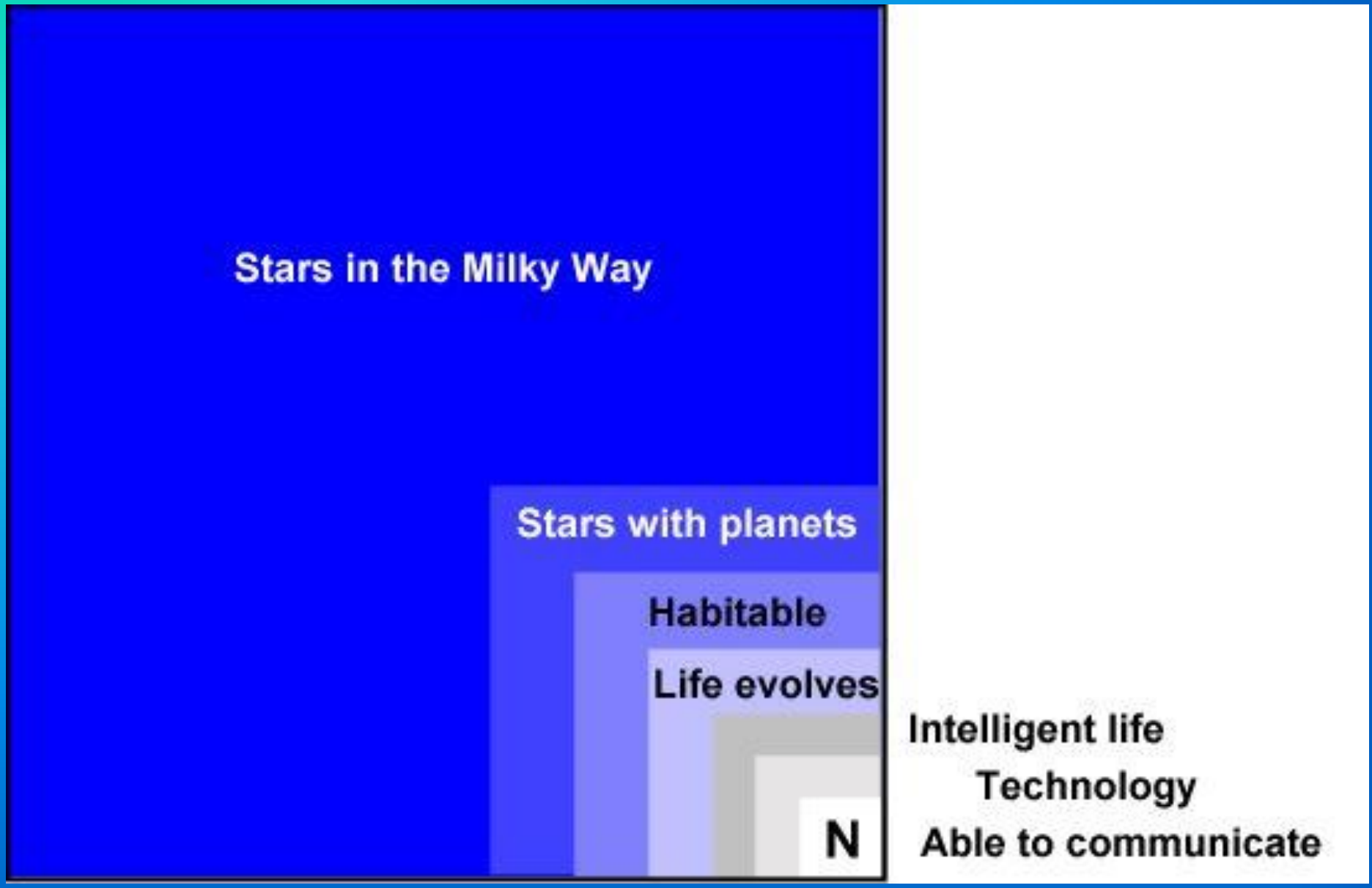
"Making Contact"

Aliens need groceries too,
and that's when we can catch them.

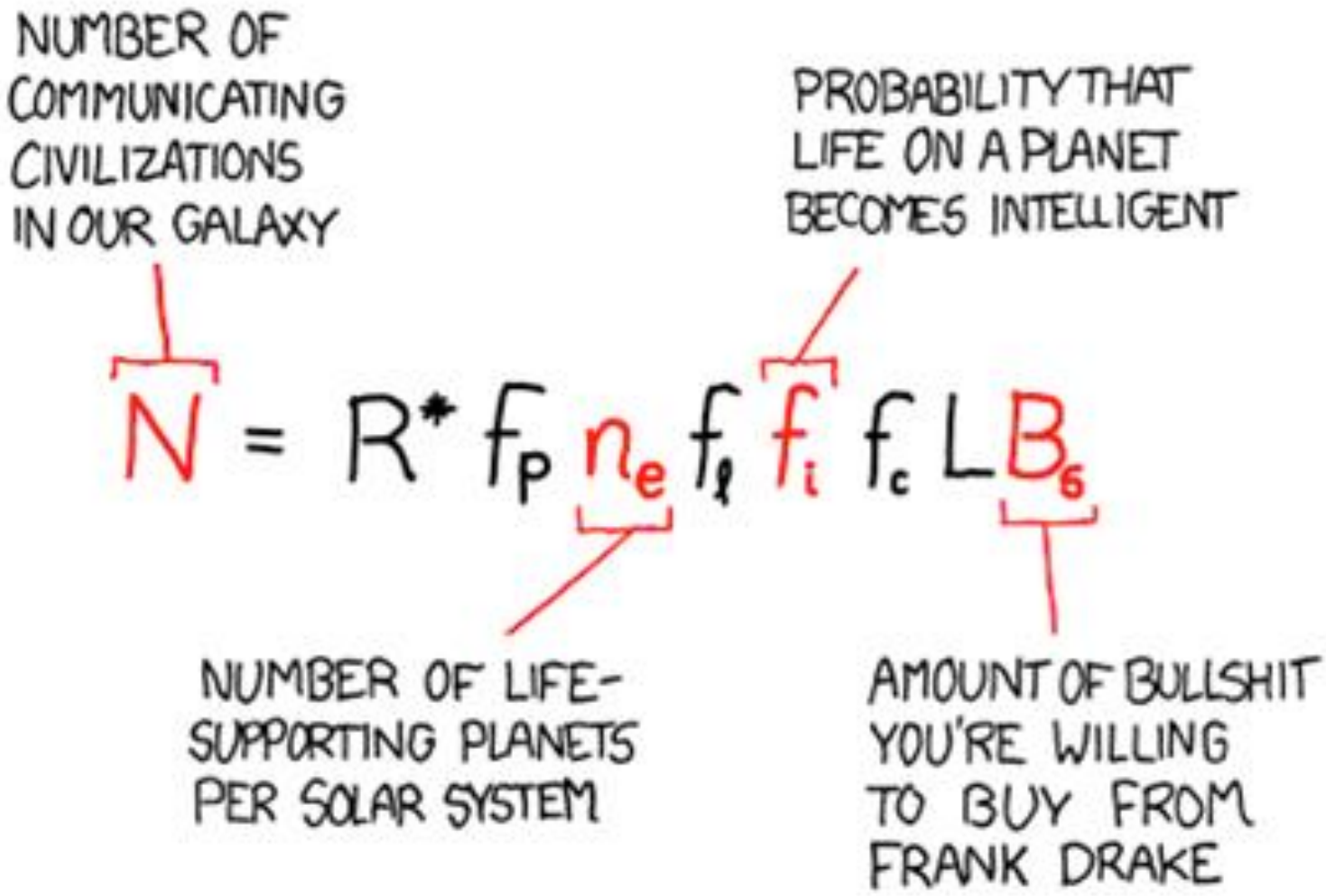


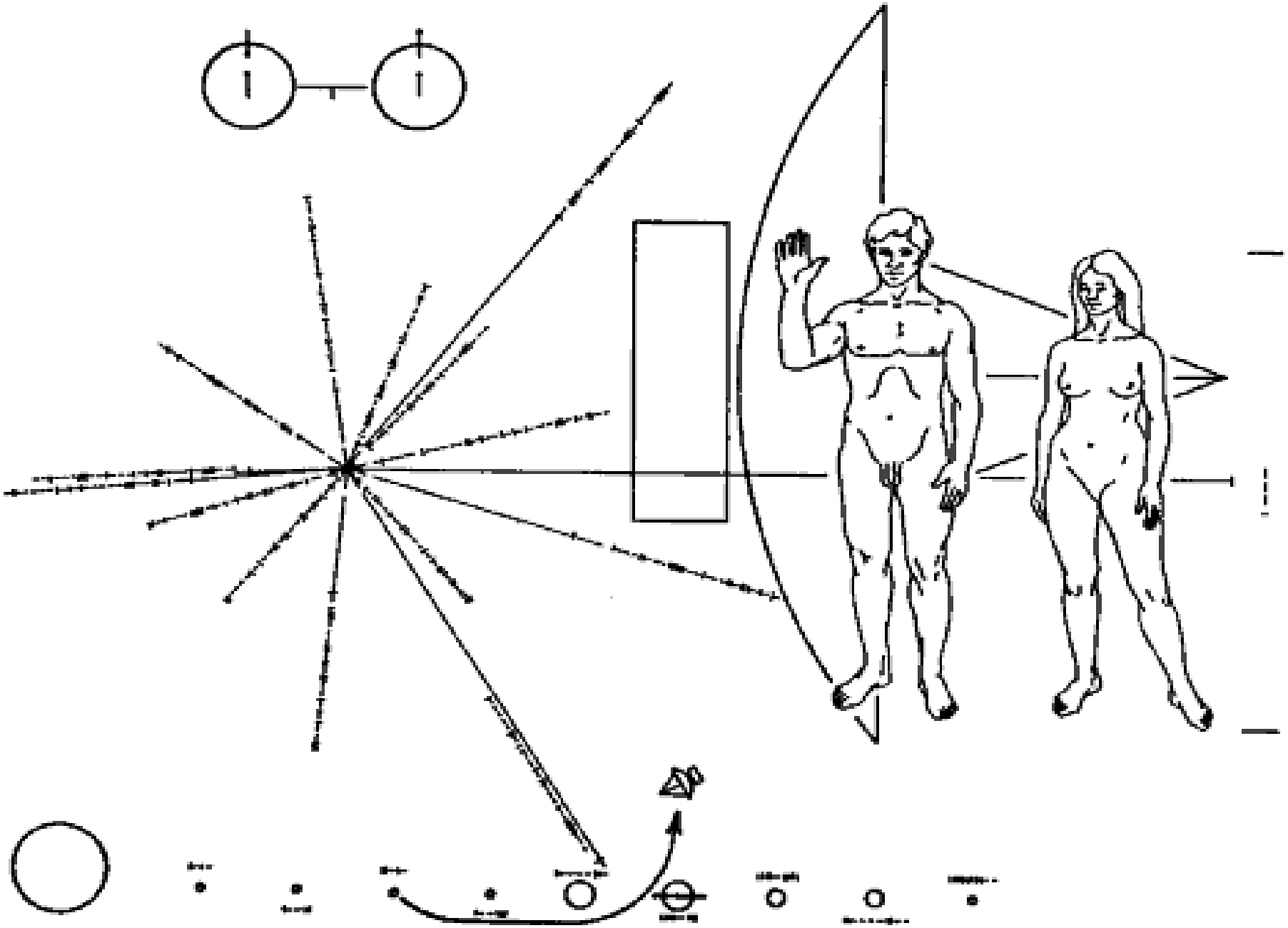
They Are Among Us



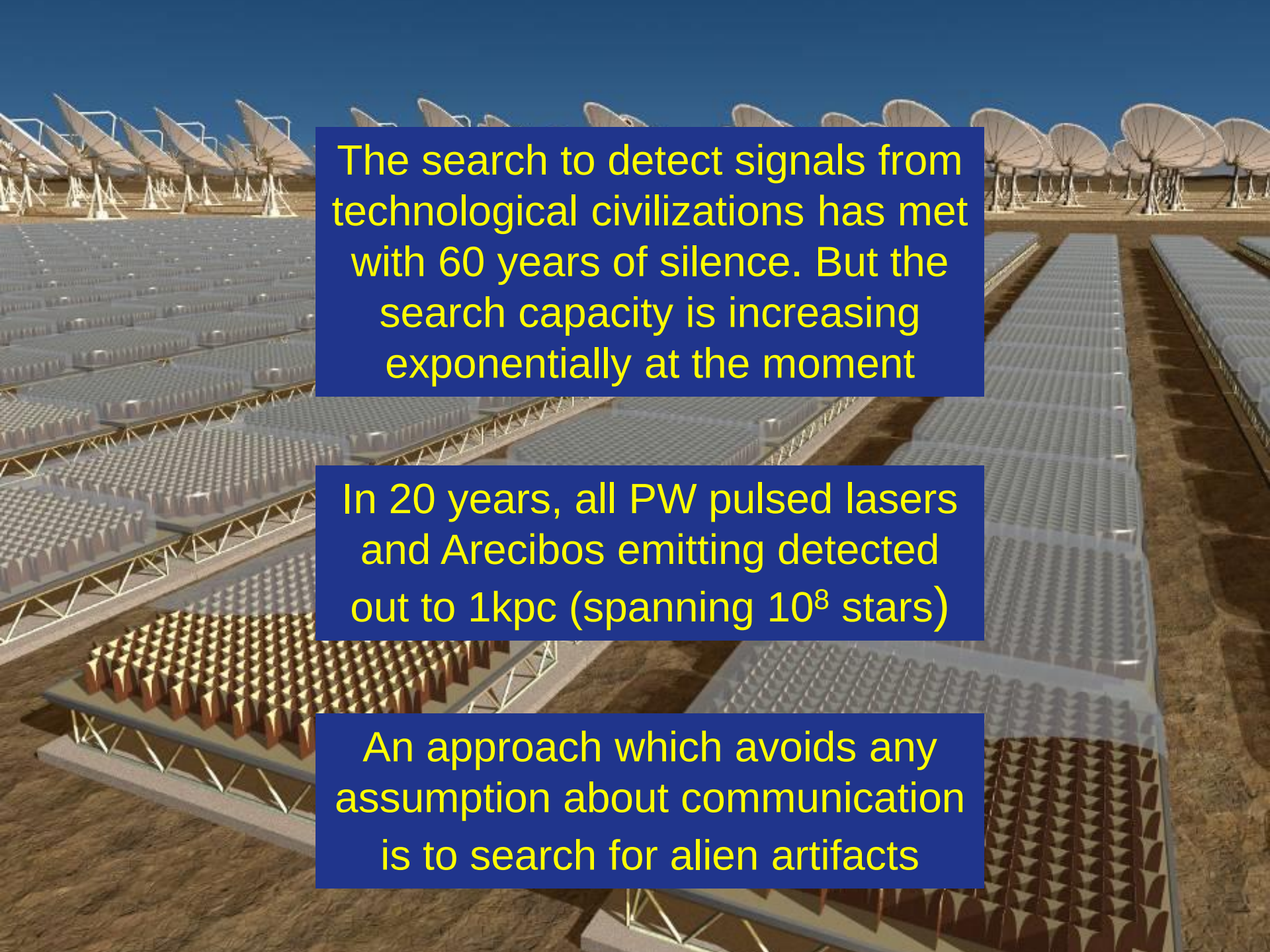

Stars in the Milky Way
Stars with planets
Habitable
Life evolves
N
Intelligent life
Technology
Able to communicate

THE DRAKE EQUATION






THE
SOUNDS
OF
EARTH
PLANET EARTH

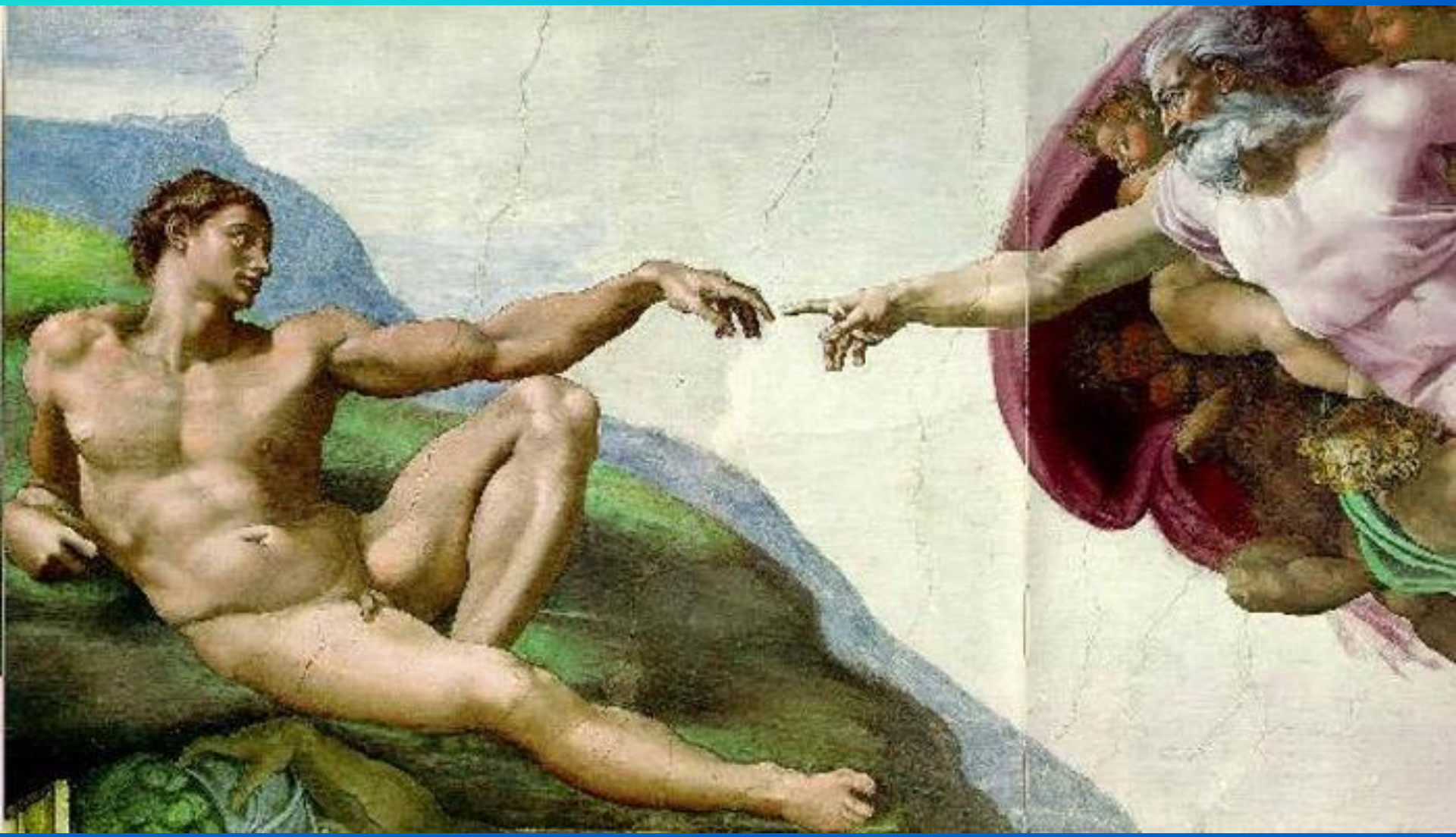


The search to detect signals from technological civilizations has met with 60 years of silence. But the search capacity is increasing exponentially at the moment

In 20 years, all PW pulsed lasers and Arecibos emitting detected out to 1kpc (spanning 10^8 stars)

An approach which avoids any assumption about communication is to search for alien artifacts

How We Like to Think of Ourselves



How Aliens Might Think of Us

THE END