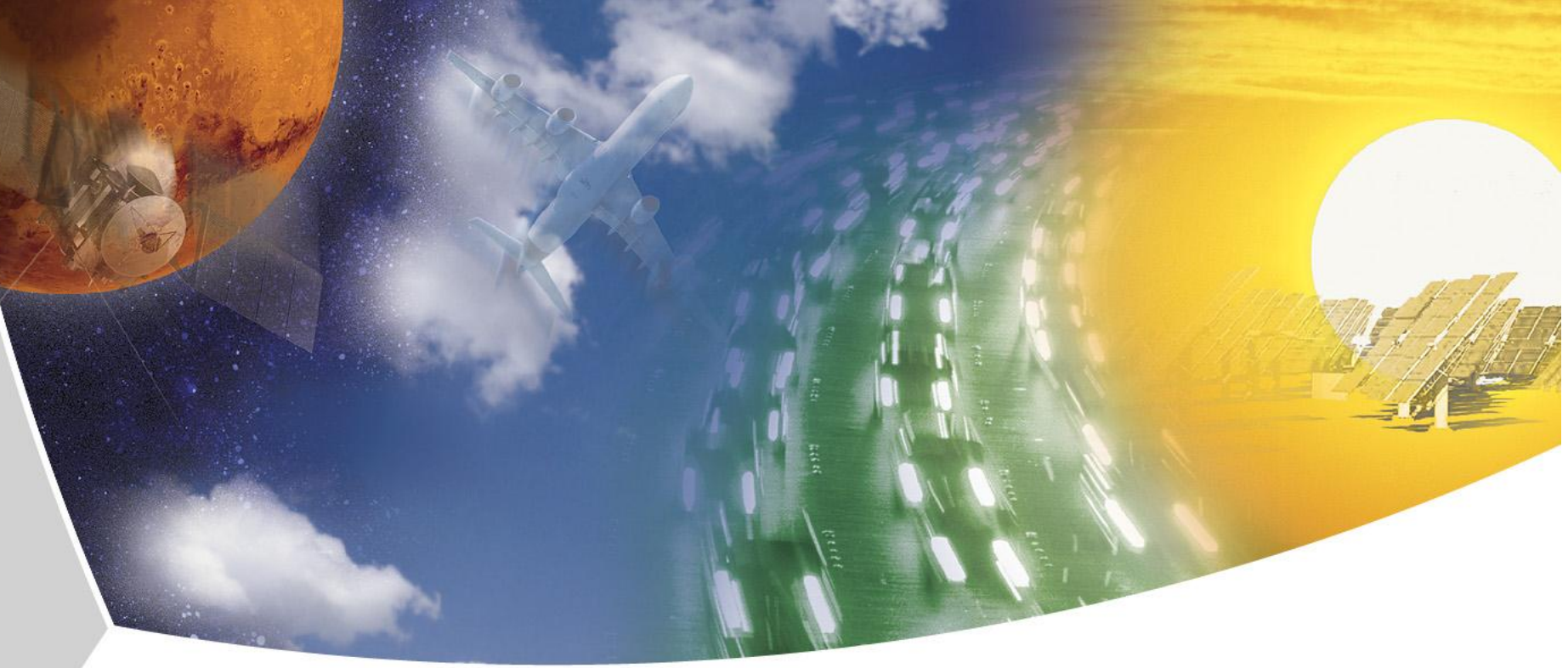
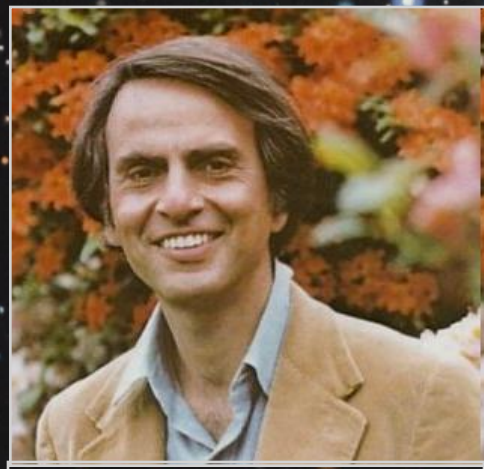


From Habitability to the Origin and Evolution of Life

Gerda Horneck
DLR, Institut für Luft- und Raumfahrtmedizin, Köln
gerda.horneck@dlr.de



9.11.1934 – 20.12. 1996

"The Earth is the only planet known to harbour life"

Carl Sagan, Pale Blue Dot, 1994

100 - 200 billion stars in our Galaxy

More than 100 billion galaxies in the Universe

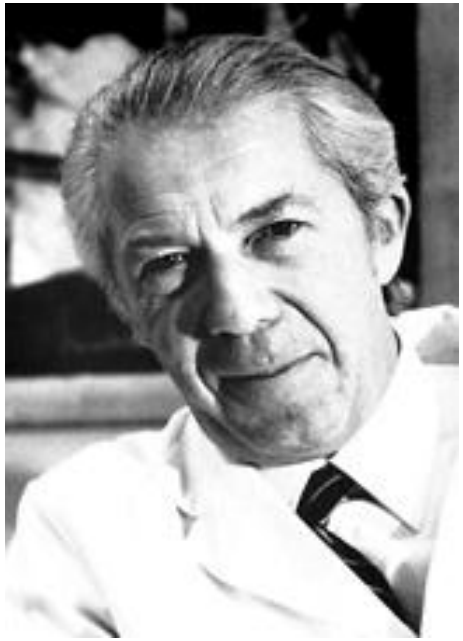
Are we alone?

Life a cosmic imperative ?

" Life emerges at a certain stage of either cosmic or planetary evolution,

if the right environmental physical and chemical requirements are provided "

Christian De Duve, 1994



Christian De Duve (born 1917) Nobel Price (1974) for his work on the structure and function of organelles in biological cells

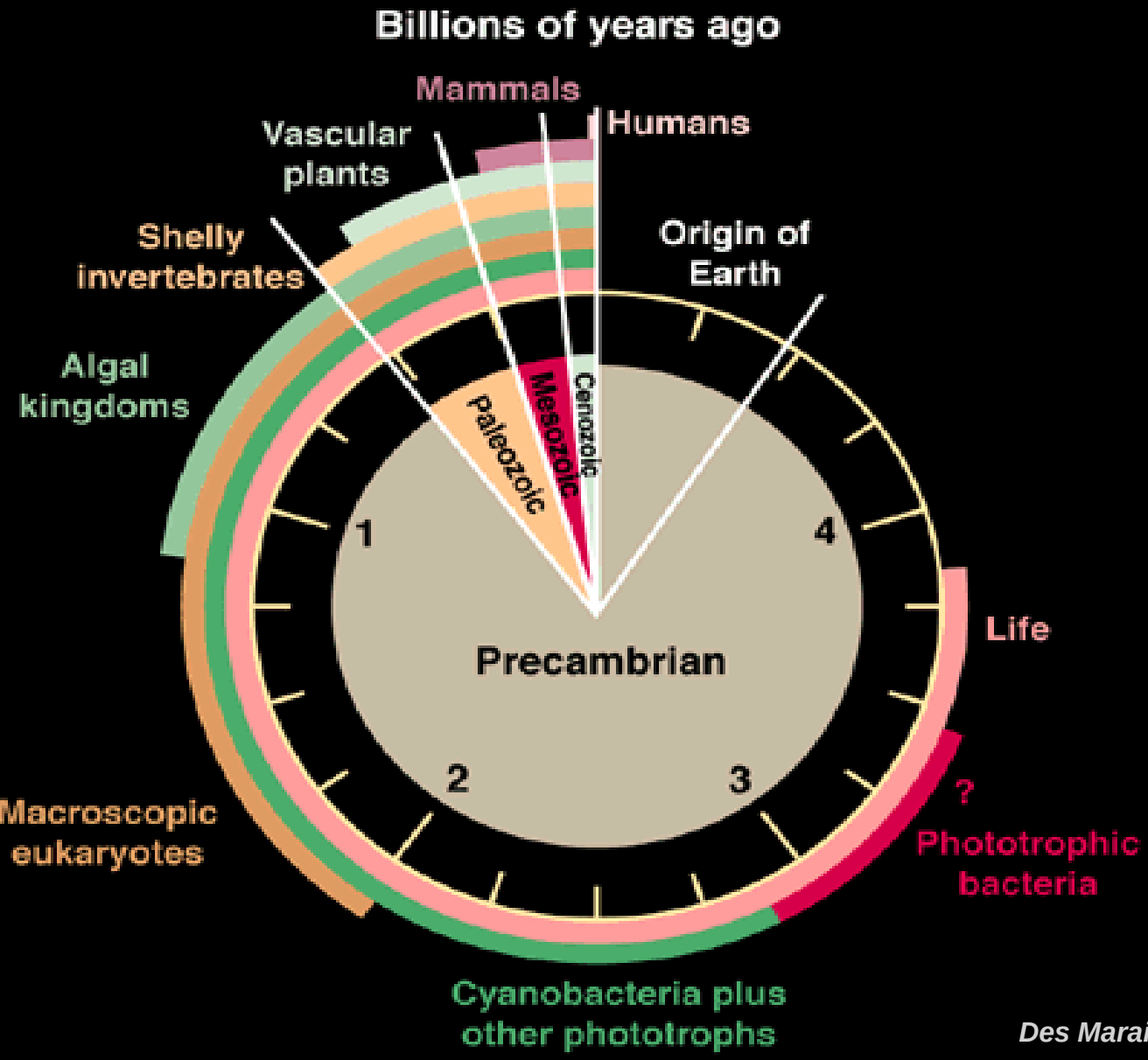
History of life on Earth

Age of the Earth: **~ 4.6 billion years**

Age of life on Earth: **> 3.5 billion years**

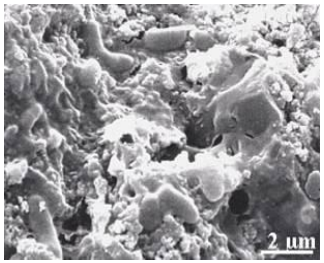
Our biosphere

Evolution of life on Earth



Des Marais (Science, 2000)

History of life on Earth: Fossil record



Precambrian

Paleozoic

Mesozoic

Cenozoic

Oldest fossils
3,600 mya

First eukaryotes
1,500 mya

Formation of Earth
4,600 mya

Multicellular organisms 650 mya

Shells and skeletons 570 mya

Formation of Pangaea 245 mya

Extinction of dinosaurs; Plants and mammals abundant 66 mya

Hominids (human ancestors) 3 mya

During life's evolution on Earth microorganisms

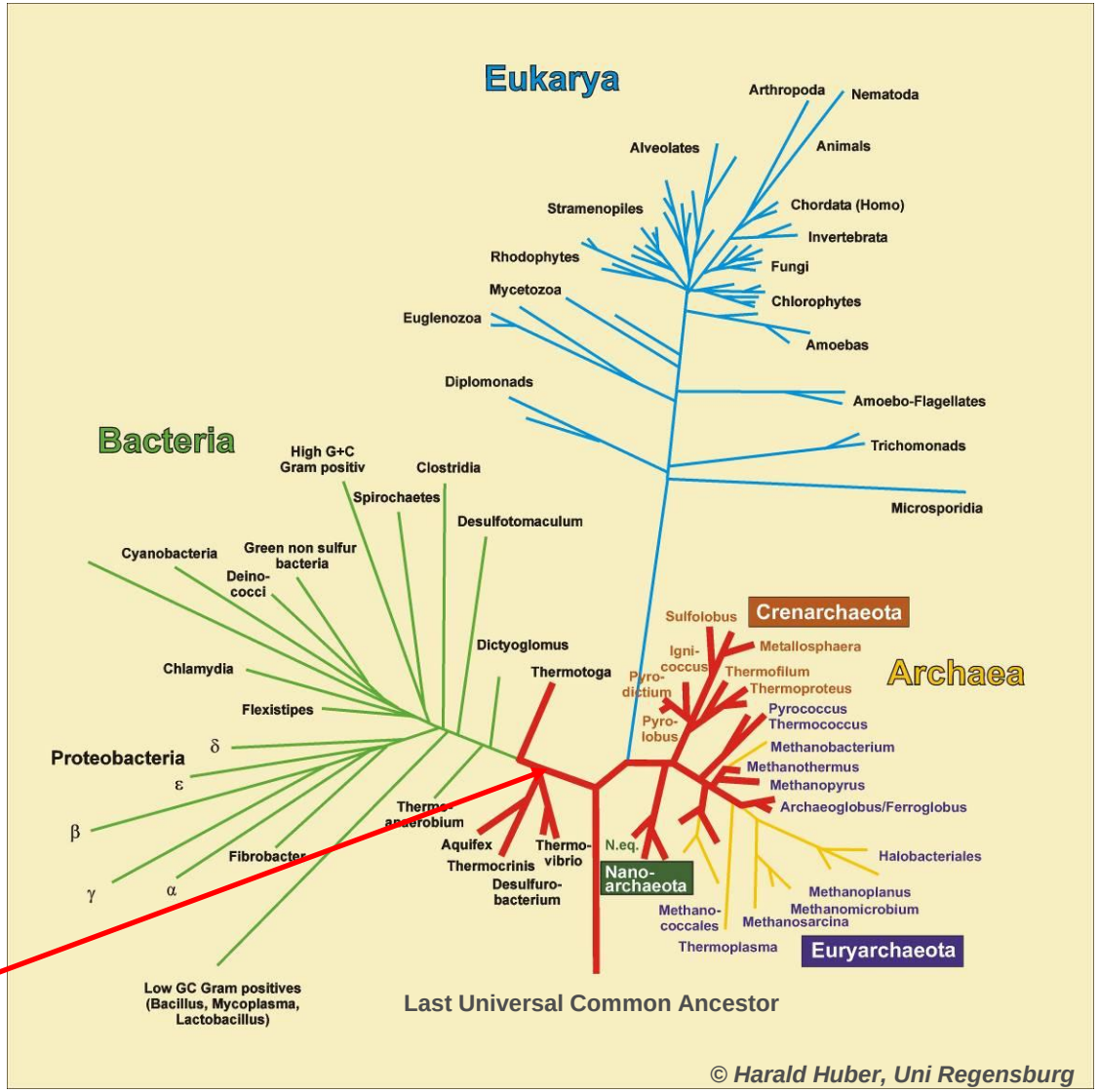
- **have existed since the emergence of life**
- **are ubiquitous**
- **inhabit "extreme" niches**

History of life on Earth: Molecular biology record

Phylogenetic tree of life

Life went through a bottle neck

Hot springs as the cradle of life?

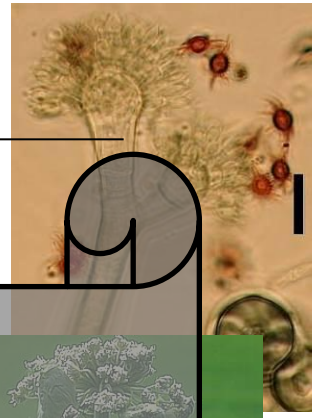


Hyperthermophilic microorganisms

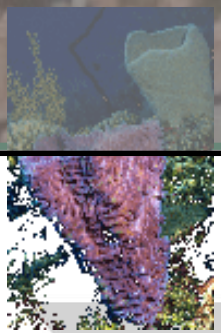
Our biosphere

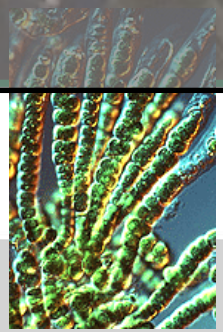
All life is based on the same principle

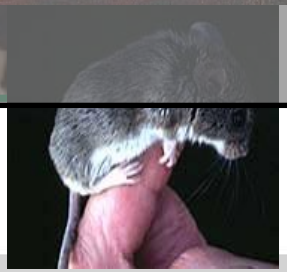
What is common to all life forms?

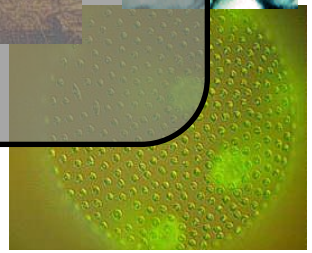


- Compartmentalization
- Carbon based chemistry
- Genetic code
- Set of amino acids in the proteins
- Machinery of transcription of information
- Machinery of translation of information
- Interactive communities (food chain)









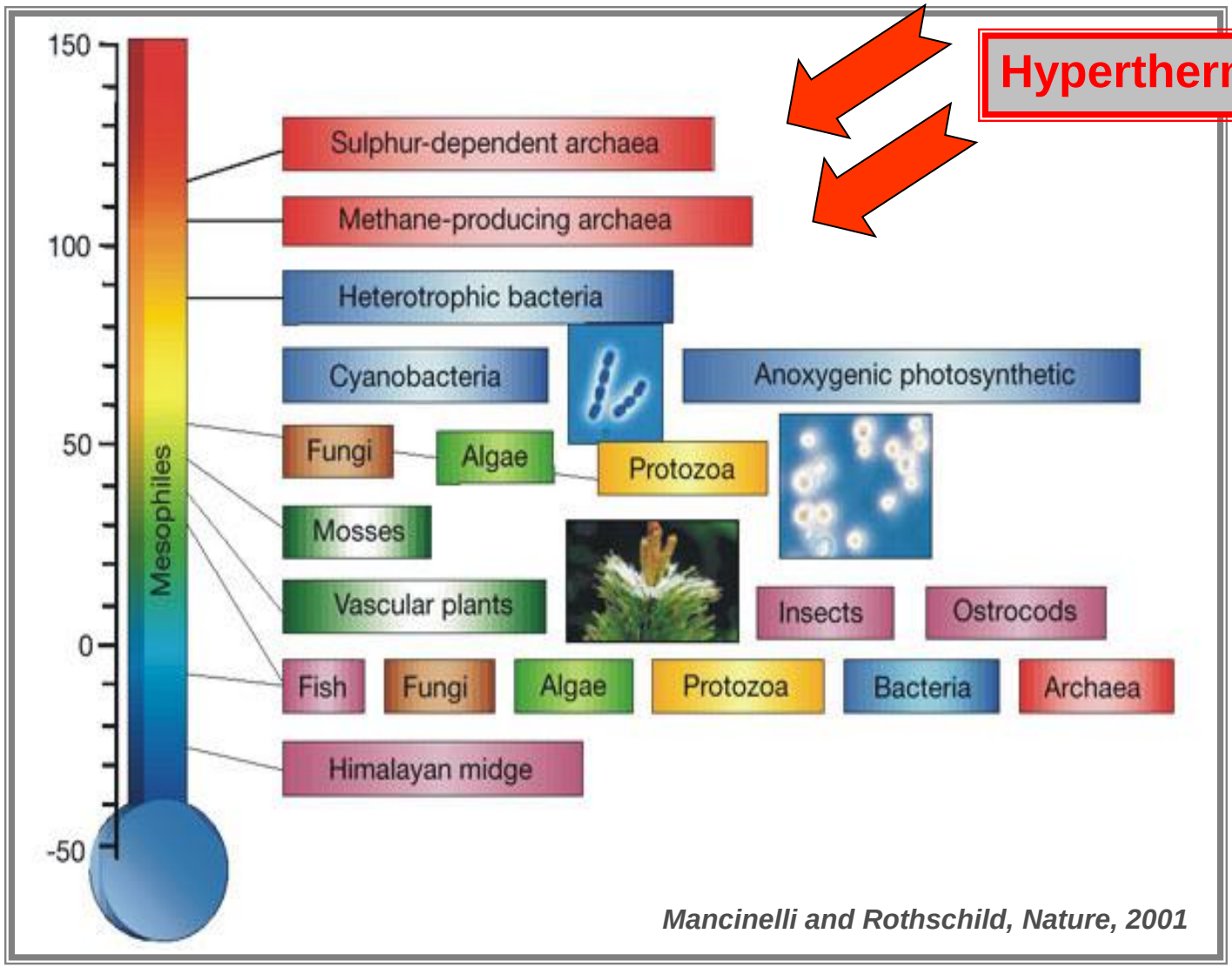
Life is a thermodynamic system

"Self reproduction, mutation und metabolism are the necessary prerequisites of natural selection."

⇒ Theory of Evolution

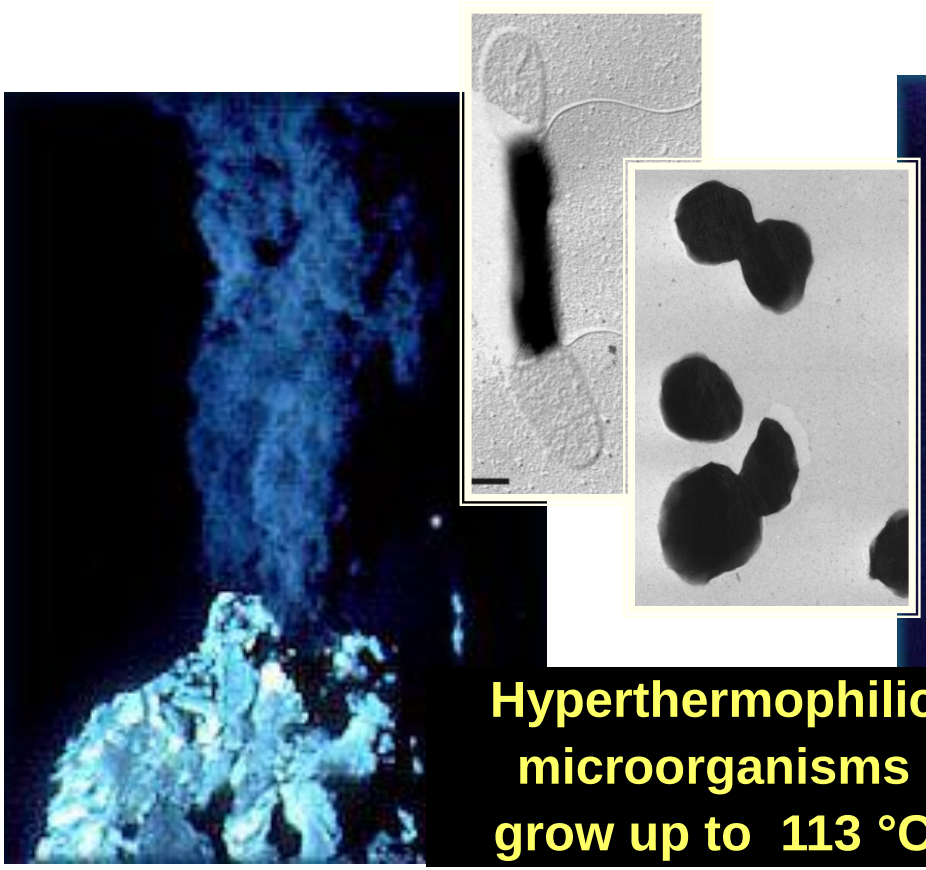
Manfred Eigen
(born 1927)
Nobel-Price in Chemistry (1967)

Limits of habitability: Temperature

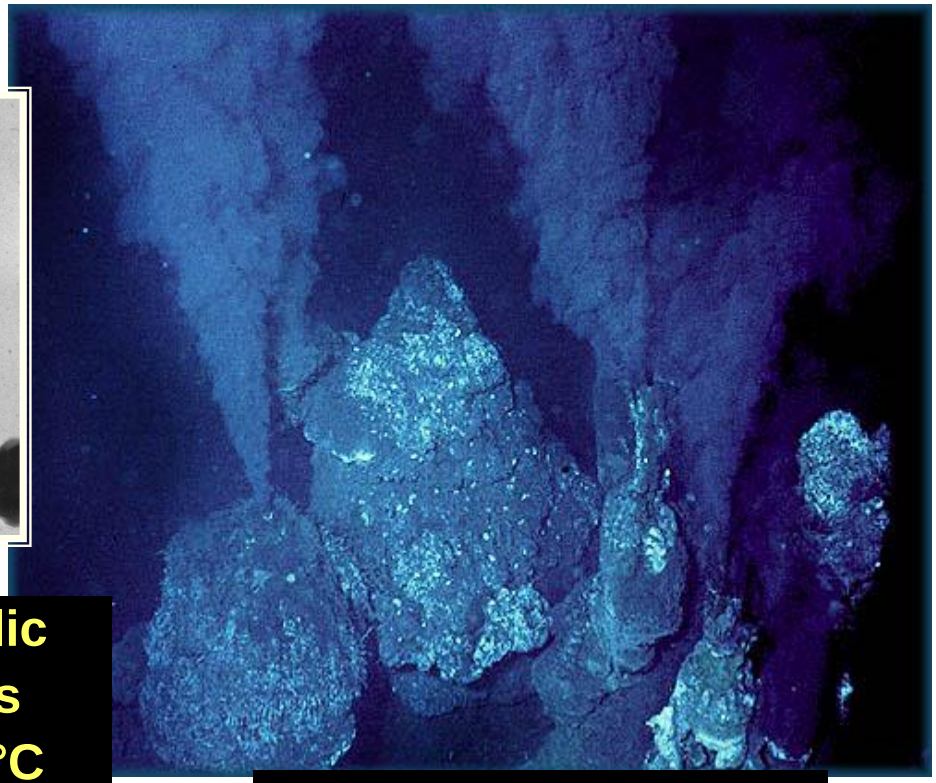


Mancinelli and Rothschild, Nature, 2001

Adaptation to high temperatures: Hyperthermophiles



Hyperthermophilic microorganisms grow up to 113 °C



Black smokers

Optimum growth temperature: 80°C and above
No growth at 60°C or below

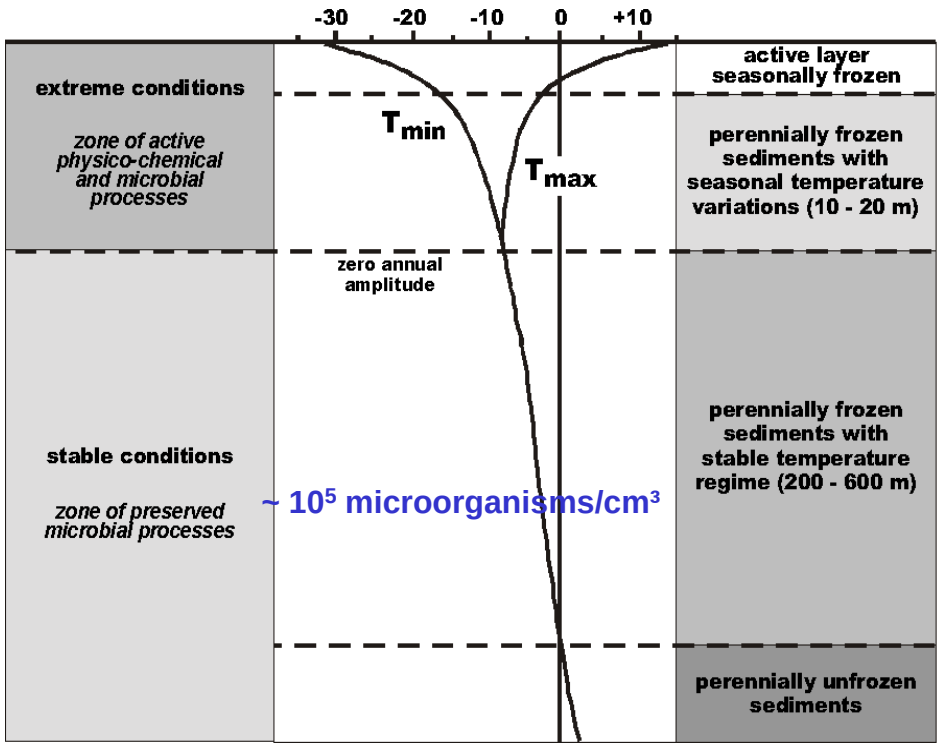
Karl Stetter

Adaptation to low temperatures: Psychrophiles

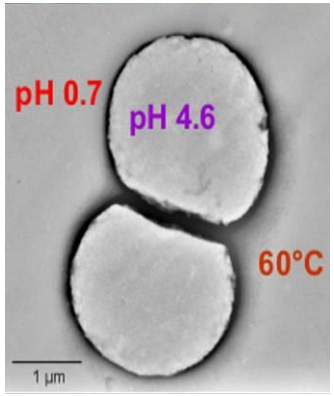
Microorganisms in Permafrost

- ≈ - 10°C (Arctic), ≈ - 25°C (Antarctic)
- 92-97% frozen, 3-8 % liquid water

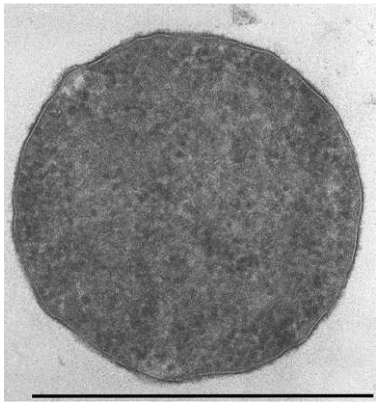
Permafrost in Sibiria



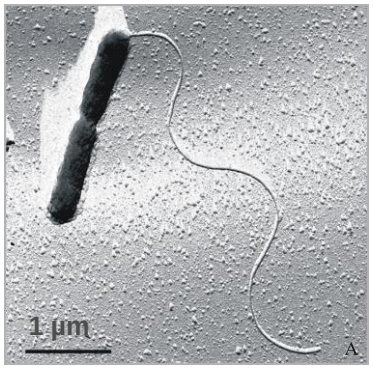
Adaptation to extreme ph values



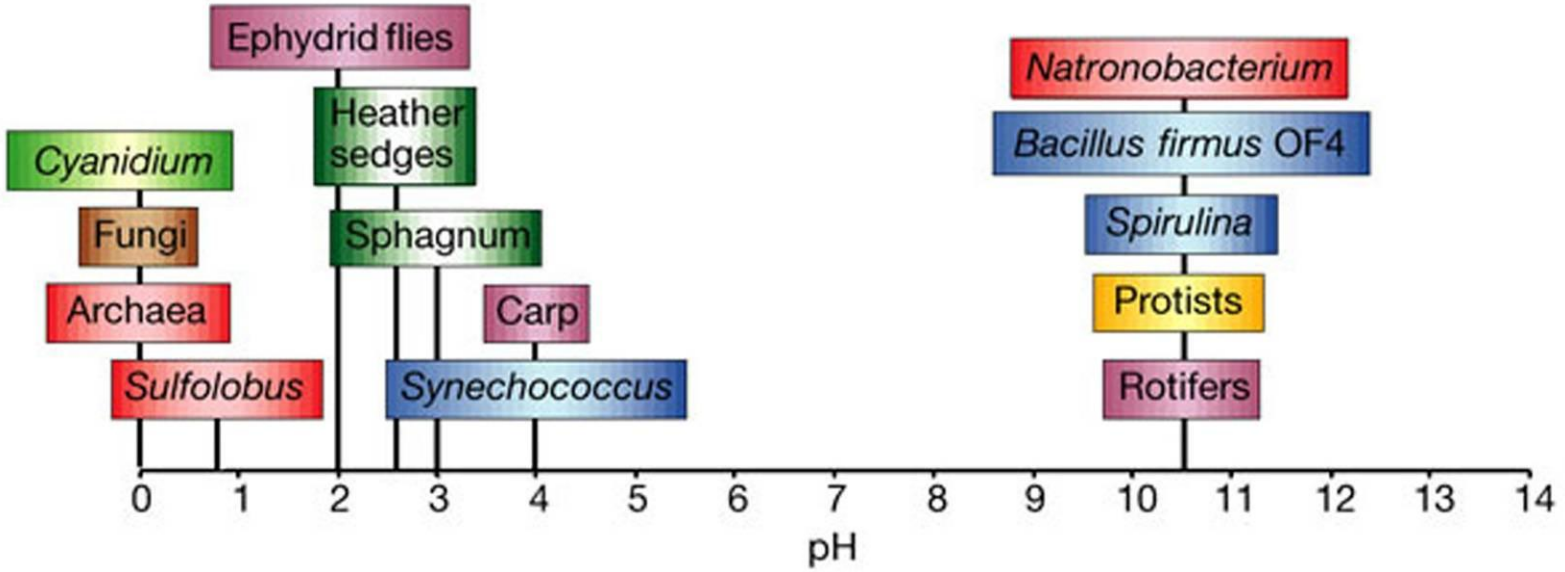
Picrophilus oshimae



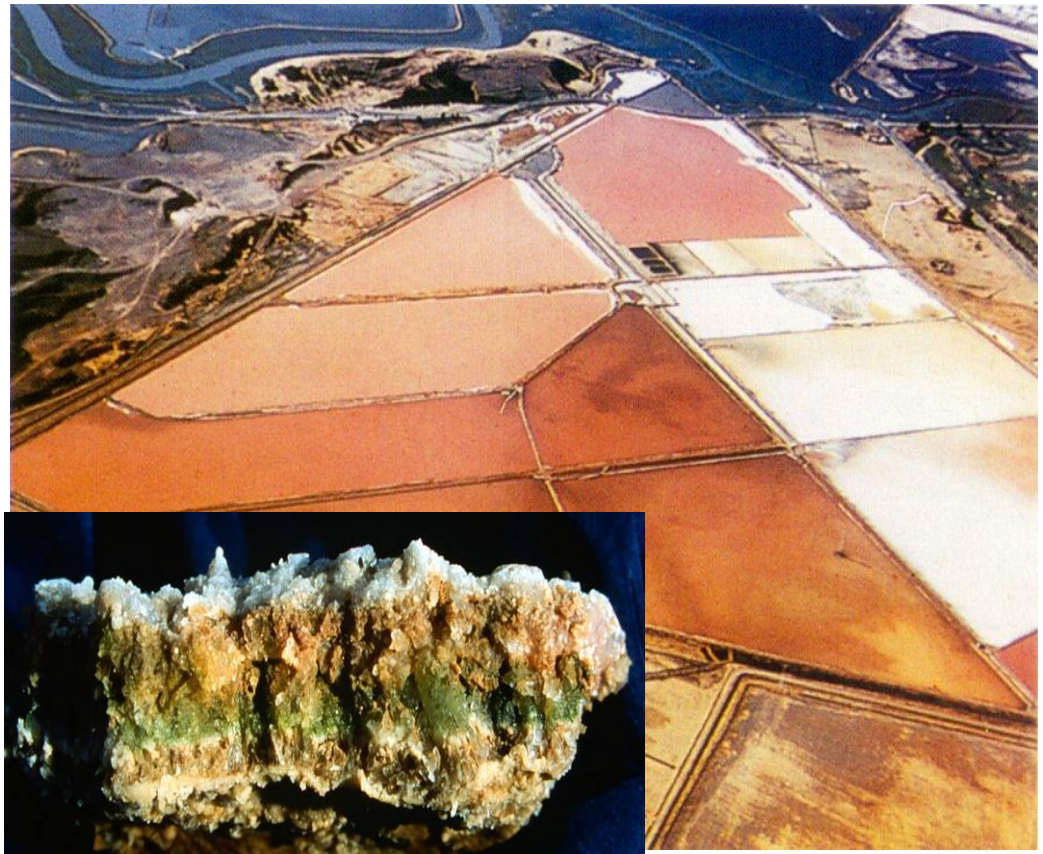
Thermoplasma acidophilum



Natronobacterium



Adaptation to high salt concentrations: Halophiles



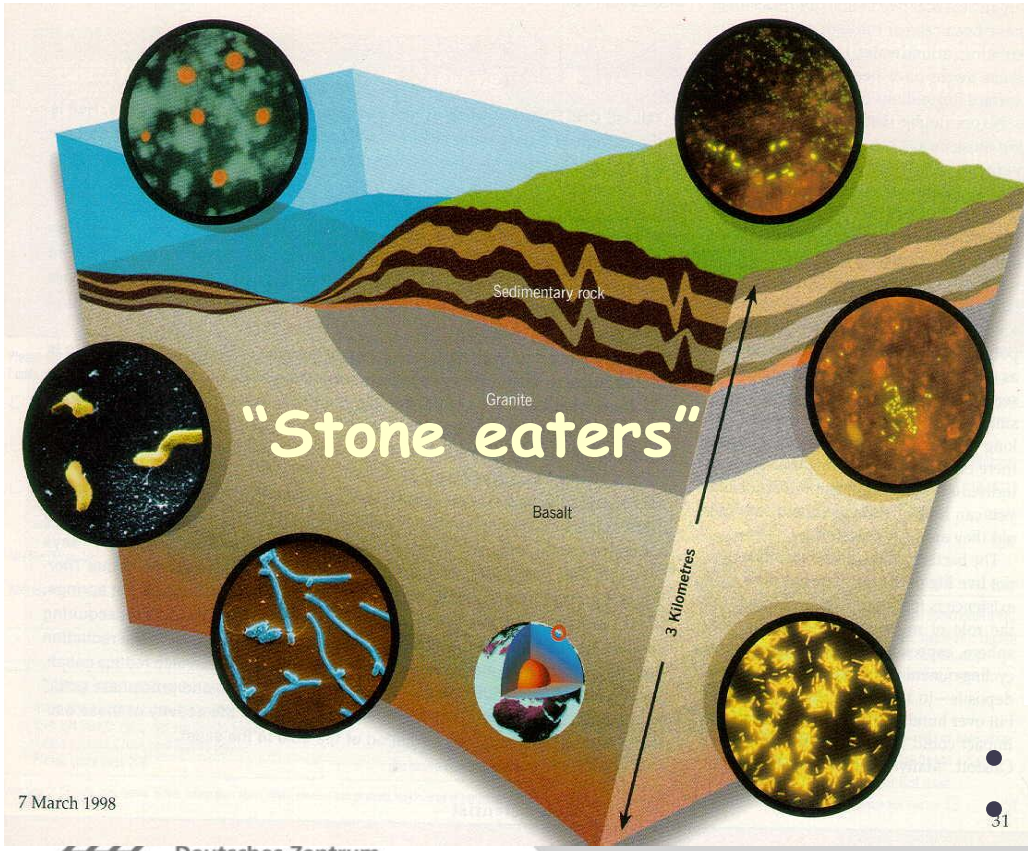
Halophiles live in brines or salt crystals

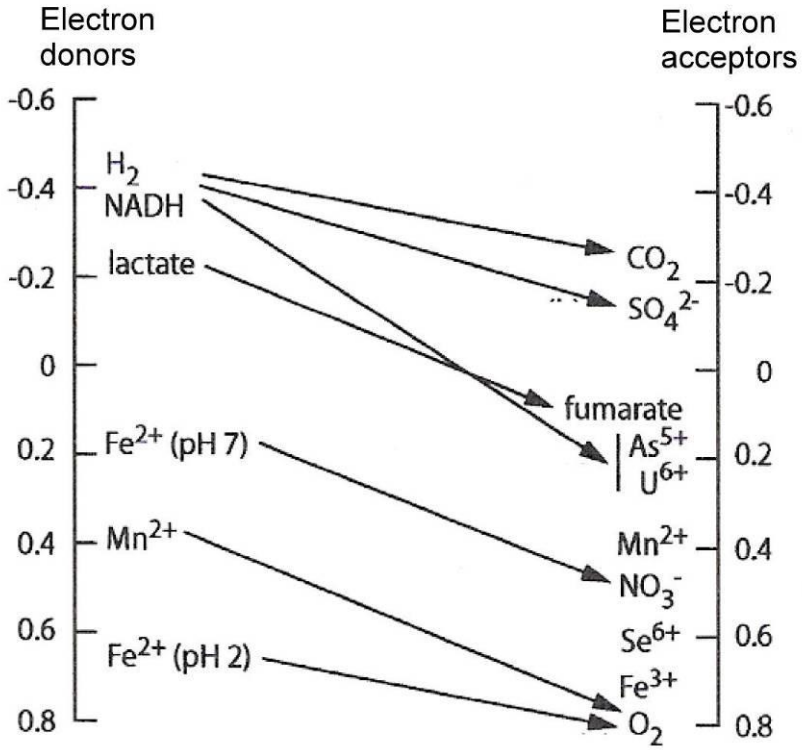
- **<u>salt-in-cytoplasm strategy</u>: adapt interior protein chemistry to high salt concentrations (high K^+ or Na^+)**

- **<u>organic-osmolyte strategy</u>: cell interior free of salts, but enriched with uncharged, highly water-soluble, organic compounds (sugars, polyols, amino acids)**

Limits of habitability: Life in the subsurface

SLIME (Subsurface Lithoautotrophic Microbial Ecosystem)





- Chemolithotrophs
- Fraction of subsurface life still unknown

Limits of habitability: Endolithic communities

Biofilm as endolithic microbial community

During life‘s evolution on Earth microorganisms

- **have existed since the emergence of life**
- **are ubiquitous**
- **inhabit “extreme“ niches**


Are we alone?

Prerequisites for habitability and life

Joan (John) Oro
(1923 - 2004)

- ***Star:*** *single star, availability of heavy elements, mass, lifetime, planetary system;*
- ***Planet:*** *mass, orbit, atmosphere, discrete liquid sphere, surface;*
- ***Chemistry:*** *solvents, element composition and concentration, energy source, redox potential, pH range;*
- ***Biology:*** *replication of informational molecules, stereospecific catalytic molecules, information transfer molecules, polymerising molecular assembly, interphasic molecular assembly.*

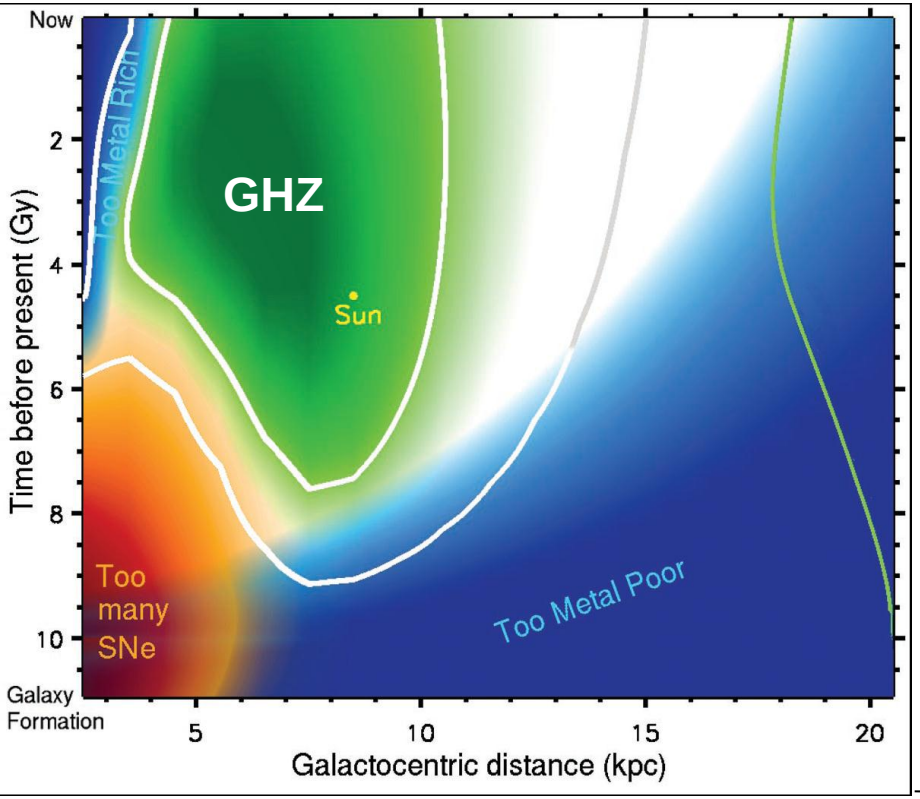
Oro, Rewers and Odom, 1982, Origins of Life, 12, 285

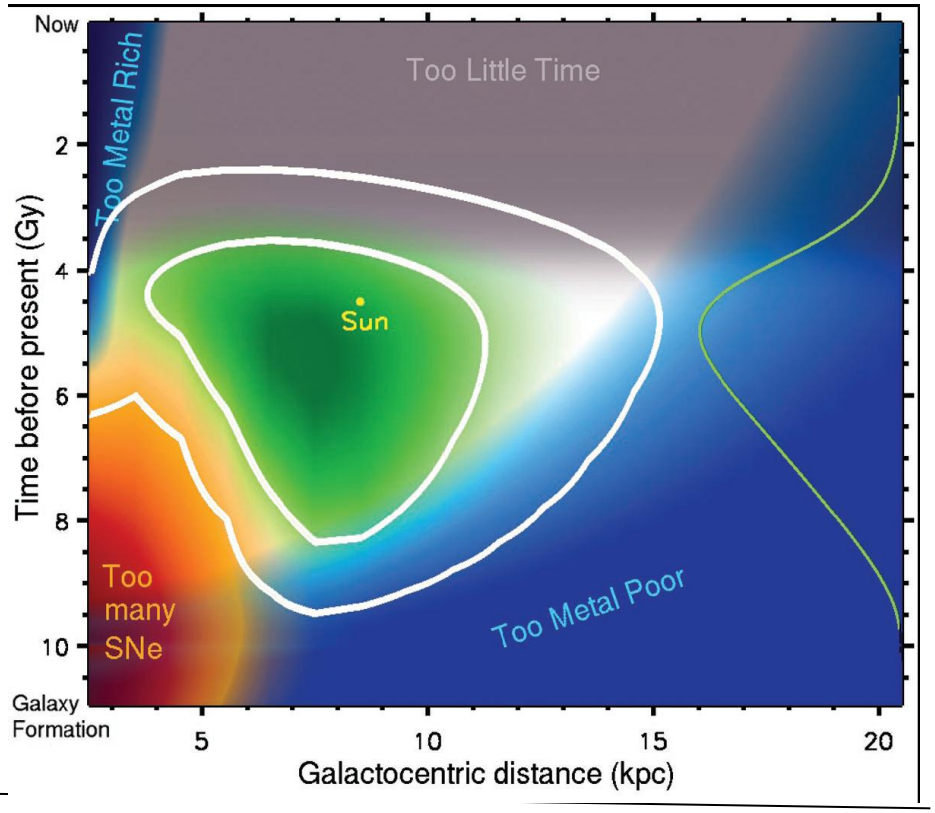
Habitability in our Galaxy

- *Presence of a host star*
- *Enough heavy elements to form terrestrial planets*
- *Sufficient time for biological evolution*
- *An environment free of life-extinguishing supernovae*

Lineweaver, Fenner and Gibson, 2004, Science, 303, 59

Galactic habitable zone: GHZ



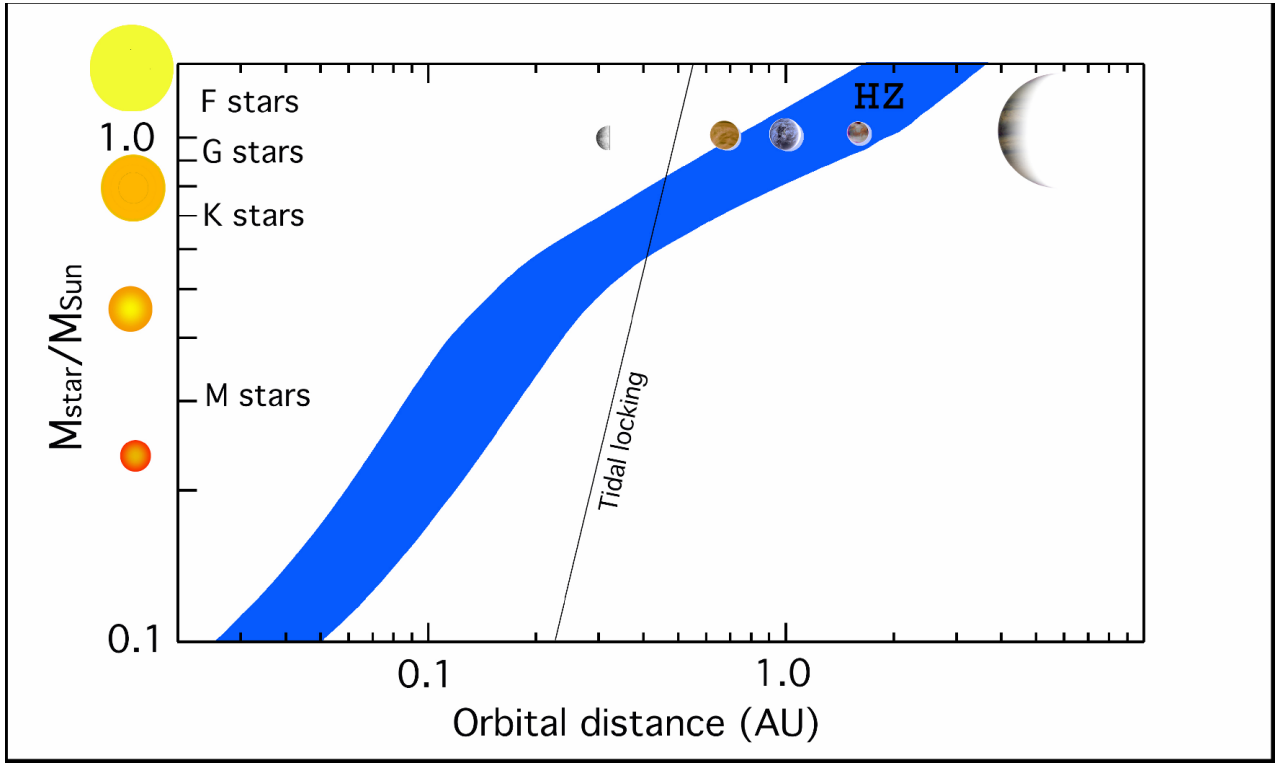


GHZ for simple, e.g. microbial life

GHZ for complex, e.g. intelligent life

Lineweaver, Fenner and Gibson, 2004, Science, 303, 59

Circumstellar habitability



- ***Presence of liquid water on the planet's surface for sufficient time for life to start and evolve.***

Kasting et al. 1993, Icarus, 101, 108

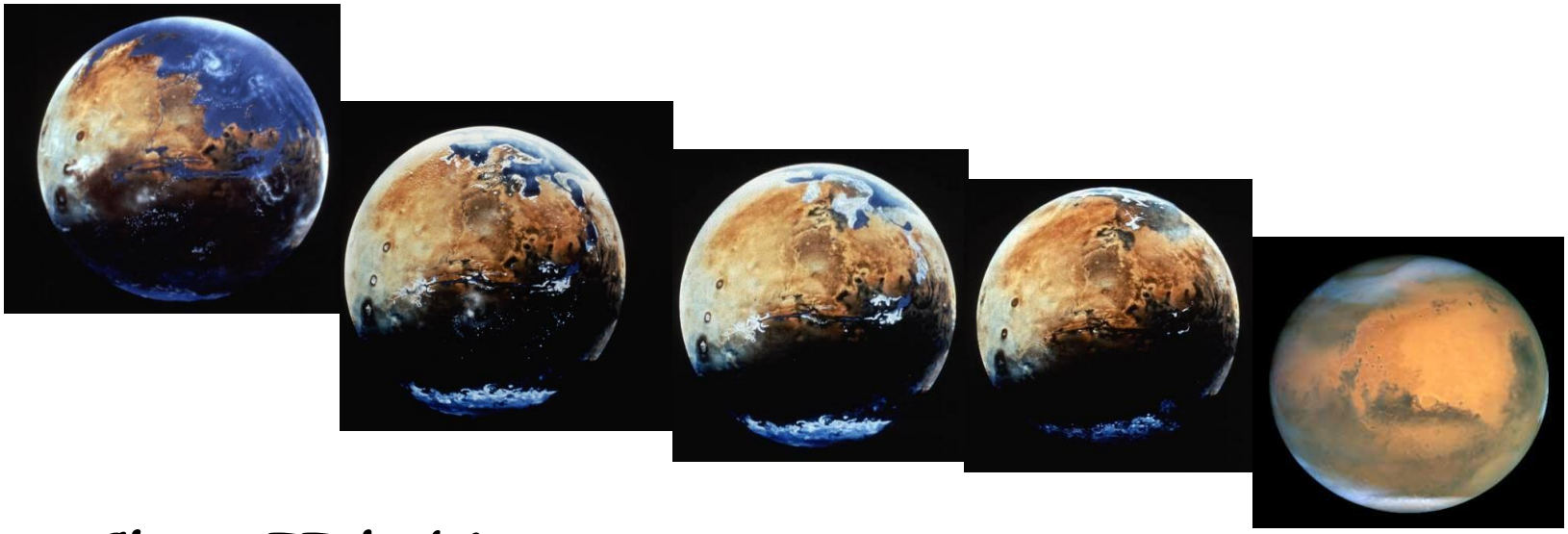
Circumstellar habitability

- ***Class I habitats:***

Bodies on which stellar and geophysical conditions allow Earth-analog planets to evolve so that complex multi-cellular life forms may evolve.

Lammer et al. 2009, Astronom. Astrophys. Rev. 17,181

Circumstellar habitability

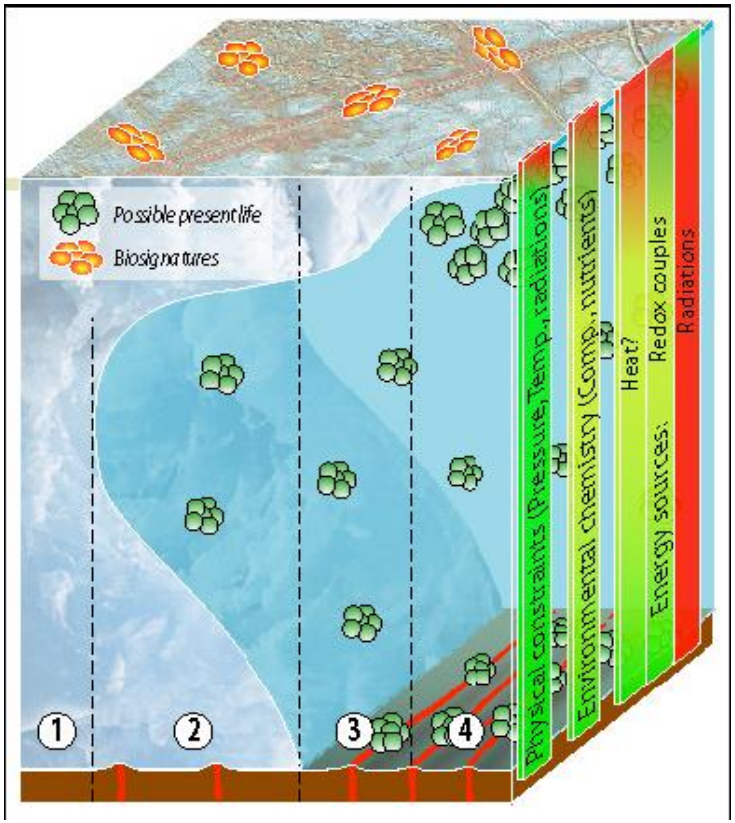


- *Class II habitats*

Bodies on which life may evolve but due to stellar and geophysical conditions that are different from the class I habitats, the planets rather evolve toward Venus- or Mars-type worlds where simple, unicellular life-forms may originate.

Lammer et al. 2009, Astronom. Astrophys. Rev. 17,181

Circumstellar habitability

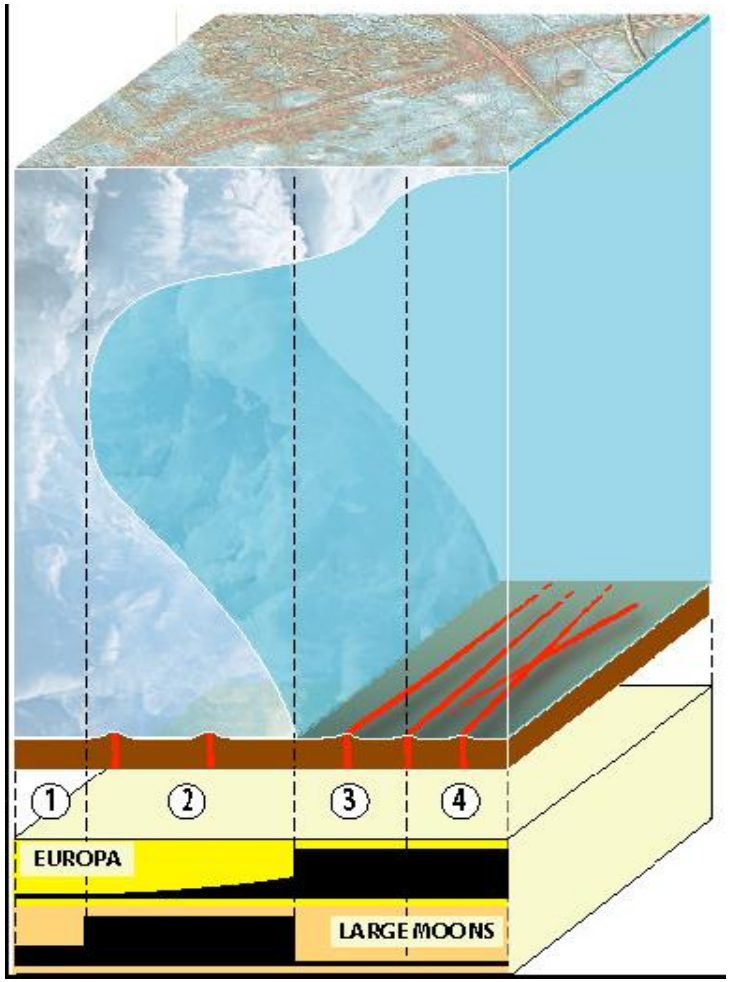


e.g., Jupiter`s Moon Europa

- ***Class III habitats Bodies where subsurface water oceans exist, which interact directly with a silicate-rich core***

Lammer et al. 2009, Astronom. Astrophys. Rev. 17,181

Circumstellar habitability



- ***Class IV habitats***
  Bodies with liquid water layers between two ice layers, or liquids above ice

Lammer et al. 2009, Astronom. Astrophys. Rev. 17,181

Prerequisites for habitability and life

- Star: single star, availability of heavy elements, mass, lifetime, planetary system;
- Planet: mass, orbit, atmosphere, discrete liquid sphere, surface;
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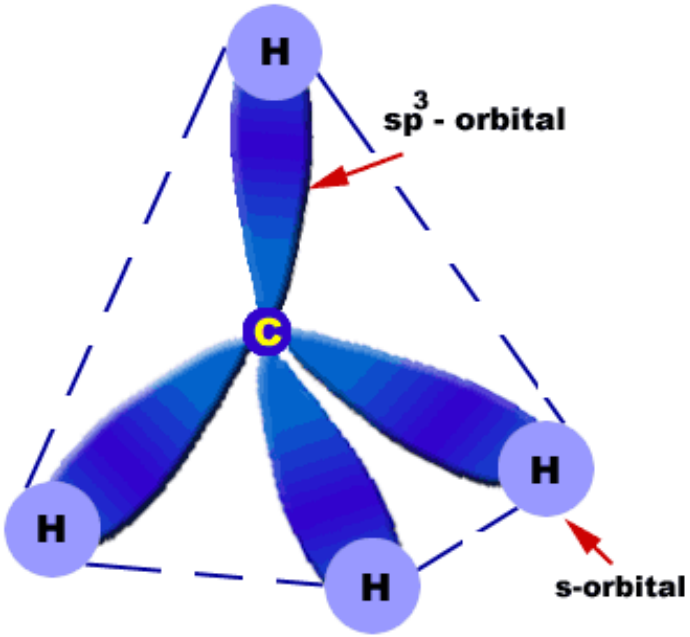
Oro, Rewers and Odom, 1982, Origins of Life, 12, 285

Elements of life



Orbital structure of methane

-All life is based on carbon chemistry

-Carbon is key to life and by definition is present in all organic compounds

Elements of life

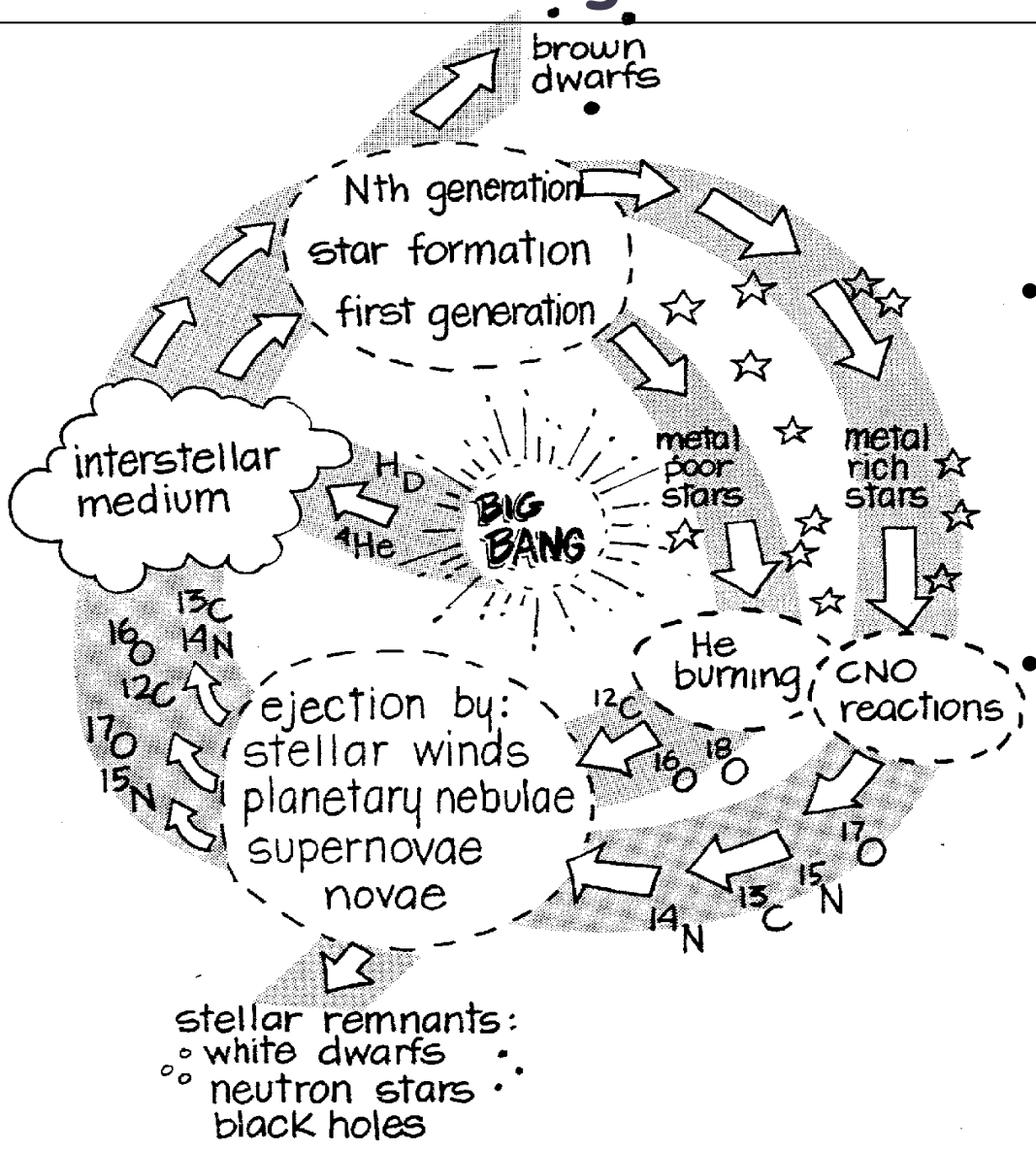
Biogenic Elements:

- Carbon C
- Hydrogen H
- Oxygen O
- Nitrogen N
- Sulfur S
- Phosphorus P

CHONSP

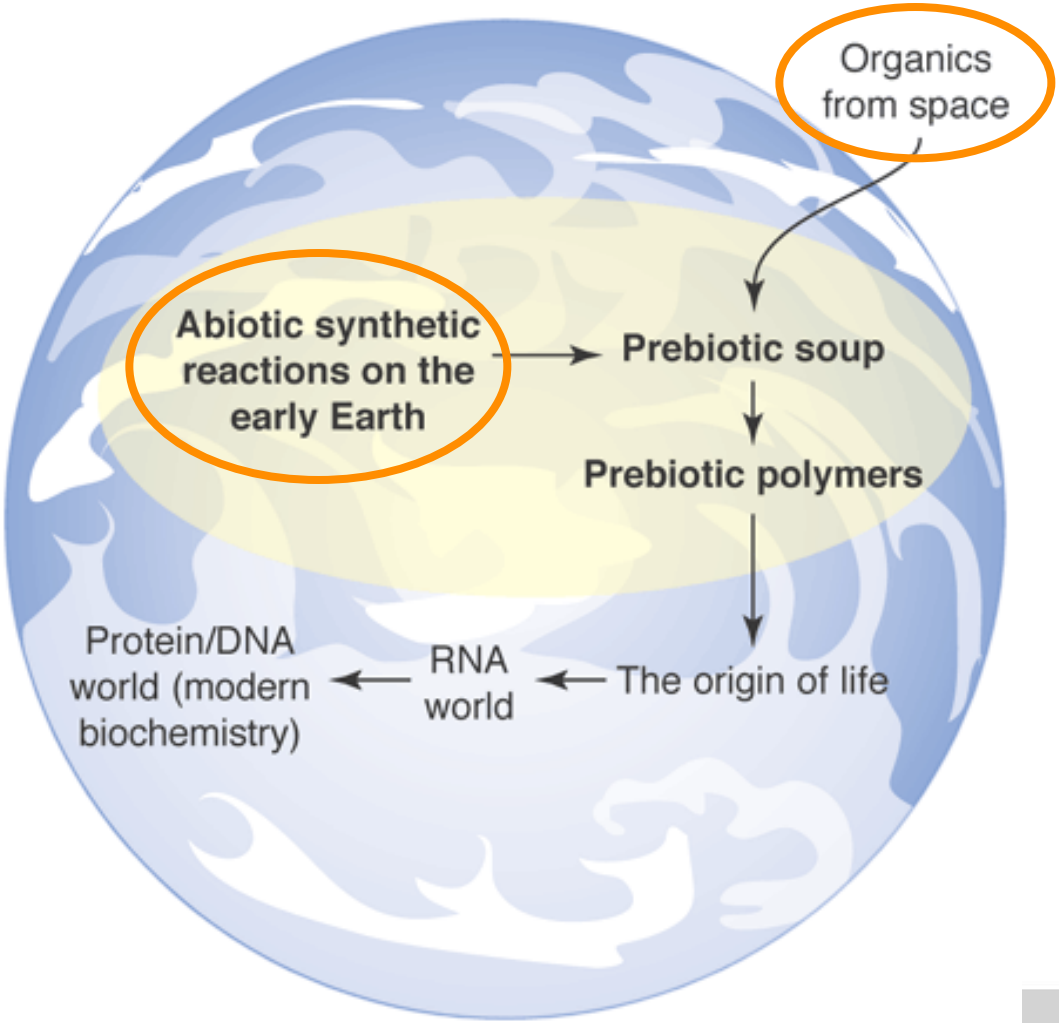
- plus many heavier elements

• Formation of biogenic elements



- **Life is composed from the ashes of previous stars:**
- **Several generations of stars are required to obtain all biogenic elements**

Sources of biogenic molecules



Sources of biogenic molecules

***Exogenous* sources of biogenic molecules**

- **Comets**
- **Meteorites**
- **Micrometeorites**

Sources of biogenic molecules

***Endogenous* sources of biogenic molecules**

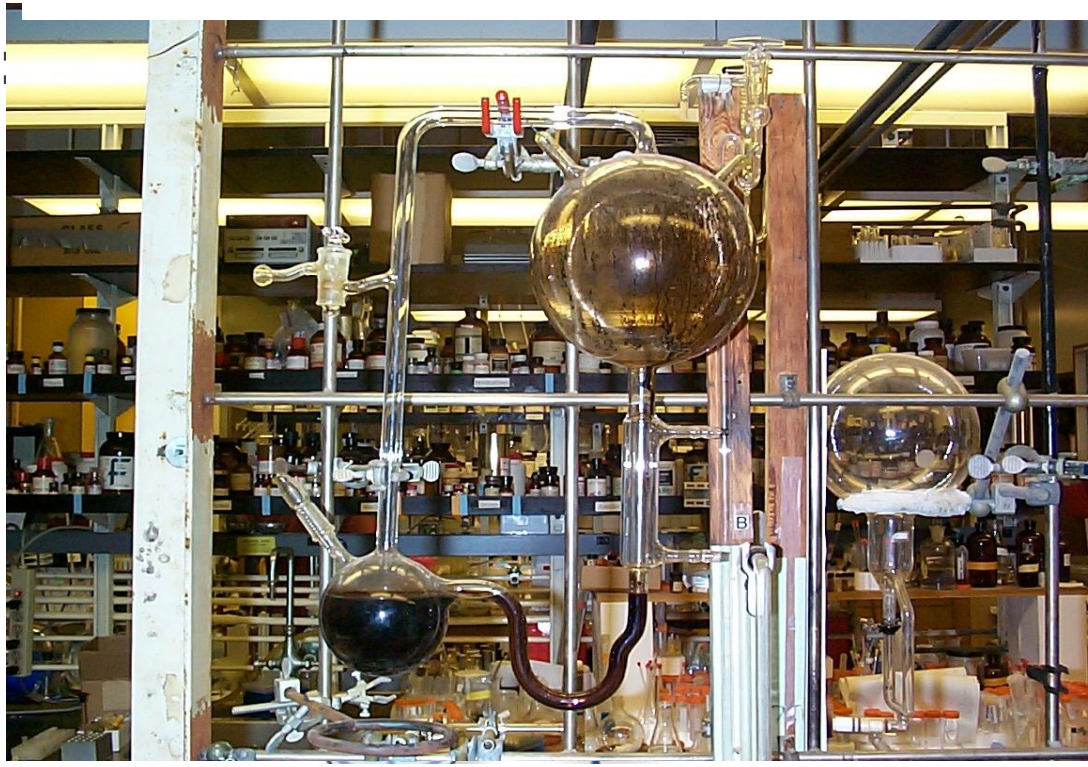
- **Early atmosphere**
- **Sea ice reactor**
- **Hydrothermal vents**
- **Mineral surfaces (pyrite)**

Sources of prebiotic organic molecules

Endogenous sources: Atmospheric synthesis

Miller-Urey Experiment:

- Published 1953
- Simulates the coupled chemistry between the primitive Earth atmosphere and warm oceans
- Assuming a reducing atmosphere a large amount of organic molecules was produced



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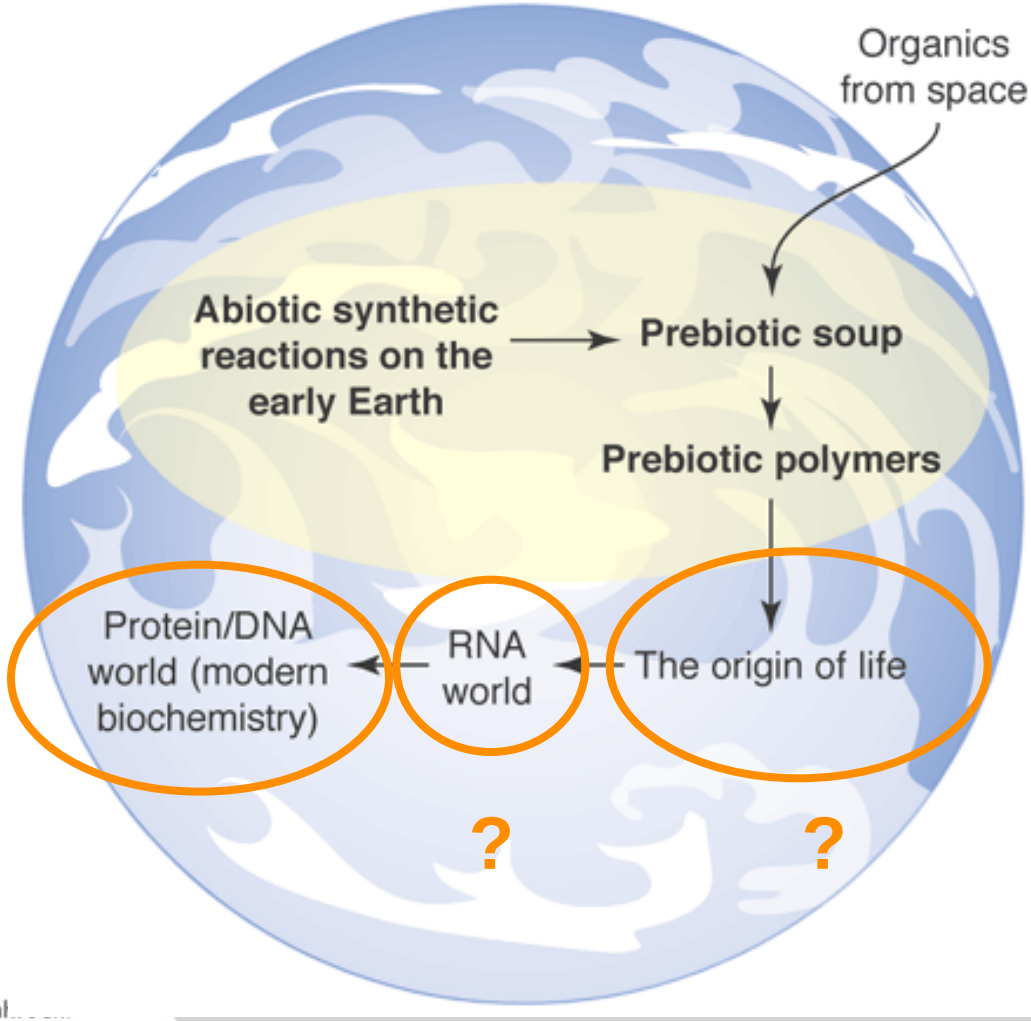
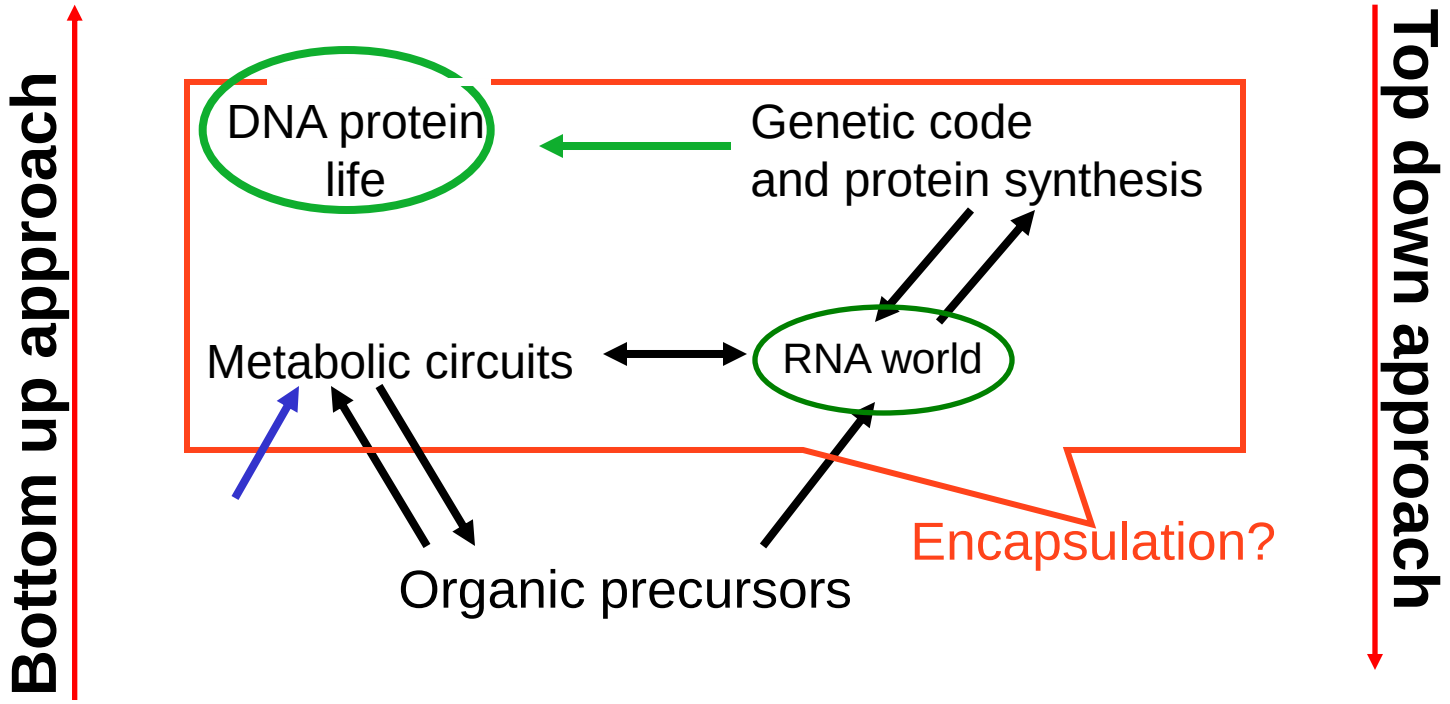
Oro, Rewers and Odom, 1982, Origins of Life, 12, 285

Steps to life

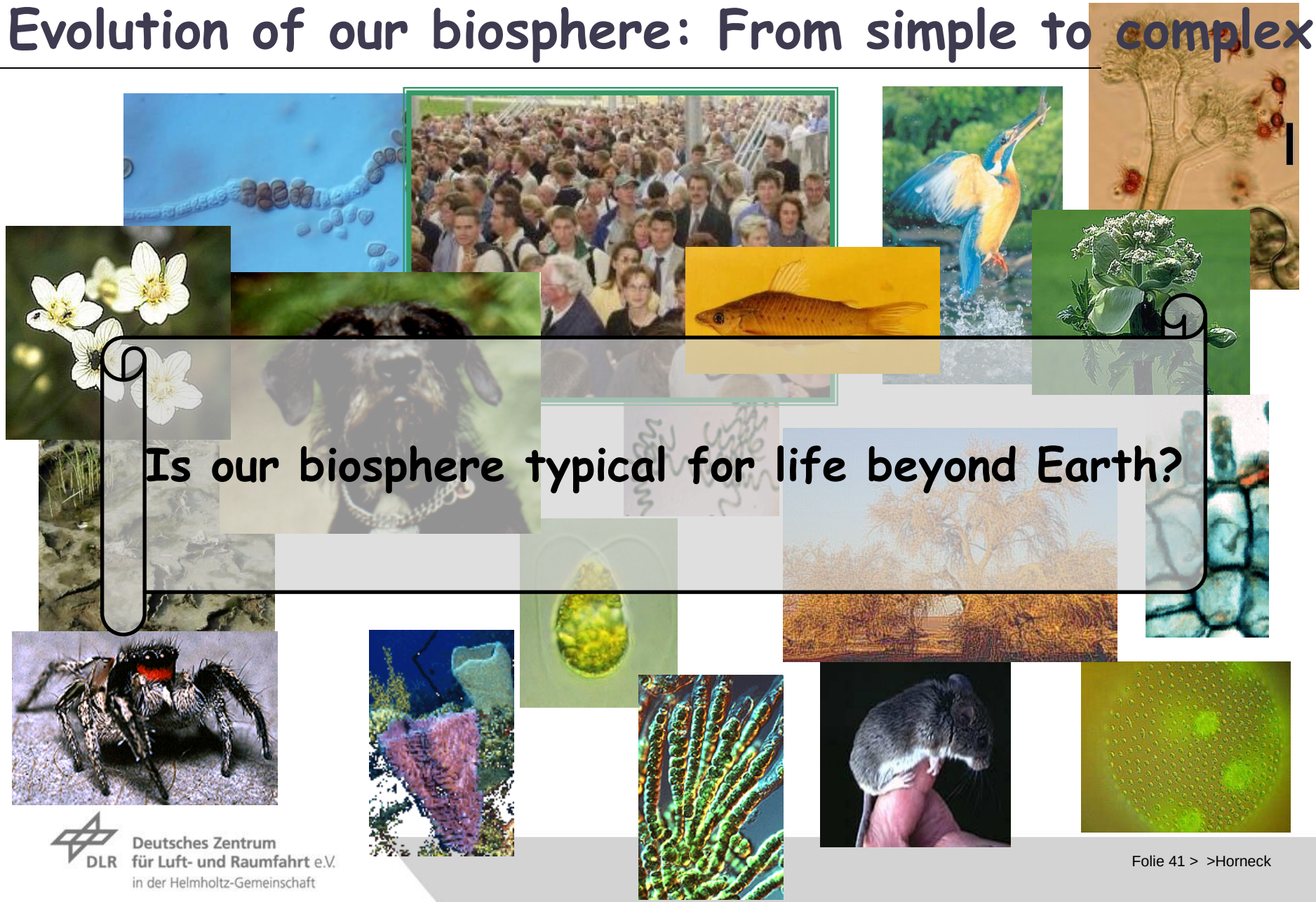


Origin of life: the crucial issue



R. Shapiro, Origin of Life: the crucial issue, in Planets and Life, Sullivan and Baross (eds.) Cambridge UP (2007)

Evolution of our biosphere: From simple to complex



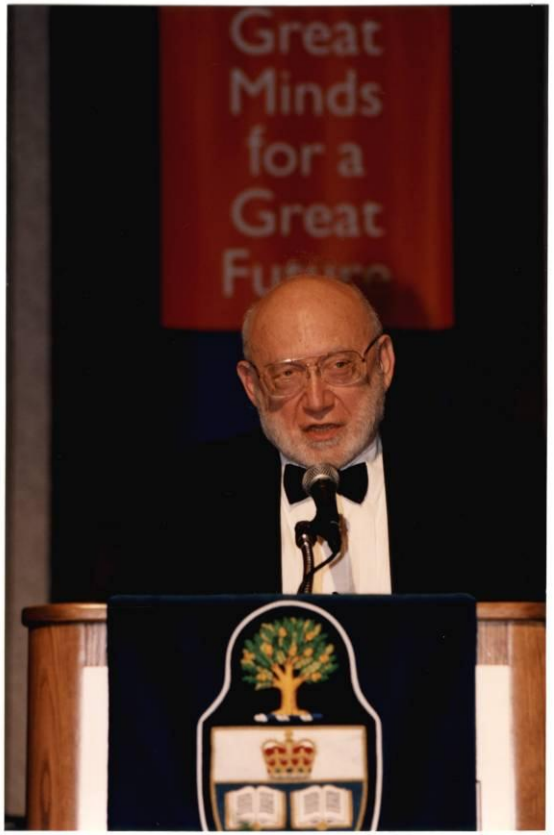
Is our biosphere typical for life beyond Earth?

Life a cosmic phenomenon ?

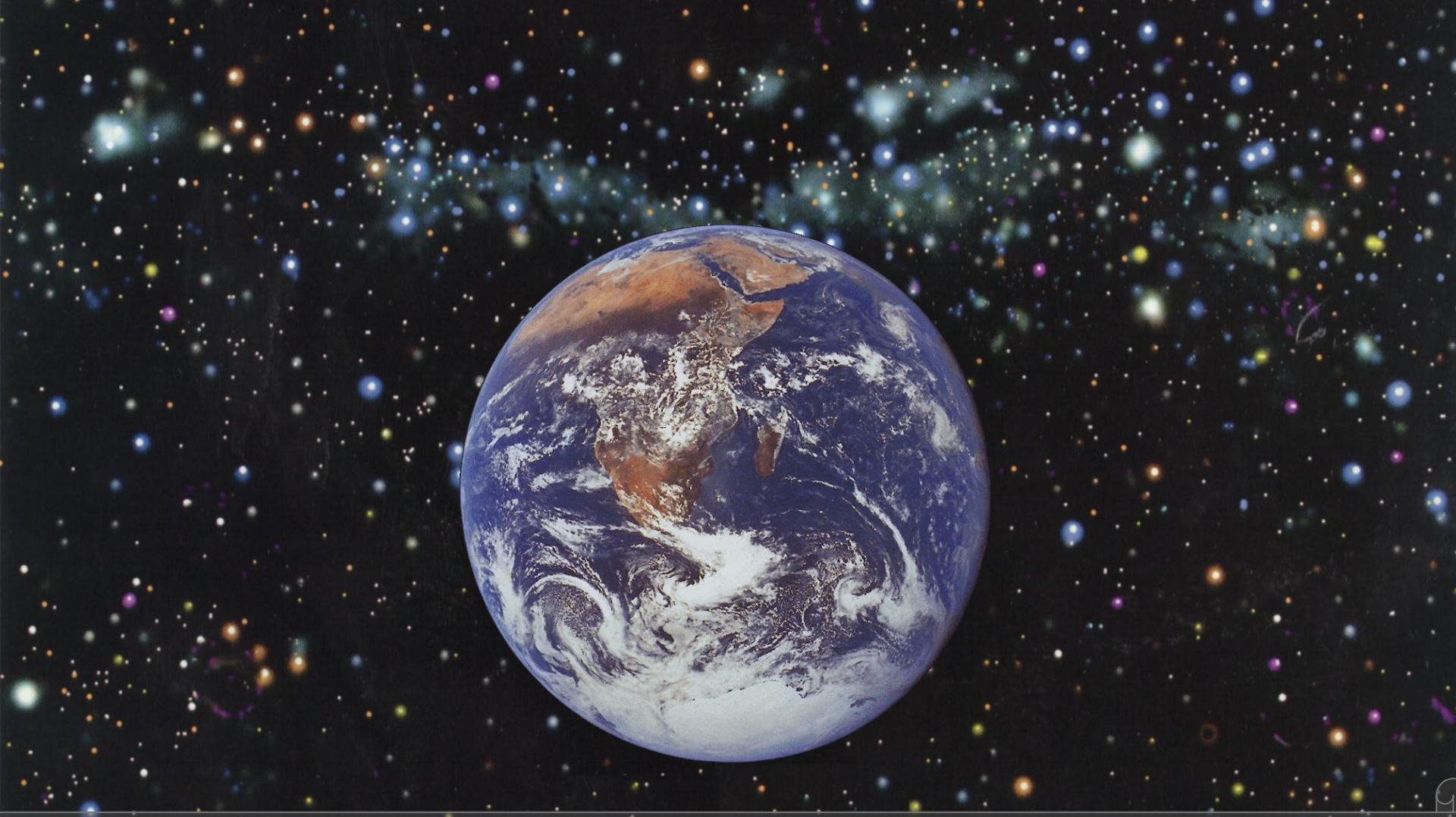
"The exploration of space has

- widened the horizon of the physical world: the concepts of mass and energy are valid throughout the universe
- led to generalization of chemistry: the spectra of the stars testify the universality of the concepts in chemistry
- has the potential to inspire biology: to build the foundations for the construction and testing of meaningful axioms to support a theory of life"

⇒ Towards a universal definition of life



Joshua Lederberg,
1925-2008
Nobel price in medicine 1959



? “The Earth is one of the planets to harbour life“ ?

EUROPEAN ASTROBIOLOGY NETWORK ASSOCIATION