NJU Course

Principles of Paleobiology

Planetary Astrobiology

Planetary Astrobiology

Definitions

Astrobiology - an interdisciplinary field that studies the origin, early evolution, distribution and future of life in the universe, including whether extraterrestrial life exists and, if so, how to detect it.

- Disciplines covered by astrobiology
  - Molecular biology
  - (Bio)physics
  - (Bio)chemistry
  - Astronomy
  - Cosmology
  - Exoplanetology
  - Geology
  - Paleontology

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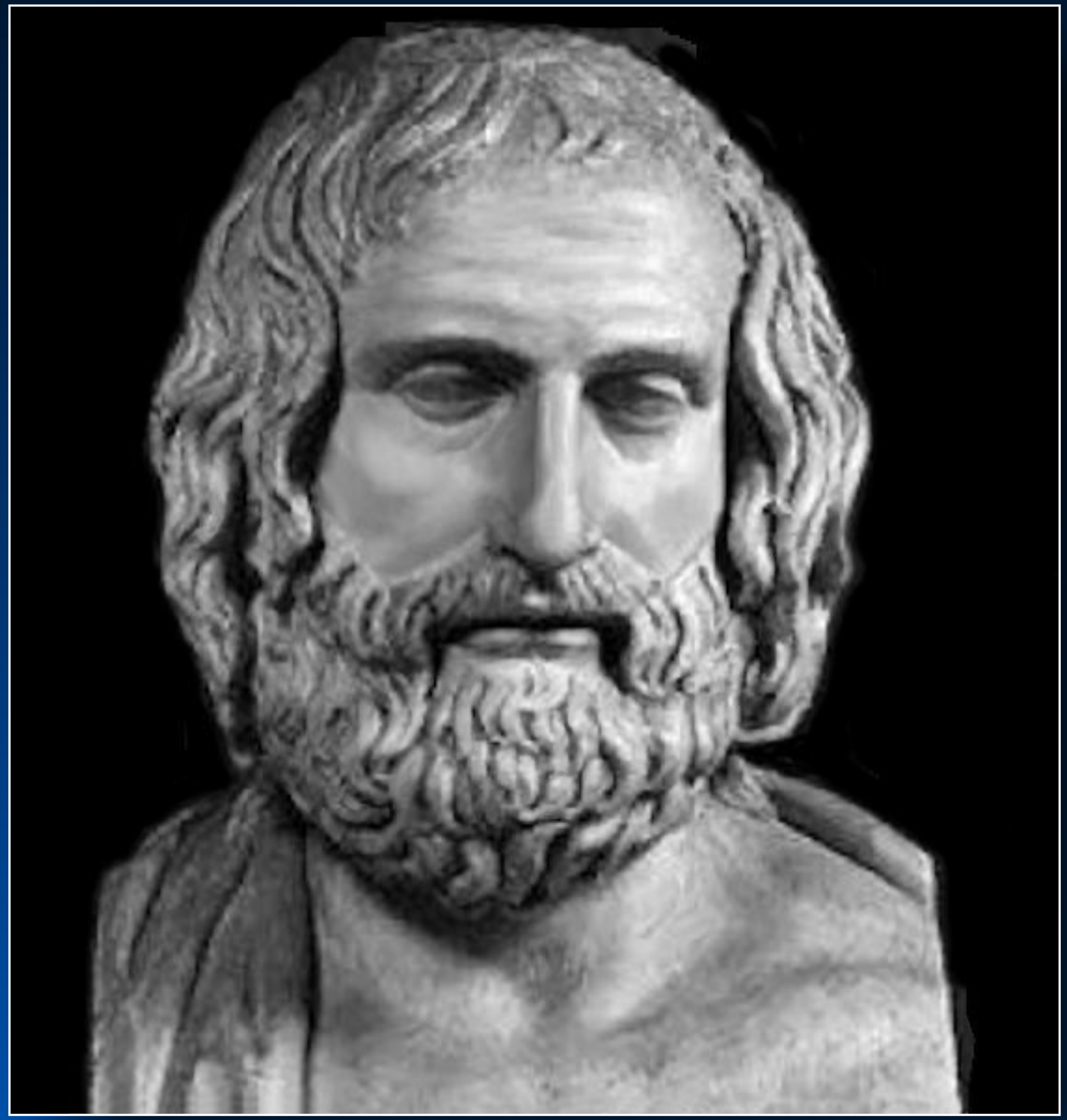
Founders of Astrobiology: Anaxagoras

Pre-Socratic Greek philosopher who wrote on many natural history topics. Anaxagoras is credited with being the first to predict a solar eclpise correctly and also speculated on the nature of rainbows and meteors.

In the area of astrobiology Anaxagoras' writings contain the first mention of the panspermia hypothesis - the idea that life on Earth was seeded from elsewhere in space. This is consistent with his cosmology in which he proposed that, initially, the universe was homogeneous and that a cosmic force (Nous) caused the separation into the heterogeneous constituents (e.g., minerals, rocks, plants, animals) we see today.

Anaxagoras' panspermia theory relocated origin of life away from the Earth, but did not address the issue of how life came about.



Anaxagoras
(c. 500 - c. 428 B.C.)

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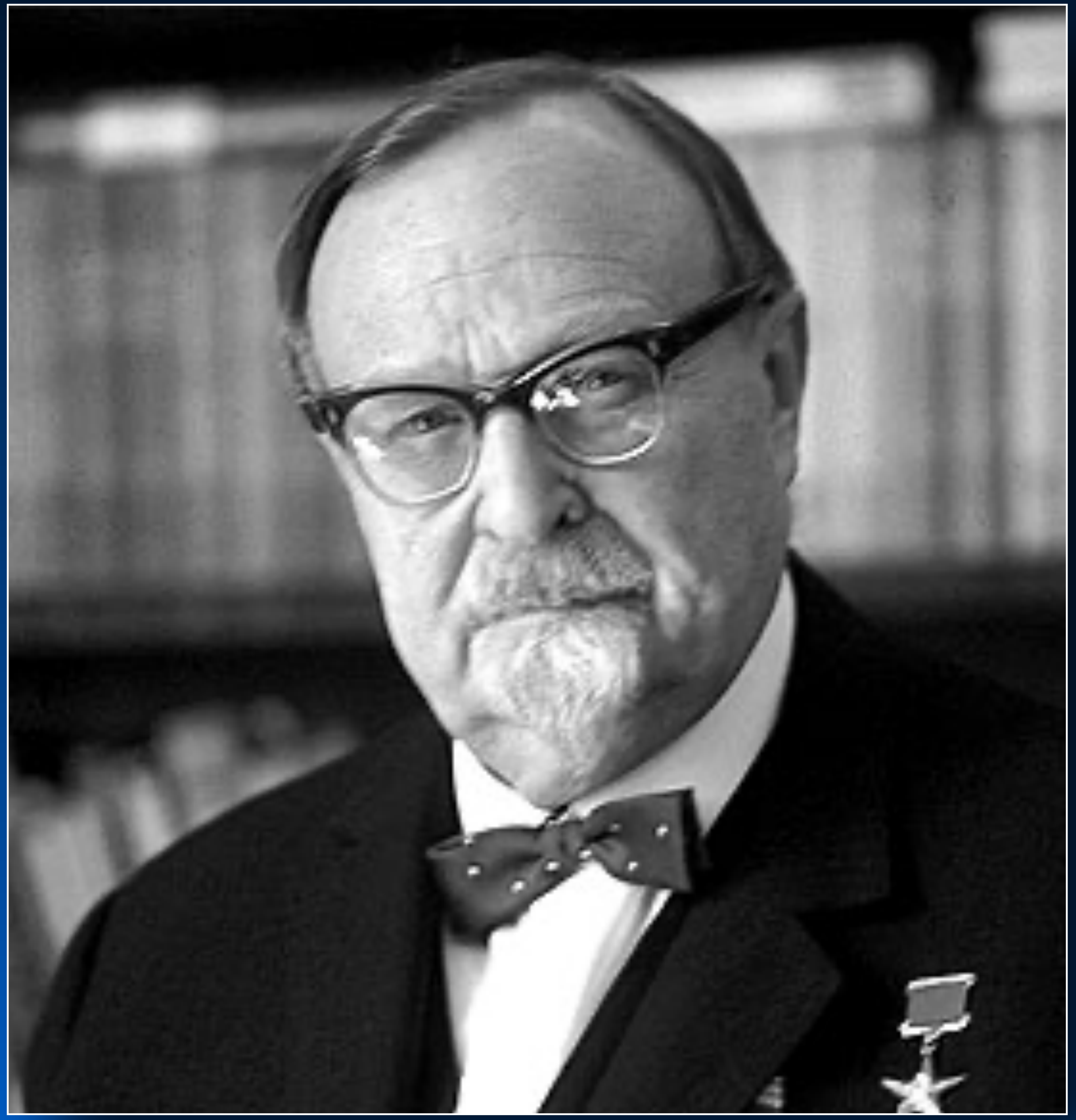
Founders of Astrobiology: Alexander Oparin

Soviet biochemist who studied the role of plant enzymes in metabolism and later founded the Biochemisty Institute of the Soviet Academy of Sciences.

In his many writings on the origin of life Oparin argued that …

- … there is no difference in the constituents of living and non-living matter, life is an issue of their organization;
- … the early Earth had a strongly reducing atmosphere rich in methane, ammonia, and water vapor;
- … life began as simple associations of molecules governed by their physical properties;
- … complexity arises via natural selection and with it life's emergent properties.



Alexander Ivanovich Oparin
(1894 - 1980)

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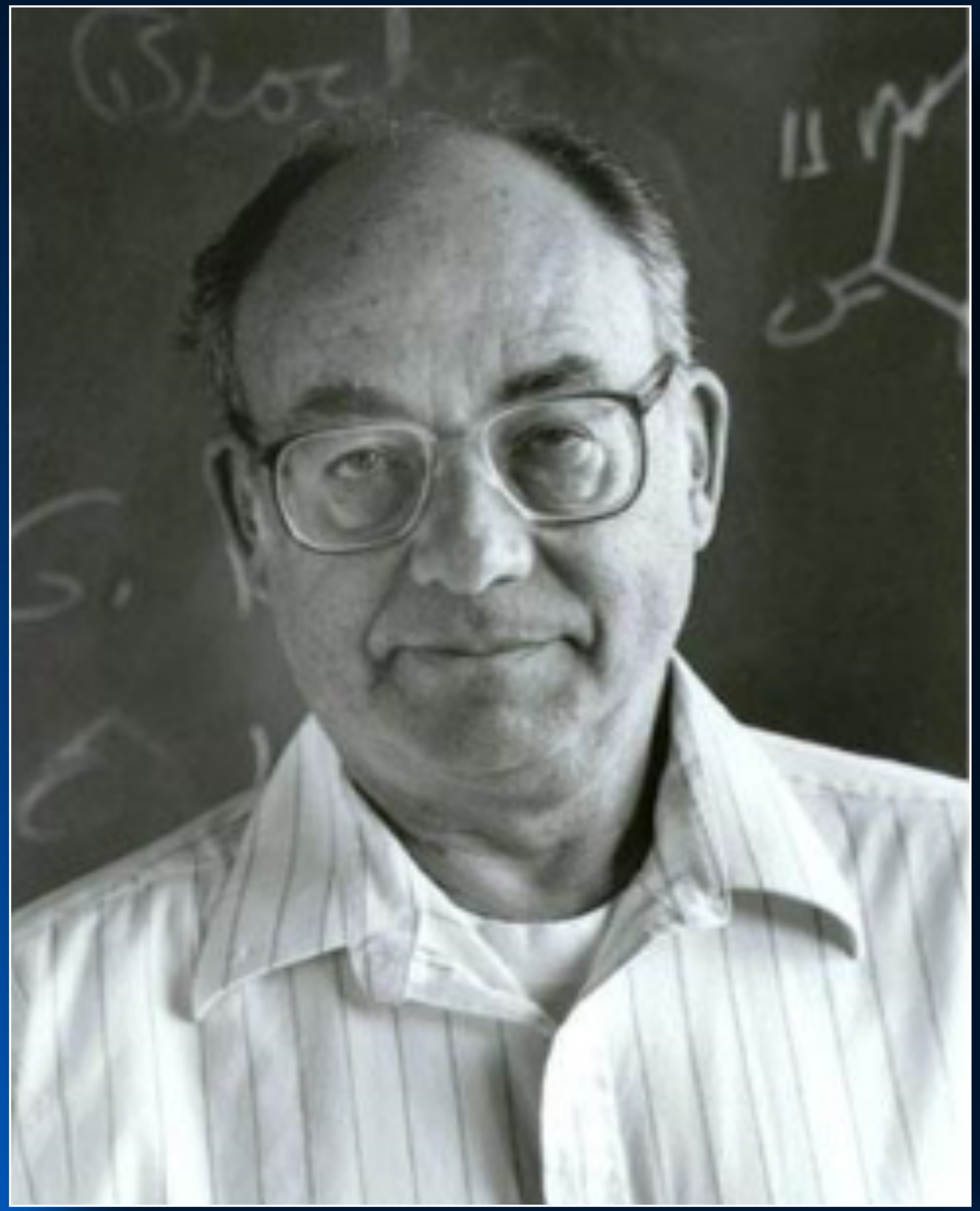
Founders of Astrobiology: Stanley Miller & Harold Urey

American biochemists who worked on a wide variety of problems.

In the context of astrobiology, are remembered for their seminal 1953 experiment, based on the insights of Alexandar Oparin, that complex organic molecules could be assembled from simple inorganic constituents by processes known, or suspected to have been operating on the pre-biotic Earth.

This experiment transformed the issue of the origin of life from a metaphysical speculation into a scientific question that, presumably, could yield to an experimental approach.



Stanley Miller
(1930 - 2007)

Harold Urey
(1893 - 1981)

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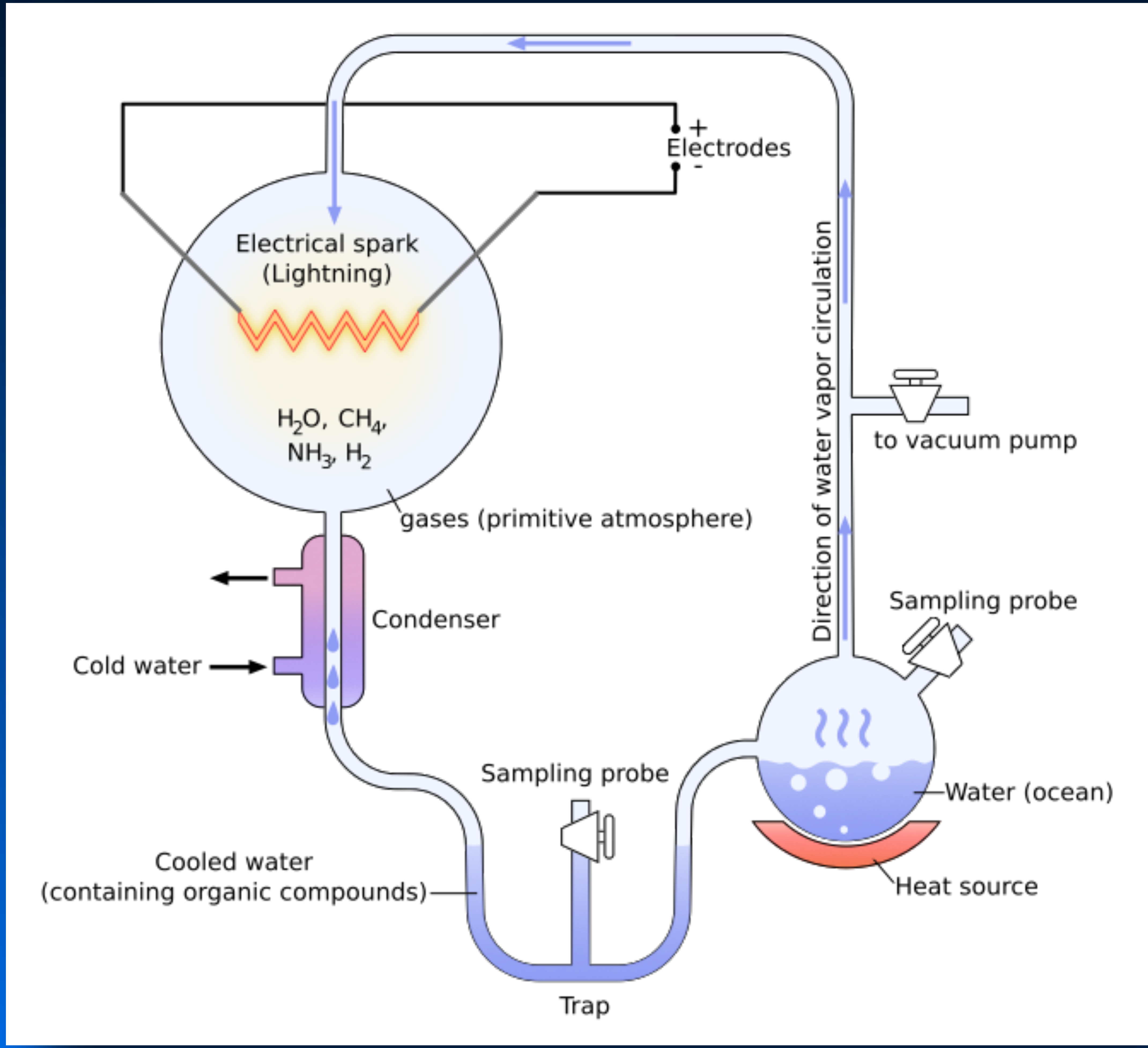
Miller-Urey Experiment

The Miller-Urey experiment constituted a laboratory simulation of what the pre-botic Earth's environment was though to be like in terms of its constituents and processes.

Miller originally claimed that 11 amino acids had been produced as a result of their experiment. Subsequent investigation showed that considerably more than the 20 that occur in the DNA molecule were actually produced.



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Founders of Astrobiology: Murchison Meteorite

Over 100 kg of material has been recovered from the impact of a large carbonaceous chondritic meteoroid near the town of Murchison, Australia on 28 September 1969.

Chemical analyses of the interior composition of the metewroeoid material by many teams of investigators has documented the presence of many organic compounds, including the amino acids glycine, glutamic acid, alanine, isovaline, pseudoleucine, serine, and threonine, Diamino acids have been recovered as well.

These results constitute direct natural verification that complex organic molecules can be synthesized by inorganic processes even in space and have been being assembled from a time close to the origin of the solar system.

Fragment of the Murchison Meteoroid
(Origin: 7×10^9 years)

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Importance of Meterorites

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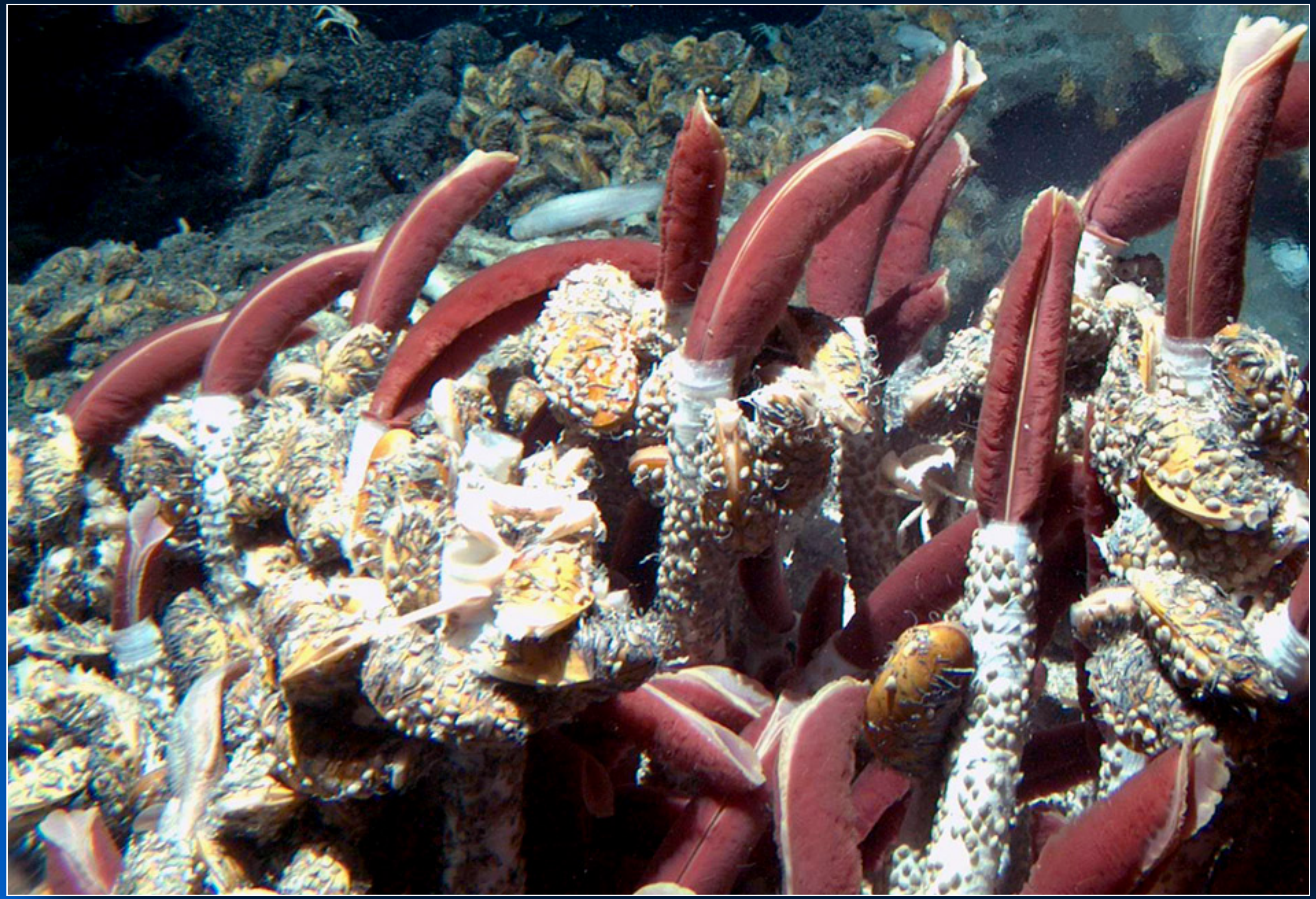
Founders of Astrobiology: Deep-Sea Vent Faunas

Hydrothermal vents are areas of the ocean floor at which volcanically heated water escapes into the ocean through cracks or fissures in the ocean crust. Owing to its heat and volcanic origin these waters have a high mineral content.

When hydrothermal vents occur in deep waters the area can be colonized by a unique ecosystem that does not derive its energy from sunlight, but rather from the heat of the water. It has been proposed that these environments exhibit the chemical and energy conditions though to be required for the abiotic origin of life, but which would also have been shielded from solar radiation.



Deep-Sea Vent Community
(Pacific Ocean)

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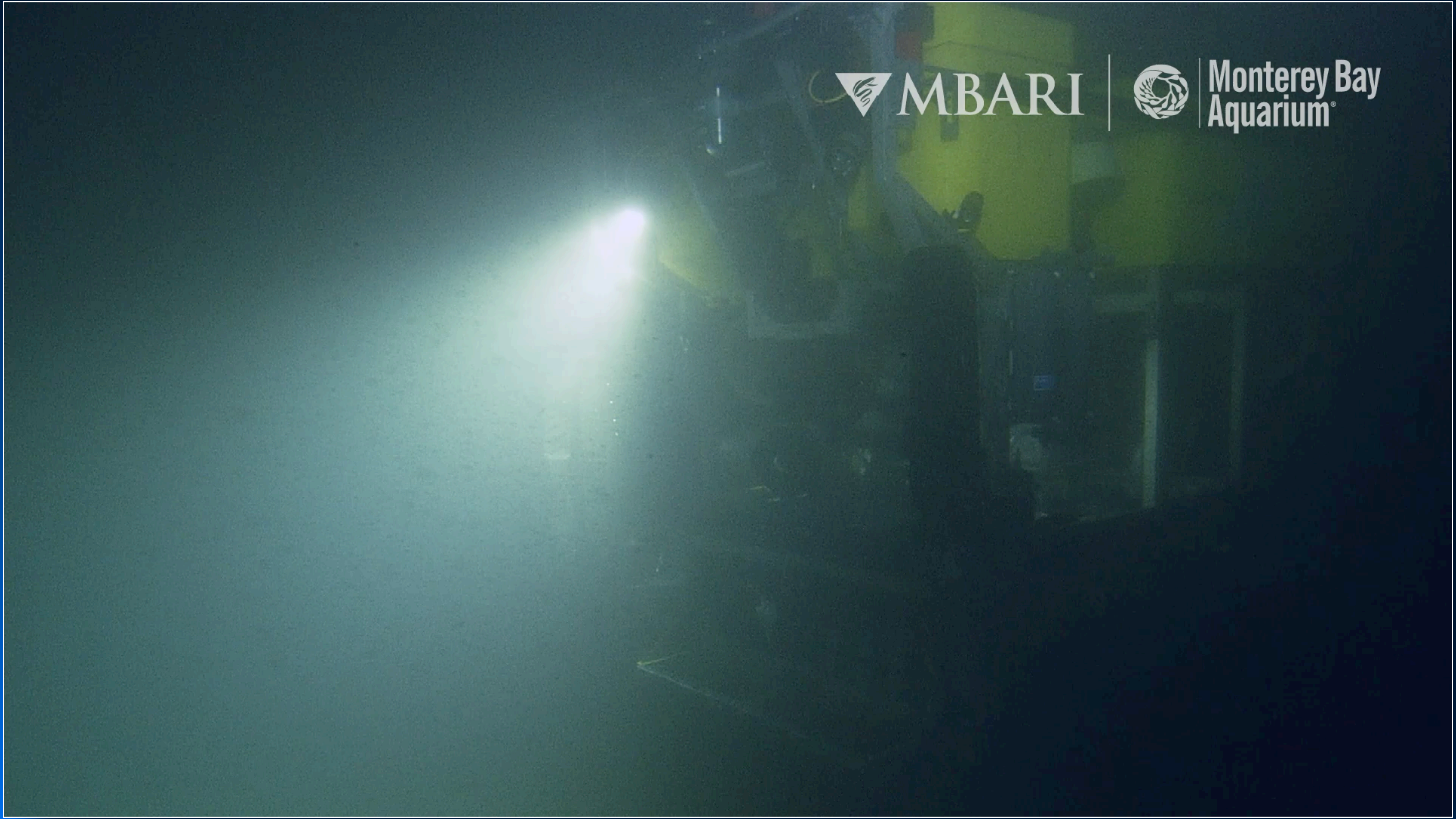
Importance of Deep-Sea Vent Faunas



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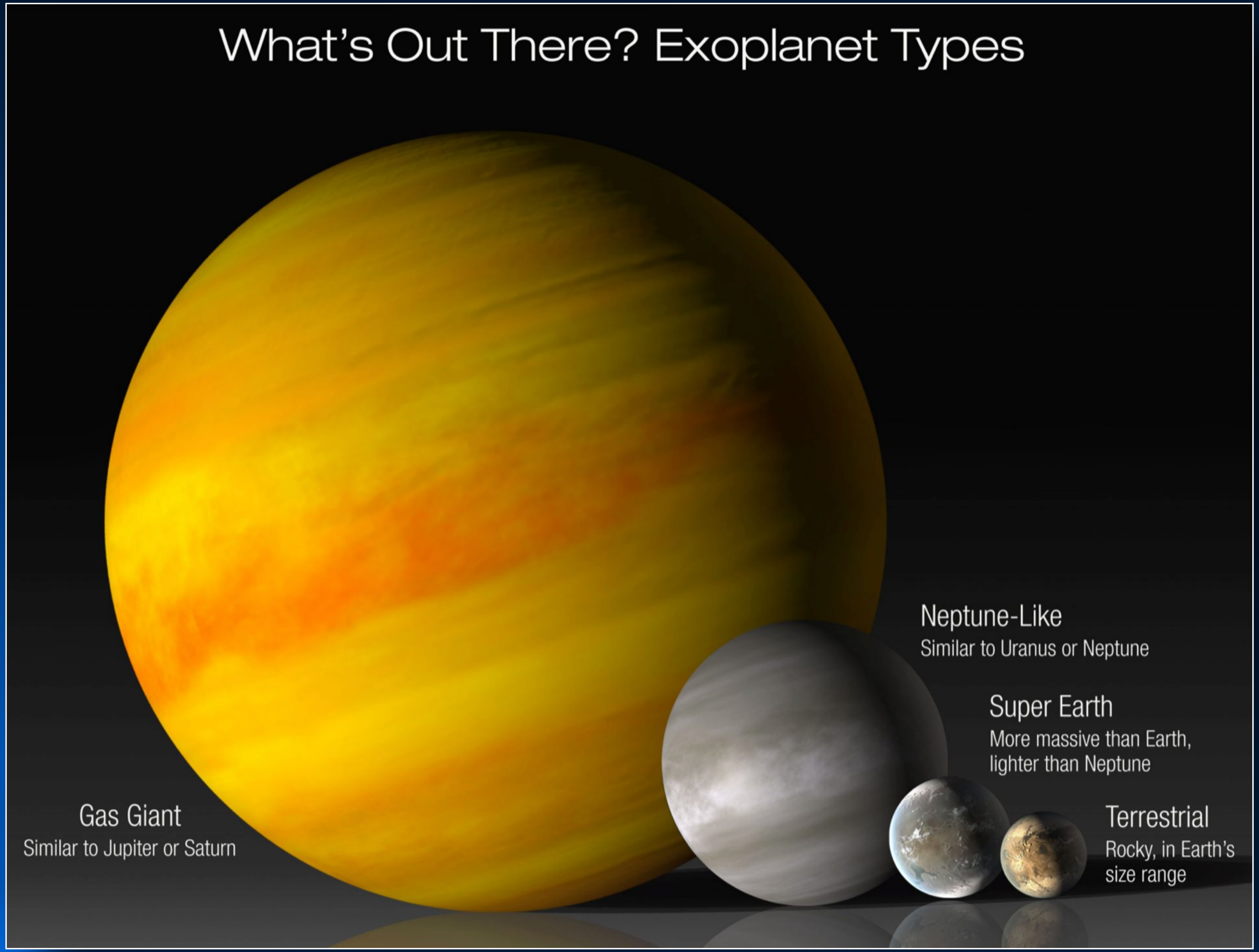
Discovery of Extra-Solar Planets

Extra-solar planets (or exoplanets) are planets that orbit stars other then our Sun (Sol). The existence of extra-solar planets has been suspected for thousands of years, and they have long been a staple of science fiction. But telescope technology reached the point where it was able to detect extra-solar planets only in the 1990s. To date the existence of over 4,000 exoplanets in our own galaxy have been confirmed.

From an astrobiological point-of-view the existence of exoplanets was regarded as a critical assumption by those speculating that extra-terrestrial life might exist. This is no longer an assumption.



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Importance of Extra-Solar Planets (Exoplanets)

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The Drake equation

Proposed in 1961 by Frank Drake (an American astronomer who led some of the first attempts to detect extraterrestrial communitions), the Drake equation attempts to summarize the main concepts that impinge on the consideration of how many radio-active extraterrestrial civilizations might exist.

While the Drake equation was never intended to be a a means whereby the number of extraterrestrial civilizations could be estimated it has often been portrayed as such by the popalar media.

Drake's original calculations suggested there were between 1,000 and 1,000,000 planets with radio-active civilizations in our galaxy, but more recent estimates have revised this to between 156,000 and 1,560,000,000.

Frank D. Drake
(b. 1930)

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The Drake equation

$$N = R_* \cdot f_p \cdot n_e \cdot f_1 \cdot f_i \cdot f_c \cdot L$$

Where:

- N = number of radio-active civilizations
- R_* = avg. rate of star formation
- f_p = proportion of planet-hosting stars
- n_e = avg. no life-supporting planets per f_p
- f_1 = proportion of life-supporting planets that host life
- f_i = proportion of f_1 that develop intelligent life
- f_c = proportion of f_i that develop radio technology
- L = length of time f_c send radio signals into space

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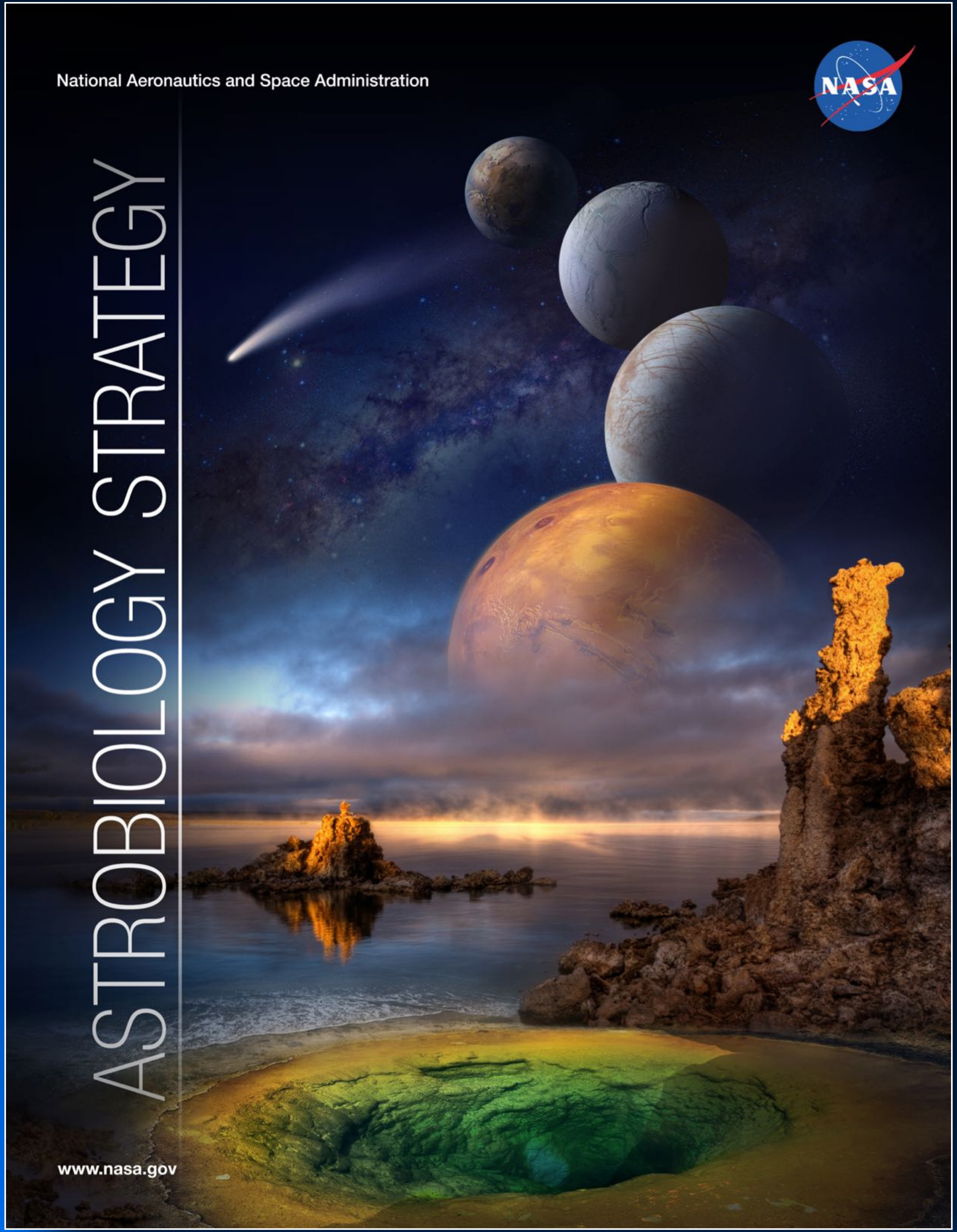
NASAs Exobiology Strategy

NASAs strategic objective in planetary science is to determine the content, origin, and evolution of the Solar System and the potential for life elsewhere (2014 NASA Science Plan). Astrobiology research sponsored by NASA focuses on three basic questions:

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

Over the past 50 years, astrobiologists have uncovered a myriad of clues to answering these "big questions".

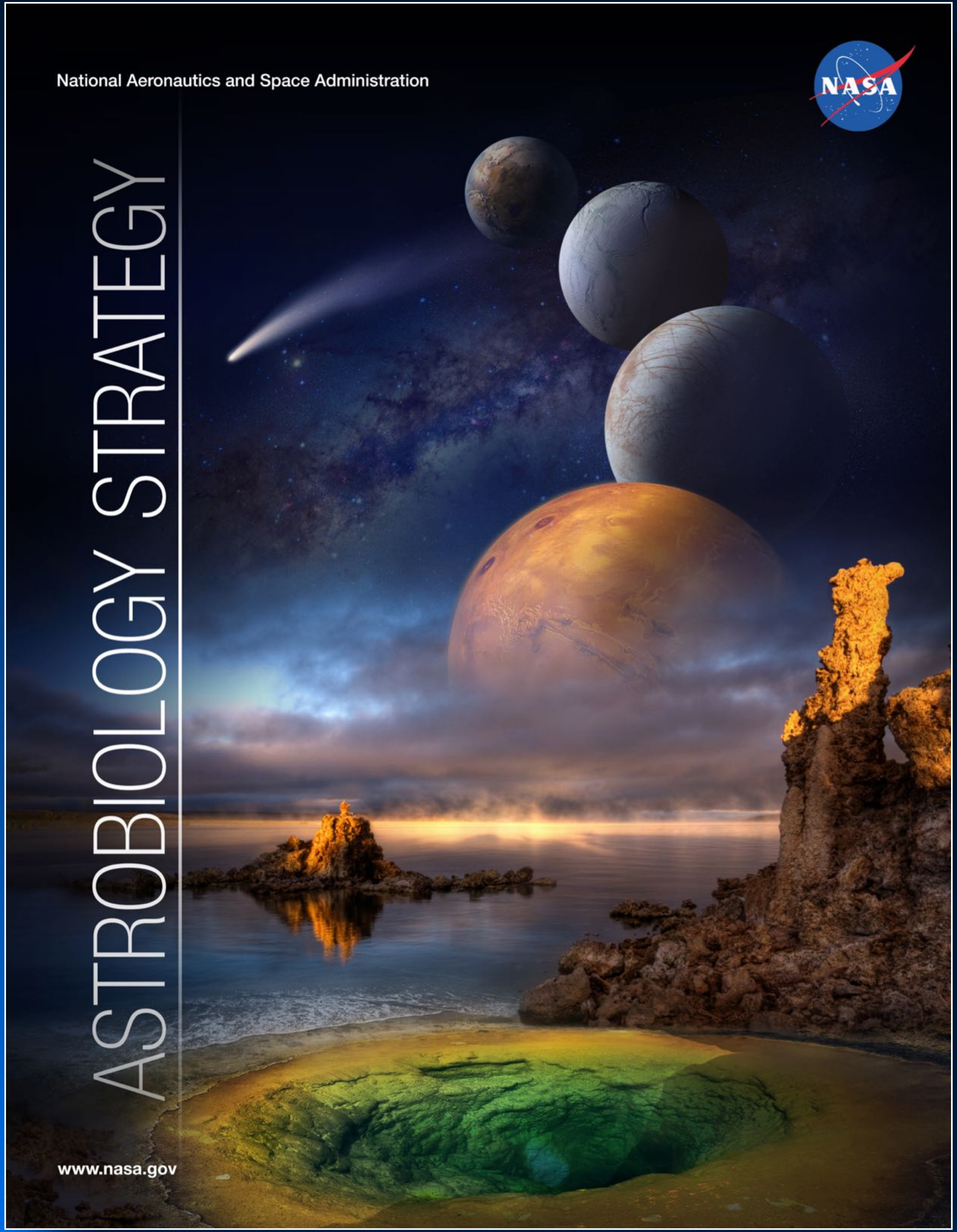


Planetary Astrobiology

NASAs Exobiology Strategy

Hundreds of members of the astrobiology community collaborated in identifying six major research topics:

- Identifying abiotic sources of organic compounds
- Synthesis and function of macromolecules in the origin of life
- Early life and increasing complexity
- Co-evolution of life and the physical environment
- Identifying, exploring, and characterizing environments for habitability and biosignatures
- Constructing habitable worlds



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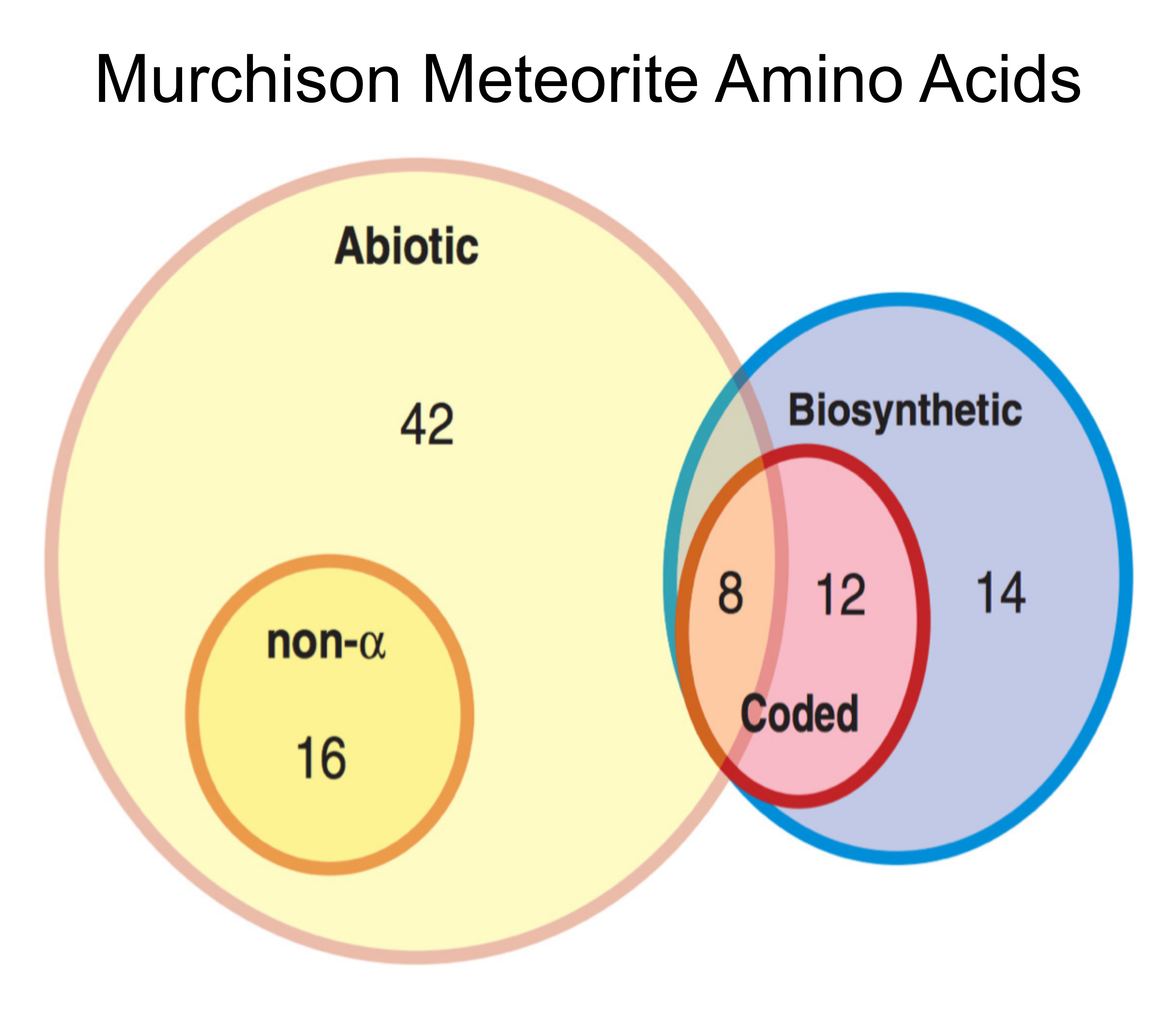
NASAs Exobiology Strategy

Identifying Abiotic Sources of Organic Compounds

Identifying and understanding the mechanisms that led to the production of prebiotic molecules in various environments is critical for establishing the inventory of ingredients from which life originated on Earth, assuming that the abiotic production of molecules ultimately influenced the selection of molecules from which life emerged.



- What were the sources, activities, and fates of Earth's organic compounds?
- What is the role of the environment in the production of organic molecules?
- What is the role of the environment on the stability and accumulation of organic molecules?
- What constraints can the rock record place on the environments and abiotic reactions of the early Earth?

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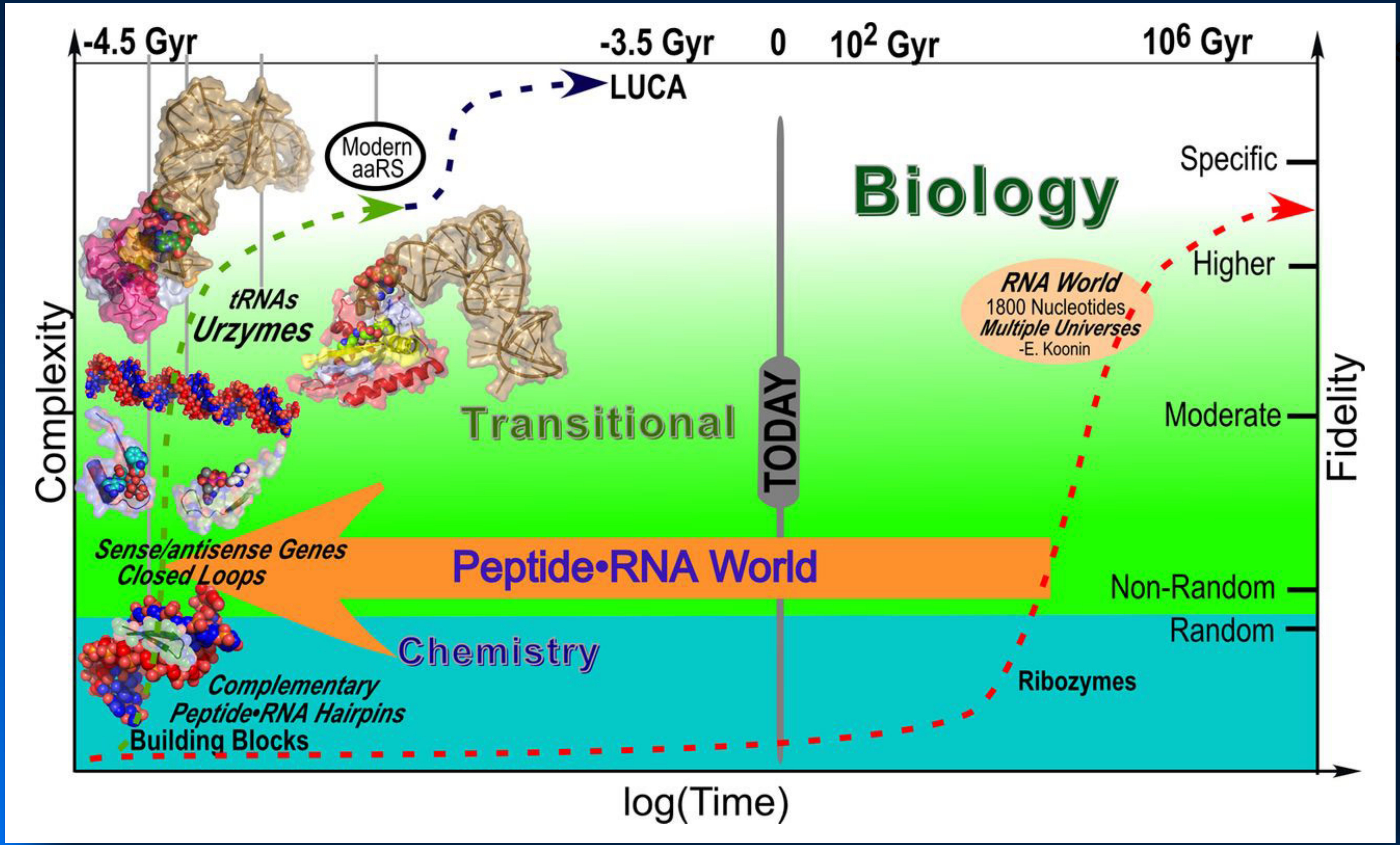
NASAs Exobiology Strategy

Synthesis and Function of Macromolecules in the Origin of Life



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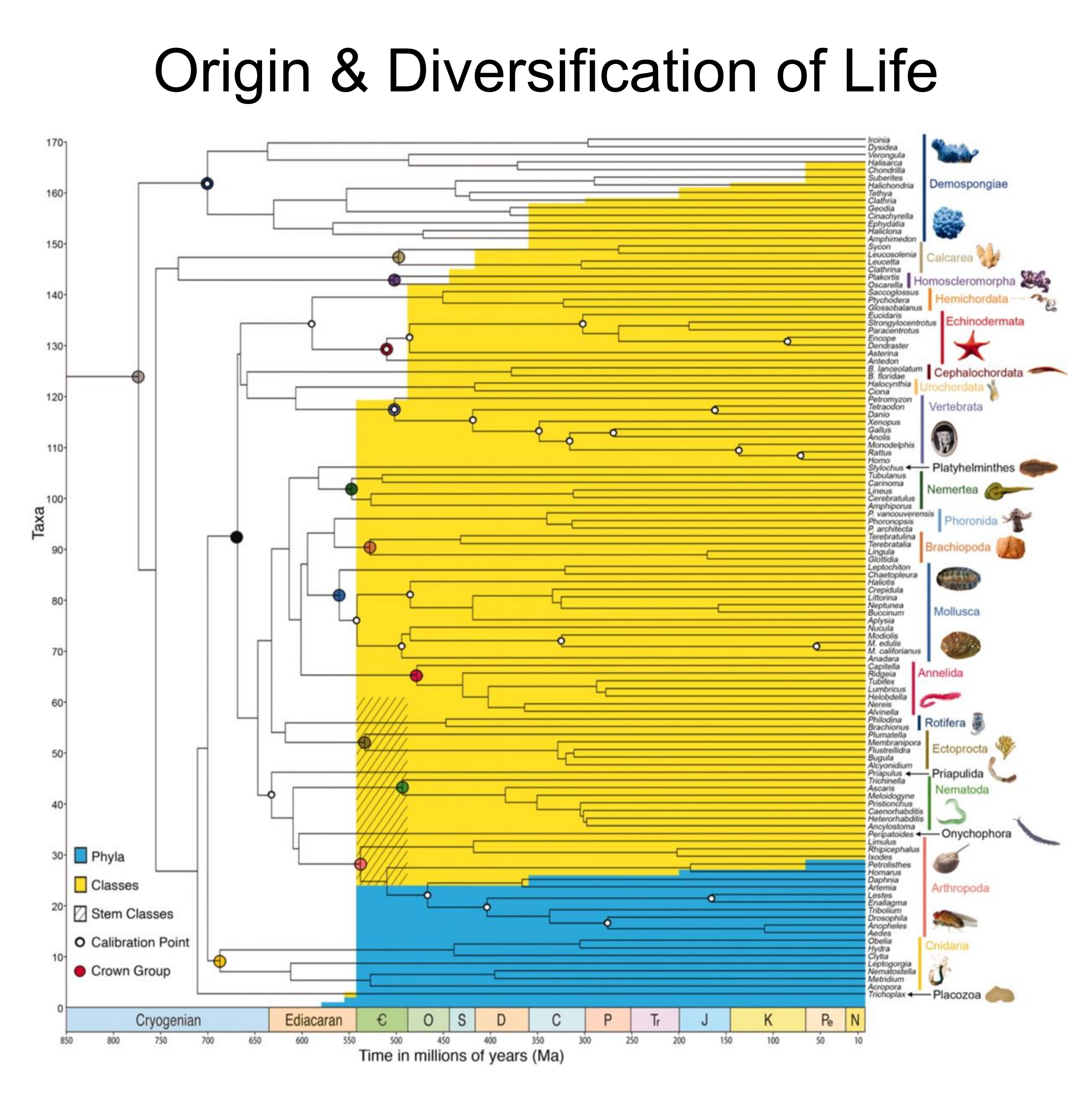
NASAs Exobiology Strategy

Early Life and Increasing Complexity

A growing understanding of the origin and history of life on Earth contributes to astrobiological goals in a basic way: better data leads to better theory and, thus, to better predictions regarding the prerequisites for the evolution and characteristics of life elsewhere in the universe.

- What are the origin and dynamics of evolutionary processes in living systems?
- What were the fundamental innovations in earliest life?
- What were the genomic, metabolic, and ecological attributes of life at the root of the evolutionary tree?
- What was the dynamics of the subsequent evolution of life?
- What are the common attributes of living systems on Earth?



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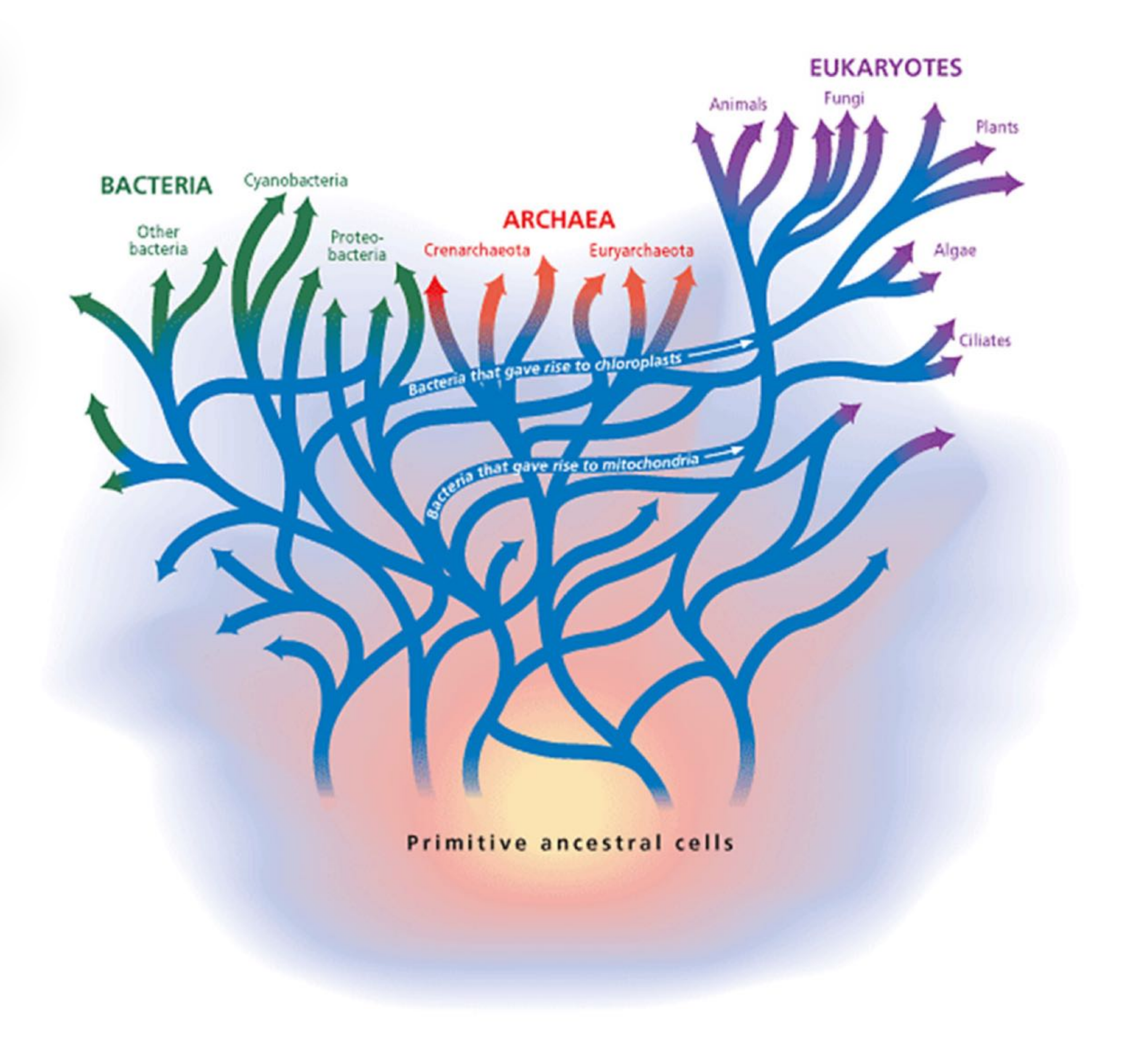
Last Universal Common Ancestor (LUCA)



While there is broad consensus that a common ancestor of all life on Earth did exist, there is no consensus regarding what the attributes of LUCA might have been. Ideas range for a single ancestral population to a diverse array of quasi-independent populations exhibiting a wide range of introgression mechanisms.

Yet, there is also a suspicion that LUCAs attributes – whatever those might have been – set the stage for all that was to follow. It is critical to understand how this transition was accomplished and that means under-standing what LUCA was.

Recent developments in bioinformatics databases, evolutionary and ecological models, high-performance computing resources, and synthetic biology permit new investigations of life at this stage of evolution to be made.

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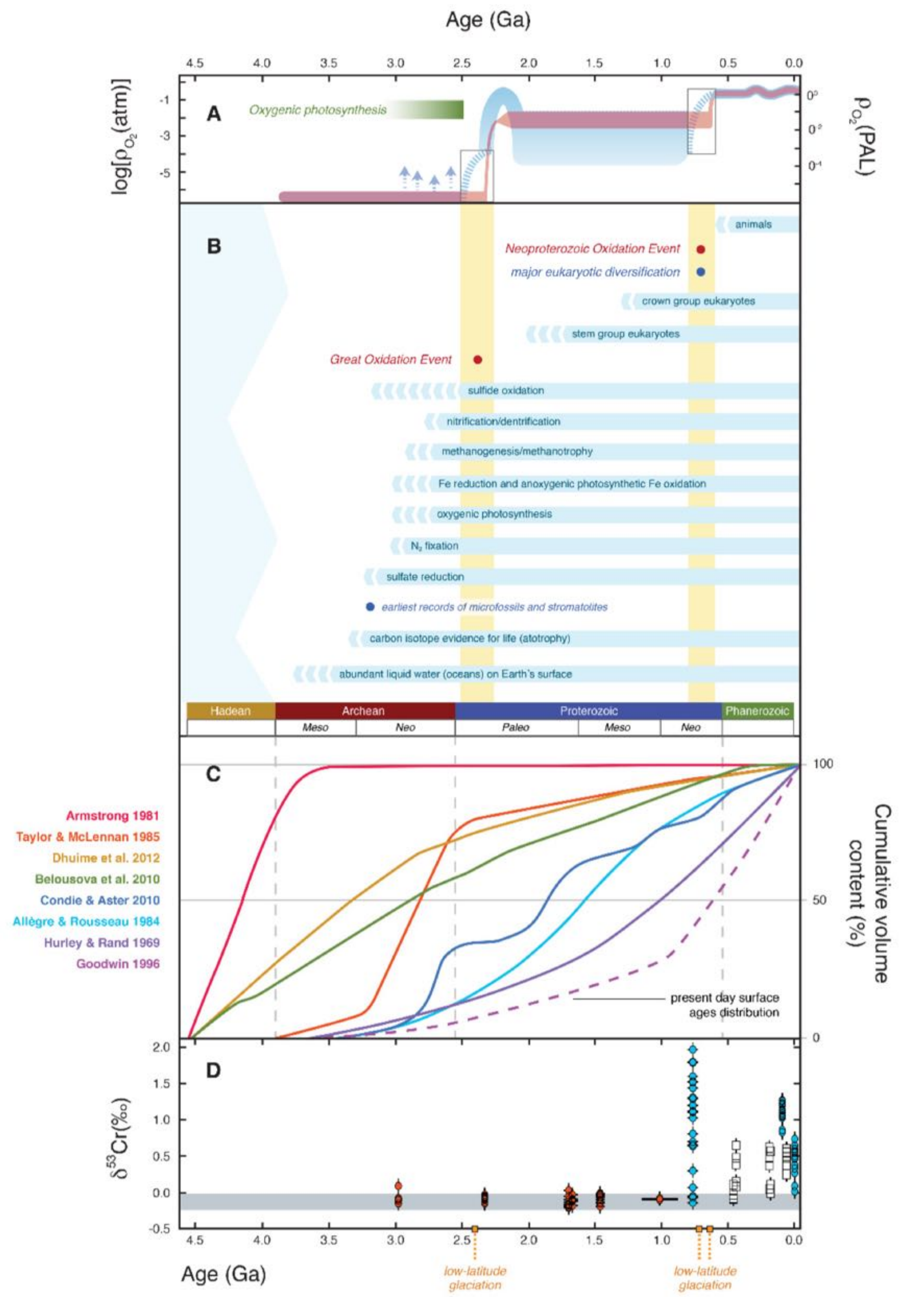
NASAs Exobiology Strategy

Co-Evolution of Life and the Physical Environment

Environmental change has accompanied every major event in the history of life—as either a cause or an effect. This relationship is the most compelling argument for co-evolution of life and the physical environment. It follows that the mechanisms that define this co-evolution be understood to explain billions of years of sustained habitability on Earth and, likely, on extraterrestrial planets..

- How does the story of Earth inform us about how the physical planet and biospheres co-evolve?
- How do interactions between life and its local environment inform our understanding of co-evolutionary dynamics?
- How does our ignorance of microbial life on Earth hinder our understanding of the limits of life?

Diversification of The Earth's Surface



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