The Abdus Salam International Centre for Theoretical Physics

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International Atomic Energy Agency

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ICTP-COST-USNSWP-CAWSES-INAF-INFN
International Advanced School
on
Space Weather
2-19 May 2006

Introduction to Astrobiology

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Origin, evolution and distribution of life in the Solar System: Constraints from space weather

Lecture 1: Introduction to Astrobiology

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R.B. Venezuela

Bibliography available at the ICTP Library

- **Astrobiology: Origins from the Big Bang to Civilisation**
  Julian Chela-Flores et al (eds.)
  Kluwer, Dordrecht, The Netherlands, 2000.

- **The New Science of Astrobiology**
  Julian Chela-Flores
  Kluwer, Dordrecht, The Netherlands, 2001 (2004, paperback).

- **An introduction to Astrobiology**
  Andrew Conway et al
  CUP, 2003.

- **Life in the Solar System and Beyond**
  Barrie Jones
  Praxis, UK, 2004.

- **Lectures in Astrobiology**
  Muriel Gargaud et al (eds.) Study Edition in two volumes
  Berlin, Springer-Verlag, 2006.

Plan of the lecture

- In part 1 we introduce the subject of astrobiology and its relation to other space sciences.
- In part 2 we discuss in some detail the origin of life in the universe.
- Finally, in part 3 we discuss whether we can detect intelligent life in other solar systems in spite of the Space Weather constraints.

Part I

The Origins:
1. The universe

- How?
- When?
- Where?

  Not relevant for the universe, given the geometric interpretation of classical General Relativity.

How did the universe start?

What is needed to understand how the universe started?

1. We are at a point where experiments must guide us as to how the universe started and what will be its ultimate destiny.

We cannot make progress without these experiments.

2. The theories of the space sciences that need to be tested are:

- General Relativity and the
- Standard Model.

The equations of General Relativity

$$\mathbf{G}_{\mu\nu} + \Lambda g_{\mu\nu} = 8\pi\, T_{\mu\nu}$$

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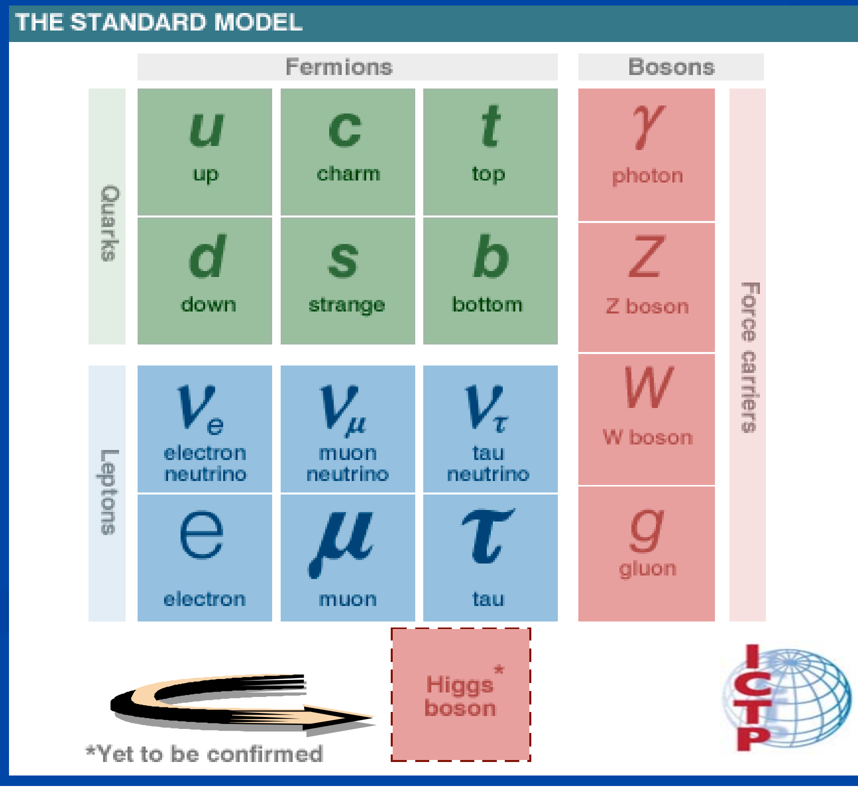
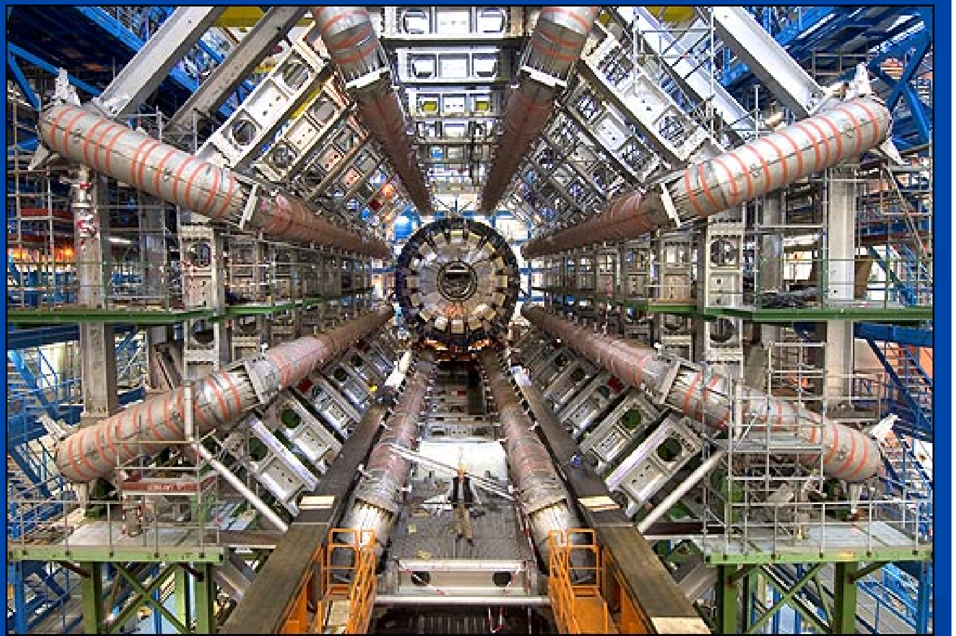


A new source of insights into how the universe started:

the Large Hadron Collider

With the LHC we will be able to search for new forms of matter with energies up to 14 TeV.



At some of the LHC detectors we will be able to test the validity of:

- Models of quantized General Relativity
  and
- The Standard Model.

The contribution of space missions

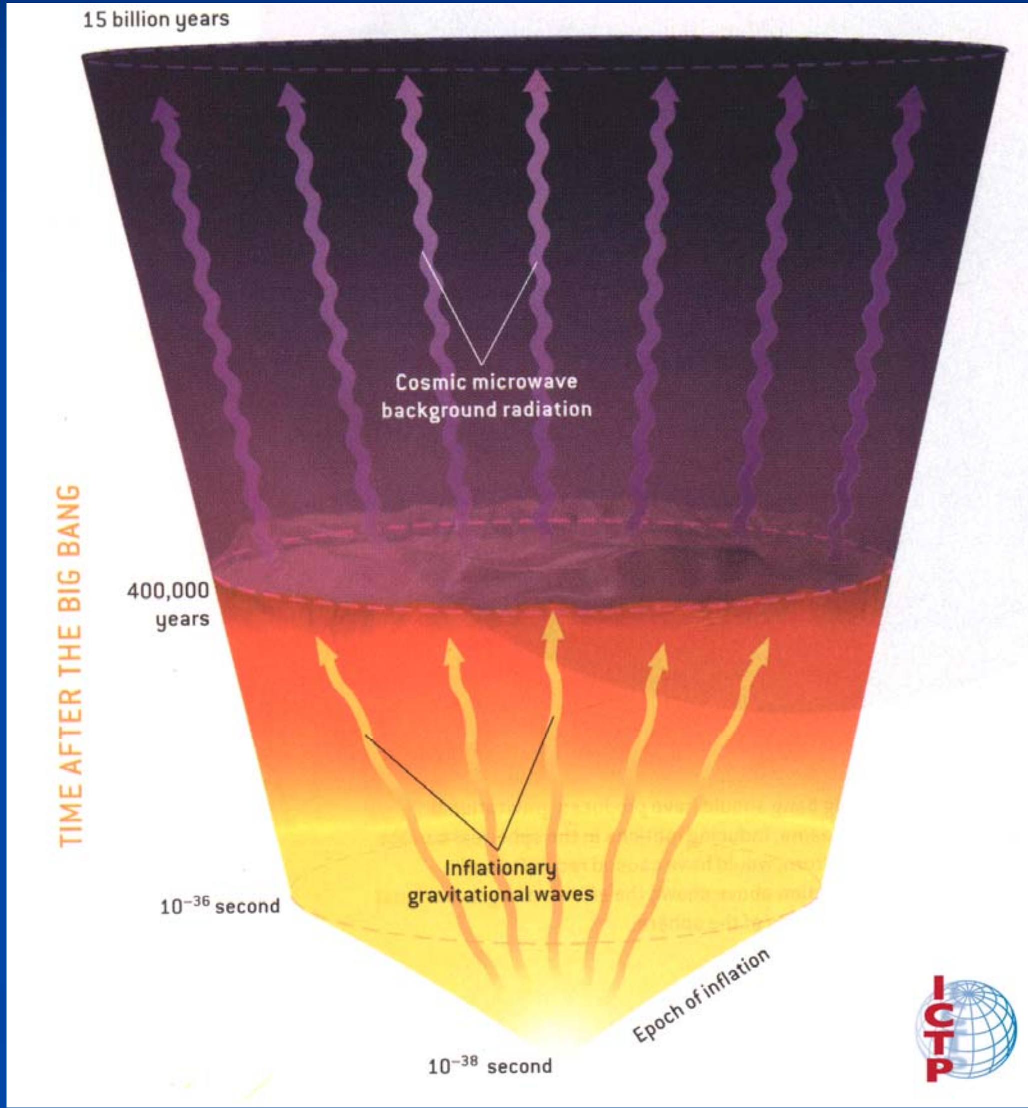
New experimental facilities such as LHC will help, but especially relevant are a few of many space missions to come:

- Planck
- CMBpol
- LISA

The Planck and CMBpol missions (2007, >2014)

These missions aim to:

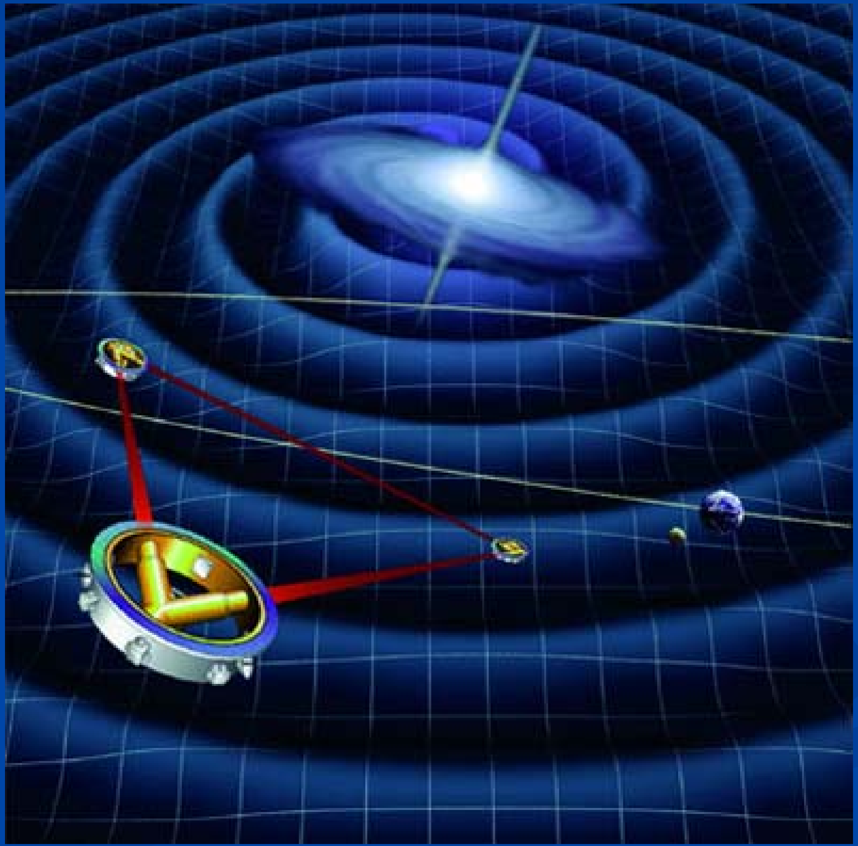
- test gravitational waves produced after the Big Bang, by careful consideration of the ripples in the early universe.



The Laser Interferometer Space Antenna (LISA)

- LISA is jointly sponsored by ESA and NASA.

- LISA will test the Theory of General Relativity, probe the early Universe, and will search for gravitational waves.




When did the universe start?

The intelligibility of the accelerating universe:

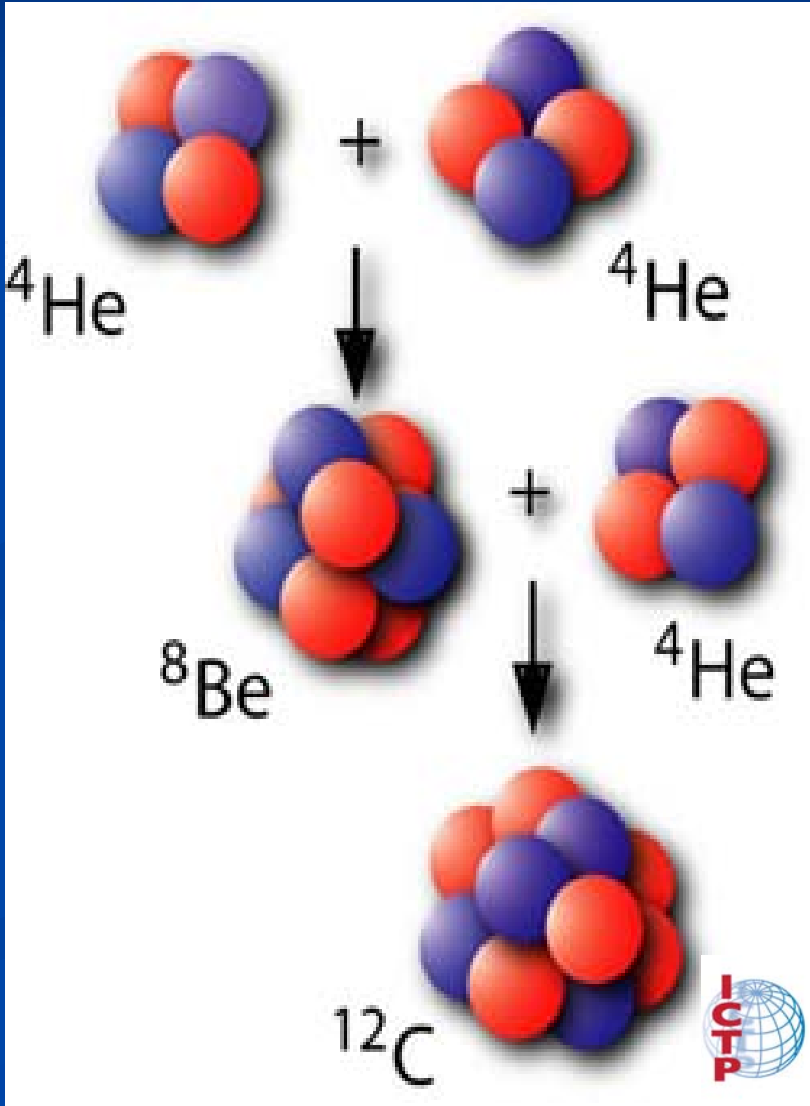
- If our universe is part of an ensemble of universes - **a multiverse**, each with different physical constants, it is conceivable that a fraction of them offer conditions favorable for life.

- We may assume that we are living in a universe in which the physical constants, favor the existence of life for a few billion years.

The anthropic approach

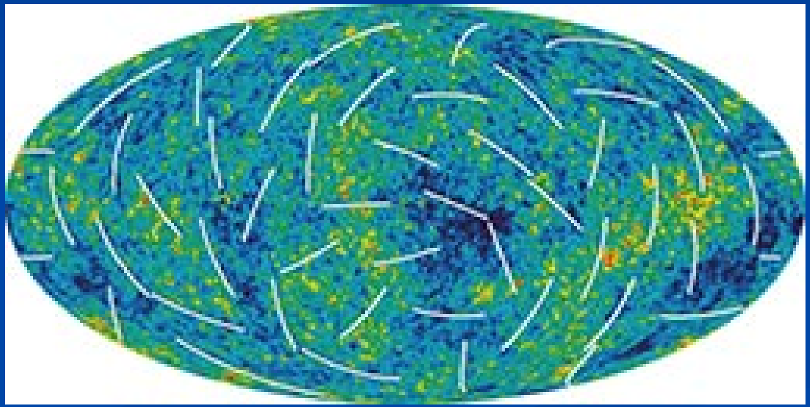
- Explaining the values of the observables of the universe in terms of the possibility of favoring life is called '<u>anthropic</u>'.

- These arguments are analogous to those originally used by Sir Fred Hoyle in the synthesis of chemical elements in stars.

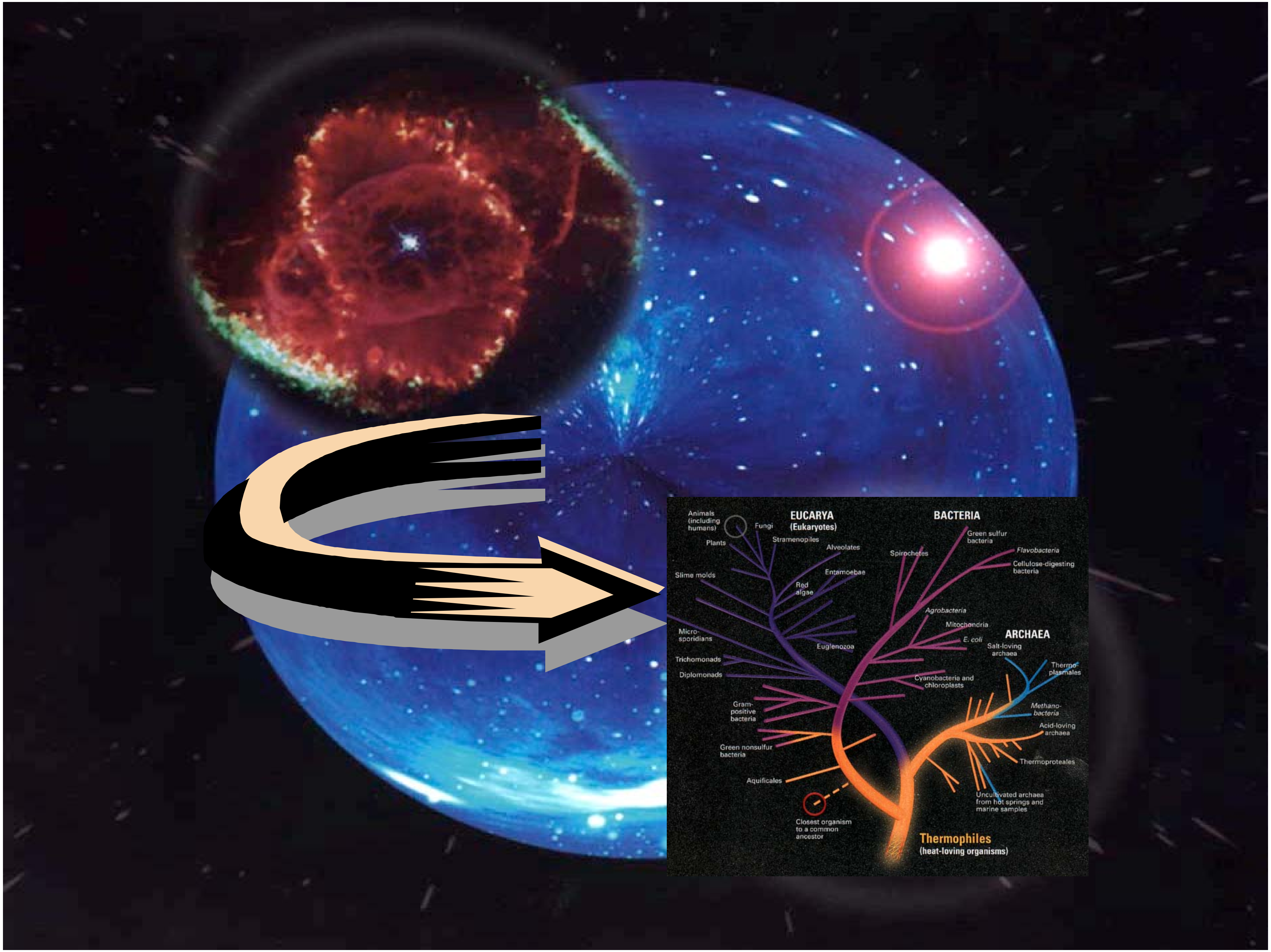


WMAP: The Wilkinson Microwave Anisotropy Probe

- has demonstrated that the universe is compatible with an age of 13.7 Gyrs.
- is composed of 73 percent dark energy, 23 percent cold dark matter, and only 4 percent atoms, and
- will expand forever.



A detailed picture of the infant universe. Colors indicate "warmer" (red) an d "cooler" (blue) spots. The white bars show the "polarization" direction of the oldest light.


EUCARYA
(Eukaryotes)
Animals (including humans)
Fungi
Plants
Stramenopiles
Alveolates
Slime molds
Entamoebae
Red algae
Micro-sporidians
Euglenozoa
Trichomonads
Diplomonads
BACTERIA
Green sulfur bacteria
Spirochetes
Flavobacteria
Cellulose-digesting bacteria
Agrobacteria
Mitochondria
E. coli
Cyanobacteria and chloroplasts
Gram-positive bacteria
Green nonsulfur bacteria
Aquificales
ARCHAEA
Salt-loving archaea
Thermo-plasmales
Methano-bacteria
Acid-loving archaea
Thermoproteales
Uncultivated archaea from hot springs and marine samples
Closest organism to a common ancestor
Thermophiles
(heat-loving organisms)

What is astrobiology?

- It is a space science that emphasizes the life sciences.
- It is a life science that emphasizes the space sciences (including space weather).

The main areas of interest are:

- The destiny of life in the universe.
- The distribution of life in the universe,

In common with the space sciences

- The evolution of life in the universe.
- The origin of life in the universe,

In common with the life sciences

Destiny of life in the universe

The first area of astrobiology

The second area (distribution) will be presented in Lecture 2

The evolution of life in the universe, universal darwinism?:

The third area of astrobiology

The theory of evolution discusses the relative importance of:

(i) contingency,
(ii) gradual action of natural selection.

- The implications of **human evolution** in astrobiology will be discussed in Part 3.

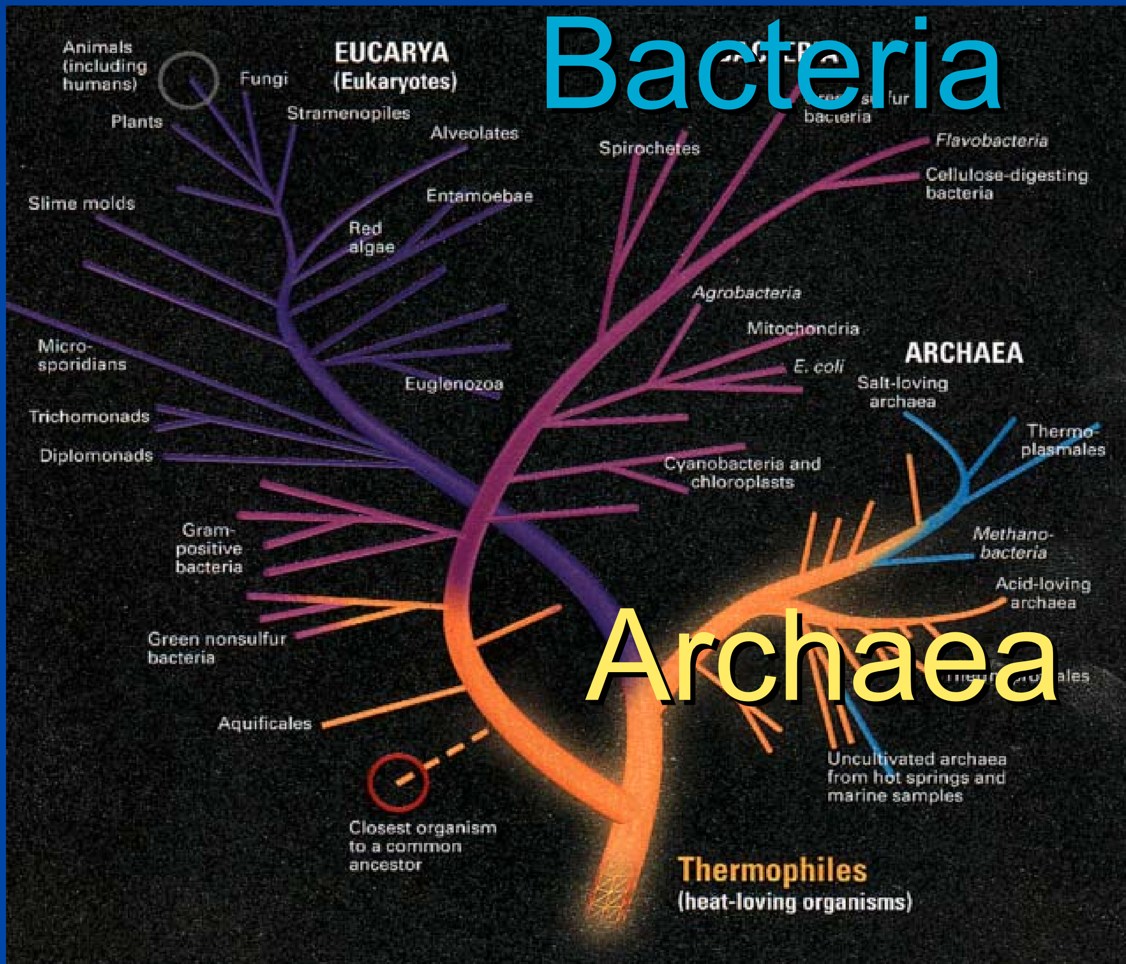
Can the outcome of evolutionary processes be predictable?

- Independent of historical contingency, natural selection is powerful enough for organisms living in similar environments (in the universe) to be shaped to similar ends (De Duve).

- To a certain extent and in certain conditions, natural selection may be stronger than chance (Conway-Morris).

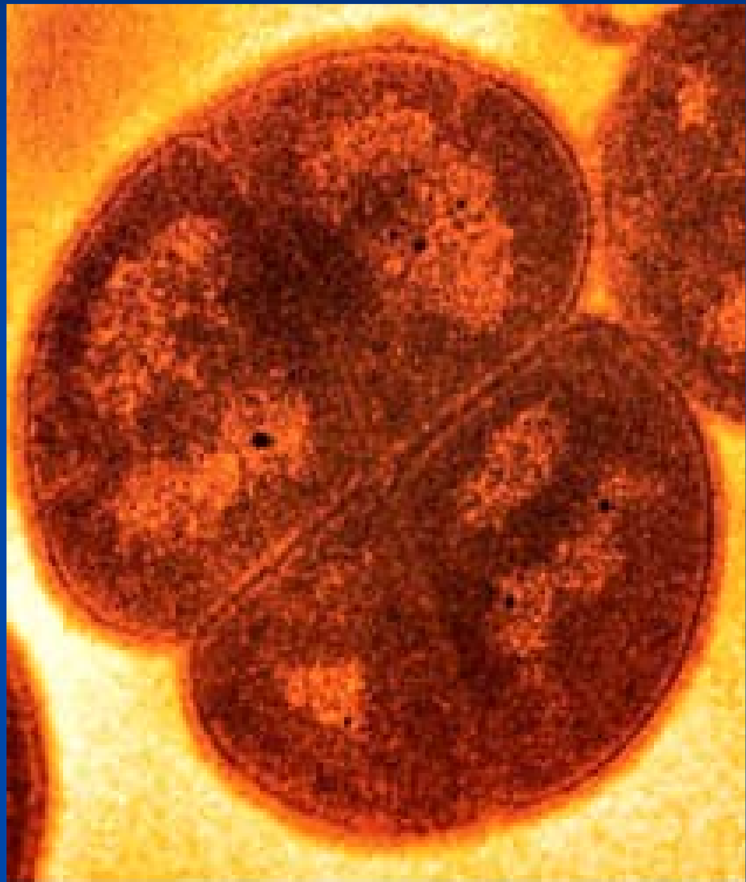
- The ubiquity of evolutionary convergence argues against the view that biological diversity on Earth is unique.

Two of the three branches of the tree of life are prokaryotes



Deinococcus radiodurans

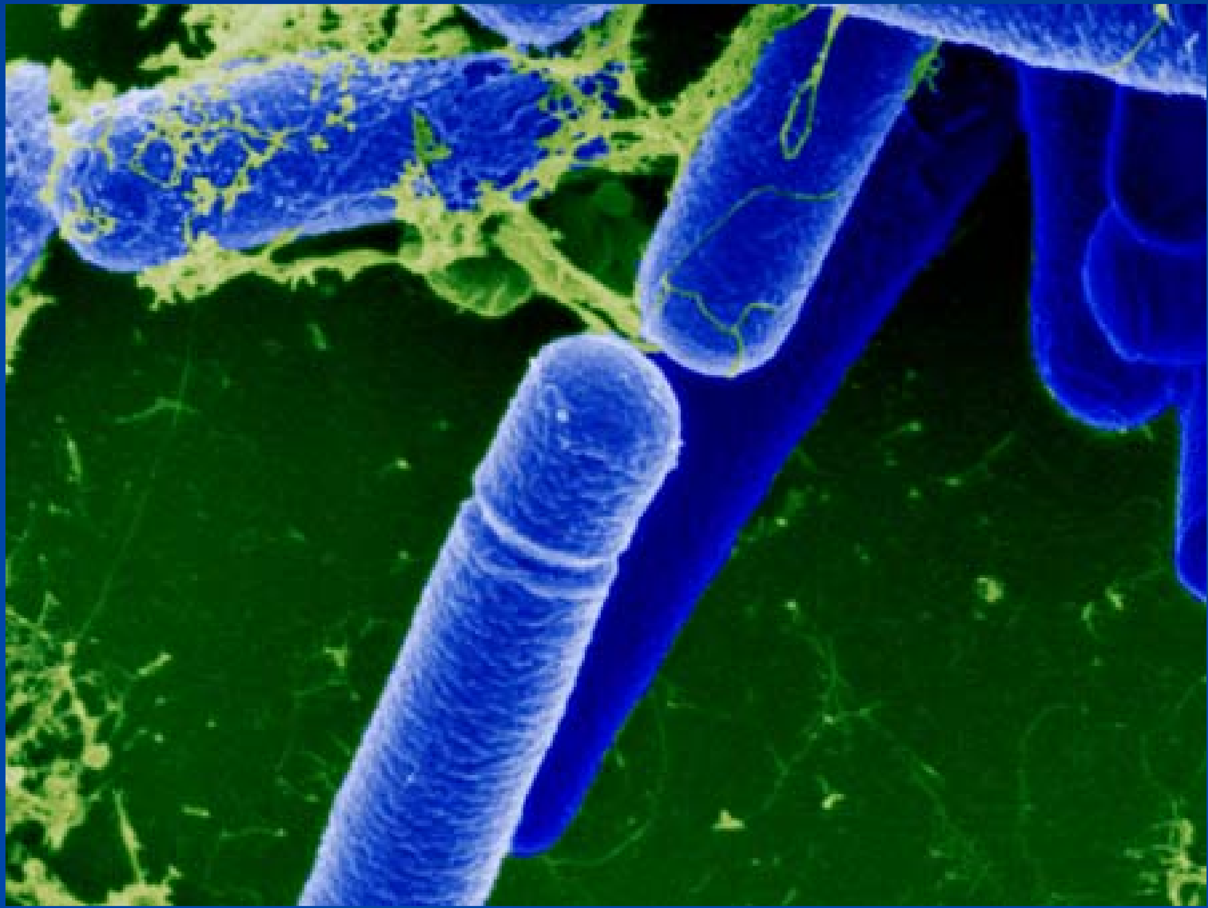
(Bacteria)



Deinococcus radiodurans in
late growth phase.
Image courtesy of M. Daly

Bacillus subtilis

(Bacteria)

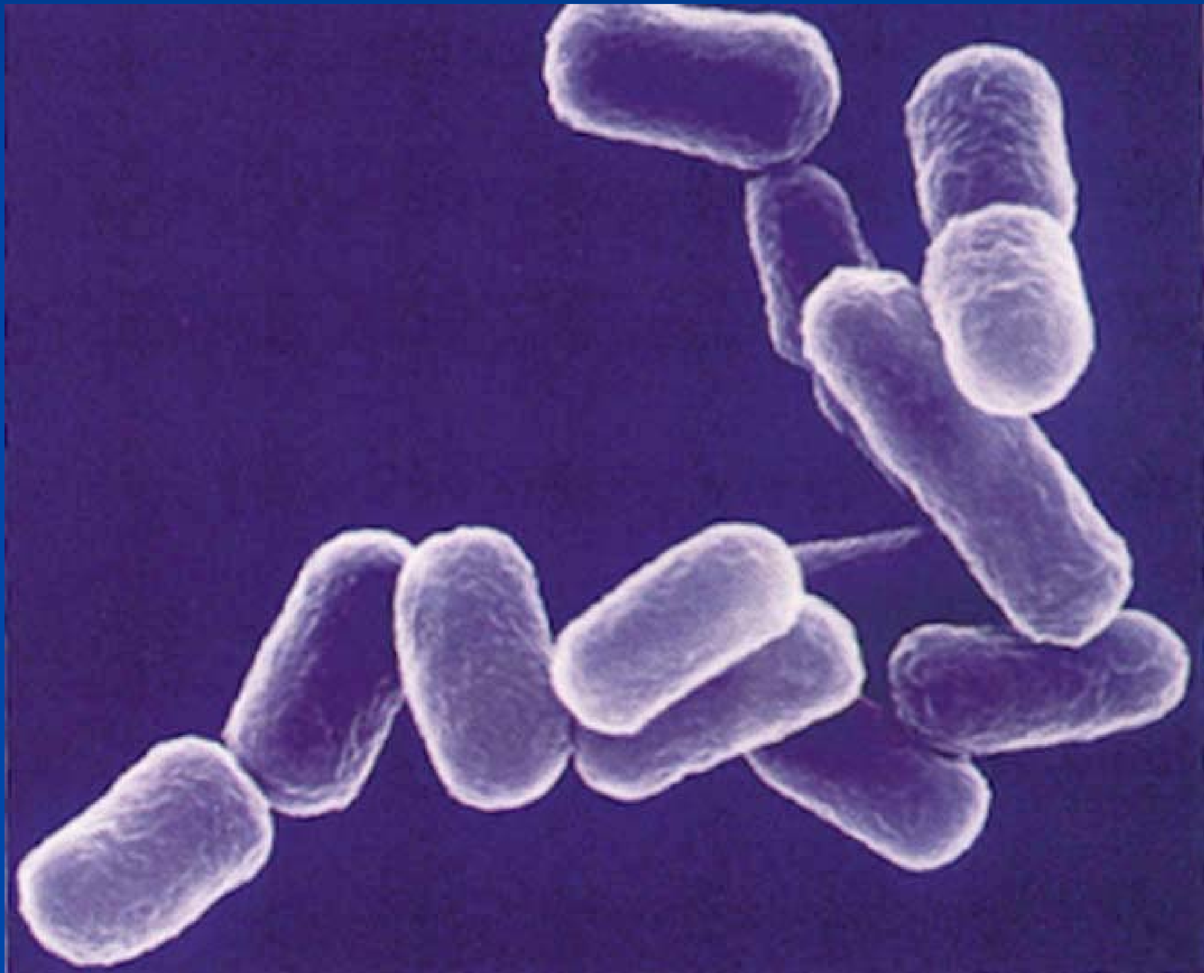


Escherichia coli

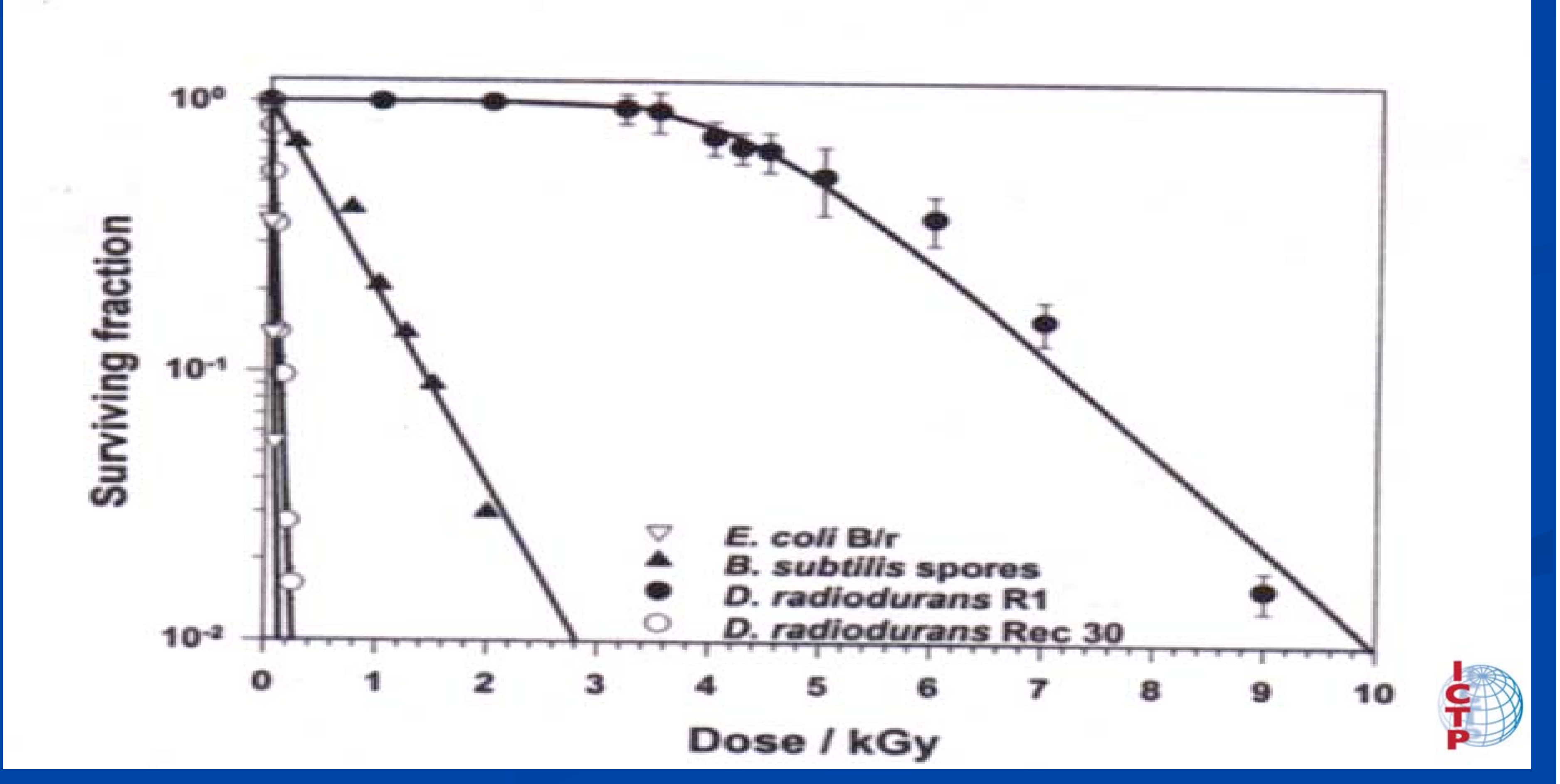
(Bacteria)

Source: NASA

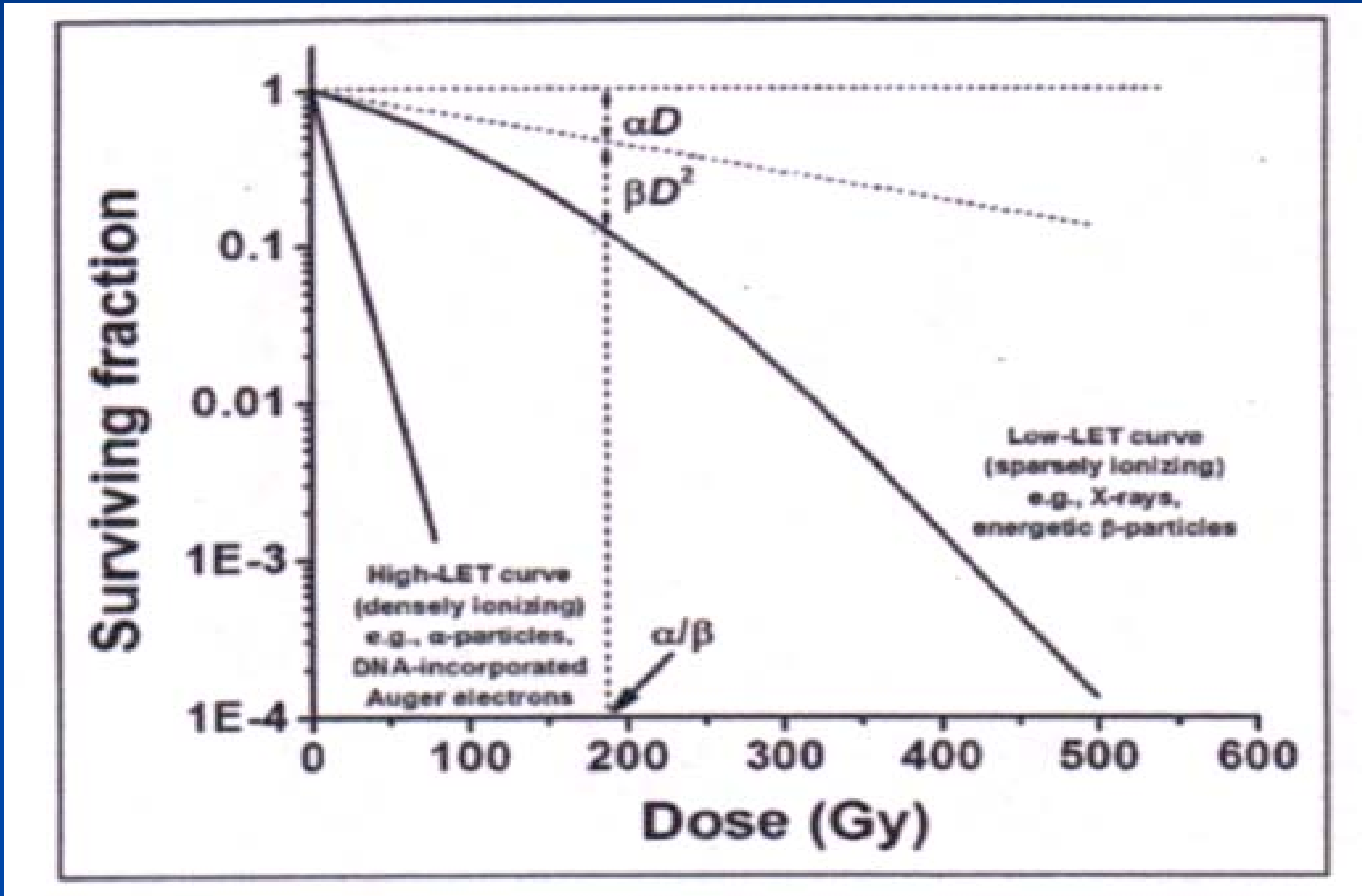
An electron micrograph depicting a group of *E. coli* bacteria.



Life on Earth: resistance to radiation
(Deinococcus radiodurans)



Survival of mammalian cells after irradiation



Part 2

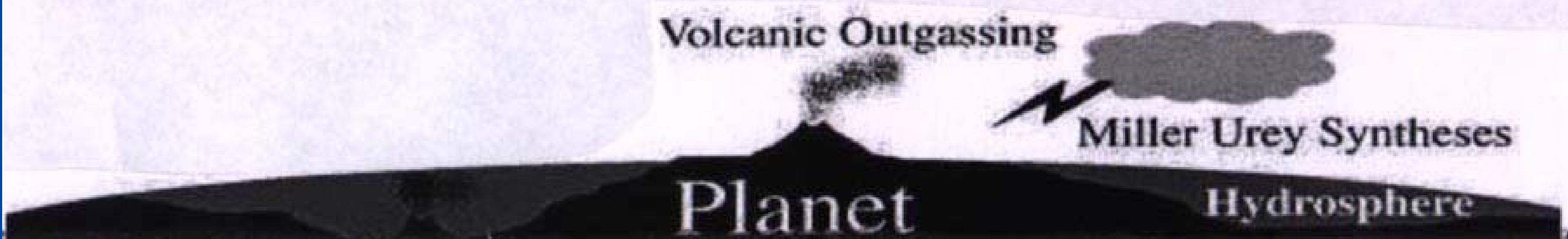
The Origins:

2. Life in the universe:

The fourth area of astrobiology

- How?
- When?
- Where?

How did life begin on Earth?



Miller-Urey Synthesis (Chemical evolution)

Precursor molecule	*Biomolecule*
Carbon monoxide + hydrogen $CO + H_2$	Fatty acids
Hydrogen cyanide HCN	Purines (adenine, guanine)
Cyanamide H_2NCN	Peptides, and phospholipids

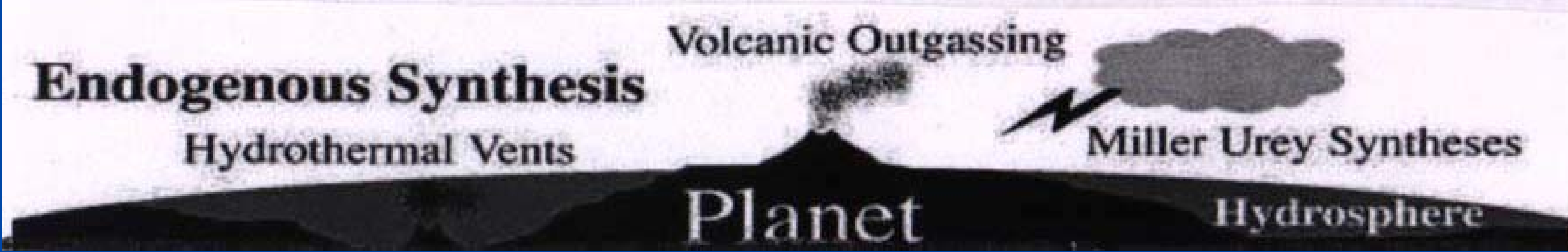
RNA World

When did life begin on Earth?

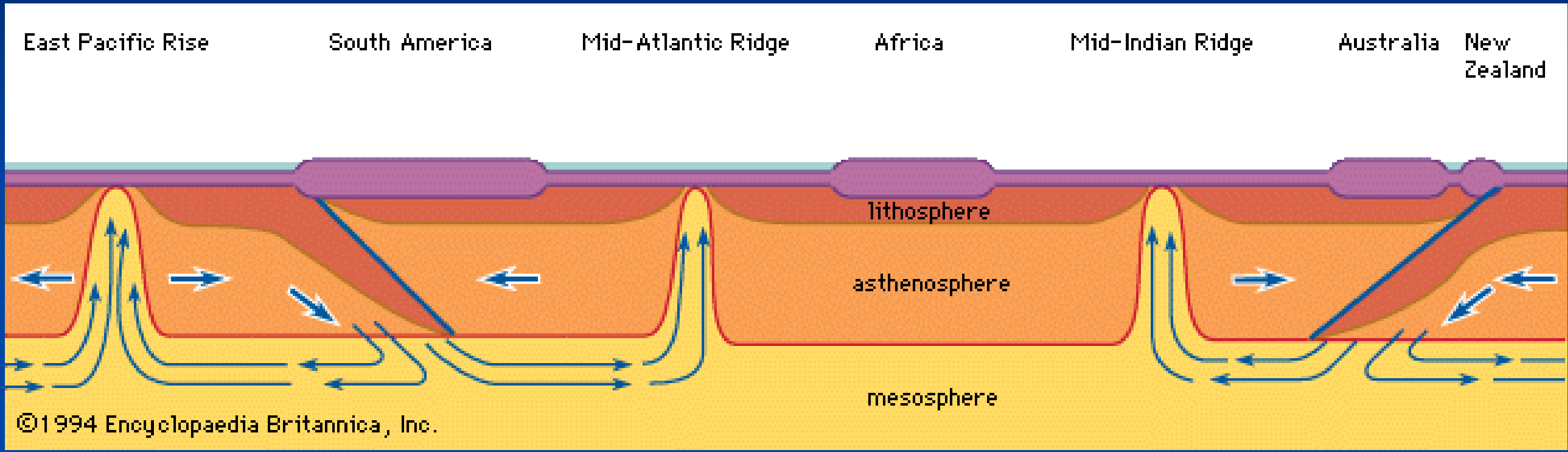
- The evidence from fossils of stromatolites is that cyanobacteria were present since the Archean over 2.5 Gyr BP.
- The exact date is still controversial.

Contemporary stromatolites
(Shark Bay, Australia)

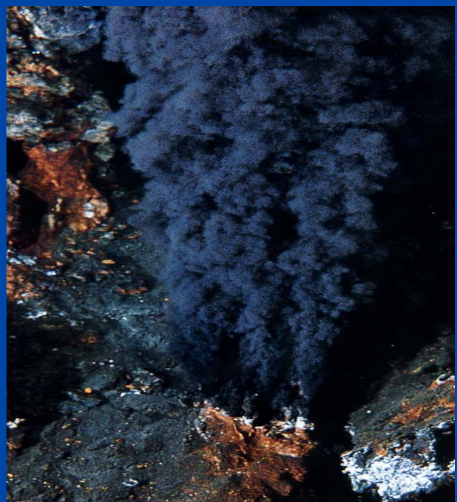
Where did life begin on Earth?



Endogenous synthesis



- In hydrothermal vents at mid-ocean ridges, lava from the Earth's mantle forms continents.



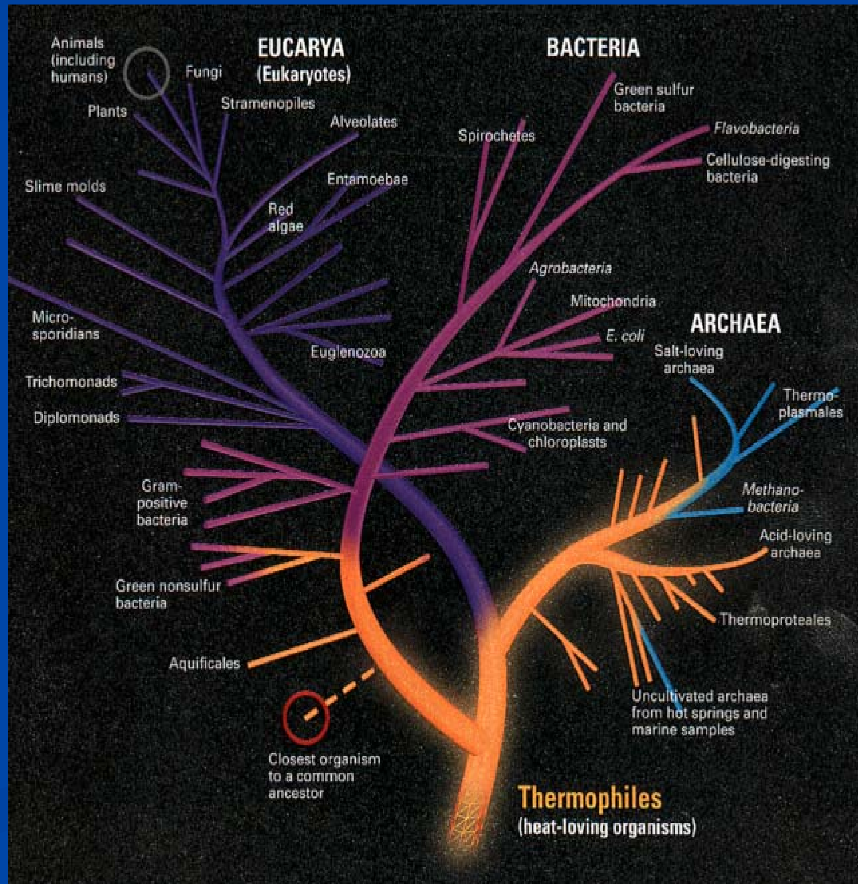
Black-smoker

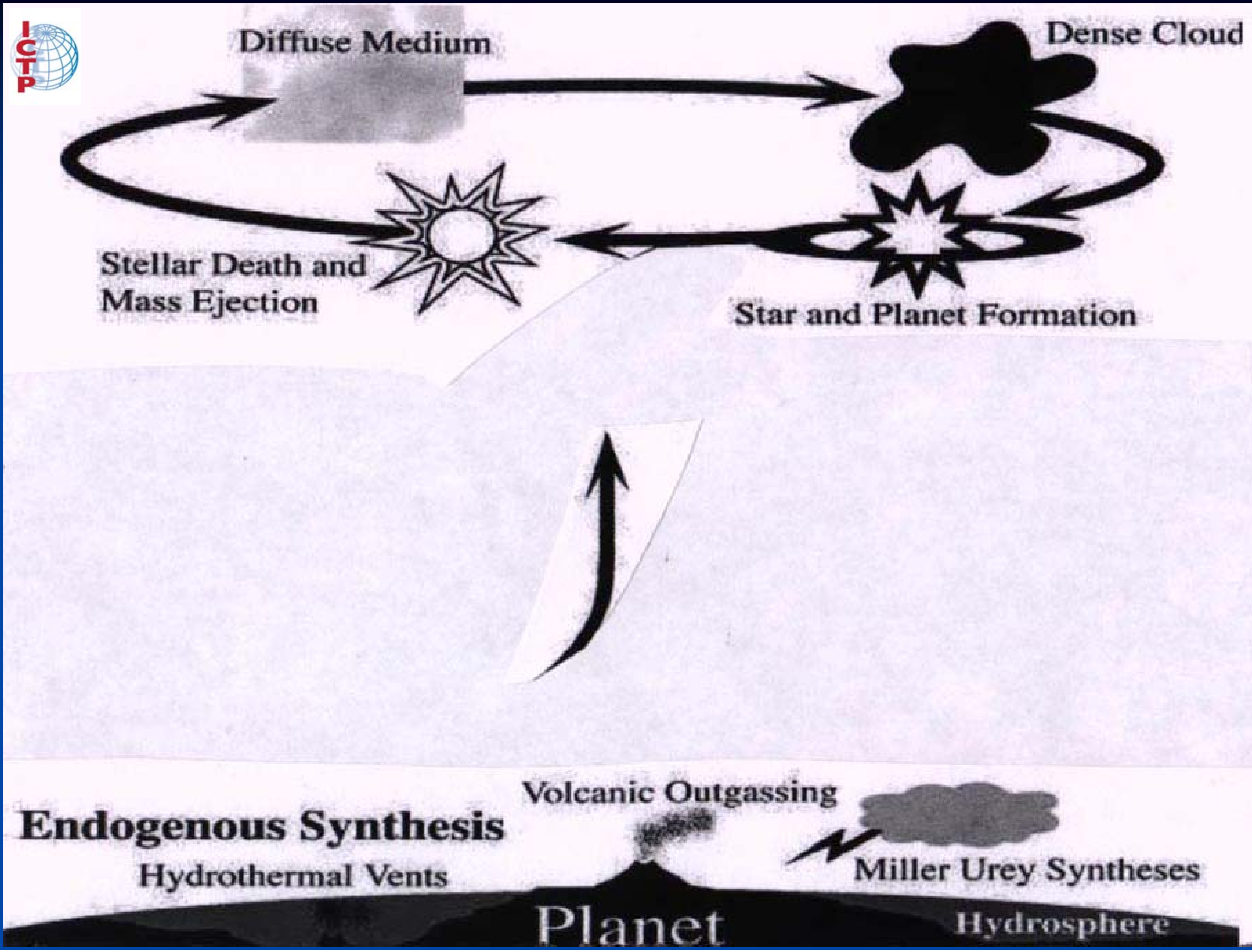
- Circulation of water heated by magma provides elements for metabolism.

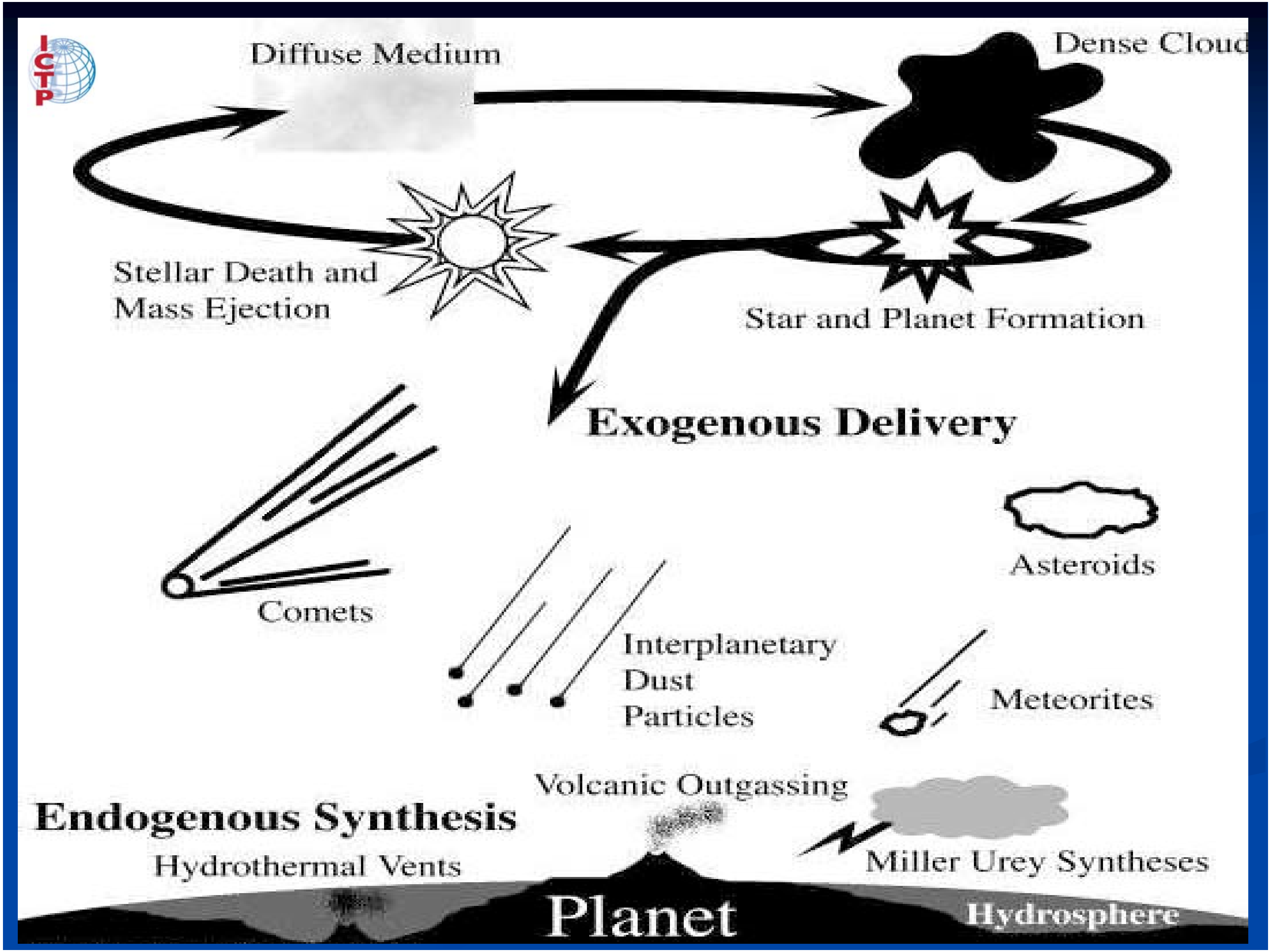
Tube worms
9 N , East Pacific Rise

Chemical and biological evolution

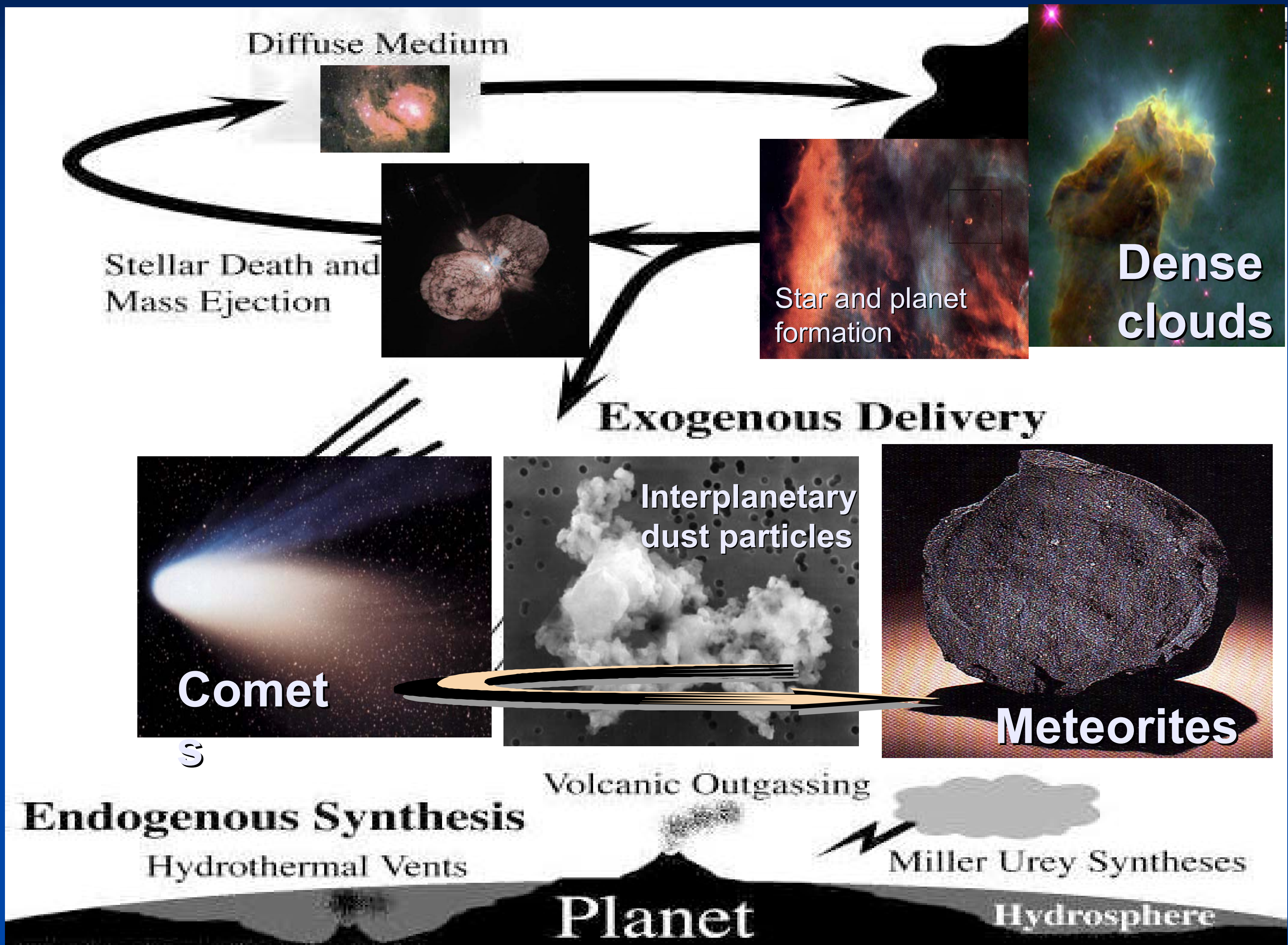
Theories	*Scientists*
Pyrite	Gunther Wachtershauser
Clays	Graham Cairns-Smith
Search for the common ancestor	Carl Woese




Diffuse Medium
Dense Cloud
Stellar Death and
Mass Ejection
Star and Planet Formation
Volcanic Outgassing
Endogenous Synthesis
Hydrothermal Vents
Miller Urey Syntheses
Planet
Hydrosphere


ICTP
Diffuse Medium
Dense Cloud
Stellar Death and
Mass Ejection
Star and Planet Formation
Exogenous Delivery
Comets
Asteroids
Interplanetary
Dust
Particles
Meteorites
Volcanic Outgassing
Endogenous Synthesis
Hydrothermal Vents
Miller Urey Syntheses
Planet
Hydrosphere

Where did life begin in the universe?

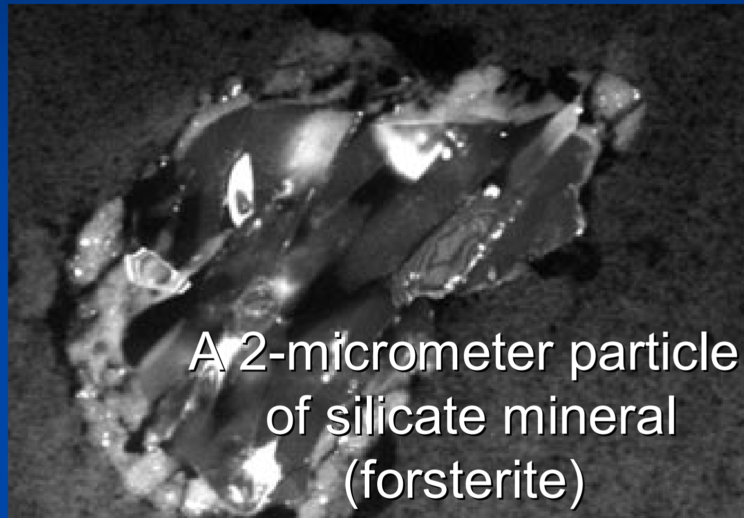


Compounds observed in the comas of comets

Compound	In Hale-Bopp
H_2O	100
CO	20
CO_2	20
H_2CO	0.1
CH_3OH	2
$HCOOH$	~0.05
$HNCO$	0.1
NH_2CHO	~0.01
$HCOOCH_3$	~0.05
CH_4	~0.6
C_2H_2	~0.1
C_2H_6*	~0.3
NH_3	0.6
HCN	0.2
HNC	0.04

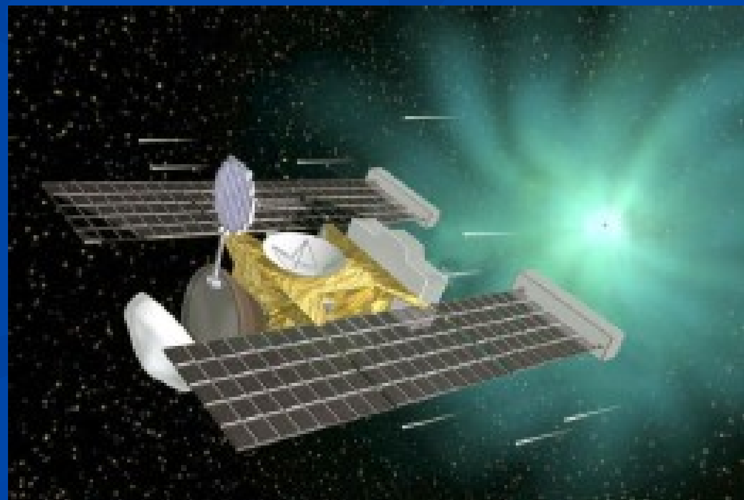
Interplanetary dust particles

- IDPs of carbonaceous material, if larger than about 100 micrometres in size, reach the ground in large quantities - a few 10^4 tons per year (micro-meterorites).



A 2-micrometer particle of silicate mineral (forsterite)

- The Stardust spacecraft was launched in 1999 to collect dust and carbon-based samples during its closest encounter with Comet Wild 2.



Organic compounds in Murchison and other meteorites

Compound	In meteorites	In biology
Biochemical building blocks		
Amino acids	+[a,b]	Proteins
Fatty acids	+[c]	Membranes
Glycerol	+	Membranes
Inorganic phosphate	+	Membranes and nucleic acids
Purines	+	Nucleic acids
Pyrimidines	+	Nucleic acids
Ribose and deoxyribose	—	Nucleic acids

When did life start?

- The evidence from fossils and contemporary stromatolites is that cyanobacteria were present since the Archean over 2.5 Gyr BP.
- The exact date is still controversial.

Contemporary stromatolites
(Shark Bay, Australia)

Contemporary cyanobacteria are filamentous

- **The stromatolites consist of filamentous bacteria, once called 'blue-green algae'.**

- **Oscillatoria is shown in the image.**

(x2,900)

Part III

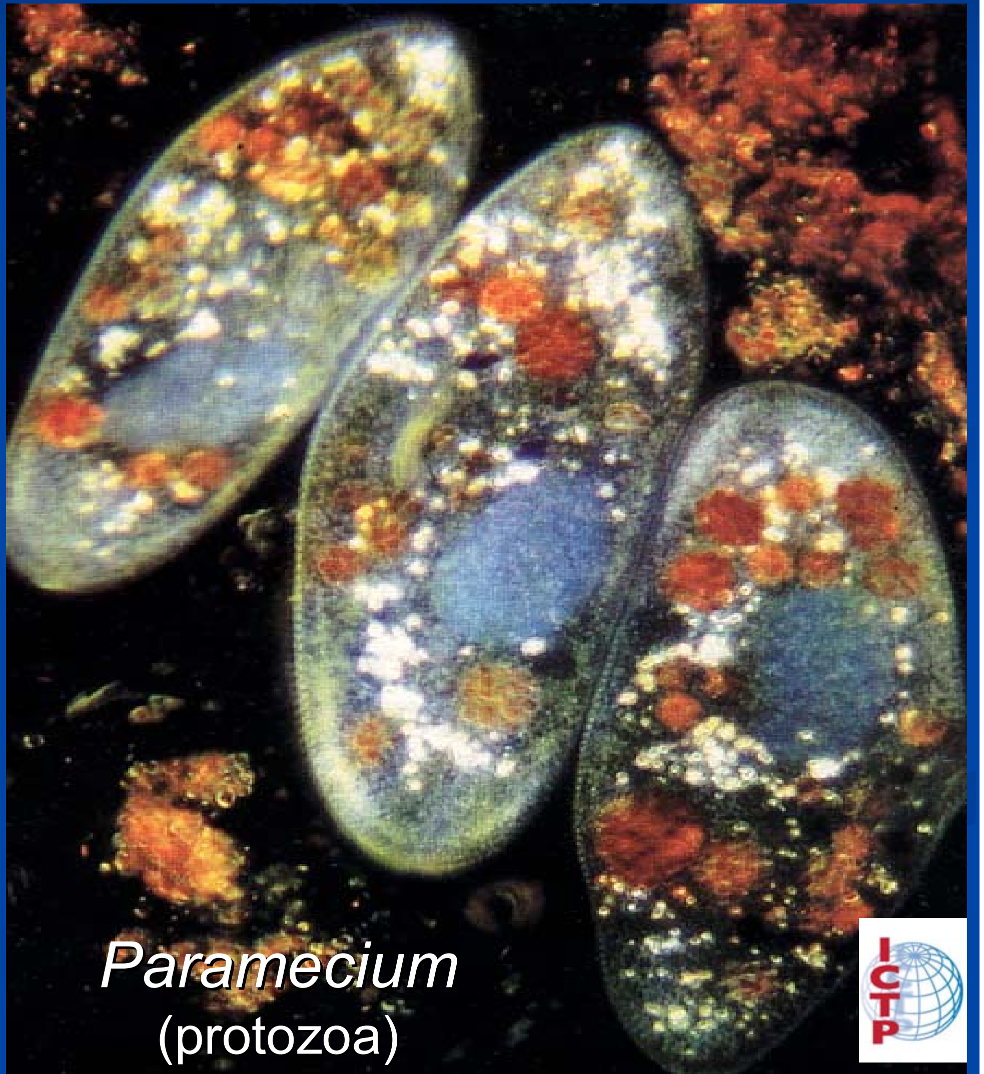
Can an exoplanet support a human-level of intelligence?

International Journal of Astrobiology (2003)

Microorganism physiology

- Calcium channels are involved in protozoan movements.

- *In archaea (Haloferax volcanii),* voltage-dependent and mechanosensitive ion channels are known.



Paramecium
(protozoa)

Invertebrate physiology

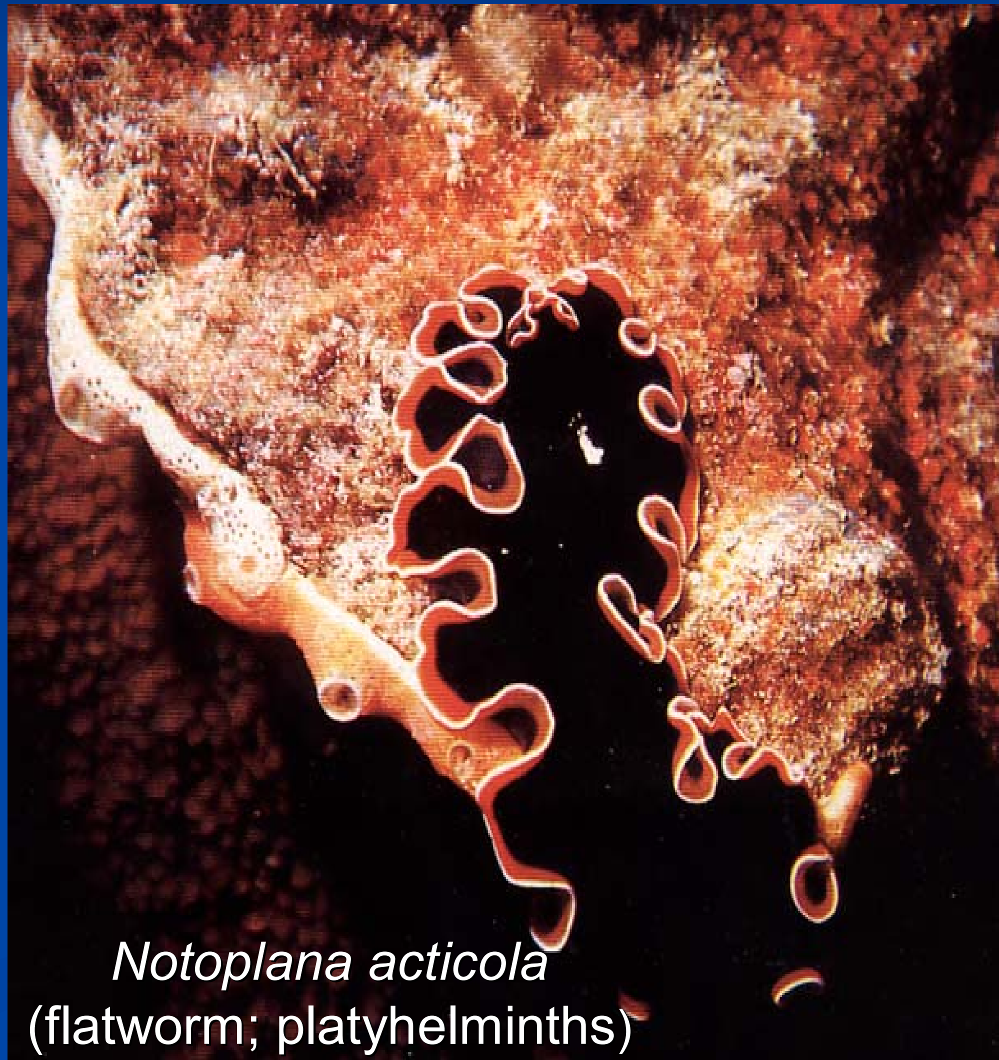
- In jellyfish action potentials (nerve nets) are known.

- Even more surprising is that in sponges Ca- and Na-dependent channels are also known.

Aglantha digitale
(cnidarian)

Cerebral ganglions

- receive inputs from sensory organs and deliver outputs to muscles, via nerve filaments.



Notoplana acticola
(flatworm; platyhelminths)

Intelligence during the spread of humans

- In the evolution of mammalian brain the appearance of intelligent life had to wait till the Magdalenian 'culture'.

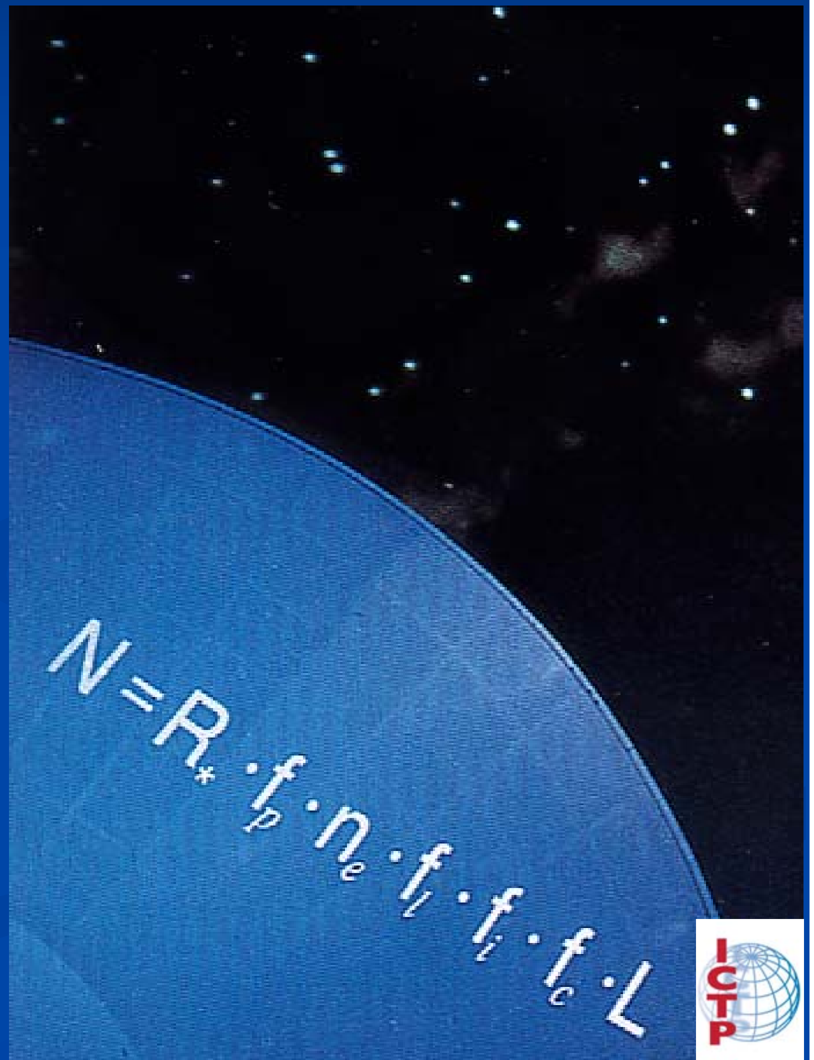
- New discoveries about the **early humans** may add further constraints on what we can expect from other intelligences (*Homo floresiensis*?)

The search of intelligent behavior

- The Drake equation assumes that evolution of intelligence, as known to us through human evolution, is a cosmic phenomenon.

- Evolutionary convergence in the universe militates in favor of intelligent behavior being independent of human evolution.

- To study whether some aspects of human brain evolution are exceptional, comparisons with other species may be fruitful. (Lori Marino has gone some way in this direction.)



ICTP

Discussion

➢What if life started outside the Solar System?

➢Brain evolution may offer hints of the probability that a human level of intelligence may arise in an independent evolutionary line.

➢The SETI project is an observational tool currently available to bioastronomers.

Discussion

- **Evolution of the universe:** Through a fleet of space missions the frontier between cosmological astrophysics and astrobiology will be extended in a joint search for its common ideals.

- **What if life started outside the Solar System?** Brain evolution may offer hints of the probability that a human level of intelligence may arise in an independent evolutionary line. The SETI project is an observational tool currently available to bioastronomy.

Conclusions

- **What is the place of humans in the universe?** To understand life as an inevitable consequence of the evolution of the universe still requires further progress in the cosmological and prebiotic evolution scenarios.

- **How, when and where did it all start?** We need further detailed discussions of prebiotic chemistry, precellular biological and human evolution coupled with the exploration of the solar system, and the eventual search for biosignatures in other solar systems.