Astrobiology
Properties and definition of terrestrial life

Planets and Astrobiology (2018-2019)
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Definition of "astrobiology"

Study of the origin, distribution, evolution and destiny of life in the universe

Short definition: study of the living universe

Astrobiology
- Term used in space missions of the National Aereonautics & Space Administration (NASA)
- Adopted by the community of biologists and chemists interested in the study of the origin of life (ISSOL)
- Now commonly adopted in all studies of life in the universe

Other terms used to design studies of life in the Universe

Bioastronomy
- Adopted by the International Astronomical Union (IAU)
- Mostly used inside the astronomical community
  - Search for planets around other stars
  - Search for interstellar molecules of biological interest
  - Detection of possible signatures of biological activity
  - …

Exobiology
- Used in space missions of the European Space Agency (ESA)
  - Search for life ouside Earth
    - By definition does not include terrestrial life and can be criticized since there is no evidence for life outside Earth so far

Classic research fields related to astrobiology

Origin of life
Appearance of life in the primitive Earth
Laboratory experiments of prebiotic chemistry
Delivery of organic material from space (comets and meteorites)

Terrestrial life in extreme conditions
Terrestrial habitats with extreme physico/chemical conditions

Search for life in the Solar System
Space missions in the Solar System

Recent astronomical studies related to astrobiology

Exoplanet research

Search for habitable exoplanets

Search for atmospheric biomarkers in extrasolar planets

Protoplanetary disks

Formation history of habitable planets

Delivery of water and organic material on terrestrial-type planets

Research fields related to astrobiology

Terrestrial life outside Earth

Resistance of terrestrial life in space conditions
(possible applications: biomedicine)

Colonization of Solar System bodies

The challenge of multidisciplinarity

Astrobiology relies on contributions from

Space Sciences

(astronomy, solar system exploration, …)

Chemistry

(organic chemistry, prebiotic chemistry …)

Life Sciences

(biochemistry, microbiology, molecular biology, evolutionary biology …)

Earth Sciences

(geology, climatology, planetary habitability, …)

Cross-fertilization is extremely advantageous,
but requires breaking cultural barriers

Biology and astronomy as "historical" sciences

Many physical laws are time-reversable (e.g. equations of motion)
so that the description of (simple) physical systems
is often independent of the previous history of such systems

On the contrary, the behaviour of complex systems
is influenced by their previous history

In astronomy we are familiar with historical processes:
Galactic formation and evolution
Planetary formation and evolution

Life that we know is the result of a long sequence of processes
and keeps memory of its previous history

At variance with many aspects of physics,
biology and astronomy are "historical" sciences

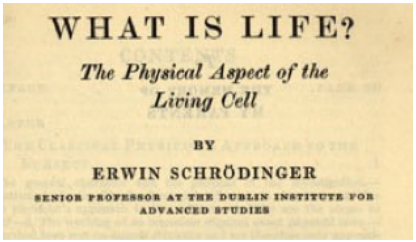
Terrestrial Life

So far, terrestrial life is the only reference for astrobiological studies:
"life-as-we-know-it"

In the first part of this course
we briefly review the main properties of terrestrial life

The topics of the course
have been selected according to their relevance in astrobiology,
with a focus on the physical and chemical properties

This is not a course of biology


WHAT IS LIFE?

The Physical Aspect of the Living Cell

BY

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There is no commonly accepted definition of life

The definition of life is still the subject of scientific debate

Basic approach:
The properties of terrestrial life are used to define life

Properties of terrestrial life

The choice of the set of properties that characterize life
varies according to different authors
and tends to change in the course of time
following the progress in our understanding of the biological world

A possible set of properties is:

Metabolism
Reproduction
Information coding and transmission
Adaptation to the environment
Self organization

Metabolism

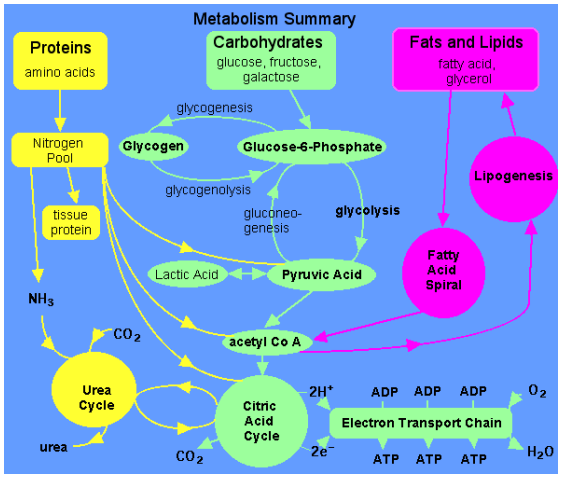
Network of the physical and chemical processes taking place at the molecular level in a living organism

Used to produce, maintain and destroy the molecular constituents and to exchange and store energy

Examples:
- Photosynthesis (carbon fixation)
- Catabolism (breaking of organic molecules)
- Anabolism (synthesis of organic molecules)
- Respiration (extraction of chemical energy)

The energy is extracted through electron transfer and stored in molecules that are later used to exchange energy

Metabolic networks are extremely complex

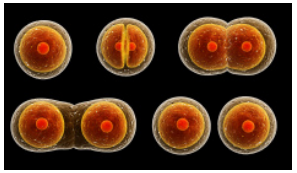


Reproduction

Capability of generating new organisms of the same species

At the molecular level, reproduction implies some form of replication of part of the molecular constituents

Reproduction is essential for the long-term perpetuation of life

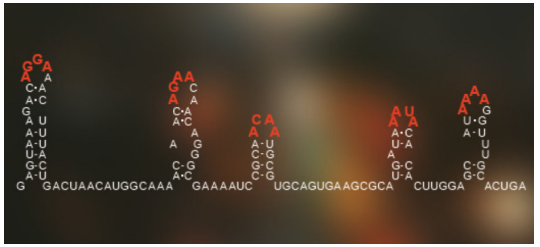


Information coding and transmission

Living organisms carry the instructions used to drive their functions (metabolism and reproduction)

The instructions are transmitted to the next generation

- Such instructions constitute the genetic information of life
- The amount of information stored in organisms is extremely high



Adaptation to the environment (1)

Life responds to variations of ambient conditions in many different ways and over different time scales

We can make a distinction between physiological (short-term) and genetic (long-term) adaptation

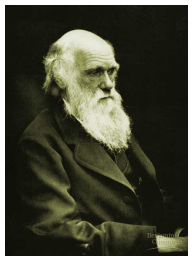
Physiological adaptation

- Short term adaptation of metabolic processes
- Feedback mechanisms that allow organisms to tune their metabolic functions in response to changes of ambient conditions

Adaptation to the environment (2)

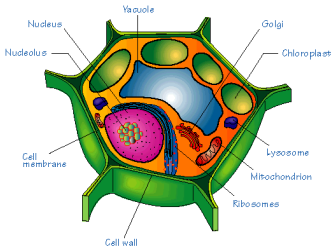
Genetic adaptation

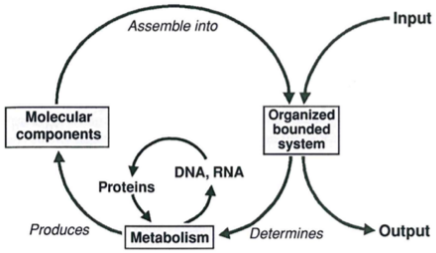
- Long term adaptation of genetic material
- Modification and natural selection of the genetic pool in response to changes of ambient conditions
- Takes place in the course of many generations, leading to Darwinian-type evolution
- This adaptation results from a gradual accumulation of changes in the genetic pool
- The genetic changes that provide best adaption to new ambient conditions are preserved



Self organization

- Living organisms organize themselves autonomously, creating a network of substructures which cooperate to carry out the metabolic, genetic and reproduction functions
- Molecular constituents lie at the lowest level of self organization
- Life tends to maintain its internal organization despite exchanges of matter, energy and entropy with the external world





Problems with the definition of life

Can we use the properties of terrestrial life to define life?

Problems with the definition of life

1) There is no single property that is intrinsic and unique to life
   - Life properties, if considered one by one, can be present also in the non biological world
2) There is no sharp separation between living and non-living systems

Metabolism is not sufficient to define life

In the non-biological world there are examples of chemical reactions with transfer of electrons and storage of energy, similar to the ones that take place in the biological world

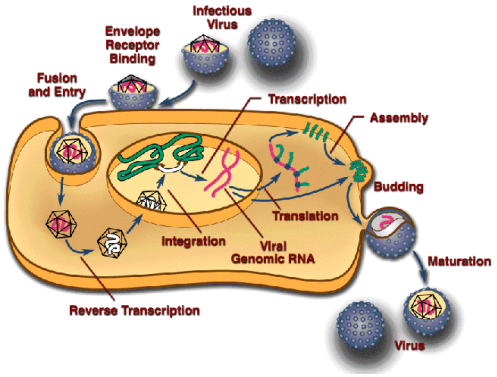
Reproduction is not sufficient to define life

Some organisms lack the capability of reproduction

For example: mules

Genetic information is not sufficient to define life

Example: viruses possess their own genetic information, but do not have an internal metabolism and can reproduce only in a host organism



Life definition and origin of life

The definition of life is an attempt to distinguish the biological world from the non-biological one

The origin of life implies a transition between the non-biological and the biological world

The problem of defining life is strictly related to the problem of understanding its origin

The origin of life is central in astrobiology

Implications of the problem of life definition

The difficulty of defining life makes hard
to define astrobiology in a rigorous way
Leaves the door open to criticism:
Does it make sense to search for something in the universe
that we are not even able to define on earth?

The problem of the definition of life is not only conceptual:
it has practical implications for our capability
of detecting life outside Earth
We need observational/experimental guidelines
to distinguish biological from non-biological signatures
in astronomical bodies

Operational definition of life

Adopted by NASA in the past (Joyce 1994)
"Life is a self-sustained chemical system capable of Darwinian evolution"

Theoretical criticism (Di Mauro & Saladino):
Life is not a system, it is a process
It is not self-sustained
(for instance, energy for life is extracted the environment)
Definining something based on the fact that it can evolve
poses an epistemological problem

Difficulties from the operational point of view:
Chemical traces are detectable, but may lead to ambiguous results
Darwinian evolution not easy to prove in remote life

A concise definition of life

Trifonov (2011)
Analysis of the vocabulary of 123 tabulated definitions of life
reveals nine groups of defining terms,
of which the groups (self-)reproduction and evolution (variation)
appear as the minimal set for a concise and inclusive definition:

"Life is self-reproduction with variations"

Generalizing terrestrial life

Life can be described as a process that involves recyprocal interactions
of its constituents and interactions with the environment

At the molecular level, life must have the capability
to carry out genetic and metabolic tasks

In terrestrial life, these tasks are performed by specialized molecules

A possible way to generalize the concept of terrestrial life is to consider
molecular processes sustained by specialized molecules
with genetic and metabolic capabilities