Astrobiology
Lecture 1

Introduction

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What is astrobiology?

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

In short: study of the living universe

"Bioastronomy" and "exobiology" have similar meanings

- They are used in the astronomical or Solar-System communities

"Astrobiology"

- Adopted by the community of biologists and chemists interested in the study of the origin of life (ISSOL)
- Now commonly adopted in most studies of life in the universe

Classic research fields of 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 planets/satellites of astrobiological interest

Recent research fields of astrobiology

triggered by advances in astronomy

Exoplanets

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

“Complex” organic molecules in space

Reconstructing the first steps of the chemical pathways of “prebiotic chemistry”

Multidisciplinarity

Physics, chemistry (general background)

Astronomy, geology, biology ("historical" approach)

Benefits

Cross-fertilization of knowledge among different communities

Challenges

Nobody can be an expert in all the research fields of astrobiology

This short course

A collection of selected topics that provide a general introduction to astrobiology

Terrestrial Life

To introduce astrobiology it is necessary to get familiar with the main properties of terrestrial life

So far, terrestrial life is the only reference for astrobiological studies:

"life-as-we-know-it"

Properties of terrestrial life

Terrestrial life is characterized by a set of properties

Different authors use different lists of properties to describe life

A possible (but certainly not unique) list of properties is:

Metabolism
Reproduction
Information coding and transmission
Self maintenance, self organization
Adaptation
Evolution

Metabolism

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

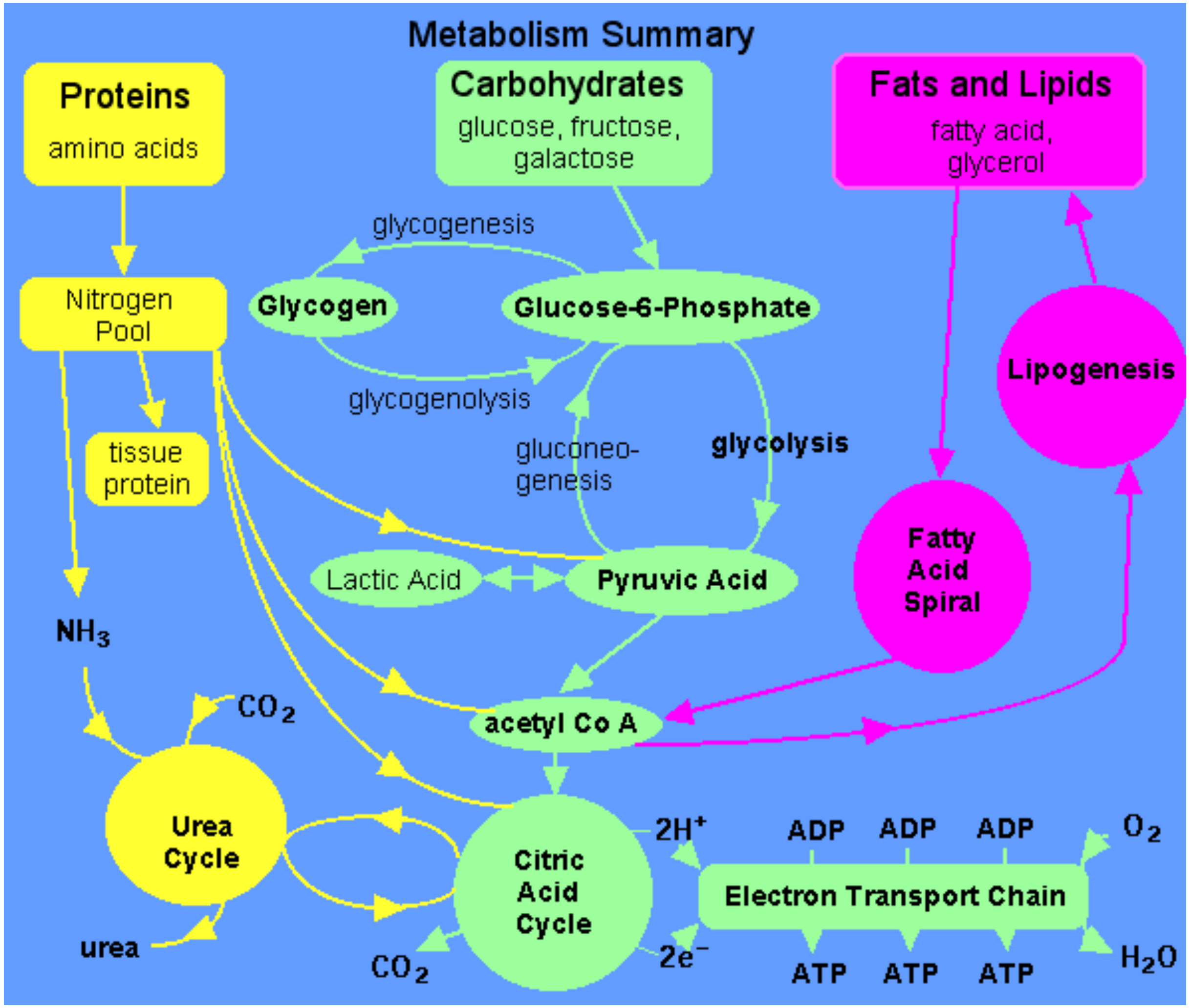
Used to produce, maintain and recicle the molecular constituents and to exchange and store energy

Examples:

- Anabolism (synthesis of organic molecules)
- Catabolism (breaking of organic molecules)
- Photosynthesis (carbon fixation)
- 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
Multiple feedbacks involving reagents and products of chemical reactions

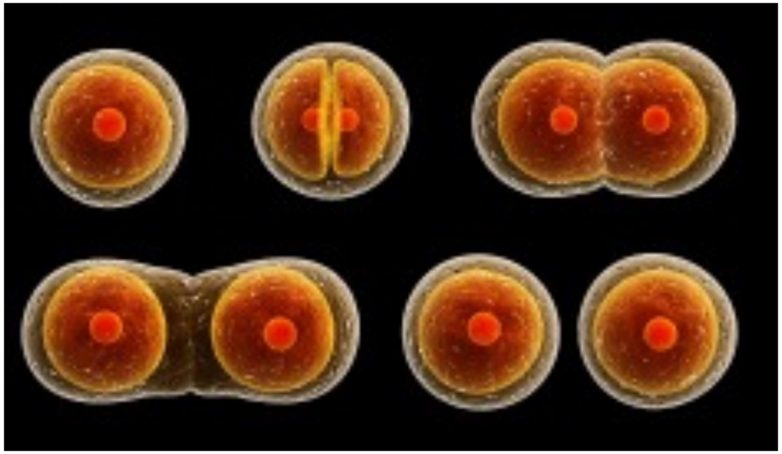


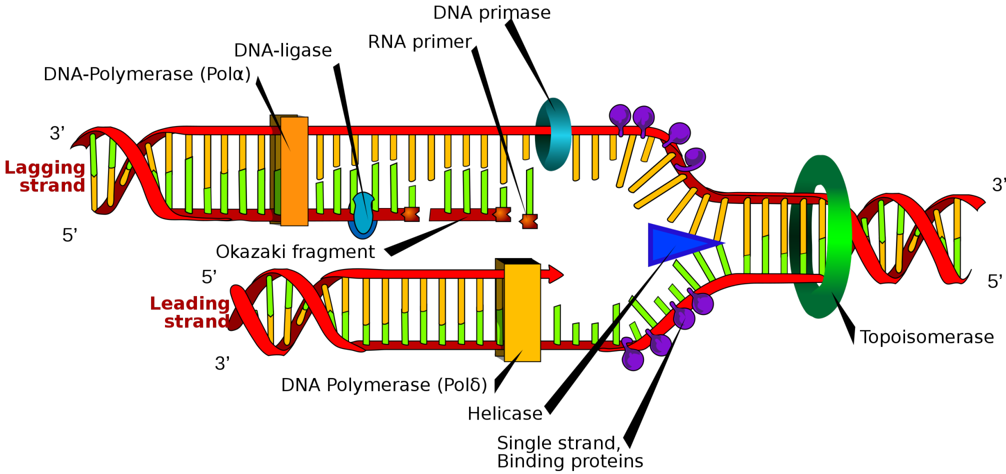
Reproduction

Capability of generating new organisms of the same species

Reproduction is essential for the long-term perpetuation of life

<u>At the molecular level, reproduction implies some form of replication</u> of part of the molecular constituents



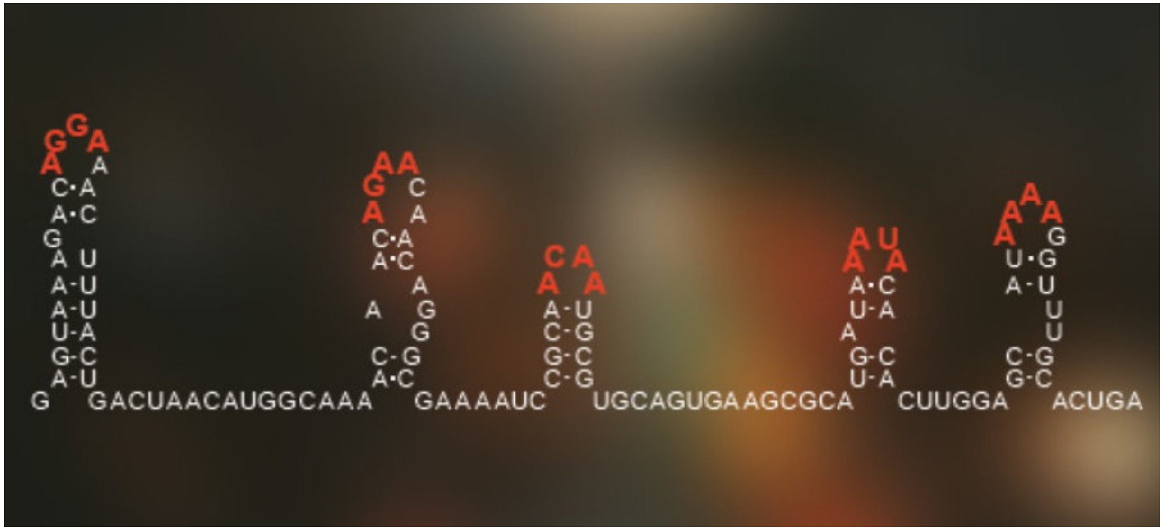


Information coding and transmission

Living organisms carry the instructions used to drive their 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
- (see Appendix in Lecture 4)

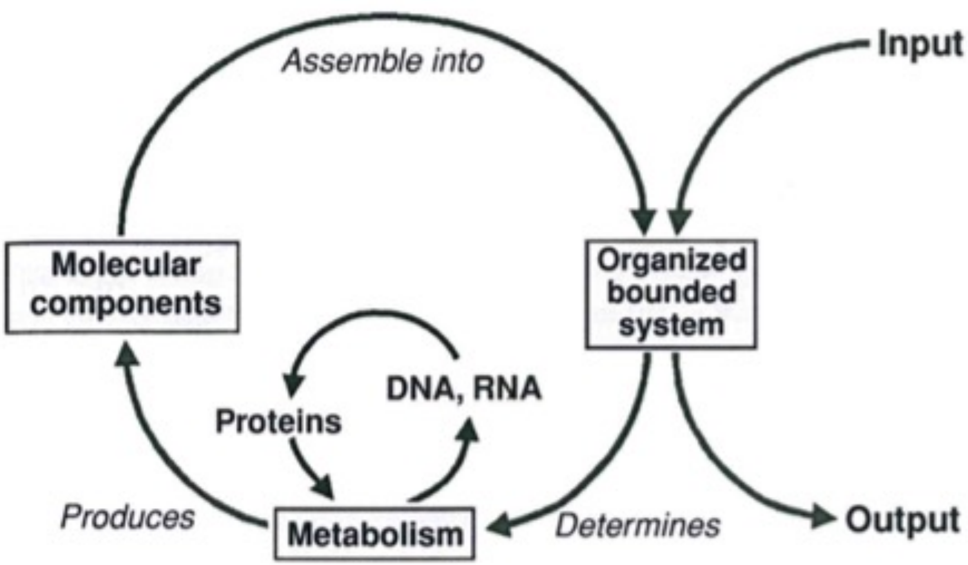


Self maintenance, self organization

Living organisms build, maintain and recicle their own constituents using an internal set of instructions

According to some authors, this property, also called autopoiesis, is the most distinctive feature of life (see e.g. Luisi 2016)

Living organisms create their own network of substructures which cooperate to carry out metabolism and reproduction



Adaptation

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

We can distinguish between:

physiological and genetic adaptation

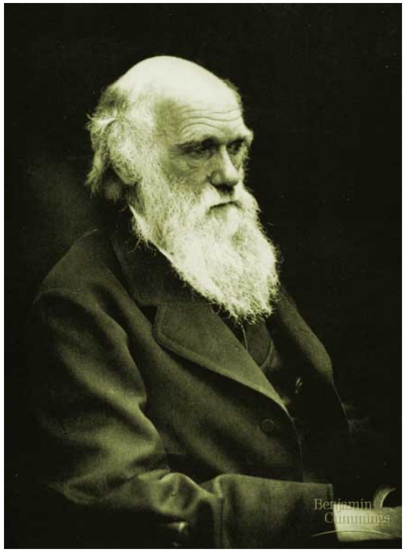
Physiological adaptation

- Feedback mechanisms that allow organisms to tune their metabolism in response to changes of ambient conditions
- Short-term adaptation
- The genetic pool does not vary

Genetic adaptation (Darwinian evolution)

<u>Variations and natural selection</u> of the genetic pool in response to changes of ambient conditions

- Long-term adaptation: takes place in the course of many generations
- Results from a gradual accumulation of changes in the genetic pool
- The genetic changes that provide best adaptation to evolving ambient conditions are preserved
- Genetic pools unfit to evolving conditions are lost (organisms with such genetic pools are extinct)



The origin of life in the context of astrobiology

Origin of life (abiogenesis):

transition between the non-biological and the biological world

The origin of life is central in astrobiology

Understanding which conditions allow life to emerge is essential to trace the potential distribution of life in the Universe

The problem of understanding the origin of life is strictly related to the problem of the definition of life

Definition of life:

attempt to distinguish the biological world from the non-biological one

Can we define “life” ?

Why is it important to define life ?

Not just an epistemological problem:

To detect life outside Earth we need to be able to discriminate life from the abiotic world

The properties of terrestrial life are used to define life

Many definitions have been proposed by different authors

There is no commonly accepted definition

Why is it difficult to define life ?

There is no sharp separation between living and non-living systems

Several properties of life, if considered one by one, may also be present in the non-biological world

Examples of problems connected with the definition of life

Metabolism

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

Some living organisms lack the capability of reproduction

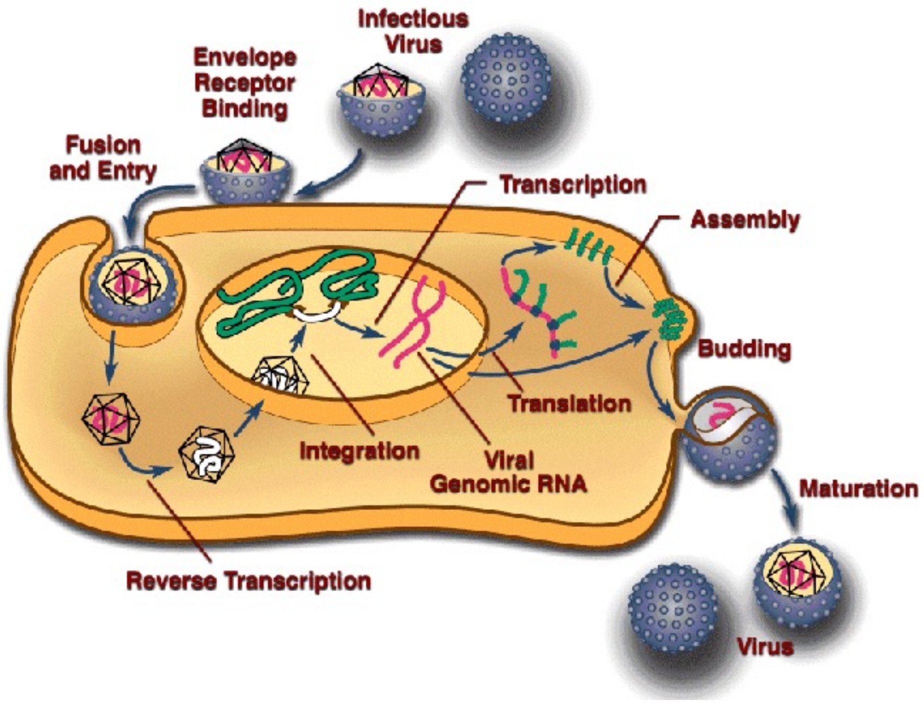
(even though their cells do grow and reproduce)

Example: mules

Genetic information

Despited being one of the most distinctive features of life, it is not sufficient, by itself, 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



Concise definitions of life in astrobiology

Operational definition adopted by NASA
Joyce (1994)

"Life is a self-sustained chemical system capable of Darwinian evolution"

Criticism: (Di Mauro & Saladino)

- Life is a process, rather than a system
- It is not self-sustained

(energy for life is continuously extracted from the environment)

Implications for the detectability of life outside Earth using the definition

"Life is a self-sustained chemical system capable of Darwinian evolution"

The chemical properties

The study of chemical traces may provides a way to detect life,
but chemical traces may lead to ambiguous results

Darwinian evolution

Is one of the most distinctive features of life,
but it is not useful to identify remote life

Detecting remote life is very challenging,
but not impossible (see final lectures on atmospheric biosignatures)

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"

The minimal unit of life

The cell is the minimum structural unit
which has all the properties that define life

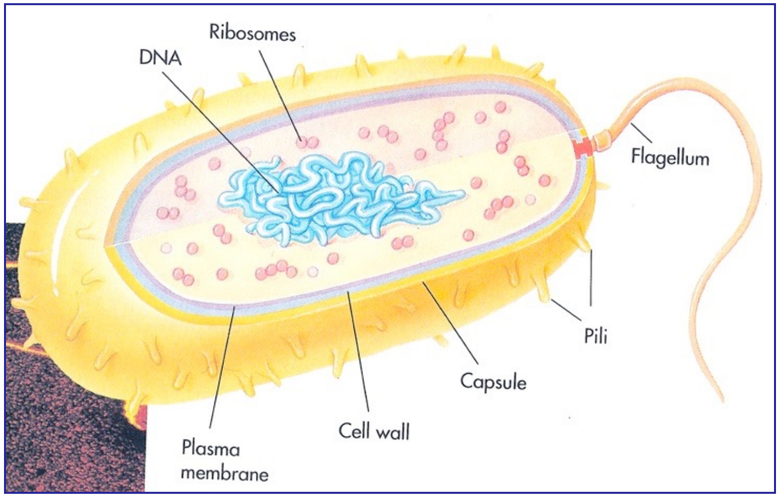
Cells are bounded by a border that provides a separation
from the external environment

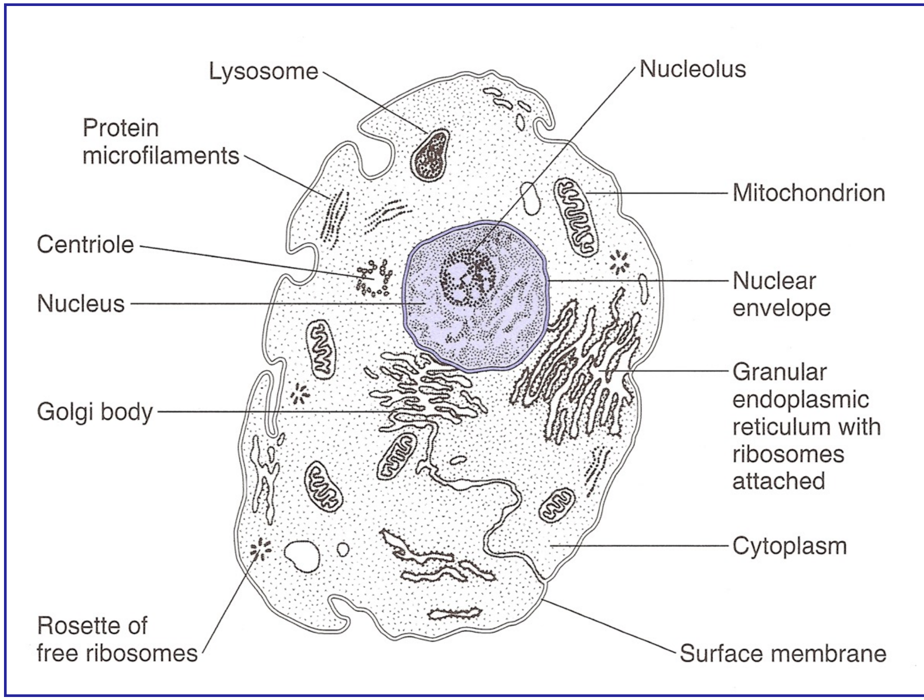
From the point of view of physics,
<u>the cell is an open system</u>
<u>that allows for exchanges of energy and matter</u>
<u>with the environment</u>

The border allows for <u>selective</u> exchanges
In terrestrial life the border is a <u>biological membrane</u>

Cells of terrestrial life

- Prokaryotic (archaea and bacteria)
- Eukaryotic
  - Eukaryotic cells have a high level of internal organization, featuring organelles with specific functional properties





Typical sizes

Prokaryotes: 1 – 5 µm

Eukaryotes: 10 – 100 µm

Unicellular and multicellular organisms

Cells may organize themselves in different ways:

In colonies a large number of cells of the same type share some limited form of cooperation

Colonies are typical of prokaryotic cells

In multicellular organisms, differentiated cells (but with same genetic information) work in strong cooperation

Only eukaryotic cells are able to form multicellular organisms