Astrobiology
Lecture 1

Introduction

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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

"Bioastronomy" and "exobiology" have similar meanings

They are used in the astronomical or Solar-System communities

"Astrobiology"

- 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 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 the Solar System

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

Biology, chemistry, physics, astronomy, geology …

Benefits

Cross-fertilization of knowledge
among different communities

Challenges

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

This course

A collection of selected topics that provide
a general background on 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 is:

Metabolism
Reproduction
Information coding and transmission
Self organization
Adaptation
Evolution

Metabolism

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

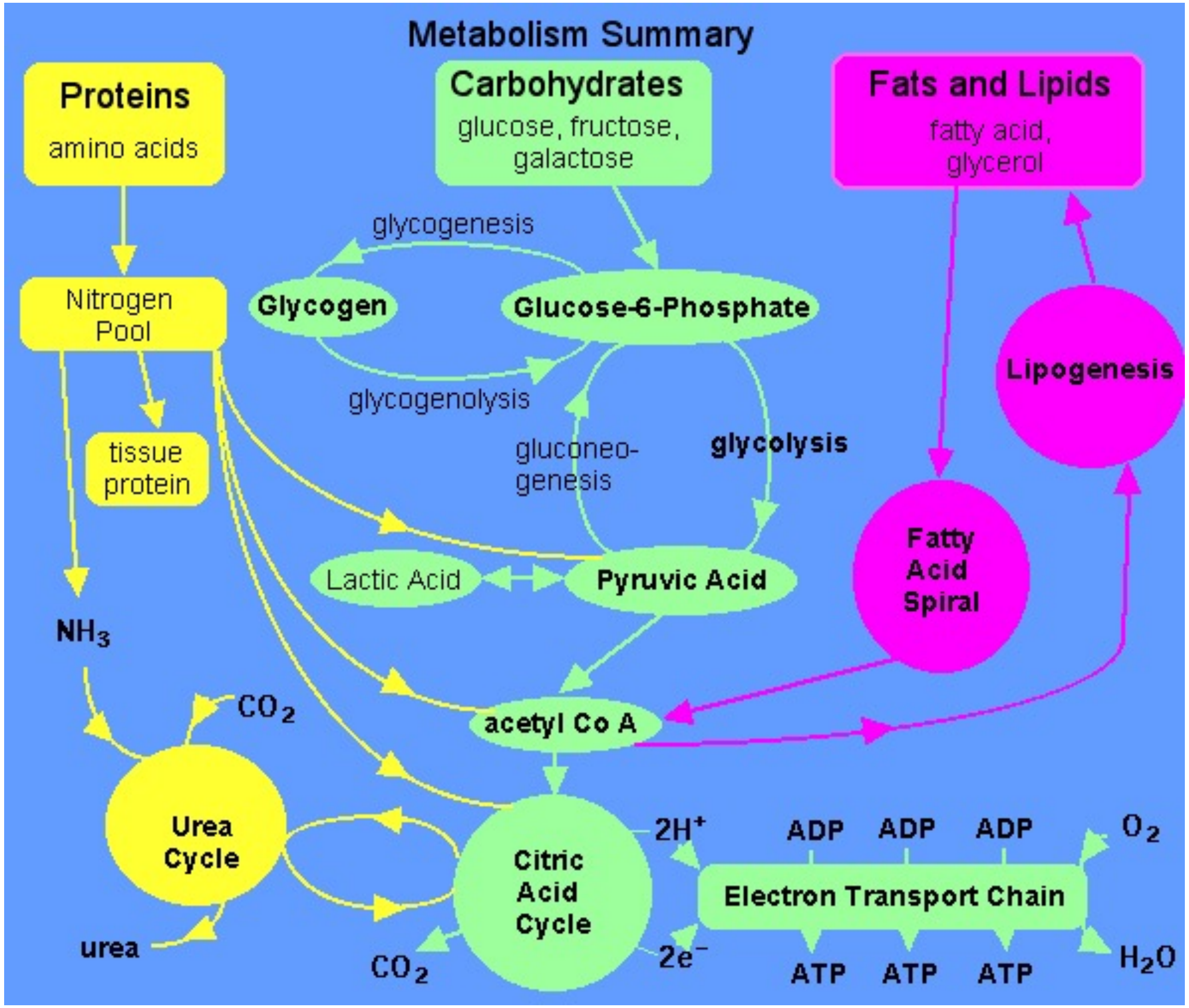
Used to produce, maintain and destroy the molecular constituents and to exchange and store energy

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

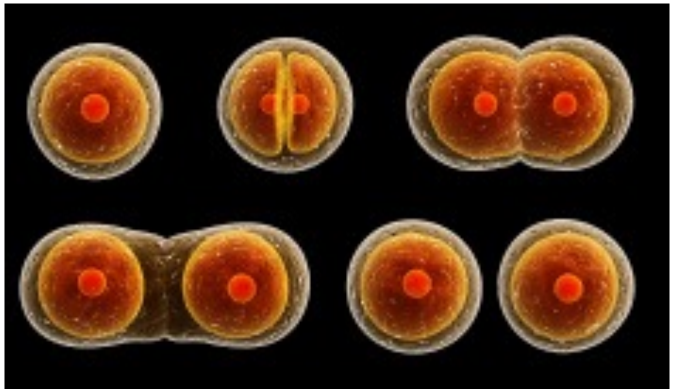


Reproduction

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

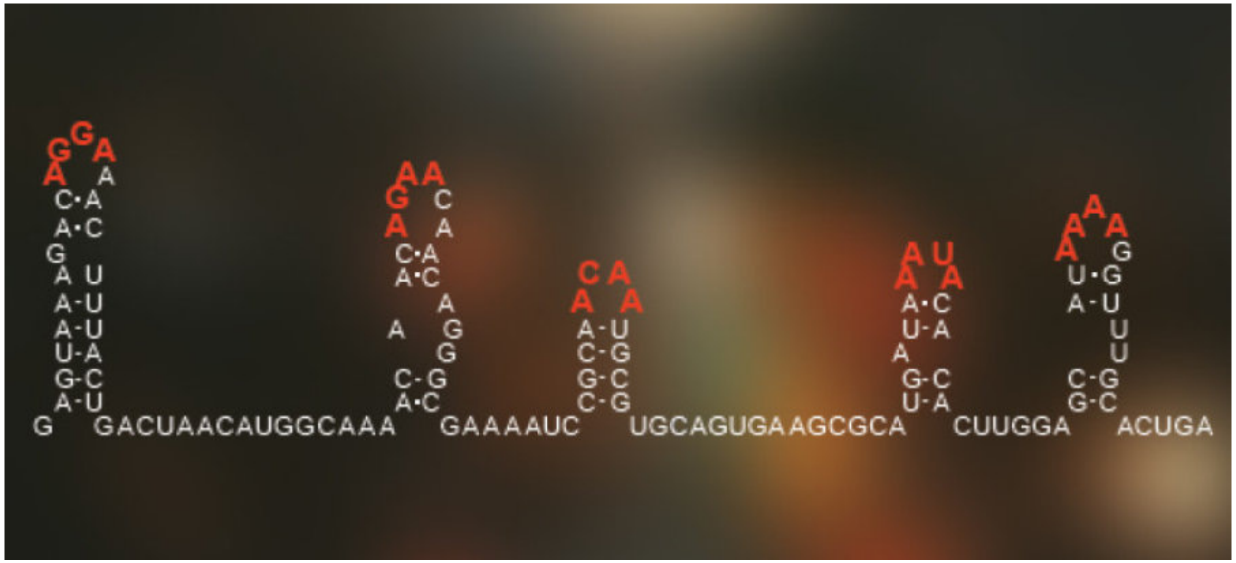


Information coding and transmission

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

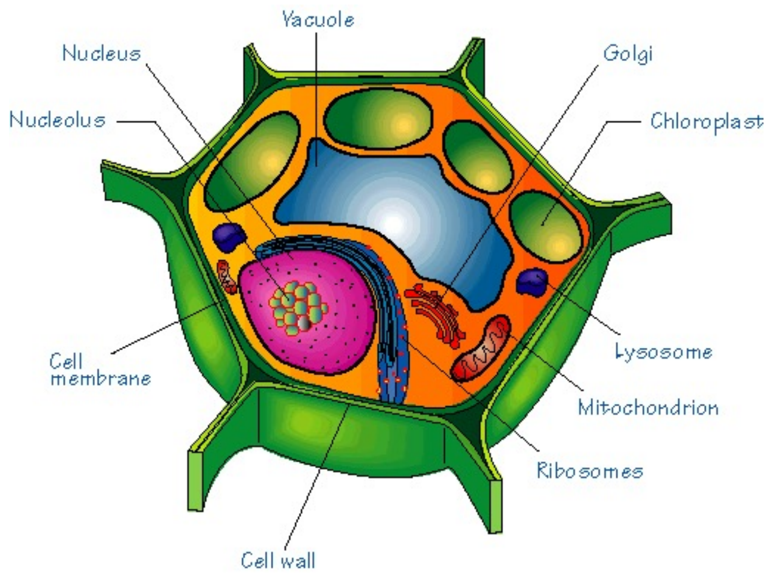


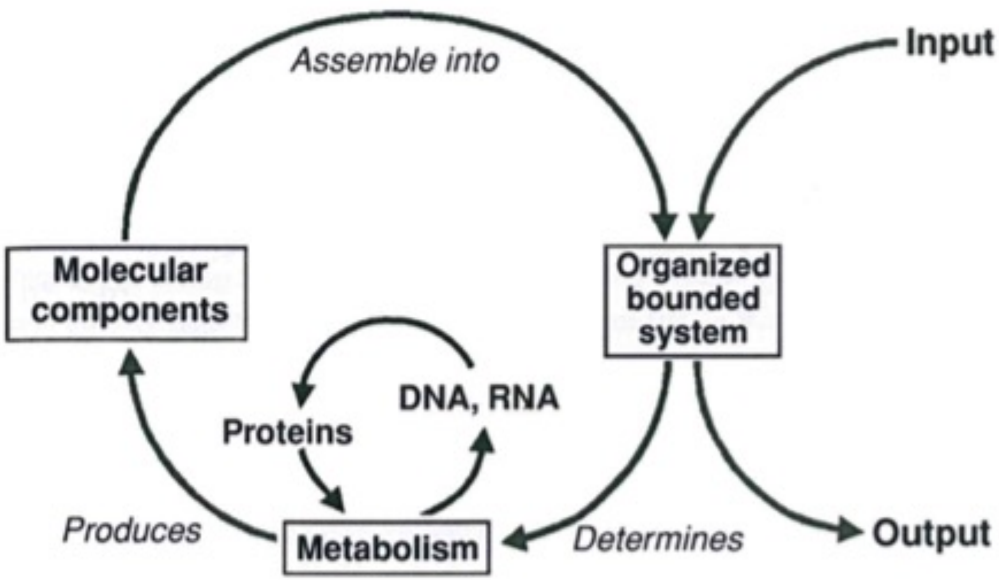
Self organization

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





Adaptation

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

We can distinguish physiological (short-term) and genetic (long-term) adaptation

Physiological adaptation

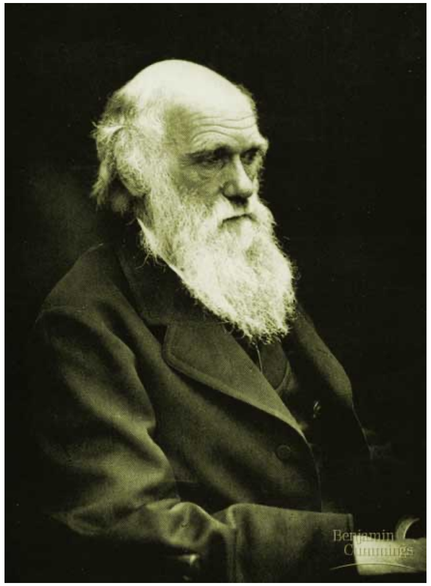
- Feedback mechanisms that allow organisms to tune their metabolic functions in response to changes of ambient conditions
- Short-term adaptation of metabolic processes
- The genetic pool does not vary

Evolution

Long-term adaptation to the environment

Genetic adaptation

- Long term adaptation of genetic material
- Variations 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 adaptation to evolving ambient conditions are preserved
- Genetic pools unfit to evolving conditions are lost



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 <u>defining</u> life is strictly related to the problem of <u>understanding its origin</u>

The origin of life is central in astrobiology

What is life ?

Can we use the properties of terrestrial life to <u>define</u> life?

There is no commonly accepted definition of life

- The definition is still the subject of scientific debate

Problems with the definition of life

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

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

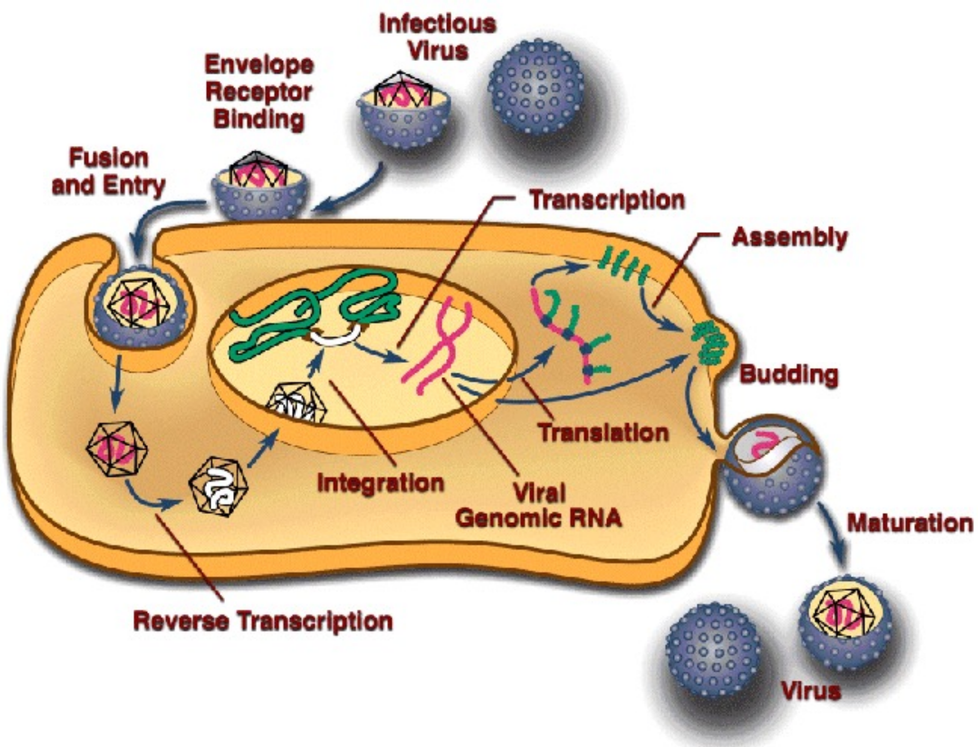
Some living organisms lack the capability of reproduction

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 not a system, it is a process

It is not self-sustained

(for instance, energy for life is continuously extracted, more or less directly, from solar photons)

Definining something based on the fact that it can evolve is not the most logical way to assign a meaning to the properties that are considered

Operational definition adopted by NASA

Joyce (1994)

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

Implications for the detectability of life outside Earth

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 characteristic features of life,
but it is not useful to identify 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"

The minimal unit of life

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

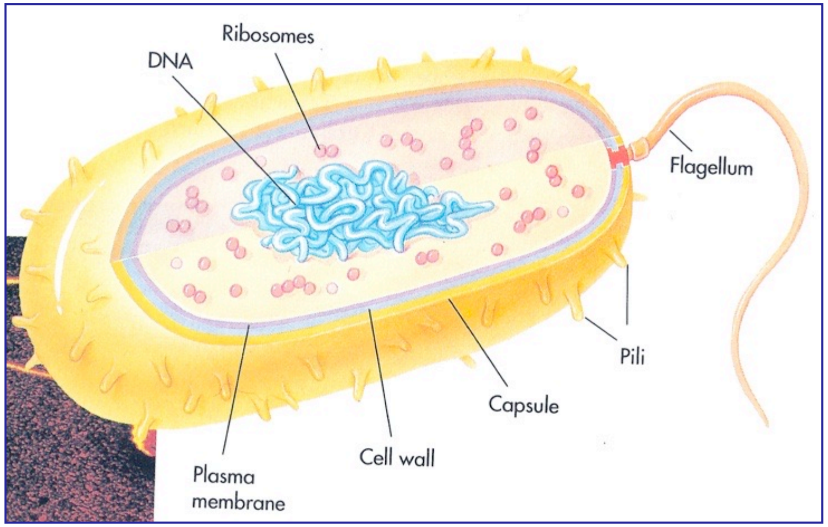
Cells are bounded by a border that provides a separation
from the external environment

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

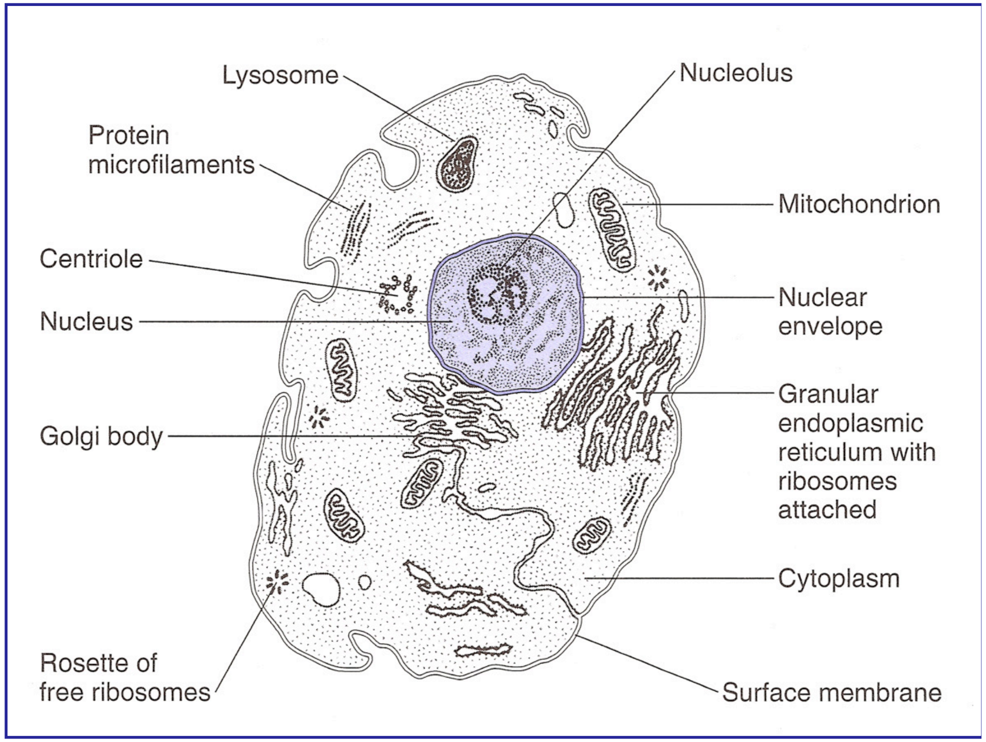
The border allows for selective exchanges
In terrestrial life the border is a biological membrane

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

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