What is Life?

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Extending our Concepts of Life

- Origins on Earth
  - What environments and evolutionary paths allowed the key components of living system(s) to develop?
  - What evolutionary paths led to the array of attributes shared by all modern organisms?
- Determinism
  - Do “nurturing” environments usually lead to life?
  - To what extent do physical and chemical factors cause life elsewhere to resemble our own?
- Diversity
  - Does Earth’s biosphere represent a subset of the (much greater?) diversity of life in the universe?
  - What are the ultimate environmental limits of life?

So what is life, anyway?

(T. Hoehler)

Some Commonly Cited Attributes:

- Capable of reproducing itself
- Can carry out chemical reactions and synthesis
- Can harness energy from the environment to drive these chemical processes
- Capable of Darwinian evolution (mutation and natural selection)

A Definition of Life

Life is the harnessing of free energy
to sustain and perpetuate,
by molecular replication and evolution,
a high density of information
in the form of complex molecules
and functionally-related larger structures

The Factory Analogy for Life

(Tori Hoehler)

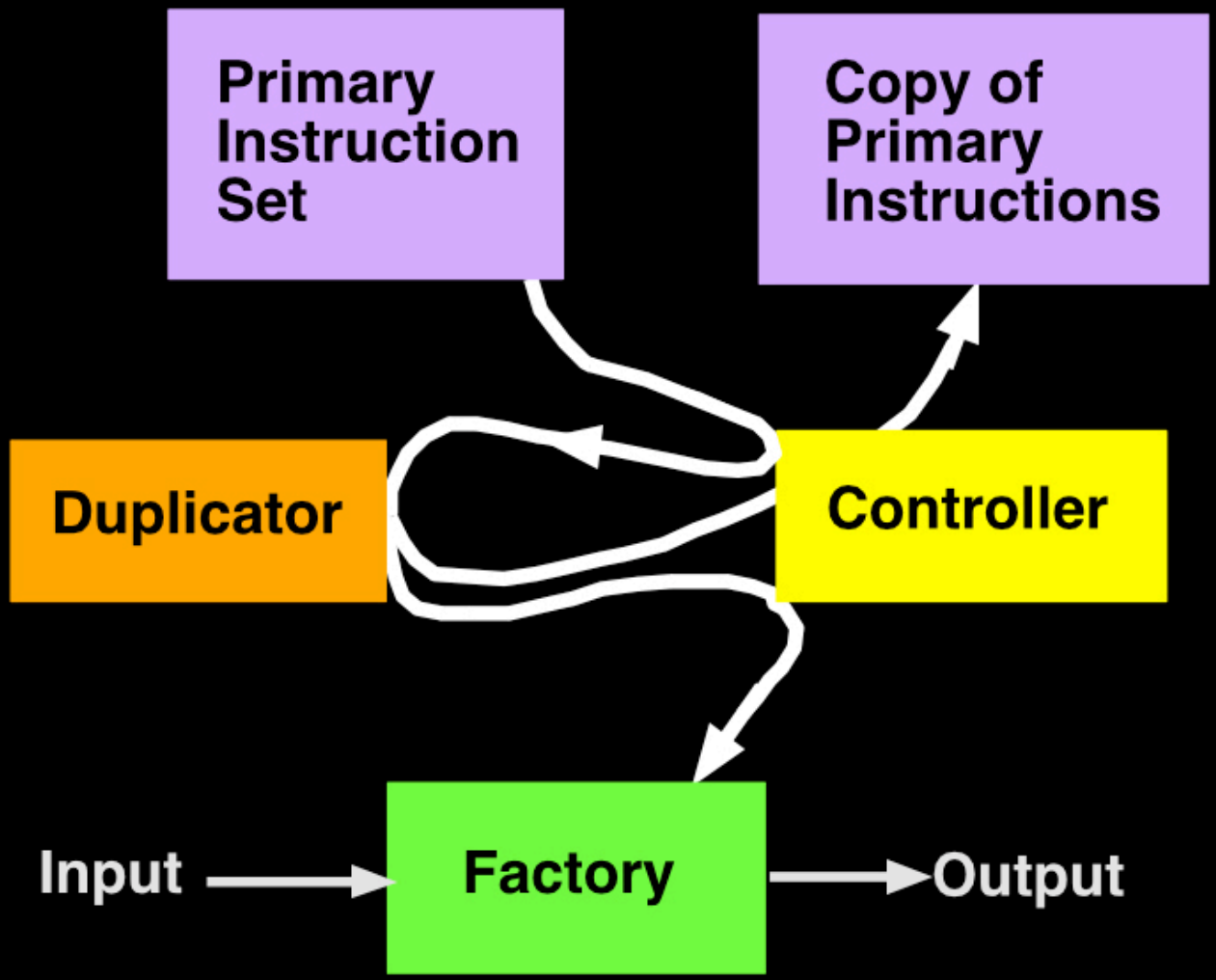
(cells are little factories that make more little factories)

To build a new factory, we require:

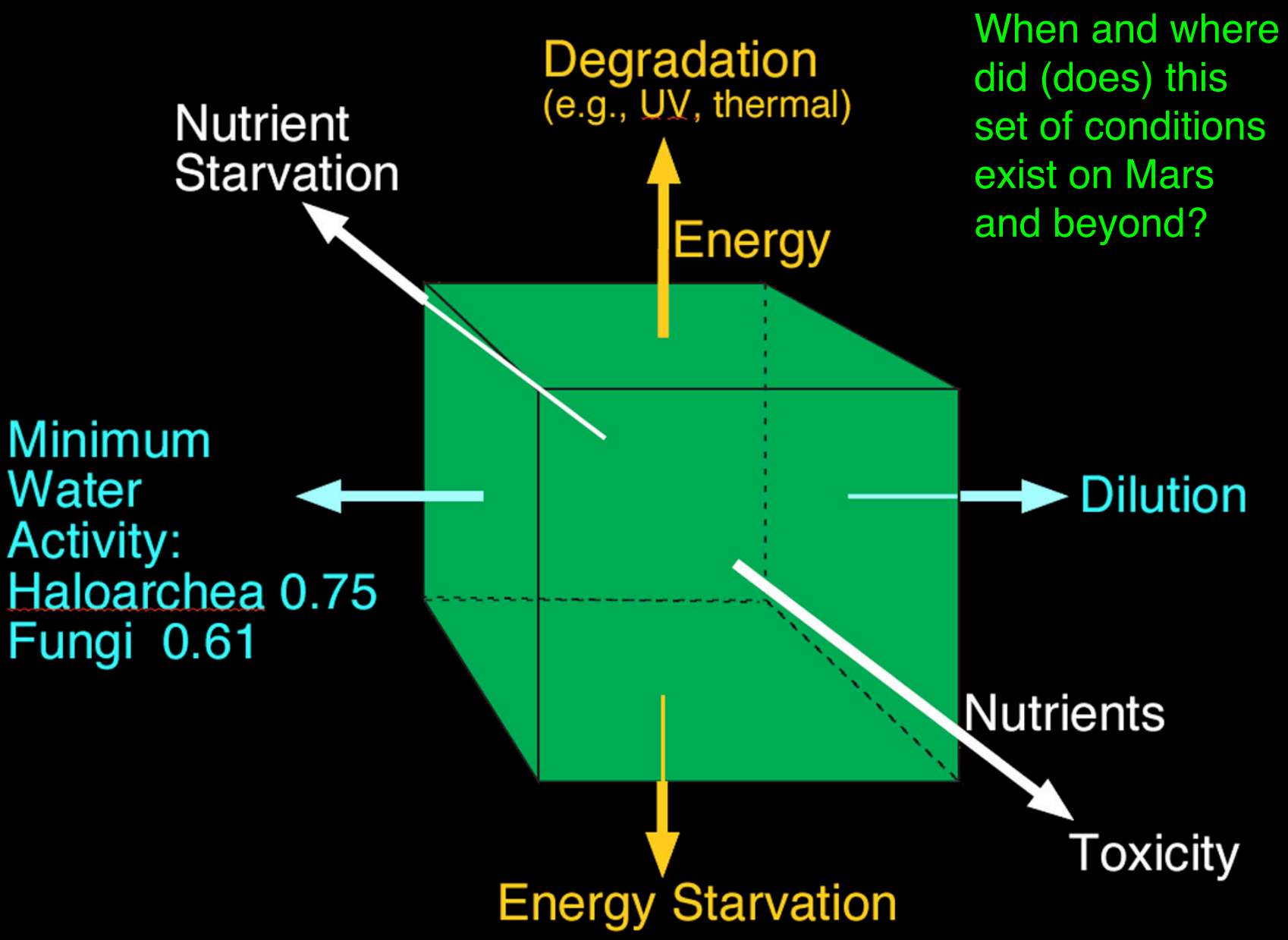
- Raw Materials
- Energy & Work
- A Blueprint
- Tools & Machinery

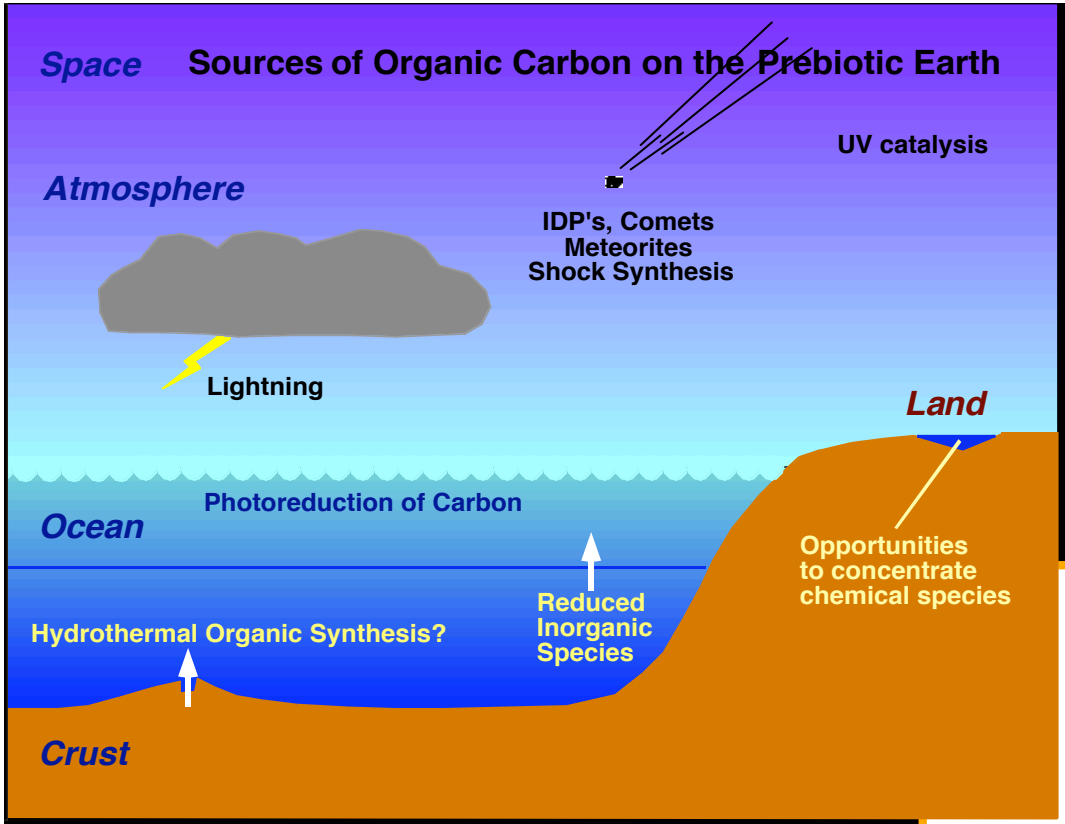
Life Requirements: Chemical Stuff, Energy, Conditions Appropriate for Complex Molecules, Solvent for Chemistry

John Von Neuman's Automaton



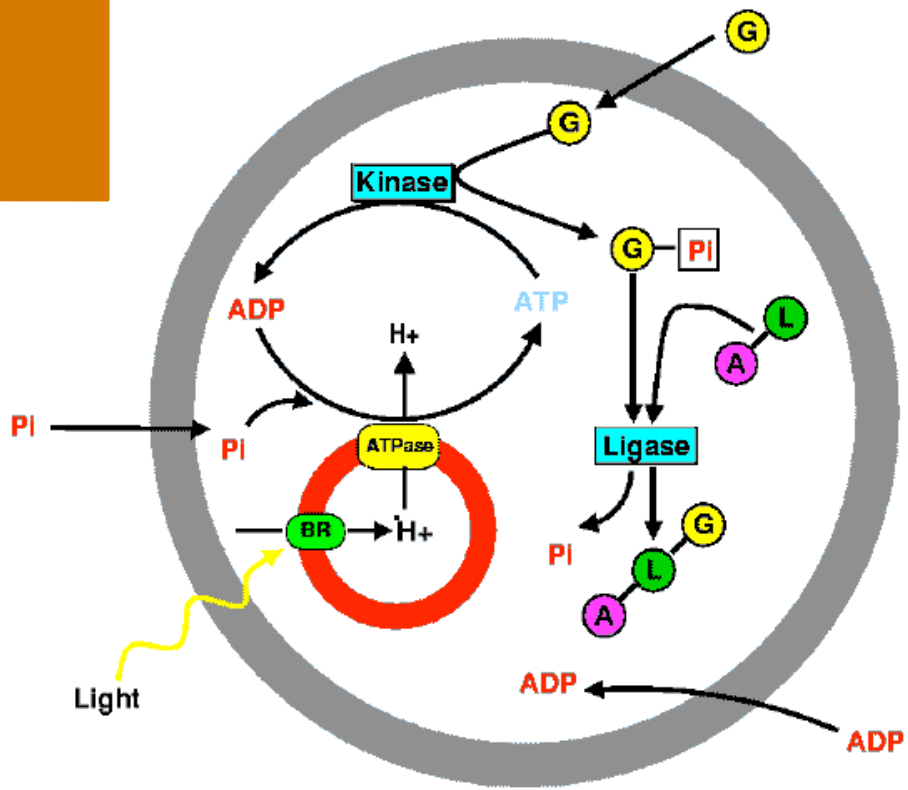
Range of Conditions that Sustains Life



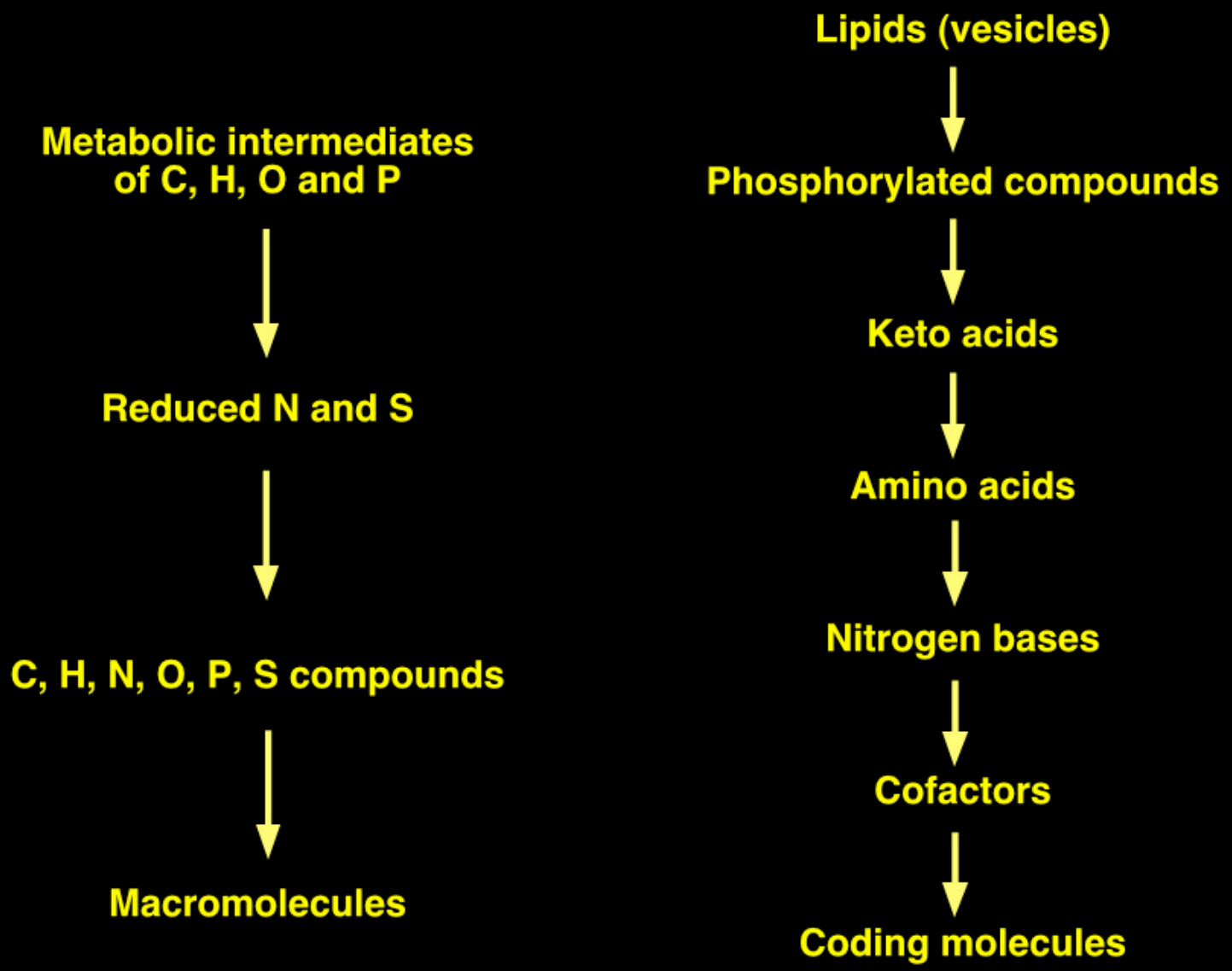


Knowledge of the actual prebiotic environment is essential to constrain the possibilities presented by physics and chemistry

Protocells: Development of critical subsystems and their "final assembly" into integrated living systems



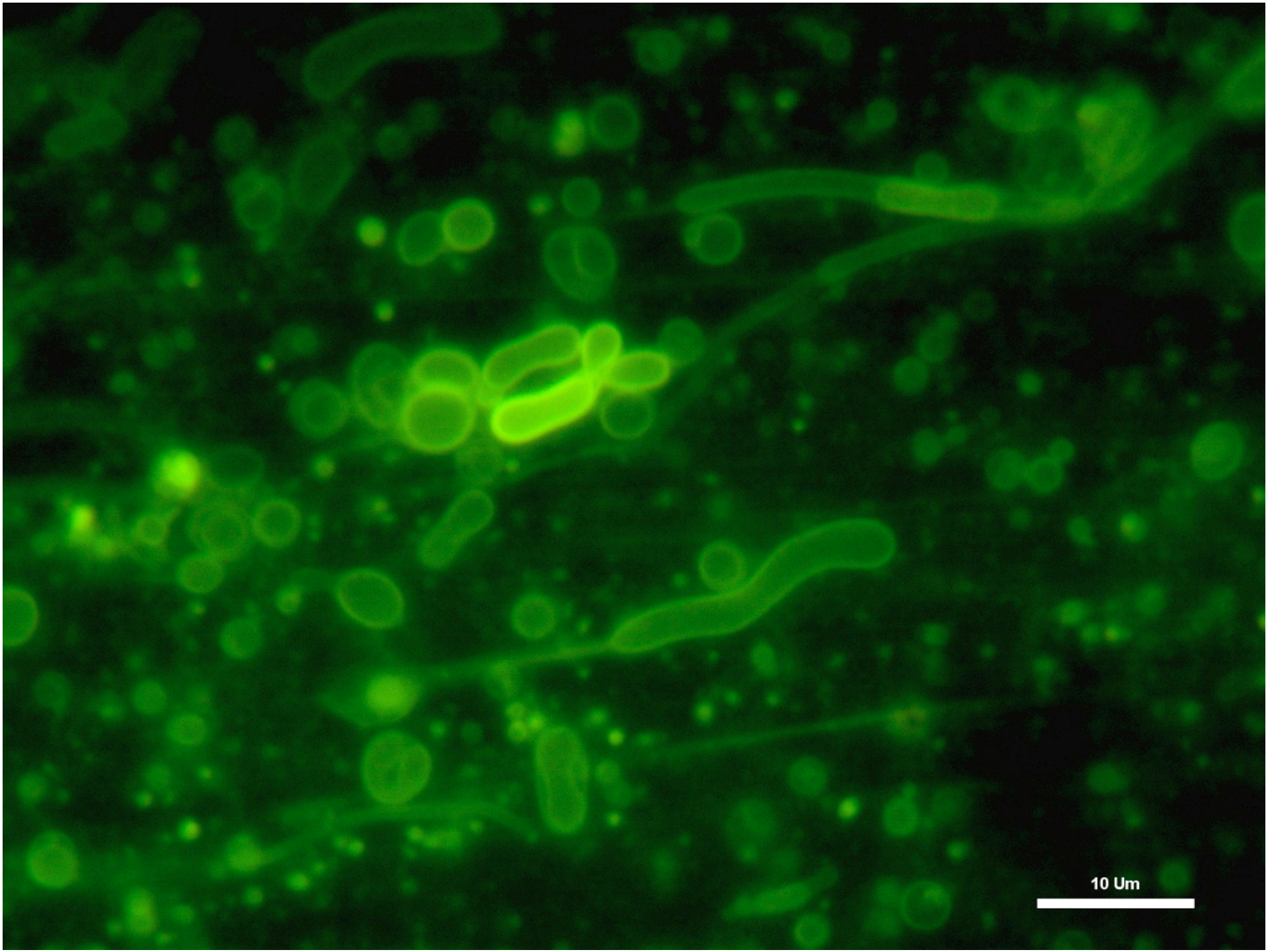
Metabolism Recapitulates Biogenesis



Continuity Principle

H. Morowitz

For any postulated stage in biogenesis, there must be a continuous path backward to the prebiotic state of the Earth and forward to modern organisms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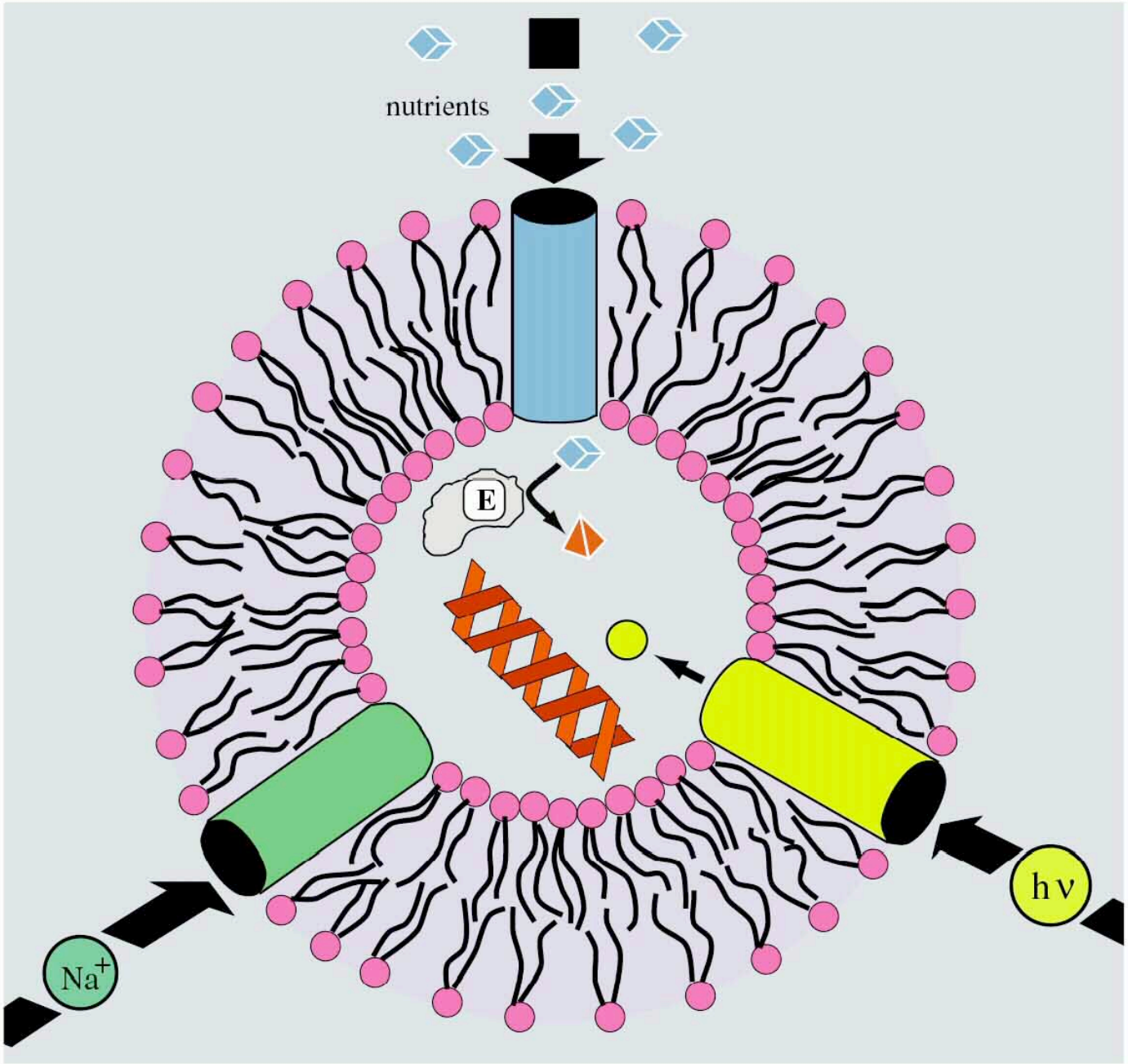
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Na+
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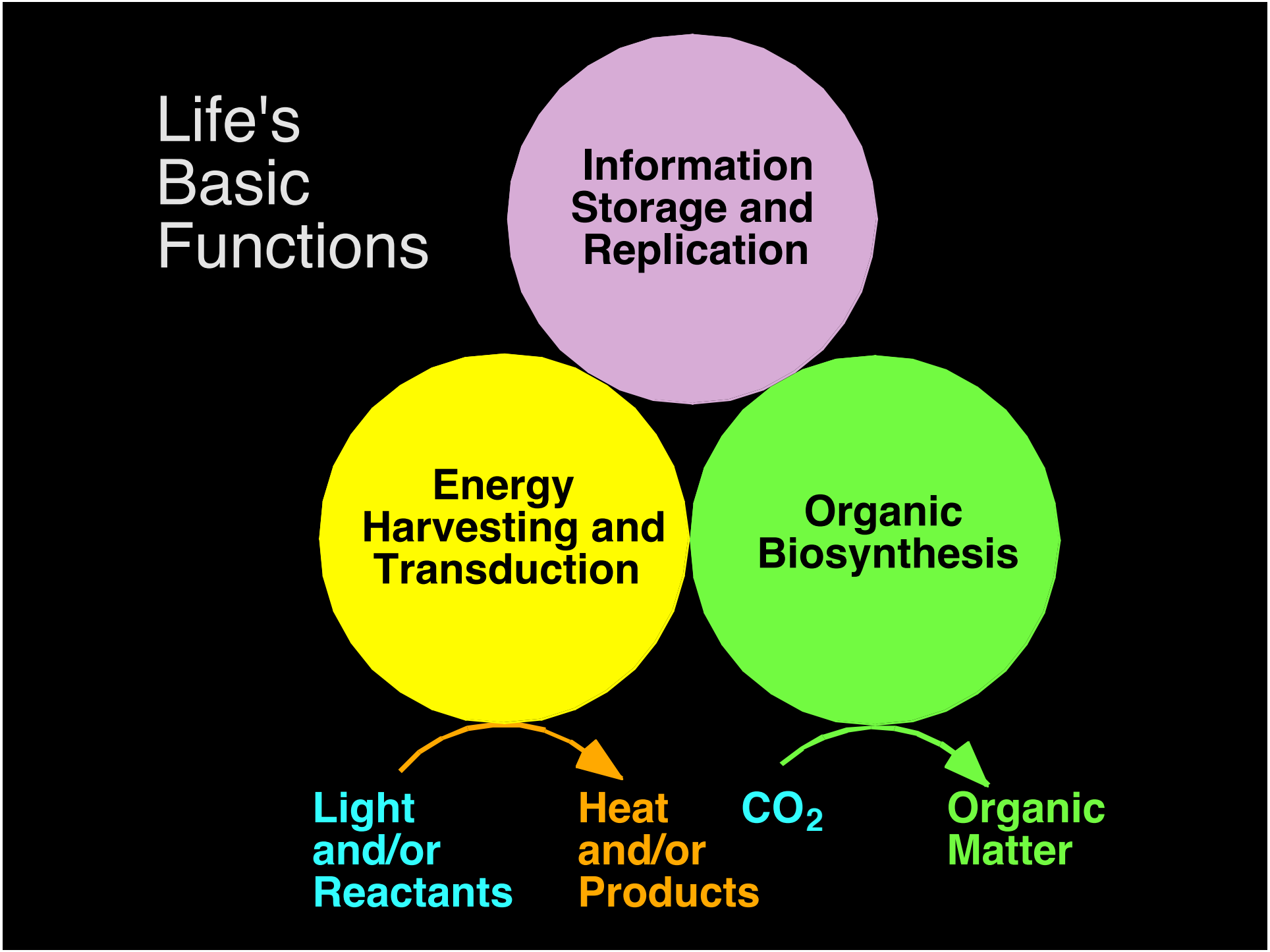
Life's Basic Functions

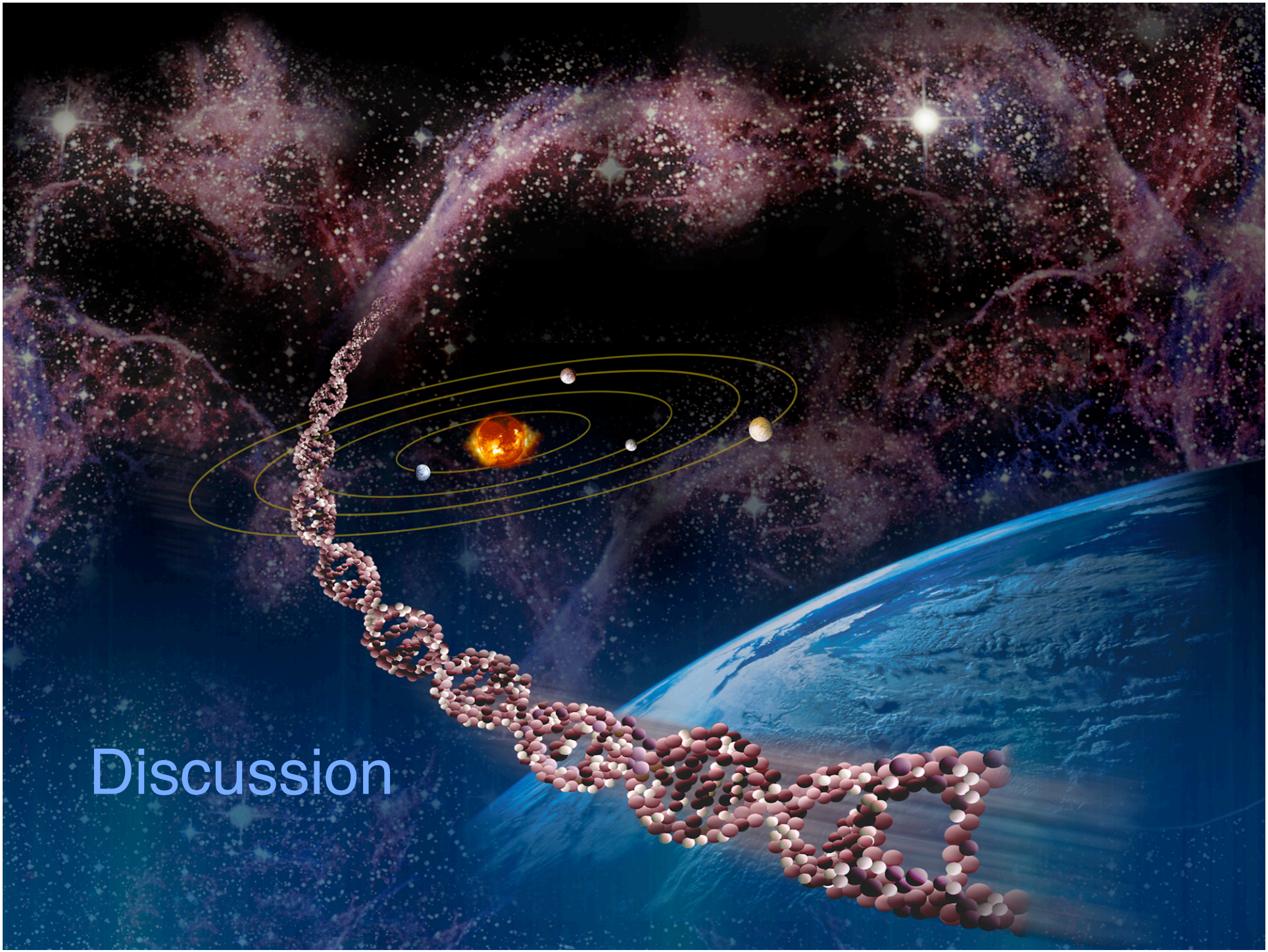


Requirements for (our) Life

(Tori Hoehler)

- Source of Energy
- Source of Carbon
- Source of Electrons
- Water
- Nutrients

Microbiologists classify organisms based on how they fulfill these needs


Discussion

End

Features of All Living Systems on Earth

- Cellularity: To define and retain cytoplasm content
- Cells require between 50 & 90 wt. % water to function
- Covalently-bonded C, H, O, N & P compounds dominate, but trace elements (e.g., transition metals) crucial
- Small number of molecules that, as a set, universally comprise most of cell mass
- Most of cell mass consists of carbohydrates, lipids, nucleic acids and proteins
- Energy flow involves formation or hydrolysis of phosphate bonds, usually ATP

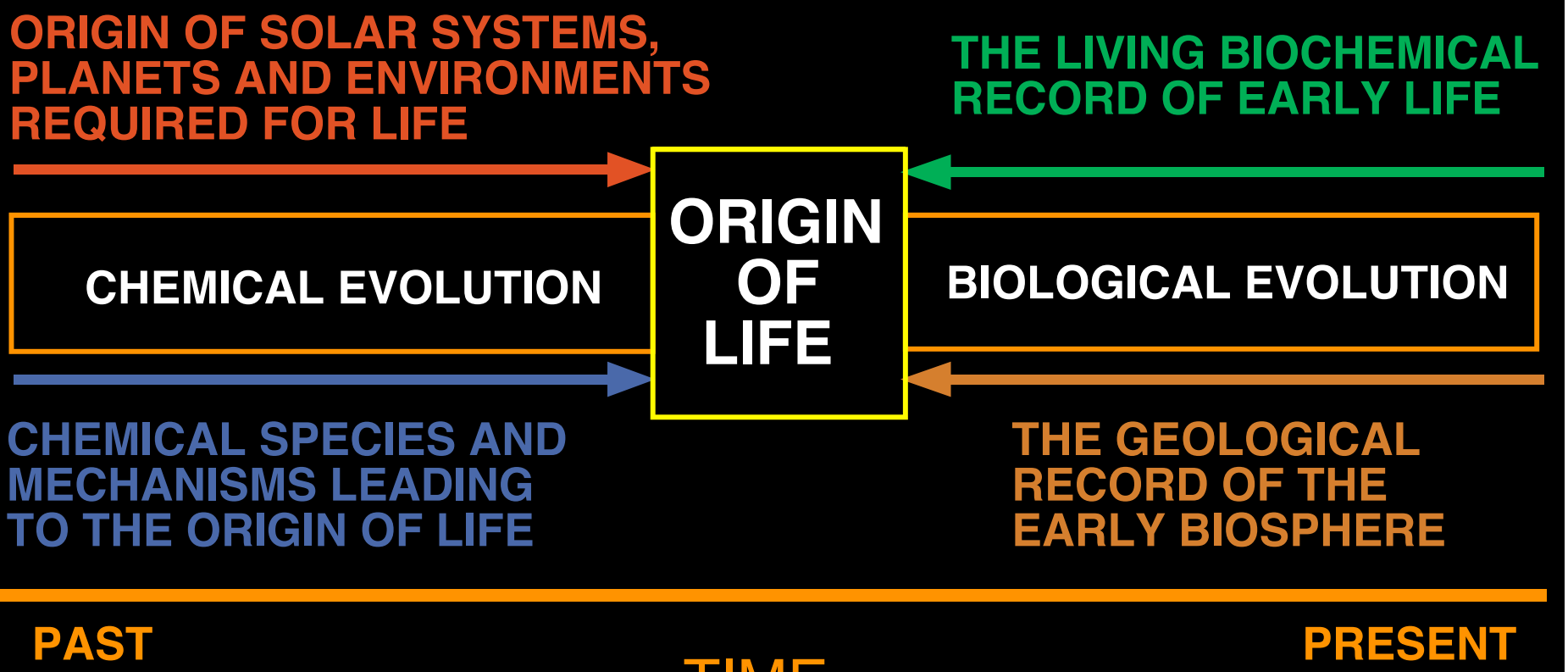
Features of All Living Systems on Earth

- Universal core network of biochemical reactions: intermediary metabolism (glycolysis, TCA cycle, etc.)
- Biochemical information is structural, not dynamic (e.g., cells taken to 0 K can recover completely
- Sustained life is the property of an ecosystem, rather than an individual cell or species
- Universal lipid bilayer structure; cell walls optional
- In replication, info. flows from DNA to RNA to proteins
- Other universal key molecules in replication include ribozymes, t-RNAs and activating enzymes
- Reactions with appreciable rates are enzyme-catalyzed

Any modern examples of a “minimal, primitive” cell?

- One of the least complex cells: Mycoplasmatales
  - Cell sizes as small as 0.3 mm
  - Genome size: ~1000 kilobases (550 proteins maximum)
  - BUT requires a complex organic medium
    - e.g., nucleotides, amino acids, fatty acids, coenzymes
    - requires a host
- Cells with minimal nutrient requirements: Cyanobacteria
  - Need only common salts found in seawater
  - BUT is a complex organism!
    - genome size: >10,000 kilobases
    - complex photosynthesis, environmental adaptations, etc.
- Cell, ecology and environment must be considered
- All modern examples of life are highly evolved

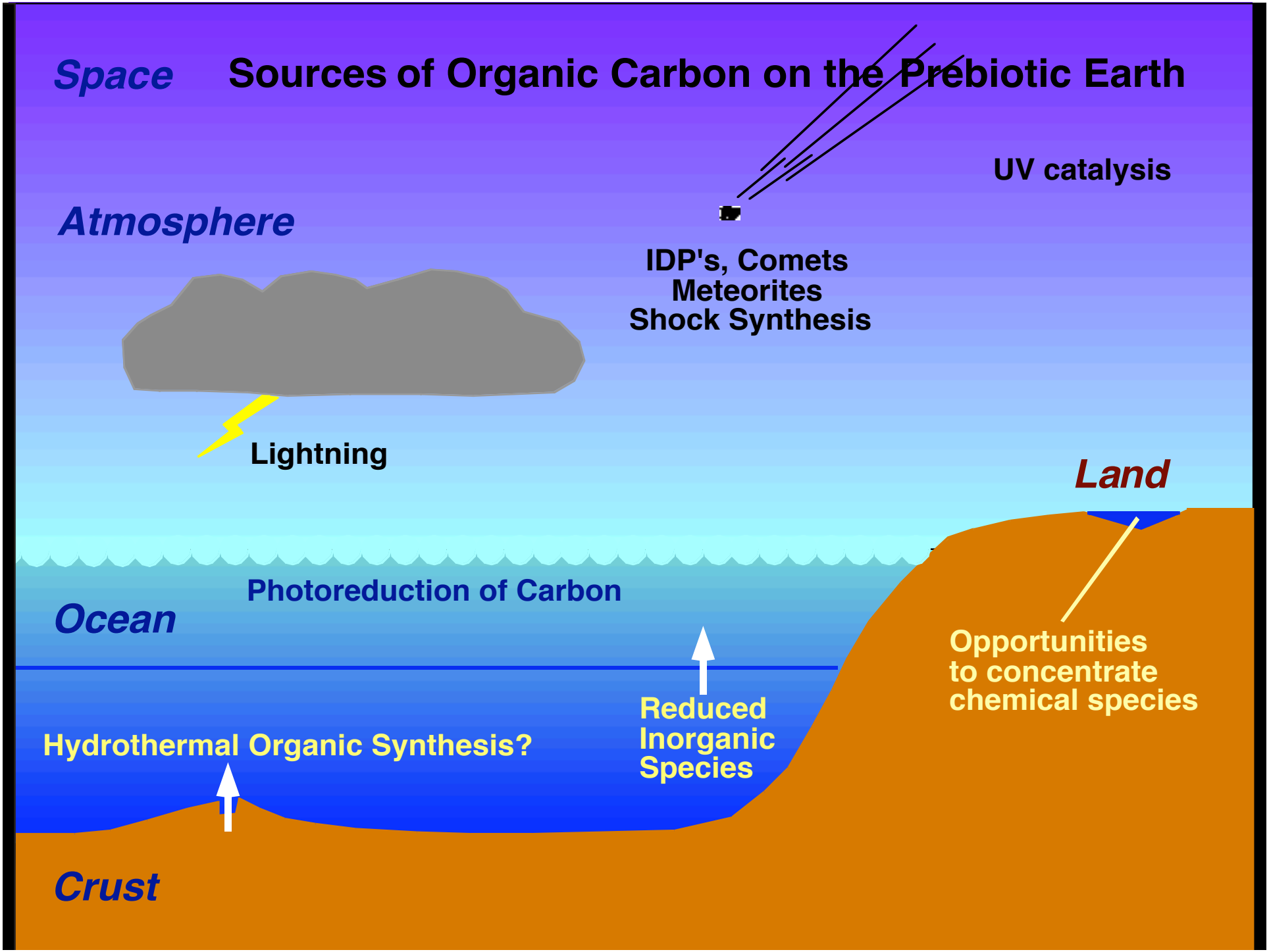
Four Approaches To Understanding the Origins of Life



Des Marais, Ames Research Center

Another Definition of Life

Life is a system
of information-rich molecules
and functionally-related larger structures
that harnesses free energy
to extend its existence
by molecular replication and evolution


Space
Sources of Organic Carbon on the Prebiotic Earth
UV catalysis
Atmosphere
IDP's, Comets
Meteorites
Shock Synthesis
Lightning
Land
Photoreduction of Carbon
Ocean
Opportunities
to concentrate
chemical species
Reduced
Inorganic
Species
Hydrothermal Organic Synthesis?
Crust