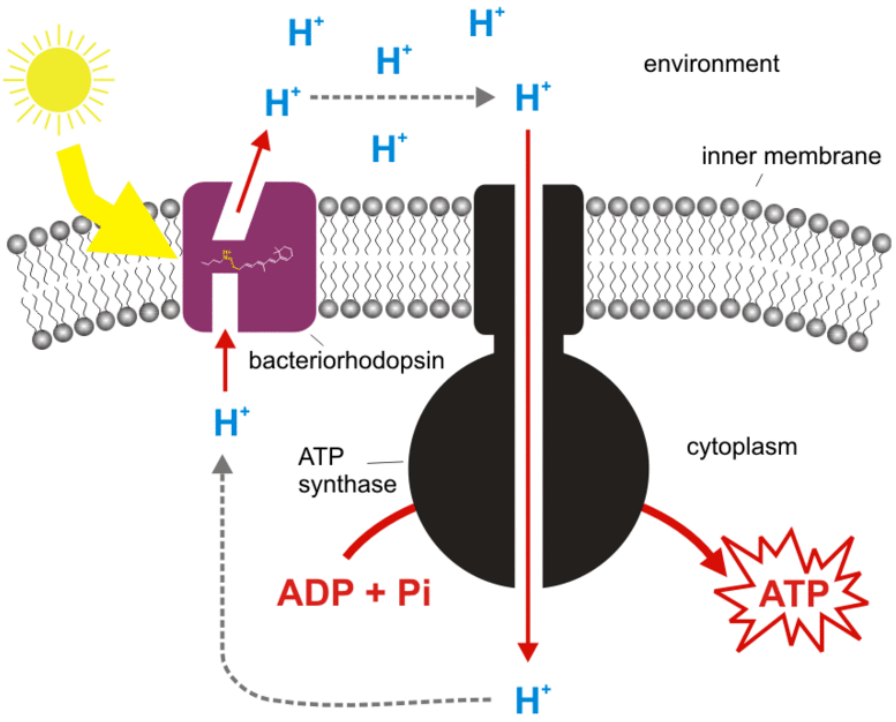
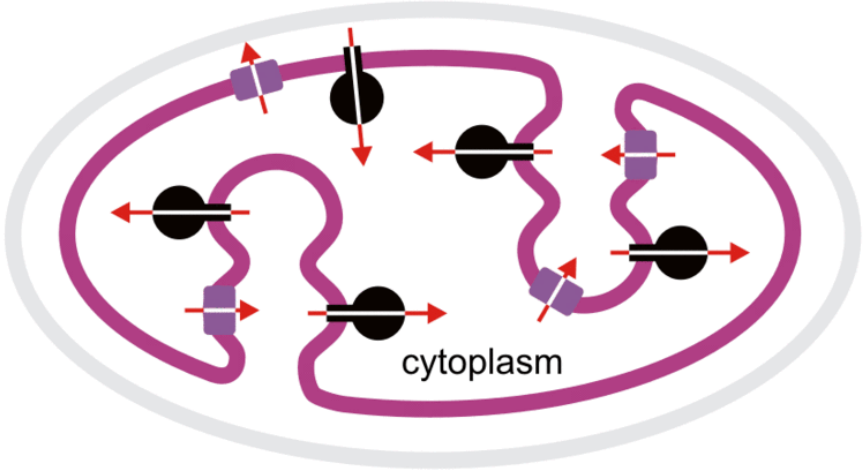
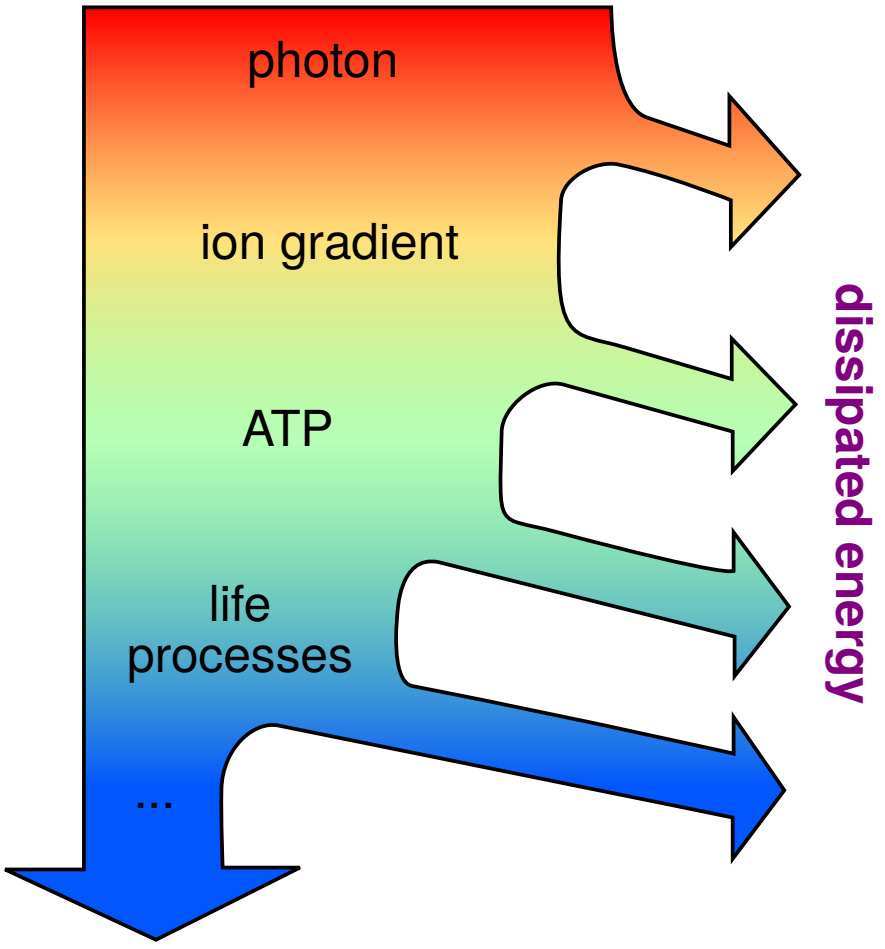
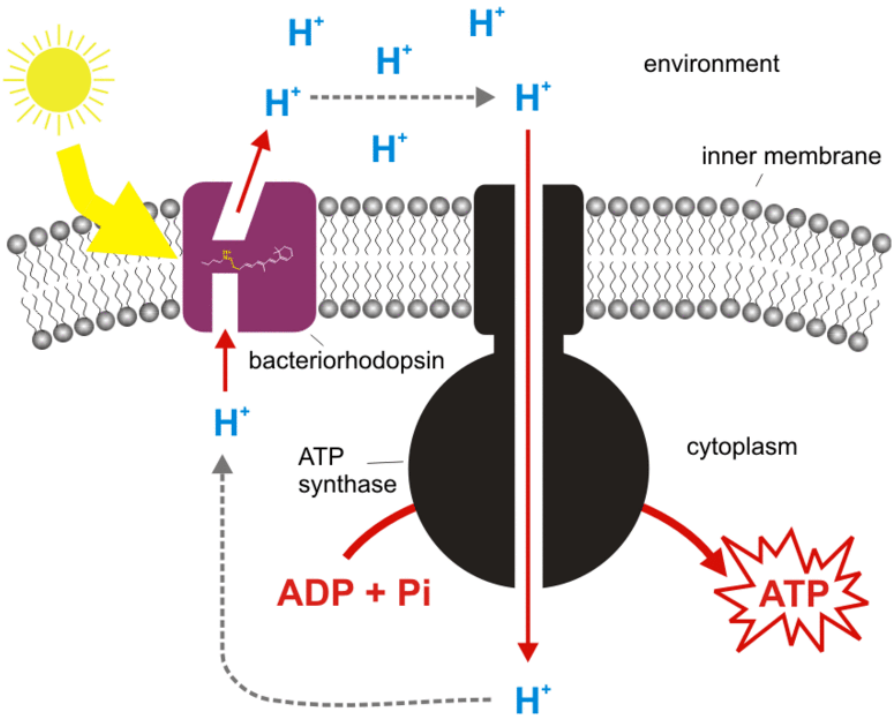
Life: cascades of energy conversion and dissipation

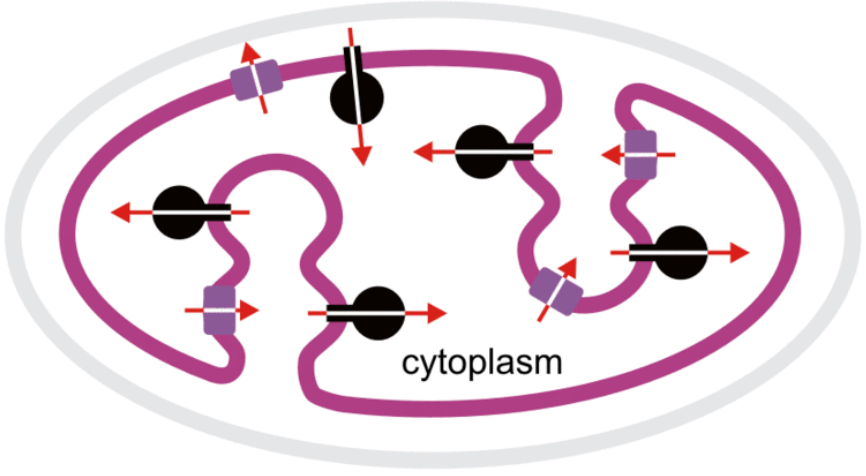


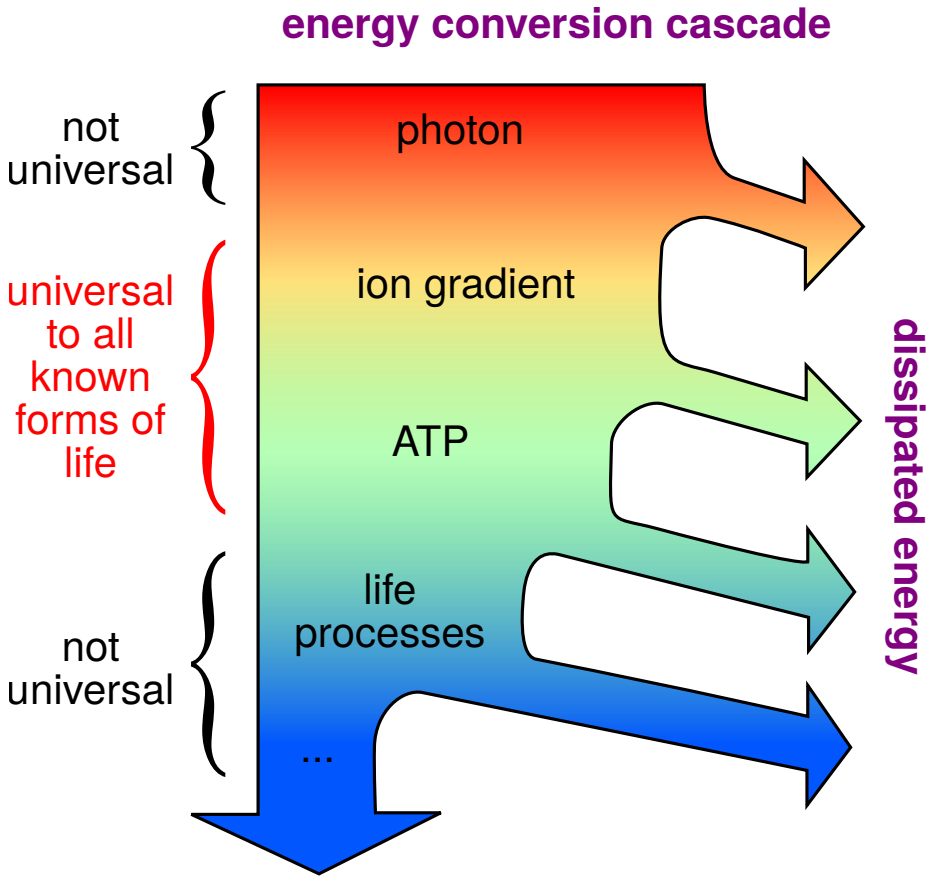




Life: cascades of energy conversion and dissipation



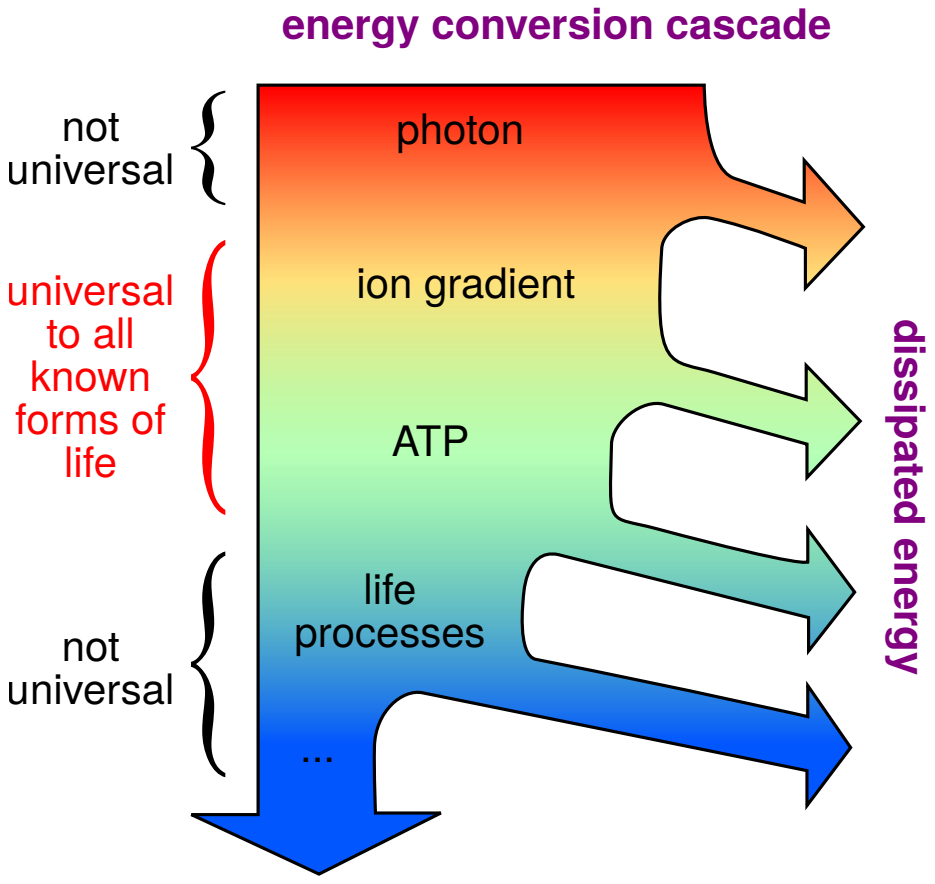




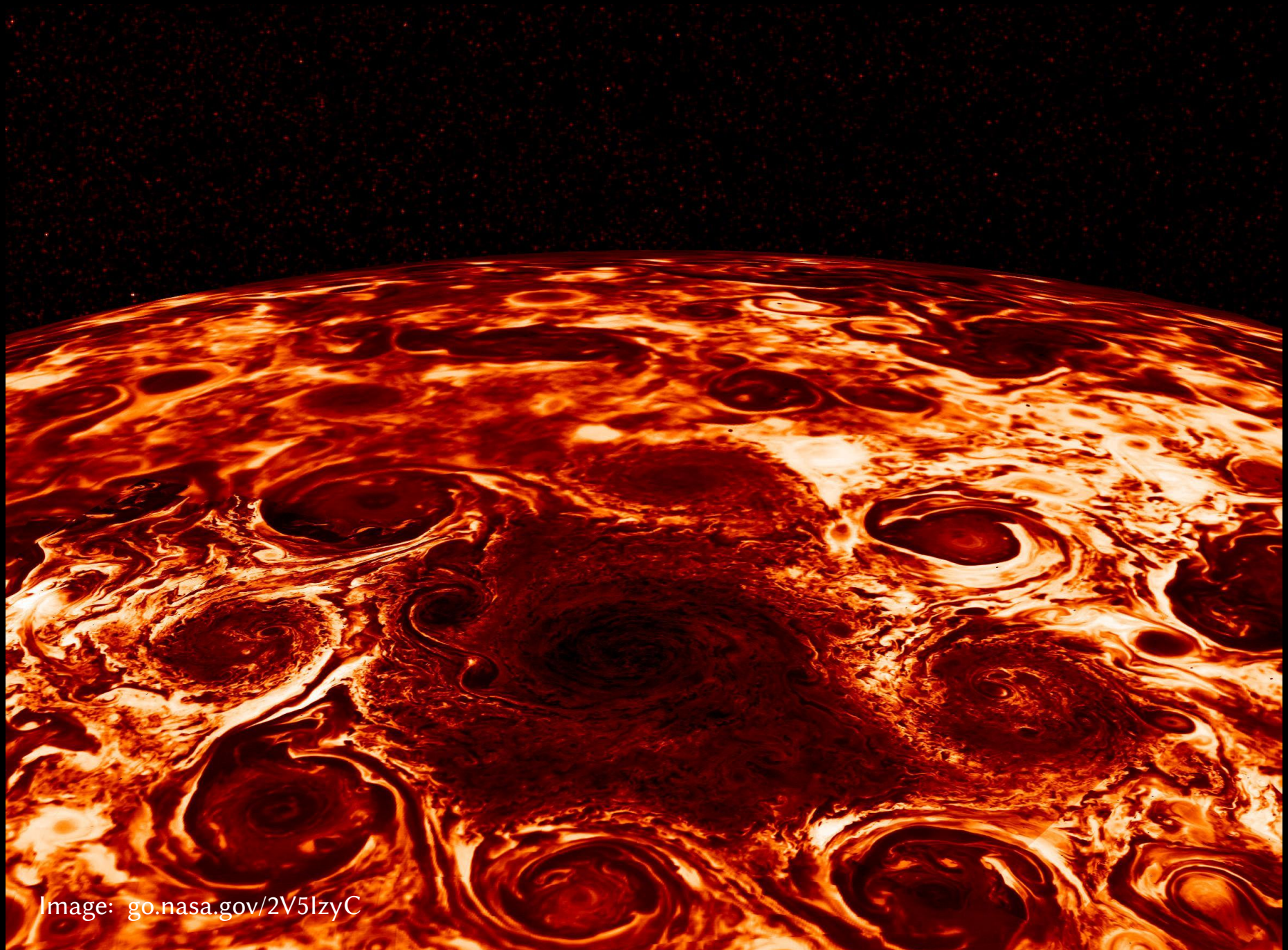
Life: cascades of energy conversion and dissipation

"Such is life... an inserting itself, a drawing off to its advantage, a parasitizing of the downward course of energy, from its noble solar form to the degraded one of low- temperature heat. In this downward course, which leads to equilibrium and thus death, life draws a bend and nests in it."

–Primo Levi, "Carbon"
(hat tip: Robin Snyder)



Other persistent nonequilibrium systems



Other persistent nonequilibrium systems

Big whorls have little whorls
Which feed on their velocity,
And little whorls have lesser whorls
And so on to viscosity.

- L.F. Richardson

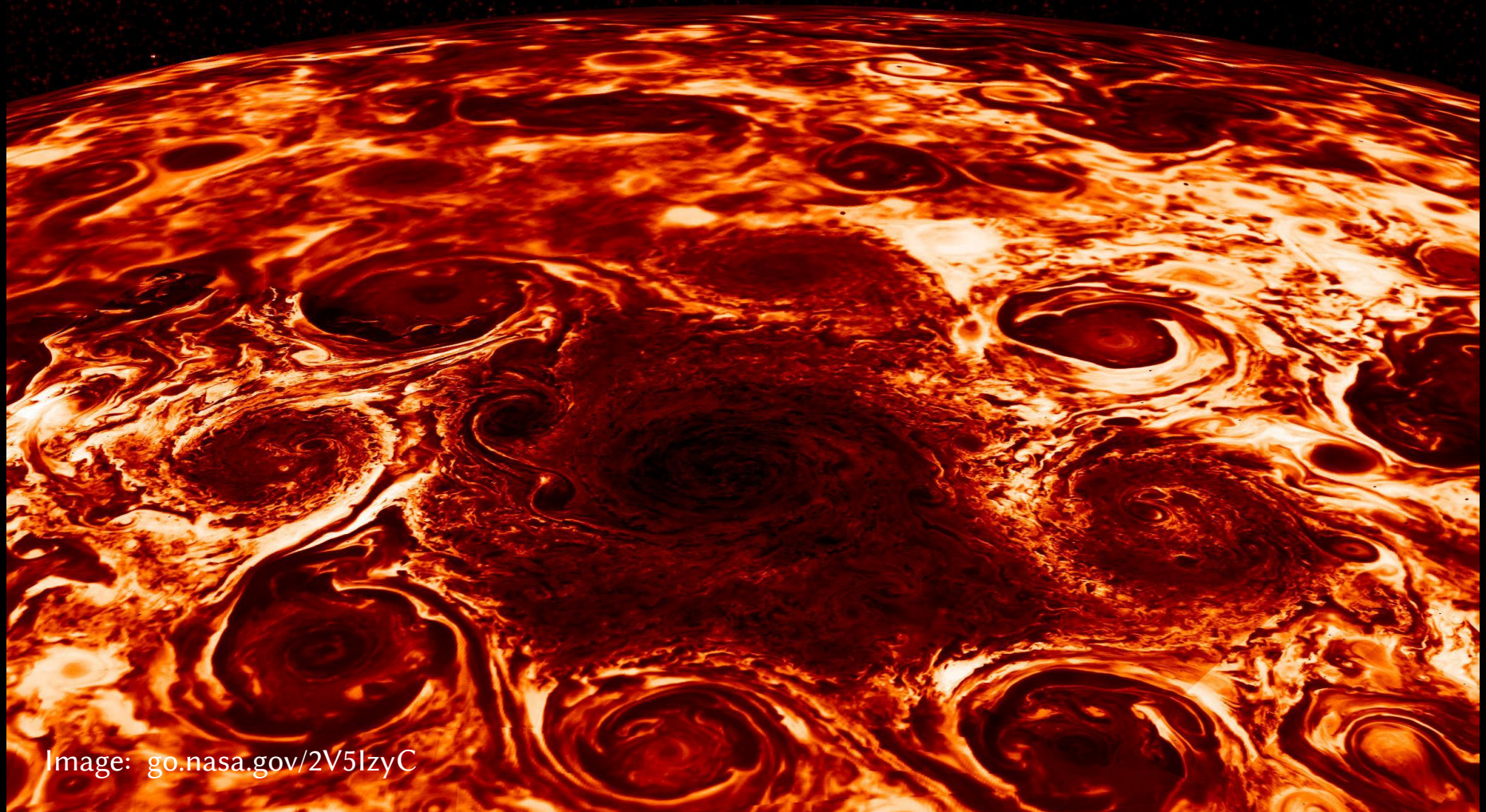
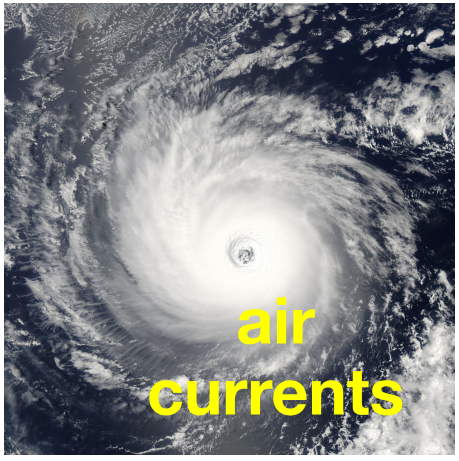
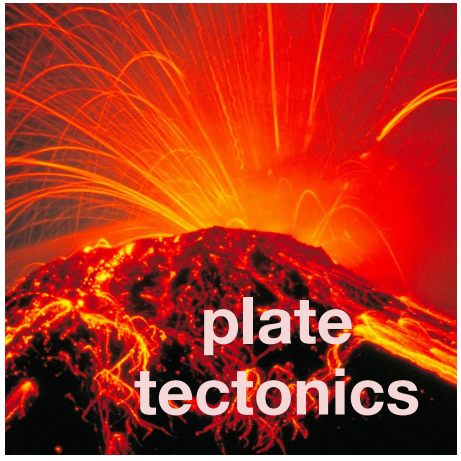


Image: go.nasa.gov/2V5IzyC

Thermodynamics and the origin of life

All nonequilibrium processes on earth:





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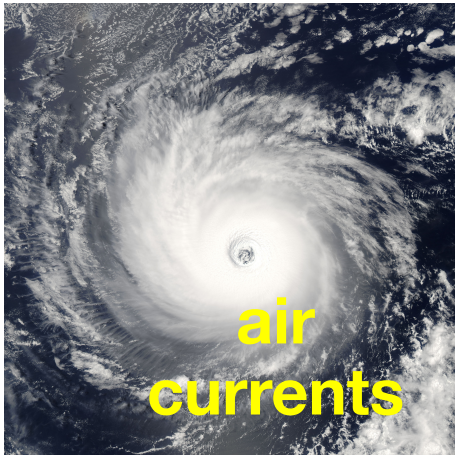
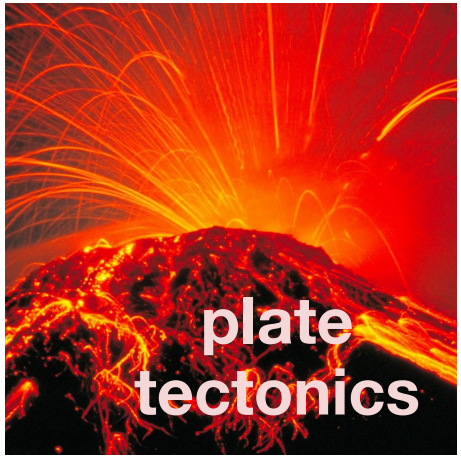
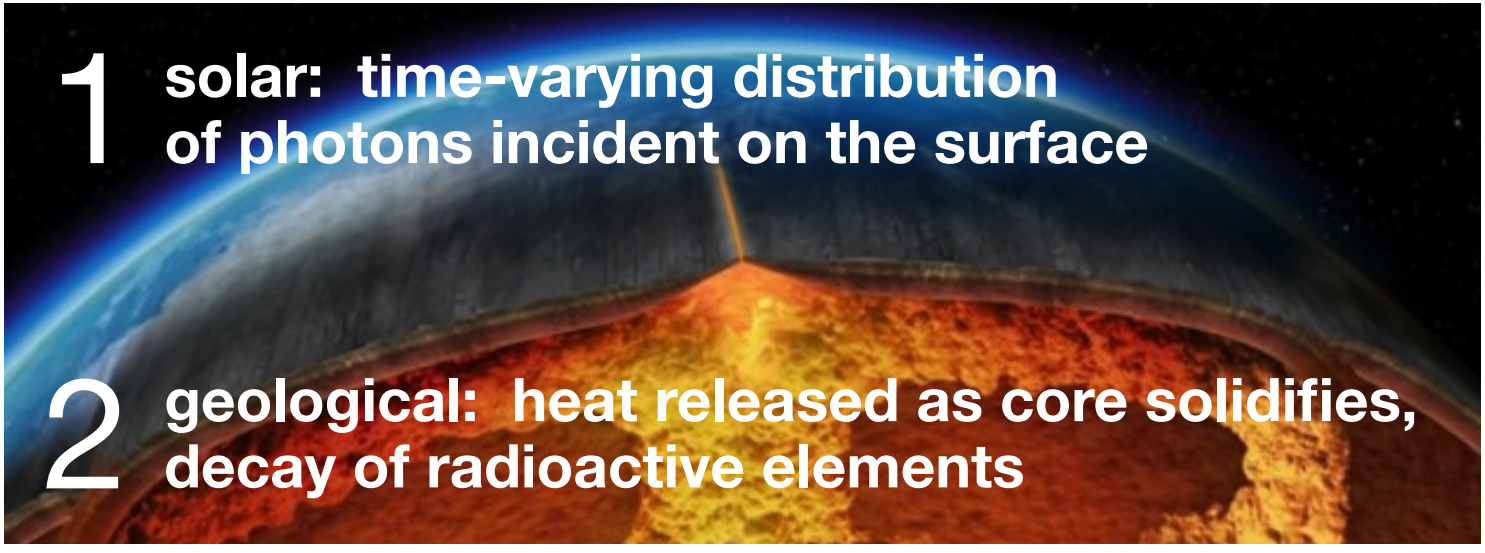


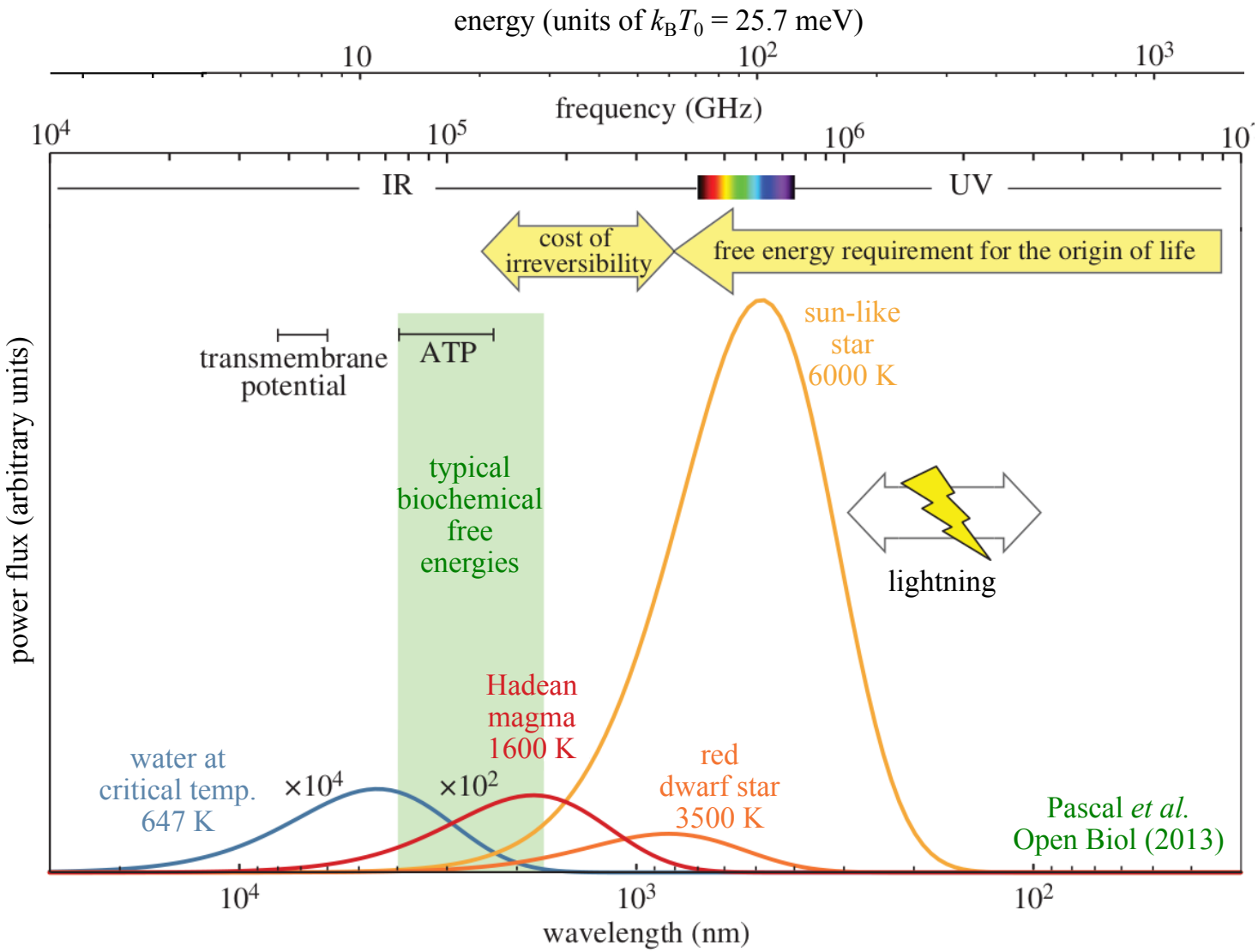


are ultimately “plugged into” two major imbalances:



Thermodynamics and the origin of life

nonequilibrium stationary state: $\dot{W} = P_{\text{in}} - P_{\text{out}} = T\dot{I} \equiv P_{\text{diss}}$



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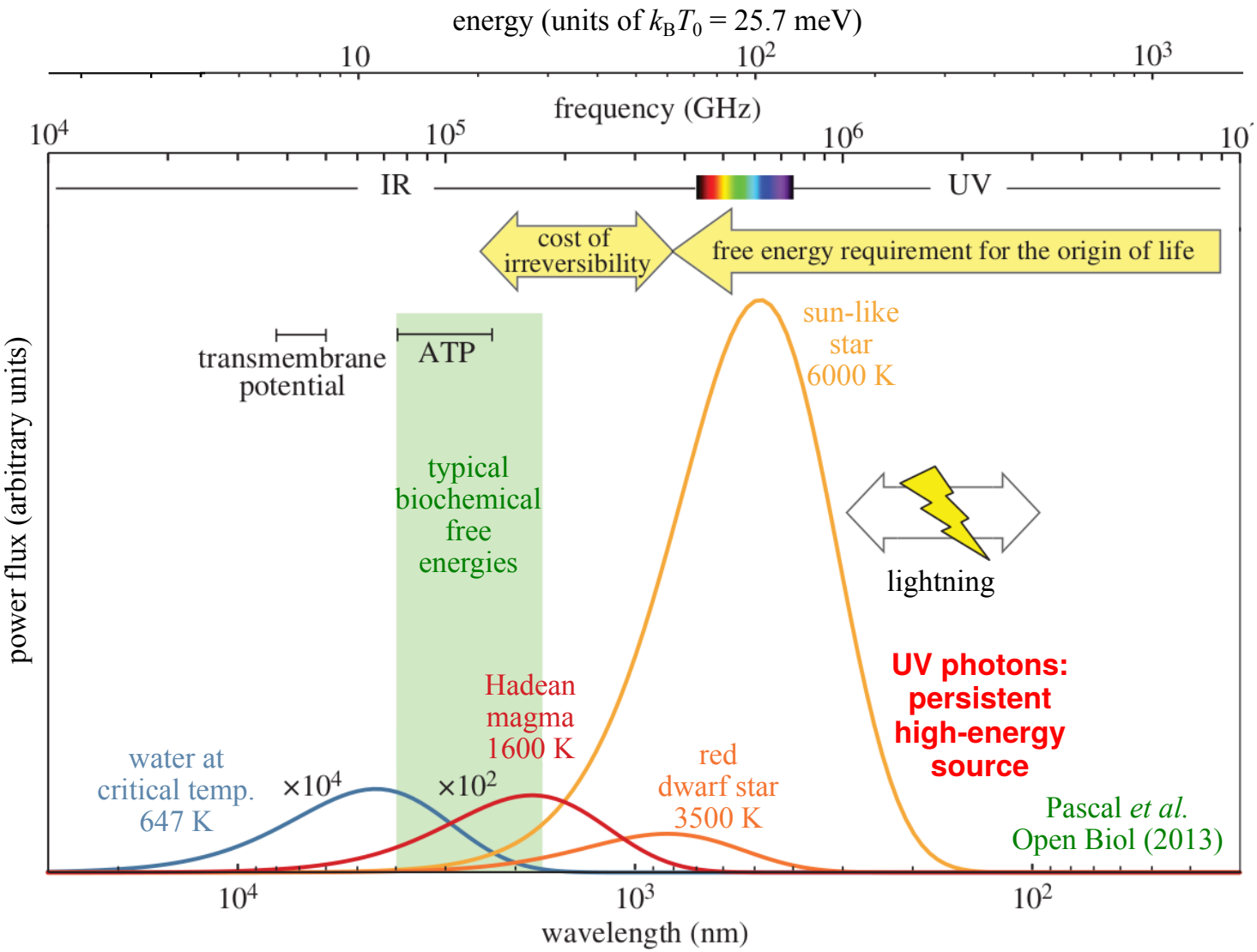
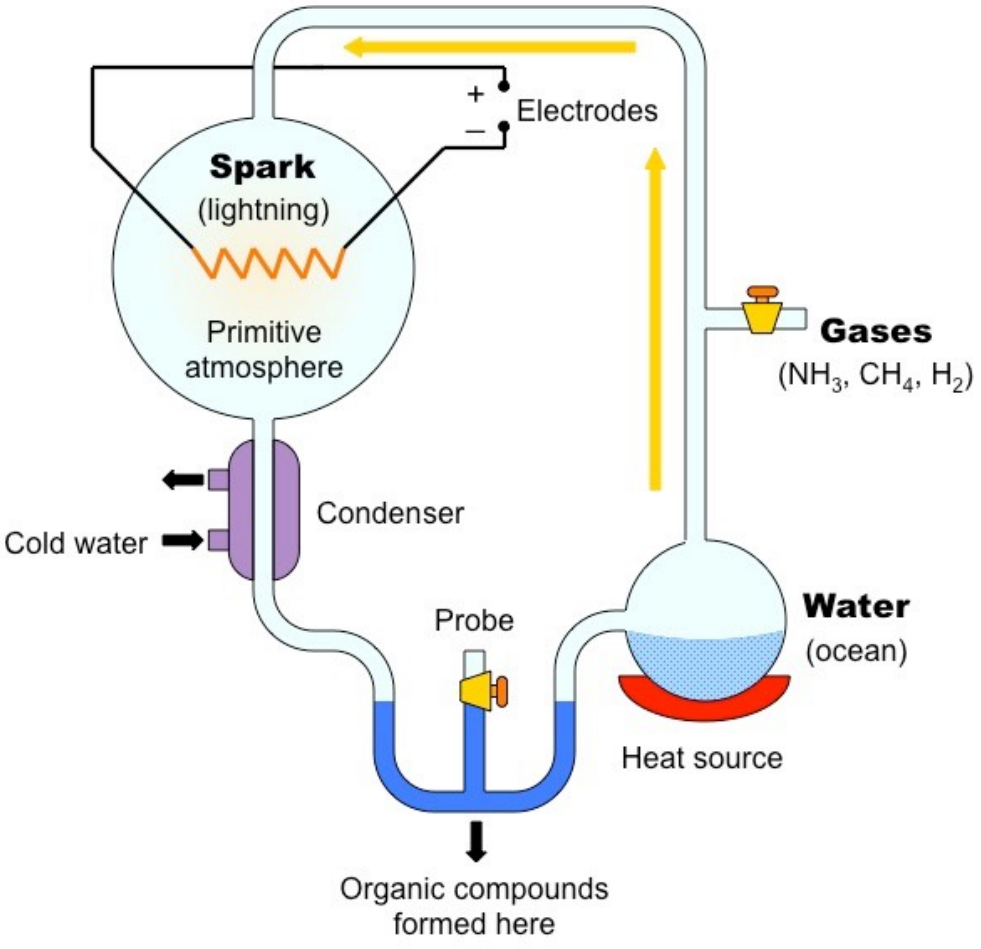
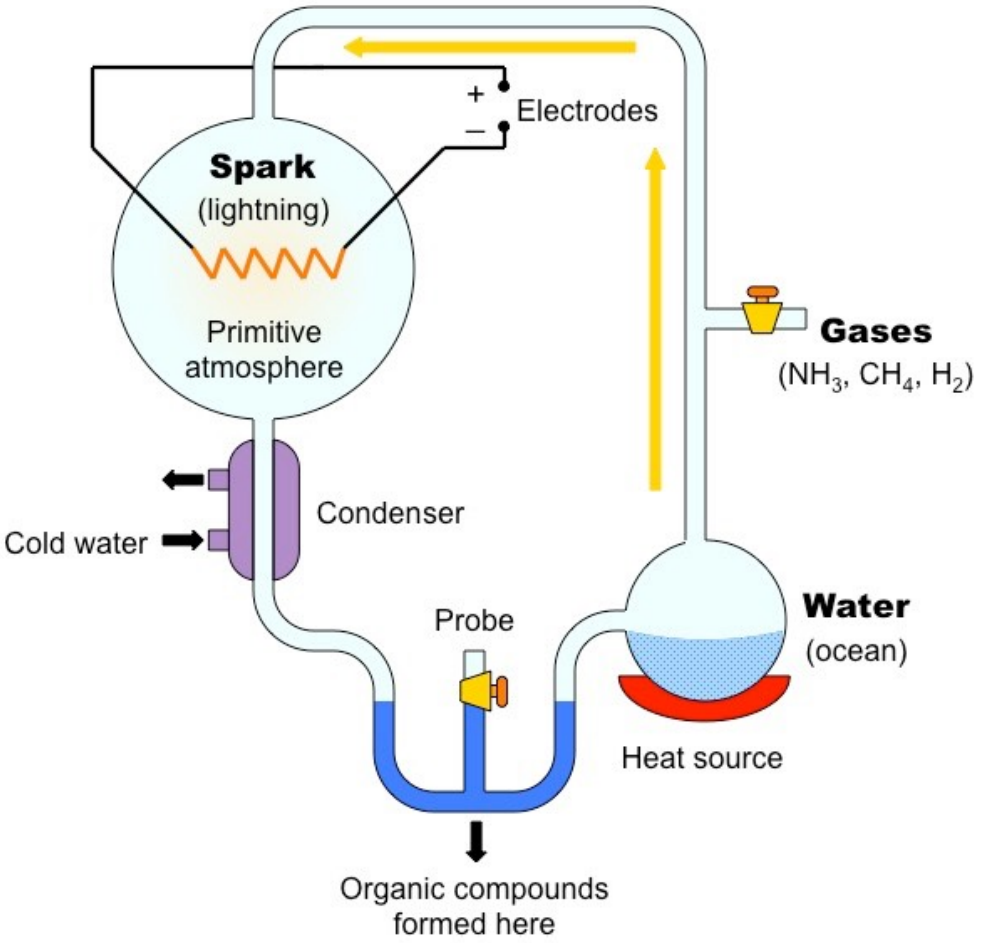


Primordial soup: Miller-Urey experiment (1952)



Classic experiment synthesizing amino acids (**protein** building blocks) in a simple atmosphere using an influx of free energy (electrical spark = “lightning”).

Primordial soup: Miller-Urey experiment (1952)



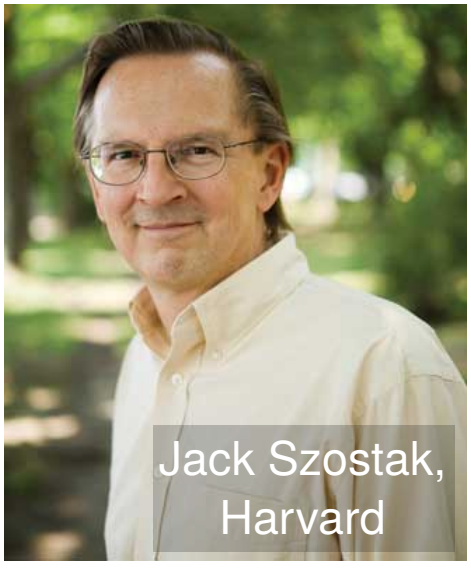
Classic experiment synthesizing amino acids (**protein** building blocks) in a simple atmosphere using an influx of free energy (electrical spark = “lightning”).

Life also requires:

- **genetic material:** DNA/RNA nucleotides
- **containers:** lipids for membranes
- **metabolism:** ATP, etc.

Which came first?

Recent landmarks in prebiotic chemistry



2003: Clay can catalyze both the formation of lipid vesicles (**containers**) and RNA strands (**genetic material**) from “activated” (chemically modified) bases (A,U,C,G).

Where do you get the precursors (bases + lipids)?

Recent landmarks in prebiotic chemistry


John Sutherland, Cambridge

2009: Activated bases can be synthesized from plausible prebiotic materials.

Vol 459|14 May 2009|doi:10.1038/nature08013 nature

LETTERS

Synthesis of activated pyrimidine ribonucleotides in prebiotically plausible conditions

Matthew W. Powner[1], Béatrice Gerland[1] & John D. Sutherland[1]

At some stage in the origin of life, an informational polymer must have arisen by purely chemical means. According to one version of the 'RNA world' hypothesis[1–3] this polymer was RNA, but attempts to provide experimental support for this have failed[4,5]. In particular, although there has been some success demonstrating that 'activated' ribonucleotides can polymerize to form RNA[6,7], it is far from obvious how such ribonucleotides could have formed from their constituent parts (ribose and nucleobases). Ribose is difficult

we have discovered a short, highly efficient route to activated pyrimidine ribonucleotides from these same precursors that proceeds by way of alternative intermediates (Fig. 1, green arrows). By contrast with previously investigated routes to ribonucleotides, ours bypasses ribose and the free pyrimidine nucleobases. Mixed nitrogenous–oxygenous chemistry first results in the reaction of cyanamide **8** and glycolaldehyde **10**, giving 2-amino-oxazole **11**, and this heterocycle then adds to glyceraldehyde **9** to give the pentose amino-oxazolines including the

Recent landmarks in prebiotic chemistry


John Sutherland,
Cambridge

2015: Potentially resolved the **chicken vs. egg** problem:

Recent landmarks in prebiotic chemistry


John Sutherland, Cambridge

2015: Potentially resolved the **chicken vs. egg** problem: the answer is **both!**

Lipids, amino acids, and RNA bases can all be derived from a common chemistry based on HCN, H_2S, and **UV light**.

nature chemistry

ARTICLES

PUBLISHED ONLINE: 16 MARCH 2015 | DOI: 10.1038/NCHEM.2202

Common origins of RNA, protein and lipid precursors in a cyanosulfidic protometabolism

Bhavesh H. Patel, Claudia Percivalle, Dougal J. Ritson, Colm D. Duffy and John D. Sutherland*

A minimal cell can be thought of as comprising informational, compartment-forming and metabolic subsystems. To imagine the abiotic assembly of such an overall system, however, places great demands on hypothetical prebiotic chemistry. The perceived differences and incompatibilities between these subsystems have led to the widely held assumption that one or other subsystem must have preceded the others. Here we experimentally investigate the validity of this assumption by examining the assembly of various biomolecular building blocks from prebiotically plausible intermediates and one-carbon feedstock molecules. We show that precursors of ribonucleotides, amino acids and lipids can all be derived by the reductive homologation of hydrogen cyanide and some of its derivatives, and thus that all the cellular subsystems could have arisen simultaneously through common chemistry. The key reaction steps are driven by ultraviolet light, use hydrogen sulfide as the reductant and can be accelerated by Cu(I)–Cu(II) photoredox cycling.

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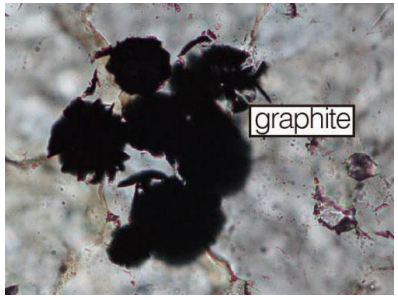
See: www.bbc.com/earth/story/20161026-the-secret-of-how-life-on-earth-began

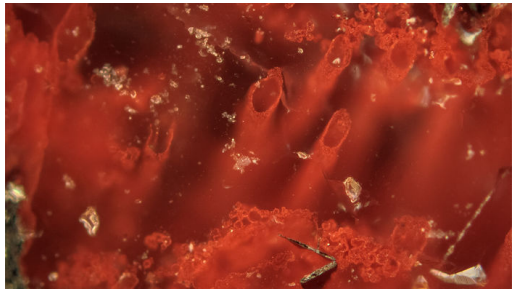
What about evidence from the fossil record?

A



September 2017: Tashiro *et al.*, Nature
biogenic graphite from 3.95 Gyr ago
found in Labrador, Canada rocks

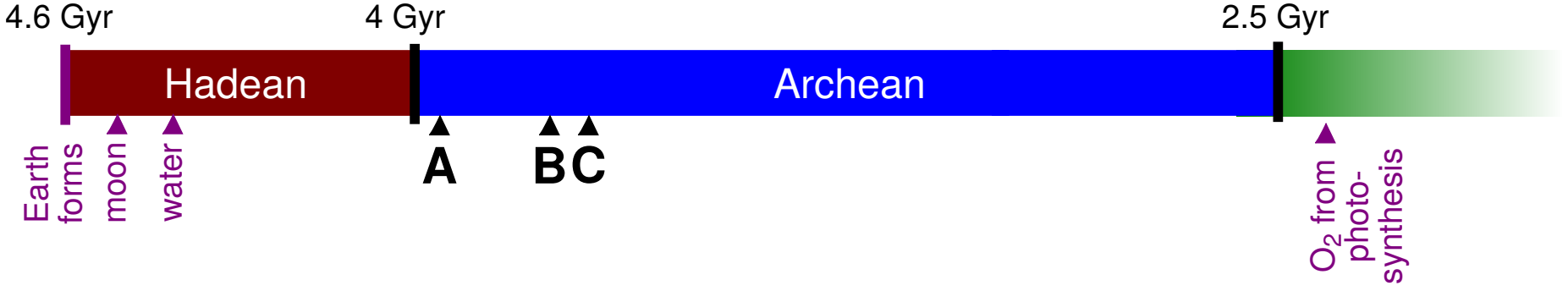
B



March 2017: Dodd *et al.*, Nature
hematite tube "microfossils" from 3.77 Gyr
found in Quebec, Canada rocks (possibly
from seafloor hydrothermal vents)

C

August 2016: Nutman *et al.*, Nature
Stromatolite (fossilized microbial colony)
from 3.7 Gyr in Greenland: earliest evidence
of anoxygenic photosynthesis?



Stromatolite controversy

The 3.7 Gyr stromatolites called into question by Abigail Allwood and coworkers, who discovered the previous record holder (3.45 Gyr stromatolites in Western Australia):

Letter | Published: 17 October 2018

Reassessing evidence of life in 3,700-million-year-old rocks of Greenland

Abigail C. Allwood ✉, Minik T. Rosing, David T. Flannery, Joel A. Hurowitz ✉ & Christopher M. Heirwegh

Nature (2018) | Download Citation ↓

Stromatolite on Mars?

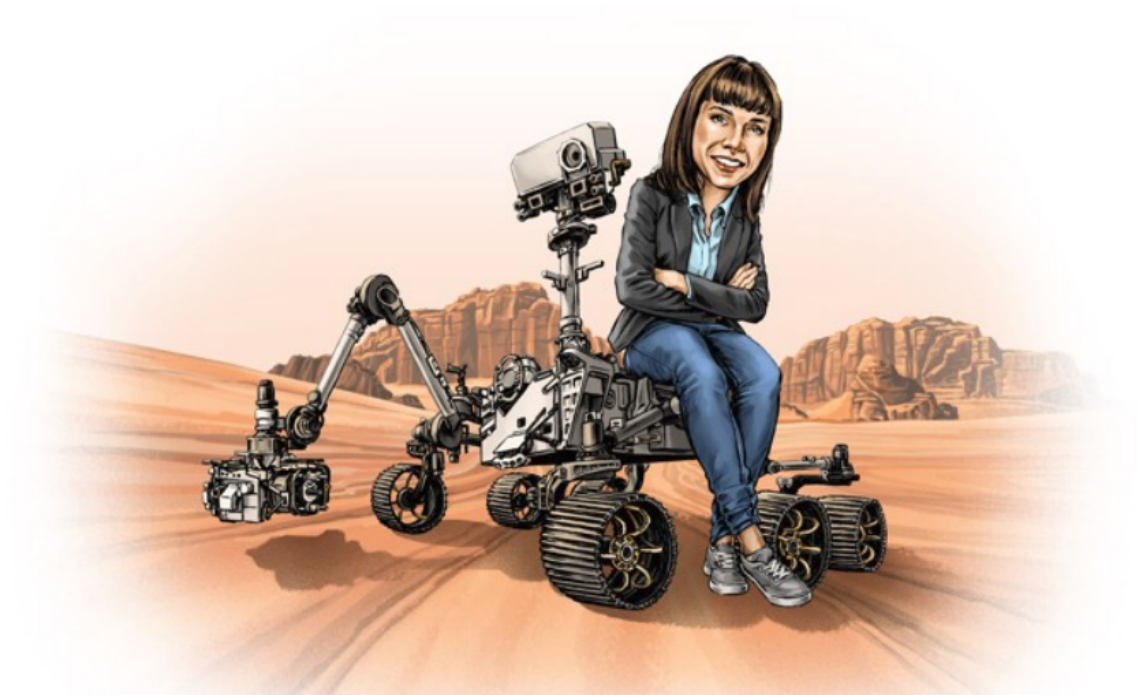
Potential stromatolites are are key target for the Mars 2020 rover mission.

SCIENCE

Can Abigail Allwood Find Life on Mars?

She made her name identifying the earliest accepted proof of life on Earth. Now NASA is counting on her to repeat the trick.

LAURA PARKER JUNE 2018 ISSUE



TIM TOMKINSON

MORE STORIES

Are Siblings More Important Than Parents?
BEN HEALY

Puppy Cuteness Is Perfectly Timed to Manipulate Humans
SARAH ELIZABETH ADLER

The Most Honest Book About Climate Change Yet
NATHANIEL RICH

When Animals Take the Night Shift
WILLIAM BRENNAN

Stromatolites on Mars?

Searching for Life in NASA's Perseverance Mars Samples

"Mars 2020 mission scientists believe that Jezero Crater, the landing site for Perseverance, could be home to such evidence. They know that 3.5 billion years ago, Jezero was the site of a large lake, complete with its own river delta."

https://www.nasa.gov/feature/jpl/searching-for-life-in-nasa-s-perseverance-mars-samples

Stromatolites on Mars?

Searching for Life in NASA's Perseverance Mars Samples

Living stromatolites are rare: undisturbed colonies of photosynthetic cyanobacteria in waters inhospitable to other life (hypersaline, high pH, etc.). Major part of fossil record until ~ 1 Gyr ago, when they fell victim to grazing by higher lifeforms.

Stromatolites on Mars?

Searching for Life in NASA's Perseverance Mars Samples

"NASA says the minerals and rock deposits at Salda are the nearest match on earth to those around the Jezero Crater where the spacecraft landed and which is believed to have once been flooded with water."

https://www.reuters.com/article/us-space-exploration-mars-turkey-idUSKBN2B10N7

Intrepid crew gathering stromatolites at Lake Salda, Turkey

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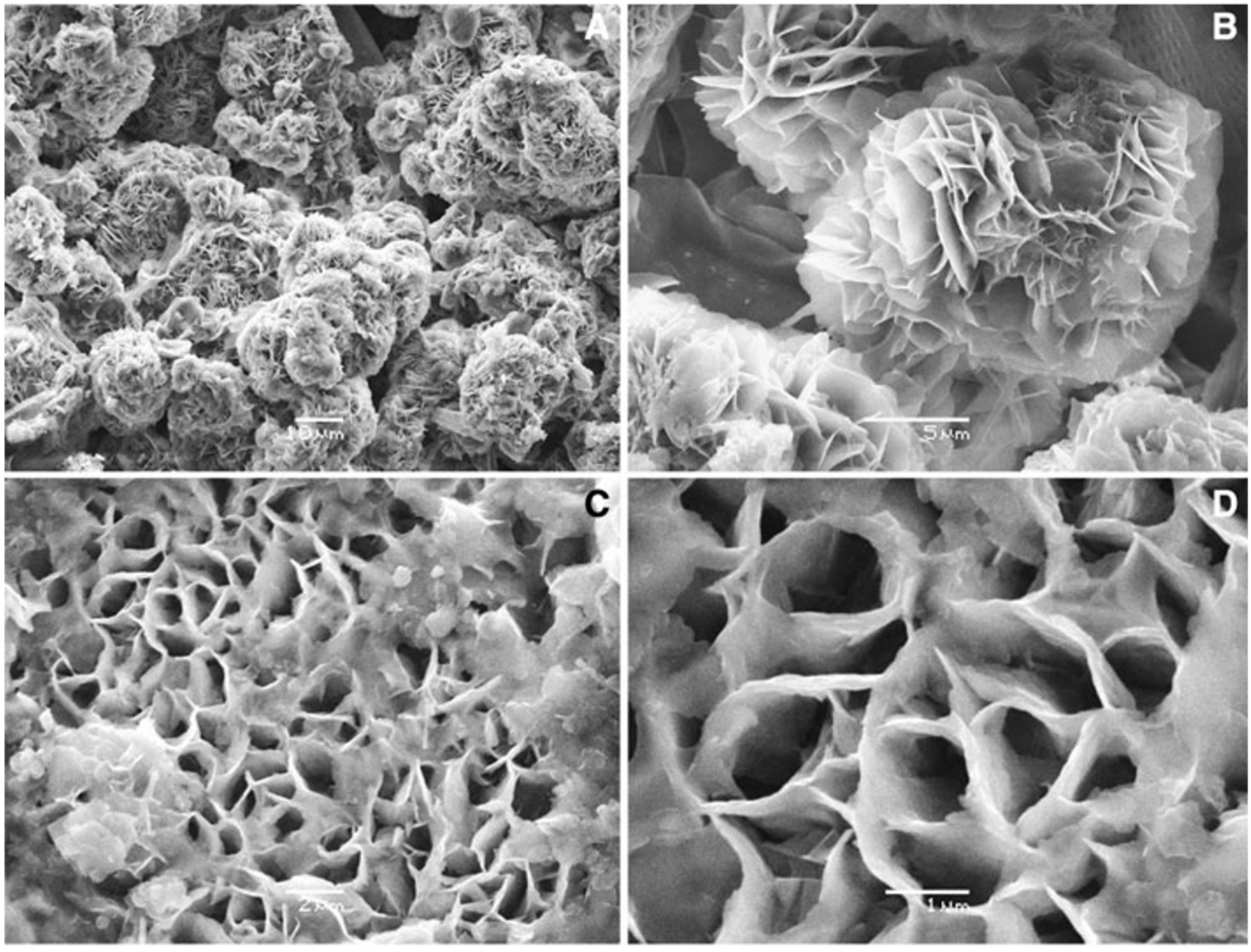
SEM images of Lake Salda stromatolites



Shirokova *et al.*, Aquat Geochem (2013)