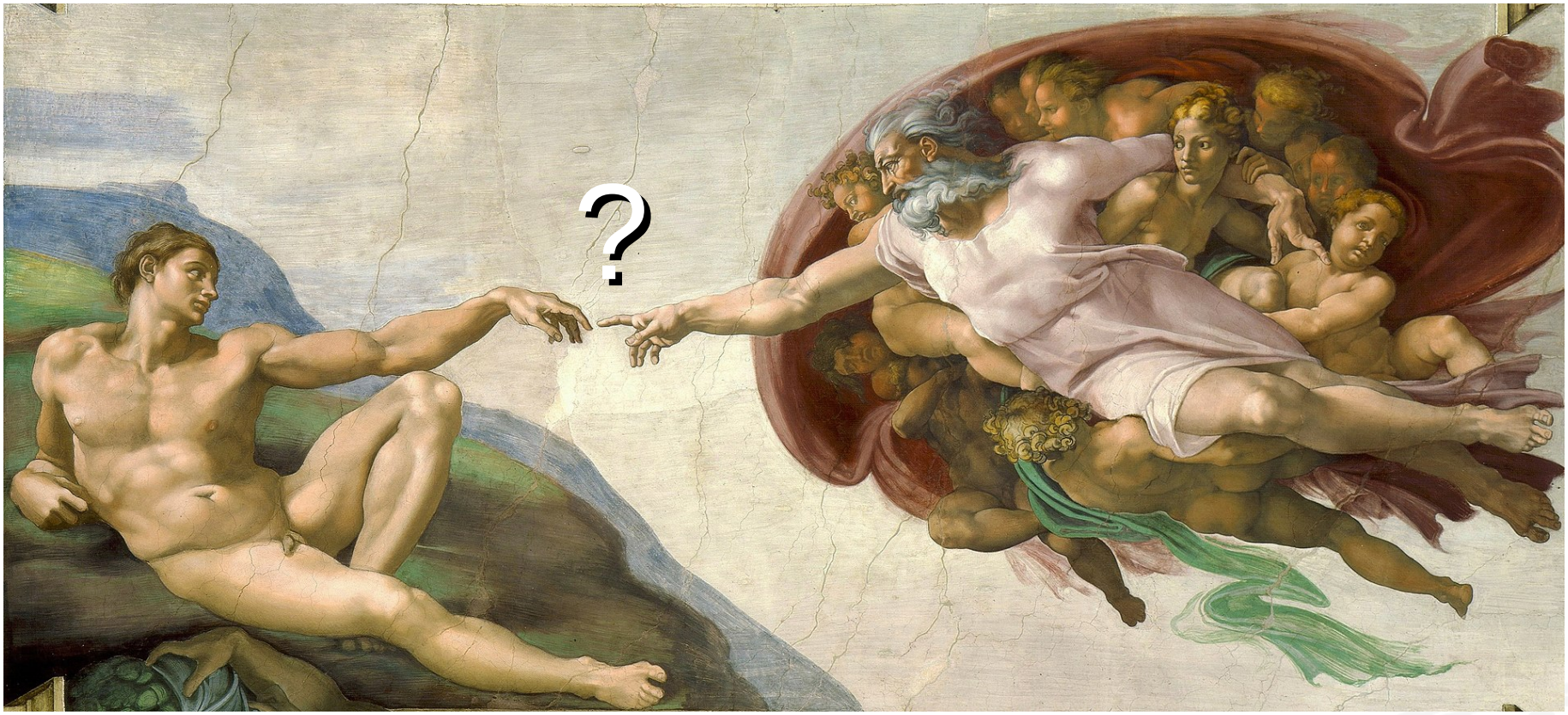
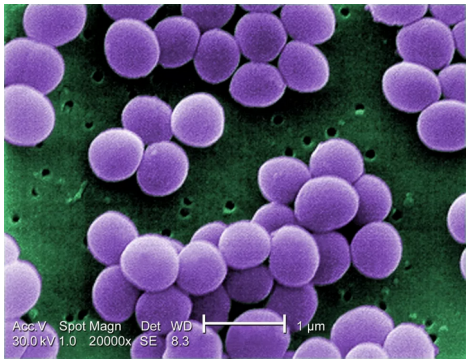


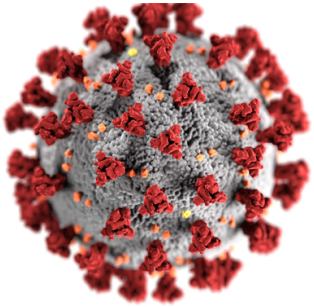
Life from a Planetary Perspective

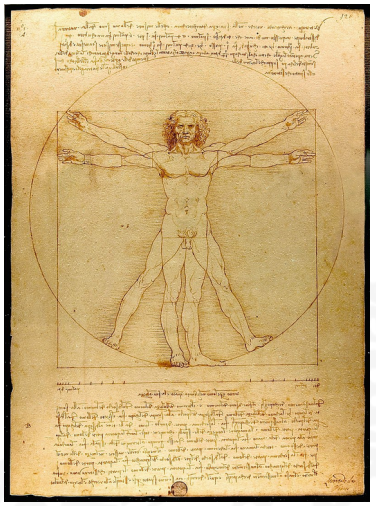
Sebastian Jung

Motivation

- Life on earth is diverse







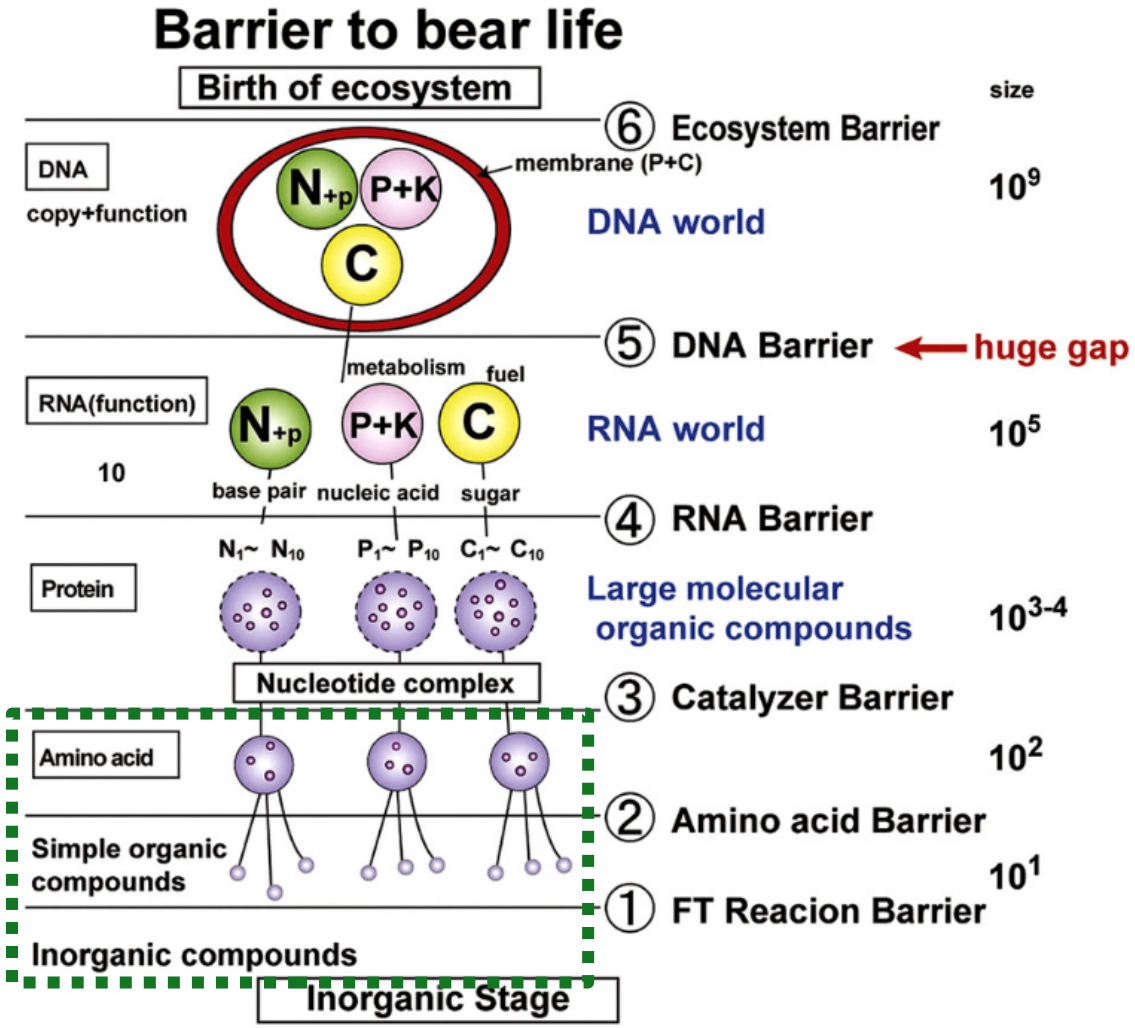
- Science: It *has* to start somewhere
- Which **conditions** are needed?
- Which **chemistry** is needed?
- How does it fit into **history of earth**?

Agenda

- Introduction
- One (possible) Pathway to Life
- Outlook
- Summary

Introduction

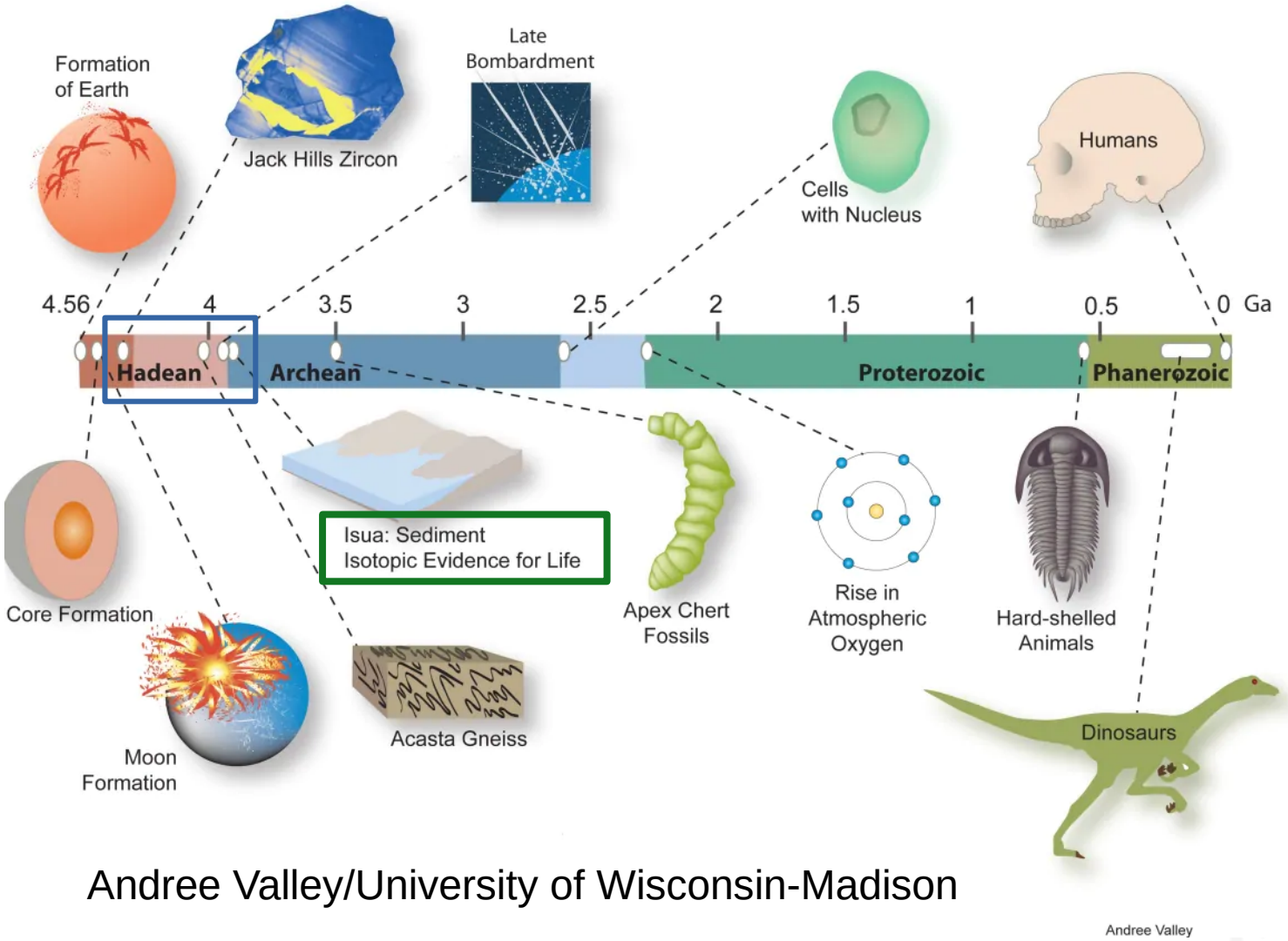
Steps to Life



S. Maruyama et al, Geoscience Frontiers (2013)

- Different theories
- Life from ground up
- **Focus of the talk: Emergence of Simple Monomers**

The History of Earth



Andree Valley/University of Wisconsin-Madison

Consens:
First living organisms ~ 3.8Ga ago

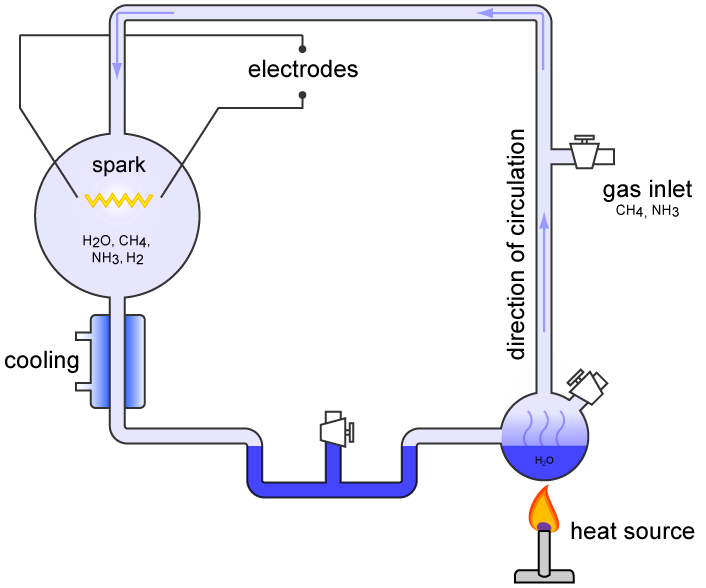
Maybe even earlier: ~4.5Ga ago[1]

Life emerged extremely fast!

[1] Betts et al, Nature Ecology & Evolution (2018)

Some Famous Examples

- Miller-Urey Experiment[1]
  - High yield of amino acids
  - Wide variety of important biological molecules[2]



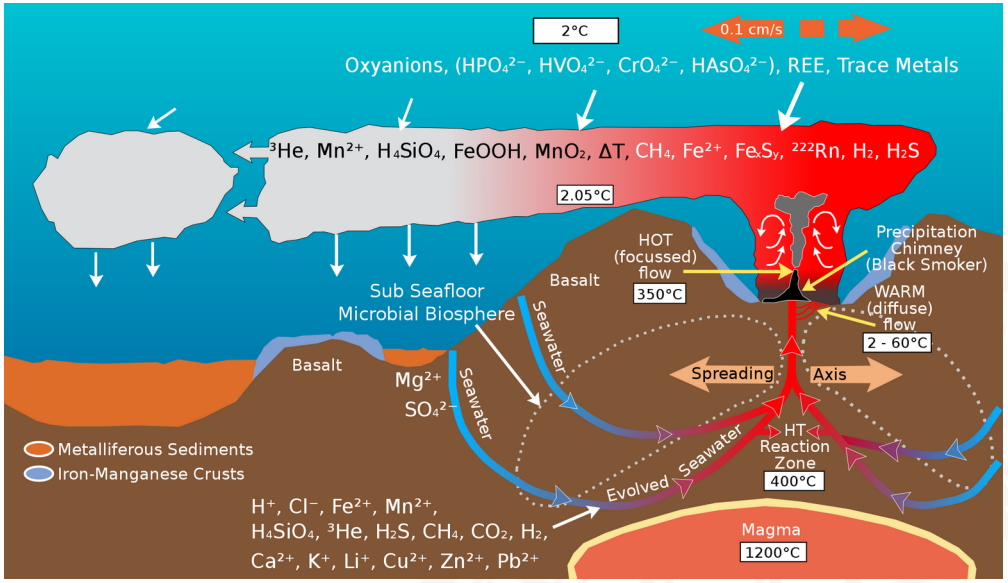
https://en.wikipedia.org/wiki/Miller%E2%80%93Urey_experiment

  - *BUT:*
    - Conditions unrealistic
      → Real conditions: Low yield, less diverse[3]
    - Many non-biological by-products[4]

[1] S. L. Miller, Science, 1953
[2] https://en.wikipedia.org/wiki/Miller%E2%80%93Urey_experiment
[3] D. D. Sasselov et al. Science Advances, 2020
[4] B. H. Patel et al. Nature chemistry, 2015

Some Famous Examples

- Deep Sea Hydrothermal Vents
  - CO_2 as Carbon source[1]
  - High energy flux
  - *BUT:*
    - Not as diverse[1]
    - Low yield[1]
    - High T → molecular instability



https://en.wikipedia.org/wiki/Hydrothermal_vent

[1] D. D. Sasselov et al. Science Advances, 2020

One (Possible) Pathway to Life

Approach

- Iterative process:
  - Biochemistry has to be supported by geologic and geochemical observations
  - Environmental conditions had to be fitting for life to emerge

Biochemistry <=> Geology

- Different to previous examples!

D. D. Sasselov et al. Science Advances, 2020

Assumptions

- Modern life retained some direct vestiges of prebiotic chemistry/planetary conditions
- No panspermia
- Basic chemicals needed
  - C, H, N, O, P, S

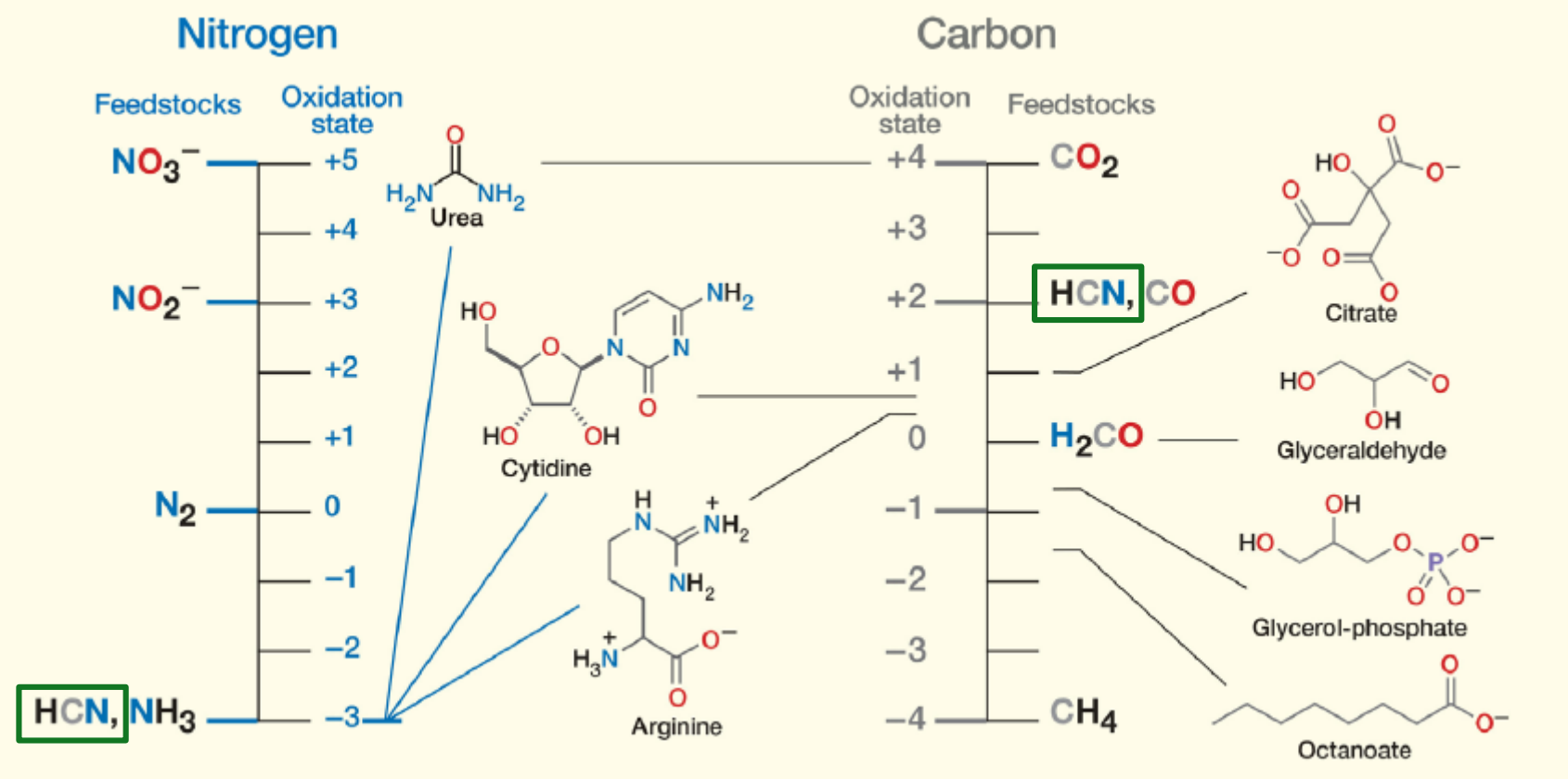
https://neelmodi.com/panspermia/

- On modern earth: No observation of life originating on its own

→ Different chemical feedstocks/conditions required

D. D. Sasselov et al. Science Advances, 2020

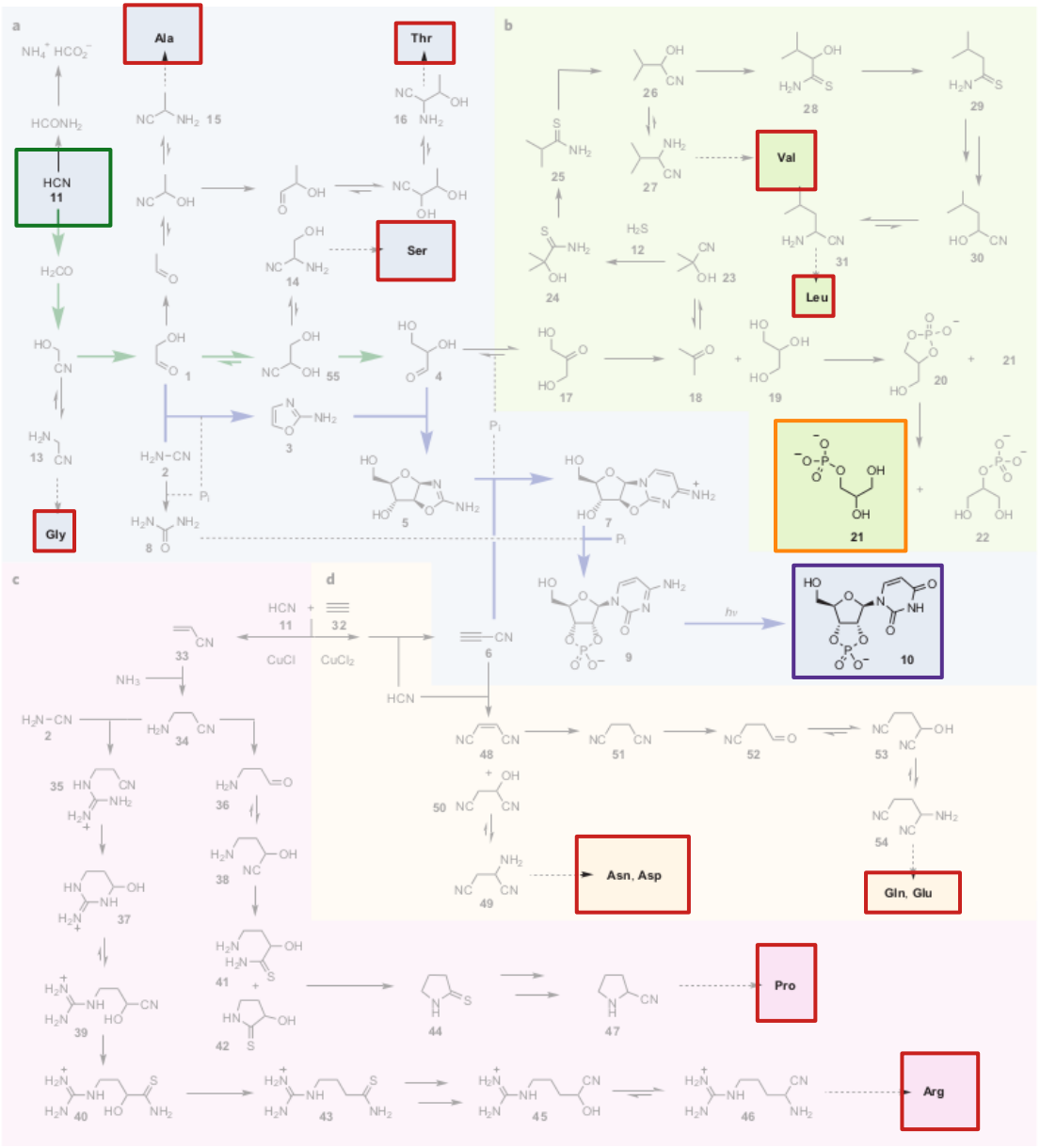
Oxidation states



- Focusing on Nitrogen and Carbon
- **Hydrogen cyanide (HCN)** ideal feedstock

D. D. Sasselov et al. Science Advances, 2020

HCN Pathways[1]



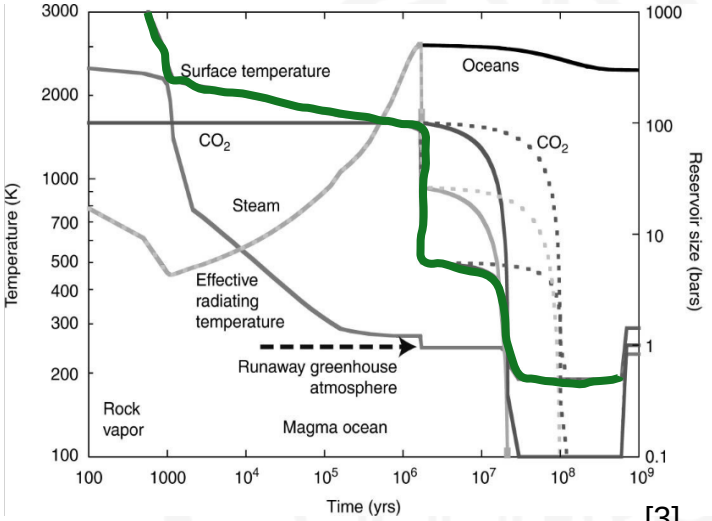
- HCN as starting point
- Ribonucleotides
- Amino acids
- Lipid precursor

- Almost no side products
- High yield
- How do we get there?

[1] B. H. Patel et al. Nature chemistry, 2015

Conditions

- Hadean (~4.6Ga-4.0Ga ago)[1]
- Secondary Atmosphere:
  - H, C, N, O → <u>High energy</u> → CN, CO, NO ...[2]
- <u>High energy</u> due to[2]
  - Meteors, Lightning, Volcanos, Solar flares
- Cooling: CN → HCN[2]



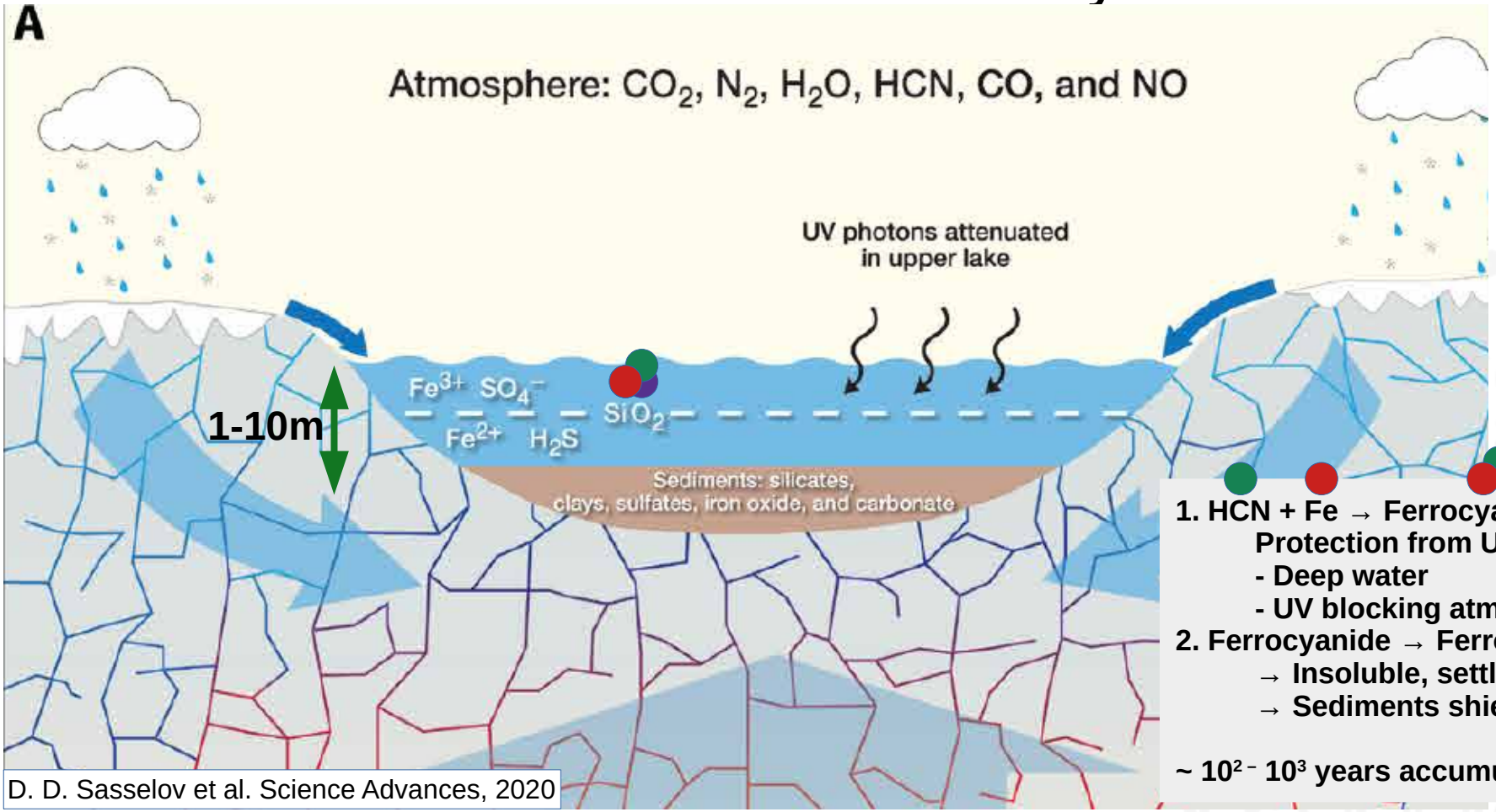
[3]

[1] https://en.wikipedia.org/wiki/Hadean
[2] D. D. Sasselov et al. Science Advances, 2020
[3] K. Zahnle et al. Cold Spring Harb Perspect Biol. 2010

Concentration of HCN

- HCN in atmosphere useless

  → Sedimentation of Ferrocyanide



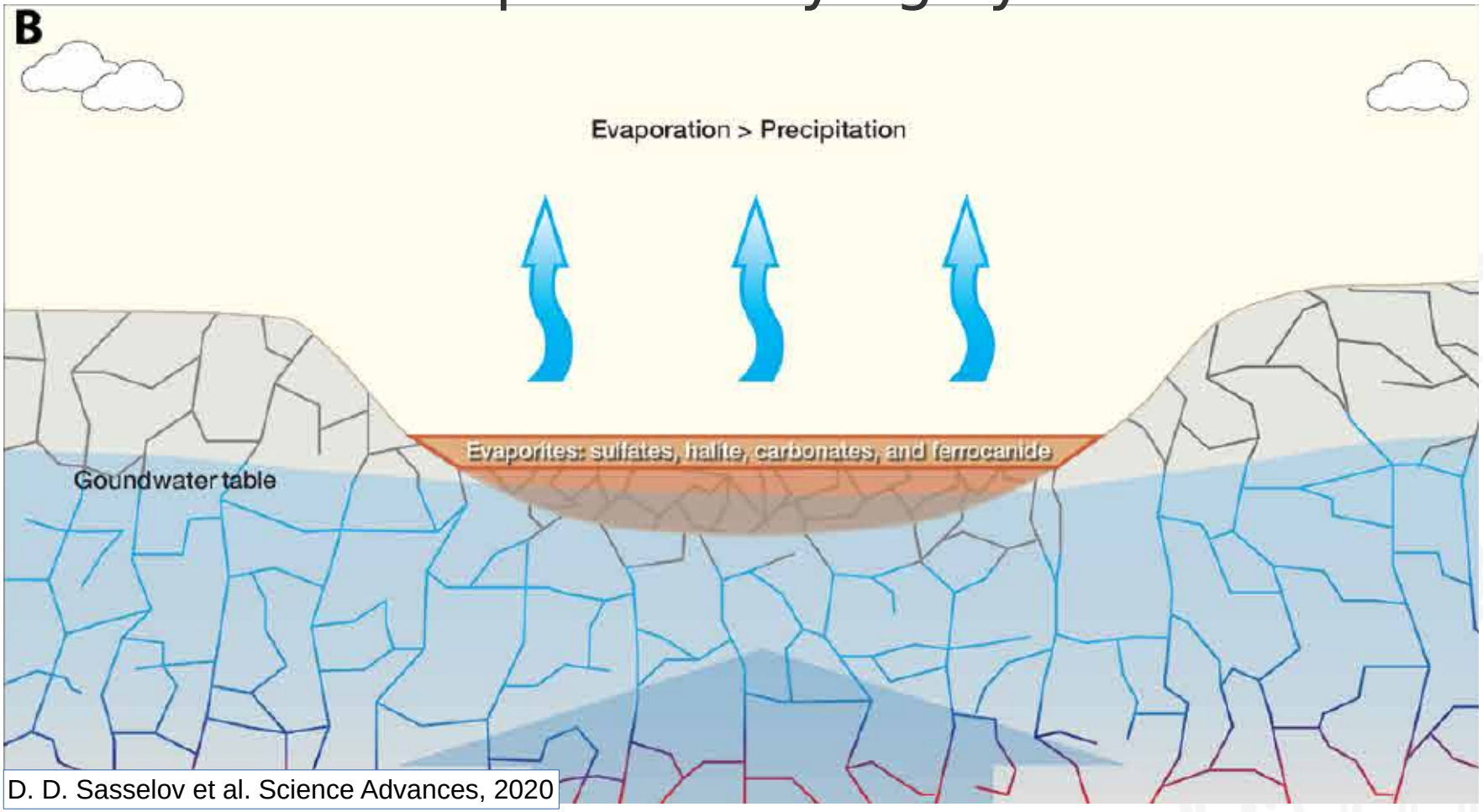
D. D. Sasselov et al. Science Advances, 2020

1. HCN + Fe → Ferrocyanide
Protection from UV needed:
- Deep water
- UV blocking atmosphere
2. Ferrocyanide → Ferrocyanide salt
→ Insoluble, settles to bottom
→ Sediments shield from UV

~ 10^2 – 10^3 years accumulation needed

Desiccation – Dry periods

- Ferrocyanide salts save under surface deposits
- Save in repeated drying cycles

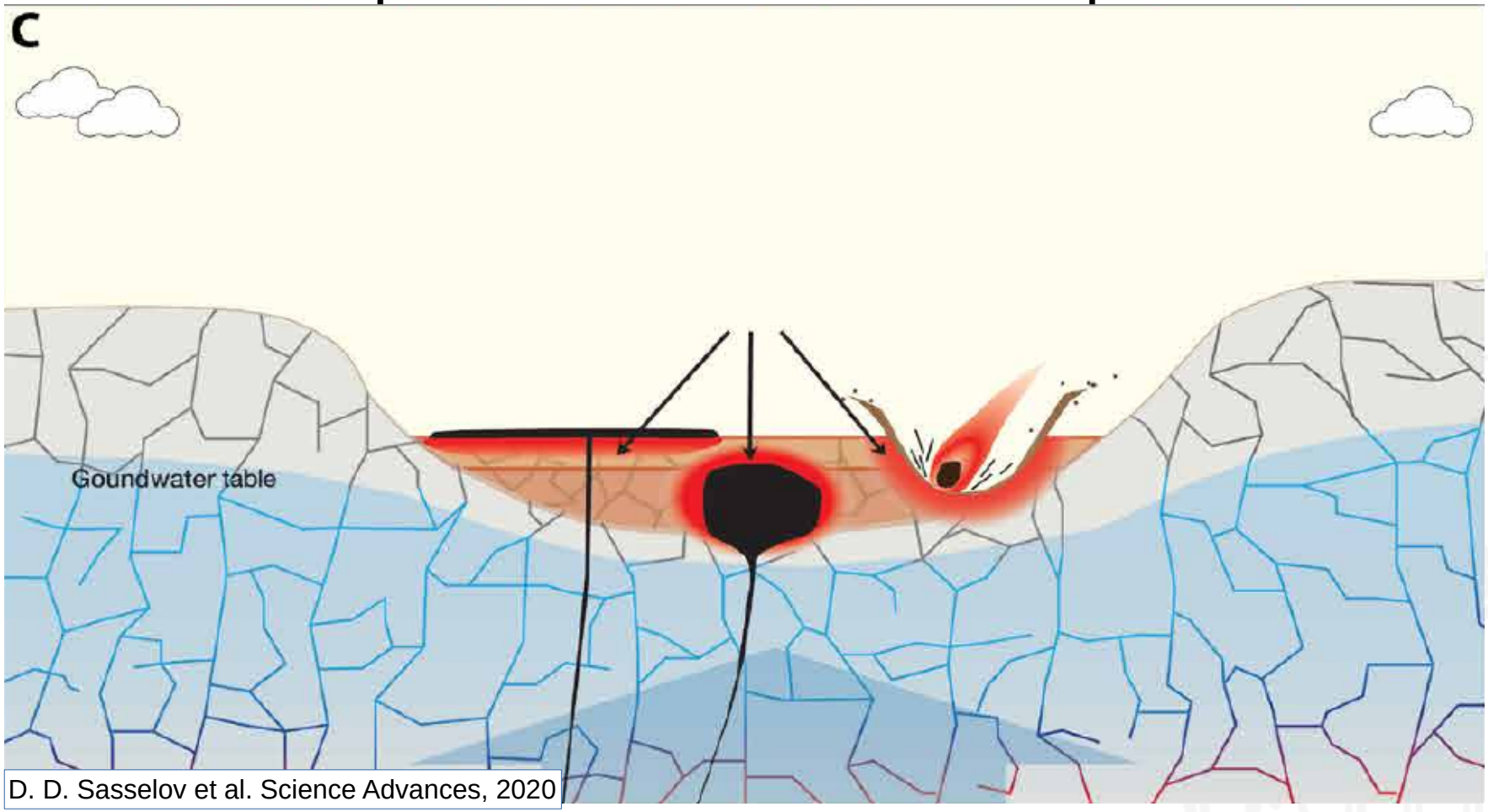


D. D. Sasselov et al. Science Advances, 2020

Thermal pulses

- Igneous intrusions, volcanic activity, impacts

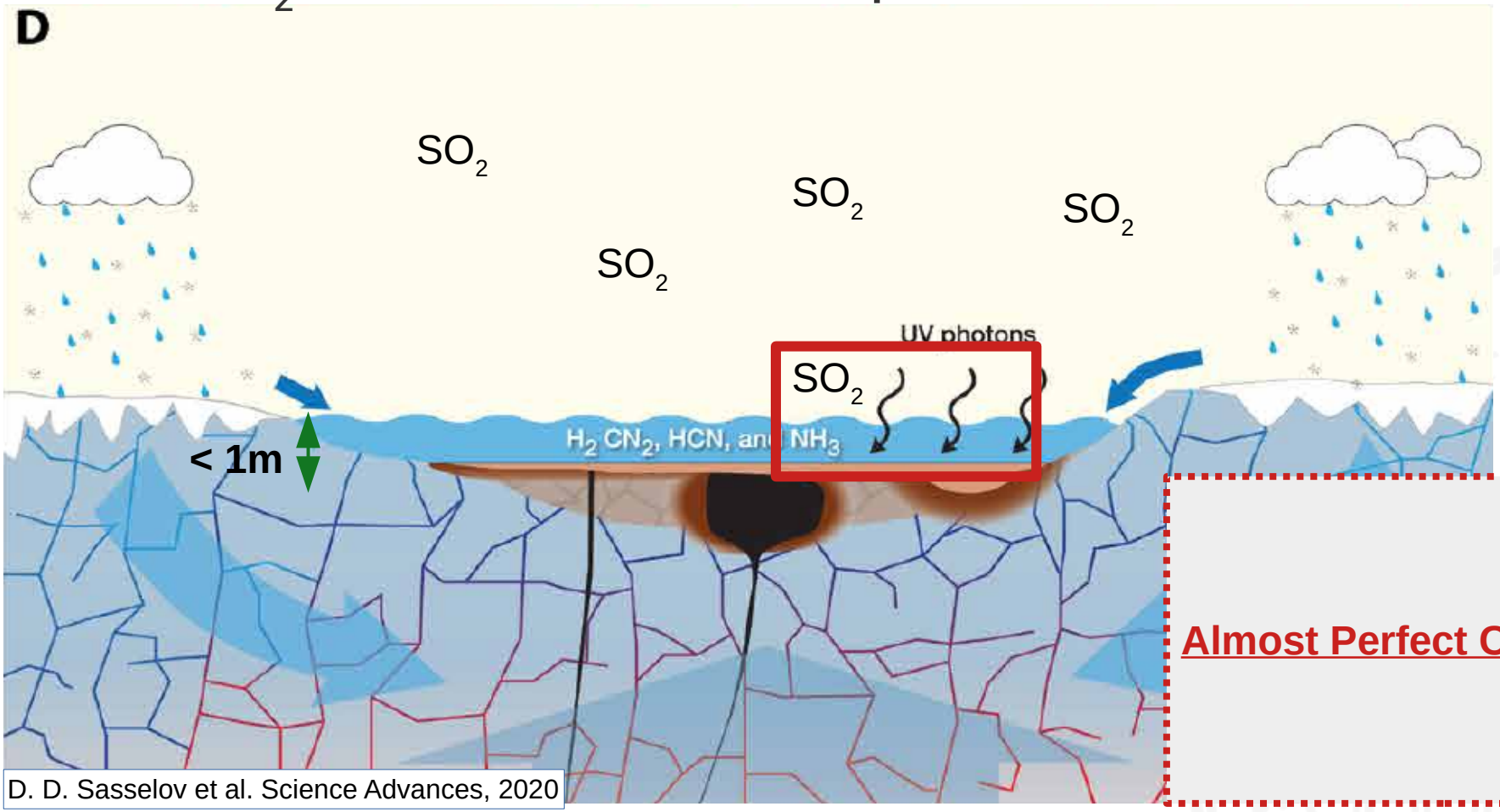
  → up to 700°C → Metamorphic reaction



D. D. Sasselov et al. Science Advances, 2020

Neutral pH Water

- Exposure to neutral pH Water
- SO_2 from volcanic eruption, Shallow water

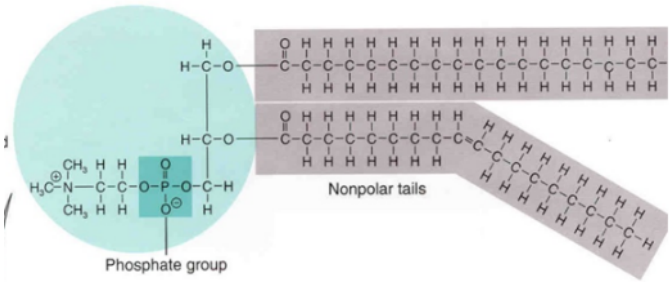


D. D. Sasselov et al. Science Advances, 2020

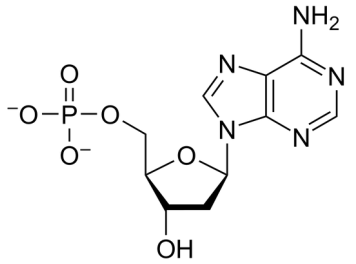
Almost Perfect Conditions!

… Almost?

- Phosphate required for nucleotides and lipid precursors



https://www.creative-proteomics.com/services/phospholipids-analysis-service.htm



https://en.wikipedia.org/wiki/Nucleotide

→ Little is known about P cycle on Earth or Mars

- Nitrite (NO_2^-) from NO in atmosphere could be needed for higher order assembly

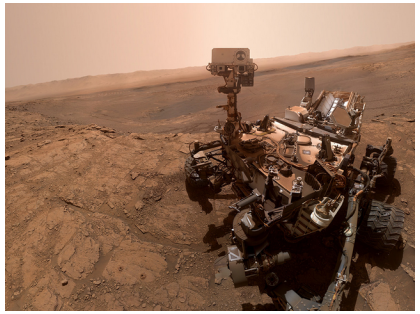
→ Would react with bisulfite (HSO_3^-)

D. D. Sasselov et al. Science Advances, 2020

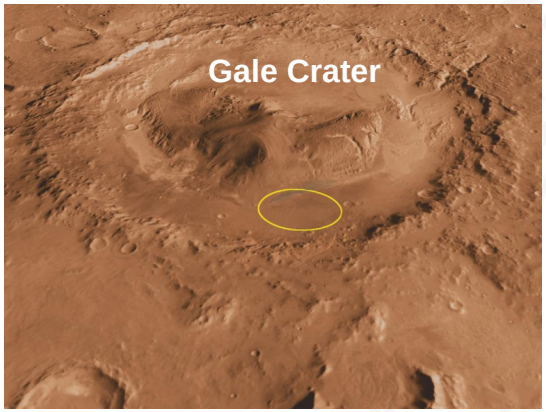
Is it plausible?

- Evidence of prebiotic chemistry on earth lost

  due to plate tectonics → Look at other planets
- Mars: No plate tectonics → Good comparison
  - Has deposits of sedimentary rocks, including rocks formed in aqueous solution
  - Curiosity found C, H, N, O, P, S in Gale Crater



https://mars.nasa.gov/news/8796/nasas-curiosity-takes-selfie-with-mary-anning-on-the-red-planet/?site=msl



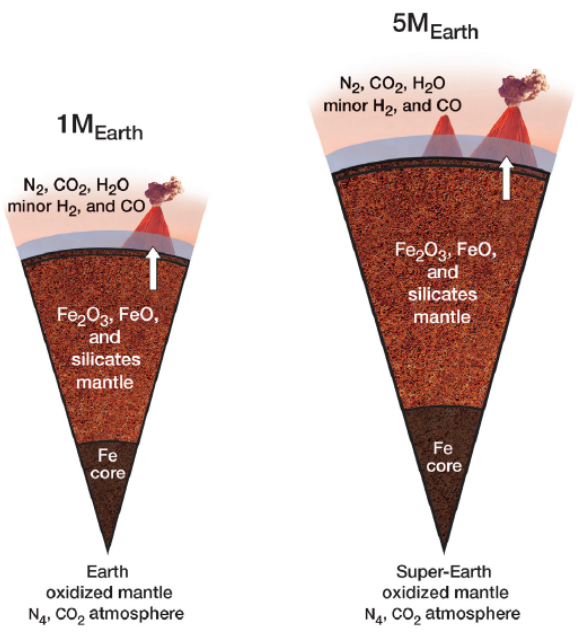
https://www.nasa.gov/mission_pages/msl/multimedia/gallery/pia14294-anno.html

D. D. Sasselov et al. Science Advances, 2020

Is it plausible?

- Atmosphere:
  - Highly reducing atmosphere (CH_4, NH_3, H_3) photochemically unstable (H escapes to space)
  - Earth-size and super-Earth exoplanets expected to have weakly reducing N_2-CO_2 atmosphere

    → Prebiotic chemistry possible



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Is it plausible?

- Hydrosphere:
  - Expected to be common in habitable zone
  - Plate tectonics contains liquid surface reservoirs
- UV irradiation:
  - CO_2 and H_2O prevent UV < 200nm
  - Probably enough mid-range (200nm-300nm) UV is reached in most Earth-like planets

We can learn from other planets!

D. D. Sasselov et al. Science Advances, 2020

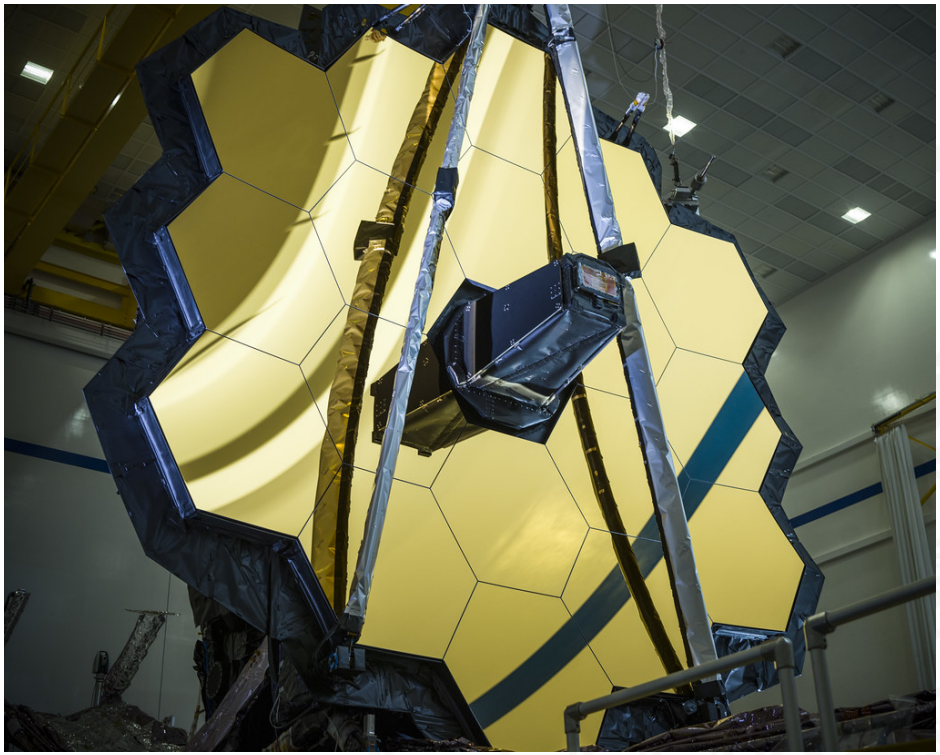
Outlook

Exoplanets

- Early Earth atmospheres unknown

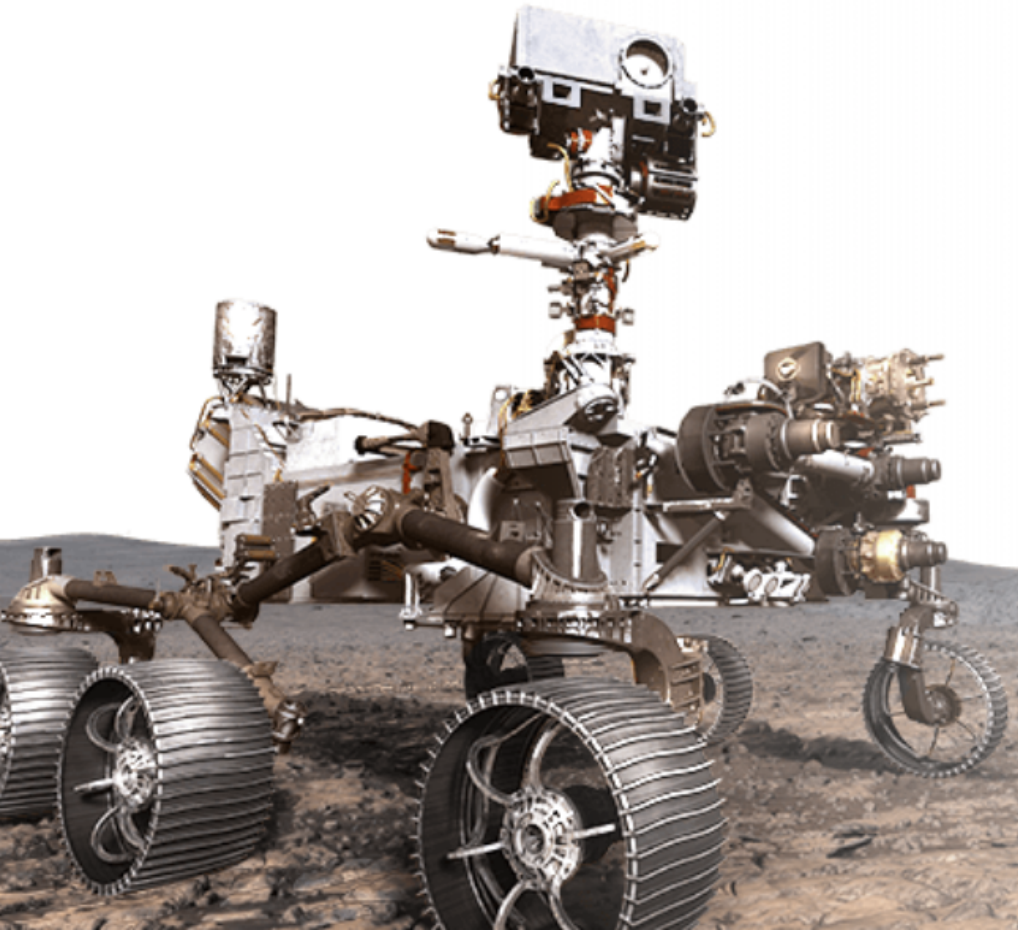
  → In the future, spectroscopic exploration of exoplanet can give more insides

  e.g. James Webb Space Telescope



https://www.jwst.nasa.gov/index.html

Mars2020



Quick Facts

Mission Name: Mars 2020

Rover Name: Perseverance

Main Job: The Perseverance rover will seek signs of ancient life and collect rock and soil samples for possible return to Earth.

Launch: July 30, 2020, Cape Canaveral Air Force Station, Florida

Landing: Feb. 18, 2021

Landing Site: Jezero Crater, Mars

Mission Duration: At least one Mars year (about 687 Earth days)

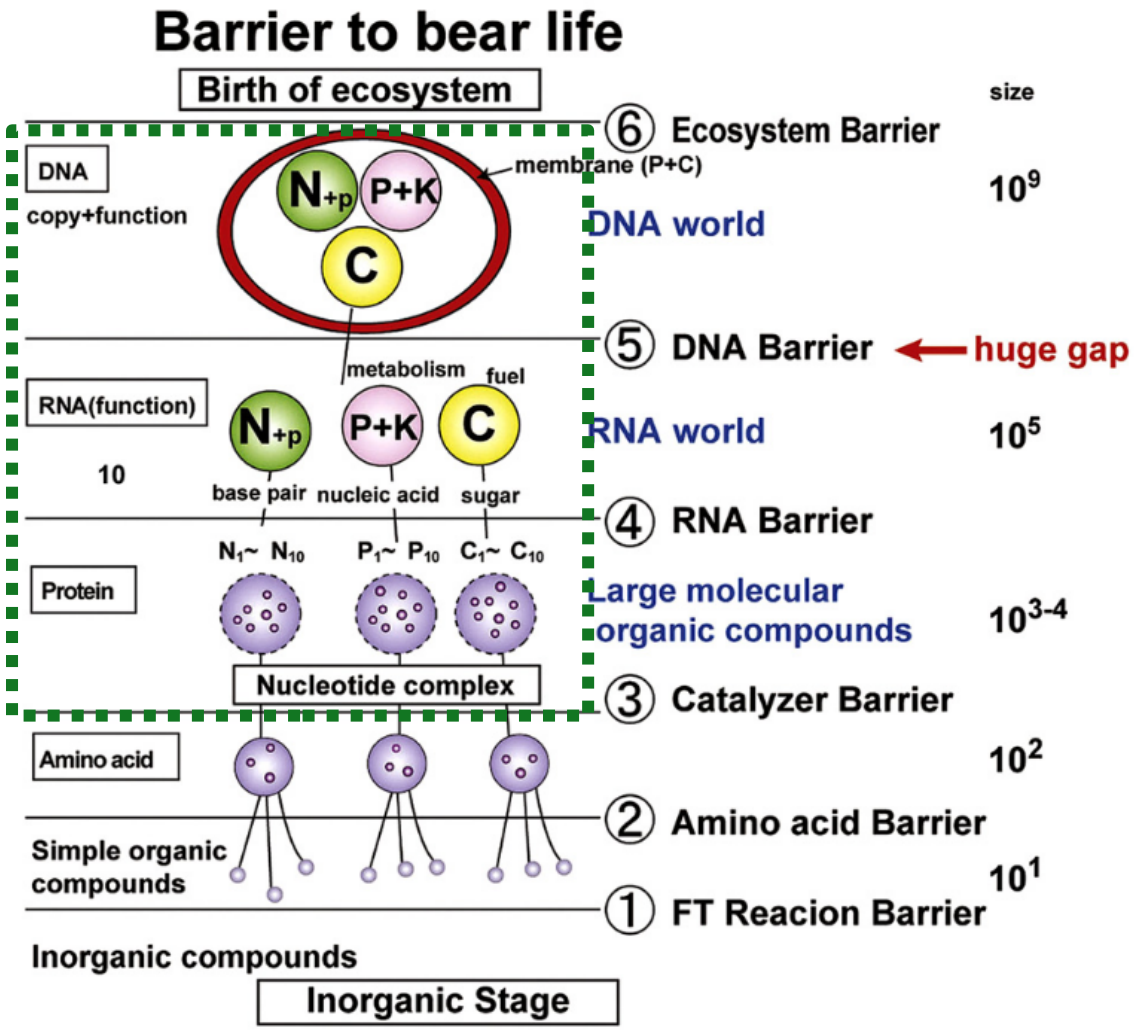
Tech Demo: The Mars Helicopter is a technology demonstration, hitching a ride on the Perseverance rover.

Fact Sheet

Launch Press Kit

https://mars.nasa.gov/mars2020/

Future steps



- After solving creation of monomers:
  - Polymerization
  - Vesicle formation
  - Encapsulation
  - Replication
  - ...

Summary

Summary

- New iterative approach:
  - Laboratory experiments <=> Planetary observation
- HNC Pathway leads to many necessary biological building blocks
- Is just one possible solution
- Analysis of other planets could give insides into earths history
- Many open questions remain

What do YOU think?

Image sources

- Title image: https://en.wikipedia.org/wiki/Creationism
- https://www.livescience.com/51641-bacteria.html
- https://www.pei.de/DE/newsroom/dossier/coronavirus/coronavirus-node.html
- http://www.bbc.com/earth/story/20150611-chimps-smile-like-us
- https://allthatsinteresting.com/interesting-plants
- https://www.gazetteandherald.co.uk/news/18796000.pictures-18-stunning-images-fabulous-funghi/
- https://en.wikipedia.org/wiki/Vitruvian_Man
- https://en.wikipedia.org/wiki/Hydrothermal_vent