UNIVERSITÄT
BIELEFELD
Faculty of Biology
Faculty of Physics

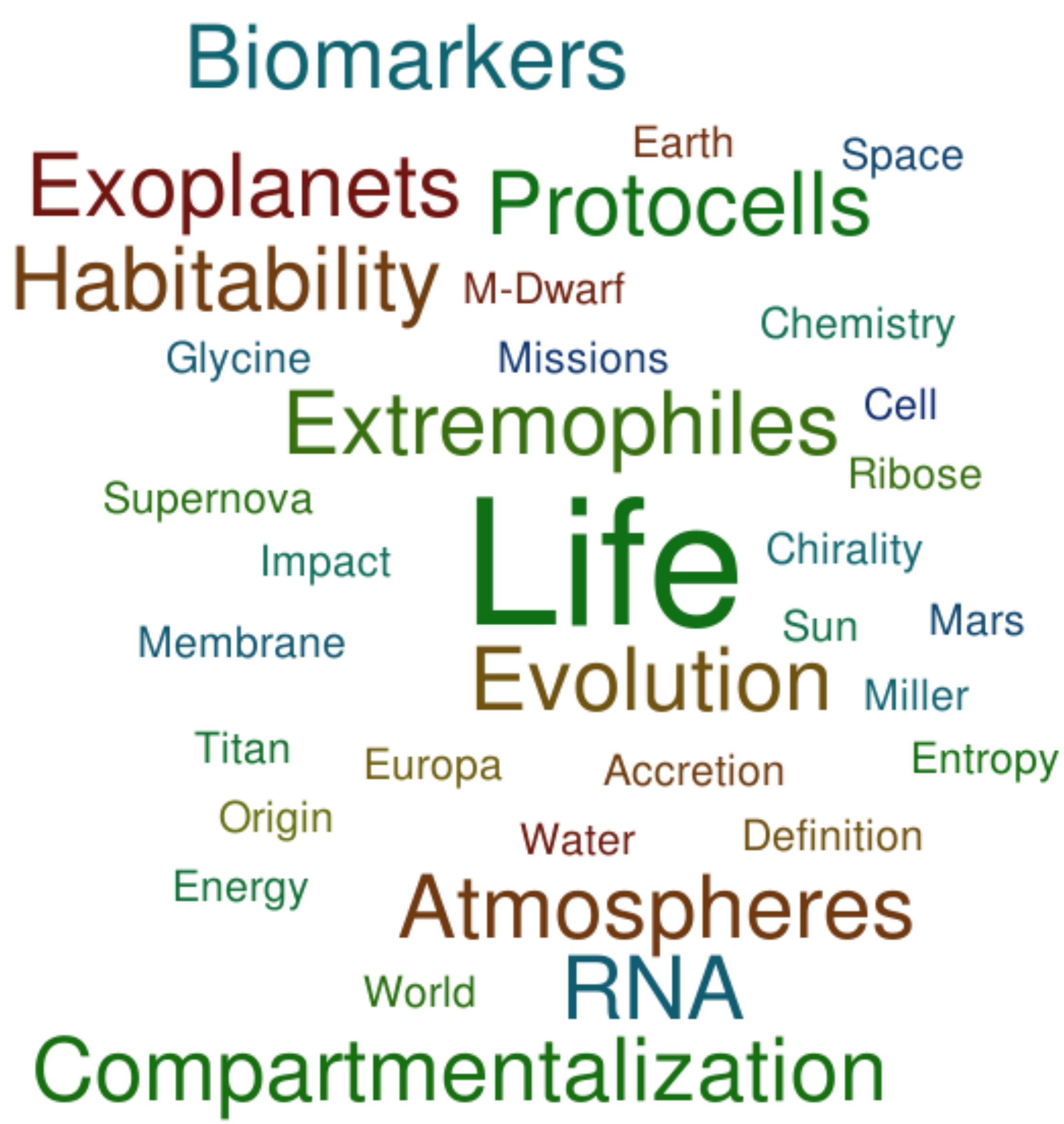
Recipes for Primordial Soups

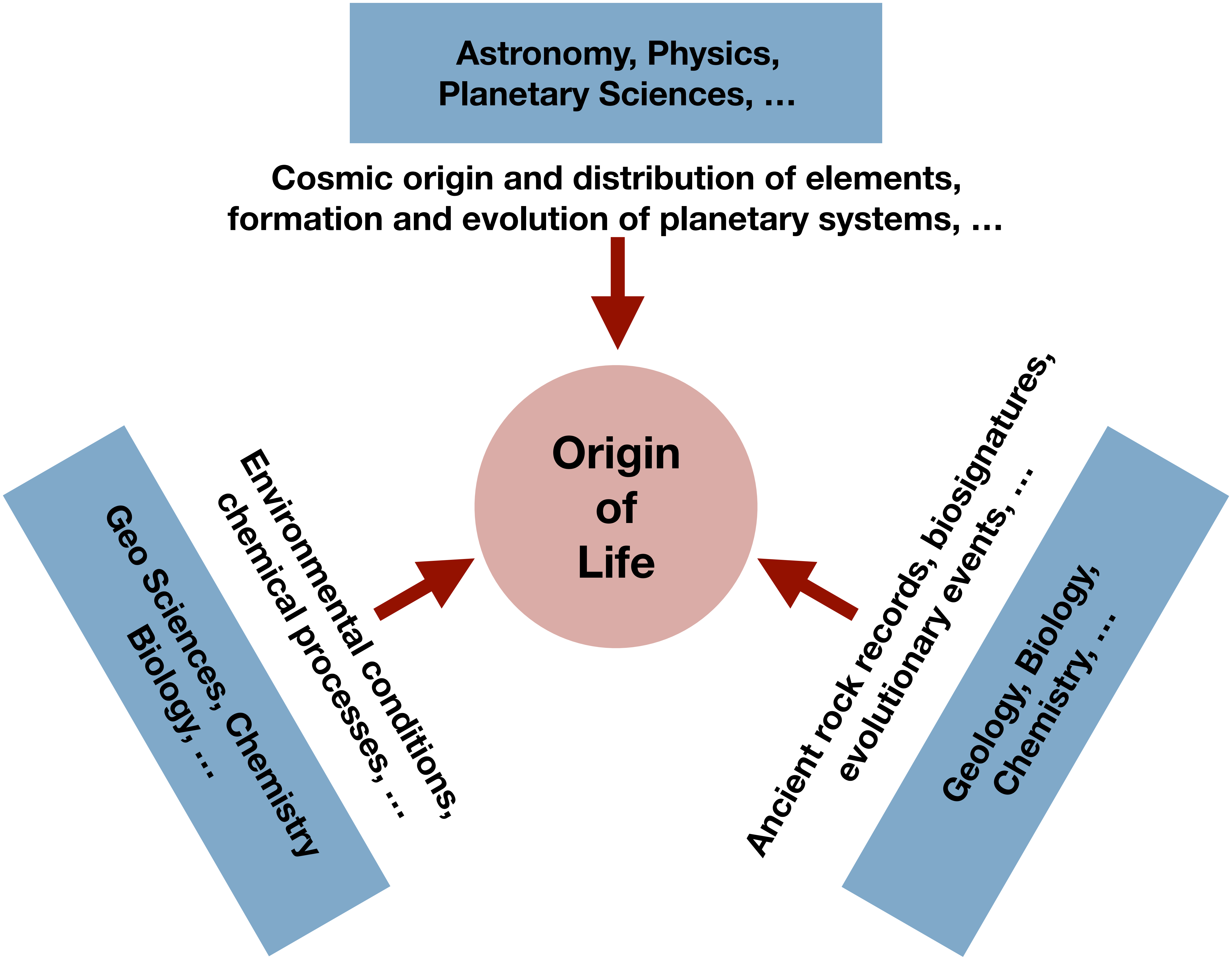
Petra Lutter and Dominik Schwarz

CORSIKA meeting, June 2020

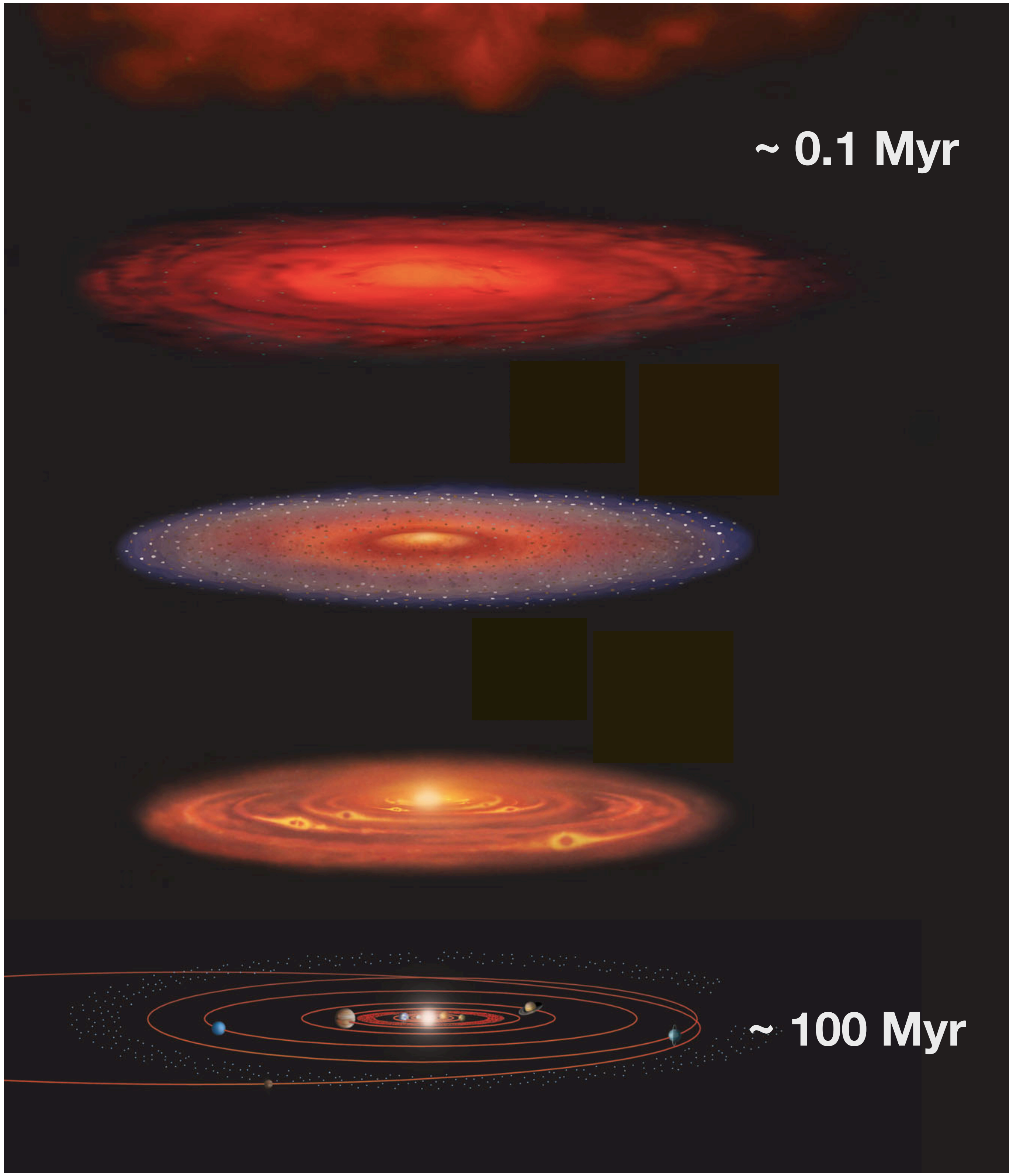
Astrobiology

Astrobiology is the study of the origin, evolution, distribution, and future of life in the Universe (Des Marais et al. 2008).




Astronomy, Physics,
Planetary Sciences, …
Cosmic origin and distribution of elements,
formation and evolution of planetary systems, …
Origin
of
Life
Geo Sciences, Chemistry
Biology, …
Environmental conditions,
chemical processes, …
Ancient rock records, biosignatures,
evolutionary events, …
Geology, Biology,
Chemistry, …

Formation of a planetary system



Credit: Bennett & Shostak

Interstellar **gas cloud**

Contraction leads to
a spinning disc of gas and dust,
a star is born in its centre

Condensation of dust:
Higher temperature in inner disc
leads to metal/rocky seeds,
lower temperature in outer disc
allows for icy seeds

Accretion forms
rocky planets (e.g. Earth), moons and
gaseous planets (e.g. Jupiter)

Clearing of planetary orbits by
planets and accretion on central star.
Leftovers (e.g. asteroid belt and
Kuiper belt), especially at rim

Habitability

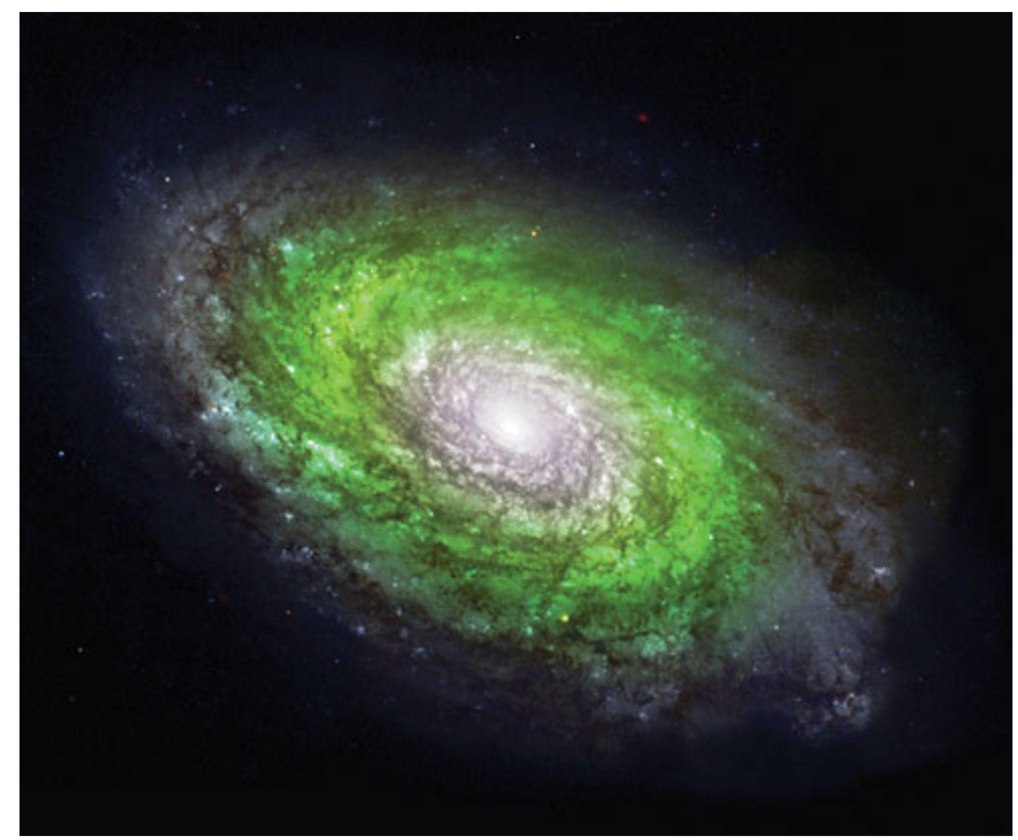
Habitable Zone: A star's habitable zone is the range of distances around it at which a planet could potentially have surface temperatures that would allow for abundant **liquid water**.

Habitability Factors:
(for a planet's surface)

- Distance from Star
- Size
- Plate tectonics
- Atmosphere
- . . .

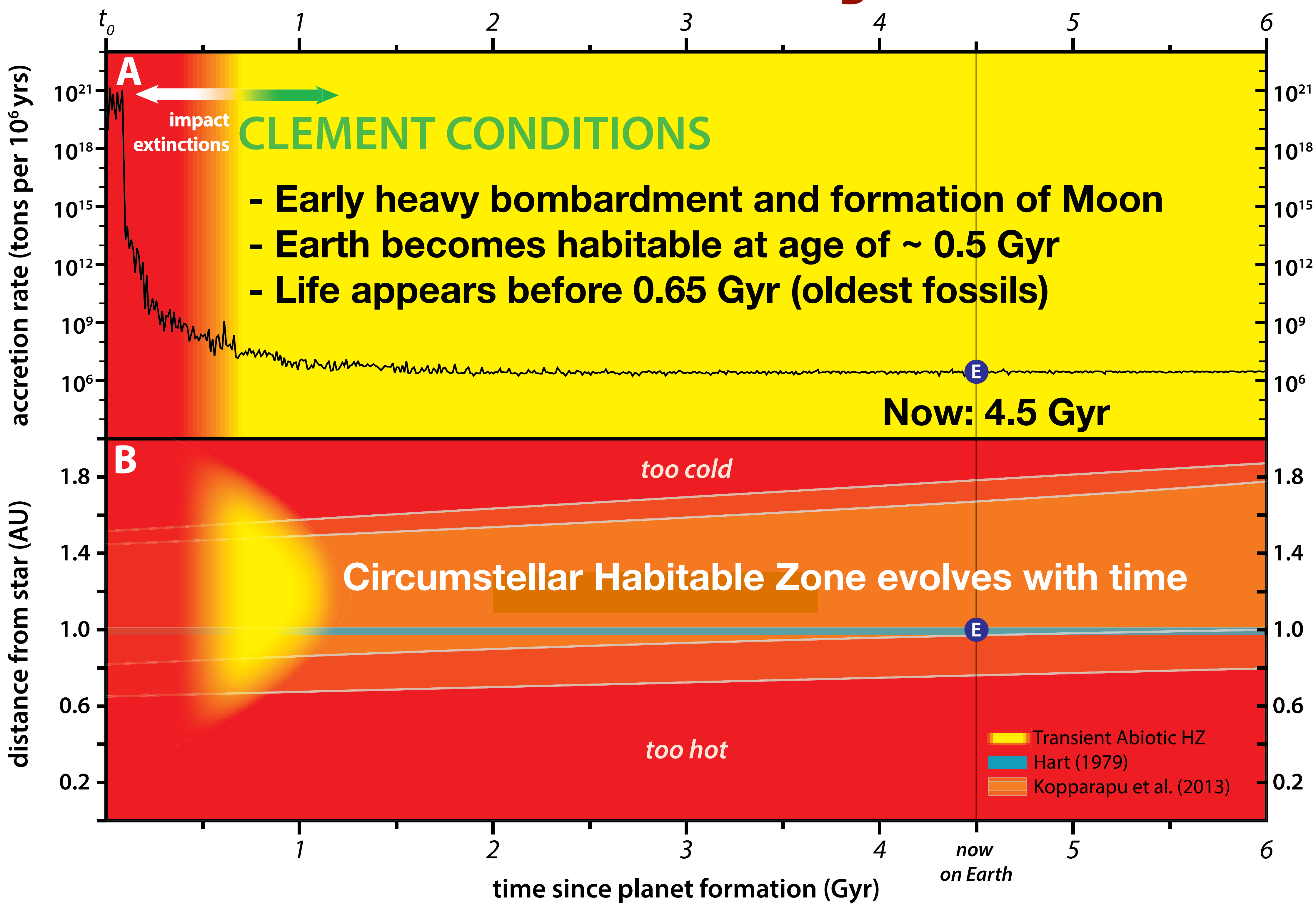
Galactic Habitable Zone:

The region of a galaxy in which life might most likely develop (metallicity - supernovae - distance from center).



Credit: Bennett & Shostak

Habitability

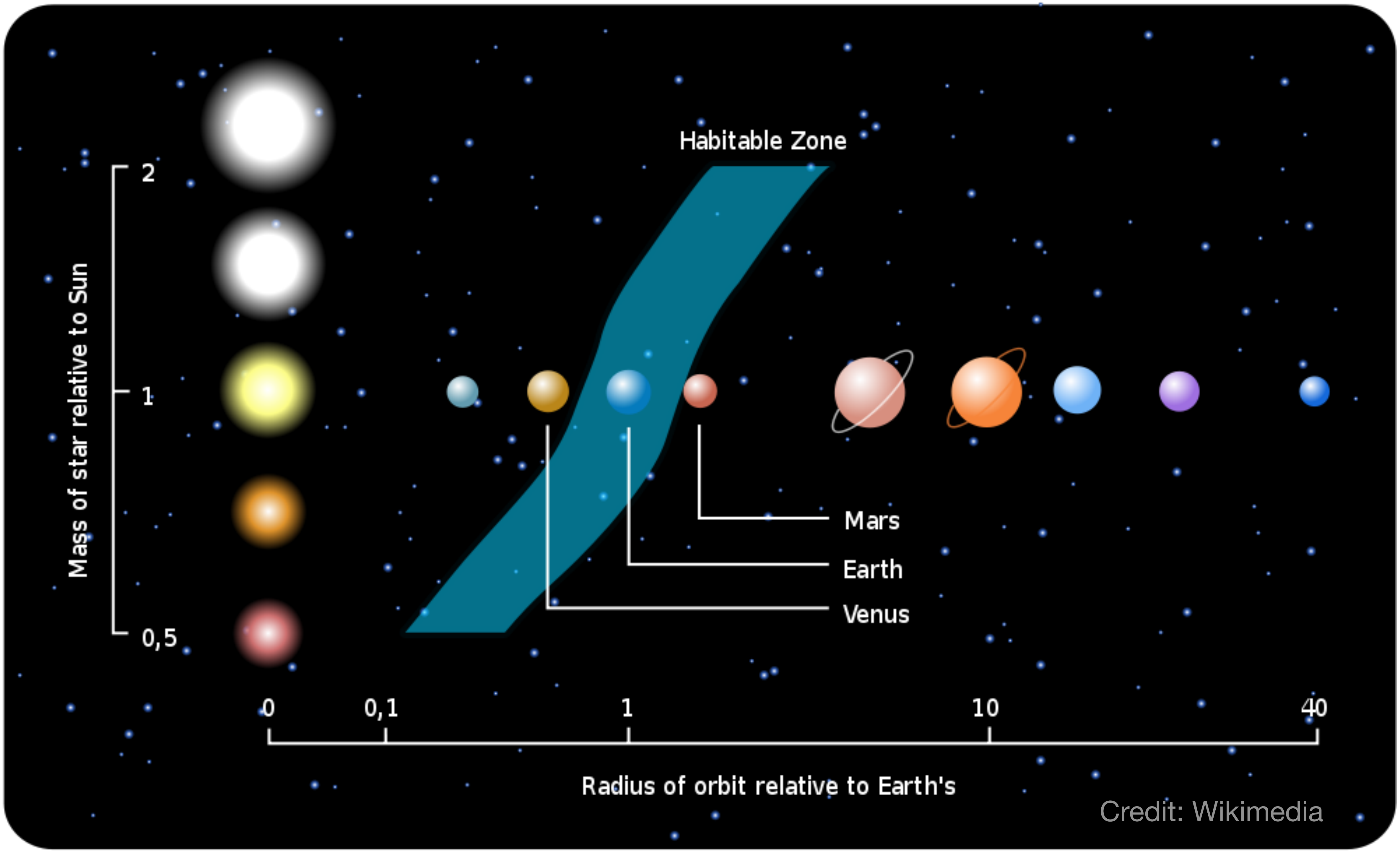


Lineweaver, Chopra, McIntyre, 2018 in Handbook of Astrobiology

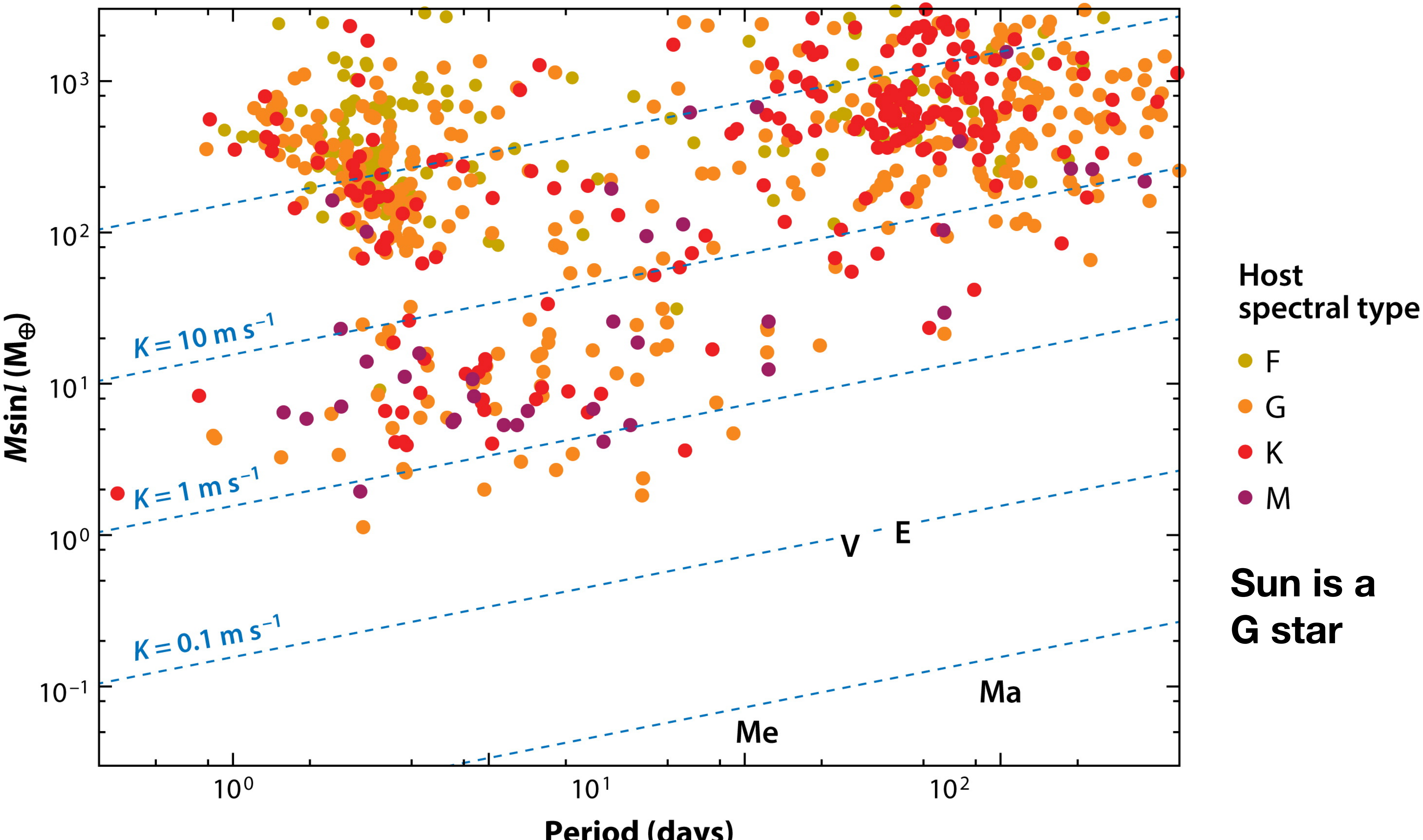
Rocky planets with atmosphere (today):
Venus: CO_2 (96.5%), N_2 (3.5%)
Earth: N_2 (78%), O_2 (21%), H_2O (1%)
Mars: CO_2 (95.3%), N_2 (2.7%)

Why Earth?

Moons with atmosphere (today), e.g.:
Titan: N_2 (95%), CH_4 (5%)



Exoplanets



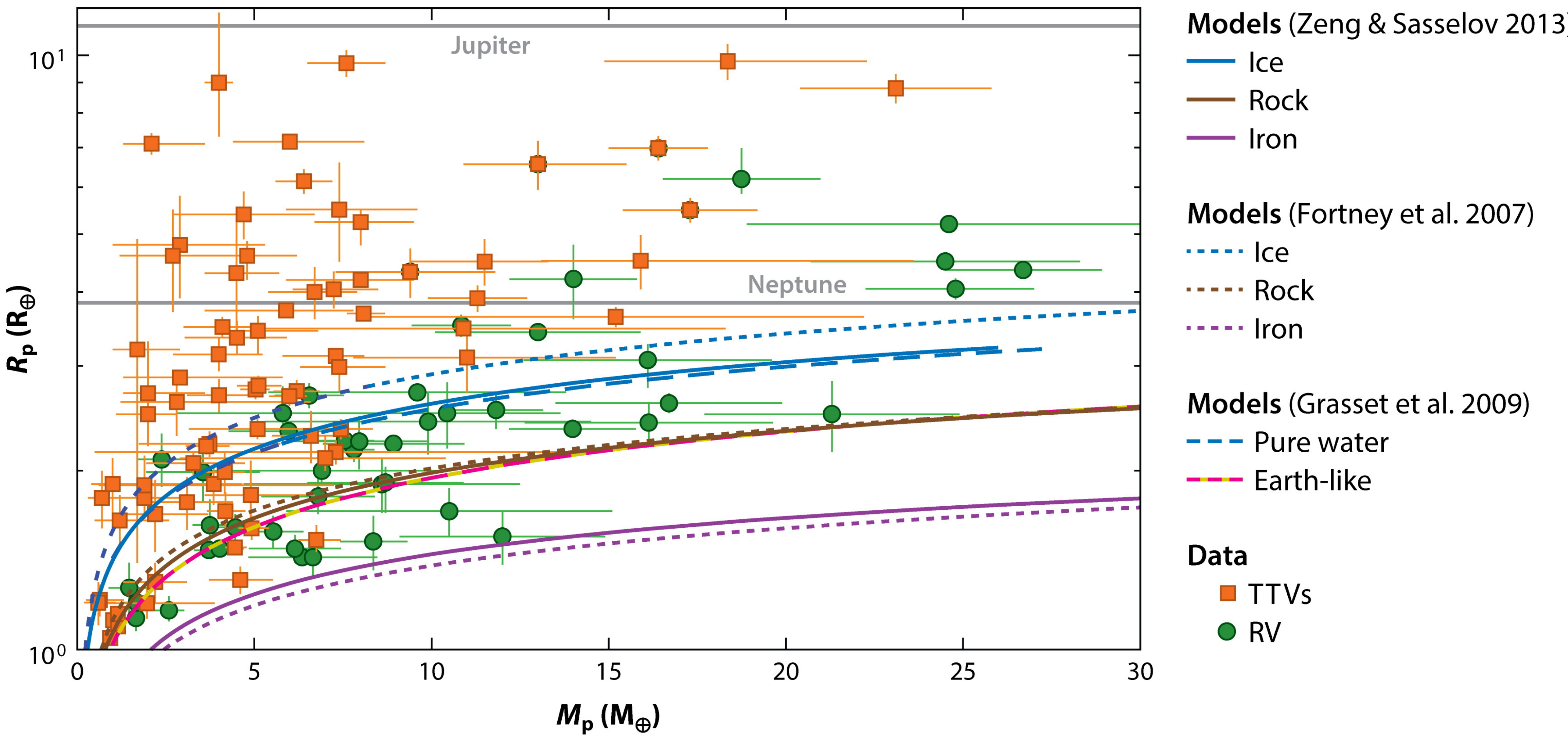
Sun is a G star

Jontuf-Hutter, 2019

Jontof-Hutter D. 2019.
Annu. Rev. Earth Planet. Sci. 47:141–71

Exoplanets have **host stars of many spectral types** — the first discovered exoplanet orbits a pulsar (Wolszczan & Frail 1992).

Exoplanets

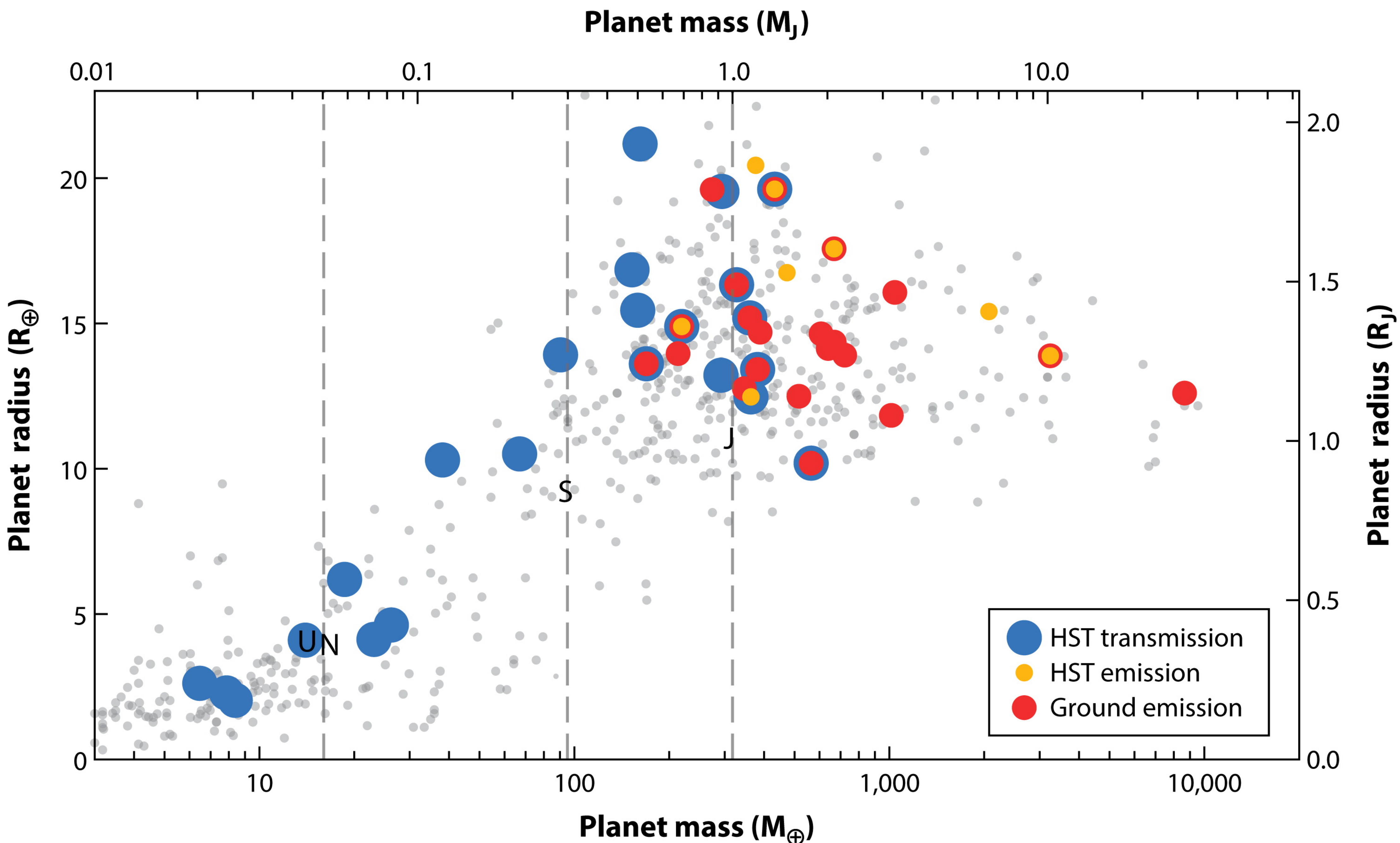


Jontuf-Hutter, 2019

Jontof-Hutter D. 2019.
Annu. Rev. Earth Planet. Sci. 47:141–71

Large variety of exoplanet masses and radii is observed. Mass-radius relation allows to guess composition of exoplanets.

Exoplanets - Atmospheres

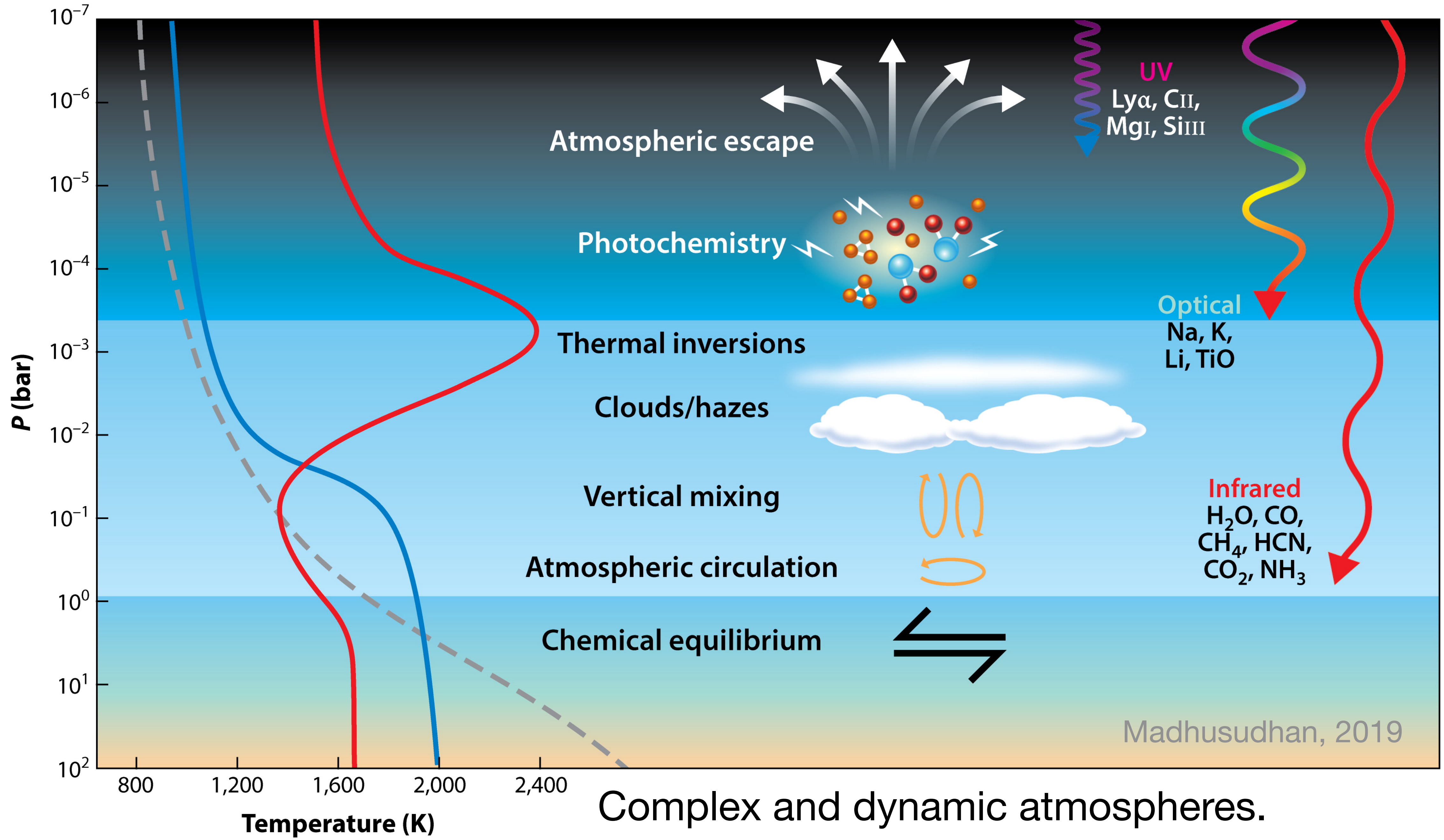


Madhusudhan, 2019

Madhusudhan N. 2019.
Annu. Rev. Astron. Astrophys. 57:617–63

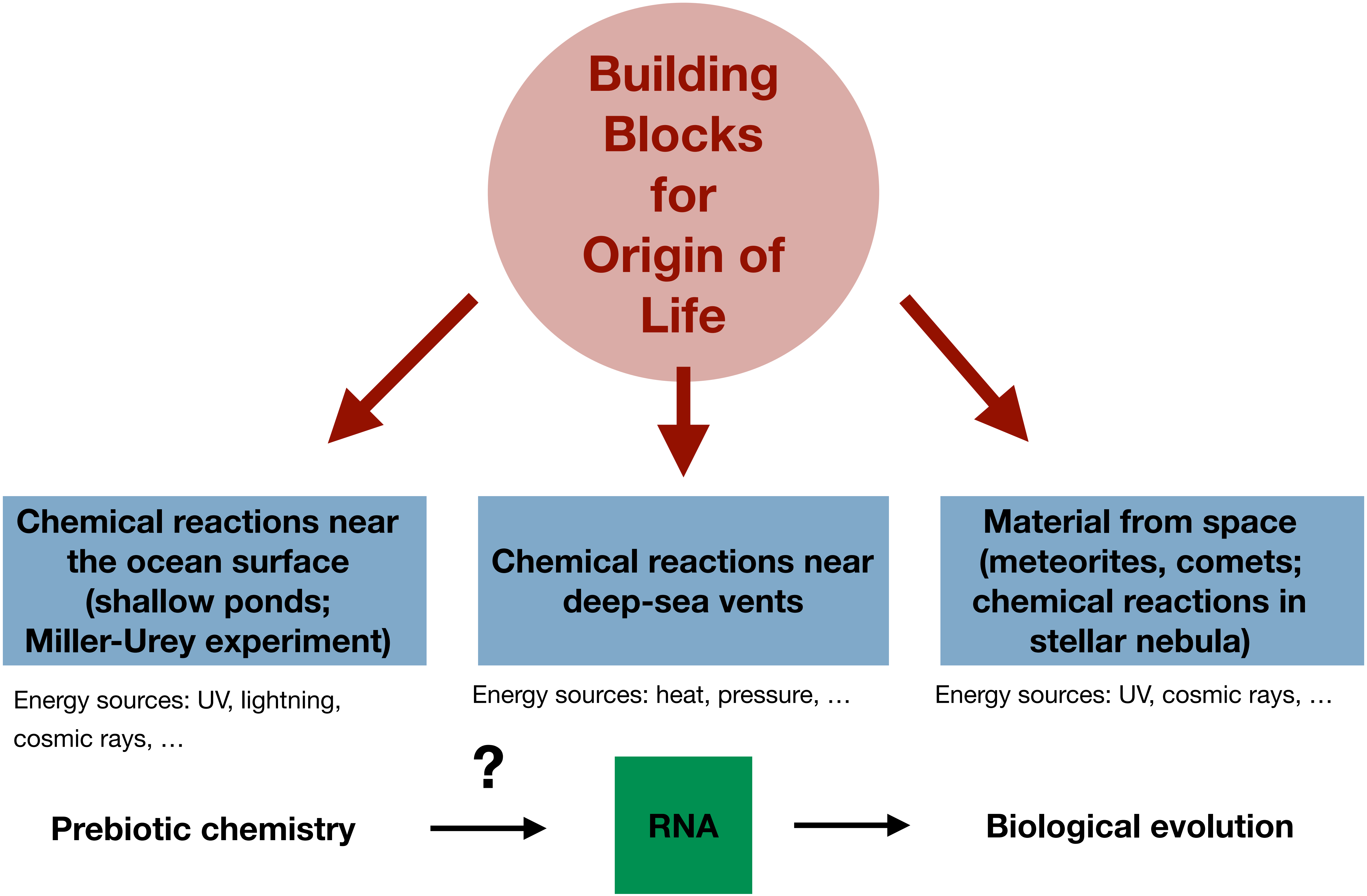
IR spectroscopy can reveal exoplanet atmospheres — mainly gas planets, so far

Exoplanets - Atmospheres

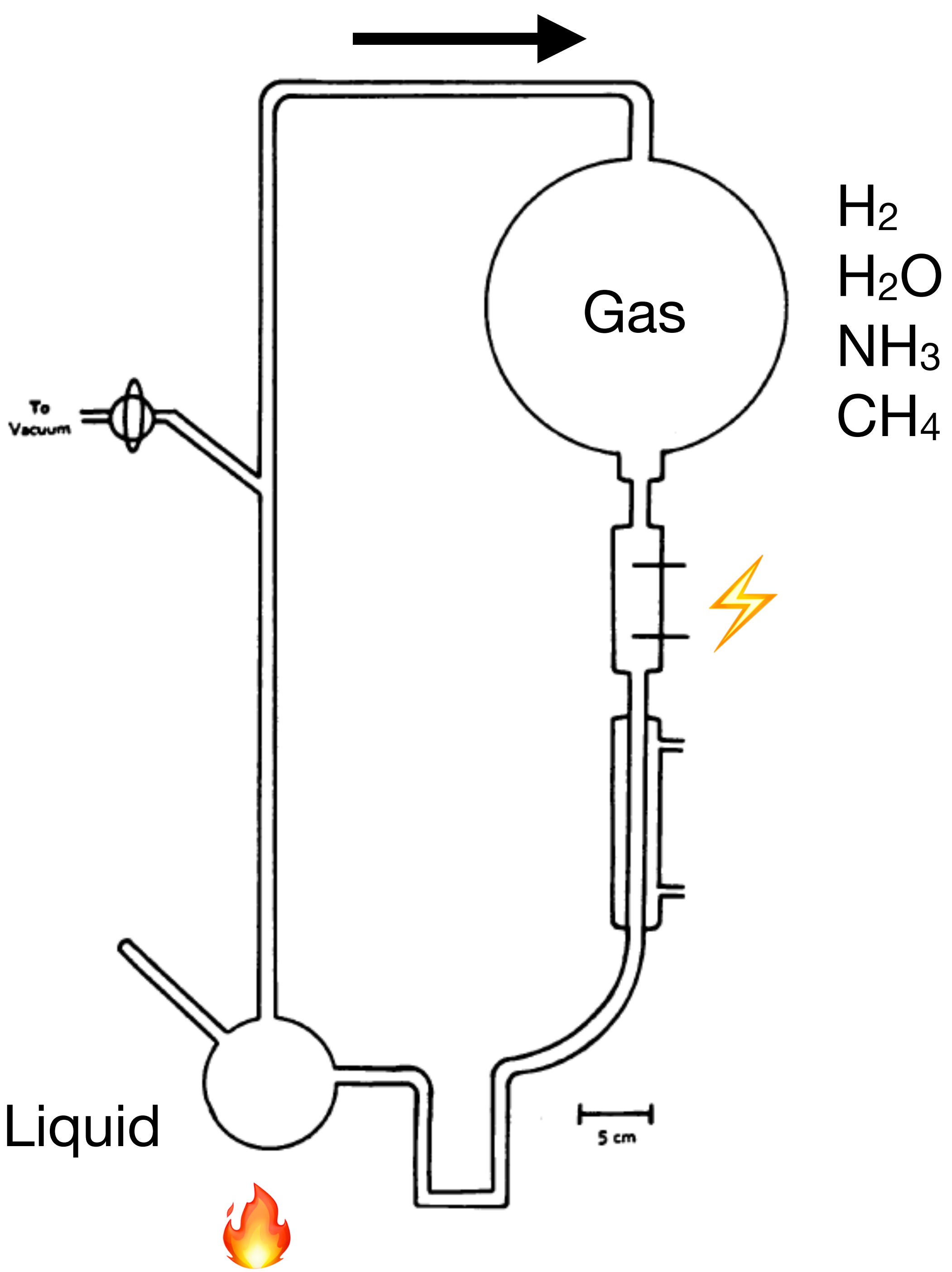


Madhusudhan N. 2019.
Annu. Rev. Astron. Astrophys. 57:617–63

Complex and dynamic atmospheres.
Models start from what is known from geo sciences.
Primeval atmosphere of Earth was reducing or neutral.
Oxygen is of biogenic origin.


Building Blocks for Origin of Life
Chemical reactions near the ocean surface (shallow ponds; Miller-Urey experiment)
Energy sources: UV, lightning, cosmic rays, …
Chemical reactions near deep-sea vents
Energy sources: heat, pressure, …
Material from space (meteorites, comets; chemical reactions in stellar nebula)
Energy sources: UV, cosmic rays, …
Prebiotic chemistry
?
RNA
Biological evolution

Miller-Urey and beyond



Miller, 1953

Raw material

↓

Monomers
(amino acids, sugars,…)

↓ **?**

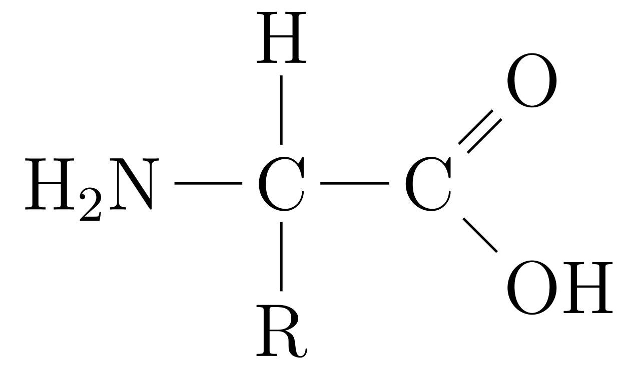
Polymerization
(chain molecules like nucleic acids, proteins,…)

Amino Acids and Sugars

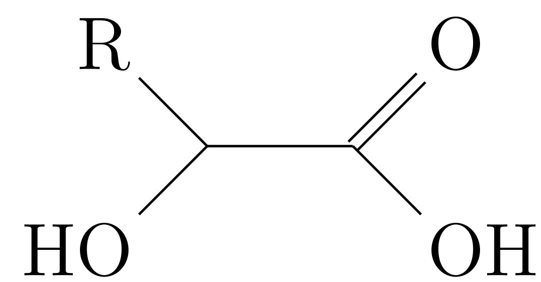
Strecker Synthesis

Needs H, C, N, O

Amino Acids



Hydroxy Acids

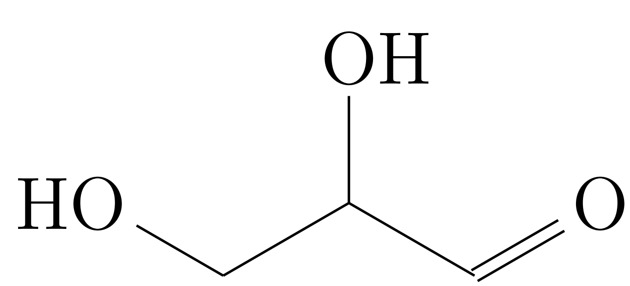


R = rest, specifies acid further

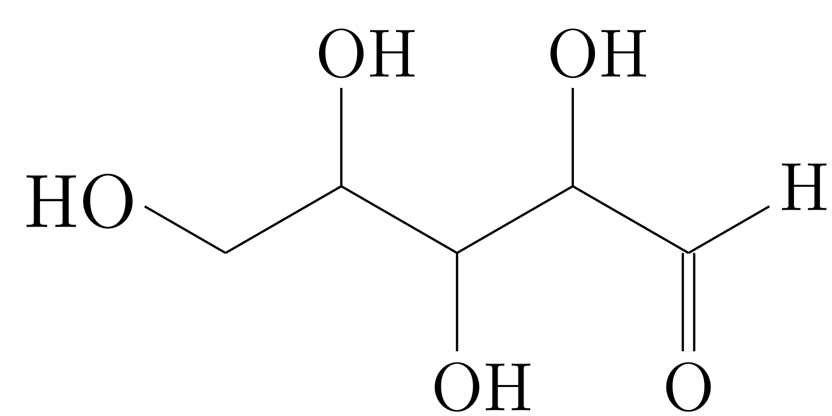
Formose Reaction → **Sugars**

Needs H, C, O

Glyceraldehyde

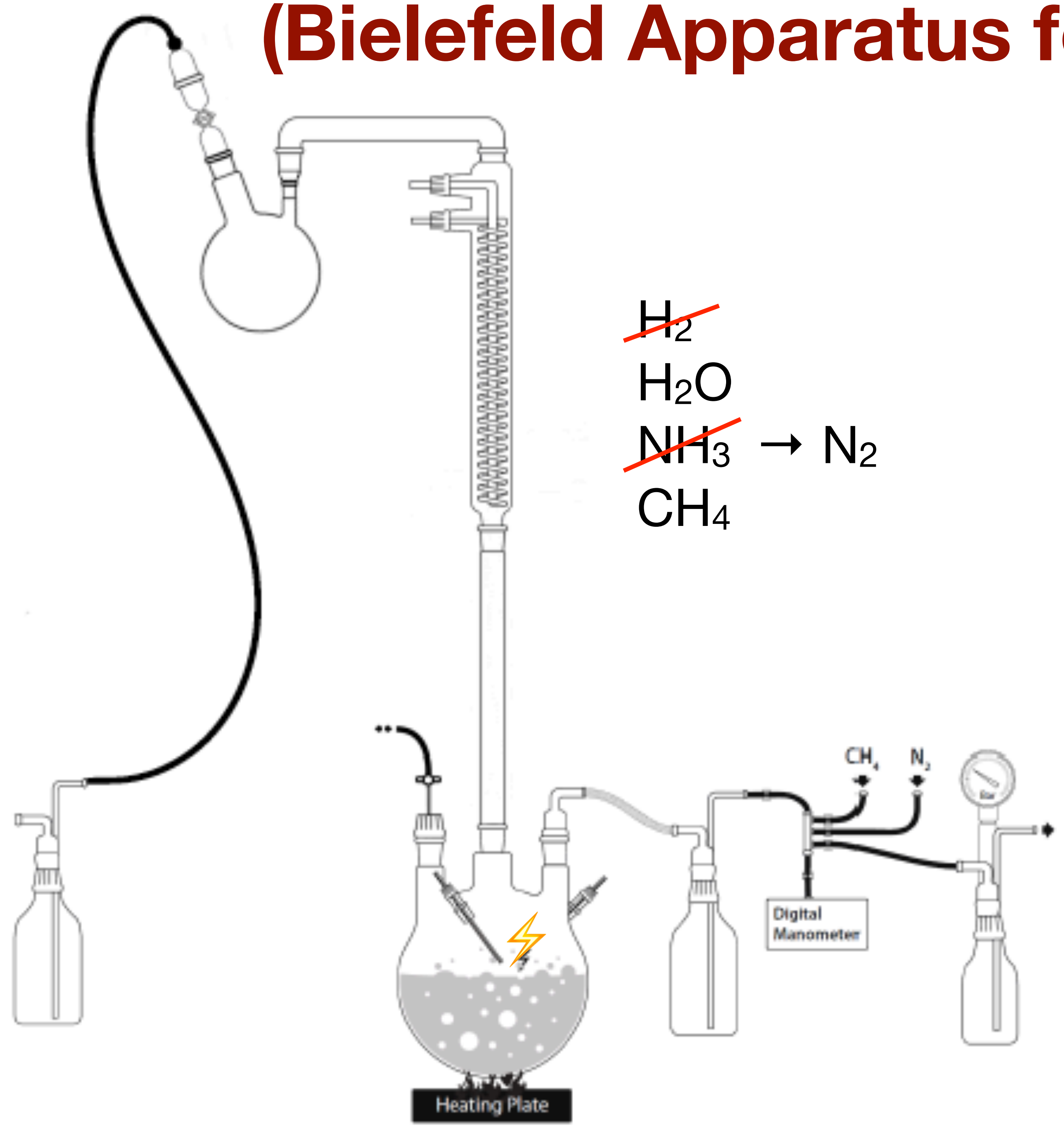


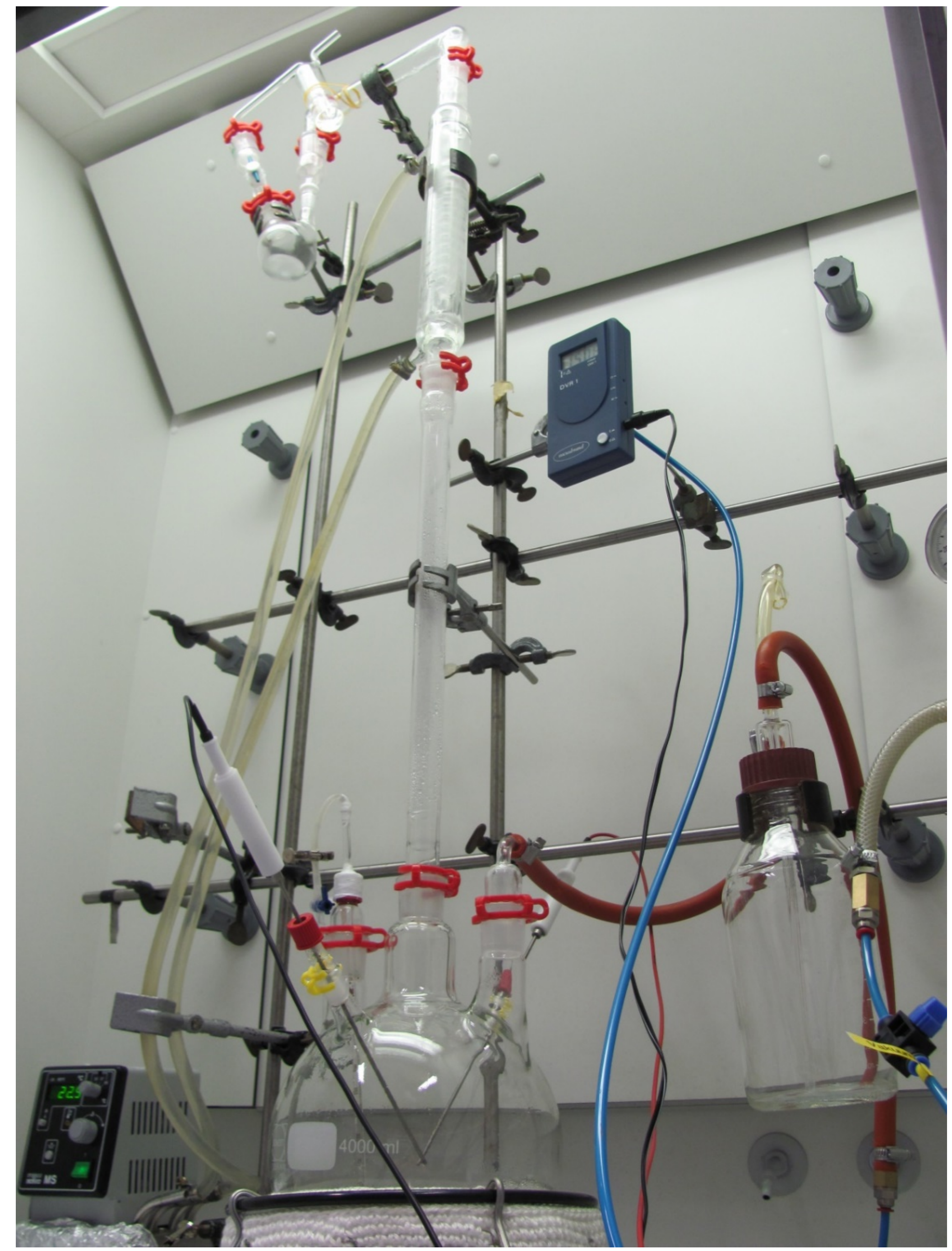
Ribose



BAPS

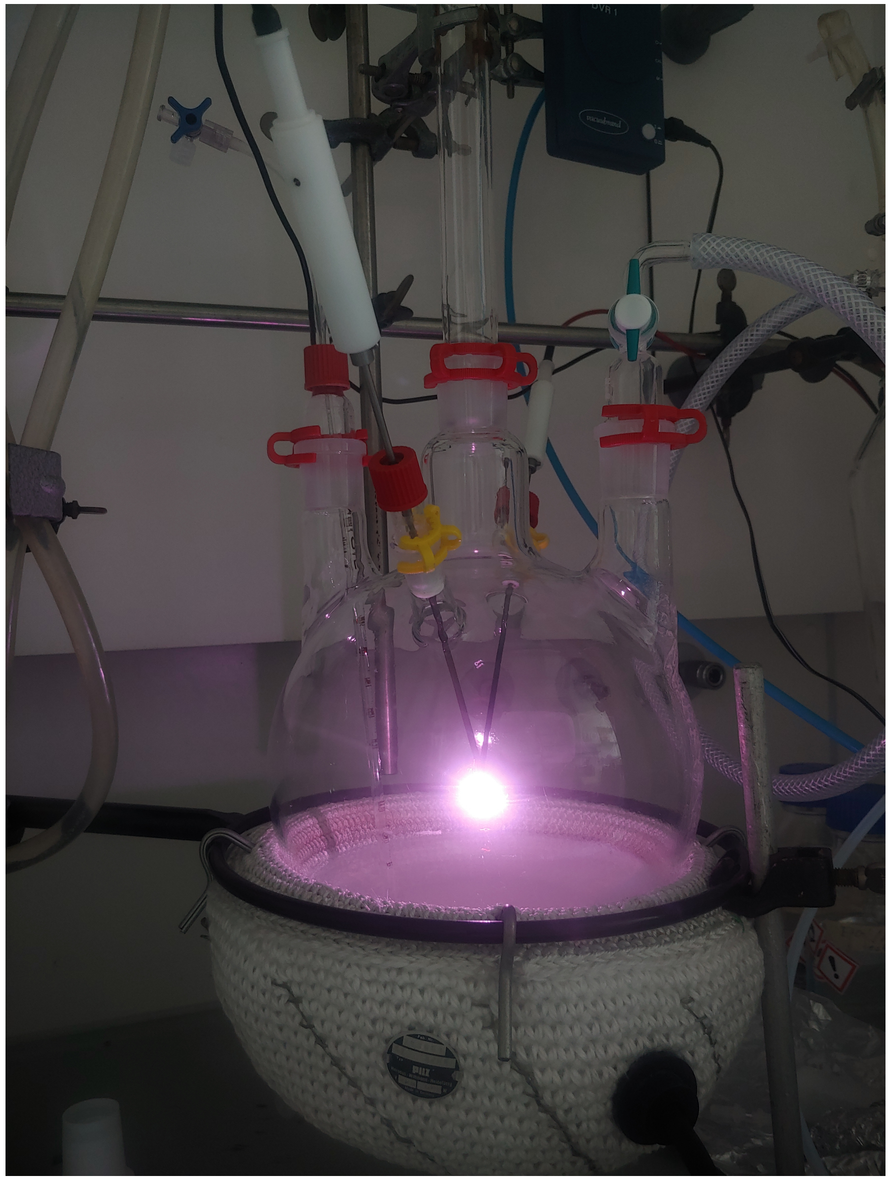
(Bielefeld Apparatus for Primordial Soup)





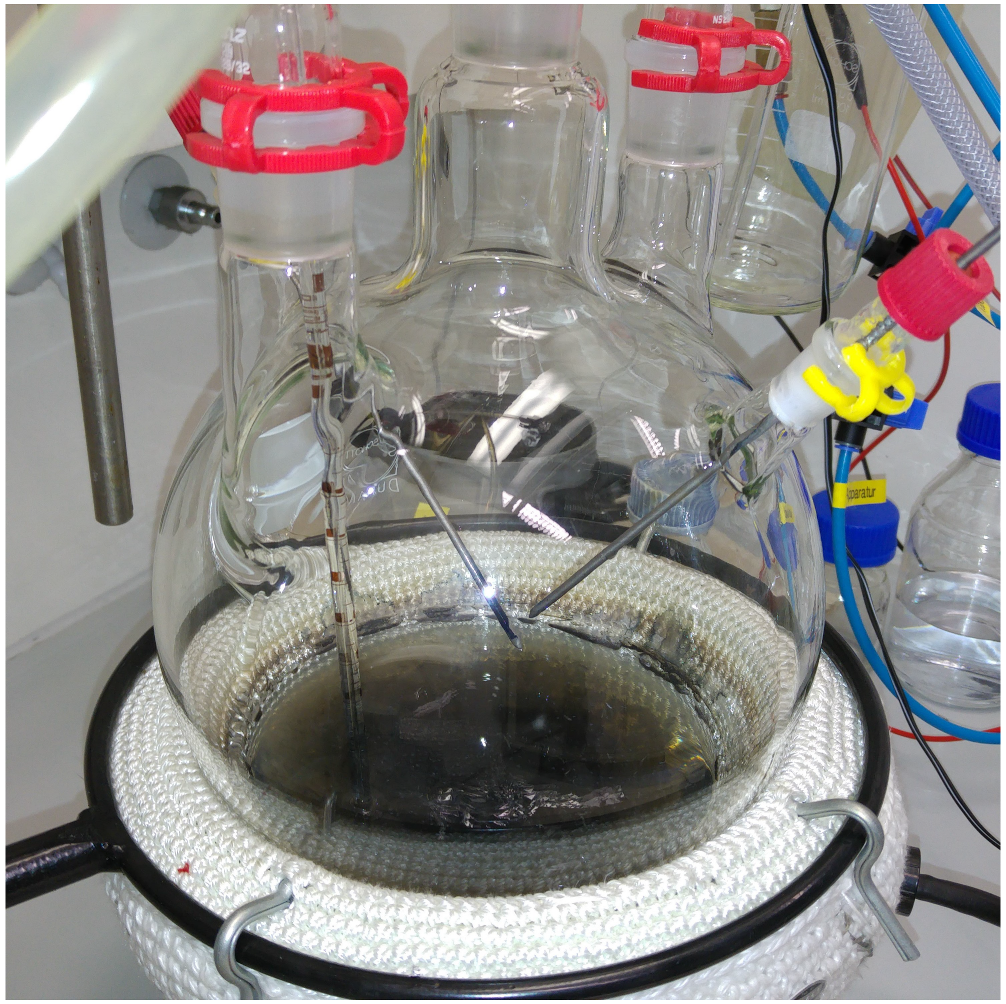
together with H. Bednarz, T. Mense, and K. Niehaus

Heat the mixture, add sparks, wait a few days…until



Sparking frequency: 1.5-2.5 Hz
Discharge at ~10 kV

…the soup is ready!

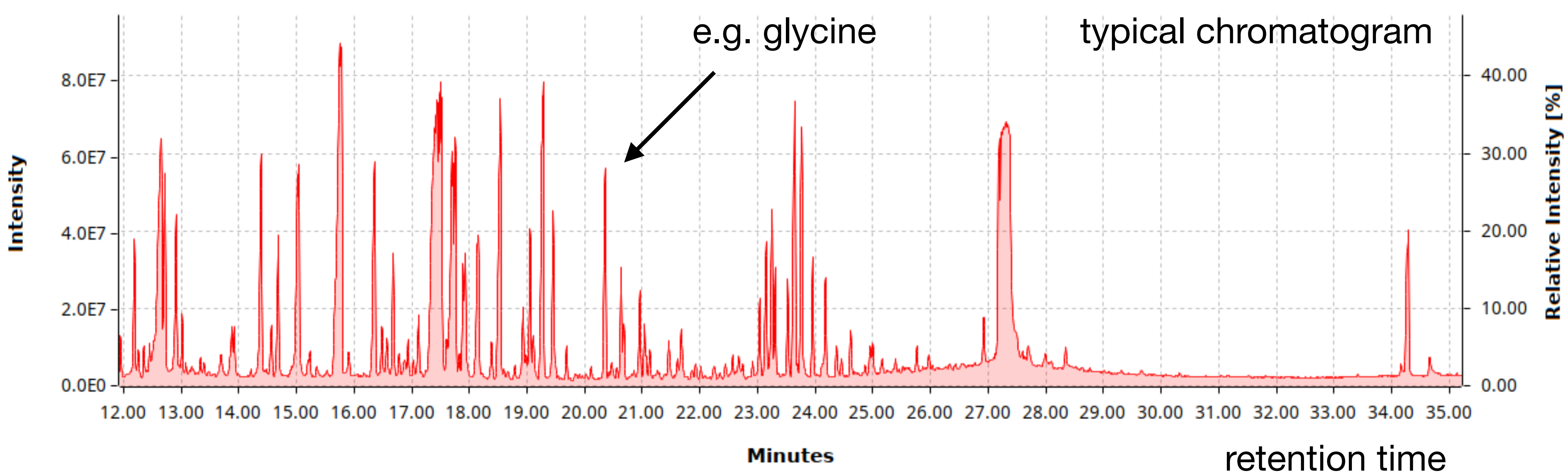


Experimental Runs and Analysis

Aim: Abiotic formation of building blocks for life,
we focus on **amino acids** and **sugars** (ribose forms backbone of RNA)

Experimental runs with different **gas mixtures** (methane, nitrogen),
with and without **catalyst** (montmorillonite clay).
Each run for 72 hours, and sampling after 1 and 72 hours

Analysis via **gas chromatography - mass spectrometry** (GC-MS)
Preparation for GC-MS: derivatisation to increase volatility and stability



Identified Substances

via gas-chromatography - mass spectrometry (GC-MS)

Amino acids: Glycine, beta-Alanine, Asparagine

Hydroxy acids: Glycolic acid, Lactic acid, Hydroxypropanoic acid, Glyceric acid, 2,4-dihydroxy-butanoic acid, Threonic acid

Sugars: Glyceraldehyde, Dihydroxyaceton, Erythrose

Dicarboxylic acids: Oxalic acid, Succinic acid, Malic acid

Others: **Boric acid**, Glyoxylic acid, Hydroxylamine, Ethanolamine, Glycerol, Lactic acid dimer

Selected Yields

Gas mix	CH_4	CH_4 & N_2	CH_4	CH_4 & N_2
Catalyst	—	—	Clay	Clay
Glycine	—	81 ± 12	—	419 ± 79
β-Alanine	—	—	—	145 ± 85
Glyceraldehyde	146 ± 24	884 ± 235	218 ± 55	498 ± 125
1,3-Dihydroxyaceton	165 ± 88	583 ± 141	1346 ± 397	2272 ± 671

Mense et al., in preparation

Concentrations given in nmol/l

CORSIKA and BAPS

What is the role of (exo-)air showers in the origin of life?

Cosmic rays and **(exo)air showers** could

— assist or thrive prebiotic chemical evolution

— destroy organic molecules and extinct life

CORSIKA could allow to extrapolate from lab experiments with exo-atmospheres to the effects of exo-air showers on various worlds

Conclusions

To study prebiotic evolution:
Combine lab experiments with observations and simulations

Miller-Urey like experiment: BAPS
Open set-up, just one flask, electric discharges, simple gases

GC-MS analysis: Protocol modified, boric acid problem handled

Results: A variety of building blocks for life identified
Higher sugar yields for gas mixture
Boosted yields with clay, favourable for amino acids

Search for ribose (pentose): Just precursors found (triose & tetrose)
Conjecture: Boric acid reacts with ribose

Further reading

S. Miller, *A production of amino acids under possible primitive earth conditions* Science **117** (1953) 528

J. Bennett & S. Shostak, *Life in the Universe* (Addison Wesley, San Francisco, 2012)

V. M. Kolb (editor), *Handbook of Astrobiology* (Routledge Handbooks Online, CRC Press, 2018)