X-rays, UV, and co: detrimental or beneficial to the origin of life?

Modelling the influence of stellar XUV-flux, cosmic rays, and stellar protons on the atmospheric composition of a hot Jupiter

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Abbreviated abstract: UV radiation and energetic particles are harmful for life, leading to the destruction of biomolecules. But has this always been the case? We investigate the effect of different types of high-energy radiation on the atmospheric chemistry of the hot Jupiter HD 189733b and their role in the production (or destruction) of prebiotic molecules. We find that these energy sources strongly increase the production of the amino acid glycine and its precursors such as formaldehyde and ethylene.

Related publications:

– Bourrier V., et al., 2020, MNRAS, 493, 559
– Lines S., et al., 2018, A&A, 615, A97
– Rimmer, P. B., & Helling, Ch. 2016, ApJS, 224:9, 33

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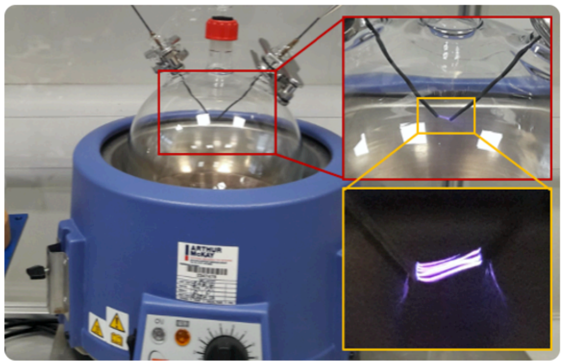
The Theory

We still can't fully explain how life started on Earth, but one very popular theory is Charles Darwin's *Warm Little Pond*: Lightning produces first organic molecules by braking up the strong bond of the N_2 molecule. These molecules rain out and accumulate in a small pond where they can form more complex, prebiotic molecules until at some point you have RNA.

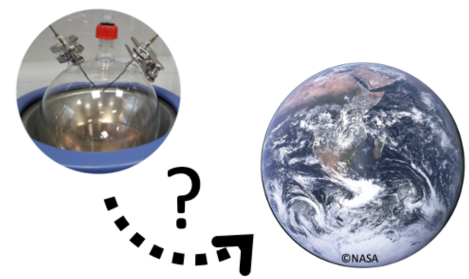


The Experiment

The Miller-Urey experiment (1952) was a famous experiment where electric sparks in a gas mixture of CH_4, NH_3, H_2 – that was believed to have been early Earth's atmosphere – formed amino acids such as glycine. We conduct a similar experiment, where we want to quantify the role of lightning in the production of prebiotic molecules in different kind of atmospheres.

The Problem

We try to simulate what happened on the surface of the Earth over millions of years and at various temperatures and pressures in a small lab experiment. To bridge the gap between experiment and reality, we simulate the atmospheric chemistry with a computer code. In addition to lightning (which is not yet included), we also take other, external energy sources into account.



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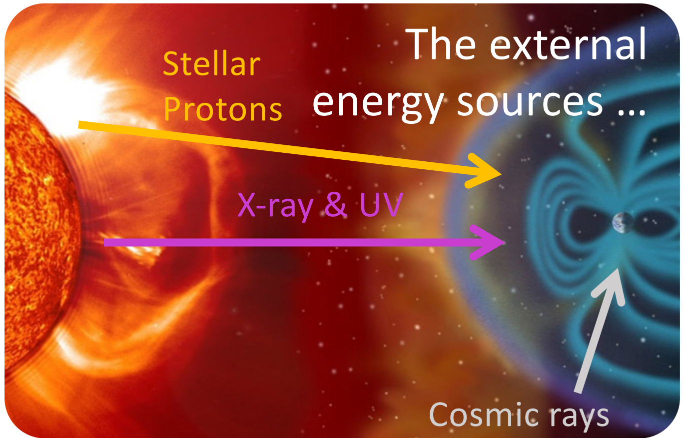
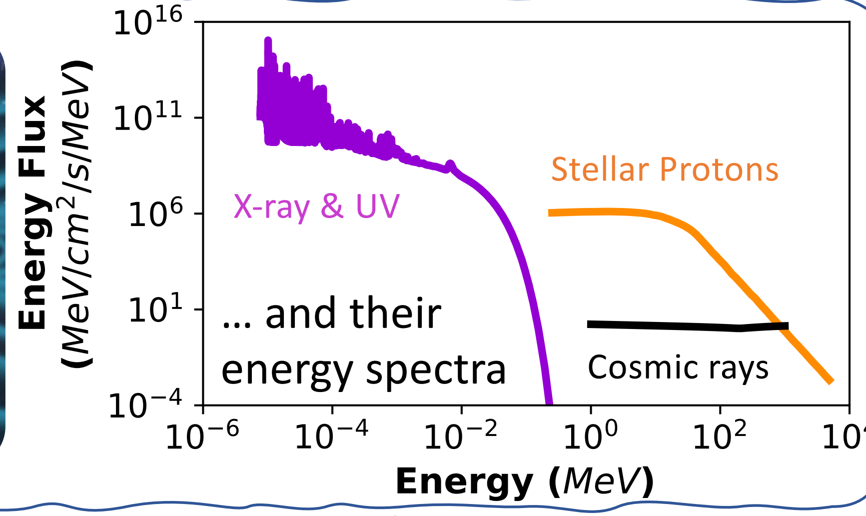
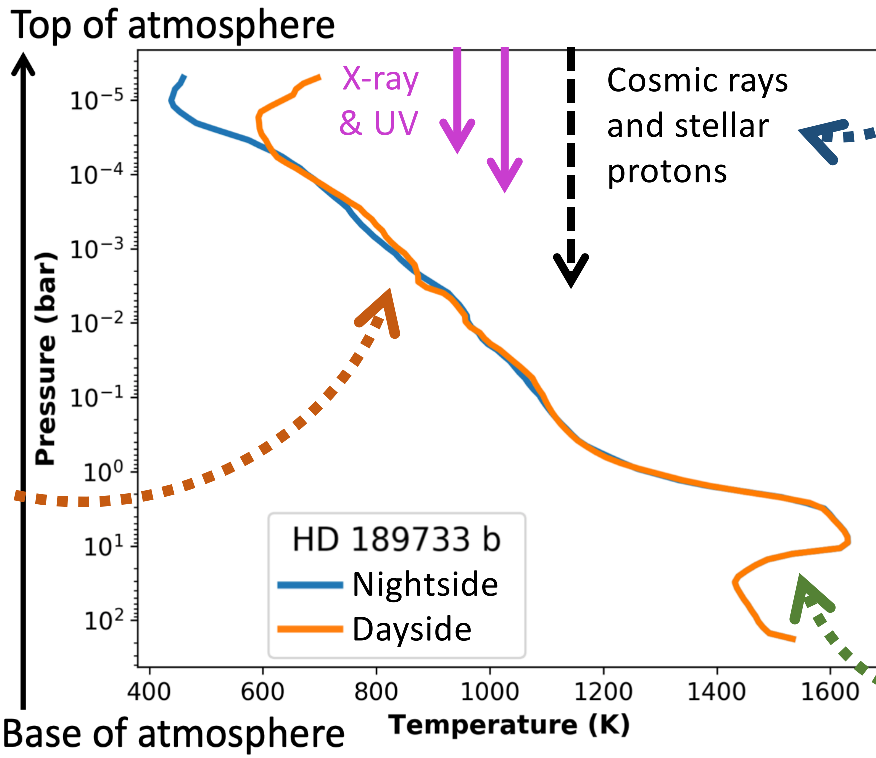
The Method

We apply a chemical network on the simulated atmosphere of an exoplanet to study the effect of different types of high-energy radiation on the chemistry. The X-ray/UV spectrum is based on observations of the host star, the proton spectrum on an X-ray flare observation and comparison to the sun, the cosmic rays on measurments by the Voyager probe.



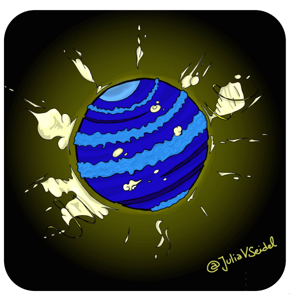




The Planet:

Hot Jupiter HD 189733b

Temperature structure from 3D simulations including cloud formation



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The network: STAND2020

H/C/N/O network
284 neutral molecules + 222 ions
Complete up to 6H, 2C, 2N, & 3O
5741 reactions
Embedded into 1D photochemistry and diffusion code ARGO

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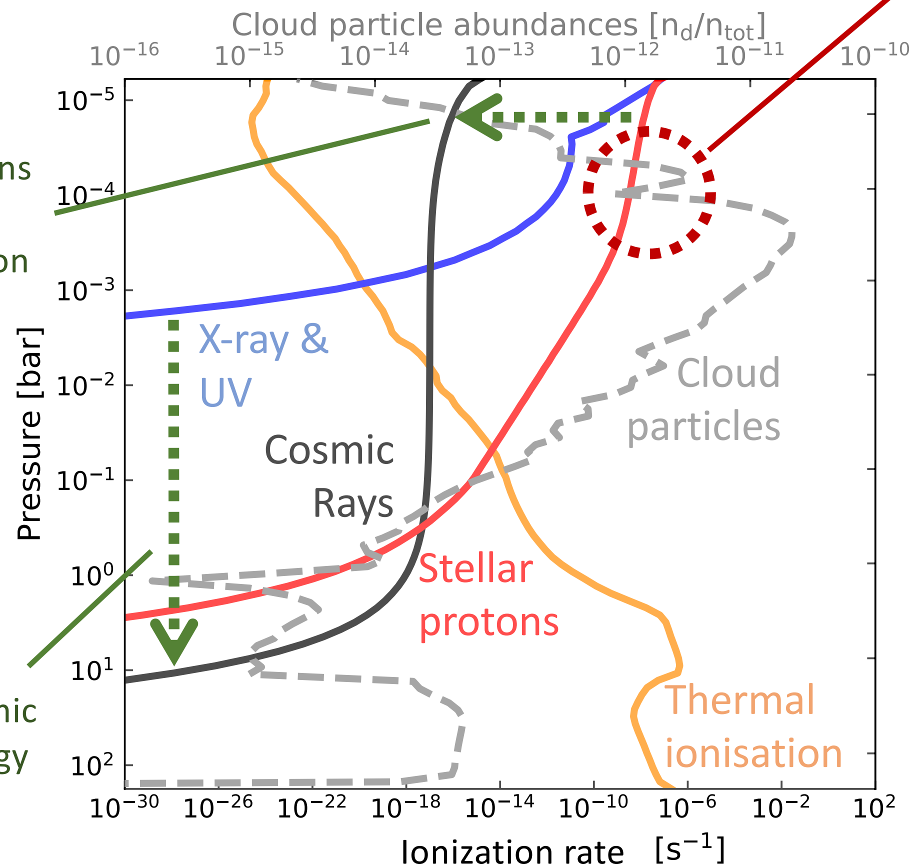
Results and Conclusions

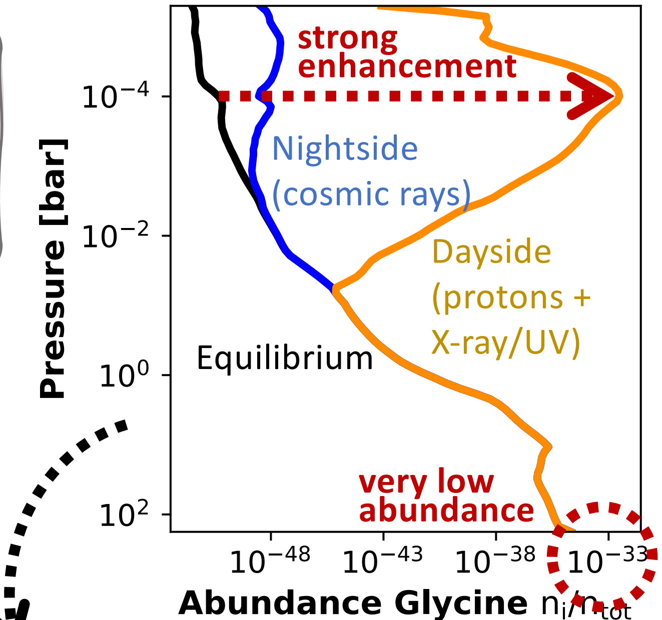
Ionization rates of different sources in comparison to cloud position show strong effect of energetic particles and suggest presence of lightning

High ionization + abundant clouds → prerequesists for lightning

Cosmic ray flux lower than protons and X-ray/UV → lower ionization rate



Protons and cosmic rays: higher energy than X-ray & UV → can reach deeper layers



All radiation sources enhance Glycine (amino acid) production but overall extremely low abundance

Glycine precursors HCN, Ethylene (C_2H_4), and Formaldehyde (CH_2O): more abundant, potentially observable, & similarily enhanced by radiation → Signatures of prebiotic synthesis

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