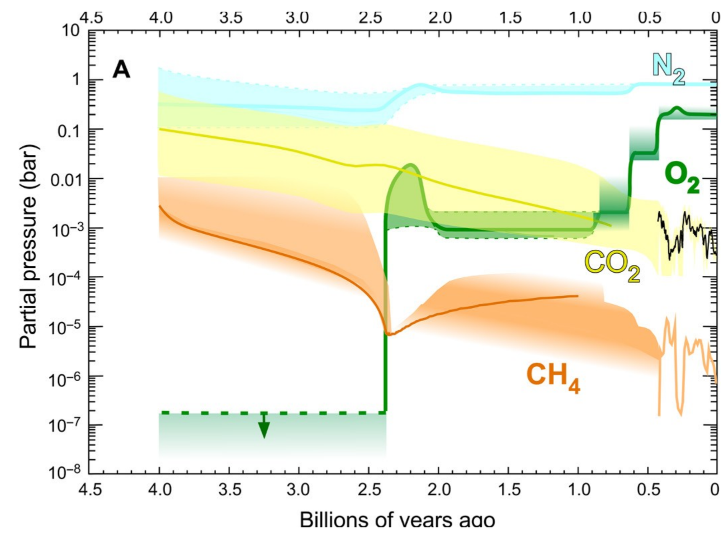
Possible favored Great Oxidation Event scenario on exoplanets around M-Stars with the example of TRAPPIST-1e

A. Y. Jaziri[1,2], N. Carrasco[1,3], B. Charnay[4]

[1] LATMOS/IPSL, UVSQ Universit Paris-Saclay, Sorbonne Universit, CNRS, Guyancourt, France.
[2] LAB, Univ. Bordeaux, CNRS, B18N, allée Geoffroy Saint-Hilaire, 33615 Pessac, France.
[3] ENS Paris-Saclay, Université Paris-Saclay, Gif-sur-Yvette, 91190, France.
[4] LESIA, Observatoire de Paris, Université PSL, CNRS, 5 Place Jules Janssen, 92190 Meudon, France

Context

Around 2.4 billion years ago, Earth underwent the **Great Oxidation Event** (GOE), a major atmospheric transition in which oxygen levels rose sharply, likely due to ozone formation reducing oxygen loss through methane oxidation; however, the exact mechanisms and timing remain uncertain because of limited geological constraints and competing hypotheses. This study investigates whether a similar oxygenation event could occur on exoplanets by modeling atmospheric evolution on TRAPPIST-1 e, exploring how its M-dwarf stellar environment may alter oxygen–ozone feedbacks and the detectability of ozone.



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Results

Fig.1 – **Methane oxidation** cycle and net reaction.

Atmospheric O_2 loss is mainly controlled by methane oxidation driven by **OH radicals**, which in this study are shown to **originate primarily from H_2O_2 photolysis** rather than directly from H_2O photolysis.

As ozone accumulates, it blocks the UV radiation needed for H_2O_2 and formaldehyde photolysis, reducing methane oxidation and creating a positive feedback that drives the rapid rise in atmospheric oxygen during the GOE.

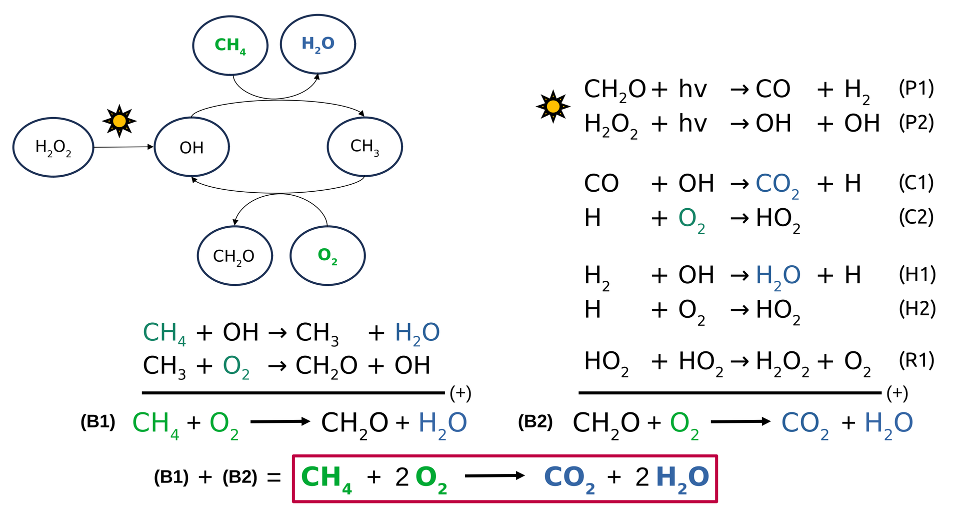


Fig.2 – Ozone profiles in mass mixing ratio (mmr).

Using the **Generic Planetary Climate Model**, this study **simulates a GOE–like transition on TRAPPIST-1 e** under early Earth conditions while accounting for its **different stellar environment** and planetary properties. The results suggest that stronger UV-driven photochemistry promotes earlier and **greater ozone formation than on Earth**, potentially creating surface ozone levels that could challenge the development of an Earth-like biosphere.

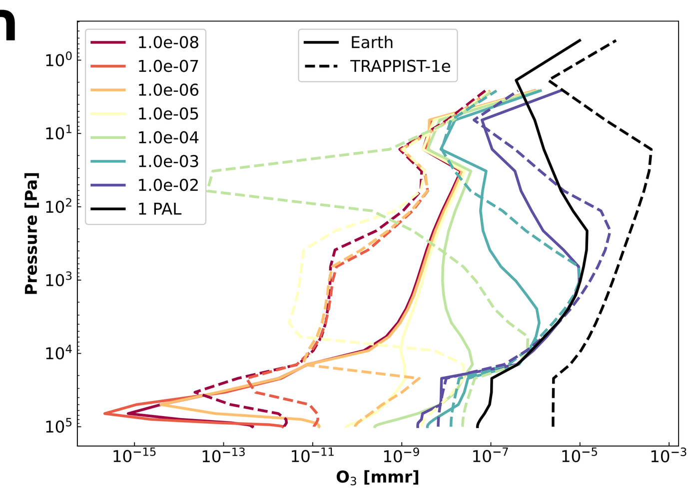


Fig.3 – Oxygen and methane vmr VS time.

Methane oxidation is the main sink of atmospheric O_2, but on TRAPPIST-1 e enhanced ozone formation strengthens UV shielding, reduces methane oxidation, and allows atmospheric oxygen to accumulate more easily. As a result, a **GOE–like transition could occur up to about 1 billion years earlier than on Earth**, potentially enabling earlier development of oxygen-rich conditions and aerobic life.

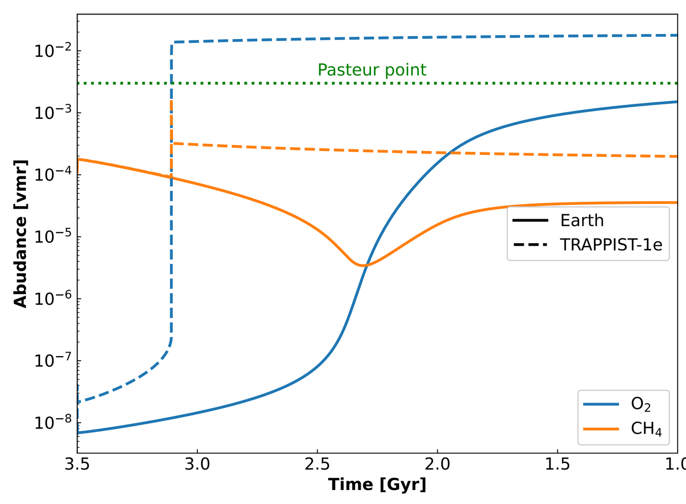
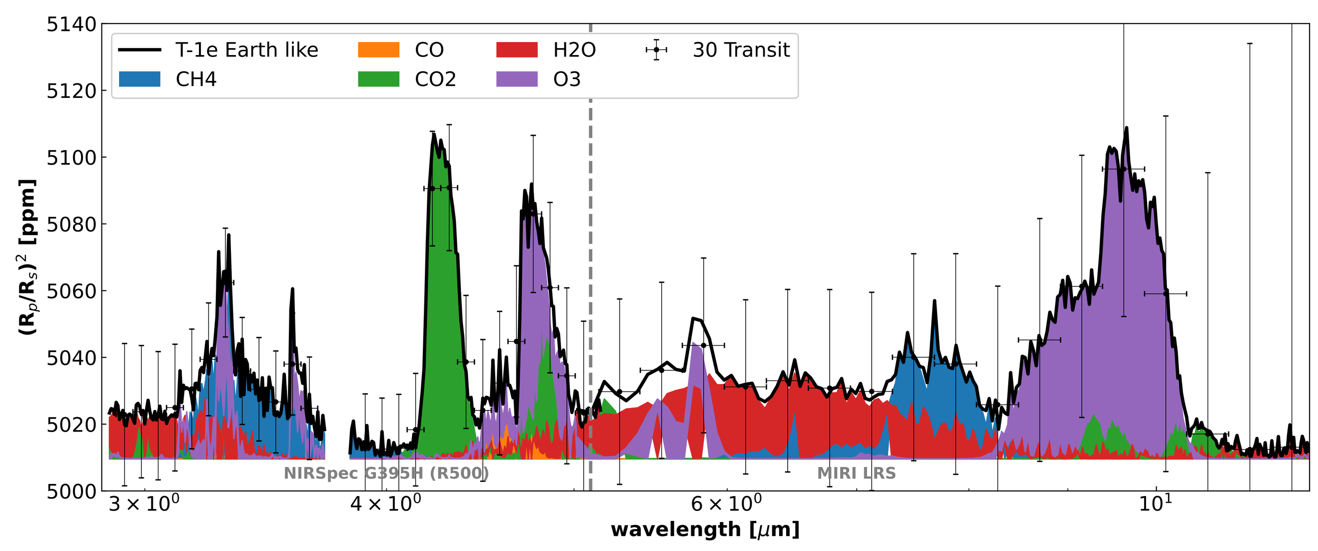
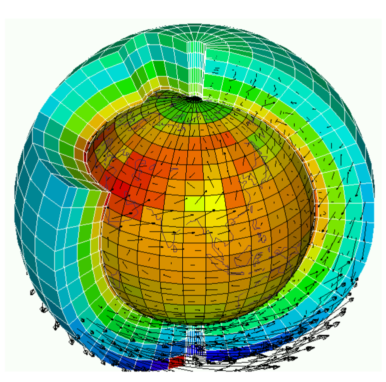


Fig.4 – TRAPPIST-1e transmission spectra



Simulations suggest that the strong ozone abundance expected on TRAPPIST-1 e could make O_3 detectable with the JWST, including through a **newly identified spectral feature at 4.6 μm** that may outperform the traditional 9.7 μm signal. Under optimistic assumptions, **O_3 could be detected in about 25 transits with NIRSpec G395H**, although stellar contamination and spectral overlap could raise the requirement closer to 50 transits for a robust detection.

Futur work



Futur work extends those studies with **fully coupled 3D climate-chemistry simulations**, allowing atmospheric circulation, clouds, and spatially varying **photochemistry** du to **tidally locked effects** to be included and providing the first systematic comparison of 1D and 3D predictions for a GOE on Earth-like planets around M-dwarfs.

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