Archean Analogue Photochemistry Across the Habitable Zone

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Why the Archean?

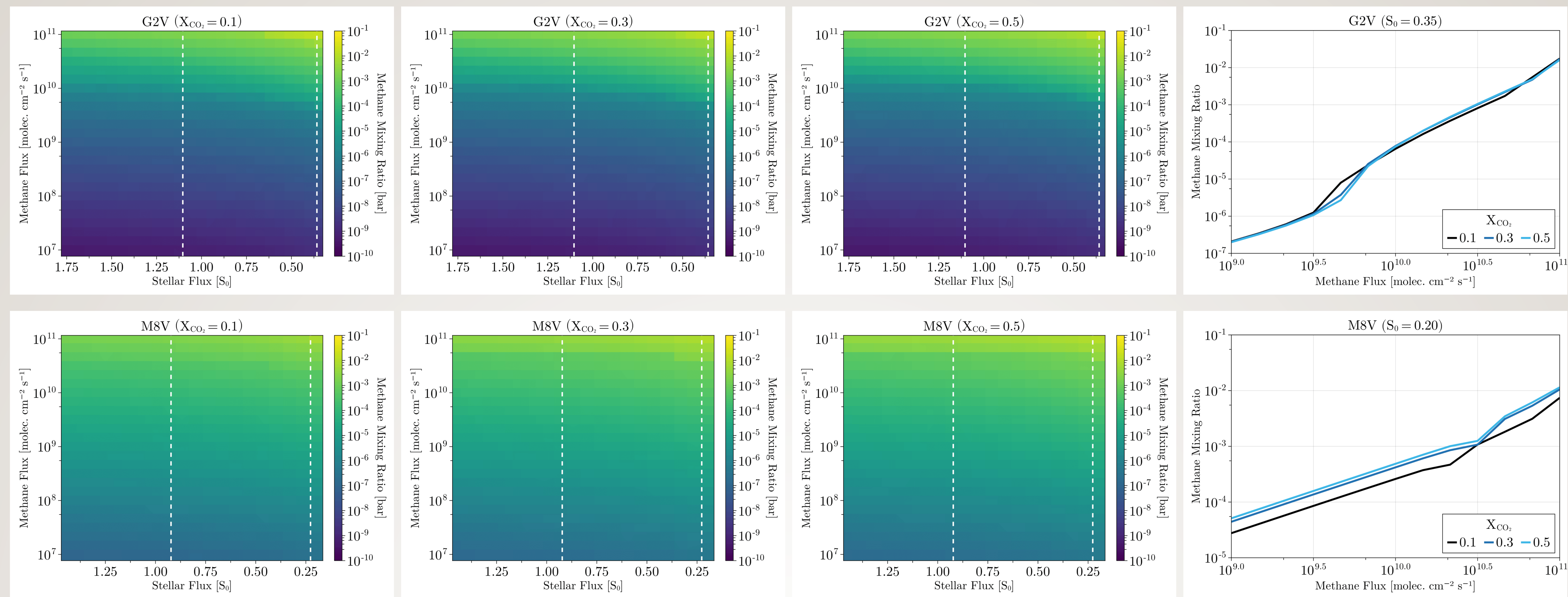
The Archean Eon, from 4.0 to 2.5 Gya, was marked by the spread of prokaryotes. During this time before the Great Oxidation Event, the Earth had a slightly reducing atmosphere with significant concentrations of methane. The organisms that created this large amount of methane are still prevalent today. However, most methane that is released today is rapidly broken down.

New and future telescopes will be used to characterize terrestrial planets in nearby star systems. *JWST* can monitor planets orbiting M-dwarf stars, while the upcoming *Habitable Worlds Observatory* will measure reflected light from directly imaged planets orbiting F, G, and K stars.

Methane has a strong near-infrared reflectance signature from 1.64 – 1.78 μm. Previous studies have determined that methane may be detectable using direct-imaging instruments in 10+ hours of observation [1].

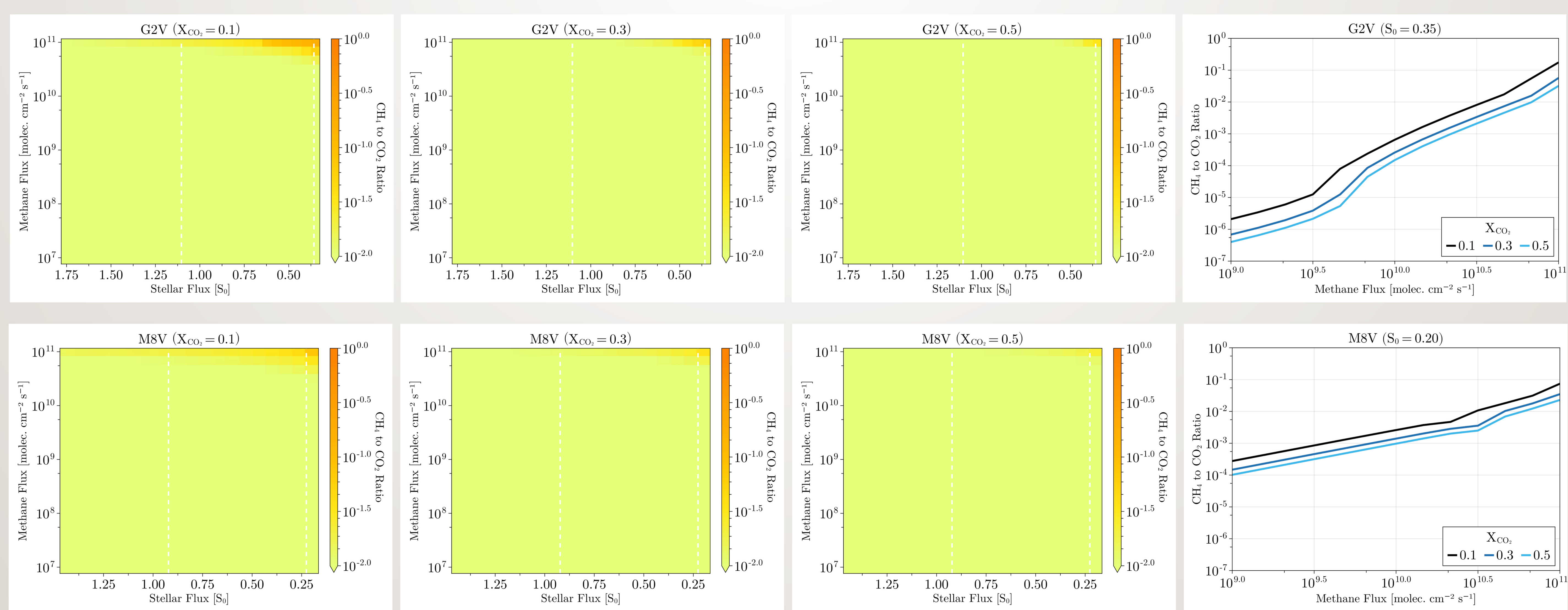
CH_4 is photolyzed when exposed to CO_2. Thus, a simultaneous observation of both gases implies a strong methane flux from the surface, forming a powerful biosignature with connections to the early Earth. Previous studies have studied its atmospheric lifetime and detectability, but research into its detectability using upcoming telescopes and new techniques is necessary. This includes searching for CH_4 throughout the entire Habitable Zone.

Surface Methane Mixing Ratios



Surface Methane Mixing Ratios are plotted as a function of stellar flux, methane flux, and carbon dioxide mixing ratio. The dashed white lines represent the edges of the conservative habitable zone [2]. The G2V star example is based on flux measurements of the Sun [3]. The M8V star is based on flux measurements of TRAPPIST-1 [4]. Impacts relating to stellar flux are modest, and M dwarfs planets sustain more methane than G dwarfs smaller methane fluxes.

What About Haze?



Organic particles polymerize to form hazes once the methane to carbon dioxide ratio exceeds 0.1 [5]. For our atmospheres, only planets that were located near the far edge of their habitable zone and had large methane fluxes formed near-surface hazes.

Base Model Parameters

Model: atmos photochemistry

The following parameters were used for all runs unless otherwise noted:

- Ar Partial Pressure = 0.01
- CO_2 Mixing Ratio = 0.5
- Planet Radius = Earth Radius
- Stellar Age: Present Age
- Stellar Flux = Modern Earth level
- Surface Albedo = 0.25
- Surface Gravity = 980.7 cm s^{-2}
- Surface Pressure = Modern Earth
- Tropopause Height = 1.3 · 10^6 cm

Next Steps

Other star types will soon be modeled to determine how atmospheric methane is retained within different star systems.

We will also iterate over other metrics, including:

- Planet Radius
- Stellar Age
- Surface Gravity

Future work will better determine the duration and observability of both hazes and atmospheric biosignatures.

Synthetic spectra will also be generated to determine the likelihood of detecting this biosignature pair.

We also anticipate running new climate calculations to better determine the habitability of planets with high methane concentrations.

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