Development of a photochemical model for estimating atmospheric glycolaldehyde production on early Mars

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Mars, our neighboring planet, currently exhibits cold and dry conditions, making its surface appear uninhabitable. Despite its present conditions, geomorphological and geochemical evidence indicates that early Mars would have been favorable for the existence and persistence of liquid water (e.g., Wordsworth, 2016). Moreover, recent Mars missions such as the Curiosity rover have detected various types of organic matter (Eigenbrode et al., 2018), which may provide valuable insights into the prebiotic chemistry and habitability of early Mars. However, the origins of this organic matter remain uncertain.

One promising scenario involves the atmospheric synthesis of organic precursors under early Martian conditions, subsequently advancing through the formose reaction. This reaction leads to the formation of sugars and amino acids and is more efficient in the presence of formaldehyde, glycolaldehyde, and ammonia (Breslow, 1956; Ono et al., 2024). Koyama et al. (2024a,b) showed a continuous supply of H2CO on the Martian surface in a dense CO2-dominated early Martian atmosphere with a higher CO and H2 concentrations.

On the Earth, the atmospheric production of glycolaldehyde was estimated (Harman et al., 2013). Due to its lower volatility compared to formaldehyde, glycolaldehyde could have accumulated in prebiotic environments, thereby facilitating the synthesis of complex sugars (Hirakawa et al., 2025). In contrast, the atmospheric production of glycolaldehyde on early Mars has not been previously estimated, leaving an unresolved aspect in our understanding of Martian prebiotic chemistry.

In this study, we develop a 1D photochemical model based on PROTEUS (Nakamura et al., 2023; Koyama et al., 2024a) to evaluate the production of glycolaldehyde on early Mars. Assuming a thick, CO2-dominated atmosphere enriched with CO and H2, our model simulates a photochemical reaction network involving N-bearing in addition to H-, C-, and O-bearing species. We then estimated the production of glycolaldehyde at various altitudes within this background. Furthermore, by varying the concentrations of CO, H2, and other relevant species, we explored a range of atmospheric scenarios to assess their influence on the chemical pathways and abundances of the key species required for an efficient formose reaction.

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