A massive primordial atmosphere on early Mars

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Abstract

Mars formed very rapidly, within the first 4 Myrs of the solar system, while the gaseous disk surrounding the Sun was still present. Geochemical analyses of noble gases on Mars indeed indicate that the planet acquired its primordial atmosphere directly from this solar gas reservoir. Subsequently, a phase of dynamical instability among the giant planets led to a bombardment of comets into the inner solar system, including Mars. However, unlike Earth, we do not detect a cometary noble gas signature in the present-day Martian atmosphere. This is surprising and suggests that the primordial Martian atmosphere, acquired from the solar gaseous disk, was sufficiently massive to dilute later cometary contributions.

By quantifying the mass of cometary material efficiently retained on Mars, we place a lower bound on the mass of the primordial Martian atmosphere. To test the robustness of our conclusions, we use cometary bombardment data from two independent studies conducted within a solar system evolutionary model consistent with its current structure.

Our calculations show that, even under the most conservative scenario, the minimal mass of the primordial Martian atmospheres would yield a surface pressure of no less than 2.9 bar. Such a massive nebular envelope is consistent with recent models in which atmospheric capture is strongly enhanced by the presence of heavier species on Mars - due to outgassing or redox buffering with a magma ocean.

As this primordial Martian atmosphere originated from the solar gas disk, it was mainly composed of hydrogen (H_2). These results, published in Joiret et al. (2025, *EPSL*), have important implications for the habitability of Mars during the Noachian.