Martian Atmospheric Ion Energization And Escape During The 2022 Disappearing Solar Wind Event: A Hybrid Simulation Study.

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Résumé

Mars has experienced substantial atmospheric loss, largely attributed to the absence of a global intrinsic magnetic field. Without such shielding, the solar wind can interact directly with the upper atmosphere, driving ion escape processes that progressively deplete the atmosphere. This long-term erosion has reduced the planet's capacity to maintain a stable climate and is thought to have contributed to the disappearance of liquid water from its surface.

Extreme solar wind events-such as Coronal Mass Ejections (CMEs), Corotating Interaction Regions (CIRs), and radially oriented Interplanetary Magnetic Field (radial IMF)-can significantly modify the plasma environment around Mars and enhance the energization and escape of atmospheric ions. Because these extreme conditions were likely more frequent and intense in the early Solar System, studying such events provides insight into the historical evolution of the Martian atmosphere.

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In this work, we investigate the response of atmospheric ions during extreme solar wind conditions, focusing on the 2022 "Disappearing Solar Wind" (DSW) event associated with a CIR, during which the solar wind density decreased by more than an order of magnitude. Simulations are performed using the latest Latmos Hybrid Simulation (LatHyS) model, in which ions are treated as macro-particles obeying Newtonian dynamics while electrons are modeled as an inertialess fluid. We analyze how variations in solar wind density-from nominal conditions ($n_{SW}=3.0 {cm^{-3}}$) to the DSW regime ($n_{SW}=0.1 {cm^{-3}}$)-affect the energization and transport of O^+ ions. Particular attention is given to escape rates through the magnetotail and plume structures, as well as to inward precipitation and the associated energy deposition into the ionosphere.

The atypical plasma environment created during the DSW event offers a rare opportunity to examine Mars–solar wind coupling under extremely low-density conditions. Combined with the hybrid modeling capabilities of LatHyS, this event provides a useful natural experiment for probing ion energization mechanisms and for constraining scenarios of atmospheric escape that may have been common during the early evolution of Mars.