

MAVEN

EXPLORES THE MARTIAN UPPER ATMOSPHERE

by Bruce M. Jakosky

After decades of exploration by landers, rovers, and orbiting spacecraft, Mars continues to capture imaginations and reveal surprises. Indeed, the more we learn about Mars, the more we see the connections between its interior, surface, and atmosphere. Answering questions about the potential for habitability, presence of water, and history of its climate requires understanding Mars as a connected system over time.

It was in this context that NASA flew the orbiting Mars Atmosphere and Volatile Evolution (MAVEN) mission (1). Its goal was to explore the modern martian upper atmosphere in unprecedented detail. MAVEN carries a suite of instruments that take measurements while directly traveling through the atmosphere as it orbits the planet, from ~125 to ~6000 km above the rocky surface. MAVEN has been operating in orbit around Mars since 18 September 2014, and the data now allow us to start addressing key science questions that had otherwise been unanswerable.

Previous Mars missions have provided compelling evidence for abundant liquid water on ancient Mars. This would seem to require a thicker CO₂ atmosphere to provide the necessary greenhouse warming. Where did the CO₂ go? Where did the water go? There do not appear to be sufficient carbon-bearing minerals on the surface or in the subsurface to account for a thick early atmosphere (2), but loss to space is thought

to be a viable mechanism for producing the observed changes in climate (1). Measurements by MAVEN shed light on how the upper atmosphere interacts with the Sun and solar wind, and the ability of gases to escape to space—both important processes for understanding planetary atmospheres. Four papers in this issue report some of the initial discoveries and are complemented by a series of companion papers in *Geophysical Research Letters* (3).

Jakosky *et al.* examine measurements made during the impact of an interplanetary coronal mass ejection onto the Mars system. The sudden and dramatic increase in solar wind density, velocity, and magnetic field intensity lead to enhancements in the production and energization of ions picked up by the solar wind as it streams by, and to an increase in the rate of gas escape to space. Solar storms might have been more abundant and more intense early in solar system history, so this increase may have implications for the early loss of Mars' atmosphere to space.

Bougher *et al.* describe in situ measurements of the Mars thermosphere; the only previous measurements came from profiles obtained during the entry of the two Viking landers in 1976. The

thermosphere, spanning roughly 120 to 200 km, connects the lower atmosphere that controls the martian climate to the exosphere that controls gases' escape to space. Its properties are central to understanding the long-term evolution of the atmosphere. The measurements provide detailed information on the composition of the neutral atmosphere and ionosphere, the variability of this region, and the energetics of ion acceleration that leads to loss.

Schneider *et al.* report the discovery of a “diffuse” aurora produced by a solar storm. The diffuse aurora was widespread geographically, as opposed to previously observed “discrete” auroras. The solar electrons responsible for the aurora probably entered the martian atmosphere directly from the solar wind. The auroras reflect active processes that produce ionization and dissociation, which may affect the overall atmospheric escape rate. The lack of a global magnetic

field on Mars probably causes the martian auroras to be more a global phenomenon than they are on Earth.

Andersson *et al.* describe the discovery of dust at orbital altitudes surrounding Mars, detected by the effect a dust grain has when it strikes the spacecraft. Dust impacts were detected from the lowest altitudes visited by the spacecraft, around 125 km above the surface, up to ~1000 km altitude. The distribution of the dust points to interplanetary debris in the solar system as the likely source. Such debris is thought to be responsible for producing discrete layers in the ionosphere and for affecting

the chemistry and energetics in that region.

Together, these measurements—along with those reported in the companion papers—are beginning to shape a new view of both modern and past processes on Mars. The upper atmosphere of Mars was probably a major contributor to the evolution of Mars' climate, and thereby influenced the stability of liquid water and the potential habitability of Mars by microorganisms. MAVEN is continuing to make measurements as it orbits the Red Planet and will be able to explore the upper atmosphere over a full Mars year and during the changing phases of the solar cycle. The measurements being reported here only scratch the surface of what remains to be learned about the connected Mars system.

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Artist's rendition of the MAVEN spacecraft over Mars.

MAVEN observations of the response of Mars to an interplanetary coronal mass ejection

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Coupling between the lower and upper atmosphere, combined with loss of gas from the upper atmosphere to space, likely contributed to the thin, cold, dry atmosphere of modern Mars. To help understand ongoing ion loss to space, the Mars Atmosphere and Volatile Evolution (MAVEN) spacecraft made comprehensive measurements of the Mars upper atmosphere, ionosphere, and interactions with the Sun and solar wind during an interplanetary coronal mass ejection impact in March 2015. Responses include changes in the bow shock and magnetosheath, formation of widespread diffuse aurora, and enhancement of pick-up ions. Observations and models both show an enhancement in escape rate of ions to space during the event. Ion loss during solar events early in Mars history may have been a major contributor to the long-term evolution of the Mars atmosphere.

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Early MAVEN Deep Dip campaign reveals thermosphere and ionosphere variability

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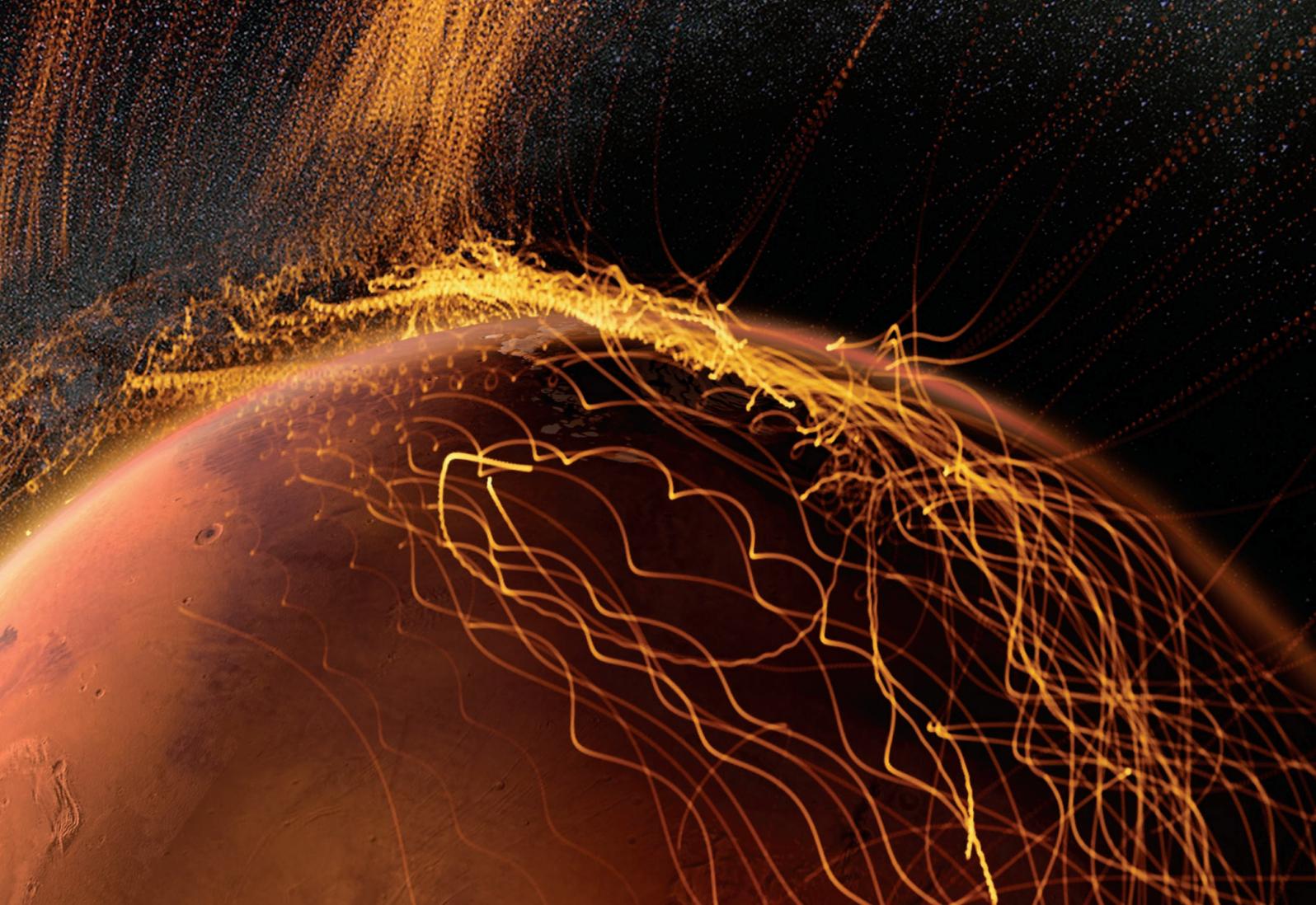


Ions escaping the martian atmosphere (right) due to solar wind radiation emitted by the Sun (left).

K. Jain, R. Jolitz, F. Leblanc, C. O. Lee, Y. Lee, F. Lefevre, R. Lillis, R. Livi, D. Lo, Y. Ma, M. Mayyasi, W. McClintock, T. McEnulty, R. Modolo, F. Montmessin, M. Morooka, A. Nagy, K. Olsen, W. Peterson, A. Rahmati, S. Ruhunusiri, C. T. Russell, S. Sakai, J.-A. Sauvaud, K. Seki, M. Steckiewicz, M. Stevens, A. I. F. Stewart, A. Stiepen, S. Stone, V. Tenishev, E. Thiemann, R. Tolson, D. Toubanc, M. Vogt, T. Weber, P. Withers, T. Woods, R. Yelle

The Mars Atmosphere and Volatile Evolution (MAVEN) mission, during the second of its Deep Dip campaigns, made comprehensive measurements of martian thermosphere and ionosphere composition, structure, and variability at altitudes down to ~130 kilometers in the subsolar region. This altitude range contains the diffusively separated upper atmosphere just above the well-mixed atmosphere, the layer of peak extreme ultraviolet heating and primary reservoir for atmospheric escape. In situ measurements of the upper atmosphere reveal previously unmeasured populations of neutral and charged particles, the homopause altitude at approximately 130 kilometers, and an unexpected level of variability both on an orbit-to-orbit basis and within individual orbits. These observations help constrain volatile escape processes controlled by thermosphere and ionosphere structure and variability.

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Discovery of diffuse aurora on Mars

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Planetary auroras reveal the complex interplay between an atmosphere and the surrounding plasma environment. We report the discovery of low-altitude, diffuse auroras spanning much of Mars' northern hemisphere, coincident with a solar energetic particle outburst. The Imaging Ultraviolet Spectrograph, a remote sensing instrument on the Mars Atmosphere and Volatile Evolution (MAVEN) spacecraft, detected auroral emission in virtually all nightside observations for ~5 days, spanning nearly all geographic longitudes. Emission extended down to ~60 kilometer (km) altitude (1 microbar), deeper than confirmed at any other planet. Solar energetic particles were observed up to 200 kilo-electron volts; these particles are capable of penetrating down to the 60-km altitude. Given minimal magnetic fields over most of the planet, Mars is likely to exhibit auroras more globally than Earth.

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Dust observations at orbital altitudes surrounding Mars

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Dust is common close to the martian surface, but no known process can lift appreciable concentrations of particles to altitudes above ~150 kilometers. We present observations of dust at altitudes ranging from 150 to above 1000 kilometers by the Langmuir Probe and Wave instrument on the Mars Atmosphere and Volatile Evolution spacecraft. Based on its distribution, we interpret this dust to be interplanetary in origin. A comparison with laboratory measurements indicates that the dust grain size ranges from 1 to 12 micrometers, assuming a typical grain velocity of ~18 kilometers per second. These direct observations of dust entering the martian atmosphere improve our understanding of the sources, sinks, and transport of interplanetary dust throughout the inner solar system and the associated impacts on Mars' atmosphere.

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