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Recent investigations of the near-Mars space environment by the planetary aeronomy and space physics community in China

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Abstract: The present issue of Earth and Planetary Physics is dedicated to the near-space neutral and plasma environments of Mars. The issue includes nine papers that present new results on the properties of the Martian exosphere, ionosphere, and magnetosphere, from both observational and modeling points of view. Due to the similarity between the two objects, the issue also includes two additional papers on the near-Venus plasma environment.

Keywords: Mars; Venus; exosphere; ionosphere; magnetosphere

1. Introduction

The present issue of Earth and Planetary Physics (EPP, http://www.eppcgs.org) is dedicated to the near-space neutral and plasma environments of Mars, including the middle and upper atmosphere, ionosphere, exosphere, and magnetosphere, along with their interactions with the solar wind (SW). In recent years, the study of the near-Mars space environments has become a burgeoning field, especially thanks to the wealth of new data accumulated by the Mars Atmosphere and Volatile Evolution (MAVEN) mission (Jakosky et al., 2015). Our understandings of this exciting field have also been greatly improved by increasingly sophisticated modeling capabilities. For instance, we are starting to elucidate, from both observational and theoretical points of view, the two-way couplings on Mars between the thermosphere and ionosphere, between the photochemically-dominated collisional ionosphere and the transport-dominated upper ionosphere, and between all these regions and the highly variable SW. Along with the world-wide enthusiasm in Mars aeronomy and space physics, the planetary science community in China, specifically focused on such a field, is also growing rapidly. In the near future, when China launches her first Mars orbiter and rover in 2020 (Wei Y et al., 2018), that growth will continue and will be expedited.

This special issue was open to the wide planetary science community across the country and has resulted in the inclusion of eleven papers, of which nine are dedicated to Mars and the remaining two dedicated to Venus, another important terrestrial planet in the Solar System with many similarities to Mars in terms of its neutral and plasma environment.

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2. The Martian Upper Atmosphere and Ionosphere

Mars contains a thick CO_2 atmosphere that also contains such other species as O, N_2, CO, and H_2 (Mahaffy et al., 2015). The Martian upper atmosphere is ionized by solar Extreme Ultraviolet (EUV) and X-ray photons on the dayside (Withers, 2009), leading to the formation of a substantial ionosphere composed mainly of O_2^+, CO_2^+, and O^+ (Benna et al., 2015). The nightside Martian ionosphere is patchy and sporadic, generally thought to be produced by either SW electron precipitation or day-to-night plasma transport (Withers et al., 2012). Several studies in this issue are dedicated to the characteristics of the Martian upper atmosphere and ionosphere in various aspects.

The exobase is traditionally defined as the upper boundary of a planetary atmosphere (Johnson et al., 2008). In their study, Fu MH et al. (2020) use the Neutral Gas and Ion Mass Spectrometer (NGIMS) measurements of atmospheric N_2 to derive Martian exobase altitudes during a large number of MAVEN orbits. Their analysis reveals interesting variations of the exobase altitude that are indicative of thermal expansion of the Martian upper atmosphere, driven either externally by solar EUV energy deposition or internally by global dust storms.

In addition to the well-known existence of O^+ in the Martian ionosphere, observation of doubly charged O^{++} was also reported recently (Benna et al., 2015). Gu H et al. (2020) identify the dominant chemical production and destruction channels of O^{++} based on MAVEN NGIMS measurements. These authors argue that on average, production is in exact balance with destruction in the dayside Martian ionosphere below 200 km, whereas a signature of strong O^{++} escape is suggested by the data at higher altitudes.

Photoelectrons are an important population of the Martian ionosphere, providing a good diagnostic of the solar EUV/X-ray radiation and the ambient magnetic field topology (Coates et al., 2011). Using MAVEN Solar Wind Electron Analyzer measurements, Cao YT et al. (2020) propose that the pitch angle distribution (PAD) of photoelectrons is mostly isotropic on the dayside. They further report evidence for field-aligned, cross-terminator photoelectron transport, indicated by highly anisotropic photoelectron PAD present on both the dayside and nightside of the planet.

3. The Solar Wind Interaction with Mars

The SW interaction with Mars leads to the formation of an induced magnetosphere, displaying a clear outer boundary characterized by magnetic field enhancement and mass loading, along with the change in plasma composition, temperature, and density (Nagy et al., 2004; Bertucci et al., 2011). The global magnetic field topology of the Martian magnetosphere is unique among Solar System bodies in that it is greatly complicated by the presence of strong crustal magnetic anomalies over the southern hemisphere of the planet (Acuña et al., 1999). Several studies in this issue are dedicated to different aspects of the SW interaction with Mars.

Three-dimensional magnetohydrodynamic (MHD) calculations are a useful approach for studying the SW interaction with Mars (Ma YJ et al., 2002). In this issue, Li SB et al. (2020) present an example with a multi-fluid code by incorporating a simplified photochemical scheme for four ionospheric species and imposing an ideal dipole-like magnetic field model at the bottom boundary over the southern hemisphere. Interesting behaviors are revealed by their calculations, such as the hindering of ion escape on Mars by the imposed crustal field within the magnetotail tail regions but away from the central tail.

In terms of the SW interaction with Mars, the direct impact of SW protons on the extended H corona is of special interest (Chaffin et al. 2015). Xu Q et al. (2020) report a case study of such an interaction during the Interplanetary Coronal Mass Ejection (ICME) event on 7 Mars 2015 using MAVEN Solar Wind Ion Analyzer (SWIA) measurements. Their analysis reveals evidence for an enhanced H corona upstream of the SW near Mars as a consequence of the ICME passage, likely accompanied by elevated H escape during the event.

A rich variety of wave phenomenon could be generated via the SW interaction with Mars, such as the foreshock ultralow frequency (ULF) waves (Brain et al., 2002) and proton cyclotron (PC) waves (Romanelli et al., 2016). With the aid of MAVEN Magnetometer (MAG) and SWIA measurements, Shan LC et al. (2020) report a case study of ULF waves in the Martian foreshock, showing characteristics consistent with the scenario of excitation by SW interaction with back-streaming ions through right-hand beam instability. In another study, Liu D et al. (2020), also using MAG and SWIA measurements, identify a large number of PC wave events from which they analyze the variations of the occurrence rate and amplitude of PC waves with the interplanetary magnetic field cone angle.

The impact of crustal magnetic fields on the near-Mars plasma environment could be manifested in a variety of ways (Ma YJ et al. 2002). In Wang J et al. (2020), the impact of crustal fields is investigated within the context of an apparent north-south asymmetry in proton density within the Martian magnetosheath regions, as suggested by MAVEN SWIA data. These authors propose a simple but reasonable interpretation of the observed asymmetry.

4. The Galactic Cosmic Ray Environment of Mars

Galactic Cosmic Rays (GCRs) are energetic charged particles omnipresent in the heliosphere with a nearly isotropic distribution and with intensity strongly modulated by solar magnetic activity. Forbush decreases (FDs) are depressions in the GCRs which could be explained as interplanetary counterparts of ICMEs (Cane, 2000) or stream interaction regions (SIRs) (Richardson, 2004). The study of FDs has been extensively conducted on Earth and has recently been initiated on Mars as well, thanks to measurements made by the Radiation Assessment Detector (RAD) on board the Curiosity rover.

Guo JN et al. (2020) present a model that is able to quantify the amplitudes of FDs near Mars during the pass-by of an ICME/SIR, combining both heliospheric and atmospheric modulation of the GCR spectra. Their model results are in reasonable agreement with Curiosity RAD data collected on the surface of Mars and MAVEN Solar Energetic Particle data collected at high altitudes.

5. Venus Studies

Similar to Mars, Venus, too, contains a CO_2 dominated atmosphere, an O_2^+ dominated ionosphere, and an induced magnetosphere in response to the planet's interaction with the SW (Bertucci et al., 2011). These two terrestrial planets therefore share many similarities in fundamental characteristics occurring in their neutral and plasma environments.

The ionopause defines the upper boundary of an ionosphere (Elphic et al., 1980). The EUV-dependence of such a boundary on Venus remain elusive. In Han QQ et al. (2020), this dependence is investigated by combining measurements made on board the Pioneer Venus Orbiter and the Venus Express (VEx). These authors show conclusively that the dayside ionopause altitude increases with increasing solar EUV flux, as expected by the solar-driven scenario for the formation of the Venusian ionosphere.

The SW interaction with Venus is characterized by intense magnetic turbulence, which can be either locally generated or convected from the upstream SW (Luhmann et al., 1983). With the aid of VEx magnetic field measurements accumulated over six years, Xiao SD et al. (2020) have thoroughly analyzed magnetic turbulence near Venus in both the MHD and kinetic regimes, presenting their distinct characteristics and highlighting the role of magnetic energy dissipation.

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References

Acuña, M. H., Connerney, J. E. P., Ness, N. F., Lin, R. P., Mitchell, D., Carlson, C. W., McFadden, J., Anderson, K. A., Reme, H., … Cloutier, P. (1999). Global distribution of crustal magnetization discovered by the Mars Global Surveyor MAG/ER experiment. *Science*, *284*(5415), 790–793. https://doi.org/10.1126/science.284.5415.790

Benna, M., Mahaffy, P. R., Grebowsky, J. M., Fox, J. L., Yelle, R. V., and Jakosky, B. M. (2015). First measurements of composition and dynamics of the Martian ionosphere by MAVEN's Neutral Gas and Ion Mass Spectrometer. *Geophys. Res. Lett.*, *42*(21), 8958–8965. https://doi.org/10.1002/2015GL066146

Bertucci, C., Duru, F., Edberg, N., Fränz, M., Martinecz, C., Szego, K., and Vaisberg, O. (2011). The induced magnetospheres of Mars, Venus, and Titan. *Space Sci. Rev.*, *162*(1-4), 113–171. https://doi.org/10.1007/s11214-011-9845-1

Brain, D. A., Bagenal, F., Acuña, M. H., Connerney, J. E. P., Crider, D. H., Mazelle, C., Mitchell, D. L., and Ness, N. F. (2002). Observations of low-frequency electromagnetic plasma waves upstream from the Martian shock. *J. Geophys. Res. Space Phys.*, *107*(A6), 1076. https://doi.org/101029/2000JA000416

Cane, H. V. (2000). Coronal mass ejections and Forbush decreases. *Space Sci. Rev.*, *93*(1/2), 55–77. https://doi.org/10.1023/A:1026532125747

Cao, Y. T., Cui, J., Wu, X. S., and Zhong, J. H. (2020). Photoelectron pitch angle distribution near Mars and implications on cross terminator magnetic field connectivity. *Earth Planet. Phys.*, *4*(1), 17–22. https://doi.org/10.26464/epp2020008

Chaffin, M. S., Chaufray, J. Y., Deighan, J., Schneider, N. M., McClintock, W. E., Steward, A. I. F., Thiemann, E., Clarke, J. T., Holsclaw, G. M., … Jakosky, B. M. (2015). Three-dimensional structure in the Mars H corona revealed by IUVS on MAVEN. *Geophys. Res. Lett.*, *42*(21), 9001–9008. https://doi.org/10.1002/2015GL065287

Coates, A. J., Tsang, S. M. E., Wellbrock, A., Frahm, R. A., Winningham, J. D., Barabash, S., Lundin, R., Young, D. T., and Crary, F. J. (2011). Ionospheric photoelectrons: Comparing Venus, Earth, Mars and Titan. *Planet. Space Sci.*, *59*(10), 1019–1027. https://doi.org/10.1016/j.pss.2010.07.016

Elphic, R. C., Russell, C. T., Slavin, J. A., Brace, L. H., and Nagy, A. F. (1980). The location of the dayside ionopause of Venus: Pioneer Venus Orbiter Magnetometer observations. *Geophys. Res. Lett.*, *7*(8), 561–564. https://doi.org/10.1029/GL007i008p00561

Fu, M. H., Cui, J., Wu, X. S., Wu, Z. P., and Li, J. (2020). The variations of the Martian exobase altitude. *Earth Planet. Phys.*, *4*(1), 4–10. https://doi.org/10.26464/epp2020010

Gu, H., Cui, J., He, Z. G., and Zhong, J. H. (2020). A MAVEN investigation of O++ in the dayside Martian ionosphere. *Earth Planet. Phys.*, *4*(1), 11–16. https://doi.org/10.26464/epp2020009

Guo, J. N., Wimmer-Schweingruber, R. F., Dumbovicx, M., Heber, B., and Wang, Y. M. (2020). A new model describing Forbush Decreases at Mars: combining the heliospheric modulation and the atmospheric influence. *Earth Planet. Phys.*, *4*(1), 62–72. https://doi.org/10.26464/epp2020007

Han, Q. Q., Fraenz, M., Wei, Y., Dubinin, E., Cui, J. Chai, L. H., Rong, Z. J., Wan, W. X., and Futaana, Y. (2020). EUV-dependence of Venusian dayside ionopause altitude: VEX and PVO observations. *Earth Planet. Phys.*, *4*(1), 73–81. https://doi.org/10.26464/epp2020011

Jakosky, B. M., Grebowsky, J. M., Luhmann, J. G., and Brain, D. A. (2015). Initial results from the MAVEN mission to Mars. *Geophys. Res. Lett.*, *42*(21), 8791–8802. https://doi.org/10.1002/2015GL065271

Johnson, R. E., Combi, M. R., Fox, J. L., Ip, W. -H., Leblanc, F., McGrath, M. A., Shematovich, V. I., Strobel, D. F., and Waite, J. H. (2008). Exospheres and atmospheric escape. *Space Sci. Rev.*, *139*(1-4), 355–397. https://doi.org/10.1007/s11214-008-9415-3

Li, S. B., Lu, H. Y., Cui, J., Yu, Y. Q., Mazelle, C., Li, Y., and Cao, J. B. (2020). Effects of a dipole-like crustal field on solar wind interaction with Mars. *Earth Planet. Phys.*, *4*(1), 23–31. https://doi.org/10.26464/epp2020005

Liu, D., Yao, Z. H., Wei, Y., Rong, Z. J., Shan, L. C., Arnaud, S., Jared, E., Wei, H. Y., and Wan, W. X. (2020). Upstream proton cyclotron waves: occurrence and amplitude dependence on IMF cone angle at Mars — from MAVEN observations. *Earth Planet. Phys.*, *4*(1), 51–61. https://doi.org/10.26464/epp2020002

Luhmann, J. G., Tatrallyay, M., Russell, C. T., and Winterhalter, D. (1983). Magnetic field fluctuations in the Venus magnetosheath. *Geophys. Res. Lett.*, *10*(8), 655–658. https://doi.org/10.1029/GL010i008p00655

Ma, Y. J., Nagy, A. F., Hansen, K. C., and DeZeeuw, D. L. (2002). Three-dimensional multispecies MHD studies of the solar wind interaction with Mars in the presence of crustal fields. *J. Geophys. Res. Space Phys.*, *107*(A10), 1282. https://doi.org/10.1029/2002JA009293

Mahaffy, P. R., Benna, M., Elrod, M., Yelle, R. V., Bougher, S. W., Stone, S. W., and Jakosky, B. M. (2015). Structure and composition of the neutral upper atmosphere of Mars from the MAVEN NGIMS investigation. *Geophys. Res. Lett.*, *42*(21), 8951–8957. https://doi.org/10.1002/2015GL065329

Nagy, A. F., Winterhalter, D., Sauer, K., Cravens, T. E., Brecht, S., Mazelle, C., Crider, D., Kallio, E., Zakharov, A., … Trotignon, J. G. (2004). The plasma environment of Mars. *Space Sci. Rev.*, *111*(1), 33–114. https://doi.org/10.1023/B:SPAC.0000032718.47512.92

Richardson, I. G. (2004). Energetic particles and corotating interaction regions in the Solar Wind. *Space Sci. Rev.*, *111*(3), 267–376. https://doi.org/10.1023/B:SPAC.0000032689.52830.3e

Romanelli, N., Mazelle, C., Chaufray, J. Y., Meziane, K., Shan, L., Ruhunusiri, S., Connerney, J. E. P., Espley, J. R., Eparvier, F., … Jakosky, B. M. (2016). Proton cyclotron waves occurrence rate upstream from Mars observed by MAVEN: Associated variability of the Martian upper atmosphere. *J. Geophys. Res. Space Phys.*, *121*(11), 11,113–11,128. https://doi.org/10.1002/2016JA023270

Shan, L. C., Ge, Y. S., and Du, A. M. (2020). A case study of large-amplitude ULF waves in the Martian foreshock. *Earth Planet. Phys.*, *4*(1), 45–50. https://doi.org/10.26464/epp2020004

Wang, J., Xu, X. J., Yu, J., and Ye, Y. D. (2020). South-north asymmetry of proton density distribution in the Martian magnetosheath. *Earth Planet. Phys.*, *4*(1), 32–37. https://doi.org/10.26464/epp2020003

Wei, Y., Yao, Z. H., and Wan, W. X. (2018). China's roadmap for planetary exploration. *Nat. Astron.*, *2*(5), 346–348. https://doi.org/10.1038/s41550-018-0456-6

Withers, P. (2009). A review of observed variability in the dayside ionosphere of Mars. *Adv. Space Res.*, *44*(3), 277–307. https://doi.org/10.1016/j.asr.2009.04.27

Withers, P., Fillingim, M. O., Lillis, R. J., Häusler, B., Hinson, D. P., Tyler, G. L., Pätzold, M., Peter, K., Tellman, S., and Witasse, O. (2012). Observations of the nightside ionosphere of Mars by the Mars Express Radio Science Experiment (MaRS). *J. Geophys. Res. Space Phys.*, *17*(A12), A12307. https://doi.org/10.1029/2012JA018185

Xiao, S. D., Wu, M. Y., Wang, G. Q., Wang, G., Chen, Y. Q., and Zhang, T. L. (2020). Turbulence in the near-Venusian space: Venus Express observations. *Earth Planet. Phys.*, *4*(1), 82–87. https://doi.org/10.26464/epp2020012

Xu, Q., Xu, X. J., Chang, Q., Xu, J. Y., Wang, J., and Ye, Y. D. (2020). An ICME impact on the Martian hydrogen corona. *Earth Planet.Phys.*, *4*(1), 38–44. https://doi.org/10.26464/epp2020006