弱い固有磁場中における火星からのイオン流出機構

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The ion escape from Mars with a weak intrinsic magnetic field

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It is recognized that ancient Mars had liquid water on the surface and thick atmosphere according to the recent space missions. However, the atmosphere was lost from the planet through some escape channels, and present-day Mars only has a thin atmosphere consisting mainly of CO_2 and does not have liquid water on the surface. It means that Mars has experienced much atmospheric loss from the past through the present. One of the important mechanisms of the atmospheric loss is the ion escape from the upper atmosphere. The ion escape is mainly controlled by the solar conditions such as solar wind parameters and solar XUV (X-ray and extreme ultraviolet) irradiances, and magnetic-field configuration. A previous numerical simulation indicated that the ion escape rate was at most five orders of magnitude higher under the past active solar condition than under the present ones. The planetary magnetic field is also an important factor in determining the ion escape rate. Present-day Mars does not have an intrinsic magnetic field, but it is leaving the magnetism in its crust. The existence of crustal magnetic field suggests that Mars had a global magnetic field of interior origin in the past. We present the ion escape mechanism under a weak intrinsic magnetic field at Mars based on a three-dimensional multi-species magnetohydrodynamics (MHD) modeling.

The simulations are performed for the two different magnetic fields with (case 1) only the interplanetary magnetic field (IMF) and (case 2) the IMF and dipole field of 100 nT on the equatorial surface of the planet. Note that the Parker spiral is adopted for the IMF. The shape of the magnetosphere appears to be hybrid between the magnetosphere with strong dipole field such as Earth and the induced magnetosphere with no dipole field such as present-day Mars, when a weak dipole field is considered. The east-west component of magnetic field is predominant at the subsolar point due to the penetration of the IMF draped field into the ionosphere rather than the north-south component of the global dipole field. On the other hand, the dipole field dominates the tail region of the magnetosphere.

The ion escape flux is obtained from the ion densities and velocities calculated. In the case 1, the flux has a peak near the center of the figure (Figure 1a). It suggests the ions created around Mars are flowing down to the tail. In contrast, in the case 2 the total flux has four peaks on the y-z plane of Mars-centered Solar Orbital (MSO) coordinate system (Figure 1b). Two of them are located in the magnetic neutral sheet (a white dased line of Figure 1b), and the others are in the higher latitudes. These results show that the difference of magnetic configuration significantly changes the ion escape flux and mechanism. The four-peak structure of flux in the case 2 is brought by the magnetosphere, which is formed by the interaction between the assumed solar wind and global dipole field. The two peaks in the high latitude are associated with the cusp region. The other two peaks are seen in the flank region of plasma sheet and generated by the complex reconnection between the dipole field and the IMF around the magnetosheath. Comparisons between the two cases suggest that the ion tailward flux increases by the magnetization of the planet and ions particularly escape through four channels in the magnetotail. This could result in the ion escape rate from the upper atmosphere enhanced.

Figure 1. The total ion flux of O^+ and $O_2{}^+$ in the two different magnetic fields with (a) IMF and (b) IMF and dipole magnetic field of 100 nT on the equatorial surface on the y-z plane at x = -5 R_M of the MSO coordinate system. The white dashed line shows the magnetic neutral sheet of B_x = 0.