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Estimation of the solar wind magnetic field from the ion distribution functions observed by Mars Express ASPERA-3

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The solar wind can directly interact with the Martian upper atmosphere, since Mars does not possess a global intrinsic magnetic field [e.g., *Acuna et al.*, 1998]. Atmospheric escape induced by the solar wind has been observed by Phobos-2 at the solar maximum, and recently by Mars Express (MEX) at the solar minimum [e.g., *Lundin et al.*, 1989; *Barabash et al.*, 2007]. Escape rates of planetary ions estimated by both spacecraft indicate large dependence on the solar wind conditions [e.g., *Barabash et al.*, 2007; *Lundin et al.*, 2008].

It has been known that escaping planetary ions, which are picked up by interplanetary magnetic field (IMF) in the solar wind, are distributed highly asymmetrically in terms of the convective electric field [*Barabash et al.*, 2007]. The convective electric field in the solar wind cannot be derived directly from MEX measurements, since MEX does not carry any magnetic field detector. However, the IMF direction can be sometimes estimated from the ring-like velocity distribution of picked-up protons observed by the ion mass analyzer (IMA), which is a part of plasma packages of ASPERA-3 onboard MEX. It is because the trajectory of picked-up ions is theoretically expected to gyrate in the plane perpendicular to the IMF direction [*Yamauchi et al.*, 2006, 2008].

Here we newly developed a new semi-automated method to estimate the IMF orientation from ring-ion distributions observed by IMA, focusing on the picked-up planetary protons. As described below, we only use ring-ion signatures whose initial energy is zero, so as to exclude the components of reflected solar wind protons at the bow shock. We assume that the magnetic field direction is nearly uniform over a distance greater than one ion gyroradius and for 192 sec., the duration of the observation cycle of three-dimensional ion distribution measured by IMA. We can then presume that picked-up planetary ions form a ring distribution with a radius of the solar wind velocity in the plane perpendicular to the local magnetic field in the solar wind rest frame. The concrete procedures of estimation are as follows:

(1) We manually select the ring distribution signature near the Martian bow shock.

(2) Automatic determination of the bulk velocity vector of the solar wind in full three-dimensional scanning of IMA.

(3) Assuming that initial velocity of picked-up protons is negligible, data bins where the ring ion component is expected to be detected are selected from IMA three-dimensional velocity distribution data.

(4) Using the selected data bins where relevant ring ion components are detected in three-dimensional velocity phase space in the solar wind rest frame, we calculate the normal unit vector to the plane of a partial ring ion distribution using the Newton-Raphson method and Lagrange multipliers. The derived normal unit vector should be parallel or anti-parallel to the IMF orientation. It should be noted that we cannot derive strength and polarity of the IMF in this method.

The heavy ion precipitations up to a few keV onto Martian atmosphere are recently discovered predominantly during CIR passages [*Hara et al.*, 2011]. On the basis of a statistical study using the derived IMF data, we will also report on the effects of the solar wind electric field direction on the heavy-ion precipitations.

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