Oxygen Ion Outflow from Venus and the Mechanism of the Ion Acceleration

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Abstract

Atmospheric escape from planets is one of the important issues to understand the planetary atmospheric evolution. The lack of an intrinsic magnetic field of Venus causes a direct interaction between its upper atmosphere and the solar wind. The solar wind interaction makes ionospheric or exospheric ions energized, and thus drives ion losses from the Venusian upper atmosphere. The mechanisms of ion acceleration and the amount of ion losses from Venus are still uncertain though many studies have been conducted to date. For dispelling this uncertainty, giving a better understanding of the mechanism for the ion outflow is needed.

This thesis describes the dependence of the oxygen ion outflow from Venus on a certain solar wind condition, namely, on the direction of the interplanetary magnetic field (IMF), and the mechanism of the oxygen ion acceleration at the upper atmosphere of Venus. All works in the thesis use the data obtained from the Analyzer of Space Plasma and Energetic Atoms (ASPERA-4) and the magnetometer (MAG) onboard Venus Express which has been orbiting Venus since April, 2006.

To understand the effects of the IMF direction on the oxygen ion outflow, the shape of the induced magnetosphere and O^+ escape fluxes in the nightside for the perpendicular IMF case and the parallel IMF case, where the IMF directs perpendicular and parallel to the Venus-Sun line, respectively, are investigated. The comparison between the two IMF cases reveals that the formation of the plasma sheet, which is an oxygen ion outflow channel, is controlled by the IMF direction. For the perpendicular IMF case the IMF drapes simply around Venus,

resulting in the formation of a single plasma sheet, and thus oxygen ions escape from the single outflow channel. For the parallel IMF case, on the other hand, the IMF drapes more complicatedly and this results in forming multiple plasma sheets, namely, forming multiple ion escape channels. Statistical analysis shows that there is no significant difference in the oxygen escape rates between the two IMF cases. In addition, it shows that temporal variations of the IMF direction do not affect the escape rate. Conclusion of this work is that the IMF direction does not change oxygen ion escape rate from Venus even though the morphology of the induced magnetosphere largely depends on it.

The velocity distribution functions of oxygen ions which can be obtained by the Ion Mass Analyzer, a part of the ASPERA-4 instrument, provides important information for identifying the ion acceleration processes. Statistical analysis of the O^+ velocity distribution functions indicates that the O^+ velocity distribution functions have broader distribution in the local convection electric field direction than other directions. Different characteristics in velocity distribution functions are found in different magnetospheric regions. In the magnetosheath, the O^+ velocity shifts from the initial phase of the ring distribution calculated from local proton velocity and magnetic field to the bulk velocity of the local proton. Such ions are mostly observed in the $+E_L$ hemisphere where the local convection electric field points away from the surface. This indicates that ion pickup occurs in the magnetosheath but the ions are immediately incorporated with the local proton bulk flow with breaking their E x B drift motion. In the dayside induced magnetosphere in the $+E_L$ hemisphere, measurements show a scattered velocity distribution function of O^+. This velocity distribution function has two ion components depending on whether their gyro radius is larger or not than the scale of the induced magnetosphere. For O^+ ions with small gyro radius (< 500 km), the O^+ velocity distribution function appears on the middle phase of the ring distribution. On the other hand for the O^+ ions with a large gyro radius (> 500 km), the O^+ velocity distribution function is similar to the one in the magnetosheath. This means that two components of O^+ ions exist in the induced magnetosphere: pickup ions subject to the E x B drift and ions moving with the local proton bulk velocity. Since both ion components flow tailward, they are convected toward the nightside to escape. In the nightside of the induced magnetosphere, velocity distribution function shows initial and last phase of the ring distributions together with a ring in the plane where the local magnetic field and the local convection electric field lie. The possible location where such velocity distribution function is realized could be the center of the plasma sheet. In summary, oxygen ion escape channel at Venus are the magnetosheath in the $+E_L$ hemisphere and the plasma sheet in the induced magnetosphere.

The studies shown in this thesis indicate that the ion escape at Venus is quite constant against the solar wind condition. Rather, it is possible that the escape rate of oxygen ions are determined by the amount of the ion source. Hisaki, the Japanese small spacecraft project, observes Venus upper atmosphere by using the EUV spectrometer aboard itself. The optical observation aimed to the ion escape of Venus have never conducted to date. Using the EUV spectrometer, we will have chances to observe variations of dayside exospheric and ionospheric components, and the nightside escaping ions from Venus. Simultaneous observations of Venus Express with Hisaki observations are planed. The observations may allow us to find relationships between the ion source and the escape rate.

In the studies described in the thesis, cold ion escape, which is believed to have a big impact on the atmospheric escape from Venus, is missing due to the instrumental restrictions. So, study of the dependence of the cold ion escape on the solar wind condition is needed in the future. NASA's mission MAVEN (Mars Atmosphere and Volatile EvolutioN mission), which was successfully launched November 2013, will arrive at Mars in September 2014 and observe Martian atmospheric escape processes. MAVEN carries excellent instruments to observe escaping particles from Mars. Mars has a similar plasma environment to Venus therefore there will be good opportunities to study the solar wind interaction with the Venus-like planet in the near future.