EPSC Abstracts
Vol. 7 EPSC2012-400 2012
European Planetary Science Congress 2012

Ion heating, acceleration and escape at Mars and Venus, similarities and differences

H. Nilsson, G. Stenberg, C. Diéval, M. Yamauchi, S. Barabash and R. Lundin
Swedish Institute of Space Physics, Kiruna, Sweden, (hans.nilsson@irf.se, 004698079050)

Abstract

Using data from the ASPERA-3 (Mars) and ASPERA-4 (Venus) instruments we have investigated the heating, acceleration and escape of ionospheric origin ions from Mars and Venus. We have first determined the average flow properties and average ion distributions in the vicinity of the planets, from which a net escape flux as well as spatial asymmetries in the escape fluxes can be determined. One of the main uncertainties concerning the net escape is the possible presence of plasma of too low energy to be observed by the ion spectrometers, but still of sufficient energy to escape. Observations show that there is a clear and efficient heating of outflowing ionospheric ions. The large temporal and spatial variability of both plasma distribution and ion heating still allows for part of this plasma to remain cold. At Earth hot and cold plasma follow different outflow trajectories and are typically found in different regions, with hot outflowing plasma in the cusp / mantle and cold outflowing plasma in the lobes. We discuss whether a similar situation may exist in the more compact induced magnetospheres of Mars and Venus. Finally we show how different the induced magnetosphere boundaries of Mars and Venus are. At Mars there is much more transport across the boundary, with ionospheric origin heavy ions flowing into the magnetosheath. Solar wind plasma consistently, though only sporadically, penetrate the induced magnetosphere boundary of Mars and precipitate. At Venus we find essentially no ionospheric origin heavy ions in the magnetosheath, and solar wind penetration cases are very rare as compared to Mars. Previous studies have shown clear differences between the bow shock regions of the two planets. It appears as if the relatively smaller size of the Mars system in terms of gyro radii of typical solar wind ions lead to a more dynamic magnetosheath and induced magnetosphere boundary, allowing for a different coupling between the solar wind and planetary plasmas as compared to Venus.

1. Introduction

We use data from the Mars and Venus Express missions to study solar wind interaction with the upper atmospheres of Mars and Venus. In previous studies we have produced average ion distribution functions in the near Mars space (Nilsson et al., 2012). We have used this data to study ion heating and acceleration at Mars (Nilsson et al., 2012) and to estimate the total ion escape and its spatial distribution (Nilsson et al., 2011). In a follow up study we used the same technique to study ion escape at Venus (Nordström et al., 2012).

We have also studied ion transport in the other direction, from the solar wind to the atmosphere (Stenberg et al., 2011; Diéval et al., 2012). We have found that the solar wind precipitation at Mars is sporadic in nature, and the average flux is rather low. Still, in certain altitude intervals of the atmosphere the precipitating solar wind ions may have a effect on the atmosphere. It has been suggested that the solar wind is a significant source of helium for the atmosphere at Mars (e.g. Stenberg et al. (2011) and references therein). In our preliminary survey of data from Venus we found very little solar wind ion precipitation in the dayside of Venus.

2 Some sample data

In Fig. 1 we show two sample average ion distribution functions, and in Fig. 2 we show ion outflow from Mars and Venus in a cylindrical coordinate system.

3 Differences between Mars and Venus

There are some interesting differences between the solar wind interaction with the upper atmospheres of Mars and Venus. The induced magnetosphere boundary (IMB) at Venus separates the solar wind origin and

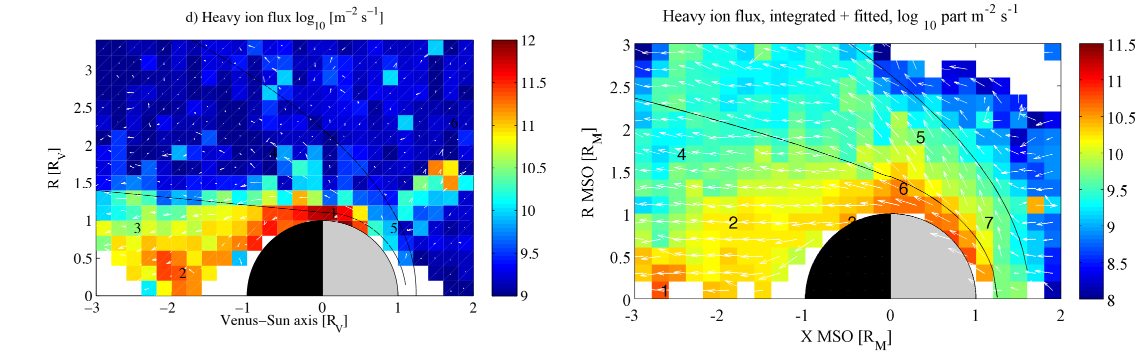

Figure 2: Heavy ion outflow in cylindrical coordinates from (a) Venus and (b) Mars.

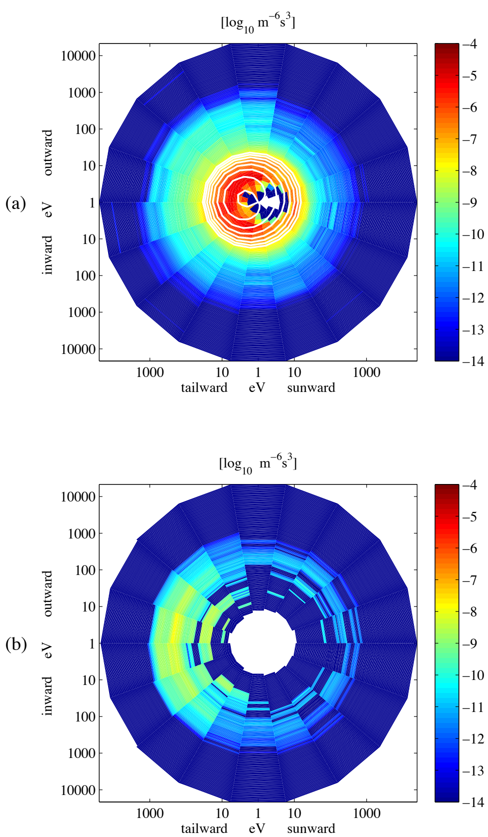

Figure 1: Two sample distribution functions (a) close to Mars and (b) in the martian tail. The white contours in (a) corresponds to a fitted Maxwellian function.

planetary origin plasma domains to a much larger degree than the corresponding IMB at Mars. Presumably the relatively larger gyro radius of ions of typical magnetosheath energies as compared to the total size of the system plays an important role. Such a difference is evident already at the bow shock (Yamauchi et al., 2011).

4 Cold ion outflow at Mars and Venus

Several recent studies with a sufficient amount of data for good coverage and good statistics yield similar net escape estimates from Mars (Lundin et al., 2008; Nilsson et al., 2011) and Venus (Fedorov et al., 2011; Nordström et al., 2012). The largest uncertainty concerns the possible presence of cold plasma with too low energy to be detected by particle detectors but still with enough energy to overcome gravity. The presence of a hot upper ionosphere which can be detected by the ASPERA ion spectrometers indicates that we frequently do have efficient heating which both affects the net escape and the ability to measure this escape with ion spectrometers. There is some indication that, by extrapolating this data to lower energies, the total escape flux is almost an order of magnitude larger than what is estimated in the above mentioned studies (Fränz et al., 2010), though this data consists of a few case studies. To fully resolve this question we may have to further understand the spatial distribution of ion outflow (so that we can in a reasonable way extrapolate a few careful measurements to obtain a total escape flux), as well as understand the heating of the upper atmosphere of Mars and Venus. Can we expect all ions to be significantly heated, or is it likely that some populations remain cold enough to avoid detection by particle spectrometers? MARSIS data suggests that there is often much more plasma than measured by ASPERA, also at some distance in the tail, but we can neither tell the composition of this plasma, nor determine whether it will escape. At earth, most escaping cold plasma consists of protons, which experience much less heating. At Earth, cold plasma exists along certain outflow trajectories, whereas in the high altitude cusp and mantle there is no significant oxygen ion population below the energy threshold of ion spectrometers most of the time (Nilsson, 2011). The induced magnetospheres at Mars and Venus are much smaller than the magnetosphere of Earth, but it is still possible that there exists different outflow paths with different amount of heating and acceleration. Determining this will greatly improve the reliability of any net escape calculations.

5 Conclusions

The next step in the studies of plasma interaction around Mars and Venus involves a careful cross-comparison of plasma phenomena at the two planets. We present some first results in this area.

References

Diéval, C., Kallio, E., Stenberg, G., Barabash, S., and Järvinen, R.: Hybrid simulations of proton precipitation patterns onto the upper atmosphere of Mars, Earth Planets Space, 64, 121–134, 2012.

Fedorov, A., Barabash, S., Sauvaud, J.-A., Futaana, Y., Zhang, T. L., Lundin, R., and Ferrier, C.: Measurements of the Ion Escape Rates From Venus for Solar Minimum, J. Geophys. Res., 116, A07 220, doi:10.1029/2011JA016 427, 2011.

Fränz, M., Dubinin, E., Nielsen, E., Woch, J., Barabash, S., Lundin, R., and Fedorov, A.: Transterminator ion flow in the Martian ionosphere, Plan. Space Sci., 58, 1442–1454, doi:10.1016/j.pss.2010.06.009, 2010.

Lundin, R., Barabash, S., Holmström, M., Nilsson, H., Yamauchi, M., Fraenz, M., and Dubinin, E. M.: A Comet-Like Escape of Ionospheric Plasma from Mars, Geophys. Res. Lett., 35, doi:10.1029/2008GL034 811, 2008.

Nilsson, H.: Heavy ion energization, transport, and loss in the Earth's magnetosphere, in: The Dynamic Magnetosphere, edited by Liu, W. and Fujimoto, M., pp. doi:10.1007/978–94–007–0501–2–17, IAGA, Springer Netherlands, 2011.

Nilsson, H., Edberg, N. J. T., Stenberg, G., Barabash, S., Holmström, M., Futaana, Y., Lundin, R., and Fedorov, A.: Heavy ion escape from Mars, influence from solar wind conditions and crustal magnetic fields, Icarus, 215, 475–484, doi:10.1016/j.icarus.2011.08.003, 2011.

Nilsson, H., Stenberg, G., Futaana, Y., Holmström, M., Barabash, S., Lundin, R., Edberg, N. J. T., and Fedorov, A.: Ion distributions in the vicinity of Mars: signatures of heating and acceleration processes, Earth Planets Space, 64, 135–148, doi:10.5047/eps.2011.04.011, 2012.

Nordström, T., Stenberg, G., Nilsson, H., and Barabash, S.: Ion outflow from Venus in VSO and VSE frames using average distribution functions from the IMA sensor on Venus Express, J. Geophys. Res., p. submitted, 2012.

Stenberg, G., Nilsson, H., Futaana, Y., Barabash, S., Fedorov, A., and Brain, D.: Observational evidence of alpha-particle capture at Mars, Geophys. Res. Lett., 38, doi:10.1029/2011GL047155, URL http://dx.doi.org/10.1029/2011GL047155, 2011.

Yamauchi, M., Futaana, Y., Fedorov, A., Frahm, R. A., Winningham, J. D., Dubinin, E., Lundin, R., Barabash, S., Holmström, M., Mazelle, C., Sauvaud, J., Zhang, T. L., Baumjohann, W., Coates, A. J., and Fraenz, M.: Comparison of accelerated ion populations observed upstream of the bow shocks at Venus and Mars, Ann. Geophys., 29, 511–528, doi:10.5194/angeo-29-511-2011, 2011.