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Temperature anisotropies of proton velocity distributions in the plasma environment of Venus

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Abstract

Using data from Venus Express, we study proton velocity distributions in the plasma environment of Venus. We focus on temperature anisotropies, that is, the difference between the proton temperature parallel and perpendicular to the background magnetic field. We present a spatial map of the average ratio between the perpendicular and parallel temperatures, $T_\perp$ and $T_{||}$ in Venus plasma environment. Near the subsolar point the perpendicular heating is strongest, forming highly unstable proton velocity distributions in a hot and dense plasma. Such conditions are ideal for frequent mirror mode wave generation.

1. Introduction

Many different plasma wave types have been observed around Venus and it is well-known that wave-particle interaction is important for ion acceleration and ion escape processes at Earth [1], but how important are they at Venus? Ion escape is observed both by Pioneer Venus Orbiter and Venus Express and the total ion outflow from Venus is estimated to be in the range 10^{24}-10^{25} s^{-1} [2, 3].

A number of processes are able to remove ions from Venus' atmosphere: tailward acceleration in the plasma sheet by the magnetic tension force, magnetotail reconnection, and ion pickup and acceleration by the convection electric field. Our aim is to investigate observed proton velocity distribution functions (VDFs) in order to better understand the interplay between particles and waves and to judge the importance of wave-particle interaction for ion escape and other processes in the induced magnetosphere around Venus.

2. Data

The investigation is based on Venus Express data recorded from May 2006 to December 2009. We use ion data from the Ion Mass Analyzer (IMA), a sensor which is part of the ASPERA-4 instrument package [4] and magnetometer data with 4-s resolution from MAG [5].

3. Preliminary results

Figure 1 shows a map of the proton temperature ratio in the X_{VSO}-R_{VSO}-plane, where $R_{VSO} = \sqrt{Y_{VSO}^2 + Z_{VSO}^2}$. The VSO-system is centered on Venus, with X_{VSO} pointing towards the sun, Y_{VSO} opposite to the orbital motion and Z_{VSO} completing the righthand system by pointing northward, perpendicular to the orbital plane.

In the solar wind we observe temperature ratios very close to $T_\perp/T_{||} = 1$. This agrees well with [6], who found that the core distribution of solar wind protons at low and medium speeds is typically isotropic at Venus' radial distance from the Sun. In high-speed solar wind, pronounced anisotropies of $T_\perp/T_{||} > 1$ have been observed in the core distribution. As the number of VDFs measured at low to medium SW speeds greatly outweighs those at high speeds, we expect to obtain median values pointing to isotropic distributions.

The ratio $T_\perp/T_{||}$ increases at the bow shock, where some of the incident ions are reflected at the shock. In the subsolar compression region, where the interaction with Venus' induced magnetosphere is strongest, perpendicular temperature anisotropies with $T_\perp/T_{||} > 4/3$ can frequently be observed.

The proton distributions become more isotropic as the plasma flows downstream past Venus. This may be attributed to the generation of low-frequency waves which serve to transfer energy between different proton populations and stabilize the downstream distributions. In the magnetotail we instead observe a slight $T_\perp/T_{||} < 1$ anisotropy.

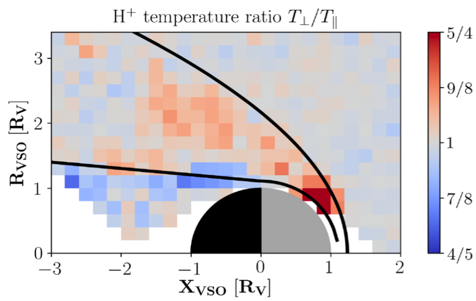

Figure 1: Proton temperature ratio $T_\perp/T_{||}$ around Venus in the X_{VSO}-R_{VSO}-plane. The colorscale has been adjusted such that for example a ratio of 3/2 is displayed in red with the same color intensity as its inverse value 2/3 in blue.

The observed proton bulk velocity together with the typical temperature ratio, $T_\perp/T_{||}$, in different regions around Venus is presented in the table below.

Table 1: Proton bulk velocity and temperature ratio in the solar wind, magnetosheath, magnetotail and subsolar compression region

	v_{bulk} [km/s]	$T_\perp/T_{||}$ ratio
Solar wind	409±14	1.00
Magnetosheath	351±19	1.02
Magnetotail	73±22	0.98
Subsolar region	201±3	1.36

4. Conclusions

We observe highly isotropic proton distributions upstream of the bow shock. Upon passing the bow shock, the protons are heated and the heating is more pronounced in directions perpendicular to the magnetic field. The VDFs in the magnetosheath are therefore slightly anisotropic with $T_\perp > T_{||}$. In the dayside magnetosheath where the compression of Venus' induced magnetosphere is strongest, the heating is strongly increased compared to the rest of the magnetosheath. Pronounced temperature anisotropies with on average $T_\perp/T_{||} \approx 4/3$ are a clear signature of plasma distributions unstable to low frequency wave generation. The instability criterion for mirror mode waves is found to be frequently fulfilled in this region, which agrees well with previous waves observations reported by [7, 8].

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