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Proton temperature anisotropies in the plasma environment of Venus - comparing with Earth

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Abstract

We use Venus Express data to study proton velocity distributions in the plasma environment of Venus, with a particular focus on temperature anisotropies. We present a spatial map of the average ratio between the perpendicular and parallel temperatures, $T_\perp$ and $T_{||}$. Near the subsolar point the perpendicular heating is strongest, forming unstable proton velocity distributions in a hot and dense plasma. The locations of previously reported in situ observations of proton cyclotron waves and mirror mode waves fit nicely with the observed anisotropies. We also compare our findings with similar studies made at Earth, a planet with an intrinsic magnetic field and a higher Mach number bow shock compared to Venus.

1. Introduction

Venus lacks an intrinsic magnetic field but the interaction between its conductive ionosphere and the solar wind creates an induced magnetosphere around the obstacle. The induced magnetosphere shares many of its features with a magnetosphere around a magnetized planet. Many different plasma wave types have been observed around Venus. To understand both the origin of the observed waves and the role they play in Venus induced magnetosphere it is important to carefully study associated particle velocity distribution functions (VDF). Ion cyclotron waves and mirror mode waves are two of the wave modes that have been observed in Venus plasma environment. They may both result from a anisotropic proton VDF, where the temperature perpendicular to the ambient magnetic field is larger than the parallel temperature. We calculate the proton temperature anisotropy and compare the results with reported wave measurements [1]. We also put our findings in context of similar studies made at Earth [3, 5].

2. Data

The investigation is based on Venus Express data recorded from May 2006 to December 2009, that is, during solar minimum. We use ion data from the Ion Mass Analyzer (IMA), a sensor which is part of the ASPERA-4 instrument package [2] and magnetometer data with 4-s resolution from MAG [7]. From the ion instrument we get a 3D distribution function every 192 s. The distribution covers a field-of-view of $90\times360°$ and an energy range of 12 eV/q to 30 keV/q divided in 96 steps. We used only data corresponding to protons.

3. Method

We use a two-stage fitting procedure to estimate the proton temperatures perpendicular and parallel to the ambient magnetic field [1]. First we determine the proton bulk velocity by fitting a 3D isotropic Gaussian to each ion observation (a 192 s long scan). After translating the VDF by the negative of the fitted bulk velocity, we rotate the VDF so that the z-axis coincide with the direction of the background magnetic field. Different perpendicular directions are not considered and in a final step the collapsed VDF is fitted to a 2D anisotropic Maxwellian.

4. Preliminary results

We observe highly isotropic proton distributions upstream of the bow shock with both parallel and perpendicular temperatures close to 13 eV. Upon passing the bow shock, the protons are heated and the heating is more pronounced in directions perpendicular to the magnetic field, especially at low solar zenith angles. The average VDFs in the magnetosheath are therefore slightly anisotropic with $T_\perp > T_{||}$. In the dayside magnetosheath where the compression of the interplanetary magnetic field is strongest, the heating is increased compared to the rest of the magnetosheath and the temperature anisotropy on average $T_\perp/T_{||} \approx 3/2$, which can be seen in Figure 1 (a). Similar temperature ratios has also been seen in the magnetosheath of the Earth [3]. However, the heating at the Earth's bow shock is more pronounced due to a higher Mach number shock.

An anisotropic proton VDF can excite both proton cyclotron waves and mirror mode waves. Both these wave modes have also been observed in the dayside magnetosheath of Venus. Mirror mode waves were most often seen near the subsolar point [6], which is also where we find the mirror mode instability criterion [4] to frequently be fulfilled (Figure 1 (b)). Our study can not explain the observations of mirror mode waves made in the magnetotail.

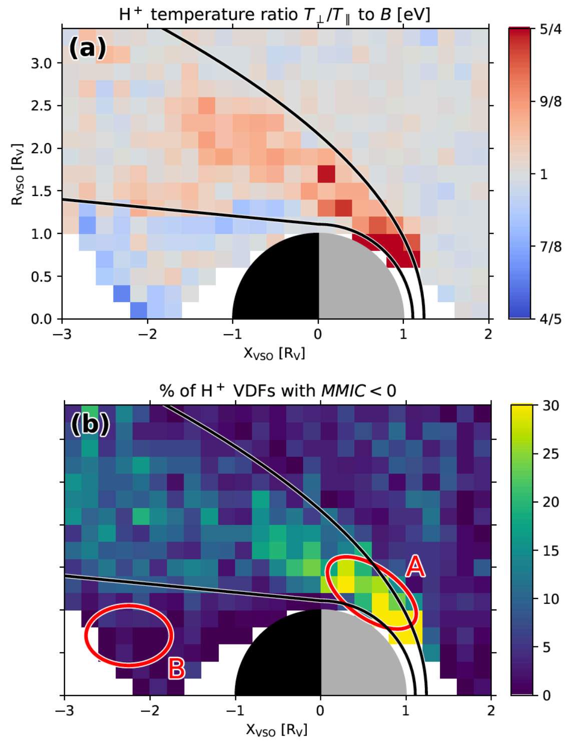

Figure 1: (a) A spatial map of the proton temperature anisotropy around Venus. The color-scale shows the median ratio of the perpendicular and the parallel temperatures. The anisotropy is largest in the dayside magnetosheath. Panel (b) shows how often the mirror mode instability criterion is fulfilled. This happens most often also in the dayside magnetosheath, which is one of the two regions were mirror mode waves have been observed (region A). Our study cannot explain the observations of mirror mode waves in region B. Figure from [1].

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