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The puzzling hydrogen corona at Venus

H. Lichtenegger (1), M. Delva (1), H. Gröller (1,2), and C. Bertucci (3)
(1) Space Research Institute, Austrian Academy of Sciences, Graz, Austria, (2) Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ, USA, (3) Instituto de Astronomía y Física del Espacio, CONICET/UBA, Buenos Aires, Argentina

Abstract

Although the existence of a hydrogen exosphere around Venus has been established already by the Mariner 5 flyby in 1967, the density and extension of the venusian hydrogen corona is still an open question. It is expected that the hydrogen population consists of a cold part in the lower exosphere and a hot part at higher altitudes. Although the hydrogen exosphere becomes most directly noticeable by means of Lyman-α observations, pick-up planetary hydrogen ions can also be detected through proton cyclotron waves. We present results of magnetic field observations aboard Venus Express, indicating permanent ionization and pick-up of hydrogen by the solar wind upstream of the planetary bow shock up to several planetary radii. In addition, the results of Monte Carlo simulations of the hot hydrogen corona at Venus are shown, suggesting lower neutral densities than those derived from magnetic field observations. The reason for this discrepancy is yet an open issue.

1. Introduction

Due to their high energies with respect to the background gas, hot atmospheric particles will form an extended corona about a planet. Since there is no intrinsic magnetic field at Venus, a substantial part of the hot corona is exposed to the solar wind and may be removed from the planet by ionization and subsequent pick-up. Since the ionization of neutral particles can lead to wave generation at the cyclotron frequency in the plasma frame, the observation of these waves is a hint for the pick-up of planetary ions. On the other hand, hot particles are expected to result from exothermic chemical reactions in the upper atmosphere. When these particles arrive at the exobase before being thermalized, they can populate the planetary environment up to high altitudes. Thus the density of the hot particle corona should be closely related to the production rates and collisional processes in the upper thermosphere.

2. Results

2.1. Magnetic field observations

Proton cyclotron waves generated by planetary pick-up ions are transverse waves which propagate nearly parallel to the magnetic field. If the velocity of the neutral at time of ionization is negligible with respect to the solar wind speed, the wave in the spacecraft frame will be observed at the local ion gyro-frequency and with specific left-hand polarization due to the anomalous Doppler-effect. Figure 1 displays the location of

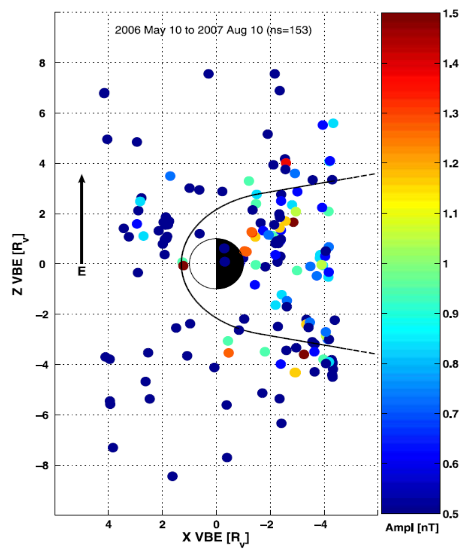

Figure 1: Positions of observations of proton cyclotron waves for two Venus-years in the x, y-plane of the electro-magnetic coordinate system VBE; the dashed line denotes the bow shock.

observed proton cyclotron waves by the VEX magnetometer for two Venus years [1] in a Venus-centered electromagnetic coordinate system (VBE: x_{VBE} axis positive towards the Sun, y_{VBE} axis positive in direction of local mean magnetic field component perpendicular to Venus-Sun line, z_{VBE} axis positive in direction of local motional electric field). Proton cyclotron waves apparently occur up to large distances from the planet with a comparable number in regions with positive and negative values of the z_{VBE} component. These findings suggest that there is sufficient local neutral hydrogen to be ionized and picked up far from the planet independent from the motional electric field.

2.2. Hot hydrogen simulations

For the simulation of the hot hydrogen corona, the following reactions in the venusian thermosphere have been considered

$$\mathrm{H^+ + H} \rightarrow \mathrm{H + H^+} \quad (1)$$
$$\mathrm{H_2 + O^+} \rightarrow \mathrm{H + OH^+} \quad (2)$$
$$\mathrm{H^+ + O} \rightarrow \mathrm{H + O^+} \quad (3)$$
$$\mathrm{H_2 + CO^+} \rightarrow \mathrm{H + HCO^+} \quad (4)$$
$$\mathrm{OH^+ + e} \rightarrow \mathrm{O + H} \quad (5)$$
$$\mathrm{H_2^+ + e} \rightarrow \mathrm{H + H} \quad (6)$$
$$\mathrm{H_2} + h\nu \rightarrow \mathrm{H + H} \quad (7)$$

Based on the thermosphere conditions given by [2], the collisional trajectories of the newly generated hot hydrogen atoms are simulated by means of a Monte Carlo model [3] up to an altitude where collisions become rare. The density of the upper corona is then calculated by assuming collisionless ballistic orbits. Figure 2 shows the resulting neutral hydrogen density profiles for a number of reactions at low solar activity conditions. The dashed line in Figure 2 indicates the proton density as derived from the Venus-Express magnetometer observations. Although the neutral hydrogen and pick up proton densities are comparable, the neutral density should be significantly higher to account for the ionization rates that produce the planetary ions.

3. Summary and Conclusions

Ion cyclotron wave observations suggest a substantial amount of neutral planetary hydrogen far upstream of the venusian bow shock. Hydrogen exosphere density simulations based on chemical reactions in the thermosphere which are believed to produce most of the hydrogen corona yield densities significantly lower than those obtained by magnetic field measurements. The reasons for this discrepancy are yet unknown.

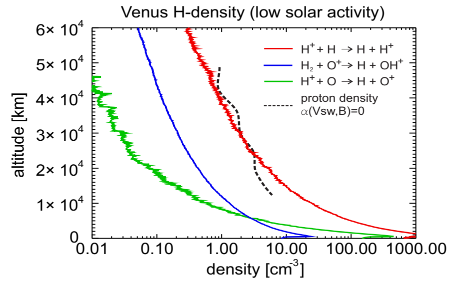

Figure 2: Hot hydrogen density profiles due to the indicated reactions. The dashed line corresponds to the planetary pick-up proton density obtained from the observed wave energy.

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