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Probing the hydrogen exosphere of Mars with ion cyclotron waves

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Abstract

Ion cyclotron waves are generated during the interaction between the solar wind and the Martian exosphere. When the atmospheric neutrals are ionized in the solar wind, the fresh ions are accelerated by the electric field and gyrate around the magnetic field in the solar wind, in a process called ion pick-up. As the ions gyrate, ion cyclotron waves grow from the free energy of the highly anisotropic distribution of these fresh ions, with left-handed polarization and a wave frequency near the ion's gyro-frequency. Observations of the ion cyclotron waves enable us to study the atmospheric loss due to solar wind pick-up process. At Mars, the exospheric hydrogen is picked up by the solar wind and produces proton cyclotron waves. The Mars Global Surveyor detected proton cyclotron waves which extend from the magnetosheath of Mars to over 12 Mars radii with amplitudes that vary slowly with distance. A hybrid simulation is applied to study the wave generation and evolution due to solar wind pick-up to try to understand the relation between the wave energy and pickup rate. By comparing the wave observations and the hybrid simulation results, we hope to better understand the hydrogen exosphere configuration and the loss of water from Mars

1. Introduction

Due to the lack of a sufficiently strong global magnetic field, ionosphere is left to stand off the solar wind. The top of the ionosphere, the ionopause, is the boundary with the magnetosheath which in turn is created from the flowing solar wind by the standing bow shock. The high-altitude atmospheric particles that reach the solar wind are ionized, accelerated by the electric field in the solar wind and carried away with the solar wind flow. This is the so-called pick-up process and it is one of the important ways by which the planetary atmospheric hydrogen atoms that dissociate from water vapor are removed by the solar wind, leading to loss of surface water. Ion cyclotron waves near the proton gyro-frequency are created during the pick-up process and were first observed at Mars by Phobos (Russell et al., 1990) and later observed by Mars Global Surveyor (MGS) (Brain et al., 2002; Wei and Russell, 2006). These waves have frequencies near the proton gyro-frequency, were left-hand elliptically polarized and propagated at a small angle to the magnetic field. They grew from the free energy of the ring distribution of the newly picked up protons in the solar wind plasma frame

2. Ion cyclotron waves at Mars: observations and simulations

Figure 1 shows an example of an ion cyclotron wave (ICW) observed on Dec. 27 1997, which has a frequency of 0.83 proton gyro-frequency, is left-handed with an ellipticity of -0.79, and a propagation angle of 22 degrees. During this orbit, ICWs are detected not only close to Mars, but also far away at distances over 12 Mars radii (R_m). The ICWs have different behavior when they are close to Mars and far away. The wave amplitude decreases fast with distance when close to Mars but slowly when far away. The waves occurr continuously when close to Mars but intermittently when far away. Wei and Russell, (2006) suggest a disk-shaped hydrogen exosphere of Mars at high altitude to explain the intermittency of the ICWs. They suggest that after protons are first picked up near Mars, the ions are neutralized by charge exchange and transported across field lines to distant regions, forming a fast neutral disk with orientations perpendicular to the interplanetary magnetic field (IMF). The rocking back and forth of this disk as the IMF changes can account for why the waves appear to turn on and off so frequently.

To understand the relationship between wave amplitudes and ion pickup rate, 1D hybrid simulation (kinetic ions, fluid electrons) is carried out with various pickup rates and pickup geometry for the Martian planetary environment (Cowee et al., 2012). Figure 2 shows the saturation wave energies versus pickup rate for varying pickup angles (0, 30, 60 and 90 degrees). These simulation results indicate that, contrary to expectations, the observed local ion cyclotron wave amplitudes cannot be simply related to local ion pickup rates because the growth time of the instability is long compared to the transit time of the waves past Mars. Thus the wave amplitude depends not only on the exospheric density profile but also on the wave growth time.

3. Figures

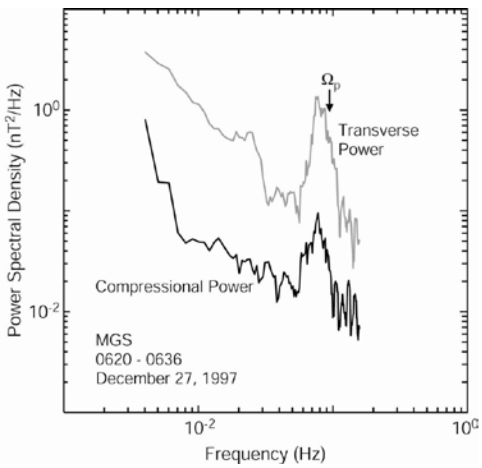

Figure 1: The power spectrum of an example of an ion cyclotron wave observed on Dec. 27 1997.

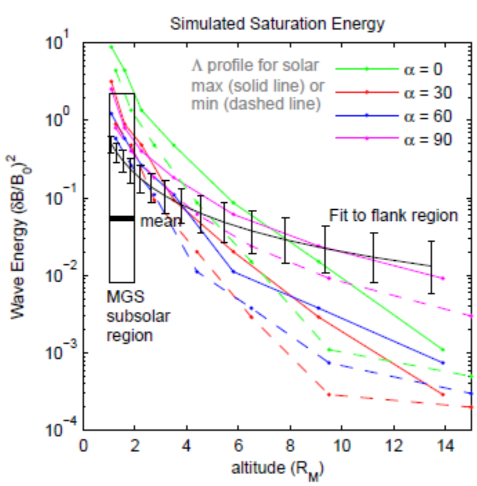

Figure 2: Simulated saturation wave energy versus radial distance for varying pickup angle for ion production profiles derived from modeled exospheric densities at (dashed lines) solar minimum and (solid lines) solar maximum. Also shown are the observed wave energies from Wei and Russell [2006] for the subsolar region (black box, with mean indicated by thick line) and the fit to the wave amplitudes observed on the flanks in the directional perpendicular to the Mars-Sun line. The amplitudes are normalized for easier comparison with simulation results (assume B_0 = 6 nT for the observations). (From Cowee et al., 2012)

4. Summary and Conclusions

Ion cyclotron waves are generated around Mars by pickup ions originated from the Martian hydrogen exosphere. The waves close to Mars are continuous and have amplitudes that decrease rapidly with distance, while the waves far from Mars are intermittent and have less variable amplitudes. These observations indicate that the hydrogen exosphere is more spherical near Mars but likely to be a disk shape far from Mars. One-dimensional hybrid simulation is carried out to understand the relationship between wave amplitudes and ion pickup rates. The simulation results indicate there is no simple relationship between wave amplitudes and local ion pickup rates, because the wave amplitude depends not only on the exospheric density profile but also on the wave growth time.

References

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