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Study on Electromagnetic Cyclotron Waves in the Solar Wind

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Electromagnetic cyclotron waves (ECWs) near the proton cyclotron frequency in the solar wind were clearly observed by Jian et al.[1] and have attracted much attention in recent years[2,3]. It is believed that these waves can play an important role in modifying the velocity distributions of solar wind ions and may lead to heating or cooling of the particles through wave-particle resonant interactions.

We conducted a series of studies on ECWs in the solar wind in the most recent years, and some interesting results are obtained [4,5,6,7]. One of the results is concerned with the generation mechanism of ECWs. It is clearly shown that the plasma kinetic instabilities (the proton cyclotron and parallel firehose) are relevant for the generation of ECWs in the solar wind. Moreover, we found some observational evidence for the effect of alpha particles on the instabilities in the solar wind.

The study was based on the *Wind* data from 2005−2015. We performed the a statistical study on plasma characteristics associated with the occurrence of ECWs. An automatic wave detection procedure was employed to identify ECWs. The procedure was developed by Zhao et al. [4,6], which mainly consists of three steps for magnetic field data in some time interval. They are (1) to identify the enhanced magnetic helicity spectrum; (2) to identify the enhanced power spectrum; (3) to set a wave amplitude criterion of 0.1 nT. An illustration for identification of ECWs is presented in Figure 1.

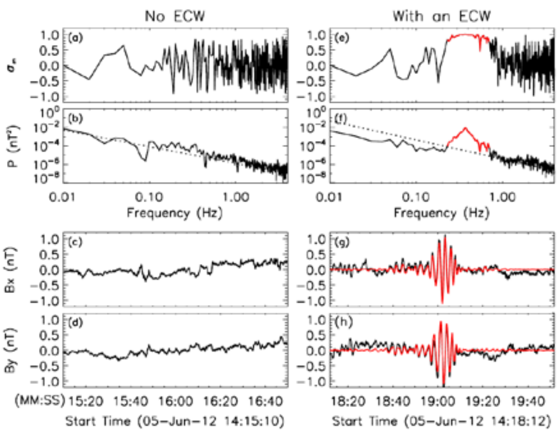

Figure 1: Illustration for identification of ECWs [6]. (a, e) The magnetic helicity spectrum; (b, f) the transverse power spectrum (P), and (c, d, g, h) the transverse components of the raw magnetic field (black lines). Left panels are for the case in the absence of ECW, while Right panels are for the case in the presence of an ECW. The red lines in right panel mark the frequency band of the wave or the filtered magnetic field via band-pass filter technique.

The probability density distributions of proton temperature anisotropy ($T_\perp/T_\parallel$) and proton parallel beta ($\beta_\parallel$) are investigated. In particular, the distributions of occurrence rates of (lift-handed polarization) ECWs in the space of ($T_\perp/T_\parallel$, $\beta_\parallel$) shows that a tendency of the occurrence rates increasing with proton temperature anisotropies. Moreover, The $\beta_\parallel$ with the maximum of occurrence rates is near 0.1 when $T_\perp/T_\parallel>1$, while it is around 1 when $T_\perp/T_\parallel<1$, as shown in Figure 2. In addition, the presence of alpha-proton differential flow with larger number density of alpha particles and/or higher differential velocity with respect to protons corresponds to a much higher occurrence rate as well as the domination of lift-handed polarization of ECWs. We thus propose that the proton cyclotron and parallel firehose instabilities with effects of alpha-proton differential flow are likely responsible for the local generation of LH ECWs in the solar wind[7].

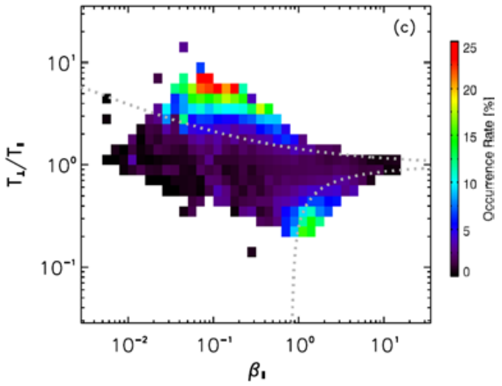

Figure 2: Color scale plot of occurrence rates of ECWs regulated by proton temperature anisotropy and proton parallel beta[7]. The gray dotted lines are for thresholds of proton cyclotron instability (upper lines) and parallel firehose instability (lower lines).

References

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