The 'proton-assisted' generation process of whistler waves at interplanetary shocks

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Abstract

Interaction between whistler waves and low energy electrons is considered to be essential for injection problems at collisionless shocks. We analyze an interplanetary shock (IPS) observed by GEOTAIL on 15 July 2000, focusing on whistler wave properties. In this IPS event, gradual increase of wave intensity toward the shock front has been identified from the lower frequency range of Alfvén waves to that of whistler waves. It is suggested that this continuous increase is due to the whistler waves generated from turbulence, cascading from Alfvén waves self-generated by protons. We discuss the contribution of these 'proton assisted' waves to the electron acceleration.

1. Introduction

When we consider diffusive shock acceleration (DSA) process, non-relativistic electrons, which cannot resonate with Alfvén waves, are thought to be scattered/accelerated by whistler waves. However, consistent comprehension about the generation and resonance mechanism of whistler waves is not yet established (e.g. [1,2]). As one of the recent observational progresses, Shimada et al. (1999) [3] identified the existence of whistler waves in the upstream region of an interplanetary shock ahead of a CME on 21 February 1994. We here analyze another IPS event observed by GEOTAIL on 15 July 2000 and reexamine the whistler wave properties.

2. Observation

We utilize the GEOTAIL fluxgate magnetic field data (FX) [4] which cover the lowest frequency range part ($\geq$ 8Hz) of whistler wave activity expected in interplanetary environment around 1 AU (1-100Hz). In our spectrum analysis, the wave power is divided into right-hand, left-hand and compressional ('R','L'

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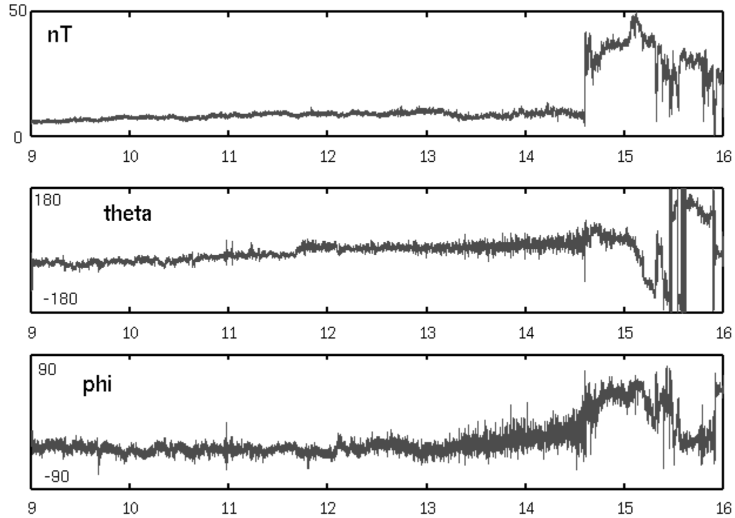

Fig. 1. Time profile of magnetic field. The shock was observed at 1435 UT.

and 'C') components. We also utilize particle data of GEOTAIL [5] , which measure electrons in the energy range of 60 eV - 38.2 keV.

The 15 July 2000 event is known as the 'Bastille day shock' for its large increase of particle flux. Shock acceleration of protons and generation of Aflvén waves in this event have been studied by several researchers (e.g. [6]). The time profile of magnetic field is shown in Fig. 1. The longitudinal and latitudinal angle of magnetic field in the second and third panel of Fig. 1 showed a clear enhancement in the level of magnetic field fluctuation after 1300 UT, which indicates that GEOTAIL went into the region affected by the IPS. Fig. 2(a) shows the wave power spectra well before (0900-1000 UT) and just upstream (1300-1400 UT) of the shock arrival, where we can see that there was one order of magnitude increase in the power spectra for the frequency range of ≥ 0.01 Hz. Simultaneous increase of proton fluxes after 1300 UT was studied in [6], which shows that this wave enhancement was due to Aflvén waves self-generated by shock accelerated protons.

As we are focusing on whistler wave properties now, we extend the polarization study to the higher frequency. Fig. 2(b) shows the average power spectrum in the frequency range of 0.01-8.0 Hz. The sharp peaks above 1 Hz are artificial noise and not natural. As in the lower frequency range, wave power after the change around 1300 UT is much higher than before. What seems remarkable is that R-component is enhanced more than L between 0.1-1.0 Hz, while R and L components are enhanced similarly in the lower frequency. The time profile of the spectra is shown in Fig. 3. As expected from the profile of magnetic field, it can be seen that wave enhancement is rather continuous, gradually increasing

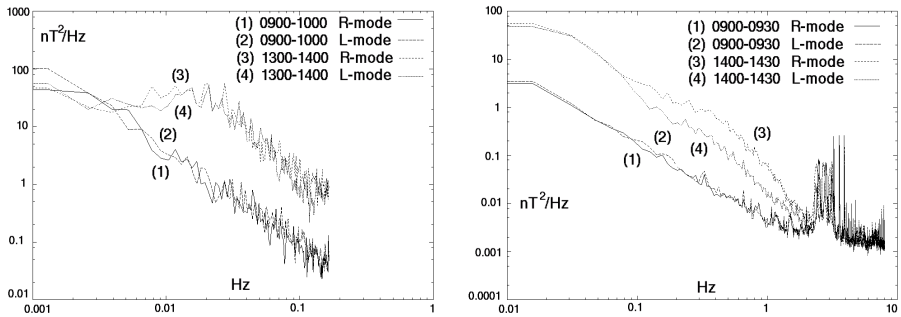

Fig. 2. (a) The power spectra of the lower frequency range. (b) The power spectra of the higher frequency range. Peaks above 1 Hz are artificial noise and not natural. In (a), spectra are calculated by using 256 point FFT of 3-second-averaged FX data (the degrees of freedom is 4); In (b), spectra are calculated by using 2048 point FFT of original 16 Hz FX data (the degree of freedom is 11).

toward the shock.

3. Discussion and Conclusion

Through the wave polarization study of the 15 July 2000 event, there appear two major characteristics in wave enhancement; one is that wave density increases gradually toward the shock front in whole frequency range (0.005-1.0 Hz), and the other is that R-mode waves are enhanced more than L-mode in the higher frequency range of 0.1-1.0 Hz. Since whistler waves assume right hand polarization, these features are suggestive that the gradual enhancement is due to whistler waves generated from the turbulence, cascading from the lower frequency range of Alfvén waves.

A present question is whether these cascading whistler waves take main part of the scatterer for low energy electrons. From the preliminary comparison between the wave observation and particle observation, we have obtained order-of-magnitude agreement: The values of spatial diffusion coefficients D_{obs} derived from the spatial gradient of electrons (0.5-40 keV), 6-10 $\times 10^{19} cm^2/s$, agree with the values from the observed wave spectra (according to the standard quasi-linear theory).

In this report, we have reported the analysis of 15 July 2000 IPS event, where it is suggested that the lower frequency Alfvén waves, generated by protons, transfer energy to higher frequency, to generate whistler waves. However, the number of IPS events in which whistler wave activity was observed is still not enough because of their accidental occurrence. In order to establish comprehensive understanding of the scattering/acceleration process of low energy electrons, we are collecting further interplanetary shock events.

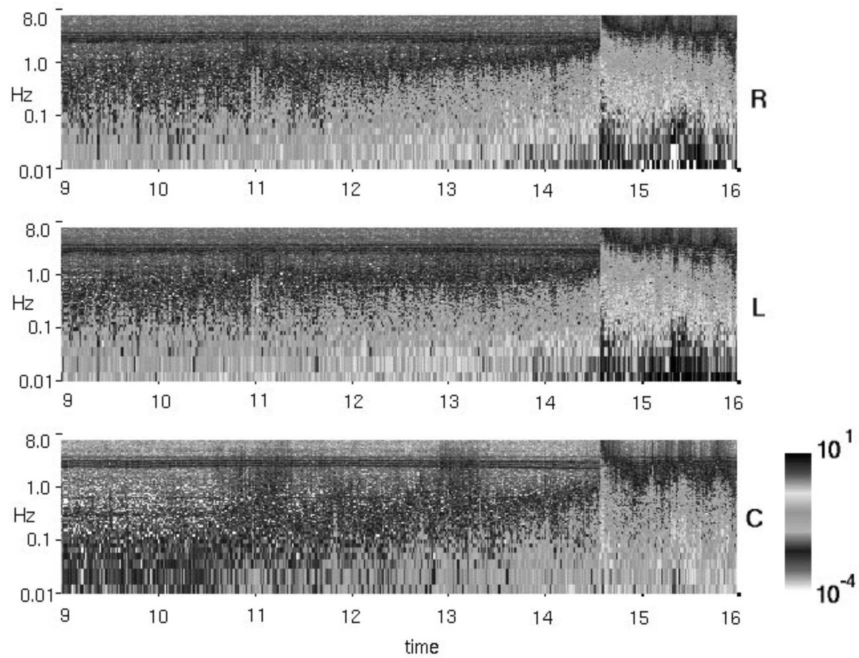

Fig. 3. Time profile of power spectra. The shock arrival time was 1435 UT. The three panels respectively show dynamic spectra of right, left and compressional component. Horizontal lines above 1 Hz are due to artificial noise and not natural.

4. References

1. Levinson, A., 1992, Astrophys. J., 401, 73-80.
2. Coroniti, F. V., et al., 1982, J. Geophys. Res., 87, 6029-6044.
3. Shimada, N., et al., 1999, Astrophy. Space Sci., 264, 481-488.
4. Kokubun, S., et al., 1994, J. Geomag. Geoelectr., 46, 7-21.
5. Mukai, T., et al., 1994, J. Geomag. Geoelectr., 46, 669-692.
6. Barmert, K., et al. submitted to GRL