Study on Electrostatic Waves in the Terrestrial Bow Shock Region via Spacecraft Observations

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Plasma waves observed in the Earth's bow shock region are presented in this thesis. Plasma waves play a very important role for acceleration, dissipation and thermalization of the electrons and ions. We, especially, focus on electrostatic waves whose frequency ranges are near 1 kHz which is commonly between the electron plasma frequency and the ion plasma frequency in the bow shock region.

One of the topics is electrostatic quasi-monochromatic (EQM) waves. Geotail plasma wave observations show the existence of intense EQM waves in the downstream region of Earth's bow shock [1]. Fig. 1 show that observed waveforms are quasi-monochromatic and their electric field oscillates parallel to the ambient magnetic field and appears at frequencies between the electron plasma and ion plasma frequencies. Although these waves have been believed to be Doppler-shifted ion acoustic waves, the typical plasma parameters observed in the downstream region do not support the generation conditions for ion acoustic waves. The existence of cold electron beam-like components accompanying EQM waves are examined based on the waveform and statistical analyses using Geotail plasma wave and particle observations. Based on linear dispersion analyses using realistic plasma parameters, it is explained that the cold electron beams cause destabilization of electron acoustic waves at frequencies consistent with those of observed EQM waves [2]. The results of observations and linear analyses suggest that EQM waves are generated by the destabilization of the electron acoustic mode.

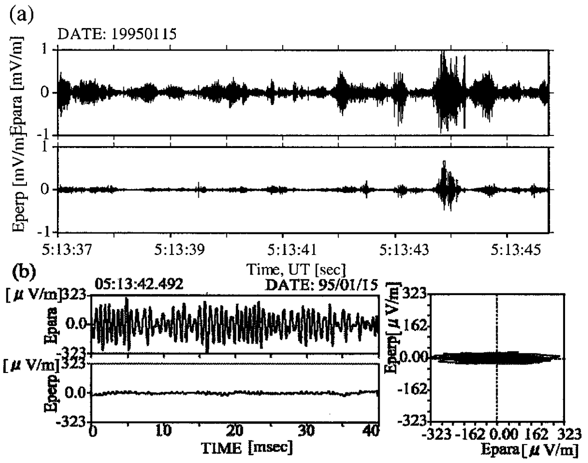

Fig. 1: (a) Waveforms of the EQM waves of the parallel (top panel) and the perpendicular (bottom panel) components with respect to the ambient magnetic field observed in the downstream region of the bow shock during the period from 5:13:37.000 UT to 5:13:45.500 UT on January 15, 1995. (b) Expanded waveforms (left panels) and corresponding hodograph (right panel) for the period of 40 milliseconds from 5:13:42.492 UT.

Next main topic is electrostatic solitary waves (ESW). We observed ESW in the upstream region of the terrestrial bow shock by the Geotail spacecraft [3] (Fig. 2). The ESW are mostly observed at a foreshock region. The foreshock region is separated into electron foreshock and ion foreshock regions dominated by energetic electrons and superthermal ions, respectively. The Geotail waveform observations show the existence of ESW in both electron and ion foreshock regions. To understand the wave features of ESW, we perform the waveform analyses and analyses of the spatial distribution of ESW. Results show that occurrences and amplitudes of ESW decrease as the distance from the bow shock transition increases. In the electron foreshock region, observations of the ESW correlate with electron beams away from the bow shock. We roughly estimate the potential depth of ESW as 0.15 eV using observed parameters. Potential depth is roughly few percent of the ambient electron temperature, similar in situation to the magnetotail ESW. In the ion foreshock region, ESW are simultaneously observed with superthermal ions reflected by the bow shock. We find two types of ESW which have different polarization in the ion foreshock region based on the orientation of their bipolar waveforms. To distinguish the characteristics of the different polarization ESW, we examine the spatial distribution of the occurrence frequency of the ESW both upstream and downstream propagating ESW (Fig. 3). The upstream propagating ESW are observed farther from the bow shock than the downstream propagation ESW. Furthermore, we examine the shock normal dependence and the Alfven Mach number dependence of the occurrences of ESW in the ion foreshock region. Results show that ESW observed in the quasi-parallel shock have characteristics different from those observed in quasi-perpendicular shock. The most plausible generation mechanism of the first type of ESW is Buneman instability based on the reflected superthermal ions and background electrons. A possible mechanism of the second type of ESW is positive potential which is propagated from the foreshock region to the bow shock, or negative potential generated by the reflected superthermal ions.

Furthermore, we observed ESW that have oblique potential structures with reference to the ambient magnetic field in the upstream region of the bow shock (Fig. 4). To understand the wave features of these ESW, we conducted the waveform and statistical analyses using wave form capture data onboard the Geotail spacecraft. The results of the statistical analyses show that the ESW with oblique potential structure are frequently observed in the vicinity of the bow shock, and the occurrence of those decreases as the distance from the bow shock increase. We conceive that generation of these ESW is highly dependent on bow shock conditions. Further, we examine the dependence of occurrence frequency of ESW and angle between the shock normal and electric field vector of the ESW. The ESW whose electric field vectors are parallel to the shock normal direction are observed mostly (Fig. 5). One of the possible generation mechanisms of oblique potential structures with the bi-polar pulses is that the oblique potential is generated by the two-stream instability with ion and electron components.

REFERENCES

[1] Shin, K., H. Kojima, H. Matsumoto, and T. Mukai, Electrostatic Quasi-monochromatic Waves Downstream of the Bow Shock: GEOTAIL Observations, *Frontiers of Magnetospheric Plasma Physics, COSPAR Colloquia Series, 16*, 293-296, 2005.

[2] Shin K., H. Kojima, H. Matsumoto and T. Mukai, Electrostatic quasi-monochromatic waves in the downstream region of the earth's bow shock based on Geotail observations, *Earth Planets Space*, 2006 (accepted for publication).

[3] Shin K., H. Kojima and H. Matsumoto, Characteristics of Electrostatic Solitary Waves in the Earth's Foreshock: Geotail Observations, *Journal of Geophysical Research*, 2007 (submitted).

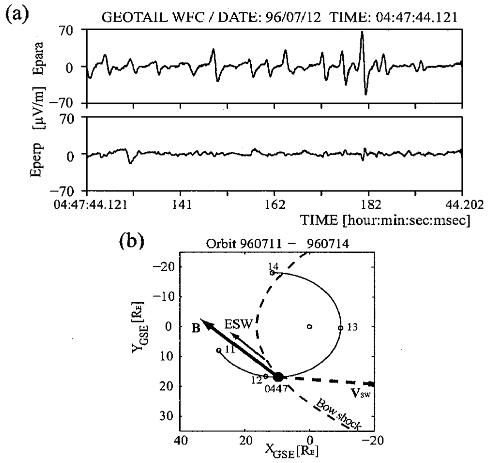

Fig. 2: (a) ESW waveforms of the parallel (upper panel) and perpendicular (lower panel) electric field component observed in the electron foreshock region on July 12, 1996. (b) Geotail orbit for the period of July 11, 1996 to July 13, 1996 in the Geocentric Solar Ecliptic (GSE) Coordinate System. Solid and dotted arrows show the directions of the ambient magnetic field (**B**) and the solar wind ion bulk flow (Vsw), respectively.

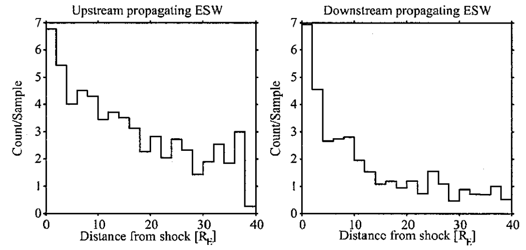

Fig. 3: Histograms of the occurrences of the (a) ESW propagating to the upstream region and (b) the ESW propagating from the bow shock with respect to the distance from the bow shock along to the ambient magnetic field.

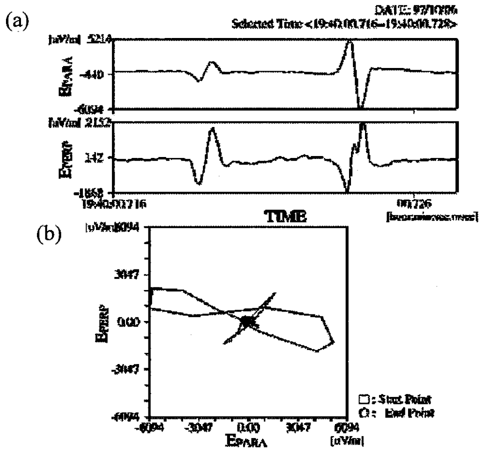

Fig. 4: (a) Waveforms of the parallel (upper panel) and perpendicular (lower panel) electric field with respect to the ambient magnetic field observed in the upstream region of the bow shock during the period from 19:40:00.716 UT to 19:40:00.728 UT on October 06, 1997 by the WFC receiver, and (b) corresponding hodograph of the observed electric field.

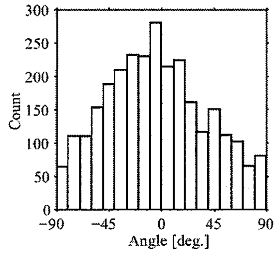

Fig. 5: Histogram of the occurrence frequency of the ESW that have oblique potential structure with respect to the angle between the shock normal and electric field vector of the ESW. Electric filed vectors of most ESW are close to the shock normal direction.