INSTABILITY OF THE ENERGETIC ELECTRON BEAMS IN THE POLAR CUSP-OBSERVATIONS BY CLUSTER AND INTERBALL-1

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ABSTRACT

Magion 4 companion of Interball 1 sometimes registered emissions with extremely high intensity around electron cyclotron frequency. These waves correlate with strong fluxes of high energetic electrons often observed within the polar cusp by Interball 1 and Magion 4 as well as by Polar satellites. Cluster measurements give new insight of these emissions. The observations of the waves at the frequencies close to electron cyclotron frequency done by Magion 4 and Cluster satellites associated with strong fluxes of energetic electrons are presented in this paper. Taking into account the plasma and magnetic field parameters in the polar cusp as well as geometry of the waves propagation, one has found that these emissions can be generated by so called "fan instability". This instability plays very important role in the nonlinear wave – particle interactions leading to the isotropisation of the fluxes of the particles and heating of the plasma.

1. INTRODUCTION

The polar cusp is the region in the plasma environment of the Earth where intensive conversion of energy takes place. Low-frequency plasma waves, which can control the dynamics of the ions in collision free plasmas, play a very important role in the formation and behaviour of this region.

The fluxes of accelerated plasma particles, electron and ion populations with a higher temperature than ambient plasma and very strong wave activity, particularly at the low frequencies, can be observed in the polar cusp. The earlier observations of waves in the polar cusp on Hawkeye- in the outer cusp, Viking in the middle cusp, and Freya and DE-1 in the lower cusp, indicate the presence of Alfven, lower hybrid, electron and ion cyclotron waves as the most typical modes in this region of the magnetosphere [1-6]. This situation indicates that the polar cusp is an ideal laboratory for studies of non-linear plasma processes important for understanding basic plasma physics as well as the magnetospheric and astrophysical application of these processes. Recently POLAR, INTERBALL and CLUSTER satellites discovered the presence of high energetic particles (electrons and ions) in the polar cusps [7]. The strong wave activity is associated with this population of plasma particles [3, 4]. The main goal of this paper is discussion dispersion properties of the fan instability together with observations of the energetic electrons and plasma waves in the frequency range just below the electron gyrofrequency.

2. FAN INSTABILITY

Fan instability has been studied first by Kadomtsev and Pogutse [8] for the case of the presence of the energetic electrons in Tokomak. For space plasma it has been discussed in relation to auroral region [9,10], solar wind [11] and magnetopause [12]. This paper is first presentation of this instability in the polar cusp. We use the dispersion relation of this instability from [10] with parameters typical for polar cusp and compare the results with observations done by CLUSTER satellites.
Fan instability is driven by a particle beam along the magnetic field lines but in contrast to the usual beam-plasma instabilities it does not require a threshold in the relative velocity and positive slope in the distribution function

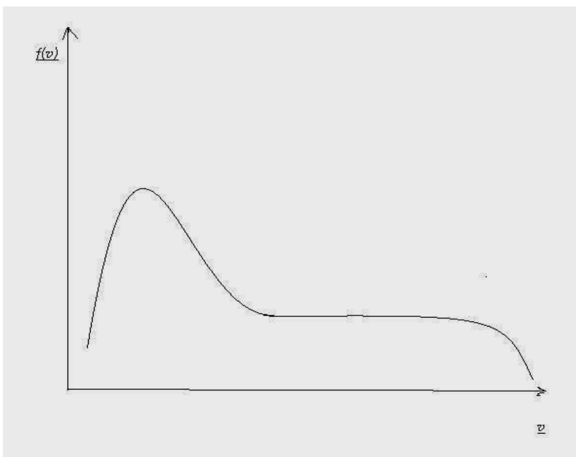

Fig.1. Schematic example of the distribution function needed for fan instability

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Long superthermal tail in the distribution function is needed for developing of this instability. Figure 1 shows the schematic shape of the distribution function, which can lead to this instability.

In [11] the model was extended on so-called electromagnetic lower hybrid waves

$$\frac{\omega^2}{\omega_p^2}+\frac{\omega^2}{\omega_c^2}\left(1+\frac{\omega_p^2}{c^2k^2}\right)=\frac{\omega_{pi}^2}{\omega_p^2}+\frac{k_z^2}{k^2+\omega_p^2/c^2}$$

They applied their model to study emissions in solar wind, where

$$\omega_p \gg \omega_c$$

The same condition is applicable for the polar cusp. It gives dispersion relation

$$\frac{\omega^2}{\omega_c^2}\left(1+\frac{\omega_p^2}{c^2k^2}\right)\simeq\frac{\omega_{pi}^2}{\omega_p^2}+\frac{k_z^2}{k^2+\omega_p^2/c^2}$$

For auroral magnetosphere they obtained

$$\frac{\omega_p}{\omega_c}\simeq 130,\ \frac{\omega_p}{2\pi}\simeq 13\,\mathrm{kHz},\ \frac{\omega_c}{2\pi}\simeq 100\,\mathrm{Hz}$$

$$2\text{-}3\ \omega_{lh}\lesssim\omega_r\lesssim\frac{\omega_c}{2},$$

$$E_b\simeq 2\text{-}12\,\mathrm{keV},\ T_e\simeq 15\ \mathrm{eV},\ \frac{T_e}{T_i}\simeq 4,$$

$$10^{-4}\lesssim k_\perp\lesssim 5\ 10^{-4}\mathrm{m}^{-1},$$

For polar cusp one can assume simplifications:
for frequency

$$\omega_{LH}\ \leq\ \omega\ <<\ \omega_{ce}$$

Oblique propagation

$$\omega = \alpha\omega_{ce}\cos\theta$$

$$\alpha = \frac{1}{\sqrt{1+\frac{\omega_{ce}^2}{\omega_{pe}^2}}}$$

$$\cos\theta = \frac{k_z}{k}$$

Maximum of the spectral density is obtained for $0.2<\cos\Theta<0.4$. And the maximum intensity should appear in the outer polar cusp for the frequency $0.19\omega_{ce}<\omega<0.38\ \omega_{ce}$

3. OBSERVATIONS IN THE POLAR CUSP

Cluster satellites crossed many time the polar cusp with the presence of the energetic electrons. To show the effect of the fan instability we have chosen 2 cases, when the strong wave activity in the frequency range corresponding to the fan instability was registered.

We use the wave data from STAFF instrument [13], identification of the cusp has been done with use of PEACE and CIS data.

3.1 Case 21.02.2003

Fig.2 shows the measurements of the ion energetic spectra and plasma parameters (density, velocity and temperature respectively) for case of the cusp crossing on 21 February 2003 by CLUSTER 1 satellite.

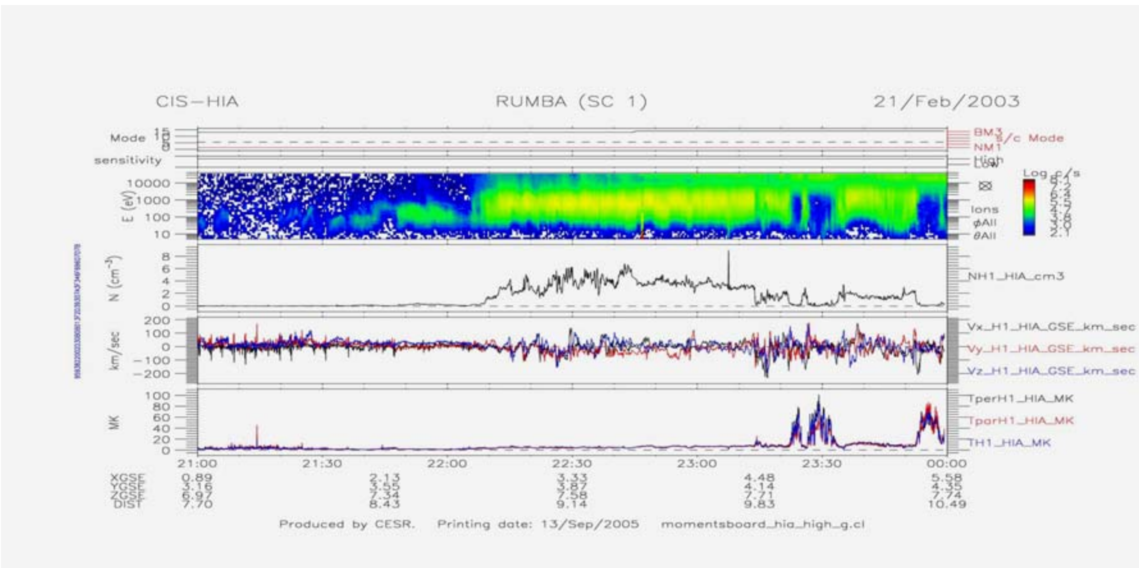

Fig.2 3 hours (21:00-24:00UT) of the measurements of the ion energetic spectra (upper panel), ion density (second panel) , ion velocity (third panel) and temperature (bottom panel) by CIS instrument on CLUSTER 1. The cusp crossing can be seen in the time interval 22:35-23:00UT, but short touch of the cusp boundary associated with registration of the velocity enhancement is seen on 23:30UT.

Cusp proper was crossed between 22:25 and 23:00 UT, but short touch of the cusp boundary one can see at 23:30UT and this touch is associated with strong enhancement of the plasma flow velocity and plasma temperature, also some increasing of the density occurs at this moment. (see Fig.2). RAPID experiments on all 4 satellites show in this time enhancements of the fluxes of the energetic electrons (Fig.3). Maximum intensity is seen around 23:30 UT, but strong variability can be noted. The energetic spectra have characteristics, which is suitable for the developing of the fan instability.

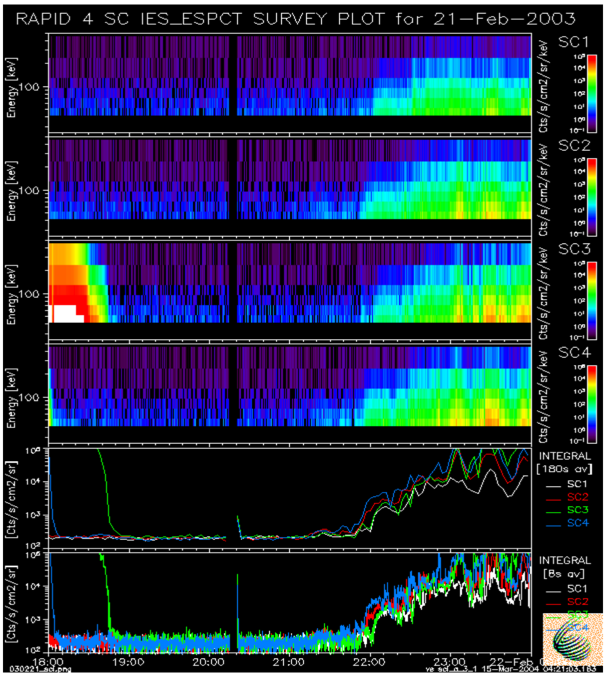

Fig.3. Spectra and fluxes of the energetic electrons obtained from RAPID instruments on four spacecrafts. The event discussed in text is seen at 23:20-23:30UT.

Fig.4 contains wave spectra measured by STAFF instrument on 21 February 2003 between 22:25 and 23:34UT. Four upper panels present the spectral density of the magnetic field fluctuations seen by four spacecrafts, next four panels show the electric component of the spectra. The intensive electrostatic waves are present during the whole time interval. The magnetic component appears during crossing of the proper polar cusp and during touch of the cusp boundary. Most interesting interval, from the point of view discussed fan instability is when intensive flux of the energetic electrons at the cusp boundary is registered 23:20-23:30UT. On the spectra of the magnetic field variations as well as of the electric field variations, some subtle dots are clearly seen at the frequency 250-300Hz. These maxima of the wave intensity correspond to the fraction of the electron gyrofrequency. In the discussed time interval value of the electron gyrofrequency was equal around 800-900Hz. It means that maximum of the spectral density both of the electric and magnetic component is around 1/3 of the electron gyrofrequency. This result is in good agreement with the measurements done by Magion 4 subsatellite for INTERBALL-1 [2, 3] and with dispersion properties of the fan instability (see chapter 2)

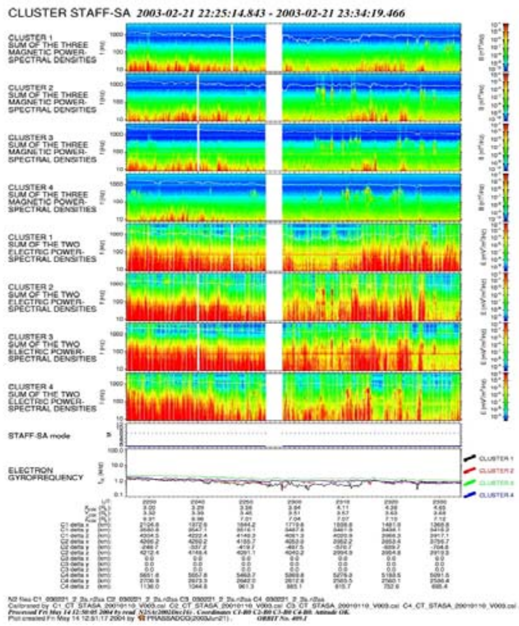

Fig.4 STAFF measurements on board of four CLUSTER satellites. The time interval of the measurements covers the crossing of the proper polar cusp and the crossings of the regions with fluxes of the energetic electrons. 4 upper panels show the magnetic component of the wave spectra registered on 4 satellites, 4 lower panels give the spectra of the electric wave component.

3.2 Case 3.04.2003

The cusp crossing as seen by CIS instrument on CLUSTER 3 satellite is shown in Fig. 5. Around 9:10-9:12UT strong variations in the energetic spectra and ion parameters are seen. The enhancement of the velocity along z axis reaches value 200km/s, the density and temperature are typical for polar cusp. The depletion of the magnetic field is also registered in this region. RAPID instrument registered strong and sudden increasing of the energetic electrons about 9:12UT (Fig.6), but on the spacecraft 4. RAPID data from CLUSTER 3 are not available for this case. The satellites 1 and 2 also registered this jump of the energetic flux and we can assume that it is common for entire region studied at this time by the set of CLUSTER satellites.

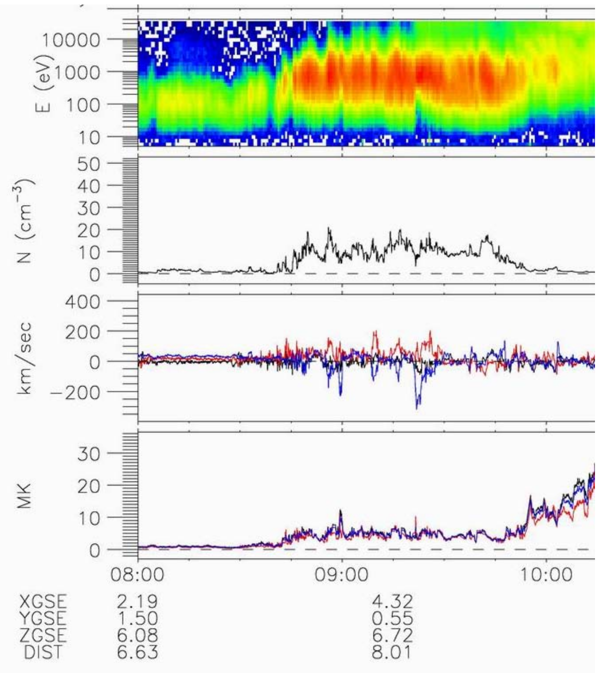

Fig.5 The same as in Fig.2, but for the case of CLUSTER 3 measurements on 3 April, 2003.

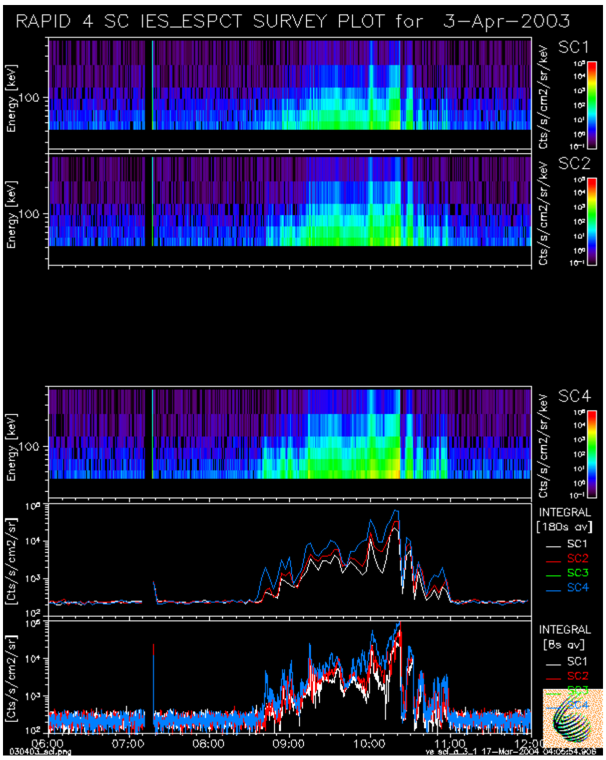

Fig.6 The same as in Fig. 3 for the polar cusp crossing on 3 April, 2003.

The wave data are shown in Fig7-Fig.10. Fig.7 gives the overall view of the wave spectra for time interval 8:19-9:24 UT. The strong wave activity in both magnetic and electric components is seen during entire time interval. For our discussion most interesting is the interval, when strong variations of the plasma parameters were registered together with enhancement of the energetic electrons flux. The magnetic spectra taken by STAFF on CLUSTER 3 satellite for this time interval are given in Fig 8. During this event one can see the presence of the maximum in the spectral density in the frequency range 200-300Hz. These values of the frequency are close to about 1/3 of the electron gyrofrequency. This is as in previous case good indicator for fan instability.

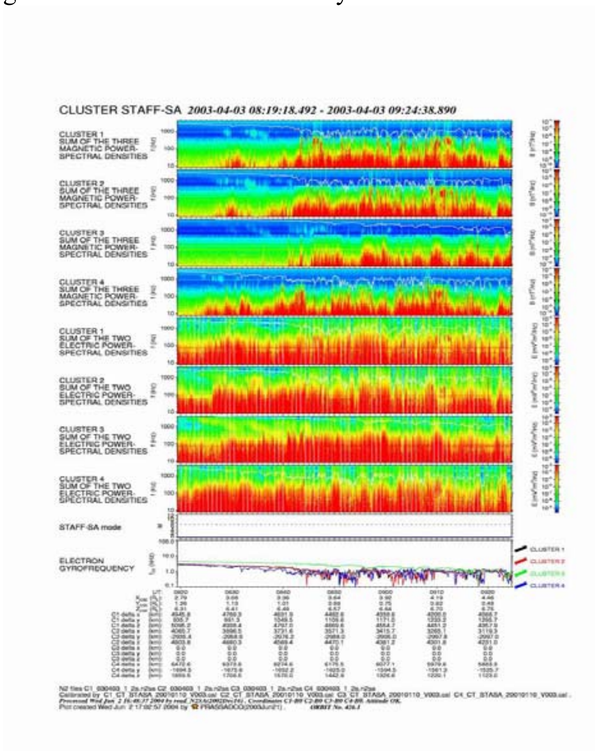

Fig.7 The same as in Fig. 4 for the case 3 April, 2003.

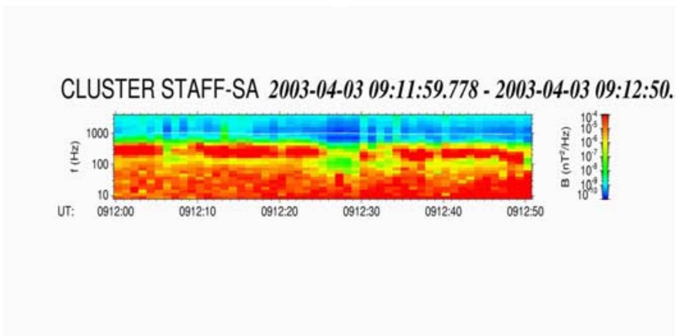

Fig.8 The spectra of the magnetic component of the waves during high energetic event on 3 April 2003. Note the presence of the strong maximum at frequency around 250-300Hz during this event.

Fig.9 shows the single spectrum chosen from the discussed time interval. This presentation gives the clear evidence that maximum of the spectral density appears at 300Hz.

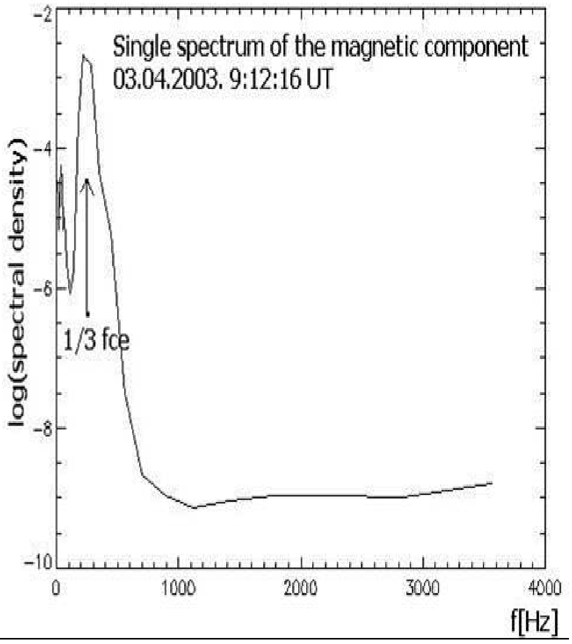

Fig.9 Single spectrum of the wave magnetic component

The results of the propagation analysis of the waves from discussed event on 3 April 2003 are presented in Fig.10.

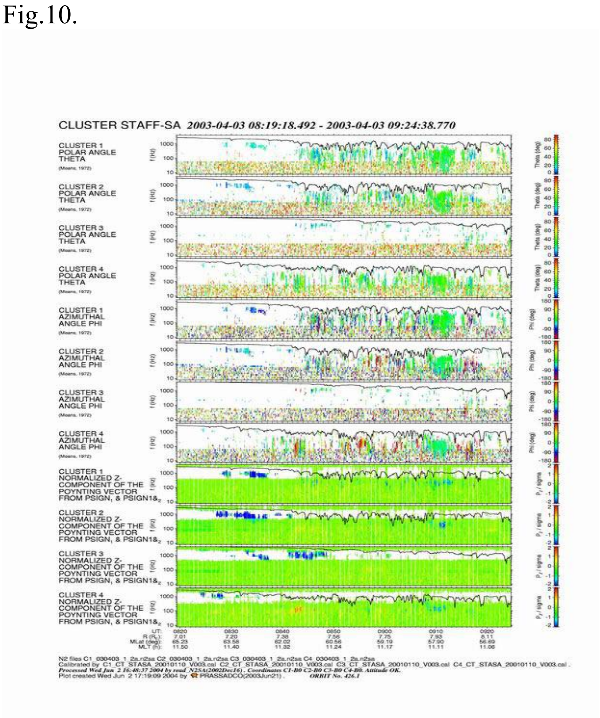

Fig.10 The propagation analysis for the case 3.04.2003. The angles between wave vector and magnetic field and Poynting vector from the measurements on four CLUSTER spacecrafts.

The waves with maximum spectral density in the frequency range 200-300Hz propagate at the angle about 40^0-60^0 to the magnetic field what is in good agreement with the linear theory of the fan instability.

4. CONCLUSIONS

Presented in this paper observations of the waves together with plasma and energetic electrons in the polar cusp done by CLUSTER satellites shown the interesting wave phenomenon this can occur in the polar cusp when the energetic electrons are present. The same type of event was registered by Magion 4 subsatellite to Interball 1 [3]. The observations (Magion 4 and CLUSTER) of the emission at the frequency above lower hybrid) and well below electron cyclotron are in good agreement with theory of fan instability.

CLUSTER and Interball observations shown that fan instability should be discussed as one of the important mechanism of waves generation in the polar cusp and mechanism responsible for the redistribution of the energy in cusp plasma. Further more detail analysis is needed.

Acknowledgements

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