Results of the Plasma Wave Sounder Experiments on Board the Akebono Satellite in the Topside Ionosphere and Plasmasphere

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Abstract

By the plasma wave sounder on board the Akebono satellite, the radio wave echoes, and plasma wave resonances have been observed through out the topside ionosphere and plasmasphere. The radio wave echoes had been observed even at altitude of 6,000 km showing feature of duct propagation. The plasma bulge structure were also confirmed in the high latitude topside ionosphere. The results of the sounder experiments show the principal resonances such as plasma resonances at f_p, upper hybrid resonances at f_{UHR} and harmonics of the electron cyclotron frequency at nfc; harmonic number n in the plasmasphere becomes higher than 10, sometimes. The sequence of the diffuse plasma resonance f_{Dn} changes the occurrence mechanism between the topside ionosphere and the plasmasphere with boundary regions around the altitude of 3,000 km. As a remarkable new finding, f_{D0} ($n=0$ case of the sequence of the diffuse plasma resonance) have been found. The occurrence of f_{D0} resonance gives confirmation to the mechanism of f_{Dn} generation as the instability of electrostatic electron cyclotron harmonic waves being associated with non linear wave particle interaction.

1. Introduction

There is a long history of studies on the artificially stimulated plasma waves relating to radio wave sounder experiments in the ionospheric plasma, starting from the experiments of sounding rockets, Alouette 1, 2 and ISIS-1 and 2 satellite [1-4]. After these contribution of the first generation of the sounder experiments, a series of the satellites were launched as Japanese contributions. That is, observations by Jikiken (EXOS-B) [5] and Ohzora (EXOS-C) [6]. Following this current, more extensively organized experiments on high frequency plasma waves (above 20 kHz to 11 MHz) have been carried out by the sounder, on board Akebono (EXOS-D) satellite, that was installed as sub-system of Plasma Wave and Sounder experiments (PWS).

The present paper describes the summary of the results of the sounder experiment, that were made in the topside ionosphere and plasmasphere.

2. Instrumentation

As a part of the instrumentation of the Plasma Wave and Sounder experiments system (PWS) on board the Akebono satellite that had been launched on Feb. 24, 1989, in a semi polar orbit with initial apogee, perigee, and inclination, respectively, of 10,500 km, 300 km, and 65°, the sounder experiments have been successfully carried out after deployment of two dipole antennae with length of 60 m from tip to tip on March 4, 1989. Using a set of the dipole which has been facilitated as part of two dipole systems installed with orthogonal relation each other, the radio wave pulses with power of 300 Watt to 600 Watt are impressed while the responses of the injected radio wave pulses are detected by the another set of the dipole antenna.

The frequency of radio wave pulses impressed on the dipole with pulse width of 292 μsec for the L-band and 92μsec for the H-band is swept from 20 kHz to 890 kHz in low frequency mode (L-band) and from 300 kHz to 11.4 MHz in high frequency mode (H-band) with full sweep interval of 32 sec, while the frequency is varied step by step with period of 32 msec. The other set of the dipole is shared for the receiving of the response of the transmitted radio waves. The sounder experiments using this SPW of sounder subsystem (SPW-SN) had been made in whole range of the satellite path starting from the level of the ionosphere to the regions of the plasmasphere. The observation periods are planed to share the operation schedule with whole other PWS system; the operation periods were set with unit of 15 minutes. In early phase of the operation of the satellite, 5 to 10 units of operation interval were dedicated to the sounder experiments.

3. Sounder Echo

3.1 Example of the Observed Iono- and Plasma-gram

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Typical echo trace observed in the topside ionosphere is given in Figures 1(a) and (b) [7]. In Figure 1(a), for an ionogram obtained at the altitude of 1,942 km, a clear trace of the Z, O and X-mode radio waves are indicated together with typical plasma resonances. In Figure 1(b), an example of the ionogram (plasma-gram) observed in the plasmasphere at altitude of 5,665 km is given. In this plasma-gram very long delayed echo of the O and X mode of the radio waves that can be attributed to a duct propagation is shown with plasma resonance at f_p, f_{UHR}, $2f_c$, $3f_c$ together with 4th sequence of f_{Qn}.

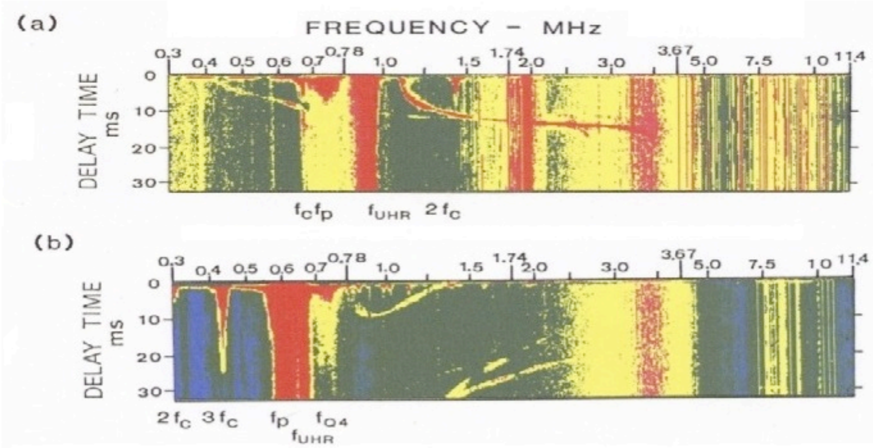

Figure 1: Ionograms observed by Akebono PWS-sounder experiments. Symbols nf_c, f_p, f_{UHR}, and f_{Q4} indicate n-th harmonics of the electron cyclotron resonance, plasma resonance, upper hybrid resonance, and 4th sequence of electrostatic electron cyclotron harmonic wave resonance, respectively. (a) The ionogram observed on April 1, 1989 at 08h 52m 15s (UT) at the altitude and magnetic dipole latitude, respectively, of 1,942 km and 53.1°. (b) The ionogram observed on March 30, 1989 at 07h 18m 12s (UT) at the altitude and magnetic dipole latitude, respectively, of 5,665 km and 9.6°.

3.2 Confirmation of Plasma Bulge in Polar Region Topside Ionosphere

By analyses of the PWS-sounder ionogram in the polar region topside ionosphere, 29 cases of the bulge structures [8] have been observed for the 6,476 cases of the analyzed ionograms obtained during 233 paths of the polar region passage of the Akebono satellite, in January 1990. The observed topside plasma bulge is characterized by the increment of electron temperature by factor 1.5 to 4 in the night time topside ionosphere in the altitude range from 800 km to 3,000 km, in regions of high latitude, higher than 70°, in terms of the invariant latitude. It has been suggested that the occurrence of the bulge structure coincide with the ion outflow in the polar region upper atmosphere (from Master thesis by S. Kodama supervised by T. Ono).

4. Observations of Highly Irregular Plasma in Polar Region Plasma Trough

By the PWS-sounder experiments in the region of polar region plasma trough, plasma density distribution along the satellite paths were observed. The detected plasma density distribution indicated extremely high irregularity. The electron density varies in a range from 4 /cc or less to 100 /cc within a few km for the case of the satellite path in altitude range of 5,000 km to 8,000 km in the magnetic latitude of 55 to 75°, these results can add another detailed information for the polar region plasma distributions that are already pointed out by IMAGE satellite observation results [9,10].

5. Sequence of Diffuse Plasma Resonance (SDPR)

5.1 Occurrence of *n=0* mode

Occurrences of the sequence of diffuse plasma resonance f_{Dn} [11] have been confirmed mostly in the topside ionosphere below 3,500 km. One of the remarkable results carried out by the SPW-sounder experiments is occurrence of the bottom sequence of SPDR at $n=0$; i. e., f_{D0}. The 440 cases of occurrence of f_{D0} resonances had been observed when the plasma condition $f_p/f_c < 2$ is satisfied for the observation interval from March 1989 to April 1996 (from Master thesis of A. Tadaoka supervised by H. Oya). For the occurrence of f_{D0}, it is confirmed that the stimulation of f_{D0} resonance is associated with stimulation of the f_{Q2} resonance and confirmed that two resonances are related by equation,

$$f_{Q2} - f_{D0} - \left(\vec{k}_{Q2} - \vec{k}_{D0}\right) \cdot \vec{V}_B \big/ 2\pi = 2f_c . \tag{1}$$

5.2 Characteristics of Stimulated Non-Linear Wave Particle Interactions in the

Plasmasphere

The characteristic points of the stimulation of SDPR in the ionosphere level are varied their feature in the region of the plasmasphere. In the C-scan diagram given Figure 2, we can see three trends of the special plasma resonance f_B, f_{U1}, and f_{U2}, in addition to regular plasma resonance such as f_p, f_{UHR}, and nf_c. For these three special plasma resonances, we can find the relations

$$f_{UHR,f} + f_{UHR,b} - \left(\vec{k}_{UHR,f} - \vec{k}_{UHR,b}\right) \cdot \vec{V}_B \big/ 2\pi = 0\,, \tag{2}$$

where $f_{UHR,f}$ and $\vec{k}_{UHR,f}$ are the frequency and wave number vector of the upper hybrid waves propagating forward direction and $f_{UHR,b}$ and $\vec{k}_{UHR,b}$ are the frequency and wave number vector of the upper hybrid waves propagating backward direction being reflected back from the local irregularity. Similar process of the nonlinear wave particle interaction can be assumed for the $f_{U1}=2f_p$ plasma resonance. For f_B resonance, we find the relation

$$f_{UHR} - f_B - \left(\vec{k}_{UHR} - \vec{k}_B\right) \cdot \vec{V} \big/ 2\pi = f_c\,. \tag{3}$$

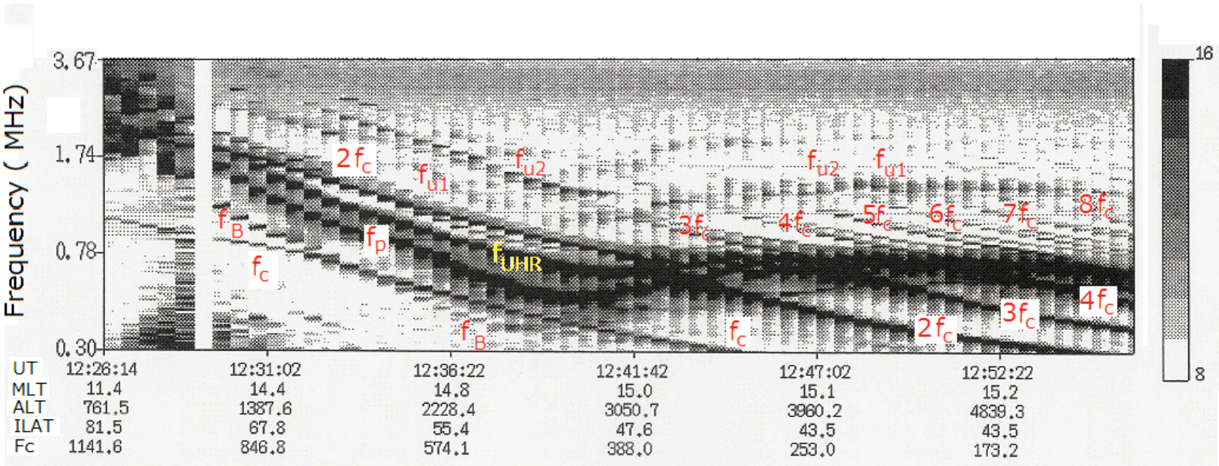

Figure 2: C-scan plot of the sounder experiment carried out on August 21, in 1989 along the satellite path in altitude range from 761.5 km to 5,700 km. C-scan plot is made from the regular ionogram taking the axis of the swept frequency to be ordinate setting sequentially observed ionograms along abscissa for every 32 sec by limiting the observation interval of the ionogram to 1.5 msec. The observed times, positions, and local electron cyclotron frequency are indicated in abscissa labeling by UT, MLT, ALT, ILAT, and Fc. Meaning of f_B, f_{U1} and f_{U2} are described in the main text.

6. Discussions

The stimulation of the SDPR resonance observed by the Akebono SWP-sounder experiments revealed two new evidences. The first is the variation of the occurrence mechanism from the case of the stimulation in the topside ionosphere region below 3,000 km to the case of the stimulation in the plasmasphere. The mechanism of SDPR formation in the topside ionosphere level is affected by the modification of plasma velocity distribution function due to the injection of RF power into the ambient plasma. The stimulation of SDPR in the plasmasphere, however, less responsible to the modification of plasma velocity distribution function due to the injection of the RF power, but largely controlled by the intrinsic plasma velocity distribution function in the plasmasphere. This difference of the modification of the plasma velocity distribution function can be attributed to the difference of the energy contained in plasma. The energy level of the plasmaspheric plasma is higher than that of the topside ionosphere by 10 to 100 times.

The second point is the new finding of stimulation of SDPR at $n=0$. The stimulation of f_{D0} resonance becomes a definite confirmation that the occurrence of SDPR is intimately related to electrostatic electron cyclotron harmonic (ESCH) waves and related to ESCH wave instability which is characterized by the coverage of a frequency range centered at $(n+1/2)f_c$. We believe then that the assumption of Osherovich [12] who proposed his force free electromagnetic field condition can not apply to the stimulated plasma wave resonance, but we should select the process of the weak turbulence associated with ESCH wave instability. That is, we should select full description of the Maxwell equation. When we select local plasma assumption for such the case of the sounder experiments, the expression is given by

$$\mathbf{j} \times \mathbf{B} = \mathbf{B} \times \frac{\partial \mathbf{D}}{\partial t}\,. \tag{4}$$

In the time scale and the spatial characteristic length of the plasma wave turbulence, we can not neglect $\partial \mathbf{D} / \partial t$ term.

7. Conclusion

The PWS-sounder on board the Akebono satellite had operated after deployment of the antenna and turn-on of the instrument on March 4, 1989. The sounder system has been facilitated as subsystem of the Plasma Wave Observation and Sounder Experiments (PWS). The results of PWS-sounder experiment indicated complete sets of response to the transmitted radio wave pulses as reflected echoes and also as plasma wave resonances both in the ionosphere and plasmasphere. One of remarkable results of the echoes from the topside ionosphere is the confirmation of the bulge effects on the scale height as the reflection of the regional increase of the electron temperature. Plasma wave resonances had indicated the principal resonances such as plasma resonances at f_p, upper hybrid resonances at f_{UHR}, and harmonics of the electron cyclotron frequency at nf_c; the n becomes sometimes larger than 10. The sequence of diffuse plasma resonances f_{Dn} with the static electrostatic electron cyclotron harmonic wave resonance f_{Qn} observed in the topside ionosphere. One of remarkable new finding is the identification of f_{D0} ($n=0$ sequence of f_{Dn} resonance) in the topside ionosphere region. The occurrence of f_{D0} resonance strengthens the concept of the occurrence mechanism of the sequence of the diffuse plasma resonances in terms of the weak turbulence of the electrostatic electron cyclotron harmonic waves. The sequence of the diffuse plasma resonance changes the occurrence feature between the topside ionosphere and plasmasphere with a boundary region around the altitude of 3,000 km. The f_{Dn} frequency in the topside ionosphere is well response to the $(n+1/2)f_c$ instability while the occurrence frequency is controlled by the non linear wave particle interactions with existing electron beam component in the plasmasphere rather than being modified by the RF power impressed by the sounder operations.

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