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Summary on Plasma Wave Emissions Observed by JIKIKEN —Preliminary Report for the Initial Phase of the Observation Results

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Abstract: JIKIKEN (EXOS-B) was successfully launched on Sept. 16, 1978 into an orbit with initial apogee of 30,056 km and perigee of 229 km, with an inclination -31.1°; the orbit is suitable for the investigation of the wave-particle interaction process near the plasmapause. The analog data transmission system is used and we can obtain fine structure of the dynamic spectrum in a frequency range from 10 kHz to 3 MHz, and wide band spectrum from several 100 Hz to 10 kHz. The important wave phenomena observed by current observations of JIKIKEN are as follows:

i) Auroral (Earth) kilometric radio waves;
ii) Upper hybrid mode emissions;
iii) $(n+1/2)f_c$ emissions;
iv) Principal phenomena of VLF frequency range such as whistler, chorus, and hiss;
v) Pure-tone emissions in VLF range;
vi) Artificially stimulated plasma waves and observation of plasma parameters;
vii) Planetary radio waves;
viii) Solar type III outburst.

As a preliminary approach to verify the wave particle interaction processes, investigations of the energy spectra have also been made for the case of the UHR mode plasma wave and pure-tone emission in ELF and VLF ranges. Very long lasting UHR resonance has been triggered by 500 μsec pulse in the stimulated plasma wave experiment. The resonance persists up to 125 msec even in VLF range (below 30 kHz) and the electron cycltoron resonances are stimulated in very high harmonics number n; in the maximum case, sometimes, n=20. Using these resonance frequencies, the plasmapause electron density distributions are obtained.

1. Introduction

The first challenge of Japanese scientific satellite to study of the magnetosphere has been carried out by JIKIKEN (EXOS-B) that was launched on Sept. 16 th, 1978. The satellite JIKIKEN has been injected into the orbit with the initial apogee of 30,056 km and the initial perigee of 229 km with the inclination of -31° and the period of 523.6 minutes. During Sept. 23 to 25, the deployment of the long antennas with length of 102 m (tip to tip) and 72 m (tip to tip) was carried out. After the deployment, observations of the wave phenomena have successfully started. In the period from Oct. 8 to 9, operations of the high voltage supply to the installed equipments such as the energetic particle analyser and the stimulated plasma wave instrument had also successfully been made. The satellite JIKIKEN thus has been established for the initially planned observation.

Many fruitful results are going to be accumulated and we are expecting the contribution to solve many important phenomena in the magnetosphere relating to the aurora formation area using the data observed by JIKIKEN. The present paper is a preliminary introduction of the results mainly focused on the wave phenomena. Consideration has also been made on the wave particle interaction processes.

2. JIKIKEN (EXOS-B) Summary

2.1 *Observation Subjects*

In EXOS-B satellite, the following scientific subjects are considered.

a) *Stimulated plasma wave experiment* (SPW)

The 300 Watts transmission of RF pulse is planned to feed on an antenna that has a length of 102 m from tip to tip in a frequency range from 20 kHz to 3 MHz that can effect on the plasma surrounding the entire range of the satellite orbits; the plasma parameters (electron temperature, temperature anisotropy, and electron density) will be obtained from the controlled triggering of waves. The processes of the plasma instabilities and the processes on the nonlinear wave-particle interaction can be studied by injecting strong electric field in the radio frequency range.

b) *Natural Plasma Waves* (NPW)

The VLF to LF electromagnetic and electrostatic waves in the deep plasmasphere can be observed in the frequency range $10^2 \sim 10^5$ Hz. MF to HF plasma waves ($10^5 \sim 10^6$ Hz) and the additional informations on the ion waves ($10^2 \sim 10^3$ Hz) will be detected in the near-earth range of the satellite orbits. Detection of the wave-wave and wave-particle nonlinear interactions are one of the significant themes relating to the particle accelerations, the turbulent plasma heating and energy transportation.

b.1) *VLF waves up to 10 kHz will be received with a wide-band VLF receiver* using long dipole antenna. The VLF emissions in the plasmasphere, $(n+1/2)f_c$ electrostatic plasma waves in the magnetosphere are the important objects.

b.2) *Planetary Radio Waves*

Using long dipole antenna (51 m–51 m antenna) the hectometer and decameter waves from planets, such as Jupiter and Saturn as well as the earth's kilometric waves are going to be received in frequency range from 20 kHz to 3 MHz.

c) *Plasma Parameter Measurement by VLF Doppleer Technique* (DPL)

The electron density and temperature can be measured from the Doppler effect on the VLF waves transmitted from the VLF transmitting station.

d) *Plasma Parameter Measured by Impedance Measuring Method* (IEF-I)

The swept frequency impedance probe provides basic data for calibration of the natural plasma wave detections and data for the estimation of the transmission efficiency for the plasma wave stimulations. One of the main objectives of this probe is to measure the electron density independently to all other techniques, that can be accurately carried out by cancelling a stray capacity.

e) *Electric Field Measurement* (IEF-F)

Using 51 m–51 m dipole, electric fields in the plasmasphere can be measured. The satellite body is coated by conductive materials to eliminate local electric fields for accurate measurement of the natural electric fields.

f) *Magnetic Vector Field and Sun Earth Detector* (MGF)

Geomagnetic vector field and its perturbation effects can be detected by a flux gate magnetometer; this gives the cordinates of the magnetosphere in terms of the magnetic field vector. The sun and earth detectors give a frame for the detection of the local attitude of the satellite.

g) *Energy Spectrum of Particles* (ESP)

Energy spectrum of particles can be analyzed using channeltron multiplier, in an energy range from 10 eV to 20 keV, both for the electron and protons. The pitch angle distribution is not planned to observe but these detectors will carry out important role for measurements of the particle behaviors correlated to the wave phenomena.

h) *Controlled Beam Emissions* (CBE)

Spacecraft potential will be controlled by an emission of electron beams to make the accurate measurement of these low-energetic particles; and also for the measurement of the conventional electrostatic probes that will give the double check-data to the results of the plasma parameters obtained from the wave phenomenological approach.

The emitted electron beam that can be controlled in an energy range from 1 eV to 200 eV makes plasma instability that contains many kinds of plasma waves; this CBE experiment provides important effects on the analysis of the wave-particle interactions.

2.2 *Other Correlated Observations*

The operations of the JIKIKEN (EXOS-B) satellite will be correlated with the observation of the KYOKKO (EXOS-A) satellite and also with observation of ground-based VLF electromagnetic waves and ULF magnetic field oscillations as well as the other geophysical phenomena that will be planned in the IMS periods.

2.3 *Initial Contributors*

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3. Natural Wave Phenomena

3.1 *Earth Kilometric Radio Waves*

The most pronounced and popular phenomena of the received radio waves by JIKIKEN are the auroral kilometric radio waves emitted from the earth's plasmasphere along L-shells connected to the auroral zone. In Figure 1(a) a typical spectrum pattern of the auroral kilometric radio wave is indicated for the case of the observation on Sept. 29, 1978 at Rev. 35. We can see a dramatic feature that indicates time variation of the auroral kilometric radiations. These spectra are characterized by peaks in a frequency range from 100 kHz to 300 kHz. (Gurnett, 1974)

The theoretical background (Oya, 1974; Benson, 1975) suggests that the observed radio wave spectrum indicates that feature of the particle precipitation along the field line where the frequency range from the electron cyclotron frequency and the upper hybrid resonance frequency corresponds to the observed radio wave frequency. Time variation of the TKR spectrum, then, inform us whole feature of the precipitating particle along the L-shell. One example of the spectrum variation has been given in

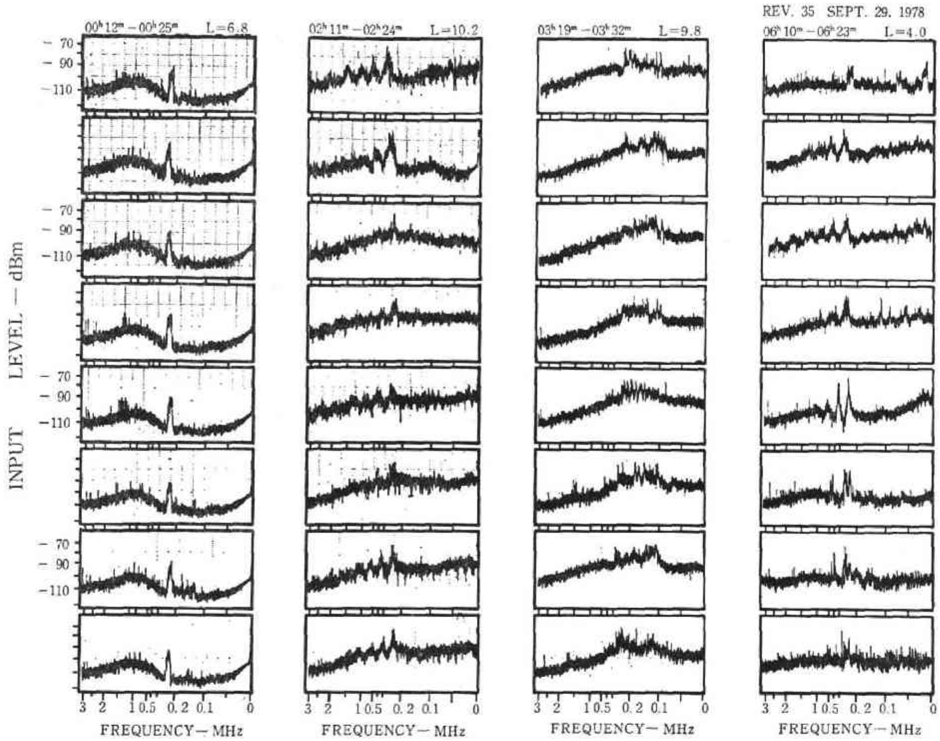

Fig. 1(a). Time variation of terrestrial kilometric radio waves; sampled spectra are shown for the data observed on Sept. 29, 1978.

Figure 1(b). The occurrence of TKR radio wave tends to be observed during all the night time. Only the activity changes indicating clear correlation to substorm activities.

Existence of the spectrum peak around 100 kHz to 300 kHz, then, indicates that a strong wave particle interaction is taking place in a range from $1.5R_e$ to $2.15R_e$ suggesting the auroral particle acceleration in this region.

3.2 *Upper Hybrid Mode Waves*

Several reports have already been made on the existence of the emission in a frequency range from the local plasma frequency to the local upper hybrid resonance frequency; this can be called upper hybrid resonance mode. An extensive survey can be possible by observation of JIKIKEN, as has been given in Figure 2; long lasting upper hybrid resonance mode wave has been normally observed indicating that the region near the plasmapause is filled by the local emission of the upper hybrid resonance mode waves. Sometimes, the intensity of the upper hybrid resonance mode increases to the level of saturation for the pre-amplifier of the receiver (larger than 10 mVolt). We can observe the higher harmonic components due to saturation as has been given in Figure 2.

The frequency range corresponding to the upper hybrid resonance mode is a channel

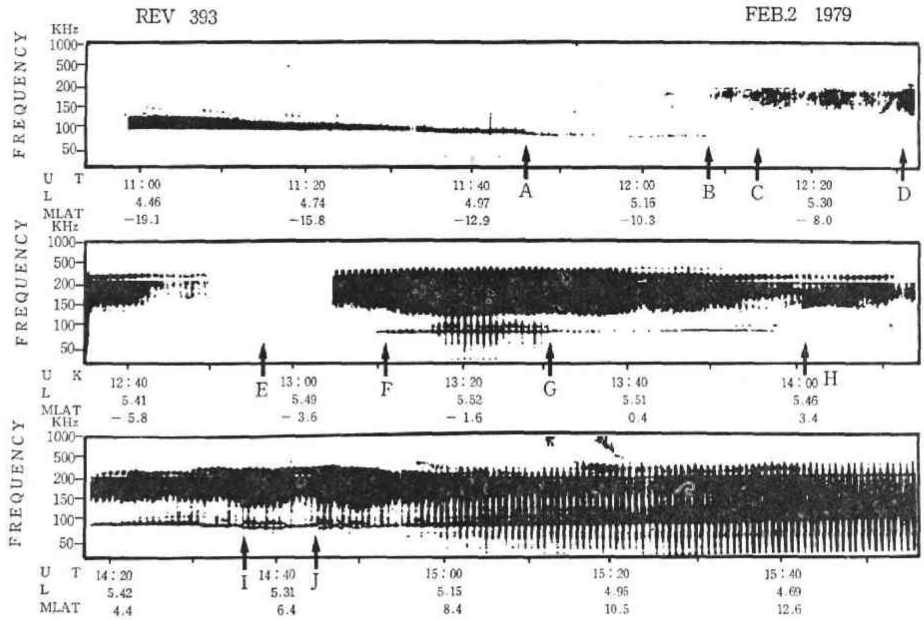

Fig. 1(b). Dynamic spectra of the terrestrial kilometric radiation; arrows indicate the time when Pi2's have been started as indicator of the onset time of the substorm.

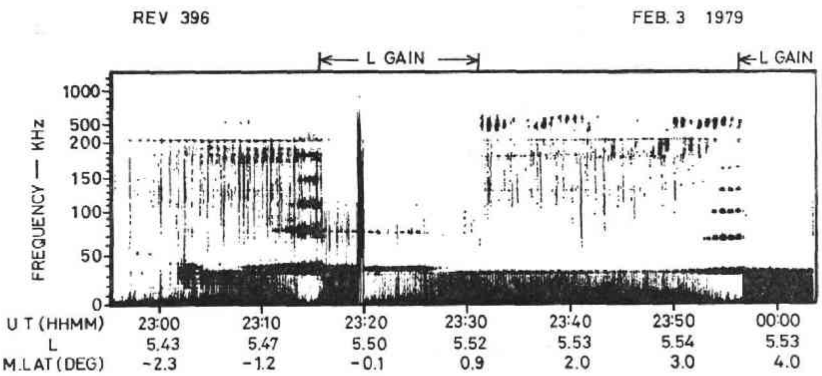

Fig. 2. Dynamic spectrum of the UHR mode wave, and $(n+1/2)f_c$ emissions (around 23:00–23:10) the higher harmonics have been produced in the preamplifier when the intensity of UHR mode wave becomes strong.

for the mode conversion from the electrostatic plasma waves to the electromagnetic waves (Oya, 1972). The wave particle interaction in wide range of the wave number of the plasma wave is dominated in this frequency range corresponding to widely spreading energy range. Detailed investigation will be given in Section 5.

3.3 $(n+1/2)f_c$ *emissions*

By OGO-5 satellite the electrostatic plasma waves near at $(n+1/2)f_c$ (where f_c is the electron cyclotron frequency) are initially observed by Kennel et al., (1970). The waves were interpreted by the existence of plasma whose velocity distribution has non-Maxwellian components that are mainly enhanced in the direction perpendicular to the magnetic field (Fredrics, 1971; Oya, 1972, Karpman 1973, and Young 1973). These waves have also been observed by the satellite JIKIKEN; an example of this $(3/2)f_c$ emission has been given in Figure 2. The injected energetic particles near the plasmapause fade into the Maxwellian plasma via a strong wave particle interaction; the trace of the $(n+1/2)f_c$ emissions over long period of the satellite observation, then,

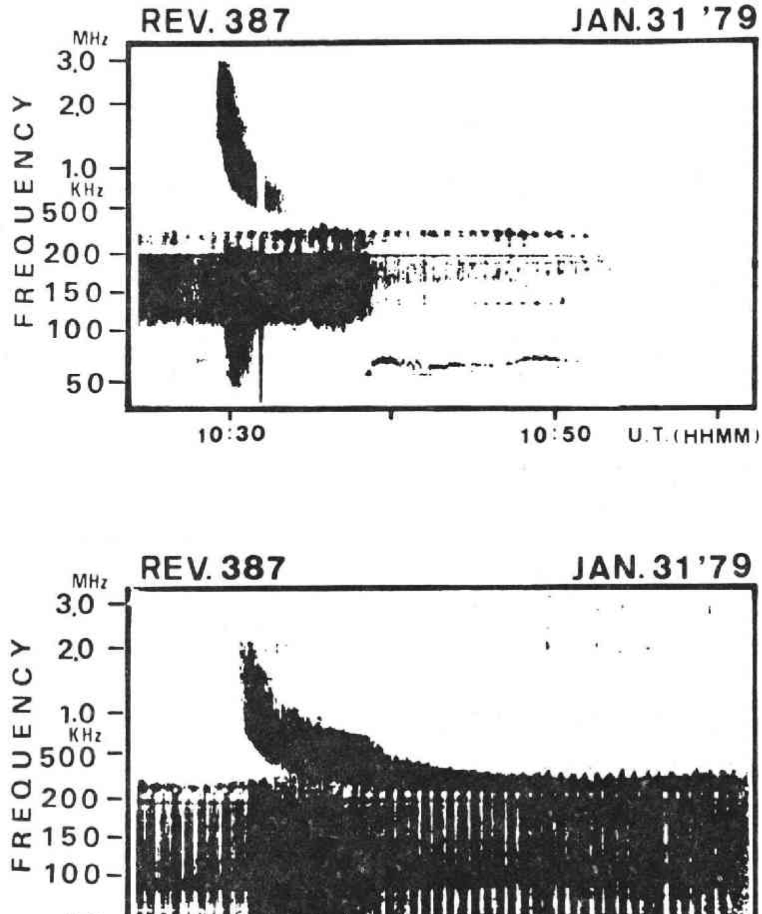

Fig. 3. Dynamic spectrum of HF emission from cerestial origin; the emissions with the spectrum of the monotonically falling tone have been identified as type III outburst (Fainberg, 1970), but some emissions given here have characteristics that can be attributed to the source located in the Jovian plasmasphere.

provides important informations on the analysis of the relaxation processes of the particle velocity distribution.

3.4 *Lower VLF and ELF Radio Waves*

In a frequency range of lower VLF and ELF waves (less than 10 kHz), also, wide variety of the radio wave emissions are currently observed in well known spectra such as whistler, chorus, and hiss. In contrast with the widely covering frequency spectrum of the whistler, chorus, and hiss, a strong pure tone of the emissions have been observed frequently in the magnetosphere surrounding the plasmapause. The origin of these pure tone emissions can be attributed to the local $f_c/2$ emissions. Since the frequency range surrounding the $f_c/2$ frequency is a channel for the mode conversion from the electrostatic waves to the electromagnetic waves; particles in wide variety of the energy range can make coupling with the electrostatic waves for the generation of these pure tone emissions.

3.5 *Radio Waves from Planets and Sun*

JIKIKEN is also receiving the radio waves from the planets and the sun. One of the most interesting phenomena is the descending tone event that resembles to the type III outburst reported by Fainberg and Stone (1970). Though the period of the observation is not suitable for separation between the Jupiter and Sun, most of these observed phenomena (see Figure 3) may be identified as type III outburst. For several cases, however, very interesting features are indicated being associated with the low frequency emission covering the range from 20 kHz to 100 kHz.

Several points have misterious features to decide as the solar origin. Recently, a report has been made on Jovian radio wave emission that the radio wave frequency makes a clear time drift just above 1.3 MHz (Observation of Voyager; PWS team; Warwick and Carr 1979). The observed emission has a possibility to be generated at the Jovian plasmasphere. Thus, observation by JIKIKEN will provide important information for the quest of the plasma states relating to the solar and planetary radio waves.

4. Active Experiments on Plasma

4.1 *Stimulated plasma waves*

Stimulation of the plasma waves have been carried out using long deployment antennas (102 m tip to tip) along all the portion of the JIKIKEN orbit. Though the observations using the plasma wave stimulation technique were carried out in ionospheric plasma as the case of Alouette 1, 2, ISIS 1, and 2, the experiments by JIKIKEN is the first case of the observation that has been made in the magnetosphere including plasmapause area with the high power transmitter of 300 Watt as a nominal value.

In Figure 4, an example of the diagram called plasma-gram is indicated. Very long duration of the UHR wave emission over 125 msec has been observed. This

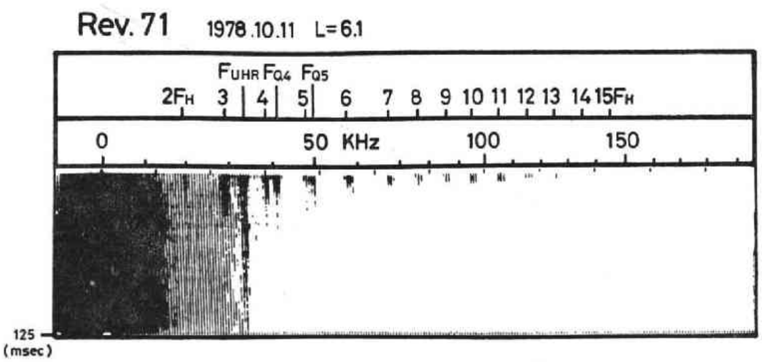

Fig. 4. An example of plasma-gram observed by SPW.

duration time is 4 or 5 times longer than the maximum duration time in the case of the ionospheric phenomena. Two causes may be important for this long lasting UHR phenomena; the first cause is in that the magnetospheric plasma is completely collisionless and the second cause is in that the magnetospheric plasma contains the non-Maxwellian component that makes the amplification of the wave whose frequency is very close to the UHR resonance frequency f_{UHR}.

Stimulation of the plasma waves also excites many harmonics of the electron cyclotron resonance; sometimes the resonances have been excited up to the 20th harmonics. This is surprisingly higher number of the harmonics compared with the case in the ionosphere. The generation of these resonances at the higher harmonic numbers is also consistent with the cause of the long lasting UHR resonance in the magnetosphere, i.e., collisionless non-Maxwellian plasma reduces the damping effects of the electrostatic plasma waves near each cyclotron harmonic resonance frequency. In addition to these principal resonances, the so-called electrostatic resonance f_{Qn} has also been observed.

In the observation of the magnetosphere these principal resonances are characterized by low or very low frequencies; UHR resonance frequency sometimes indicates a value near 15 kHz and $2f_c$ (the second harmonics of the electron cyclotron resonance frequency) indicates even 12 kHz; i.e., f_c=6 kHz.

4.2 *Plasmapause Structure*

Using observed f_{UHR} and f_c values, we have calculated the electron density; in Figure 5, the plasmapause structures observed by this stimulated plasma wave have been plotted against the Σ Kp indices of the magnetic field disturbances. New evidences have been discovered by this method; the first is the discovery of existence of the relatively cold and dense plasma just outside of the plasmapause. This plasma makes an important contribution to the generation of the plasma waves. The second is a discovery of the large fluctuating component, up to 70% of the plasma density in the outer region of the plasmapause. This fluctuating component may produce many important effect into the irregularities of the plasmasphere and the trough region when these large fluctuations are transported to the inner region of the plasmasphere.

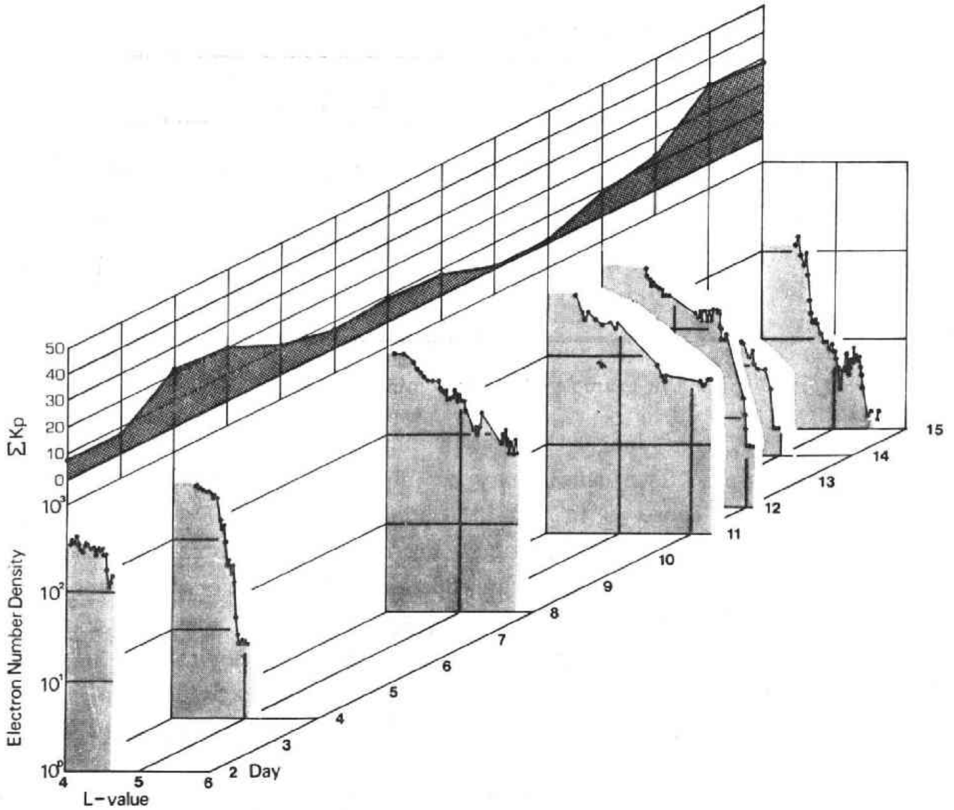

Fig. 5. The plasmapause structure deduced from the upper hybrid resonance frequency; the observed electron density distribution has been indicated against the indices of magnetic field distrubances.

5. Preliminary Study on Wave Particle Interactions

One of the important objectives of the JIKIKEN emission is to verify the wave-particle interaction feature in the magnetosphere. Since the data analysis of the energetic particle measurements are still on a process, we can here make study on only limitted cases; the cases of UHR and the pure tone emissions.

5.1 *Wave-particle interaction processes relating to UHR mode waves*

As has been described in Section 3, the upper hybrid resonance mode wave is one of the most popularly existing waves in the magnetospheric plasma. Sometimes it makes so strong emission that the receiver of JIKIKEN has been completely saturated over the maximum level of 0.3 mVolt. In Figure 6 (a), 6 (b) and 6 (c), sampled features of the measured wave-particle relationships are indicated. The results indicate that the UHR mode waves are generated by injected soft electrons whose energy spectrum enhanced in a range from several 100 eV to 2 keV. These surprisingly low energetic electrons can only interact with the waves which have very large wave numbers when the frequency approaches to the upper hybrid resonance

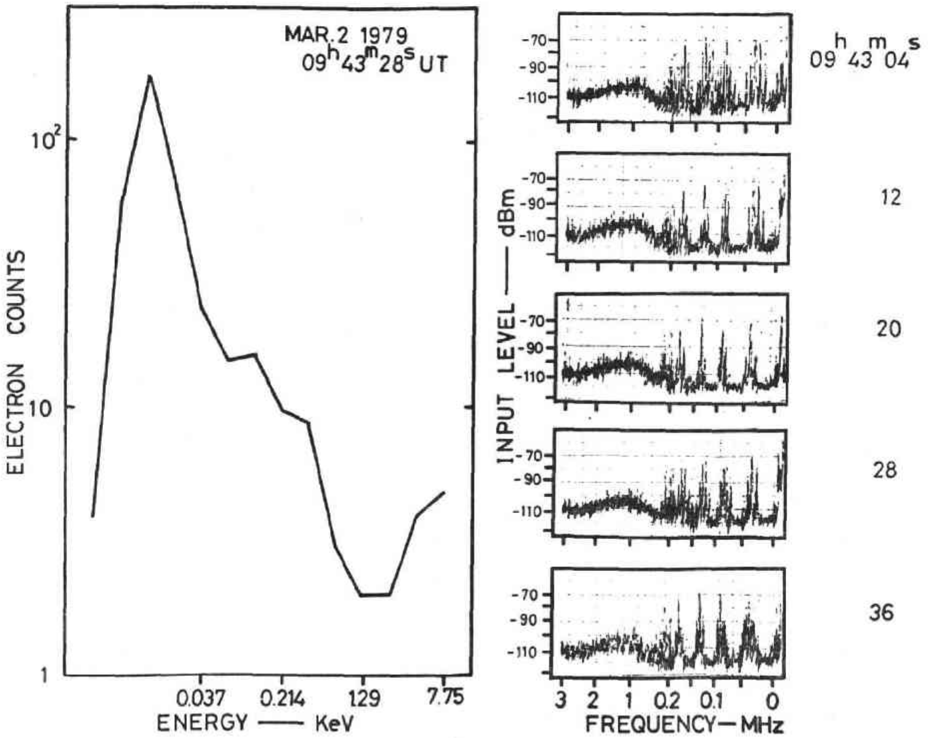

Fig. 6(a). The energetic particle spectrum measured by ESP during the observed period of the UHR mode emission on Mar. 2, 1979 in Rev. 481.

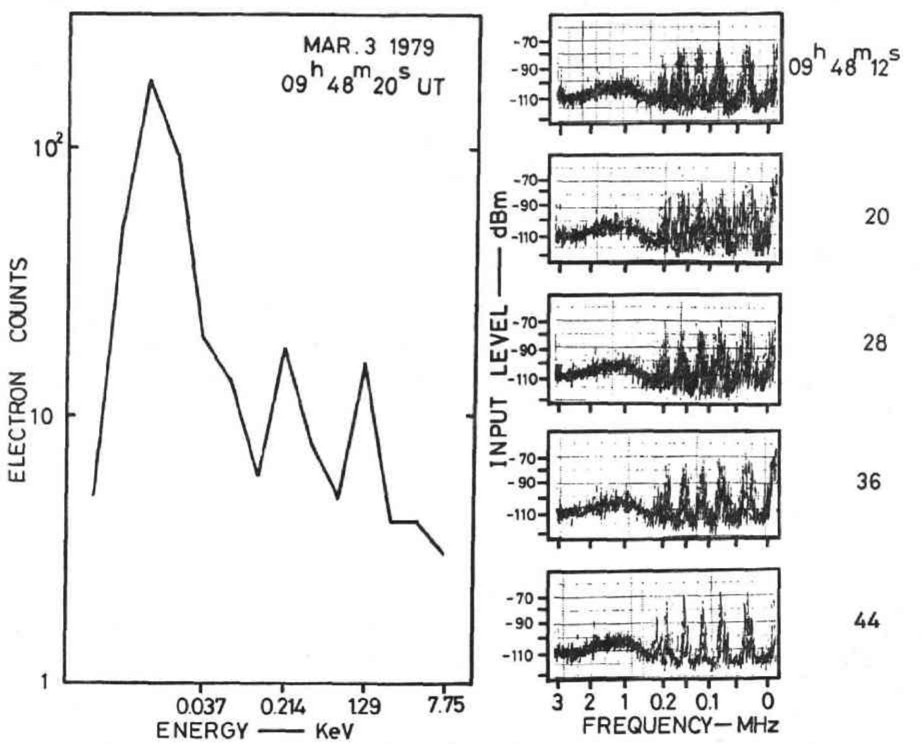

Fig. 6(b). Same as (a). This is the case of the very strong UHR emissions; the flux of electrons in soft energy range from 200 eV to 1 keV have been enhanced.

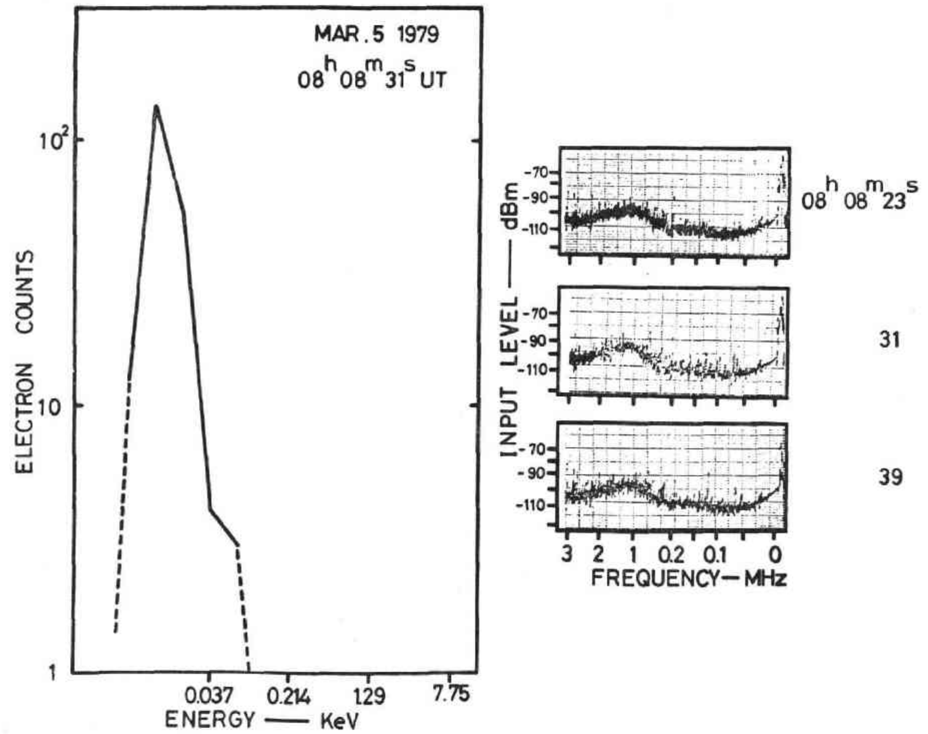

Fig. 6(c). Same as (a). This is the case of calm state where the emission of UHR mode waves is very weak. No enhancement of the electron flux in a soft energy range was observed.

value, since the k vector has the direction almost perpendicular to the magnetic field. Observation of this UHR mode emissions is possible even in the dayside plasmasphere where the soft electrons are circulating due to drift effects in the region outside the plasmapause.

5.2 *Pure-tone VLF and ELF emissions*

In VLF and ELF range, a sharp pure-tone of the emissions have been frequently observed. An example of these emissions observed around 15h 49 m (UT) on Nov. 6, 1978 is shown in Figure 7 where the pure-tone frequency is indicated around 3.5 to 4 kHz. Around 750 Hz, also we can see another trend of the pure-tone emission that can be attributed to another source located L>8. The particle energy distributions have been measured simultaneously at JIKIKEN when the satellite is located along the L-shell of L=5.1 (see Figure 8). The results indicate that the energy distribution

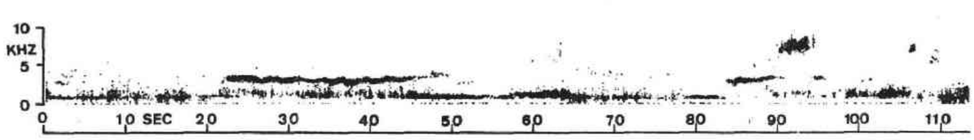

Fig. 7. Pure-tone emissions in ELF and VLF range observed on Nov. 6, 1978.

makes strong enhancement in a range from 1 keV to 10 keV both in the ion and electron channels. The most possible process may be in that the wave particle interaction is taking place in a frequency range between the LHR resonance frequency and the electron cyclotron frequency centered at $f_c/2$, where the plasma wave can make interaction even with low energetic particles.

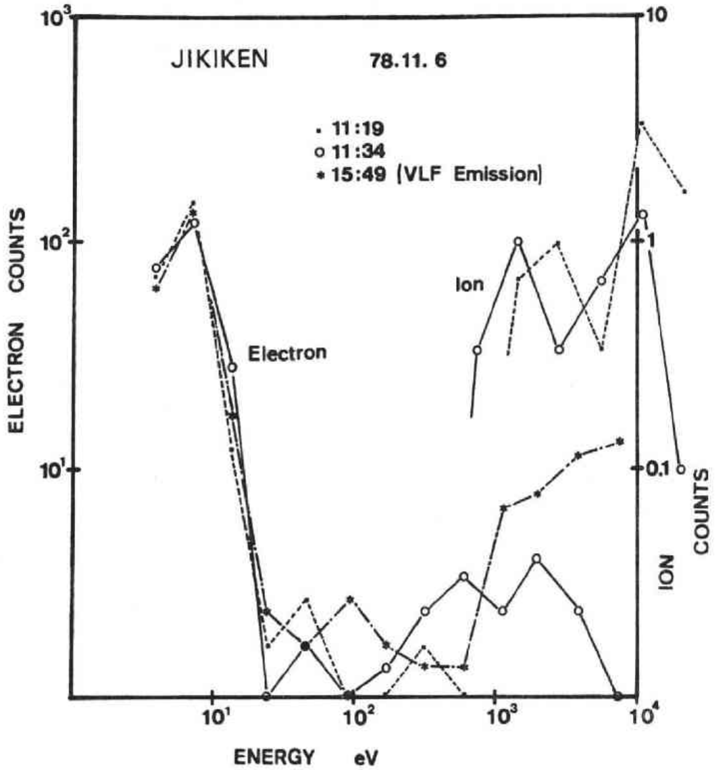

Fig. 8. The energy spectra of particles, large enhancement of the electron flux is detected in an energy range from 1 keV to 10 keV when the pure-tone ELF and VLF emissions take place.

6. Conclusion

Successful operations of JIKIKEN are providing many important data in wave phenomena from ELF to HF range. Especially important results are being accumulated as follows;

i) Auroral (Earth) kilometric radio waves,
ii) Upper hybrid resonance mode emissions,
iii) $(n+1/2)f_c$ emissions,
iv) Principal phenomena of VLF frequency range such as whistler, chorus and hiss,
v) Pure-tone emission in VLF range,
vi) Artificially stimulated plasma waves and observation of plasma parameters,

vii) Planetary radio waves,

viii) Solar type III outburst

Further elaborated works are required to make clear separation between the planetary radio waves and the solar type III outburst.

To verify the wave-particle interaction process is also significant purpose of the JIKIKEN observation. Preliminary results are started on the UHR wave mode emissions and the pure-tone VLF and ELF plasma wave emissions with comparison to the energetic particle velocity distribution. The former was produced by soft energetic electrons in a range from several 100 eV to 1 keV; the later case was related to the enhancement of the ions and electrons in an energy range from 1 keV to 10 keV.

The present paper is a preliminary introduction to the JIKIKEN observation data focussed on wave phenomena with a certain relation to the particle events. More complete reports using JIKIKEN data will be made in the near future.

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