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# Double-frequency oscillations of low energy plasma associated with transverse Pc 5 pulsations: GEOTAIL satellite observations

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The GEOTAIL satellite observed an interesting oscillation phenomenon of low energy plasma (LEP) in the dawnside outer magnetosphere. The oscillation was taking place with a frequency double that of the transverse oscillation of Pc 5 pulsations. The double-frequency oscillation appeared in the plasma density and temperature, clearly showing an out-of-phase relationship between them. However, this phenomenon is revealed to be an instrumental effect of the LEP detector, which has a low energy threshold of measuring an ion population at 32 eV/Q. The imbedded ion population is found to be composed of cold ions with an energy of less than the threshold. They are convected past the LEP detector by the Pc 5 wave and enter the detector energy window twice per wave period. Plasma bulk parameters calculated using the detected ions produce an oscillation that has a frequency exactly double that of the Pc 5 wave. However, it should be noted that this phenomenon is observed with a large amplitude electric field oscillation only in intervals when the satellite passes through the dawnside outer magnetosphere under very quiet magnetic conditions, i.e., periods of the northward interplanetary magnetic field.

## 1. Introduction

A couple of decades ago, Kokubun *et al.* (1977) investigated particle flux variations associated with low-frequency hydromagnetic waves by using Ogo 5 satellite observations from which several types of variations have been found. They found low energy ion oscillations at Pc 5 frequencies. This was the first report concerning ion density oscillations closely associated with shear Alfvén waves of Pc 5 pulsations. The oscillating region was found to be at $L = 6$–11 in the morningside of the magnetosphere. The ion density oscillations were systematically either 90° and/or 270° out-of-phase with the magnetic perturbations. Based on this observed phase difference between the ion density and the magnetic field oscillation, they suggested that the ion density perturbations were not actual ion density oscillations, but were bulk velocity modulations attributed to the induced electric field of the Pc 5 pulsations.

Kivelson (1976) surveyed ion density oscillations similar to those found by Kokubun *et al.* (1977). She noted that they occurred in association with detached plasma regions beyond the plasmapause based on the data of the plasma measurement by Ogo 5. Singer and Kivelson (1979) also studied the latitudinal structure of Pc 5 pulsations by using both magnetic field and ion flux data obtained by the Ogo 5 satellite. From these studies, it has been recognized that large amplitude oscillations of ULF waves are closely correlated with ion flux oscillations in detached plasma regions.

In this paper, very clear oscillations of the low energy plasma with a frequency double that of associated large amplitude shear Alfvén type Pc 5 oscillations are presented. They were observed near the outer edge of the plasma sheet by the GEOTAIL satellite. The oscillations were observed with a small perturbation of the magnetic field but a substantial perturbation of the electric field. This is due to the fact that the satellite was situated near the magnetic equator, where the magnetic perturbation shows a node for an odd mode field-line oscillation. This is consistent with the model calculations for resonant oscillations of the magnetic field-line proposed by Cummings *et al.* (1969). In this study, we used data obtained when the GEOTAIL satellite was located below the magnetic equator at $\sim 9^\circ$.

The term "frequency-doubling" oscillation used in this paper does not have the same meaning as that used for the compressional Pc 5 oscillations recently reported by Southwood and Kivelson (1997). The compressional magnetic oscillations have been found to be closely related to high-energy plasma oscillations, and have been observed to be dominant in the afternoon sector, which have been extensively studied since first reported in the 1960s (Brown *et al.*, 1968; Sonnerup *et al.*, 1969). They show an anti-phase relation between the plasma and the magnetic field. Frequency-doubling oscillations in compressional Pc 5 oscillations were originally reported by Higuchi *et al.* (1986) based on the magnetic field data observed at geosynchronous orbit. Extensions of the analysis and its excitation mechanism have been proposed by Takahashi *et al.* (1987a,b, 1990) by using AMPTE/CCE satellite data. Southwood and Kivelson (1997) have proposed a new mechanism attributing these phenomena to a nonlinear effect of ring current particles,

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which drives high-m waves. However, these studies have focused on compressional oscillations, which are different from the oscillations dealt with in this paper.

The data used in the present analysis are briefly described in Section 2. Section 3 demonstrates a typical example indicating frequency-doubling oscillations in density and temperature perturbations of the low energy plasma in association with simultaneously observed oscillations of transverse Pc 5 pulsations. A brief discussion will be presented in the last section.

## 2. Data Used

Data used in this study are the magnetic (MGF) and electric field (EFD) data, and low energy plasma (LEP) data obtained by the GEOTAIL satellite when the satellite surveyed in the low latitude outer plasma sheet. The most important point to be noticed here is that all of these data are available for simultaneous use in this study. The instruments and data processing have been described in detail for magnetic field, electric field and low energy plasma (ion) data by Kokubun *et al.* (1994), Tsuruda *et al.* (1994), and Mukai *et al.* (1994), respectively.

The data of the low energy ion plasma (assumed to be $H^+$) used in this study are those measured by the LEP-EA ion instrument and its energy range covers from 32 eV to 39 keV, which does not include the lower energy component of cold plasma. Therefore, the terms "density" and "temperature" in this paper mean the average density and temperature of the plasma measured in the above-mentioned limited energy range.

The magnetic and electric field data are used from samplings at 3 sec intervals, and the plasma data from samples at 12 sec intervals.

## 3. A Typical Example of a Double-Frequency Oscillation of Low Energy Plasma

### 3.1 A transverse Pc 5 pulsation

The GEOTAIL satellite observed a large amplitude, low energy plasma (LEP) oscillation associated with Pc 5 pulsations in the morningside of the outer magnetosphere. A typical example of such an event observed on January 14, 1995 is examined in this section. The satellite trajectory of the day is shown in Fig. 1 with the projection into the $X$-$Y$ plane of the GSM coordinates. The interval during which the large amplitude oscillation of the LEP was observed is indicated by a thick mark on the trajectory.

Three components of the magnetic field, $B_r$, $B_d$ and $B_m$, and two components of the electric field, $E_r$ and $E_d$, are presented in Fig. 2 from the top to bottom panels in mean-field-aligned coordinates, and the corresponding three components of plasma bulk velocity, $V_r$, $V_d$, $V_m$, and the corresponding magnitude, $V_t$, low energy ion density, $N$ and two components of ion temperature, i.e., the perpendicular, $Tyy$, and parallel, $Tzz$, components to the satellite spin axis are presented in the top to bottom panels in Fig. 3. These parameters are plotted against universal time, satellite location in $L$-value, magnetic local time (MLT), and magnetic latitude (LAT).

In Figs. 2 and 3, a mean-field-aligned coordinate is used in order to present oscillation characteristics with respect to the mean-magnetic-field direction, where $\boldsymbol{e}_m$ is in the direction of the mean magnetic field; $\boldsymbol{e}_d$ is parallel to $\boldsymbol{e}_m \times \boldsymbol{r}$, where $\boldsymbol{r}$ is a position vector of the satellite relative to the center of the Earth; and $\boldsymbol{e}_r$ (radial) is given by $\boldsymbol{e}_r = \boldsymbol{e}_d \times \boldsymbol{e}_m$. We assume that the parallel electric field $E_m$ is zero.

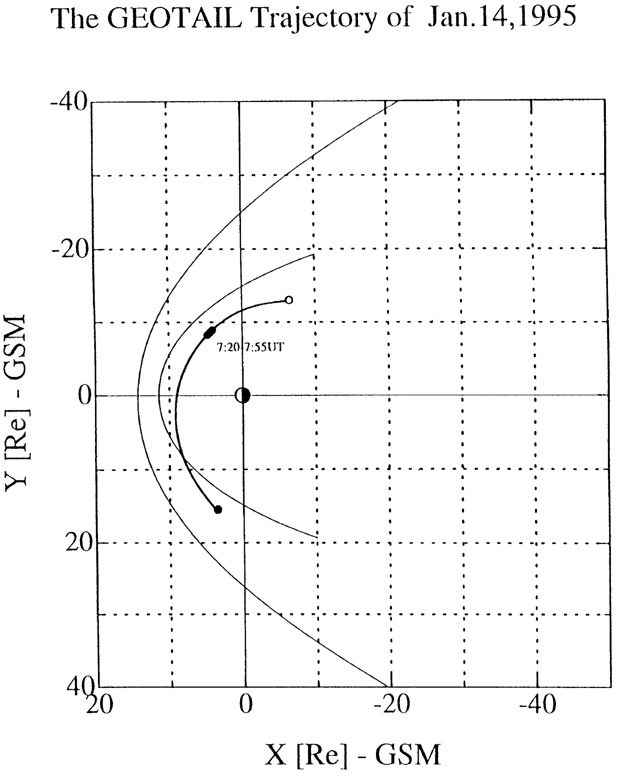

Fig. 1. The GEOTAIL satellite trajectory of January 14, 1995, projected into the GSM coordinates, $X$-$Y$ plane. The thick mark indicates the observed location of the large amplitude oscillations of the LEP of interest.

Large amplitude oscillations are clearly seen in the radial component of the electric field, $E_r$ with a frequency of ~3 mHz, which corresponds to the frequency of the Pc 5 pulsation. The Pc 5 pulsation is not clear in the azimuthal component of the magnetic field, although two pulses are identified around ~0745 UT. At this instance, the GEOTAIL satellite was located at ~9° below the magnetic equator.

The small amplitude oscillation of the azimuthal component of the magnetic field and the large amplitude radial component electric field oscillation suggest that the satellite observed a magnetic node for the oscillating field-line, i.e., a maximum or antinode of the field-line displacement. This observed fact suggests that the oscillation of the Pc 5 is an odd mode (fundamental, third harmonic, etc.) oscillation.

The period (frequency) of the oscillation is another factor in identifying whether this oscillation is a fundamental or a third harmonic. In this Pc 5 event, the dominant frequency is 3 mHz, which is consistent with the previous observations of the Pc 5 event in the outer magnetosphere (Kokubun *et al.*, 1976; Singer and Kivelson, 1979; Kivelson, 1976; Kivelson and Southwood, 1983). They have examined the oscillation frequency and identified that a frequency of about 3 mHz is the dominant frequency observable in the outer magnetosphere and is identified as a fundamental mode field-line

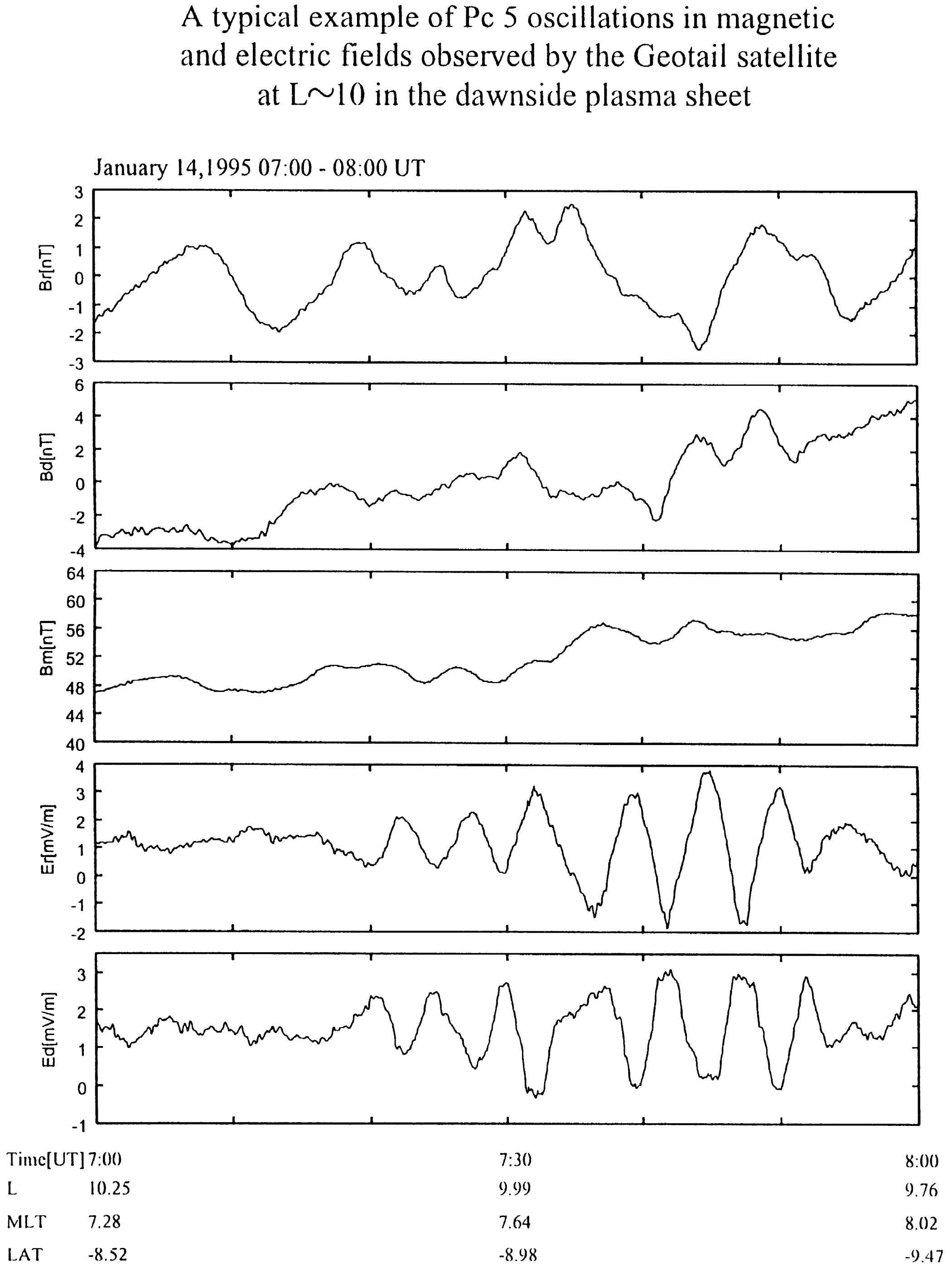

Fig. 2. Three components of the magnetic field and two components of the electric field in mean-magnetic-field coordinates during the interval of our interest are illustrated in the top to bottom panels. A clear oscillation with a frequency of 3 mHz is identified in the radial component of the electric field, $E_r$.

oscillation. The frequency and other oscillating characteristics observed in this study are consistent with those of a fundamental mode of the magnetic field-line oscillation discussed by them.

The field-line resonant oscillation can be certainly confirmed by comparing a relative-phase relationship between $B_d$ and $E_r$, as shown in Fig. 4. We can see that these two components oscillate in quadrature. Therefore, this phase relationship shows strong evidence for the resonant oscillation. Moreover, Poynting flux can be calculated and is shown with a solid curve in the bottom panel. The curve of the Poynting flux clearly oscillates up and down, suggesting that the wave energy bounces back and forth along the magnetic field-line. In addition, the oscillation is not symmetric with respect to the horizontal line. The broken curve shows average values of the oscillations and is slightly upward with respect to the horizontal line. This fact suggests that the wave energy flowed from the ionosphere to the magnetosphere. There-

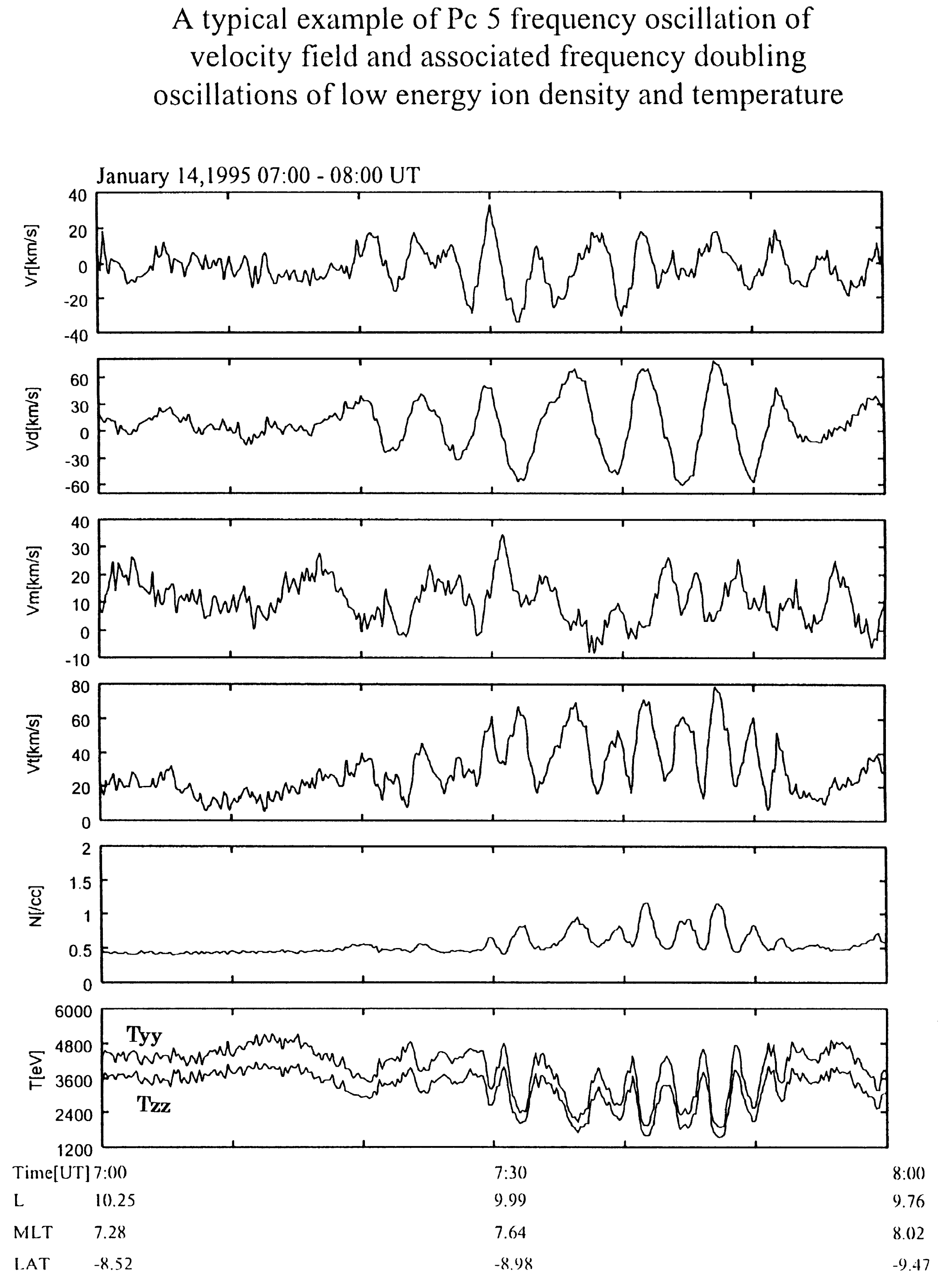

Fig. 3. Three components of the velocity field, total velocity, low energy ion density and two components of ion temperature, parallel ($Tzz$) and perpendicular ($Tyy$) to the Sun-aligned spin axis are, respectively, presented in the top to bottom panels. Note that a frequency-doubling oscillation with a frequency of 6 mHz is observed in the panels of the low energy plasma density and temperatures.

fore, these results are consistent with the characteristics of the resonant field-line oscillations expected from the theoretical work of Cummings *et al.* (1978).

### 3.2 Low energy plasma oscillations

From Fig. 3, large amplitude LEP density and temperature (energy) oscillations can be identified in an interval of about 20 min from 0730 UT (7.64 MLT) to 0750 UT (7.84 MLT), which corresponds to the interval of appearance of the large amplitude Pc 5 oscillations seen in the $E_r$ and $V_d$ components discussed above. The frequency of the plasma density and temperature oscillations is 6 mHz, double the frequency of the $E_r$ and/or $V_d$ components. The oscillating amplitude of $E_r$ attains about 3 $\sim$ 4 mV/m, exceeding the average amplitude of 1 $\sim$ 2 mV/m, which can be identified for the oscillations recorded in the preceding interval from 0500 to 0600 UT (not shown here).

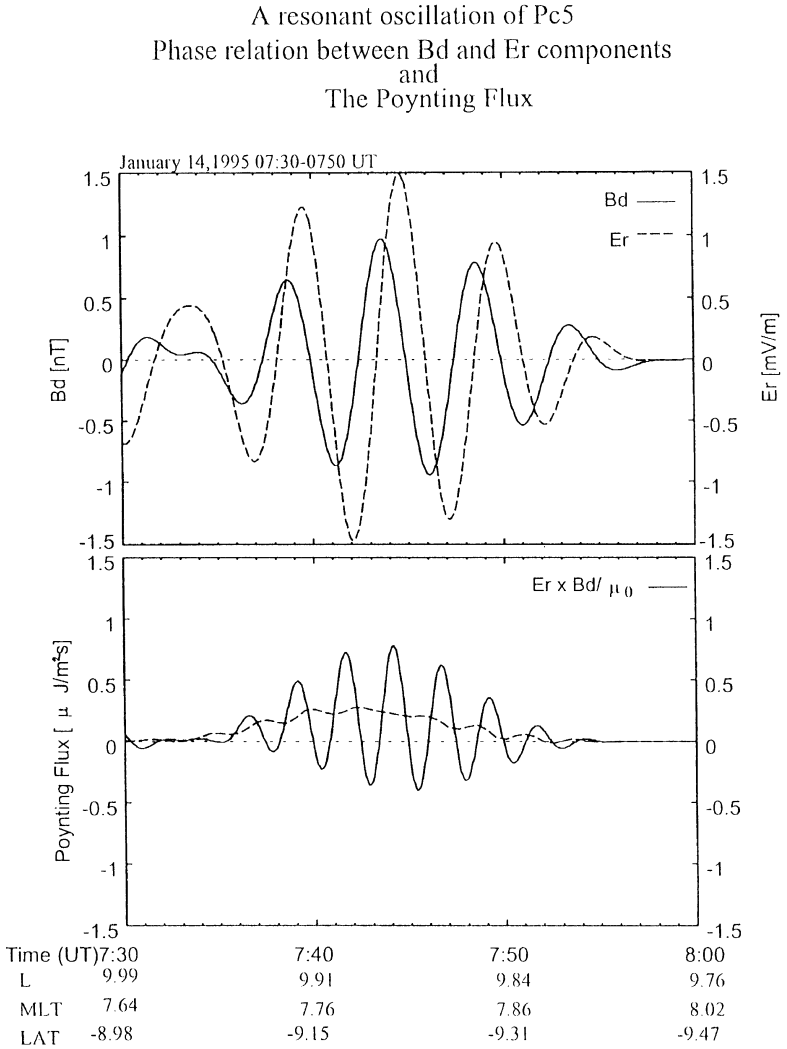

Fig. 4. Plot of a phase relationship between $B_d$ and $E_r$ components of the Pc 5 oscillation and the corresponding Poynting flux in the upper and lower panels, respectively. Low-pass-filtered signals of these two components behave as an oscillation in quadrature, and the Poynting flux shown in the bottom panel indicates that the wave energy is propagating upward along the magnetic field-line.

Detailed inspection of the plasma oscillations shown in Fig. 3 provides more important information on the characteristics of the plasma's behavior. As shown in Fig. 5, a peak density in the third panel occurs at a peak of $E_r$ in the top panel, and corresponds to a peak of $V_d$ in the second panel. Moreover, the density peaks correspond to the troughs of the plasma temperature in the bottom panel. The peak densities shown with the solid lines, (A) and (C) are not the same, since they represent the peak density corresponding to the upward (outward) and downward (inward) extreme values of the $E_r$ oscillation. The line labeled with (B) crosses a node of the $E_r$ oscillation, and its value is 1.56 mV/m on average during the interval from 0730 to 0750 UT. Thus, the oscillation of $E_r$ in this interval is supposed to be biased and so this value should be reconsidered as an actual base-line value for this interval of the $E_r$ oscillation, i.e., $E_r = 0$. Thus, we can estimate the background LEP density and temperature from this crossing point, where the oscillating electric field strength is zero and the density at this moment is considered not to be attributed to the electric field modulation. The estimated density is ~0.5/cc and the temperature is ~4300 eV. These values are typical values for the ions observed in the outer magnetosphere.

## 4. Interpretation of Density and Temperature Variations

We can interpret these density and temperature variations in terms of the electric field drift motion of low energy ions due to Pc 5 electric field oscillations. This idea is analogous to that of the gyration acceleration process proposed by Kivelson and Southwood (1983).

The relative position of the satellite with respect to the oscillating electric field is shown in Fig. 6, in which a hodograph of the Pc 5 electric field oscillation in the plane perpendicular to the mean magnetic field is illustrated with the satellite position, which rather sets at one side where the downward (inward) electric field is more dominant.

Panel (A) of Fig. 7 shows how the satellite can detect the low energy ions which are accelerated by the oscillating radial component of the electric field $E_r$ of the Pc 5. As

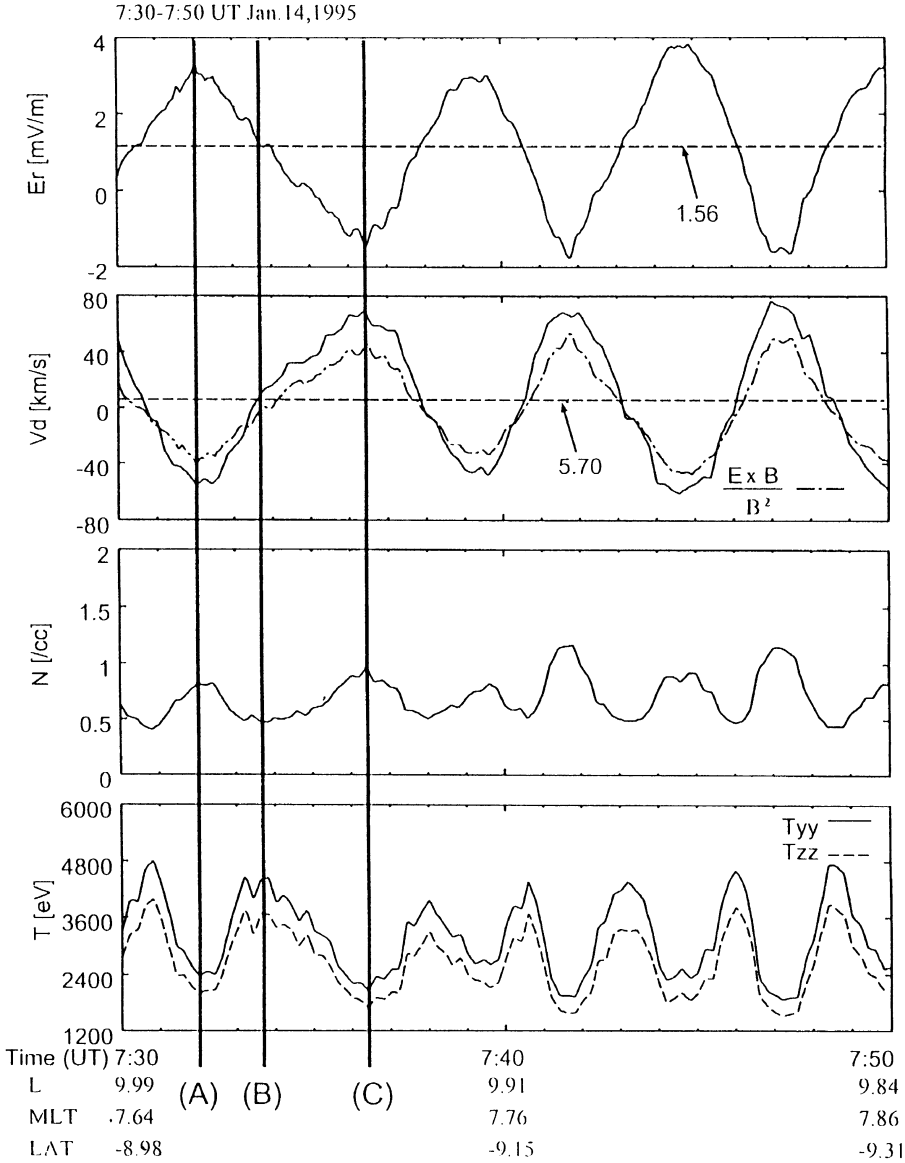

Fig. 5. Enlarged display of the oscillation of (a) the $E_r$ component, (b) azimuthal component of the plasma bulk velocity, $V_d$, (c) plasma density and (d) temperature of the LEP. Three solid vertical lines labeled with (A), (B), and (C) represent the maximal, zero, and minimal values of $E_r$. The horizontal dashed lines in the upper two panels indicate mean values for $E_r$ and $V_d$ variations, i.e. each off-set value in the interval of our interest from 0730 to 0750 UT.

shown in the left-hand column of the figure, $E_r$ is positive (upward and outward), gyrating low energy ions are accelerated upward, and are conveyed to the right (indicated with solid semi-circles) according to the electric field drift motion ($V_d$). The magnetic field is assumed to be directed off the page. This drift yields a tailward motion of the ions. Therefore, the satellite can detect the ions coming from the left (sunward), and then the increase of the tailward ion flux (Flux A (tailward ion flux) is larger than Flux B (sunward ion flux)).

In the other half cycle shown in the right-hand column of panel (A) of Fig. 7, $E_r$ changes its direction negatively (downward and inward), and then accelerates the ions downward. This means a reversal of the drift motion. The ions can be conveyed to the left, i.e., an increase in the sunward ion flux. The tailward and sunward motions of the LEP are associated with alternate changes in the direction of the radial component electric field, $E_r$. Therefore, the satellite can detect two maxima of the ion flux within one cycle of the Pc 5 electric field oscillation. These two maxima of the ion flux are indicated with two solid vertical lines labeled (A) and (C) in Fig. 5, which are also indicated by (A) and (C) in the bottom panel of Fig. 7.

The sampling time of the LEP was 12 sec, and the oscillation period of the Pc 5 was about 300 sec which is much longer than the sampling time. Therefore, the satellite can detect two maximal ion fluxes in accordance with the $E_r$ extremes within one oscillation period of the Pc 5.

Next, we consider the portion at $E_r = 0$, which is indicated in the center column, where the drift velocity $V_d = 0$. The flux (A) equals the flux (B). The detector can measure equal ion fluxes from the tailward and sunward directions.

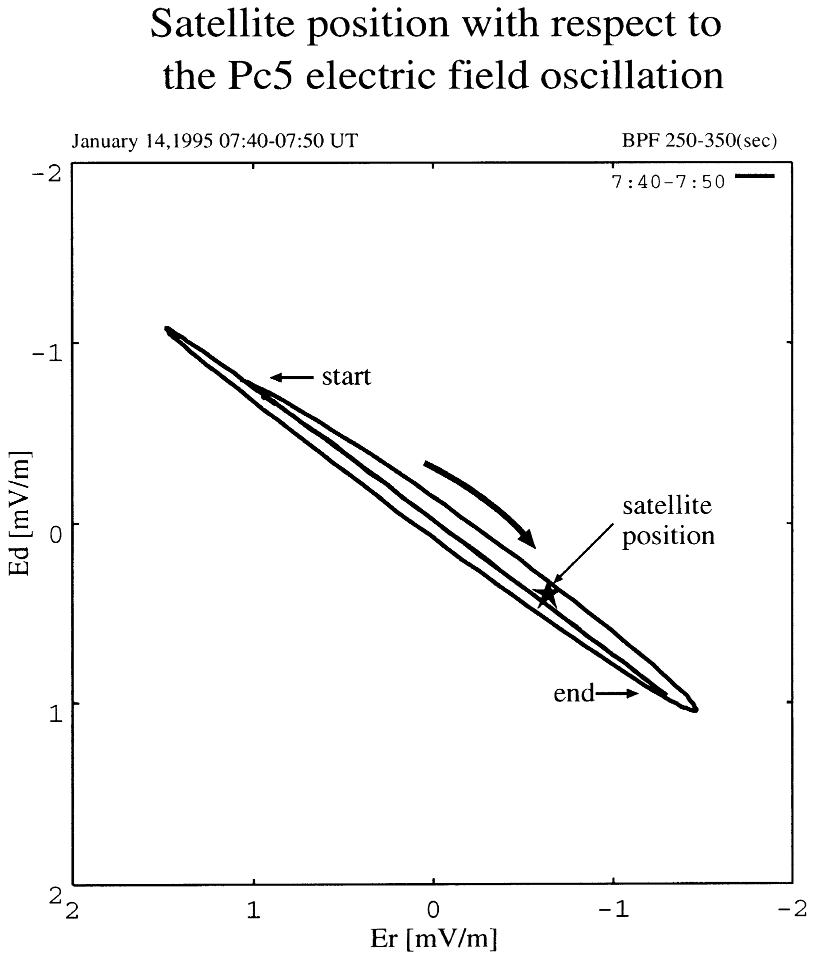

Fig. 6. The GEOTAIL satellite position with respect to the electric field oscillation. A hodograph of the Pc 5 electric field oscillation in a plane perpendicular to the mean-magnetic-field is shown with the GEOTAIL satellite position indicated by an asterisk in the electric field oscillation. The satellite was not located at the center of the $E_r$ oscillation and was situated at the position where the Earthward $E_r$ was larger than that of the outward $E_r$.

Thus, the density measured at this time corresponds to the background ion density, which is indicated by the shaded area of the distribution function shown in the second panel (B) of Fig. 7. The LEP detector can measure the ions within the limited energy range from 32 eV to 39 keV, as indicated by the horizontal arrow below the distribution function in Fig. 7.

These considerations of the ion distribution functions are justified by the in-situ observation of the distribution function, which is shown in Fig. 8. Omni-directional energy distributions in the equatorial plane, and velocity distribution function cuts in various directions, including the sunward (left-side) and tailward (right-side) directions, are presented in the left and right columns, respectively.

Three cases are shown, from the top to the bottom of the figure, in an order corresponding to the labels (A), (B) and (C) in both Figs. 5 and 7. We wish to focus especially on the lower energy part which is less than 0.3 keV/Q of these distributions. Thus, the spectral behavior of the lower-energy ion fluxes can be identified from both presentations in the contour map and the velocity distribution function. The modulations are clearly identified with the lowest energy part which is shown together with the energy variation of the inside of the contour and in the velocity distribution function.

The top panel corresponds to the case (A), i.e., upward $E_r$ extreme. A clear increase in the tailward ion flux can be identified on the contour map. This is also understood from the velocity distribution function. The low energy part is dominant in the tailward direction rather than that in the sunward direction. The middle panel corresponds to the case (B), i.e., $E_r = 0$. The contour shows that ion fluxes from all directions are almost equal, and the velocity distribution function is also symmetric with respect to the center, suggesting that the tailward and sunward ion fluxes are almost equal. Next, the case (C) is shown in the bottom panel. The sunward ion flux is clearly dominant. This is understood from both presentations. Therefore, these observations justify our consideration described above.

Temperature (energy) variations can be also interpreted as follows. As described above, the background ions are modulated by the electric field of the Pc 5 oscillation. The peak value of the electric field was about $-1.6$ mV/m and occurred at ~0742 UT. Moreover, taking into account an off-set value of 1.5 mV/m, this peak value of the electric field corresponds to $-3.1$ mV/m. This electric field provides a drift velocity $V_d$ of about 76 km/s and an energy of about 30 eV. This value is

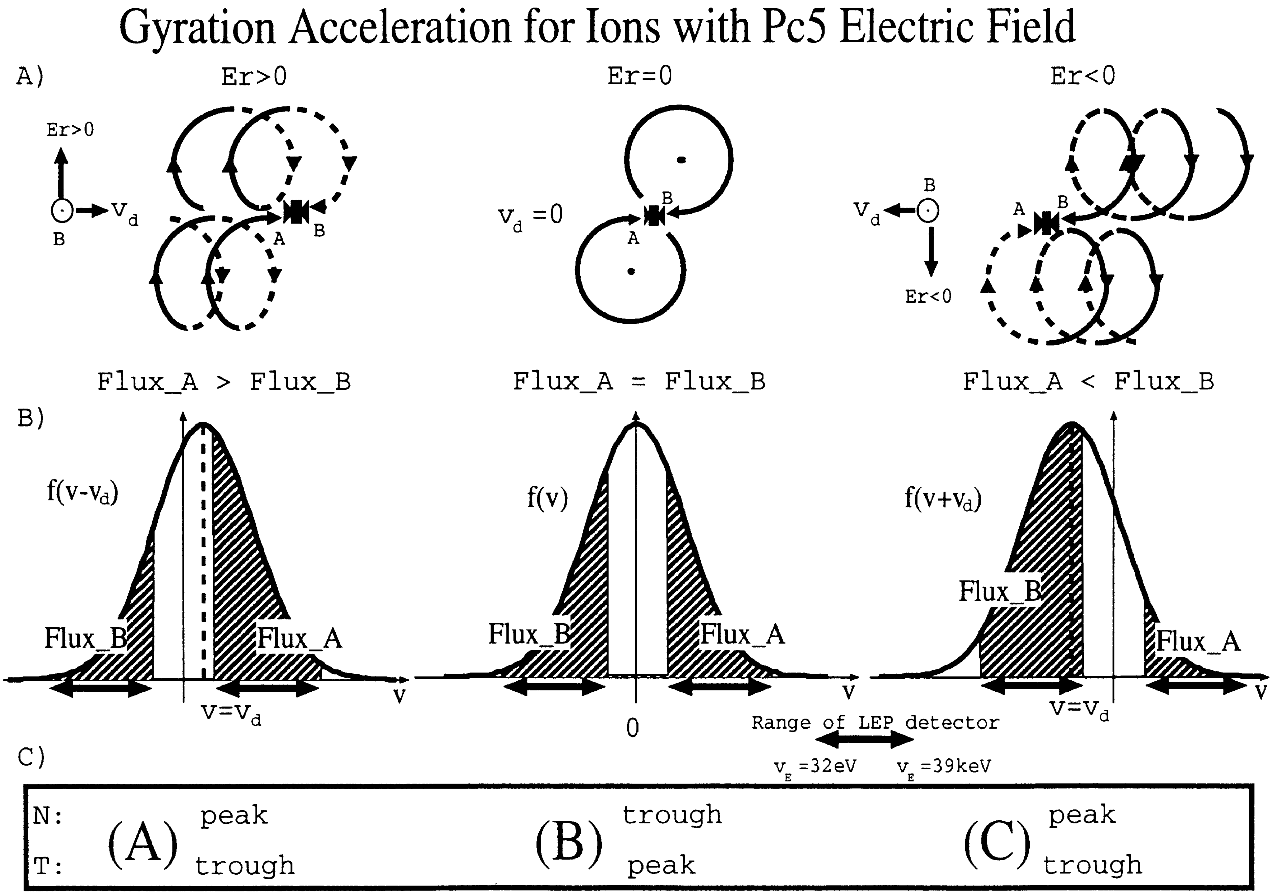

Fig. 7. Panel (A): Schematic presentations of gyration acceleration for ions in a Pc 5 oscillating electric field. Three cases, $E_r \geq 0$, $E_r = 0$, $E_r \leq 0$, are illustrated from left to right, respectively. Panel (B): A velocity distribution function is displayed in each case. The shaded area in the distribution indicates the ions measured with the LEP detector, whose energy range is limited from 32 eV to 39 KeV, denoted by horizontal arrows below the distribution curves. Panel (C) shows that each of the three cases corresponds to each of the solid line labeled with (A), (B) and (C) in Fig. 5.

almost the same as the lowest threshold energy of the LEP detector (32 eV). Therefore, the ion distribution function shifts with this energy. Owing to this shift, the satellite can detect a number of lower energy ions. Therefore, the temperature (energy) of the ions becomes lower and results in showing the minimum temperature at the extreme of the upward $E_r$.

Another important point to be noticed here concerns the schematic variation of ion density and/or temperature variation. By inspecting in detail the density and temperature variations shown in Fig. 5, we can find that a large and/or small density peak occurs alternately, and they correspond to a small and/or large temperature trough, respectively. This alternate variation in the density and temperature can be explained through electric field variations. From Fig. 5, it is clear that the intensity of the upward peak of $E_r$ is less than that of the downward $E_r$. Therefore, the density peaks and/or temperature troughs corresponding to the upward peaks of $E_r$ are smaller than those of the downward $E_r$. Thus, the alternate change of the density peak and temperature trough can be explained through the peak values of the oscillating electric field $E_r$ of the Pc 5 pulsation.

## 5. Discussion and Conclusions

The GEOTAIL satellite is in a unique orbit which allows it to skim the dayside magnetopause and to provide various information in the LLBL and the plasma sheet. The present study was performed by examining a remarkable feature observed as a frequency-doubling oscillation of low energy plasma in the ion density and temperature, simultaneous with a Pc 5 electric field oscillation in the dawnside outer magnetosphere.

Several examples of ion oscillations similar to the typical event discussed above are observed and are presented in Table 1. They are found only in the morningside of the outer magnetosphere. The period of this phenomenon is also found to correspond to that of the northward orientation of the IMF Bz, which is indicated in the last column of Table 1.

The occurrence distribution is illustrated in Fig. 9. No evidence of occurrence in the duskside of the magnetosphere is found in our survey of 26 months' data from November, 1994 through December, 1996, indicating a very distinct dawn-dusk asymmetry in the occurrence of this phenomenon.

The asymmetry of occurrence obtained in this study is consistent with the previous studies for Pc 5 occurrences obtained with the Ogo 5 satellite in the outer magnetosphere by Kokubun *et al.* (1976) and Yumoto *et al.* (1983), with the AMPTE/CCE satellite data by Anderson *et al.* (1990), and with the synchronous orbit satellite data by Takahashi and McPherron (1984), Kokubun (1985), and in the inner magnetosphere with the DE-1 satellite observations by Nose

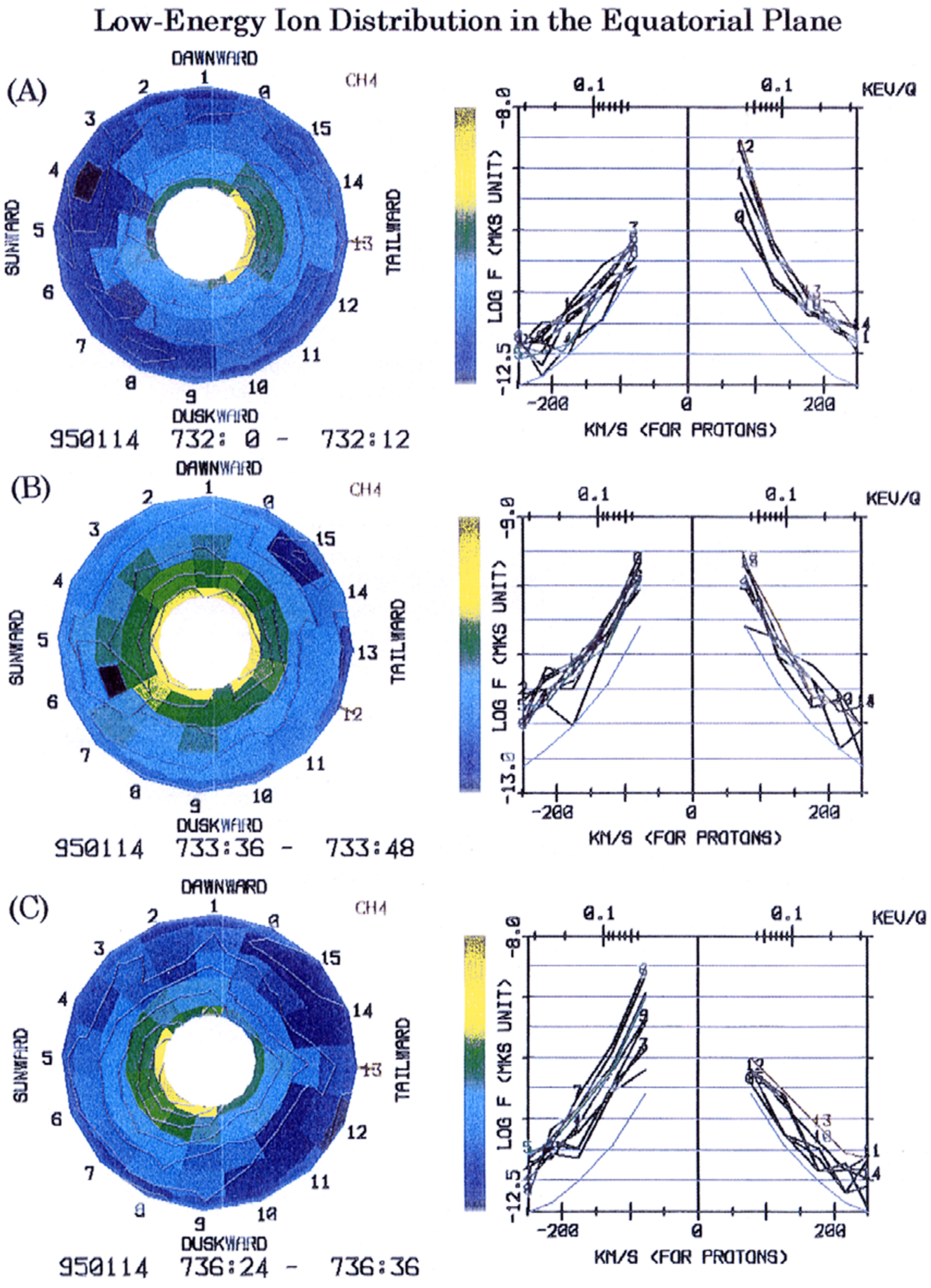

Fig. 8. In-situ observation by the GEOTAIL satellite of energy distribution contour (left column) and velocity distribution function (right column) taken in the equatorial plane is given in order from the top to bottom for three cases corresponding to (A), (B) and (C) shown in Fig. 5. Note that the tailward and sunward ion fluxes are clearly recognized in (A) and (C), respectively, and the distribution is symmetric with respect to the vertical axis in panel (B).

*et al.* (1995).

As shown in Fig. 9, occurrence of the double-frequency oscillations is very rare and is limited to the region of the morningside of the outer magnetosphere. The rarity of the occurrence seems to contradict the fact that Pc 5 oscillations are always observed when the satellite passes through the dawnside outer magnetosphere. By considering the fact that the frequency-doubling oscillations were found during the interval when large amplitude Pc 5 oscillations were simultaneously observed, there might be some corresponding important factors in controling the occurrence.

We can consider two important factors for the occurrence.

Table 1. List of observed double-frequency LEP oscillations.

| Date (YYMMDD) | UT | MLT | $L$-value | LAT. | $K_p$ | IMF-Bz |
|---|---|---|---|---|---|---|
| 950114 | 0720–0750 | 7.31–8.01 | 10.08–9.84 | $-8.83\sim-9.31$ | $1_+$ | $\geq 0$ |
| 950123 | 0940–1020 | 8.06–8.36 | 9.94–9.76 | $-7.03\sim-7.38$ | $1_+$ | $\geq 0$ |
| 950320 | 0650–0740 | 5.27–6.00 | 10.66–10.61 | $-9.02\sim-8.57$ | $1_-$ | $\geq 0$ |
| 960402 | 1220–1250 | 3.06–4.29 | 11.78–11.67 | $-9.57\sim-10.70$ | $1_-$ | $\geq 0$ |
| 960520 | 1910–1930 | 5.50–6.02 | 11.73–11.81 | $-18.28\sim-17.93$ | $2_+$ | $\geq 0$ |

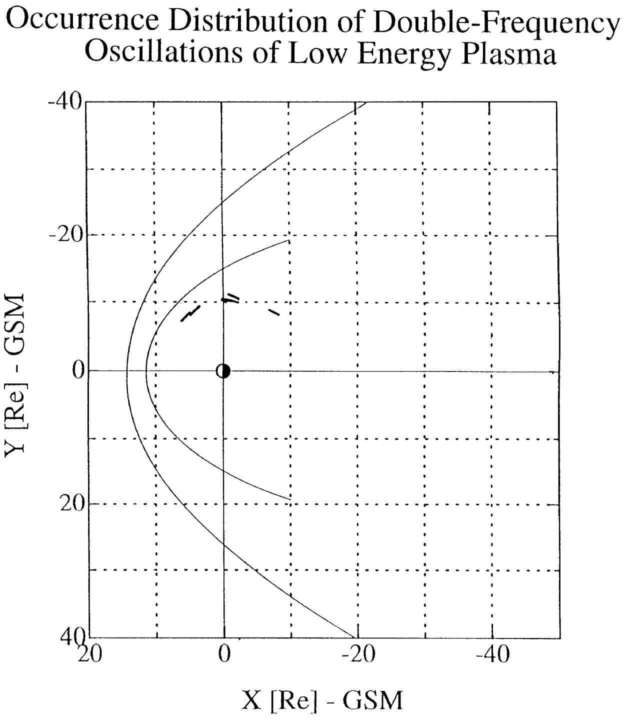

Fig. 9. Occurrence distribution of the frequency-doubling oscillations observed by the GEOTAIL satellite for the period of 24 months from November, 1994 to December, 1996.

One may be related to the generation of a Pc 5 pulsation itself. It might depend on a generation mechanism, such as the Kelvin-Helmholtz (K-H) instability at the magnetopause, which has been applied to Pc 5 generation by many researchers, originally by Southwood (1974) and Chen and Hasegawa (1974) and, more recently, theoretically extended by Miura (1995).

Miura (1995) presented his computer simulation for the K-H instability at the magnetopause, in which the northward magnetosheath Bz is revealed to be more favorable than the southward Bz. For the events dealt with in this study, the north-south orientation of the IMF was always northward, as indicated in Table 1. Therefore, the condition of the IMF orientation seems to satisfy the occurrence condition of the K-H instability at the magnetopause.

Another factor is the condition in the inner magnetosphere for establishing a large amplitude Pc 5 oscillation, since the frequency-doubling oscillations were observed in association with large amplitude Pc 5 oscillations. This is another important factor for controling whether or not the frequency-doubling oscillations in the LEP are able to be excited.

In order to establish a clear standing oscillation of field-line resonance, an appropriate trapping mechanism for HM wave energy transmitted from the magnetopause might be required at some localized region, where a well-organized conversion process of wave energy from compressional wave to shear Alfvén wave needs to be accomplished (Chen and Hasegawa, 1974). From our survey of the LEP data, a background density enhancement is observed in every case at the position where the event is observed and the position seems to be localized.

The localization of the occurrence has been also expected from previous articles dealing with ion density modulations with Pc 5 oscillations reported by Kivelson (1976), Kokubun *et al.* (1976) and Singer and Kivelson (1979). In their reports, large amplitude ion density oscillations were observed in association with Pc 5 oscillations in a "detached plasma" region of the outer magnetosphere ($L = 8$–$9$). Thus, it is well known that such plasma density oscillations can occur in localized regions with enhanced densities in the outer magnetosphere. However, from our present study, the region is not the same boundary as that of the magnetopause, where large amplitude plasma density modulations were frequently observed, as reported by Engebretson *et al.* (1983). The ion energy of the LEP observed in this event was about ~4 keV, which suggests the energy of the ions usually observed in the outer magnetosphere.

A recent statistical study on the relationship between plasma sheet density and the IMF orientation performed by Terasawa *et al.* (1997) has clarified that the plasma sheet density increases when the northward IMF continues to be dominant. This observed result also supports our result that the frequency-doubling oscillation was observed during the northward IMF conditions.

Density enhancements were also observed in the detached plasma regions reported by Chappell (1974). The dominant occurrence region of the "detached plasma" concentrates in the afternoon-dusk sector from 12 to 18 LT in the region of the plasma bulge. A secondary peak of occurrence is recognized in the prenoon sector from 8 to 12 LT and a minor occurrence probability was in the early morning sector, as shown in Figs. 3 and 4 in Chappell (1974). In addition, detached plasma has been observed during moderate and disturbed magnetic conditions (see Fig. 6 in Chappell (1974)).

Therefore, if the detached plasma could be related to the occurrence of the density modulations of Pc 5 oscillations, the occurrence probability might be expected to be very low since large amplitude shear Alfvén type Pc 5 oscillations found in the present study occur only in the dawnside and under very quiet magnetic conditions. The rarity of the occurrence might be attributed to these factors.

In conclusion, the two requirements for the occurrence of the frequency-doubling in the LEP data are the occurrence of large-amplitude Pc 5 waves and the presence of ions with thermal energy below the lower energy threshold of the LEP instrument. These requirements are met only on the dawnside flank of the magnetosphere.

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