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TYPE IPDP MAGNETIC PULSATIONS AND THE DEVELOPMENT OF THEIR SOURCES

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Abstract. Intervals of pulsations of diminishing periods (IPDP) magnetic pulsation data have been analyzed from several recording campaigns and from stations that are widely spaced in both meridional and azimuthal directions. On the basis of their local time occurrence it seems useful to divide the events into at least two main categories: 1400 < LT < 1800 and 1800 < LT < 2400. Those events which are only observed at auroral latitudes typically develop slowly and extend at the most to 1 Hz, whereas those events that are observed at a low-latitude station may extend to several Hz. Simultaneous observations at several meridians extending over 100° show that the IPDP source region moves from east to west at a speed of 2-5° min^{-1}. There are necessarily no remarkable changes in frequency-time characteristics of IPDP pulsations. In the radial direction, IPDP wave frequency seems to be related to the He^+ gyrofrequency in the equatorial plane. Observations are shown to be in general agreement with the evolution of the ion cyclotron instability in the plasma convection system of the magnetosphere. Several mechanisms seem to contribute simultaneously to the frequency shift of pulsations during IPDP events.

1. Introduction

Particle injections into the magnetosphere during an auroral substorm are associated with several plasma wave events that can be recorded on the ground. In the ULF frequency range these waves are termed as Pi magnetic pulsations. They are typically broad-band pulsations, and their generation is only poorly known [see Nishida, 1978; McPherron, 1981]. However, IPDP magnetic pulsation events that are characterized by a rise of the pulsation frequency from 0.1 to 1-2 Hz in 0.5-2 h [Troitskaya and Melnikova, 1959; Heacock, 1967] are often well-defined signatures of substorm processes [Troitskaya and Melnikova, 1959; Heacock, 1967, 1971; Fukunishi, 1969; Kangas et al., 1974; Lukkari et al., 1975]. It is generally accepted that IPDP pulsations are generated via the ion cyclotron resonance mechanism where energy is transferred to the waves from the westward drifting hot particles injected into the magnetosphere during the substorm [Troitskaya, 1961; Heacock, 1967; Gendrin, 1970, 1975]. On the other hand, it is not known what the main mechanism is which could explain the frequency shift in IPDP.

Both radial and azimuthal motions of interacting plasma clouds have been proposed as an interpretation of the frequency shift [Gendrin et al., 1967; Troitskaya et al., 1968; Fukunishi, 1969; Maltseva et al., 1970]. Maltseva et al. [1981] have shown that the amplitude maximum of IPDP pulsations moves radially inwards in the course of the IPDP event. Azimuthal time delays have also been observed [Fukunishi, 1969; Maltseva et al., 1970]. Fraser and Wawrzyniak [1978] and Barkova and Solovjev [1979] reported both radial and azimuthal motions of the IPDP source region. Heacock et al. [1976] have shown that the radial $\bar{E} \times \bar{B}$ drift may explain the rising frequency of IPDP pulsations in the midnight sector.

Motions of the plasmapause must also be considered together with the radial drift of interacting particles as the plasmapause is often believed to be the favorable region for the generation of ion-cyclotron waves [Cornwall et al., 1970; Gendrin, 1975]. Lin and Parks [1974] have shown that changes in cold plasma density should produce the frequency shift characterizing IPDPs. However, Perraut and Roux [1975], Gendrin [1975] and Perraut et al. [1976] have re-estimated the role of the cold plasma density to be less significant than expected. Most recently, Young et al. [1981] have shown that the density of heavy ions seems to be a more important parameter for the generation of ion-cyclotron waves than the cold plasma density alone. They have also pointed out that heavy ions considerably modify the propagation characteristics of waves in the magnetosphere.

In order to study the extension and motions of IPDP sources suitable networks of recording stations are needed. However, only few such experiments have been carried out [Maltseva et al., 1970; Heacock, 1973; Fraser and Wawrzyniak, 1978; Barkova and Solovjev, 1979; Maltseva et al., 1981]. Many of the conclusions have been made on the basis of incomplete data sets. In this paper, data from several stations that form both the latitudinal and longitudinal networks will be analyzed in order to study the development of the IPDP sources. For the interpretation of ground-based observations, the development of ion-cyclotron instability in the magnetosphere [Kaye et al., 1979] will be discussed. In addition, recent satellite observations of ion-cyclotron waves [Young et al., 1981] as well as ionospheric propagation of pulsations will be considered.

2. Experiments

Magnetic pulsation data analyzed here are collected from several campaigns in 1971-1976. The

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TABLE 1. Location of Pulsation Magnetometer Stations

Station	L Value	Geographic Coordinates		Geomagnetic Coordinates			
				Dipole		Corrected	
		Latitude	Longitude	Latitude	Longitude	Latitude	Longitude
Kevo	6.0	69.8°	27.0°E	65.6°	124°	66.2°	111°
Lovosero	5.1	68.0°	35.0°E	69.1°	127°	63.8°	118°
Sodankylä	5.1	67.4°	26.6°E	63.8°	120°	63.9°	109°
Oulu	4.3	65.1°	25.5°E	61.7°	118°	61.8°	107°
Lerwick	4.0	60.1°	1.2°W	62.5°	89°	59.4°	83°
Sogra	3.6	62.8°	46.3°E	56.4°	131°	57.0°	128°
Nurmijärvi	3.3	60.5°	24.7°E	57.9°	112°	57.0°	103°
Borok	2.8	58.0°	39.0°E	53.0°	123°	53.0°	114°
Irkutsk	2.1	52.2°	104.5°E	40.7°	174°	41.0°	176°

selection of events have been made in order to extend the observation area as much as possible. The main comparison is made between Irkutsk (U.S.S.R.) and the Finnish meridional chain of stations (see Table 1). For some events in 1974-1975, important supplementary data have been available from several stations operated during a special campaign [Glangeaud and Lambert, 1975].

As different registration systems have been used, data are not homogeneous. Induction coil magnetometers have been used that have been sensitive to Pi 1 pulsations. In most cases pulsations have been recorded on magnetic tape, thus permitting the analysis of signals by the sonagraph. In some cases (Irkutsk, Yakutsk) only pen recordings have been available.

Because of the differences in registration only clear-cut events are included in the analysis. The onset, duration, and frequency range of the events are measured. Some supplementary data have been used, especially riometer recordings from the Finnish meridional chain of stations.

3. Type IPDP Magnetic Pulsation Events

Fukunishi et al. [1981] have made an extended classification of magnetic pulsations in the frequency range 0.1-2.0 Hz. They use the term "hydromagnetic emissions" as a general name for magnetic pulsations that seem to be due to ion-cyclotron waves generated in the magnetosphere. Fukunishi et al. [1981] divide IPDPs into two subtypes: IPDP and morning IPDP. The type IPDP is more common. As they may be observed in a time sector extending from midnight to noon quite different conditions for their generation may have to be considered. Possibilities for further classification of IPDPs will be studied here.

Well-defined IPDPs recorded at Oulu in 1974-1975 are divided into three categories according to their local time of occurrence: $LT < 1400$, $1400 < LT < 1800$ and $1800 < LT < 2400$. The distribution of the frequency-time plots is shown in Figure 1. The events are rare in the local noon and near midnight sectors. It is notable that the slope of many IPDP events in the dusk sector is steep.

It is difficult to locate the source field line of IPDP pulsations because of the horizontal scattering of signals. Lukkari et al.[1977] have shown that the maxima of both pulsation and riometer absorption amplitudes are observed at the same station and they shift together equatorward in the course of the events. Arnoldy et al. [1979] have pointed out that the waves are L polarized at the location of the electron precipitation events. All this suggests that riometer

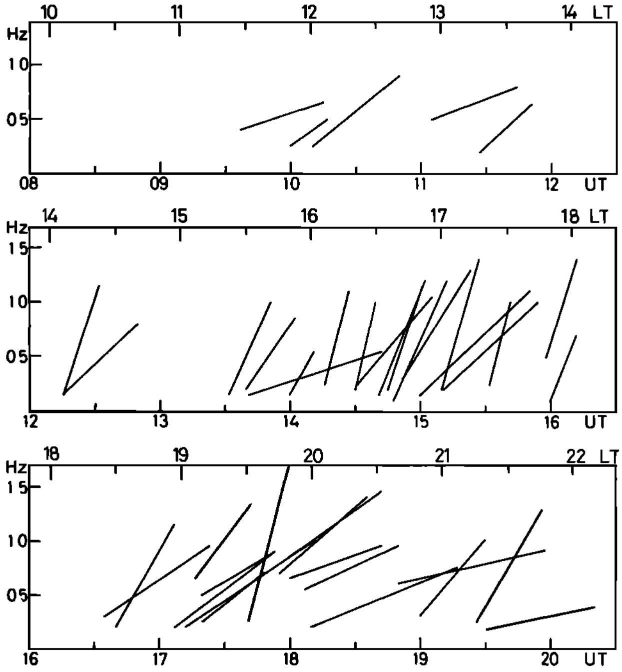

Fig. 1. Frequency-time plots of well-defined IPDPs observed at Oulu, in 1974-1975. Events are divided into three groups according to their local time occurrence.

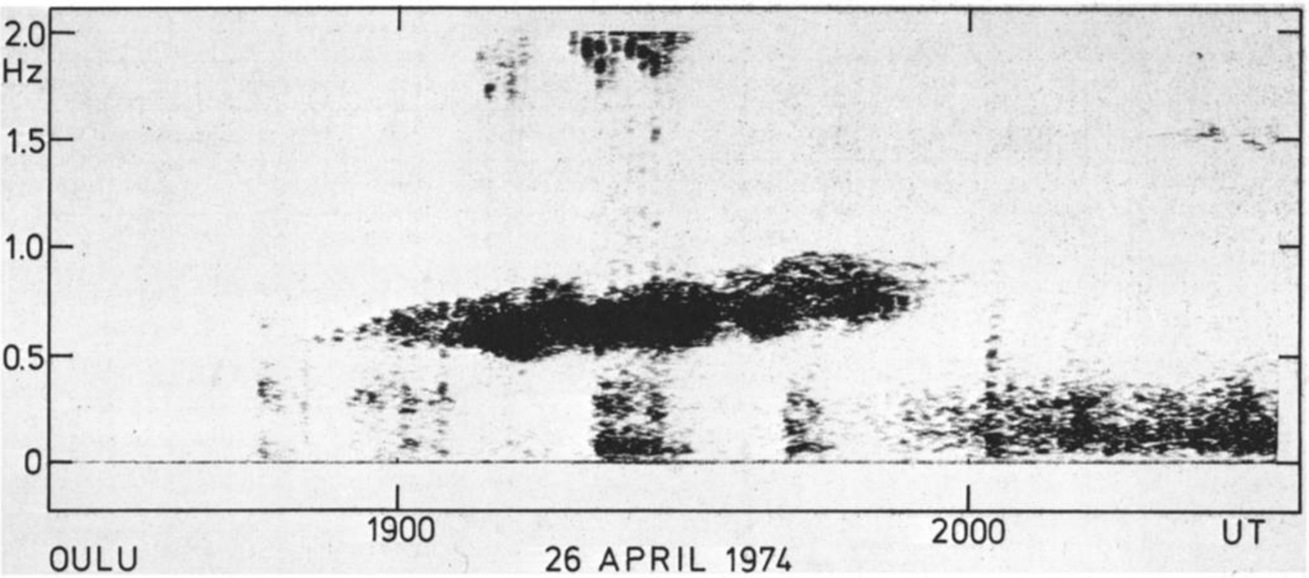

Fig. 2. Dynamic spectrum of an IPDP observed at Oulu on September 20, 1974.

absorption data may be used to locate the source region of IPDP magnetic pulsations.

As a typical example the IPDP event recorded at Oulu on September 20, 1974, is shown in Figure 2. The observed frequency domain extends to about 1.5 Hz (LT ≈ UT + 2 h). This event seems to be quite local as it appears only weakly at other nearby stations. It has also been recorded as a strong riometer absorption event at Oulu.

In Figure 3 we present quite a common example of an IPDP event in the late evening sector as observed at Oulu. The frequency of this IPDP event increases slowly starting at about 0.5 Hz; pulsations at frequencies below 0.5 Hz are absent. A weak IPDP with the same frequency-time characteristics has been observed at Sodankylä (not shown), whereas type PiB and PiC magnetic pulsations [see Heacock, 1967] can be identified in Kevo pulsation recordings (only pen recordings are available from Kevo). As to riometer data the most intense absorption was recorded at Kevo, no absorption at Sodankylä and a weak event at Oulu. This confirms the previous observations by Kangas et al. [1976], who showed that in the evening to midnight sector of the magnetosphere Pi 1 pulsations appear at high-latitudes simultaneously with IPDP pulsations observed at low-latitude stations.

Sometimes two subsequent IPDPs appear as seen in Figure 4. (See also Fukunishi et al. [1981], their Figure 2c.) The second of the two consecutive events is characterized by a less steep slope. It is possible that such events are due to echoes from westward drifting protons. This interpretation may fail as the short time-delay between the events is indicative of interactions of high energy particles (hundreds of keV). On the other hand, it has been shown that the particle energy is typically less than 100 keV [Horita et al., 1979; Söraas et al., 1980].

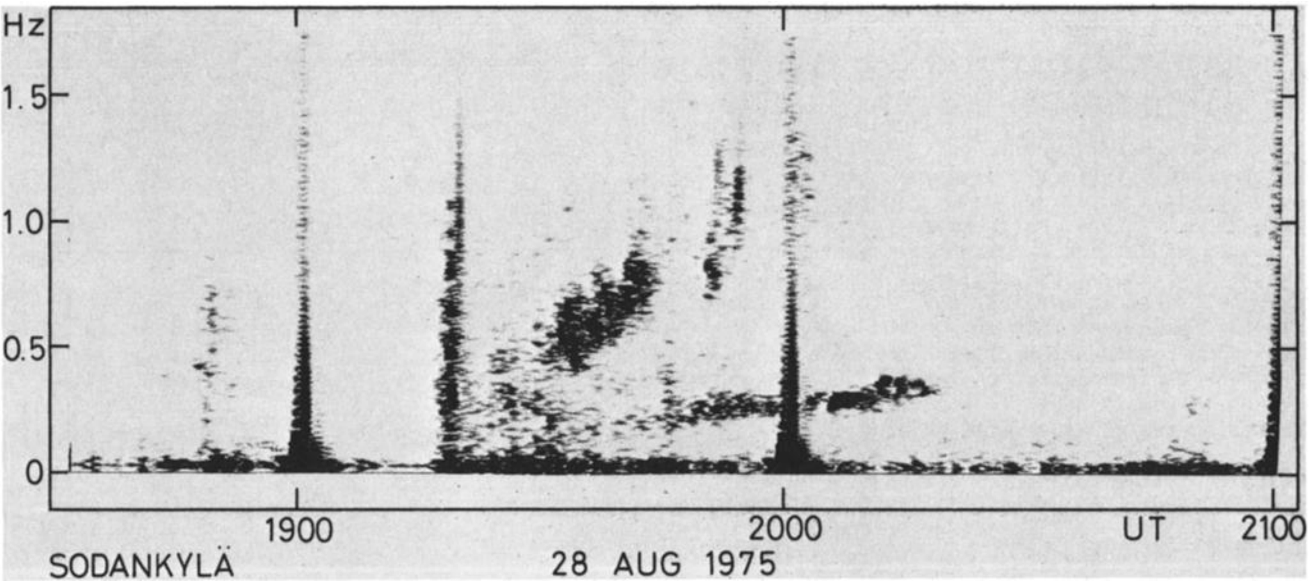

Fig. 3. Dynamic spectrum of an IPDP recorded at Oulu on April 26, 1974.

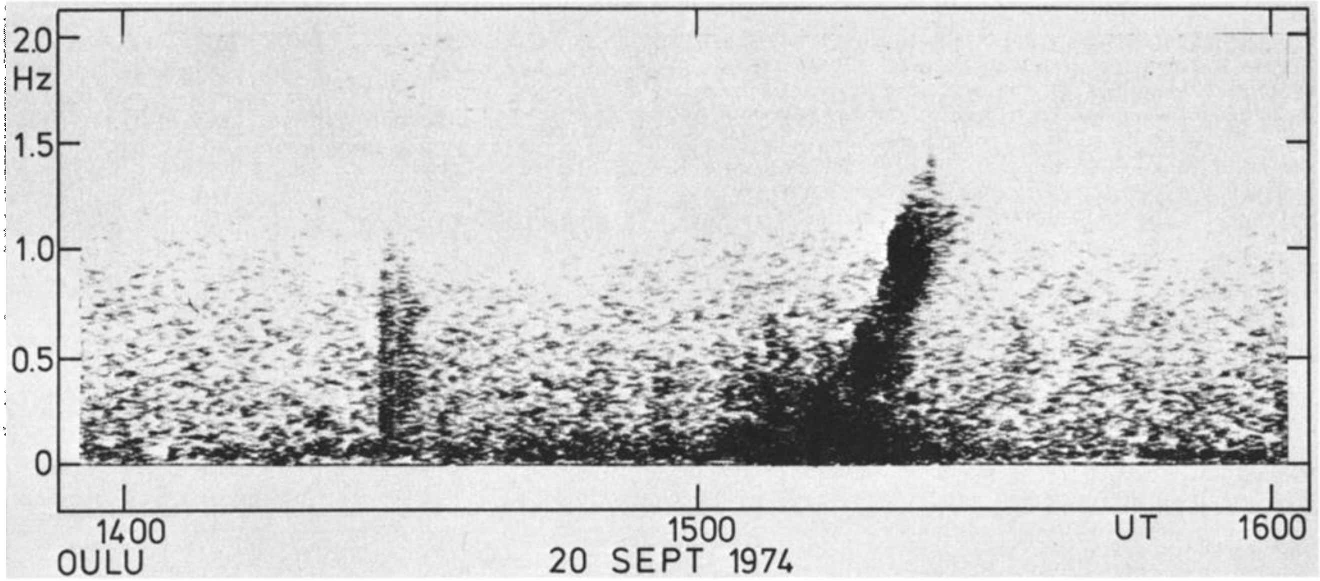

Fig. 4. Dynamic spectrum of Pi magnetic pulsations recorded at Sodankylä on August 28, 1975. Broadband pulsations at 1920 UT are called PiB pulsations. Vertical lines at 1900, 2000, and 2100 are due to hour marks.

Fukunishi et al. [1981] report a low probability to observe IPDP events at L ≈ 6. The frequency of pulsations observed by Fukunishi et al. [1981] seldom extends to 1 Hz, which indicates that they do not include in their analysis the IPDPs originating at low L shells. The morning IPDP events reported by Fukunishi and Toya [1981] seem to belong to high-latitude phenomena as we have observed so far only one of them at our stations at L < 6.

In conclusion, type IPDP magnetic pulsation events may have quite different characteristics that reflect the variable plasma conditions during the excitation of ion-cyclotron waves in the magnetosphere. However, it seems useful to divide the events into at least two main categories on the basis of their local time occurrence.

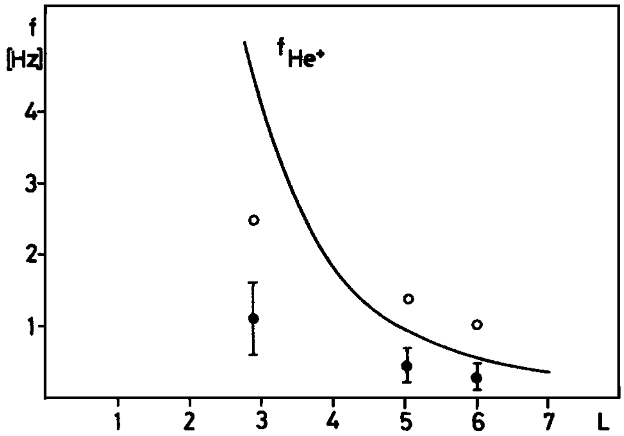

Fig. 5. The maximum (o) and most typical (•) end frequency of IPDP's at Borok (L = 2.8) and Lovosero (L = 5.1). Corresponding figures at L ≈ 6 (Syowa station) have been taken from Fukunishi et al. [1981]. Solid line gives the He$^+$ gyrofrequency in the equatorial plane as the function of L.

4. IPDP Observations at the Same Meridian

In this section the meridional development of the IPDP events is studied. It is known from previous studies that the IPDP frequencies are typically higher at low latitudes than at high latitudes [Knaflich and Kenney, 1967; Söraas et al., 1980]. Maltseva et al. [1981] have shown that the amplitude maximum of IPDP pulsations moves to lower latitudes in the course of the event.

In the present study, long series of observations from two stations, Borok and Lovosero, have been analyzed in order to demonstrate the dependence of IPDP pulsation frequency on the L value of the point of observation. The highest frequency of every IPDP event has been determined and their most probable value has been calculated

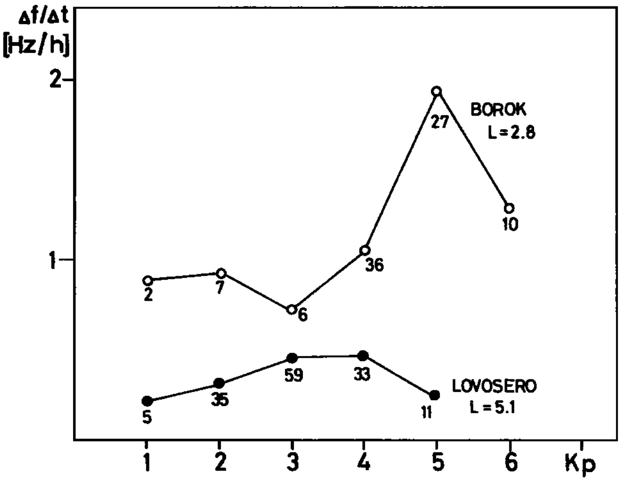

Fig. 6. The slope of IPDP events observed only at Borok (o) and only at Lovosero (•) at different Kp values. Number of events for the given Kp is indicated.

for both stations. These values are given in Figure 5 together with the highest IPDP frequencies ever observed at the two stations. In order to extend the study to higher L shells observations from Syowa Base ($L \approx 6$) have been added in Figure 5 [Fukunishi et al., 1981]. The He^+ gyrofrequency is drawn in the same figure as it seems to control the ion-cyclotron wave spectrum in the magnetosphere [Young et al., 1981]. Figure 5 shows that the IPDP events observed at auroral latitudes seldom extend to 1 Hz, whereas those observed at a low-latitude station may extend to several Hz. IPDP frequencies are typically below the He^+ gyrofrequency in the equatorial plane at the corresponding L value.

The slope of the IPDP event gives important information about the generation mechanisms as discussed, e.g., by Heacock et al. [1976]. We have compiled an extended set of data from Borok ($L \simeq 2.8$) and Lovosero ($L \simeq 5.1$) in Figure 6. These stations are at about the same meridian, and in 1971-1975 312 IPDP events were recorded on this meridian. In 82 of the cases both stations recorded simultaneously an IPDP with identical slopes on frequency-time graphs. One hundred forty events are seen only at Lovosero and the remaining 90 events are seen only at Borok. The two last data sets have been used in Figure 6. The comparison is made for different magnetic activities characterized by the Kp index. It is seen that the slope is distinctly greater at Borok than at Lovosero. At Kp = 5 the difference is particularly great. The slope at $L \simeq 5.1$ does not depend in any important way on the level of the magnetic activity.

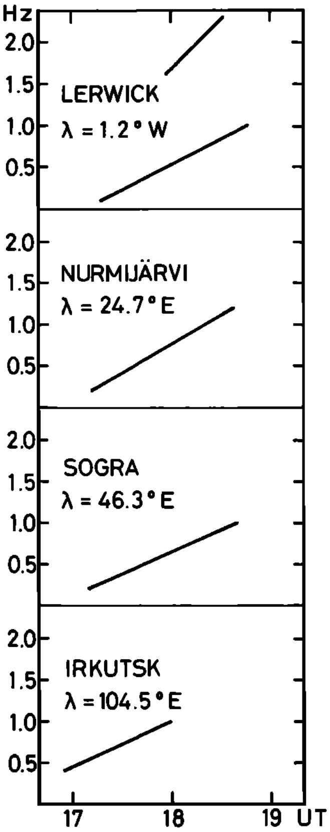

Fig. 7. Schematic presentation of IPDPs observed at four meridians on January 31, 1975.

5. Azimuthal Development of IPDP Events

There are only few observations of the development of IPDP pulsation events in the east-west direction. Usually data have been available from one pulsation station and the delay time with respect to the onset of substorm activity has been determined [Fukunishi, 1969; Lukkari et al., 1975]. More details about the source movements come from Maltseva et al. [1970] who used simultaneous recordings from Irkutsk and Borok separated by about 65° in longitude, from Fraser and Wawrzyniak [1978] who analyzed low-latitude IPDP observations by the triangular method and from Barkova and Solovjev [1979], who used data from a high-latitude net of stations. The results of these studies show that the IPDP events appear on the evening side of the magnetosphere after the onset of the substorm and that the typical drift rate is 2-5° min^{-1} to the west.

In this study we use two techniques to analyze the east-west development of IPDP events. First, we study magnetic pulsation recordings from two meridians separated by about 70° in longitude. The easternmost station gives the timing of the onset processes in the midnight sector, and a careful analysis of the time delay for IPDPs on the evening side can be made. Second, simultaneous IPDP data from several meridians are available for some events, which makes it possible for the first time to determine the changes in IPDP characteristics in the course of the westward drift. At the best the observation area extends more than 100° in the east-west direction.

TABLE 2. Mean Drift Rate of IPDP Events Observed at Finnish Stations With Respect to the PiB Recorded at Irkutsk

Local Time	Number of Events	Time Delay [min]	Drift Rate [°/min]
1400-1800	10	14	6.1
1800-2200	13	18	5.4

A broad-band magnetic pulsation burst (PiB; see Heacock [1967] and Kangas et al. [1979]) in the midnight sector is a good indicator of the onset of the substorm. It can be observed simultaneously over a longitudinal distance of 30° and it may propagate westward with a speed of 2-10° min^{-1} [Parkhomov et al., 1976]. On some occasions, a short series of Pc 1 pulsations at low latitudes is associated with a PiB at auroral latitudes [Parkhomov et al., 1977]. In comparing magnetic pulsation data from Irkutsk (U.S.S.R.) and Finnish stations we use a PiB (or a short series of Pc 1 pulsations) at the Irkutsk meridian as the timing of the onset of the substorm. The delay of the onset of IPDP events observed at Finnish stations has been determined on the basis of such a timing.

The analysis has been made for 23 IPDP events observed at Finnish stations. Ten events belong to the local time sector 1400-1800 and the others to the evening to midnight sector. The mean

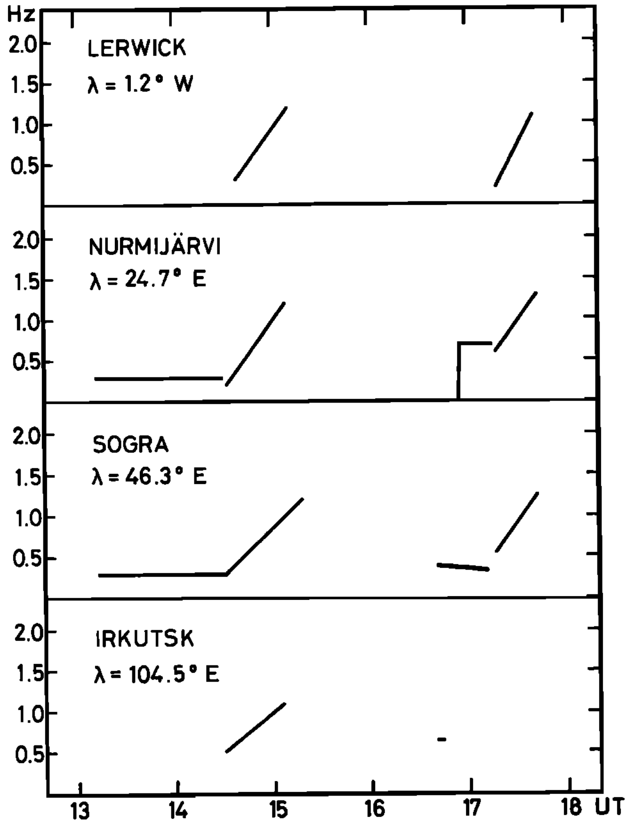

Fig. 8. Frequency versus time plots of magnetic pulsations at four meridians on February 10, 1975.

values of the time delays and corresponding drift rate are given in Table 2. The drift rate varied for the 23 events from 1.4 to 14 degrees per minute.

Three IPDP events recorded at several meridians have been available for a more detailed analysis. On the basis of the previous section we assume that the IPDP event observed at any latitude at a certain time gives a good measure of the frequency-time characteristics of ion-cyclotron waves at this specific meridian at this specific time.

On January 31, 1975, IPDP type magnetic pulsations have been recorded over an extended area from Irkutsk to Lerwick, England, at about 1800 UT. The schematic presentation of frequency-time characteristics at four meridians is shown in Figure 7. Several results can be pointed out:

1. There is a westward drift of the event. If the rate is estimated at 0.6 Hz it is 2.6° min^{-1} between Irkutsk and Nurmijärvi and 1.4° min^{-1} between Nurmijärvi and Lerwick.
2. The duration of the event is longer in the dusk sector than in the midnight sector.
3. There is no drastic change in the slope of the event from east to west.
4. There is some evidence for the low-frequency part below 0.5 Hz to be less intense in the late evening-midnight sector.

A similar data set has been available for IPDP activity studies on February 10, 1975. Two IPDPs can be recognized: one around 1500 UT over an area from Irkutsk to Lerwick and another one after 1700 UT at least from the Sogra meridian to Lerwick. The schematic presentation similar to Figure 7 is given in Figure 8. The first event is very weak at Lerwick, and for the second event a short Pc 1 event appears in the Irkutsk meridian demonstrating very probably the onset of the substorm. The main conclusions are the same as in Figure 7.

As the data to study the azimuthal development of IPDP events is very poor, we show one more detailed analysis. During a special campaign on March 15, 1976, identical recordings of an IPDP have been made at three stations located at approximately the same latitude: Tixie Bay (geomagnetic latitude 65.6°N, geomagnetic longitude 194.9°E), Chokurdakh (65.5°N, 210.1°E), and Cape Schmidt (64.4°N, 234.2°E). The frequency versus time plots are shown in Figure 9. If we take into account also the amplitude variations observed during this event at the three stations (not shown in Figure 9) we arrive at conclusions 1, 2, and 4 mentioned above on the basis of Figure 7. But the slope of the event becomes significantly smaller at more western stations, which could not be identified in Figure 7.

In the previous analysis the IPDP event was characterized by its average development in time. However, it is well demonstrated in the dynamic spectra shown in this paper that pulsations at a fixed frequency can be recorded at one site during several tens of minutes. On the other hand it has also been shown that at certain times quite a broad spectrum of pulsations can be observed. This information may be used to estimate the extension of the emitting particle population. If we use the drift rate of 2° min^{-1} we arrive at values 15° and 80° for the east-west extension for the extreme cases shown in Figures 2 and 3, respectively. The north-south extension may also be very variable. If we take the width of the IPDP spectrum as its measure it should be much greater for the event shown in Figure 2 than for the event shown in Figure 3.

6. Summary and Discussion

In this paper data sets from different networks of pulsation magnetometers have been used

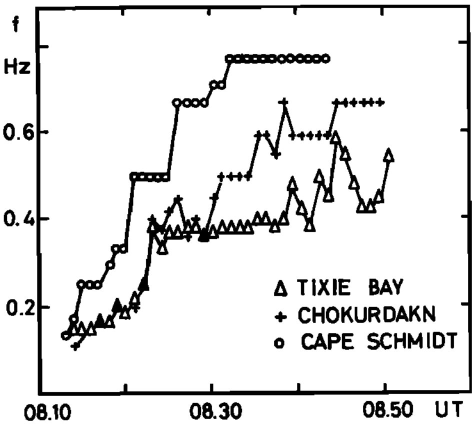

Fig. 9. The frequency as a function of time for the IPDP event observed on March 15, 1976 at three sites that are at about the same latitude. The longitudinal separation of the furthermost stations is 40°.

to characterize type IPDP magnetic pulsation events and their development in time and space. The main observational findings can be summarized as follows.

1. Slopes on frequency-time graphs of the events observed in the afternoon to evening sector of the magnetosphere are often steep.
2. The frequency of IPDP pulsations in the evening to midnight sector is typically increasing slowly, and often the low-frequency pulsations are missing.
3. The slope of typical high-latitude events is smaller than that of the low-latitude events. However, if IPDP pulsations are observed simultaneously at different latitudes, their frequency-time characteristics are similar.
4. The end frequency of the IPDP pulsations increases with decreasing latitude and is typically smaller than the He^+ gyrofrequency at the corresponding field line in the equatorial plane.
5. The IPDP events are delayed with respect to the substorm activity in the midnight sector, and the drift rate of the IPDP onset is $5\text{-}6^{\circ}$ min^{-1}.
6. Simultaneous observations at several meridians show that an IPDP event may develop with quite similar characteristics over an extended area. The westward drift rate at a fixed frequency is typically $2\text{-}5^{\circ}$ min^{-1}.
7. The duration of the IPDP event increases during the westward drift.

According to the theory of ion-cyclotron waves, the growth rate depends on the magnetic field strength, thermal energy of the plasma, anisotropy, and density of cold and hot plasma [Kennel and Petschek, 1966; Gendrin, 1970, 1975; Lin and Parks, 1974] as well as on the heavy ion composition [Young et al., 1981]. Thus proper magnetospheric conditions and proper energetic particle distribution are needed for the generation of IPDP magnetic pulsations.

Kaye et al. [1979] have calculated the evolution of ion cyclotron instability in the plasma convection system of the magnetosphere. They show that the instability inside the plasmapause is confined to the dusk sector. They also show that the range of unstable frequencies is effectively reduced when moving away from the dusk to the midnight sector (see Figure 5 in Kaye et al. [1979]). We believe that our observations support these calculations, and favorable conditions for IPDP generation are met within the plasmapause, especially in the dusk sector of the magnetosphere.

Even if the data collection shown here is not great, it is important to note that the IPDP event may occur over an extended area but with a time delay. It indicates that proper conditions for the wave generation are met during a substorm at different local time sectors. Furthermore, it demonstrates that the wave propagation in the ionospheric duct in the east-west direction is not as important as in the north-south direction. This conclusion confirms the theoretical calculations by Greifinger and Greifinger [1973].

McPherron [1981] states in this review article on substorm associated magnetic pulsations that there is no detailed explanation for the upward sweep of the frequency of IPDP pulsations seen at the ground. However, he proposes that the phenomenon may be due to either inward drift or azimuthal dispersion of a cloud of resonant protons. As other possibilities have been introduced (see, e.g., Heacock et al. [1976], Bossen et al. [1976], and Maltseva et al. [1981]) we evaluate some of them in the frame of the present experimental data.

The theory first suggested by Fukunishi [1969] explains the IPDP frequency shift to be caused by azimuthal dispersion of drifting protons in the magnetosphere. Higher-energy protons arriving first at the meridian of observation would generate lower frequency waves. This theory suggests that the slope of IPDP events should decrease and their duration should increase in the course of the westward development. Much of our observations summarized above are in accord with these expectations (see, e.g., Figure 9). But on the other hand, the data given in Figures 7 and 8 show surprisingly little change of the slope of the events observed at well separated meridians. It is also well documented that the geostationary satellite does not see IPDP type pulsations. All this indicates that the IPDP characteristics cannot be explained solely by the drift dispersion mechanism. The minor role of the energy of drifting protons in determining wave frequency has been demonstrated by Fraser and Wawrzyniak [1978], who showed that the protons responsible for the generation of IPDP pulsations at the end of the event are even more energetic than those resonating with the waves at the beginning of the event (see also Maltseva et al. [1981]).

According to the IPDP mechanism suggested by Gendrin et al. [1967] and by Troitskaya et al. [1968] energetic plasma drifting inward produces progressively higher frequency pulsations as the plasma convects to the regions of a more intense magnetic field. The observations by Heacock et al. [1976] and by Maltseva et al. [1981] have greatly supported this view as was mentioned in the introduction. We have been able to give a further demonstration of the great importance of the magnetic field intensity in determining the wave frequency by showing a definite increase of the IPDP end frequency with decreasing latitude. It seems that the wave frequency observed on the ground is controlled by the He^+ gyrofrequency at the equatorial plane as could be expected on the basis of satellite observations [Young et al., 1981].

Heacock et al. [1976] discussed the possibility that the IPDP slope is primarily related to the radial gradient in cold plasma density at the plasmapause. It is known that the further in the plasmapause is, the steeper it is. The low-latitude IPDPs should then be typically steeper than the high-latitude events. Heacock et al. [1976] could not find any definite support on this view from their observations. We believe that our analysis, which separates the high-latitude events from low-latitude ones, gives an evidence that the radial plasma gradient may be an important parameter to explain the IPDP frequency shift.

It seems most probable that typically more than one mechanism contributes to the frequency shift of IPDP pulsations [see Heacock, 1973; Kangas et al., 1974; Fraser and Wawrzyniak, 1978]. This leads to a conclusion that IPDP pulsations cannot easily be used to derive such magnetospheric parameters as electric fields and plasmapause structure. But it may be important in future studies to make a difference between high-latitude and low-latitude events as demonstrated in the present paper. In this respect, the multiple events (see our Figure 4) seem very promising to test ideas. They seem to indicate the simultaneous existence of plasma and field conditions at one meridian which are typical both for high-latitude and low-latitude IPDP events.

A short reference to the observations of Pc 1 pulsations needs to be made here (as a general review on Pc 1, see Jacobs [1970]). Pc 1 pulsations are also considered as ion-cyclotron waves generated in the magnetosphere. The frequency range of high-latitude Pc 1s is within high-latitude IPDP frequencies and the same conclusion is valid also for low-latitude Pc 1 and IPDP observations. Baransky et al. [1981] showed that high-frequency Pc 1 events are generated deep inside the plasmasphere, whereas low-frequency Pc 1s seem to occur at high latitudes within the plasmapause region. Baransky et al. [1981] demonstrated also that the sources of high- and low-latitude pulsations may exist at the same time. Even if Pc 1 pulsations characterize quiet post-storm magnetospheric conditions correlative studies between IPDP and Pc 1 pulsations might be useful.

7. Conclusions

In the present study, several new data sets of ground-based IPDP observations have been used. The observations are in general agreement with the evolution of ion cyclotron instability in the plasma convection system of the magnetosphere. It has proved useful to divide the events on the basis of their local time of occurrence as well as their latitudinal extension. This division seems to help to understand IPDP mechanisms several of which may operate simultaneously. The IPDP source region moves to the west by about $2-5^\circ$ min^{-1} and proper conditions for the amplification of waves are met over a region extending 100° in the east-west direction. It is remarkable that no drastic changes in frequency-time characteristics of IPDP pulsations are necessarily observed. In the radial direction, IPDP wave frequency seems to be related to the He$^+$ gyrofrequency in the equatorial plane.

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