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Bursts of Irregular Magnetic Pulsations During the Substorm

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Abstract. New characteristics of PiB magnetic pulsations which are associated with the substorm in the local midnight sector are revealed from the recordings of a meridional network of ground stations. PiB's are observed during distortions of the auroral arc which enclose a local region of upward directed field-aligned current. An enhancement at about 0.3–0.4 Hz is shown to be a permanent feature of PiB's. In addition, a secondary amplitude maximum at about 1 Hz sometimes appears in the recordings far from the auroral zone. The generation of PiB pulsations in the Pi1 period range is located at auroral latitudes at a low altitude. Low-altitude electric fields and acceleration of auroral particles, low-altitude resonance cavities and isotropic propagation of waves is discussed in the interpretation of PiB pulsations.

Key words: Magnetospheric substorm – PiB magnetic pulsations.

Introduction

Magnetic pulsations which are observed during the magnetospheric substorm near the midnight sector are termed Pi pulsations. Pulsations with a period less than 40 s are called Pi1 pulsations and those of a longer period Pi2 pulsations. For irregular pulsations $T > 150$ s a term Pi3 has been adopted recently (see general reviews by Saito, 1969; and Nishida, 1978).

Pi pulsations are characterized by a wide range a frequencies in their dynamic spectra. However, it appears useful to have a further classification, and the terms like PiB (Pi burst) and PiC (Pi continuous) have been adopted (Heacock, 1967). IPDP pulsations (interval of pulsations of diminishing periods) should also be discussed together with Pi pulsations due to their close association with the substorm although the dynamic spectrum of an IPDP event in some respects resembles the spectra of more regular Pc pulsations (see Saito, 1969; Nishida, 1978).

During the development of a typical substorm a PiB event appears at the onset of the substorm around the midnight sector. This burst lasts only some

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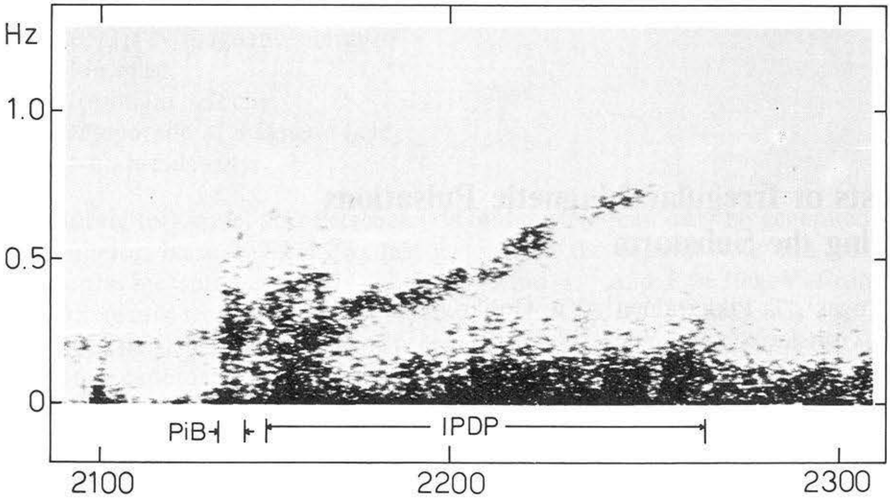

Fig. 1. Dynamic spectrum of magnetic pulsations at Sodankylä on October 5, 1974, illustrating the appearance of PiB and IPDP events

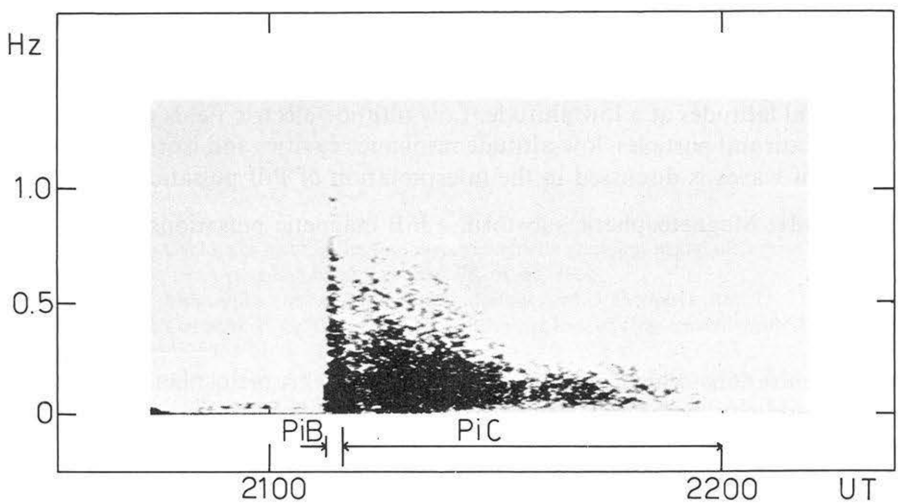

Fig. 2. An example of PiB and PiC events at Oulu on March 2, 1974

minutes and is followed by an IPDP event on the evening side of the auroral zone and by a PiC event on the morning side. Near the local midnight the dynamic spectrum is usually characterized by the combinations PiB + IPDP or PiB + PiC as shown in Figs. 1 and 2.

A PiB event appears in a dynamic spectrum as a short vertical line as shown in Figs. 1 and 2, extending sometimes up to several Hz. This means that a PiB contains both Pi1 and Pi2 pulsations. Heacock (1967) reports that these ranges may be separated partly especially in summer time when an enhancement at about 0.3 Hz is often seen. Such an enhancement has also been observed at the ATS-1 geostationary location (Coleman and McPherron, 1976) but at a little higher frequency than simultaneously on the ground.

In this paper, data from several stations are used in order to study the latitudinal profile of PiB events in the Pi1 period range. Some other simultaneous observations have also been analysed in order to relate the generation of PiB magnetic pulsations with the magnetospheric processes during the substorm.

Observations and Results

Spectral Analysis of PiB Events

In October 1974, several pulsation magnetometers have been operated in the Soviet Union at about the same meridian with the Finnish stations. Later during some IMS periods similar measurements have been made. The locations of these stations are given in Table 1. Core type induction magnetometers with similar frequency characteristics in the Pi1 period range at all stations have been used.

PiB pulsation events have been identified from dynamic spectra (sonagrams) which give the frequency of pulsations. To get more information of the wave amplitudes, band-pass filters have been used. The frequency band from about 0.2 Hz to about 1.5 Hz has been analysed in this way. Some spectra will be shown below.

All the events presented here have been measured during strong magnetic activity. Due to difficulties to separate overlapping substorms no attempt has been made to correlate PiB's more exactly with the development of the substorm. On October 18 and 20, 1974, several PiB's occurred as shown by the dynamic spectra from Sodankylä in Figs. 3 and 4. Amplitude spectra have been analysed for the events at 17.55, 18.35, and 18.45 UT on October 18 and at 17.20 UT on October 20. The maximum amplitude at about 15 frequency bands has been determined. For comparison, spectra from one auroral zone station (Sodankylä) and from one midlatitude station (Nurmijärvi) have been presented in Figs. 5–8. Some main characteristics can be summarized as follows.

Table 1. Locations of Finnish and Russian pulsation magnetometer stations

	L-value	Geomagn. coord. (corrected)	
		Latitude	Longitude
Kevo	6.0	66.2°	111°
Sodankylä	5.1	63.9°	109°
Oulu	4.3	61.8°	107°
Kostamuska	4.1	60.5°	110°
Suckozero	3.8	59.0°	111°
Nurmijärvi	3.3	57.0°	103°

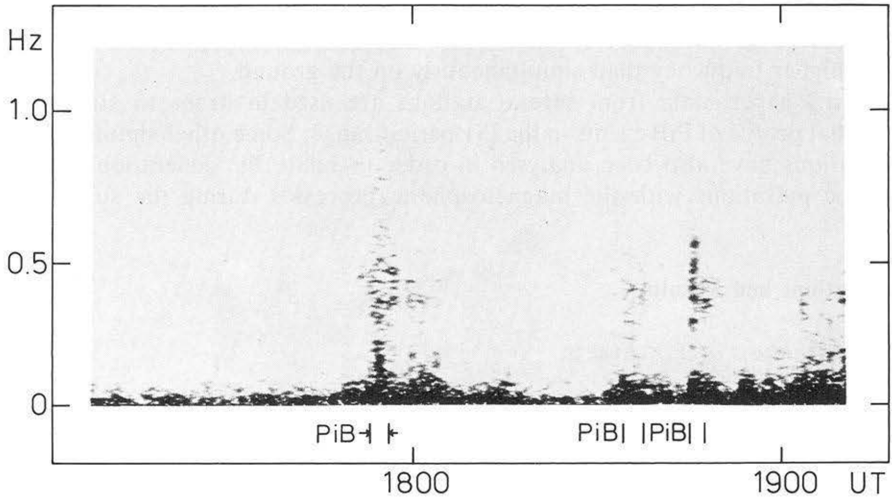

Fig. 3. Dynamic spectrum of Pi pulsations at Sodankylä on October 18, 1974. PiB events at 17.55, 18.35, and 18.45 UT are denoted

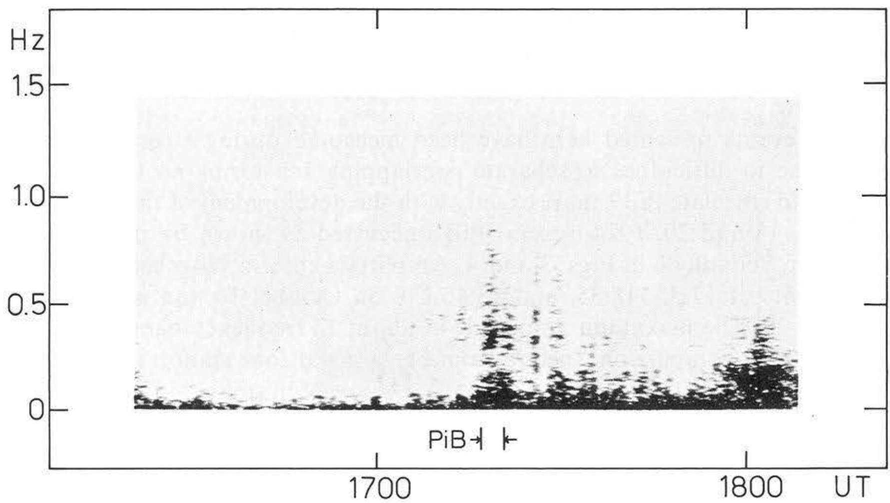

Fig. 4. Dynamic spectrum of Pi pulsations at Sodankylä on October 20, 1974. A PiB event at 17.20 UT is denoted

1. An intense peak at about 0.3–0.4 Hz appears in the high-latitude spectra.
2. A smaller peak at about the same frequency is always seen in the low-latitude spectra.
3. A secondary maximum at about 1 Hz sometimes appears in the low-latitude spectra. The amplitude of these high-frequency pulsations may be even greater than that in the auroral zone.

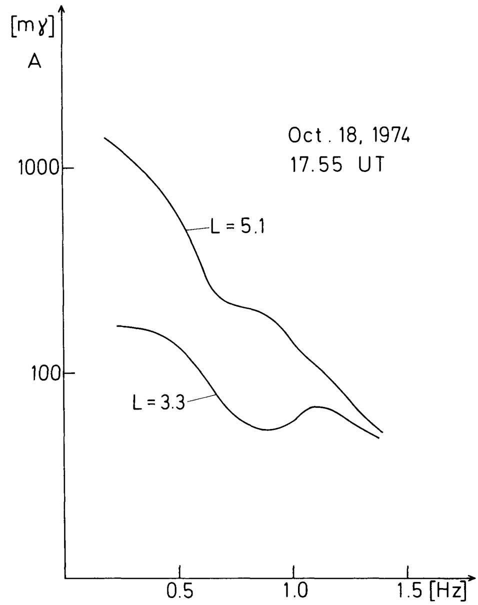

Fig. 5. Amplitude spectra of the PiB event on October 18, 1974 at 17.55 UT for the station Sodankylä ($L \sim 5.1$) and Nurmijärvi ($L \sim 3.3$)

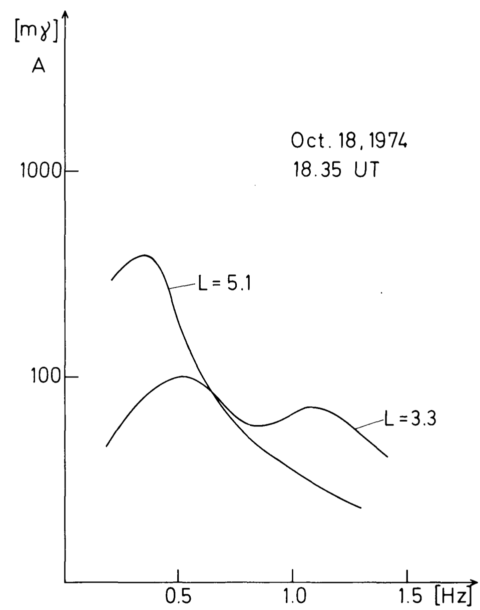

Fig. 6. Same as Fig. 5, but for the PiB event on October 18, 1974, at 18.35 UT

Dynamic spectra show a minimum of the intensity of pulsations at about 0.2 Hz. At lower frequencies Pi2 activity is dominating. This enhancement is seen clearly only in one amplitude spectrum (Fig. 7) because the method of analysis used here does not permit to continue the analysis down to low frequencies with a sufficient resolution.

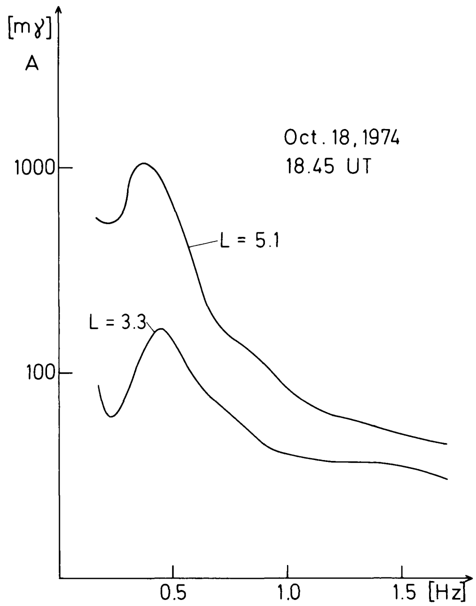

Fig. 7. Same as Fig. 5, but for the PiB event on October 18, 1974, at 18.45 UT

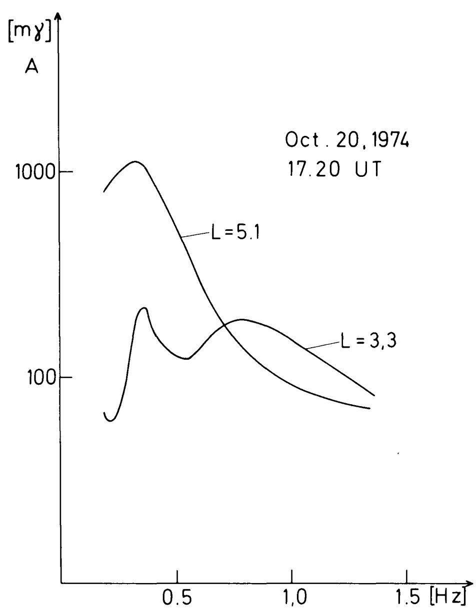

Fig. 8. Same as Fig. 5, but for the PiB event on October 20, 1974 at 17.20 UT

As a further example of the latitudinal behaviour of PiB's an event on December 1, 1977, at 20.30 UT (see Fig. 9) is presented in Fig. 10. The amplitude of magnetic pulsations at six frequency bands characterized by the center frequency has been plotted as a function of latitude. Frequencies from 0.2 to 1 Hz have been used. The same features as above can easily be noted. The maximum amplitude at low frequencies has been observed at high-latitude station

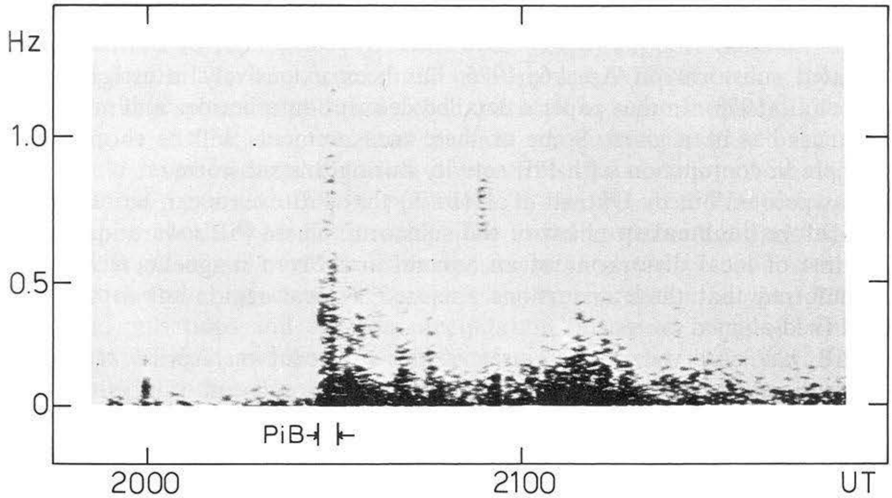

Fig. 9. Dynamic spectrum of Pi pulsations at Sodankylä on December 1, 1977. A PiB event at 20.30 UT is denoted

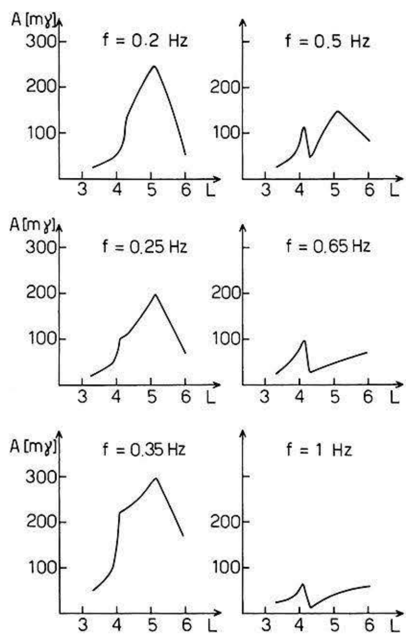

Fig. 10. Latitudinal profiles of the amplitude of PiB pulsations on December 1, 1977 at 20.30 UT at six frequencies

but at higher frequencies a secondary maximum developes at the more southern stations.

Two more characteristics of PiB events can be identified in dynamic spectra. In all cases presented here no clear dispersion of waves is observed. On the other hand, often several PiB's occur as a series of bursts. This is seen in Fig. 4 where at least three PiB's can be identified within about 10 min.

PiB Events and Auroral Structures

An isolated substorm on April 6, 1975, has been extensively investigated by Untiedt et al. (1978). In that paper a detailed description of aurora and magnetic disturbances has been given. Some of these measurements will be shortly discussed here in conjunction with PiB activity during this substorm.

It was pointed out by Untiedt et al. (1978) that PiB events can be observed already before the breakup phase of the substorm. These PiB's were identified at the time of local distortions of an auroral arc. From magnetic recordings it was inferred that these distortions enclosed a local region of an upward directed field-aligned current.

A PiB was observed at the onset of the substorm on April 6, 1975, at the same time with an impulsive riometer absorption event (Untiedt et al., 1978). This is in accordance with Heacock's result (1967) that a Pi burst always appears when an impulsive electron precipitation event is observed. The reverse is not true but this seems to be due to lack of suitable riometer stations in Heacock's analysis. Later Heacock and Hunsucker (1977) concluded, that PiB events seem to correspond to inverted-*V* precipitation events.

Discussion and Conclusions

PiB magnetic pulsations are intimately associated with the development of the magnetospheric disturbances. They occur at the onset of the substorm but also during the pre-breakup phase of the substorm as was shown by Untiedt et al. (1978). There are now strong indications that they should be related to the processes which result in the generation and development of discrete auroral arcs.

Strong electric fields, both horizontal and vertical, and magnetic field aligned currents characterize the discrete aurora (Davis, 1978). Observations of field-aligned currents have been reviewed recently by Potemra (1978) and the existence of horizontal and vertical electric fields at the height of some thousand kilometers has now been confirmed (see reviews by Block, 1978, and Swift, 1978). The observations of the inverted-*V* electron precipitation events associated with the discrete aurora seem to agree with the models for the electric field configuration above auroras (Frank and Ackerson, 1971; Ackerson and Frank, 1972; Swift, 1978).

Several proposals have been made for the generation of the electric field along the geomagnetic field (Block, 1978; Swift, 1978). The potential double layer is of a special interest in the present context as it has been used recently by Petelski et al. (1978) in modelling of some auroral pulsation phenomena.

A double layer represents an instability of the field-aligned current. According to Carlqvist (1972), the Birkeland current must be strong enough in order to initiate a magnetospheric double layer. The generation and characteristics of the double layer have been much investigated in the laboratory plasma (Torven and Babic, 1975; Quong and Wong, 1976; Torven and Andersson, 1978).

We assume that local changes in the field-aligned current at the time of PiB pulsations as reported by Untiedt et al. (1978) support the view that the potential double layer may occur simultaneously with PiB pulsations. The double layer should be placed at a low altitude, perhaps at some thousand kilometers according to the electric field and particle measurements mentioned above. This would result in an acceleration of electrons. According to Nishida (1964) such electron beams can excite pulsations in the Pi1 and Pi2 period range. Waves up to about 10 Hz are possible. The broad spectrum and lack of dispersion of PiB pulsations could be explained in such a model.

Heacock and Hunsucker (1977) report a close correlation between PiB magnetic field pulsations and electron precipitation pulsations. Only a small time delay between field and particle pulsations was observed. Heacock and Hunsucker conclude that the waves are generated by the precipitation pulsations. They locate the source of PiB pulsations also at a relatively low altitude.

After being generated at a height of some thousand kilometers waves are propagating isotropically (*R*-mode) or anisotropically (*L*-mode). As was pointed out by Petelski et al. (1978) the steep density gradients within the double layer facilitate mode coupling between *L*- and *R*-mode pulsations. Toward the earth two resonance cavities are formed below the source region: one between the maximum of the Alfvén velocity (about 2,000 km) and the lower ionosphere and another between the double layer and the level of 2,000 km. Using typical values for the Alfvén velocity ($v_A \sim 10^6$ m/s in the lower cavity and $v_A \sim 6 \cdot 10^6$ m/s in the higher cavity) we arrive at resonance frequencies of about 0.3 Hz and 0.8 Hz, respectively. The altitude of the double layer is estimated to be 6,000 km.

Due to the cavity resonance intense pulsations at about 0.3 Hz should be expected below the source region. Other parts of the spectrum are attenuated. At the ionospheric level horizontal propagation of waves is possible and the waves around 0.3 Hz can be observed far from the source region. Some attenuation occurs, and the amplitude of these waves at low latitude stations is smaller.

Another band around the higher resonance frequency is only partly penetrating to the ground below the source region. However, it is able to propagate isotropically. These high-frequency waves can be guided to the ground at the plasmapause region. This may explain our observations of the secondary maximum in certain low-latitude recordings.

Laboratory plasma experiments show that the double layer may become unstable at certain conditions (Torven and Babic, 1975; Quong and Wong, 1976) and that the plasma begins to radiate electromagnetic emissions with a broad spectrum. However, these observations refer to non-magnetic plasmas. It is not clear how they can be extrapolated to the magnetospheric plasma. Moreover, we feel that there is one serious difficulty with this model where the electric current is flowing against the direction of the magnetic field. In such a case the emission of waves should be confined in a cone directed upwards, and it would be difficult to explain the pulsations observed on the ground.

In this paper, the emphasis has been put on Pi1 pulsations. However, it is important to note that according to Stuart (1974), Lanzerotti and Fukunishi (1974), and Saito et al. (1976) the amplitude of Pi2 waves shows the main maximum in the auroral zone and a secondary maximum, at a higher frequency, at the plasmapause region. This indicates also that the plasmapause has an important effect on the propagation of hydromagnetic waves.

Summary

Some new characteristics of PiB magnetic pulsations for the Pi1 period range have been revealed in the present paper. These results are summarized in the following way:

1. PiB's are observed simultaneosly with the brightening and local distortions of the auroral arc.
2. PiB dynamic spectrum does not indicate any pronounced dispersion of waves. Sometimes several PiB's occur as a series of bursts.
3. An intense amplitude maximum of waves appears at auroral latidues at about 0.3–0.4 Hz; a less entense maximum at the same frequency is observed at lower latitudes.
4. A secondary amplitude maximum at about 1 Hz is sometimes seen in the PiB spectrum at certain lower latitude stations.

We think that the generation of PiB pulsations in the Pi1 period range should be placed at auroral latitudes at a low altitude where also the acceleration of auroral electrons seems to take place. Some of our observations indicate the existence of low-altitude resonance cavities. Also the isotropic propagation seems to contribute in an important way to the characteristics of PiB magnetic pulsations on the ground.

PiB events have several well-defined characteristics. It is expected that they could give useful information about the low-altitude electric fields and acceleration of auroral particles. More details about the relationship between PiB's, field-aligned currents and auroral structures are being collected during the present IMS. Also the relation between Pi1 and Pi2 pulsations during the PiB event needs to be studied.

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