CLASSIFICATION OF Pc 1 AND Pi 1 WAVES OBSERVED IN HIGH LATITUDES

Takesi NAGATA, Takeo HIRASAWA, Hiroshi FUKUNISHI,
Masaru AYUKAWA, Natsuo SATO, Ryoichi FUJII
National Institute of Polar Research, 9–10, Kaga 1-chome, Itabashi-ku, Tokyo 173

and

Makoto KAWAMURA
Kakioka Magnetic Observatory, 595 Kakioka, Yasato-machi, Niihari-gun, Ibaraki 315–01

Abstract: A classification of the ULF-waves in the pc 1 and pi 1 frequency range was attempted on the basis of recent data (1976–78). Referring to the spectral structures of ULF waves, their similarities at the conjugate pair stations, their association with SC and SI events, and the correlations between auroras and VLF, it is shown that pc 1 and pi 1 ULF waves can be classified into six types with nine subclasses, as summarized in Table 1.

1. Introduction

ULF emissions with the frequency above 0.2 Hz, which are most frequently observed in the polar region, are called pc 1 and pi 1 according to the definition adopted by IAGA in 1963. Since then, spectral studies, using frequency/time analyses (*f-t* diagram), have revealed various kinds of distinct types of spectral forms in this frequency range. For example, KOKUBUN (1970) proposed a spectral classification for the fine-structured ULF emissions and indicated that there exist four kinds of the ULF emissions with three subclasses in the frequency range above 0.1 Hz. As an extension of KOKUBUN's work, a further attempt to classify the ULF emissions in the pc 1 and pi 1 frequency range in more detail was made based on the *f-t* diagram data obtained in 1976–78 at Japanese Antarctic Stations, Syowa and Mizuho and at Husafell in Iceland which is located in the conjugate area of Syowa Station.

2. Spectral Structure of ULF Emissions

Spectral analyses, using the *f-t* diagram (sonograph) technique, have indicated the appearance of a number of distinct types of spectral forms in the frequency range above 0.1 Hz. KOKUBUN (1970) showed that the ULF emissions can be classified into four types, *i.e.* the hydromagnetic (HM) whistler (OBAYASHI, 1965; JACOBS and WATANABE, 1967) (Fig. 1), the periodic HM emission (JACOBS and WATANABE, 1967), the HM chorus (Fig. 2) and IPDP (sweeper) (TROITSKAYA, 1961; HEACOCK, 1967) (Fig. 3). This classification was made referring to VLF emission spectra, because the ULF emissions show characteristics similar to the VLF emissions in many respects. For the periodic HM emission, three subtypes were defined, *i.e.* non-dispersive (Fig. 4), dispersive and drifting, as in the case of VLF emissions.

In addition to KOKUBUN's classification, several new types of ULF emissions are found in the *f-t* diagrams obtained at Syowa and Mizuho Stations in 1976–78. Spectral characteristics of these newly identified ULF emissions are summarized as follows.

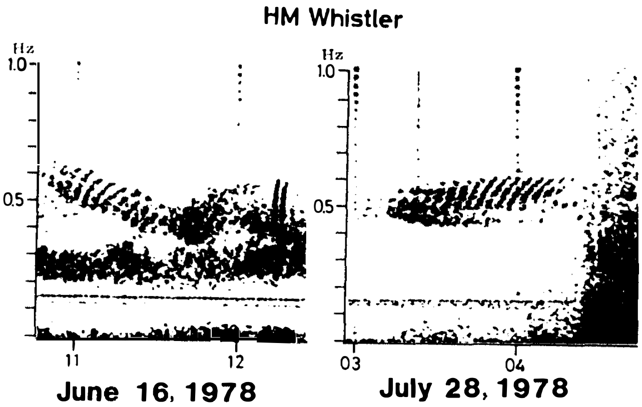


Fig. 1. Typical examples of HM whistler observed at Syowa Station. The time-gradient of each rising element in HM whistler becomes successively smaller with time.

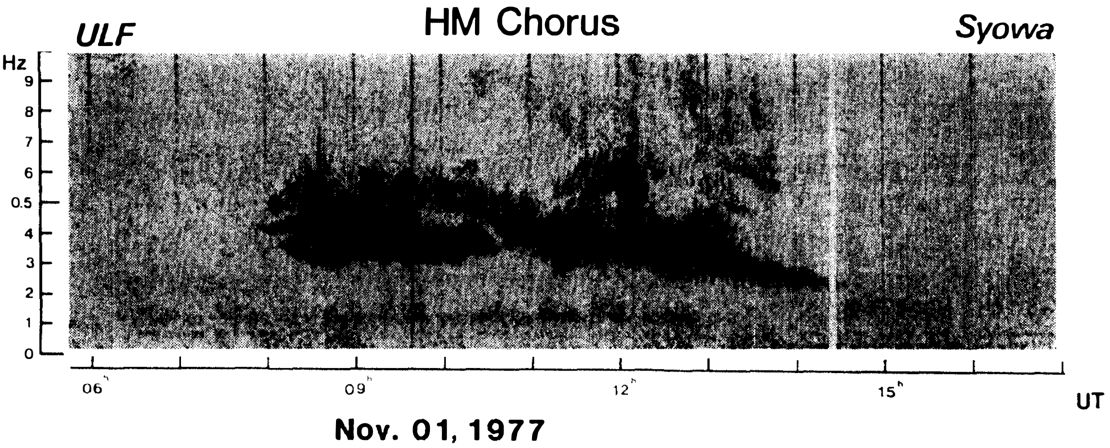


Fig. 2. An example of HM chorus emission. The spectrum of HM chorus contains the irregularly spaced rising elements or dots, sometimes overlapping one another, with the strong diffuse noise.

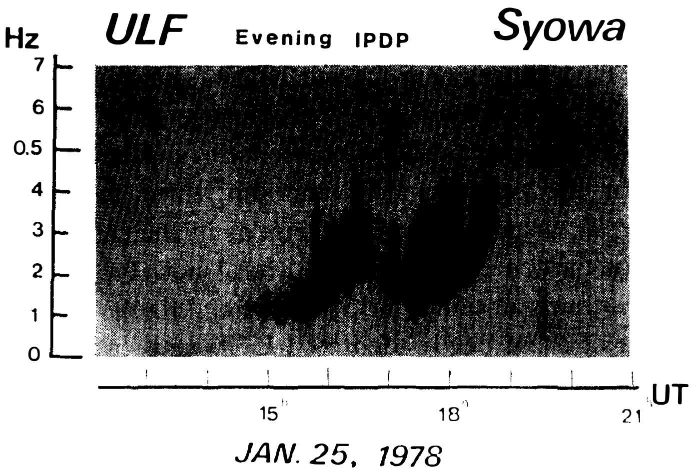


Fig. 3. An example of IPDP emissions. The mid-frequency of IPDP increases with time and the spectrum of the emissions contains unstructured diffuse noise and irregularly spaced rising elements. IPDP are mainly observed in the evening hours.

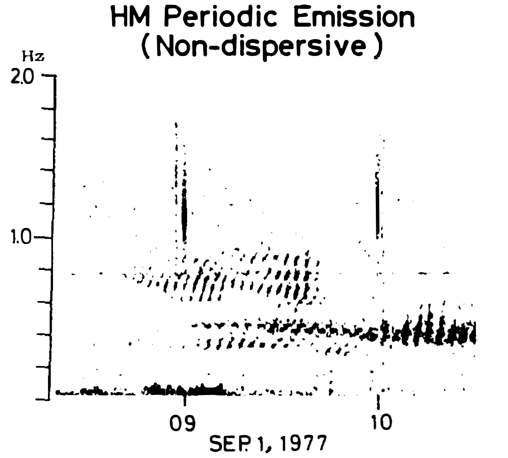


Fig. 4. An example of non-dispersive HM periodic emissions consisting of almost parallel risers.

(1) HM periodic emission with diffuse noise (the fourth sub-type of HM periodic emission): The continuous band-limited ULF emission with diffuse noise containing rising elements or dots with a regular spacing. As illustrated in a typical example of ULF emission of this type in Fig. 5, the continuous diffuse noises overlap the rising elements of HM whistler (from 07h to 09h, May 9, 1977) and HM periodic emission (from 09h to 12h) (*cf.* Figs. 1 and 4).

(2) HM emission burst: A series of burst-like spectral structure with a duration of about 5–10 minutes as shown in Fig. 6. The spectrum of HM burst does not consist of the spaced rising elements, but of the unstructured noise.

(3) Morning IPDP (the subtype of IPDE) (Fig. 7): This emission is observed mainly in the morning hours and consists of rather unstructured rising elements.

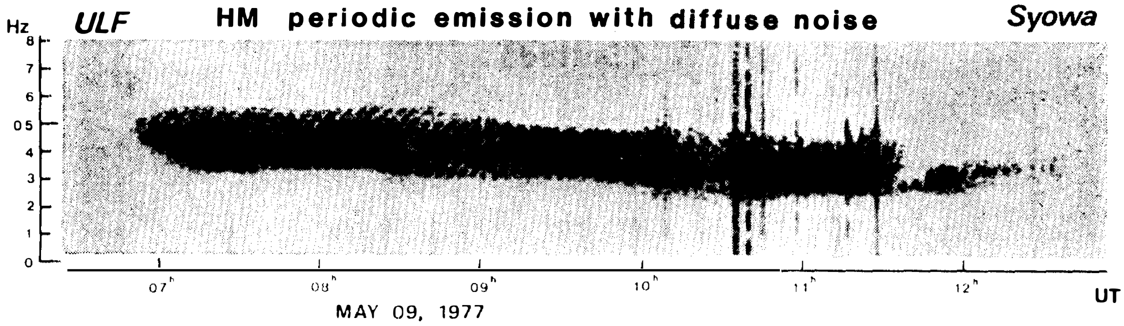


Fig. 5. Typical example of HM periodic emission with diffuse noise.

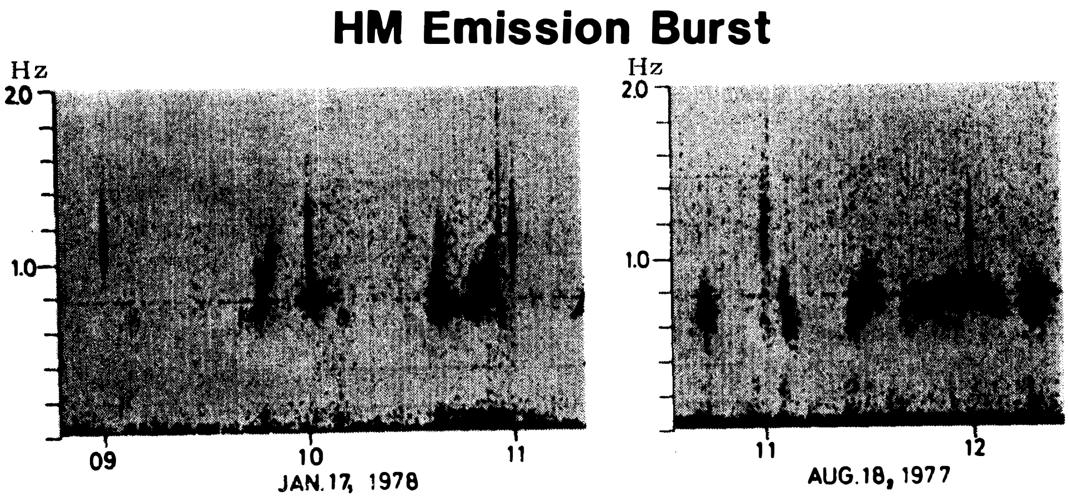


Fig. 6. Examples of the successive occurrences of HM emission burst.

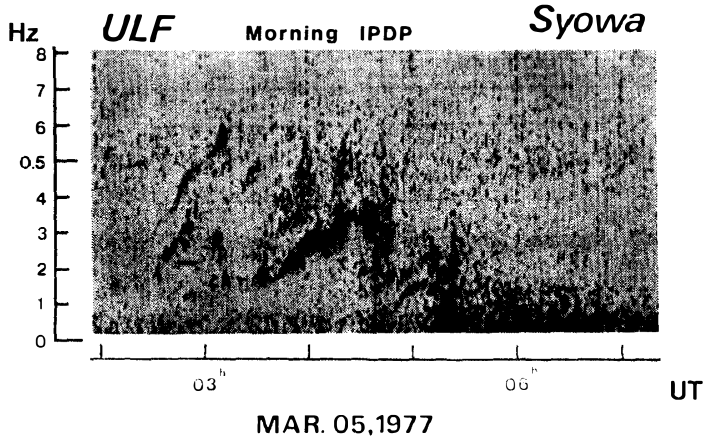


Fig. 7. Successive occurrences of morning type IPDP emissions.

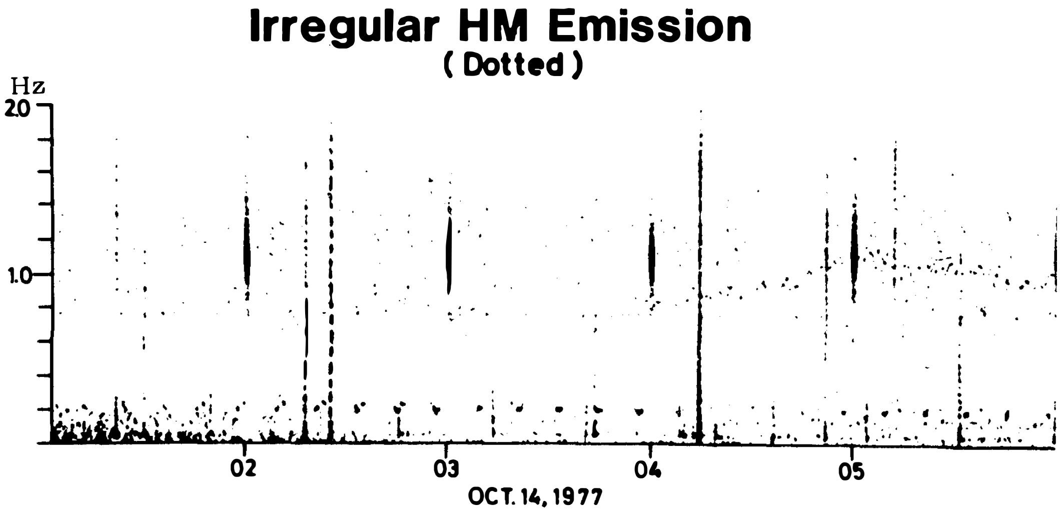


Fig. 8. A series of irregular HM emission with the dotted spectral form around the frequency of 0.2 Hz.

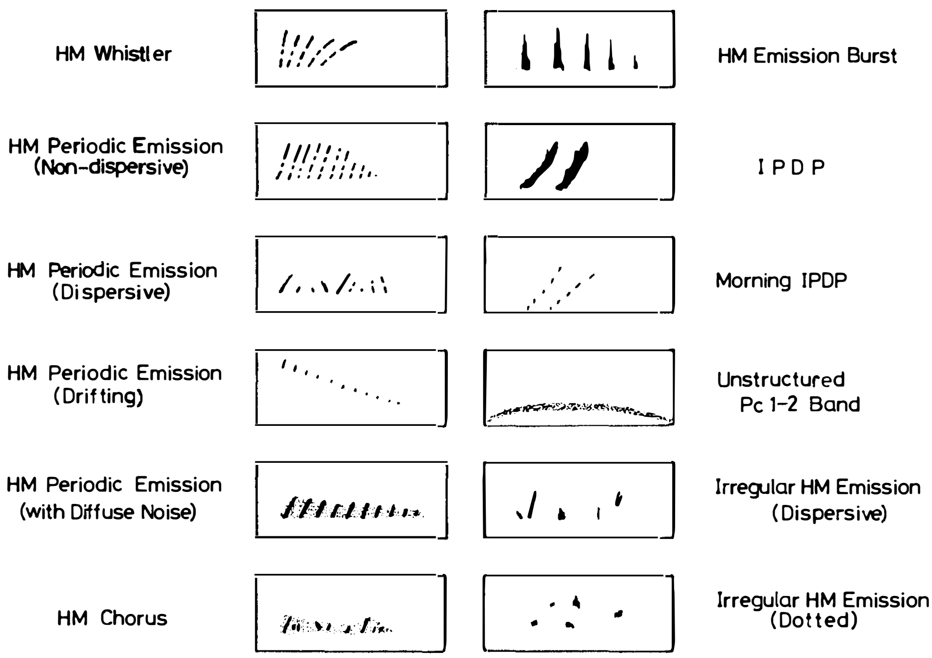


Fig. 9. Schematic spectral forms of ULF emissions with frequency above 0.1 Hz.

The centered frequency rise is one octave or more within about an hour or so. The frequency width of the spectral band of morning IPDP is narrow in comparison with that of IPDP which is observed mainly in the evening hours (*cf.* Fig. 3).

(4) Unstructured pc 1–2 band: Long-lasting band-limited ULF emission with nearly constant frequencies of about 0.1–0.3 Hz. This emission is occasionally

observable through out the day.

(5) Irregular HM emission (dispersive and dotted): The emission of this types is observed as a group of risers (dispersive) or dots and occasionally as isolated risers or dots. This emission tends to appear during periods of disturbed magnetic conditions (Fig. 8).

As briefly described above, five spectral types of new ULF emissions besides the ULF emissions classified by KOKUBUN have been found by examinations in detail of the *f-t* diagrams obtained at Syowa and Mizuho Stations during a period of over two years (1977–78). In Fig. 9, the proposed model spectra of fine-structured ULF emissions of frequency above 0.1 Hz are schematically summarized. This schematic diagram includes six basic types of ULF emission spectral forms; *i.e.* periodic emission, hydromagnetic (HM) chorus, irregular emission, HM emission burst, unstructured pc 1–2 band and IPDP emission. Periodic emission includes five subtypes; *i.e.* HM whistler, non-dispersive, dispersive, drifting and periodic emission with diffuse noise.

3. Occurrences of ULF Emissions

From available *f-t* diagrams at Syowa Station, more than 3000 ULF emissions in the pc 1 and pi 1 frequency range were picked up from data obtained in 1977 and 1978. As the basic analysis, the occurrence frequencies of the six types of ULF emissions are statistically investigated, the result being illustrated in Fig. 10. These

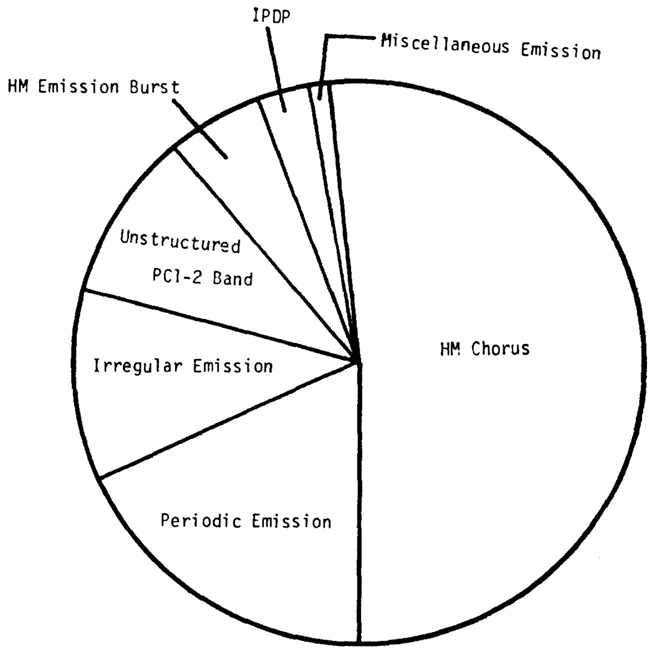


Fig. 10. Occurrence frequency of ULF emissions of various types.

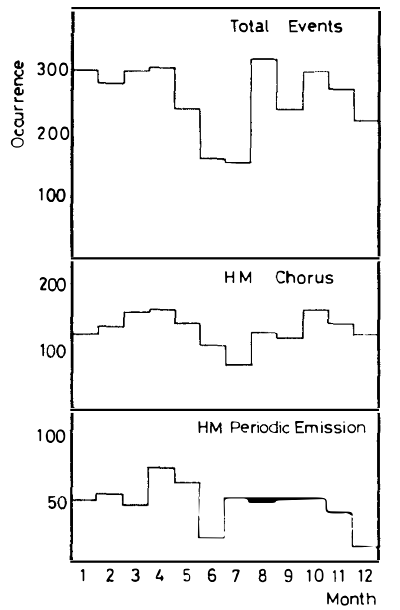


Fig. 11. Seasonal variation in the occurrence of ULF emissions.

ULF emissions in occurrence percentages are 51.7% for the HM chorus, 18.7% for the periodic emissions, 9.8% for the irregular emissions, 8.7% for the unstructured pc 1–2 band, 5.3% for the HM emission burst and 2.9% for the IPDP emissions. Statistically the most frequent ULF emission in high latitudes is HM chorus of 0.2–0.5 Hz in average frequency.

The dependence of ULF emission occurrence on seasons also has been examined. In Fig. 11, it is noted that, during the winter season (June and July in the southern hemisphere), the occurrence of total ULF emissions shows a decrease of about 50% compared with the other seasons. In the cases of HM chorus and periodic emissions, their occurrence frequencies increase slightly during the equinox months. These tendencies are consistent with the seasonal variations in the occurrence of pc 1 pulsations reported by several research workers, including KENNEY and KNAFLICH (1967).

4. Diurnal Variation in ULF Emissions of Various Types

The diurnal variation in the occurrence frequency of ULF emissions in the pc 1 category has been investigated with a wide network of stations. According to TROITSKAYA's results (1967), pc 1 ULF's are frequently observed around the midday or in the afternoon hours at high latitudes, and in the night and early morning hours at middle and low latitudes. A diurnal variation in the mid-frequency of pc 1's has been found by CAMPBELL and STILTNER (1965) and KOKUBUN (1970); that is, higher frequencies occur in the post-midnight hours while lower ones near the early afternoon.

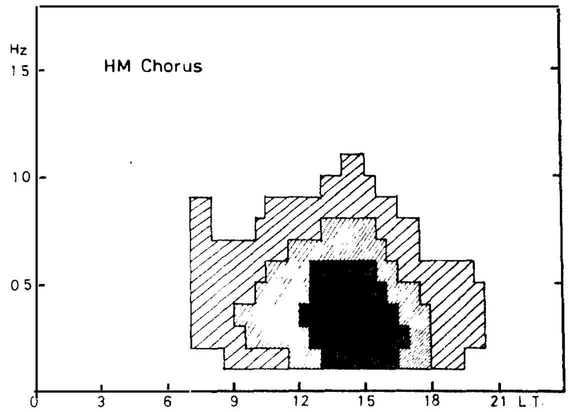
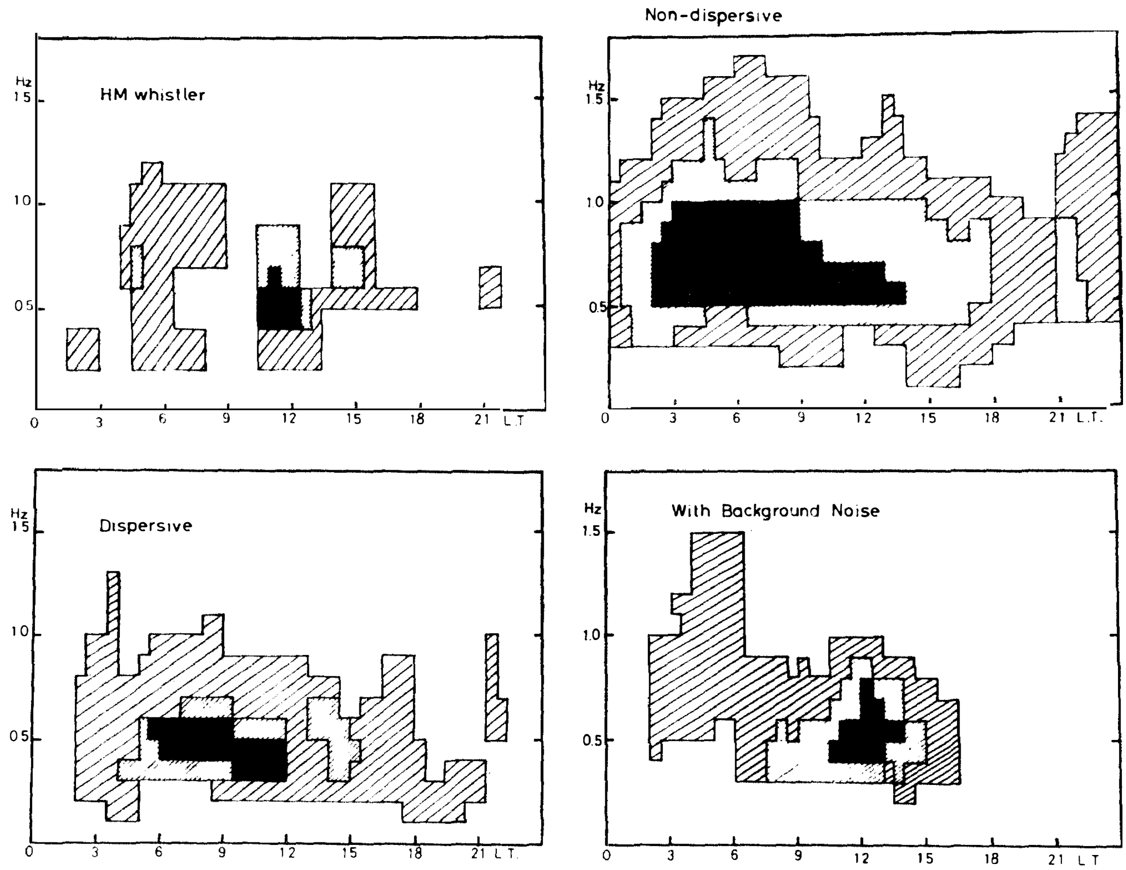


Fig. 12a. Diurnal occurrence pattern of HM chorus.



HM-Periodic Emission

Fig. 12b. Diurnal occurrence pattern of HM periodic emission.

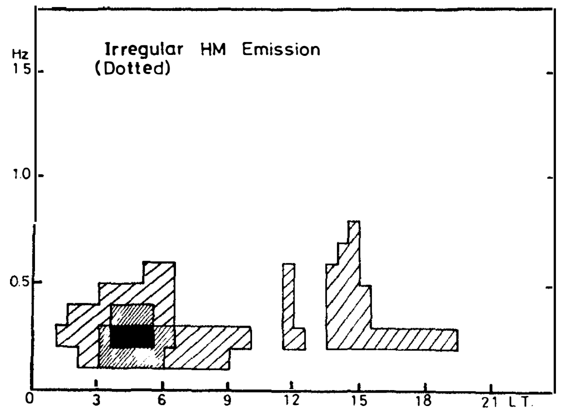


Fig. 12c. Diurnal occurrence pattern of irregular HM emission.

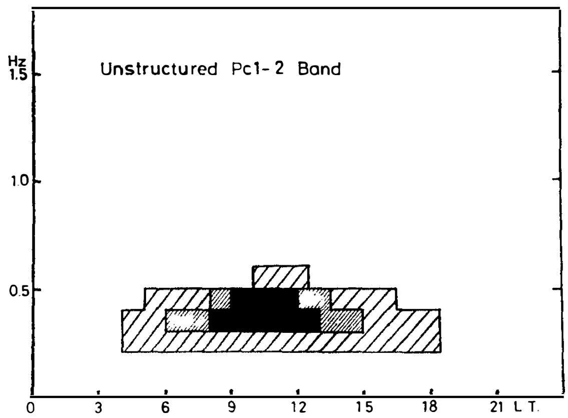


Fig. 12d. Diurnal occurrence pattern of unstructured pc 1–2 band.

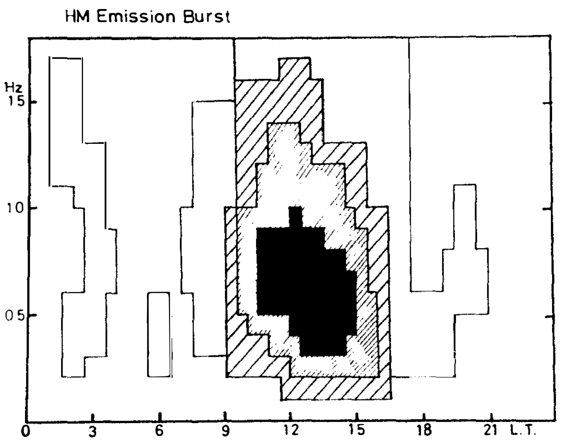


Fig. 12e. Diurnal occurrence pattern of HM emission burst.

From a viewpoint of the spectral pattern of ULF emissions, however, several different kinds of the distinguished ULF emissions in the pc 1 category are observable in the *f-t* diagrams, as described in Section 3. Therefore, investigations of the diurnal occurrences based on a reasonable classification scheme of ULF emissions

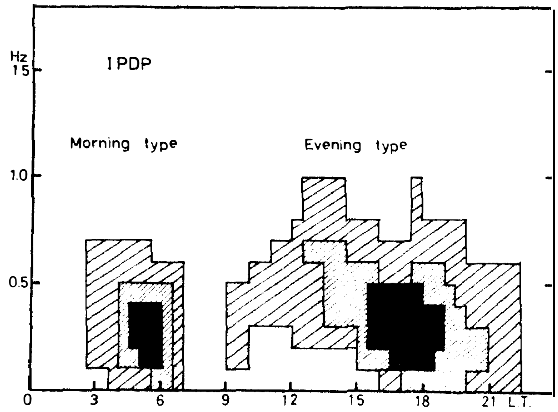


Fig. 12f. Diurnal occurrence pattern of IPDP emission.

will be necessary. In Fig. 12 (a-f) the diurnal variations in the occurrence frequency pattern of ULF emissions of various types of frequencies above 0.1 Hz are summarized as individual statistical *f-t* diagrams.

In Fig. 12 (a-f), the following tendencies can be noticed.

(1) The HM chorus is a daytime ULF emission and is the most frequently observed in the early evening hours (around 15h) with the average frequency of 0.3–0.4 Hz (Fig. 12a).

(2) The HM periodic emission consists of five subtypes (see Fig. 9). Among them, the HM periodic emissions with the drifting spectrum are scarcely observed and the percentage of their occurrence is less than 1% of the total number of the events picked up in the present analyses. Therefore, the statistical result about this subtype periodic emissions will not be fully reliable. The statistical *f-t* diagram of the other four subtypes of periodic emissions are given in Fig. 12b, separately. The HM whistler occurs in the morning hours (around 6h) and also in the midday (around 12 h). The morning HM whistler has a little higher average frequency of about 0.7 Hz, while the midday one has the average frequency of about 0.5 Hz. The periodic emissions with non-dispersive elements appear throughout the day and are observed most frequently during the morning hours of 3h–6h LT. Their median frequency shows a gradual decrease from 0.7 to 0.5 Hz towards the midday. The periodic emissions with dispersive elements show a similar occurrence tendency to that of those with non dispersive elements, but the average frequency ($\sim$0.4 Hz) of periodic emission with dispersive elements is somewhat lower than that of the periodic emission with non-dispersive elements ($\sim$0.7 Hz). The periodic emissions with background noise occur mainly during the morning hours and are most active around the midday ($\sim$12h LT). The average frequency of this emission is about 0.3 Hz or so.

(3) Fig. 12c shows that the irregular HM emissions with dotted elements are observed mainly in the early morning hours (3h–6h LT) in a frequency range of

about 0.2–0.3 Hz. On the other hand, those emissions which appear in the afternoon (12h–15h LT) have a rather higher frequency of about 0.4 Hz.

(4) The unstructured pc 1–2 band emissions are daytime ULF emissions which are most active in the late morning hours (9h–12h LT) (Fig. 12d). The emissions are long-lasting ones, occasionally lasting throughout the daytimes.

(5) Appearances of the HM emissions with burst-like spectral structure are concentrated in the daytime, mainly from 9h to 17h LT over a wide frequency range from 0.3 to more than 1.0 Hz (Fig. 12e).

(6) The diurnal occurrence pattern of IPDP (intervals of pulsations diminishing period defined by TROITSKAYA) emissions are shown in Fig. 12f. This figure clearly shows that the two occurrence maxima of IPDP emissions are observable in the morning hours and in the evening ones respectively. As described in Section 3, the spectral structure of IPDP which is observed in the morning is quite different from that of IPDP in the evening hours; *i.e.* the frequency width of the spectral band of morning type IPDP is narrow in comparison with that of the evening type one, while the median frequency rises of both types of IPDP are nearly the same, the frequency rising by one octave or more within about an hour in both cases (see Figs. 3 and 7).

There still remains a certain difficulty in exactly separating or classifying all ULF emissions into several definite types on the basis of the spectral structures on *f-t* diagrams because there are some ambiguous cases which can hardly be assigned to one of the proposed categories. As shown in Fig. 1 through Fig. 12, however, each ULF emission type proposed in the present work is characterized by its frequency range as well as its diurnal occurrence pattern, separate from one another.

5. SC and SI Effect on ULF Emissions

The HM chorus is an irregularly spaced sequence of rising elements or an unstructured continuous noise band near 0.3 Hz in frequency. A typical spectrum of HM chorus shown in Fig. 13 is a long-duration event lasting more than ten hours. In this sequence of HM chorus, an SSC event occurred at 14h39m (UT) on March 8, 1978, as clearly identified in the magnetic *H*-component record obtained at a low-latitude station, Kakioka (mag. lat. = +26.0). Associated with the SSC, the HM chorus emission band characteristics changed markedly; nearby the centered frequency of HM chorus band suddenly stepped up from 0.25 Hz to 0.5 Hz, and its intensity was strongly enhanced. In the magnetic *H*-component record at Kakioka shown at the top of Fig. 13, positive SI variations with a range of about 3–5 nT took place successively around 10h, 12h and 13h15m (UT). The magnetic variation of this type could be interpreted to have been caused by compression of the magnetosphere (NISHIDA, 1964; HIRASAWA *et al.*, 1966). Corresponding to these magnetic positive variations, the activity of the HM chorus band was intensified and its

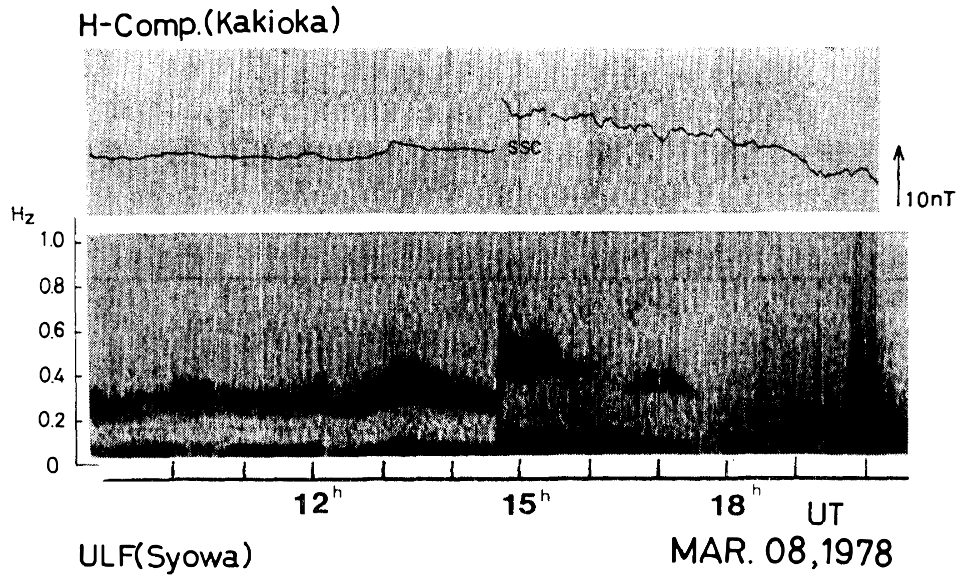


Fig. 13. Magnetic H-component variation recorded at low-latitude station, Kakioka (top) and f-t diagram of HM chorus emission at Syowa Station (bottom).

frequency increased.

The typical *f-t* diagram of HM emissions with burst-like spectral structure (HM emission burst) is shown together with the simultaneous *H*-component record at Kakioka in Fig. 14. In the *f-t* diagram, HM emission bursts occurred successively between 10h and 13h (UT), July 1, 1978. From a comparison between the HM emission bursts in the *f-t* diagram and the magnetic *H*-component variation at Kakioka, it is noted that the enhancement of each HM emission burst with a duration of about 5–10 minutes corresponds well to the positive variation of magnetic *H*-component with amplitude of about 2–3 nT. These magnetic variations also are considered to be the SI type ones, which are caused by compression of the magnetosphere.

From the studies of the SSC and SI effects on the ULF emissions on the basis of the data illustrated above, it may be concluded that most of ULF emissions, except the unstructured pc 1–2 band emissions, are considerably affected by SSC and SI events. The fact may indicate that most of ULF emissions are caused by the proton cyclotron instability originated from the anisotropic pitch angle distribution, as discussed by KENNEL and PETSCHEK (1966). KOKUBUN (1970) also illustrated that the magnetospheric compression at the time of SSC and SI tends to result in an enhancement of anisotropy in the pitch angle distribution of energetic protons through the betatron acceleration. Then, the enhanced anisotropy may increase the wave energy through the cyclotron instability process.

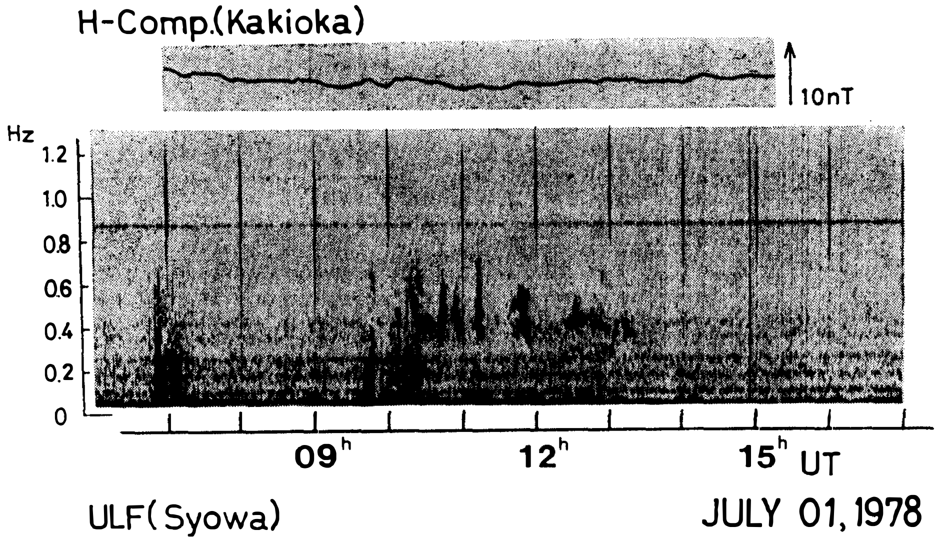


Fig. 14. Magnetic H-component variation recorded at low-latitude station, Kakioka (top) and f-t diagram of HM emission burst (bottom).

6. Summary

Diurnal characteristic of the dynamic spectra of various types of ULF emissions of frequency range from 0.1 Hz to 1.2 Hz, observed at Syowa Station, are sche-

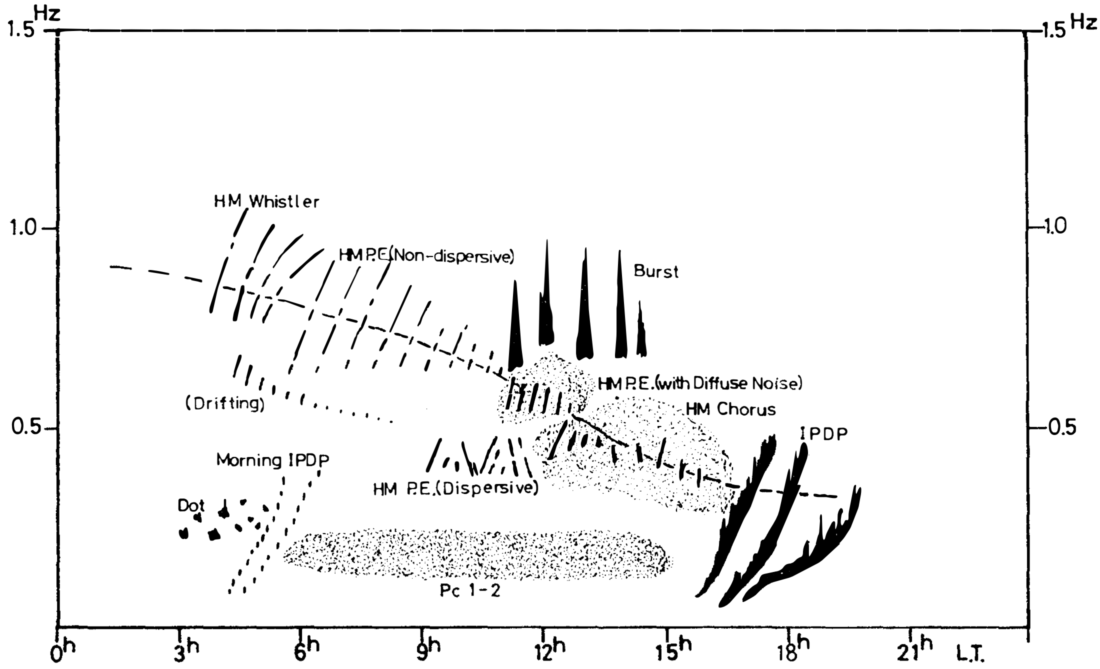


Fig. 15. Schematic average f-t diagram of ULF emissions with frequency above 0.1 Hz.

Table 1. Characteristics of ULF emissions (pc 1–2 and pi 1).

Type		Average frequency (Hz)	Diurnal variation in activity	Correlation with		
				Auroras	SC and SI events	Conjugate pair
HM-periodic emission	Whistler	0.5$\sim$1.0	Active around noon	Occasionally proton auroras	Occasionally good	Occasionally good
	Non-dispersive	0.5$\sim$1.0	Active in the morning hours			
	Dispersive	$\sim$0.5	Active at 9 h$\sim$12 h			
	Drifting	$\sim$0.5				
	With diffuse noise	$\sim$0.5	Active around noon			
HM chorus			In the evening hours, most active around 15 h	Occasionally electron auroras	Good	Good
HM emission burst		0.4$\sim$0.8	Active at 12 h$\sim$15 h		Good	Good
IPDP	Evening type	0.2$\sim$0.5	Most active around 18 h	Occasionally proton auroras	Occasionally good	Good
	Morning type	0.2$\sim$0.4	Active at 3 h$\sim$6 h			
Unstructured Pc 1-2 band		$\sim$0.2	In the daytime, most active at 9 h$\sim$12 h		None	Occasionally good
Irregular HM emission	Dispersive	$\sim$0.3			Good	Good
	Dotted	$\sim$0.3	Active at 3 h$\sim$5 h			

matically summarized in Fig. 15. This schematic diagram of daily variation of dynamic spectra of ULF emissions includes HM periodic emissions with five subtypes, HM chorus, HM emission with two subtypes, irregular HM emission, unstructured pc 1–2 band and IPDP emissions. One of obvious features characterizing this diagram will be the change in the types of the ULF emissions with local time. Along the dashed line indicated in the figure, the ULF emissions with fine spectral structure change their types with local time; namely (a) the HM whistler with the average frequency of 1.0 Hz, observed mainly in the early morning hours (3h–6h LT), (b) the HM periodic emission with non-dispersive elements (the average frequency ~0.8 Hz, observed mainly at 6h–12h LT), (c) the HM periodic emission with diffuse noise (~0.6 Hz around 12h LT), (d) the HM periodic emission with dispersive elements (~0.5 Hz around 9h–12h LT) and (e) the HM chorus which is the most dominant ULF emissions and observed in the daytime of 12h–18h LT with the average frequency of 0.4–0.3 Hz. It might be concluded, therefore, that the five types of ULF emissions mentioned above will be caused by a nearly the same physical mechanism which sharply depends on the condition of the local time sector of the magnetosphere.

The spectral structure of morning type IPDP is quite different from that of evening IPDP which has been reported by many research workers to data. Investigations of the characteristics of morning type IPDP in more detail will be needed in the future.

Finally in Table 1, the classification of ULF emissions proposed in the present paper and their diurnal characteristics are summarized based on the obtained results, together with their correlations with auroras, SSC and SI events, and their conjugacies (see ULF-VLF waves observed at Syowa Station—Iceland conjugate pair, in this volume).

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