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Magnetospheric Chorus Emissions Recorded at Low Latitude

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Abstract

Chorus emissions observed on ground based station and in the earth's magnetosphere in January 1999 at Jammu (geomag. Lat. 22^0 $26^/$ N) are presented. It is shown that these emissions are generated in the equatorial plane (L = 4) by cyclotron resonance between the propagating whistler wave and the gyrating electrons.

Keywords: *Chorus emissions; Cyclotron resonance; Growth rate; Gyrating electrons; Magnetosphere.*

1. INTRODUCTION

Chorus is distinguished from other type of low frequency whistler-mode emissions by the form of its frequency time spectrum which presents a close superposition or interaction of quasi-monochromatic (with a band with sometimes as small as 100 kHz) signals in the frequency range from hundreds of hertz to 5 kHz. Its frequency increases with time (Risers) in most cases. The discrete emissions are isolated quasi-monochromatic signals with similar forms of spectrum mostly observed on the earth's surface (Helliwell, 1965; Sazhin and Hayakawa, 1992).

Magnetic impulses (impulsive magnetic variations) with a duration of 2s coincide with the occurrence of groups of VLF risers with a similar duration in the local morning to noon sector, according ro park side station (L = 4.4) data, these impulses were interpreted as a result of ionospheric conductivity enhancement due to electron precipitation induced by whistler mode waves (Kokubun *et al.* 1981; Sazhin and Hayakawa, 1992). Burton and Holzer (1974) have noticed that chorus emissions are observed only when anisotropy ($A_e = T_t/T_{II}$) of energetic electrons was above unity, which is consistent with the hypothesis that these emissions are excited due to the whistler cyclotron instability. Correlation between chorus and energetic electron enhancement has also been observed (Anderson and Maeda, 1977; Maeda *et al.* 1976 a, b; Sazhin and Hayakawa, 1992). Observations in the inner-magnetosphere at L< 3 have led to the identification of new type of discrete whistler-mode emission occurring at middle to low latitude (Poulsen and Innan, 1988; Gurnett and Innan, 1988). During the course of analysis of the huge amount of whistler data collected at Jammu some excellent records of discrete chorus type emissions have found which are reproduced here together with their most probable generation mechanism.

It was pointed out that each strong X-ray burst was related to the corresponding riser and vice versa. Correlated pairs of X-ray bursts and risers appeared quasi-periodically with the dominant period of about 6s. The waves led the X-ray bursts by 0.3-0.4 s which was interpreted as showing that the waves generated in the equatorial magnetosphere due to whistler cyclotron instability propagated to the observer's hemisphere along the magnetic field lines, while the resonant electrons travelled first to the opposite hemisphere and then were reflected back to precipitate into the ionosphere of the observer's hemisphere (Sazhin and Hayakawa, 1992).

2. OBSERVATIONS

Fig. 1 illustrates the temporal variations of geomagnetic activity during this event. The times of having observed VLF emissions are also indicated by rectangles just above the abscissa of the panel. The occurrence of VLF emission appears to be well correlated with a substorm designated by a peak in K index at 6 hrs UT on 6 January 1999, and the delay of the VLF emission behind the substorm is about 9 hours. Taking into consideration the relationship of local time IST (Indian Standard Time) = U.T. + 5.5 hrs, every emission described below have taken place after midnight hour (the dawn sector). The spectrum analysis of the nighttime VLF/ELF emissions recorded on 6 January, 1999 at Jammu showed a number of discrete rising tone chorus emissions with frequency drift between 0100 hrs IST and 0300 hrs IST. Some selected examples of 2.54 sec sonogram of rising tone discrete chorus emissions out of a large number of events of 6 January are presented in fig. 2 and fig. 3 observed at Jammu. Fig. 2(a) shows three groups of discrete chorus riser emissions occurred at 0119 hrs IST.

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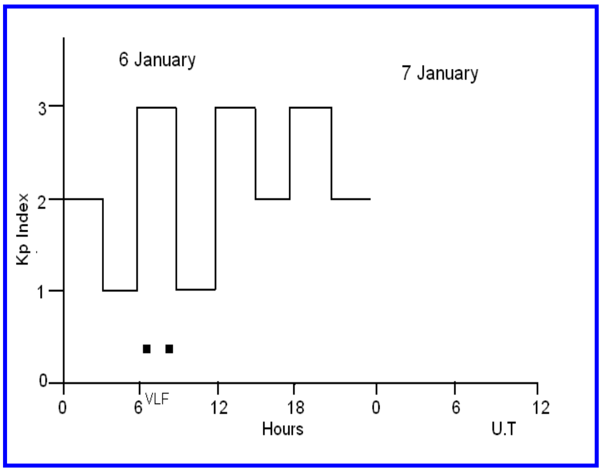

Fig. 1: Temporal evalution the geomagnetic activity K_p index for the event of 6th January 1999. The times when VLF emissions are observed are indicated by rectangles just above the abscissa of the panel.

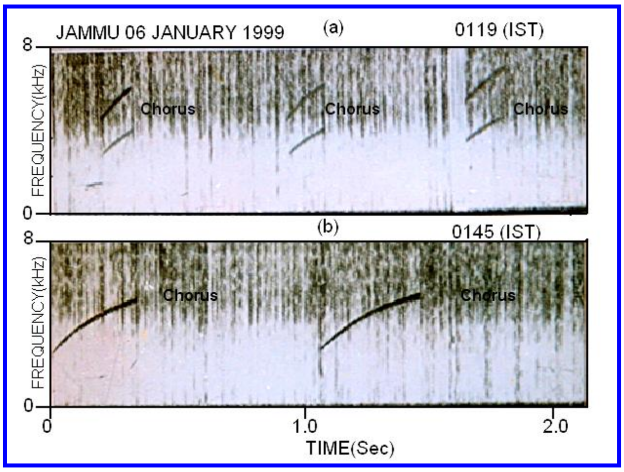

Fig. 2: Temporal variation of frequency spectra of discrete chorus emissions observed at Jammu (L = 1.17) on 6th January 1999 at (a) 0119 IST and (b) 0145 IST.

Each group consists of rising tone discrete emissions in two frequency bands. In the lower band of the first group, the lower and upper frequencies of the discrete riser emission lie in the frequency range 3.1–4.4 kHz, respectively. The corresponding frequencies for the upper band lie in the range 4.9–6.4 kHz, respectively. The lower band emission of the second group is found in the frequency range of 3.1–4.4 kHz, whereas the upper band emission is found in the frequency range of 4.7 to 6.5 kHz. In the third group, the lower and upper frequencies in the lower band lie in the frequency range 3.5 to 4.8 and the corresponding frequencies in the upper band lie in the frequency range 5.2 to 7.0 kHz. Fig. 2(b) refers to two spectrograms of rising tone discrete chorus emissions at 0145 hrs IST. The first riser emission lies in the frequency range 2.8-5.5 kHz, whereas the second riser emission lies in the frequency range 2.8–5.8 kHz. Fig. 3(a) contains only a single spectrogram of discrete chorus riser emission of long duration (~0.7 sec) observed at 0210 hrs IST in the frequency range 3.6 to 6 kHz. In Fig. 3(b) two groups of riser emissions in two frequency bands recorded at 0226 hrs IST are reported. The first riser emission of the single group lies in the frequency range 3.4 to 5.9 kHz whereas the second riser of this group lies in the frequency range 5.2 to 8 kHz. The other two riser emissions of second group have occurred in the frequency range 3.8 to 5.4 and 5.9 to 7.9 kHz, respectively. The rising tone discrete chorus emission events shown in Fig.s 2–3 were observed in winter local night times. The magnetic activity during the period of observation was magnetically disturbed (K = 18+). One hour after the commencement chorus activity as in Fig. 2(a), we noticed a clear shift of the centre frequency of the rising tone discrete chorus emissions towards higher frequency. The rate of frequency increase in this case is estimated to be ~2 kHz h^{-1}.

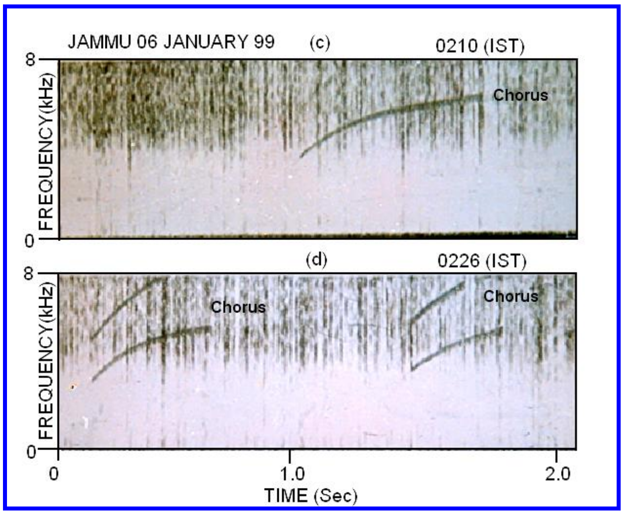

Fig. 3: Temporal variation of frequency spectra discrete chorus emissions observed at Jammu (L = 1.17) on 6th January 1999 at (a) 0210 IST and (b) 0226 IST.

3. DISCUSSION

The emissions reported here are different in frequency and rate of change of frequency with time from those of the riser whistlers observed earlier at low latitude ground station of Gulmarg (geomag. Lat. 24° 10/N) (Dikshit *et al.* 1971) and observed at Nainital by (Khosa *et al.* 1983). The receptions of VLF/ELF waves on the earth's surface clearly shows that the waves may have been propagated along the geomagnetic field lines either in ducted mode or in non ducted pro-longitudinal mode. The source may lie in the equatorial region of low latitudes or in the plasma pause auroral region. It is commonly believed so for from the study of VLF/ELF emissions observed at low latitudes that they originate in the equatorial magnetosphere of mid/high latitudes and may have propagational along higher L-values and after existing from the duct, they penetrated the ionosphere and are trapped in the earth-ionosphere wave guide. The wave normal at the entrance into the wave guide is such that they propagated towards the equator and are received at our low latitude ground station Jammu. The upper boundary frequency (UBF) method as developed by Smirnova (1984) has been generally used to find out the location of VLF/ELF emissions at low latitude ground stations. The upper boundary frequency (f_{UB}) of the ground observed VLF/ELF emissions are determined on the assumption of dipolar geomagnetic field configuration, by the half electron gyrofrequency in the generation region irrespective of the observation station. The L-value of the VLF/ELF sources is then computed with the help of the relation (Smirnova, 1984).

$$L=(440/f_{UB})^{1/3} \quad (1)$$

Thus our spectrum analysis clearly shows that the source of VLF/ELF emissions observed at Jammu is in the (L~ 4) plasmapause region.

The cyclotron resonance possible generation mechanism, the resonant energy of the high energy interacting electrons and the growth rate of the whistler waves at (L= 4) in the equatorial plane are calculated for various frequencies of the emissions from the expression (Tsurutani *et al.* 1975).

$$E_{\shortparallel}=(\gamma_n-1)m_o c^2 \quad (2)$$

Where m_o is the rest mass of electron, c is the velocity of light in vacuum and γ is the relativistic factor to be obtained from the relation

$$\gamma_n^2 -1 \equiv (\Omega^- /\omega_p)^2 (\Omega/\omega) (1 + (\Omega^+ /\omega)) \quad (3)$$

Here Ω^- is the electron gyro frequency, $\Omega^{-+}$is the proton gyro frequency, ω_p the plasma frequency and ω the wave frequency from ionospheric mode of which yields an electron density of 4.2×10^2 electrons cm^{-3} at (L= 4) (Singh *et al.* 2003; Altaf *et al.* 2013; 2014). The resonant energy for various frequencies of the emission were found to be in the range 15- 32 keV. Burton and Holzer (1974) have shown that the chorus is generated by cyclotron resonance with electrons in the approximate energy range 5-150 keV with pitch angle distribution peaked at 90° to B and anisotropy greater than a critical value.

The growth rates of these waves was calculated from the expression of Kennel and Petshek (1966) for the case $\omega <<\Omega$ reduces to

$$\gamma = \pi\, \Omega^- \eta\, A \quad (4)$$

where η is the ratio of the density of energetic electrons to that of thermal electrons and A is the pitch angle anisotropy. The pitch angle anisotropy A was calculated from the relation (Kennel and Petschek, 1966).

$$A=½ \log_e (1/\alpha_o) \quad (5)$$

Here α_o being the equatorial loss cone angle, mirror height = 1000 Km and was found to be 2.08. If we assume a pitch angle distribution of the form $\sin^m \varphi$ (m = 4, and φ is pitch angle) and compare the calculated pitch angle verses intensity curve with that of Katz (1966), the two distributions are found to be nearly same. The density of energetic electrons at L= 4 were taken from the observed intensity versus L-value curve (energy > 1 MeV) given by Katz (1966) for the inner zone radiation belt. The curve indicated a flux of 3×10^6 $el.cm^{-2}$ sr^{-1} at L = 4 which yields a density of 3-5 MeV electrons as roughly 2.26×10^{-3} el. cm^{-3}.

By substituting the values of Ω^- ,η and A in equation (4) the growth rates for various frequencies of the emission were calculated and found to be about 3 rad. s^{-1} indicating significant wave amplification.

4. CONCLUSION

The characteristics of VLF chorus emissions recorded at Jammu are reported. Analysis of the observed dynamic spectra of chorus emissions shows that each chorus element originated from the underlying hiss band. These chorus emissions may have been generated near the equatorial region of L-value corresponding to the recording station and have propagated in whistler-mode to be received at the Jammu Station. A generation mechanism for various temporal and spectral features of recorded VLF chorus emissions is presented on the basis of the cyclotron resonance. It is observed that the growth rates for various frequencies of the emission were calculated and found to be about 3 rad. s^{-1} indicating significant wave amplification. The frequency sweep rate of chorus element calculated from the theory is consistent with observations. Thus, our result conformed that the above theory of chorus generation is consistent with the analysis of chorus emissions recorded at Jammu Further experimental and theoretical studies of VLF chorus emissions using some more long data sets are required for a complete understanding of this phenomenon.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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