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Discrete Chorus Emissions Recorded at Nainital

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Abstract. Discrete Chorus type emissions recorded in May/June 1970 at our ground based observation station at Nainital (geomagnetic lat. 19°1′N) are presented. It is shown that these emissions are generated in the equatorial plane ($L \sim 1.2$) by cyclotron resonance between the propagating whistler wave and the gyrating electrons.

Key words: Whistlers – VLF emissions – Discrete chorus emissions – Absorption band – ELF hiss – Cyclotron resonance – Electron density – Gyrating electrons – Growth rate.

Introduction

The study of whistlers and VLF (Very Low Frequency) emissions at low latitudes dates back to the pioneering work of Japanese scientists. The low latitude whistlers were first recorded at Toyakawa (geomagnetic lat. 24° 5′N) (Iwai and Outsu, 1956), and later on, efforts were made to record them at still lower latitudes (Ondoh and Tanaka, 1973; Kotaki et al., 1977). The first successful records of whistlers in India were obtained at Gulmarg (geomagnetic lat. 24° 10′N) by Somayajulu et al. (1965). Recording was later carried out at Nainital (geomagnetic lat. 19° 1′N) and whistlers with comparatively lower dispersion and reduced rate of occurrence were reported (Lalmani, 1974). Singh et al. (1977) carried out successful recording of low dispersion whistlers at their low latitude ground-based station at Varanasi (geomagnetic lat. 14° 55′N) which previously was believed to lie in what was then supposed to be some sort of a low latitude cut-off for whistler waves (Rao et al., 1974). Very low frequency emissions of this type have frequently been observed at the Japanese low latitude ground stations (Nishino and Tanaka, 1960; Ondoh, 1963; Iwai and Tanaka, 1968; Tanaka et al., 1970; Tanaka, 1972). An excellent review of low latitude VLF emissions has been given by Kimura (1967). No successful attempts were made to record the VLF emissions in India. During the course of our analysis of the huge amount of whistler data collected in May/June 1970 at Nainital we have found some excellent records of discrete chorus type emissions which we reproduce here together with their most probable generation mechanism.

Observations

On 13 May and 8 June 1970, we observed about thirty discrete rising emissions between 2200 and 0315 hours IST local time. Some of the emissions are shown in Fig. 1. The emissions recorded on May 13, 1970 occurred in the frequency range 2.5–4.5 kHz and 4.5–7 kHz, while emissions on 8 June 1970 occurred in the frequency range 3.5–5.5 kHz. Figure 1 (a) shows a single trace rising emission in the frequency range 2.5–4.5 kHz. Figure 1 (b) shows two rising emissions occurring at the same time in two different frequency ranges 2.5–4.5 kHz and 4.5–7 kHz. Figure 1 (c) shows a single trace rising emission of long duration in the frequency range 3.5–5 kHz. Figure 1 (d) shows two rising emissions with almost similar features as shown in Fig. 1 (b). Figure 1 (e–g) depicts rising emission of long duration in the frequency range 3.5–5.5 kHz recorded on 8 June 1970.

Discussions

Observed emissions differ markedly in frequency and rate of change of frequency with time from those of the riser whistlers observed earlier at the low latitude ground station of Gulmarg (geomagnetic lat. 24° 10′N; Dikshit et al., 1971). Further, because of the presence of a strong absorption band around 2 kHz these emissions could not have been high latitude discrete type chorus emissions propagating to our low latitude station in the Earth-ionosphere wave guide. The possibility that these emissions are generated at high L-values in the vicinity of the plasmapause and have propagated to our ground station after successive magnetospheric reflections in a manner similar to those of the ELF (Extremely Low Frequency) hiss observed by satellites in the inner zone (Muzzio and Angerami, 1972; Tsurutani et al., 1975) does not seem to be tenable. This is because of the fact that heavy attenuation would make the amplitude of these signals extremely small and so they could not have been detected. At the base of the F-region ionosphere, the wave normal angles of these waves are such that the downward waves are unlikely to penetrate the lower ionosphere and reach the ground. Wave normals of chorus in the outer magnetosphere have been determined for the first time from data obtained with OGO5 search coil magnetometre by Burton and Holzer (1974).

It is, therefore, believed that these emissions are generated in the equatorial plane in the inner zone radiation belt ($L \sim 1.2$) by the cyclotron resonance between whistler mode waves and the inner zone radiation belt electrons (Rycroft, 1972; Imhof et al., 1973). All such emissions generated at higher L-values will reach the ground stations corresponding to higher latitudes than that of Nainital and

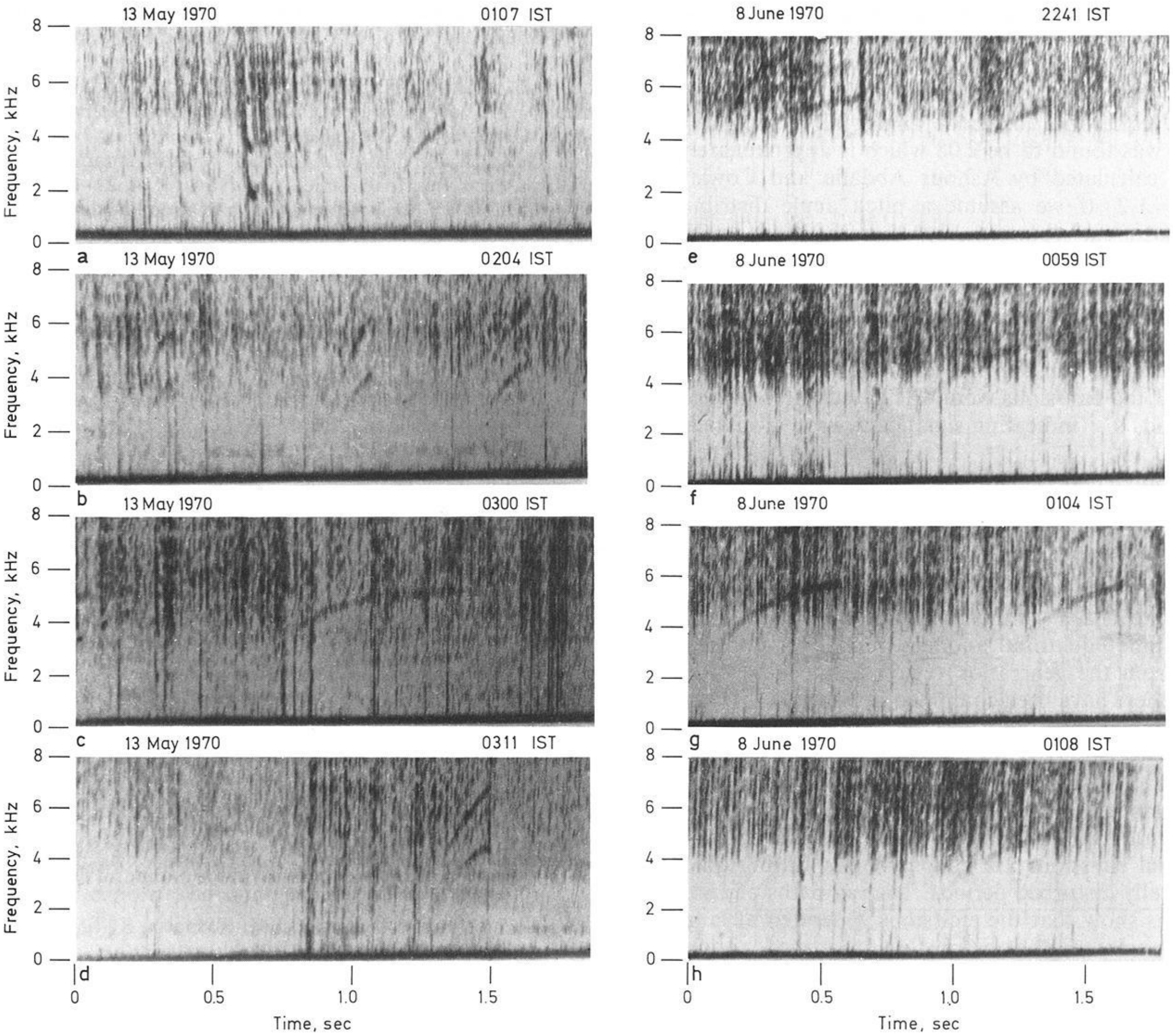

Fig. 1. Sonograms of discrete chorus emissions observed at Nainital

the chances for the generation of these emissions for values of $L<1.2$ are small because of the non-availability of such high energy electrons in large numbers. In order to test cyclotron resonance as a possible generation mechanism for these emissions, we have calculated the resonant energy of the high energy interacting electrons and growth rate of the whistler waves at $L=1.2$ in the equational plane. The resonant energies for various frequencies of the emissions were calculated from the expression (Tsurutani et al., 1975)

$$E_{11}=(\gamma_n-1)\,m_o C^2 \tag{1}$$

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

$$\gamma_n{}^2-1\cong\left(\frac{\Omega^-}{\omega_p}\right)^2\left(\frac{\Omega}{\omega}\right)\left(1+\frac{\Omega^+}{\omega}\right). \tag{2}$$

In Eq. (2) Ω^- is the electron gyrofrequency, Ω^+ the proton gyrofrequency, ω_p the plasma frequency and ω the wave frequency. The plasma frequency ω_p was calculated from the ionospheric model of Singh (1976) which yielded an electron density of 8.13×10^3 electrons cm^{-3} at $L=1.2$. The resonant energies for various frequencies of the emissions were found to be in the range 3–5 MeV. Recently 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. Further, it has also been shown by Lalmani et al. (1970) that the resonant energies for various frequencies of the emission at $L=1.2$ are in the MeV range.

The growth rates of these waves was calculated from the expression (2.20) of Kennel and Petschek (1966), which for the case of $\omega\ll\Omega^-$ reduces to

$$\gamma=\pi\Omega^-\eta A \tag{3}$$

where η is the ratio of the density of energetic electrons to that of thermal electrons and A, the pitch angle anisotropy. The density of energetic electrons at $L=1.2$ were taken from the observed intensity versus L-value curves (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 $L=1.2$ which yielded a density of 3–5 MeV electrons as roughly 1.26×10^{-3} el cm^{-3}. The pitch angle anisotropy

A was calculated from the relation (Kennel and Petschek, 1966)

$$A = \tfrac{1}{2}/\log_e (1/\alpha_o)$$

(α_o being the equatorial loss cone angle, mirror height = 100 km) and was found to be 2.08 which is approximately the same as calculated by Ashour Abdalla and Cowley (1974) at $L = 1.2$. If we assume a pitch angle distribution of the form $\sin^m \Phi$ ($m = 4$, and Φ is the pitch angle) and compare the calculated pitch angle versus intensity curve with that of Katz (1966), the two distributions are found to be nearly the same. Thus the value of anisotropy $A = 2.08$ at $L = 1.2$ is justified. By substituting the values of Ω^-, η and A in Equ. (3), the growth rates for various frequencies of the emissions were calculated and found to be about 3 rads s^{-1} indicating significant wave amplification.

Recently Singh (1981) has studied the propagation characteristics; of low latitude VLF emissions with the help of ray tracing computation in the presence of negative horizontal density gradients of the equatorial anomaly. Assuming that the low latitude emissions are generated in the equatorial plane at $L = 1.2$, the ray paths of these emissions in the quiet time equatorial anomaly model for different frequencies from the generation region to the base of F-region ionosphere have been computed by Singh (1981) and it has been shown that the waves lie in the transmission cone and can be observed on the ground. Further, Singh (1981) calculated the ray paths of these waves in the equatorial anomaly model which corresponds to disturbed periods and has shown that the propagation characteristics of daytime equatorial emissions are almost similar during quiet and magnetically disturbed periods. The ray paths of night time emissions show that the emissions generated at large wave normal angles may be observed on the ground without any influence of density gradients of the anomaly (Singh 1981). During disturbed periods the night time anomaly extends to a wide latitude range around the equator. This produces negative horizontal density gradients in the ionization at low latitudes (Singh, 1976; Singh et al., 1978). Singh et al. (1978) have shown that the final wave normals of the night time VLF emissions are tilted almost along the downward vertical direction as a result of such horizontal density gradients.

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