

Compilation of Information on Chorus, Electron Microbursts, and Their Interaction

Chorus

The below information is very general and relates to chorus with various origins including from lightning. More detailed information on chorus that may be related to microbursts will be in the following section.

Whistler Mode Chorus are bursts of very-low-frequency (VLF) electromagnetic energy produced through various means. These chorus bursts propagate within plasma in the radiation belts which follow earth's magnetic field lines. They can follow these field lines to a distance many radii beyond the earth's surface (Helliwell 1965).

Whistlers are a specific type of chorus in which the signal sounds like a whistle when converted into audible radio frequencies. Typically they begin at high frequency and rapidly (~1 sec) drop in frequency to roughly 1000 cycles/sec (cps). Typically the frequency of whistlers ranges from 5,000 cps to 1,000 cps but can in extreme cases range from 35,000 cps to 300 cps. Whistlers often appear in groups causing the appearance of an echo or "train". Whistlers may be exclusively right-hand polarized (fact check needed).

Chorus generation spontaneously occurs through gyro-resonance interaction in which a triggering plasma wave from the noise background is amplified by energetic radiation electrons with an anisotropic temperature distribution (where temperature is related to velocity through average kinetic energy). For a wave to grow in resonance it requires a net decrease of energy (of the particle) as particles diffuse down phase space density gradient.

For whistlers the frequency of the wave (f_w) must be less than the cyclotron frequency (f_{ce})

$$f_w < f_{ce}$$

Electrons (with average frequency at resonance) and waves must travel towards each other so as to increase the Doppler-shifted wave frequency up to the gyro-frequency (f_{ce}).

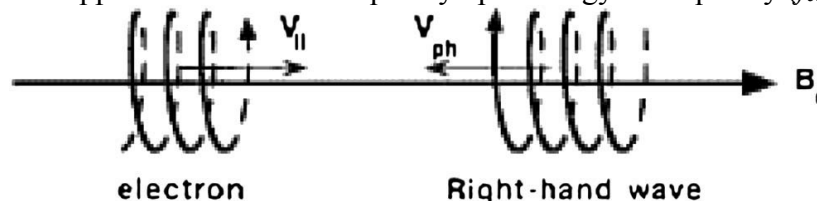


Figure 1: A schematic of a "normal" Doppler-shifted cyclotron resonance between an electron and a right-hand polarized electromagnetic wave. Taken from Tsurutani and Lakhina [1997], their Figure 8.

As electrons move from high to low pitch angle $\alpha = \tan^{-1}\left(\frac{V_{\parallel}B}{V_{\perp}B}\right)$ (the angle of travel with relation to magnetic field line) they lose energy in the plasma frame of reference. These electrons can generate whistler mode waves if there is a loss cone in the distribution. This may be the source of the temperature anisotropy necessary for chorus generation to occur (Brice 1964).

Conditions of particles that are in a loss cone: $\frac{V_{\parallel}B}{V_{\perp}B} < \sqrt{\frac{B_{Max}}{B_{Min}} - 1}$

Perpendicular temperature must be greater than parallel temperature.

-(Kivellson & Russel: Space Physics & Bell et al 2009)

Source Regions of Banded Chorus

“Extremely low and very low frequency (ELF and VLF respectively) chorus emissions are intense electromagnetic plasma waves that are naturally and spontaneously excited near the equatorial plane outside the plasmasphere during periods of magnetic disturbance.” (Bell et al 2009)

Chorus appears in two distinct frequency bands, one below $f_{ce}/2$ and one above $f_{ce}/2$ where f_{ce} is the local electron cyclotron frequency. Source region of chorus found by Cluster 1 spacecraft with Wideband (WBD) instrument when the craft was located $\sim 3^\circ$ from equator. $f_{ce} = \sim 6.8\text{kHz}$ at this time.

Lower-band chorus extends from $\sim 1\text{-}3\text{kHz}$ and upper-band chorus extends from $\sim 3.3\text{-}4.5\text{kHz}$. The region between upper and lower band chorus cannot be in resonance because the plasma wave intensity is $\sim 40\text{ dB}$ below that of chorus.

During periods of magnetic disturbance banded chorus have been detected from $4 \leq L \leq 9$ and are most common in the midnight-noon local time sector.

The condition for chorus emissions (anisotropic velocity distribution of electrons amplifying plasma waves in the background) is given by the relationship $v_z \approx \frac{\omega_{ce}}{\gamma - \omega} \cdot k_z$

Where:

v_z = velocity of energetic electrons along the direction of earth's magnetic field

ω_{ce} = electron gyrofrequency

γ = wave frequency

k_z = component of the wave vector K along the magnetic field line

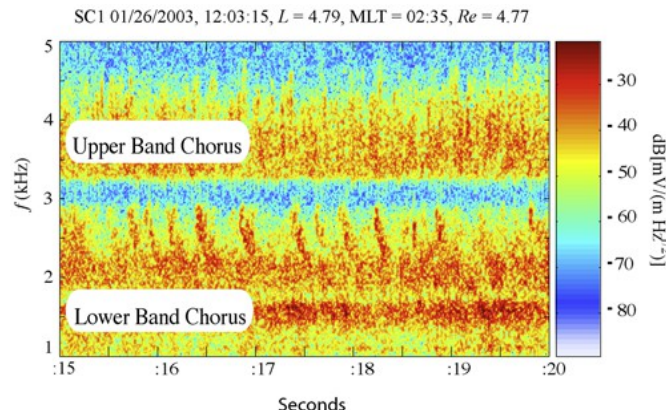


Figure 1. Frequency-time spectrogram showing an example of banded-chorus as observed on the CLUSTER 1 spacecraft on 01/26/2003. (Bell et al 2009)

The following are suspected conditions for the two distinct bands of chorus. There is not enough data to verify if these conditions are always true or only for the case shown above.

For frequencies $0 \leq f < \frac{f_{ce}}{2}$ whistlers can only be trapped in ducts of enhanced cold plasma.

For frequencies $\frac{f_{ce}}{2} < f \leq f_{ce}$ whistlers can only be trapped in ducts of depleted cold plasma.

The ducting theory outlined above explains why whistlers do not occur at $f_{ce}/2$ because the condition for whistler enhancement must be either above or below this value.

The above model needs further work to determine if it is accurate. One possible issue is that plasma density does not vary smoothly over L-shell so enhancement and depletion ducts can occur quite randomly. This is depicted below:

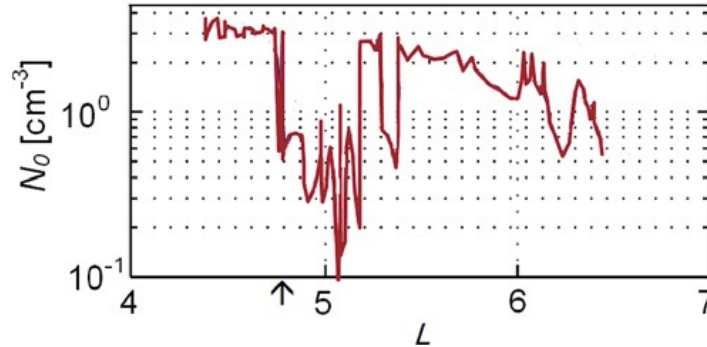


Figure 3. A plot of cold plasma density as a function of L shell in the magnetic equatorial plane.

Bell et al (2009) believe this ducting model to be advantageous because it allows for the explanation of whistler trains. The regions of enhanced and depleted cold plasma are typically small ($< 1,000$ km) which they believe leads to the following phenomena.

When a chorus emission forms in a plasma duct and travels along the field line a portion of the wave is reflected back into the duct at the edge (i.e. where the plasma density changes and the main wave is leaving the source region). This reflected portion of the wave travels back through the source region and can amplify again into another chorus wave which can reflect at the edge of the duct as well. In this way a single initial wave can lead to several chorus emissions before the reflected wave is too weak to be amplified into another distinct chorus emission.

Microbursts

Microbursts are bursty energetic particle precipitation down onto the ionosphere. Commonly observed as a sign of rapid radiation belt electron scattering. Low energy microbursts are tied to whistler mode chorus.

Note: The connection between low energy microbursts and chorus is well established. The connection between chorus and microbursts with energy $> 1\text{MeV}$ is what is not yet established firmly.

Using Polar and SAMPEX Lorentzen et al (2001) found that coherent oblique whistler mode chorus elements may provide the scattering mechanism that drives precipitation.

Microbursts could be main source of $>1\text{ MeV}$ electron loss from the radiation belts. Single event typically lasts $<1\text{ sec}$ and is observed towards the outer edges of radiation belt (L4-L6).

Microburst events have been detected at all local times but occur predominantly in the morning sector. (Morning sector bursts are associated with VLF Chorus).

Electrons are scattered into a loss cone by some event (proposed source is chorus) which causes them to precipitate down onto the atmosphere.