Remarks on the whistler type waves registered in space

Jan Błęcki,
Space Research Centre PAS Warsaw

Milestone Meeting Swarm4anomaly,
21.10.2019, ESRIN Frascati

Atmospheric whistlers

„The whistler mode is a cold plasma wave mode with an upper cutoff frequency at the plasma frequency (f_{pe}) or cyclotron frequency (f_{ce}), whichever is lower.
Waves propagating in whistler mode (W-mode) are found in all regions of the Earth's magnetosphere. They are also found in the magnetospheres of other planets. These waves may originate in sources residing outside the magnetosphere, such as lighting or VLF transmitters, or they may originate within the magnetosphere as a result of resonant wave-particle interactions.
W-mode waves have been detected on every spacecraft carrying a plasma wave receiver and at numerous ground stations."

V.S. Sonwalkar

Atmospheric whistlers

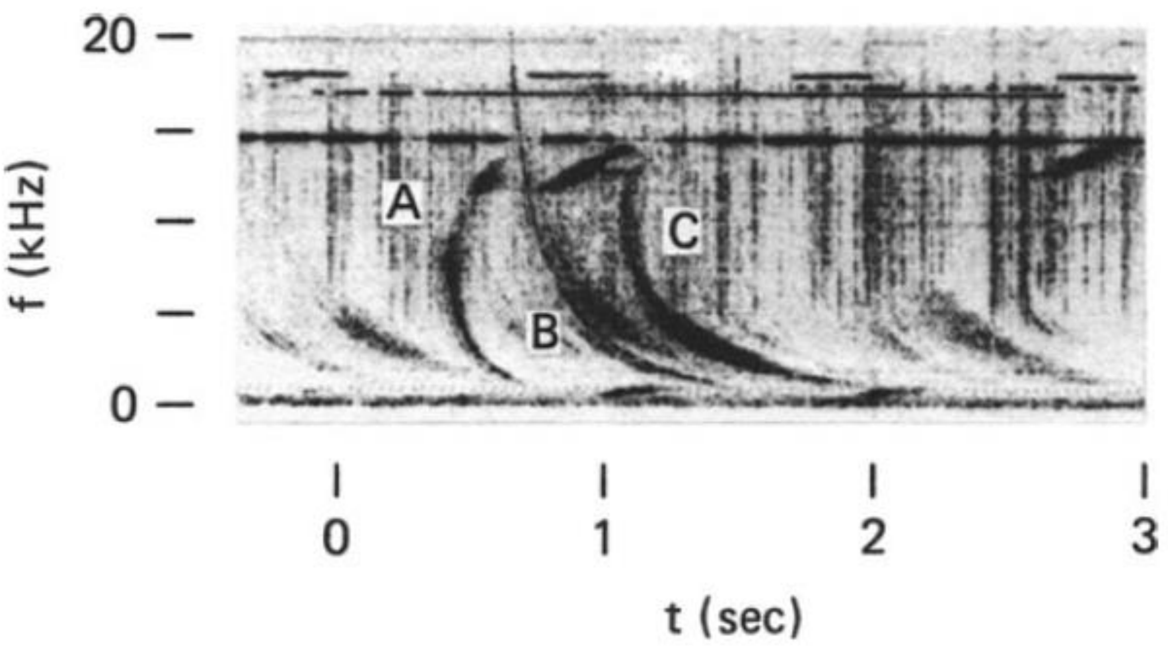
Ionospheric whistlers were discovered during World War I while German radio monitors were trying to intercept Allied radio transmissions [Barkhausen 1919]. Without narrow band tuners, the whistlers occurred as declining tones in the audio band. They were later traced to lightning and propagation in the ionosphere and the magnetosphere [Barkhause 1930].

It occurs in frequency range:

$$\omega_{ci} \ll \omega \ll \omega_{ce} \sim \omega_{pe},$$

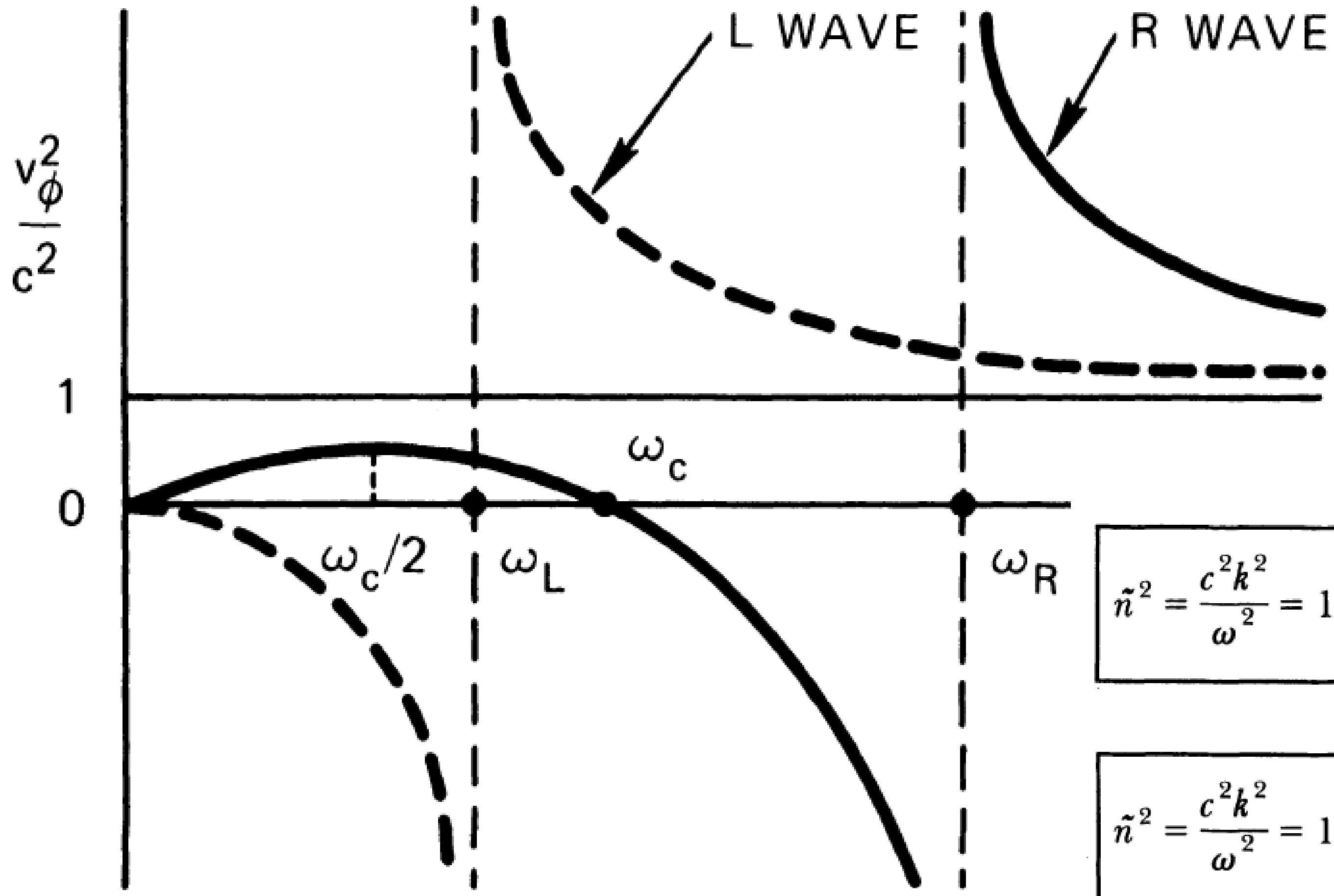
so we are above the lower hybrid resonance but well below the electron cyclotron resonance.

Atmospheric whistlers



Actual spectrograms of whistler signals, showing the curvature caused by the low-frequency branch of the *R*-wave dispersion relation (Fig. 4-39). At each time *t*, the receiver rapidly scans the frequency range between 0 and 20 kHz, tracing a vertical line. The recorder makes a spot whose darkness is proportional to the intensity of the signal at each frequency. The downward motion of the dark spot with time then indicates a descending glide tone. [Courtesy of D. L. Carpenter, *J. Geophys. Res.* **71**, 693 (1966).]

Atmospheric whistlers



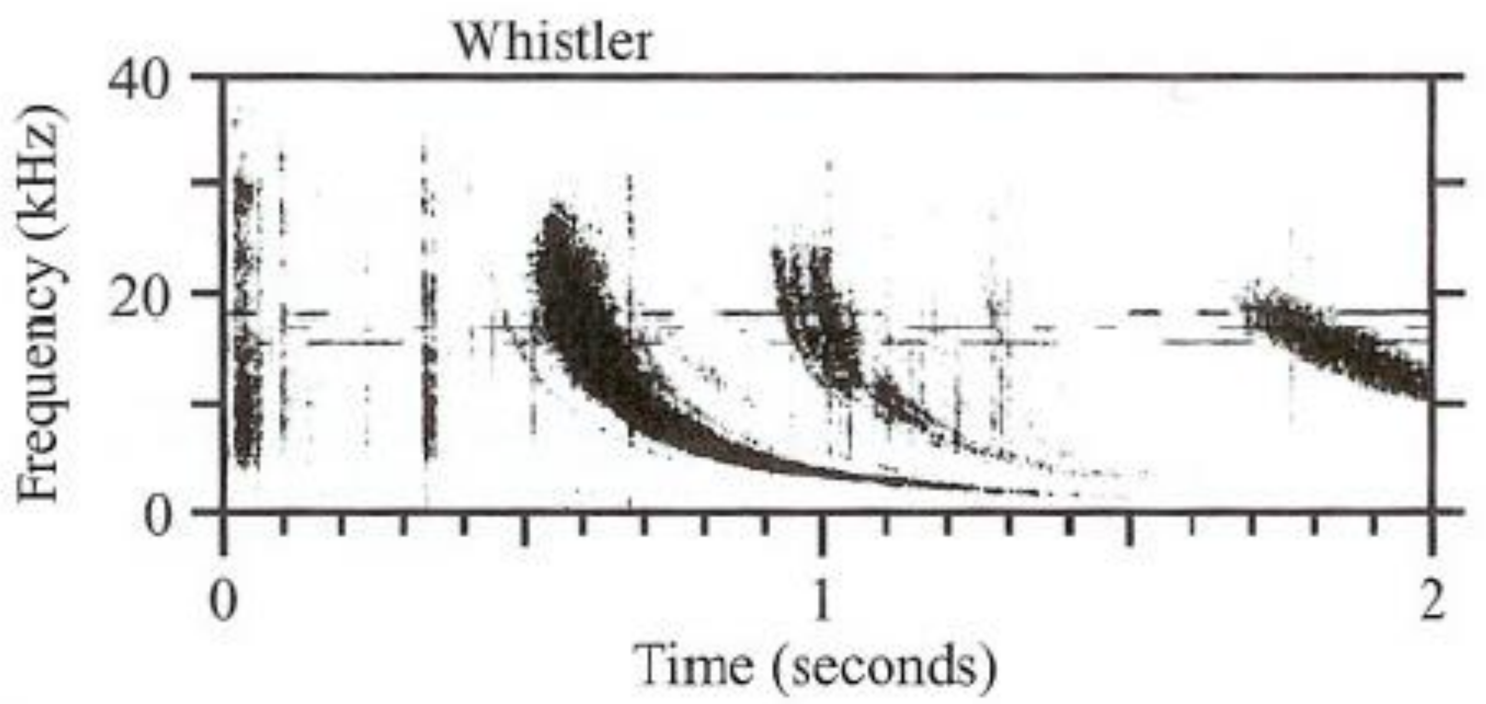
$$\tilde{n}^2 = \frac{c^2k^2}{\omega^2} = 1 - \frac{\omega_p^2/\omega^2}{1-(\omega_c/\omega)}$$ (R wave

$$\tilde{n}^2 = \frac{c^2k^2}{\omega^2} = 1 - \frac{\omega_p^2/\omega^2}{1+(\omega_c/\omega)}$$ (L wave

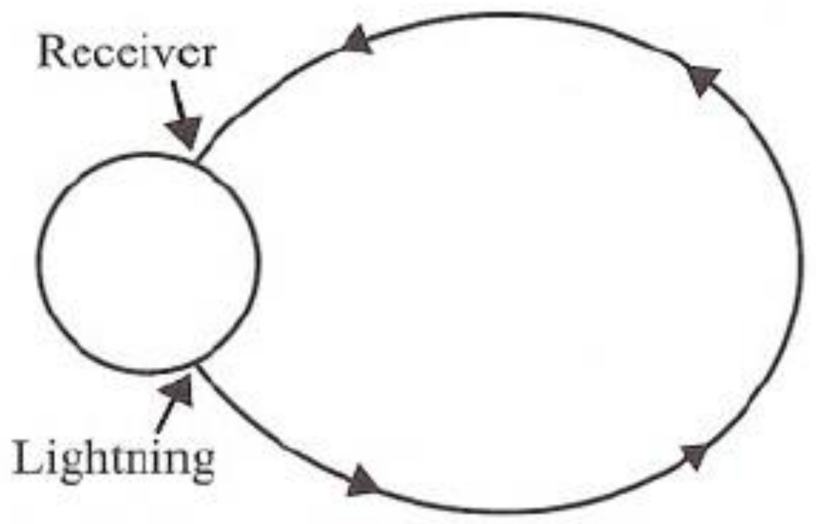
The v_ϕ^2/c^2 vs. ω diagrams for the L and R waves. The regions of nonpropagation ($v_\phi^2/c^2 < 0$) have not been shaded, since they are different for the two waves.

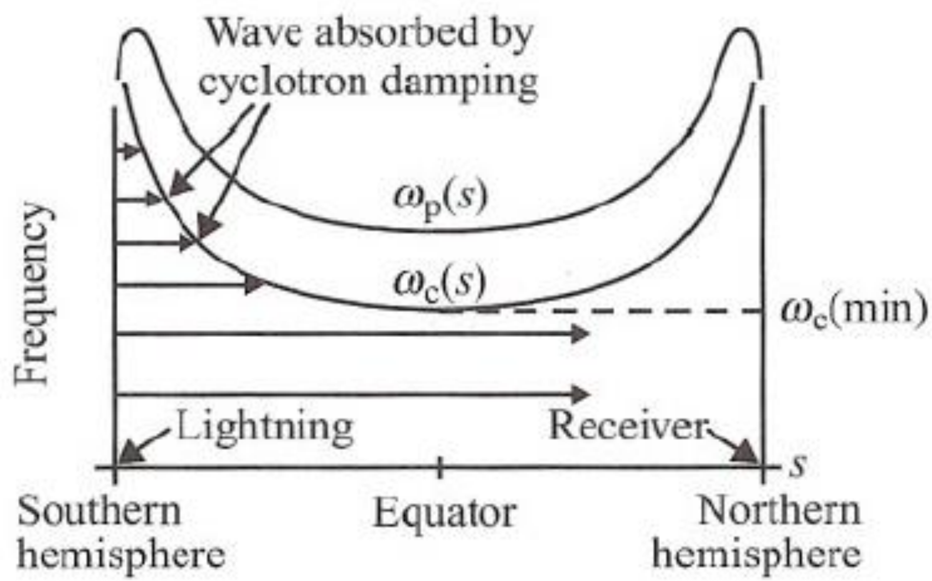
Francis F. Chen

Atmospheric whistlers



$$n^2 = \frac{\omega_p^2}{\omega(\omega_c - \omega)}$$





$$v_g = 2c \frac{\omega^{1/2}(\omega_c - \omega)^{3/2}}{\omega_c \omega_p}$$

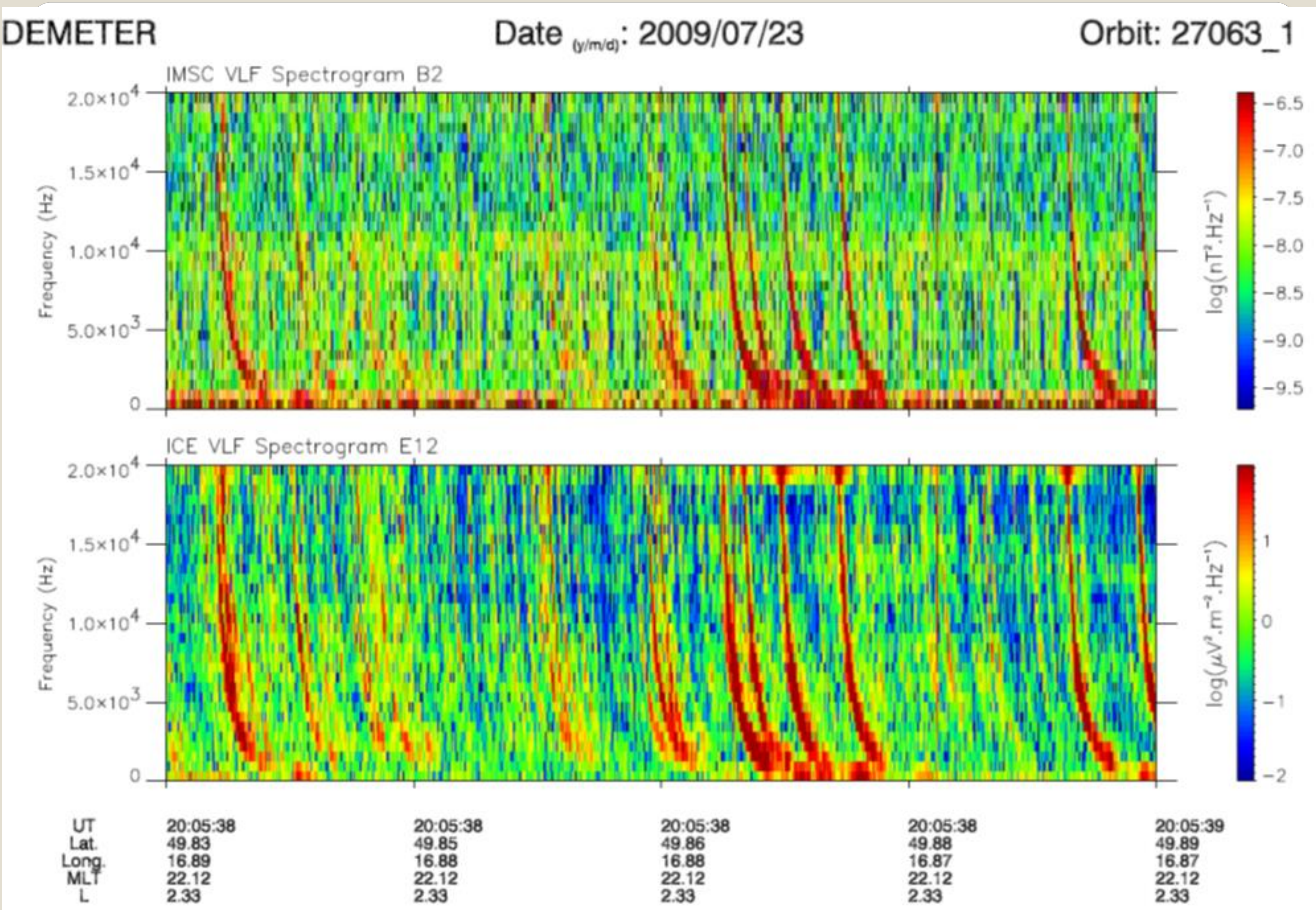
$$t(\omega) = \frac{1}{2c\omega^{1/2}} \int \frac{\omega_p \omega_c}{(\omega_c - \omega)^{3/2}} \, ds$$

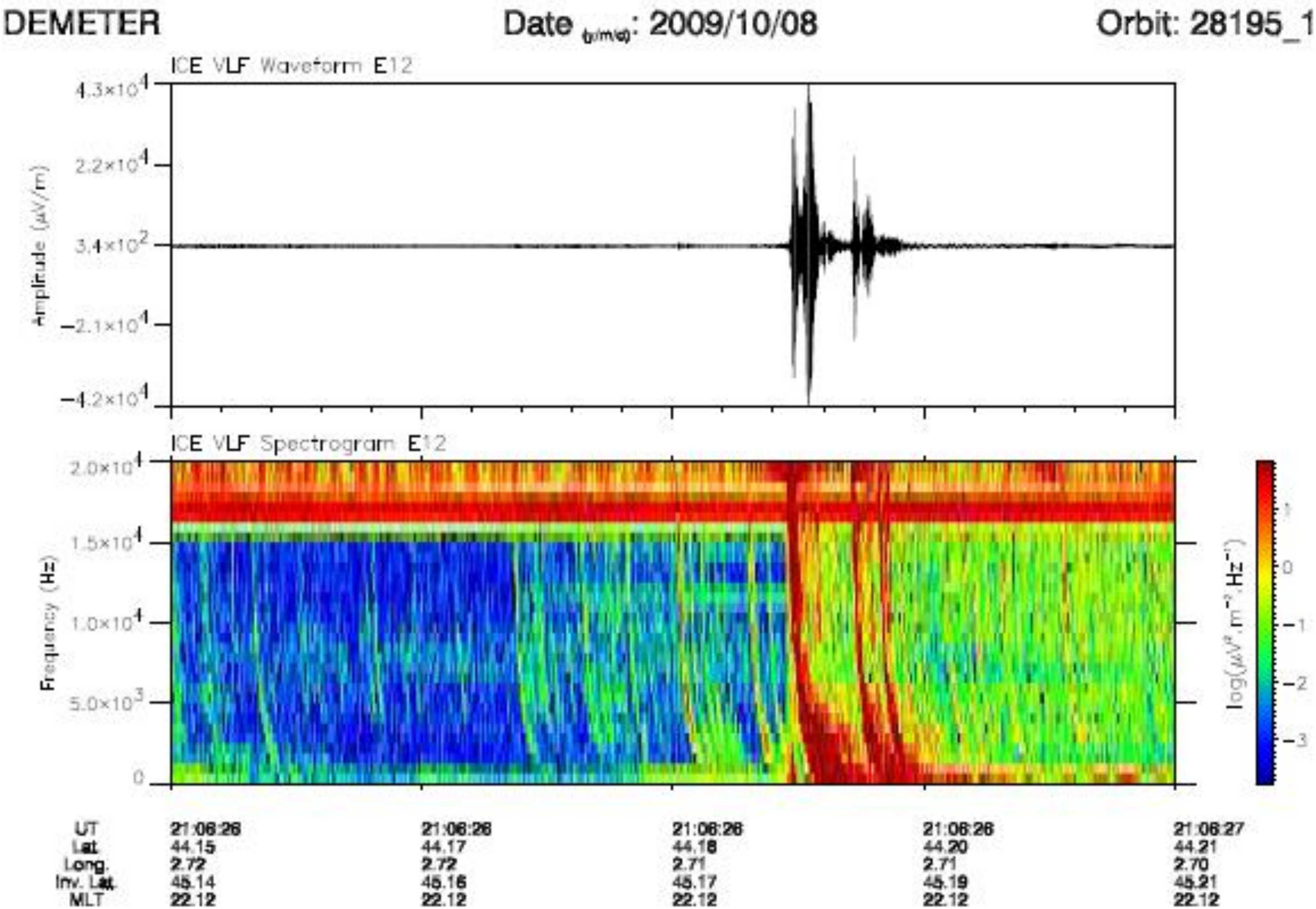
$\omega \ll \omega_c$

$$t(f) = D_W / f^{1/2}$$

$$D_W = \frac{1}{2c} \int \frac{f_p}{f_c^{1/2}} \, ds$$

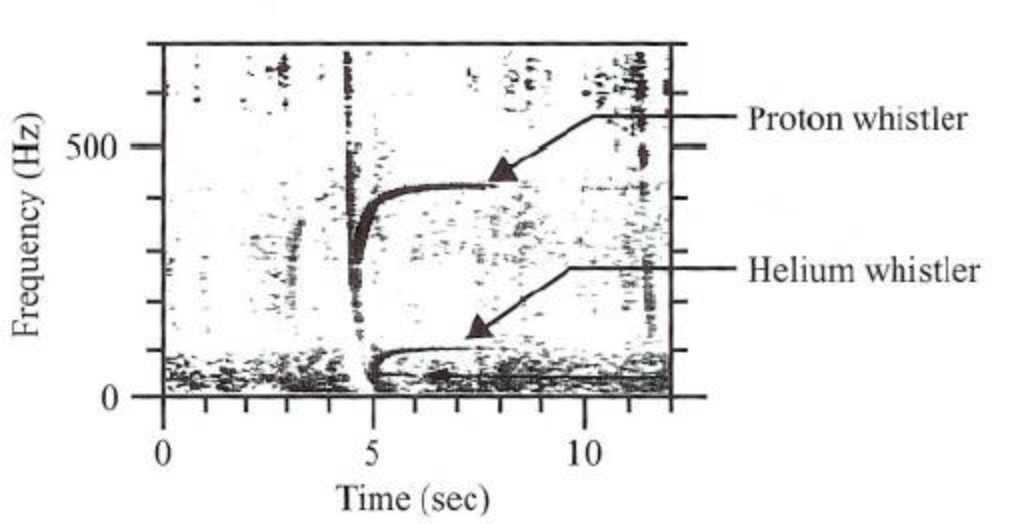
$$(n_e/B)^{1/2}$$

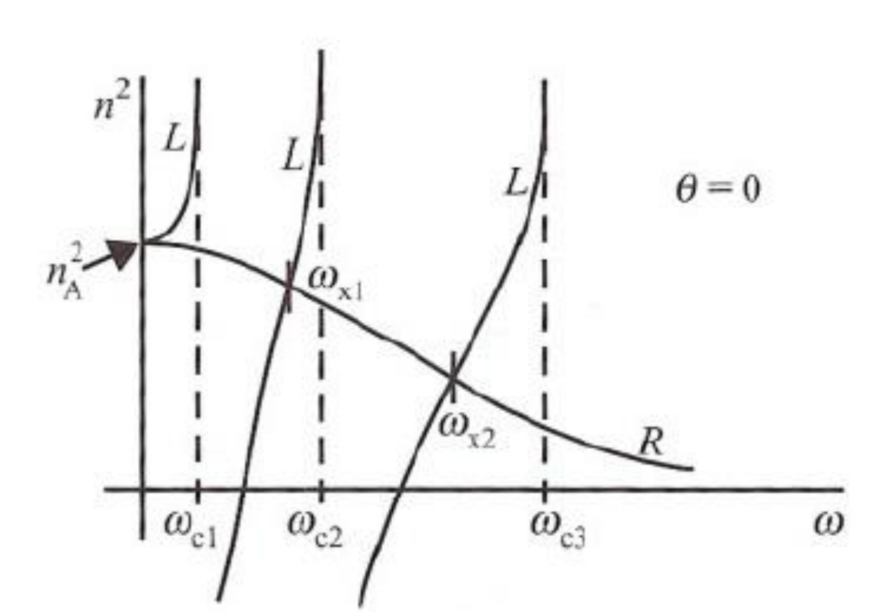

DEMETER
Date (y/m/d): 2009/07/23
Orbit: 27063_1
IMSC VLF Spectrogram B2
ICE VLF Spectrogram E12
Frequency (Hz)
2.0×10^4
1.5×10^4
1.0×10^4
5.0×10^3
0
log(nT².Hz⁻¹)
-6.5
-7.0
-7.5
-8.0
-8.5
-9.0
-9.5
log(μV².m⁻².Hz⁻¹)
1
0
-1
-2
UT 20:05:38 20:05:38 20:05:38 20:05:38 20:05:39
Lat. 49.83 49.85 49.86 49.88 49.89
Long. 16.89 16.88 16.88 16.87 16.87
MLT 22.12 22.12 22.12 22.12 22.12
L 2.33 2.33 2.33 2.33 2.33



DEMETER
Date (y/m/d): 2009/10/08
Orbit: 28195_1
ICE VLF Waveform E12
Amplitude (μV/m)
4.3×10^4
2.2×10^4
3.4×10^2
−2.1×10^4
−4.2×10^4
ICE VLF Spectrogram E12
Frequency (Hz)
2.0×10^4
1.5×10^4
1.0×10^4
5.0×10^3
0
log(μV².m⁻².Hz⁻¹)
1
0
−1
−2
−3
UT 21:06:26 21:06:26 21:06:26 21:06:26 21:06:27
Lat. 44.15 44.17 44.18 44.20 44.21
Long. 2.72 2.72 2.71 2.71 2.70
Inv. Lat. 45.14 45.16 45.17 45.19 45.21
MLT 22.12 22.12 22.12 22.12 22.12

Ion –cyclotron whistlers

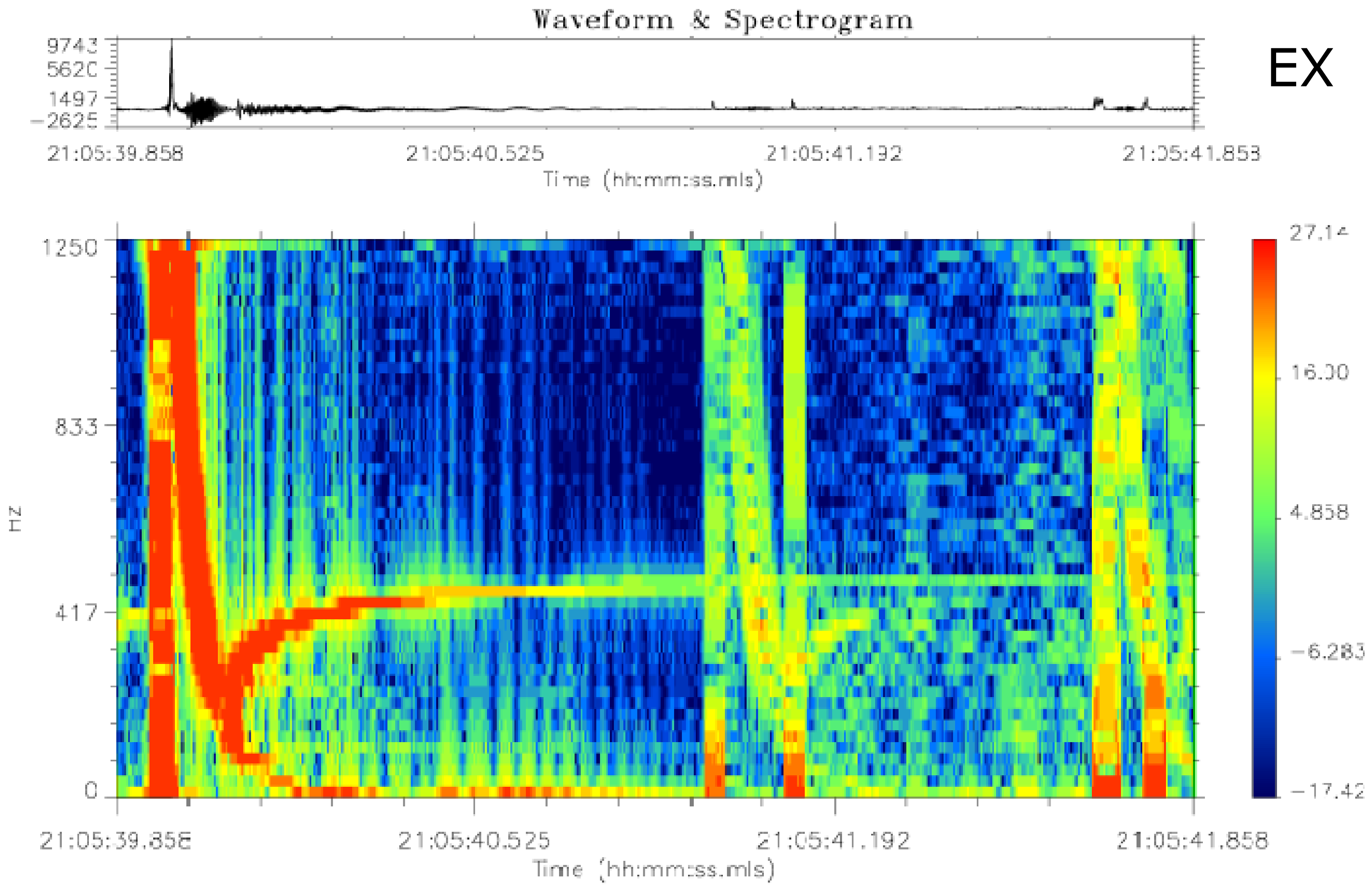


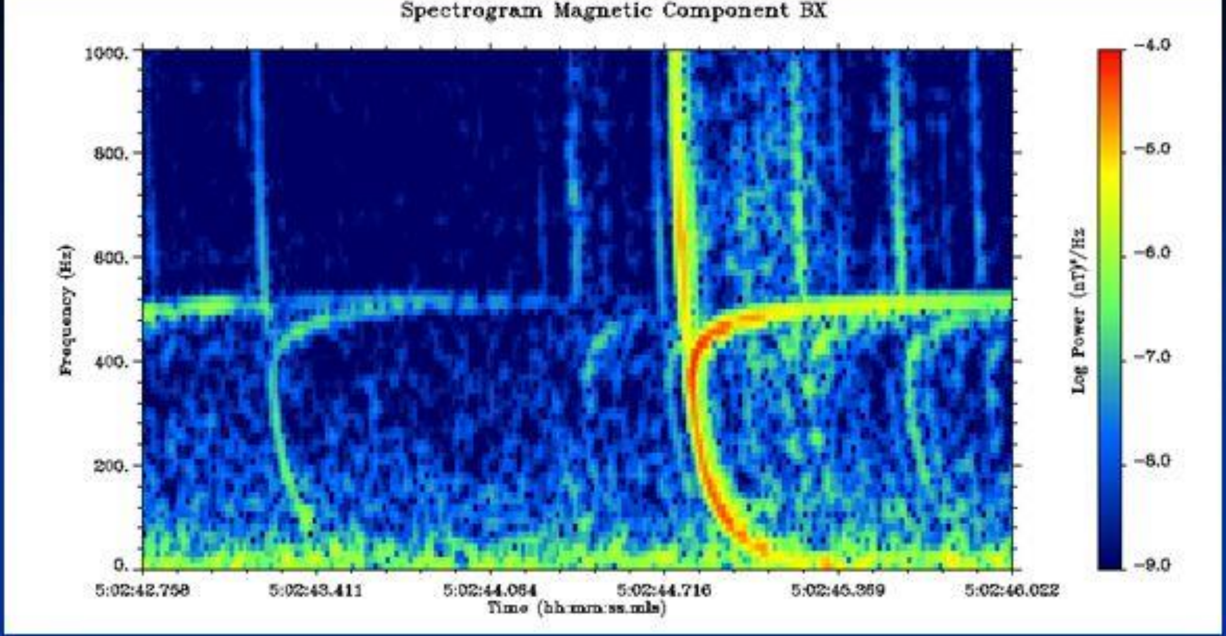


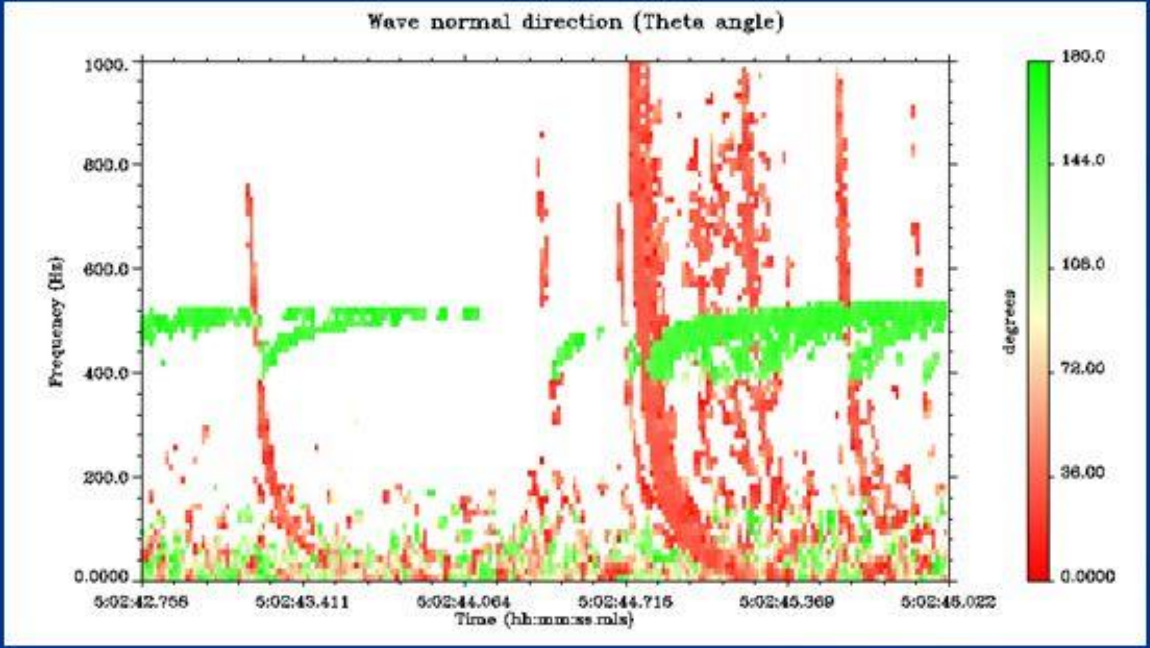
ω_x $D = 0$

$$D = \sum_s \frac{\omega_{ps}^2 \omega_{cs}}{\omega_x \left(\omega_x^2 - \omega_{cs}^2\right)} = 0$$

08/10/09 21:05:39 43.1157 3.9521 -20.6 674356400 08/10/09 21:05:40 43.8132 3.9013 -68.0 5787087 08/10/09 21:05:40 44.5801 4.3780 -30.0 6201475







Proton whistlers

- upgoing by definition
- R part (electron whistler)
- L part (proton whistler)

Observation :

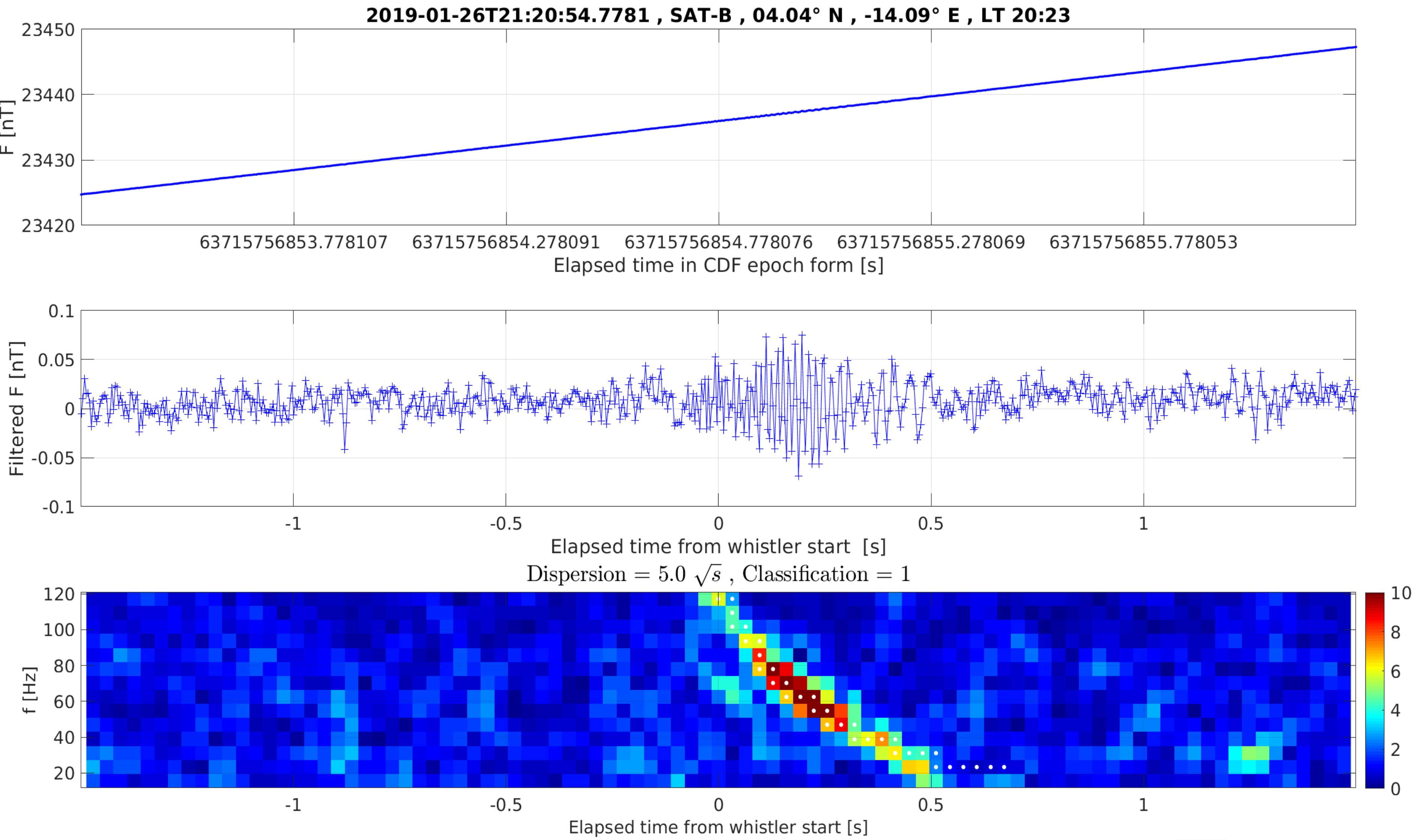
- R and L waves seen on E and B spectra
- no energy gap on the R wave between f_{cr} and f_{H^+}

Agreement with the Wang (1971) model :

- the « electron whistler » propagates with θ~0° ,
- the « proton whistler » propagates with large θ values
- The DEMETER observation explained for 0 < θ < 30°.

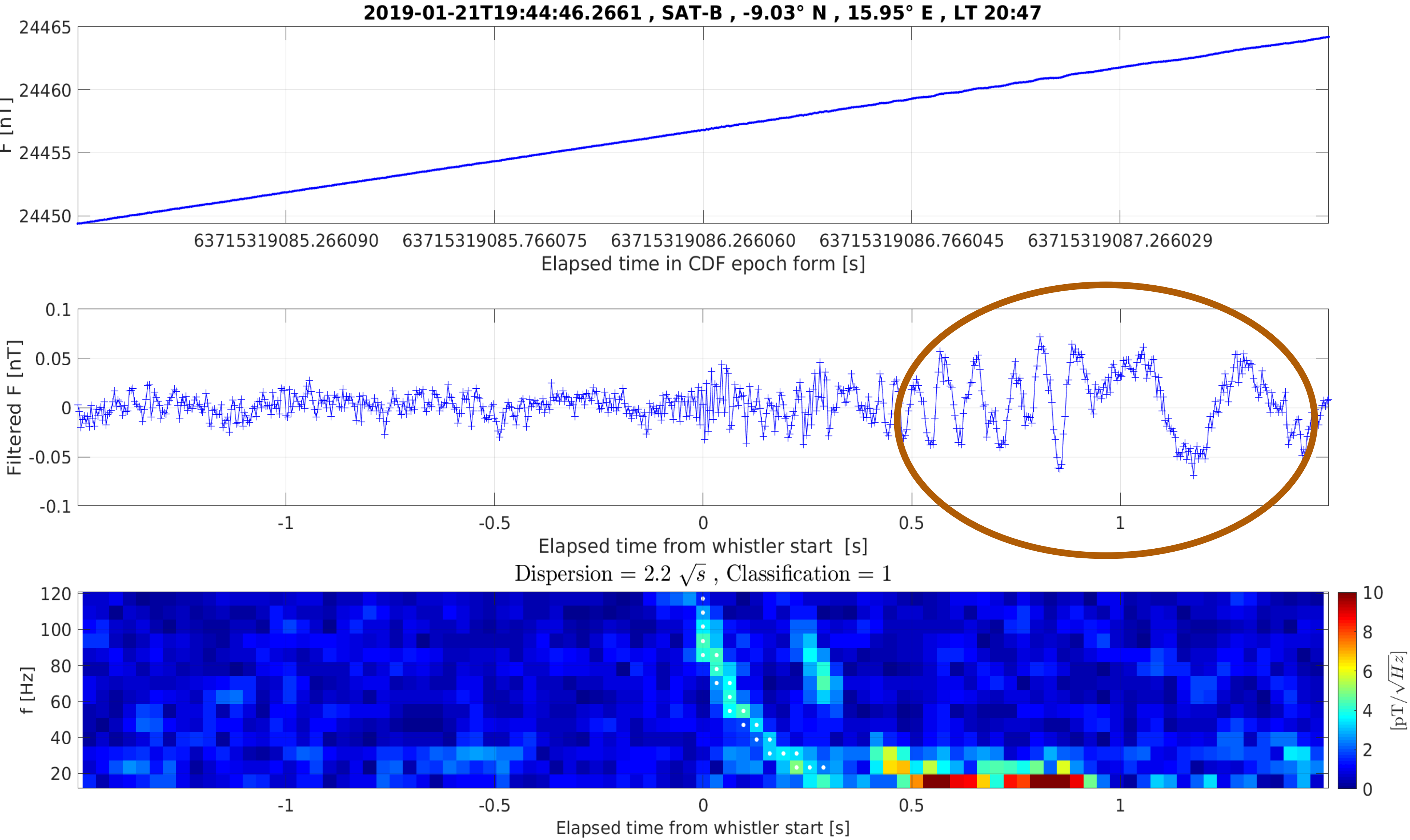
F. Lefeuvre

ELF „Whistler" like emissions registered by Swarm

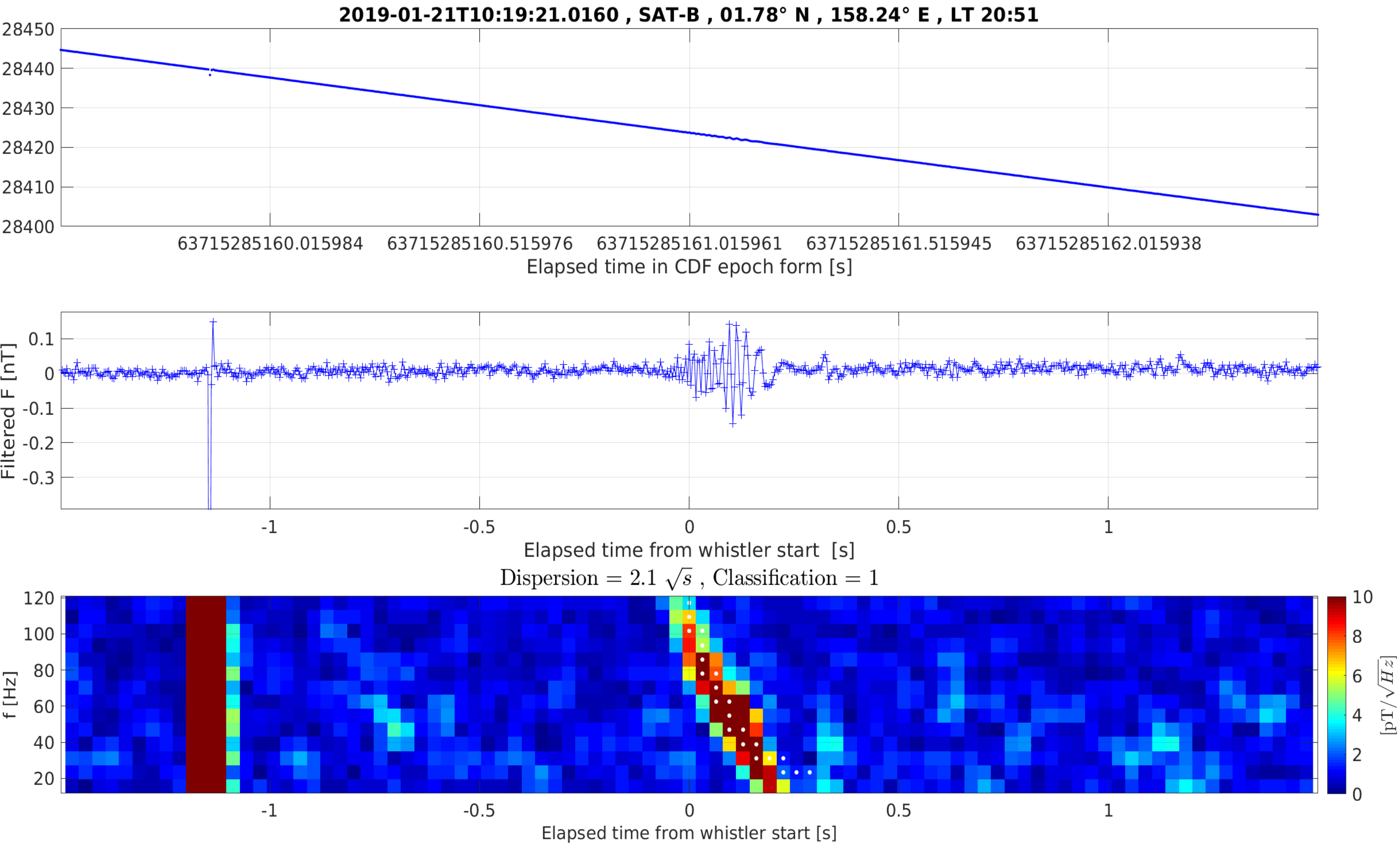


Gautier Hulot et al..

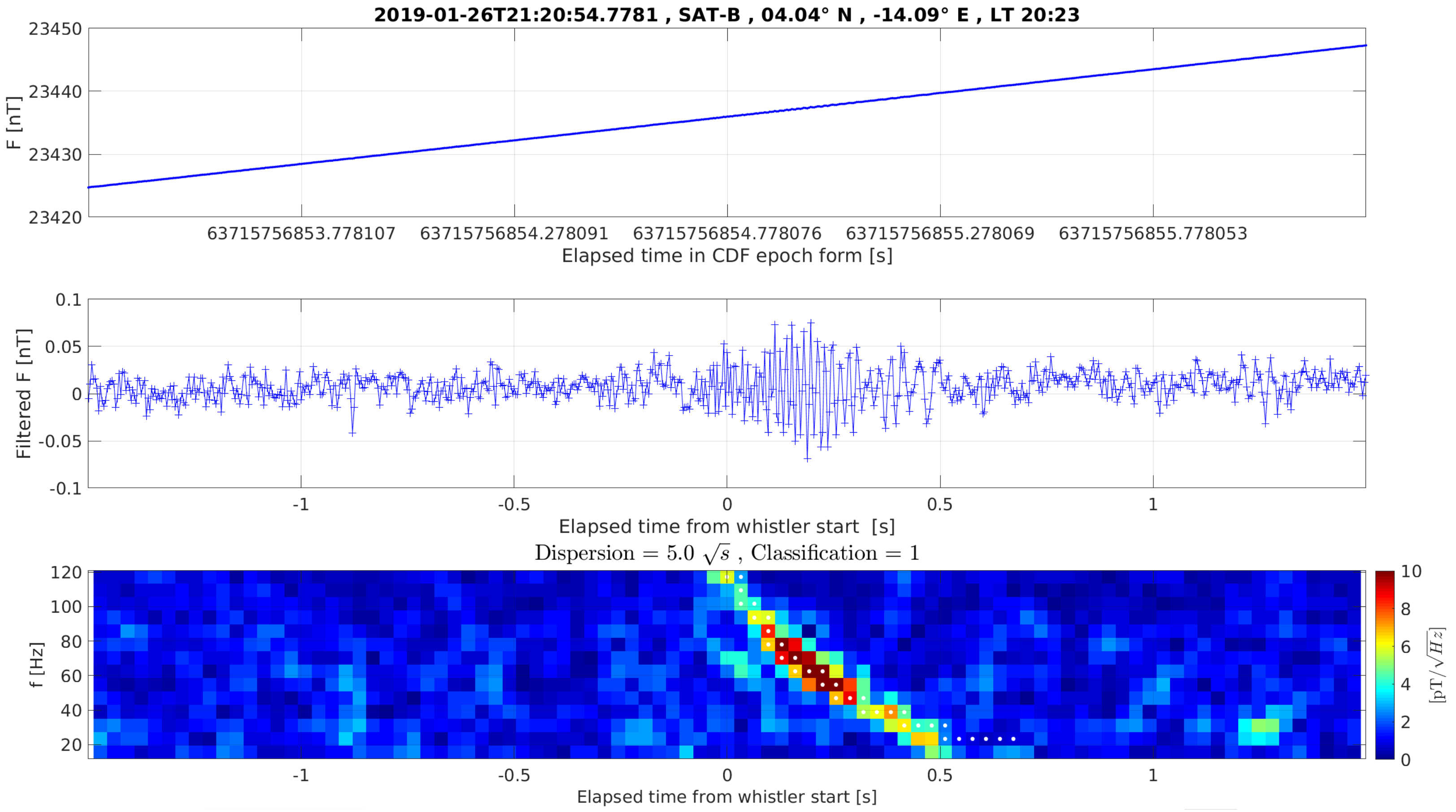
ELF „Whistler" like emissions registered by Swarm



ELF „Whistler" like emissions registered by Swarm



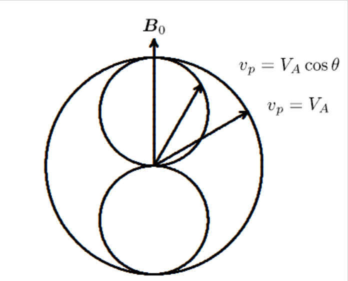
ELF „Whistler" like emissions registered by Swarm



The waves which can be seen below ion cyclotron frequency

1) **Alfven Waves**

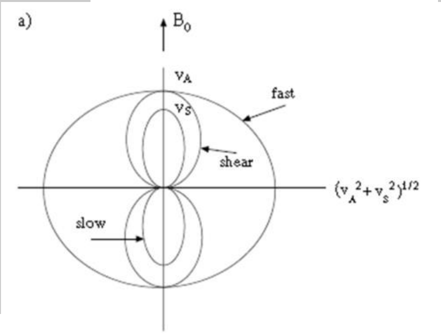
$$\mathbf{v}_A = \frac{\mathbf{B}_0}{\sqrt{\mu_0 \rho_{m0}}}.$$



no dispersion

2) **Magnetoacoustic waves**

$$\left(\frac{\omega}{k}\right)^2 = \frac{1}{2}(v_s^2+v_A^2) \pm \frac{1}{2}[(v_s^2+v_A^2)^2 - 4v_s^2 v_A^2 \cos^2\theta]^{1/2}.$$



no dispersion

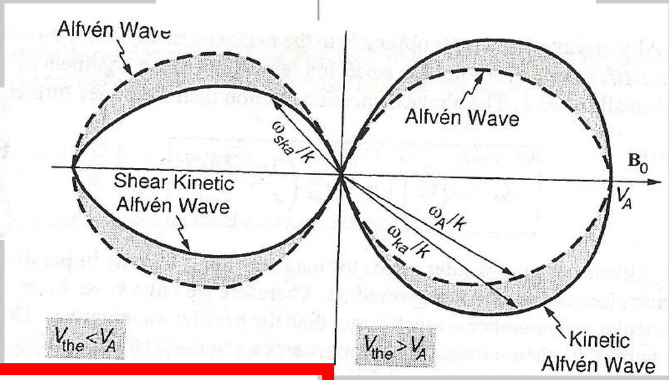
3) **Kinetic Alfven Waves**

$$\omega_{ka}^2 = k_\parallel^2 v_A^2\left[1+k_\perp^2 r_{gi}^2\left(\frac{3}{4}+\frac{T_e}{T_i}\right)\right]$$

$$\omega_{ska}^2 = k_\parallel^2 v_A^2 \frac{1+k_\perp^2 r_{gi}^2}{1+k_\perp^2 c^2/\omega_{pe}^2}$$

no dispersion?

$$\left(\frac{\partial\omega_{ka}}{\partial k}\right)^2 \approx 2v_A^2\left(1+\tfrac{1}{8}\cos^4\theta\right) \approx 2v_A^2$$



4) **Electromagnetic Ion Cyclotron Waves**

$$\frac{k_\parallel^2 c^2}{\omega_{gi}^2} = \frac{\omega^2}{\omega_{gi}^2}\left[1-\frac{\omega_{pi}^2}{\omega_{gi}^2}\left(1-\frac{\omega_{gi}^2}{\omega(\omega_{gi}-\omega)}\right)\right]$$

$$\frac{k_\parallel^2 v_A^2}{\omega_{gi}^2} = \frac{\omega^2}{\omega_{gi}(\omega_{gi}-\omega)}$$

Dispersion similar to that of electron whistlers!

Conclusions and discussion

Whistlers are very often present in space plasma

Origin of them can be very different

The classical definition of whistler is associated with the characteristic dispersion in time and frequency are in the range

$$\omega_{ci} \ll \omega \ll \omega_{ce} \sim \omega_{pe},$$

and are called electron whistlers

The waves with frequencies below ion cyclotron frequency are called ion whistlers and have different dispersion

Another waves below ion cyclotron frequency with dispersion similar to electron whistlers are often called ELF whistler like

The type of waves related to these emissions are likely electromagnetic ion cyclotron waves.