

STRANGE VLF EVENTS AT AURORAL LATITUDES

J. Manninen¹, N.G. Kleimenova², T. Turunen¹

¹Sodankyla Geophysical Observatory, Sodankylä, Finland

²Schmidt Institute of the Physics of the Earth RAS, Moscow, Russia

e-mail: jyrki.manninen@sgo.fi, kleimen@ifz.ru

Abstract. Few puzzling VLF events were found during several Finnish VLF winter campaigns at temporal station KAN located at ~40 km from Sodankyla Geophysical Observatory. Some expressive VLF emissions are presented here: (i) a few hours lasting quasi-periodic emissions in the frequency range of 1–5 kHz with the multi-scale time periodicity of the structure as a mixture of the different frequency band signals, which seem to have independent origins; (ii) a series of short separated bursts of the VLF emissions in the frequency range of 2–3 kHz with a complicated do not repeated spectral structure; (iii) the unusual daytime peculiar discrete right-hand polarized VLF signals in the high frequency range of ~6–10 kHz which were discovered after the special filtration of impulsive signals like atmospherics; (iv) the morning unstructured VLF left-hand polarized hiss at ~4–11 kHz and some others VLF emissions. The most part of the discussed VLF events were observed under very quiet geomagnetic conditions and only in the winter season. The main part of quasi-periodic VLF emissions may be generally attributed to the auto-oscillations of the Earth radiation belts cyclotron instability as it was developed by V.Yu. Trakhtengerts and P.A. Bespalov. However, an exact theoretical interpretation of the unusual signal details remains unknown.

Introduction

In the Earth's magnetosphere where different types of the natural whistler mode emissions occur at frequencies from a few hundreds of Hz to several kHz, well known as chorus and hiss. Most of them are generated in the disturbed magnetosphere as discussed in chapters 9 and 12 of *Trakhtengerts and Rycroft* monograph (2008). However, there is another type of VLF emission representing a spectacular sequence of repeated spectral elements or short noise bursts (lasting from several to tens of seconds). These events can be attributed to the quasi-period (QP) type of the VLF emissions [e.g., *Sazhin and Hayakawa*, 1994].

During last years, several VLF campaigns have been carried out at Kannuslehto (KAN), in Northern Finland ($\varphi=67.74^\circ$ N, $\lambda=26.27^\circ$ E, $L\sim 5.5$). Several puzzling QP emissions were found there and some results of their analysis have been published in *Manninen et al.* (2012, 2013, 2014a and 2014b). Most of these long-lasting QP emissions were not described in the literature early. The considered events were mostly observed in the winter time and under quiet solar wind and Interplanetary Magnetic Field (IMF) conditions. That provides the idea that such QP emissions could be interpreted as the self-oscillations of the magnetospheric maser [*Bespalov*, 1982; *Bespalov and Trakhtengerts*, 1986]. The aim of this paper is to show several recently observed events of puzzling VLF emissions which need the future development of a theory.

Observations of some strange VLF events

In the first part of this paper, we show three examples of long lasting (up to several hours) events of QP emissions with a strange spectral structure. These events were not associated with geomagnetic pulsations. Further we present two expressive high-frequency VLF events, which analysing is just in beginning.

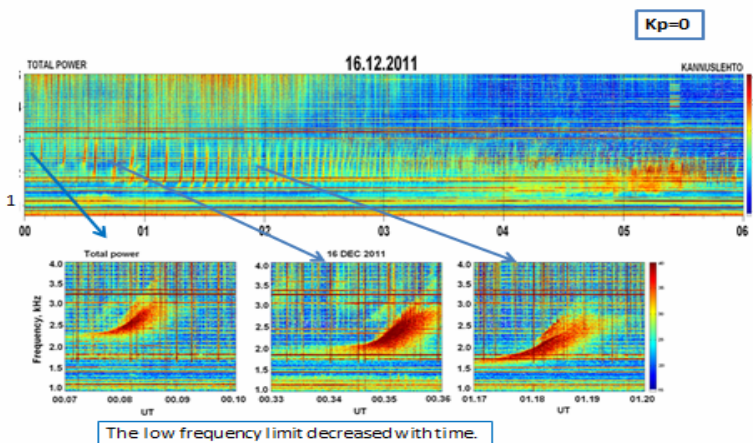


Figure 1. The 1–4 kHz spectrogram of QP VLF emissions on 16/12/2011 (upper panel) and its separate signals (bottom panel).

The QP event of 16 December 2011. This event was observed in the morning and lasted about 6 hours. Some details of this event were discussed in the paper [Manninen *et al.*, 2013]. The (1-4 kHz) spectrogram of this event is given in Fig.1 (upper panel). It is seen that the signal repetition period gradually decreased and the signal low frequency decreased also from ~ 2.3 kHz to ~ 1.7 kHz. That could be explained as a result of removing the VLF emission generation region to the higher L-values (to lower values of the electron gyro-frequency). However, the signal upper frequency did not change (bottom panel in Fig. 1). The separated signals present a strange duplet structure. The temporal signal structure is not yet theoretically explained in details.

The QP event of 18 December 2011. This event was observed in the evening and lasted also about 6 hours. The 1-5 kHz spectrogram of this event and a few 10-min intervals from it is given in Fig. 2. Some details of this event were discussed in the paper [Manninen *et al.*, 2012]. The event presented a sequence of discrete rising signals in the frequency band of ~ 2 -4 kHz with a time-changing spectral structure. There was a superposition, at least, of three different emissions: at higher frequencies (~ 3 -5 kHz) – hiss, replaced by quasi-periodic discrete non-dispersive emissions at the same frequency band; at middle frequencies (~ 2.0 -3.5 kHz) – QP emissions with decreasing repetition periods; and at lower frequencies (~ 1.8 -2.2 kHz) - short discrete rising signals, each having the duration of about 15 s. The appearance and generation of the superposition of these different emissions at different frequency seems to be independent. As in previous event, now there is no theoretical explanation of such phenomena.

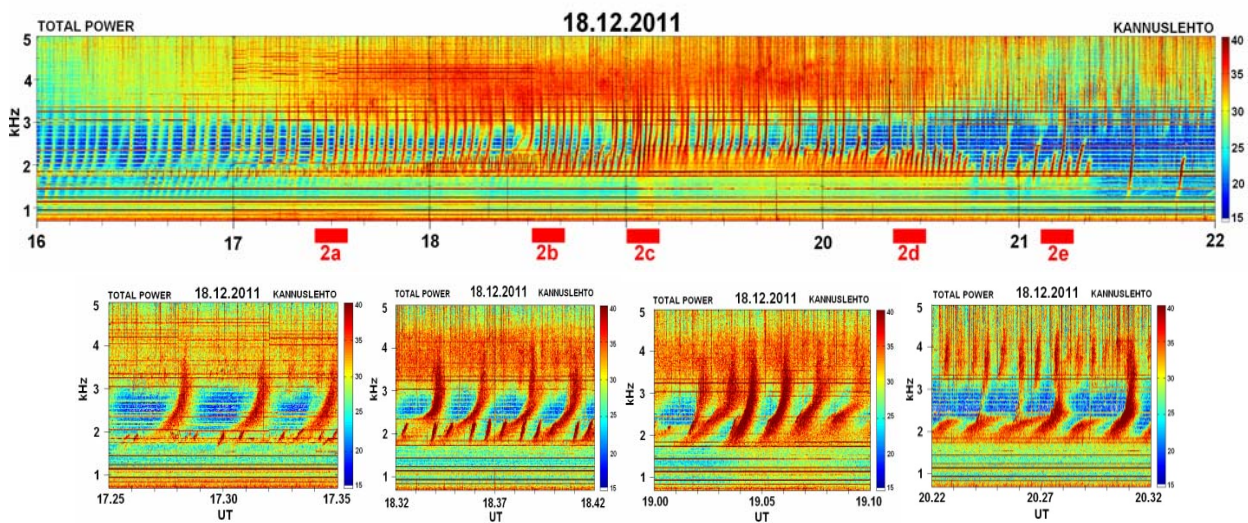


Figure 2. The (1-5) kHz spectrogram of the QP VLF event on 18/12/2011 and four 10-min successive intervals

The series of puzzling short VLF bursts on 22 March 2013. A series of short (~ 1 min) and strange VLF bursts at ~ 2 -4 kHz were observed during few hours on magnetically quiet day with $K_p=0-1$ after geomagnetic disturbances recorded in the previous day. Two examples of such signals are shown in Fig. 3.

The event on left panel looks like a superposition of two short hiss bursts: one burst at the constant frequency at about 3.5 kHz with the decreasing frequency band from ~ 1 kHz in the beginning to ~ 200 -300 Hz in the end, and the second one at the slowly increased frequency from 2.5 kHz to 3.5 kHz showing the intensity variations with periodicity of ~ 3 s and an the increased frequency band from ~ 200 Hz to ~ 1.5 kHz. The event on right panel shows a multi-hop whistler with ~ 3 s periodicity of slowly dispersed signals superposing on a short hiss burst. Both events could argue an existence of a complicated wave interaction in the magnetosphere plasma.

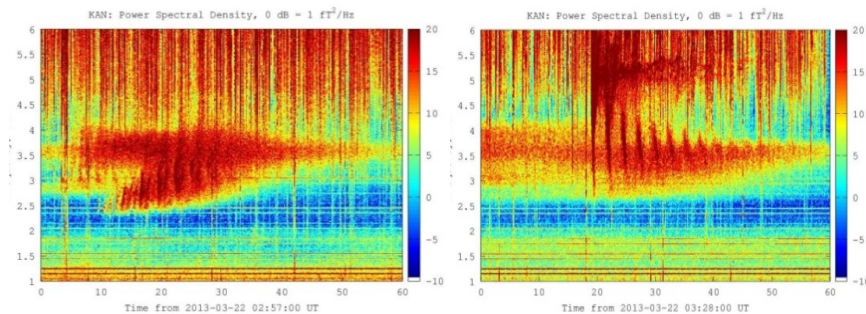


Figure 3. 1-min spectrograms of short VLF events on 22/03/2013 in the frequency range of 1-6 kHz: the left plot – 02.57-0.58 UT, the right plot - 03.28-03.29 UT

The daytime peculiar discrete high-frequency VLF signals. These emissions were discovered only after an applying of the specific high frequency filtering of the impulsive signals like atmospheric. Fig. 4 shows the result of this filtration: left plot presents an ordinary 1-hour spectrogram without the filtration. The very strong atmospheric are seen. The right plot demonstrates the same spectrogram after the applying of the atmospheric filtration. One can see some peculiar discrete high frequency signals which were hidden earlier by atmospheric.

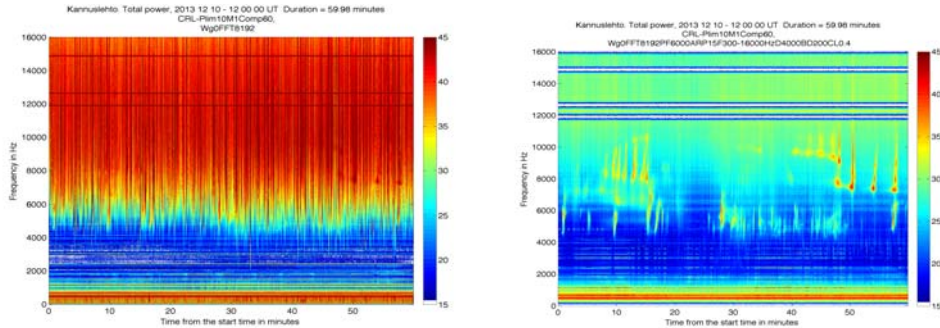


Figure 4. 1-hour spectrograms in the frequency range of 1-16 kHz: the left plot – without filtering, the right one – after high frequency filtering. The strong horizontal lines – power line signals.

Thus, the application of high frequency filtration allowed us to establish the new, previously unknown high-frequency VLF emissions. Some of them were observed in the daytime under quiet geomagnetic conditions. The investigations of these emissions are just in beginning. One typical event is presented in Fig. 5. We cut off the high frequency of spectrograms up to 11 kHz to avoid the 12 kHz (and higher) navigation transmitter signals.

The analysis showed that the considered high-frequency signals were right-hand polarized (right panel in Fig.5), that supports that the ionosphere exit point of these signals is located in the vicinity of the receiver. The dynamic spectra of separated short bursts demonstrated the complicated noise-like rising structures in the frequency range of ~6-9 kHz. The generation mechanisms of these waves are still unknown.

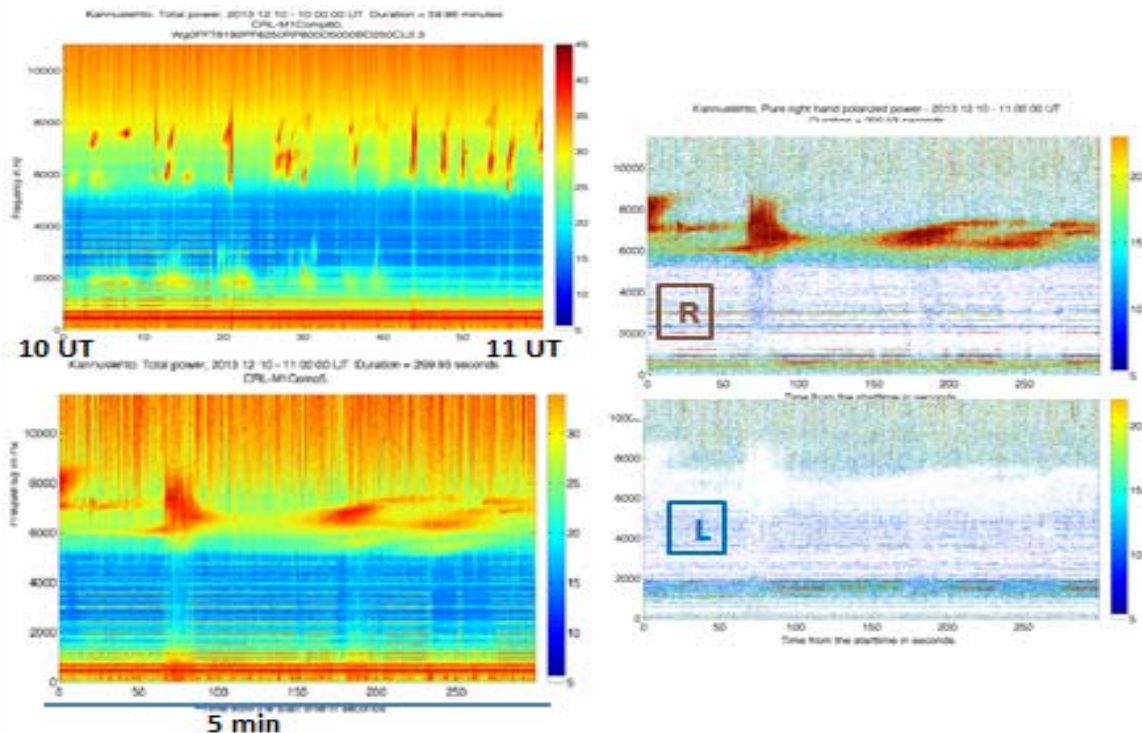


Figure 5. The left panels 1-hour (upper plot) and 5 min (bottom plot) spectrograms in the frequency range of 1-11 kHz: the left plot – the spectrogram without filtering, the right one – the same spectrogram after high-frequency filtering. The right panels show the right-hand (R) and left-hand (L) polarized signal power.

The morning high-frequency “funny” hiss. The two-hours lasting VLF hiss burst at the untypically high frequency band ($\sim 4\text{--}10$ kHz) was recorded on 8 December 2013 in the initial phase of the moderate magnetic storm (Fig. 6). The left panel shows the 24 hours spectrogram. The high-frequency “funny” hiss is seen in the early morning (00-03 UT) hours with temporal structure (the right panel in Fig. 6) differs from classical auroral hiss which was recorded in this day at 18-19 UT. The frequencies of “funny hiss” were much higher than frequencies of typical daytime hiss observed at auroral and subauroral latitudes.

The considered high-frequency “funny hiss” was left-hand polarized (in contrast to typical auroral hiss which is usually right-hand polarized), therefore the ionosphere exit point of these waves was located far from receiver. The wave arriving study showed the East-West direction. Thus, the “funny hiss” could be generated in the dayside magnetosphere, probably, inside or near the plasmopause by electron-cyclotron mechanism. But the possibility of this scenario and the wave propagation to the receiver is still open problem.

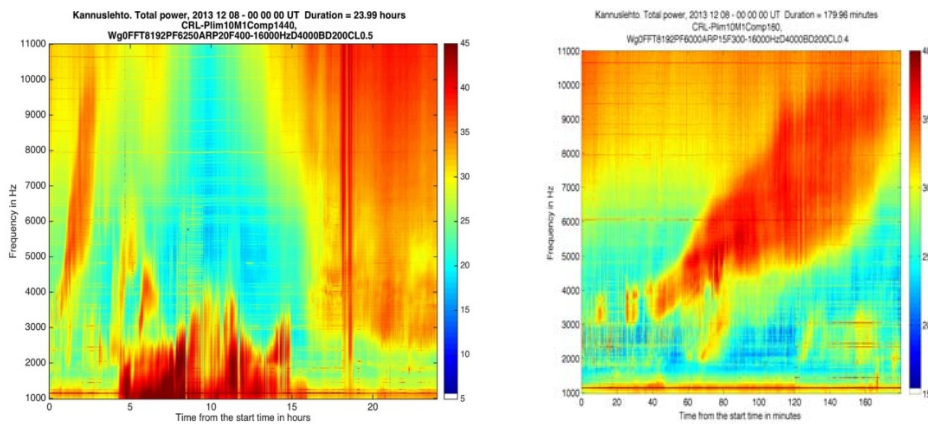


Figure 6. The left panel 24-hours 1-11 kHz spectrogram on 8 December 2013; the right panel - 3-hours (00-03 UT) spectrogram of the “funny” hiss.

Discussion and summary

We presented here several new, previously unknown events of long-lasting non-typical quasi-periodic VLF emissions observed mainly in the winter season under quiet geomagnetic conditions, but after geomagnetic disturbances. That supports the idea of an internal source of these VLF emissions generation. The general behaviour of these VLF emissions could be interpreted as the self-oscillations of the magnetospheric maser [Bespalov, 1982; Bespalov and Trakhtengerts, 1986]. But the exact mechanism explaining the temporal dynamics and the wave spectral composition, especially a superposition of different emissions at different frequency, is still unknown.

The application of the high-frequency filtering of impulsive atmospherics has revealed new dayside natural right-hand polarized emission at frequencies of $\sim 6\text{--}9$ kHz observed mainly in the daytime. The nature of these emissions is still unknown.

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