RECENTLY REVEALED DAYTIME VLF EMISSIONS OBSERVED UNDER QUIET SPACE WEATHER CONDITIONS

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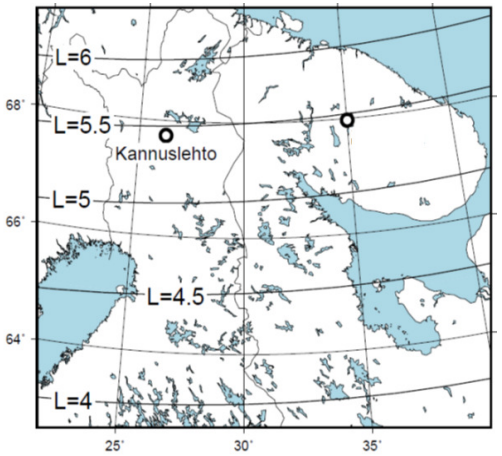
It is well known that lots of geomagnetic waves are generated under different solar wind disturbances. However, here we present some natural electromagnetic VLF waves occurring during very quiet solar wind and geomagnetic conditions.

Our study is based on the VLF signal (0.2 – 39 kHz) observations at Kannuslehto (KAN, L~ 5.5) in Northern Finland.



Natural VLF emissions

- **The natural electromagnetic waves at audio frequencies called Very Low Frequency (VLF) emissions are typically generated in the magnetosphere via the electron-cyclotron resonance mechanism. These whistler-mode waves are guided to the ionosphere by the geomagnetic field with the upper cut-off frequency at half of the equatorial electron gyrofrequency ($f_{ce}/2$) at a given L-shell.**

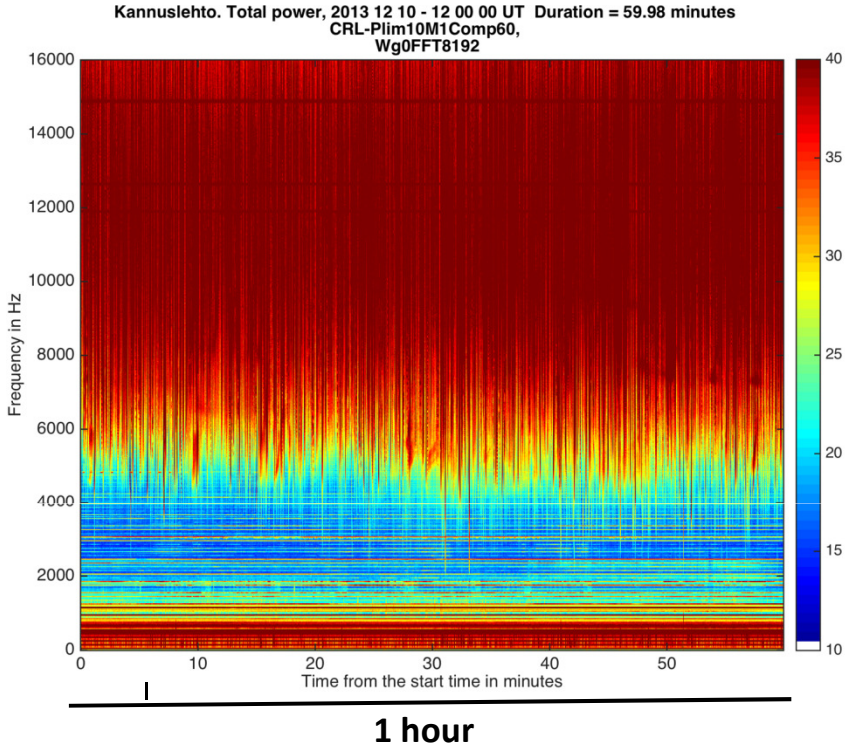
- **The most typical natural VLF emissions are widely known as chorus and hiss. Despite significant successes of many different ground-based and satellite observations, the full nature and behaviour of different VLF waves is not yet fully understood.**

- **Many naturally occurring VLF waves at higher frequencies (above 4-6 kHz) could not be studied due to strong atmospherics (sferics) originating in lightning and hiding all such waves.**

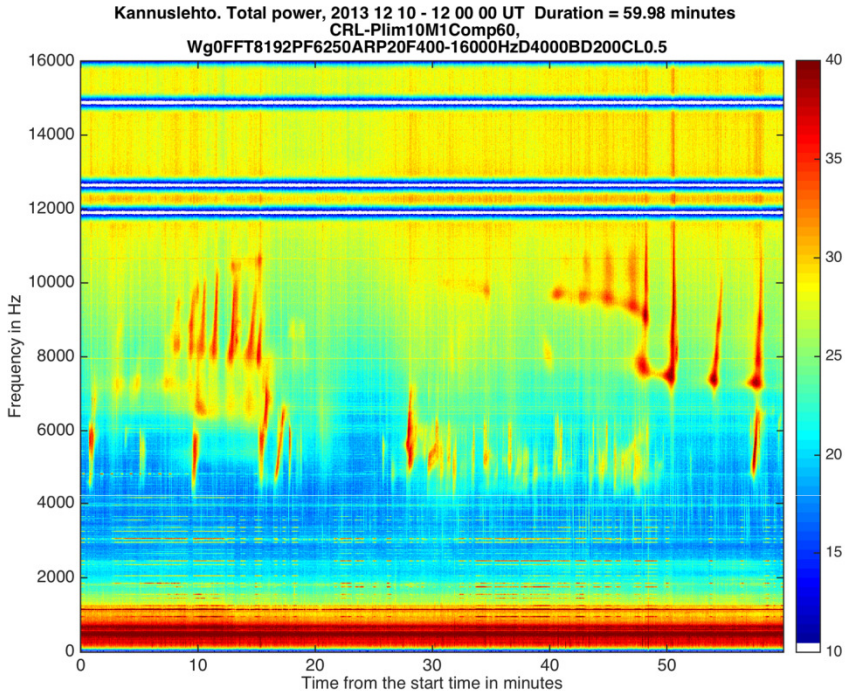
- **To study these waves, we have to apply special digital programs, which filter out the strong impulsive sferics.**

The row and filtered VLF spectrograms

An example of an initial spectrogram



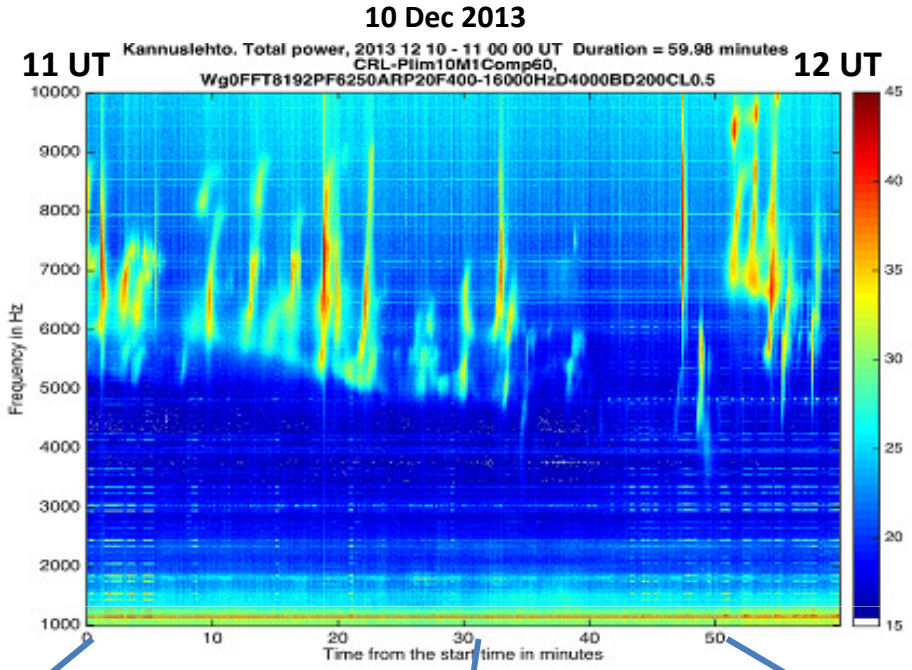
The same data after filtering out the sferics



It is seen that new unusual signals appear after filtering. These recently revealed VLF emissions have never seen earlier because the signals were hidden by strong impulsive sferics.

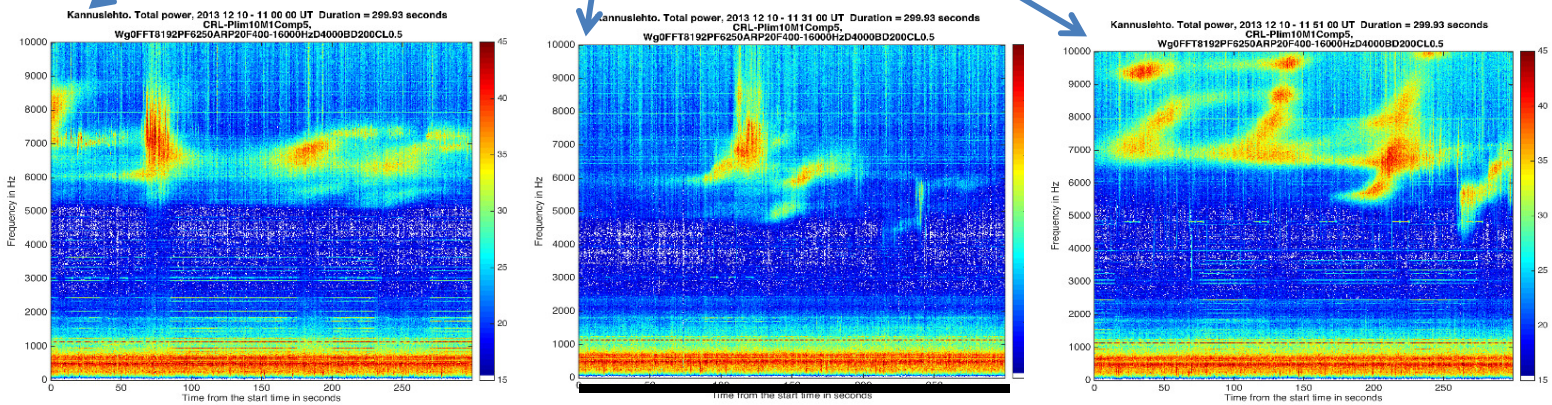
We found that the emissions are usually observed during several hours in daytime and contain short (~1-3 min) burst-like structures at frequencies higher than 4 kHz, even up to 15 kHz.

The example of the new type VLF emission spectrogram



Very complex spectral shapes of the signals are seen. Sometimes they resemble the flying birds.

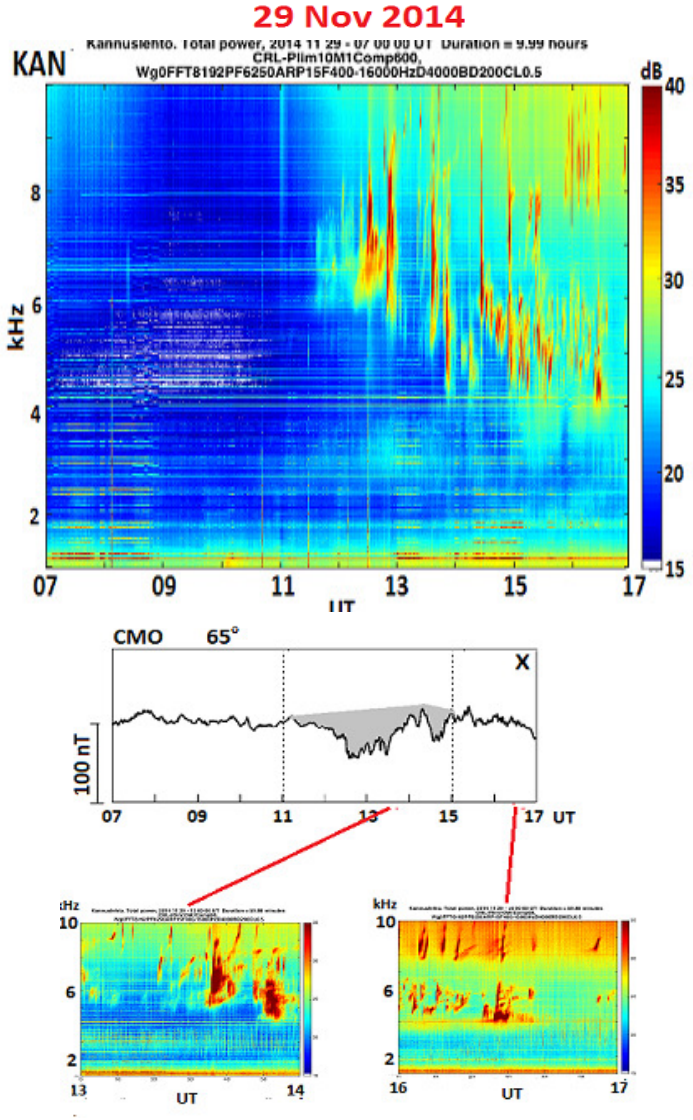
11:00 UT **11:31 UT** **11:51 UT**



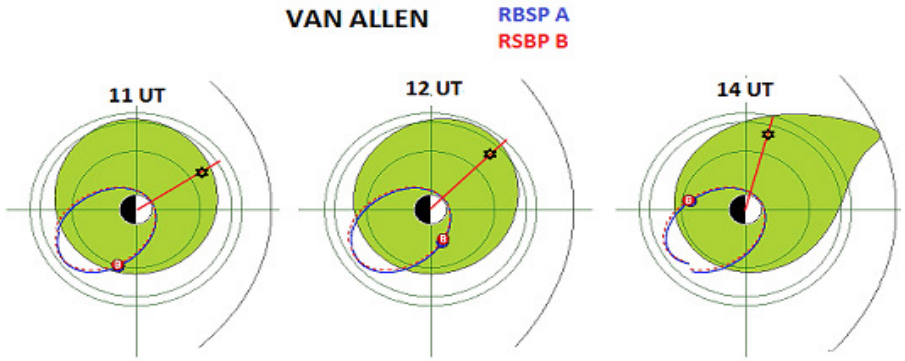
5 min

One hour VLF spectrogram (upper plot) and 5 min spectrograms (bottom plots).

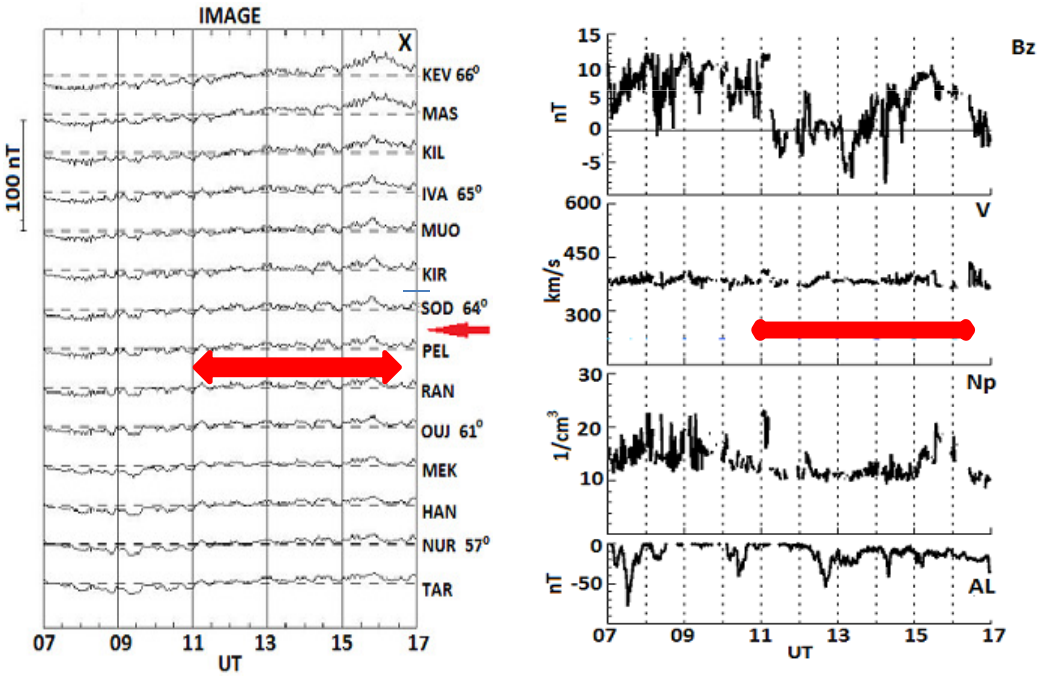
An example of new emissions with geomagnetic and solar wind activity



A very small (~60 nT) substorm occured in the night side (CMO station).

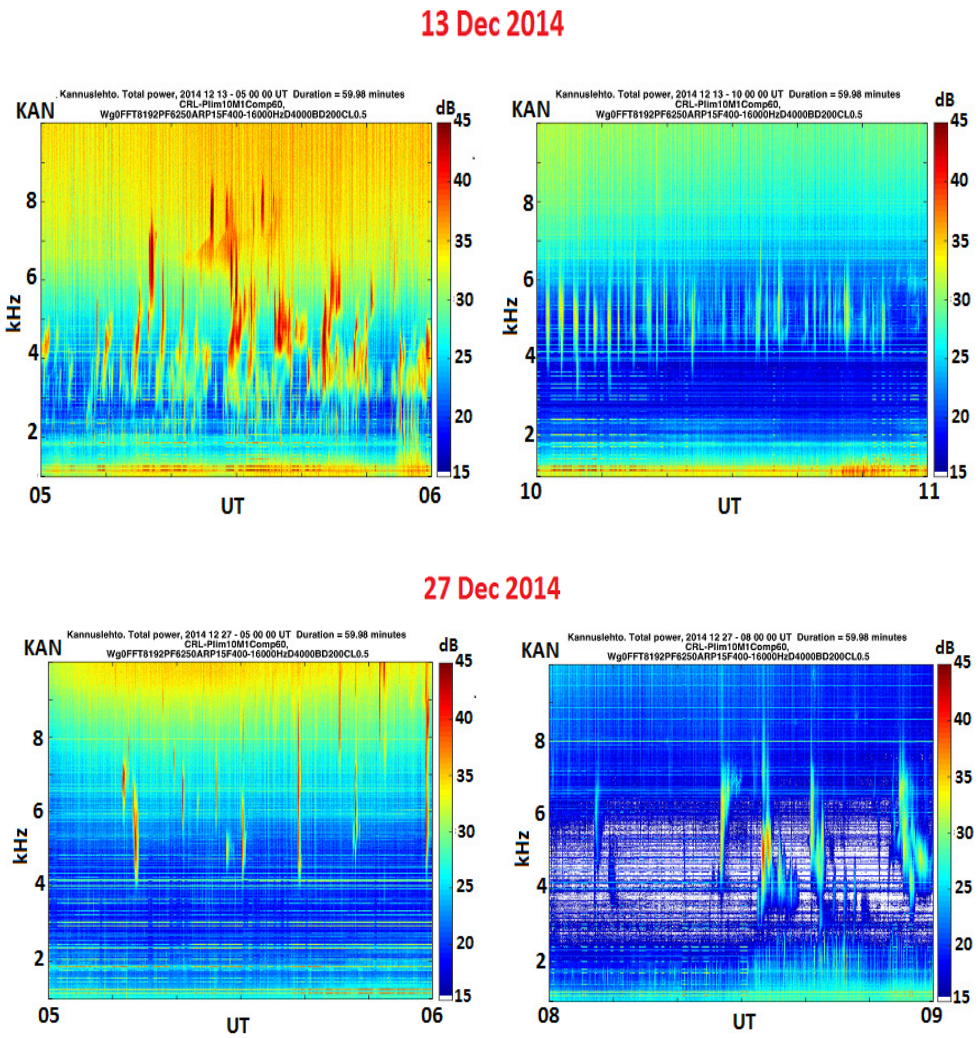


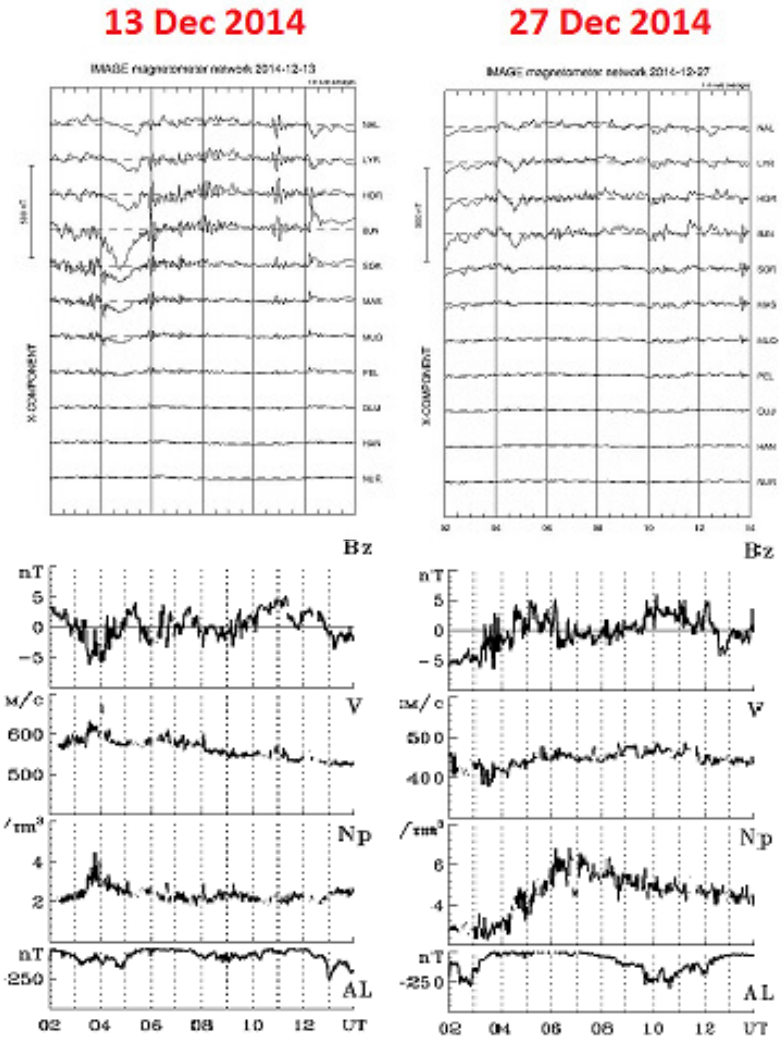
The Van Allen Probe data show that during this event KAN was mapped inside of the plasmasphere.



Both geomagnetic and solar wind conditions were quiet.

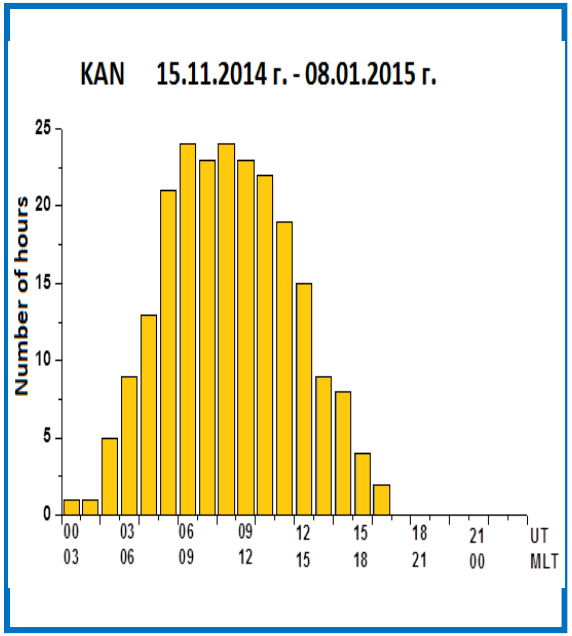
The solar wind and geomagnetic parameters during new VLF types (‘bird’ emissions)





It is seen that these VLF emissions are generated under quiet solar and magnetic conditions.

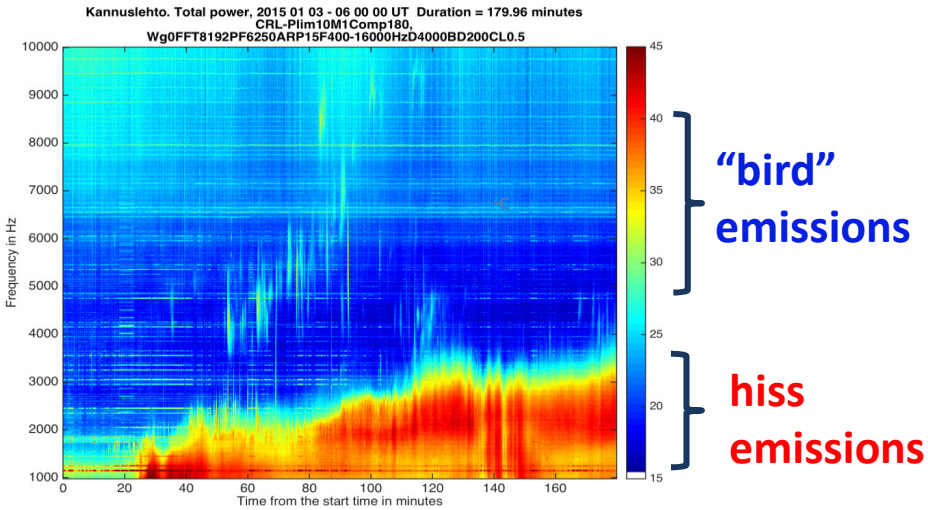
Diurnal distribution of the new type VLF emissions



Diurnal variations of the occurrence of studied events. Here total duration of events is ~230 h.

In five Finnish winter-time VLF campaigns (2006-2016) at different phases of the 11 year solar cycle, these VLF emissions were observed in the day time with the maximum at 09-15 MLT (an example of distribution in 2014-2015).

The studied VLF emissions have been observed both in the presence and absence of typical lower frequency VLF emissions like chorus, hiss, and quasi-periodic events.



An example of the simultaneous occurrence of different VLF signals

Summary

- **Based on the VLF observations in Northern Finland at Kannuslehto (KAN, L~ 5.5, where f_{ce} ~ 5.3 kHz), we revealed new and totally unexpected natural VLF electromagnetic emissions at frequencies higher than 4 kHz, i.e. well above $f_{ce}/2$ at L~ 5.5.**

- **These emissions are observed as the right-hand polarized waves lasting for several hours in the daytime and containing short (~1-3 min) burst-like structures.**

- **The low solar wind and geomagnetic activity (V_{SW} < 400-500 km/s, Np < 5-8 cm^{-3}, AE < 150-200 nT) are the favourable conditions for the VLF wave generation and propagation. These emissions appear after moderate geomagnetic disturbances or in the late recovery phase of geomagnetic storms.**

- **We suppose that these emissions are generated deep in the magnetosphere via electron-cyclotron instability at much lower L-values than KAN (L~ 5.5). The small substorm developing in the night sector could be a source of the resonant electrons injected into the magnetosphere from the magnetotail and trapped into the Earth's radiation belts.**

- **However, the details of the mechanism of the generation and propagation of these newly discovered VLF emissions remain unknown.**