Group 02

SYMPHONIES OF THE ELECTROMAGNETIC UNIVERSE: WHISTLERS, HISSES AND DAWN CHORUS

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INTRODUCTION

"In World War I, soldiers operating communication lines reported hearing strange sounds consisting of a falling tone, sounding like someone was whistling. 'You can hear the grenades falling', some used to say." [1]

What they were really hearing was an indirect version of lightning energy, known today as whistlers, coupling into the communication lines.

WHISTLERS

Whistlers are VLF (Very Low Frequency) emissions in the atmosphere that are characterised by a tone of *rapidly descending frequency*. They are known to be generated by lightning strikes and propogate through the earth-ionosphere waveguide to the opposite hemisphere.

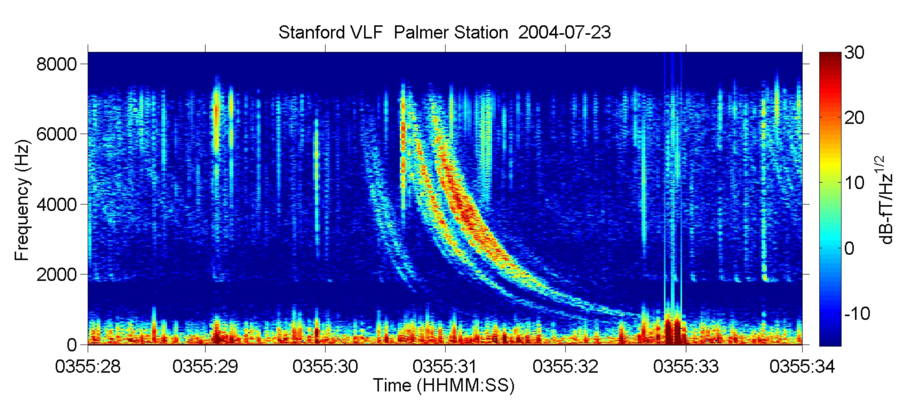

Fig 1 - Spectrogram of a Whistler
Source: https://vlf.stanford.edu/research/introduction-whistler-waves-magnetosphere

SOURCES AND GENERATION OF WHISTLERS

Though the literature about the sources of whistlers is fairly limited, there is considerable evidence pointing to the fact that the source of whistlers must not be very different from lightning.

The estimated electromagnetic energy of a whistler producing stroke (after accounting for attenuation losses), comes out to be about *ten times as high as that in the average lightning flash*. A sufficiently strong lightning flash should be able to produce whistler-mode signals - this is supported by the fact that a detectable whistler-mode can be excited by a source at the ground that emits vertically polarised energy.[2]

PROPAGATION AND DISPERSION OF WHISTLERS

Energy from a lightning source near the earth's surface *travels in the earth-ionosphere waveguide* and enters the ionosphere continuously along the lower surface of the ionosphere. Wave components that enter the ionosphere at the location of a duct are then trapped and "conveyed" to the opposite hemisphere along the same line of force, where they emerge from the ionosphere and re-enter the earth-ionosphere waveguide. Due to the *dispersion of waves in the ionosphere depending on their frequencies*, different frequencies are received at different times, with the higher frequencies being received first. This is why a whistler is a tone of descending frequency.

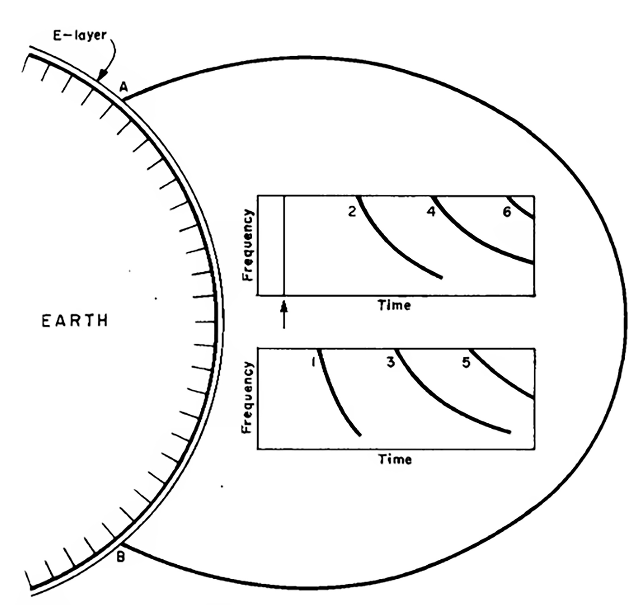

Fig 2 - An illustration of a whistler
Source: Robert A. Helliwell, Whistlers and Related Ionospheric Phenomena

DETECTION

The wavelength of these waves are extremely huge (100 km for a 3kHz wave). This means that it is not possible to have a full-wavelength antenna. So with a typical VLF receiver length (<60ft), there is very little signal current for reception. Using a cascaded combination of *high gain, high input impedance* (for better sensitivity) amplifiers and low pass filters, we can make up for the difference.[3]

ESTIMATING THE SOURCE LOCATION

To estimate the position of the source of the whistler, a common method used is *triangulation using direction-finding*[2]. Two cross-looped antennas (which are sensitive to direction), placed at two different locations are used to record the same source. Based on the angle of arrival of the signal to the two stations, the position of the source of the whistler can be estimated using triangulation.

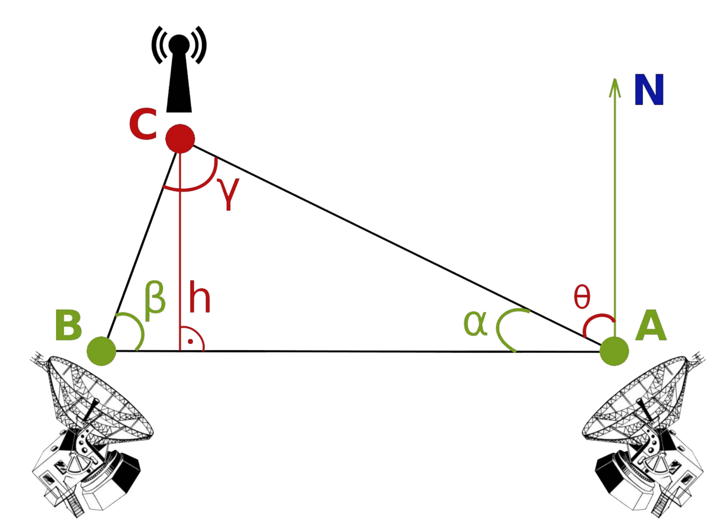

Fig 3 - Radio Triangulation
Source: https://upload.wikimedia.org/wikipedia/commons/b/b8/Radiotriangulation.jpg

UNDERSTANDING WHISTLER SPECTROGRAMS

One hop whistlers are those which enter the ionosphere in one hemisphere and are observed in the opposite hemisphere, after traversing the path once. *Two hop whistlers* are one hop whistlers which have been reflected back to the hemisphere of origin.

According to dispersion theory, every whistler should have a *characteristic frequency* (not necessarily the maximum frequency detected), that has the minimum time delay. This frequency is called the *nose frequency*. This is apparent in whistlers of the frequency range around 10 KHz.

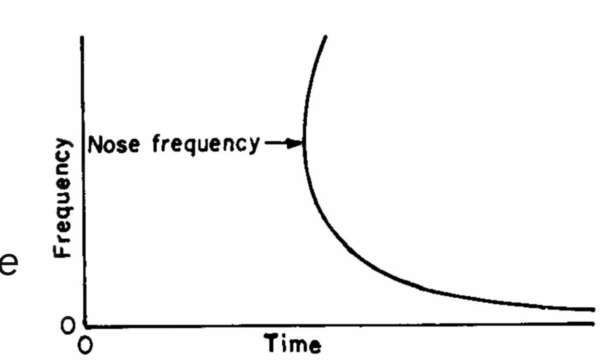

Fig 4 - Idealised spectrum of a nose whistler
Source: Robert A Helliwell, Whistlers and Related Ionospheric Phenomena

APPLICATIONS

The nose frequency of a whistler is related to the electron distribution of the ionosphere. So one of the main applications of whistler waves is to *map the electron distribution of the ionosphere*.[2]

Studies of the interaction of whistler-mode waves with the charged particles of the atmosphere have indicated that it maybe possible to accelerate charges by means of man-made whistler-mode signals. This has been *proposed to help protect satellites* from the charged particles of the Van Allen radiation belt, during their launch.[2][3]

REFERENCES

[1] https://vlf.stanford.edu/research/introduction-vlf
[2] Robert A Helliwell, Whistlers and Related Ionospheric Phenomena, Stanford University Press, 1965.
[3] Tatiana Ivanova, Bombs away: 'Whistler waves' to protect communications from nuclear blast, https://www.dw.com/en/bombs-away-whistler-waves-to-protect-communications-from-nuclear-blast/a-18390787, DW News, 2015.
[4] https://space-audio.org/sounds/EarthChorus/EarthChorus.html
[5] Summers, D., Omura, Y., Nakamura, S., and Kletzing, C. A. (2014), Fine structure of plasmaspheric hiss, J. Geophys. Res. Space Physics, 119, 9134– 9149, doi:10.1002/2014JA020437.
[6] https://eos.org/research-spotlights/new-clues-to-mysterious-hiss-in-earths-plasmasphere

DAWN CHORUS

A typical dawn chorus consists of *many rising tones*, mainly in the 2 - 4 KHz range. When converted to audio, it sounds very similar to birds singing at the crack of dawn, and thus the name.

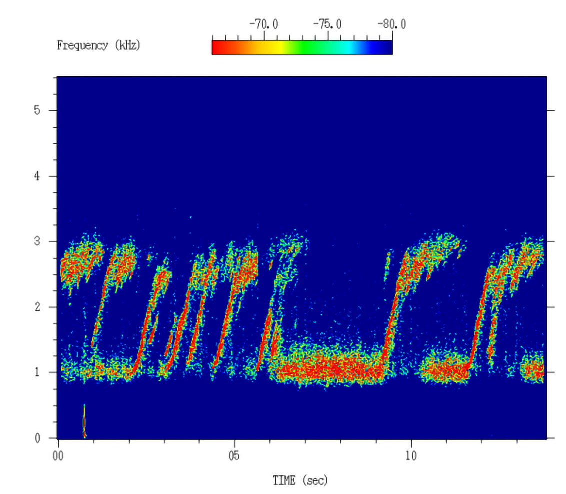

Fig 5 - Spectrogram of Dawn Chorus
Source: https://pwg.gsfc.nasa.gov/istp/polar/polar_pwi_sounds.html

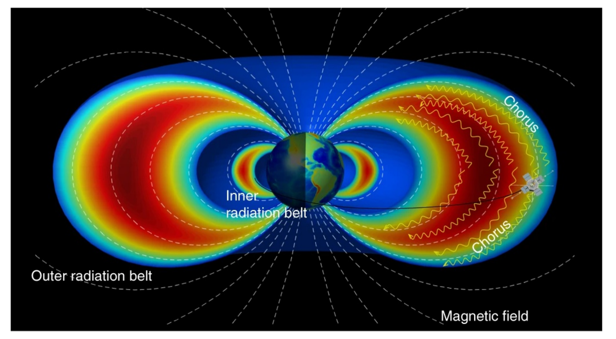

Fig 6 - Outer Radiation Belt
Source: https://www.nature.com/articles/s41467-019-12561-3

Chorus waves are *generated in the Van Allen radiation belts* of the magnetosphere, by electrons spiraling along Earth's magnetic field lines in this region. Once generated, the chorus waves interact with the electrons in the region, disturbing their spiral orbits, and causing them to *fall into Earth's upper atmosphere*, along the magnetic field lines.

Chorus waves in the Earth's magnetosphere have been observed to occur in *two distinct frequency bands*: a lower-band (0.1–0.5 f_{ce}) and an upper-band (0.5–0.8 f_{ce}), where f_{ce} represents the equatorial electron gyro-frequency.[4]

HISS

The hiss is an ever-present disturbance from the inner regions of Earth's magnetic field. It *sounds like pure static* (when converted to audio), spanning from 100 Hz to several kilohertz. Hisses play a crucial role in *shaping the structure of the Earth's radiation belts*, disrupting them by knocking their energetic particles out into the atmosphere.

However, the *source of the hiss is unknown*. One theory says that it is the direct result of spiraling electrons, high over the Earth's equator. Others propose that it consists of the remnants of distant whistlers or chorus waves that devolve into incoherence, like the expressionless chop far out at sea.[6]

Hisses were *relatively less studied* due to the dearth of high resolution instruments. However a recent study[5] using high resolution spectrogram indicates that hisses are in fact *coherent emissions with a complex fine structure*. It also showed that the time scales for rising and falling tones of hiss elements are relatively short - a few wave periods.

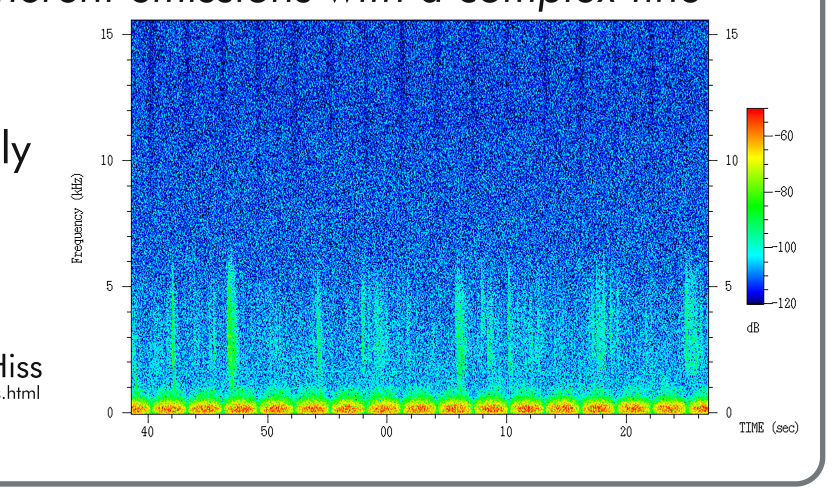

Fig 7 - Spectrogram of Hiss
Source: https://pwg.gsfc.nasa.gov/istp/polar/polar_pwi_sounds.html

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