On the nature of VLF propagation perturbations induced by meteors

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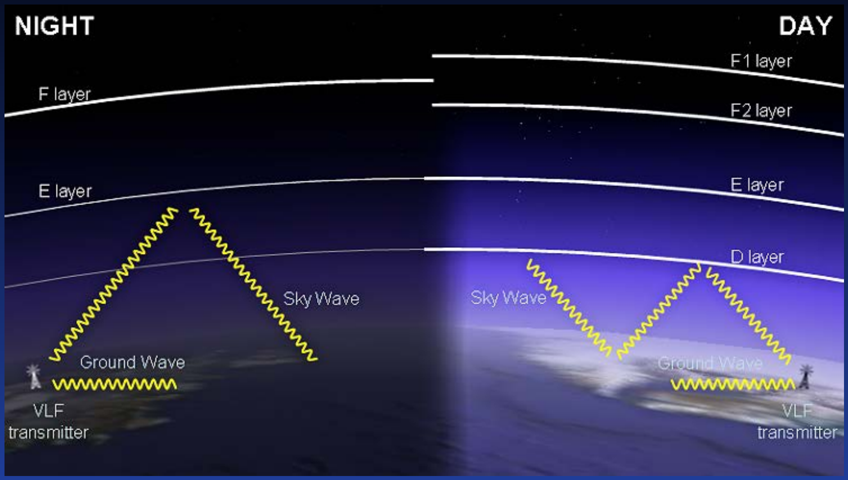
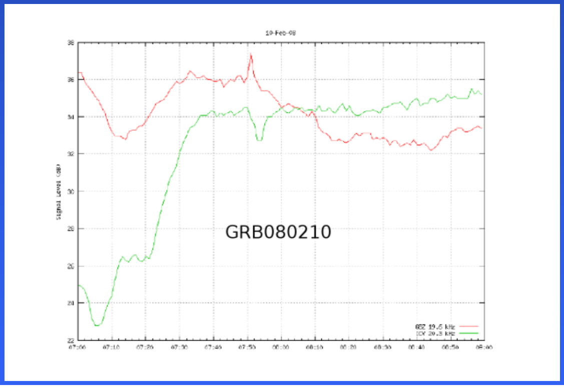
The upper atmosphere of the Earth consists of several concentric ionized layers constituting the ionosphere



These layers influence the propagation of the radio waves (by reflection, diffraction, absorption, etc)

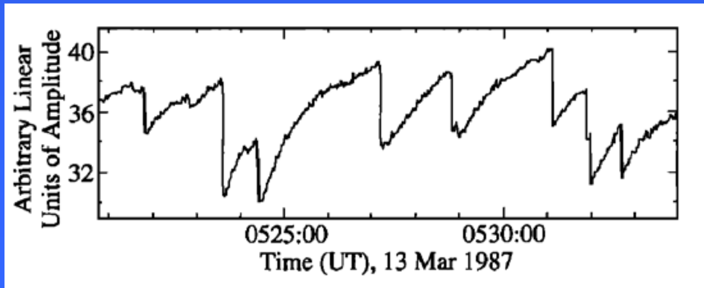
Various phenomenons modify the altitude and/or the density of the free electrons of these layers, such as:

- X ray and UV bursts from Sun flares



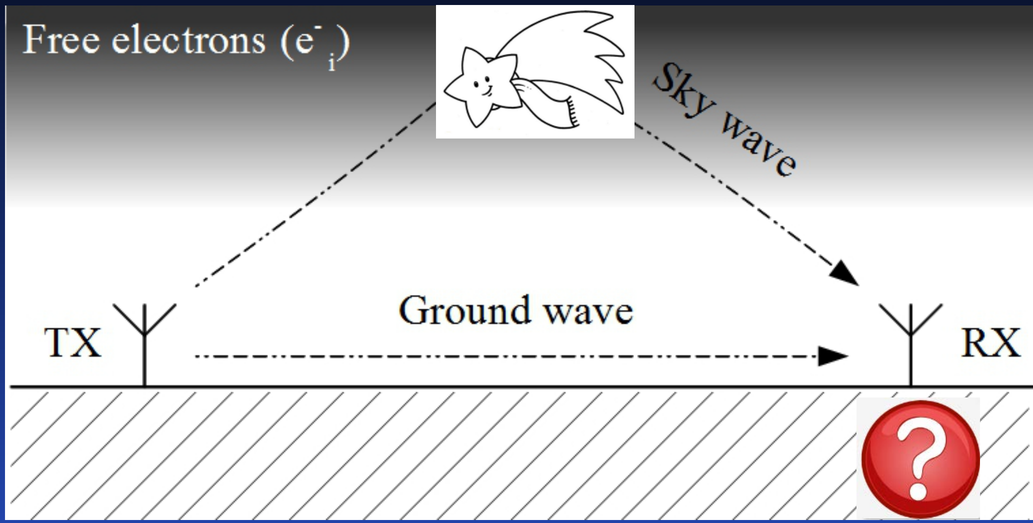
- GRB (gamma ray bursts) from distant stars

- LEP (lightning induced electron precipitations)



- Nuclear explosions, etc

On Earth, the propagation of the natural and man made VLF (very low frequency) radio waves in the Earth ground / ionosphere cavity is particularly depending on the D/E layers parameters (density and altitude or the free e^-)



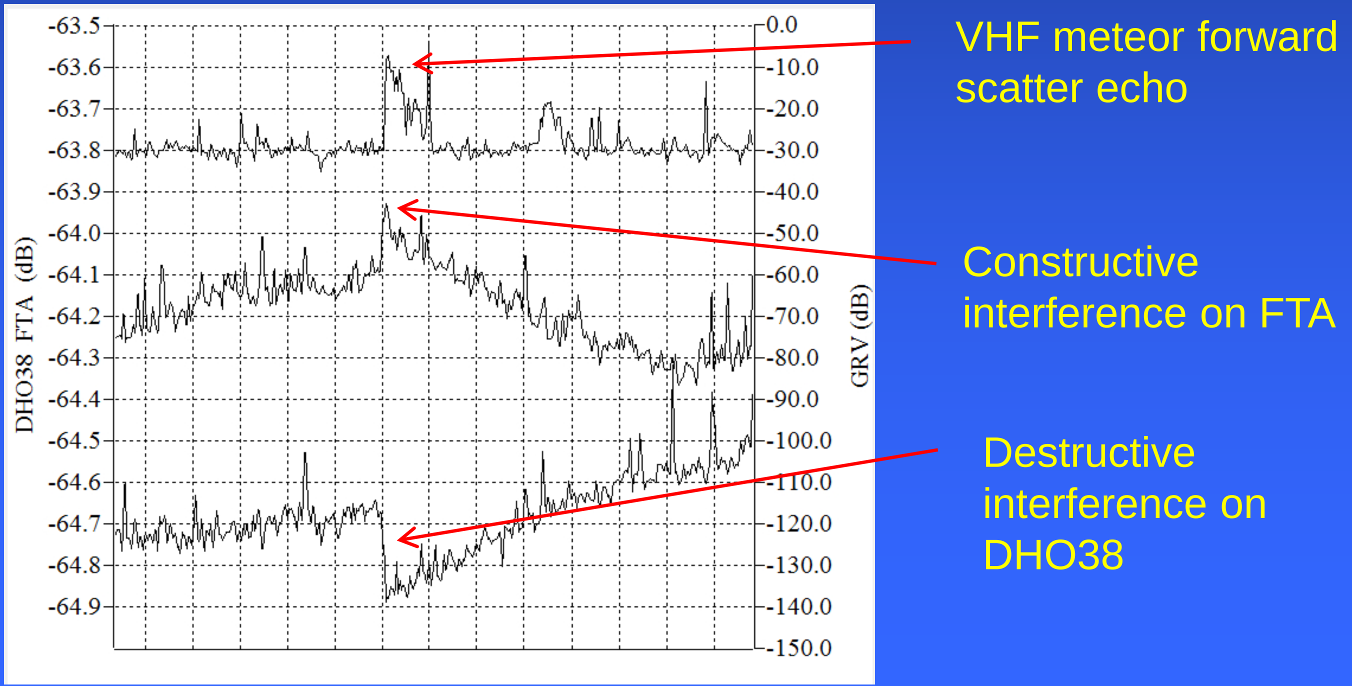
The interactions between meteors and atmosphere occur at the altitude of the D and E layers …

So the question is: « Do the meteors disturb the propagation of the VLF radio waves? »

Chilton (1961) observed global phase changes (based on daily average curves) on the VLF signals during Lyrid, δ-Aquarid, and Perseid showers

De et al. (2006) reported statistical variations on the signal strength of VLF transmissions during the Leonid 2004 shower (based on average amplitude measurements before, during and after the shower)

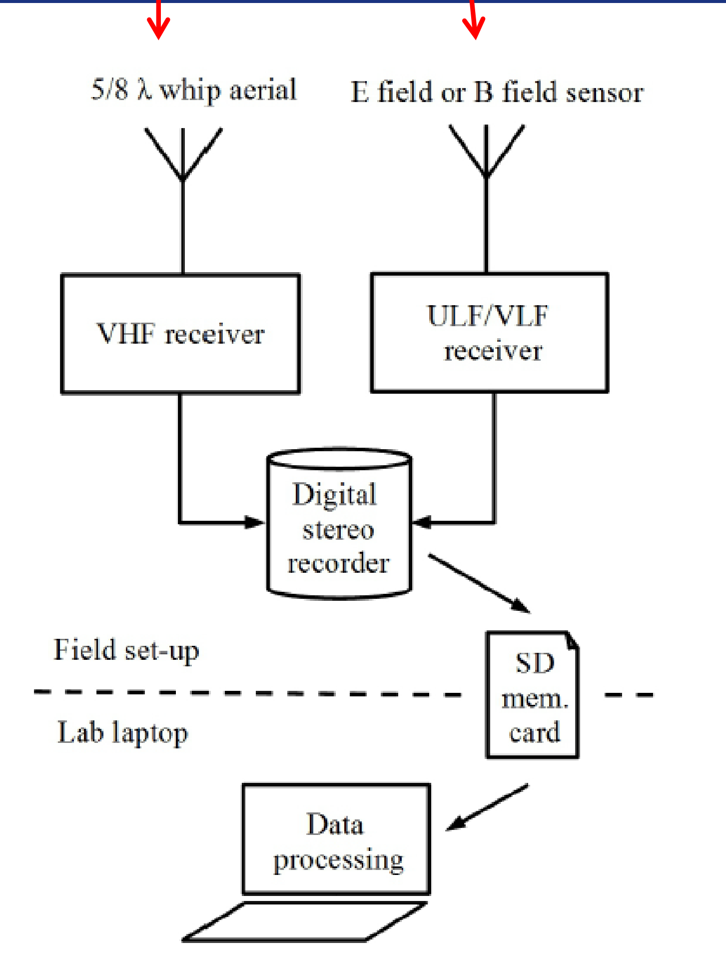
A first evidence of a VLF disturbance associated with a single meteor was found (Rault, 2013) during a Geminids 2010 radio/video campaign at Pic du Midi Observatory



Observation set-up

143 MHz GRAVES radar echoes

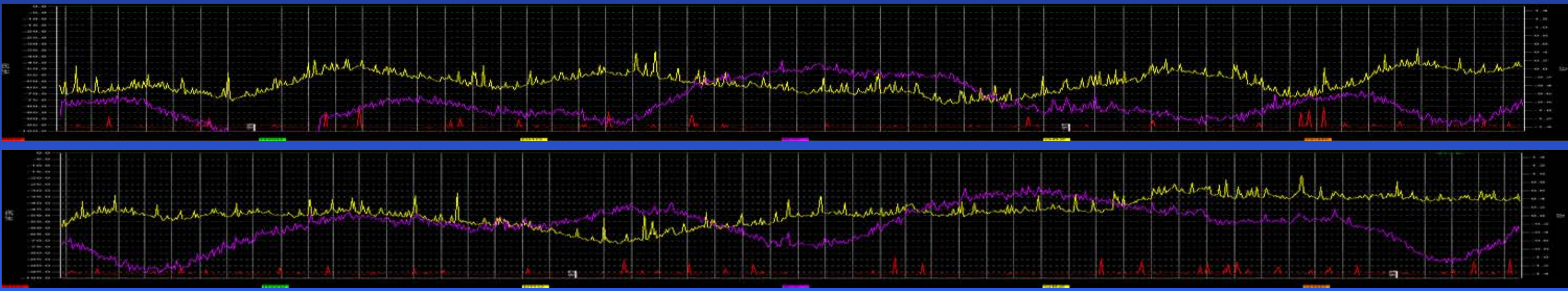
5 Hz / 24 kHz ELF/VLF



Data reduction

Searching for correlations between meteor decays and VLF amplitude disturbances consist in:

- plotting simultaneously meteor VHF forward scatter echoes and VLF transmissions amplitudes



- looking visually for any correlations

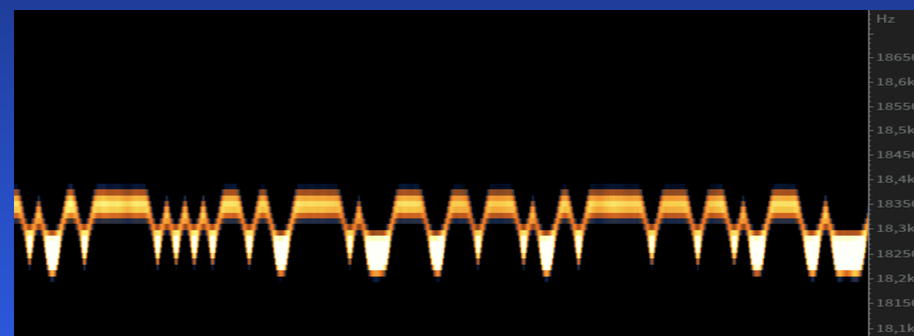
To improve the data reduction duration , the records are processed (FFT, amplitude computation and plotting) at 8 times the real time

The military VLF transmissions use a MSK (Minimum Shift Keying) waveform

Example: HWU @ Rosnay, France:

- Baud rate: 200 Bd / Frequency shift: 100 Hz

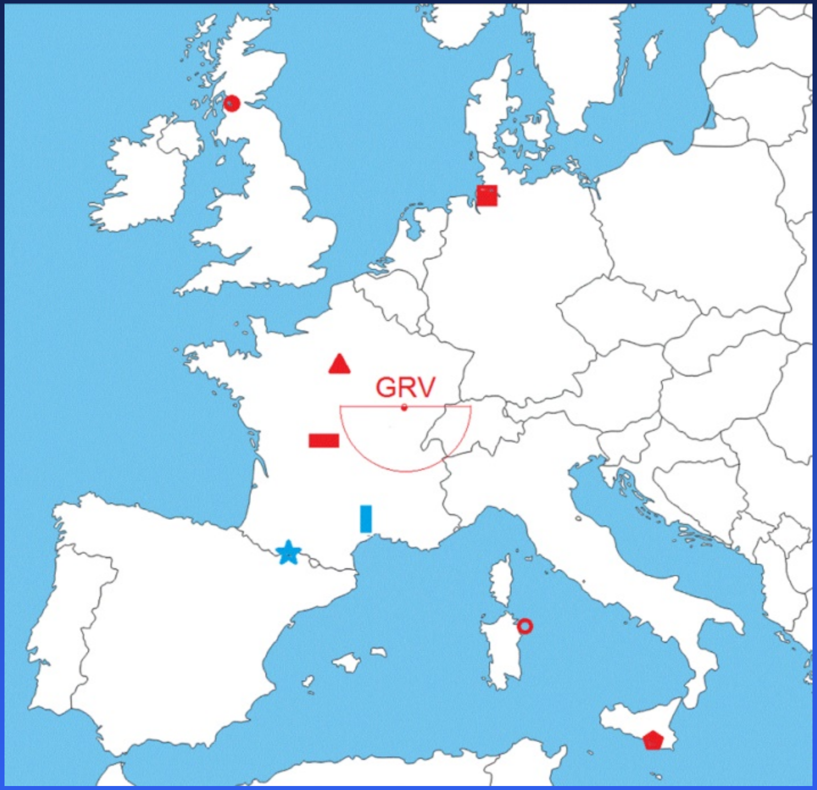
Frequency domain



Time domain

$$A(t) = \frac{1}{n}\sum_{i=1}^{n} \boldsymbol{FFT\ channel\ i}$$

Location of the VLF transmitters, VHF radar and observation areas used in this study



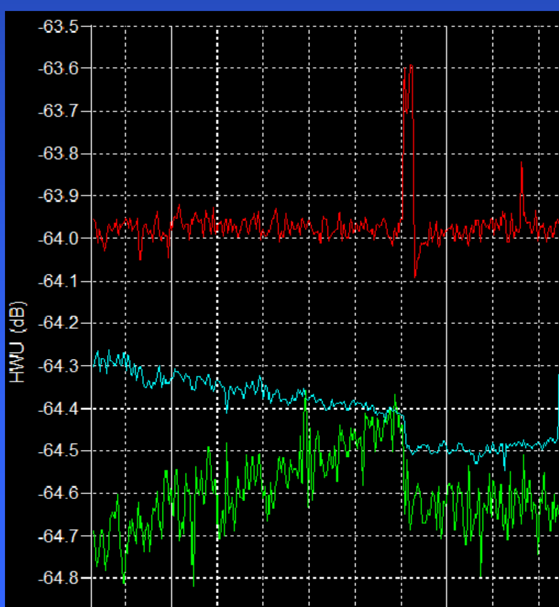
VLF transmitters: ● GBZ 19,6 kHz & GQD 22,1 kHz ■ DHO38 23,4 kHz ▲FTA 20,9 kHz ▬ HWU 21,75 kHz OICV 20,27 kHz.

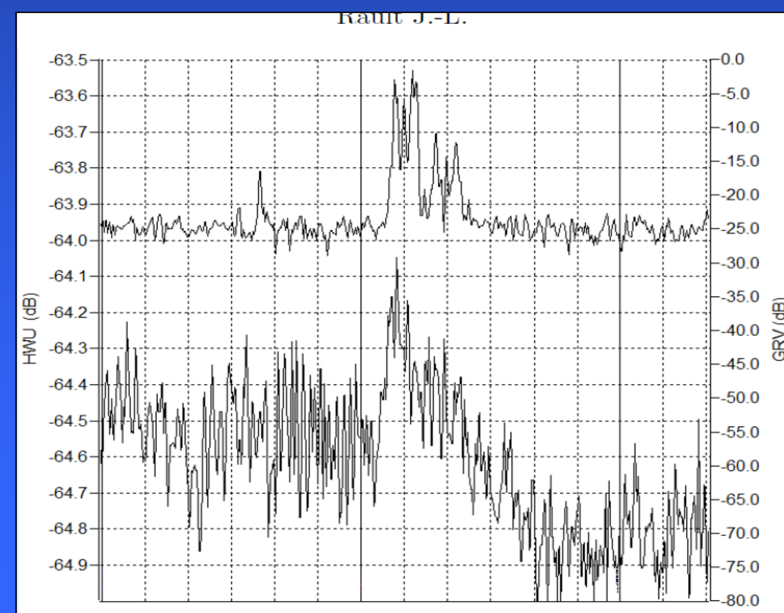
VHF radar used for meteor scatter detection: **GRV**

Observation locations: ▮ Baraque de l'Air (Lozère) ★Pic du Midi observatory

Further to the observation of a first M-SID (Meteor Sudden Ionospheric Disturbance), 29 meteors showers VLF/VHF observation campaigns since 2008 (Perseids, Geminids, Draconids, Leonids, Quadrantids, η-Aquariids and Lyrids) and some sporadic activity were re-examined to find other similar phenomenons

Numerous other M-SIDs were found among the 1,5 terabytes of recorded data, confirming the first observation.

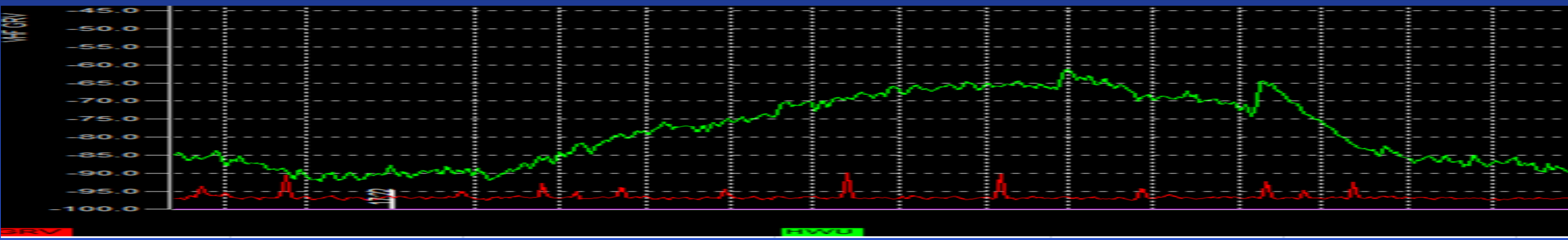




The main findings were as follows:

- To each VHF meteor detection does not correspond a particular detectable VLF amplitude disturbance …

- … and vice versa



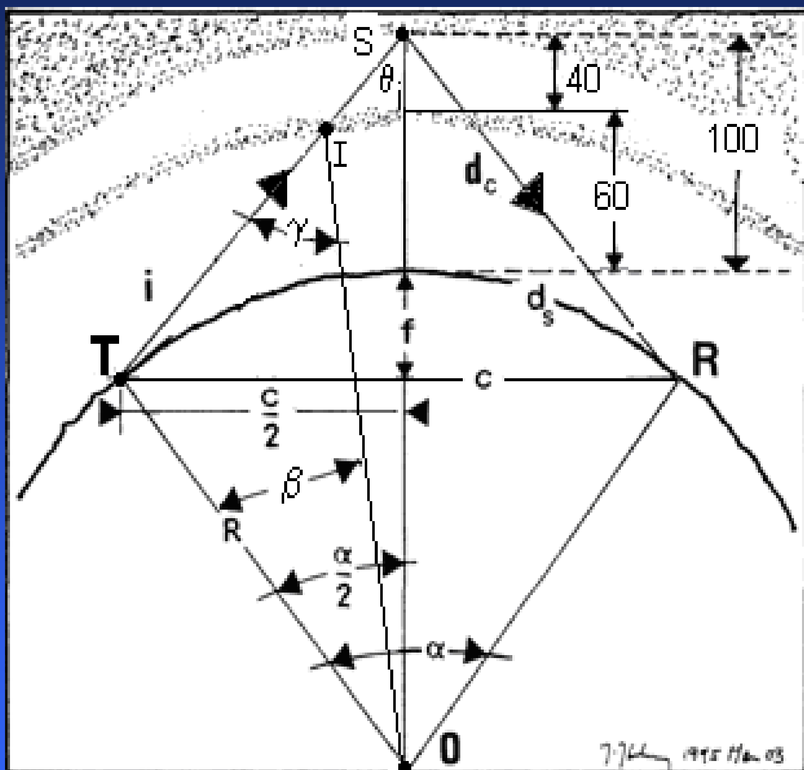
- Meteor / VLF correlations were found only during night time observation periods (no D layer present)

- An average VLF amplitude disturbance is a few tenth of dB

- Its average duration is ≤ 60 s

Analysis of the observed phenomena

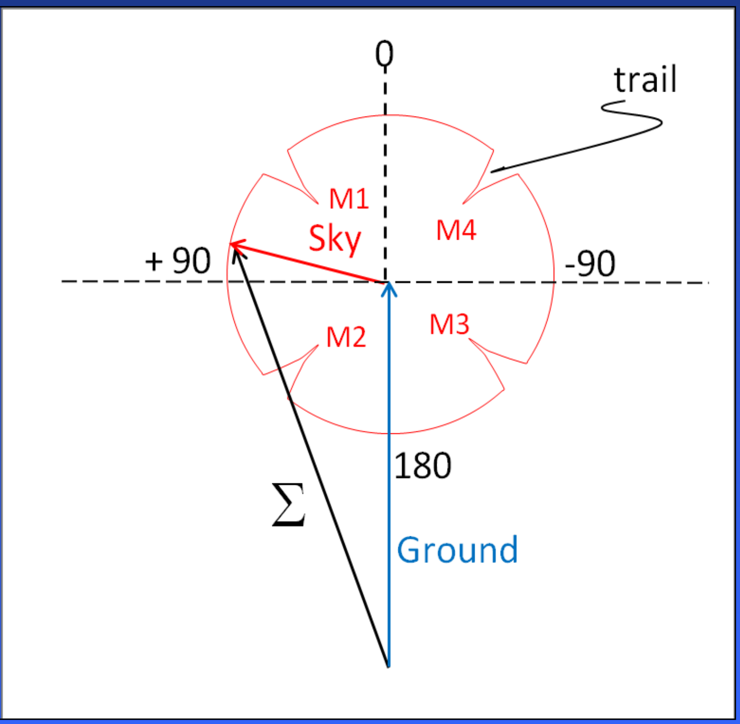
Constructive or destructive interference ?



VLF Circuit geometry

$$\varepsilon = \frac{2\sqrt{2R\,[R+h]\left[1-\cos\frac{d_S}{2R}\right] + h^2} - d_S}{\lambda} = f[h, d_S, \lambda]$$

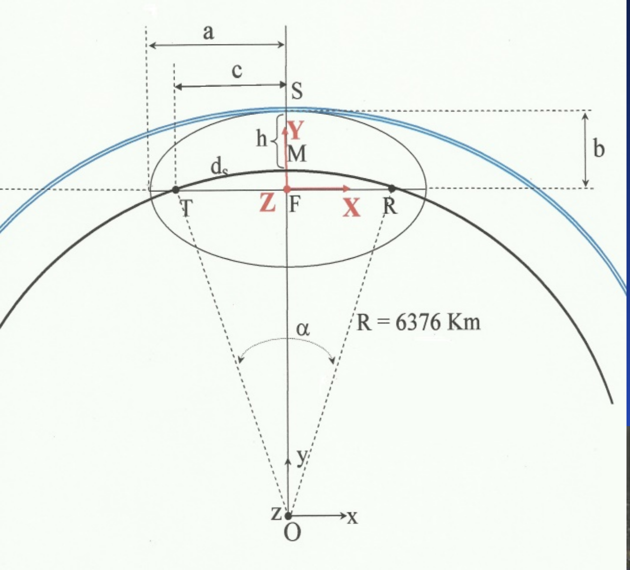
For a given distance between the transmitter and the receiver, the amplitude of the VLF signal at the reception location depends on relative phase between the sky wave and the ground wave:



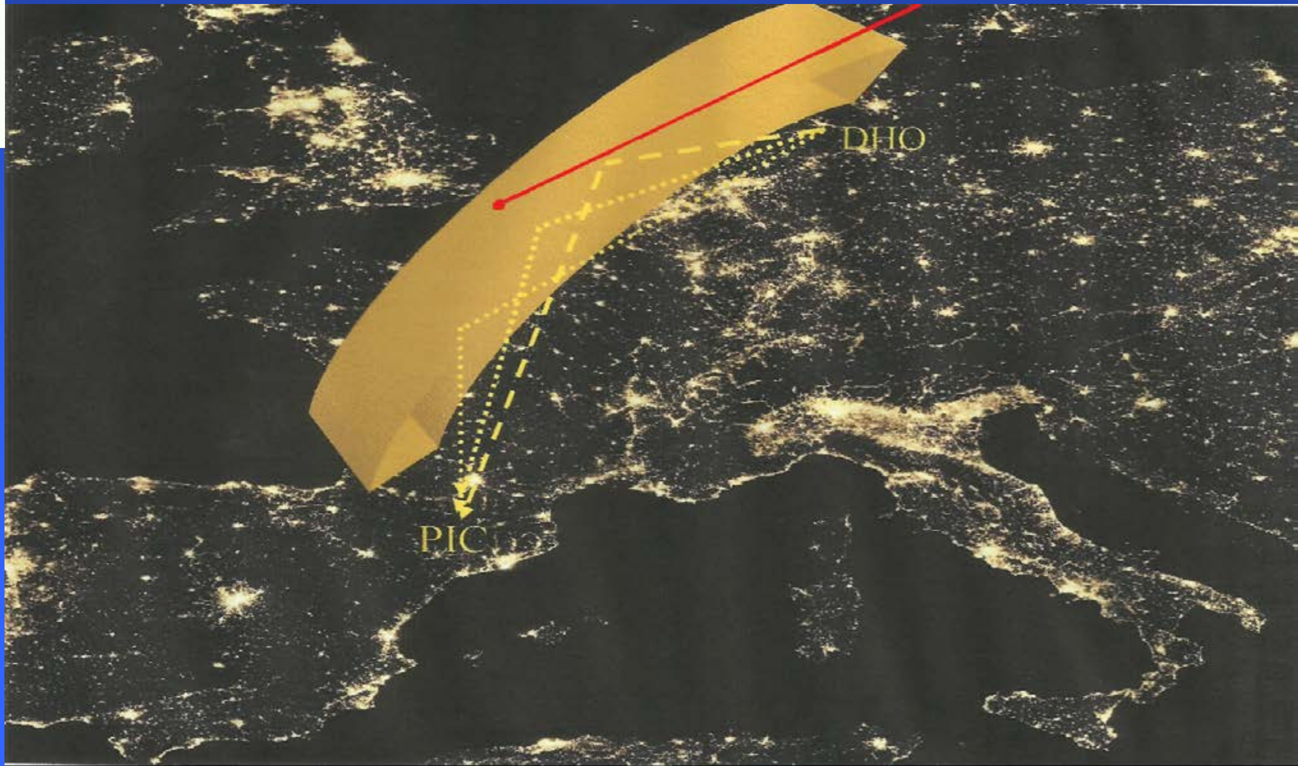
- lower signal level if $-\pi/2 < \varphi < +\pi/2$ rd
- higher signal level if $+\pi/2 < \varphi < +3\pi/2$ rd.

For the 4 events examined in detail in this presentation, the respective meteor trails altitudes were found to be 90 to 95 km

In fact, we must consider a 3D configuration because many different sky paths are possible

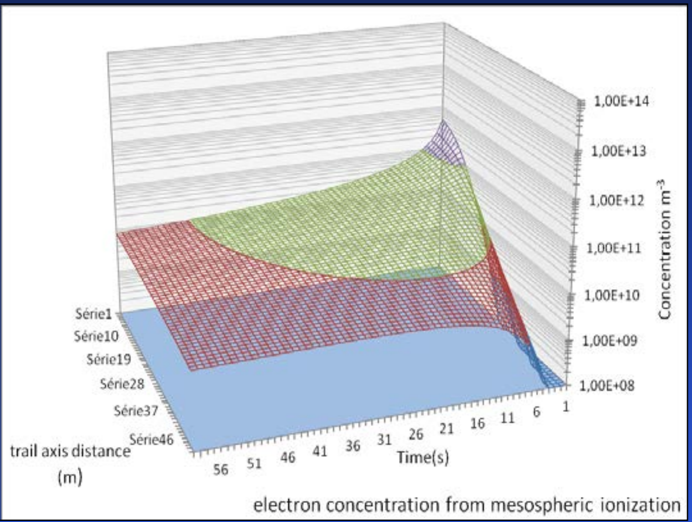


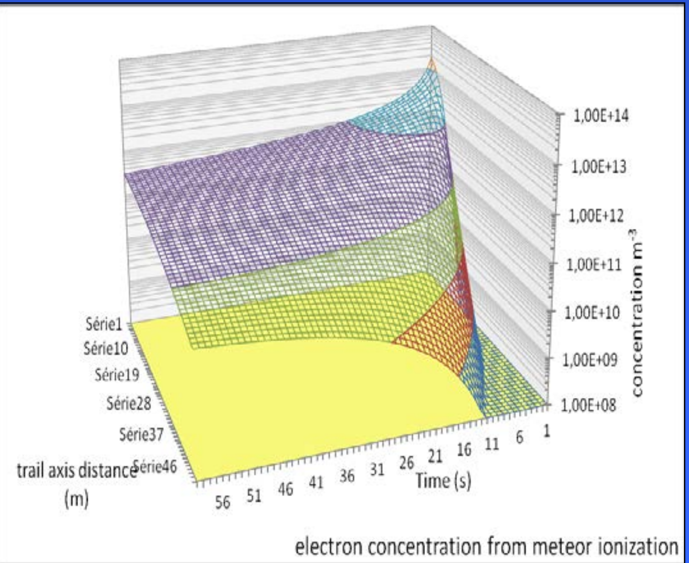
If we accept the criteria of delta Y ≤ lambda/10 for a reasonable diffraction pattern on the site of reception for d_s = 1000 km and for a few millimetres large meteor, we can expect a meteor VLF signature if the meteor decay occurs in a volume of ionosphere 200 km long, 40 km wide (S = 8 000 km^2), 20 km wide and 10 km thick and centered on the virtual point of reflection the meteor.



Analysis of the observed phenomena

What about the shape and duration of the VLF transients ?





They comply with the laws of diffusion of the free electrons of the trail

After 60 s which is the average duration observed for the VLF meteor signatures, the electron density of mesospheric origin is around 2.10^{9} m^{-3}, i.e. the same as the mesospheric background …

… while the meteoritic free electron density is in the range of 2.10^{10}, thus always discernible by the incident VLF wave

Thanks for your attention
Any questions ?