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Broad-band electric field measurements above thunderstorms by the IME-HF instrument prepared for the TARANIS mission

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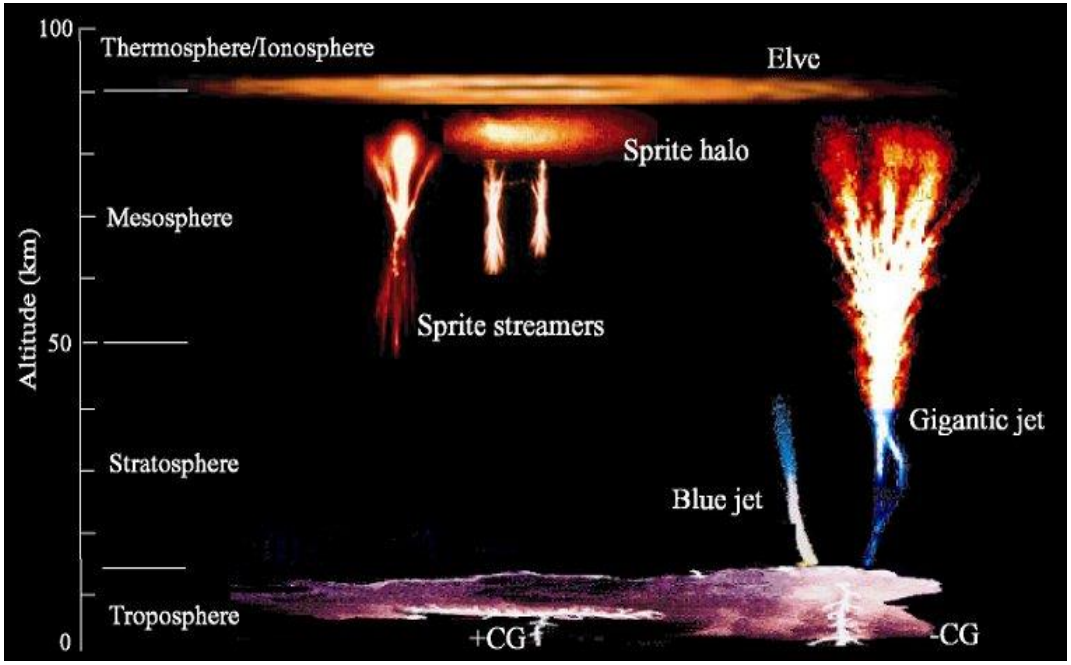
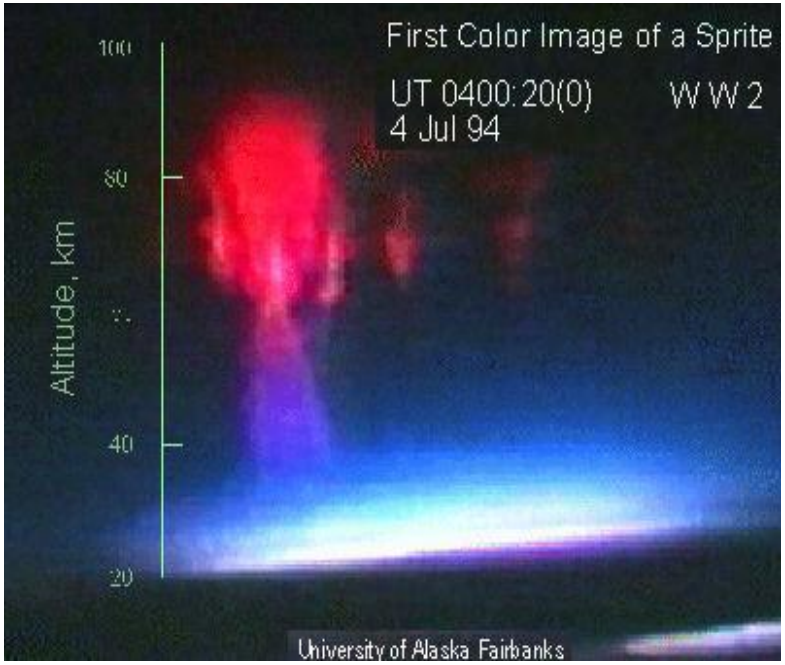
TARANIS:

(Tool for the Analysis of Radiation from lightNIng and Sprites)

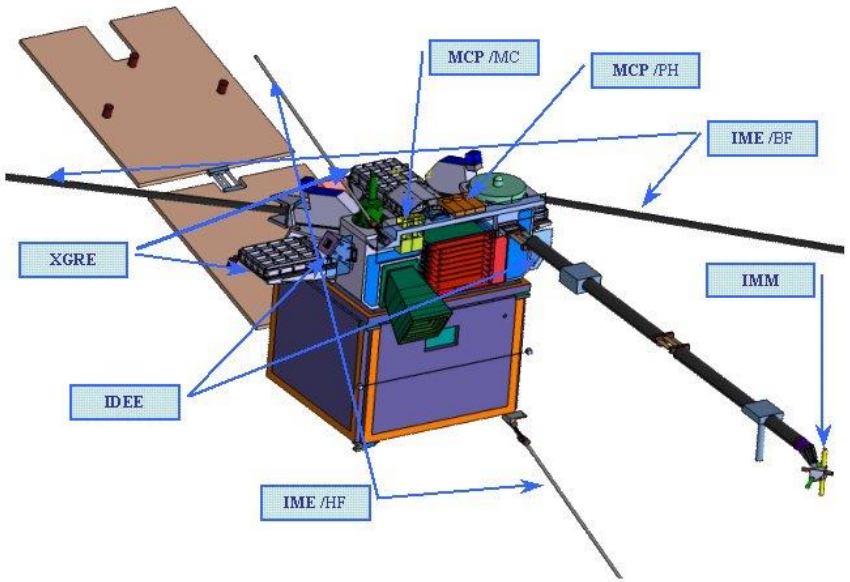
- French space agency CNES, launch in August 2020 (?)
- Scientific team lead by J-L. Pincon, LPC2E Orleans: French institutes and universities, international participation (Czechia, Poland,USA).
- Main focus: **Transient luminous phenomena, Terrestrial gamma ray flashes**

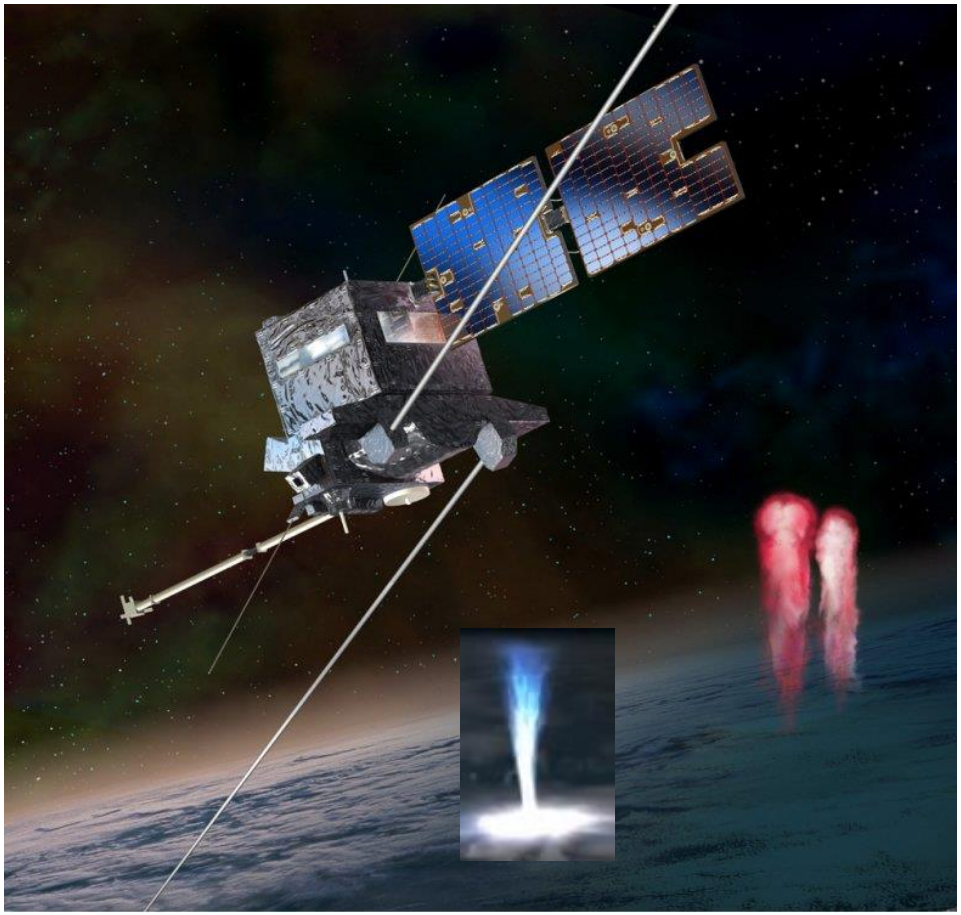




TARANIS

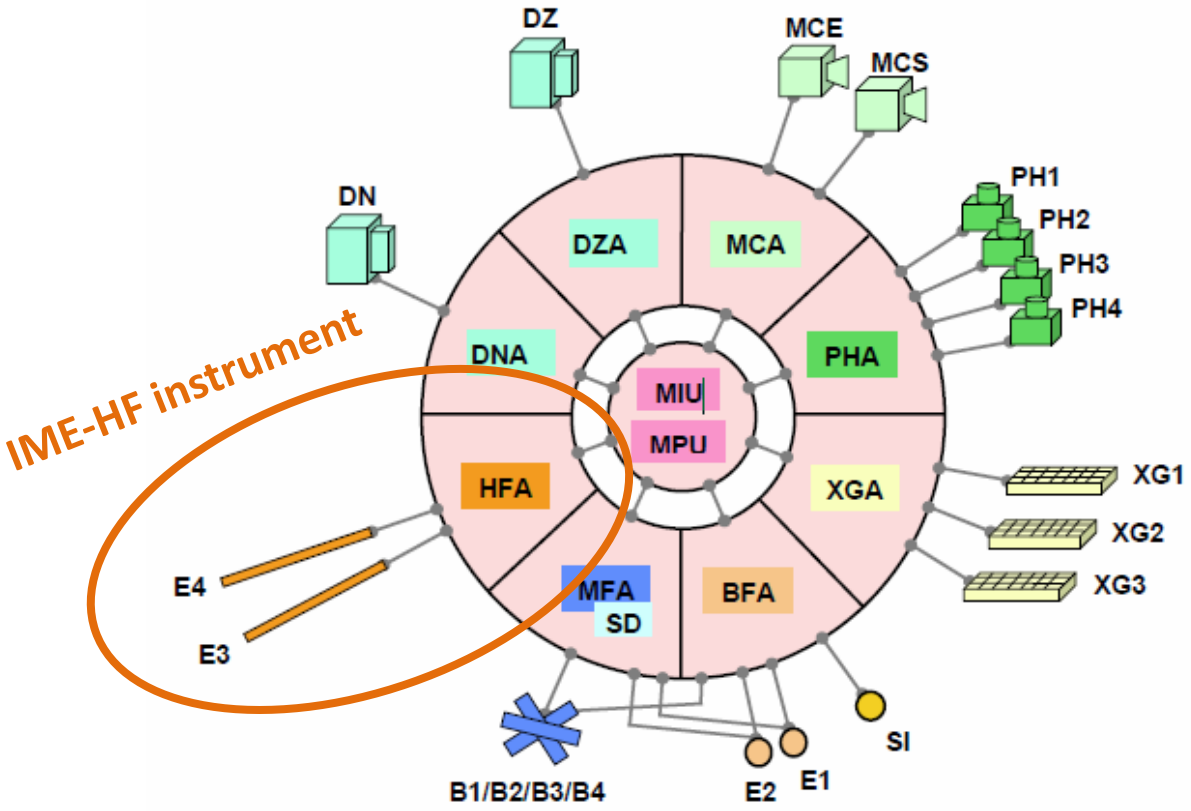
- Sun-synchronous high inclination low-Earth orbit (700 km)
- CNES MYRIDE microsat (the same as DEMETER), 160 kg
- 2-3 yeas of operations are anticipated





TARANIS

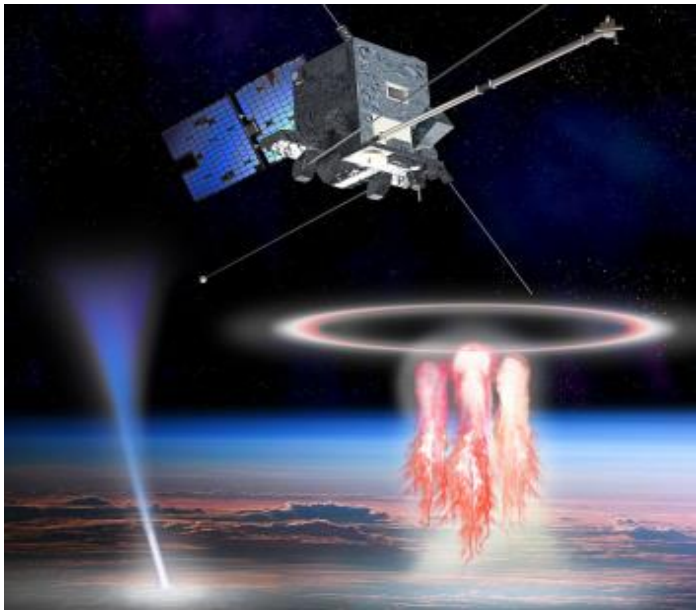
2 microcameras, 4 photometers, 2 detectors of energetic electrons, 3 X-ray detectors, instruments to measure electromagnetic fields in 3 frequency bands, onboard analysis and synchronous triggering



IME-HF instrument

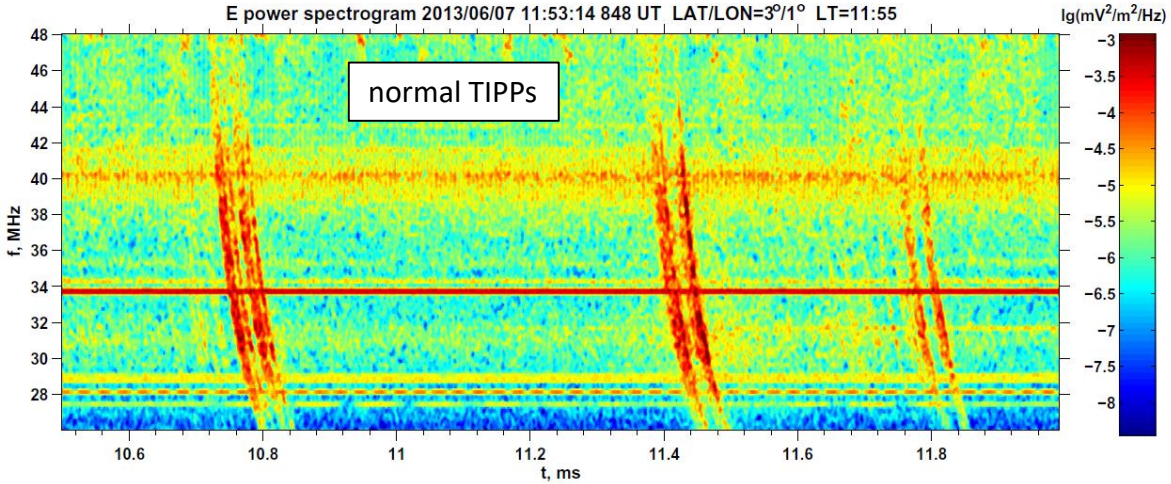
A broad-band (5 kHz – 37 MHz) analyzer intended to study radiation originating in atmospheric lightning discharges and in optical phenomena (Transient Luminous Events) observed between the Earth troposphere and ionosphere.

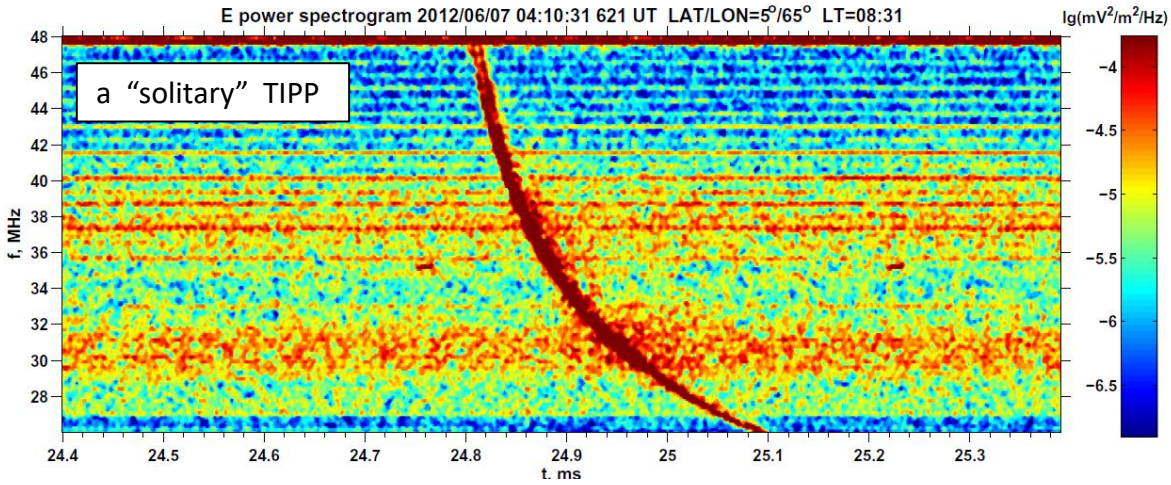
- Identification of wave signatures associated with transient luminous events and terrestrial gamma-ray flashes
- Characterization of lightning flashes from their HF electromagnetic signatures
- Identification of possible HF electromagnetic or/and electrostatic signatures of precipitated and accelerated particles
- Determination of characteristic frequencies of the medium using natural waves properties
- Global mapping of the natural and artificial waves in the HF frequency range, with an emphasis on the transient events

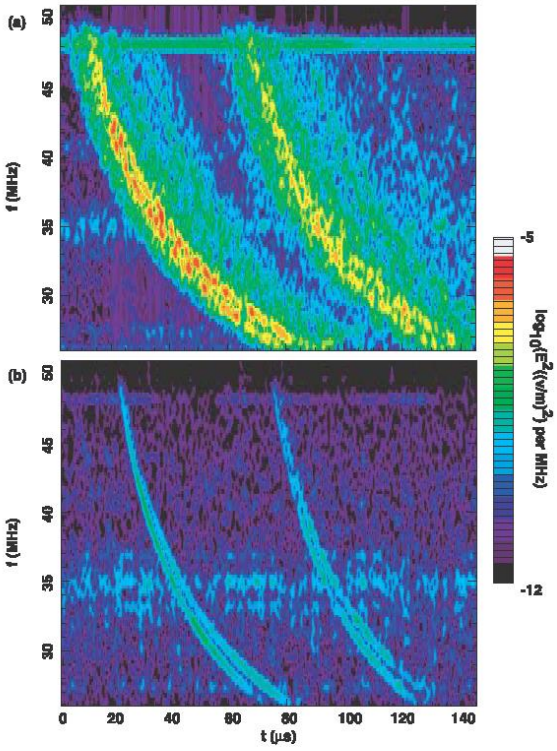


Trans-ionospheric pulse pairs (TIPPs)

- **pairs of short VHF bursts separated by a few tens of microseconds**
- **the first burst accompanies an IC discharge (Compact Intracloud Discharge)**
- **the second burst is a the ground reflection of the first burst**



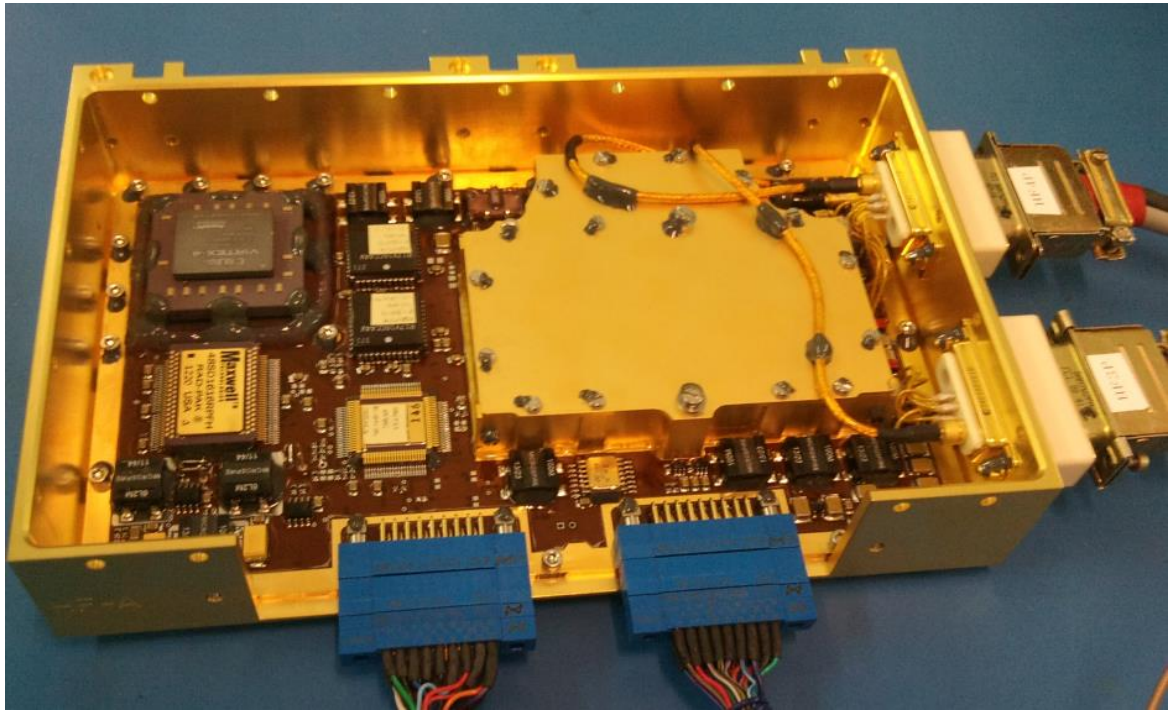




Jacobson and Light, 2003
(FORTE satellite observation)

IME-HF Analyser for the TARANIS satellite

- Broadband waveform measurements of the HF electric field between 5 kHz and 37 MHz
- Sampling frequency 80MHz, processing on a VIRTEX4 FPGA
- Onboard data selection algorithm, generation of alert signal
- 128 Mbits event mode data, 40 kbit/s survey mode data
- Power 3.8W
- Mass 470g



IME-HF Data structure

Survey data:

- Regular 80 MHz waveform snapshots (12 bit, 17us every 0.8s);
- Averaged filter bank output (12 channels, no gaps, 7.4ms resolution);
- Automatically selected best 80 MHz waveform snapshots (12 bits, 300us every 15s, enough to capture TIPPS and signals from other lightning processes).

Event data:

- Up to 416 ms of 80-MHz waveforms of internally or externally triggered events, nominally 3 events of 42 ms per half-orbit
- Full resolution 12 us filter bank data, 12 channels, up to 32 events

Radio waveforms:

- programmable down-converted 16 bit waveforms,
- bandwidths of 5 kHz, 10 kHz, 20 kHz, or 80 kHz

Flexible Detection Algorithm

1. Detection algorithm for transient signals based on filter bank channels

A rank is calculated as a sum of weighted differences between maxima and averages of the RMS values of the twelve bandpass filters.

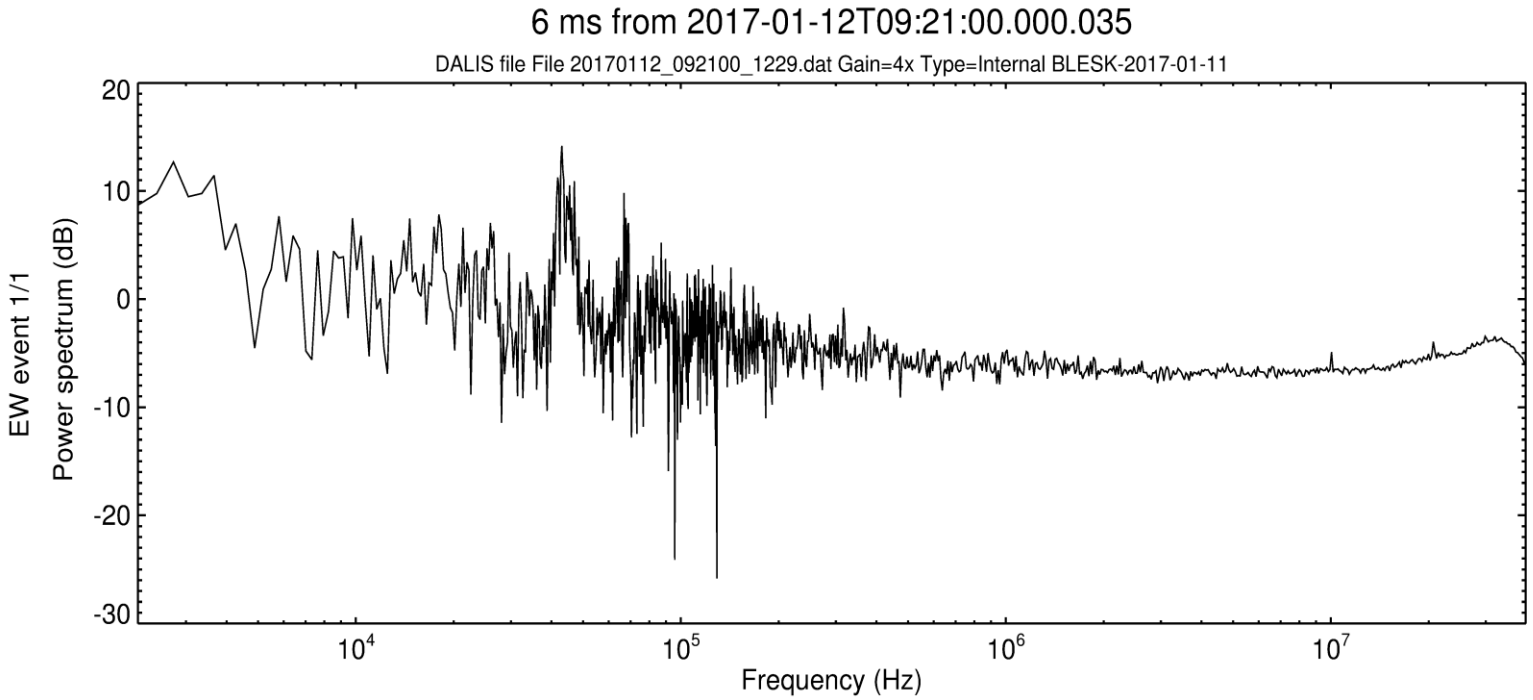
We can adjust the weight for each band-pass filter, the number of filter-bank samples over which the maximum amplitude is obtained and the interval over which the average values are calculated.

2. Detection algorithm for transient signals based on waveform

A simplified rank is calculated as a difference between maximum over a series of waveform samples and its average

Analyzer sensitivity

Analyzer withour sensors, from telemetry data, 2kHz - 40MHz :

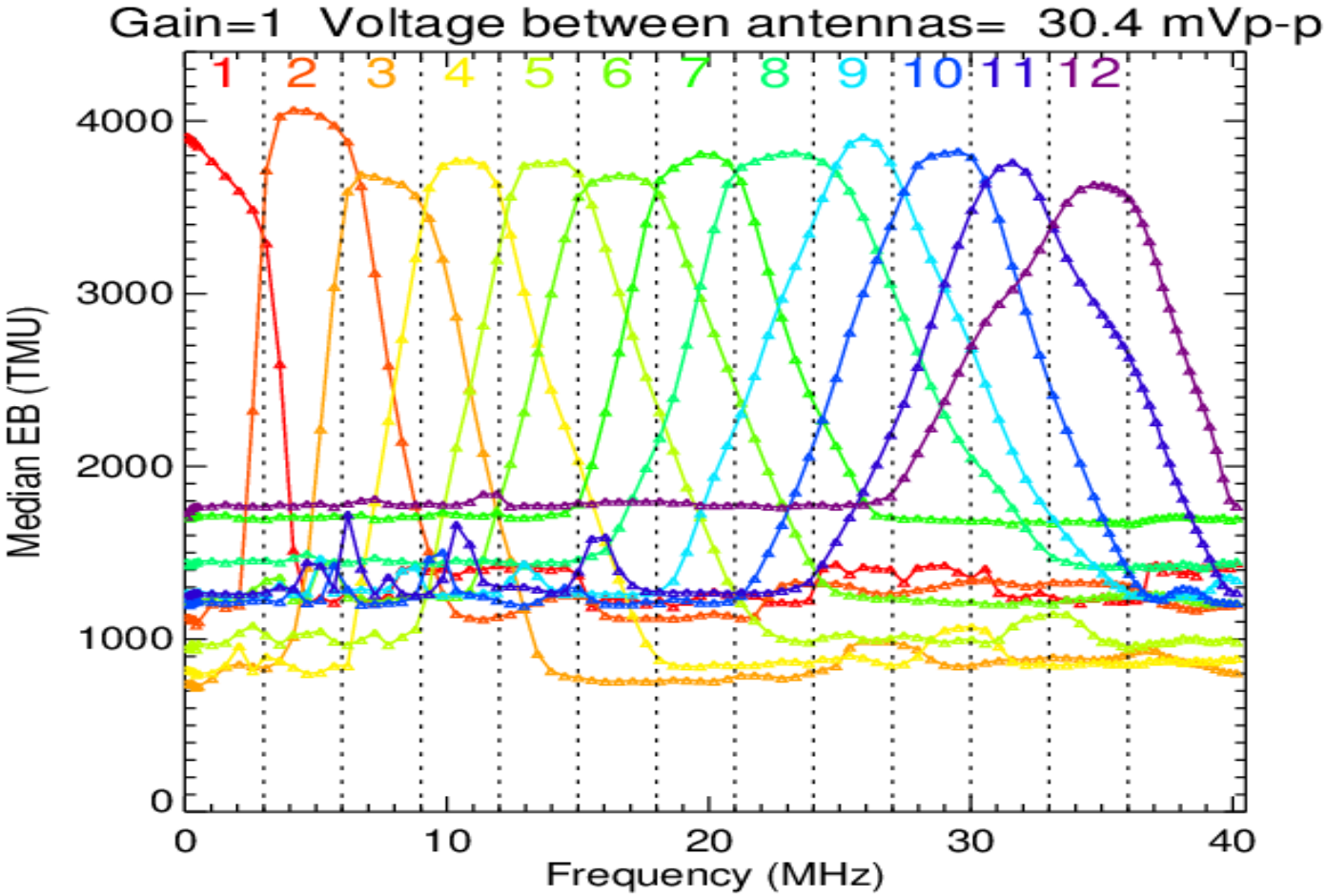


Gain 4x … amplitudes from **12 uV_{pp} m^{-1}** à **49 mV_{pp} m^{-1}**

0 dB corresponds to spectral amplitude **1.9 nV m^{-1} $Hz^{-1/2}$** (L_{eff}=1m)

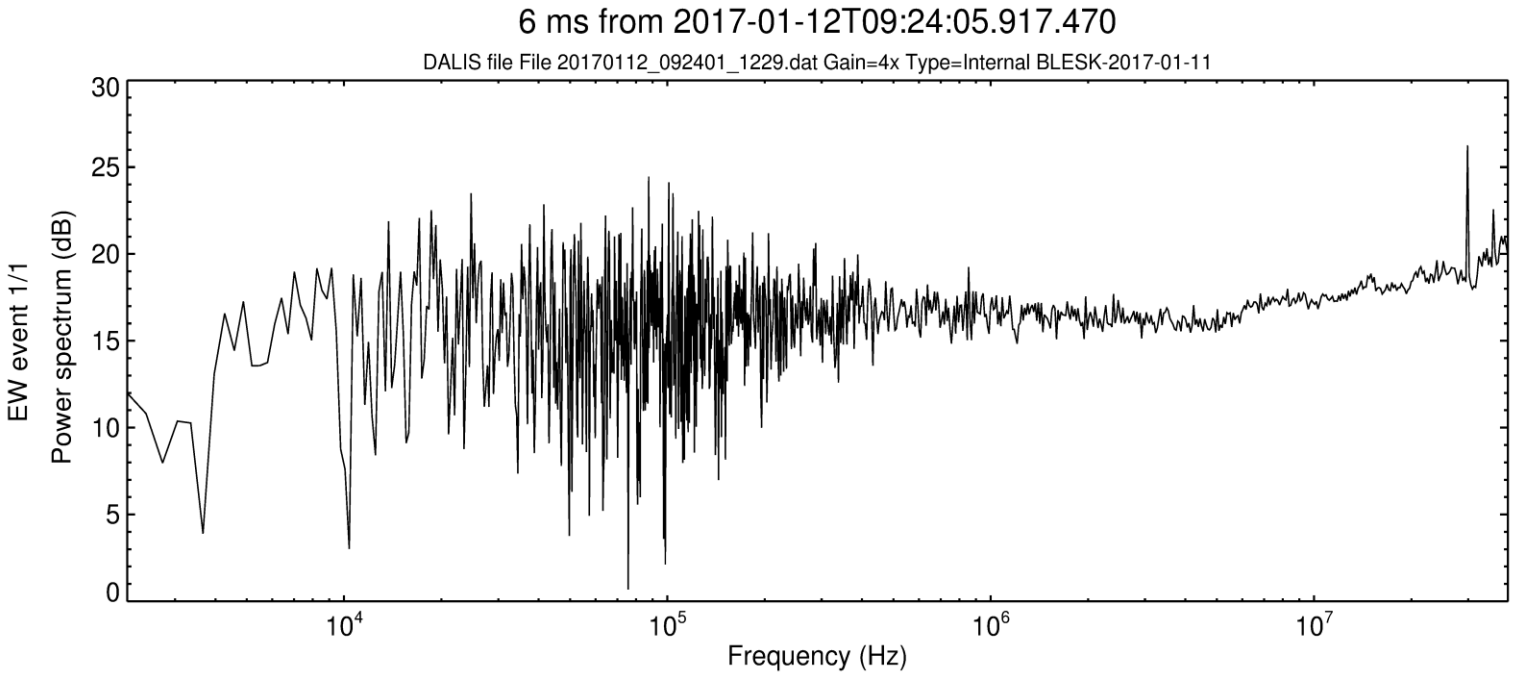
-5 dB at 1 MHz -> sensitivity **1.1 nV m^{-1} $Hz^{-1/2}$**

Filterbank frequency response



Instrument sensitivity

Sensors+ analyzer, from telemetry data, 2kHz - 40MHz :



Gain 4x … amplitudes from **12 uV$_{pp}$ m^{-1}** à **49 mV$_{pp}$ m^{-1}**

0 dB corresponds to spectral amplitude **1.9 nV m^{-1} Hz$^{-1/2}$** (L_{eff}=1m)

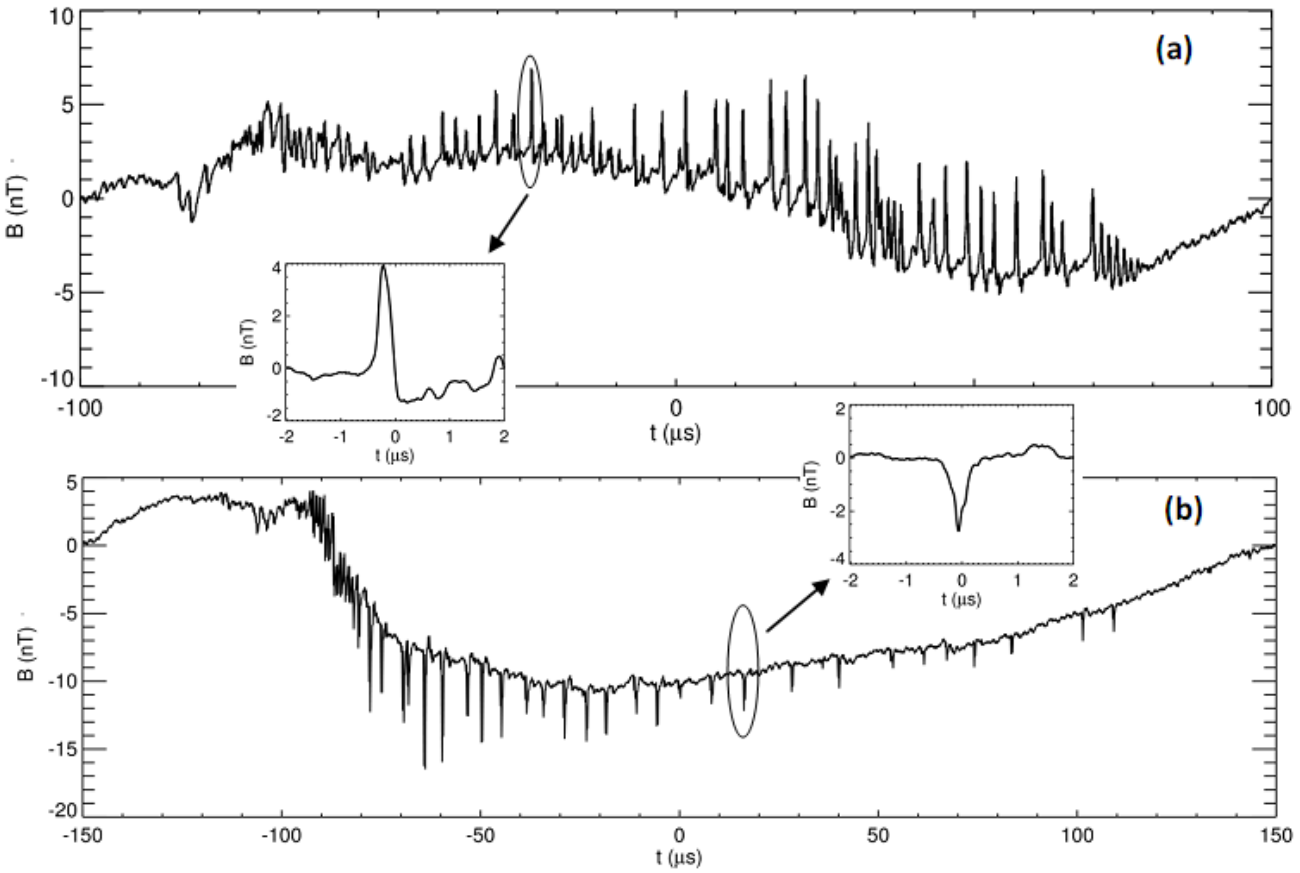
18 dB at 1 MHz -> sensitivity **15 nV m^{-1} Hz$^{-1/2}$**

Ground-based measurements

IME-HF Analyser for the TARANIS satellite is also used in high-resolution ground-based measurements of electric and magnetic fields (using Shielded Loop Antenna with Versatile Integrated Amplifier)

- Measuring station La Grande Montagne, Plateau d'Albion, in cooperation with LSBB Rustrel, France; 4 antenna interferometer, 3-component VLF measurements;
- Measuring station Corsica in cooperation with the Institute of Aerologie, Toulouse, France; with LMA;
- Measuring station Lomnicky stit observatory, High Tatras, in cooperation with the IEP SAS, Kosice, Slovakia; with cosmic ray detectors
- Measuring site Milesovka meteorological observatory, Czechia;
- Measuring site, Ter Wisch, Netherlands; with LOFAR.

Measurement of inter-stroke pulse sequences

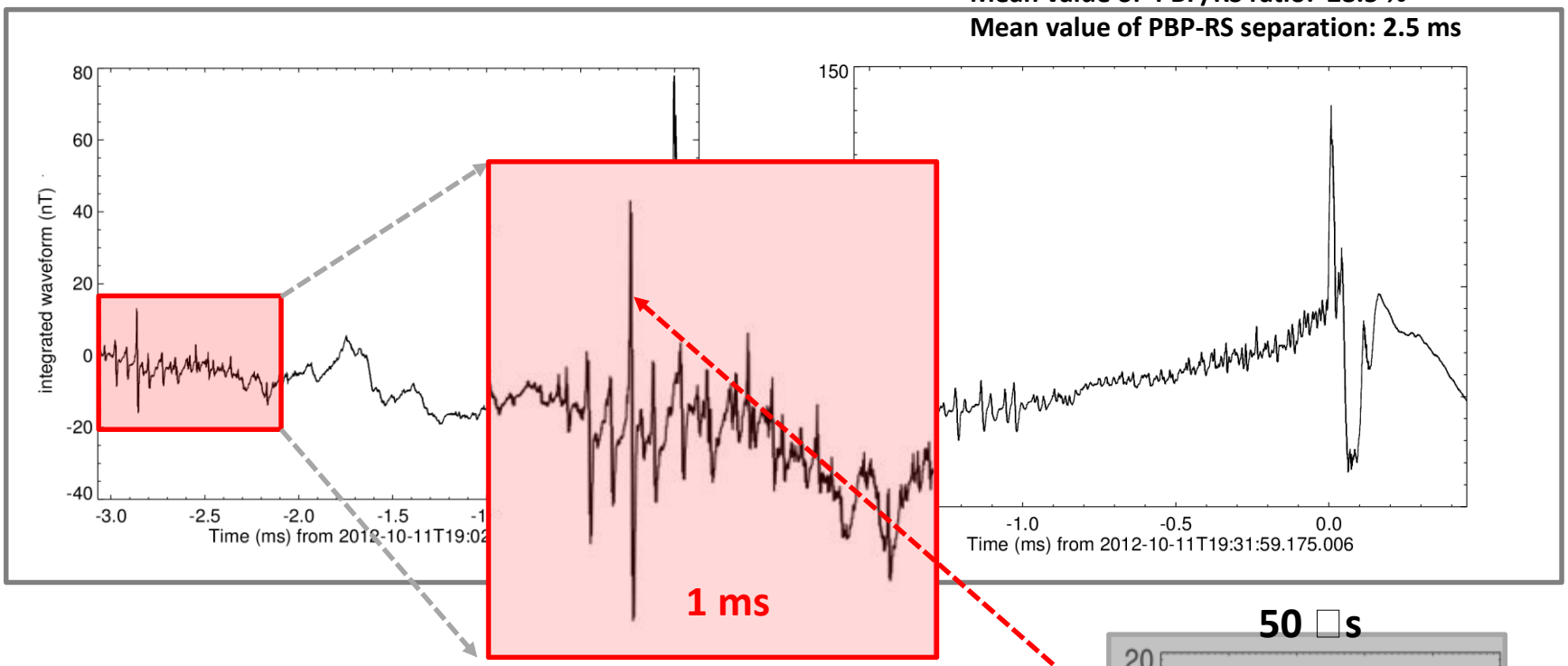


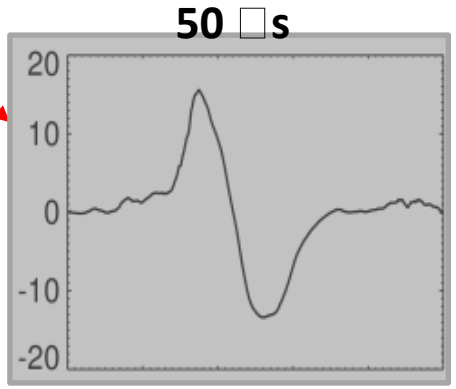
Kolmašová, I., and O. Santolík (2013), Properties of unipolar magnetic field pulse trains generated by lightning discharges, *Geophys. Res. Lett.*, 40, 1637–1641, doi:10.1002/grl.50366.

Kašpar, P., O. Santolik, and I. Kolmašová (2015), Unipolar and bipolar pulses emitted during the development of lightning flashes, *Geophys. Res. Lett.*, *42*, 7206–7213, doi:10.1002/2015GL064777.

Measurement of short pre-stroke pulse sequences

Mean value of PBP/RS ratio: 28.5 %
Mean value of PBP-RS separation: 2.5 ms

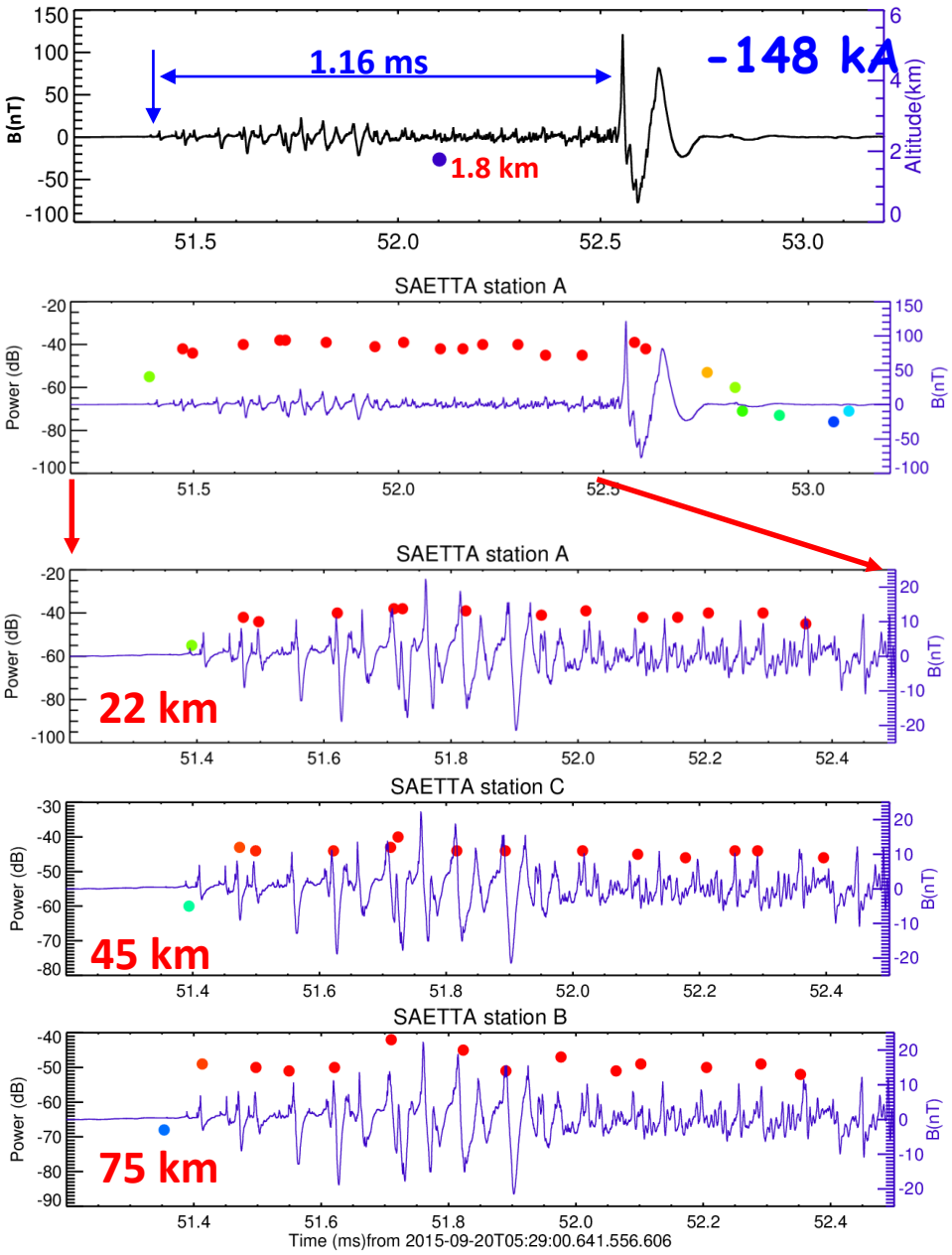


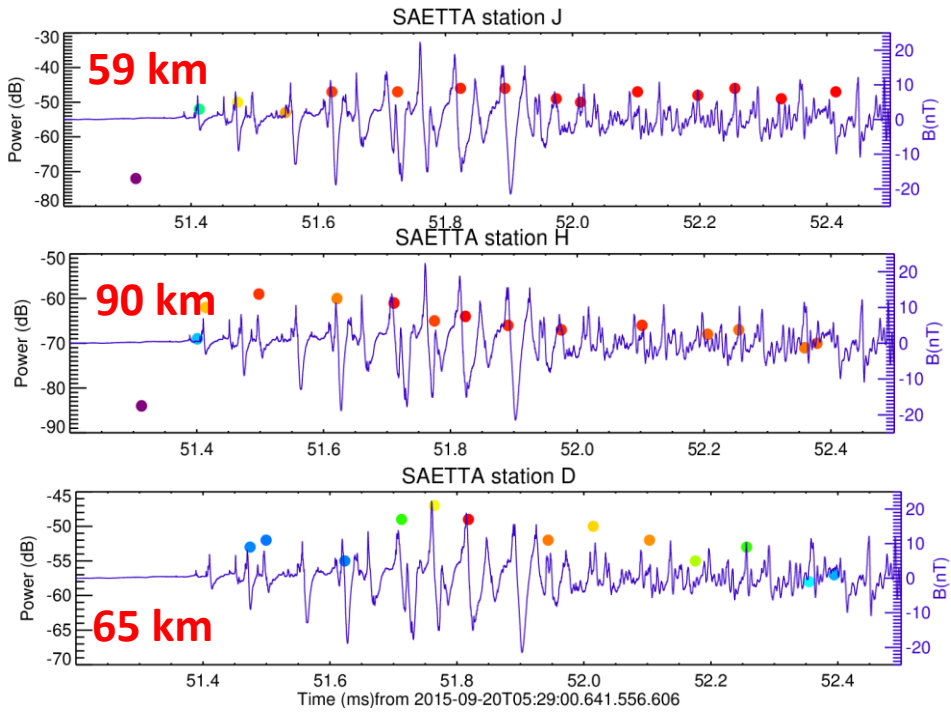


Kolmašová, I., O. Santolík, T. Farges, W. Rison, R. Lán, and L. Uhlíř (2014), Properties of the unusually short pulse sequences occurring prior to the first strokes of negative cloud-to-ground lightning flashes, *Geophys. Res. Lett.*, 41, 5316–5324, doi:10.1002/2014GL060913.

Kolmašová, I., O. Santolík, T. Farges, S. A. Cummer, R. Lán, and L. Uhlíř (2016), Subionospheric propagation and peak currents of preliminary breakdown pulses before negative cloud-to-ground lightning discharges, *Geophys. Res. Lett., 43*, 1382–1391, doi:10.1002/ 2015GL067364.

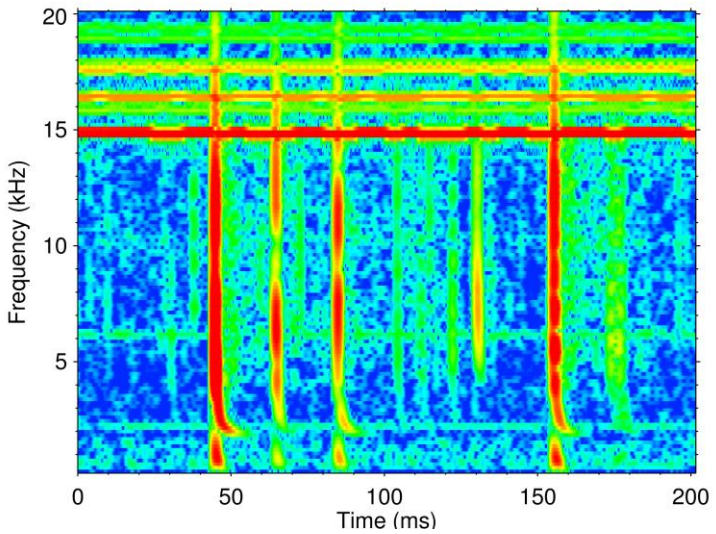
Broadband measurements x SAETTA

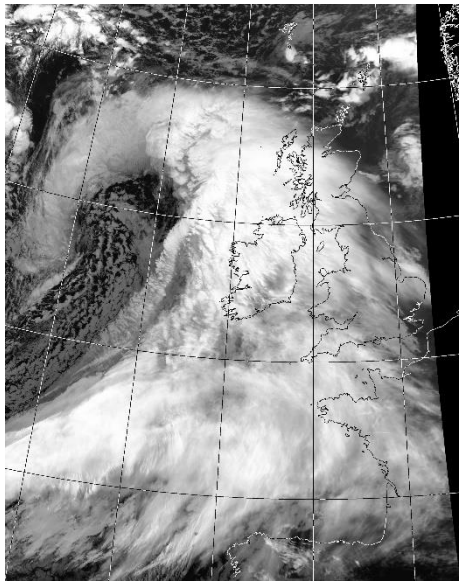


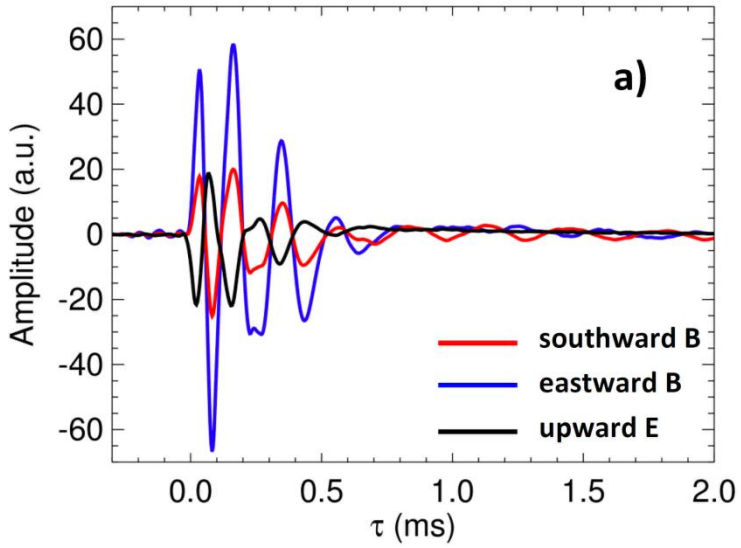


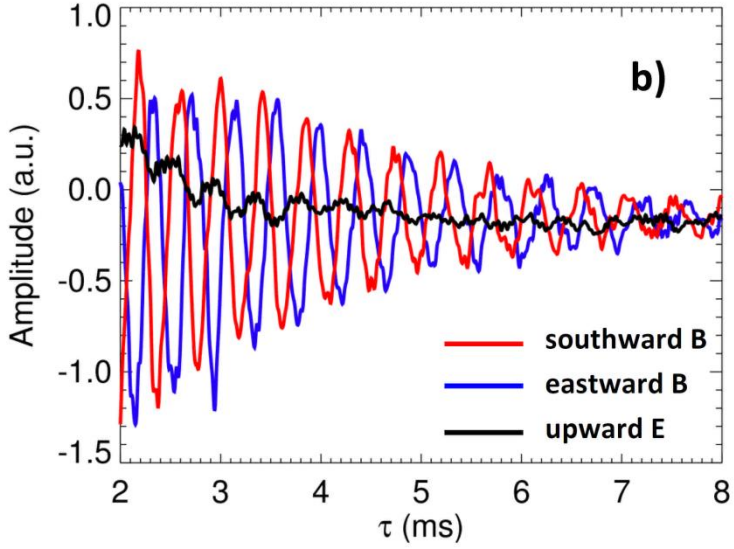
Kolmašová, I., O. Santolík, E. Defer, W. Rison, S. Coquillat, S. Pedeboy, R. Lán, L. Uhlíř, J.-P. Pinty, S. Prieur, V. Pont (2018), Lightning initiation: Strong pulses of VHF radiation accompany preliminary breakdown, Scientific Reports, 8, 1, 3650

Daytime Tweek Atmospherics









Santolík, O., I. Kolmašová (2017), Unusual Electromagnetic Signatures of European North Atlantic Winter Thunderstorms, Scientific Reports, 7,1, 13948.

Conclusions

- Broad-band electric field measurements up to 37 MHz have been prepared for the TARANIS spacecraft, waiting for launch;
- Ground based measurements in the same frequency range and at different measurement site in Europe will support the TARANIS mission;
- Examples of recent results of these measurements show a range of subjects from the preliminary breakdown processes, through interstroke pulse sequences, to tweek atmospherics.