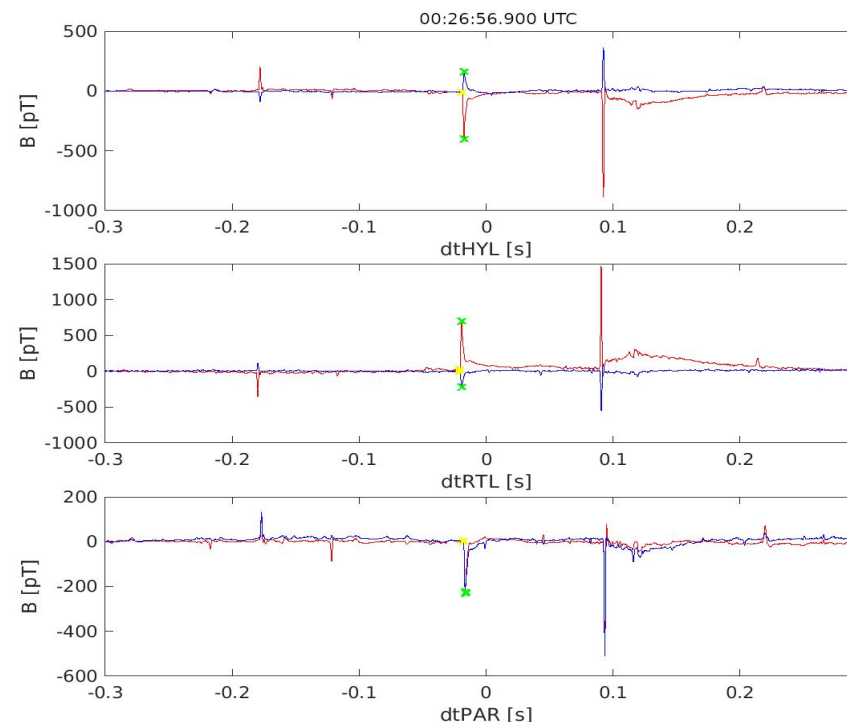
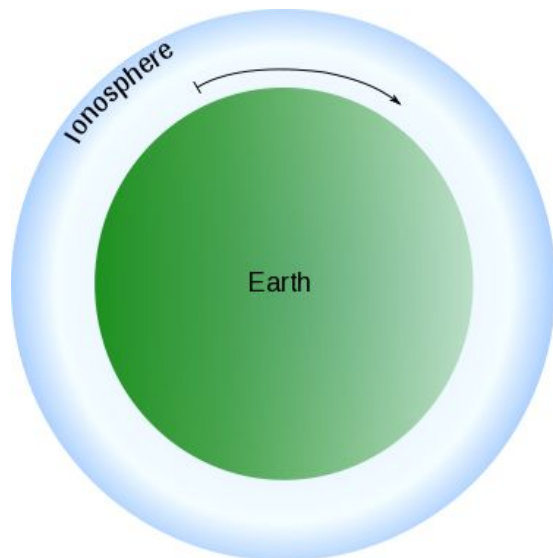


ELF research at AGH University of Krakow

Janusz Mlynarczyk, Andrzej Kulak, Jerzy Kubisz, Slawomir Klucjasz, and the Krakow ELF group

Main interests:

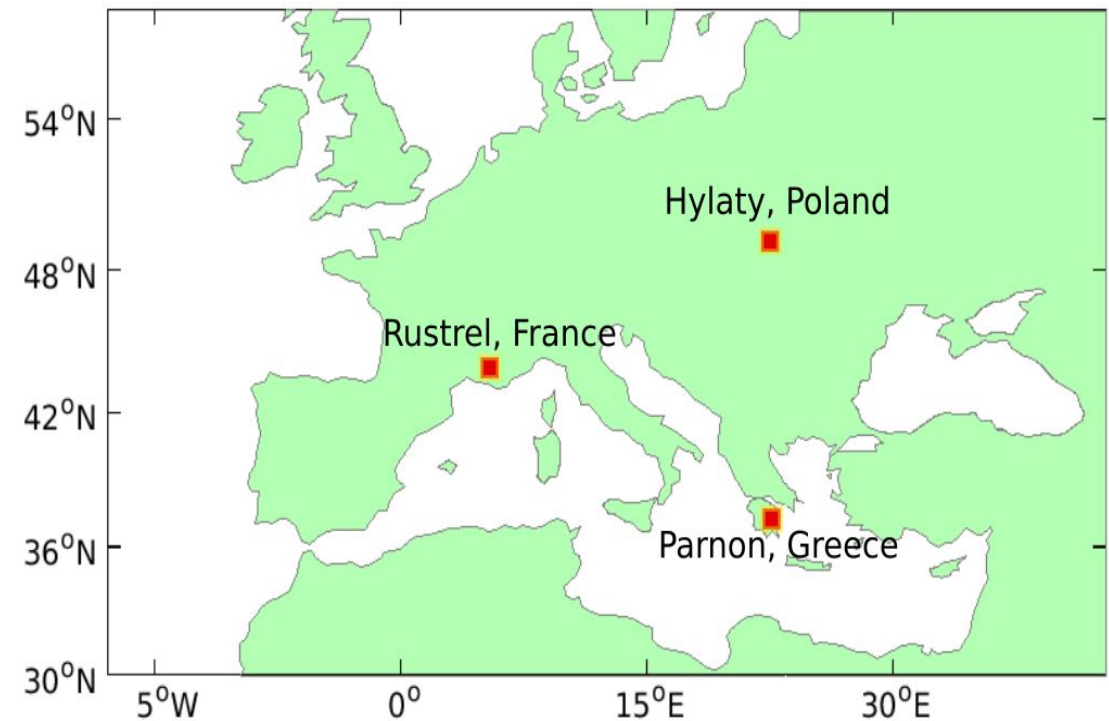
- Studying radiowave propagation in the ELF range and improving the models
- Studying ELF transients, with focus on powerful lightning discharges associated with Transient Luminous Events, and with ELF Whistlers
- Designing state-of-the-art ELF equipment



■ New broadband ELF measurement system

Our new system was designed mainly for studying individual lightning discharges, especially those associated with Transient Luminous Events (TLEs)

- Two active magnetic antennas (coils) with the frequency range from 0.02 Hz to 1.1 kHz
 - ✓ a very small lower cut-off frequency is crucial for reliable measurement of continuing current phase, which sometimes lasts for hundreds of milliseconds
 - ✓ a high upper cut-off frequency allows us to obtain a high signal-to-noise ratio for individual lightning discharges (the higher the upper cut-off frequency, the higher the recorded peak amplitude. Since we have no influence on the Schumann resonance background level, the higher the impulse peak amplitude the weaker the iCMC that can be measured reliably)

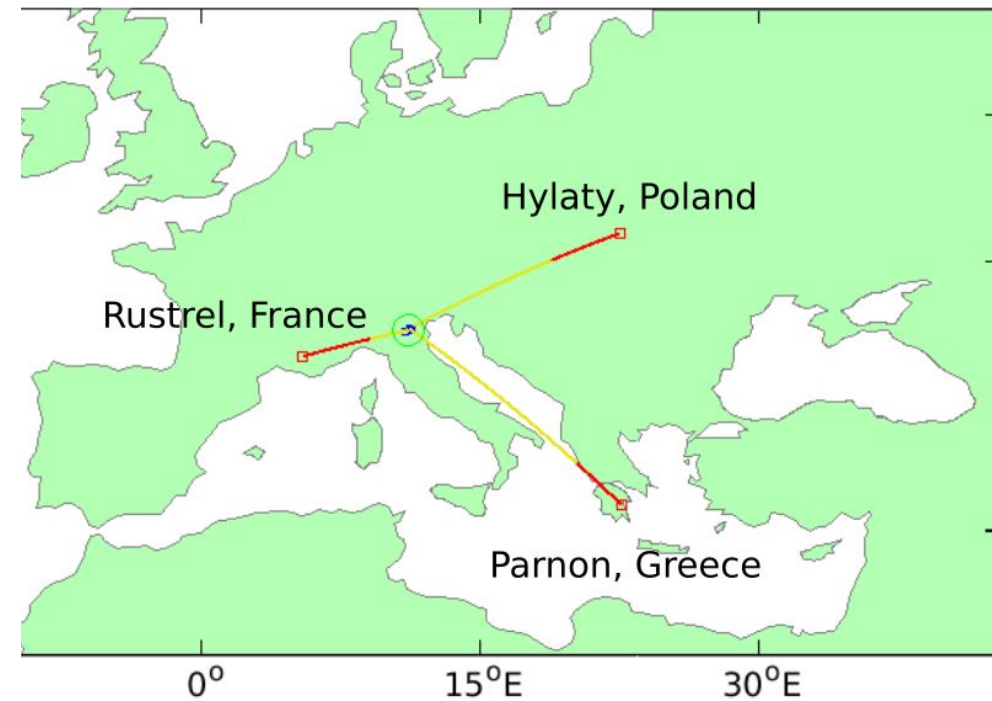
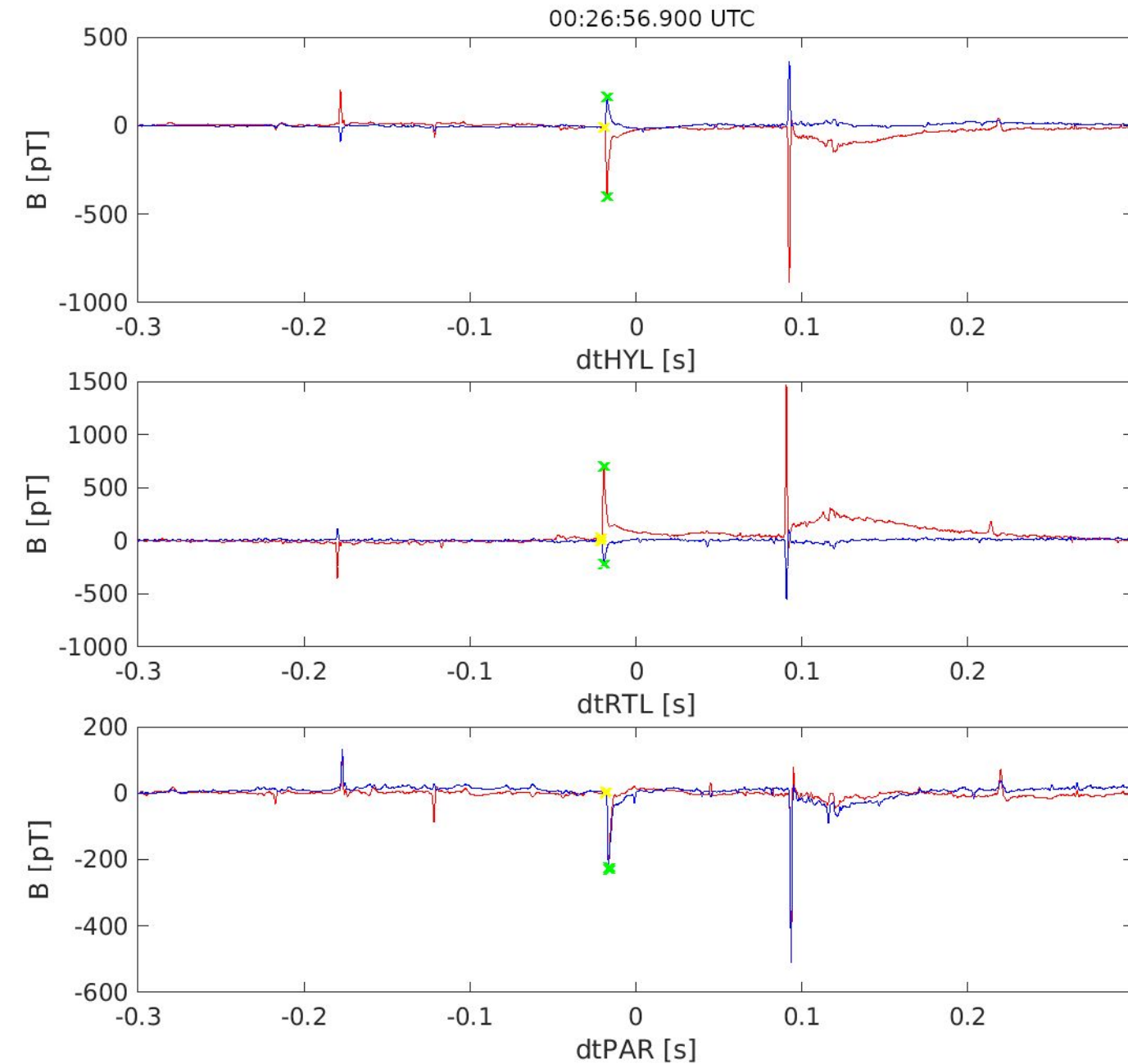


Broadband ELF Radiolocation System (BERS)

Current location of the measurement stations

- A receiver that features a Bessel anti-aliasing filter with the energy bandwidth of 900 Hz and a sampling frequency of 3 kHz
 - ✓ a Bessel filter allows us to measure the ELF signatures of individual lightning without distortions caused by other types of commonly used anti-aliasing filters

■ Broadband ELF Radiolocation System (BERS)



ELF research at AGH University of Krakow

- Use of ELF measurements in research on lightning and Transient Luminous Events (TLE).



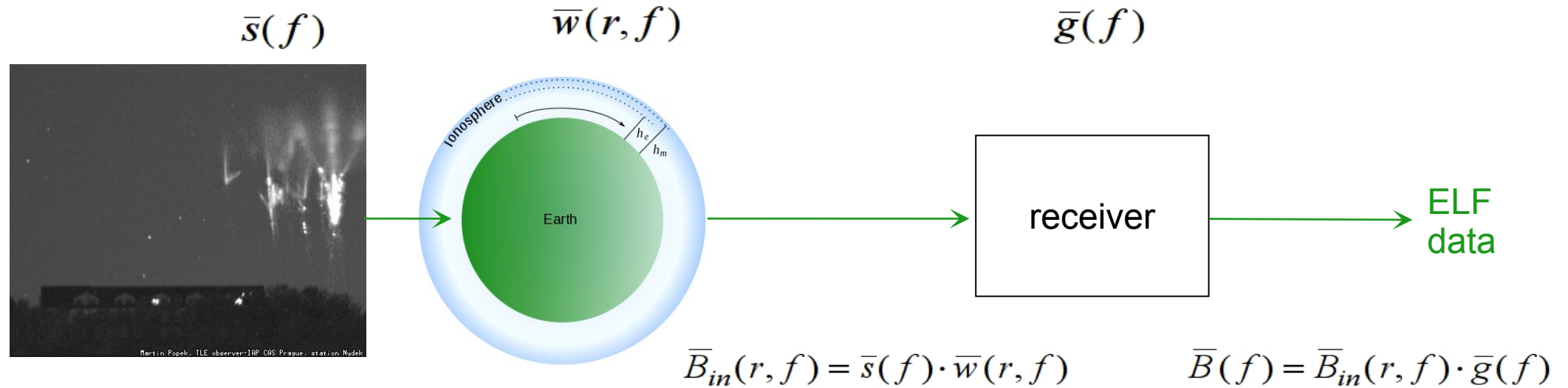
A sprite recorded by Martin Popek in Nydek, Czechia
from the distance of 467 km



An upward cloud-to-air discharge above a Mediterranean Storm
[Soula et al, GRL, 2023]

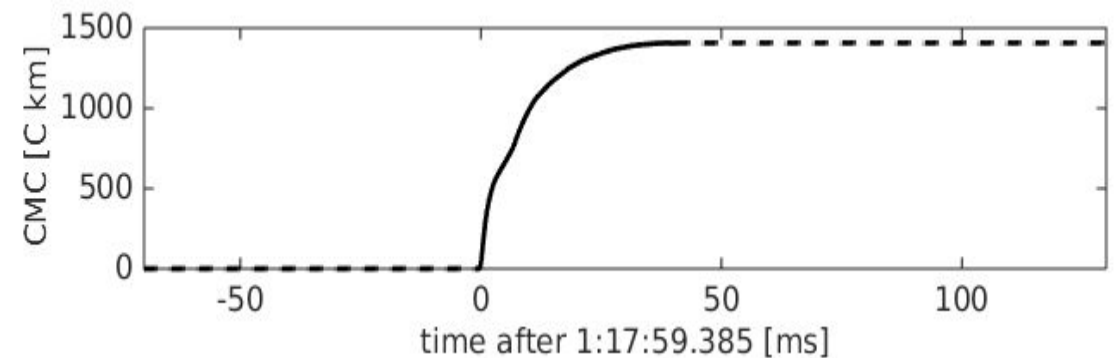
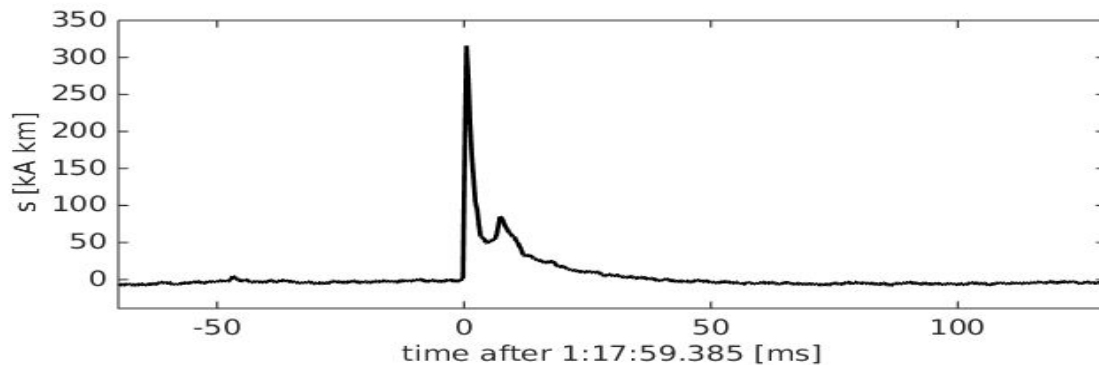
Reconstructing the current moment waveform

- Using our signal processing method and ELF radio wave propagation model we can reconstruct the current moment waveform of the source. It shows the product of the lightning current and the channel length



$$s(t) = IDFT [\bar{s}(f)]$$

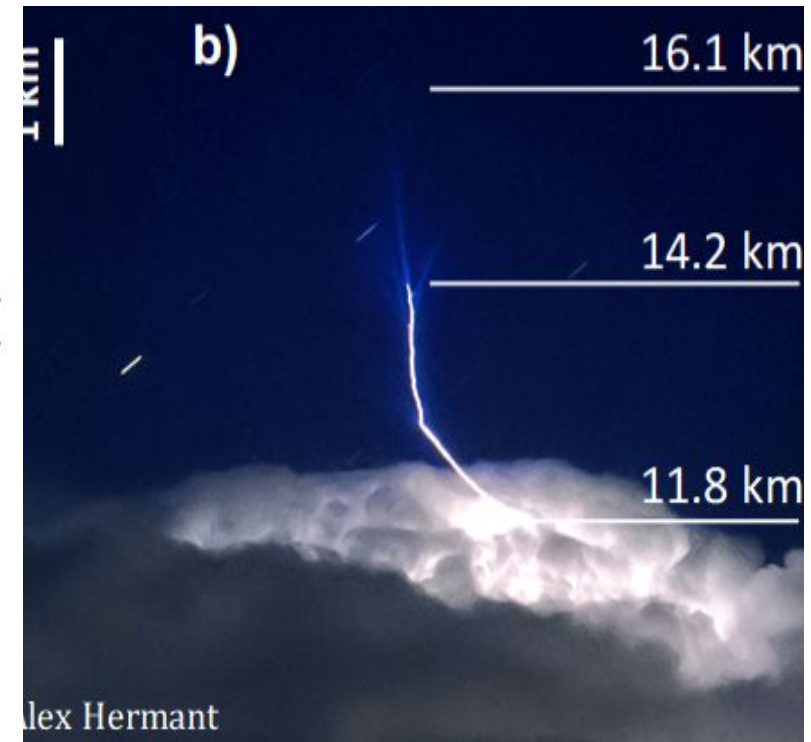
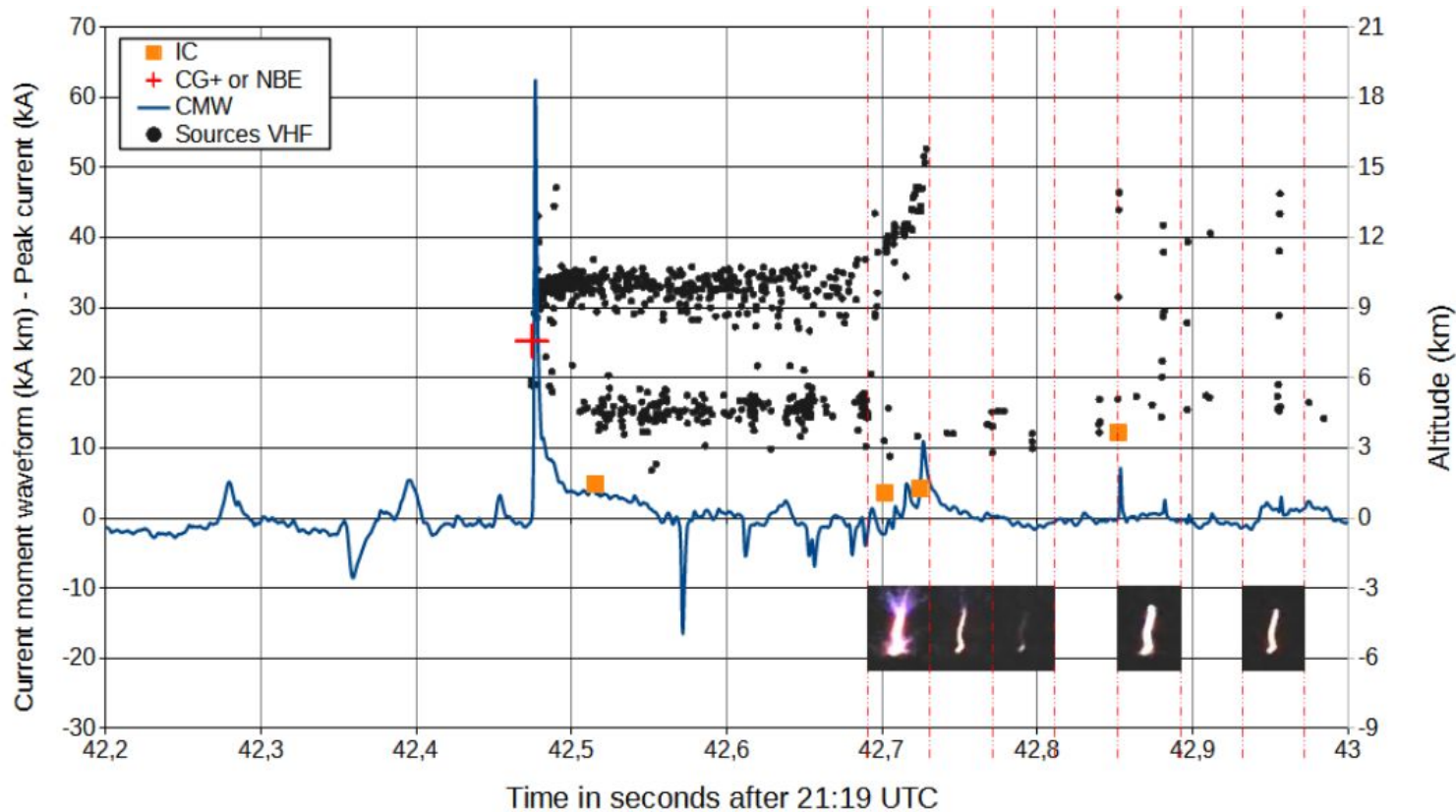
$\bar{w}(r, f)$ - the channel transfer function



Reconstructed current moment waveform associated with the sprite event (left) and the charge moment change (right).

ELF research at AGH University of Krakow

■ Use of ELF measurements in research on lightning and Transient Luminous Events (TLE).



Combination of optical and electrical information during the luminous event: time series of the current moment waveform issued from ELF radiations (blue curve, in kA km), the altitude of VHF sources from SAETTA (black dots), the peak current (in kA) of NBE pulse (red plus) and IC pulses (orange square) from Météorage, and the images from a video (red bars represent the exposure duration and time of the images). [Soula et al, 2023]

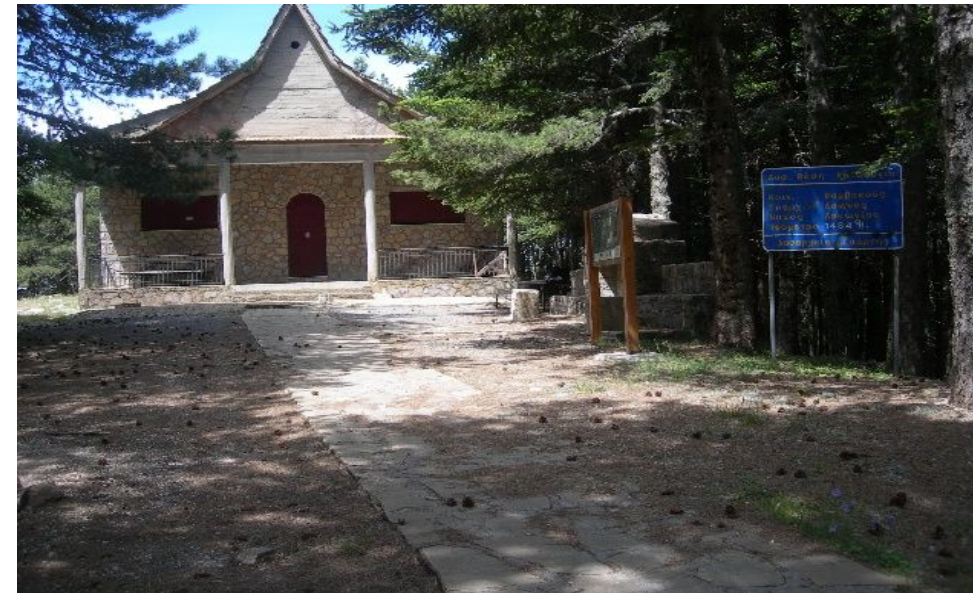
Broadband ELF Radiolocation System (BERS)



Measurement site in the Bieszczady mountains in Poland



Measurement site in Rustrel (LSBB), France.



Measurement site in Parnon, Greece.