

# A sequence of sprites - an analysis of ELF signals and optical recordings

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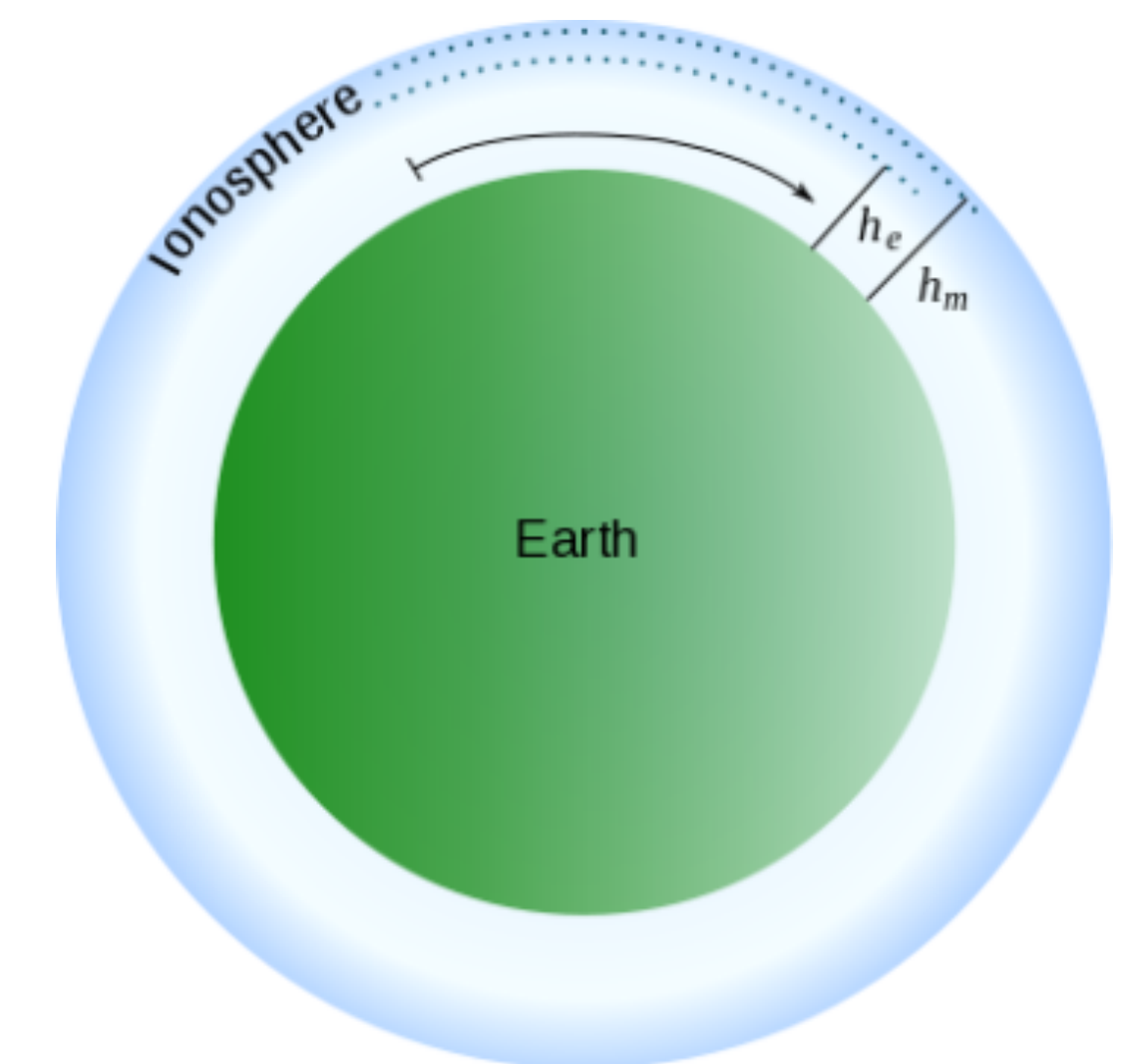
## Background

**ELF = Extremely Low Frequency;** the range of radio waves with frequencies below 3 kHz

Atmospheric discharges generate radio waves in a broad frequency range. However, the sprite associated electrical current changes relatively slowly, therefore the electromagnetic field it generates can be observed only in the lowest part of the radio spectrum (below 100 Hz in most cases).

This makes the ELF recordings very useful for TLE studies.

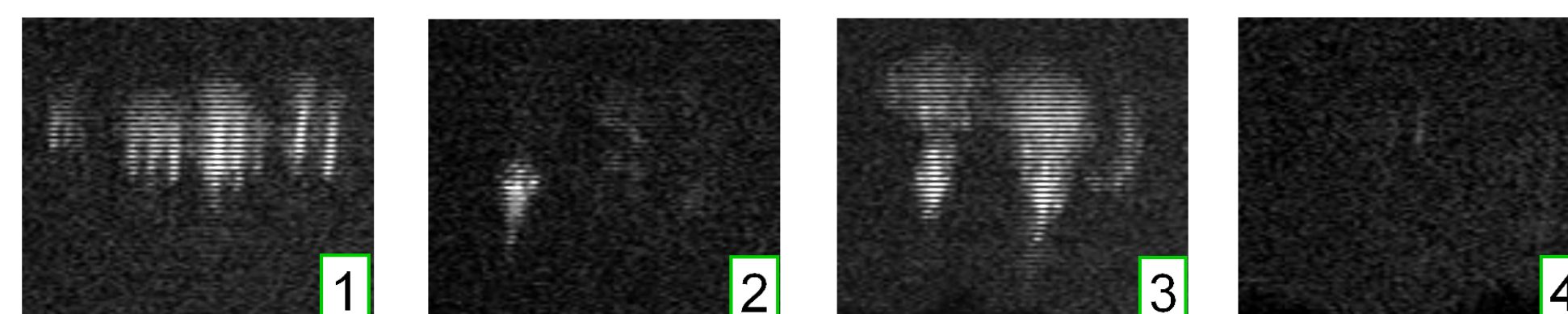
Based on the recorded ELF signal we can reconstruct the complete current moment waveform of the discharge and calculate its charge moment change.



## The analyzed case

During the night from 6 to 7 August 2013, we have captured a large number of sprites.

In this work we analyze a sequence of four sprites that occurred in rapid succession within a 1-second time frame.



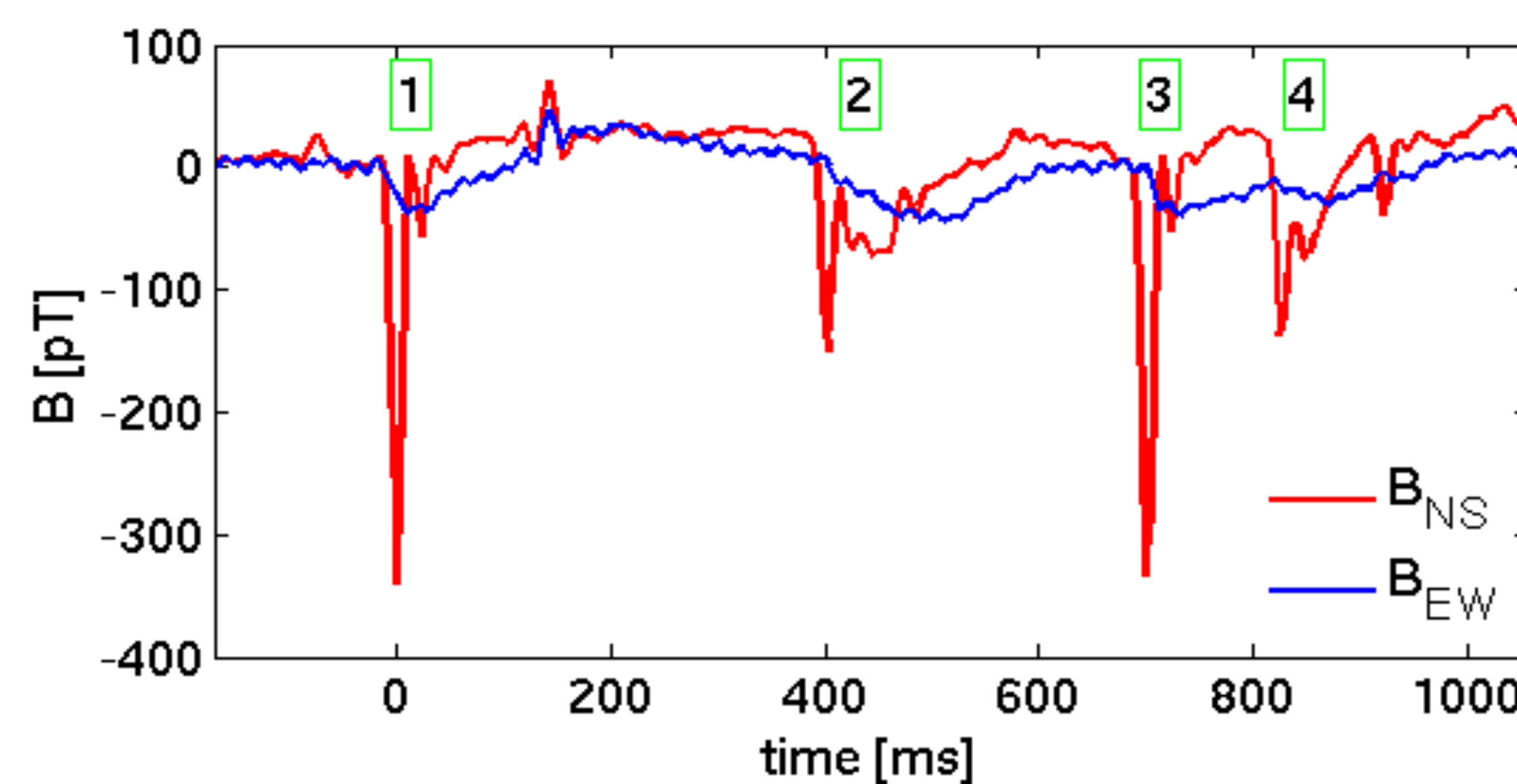
The four sprites registered optically at Nydek, Czech Republic

## Optical recordings

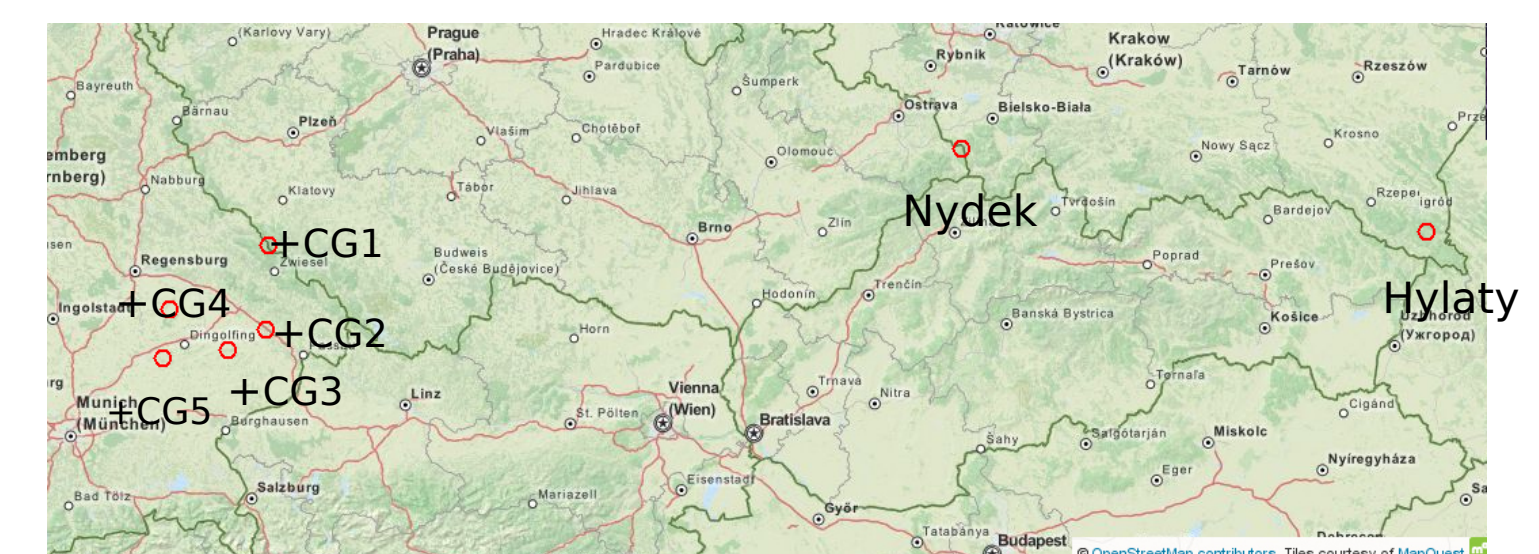


### Optical registrations at Nýdek:

Two Watec 902H2 Ultimate (CCIR)+Computar 8/1,3, Watec 910HX+ Computar 3,5-10,5 and Auto Revuenon 55/1,4/UFO Capture



The magnetic field components of the radio wave registered at the Hylaty ELF station by the north-south (red line) and east-west (blue line) antennas at 21:56 UT.



	Distance [km]	Azimuth [deg]	$I_{max}$ [kA] (VLF)
+CG <sub>1</sub>	684.2	273.4	94.5
+CG <sub>2</sub>	691.7	269.3	33.1
+CG <sub>3</sub>	715.6	268.6	76.3
+CG <sub>4</sub>	747.1	270.8	93.2
+CG <sub>5</sub>	755.0	268.7	47.3

Distance and azimuth of the +CG discharges.

## ELF Measurements

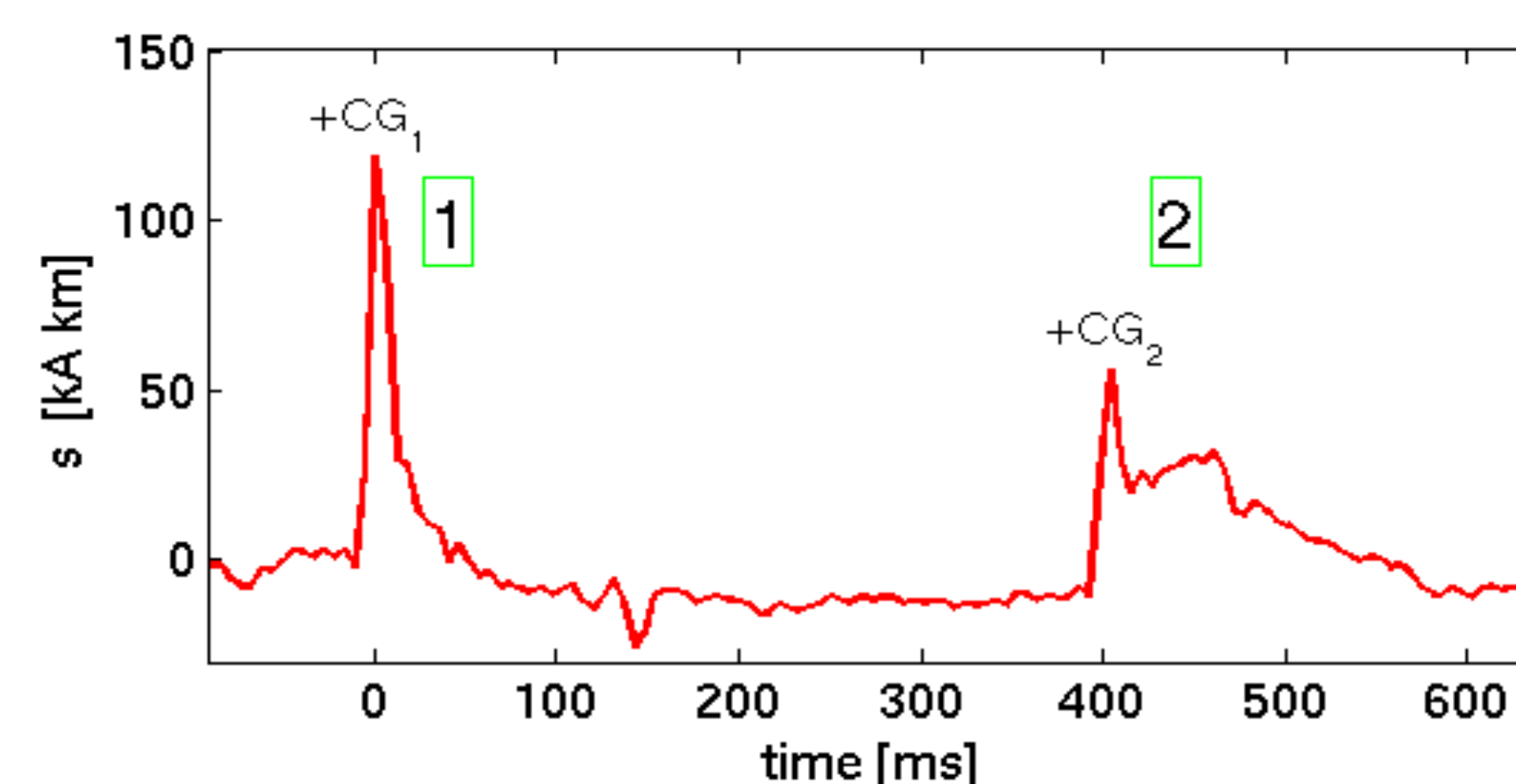


### Hylaty ELF station specifications [Kulak et al., 2014]

Two receivers: 0.03 to 55 Hz and 0.03 to 300 Hz  
Two signal channels NS and EW for each receiver  
Sampling frequencies: 175 and 900 samples/s

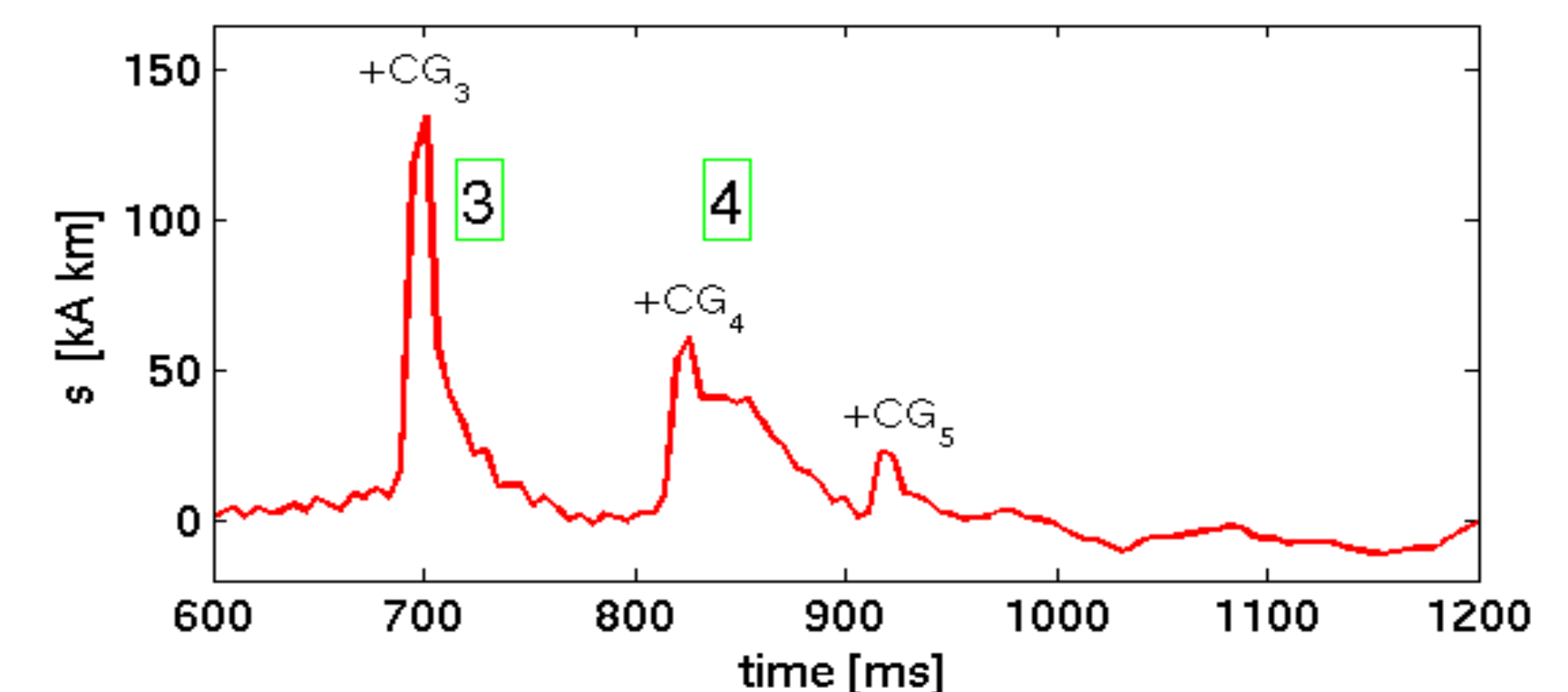
ELF data recording since 1993

Automatic data acquisition since 2005



Calculated current moment waveform of the first two sprite associated discharges.

Sprite 1 and 2 were initiated by +CG discharges, but the first sprite had the maximum current moment twice higher than the second sprite. The continuing current associated with the second sprite lasted much longer (180 ms vs. 50 ms), and had a different waveform, with a clearly visible maximum about 50 ms after +CG stroke. The calculated charge moment change in the first case was almost **1900 C km** and in the second case **2800 C km** (including +CGs).



Calculated current moment waveform of the following two sprite associated discharges.

Sprite 3 and 4 were also initiated by +CG discharges. In the first case the +CG had larger charge moment, the continuing current was shorter and the sprite was much brighter than in the second case. However, the calculated charge moment changes were similar in both cases, nearly **2900 C km** and **2700 C km**, respectively, including +CGs. The sequence was followed by a +CG discharge (+CG5) at a similar location, but no sprite was registered by the cameras.