# ELF Electromagnetic Signatures of Sprites Observed at Short Distances

AE33A-0329

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## Background

A Sprite is a type of Transient Luminous Event (TLE), an optical phenomenon that occurs in the upper atmosphere and is directly related to the electrical activity of a thunderstorm.

The sprite-related electrical current changes relatively slowly, therefore the eleatromagnetic field it generates can be observed only in the Extremely Low Frequency (ELF) range.

The attenuation in the ELF range is so small that the Sprite associated electromagnetic signatures can be recorded even a few thousand kilometers away from their sources.

The recorded signal can be used to reconstruct the current moment waveform and charge moment changes of the Sprite associated discharges.

On August 6 2013, a huge thunderstorm developed in Central Europe. Several dozens of Sprites were optically registered during the night. We have analyzed their ELF signatures. The thunderstorm was located only several hundred kilometers away form our ELF station, which allowed us to obtain high quality waveforms.

## Measurements

### Extremely Low Frequency (ELF) electromagnetic field measurements at the Hylaty station in Poland

Our station is located in a sparsely populated area of the Bieszczady Mountains (49.204°N, 22.544°E) far from major electric power lines.

Hylaty ELF station specifications [*Kulak et al.*, in draft]:
- Two ELF 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
- Sensitivity 0.05 pT/sqrt(Hz) at 10 Hz
- Dynamic range 16 bit / 96 dB
- Battery powered

ELF data recording since 1993, automatic data acquisition since 2005

### Optical recordings of the Transient Luminous Events in the Czech Republic

The observation site is located in Nydek (49.668°N, 18.769°E) 482 m amsl.

System specification:
Two Watec 902H2 Ultimate (CCIR)+Computar 8/1,3, Watec 910HX+ Computar 3,5-10,5 and Auto Revuenon 55/1,4/UFO Capture
Time information: PC time
Analog-to-digital converter:Dazzle DVC 100
Camera position: manually controlled
Observer: Martin Popek

## Methods

The recorded ELF waveforms depend on the discharge process, the Earth-ionosphere waveguide properties on the source-receiver path and the transfer function of the receiver.

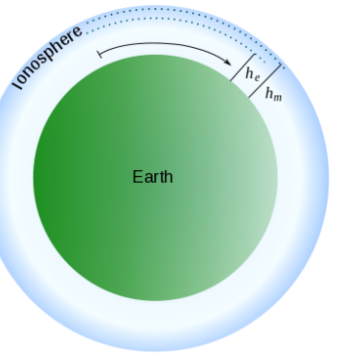
In order to reconstruct the source parameters from the recorded signal a reliable model of the radio wave propagation in the Earth-ionosphere waveguide as well as practical signal processing techniques are required.

The spectrum of the recorded magnetic field depends on the spectral density of the source current moment $\overline{s}(f)$

$$\overline{B}(r,f) = \overline{s}(f)\,\overline{w}(r,f)\,\overline{g}(f) \qquad (1)$$

where $\overline{g}(f)$ is the receiver's transfer function and $\overline{w}(r,f)$ is the transfer function of the Earth-ionosphere propagation channel for a given distance $r$. The current moment waveform *s(t)* can be obtained by ruturning $\overline{s}(f)$ to the time domain.

In order to obtain the channel transfer function we used a fully analytical solution for Maxwell equations for a vertical electric dipole (VED) placed in the Earth-ionosphere waveguide:



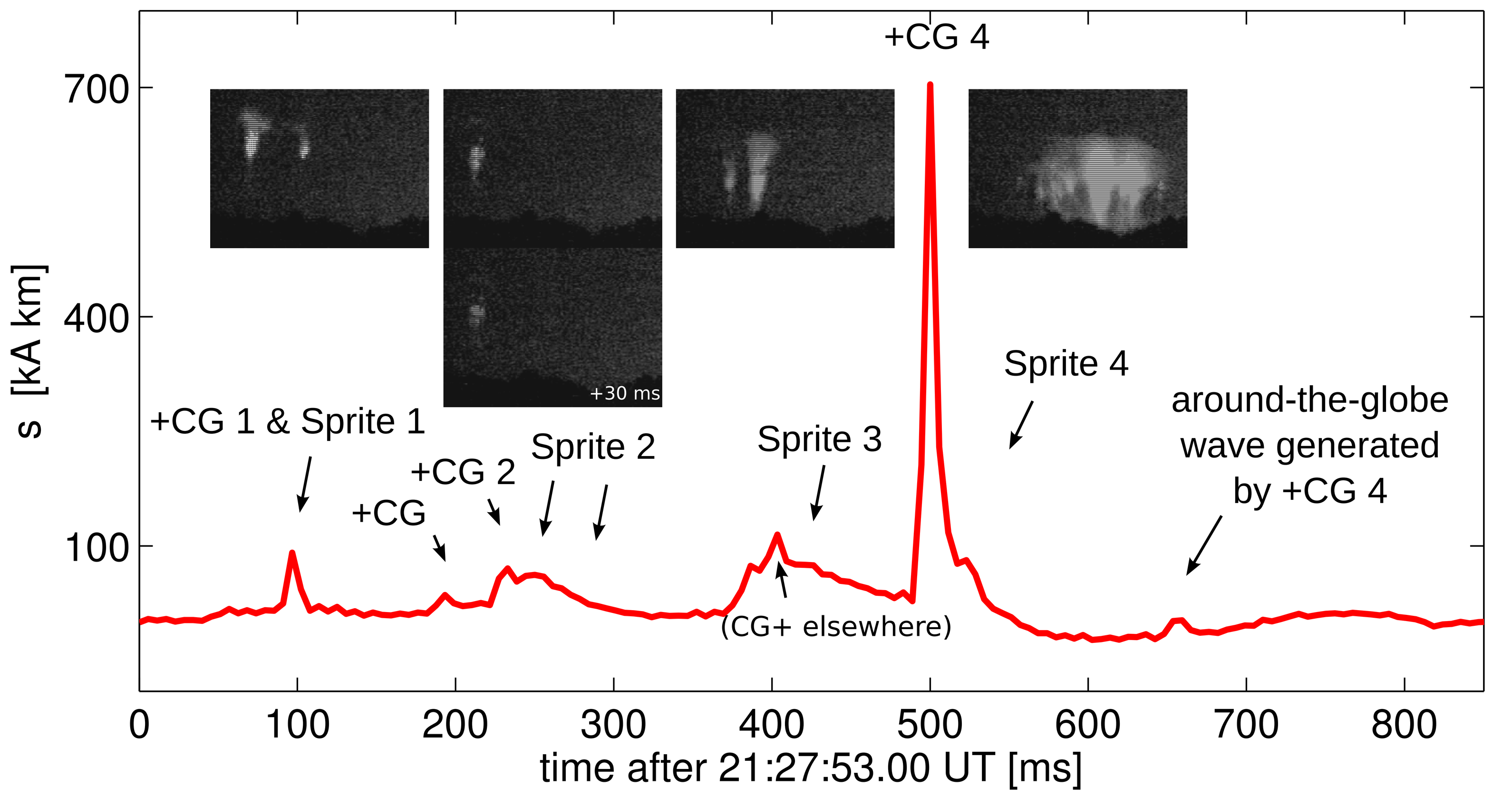

$$\overline{w}(r,f) = -i\frac{\pi\mu_0 f}{2h_m(f)v_{ph}(f)}\sqrt{\frac{r/a}{\sin(r/a)}}\,H_1^{(2)}\left(2\pi r\frac{f}{v_{ph}(f)}\right)e^{-\alpha(f)r}$$

with: $v_{ph}(f) = \frac{c}{\mathrm{Re}\,\overline{S}_o(f)}$ $\quad \alpha(f) = \frac{\omega}{c}\mathrm{Im}\,\overline{S}_o(f)$ and $\overline{S}_o^{\,2}(f) = \frac{\overline{h}_m(f)}{\overline{h}_e(f)}$

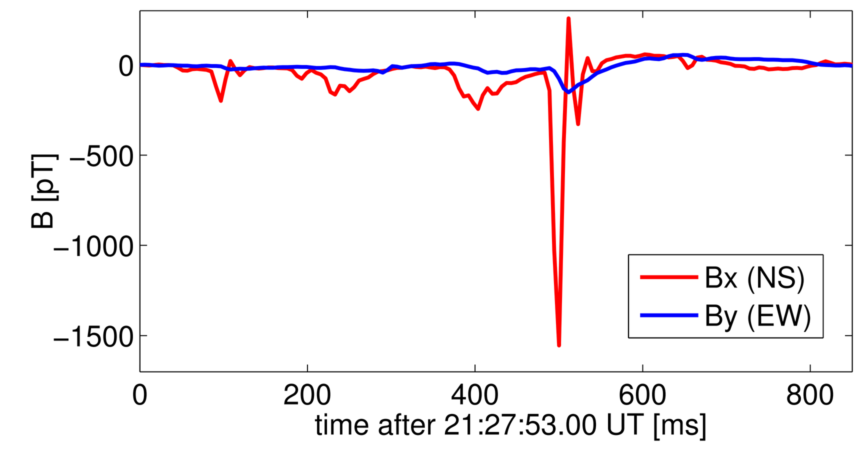
where $\overline{h}_m(f)$ and $\overline{h}_e(f)$ are the magnetic and electric characteristic altitudes of the Earth-ionosphere waveguide and $\overline{S}_o(f)$ is the propagation parameter.

## Results

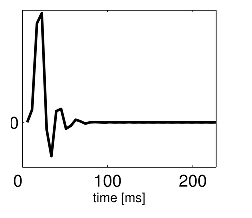
We present one of the most interesting cases: a sequence of 4 Sprites that occurred in a 500 ms time frame on August 6, 2013 at 21:27 UT. They had different ELF signatures and optical shapes.




Current moment waveform of a sequence of 4 Sprite associated discharges




Magnetic field components recorded at the Hylaty ELF Station on August 6, 2013 at 21:27 UT.

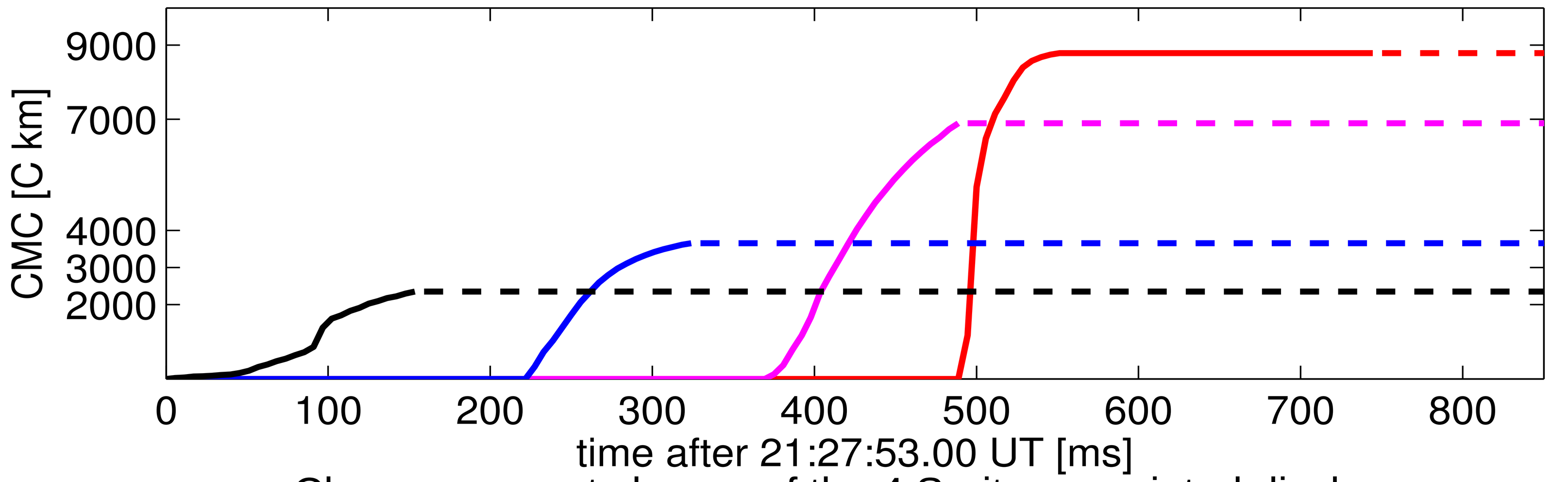


Impulse response of the receiver *g(t)*

Sprite 1 and 2 were triggered by +CG discharges with charge moments between 500 and 700 C km.

No +CG were detected before or during Sprite 3. The only +CG detected by the LINET VLF Network was located nearly 700 km away and can be clearly seen in the current moment waveform.

The 4th Sprite was triggered by an unusually strong +CG (charge moment of 5200 C km). This +CG generated such a strong electromagnetic wave that the around-the-globe wave was clearly seen in the signal 157 ms later. This delay perfectly agrees with our propagation model.




Charge moment change of the 4 Sprite associated discharges

Charge moment of each of the four Sprite associated discharges had different maximum value (between 2300 and 8900 C km) and different time constants.


Hylaty ELF station, optical observation sites in Nydek and +CG locations. The distance between +CG1 and +CG2 locations was only of 3.6 km, and the distance between +CG2 and +CG3 was of 59 km.

## Conclusions

The initial data analysis shows that the Sprites we recorded had a wide range of charge moments. In some cases there were triggered by very strong +CG discharges, in some other cases the +CG flashes were much weaker or no +CG lightning was detected by a VLF/LF network. Some of the recorded +CG discharges were so strong that the around-the-globe wave was clearly seen.

Some Sprites occurred in rapid succession in time frames that were significantly shorter than previously reported.

We have also noticed that most Sprites were associated with a particular very low frequency waveform (below 5 Hz) in the antenna that was nearly parallel to the Sprite-related discharge and should not have recorded the magnetic field component generated directly by the discharge current.

**Acknowledgment**

This work was supported by the National Science Centre under Grants 2012/04/M/ST10/00565 and 2011/01/B/ST10/06954.
The cloud-to-ground lighthing locations were kindly provided by LINET (nowcast GmbH).

**AGU Fall Meeting 2013, San Francisco, 8 - 14 December 2013**