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

J. Mlynarczyk[1], A. Kulak[1,2], J. Kubisz[2], M. Popek[3], A. Michalec[2], M. Ostrowski[2]

[1] *AGH University of Science and Technology, Department of Electronics, Krakow, Poland*
[2] *Astronomical Observatory, Jagiellonian University, Krakow, Poland*
[3] *AMSos, Eurosprite, Nýdek, Czech Republic.*

A powerful thunderstorm moved across Central Europe in the second week of August 2013. A large number of sprites were optically registered at an observation site in Nydek, Czech Republic, and their electromagnetic signatures were recorded at the Hylaty ELF station in Poland. Since the distance to the thunderstorm was relatively small, we have obtained high quality waveforms. In some cases the sprite associated discharge current was short and in some cases it lasted a few hundred milliseconds. Most of the recorded sprites were accompanied by +CG discharges, which had a wide range of charge moments. We present a case of four sprites that occurred in rapid succession. We have reconstructed their current moment waveforms and calculated their charge moment changes.

## 1. Introduction

Atmospheric discharges generate electromagnetic 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 (Extremely Low Frequency) range very useful in sprite studies.

## 2. The recorded data

During the night from 6 to 7 August 2013, we have captured a large number of sprites [1]. In this paper we analyze a sequence of four sprites that occurred in rapid succession within a 1-second time frame.

### 2.1. Electromagnetic recordings

The electromagnetic signatures were recorded at the Hylaty station, located in a sparsely populated area of the Bieszczady Mountains (49.204°N, 22.544°E) in Poland [2]. In this study we use the data recorded by a receiver that has the frequency bandwidth of 0.03 to 52 Hz and the sampling frequency of 176 Hz. The receiver measures continuously two magnetic field components of the ELF electromagnetic field: NS (North-South) and EW (East-West).

Figure 1 shows the electromagnetic signature of a sequence of sprites recorded on August 6, at 21:56 UT.

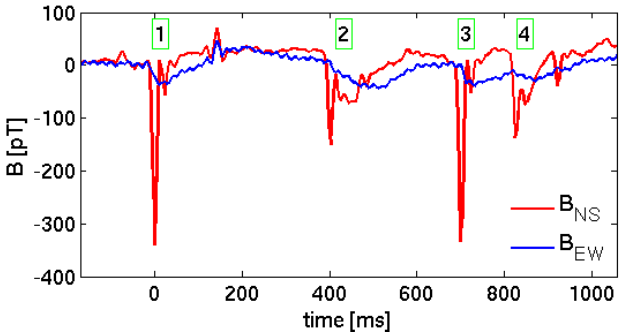


Fig. 1. The electromagnetic signature of a sequence of sprites recorded at the Hylaty ELF station at 21:56 UT.

### 2.2. Optical recordings

The optical images were registered from Nydek, Czech Republic (49.668°N, 18.769°E). The site is equipped with two Watec 902H2 Ultimate and Watec 910HX cameras. Figure 2 shows the recorded images of the four sprites.

## 3. Results and discussion

The electromagnetic field recorded by the receiver depends directly on the current moment of the discharge and the properties of the radio channel and receiver. In order to reconstruct a complete current moment waveform of the sprite associated discharges we have used the ELF radiowave propagation model described in [3].

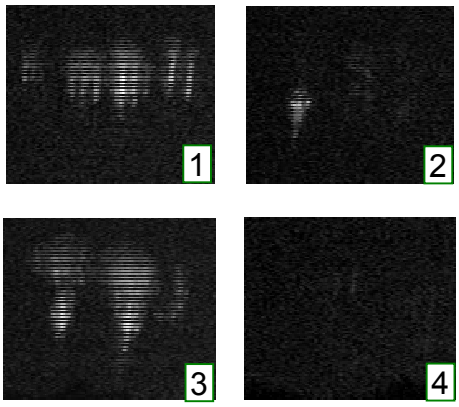


Fig. 2. The four sprites registered optically in Nydek, Czech Republic.

Figure 3 shows the current moment waveform of the first 2 sprites in a sequence of 4, reconstructed from the recording presented in Figure 1.

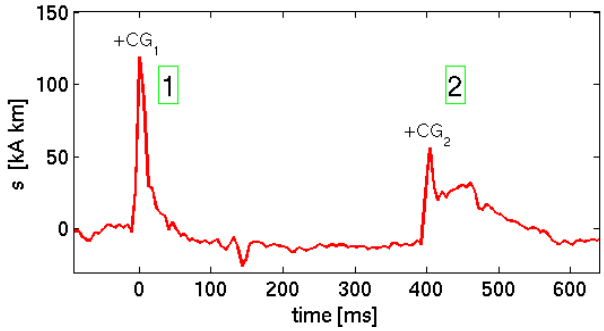


Fig. 3. The current moment waveform of the first two sprites from the sequence presented in Figure 1.

Both sprites were initiated by +CG discharges but the first of them had the maximum current moment twice as high as the second. 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 +CG discharges).

Figure 4 shows the current moment waveform of the following two sprites from the recorded sequence. The third and fourth sprites 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 and 2700 C km, respectively, including +CG discharges.

The sequence of four sprites was followed by a relatively strong +CG discharge (+$CG_5$ in Figure 4) at a similar location, but no sprite was registered by the cameras.

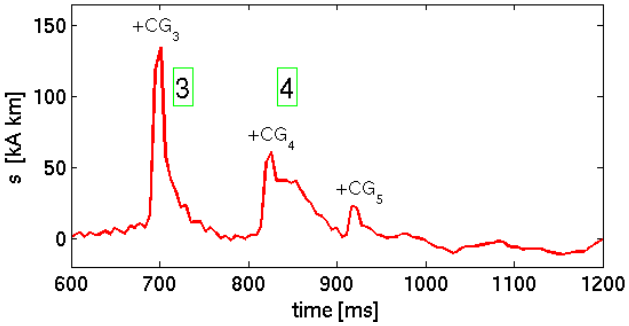


Fig. 4. The current moment waveform of the third and fourth sprite from the sequence shown in Figure 1.

As can be seen in Figure 1, all the sprite associated signals were recorded by the NS antenna, because the discharges were located east of our ELF station. Using the data from a VLF lightning detection network (LINET) we have found the locations of the five +CG discharges (Table 1).

Table 1. Distance and azimuth to the five +CG discharges

| | Distance [km] | Azimuth [deg] | $I_{max}$ [kA] (VLF) |
|---|---|---|---|
| +$CG_1$ | 684.2 | 273.4 | 94.5 |
| +$CG_2$ | 691.7 | 269.3 | 33.1 |
| +$CG_3$ | 715.6 | 268.6 | 76.3 |
| +$CG_4$ | 747.1 | 270.8 | 93.2 |
| +$CG_5$ | 755.0 | 268.7 | 47.3 |

**Acknowledgement**

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

## 4. References

[1] J. Mlynarczyk, A. Kulak, M. Ostrowski, J. Kubisz, A. Michalec, M. Popek, "ELF Electromagnetic Signatures of Sprites Observed at Short Distances", AGU Fall Meeting, 2013.

[2] A. Kulak et al., "Extremely Low Frequency Electromagnetic Field Measurements at the Hylaty Station and Methodology of Signal Analysis", Submitted to Radio Science, 2014

[3] A. Kulak and J. Mlynarczyk, "ELF propagation parameters for the ground-ionosphere waveguide with finite ground conductivity", IEEE Transactions on Antennas and Propagation, vol. 61, no. 4, pp. 2269–2275, 2013.