Imaging Sprites with High Time Resolution

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Sprites are short-lived, a few to a few 100 ms, optical emissions in the mesosphere caused by thunderstorm activity in the troposphere. They are highly dynamic with streamers moving at velocities up to half the speed of light. To resolve their spatial and temporal behaviour requires high speed imaging. Our group has over the last decade made sprite observations at up to 20,000 frames per second with down to 20 m spatial resolution. But even at 20,000 fps there are sprite features, for example splitting of streamer heads, which requires even higher framing rates to be resolved. The presentation will focus on examples of our high frame rate observations, our imaging capabilities, and what we can learn from such observations.

1. Sprites

Sprites occur in the mesosphere caused by transient electric fields associated with tropospheric lightning activity. They are typically observed in the 60-90 km altitude range, and they last from a few ms to more than 100 ms. The most spectacular and dynamic sprite features are streamer heads. They are relatively small, 10 m to a few 100 m, moving up and down at velocities in the 10^5 to 5 10^7 m/s range. We have observed velocities up to 1.5 10^8 m/s (half the speed of light). General reviews of the observations may be found in references [1,2].

Sprites have a number of easily identifiable optical features: Elve, halo, sprite streamers, sprite glow, and beads. Their occurrence varies considerably between events and may not all be observed. The elve is well understood; it is caused by the electromagnetic pulse radiated from the lightning strike exiting airglow emissions at an altitude near 95 km [3]. When observed, the elve is an excellent parameter for timing the causal lightning strike. The halo and sprite follow the elve. Their onset can be many 10s ms after the elve [4,5], and they are triggered by the quasi-static mesospheric electric field resulting from the redistribution of electric charges due to the lightning strike. The halo is a large, diffuse, pancake-like luminous feature, while the streamers and glow are the result of electrical break-down in the local atmosphere [6]. The onset altitude of the sprite streamer is in the 65 to 85 km range with prompt streamers typically at the higher altitude [4,7].

Based on video observations sprites have been classified as ‘carrot sprites’ or ‘Columnar sprites’ (C-sprites). Our high speed observations show that carrots have both down and upward propagating streamers, while C-sprites only have downward streamers [1]. The streamer activity typically lasts up to 10 ms, while the glow can remain visible for 100s ms. Finally, sprite beads are small, largely stationary optical features often, but not always, associated with streamer activity. They may be associated with mesospheric inhomogeneities [8]. We have also observed beads at low altitudes, ~30 km.

The sprites are very bright which is fortunate as this makes high speed optical observations possible. They often outshine Jupiter and Venus in our observations [2]. The brightest emissions are from the 1P molecular nitrogen band emitting in the in the 600-900 nm wavelength range [9].

Propagating streamers are often observed to suddenly split into many smaller streamers [2]. It is interesting to note that in laboratory discharges streamers rarely split into more than 2 whereas in sprites we see up to 10 sub streamers. The splitting process is very fast. While 10,000 fps is adequate to resolve streamer formation and movement, we estimate that a frame rate of 50,000 fps is needed to resolve splitting. Fortunately, streamers are bright enough to allow such observations using our current imagers.

Sprite streamer activity always starts with one or more downward propagating streamer. This is illustrated in Figure 1, where we have created an image time series from a from a carrot sprite event recorded at 10,000 fps. The initial downward streamer starts at 82 km and the upward streamer, about 2.5 ms later, at 73 km.

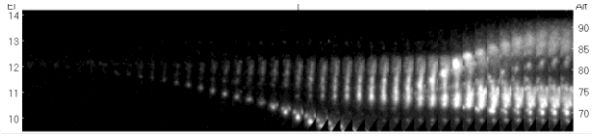

Figure 1. Image time series shows the initial downward streamer and a later upward streamer. Time series covers 4.5 ms. Recording speed is 10,000 fps. The image strips cover the altitude range 65 to 95 km. The maximum downward and upward streamer head velocities are 1.3 10^7 m/s and 2.3 10^7 m/s respectively. (Figure adapted from [1]).

The initial downward streamer may form near the steep increase in electron density at the bottom of the ionosphere where a screening charge will effectively prevent the formation of an upward streamer. Streamer onset at lower altitudes may be initiated in naturally occurring electron density irregularities [10,11,12], but then, if the causal field is large, also upward streamers might form [5], which, as mentioned above, we have never observed. This issue appears to have been resolved in recent 3-D streamer simulations [13]. If the causal electric field is above the local electric field break-down value, E_k, break-down will occur throughout the volume. This effectively prevents streamer formation, and only a halo will be observed. The conditions for the formation of positive (downward) streamers are less stringent that for negative (upward) streamers, and consequently, for an ambient initial field strength near or below E_k only the downward streamer will appear.

Much progress has been made in understanding the processes involved in sprites, but the role of sprites within the larger atmospheric system, in particular the impact of chemical processes initiated by the sprites, and the contribution from sprites to the global electric field is still little understood.

4. References

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