Streamers and Diffuse Glow Observed in Upper Atmospheric Electrical Discharges

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***Abstract*—A telescopic imaging system was designed to observe fine structure in high-altitude lightning-related electrical discharges known as "sprites." Hundreds of sprites were observed and much of the fine structure can be categorized in terms of streamer and diffuse glow discharges. A streamer/diffuse glow transition occurs at varying altitudes and is dependent on the ambient mesospheric/lower ionospheric conductivity profile. Both stationary and dynamic beading is observed and this feature is currently unexplained by prevailing sprite theories.**

***Index Terms*—Glow discharges, lightning, sprites, telescopes.**

SPRITES are large luminous lightning-related discharges that appear in the altitude range of ~40 km–90 km above thunderstorms (e.g., [1]). It is generally accepted that the dominant mechanism involved in sprite production is the quasi-static electric field between the clouds and the ionosphere, caused by the occurrence of a cloud-to-ground lightning stroke ([2]). In order to determine the nature of fine structure in sprites, to measure its features at substantially higher resolution, and to verify predictions of smallest feature sizes of a few tens of meters, we developed a telescopic imaging system, which acquired telescopic images of hundreds of events, recorded during the summers of 1998–2000.

The telescopic imaging system consists of two intensified charge coupled device (CCD) video cameras. The narrow field of view (FOV) camera is attached to the eyepiece of a ~41 cm diameter, f/4.5 Dobsonian-mounted Newtonian reflecting telescope and has an angular viewing region of ~0.7° by 0.92°. The wide FOV camera is strapped onto the telescope and boresighted. The telescopic camera uses a Varo second generation (GenII) multichannel plate intensifier tube and a Pulnix TM200 1/2 in CCD. The telescopic camera is run in a field-selected mode, creating images exposed for ~17 ms while the wide FOV camera is run in interlaced frame mode creating images exposed for ~33 ms. An unfiltered 50-mm, f/1.4 lens is used for the wide FOV camera generating an angular viewing region of ~9° by 12°. Data from both cameras is stored on VHS or S-VHS video tapes using standard VCR equipment and a global positioning system (GPS) signal is used for time-stamping.

Unlike cloud-to-ground (CG) discharges, the electrical breakdown mechanism observed in sprites exhibits high variability, primarily due to the rapid height variation of atmospheric properties at high altitudes (i.e., neutral density, electron density). Streamer breakdown prevails at lower altitudes while diffuse glow is dominant at higher altitudes. Fig. 1 shows a large sprite observed on July 13 at 06:00:00 UT, which lasted a maximum of ~50 ms (one video frame) ([3]). The lefthand panel displays the wide FOV while the righthand panel shows the narrow (telescopic) FOV. The white rectangle on the upper panel outlines the position of the narrow FOV within the wide FOV. Time stamps correspond to the beginning of the exposure time for each image. It is evident from the narrow FOV image that such sprite structures consist of densely-packed branching filaments. The transverse scale of filamentary structures in this image ranges from 60 to 145 m (±12 m) in the altitude range of 60–64 km (±4.5 km).

Fig. 2 displays an example of the transition region between streamer formation and glow discharge in a sprite ([4]). The diffuse glow/streamer transition altitude can be used (in combination with a theoretical model) to identify the ambient mesospheric/lower ionospheric conductivity profile and the observation of this transition altitude potentially provides a new means of remotely sensing the lower ionosphere ([5]). The transition region only exists over a narrow region of 1–2 km in height at an altitude of ~80 km, consistent with model predictions ([6]).

Falling neither into the category of streamers nor diffuse glow, beads are frequently observed in sprites. Telescopic images of beads show them to sometimes move up or down preexisting streamer channels and at other times to remain stationary. The beads may persist for less than a video field (~17 ms) or for hundreds of milliseconds. Beads observed thus far by the telescope range in radius from 25–200 m. Current sprite theories do not account for the existence or underlying cause of beads. The sprite event in Fig. 3 exhibits the fine beading that often occurs in the middle regions of sprites ([4]). The beads are strung along upward-branching channels at fairly regular intervals and range in size from ~70–150 m.

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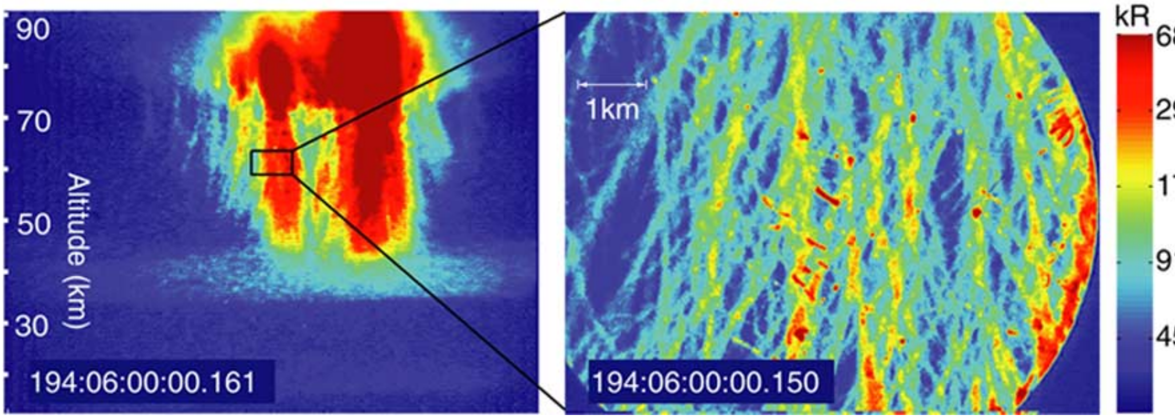

Fig. 1. Wide (left-hand panel) and narrow (right-hand panel) FOV images of a bright sprite event. Time-stamping (GPS) corresponds to the beginning exposure time for each image. Narrow FOV with respect to the wide FOV is outlined by a black rectangle in the left-hand panel. Altitude scaling shown in the wide FOV panel corresponds to the location of the causative CG as recorded by the National Lightning Detection Network (NLDN). This telescopic image demonstrates that while the sprite appears to be amorphous in the wide FOV image, the lower portion of this sprite in fact consists of a volume of densely packed filaments.

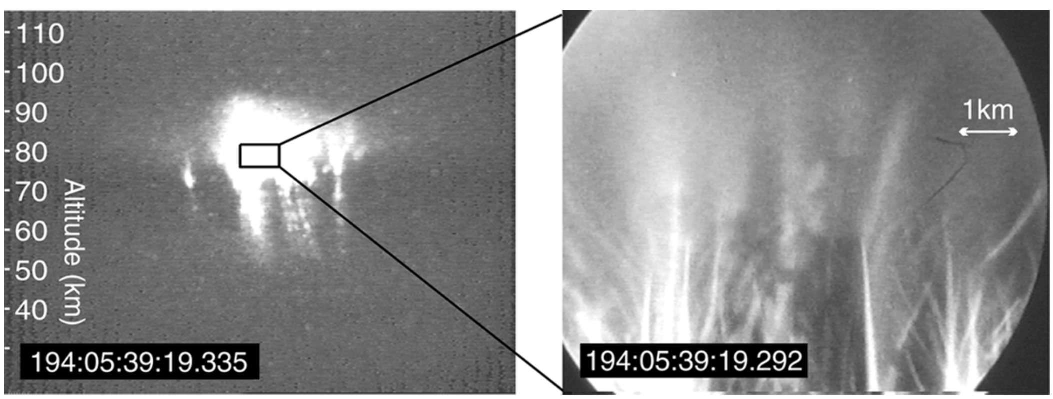

Fig. 2. Transition between the streamer region and the diffuse glow region as seen in a large sprite event at 05:39:19.335 UT. Transition region only exists over a narrow region of 1–2 km in height at an altitude of ~ 80 km, consistent with model predictions that the transition region should exist between 75–85 km.

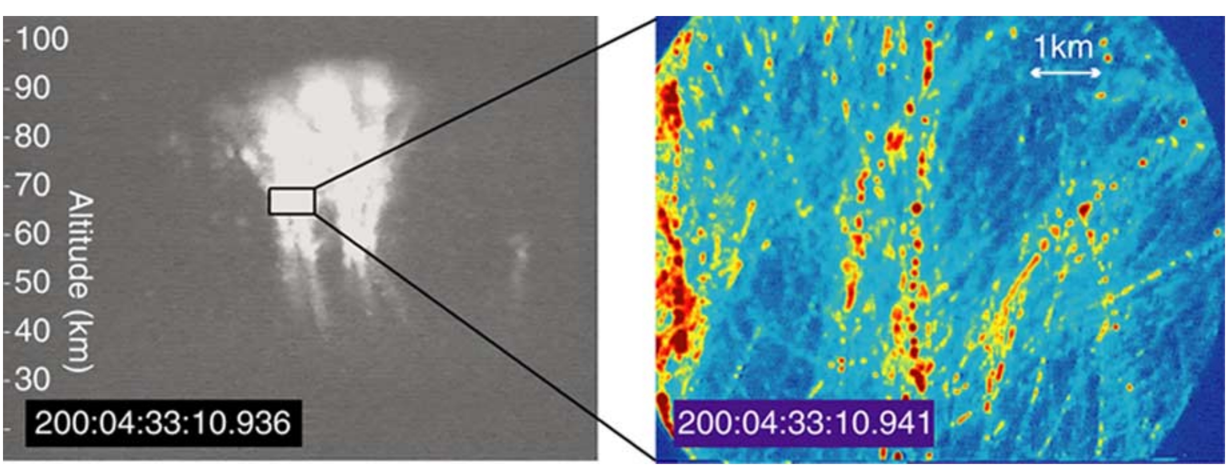

Fig. 3. Example of fine beading in negative streamers during a large sprite at 04:33:10 UT July 19, 1998.

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