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Observations of decameter-scale morphologies in sprites☆

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Abstract

Using telescopic imaging it is observed that sprite morphologies such as upward branching, downward branching, beading, and columns can assume a wide variety of shapes, sizes, and time scales. Beads at the base of columniform sprites can glow for over 100 ms while slowly drifting upward. Faint positive streamers are observed at the base of angel sprites and immediately prior to bright sprite events. A transition region between streamer formation and diffuse glow is observed at ~80 km altitude. Telescopic images containing these features are presented for a number of cases.
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1. Introduction

Video observations of sprites have revealed fine structure in sprites, including upward and downward branching (Sentman et al., 1996; Taylor and Clark, 1996; Stanley et al., 1996; Fukinishi et al., 1996). High speed imaging has captured the temporal development of some of the fine structures seen in sprites such as the upward and downward branching and slowly moving beads (Stanley et al., 1999; Stenbaek-Nielsen et al., 2000). Telescopic imaging has shown that the fine structure covers a wide range of features, including branching tree-like shapes and well defined but isolated columns (Gerken et al., 2000). Theoretical explanations of observed spatial fine structures in sprites have been put forth in the context of streamer-based models of electrical breakdown above thunderstorms (Raizer et al., 1998; Pasko et al., 1998). In this paper we give examples of some fine structure morphologies observed telescopically in sprites.

2. Experimental setup

The data shown here was acquired during the summer of 1998 using a telescopic imaging system to observe sprites from the Langmuir Laboratory (LL), located in the Magdalena mountains of central New Mexico and operated by the New Mexico Institute of Mining and Technology. The system consisted of a ~41 cm diameter, f/4.5 Dobsonian-mounted Newtonian reflecting telescope with an intensified CCD camera attached to its eyepiece and a bore-sighted wide field of view (FOV) camera mounted on its top. The FOV of the telescope (0.5 in CCD) was 0.7° by 0.92° while that of the bore-sighted camera (0.33 in CCD, 50 mm lens, f/1.4) was 9° by 12°. The narrow FOV camera was field-selected, creating images exposed for ~17 ms while the wide FOV camera was in interlaced frame mode creating images exposed for ~33 ms. GPS video time-stamping and IRIG-B code were used for timing. Electromagnetic signatures of causative lightning discharges known as radio atmospherics (or sferics) were recorded using crossed-loop magnetic antennas and ELF/VLF receiving system located at Stanford University. As described in Gerken et al. (2000), each sprite altitude was calculated using the range of the associated +CG as determined by the National Lightning Detection Network (NLDN) and the elevation of the background starfield. The systems spatial resolution is determined by the range of the object being imaged (e.g., at a range of 500 km, each pixel maps to ~12.5 m × ~12.5 m).

3. Fine structure examples

While widely ranging in morphology, patterns have been found in hundreds of cases of fine structure in

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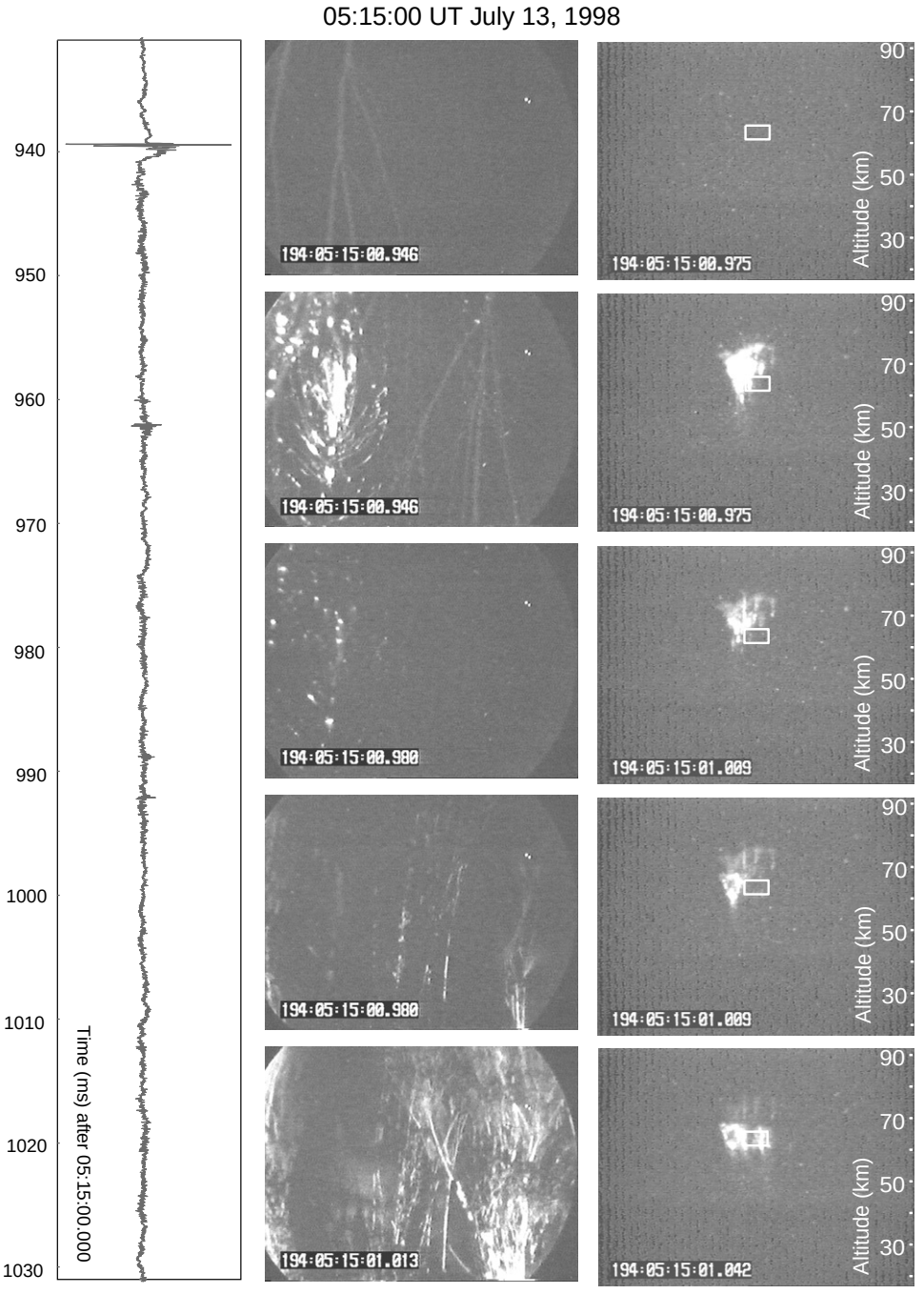

Fig. 1. Sprite event exhibiting several types of features including faint downward positive streamers, bright upward negative streamers, and beading. The leftmost panel contains the Stanford ELF recording during the event. The middle column shows the telescopic field of view and the rightmost column shows the wide field of view. The narrow field of view with respect to the wide field of view is depicted by a white box in the wide field of view images.

sprites observed by the Stanford telescopic imaging system. Sprite structure such as upward and downward branching, beading, and streamer/diffuse glow transition regions are repeatedly observed. We use selected cases from July 13 and July 19 to illustrate these morphologies.

3.1. Case I: 05:15:00 July 13 1998

A wide range of morphologies is possible in the fine structure of a single sprite event. These morphologies include faint downward-branching streamers, upward-branching tree-like structures, non-branching streamers, and beads. On this and other days, one or more of these broad categories of features appear in the majority of sprites observed with the telescopic imager.

We often observe faint downward branching streamers either at the base of a sprite or prior to a bright sprite event. In the 05:15:00 July 13, 1998 event shown in Fig. 1 both types occur. In the first narrow field of view panel faint downward-branching streamers precede the main sprite event. The second narrow field of view panel similarly has a downward-branching structure but this one is at the base of a bright sprite as can be seen in the corresponding wide field of view image. In both cases, no beading is apparent.

The second narrow field of view panel also shows an upward-branching structure on the left where the downward branching had occurred in the previous panel. The downward branching streamers are interpreted to be positive streamers because they develop in the direction of the quasi-static electric field produced by the causative cloud-to-ground discharge which is primarily downward. Conversely, the upward branching streamers are interpreted to be negative streamers and are much brighter (∼240 kR) than the positive streamers preceding them.

3.2. Case II: 04:33:10 UT July 19, 1998

In this sprite event fine beading occurs as is typically observed in the middle regions of sprites. The event is made up of a series of sprites which move from right to left across the wide field of view video frames (not shown). The image shown in Fig. 2 depicts the second sprite in the series. Ranging in size from ∼70 to 150 m, the beads are strung along upward-branching channels at fairly regular intervals. In subsequent video fields the beads persisted for 2–3 fields but remained stationary.

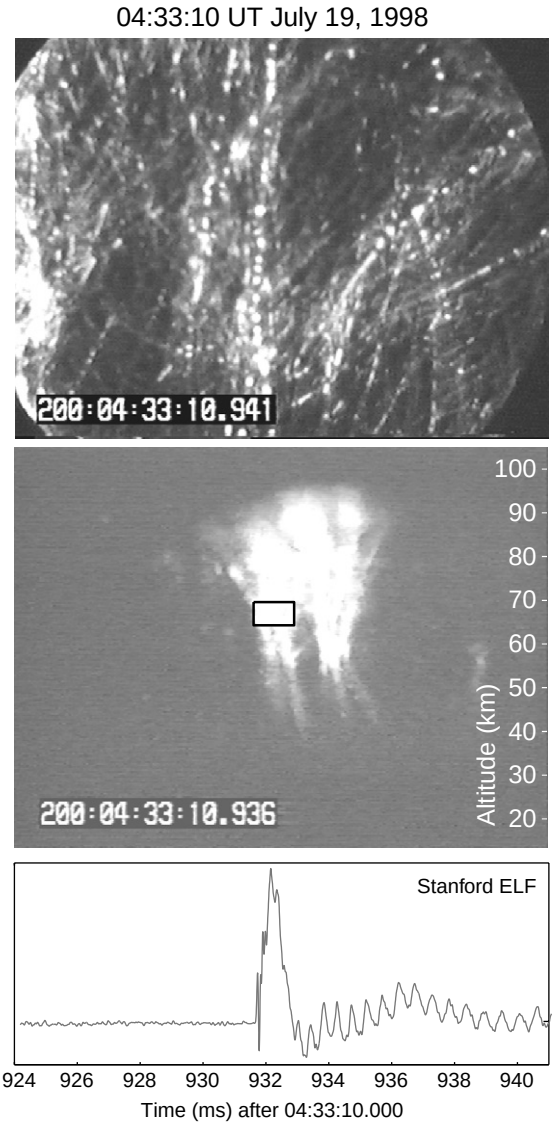

Fig. 2. Example of fine beading in negative streamers during a large sprite at 04:33:10 UT July 19, 1998.

3.3. Case III: 05:43:10 UT July 19, 1998

Fig. 3 displays an example of a single "columniform" sprite (Wescott et al., 1998) imaged by the telescope. Preceding and subsequent video frames of the wide field of view camera (selected frames shown) indicate that this sprite is the middle part of a sequence of sprites moving from right to left across the frames. The event starts with a collection of ∼15 columniform sprites occuring at approximately the same altitude (∼80 km) as the telescopically imaged column. Several large carrot-shaped sprites then form beneath the wake of fading columns while some of the columns are re-ignited. The carrot-shaped sprites are about five times the height of the columns. A couple of the columns appear to become part of the carrot structures. As the carrot-shaped sprites fade over the following frames, the single columniform sprite shown in the telescopic images emerges. This column exists by itself for three video fields. Finally, five frames later a collection of ∼10 columniform sprites appears at ∼70 km altitude and then fades away.

Three selected frames from the wide field of view camera are displayed in the top panels of Fig. 3. Two of the images display the bright column in the center of the field with the wake of the carrot-shaped sprites on the right. The middle panels show a sequence of slices through the narrow field of view containing the bright single columniform sprite. As

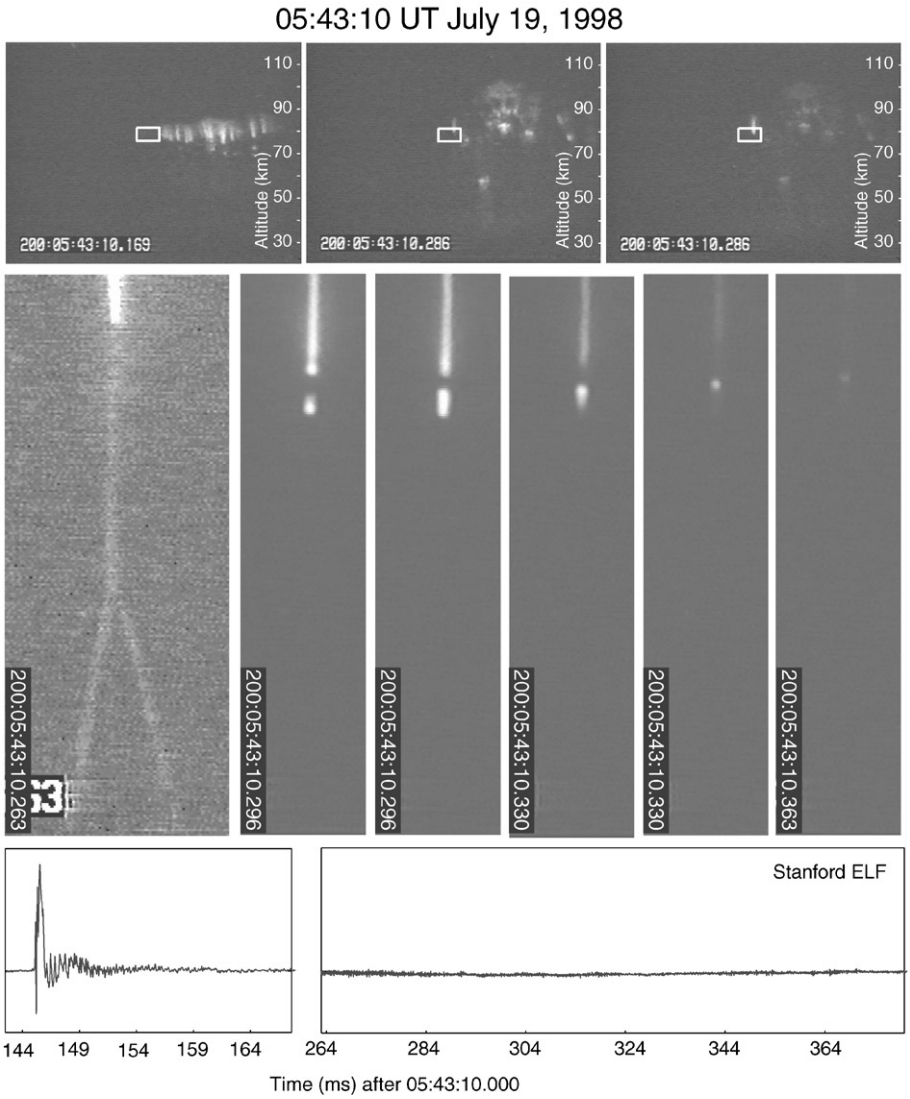

Fig. 3. Single columniform sprite with initial downward branching and a slowly moving bead at 05:43:10 UT July 19, 1998. Note that the wide field of view panels on top of the figure are not successive frames but rather contain bright features from the dancing sprite sequence of which the column sprite was a part. The telescopic images have been cropped to better display the columnar development and range from 05:43:10.263 to 05:43:10.380. The sferic record at the bottom left shows the sferic related to the causative cloud-to-ground lightning stroke which occurred over 100 ms prior to the column sprite. The sferic record at the bottom right shows the recording during the interval of the column sprite as displayed in the telescopic images.

shown in these panels, the columniform sprite starts as a faint positive downward-branching streamer branching once in the field of view and having a slightly brighter segment on the top. In the subsequent fields the branching streamer is not present and the upper segment becomes much brighter, extends downward, and develops a single bead at its base which travels upward along the channel as the bright segment fades. The entire sequence lasts ~120 ms. Beads often persist for several frames either remaining stationary or drifting slowly as was observed by Stenbaek-Nielsen et al. (2000). The column width of 150 m is slightly larger than predicted for this altitude (Pasko et al., 1998) and was previously documented (Gerken et al., 2000). The column appears to have boundaries which are sharper than the resolution of the camera.

The bottom panel in Fig. 3 displays the sferic record associated with this sprite event. While there is a sferic at the time of the initial sprite of the sequence (left bottom panel),

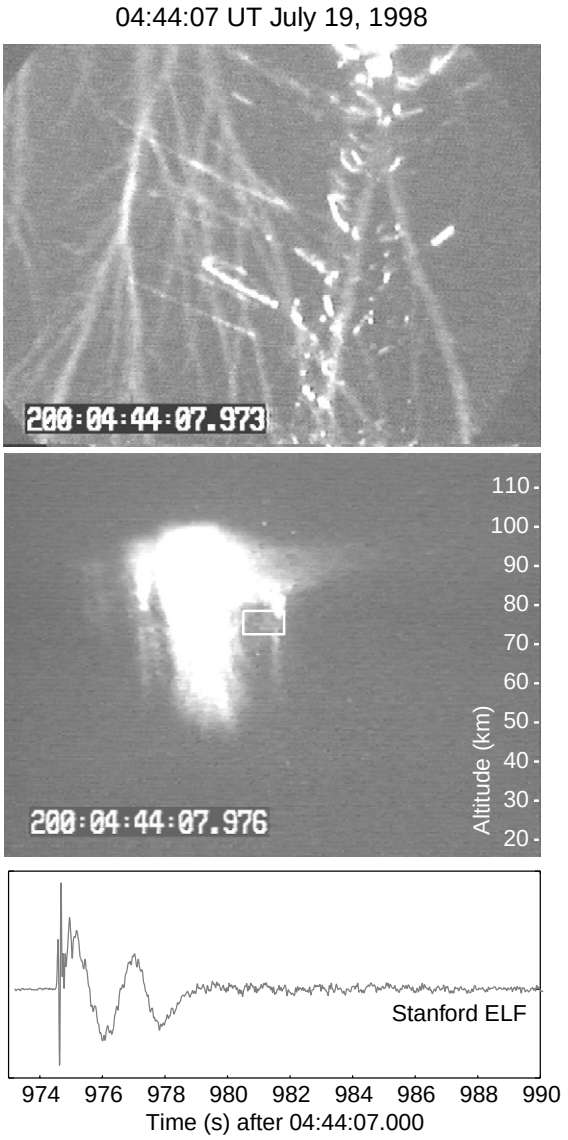

Fig. 4. Faint downward branching positive streamers during a large angel sprite event at 04:44:07 UT July 19, 1998.

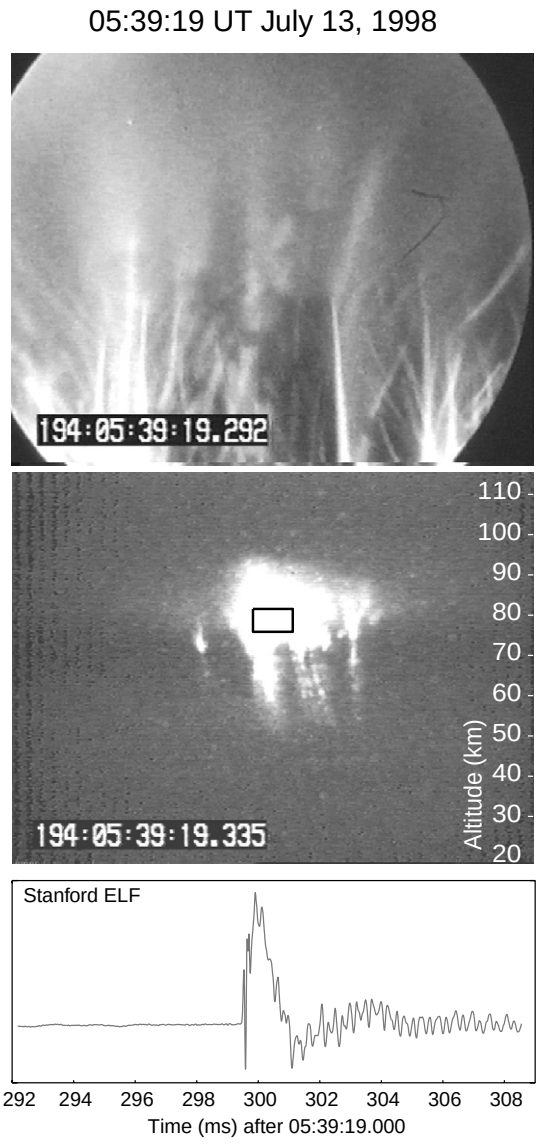

Fig. 5. Transition between the streamer region and the diffuse glow region as seen in a large sprite event at 05:39:19.335. The transition occurs as predicted at ~80 km altitude.

no sferic activity is present during the interval in which the lone column exists (right bottom panel). The entire sequence lasts ~450 ms. The long delay between sferic and much of the sprite activity suggests the presence of continuing currents either within the thunderstorm (Bell et al., 1998) or to ground (Cummer and Fullekrug, 2001).

3.4. Case IV: 04:44:07 UT July, 19 1998

Faint positive downward-branching streamers found at the base of a small carrot-shaped sprite on the side of a large "angel" sprite are shown in Fig. 4. As opposed to the dense filamentary structure observed at the base of angel sprites (Gerken et al., 2000), these tendrils are more isolated with fewer bright spots. The bifurcating branching angles are similar to that modeled by Pasko et al. (1998) and to other examples shown in Fig. 1. Some beading does occur but it appears to be following an upward-branching path. This beading may be part of another sprite structure in front of the tendrils or it could be a negative streamer traveling back up the positive streamer channel and branching upwards. As shown, the top portion of the rightmost tendril group becomes bright and is in the base of the bright region of the carrot sprite.

3.5. Case V: 05:39:19 UT July 13, 1998

The transition region between the streamer formation region and the glow discharge region in a sprite is shown in Fig. 5. The streamers taper and fade with altitude to a broadly expanding, less luminous diffuse glow. The transition region only exists over a narrow region of 1–2 km in height at an elevation of ~80 km, consistent with the altitude predicted by Pasko et al. (1998) where the transition region is modeled to exist between 75 and 85 km. Since no branching is evident the polarity of the streamers is ambiguous.

4. Conclusions

Although sprite structure is observed to have a wide variety of shapes, sizes, and time scales, features such as beading, faint downward branching, bright upward branching and columns are found to recur. As we have shown, some sprite events exhibit several different types of structural features while other events only exhibit one morphology. Beads at the base of columns can glow for over 100 ms while slowly drifting upward. Faint positive streamers are observed at the base of angel sprites. A transition region between streamer formation and diffuse glow is observed at ~80 km altitude.

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