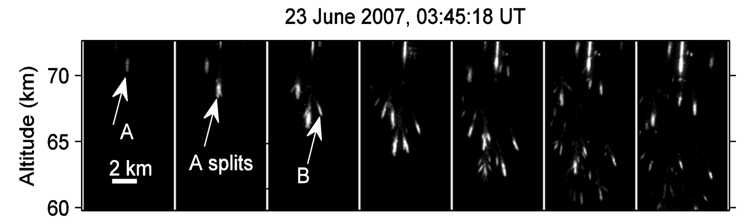
Telescopic Observations of Streamer Tip Splitting in Sprites

Dr. Matthew G. McHarg, United States Air Force Academy
H C. Stenbaek-Nielsen, Takeshi Kammae; University of Alaska, Fairbanks
Ryan K Haaland; Fort Lewis College

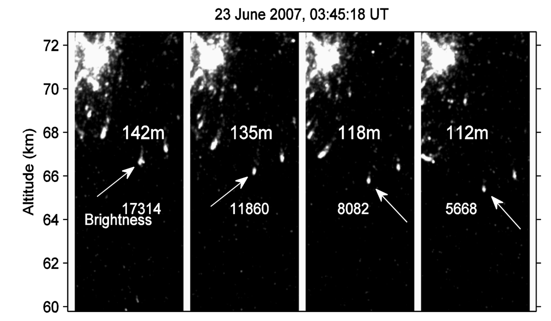
Thunderstorm Effects on the Atmosphere-Ionosphere System

Introduction

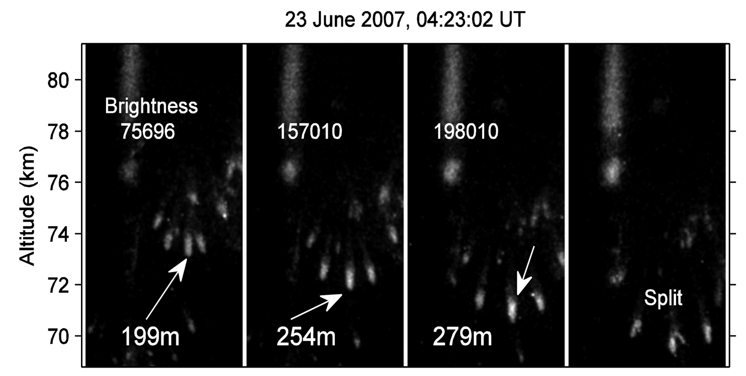
Branching; or splitting is a fundamental phenomenon in streamers. The time history of an individual streamer splitting in the laboratory is very challenging due to the extremely fast (ns) time scales involved. Recent observations of streamer tip splitting in sprites are possible due to the reduced ambient pressure at sprite altitudes. We report on telescopic observations of sprites obtained in 2007 and 2010 using long focal length lenses to resolve the splitting. In 2007 a 300 mm lens was used, while in 2010 a 500mm Takahashi Sky 90 lens was used on a Phantom 7 camera with a Video Scope VS4_1845-HS image intensifier. The sprite locations were determined either by triangulation using data from remote observation sites, or by assuming that sprites are at ranges of the parent lightning strokes as reported by National Lightning Detection Network. The locations of the parent lightning strikes were either located using the National Lightning Detection Network, or triangulation using remote observations sites. We observe streamers splitting into smaller and smaller streamer tips once the splitting starts. We report on the time and spatial scales of streamer tip splitting, and compare these to known models and laboratory observations of streamer tip splitting.



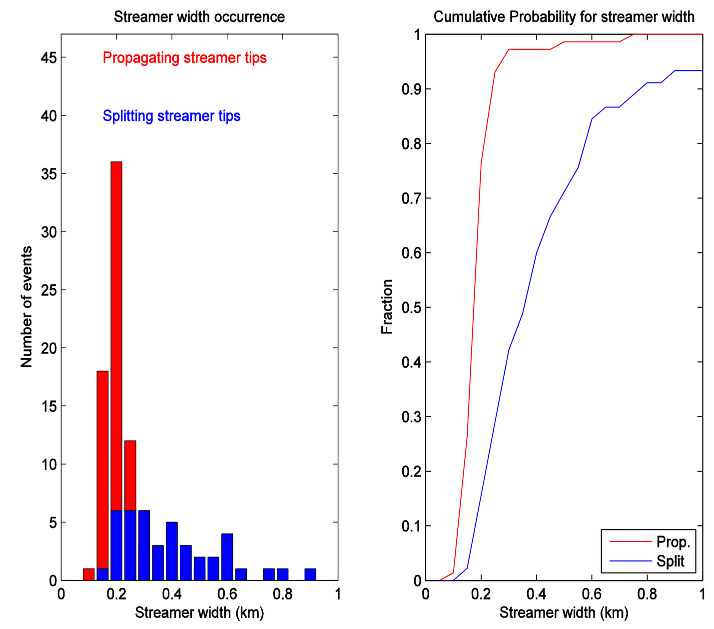
Seven successive images from a sprite event occurring at 03:45:18 UT on 23 June 2007. Data were recorded at 10,000 fps, i.e. 100 ms between images using a 300mm lens. The altitude was determined using the location of the causative positive cloud to ground strike determined by NLDN. A single streamer tip is seen at approximately 71 km altitude in the first image, with a second streamer tip entering the field of view in the second image. The streamer tip labeled A divides starting in the third and subsequent images [1].



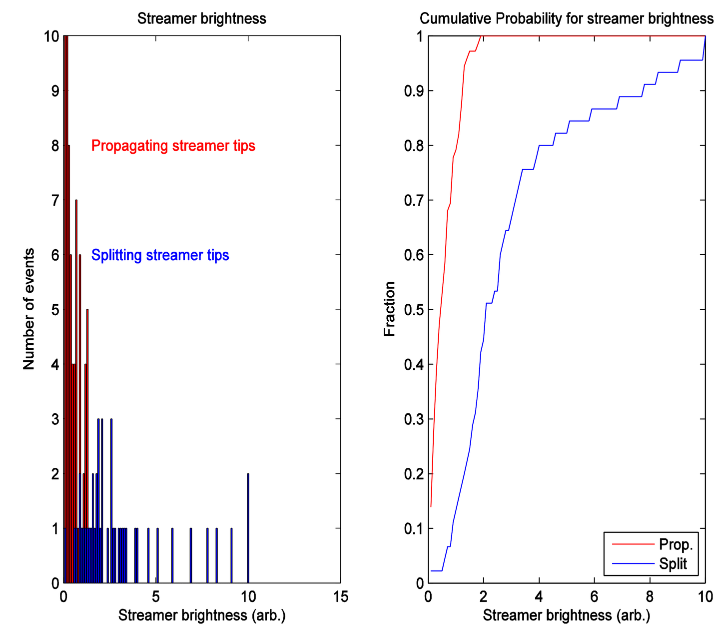
Four successive images for sprite event occurring at 03:45:18 UT on 23 June 2007. The gray scale has been enhanced to see the streamer tip, but the relative brightness can be compared with the previous figures. Note the streamer tip does not split and is significantly smaller in width and dimmer than the splitting example showed before. [1]



Four successive images from a sprite event occurring at 04:23:02 UT on 23 June 2007. Same as Figure above. Note the splitting streamer tip in the fourth image. The width and brightness of the streamer tip are shown in each image. The contrast is enhanced to see the streamers clearly. In all figures the arbitrary brightness value can be used to compare relative streamer tip brightness. The streamer brightens and becomes wider immediately preceding division [1].



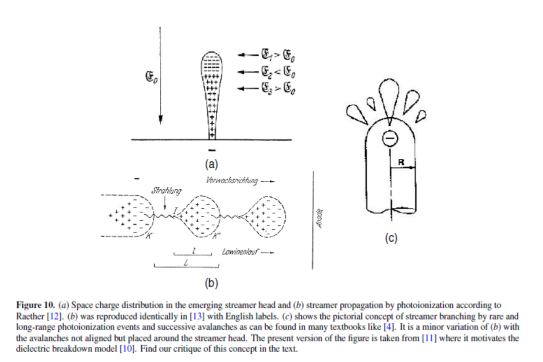
(left) Histogram of both propagating and splitting streamer tip widths. Note the splitting streamers are significantly wider. (right) Cumulative probability of propagating and splitting streamer tip widths displayed as a fraction. Median value is 193m and 389m for the propagating and splitting streamers respectively [1].

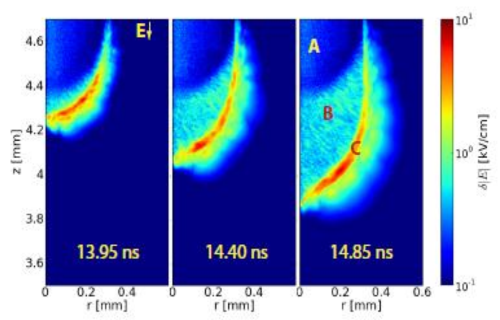


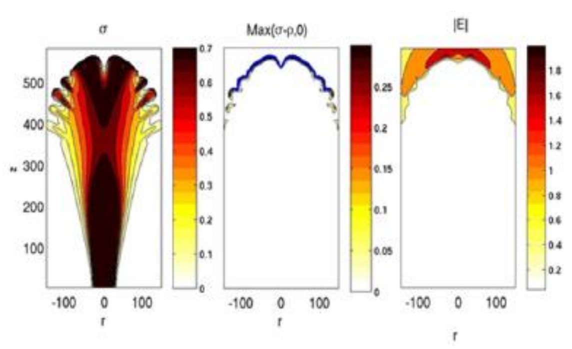
(left) Histogram of both propagating and splitting streamer brightness. Note the splitting streamers are significantly brighter. (right) Cumulative probability of propagating and splitting streamer brightness displayed as a fraction. Note the median value for splitting streamer brightness is 4.3 times that of the propagating streamers [1].

What causes splitting?

The concept of splitting dates to very early work in streamers [2,3]. Figure 10 in of Ebert et al. [3], reproduces the branching concept of Raether. Effectively Raether postulated the branching is the result of "…rare and long range photoionization events and successive avalanches…" [3].





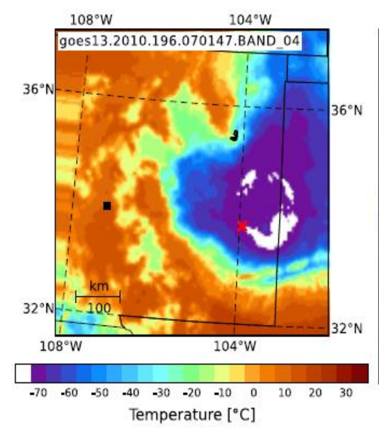


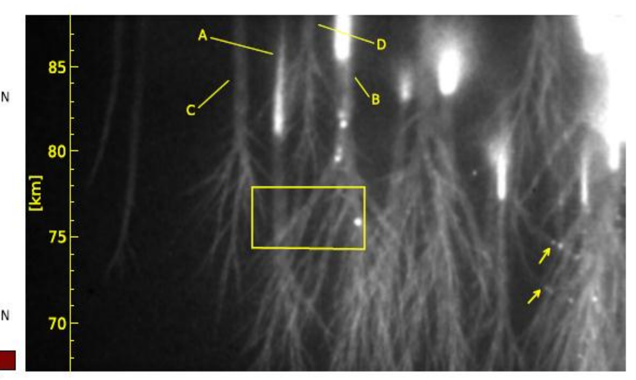
(left) Figure 10 from Ebert et al. reproducing the initial branching concept of Raether. (middle) Figure 3 from Luque and Ebert showing the highest deviation of the absolute value of the electric field from its azimuthal average at three snapshots. Larger fluctuations at the surface close to the tip of the streamer (C) have higher amplitude fluctuations, which can give rise to subsequent branching. (right) Top row of Figure 6 from Ebert et al. showing the a negative streamer head splitting. Left panel is the electron density, middle panel is the space charge density, right is the absolute value of the electric field. Note that the streamer filaments into multiple pieces when the space charge becomes very thin and the conductivity in the body of the streamer is effectively infinite, excluding the electric field.

More recent numerical and analytical stability analysis show that curved moving boundary models are linearly stable. Ebert et. al. conclude for negative streamers [4] "Therefore, a finite perturbation is necessary to destabilize the streamer tip and make it branch." Luque and Ebert propose that fluctuations in the electron number density due to a finite particle number in streamers can be the cause of the required perturbation [5]. Liu and Pasko propose that photoionization plays an important role in streamer branching [6]. They predict a maximum stable streamer diameter that corresponds to the point where the streamer becomes larger than the pre-ionization distance. For sprites at 70 km this diameter is 97m, in approximate agreement with our measurements.

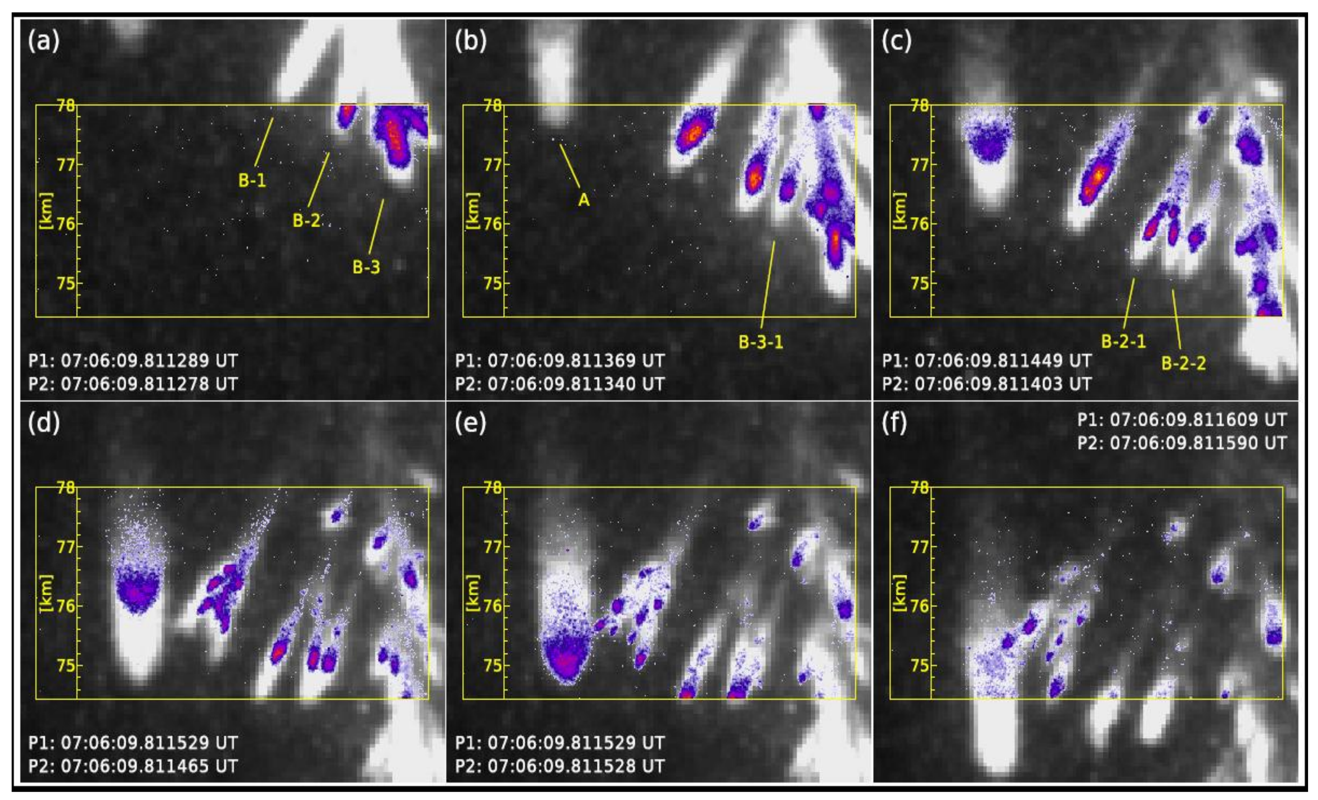
Sprite streamer splitting into multiple pieces

In 2010, we fielded 2 high speed imagers with overlapping fields of view at Langmuir Laboratory, New Mexico (33.975º N, 107.181ºW, 3255 m). Imager 1 had an 85mm lens, giving a field of view of 7.3x3.7º. Imager 2 used a 500mm lens, giving a 1.3x0.6º field of view. Imager 1 was recording continuous at 10,000 fps, while Imager 2 was recording at 16,000 fps with an integration time of 20µs.





(left) Observing geometry for the event 07:06:09 UT on 15 July 2010 on top of the cloud top temperature map reproduced from the GOES-13 image. The locations of the Langmuir laboratory and the parent lighting strike reported by NLDN are shown as a black rectangle and a red cross respectively. (right) Time-integrated (4ms) image recorded by Imager 1. The field of view of Imager 2 is shown as a box. The altitude scale was determined assuming the sprite occurred at the range to the NLDN strike.



Panels a-f are superimposed images for Imager 1 and Imager 2 of the 07:06:09 15 July 2010 event. Times for the images are shown in each panel. Note streamer B-1 splits into at least 8 pieces between panel c and d (62 µs), streamer B3 has split into 5 pieces between panels a and c.

Summary:

Sprite streamers become wider and brighter within ~100µs of splitting. Median full width at half maximum of propagating streamer tips is 193m, while splitting streamer tip median FWHM is 389m. Sprite streamers are seen to fall into at least 8 pieces in successive frames (δt=62.5µs). Streamers appear to split when the conductivity inside the body becomes large, and the charge density at the head of the streamer thins.

References:

(1) McHarg, M, H. Stenbaek-Nielsen, T. Kammae, and R.K. Haaland, Streamer tip splitting in sprites (2010), Journal of Geophysical Res., Vol. 115, A00E53, doi:10.1029/2009JA014850,2010.
(2) Raether H 1939 Z. Phys **112**, 464.
(3) U. Ebert, C. Montijn, T.M.P. Briels, W. Hundsdorfer, B. Meulenbroek, A. Rocco, and E. M. van Veldshuizen, Plas Sour. Sci. Technol. **15**, 118 (2006).
(4) U Ebert, F. Brau, G. Derks, W. Hundsdorfer, C-Y Kao, C. Li, A. Luque, B Meulenbroek, S. Nijdam, V. Ratushnaya, L Schafer and S. Tanveer, Multiple scales in streamer discharges, with an emphasis on moving boundary approximations, Nonlinearity **24**, 2011. doi:10.1088/0951-7715/24/1/C01
(5) A. Luque and U. Ebert, Electron density fluctuations accelerate the branching of streamer discharges in air, Phys. Rev. E, 84, 046411 (2011).
(6) Liu N Y and Pasko, V P Effects of photoionization on propagation and branching of positive and negative streamers in sprites, J. Geophys. Res. (Space Phys.) **109**, A04301, 2004.