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High-Speed Plasma Imaging: A Lightning Bolt

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Abstract--Using a gated, intensified, digital Kodak Ektapro camera system, we captured a lightning bolt at 1000 frames per second, with 100 microsecond exposure time on each consecutive frame. As a thunder storm approached while darkness descended (7:50pm) on July 21, 1994, we photographed lightning bolts with an f22, 105 mm lens, and 100% gain on the intensified camera. This 15-frame sequence shows a cloud to ground stroke, at a distance of about 1.5 km, which has a series of stepped leaders propagating downwards, followed by the upward-propagating main return stroke.

Modern high-speed imaging of plasmas to study plasma/pellet interactions^[1], plasma/wall interactions, coherent structures rotating in the plasma, and disruptions in tokamaks has proven to be a useful tool. In this paper we apply this technology to study an outdoor plasma: a lightning bolt.

We employ a commercially available Kodak Ektapro EM1012 processor, coupled to a Kodak model VSG intensified imager, with modest spatial resolution (239x192 pixels), and 400 Megabytes (1600 frames) of digital storage. The entire system is controlled over a fiber-optic GPIB-link from a 486-PC computer running National Instruments LabView software under Windows NT, using a virtual instrument software driver that we developed. The Kodak chip uses 12 parallel A/D readouts in order to process each image at a full frame rate of 1000 frames/second. The two-stage gated intensifier is also remotely-controlled over the GPIB link, and can be gated down to 1 microsecond exposure times, one or more times per frame. Presently, this digital system (with different optics) is now installed and operating at the MIT Alcator C-Mod tokamak. For many purposes film is a superior data recorder, but although the resolution of film is excellent, it is very inconvenient to use remotely. It also can not be "post-triggered". By comparison to the Kodak system, Imacon streak cameras (from Hadland Photonics) can take a sequence of very fast (less than 1 microsecond exposure) images, but they are typically limited to only 8-32 discrete frames, and must be outfitted with special high resolution CCD's.

In order to observe lightning bolts(see footnote ¹), the whole system was run on an uninterruptable power supply, with a single ground point. Manual triggering was employed, since the Kodak system can be run in a continuous acquisition mode, storing up to 1600 pretrigger frames. When a bright flash was seen in the general field of view, a stop command was given. Then the pretrigger frames could be played back at any desired rate (from 1 to 60 frames/second) and saved digitally or recorded to video tape as desired.

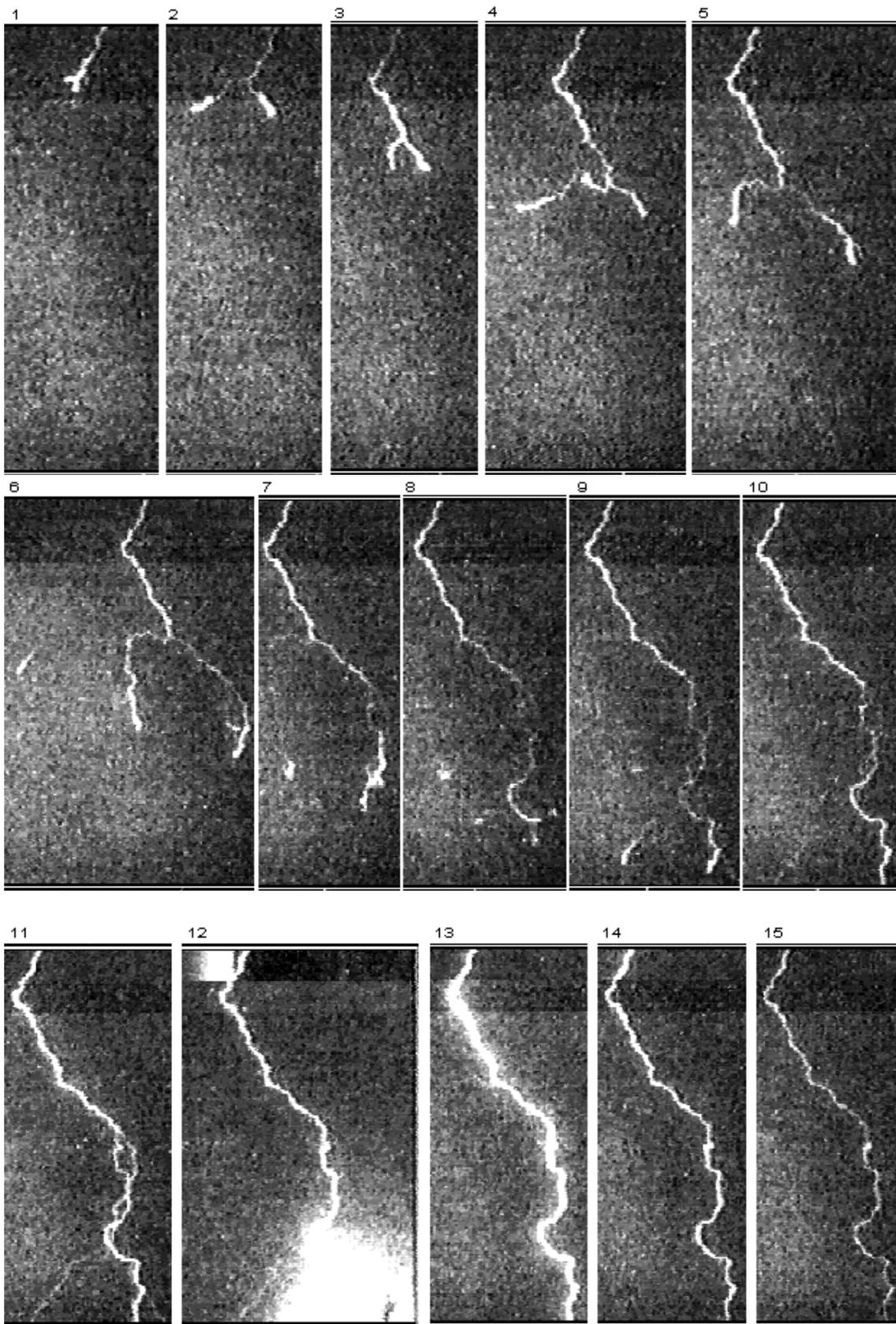


Fig. 1. Time-resolved sequence of a lightning bolt.

We are not experts on lightning#[2], and have only seen a few time-resolved lightning bolt photographs. Nevertheless, a few features stand out. The first thing to notice in frames 1-9 (before the bolt connects to the ground), is that the downward-propagating leader is always forked. At each point in time, one fork or the other will "survive", and be selected as the stroke meanders downward. There is an interesting propagating remnant in frames 6, 7, and 8, which looks like a "blob" of plasma. Multiple filaments in frames 9, 10, and 11 are observed to be helically intertwined, and the current channels are probably self-attracting. The return stroke in frame 12 was too bright, and caused a camera artifact near the top of that image. We did not count the seconds from the flash to the thunder, but the range to the bolt can be estimated by noting that the object at the bottom of the flash in frame 12 is a high-voltage electric transmission tower on the west side of the White Rock canyon, overlooking the Rio Grande river, and it is silhouetted in the flash. The tower is 50 meters tall, and the bolt was at least 1.5 km away. The field of view of the image is therefore approximately 800 meters vertically, and the leader is propagating downwards at a speed of 1×10^5 m/sec or greater. The current faded away slowly in frames 13-18, until it was invisible, without changes in position. This bolt did not exhibit later strokes, as is often the case. From analysis of these pictures, one can conclude that this lightning bolt had a "typical propagation speed" for its downward propagating " α -stepped leader"#[3]. The image is also available as an MPEG movie file at on the World Wide Web at <http://wsx.lanl.gov/gwurden.htm>. This work was supported by US DOE contract W-7405-ENG-36.

References

[1]. G. A. Wurden, K. Buechl, J. Hofmann, R. Lang, A. Rudyj, and W. Sandmann. "Pellet imaging techniques in the ASDEX tokamak", *Rev. Sci. Instrum.*, vol. 61, no. 11, pp. 3604-3608, 1989.

[2]. M. A. Ullman, *Lightning*. New York: Dover, 1969.

[3]. B. F. J. Schonland, D. J. Malan, and H. Collens, "Progressive lightning", in *Proc. Roy. Soc. (London)*, vol A152, pp. 595-625, (1935).

1. We had actually set up with a 10" telescope to observe the Comet Shoemaker-Levy 9 crash on Jupiter, but the weather did not cooperate for astrophotography.