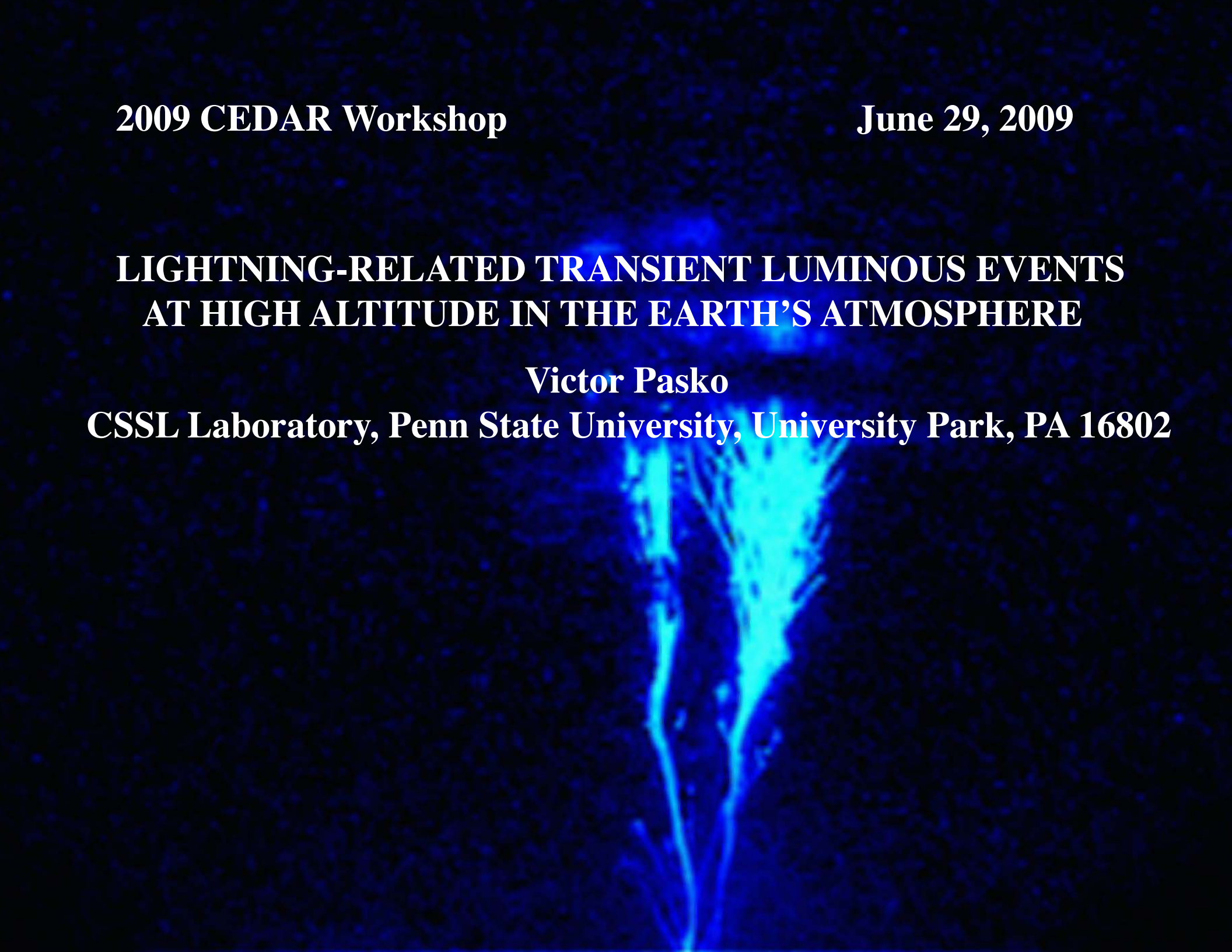
2009 CEDAR Workshop June 29, 2009

LIGHTNING-RELATED TRANSIENT LUMINOUS EVENTS AT HIGH ALTITUDE IN THE EARTH'S ATMOSPHERE

Victor Pasko
CSSL Laboratory, Penn State University, University Park, PA 16802



LIGHTNING-RELATED TRANSIENT LUMINOUS EVENTS AT HIGH ALTITUDE IN THE EARTH'S ATMOSPHERE

Victor Pasko
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2009 CEDAR Workshop,
Eldordado Hotel, Santa Fe, New Mexico, USA

28 June - 2 July, 2009

Outline

- Introduction
- Phenomenology and Physical Mechanism of Elves
- Phenomenology and Physical Mechanism of Sprites
- Phenomenology and Physical Mechanism of Blue Jets and Gigantic Jets
- Report on AGU Chapman Conference on Effects of Thunderstorms and Lightning in the Upper Atmosphere

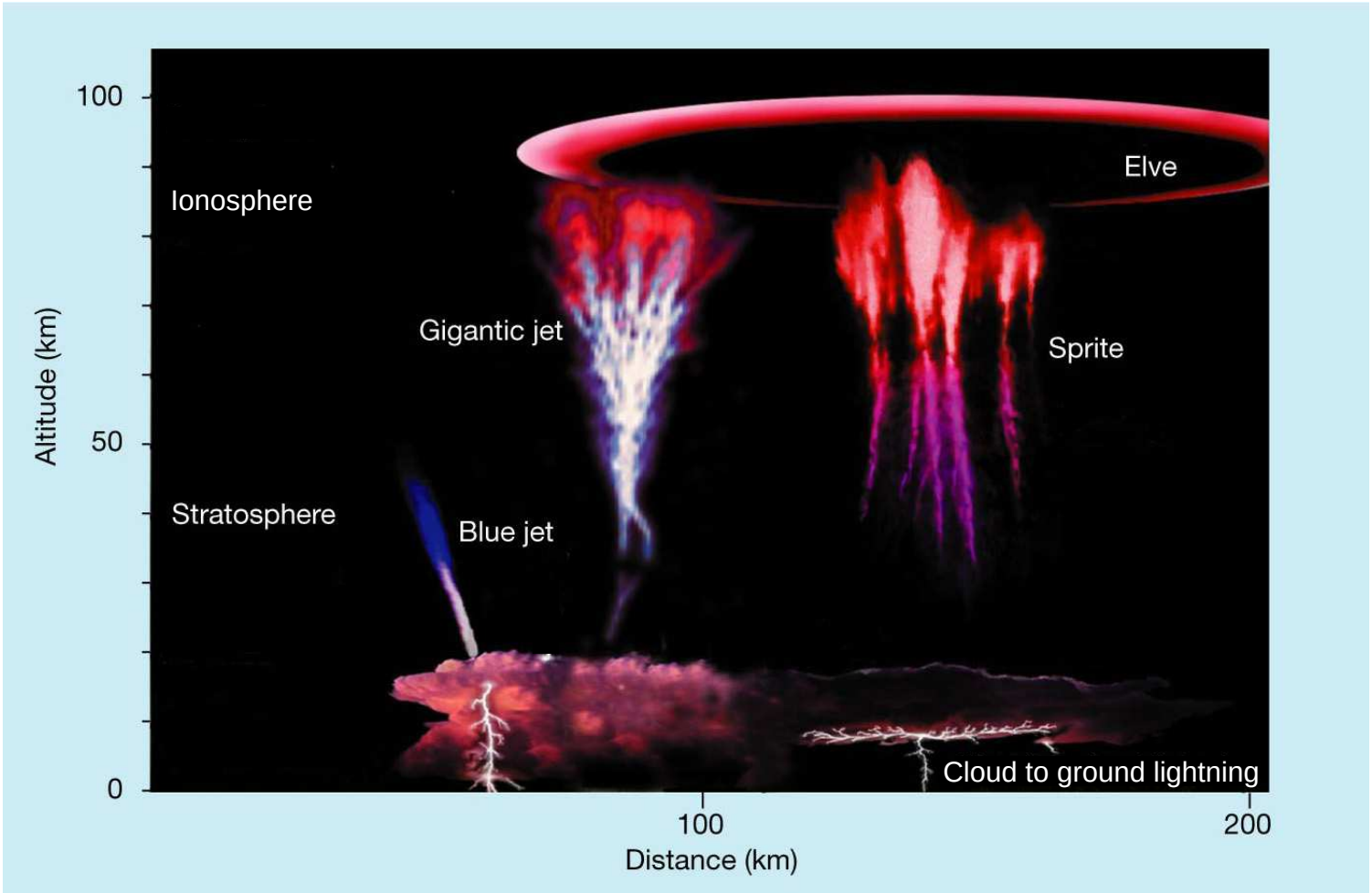
The First TV Image of an Optical Flash Above Thunderstorms

- The first recorded TV image of unusual optical flashes occupying large volumes of space above thunderstorms was obtained serendipitously on July 5, 1989 during a test of a low-light-level TV camera at the O'Brien Observatory of the University of Minnesota near Minneapolis [*Franz et al.,* Science, 249, 48, 1990].

A Sprite Event Recorded on Color Video [*Sentman et al.*, 1995]

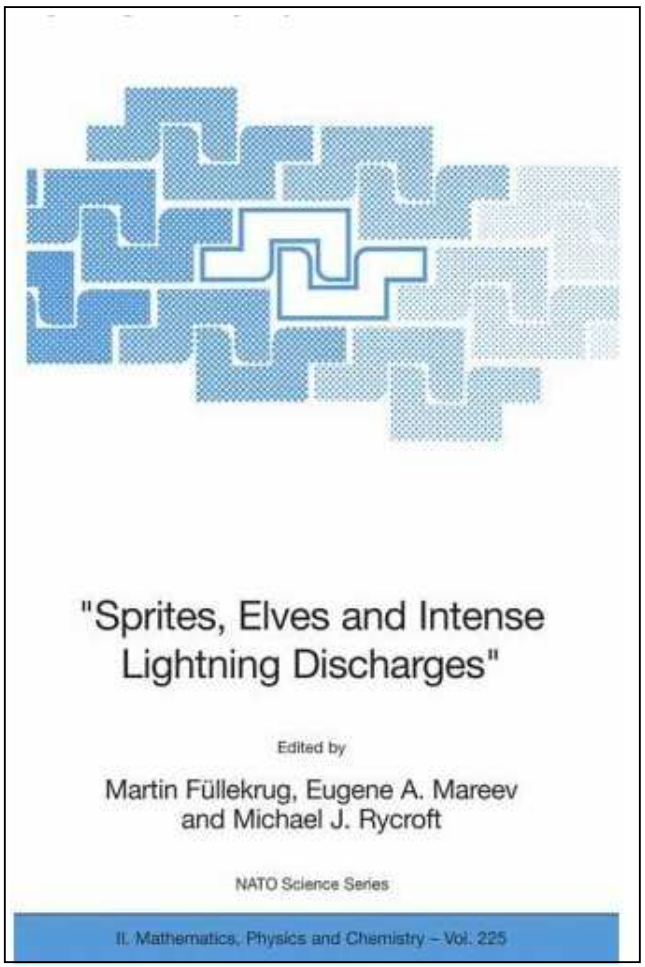
- A sprite event (one of the largest) recorded on color video on 4 July 1994 at 0400:20 UT [*Sentman et al.*, Geophys. Res. Lett., 22, 1205, 1995]

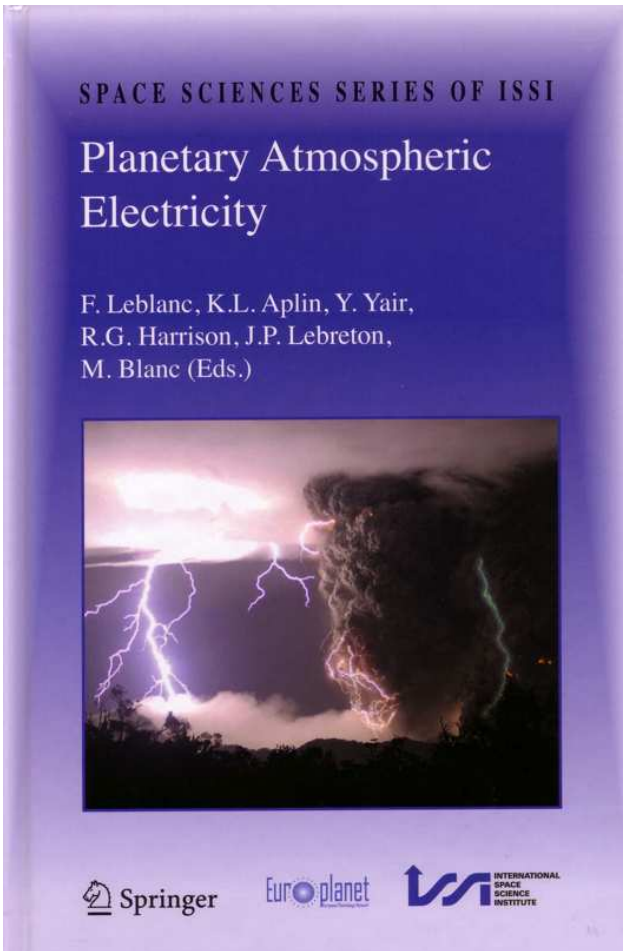
Lightning-Related Middle Atmospheric Transient Luminous Events



[Lyons et al., BAMS, 84, 445, 2003; Pasko, Nature, 423, 927, 2003]

Books on Transient Luminous Events





Recently Published Reviews on Transient Luminous Events

- Ebert, U., and D. Sentman, Editorial Review: Streamers, sprites, leaders, lightning: from micro- to macroscales, *J. Phys. D: Appl. Phys., 41,* 230301, 2008.
- Mishin, E., G. Milikh, Blue jets:Upward lightning, *Space Sci.Rev.,137,*473, 2008.
- Neubert, T., et al., Recent results from studies of electric discharges in the mesosphere, *Surv. Geophys., 29,* 71-137, 2008.
- Pasko, V. P., Topical Review: Red sprite discharges in the atmosphere at high altitude: the molecular physics and the similarity with laboratory discharges, *Plasma Sources Sci. Technol., 16,* S13-S29, 2007.
- Pasko, V. P., Blue jets and gigantic jets: transient luminous events between thunderstorm tops and the lower ionosphere, *Plasma Phys. Control. Fusion, 50,* 124050, 22 pp., 2008.
- Roussel-Dupre, R., et al., Physical processes related to discharges in planetary atmospheres, *Space Sci. Rev., 137,* 51-82, 2008.
- Siingh, D., et al., Thunderstorms, lightning, sprites and magnetospheric whistler-mode radio waves,*Surv. Geophys., 29,* 499-551, 2008.

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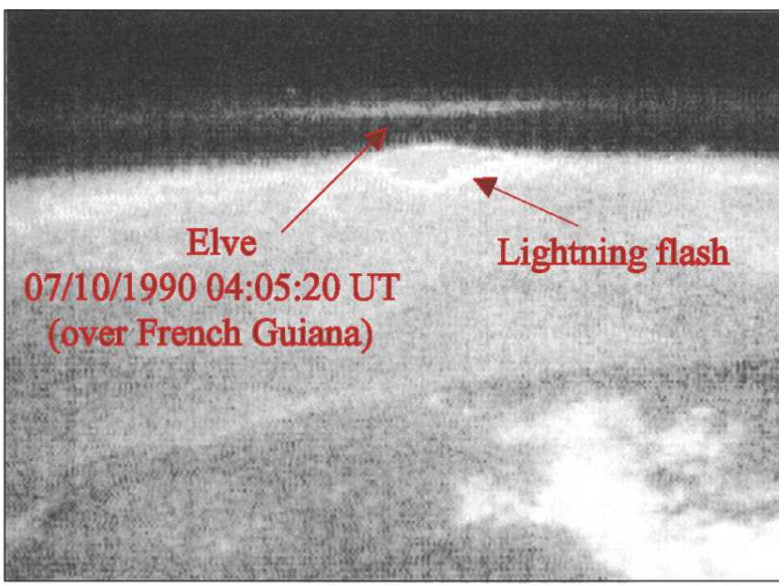
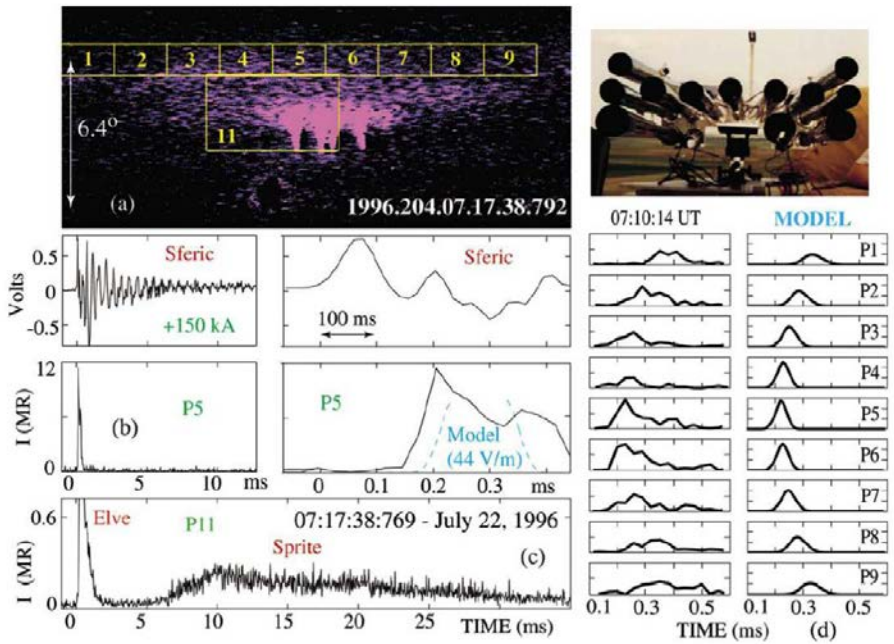
Physical Mechanism of Elves

- *Inan et al.* [GRL, 18, 705, 1991] predicted optical emissions as a result of lightning EMP interaction with the lower ionosphere.
- *Boeck et al.* [GRL, 12, 99, 1992] reported first unambiguous observation of what is now known as 'elves' suggesting the mechanism presented by *Inan et al.* [1991] as explanation:



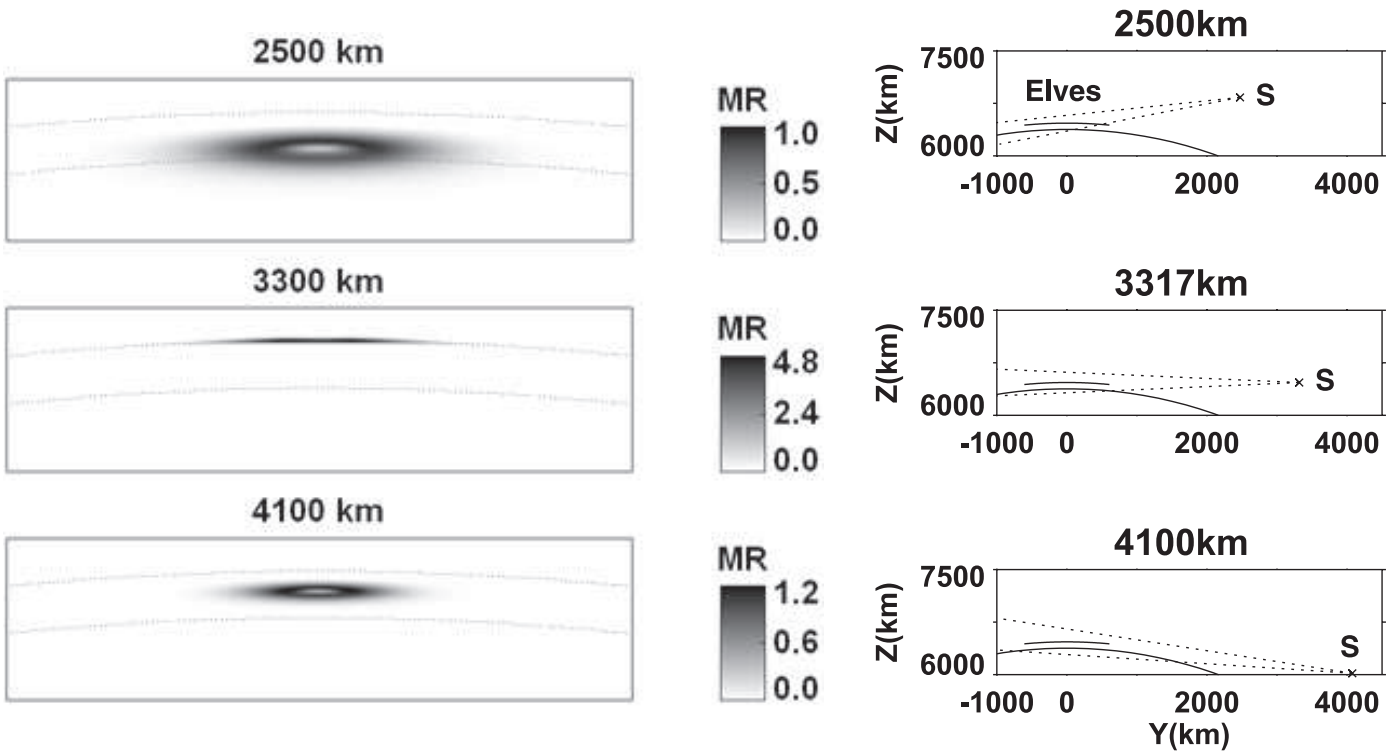
Phenomenology of Elves

- *Fukunishi et al.* [GRL, 16, 2157, 1996] realized first definite observation of elves from the ground using photometers.
- *Inan et al.* [GRL, 24, 583, 1997] used Fly's Eye instrument for definite test of the EMP mechanism:



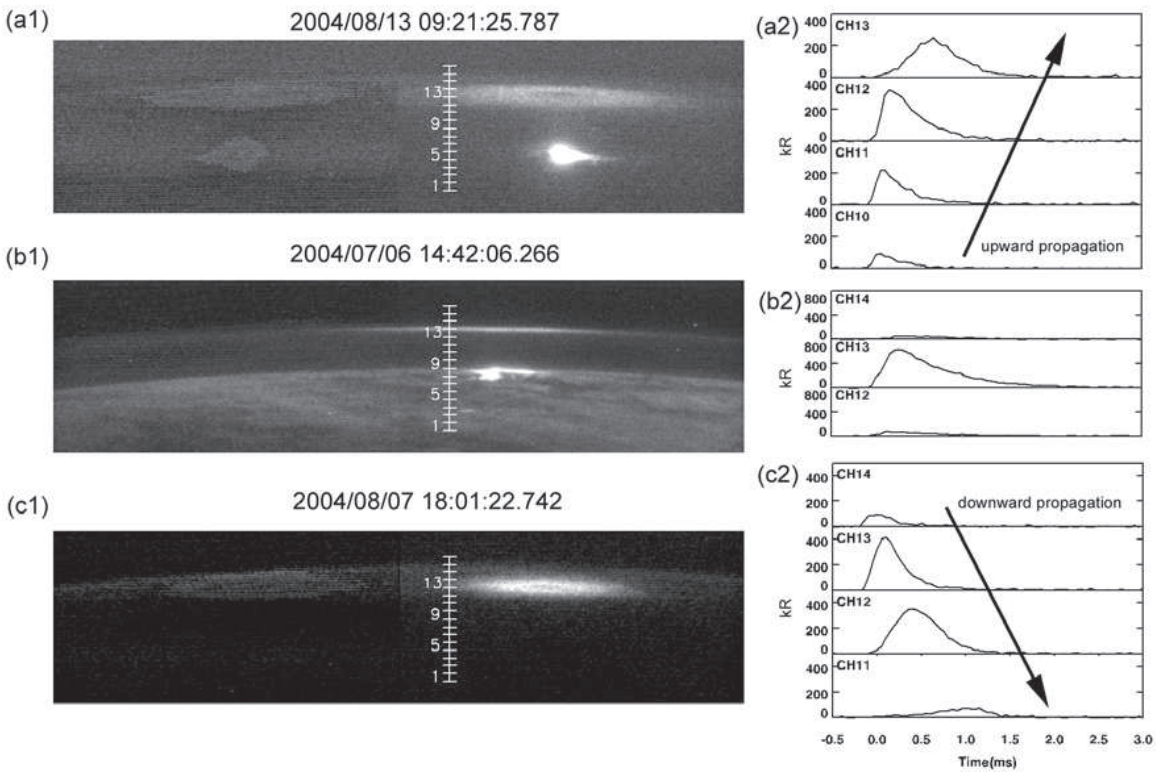
Modeling of Elves Observed by FORMOSAT-2 [*Kuo et al.*, 2007]

- Optical emissions of first positive band system of N_2 of a modeled elve (peak current 280 kA) in front (2500 km), at (3300 km) and behind (4100 km) the limb [*Kuo et al.*, JGR, 112, A11312, 2007]:



Observations of Elves by FORMOSAT-2 Satellite [*Kuo et al.*, 2007]

- ISUAL Imager (a1, b1, c1) and Array Photometer (a2, b2, c2) data for elves occurring in front, at, and behind the limb, respectively [*Kuo et al.*, JGR, 112, A11312, 2007]:



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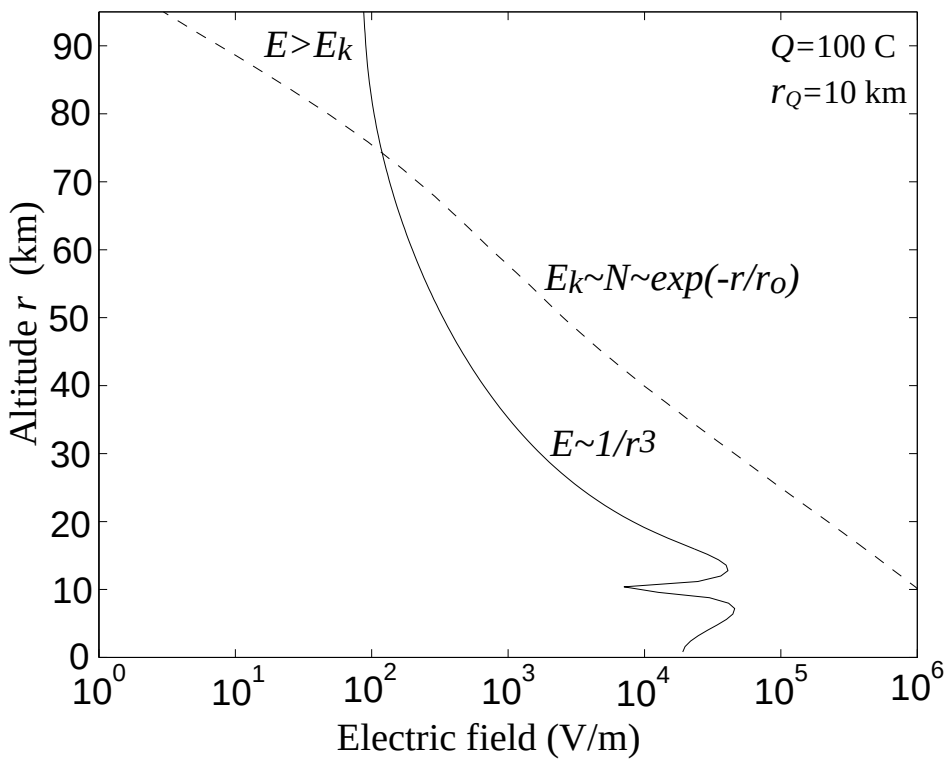
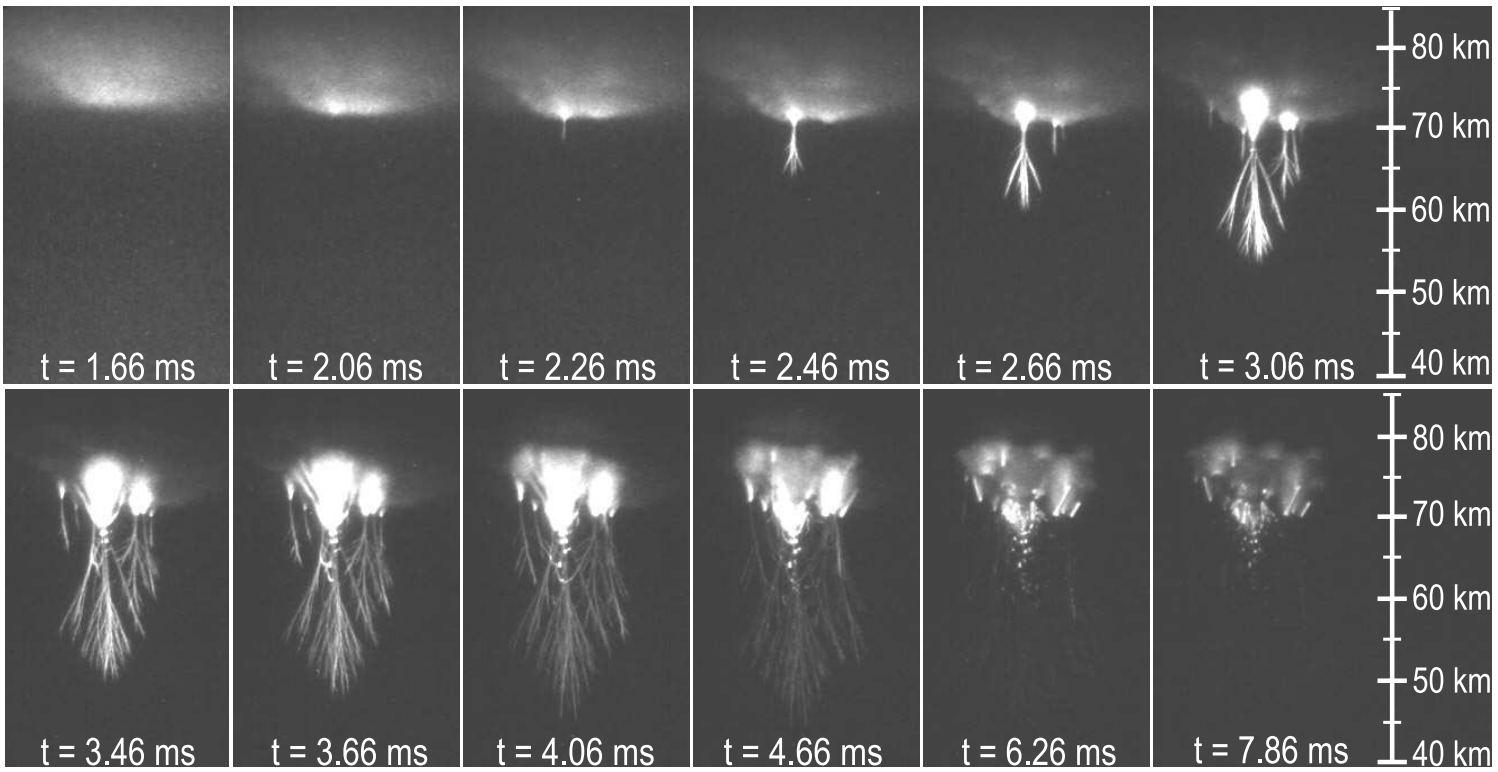
Physical Mechanism of Sprites

"While the electric force due to the thundercloud falls off rapidly as r increase, the electric force required to cause sparking (which for a given composition of the air is proportional to its density) falls off still more rapidly. Thus, if the electric moment of a cloud is not too small, there will be a height above which the electric force due to the cloud exceeds the sparking limit."

C.T.R. Wilson, Proc. Phys. Soc. Lond., Vol. 37, P. 32D, 1925



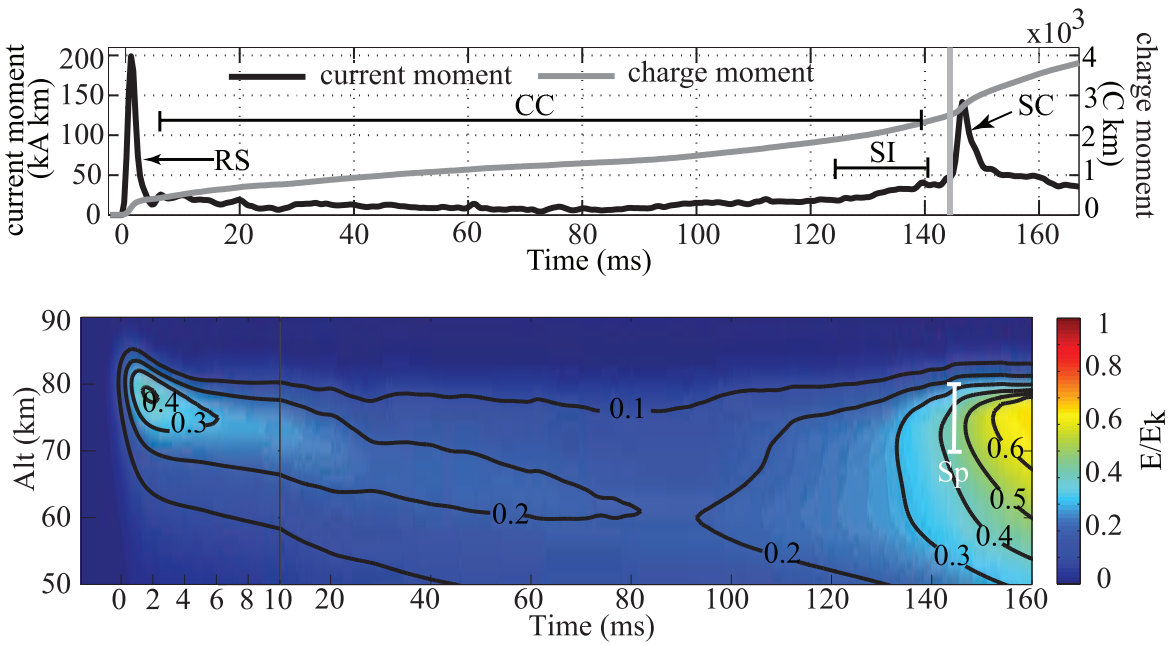
Phenomenology of Sprites



[Cummer et al., Geophys. Res. Lett., 33, L04104, 2006]

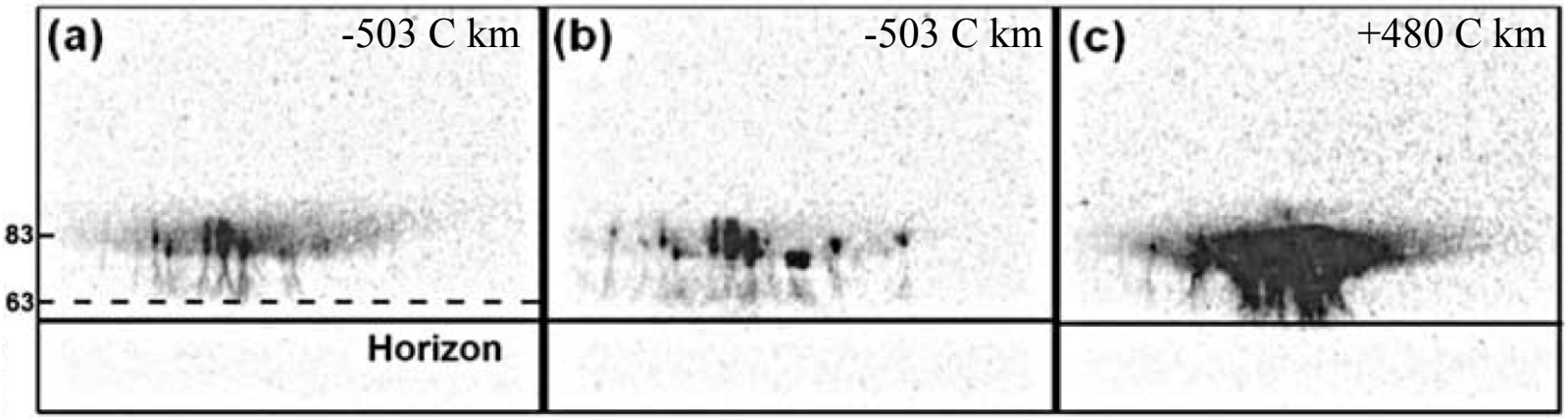
Modeling of Electric Fields Driving Delayed Sprites [*Li et al.*, 2008]

- The normalized electric fields producing long-delayed sprites are E/E_k=0.45 [*Li et al.*, JGR, 113, D20206, 2008], which are similar to those for typical short-delayed sprites that are neither remarkably bright or dim [*Hu et al.*, JGR, 112, D13115, 2007]. Comparison of modeling and observations indicate that the long-delayed sprites initiate 5 km lower than short-delayed sprites [*Li et al.*, 2008].



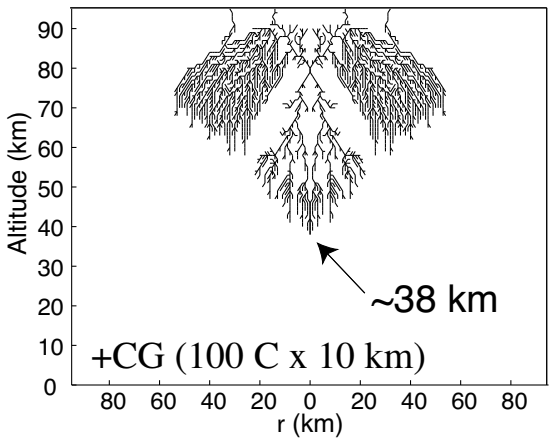
Sprites Produced by Positive and Negative Lightning Discharges

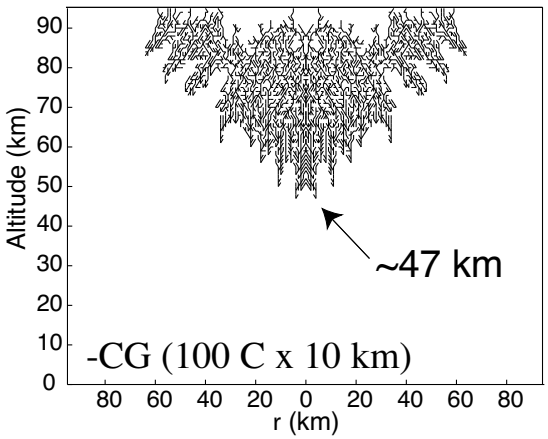
- *Taylor et al.* [GRL, 35, L14812, 2008] reported limited altitude extend of a sprite produced by -CG when compared to a sprite produced by +CG with similar charge moment change:

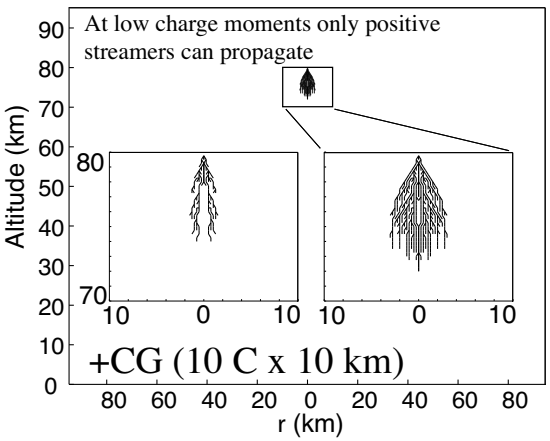


Fractal Modeling of Sprites

- The observed initiation of positive streamers in sprites before the negative ones may be related to relatively slow variation of the driving electric field (∼1 ms) [*Hu et al.*, J. Geophys. Res., 112, D13115, 2007] and the lower electric field threshold required for propagation of positive streamers [*Pasko et al.*, Geophys. Res. Lett., 4, 497, 2000]:

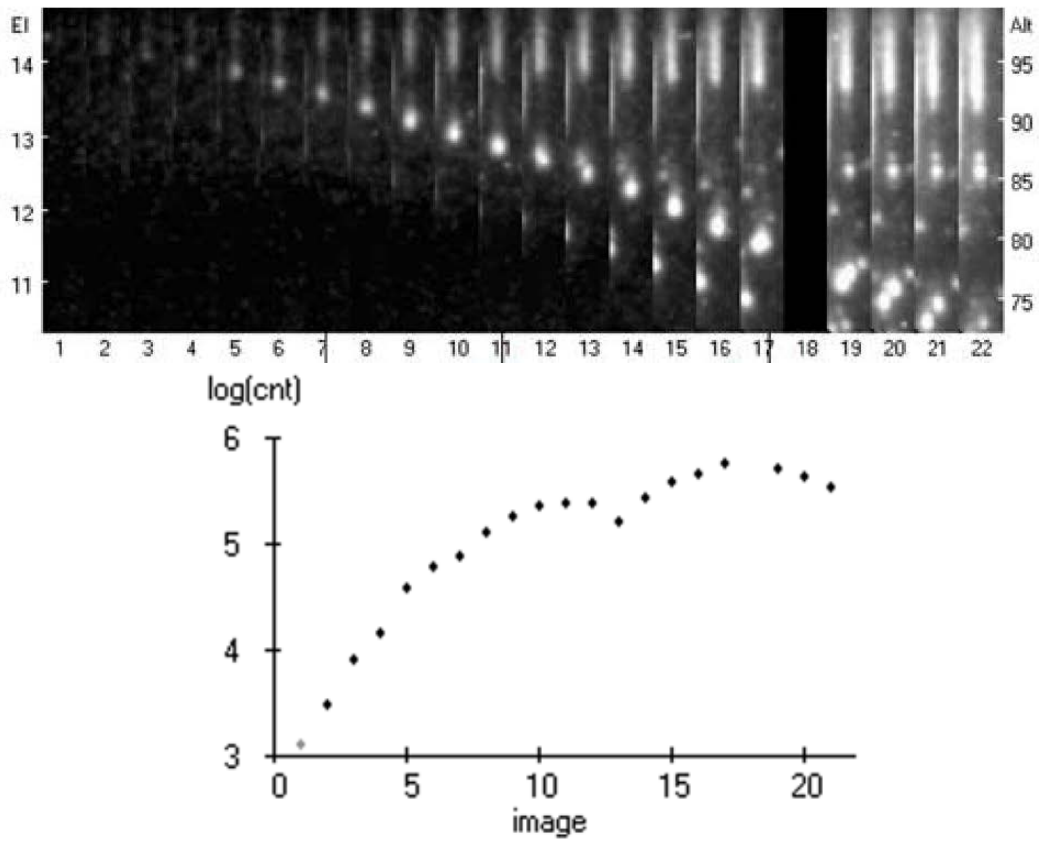






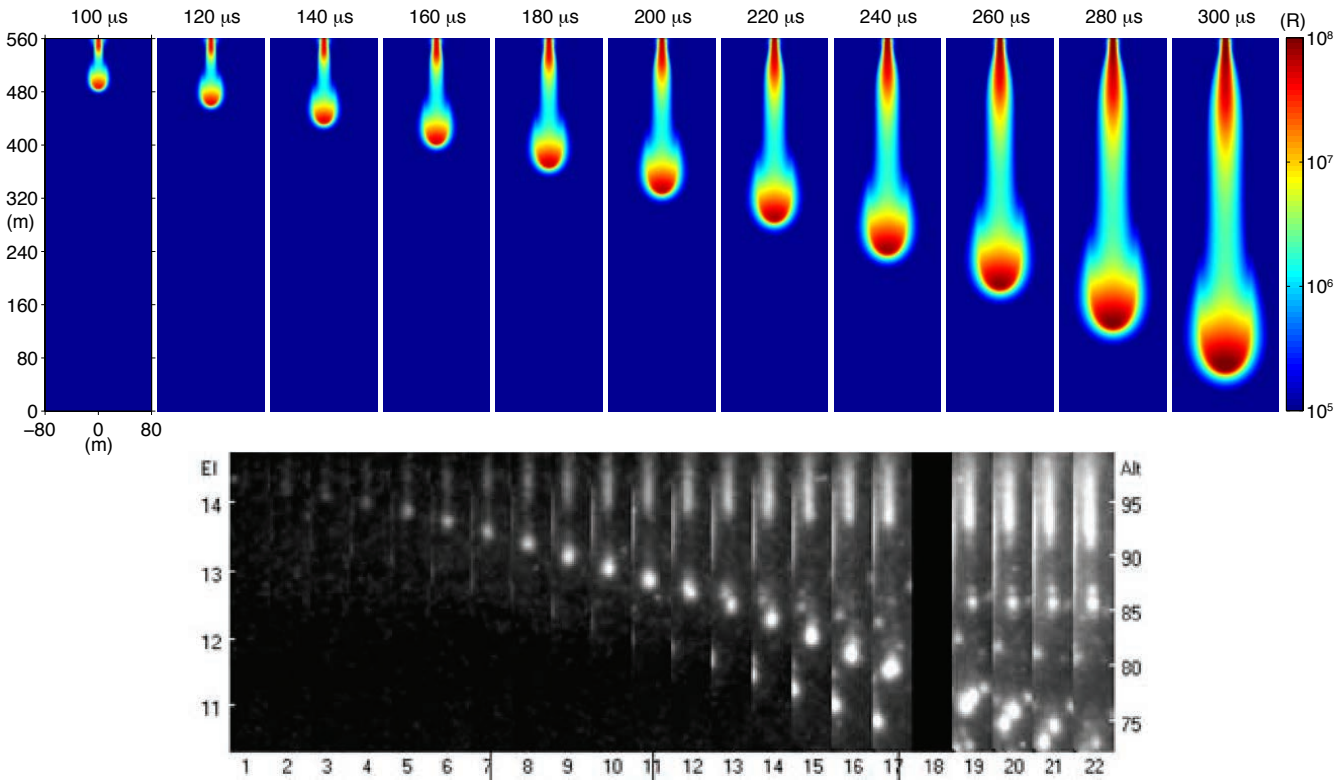
Positive Streamers in Sprites Are Initiated Before Negative Ones

- Sprite images recorded at 10,000 fps with 50 μs exposure time [*McHarg et al.*, 2007; *Stenbaek-Nielsen et al.*, 2007]:

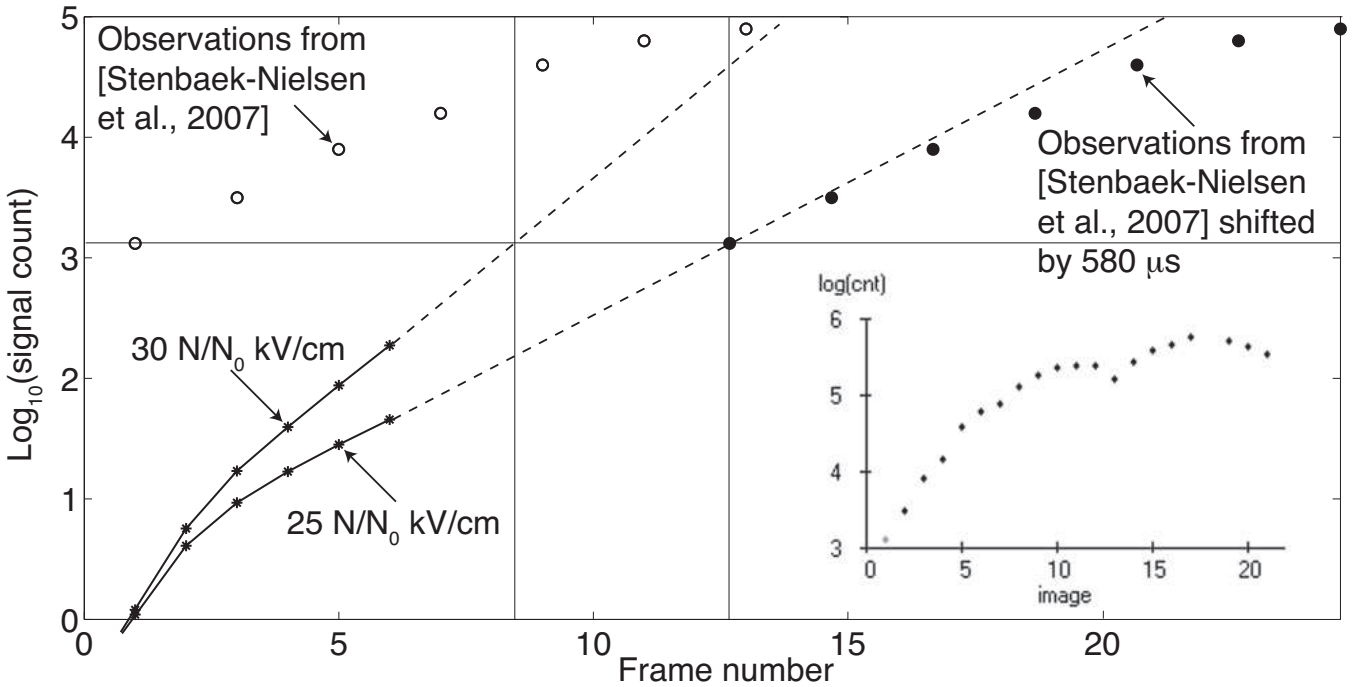


Acceleration of the Model Streamer [*Liu et al.*, 2009]

- A time sequence of the intensity distribution of $1PN_2$ for the downward propagating model positive streamer at 75 km altitude [*Liu et al.*, JGR, 114, A00E03, 2009].



Exponential Increase of the Brightness of a Streamer Head



- The model streamer corresponds to the initial stage of the observed streamer.
- The exponential growth rate depends on the external field, and its measurement can be used for remote sensing of electric fields driving sprites [*Liu et al.*, 2009].

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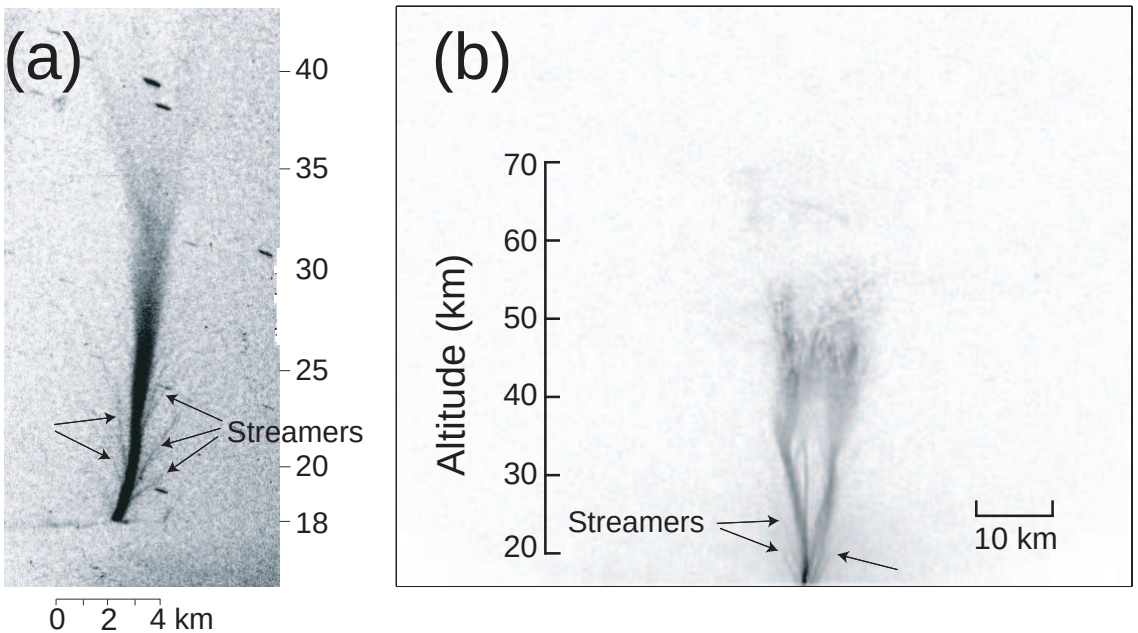
Physical Mechanism of Blue Jets and Gigantic Jets

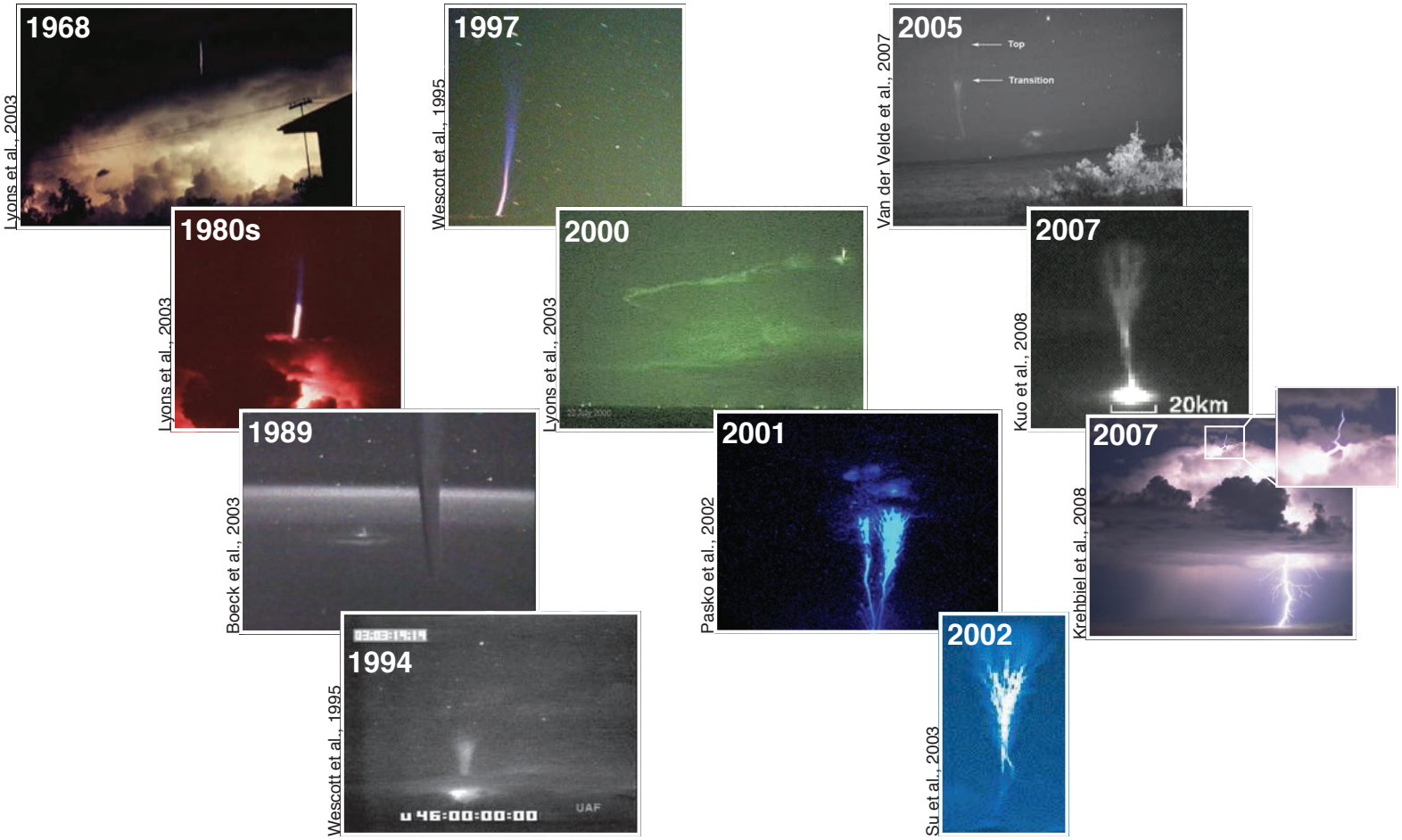
- *Petrov and Petrova* [Tech. Phys., 44, 472, 1999] have suggested that blue jets correspond qualitatively to the development of the streamer zone of a positive leader and therefore should be filled with a branching structure of streamer channels.



(a) A black and white image of a 2-min time exposure of a blue jet [Wescott et al., JGR, 106, 21549, 2001]

(b) Processed image obtained by averaging the sequence of video fields from [Pasko et al., Nature, 416, 152, 2002; http://pasko.ee.psu.edu/Nature/].

Phenomenology of Blue Jets and Gigantic Jets

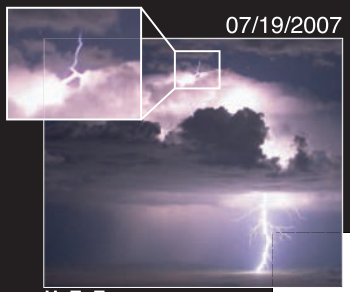


Upward Electrical Discharges From Thunderstorms

Paul R. Krehbiel, Jeremy A. Riousset, Victor P. Pasko, Ronald J. Thomas, William Rison, Mark A. Stanley & Harald E. Edens

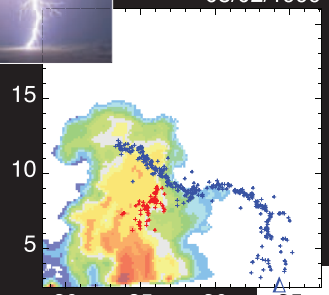
Nature Geoscience, Vol 1, No 4, April, 2008

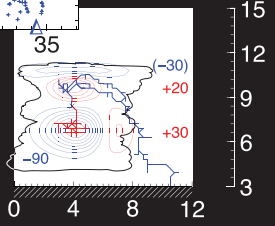
07/19/2007



H. E. Edens

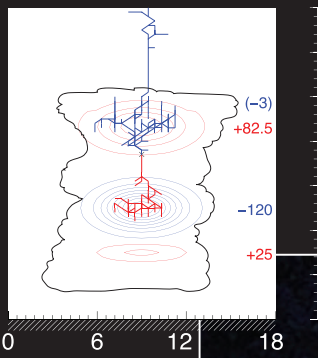
08/02/1999



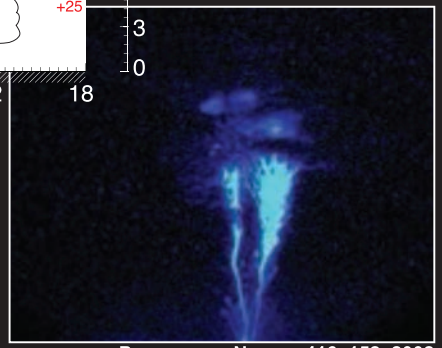


From Bolt-from-the-Blue...

... to Gigantic Jet



09/15/2001



Pasko et al., Nature, 416, 152, 2002

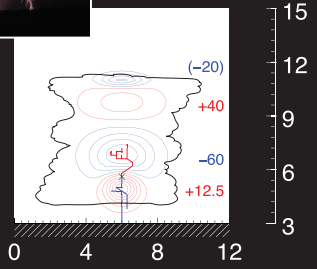
Upward Electrical Discharges From Thunderstorms

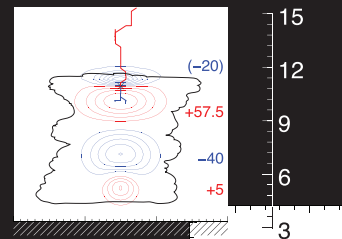
Paul R. Krehbiel, Jeremy A. Riousset, Victor P. Pasko, Ronald J. Thomas, William Rison, Mark A. Stanley & Harald E. Edens

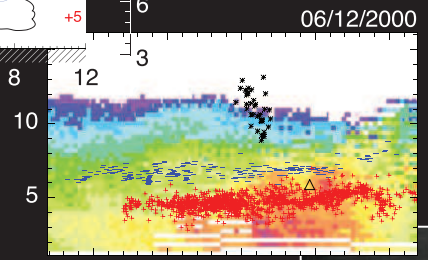
Nature Geoscience, Vol 1, No 4, April, 2008

... to Upward Blue Jet

H. E. Edens







Wescott et al., GRL, 22(10), 1209, 1995

From Downward Cloud-to-Ground Lightning...

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Chapman Conference on the Effects of Thunderstorms and Lightning in the Upper Atmosphere

Penn State University, State College, PA, USA
May 10–14, 2009

Topics:

- Observations of Transient Luminous Events
- Theory of Transient Luminous Events
- ELF/VLF Effects of Lightning and Transient Luminous Events
- Energetic Radiation from Lightning and Terrestrial Gamma Ray Flashes

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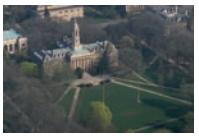
Image Courtesy of Hans Stenbaek-Nielsen


Conveners:

Davis Sentman,
Univ. Alaska, Fairbanks, USA
Victor Pasko,
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Jeff Morrill,
NRL, USA

Chapman Conference Conveners

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  Naval Research Laboratory
  Washington DC 20375-5352
  Email: jeff.morrill@nrl.navy.mil

- The final program and complete list of abstracts are available at http://www.agu.org/meetings/chapman/2009/bcall/

Chapman Conference Scientific and Program Committee

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Earle Williams, MIT, ELF Observations

Chapman Conference Program

Monday, 11 May

Observations of Transient Luminous Events: Recent Advances and Future Prospects
(Field and satellite experiments, optical/infrared/UV, FUV, morphology, infrasound, etc.)

Tuesday, 12 May

Theory of Transient Luminous Events: Recent Advances and Future Prospects
(Optical/infrared/UV/FUV emissions, streamers, chemical effects)

Wednesday, 13 May

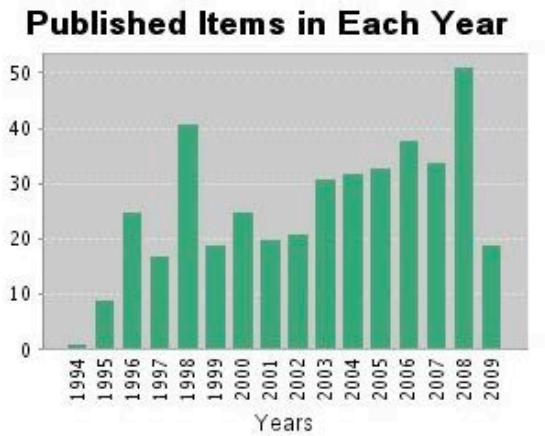
ELF/VLF Effects of Lightning and Transient Luminous Events
(Observations and Theory)

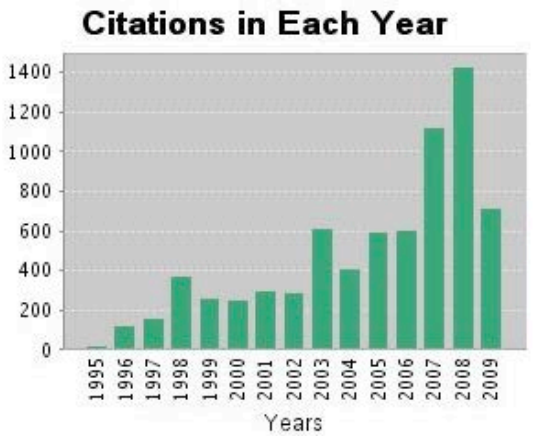
Thursday, 14 May

Energetic Radiation From Lightning, and Terrestrial Gamma-ray Flashes
(Observations and Theory)

Chapman Conference Facts

- The conference coincides with the 20th anniversary of the first recorded image of a transient luminous event in the upper atmosphere by John R. Winckler of the University of Minnesota.
- The conference is a culmination of the dynamic growth of research on Transient Luminous Events and Terrestrial Gamma Ray Flashes during last two decades.





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Sum of the Times Cited [?] : 7,269

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h-index [?] : 42

Chapman Conference Facts

- Total number of participants: 110
- Total number of students: 30
- Total number of participants receiving financial support: 41
- Total number of represented countries: 16 (Brazil, Canada, Denmark, France, Fiji, Greece, Israel, Italy, Japan, the Netherlands, Norway, Russia, Spain, Taiwan, United Kingdom and United States)

JGR-Space Special Section (Submission Deadline: 14 August 2009)

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Effects of Thunderstorms and Lightning in the Upper Atmosphere

Guest Editor(s): D. Sentman

Description: This Special Section of the Journal of Geophysical Research, Space Physics, includes papers presented at the AGU Chapman Conference "Effects of Thunderstorms and Lightning in the Upper Atmosphere" 10–14 May 2009 at Penn State University, as well as papers relevant to the subject of the conference recently published in JGR Space Physics. The Special Section covers topics across the full spectrum of disciplines relevant to the subject, ranging from the underlying meteorology of sprite-associated lightning, gas breakdown and discharge processes, electromagnetic effects, energetic processes, and photochemical, kinetic and transport mechanisms.

Liu, N., V. P. Pasko, H. U. Frey, S. B. Mende, H. Su, A. B. Chen, R. Hsu, and L. Lee
Assessment of sprite initiating electric fields and quenching altitude of $a^1\Pi_g$ state of N_2 using sprite streamer modeling and ISUAL spectrophotometric measurements
J. Geophys. Res., 114, A00E02, doi:10.1029/2008JA013735
26 March 2009 [Abstract] [Full Article] [Print Version]

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Road Scholars conclude 14th annual tour
May 13, 2009

Penn State to host Geophysical Union conference on the atmosphere

Tuesday, May 5, 2009

The Chapman Conference of American Geophysical Union Series will be held at the University Park campus on May 10-14.

The conference, titled "The Effects of Thunderstorms and Lightning in the Upper Atmosphere" is being convened by Davis Sentman, professor of physics at the University of Alaska, Fairbanks; Victor Pasko, associate professor of electrical engineering at Penn State; and Jeff Morrill, a research physicist at the Naval Research Laboratory.

This international conference will focus on the observations of transient luminous events (TLE), theory of transient luminous events, ELF/VLF effects of lightning and transient luminous events and energetic radiation from lightning and terrestrial gamma ray flashes. TLEs are atmospheric optical phenomena that occur above storm clouds and are believed to be electrically induced form of large scale gas discharge. These events are more commonly known as red sprites, blue jets and elves.

There were 114 abstracts submitted, from Brazil, Canada, Denmark, France, Fiji, Greece, Israel, Italy, Japan, the Netherlands, Norway, Russia, Spain, Taiwan, United Kingdom and United States. Conference participant presentations will be published as a collection of articles in a special section of the Journal of Geophysical Research-Space Physics.

The conference coincides with the 20th anniversary of the first recorded image of a transient luminous event in the upper atmosphere by John R. Winckler of the University of Minnesota.

Winckler was testing a low-light television camera when he serendipitously captured two frames of the image. After the observation of this phenomenon, a review of NASA video tapes from the space shuttle payload bay low-light television camera confirmed the discovery by capturing more than a dozen of these events from space. Since this discovery, researchers have filmed and documented thousands of events leading to more questions than answers.

This conference will bring together active researchers in the field to assess and review the current state of both experimental and theoretical research. Participants will identify key theoretical problems and coupling processes of possible relevance to the larger geophysical system and discuss ideas on possible new types of measurements that could help elucidate key aspects of underlying physical processes.

Funding for the conference is provided by the National Science Foundation, Office of Naval Research, Air Force Office of Scientific Research and European Office of Aerospace Research and Development.

More on the conference can be found online at www.agu.org/meetings/chapman/2009/bcall/.

Special Thanks to Chapman Conference Sponsors!

- National Science Foundation (Cassandra Fesen - Aeronomy, Brad Smull - Physical and Dynamic Meteorology)
- Office of Naval Research (Stefan Thonnard)
- Air Force Office of Scientific Research (Kent Miller)
- European Office of Aerospace Research and Development (George York)
- Total conference support is approximately $75,000