CEDAR Student Workshop June 15, 2003

TRANSIENT LUMINOUS EVENTS BETWEEN THUNDERSTORM TOPS AND THE LOWER IONOSPHERE

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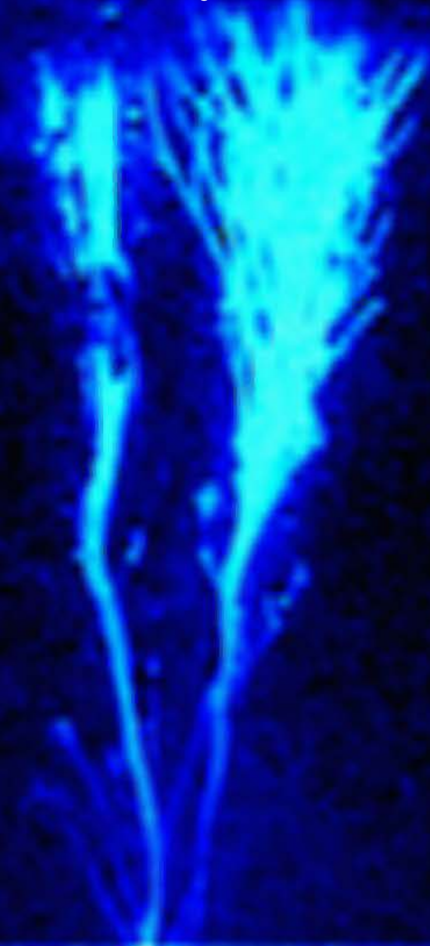


Plan of presentation:

1. Introduction

2. Summary of experimentally observed features of sprites

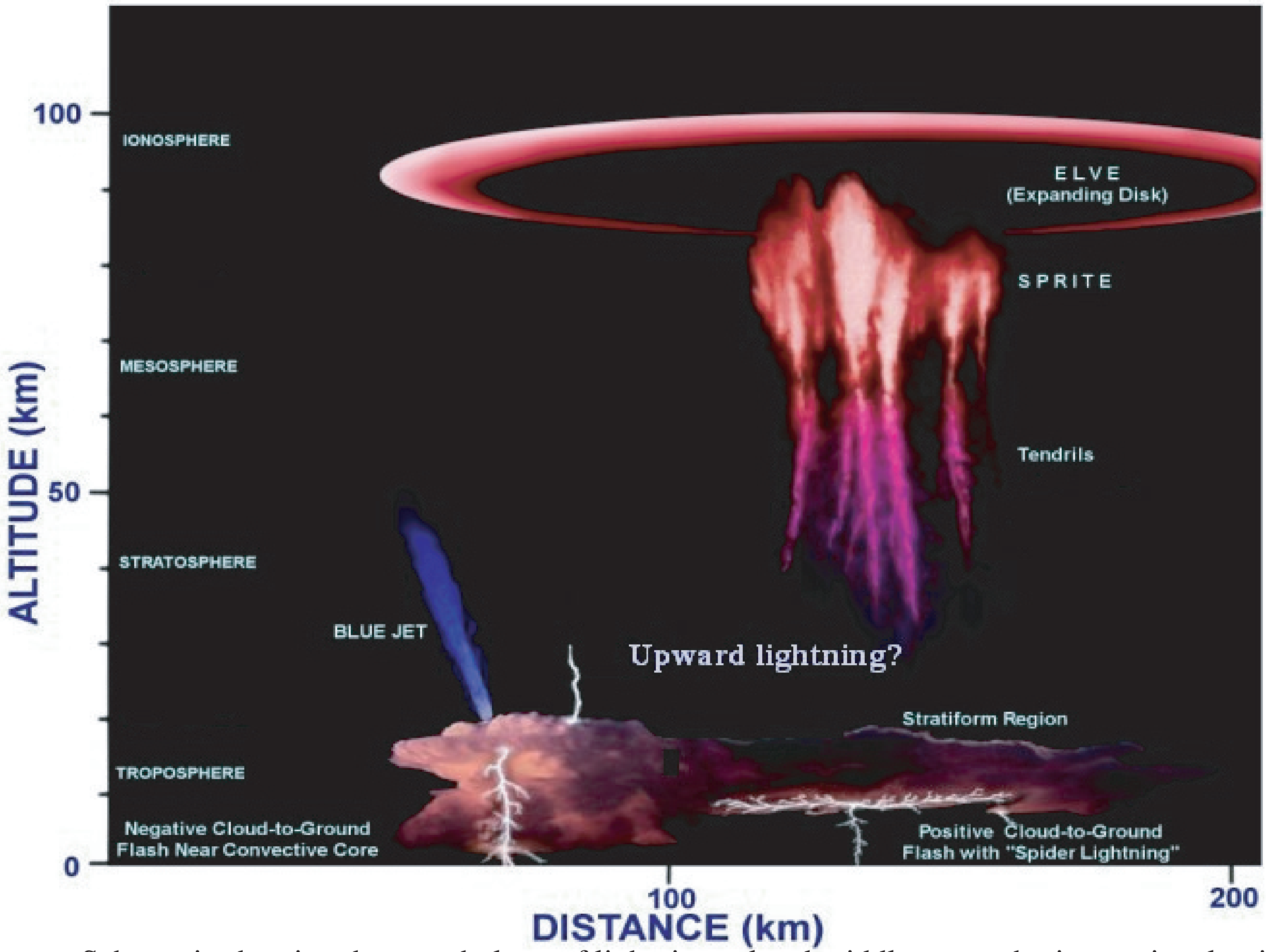
3. Summary of experimentally observed features of blue jets

4. Theoretical modeling of sprites

5. Theoretical modeling of blue jets

6. Conclusions

Lightning-related middle atmospheric transient luminous events



Schematic showing the morphology of lightning-related middle atmospheric transient luminous events including red sprites, blue jets and elves. Also indicated is an additional type of discharge from cumulonimbus tops that may be a true "cloud-to-stratosphere" lightning or simply another manifestation of the blue jet phenomenon. Adapted from Lyons et al. (2000)

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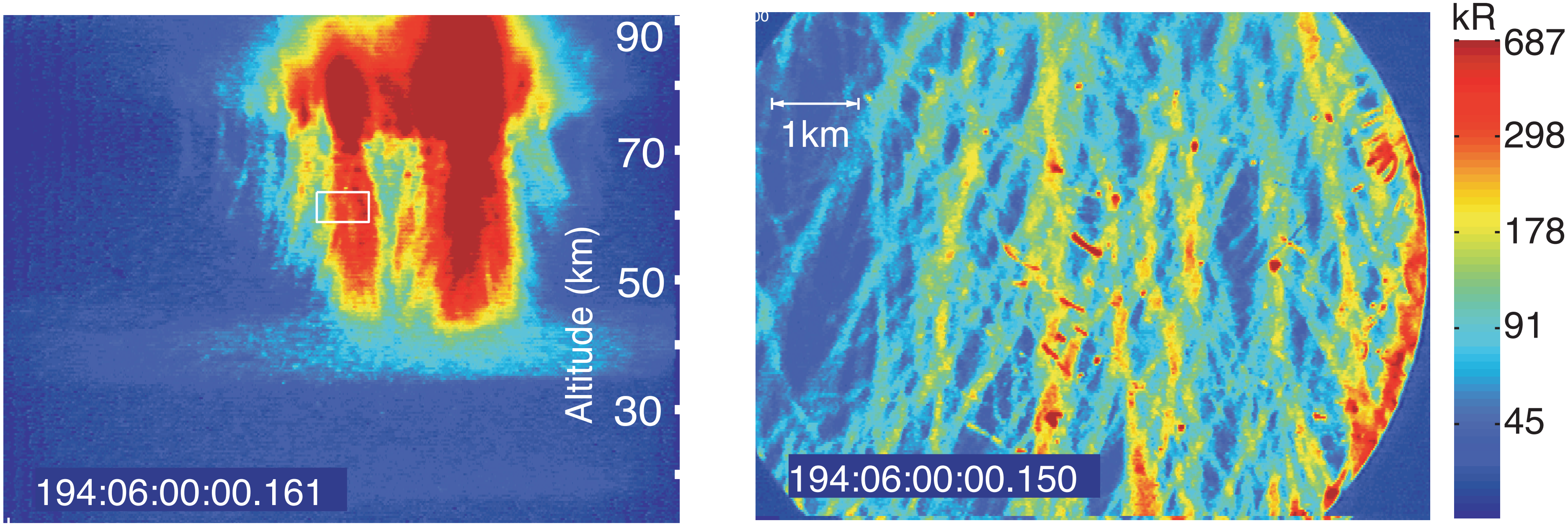
The first TV image of an optical flash above thundersorms [Franz et al., 1990]

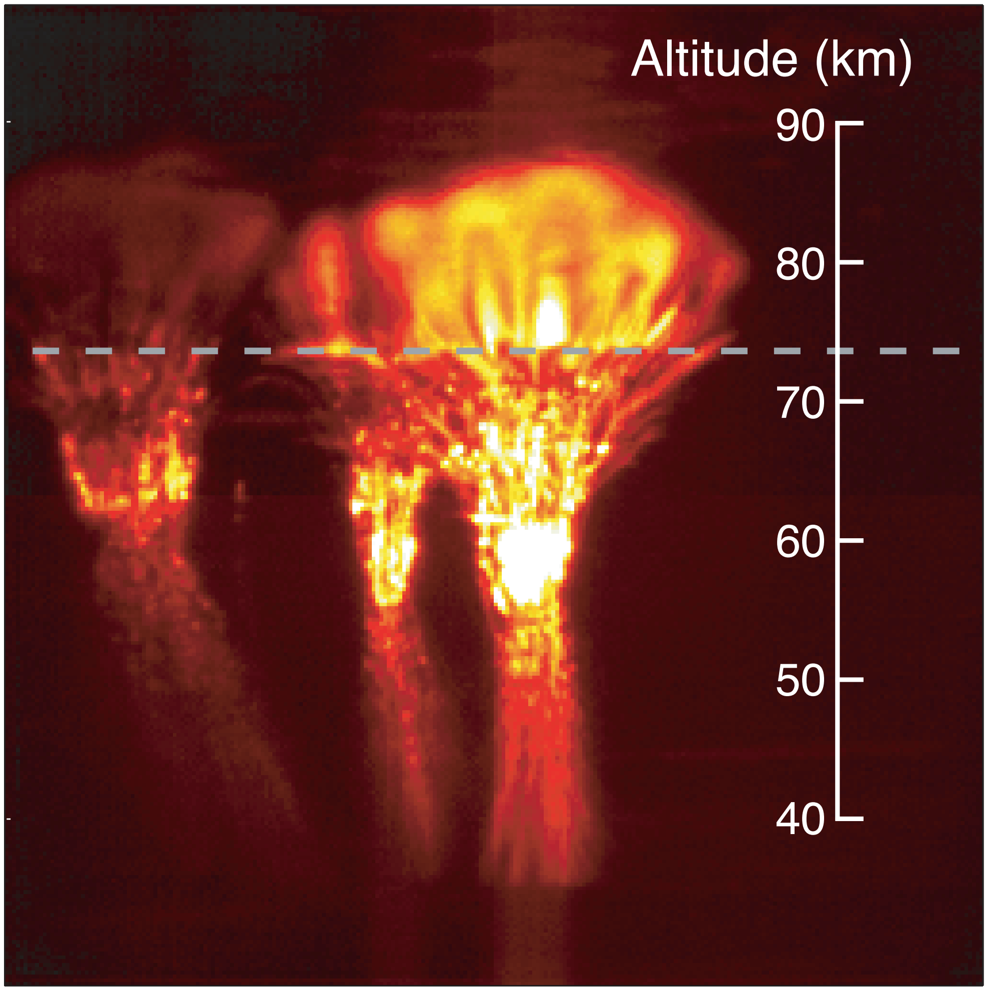
The first recorded image of unusual optical flashes occupying large volumes of space above thunderstorms was obtained serendipitously on July 5, 1989 during a test of a low-light-level TV camera at the O'Brien Observatory of the University of Minnesota near Minneapolis.

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

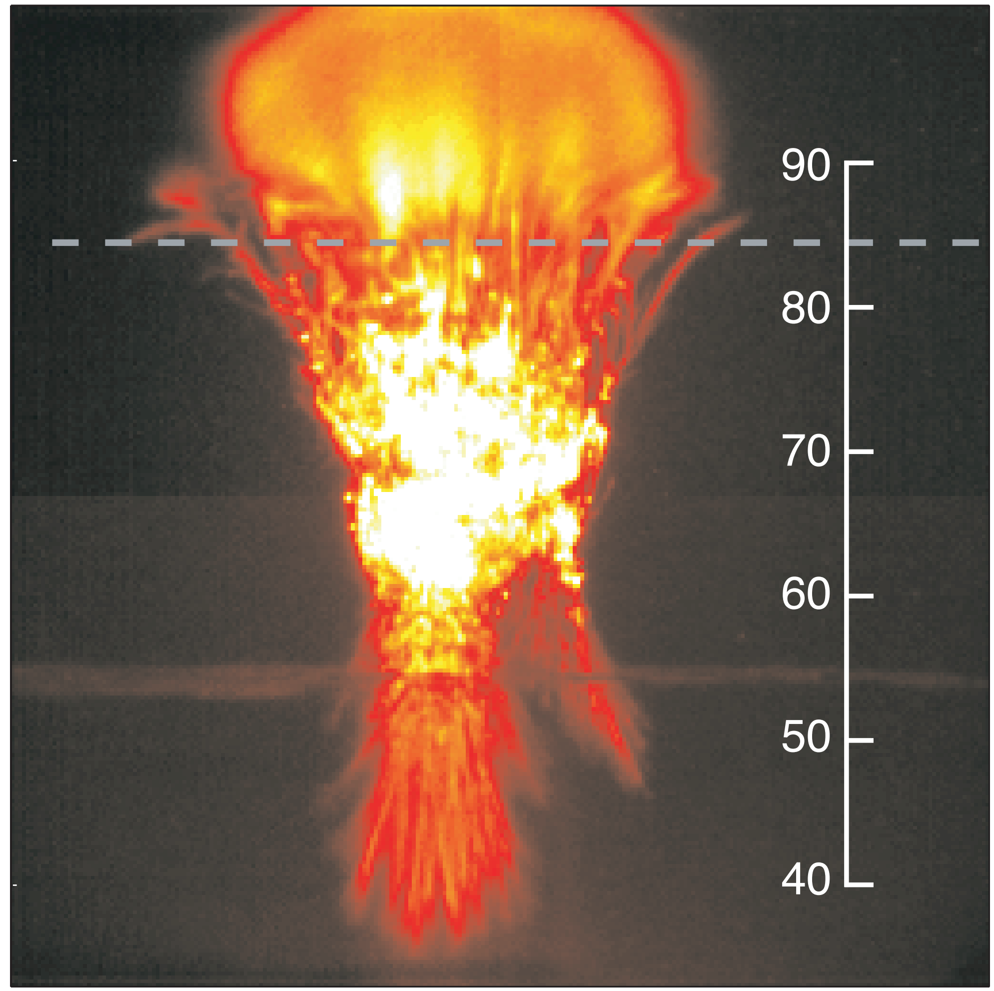
Telescopic imaging of sprites. Wide (left panel) and narrow (right panel) field of view images of a bright sprite event [Gerken et al., 2000].



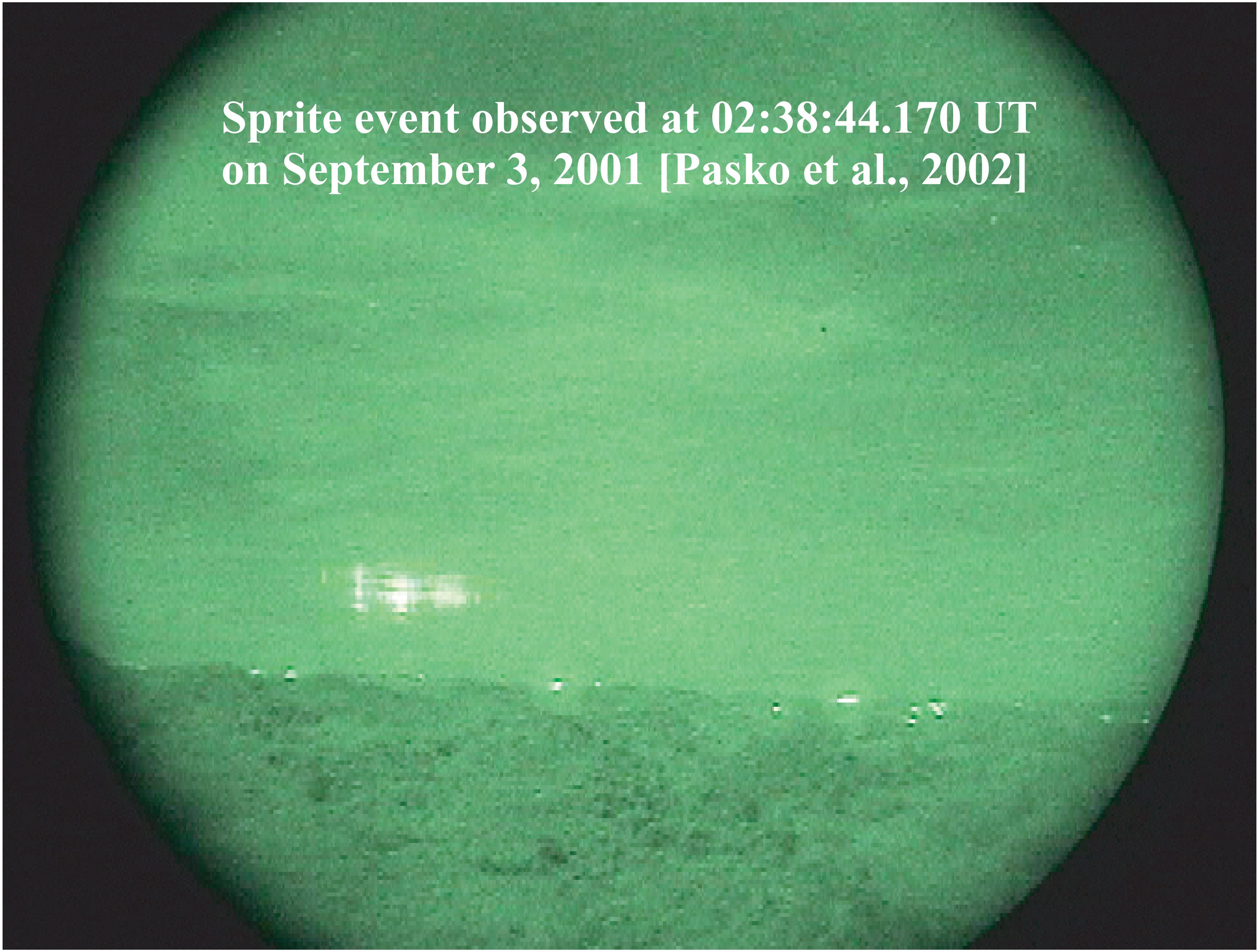
The images illustrating the altitude transition between diffuse and streamer regions in sprites observed on August 18, 1999 by Stenbaek-Nielsen et al. [2000]



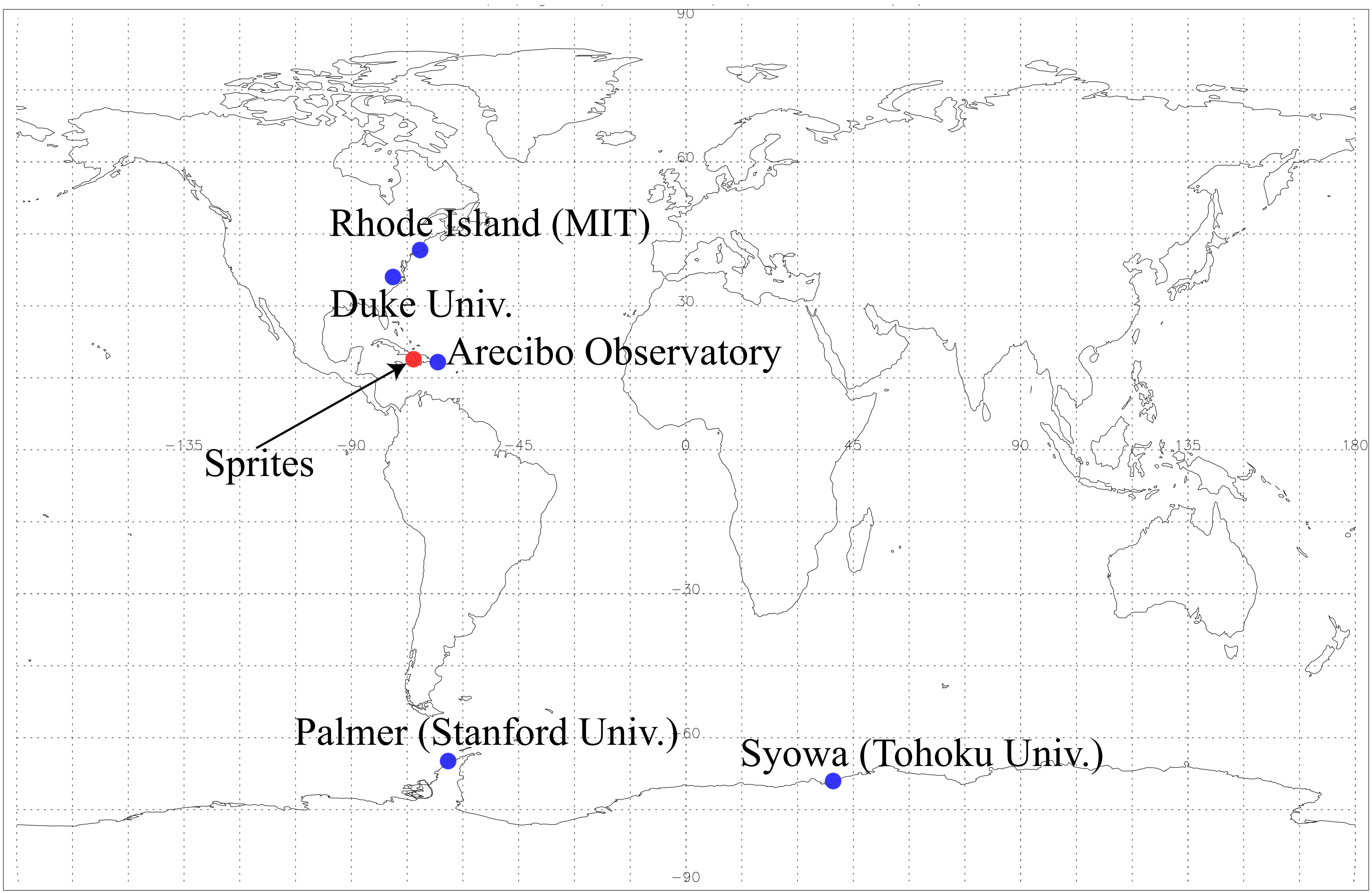
04:36:09.230 UT

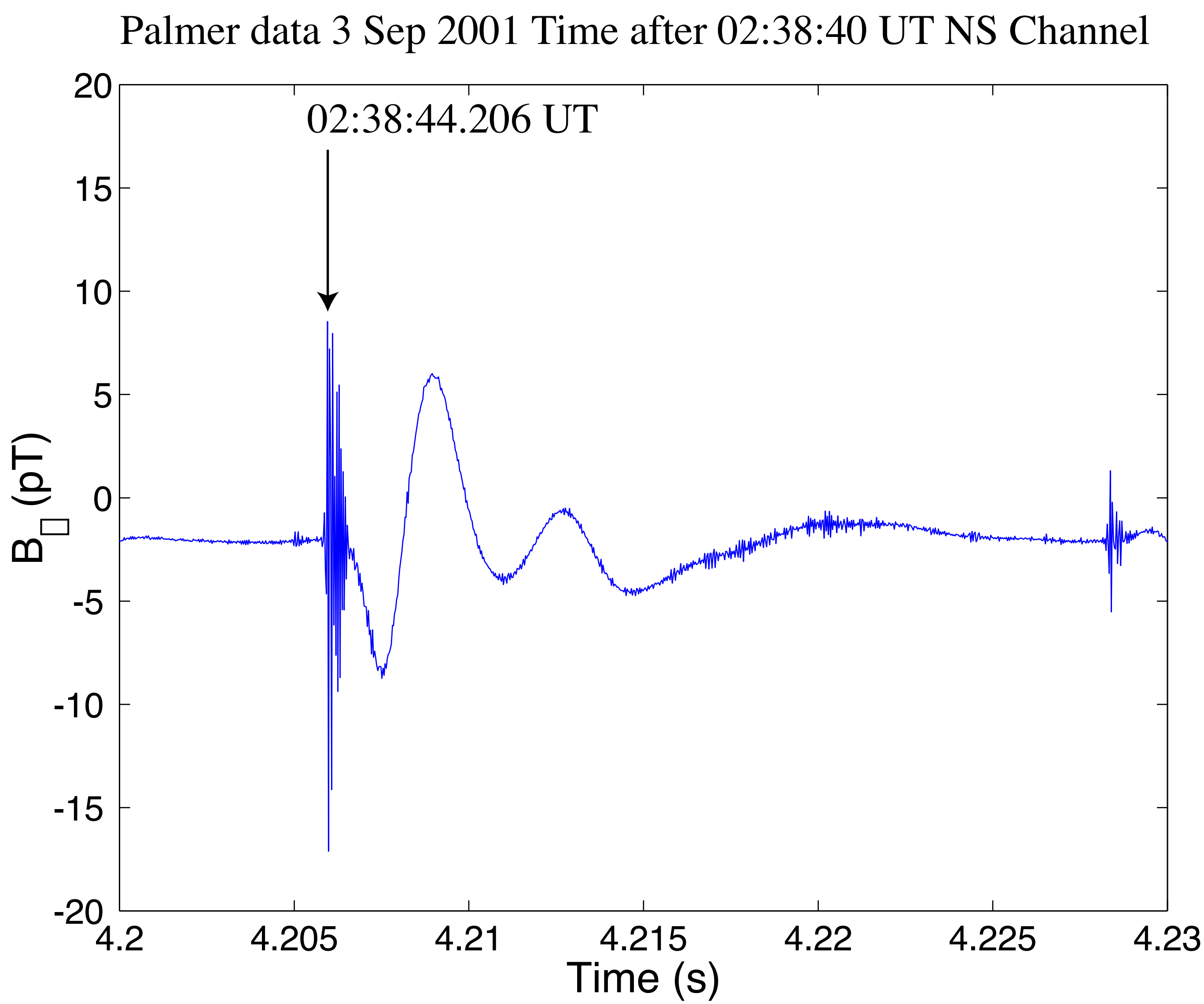


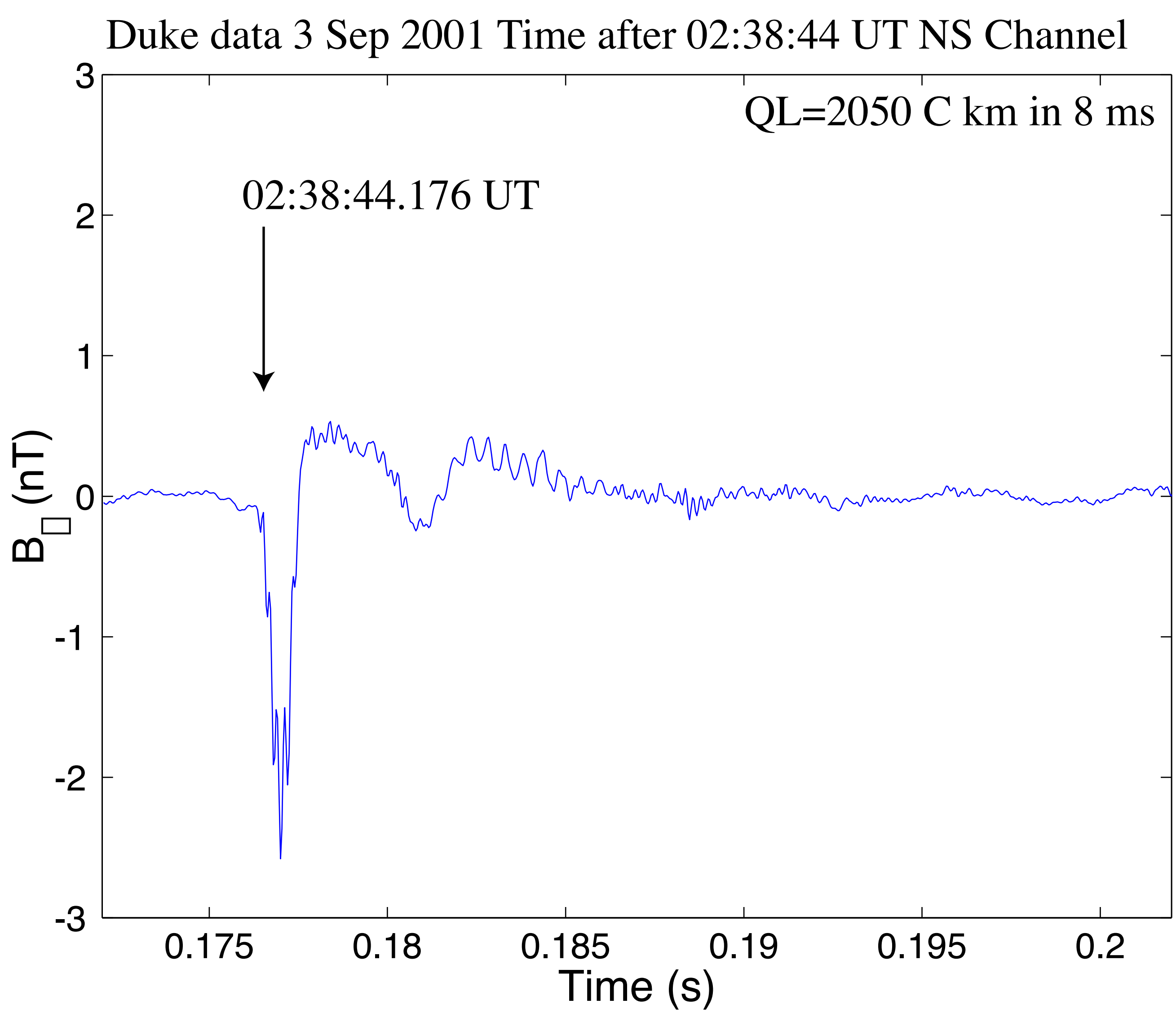
05:24:22.804 UT


Sprite event observed at 02:38:44.170 UT
on September 3, 2001 [Pasko et al., 2002]

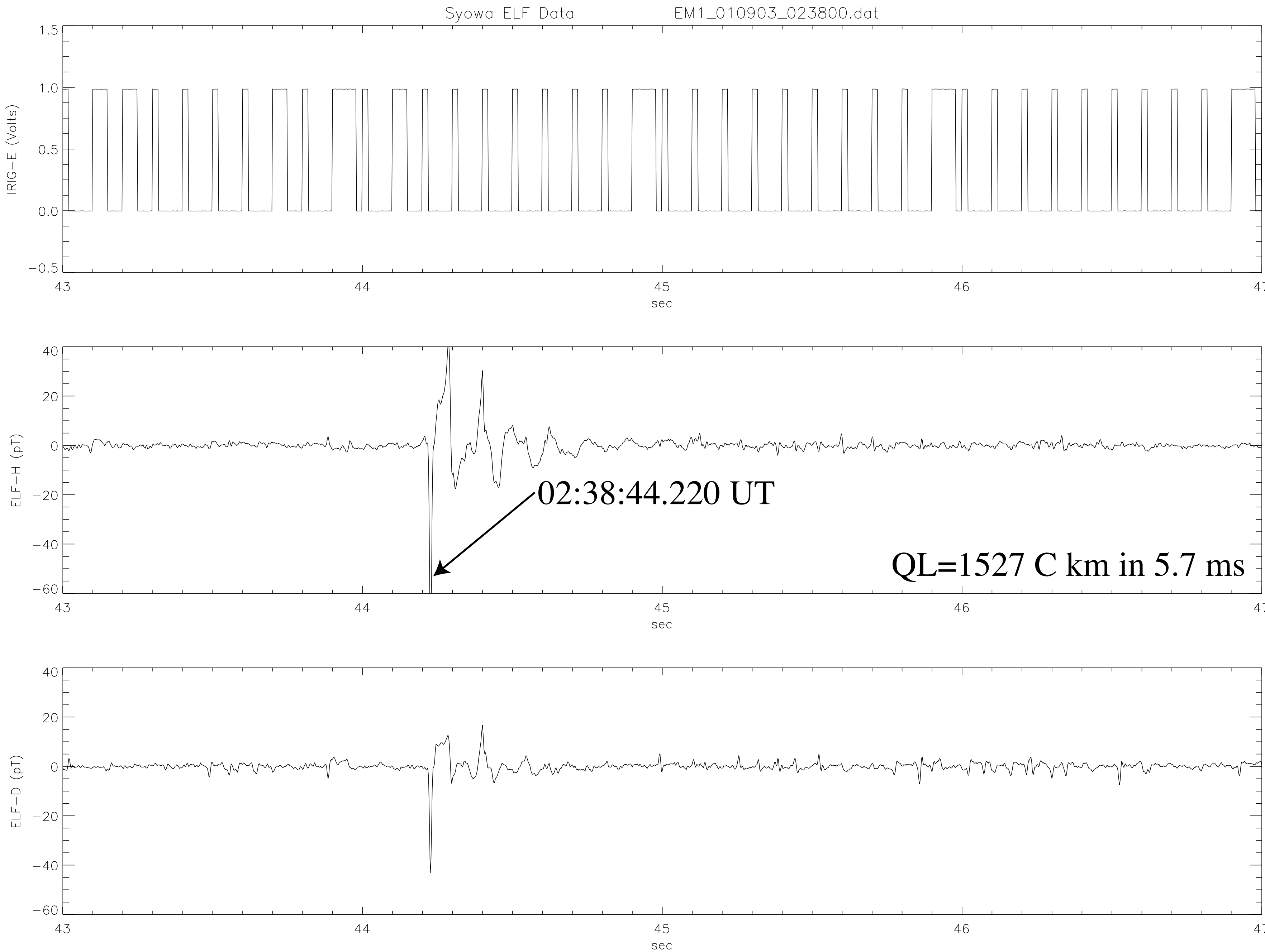
ELF Measurements



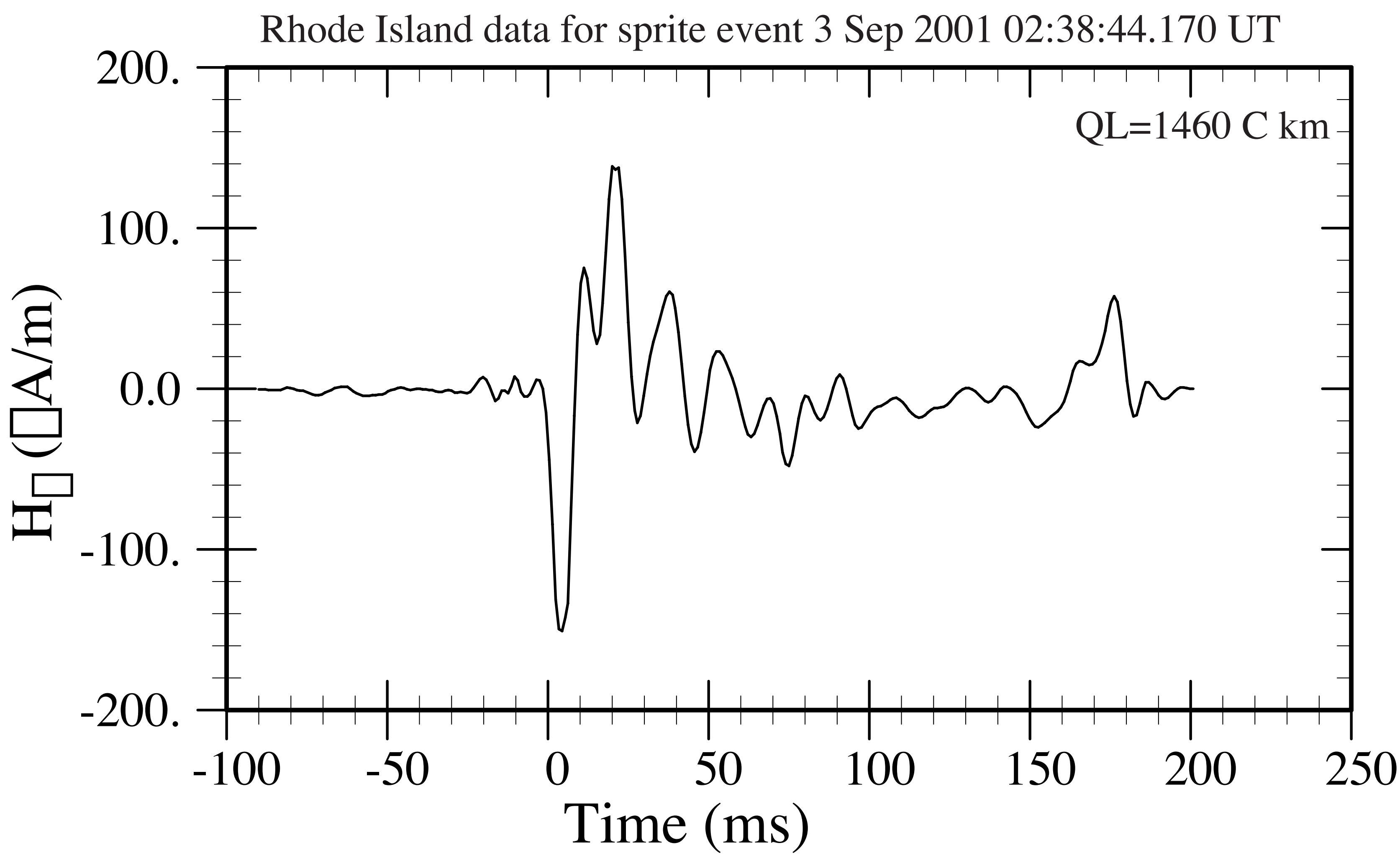

Palmer data 3 Sep 2001 Time after 02:38:40 UT NS Channel
02:38:44.206 UT
20
15
10
5
0
-5
-10
-15
-20
B (pT)
4.2
4.205
4.21
4.215
4.22
4.225
4.23
Time (s)



Duke data 3 Sep 2001 Time after 02:38:44 UT NS Channel
QL=2050 C km in 8 ms
02:38:44.176 UT
3
2
1
0
-1
-2
-3
B (nT)
0.175
0.18
0.185
0.19
0.195
0.2
Time (s)



Syowa ELF Data
EM1_010903_023800.dat
IRIG-E (Volts)
ELF-H (pT)
ELF-D (pT)
sec
02:38:44.220 UT
QL=1527 C km in 5.7 ms


Rhode Island data for sprite event 3 Sep 2001 02:38:44.170 UT
QL=1460 C km
200.
100.
0.0
-100.
-200.
-100
-50
0
50
100
150
200
250
Time (ms)

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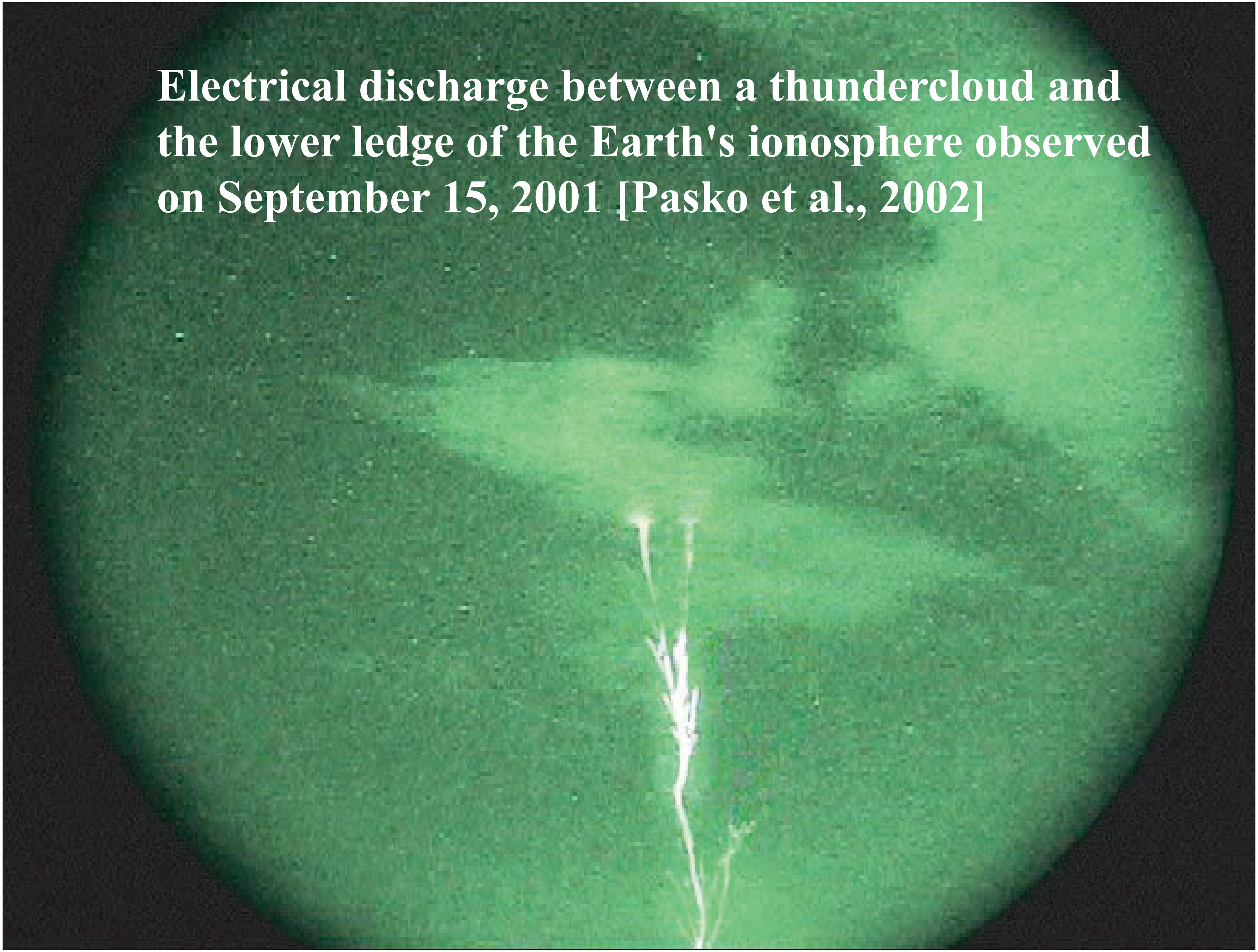
Upward discharge captured on film by Australian photographer Peter Jarver. The image was obtained during a time exposure of a lightning illuminated thunderstorm near Darwin during the 1980s. Though difficult to see in reproduction, the original transparency shows an upward flaring blue flame at the tip of the white channel which extends at least as far again upwards. Photograph kindly made available by Earle Williams.

A blue jet event [Wescott et al., 1995]

A remarkable color photograph of a blue jet taken from Reunion Island in the Indian Ocean (March 1997), which shows details of streamers never before seen [Wescott et al., 2001].


Electrical discharge between a thundercloud and the lower ledge of the Earth's ionosphere observed on September 15, 2001 [Pasko et al., 2002]

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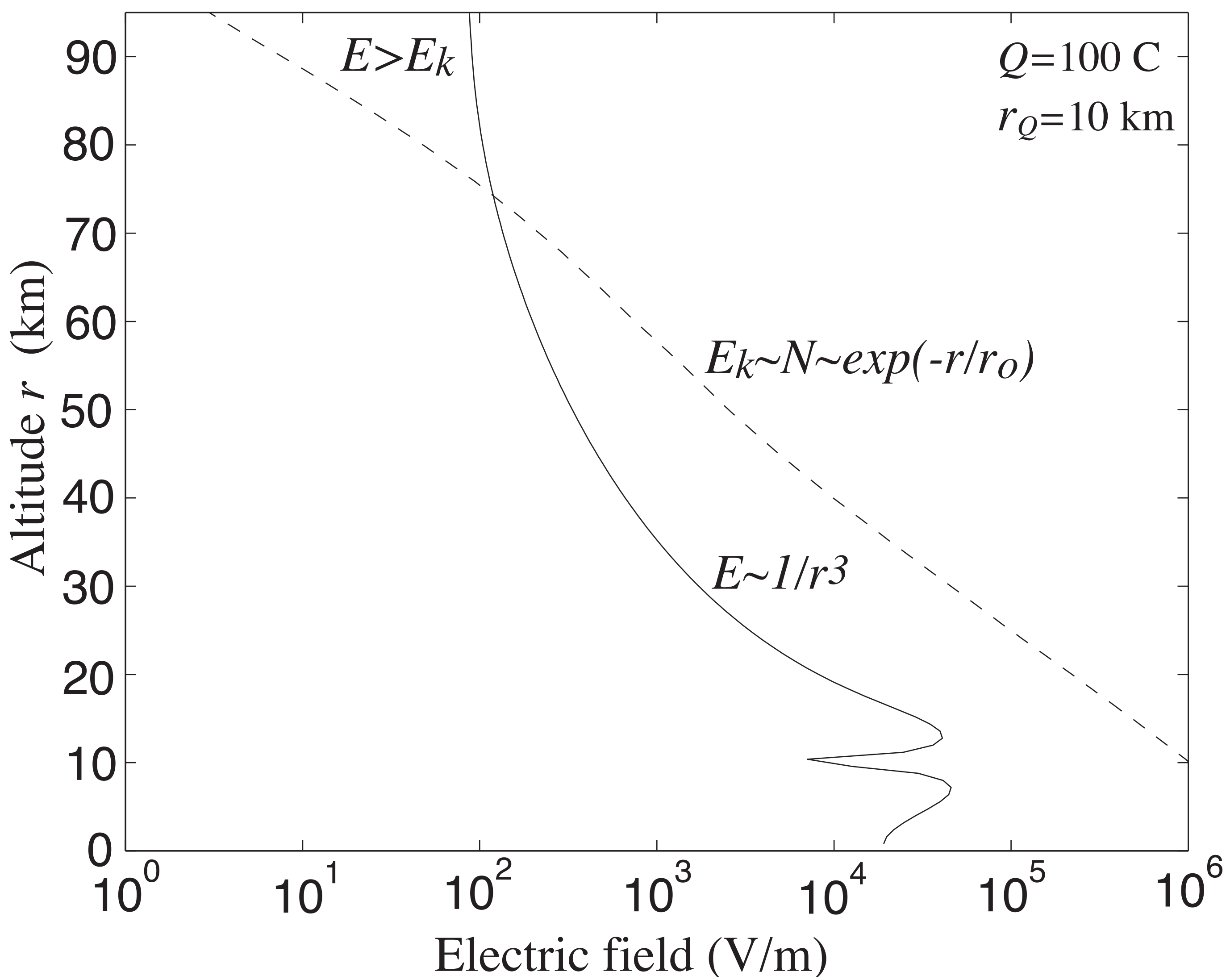
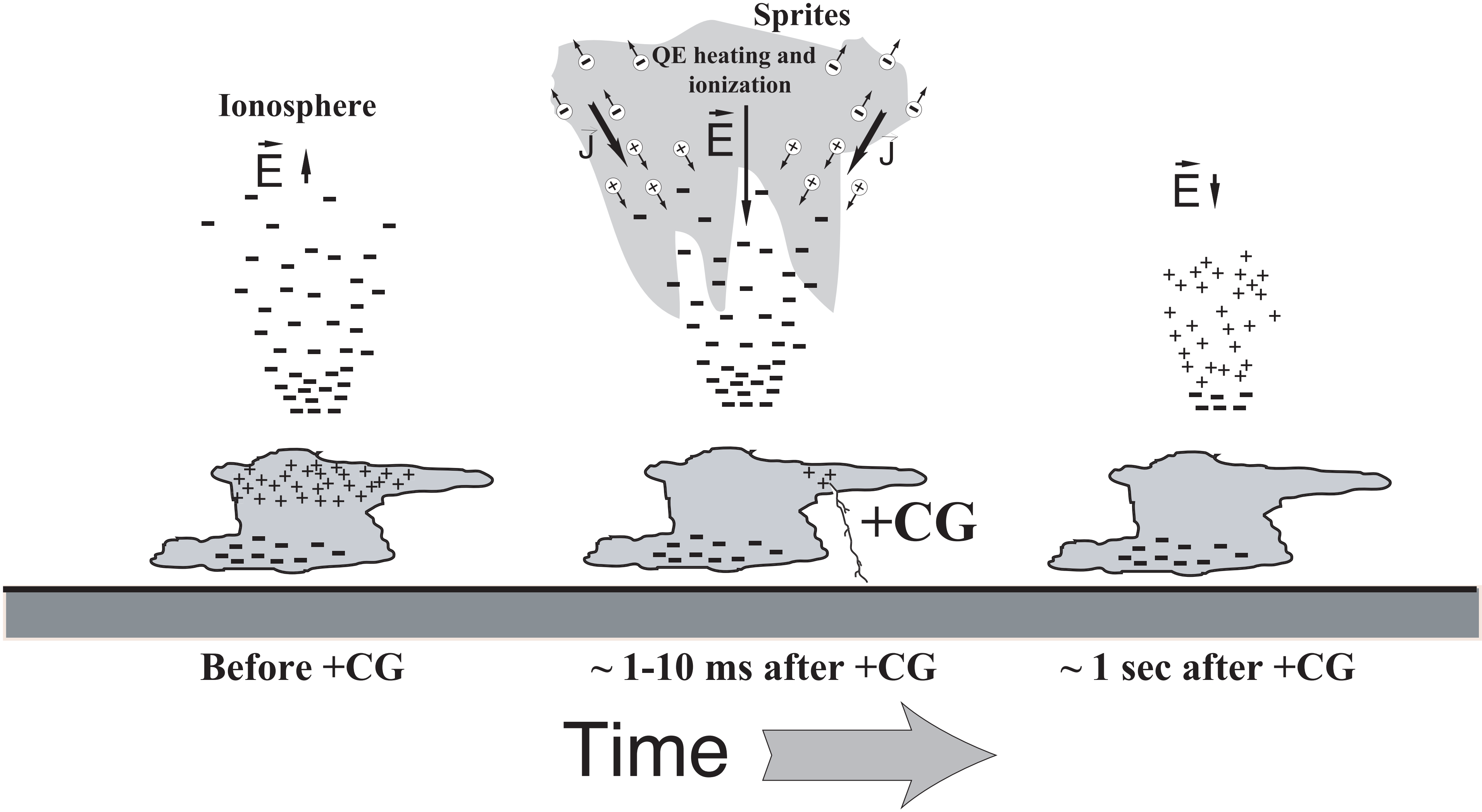
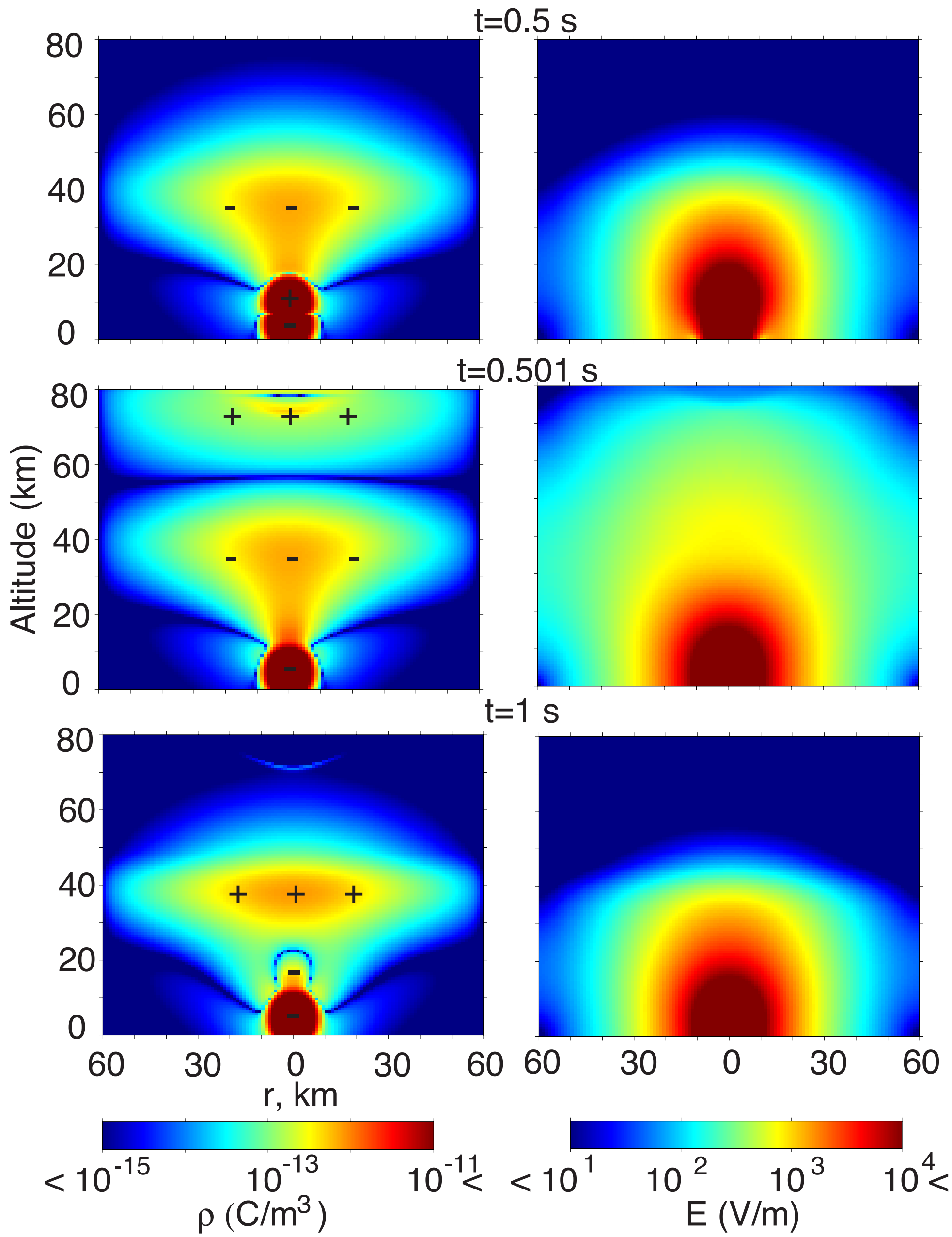
"While the electric force due to the thundercloud falls off rapidly as r increase, the electric force required to cause sparking (which for a given composition of the air is proportional to its density) falls off still more rapidly. Thus, if the electric moment of a cloud is not too small, there will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



Physical mechanism of sprites





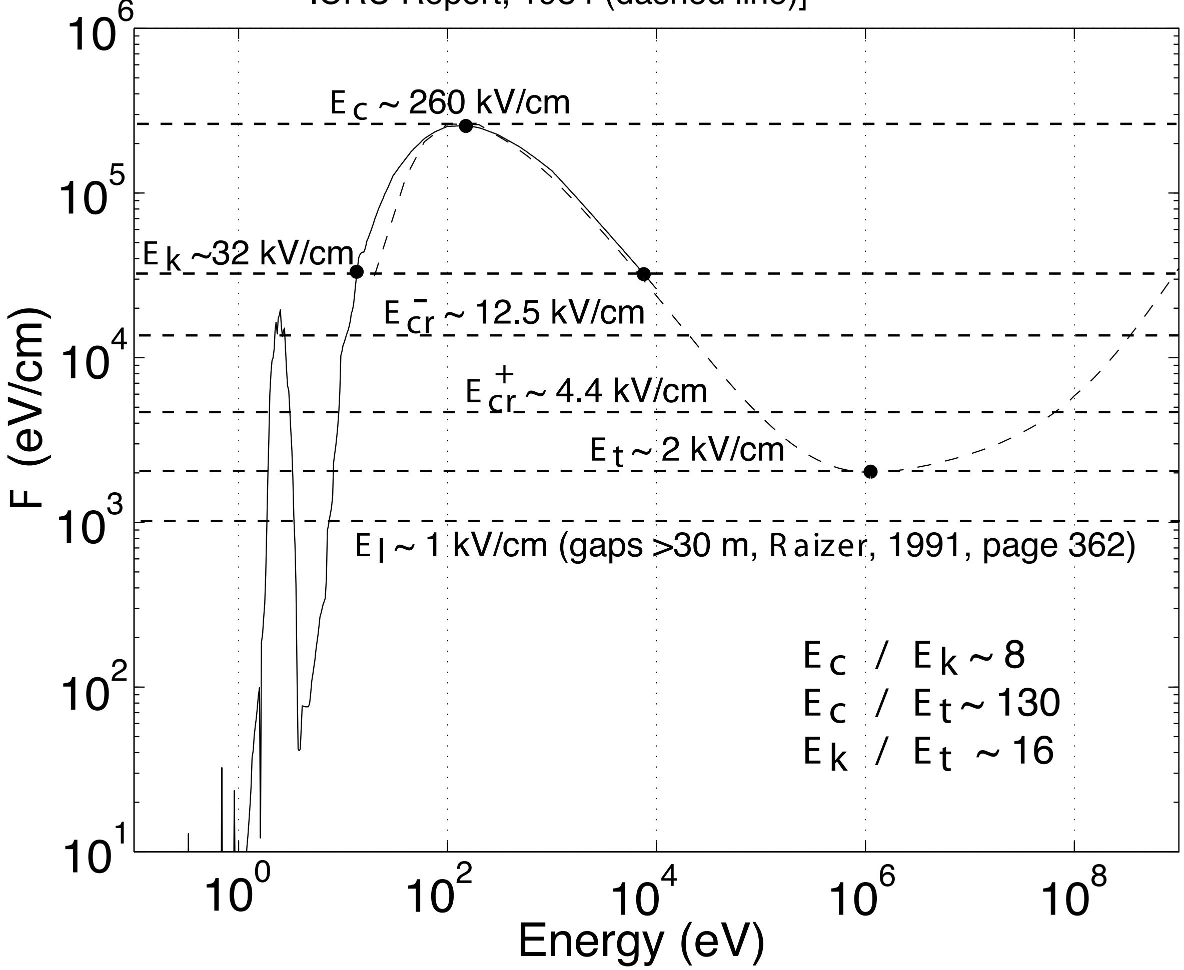
A cross-sectional view of the distribution of the absolute values of the (left) charge density and the (right) total electric field before (t=0.5 sec) and after (t=0.501, 1 sec) a lightning discharge with duration 1 ms moving the upper positive thundercloud charge to ground [Pasko et al., JGR, 102, 4529, 1997].

Breakdown Mechanisms

Dynamic friction force of electrons in air:

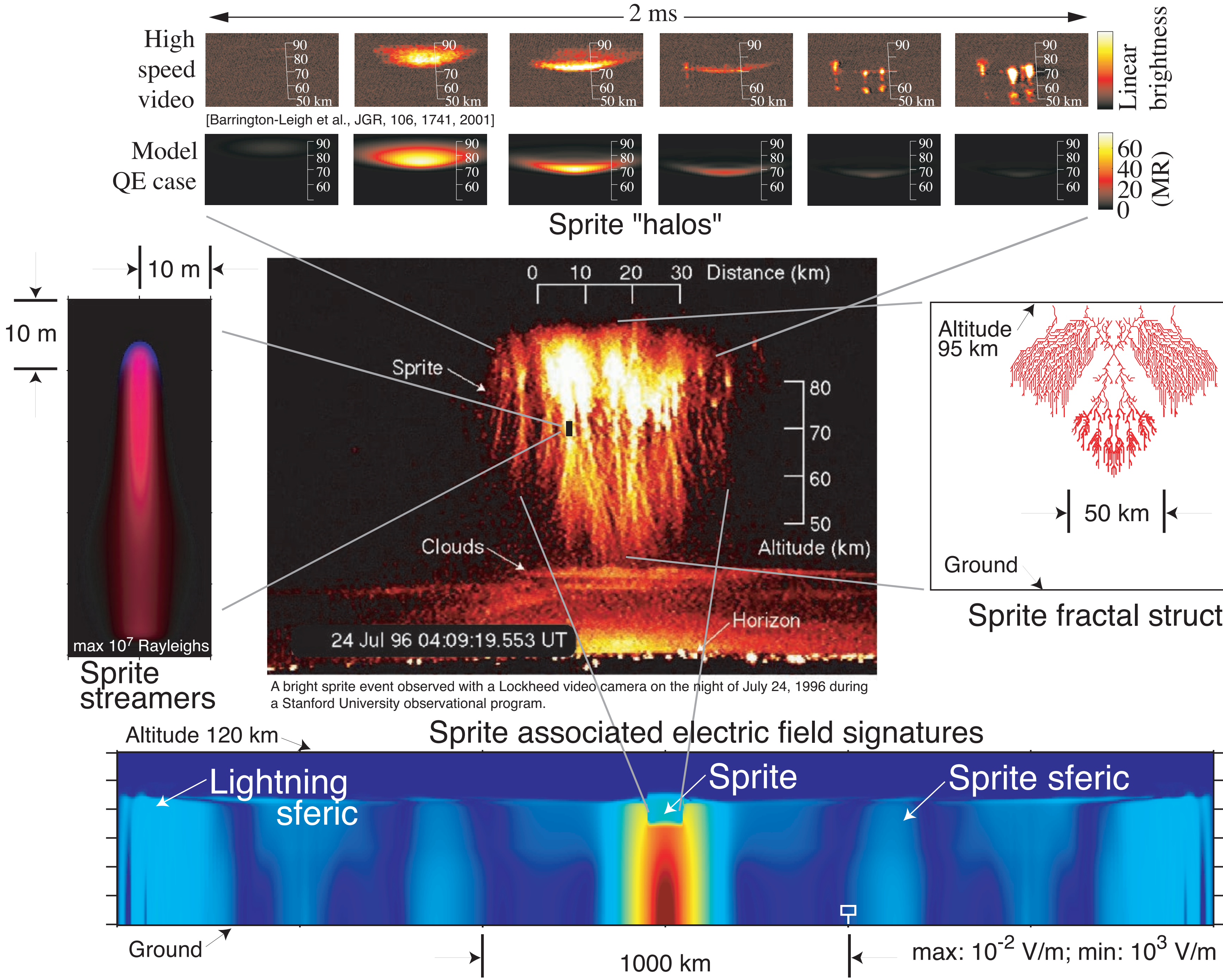
$$F = \sum N \, \sigma_i(v) \, \Delta\varepsilon_i \qquad [\text{eV/cm}]$$

Total number of inelastic processes: 43
[Phelps, A.V., jila.colorado.edu/collision_data (solid line);
ICRU Report, 1984 (dashed line)]



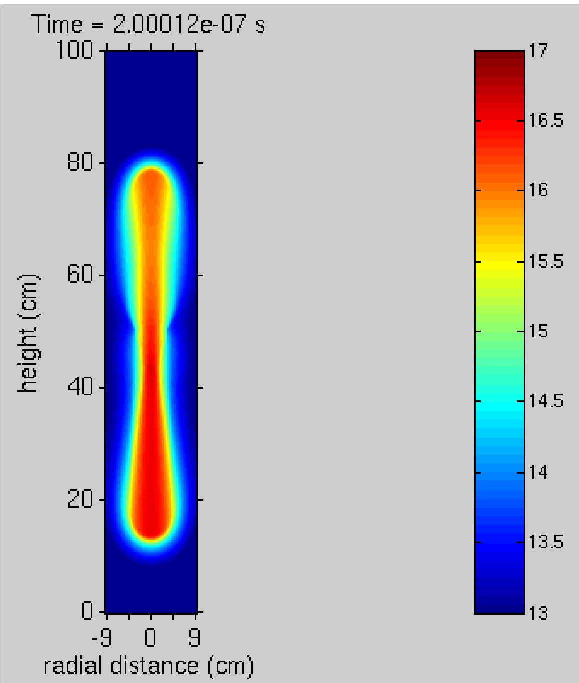
Thermal runaway:	$E_c \sim 260$ kV/cm	Positive streamer:	$E^-_{cr} \sim 4.4$ kV/cm
Conventional:	$E_k \sim 32$ kV/cm	Relativistic:	$E_t \sim 2$ kV/cm
Negative streamer:	$E^+_{cr} \sim 12.5$ kV/cm	Leader:	$E_l \sim 1$ kV/cm

Overview of existing sprite models

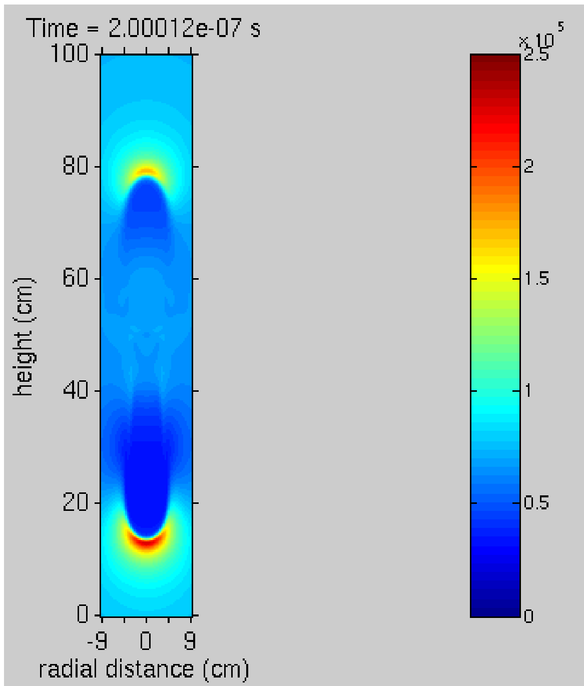


Modeling of Sprite Streamers

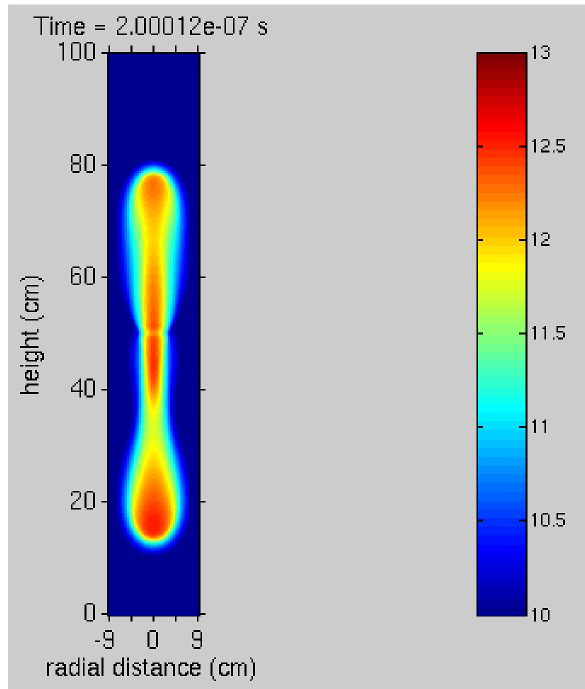
Electron density (m^{-3})



Electric Field (V/m)



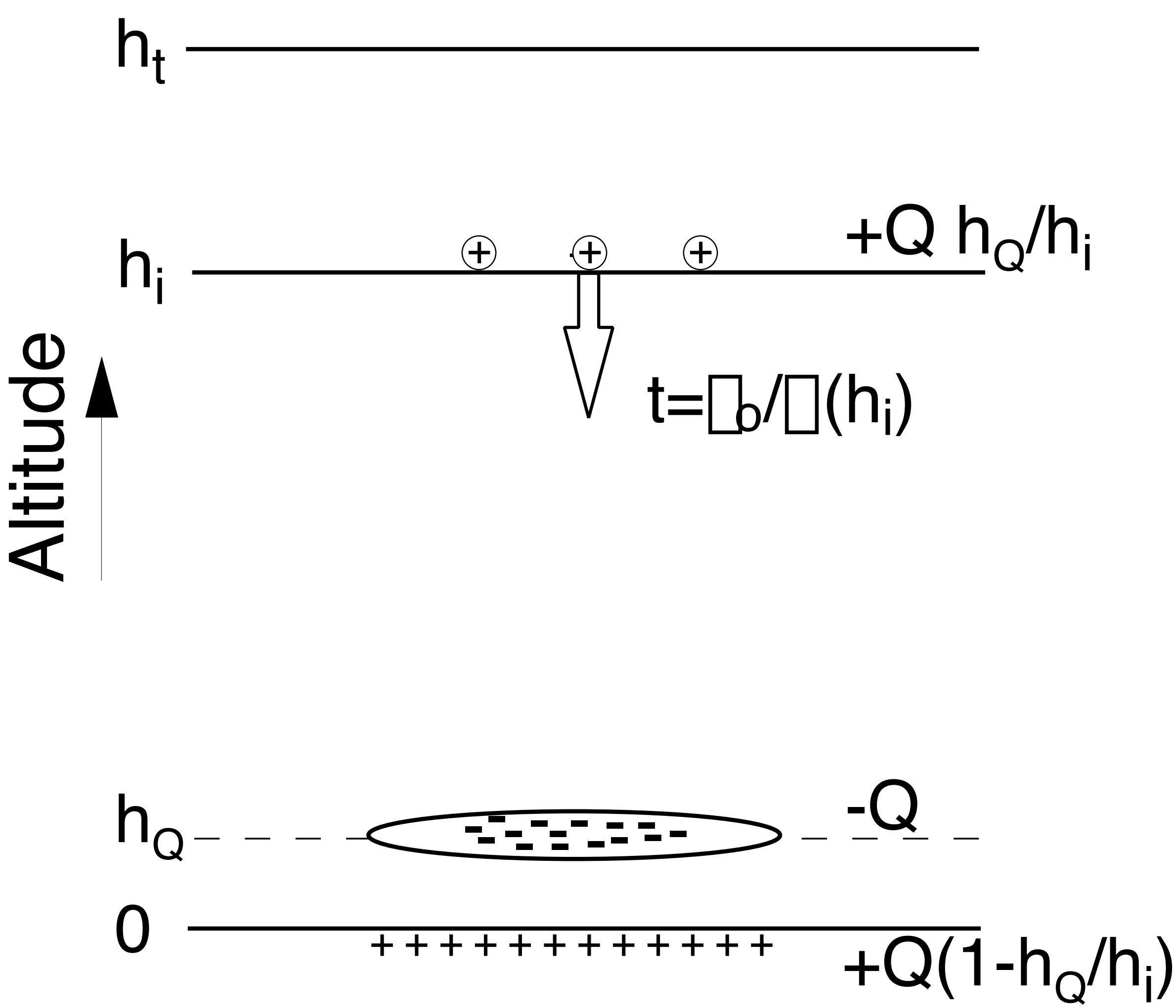
Optical Emissions 1PN2 (R)



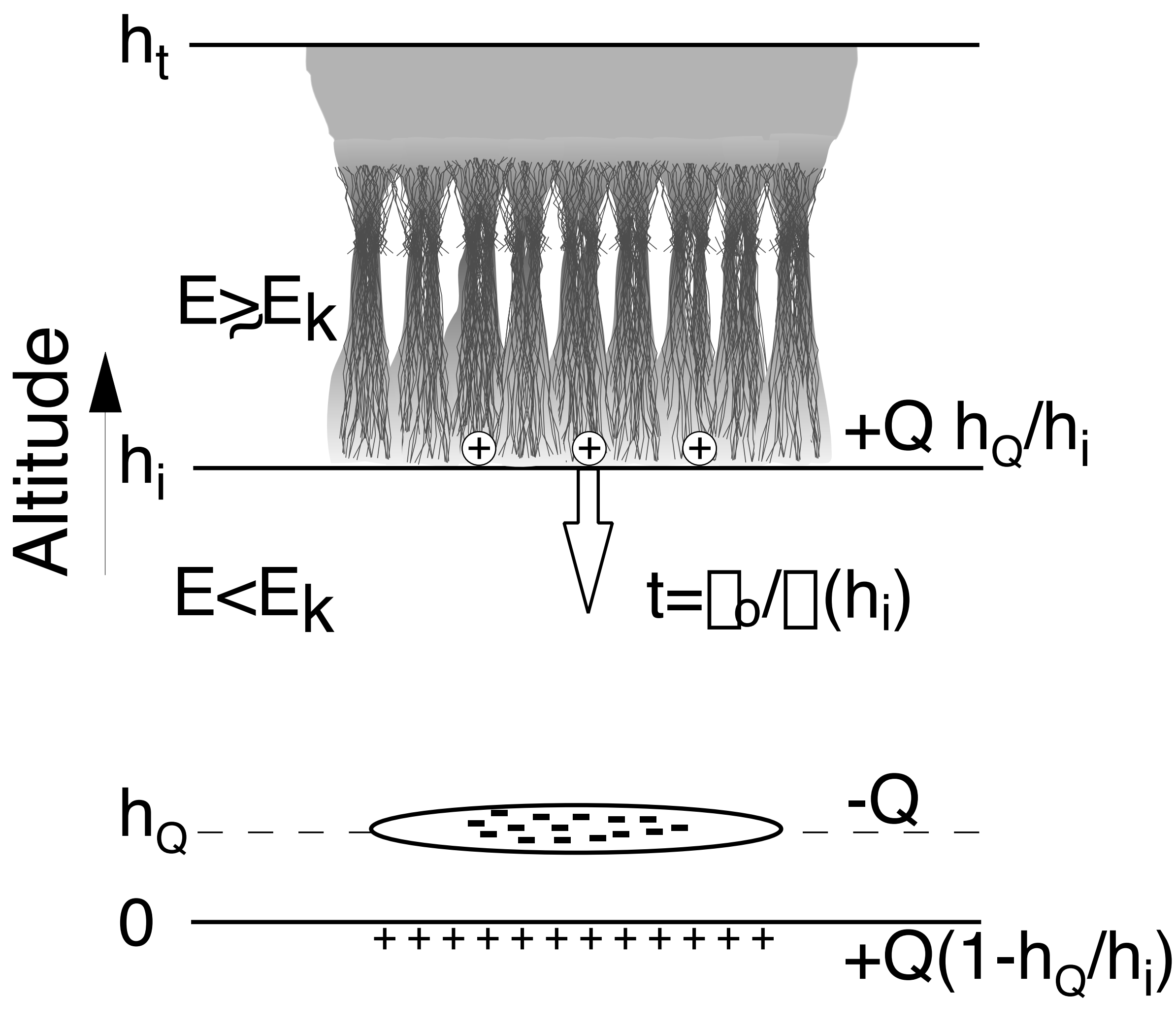
Created by Ningyu Liu, Penn State University, 2003

Current and charge systems associated with sprites

[Greifinger and Greifinger, 1976;
Hale and Baginski, 1987]



[Greifinger and Greifinger, 1976;
Hale and Baginski, 1987]



The global electric circuit

Bering et al., Physics Today, P. 24-30, October 1998

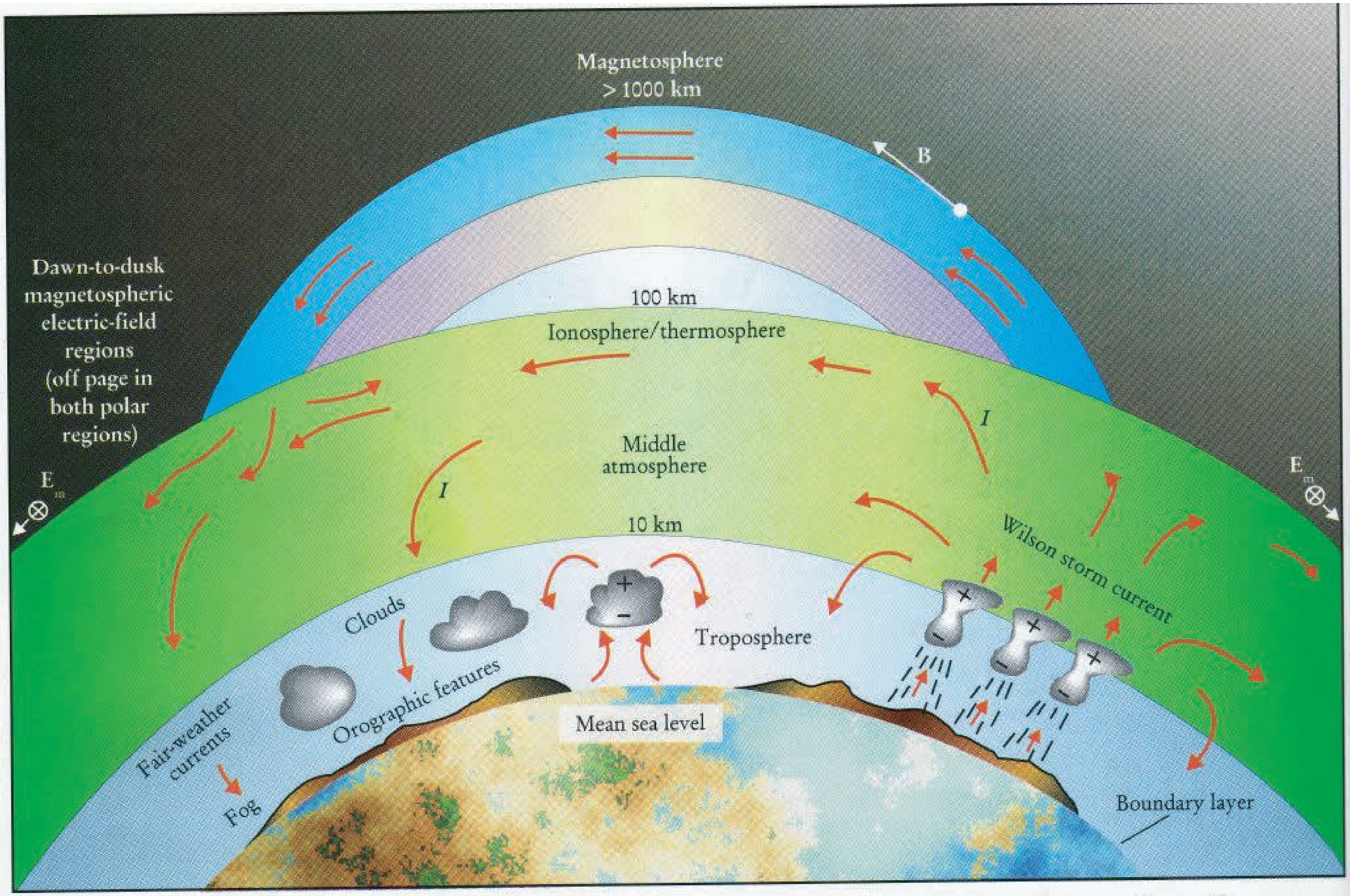


FIGURE 2. FLOW OF ELECTRIC CURRENT in the global circuit. All of the unlabeled arrows represent current flow. The strongest batteries in the circuit are the thunderstorms indicated on the right. They produce the Wilson current. The fair-weather currents are indicated by downward-pointing arrows away from the thunderstorms. (Based on a diagram by Ray G. Roble.)

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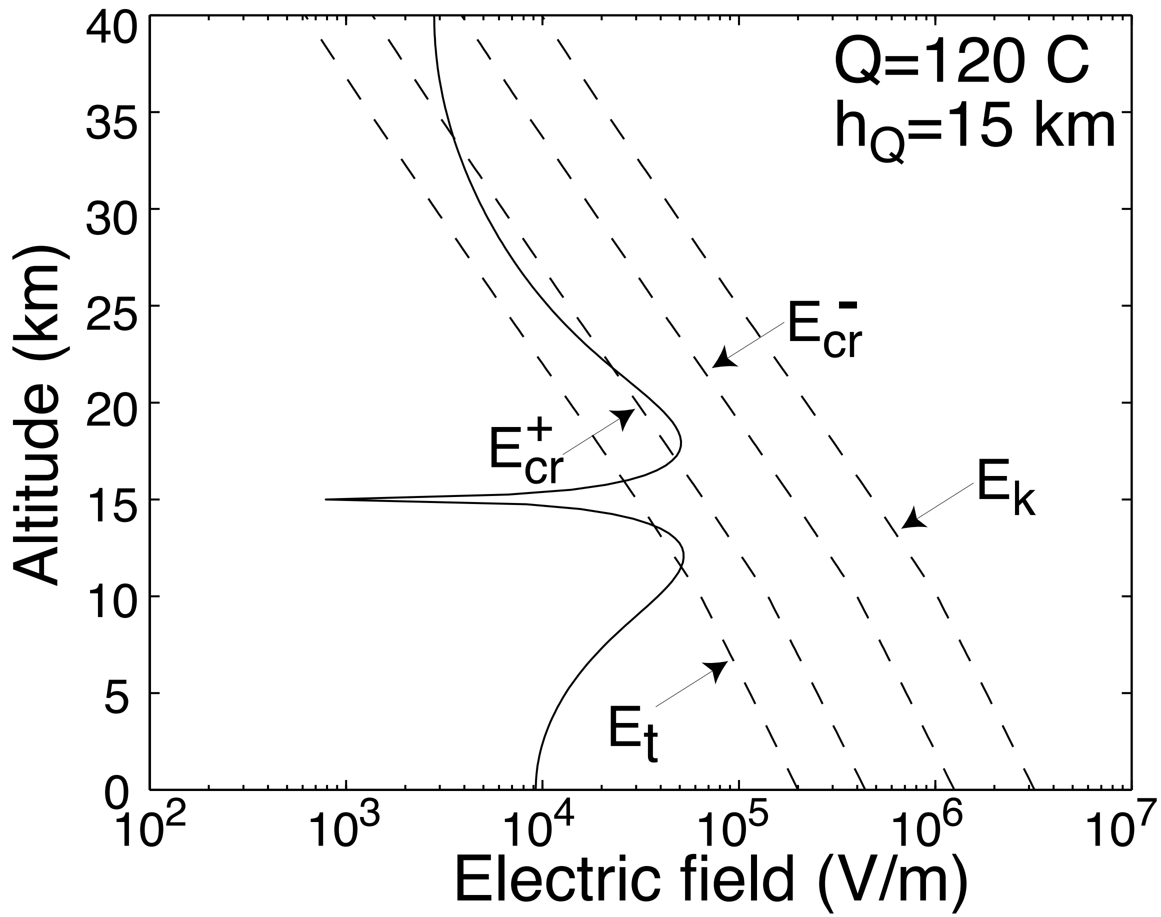
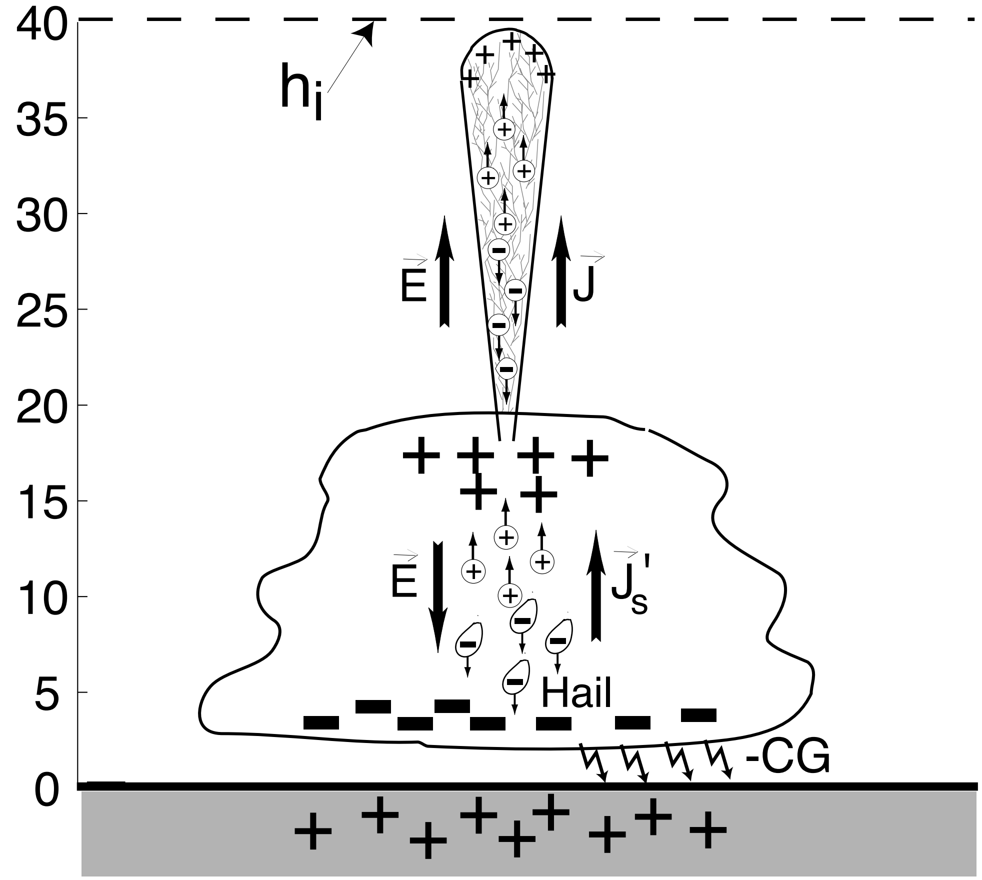
"The discharges above the cloud would doubtless give rise to atmospherics. If, as has been maintained, atmospherics frequently originate in regions of rain unaccompanied by thunder, they may in such cases be due to discharges of this nature."

C. T. R. Wilson, Proc. Phys. Soc. London 37, 32D-37D (1925).

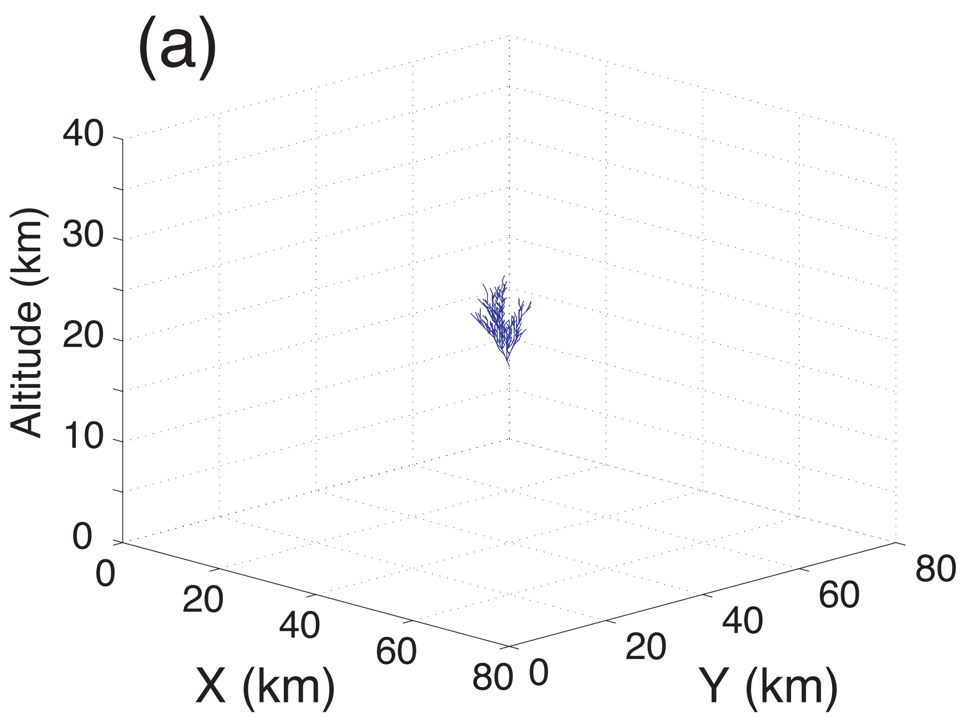


Physical mechanism of blue jets

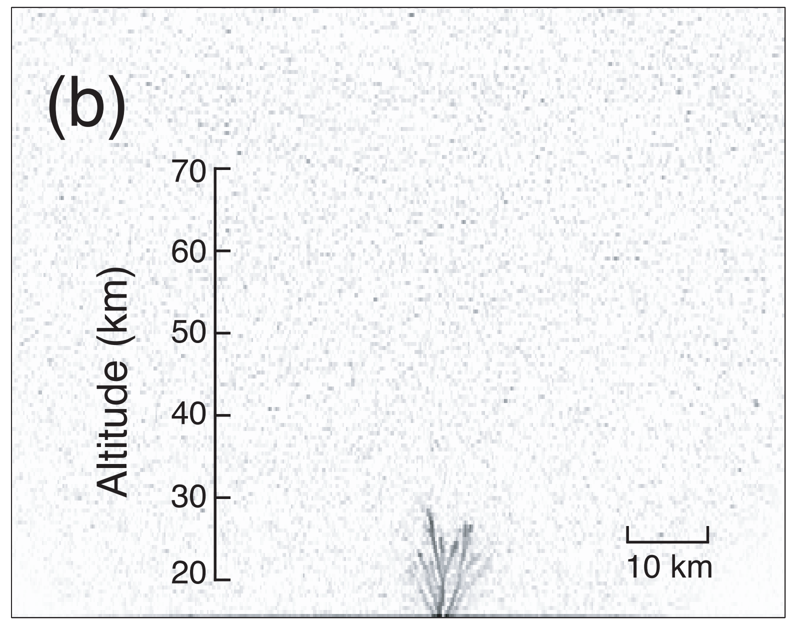


Theoretical modeling of blue jets

- *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.

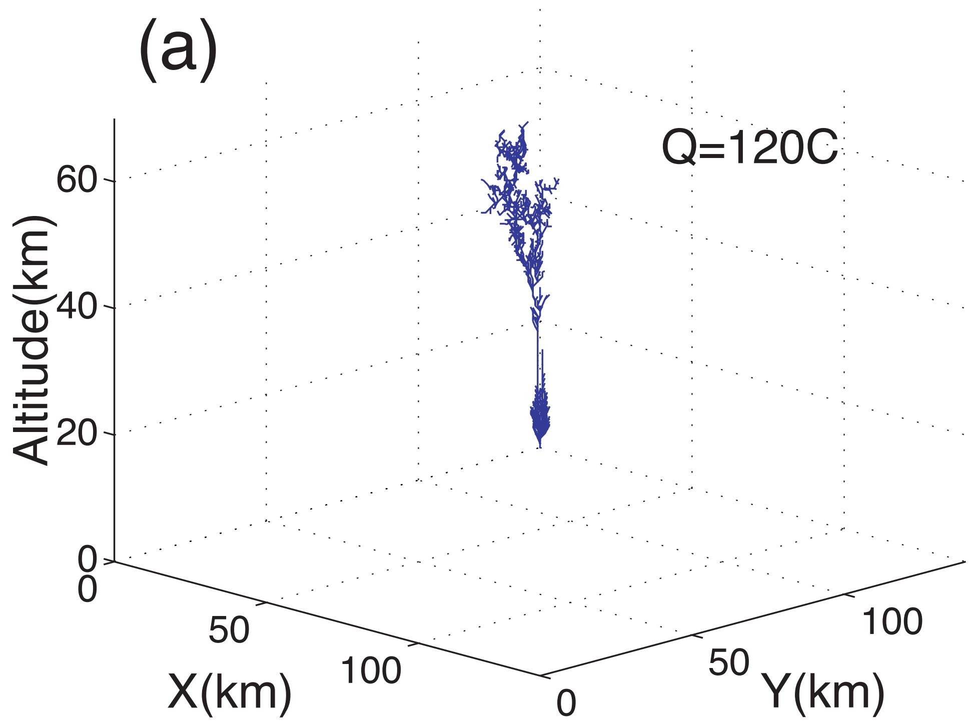


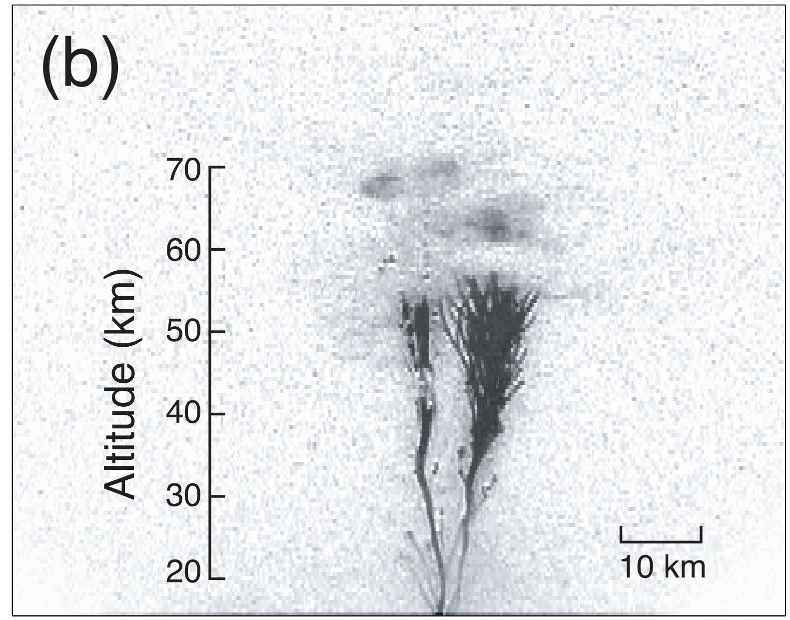
(a) Initial growth stage of a model blue jet corresponding to Q=140 C [Pasko and George, 2002]



(b) An initial video frame of the blue jet event reported by Pasko et al. [2002].

Comparison with recent observations of blue jets





(a) Model results for thundercloud charge Q=120 C and the upper simulation box boundary at 70 km [Pasko and George, 2002].

(b) Image of a blue jet at the moment of attachment to the lower ionospheric boundary [Pasko et al., 2002].

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Categories of problems in theory of transient luminous events (TLEs)

1. Breakdown mechanisms responsible for TLEs

2. Initiation of TLEs

3. Chemical effects of TLEs

4. Global electric circuit effects of TLEs

5. Spatial structure and dynamics of TLEs

6. Electromagnetic radiation of TLEs

Transient Optical Emissions in the Upper Atmosphere

Convenors:
Victor Pasko, Penn State University, vpasko@psu.edu
Mike Taylor, Utah State University, mtaylor@cc.usu.edu
Mark Stanley, Los Alamos National Laboratory, stanleym@lanl.gov

Apache Group: 1:00-3:00 PM

Wednesday, June 18, 2003

This workshop will discuss various questions related to the physical nature and energetics of sprites and related optical phenomena formed as a result of strong electrodynamic coupling of tropospheric thunderstorms to the mesospheric and lower ionospheric regions.

Sprites are spectacular luminous glows which occupy volumes in excess of thousands of cubic kilometers in clear air above thunderstorms in the altitude range ~40-90 km. Sprites often exhibit an amorphous non structured glow at their tops, which gradually converts to highly (predominantly vertically) structured breakdown regions at lower altitudes. Sprites are transient in nature and last only a small fraction of a second following intense positive or negative lightning discharges (more than 90% of sprites are associated with positive lightning discharges). It appears from space shuttle observations that sprites occur over most regions of the globe (in temperate and tropical areas, over the oceans, and over the land). To date sprites have been successfully detected from ground and airborne platforms in North, Central and South America, in Europe, in Australia and over winter storms in Japan.

This year's workshop will include discussion of some recent and forthcoming sprite related experiments, including 2002 Sprite Balloon experiment in Brazil and the Imager of Sprites and Upper Atmospheric Lightning (ISUAL) experiment on ROCSAT 2 satellite, which is planned for launch in mid-2003.

Please see the following web sites for more information on sprites and related atmospheric optical effects:

1. http://elf.gi.alaska.edu/
2. http://www-star.stanford.edu/~vlf/
3. http://www.FMA-Research.com/
4. http://ibis.nmt.edu/sprites/
5. http://sprg.ssl.berkeley.edu/atmos/isual.html

There will be brief talks limited in number of viewgraphs with lots of discussion. Confirmed speakers are:

- Robert Holzworth (bobholz@ess.washington.edu)
- Stephen Mende (mende@ssl.berkeley.edu)
- Walter Lyons (walyons@frii.com)
- Steven Cummer (cummer@ee.duke.edu)
- Ningyu Liu (nul105@psu.edu)
- Victor Pasko (vpasko@psu.edu)
- Michael Taylor (mike.taylor@sdl.usu.edu)
- Mark Stanley (stanleym@lanl.gov)

NATO Advanced Study Institute on
Sprites, Elves and Intense Lightning Discharges
Corte in Corsica, July 21–30, 2004

(I) Meteorology and intense lightning discharges
- a: W.A. Lyons (meteorolgy of thunderstorms)
- b: Y. Yair (cloud microphysics)
- c: E.R. Williams (intense lightning discharges)
- d: C. Price (global lightning activity)

(II) Optical sprite observations
- a: D.D. Sentman (sprite frontiers)
- b: T. Neubert (optical observations)
- c: H. Fukunishi (elves)
- d: Y. Takahashi (high speed imaging)

(III) ULF/ELF/VLF radiation
- a: U.S. Inan (atmospheric electrodynamics)
- b: C. Rodger (VLF)
- c: S. Cummer (ELF)
- d: Y. Hobara (ULF/ELF)

(IV) Theory and moedelling
- a: M. Rycroft (foundations of sprite research)
- b: V.P. Pasko (sprite modelling)
- c: E. Mareev (fine structure of sprites)
- d: V.Y. Trakhtengerts (energetic electrons)

Contact: Martin Füllekrug

http://www.geophysik.uni-frankfurt.de/~fuellekr/SUMMER/