UV Flashes of Millisecond Scale from Red Sprites and Gigantic Blue Jets

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Outline

•Transient Luminosity Events (TLE)

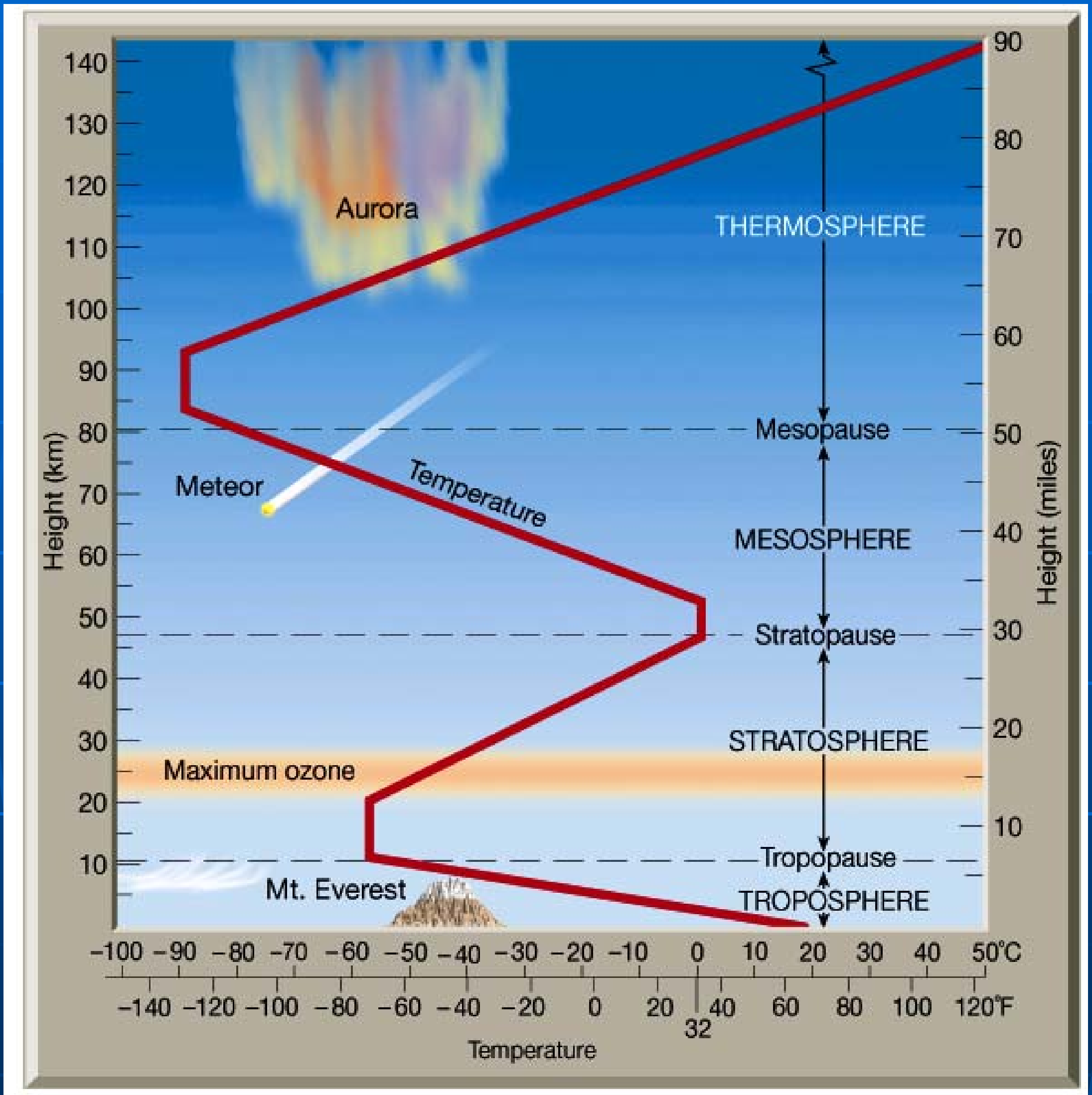
✓Red Sprites: observation data and theory

✓Blue Jets and Gigantic Blue Jets: observation data and theory

•Physical reasons and mechanisms for observed UV flashes in upper atmosphere

•Conclusions

Atmospheric Structure



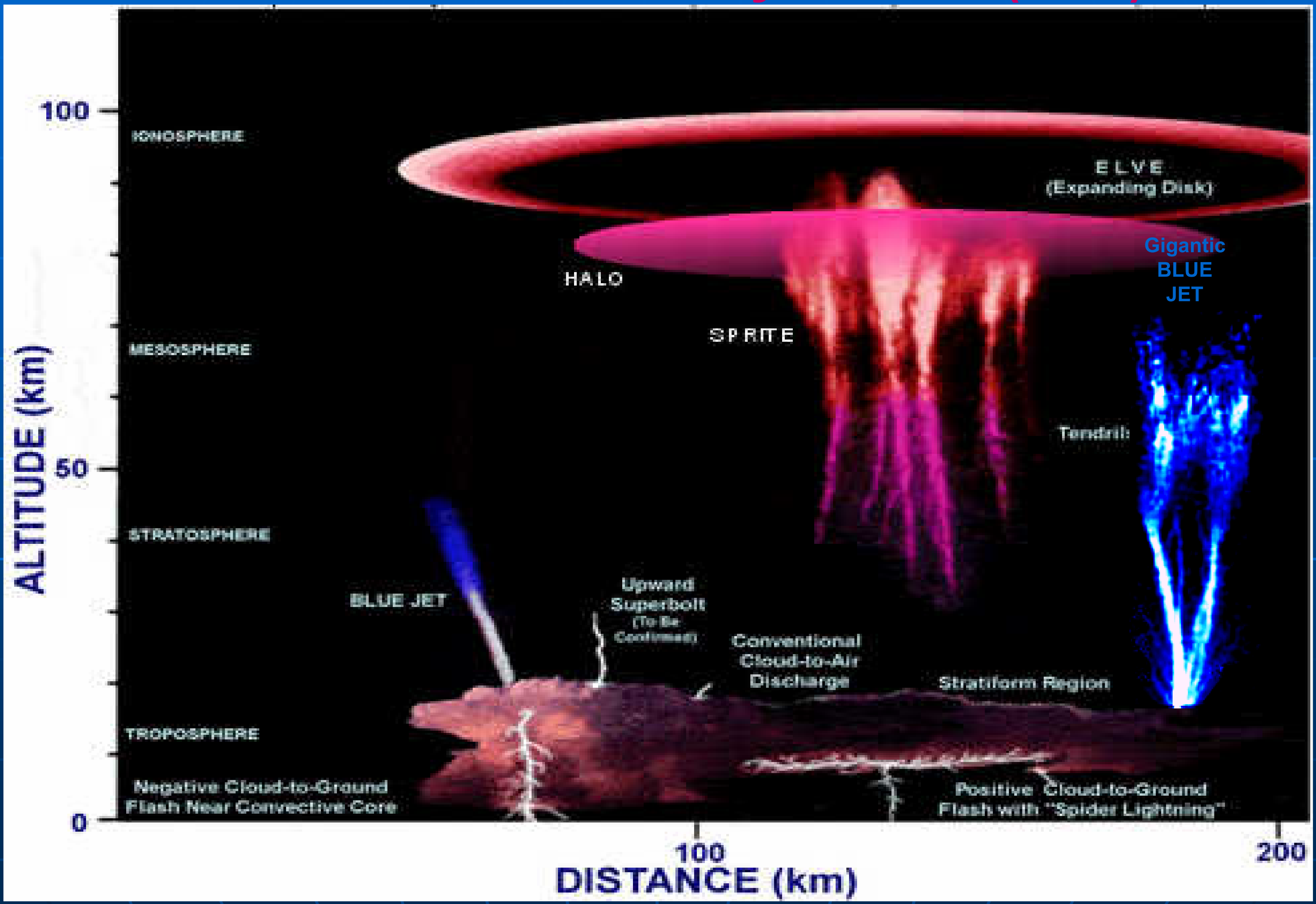
Ionosphere: 80-400 km

“ignorosphere”: 20-80 km

Scientists, sometimes only half jokingly, call parts of the middle atmosphere the “ignorosphere.” For a long time it was ignored simply because of the difficulty in obtaining information from this region.

Figure 1-19, p. 20 in Lutgens and Tarbuck's *The Atmosphere*, 2001

Red Sprites, Blue Jets and Elves: Transient Luminosity Events (TLE)



(Adapted from Lyons et al. 2000)

http://www.albany.edu/faculty/rgk/atm101/sprite.htm

Red Sprites and Blue Jets: history

•Human beings have probably noticed red sprites out of the corner of their eye since they first began roaming the Earth.

•Since 1886, scientists have periodically reported in scientific journals that they thought they had seen something they did not understand high above thunderstorms.

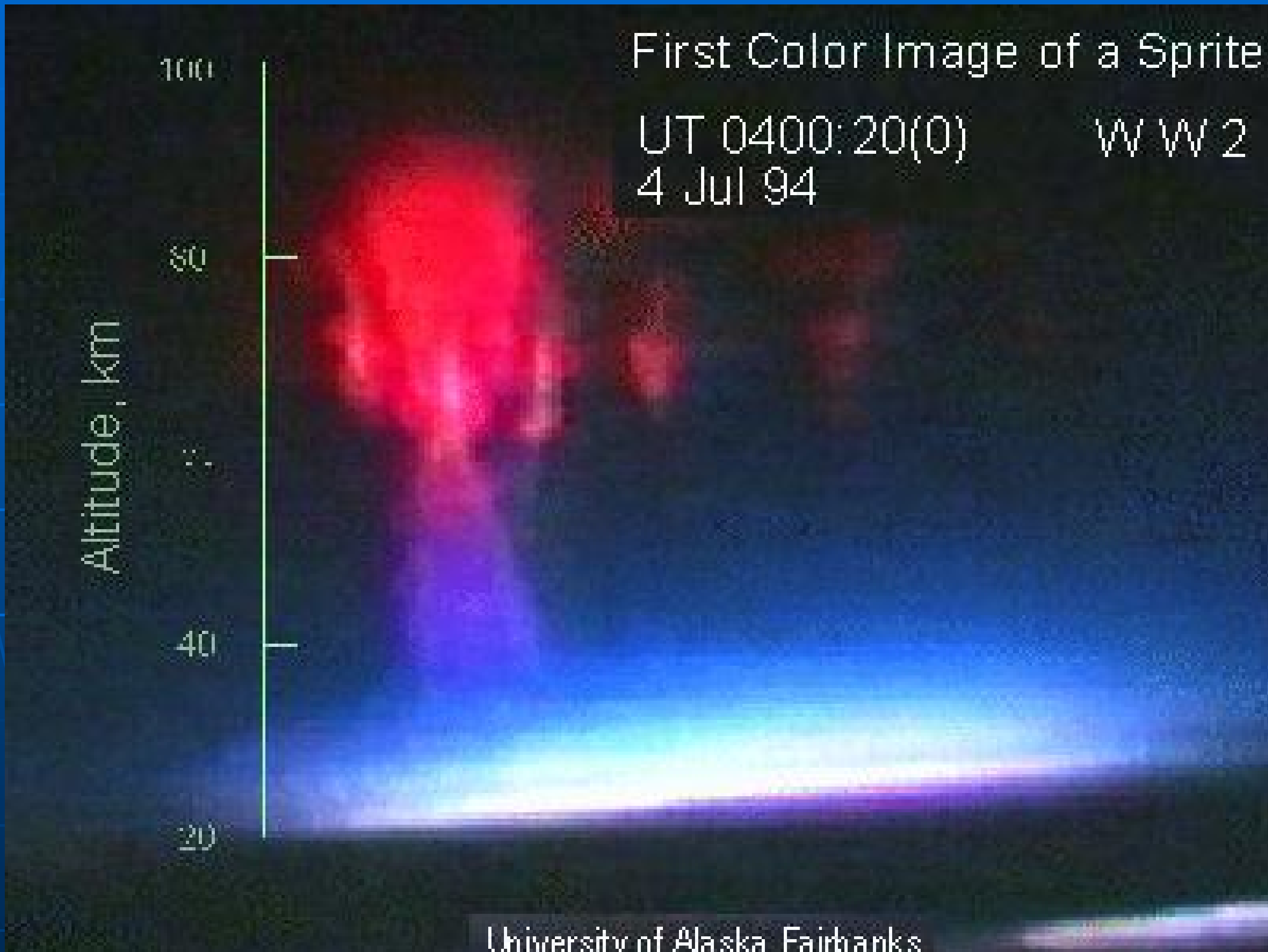
•The "discovery" can be traced to **6 July 1989** when University of Minnesota Physics Professor John R. Winckler was testing a low-light video camera for an upcoming research rocket flight. On playing back the tape, he and his graduate students, Robert Franz and Robert Nemzek, were astounded to find two fields of video showing two giant columns of light towering high above distant thunderstorms in northern Minnesota. They were quick to realize this "accident" might actually explain over a century of unexplained visual reports of strange lights above thunderstorms.

• Haven't airline pilots seen Sprites or Blue Jets? Yes. For many years, along with blue jets and other strange sights. But commercial pilots have to pass annual physical exams. And for a long time, no one dared tell stories about these "strange lights" less the reports be misinterpreted as an indication the pilot wasn't "quite right in the head."

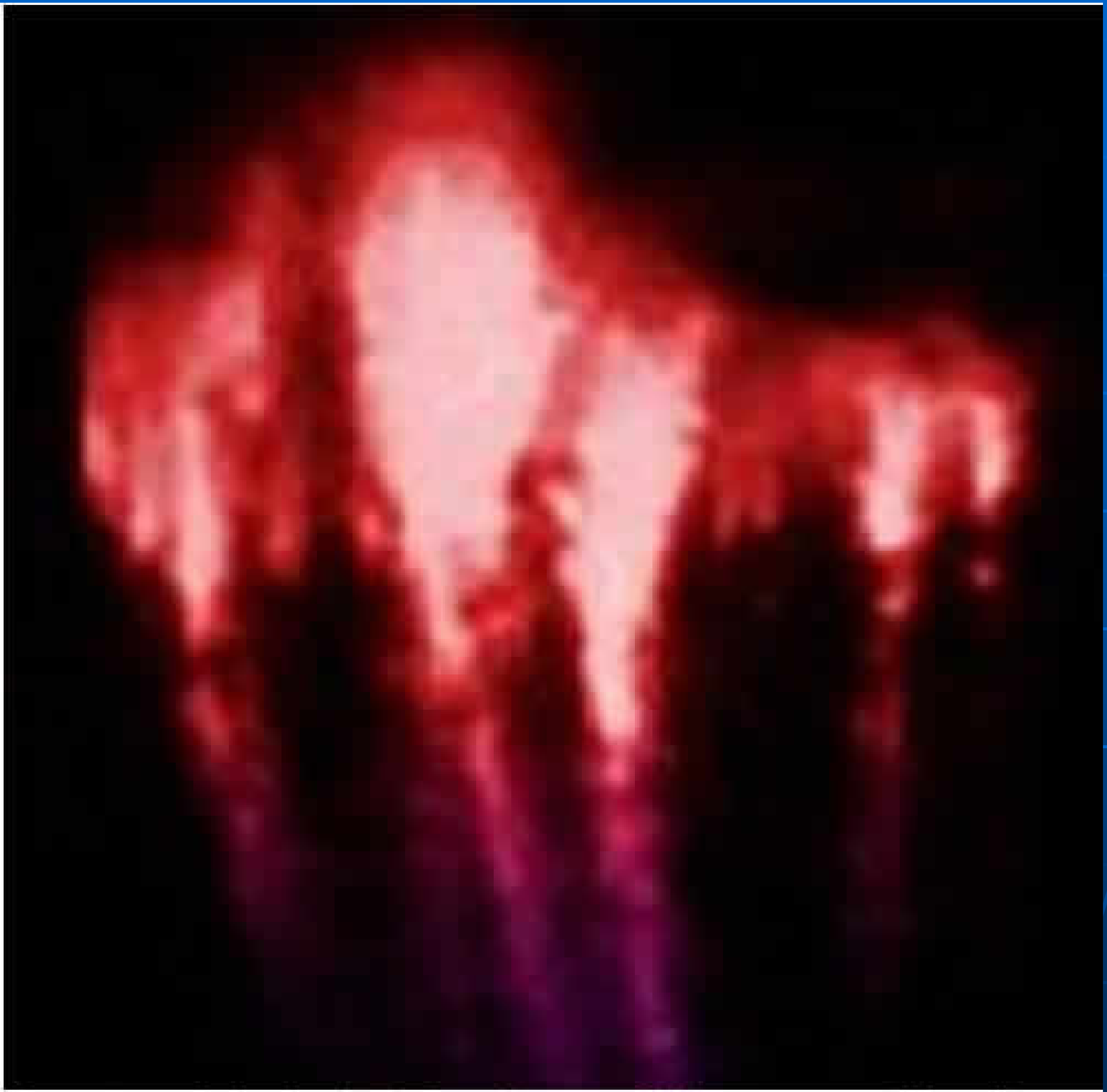
•Are there TLE's on other planets? Probably "Yes" . A lot of publications.

http://sky-fire.tv/index.cgi/Sprites.html

Red Sprites

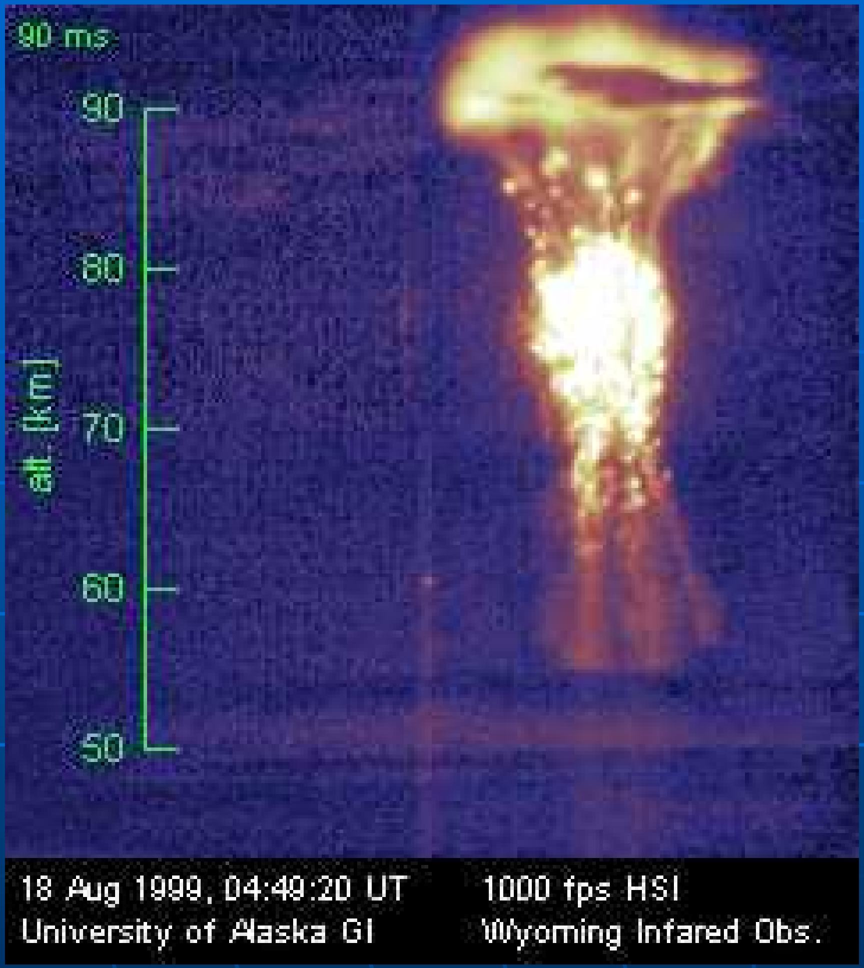

First Color Image of a Sprite
UT 0400:20(0)
W W 2
4 Jul 94
Altitude, km
100
80
40
20
University of Alaska Fairbanks

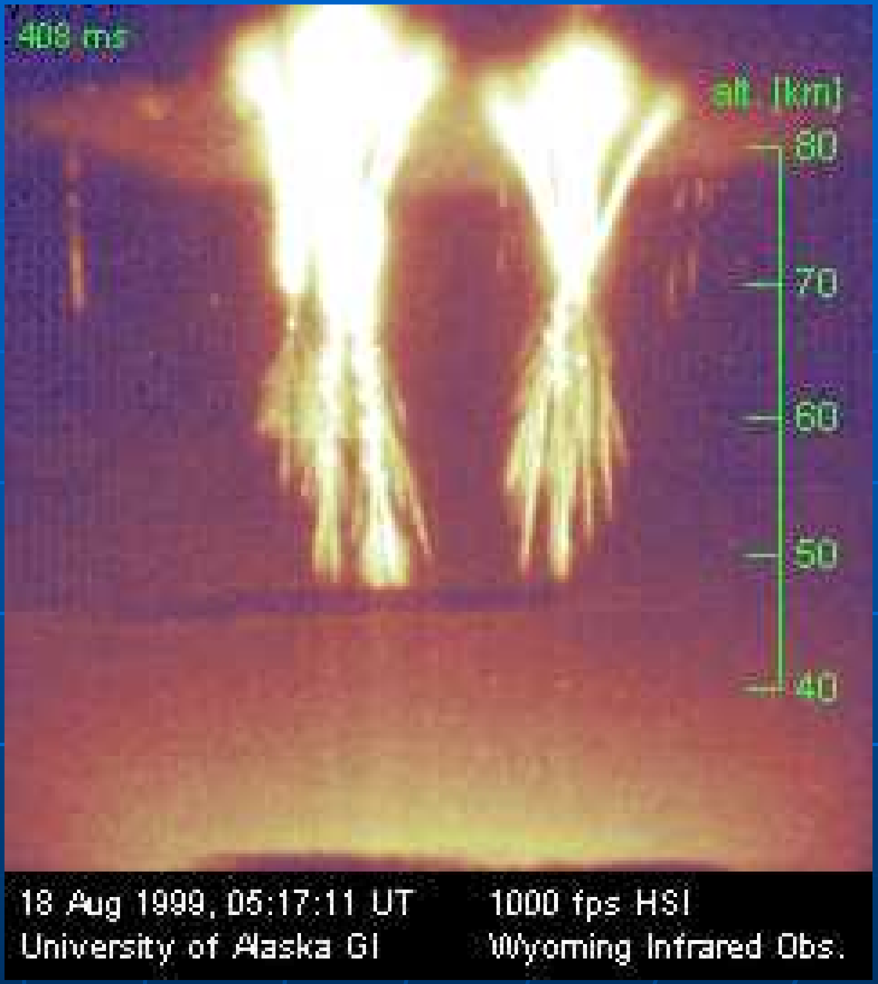
Red Sprites



Computer colorized sprite in the skies over Oklahoma, some 400+ miles from the low-light camera site in Colorado. Many sprites appear as clusters of smaller elements. Courtesy Russ Armstrong © Sky Fire Productions.

Red Sprites


90 ms
90
80
70
60
50
alt. [km]
18 Aug 1999, 04:49:20 UT
University of Alaska GI
1000 fps HSI
Wyoming Infared Obs.


408 ms
alt. [km]
80
70
60
50
40
18 Aug 1999, 05:17:11 UT
University of Alaska GI
1000 fps HSI
Wyoming Infrared Obs.

Red Sprites: theory

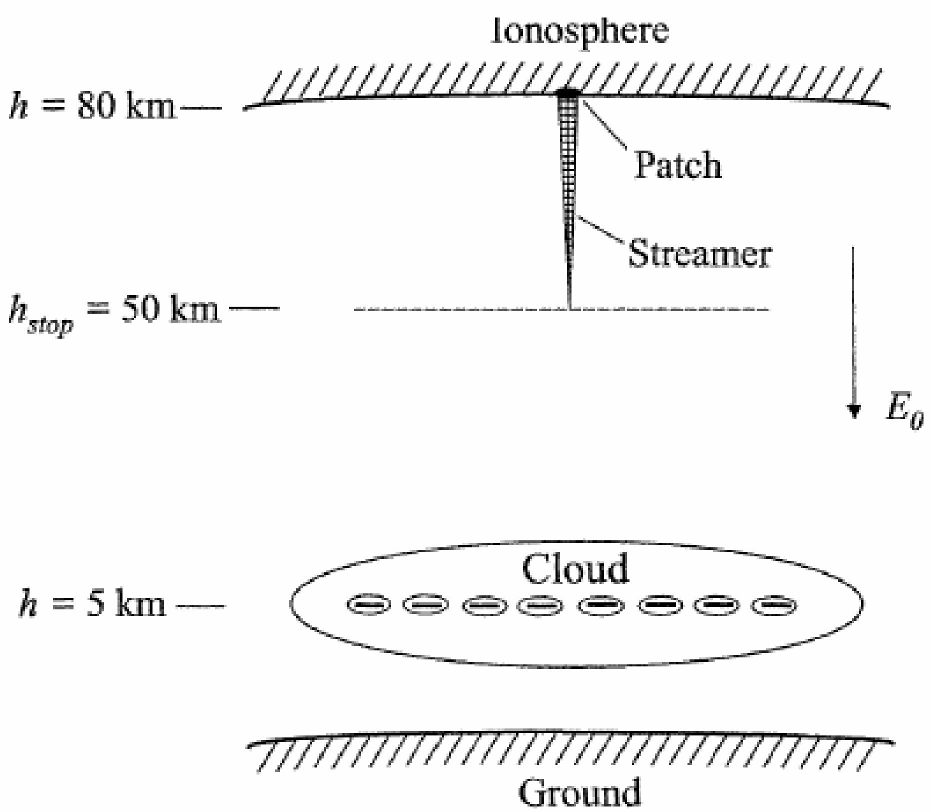


Figure 1. Schematic diagram of streamer development above thundercloud.

$$E = \frac{zQ}{\pi\epsilon_0 h^3}\left[1 + \left(\frac{h}{2h_i - h}\right)^3\right]$$

$$N(h) \propto \exp(-Mgh/kT) \propto \exp(-h/\Delta)$$

$$\Delta \approx 7.2\ \mathrm{km}$$

$$E \propto 1/h^3 \Rightarrow$$

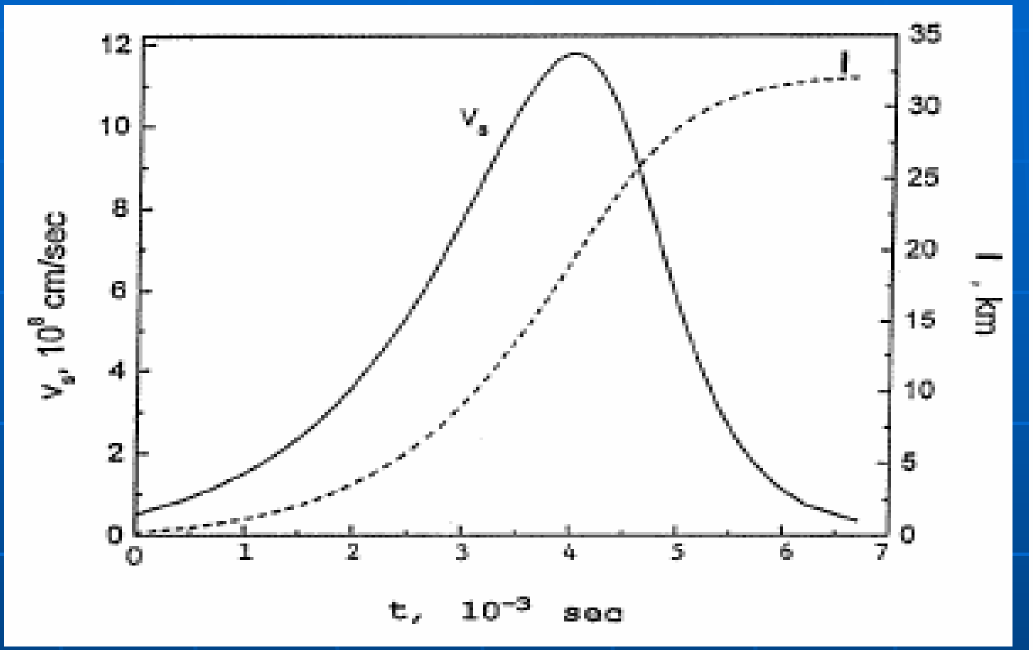
$$\Rightarrow E/N \propto \exp(h/\Delta)/h^3$$

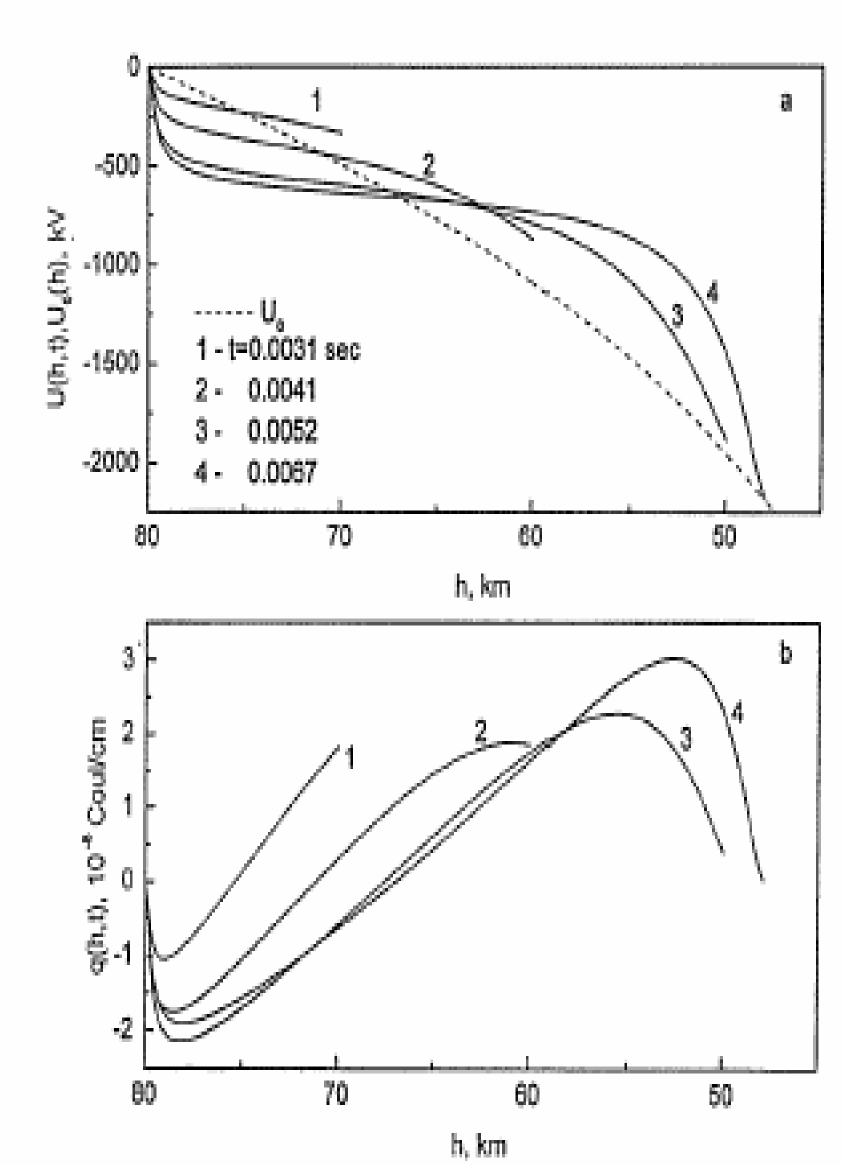
At h=80 km: E/N ≈ 120 Td

At h=0 km: 120 Td ↔ 30 kV/cm !

Raizer, Milikh, Shneider, J.Phys.D 1998

Red Sprites: 1D numerical model of streamer growth





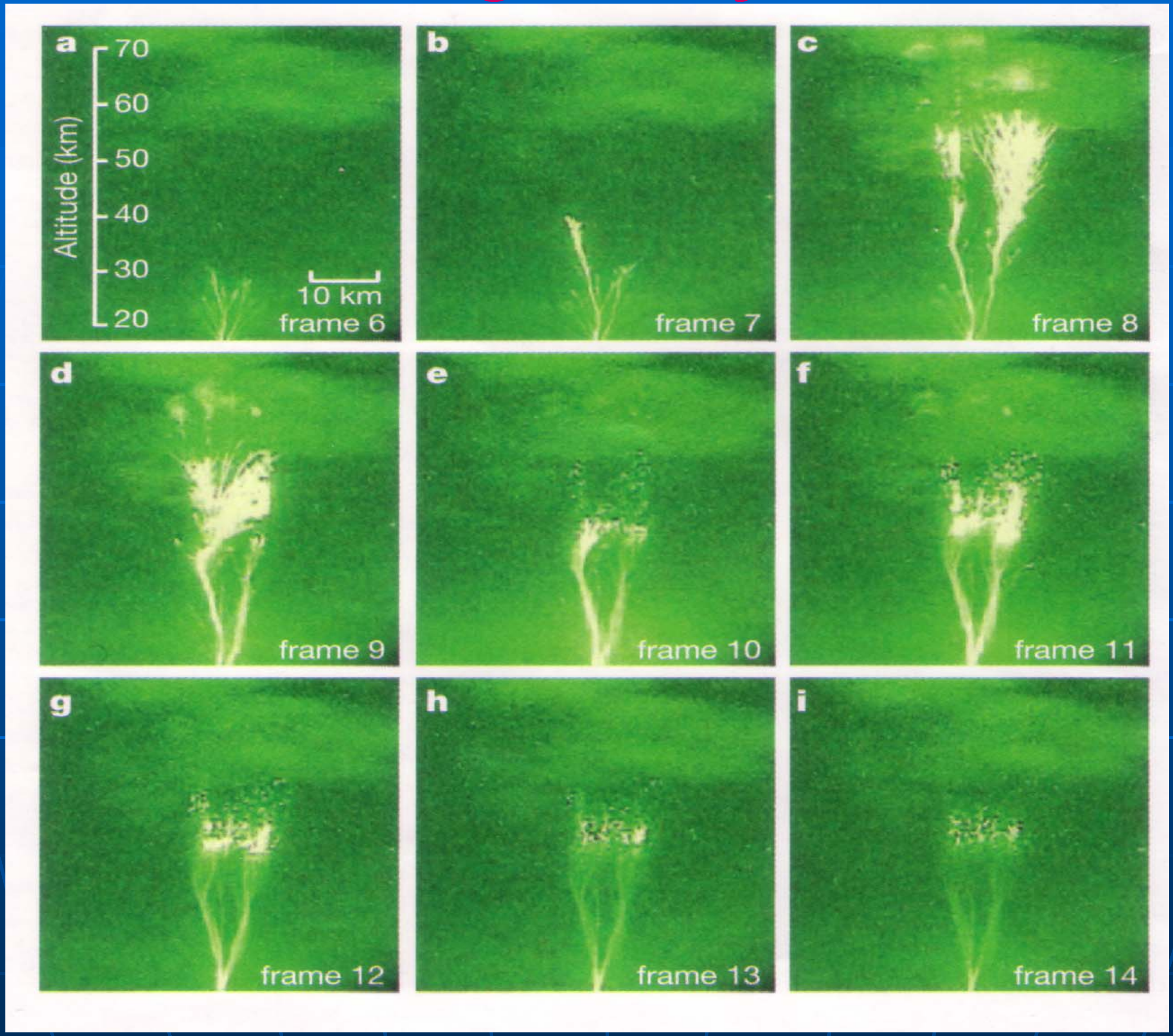
Red Sprite's computed propagation velocity and length are very close to the observation data

Raizer, Milikh, Shneider, J.Phys.D 1998

Blue Jets

An Australian photographer using a conventional film camera caught this upward lighting bolt tipped with a blue flame. Courtesy Peter Jarver and Earle Williams

Video recording GBJ by Pasko et al., 2002



Time between frames = 0.033 s; BJ lifetime ~ 0.3 s

Summarizing characteristics of Jets/Starters

- Emanate from the tops of the electrical core of thunderstorms as faint blue cones of light that propagate upwards at speeds of ~100 km/sec .
- Resemble a tall tree with a thin trunk and the branches on the top. Their brightness exceeds 0.5 MJ of radiated energy.
- Termination altitude is ~50 km (jets), ~30 km (starters), ~70-90 km (gigantic jets).
- Unlike sprites are not associated with cloud-to-ground lightning discharges.
- Occur much less frequently than sprites, although sampling bias may play a role in this assessment since observations are more difficult.

The BJ Formation Mechanism:
Streamer versus Leader

A streamer is a thin cold ionized channel, which grows in a relatively weak external field due to the sharp increase of the field near its tip, which provides intensive ionization.

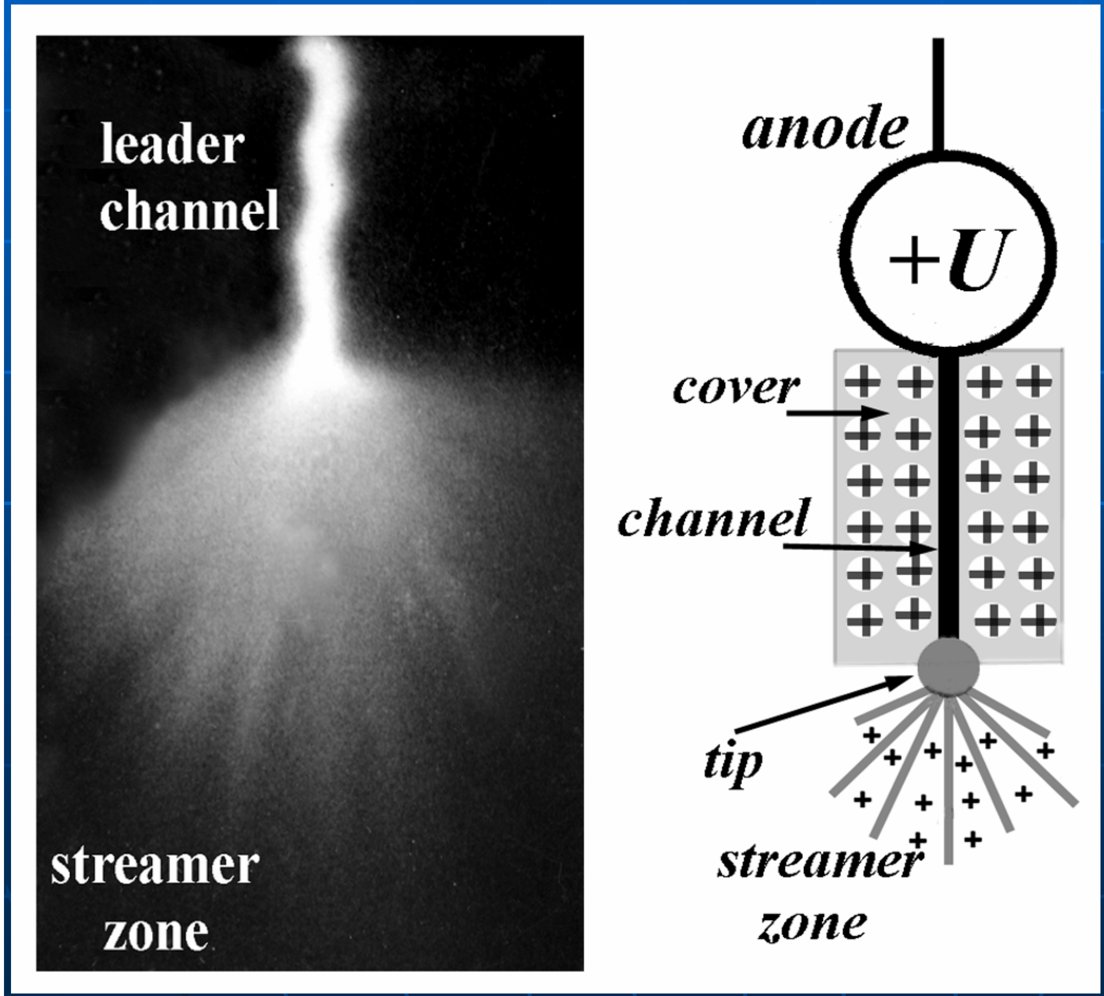
In a dense air streamer rapidly loses its conductivity due to electron attachment to atmospheric oxygen in triple collisions.

Thus it takes a leader mechanism to develop a long spark or lighting.

It is impossible to manage by means of the streamers only, without participation of a leader!

Attachment losses: $e^- + O_2 + M \rightarrow O_2^- + M \sim N^2$ are high at $h=h_{cloud}$

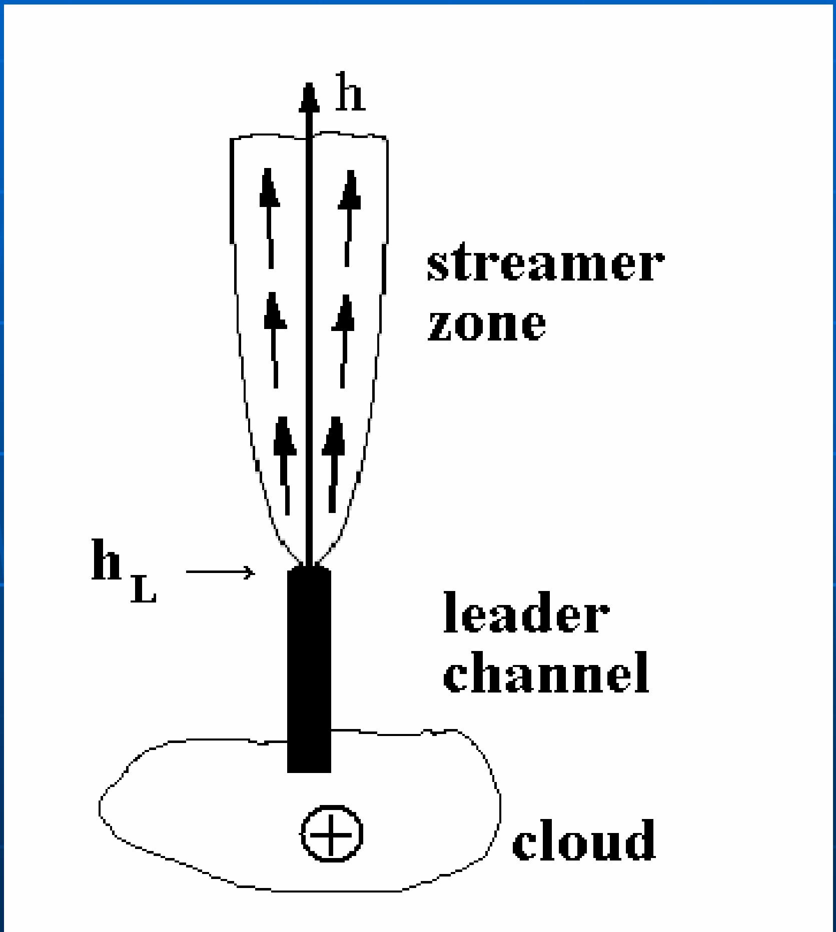
Photograph and scheme of a positive laboratory leader



- In a leader channel the gas is heated above 5,000K, thus maintaining its conductivity as in an arc channel.
- The leader tip continuously emits a fan of streamers at the rate of 10^9 1/s, which forms the streamer zone, and the current heats up the leader channel. Space charge of the stopped streamers covers the leader channel which prevents its expansion and cooling.

The new, leader-streamer model of blue jets

Raizer, Milikh and Shneider
Geophys. Res. Letters, December 2006
J. Atmosph. Solar and Terrestrial Physics, 2007



What gives a leader:

- transfers the high potential U~30-50 MV outside cloud up to h ~ 30 km,
- here $\tau_a \sim 10^{-2}$ s >> τ_a(18 km),
- plasma conductivity is kept much longer,
- streamers require field $E_S << E_S$(18 km).

The main problems for BJ theory

• To describe mathematically how the self-consistent field is formed in the streamer zones of an usual leader and of blue jets

• What does determine the blue jets velocity ?

• 2 scale of times and GBJ velocities: leader time ~ 100 ms; streamer time ~ 1-10 ms

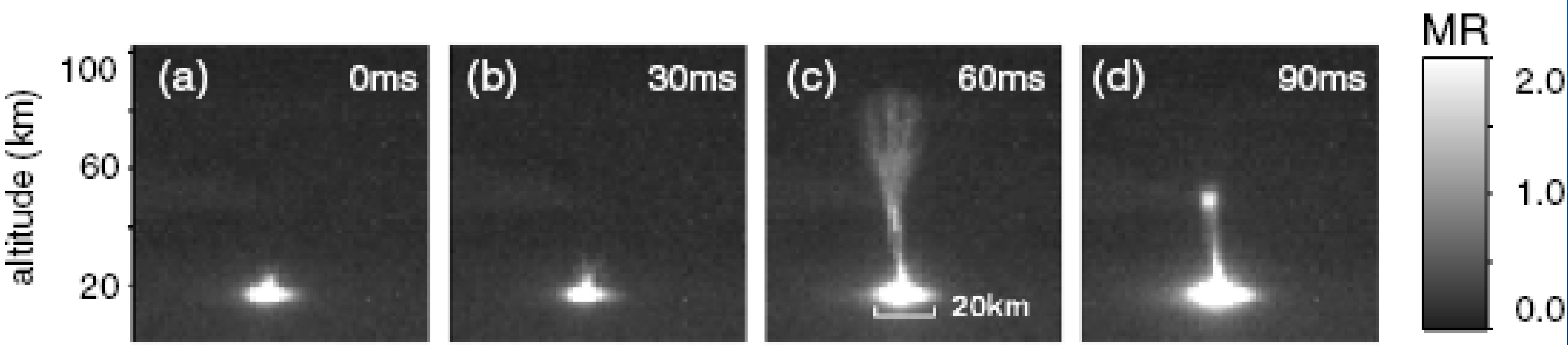


Figure 8. Time sequence of an ISUAL GJ on 28 May 2007 06:34:08.666 UT.

Kuo et al. J. Phys. D: Appl. Phys. **41** (2008) 234014

The Imager of Sprites and Upper Atmospheric Lightning (ISUAL) experiment on the FORMOSAT-2

It is obvious that any of ionization phenomena in atmosphere and ionosphere may be a source for observed radiation emission in different spectral ranges, including UV.

In the analysis we consider the following criteria for choosing a proper mechanism for generation of the observed UV flashes:

- temporal characteristics of the UV radiation,
- total radiated energy in the given spectral range, and
- geographic location of the UV sources

UV flashes detected by the "Tatiana" satellite

•Flashes with duration 1-64 ms originated in the equatorial region of the Earth [Garipov et al., 2005].

"Tatiana" satellite

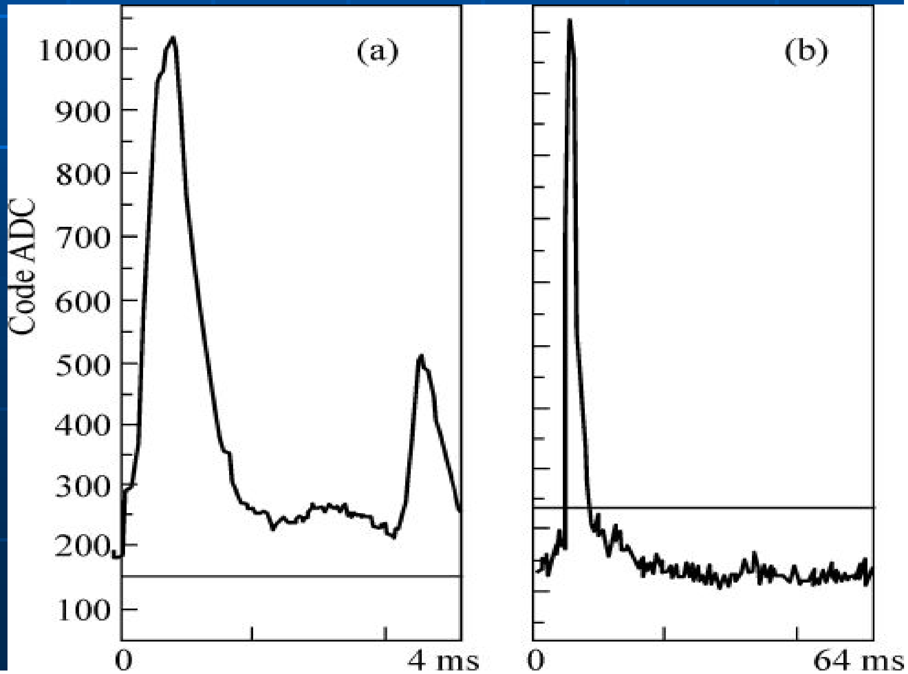
•The detector operates in the wavelength range 300-400 nm.

•The satellite was flying on the height 950 km along the circular orbit with an inclination of 82 degree.

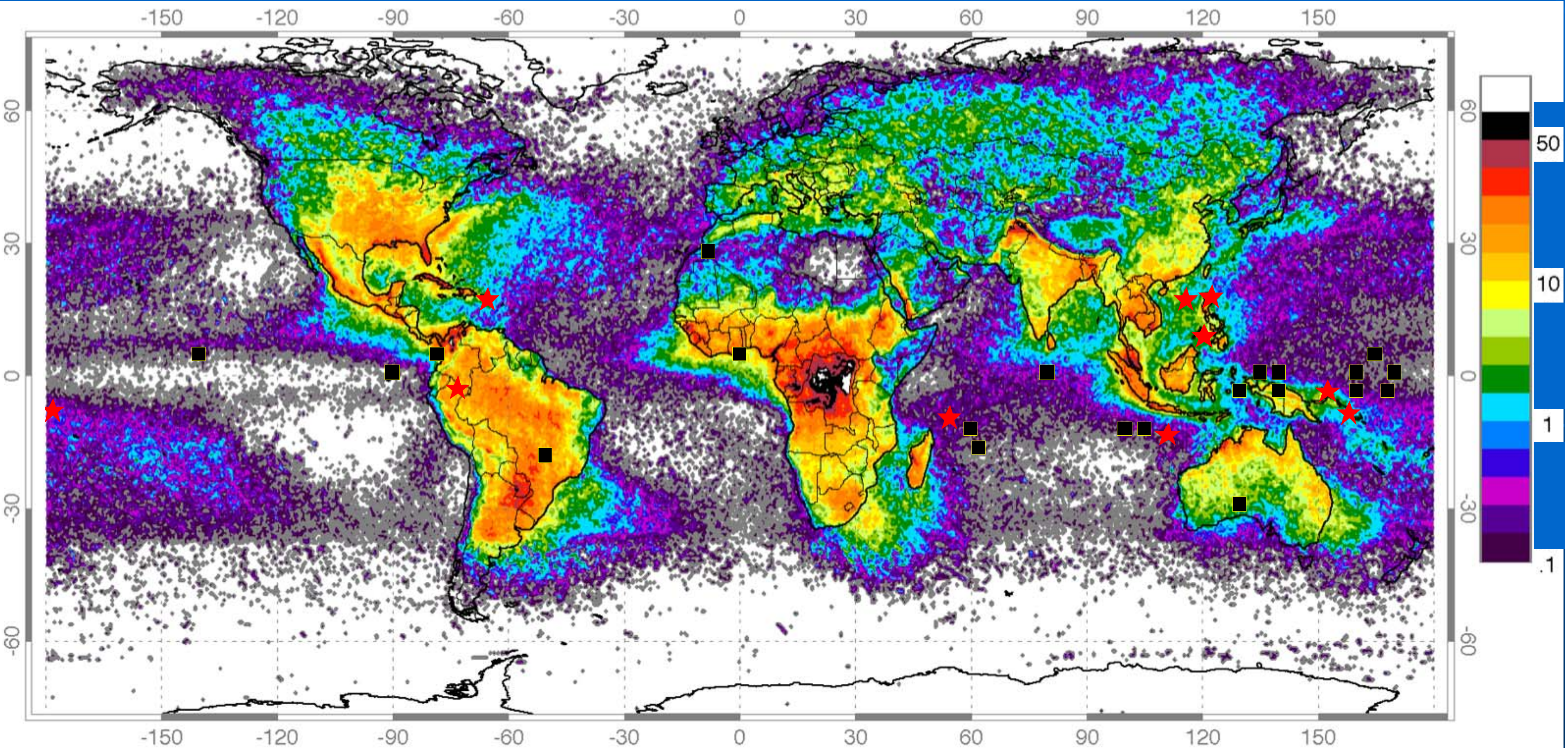
•The UV flashes were detected mainly over oceans and shores where the rate of lightning flashes is low.

Samples of UV flashes detected by "Tatiana" [Garipov et al., 2005]

Similar flashes observed by FORMOSAT-2



Global lightning map



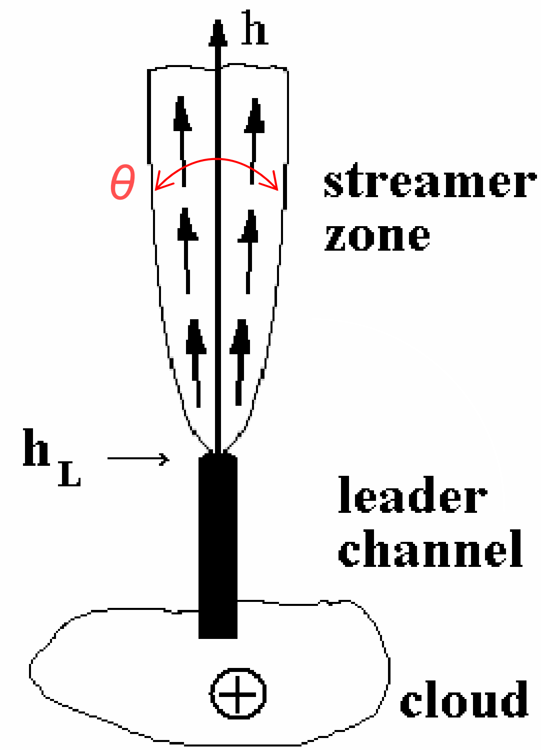
Superimposed are locations of GBJ events (stars), and UV flashes (squares)

http://thunder.nsstc.nasa.gov/images/HRFC AnnualFlashRate cap.jpg

Milikh, Shneider, J.Phys.D 2008

Gigantic Blue Jets as a source for detected UV flashes

The classic blue jet, the first ever documented to extend from the cloud top to the base of the ionosphere. It was captured above a storm near Puerto Rico. Courtesy Prof. Victor Pasko © Penn State University



In the paper: **Milikh, Shneider, J.Phys.D 2008** we suggested that UV flashes detected by "Tatiana" may be generated **by the bunch of long streamers which form a streamer zone of Gigantic Blue Jets.**

Leader-streamer model of blue jets published in:

Raizer, Milikh, and Shneider;
Geophys. Res. Lett., 2006, 33, L23801;
J. Atmos. & Solar-Terr Phys., 2007, 69, 925-938.

Approach and model

- Apply model of long ascending streamers in the exponential atmosphere and find the spatial and temporal distribution of the electric field near the streamer tip

- Compute the excitation rate of $N_2(C)$ which generates 2P emission of molecular nitrogen

- Consider collision quenching and photon propagation losses and find the number of photons reaching the UV detector from the source

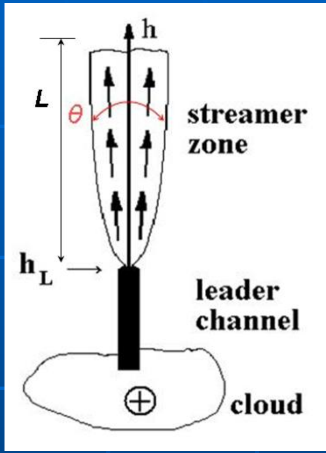
- Check the model against “Tatiana” observations

Milikh and Shneider, J.Phys.D 2008

Consider the UV emission generated by a bunch of streamers forming a streamer zone

According to observations of GBJ, the prongs look like an expanding cone with an angle θ. The radius of the expanding cone of length, *L*, is

$$R(L) \approx L \tan(\theta/2)$$

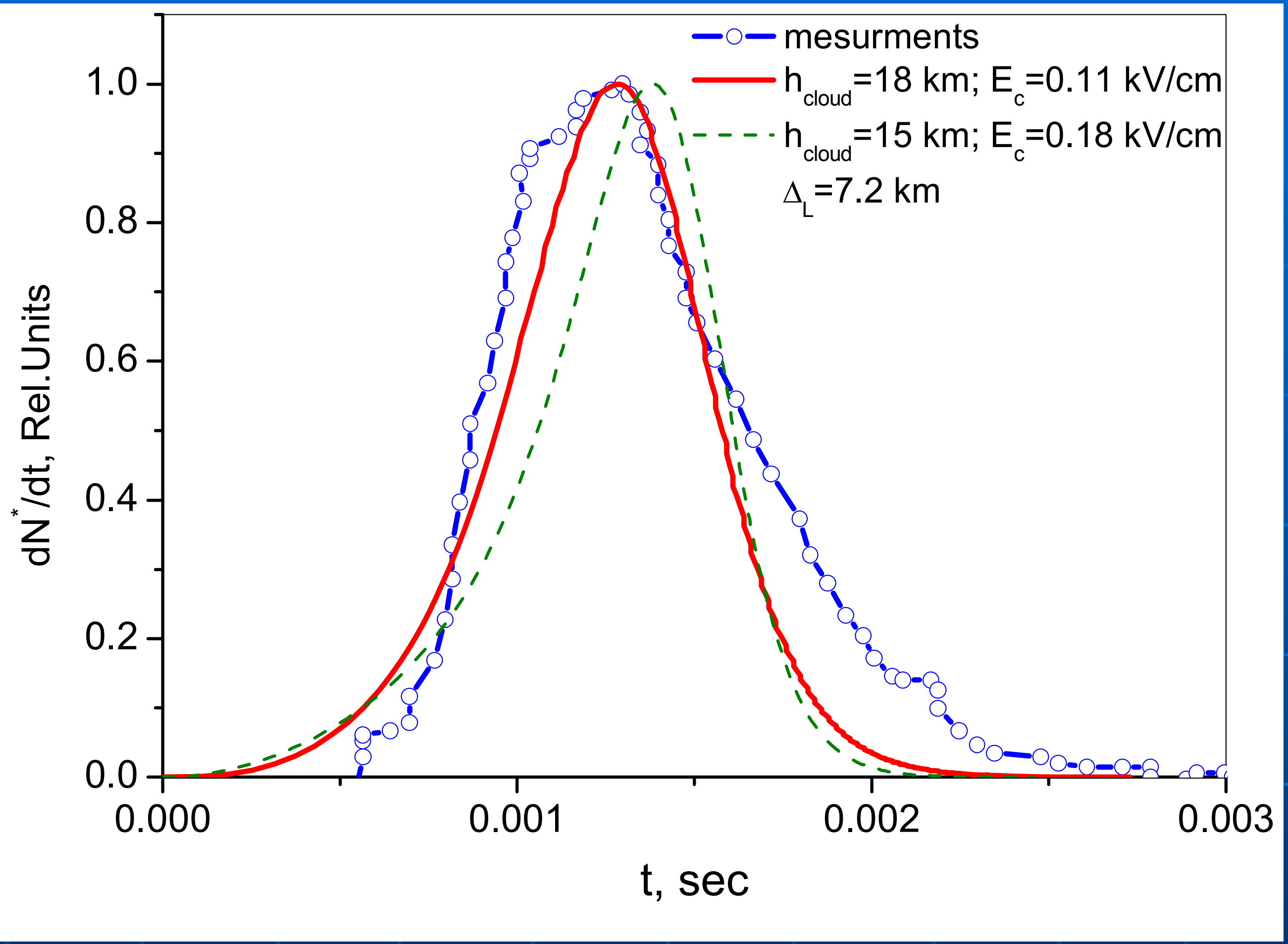


The total number of streamers in the blue jet head at altitude, *h*, is

$$\xi \approx [R(L)/r_m(h)]^2 \times F_{pack}$$

The packing factor (F_{pack} <<1) is the ratio of the area covered by the streamers to the total cross-area of the streamer zone. The total rate of excitations in the blue jet head region due to the streamer bunch is:

$$\frac{dN^*}{dt} = 2\pi R^2(L) F_{pack} \int_{r_m-\Delta r}^{\infty} k_{ex}[E(x)/N(h)] N_{N_2} n_e(x) dx$$



Normalized UV pulse shapes generated by the blue jet for different cloud altitudes: computed and that detected by the “Tatiana” micro satellite (white circles).

The normalized emission rate doesn’t depend on the cone angle θ, but the total number of photons does.

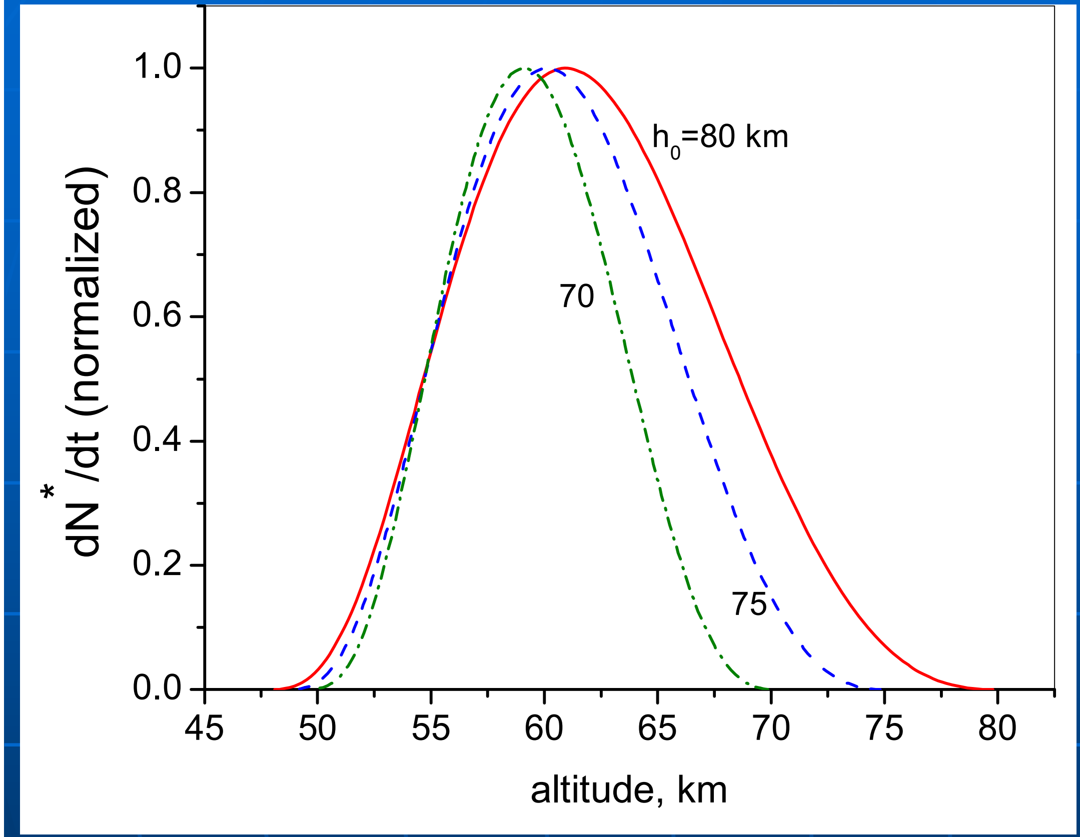
The total photon number: model versus observations

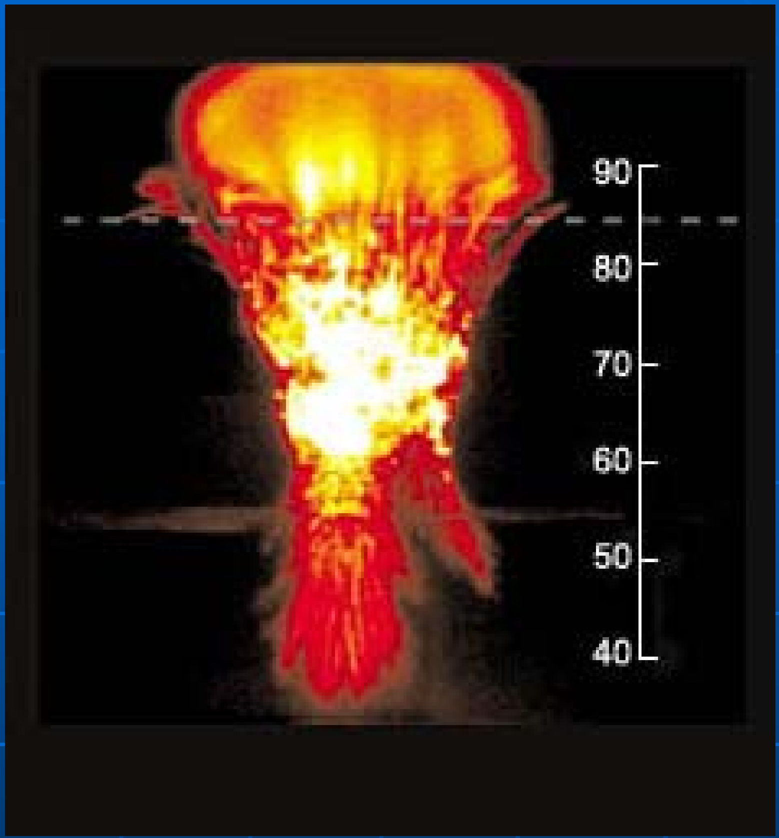
Number of photons radiated by a gigantic blue jet streamer zone computed for the different cone angle at $F_{pack} = 0.1$

Cone angle, θ (degrees)	Total number of photons: N_{ph}
2.5	$0.66 \cdot 10^{24}$
5.0	$2.64 \cdot 10^{24}$
10.	$1.06 \cdot 10^{25}$

The detected flashes correspond to about 10^{22}-10^{23} radiated UV photons, and in a few cases reaches 10^{24} photons [Garipov et al., 2005].
This implies that the narrow cone emission occurs $\theta < 5$ degrees.

Red Sprites: different start altitudes





www.rps.psu.edu/0309/electric.html

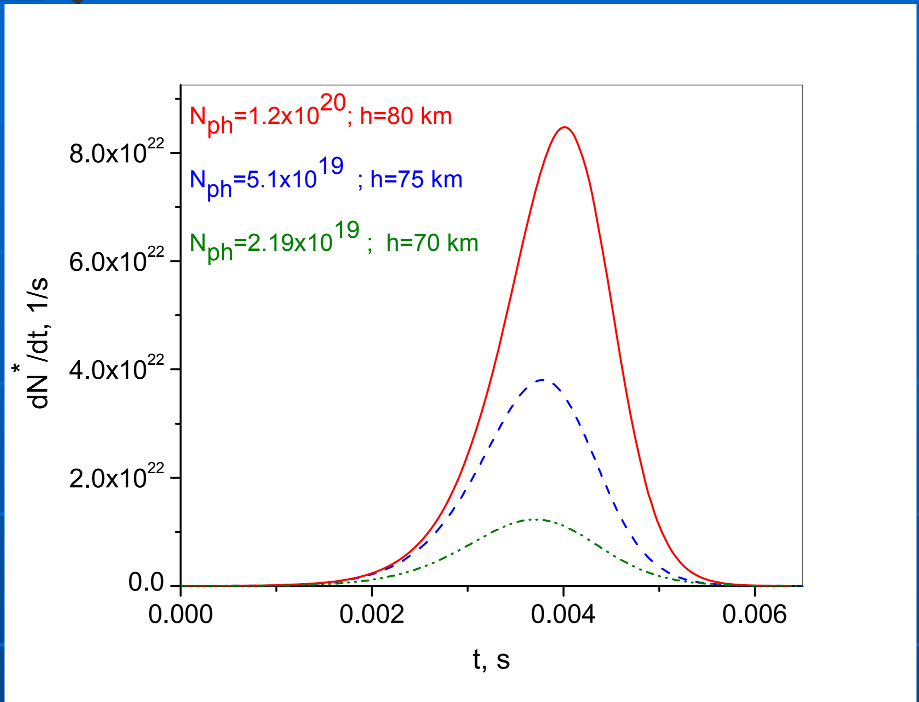
Calculations based on:

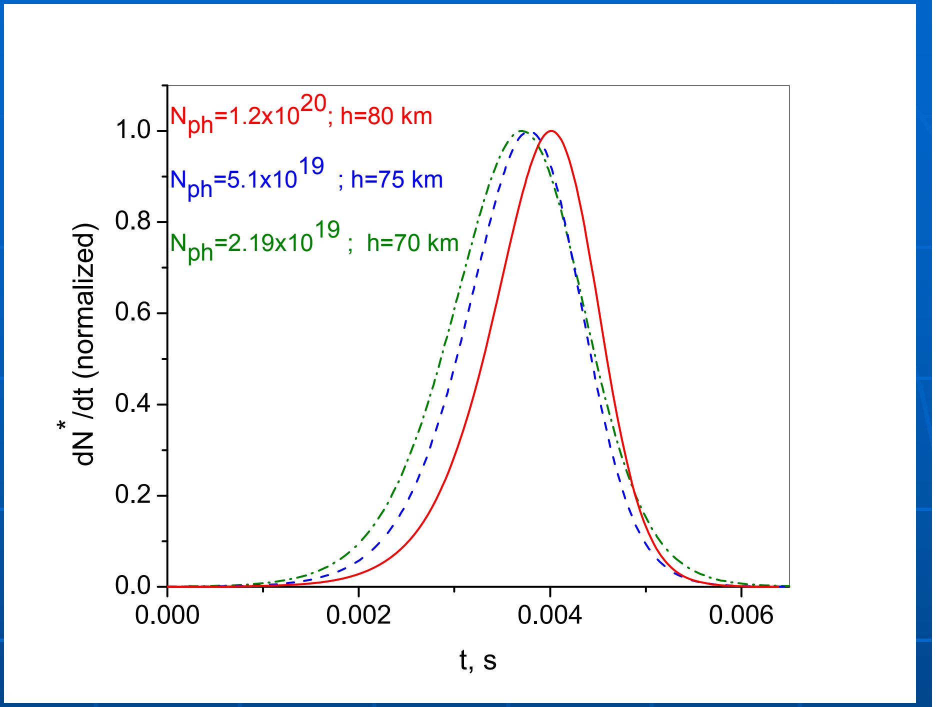
Raizer, Milikh, Shneider, J.Phys.D 1998

Milikh and Shneider, J.Phys.D 2008

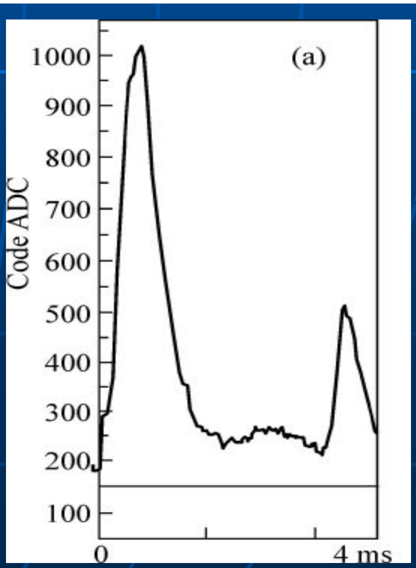
Shneider and Milikh, JGR 2010

Red Sprites: different start altitudes





Temporal profiles are **similar** to the "Tatiana" satellite observations, but the intensity of radiation and, therefore, the total number of photons are many orders smaller than what is produced by the blue jet



Increasing of the UV detection apparatus sensitivity may observe UV flashes, induced by the Red Sprites

Shneider and Milikh, JGR 2010

Summary

- Physical reasons and mechanism for observed UV flashes in upper atmosphere are discussed
- UV flashes detected by “Tatiana” is explained as generated by GBJ
- The radiation calculated on the basis of the developed GBJ model reproduces the temporal behavior of the UV flashes
- Red Sprites can be a source for low intensity UV flashes with similar temporal profile: interesting to test with more sensitive UV detectors