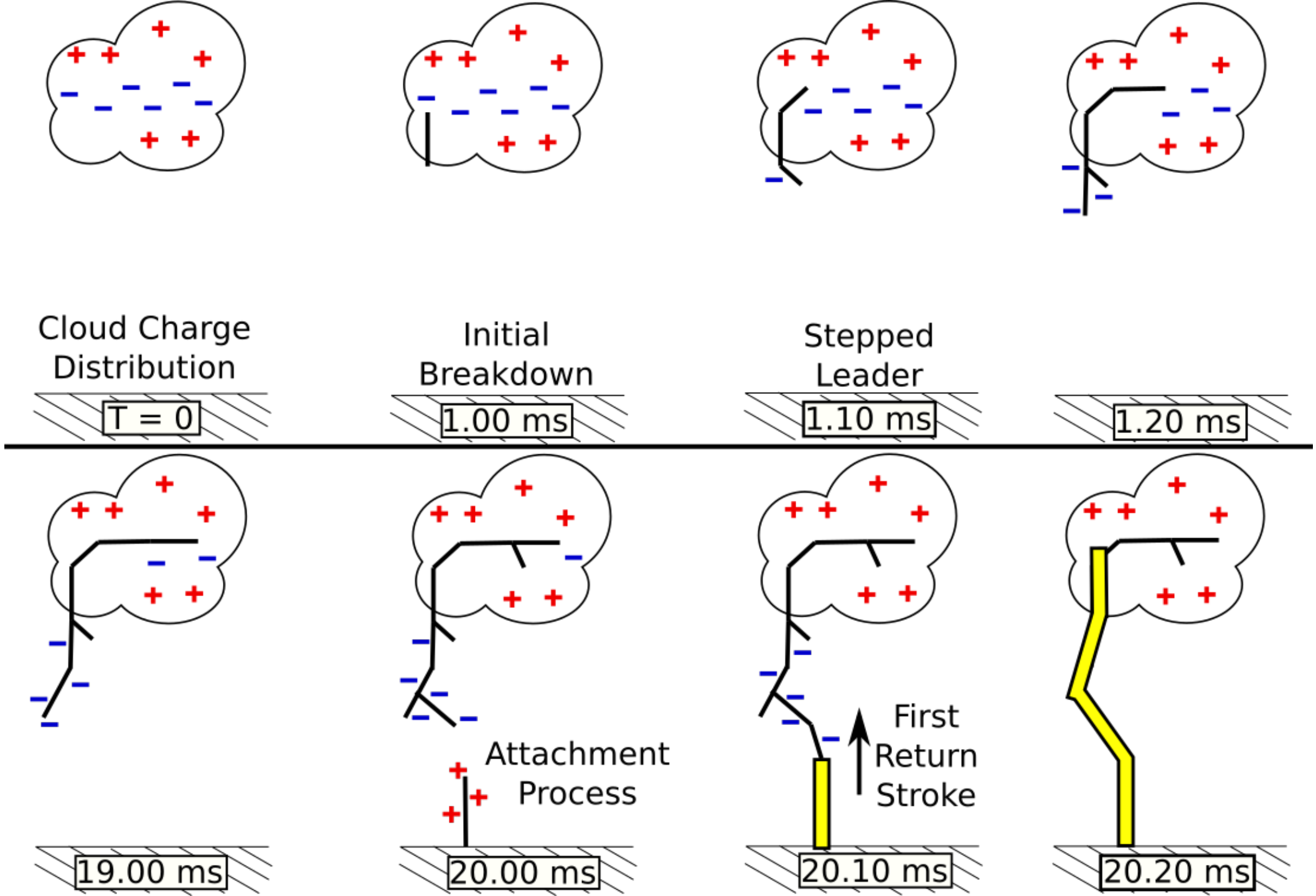
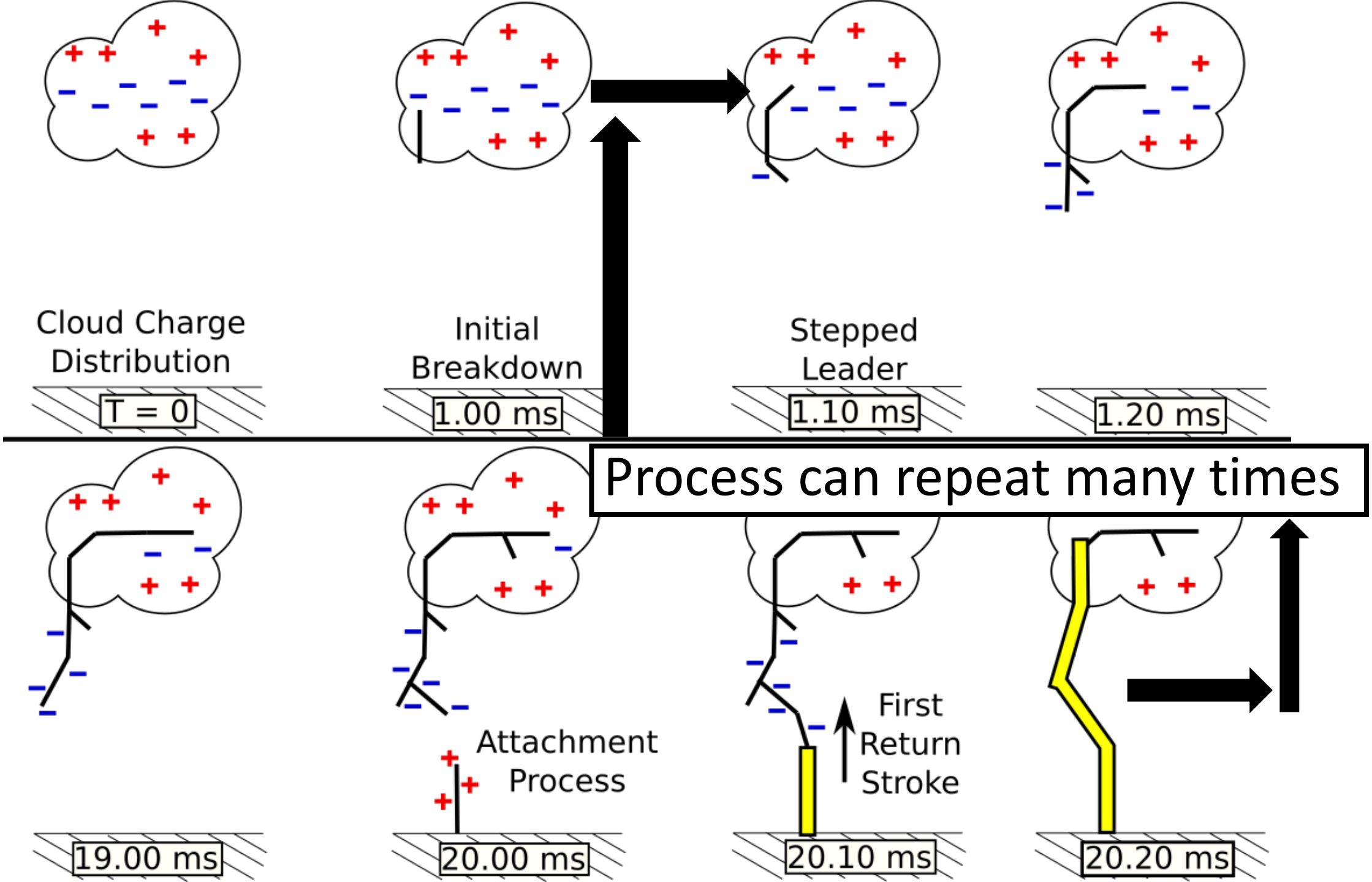
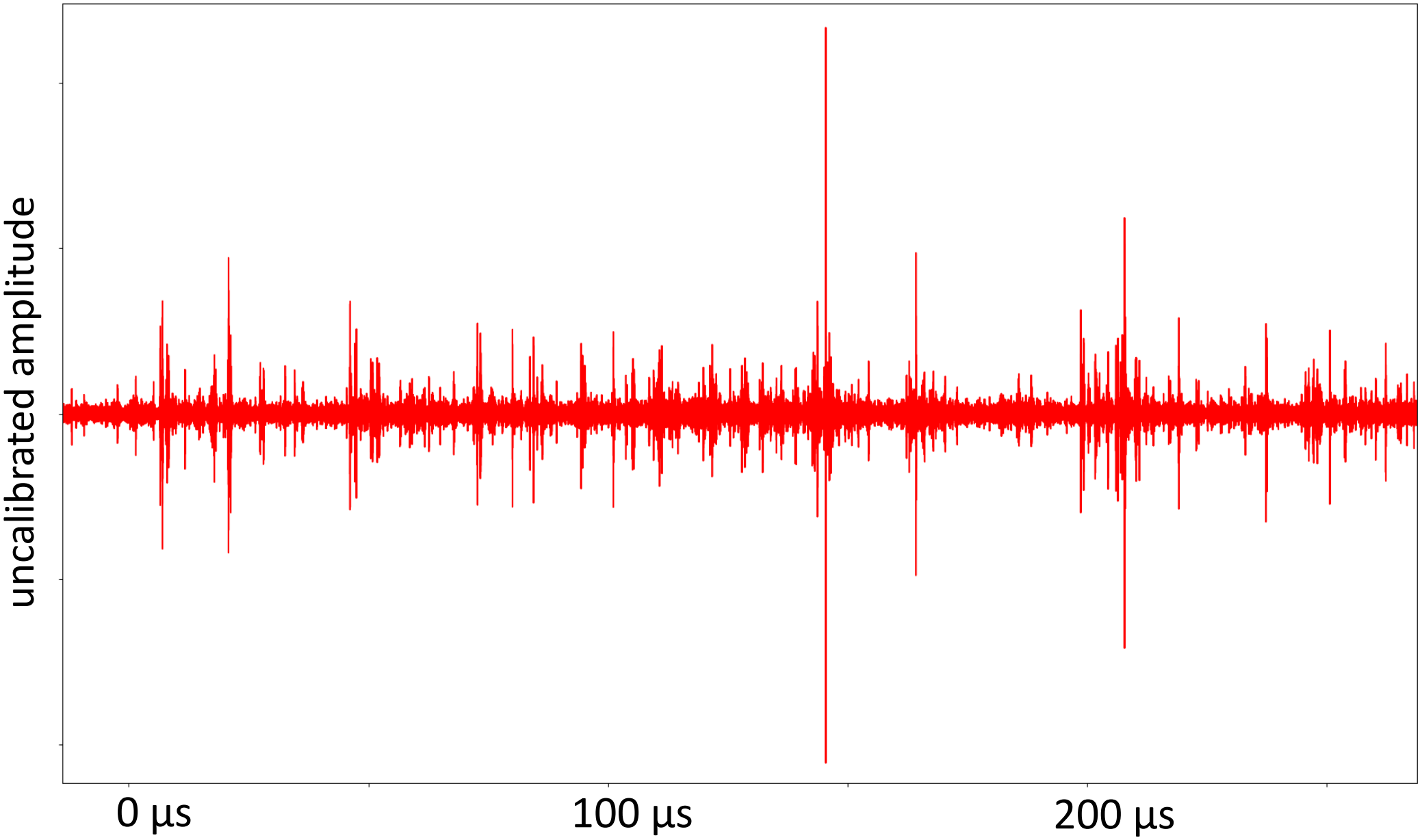
Lightning Leaders Imaged with Meter-Scale Resolution

Brian Hare
& Cosmic Ray KSP

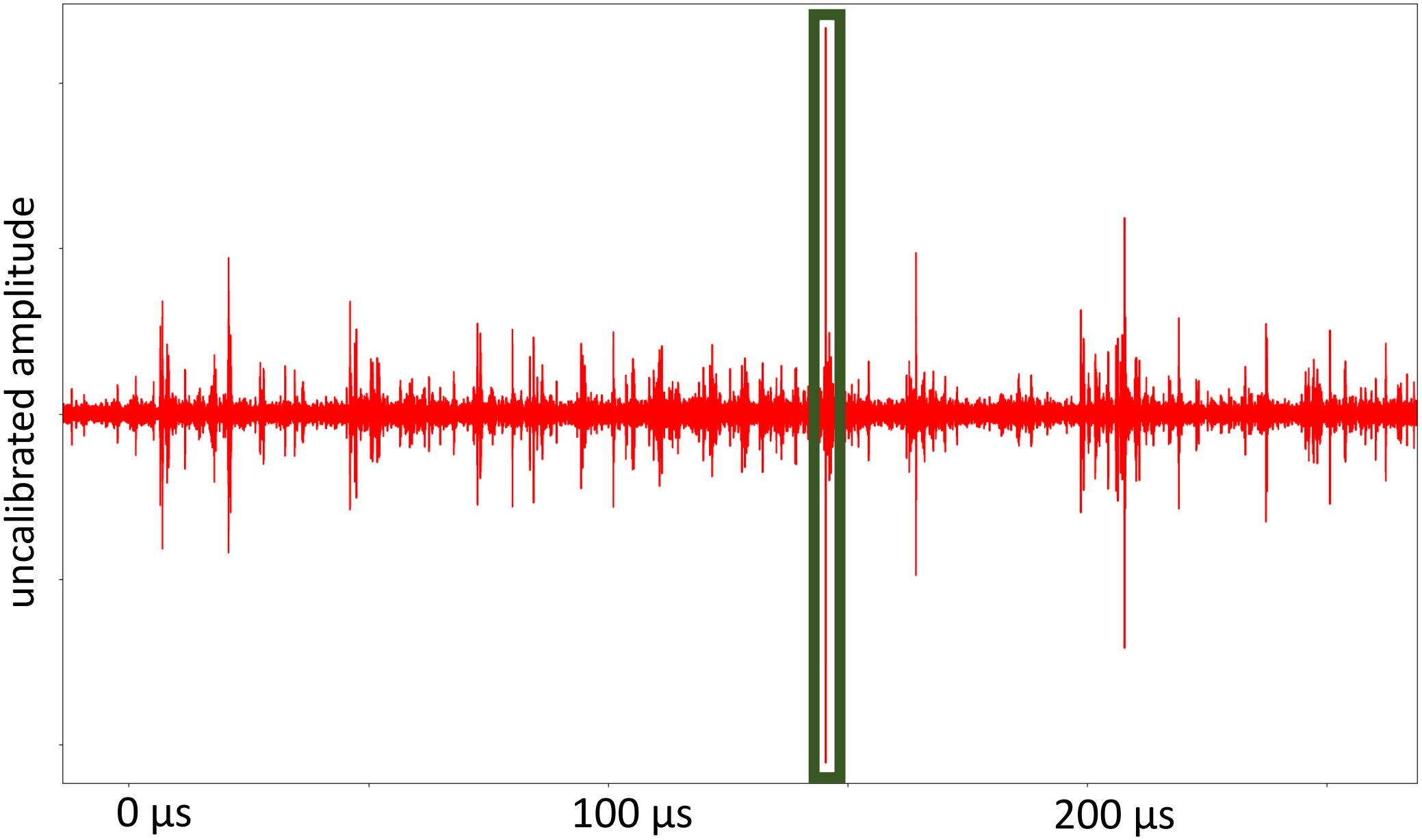

Cloud Charge Distribution
T = 0
Initial Breakdown
1.00 ms
Stepped Leader
1.10 ms
1.20 ms
19.00 ms
Attachment Process
20.00 ms
First Return Stroke
20.10 ms
20.20 ms


Cloud Charge Distribution
T = 0
Initial Breakdown
1.00 ms
Stepped Leader
1.10 ms
1.20 ms
Process can repeat many times
19.00 ms
Attachment Process
20.00 ms
First Return Stroke
20.10 ms
20.20 ms

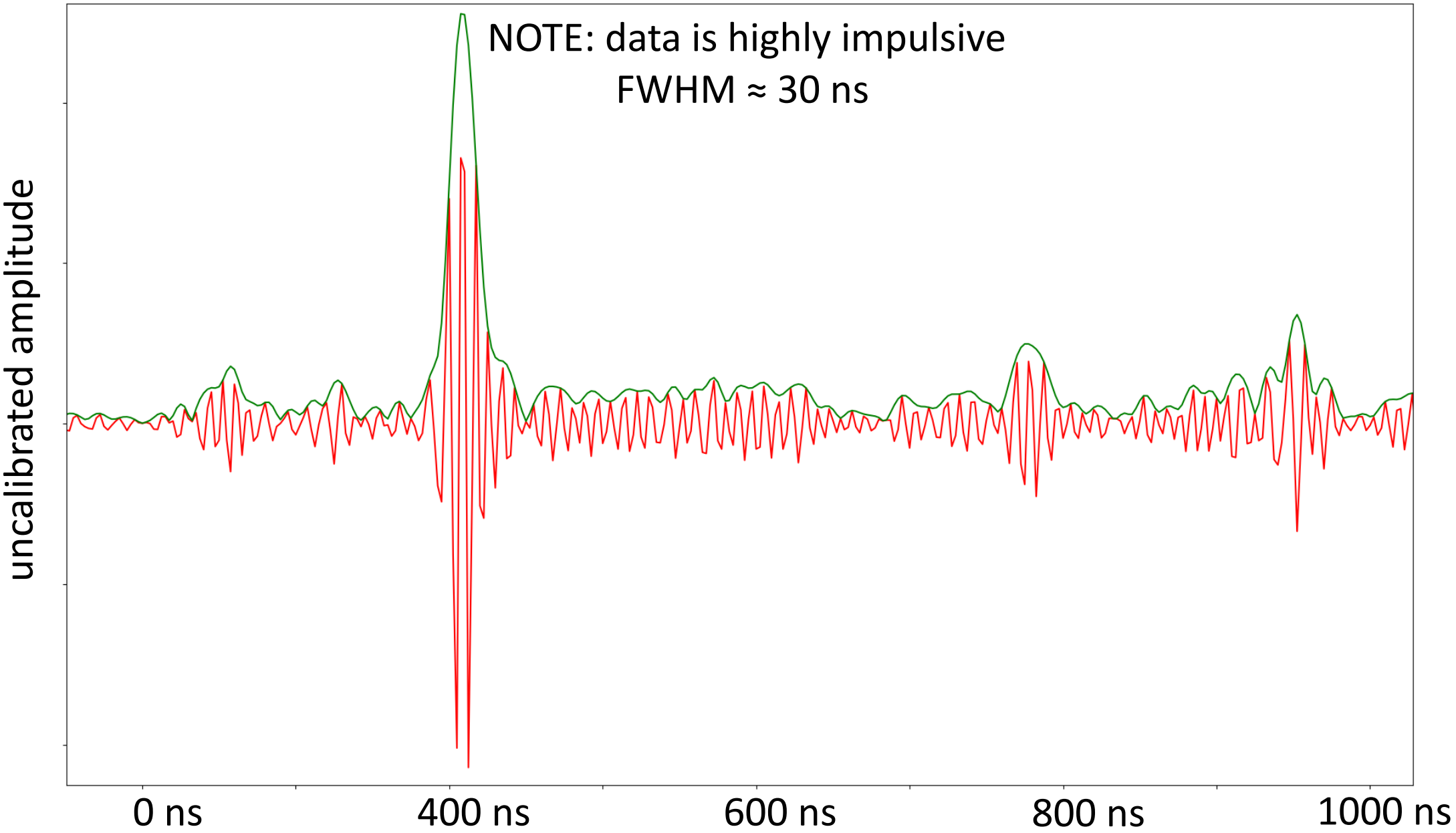
Typical LBA-TBB Trace



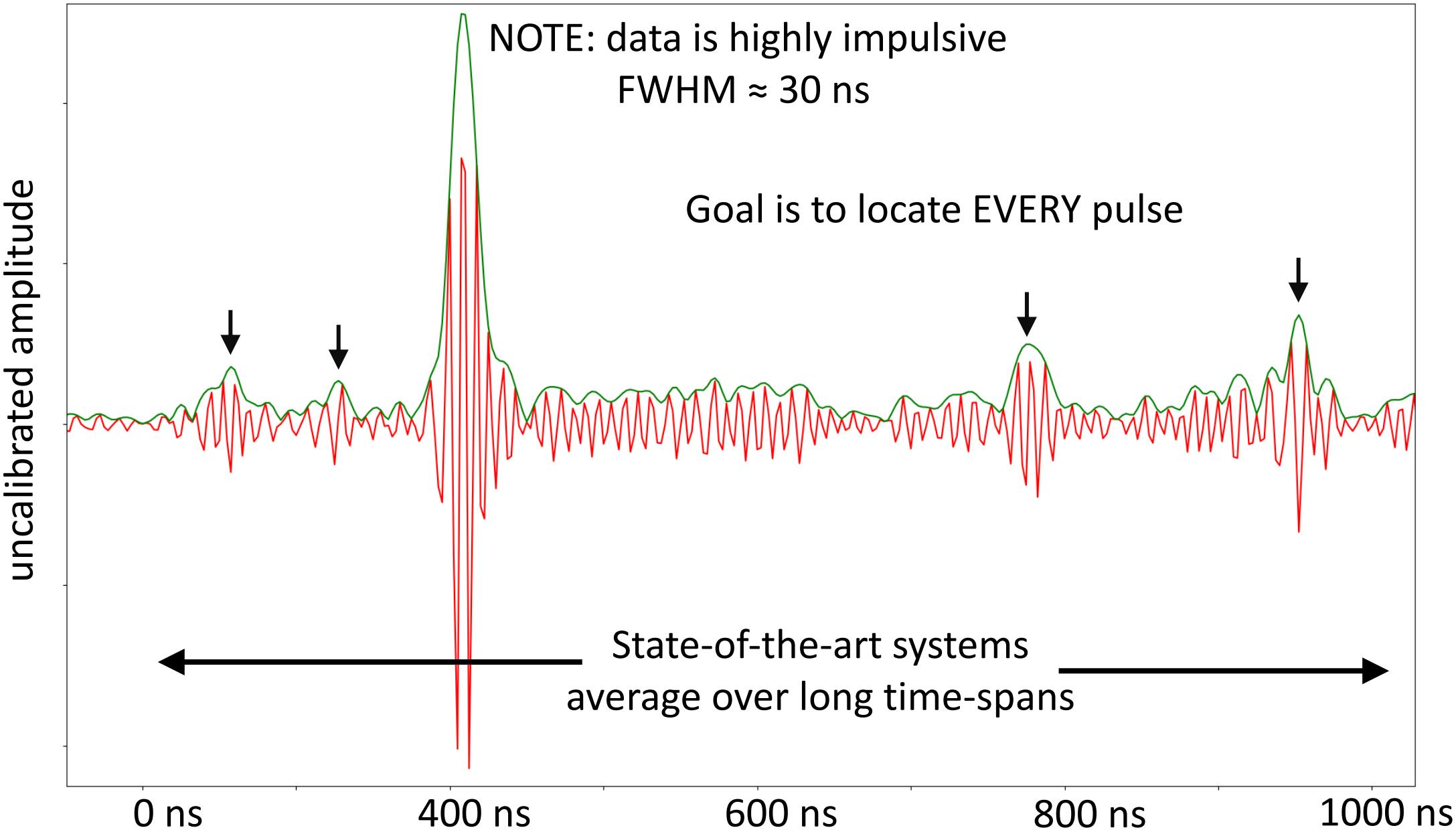
Typical LBA-TBB Trace



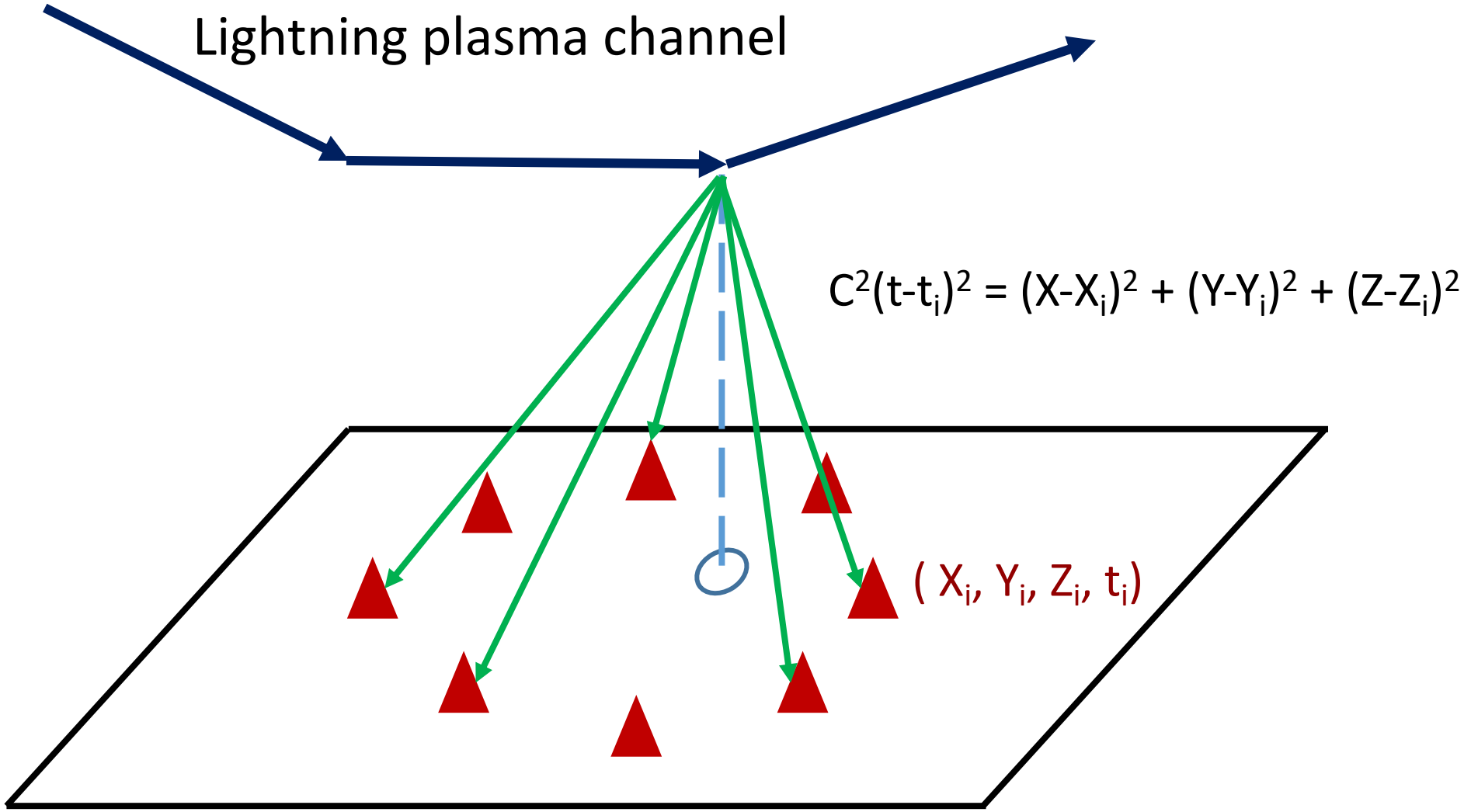
Typical LBA-TBB Pulse

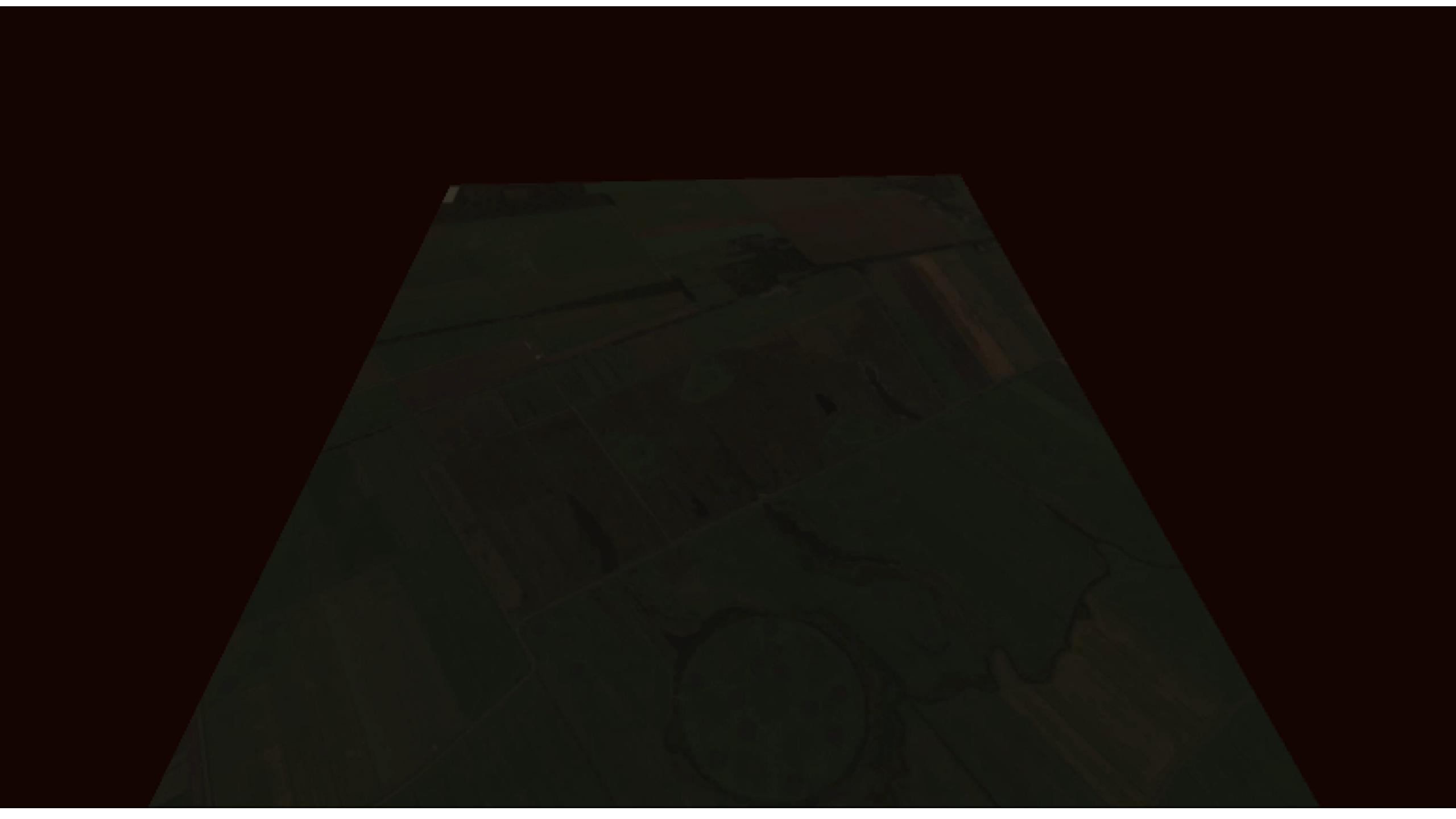


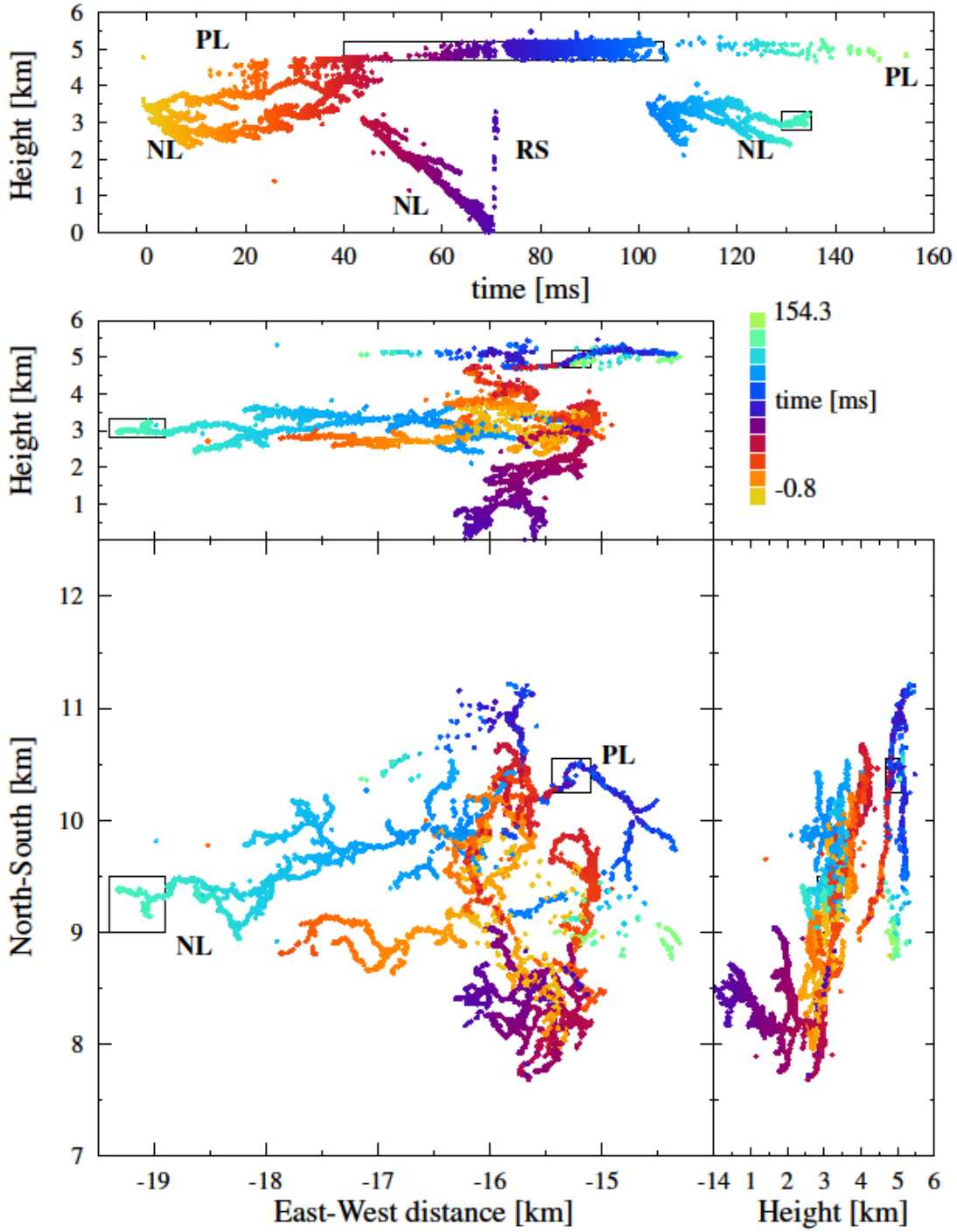
Typical LBA-TBB Pulse



Time-of-Arrival mapping







PL- positive leader
NL- negative leader
RS- return stroke

Each dot is a location of a VHF source

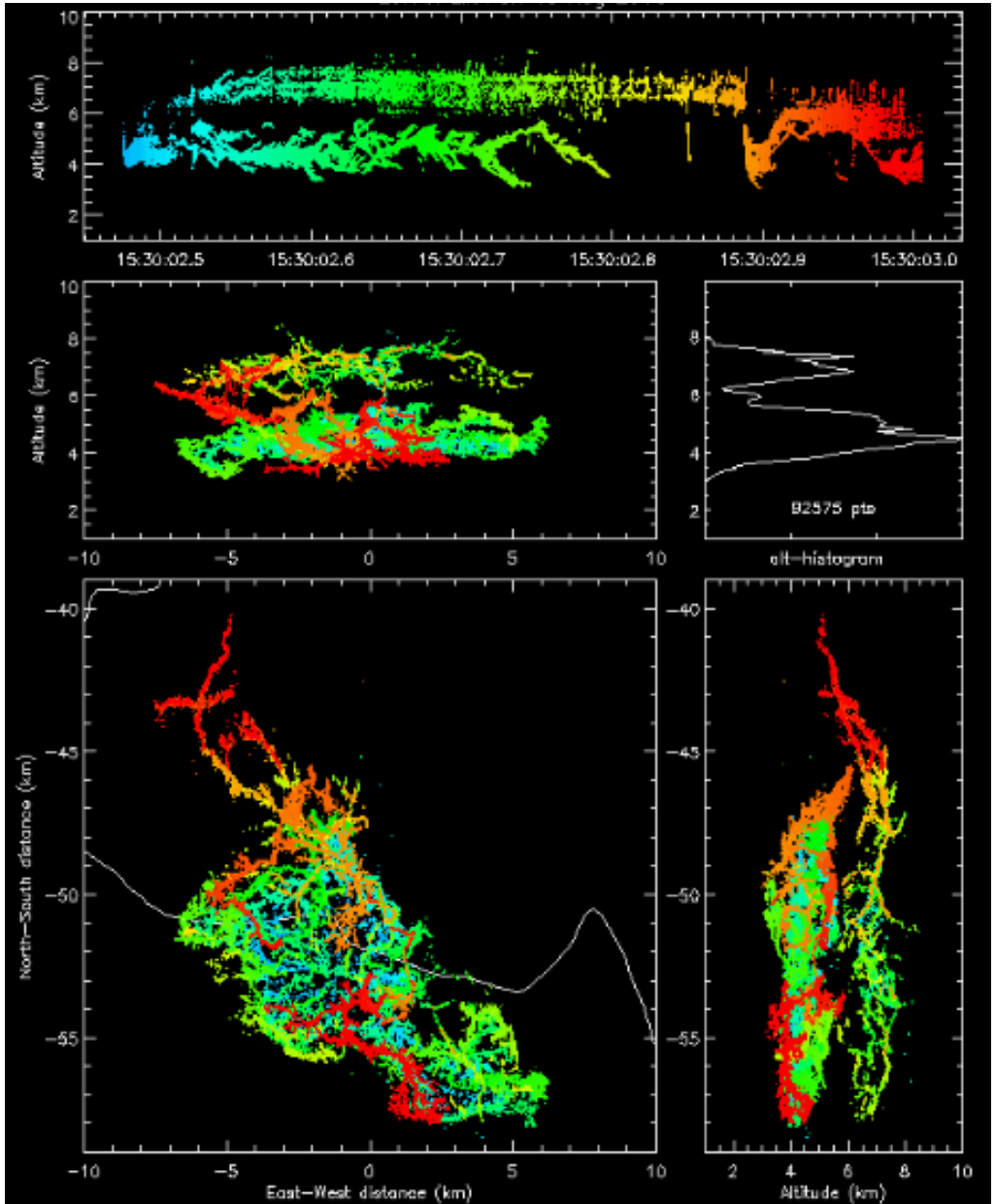
15,000 sources after cuts
≈ 100 sources per ms

120 ns minimum between sources

Horizontal accuracy better then 2 m

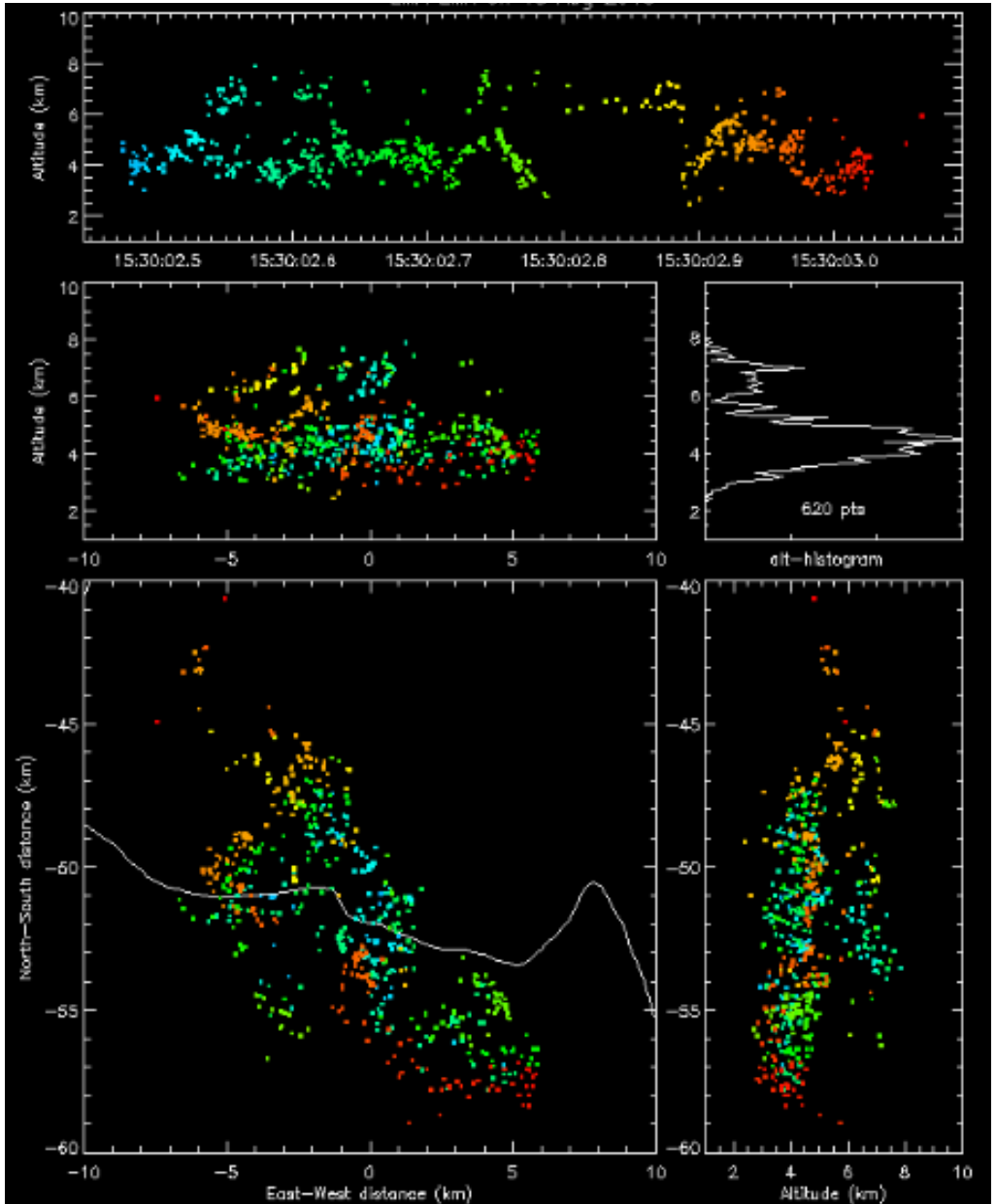
Our Results

Plotted by an American lightning expert

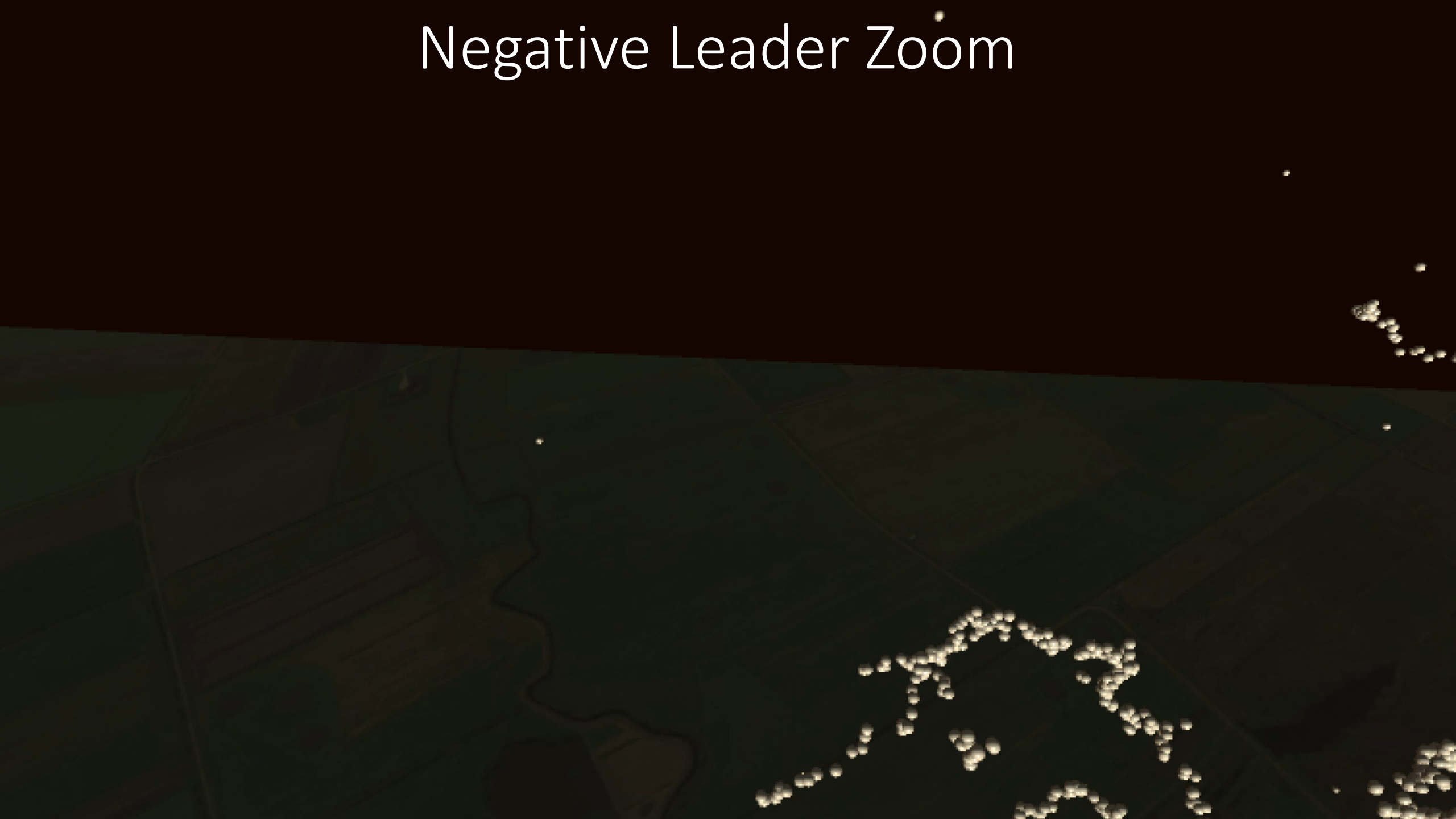


State-of-the-art

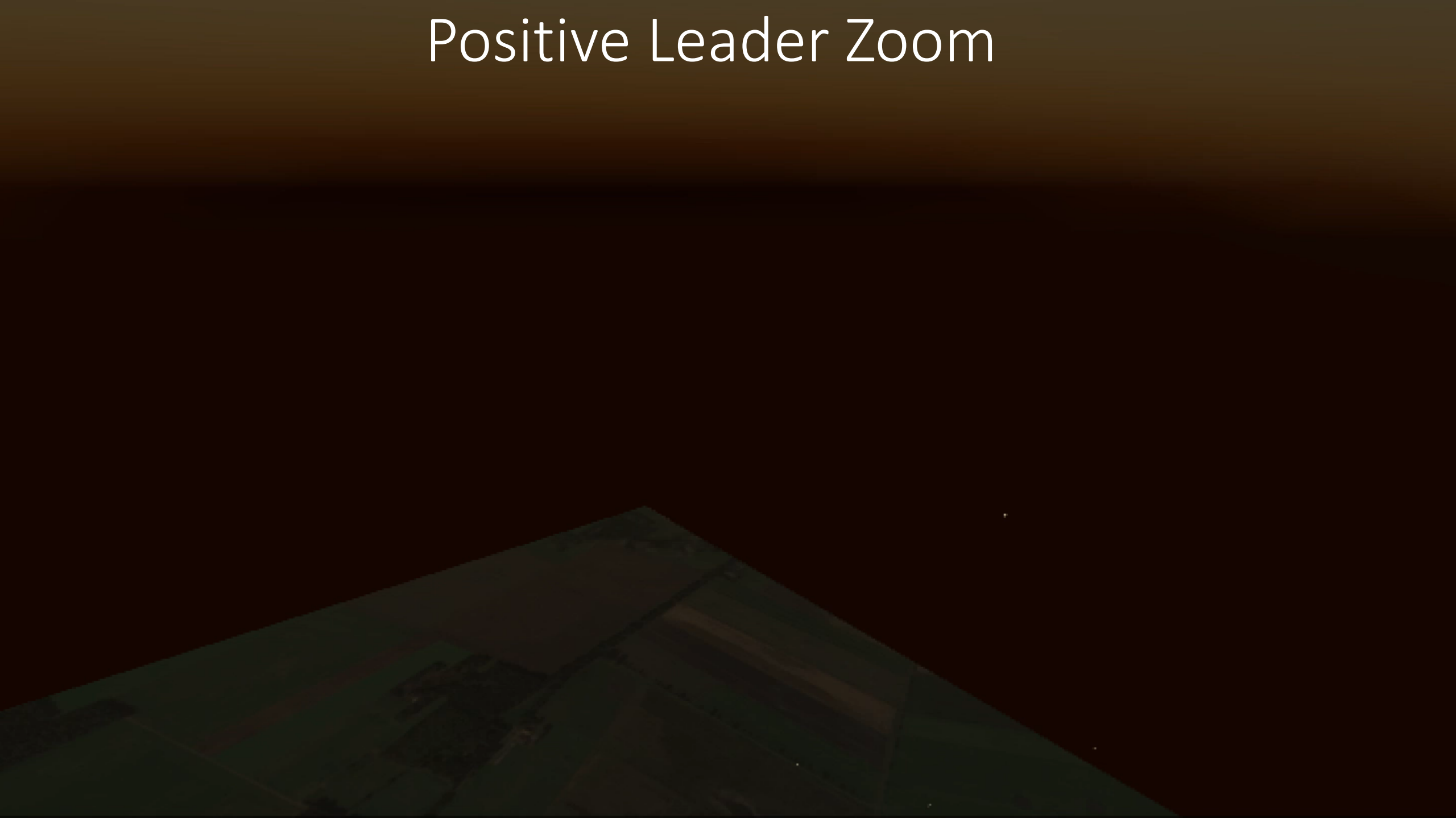
(same flash)



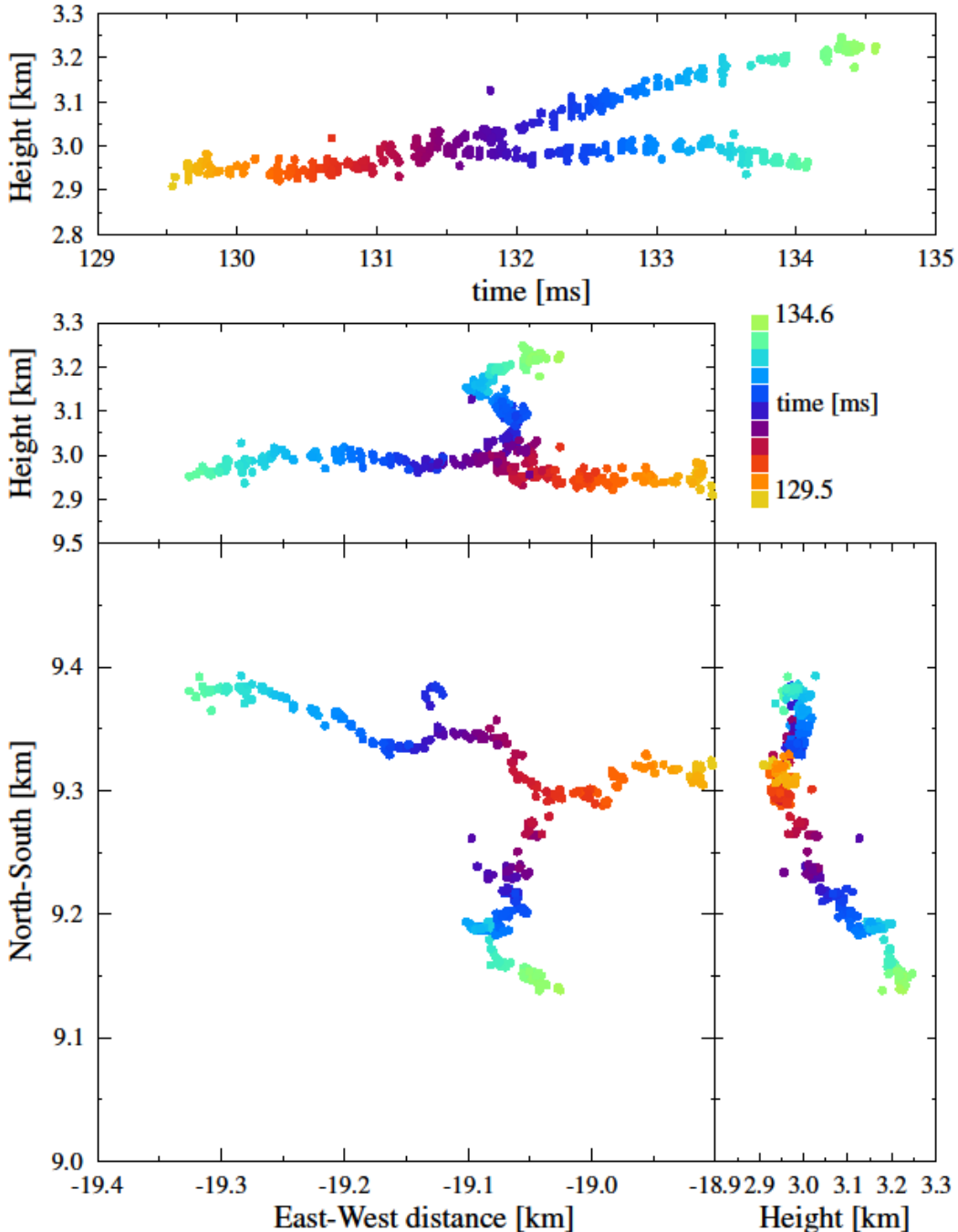
Negative Leader Zoom



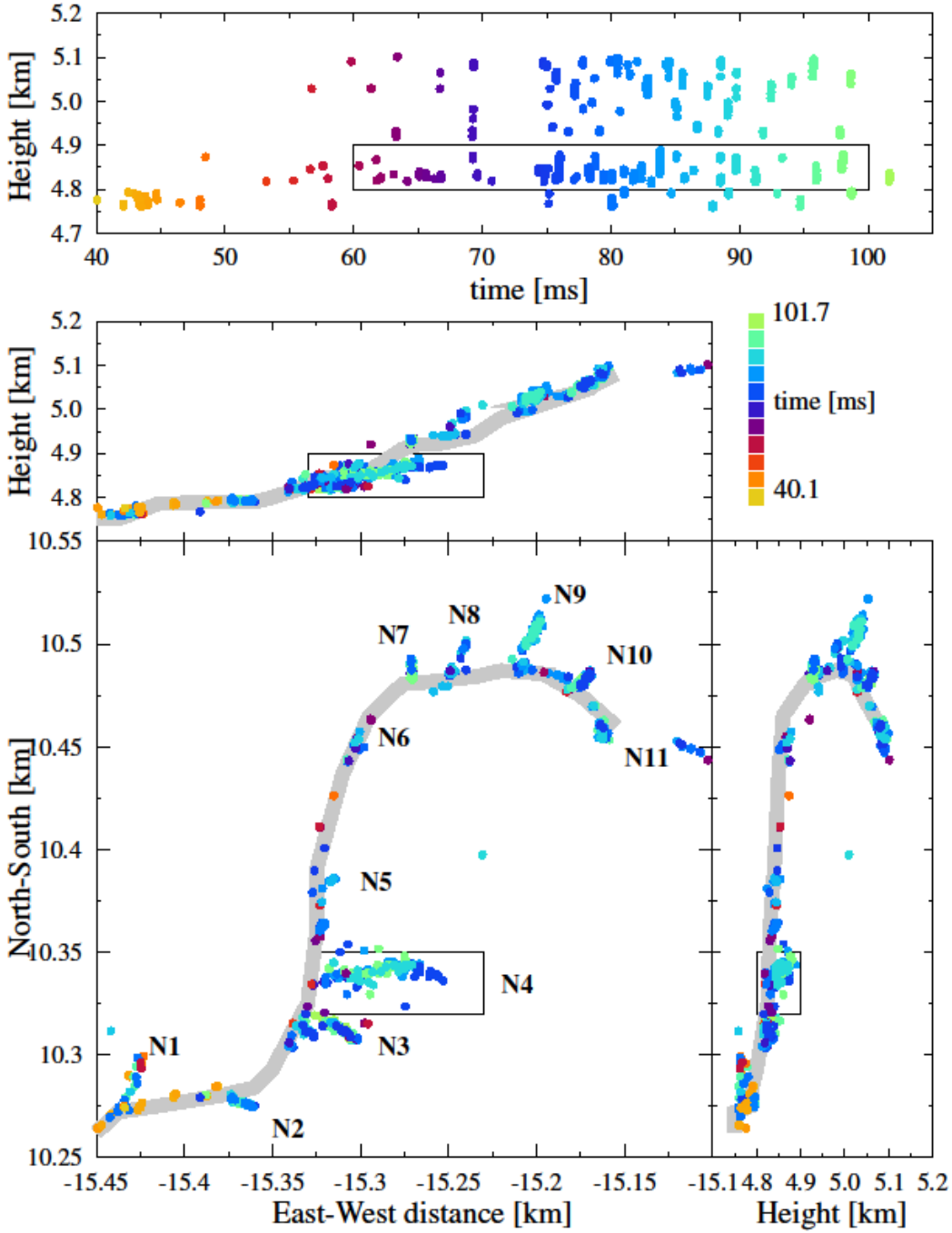
Positive Leader Zoom



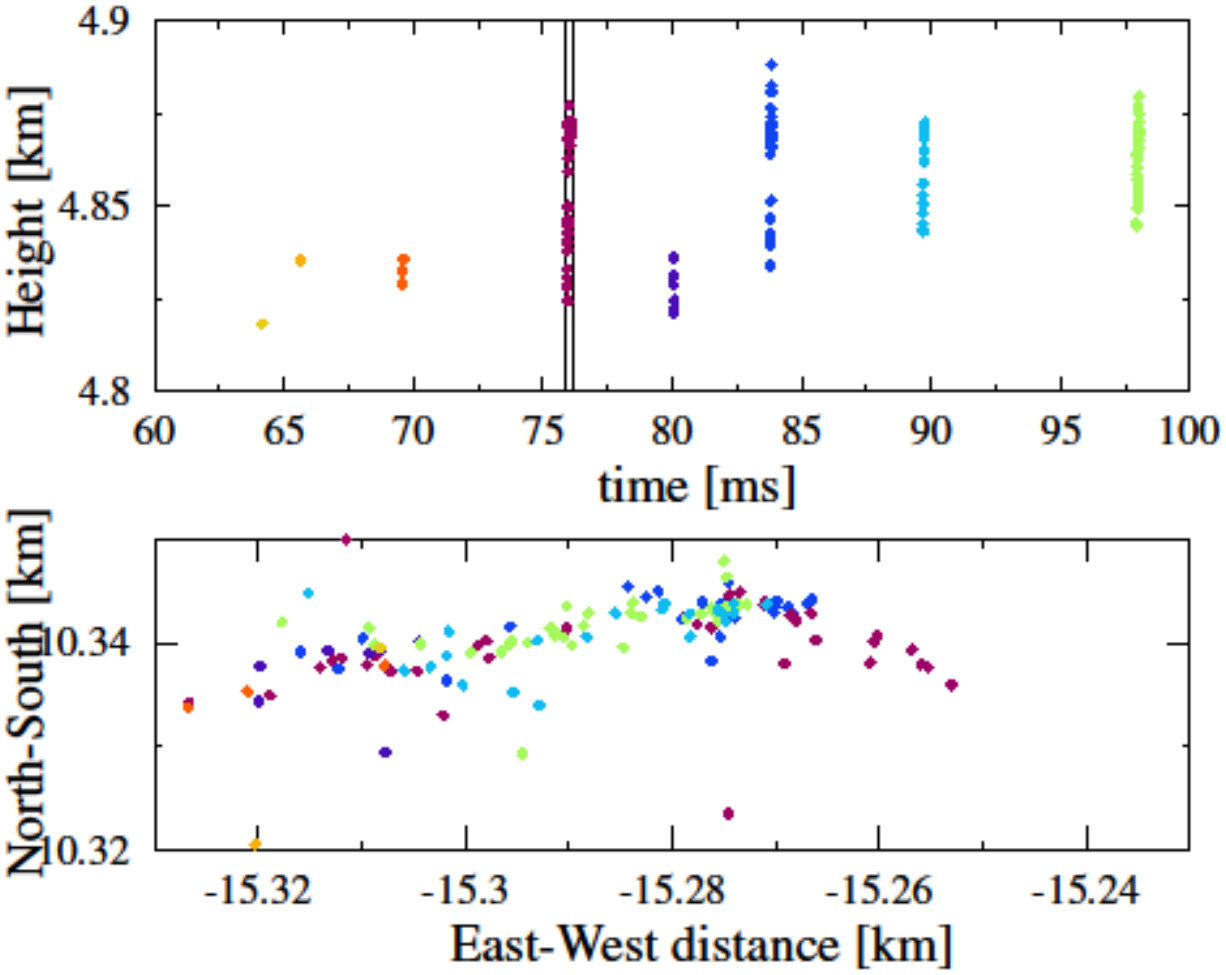
Negative Leader



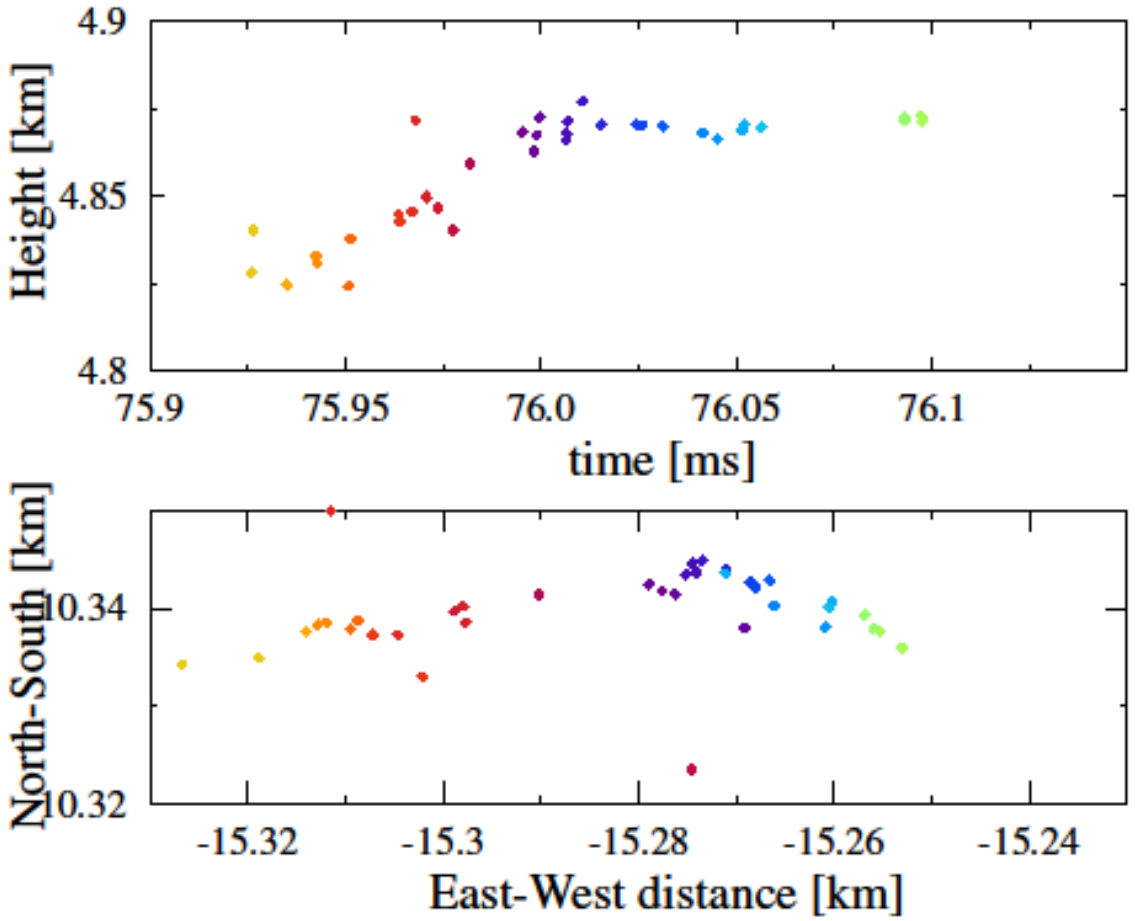
Positive Leader



One flickering positive leader structure

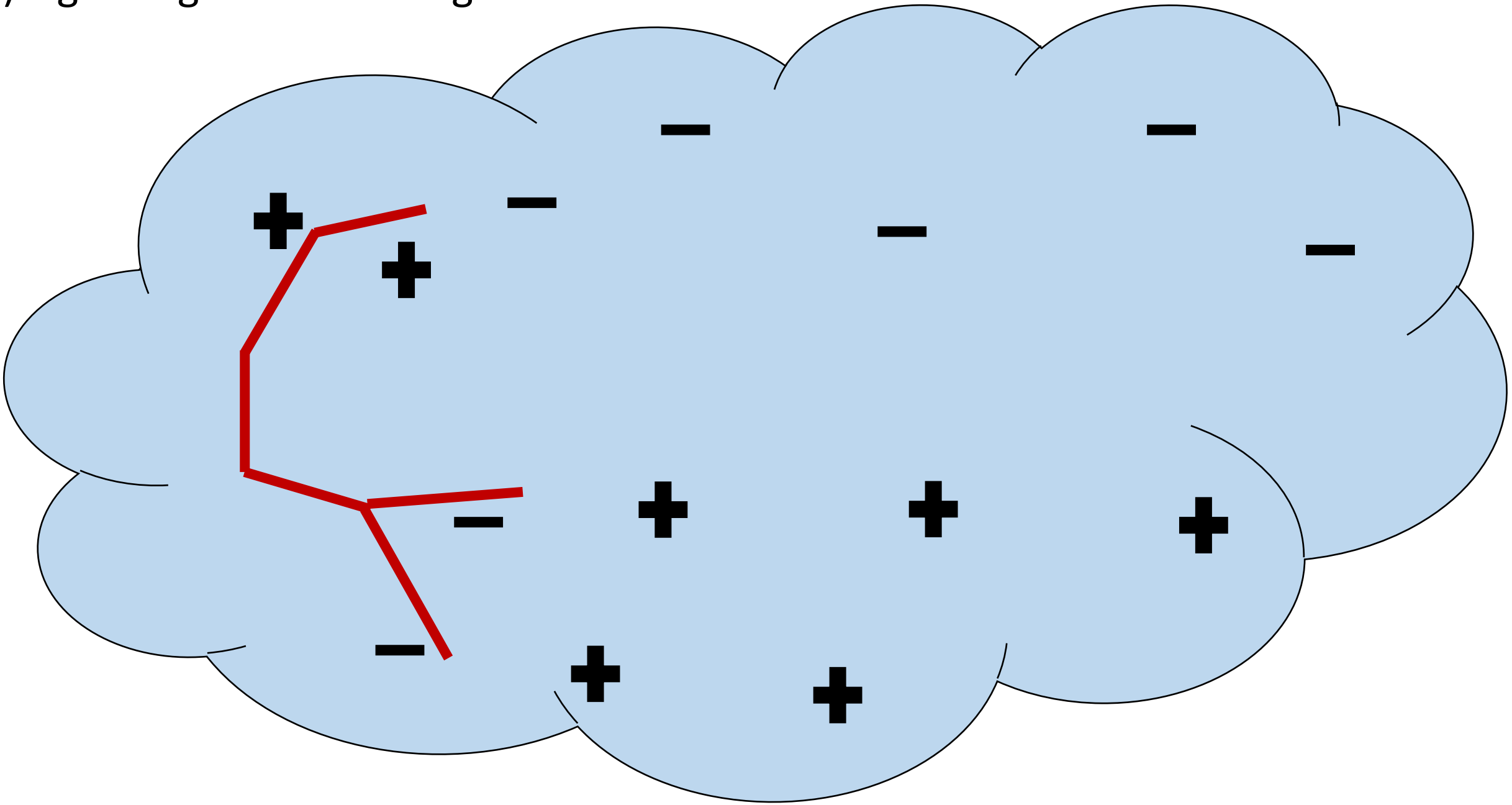


Time zoom-in

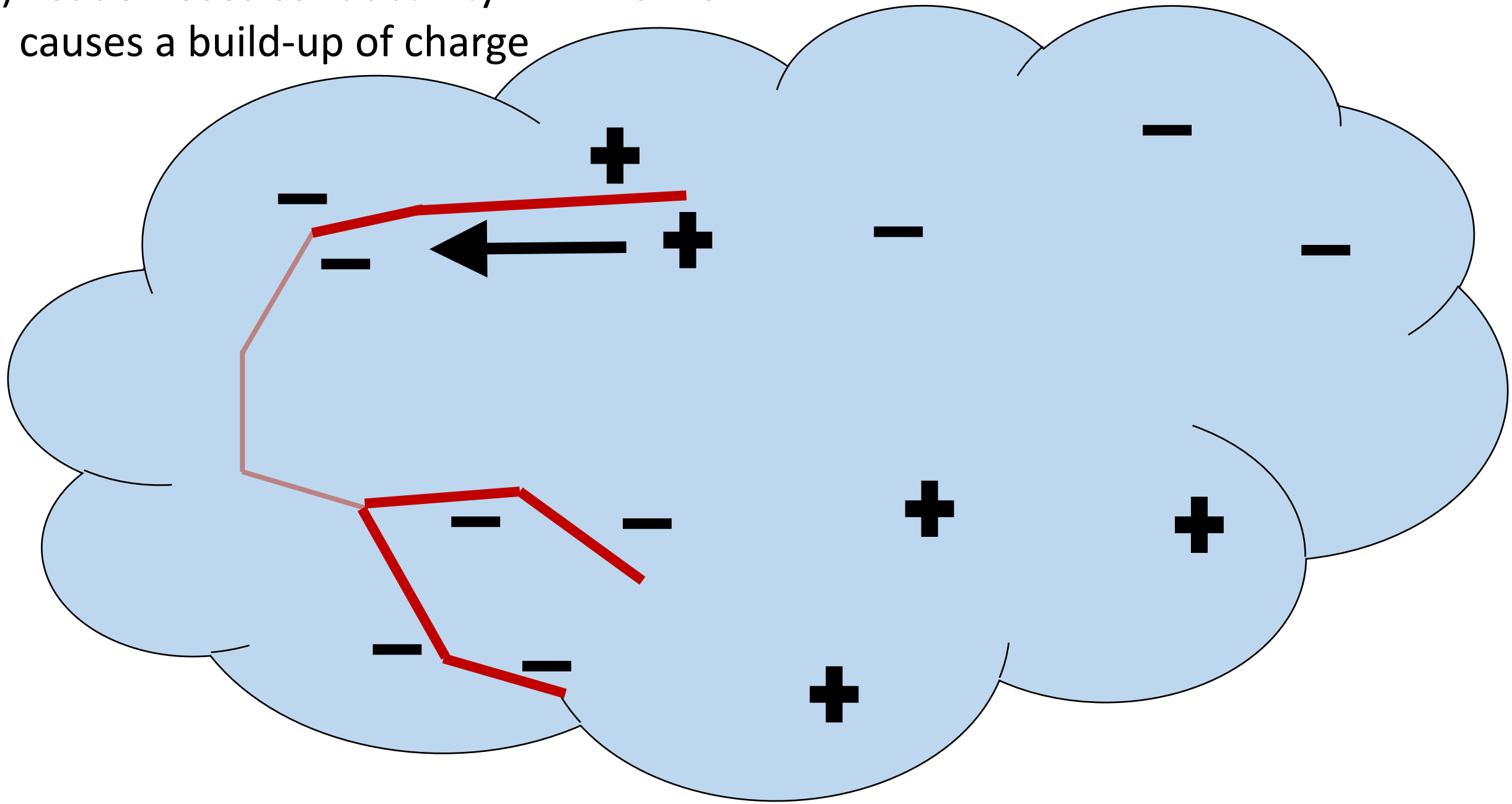


← Positive Leader channel to the West ←

1) Lightning initiates and grows < 10 ms

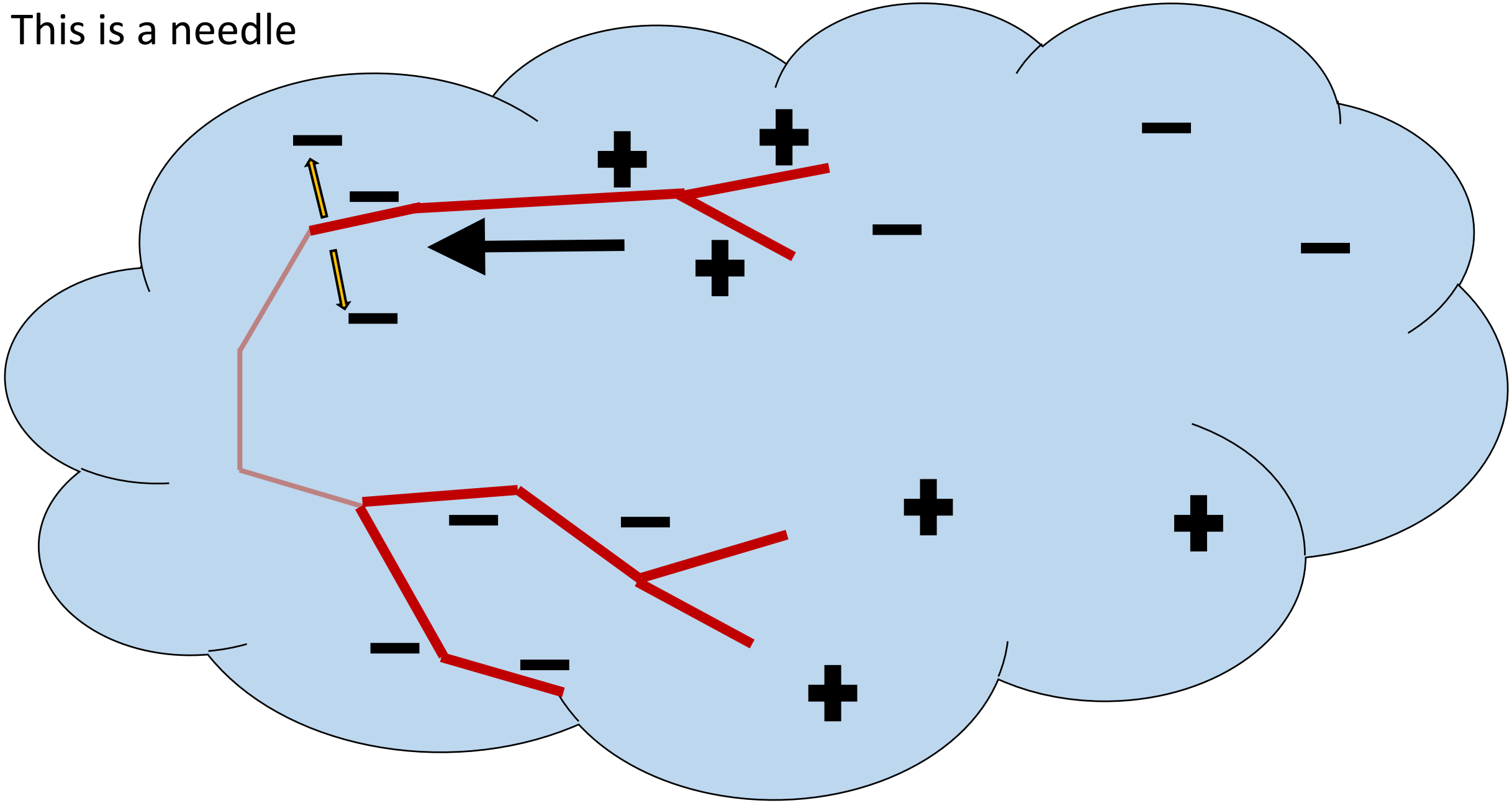


2) Leader loses conductivity causes a build-up of charge ≈20 ms

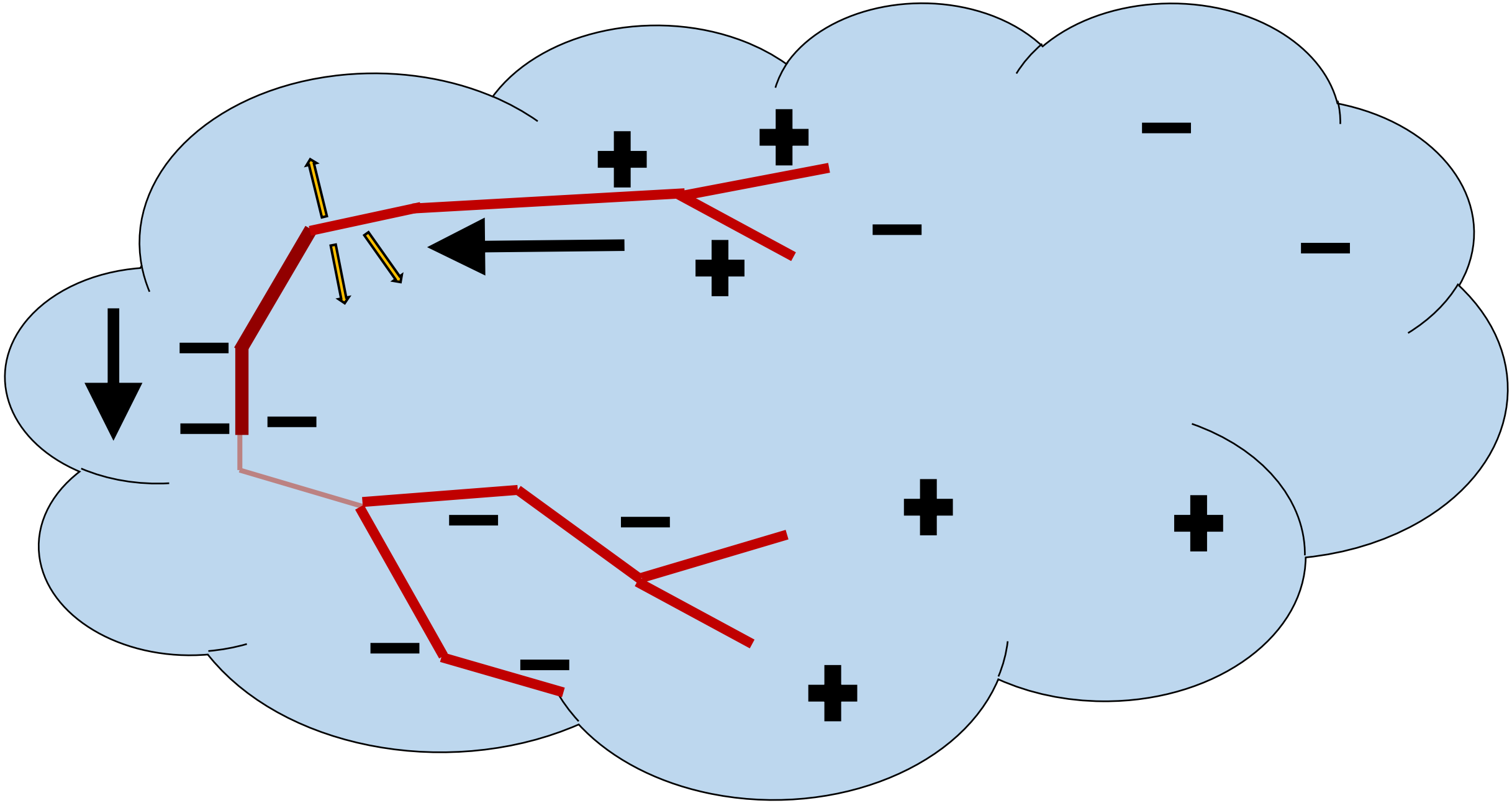


3) Soon, there is dielectric breakdown > 20 ms

This is a needle



3) Eventually, the charge is sent back down the channel ≈100 ms



Needles

- Brand new structure
  - Too small to be observed with other techniques

- Lots of questions!!
  - What is the precise mechanism of needle propagation?
  - How conducting are they?
  - Can needles be seen in visible light?
  - How do needles interact with the rest of the flash?

- Just published in *Nature*

Next Project :
The Negative Leader

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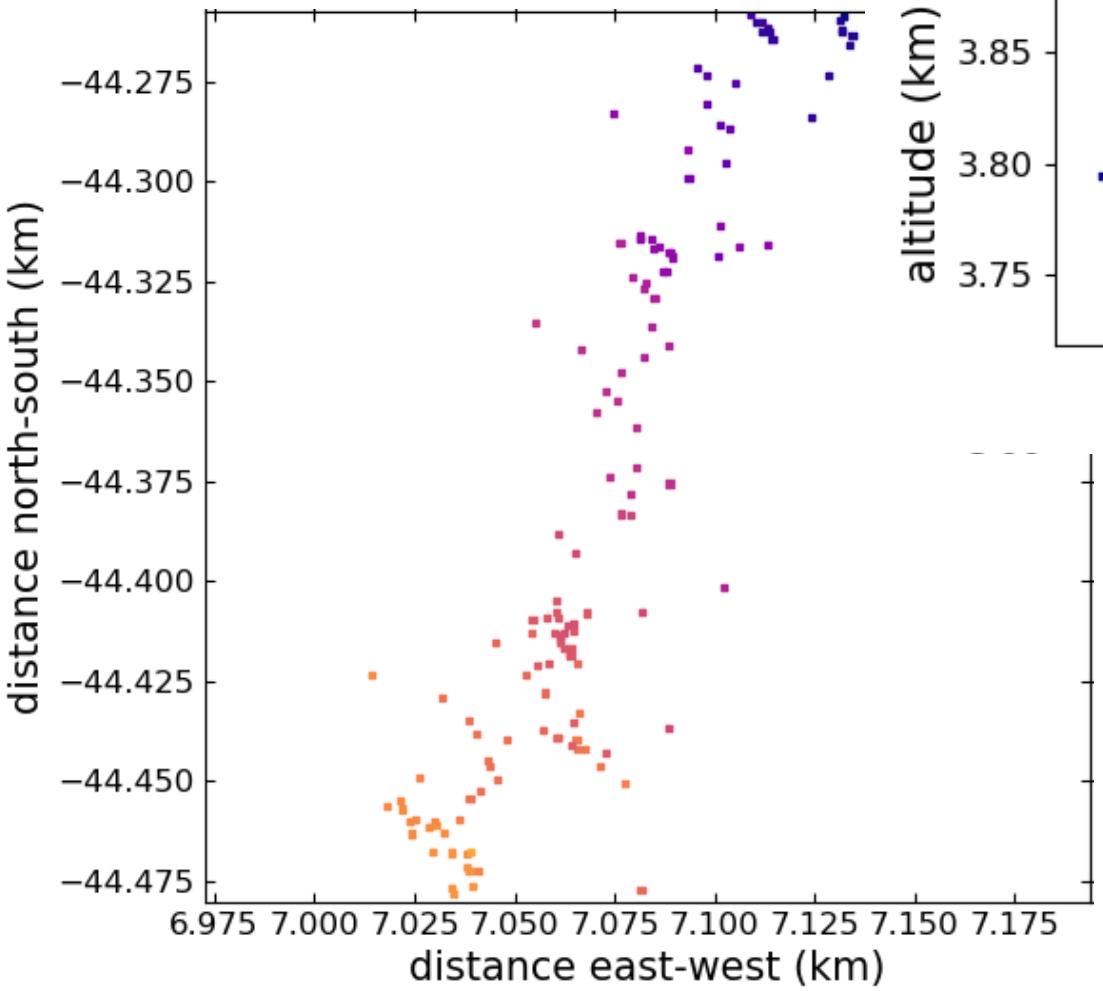
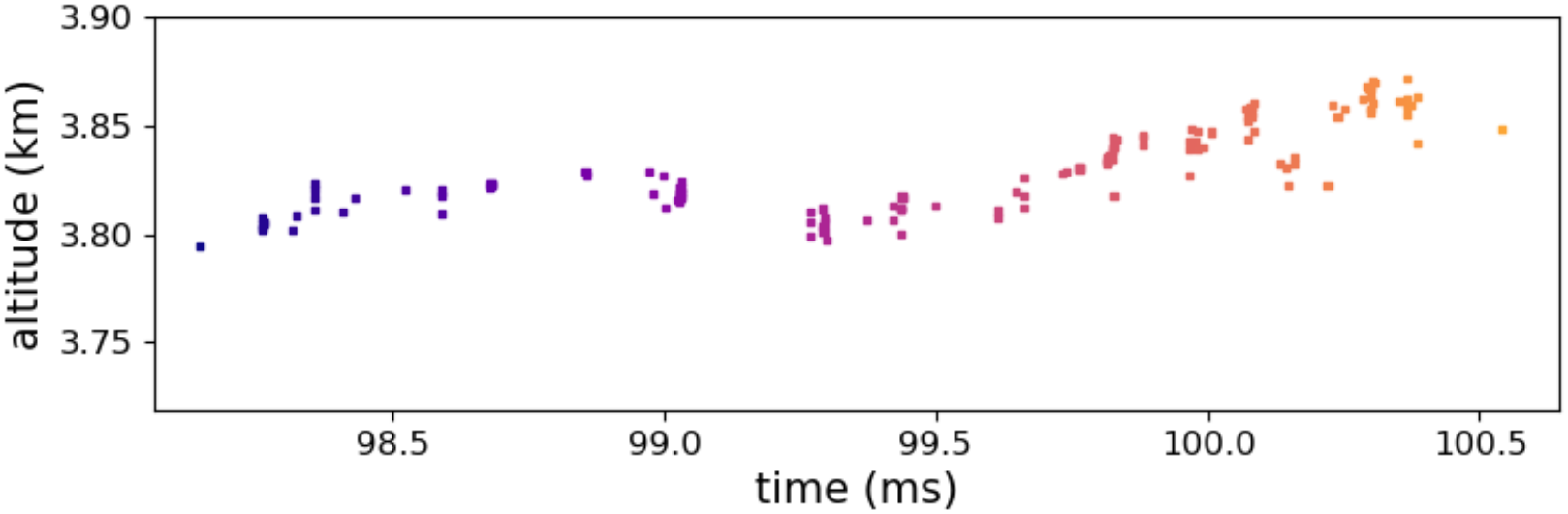
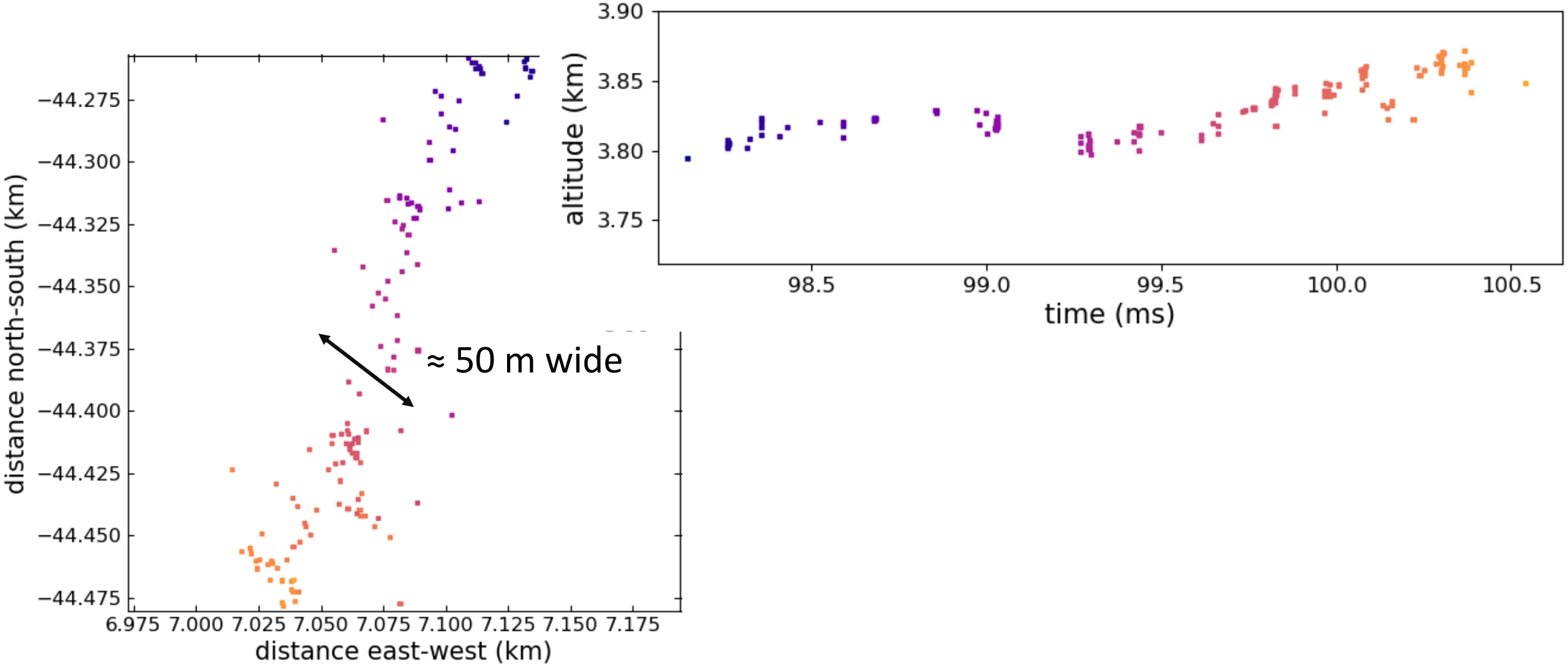
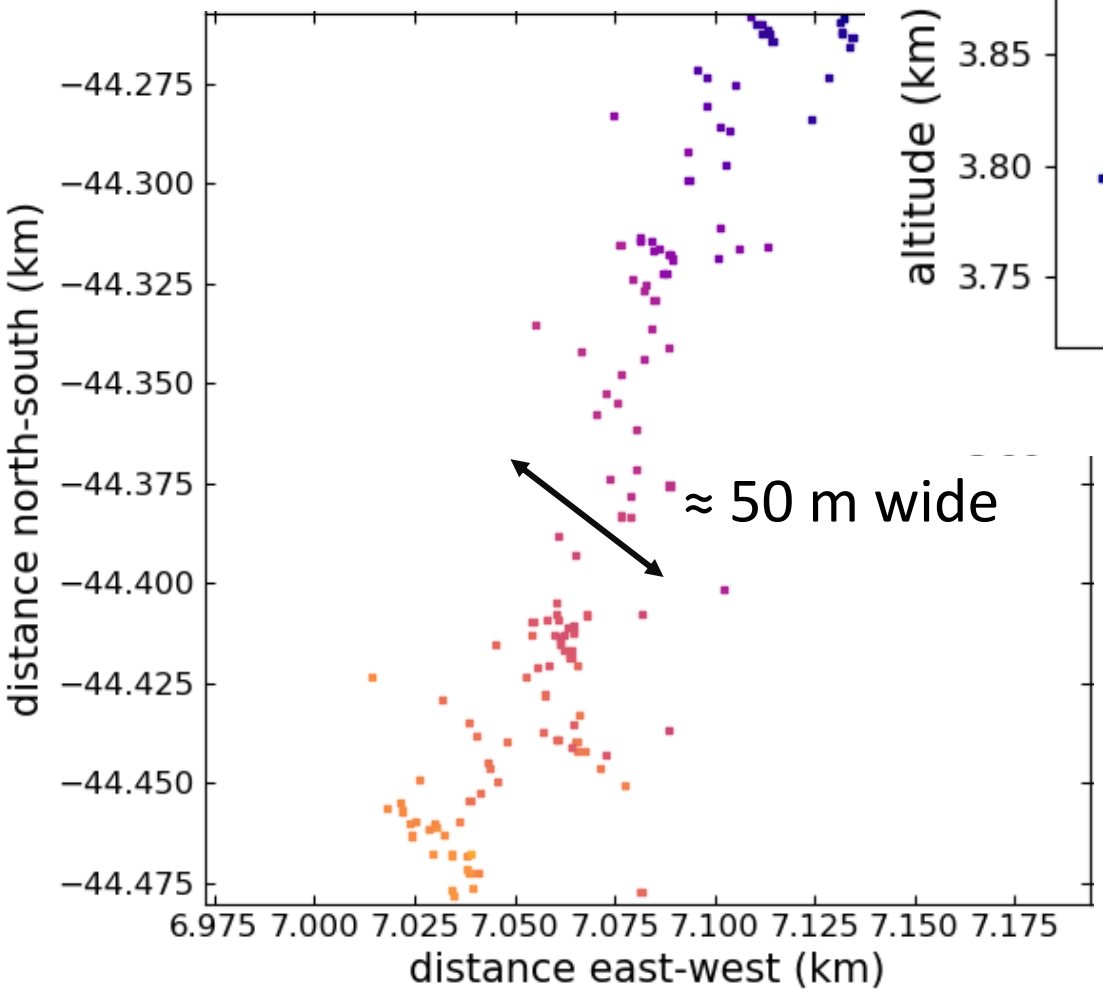


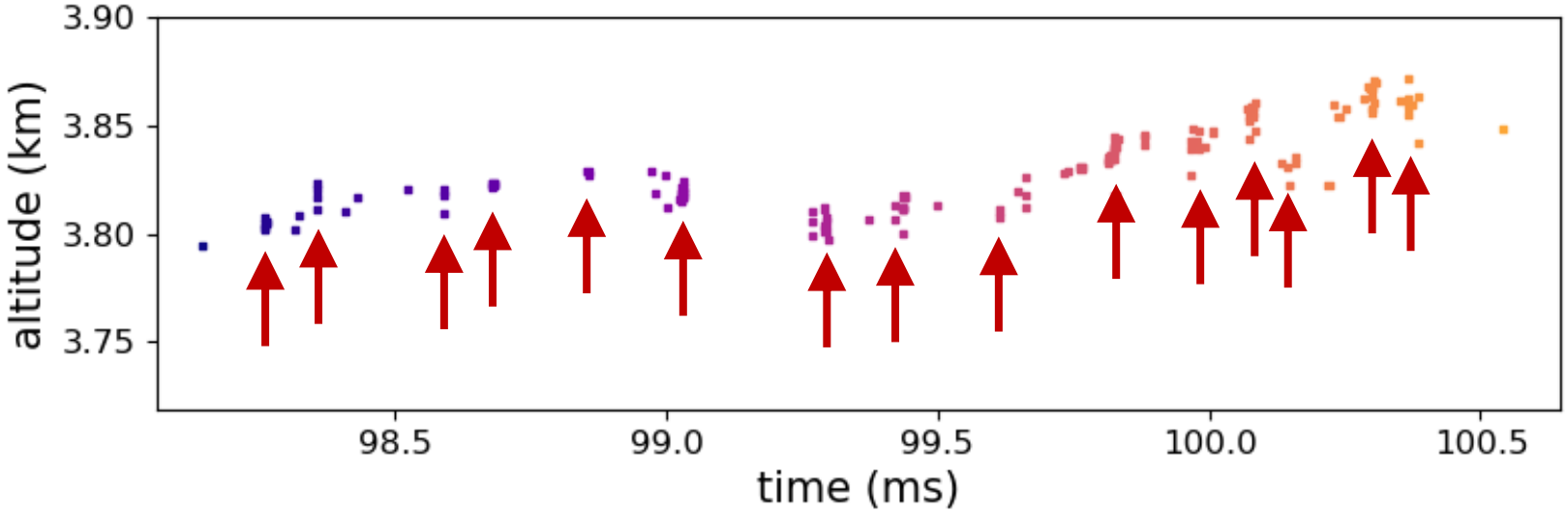


Next Project :
The Negative Leader



Next Project :
The Negative Leader

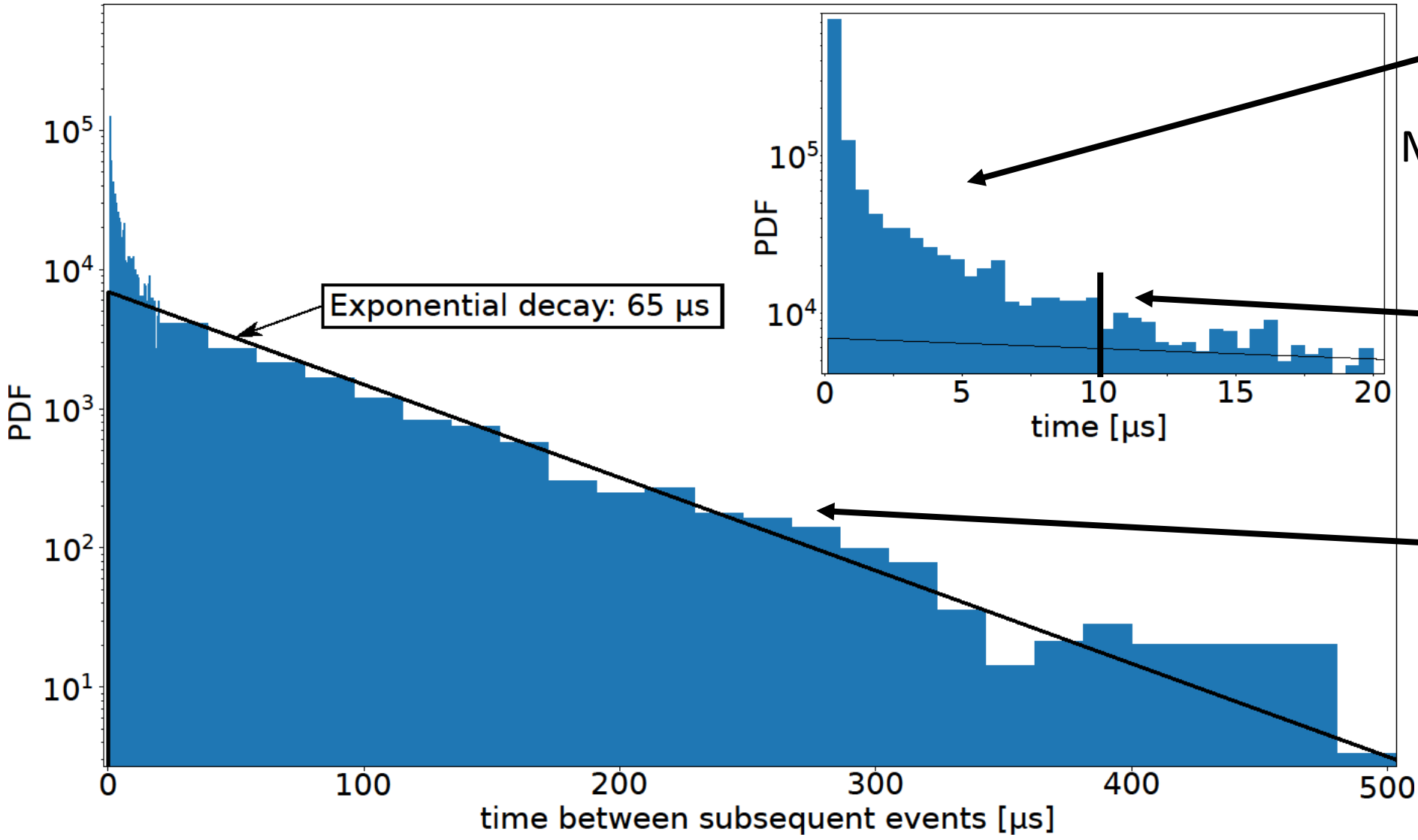




VHF bursts
sources grouped in time

No corresponding grouping in space

Distribution of time between sources



Fast Process

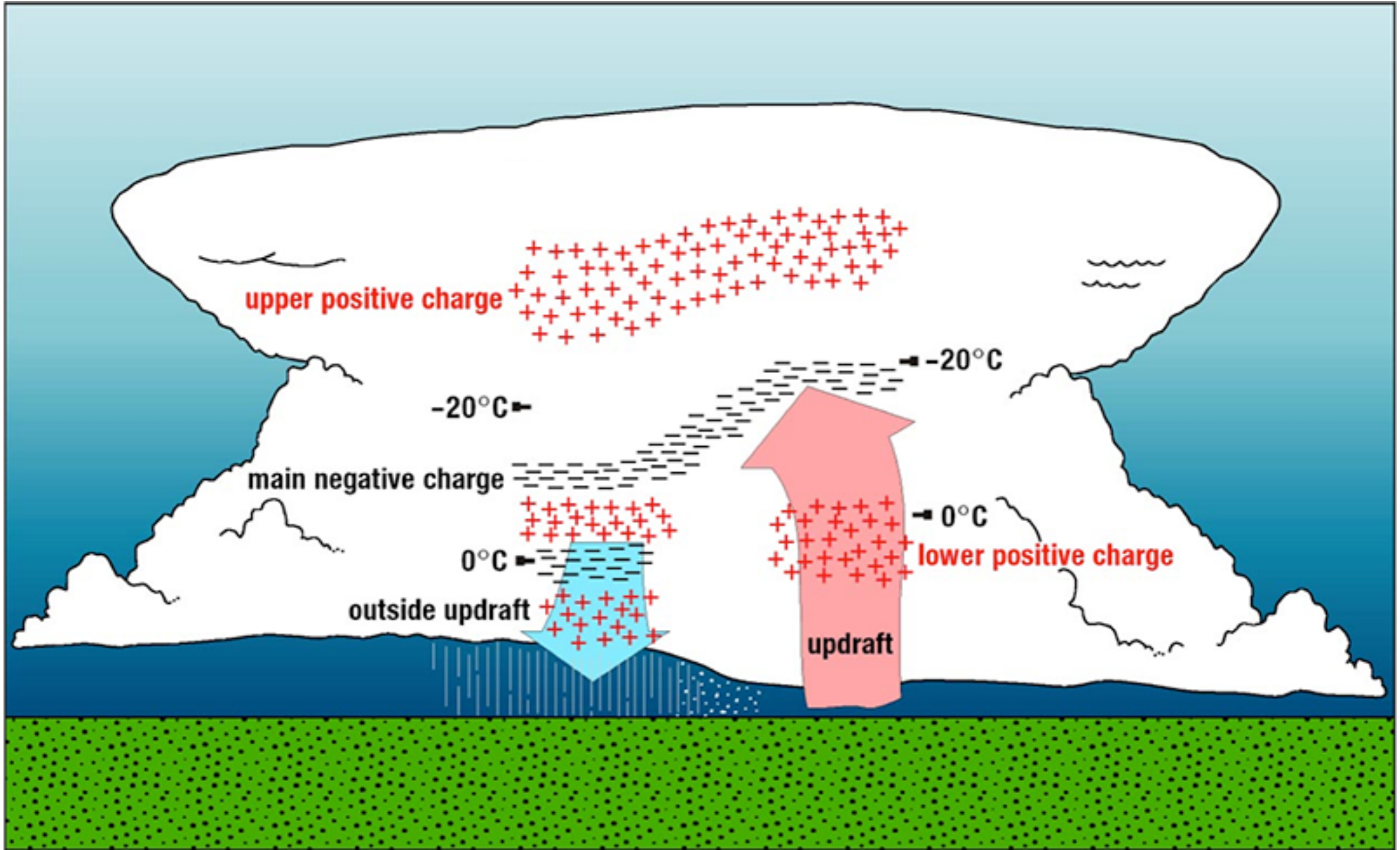
Multiple sources per burst

Cutoff at 10 µs

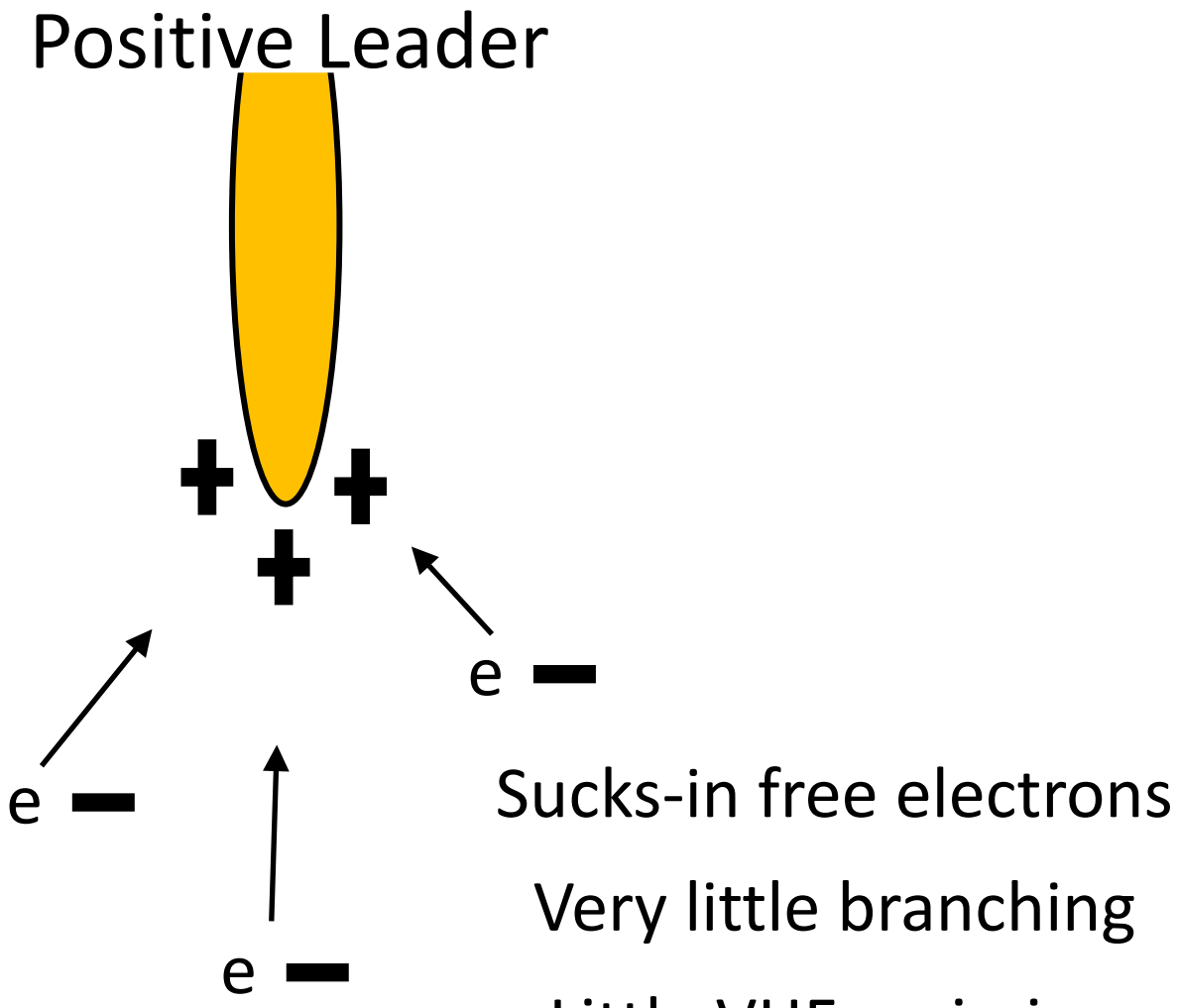
Slow Process

Conclusions

- LOFAR allows for meter scale precision
  - Needed to probe the physics behind lightning propagation
- New needle-like structures discovered on positive leaders
  - Could explain why lightning attaches to ground multiple times
- Current work: Negative Leaders


upper positive charge
-20°C
-20°C
main negative charge
0°C
0°C
lower positive charge
outside updraft
updraft

Next Project :
The Negative Leader



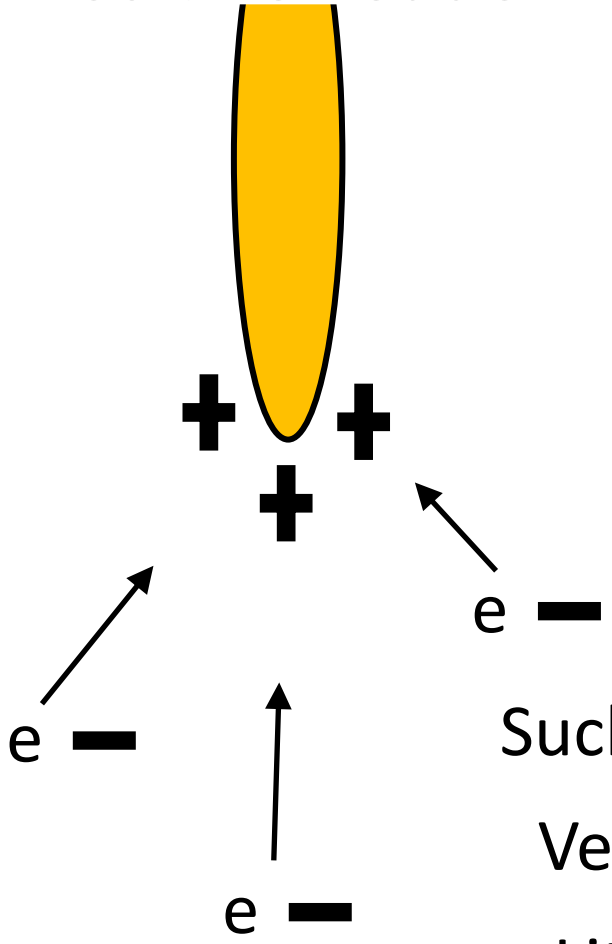
Sucks-in free electrons

Very little branching

Little VHF emission

Next Project :
The Negative Leader

Positive Leader



Sucks-in free electrons

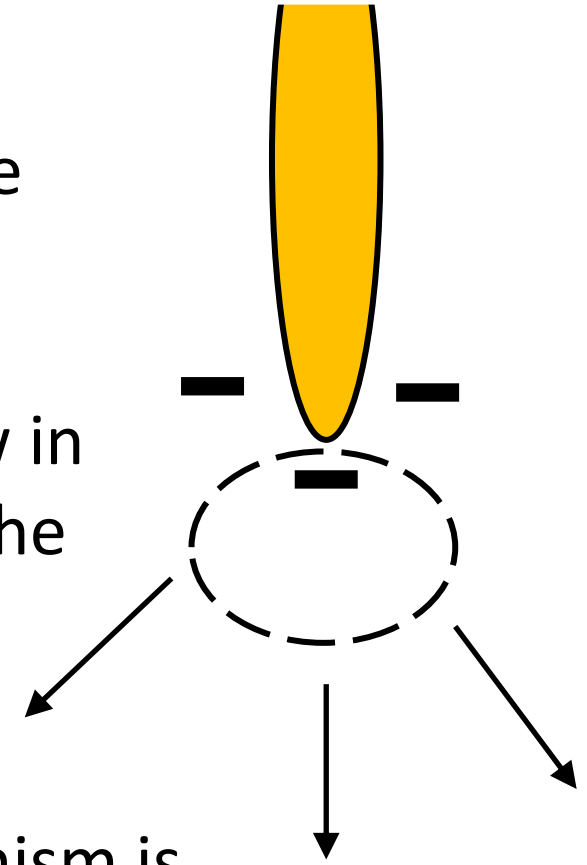
Very little branching

Little VHF emission

Negative Leaders

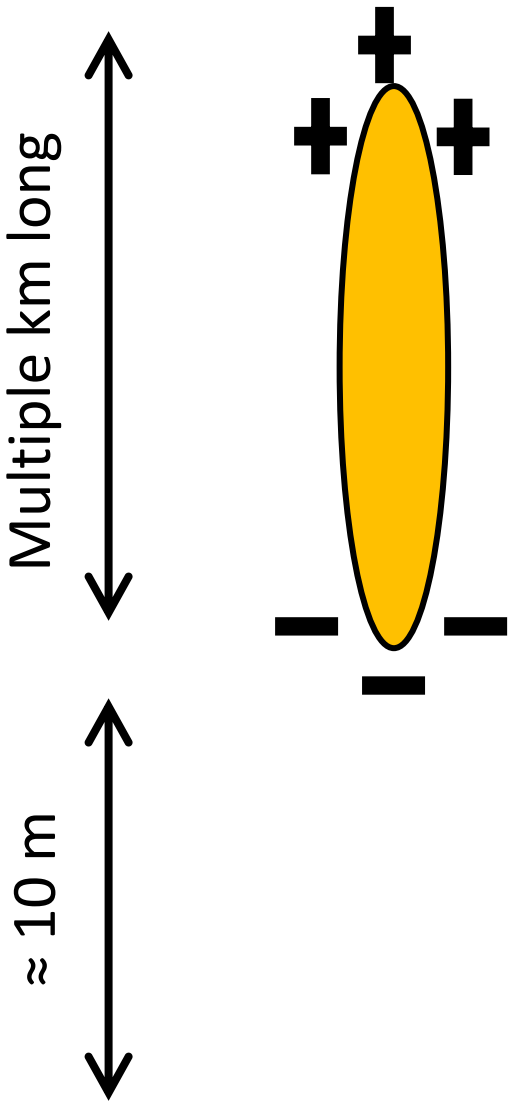
Need to expel free electrons

However, very few in volume close to the leader



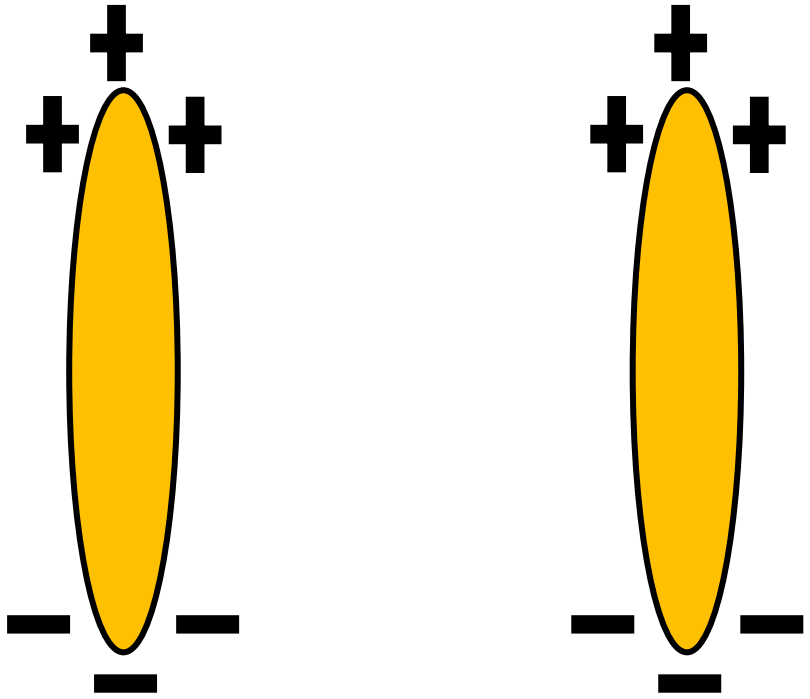
Resulting mechanism is very complex

Negative Leader Propagation



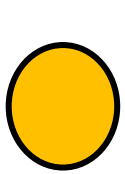
Initial conducting leader

Negative Leader Propagation



Multiple km long

≈ 10 m



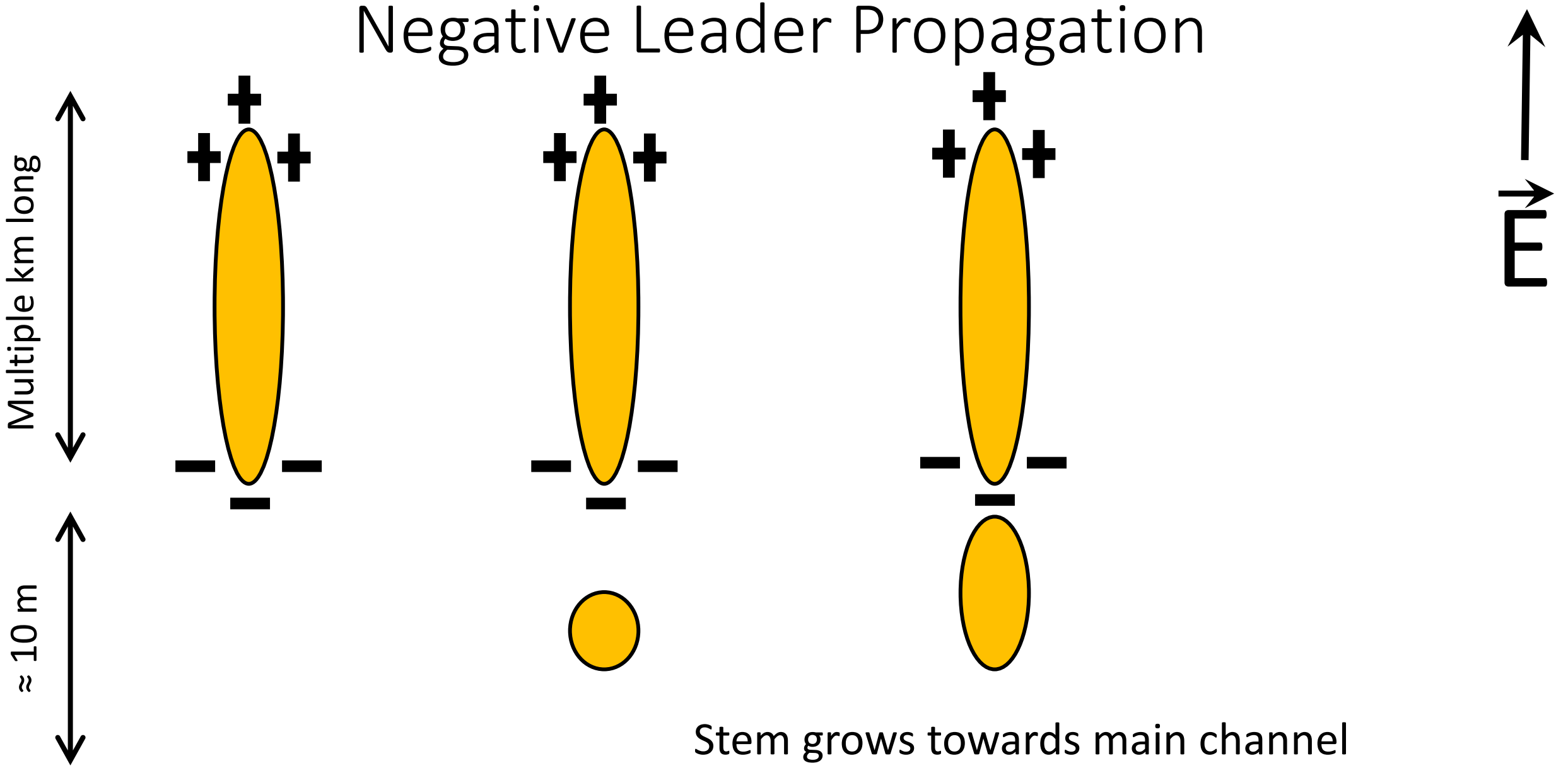
Form “stem” in-front of leader

Seen as a glowing spot in camera footage

Assumed to be conducting

$\vec{E}$

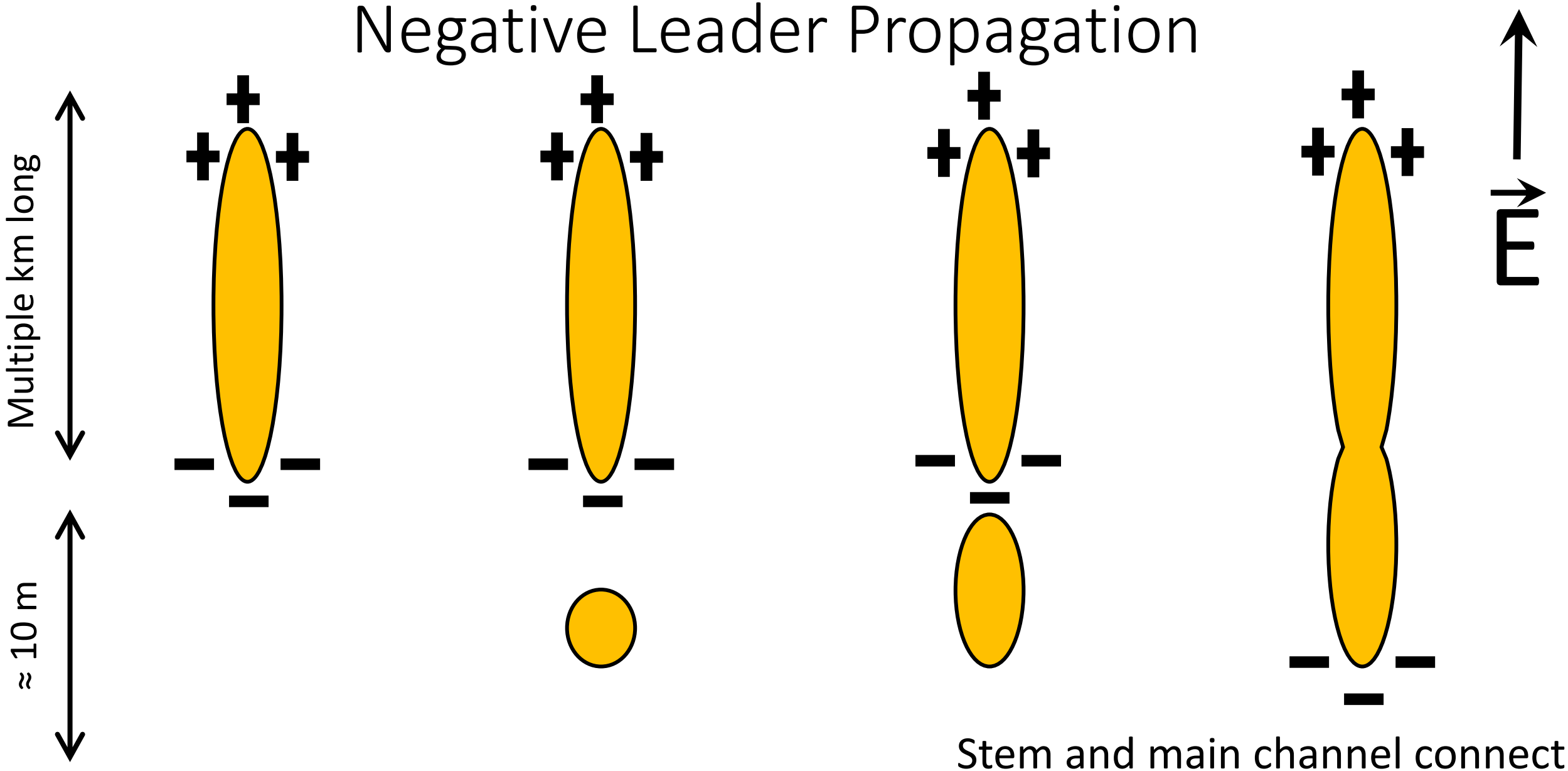
Negative Leader Propagation



Stem grows towards main channel

Assumed to grow in conductivity

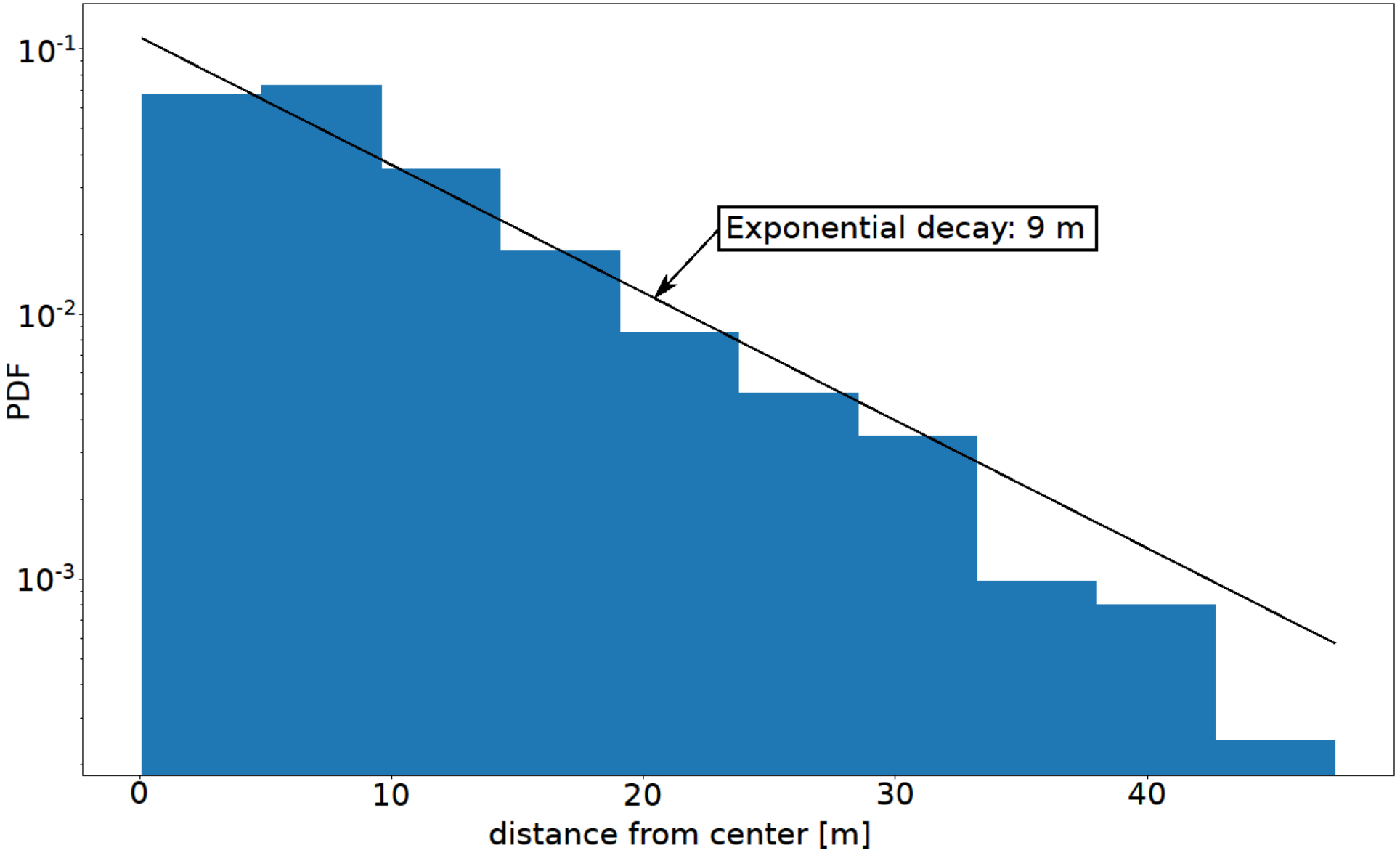
Negative Leader Propagation



Stem and main channel connect

Produces a current pulse

Spatial Distribution inside VHF burst



Radius of radio frequency-emitting corona

Leader speed:
1.0×10^5 m/s

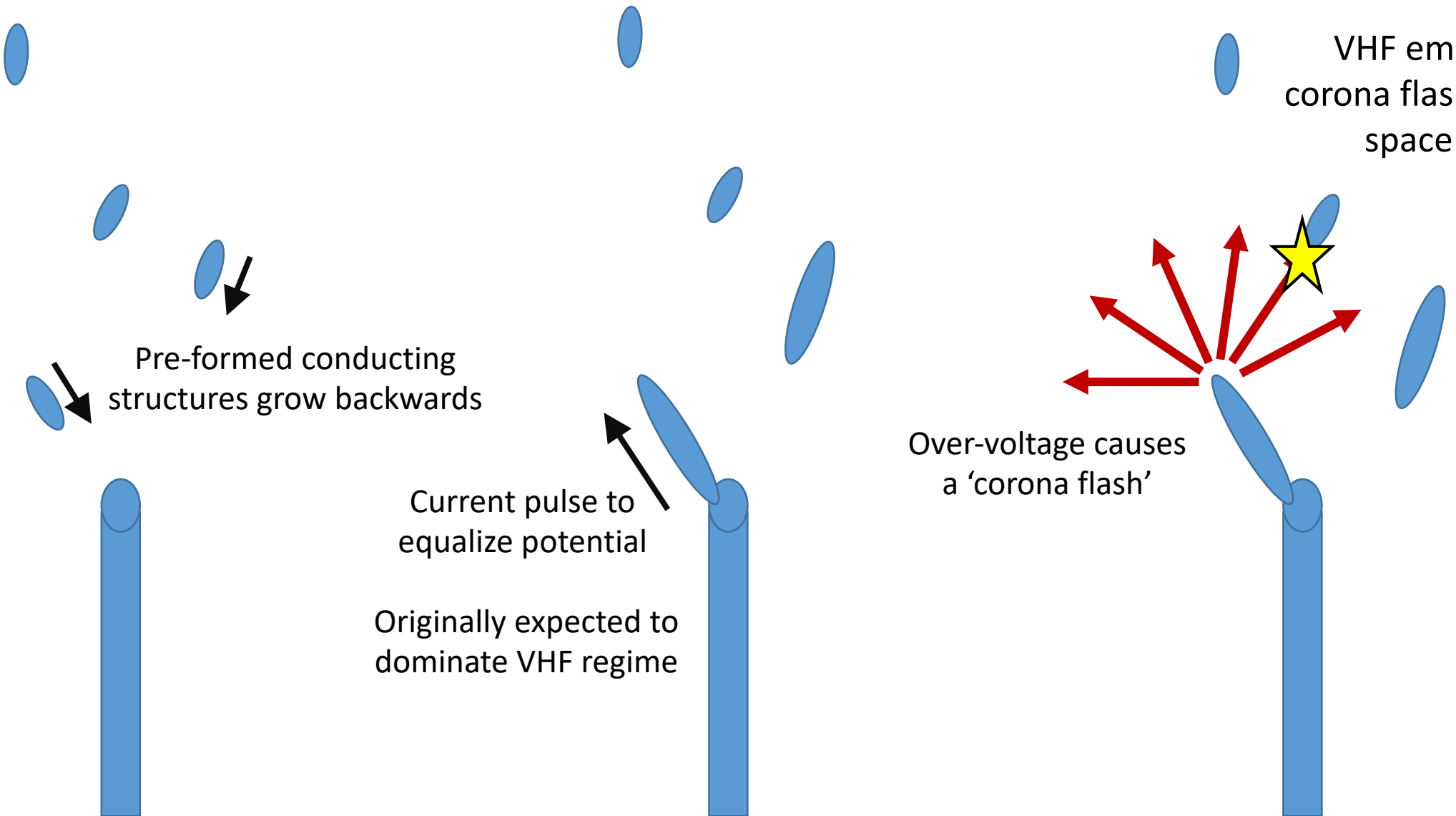
Ave. step time:
<< 50 µs

Ave. step length:
<< 5 m

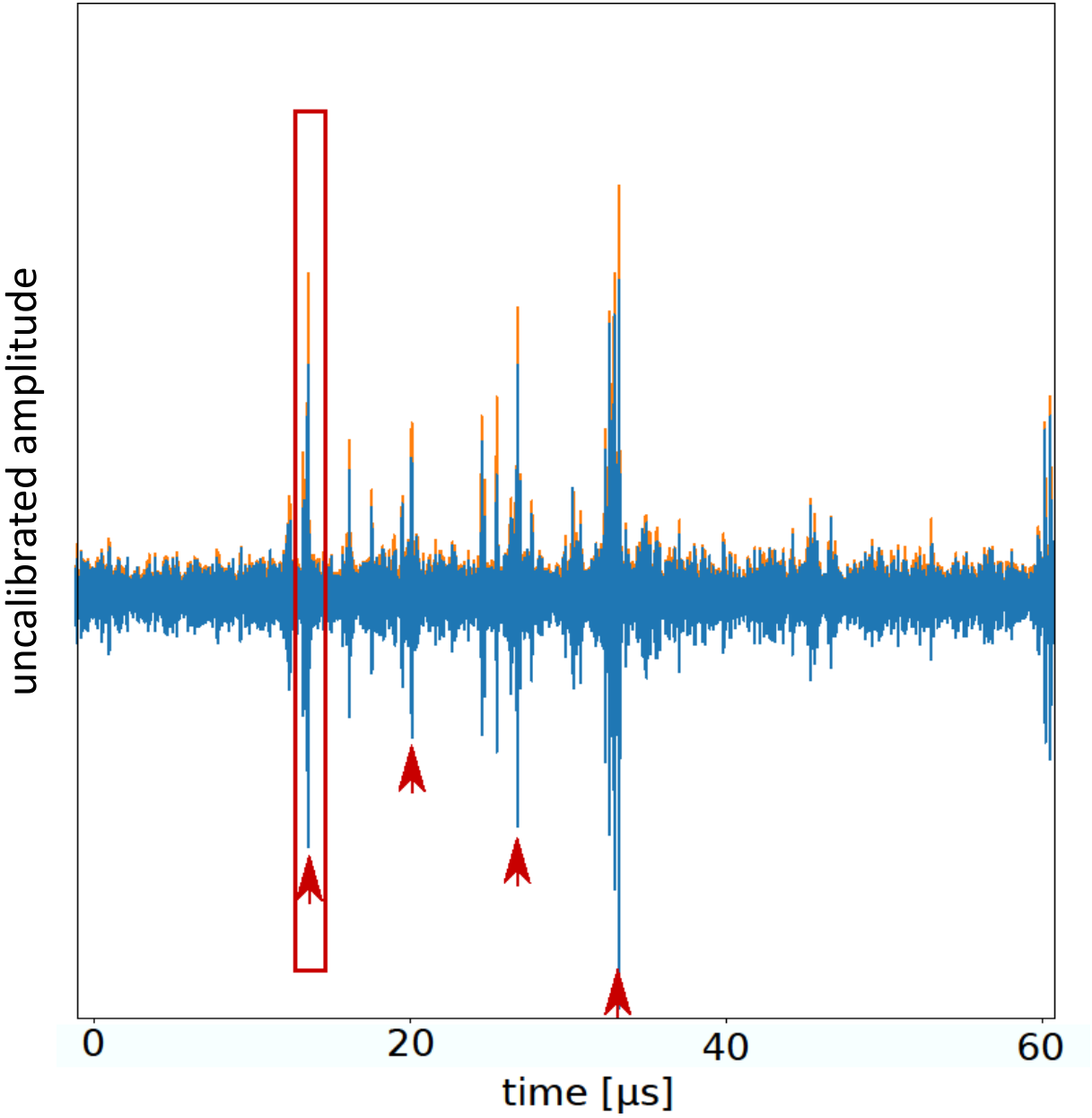
start with structures ahead of main channel

space leader attachment

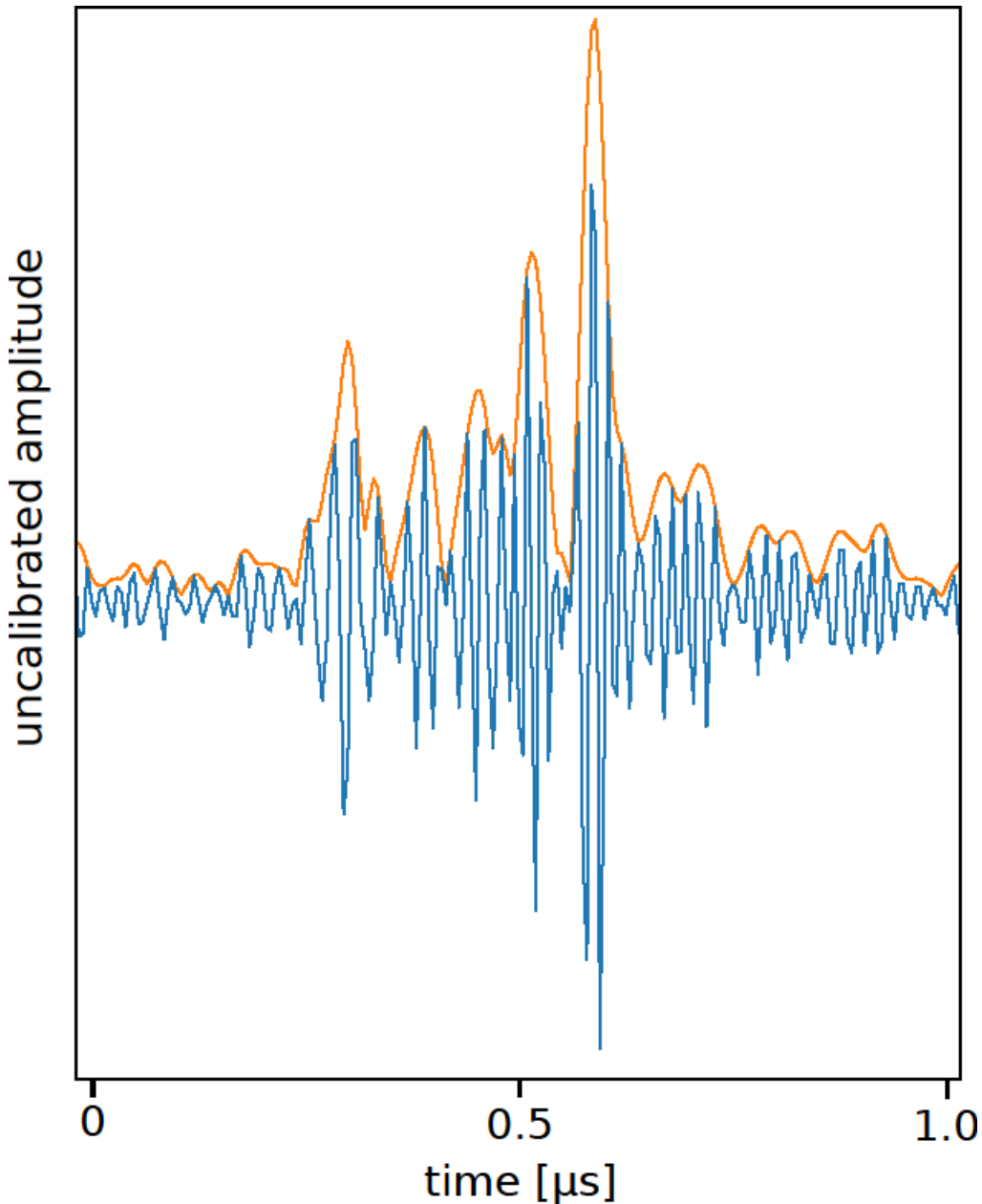
corona flash



Four steps:

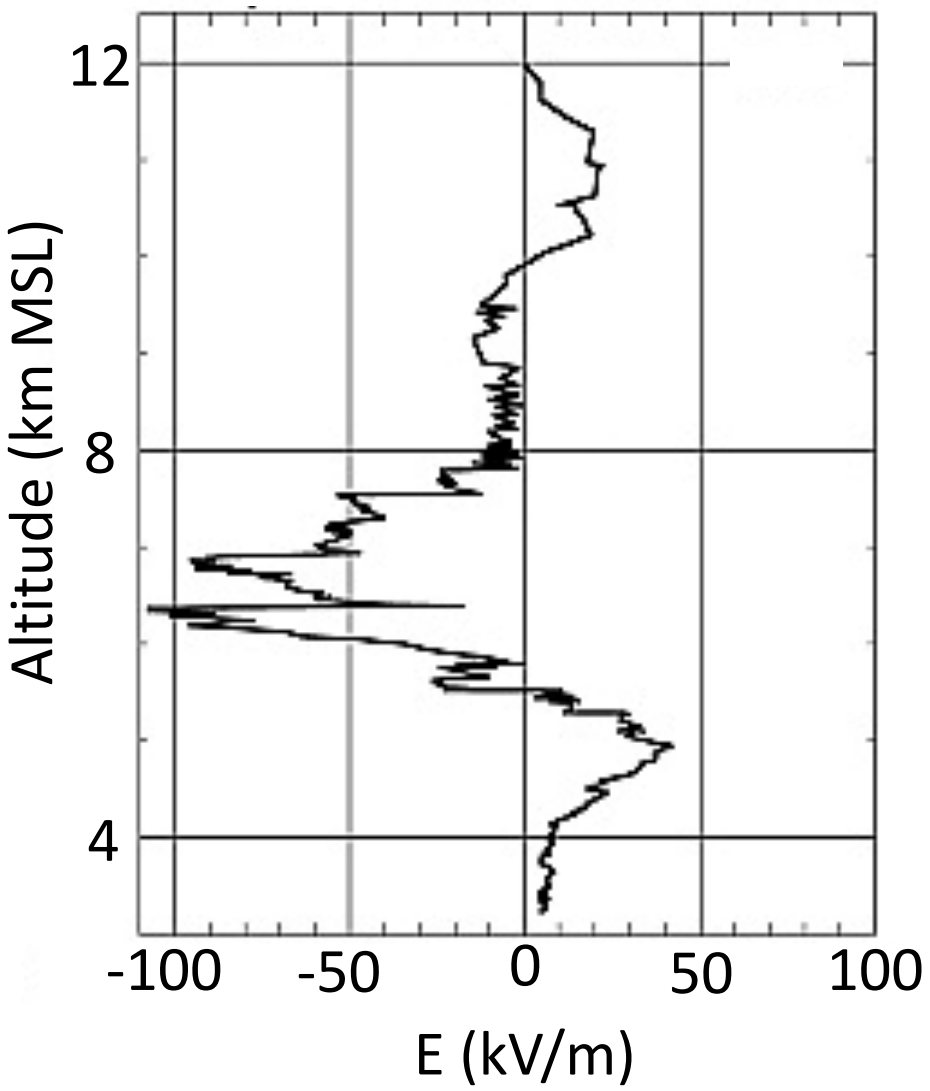


One step zoom:



Future Work: Initiation

balloon-borne electric field measurement



Dielectric strength of air is 3000 kV/m

Order-of-magnitude higher then measured thunderstorm electric fields

Two current major hypothesis:

-Cosmic Ray Air Showers

-Electric field amplification by hydrometeors

-There are others

Initiation difficult to map

VHF emission at start of flash