A Tour of Lightning With HAMMA

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THE UNIVERSITY OF ALABAMA IN HUNTSVILLE

The HAMMA Team:
Hugh Christian, Mike Stewart, Jeff Burchfield, Scott Podgorny, David Corredor,
Veronica Franklin, John Hall, and Evgeny Kuznetsov

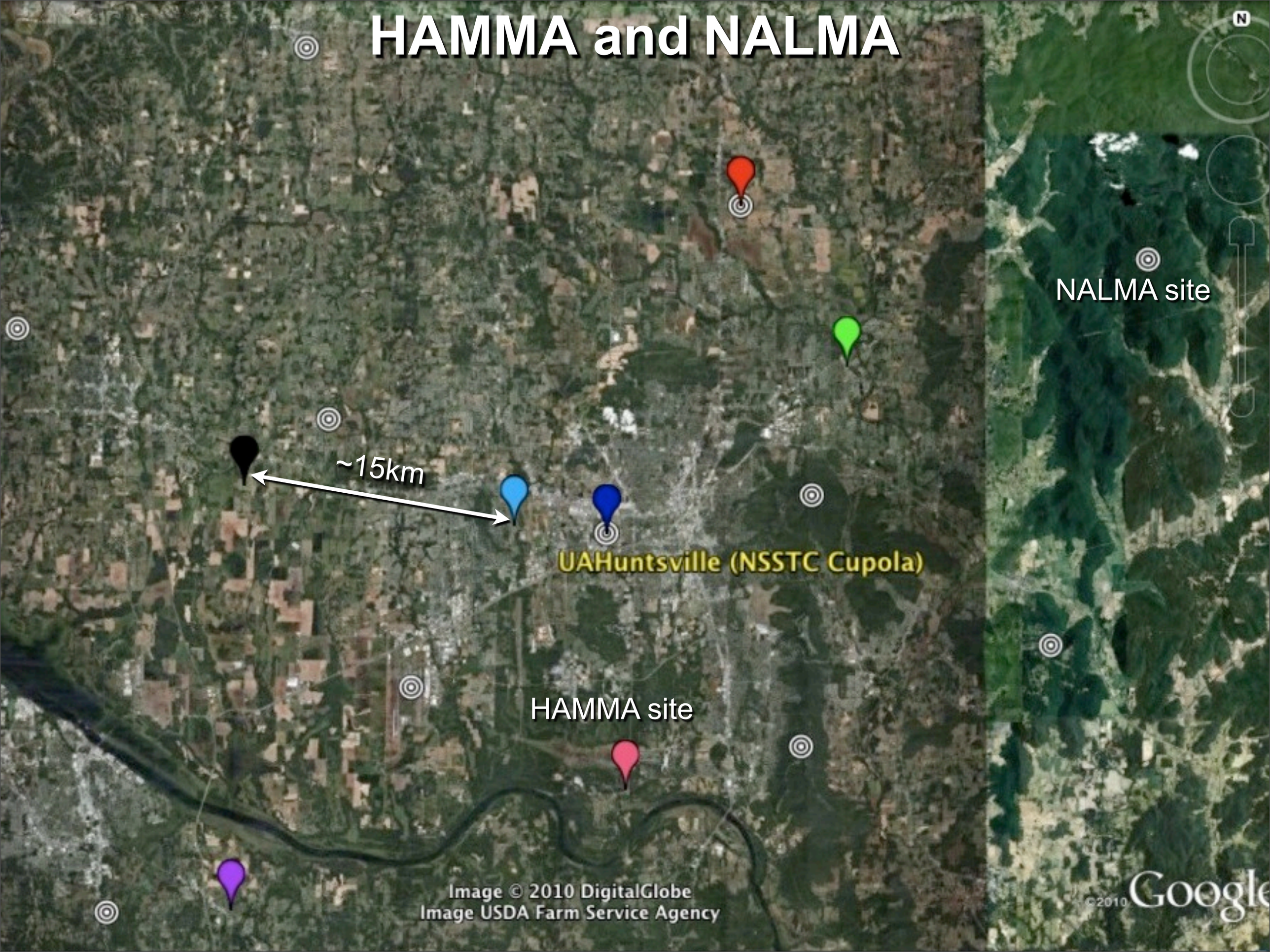
Special thanks to:
Monte Bateman and Dennis Buechler

Dan Cecil, Henry Everitt and Martin Heimbeck, Chris and Elise Schultz,
Brandon and Anne Marie Strickland, and Winfred Thomas Agricultural Research Station

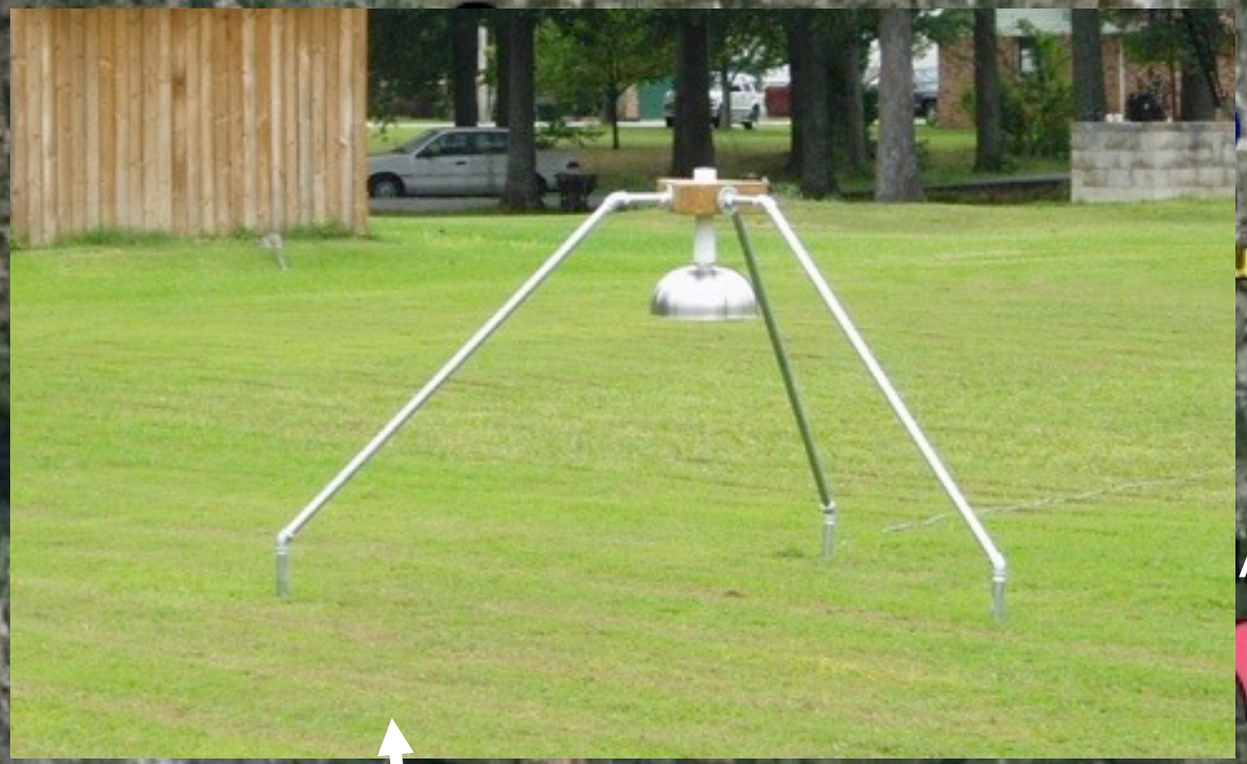
Fundamental question for *scientific* validation:

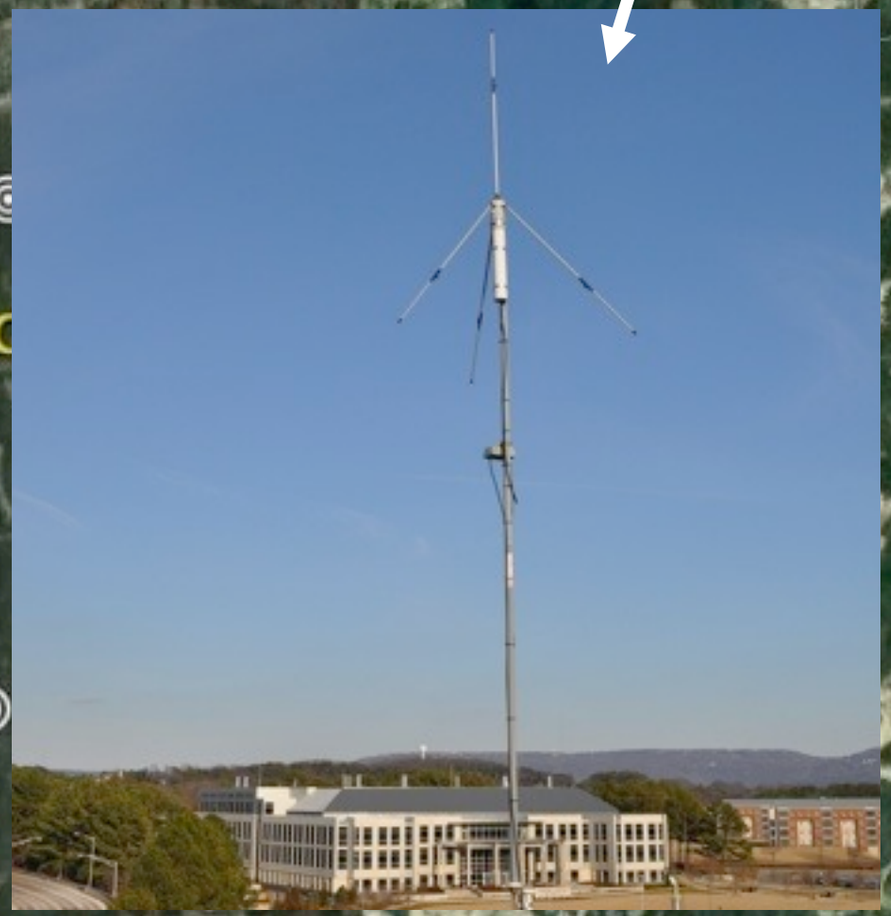
What is the best way from the ground to characterize what LIS "sees?"

HAMMA and NALMA



HAMMA and NALMA





NALMA site

A site

Image © 2010 DigitalGlobe
Image USDA Farm Service Agency

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HAMMA

Huntsville Alabama Marx Meter Array

NALMA

North Alabama Lightning Mapping Array

HAMMA

Huntsville Alabama Marx Meter Array

Wideband ~1Hz-500kHz
Sample Rate: 1MHz

NALMA

North Alabama Lightning Mapping Array

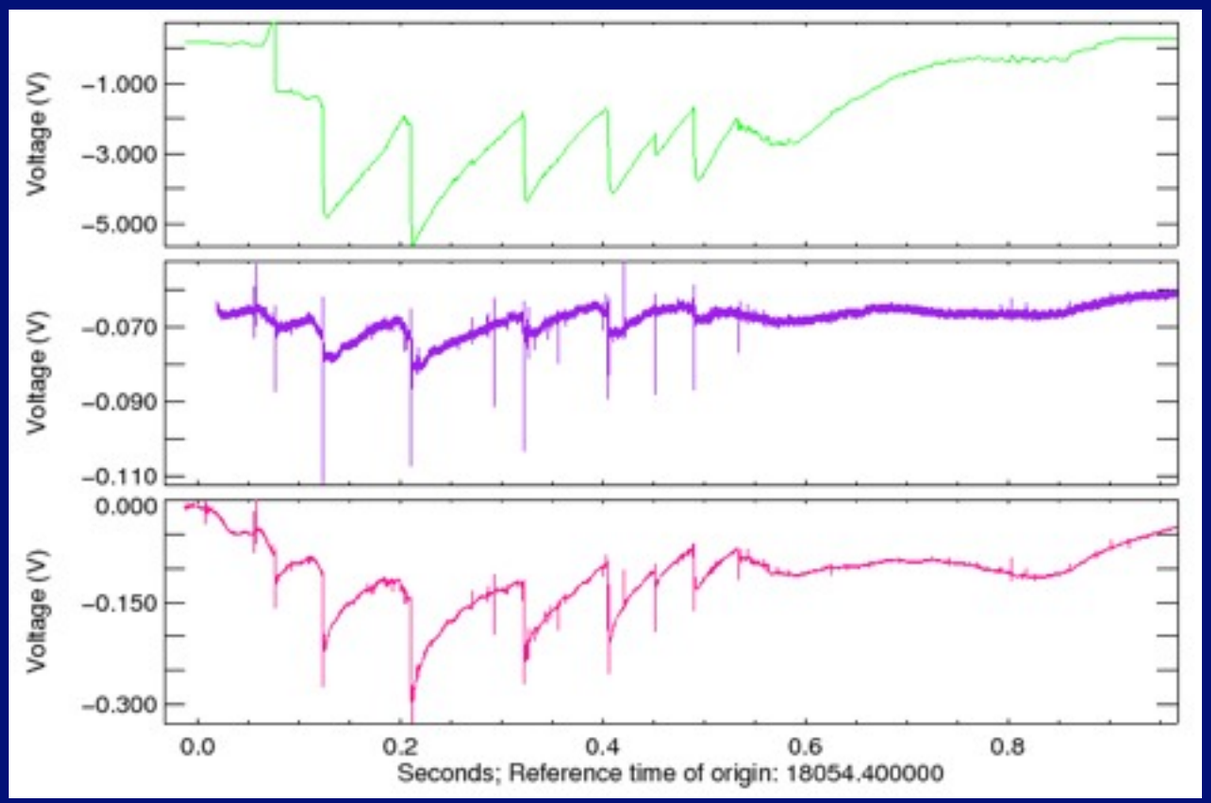
Narrowband VHF ~80 MHz
Sample Rate: 20MHz

HAMMA

Huntsville Alabama Marx Meter Array

Wideband ~1Hz-500kHz
Sample Rate: 1MHz

Can identify polarity/type of discharge

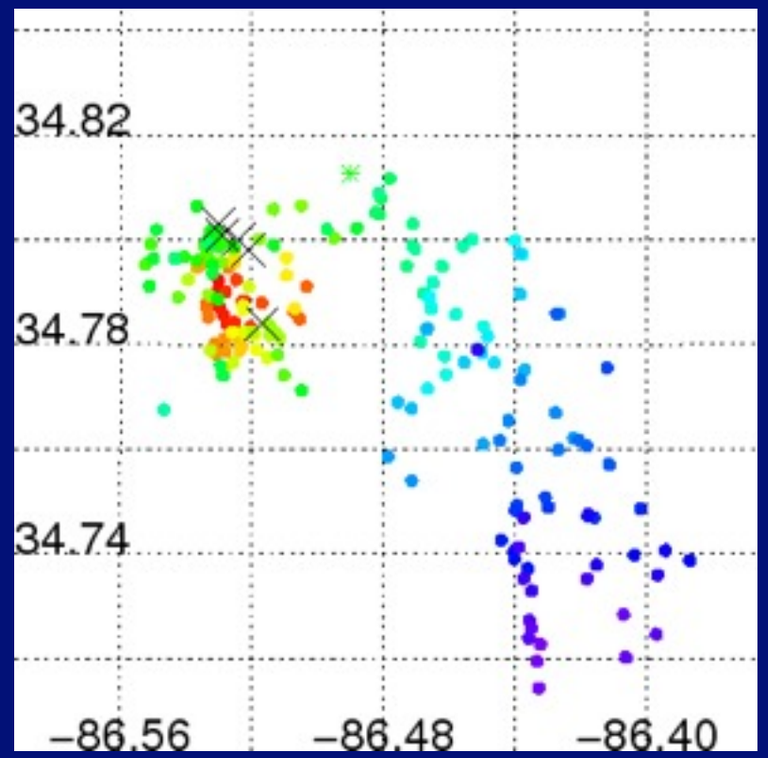


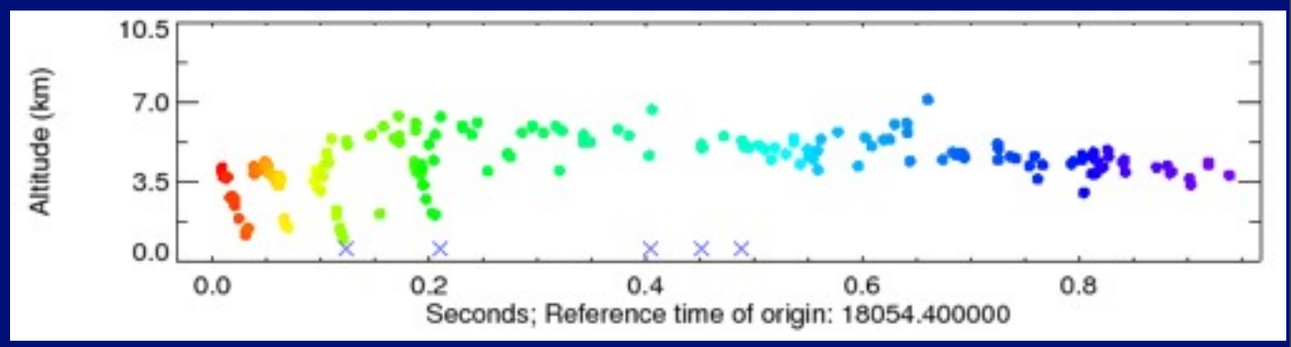
NALMA

North Alabama Lightning Mapping Array

Narrowband VHF ~80 MHz
Sample Rate: 20MHz

Provides accurate “maps” of lightning





HAMMA

Huntsville Alabama Marx Meter Array

Wideband ~1Hz-500kHz
Sample Rate: 1MHz

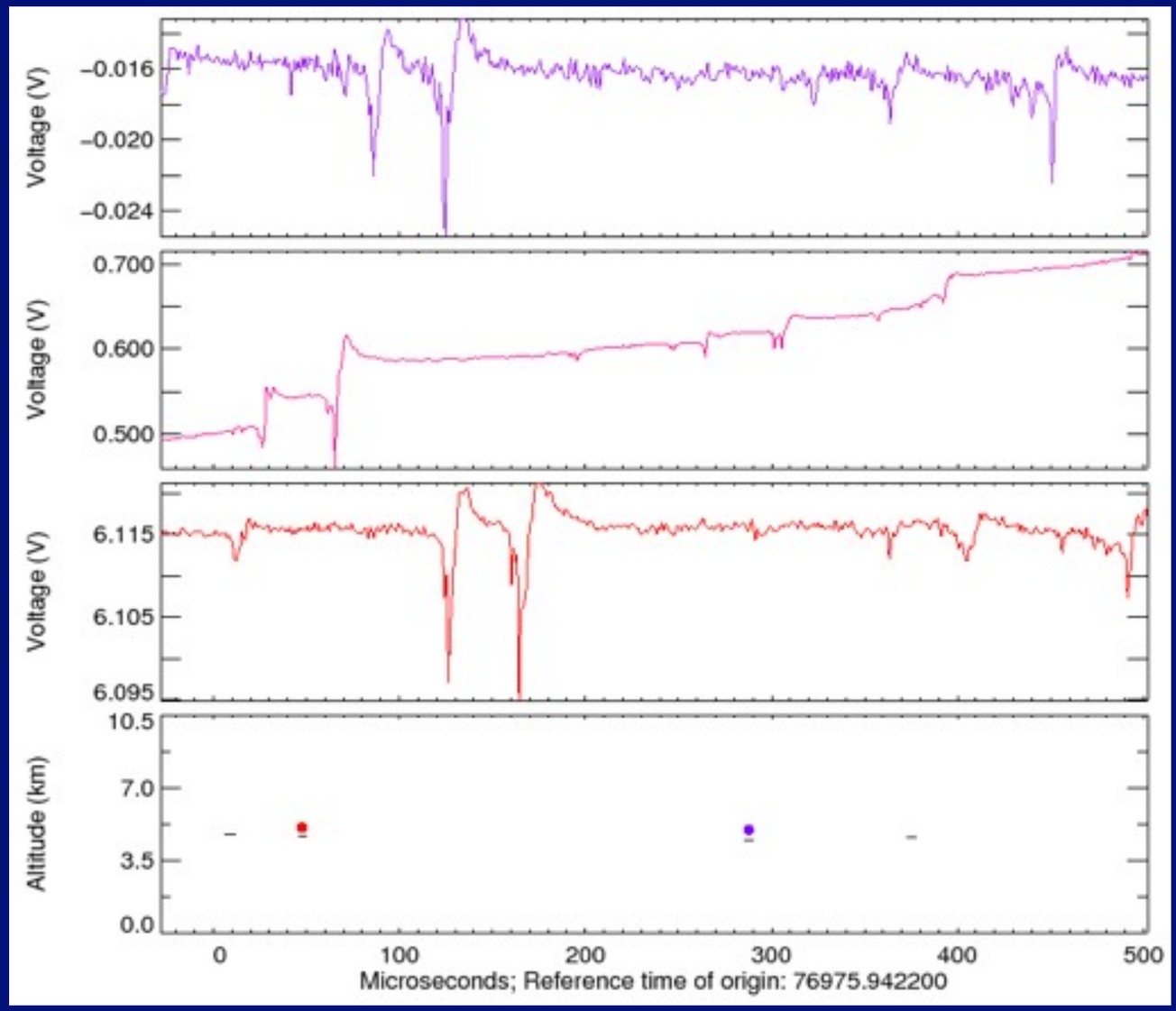
Can identify polarity/type of discharge

NALMA

North Alabama Lightning Mapping Array

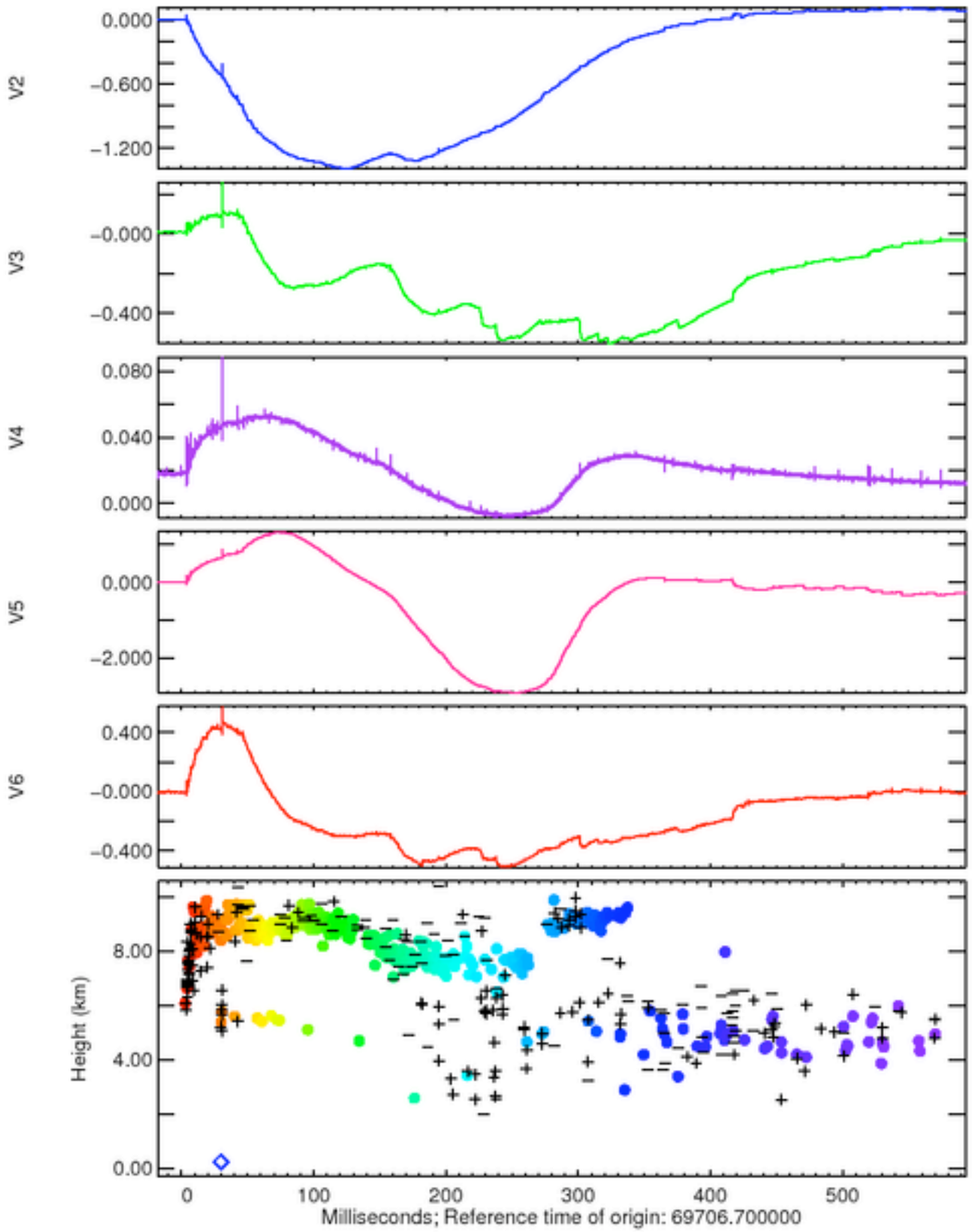
Narrowband VHF ~80 MHz
Sample Rate: 20MHz

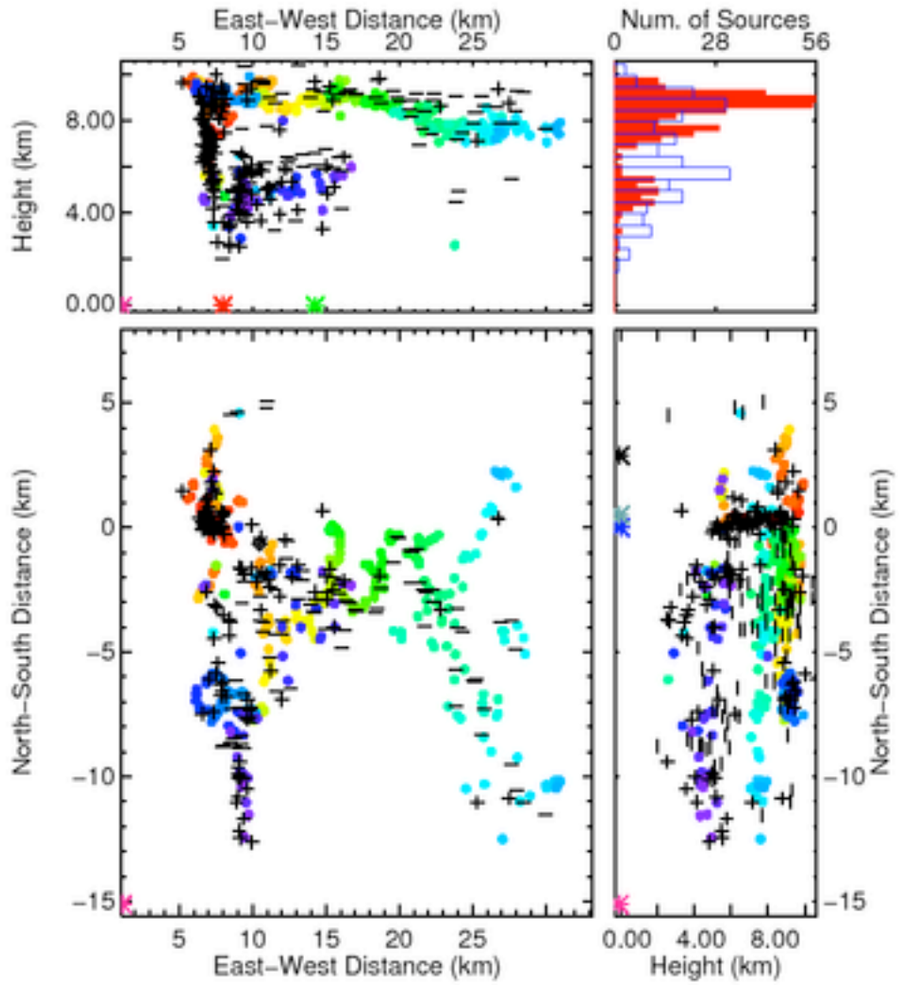
Provides accurate “maps” of lightning



Both arrays can locate sources via time-of-arrival; HAMMA can also provide energetic information

2010/06/25 19:21:46





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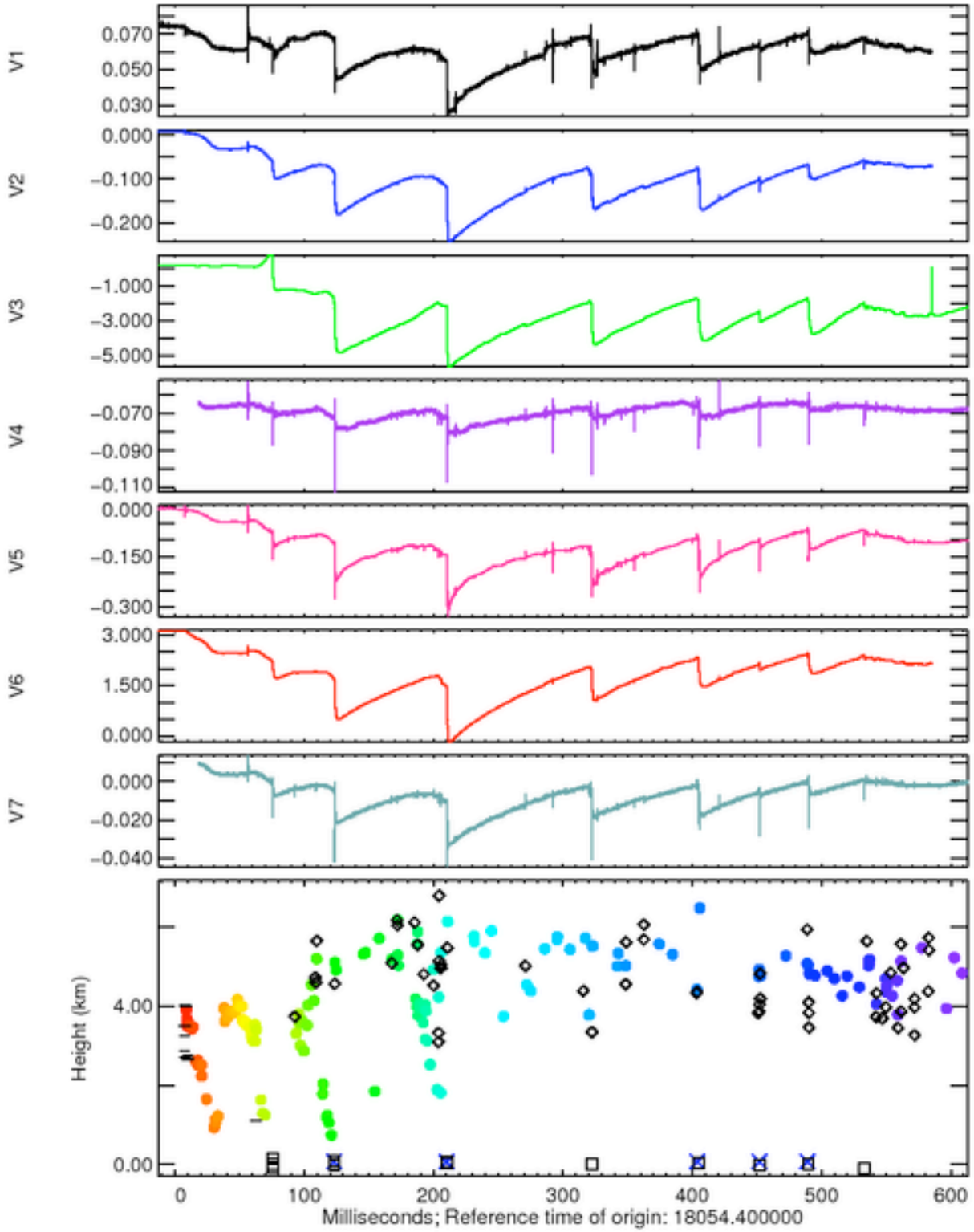
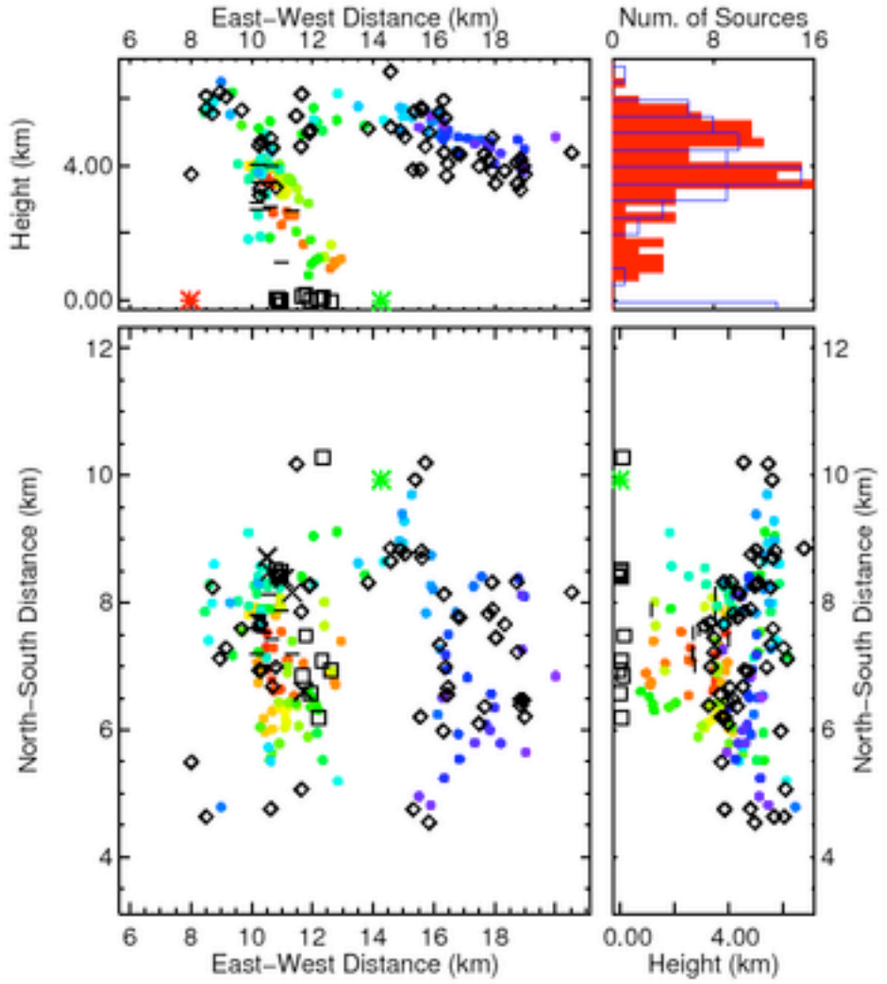
Stop time:	69707.292752
Time Elapsed:	0.610392

2010/10/25 05:00:54

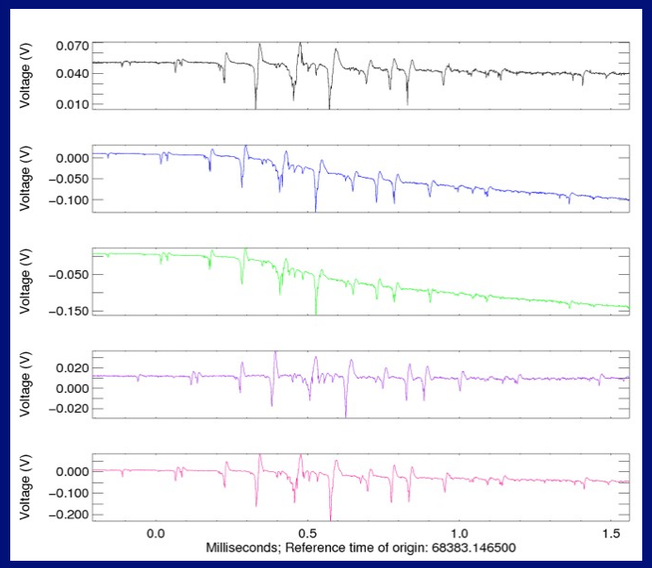


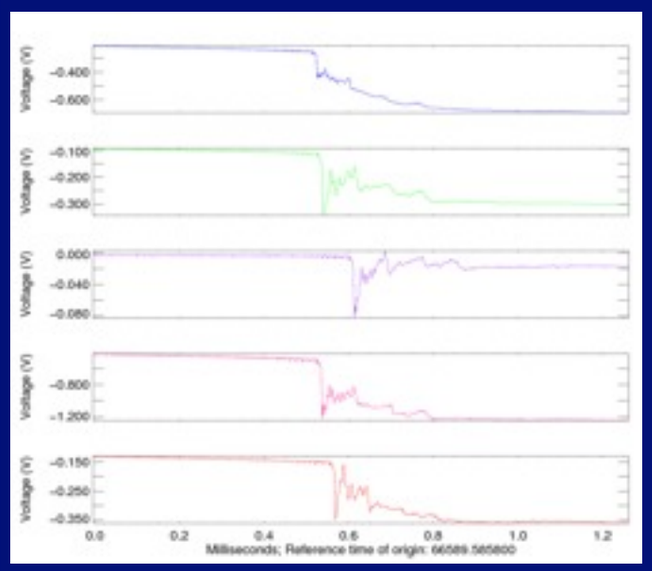


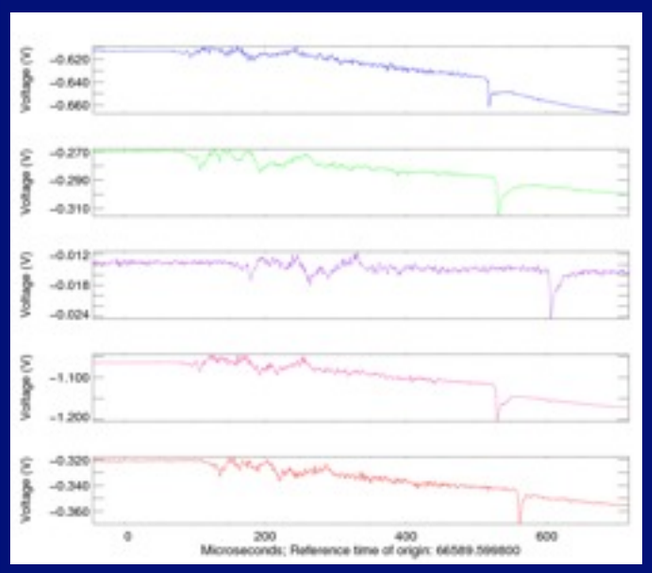
Base time: 18054.387327

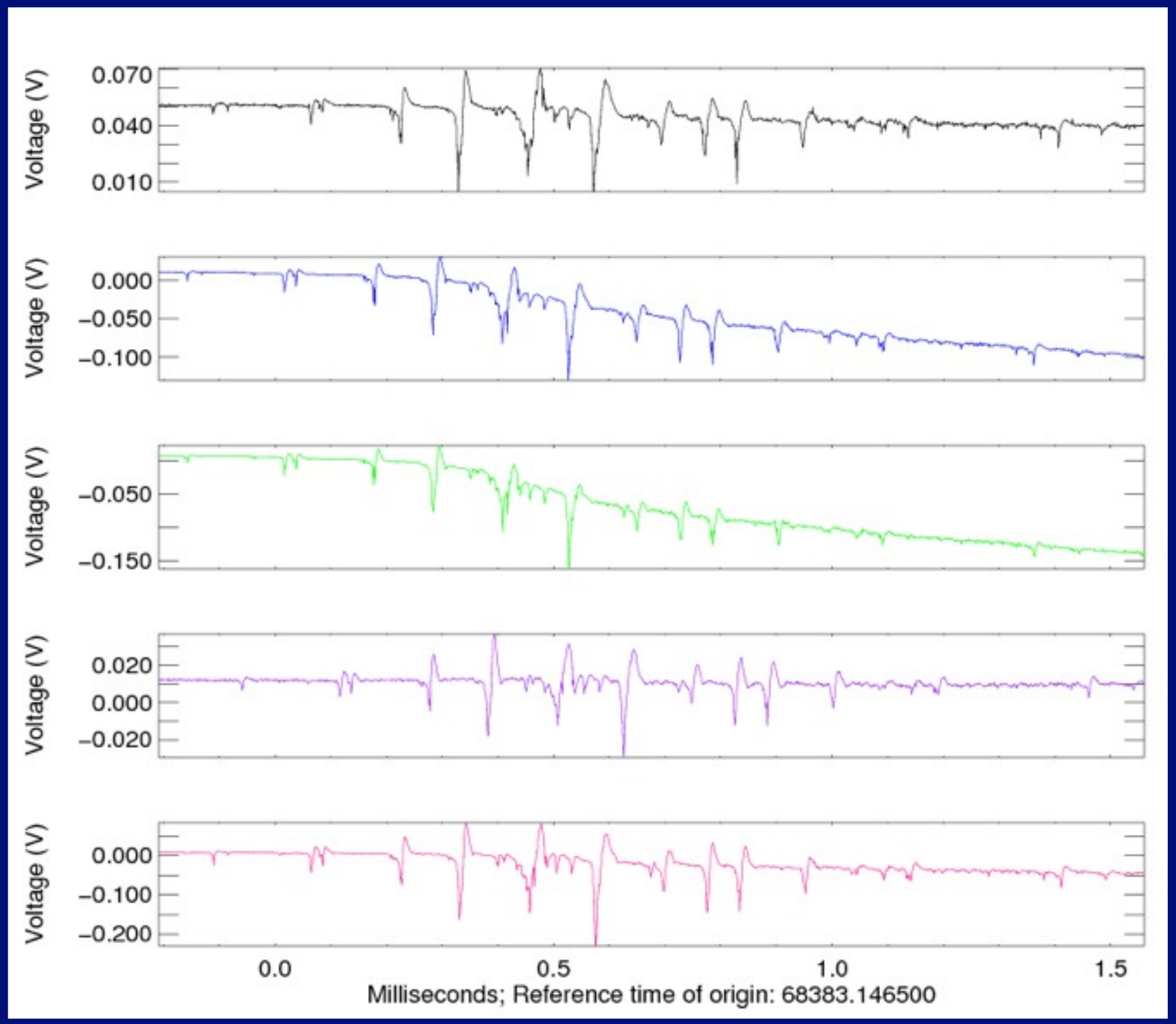
Stop time: 18055.012631

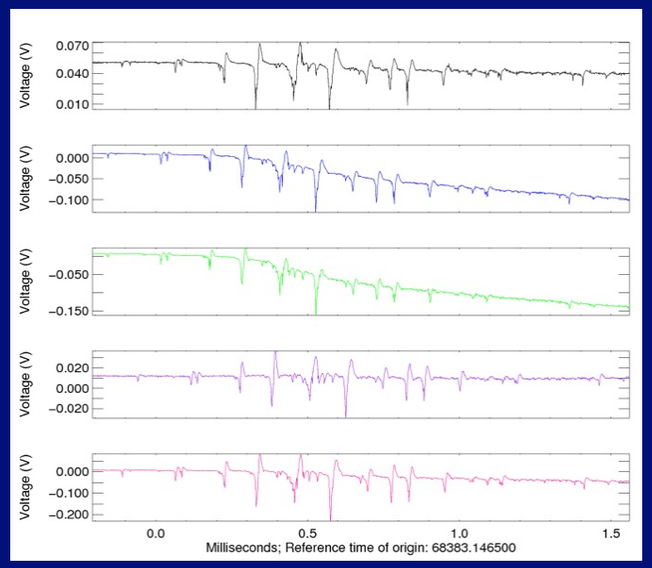
Time Elapsed: 0.625304

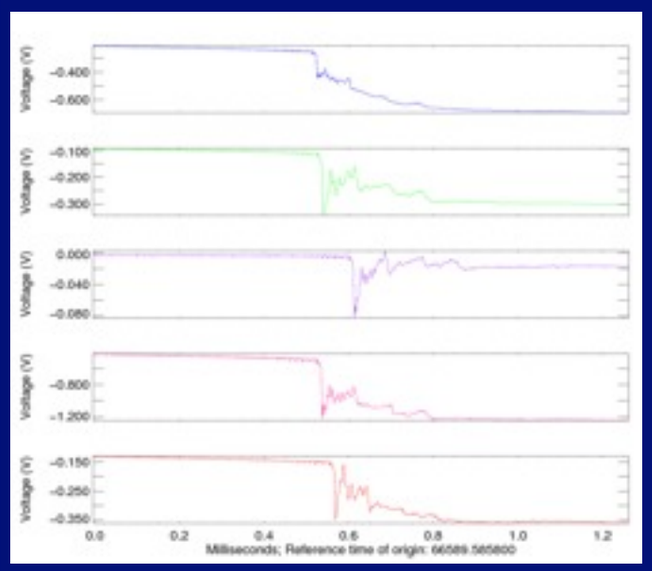

Voltage (V)
0.070
0.040
0.010
0.000
−0.050
−0.100
−0.050
−0.150
0.020
0.000
−0.020
0.000
−0.100
−0.200
0.0
0.5
1.0
1.5
Milliseconds; Reference time of origin: 68383.146500

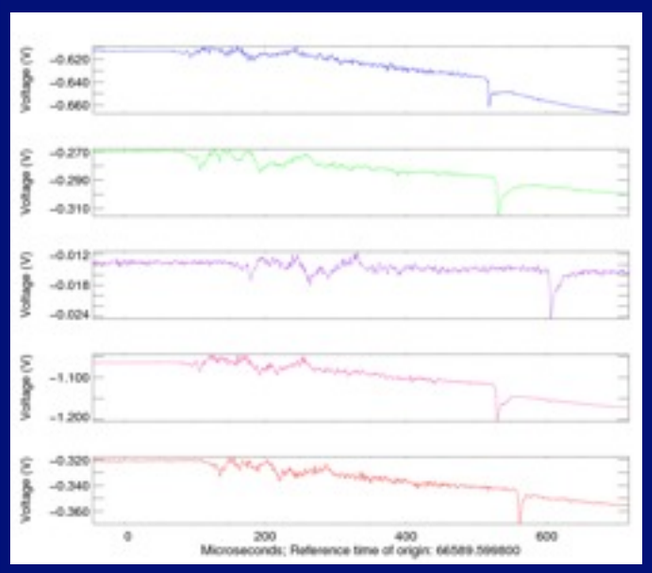

Voltage (V)
Milliseconds; Reference time of origin: 66589.565800

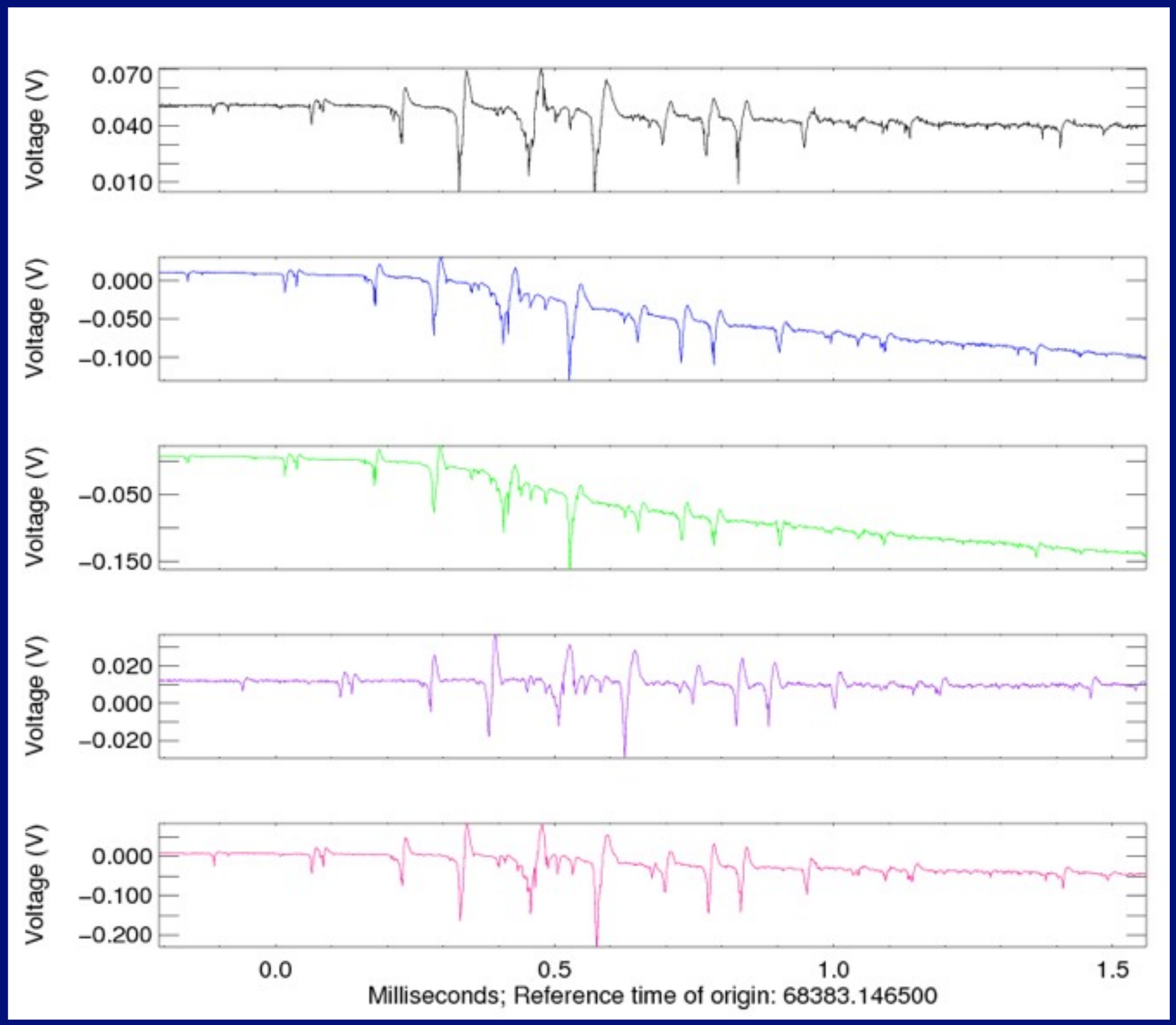

Voltage (V)
Microseconds; Reference time of origin: 66589.599800


Voltage (V)
0.070
0.040
0.010
0.000
−0.050
−0.100
−0.050
−0.150
0.020
0.000
−0.020
0.000
−0.100
−0.200
0.0
0.5
1.0
1.5
Milliseconds; Reference time of origin: 68383.146500

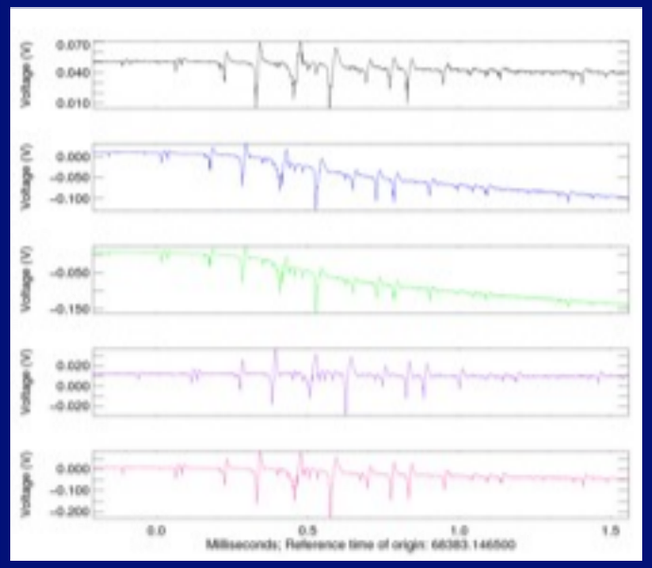


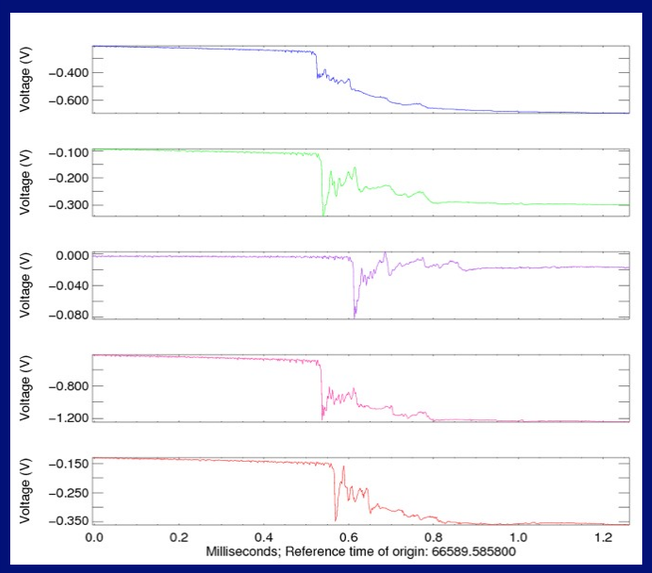


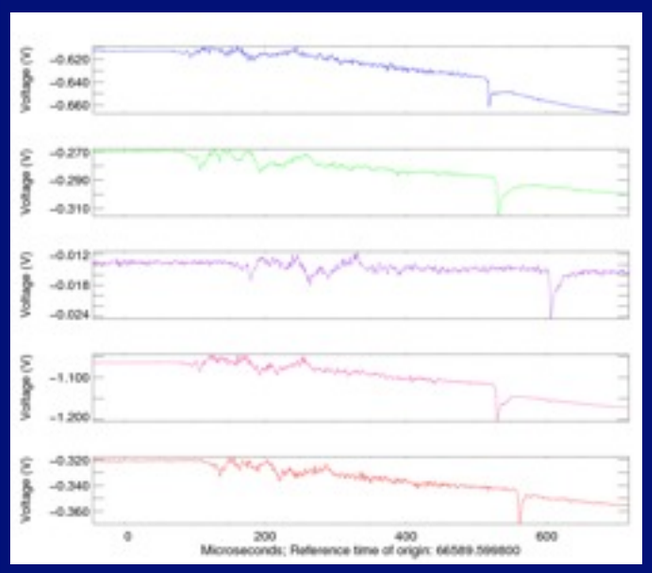


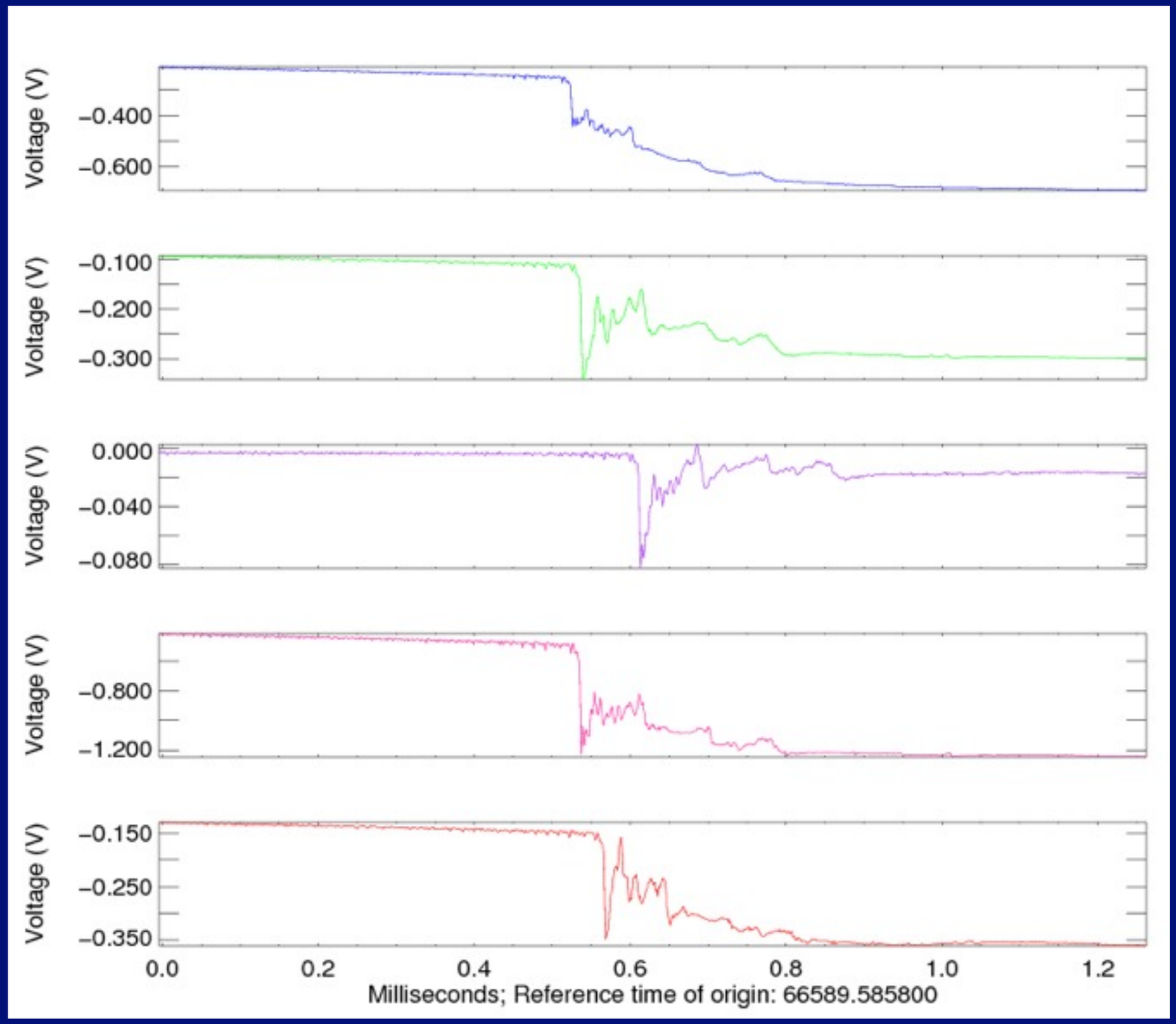


preliminary breakdown pulse train

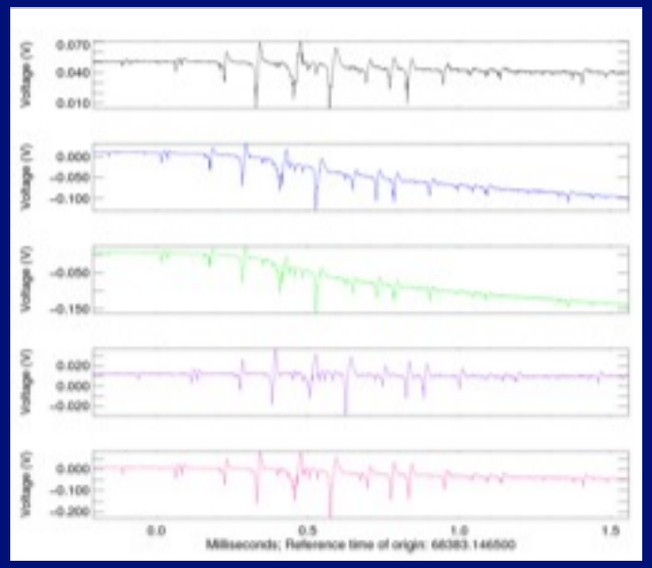


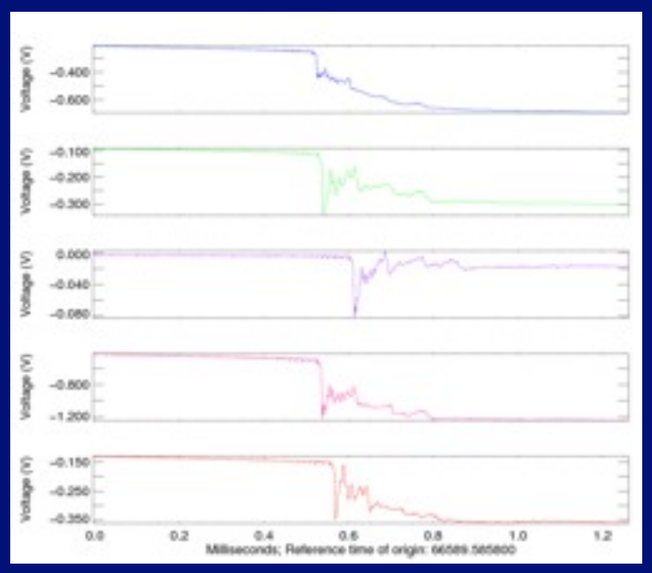


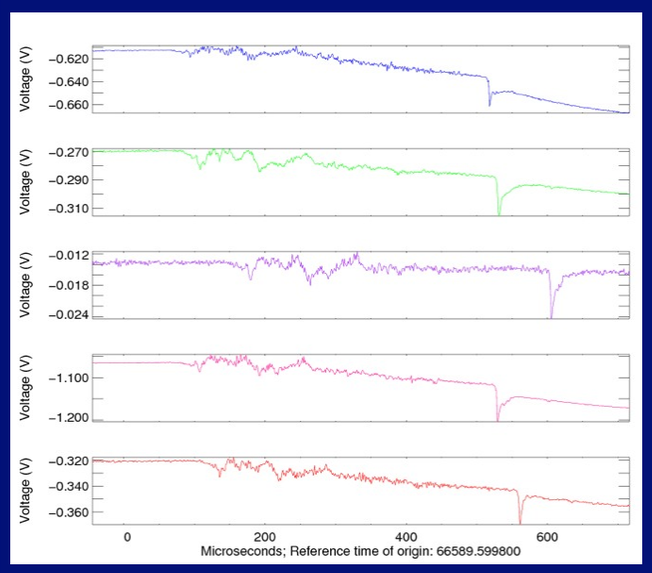


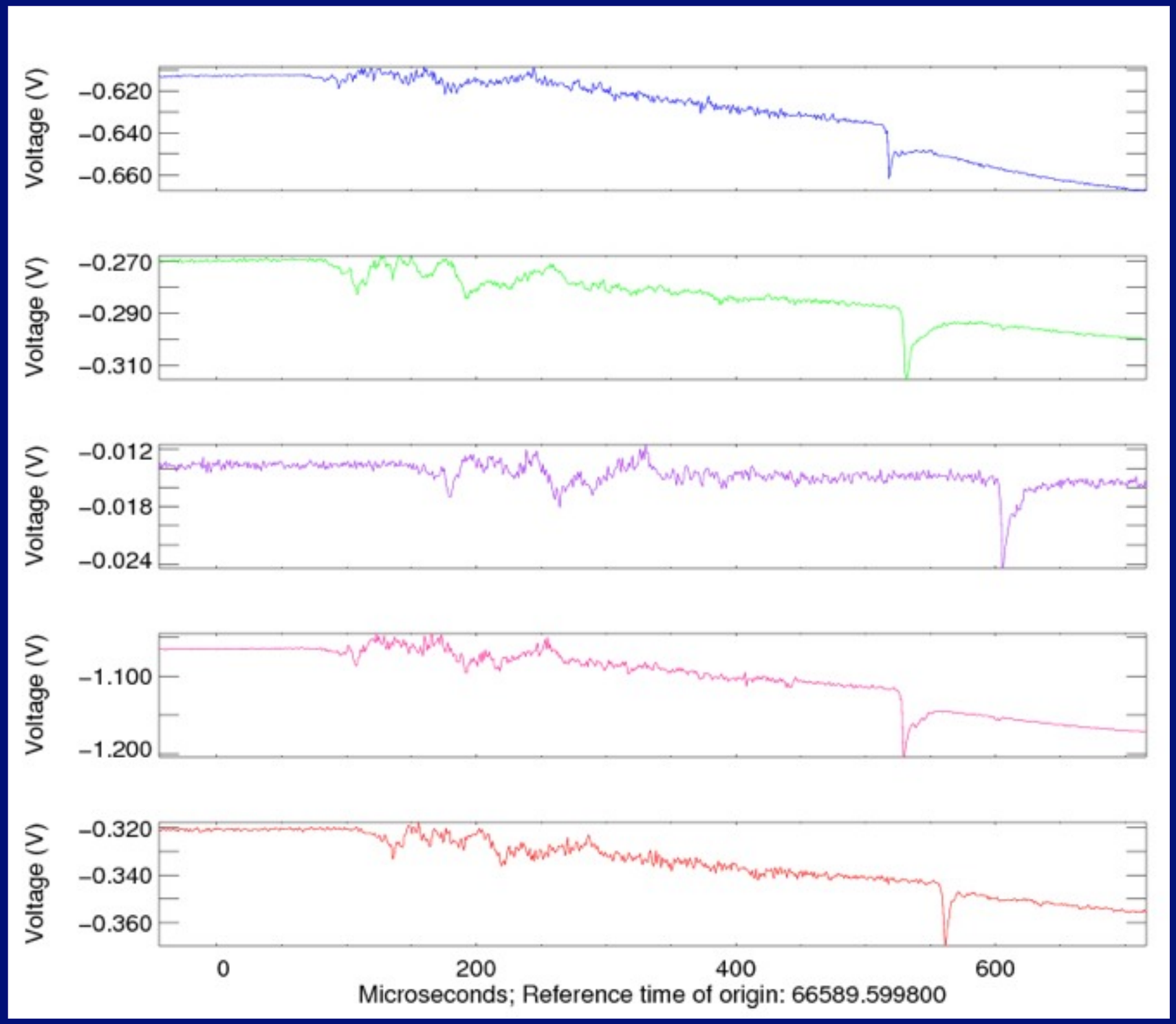


early return stroke

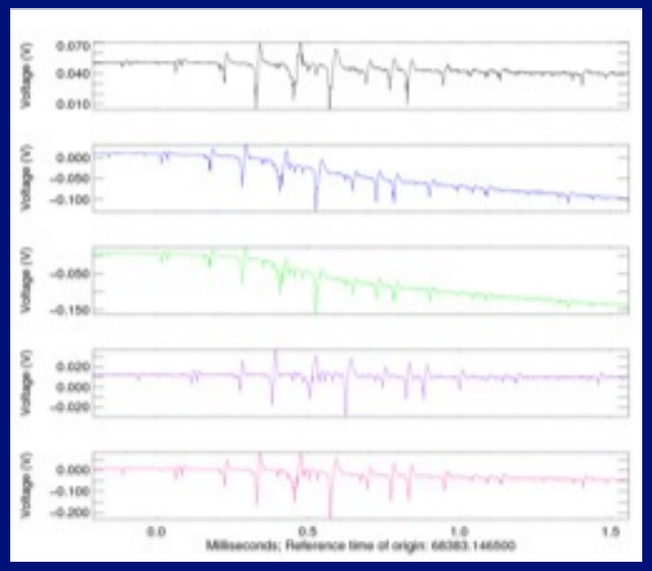


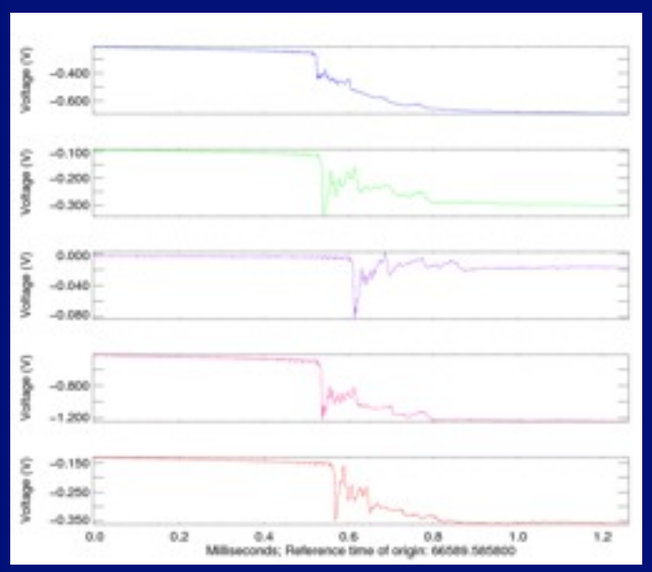


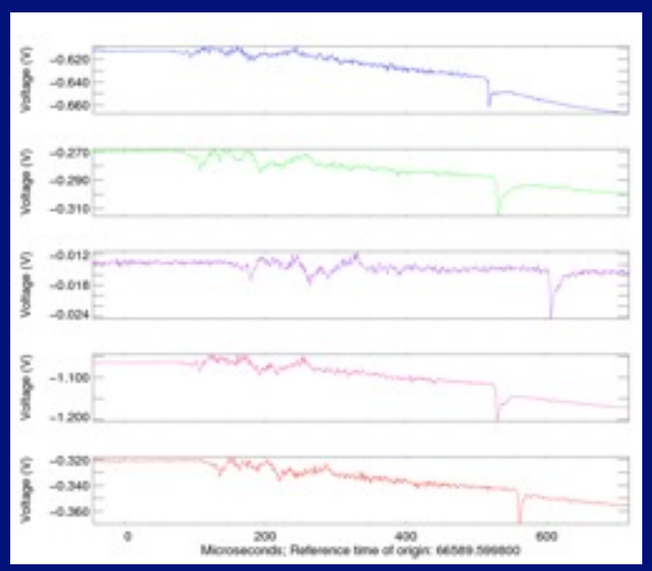




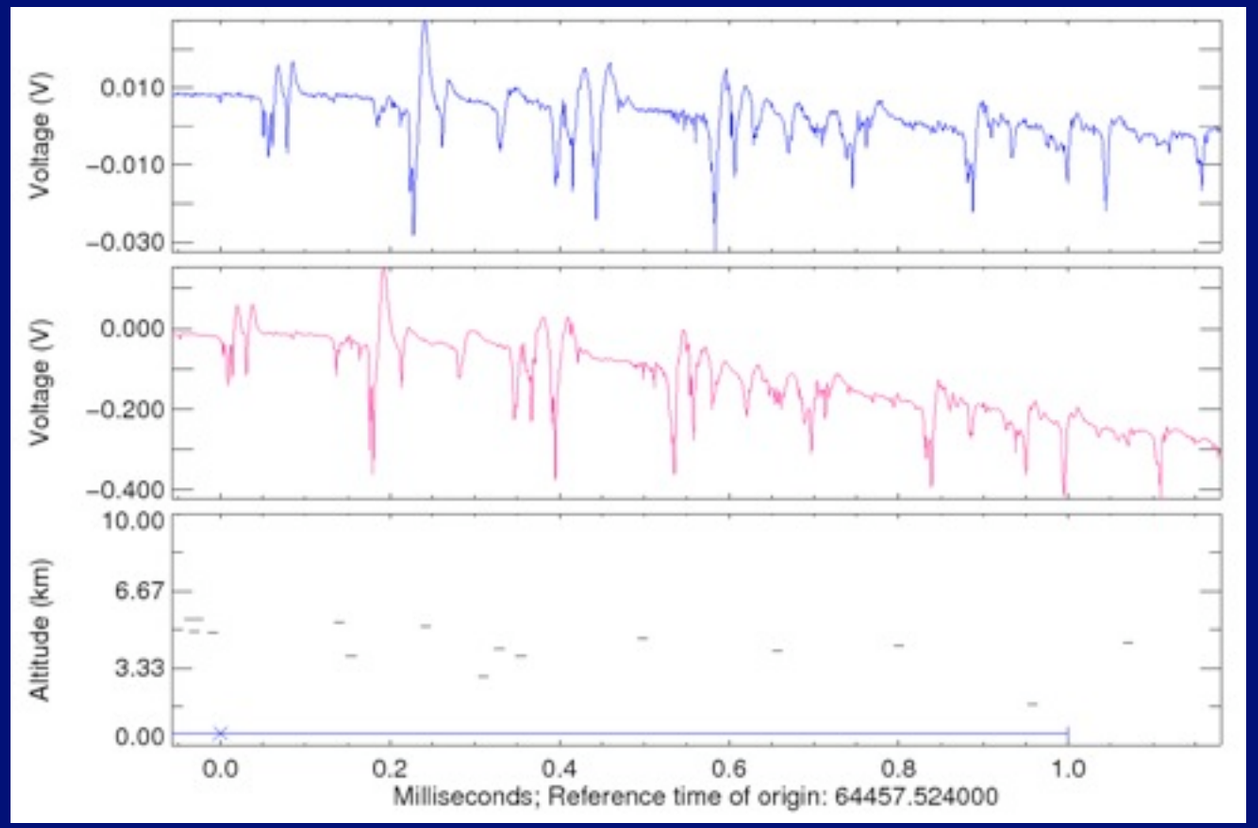
subsequent return stroke


Voltage (V)
0.070
0.040
0.010
Voltage (V)
0.000
-0.050
-0.100
Voltage (V)
-0.050
-0.150
Voltage (V)
0.020
0.000
-0.020
Voltage (V)
0.000
-0.100
-0.200
0.0
0.5
1.0
1.5
Milliseconds; Reference time of origin: 66383.146500

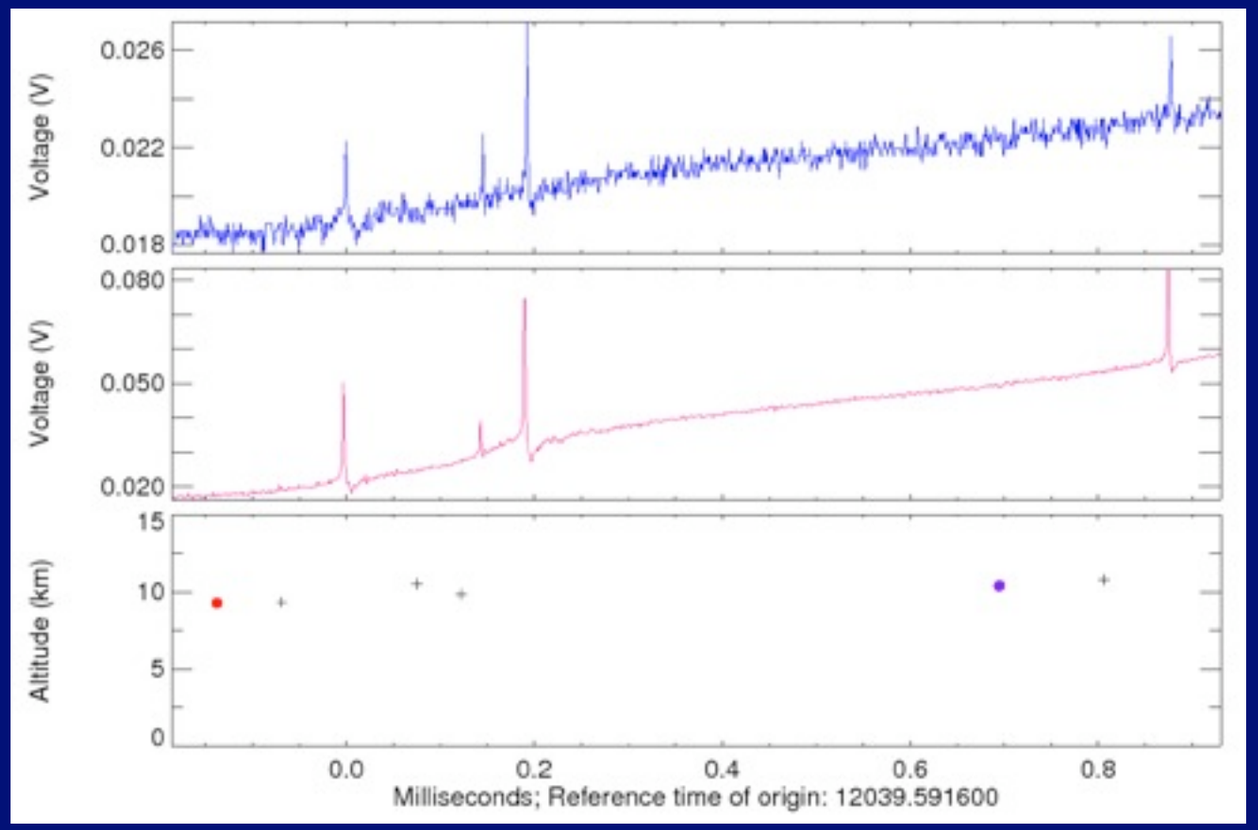

Voltage (V)
-0.400
-0.600
Voltage (V)
-0.100
-0.200
-0.300
Voltage (V)
0.000
-0.040
-0.080
Voltage (V)
-0.600
-1.200
Voltage (V)
-0.150
-0.250
-0.350
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Milliseconds; Reference time of origin: 66589.585800


Voltage (V)
-0.620
-0.640
-0.660
Voltage (V)
-0.270
-0.290
-0.310
Voltage (V)
-0.012
-0.018
-0.024
Voltage (V)
-1.100
-1.200
Voltage (V)
-0.320
-0.340
-0.360
0
200
400
600
Microseconds; Reference time of origin: 66589.599800

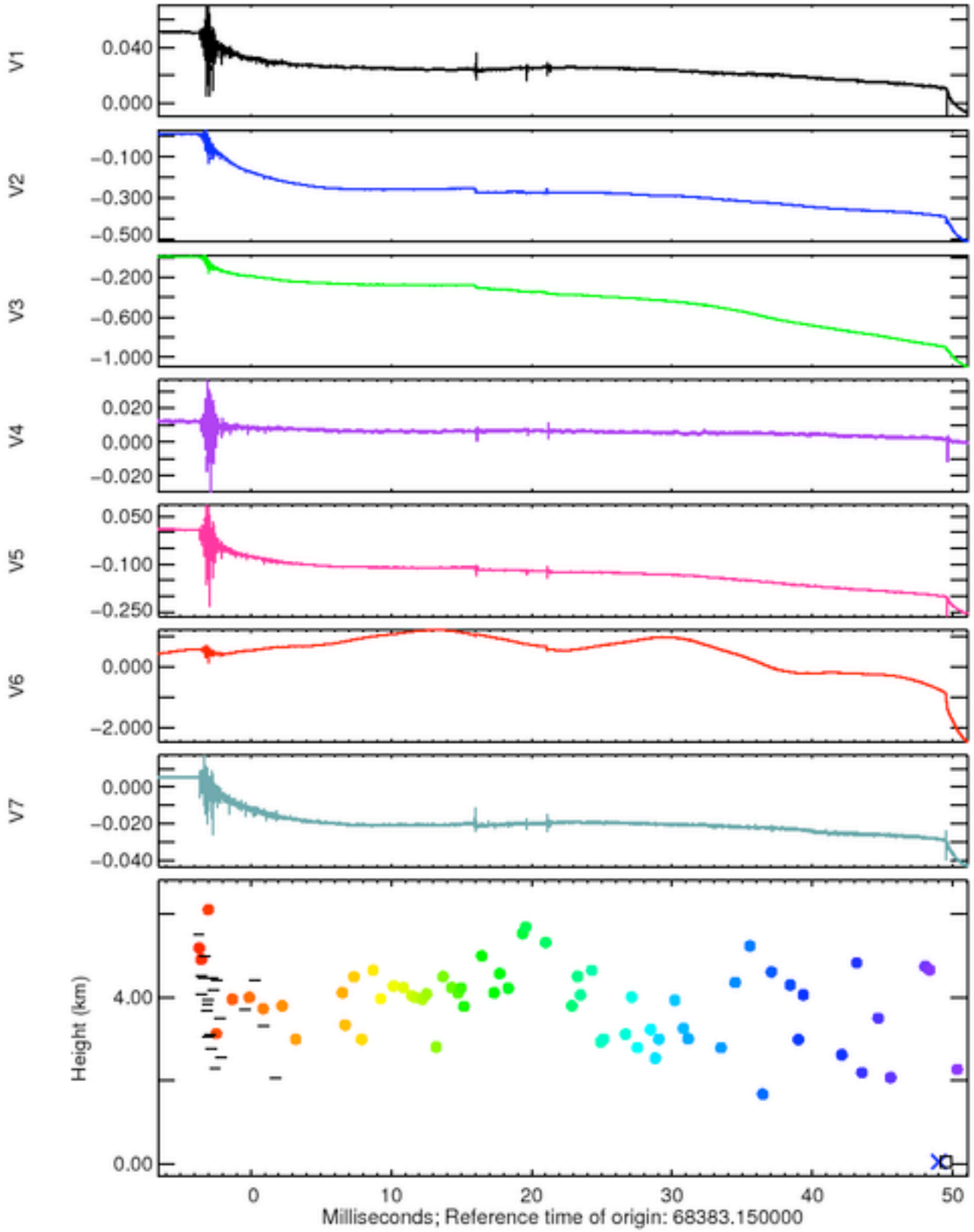
Negative CGs produce a preliminary breakdown pulse train with negative polarity pulses

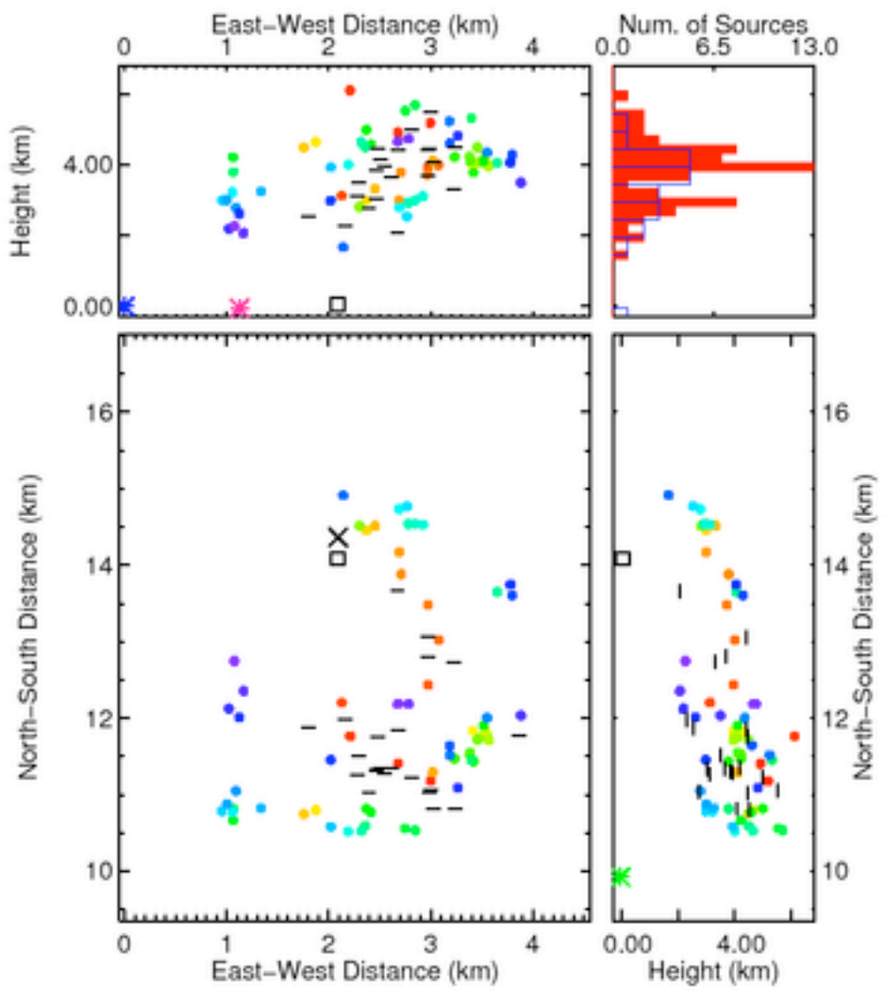


Flashes with an initial intracloud component begin with positive polarity pulses



2010/10/26 18:59:43





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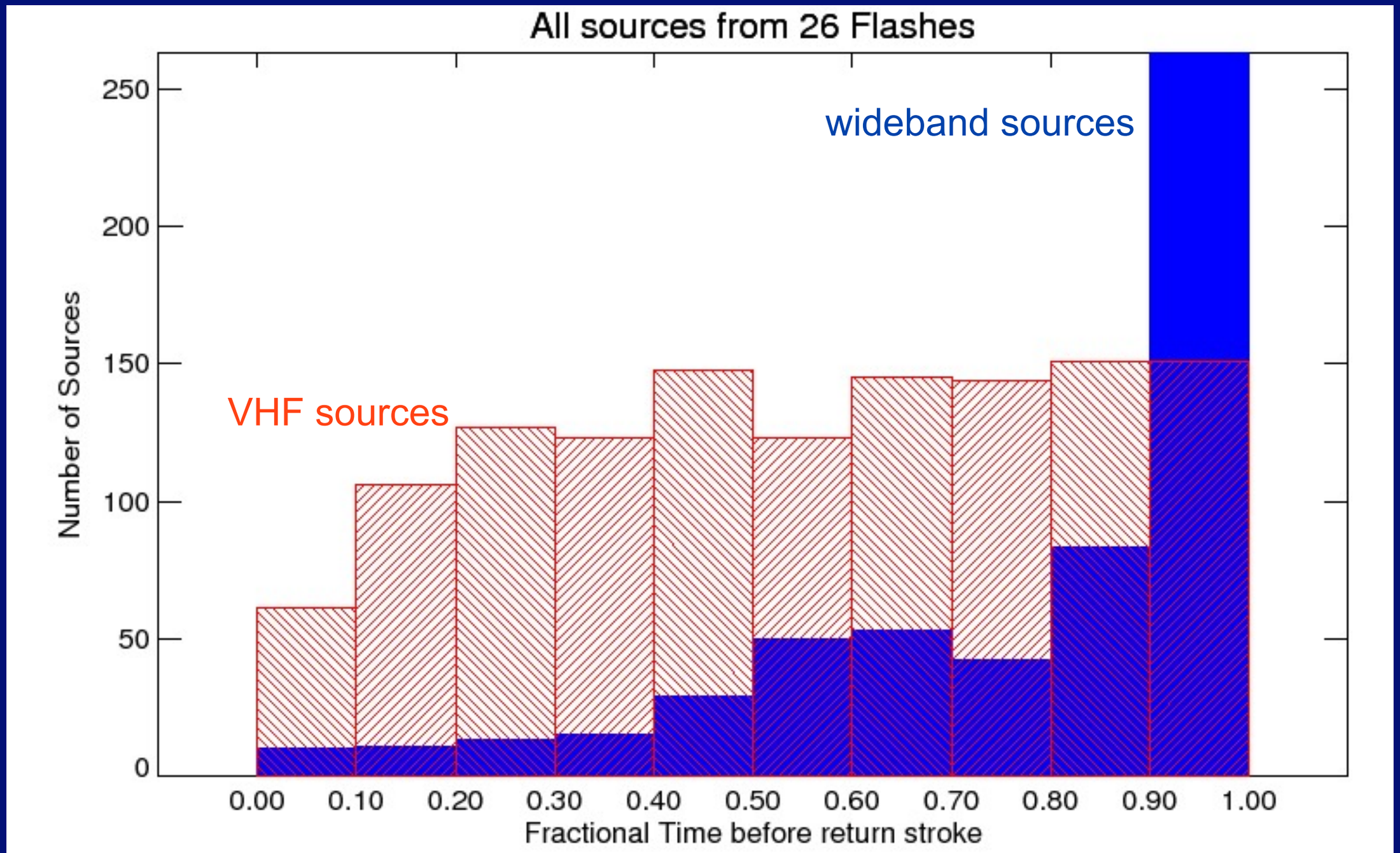
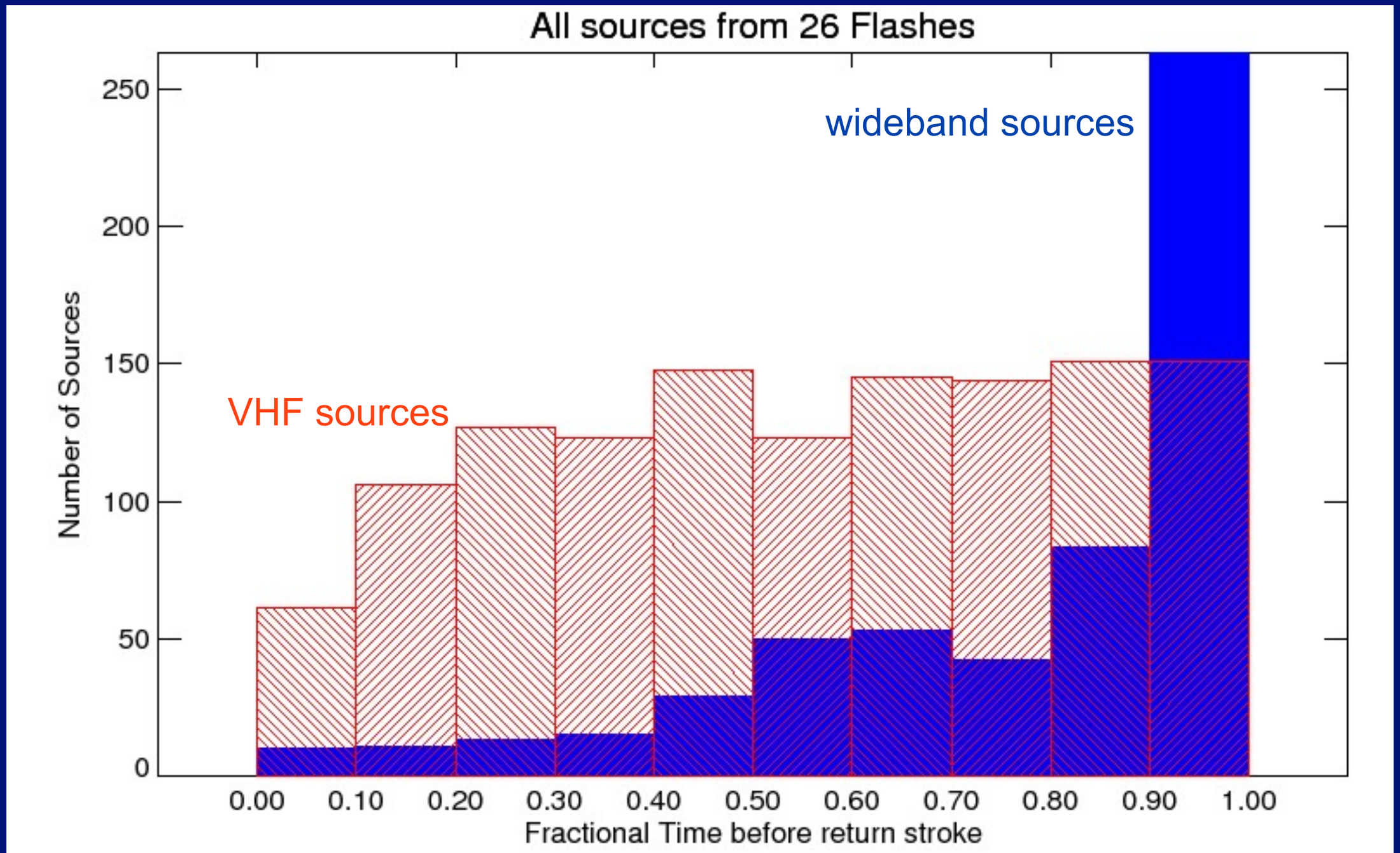
Stop time:	68383.201023
Time Elapsed:	0.057596



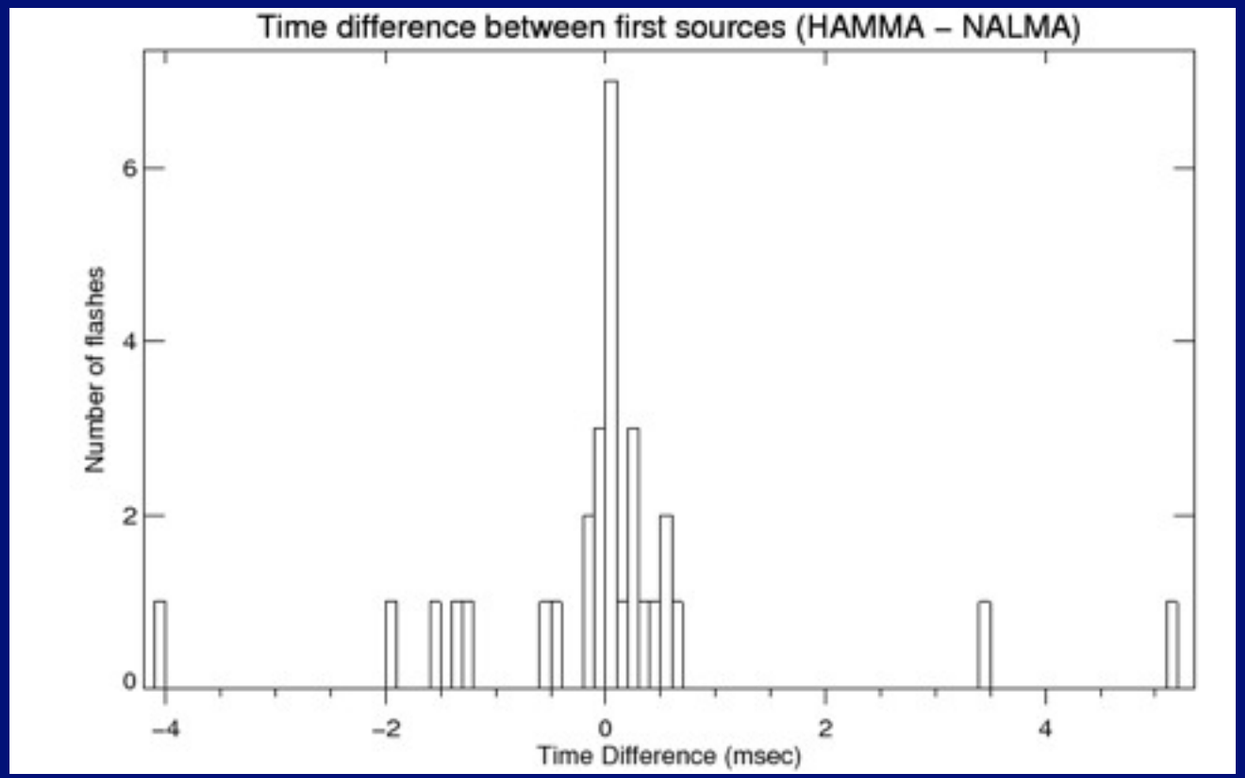
HAMMA is “very” active in the beginning of a flash

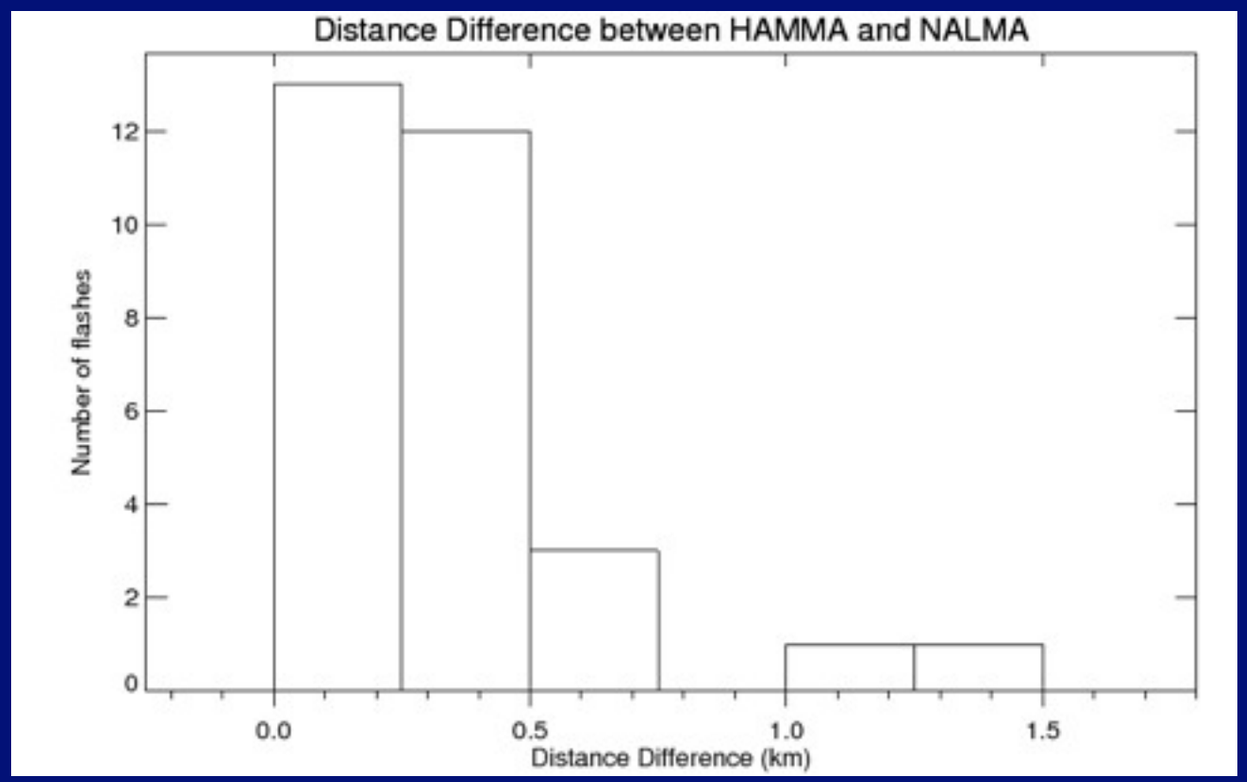


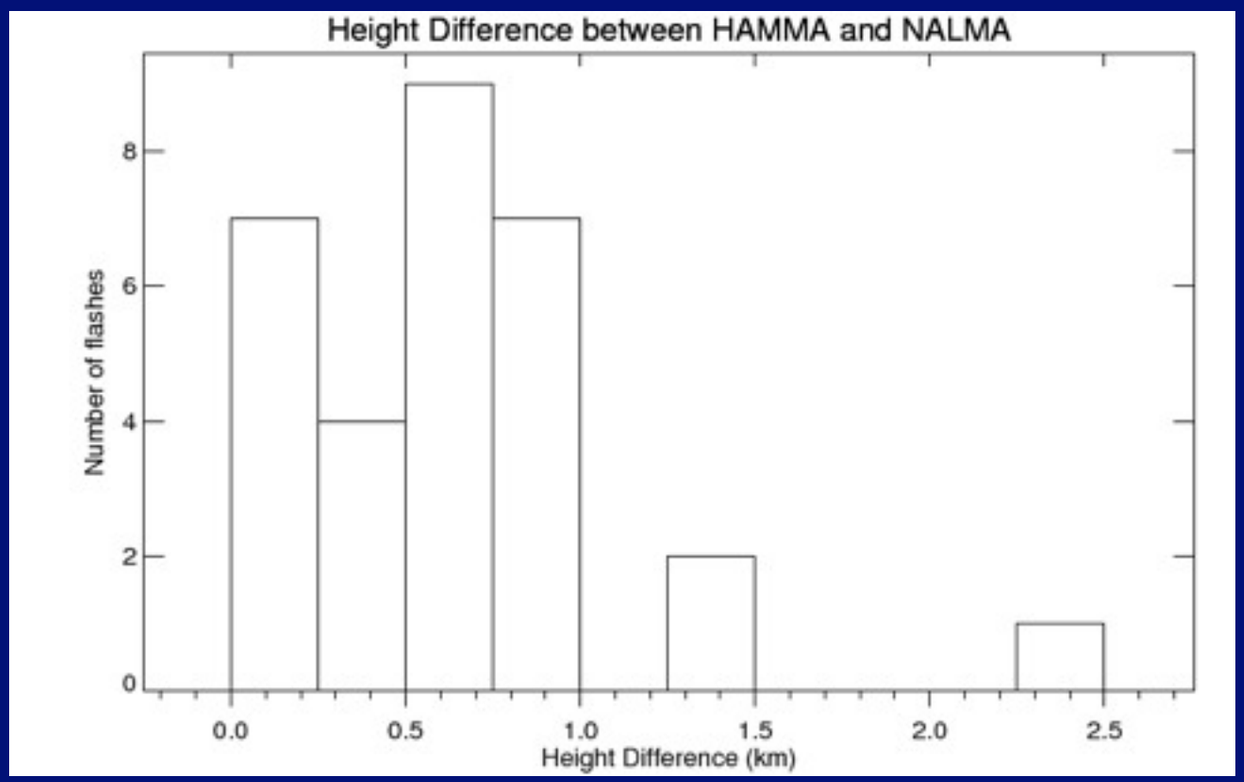
HAMMA is “very” active in the beginning of a flash

=> *wideband sources are well tuned to identify initiation*

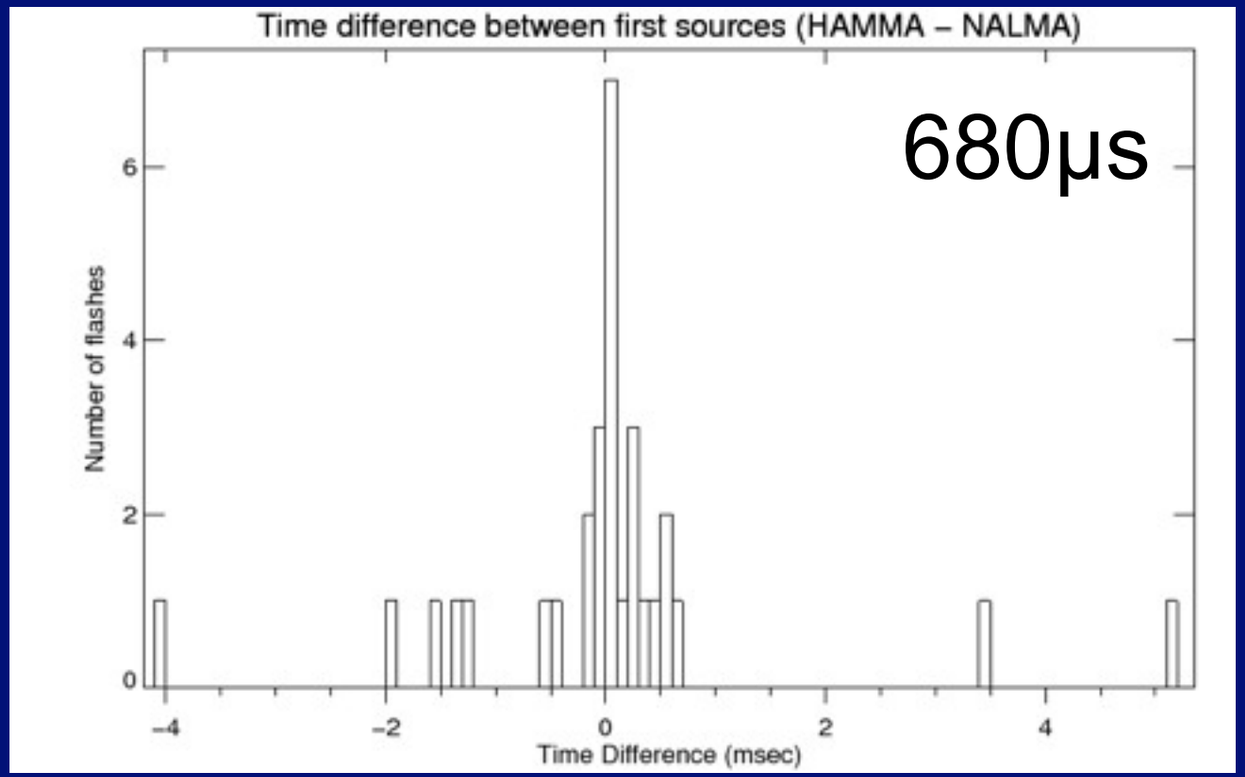
What's the difference in wideband and VHF?

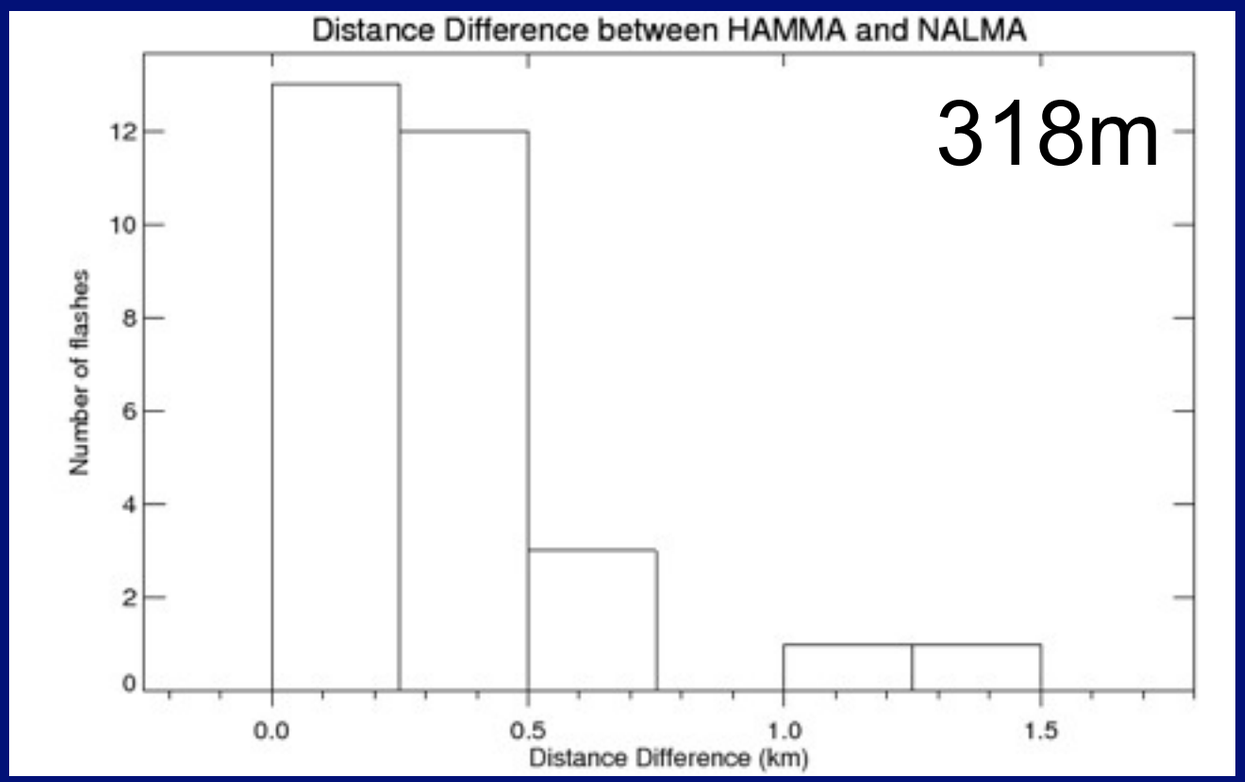


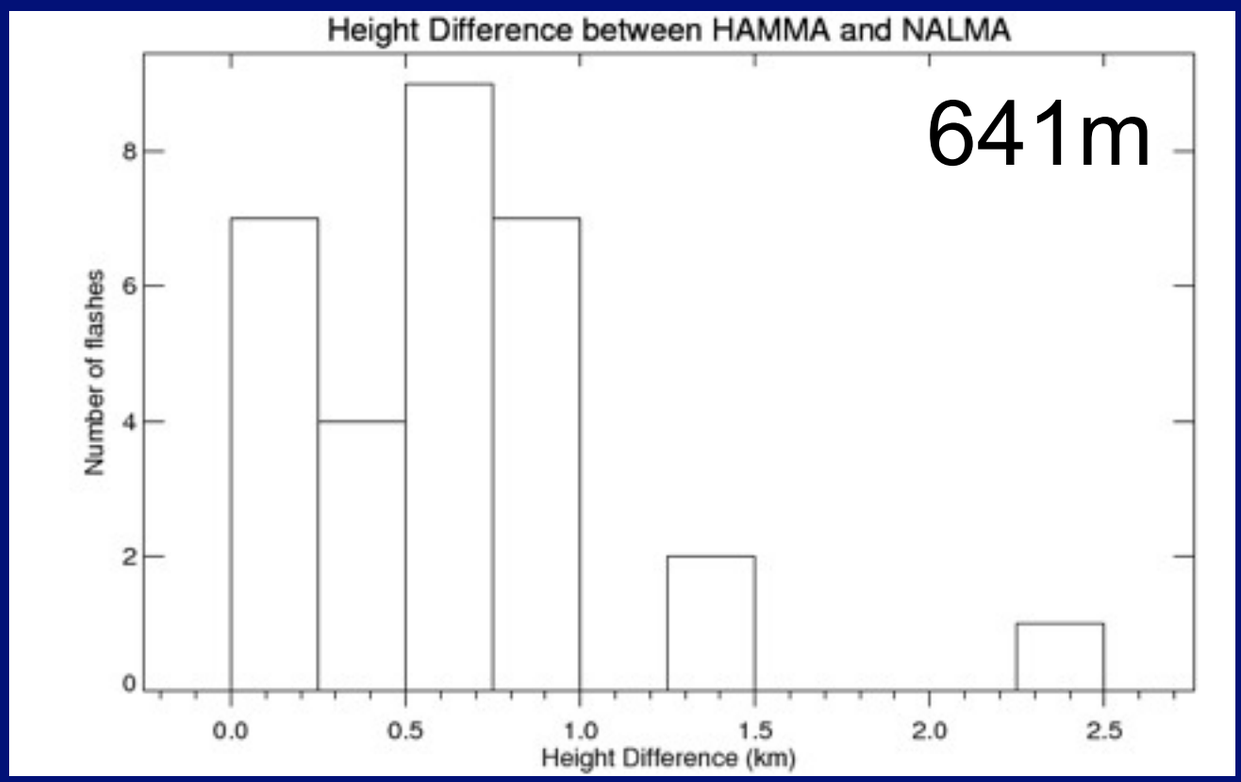


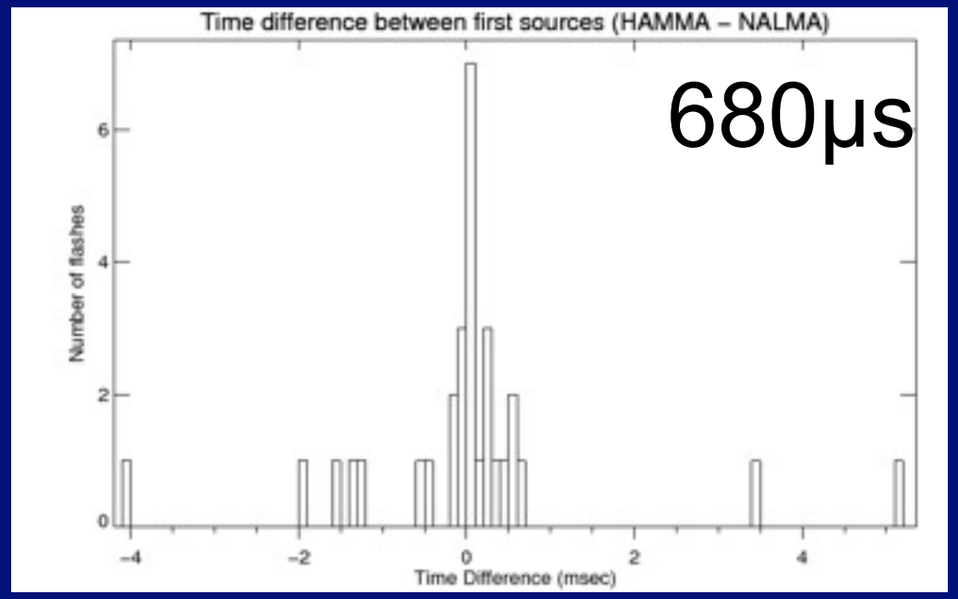


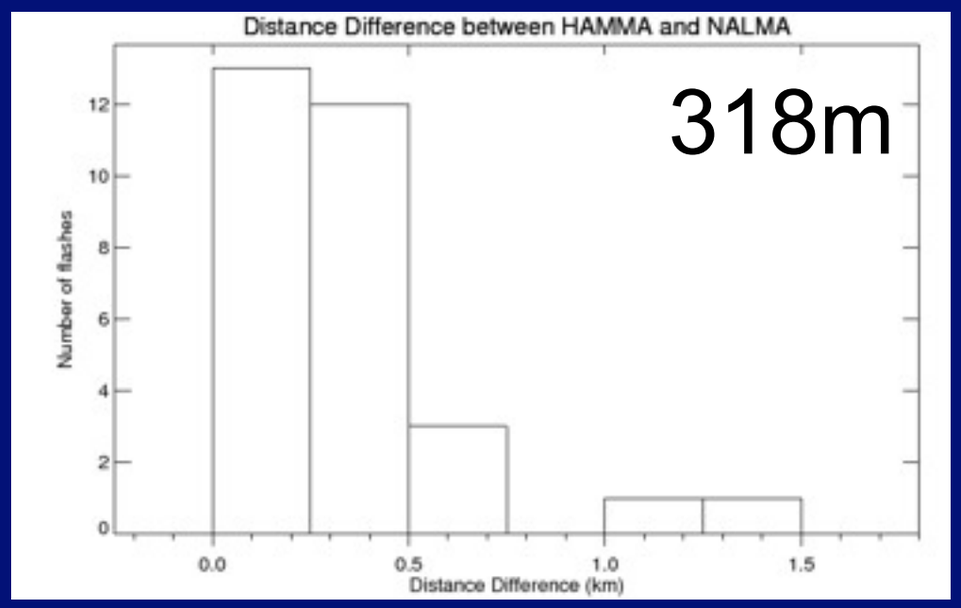
What's the difference in wideband and VHF?

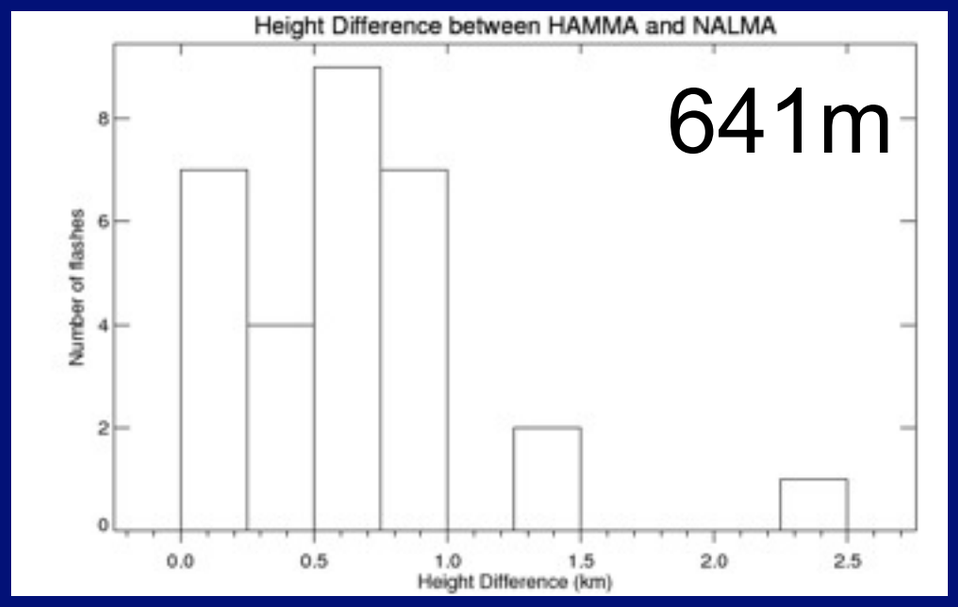


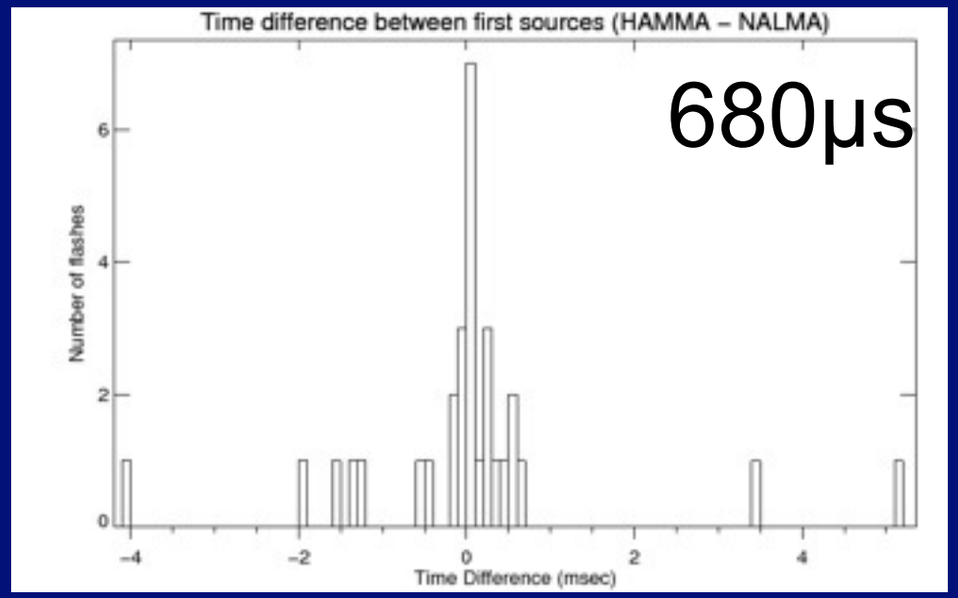


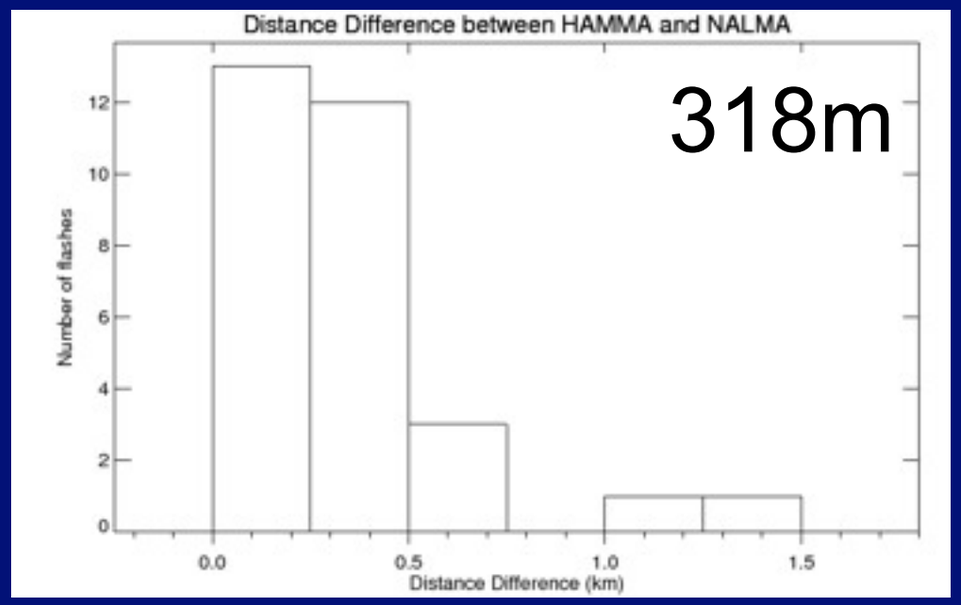


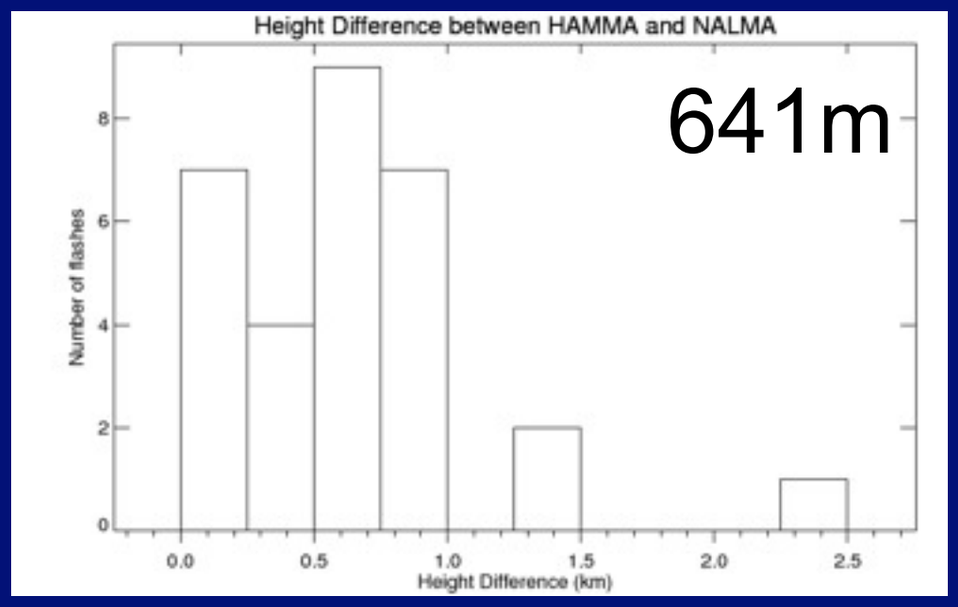

Time difference between first sources (HAMMA – NALMA)
680µs
Number of flashes
Time Difference (msec)
0
2
4
6
−4
−2
0
2
4


Distance Difference between HAMMA and NALMA
318m
Number of flashes
Distance Difference (km)
0
2
4
6
8
10
12
0.0
0.5
1.0
1.5

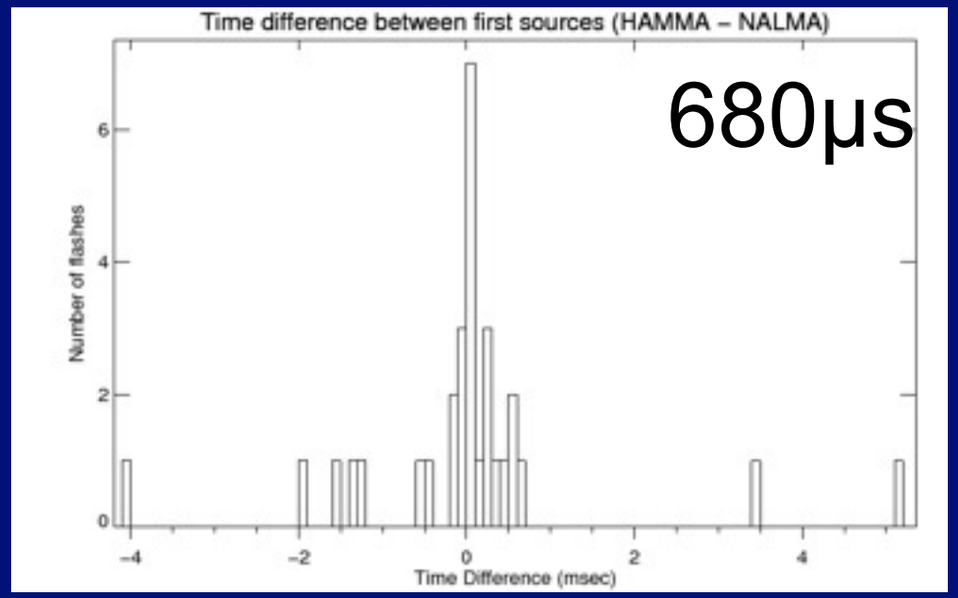

Height Difference between HAMMA and NALMA
641m
Number of flashes
Height Difference (km)
0
2
4
6
8
0.0
0.5
1.0
1.5
2.0
2.5

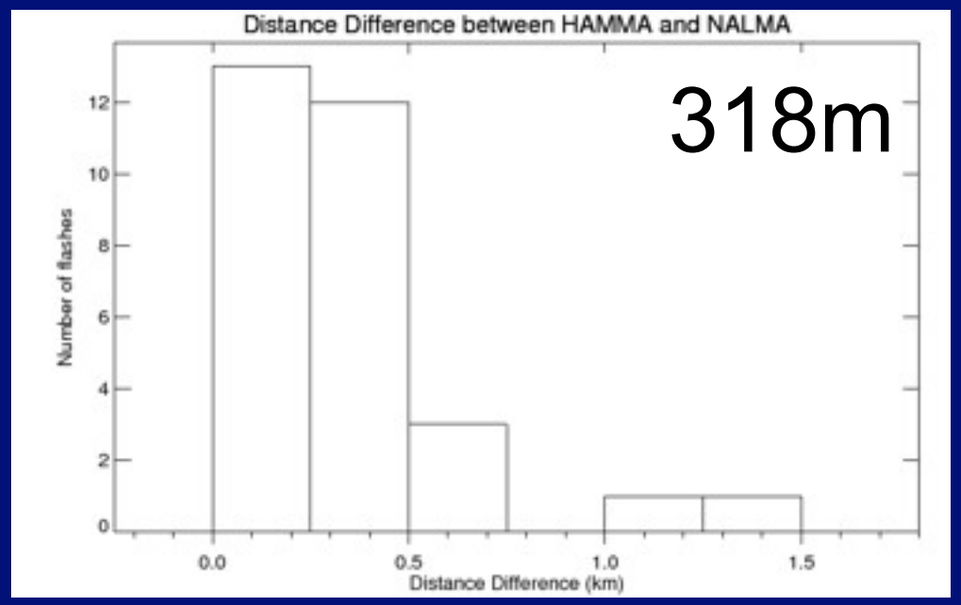


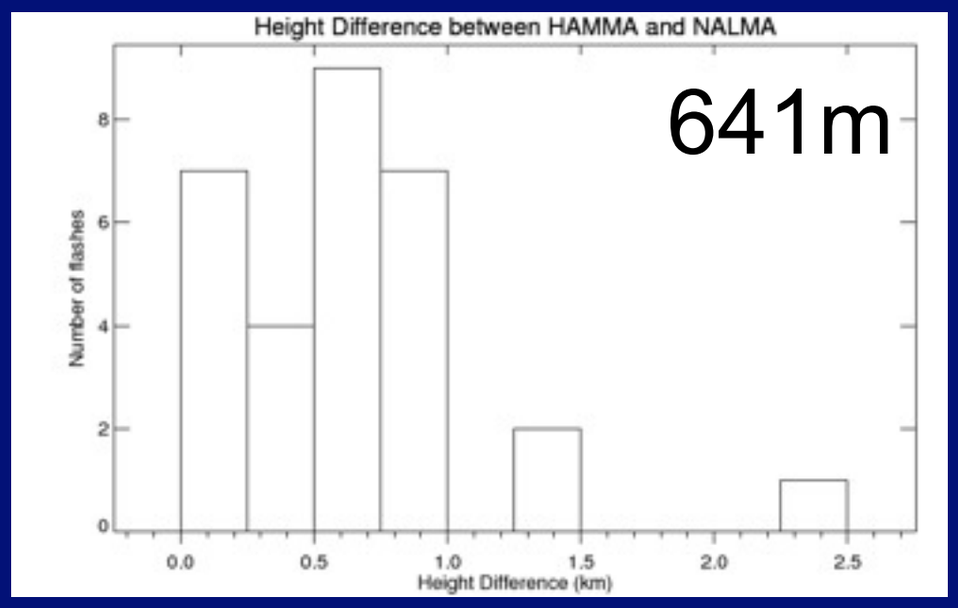




***On average**, initiation in the wideband and VHF are spatially and temporally similar…*







***On average**, initiation in the wideband and VHF are spatially and temporally similar…*

…but what does this mean for the initiation mechanism?

Gurevich (1999) predicts that initiation via relativistic runaway breakdown would produce wideband radiation prior to VHF radiation...

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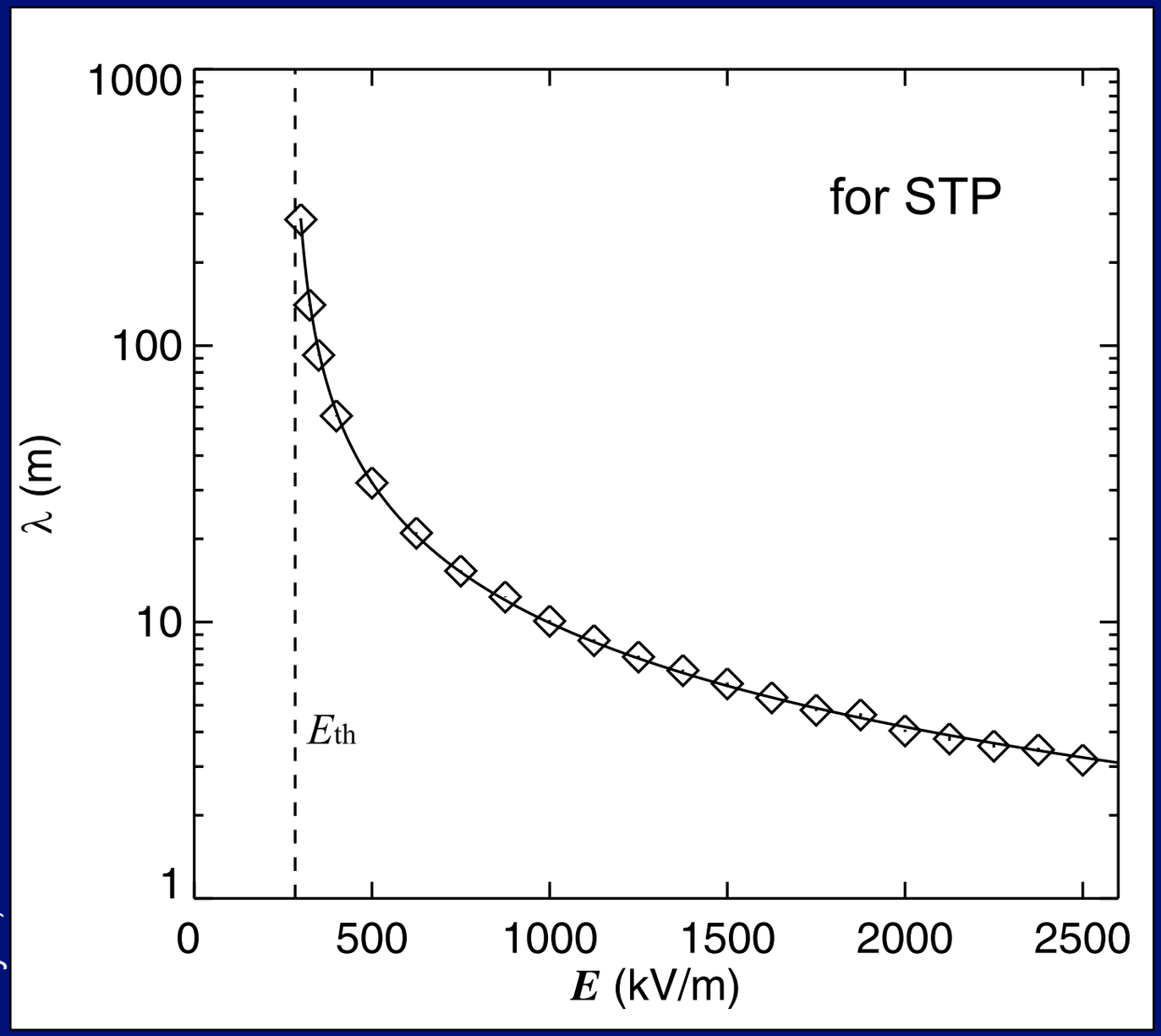

Dwyer, 2003

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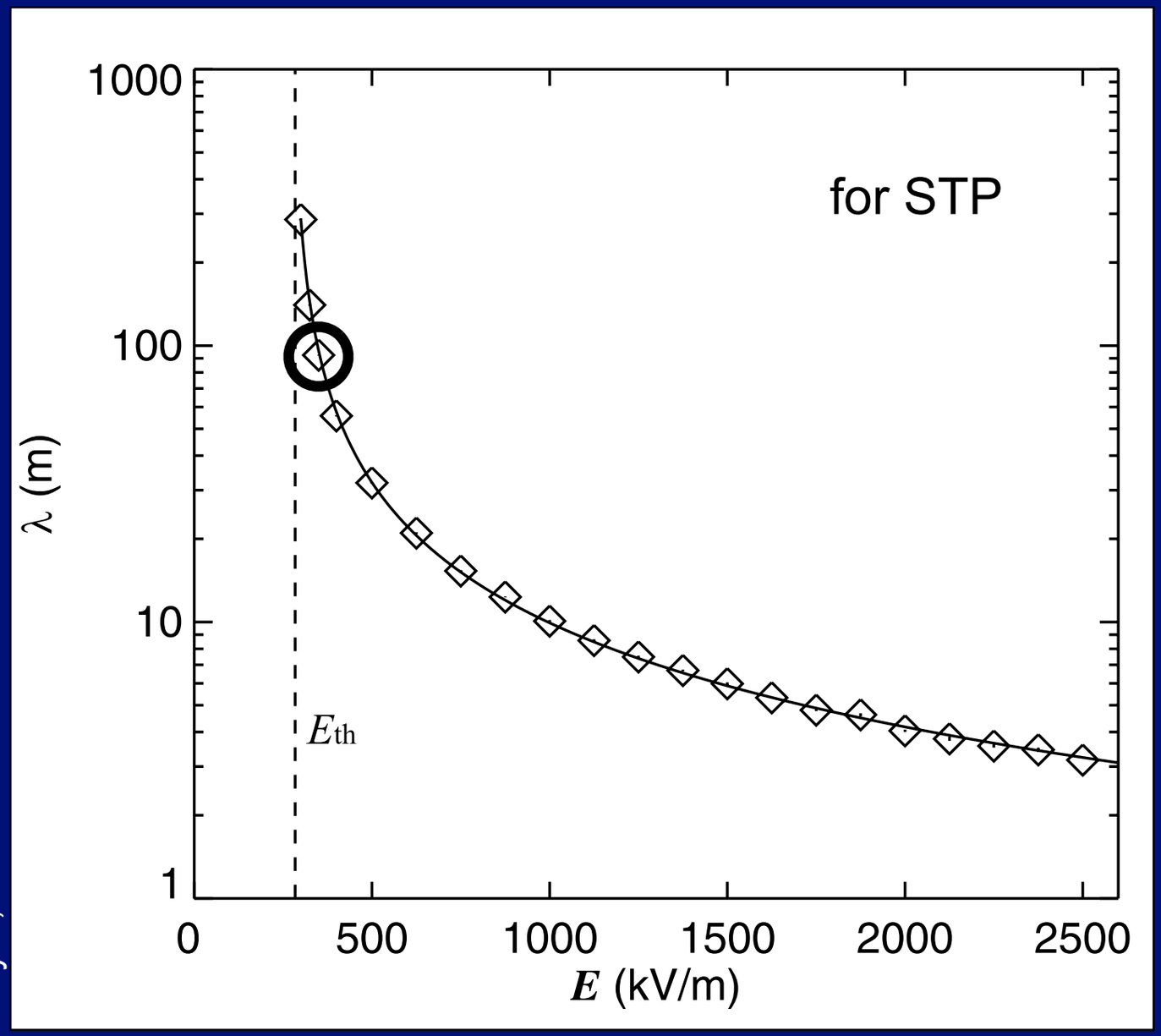

Assume:

initiation height of 6km

electric field of 175 kV/m

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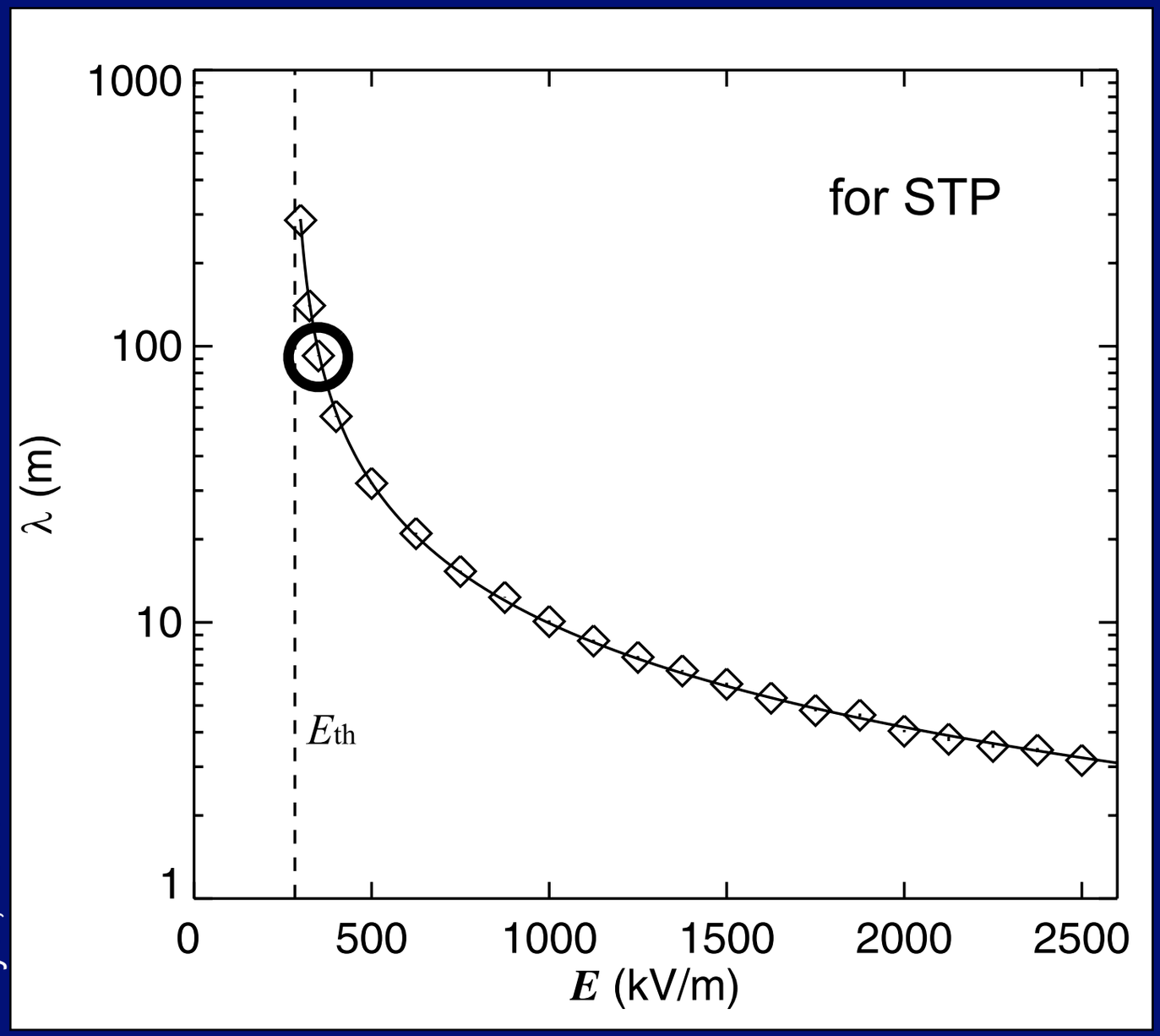

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Implies:

avalanche length is ~200m

total length of the high field region is ~2km

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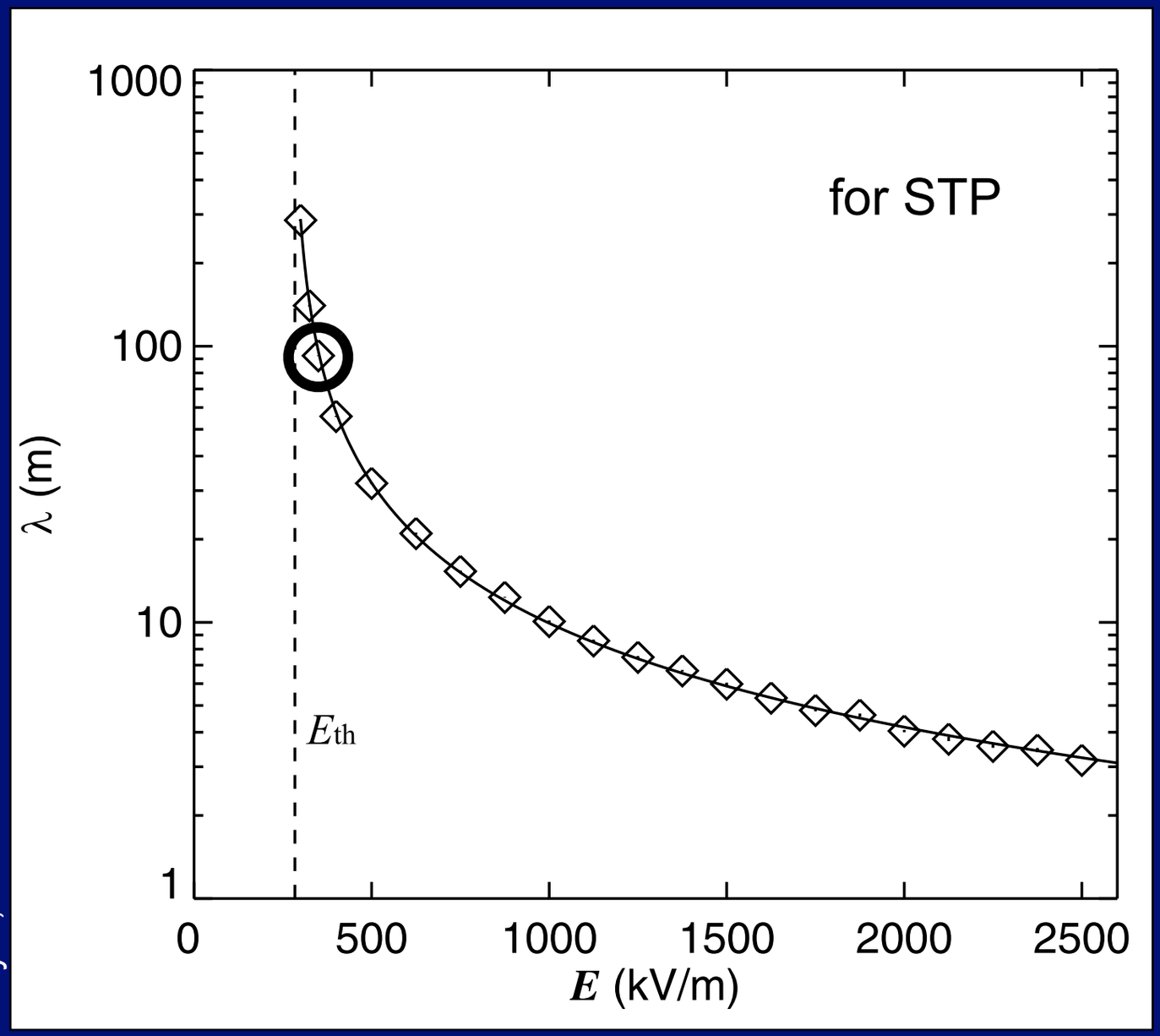

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electric field of 175 kV/m

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Further, Coleman and Dwyer (2006) show that the avalanche progresses with a speed of 0.89c

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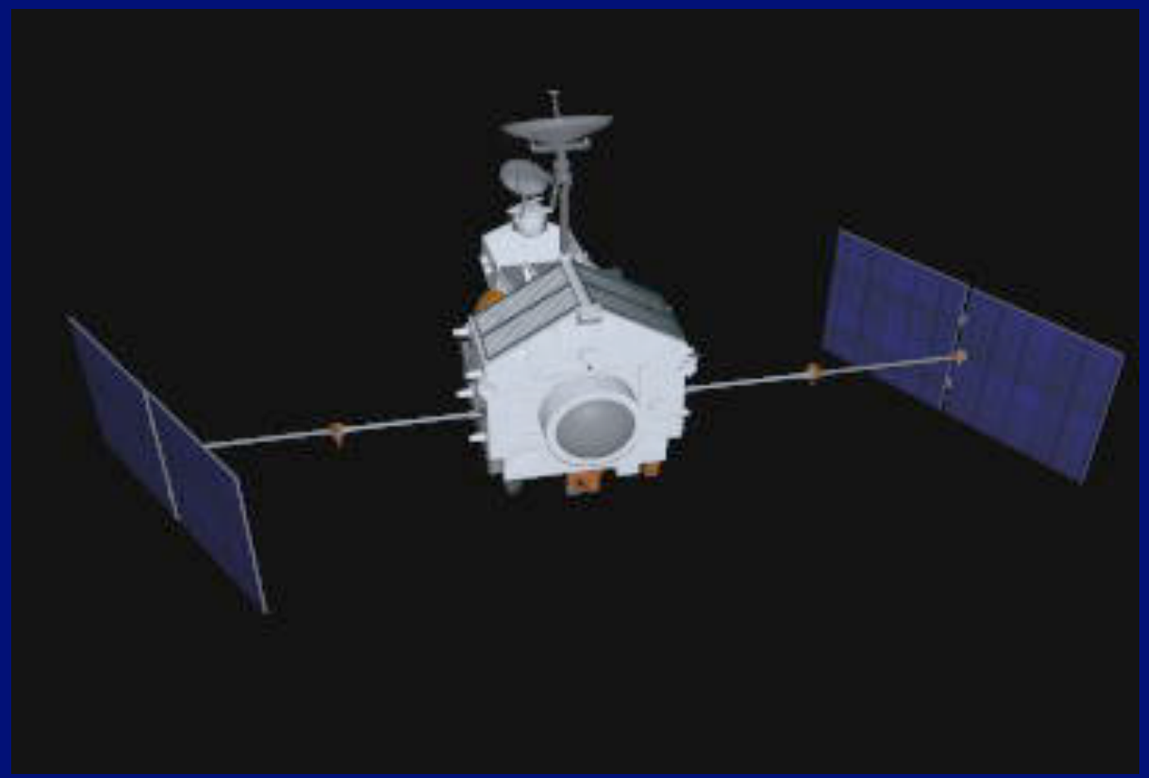
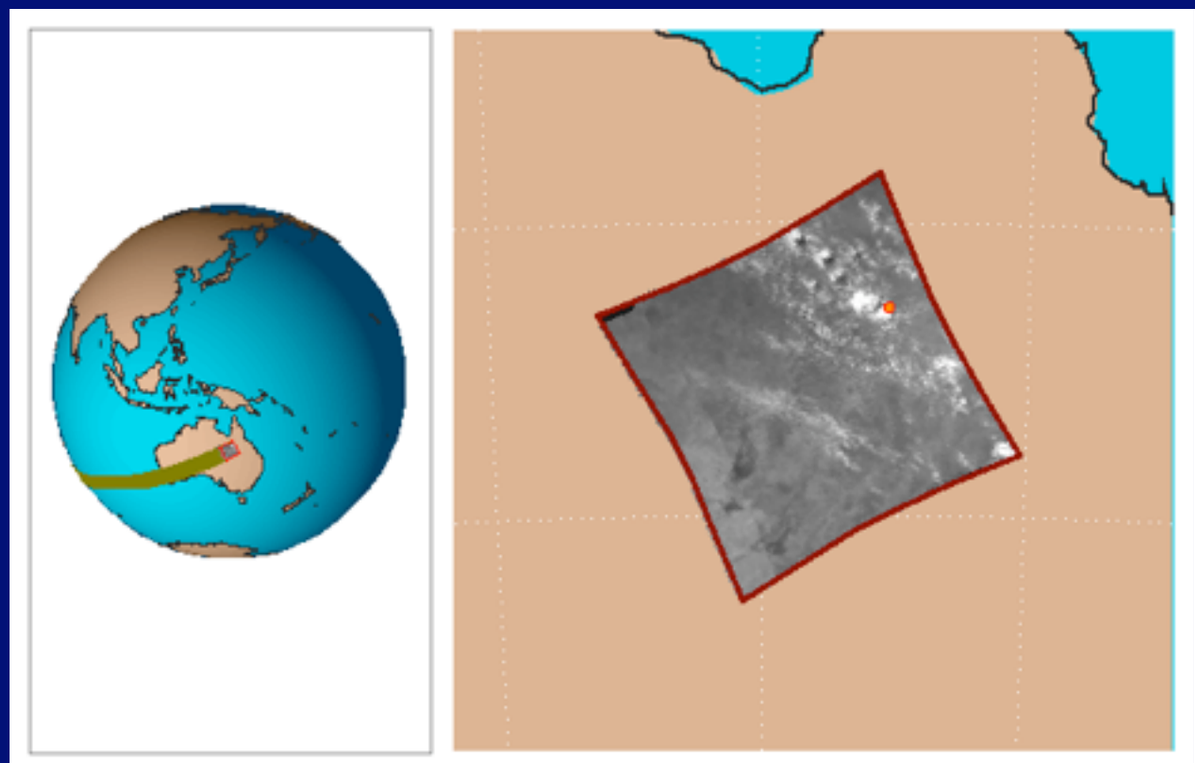
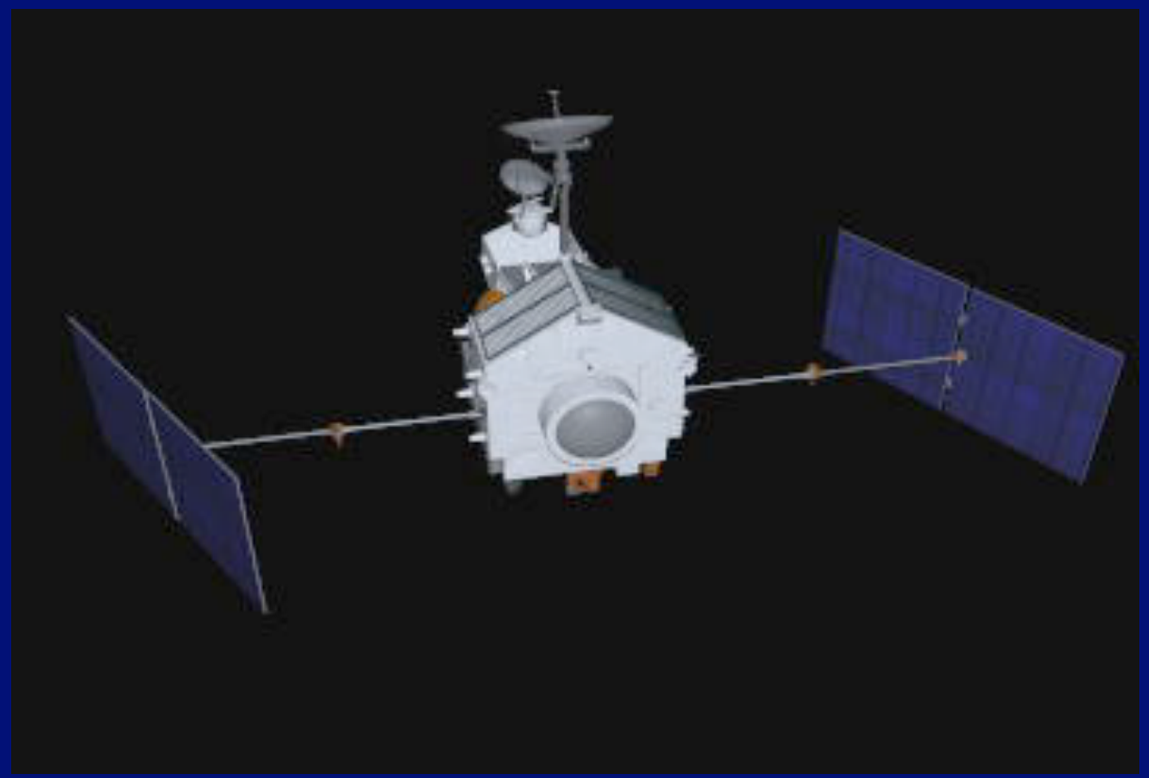
Further....
simulations (Dwyer, 2010) show the region of slow electrons is far too diffuse to yield the required conductivity.

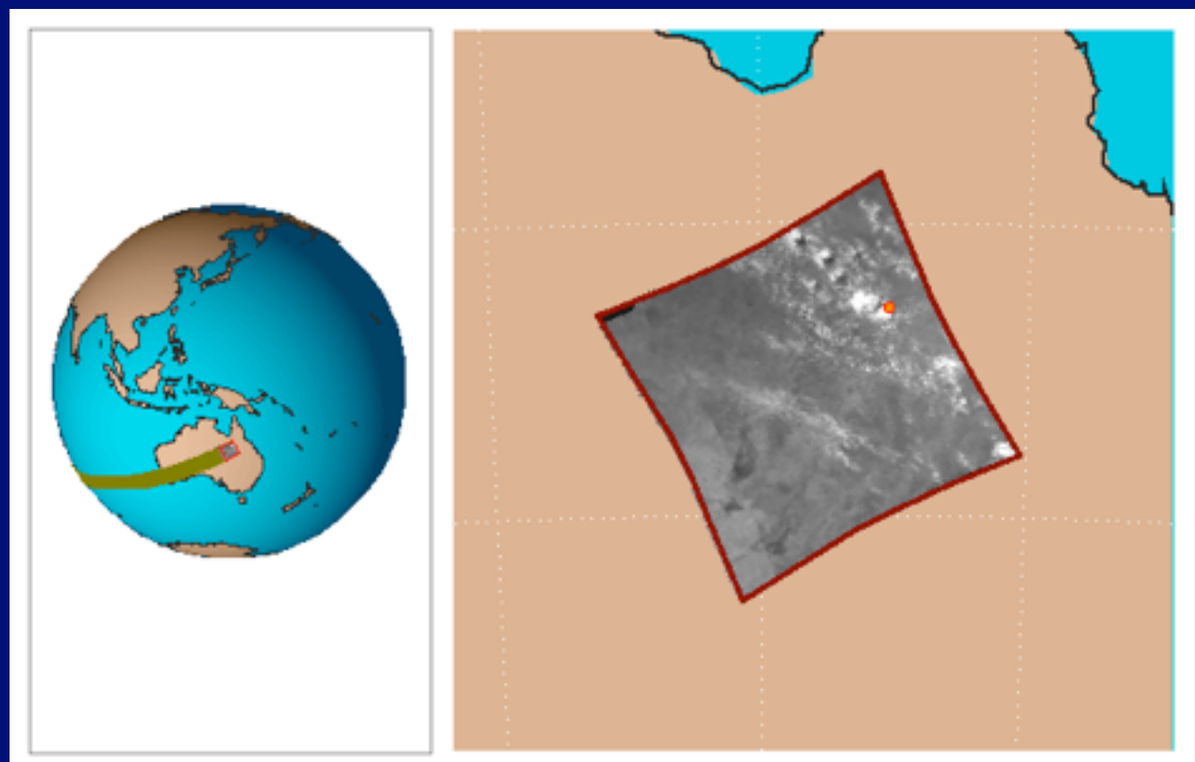
LIS (and by extension, GLM)
does not
detect *flashes...*





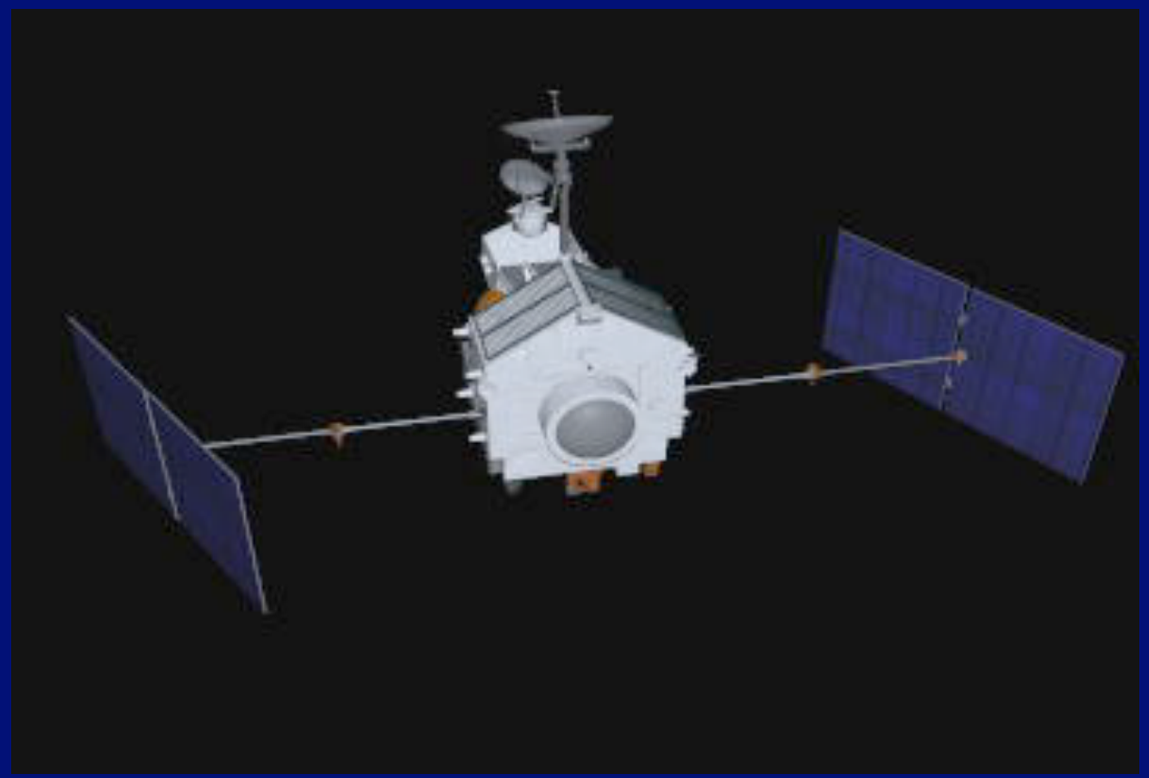
LIS is an **optical *event* detector**

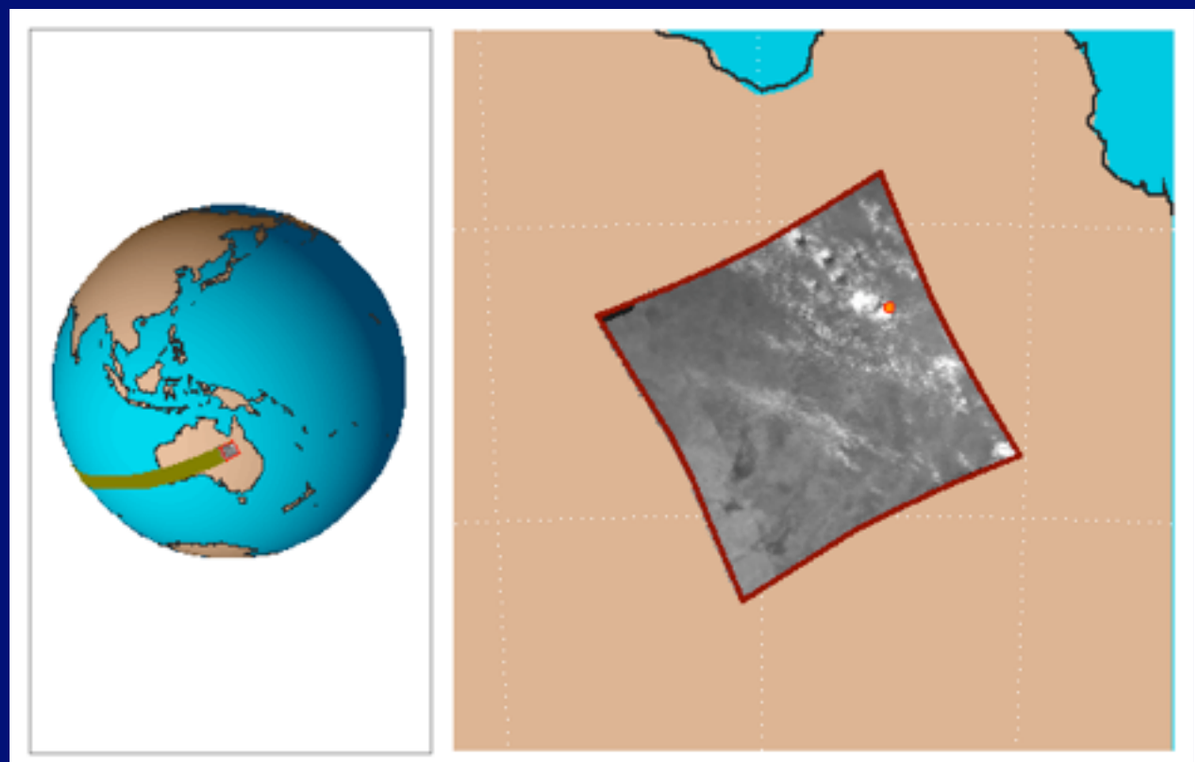




LIS is an **optical *event* detector**

These events can be classified into ~~strokes~~ groups and flashes.



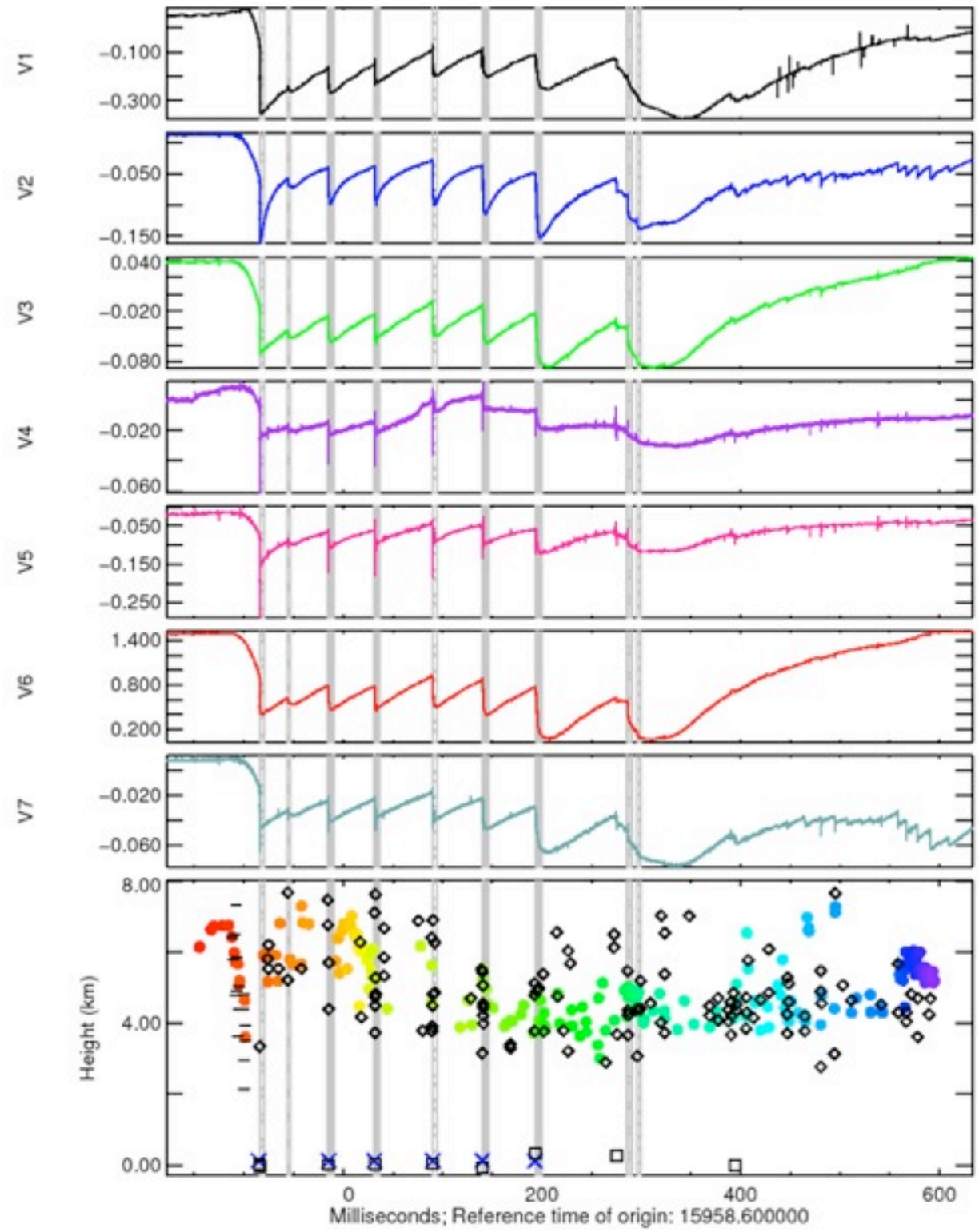


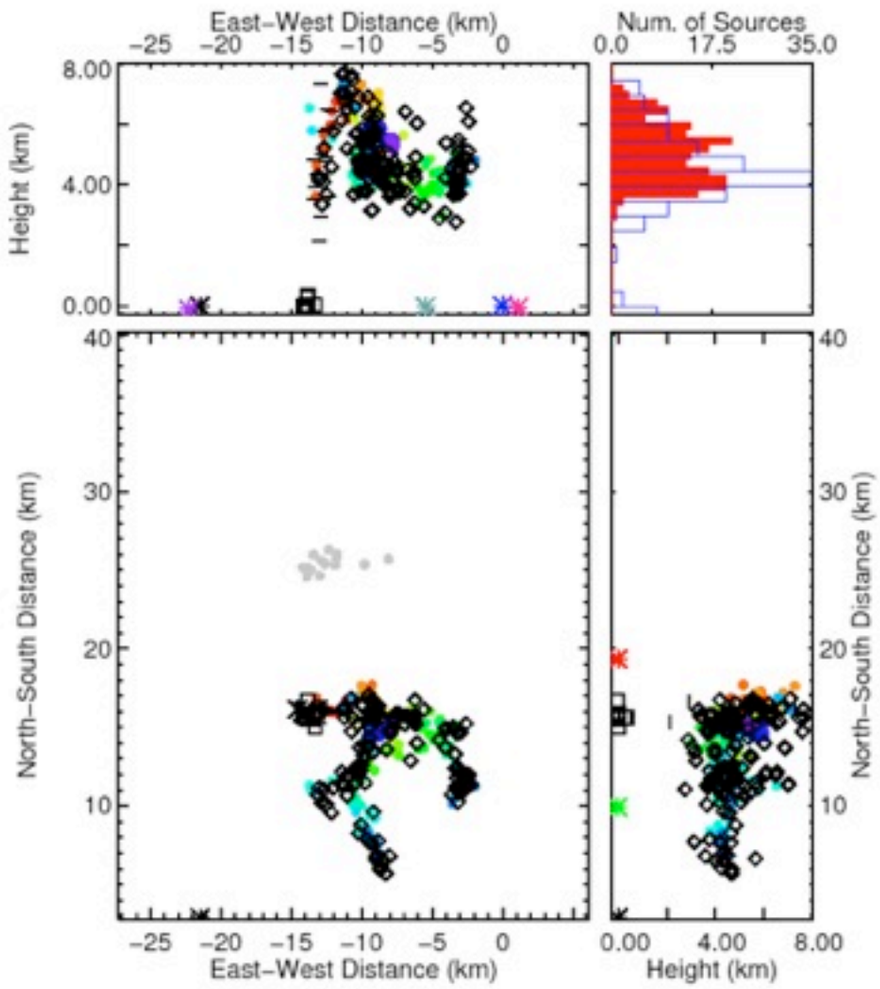
LIS is an **optical *event* detector**

These events can be classified into
~~strokes~~ groups and flashes.

Validation of LIS/GLM measurements
should use instruments sensitive to the part of the lightning
discharge which produces optical emission

2010/10/25 04:25:58



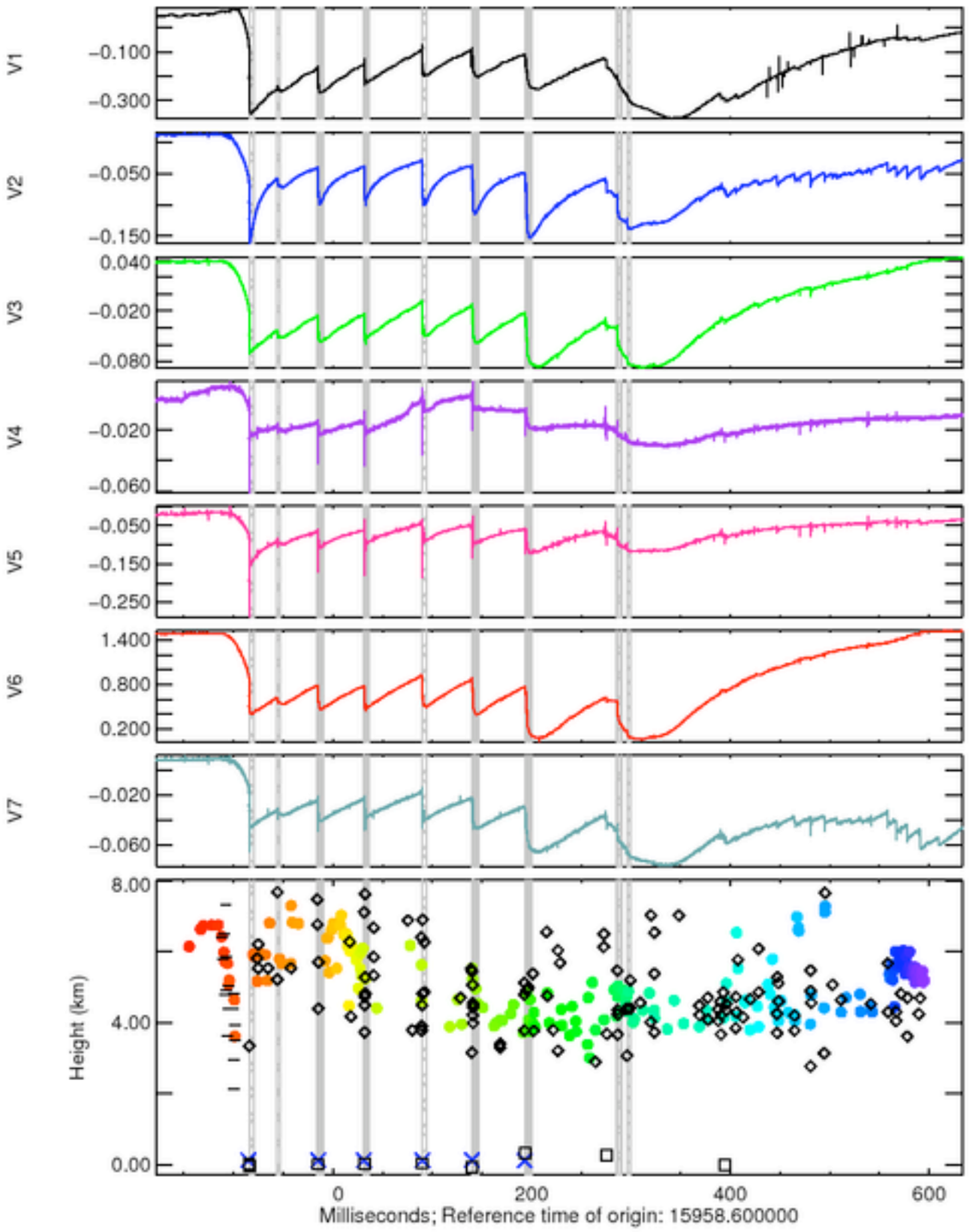


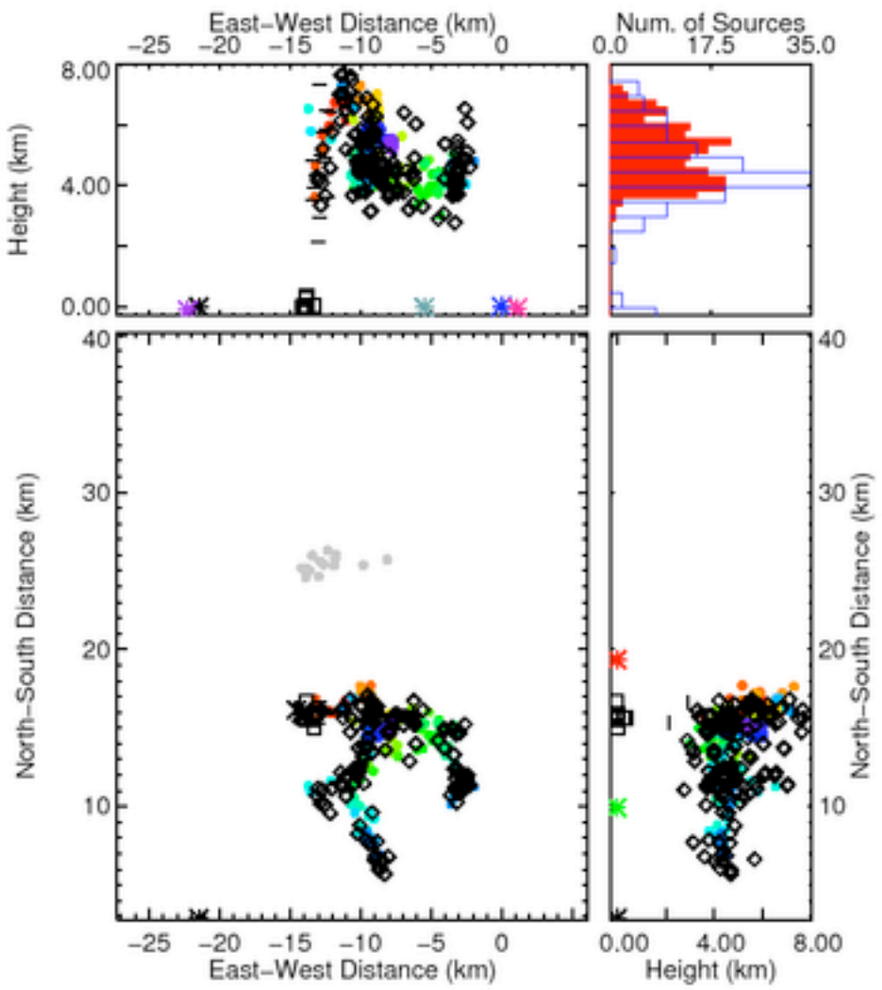
Base time: 15958.422249

Stop time: 15959.233089

Time Elapsed: 0.810840

2010/10/25 04:25:58



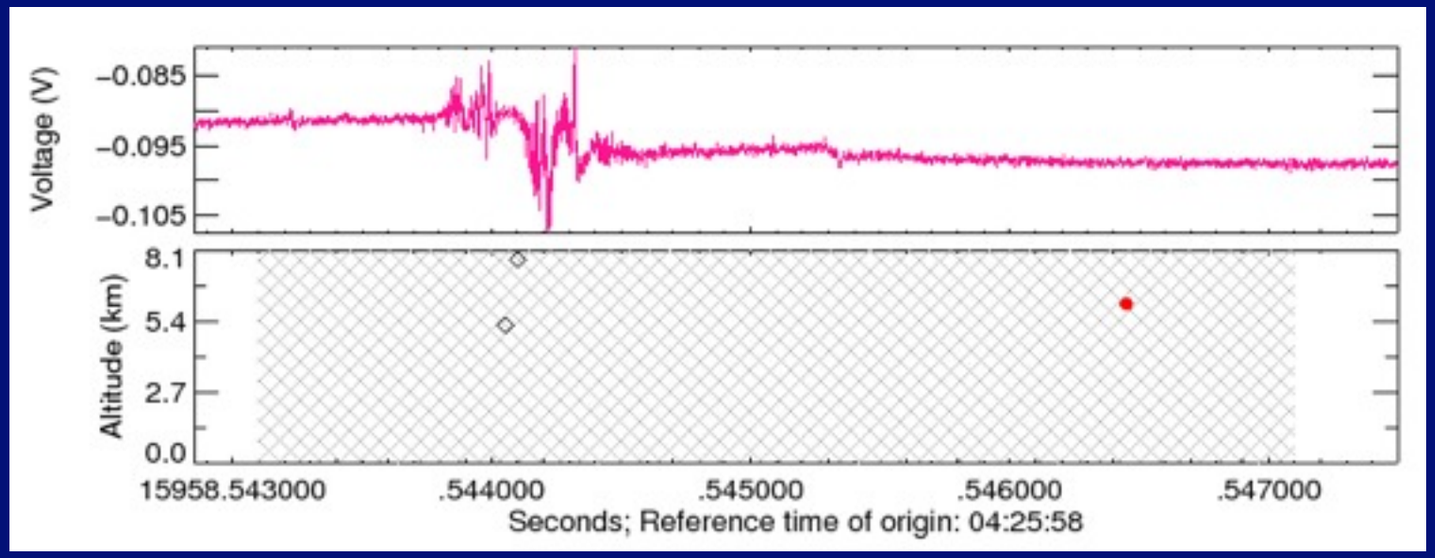


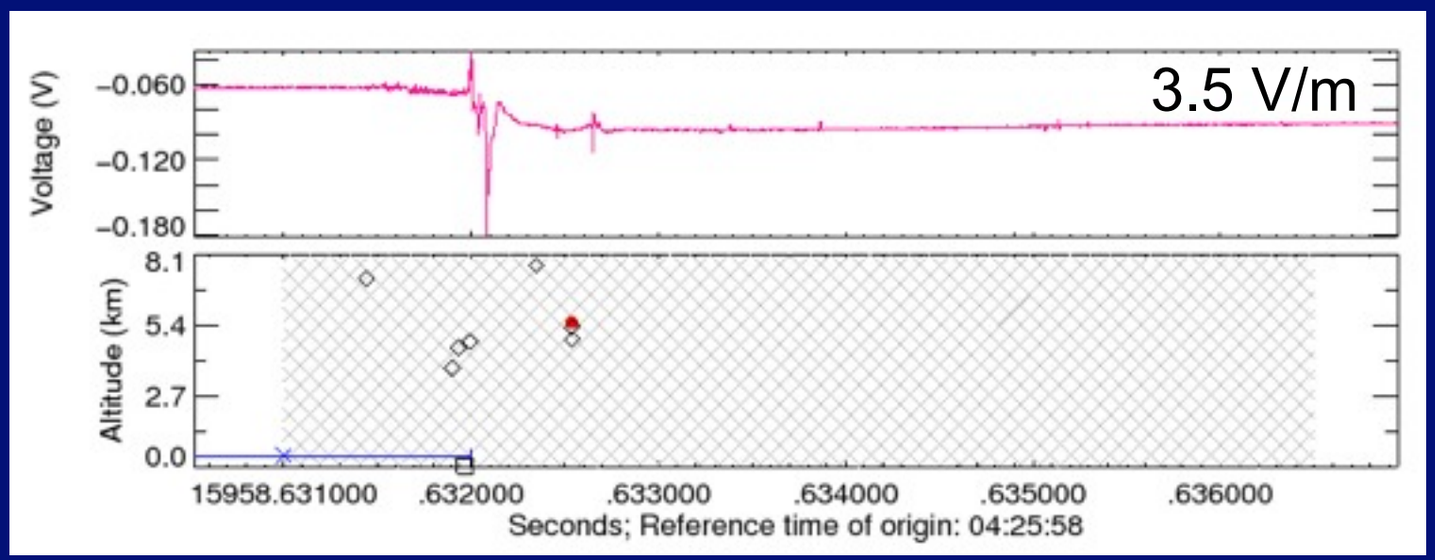
Base time: 15958.422249

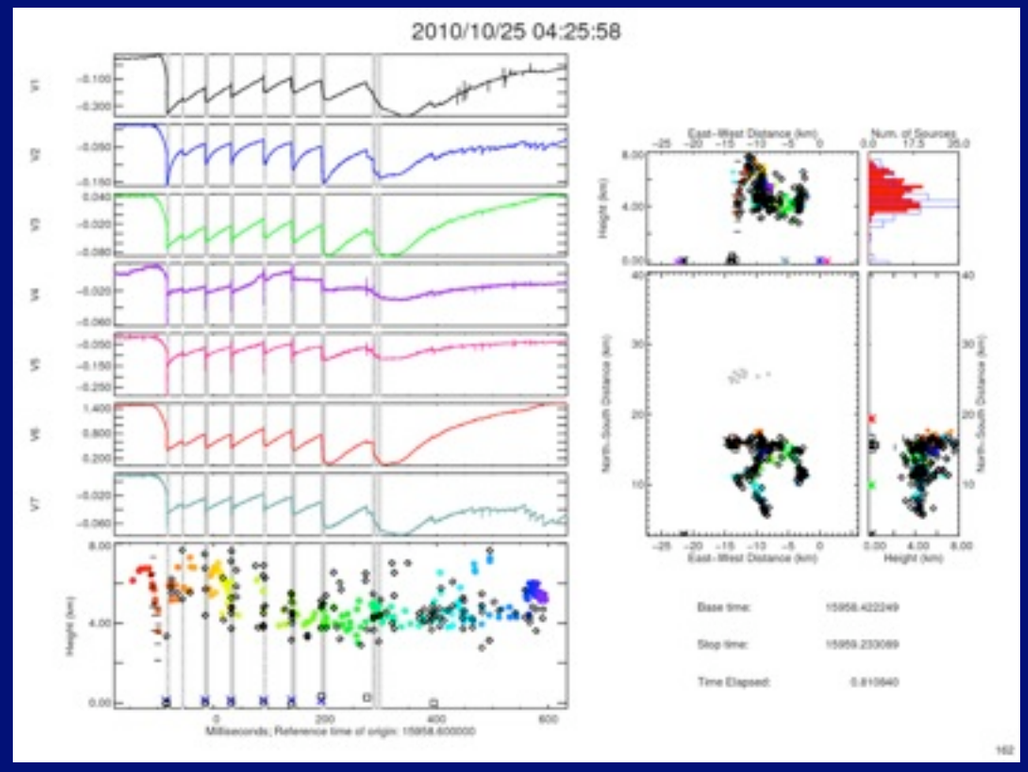
Stop time: 15959.233089

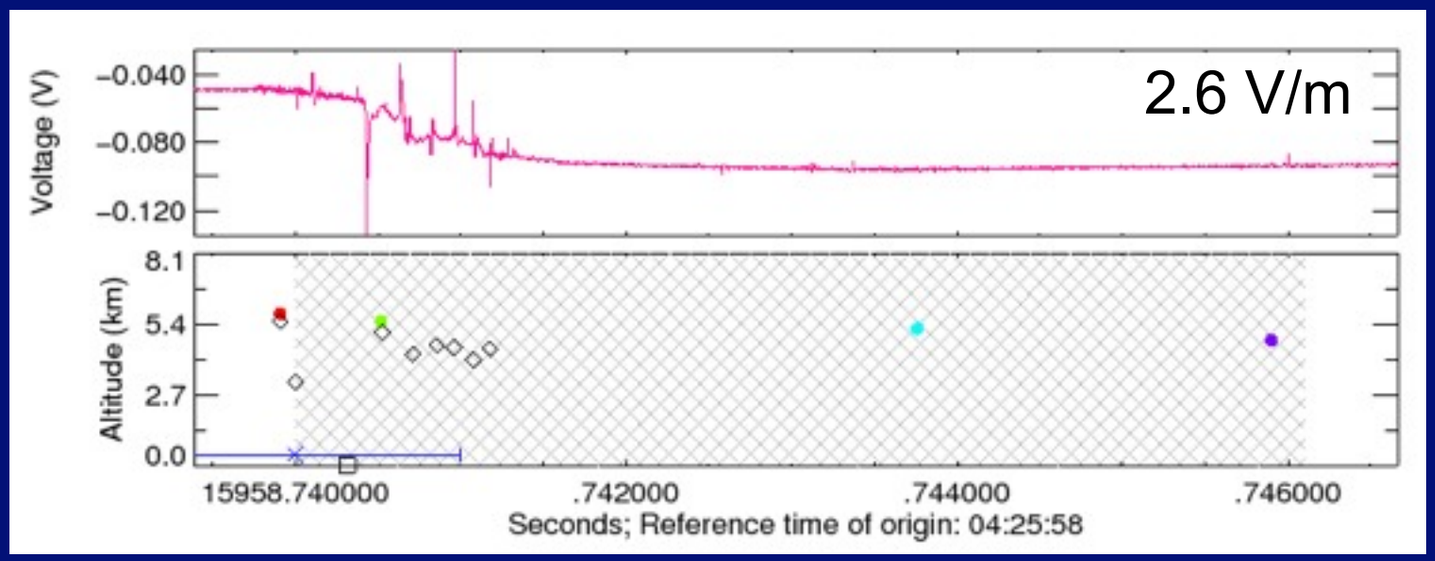
Time Elapsed: 0.810840

What is a hit?


Voltage (V)
−0.085
−0.095
−0.105
Altitude (km)
8.1
5.4
2.7
0.0
15958.543000
.544000
.545000
.546000
.547000
Seconds; Reference time of origin: 04:25:58


3.5 V/m
Voltage (V)
−0.060
−0.120
−0.180
Altitude (km)
8.1
5.4
2.7
0.0
15958.631000
.632000
.633000
.634000
.635000
.636000
Seconds; Reference time of origin: 04:25:58


2010/10/25 04:25:58
East-West Distance (km)
Num. of Sources
Height (km)
North-South Distance (km)
Base time:
Stop time:
Time Elapsed:
Milliseconds; Reference time of origin:


2.6 V/m
Voltage (V)
−0.040
−0.080
−0.120
Altitude (km)
8.1
5.4
2.7
0.0
15958.740000
.742000
.744000
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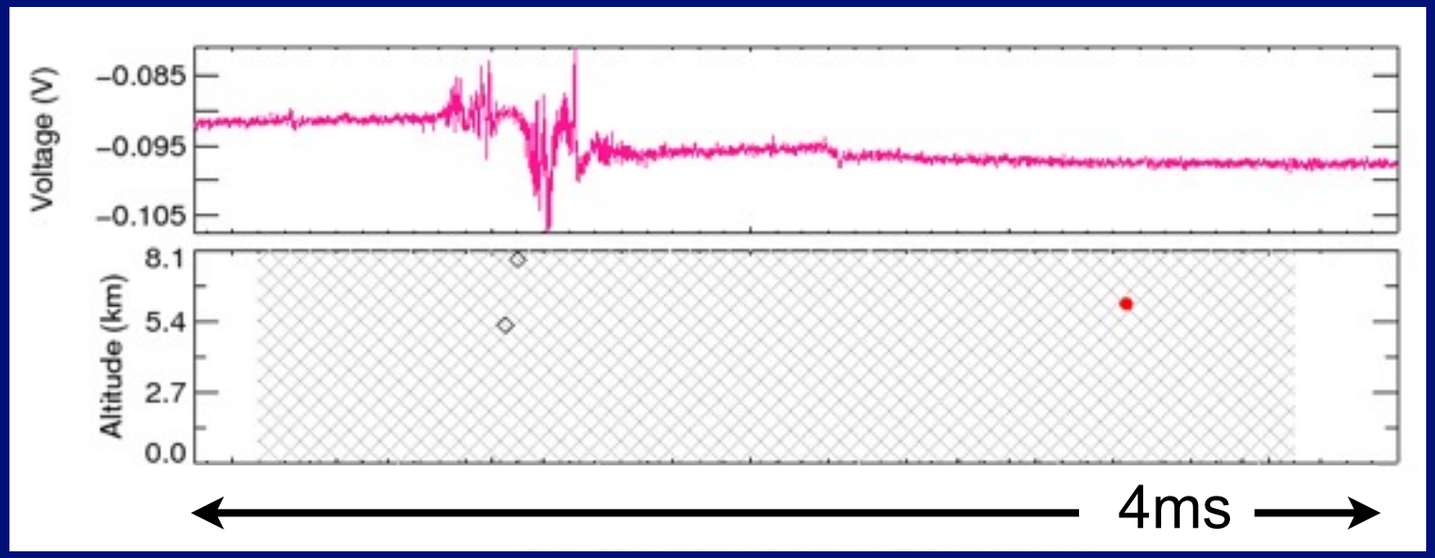
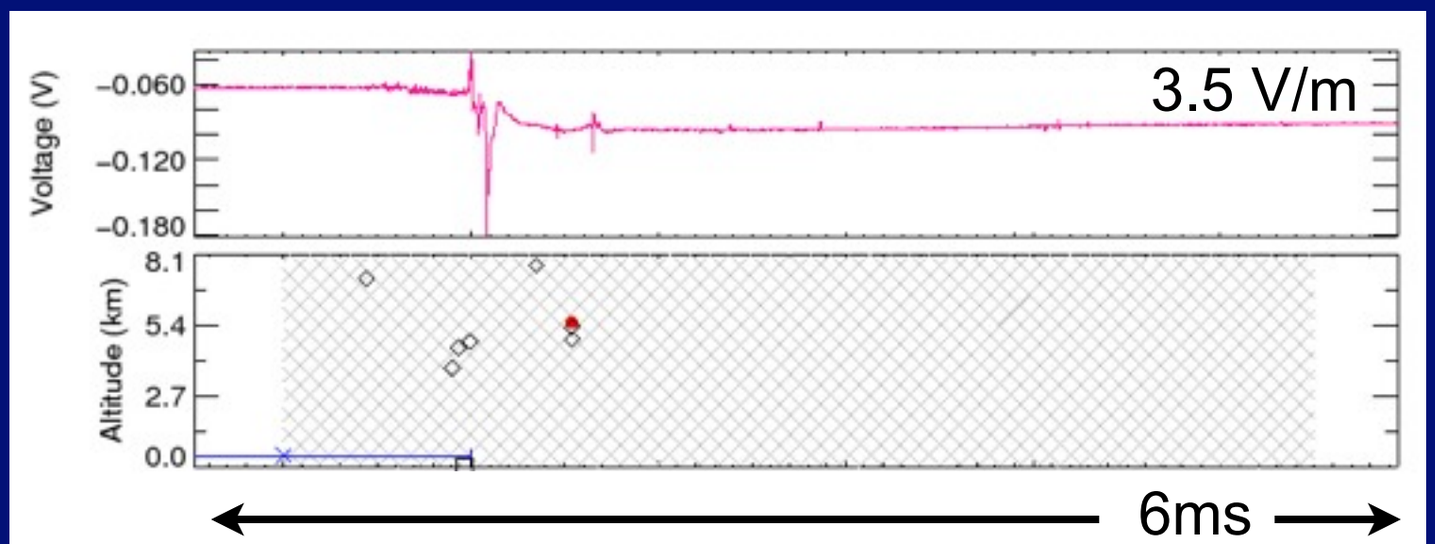
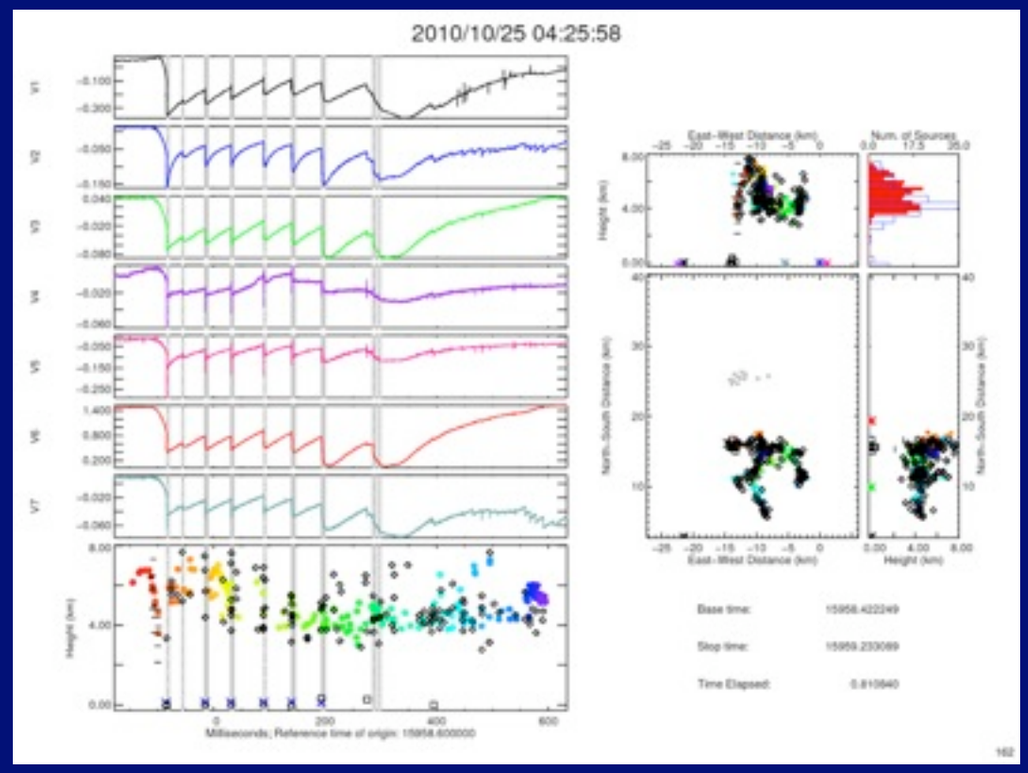
Seconds; Reference time of origin: 04:25:58

What is a hit?


Voltage (V)
−0.085
−0.095
−0.105
Altitude (km)
8.1
5.4
2.7
0.0
4ms


Voltage (V)
−0.060
−0.120
−0.180
3.5 V/m
Altitude (km)
8.1
5.4
2.7
0.0
6ms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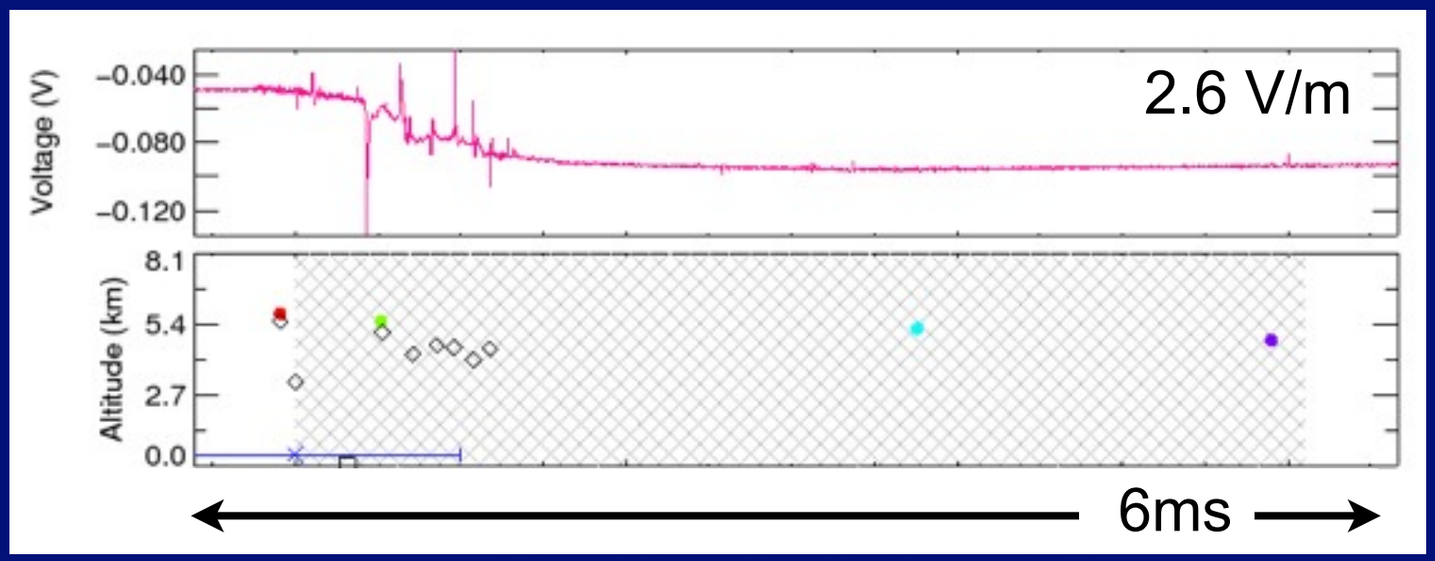
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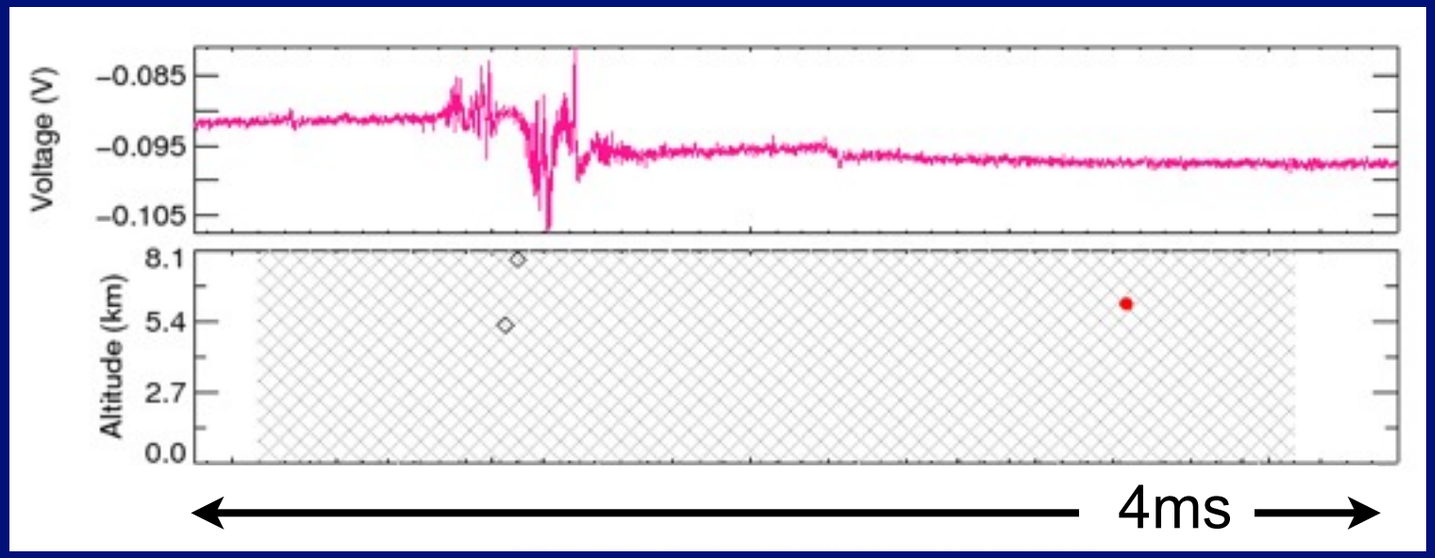
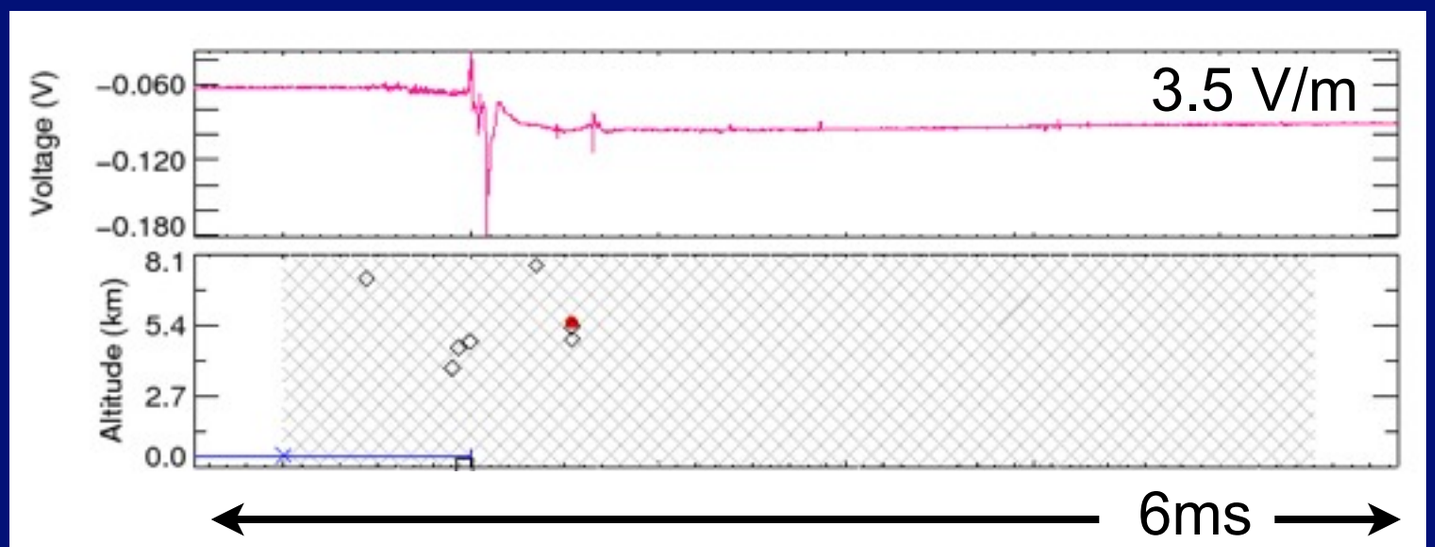
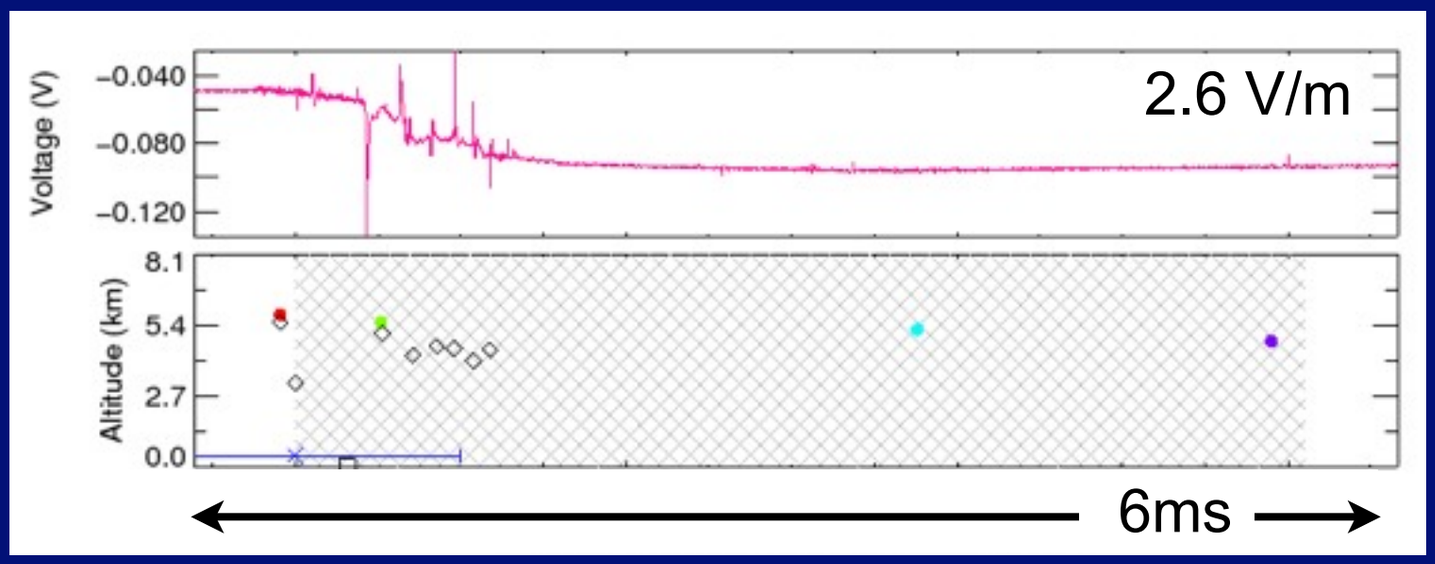
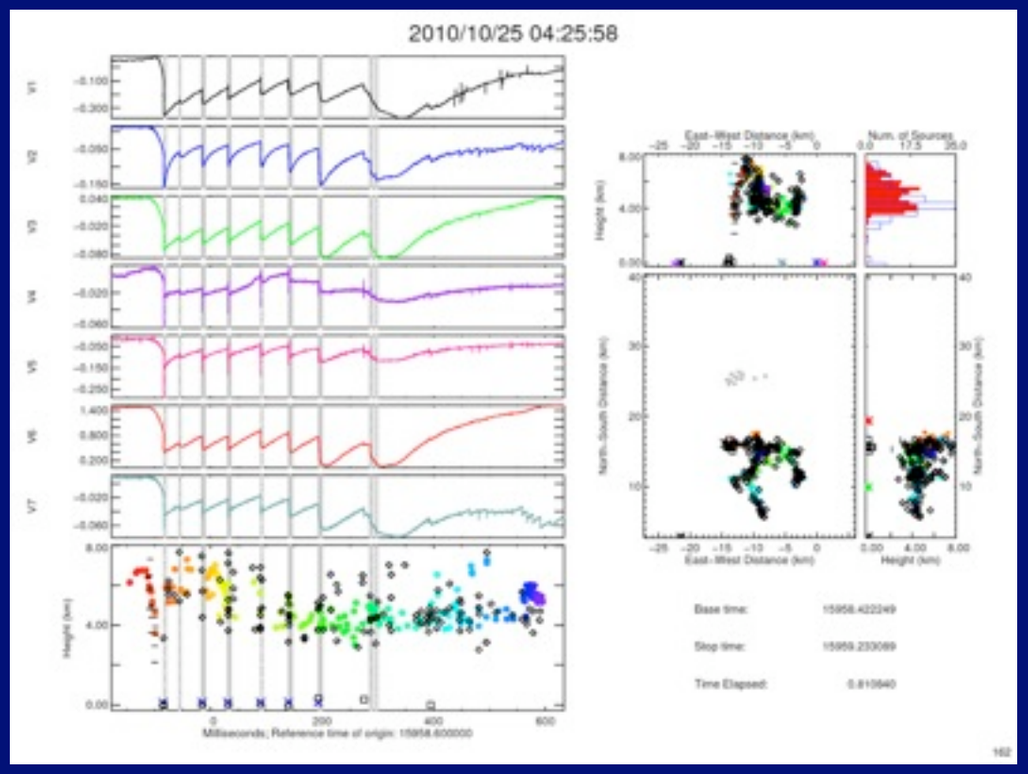
Altitude (km)
8.1
5.4
2.7
0.0
6ms

What is a hit?



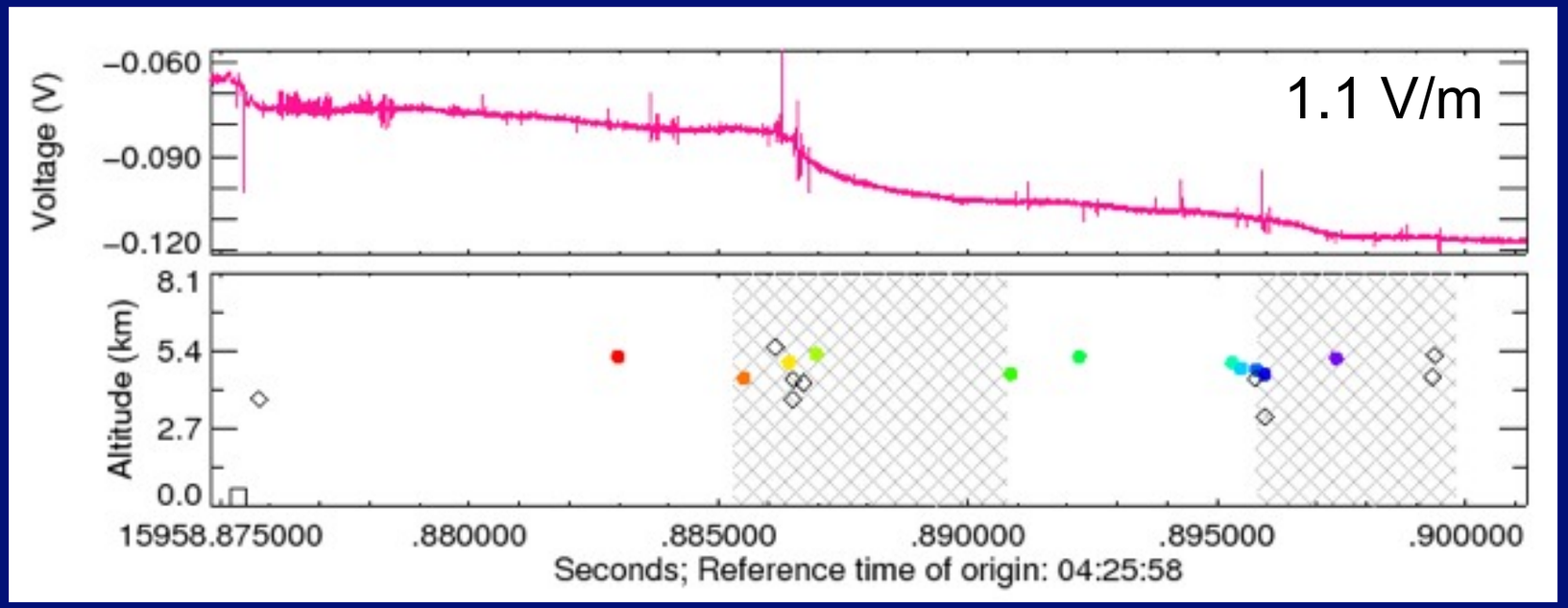


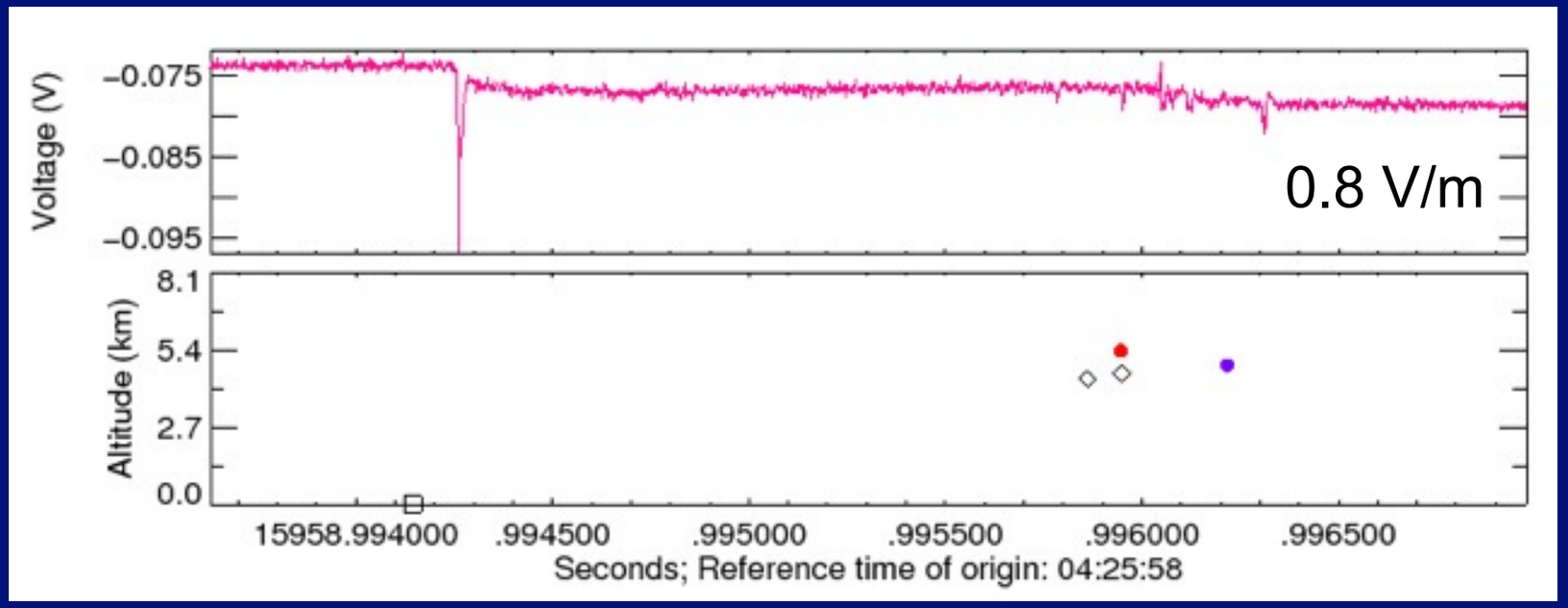




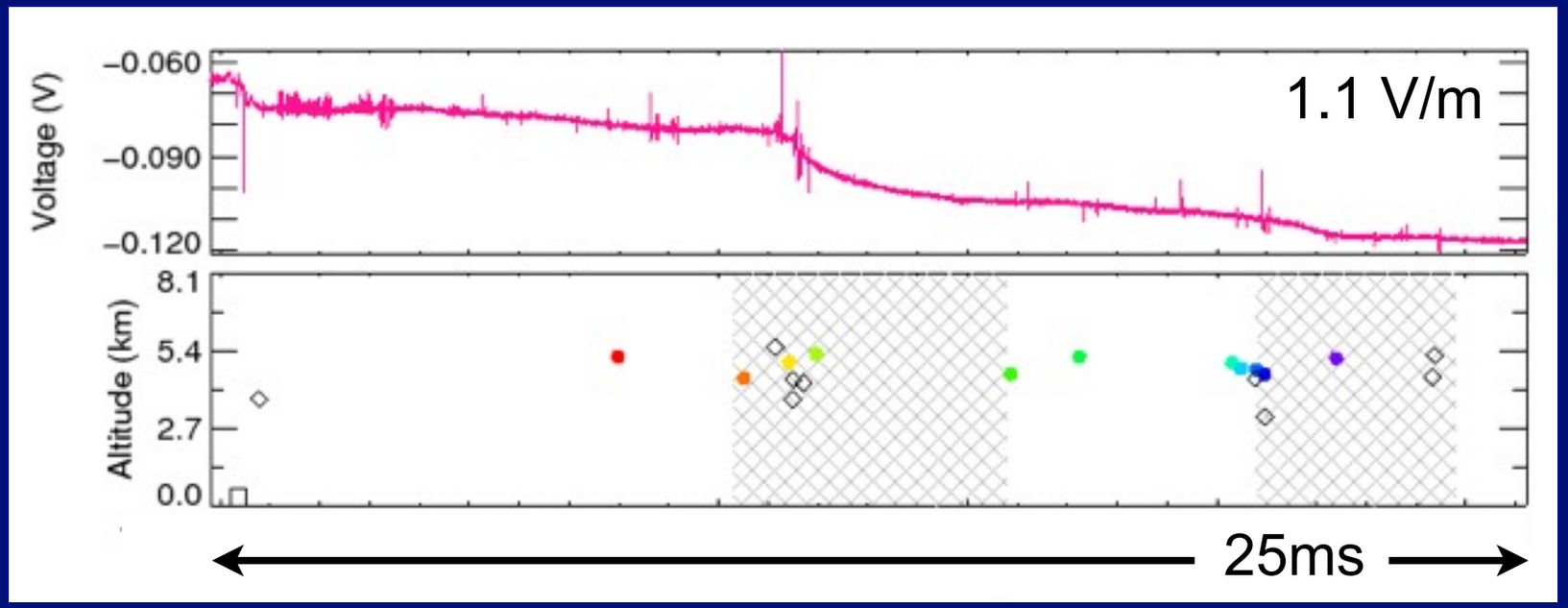
Wideband record indicates activity during LIS groups

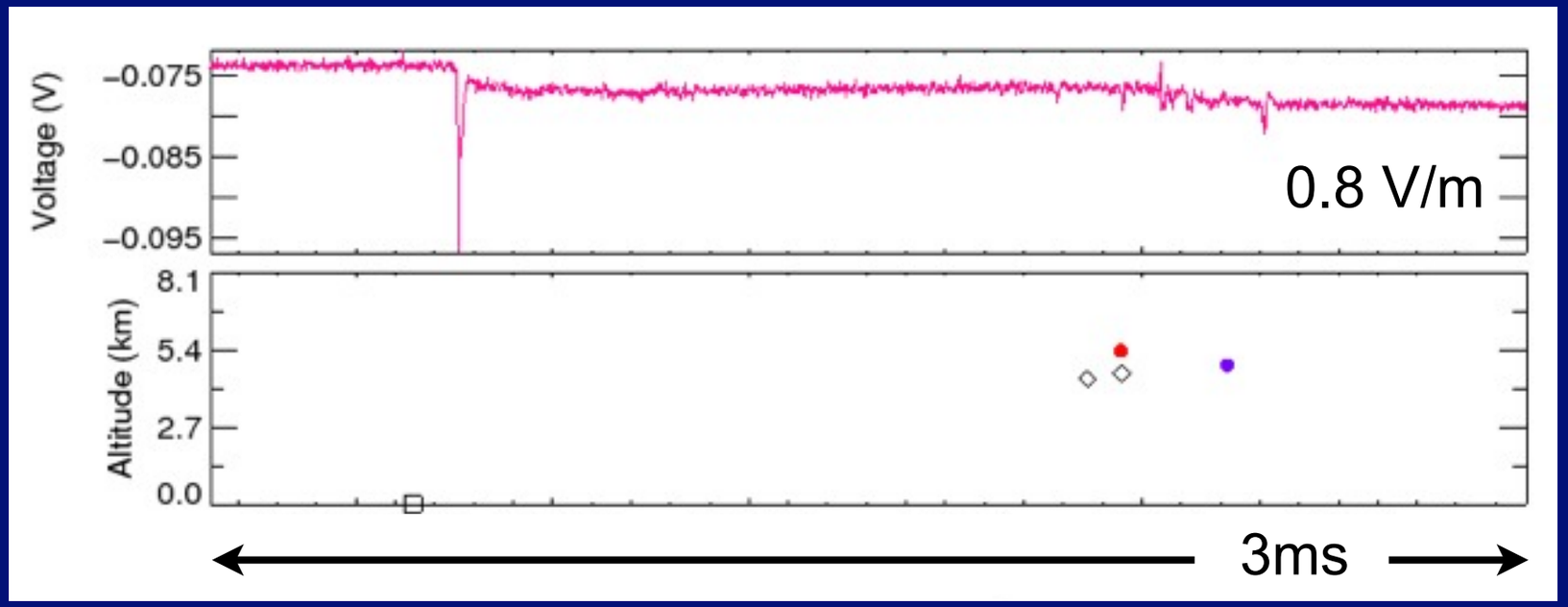
What is a miss?



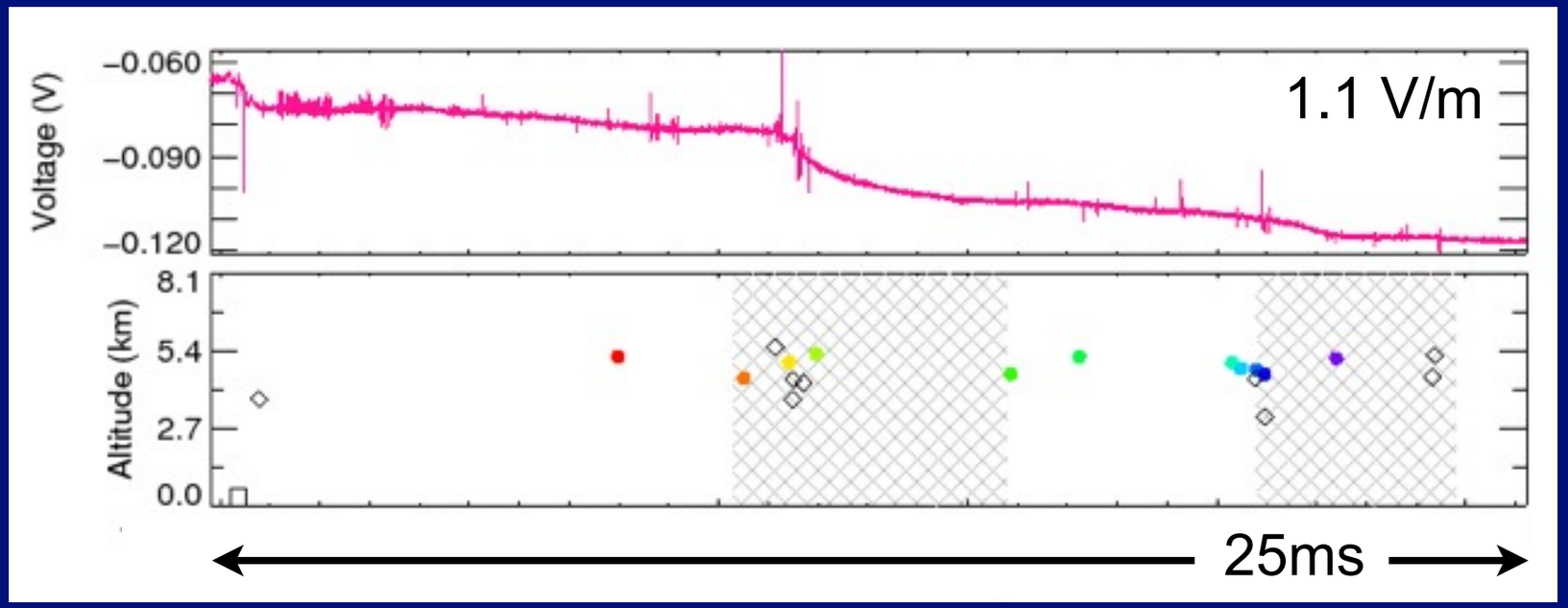


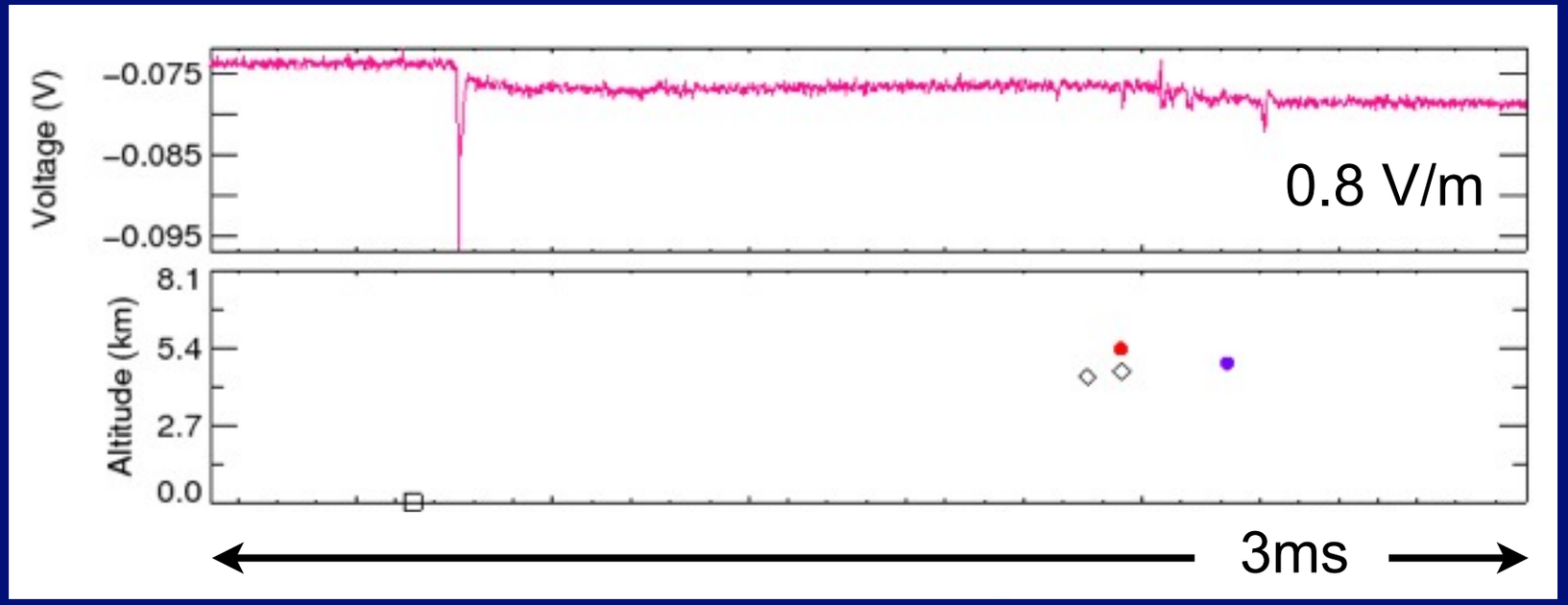
What is a miss?





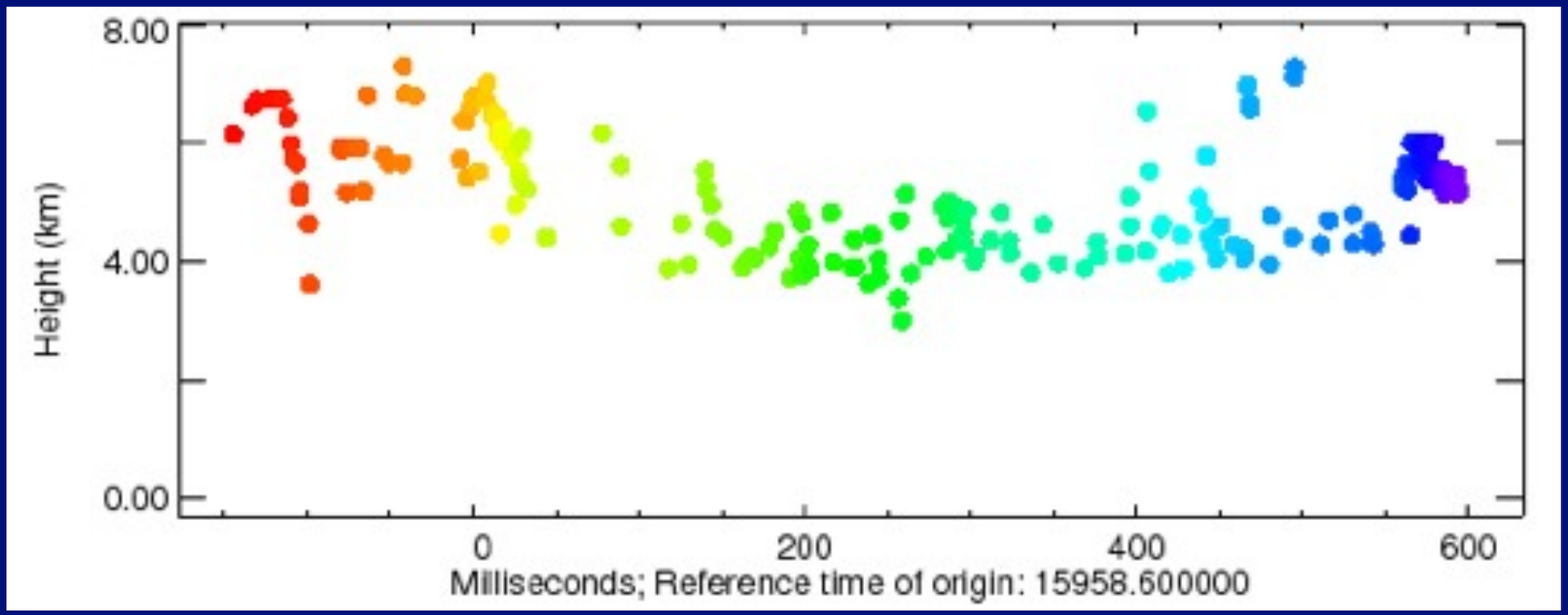
What is a miss?





Electric field measurements indicate that LIS missed these strokes because they are not very ***energetic***

What can VHF tell us?



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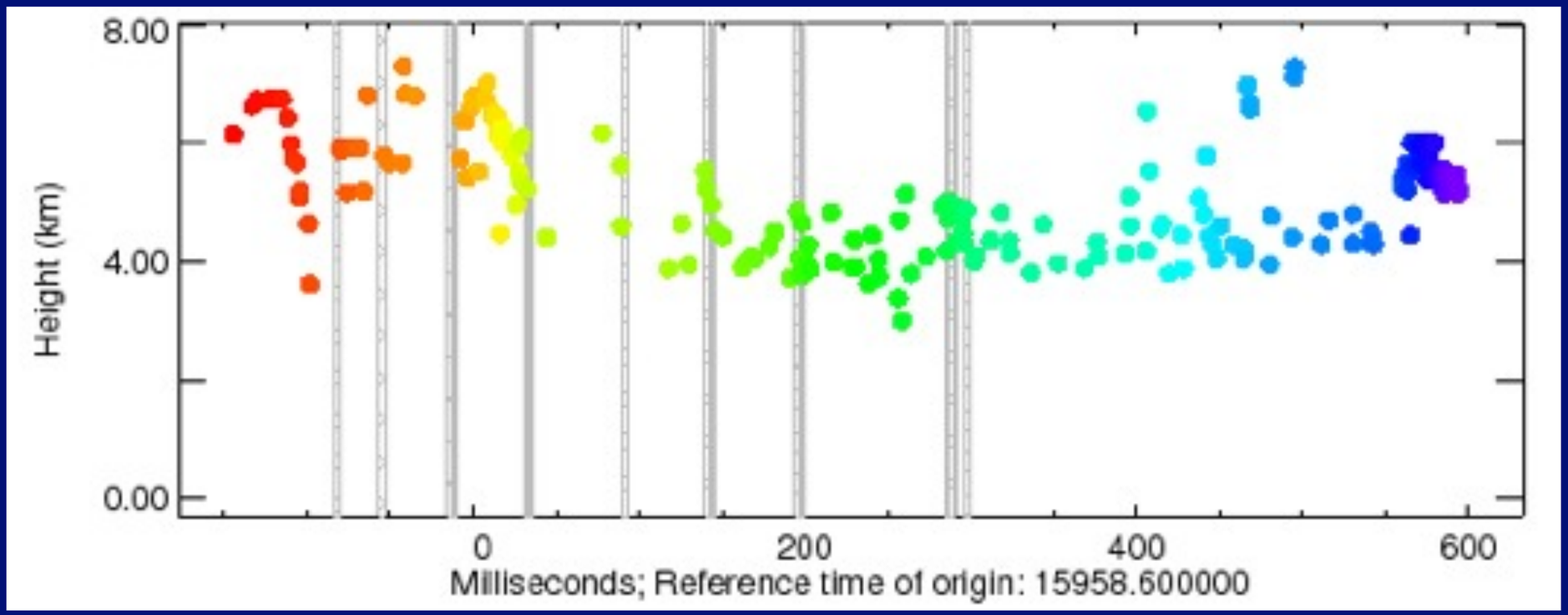

Nothing is really unique about VHF sources...

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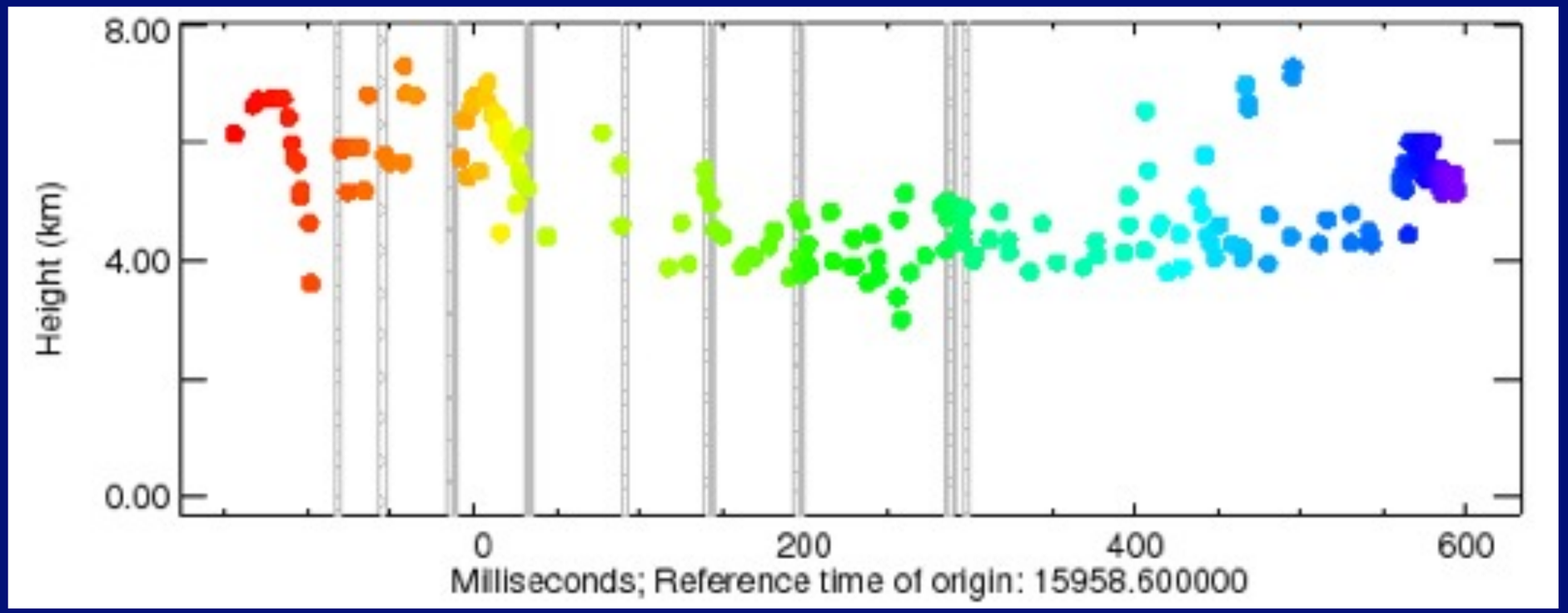

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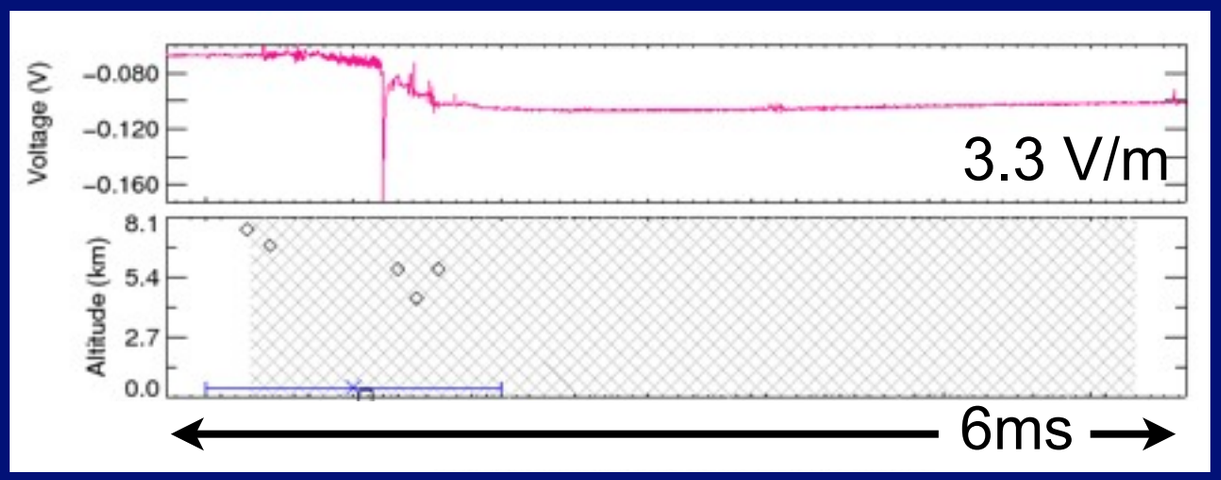

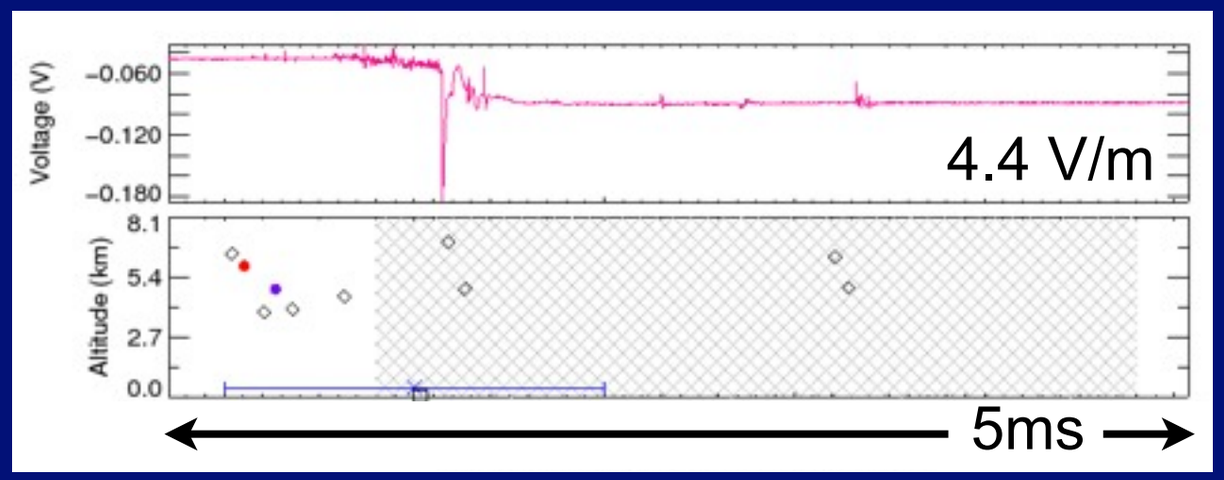

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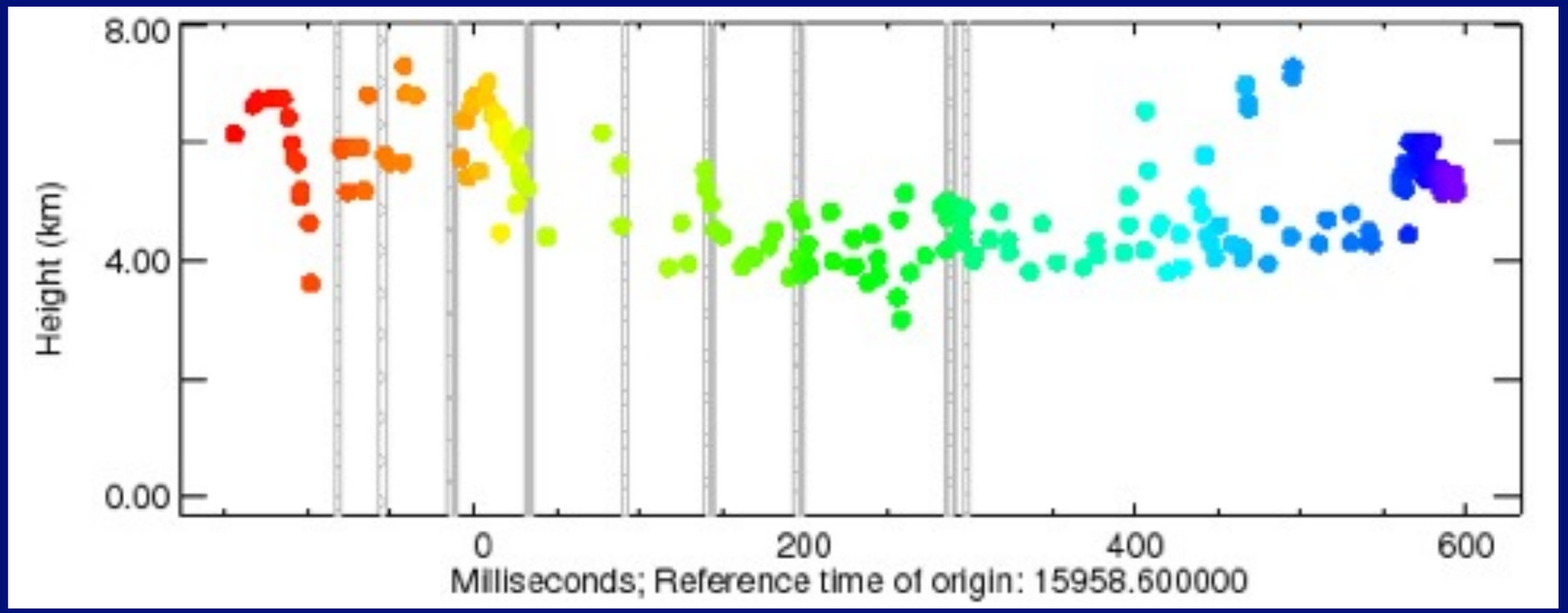

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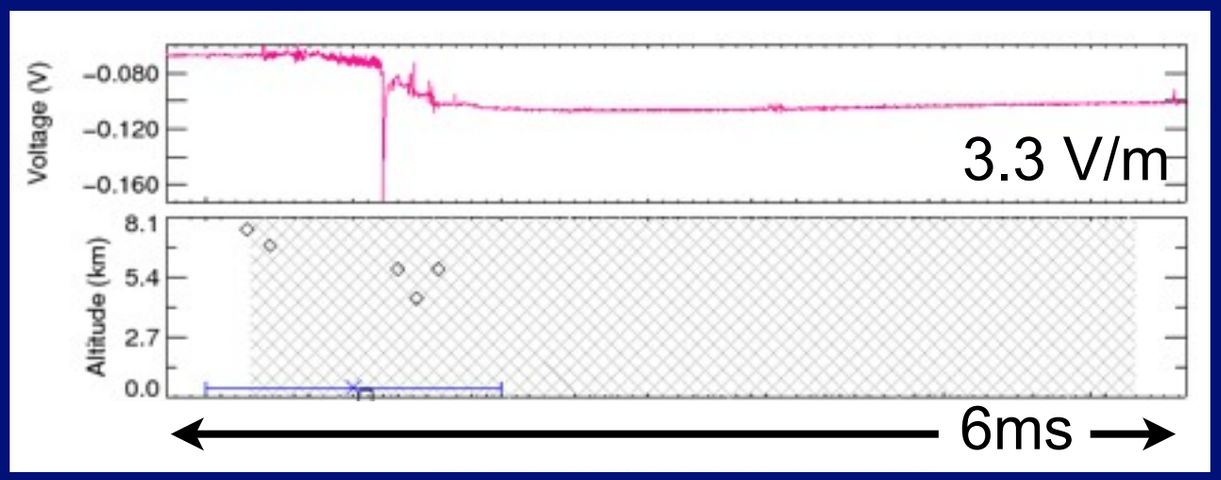
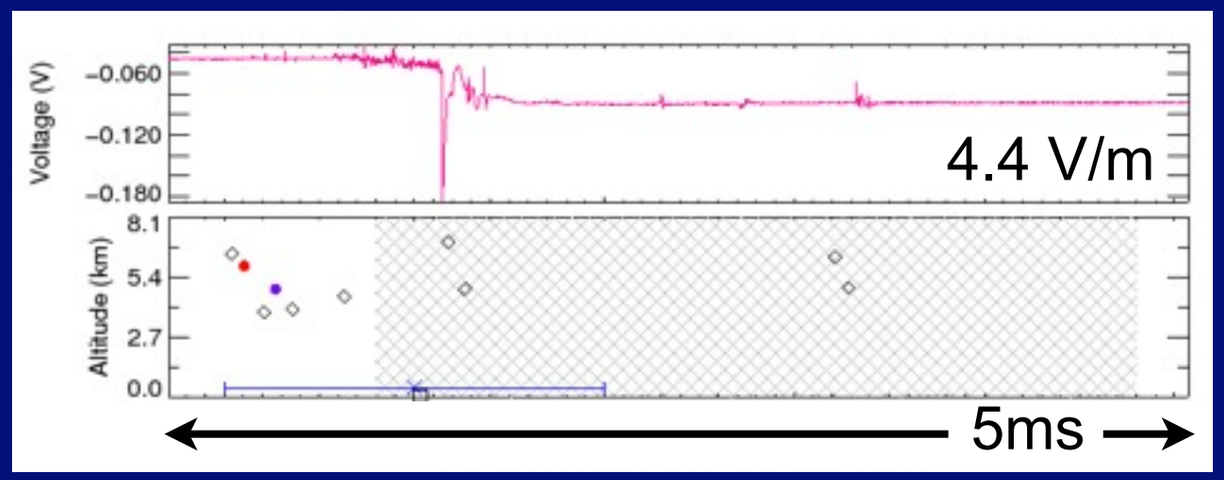
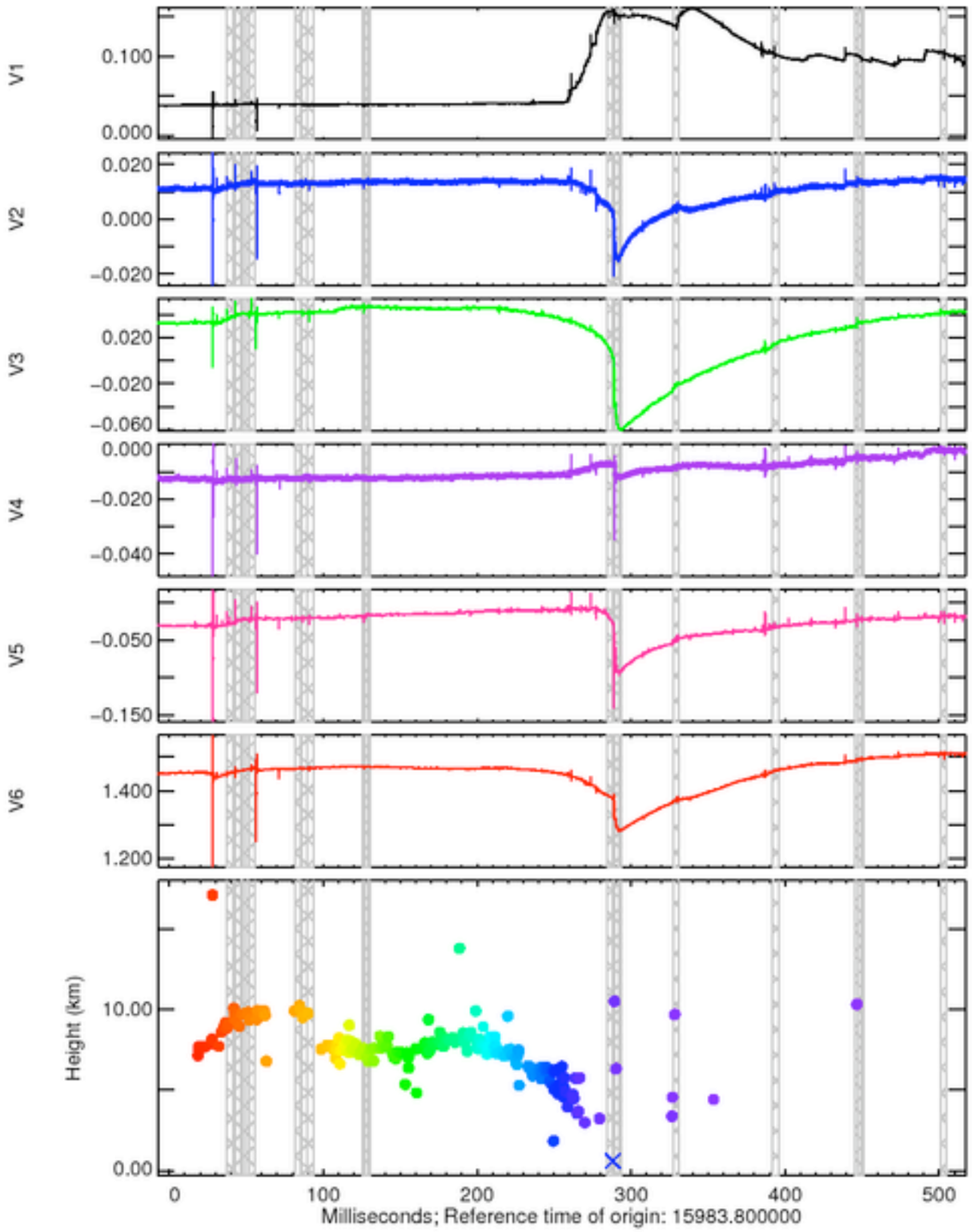
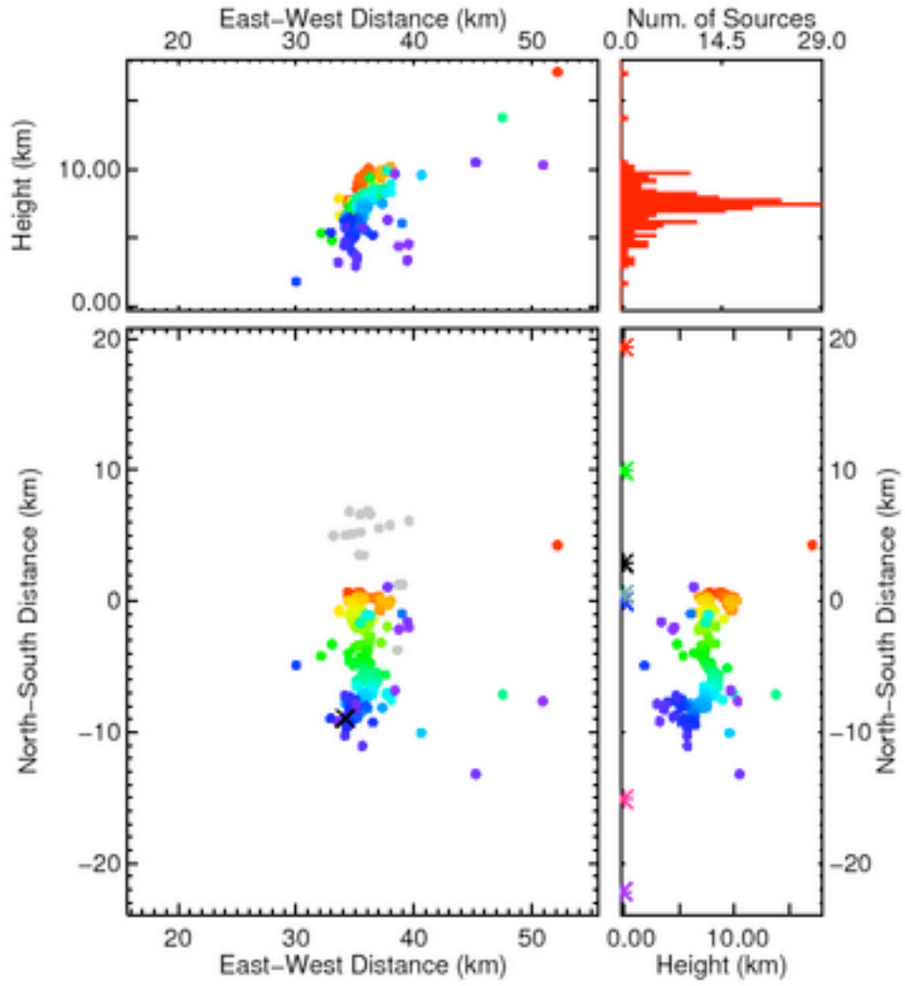




...in fact, there are LIS groups without any detected VHF sources!

2010/10/25 04:26:23





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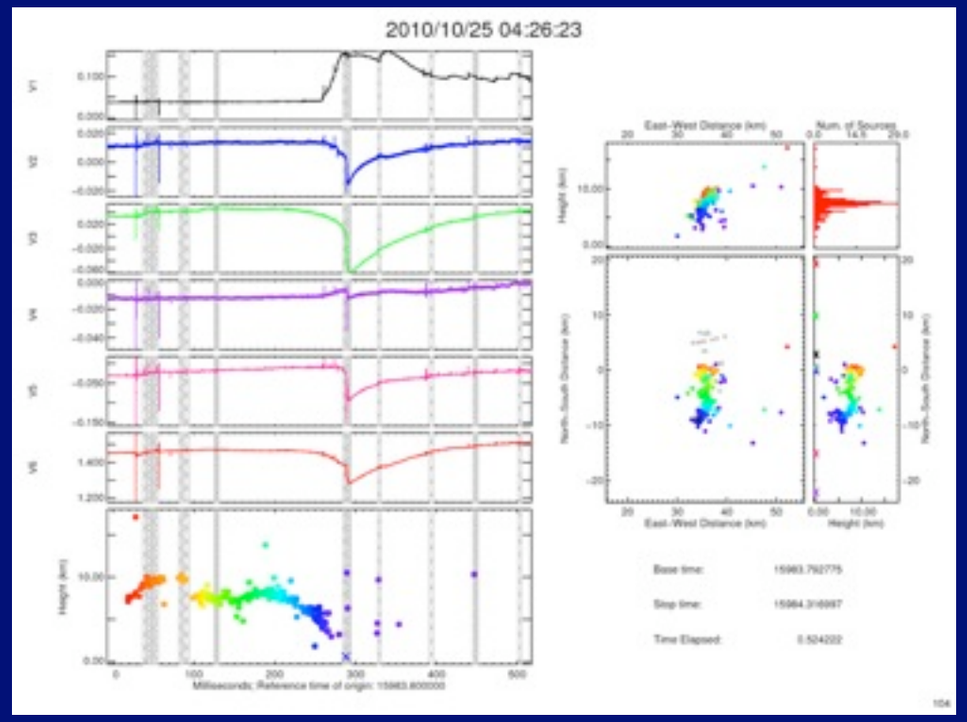
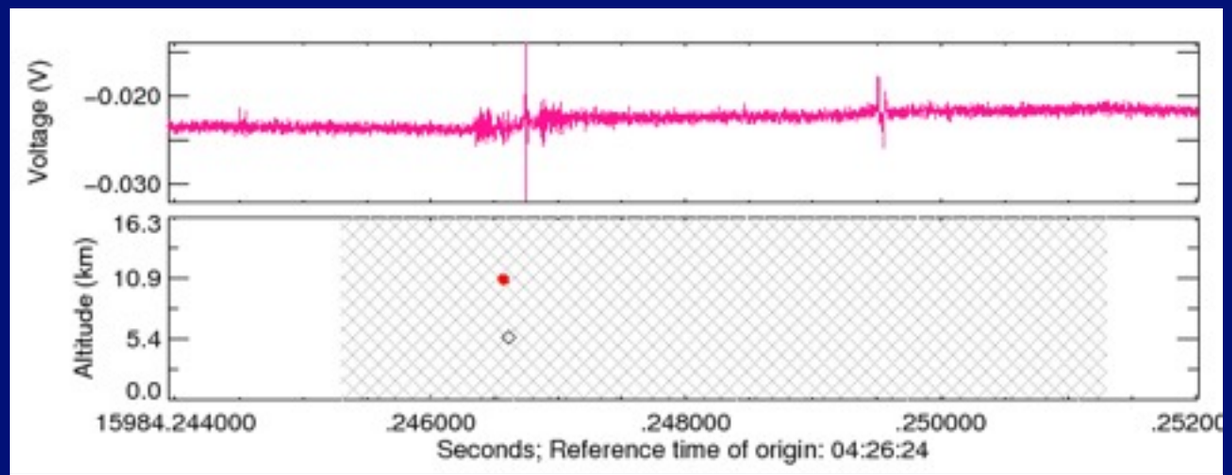
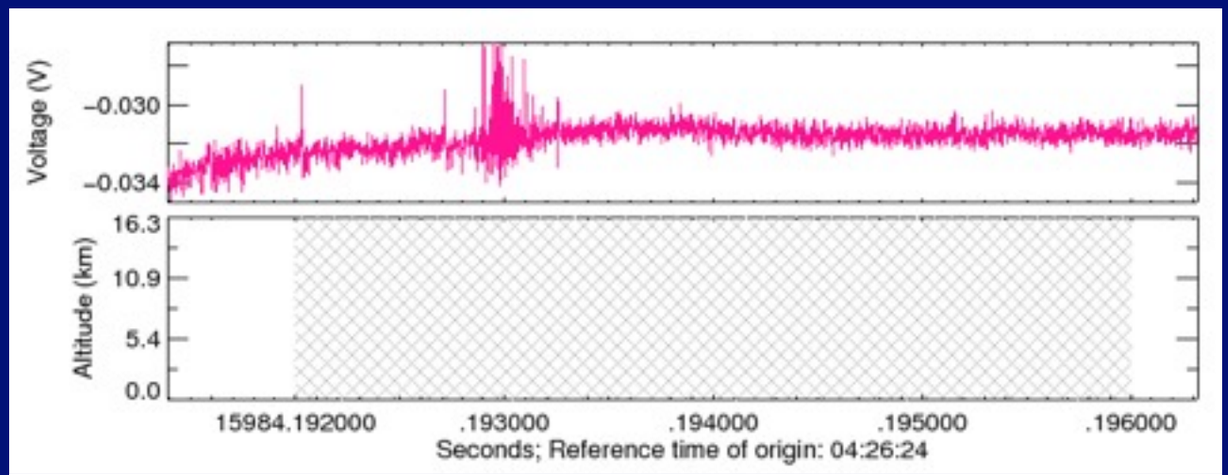
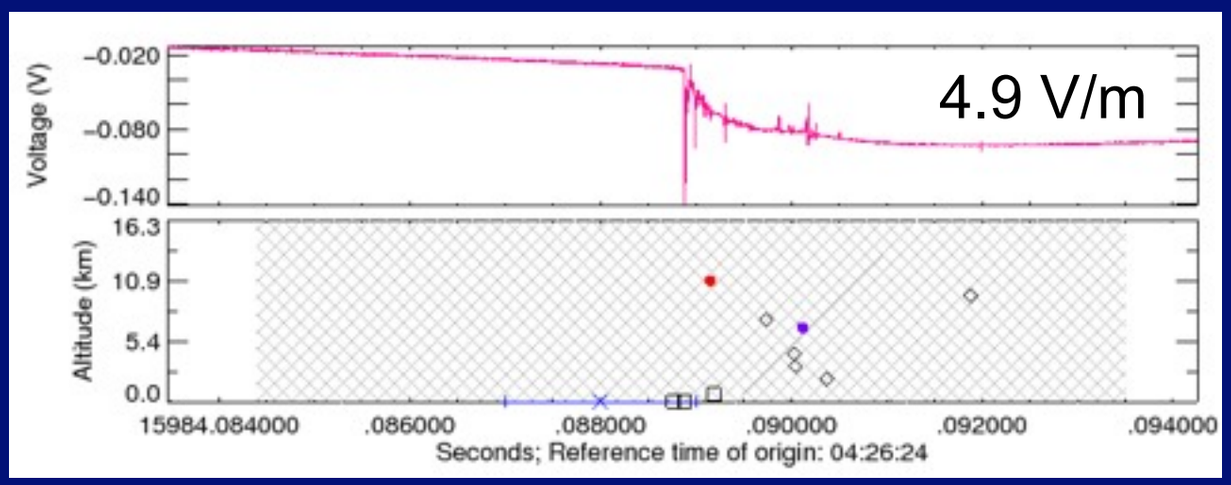
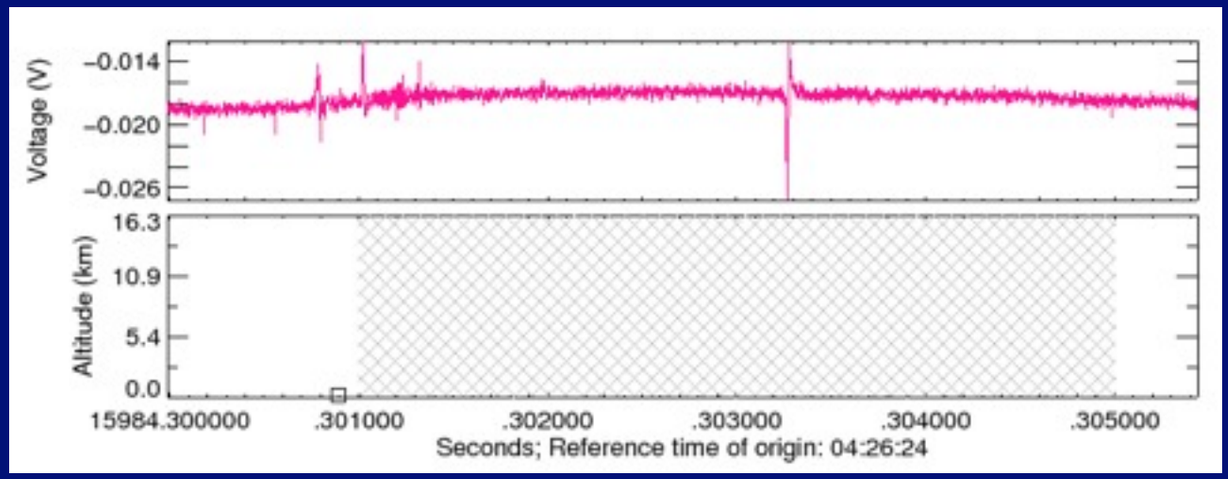
Stop time:	15984.316997
Time Elapsed:	0.524222

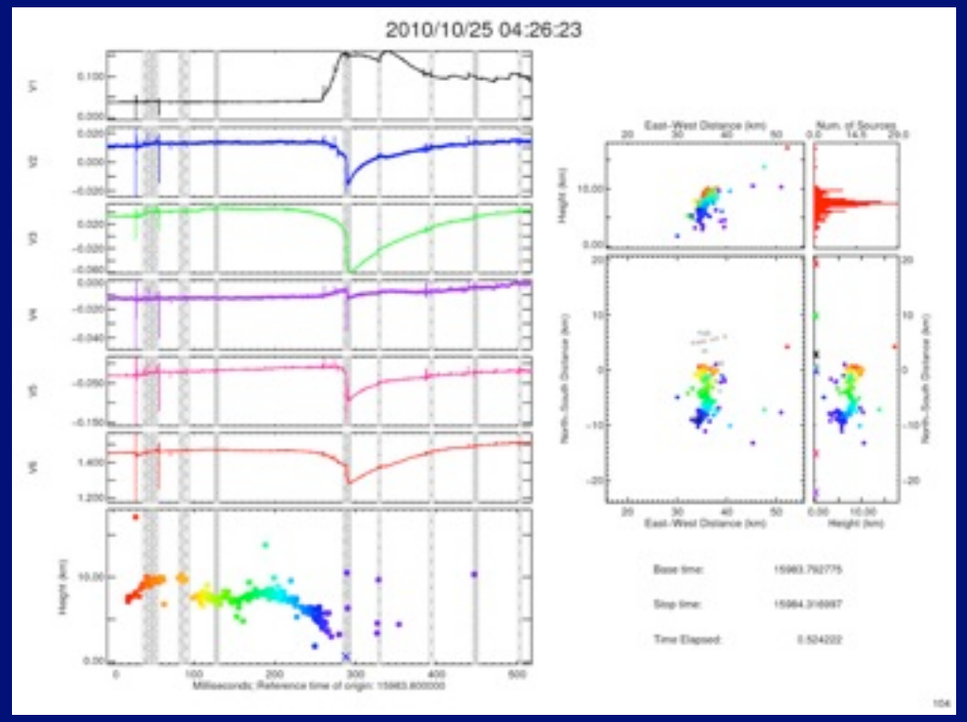

2010/10/25 04:26:23
East-West Distance (km)
Num. of Sources
Height (km)
North-South Distance (km)
Base time:
Stop time:
Time Elapsed:
Milliseconds; Reference time of origin:

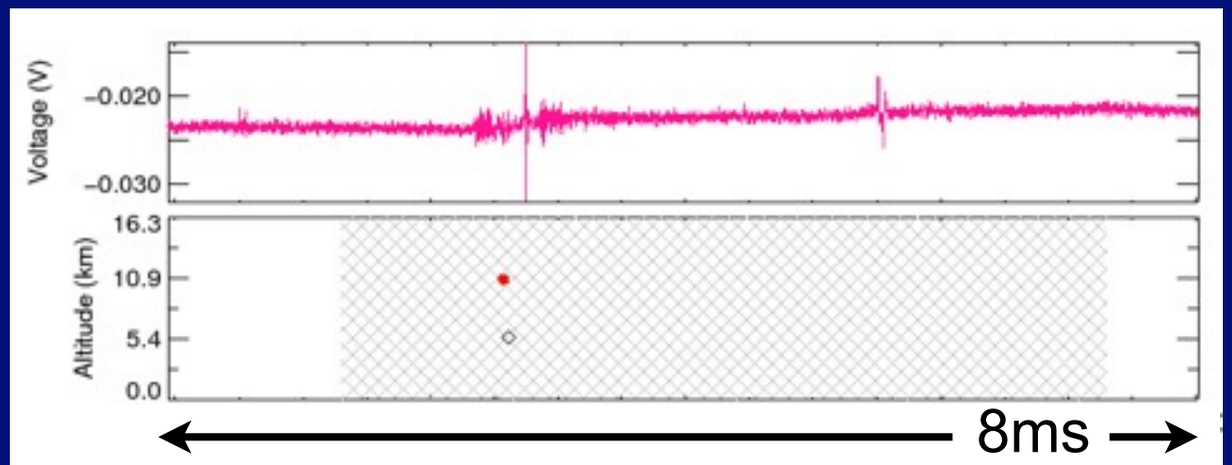

Voltage (V)
-0.020
-0.030
Altitude (km)
16.3
10.9
5.4
0.0
15984.244000
.246000
.248000
.250000
Seconds; Reference time of origin: 04:26:24

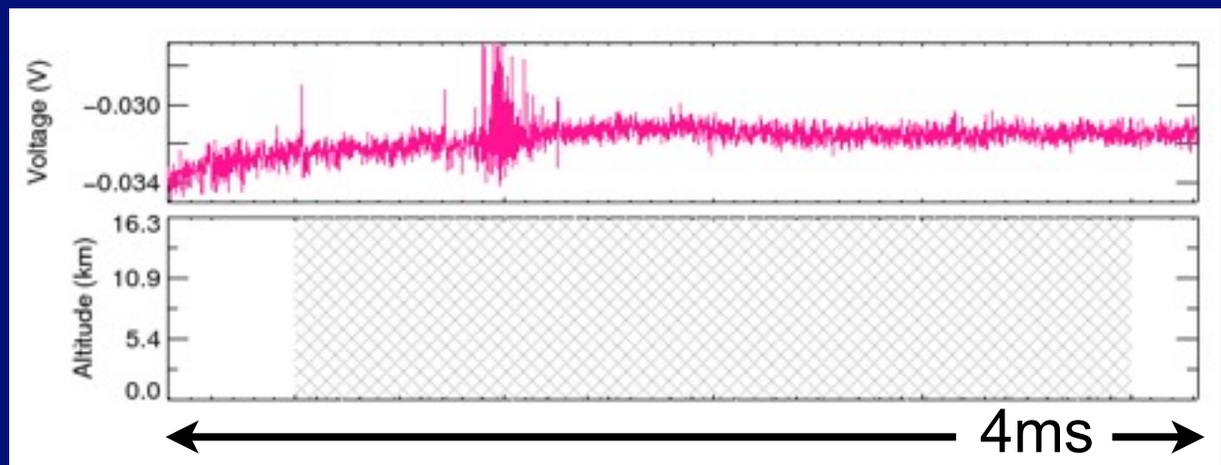

Voltage (V)
-0.030
-0.034
Altitude (km)
16.3
10.9
5.4
0.0
15984.192000
.193000
.194000
.195000
.196000
Seconds; Reference time of origin: 04:26:24

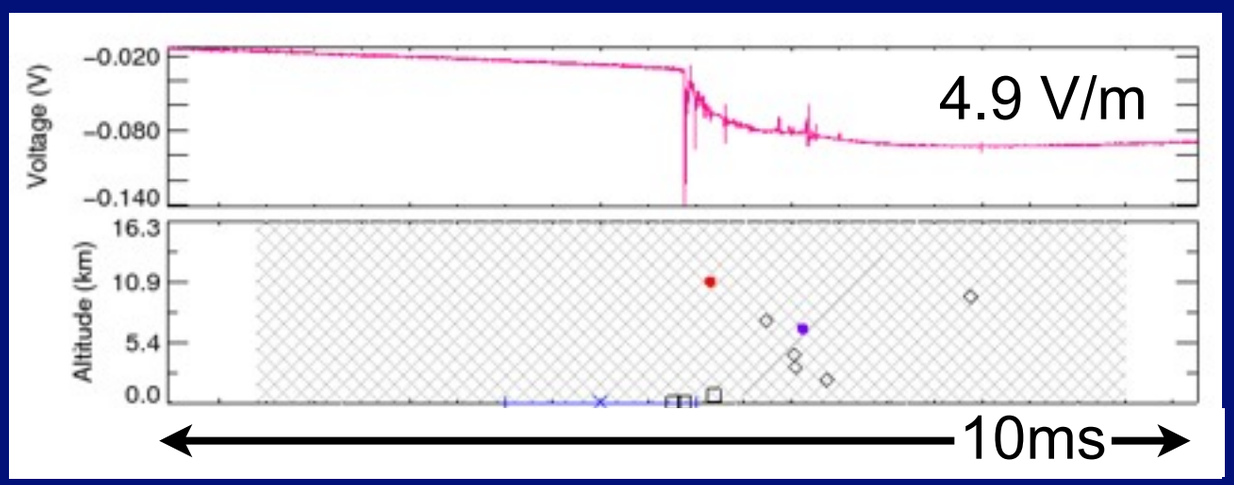

4.9 V/m
Voltage (V)
-0.020
-0.080
-0.140
Altitude (km)
16.3
10.9
5.4
0.0
15984.084000
.086000
.088000
.090000
.092000
.094000
Seconds; Reference time of origin: 04:26:24

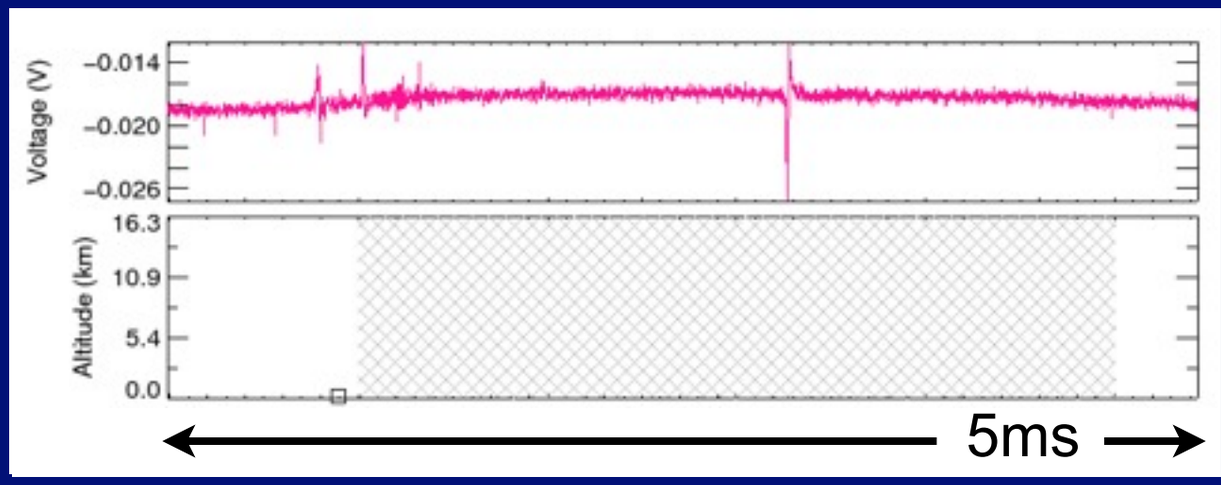

Voltage (V)
-0.014
-0.020
-0.026
Altitude (km)
16.3
10.9
5.4
0.0
15984.300000
.301000
.302000
.303000
.304000
.305000
Seconds; Reference time of origin: 04:26:24

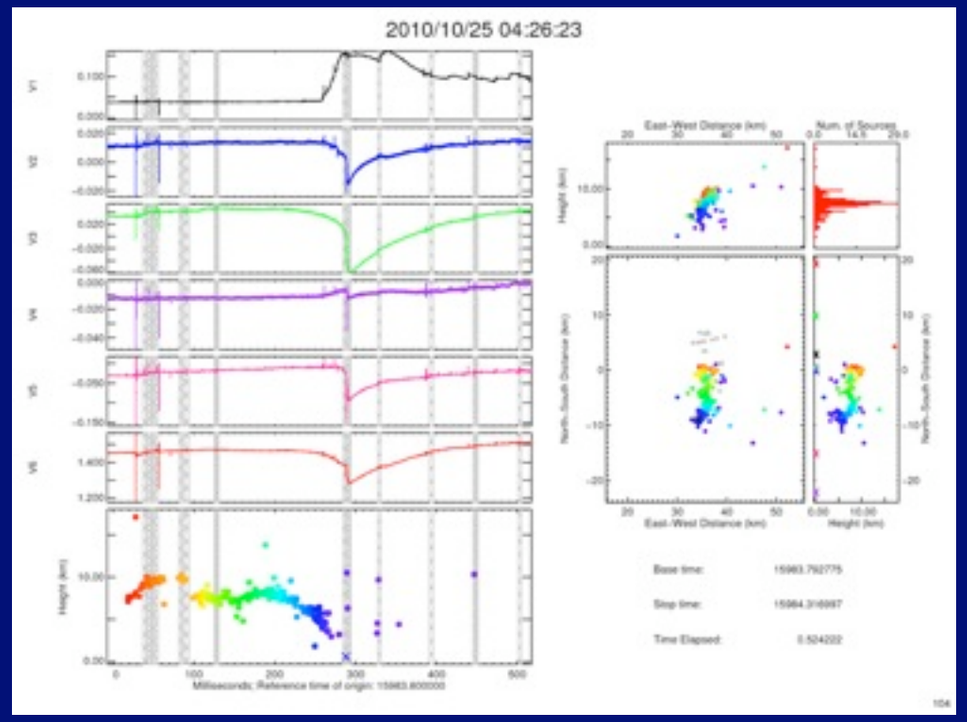

2010/10/25 04:26:23
East-West Distance (km)
Num. of Sources
Height (km)
North-South Distance (km)
Base time:
Stop time:
Time Elapsed:
Milliseconds; Reference time of origin:

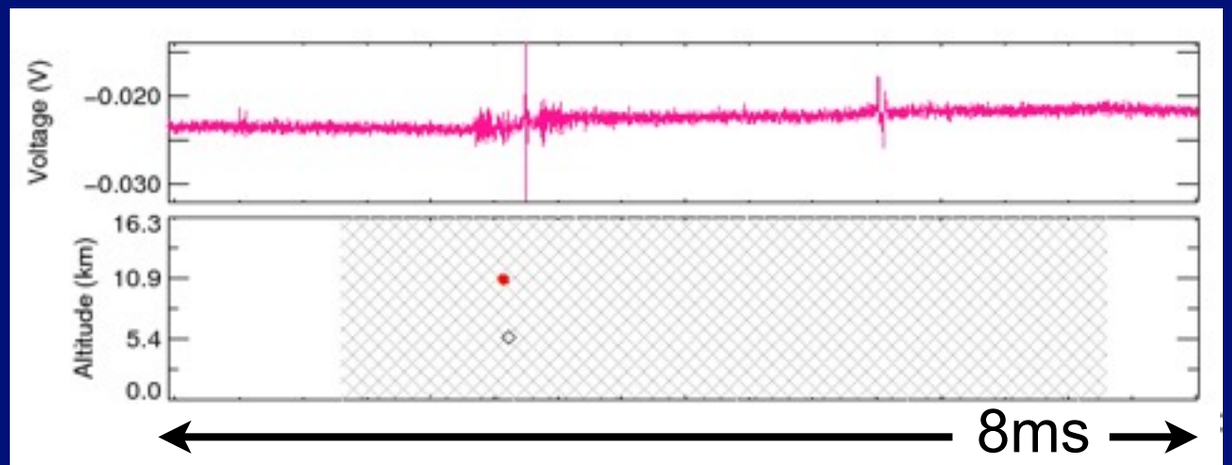

Voltage (V)
-0.020
-0.030
Altitude (km)
16.3
10.9
5.4
0.0
8ms

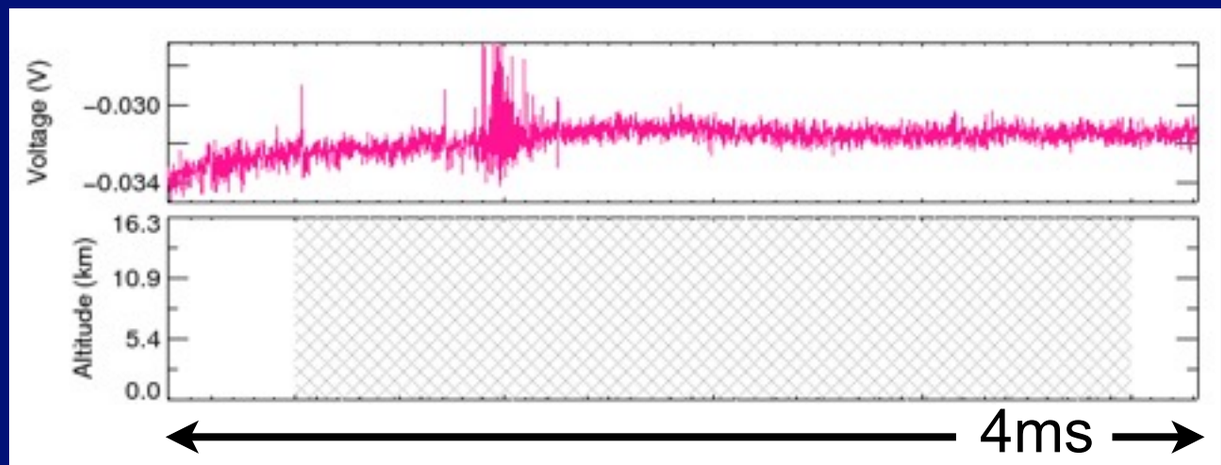

Voltage (V)
-0.030
-0.034
Altitude (km)
16.3
10.9
5.4
0.0
4ms

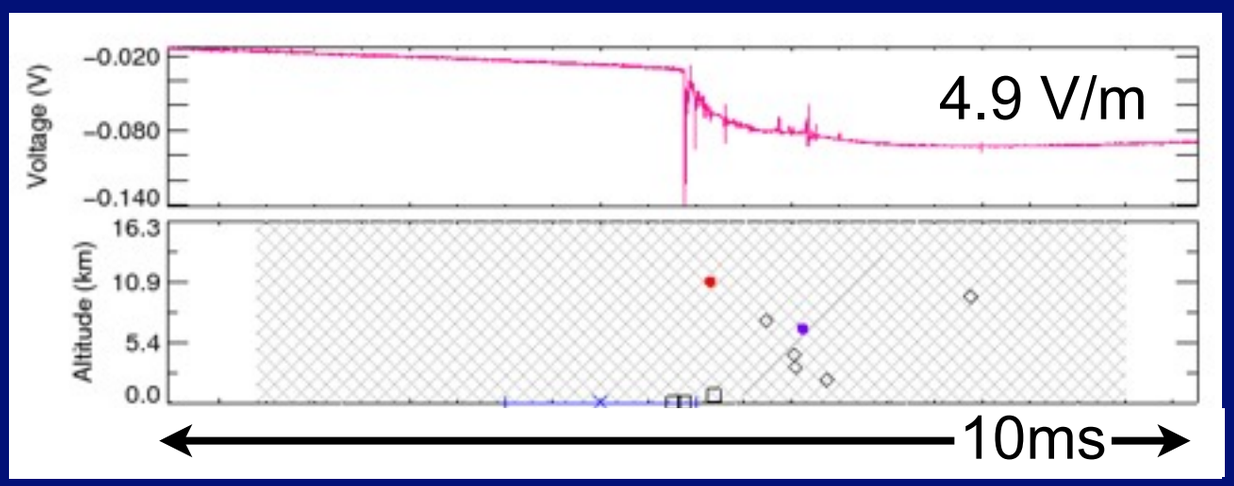

Voltage (V)
-0.020
-0.080
-0.140
4.9 V/m
Altitude (km)
16.3
10.9
5.4
0.0
10ms

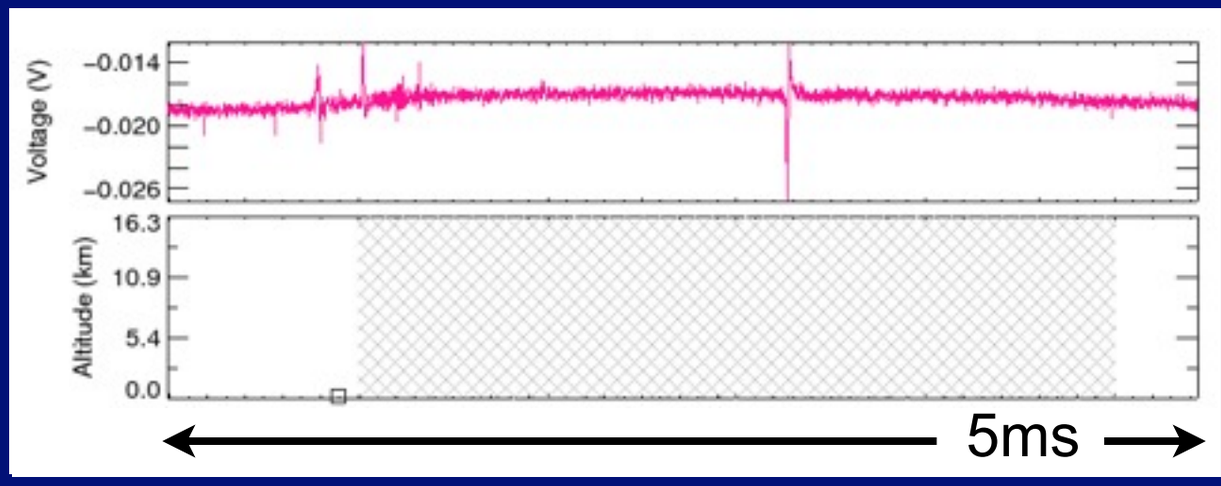

Voltage (V)
-0.014
-0.020
-0.026
Altitude (km)
16.3
10.9
5.4
0.0
5ms



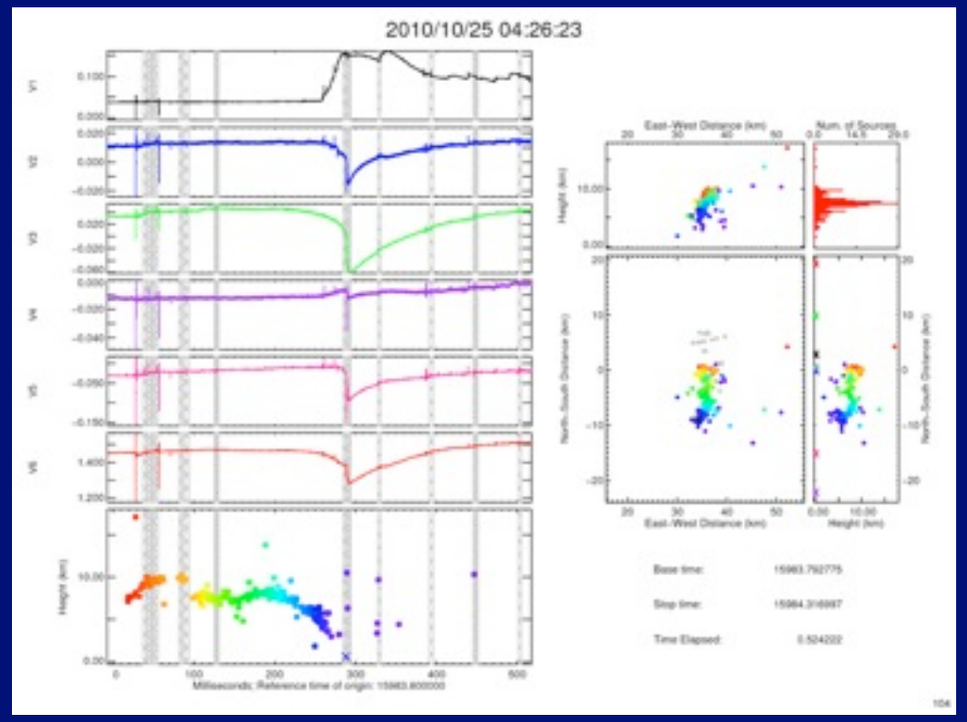


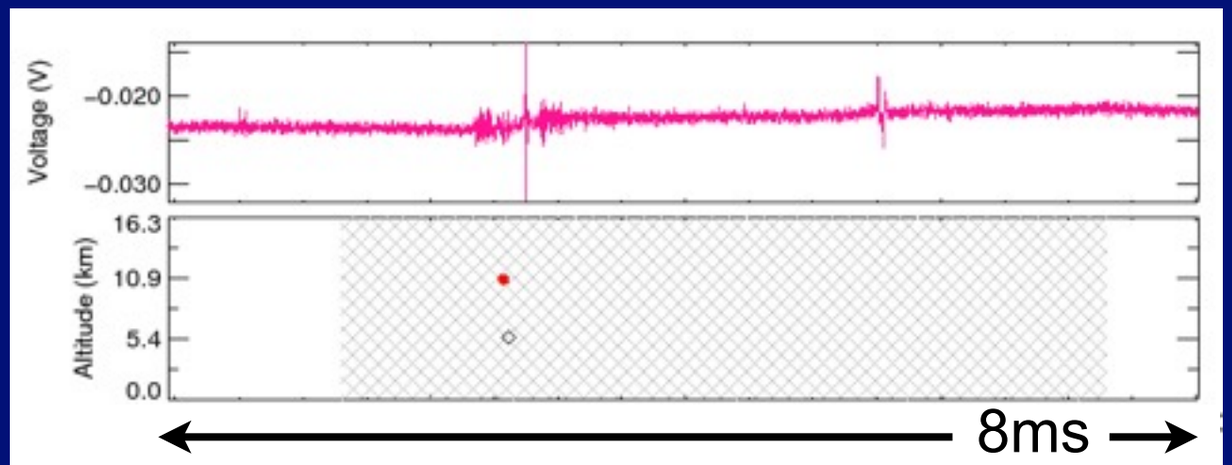


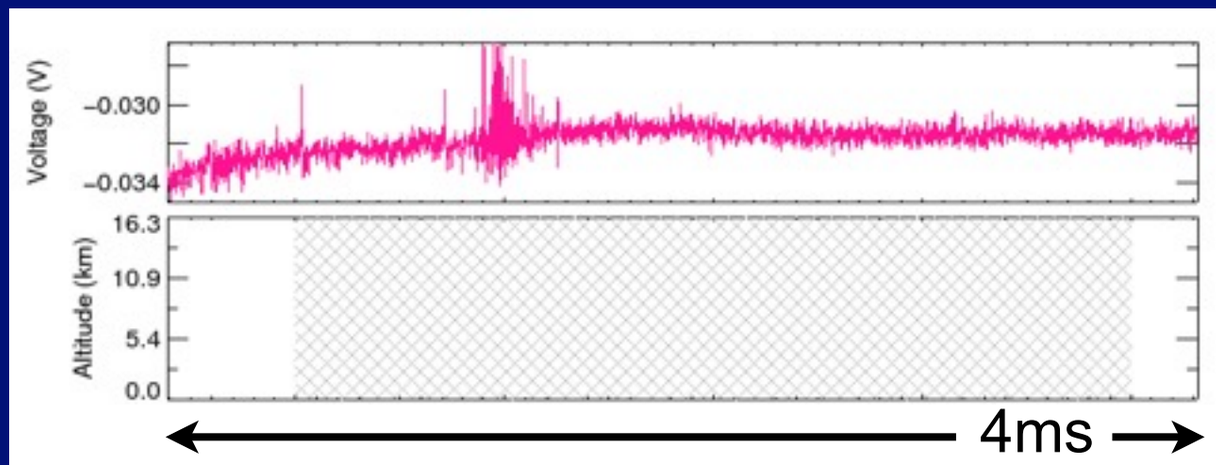


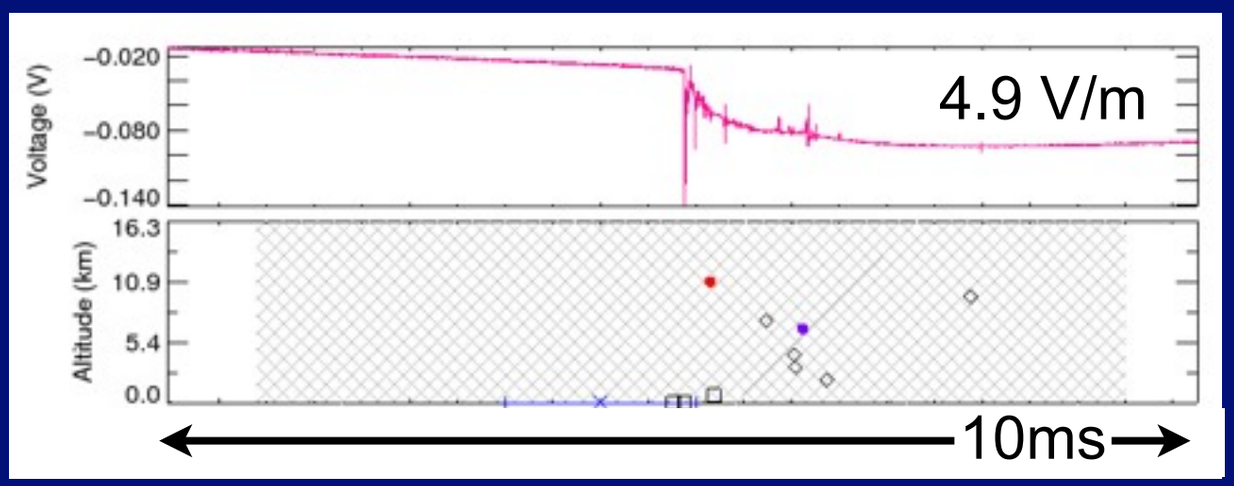


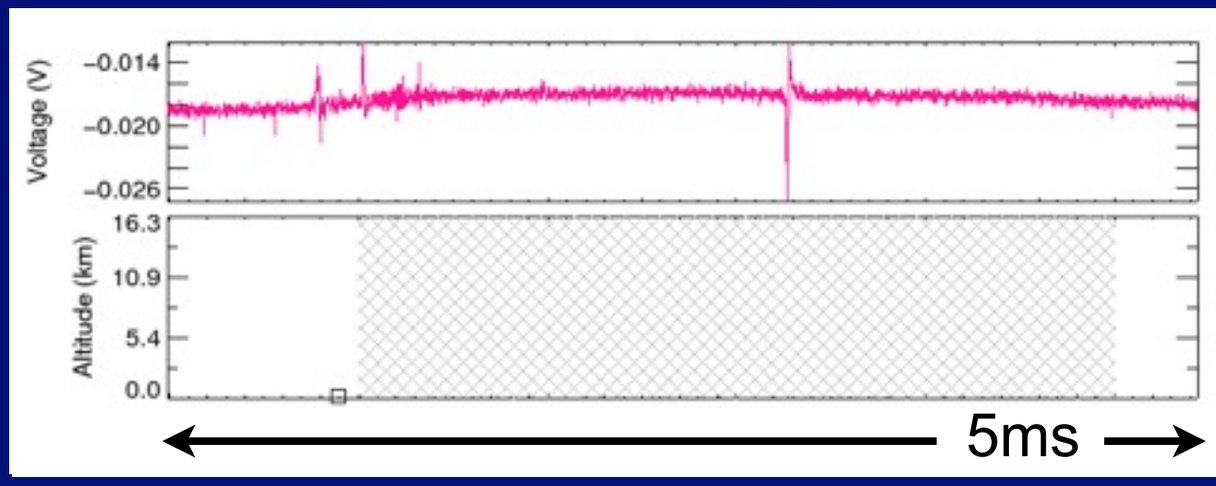
Again, the wideband record is active...











Again, the wideband record is active...

...and there are LIS groups without detected VHF sources.

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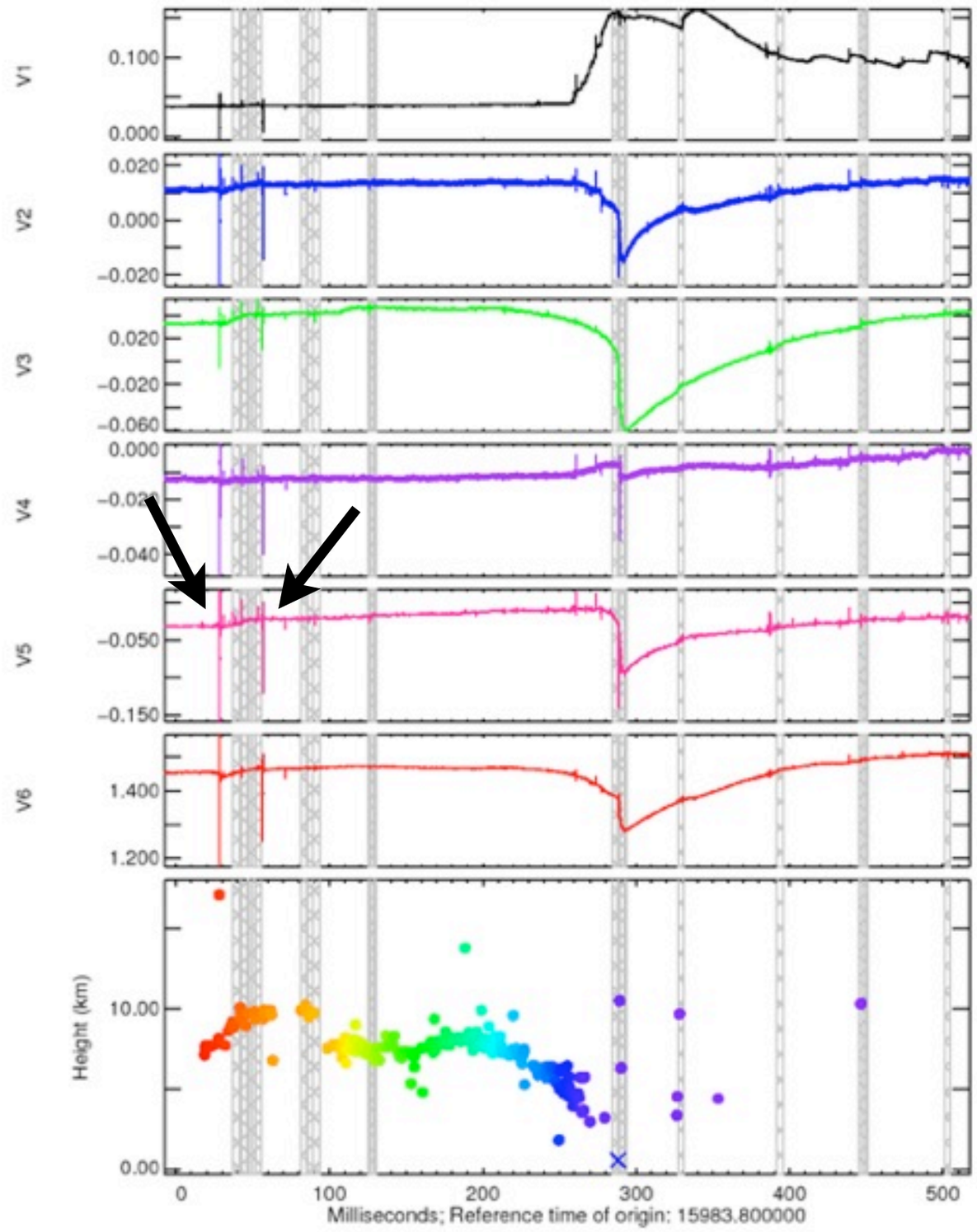
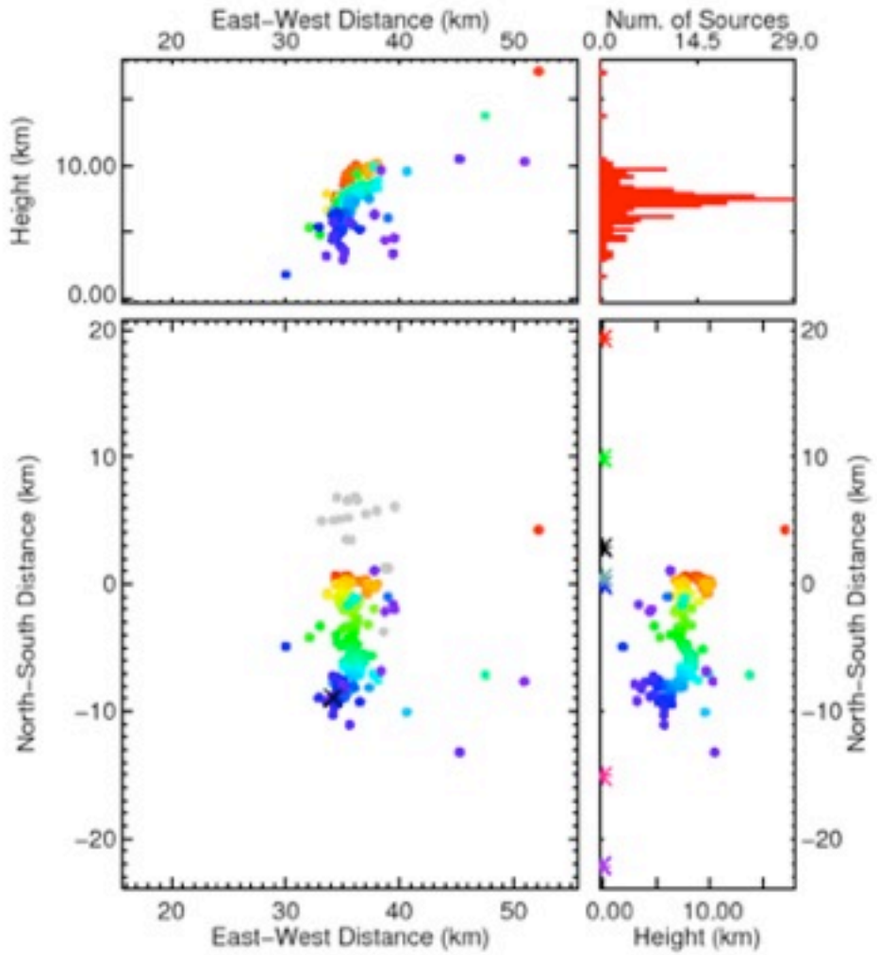
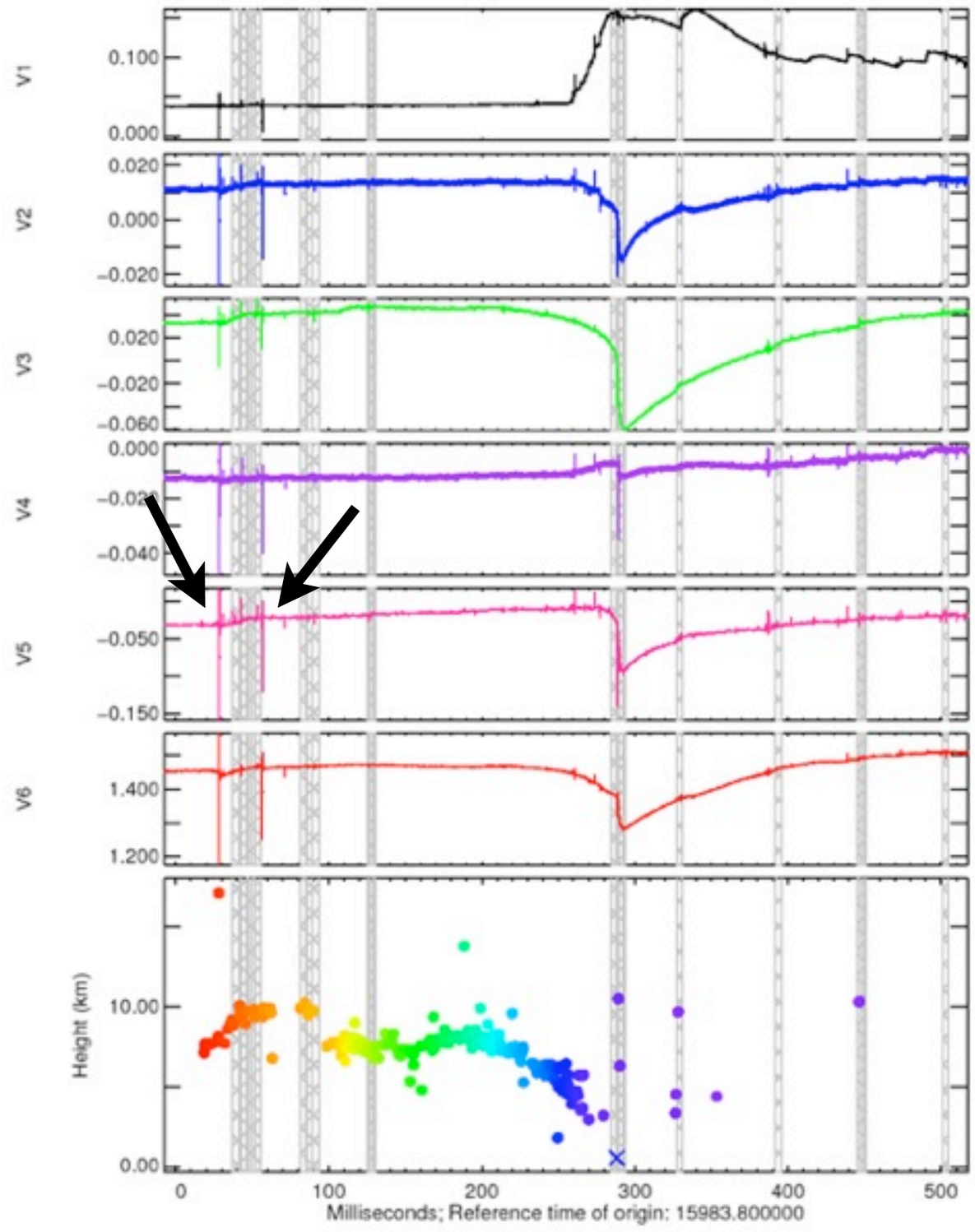


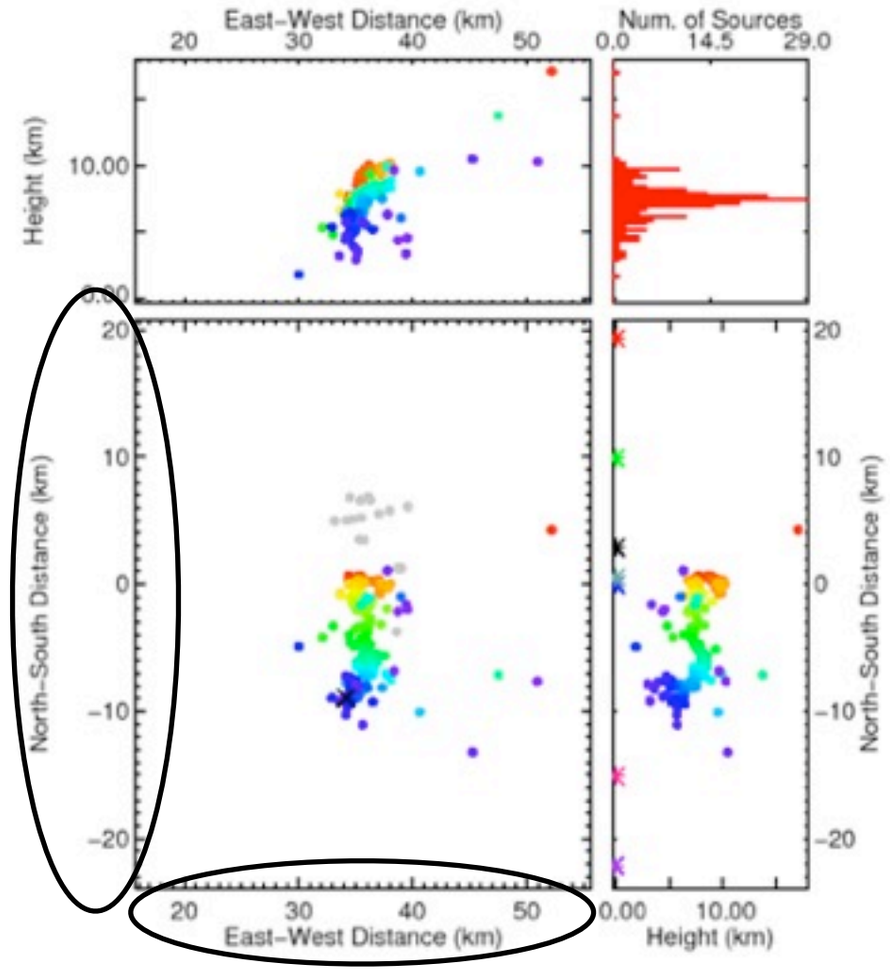


Base time:	15983.792775
Stop time:	15984.316997
Time Elapsed:	0.524222

104

2010/10/25 04:26:23

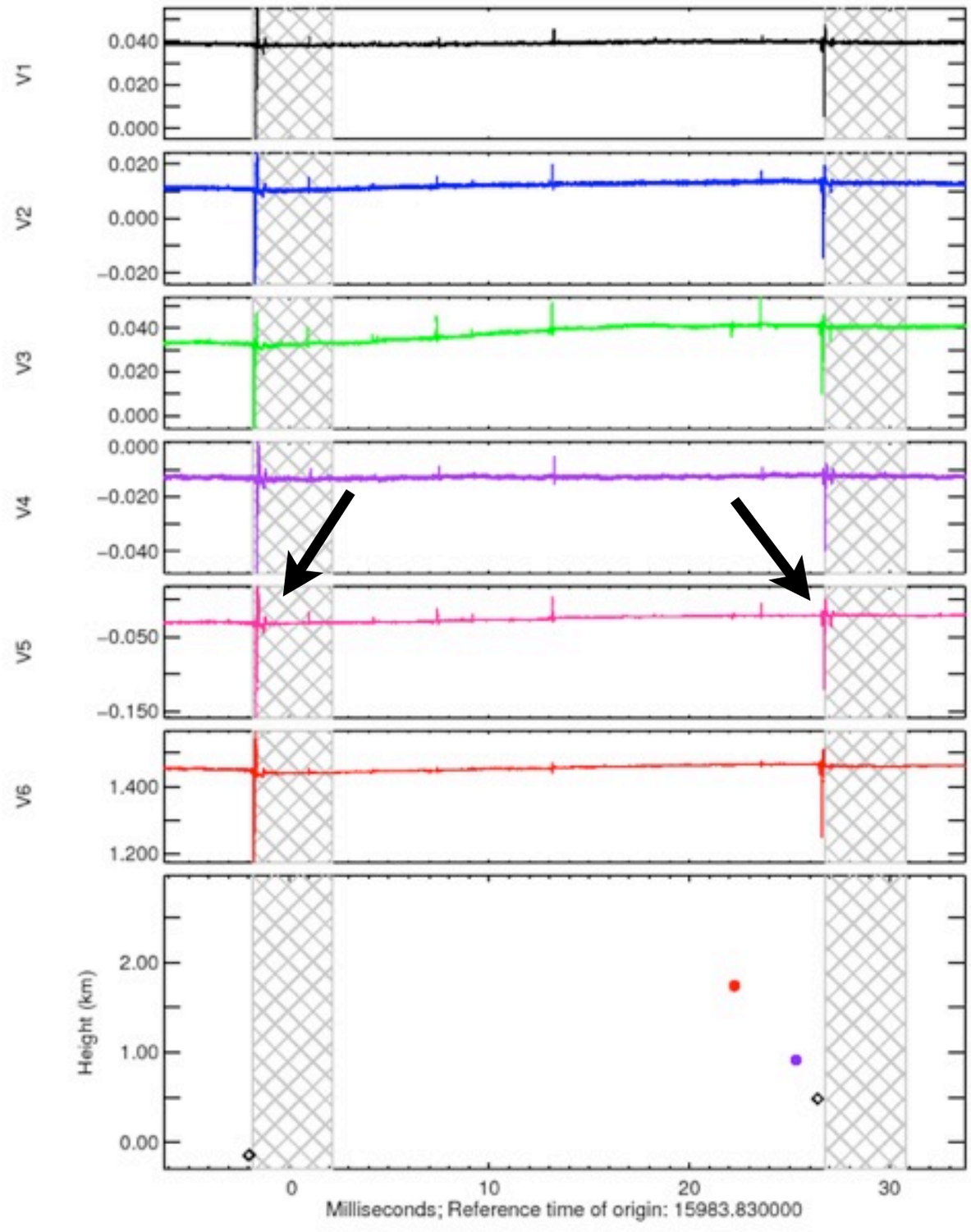


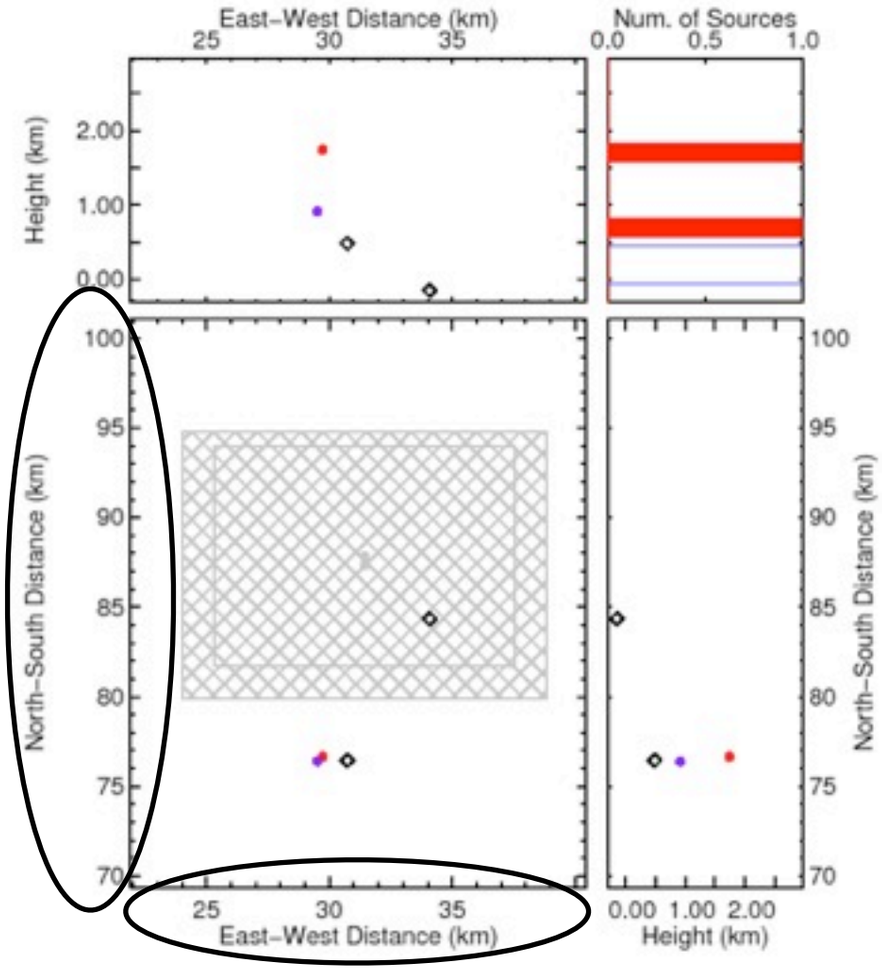


Base time:	15983.792775
Stop time:	15984.316997
Time Elapsed:	0.524222

104

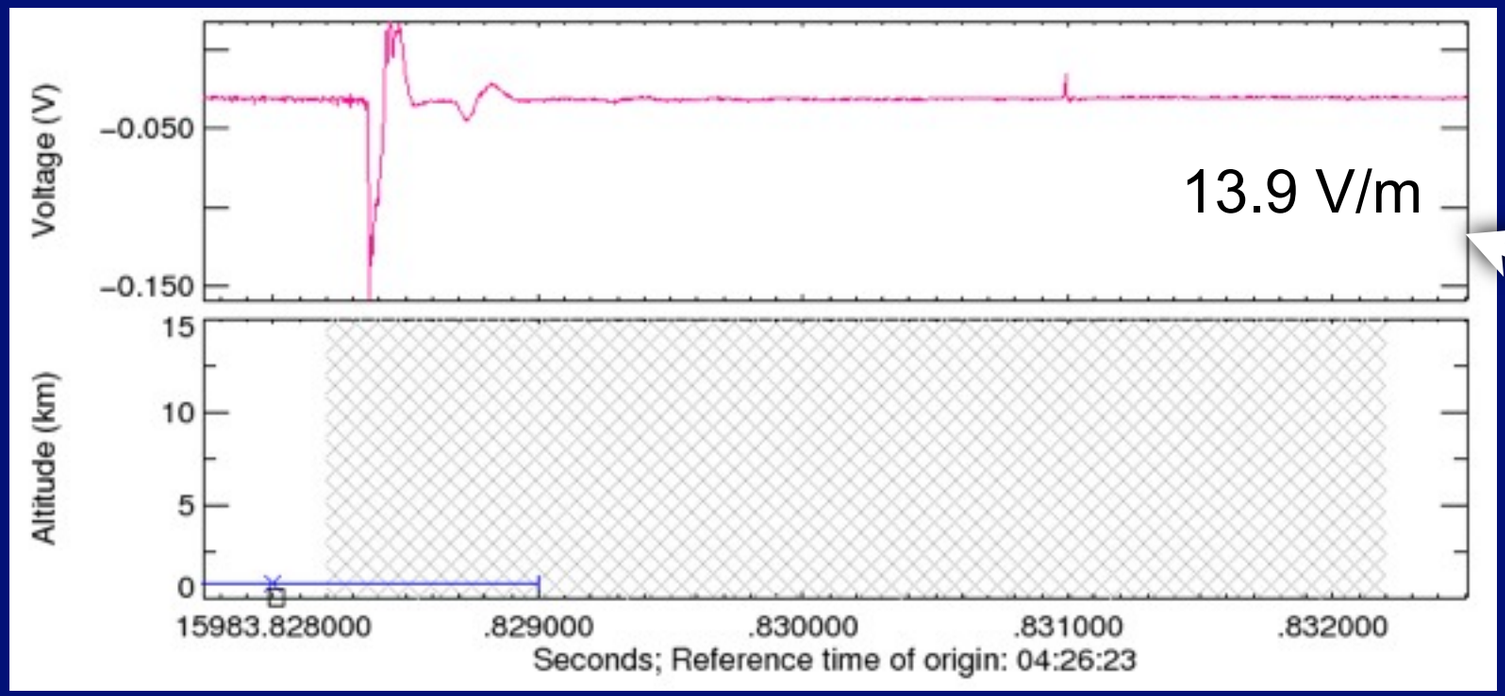
2010/10/25 04:26:23

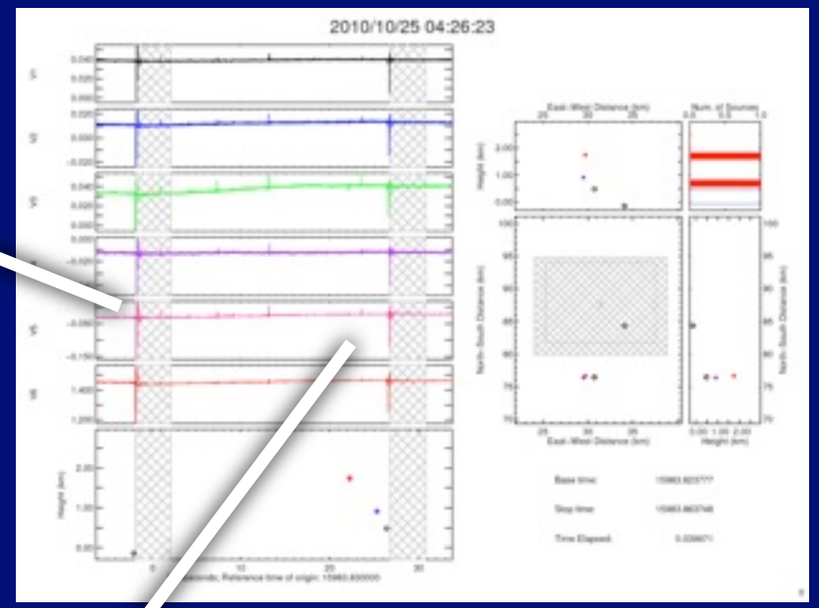


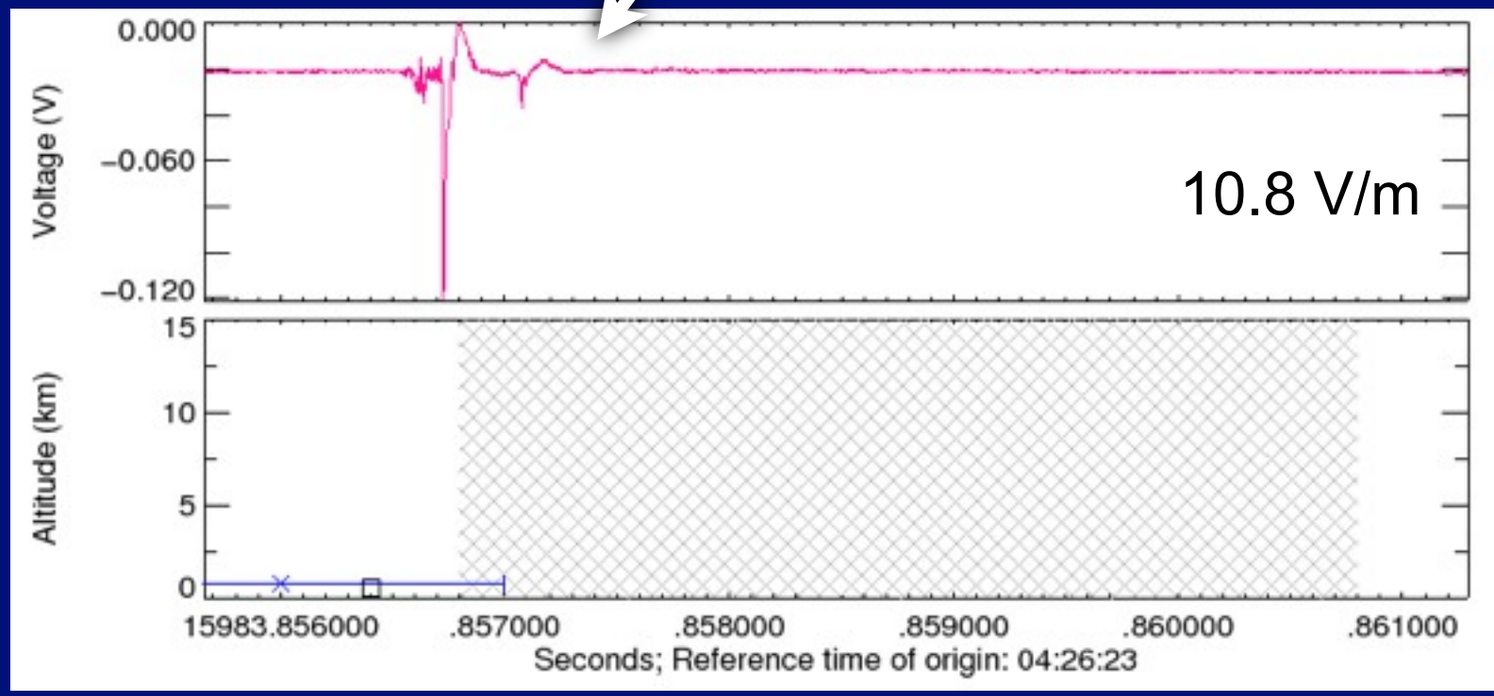


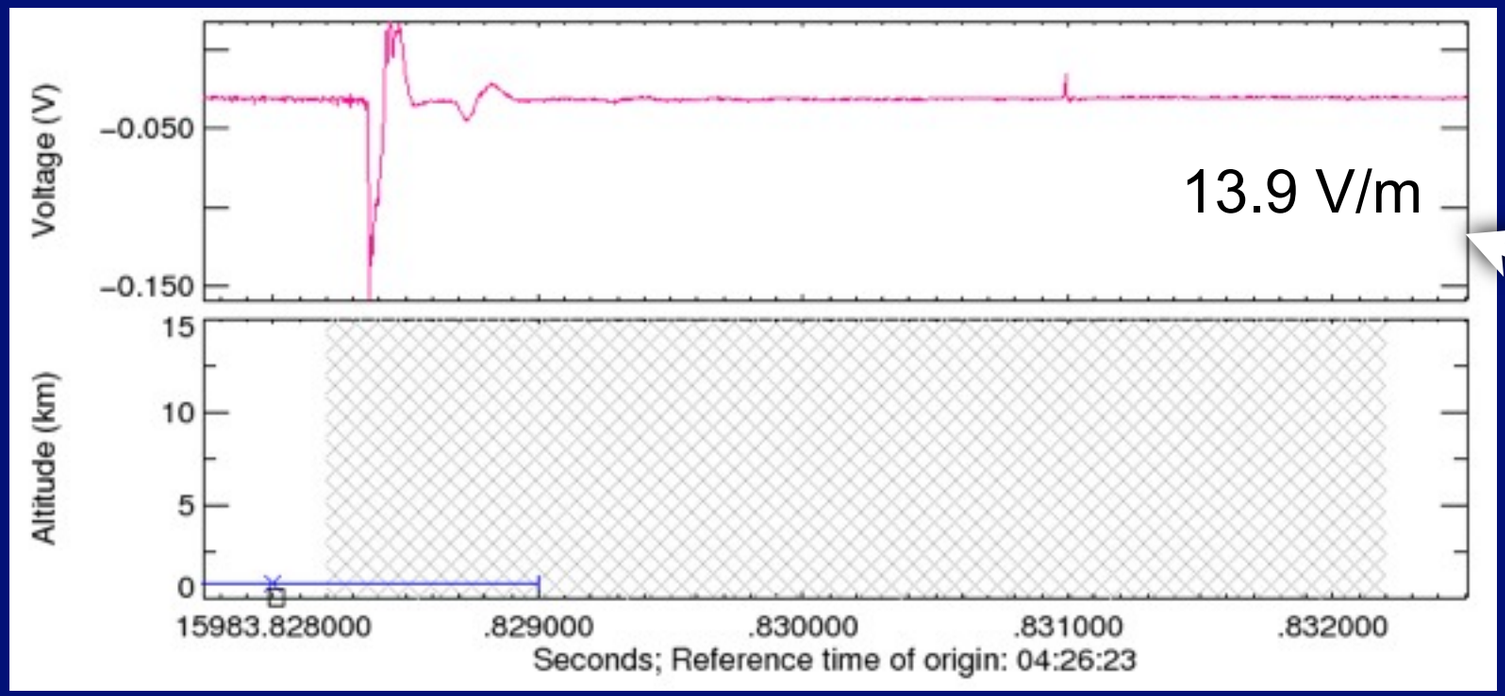
Base time:	15983.823777
Stop time:	15983.863748
Time Elapsed:	0.039971

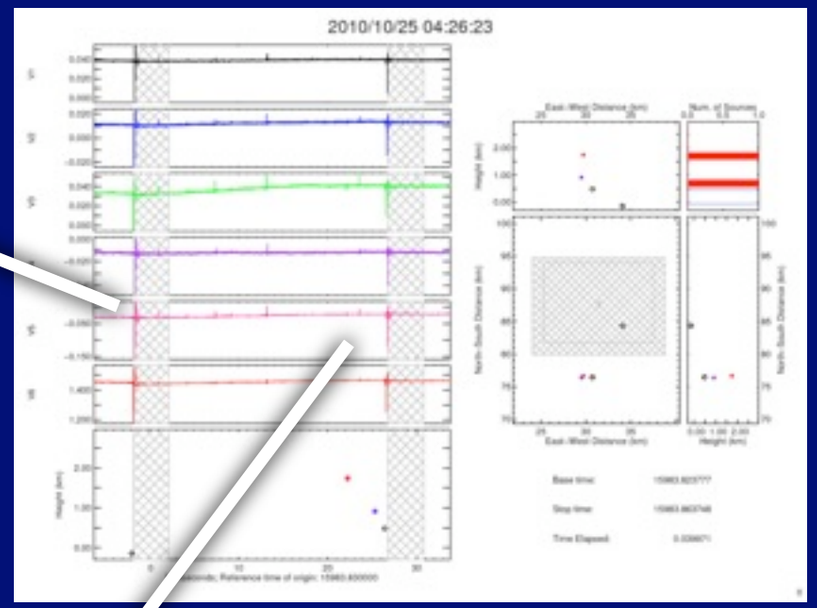
0


Voltage (V)
−0.050
−0.150
Altitude (km)
15
10
5
0
15983.828000
.829000
.830000
.831000
.832000
Seconds; Reference time of origin: 04:26:23
13.9 V/m

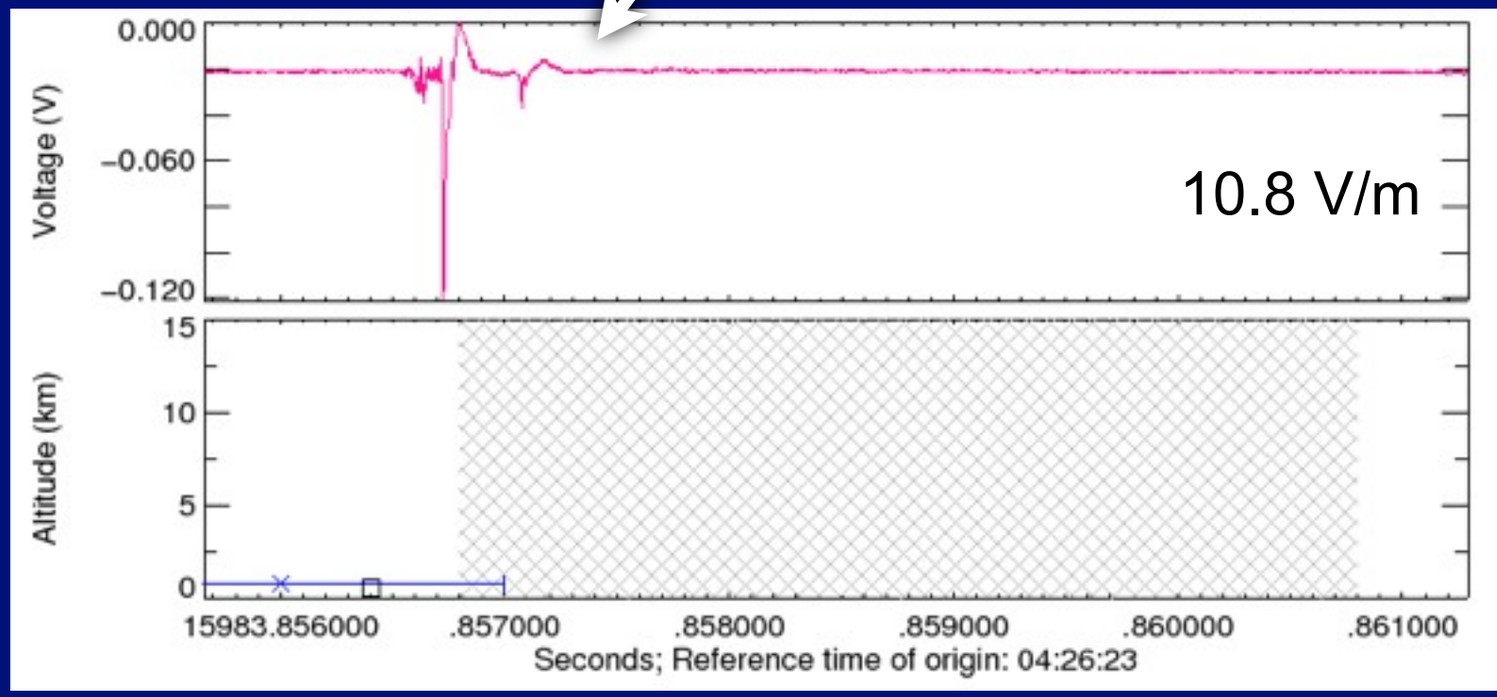

2010/10/25 04:26:23


Voltage (V)
0.000
−0.060
−0.120
Altitude (km)
15
10
5
0
15983.856000
.857000
.858000
.859000
.860000
.861000
Seconds; Reference time of origin: 04:26:23
10.8 V/m





Without an array of wideband sensors, these might have been misinterpreted as “misses”



Since LIS/GLM does not detect "flashes,"
we must find a way to validate what
LIS/GLM does detect.

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Clearly, wideband measurements are
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we must find a way to validate what
LIS/GLM does detect.

Clearly, wideband measurements are
better correlated to these optical events...

and even suggest there is a
lower limit to what LIS can detect!

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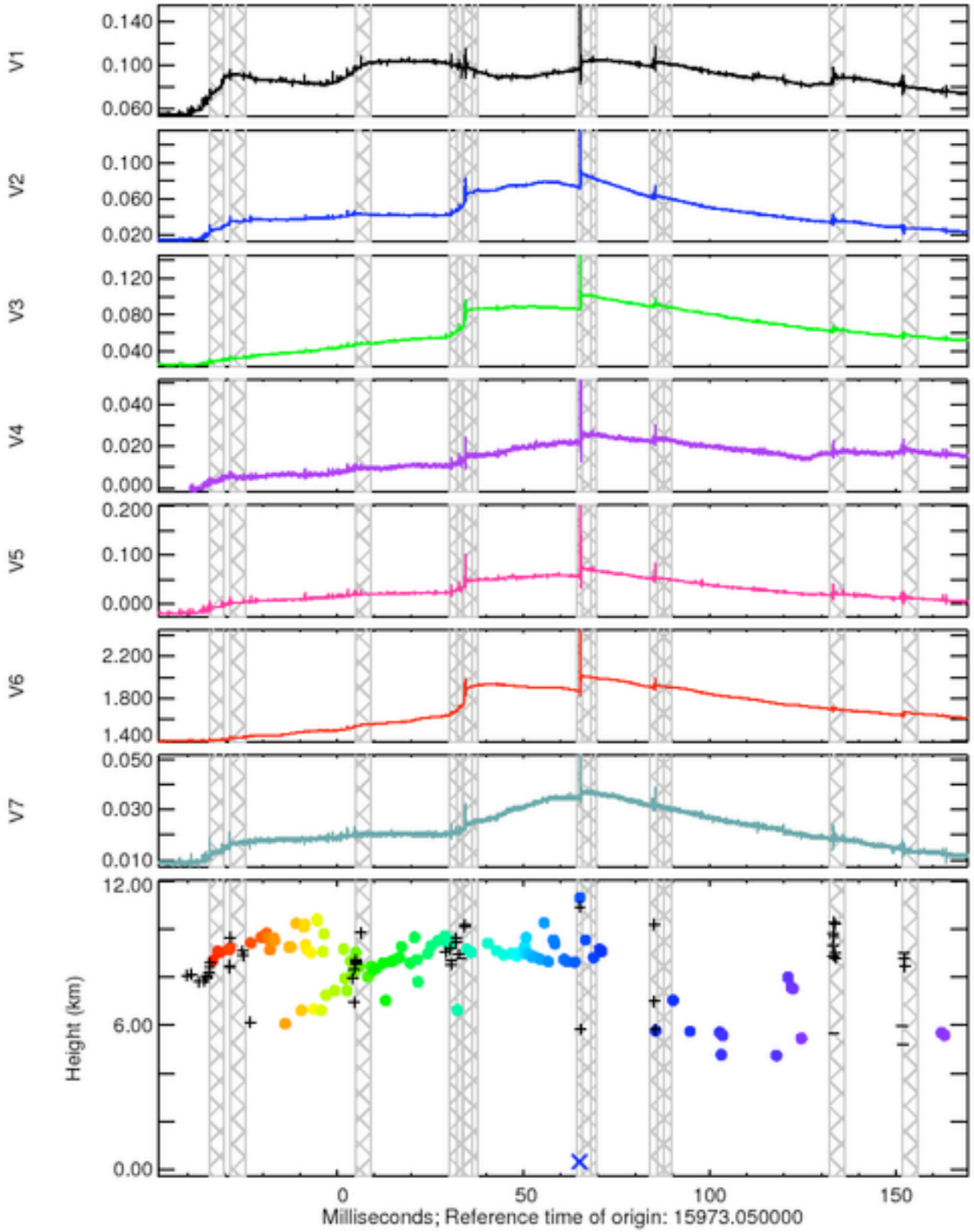

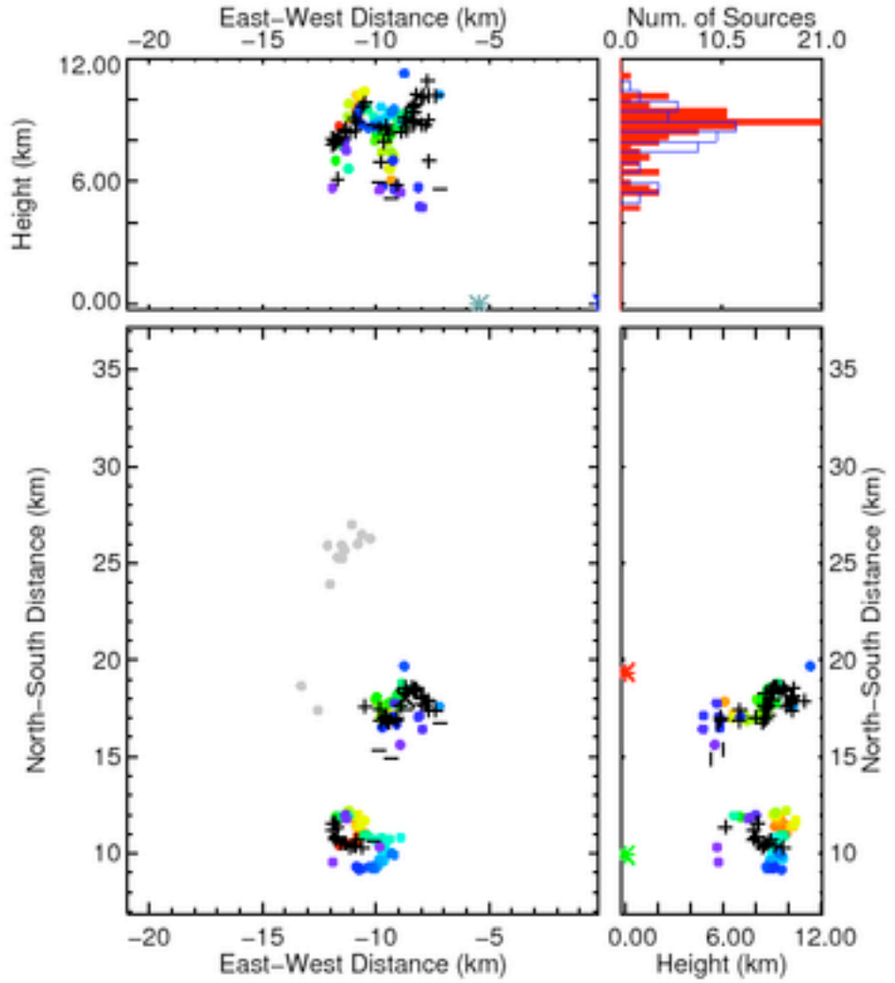

Base time:	15973.002030
Stop time:	15973.219127
Time Elapsed:	0.217097

Fundamental question for *scientific* validation:

What is the best way from the ground to characterize what GLM “sees?”

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What is the best way from the ground to characterize what GLM "sees?"

Wideband measurements are ideally suited to the processes in lightning that produce optical emission