

Observation of Gamma Rays at Ground Level Associated with Nearby Thunderstorms

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Observations of TGFs from ground level :

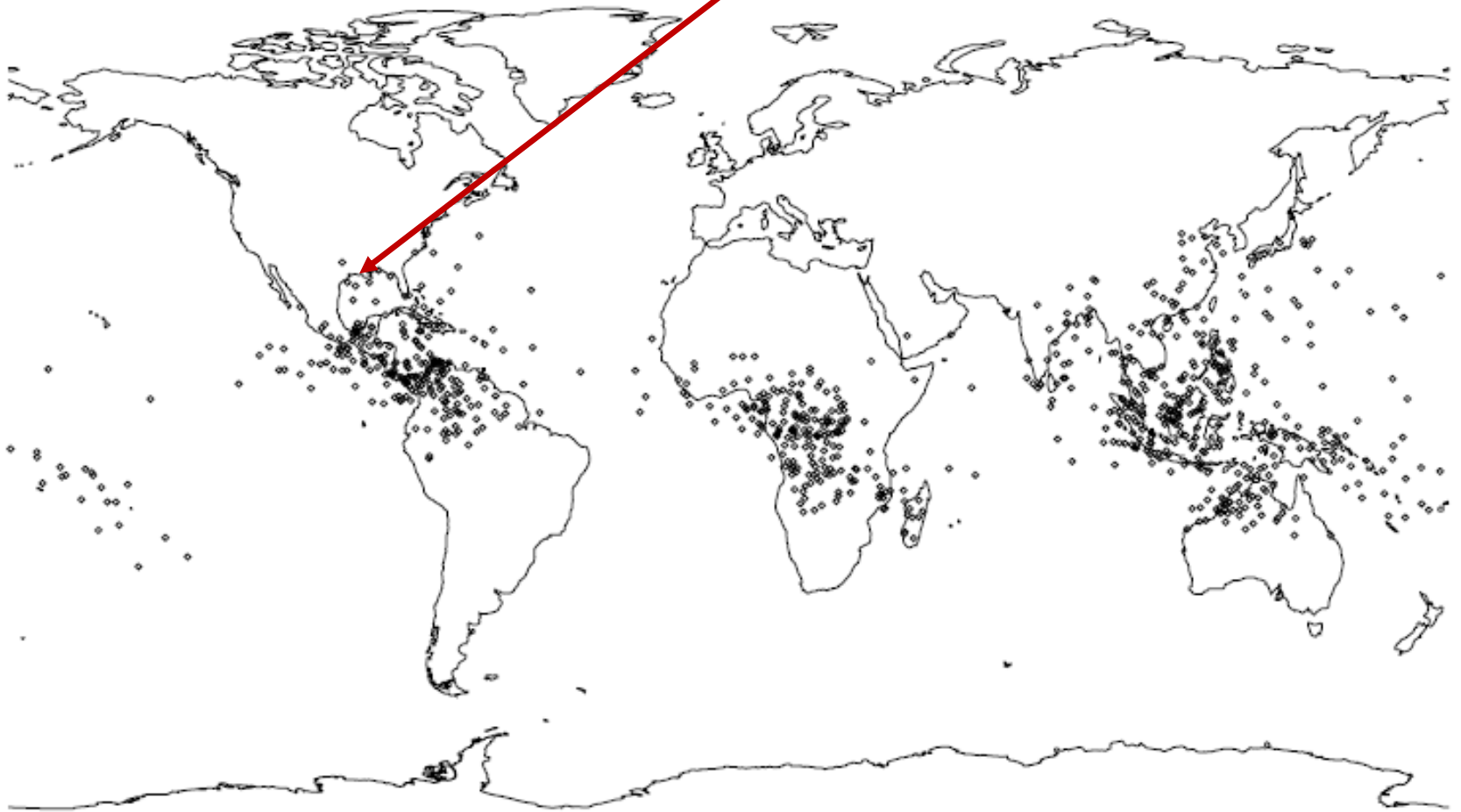
- **X-rays, gamma rays, energetic particles from lightning observed previously --**
- **ICLRT (Dwyer et al., 2004, 2012)**
- **Millisec bursts of X-rays associated with CG lightning (Moore et al., 2001)**
- **Long duration ~second-minute scale (Torii, 2002, 2011; Tsuchiya et al., 2011, 2013)**
- **Aragats observations (Chilingarian et al., 2010, 2011)**
- **ADELE aircraft observations at 14 km (Smith et al., 2011)**

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Here we report observation of 24 events with durations 0.02- 4.2 msec over 2.6 years associated with nearby lightning.

Louisiana



Map of RHESSI TGFs

TGF and Energetic Thunderstorm Rooftop Array (TETRA) -- Ground array of 4 detector boxes of 3 NaI scintillators on rooftops on Louisiana State University campus in Baton Rouge



- 5" Photomultiplier tube (PMT)
- Acrylic light guide
- 8 in x 8 in x 1/4 in NaI scintillator





**40" by 48" by 30" tall.
Weight ~ 100 lbs**

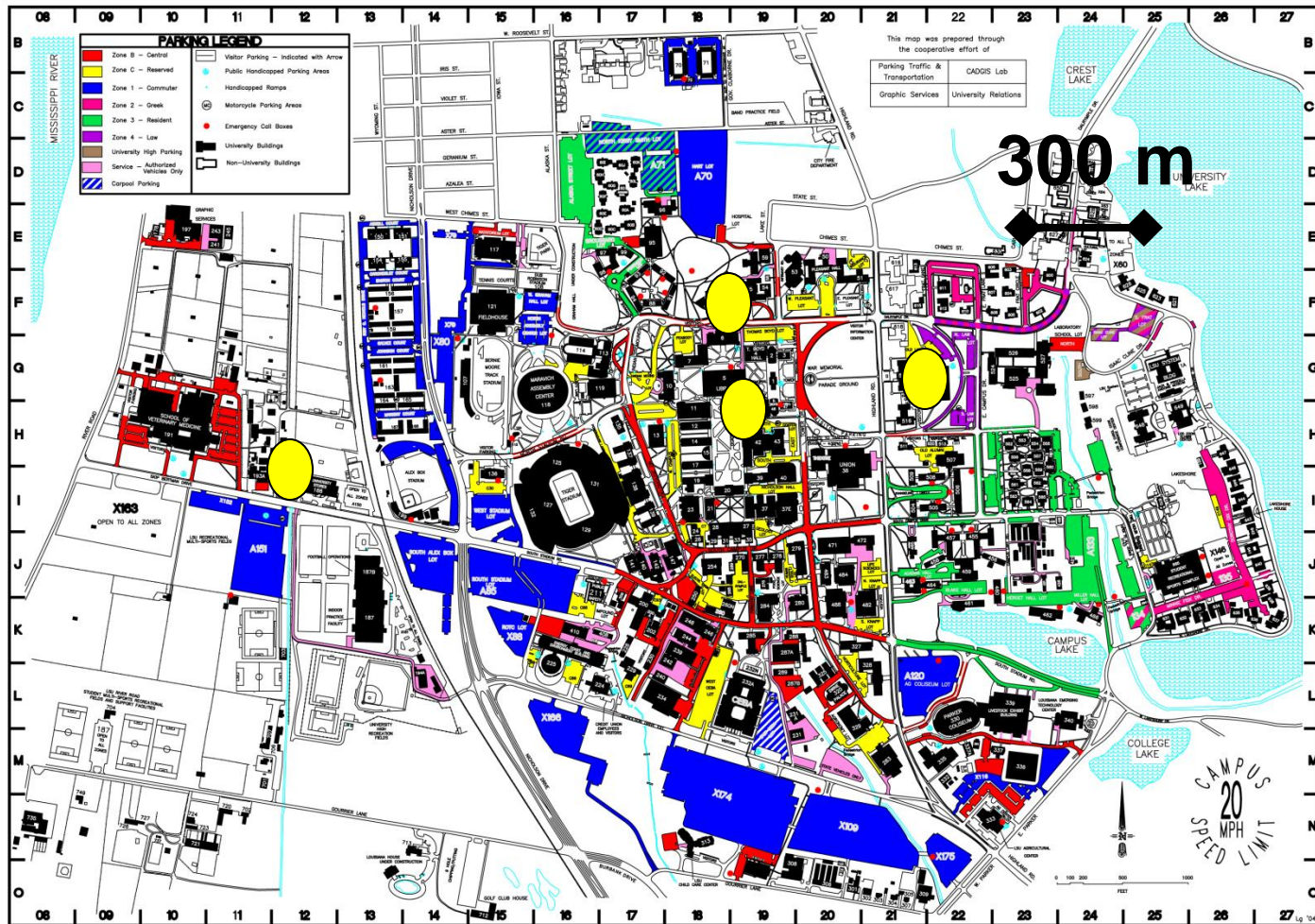
**4 detector boxes assembled and deployed on
LSU rooftops starting July 2010**

Response over 50 keV – 3 MeV

Calibrated with γ ray sources (^{241}Am , ^{137}Cs , ^{60}Co) and
minimum ionizing muons

Individual detector energy resolution @ 662 keV:
9 – 13.5% FWHM

Boxes distributed to high rooftops with unobstructed views, 110 V, wireless connections, access, security, real-time lightning stroke data – US Precision Lightning Network (USPLN) Unidata Program

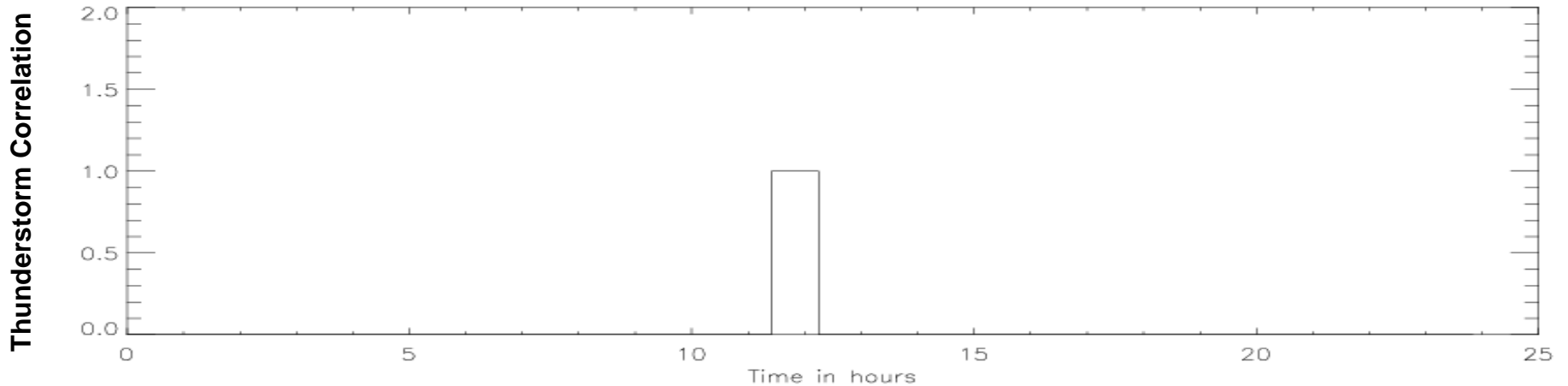
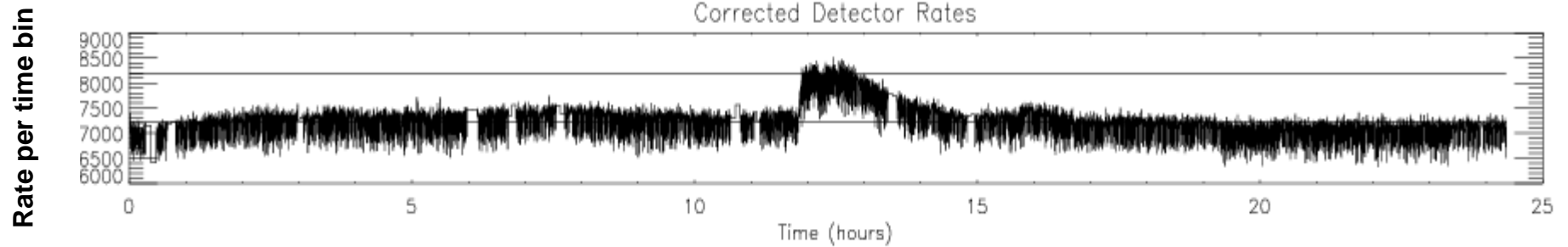
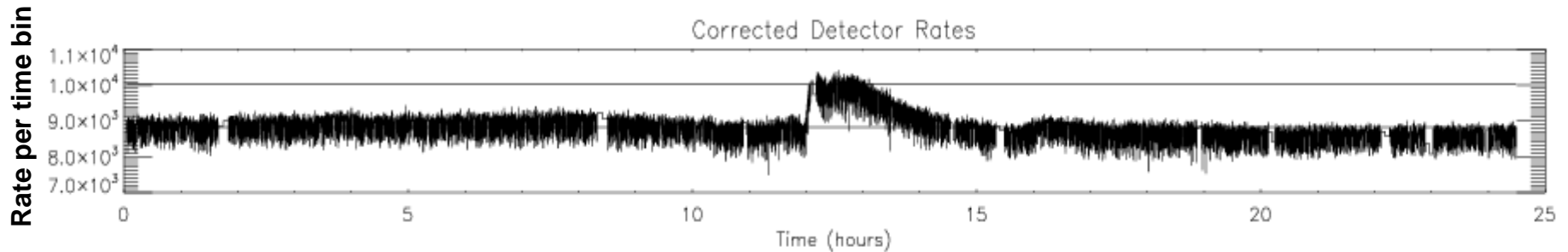




Red = 52 – 64 dBZ

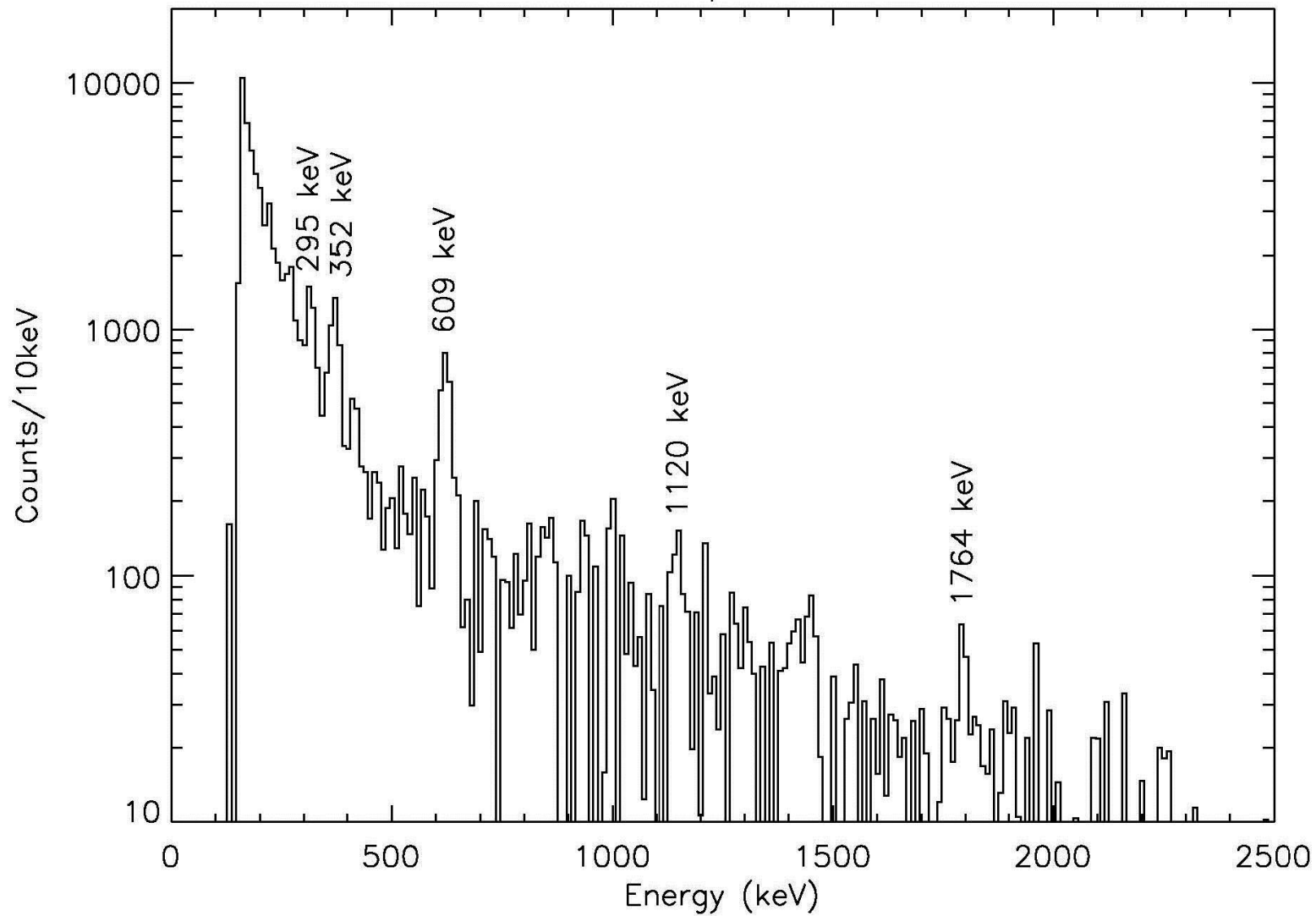
LSU TGF Rooftop - Data

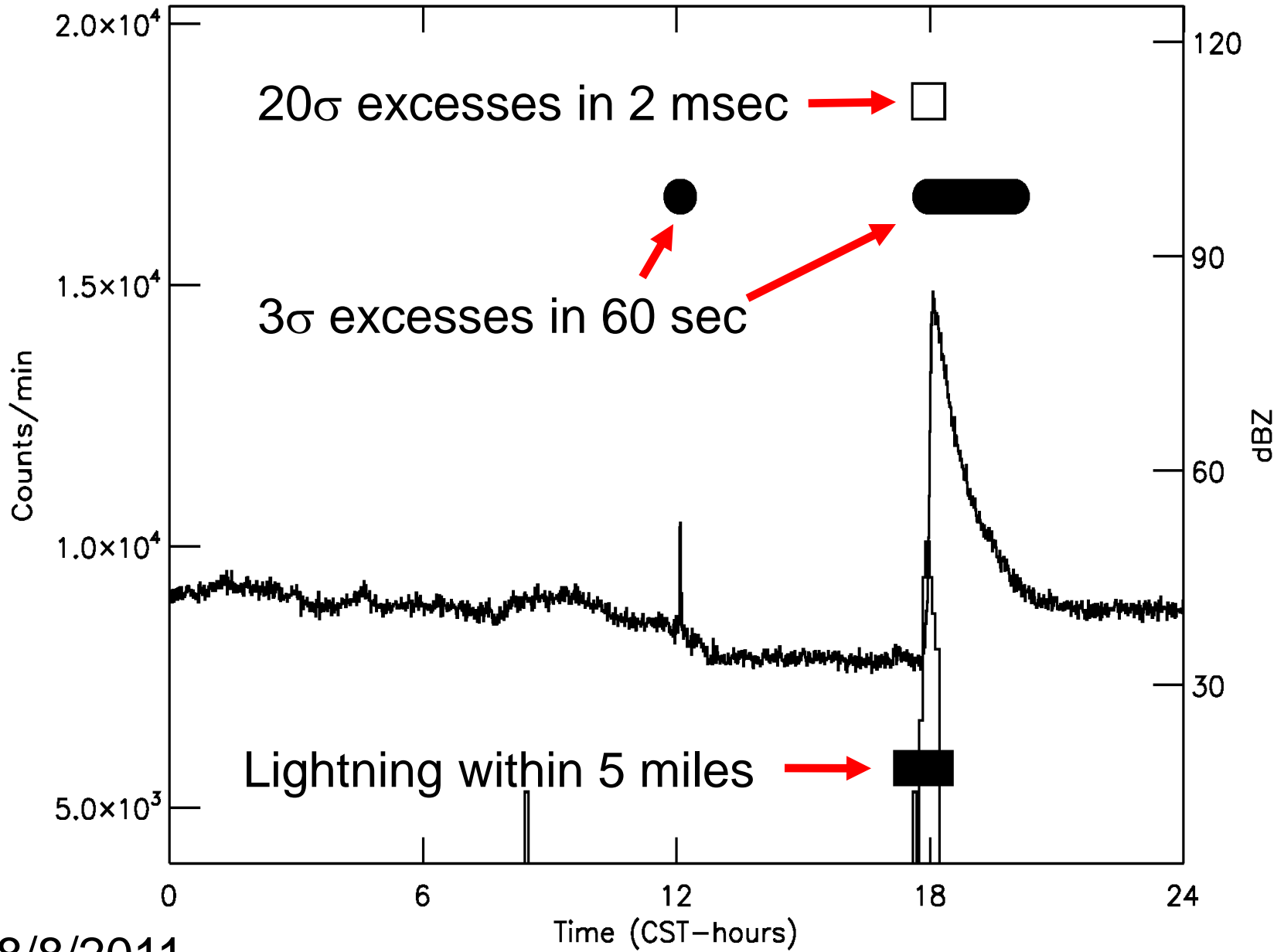
July 5, 2010: Count rates from boxes 1 and 2 and storm histogram



Background Subtracted Rain Spectrum 2011-09-03 (6 hrs)

LaBr Spectrum





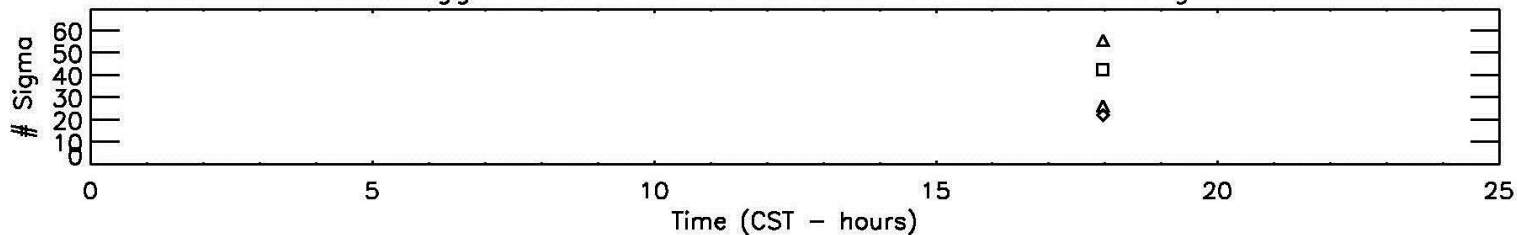
8/8/2011

TETRA Daily Report for 2011-08-18

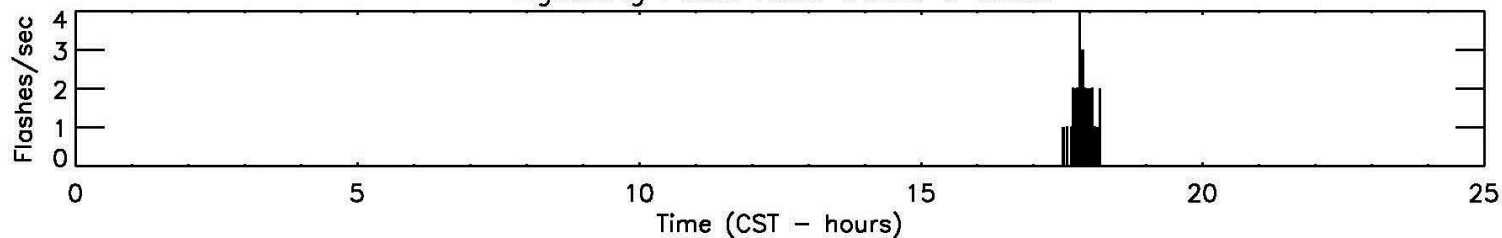
Diamond - Box 1
Plus Sign - Box 2

Triangle - Box 3
Square - Box 4

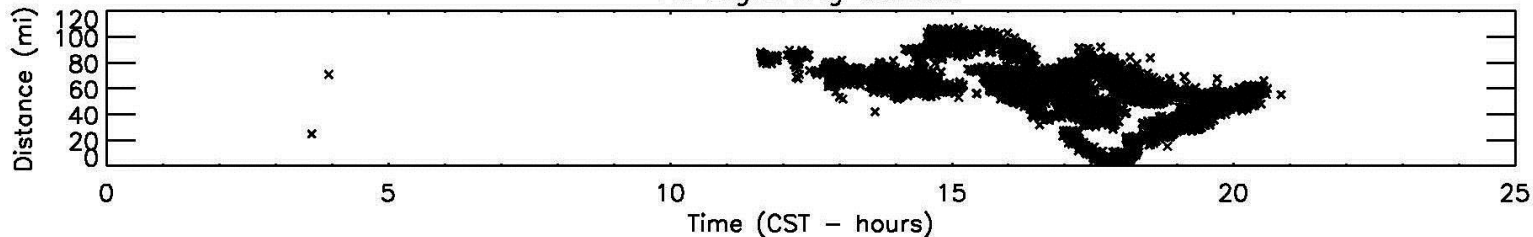
Triggers Detected Above Threshold for 2ms Binning



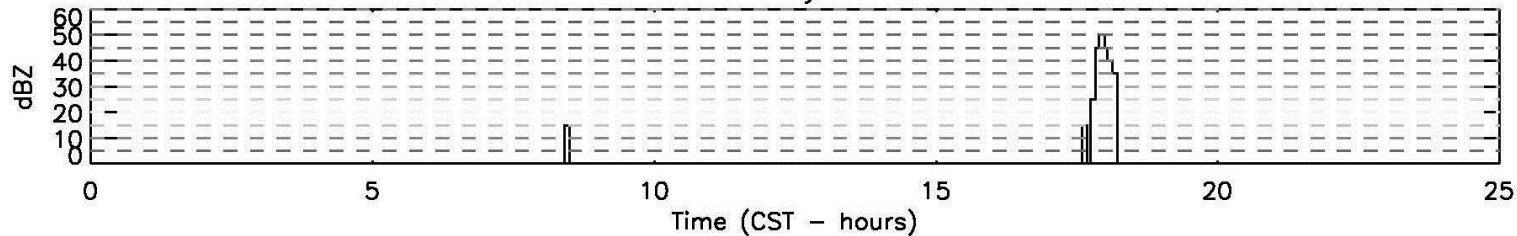
Lightning Flash Rate Within 5 Miles

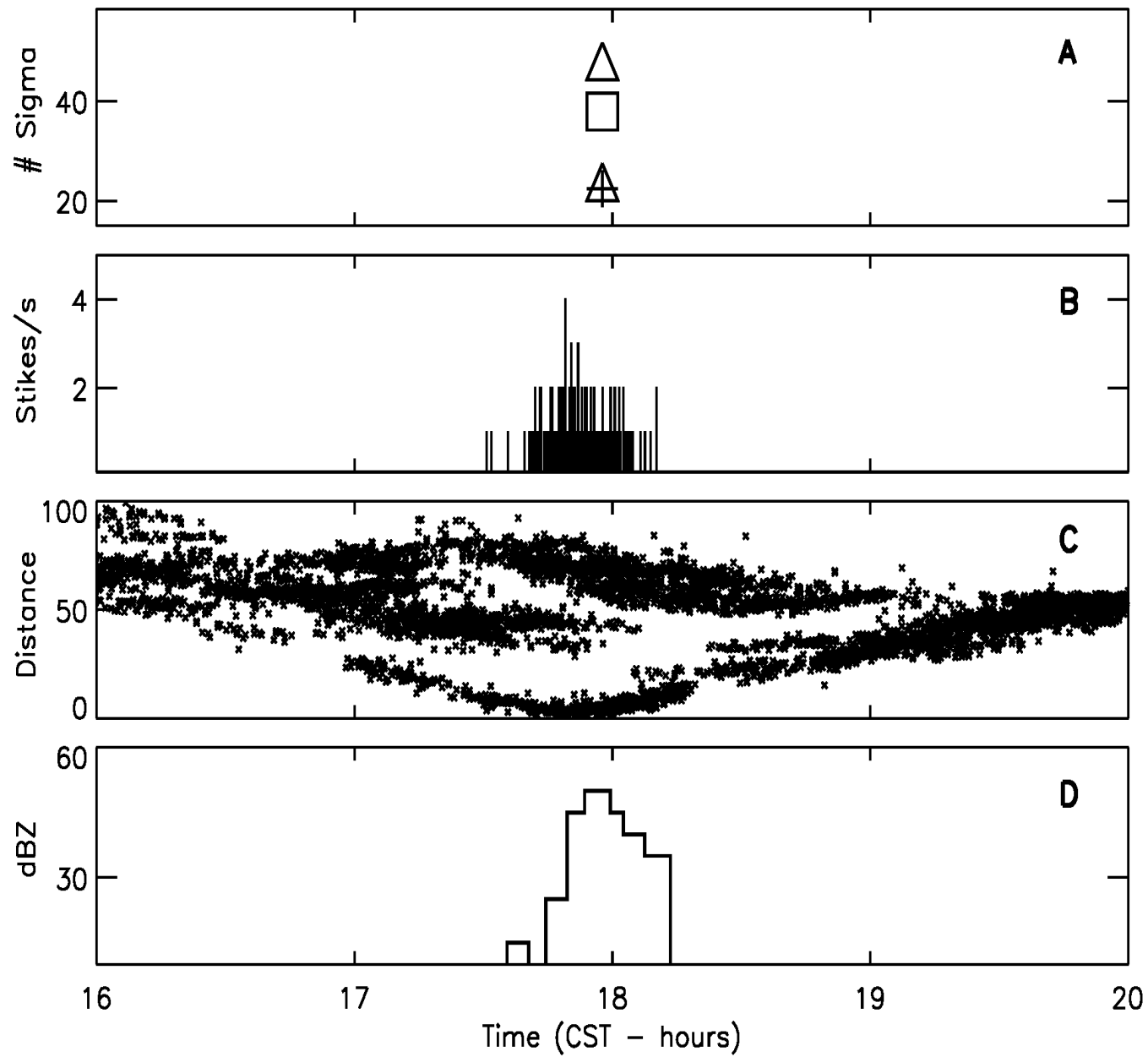


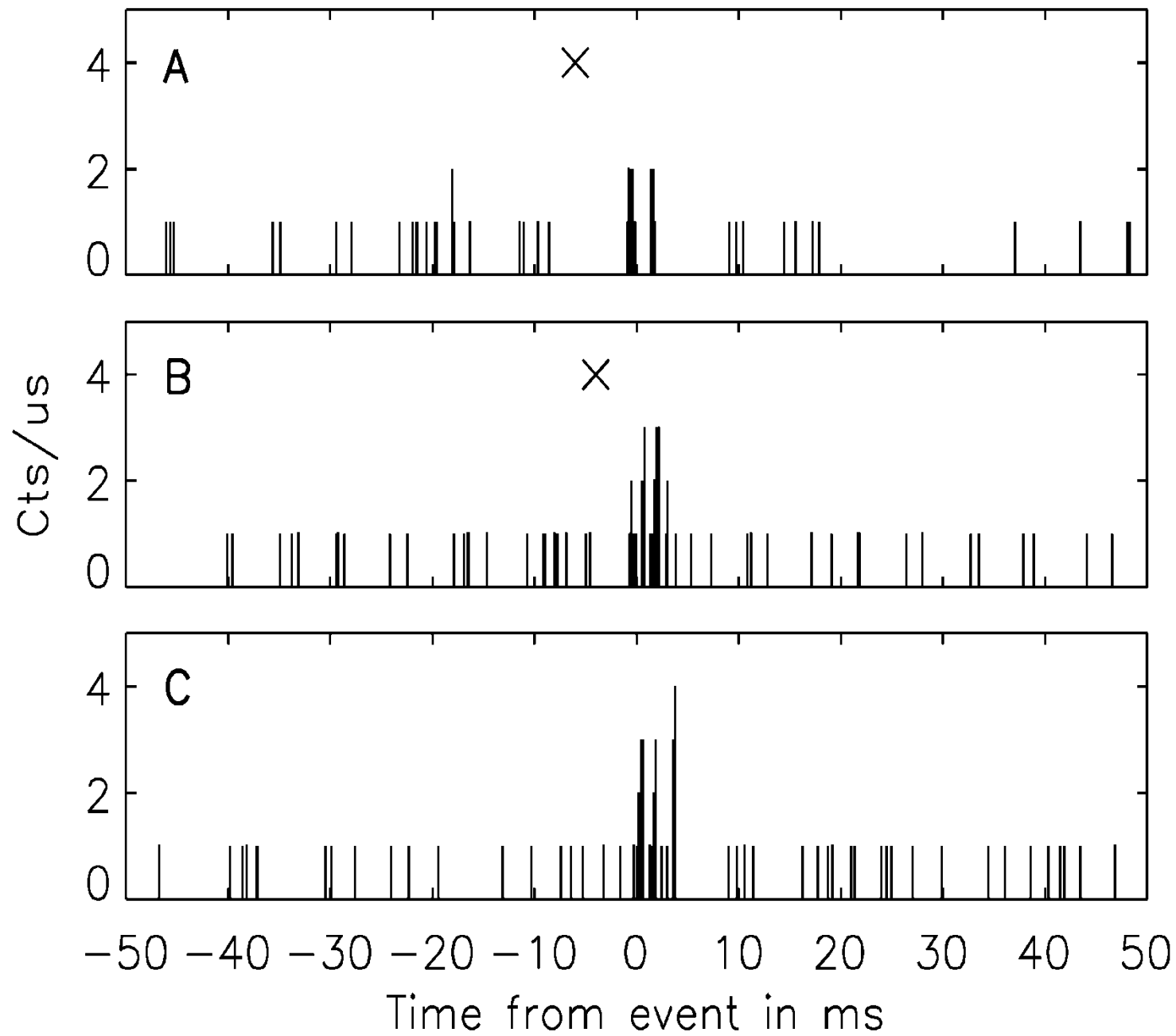
All Lightning Strikes

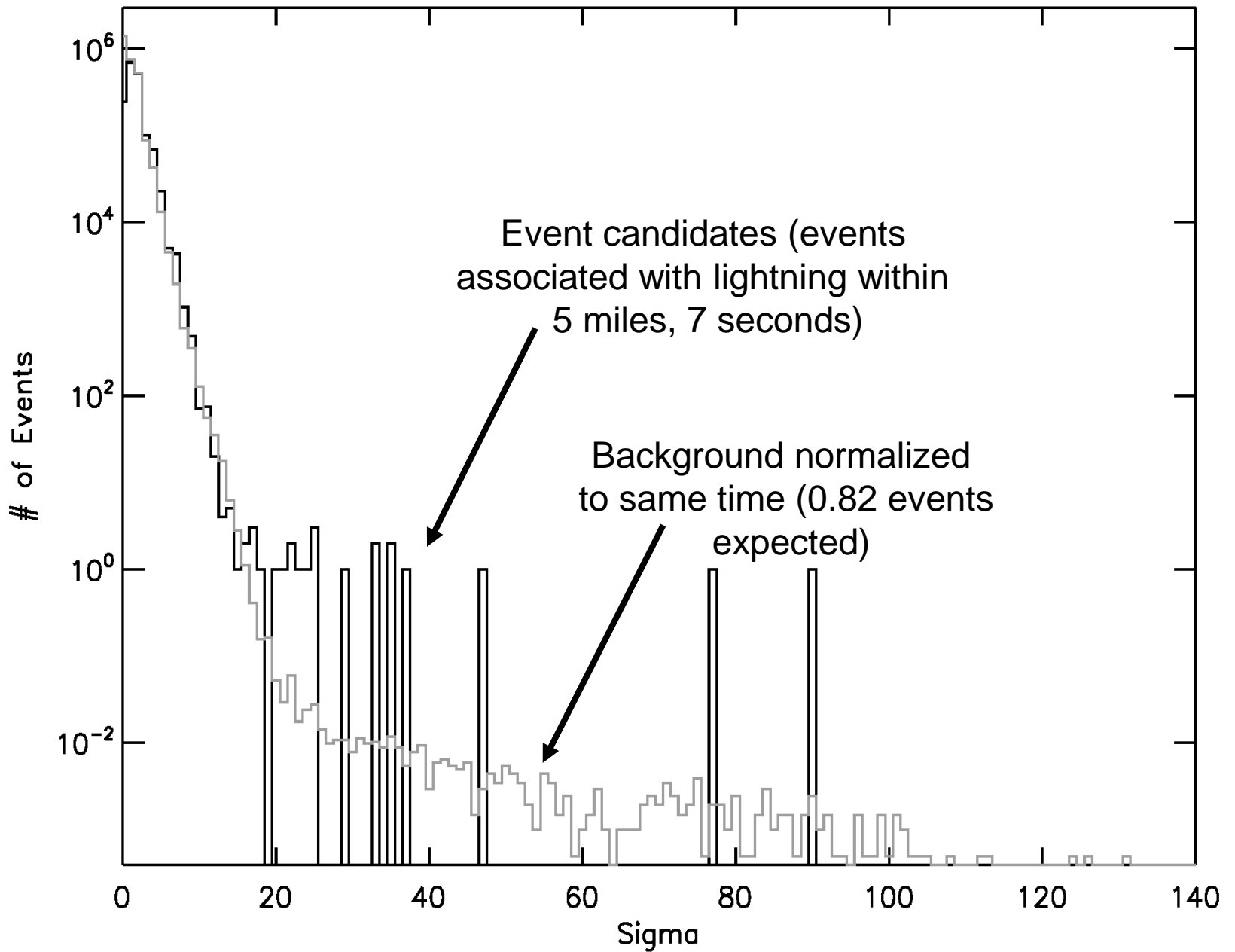


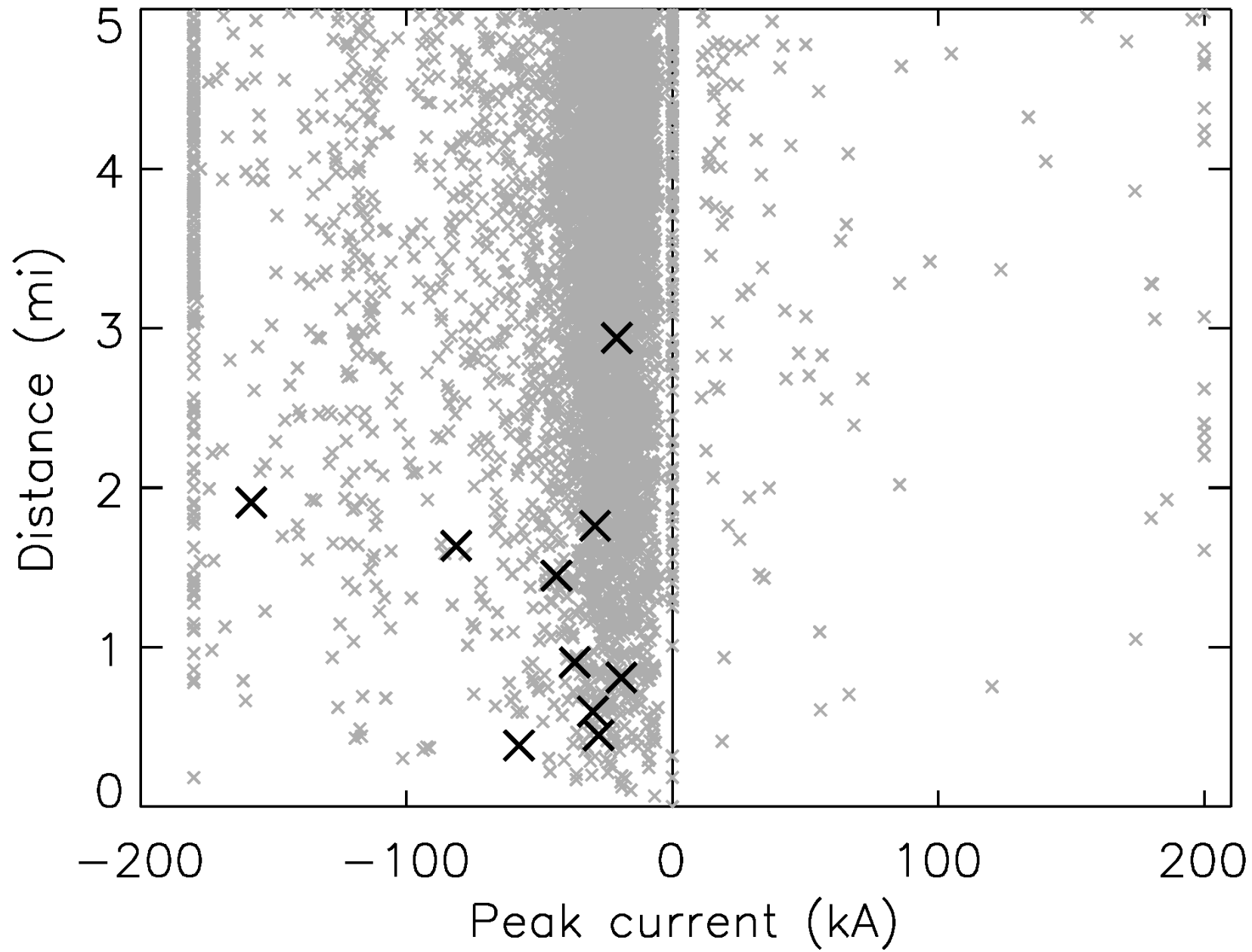
Cloud Density Overhead



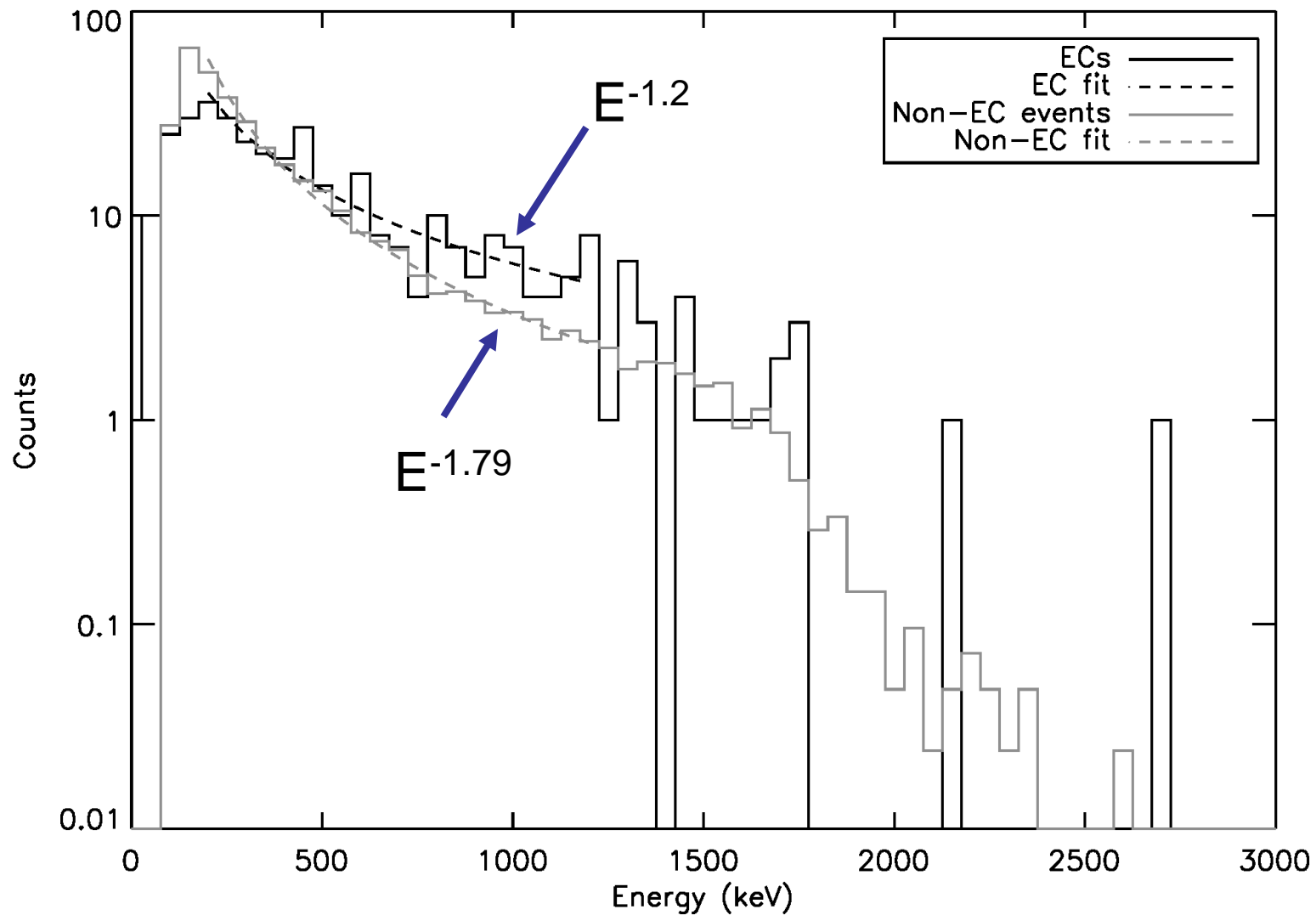




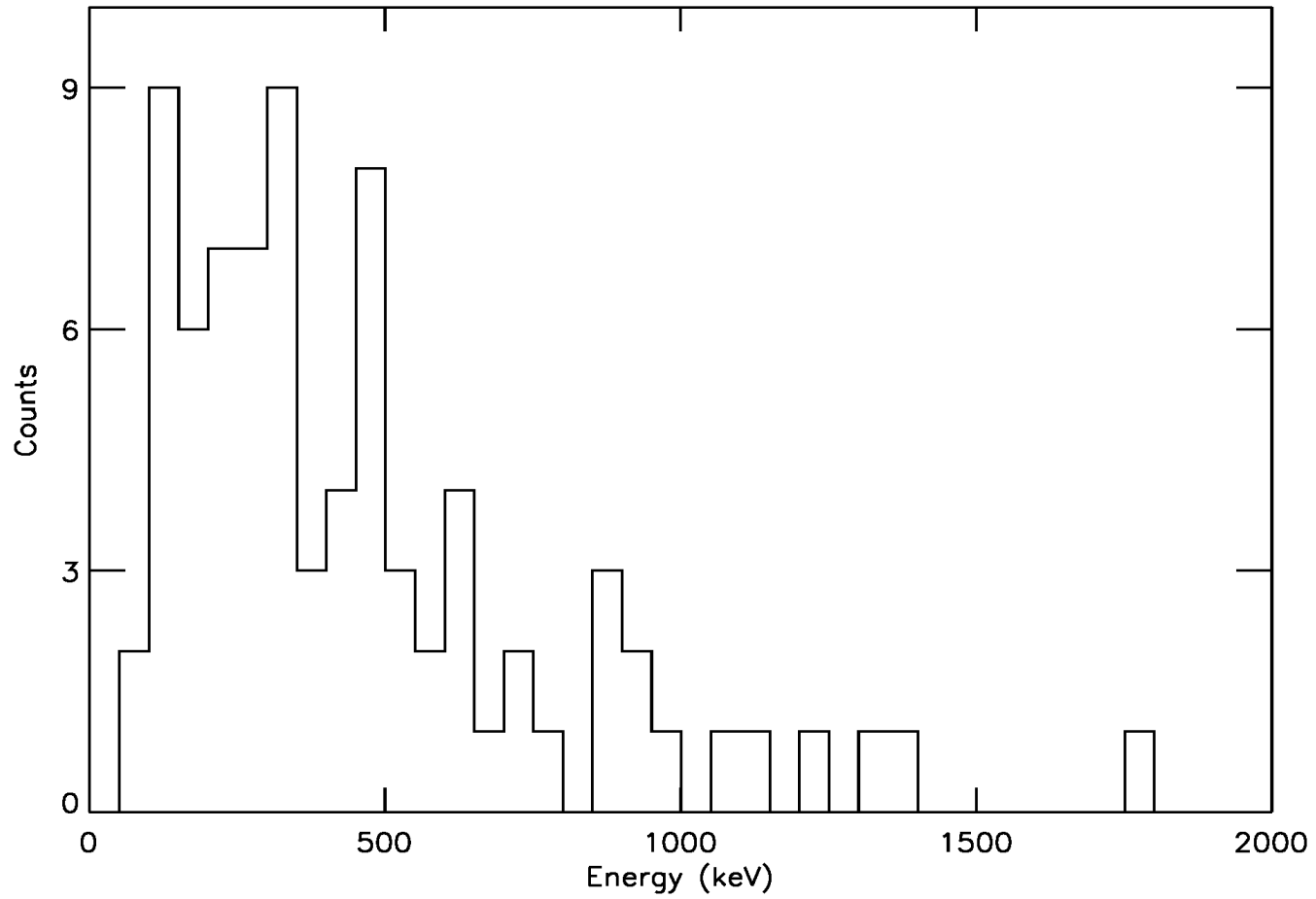




Event candidate photon spectrum

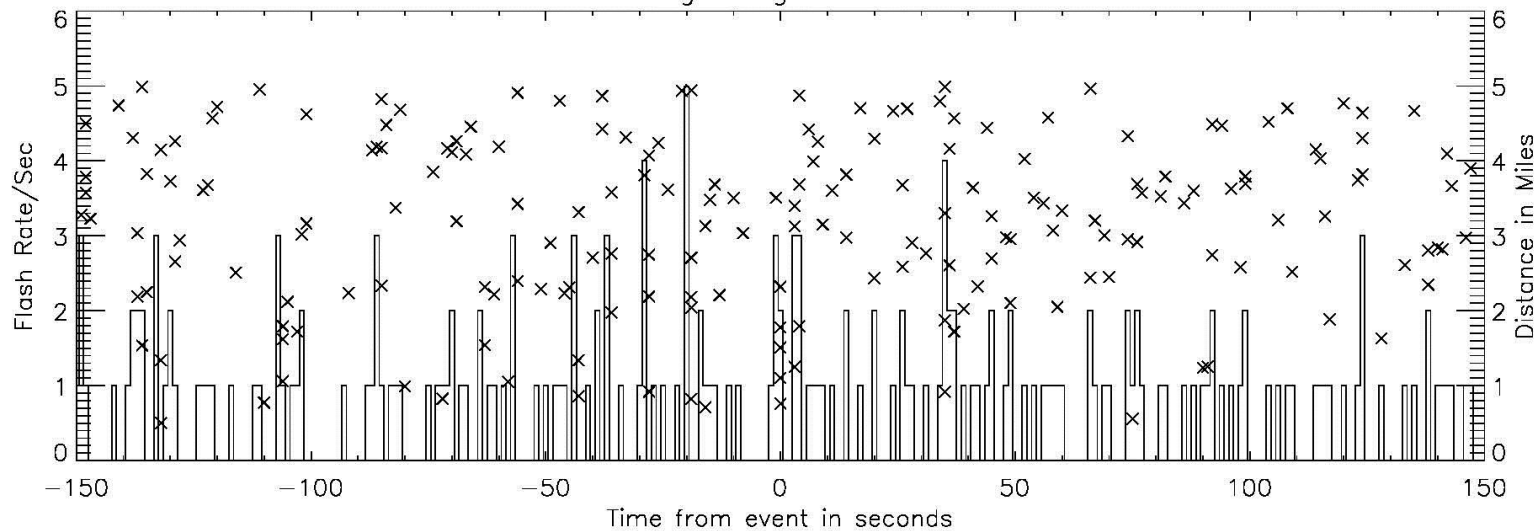


Photon spectrum of coincident event candidates

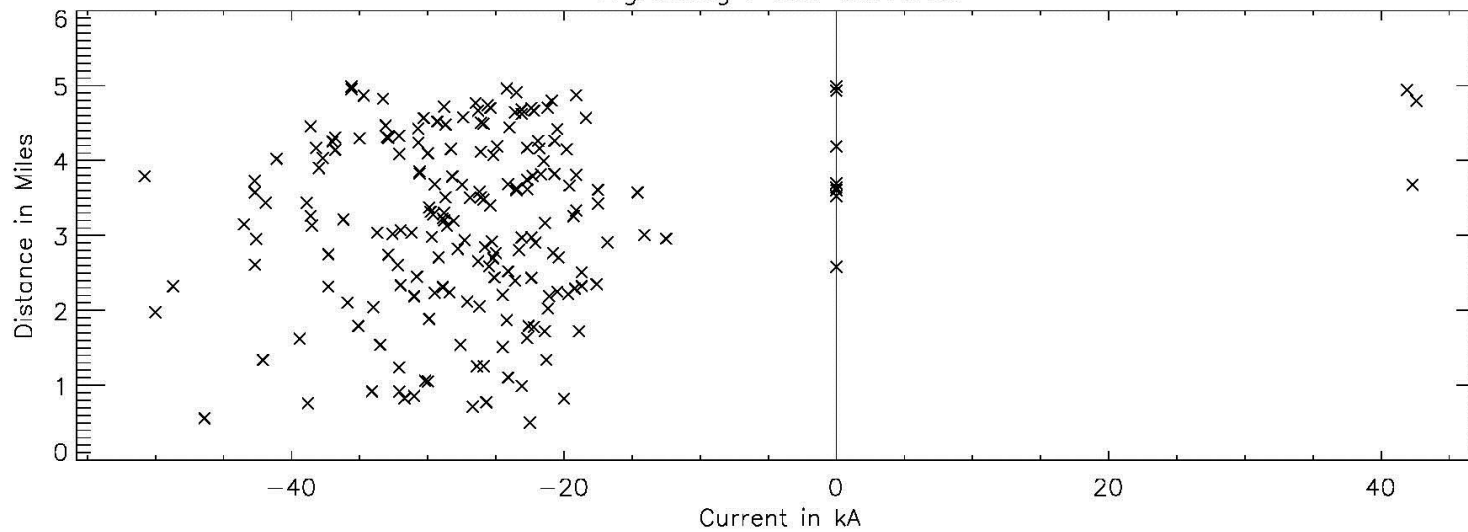


197 lightning strikes within 5 miles and 5 minutes of 2013-05-10-03-55-05-398 on Box 3.
Closest lightning strike was -67 ms and 0.7609 miles away with peak current of -38.8 kA, 37.4 ns timing error.

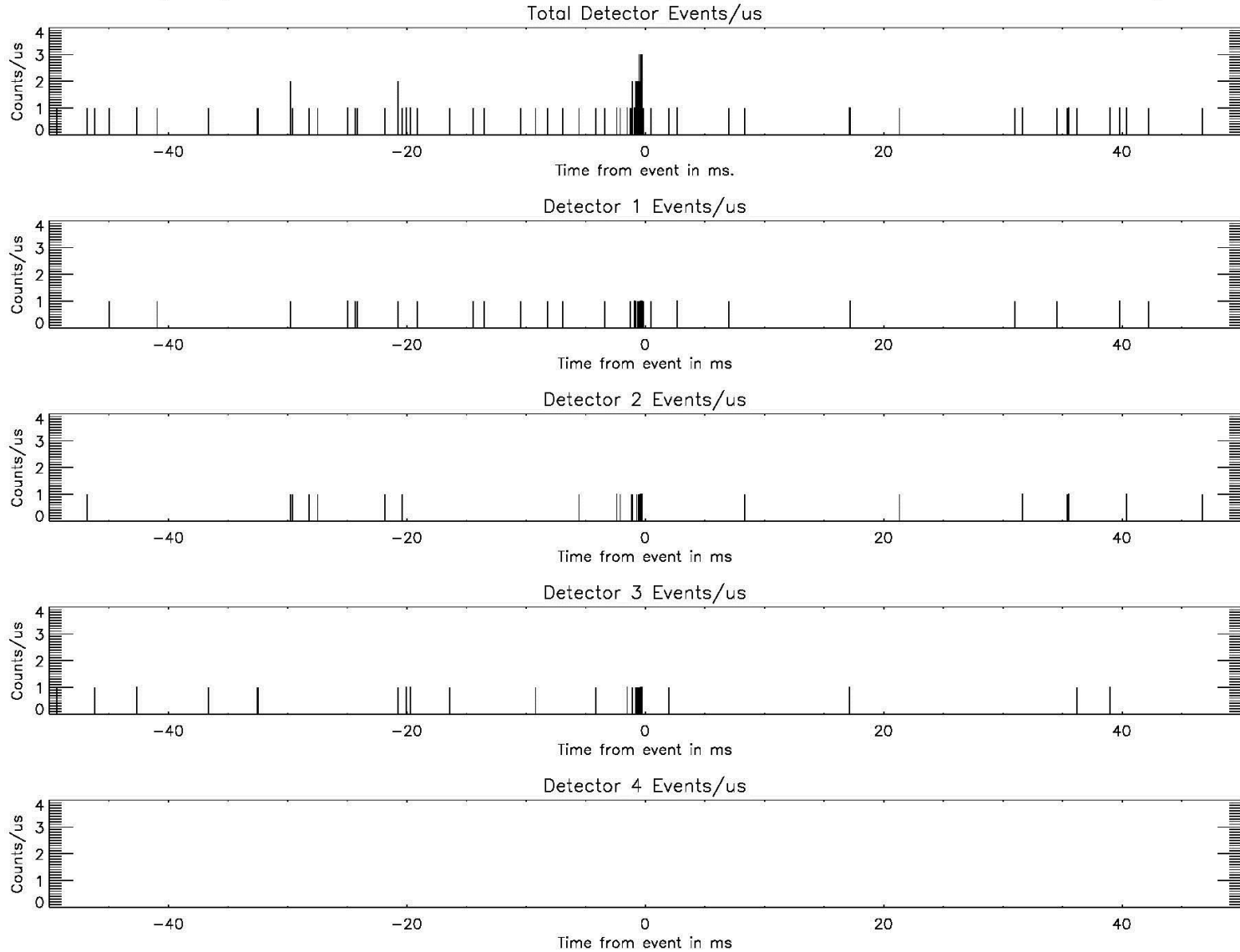
Lightning Strikes



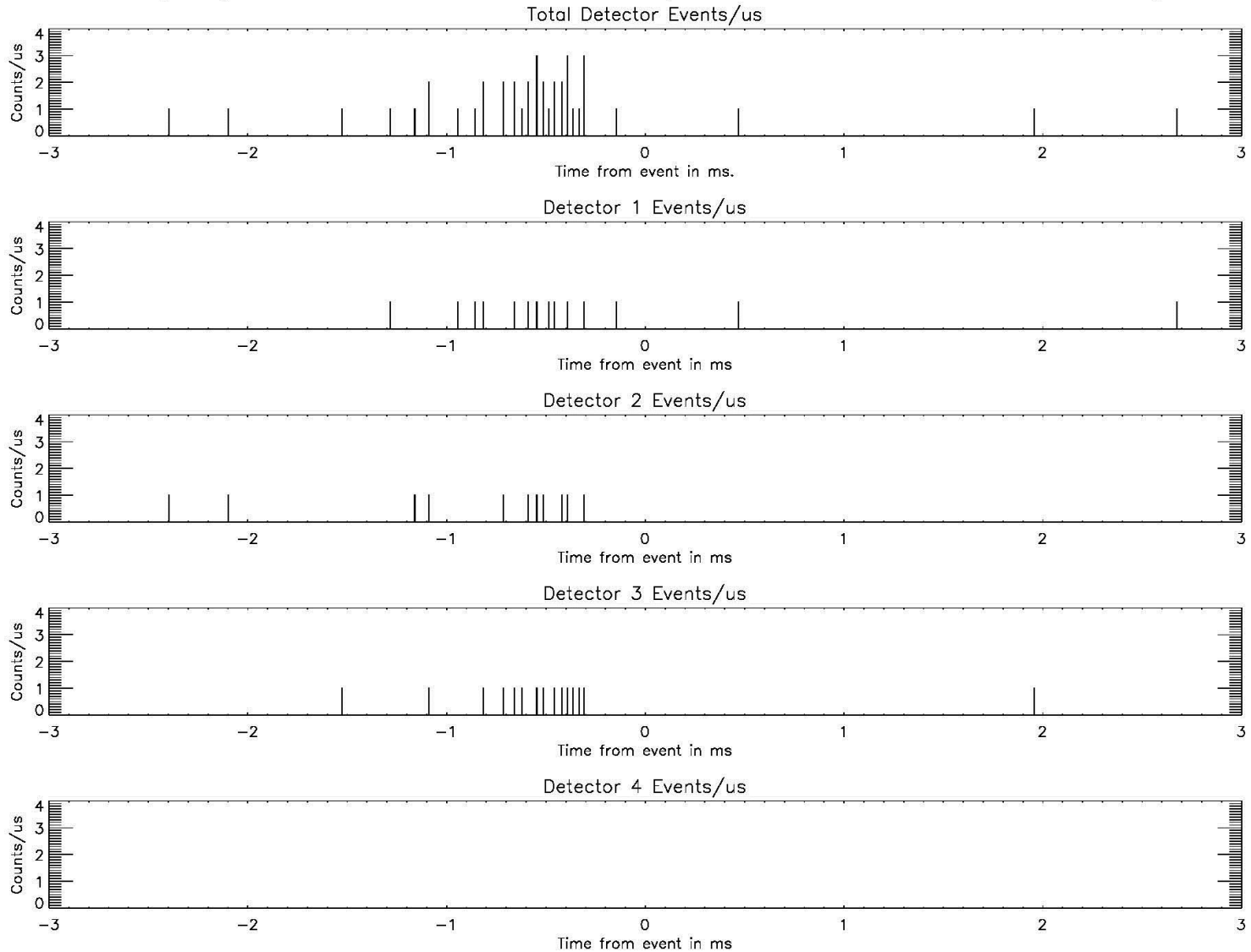
Lightning Peak Currents



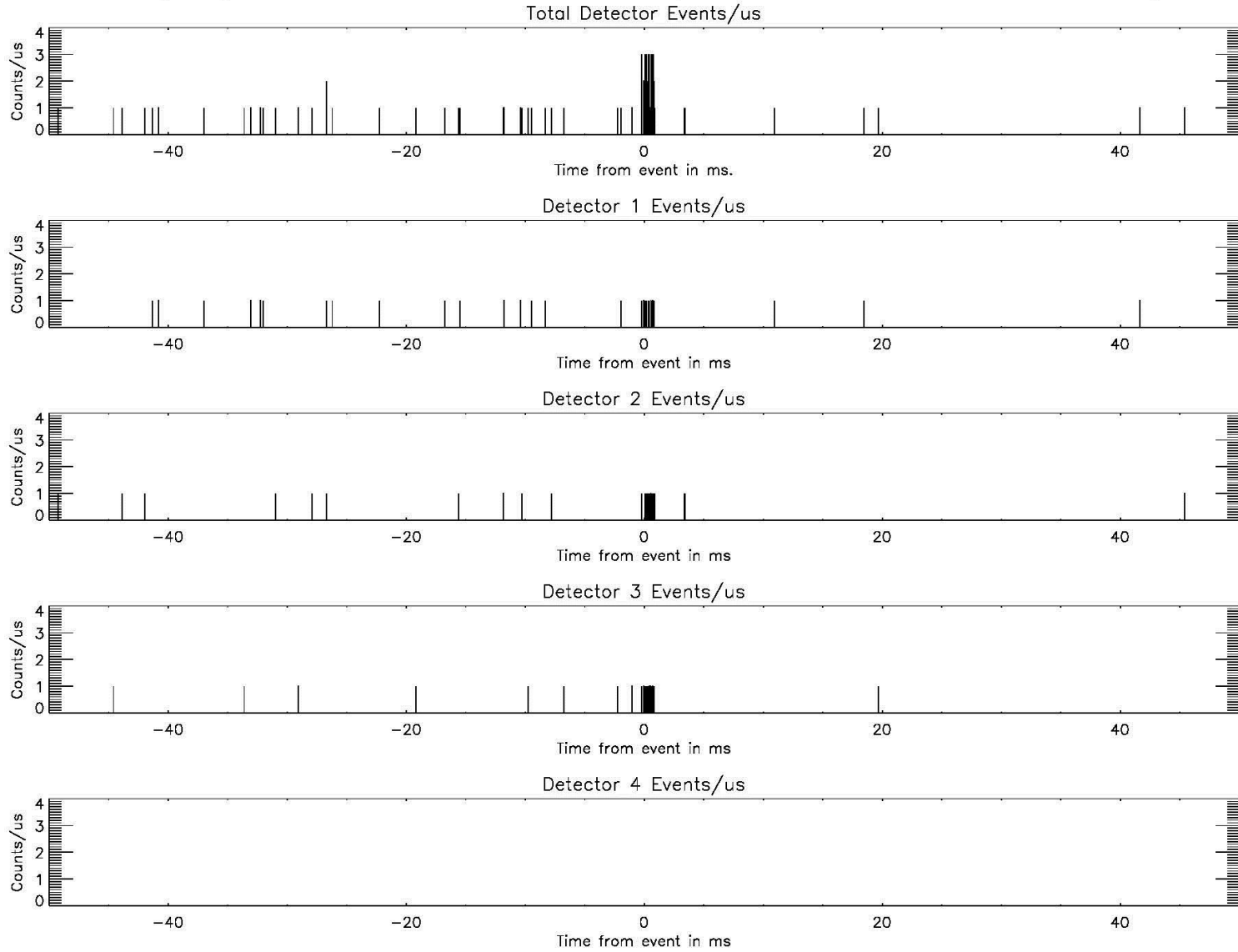
Box 3 Events/us for 100ms Window Centered on 2013-05-10-03-55-05-398 (91 Events Found).
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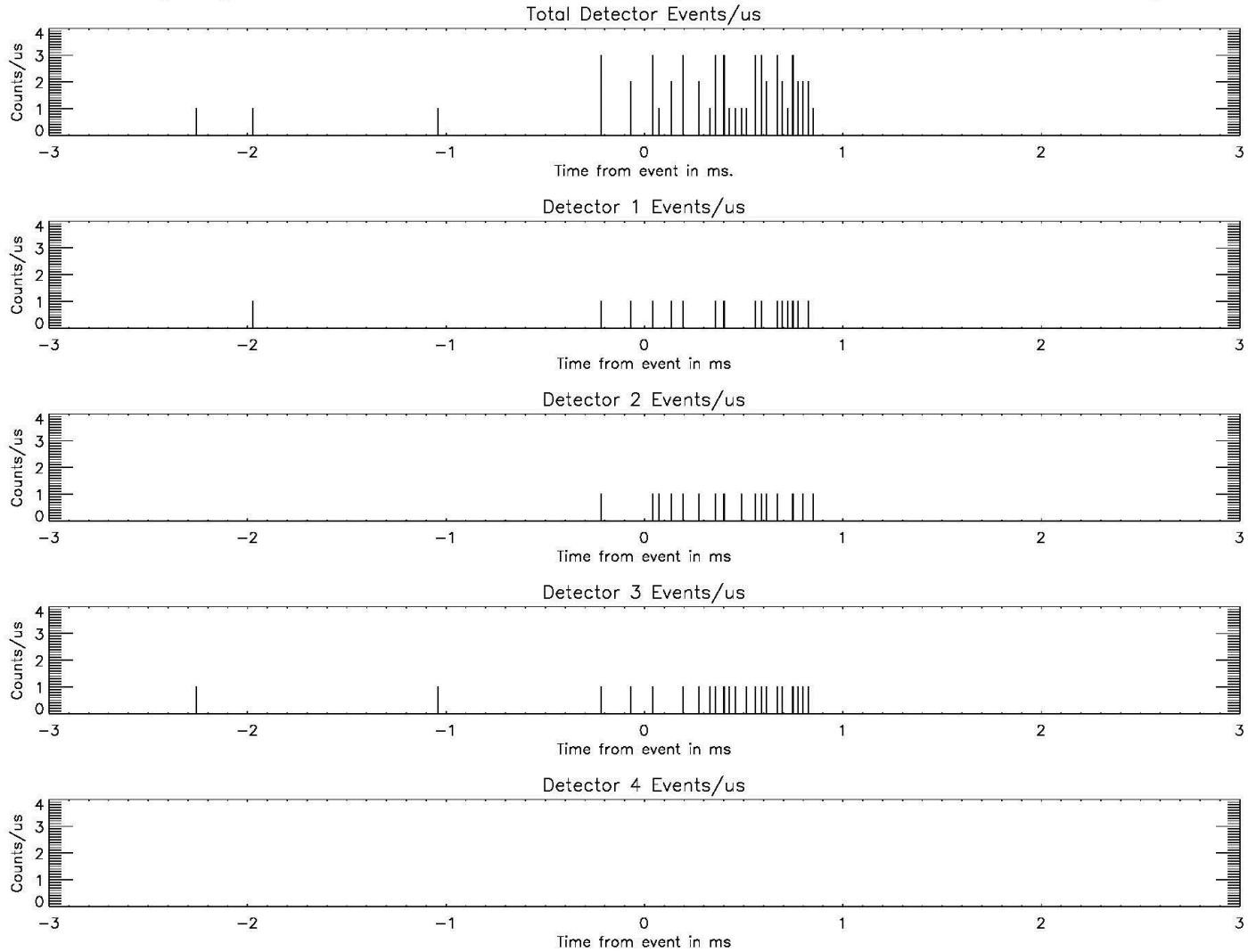
Box 3 Events/us for 10ms Window for 2013-05-10-03-55-05-398 (40 Events Found).
Closest lightning strike was -67 ms and 0.7609 miles away with peak current of -38.8 kA. 37.4 ns timing error.



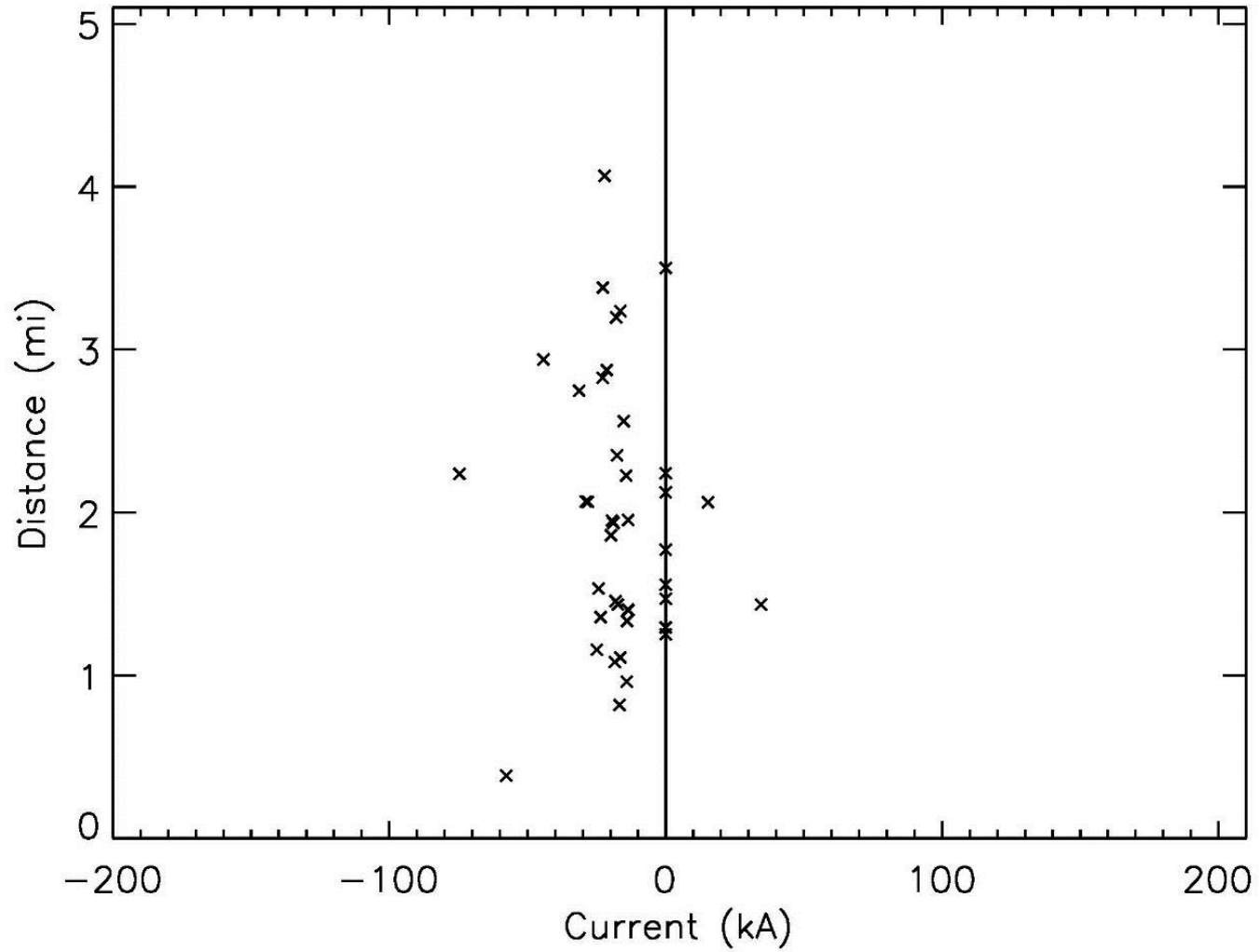
Box 3 Events/us for 100ms Window Centered on 2013-05-10-03-56-48-054 (92 Events Found).
Closest lightning strike was 1933 ms and 4.5211 miles away with peak current of -29.3 kA. 0.0 ns timing error.



Box 3 Events/us for 10ms Window for 2013-05-10-03-56-48-054 (54 Events Found).
Closest lightning strike was 1933 ms and 4.5211 miles away with peak current of -29.3 kA, 0.0 ns timing error.



42 lightning strikes within 5 miles and 5 min of 2011-07-29-10-38-58-932.

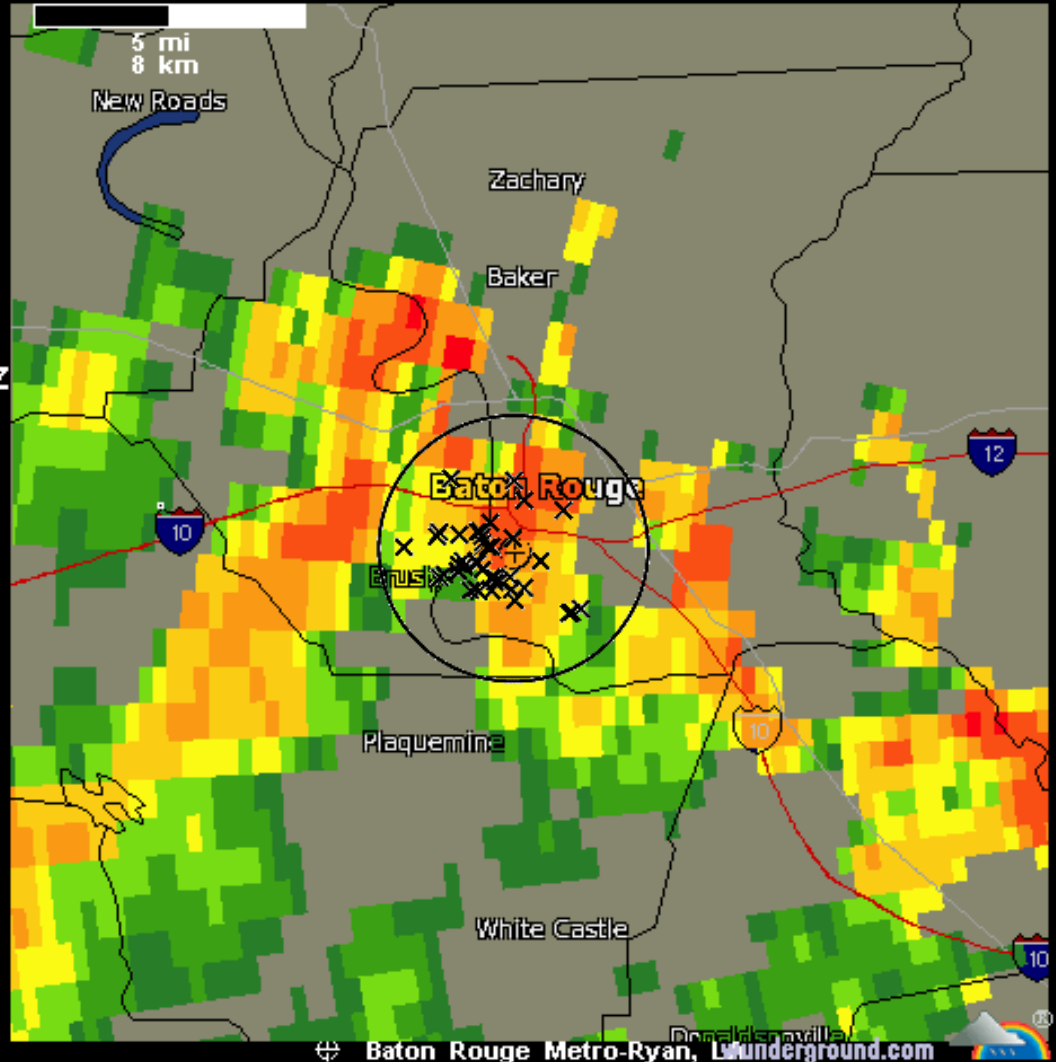
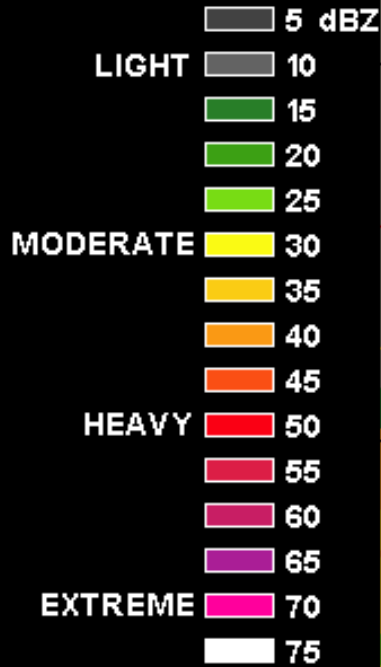


11:40 CDT
07/29/11



16:40 UTC
07/29/11

Max reflectivity 55 dbZ
Vol. cov. pattern 21



Date	Trigger Time (CST) (hh-mm-ss)	Max Lightning Rate within 5mi. (sec ⁻¹)	Cloud Density (dBz)	Storm Type	# Flashes within 5mi. and 5min.	Trigger-Lightning Difference (ms)	Lightning Distance (mi)	Lightning Current (kA)	T ₉₀ Event Duration (us)	Total γ Rays Detected	Total Energy (MeV)	σ Above Mean	Probability of CEC
7/31/2011	16-21-44.976	2	45	Coastal	12	-6	1.4	-43.6	702	22	14.7	25.2	2.59E-06
7/31/2011	16-21-45.300	2	45	Coastal	12	-4	1.8	-29.1	1326	24	11.7	25.2	2.59E-06
8/18/2011	17-57-38.984	4	50	Coastal	40	6743	1.3	-23.4	1318	40	20.3	22.5	3.75E-13
2/24/2011	23-11-15.787	3	45	Front	1	-6	2.9	-20.9	953	20	1.7	24.6	-
7/29/2011	10-38-58.932	6	45	Coastal	42	5	0.4	-57.7	153	8	4.8	23.0	-
8/18/2011	17-57-39.202	4	50	Coastal	40	6525	1.3	-23.4	24	7	3.6	26.1	-
3/12/2012	11-30-16.500	6	45	Front	4	5	1.6	-81.3	1997	7	3.2	21.8	-
4/2/2012	12-29-30.554	3	50	Front	8	6	0.6	-29.9	464	30	31.6	104.3	-
4/4/2012	02-49-21.900	5	55	Front	21	-3	1.9	-158.4	515	24	21.3	88.6	-
8/5/2012	14-43-35.661	7	40	Coastal	16	-849	0.6	-56.5	392	18	12.4	40.6	-
8/6/2012	19-17-33.359	5	50	Coastal	1	1017	0.8	-23.1	465	13	4.5	21.9	-
8/9/2012	15-27-29.804	4	50	Front	21	2	0.4	-27.8	2412	12	2.9	29.0	-
8/9/2012	15-28-36.070	4	50	Front	27	80	0.9	-36.7	4217	24	7.4	41.3	-
8/9/2012	15-28-36.560	4	50	Front	27	2	0.8	-19.2	146	12	8.0	33.9	-
6/6/2012	15-44	6	55	Coastal	16	-	0.9	-6.7	609	14	8.5	45.7	-
6/6/2012	15-37	6	55	Coastal	40	-	0.6	-5.4	865	45	27.2	86.1	-
6/6/2012	19-23	6	55	Coastal	40	-	0.5	-9.6	2979	18	6.7	45.7	-
6/6/2012	19-29	6	55	Coastal	33	-	0.2	-8.9	2376	24	9.7	55.3	-
6/6/2012	19-31	6	55	Coastal	19	-	0.2	-8.9	919	40	29.8	48.3	-
6/6/2012	19-32	6	55	Coastal	19	-	0.3	-9.1	827	9	5.4	21.0	-
6/6/2012	19-36	6	55	Coastal	18	-	0.6	-14.2	2035	8	5.2	20.1	-
6/6/2012	19-36	6	55	Coastal	18	-	0.6	-14.2	631	32	31.4	63.1	-
6/9/2012	13-40	6	50	Coastal	1	-	4.6	0.0	1930	15	8.6	55.1	-
7/7/2012	17-38	5	45	Coastal	1	-	0.6	-11.8	510	14	8.0	33.9	-

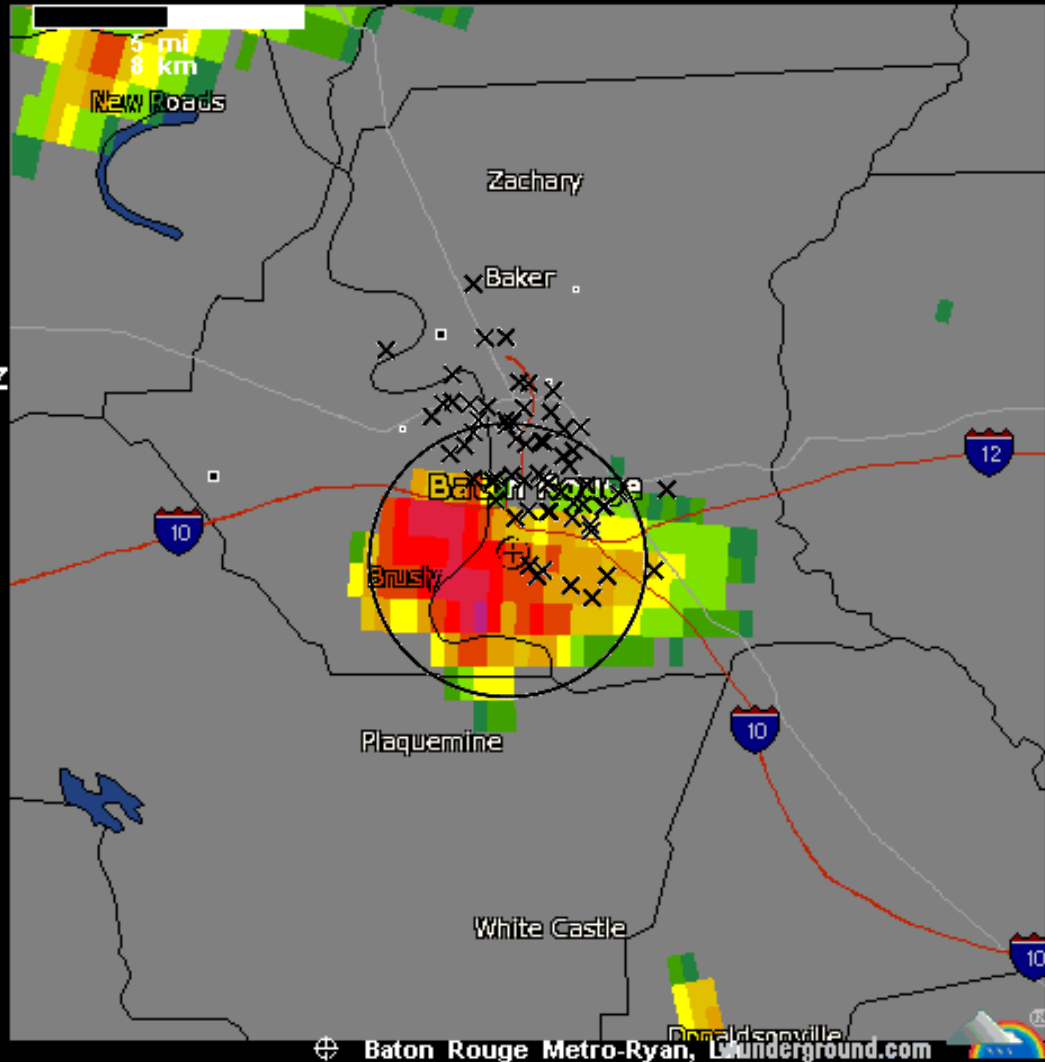


18:57 CDT
08/18/11



23:57 UTC
08/18/11

Max reflectivity 63 dBZ
Vol. cov. pattern 212

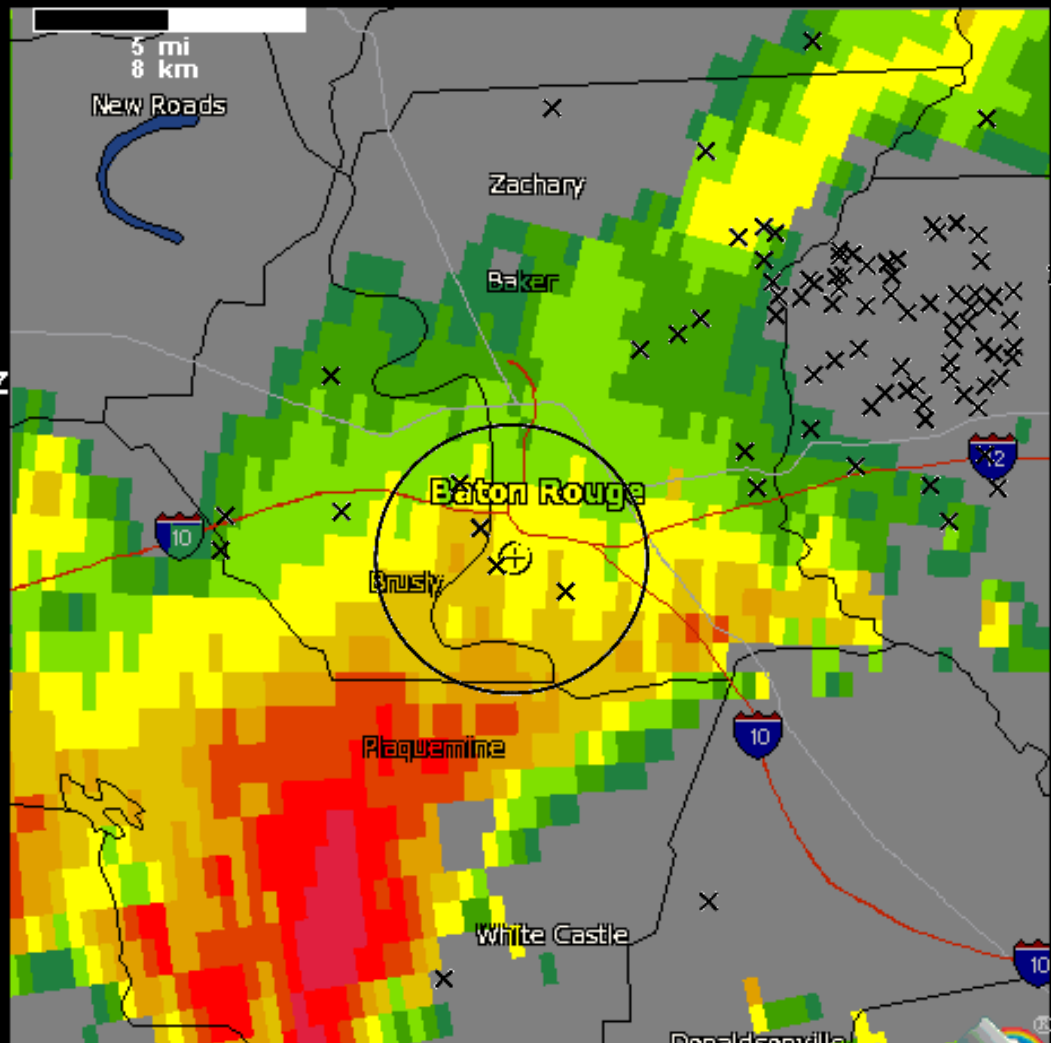
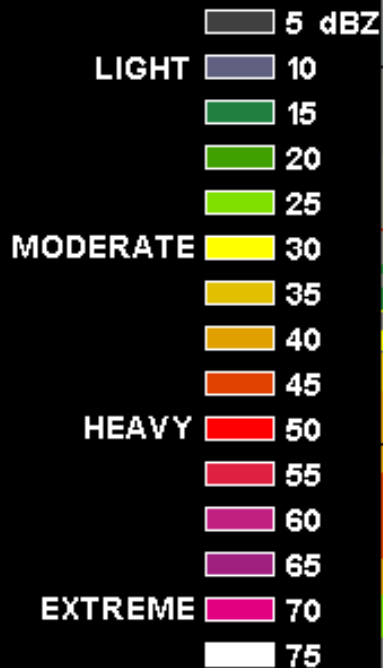


12:32 CDT
03/12/12



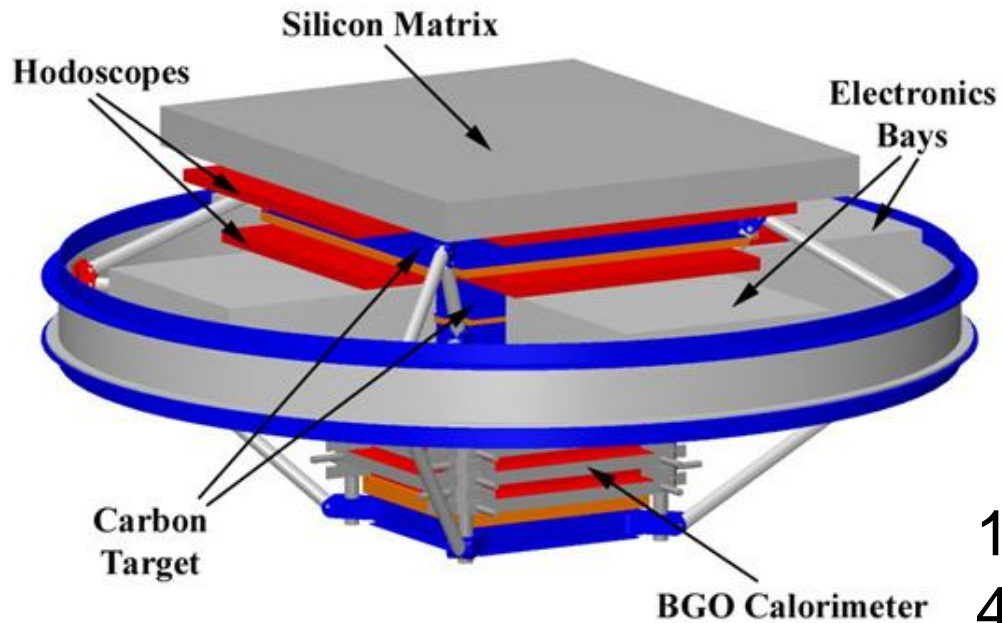
17:32 UTC
03/12/12

Max reflectivity 60 dBZ
Vol. cov. pattern 212

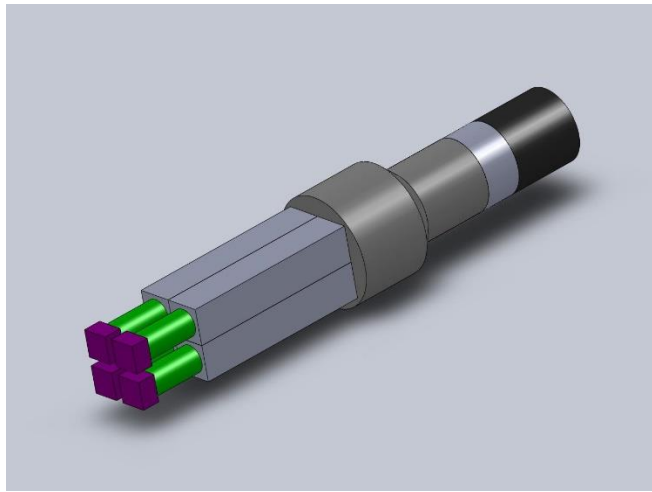


Program of Balloon Observations

Based on supply of BGO scintillators from ATIC high energy electron experiment



10 trays of
40 $2.5\text{ cm} \times 2.5\text{ cm} \times 25\text{ cm}$
BGO crystals in each tray
22 radiation lengths depth



- Assembly of four ATIC BGO scintillator elements viewed by a single 3" PMT at one end and four 1" PMTs at the other end.
- Same front end electronics and data acquisition system as rooftop array
- Include bare PMTs without scintillators attached as background/noise monitors.
- Entire package, including launch system electronics, telemetry, cutdown system, etc. -- less than 100 lbs total weight, suitable for manual launch.

Payload has its own mounting plate containing all electrical connectors and mechanical mounting footprint.

100 W @ 32 VDC power

Uplink / downlink serial interface of about 50 kilobits per second

On-board storage (50 gigabytes)

Analog downlink and discrete command channels

Current GPS latitude, longitude, and altitude information, UTC time to within one millisecond.

TGF flight #1 -- 2012:

Integrated with NASA Columbia Scientific Balloon Facility (CSBF) launch system at the CSBF site in Palestine, TX prior to the start of the 2012 spring thunderstorm season.

Flight plan -- Wait at CSBF in Palestine until a promising frontal system with strong thunderstorm activity approaches Palestine, launch manually 4-5 hours ahead of the storm, and fly alongside or above the storm as it passes.

Launch #1 – May 2012

No gamma ray events detected

TGF flight #2 – expected Sept., Oct. 2013

Currently awaiting promising storm activity at CSBF launch site in Ft. Sumner, NM

Future plans:

TETRA will continue operating.

Hope to be able to detect γ -rays from a balloon flight close to a thunderstorm in Texas or New Mexico