

Comments in red are annotations made for posting the talk online

# RHESSI Terrestrial Gamma-ray Flashes: Current Status

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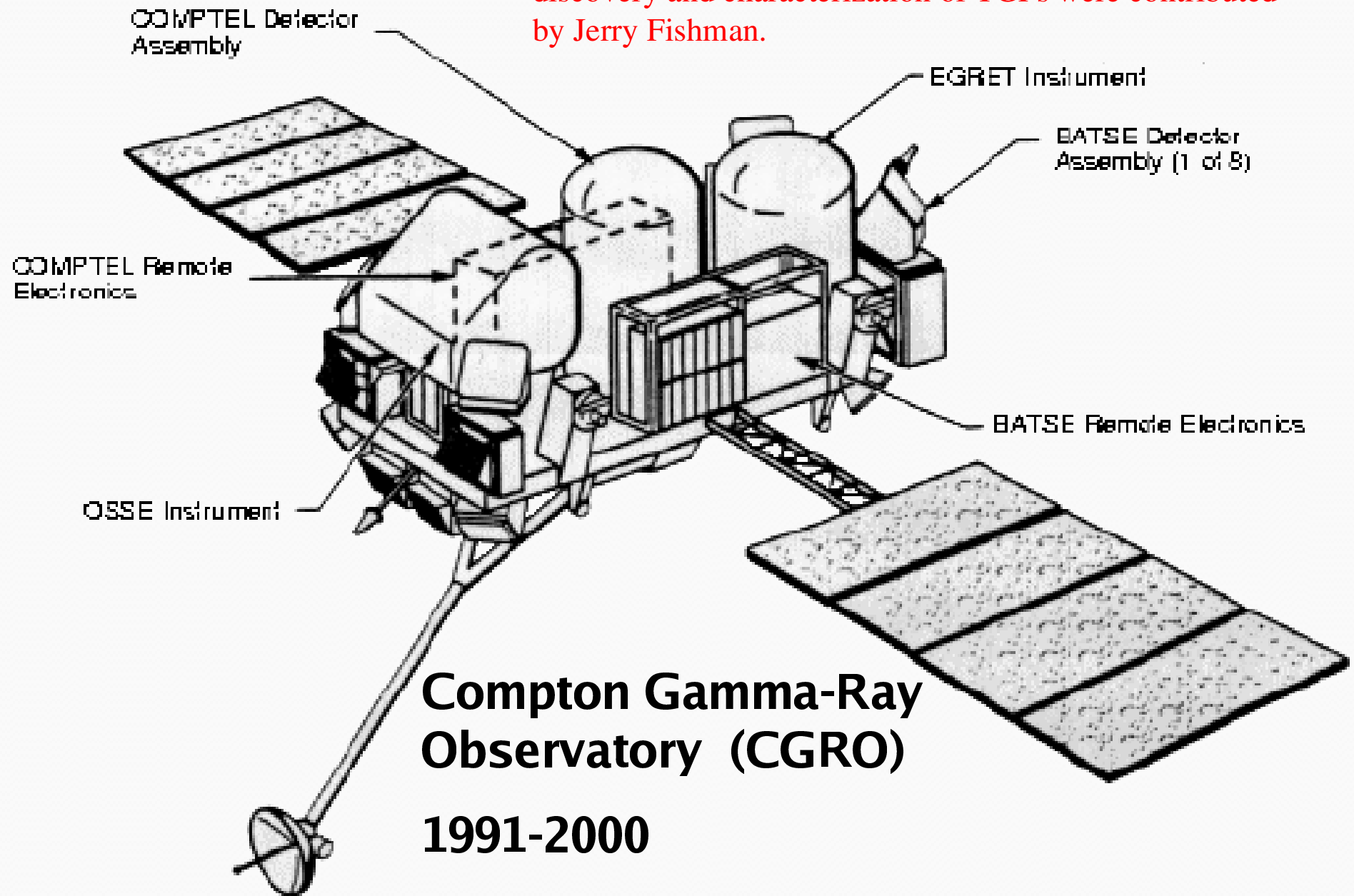
INTRODUCTORY SLIDES ON BATSE RESULTS  
CONTRIBUTED BY G. FISHMAN, MSFC

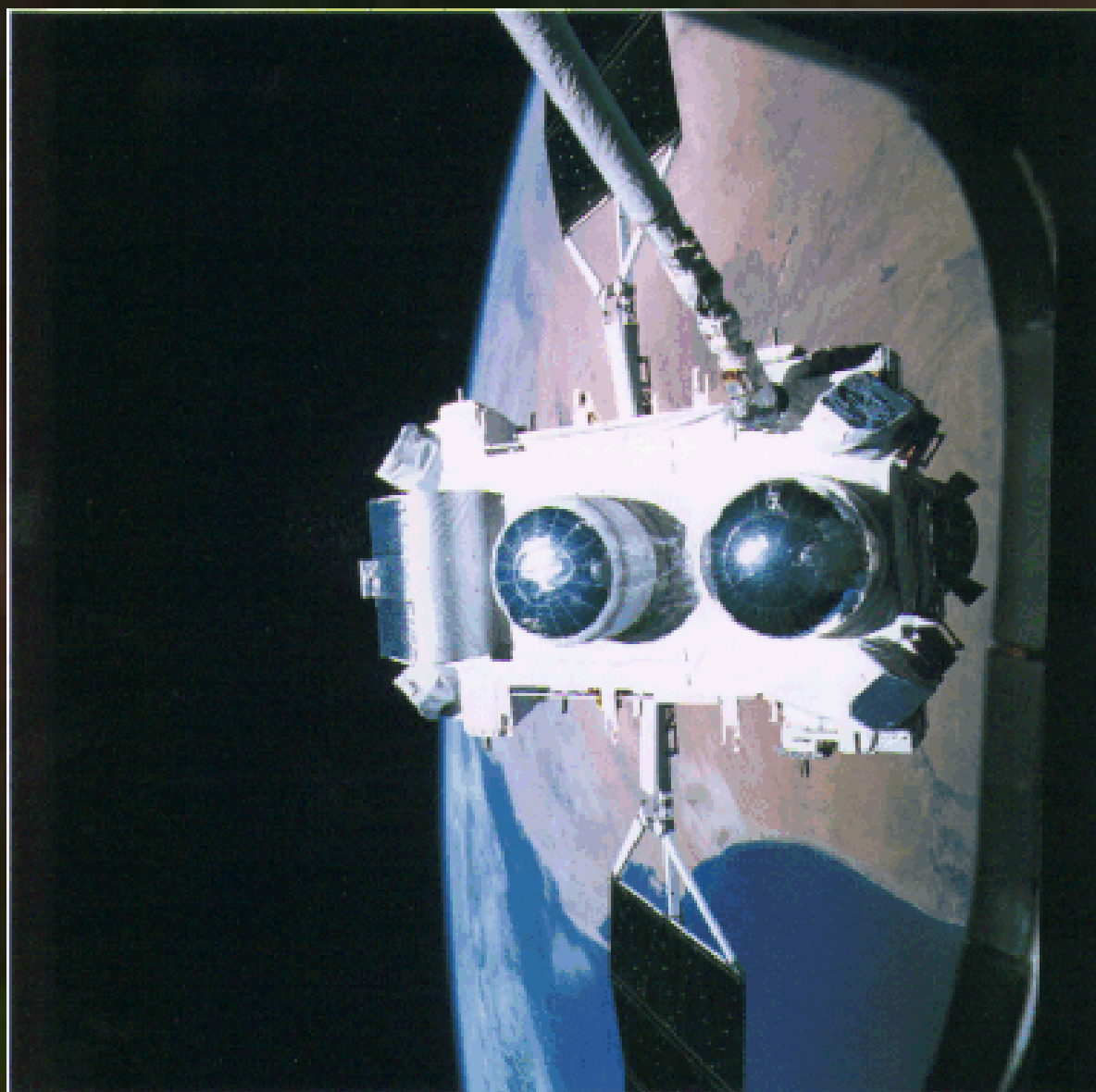
Seminar at UCB/SSL, 2/15/05

RHESSI is funded by NASA contract NAS5-98033



Annotation: this and the subsequent slides on BATSE's discovery and characterization of TGFs were contributed by Jerry Fishman.

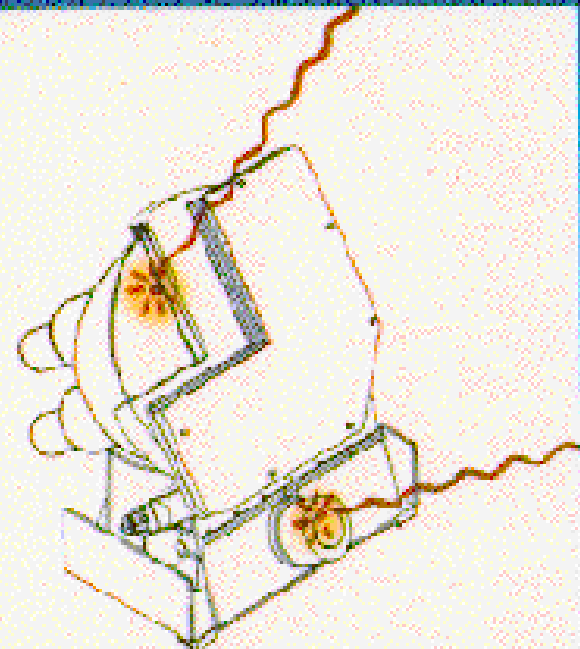
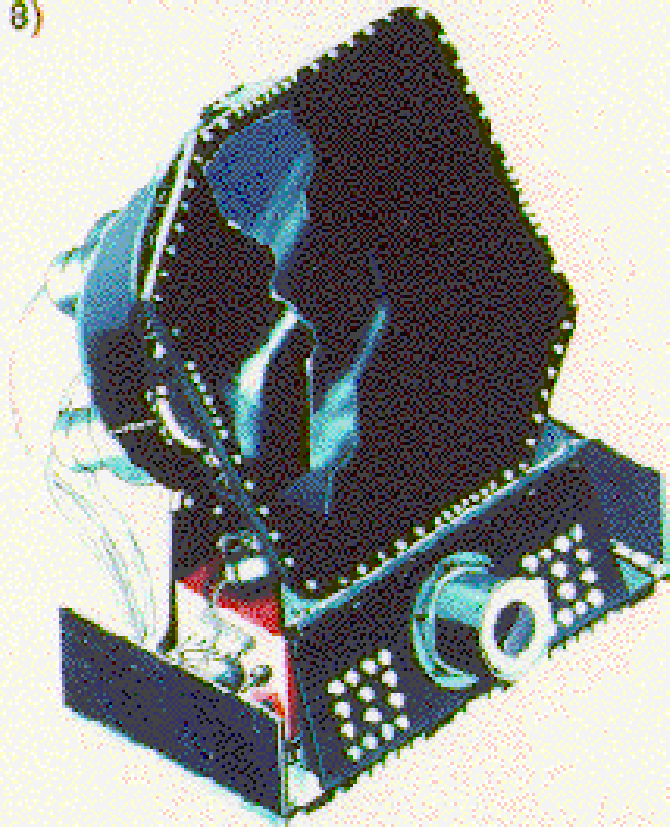




Each BATSE module was  
large, 2025 cm<sup>2</sup>.

## Burst and Transient Source Experiment (BATSE)

BATSE  
DETECTOR MODULE  
(1 OF 8)



# TTE Data for Trigger #5587

9-SEP-1996 11:33:24

Created by MOPS BD  
(Burst Display)  
Version 2.23

Trigger # : 5587

Trigger Time:  
10322 / 74000.906

Burst Data Type:  
TTE

Multiple Events  
Ignored: 6

Deadtime  
Corrected: N

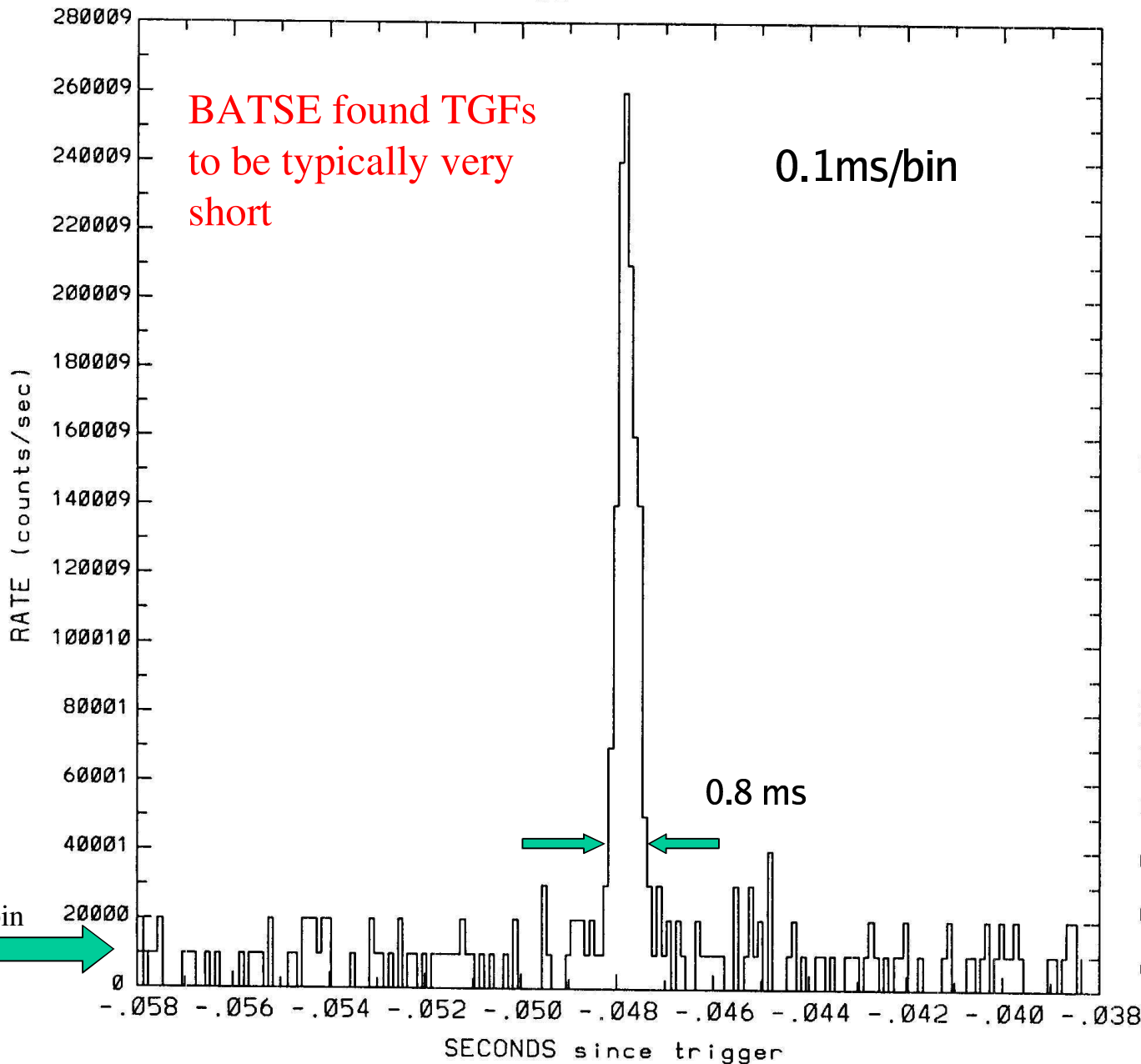
Background Data  
Type: DISCLA

Minimum Integ. Time:  
0.000100 second(s)

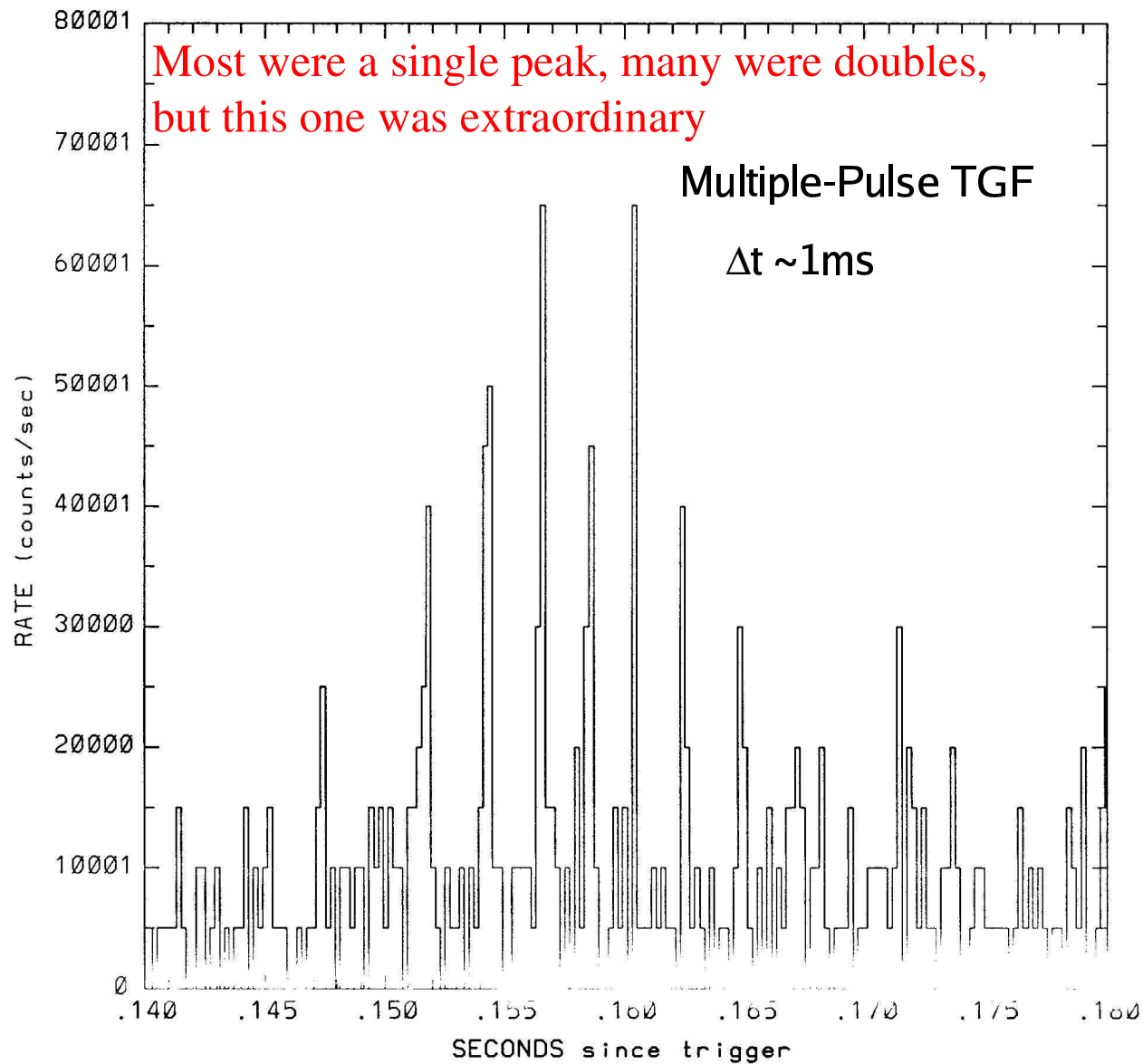
Detectors [7..0]:  
-----2-0

Discriminators:  
( 1, 4)

Quality Mask:  
BDISP0



# TTE Data for Trigger #5578



10-SEP-1996 15:00

Created by MOP  
(Burst Display)  
Version 2.2

Trigger # : 5578

Trigger Time:  
10312 / 46631.6

Burst Data Type:  
TTE

Multiple Events  
Ignored: 7

Deadtime  
Corrected: N

Background Data  
Type: DISCLA

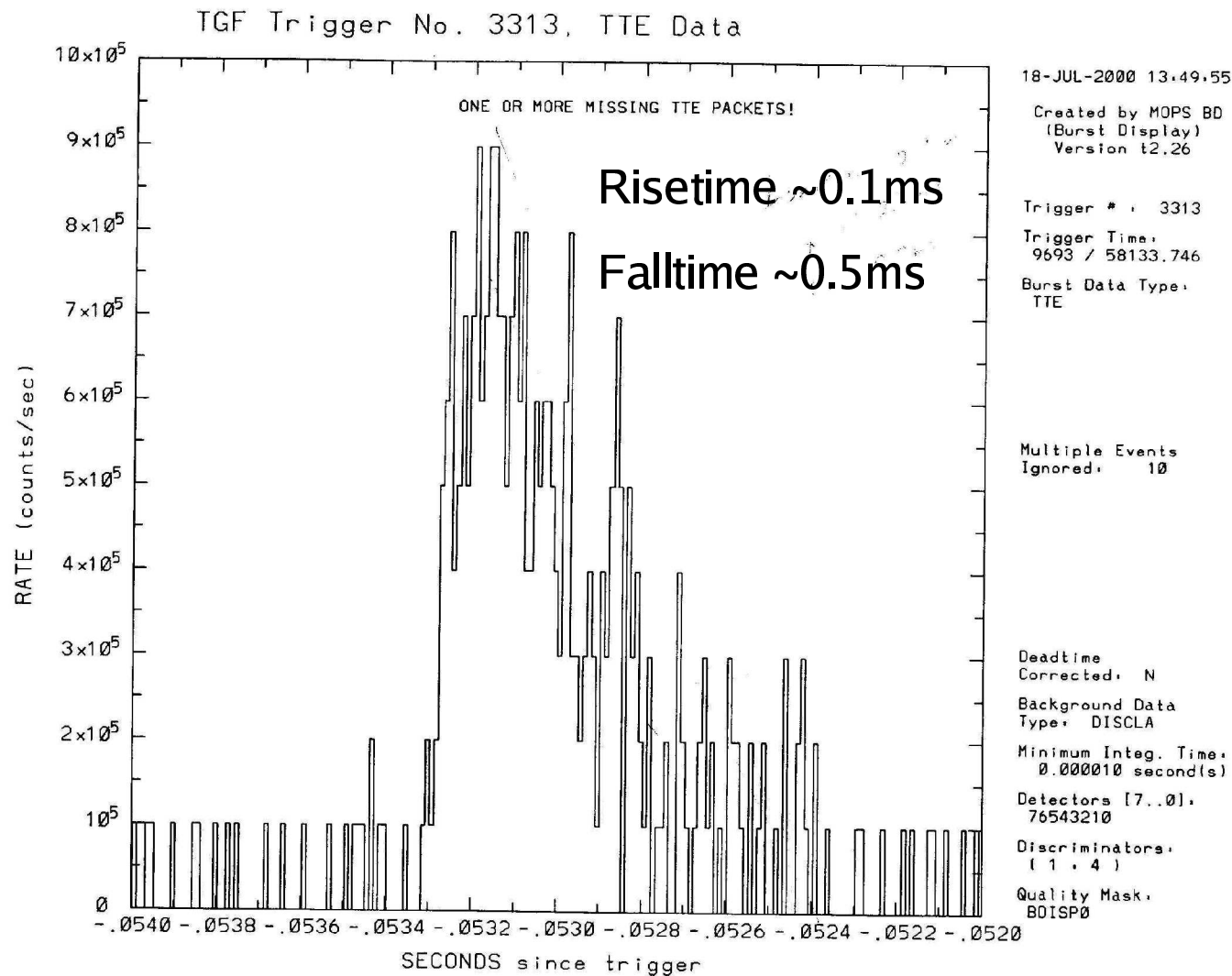
Minimum Integ.  
0.000200 sec

Detectors [7...  
-6---2--

Discriminators  
(1, 4)

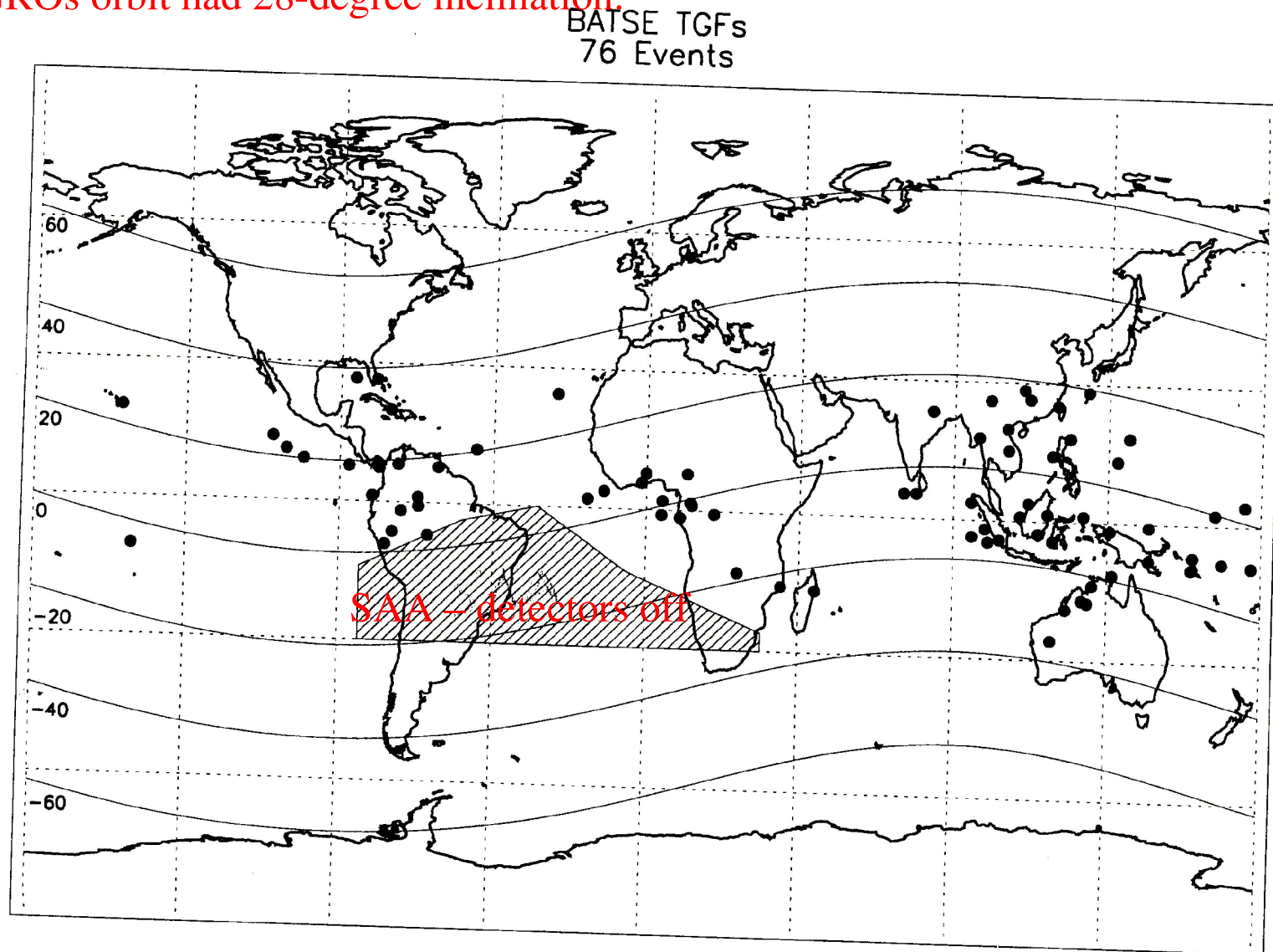


BATSE was capable of extremely high time resolution when bursts were triggered, and registered enough counts to make detailed lightcurves:





The BATSE TGF map highlights regions with lots of thunderstorm activity.  
CGROs orbit had 28-degree inclination.





# BATSE

## – Energy Channels for TTE Data

<u>Chan. No.</u>	<u>Approx. Energy Range</u>
1	25 - 50 keV
2	50 – 100 keV
3	100 – 300 keV
4	> 300 keV

BATSE had no way of knowing the energy distribution above 300 keV, just that a very large fraction of the counts were at high energies.



# BATSE Summary

- ~ 76 TGFs observed with BATSE over 9 years
- ~1 per week, when in optimum energy trigger mode
- Many TGFs unobserved due to long trigger window and non-optimum trigger energy band
- Typical timescales: ~0.4ms rise /fall; duration ~ 1.0 ms



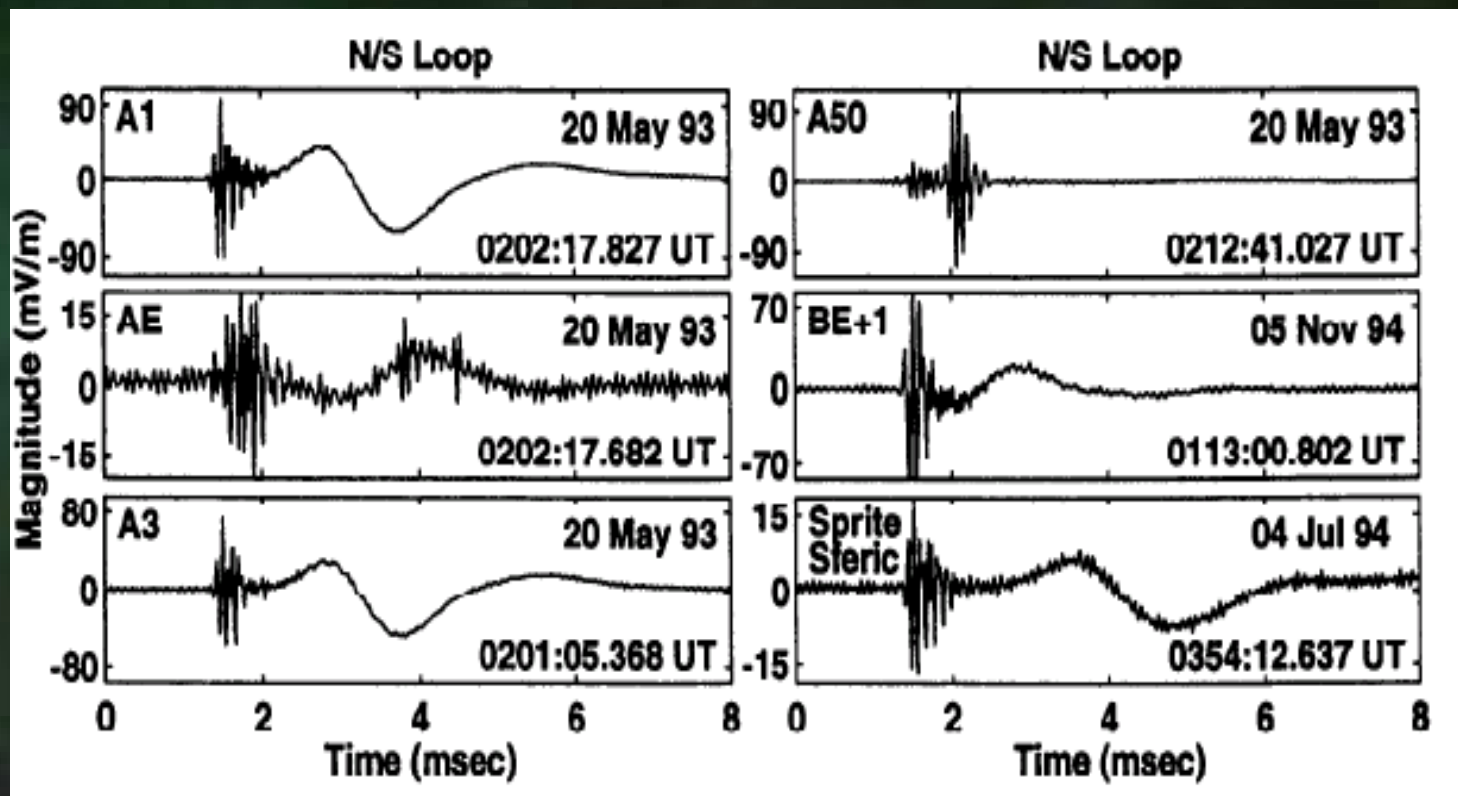
# BATSE Summary (cont.)

- Multiple pulses seen in  $\sim 30\%$  of TGFs
- Intensity distribution unknown; only the strongest are observed
- Typ. Energy per TGF :  $\sim 10^4 - 10^5$  Joules
- Assumes isotropic emission;  $\sim 10$  MeV per count;  
 $d=600\text{km}$

End of slides contributed by Jerry Fishman. Annotations were by David Smith.



One BATSE TGF unequivocally associated with  
a VLF/ELF sferic similar to those that make sprites  
(Inan et al. 1996, GRL 23, 1017)



# The Reuven Ramaty High Energy Solar Spectroscopic Imager

Sees to higher latitude than BATSE

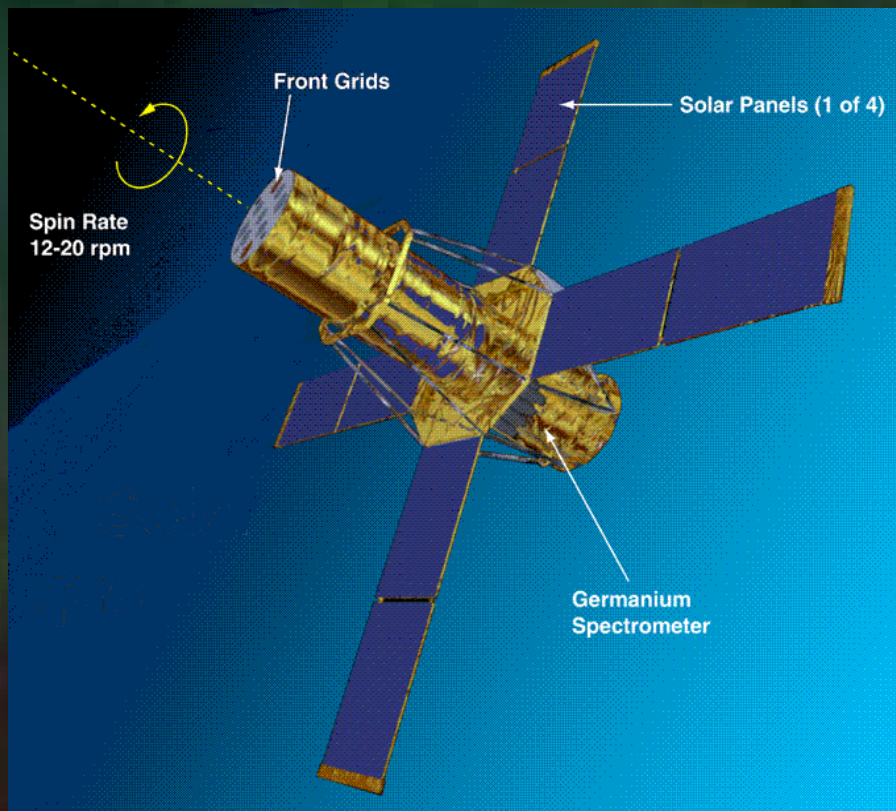
NASA Small Explorer spacecraft, 38 degrees LEO  
Launched February 12, 2002 to study solar flares  
Detectors smaller than BATSE's, but:

better high-energy response

high energy resolution

no onboard trigger required  
to recover events

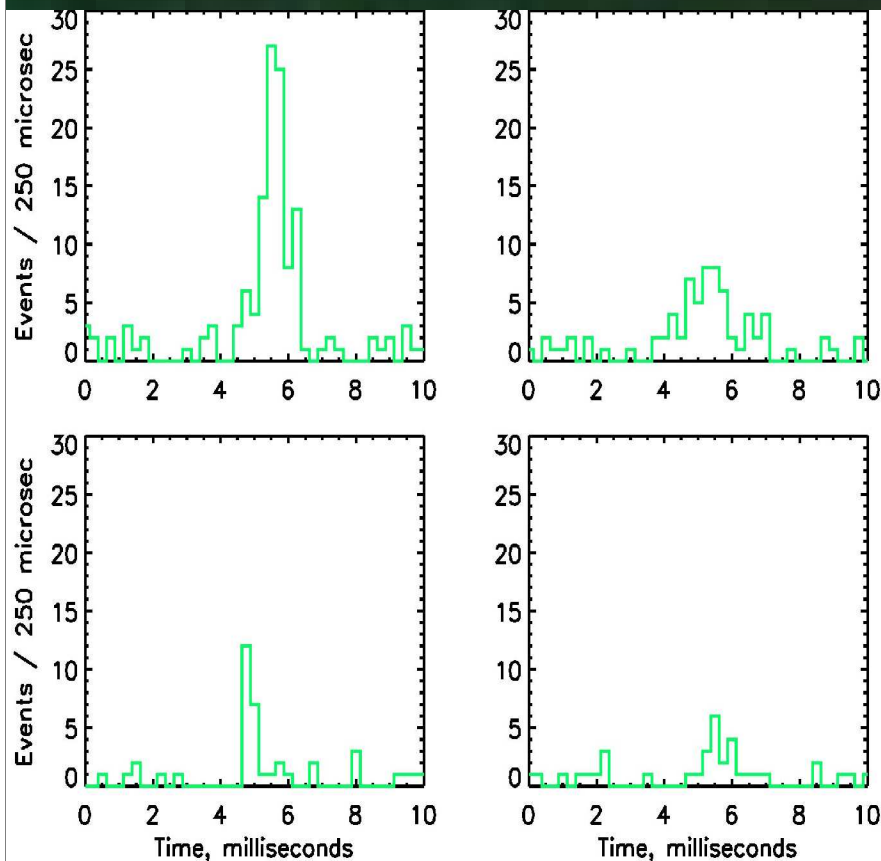
So we see far more events, but fewer  
total counts per event.



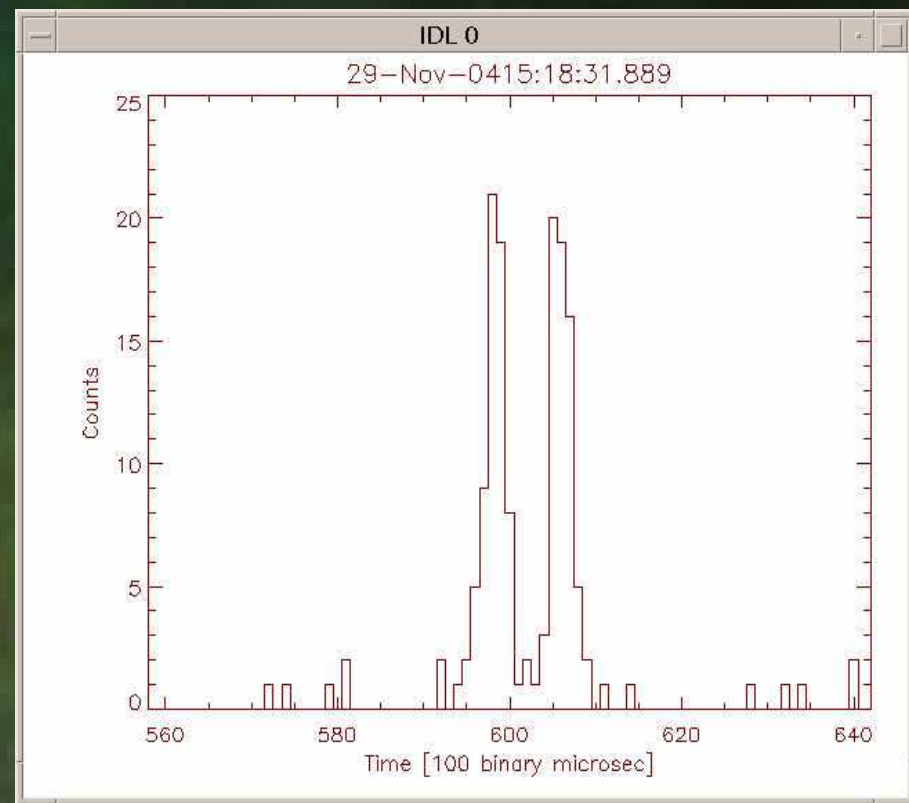
# RHESSI TGFs: Lightcurves

Durations from 200  $\mu$ s to 3.5 ms. 99% single-peak in contrast to BATSE, whose trigger was biased toward the longer, brighter multi-flash events.

Typical single-peaked RHESSI TGFs



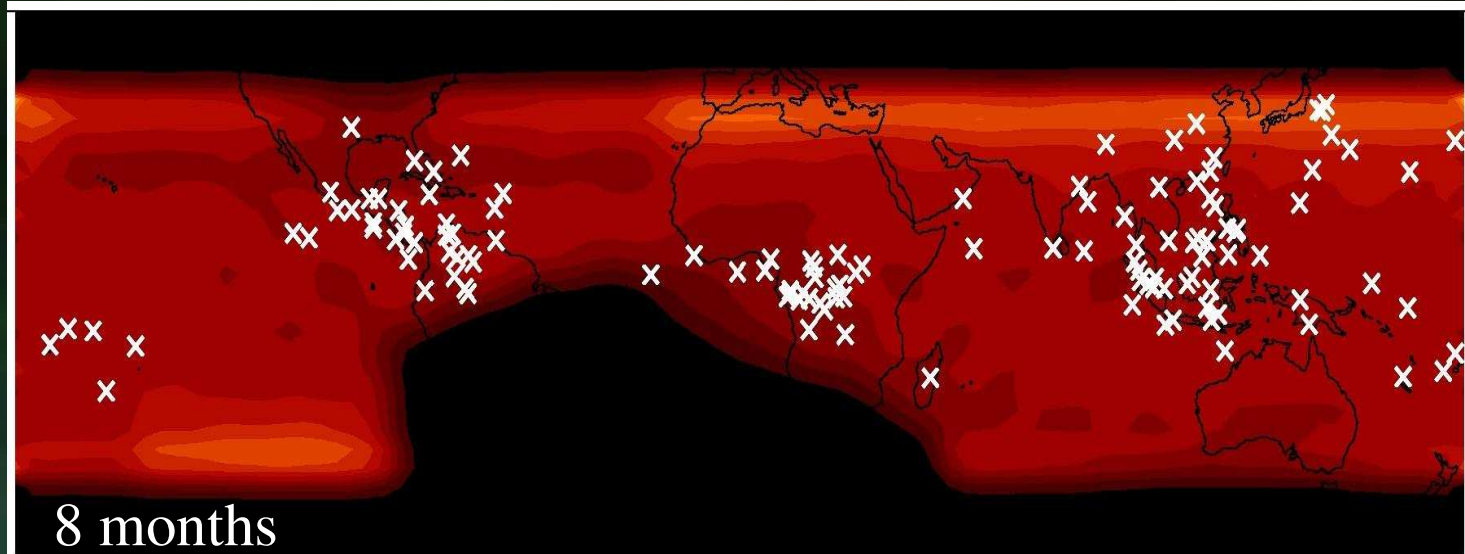
RHESSI's 2nd-brightest TGF is double-peaked:



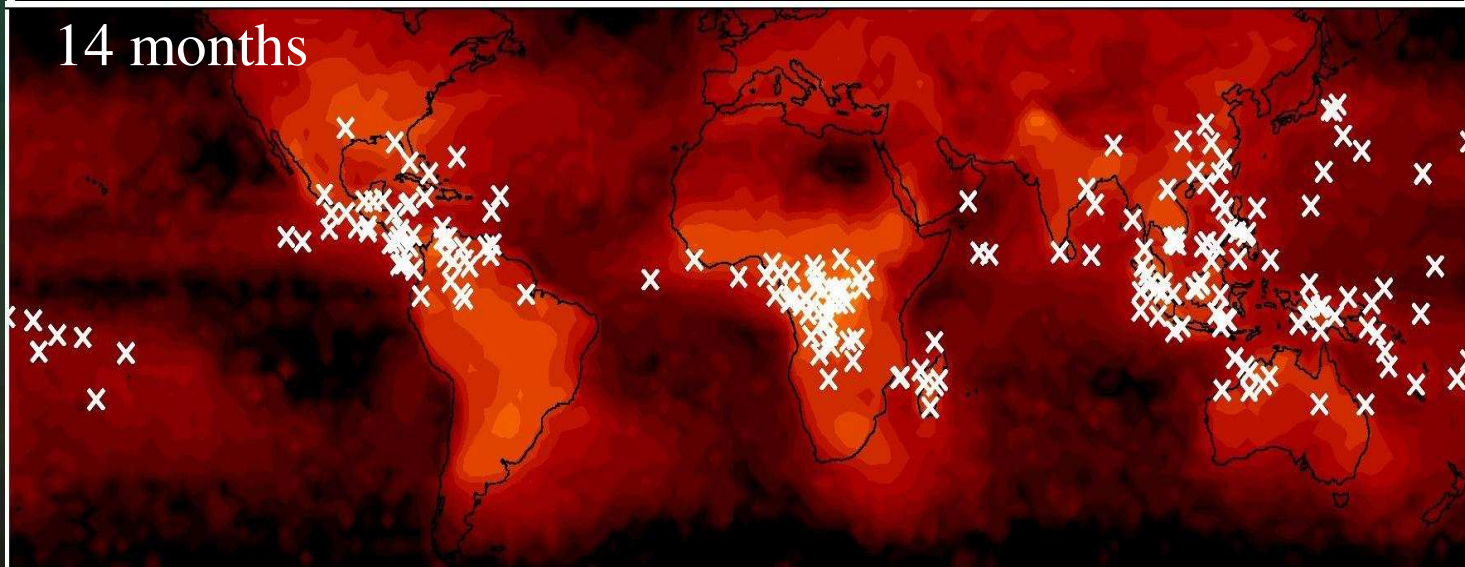


# RHESSI TGFs: Locations

125 events in 8 months analyzed so far



Shown with  
# expected  
for uniform  
global  
distribution



Shown with  
global  
average  
lightning  
flash rate \*

\* Lightning Map from NASA LIS/OTD science team

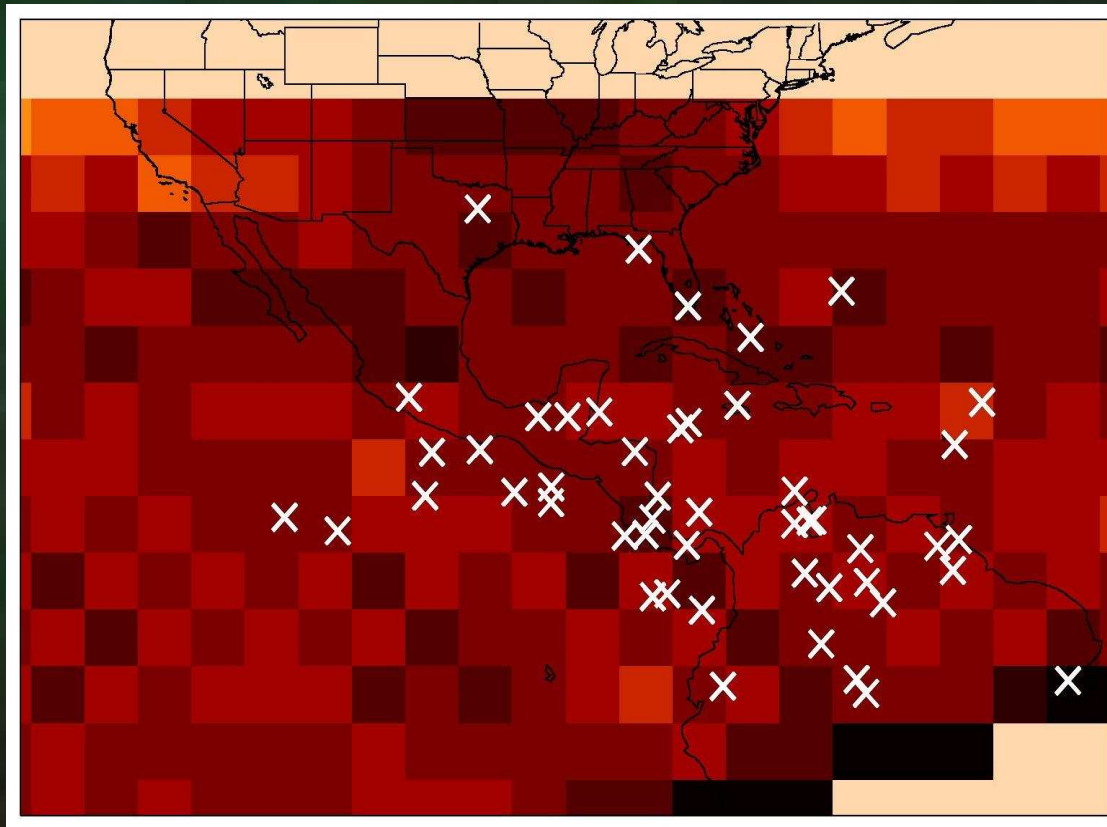




# The mysterious lack of events over the Southern US:

Many strong +CG strokes and sprites observed over TX, OK, etc.  
RHESSI coverage of this region is comparable to Caribbean, Congo  
(more time but higher background)

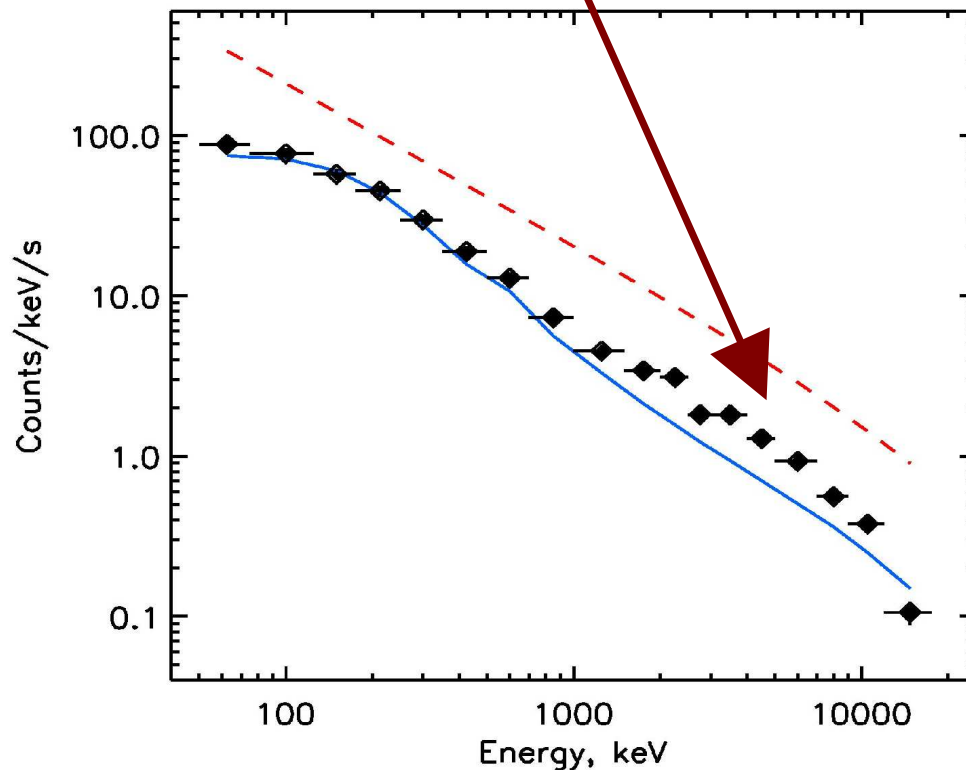
Upward avalanches should be *more* effective at high magnetic latitudes where B is not purely horizontal (Lehtinen, Bell & Inan 1999, Babich et al. 2001)



# RHESSI TGFs: Spectra

Summed spectrum for 85 TGFs shows emission to  $> 20$  MeV, very hard spectrum.

Bump  $>$  several MeV could be sign of beaming (R. Roussel-Dupre) or direct e- detection (unlikely!)

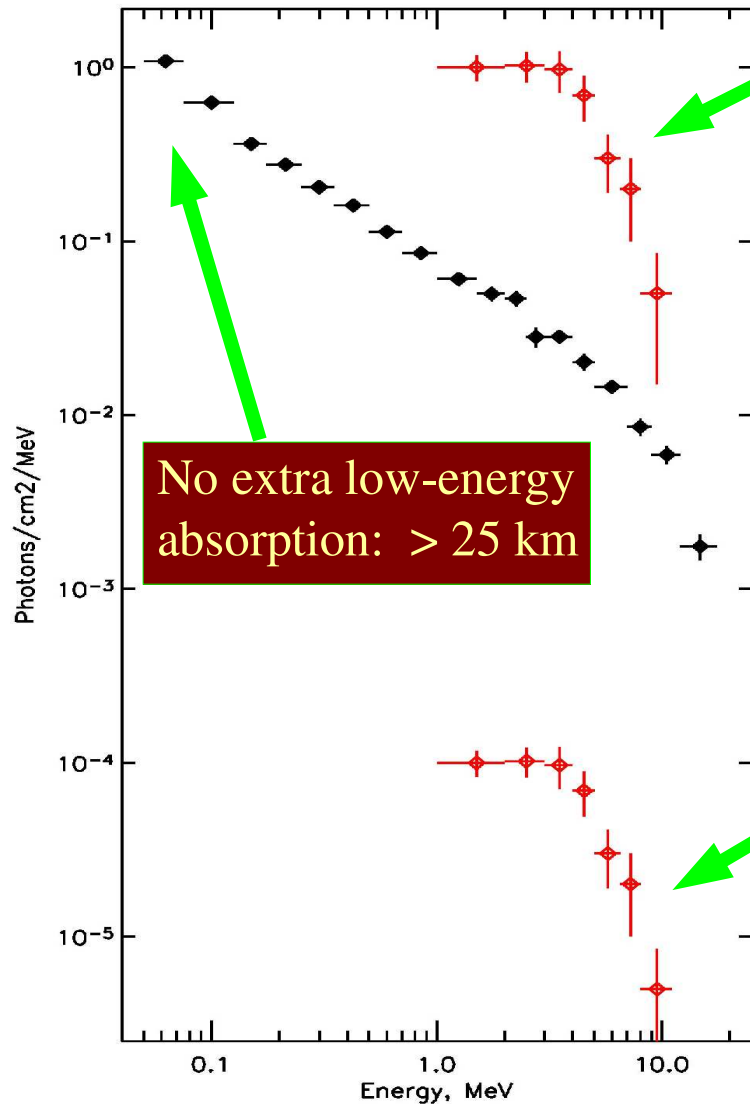


Model is isotropic  
bremsstrahlung from  
35 MeV electrons

Red line: model. Blue  
line: model with instrument  
response included.



Observation of gamma-rays on the ground from a process probably in a thundercloud (Dwyer et al. 2004) demonstrates low-energy absorption due to high atmospheric depth.



No extra low-energy absorption:  $> 25$  km

Dwyer et al. 2004 seen from the ground, estimated altitude 6-8 km

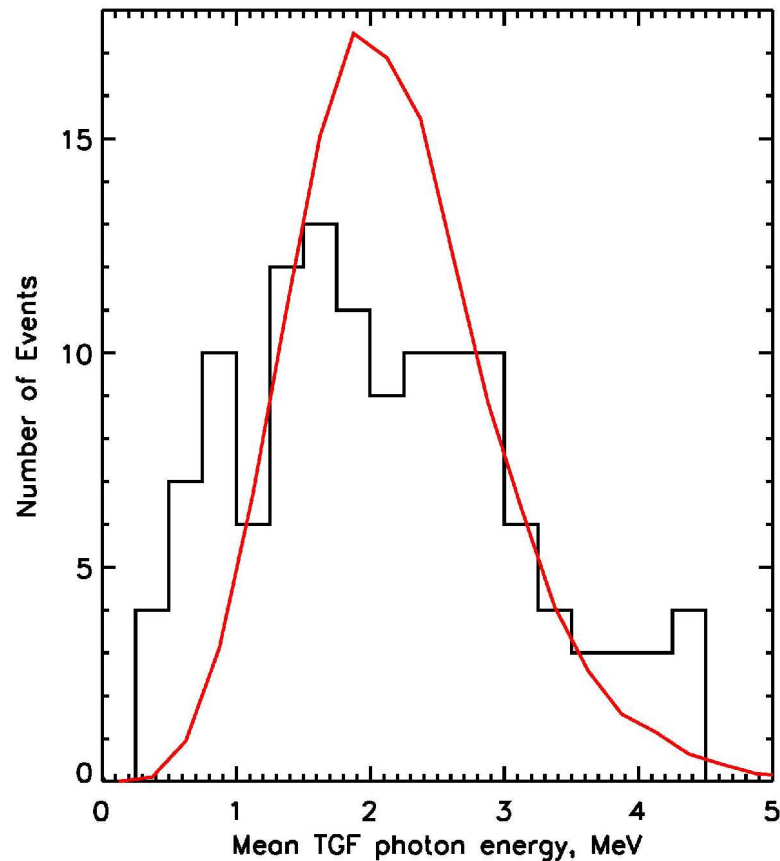
Annotation: based on some of Joe Dwyer's results, it is clear that atmospheric Compton scattering must be accounted for carefully before setting limits on the depth based on a lack of absorption (like the 25 km shown at left)

Dwyer et al. 2004 scaled to 600 km distance, same absorption column (approximately right)

**\*BUT**, there is a factor of ~million absorption, so only a couple of km higher could make it **much** brighter.

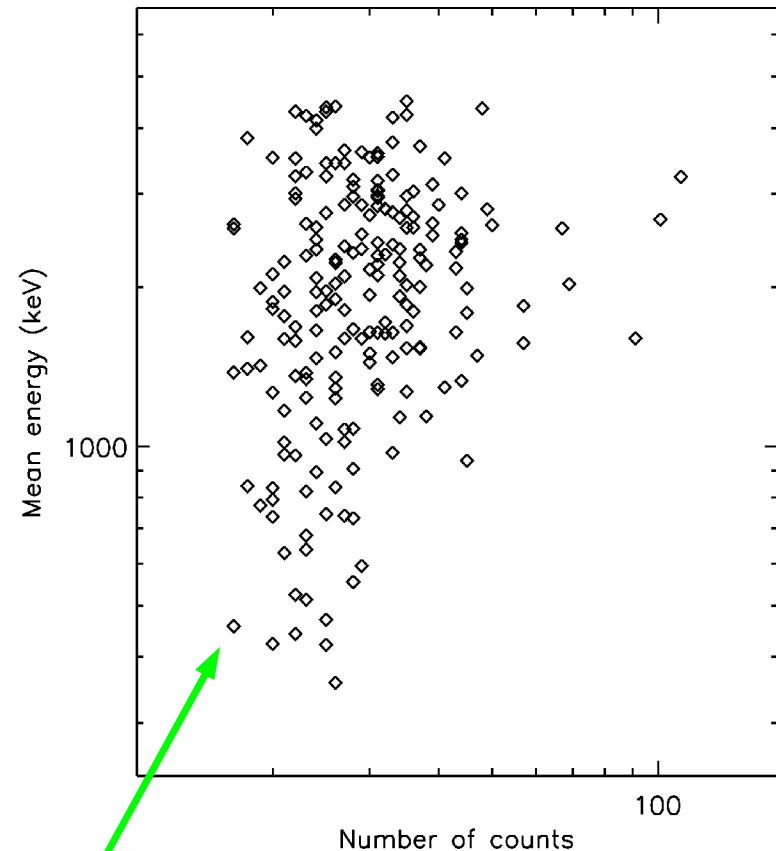


# Spectral variability?



Distribution of mean energies is broader than predicted for a uniform spectrum (red curve)

The red curve is the distribution of mean gamma energy for artificial TGFs drawn from the total spectrum; it is not a delta function because each TGF has a small number of counts, so the mean energy has scatter.



The low-energy population is also faint.



Faint, soft events, if a separate population, may be either

- 1) Viewed near the edge of the upward beam, or
- 2) Due to acceleration at the magnetic conjugate point, with the electrons entering the atmosphere downwards.

Annotation: Compton scattering will soften off-axis events even more effectively than the intrinsic softening due to being off the peak of the Bremsstrahlung beam. Thanks to J. Dwyer

These might be distinguished shortly by either

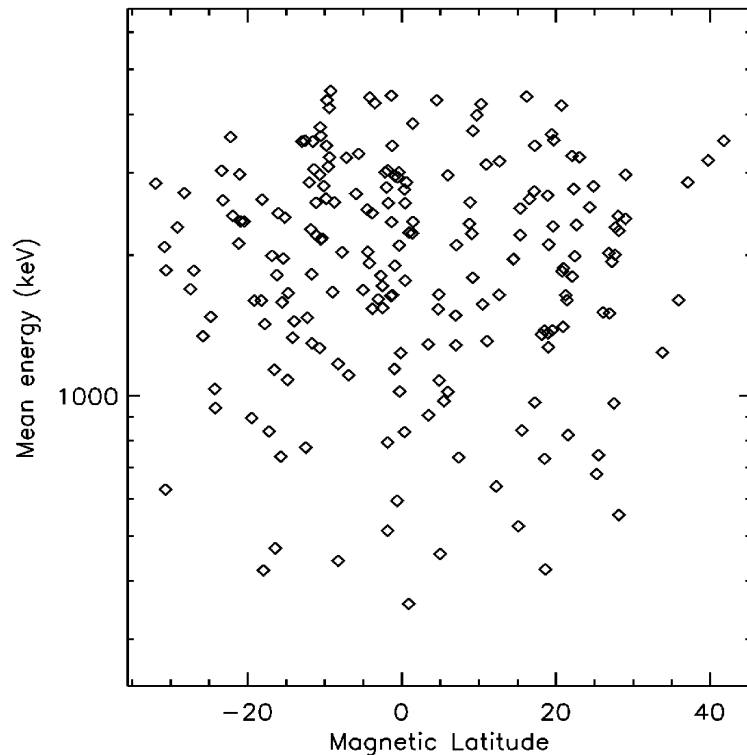
- 1) Localization of associated sferics (certain), or
- 2) Spectral characteristics corresponding to backwards & Compton scattered bremsstrahlung vs. direct bremsstrahlung slightly off the beaming axis (model dependent)
- 3) Magnetic latitude of the events: events near the magnetic equator might not reach high enough altitudes to travel far (model dependent)

Annotation: the strongest argument against the faint events being conjugate is that none of them appear over the Sahara, which is conjugate to the largest cluster of “normal” TGFs (in sub-Saharan Africa).



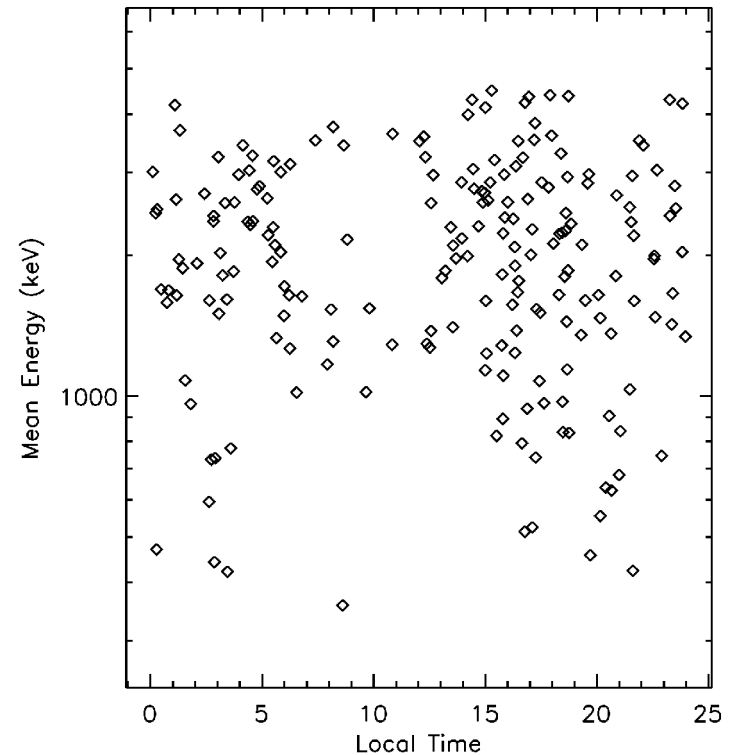
# No clear relation between hardness and:

## Magnetic latitude



No effect of harder events = longer distance for acceleration at high latitudes – perhaps the events are so deep that electrons don't magnetize?

## Local time



Might have been some variation expected because ionospheric height varies between day and night (S. Mende) – but with no variation, again suggests source is deep.

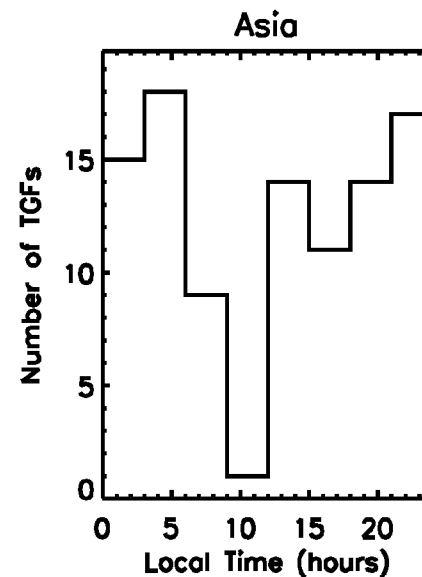
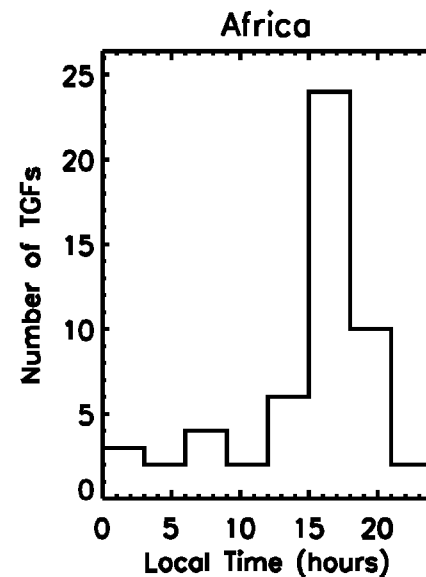
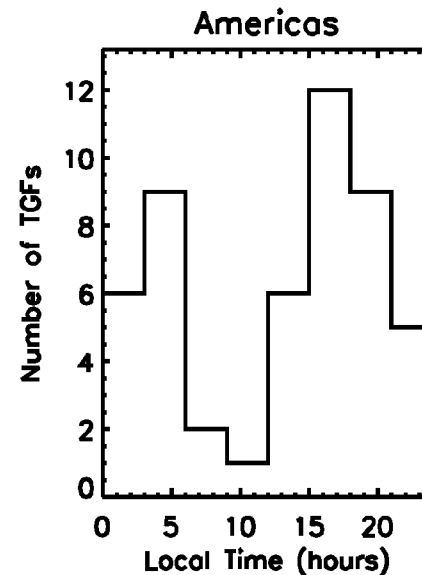
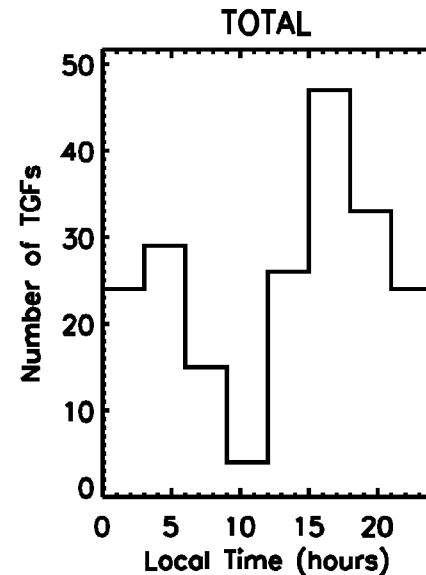




# Local time dependence favors evening (and predawn except in Africa)

This general pattern is also typical of thunderstorms.

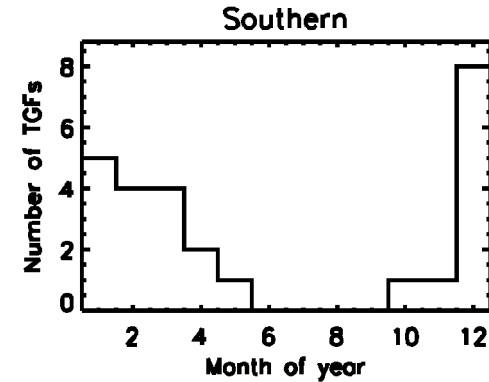
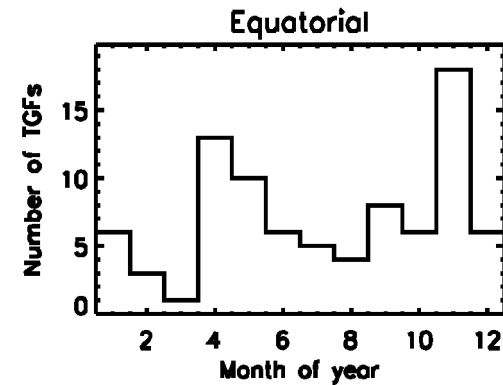
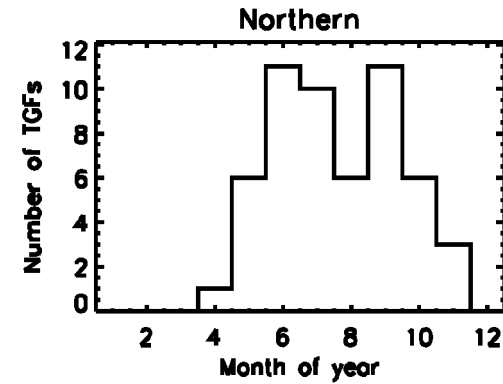
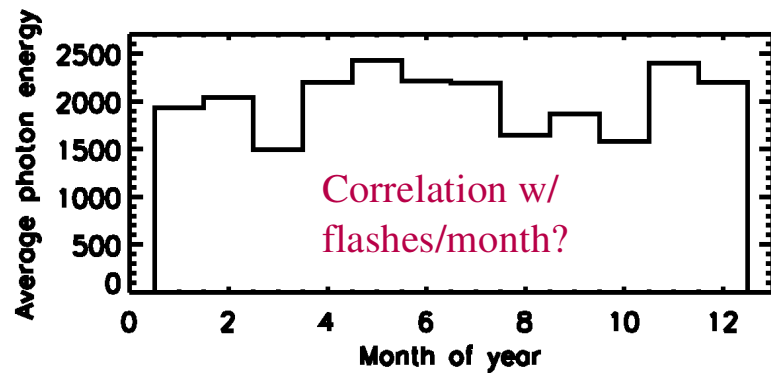
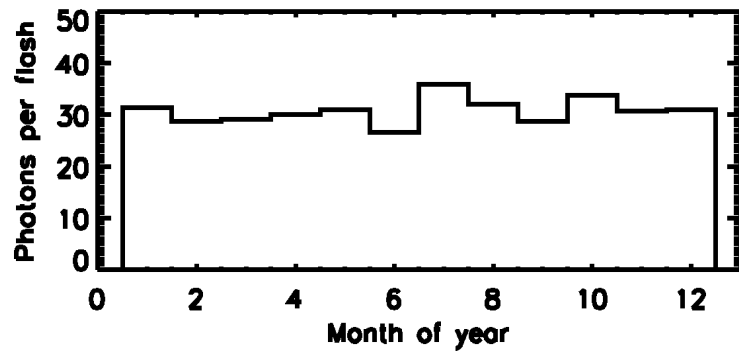
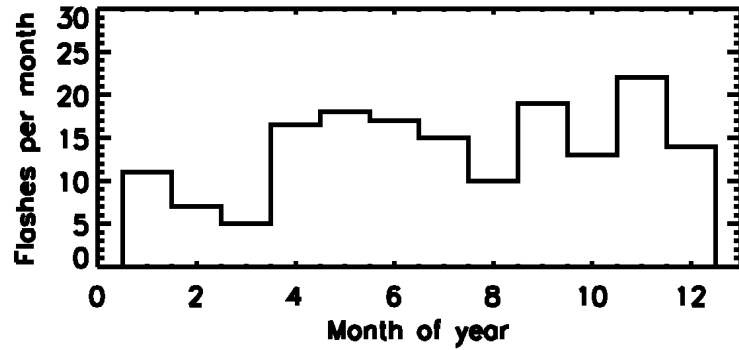
Not sure if the lack of predawn t-storms in Africa is also typical.





# Variations with season?

TGFs, like t-storms, always in summer:



Rough estimate of number of monoenergetic 35 MeV electrons responsible for gamma rays:

Assume isotropic bremsstrahlung \*

Assume thick target \*\*

~  $3 \times 10^{15}$  electrons, or

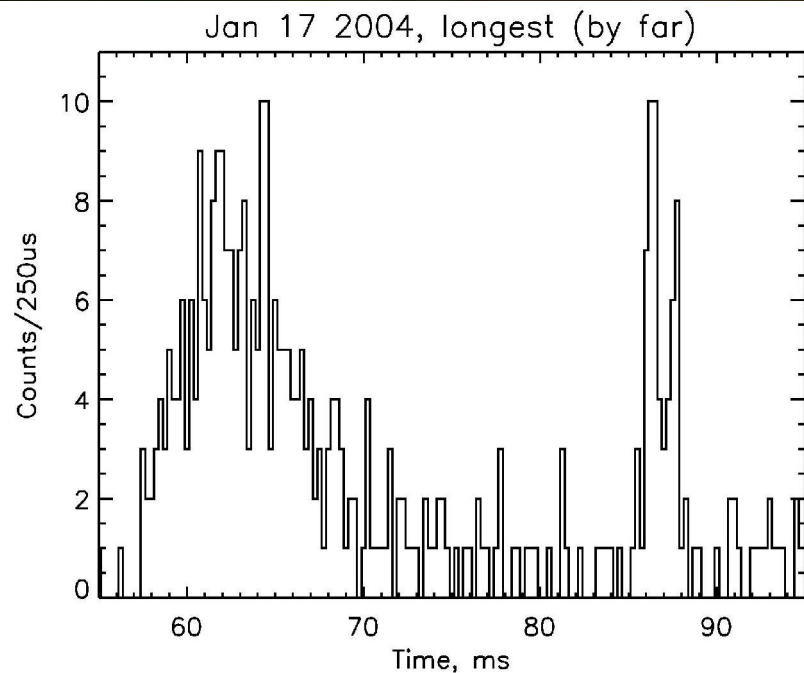
~ 20 kJ (lightning is many MJ)

There is a population of  $> 10$  MeV electrons in the inner belt (Galper et al. 1999, JGR); estimating the TGF contribution is TBD, and will require a significant sample of mid-latitude events

\* Tends to overestimate the e- content compared to a beam

\*\* Tends to underestimate the e- content compared to a thin target





**Today's scoop: Jan 17 2004, 12:46:50.970**

Longest and brightest RHESSI TGF  
Northern Chad (Sahara). No storms  
here, but plenty of storms in January  
at the conjugate point.

If every TGF has a conjugate flash,  
the first Sahara event we see should  
be faint, not bright! Unless.....

We got lucky and caught the e- beam  
directly with the spacecraft!

That would explain why it's both bright and rare.

