GRB analysis with Fermi GBM

(and some other things)

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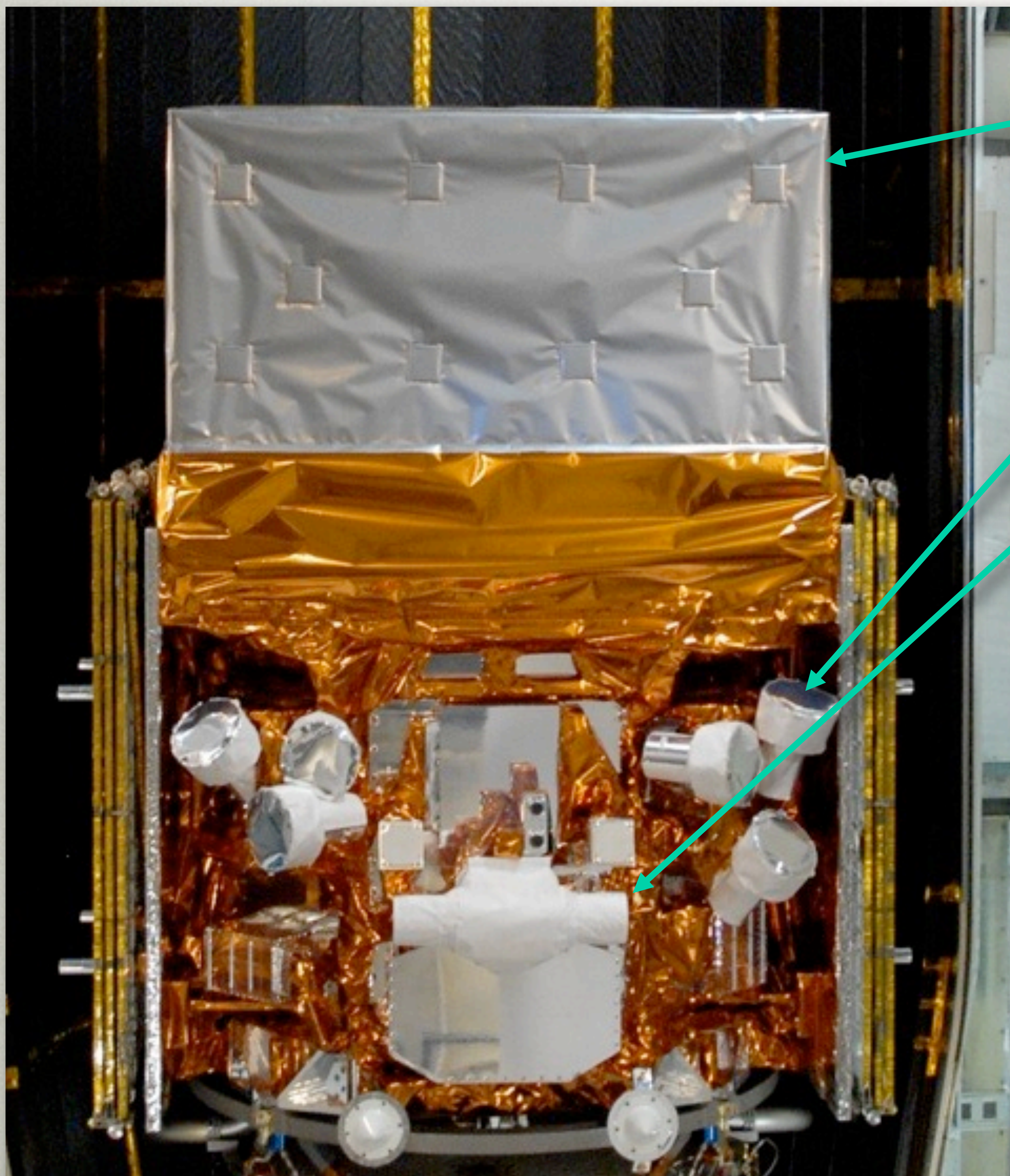
The Fermi Spacecraft



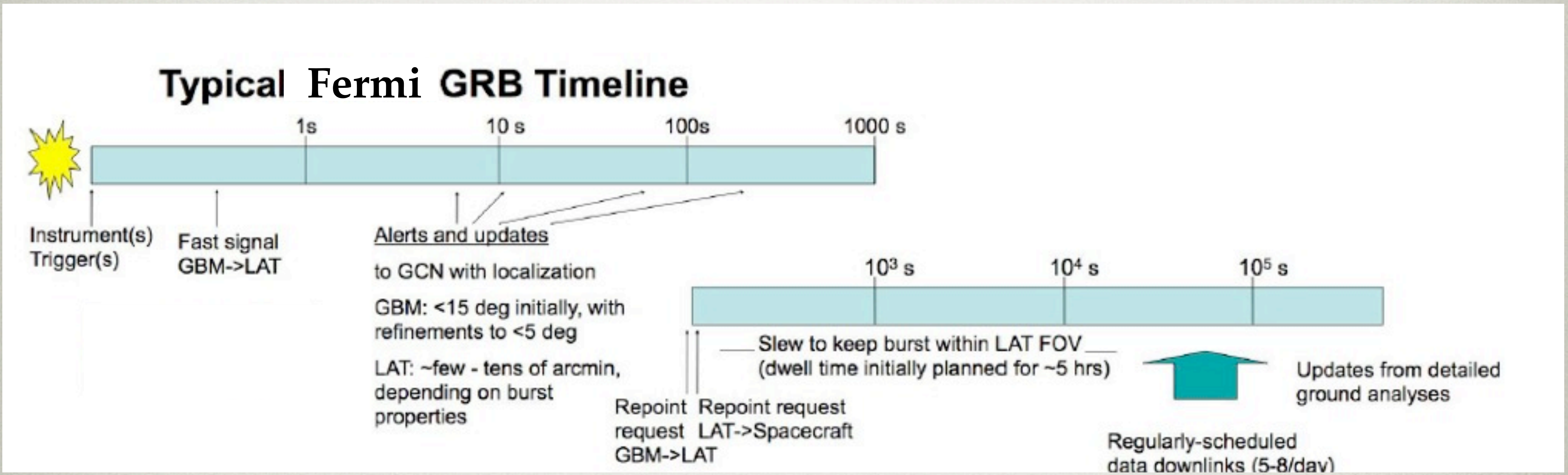
Large AreaTelescope (LAT)
30 MeV - >300 GeV

Gamma-ray Burst Monitor (GBM)
NaI and BGO Detectors
8 keV - 40 MeV

KEY FEATURES

- **Huge field of view**
  - **–LAT: 20% of the sky at any instant; in sky survey mode, expose all parts of sky for ~30 minutes every 3 hours. GBM: whole unocculted sky at any time.**
  - **–Decreased detection dead time 2.6 μs**
- **Huge energy range, including largely unexplored band 10 GeV - 100 GeV. Total of >7 energy decades!**
- **Large leap in all key capabilities. Great discovery potential.**

GBM Triggering

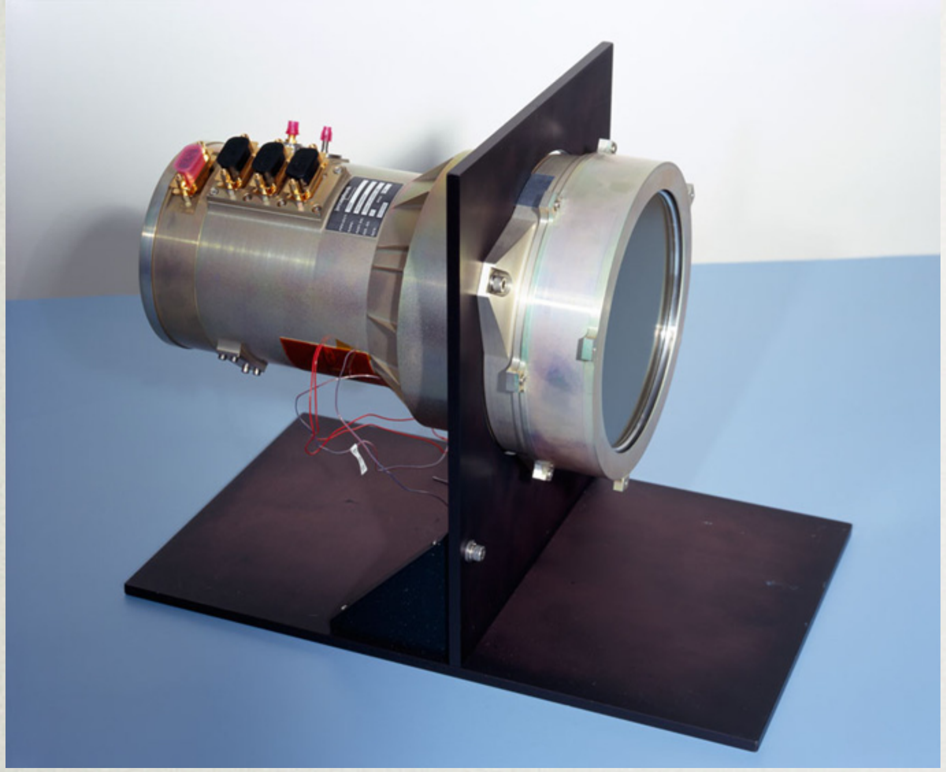


The GBM Burst Advocate localizes the GRB usually within one hour after trigger.

After a period of 2-5 hours after the trigger, the Burst Advocate is able to perform a detailed duration estimate and spectral analysis

GBM Detectors

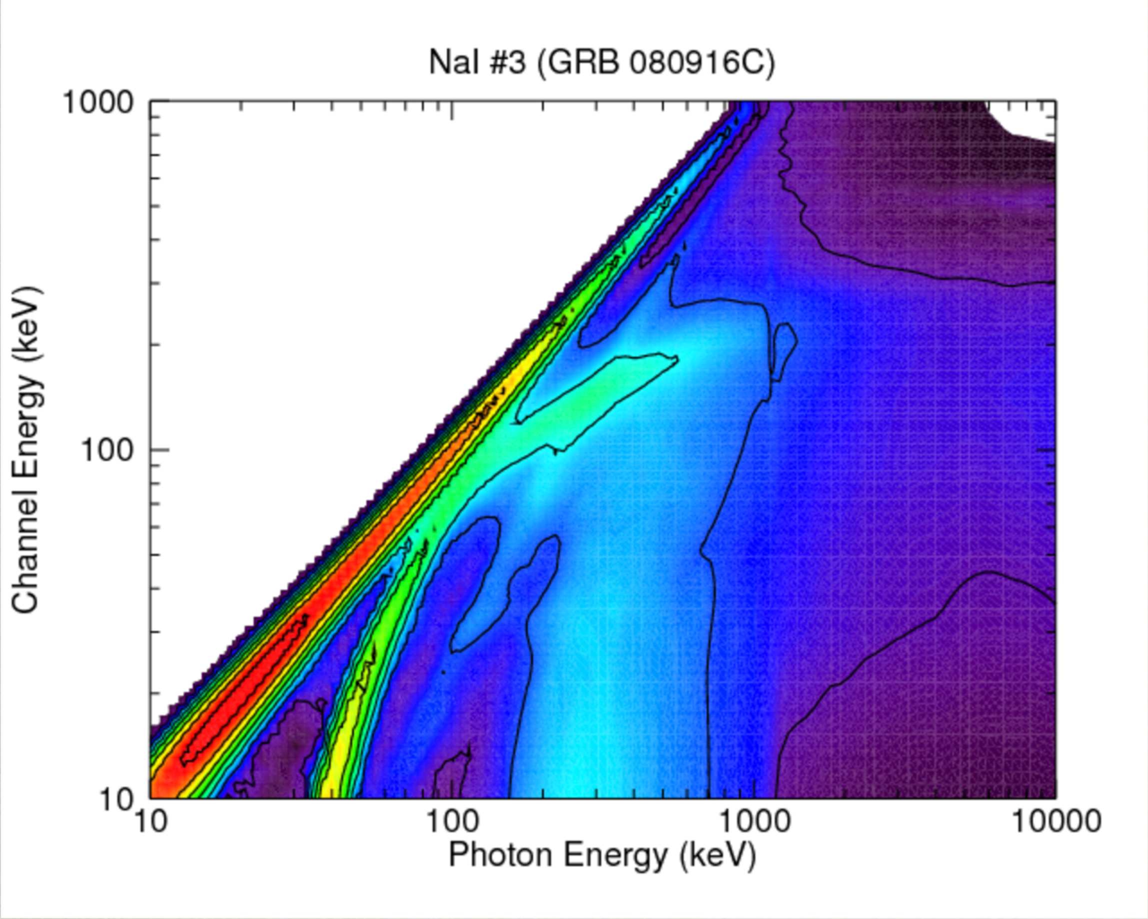
NaI

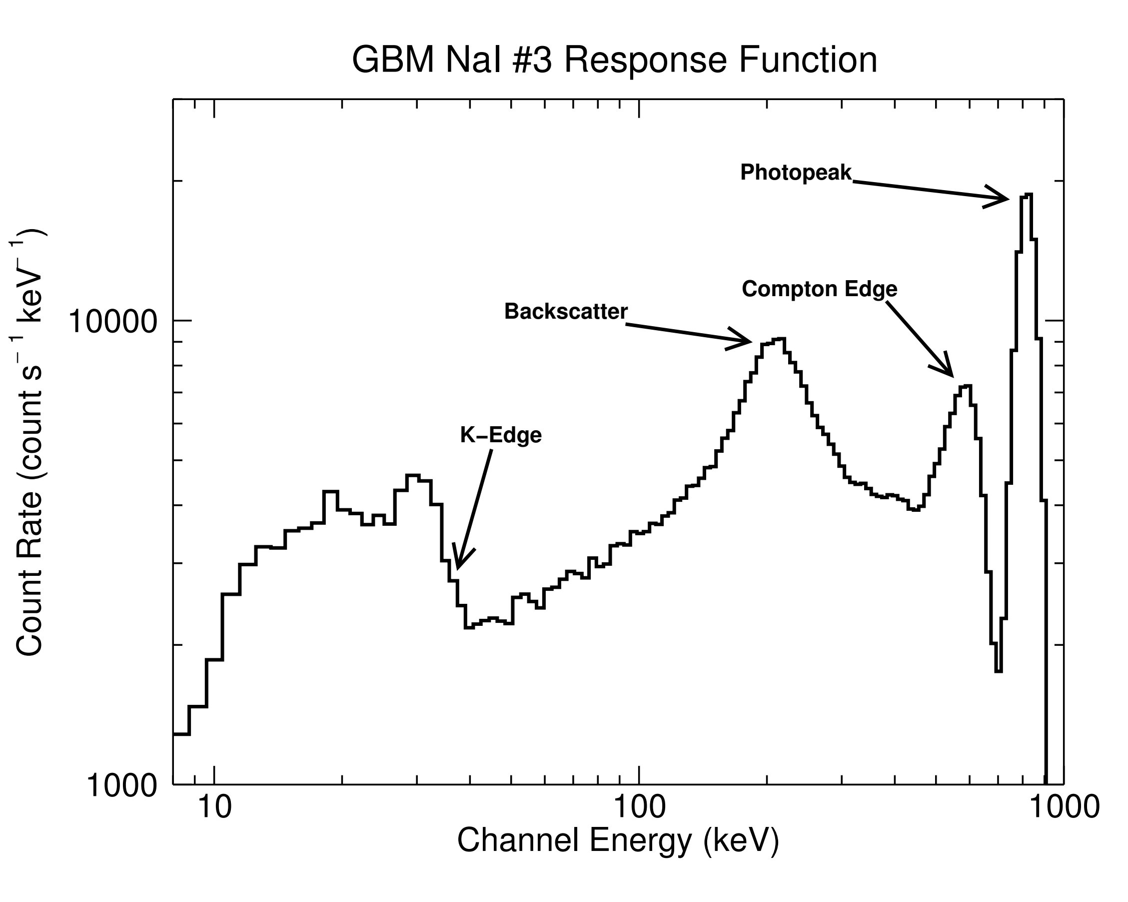


BGO

- GBM detectors are PMTs - scintillating crystals attached to photomultipliers
- NaI: 8 - 1000 keV via Photoelectric absorption & Compton scattering
- BGO: 200 keV - 40 MeV via Compton scattering & Pair production

Detector Response





Simulated photons at 800 keV

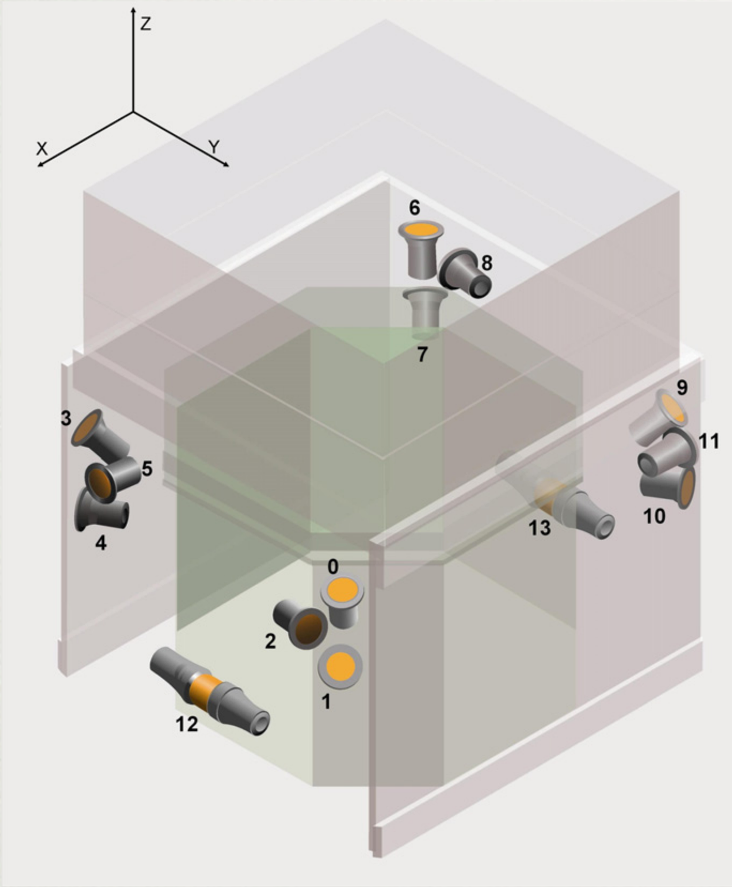
- The response associates the photoelectron energies deposited into electronic channels with the original incident photon energies -> energy dispersion
- Number of different physical processes
- The response is a function of the source-spacecraft-Earth geometry
- Response rapidly decreases at a source-spacecraft angle >60 degrees

Data Types

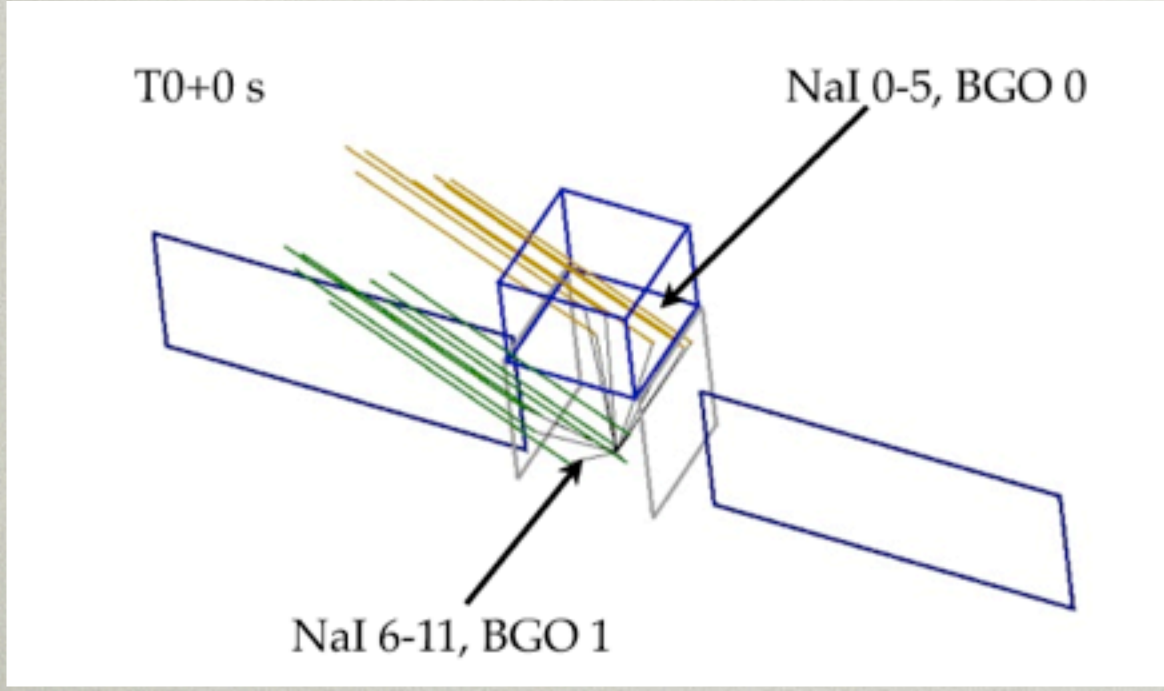
Data Type	Time Resolution	Energy Resolution
TRIGDAT	1024/256/64 ms	8 channels
CTIME	256/64 ms	8 channels
CSPEC	4096/1024 ms	128 channels
TTE	2 μs	128 channels

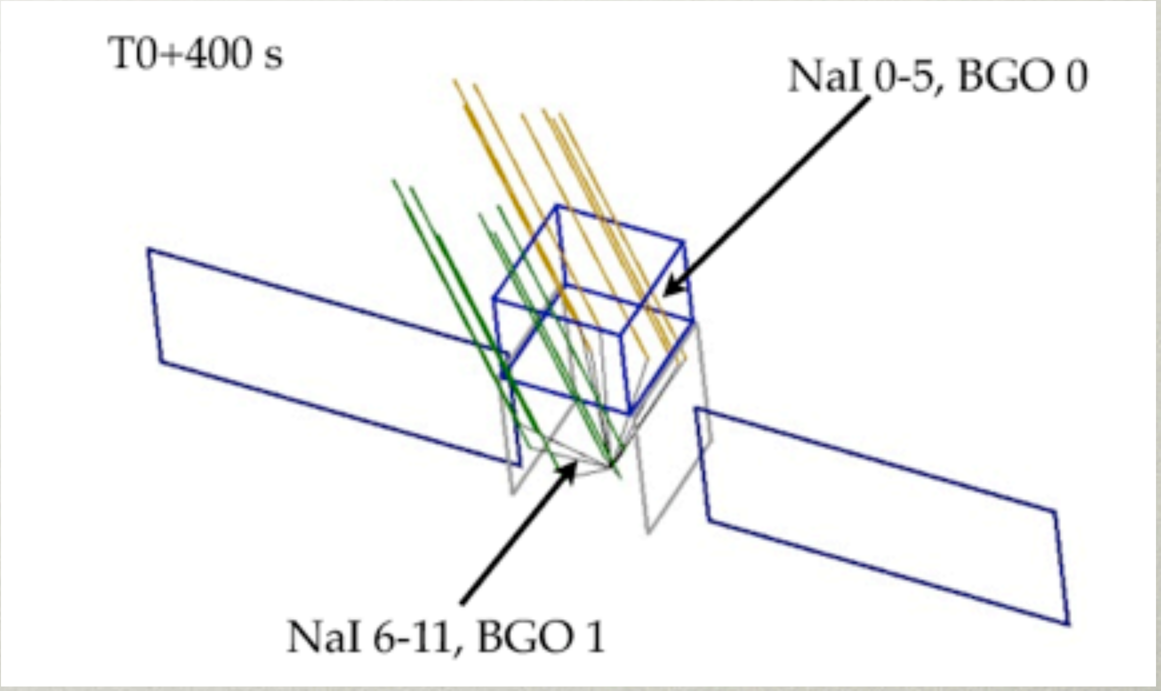
- TRIGDAT used primarily for localization & quick look.
- CTIME is typically used for temporal studies
- Initially TTE was available ~30s pre-trigger - ~300 s post-trigger
- Continuous TTE implemented on November 26, 2012

Problems with Earth-Detector-GRB Orientation



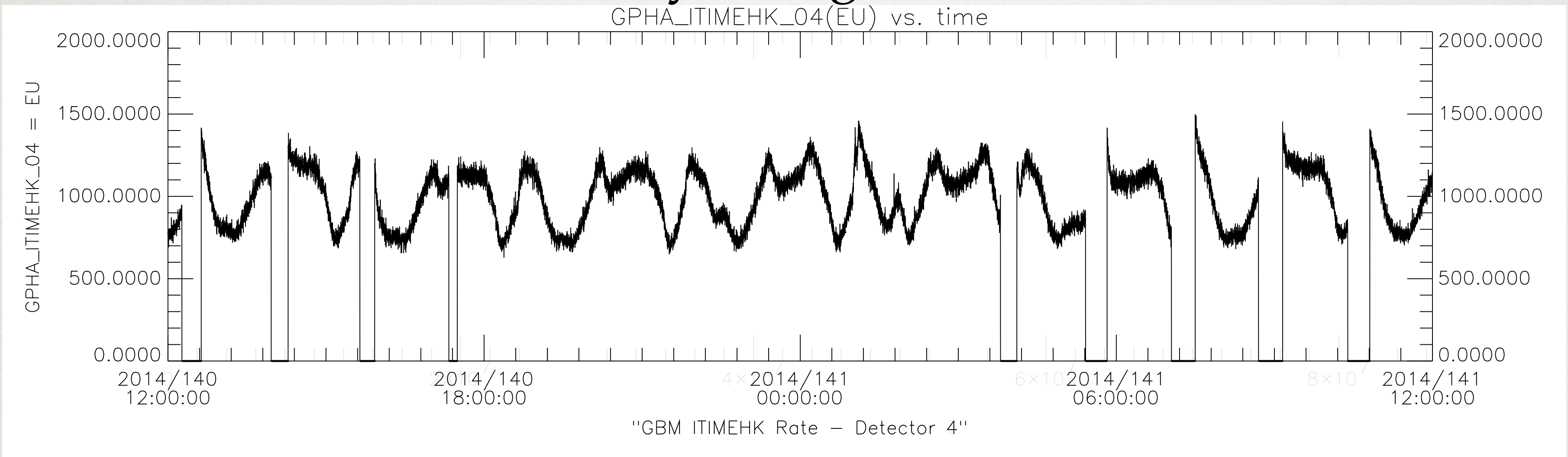
- Spacecraft Blockage
- Solar Panel Orientation
- Atmospheric Scattering
- Spacecraft Slew (ARR)



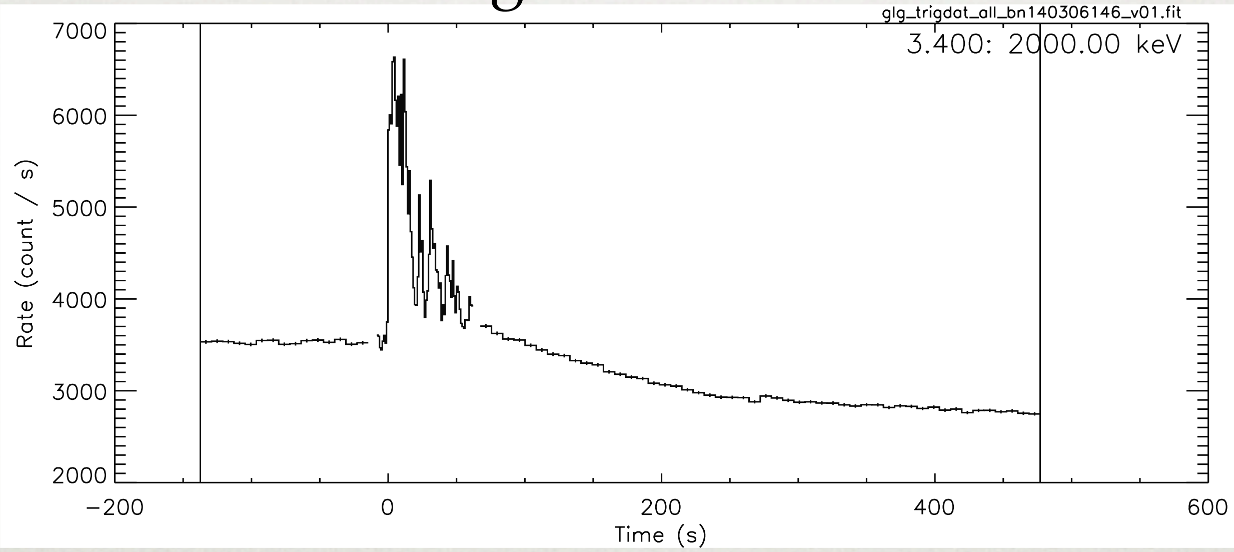


GBM Backgrounds

Daily Background

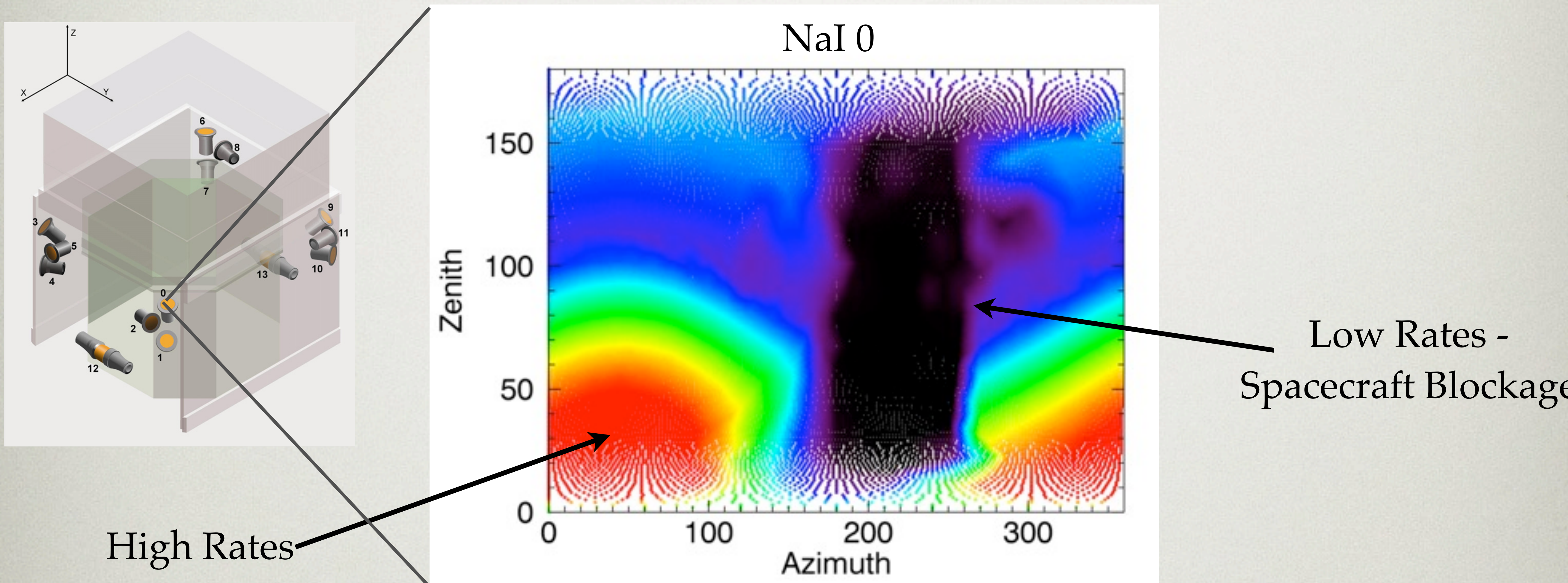


Background - ARR



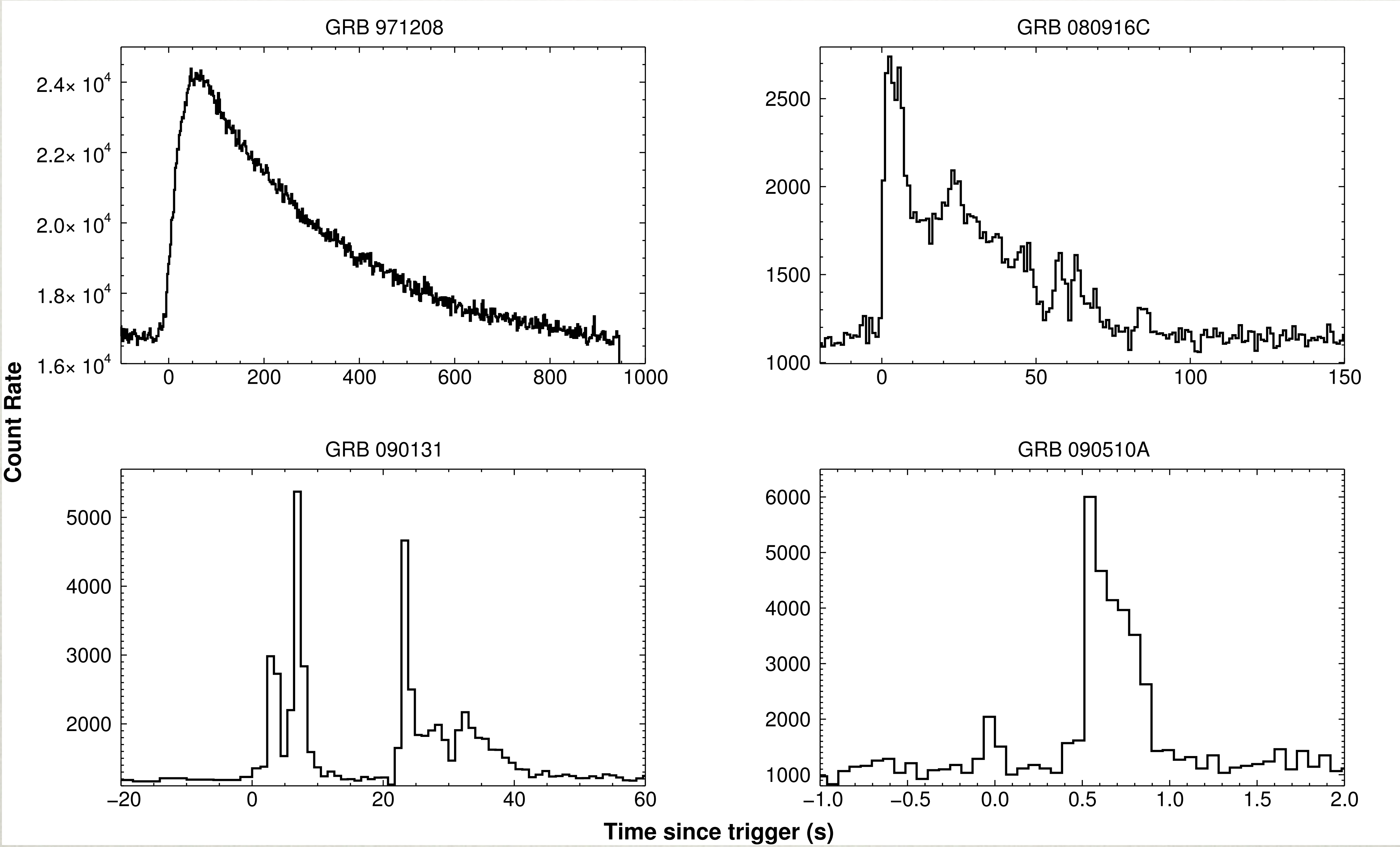
- PMTs are generally high-background instruments
- Numerous sources, diffuse emission, and energetic particles contribute to the background
- Fermi is not inertially pointed -> background can change dramatically
- ARRs complicate the background even more

GBM Localization Method

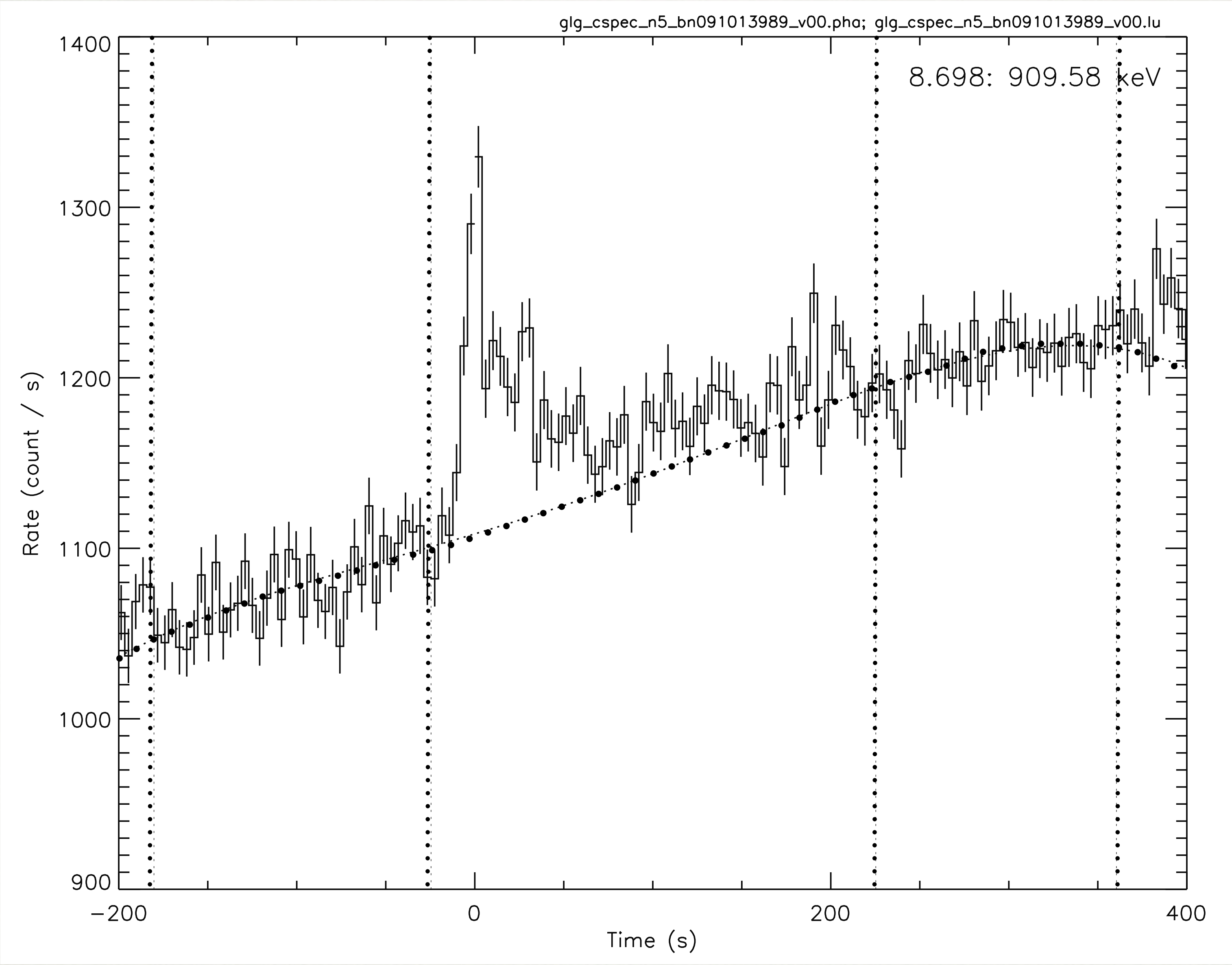


- Localization is performed by comparing the relative observed rates from the GRB in each detector to the expected rates given that the GRB is emanating from any of equally spaced 41,168 points in SC Az/Zen
- This requires an assumption of the spectrum, and the sky grid limits to a statistical minimum uncertainty of 1 degree radius.

GRB Lightcurves



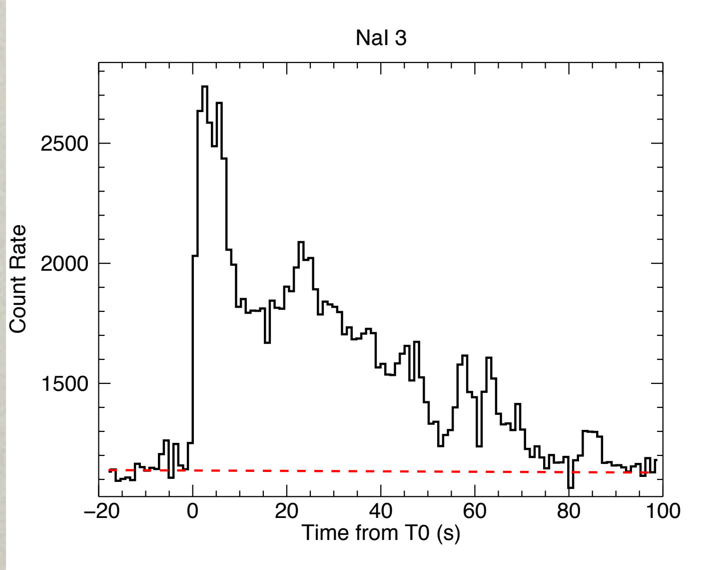
Background Fitting



- Inspect background before and after GRB
- Use a 1st-4th order polynomial fit to the background
- Problems with very long-lasting emission, and rapid SC movement from ARR

Signal Selection

- Numerous ways to do signal selection
- Catalogs - 3.5 σ SNR selection & 1 s/64 ms peak flux selection
- >1 detectors = difficulty



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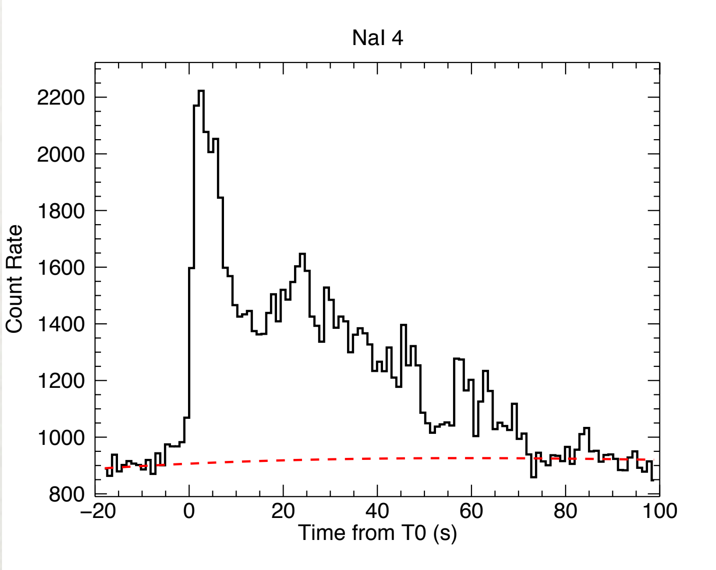

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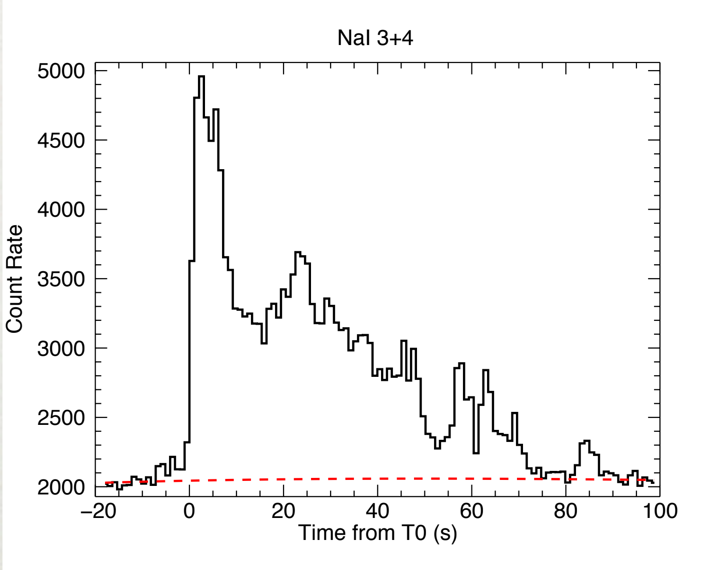
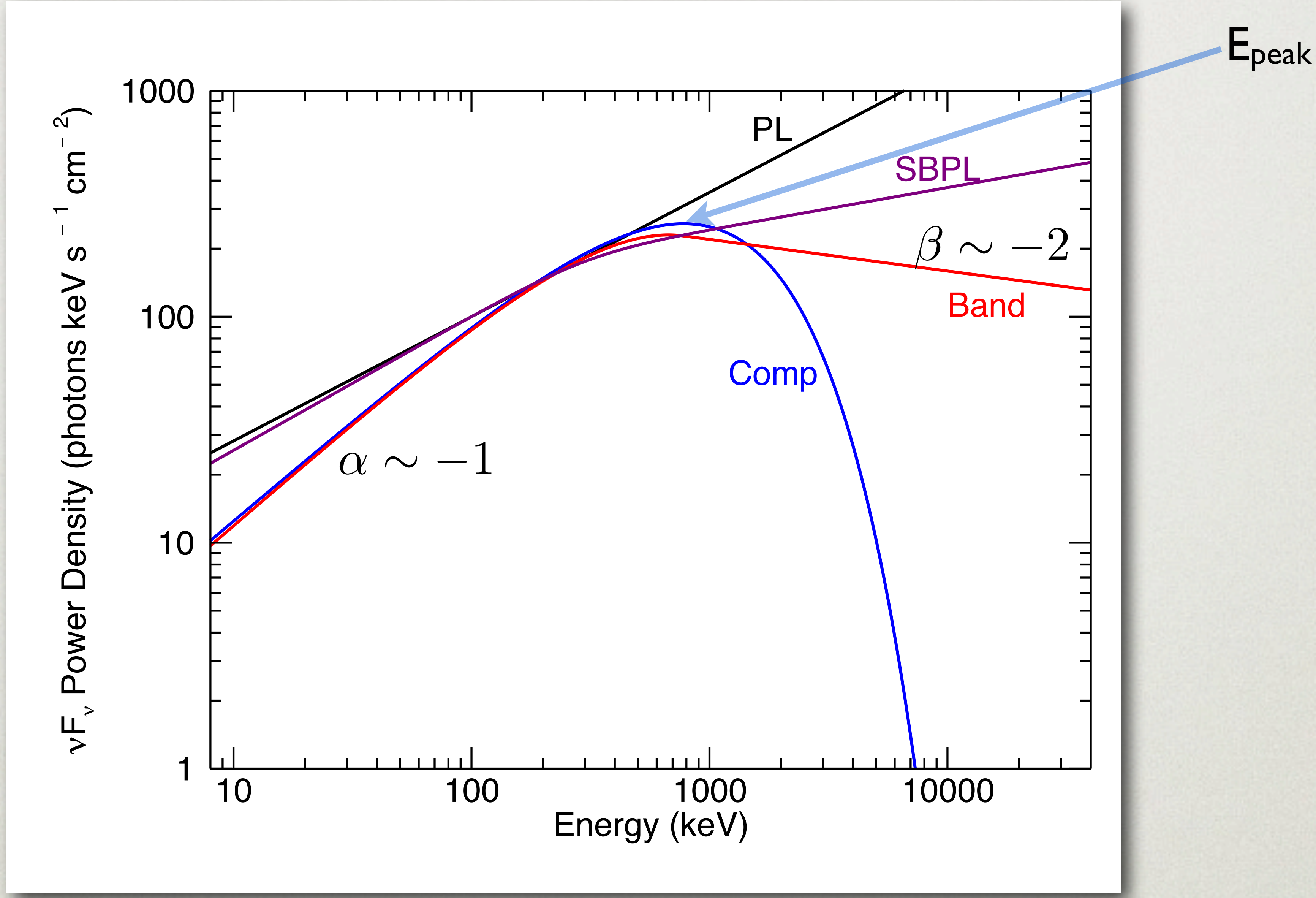


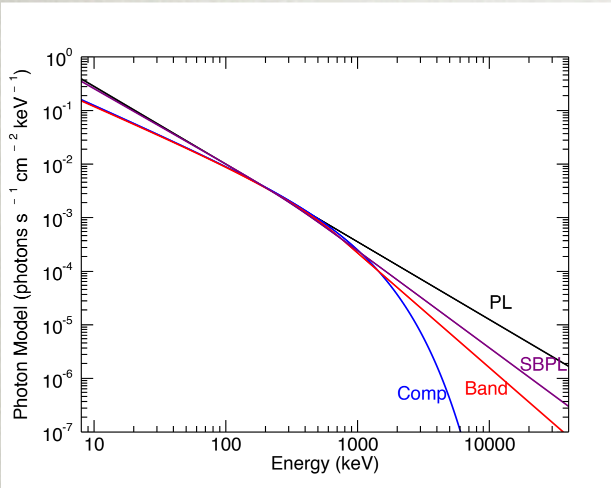
1. Sum lightcurves, weighting by source angle (NaI only)
2. Select the bin(s) that satisfy the SNR requirements
3. Apply the selection to each individual NaI detector (and BGO)
4. Perform joint spectral fit

Empirical Spectral Models

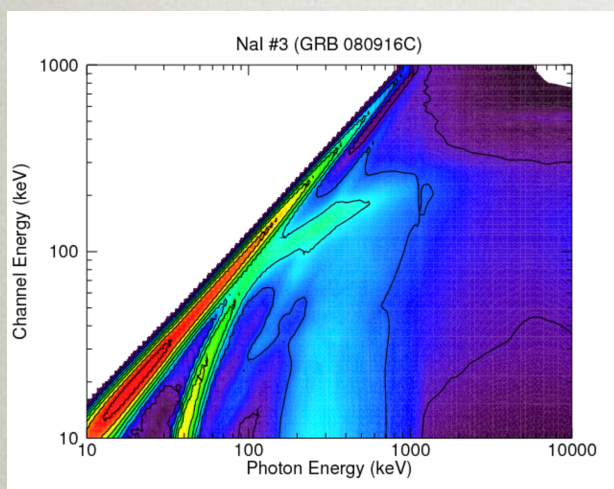


- Typical bright GRBs are well fit in GBM by a smoothly broken PL (Band or SBPL)
- Moderately bright (most GBM GRBs) are best fit with a cutoff PL (COMP)
- Very weak bursts can only be fit with a PL
- Suggests that the best fit model is a dependent on the GRB flux

Spectral Fitting



X



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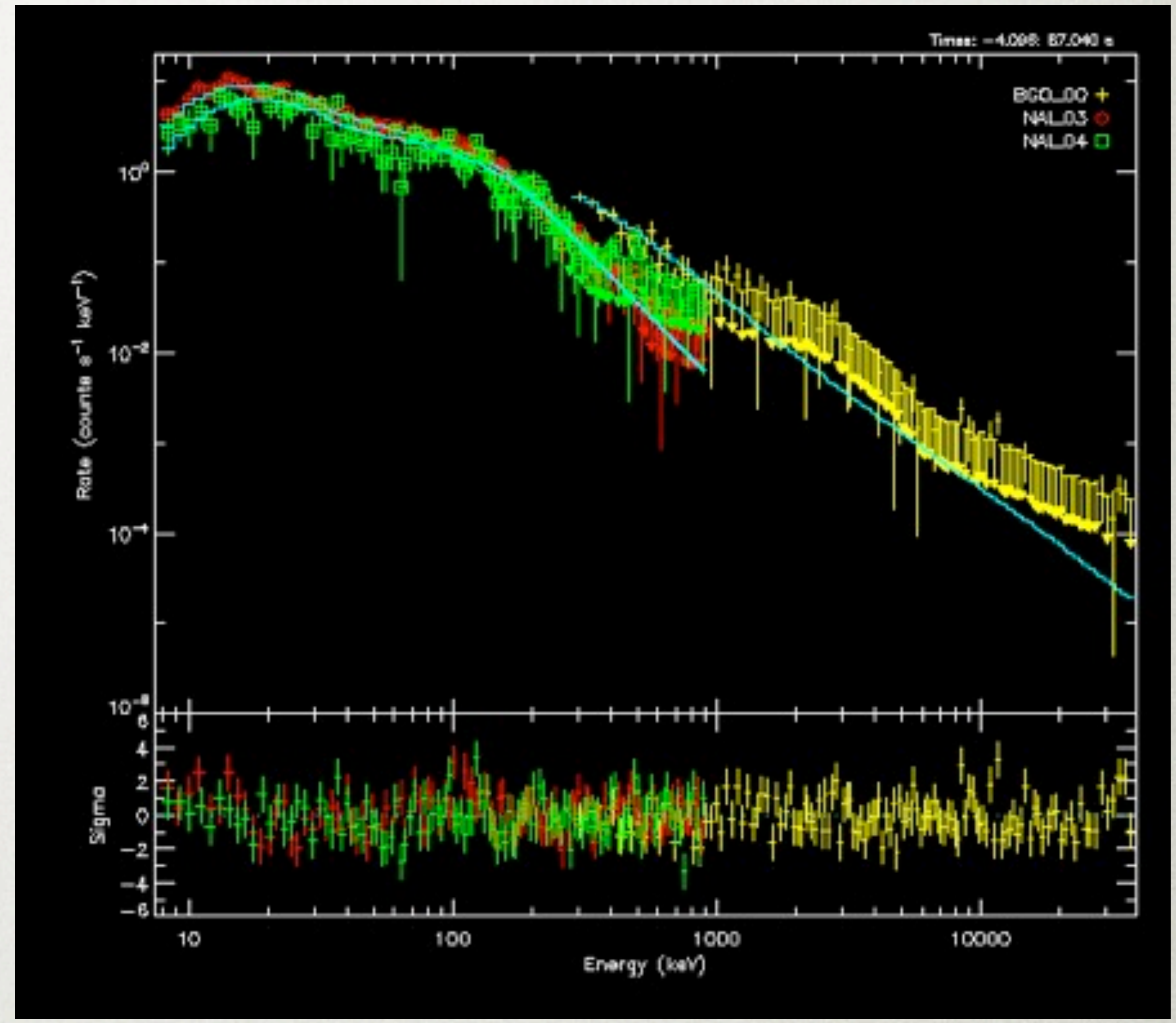
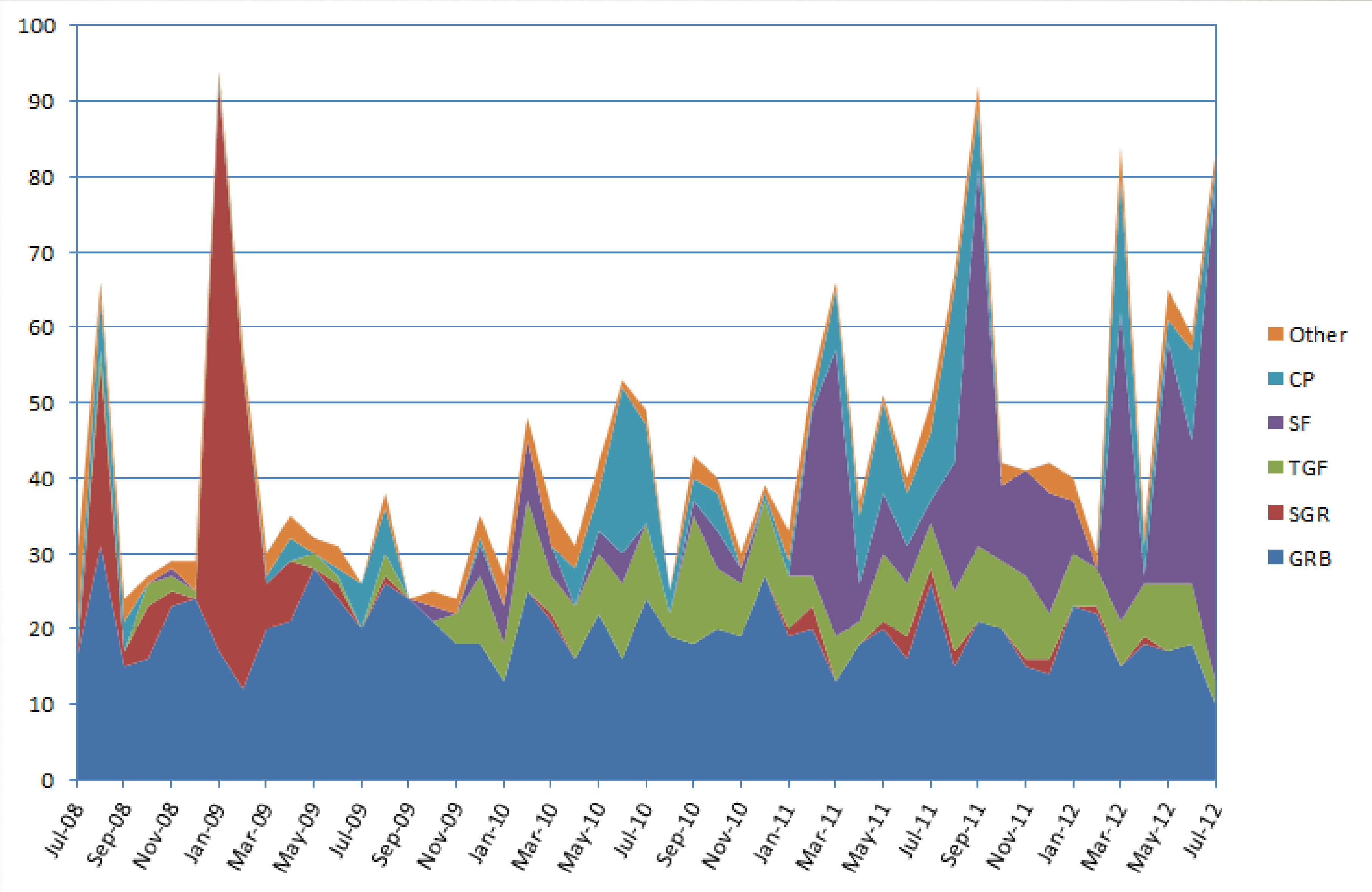


- Forward-Folding technique (using Levenberg-Marquardt)
- Assume a photon model with guess parameter values
- Fold the photon model through the detector response
- Compare the folded photon model (now a counts model) to the counts data

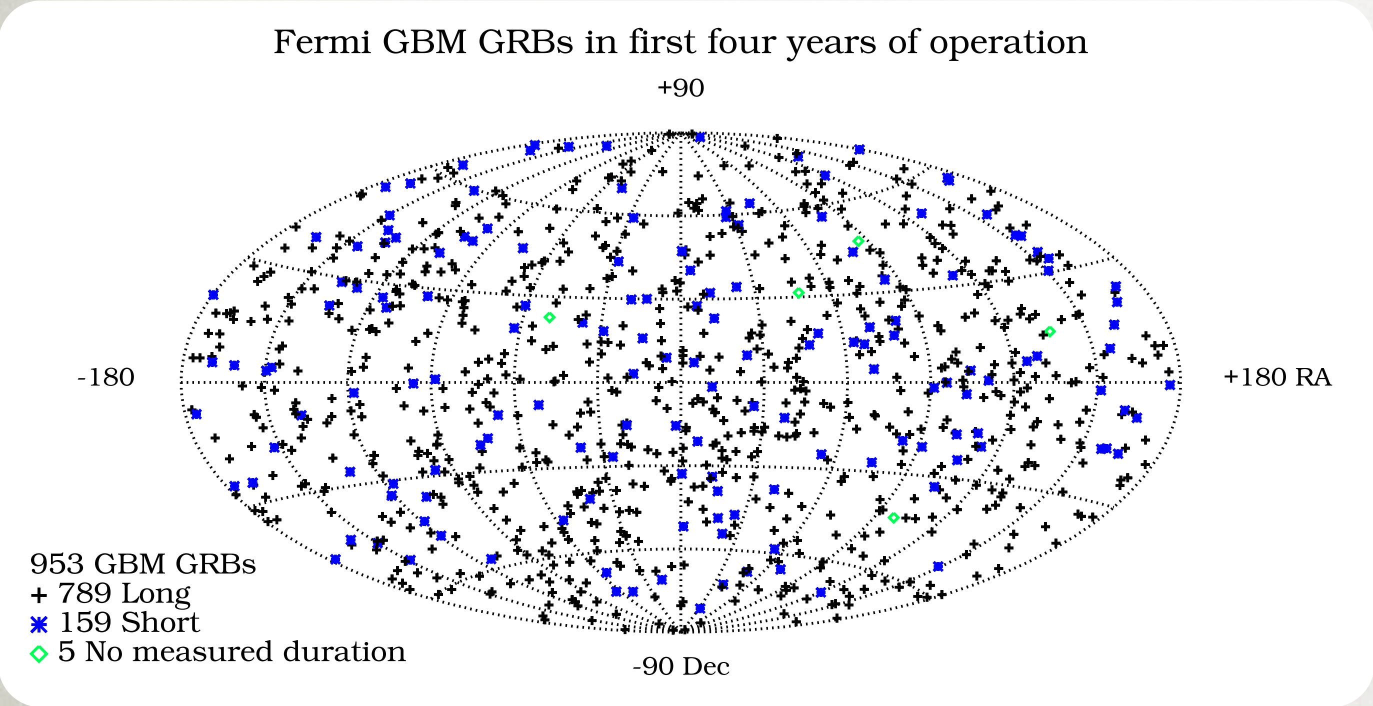
GBM Triggers - First 4 years
July 2008 - July 2012

- 953 GRBs
- 410 Solar Flares
- 273 TGFs
- 201 Charged Particles
- 192 SGRs

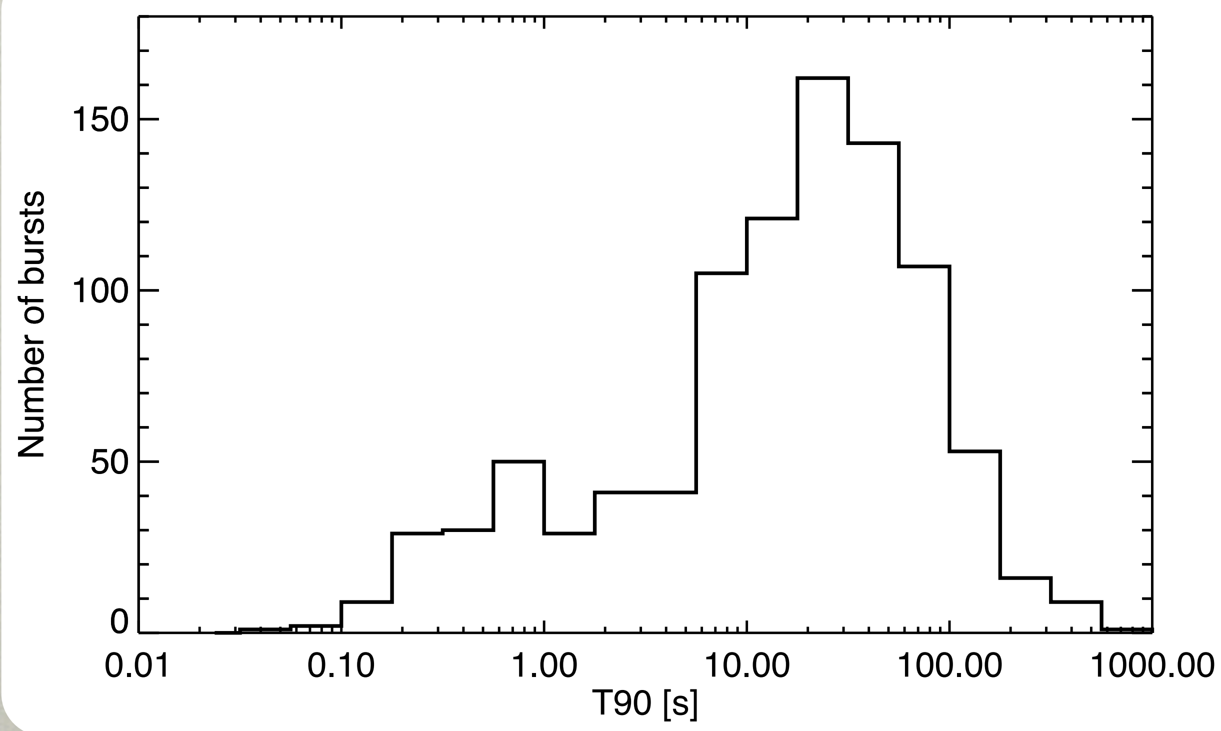


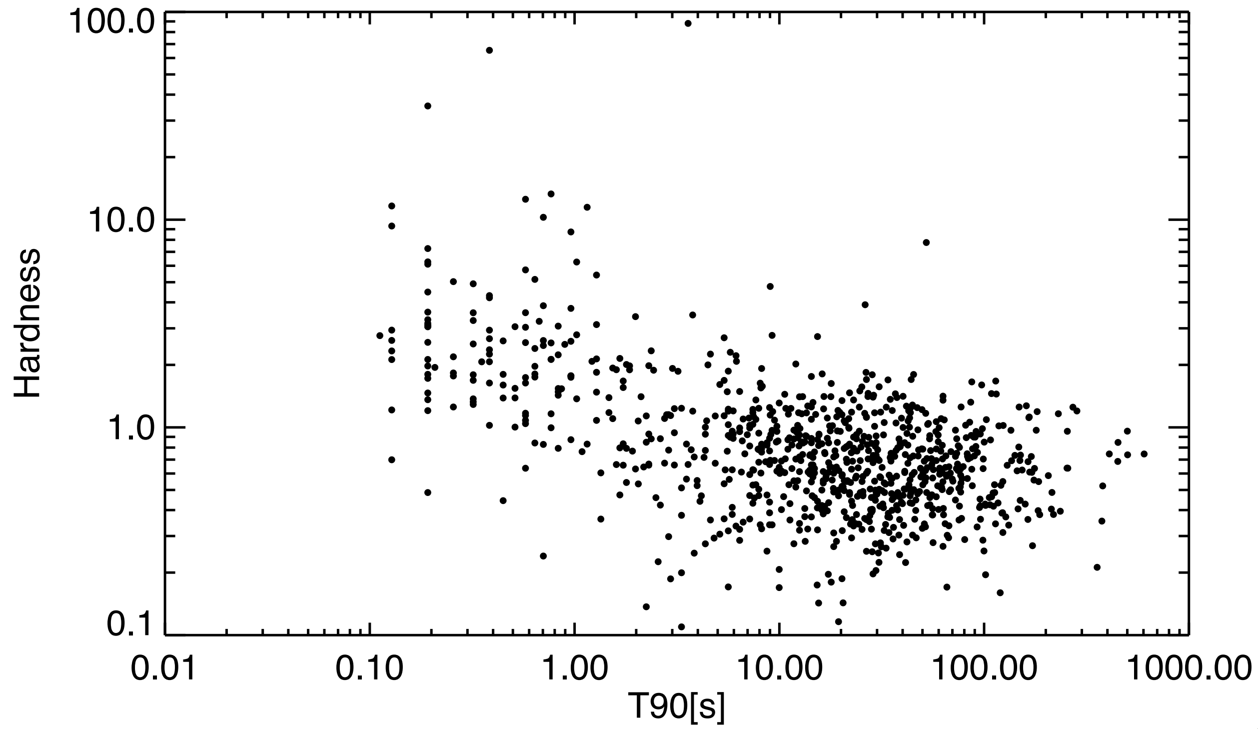
von Kienlin+ 2014, ApJS, 211, 13

GBM 4-year GRB Catalog
(07/2008 - 07/2012)



- 953 GRBs
- Locations/Localizing Instrument
- T50/T90 (50-300 keV)
- Peak flux (64/256/1024 ms; 50-300 & 10-1000 keV)
- Fluence (50-300 & 10-1000 keV)





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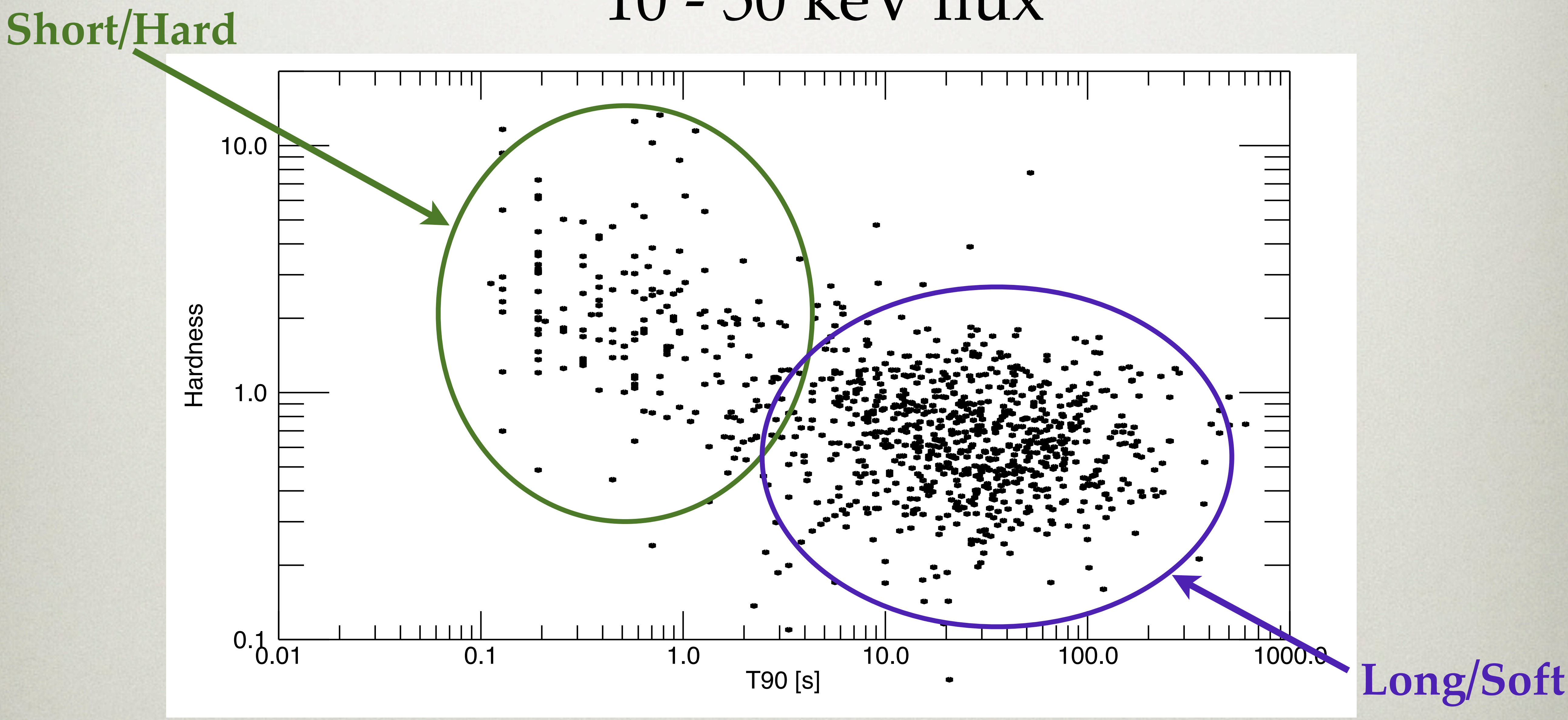
Hardness-Duration Classification

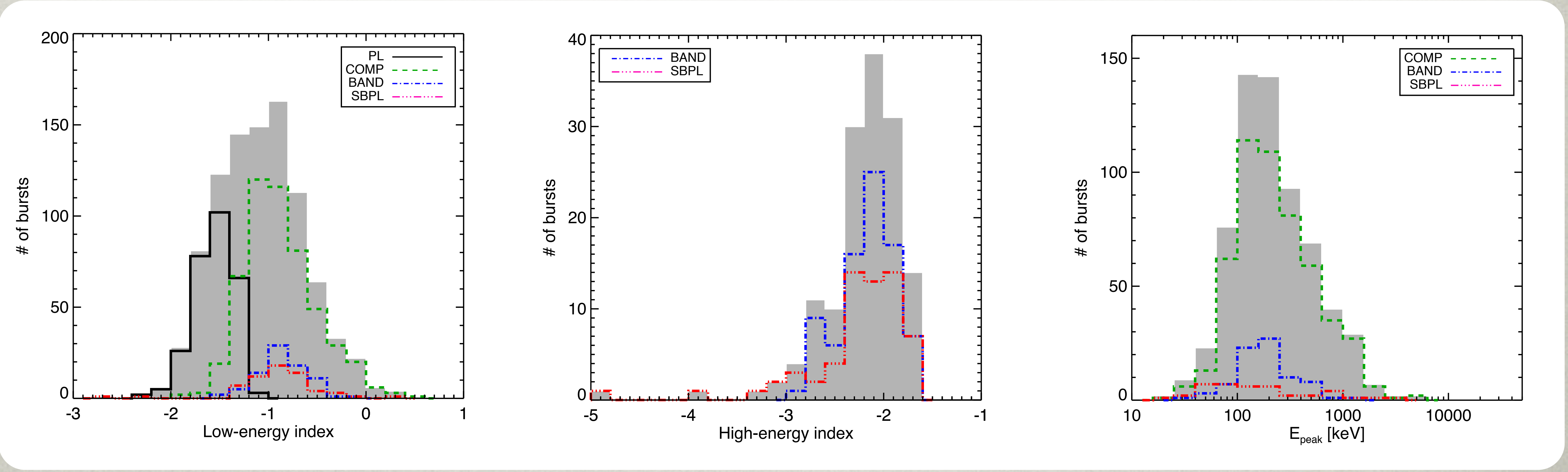
$$H = \frac{50 - 300 \text{ keV flux}}{10 - 50 \text{ keV flux}}$$



von Kienlin+ 2014, ApJS, 211, 13

GBM 4-year GRB Spectral Catalog
(07/2008 - 07/2012)

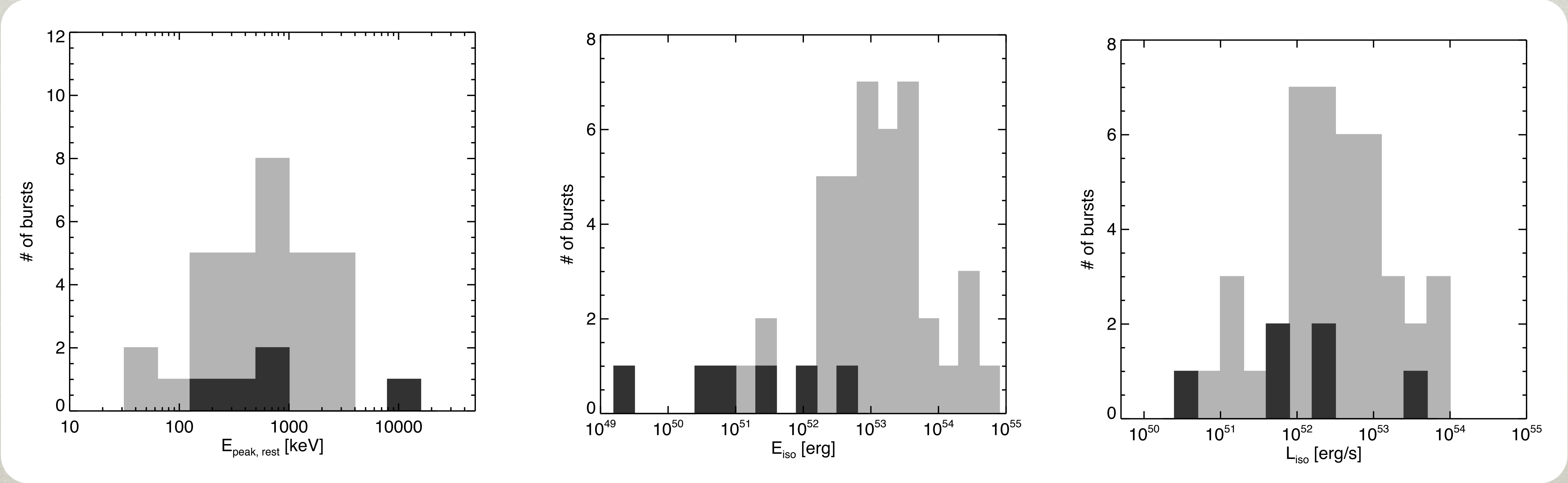
- 943 GRBs
- 2 types of spectra: 3.5 sigma SNR duration-integrated & (1024/64 ms) peak
- 4 spectral models (Band, SBPL, Comp, PL)
- >7500 spectral fits
- GOOD spectra: Parameter uncertainties below set threshold
- BEST spectra: The single best-fitting spectrum for each GRB (subset of GOOD)



Gruber+ 2014, ApJS, 211, 12

GBM GRB Spectral Catalog - Redshift Bursts

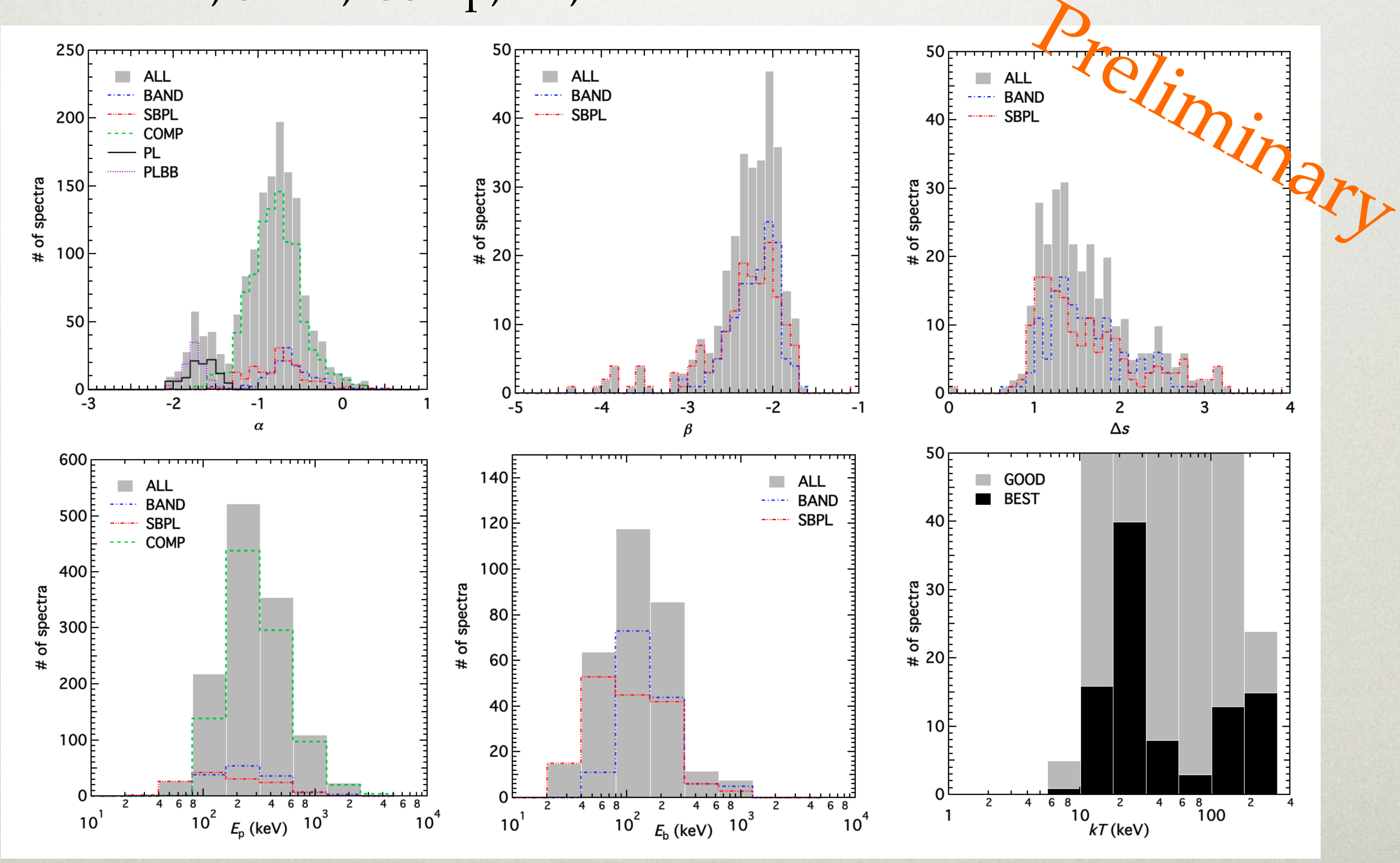
- 48 GRBs with redshift (42 long, 6 short)
- Rest-frame energetics calculated: E_{peak}, E_{iso}, L_{iso}
- Sufficient sample size to start studying correlations and consistency with samples from other instruments



Gruber+ 2014, ApJS, 211, 12

GBM Time-Resolved Spectral Catalog

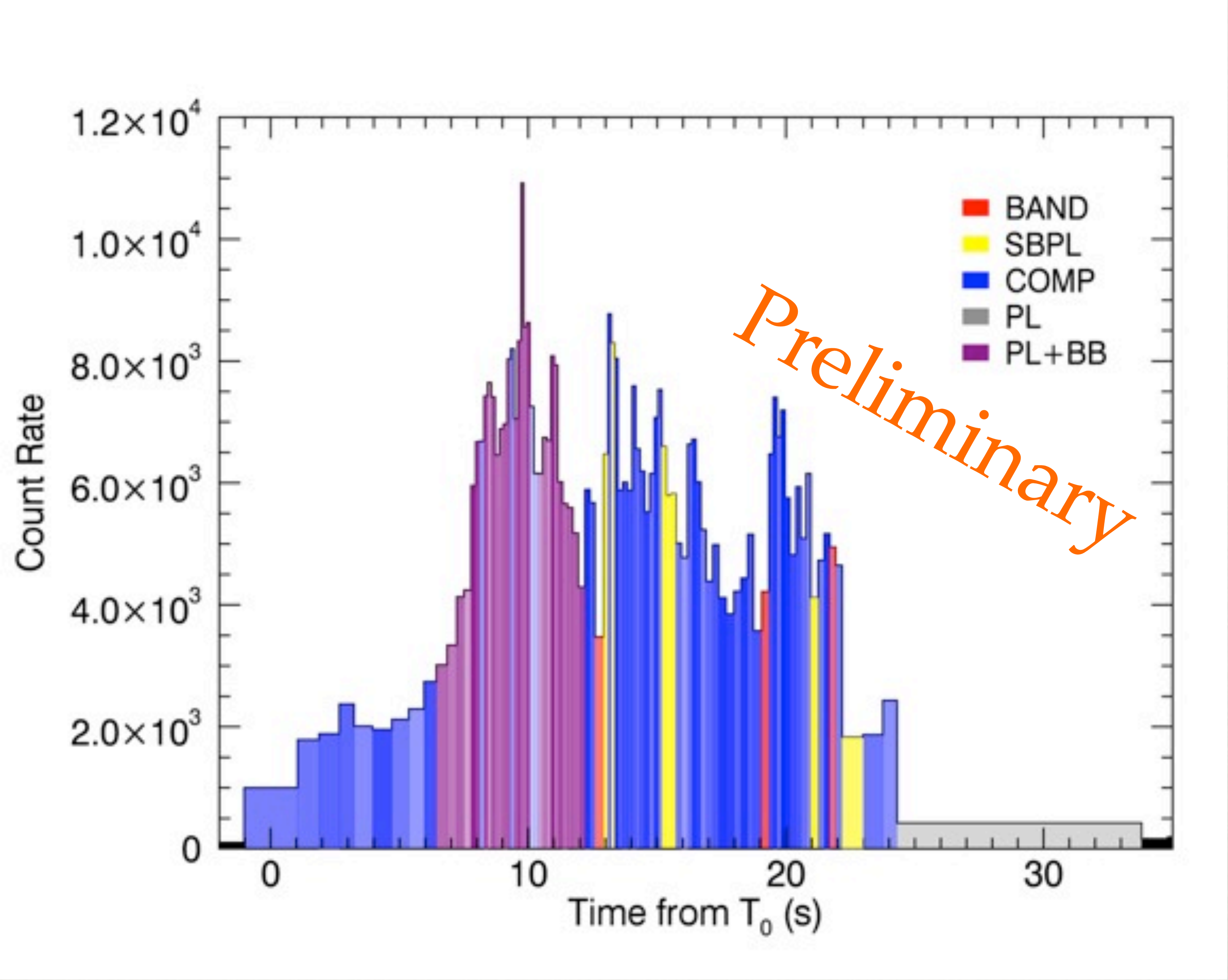
- 81 GRBs, 1495 spectra
- Fluence > 4e-5 erg/cm2 (10-1000 keV)
- Peak Flux > 20 ph/s-cm2 (10-1000 keV; 64, 256 & 1024 ms)
- > 4 time bins with SNR = 30
- Band, SBPL, Comp, PL, PL+BB



Yu+, in prep.

Time-Resolved LC Example

GRB 090902B



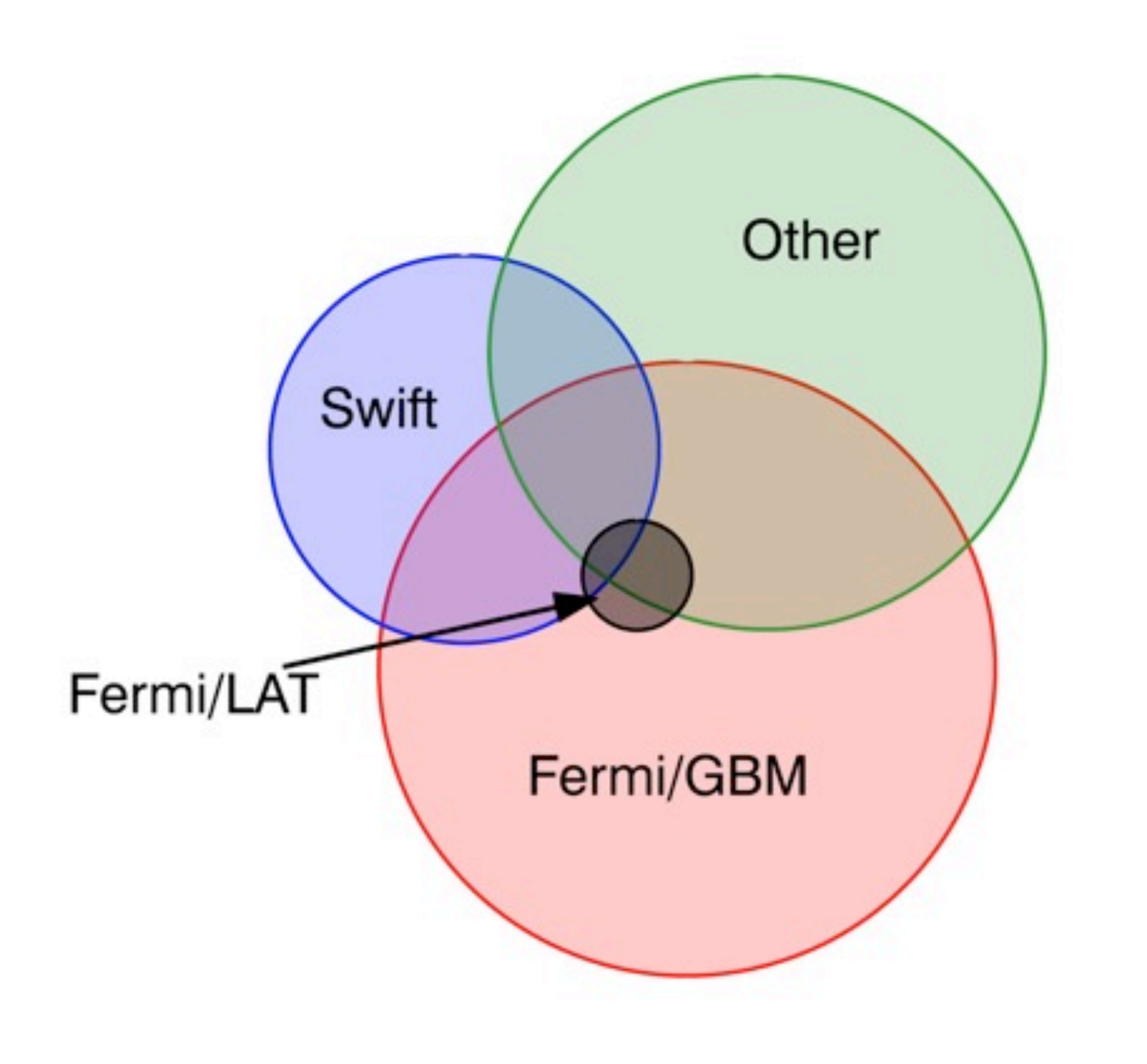
Other Projects

- Increasing Follow-up Observations
- Orbital Background Subtraction
- Low-Energy Spectral Excess
- Thermal Emission Modeling
- Non-Thermal Emission Modeling
- Solar Flares
- Terrestrial Gamma-ray Flashes
- Monitoring of persistent sources via Earth occultation

Observational Synergy

Through May 2014:

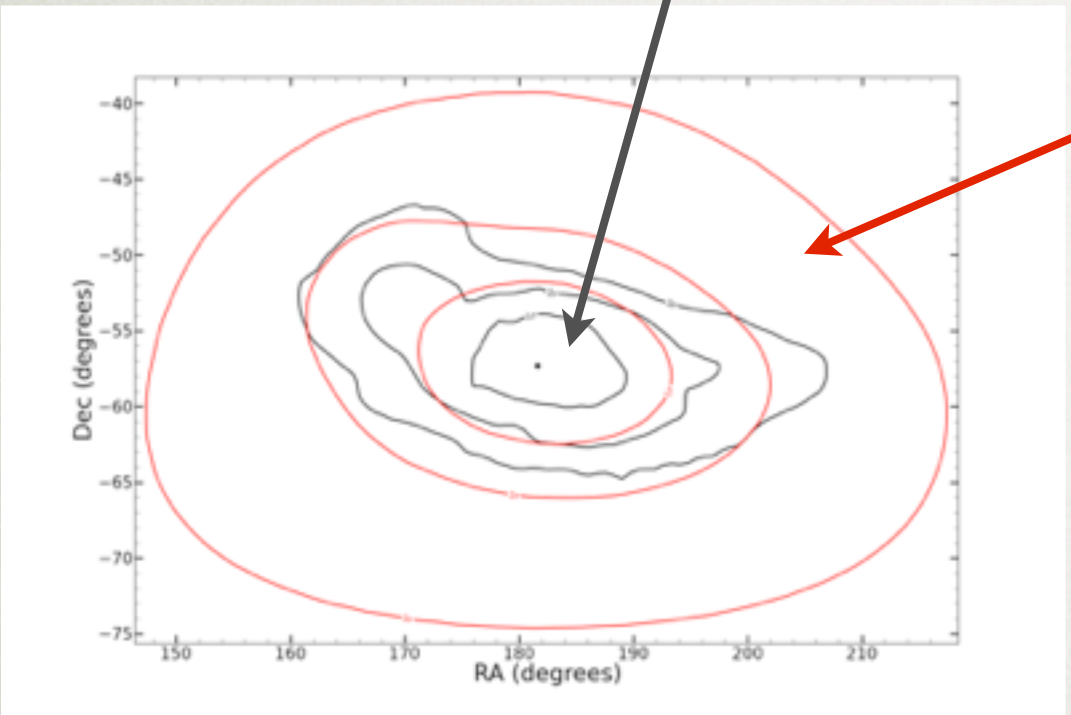
- 1380 GRBs
- ~230 Swift+GBM
- ~50 LAT+GBM
- >300 GBM+other
- 329 GRBs resulting in 3272 GCN Circulars (since Sep 2009)

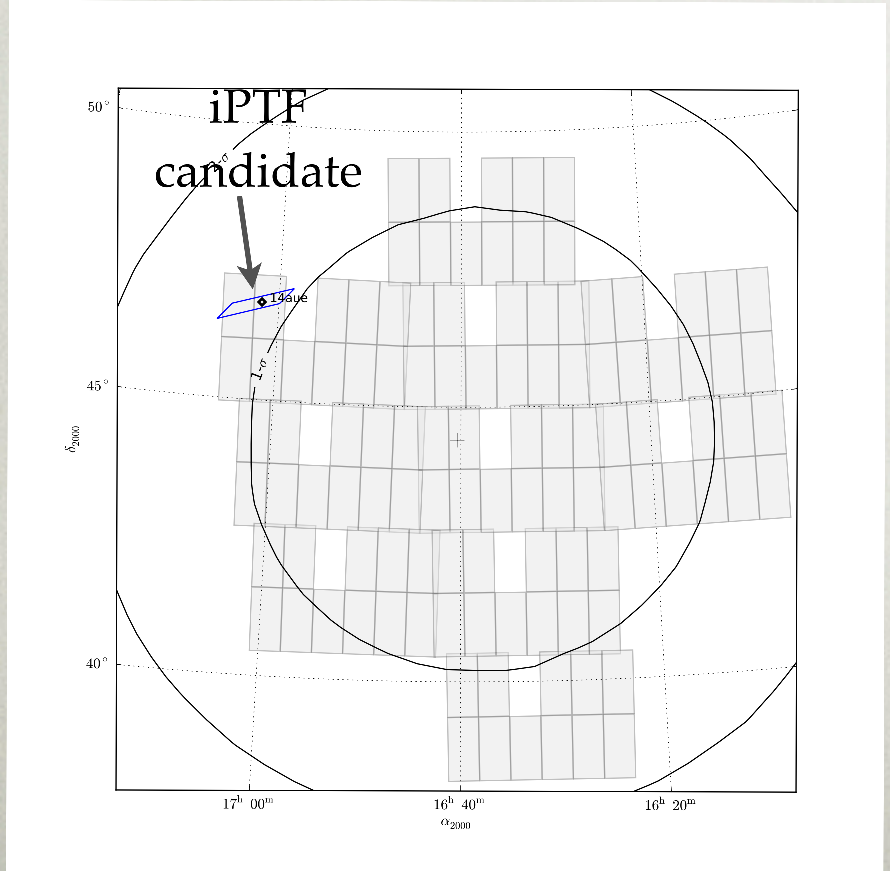


Total Localization Uncertainty Contours

Statistical Uncertainty

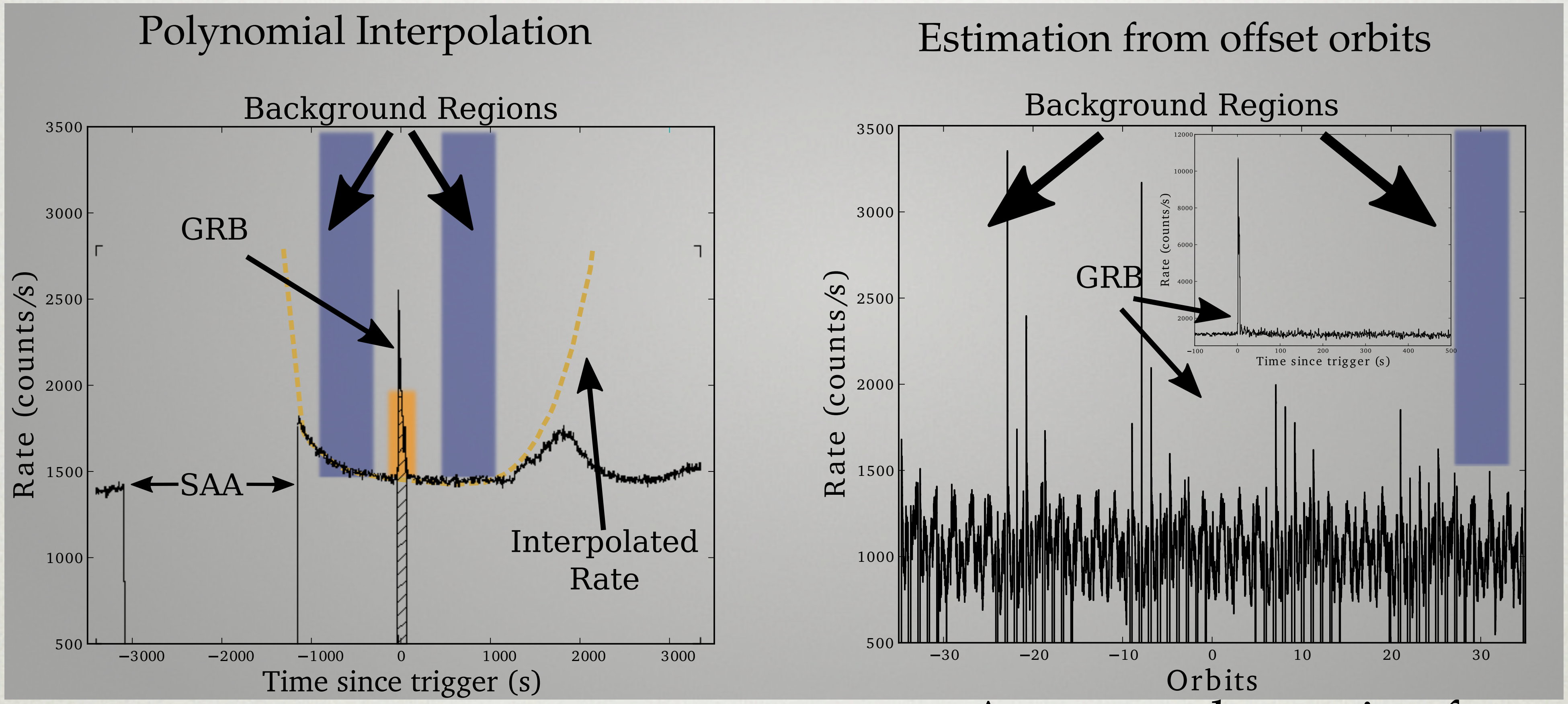
Total Uncertainty

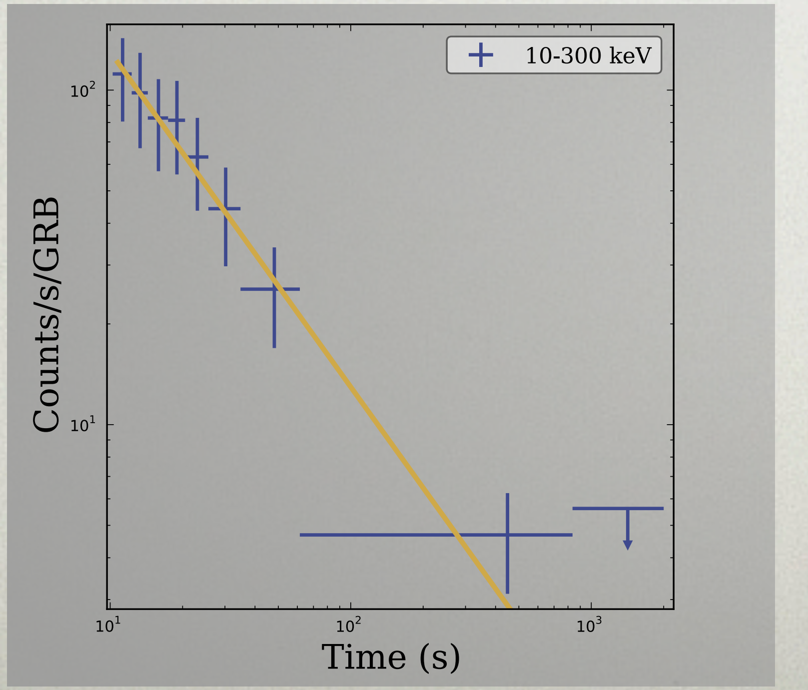




- Files created when a final position GCN notice is sent (since Jan. 2014)
- Contour files are available at FSSC website as an official data product
- Developing FITS probability maps
- Already 4 successful follow-ups with iPTF using the contour files (130702A, 131011A, 131231A, & 140508A)
- Preparing for aLIGO/Virgo era
- Building collaborations with iPTF, IPN, FIGARO, RAPTOR, MASTER, aLIGO, IceCube, Swift

Orbital Background Subtraction

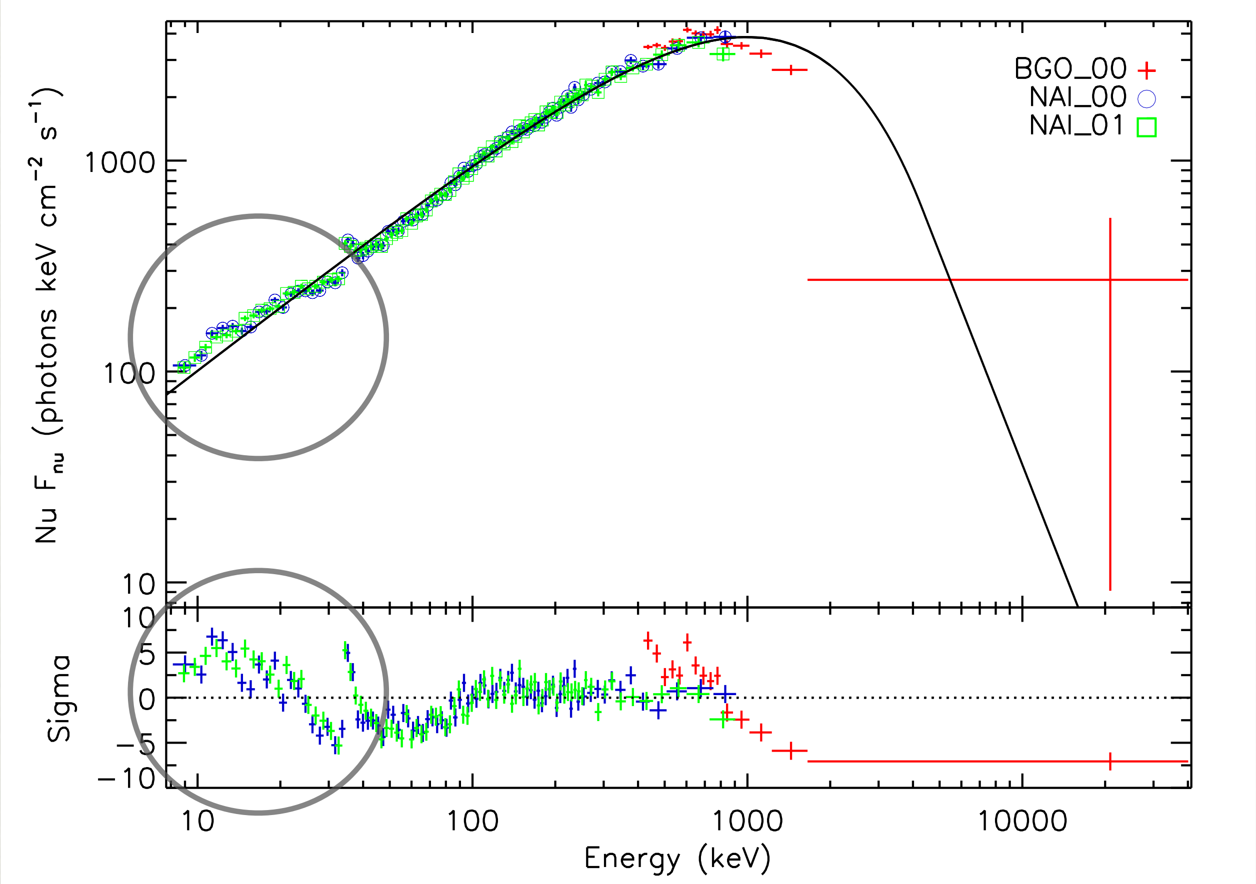




- Accurate alternative for polynomial-fitting for long-lasting emission scenarios
- Potentially used to study extended gamma-ray emission. Lightcurve stacking suggests a PL decay of the lightcurve.

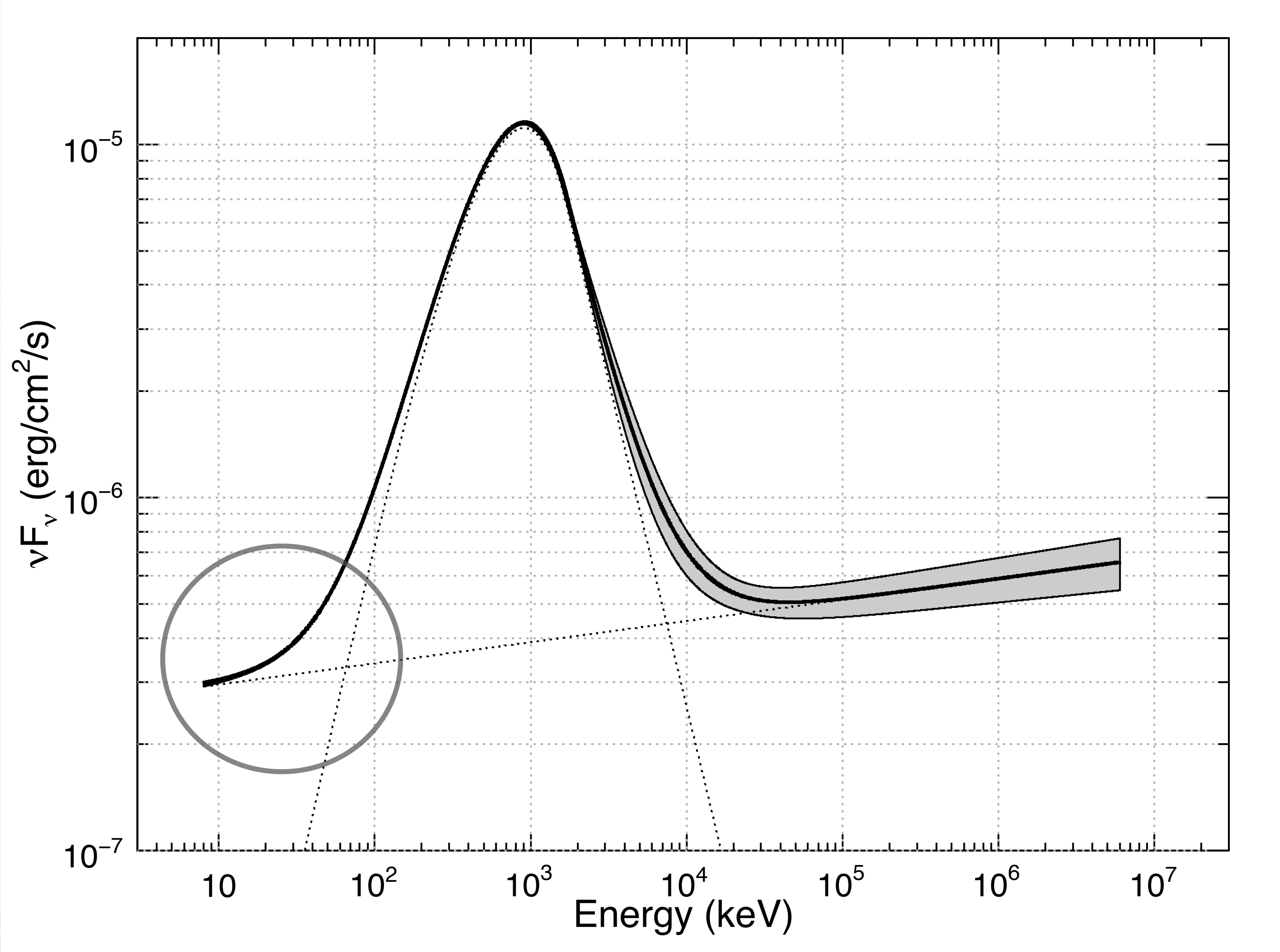
Fitzpatrick+ arXiv:1111.3779

Low-Energy Excess



Tierney+ 2013, arXiv: 1301.4859

GRB 090902B

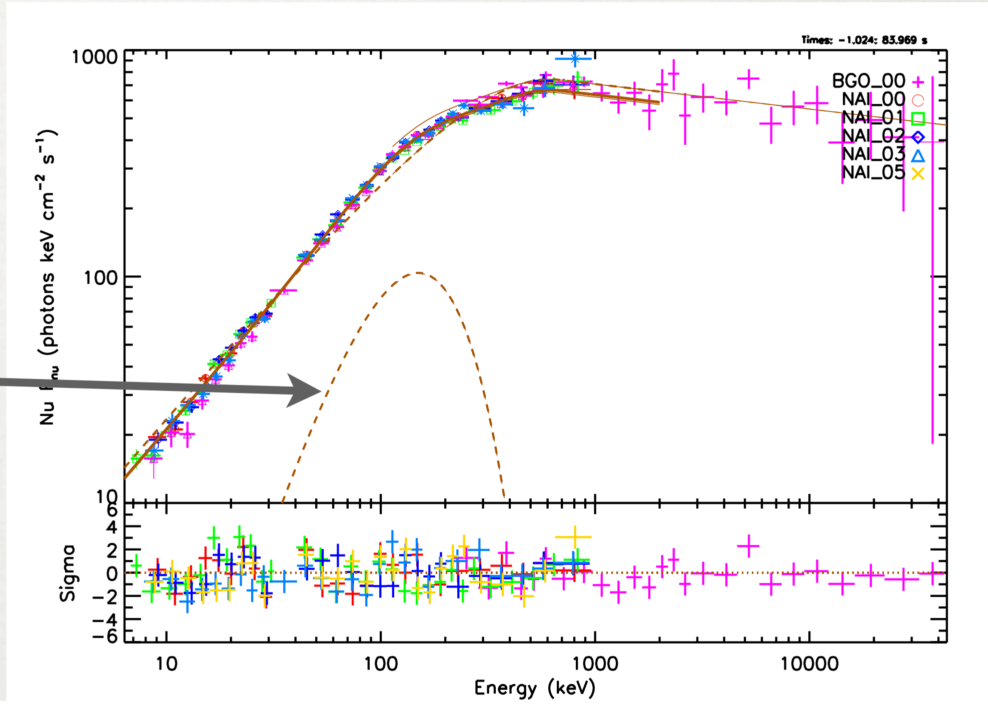


Abdo+ 2009, ApJL 706, 138

Thermal Emission - Photospheric?

GRB 100724B

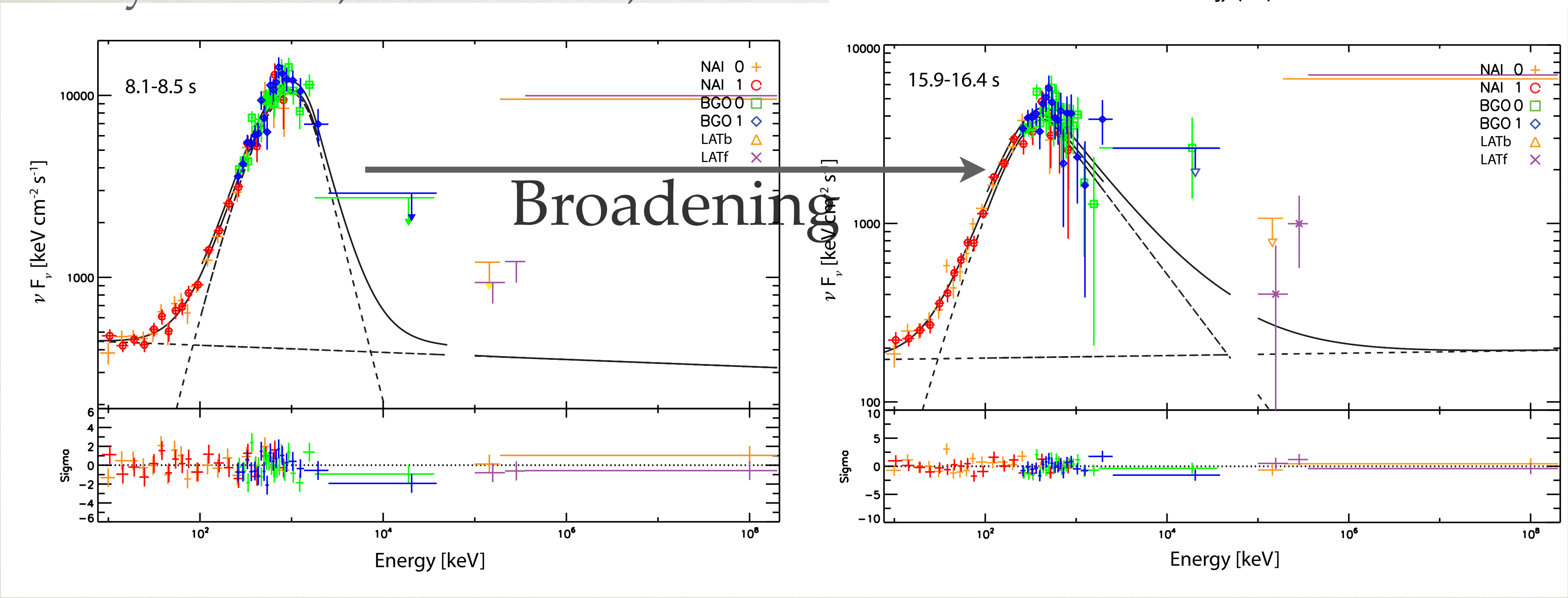
Guiriec+ 2011, ApJL 727, L33



Blackbody

GRB 090902B

Ryde+ 2011, MNRAS 415, 3693

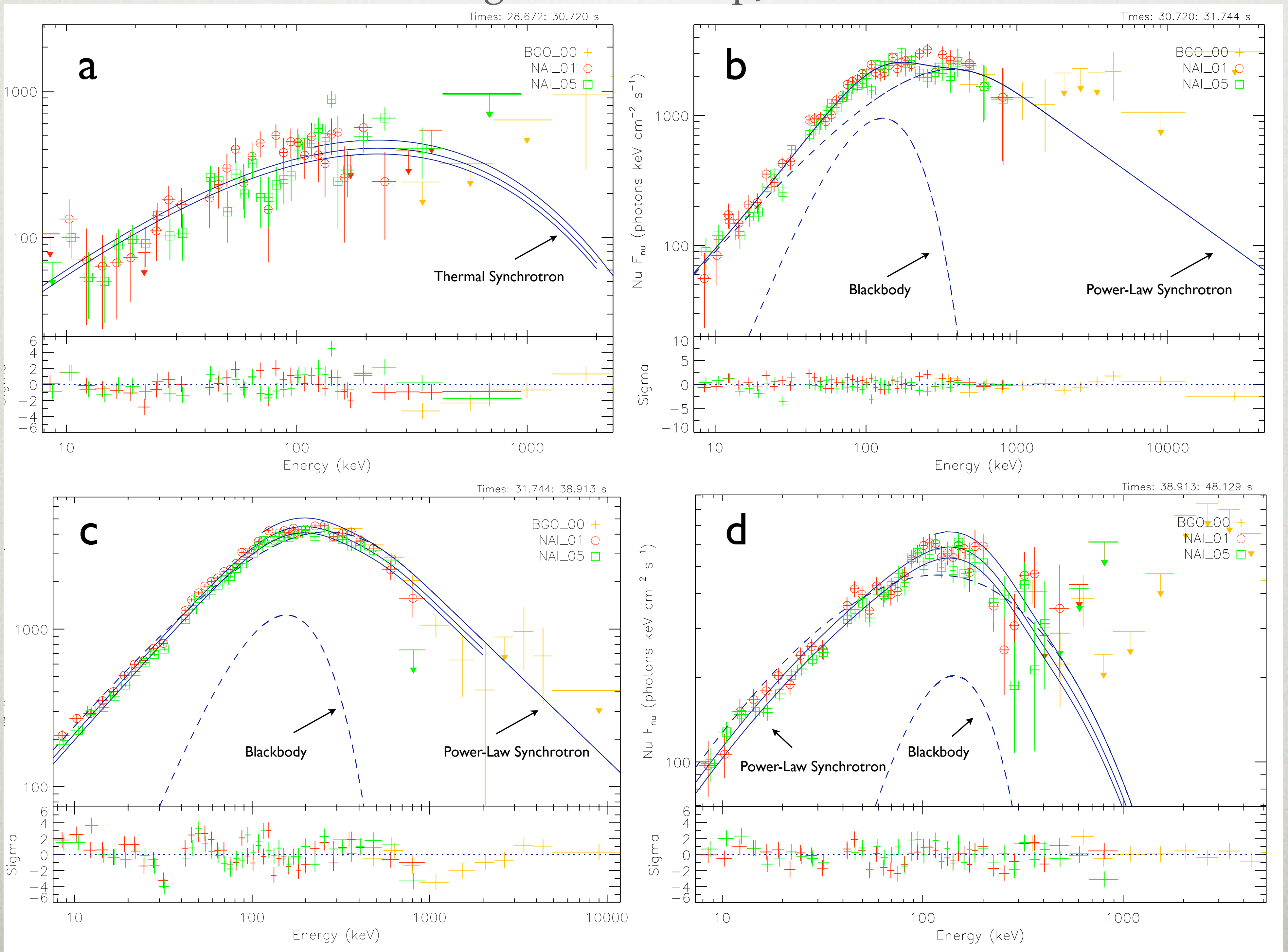


Broadening

Non-Thermal Emission - Synchrotron?

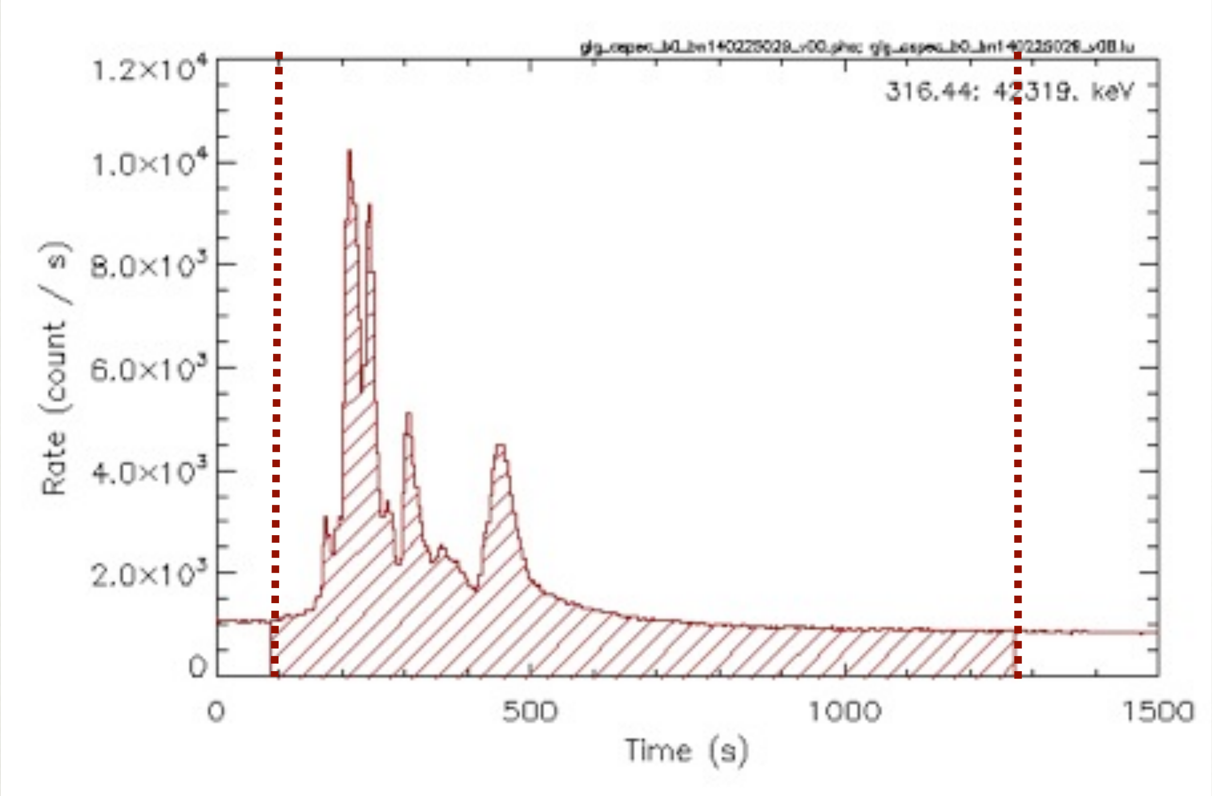
GRB 090820A

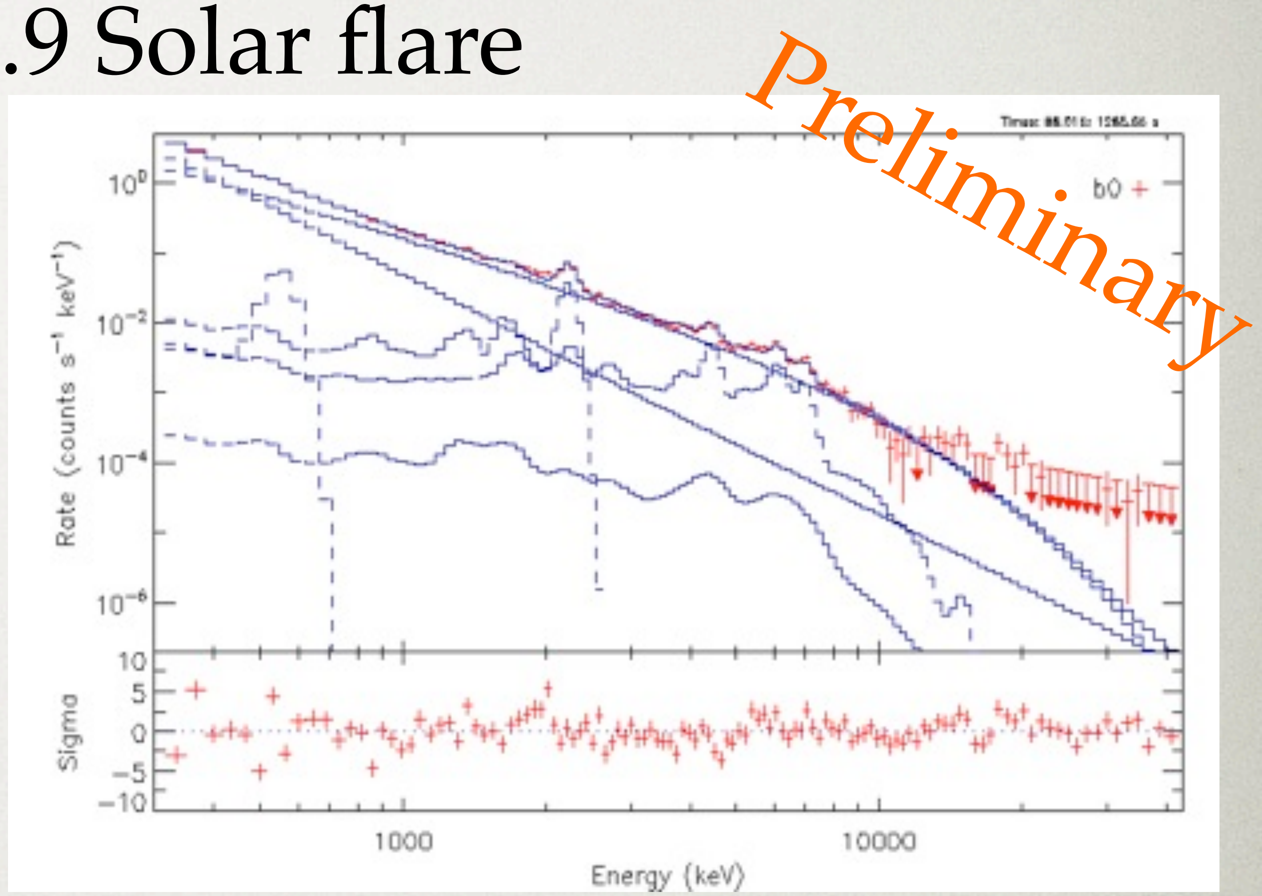
Burgess+ 2011, ApJ 741, 24



Solar Flares

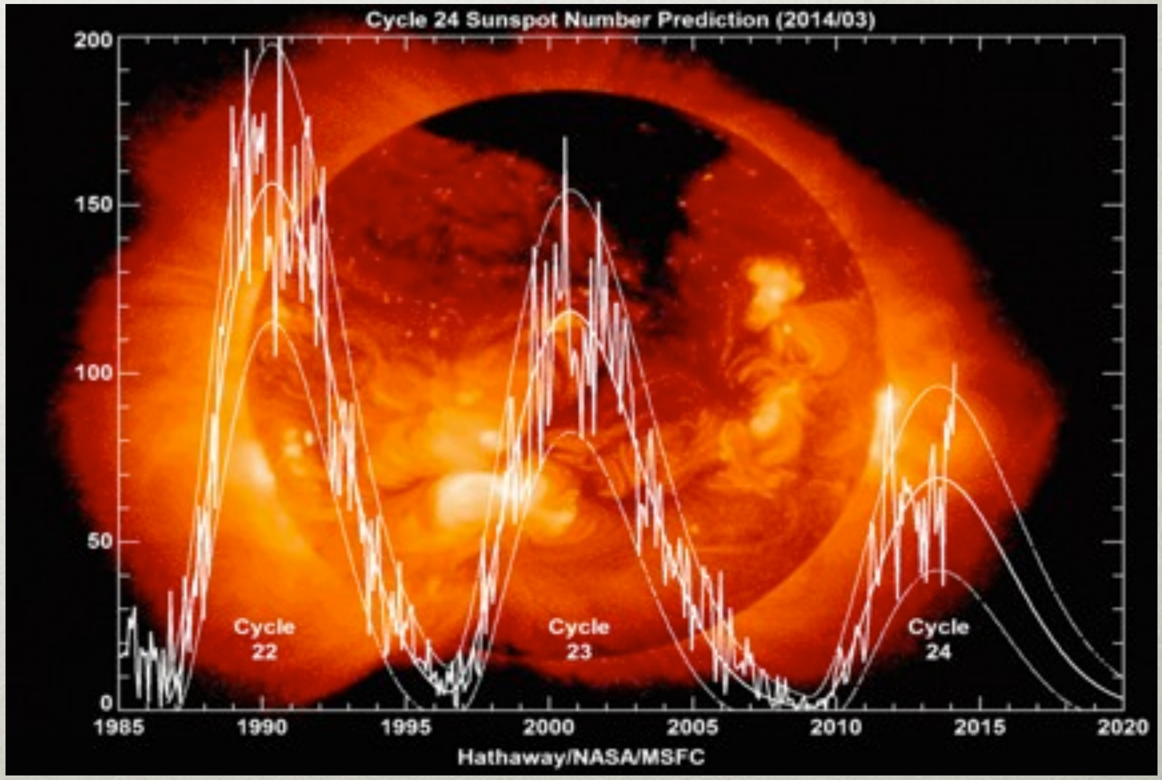
Feb 25 2014 X4.9 Solar flare





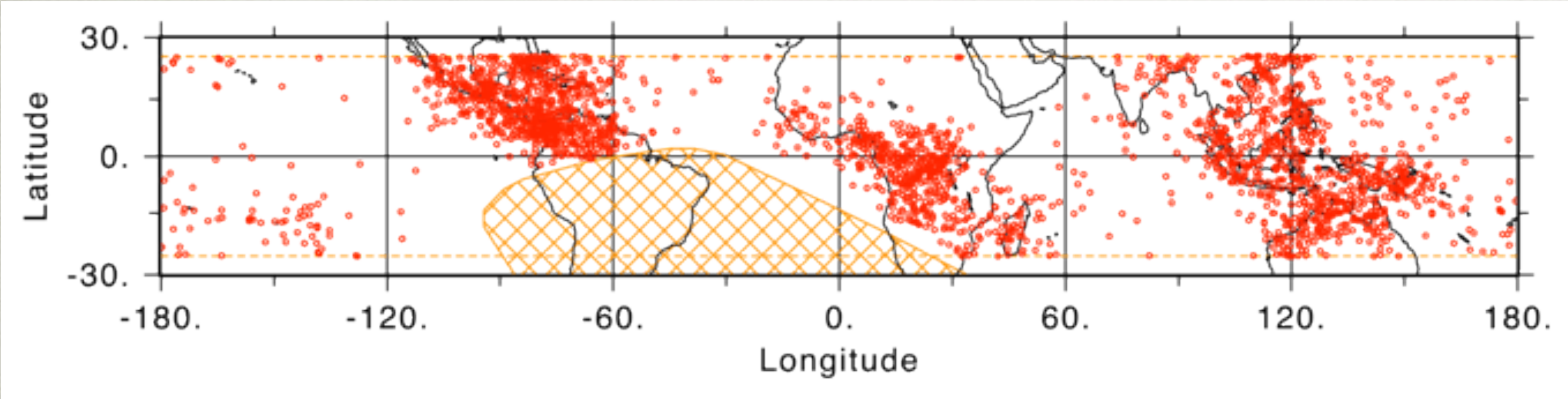
Spectral Components

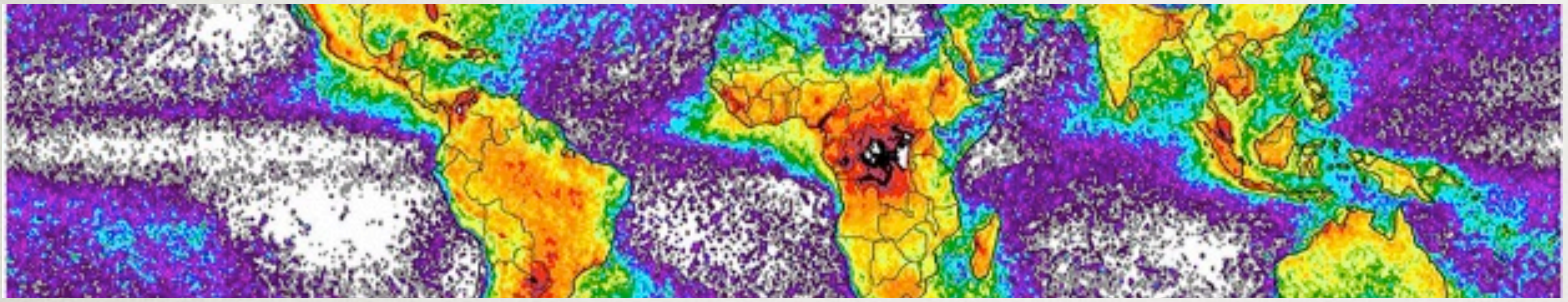
- e- bremsstrahlung
- 511 keV e+/e- annihilation
- 2.2 MeV n-capture line
- 1 - 8 MeV nuclear lines

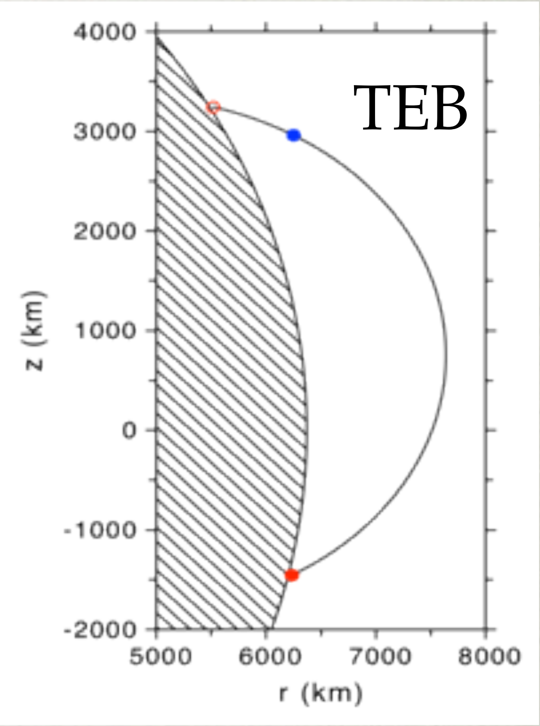


Pelassa+ in prep.

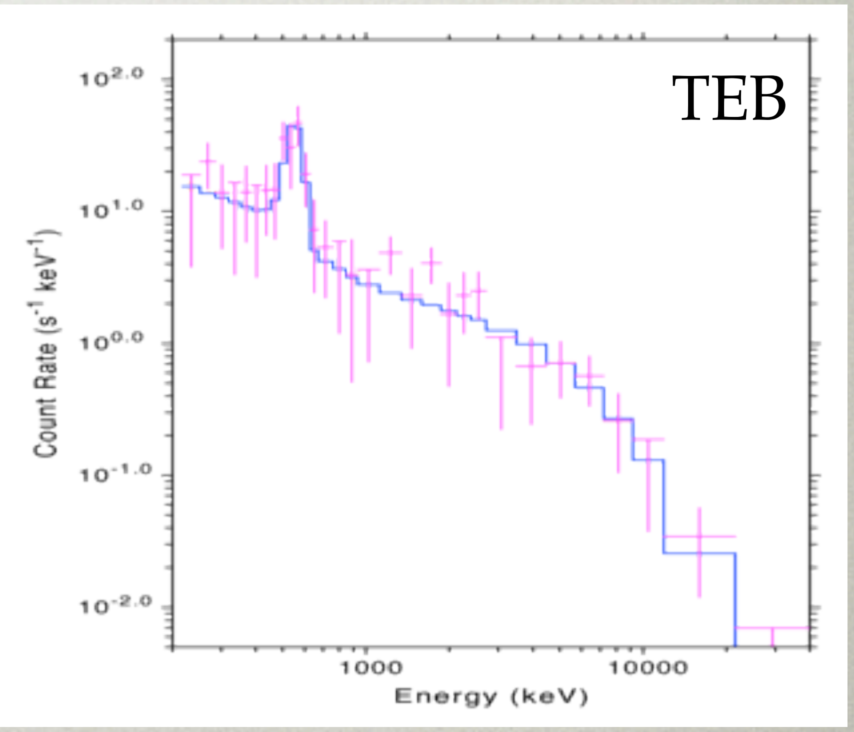
TGFs and TEBs



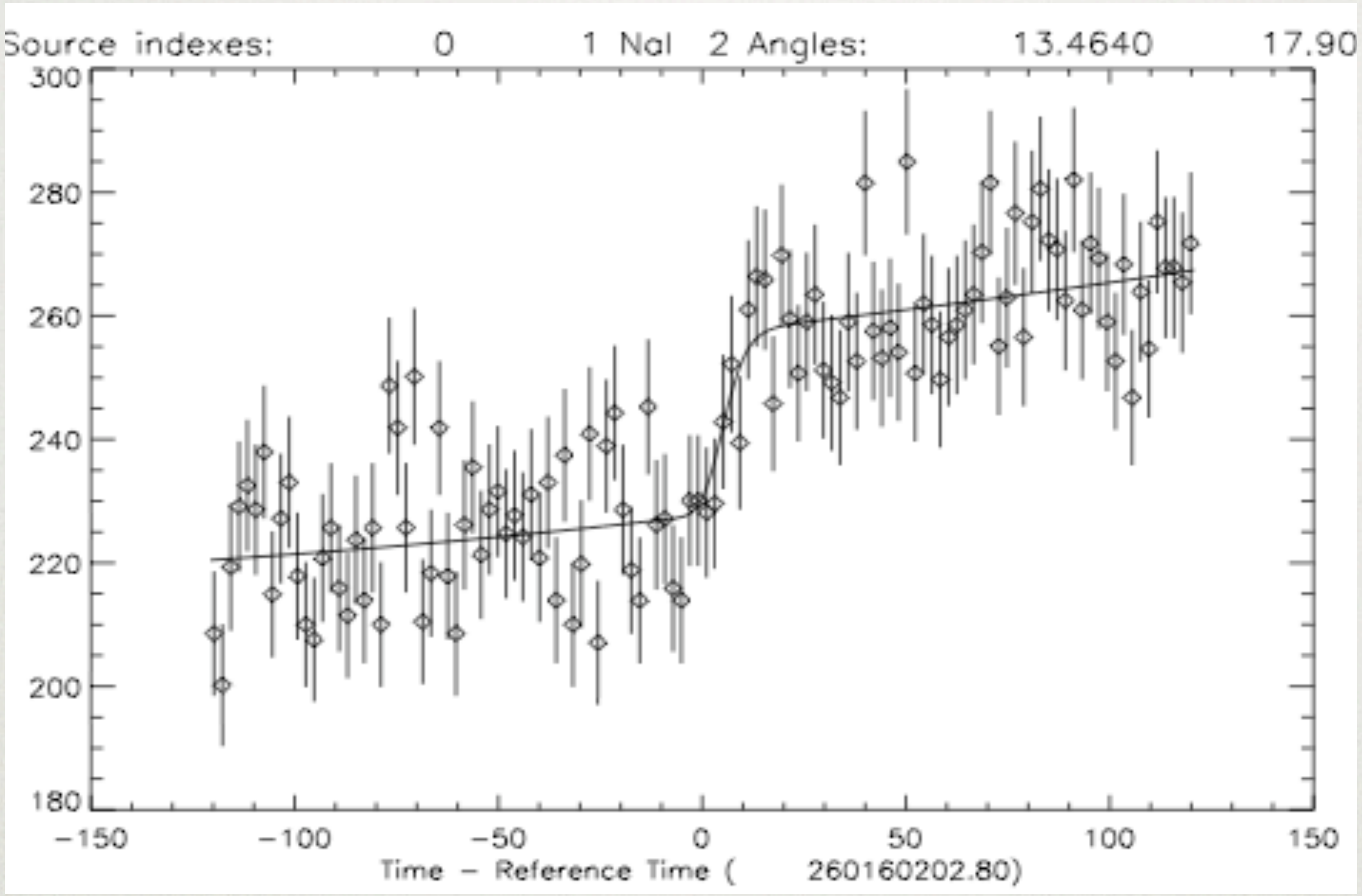




- 2270 TGFs
- < few ms duration
- Spectrum is harder than GRBs, usually trigger BGO
- TGFs correlate with lightning (WWLLN & LIS)
- Runaway Electron Avalanches via Relativistic Feedback
- GBM discovered physics of Terrestrial Electron Bursts (TEBs)
- TEBs have a strong annihilation signal (20% e+ fraction)
- **Money for a postdoc**



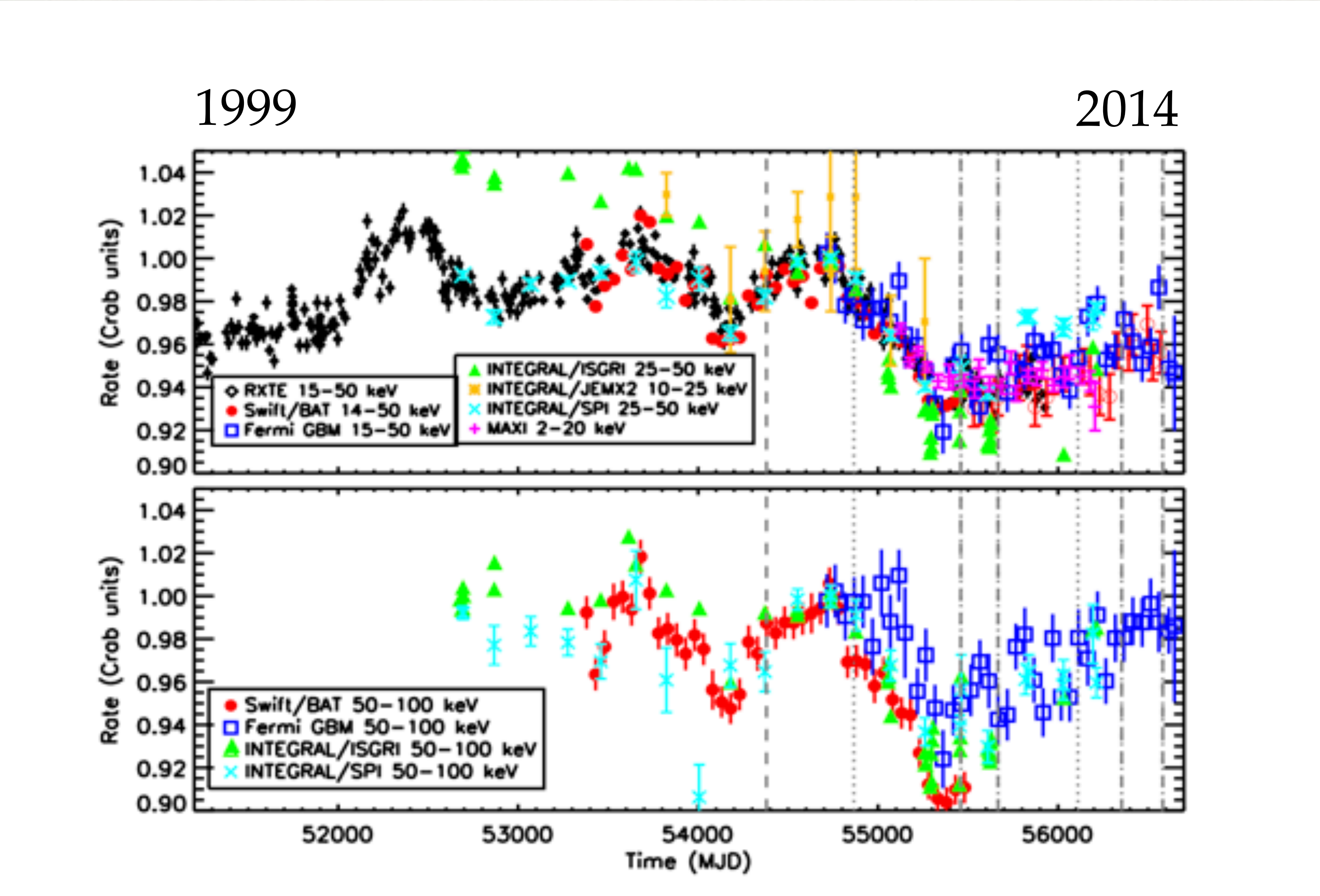
Earth Occultation of Persistent Sources



- Observed count rate is fit by a quadratic background + source
- Source count rate is modeled by assuming a spectrum and folding it through the detector response
- Typical Source exposure times are 3 ks/day
- First 3 years: 41 LMXBs, 31 HMXBs, 12 BHCs, 12 AGN, the Sun, and the Crab
- http://heastro.phys.lsu.edu/gbm

Wilson-Hodge+ 2012, ApJS, 201, 33

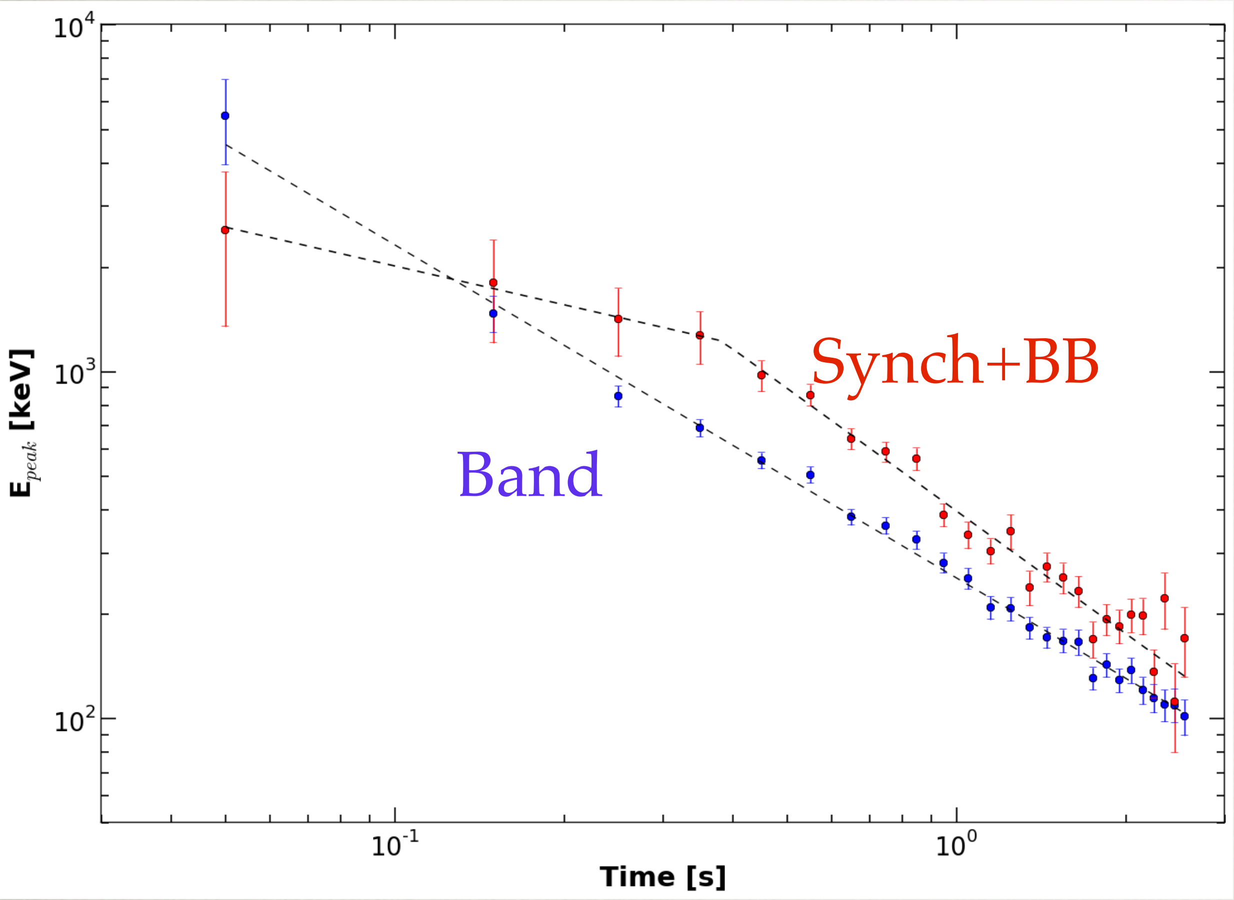
The Variable Crab Nebula

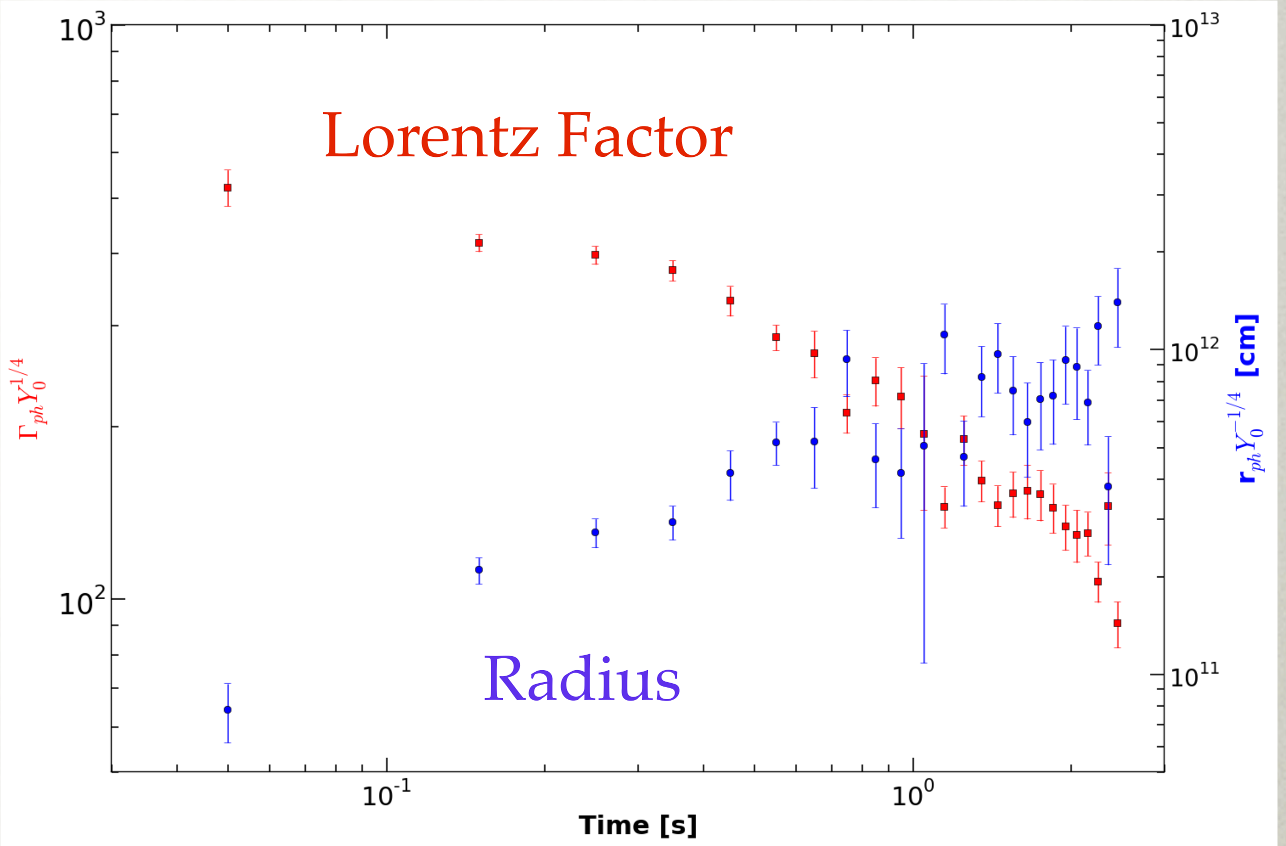


- 7% decline in flux from 2008 to 2010
- Spectral softening during this period
- Flux has since started to recover from the decline

Wilson-Hodge+ 2011, ApJ, 727, L40

GRB 130427A



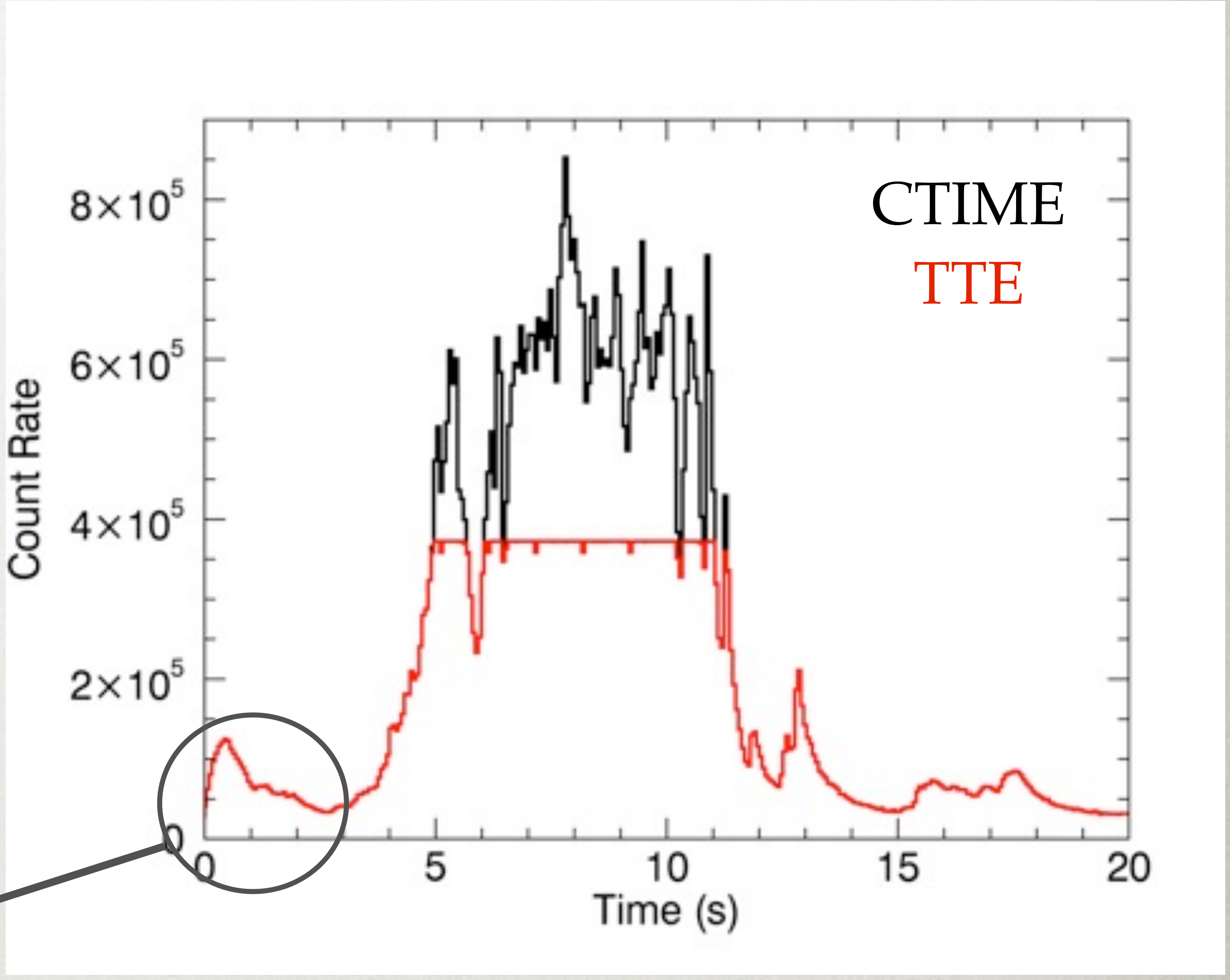


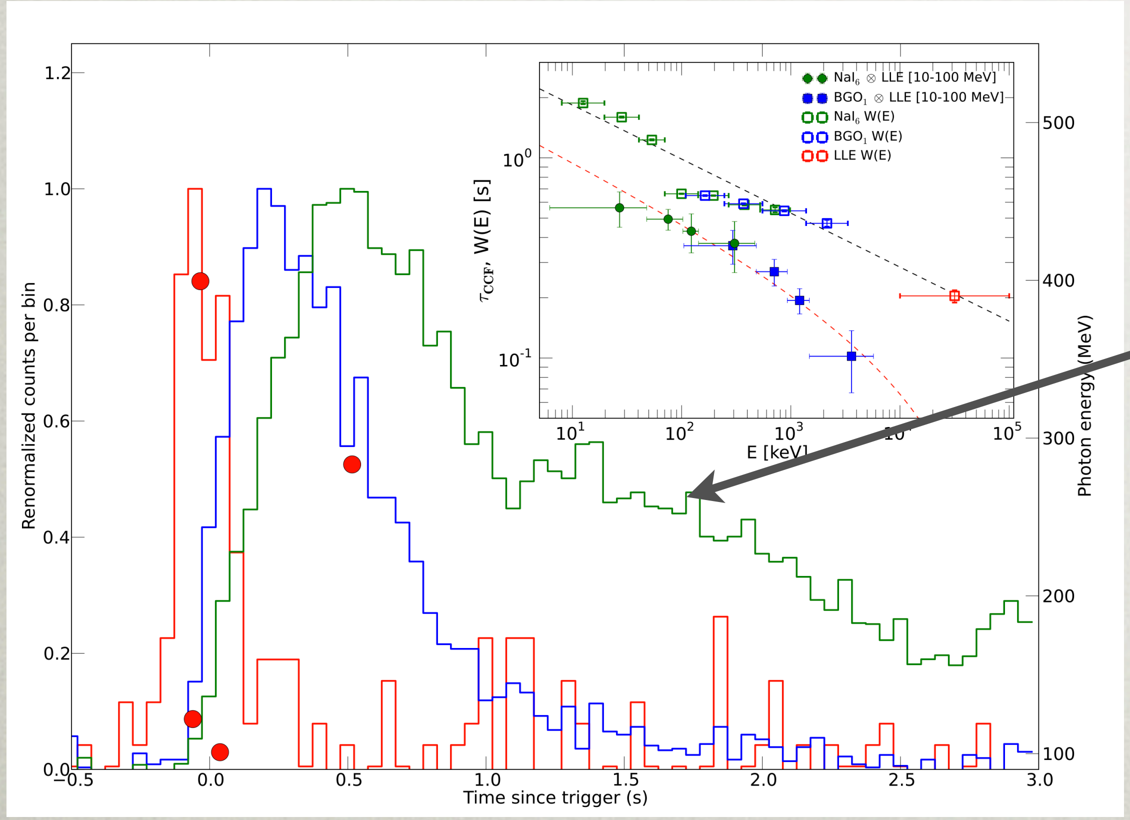
Preece+ 2014, Science, 343, 51

- Very bright (brightest observed?), but very close (z=0.34)
- Rest-frame luminosity is ~average
- Hard-to-soft spectral evolution
- Broken PL spectral evolution when using synchrotron
- Photosphere Lorentz factor decreases as photospheric radius increases

The Problematic Case of GRB 130427A

- CTIME & CSPEC not saturated; simple counter
- TTE saturated and up to >50% of data lost!
- At >80k counts, spectra is significantly affected by pulse pile-up





- First pulse not affected by saturation or pulse pile-up
- First pulse is one of the brightest 'clean' pulses ever detected

Preece+ 2014, Science, 343, 51

Current GBM Public Data

- Localization Probability Maps - **NEW**!
- Trigger data
- Continuous/daily data
- GRB trigger and spectral catalogs
- GRB lightcurves
- Earth occultation lightcurves, pulsar spin histories, etc.
- Spectral analysis software - RMfit

http://fermi.gsfc.nasa.gov/ssc/data/access/