The Fermi Gamma-ray Burst Monitor

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at Marshall Space Flight Center
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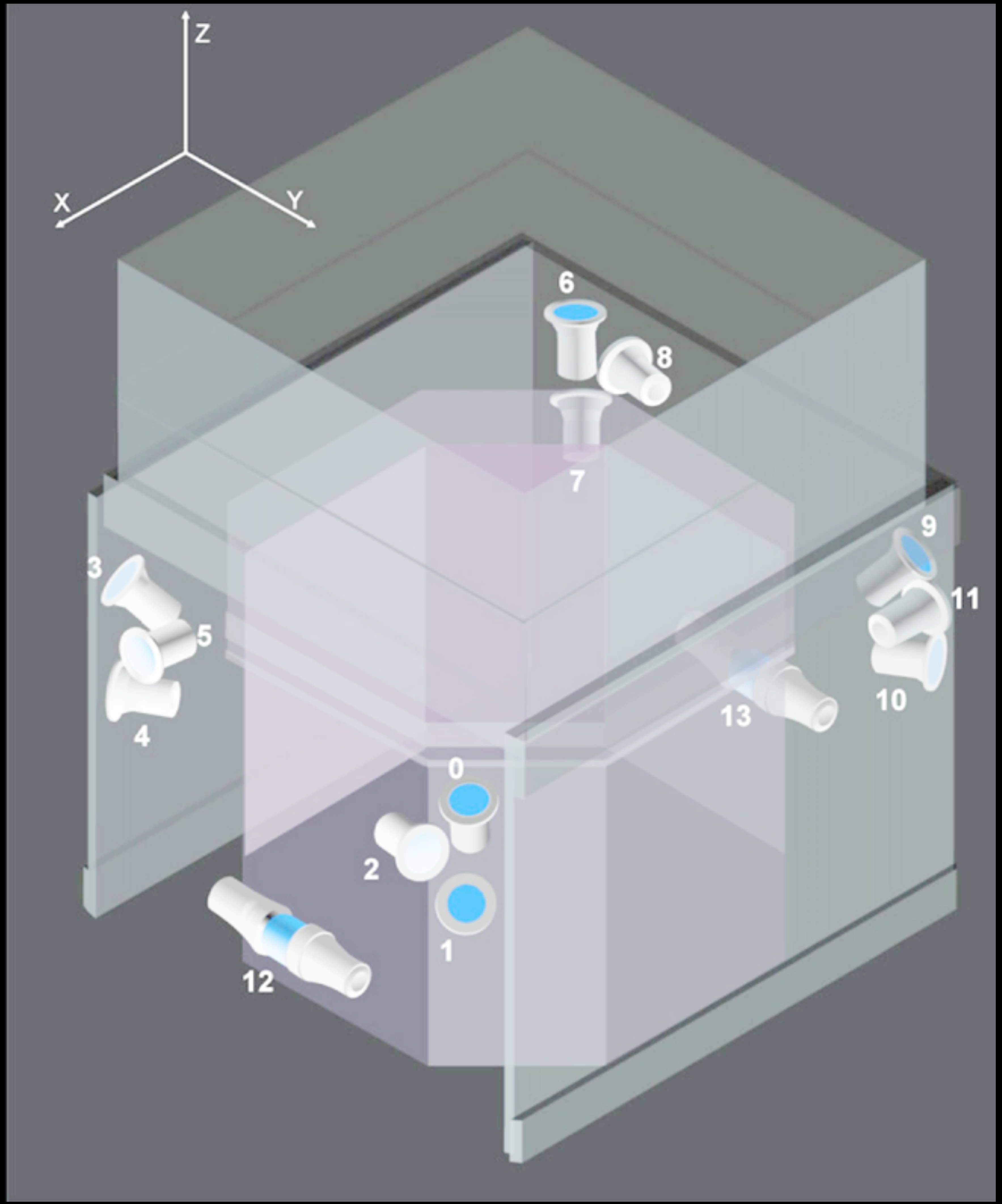
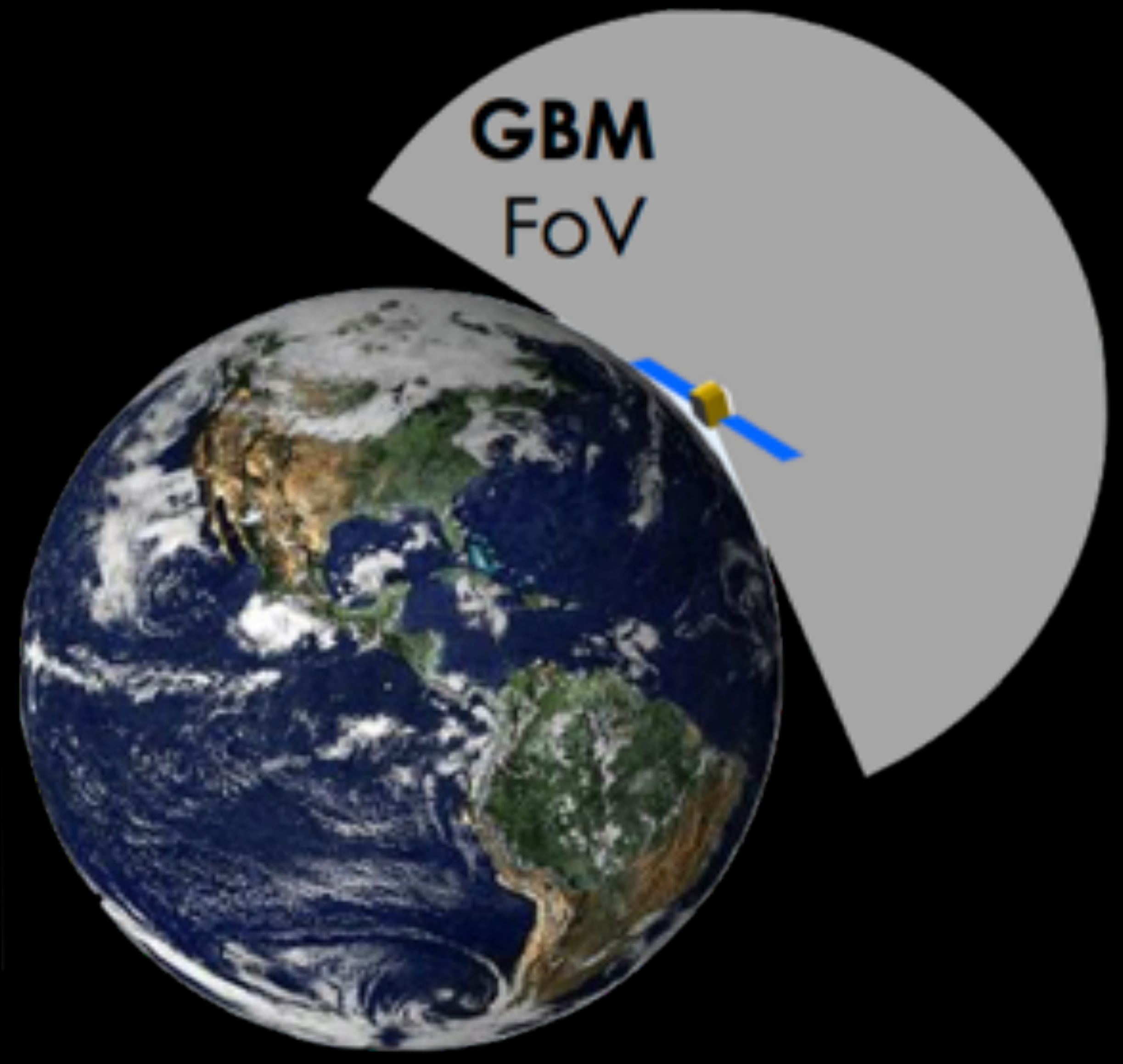
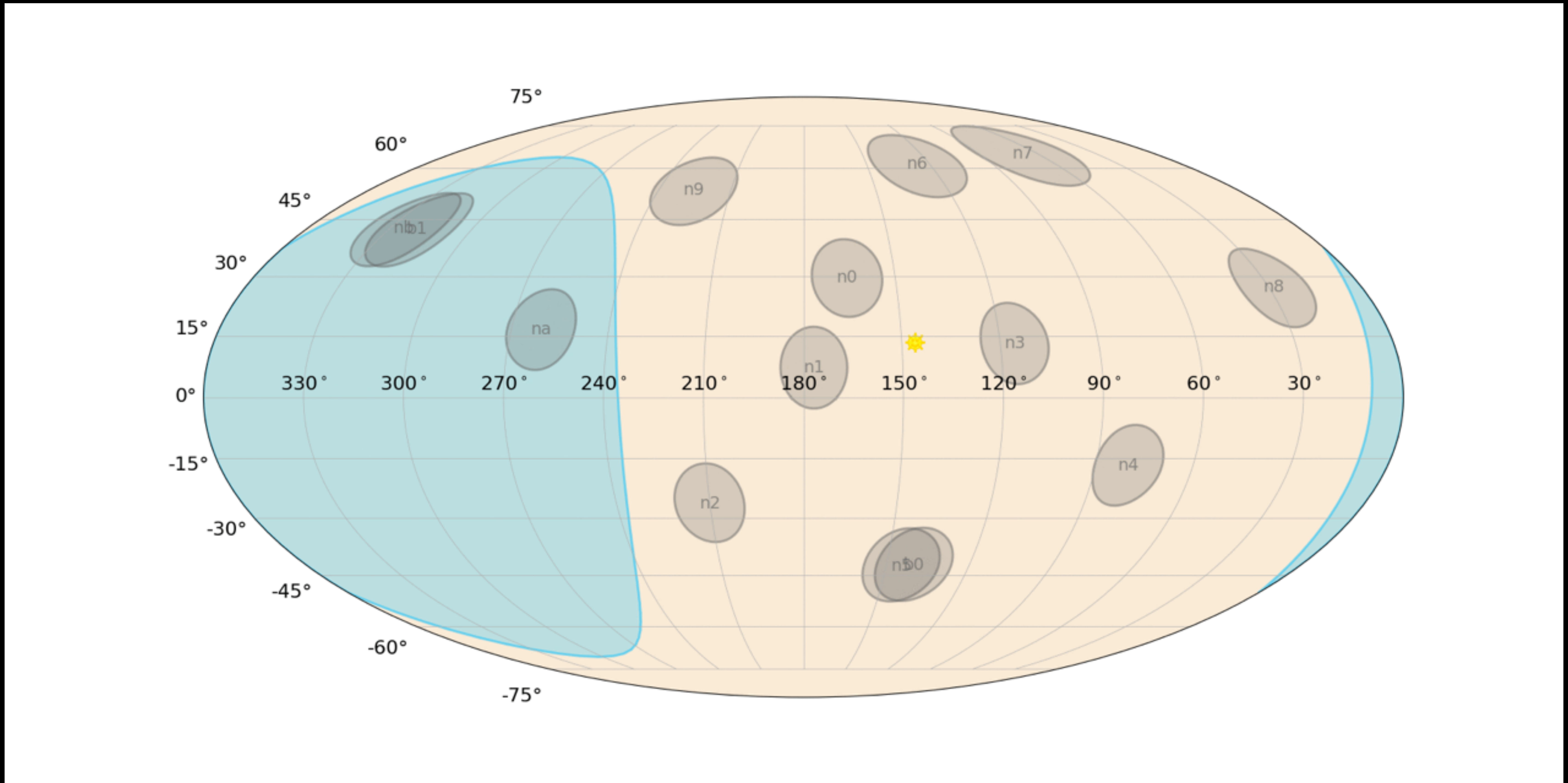
Fermi
Gamma-ray
Space Telescope

The Fermi Gamma-ray Burst Monitor

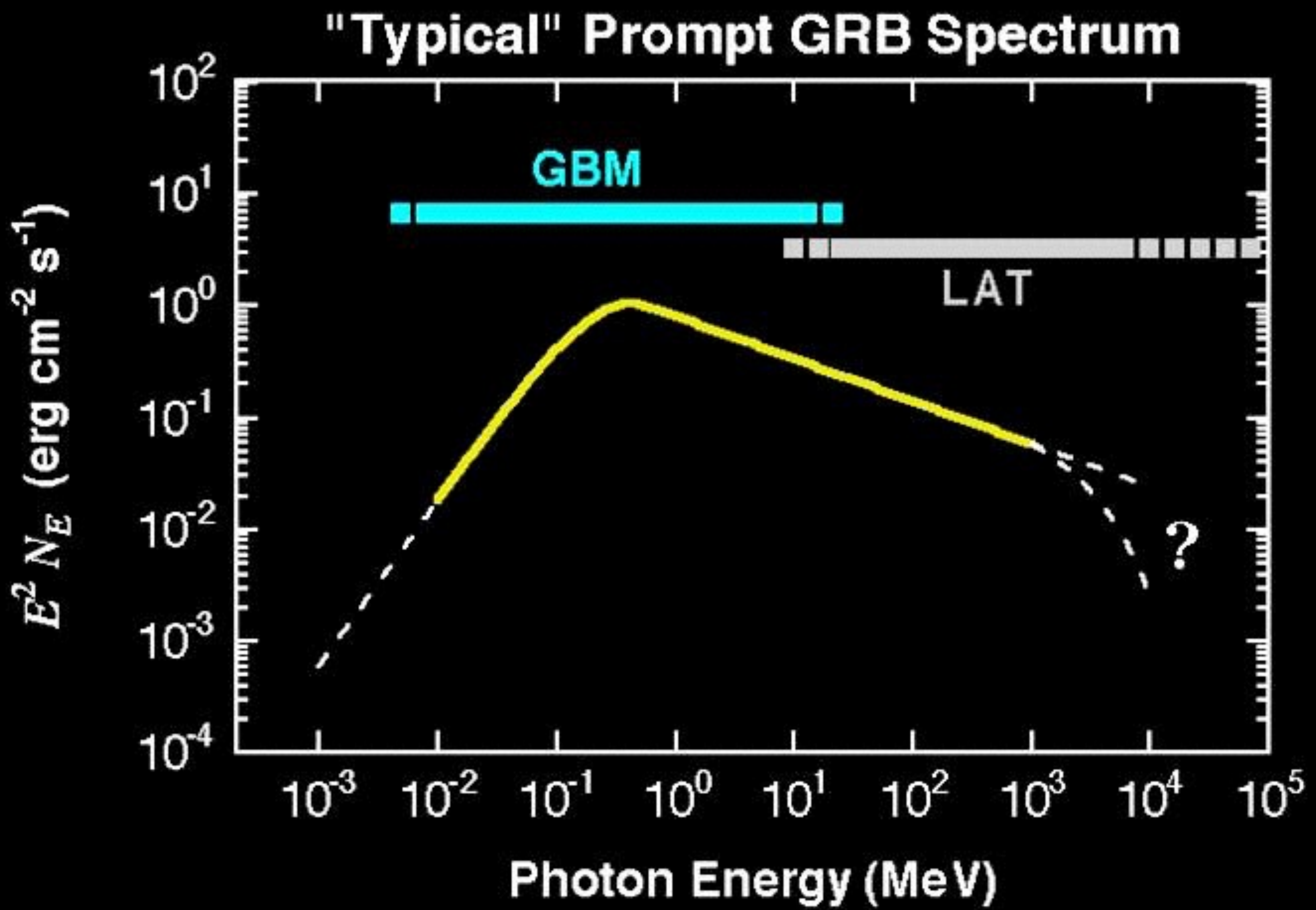


All-Sky Monitoring





Energy Coverage



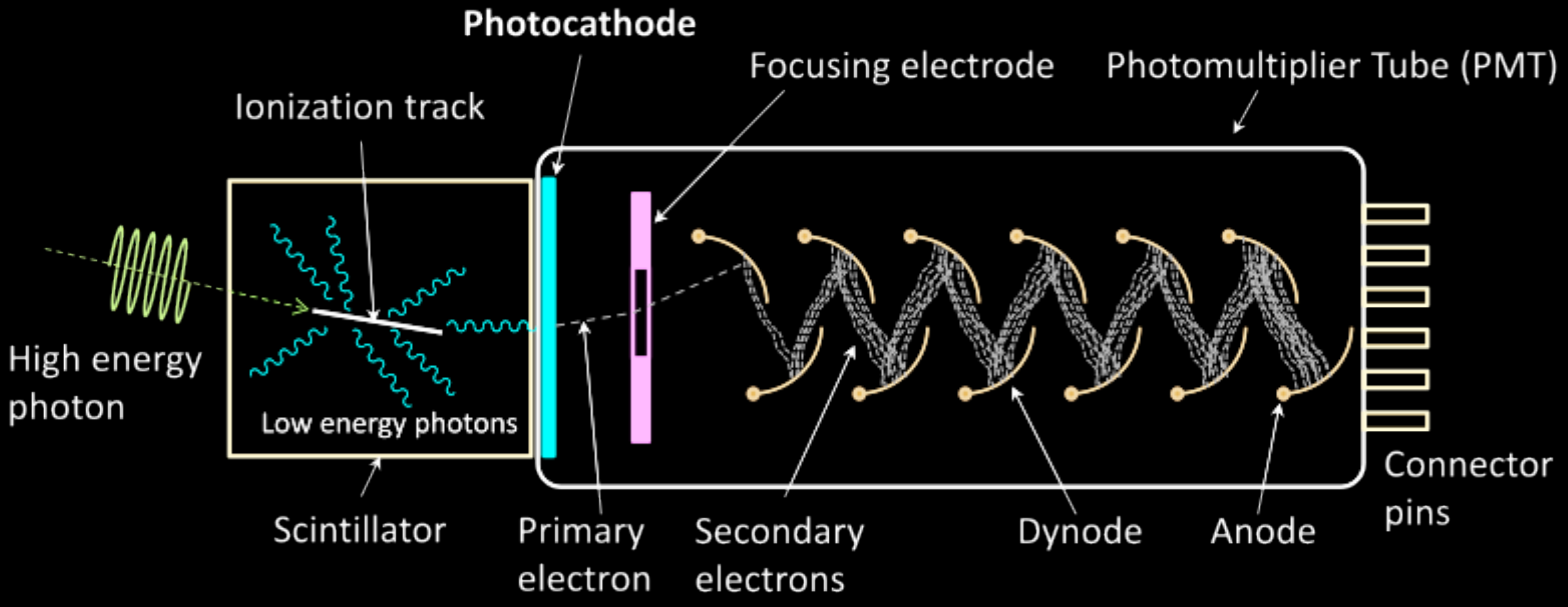
NaI detectors:

~8—1000 keV

BGO detectors:

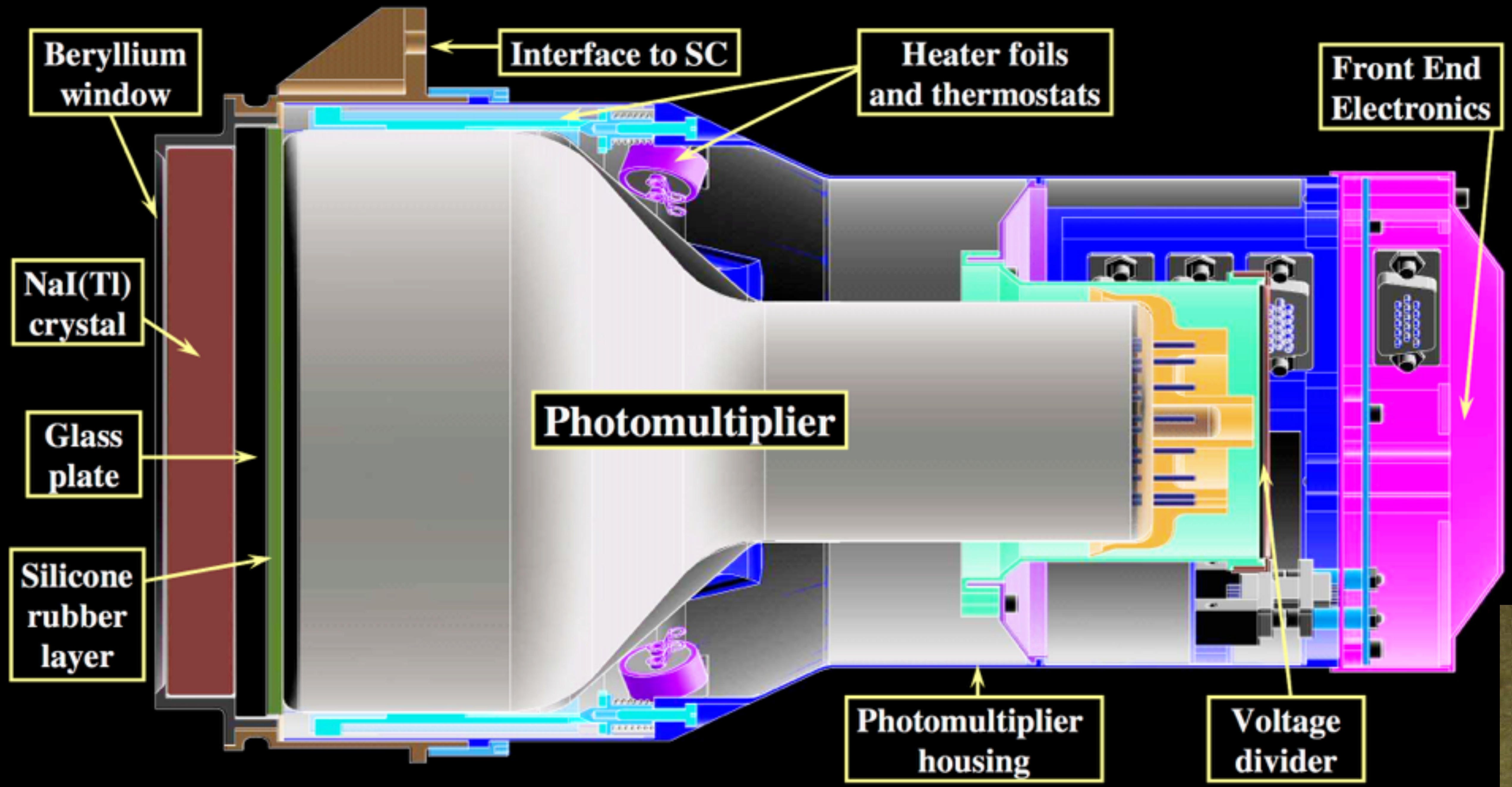
~200 keV—40 MeV

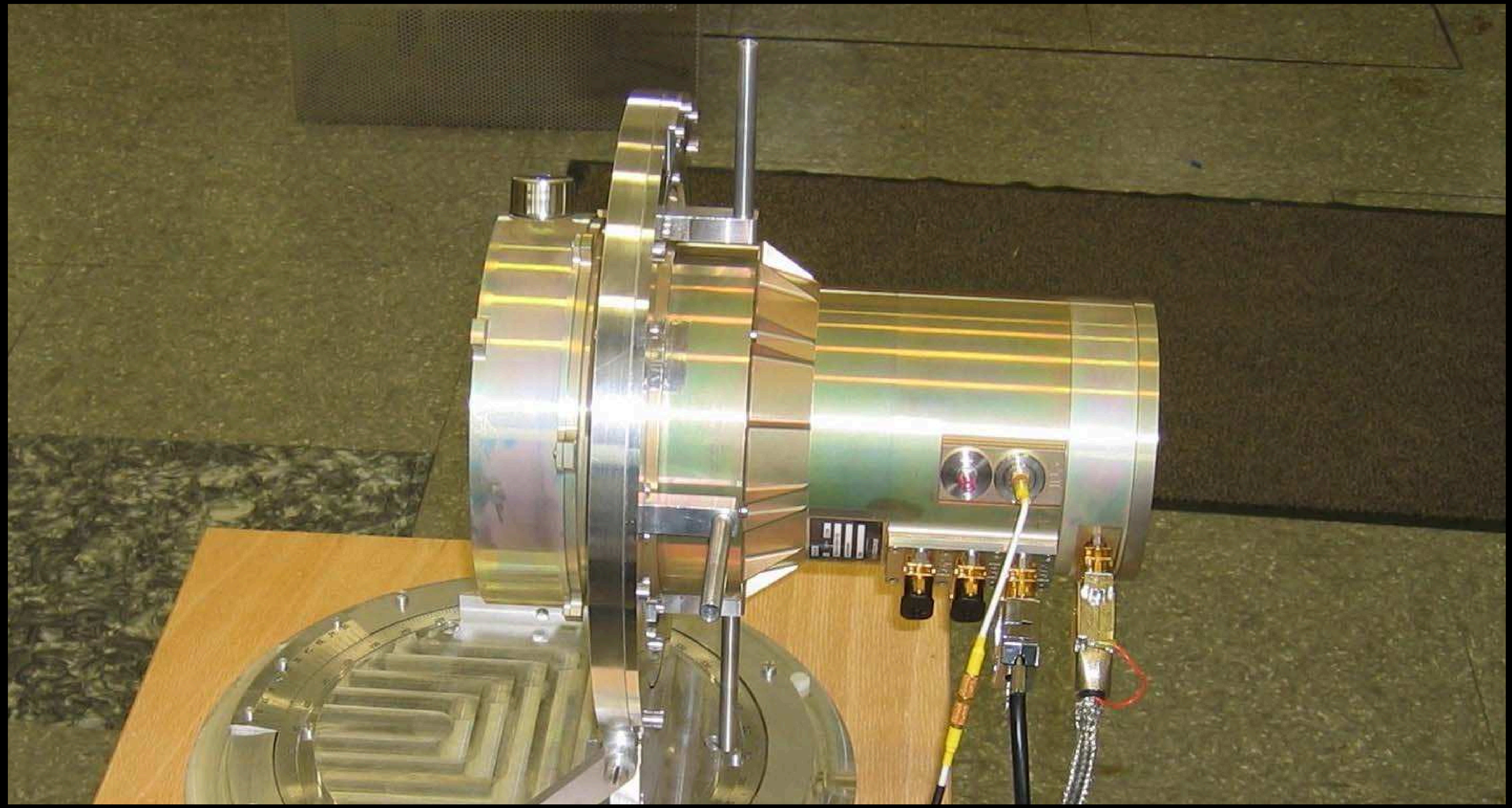
Scintillation Detectors and PMTs



- Incident photons interact and produce scintillation photons
- Scintillation photons produce electron(s) at the Photocathode
- An electric potential (voltage) is applied to the Photocathode and Anode
- Electron(s) travel toward the Anode and are "multiplied" along the Dynodes
- The avalanche of electrons produces a bright spike of current
- The current is then sent to a Pulse Height Analyzer (PHA) to digitize

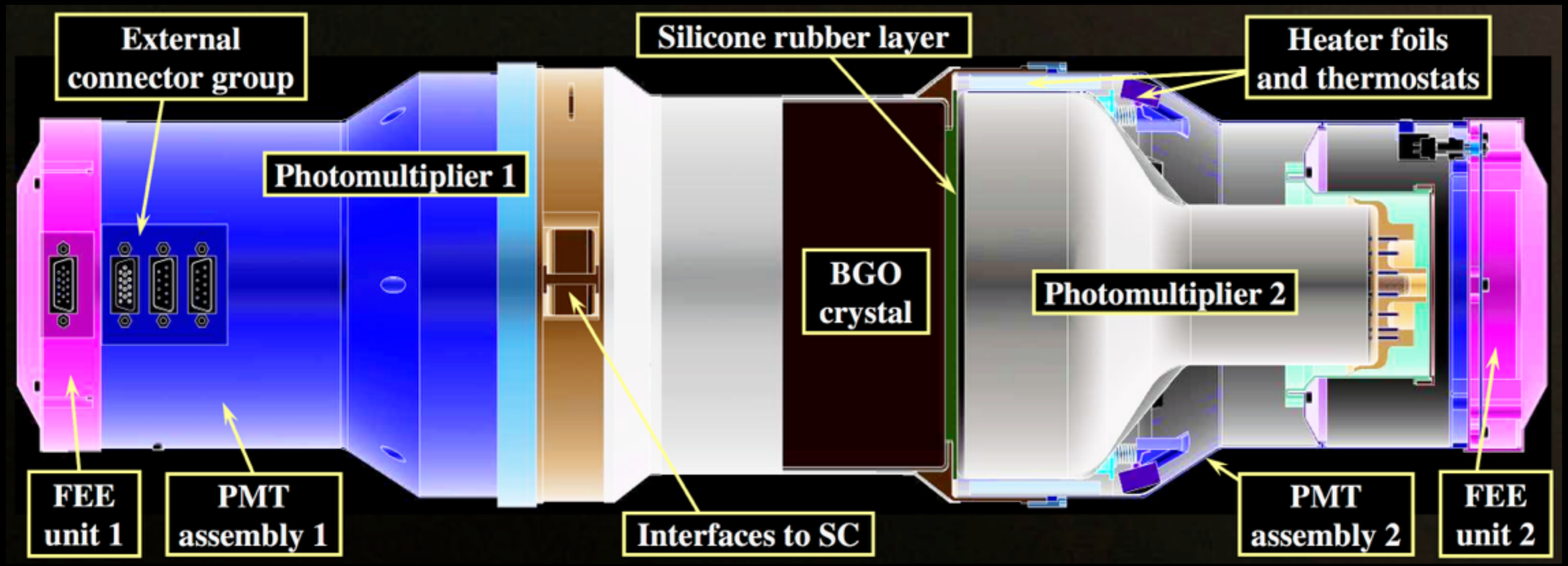
GBM Sodium Iodide (NaI) Detector





- NaI is very hygroscopic; any moisture will damage it
- High light output
- Photons emitted at Near UV

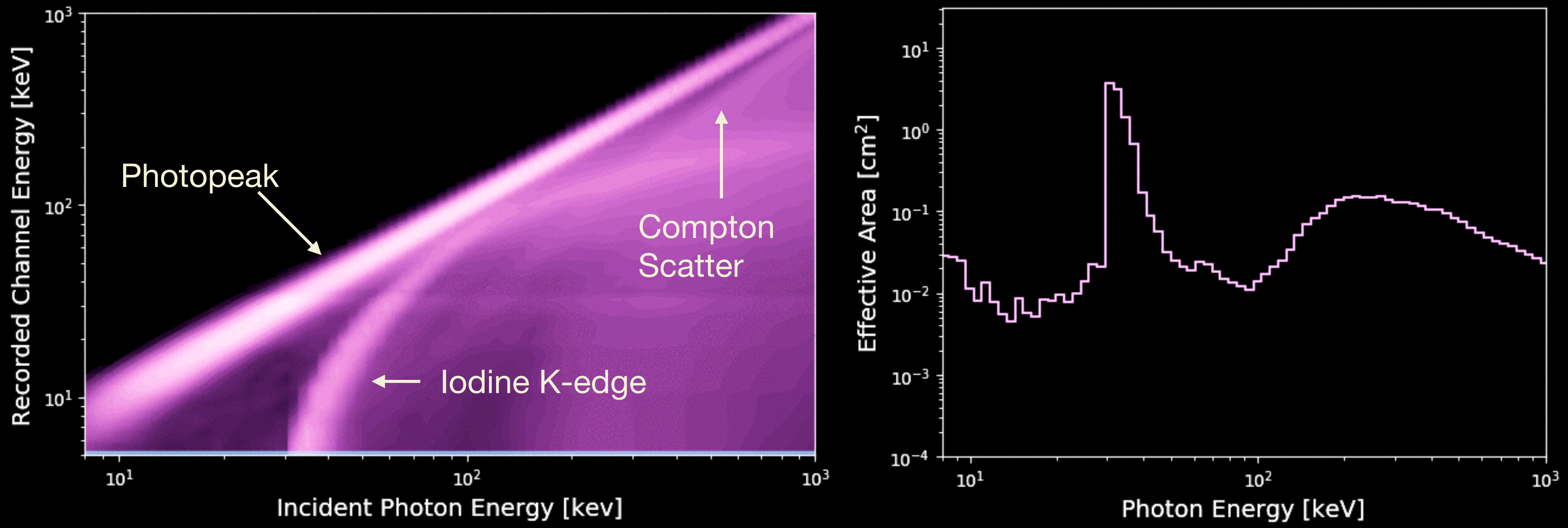
GBM Bismuth Germinate (BGO) Detector



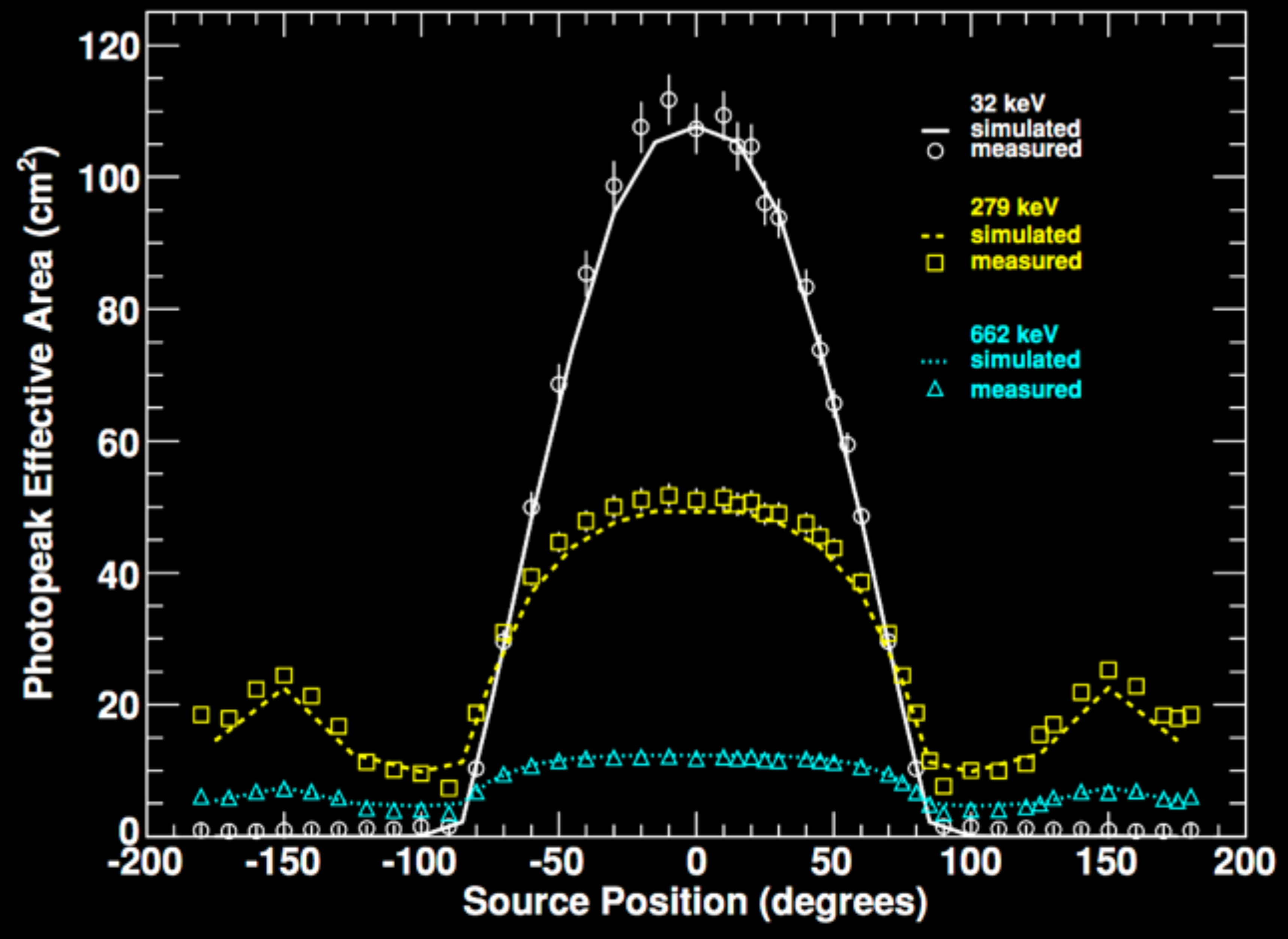
- Higher Stopping Power -> Higher Energy
- Lower light output -> Need 2 PMTs
- Photons emitted from visible Red -> near UV

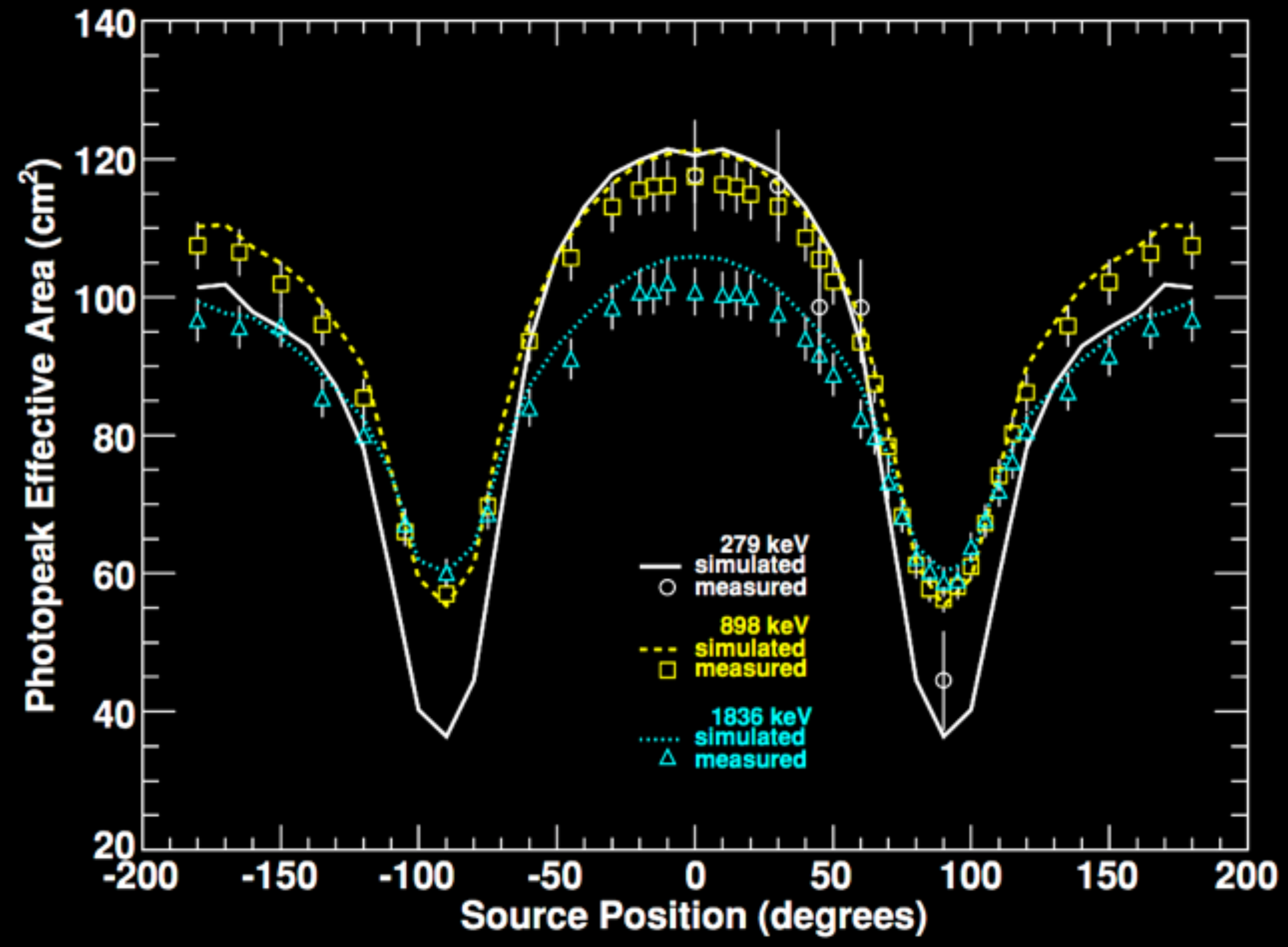
The Response Function

- The Response function maps the incident photon energies to the recorded “channel” energies
- Mono-energetic photons can be dispersed to a variety of channels, the probability of which is proportional to the effective area for that particular energy -> channel mapping
- This mapping can be stored as a Detector Response Matrix (DRM), and is used for spectroscopy. The DRM is highly singular and non-invertible, so unfortunately we can never “know” the precise incident spectrum



The GBM Response Function

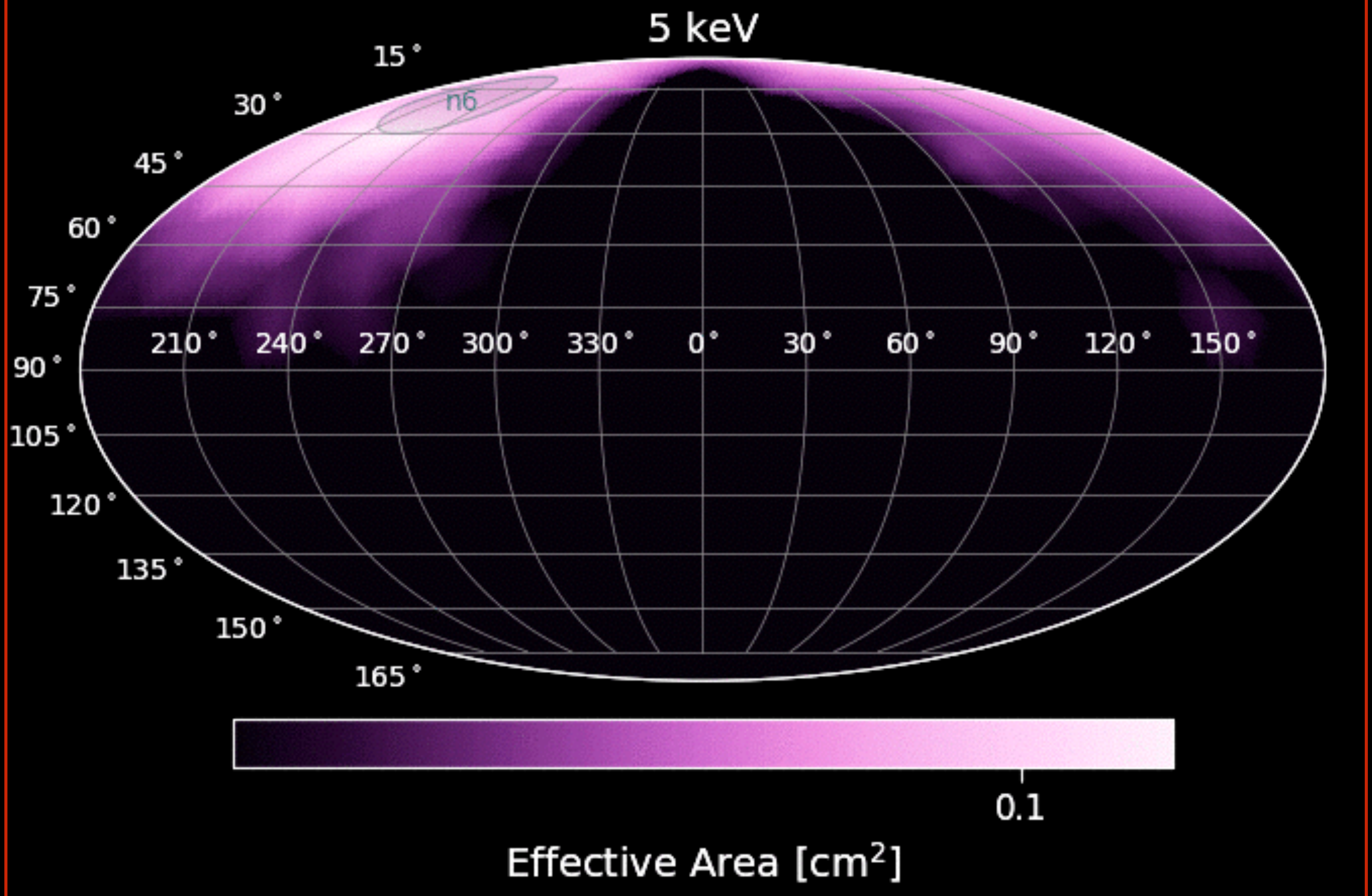




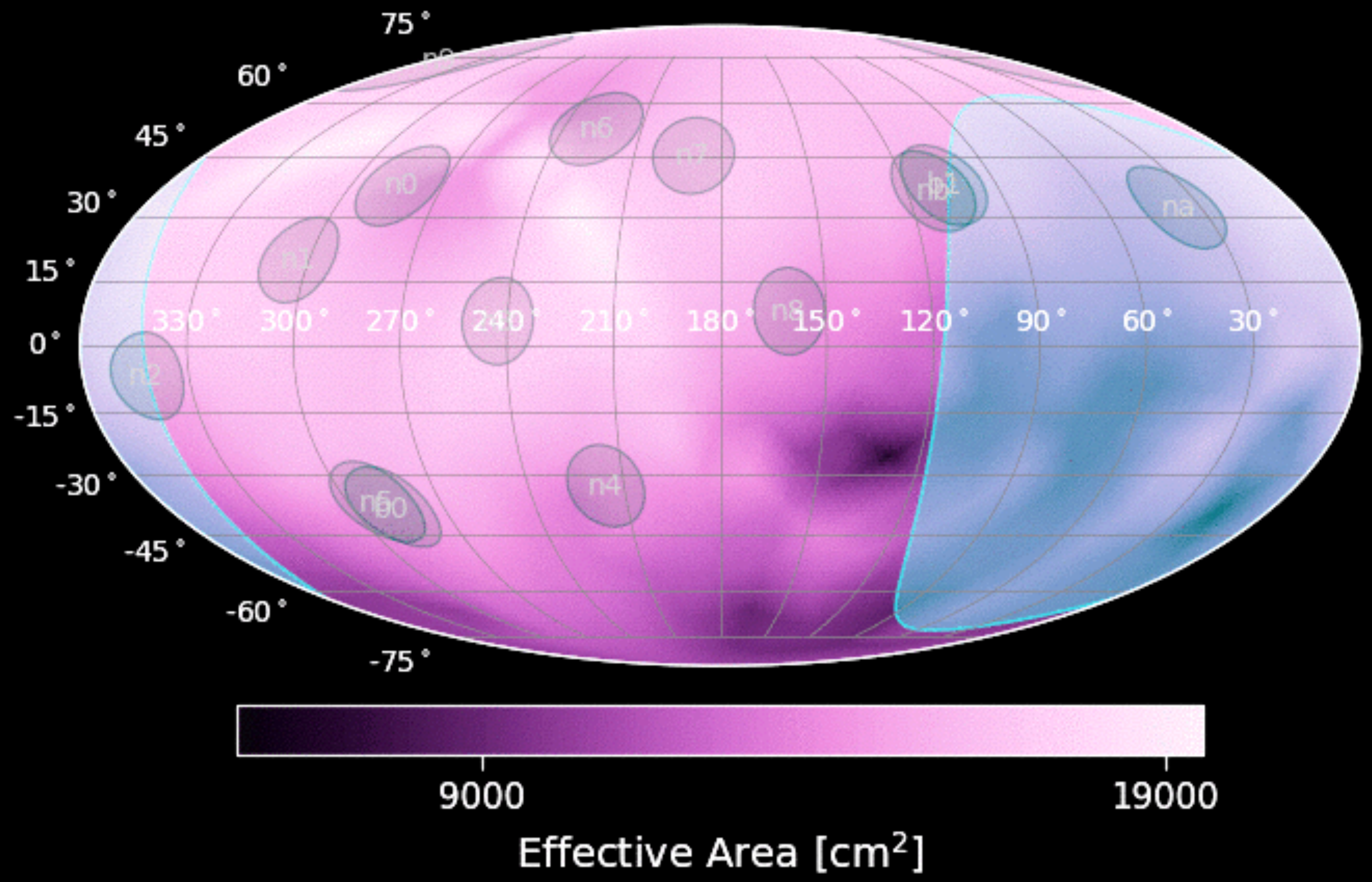
- The response function also has an angular dependence
- For NaI, approx cosine angular response, but can also observe photons through the back of the detector
- Angular response also changes as function of photon energy
- The BGO angular response is much broader

All-Sky Response

GBM NaI 6 response on the sky
(S/C coords)

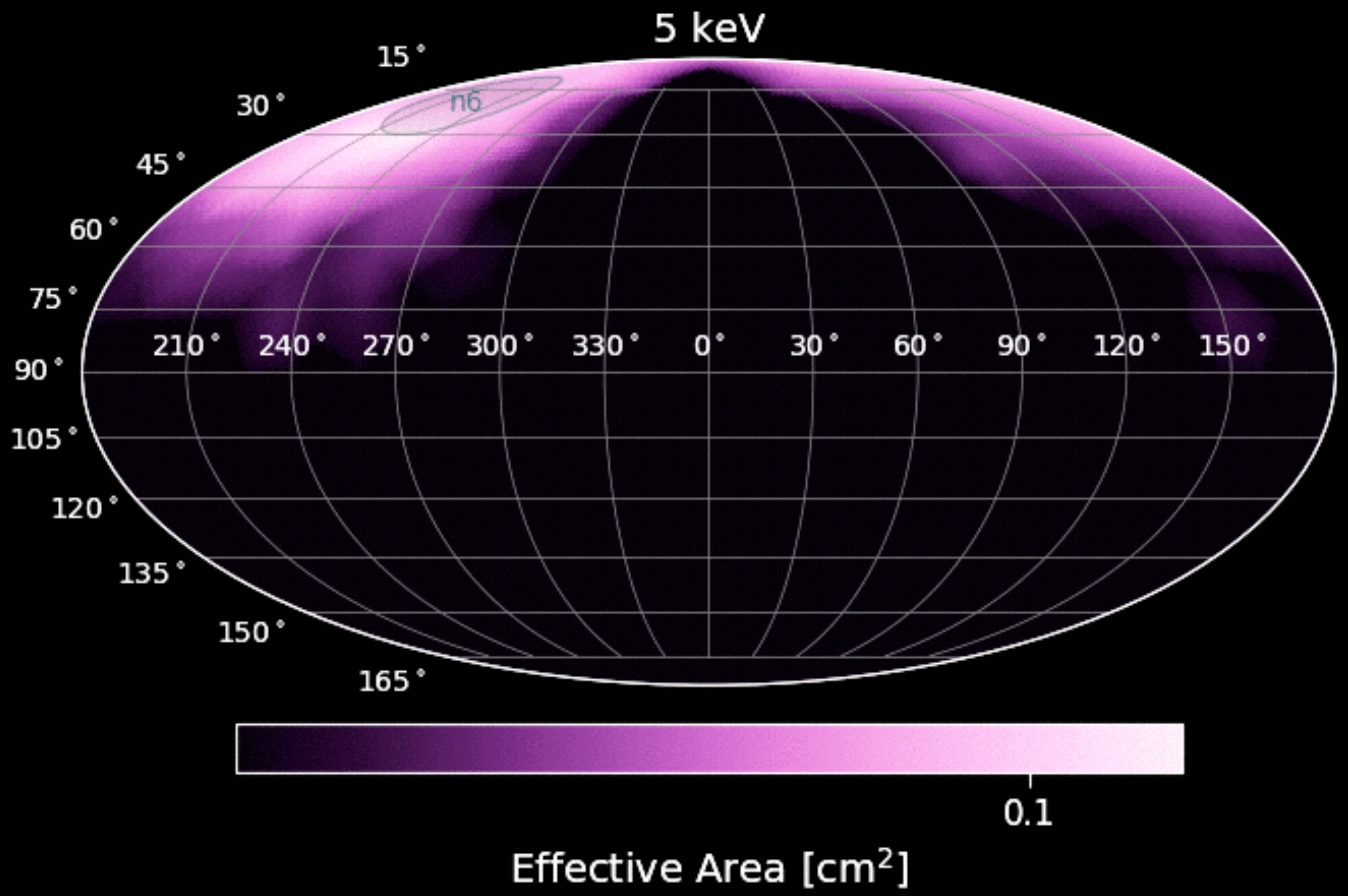


Combined GBM NaI response
over 50—300 keV
(Equatorial coords)



All-Sky Response

GBM NaI 6 response on the sky
(S/C coords)



Combined GBM NaI response
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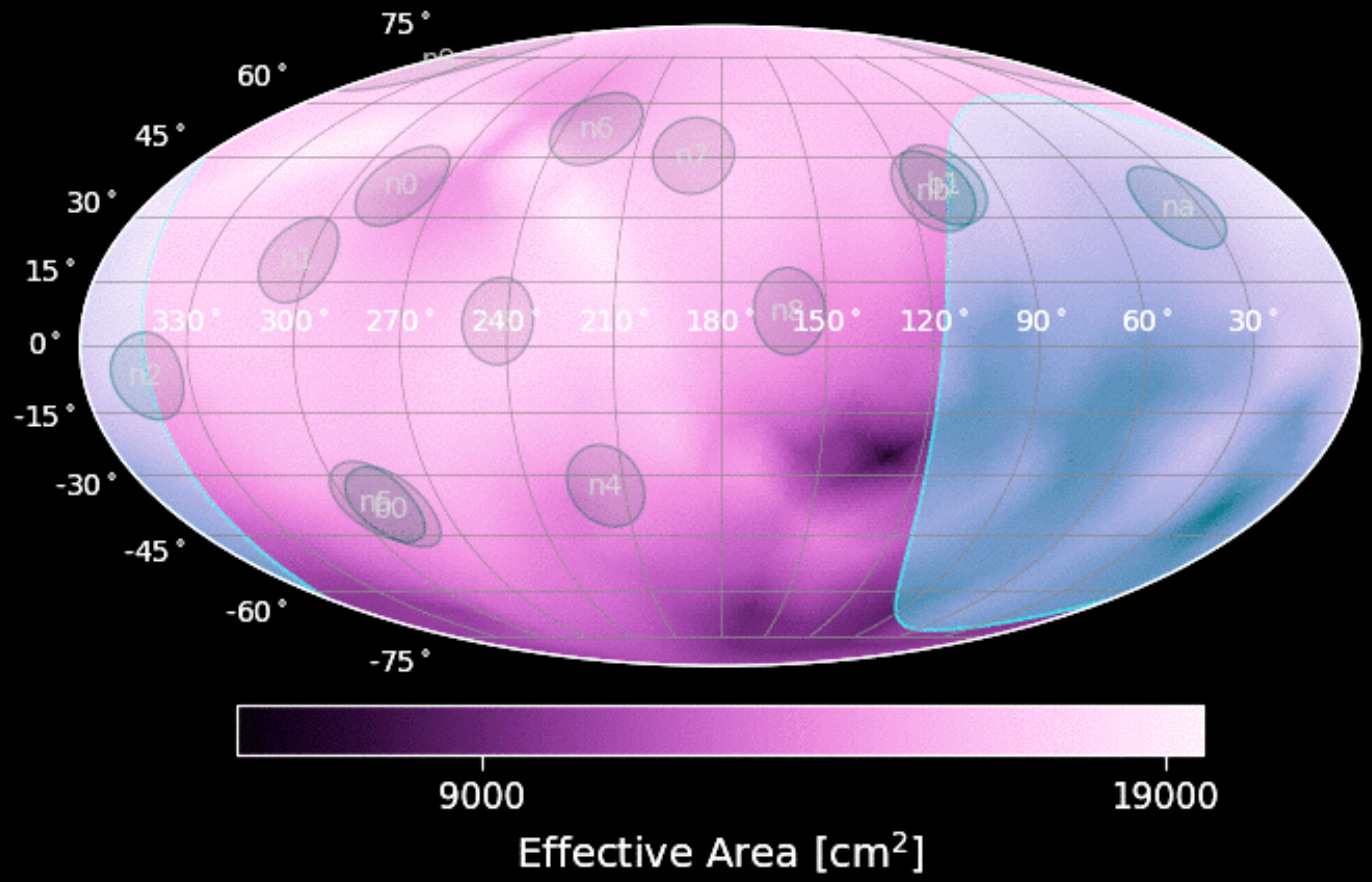
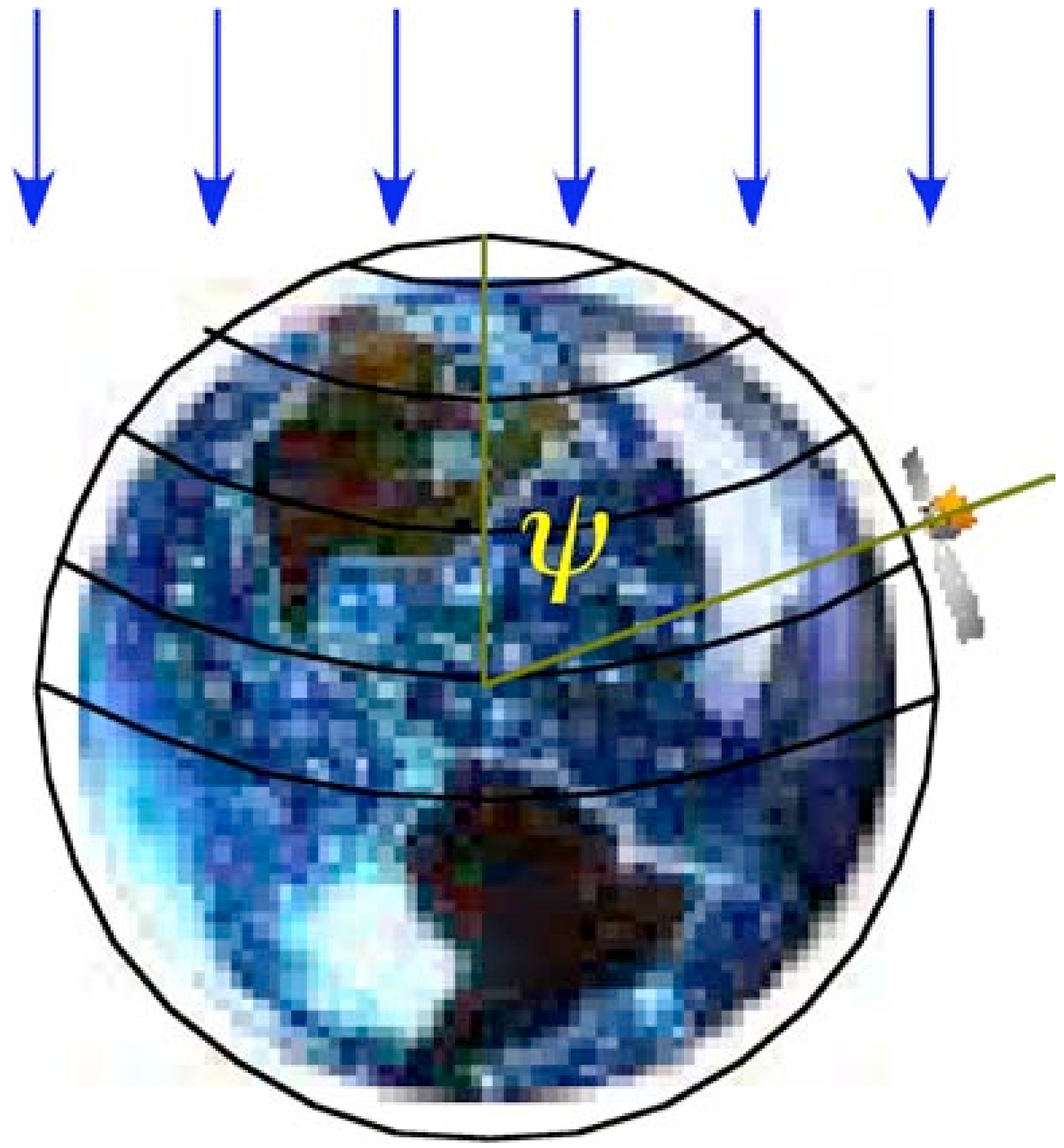


Atmospheric Scattering

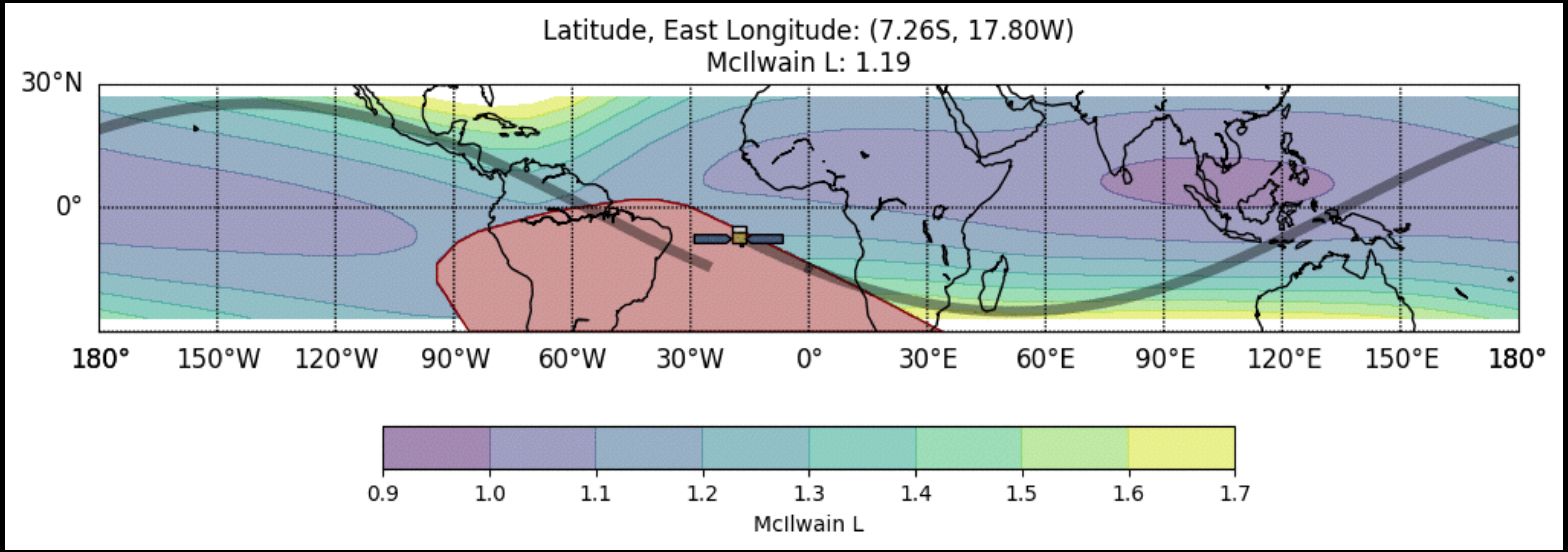


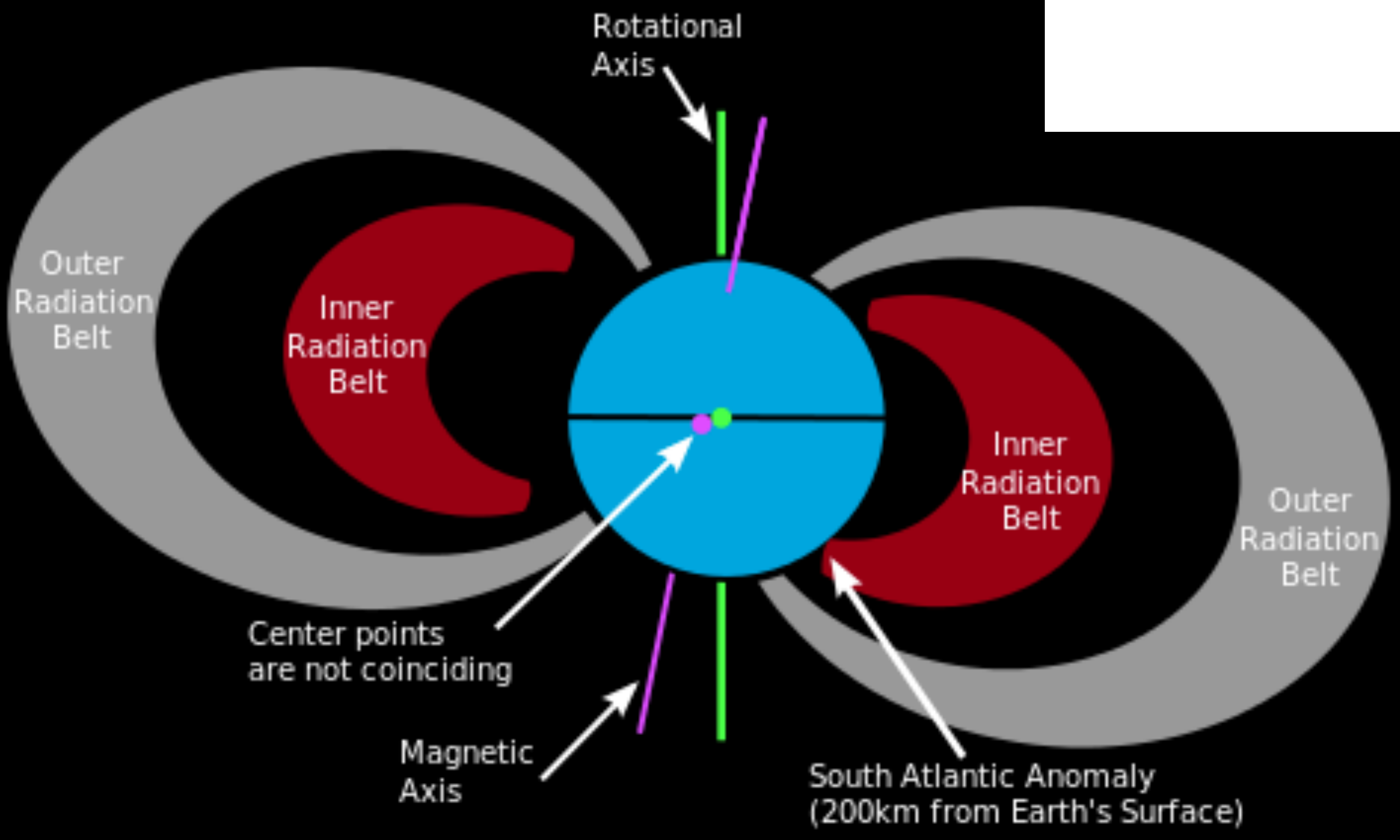
$$\mathfrak{R}_{\mathrm{A}}\left(\psi, A, \vartheta', \varphi', E_\gamma, E_s\right)$$

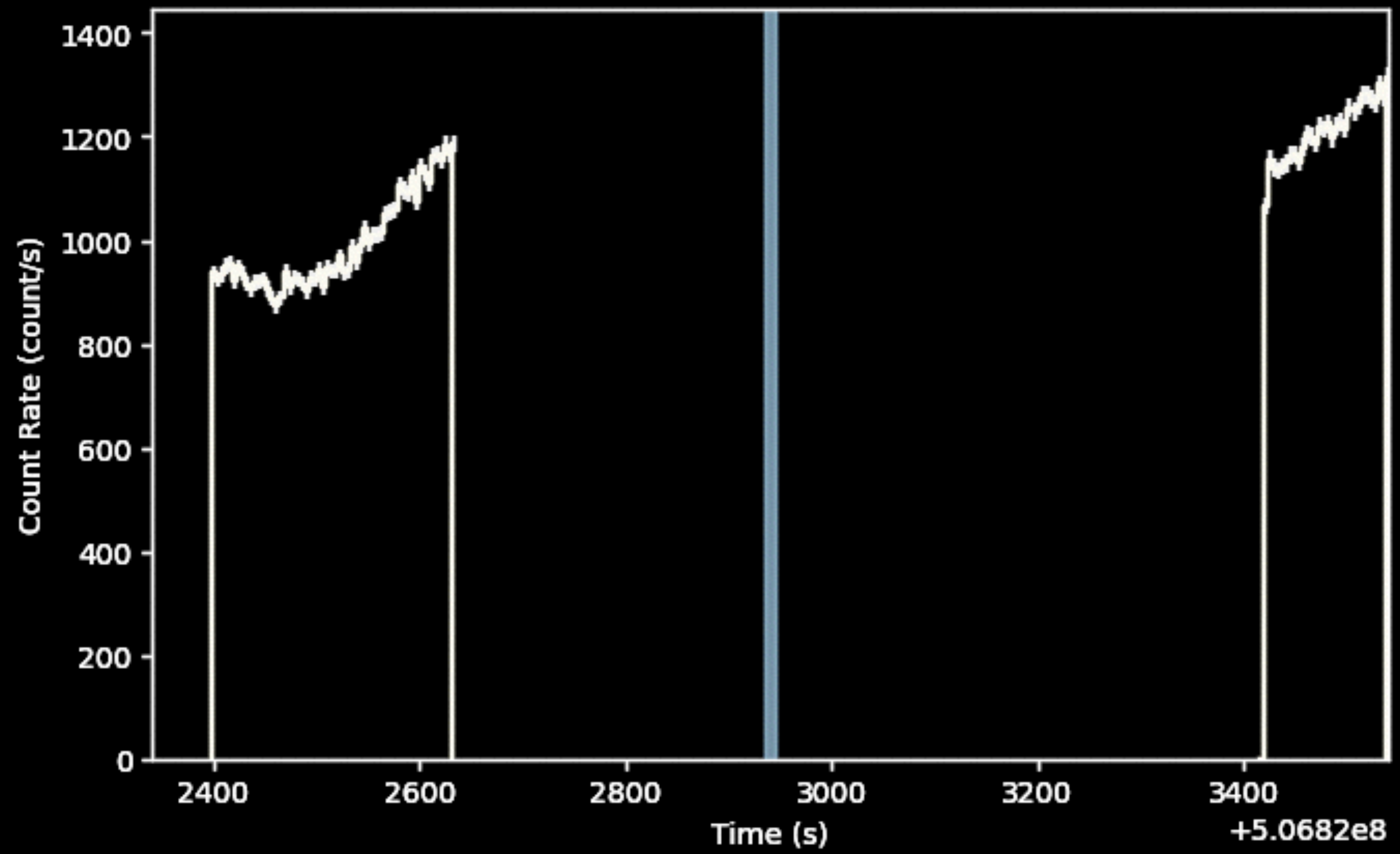
- Detector response is only half the story…
- Photons can back-scatter off atmosphere and be detected by detectors not directly observing a source
- Has significant implications for localization and spectroscopy
- The atmospheric scattering geometry is fairly complex: dependent on the source-detector-Earth geometry and modifies the incident spectrum
- This component is calculated separately and then combined with the direct flux response

Orbit, SAA, Background

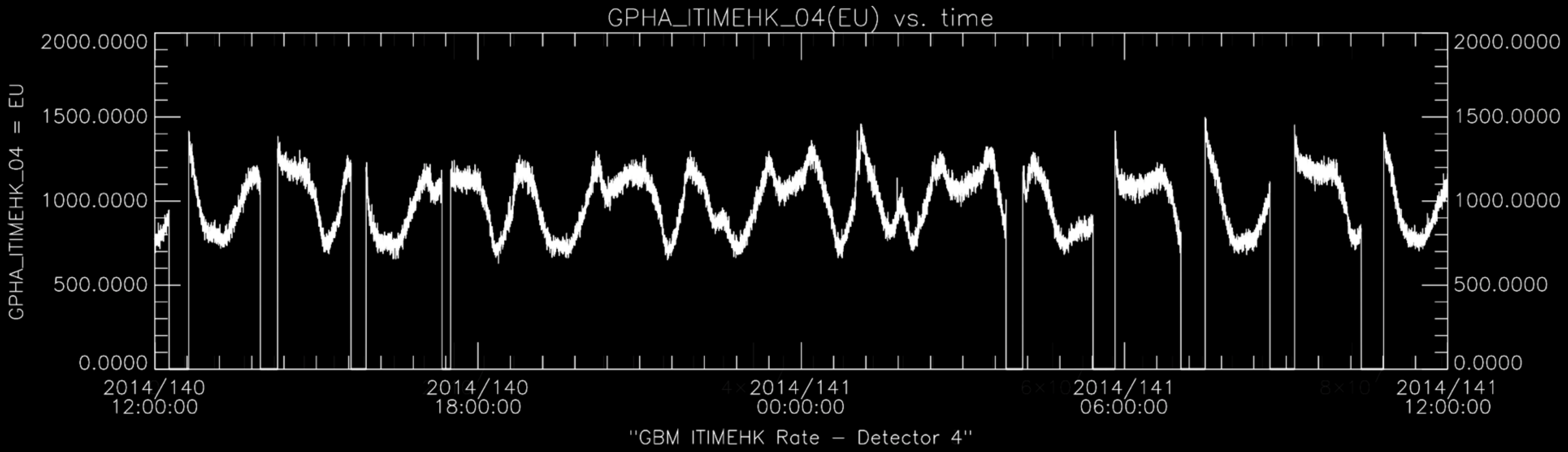
- Background affected by orbit (+ other things)
- Geomagnetic latitude (McIlwain L) changes GBM detection efficiency
- Mcilwain L > ~1.5 results in more likely detections of charged particle activity



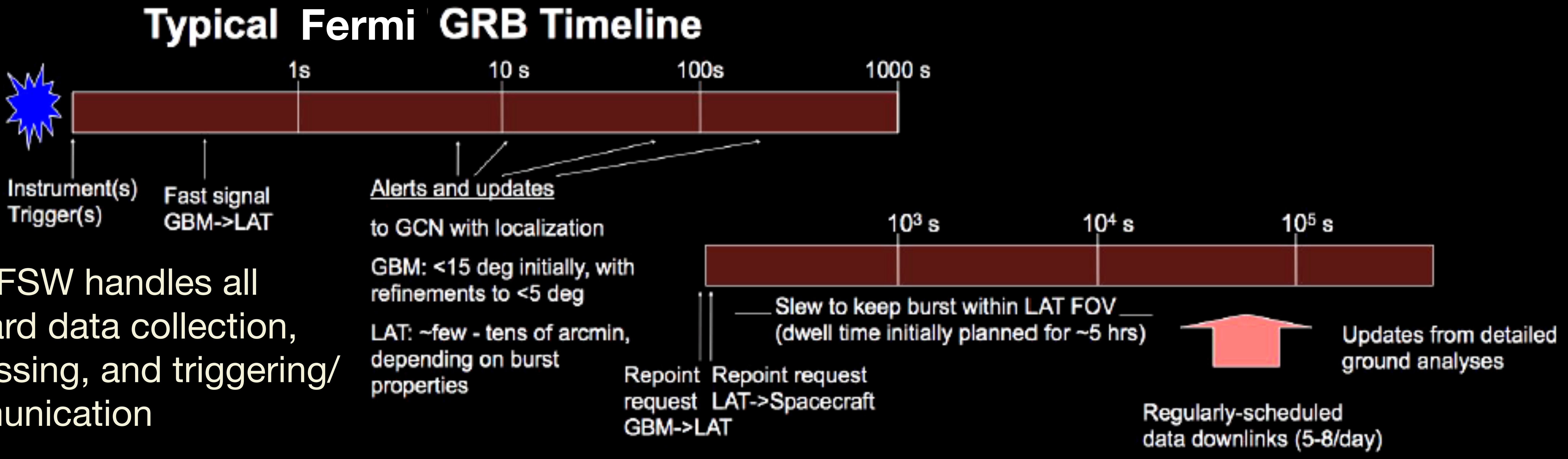




Orbit, SAA, Background



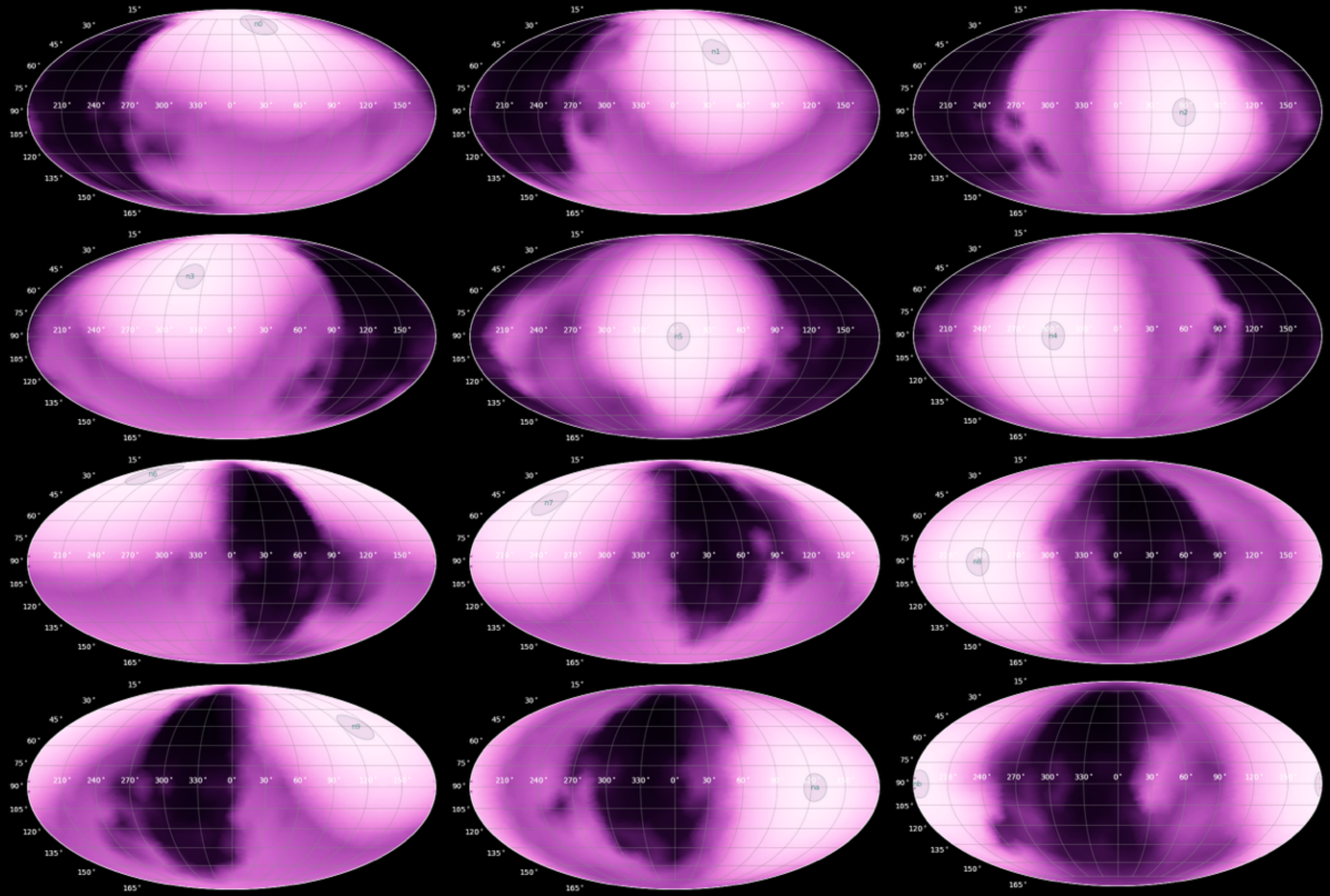
GBM Trigger Timeline



GBM FSW handles all onboard data collection, processing, and triggering/ communication

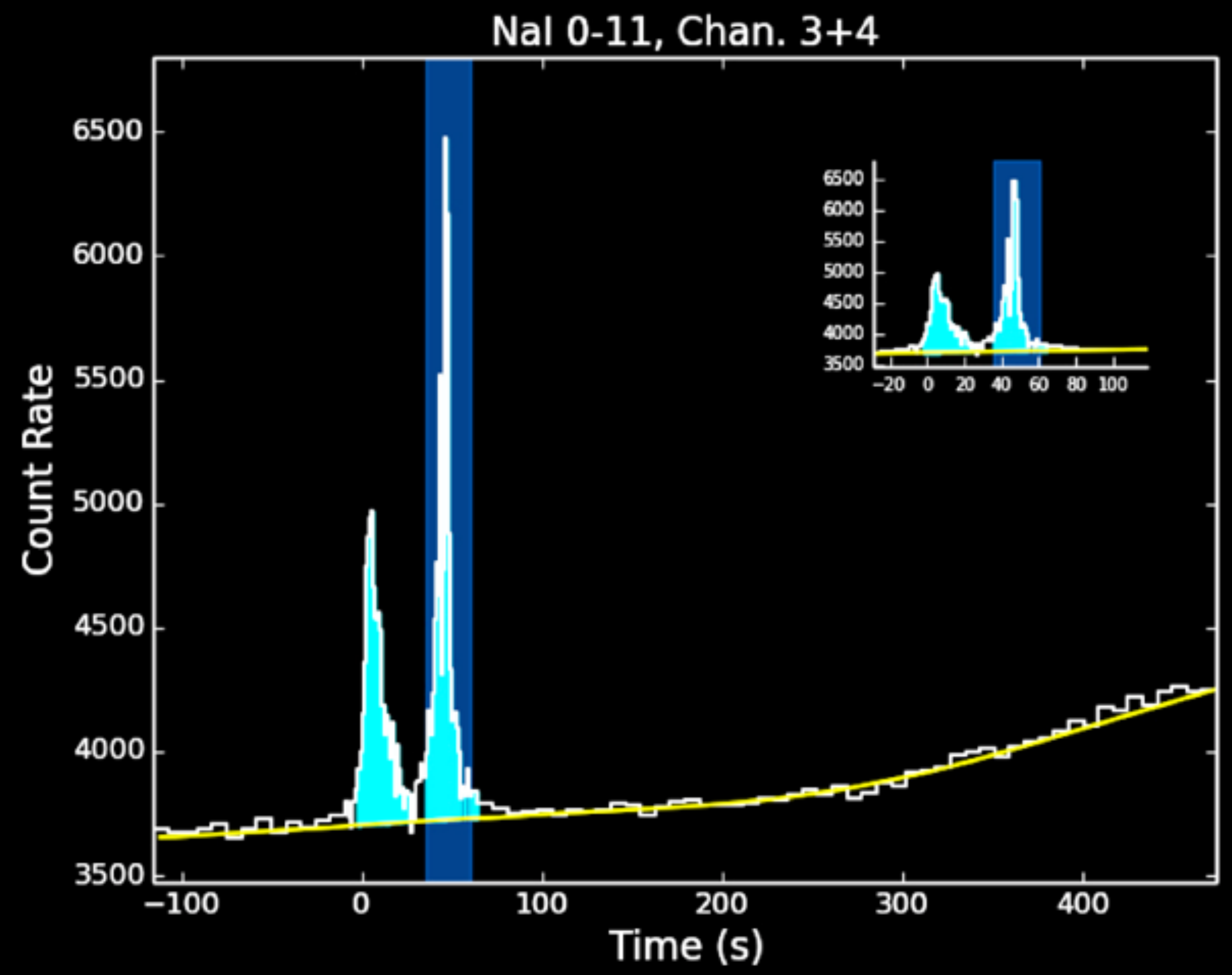
- Trigger alerts go out within seconds, full automated processing completes within 10 minutes
- Fermi GBM has Burst Advocates (BAs) that are on-call for triggers
- BAs check that the automated classification is correct and, if a GRB, that an automated localization went out
- If something isn't quite right, the BA will update the classification, perform a manual localization, and may send out a science circular if sufficiently interesting

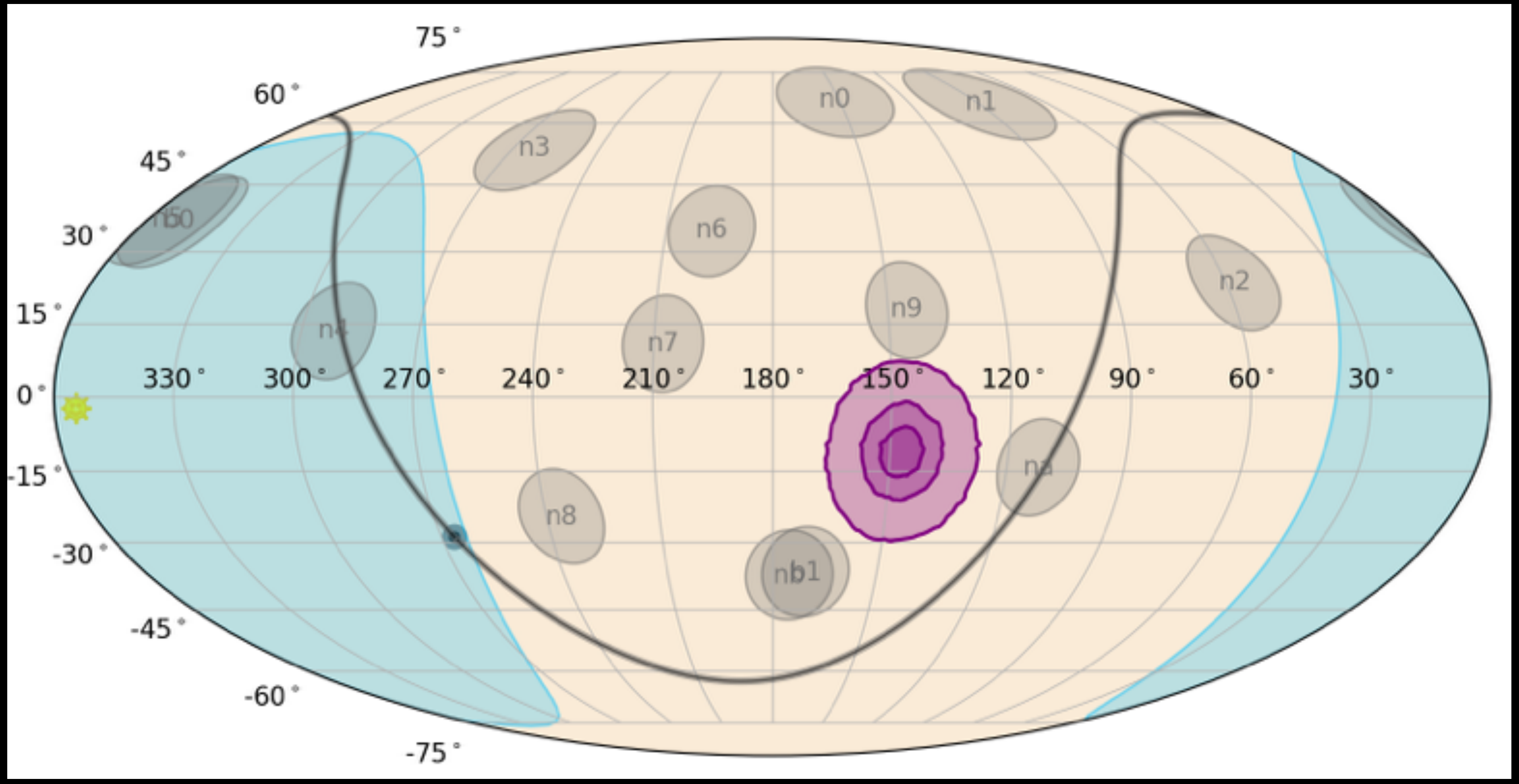
Localization



- Localization uses all 12 NaI detectors
- For a distant point source, there will be a different flux in each detector
- Assume some reasonable GRB-like spectrum, fold through response of each detector to get expected counts
- The comparison of the relative **observed** flux to the relative **expected** flux tells us where the source is
- Traditionally this is done in 50—300 keV (sweet spot for GRBs)

Fermi GBM RoboBA





- First implemented in early 2016
- Automatically runs w/in 10 minutes
- Successful ~80% of the time
  - Most failures due to dropped data packets in realtime stream
  - Human BA performs localization in that case
- Sends out a final localization notice
  - Localization
  - Links to lightcurve and localization plot
  - HEALPix FITS sky maps
  - An estimate of type of GRB: long/short
- Planned to expand capabilities to do complete BA analysis
- <u>Automated circulars now go out for every RoboBA-localized GRB</u>

GBM Science Data (Level 1)

- CTIME (Continuous TIME)
  - 256 ms time resolution (64 ms around triggers)
  - 8 energy channels
- CSPEC (Continuous SPECtra)
  - 4.096 s time resolution (1.024 s around triggers)
  - 128 energy channels
- TTE (Time-Tagged Events)
  - 2 μs GPS timing precision
  - 128 energy channels
  - Fully continuous TTE since ~Dec. 2012
  - Est. > 4 Trillion events, 38 TB
- RSP(2) (Response files)
  - .rsp single DRM
  - .rsp2 multiple DRMs

Index of /FTP/fermi/data/gbm/triggers

Name	Last modified	Size	Description
Parent Directory		-	
2008/	12-Mar-2013 15:23	-	
2009/	07-Jun-2010 14:55	-	
2010/	18-Mar-2011 05:24	-	
2011/	31-Dec-2011 11:29	-	
2012/	31-Dec-2012 05:51	-	
2013/	31-Dec-2013 17:00	-	
2014/	30-Dec-2014 16:02	-	
2015/	31-Dec-2015 14:15	-	
2016/	31-Dec-2016 16:38	-	
2017/	31-Dec-2017 18:50	-	
2018/	31-Dec-2018 18:05	-	
2019/	25-May-2019 12:14	-	

https://heasarc.gsfc.nasa.gov/FTP/fermi/data/gbm/daily/
https://heasarc.gsfc.nasa.gov/FTP/fermi/data/gbm/triggers/
https://heasarc.gsfc.nasa.gov/FTP/fermi/data/gbm/bursts/

Other GBM Data (Level 1+)

- POSHIST (POSition HISTory)
  - Contains information on spacecraft orbital position and attitude
- TRIGDAT (TRIGger DATa)
  - 8.192 s/1.024 s/264 ms/64 ms time resolutions
    - Variable resolution to handle both long and short GRBs
  - 8 energy channels
  - Contains limited POSHIST info
  - 50 KB
- HEALPix
  - GRB localization maps
- “Quicklook” products (i.e. lightcurve plots, etc)

Quicklook directory on FTP site


Name

Parent Directory
README
glg_healpix_all_bn190525032.fit
glg_lc_all_bn190525032.gif
glg_lc_chan12_bn190525032.pdf
glg_lc_chan34_bn190525032.pdf
glg_lc_chan567_bn190525032.pdf
glg_lc_chantot_bn190525032.pdf
glg_lc_hires12_bn190525032.gif
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glg_lc_tot_bn190525032.pdf
glg_lc_zxradec_bn190525032.gif
glg_skymap_all_bn190525032.png

GRB Higher-Level Data products

- BCAT (Burst CATalog)
  - Duration information
  - Peak energy and photon flux info on different timescales
- SCAT (Spectral CATalog)
  - Spectral fit parameters, fit statistic, etc
  - Resulting deconvolved photon flux model data
- The online catalogs
  - Trigger catalog
  - Burst catalog
- Analysis software
  - RMfit - Soon to be deprecated
  - GSpec and GBM Data Analysis Tools

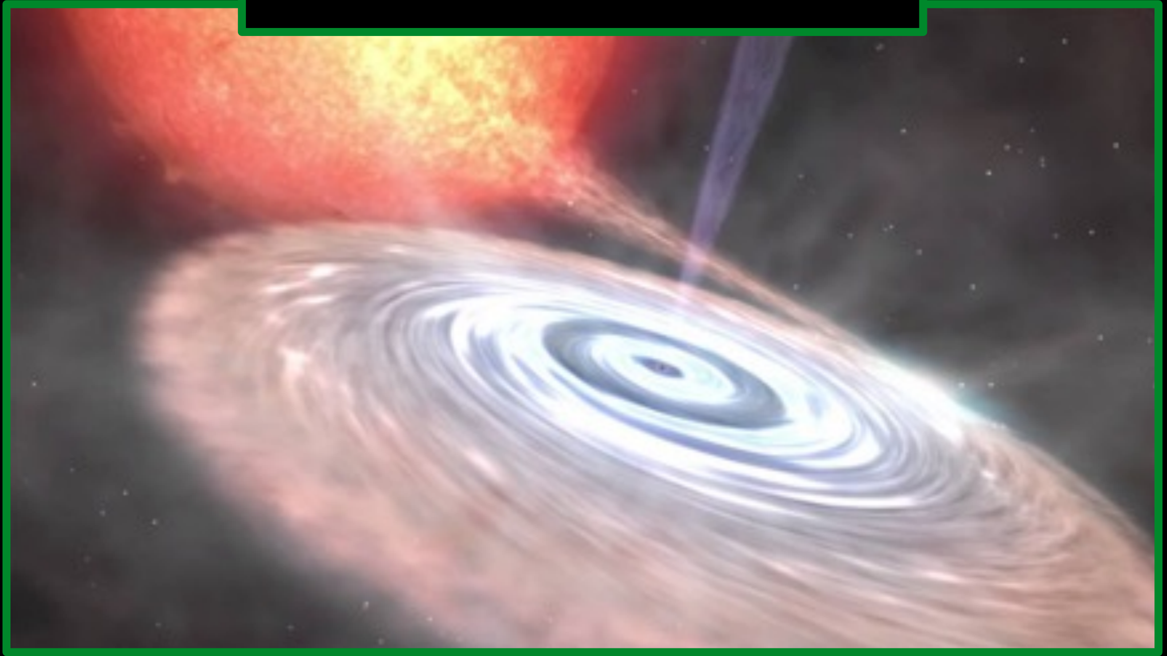
View All	Sort	Parameter (Unit)	Query Terms	Min Value	Max Va
		name		GRB080714086	GRB19052503
		ra		00 01 04.8	23 58 57.6
		dec		-89 00 33	+88 36 19
		trigger_time		2008-07-14 02:04:12.053	2019-05-25 00
		t90 (s)		0.008	828.672
		t90_error (s)		0.023	53.762
		t90_start (s)		-807.424	188.451
		fluence (erg/cm^2)		2.5271e-08	2.4620e-03
		fluence_error (erg/cm^2)		3.6450e-09	1.4373e-05
		flux_1024 (photon/cm^2/s)		0.2429	1051.8600
		flux_1024_error (photon/cm^2/s)		0.0869	279.7320
		flux_1024_time (s)		-137.664	438.597
		flux_64 (photon/cm^2/s)		1.4874	3054.1000
		flux_64_error (photon/cm^2/s)		0.3503	4475.6300
		flnc_band_ampl (photon/cm^2/s/keV)		1.171112e-03	1.292132e+05

https://heasarc.gsfc.nasa.gov/W3Browse/fermi/fermigbrst.html

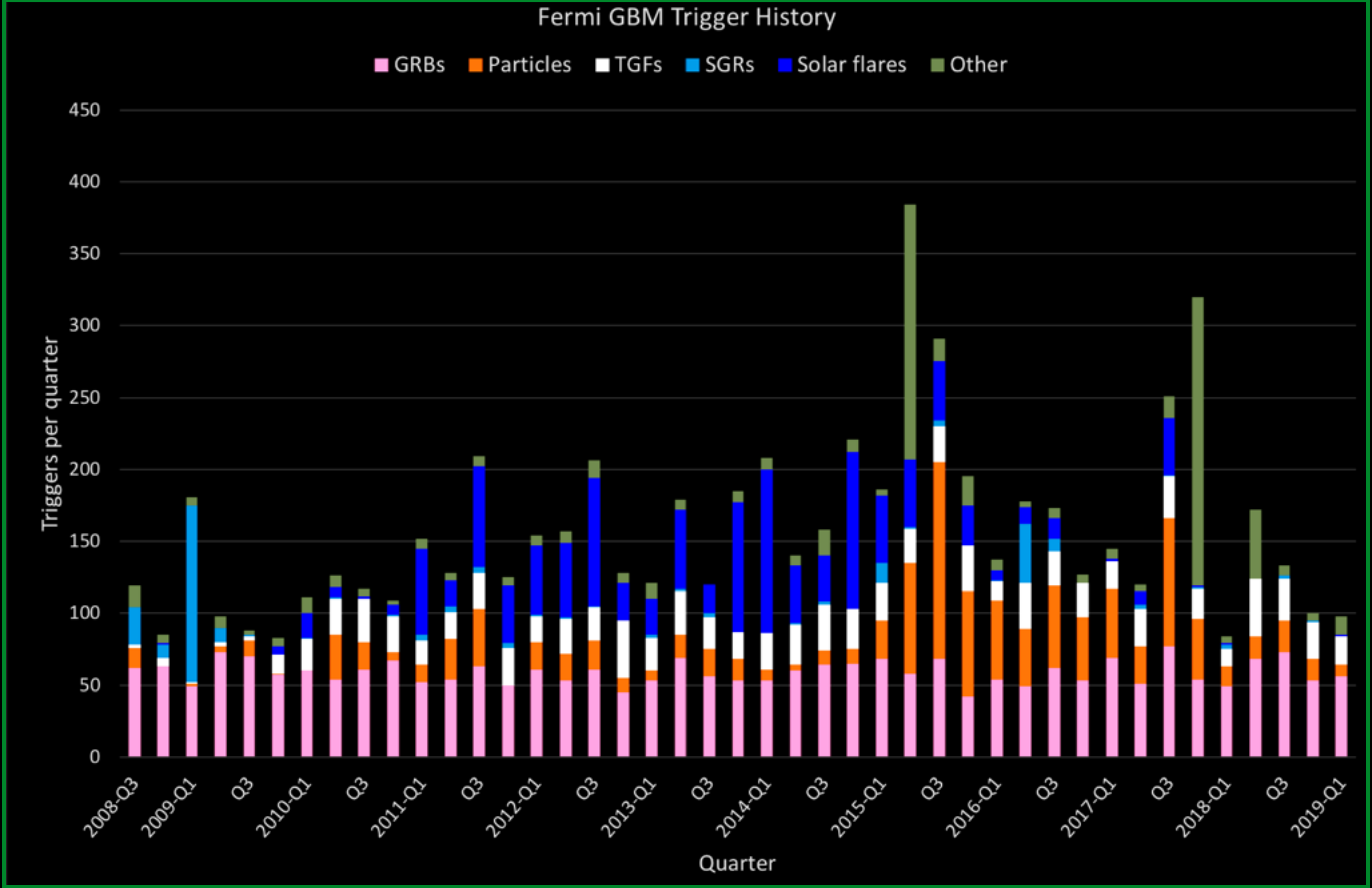
What Does Fermi GBM See?

Terrestrial Gamma-ray Flashes

X-ray Binaries

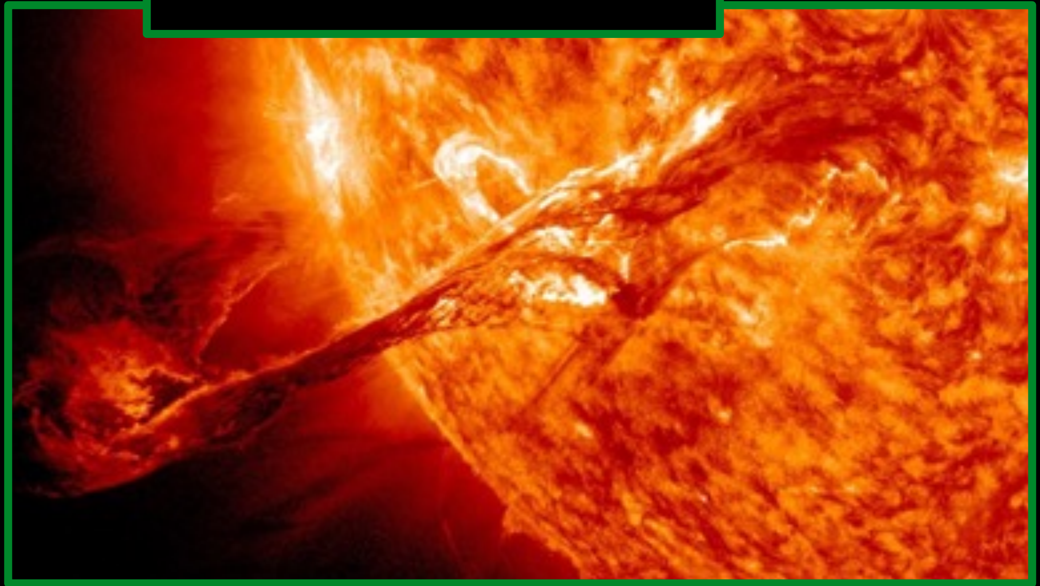


GRBs of course!

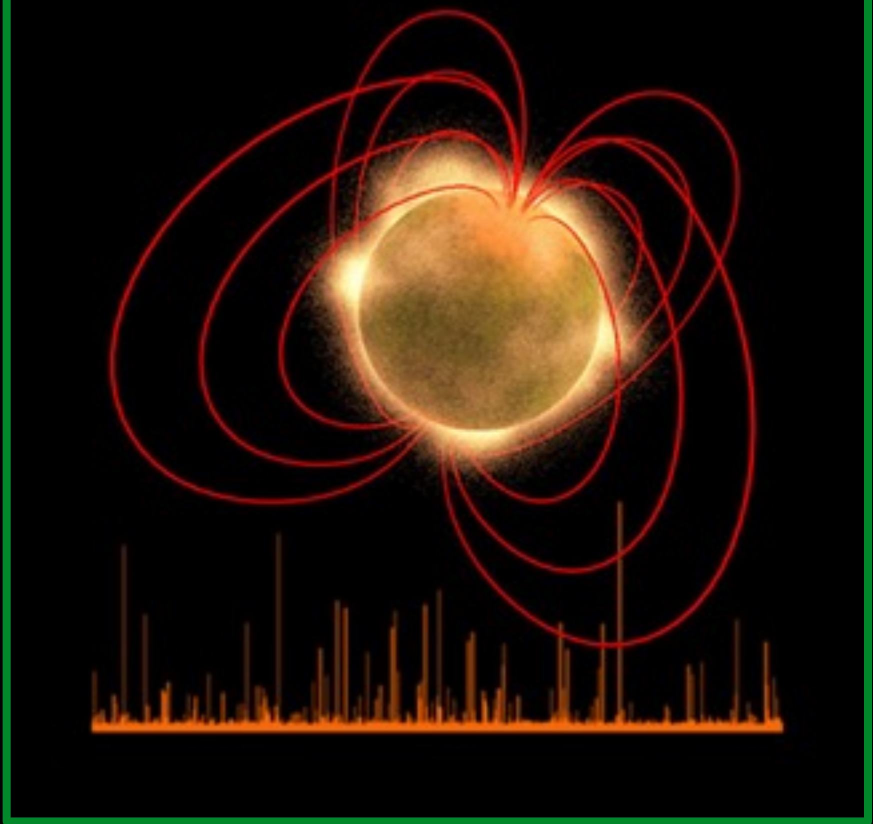


Unique intersection for astrophysics, heliophysics, and Earth science

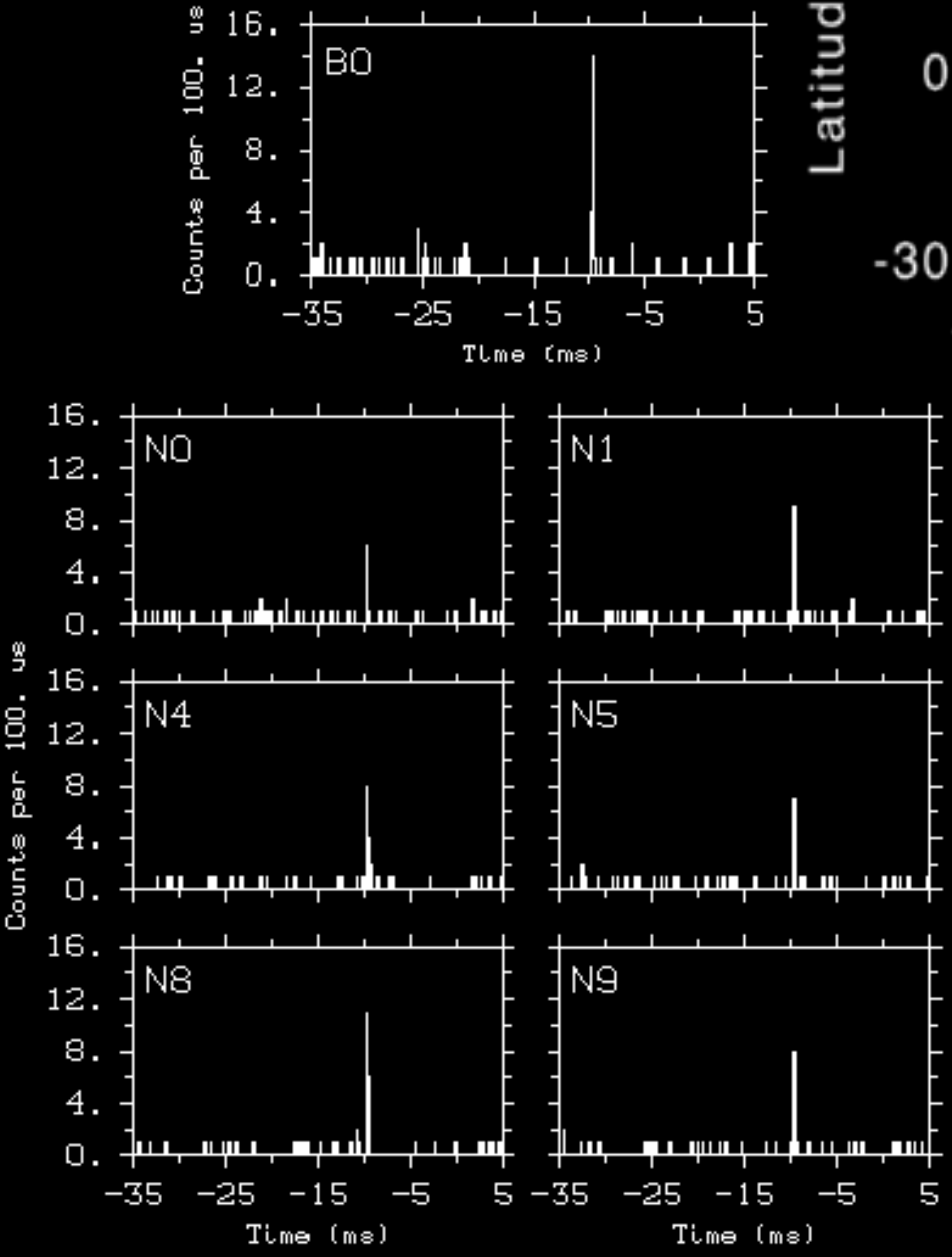
Solar Flares

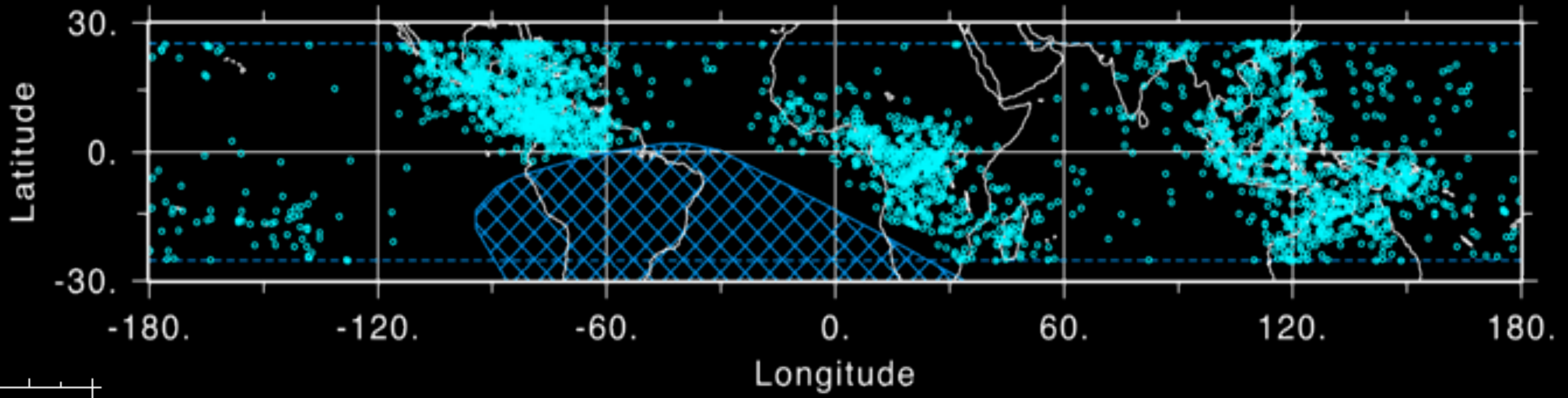


Soft Gamma Repeaters

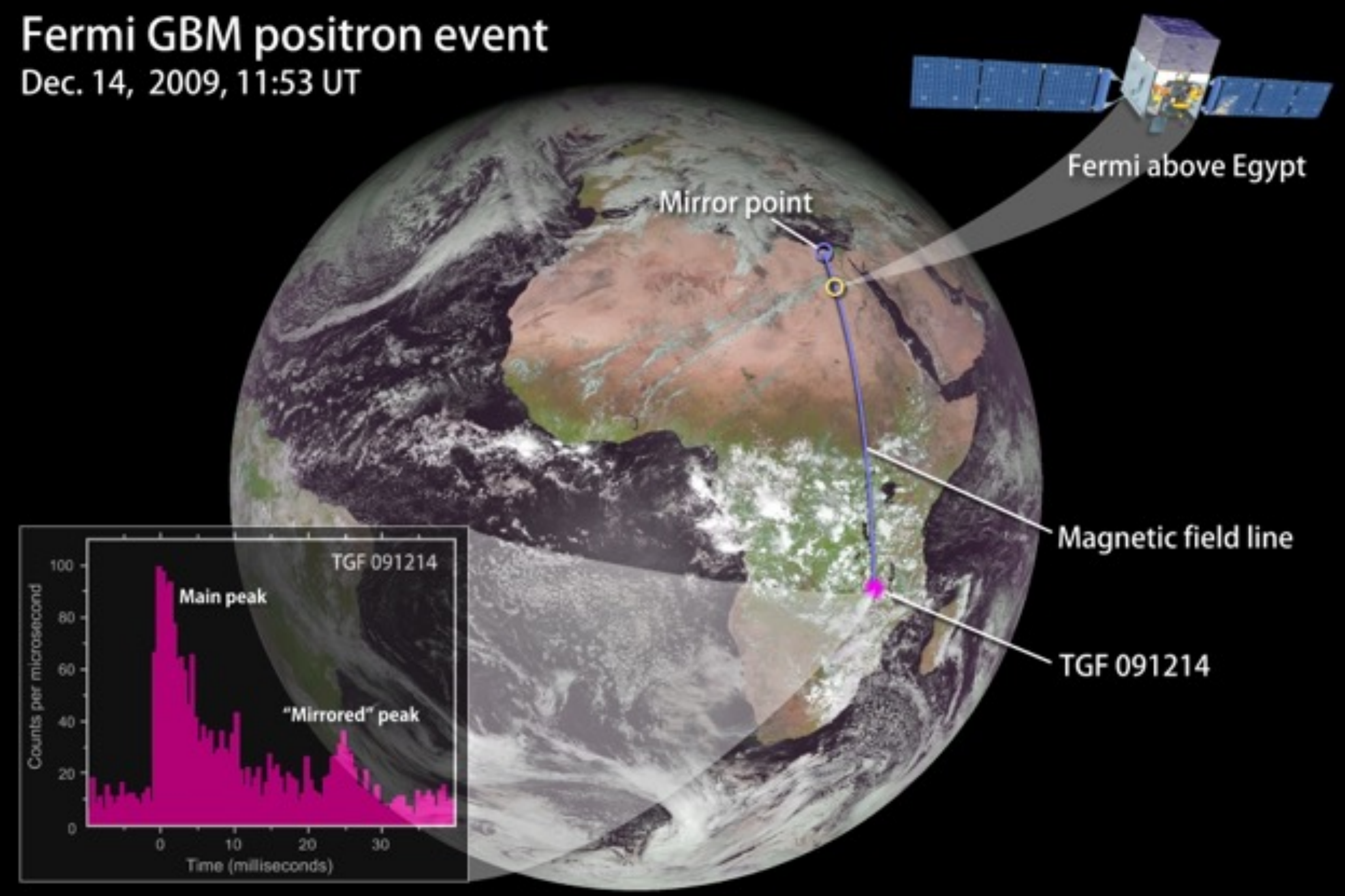


Terrestrial Gamma-ray Flashes (TGFs)



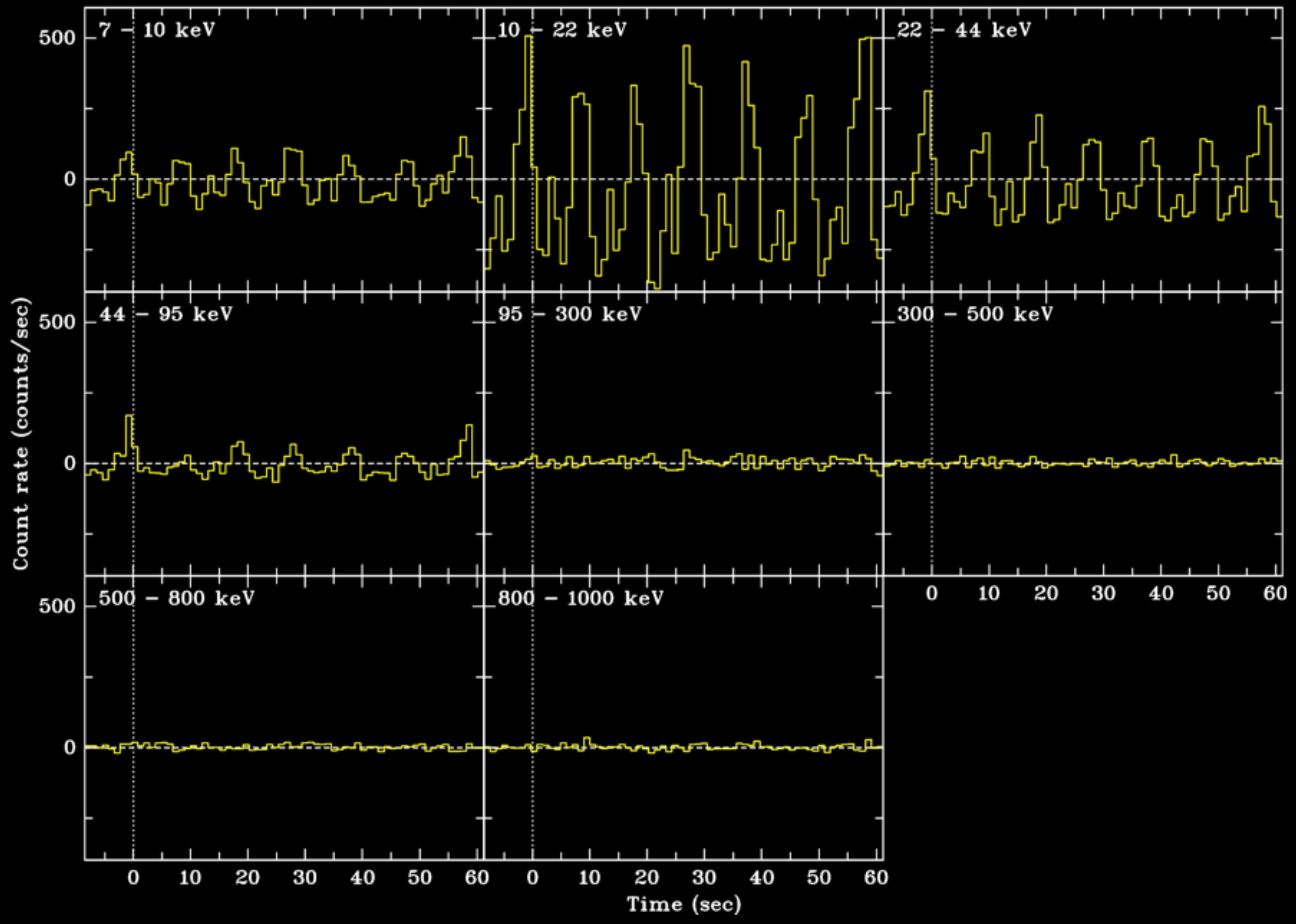


...and TEBs

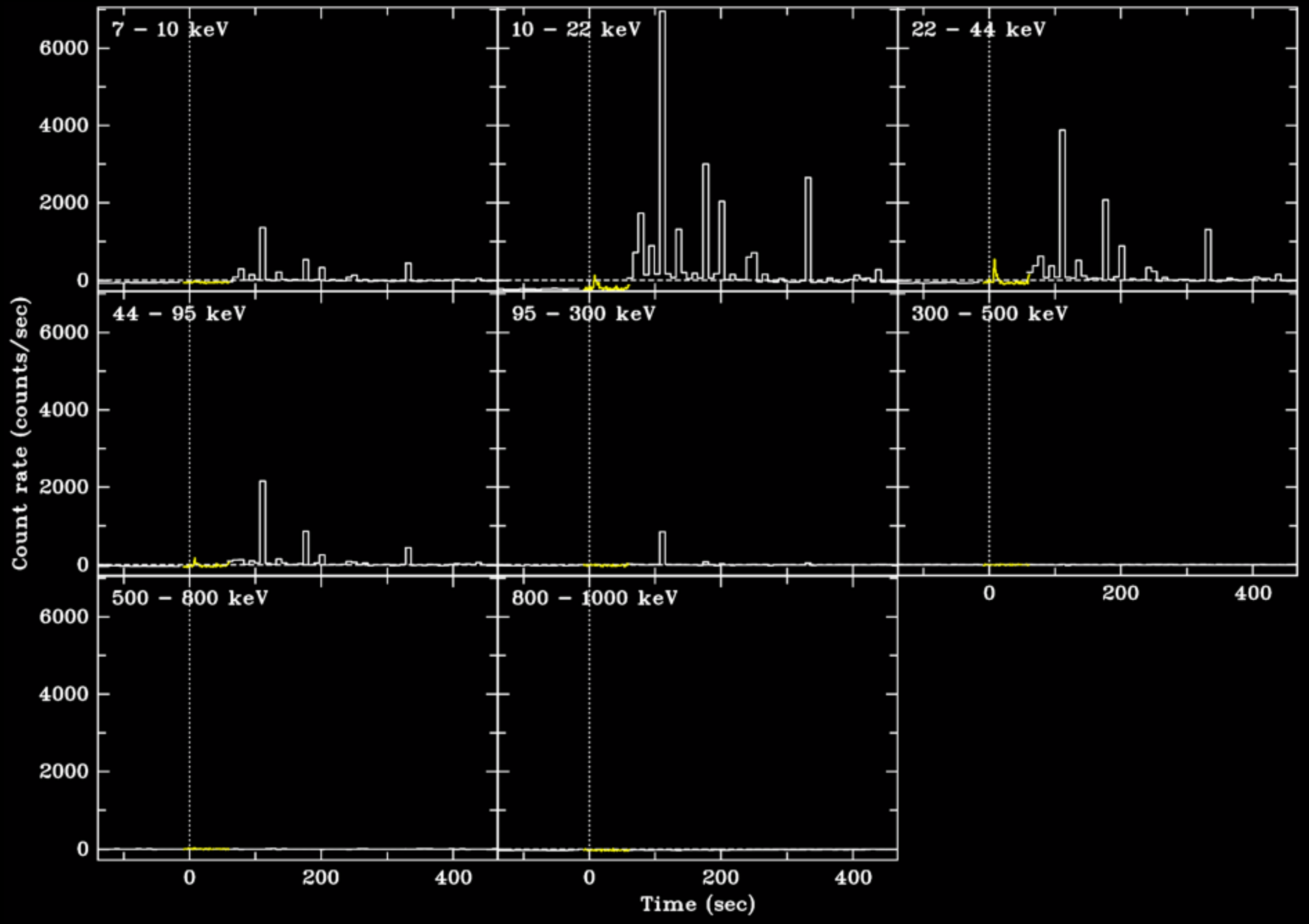


Flaring/Pulsing Galactic Sources

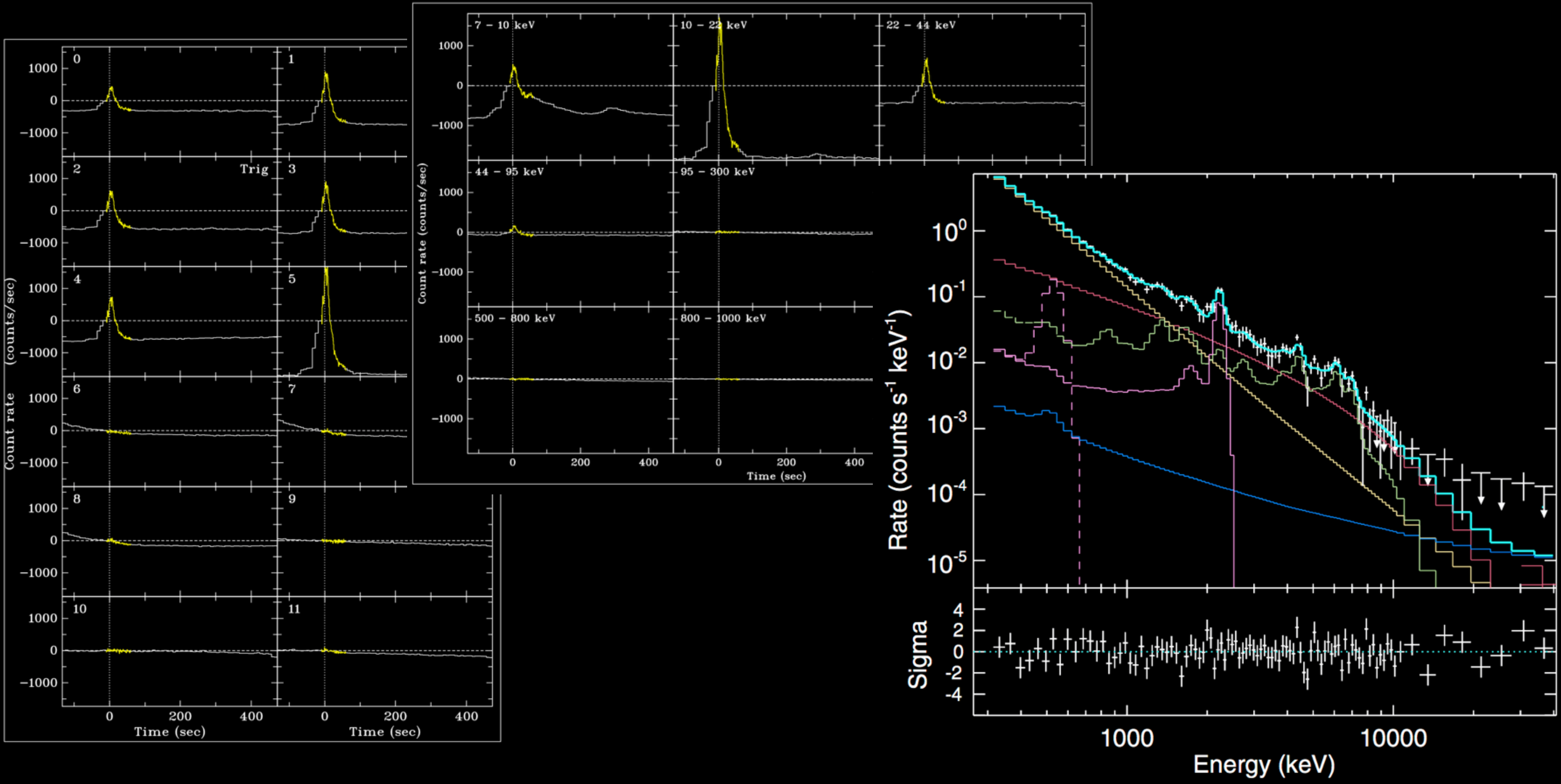
Swift J0243.6+6124
(First Galactic UL X-ray Pulsar)



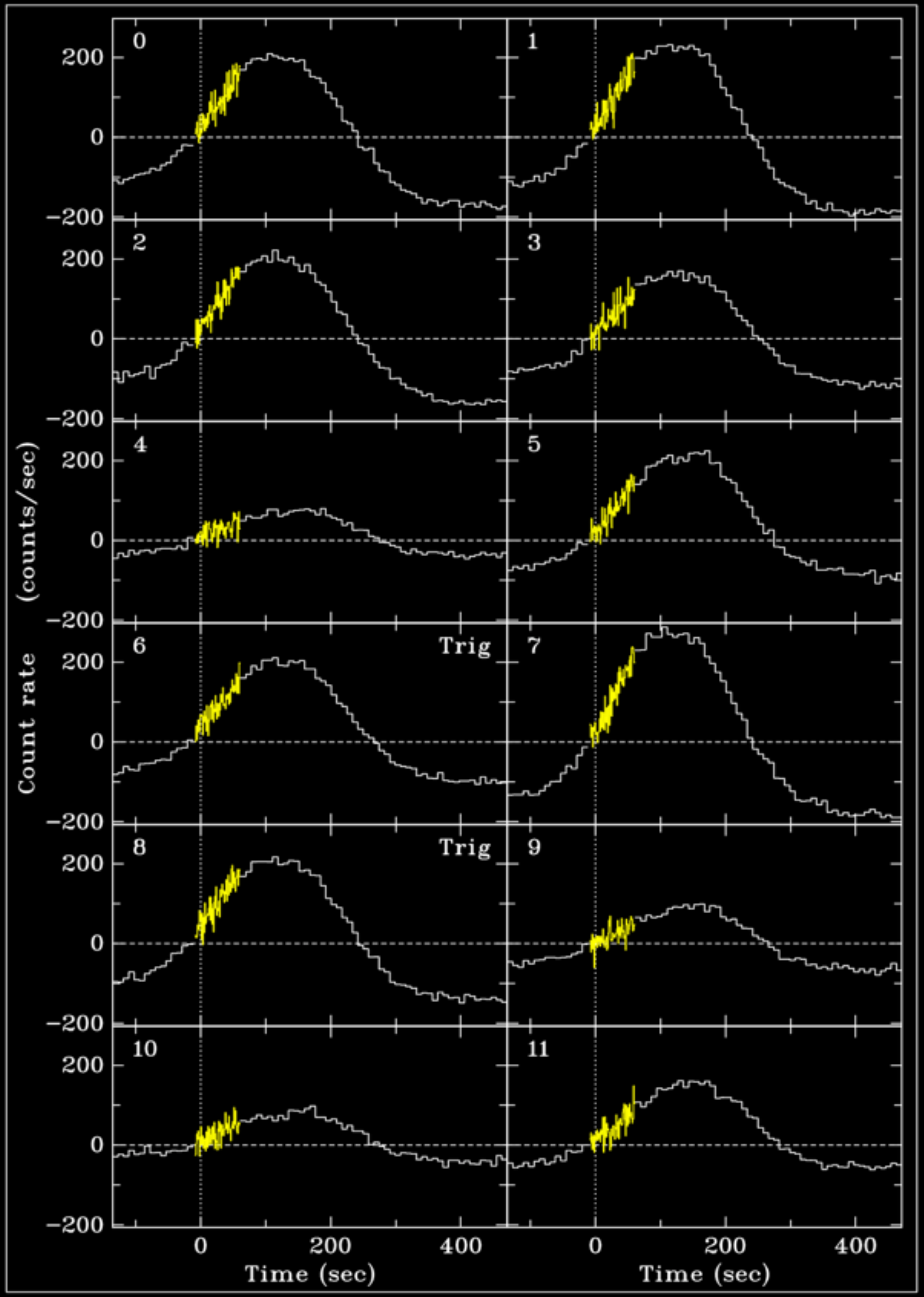
SGR 1547-5408
(Magnetar)



Solar Flares



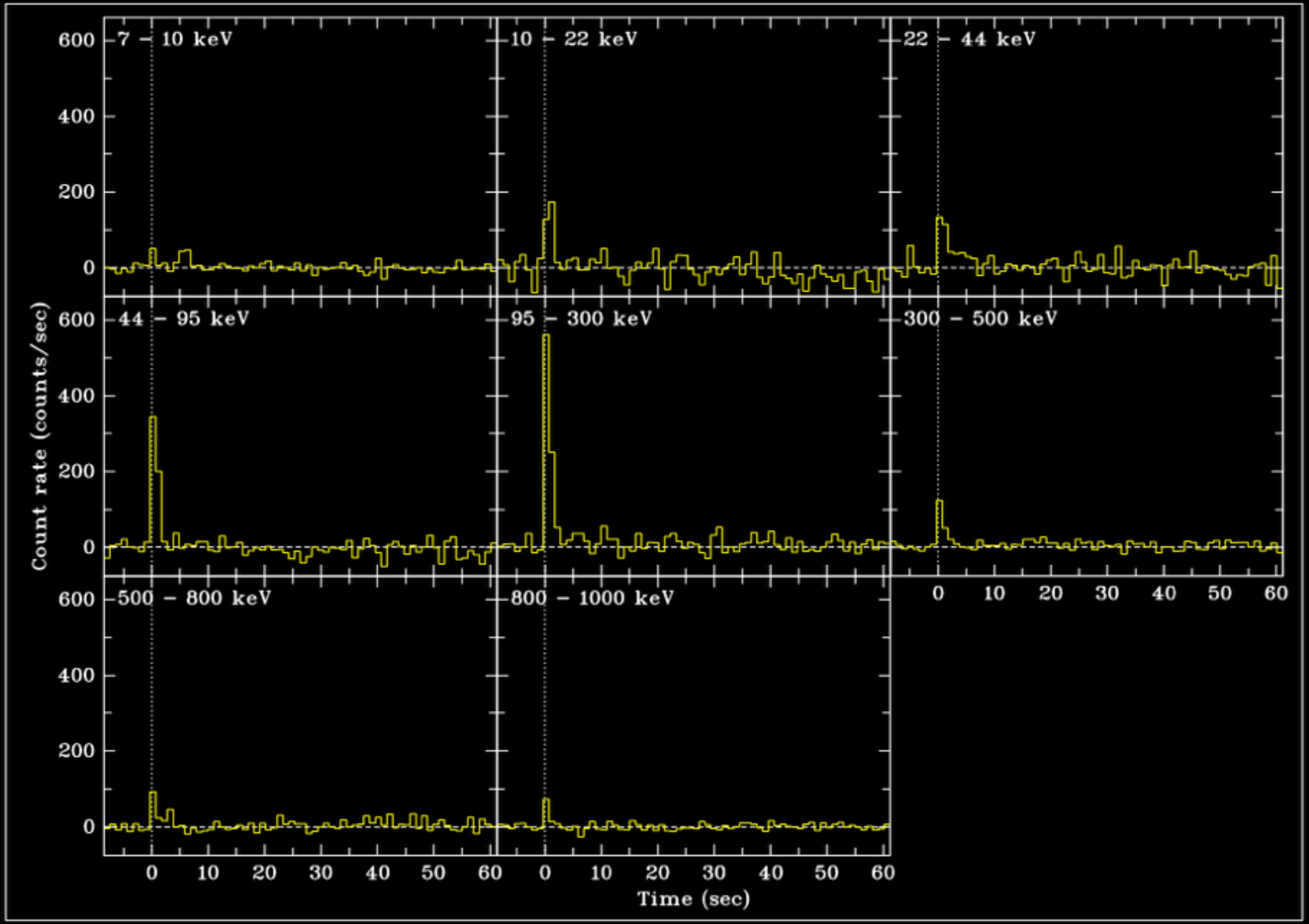
Magnetospheric Particles

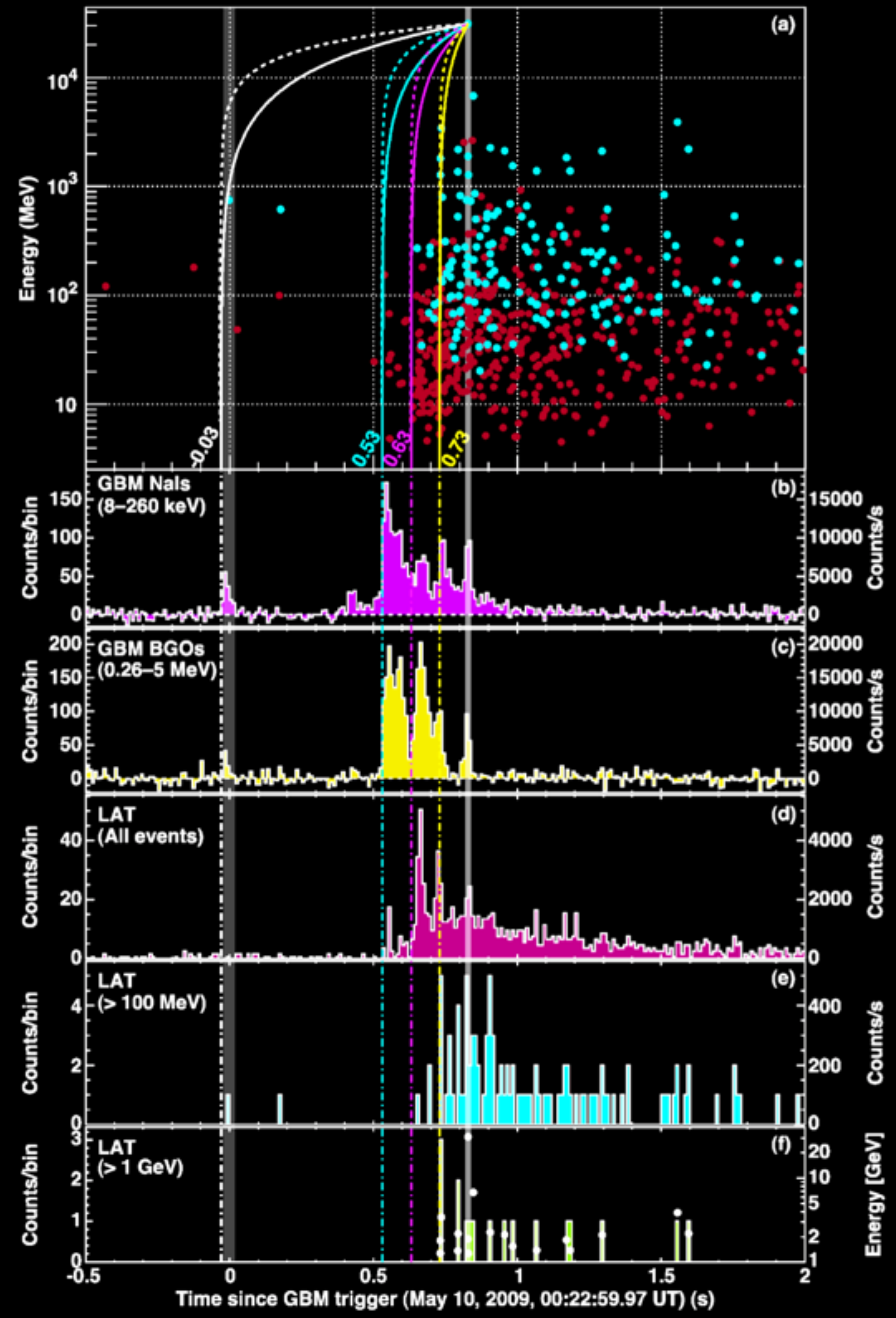


Not necessarily interesting…

…mostly just a pain in the @ss

GRBs


7 – 10 keV
10 – 22 keV
22 – 44 keV
44 – 95 keV
95 – 300 keV
300 – 500 keV
500 – 800 keV
800 – 1000 keV
Count rate (counts/sec)
Time (sec)

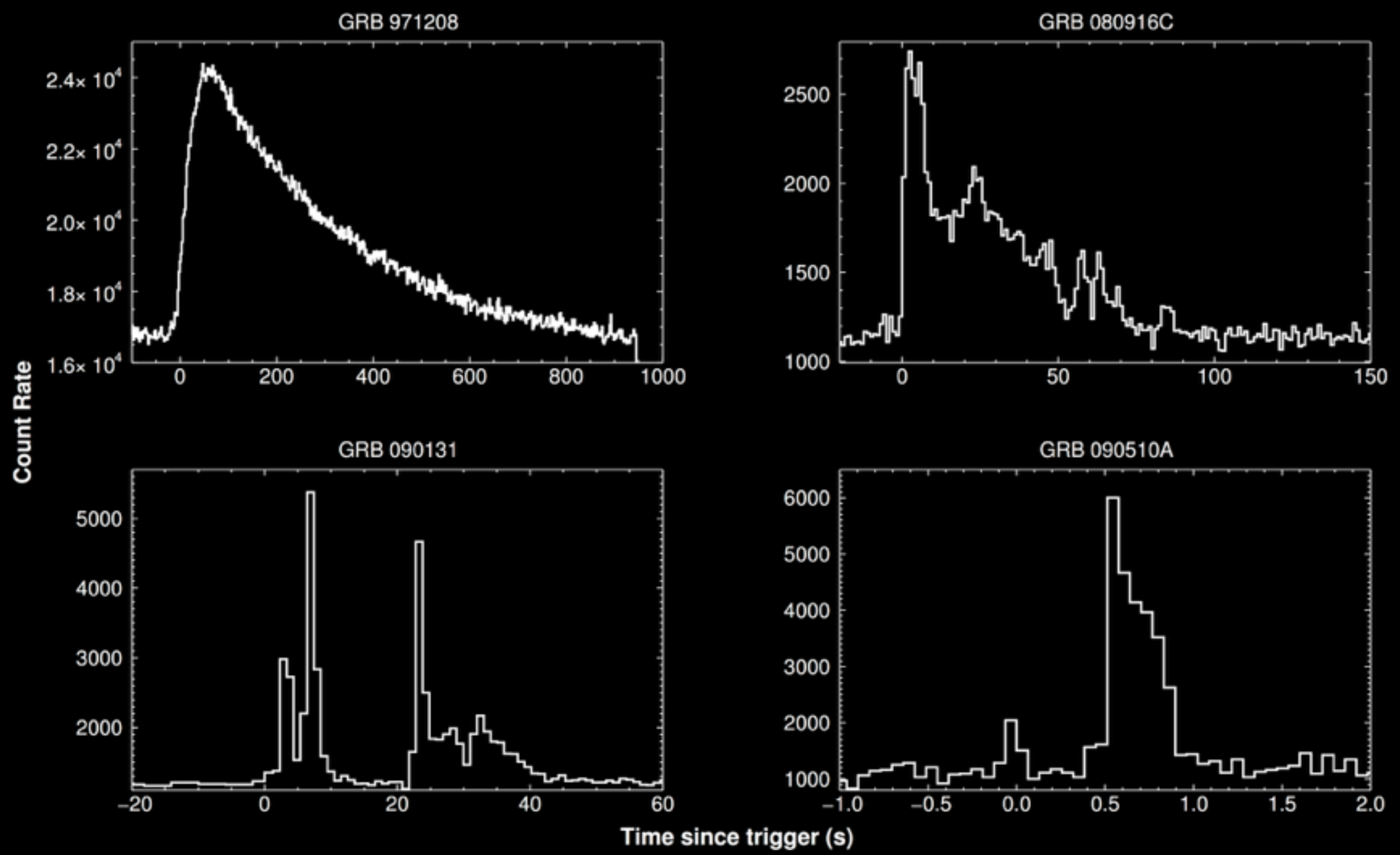

(a)
Energy (MeV)
-0.03
0.53
0.63
0.73
(b)
GBM NaIs
(8–260 keV)
Counts/bin
Counts/s
(c)
GBM BGOs
(0.26–5 MeV)
(d)
LAT
(All events)
(e)
LAT
(> 100 MeV)
(f)
LAT
(> 1 GeV)
Energy [GeV]
Time since GBM trigger (May 10, 2009, 00:22:59.97 UT) (s)

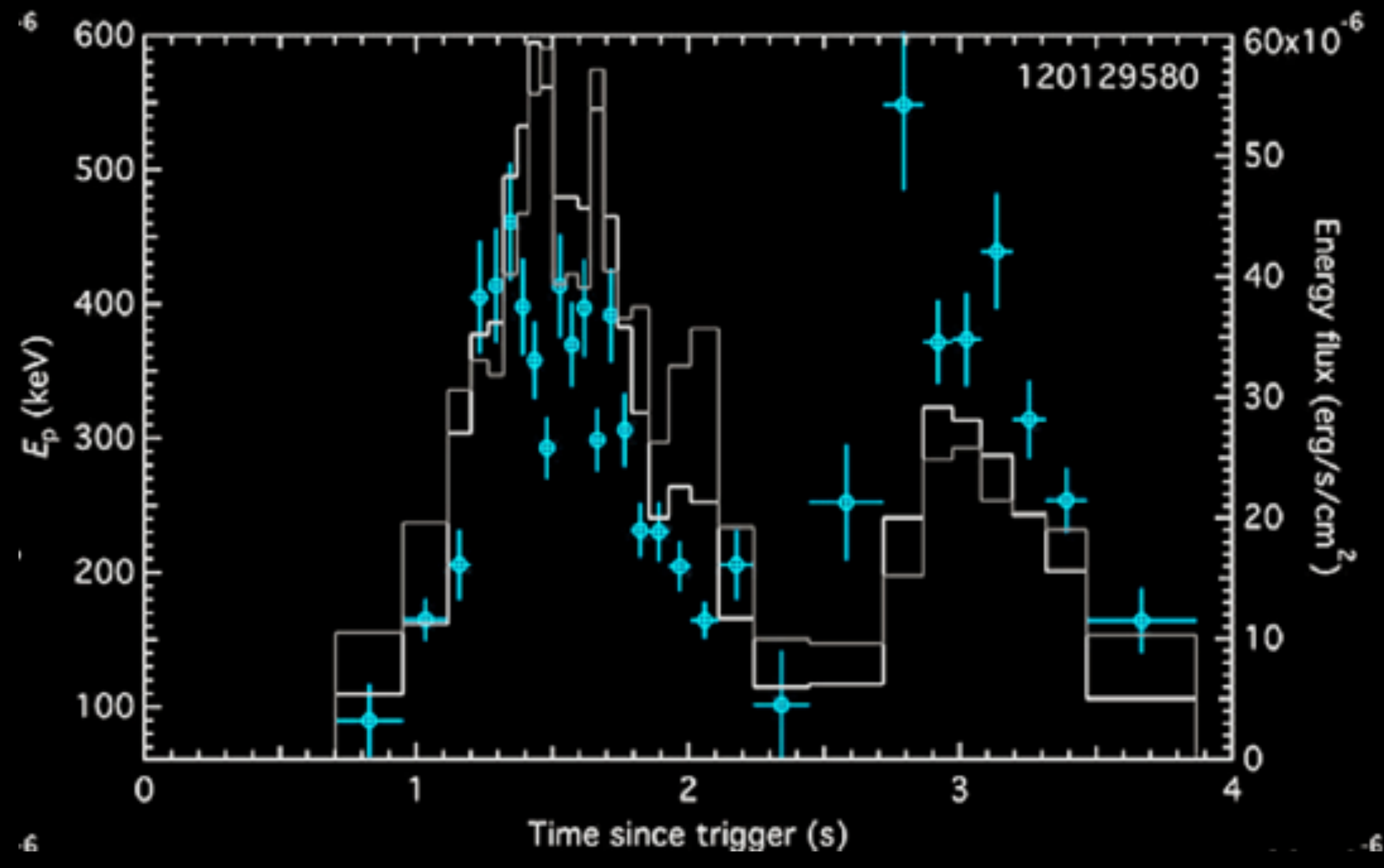
Observed GRB Properties

A Zoo

- Detected Redshift range z < 0.01 — 9
- Energetics: E_{iso} ~10^{46}–10^{54} erg
- Durations: 10s of ms —several minutes
- Wide variety of SED peak energies
- Wide variety of lightcurves
- Spectral evolution throughout burst

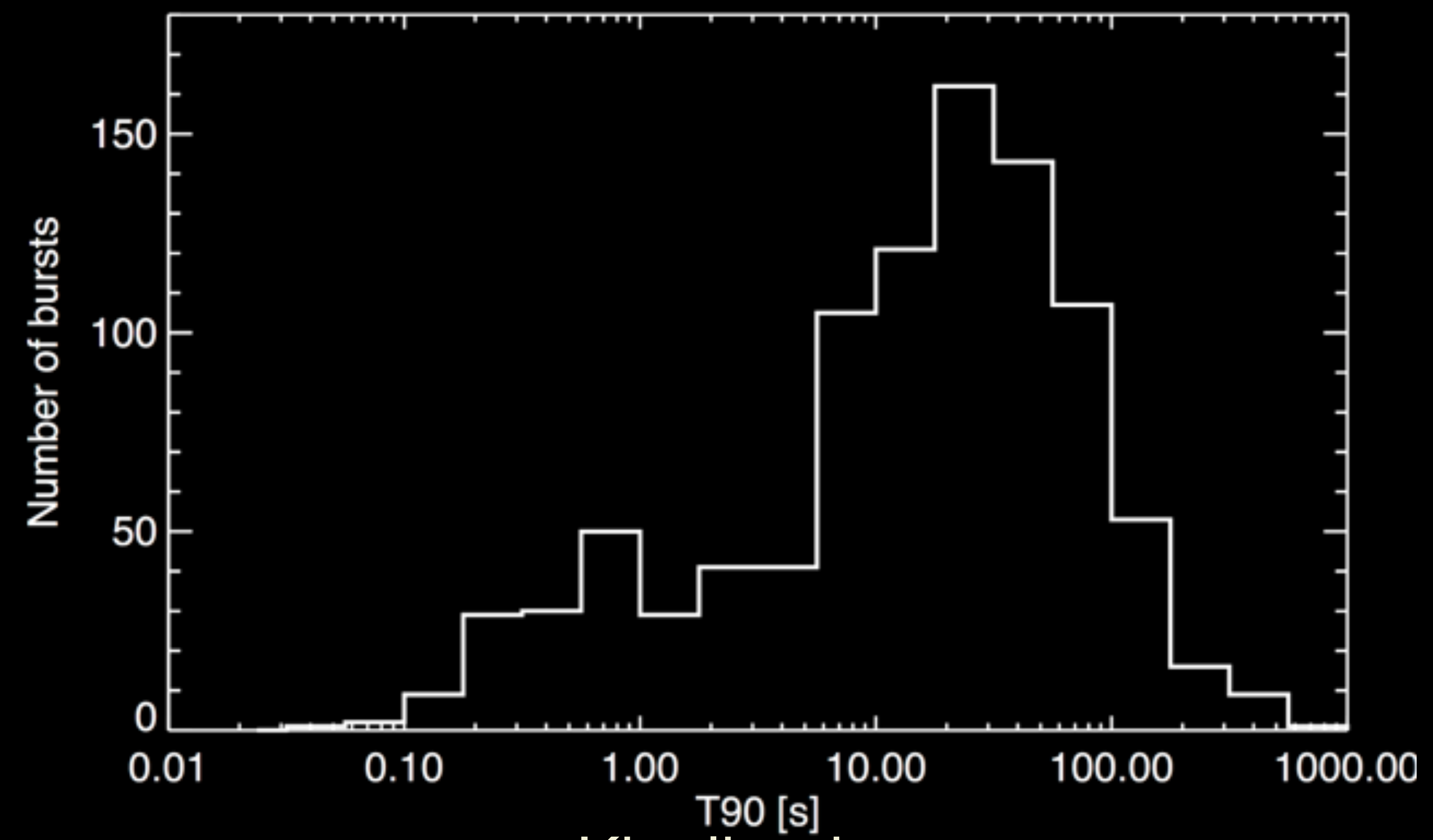
- Long GRBs
  - Collapse of massive star
  - Higher redshift; Pop III?
- Short GRBs
  - Merging of NS-NS or NS-BH
  - More nearby
- Both are the result of a relativistic jet



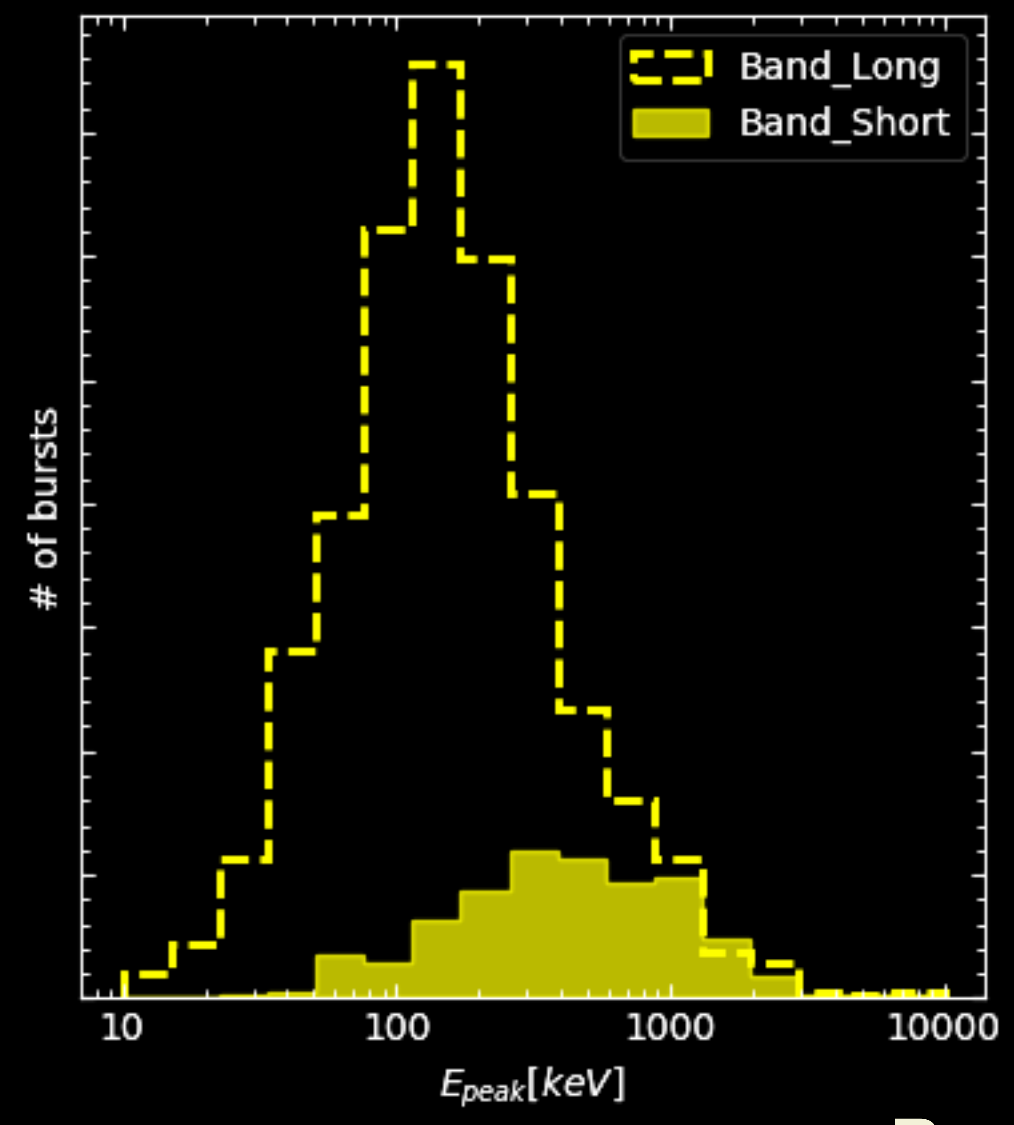


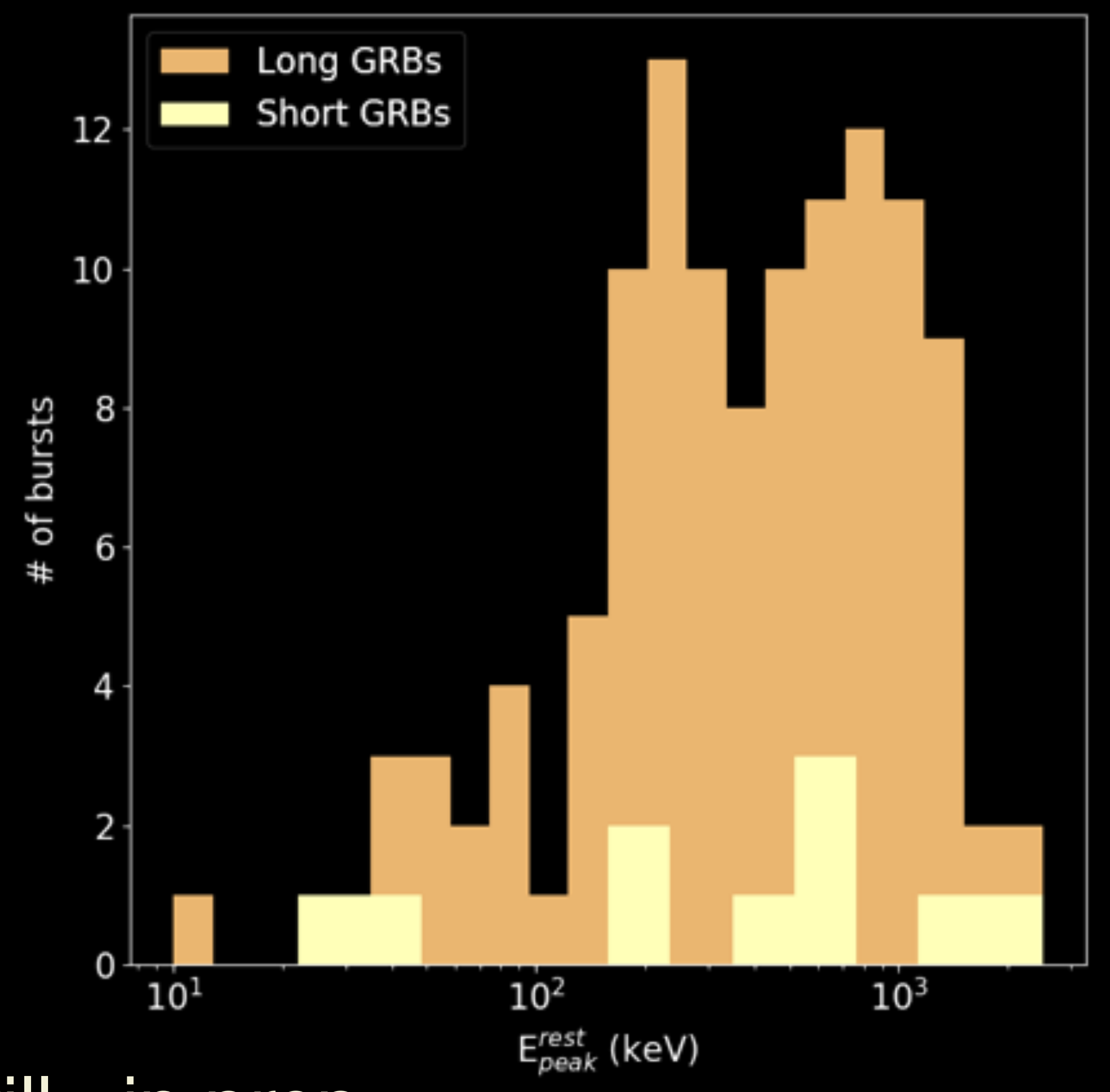
10+ Years of Observations

- 2357 GRBs over 10 years
  - Projected to exceed BATSE by end of year
  - ~400 short GRBs
  - ~2000 long GRBs
  - 135 GRBs with redshift
- 10-year Burst and Spectroscopy catalogs
  - Peak fluxes, fluences, durations, locations
  - Spectra, energetics
- With GBM observations of GRBs we have:
  - Produced groundbreaking understanding of the prompt energetics and jet structure
  - Enabled tight constraints on LIV
  - First coincident and independent detections of a single event in GWs and EM
  - Measured the speed of gravity relative to the speed of light



von Kienlin+ in prep.

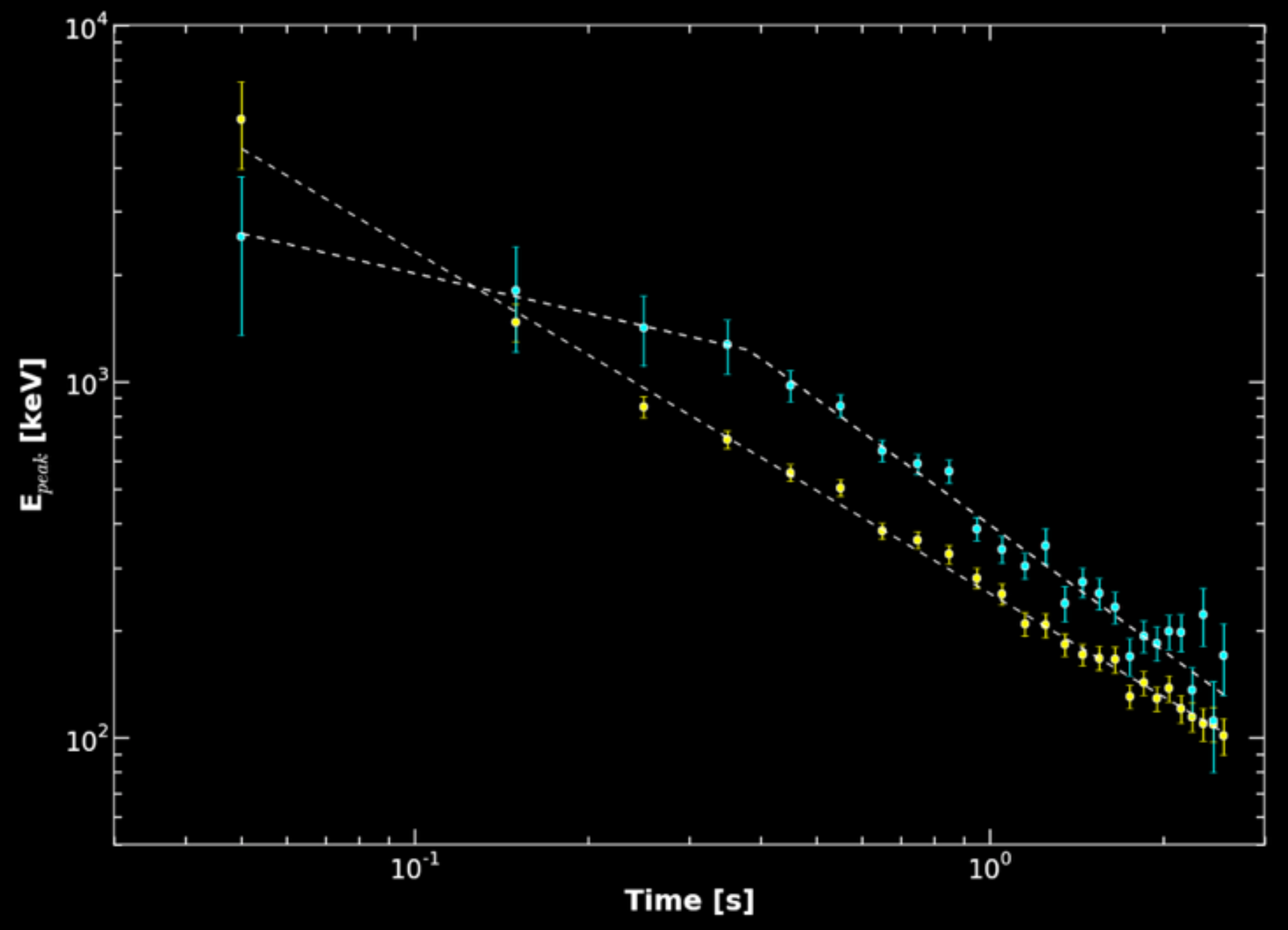


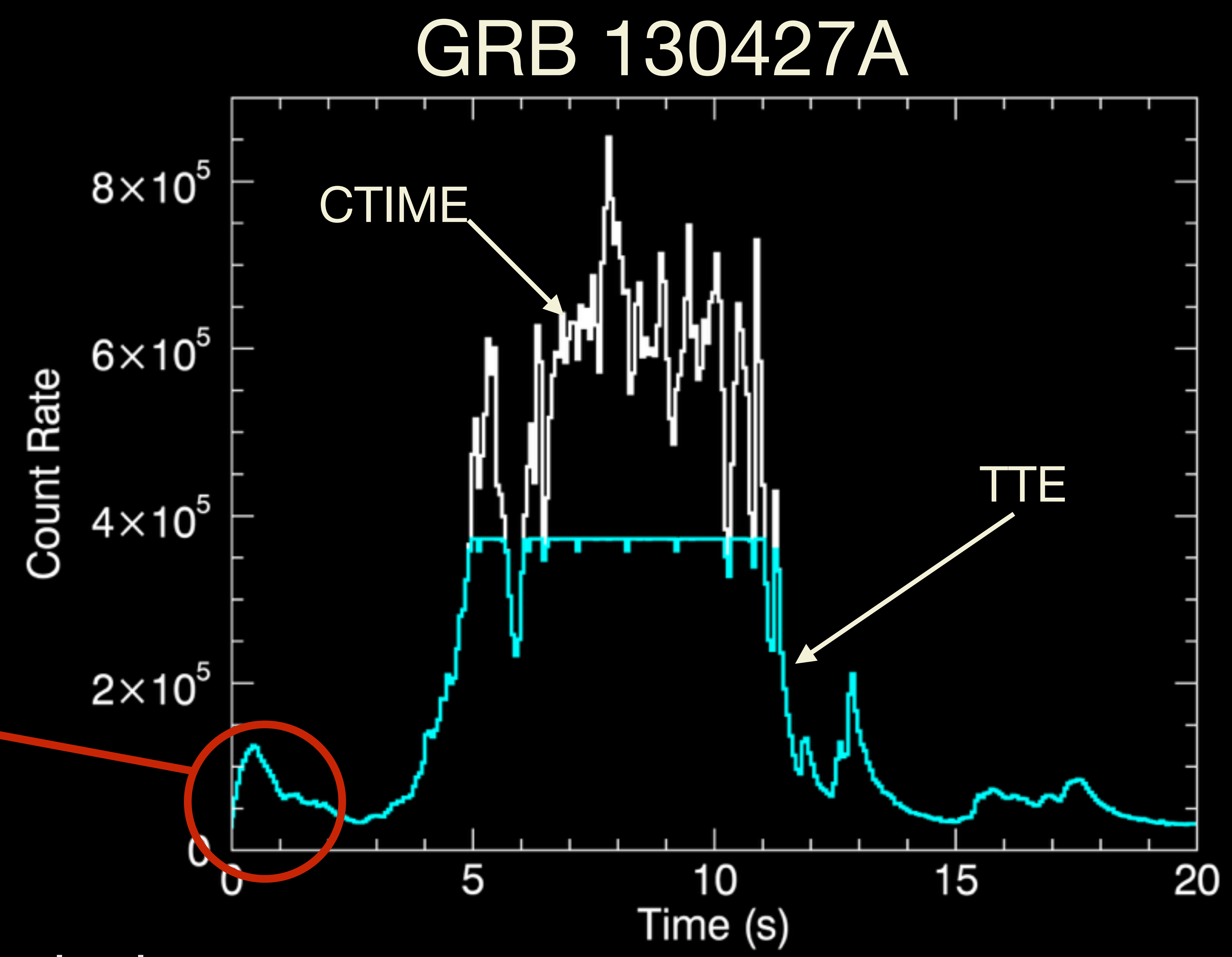


Poolakill+ in prep.

Backup

The Brightest(?) Observed GRB





- Rest-frame luminosity is ~average
- Hard-to-soft spectral evolution
- TTE data saturated
- First pulse is still extremely bright