FERMI GAMMA-RAY BURST MONITOR

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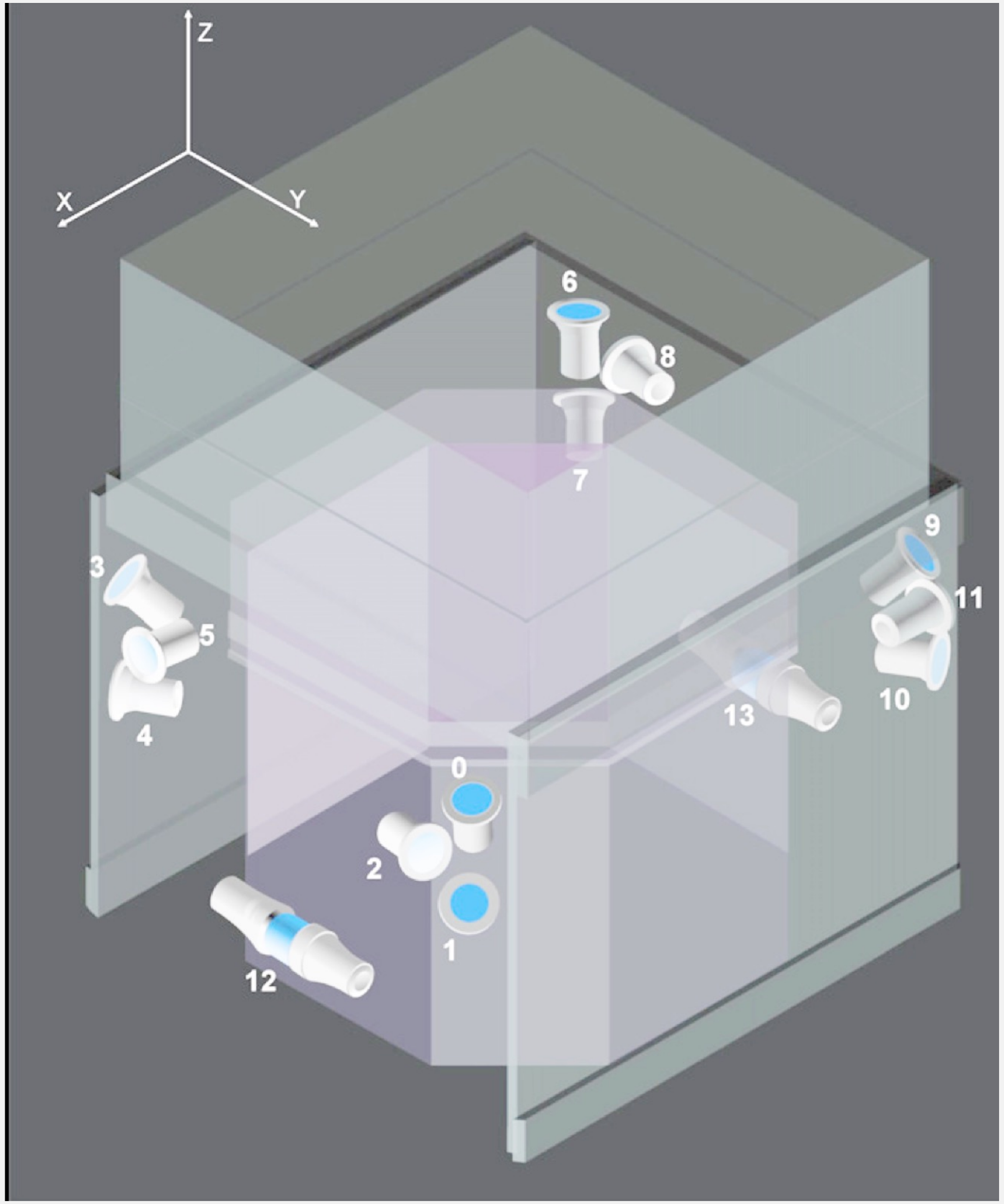
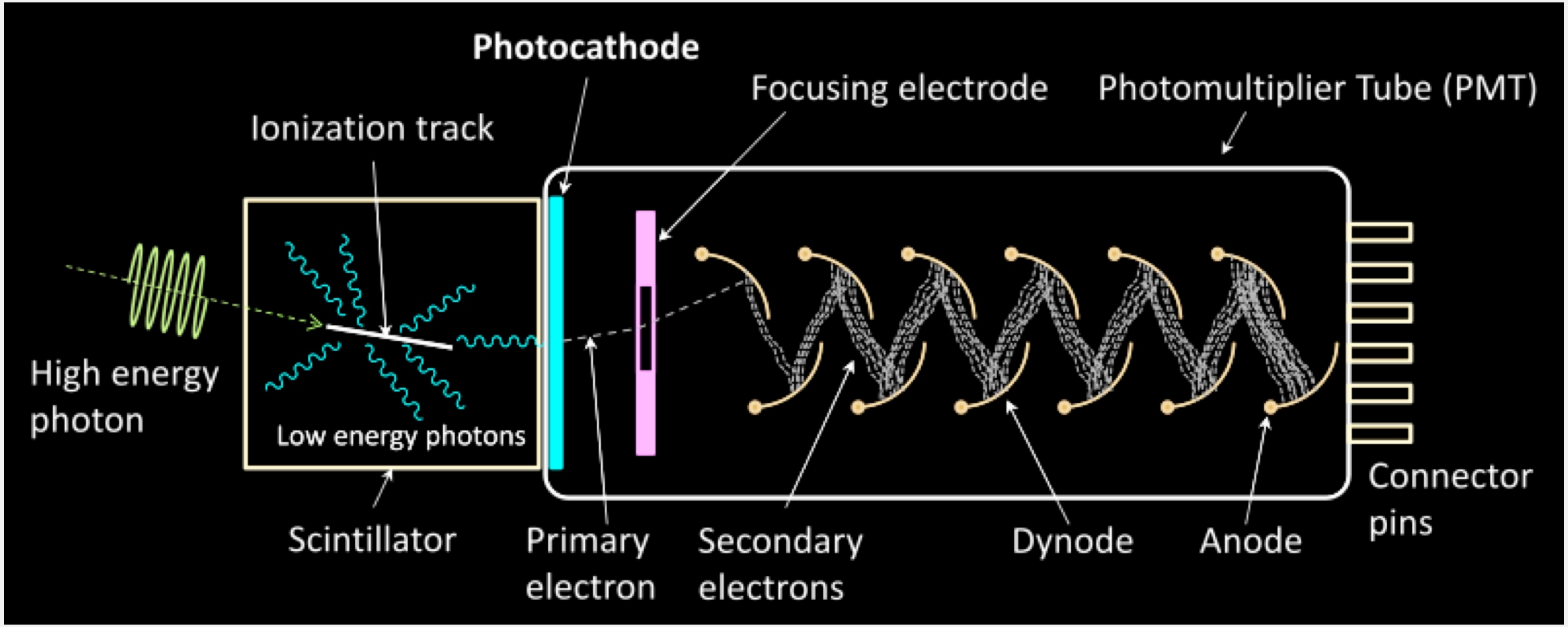
The Fermi Gamma-ray Burst Monitor (GBM)

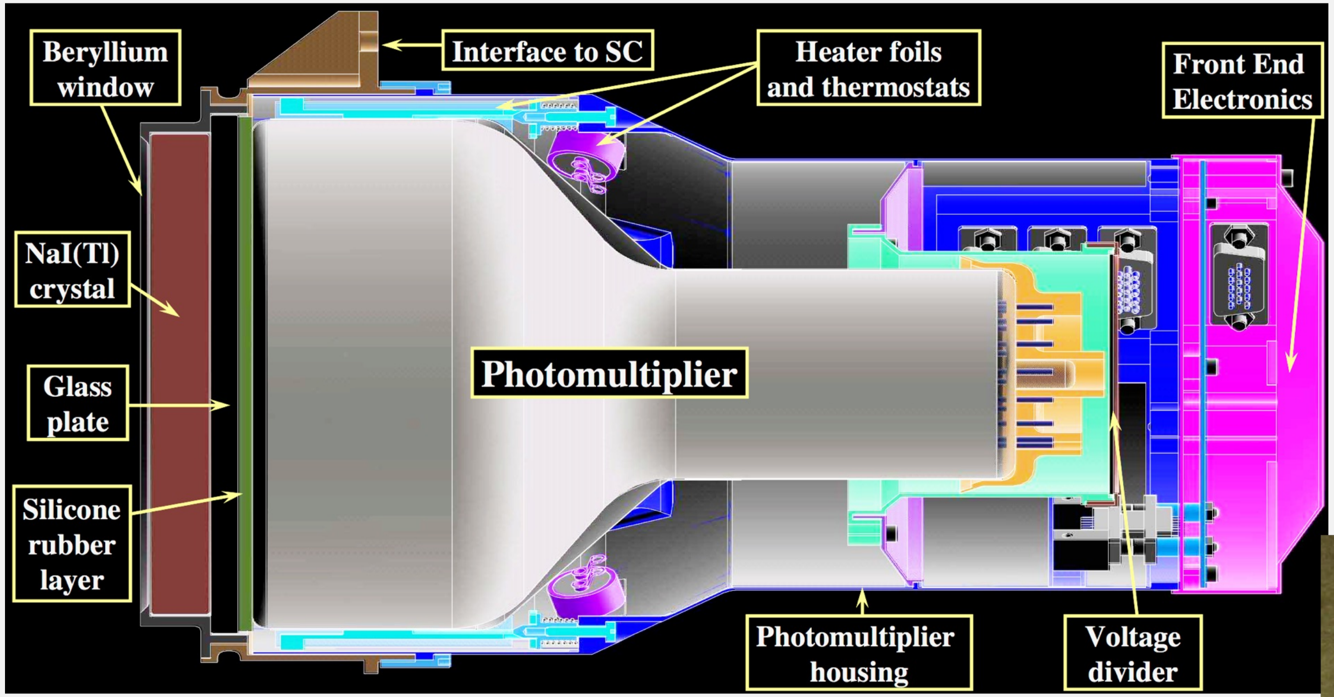


Scintillation Detectors and PMTs

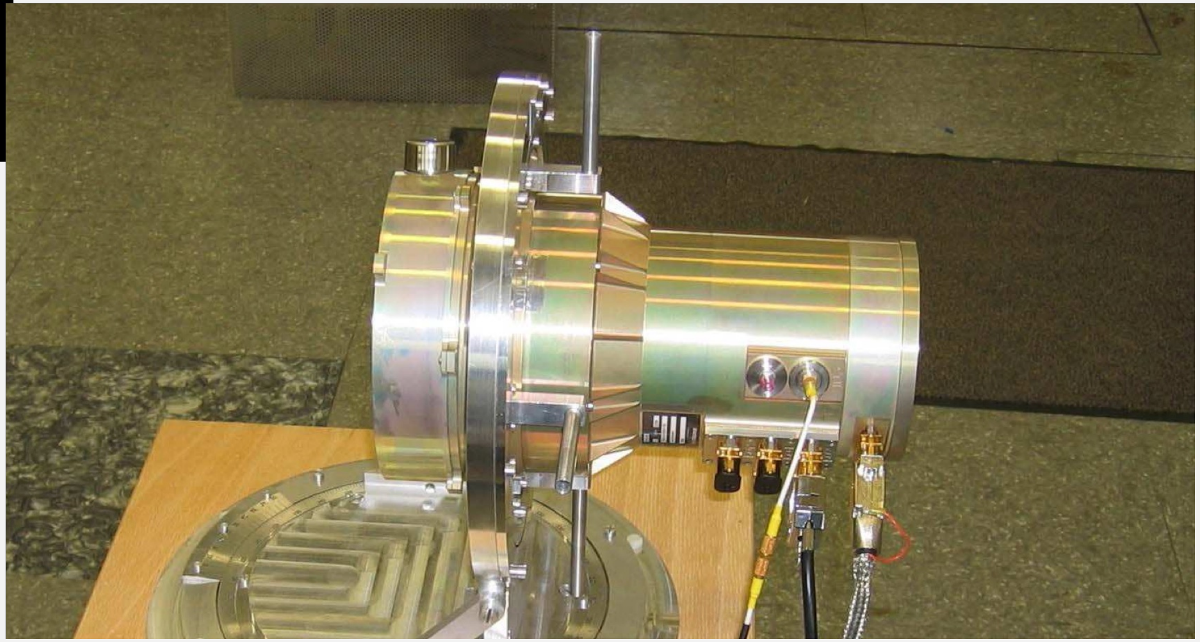


- Incident photons interact and produce scintillation photons
- Scintillation photons produce electron(s) at the Photocathode
- An electric potential (voltage) is applied to the Photocathode and Anode
- Electron(s) travel toward the Anode and are "multiplied" along the Dynodes
- The avalanche of electrons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

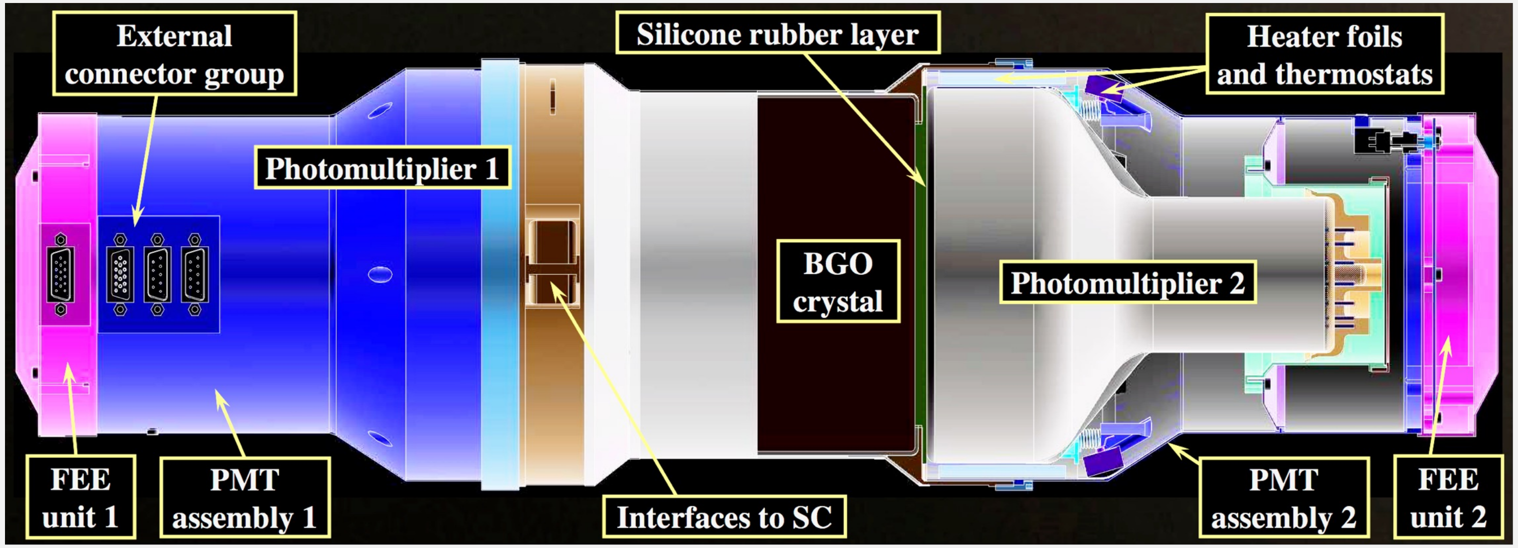
GBM Sodium Iodide (NaI) Detectors



- Very hygroscopic (any moisture will damage it)
- High light output
- Photons emitted at Near UV energies

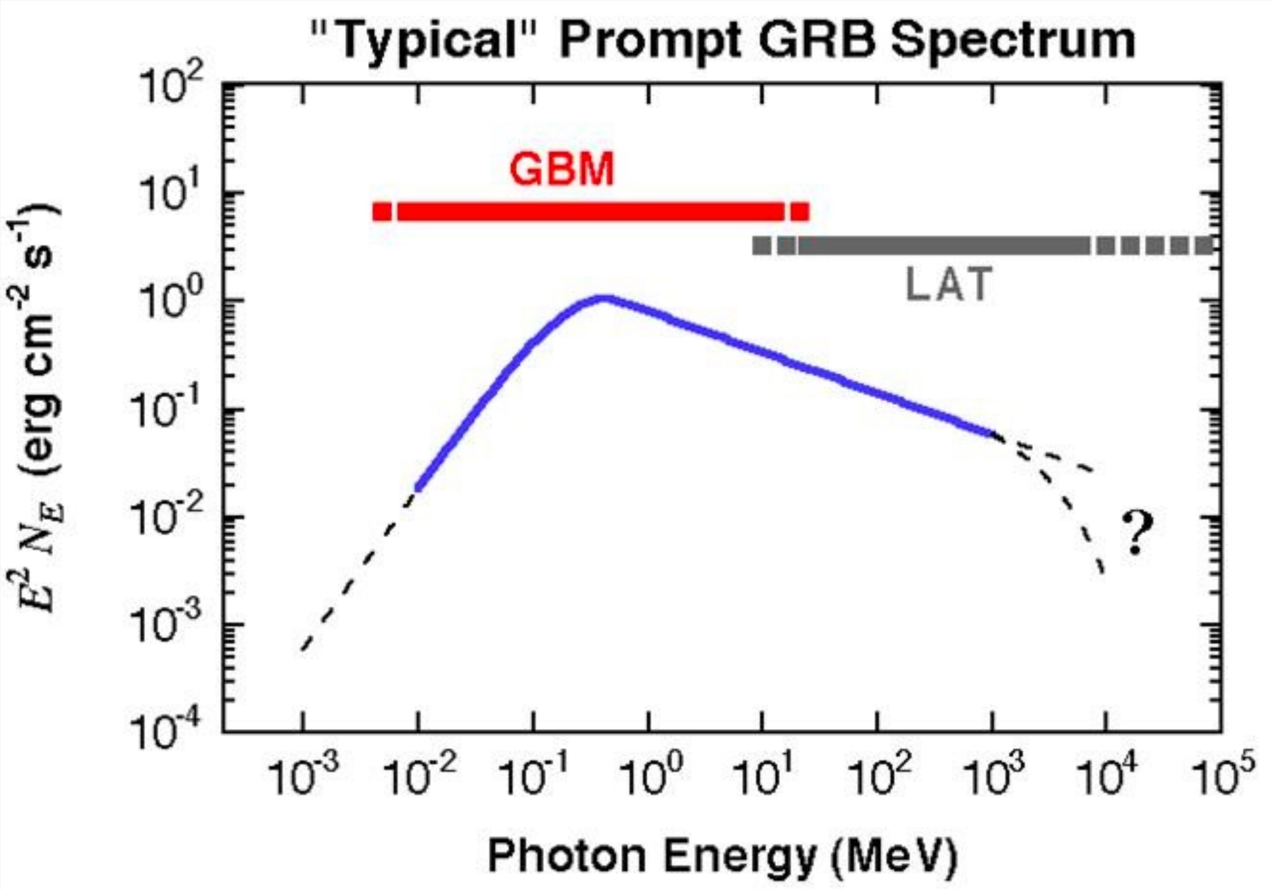


GBM Bismuth Germinate (BGO) Detector



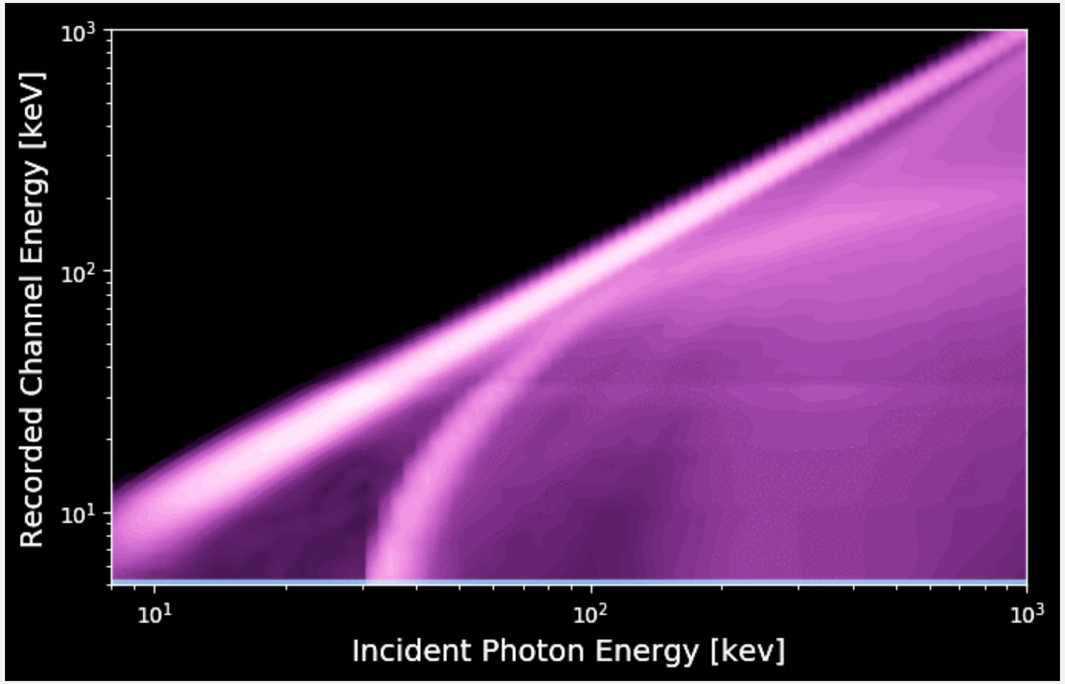
- Higher Stopping Power (higher energies)
- Lower light output (needs 2 PMTs)
- Photons emitted from visible red to near UV

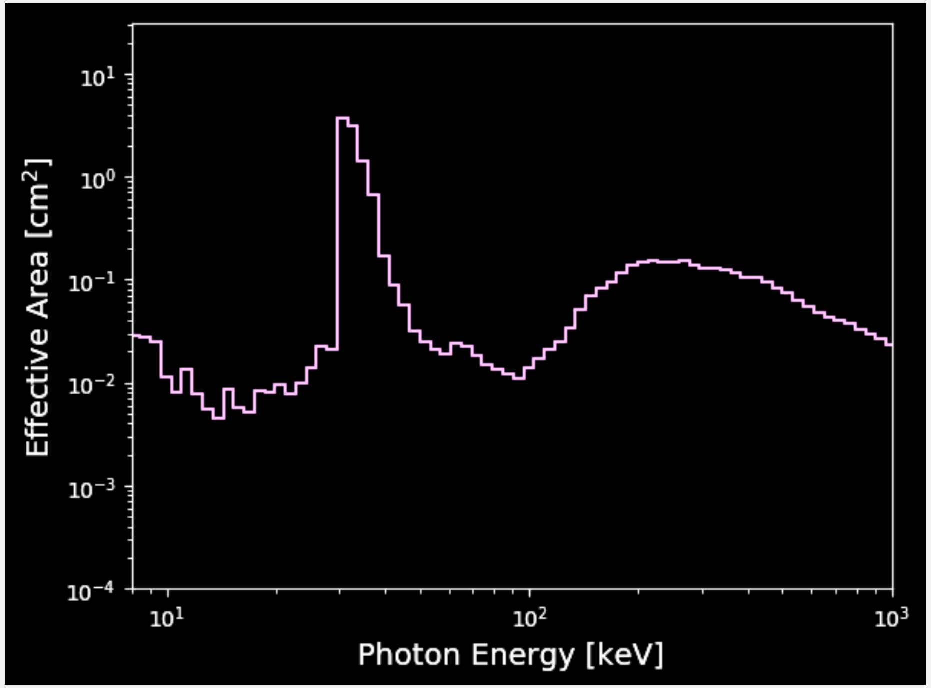
GBM Energy Range



- NaI detectors ~8—1000 keV
- BGO detectors ~200 keV—40 MeV

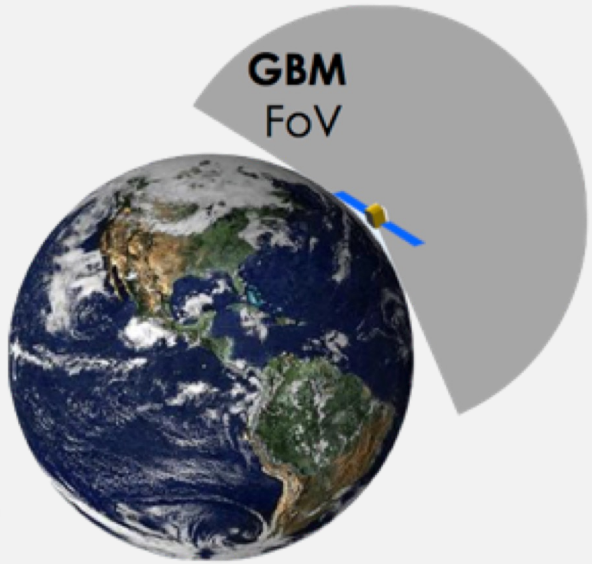
Energy Response

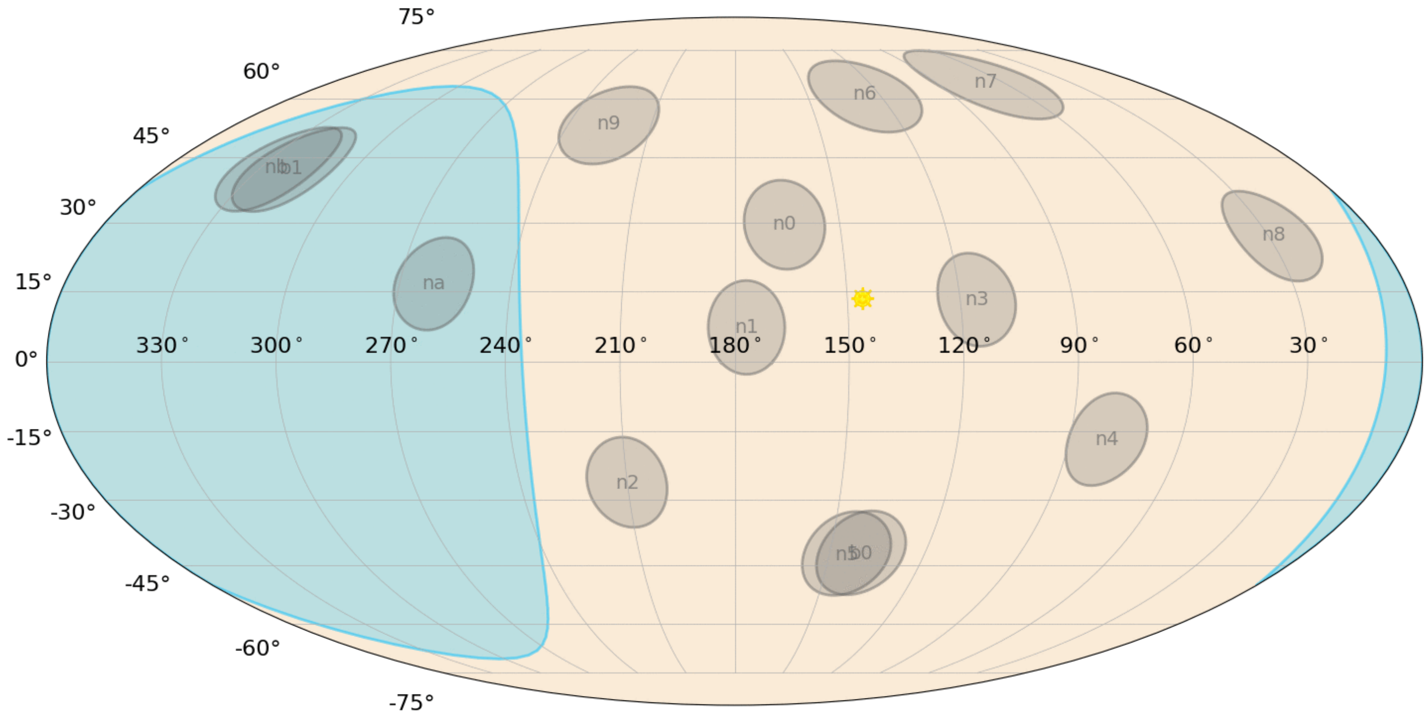




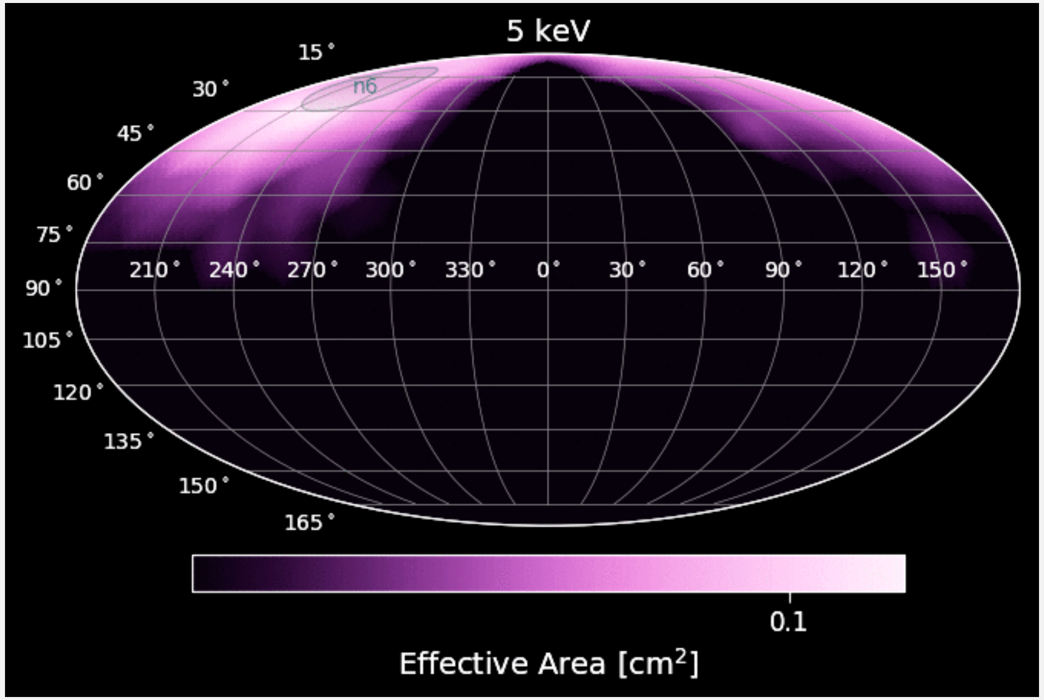
- The Response function maps the incident photon energies to the recorded "channel" energies
- Mono-energetic photons can be dispersed to a variety of channels, the probability of which is proportional to the effective area for that particular energy -> channel mapping
- This mapping can be stored as 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

All-Sky Monitoring



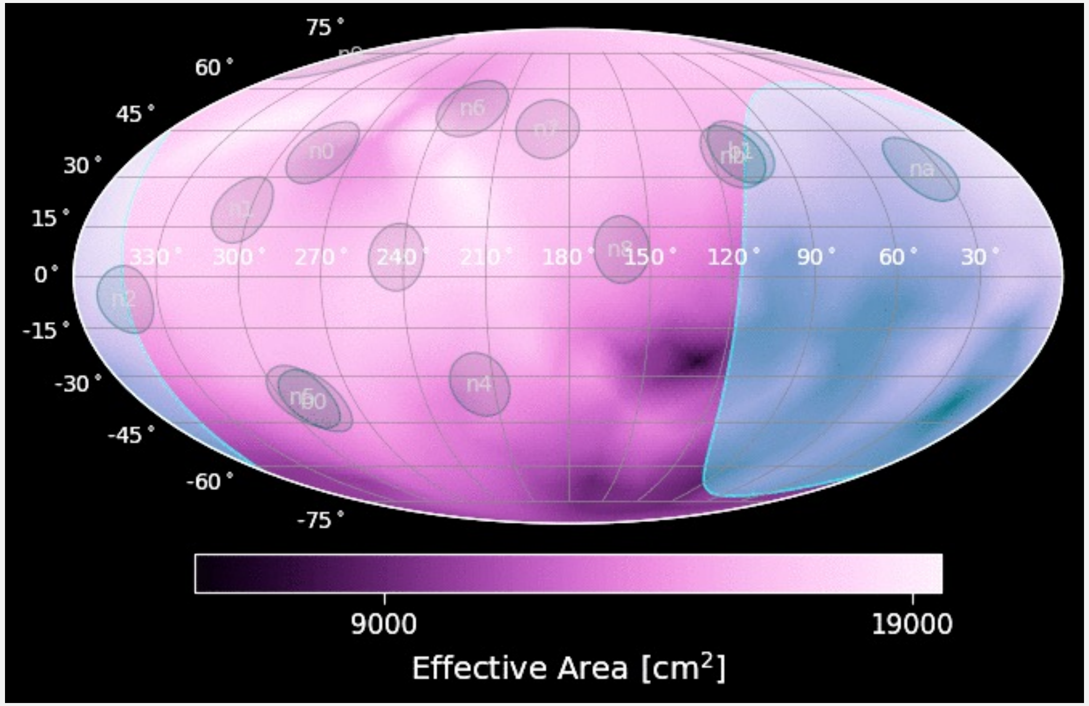


All-Sky Response



GBM NaI 6 response on the sky

(S/C coords)

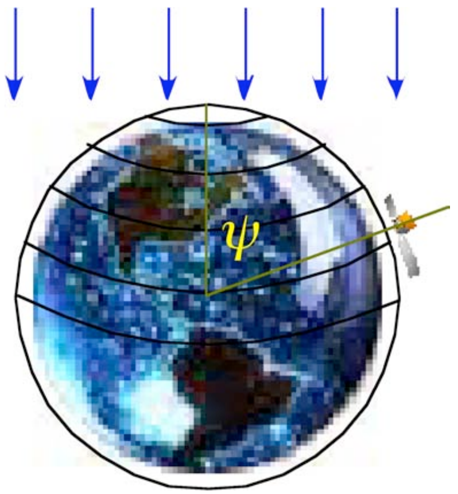


Combined GBM NaI response over 50—300 keV

(Equatorial coords)

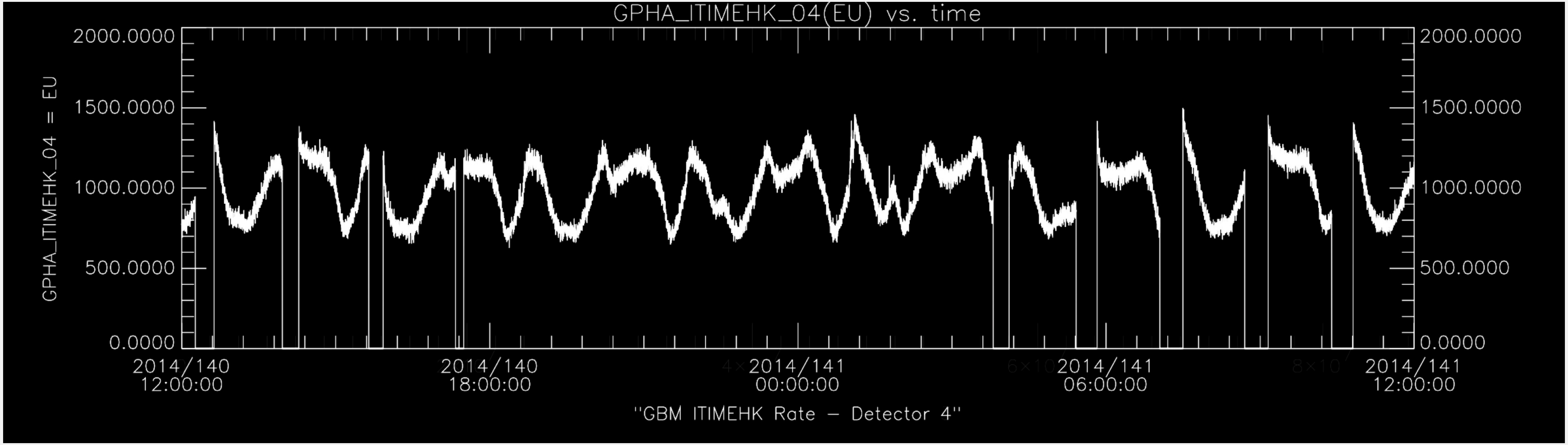
Atmospheric Scattering

- 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

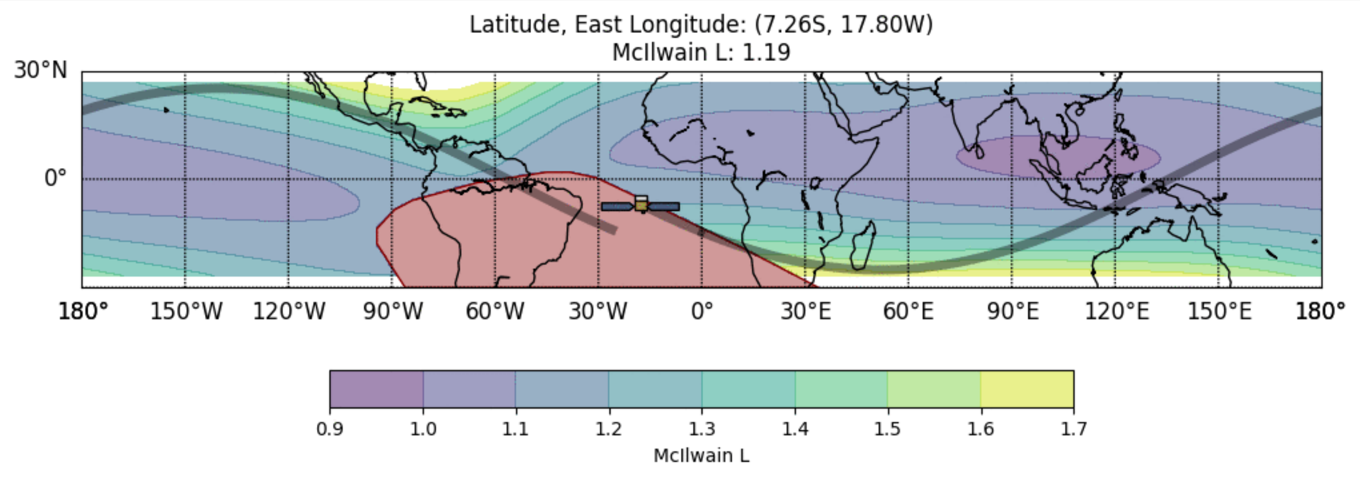


$$\Re_{\mathrm{A}}\left(\psi, A, \vartheta', \varphi', E_\gamma, E_s\right)$$

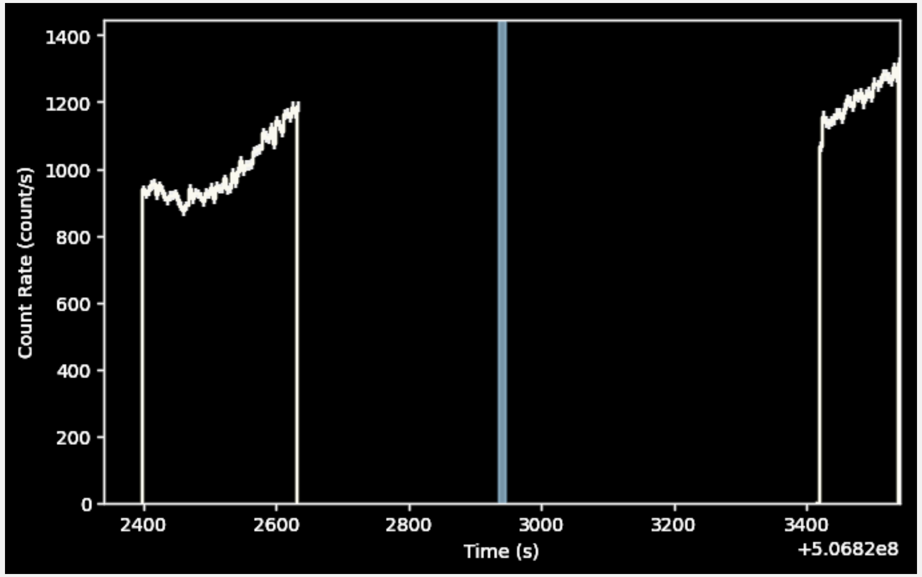
GBM Orbit

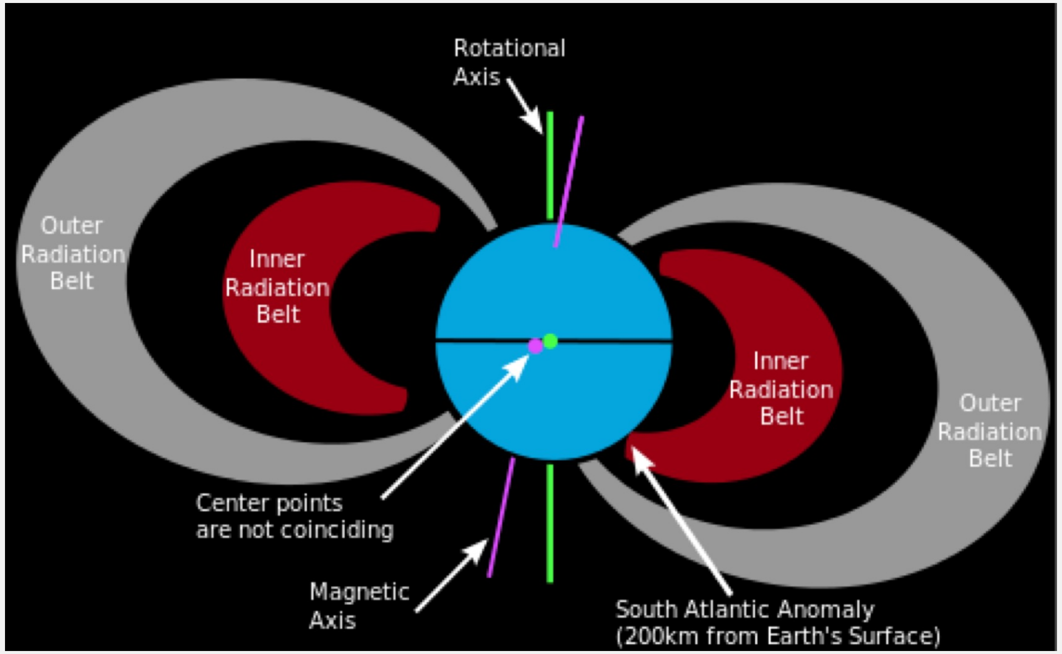

GPHA_ITIMEHK_04(EU) vs. time
GPHA_ITIMEHK_04 = EU
2000.0000
1500.0000
1000.0000
500.0000
0.0000
2014/140 12:00:00
2014/140 18:00:00
2014/141 00:00:00
2014/141 06:00:00
2014/141 12:00:00
"GBM ITIMEHK Rate – Detector 4"

GBM Orbit

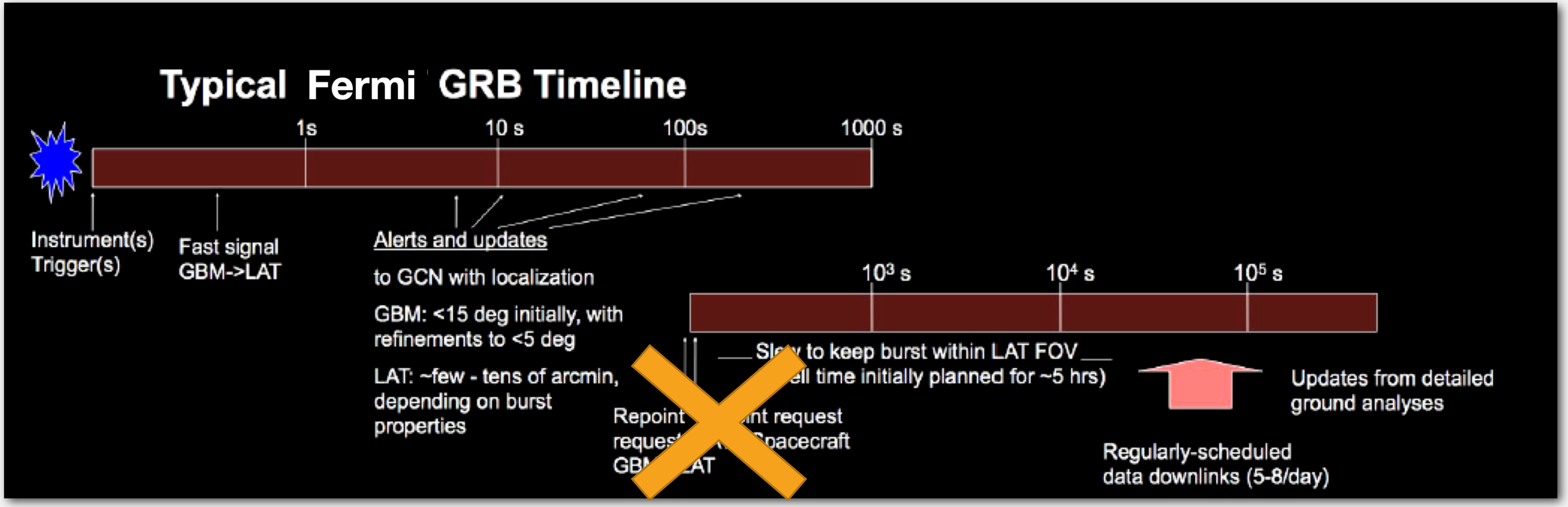


- Background affected by orbit
- Geomagnetic latitude (McIlwain L) changes GBM detection efficiency
- Mcilwain L > ~1.5 results in more likely detections of charged particle activity



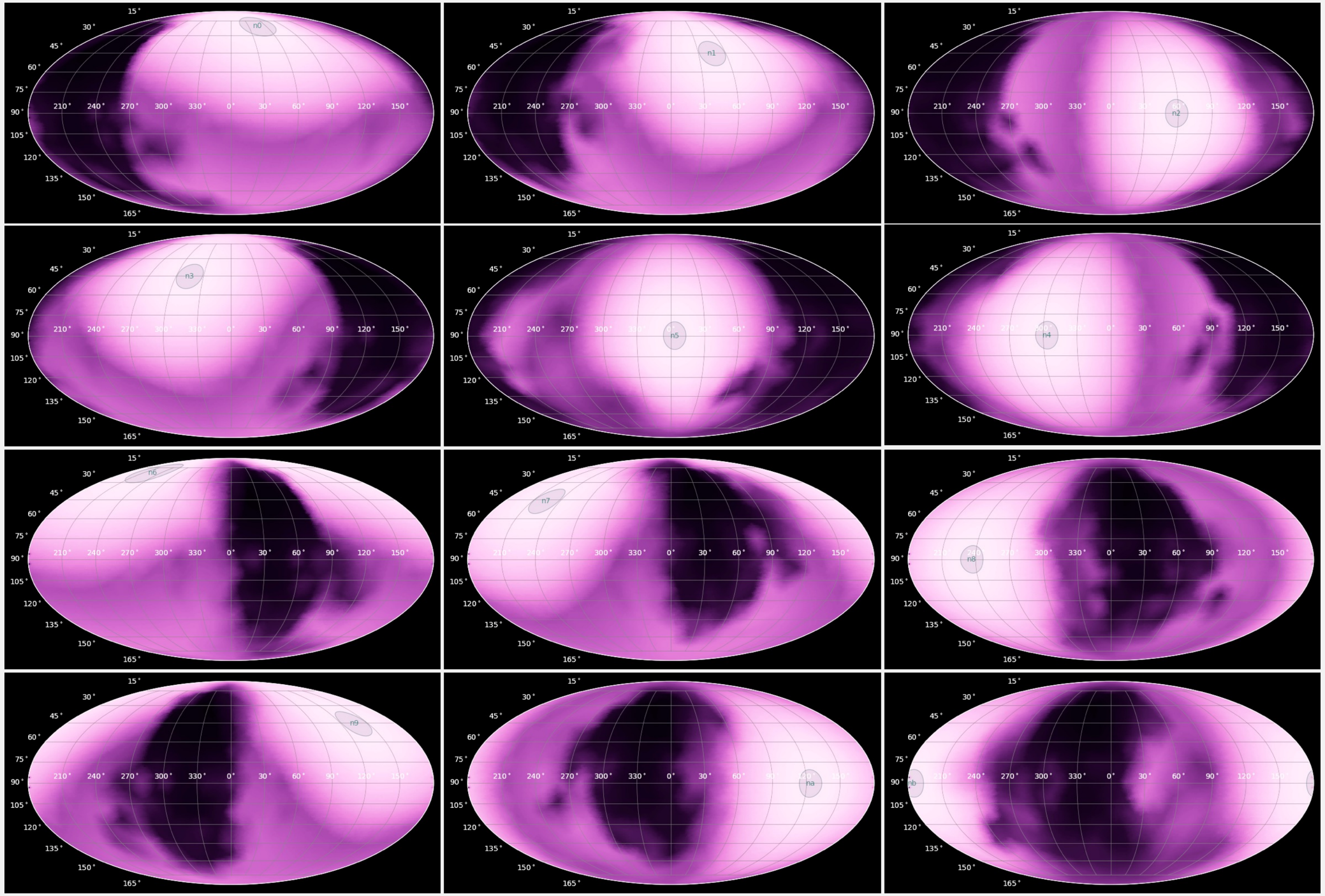


Trigger Timeline



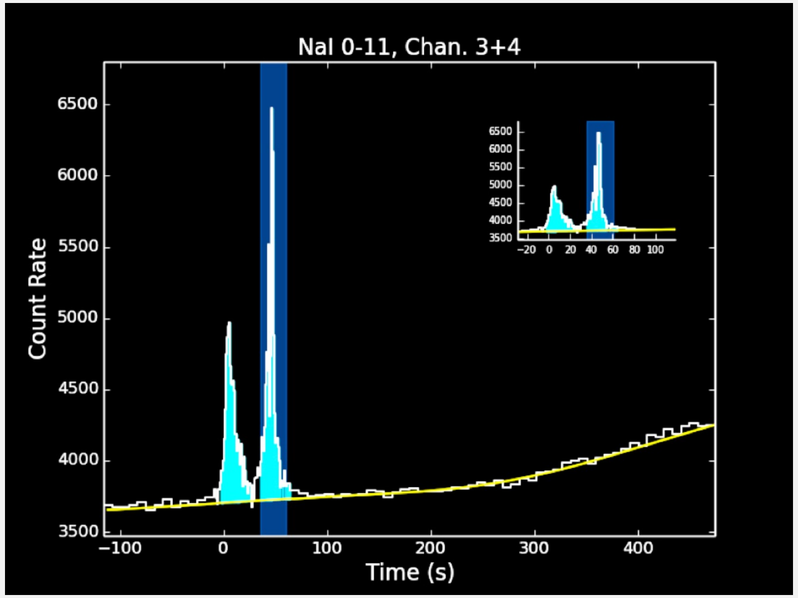
- Trigger alerts go out within seconds, full automated processing completes within 10 minutes
- Fermi GBM has Burst Advocates (BAs) that are on-call for triggers
- BAs check that the automated classification is correct and, if a GRB, that an automated localization went out
- If something isn't quite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

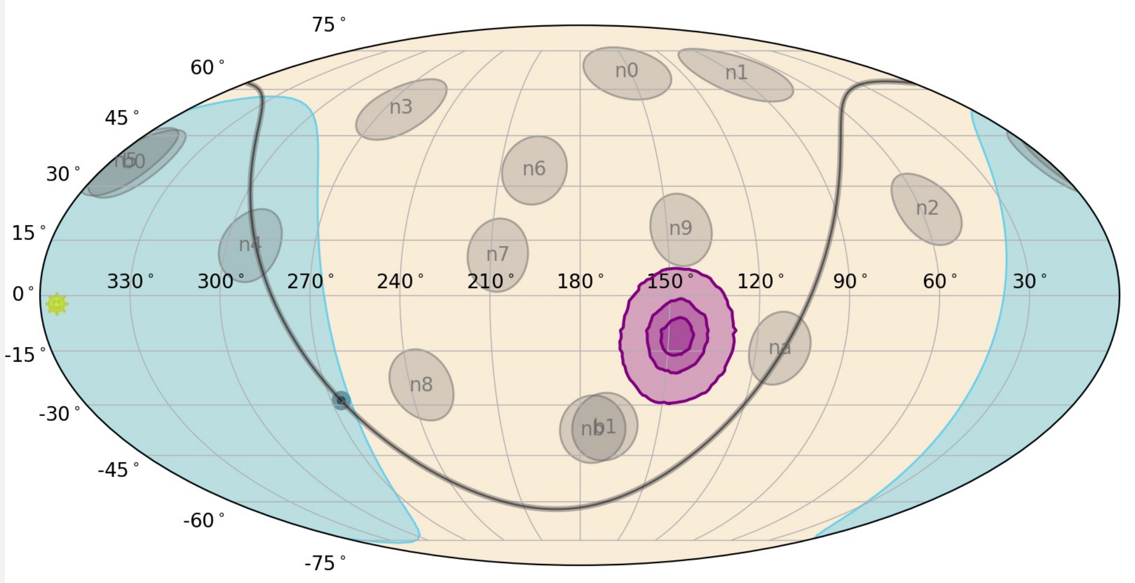
Localization



- 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

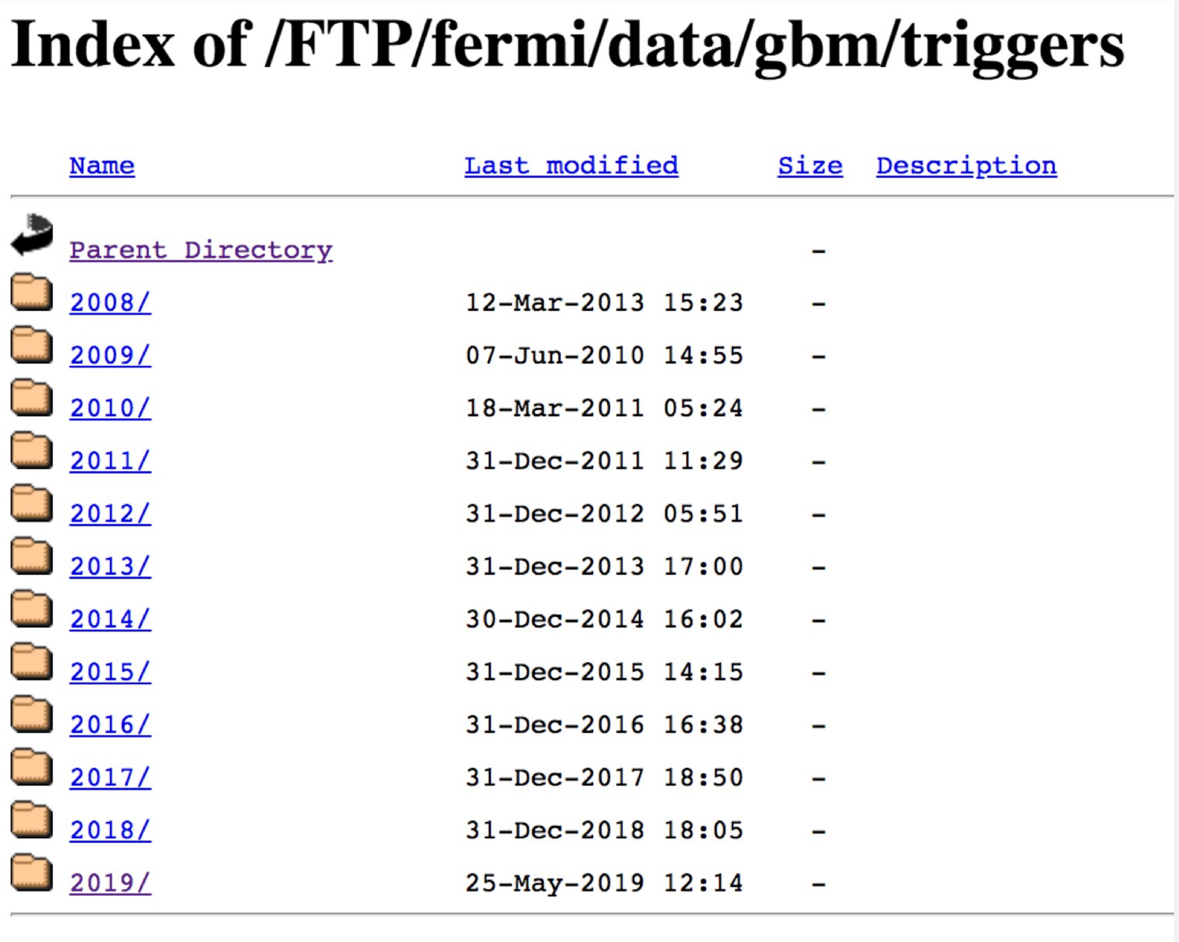




- First implemented in early 2016
- Automatically runs w/in 10 minutes
- Successful ~80% of the time
  - Most failures due to dropped data packets in realtime stream
  - Human BA performs localization in that case
- Sends out a final localization notice
  - Localization
  - Links to lightcurve and localization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

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/

GBM Science 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

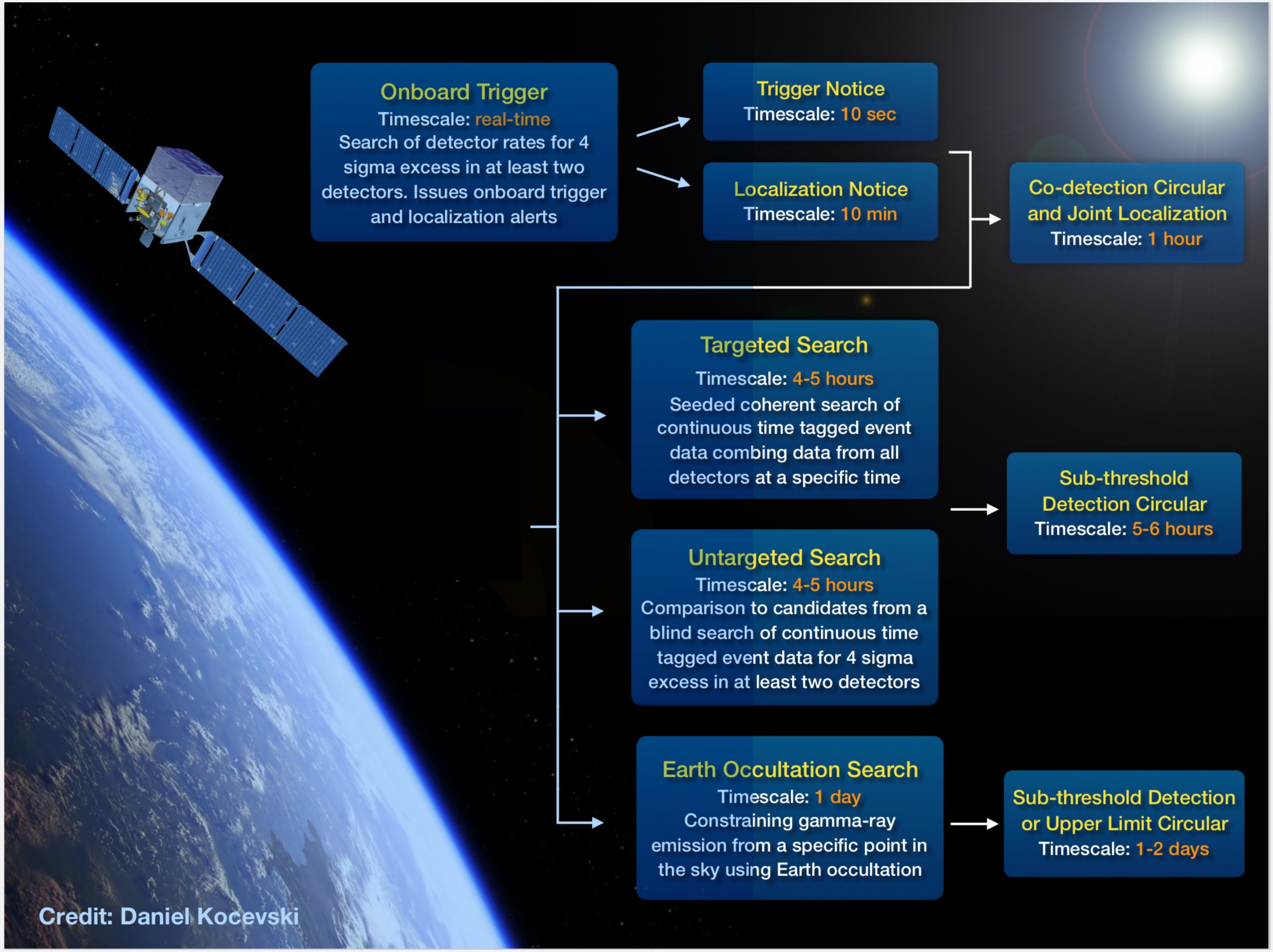
Higher Level Data (Level 1)

- 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 Value	Value Type
		name		GRB080714086	GRB190525032	string
		ra		00 01 04.8	23 58 57.6	position
		dec		-89 00 33	+88 36 19	position
		trigger_time		2008-07-14 02:04:12.053	2019-05-25 00:45:47.652	date
		t90 (s)		0.008	828.672	float
		t90_error (s)		0.023	53.762	float
		t90_start (s)		-807.424	188.451	float
		fluence (erg/cm^2)		2.5271e-08	2.4620e-03	float
		fluence_error (erg/cm^2)		3.6450e-09	1.4373e-05	float
		flux_1024 (photon/cm^2/s)		0.2429	1051.8600	float
		flux_1024_error (photon/cm^2/s)		0.0869	279.7320	float
		flux_1024_time (s)		-137.664	438.597	float
		flux_64 (photon/cm^2/s)		1.4874	3054.1000	float
		flux_64_error (photon/cm^2/s)		0.3503	4475.6300	float
		flnc_band_ampl (photon/cm^2/s/keV)		1.171112e-03	1.292132e+05	float

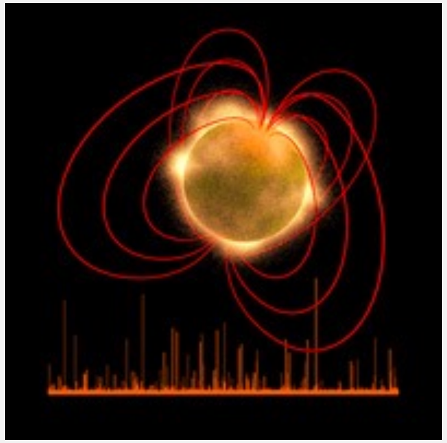
https://heasarc.gsfc.nasa.gov/W3Browse/fermi/fermigbrst.html

GBM Sub-threshold Searches

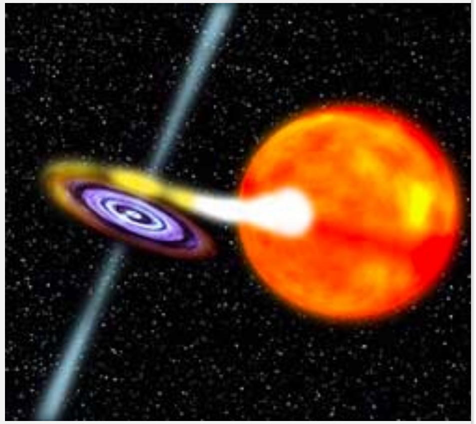


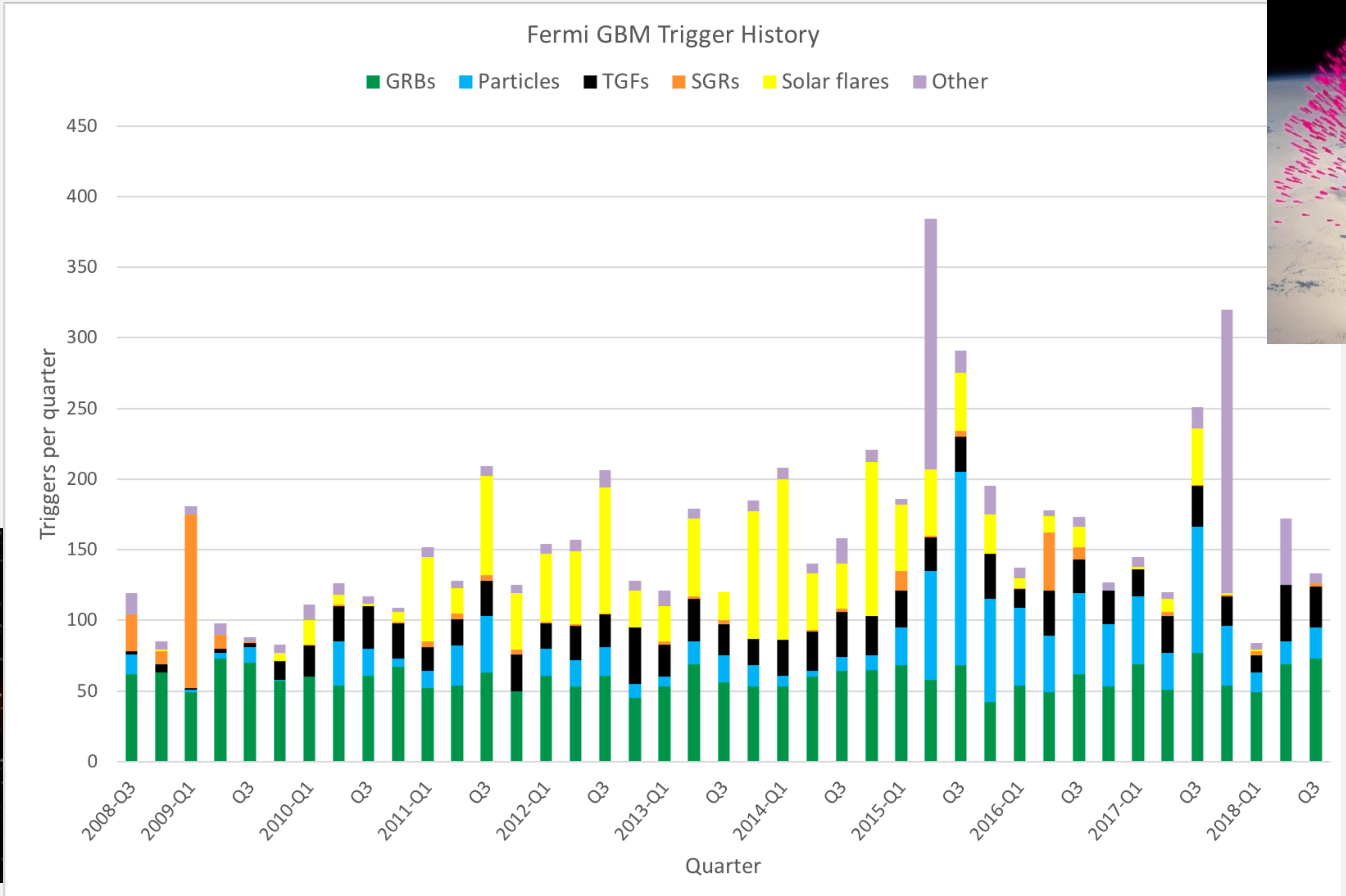
What does GBM observe?

Soft Gamma-ray Repeaters/Magnetars

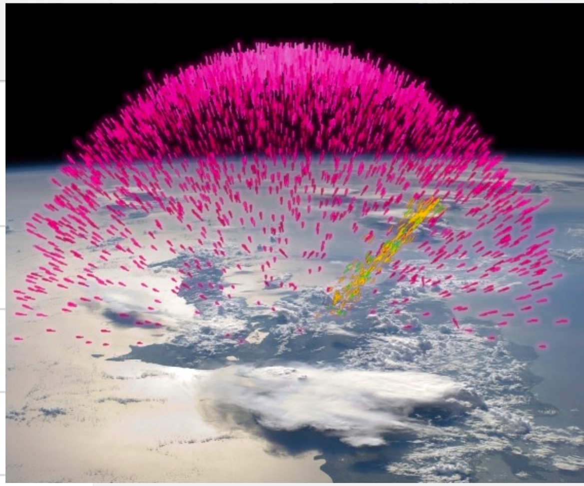


X-ray Binaries

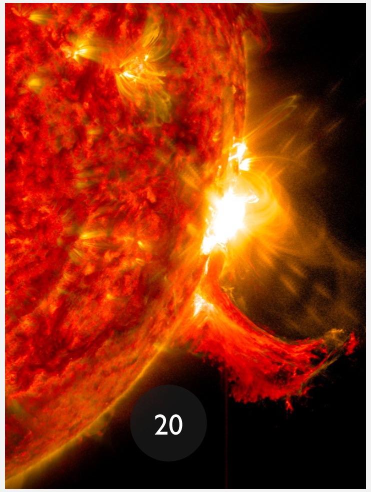




TGFs



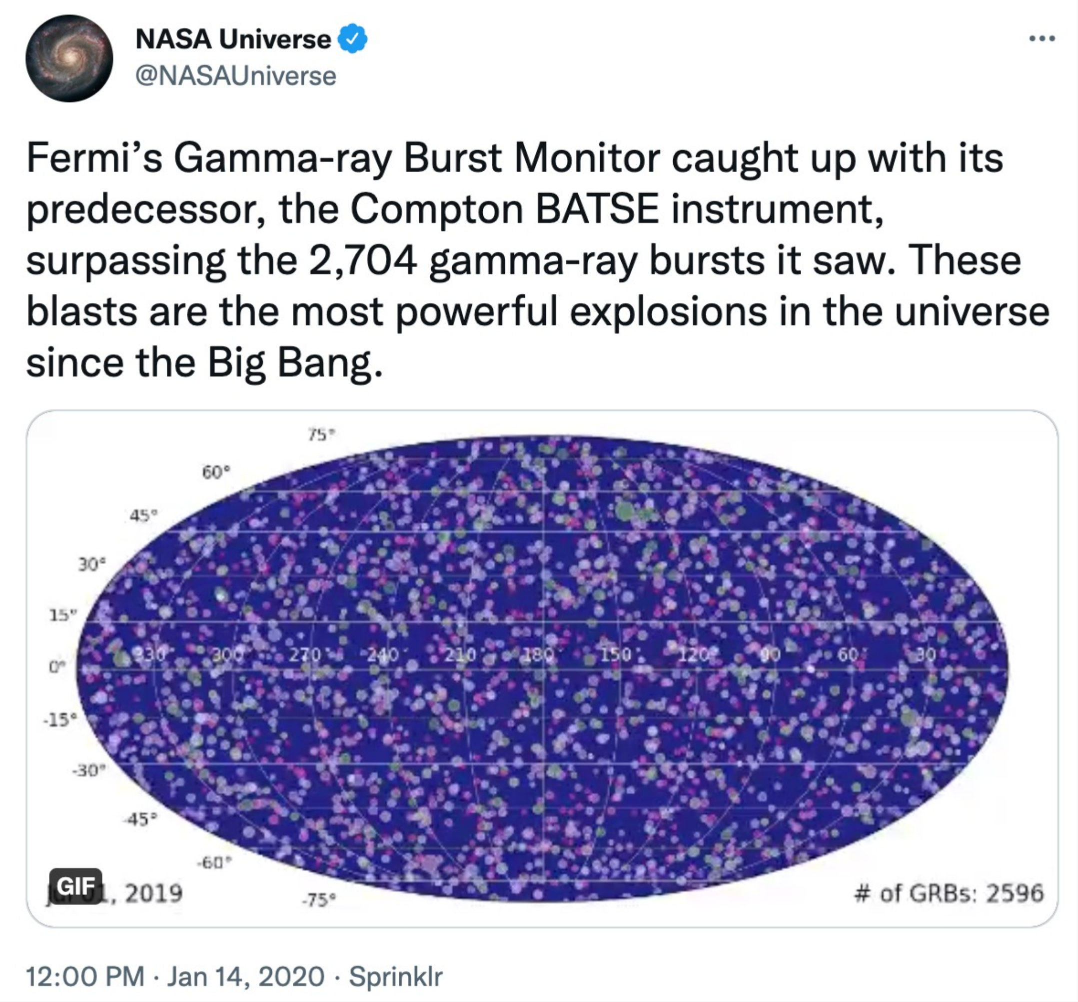
Solar Flares



10+ Years of Observations

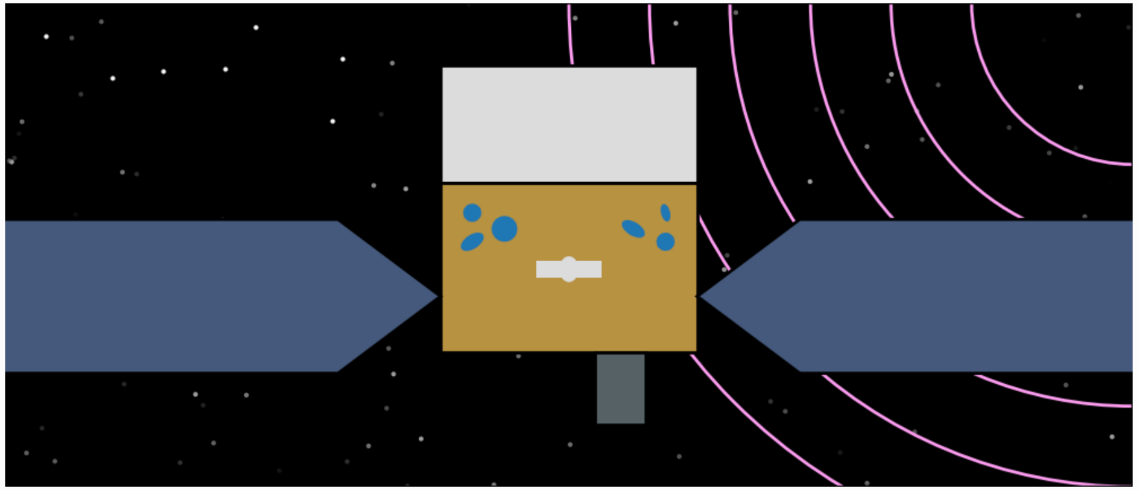
- more than 2300 GRBs over 10+ years
  - exceeded BATSE !
  - ~400 short GRBs
  - ~2000 long GRBs
  - 135 GRBs with redshift
- 10-year GRB Catalog (von Kienlin et al. 2020)

and Spectroscopy Catalog (Poolakkil et al. 2021)
  - Peak fluxes, fluences, durations, locations
  - Spectra, energetics
- With GBM observations of GRBs we have:
  - Produced groundbreaking understanding of the prompt energetics and jet structure
  - First coincident and independent detections of a single event in GWs and EM
  - Measured the speed of gravity relative to the speed of light



How Can You use GBM Data?

Welcome to the Fermi GBM Data Tools documentation!



Hello, I'm Fermi. Pleased to meet you!

https://fermi.gsfc.nasa.gov/ssc/data/analysis/rmfit/gbm_data_tools/gdt-docs/ (Check out the tutorials!)

https://github.com/USRA-STI/gdt-fermi

- The Fermi GBM Data Tools were released in 2022
- You can perform:
  - Download data
  - Look at the response files
  - See where Fermi was in orbit
  - Plot lightcurves
  - Do a localization
  - Do a spectral analysis
  - Simulate GBM data
  - And much more!
- We are currently expanding the GBM Data Tools to be the "Gamma-ray Data Tools"
  - This will include user friendly ways of using data from various gamma-ray missions (past and future)
  - Hosted on Github so community can contribute and provide feedback of issues.

Useful Links

- GBM Website: https://gammaray.nsstc.nasa.gov/
- GBM Data Tools Documentation: https://fermi.gsfc.nasa.gov/ssc/data/analysis/gbm/gbm_data_tools/gdt-docs/
- GBM Instrument Paper: https://iopscience.iop.org/article/10.1088/0004-637X/702/1/791/pdf
- Targeted Search Papers: https://arxiv.org/pdf/1903.12597.pdf, https://arxiv.org/pdf/1806.02378.pdf