



Overview of Fermi Gamma-ray Burst Monitor

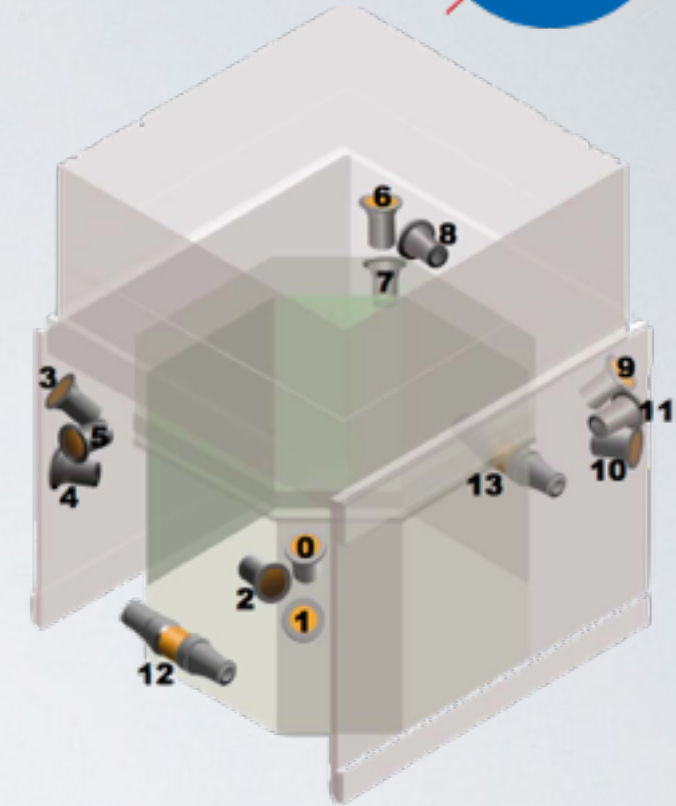
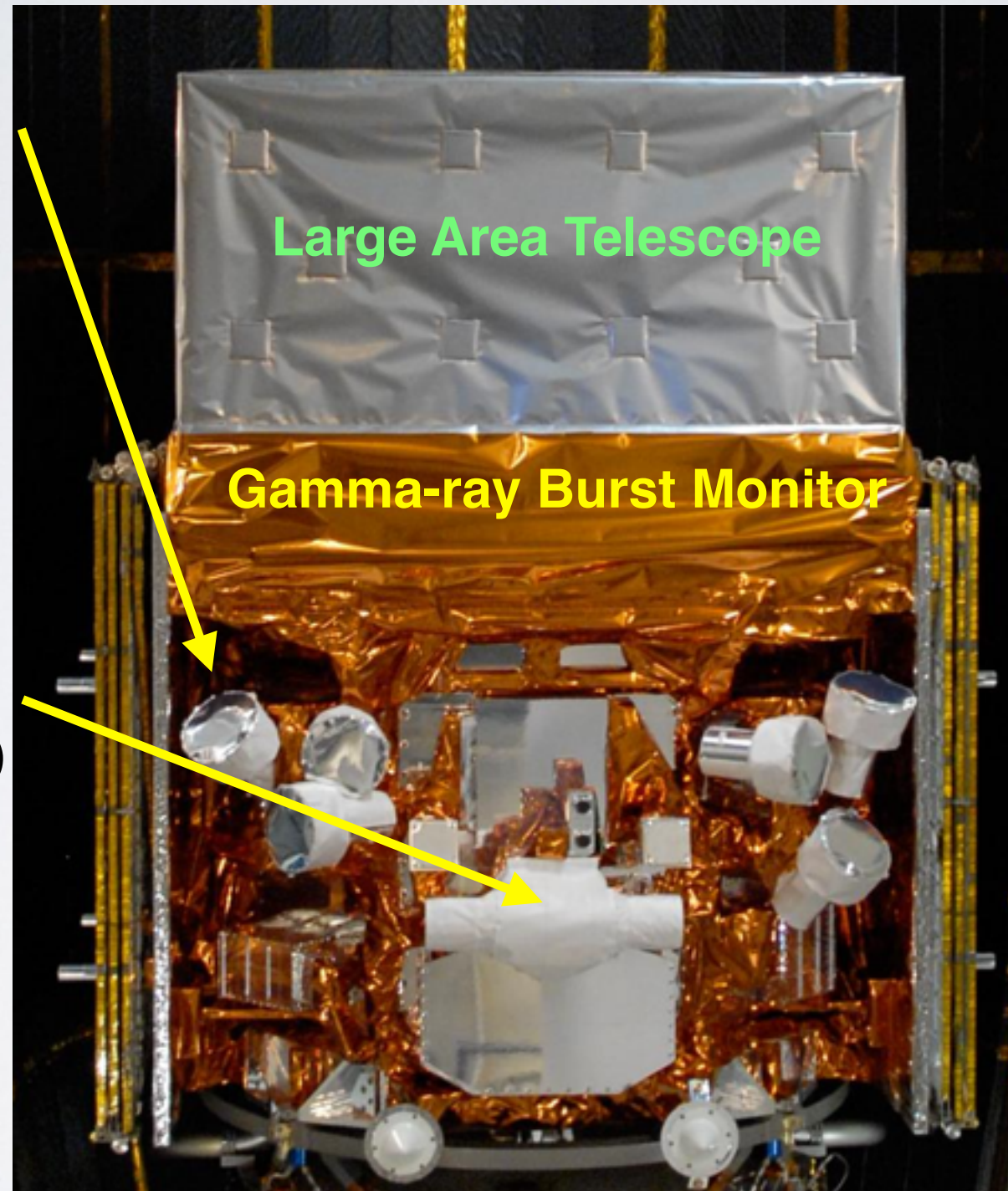
C. Michelle Hui, NASA/MSFC
Fermi Summer School 2018



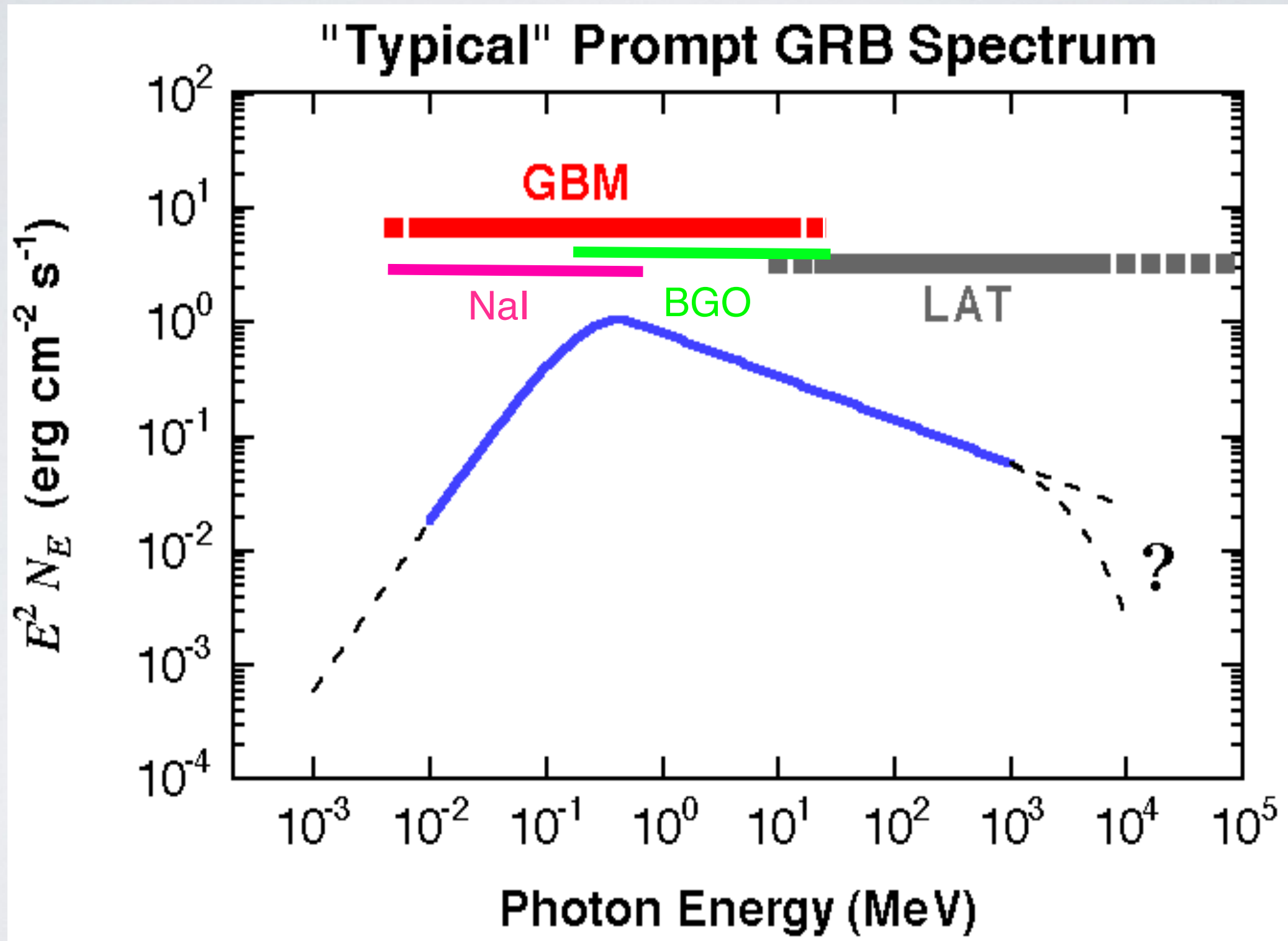
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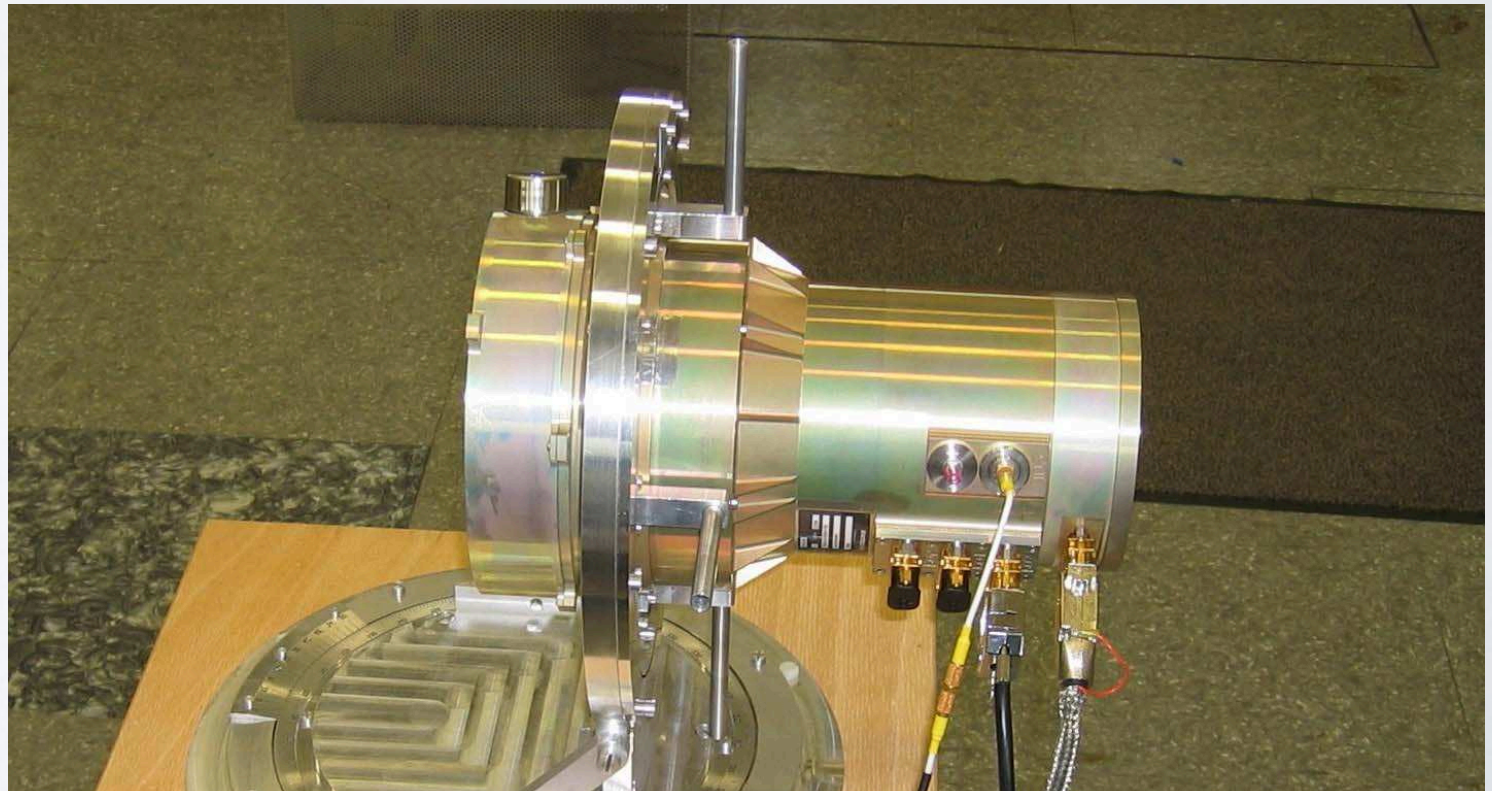
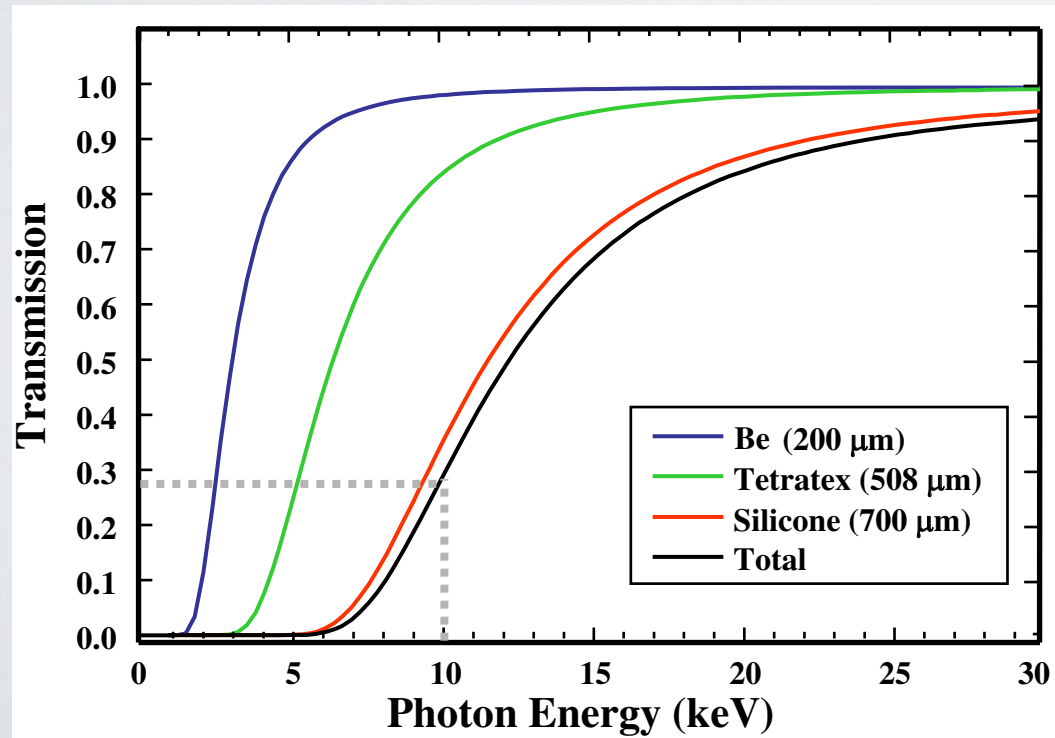
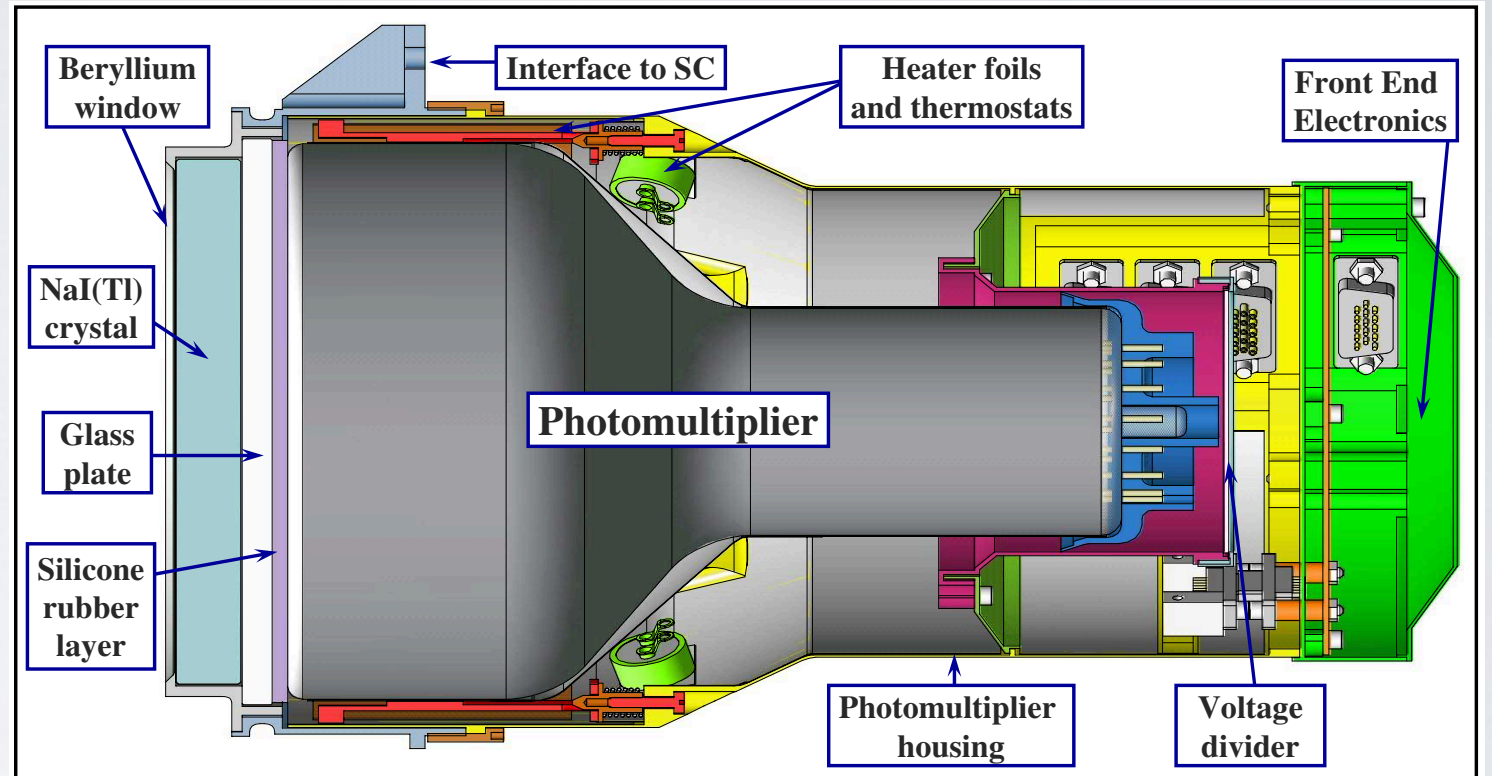
12 NaI detectors
(8keV—1MeV)



2 BGO detectors
(200keV—40MeV)

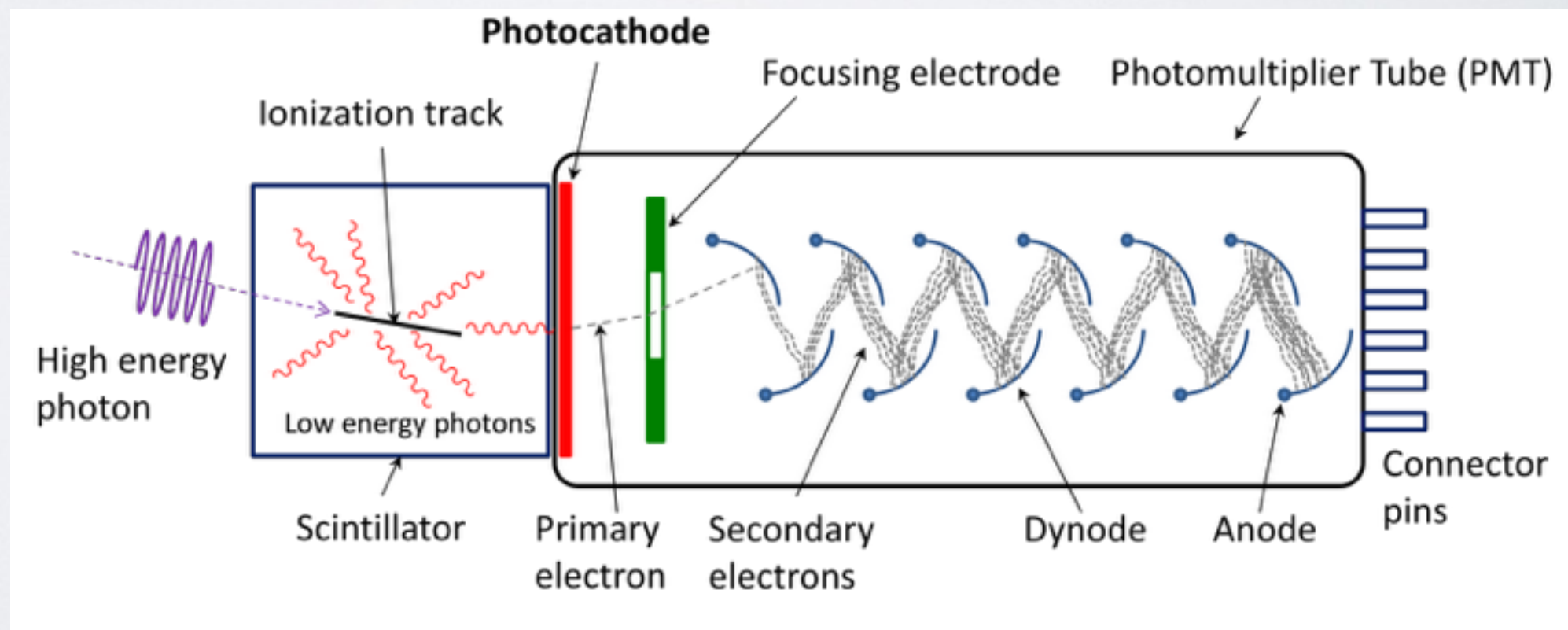
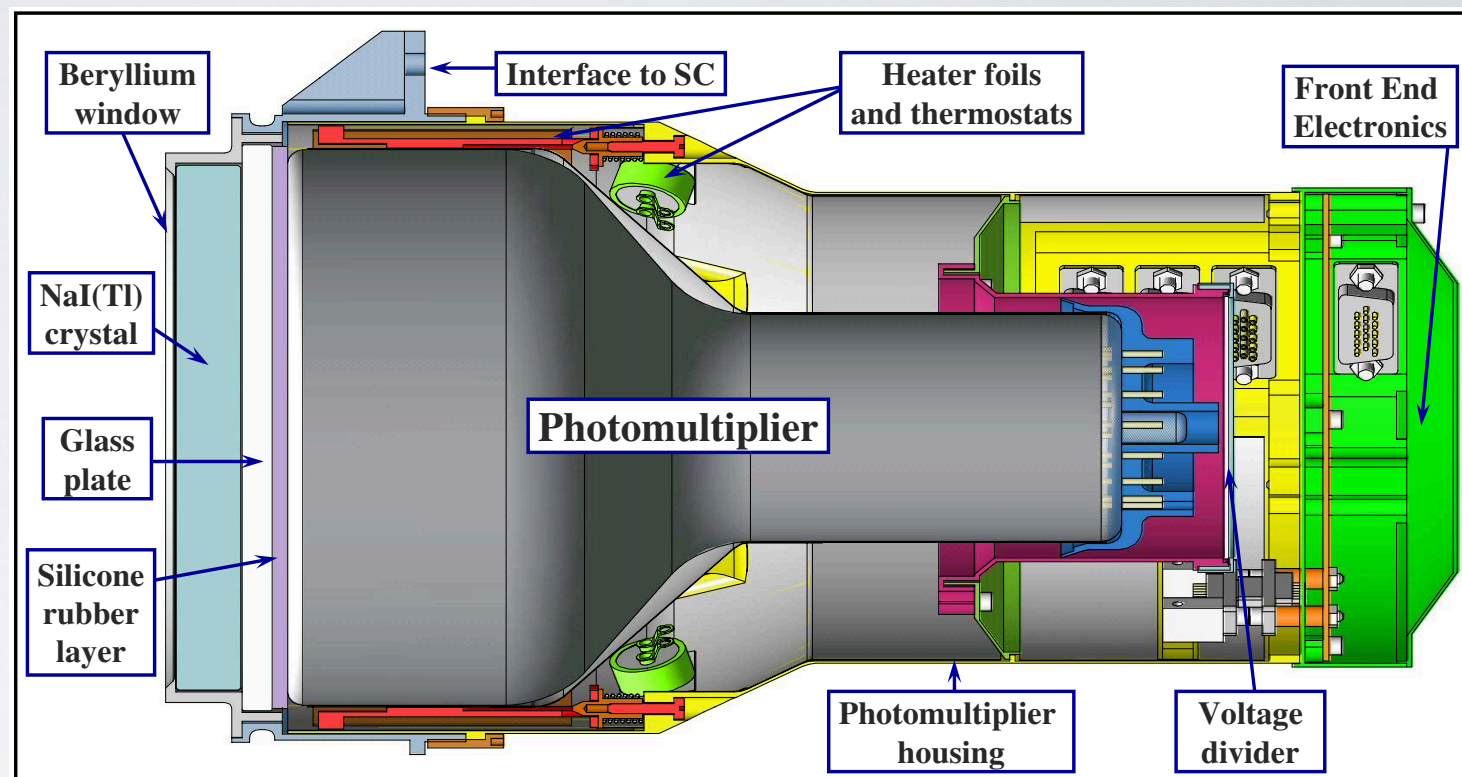


- 5" thick NaI crystal
- NaI is hygroscopic, hermetically sealed in Al-housing with Be window (transmission down to 5keV)
- Si layer for stability



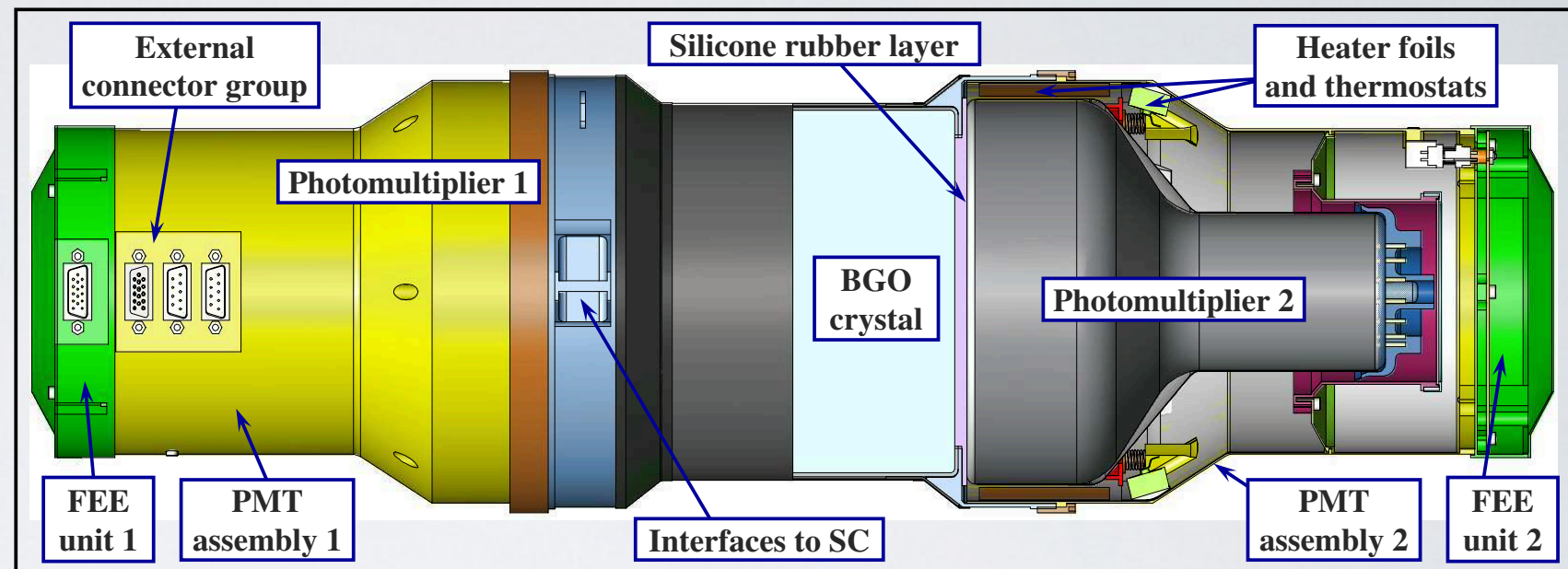
Gamma-ray Burst Detector

- 5" thick NaI crystal
- NaI is hygroscopic, hermetically sealed in Al-housing with Be window (transmission down to 5keV)
- Si layer for stability



Gamma-ray Burst Detector

- BGO extends to higher energies (0.2 – 40 MeV)
- mounted on opposite sides of spacecraft
- two PMTs for better light collection and redundancy



Gamma-ray Burst Detector Performance

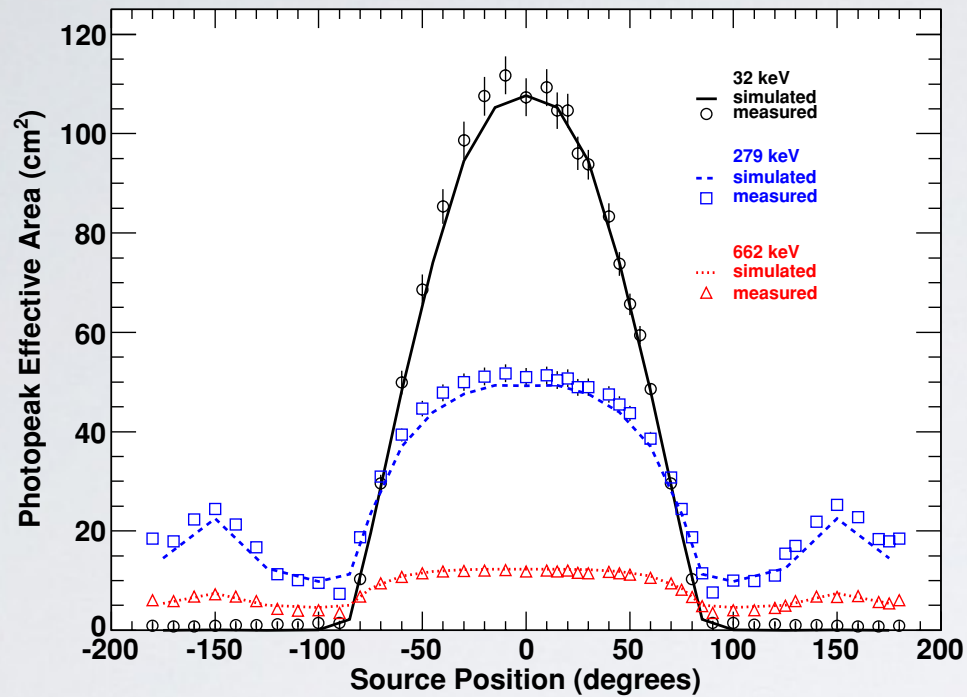


Figure 12. Angular dependence of the NaI detector effective area.

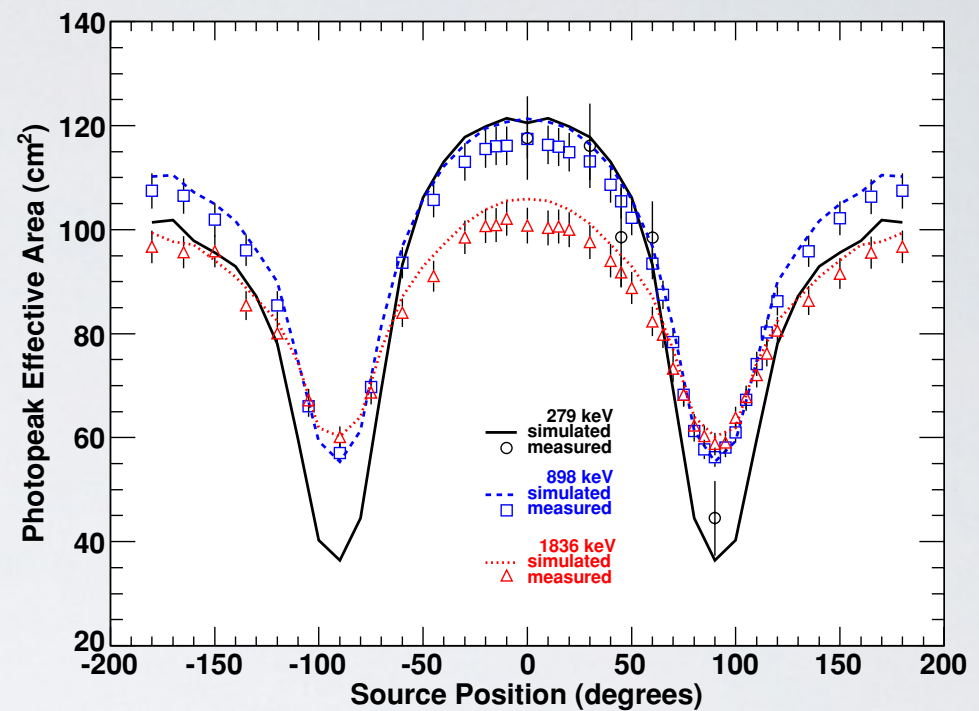
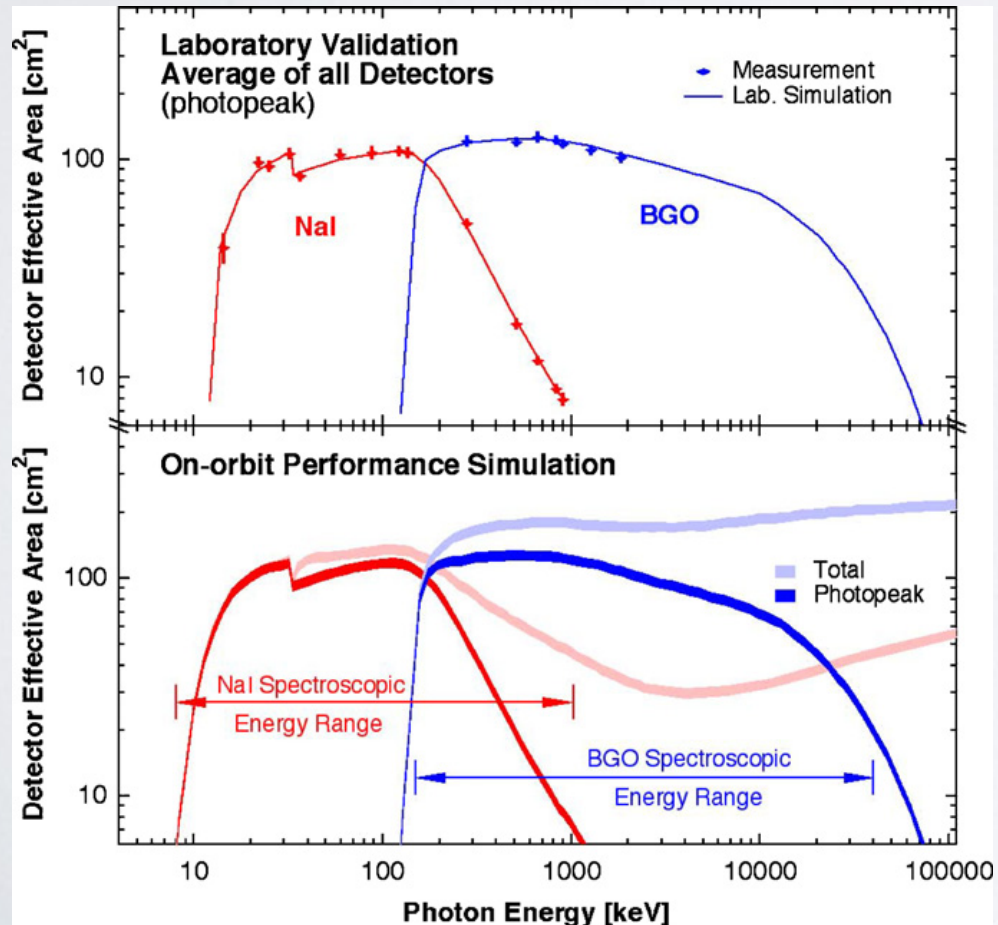
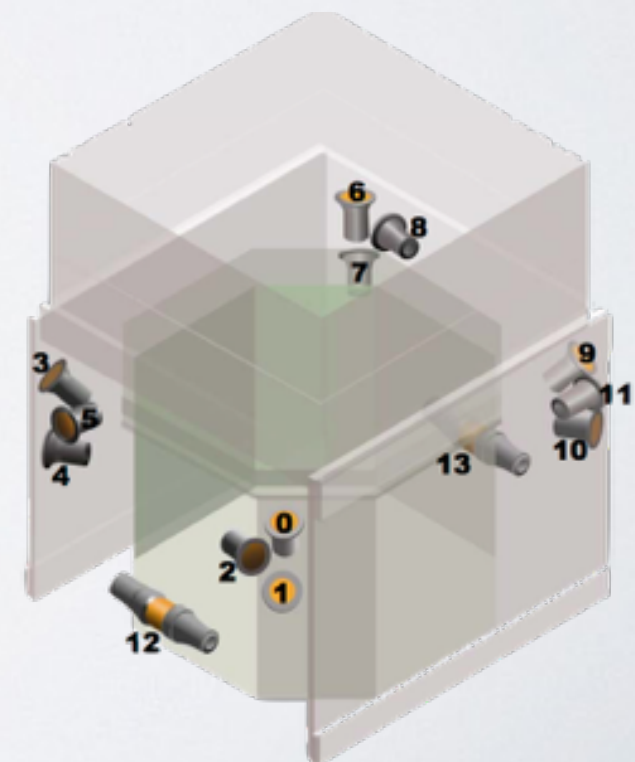


Figure 13. Angular dependence of the BGO detector effective area.

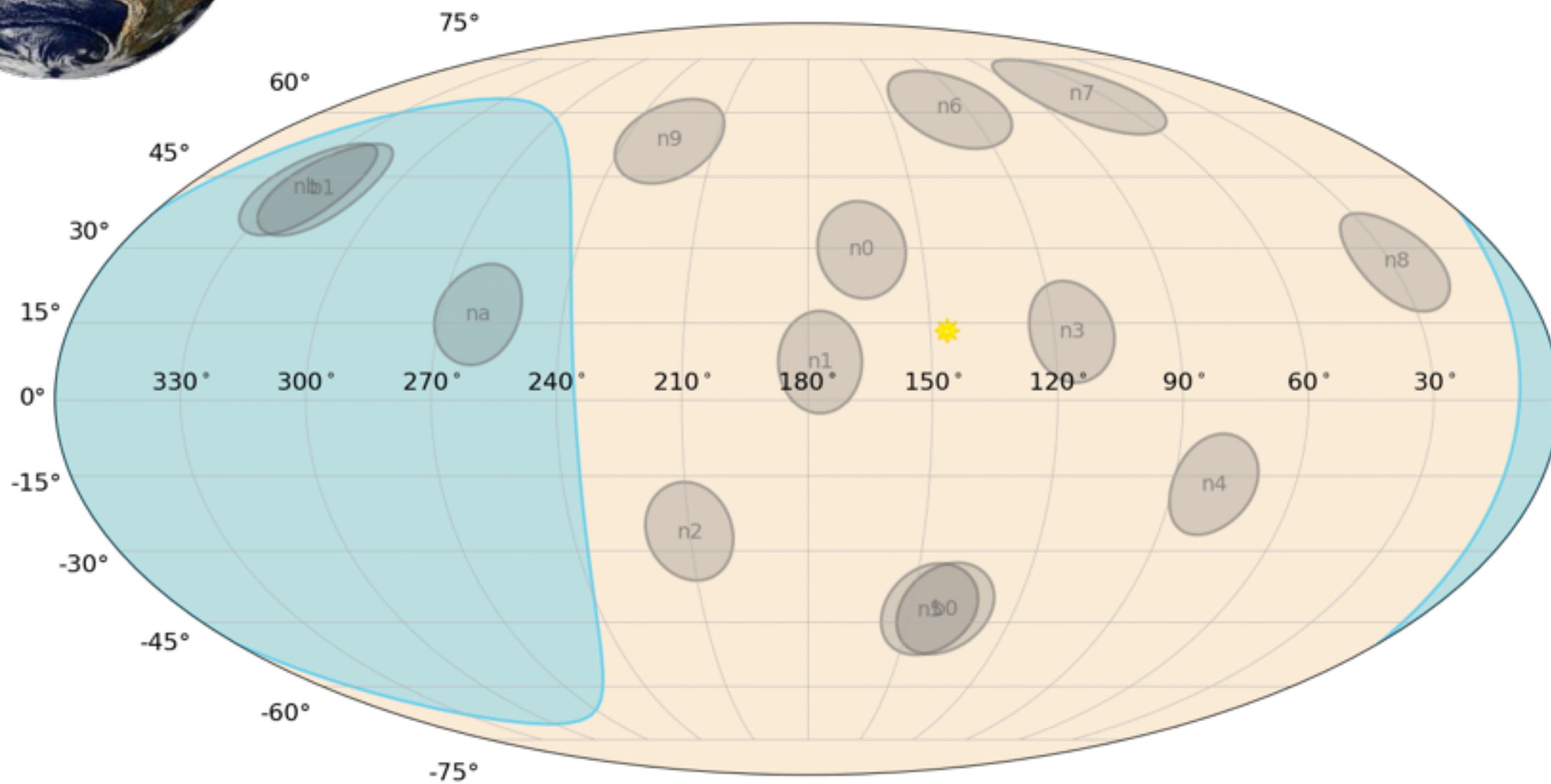


- angular response: shadowing by detector housing
- on-orbit simulation includes spacecraft blockage and scattering.



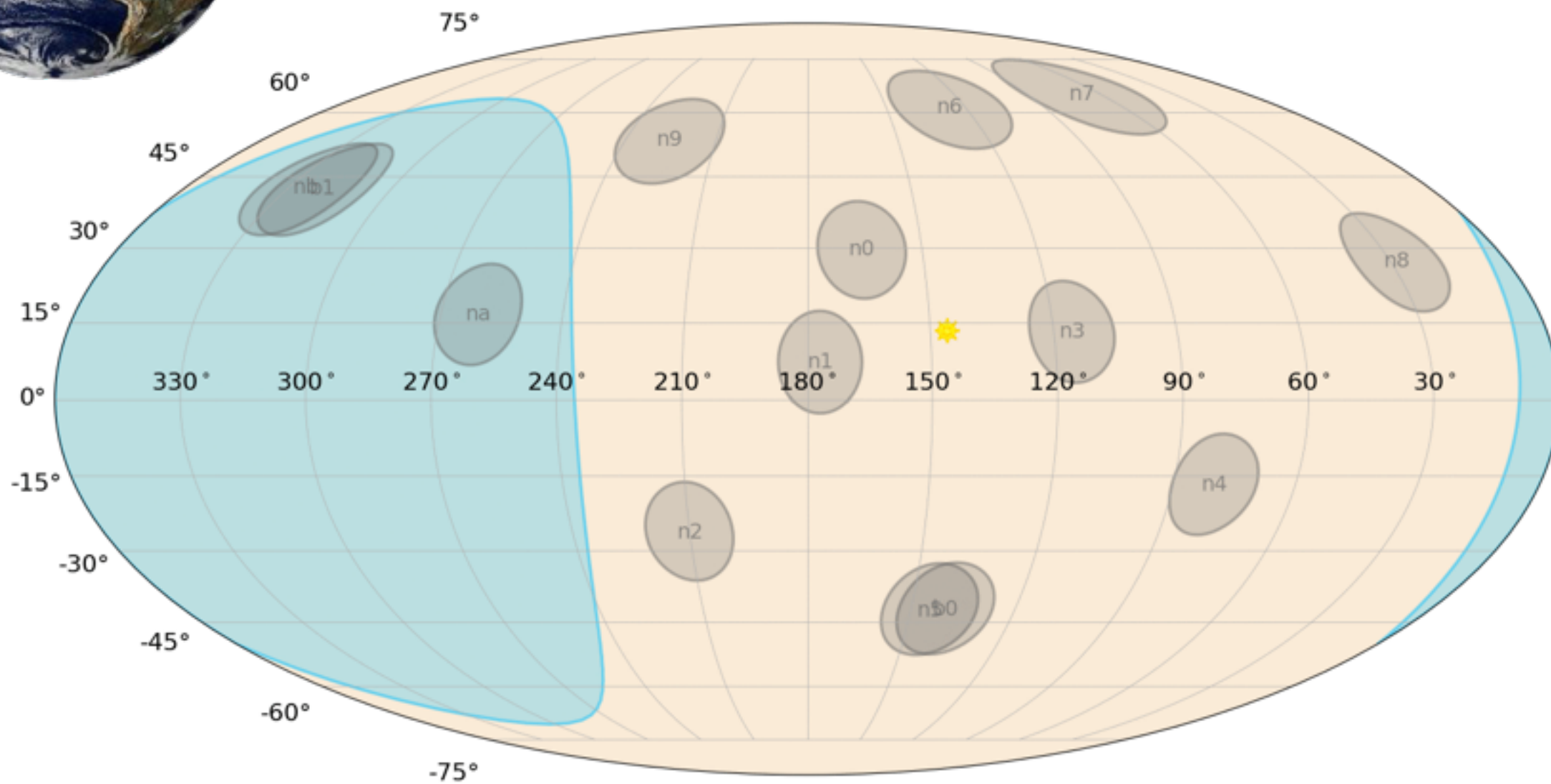
GBM Sky Coverage

GBM instantaneous field of view: ~70% of the sky
~87% uptime (off during South Atlantic Anomaly)

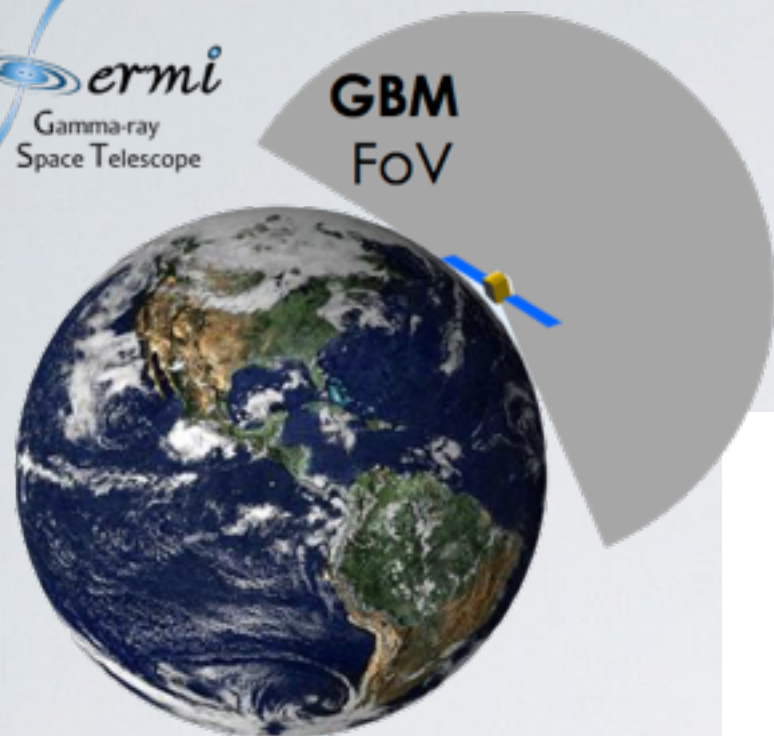


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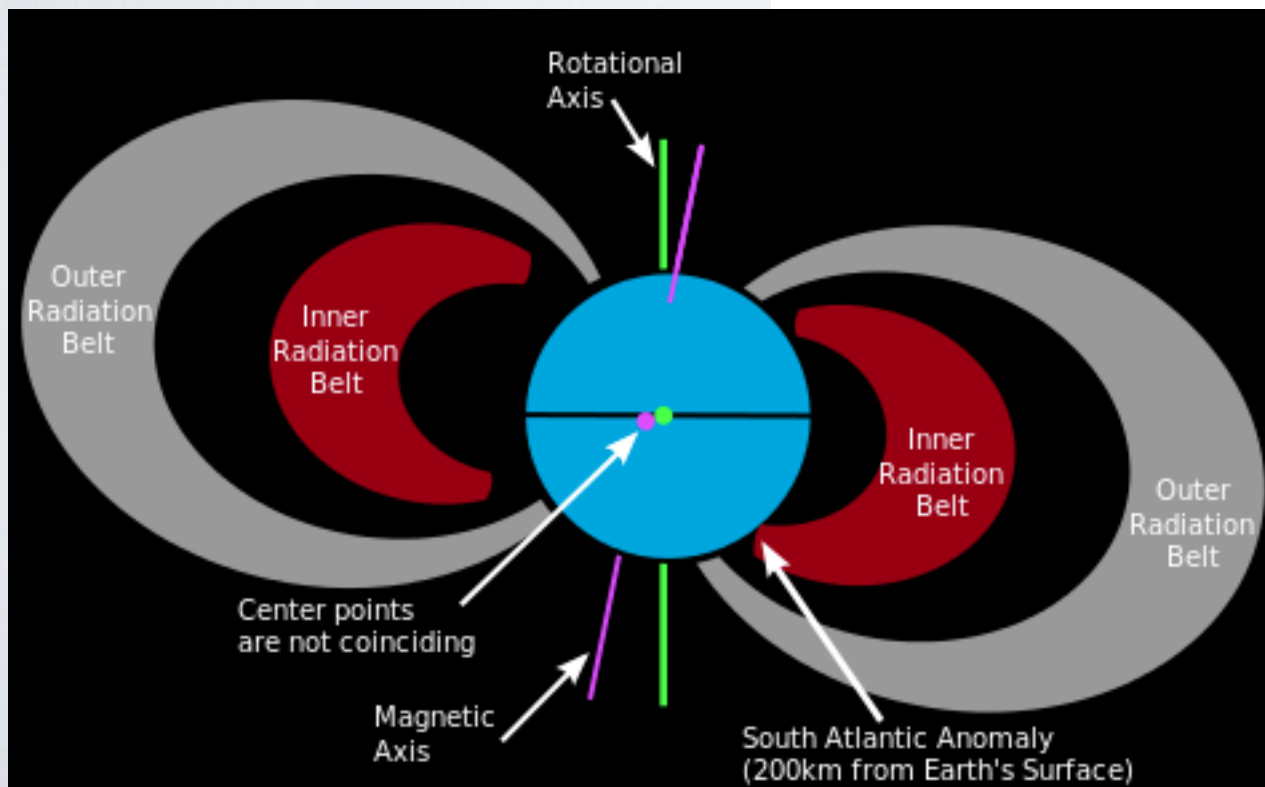
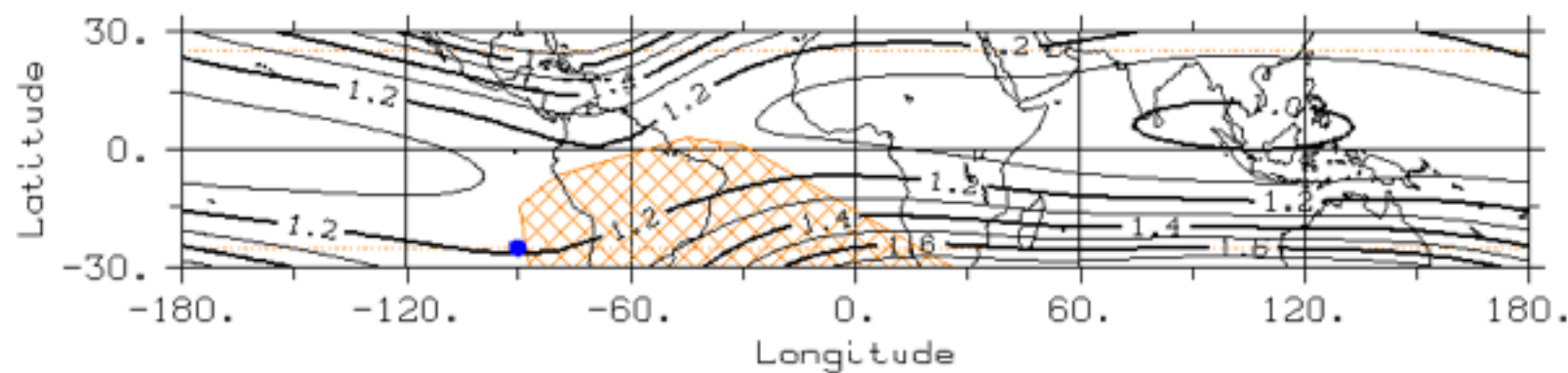


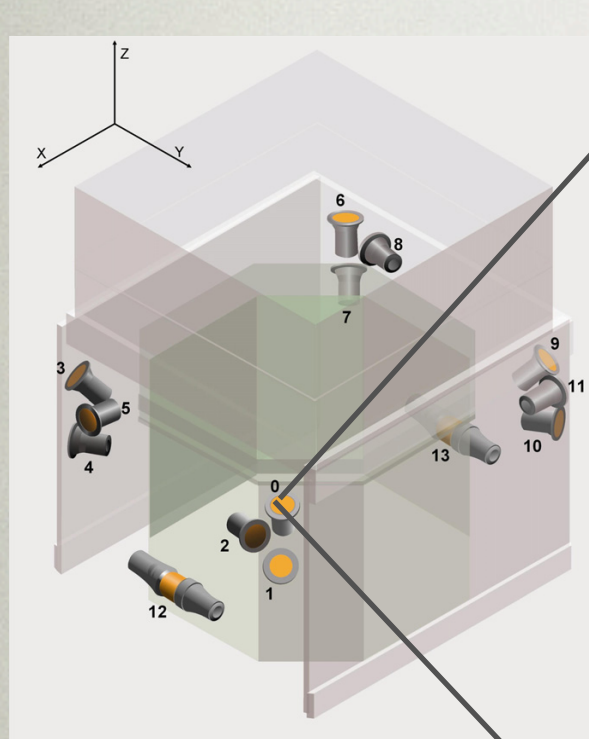
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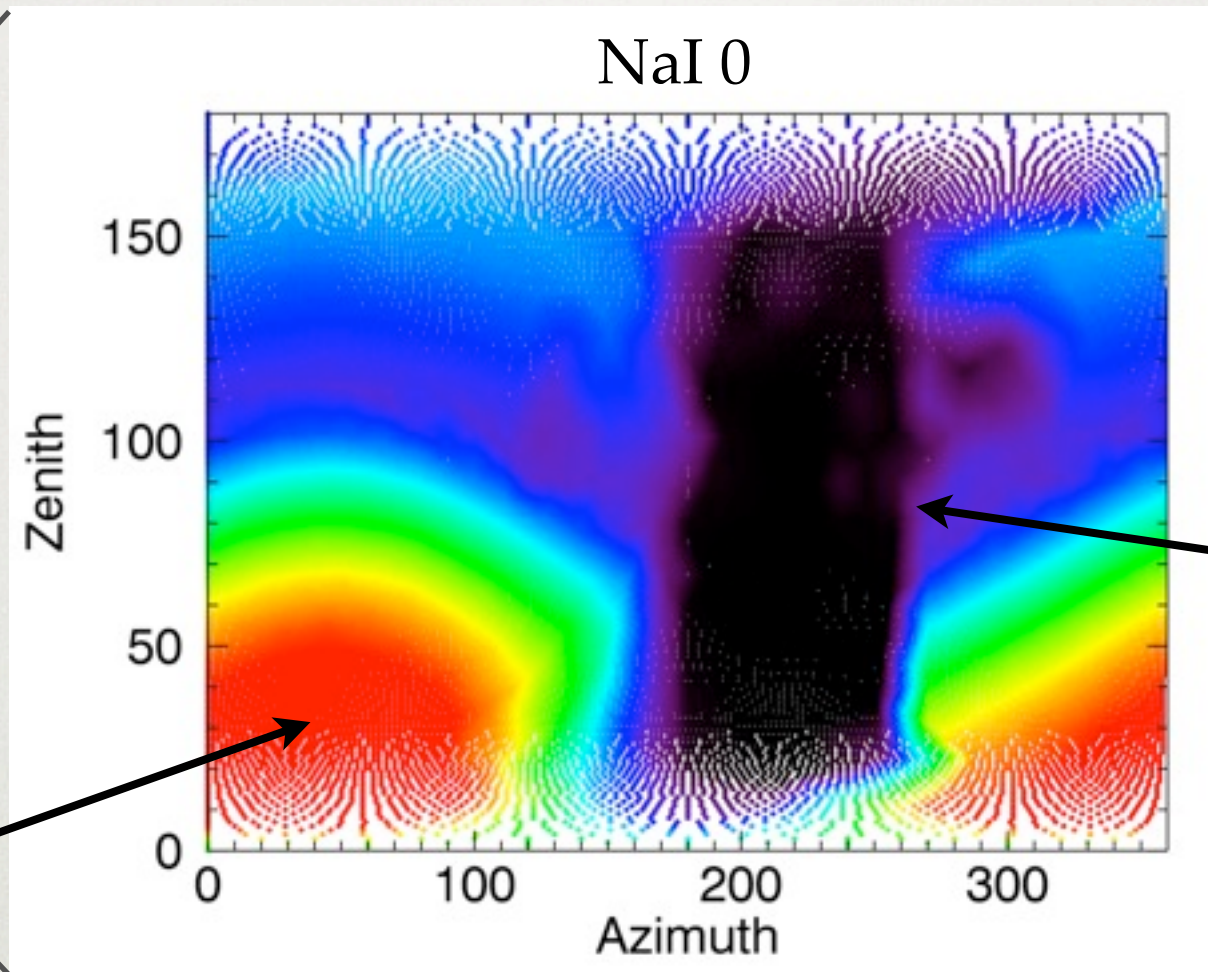
GBM instantaneous field of view: ~70% of the sky
~87% uptime (off during South Atlantic Anomaly)

GBM Trigger 180509237
East Longitude = 269.67 deg & Latitude = -25.28 deg
McIlwain L = 1.19





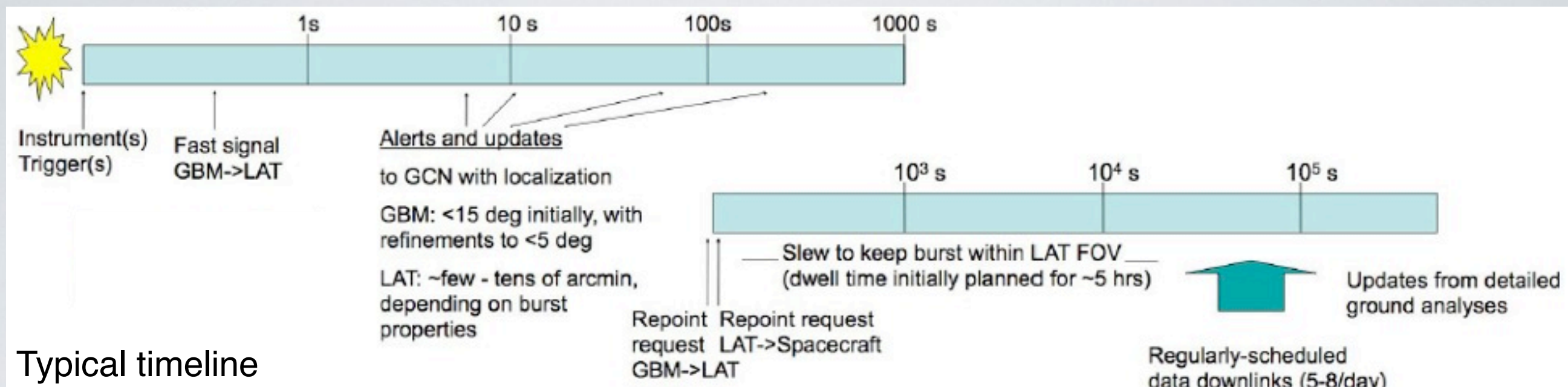
High Rates



Low Rates -
Spacecraft Blockage

- Localization is performed by comparing the observed rates from the trigger in each detector to the expected rates on a 1deg grid.
- Requires spectral assumption (3 templates), and sky grid limit to statistical minimum uncertainty of 1 deg radius.

GBM Trigger Timeline



GCN: The Gamma-ray Coordinates Network

Notices by Fermi-GBM:

FERMI_GBM_ALERT	~10s	triggered time, lightcurves
FERMI_GBM_FLT_POSITION	~30s	flight location, classification, lightcurves
FERMI_GBM_GND_POSITION	~45s	ground location, lightcurves, map
FERMI_GBM_FINAL_POSITION	minutes — hour	final position, lightcurves, map (healpix)
Circular	few hours	temporal and spectral analyses, or misclassification report

Triggering algorithms:

- In-orbit count rate increase in 2+ NaI detectors above adjustable threshold above background (70 algorithms operating simultaneously)
 - between 4.5 and 7.5 sigma
 - 10 timescales — 16ms up to 8.096s
 - 4 energy ranges — [50-300], [25-50], >100, >300 keV
- Ground-based offline search for rate increase
- Long transients and persistent sources:
 - Earth occultation
 - Pulsar phase folding

GBM Data Products

<https://fermi.gsfc.nasa.gov/ssc/data/access/gbm/>

Data products:

- TRIGDAT, triggered data — mainly for localization and quick look
 - 1024/256/64 ms, 8 energy channels
- CTIME, continuous high time resolution
 - 256 (64) ms, 8 energy channels
- CSPEC, continuous high spectral resolution
 - 4096 (1024) ms, 128 energy channels
- TTE / CTTE, time tagged events
 - 2 μ s, 128 energy channels
 - Continuous TTE enabled Nov 2012, hourly files available

daily (triggered burst)

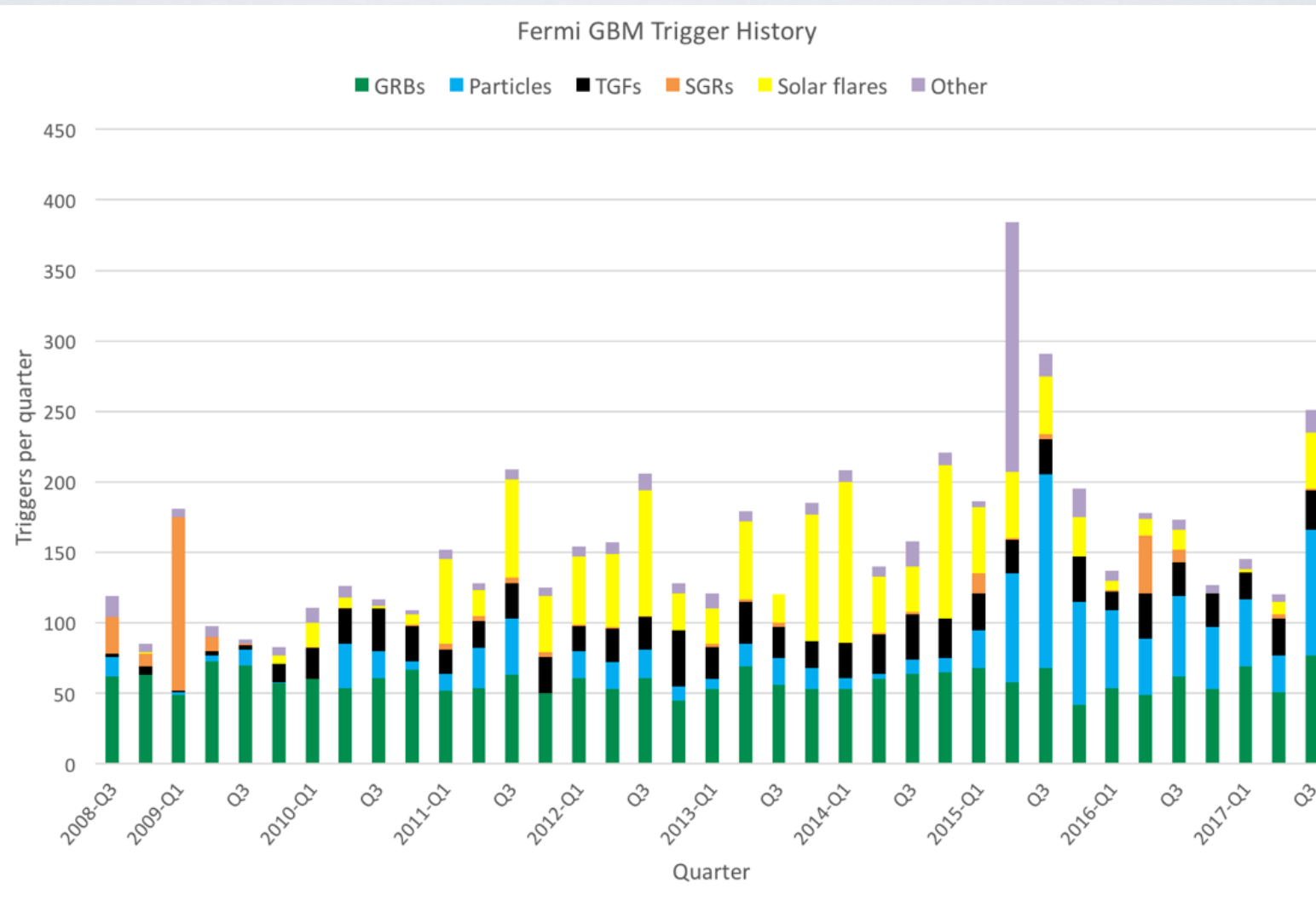
GBM Triggers

6222 triggers in ~9 years

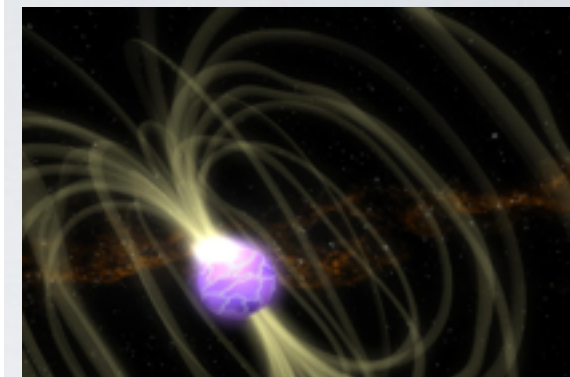
2238 GRBs



1176 Solar Flares



275 Magnetars



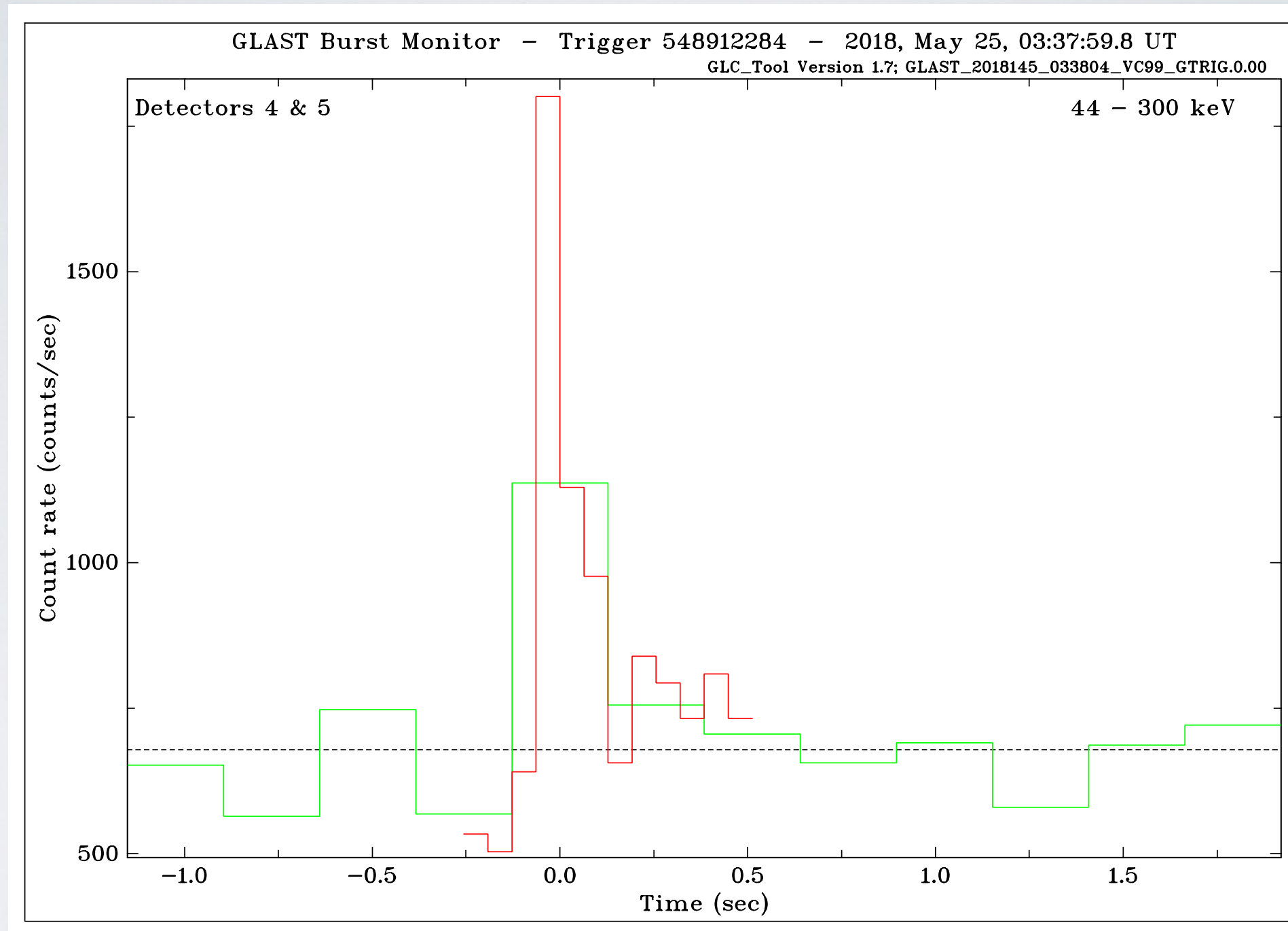
875 TGFs



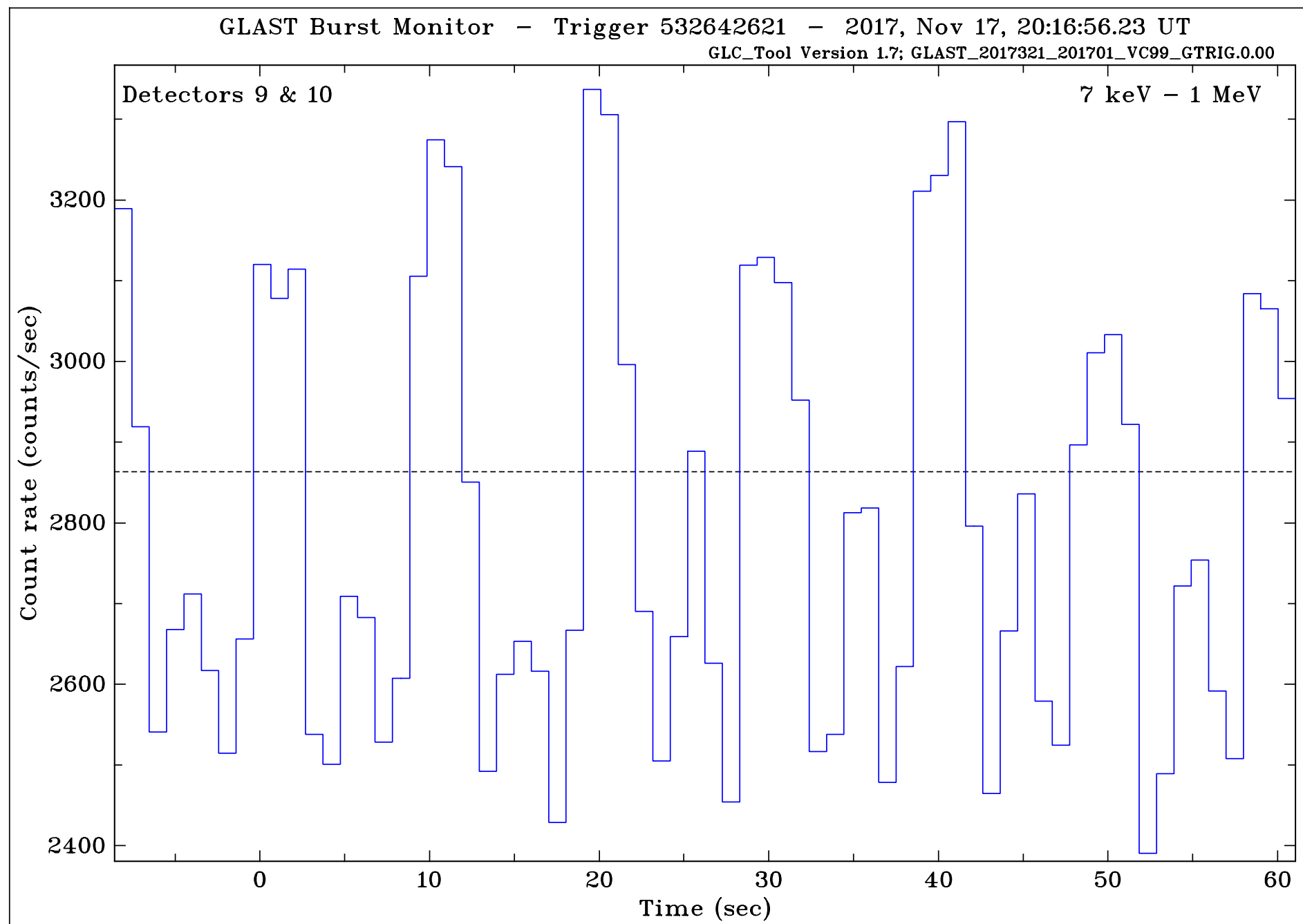
668 Others (pulsars and binaries)

1041 particles

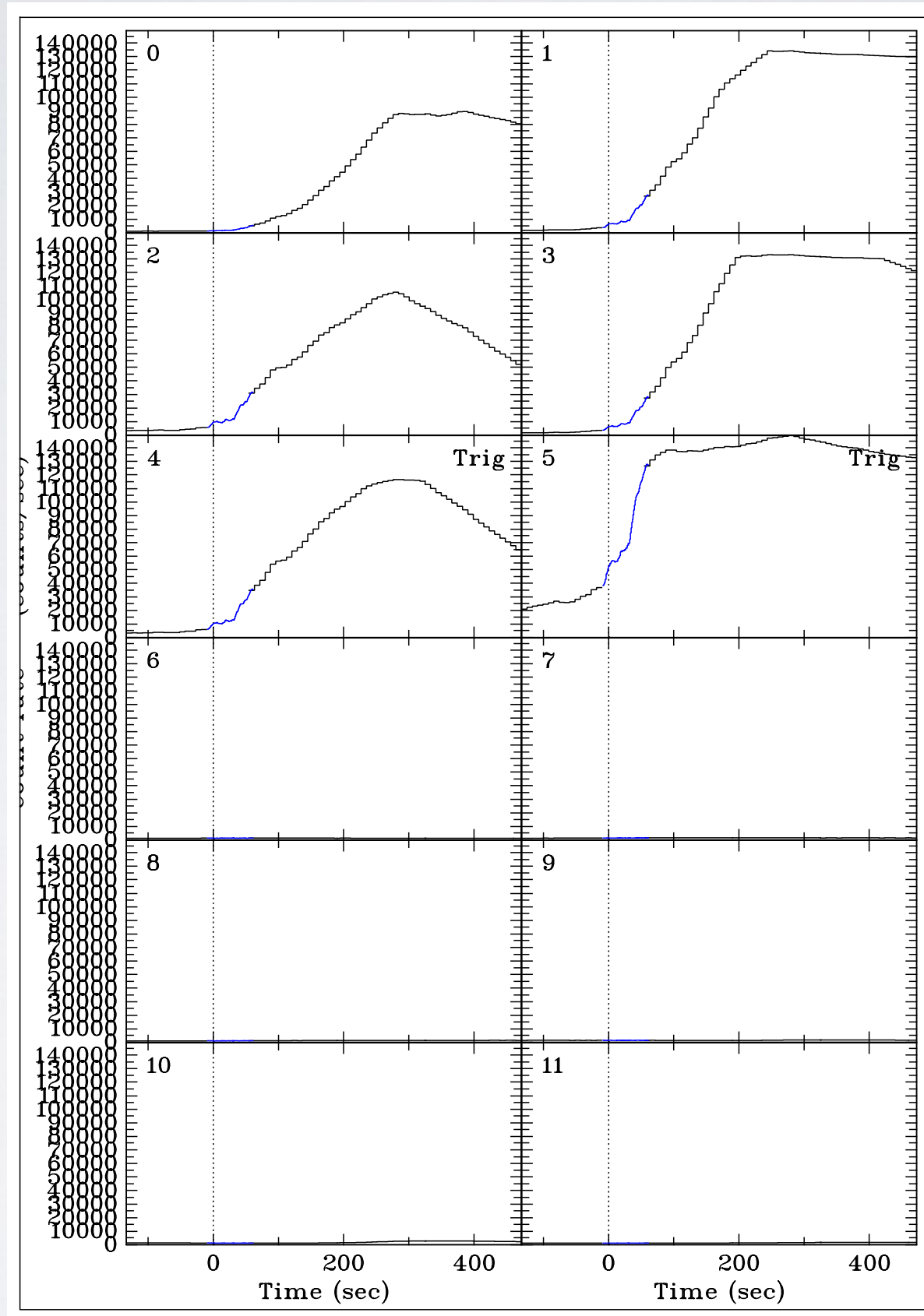
GBM Triggers



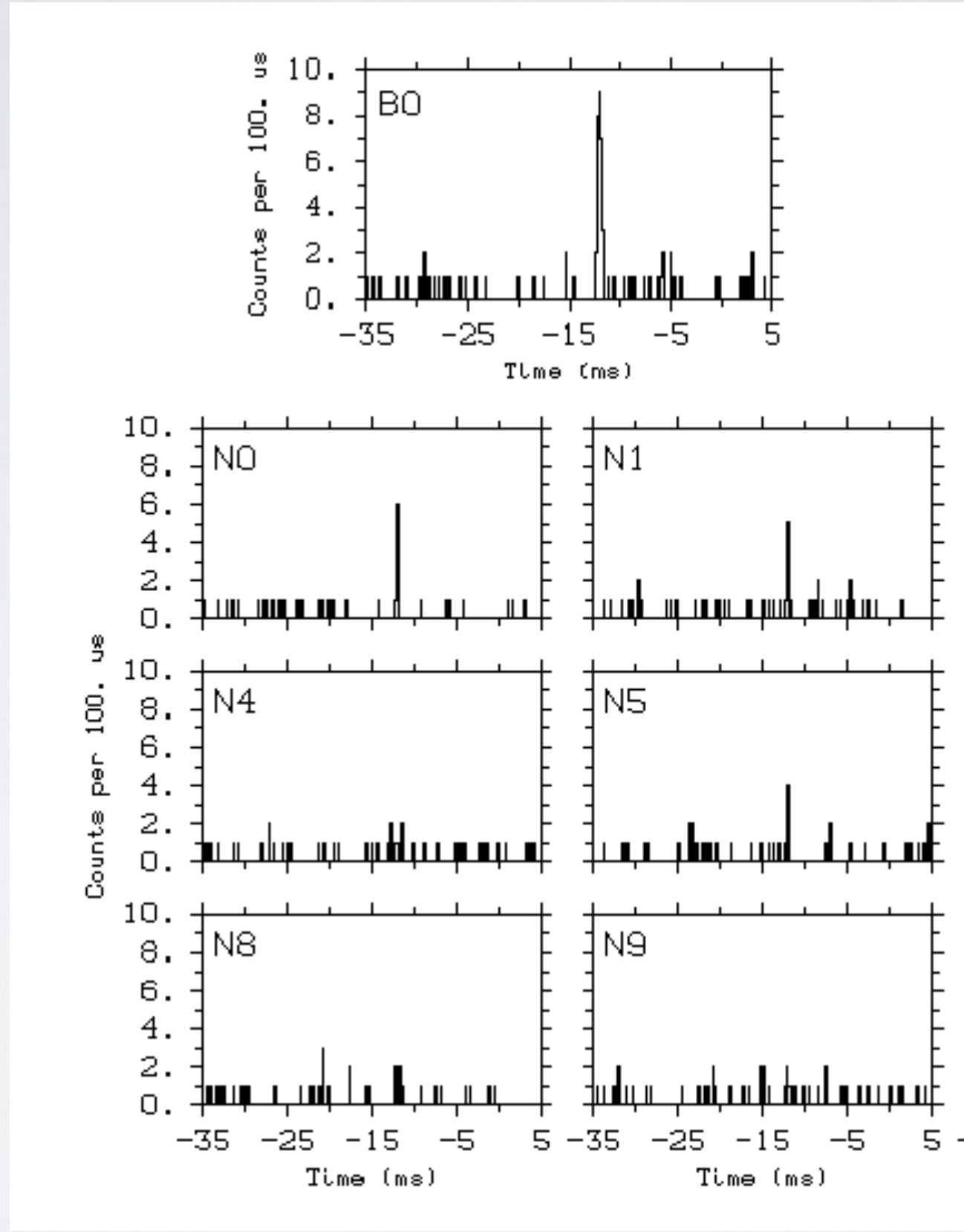
GBM Triggers



GBM Triggers



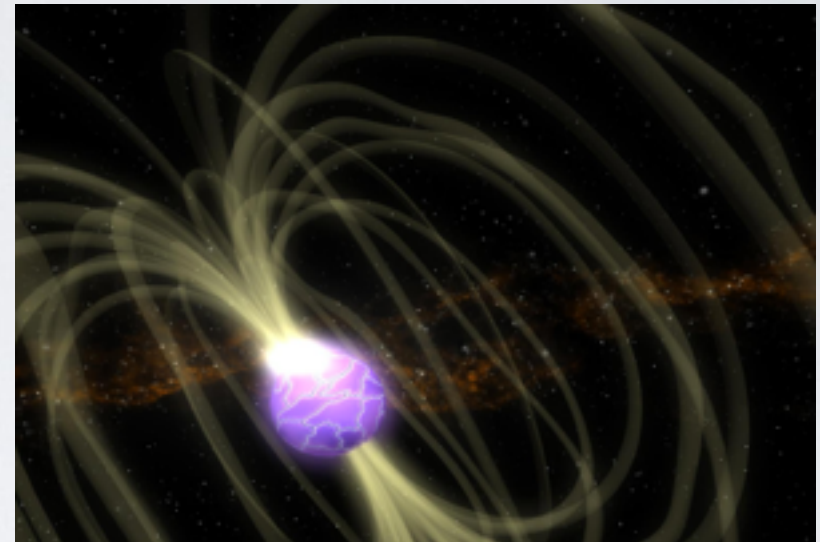
GBM Triggers



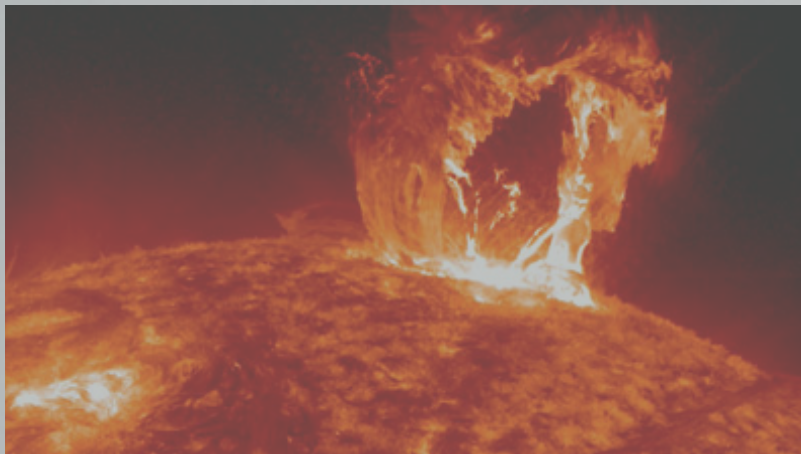
Gamma-ray Burst



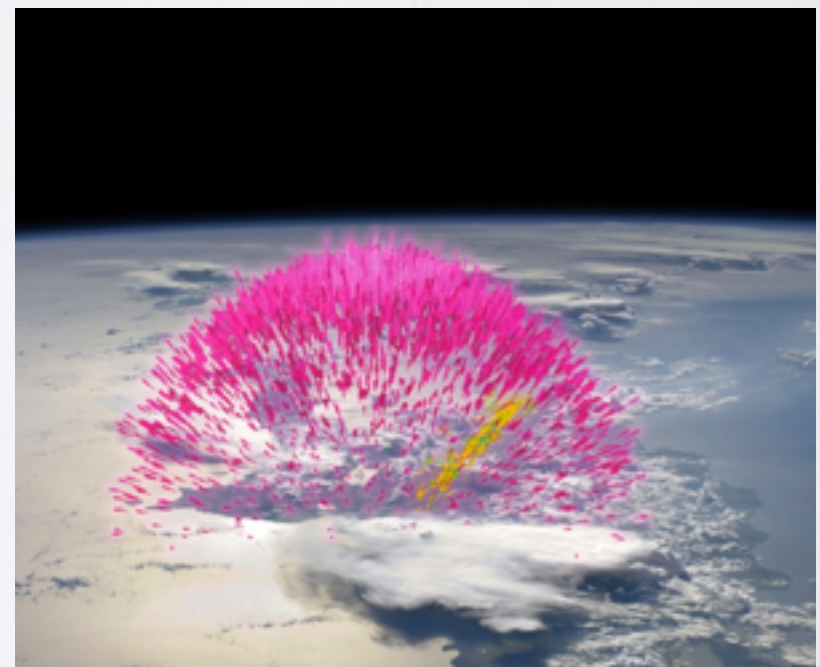
Galactic — pulsars, magnetars



Solar flares



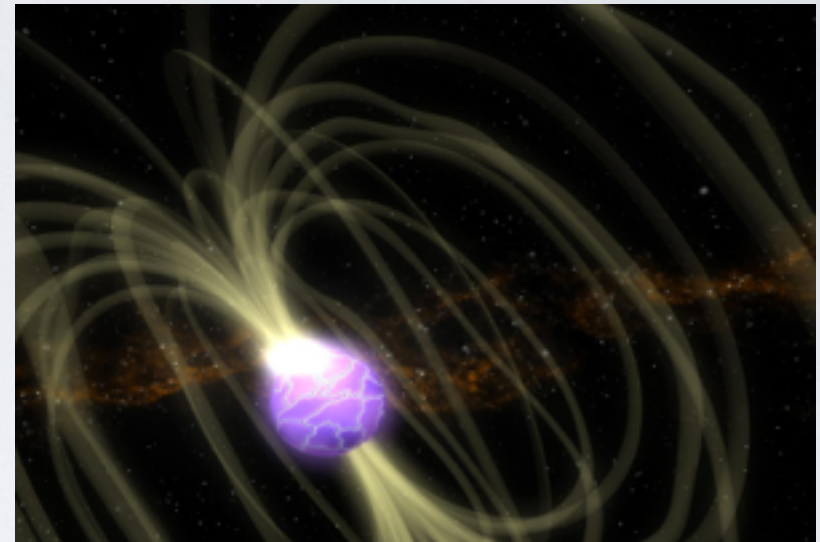
Terrestrial Gamma-ray Flashes



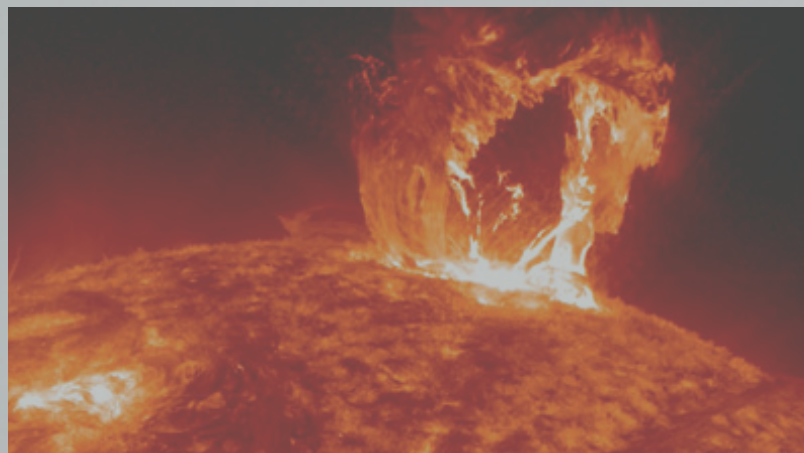
Gamma-ray Burst



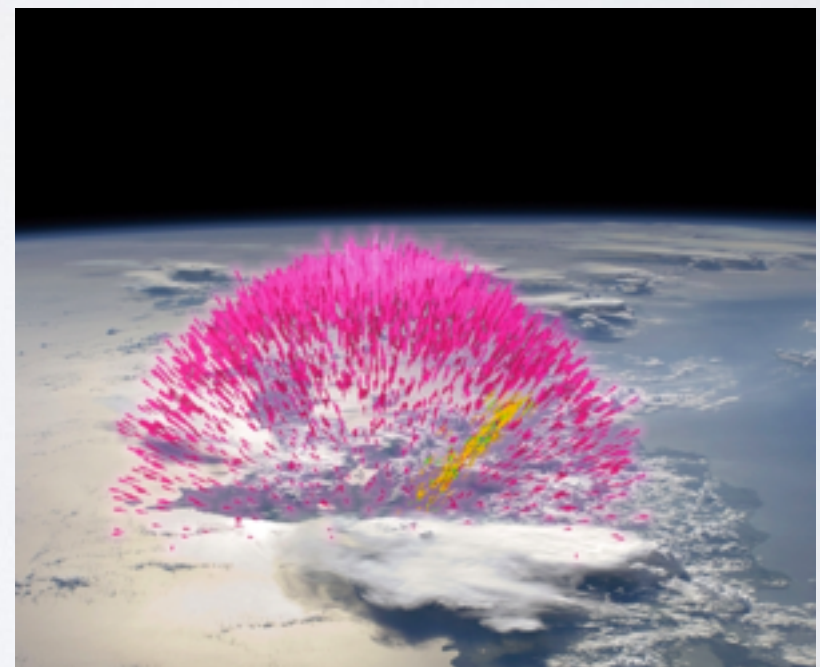
Galactic — pulsars, magnetars



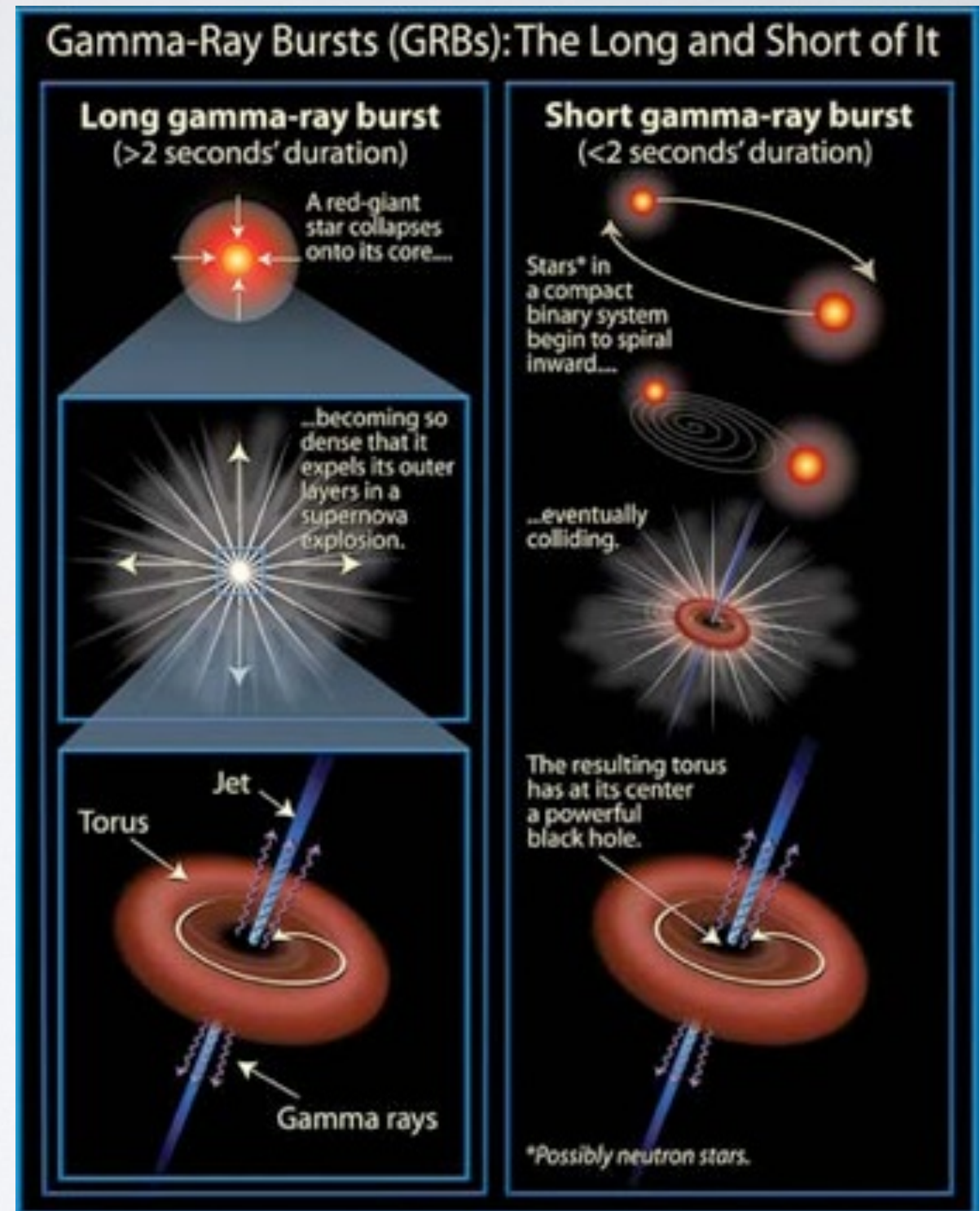
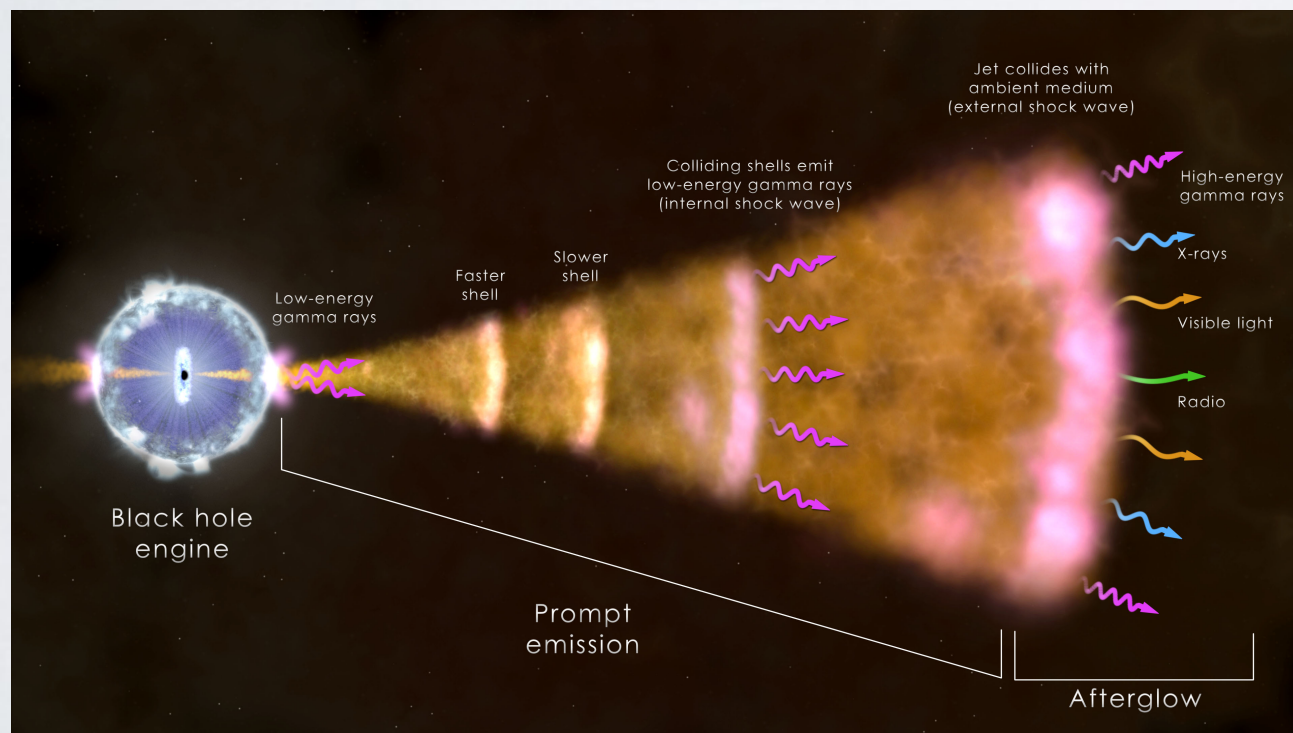
Solar flares



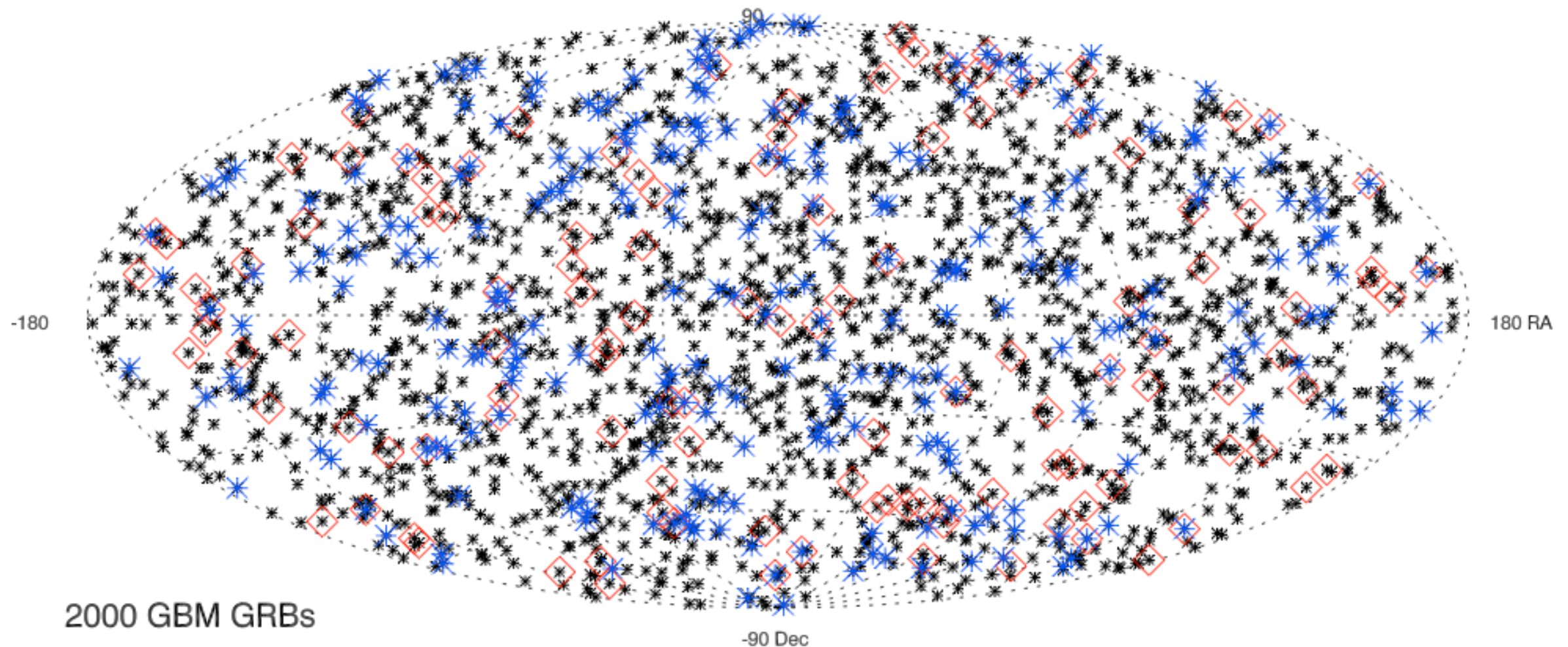
Terrestrial Gamma-ray Flashes



- Collapse of a massive star or merger of two compact objects.
- Collimated relativistic outflow.
- Prompt keV-MeV emission, afterglow in other wavelengths.
- Detected ~ once per day, distributed all over the sky.



2000 Fermi GBM GRBs



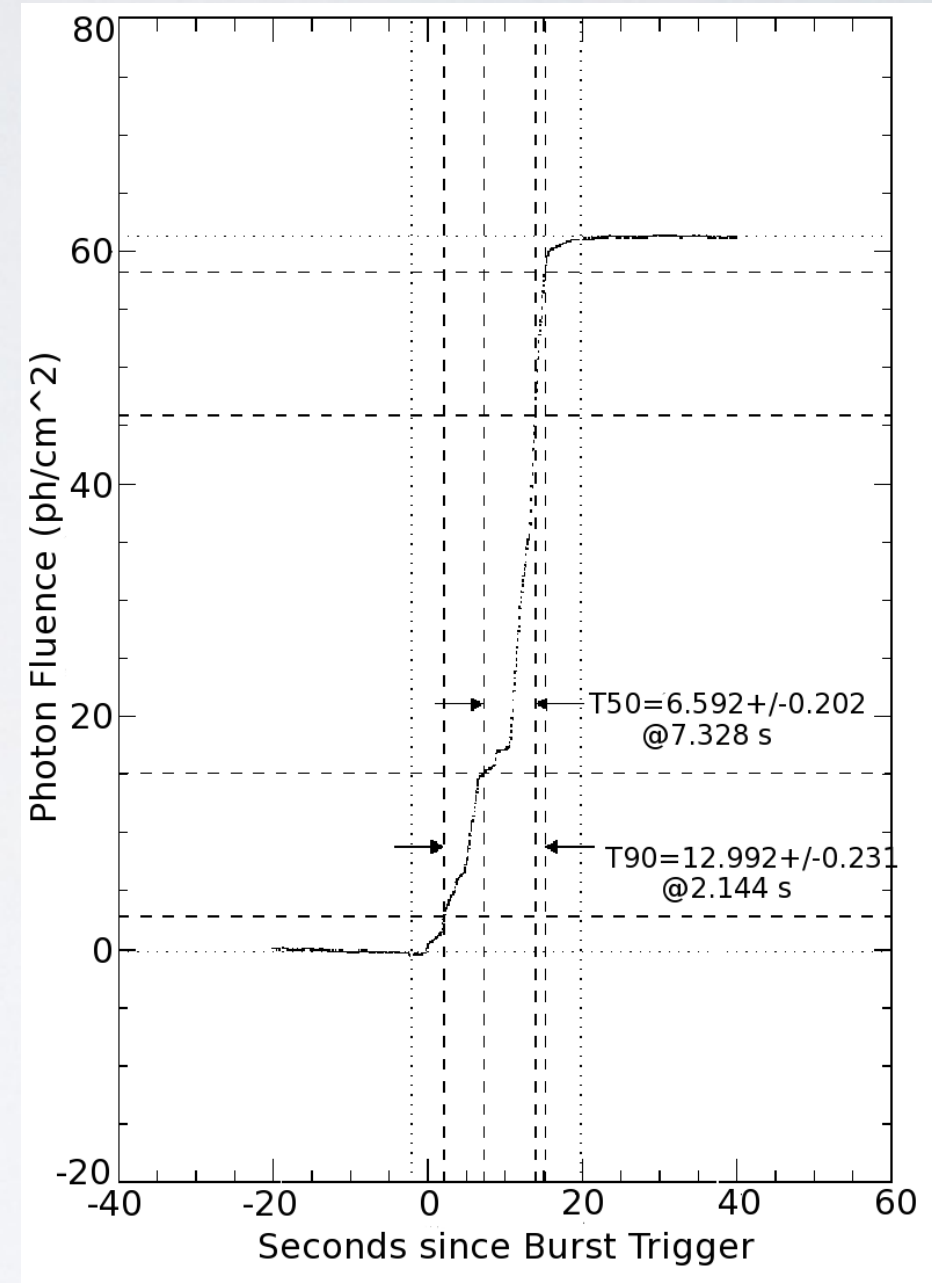
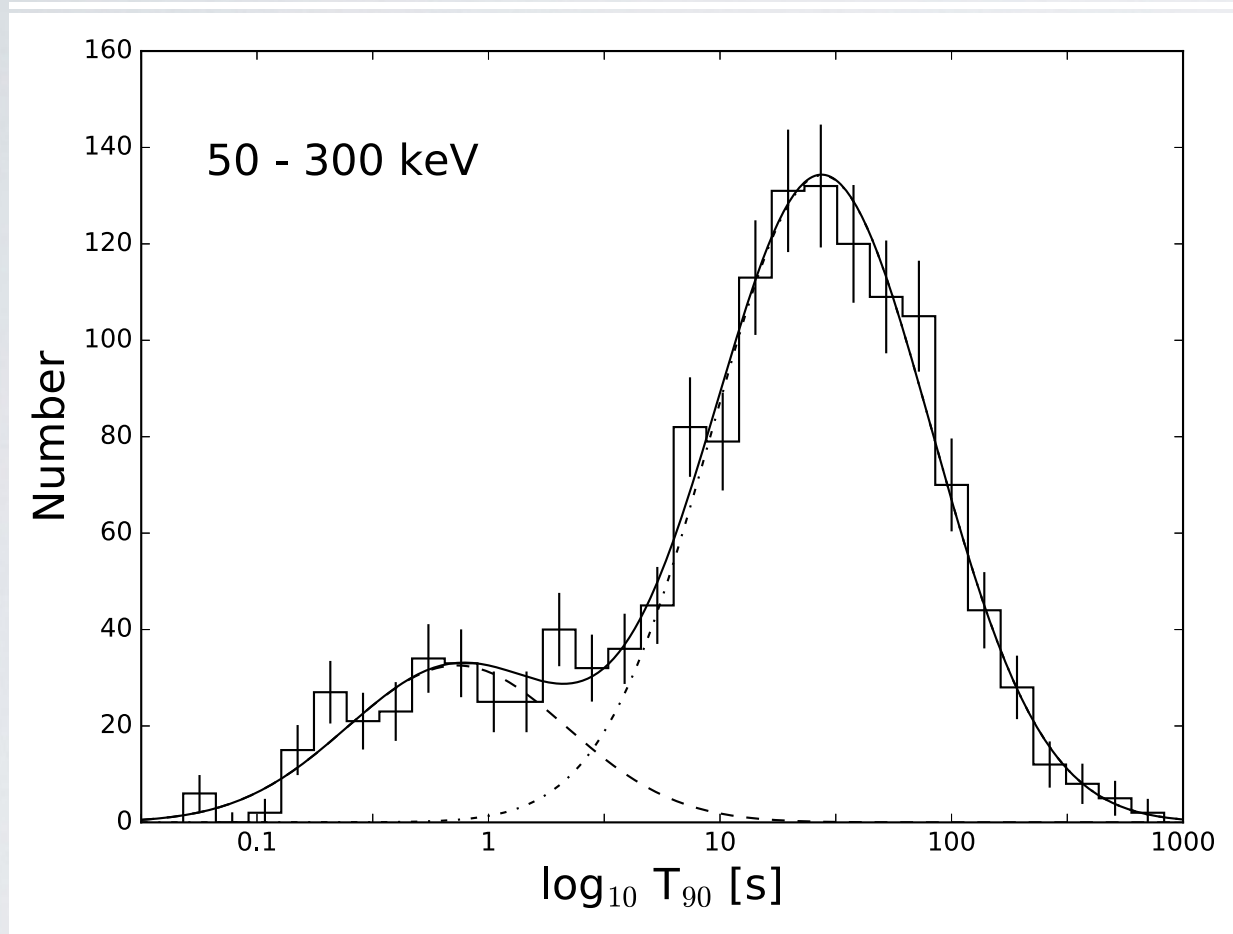
2000 GBM GRBs

266 Swift GRBs

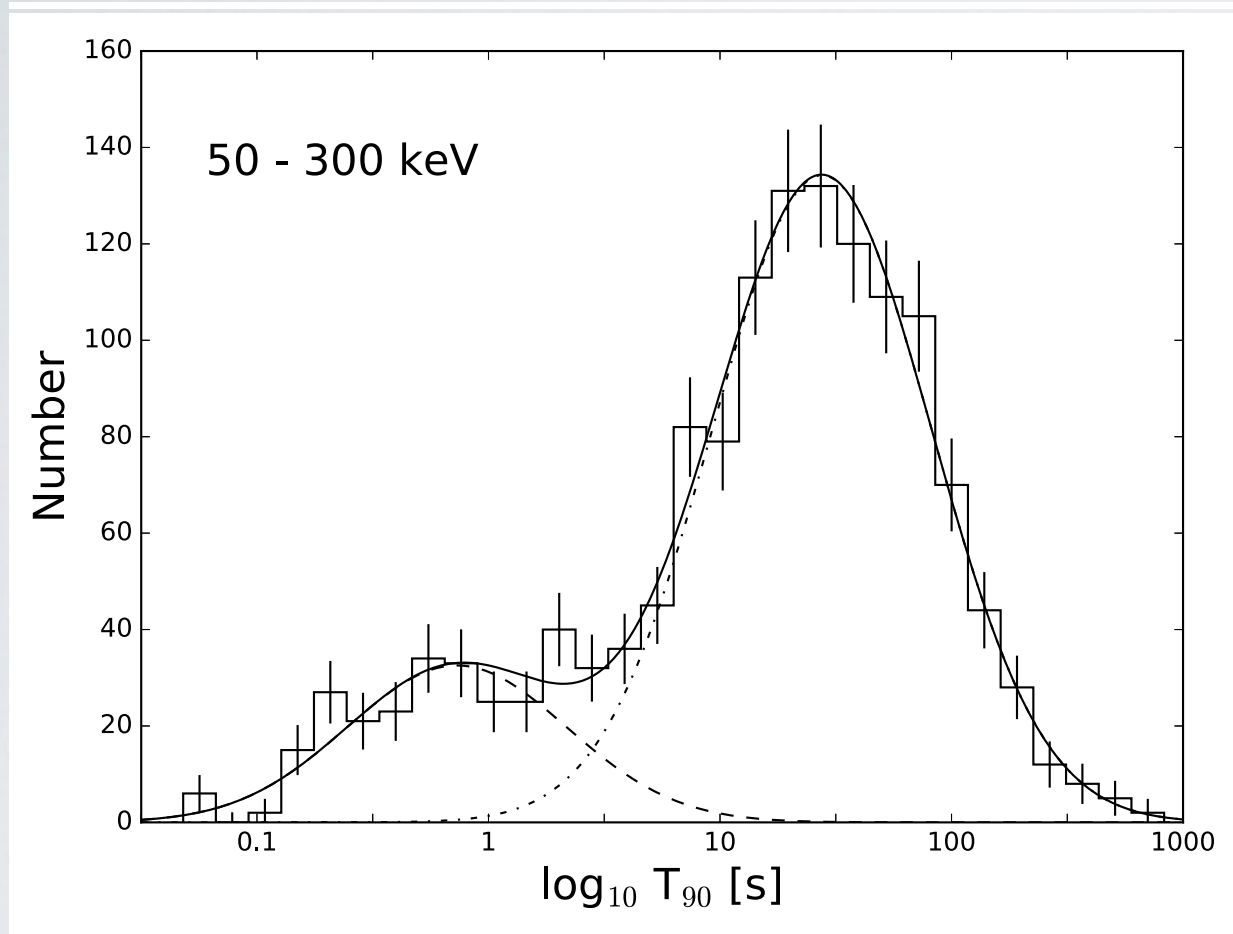
121 LAT GRBs

- Over 2000 GRBs have been detected since launching in 2008.
 - 200 long GRBs / year -> massive star collapse.
 - 40 short GRBs / year -> compact merger event.
 - 52% within LAT FOV, 6% detected (14 / year).
 - 13% seen by Swift (30 / year, 9 short GRB / year).

Duration distributions

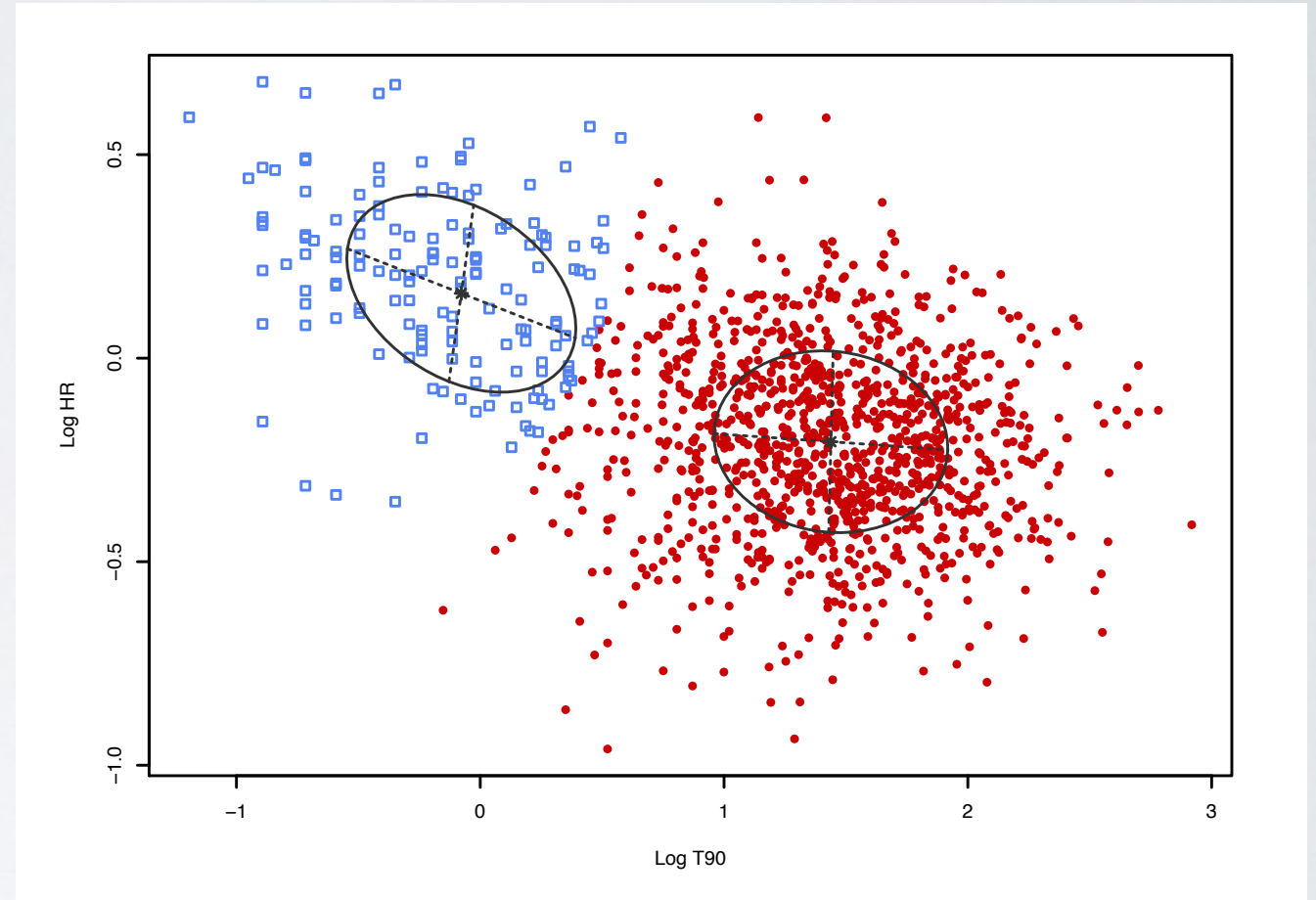


Duration distributions



Hardness Ratio

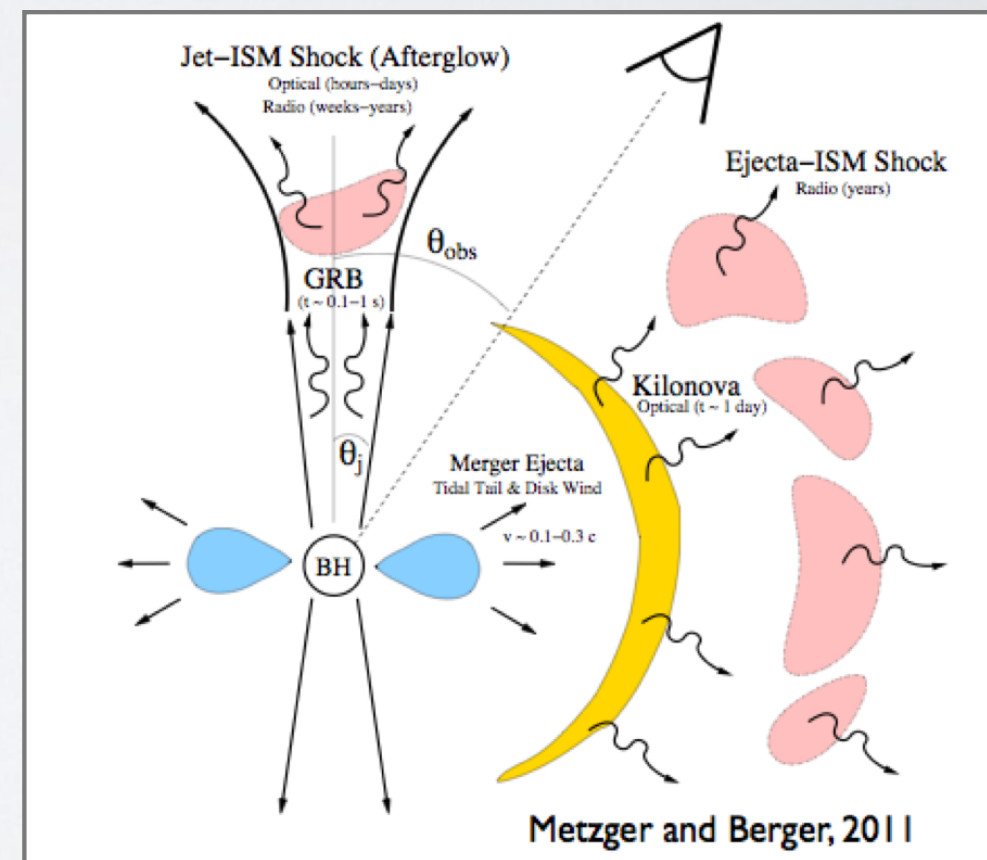
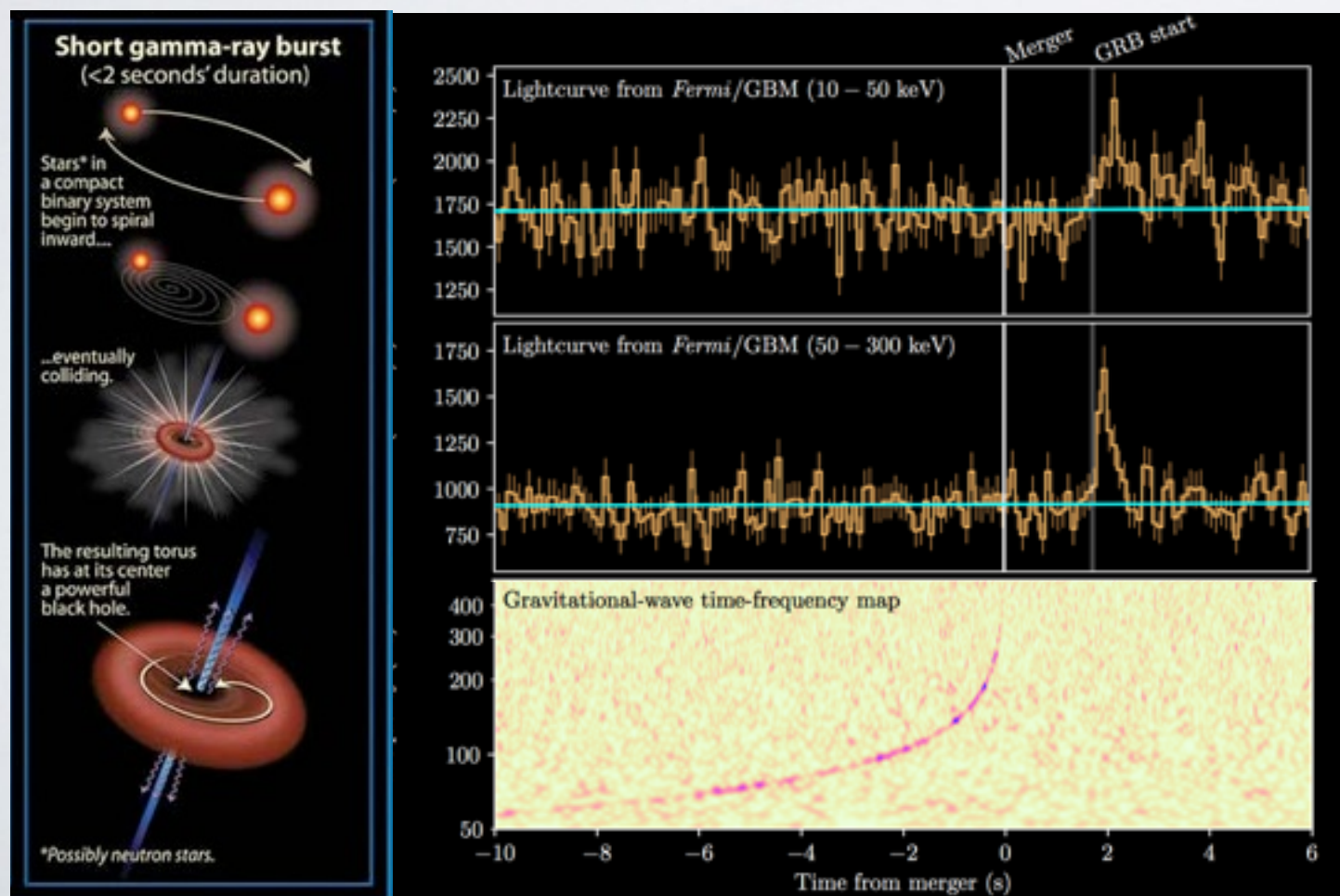
Short/Hard



Long/Soft

Binary neutron star merger and short gamma-ray burst association confirmed!

- GRB 170817A detected by GBM 1.7s after GW170817, a BNS merger event
 - extensive electromagnetic followup resulting in detection of a kilonova.
 - two components: initial GRB spike and weak thermal tail (blackbody $kT \sim 10\text{keV}$).
- joint science:
 - tightest constraint on speed of gravity (consistent with speed of light within $1e-15$)
 - constraints on neutron star equation of state
 - open questions: merger and jet geometry, intrinsic properties, population characteristics

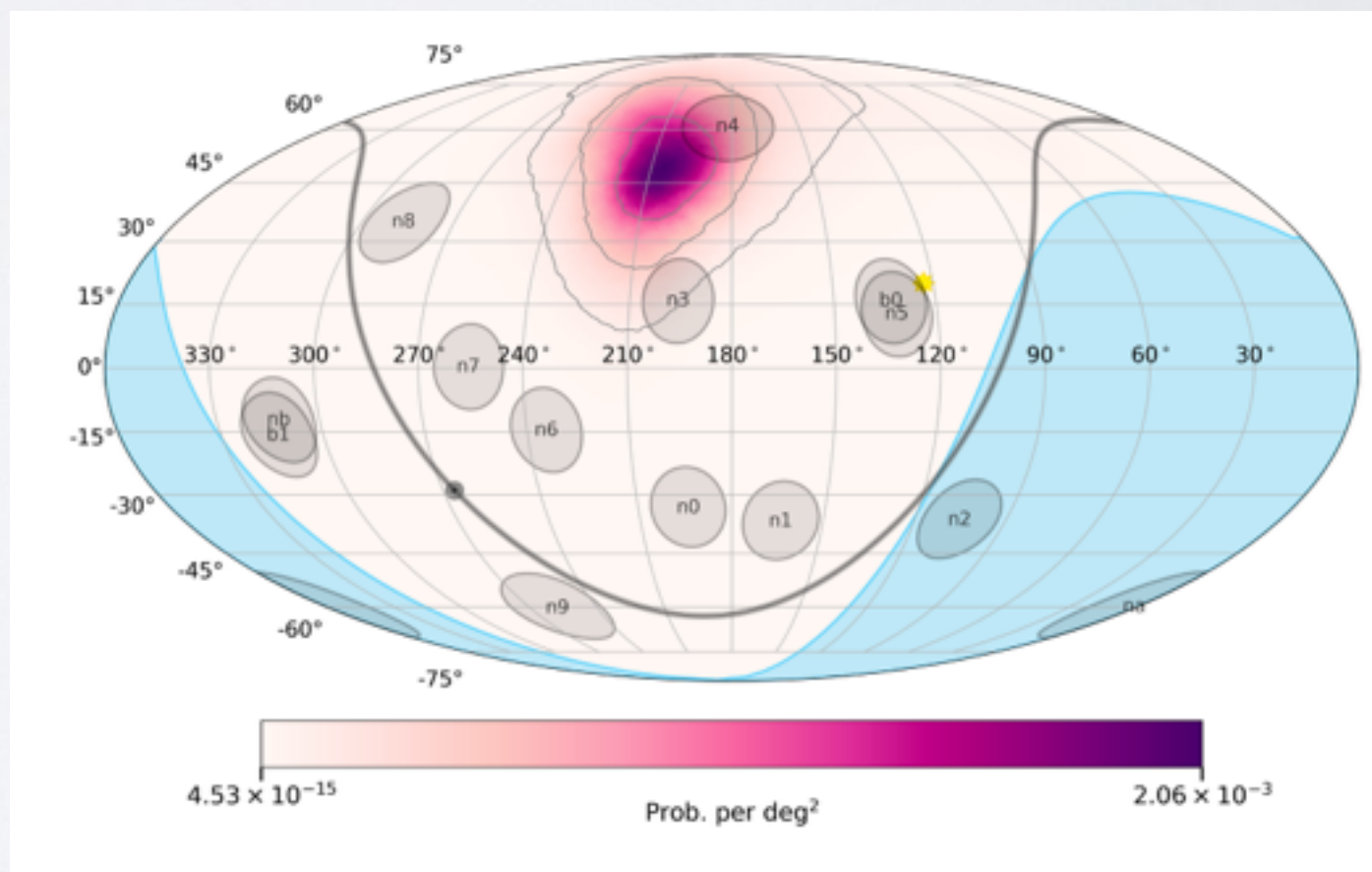


Untargeted Search

On ground blind search for below trigger threshold transients

- Extends the onboard trigger algorithms, with improved background model.
- GCN notice type Fermi-GBM SubThreshold now available.
https://gcn.gsfc.nasa.gov/fermi_gbm_subthreshold.html
- Time delay for notice range from 0.5 to 6 hours, due to telemetry schedule.
- List of candidates from older data (2013 and on) are available.
http://gammaray.nsstc.nasa.gov/gbm/science/sgrb_search.html
- Available with the GCN notice:
 - Localization FITS file
 - Contour sky map
 - Lightcurve

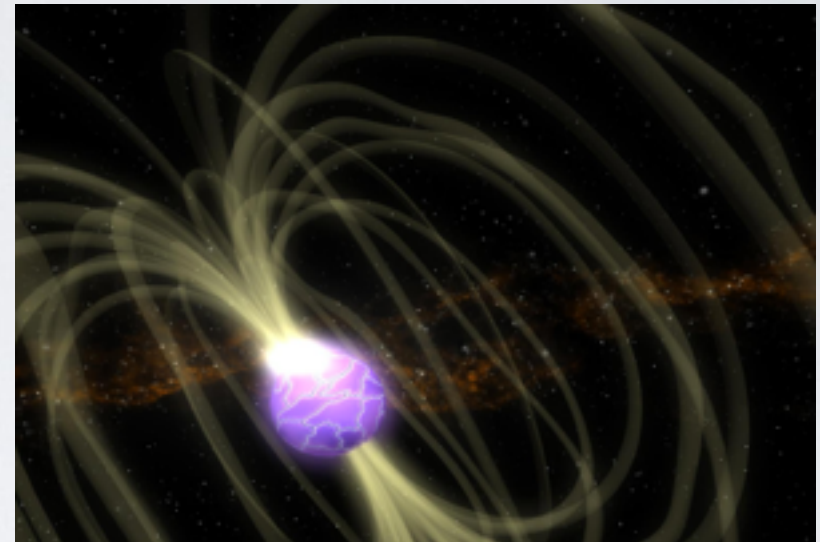
More on Monday



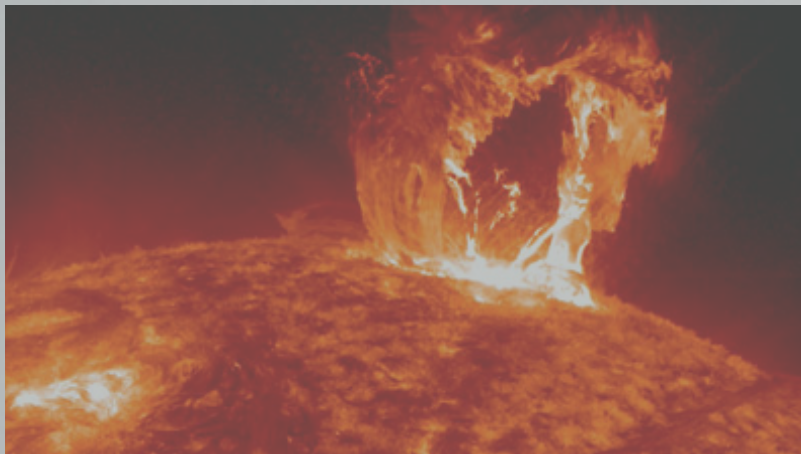
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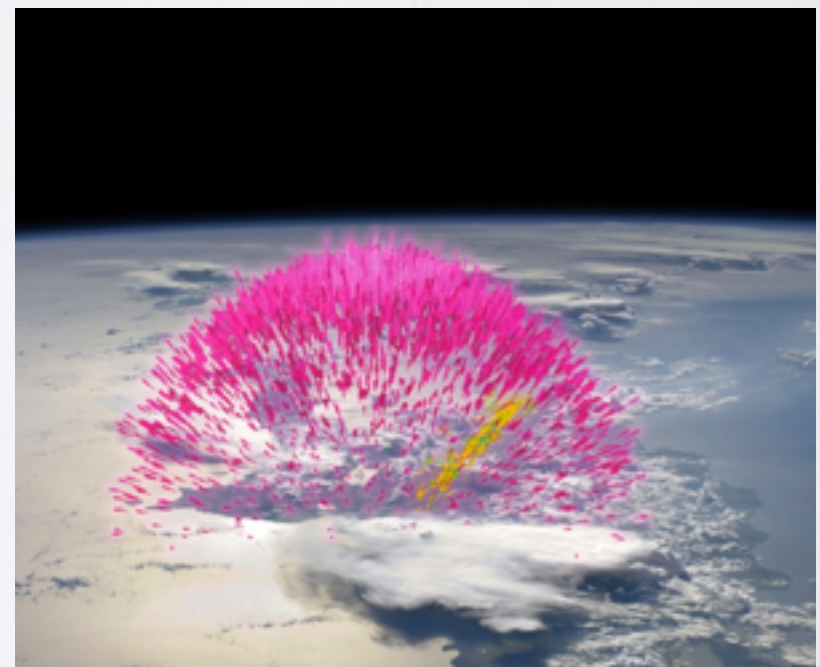
Galactic — pulsars, magnetars



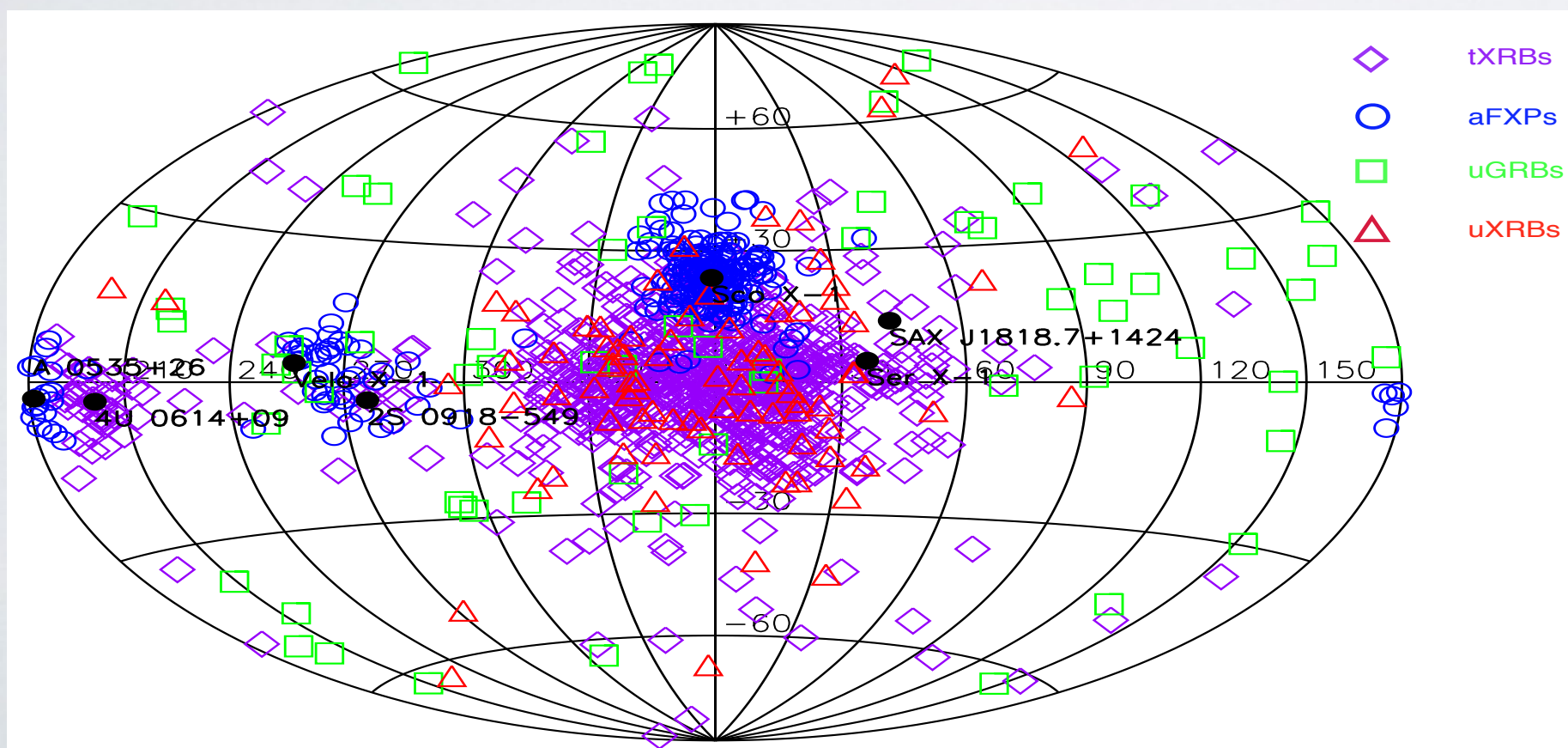
Solar flares



Terrestrial Gamma-ray Flashes



- 1084 X-ray bursts detected between 2010 and 2013 (Jenke et al. 2016).
 - concentrated towards Galactic bulge.
 - 1.4 detection per day at distance <10 kpc.
 - Thermonuclear bursts: accreted matter piles up on surface of neutron star and trigger thermonuclear runaway when ignited.
 - GBM measured average blackbody temperature 3.2 ± 0.3 keV.
 - 84 bursts with $kT > 4$ keV, cluster towards Galactic center, unknown type.

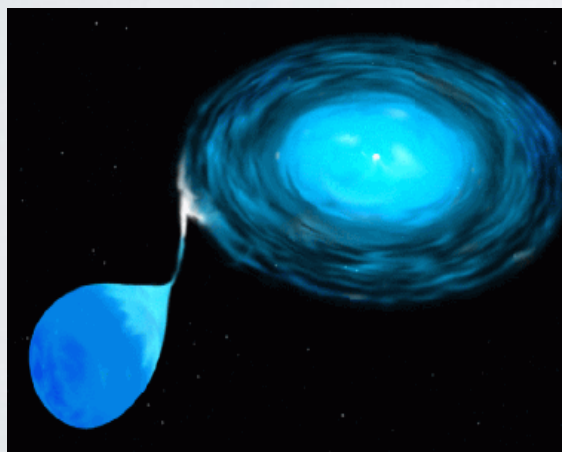
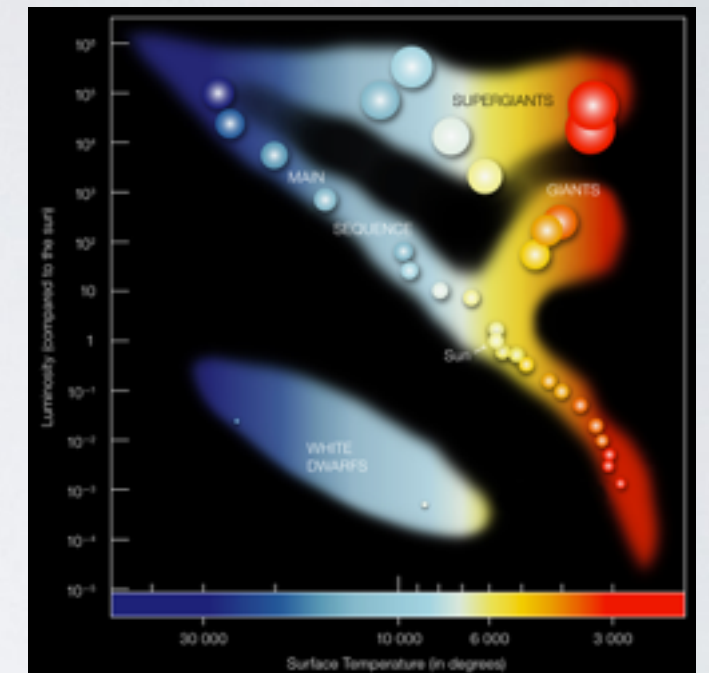


671 thermonuclear X-ray bursts
 267 accretion flares and pulses
 65 untriggered GRBs
 84 unknown X-ray bursts

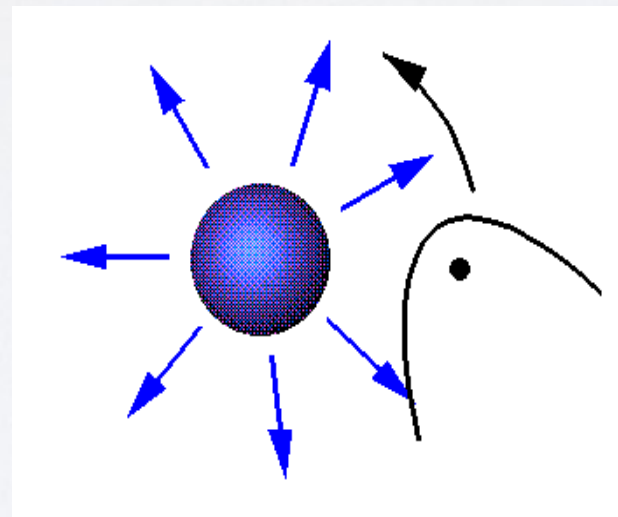
classification based on:

- location
- lightcurves
- spectral analysis

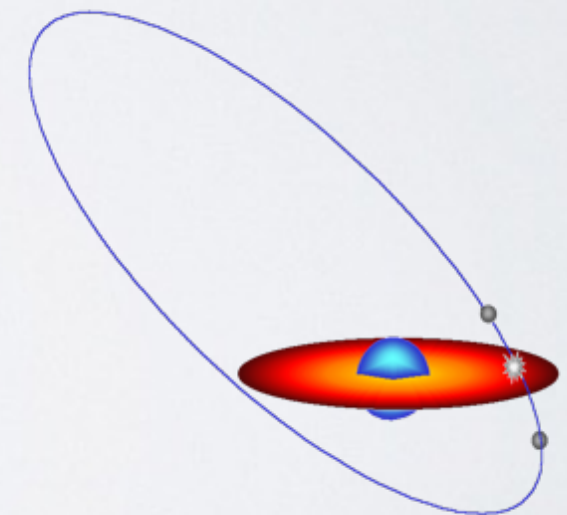
- Magnetized neutron star accreting matter from a supergiant or Be type companion star.
- Daily Blind search for new pulsars and outbursts
- Dedicated search
 - search around known frequencies
 - monitoring 39 systems, 36 detected
- Typically $> 40,000$ s on source every day



Roche lobe overflow



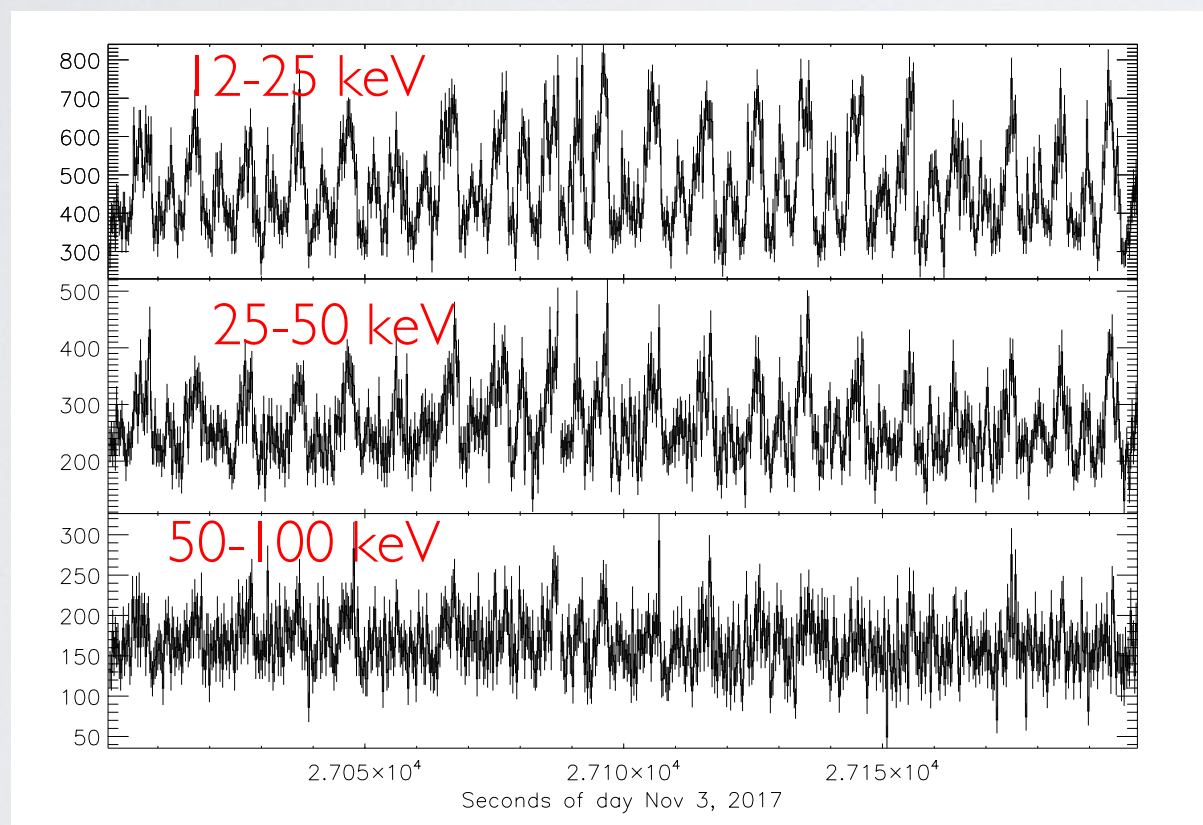
Wind accretion



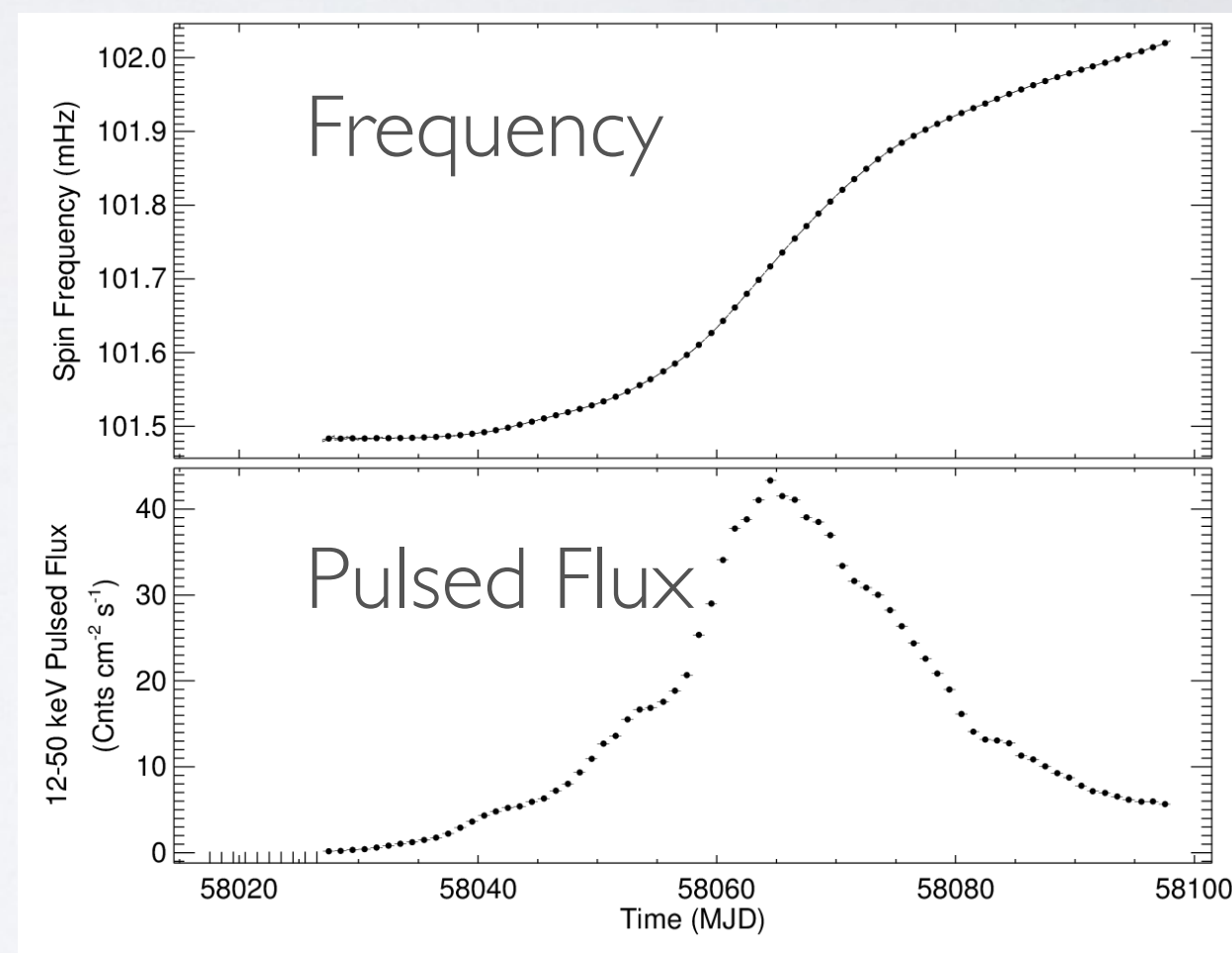
Accretion from a Be star's circumstellar disk

Brightest pulsar detected by GBM — Swift J0243.6+6124

- 9.8s pulsar discovered with Swift in early October 2017.
- 189 triggers, 42 on Nov 3 2017.
- Giant outburst up to 10x Crab in GBM band.



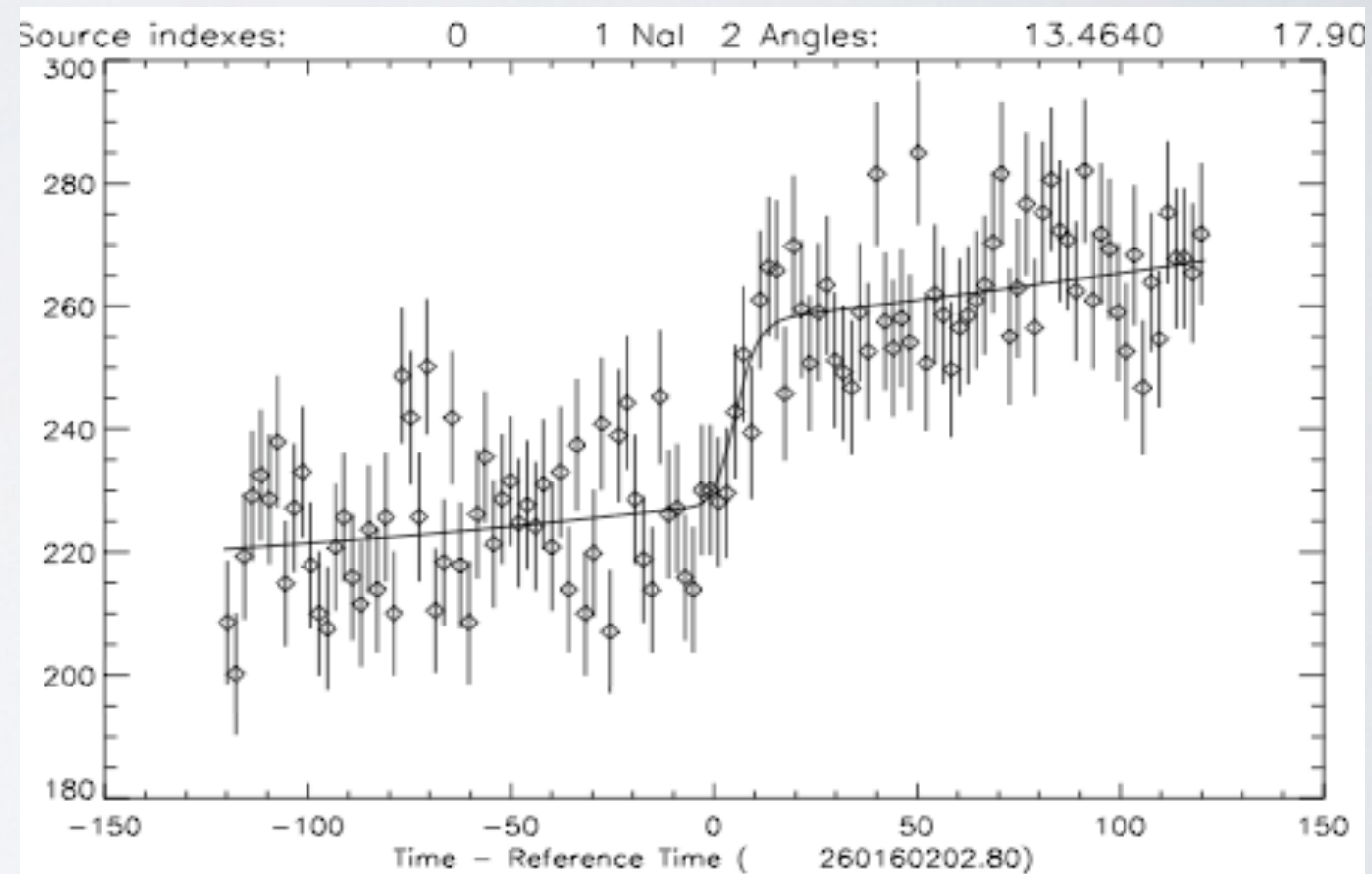
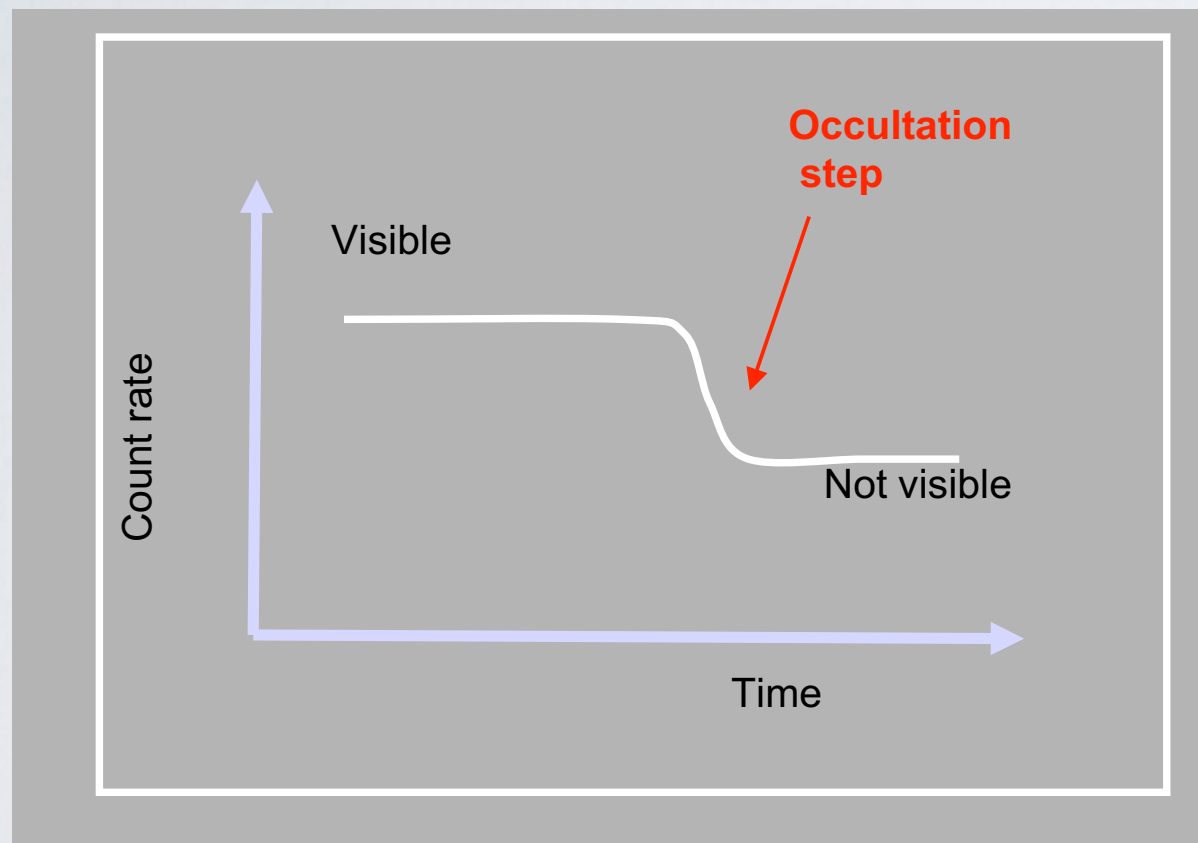
- pulses visible by eye in raw data



Monitoring by Earth Occultation technique

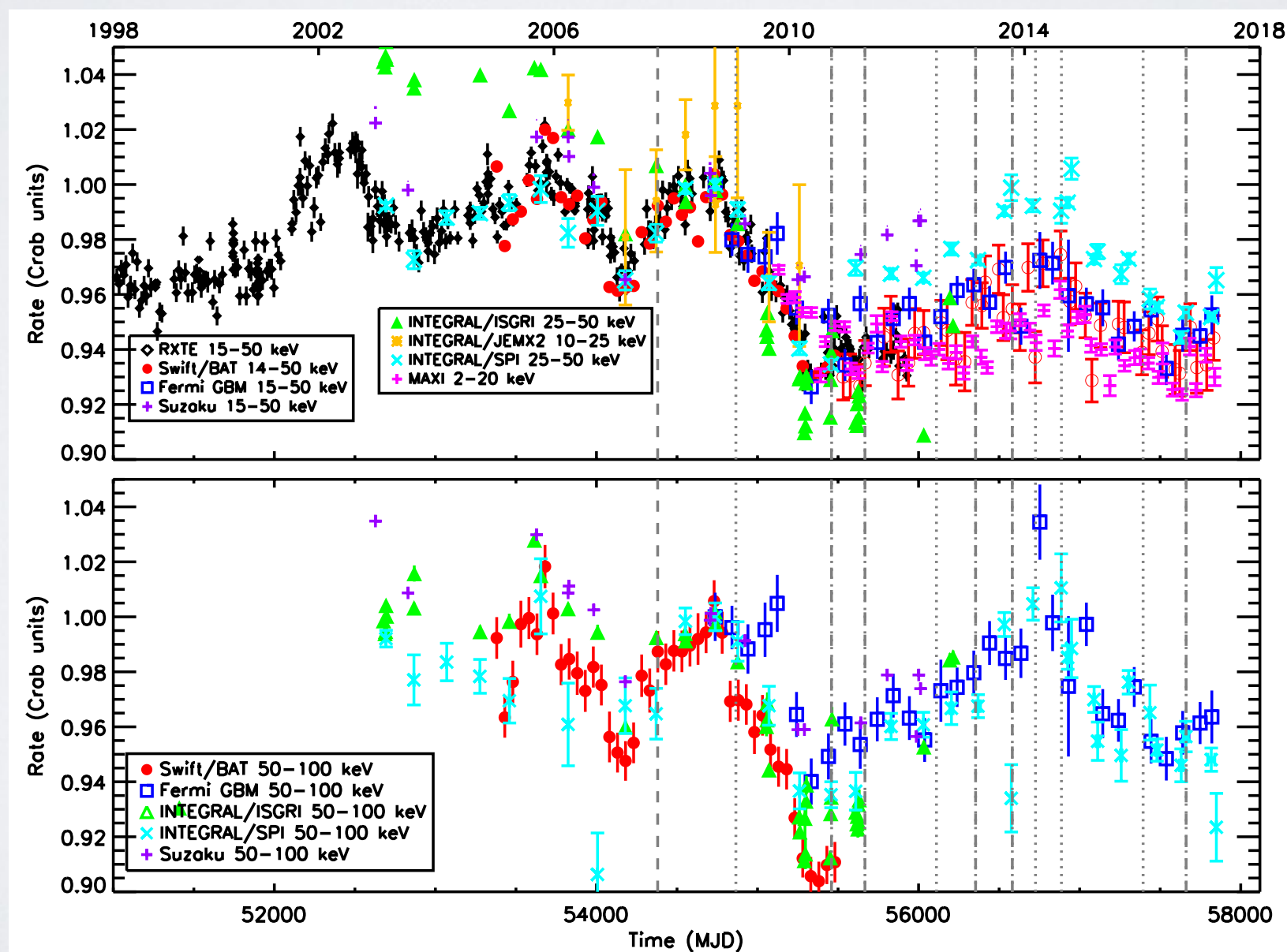
https://gammaray.nsstc.nasa.gov/gbm/science/earth_occ.html

- Sources rise above and set below Earth's horizon -> occultation step
- 200+ sources are monitored from X-ray binaries to Active Galactic Nuclei.
 - 102 detections, 9 at >100 keV.



Monitoring by Earth Occultation technique

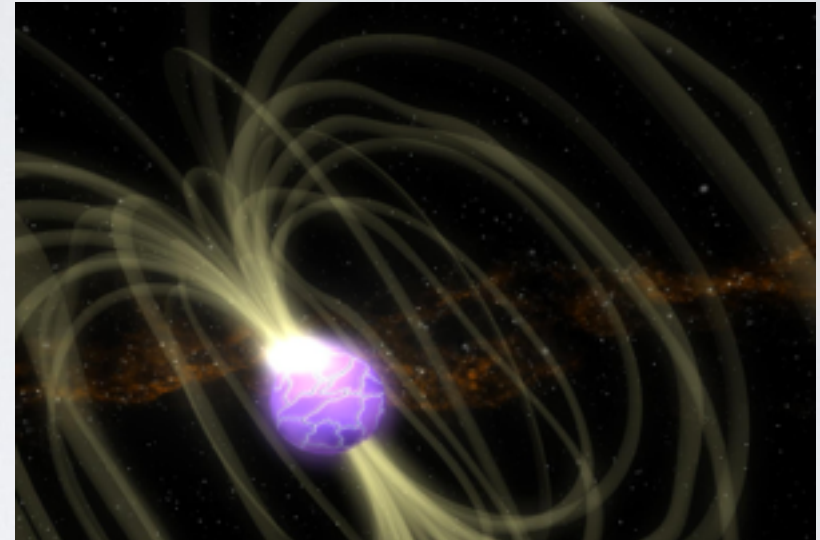
- 200+ sources are monitored from X-ray binaries to Active Galactic Nuclei.
 - 102 detections, 9 at >100 keV.
- Crab Nebula flux variations over the past decade, averaging 10% and up to 40% at 300–500 keV (Wilson-Hodge et al. 2011).
 - Changes in shock acceleration or nebular magnetic field



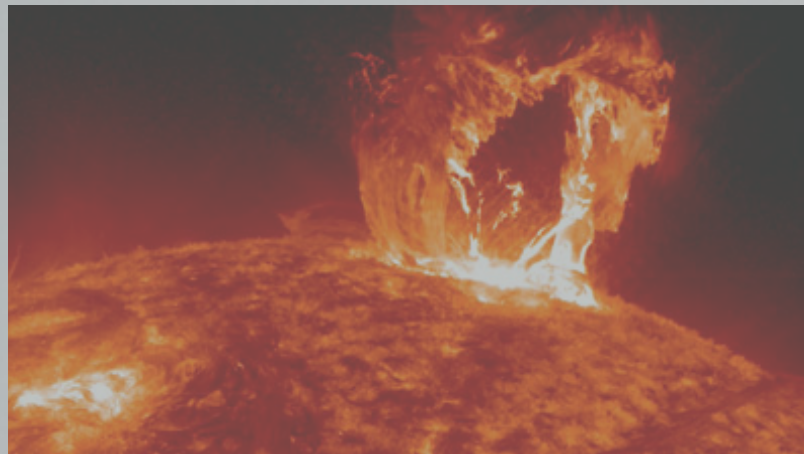
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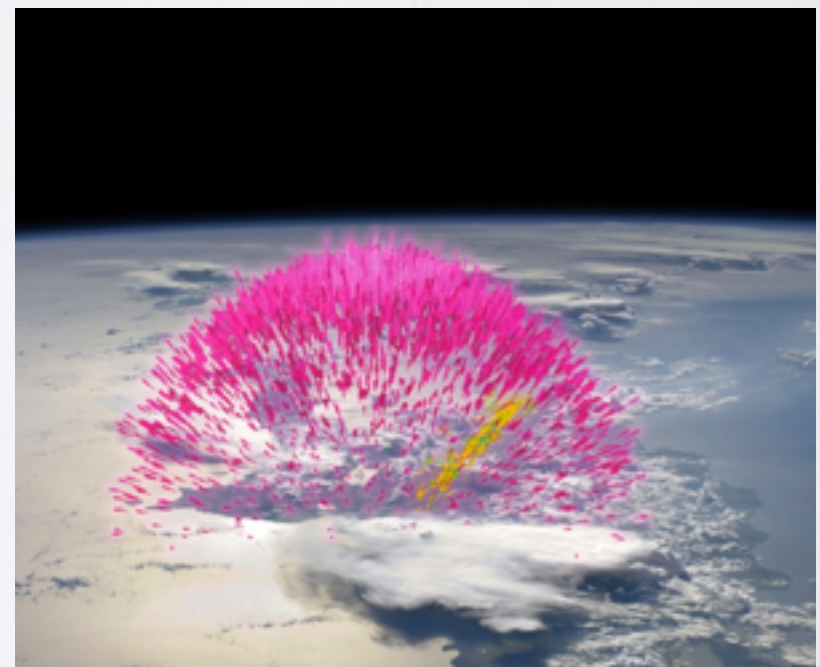
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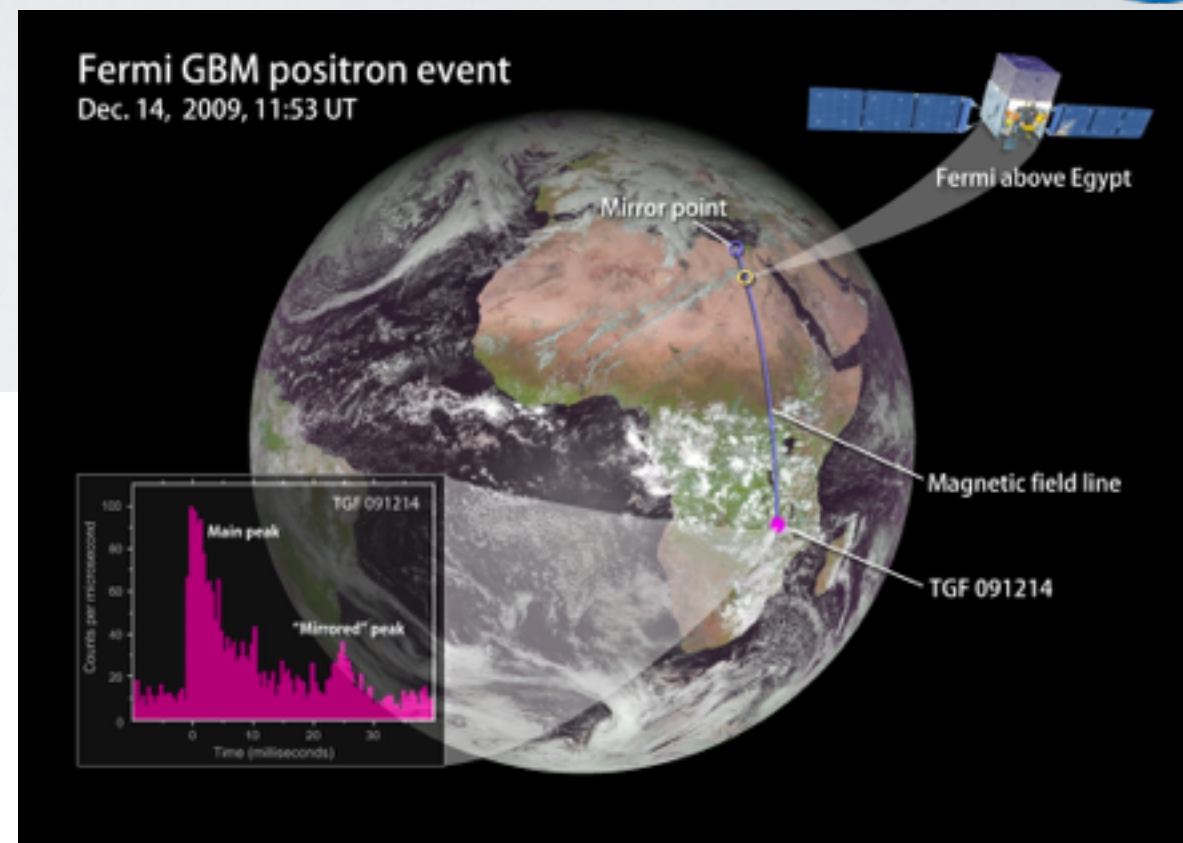
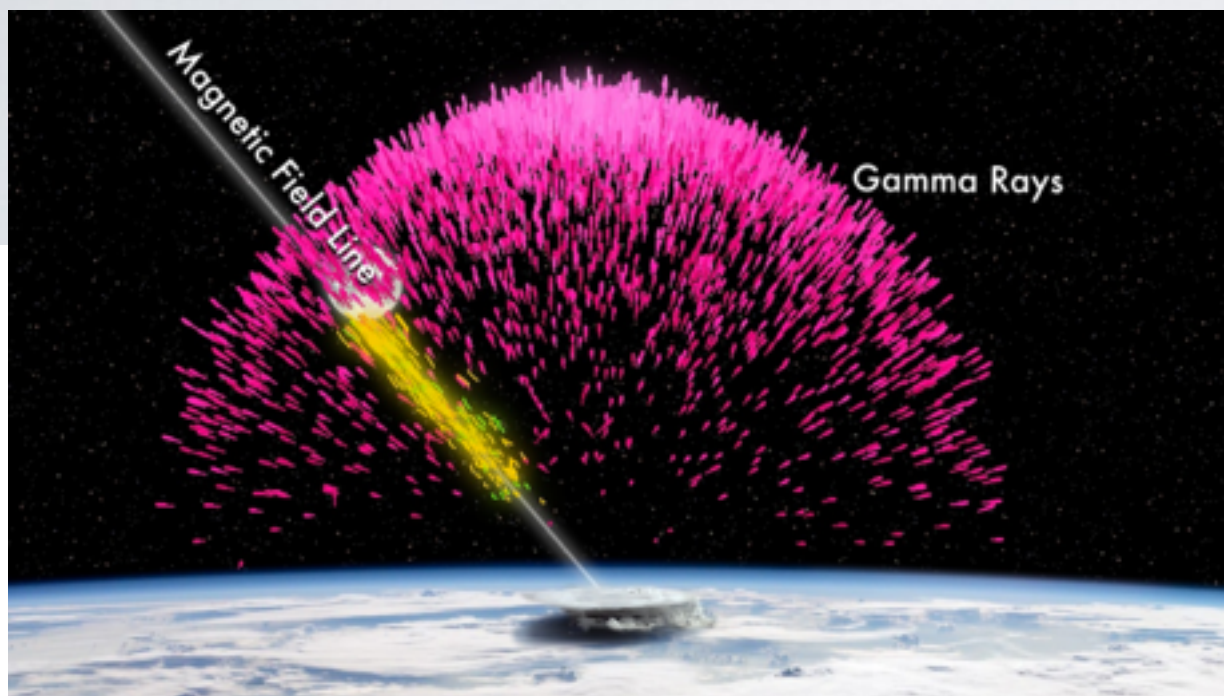
Solar flares



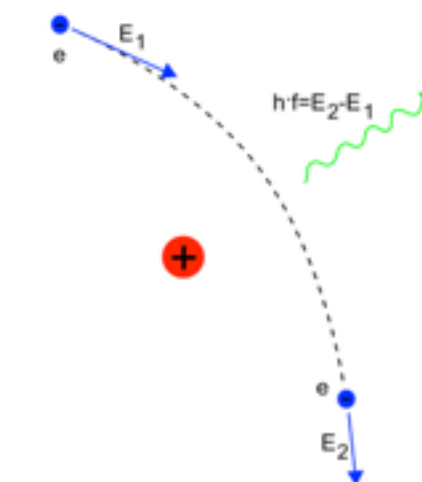
Terrestrial Gamma-ray Flashes



Terrestrial Gamma-ray Flashes / Terrestrial Electron Beam

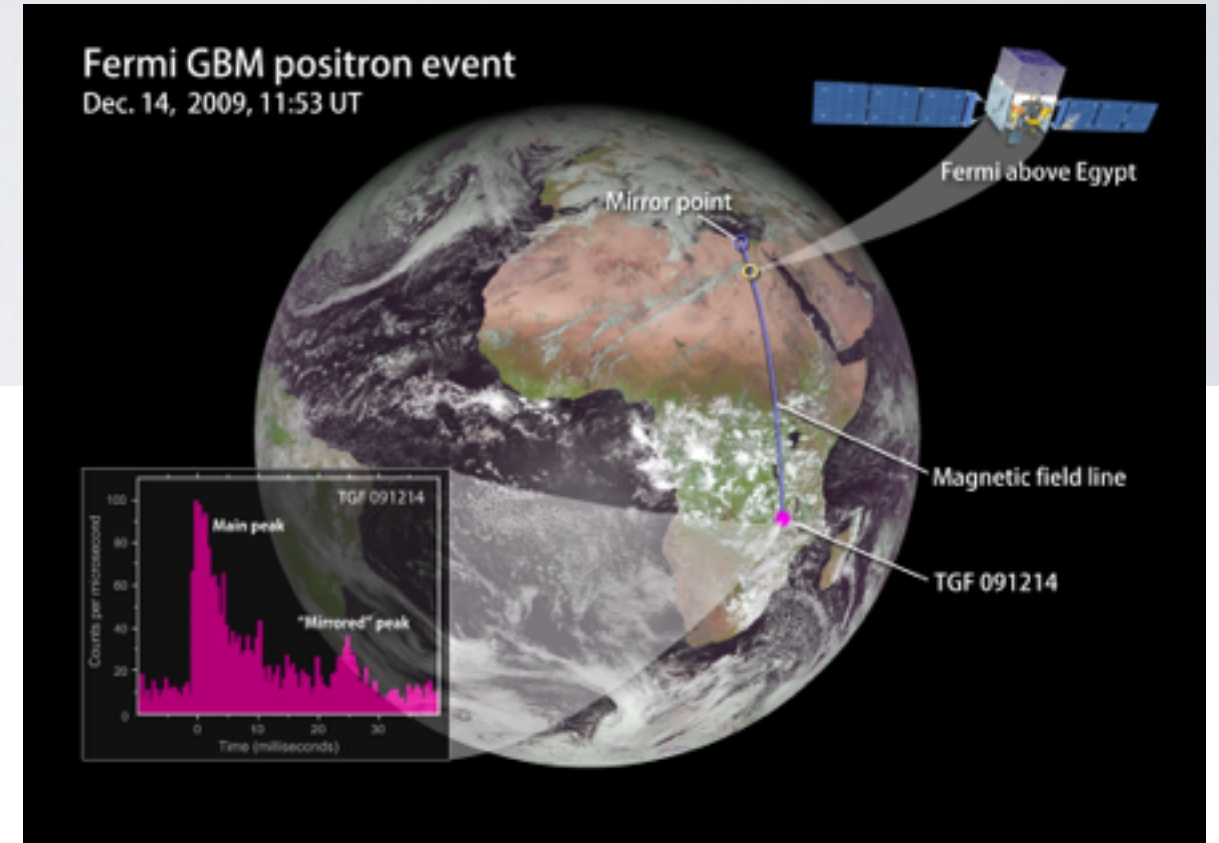
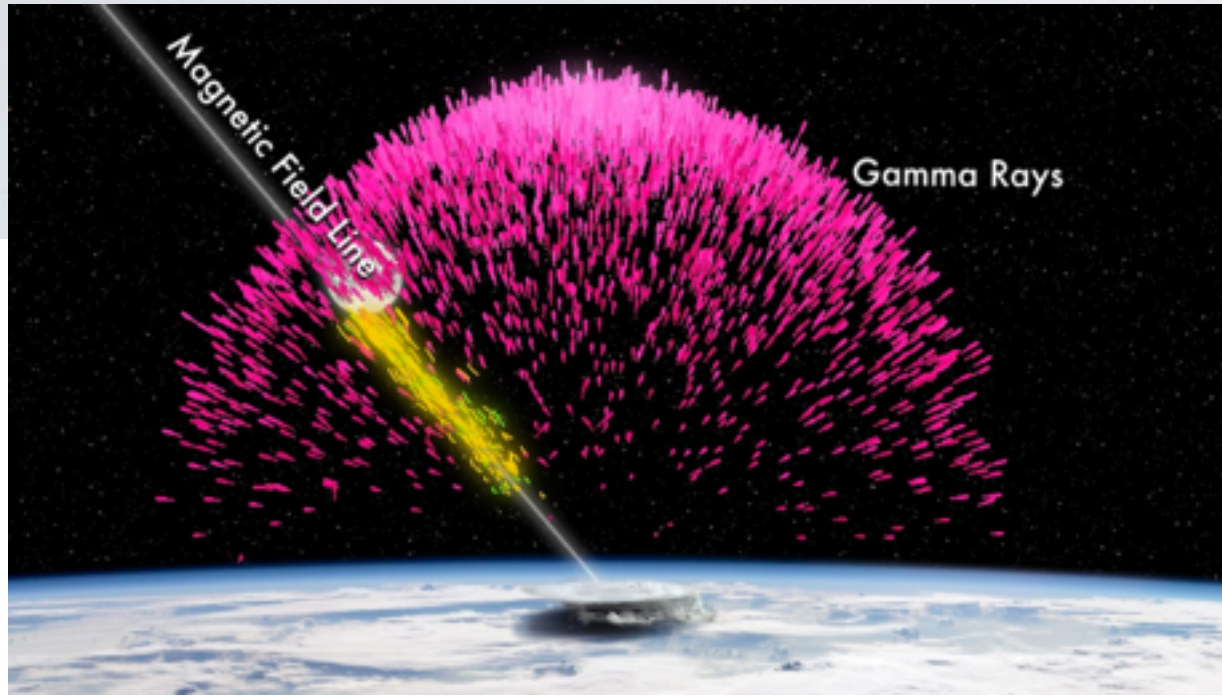


- Brief flashes (<1 millisecond) of gamma rays from top of thunderstorm.
- Charged particles accelerated by strong electric field, gamma rays produced via bremsstrahlung.
- Temporal association with lightning detection by the World Wide Lightning Location Network (WWLLN), which also provides location.

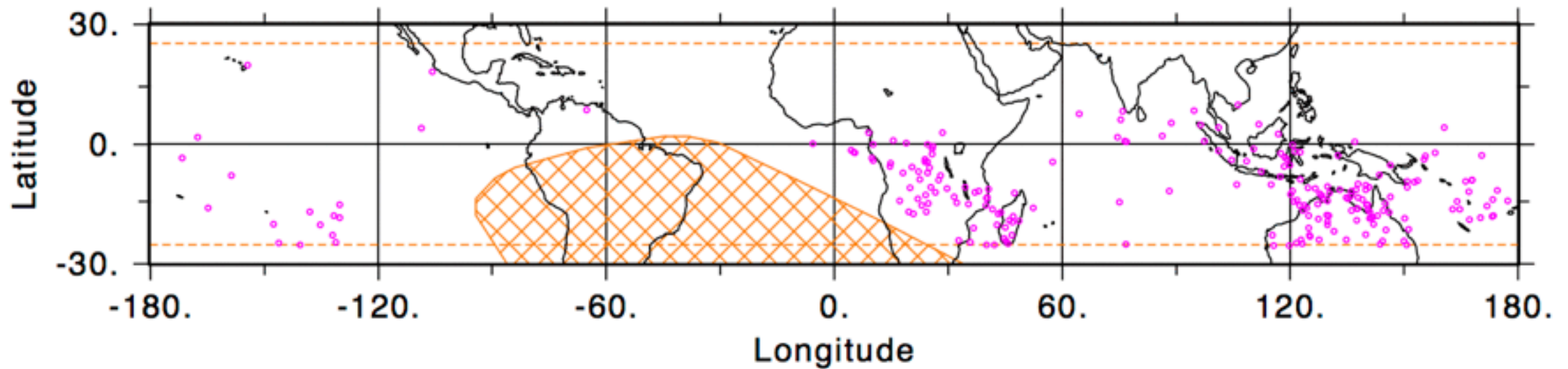


<http://wwlln.net/new/map/>

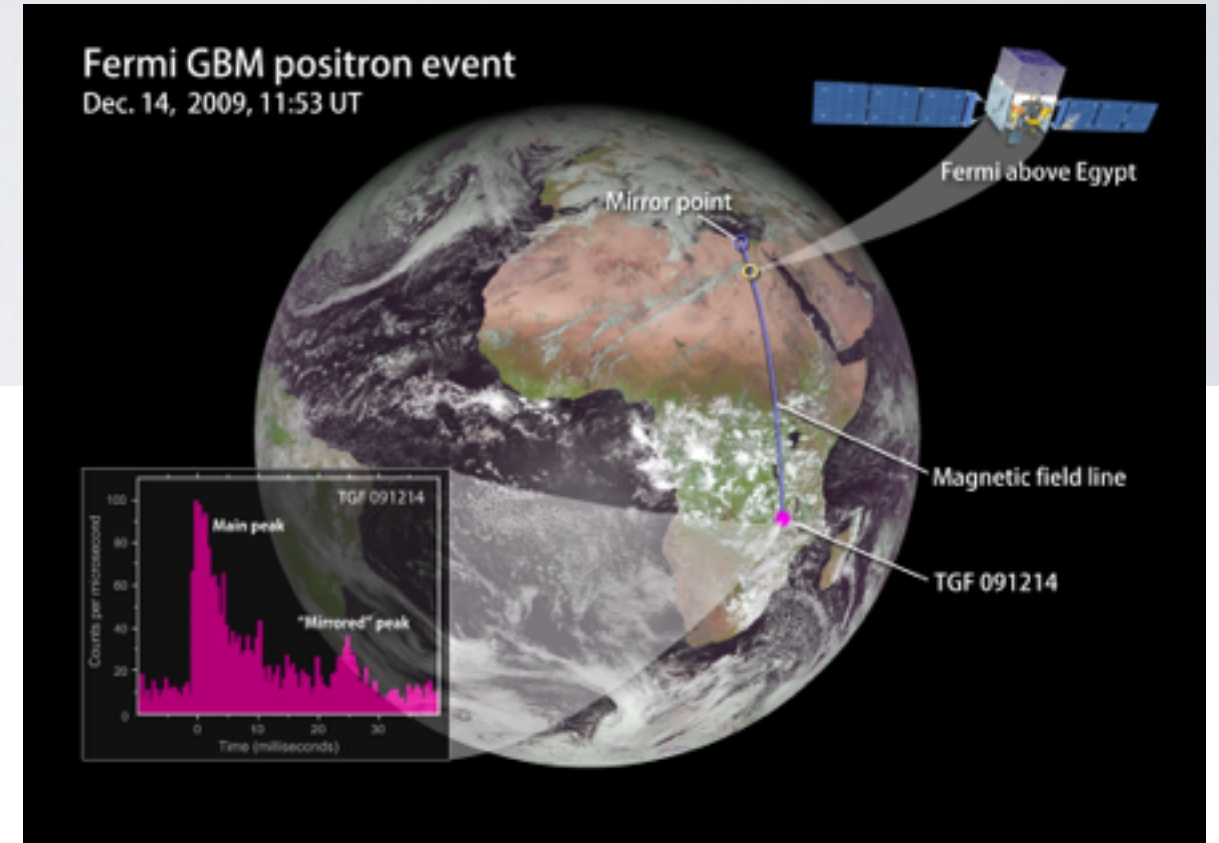
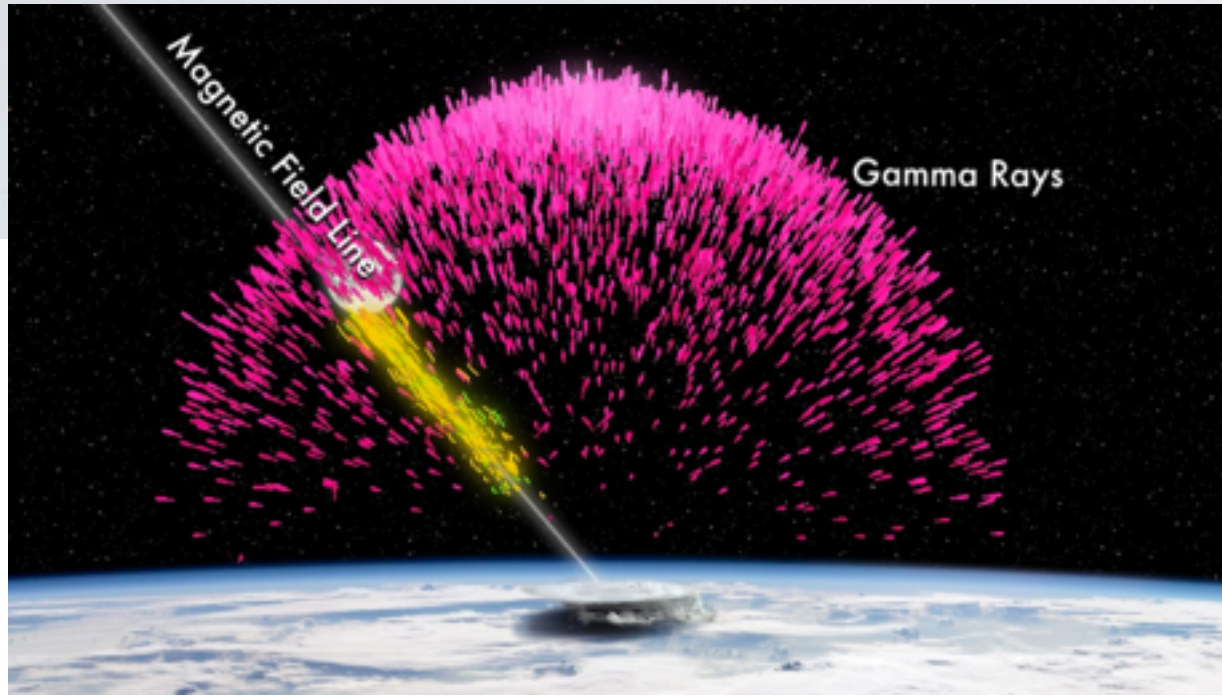
Terrestrial Gamma-ray Flashes / Terrestrial Electron Beam



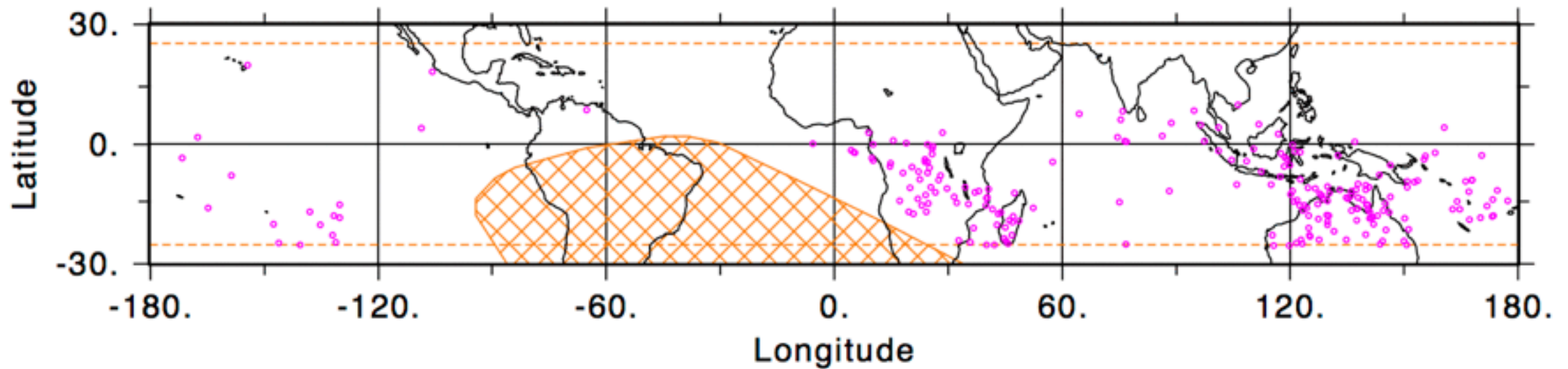
January



Terrestrial Gamma-ray Flashes / Terrestrial Electron Beam



January

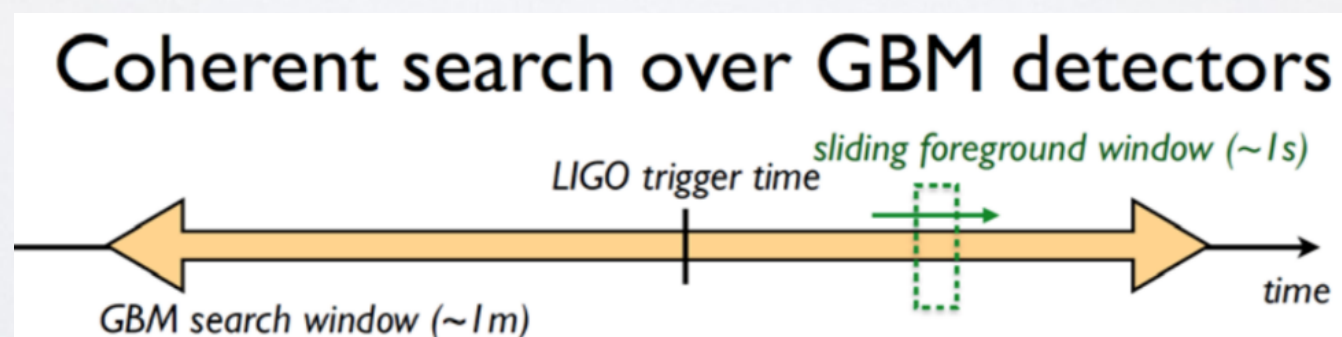


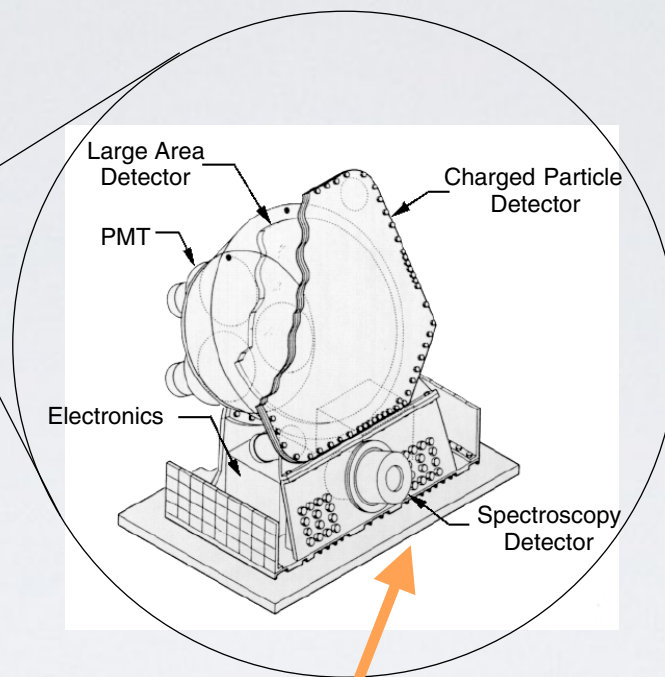
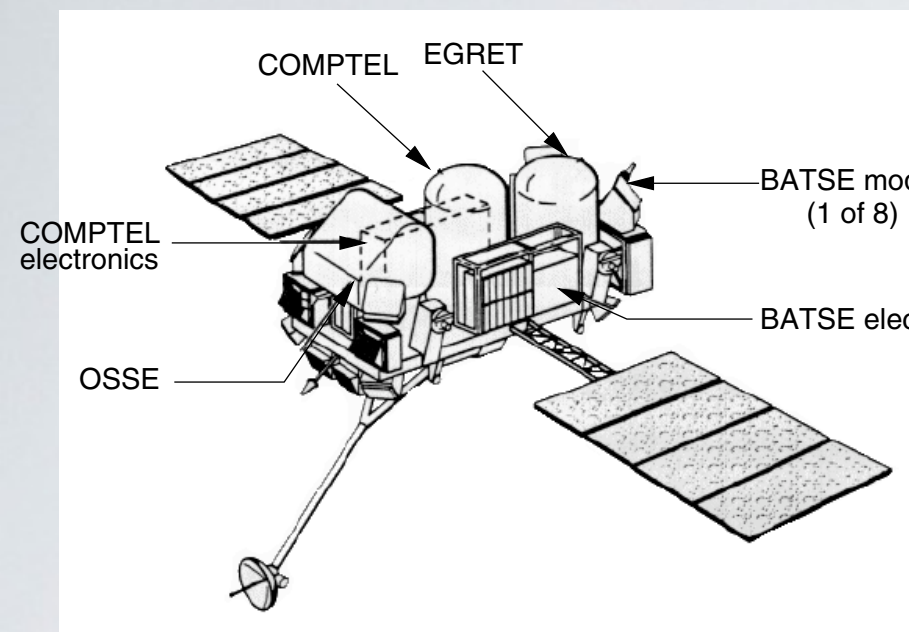
- GBM continues to be prolific in detecting GRBs and monitoring pulsars and Galactic transients with various detection and search algorithms.
 - On-board triggers
 - Targeted search using input event time (± 30 s)
 - Untargeted search for subthreshold GRB candidate events (64ms—30s)
 - Earth occultation technique (± 1 day timescale)
- Continued development of search pipelines for joint detection of astrophysical transients with neutrinos and gravitational waves.

Targeted Search using continuous time tagged events:

[More on Monday](#)

- search for coherent signals in all detectors given input time and optional sky map
- sliding time window with 3 spectral templates, searching ± 30 s within input time





BATSE (Burst And Transient Source Experiment) [1991 – 2000]

- ~2700 GRBs (~one per day)
- showed that GRBs are extragalactic
- temporal profile: short vs long
- discovered TGFs and soft gamma-ray repeaters
- 8000 triggers over 9-year mission



Fermi GBM [2008 – present]

Future Gamma-ray Instruments:
talks by Jeremy and Judy
next Thursday