


10 Years of Science with the Fermi Gamma-Ray Burst Monitor

A detailed view of the Fermi Gamma-Ray Burst Monitor (GBM) instrument. It features a large, rectangular array of blue, grid-like detector panels. To the right, the white, metallic structure of the satellite's payload bay is visible, showing various instruments and support structures. The background is a deep black space filled with numerous small, distant stars.

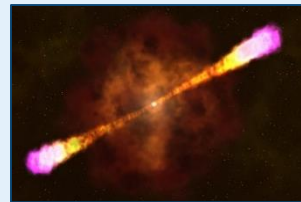
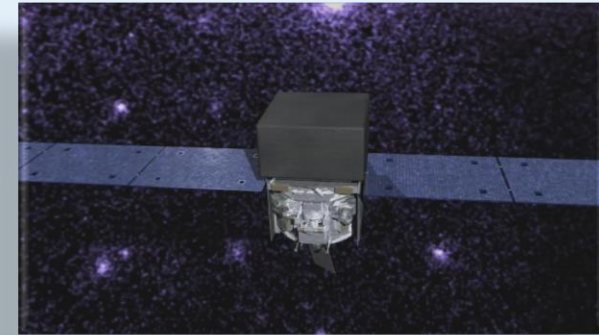
Elisabetta Bissaldi*

Politecnico & INFN Bari – elisabetta.bissaldi@ba.infn.it

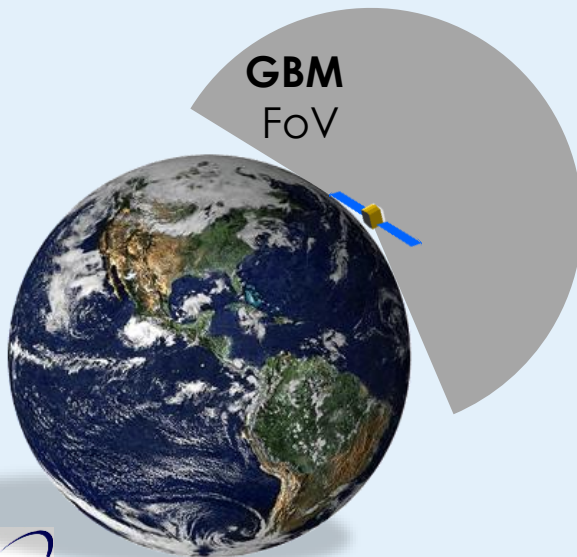
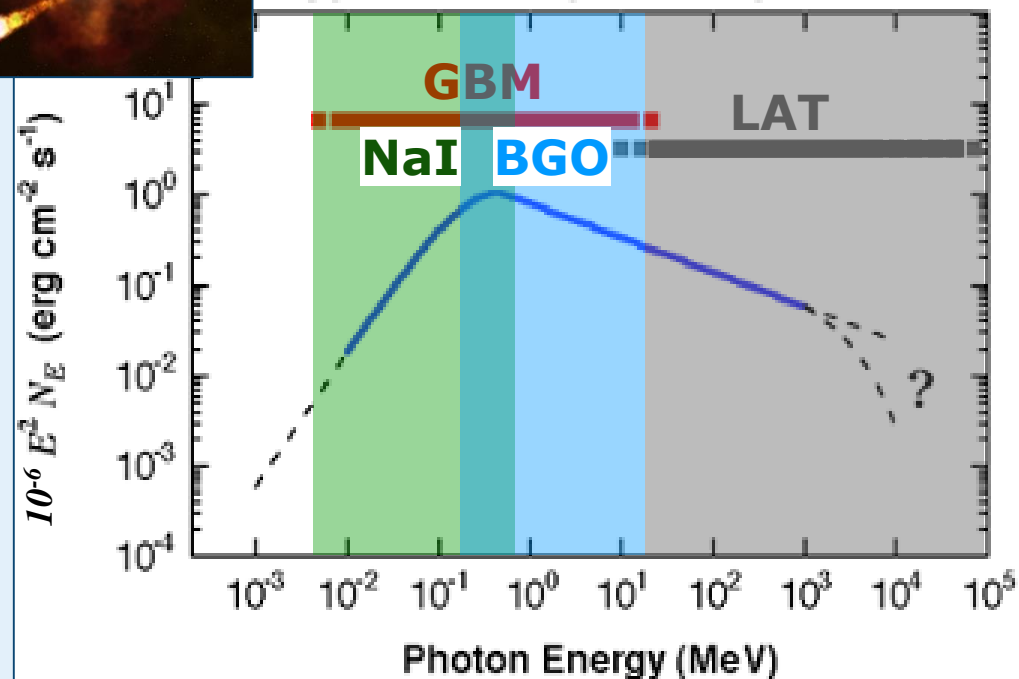
**On behalf of the Fermi GBM Team*

The Fermi Gamma-Ray Burst Monitor

- Designed to study Gamma-Ray Bursts
- **Primary objectives** of GBM:
 1. Extend the **energy range** downward from the Fermi-LAT one (100 MeV – 300 GeV)
 2. Compute **burst locations** onboard to allow re-orienting the spacecraft

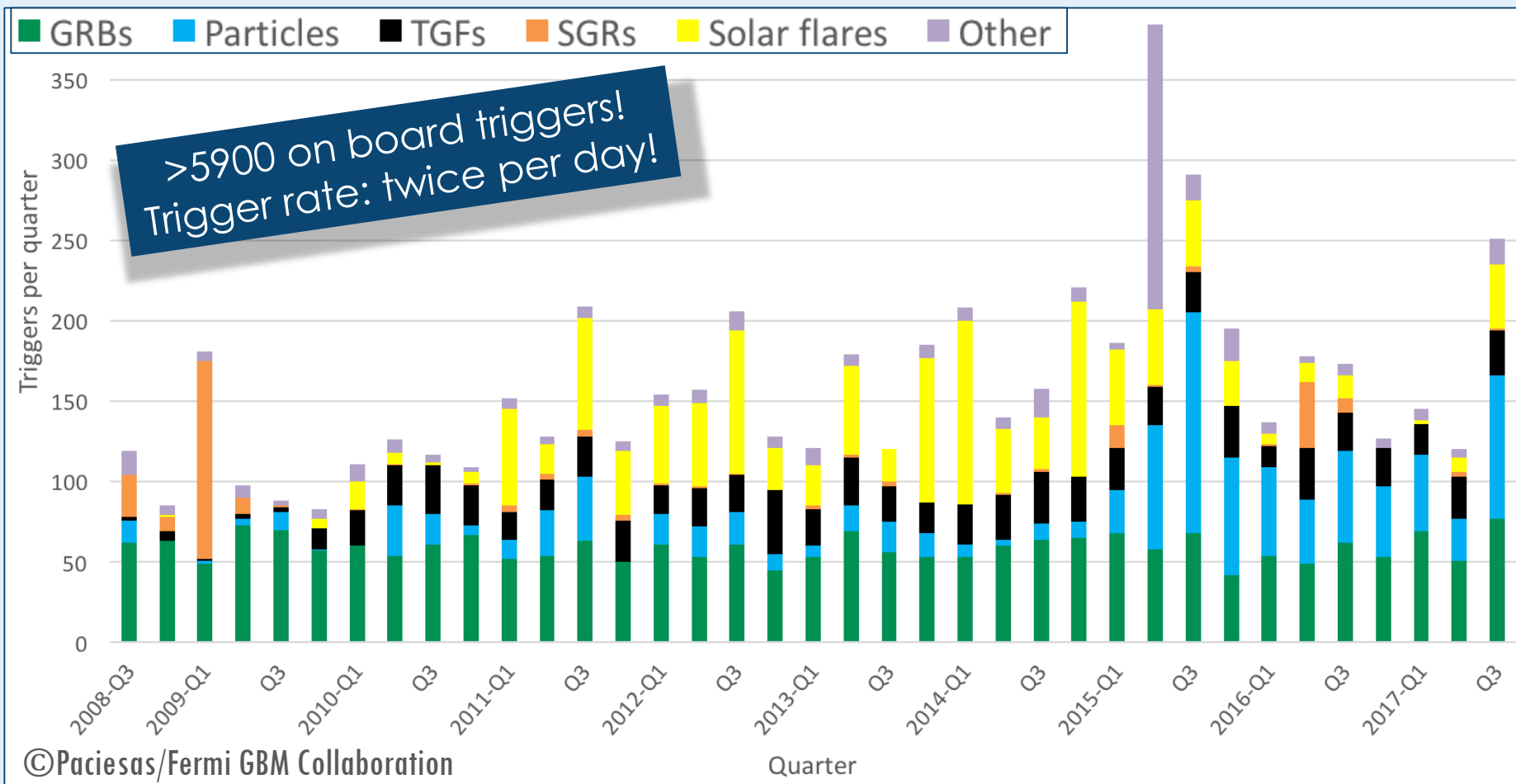


"Typical" Prompt GRB Spectrum



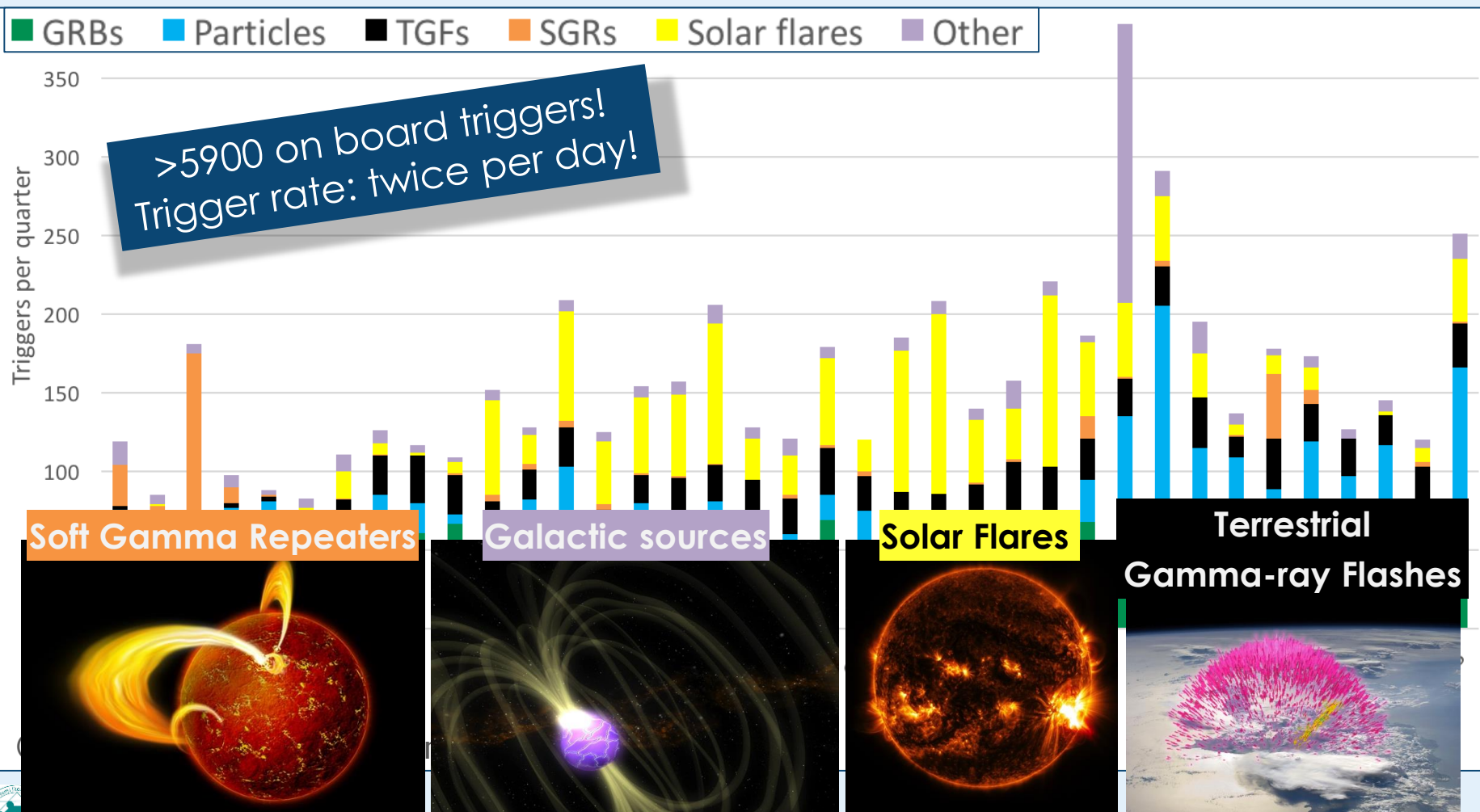
What does GBM see?

Quarterly trigger statistics over 9.5 years of the mission



What does GBM see?

Quarterly trigger statistics over 9.5 years of the mission



GRB observations in the Fermi Era

GBM Team GRB publications

- >20 joint GBM+LAT papers dedicated to outstanding individual GRBs
 - >10 joint GBM papers dedicated to individual GRBs
- 6 GBM & 1 GBM+LAT catalogs
- >20 GBM papers regarding population studies, correlations, analysis techniques

Not mentioning
LOTS OF PAPERS
using public
GBM data!

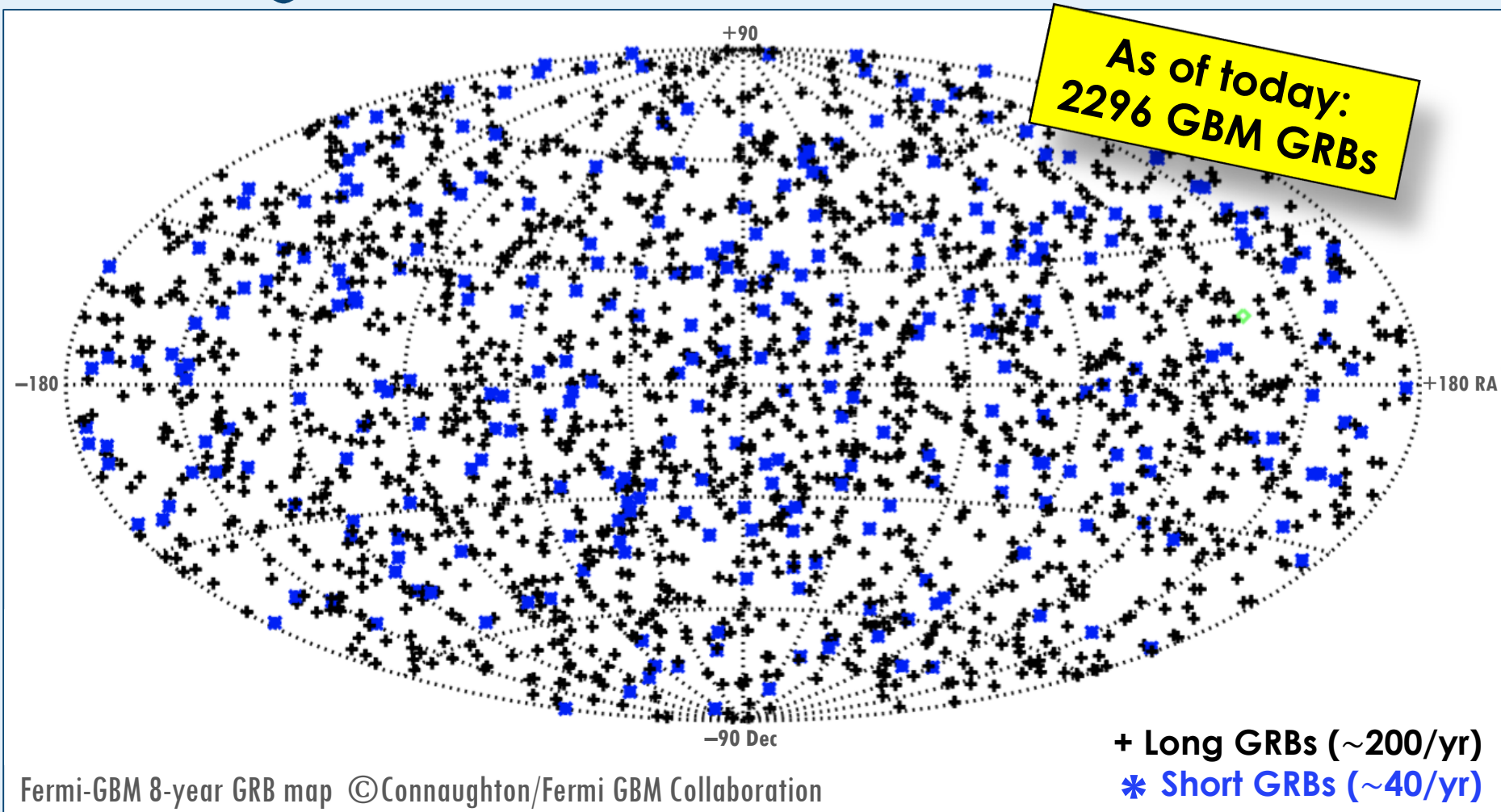


Online catalogs/tables

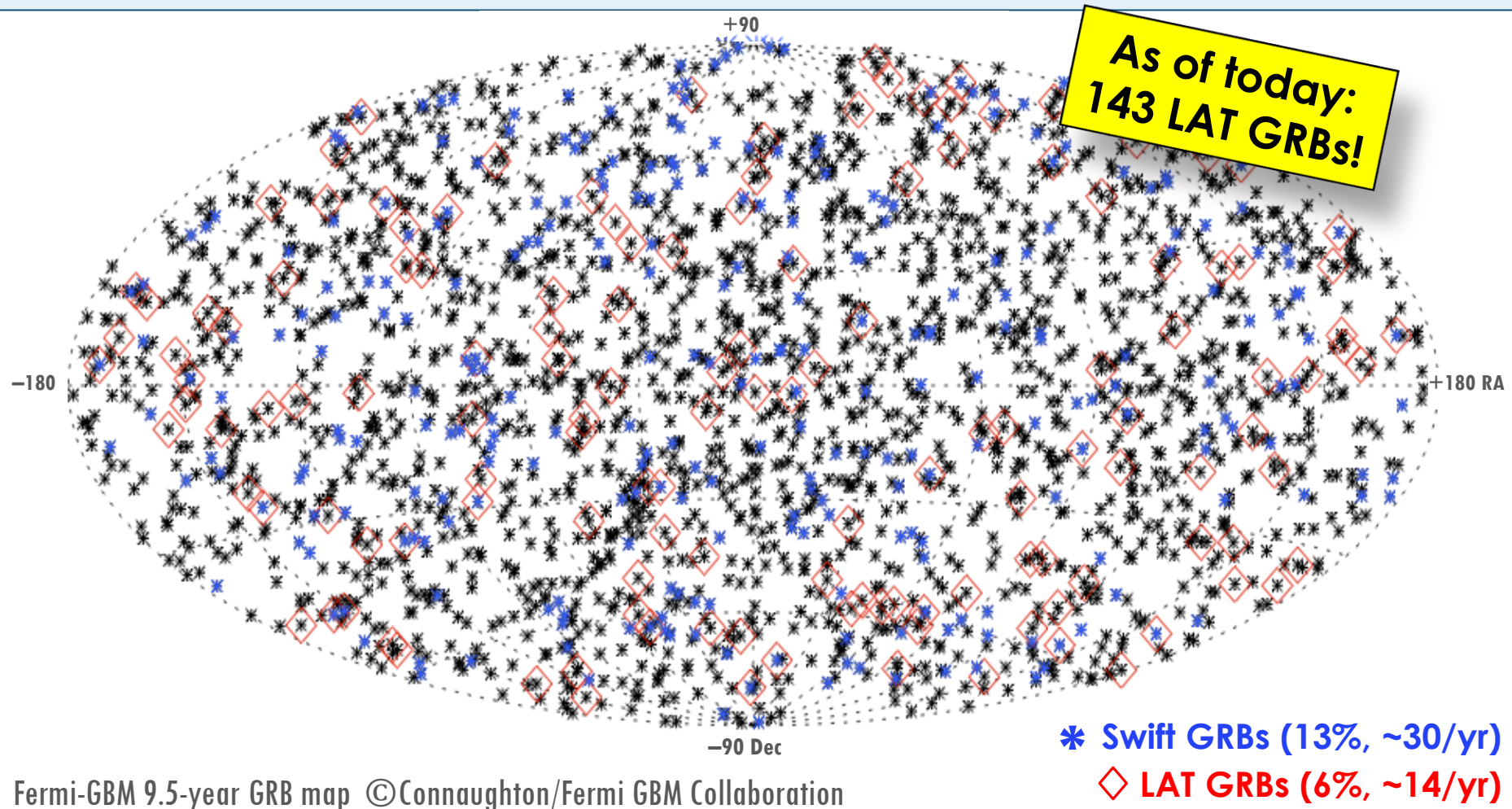
GBM <http://heasarc.gsfc.nasa.gov/W3Browse/fermi/fermigbrst.html>

LAT http://fermi.gsfc.nasa.gov/ssc/observations/types/grbs/lat_grbs/table.php

Fermi GBM skymaps



Fermi GBM skymaps



Swift BAT: only 9 sGRBs/yr
BUT arcmin localization facilitating follow-ups

Fermi GBM ~~GRB~~ catalogs

In preparation!

2018

- GBM 10yr **GRB** trigger Catalog [von Kienlin+2019 \(in prep\)](#)
- GBM 10yr **GRB** spectral Catalog [Poolakkil+2019 \(in prep\)](#)
- GBM 10yr **GRB** time-res. spectral Catalog [Bissaldi+2019 \(in prep\)](#)
- GBM 10yr **Accreting Pulsar** Catalog [Malacarian+2019 \(in prep\)](#)
- GBM 8yr **TGF** Catalog [Roberts+2018\(submitted\)](#)
- GBM 6yr **GRB** trigger Catalog (3FGBM) [Bhat+2016.ApJSS223](#)
- GBM 5yr **Magnetar** Burst Catalog [Collazzi+2015.ApJSS218](#)
- GBM 4yr **GRB** time-res. spectral Catalog [Yu+2016.A&A588](#)
- GBM 4yr **GRB** spectral Catalog [Gruber+2014.ApJSS211](#)
- GBM 4yr **GRB** trigger Catalog (2FGBM) [von Kienlin+2014.ApJSS211](#)
- GBM 3yr **X-ray Burst** Catalog [Jenke+2016.ApJ826](#)
- GBM 3yr **EOM** catalog [Wilson-Hodge et al. 2012](#)
- GBM 2yr **GRB** spectral Catalog [Goldstein+2012.ApJSS199](#)
- GBM 2yr **GRB** trigger Catalog (1FGBM) [Paciesas+2012.ApJSS199](#)

2008

Fermi GBM GRB highlights

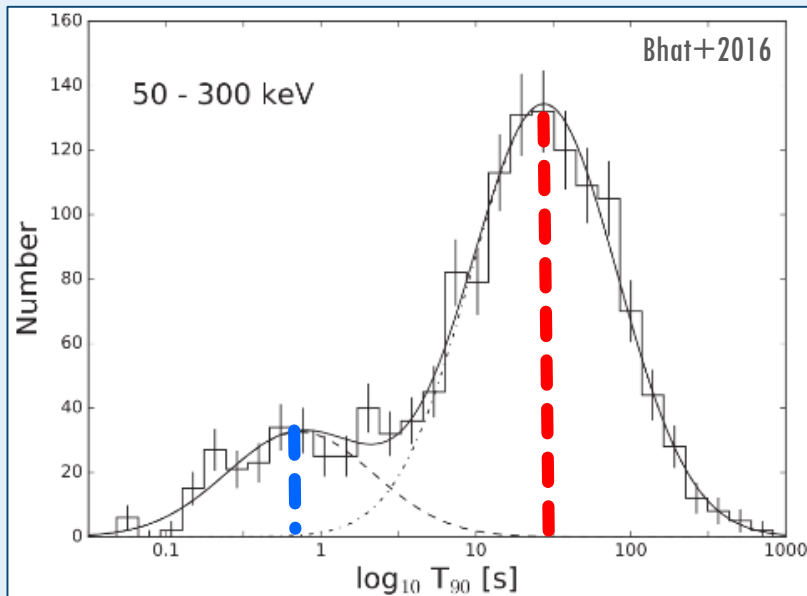
GBM GRB rate: $242 \pm 6/\text{yr}$
GBM: ~ 40 sGRBs/yr
Swift: ~ 9 sGRBs/yr

3rd GBM GRB Catalog (Bhat+2016ApJSS223)

For each GRB: **location, duration, peak flux & fluence**

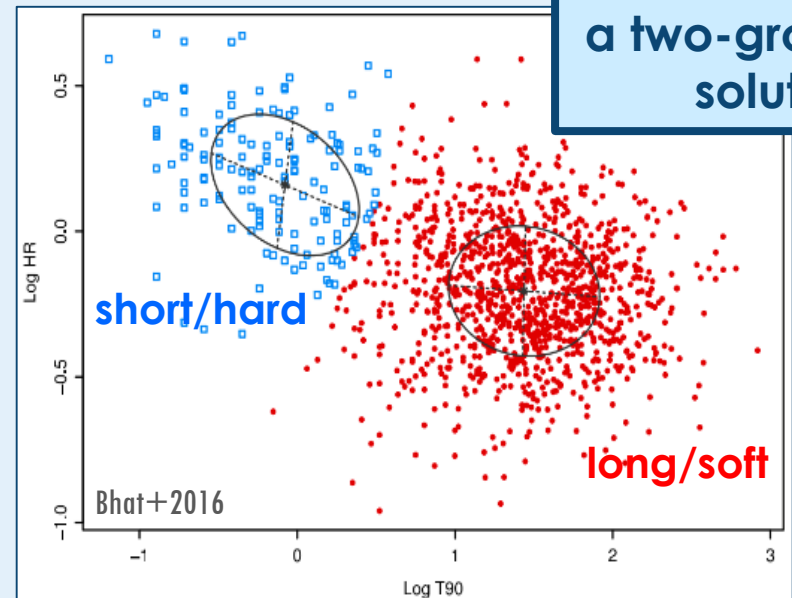
Distribution of GRB durations

- “ T_{90} ” interval between the times where the burst has reached 5% and 95% of its maximum fluence
- **Median T_{90} values:**
 - **0.58 s (short), 26.62 s (long)**



Hardness-duration diagram

- “**Hardness**”: Ratio of burst fluence during the T_{90} intervals in the energy band **50–300 keV** to that in the **10–50 keV** band



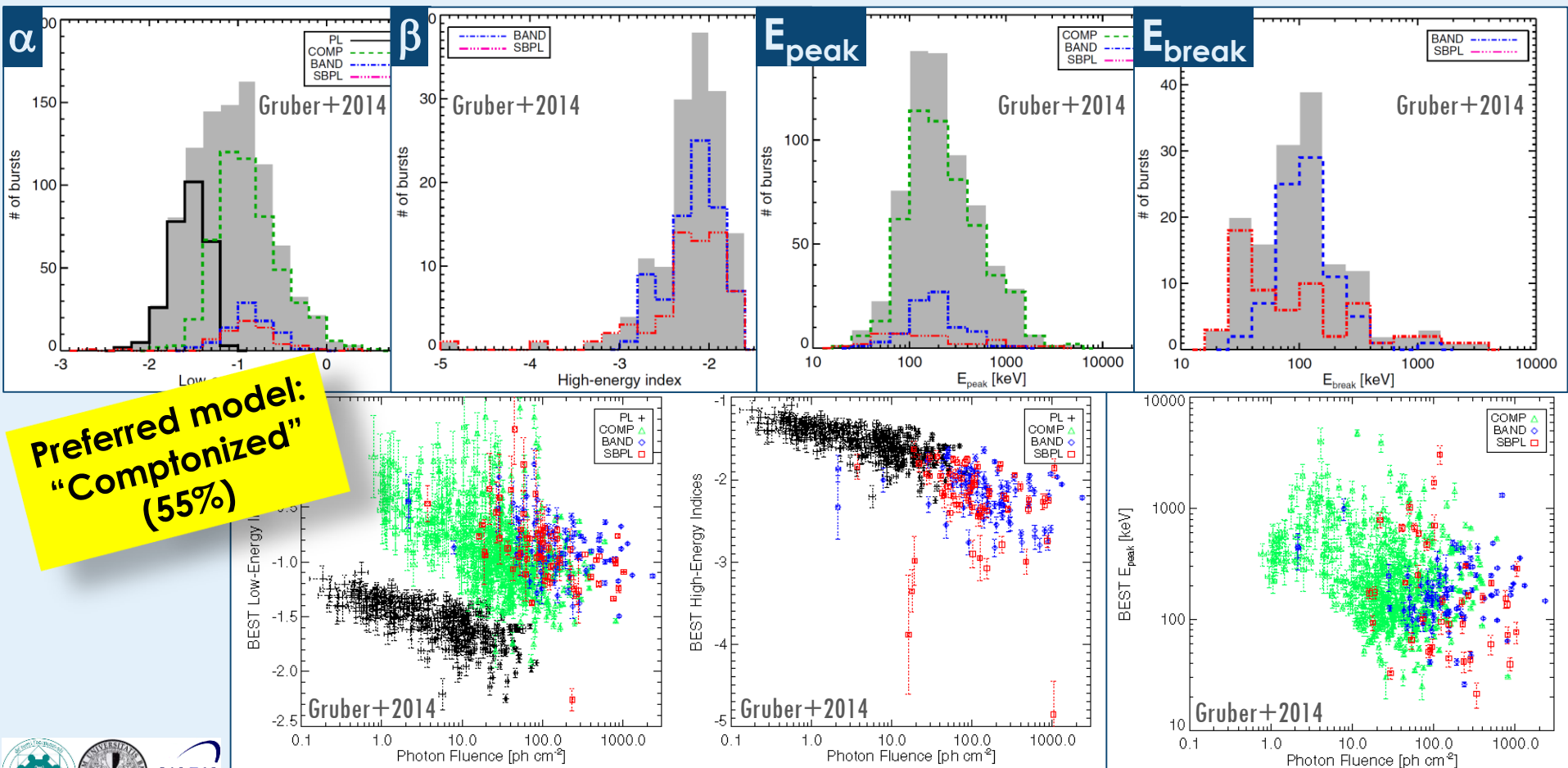
→ **Strong evidence for a two-group solution**

Ellipses show the best-fitting multivariate Gaussian models

Fermi GBM GRB highlights

2nd GBM GRB Spectral Catalog (Gruber+2014ApJ211)

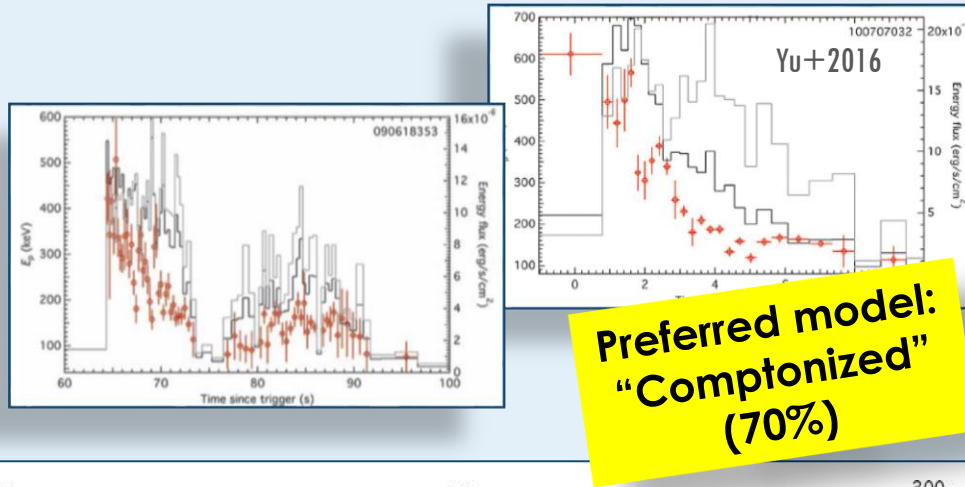
Time-integrated spectral fits + spectral fits at the brightest time bin fitted with 4 spectral models (PL, SBPL, Band, Comp)



Fermi GBM GRB highlights

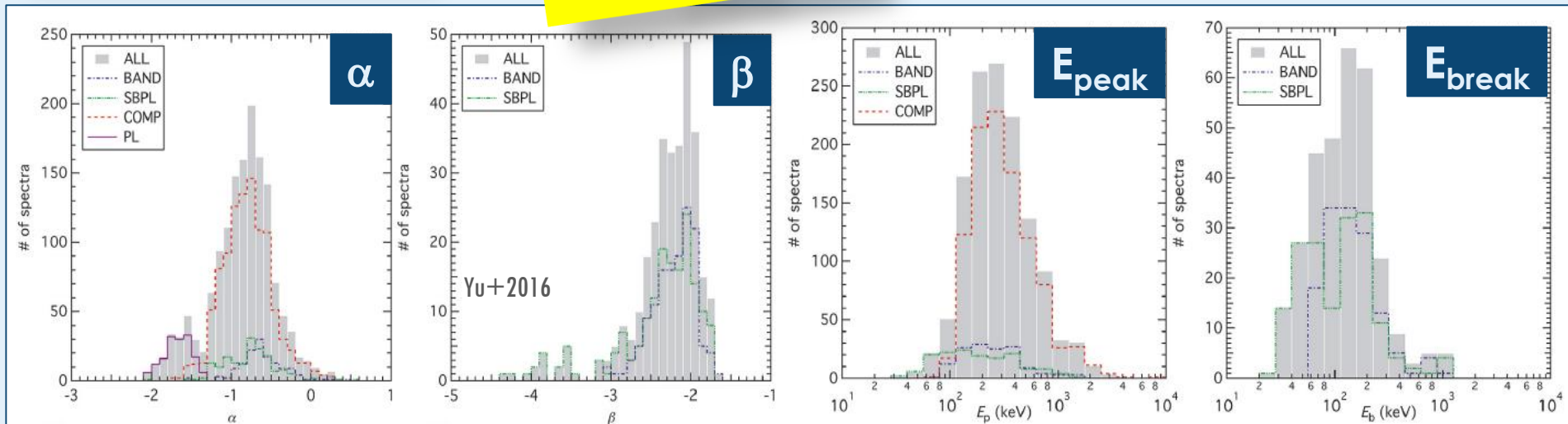
1st Time-resolved spectral catalog (Yu+2016A&A588)

Distributions of parameters, statistics of parameter populations, correlations



Bright GRB subsample

- Selection criteria**
 - fluence ($f > 4 \times 10^{-5}$ erg cm $^{-2}$)
 - peak flux ($F_p > 20$ ph s $^{-1}$ cm $^{-2}$)
 - (S/N)=30 in at least 5 time bins
- 81 GRBs for a total of **1802 spectra**
- Four empirical models** fit to each spectrum: **PL, COMP, Band, SBPL**



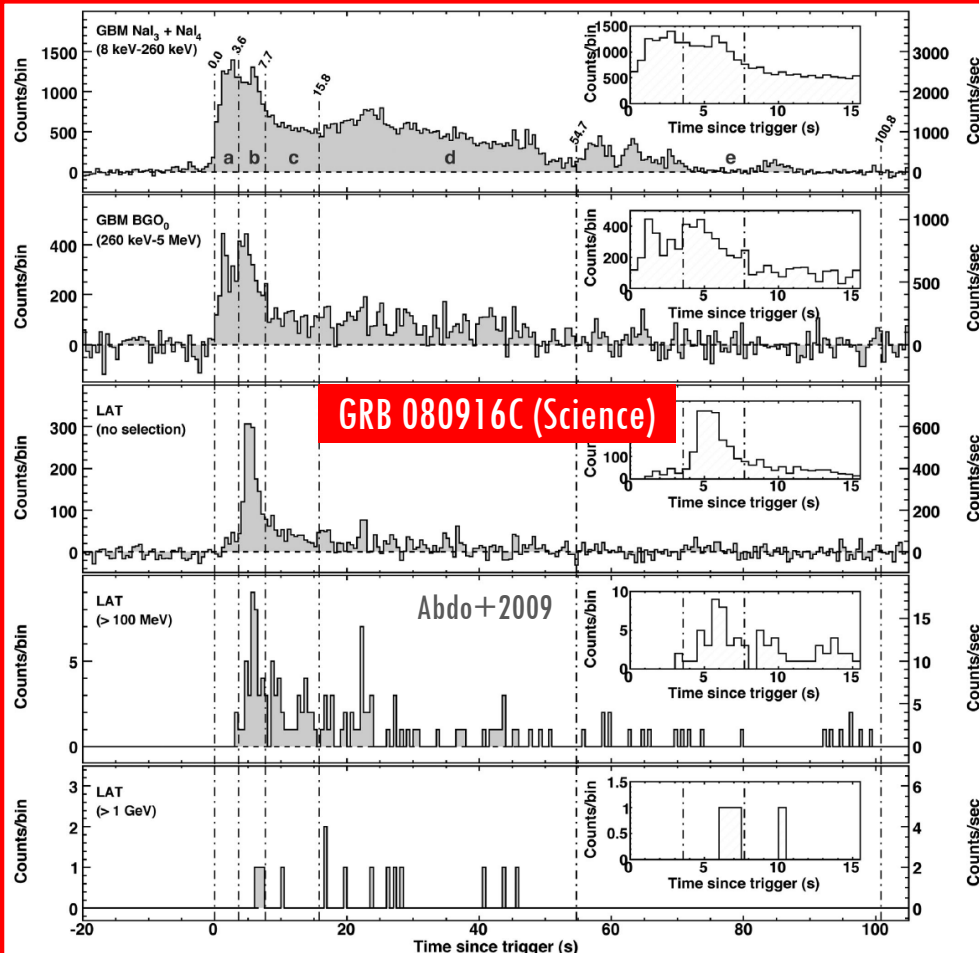
Fermi GBM GRB highlights

Individual GRB papers

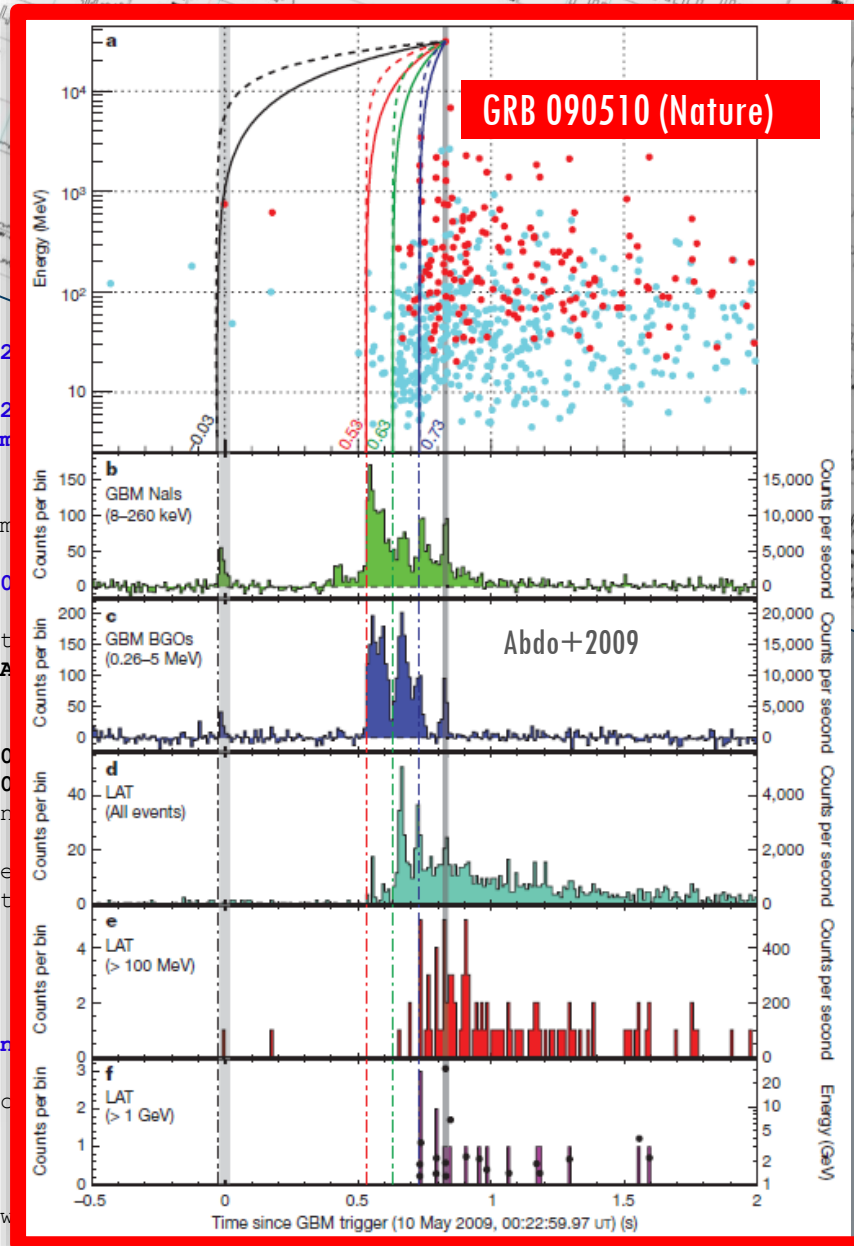
- Multiwavelength observations of the energetic GRB 080810: detailed mapping of the broad-band spectral evolution, [Page+2009](#)
- Fermi Observations of HE Gamma-ray Emission from GRB 080825C, [Abdo+2009](#)
- Fermi Detection of Delayed GeV Emission from the Short GRB 081024B, [Abdo+2010](#)
- Fermi Observations of HE Gamma-Ray Emission from GRB 080916C, [Abdo+2009](#)
- Fermi Observations of HE Gamma-ray Emission from GRB 090217A, [Ackermann+2010](#)
- A limit on the variation of the speed of light arising from quantum gravity effects (GRB 090510), [Abdo+2009](#)
- Swift and Fermi Observations of the Early Afterglow of the Short Gamma-Ray Burst 090510, [De Pasquale+2010](#)
- Fermi Observations of GRB 090510: A Short-Hard Gamma-ray Burst with an Additional, Hard Power-law Component from 10 keV TO GeV Energies, [Ackermann+2010](#)
- Time-resolved Spectroscopy of the **Three Brightest and Hardest Short Gamma-ray Bursts** Observed with the Fermi Gamma-ray Burst Monitor, [Guiriec+2010](#)
- Constraints on the Synchrotron Shock Model for the Fermi GRB 090820A Observed by Gamma-Ray Burst Monitor, [Burgess+2011](#)
- Fermi Observations of GRB 090902B: A Distinct Spectral Component in the Prompt and Delayed Emission, [Abdo+2009](#)
- Identification and Properties of the Photospheric Emission in GRB090902B, [Ryde+2010](#)
- Detection of a Spectral Break in the Extra Hard Component of GRB 090926A, [Ackermann+2011](#)
- Fermi/GBM observations of the ultra-long GRB 091024. A burst with an optical flash, [Gruber+2010](#)
- Detection of a Thermal Spectral Component in the Prompt Emission of GRB 100724B, [Guiriec+2011](#)
- GRB110721A: An Extreme Peak Energy and Signatures of the Photosphere, [Axelsson+2012](#)
- Multiwavelength Observations of GRB 110731A: GeV Emission from Onset to Afterglow, [Ackermann+2013](#)
- The First Pulse of the Extremely Bright GRB 130427A: A Test Lab for Synchrotron Shocks, [Preece+2014](#)
- Probing Curvature Effects in the Fermi GRB 110920, [Shenoy+2013](#)
- Evidence for a Photospheric Component in the Prompt Emission of the Short GRB 120323A and Its Effects on the GRB Hardness-Luminosity Relation, [Guiriec+2013](#)
- Fermi-LAT Observations of the Gamma-Ray Burst GRB 130427A, [Ackermann+2014](#)
- The Bright Optical Flash and Afterglow from the Gamma-Ray Burst GRB 130427A, [Vetsrand+2014](#)
- NuSTAR Observations of GRB 130427A Establish a Single Component Synchrotron Afterglow Origin for the Late Optical to Multi-GeV Emission [Kouveliotou+2013](#)
- Synchrotron Origin of the Typical GRB Band Function—A Case Study of GRB 130606B, [Zhang+2016](#)
- GROND coverage of the main peak of GRB 130925A, [Greiner+2014](#)
- GRB 130925A: an ultralong gamma ray burst with a dust-echo afterglow, and implications for the origin of the ultralong GRBs, [Evans+2014](#)

https://gammaray.nsstc.nasa.gov/gbm/science/grbs/month_listings/

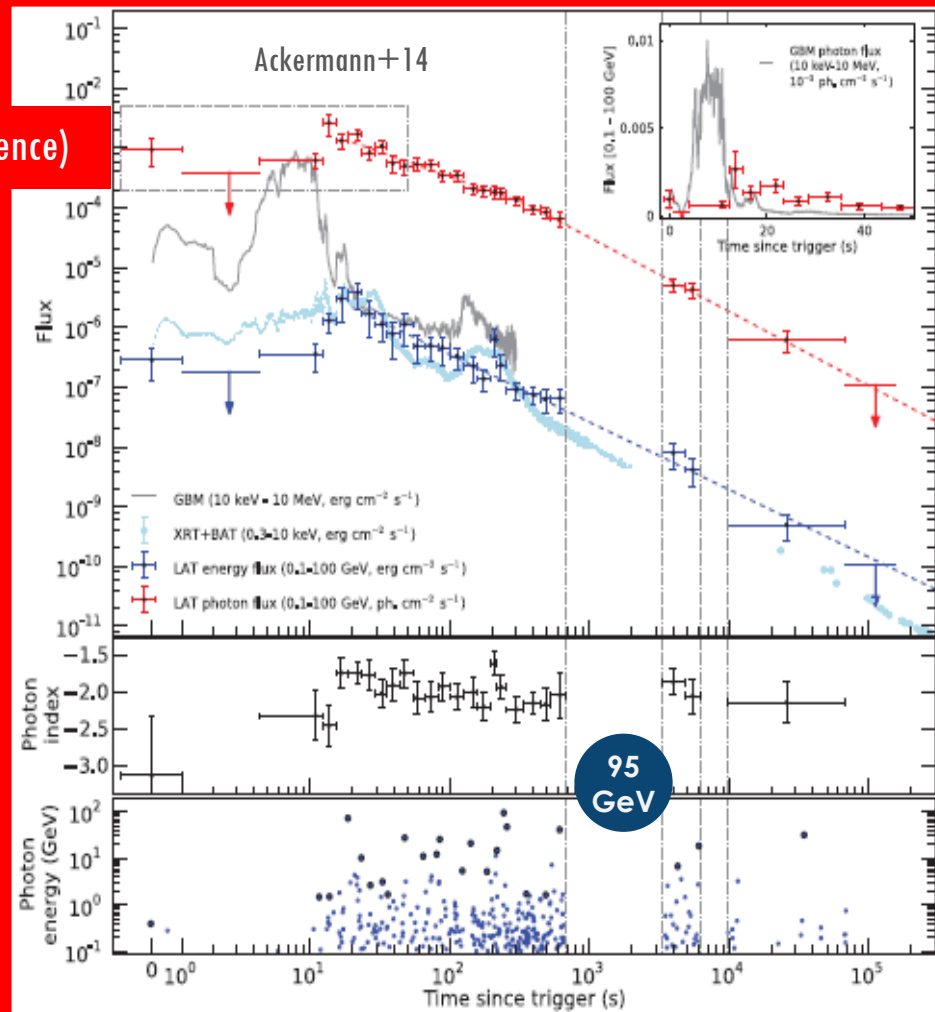
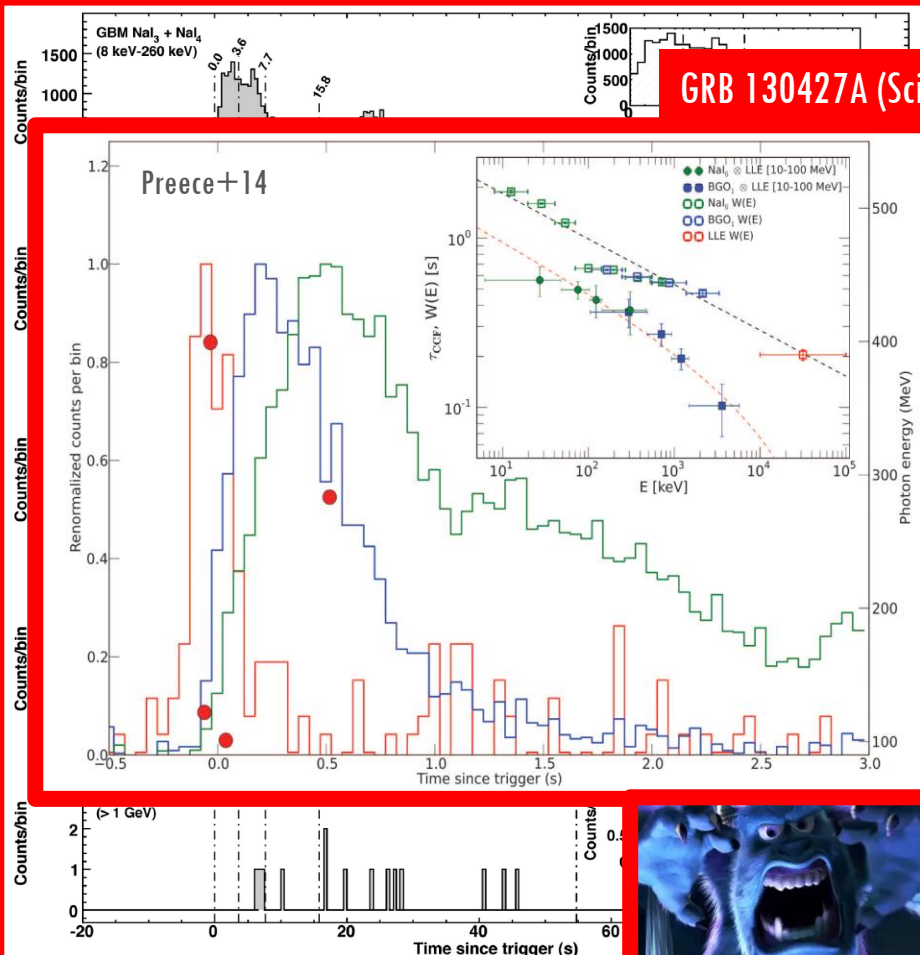
Fermi GBM GRB highlights



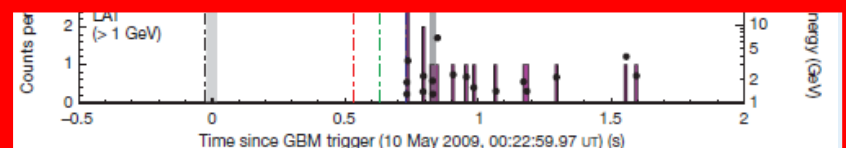
- NuSTAR Observations of **GRB 130427A** Establish a Single Component Synchrotron Origin for the Late Optical to Multi-GeV Emission [Kouveliotou+2013](#)
- Synchrotron Origin of the Typical GRB Band Function—A Case Study of **GRB 130925A**, [Greiner+2014](#)
- GROND coverage of the main peak of **GRB 130925A**, [Greiner+2014](#)
- **GRB 130925A**: an ultralong gamma ray burst with a dust-echo afterglow and implications for the origin of the ultralong GRBs, [Evans+2014](#)



Fermi GBM GRB highlights



- NuSTAR Observations of **GRB 130427A** Establish a Single Component Synchrotron Origin for the Late Optical to Multi-GeV Emission [Kouveliotou+2013](#)
- Synchrotron Origin of the Typical GRB Band Function—A Case Study of GROND coverage of the main peak of **GRB 130925A**, [Greiner+2014](#)
- **GRB 130925A**: an ultralong gamma ray burst with a dust-echo afterglow implications for the origin of the ultralong GRBs, [Evans+2014](#)



General GRB papers

- First-year Results of **Broadband Spectroscopy** of the **Brightest** Fermi-GBM Gamma-Ray Bursts, [Bissaldi+2011](#)
- **Rest-frame properties** of 32 gamma-ray bursts observed by the Fermi Gamma-ray Burst Monitor, [Gruber+2011](#)
- **Quasi-periodic pulsations in solar flares**: new clues from the Fermi Gamma-Ray Burst Monitor, [Gruber+2011](#)
- An overview of the current **understanding of Gamma Ray** Bursts in the Fermi era, [Bhat+2011](#)
- The **lag-luminosity relation** in the GRB source frame: an investigation with Swift BAT bursts, [Ukwatta+2012](#)
- **Constraining the High-energy Emission** from Gamma-Ray Bursts with Fermi, [Ackermann+2012](#)
- **Temporal Deconvolution Study** of Long and Short Gamma-Ray Burst Light Curves, [Bhat+2012](#)
- The **Interplanetary Network** Supplement to the Fermi GBM Catalog of Cosmic Gamma-Ray Bursts, [Hurley+2013](#)
- **Anomalies** in low-energy gamma-ray burst spectra with the Fermi Gamma-ray Burst Monitor, [Tierney+2013](#)
- **How Long** does a Burst Burst?, [Zhang+2014](#)
- An Observed **Correlation** between **Thermal and Non-thermal Emission** in Gamma-Ray Bursts, [Burgess+2014](#)
- Time-resolved Analysis of Fermi Gamma-Ray Bursts with **Fast- and Slow-cooled Synchrotron Photon Models**, [Burgess+2014](#)
- The **sharpness** of gamma-ray burst prompt emission **spectra**, [Yu+2015](#)
- **Synchrotron Cooling** in Energetic Gamma-Ray Bursts Observed by the Fermi Gamma-Ray Burst Monitor, [Yu+2015](#)
- **Localization** of Gamma-Ray Bursts Using the Fermi Gamma-Ray Burst Monitor, [Connaughton+2015](#)
- Which Epeak? - The **Characteristic Energy** of Gamma-Ray Burst Spectra, [Preece+2016](#)
- Do the **Fermi** Gamma-Ray Burst Monitor and **Swift** Burst Alert Telescope see the Same **Short Gamma-Ray Bursts**?, [Burns+2016](#)
- Estimating Long GRB **Jet Opening Angles** and **Rest Frame Energetics**, [Goldstein+2016](#)

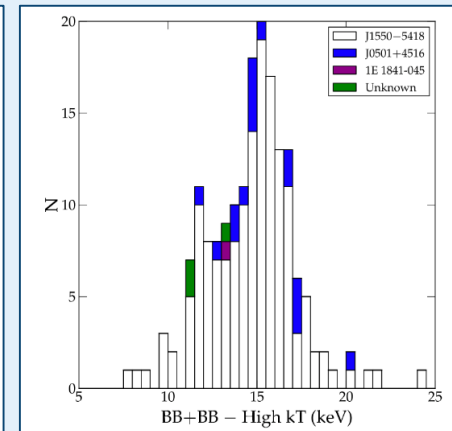
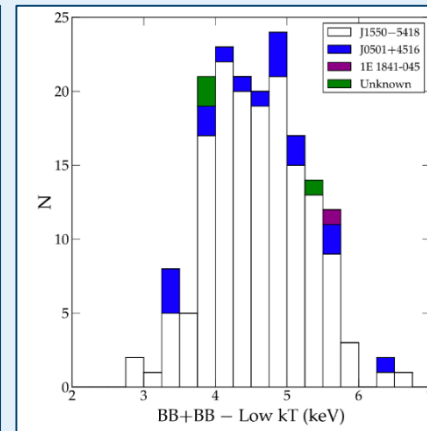
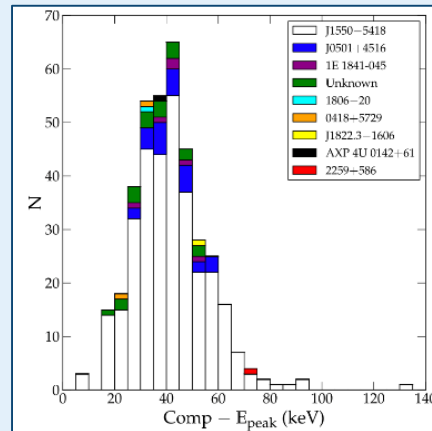
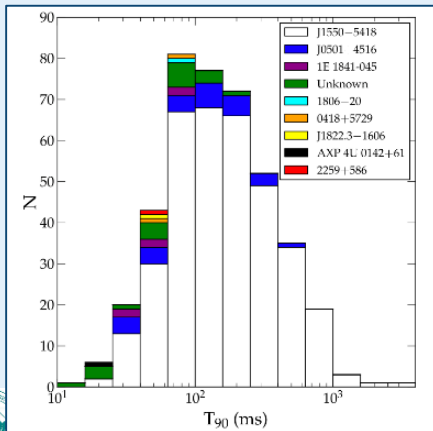
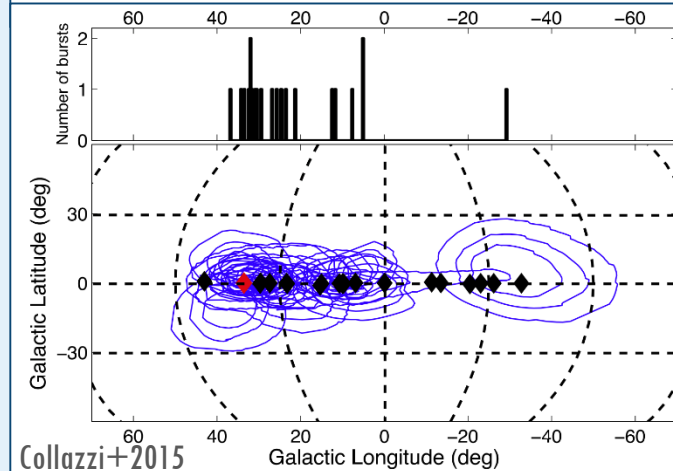
Fermi GBM Magnetar highlights

1st Magnetar Burst Catalog (Collazzi+2015ApJSS218)

- Temporal & spectral analysis of **446 magnetar bursts** collected in 5 years
 - durations, spectral parameters for various models, fluences, and peak fluxes
- Small sample of **magnetar-like bursts of unknown origin**
- Combined **durations and spectral parameters** show similarities:
 - $T_{90} \sim 100$ ms
 - $E_{\text{peak}} \sim 40$ keV
 - BB+BB Temp. around ~ 4.5 and ~ 15 keV

Summary of GBM Magnetar Bursts

Source	Burst Active Periods	Number of Bursts with TTE data
SGR J1550-5418	2008 Oct-2009 Apr	386
SGR J0501+4516	2008 Aug/Sep	29
1E 1841-045	2011 Feb-Jul	6
SGR J0418+5729	2009 Jun	2
SGR 1806-20	2010 Mar	1
SGR J1822.3-1606	2011 Jul	1
AXP 4U 0142+61	2011 Jul	1
AXP 1E 2259+586	2011 Aug	1
Unknown	...	19

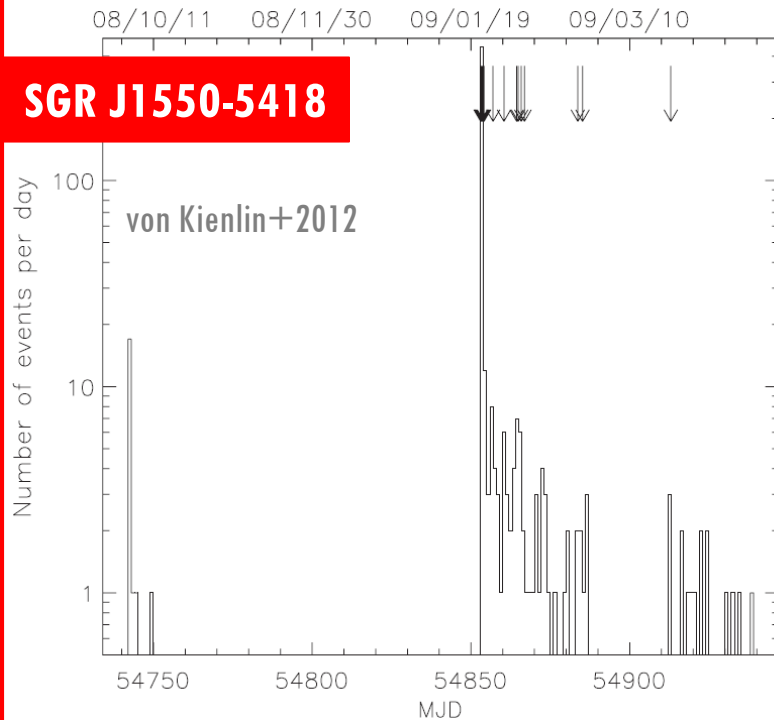


Magnetar papers

- **Photospheric radius expansion** during magnetar bursts, [Watts+2010](#)
- Discovery of a **new** soft gamma repeater: **SGR J0418+5729**, [van der Horst+2010](#)
- Magnetar twists: Fermi/Gamma-ray Burst Monitor detection of **SGR J1550-5418**, [Kaneko+2010](#)
- Fermi/GBM Observations of **SGR J0501+4516 Bursts**, [Lin+2011](#)
- Detection of **Spectral Evolution** in the Bursts Emitted during the 2008-2009 Active Episode of **SGR J1550-5418**, [von Kienlin+ 2012](#)
- **SGR J1550-5418** bursts detected with the Fermi Gamma-ray Burst Monitor during its **most prolific activity**, [van der Horst+2012](#)
- Broadband Spectral Investigations of **SGR J1550-5418 Bursts**, [Lin+2012](#)
- **Time Resolved Spectroscopy** of **SGR J1550-5418 Bursts** Detected with Fermi/Gamma-Ray Burst Monitor, [Younes+2014](#)
- Magnetar-like X-Ray Bursts from a **Rotation-powered Pulsar**, **PSR J1119-6127**, [Gogus+2016](#)
- The **Wind Nebula** around Magnetar **Swift J1834.9-0846**, [Younes+2016](#)
- X-Ray and Radio Observations of the **Magnetar SGR J1935+2154** during Its 2014, 2015, and 2016 Outbursts, [Younes+2017](#)
- Burst and Outburst Characteristics of **Magnetar 4U 0142+61**, [Gogus+2017](#)
- Detection of Very Low-frequency, **Quasi-periodic Oscillations** in the 2015 Outburst of **V404 Cygni**, [Huppenknoten+2017](#)

Fermi GBM Magnetar highlights

SGR J1550-5418



Magnetar papers

during magnetar bursts, [Watts+2010](#)
repeater: **SGR J0418+5729**,

day Burst Monitor detection of SGR

J0501+4516 Bursts, [Lin+2011](#)

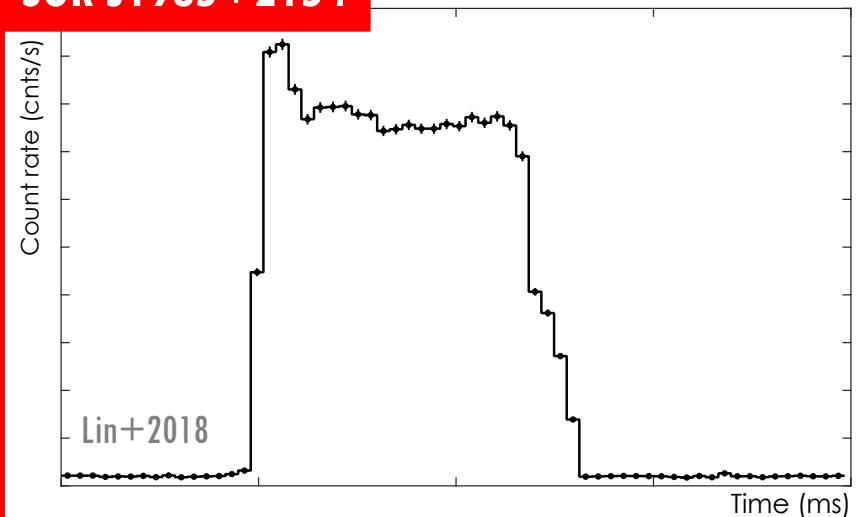
in the Bursts Emitted during the

SGR J1550-5418, [von Kienlin+ 2012](#)

with the Fermi Gamma-ray Burst

activity, [van der Horst+2012](#)

SGR J1935+2154



- X-ray and Radio Observations of
Its 2014, 2015, and 2016 Outbursts
• Burst and Outburst Characterization
[Gogus+2017](#)
- Detection of Very Low-frequency
2015 Outburst of **V404 Cygni**, [Hu](#)

Fermi GBM X-ray Burst highlights

The Fermi-GBM
X-Ray Burst Monitor:
Thermonuclear Bursts
from **4U 0614+09**,
Linares+2012

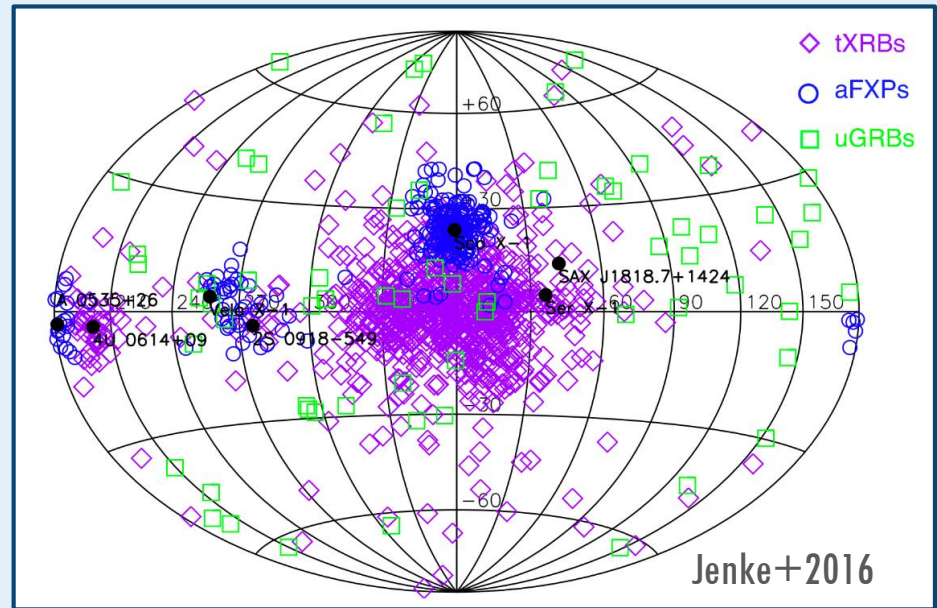
1st X-ray Burst Catalog (Jenke+2016ApJ826)

- Systematic search over 3 years of data for **transients** in the **12–25 keV energy band**, with a min. time resolution of **8.2 s**

→ 1084 events

- classified using spectral analysis, location, and spatial distributions

752 thermonuclear X-ray bursts
267 accretion flare events
+ X-ray pulses
65 untriggered GRBs

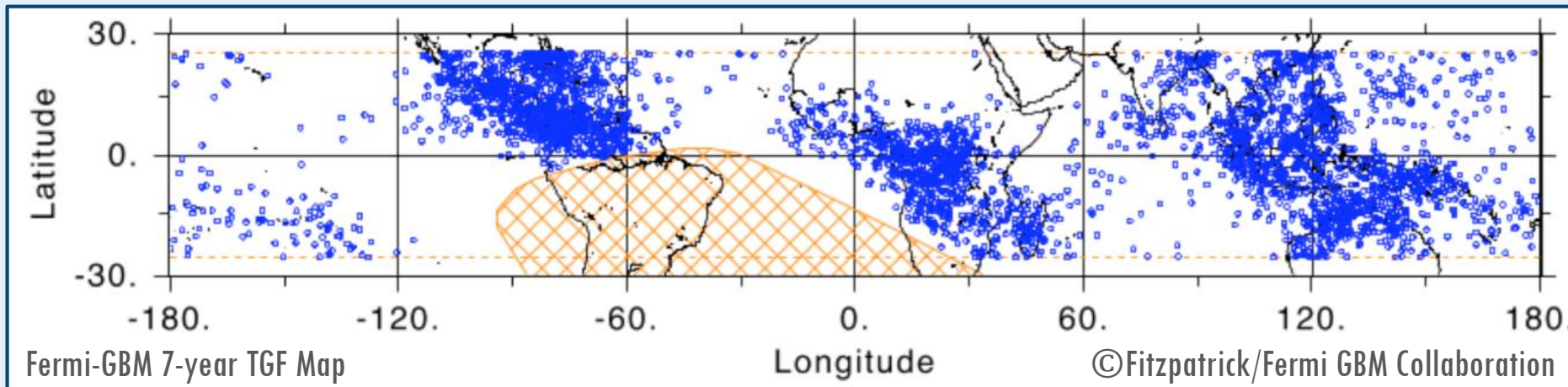
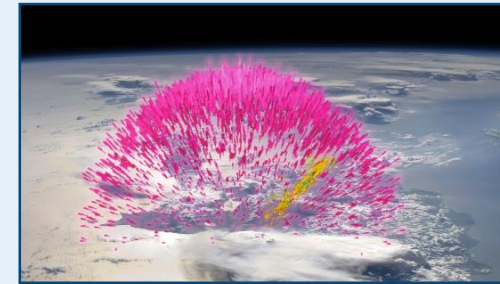


- tXRBs have peak **blackbody** temperatures (3.2 ± 0.3 keV) broadly consistent with **photospheric radius expansion** (PRE) bursts
- Average rate: **1.4 PRE bursts per day**, integrated over all Galactic bursters within about 10 kpc

Fermi GBM TGF highlights

1st TGF catalog (Roberts+2018submitted)

- Over 8 years, 4144 TGFs, **>80% untriggered** found in dedicated offline searches, 800 TGFs/yr!
 - Terrestrial Electron Beams (TEBs)**: 20 reliable, 10 possible
 - Over 1500 TGFs have **very low frequency (VLF) geo-locations** good to ~10 km



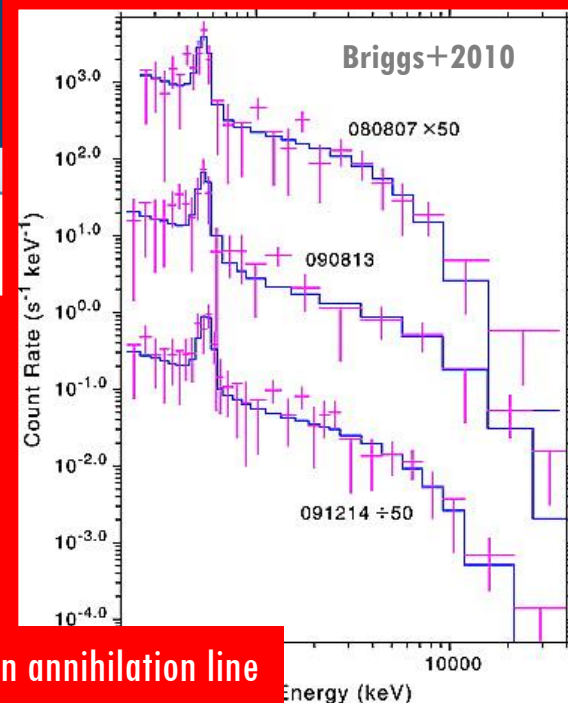
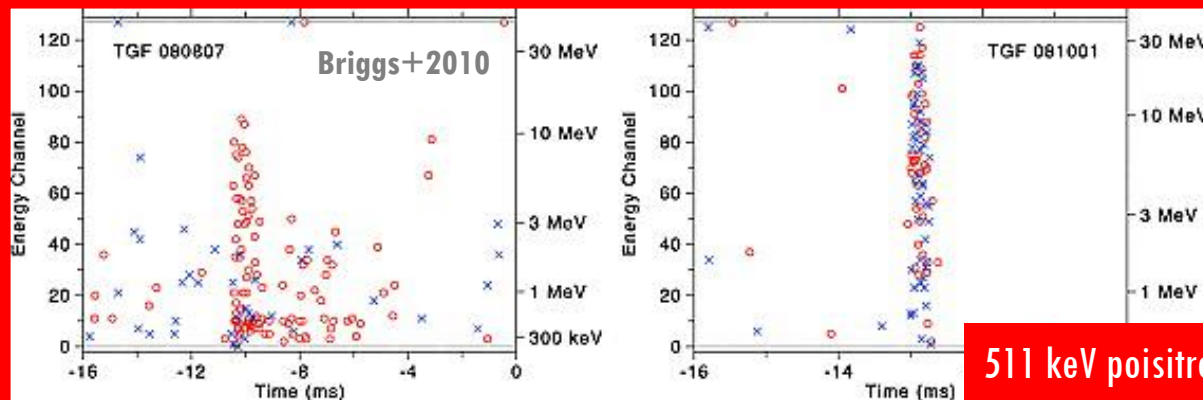
- 2nd online catalog (tables & tools):
<http://fermi.gsfc.nasa.gov/ssc/data/access/gbm/tgf/>

TGF papers

- First Results on **Terrestrial Gamma-ray Flashes** from the Fermi Gamma-ray Burst Monitor, [Briggs+2009](#)
- **Electron-Positron Beams** from Terrestrial Lightning Observed with Fermi GBM, [Briggs+2010](#)
- Associations between Fermi GBM Terrestrial Gamma-ray Flashes and sferics from the WWLLN, [Connaughton+2010](#)
- A lightning discharge producing a beam of **relativistic electrons** into space, [Cohen+2010](#)
- The **lightning-TGF relationship** on microsecond timescales, [Cummer+2011](#)
- **Temporal properties** of the terrestrial gamma-ray flashes from the Gamma-Ray Burst Monitor on the Fermi Observatory, [Fishman+2011](#)
- **Location prediction** of electron TGFs, [Xiong+2012](#)
- **Radio signals** from electron beams in Terrestrial Gamma-ray Flashes, [Connaughton+2012](#)
- Terrestrial Gamma-ray Flashes in the Fermi era: **Improved Observations** and Analysis Methods, [Briggs+2013](#)
- **Fluence Distribution** of Terrestrial Gamma-ray Flashes Observed by the Fermi Gamma-Ray Burst Monitor, [Tierney+2013](#)
- **Pulse properties** of terrestrial gamma-ray flashes detected by the Fermi Gamma-Ray Burst Monitor, [Fitzpatrick+2014](#)
- **Compton scattering** in terrestrial gamma-ray flashes detected with the Fermi gamma-ray burst monitor, [Fitzpatrick+2014](#)
- The **Source Altitude, Electric Current, and Intrinsic Brightness** of Terrestrial Gamma Ray Flashes, [Cummer+2014](#)
- **Characteristics of Thunderstorms** that produce Terrestrial Gamma-ray Flashes, [Chronis+2015](#)
- A **Lightning-Based Search** for Nearby Observationally Dim Terrestrial Gamma-ray Flashes, [McTague+2015](#)
- The **Spectroscopy** of Individual Terrestrial Gamma-ray Flashes: Constraining the Source Properties, [Mailyan+2016](#)
- **Terrestrial gamma ray flashes** due to particle acceleration in tropical storm systems, [Roberts+2017](#)

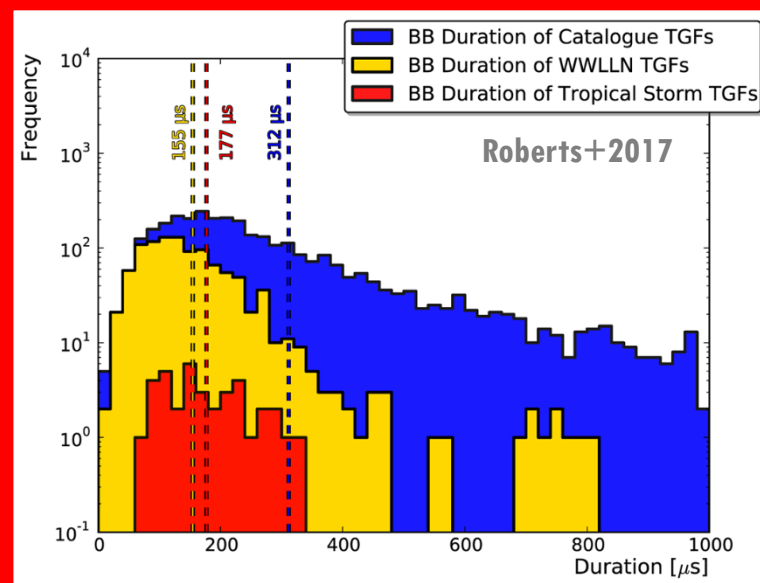
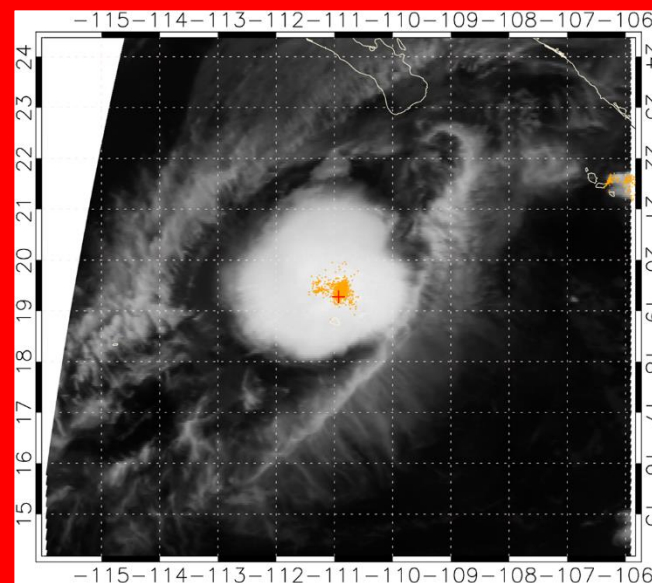
Fermi GBM TGF highlights

TGF papers



511 keV positron annihilation line

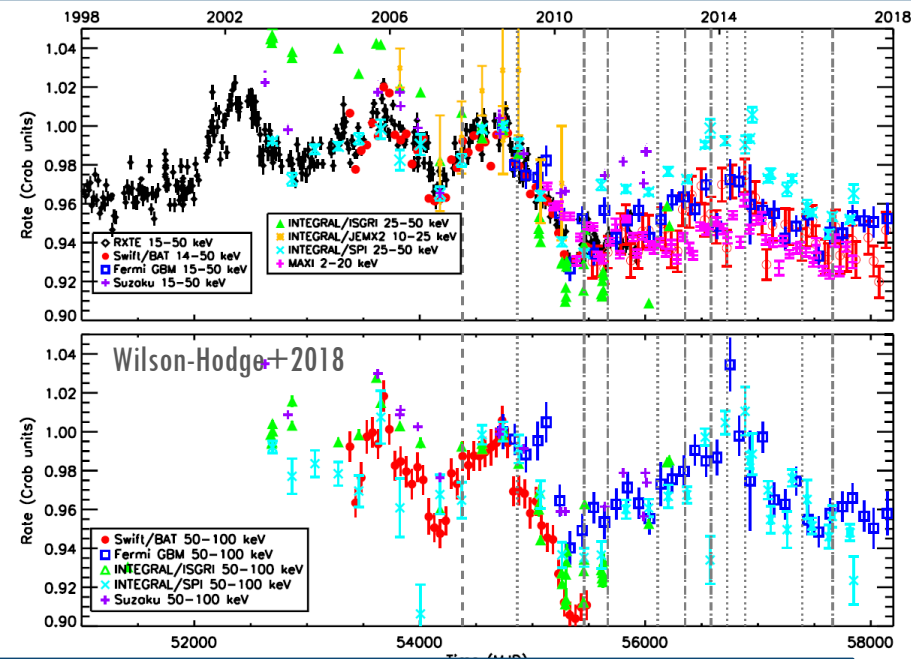
- Terrestrial Gamma-ray Flashes, **Briggs+2010**
- Fluence Distribution of TGFs, **Briggs+2010**
- Burst Monitor, **Briggs+2010**
- Pulse properties of TGFs, **Fitzpatrick+2010**
- Compton scattering in TGFs, **Fitzpatrick+2010**
- The Source Altitude of TGFs, **Cummer+2010**
- Characteristic Timescales of TGFs, **Cummer+2010**
- A Lightning-Based Model for TGFs, **McTague+2015**
- The Spectroscopic Properties of TGFs, **McTague+2015**
- Terrestrial gamma-ray flashes, **Roberts+2017**



Roberts+2017

Fermi GBM EOM highlights

- Earth Occultation Monitoring:
Change in the count rate observed in the GBM detectors when the source **enters** or **exits** Earth occultation
 - Counts in each energy channel converted to fluxes using an assumed spectrum for each source
 - ~250 sources are monitored** (X-ray binaries, AGNs, etc.)
- Crab Nebula Hard X-ray Variations



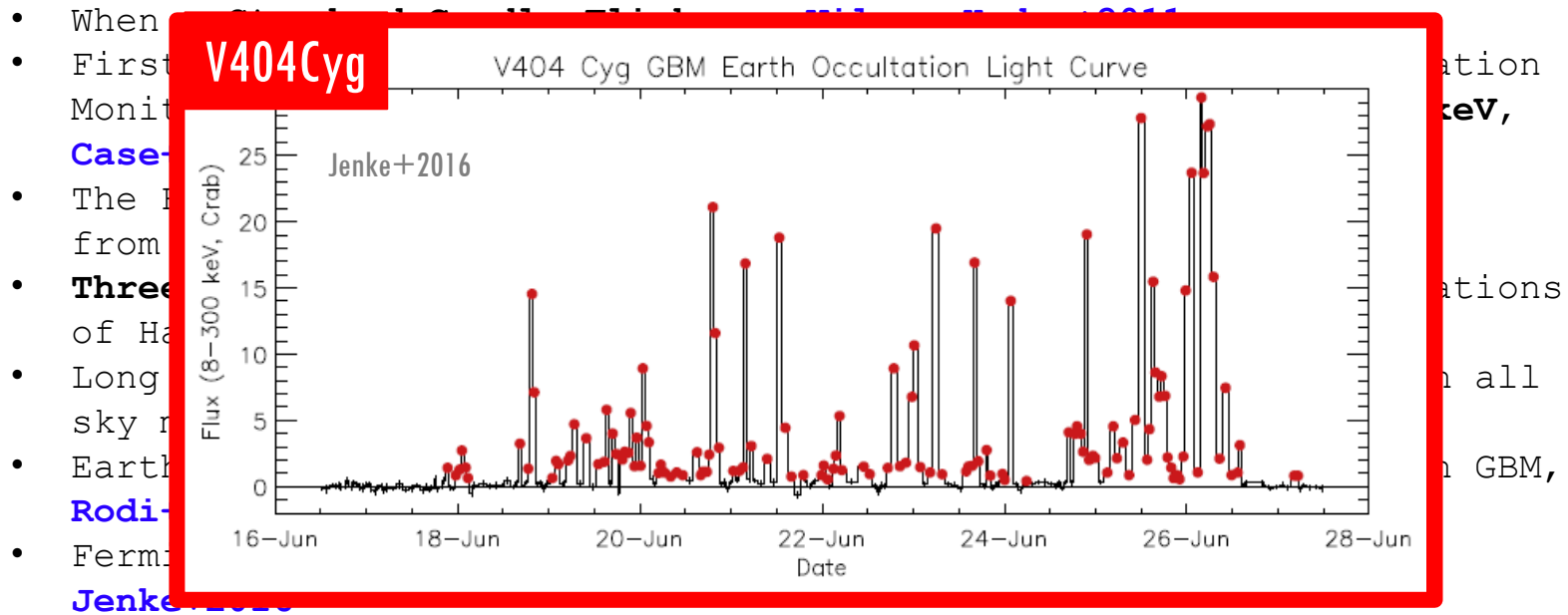
https://gammaray.nsstc.nasa.gov/gbm/science/earth_occ.html

#	SOURCE NAME	RA (DEG)	DEC (DEG)	L (DEG)	B (DEG)	OBJECT TYPE
1	SUN	0.000	0.000	96.337	-60.189	Star
2	IGR_J00234+6141	5.740	61.685	119.561	-1.000	CV
3	V709_CAS	7.204	59.289	120.042	-3.456	CV/DQ Her
4	BD+6270	9.300	61.380	121.227	-1.445	Star
5	FERMIJ0109+6134	17.445	61.558	125.115	-1.236	AGN
6	SMCX-1	19.275	-73.433	300.412	-43.569	HMXB/NS

Earth Occultation Monitoring papers

- When **Supernova** **Candle Flickers**, [Wilson-Hodge+2011](#)
- First **V404Cyg** from Fermi Gamma-ray Burst Monitor Earth Occultation Monitoring. Observations of **Soft Gamma-ray Sources Above 100 keV**, [Case+2011](#)
- The Fermi-GBM X-ray burst monitor: **thermonuclear bursts** from **4U 0614+09**, [Linares+2012](#)
- **Three years** of Fermi GBM Earth Occultation Monitoring: Observations of Hard X-ray/Soft Gamma-Ray Sources, [Wilson-Hodge+2012](#)
- Long term variability of **Cygnus X-1**. V. State definitions with all sky monitor, [Grinberg+2013](#)
- Earth occultation imaging of the **low energy gamma-ray** sky with GBM, [Rodi+2014](#)
- Fermi GBM Observations of **V404 Cyg** During its **2015 Outburst**, [Jenke+2016](#)

Earth Occultation Monitoring papers

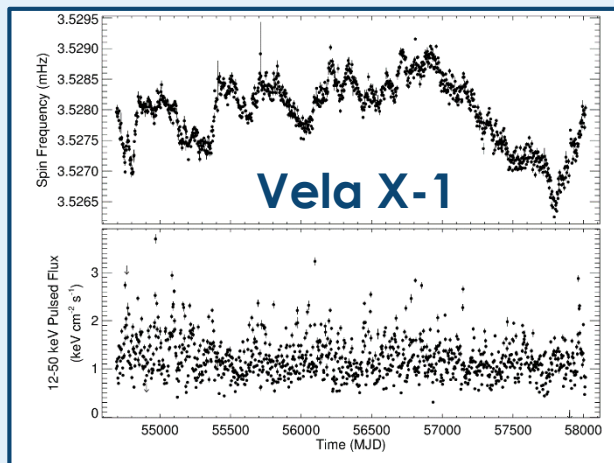
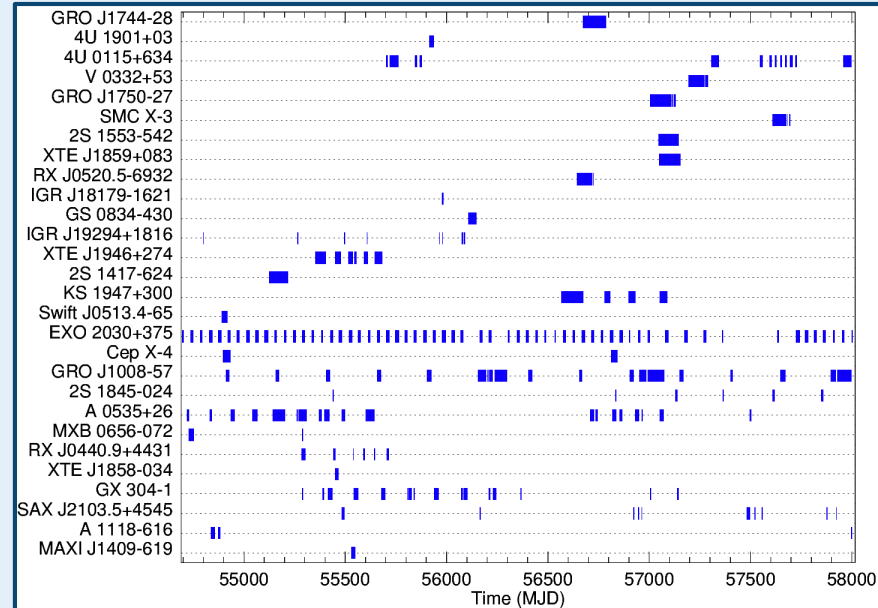


Fermi GBM Pulsar highlights

- **Daily blind searches** for new pulsars and new outbursts
- Accreting Pulsars Monitoring Program using **epoch folded searches** includes 39 sources
 - **36 sources detected**
 - **8 persistent, 28 transient sources**
- Online pulsar list

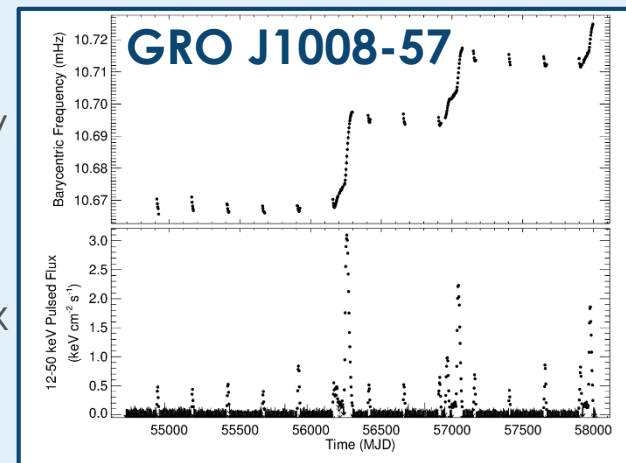
<http://gammaray.nsstc.nasa.gov/gbm/science/pulsars.html>

Times of Transient Outburst Detections



Frequency

Pulsed Flux



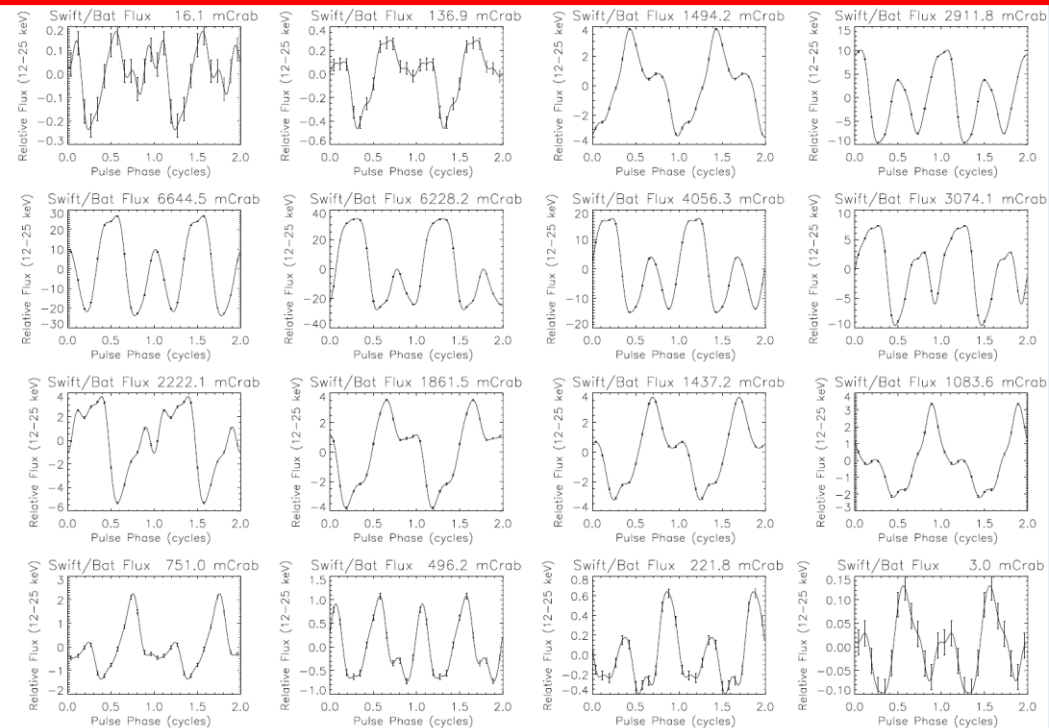
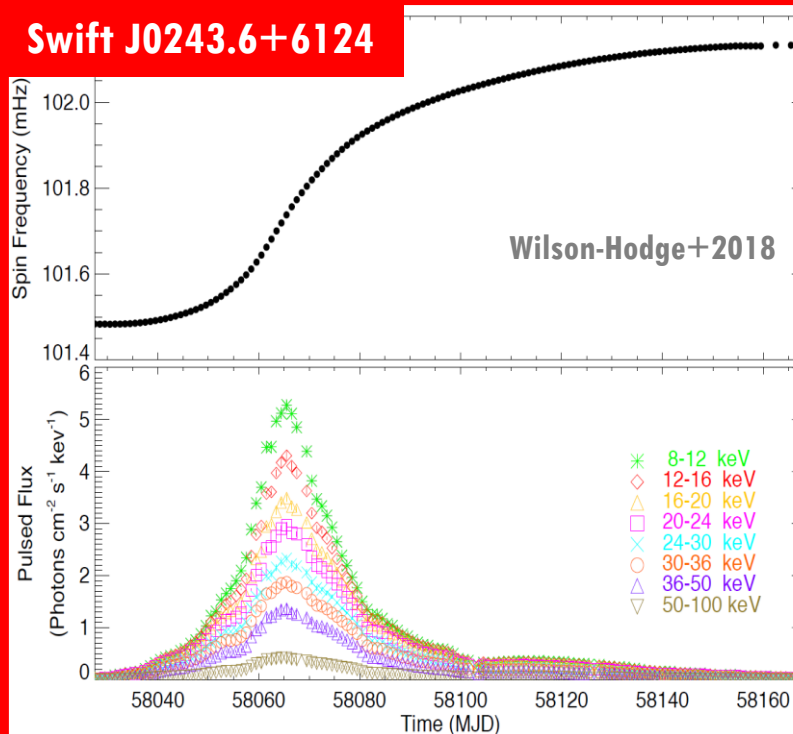
Pulsar papers

- New **Torque Reversal and Spin-up** of **4U 1626-67** Observed by Fermi/Gamma-ray Burst Monitor and Swift/Burst Alert Telescope, [Camero-Arranz+2011](#)
- **4U 1626-67** as seen by Suzaku before and after the 2008 torque reversal, [Camero-Arranz+2012](#)
- **Orbital Decay** and Evidence of **Disk Formation** in the **X-ray Binary Pulsar OAO 1657-415**, [Jenke+2012](#)
- X-Ray and Optical Observations of **A 0535+26**, [Camero-Arranz+2012](#)
- **Spin period evolution** of **GX 1+4**, [González-Galán+2012](#)
- A **Double-peaked Outburst** of **A 0535+26** Observed with INTEGRAL, RXTE, and Suzaku, [Caballero+2013](#)
- The Transient **Accereting** X-Ray Pulsar **XTE J1946+274**: Stability of the X-Ray Properties at Low Flux and Updated Orbital Solution, [Marcu-Cheatham+2015](#)
- **Swift J0513.4-6547 = LXP 27.2**: a new **Be/X-ray binary system** in the Large Magellanic Cloud, [Coe+2015](#)
- Luminosity and spin-period evolution of **GX 304-1** during outbursts from 2009 to 2013 observed with the MAXI/GSC, RXTE/PCA, and Fermi/GBM, [Sugizaki+2015](#)
- **Spin-up/spin-down** of neutron star in **Be-X-ray binary system GX 304-1**, [Postnov+2015](#)
- NuSTAR discovery of a cyclotron absorption line in the **transient X-ray pulsar 2S 1553-542**, [Tsygankov+2016](#)
- NICER and Fermi GBM Observations of the Transient **Be/X-ray pulsar Swift J0243.6+6124**, [Wilson-Hodge+2018](#)

Fermi GBM Pulsar highlights

Pulsar papers

Swift J0243.6+6124



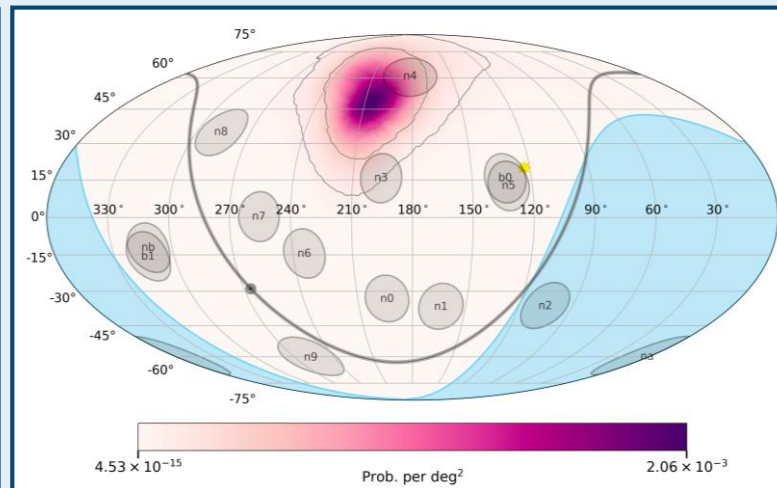
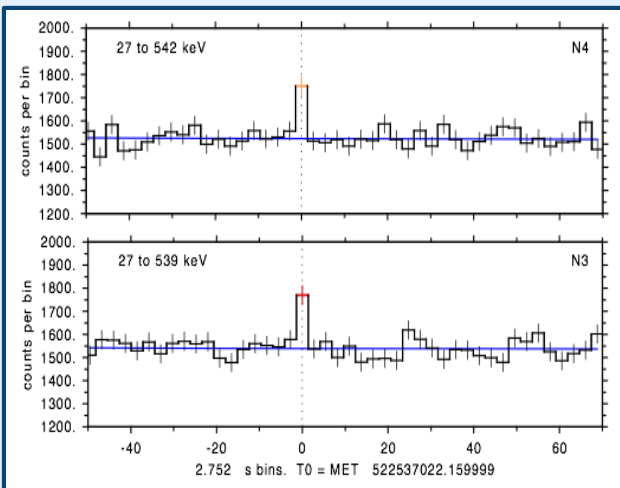
- **Transient X-ray pulsar 2S 1355-542, [Isyankov+2016](#)**
- **NICER and Fermi GBM Observations of the Transient **Be/X-ray pulsar Swift J0243.6+6124**, [Wilson-Hodge+2018](#)**

Fermi GBM untriggered GRB searches

■ Since 2013: More short GRBs found by **automatic on-ground search** of CTTE data

- 4 energy ranges and 10 timescales (0.064 – 2.8 s)
- Significant rate increases **in 2 or more detectors**
- Removing of soft and long transients
- Catalog: http://gammaray.nsstc.nasa.gov/gbm/science/sgrb_search.html

Additional
~100 GRBs/yr, mostly
undetected by
other instruments
(verification in progress)



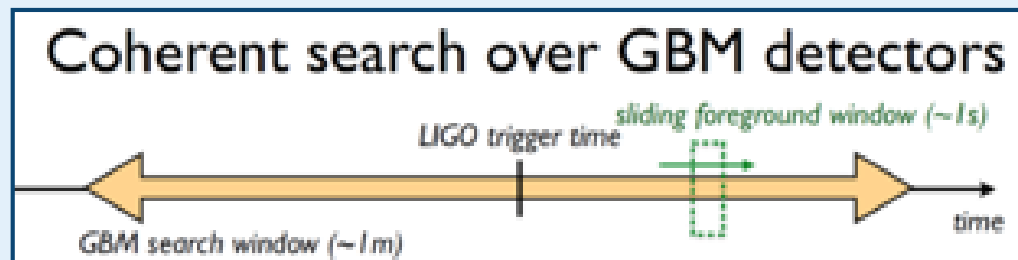
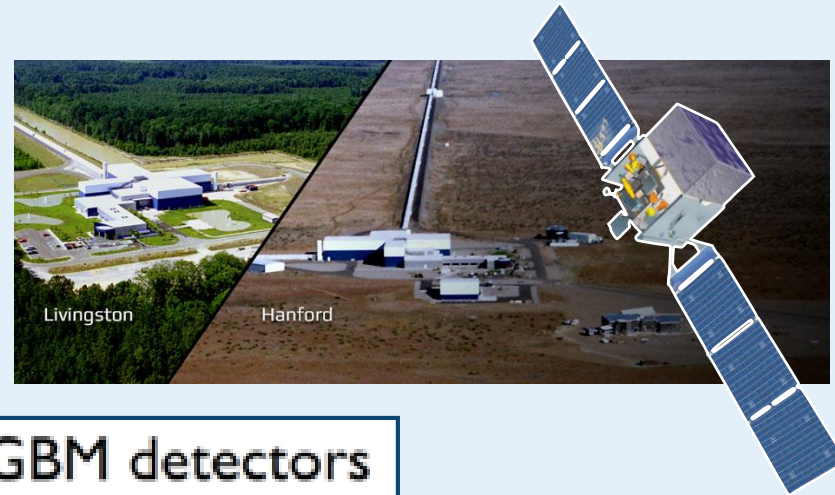
Location
uncertainties
are in the
range of 10
to 40 deg
(68%)

**Current time
delays range
from 0.5 to 6
hrs due to
ground
processing
and data
downlink**

Now available as **automated GCNs**, see:
https://gcn.gsfc.nasa.gov/fermi_gbm_subthreshold.html

Targeted GBM searches to GW events

- Targeted search in **CTTE data**
(Blackburn+2015, Goldstein+2017)
 - Looks for **coherent signals in all detectors** given an input time and optional skymap.



- **Sliding timescales** from 0.064 s to 8 s with a factor of 4 phase shift
- 3 source spectral templates using Band function: soft, normal, and hard
- Many Improvements during O1 and O2: Various bug fixes, better background estimation, more realistic hard spectral template

The transient “GW150914-GBM”

■ Targeted search around **GW150914**:

- **Best candidate:** Hard transient @ $t_{\text{GW}} + 0.4$ s, 1 s long “**GW150914-GBM**”
- 0.2% probability of occurring by chance (2.9σ)

FAR = 27 hard events in 218821.1 s of GBM live time, factor of 3 for spectra searched, 90% confidence

$$P = 2 \times (4.79 \times 10^{-4} \text{ Hz}) \times 0.4 \text{ s} \times (1 + \ln(30 \text{ s} / 0.256 \text{ s})) = 0.0022$$

Offset between GW T0 and GBM event start
Factor of 2 to account for offset in time in either direction

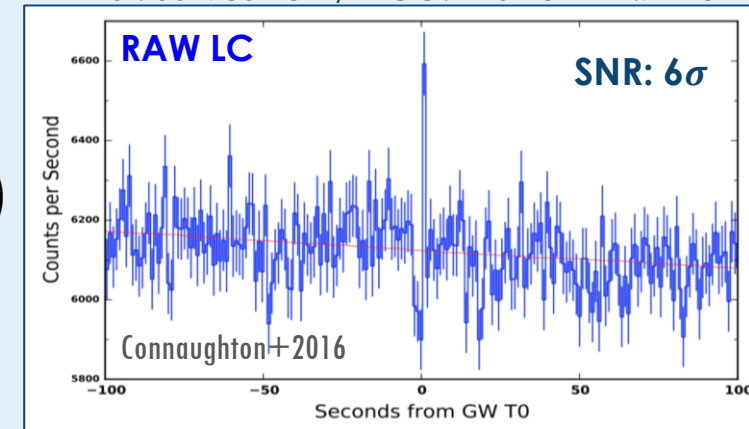
Effective trials factor for non-independent, variable time bins (30s is maximum offset set by the search window, 0.256 is the minimum set by native CTIME data)

■ **Localization:** source direction underneath the spacecraft ($\theta = 163^\circ$)

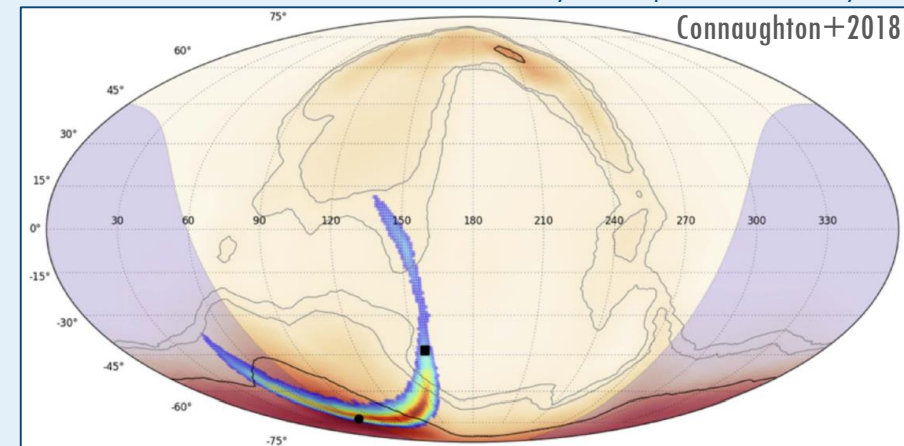
■ **Energy spectrum** peaking in BGO energy range. Best fit simple PL with index -1.4 (**average for sGRBs**), fluence $2.4 \times 10^{-7} \text{ erg cm}^{-2}$ (**weaker than average for sGRBs**)

Raw count rates:

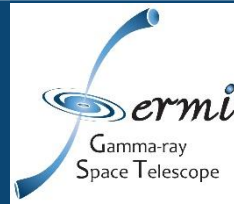
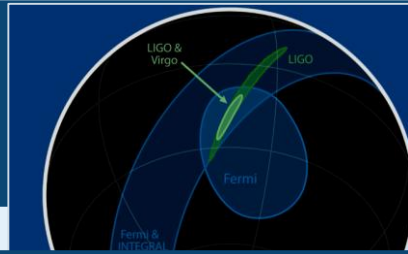
Sum of all GBM detectors: 12 x NaI + 2 x BGO
NaI: 50–980 keV / BGO: 420 keV – 4.7 MeV



Recent verification that original spectral analysis not biased. FAR and FAP unaffected by the spectral analysis!



GRB 170817A and GW170817



- Conclusive evidence for the **BNS-sGRB connection**
 - Chance temporal and spatial coincidence for GRB170817A and GW170817 arising from two independent astrophysical events: $P = 5 \times 10^{-8}$

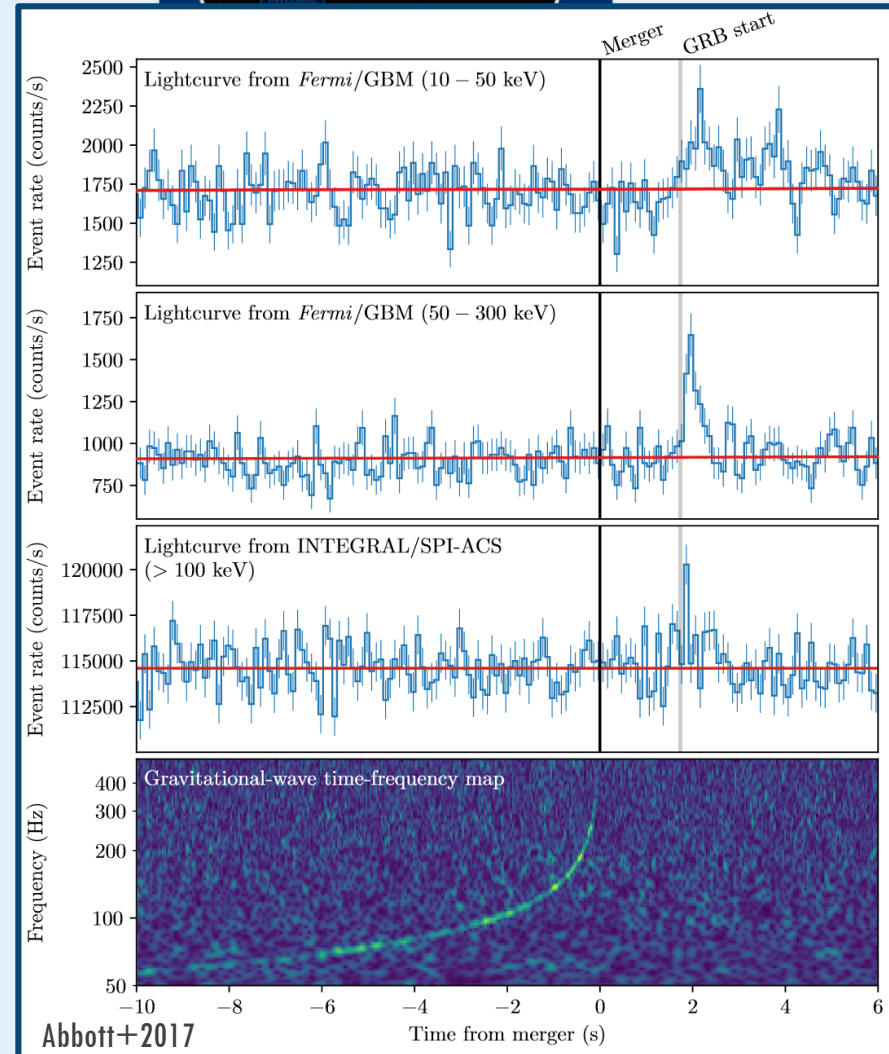
➔ **GW-GRB association significance: 5.3σ**

- Theory confirmed!
 - The **onset** of gamma-ray emission from a BNS merger progenitor is predicted to be within **a few seconds after** the merger

➔ $\Delta t = 1.74 \pm 0.05 \text{ s}$

- **Constraint** on the fractional speed difference between gravity and light

$$-3 \times 10^{-15} \leq \frac{\Delta v}{v_{\text{EM}}} \leq +7 \times 10^{-16}$$

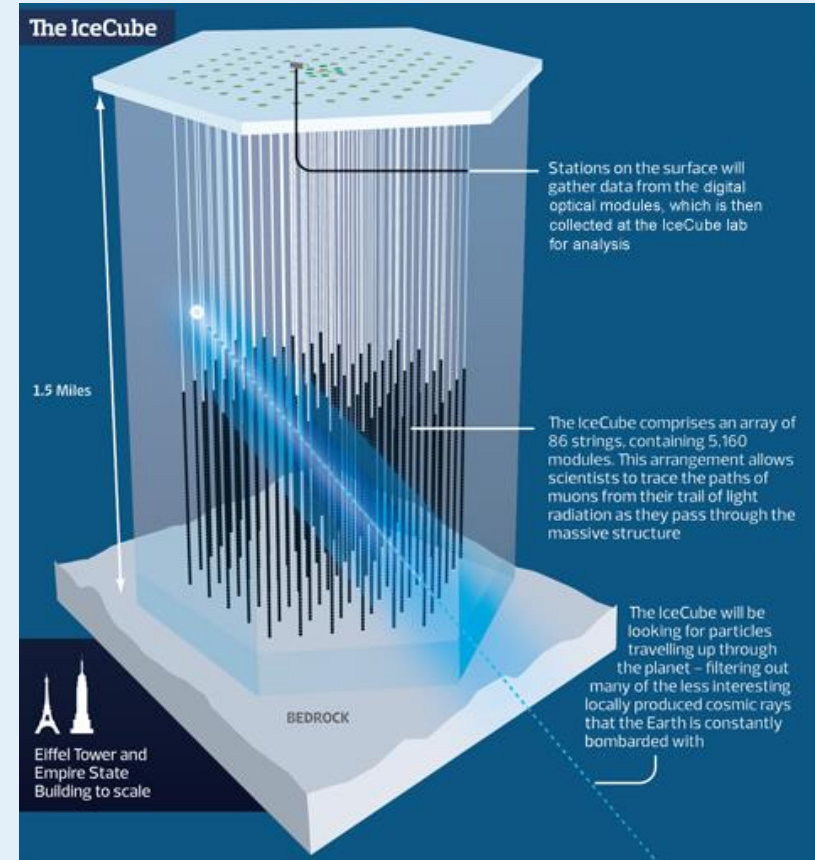


GW papers

- Localization and Broadband Follow-up of the Gravitational-wave Transient GW150914, [Abbott+2016](#)
- Fermi GBM Observations of LIGO Gravitational Wave event GW150914, [Connaughton+2016](#)
- Gravitational-wave Observations May Constrain Gamma-Ray Burst Models: The Case of GW150914-GBM, [Veres+2016](#)
- Updates to the Fermi-GBM Short GRB Targeted Offline Search in Preparation for LIGO's Second Observing Run, [Goldstein+2016](#)
- Searching the Gamma-ray Sky for Counterparts to Gravitational Wave Sources: Fermi GBM and LAT Observations of LVT151012 and GW151226, [Racusin+2017](#)
- Fermi Observations of the LIGO Event GW170104, [Goldstein+2017](#)
- Multi-Messenger Observations of a Binary Neutron Star Merger, [Abbott+2017](#)
- Gravitational Waves and Gamma-Rays from a Binary Neutron Star Merger: GW170817 and GRB 170817A, [Abbott+2017](#)
- An Ordinary Short Gamma-Ray Burst with Extraordinary Implications: Fermi-GBM Detection of GRB 170817A, [Goldstein+2017](#)
- On the interpretation of the Fermi GBM transient observed in coincidence with LIGO Gravitational Wave Event GW150914, [Connaughton+2018](#)

Follow-up of IceCube neutrino events

- Utilizes **all search methods**:
 - On-board **triggers**
 - **Untargeted** search within the hour
 - **Targeted** search using event time
 - **Earth occultation** technique
- Good follow-up observation for **IceCube-161103**, upper limit published in GCN 20127.
 - Other follow-up observations:
Antares (GCN 18352),
IceCube 160731 (GCN 19758),
IceCube-160806A (GCN 19817),
IceCube-160427A (GCN 19364),
IceCube-170321A (GCN 20932)
- Also can use these techniques to search for counterparts to **Fast Radio Bursts**



Conclusions

The **GBM** had 10 very successful years, especially 2017

- The instrument (and the team) remain healthy and operating well
- The joint GW-GRB science is amazing!
 - The GBM announcement was **the first of a long chain** of events contributing to the historic observations of GRB 170817A, GW170817, AT2017gf
 - We should expect **future detections** in the upcoming O3 runs planned for LIGO/Virgo

Thank
You!

