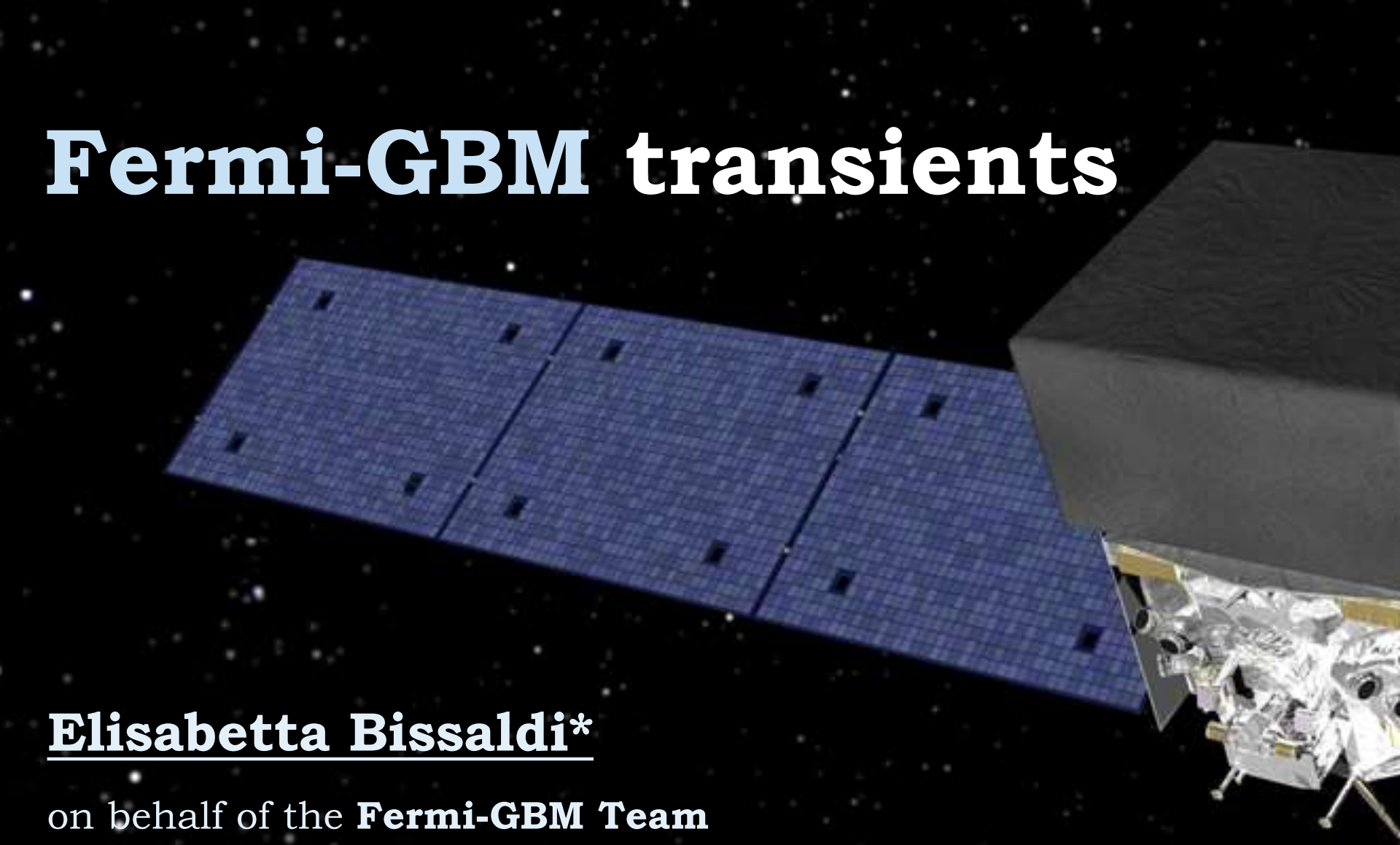
Fermi-GBM transients

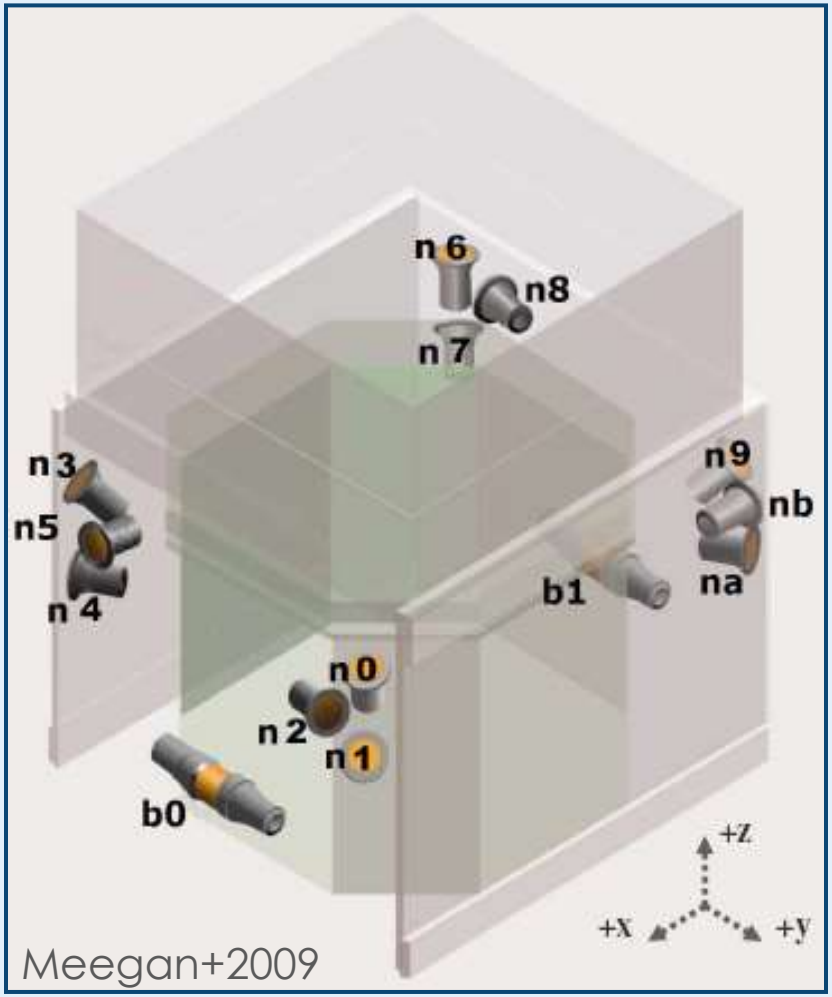


Elisabetta Bissaldi*

on behalf of the **Fermi-GBM Team**

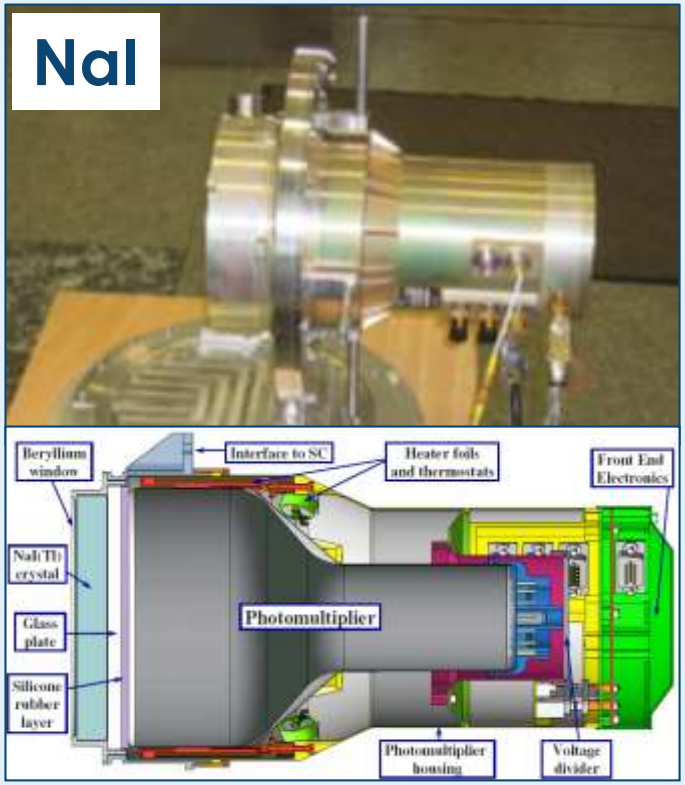
*Politecnico & INFN Bari – **elisabetta.bissaldi@ba.infn.it**

The Fermi Gamma-Ray Burst Monitor

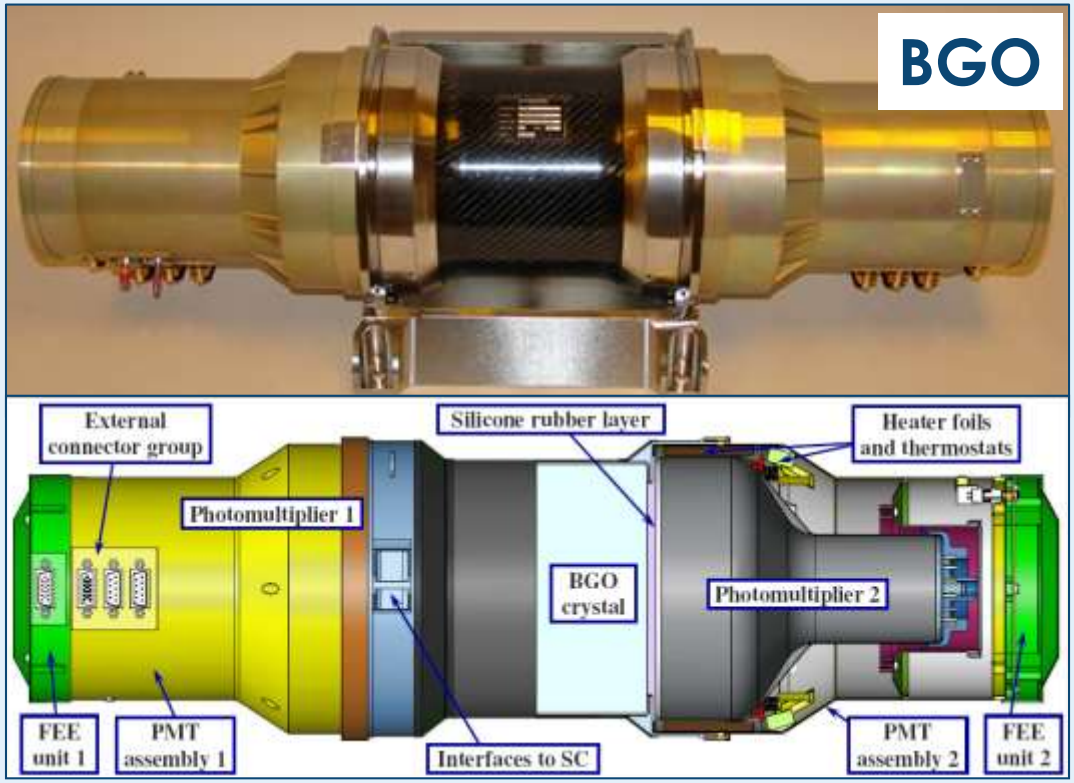


The Fermi Gamma-Ray Burst Monitor

GBM detectors: scintillating **crystals** attached to **photomultipliers**



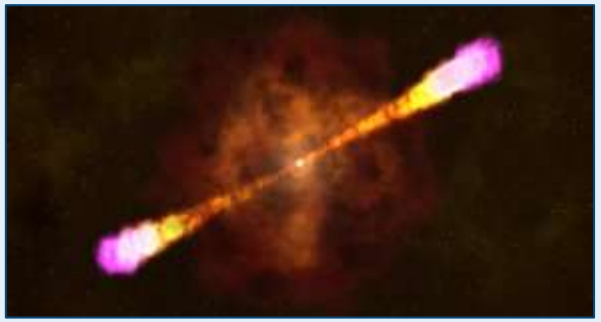
- ∅: 12.7 cm, Thickness: 1.27 cm
- **Energy range: 8 keV – 1 MeV**
- Photoelectric absorption & Compton scattering



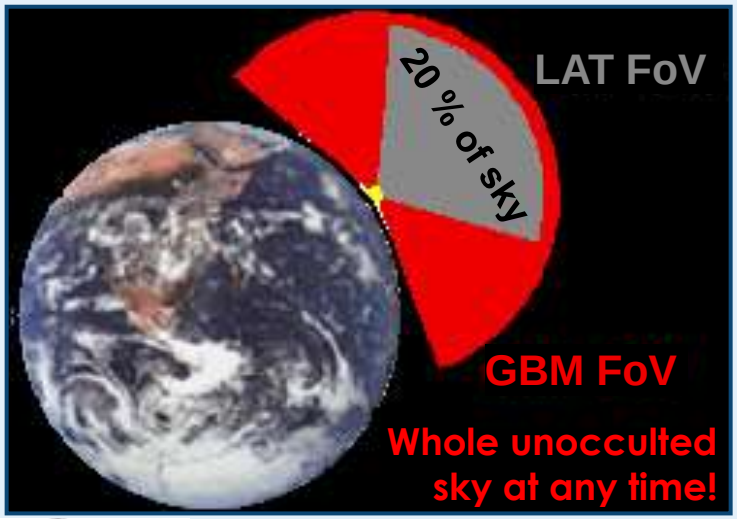
- ∅: 12.7 cm, Thickness: 12.7 cm
- **Energy range: 250 keV – 40 MeV**
- Compton scattering & Pair production

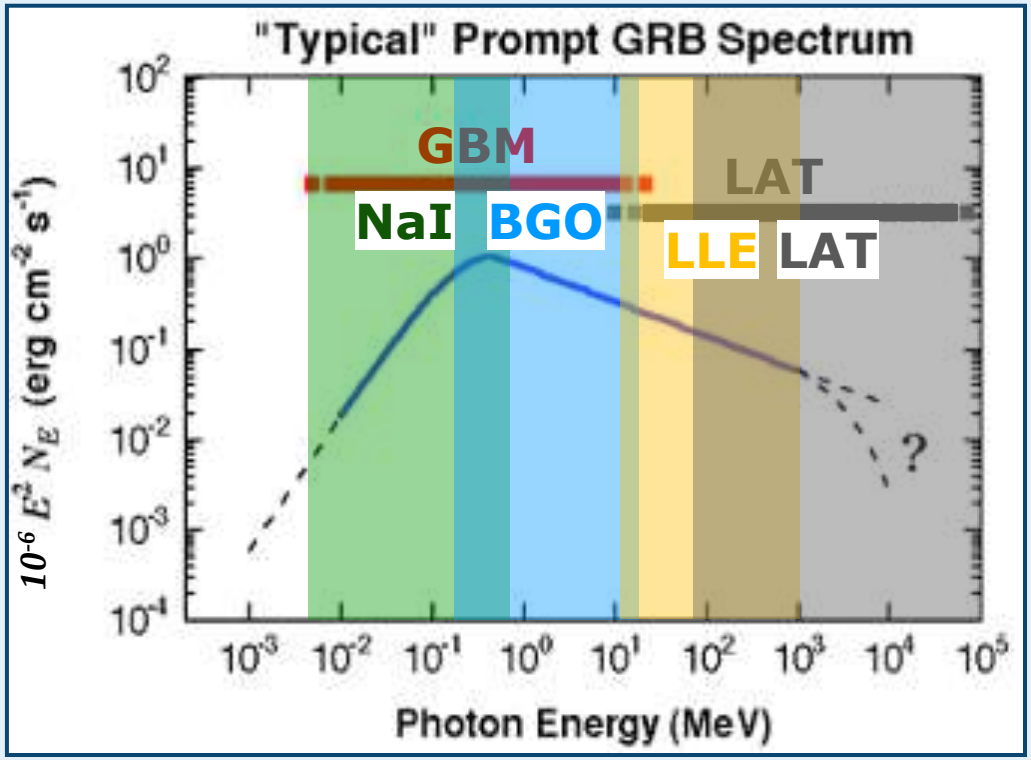
The Fermi Gamma-Ray Burst Monitor

- Designed to study **Gamma-Ray Bursts**
- Primary **objectives** of GBM: [Meegan+2009]

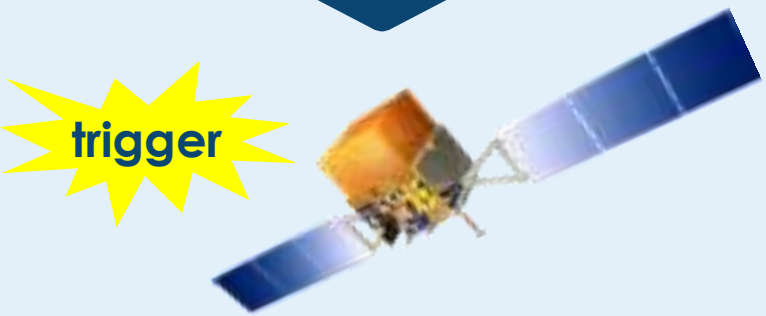


1. Extend the **energy range** downward from the Fermi-LAT one
2. Compute **burst locations** onboard to allow re-orienting the spacecraft





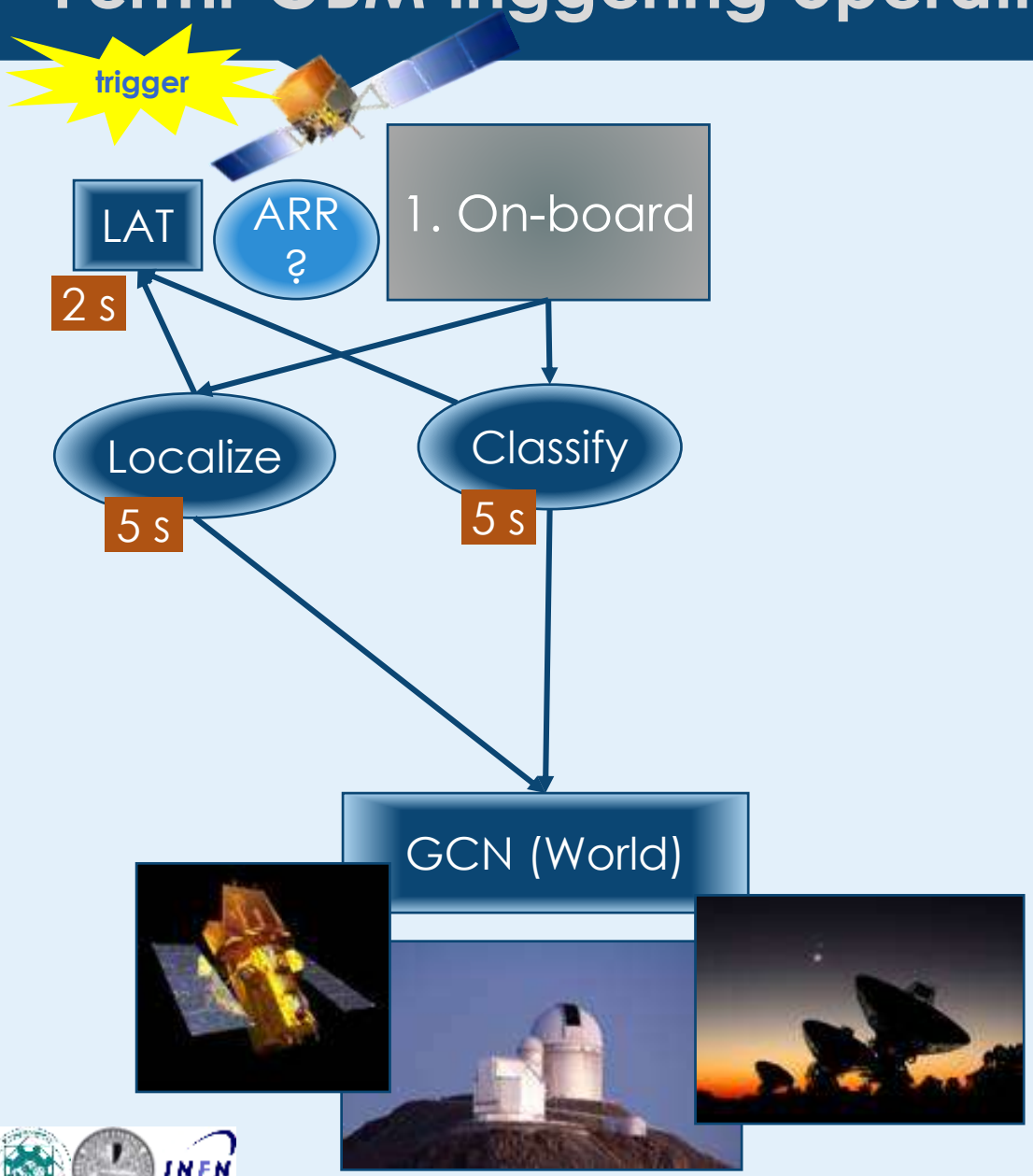
Fermi-GBM triggering operations



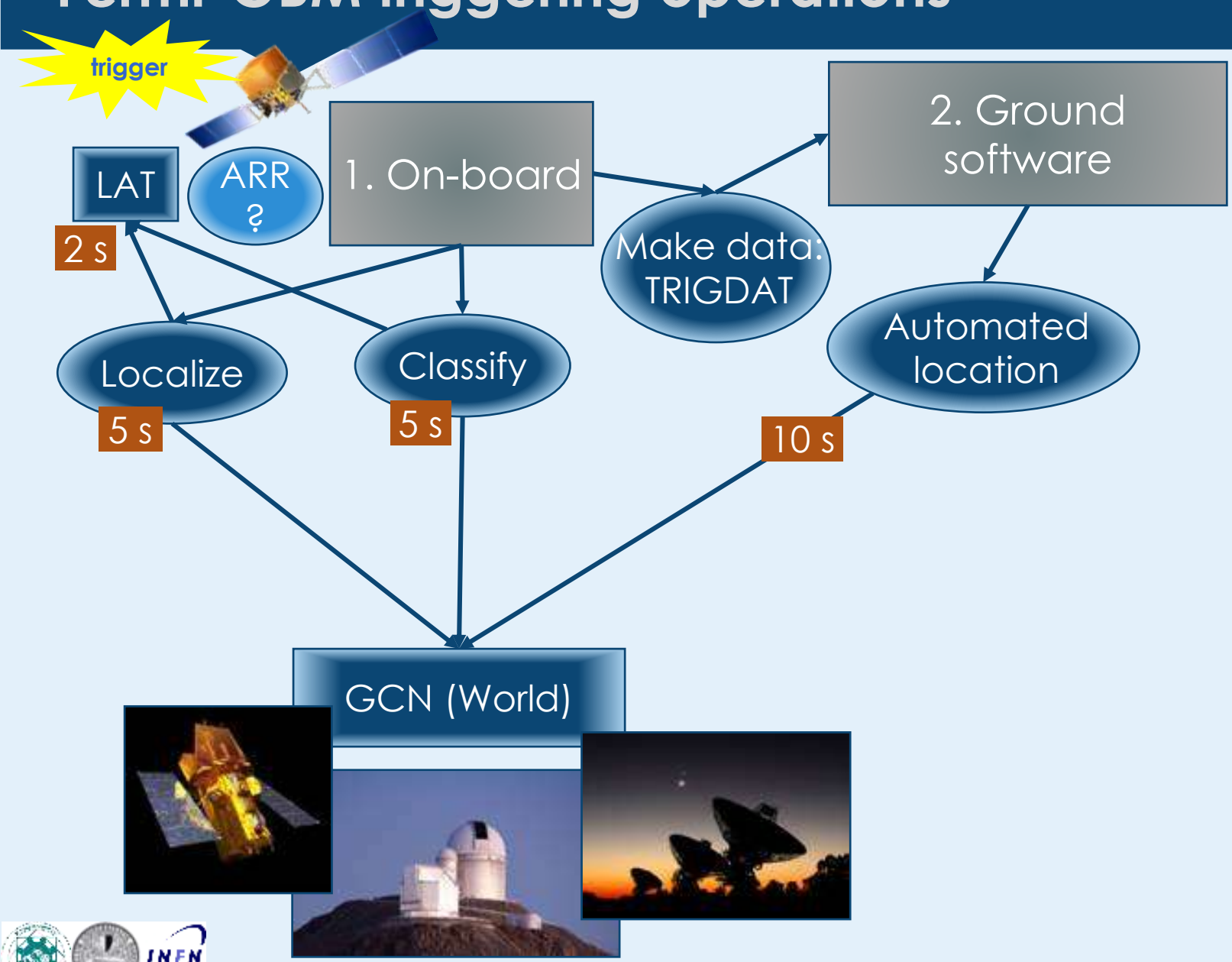
A total of **120 different triggers** can be specified, each with a distinct threshold

- GBM triggers when **2 or more detectors** exceed a preset but adjustable threshold specified in units of the standard deviation of the **background rate**.
  - Background rate: average rate accumulated over the previous 17 s, excluding the most recent 4 s
- Four **energy** ranges
  - 25 – 50 keV
  - 50 – 300 keV
  - 100 – 300 keV
  - >300 keV
- Ten **timescales**
  - from 16 ms to 8.192 s in steps of a factor of 2

Fermi-GBM triggering operations



Fermi-GBM triggering operations



Fermi-GBM triggering operations

LAT

2 s

ARR
?

1. On-board

Make data:
TRIGDAT

2. Ground
software

Localize

5 s

Classify

5 s

Automated
location

10 s

Robotic or
Human location
& classif.

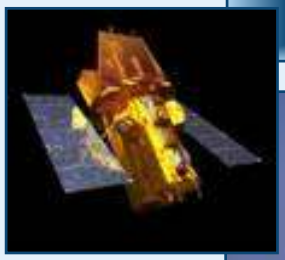
5 min – hrs

Spectra
etc.

1 day

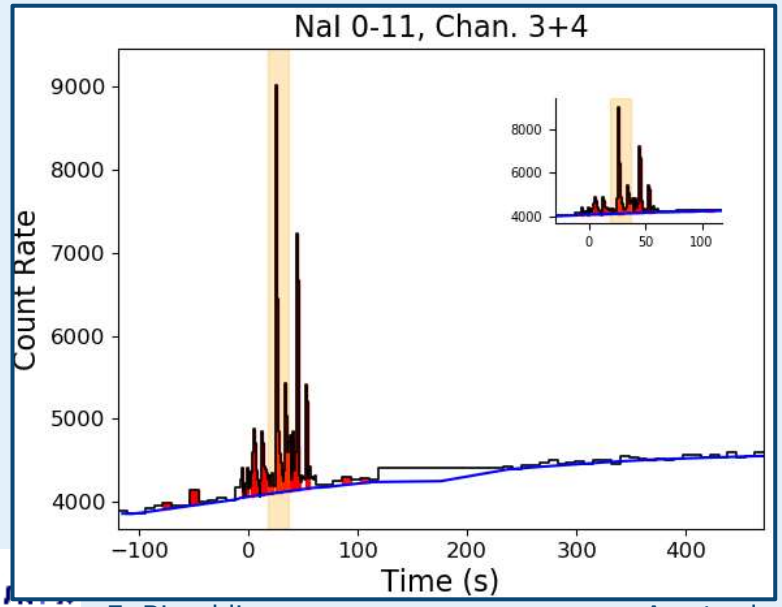
GCN (World)

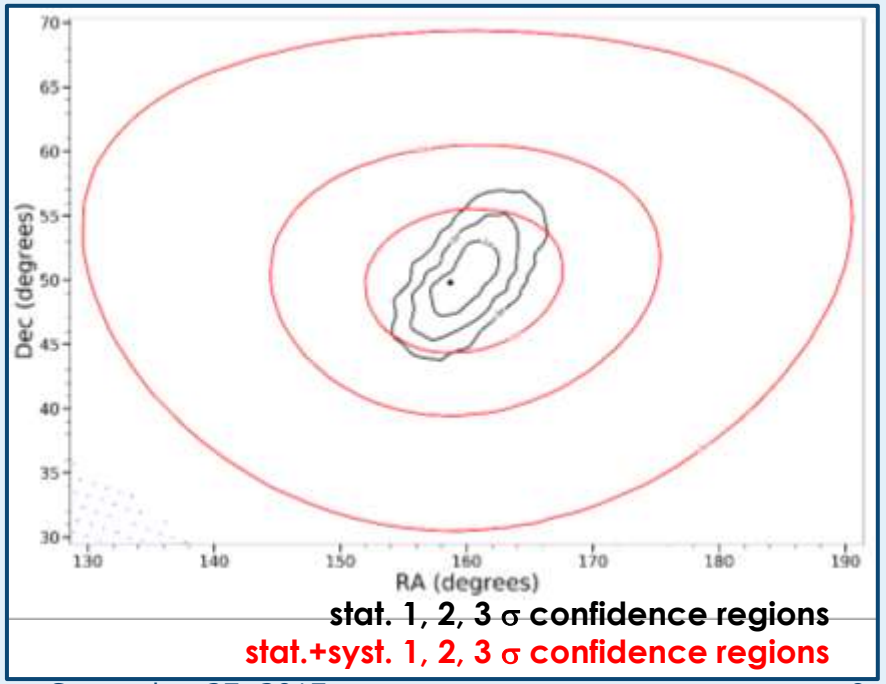
3. Catalog



Robotic Burst Advocate - RoboBA

- Set of **algorithms** integrated into the **Burst Alert Processor pipeline** (operative since **Feb. 2016** – Goldstein+)
  - Perform a **background fit**, make a **signal identification** and **selection**, and create a file that can be fed to the localization software.
    - Final localization notices within **10 minutes** of trigger time;
    - All algorithms and current configurations were **tested** and tweaked on GBM's first ~1700 GRBs



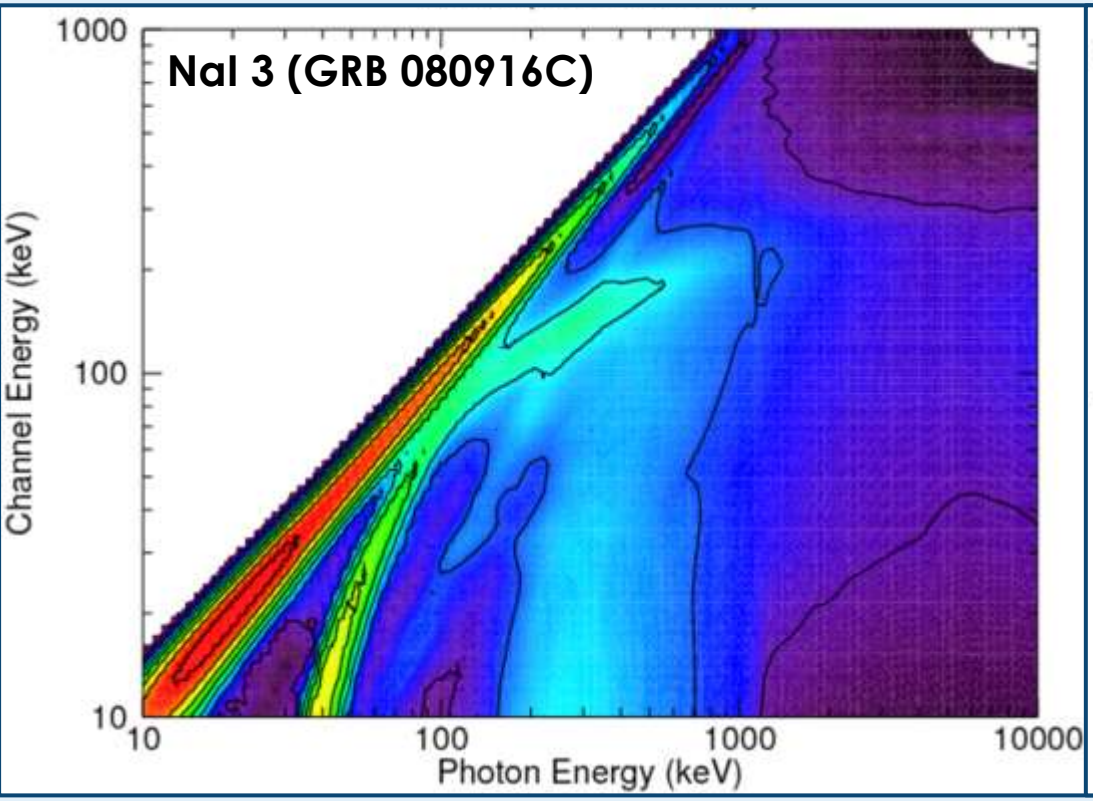


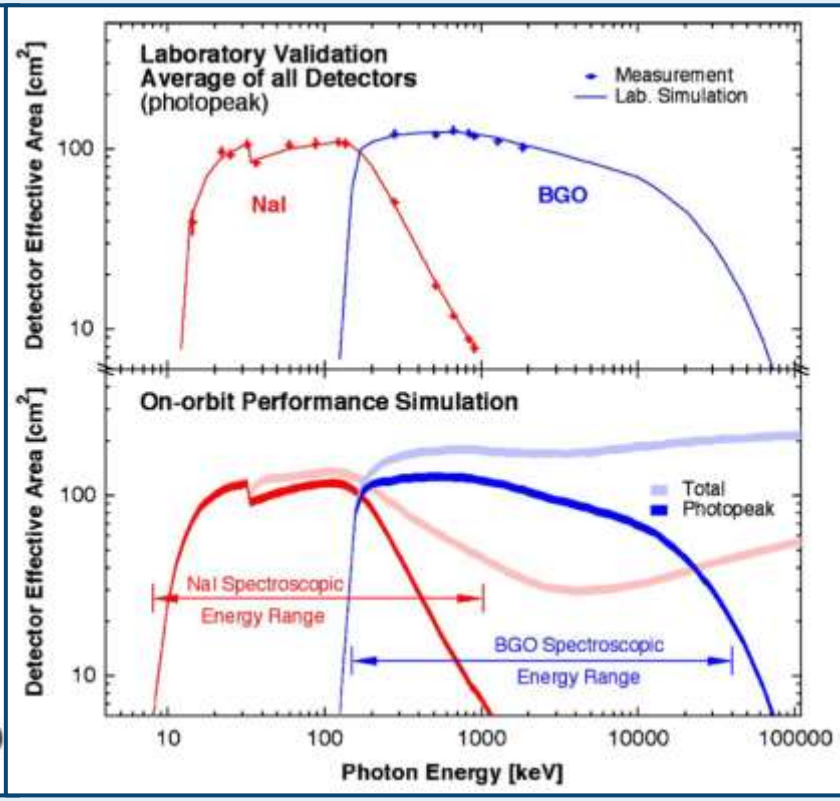
Fermi-GBM data and detector response

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

- **TRIGDAT** used primarily for localization & quick look
- **CTIME**: temporal analysis
- **CSPEC**: spectral analysis
- **TTE**: e.g. time-resolved spectral analysis
  - Initially available ~30 s pre- to ~300 s post-trigger
  - Continuous TTE **(CTTE)** implemented on November 26, 2012

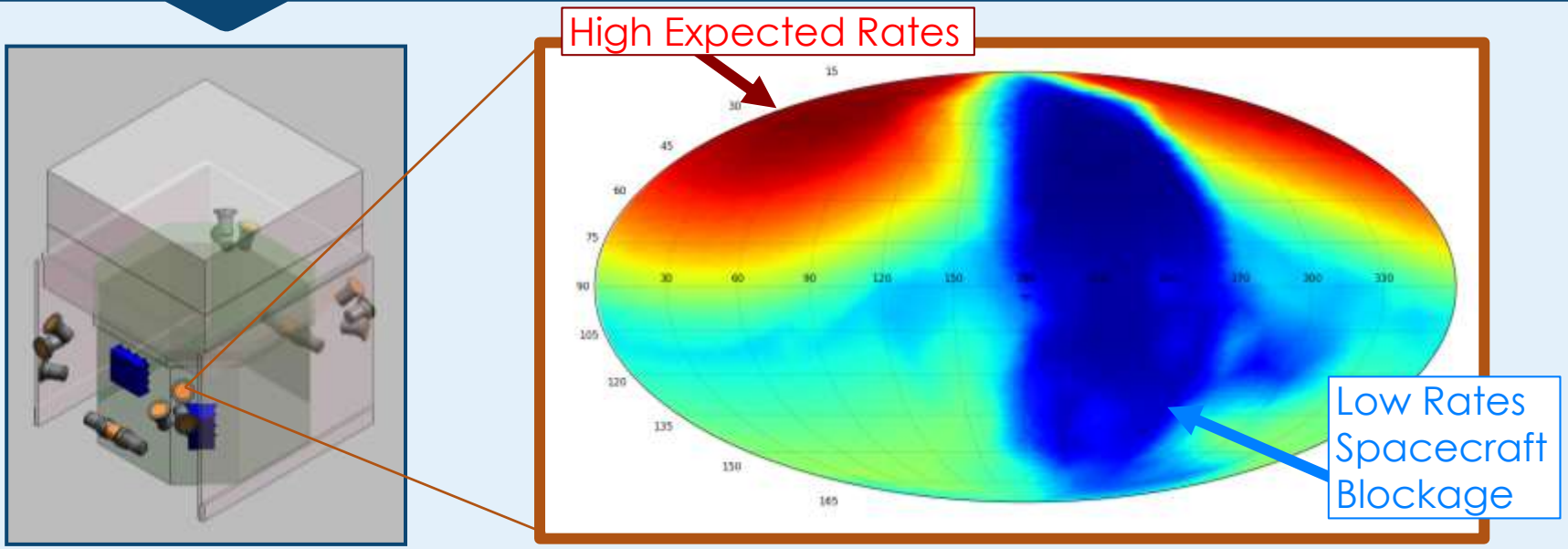
Fermi-GBM data and detector response





- The response is a function of the **source-spacecraft-Earth geometry**
- Response rapidly **decreases** at a source-spacecraft **angle >60 degrees**
- Also need a **separate atmospheric response for back-scatter**

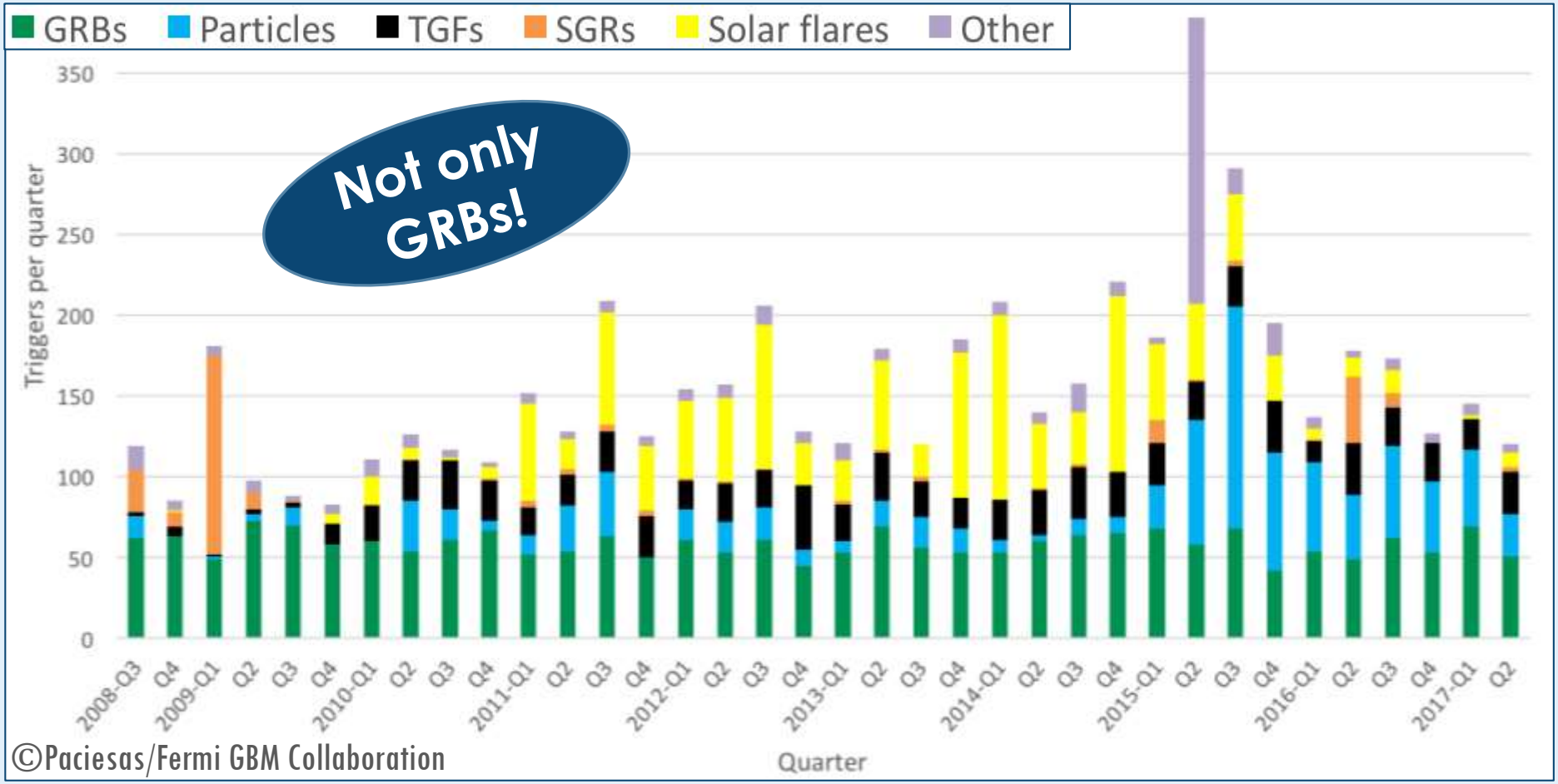
Fermi-GBM localization method



- **Localization** performed by comparing the relative observed **rates** from the GRB in **each detector** to the expected rates on a 1° grid
  - This requires an **assumption of the spectrum**, and the sky grid limits to a **statistical minimum uncertainty of 1 degree radius**
  - Distribution of **systematic uncertainties** is well represented (68% c.l.) by a **3.7°** Gaussian with a non-Gaussian tail that contains about 10% of GBM-detected GRBs and extends to approximately 14° [Connaughton+2014]

Fermi-GBM triggers

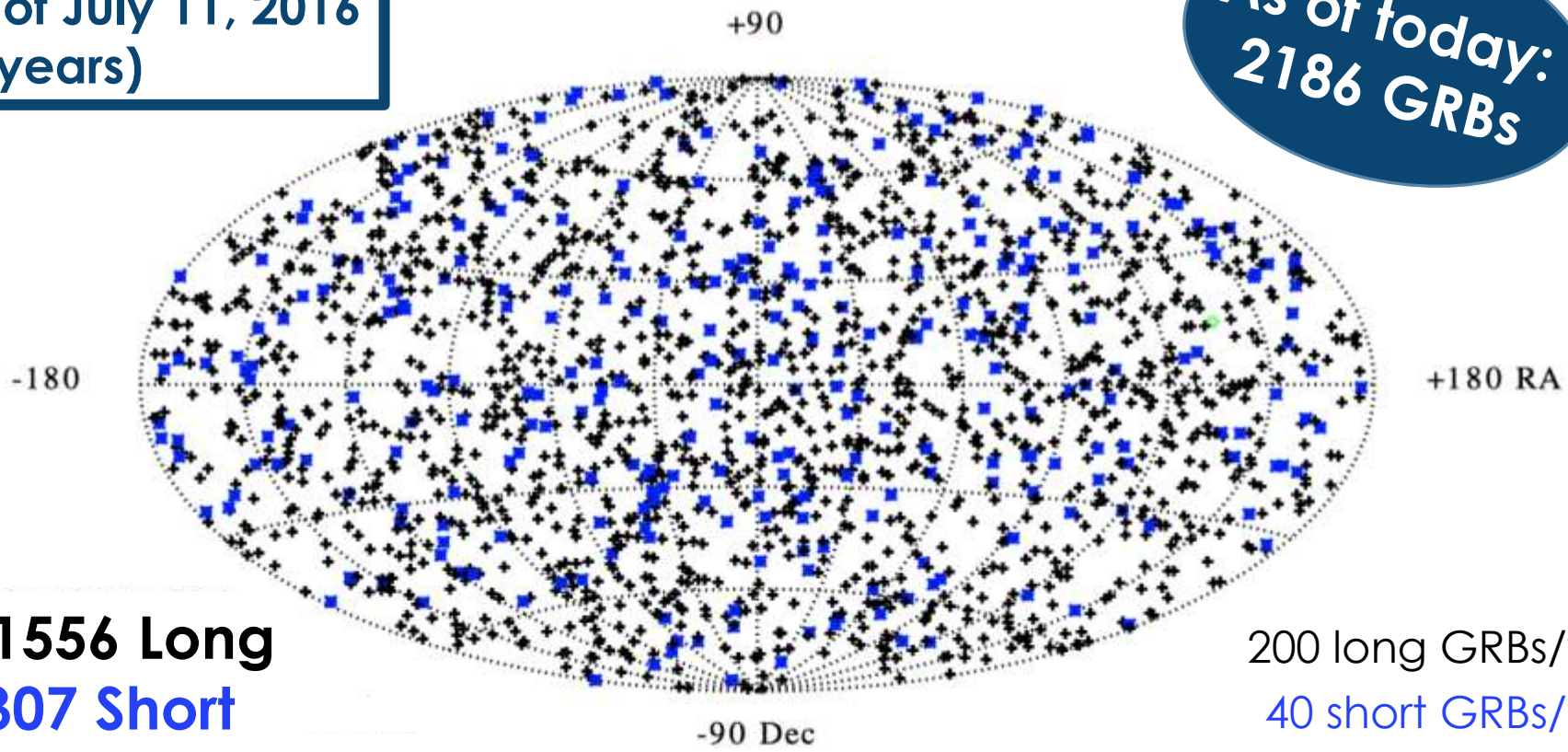
Quarterly trigger statistics over **9 years** of the mission



Fermi-GBM GRBs

1864 GBM GRBs as of July 11, 2016 (8 years)

As of today: 2186 GRBs



+ 1556 Long

*** 307 Short**

200 long GRBs/yr

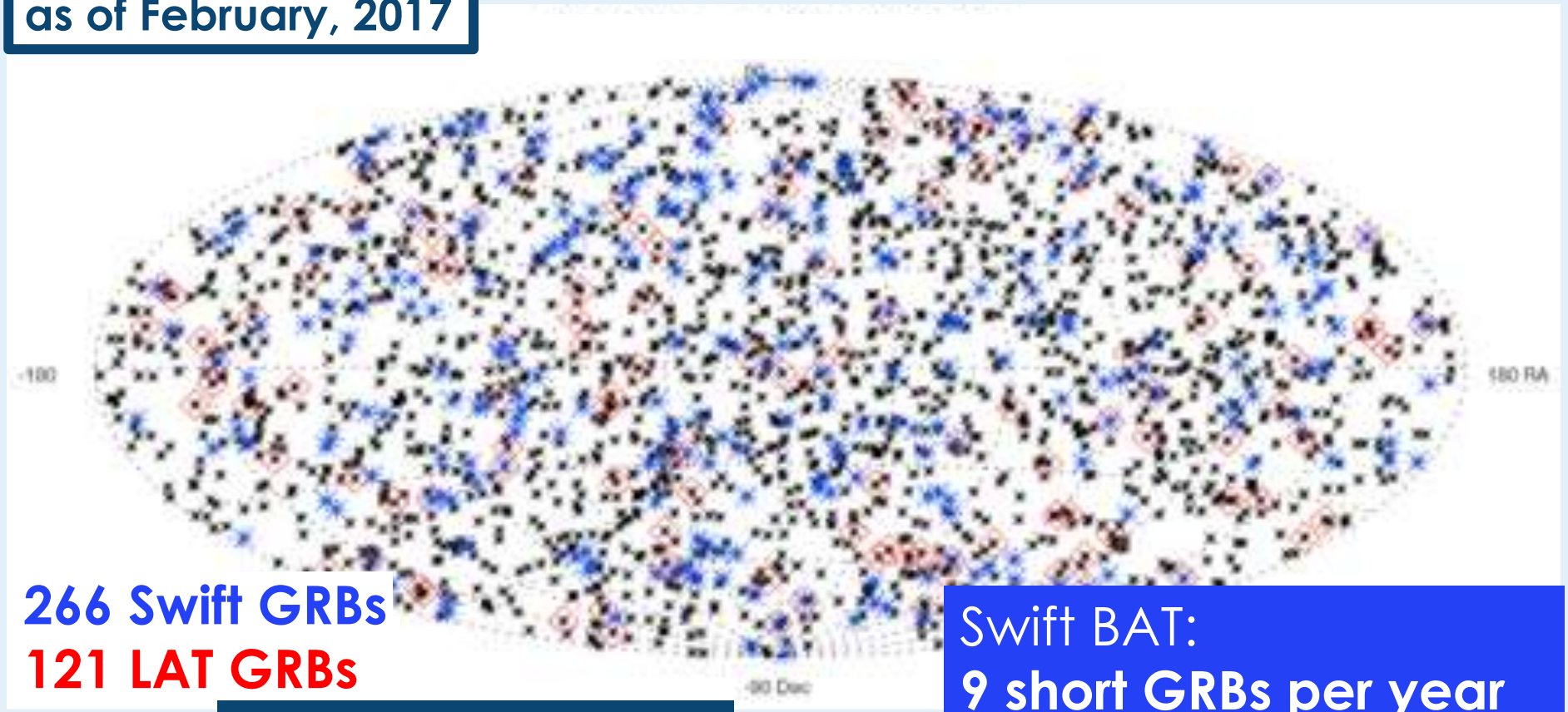
40 short GRBs/yr

The **GBM GRB online catalog** is updated **within 1 hour**:

➔ http://heasarc.gsfc.nasa.gov/W3Browse/fermi/fermigbrst.html

Fermi-GBM GRBs

2000 GBM GRBs
as of February, 2017



266 Swift GRBs
121 LAT GRBs

13% seen by Swift
52% within Fermi LAT FOV
6% detected

Swift BAT:
9 short GRBs per year
BUT: arcmin localization facilitating follow-ups

Fermi-GBM catalogs

2018

- GBM 8yr **GRB trigger+spectral** Catalogs (in preparation)
- GBM 8yr **TGF** Catalog

- GBM 6yr **GRB trigger** Catalog (3FGBM)
- GBM 5yr **Magnetar** Burst Catalog

- GBM 4yr **GRB time-resolved spectral** Catalog
- GBM 4yr **GRB spectral** Catalog
- GBM 4yr **GRB trigger** Catalog (2FGBM)
- GBM 3yr **X-ray Burst** Catalog

- GBM 2yr **GRB spectral** Catalog
- GBM 2yr **GRB trigger** Catalog (1FGBM)

2008

Fermi-GBM catalogs

3rd GRB trigger Catalog (6 years catalog)

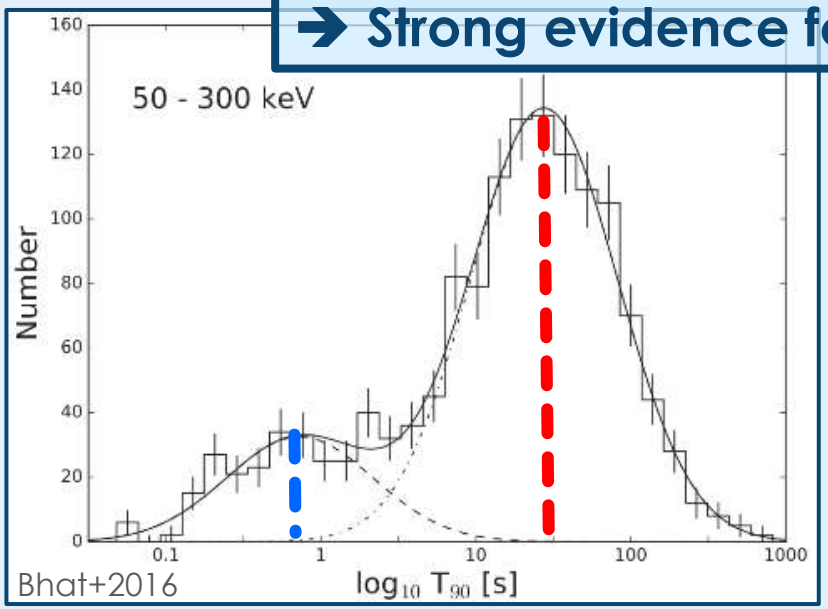
Distribution of GRB durations

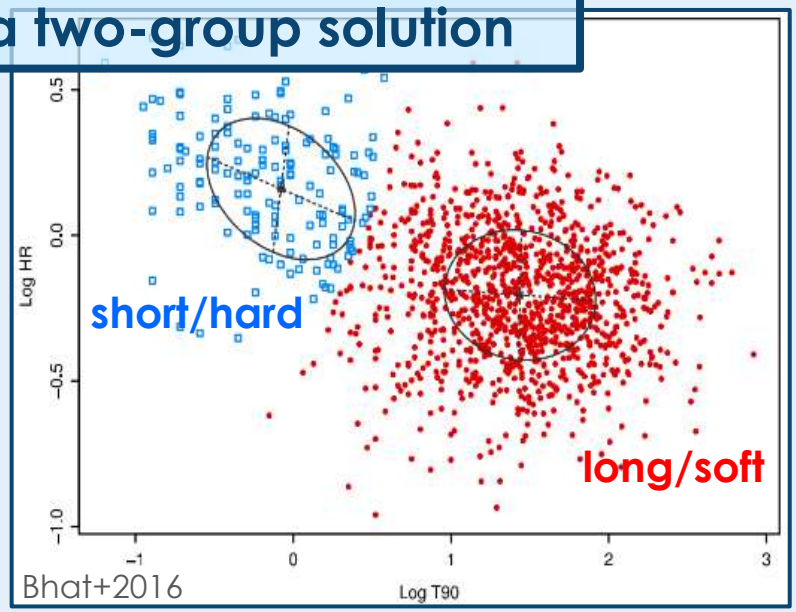
- "T_{90}" interval between the times where the burst has reached 5% and 95% of its maximum fluence
- **Median T_{90} values**:
  - **0.58 s (short), 26.62 s (long)**

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 catalogs

1st GRB Time-resolved Spectral Catalog (4 years catalog)

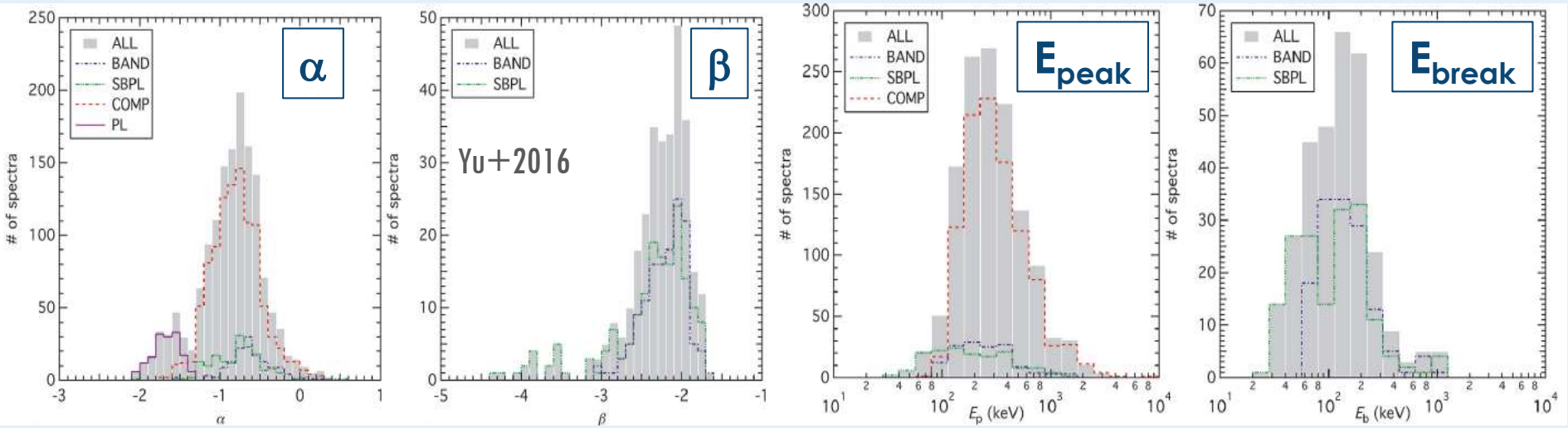
Bright GRB subsample

- **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, HECPL, Band, SBPL**

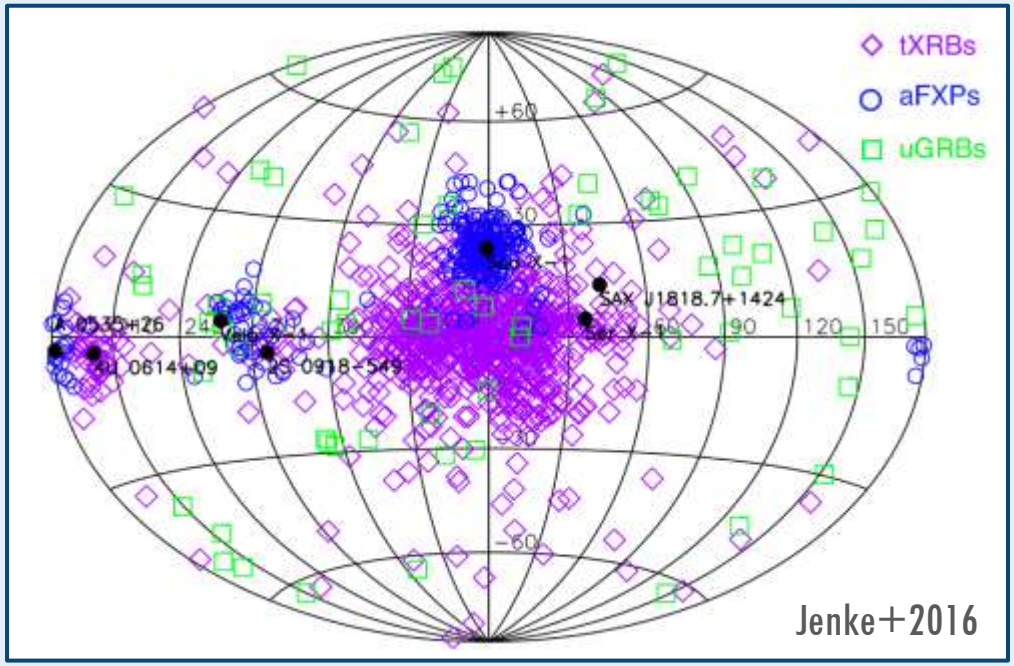
➔ **Preferred model (69%):** power-law model with a high-energy exponential cutoff



Fermi-GBM catalogs

1st X-ray Burst Catalog (3 years catalog)

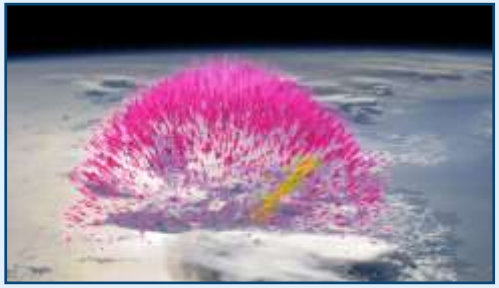
- Systematic search for **transients** in the **12–25 keV energy band**, with a time resolution of **8.2 s**
- **1084 events**, classified using spectral analysis, location, and spatial distributions



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

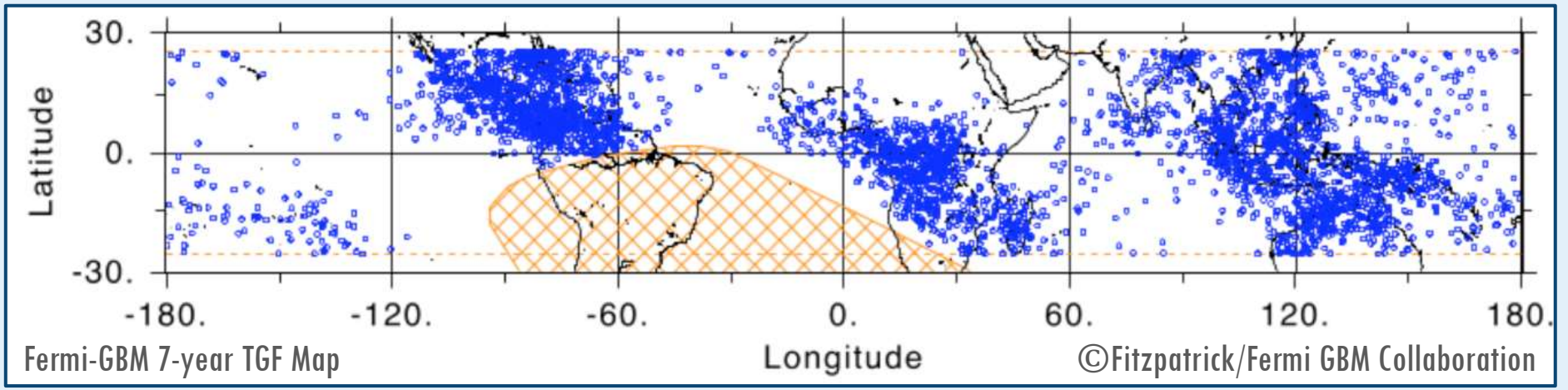
- tXRBs have peak **blackbody** temperatures (3.2 ± 0.3 keV) broadly consistent with **photospheric radius expansion** (PRE) bursts

Fermi-GBM catalogs



1st TGF catalog (8 years catalog)

- 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/*

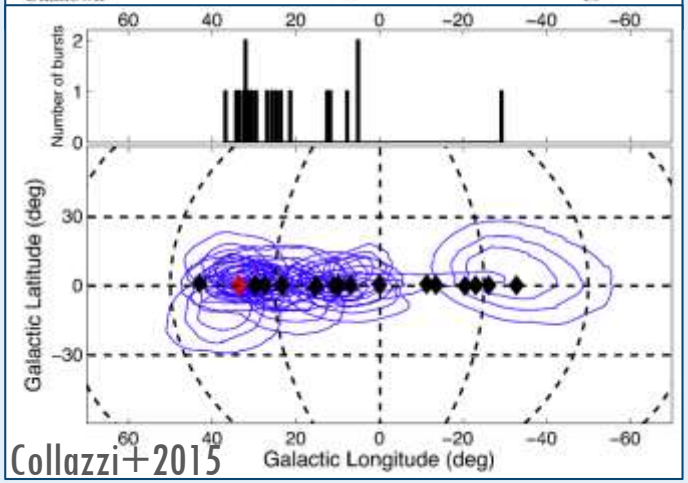
Fermi-GBM catalogs

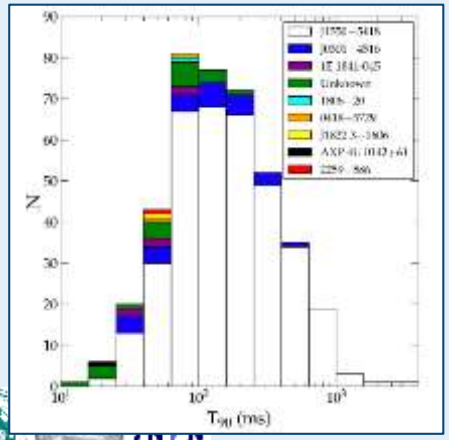
1st Magnetar Burst Catalog (3 years catalog)

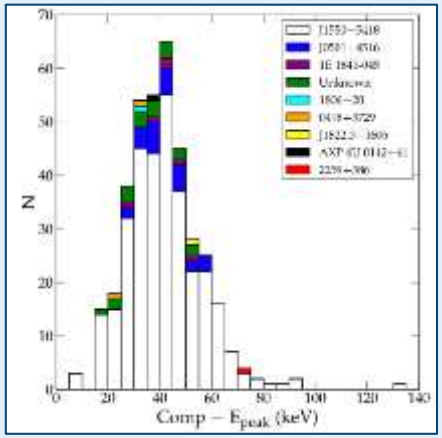
- Temporal & spectral analysis of **446 magnetar bursts**
  - durations, spectral parameters for various models, fluences, and peak fluxes
- Small sample of magnetar-like bursts of **unknown origin**
- Combined **durations and spectral parameters** show similarities:
  - T90 ~100 ms
  - E_{peak} ~40 keV
  - BB+BB Temp. around ~4.5 and ~15 keV

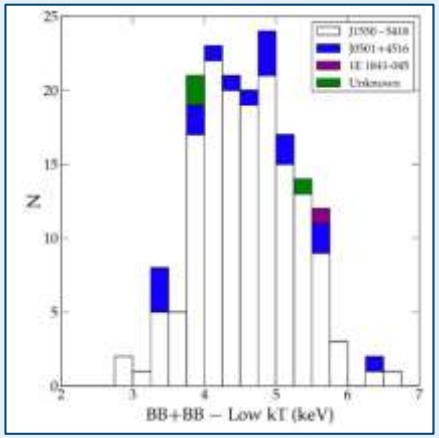
Summary of GBM Magnetar Bursts

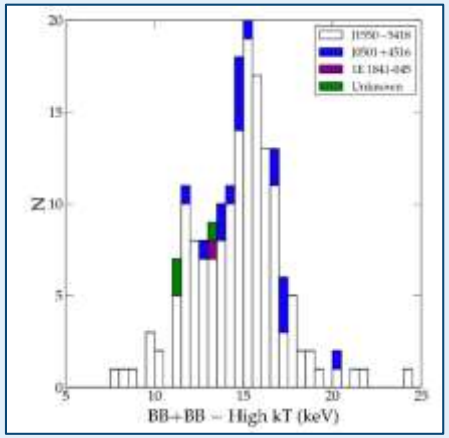
Source	Burst Active Periods	Number of Bursts with TTE data
SGR J1550–5418	2008 Oct–2009 Apr	386
SGR J0501+4516	2008 Aug/Sep	29
1E 1841–045	2011 Feb–Jul	6
SGR J0418+5729	2009 Jun	2
SGR 1806–20	2010 Mar	1
SGR J1822.3–1606	2011 Jul	1
AXP 4U 0142+61	2011 Jul	1
AXP 1E 2259+586	2011 Aug	1
Unknown	...	19





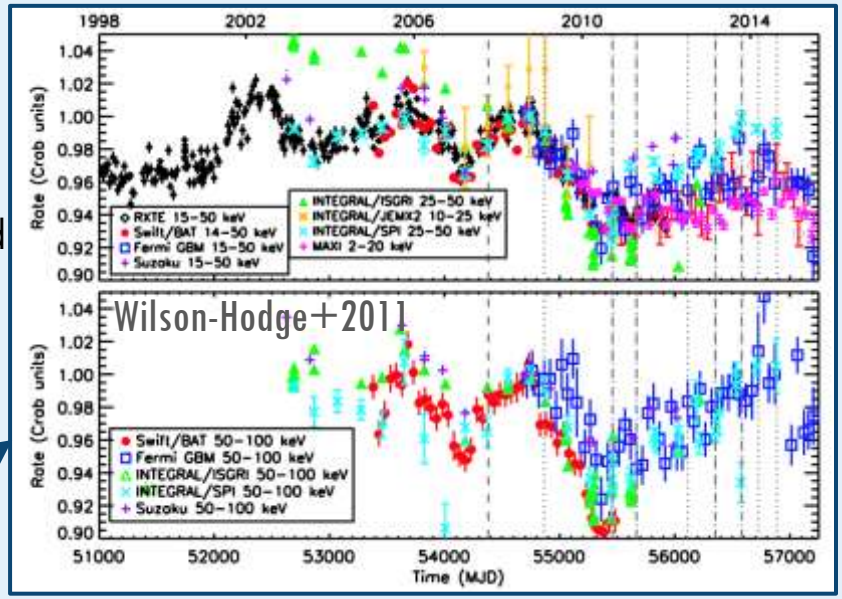






Fermi-GBM Earth Occultation monitoring

- Measure of the **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

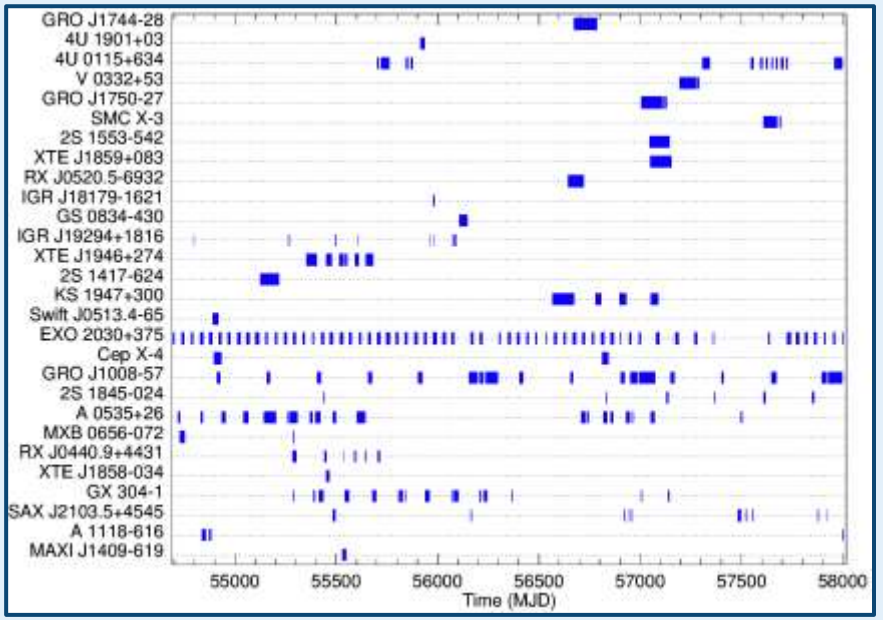
#	SOURCE NAME	RA (DEG)	DEC (DEG)	*L* (DEG)	*B* (DEG)	OBJECT TYPE
1	SUN	0.000	0.000	96.337	-60.189	Star
2	IGR_J00234+6141	5.740	61.685	119.561	-1.000	CV
3	V709_CAS	7.204	59.289	120.042	-3.456	CV/DQ Her
4	BD+6270	9.300	61.380	121.227	-1.445	Star
5	FERMIJ0109+6134	17.445	61.558	125.115	-1.236	AGN
6	SMCX-1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

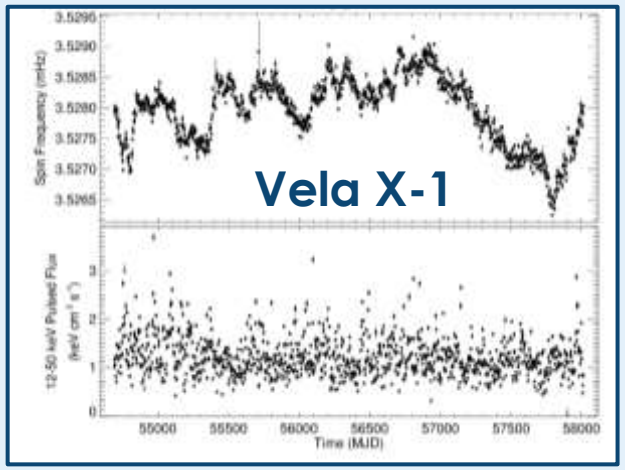
Fermi-GBM pulsar monitoring

- **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 pulsars**
- Online pulsar list

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

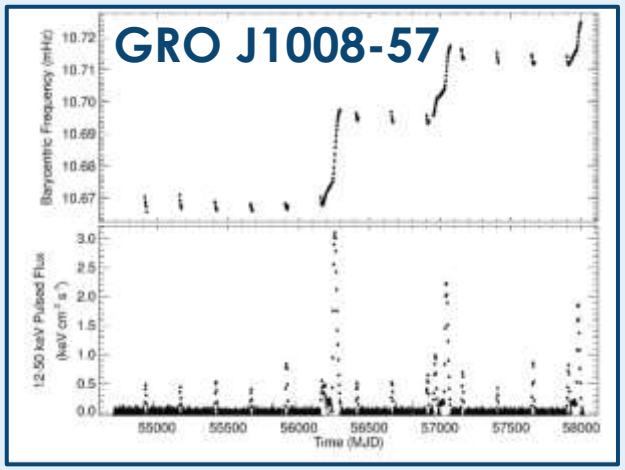
Times of Transient Outburst Detections





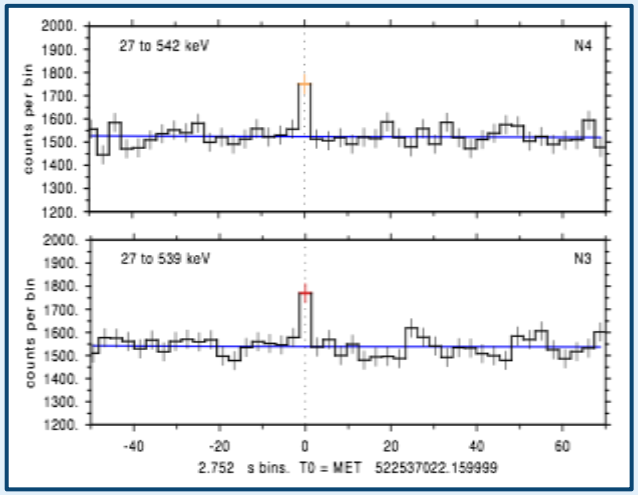
Frequency

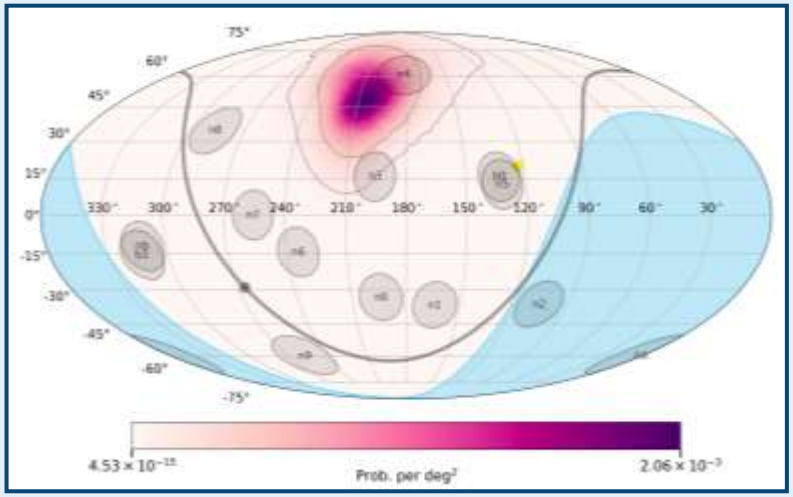
Pulsed Flux



Untriggered GBM GRB candidates

- 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





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

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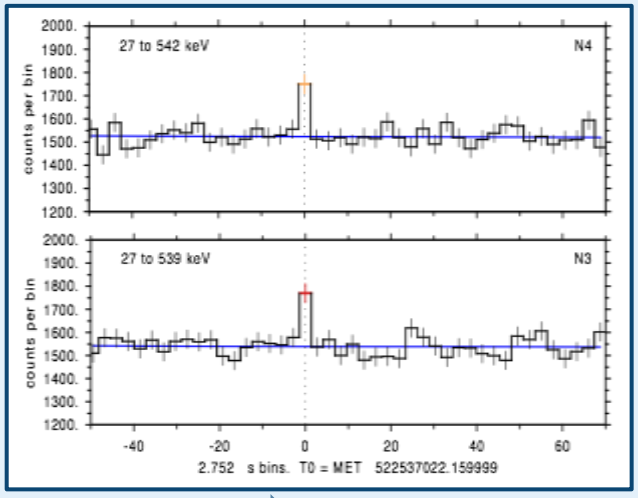
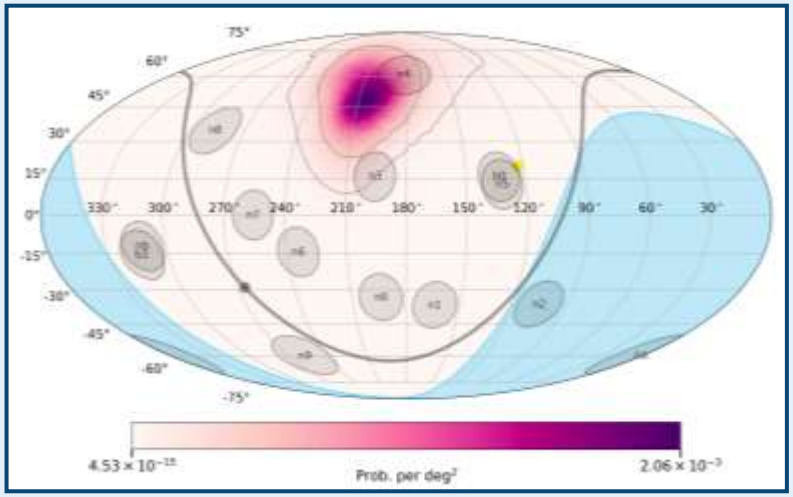
Additional ~100 GRBs/yr, mostly undetected by other instruments (verification in progress)





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

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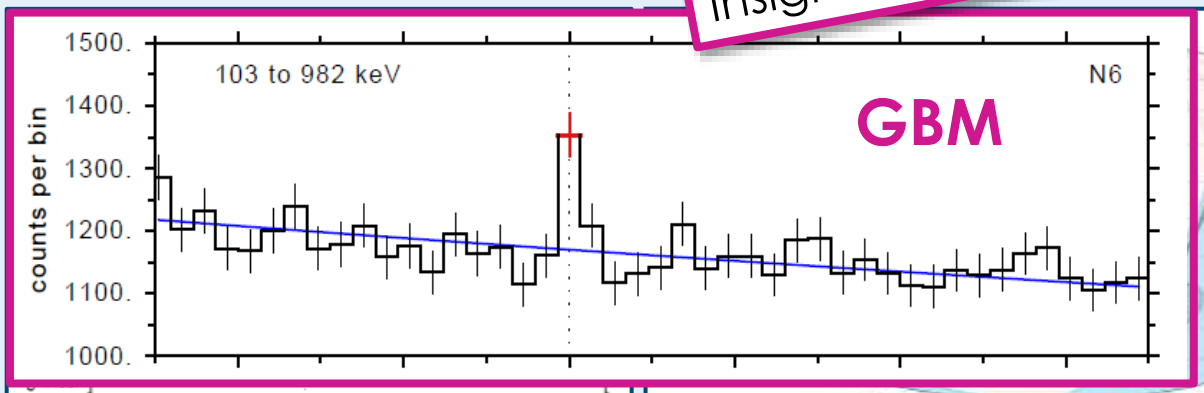
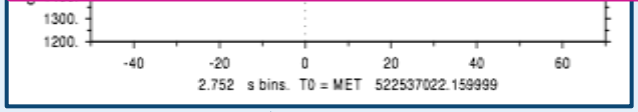
GCN#21919
GRB 170921A:
Insight-HXMT detection

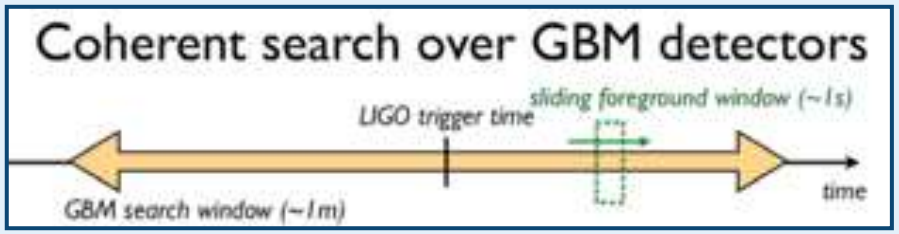




from 0.5 to 6 hrs due to ground processing and data downlink

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

Targeted searches to GW events

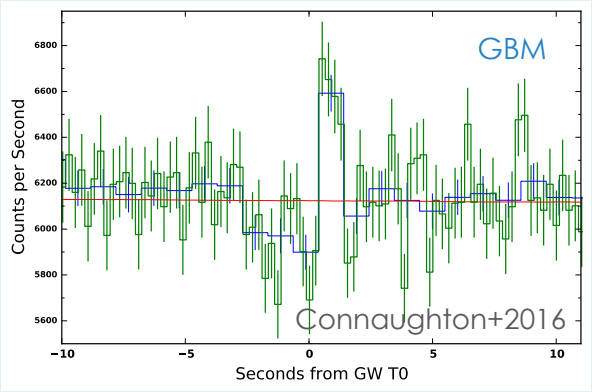


- Targeted search in **CTTE data** (Blackburn+2015, Goldstein+2017)
  - Looks for **coherent signals in all detectors** given an input time and optional skymap.
  - Calculate **likelihood ratio** of source and background.
  - Search **+/- 30 seconds** of input event time.
  - **Sliding timescales** from 0.256 to 8 s (capable down to 0.064 s) with a factor of 4 phase shift.
  - 3 source spectral templates using Band function: soft, normal, and hard.

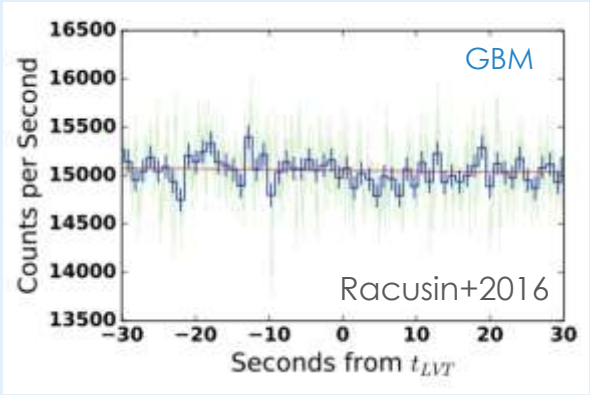
			GBM	LIGO
Ideal Scenario	Bright GBM	Bright LIGO		
GW150914 Scenario	Sub-threshold GBM	Bright LIGO		
Typical more distant short GRB	Bright GBM	Sub-threshold LIGO		
Both Sources Faint	Sub-threshold GBM	Sub-threshold LIGO		

Fermi-GBM Observations of GW Events

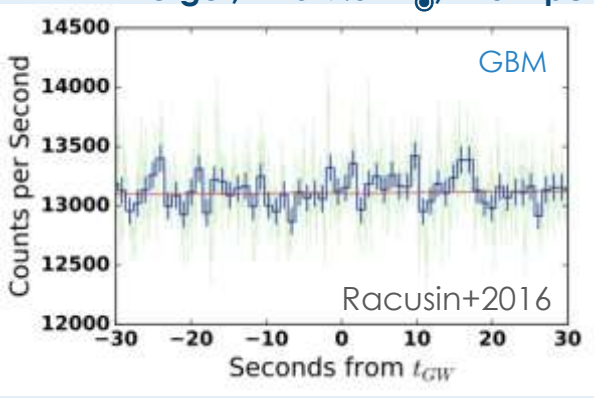
GW 150914
BH+BH Merger, 36 & 29 $M_\odot$, 410 Mpc



LVT 151012
Candidate BH+BH, 23 & 13 $M_\odot$, 1100 Mpc



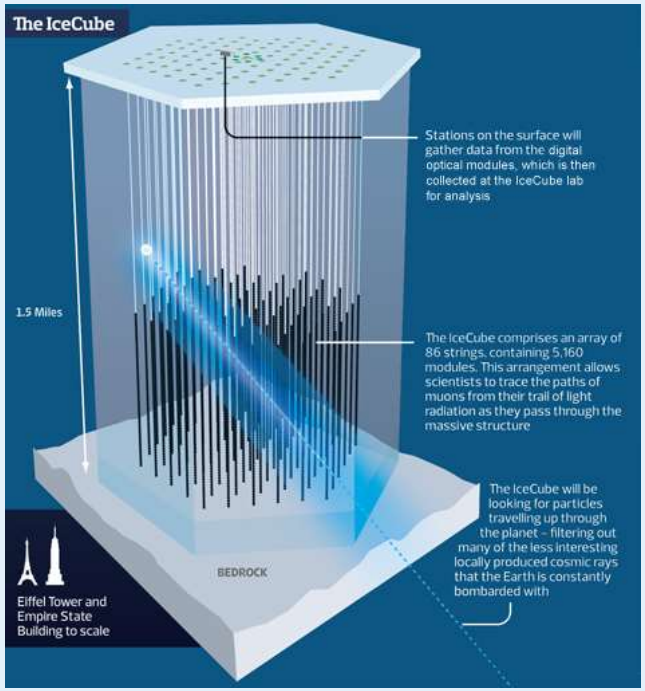
GW 151226
BH+BH Merger, 14 & 7.5 $M_\odot$, 440 Mpc

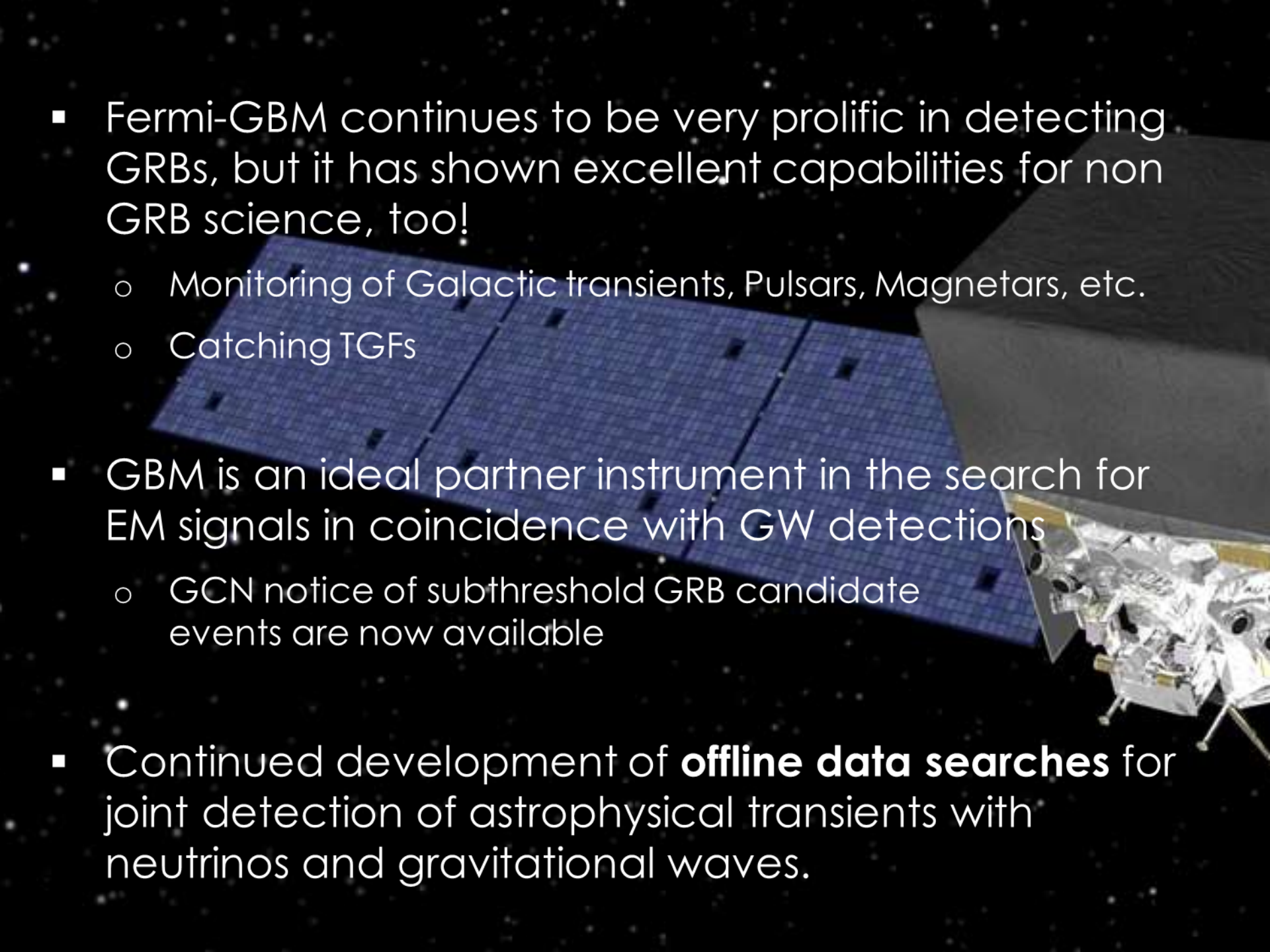


- **GW150914-GBM, a 2.9 σ event** consistent with a **short GRB**
  - Not predicted by theoretical models, poorly localized but consistent
- **No gamma-ray detections** for LVT151012 or GW151226 – not constraining
  - 32% and 17% of LIGO localization region blocked by Earth for GBM
  - Backgrounds were 18% and 3% higher in GBM
  - Distance for LVT151012 was 3x larger
- **Need more events** before we can say more!

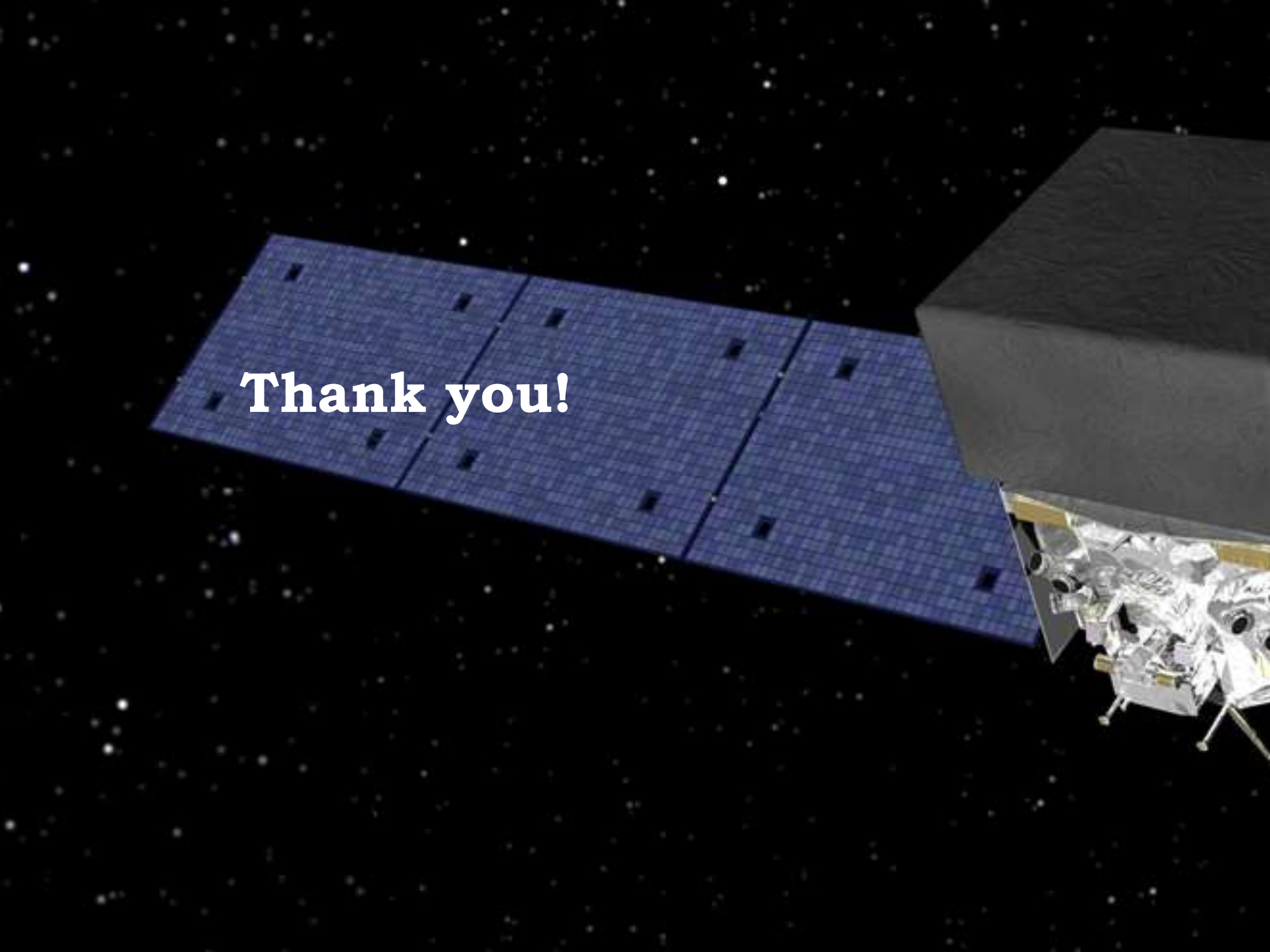
Follow-up of IceCube neutrino events

- 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 with limited GBM coverage:
  - **IceCube-170321A** (GCN 20932)
- Also can use these techniques to search for counterparts to **Fast Radio Bursts**





- Fermi-GBM continues to be very prolific in detecting GRBs, but it has shown excellent capabilities for non GRB science, too!
  - Monitoring of Galactic transients, Pulsars, Magnetars, etc.
  - Catching TGFs
- GBM is an ideal partner instrument in the search for EM signals in coincidence with GW detections
  - GCN notice of subthreshold GRB candidate events are now available
- Continued development of **offline data searches** for joint detection of astrophysical transients with neutrinos and gravitational waves.


Thank you!