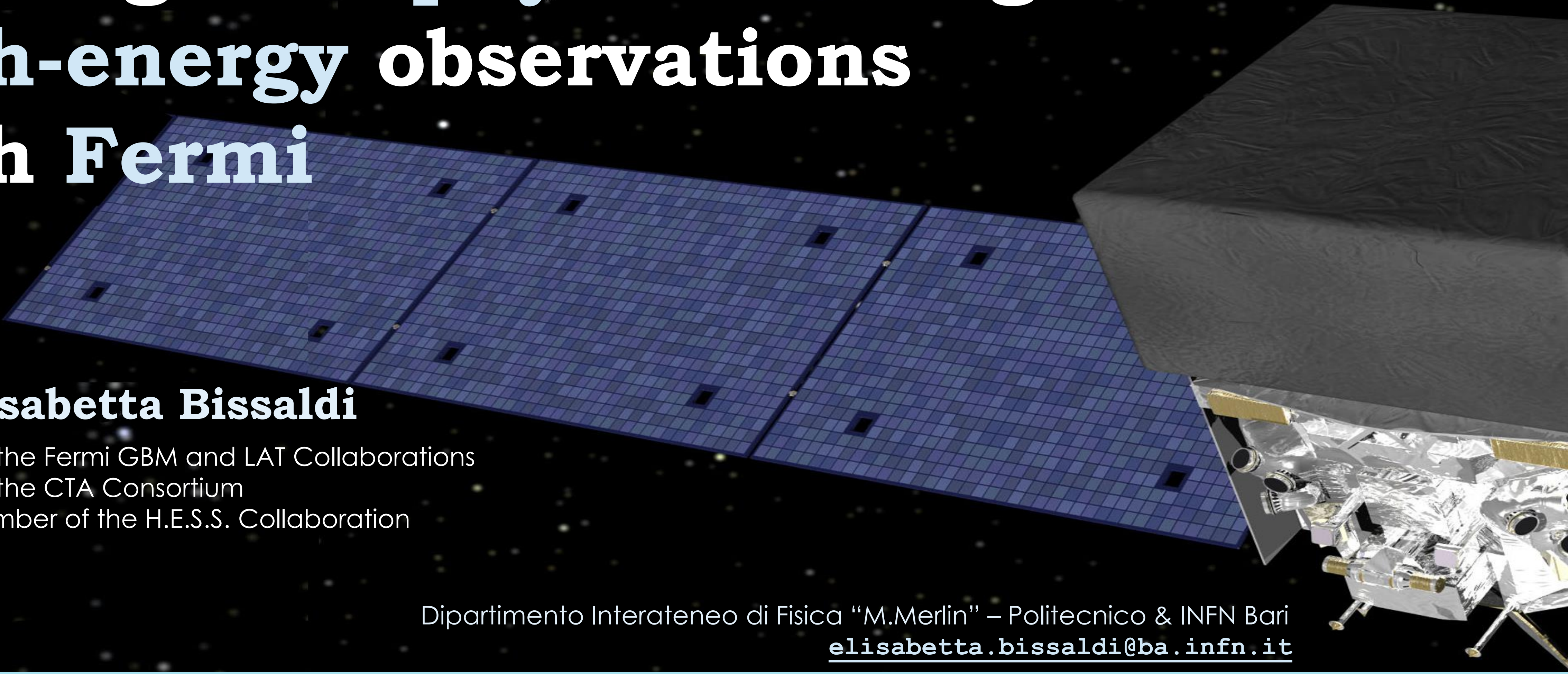
Probing GRB physics through high-energy observations with Fermi



Dr. Elisabetta Bissaldi

Member of the Fermi GBM and LAT Collaborations
Member of the CTA Consortium
Affiliate member of the H.E.S.S. Collaboration

Dipartimento Interateneo di Fisica "M.Merlin" – Politecnico & INFN Bari
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Sixteenth Marcel Grossmann Meeting - MG16

Virtual Meeting - July 5-10, 2021

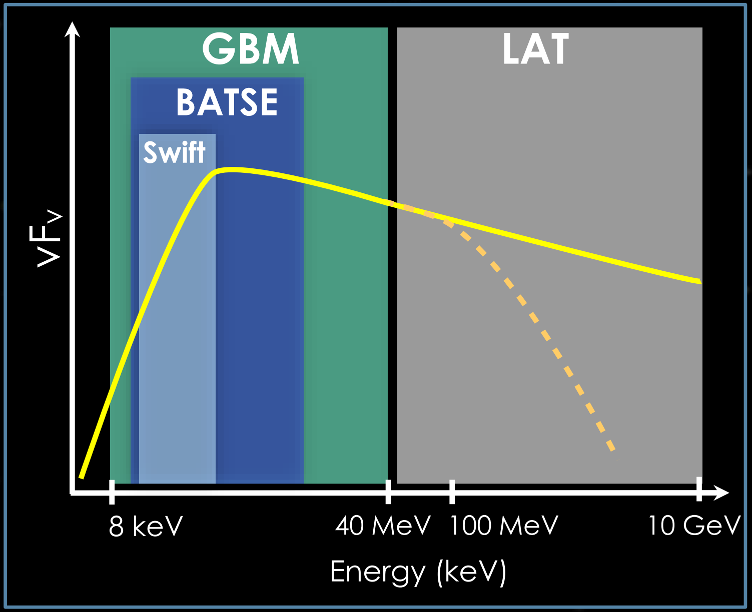
The Fermi mission

Launched on June 11, 2008

Key features
huge **FoV**
&
large **energy range**

Large Area Telescope (LAT)
Pair conversion telescope
20 MeV → 300 GeV

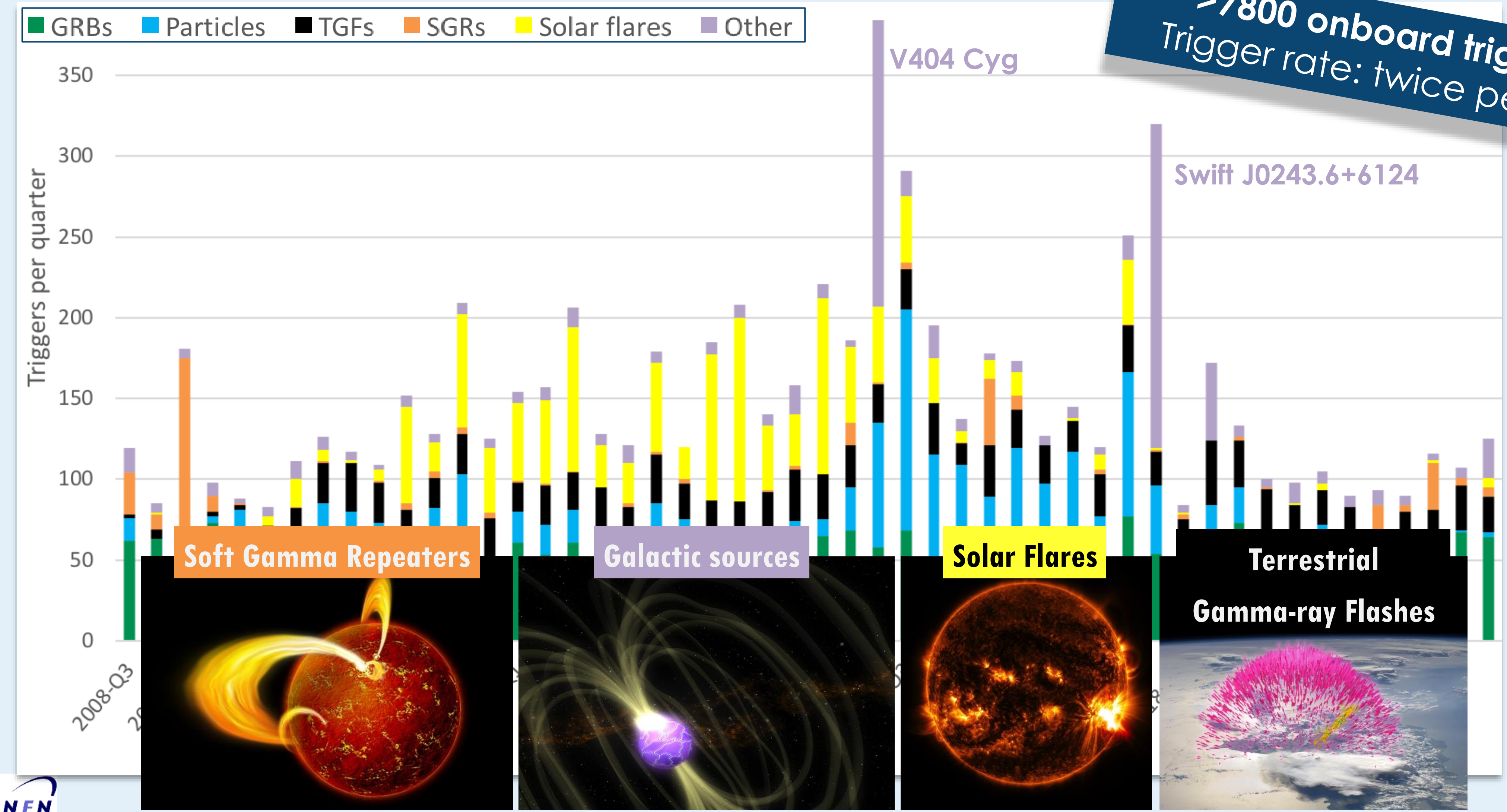
Gamma-ray Burst Monitor (GBM)
14 Plastic scintillator detectors
8 keV – 40 MeV



Fermi GBM trigger statistics

- **Quarterly trigger statistics** over **12.5 years** of the mission

>7800 onboard triggers!
Trigger rate: twice per day!

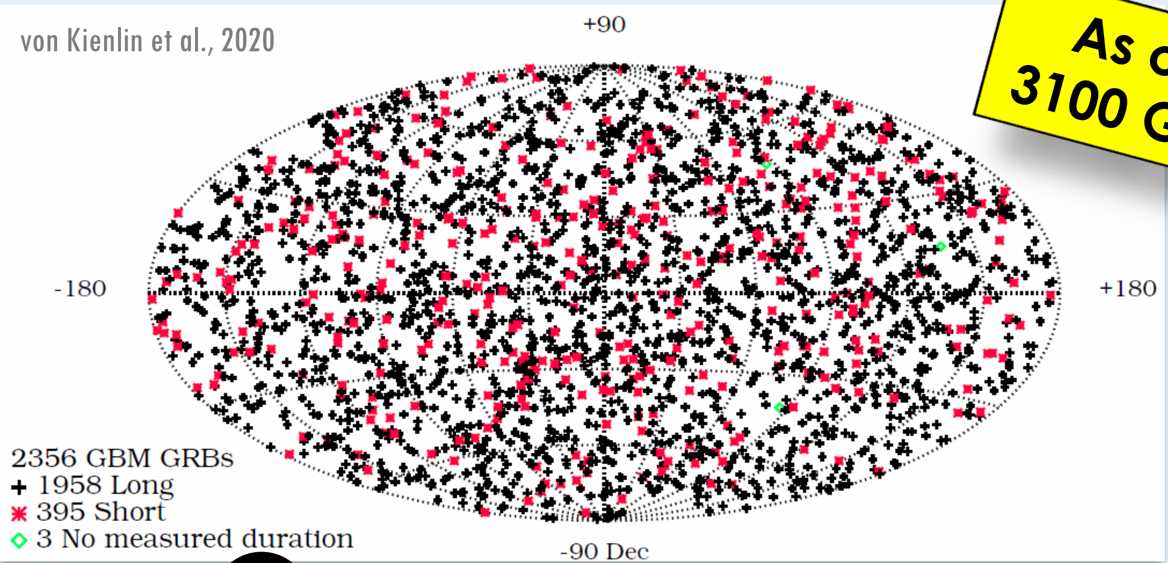


4^{th} GBM GRB Trigger Catalog [von Kienlin+2020]

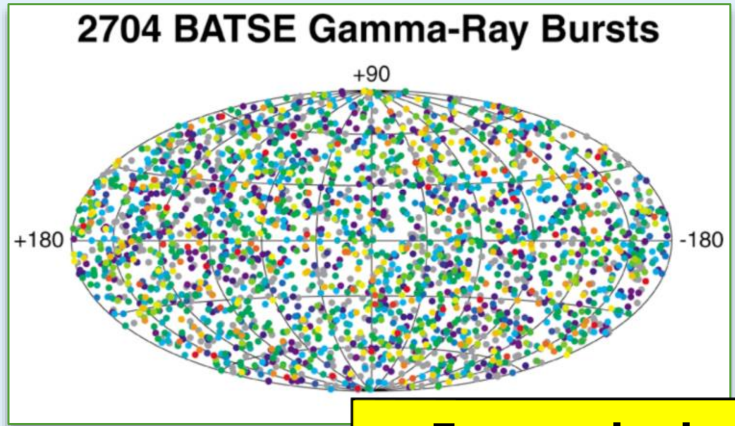
GRBs	SGRs	TGFs	SFs	Galactic	CPs	Other	Sum	ARRs	LAT GRBs
2360	258	880	1176	407	1023	331	6434	220	186

GBM Triggers

- **10 years** of data [2008 July 12 – 2018 July 11]
- **1^{st}, 2^{nd}, 3^{rd} catalog**
  2 years [Paciesas+2012], 4 years [von Kienlin+2014], 6 years [Bhat+2016]
- For each GRB: location, duration, peak flux & fluence (50–300 keV, 10–1000keV)
  - PLUS: Information on triggering criteria, exceptional operational conditions, GCN products



As of today: 3100 GBM GRBs



Exceeded BATSE in January 2020!

83% Long GRB rate: ~200 /year

17% Short GRB rate: ~40 /year

GBM: ~ 40 sGRBs/year
Swift: ~ 9 sGRBs/year

4th GBM GRB Trigger Catalog [von Kienlin+2020]

GRBs	SGRs	TGFs	SFs	Galactic	CPs	Other	Sum	ARRs	LAT GRBs
2360	258	880	1176	407	1023	331	6434	220	186

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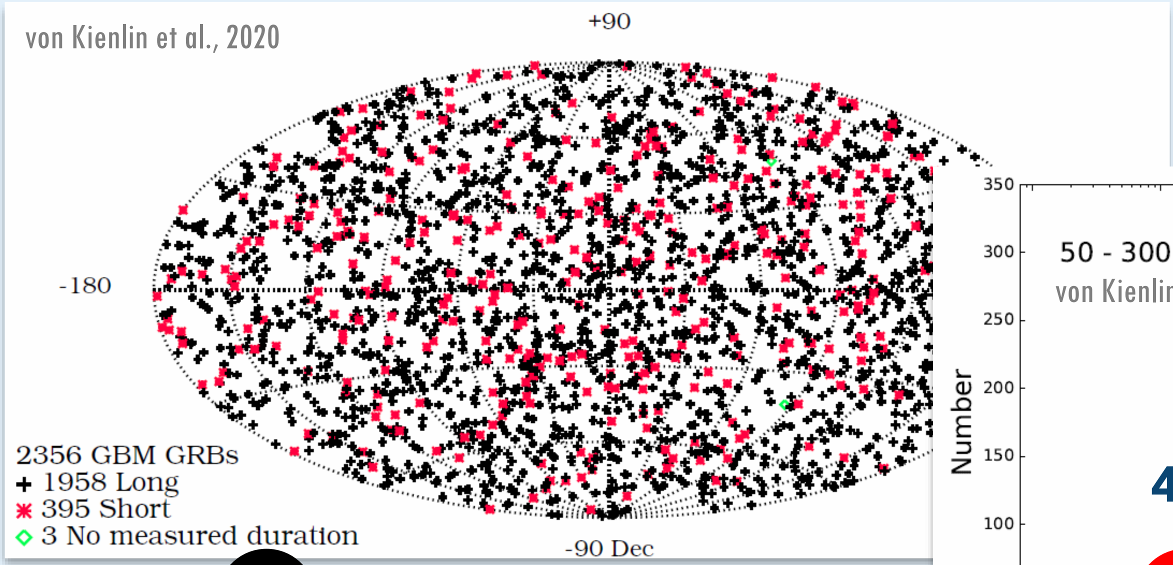

83% Long GRB rate: ~200 /year

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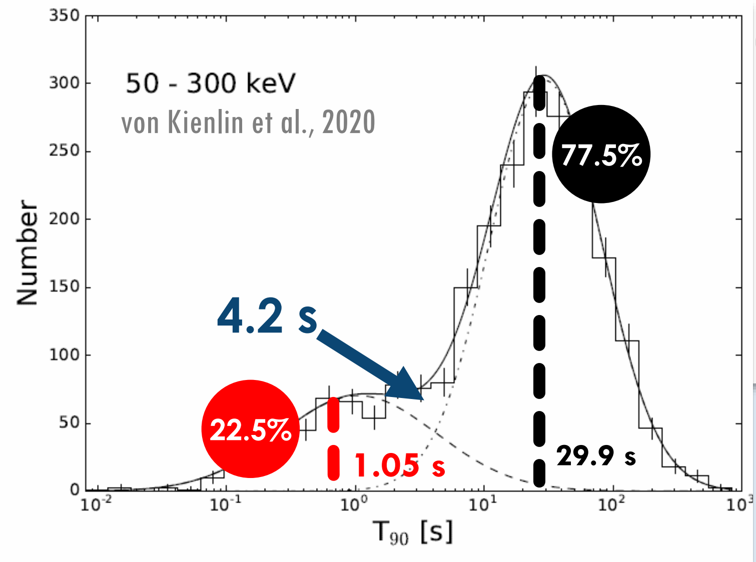
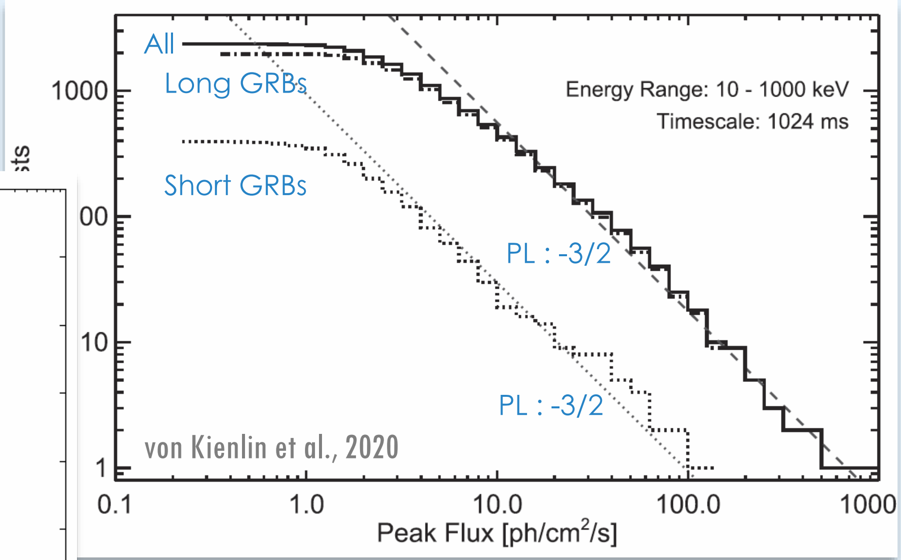




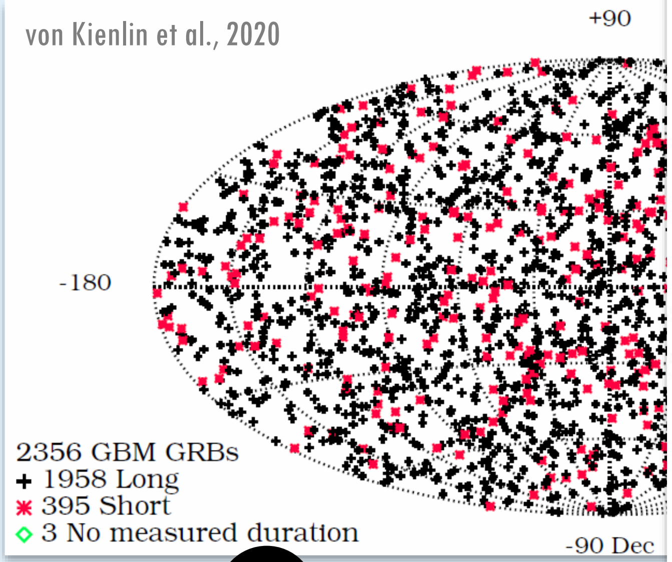
Complete results available @ HEASARC

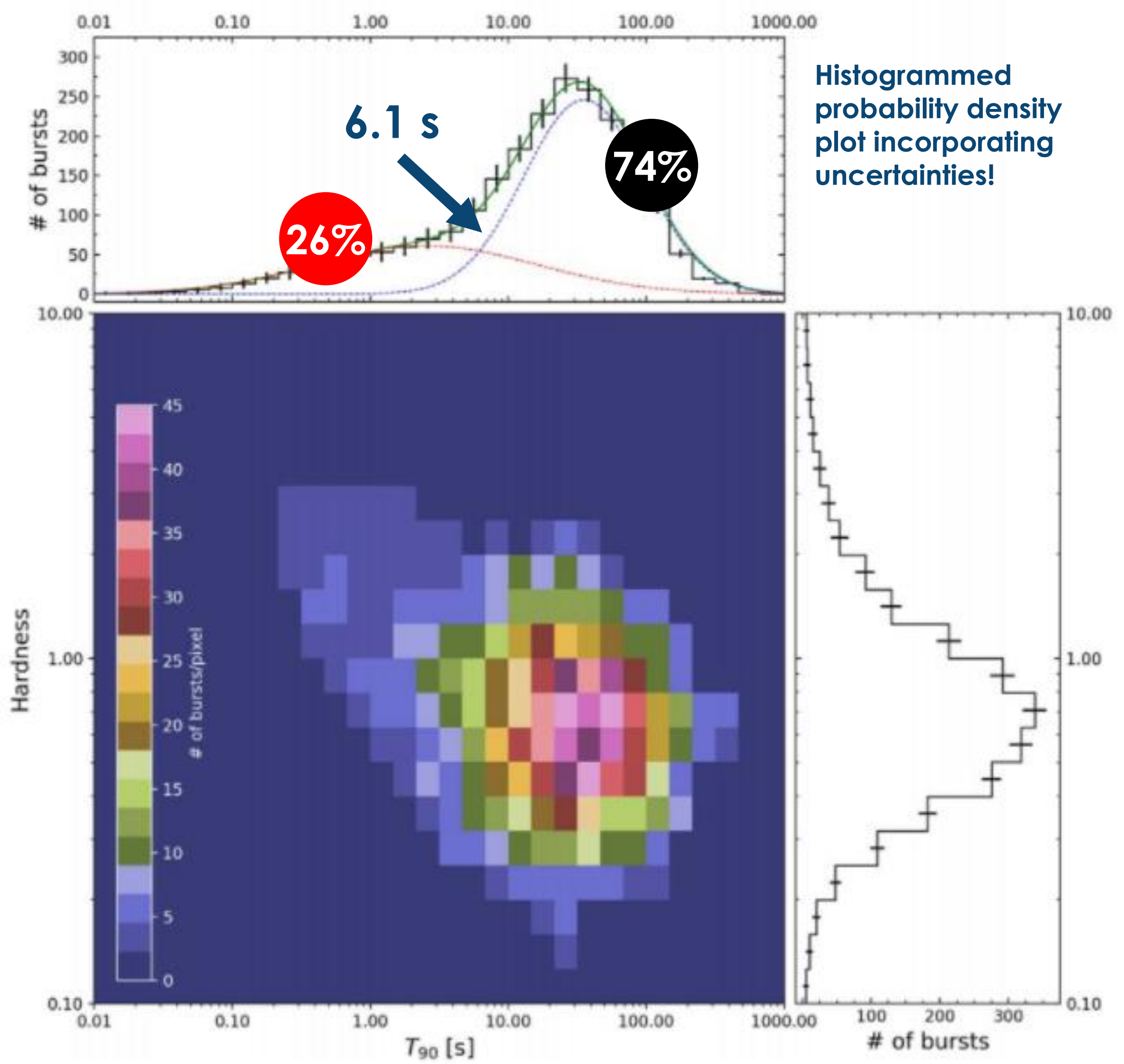
4th GBM GRB Trigger Catalog [von Kienlin+2020]

- **10 years** of data [2008 …
- **1st, 2nd, 3rd catalog**
  2 years [Paciesas+2012], 4 y…
- For each GRB: locatio… …0keV)
  - PLUS: Information on … …ns, GCN products

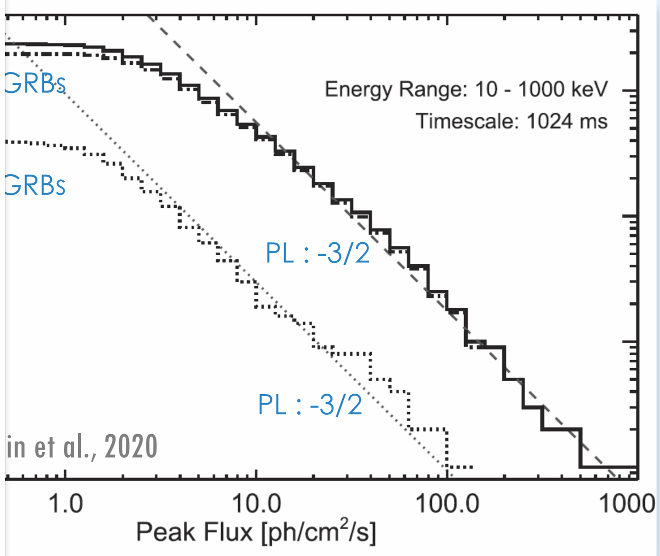
Galactic	CPs	Other	Sum	ARRs	LAT GRBs
407	1023	331	6434	220	186

GBM Triggers





Histogrammed probability density plot incorporating uncertainties!



…plete results available @ HEASARC

3rd GBM GRB Spectral Catalog [Poolakkil+2021]

- **10 years** of data [2008 July 12 – 2018 July 11]
- **1st, 2nd catalog**
  2 years [Goldstein+2012], 4 years [Gruber+2014]

- Systematic spectral analysis of **2297 GRBs**, two types of spectra:
  - Time-integrated spectral fits ➔ '**fluence**' spectrum
  - Spectral fits at brightest time bin (1.024s/64 ms) ➔ '**peak flux**' spectrum
    ➔ Resulting in a compendium of over 18000 spectra!

- 4 different empirical spectral models
  - PLAW (A, λ), COMP (A, α, E_{peak}), BAND (A, α, β, E_{peak}), SBPL (A, λ_1, λ_2, E_{break}, Δ)
  - **New!** two-sided uncertainties!
  - Fit ratings:
    - **GOOD -** parameter error of all model parameters are within certain limits
    - **BEST -** best representation model, based upon goodness of fit criteria

The Astrophysical Journal, 913:60 (20pp), 2021 May 20 https://doi.org/10.3847/1538-4357/abf24d

CrossMark

The Fermi-GBM Gamma-Ray Burst Spectral Catalog: 10 yr of Data

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Received 2021 February 3; revised 2021 March 18; accepted 2021 March 19; published 2021 May 25

Abstract

We present the systematic spectral analyses of gamma-ray bursts (GRBs) detected by the Fermi Gamma-Ray Burst Monitor during its first ten years of operation. This catalog contains two types of spectra: time-integrated spectral fits and spectral fits at the brightest time bin, from 2297 GRBs, resulting in a compendium of over 18,000 spectra. The four different spectral models used for fitting the spectra were selected based on their empirical importance to the shape of many GRBs. We describe in detail our procedure and criteria for the analyses, and present the bulk results in the form of parameter distributions both in the observer frame and in the GRB rest frame. 941 GRBs from the first four years have been refitted using the same methodology as that of the 1356 GRBs in years five through ten. The data files containing the complete results are available from the High-Energy Astrophysics Science Archive Research Center.

Unified Astronomy Thesaurus concepts: Gamma-ray bursts (629)
Supporting material: machine-readable table

Poolakkil+ ApJ Vol.913:60 (2021)

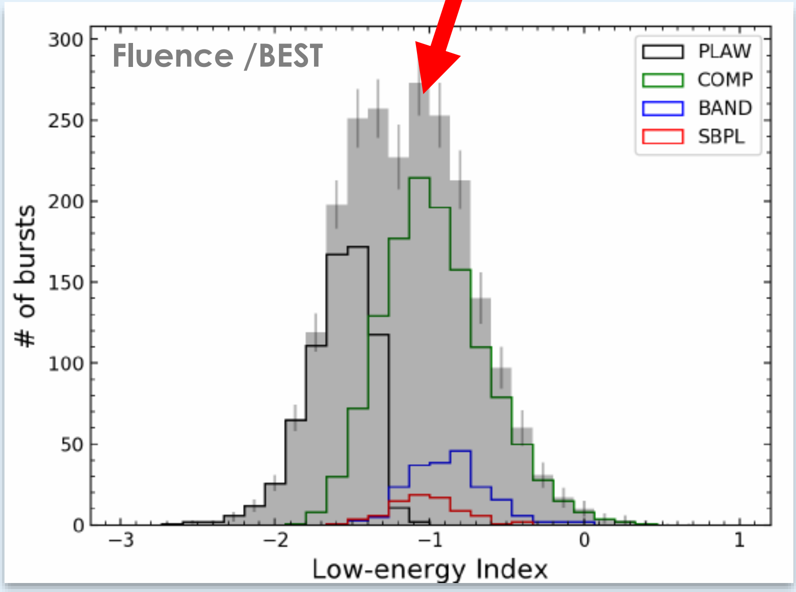
3rd GBM GRB Spectral Catalog [Poolakkil+2021]

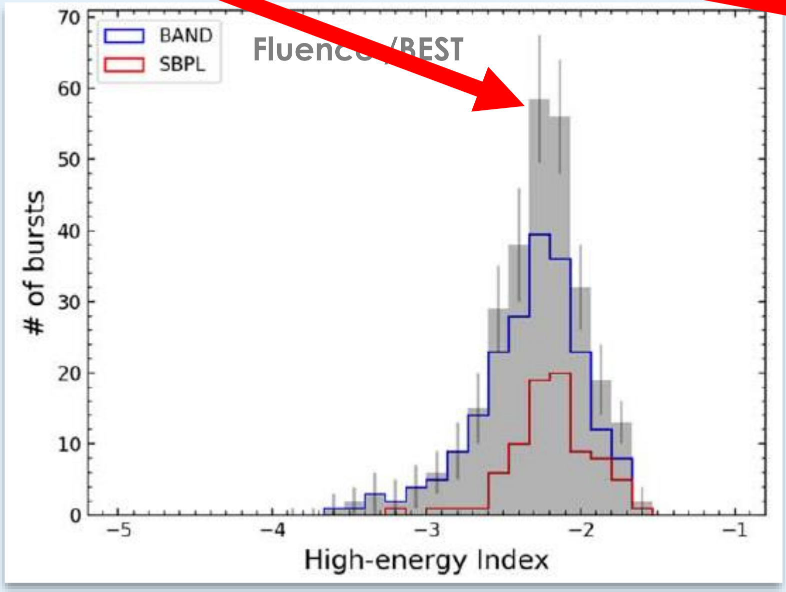
- **Parameter distributions**
  - Fluence and peak flux spectra
  - GOOD / BEST categories

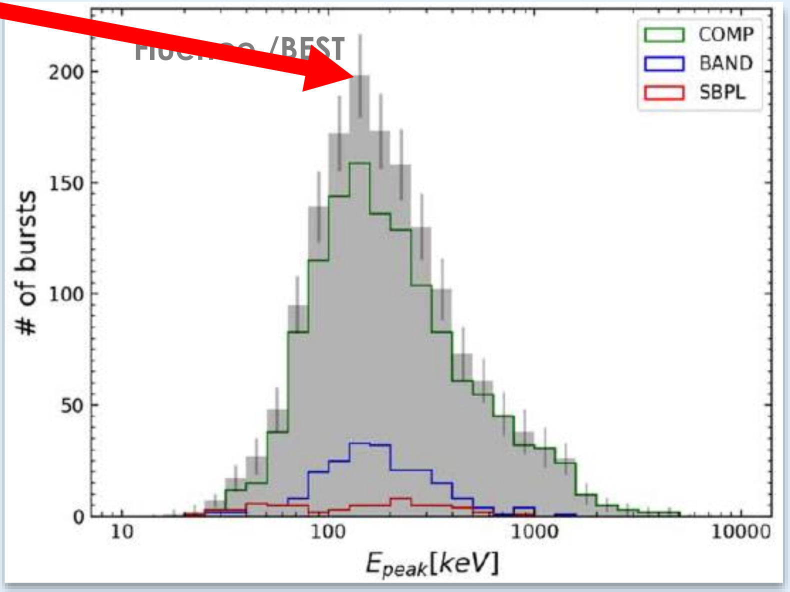
Data Set	Low-energy Index	High-energy Index	E_{peak} (keV)
This Catalog BEST	$-1.08^{+0.45}_{-0.44}$	$-2.20^{+0.26}_{-0.29}$	180^{+307}_{-88}
Gruber et al. (2014)	$-1.$[illegible]$8^{+0.43}_{-0.44}$	-2.14[illegible]	196[illegible]$_{-100}$
Goldstein et al. (2012)	$-$[illegible]$05^{+0.44}_{-0.45}$	$-2.25^{+0.34}_{-0.73}$	2[illegible]$^{+359}$
Kaneko et al. (2006)	$-$[illegible]$.14^{+0.20}_{-0.22}$	$-2.33^{+0.24}_{-0.26}$	251^{+122}_{-68}

GOOD and BEST GRB Models

	PLAW	COMP	BAND	SBPL
Fluence Spectra				
This Catalog GOOD	2295 (99.9%)	1616 (70.3%)	666 (29.0%)	1013 (44.0%)
Gruber et al. (2014) GOOD	941 (99.7%)	684 (72.5%)	342 (36.2%)	392 (41.5%)
This Catalog BEST	693 (30.2%)	1311 (57.0%)	209 (9.0%)	82 (3.5%)
Gruber et al. (2014) BEST	282 (29.9%)	516 (54.7%)	81 (8.6%)	62 (6.6%)
Peak Flux Spectra				
This Catalog GOOD	2287 (99.5%)	1047 (45.5%)	328 (14.2%)	522 (22.6%)
Gruber et al. (2014) GOOD	932 (98.7%)	430 (45.6%)	153 (16.2%)	196 (20.8%)
This Catalog BEST	1248 (54.3%)	931 (40.5%)	79 (3.4%)	29 (1.2%)
Gruber et al. (2014)BEST	514 (54.4%))	375 (39.7%)	25 (2.6%)	18 (1.9%)



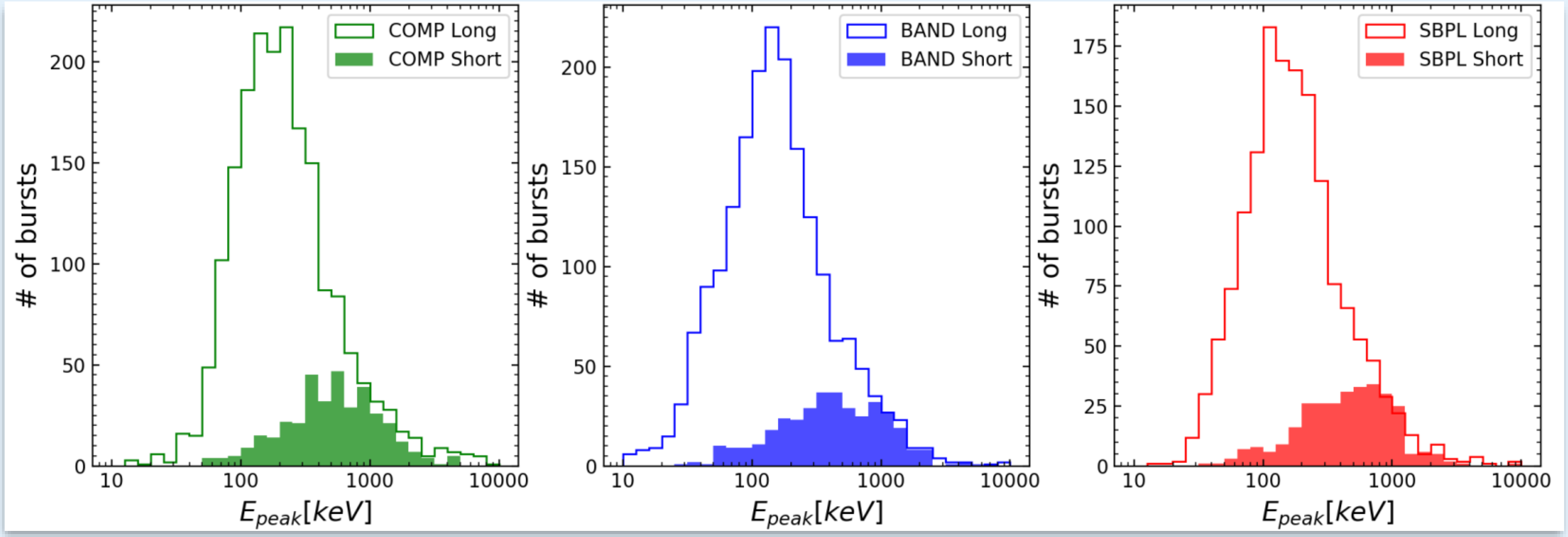


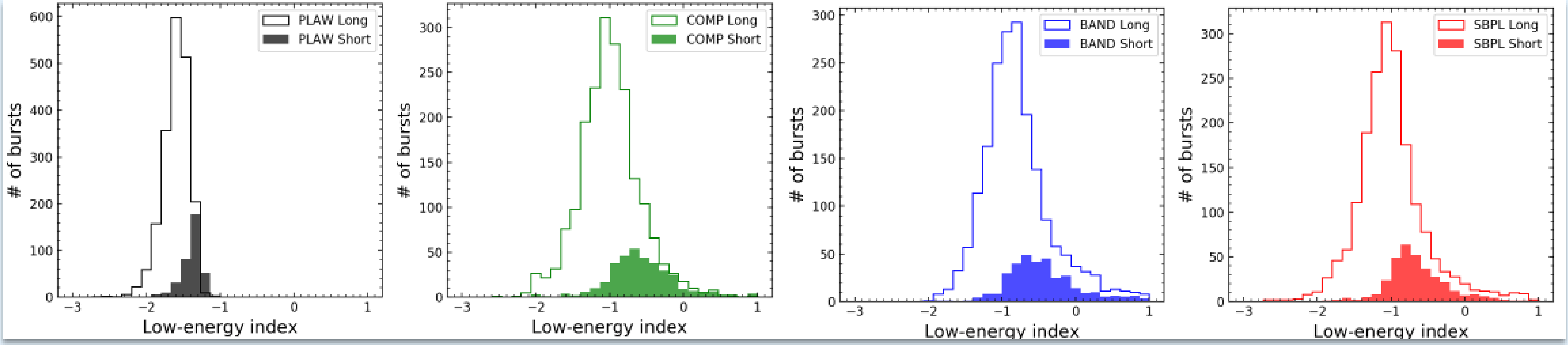


3rd GBM GRB Spectral Catalog [Poolakkil+2021]

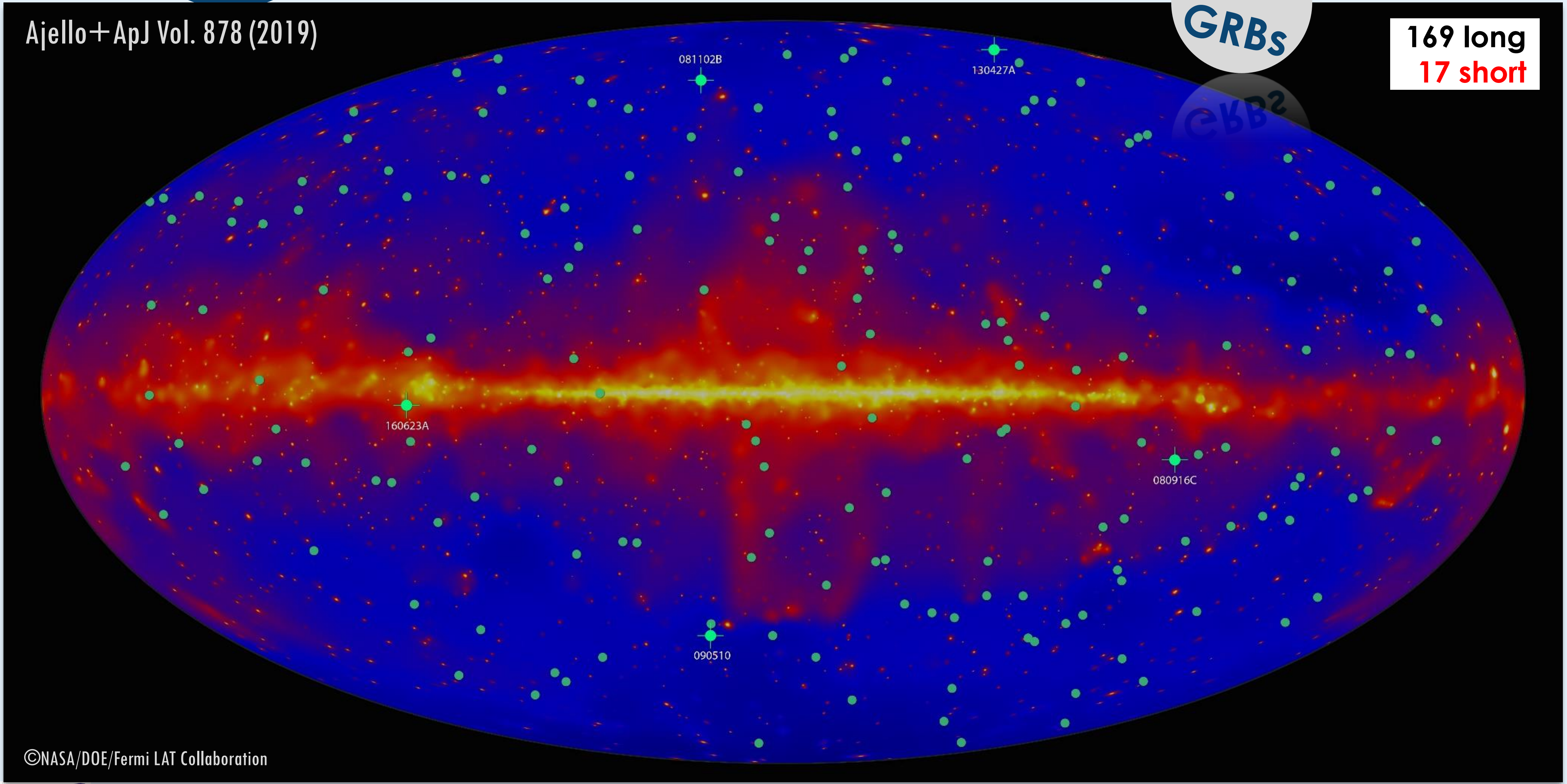
Long vs. Short GRBs

- Short bursts show a **higher median value of Epeak** and a **harder low-energy power law index**





2nd LAT GRB Catalog [Ajello+2019]

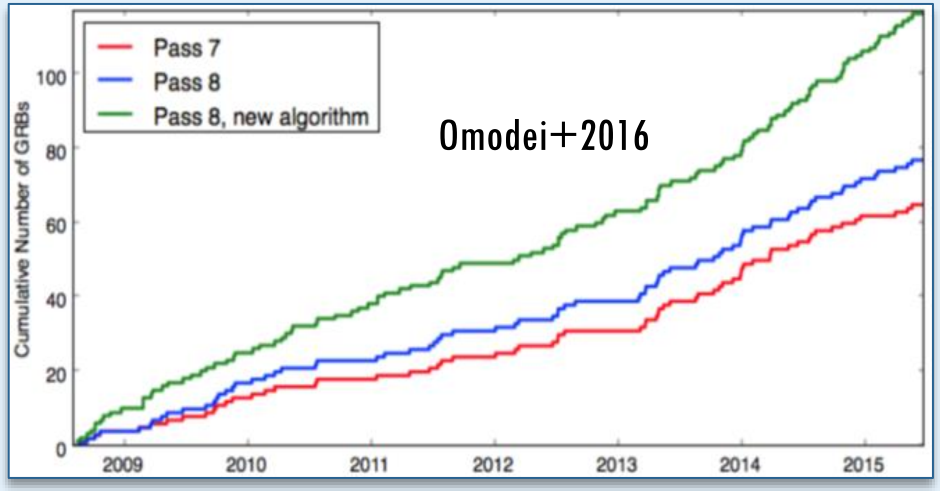


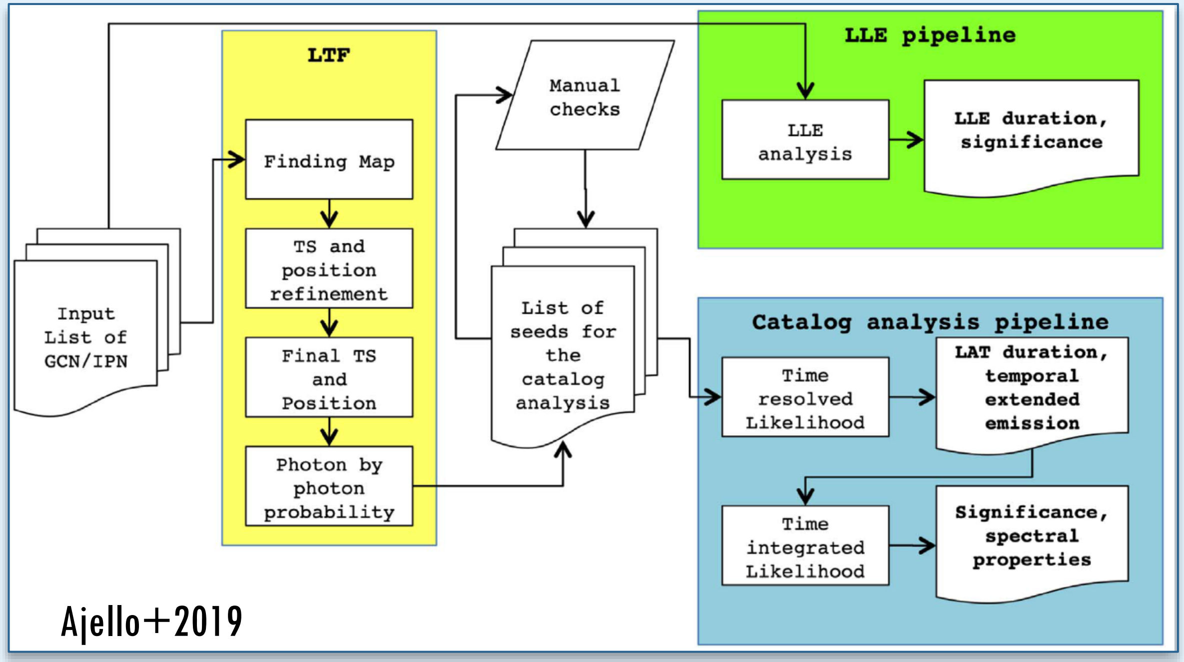
186 GRBs

169 long
17 short

2nd LAT GRB Catalog [Ajello+2019]

- **10 years** of data [2008 July 12 – 2018 July 11]
  - **1st catalog**
    3 years [Ackermann+2013]
- Search for emission from 3044 GRBs triggered by several instruments including:
  - GBM, Swift, Integral, AGILE, IPN
- Detection algorithm searching 5 time windows, from 10 s to 10 ks, and over bigger ROI
  - **LAT Transient Factory** (LTF, Vianello+2015)
- Every detection analyzed by a standardized analysis pipeline
- Compared with the 1FLGC
  - New detection algorithm: 50% improvement
  - Using Pass8 data: 10% improvement

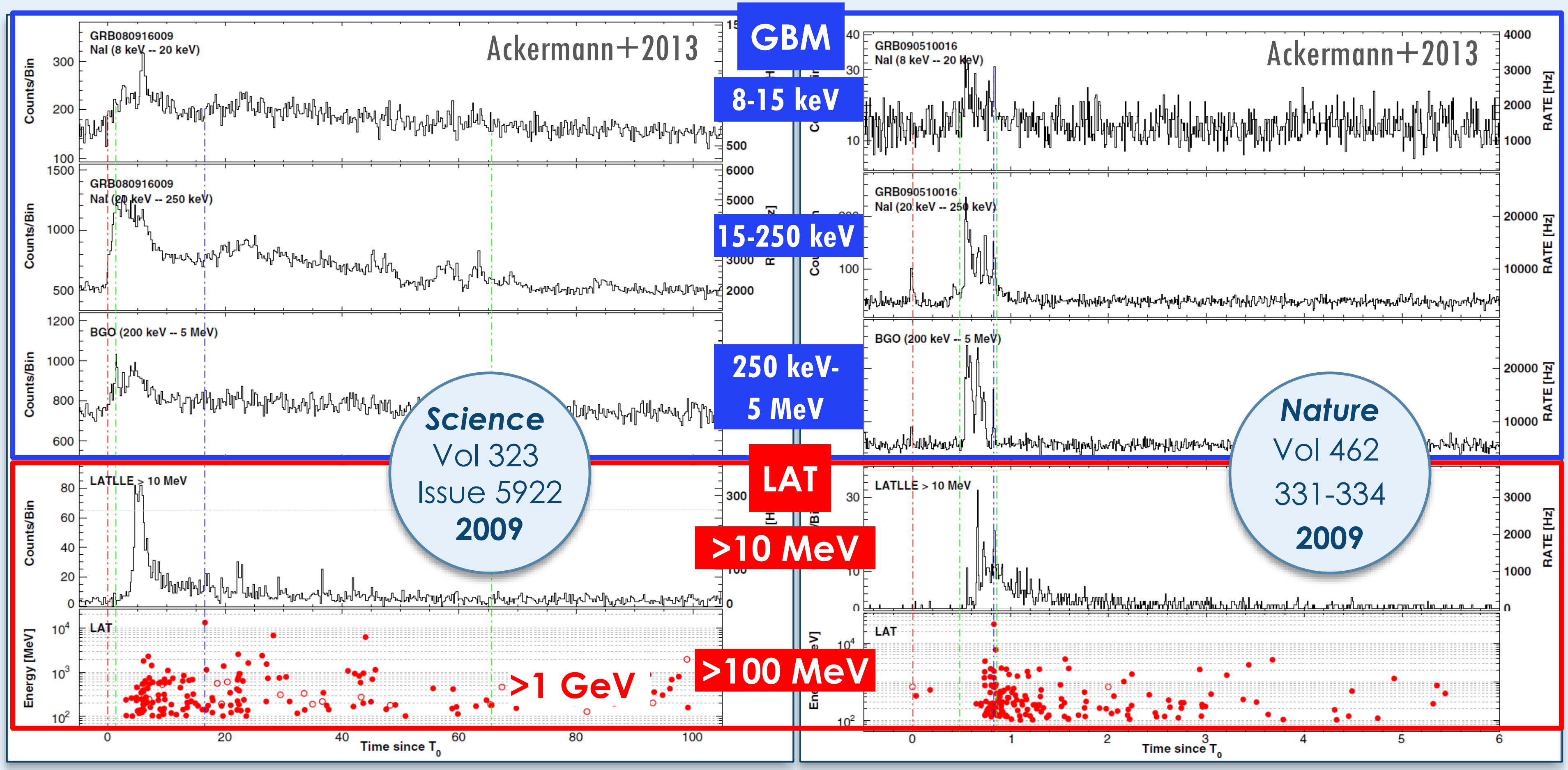




2nd LAT GRB Catalog [Ajello+2019]

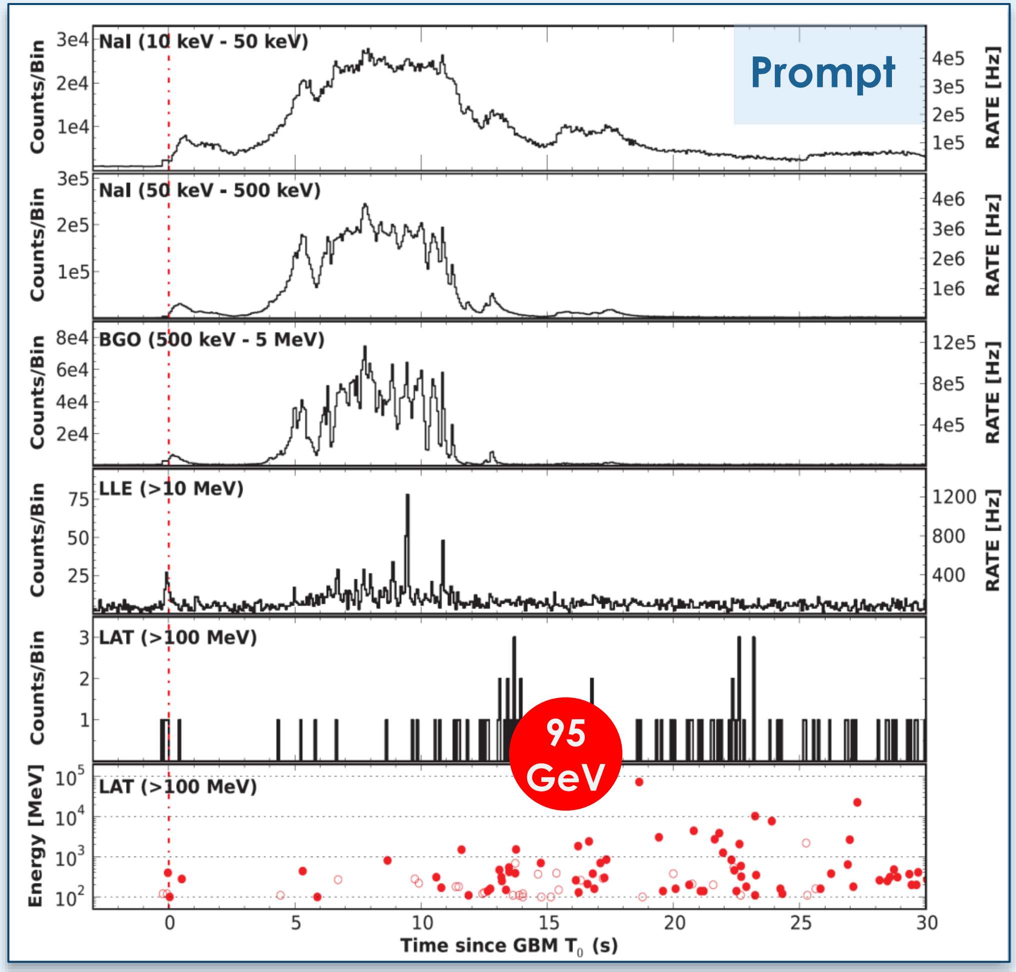
<u>**The most "famous" LAT GRBs**</u>

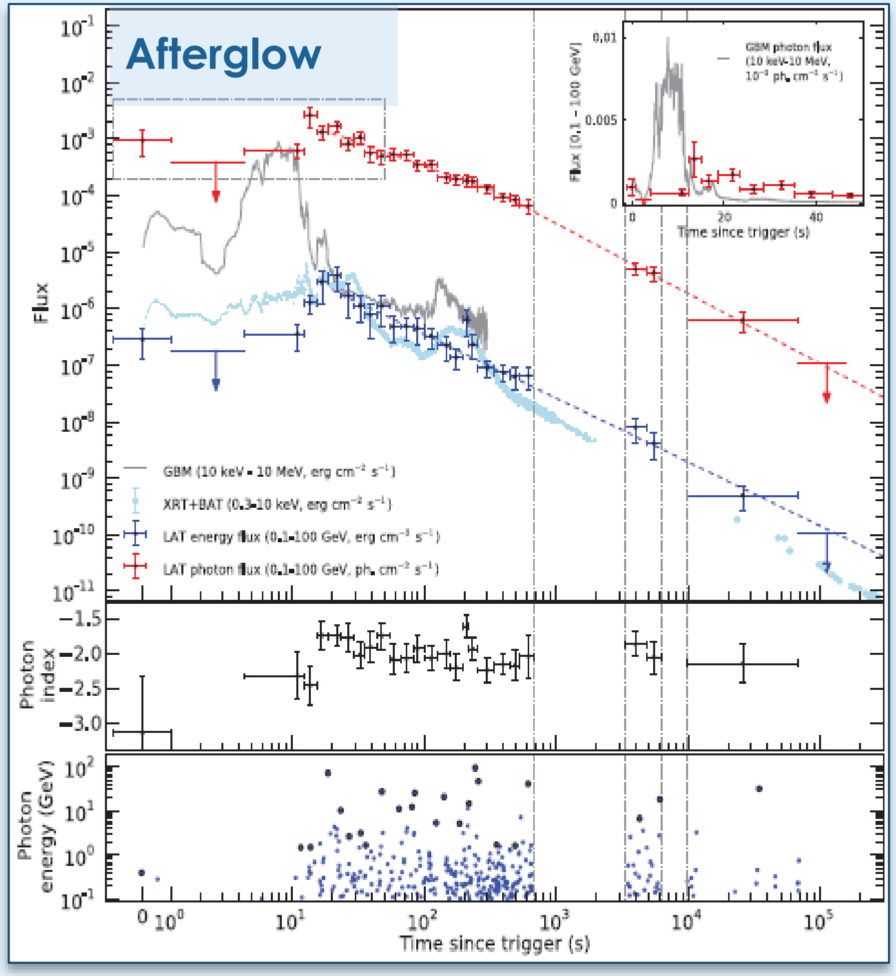
Long **GRB 080916C** | Short **GRB 090510**



2nd LAT GRB Catalog [Ajello+2019]

GRB 130427A – The "monster" burst

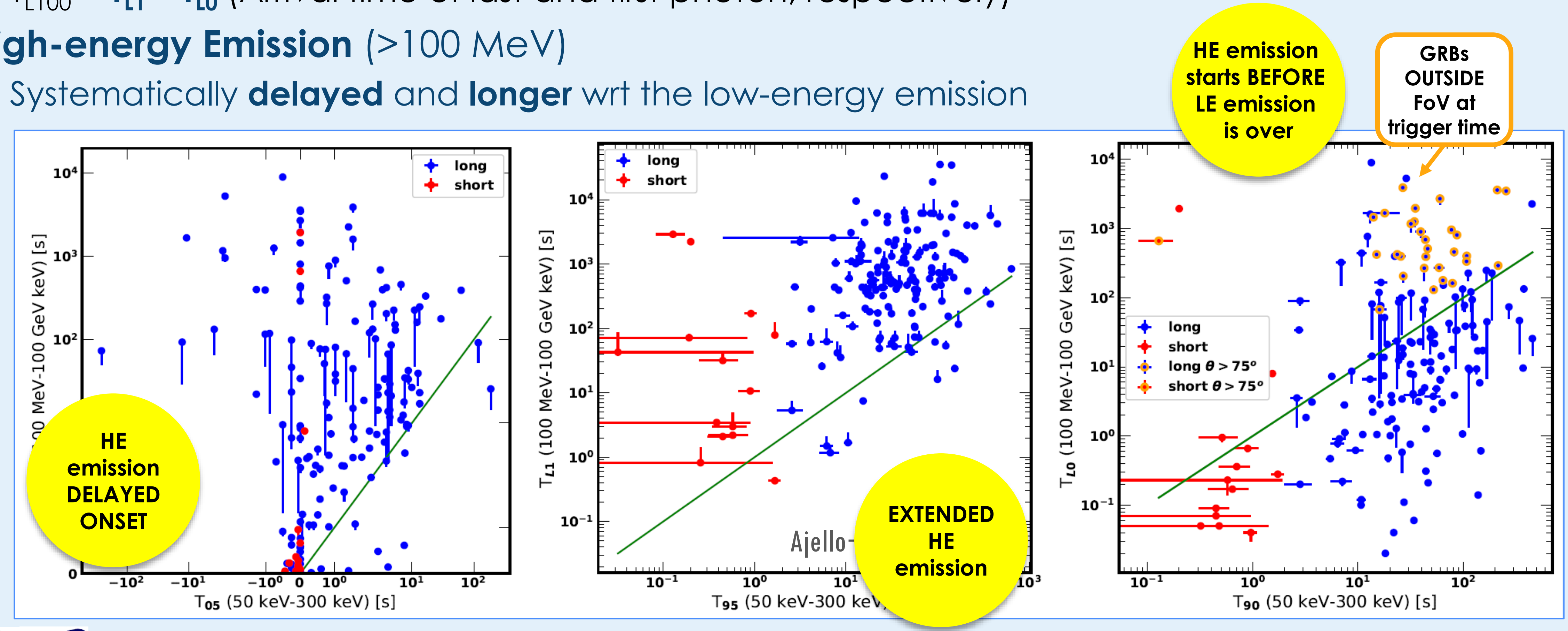




Preece+2014, Ackermann+2014 Science

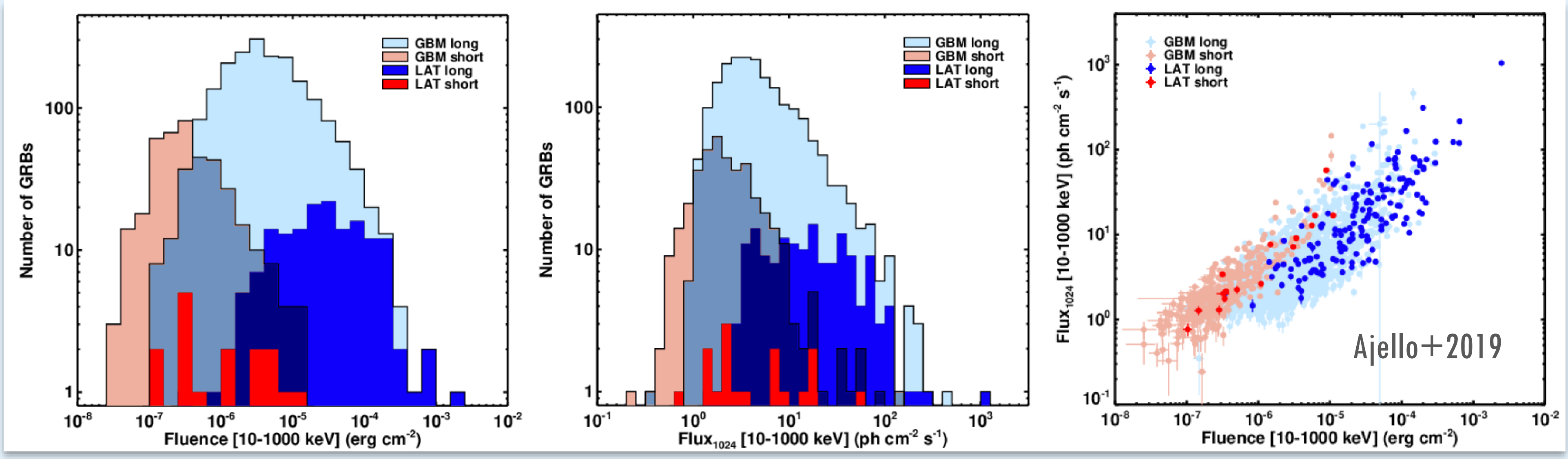
2^{nd} LAT GRB Catalog [Ajello+2019]

- Detailed study of the **onset** and **duration** of the high-energy emission
  - $\mathbf{T_{L100}}$ = GRB duration measured by LAT [**100 MeV – 100 GeV**]
  - T_{L100} = $\mathbf{T_{L1}}$ – $\mathbf{T_{L0}}$ (Arrival time of last and first photon, respectively)
- **High-energy Emission** (>100 MeV)
  - Systematically **delayed** and **longer** wrt the low-energy emission



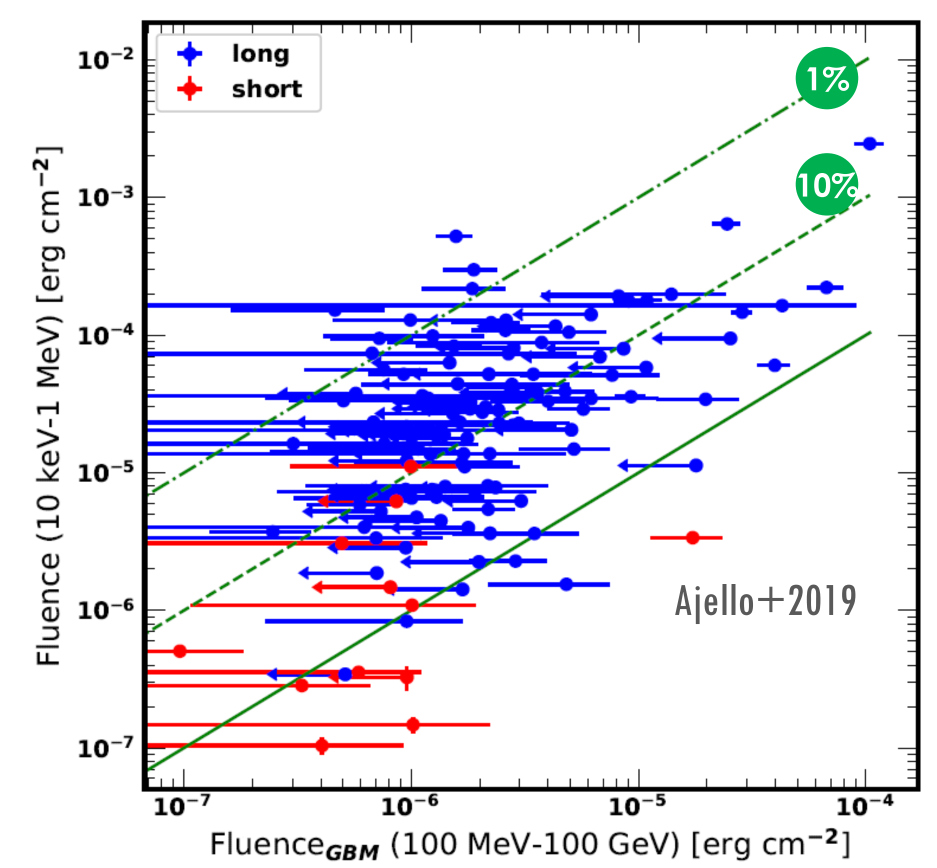
2nd LAT GRB Catalog [Ajello+2019]

- Comparison of low-energy (LE) properties of LAT-detected GRBs with the entire **10yr GBM sample** (**~2400 GRBs**)

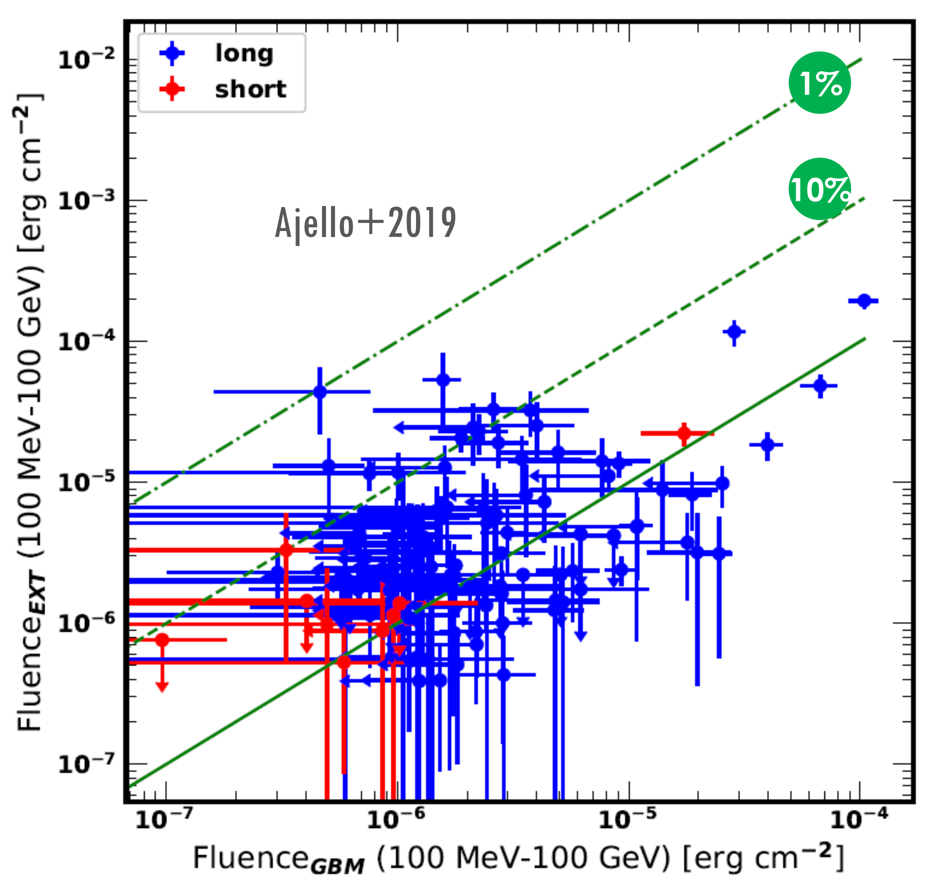


- Distribution of short and long bursts are **different**
- LAT tends to sample brighter bursts
  - BUT: **MUCH LARGER SPREAD** now than in the first LAT catalog!
    - Detection of HE emission also **from weak GBM bursts**!

2nd LAT GRB Catalog [Ajello+2019]



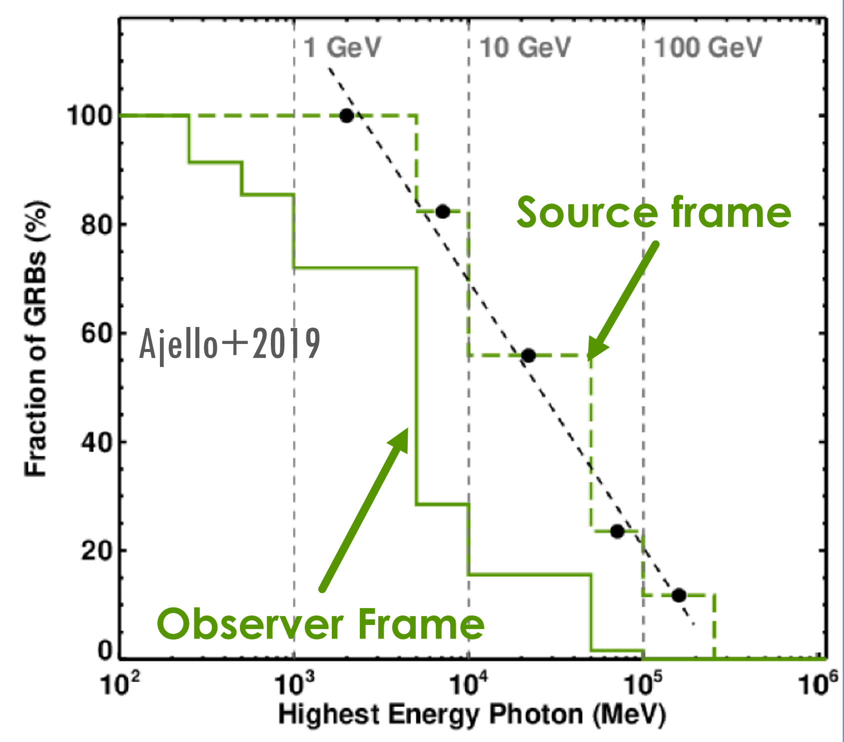
- LE (10-1000 keV) fluence is >10 x larger than HE (100 Mev-100 GeV) fluence in the «GBM» time window
  - The majority of the burst **energy** is emitted at **lower energies**!

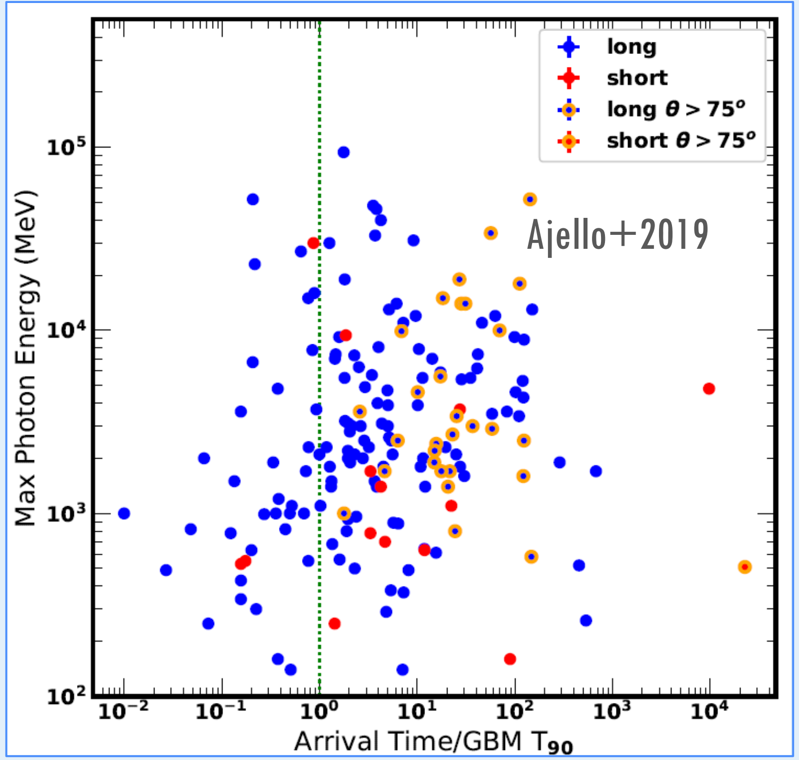


- At HE (100 Mev-100 GeV), the fluence measured at late times («EXT» winodw) is **comparable** to the one measured during the prompt phase («GBM» window)

2nd LAT GRB Catalog [Ajello+2019]

- **Highest-energy photons** from GRBs
  - **<5%** of GRBs have **E > 50 GeV**
  - Sharp drop @5 GeV (obs.frame)
  - Record holder: **GRB 130427A**
    - **95 GeV @243 s, 77 GeV @19s, 34 GeV @34 ks**





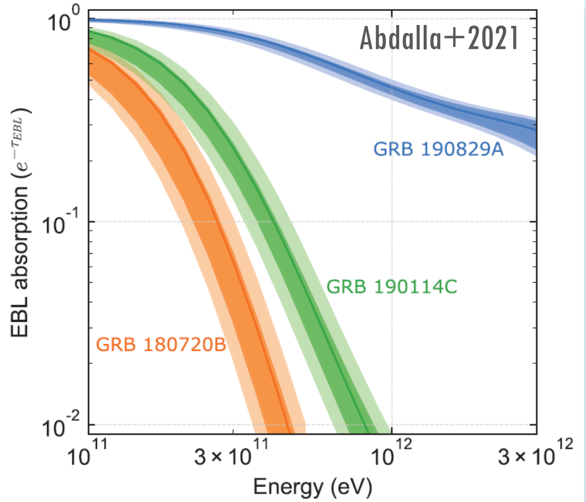
- HE photons often **arrive after the low-energy emission is over, BUT**

  ➡ Highest energies can be produced either very quickly or very late: challenge for models!

Breakthrough: GRB detections @VHE

- Announcements on November 20, 2019
  1. H.E.S.S. observation of **GRB 180720B**
  2. MAGIC observation of **GRB 190114C**
- Announcement on June 4, 2021
  3. H.E.S.S. observation of **GRB 190829A**

GRB 201216C MAGIC detection
Blanch+GCN #29075



nature

Article | Published: 20 November 2019

A very-high-energy component deep in the γ-ray burst afterglow

H. Abdalla, R. Adam, [...] O. J. Roberts

Nature 575, 464–467(2019) | Cite this article
3478 Accesses | 382 Altmetric | Metrics

z = 0.653

Abstract

Gamma-ray bursts (GRBs) are brief flashes of γ-rays and are considered to be the most energetic explosive phenomena in the Universe[1]. The emission from GRBs comprises a short (typically tens of seconds) and bright prompt emission, followed by a much longer afterglow phase. During the afterglow phase, the shocked outflow—produced by the interaction between the ejected matter and the circumburst medium—slows down, and a gradual decrease in brightness is observed[2]. GRBs typically emit most of their energy via γ-rays with energies in the kiloelectronvolt-to-megaelectronvolt range, but a few photons with

nature

DOI: 10.1038/s41586-019-1750-x

Article | Published: 20 November 2019

Teraelectronvolt emission from the γ-ray burst GRB 190114C

MAGIC Collaboration

Nature 575, 455–458(2019) | Cite this article
4230 Accesses | 493 Altmetric | Metrics

z = 0.4245

Abstract

Long-duration γ-ray bursts (GRBs) are the most luminous sources of electromagnetic radiation known in the Universe. They arise from outflows of plasma with velocities near the speed of light that are ejected by newly formed neutron stars or black holes (of stellar mass) at cosmological distances[1,2]. Prompt flashes of megaelectronvolt-energy γ-rays are followed by a longer-

Science Contents News Careers Journals

REPORT

Revealing x-ray and gamma ray temporal and spectral similarities in the GRB 190829A afterglow

H.E.S.S. Collaboration[*,†], H. Abdalla[1], F. Aharonian[2,3,4], F. Ait Benkhali[3], E. O. Angüner[5], C. Arcaro[6], C. Armand[7], T. Armstro...
+ See all authors and affiliations

Science 04 Jun 2021:
Vol. 372, Issue 6546, pp. 1081-1085
DOI: 10.1126/science.abe8560

z = 0.0785

Article | Figures & Data | Info & Metrics | eLetters | PDF

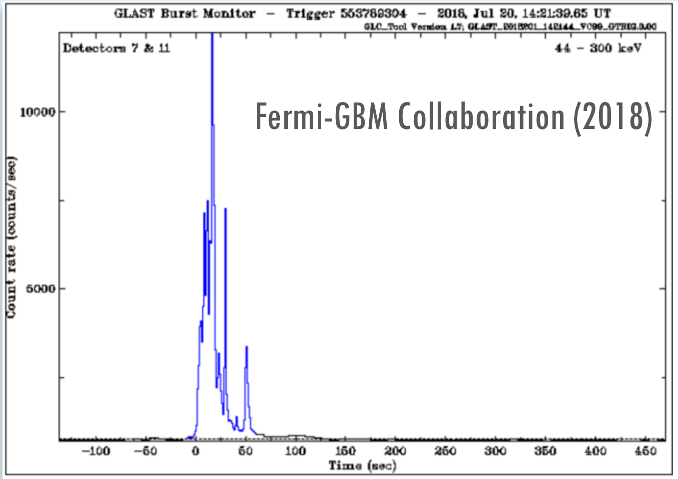
Abstract

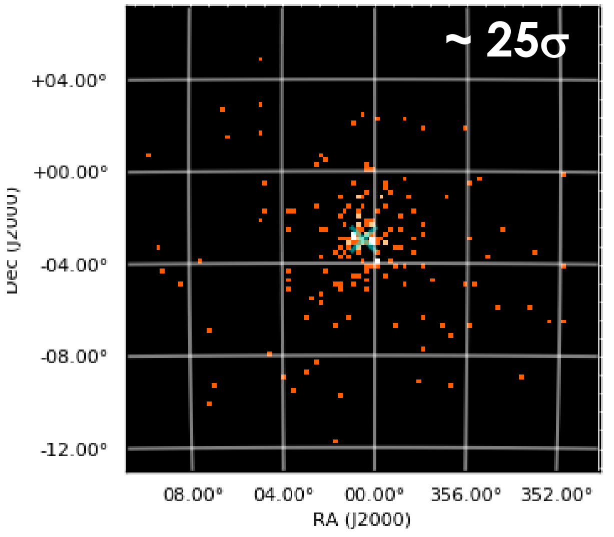
Gamma-ray bursts (GRBs), which are bright flashes of gamma rays from extragalactic sources followed by fading afterglow emission, are associated with stellar core collapse events. We report the detection of very-high-energy (VHE) gamma rays from the afterglow of GRB 190829A, between 4 and 56 hours after the trigger, using the High Energy Stereoscopic System (H.E.S.S.). The low luminosity and redshift of GRB 190829A reduce both internal and external absorption, allowing determination of its intrinsic energy spectrum. Between energies of 0.18 and 3.3 tera–electron volts, this spectrum is described by a power law with photon index of 2.07 ± 0.09, similar to the x-ray spectrum. The x-ray and VHE gamma-ray light curves also show similar decay profiles. These similar characteristics in the x-ray and gamma-ray bands challenge GRB afterglow emission scenarios.

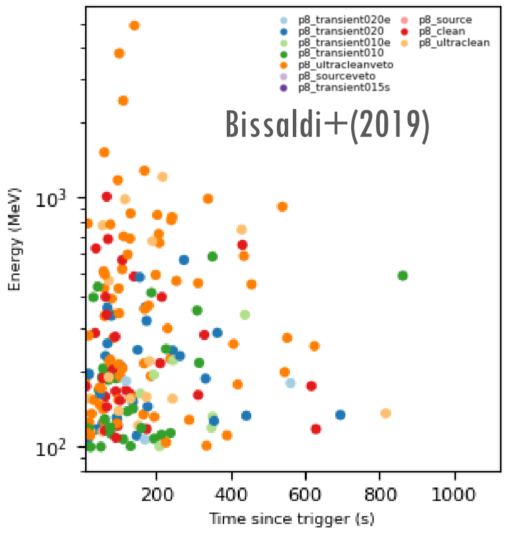
GRB 180720B seen by Fermi

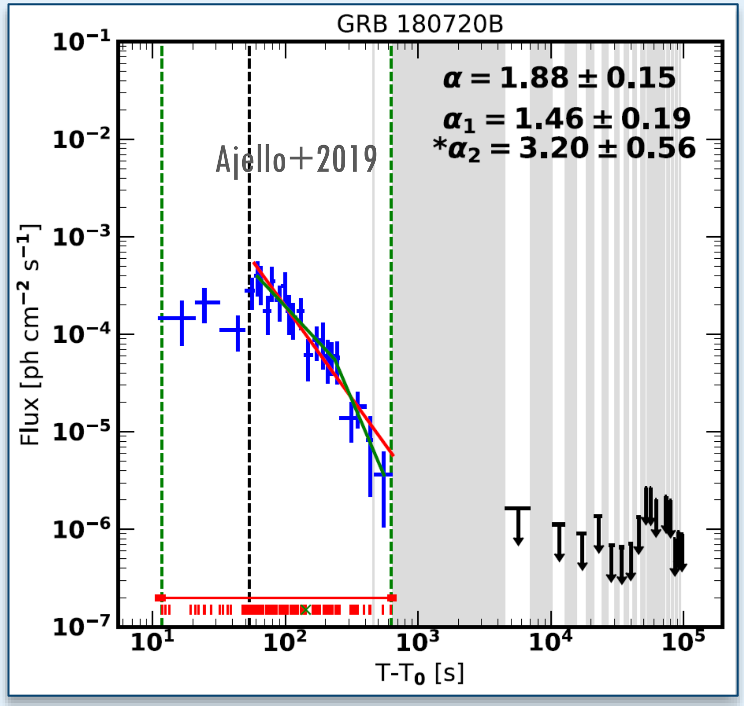
- Bright GRB on **July 20th, 2018**
  - Triggered **Fermi-GBM** [Roberts+2018, GCN #22981]
    - GBM T_{90} (50-300 keV) = **48.9 ± 0.4 s**
    - E_{iso} = (6.0 x 0.1) 10^{53} erg – **7° brightest** in GBM
  - Clear **Fermi-LAT** detection [Bissaldi+2018, GCN #22980]
    - Max photon energy: **5 GeV** @T_0+142 s
    - GRB rapidly moving **out of the LAT FoV**

➔ **No further LAT detection** beyond T0+700 s



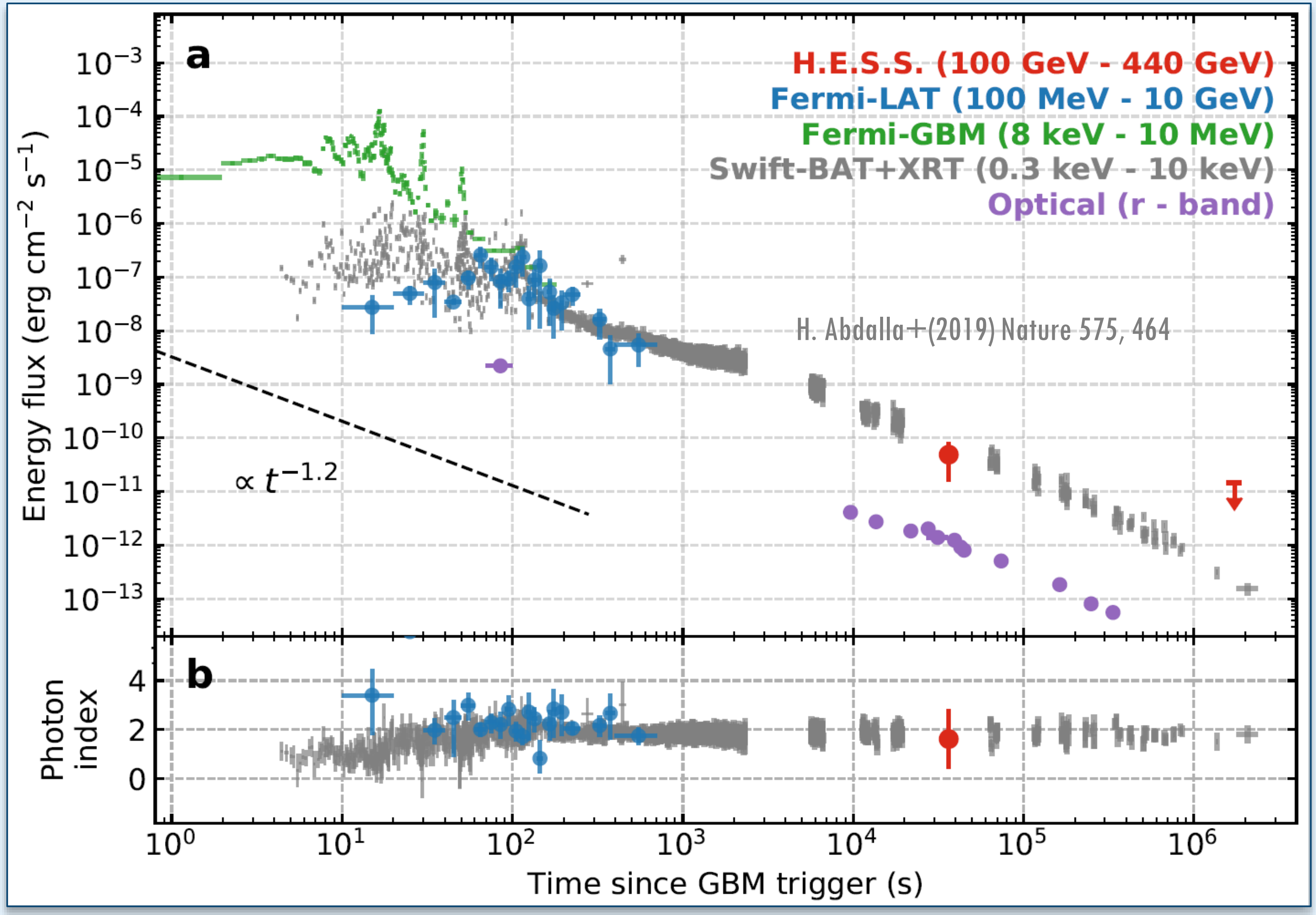






GRB 180720B seen by Fermi

Energy flux lightcurves at different wavelengths

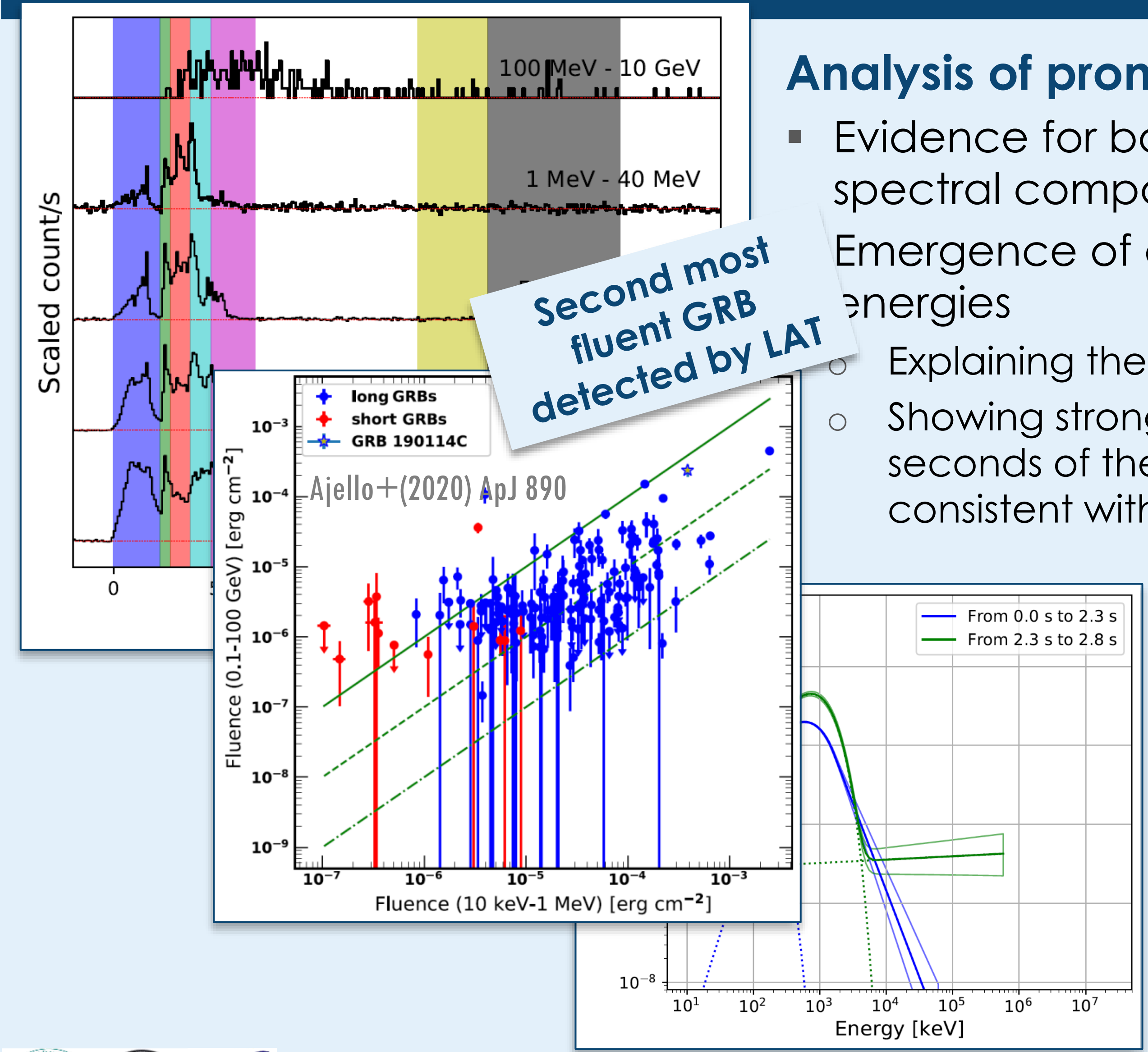


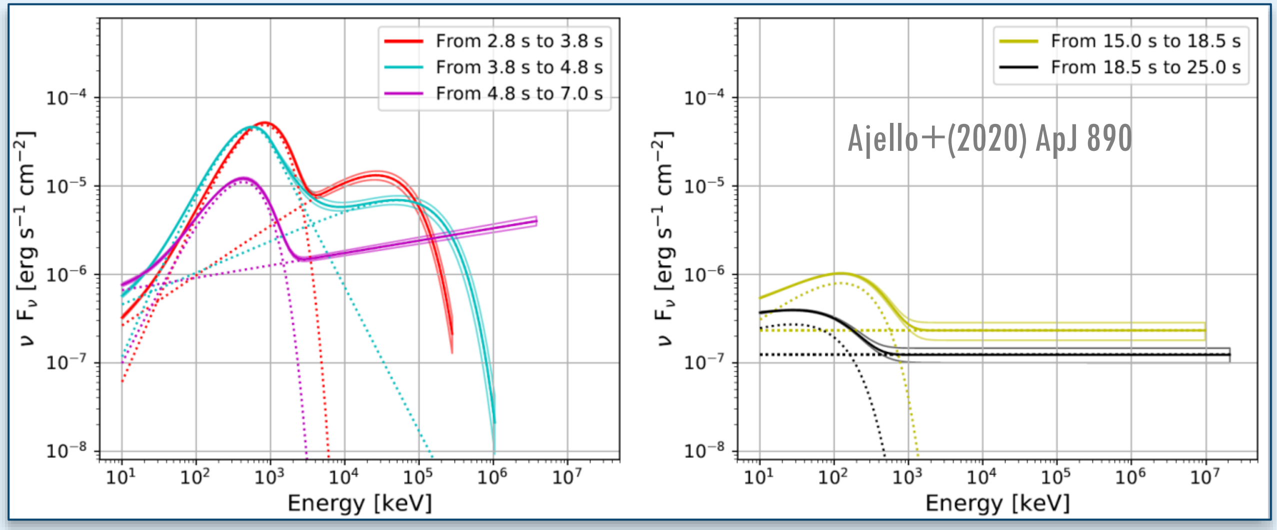
GRB 190114C seen by Fermi

Analysis of prompt emission with GBM+LAT data

- Evidence for both **thermal** (BB) and **non-thermal** (CPL or Band) spectral components commonly seen in GRB spectra
- Emergence of an **additional PL component** extending to high energies
  - Explaining the **delayed onset** of the LAT-detected emission
  - Showing strong evidence for spectral attenuation >40 MeV in the first few seconds of the burst, before transitioning to a **harder spectrum** that is consistent with the afterglow emission observed by XRT+BAT at later times

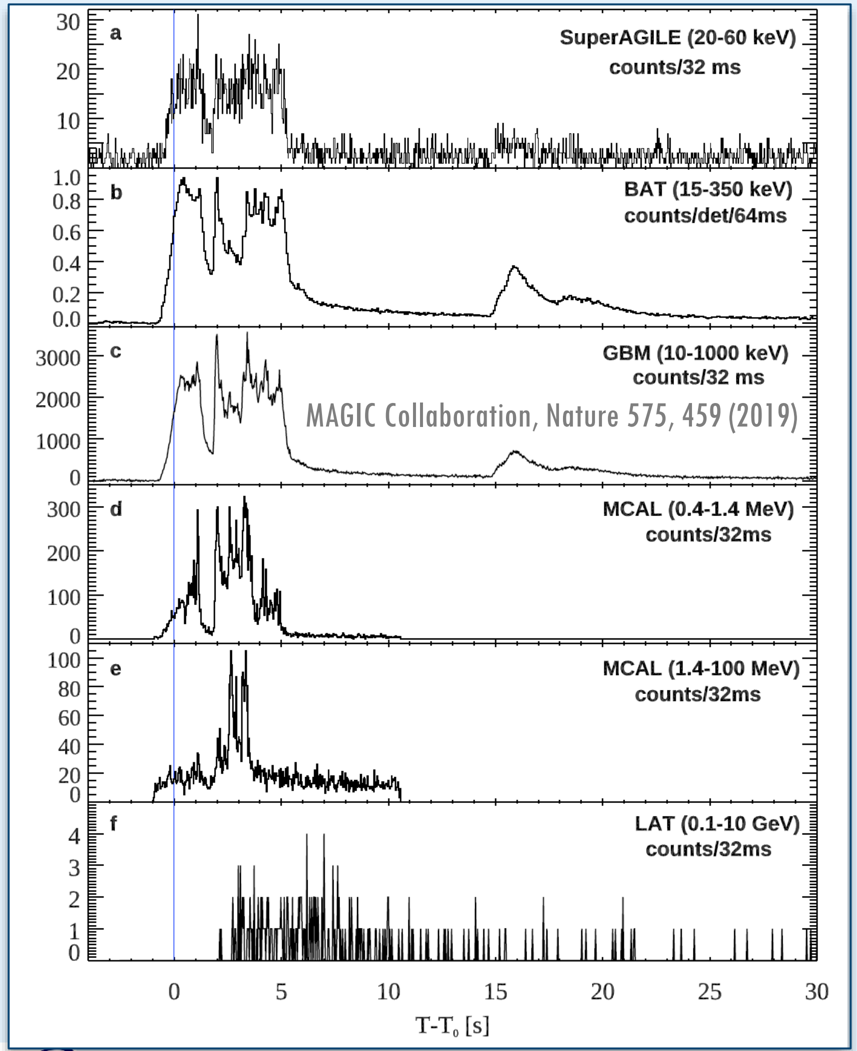
Second most fluent GRB detected by LAT

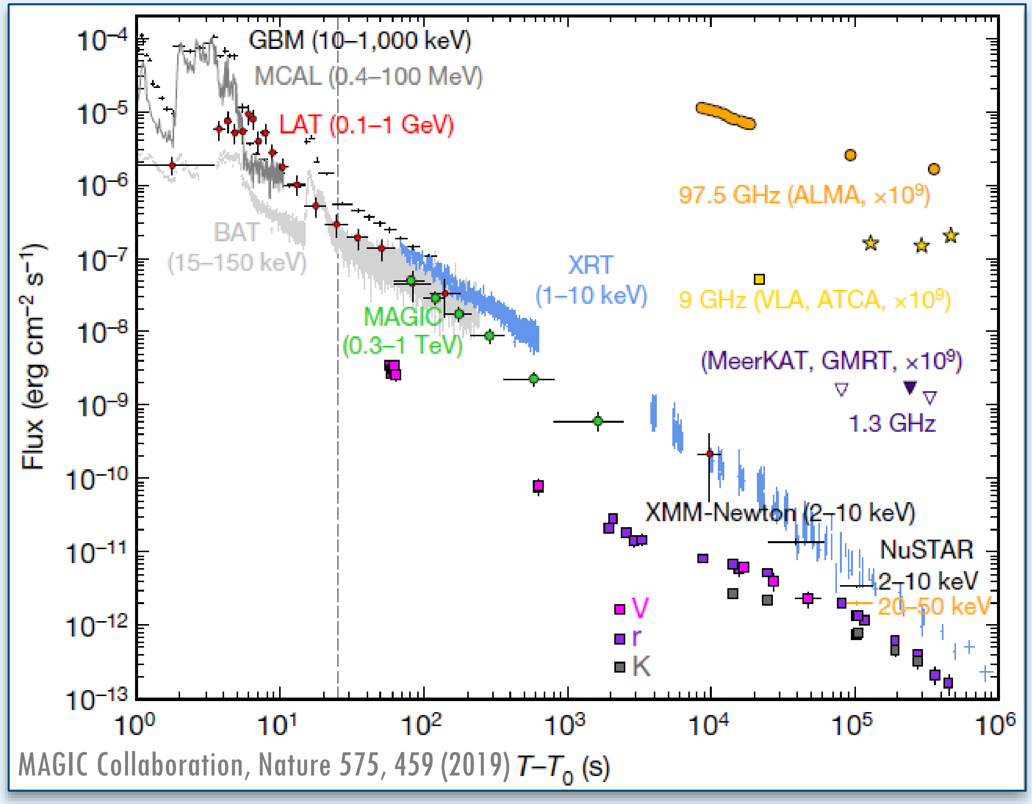




GRB 190114C seen by Fermi

Prompt-emission lightcurves from different detectors



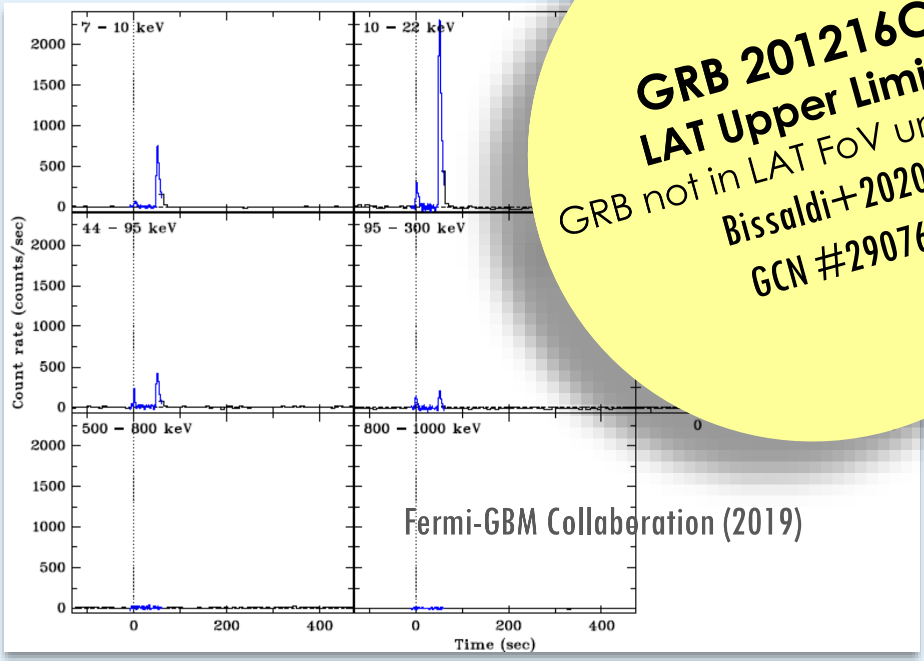


Energy flux lightcurves at different wavelengths, from radio to gamma-rays

➔ Vertical dashed line: end of the prompt-emission phase, identified as the end of the last flaring episode

GRB 190829A seen by Fermi

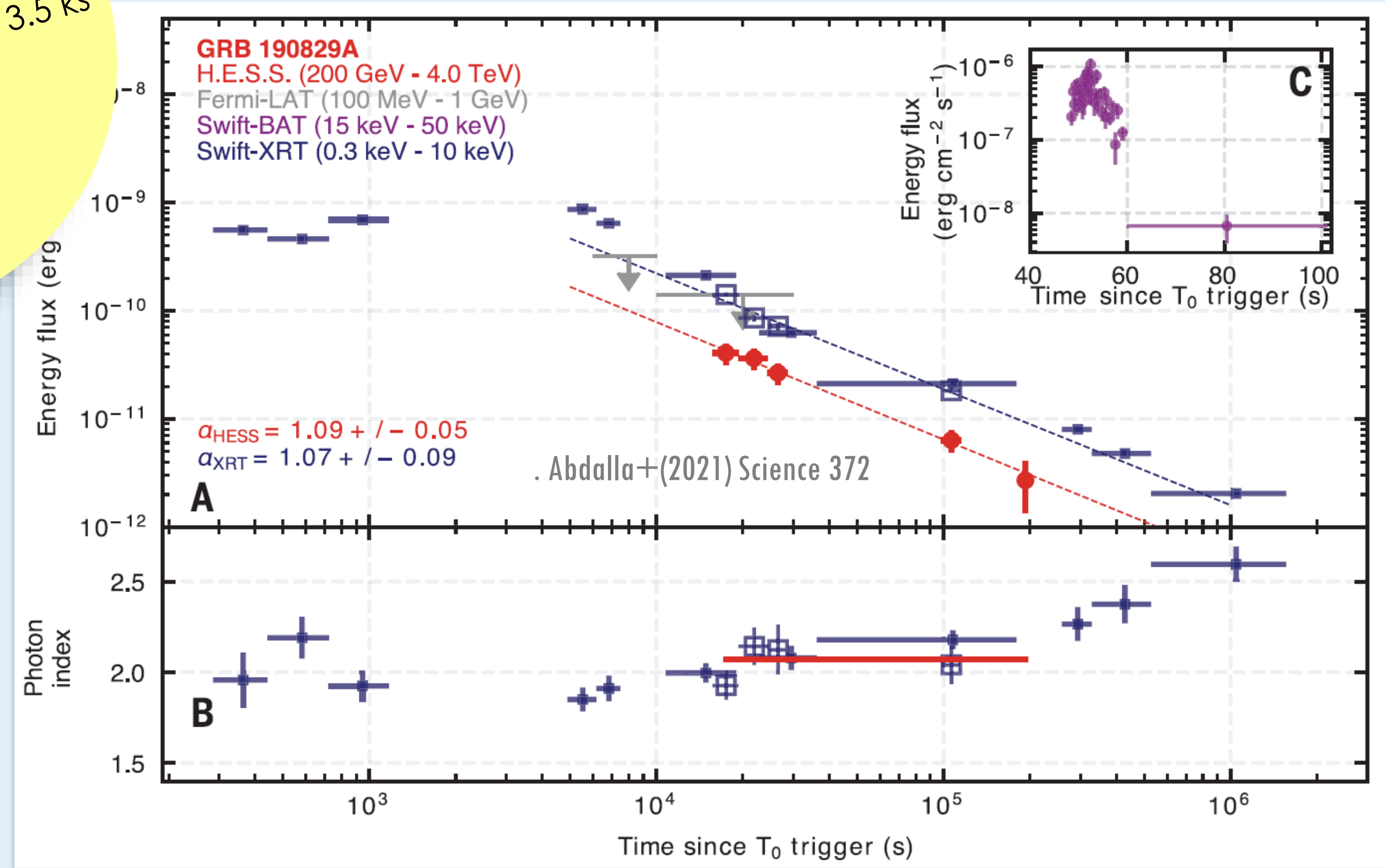
GRB 201216C
LAT Upper Limits
GRB not in LAT FoV until 3.5 ks
Bissaldi+2020
GCN #29076



GBM T_{90} (50-300 keV) = **59.4 ± 0.6 s**
[Lesage+2019, GCN #25575]

No LAT detection (only Upper limits)
θ=33°, in the LAT FoV until 1.1 ks
[Piron+2019, GCN #25574]

Energy flux lightcurves at different wavelengths



Summary and future prospects

- Since 13 years, the **Fermi mission** constantly provides a great dataset for GRB science
  - **GBM (>3100)** and **LAT (>210)** are the **most prolific GRB instruments** in their respective energy band
  - Together with Swift-BAT, **GBM and LAT** GRB detections are fundamental in order to trigger **multiwavelength** and **multimessenger** follow-up campaigns
    - Tricky to **simultaneosly explain all LAT results**! Difficulty in explaining both delayed onset and long duration at the same time

- The **first VHE GRB detections** with **H.E.S.S.** and **MAGIC** during the early to late afterglow phases provided additional insight into the **nature of GRBs**
  - Looking forward to the **Cherenkov Telescope Array (CTA),** which will have ~10 times better sensitivity than current instruments

    ➔ **Boost VHE** GRB detection rate in both **prompt** and **afterglow** emission phases


Thank you!