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Telescope

# High-energy emission from GRBs: 10 years with Fermi-LAT

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# The Fermi Mission

Launched on June 11, 2008

#### Large Area Telescope (LAT)

- Pair conversion telescope [20 MeV >300 GeV]
- Observes 20% of the sky at any instant
- Entire sky every 3 hrs absolute timing to ~300 ns

International and interagency collaboration between NASA and DOE in the US and agencies in France, Germany, Italy, Japan and Sweden

### Gamma-ray Burst Monitor (GBM)

- 12 Nals, 2 BGOs, [8 keV 40 MeV]
- Observes entire unocculted sky
- Absolute timing ~2 µs



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#### Ajello+2019 (2008 – 2018, 186 GRBs)

- Search for emission from **3044 GRBs** triggered by other instruments
  - 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 LLE pipeline LTF Manual New detection algorithm: 50% improvement checks LLE duration, LLE significance analysis - Using Pass8 data: 10% improvement Finding Map TS and Pass 7 position 100 Pass 8 refinement List of Input Pass 8, new algorithm GRB Catalog analysis pipeline Omodei+2016 seeds for List of 80 LAT duration, Final TS the GCN/IPN Time temporal and catalog resolved extended analysis Position 60 Likelihood emission Photon by 40 photon probability Significance, Time spectral integrated 20 properties Likelihood Aiello+2019 2015 2009 2010 2011 2012 2013 2014



### **GRB** detections



#### **<u>186 LAT detections</u>** – 169 long (90%), 17 short (10%)

- 91 LLE GRBs (85 long, 6 short)
  - LLE only GRBs (15 long, 2 short)



 $\rightarrow$  176 joint detection with GBM

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- 10 non-GBM detections (2 Swift-BAT, 8 IPN)
- 34 GRBs have redshift measurements •



10-1 10<sup>0</sup> 101 10<sup>2</sup>

T-To [s]

10<sup>3</sup>

104

10<sup>2</sup>

10-1

10-2

- 10<sup>-3</sup>

5 10-4

10-6

10-





#### • GRB HE duration definitions

- T<sub>90</sub>: Canonical GRB duration measured by GBM [50 300 kev]
  - $T_{90} = T_{95} T_{05}$

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- T<sub>L100</sub> : new GRB duration measured by LAT [100 MeV 100 GeV]
  - $T_{L100} = T_{L1} T_{L0}$  (Arrival time of last and first photon, respectively)







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# Temporal properties (2)



• Highlights:

Gamma-ray Space Telescope

- Longest bursts
   1. GRB 130427A
   T<sub>L100</sub> = 34 ks
   2. GRB 160623A
   T<sub>L100</sub> = 35 ks
- LLE bursts
  - [30 MeV 1 GeV]

- Definition of duration similar to the GBM one
- Behavior similar to low-energy (LE) emission



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• Comparison of LE properties of LAT-detected GRBs with 10 yr GBM bursts (~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!
- We now detect HE emission also from weak GBM bursts!



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## Energetics (2)



- During the GRB prompt emission window ("GBM")
  - LE [10–1000 keV] fluence >10 x larger than HE [100 Mev–100 GeV] fluence
- → Majority of burst energy emitted at lower energies!



- Prompt vs late times ("EXT" time window)
  - HE fluence comparable
    - Equal contribution to energy budget









#### Photon index $\Gamma$ vs duration in the prompt and late time windows



- No sign of correlation
  - Slightly harder at late times
- Same component at work in the HE range the whole time
  - Is it the same emission? Possible contamination from the component that dominates in the LE energy range

### **Temporal decay**



### • Time-resolved analysis

- 86 long and 2 short GRBs



- Simple and broken PL fits

$$F(t) = F_0 \left(\frac{t}{T_0}\right)^{-\alpha} F(t) \propto t^{-p} \begin{cases} p = \alpha_1 & \text{for } t < T_b \\ p = \alpha_2 & \text{for } t \ge T_b, \end{cases}$$

• 12 bursts best fit with BPL

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→ Compatible with 1FLGC, but better constrained!







- 34 GRBs (33 long and 1 short) have an estimated redshift
  - Study of properties in the **source frame**

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Comparing with Swift and GBM samples we detect brighter bursts!



## Highest-energy photons from GRBs



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Samma-ray

- Sharp drop @5 GeV (obs .frame) Record holder: GRB 130427A 77 GeV @19s long short long  $\theta > 75^{\circ}$ short  $\theta > 75^{\circ}$ **10**<sup>5</sup> (MeV) Energy ( Photon × ⊵ 10³ Ajello+2019 10<sup>2</sup> 10<sup>3</sup>  $10^{-2}$ 10<sup>-1</sup> 10<sup>0</sup> 10<sup>1</sup> 10<sup>2</sup> 104 Arrival Time/GBM T90
- HE photons often arrive **after** the LE emission is over
  - BUT: Highest energies can be produced either
     very quickly or very late → challenge for the models!





#### Tricky to simultaneosly explain all LAT results!

- Detection of HE emission implies high Lorentz factors
- Difficult to explain both delayed onset and long duration at the same time
  - SSC: difficulties with very large delays
    - Comptonization kicks off very quickly
  - External Forward shock: difficulties with HE seen at very late times
  - Pair loading model: difficulties with very large delays and large differences in duration between LE and HE emission
- Closure relations: Testing wind and ISM environments





### Conclusion

- More things we did not mention now, but you can find in the paper:
  - A lot (!!!) of tables and figures
  - Discussion of prospects for GRB detections at VHE (with CTA)
  - LAT short GRBs and implications for gravitational wave counterparts observations
- Paper published on June 13, 2019: Ajello+2019, ApJ 878, 52,
- <u>doi: 10.3847/1538-4357/ab1d4e</u>
- LAT FITS files made publicly available:
  - <u>HEASARC</u>
  - <u>Glast.Stanford.edu</u>
- More follow-up papers to come:
  - Stay tuned!!!

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Figures and data files associated with the Fermi LAT paper "A Decade of Gamma-Ray Bursts Observed by Fermi-LAT: The Second GRB Catalog"





# Backup slides



www.nasa.gov/fermi



- For each correction, the spread is reduced and all points seem to line up
  - In the rightmost plot: division by E<sub>iso</sub> (Proxy for total energy budget)
    - Fit result shown together with theoretical expectation





- Difference in HE and LE emission start time vs theta angle
  - Most GRBs with a large  $T_{L0} T_{05}$  difference are outside the FoV at trigger time



- ~30% of out-of-FoV GRBs had a positive ARR
  - Unfortunately, ARRs have been disabled since March 2018







LAT Fluence calculated over the «GBM» time window  $(T_{90})$  vs duration

- No clear correlation
- Hint of distinction between short and long bursts
- Wrt 1FLGC: Much wider range: no more clear outliers!





