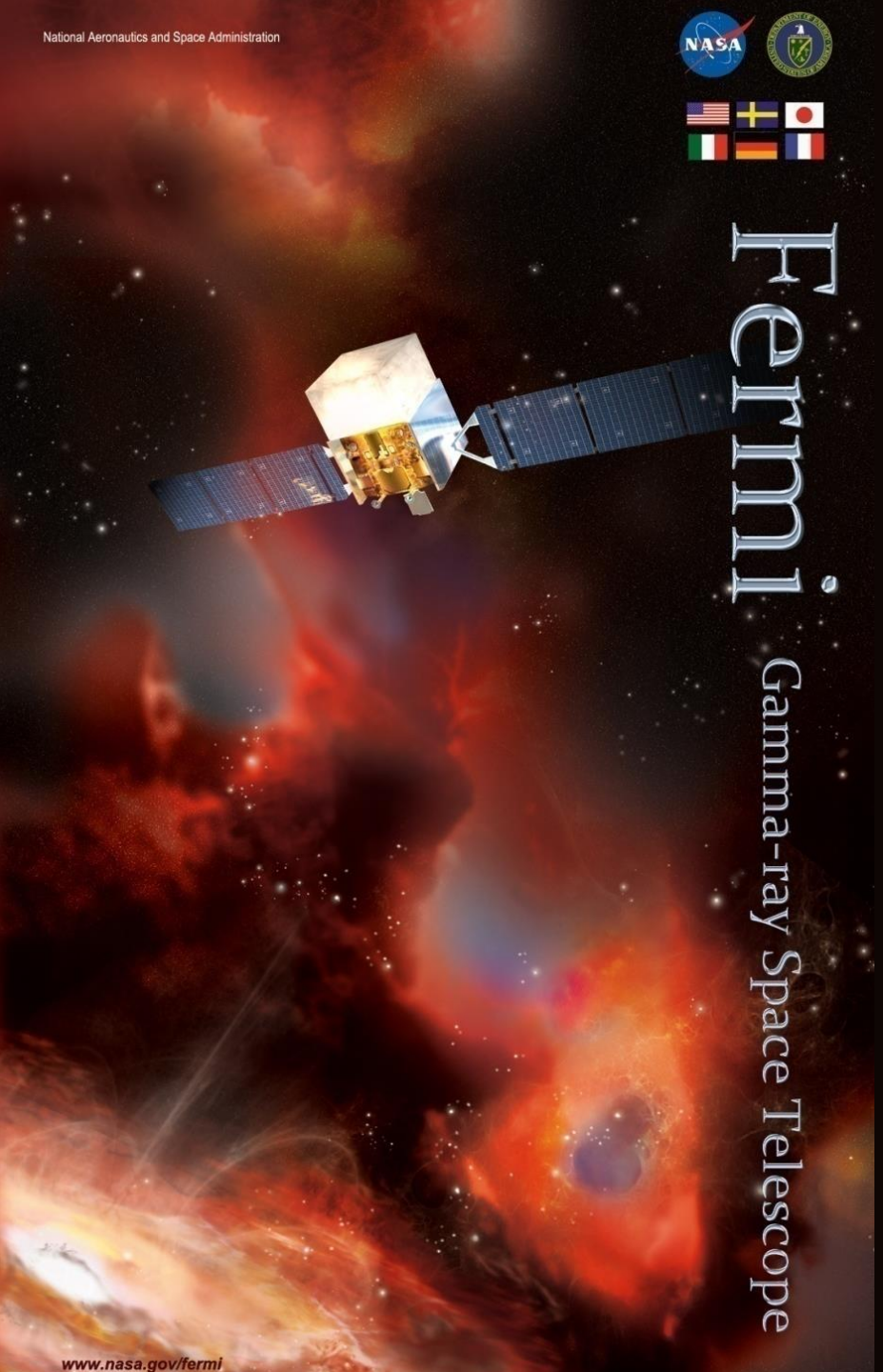


High-energy emission from GRBs: 10 years with Fermi-LAT

Elisabetta Bissaldi*, Magnus Axelsson, Nicola Omodei & Giacomo Vianello
on behalf of the **Fermi-LAT Collaboration**

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

Fermi Gamma-ray Space Telescope

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

Gamma-ray Burst Monitor (GBM)

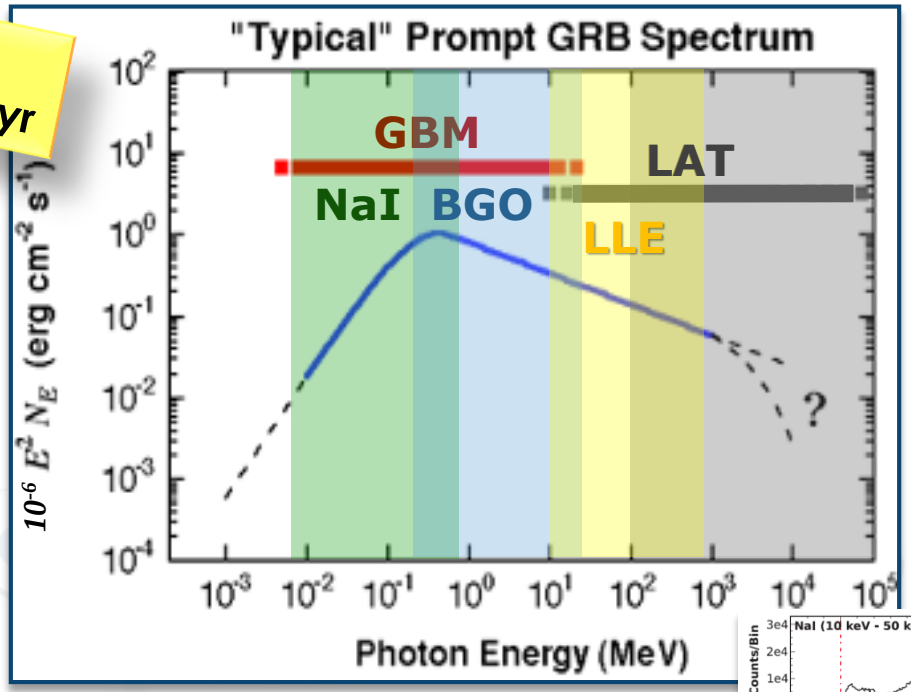
- **12 NaIs, 2 BGOs, [**8 keV – 40 MeV]
- Observes entire unocculted sky
- Absolute timing ~2 μs

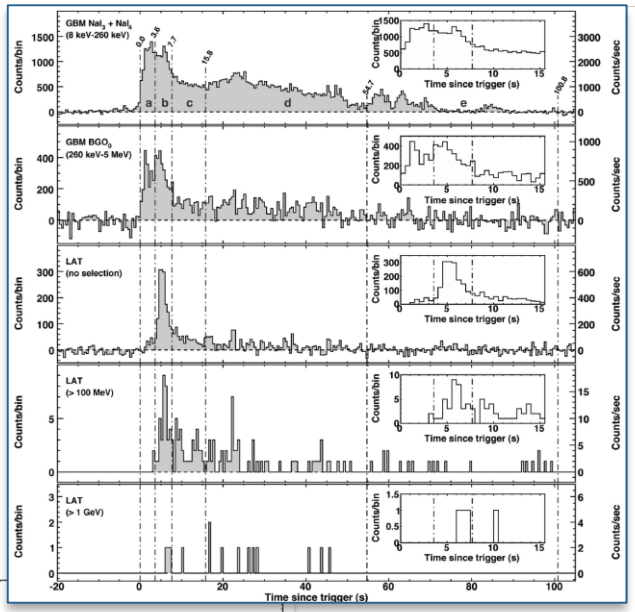
International and interagency collaboration between NASA and DOE in the US and agencies in France, Germany, Italy, Japan and Sweden

Gamma-ray Burst Observations with Fermi

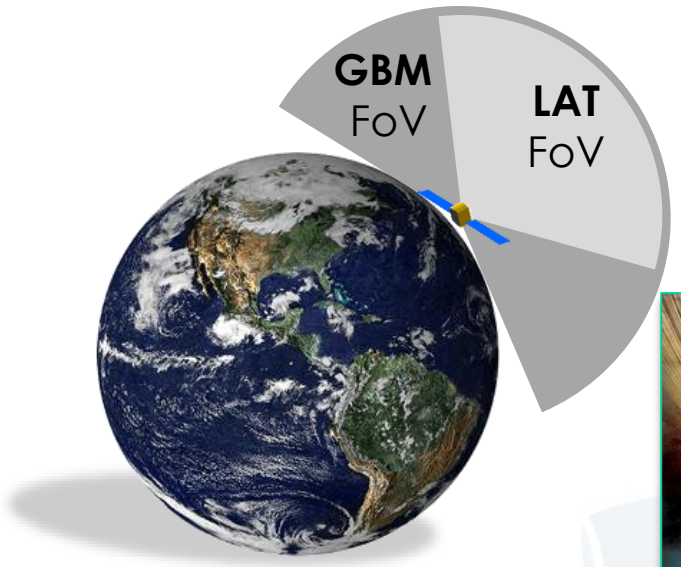
- **GBM**
  - NaI: 8 – 900 keV
  - BGO: 250 keV – 40 MeV
- **LAT**
  - LLE: 10 MeV – 1 GeV
  - Std: 100 MeV – 300 GeV

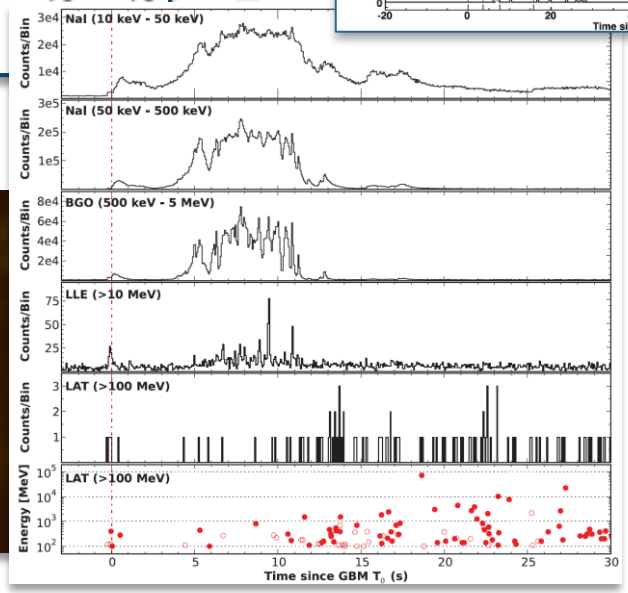
GBM rate: ~240 GRBs/yr





Abdo+09





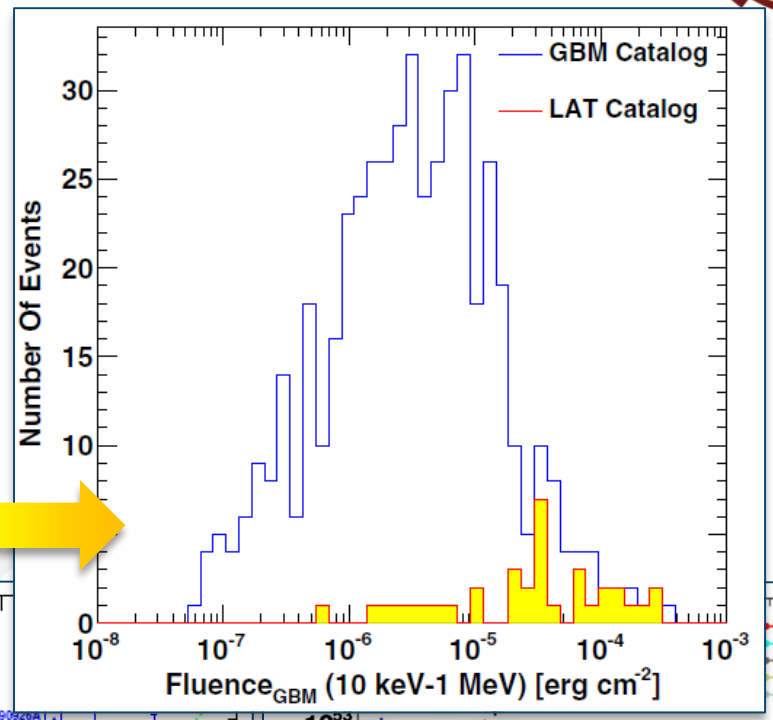
Ackermann+13

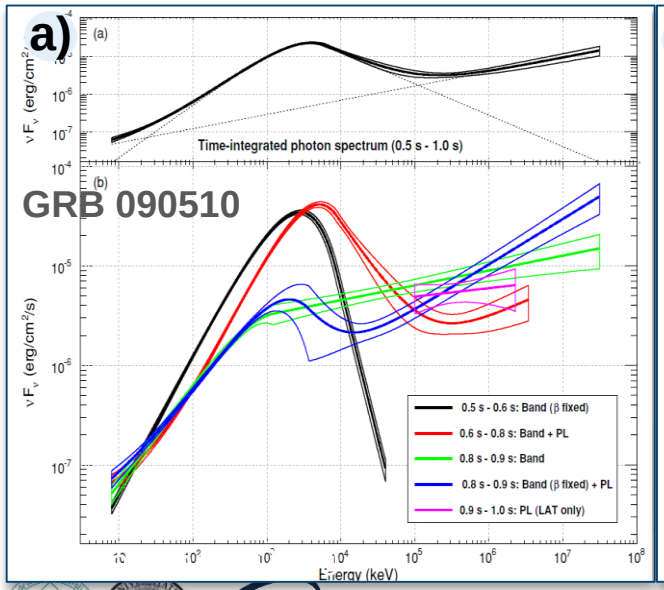
The first LAT GRB Catalog - 1FLGC

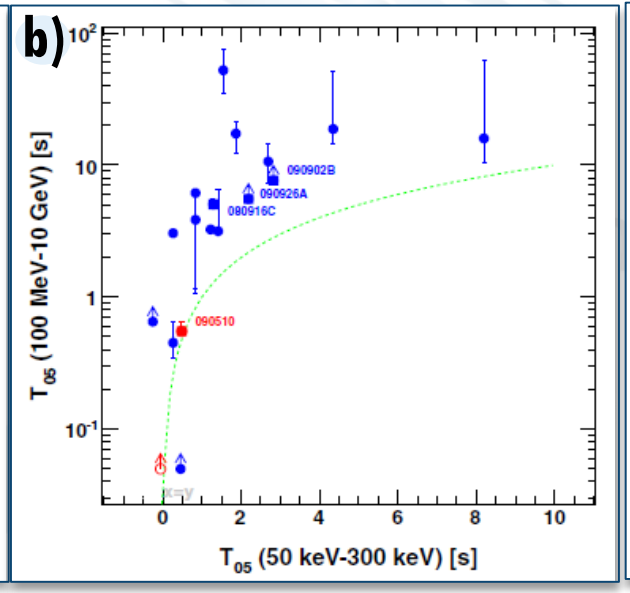
Ackermann+2013 (2008 – 2011, 35 GRBs, 7 LLE-only)

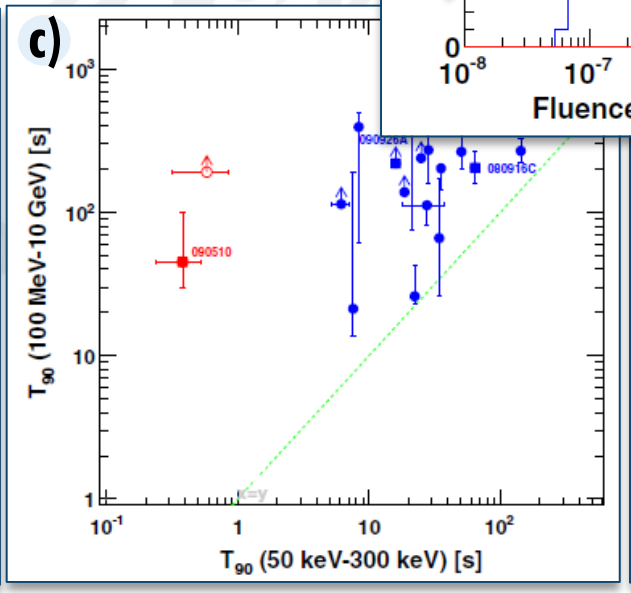
- **High-energy (HE) features**:
  - a) **Extra PL component** required to fit spectra
  - b) Emission >100 MeV systematically **delayed**
  - c) Emission >100 MeV systematically **longer**
  - d) Emission >100 MeV decays smoothly as a **PL (index -1)**

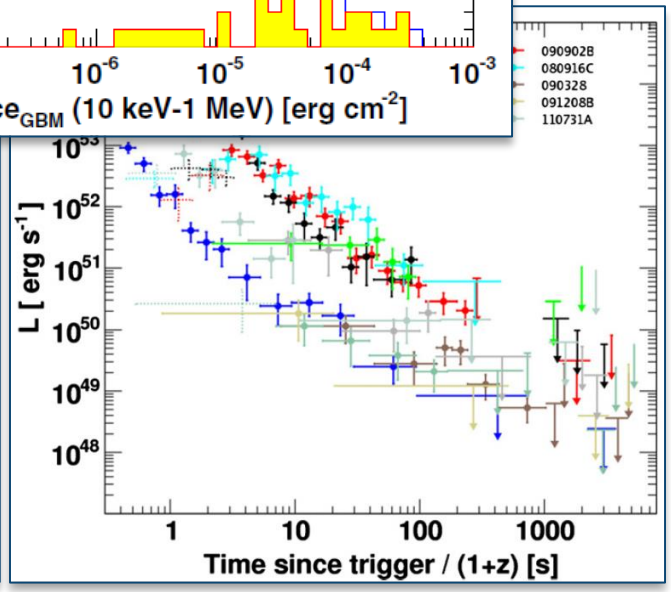
➔ **LAT GRBs considered among the brightest GBM ones!**







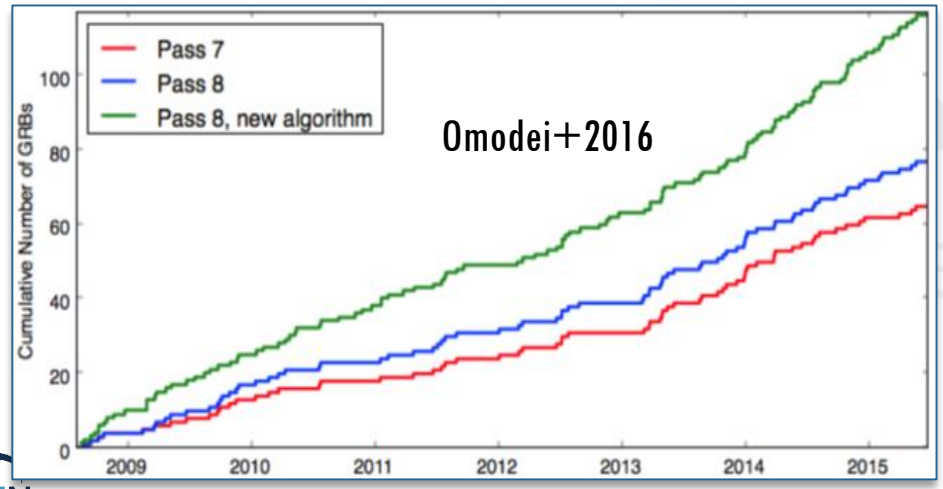


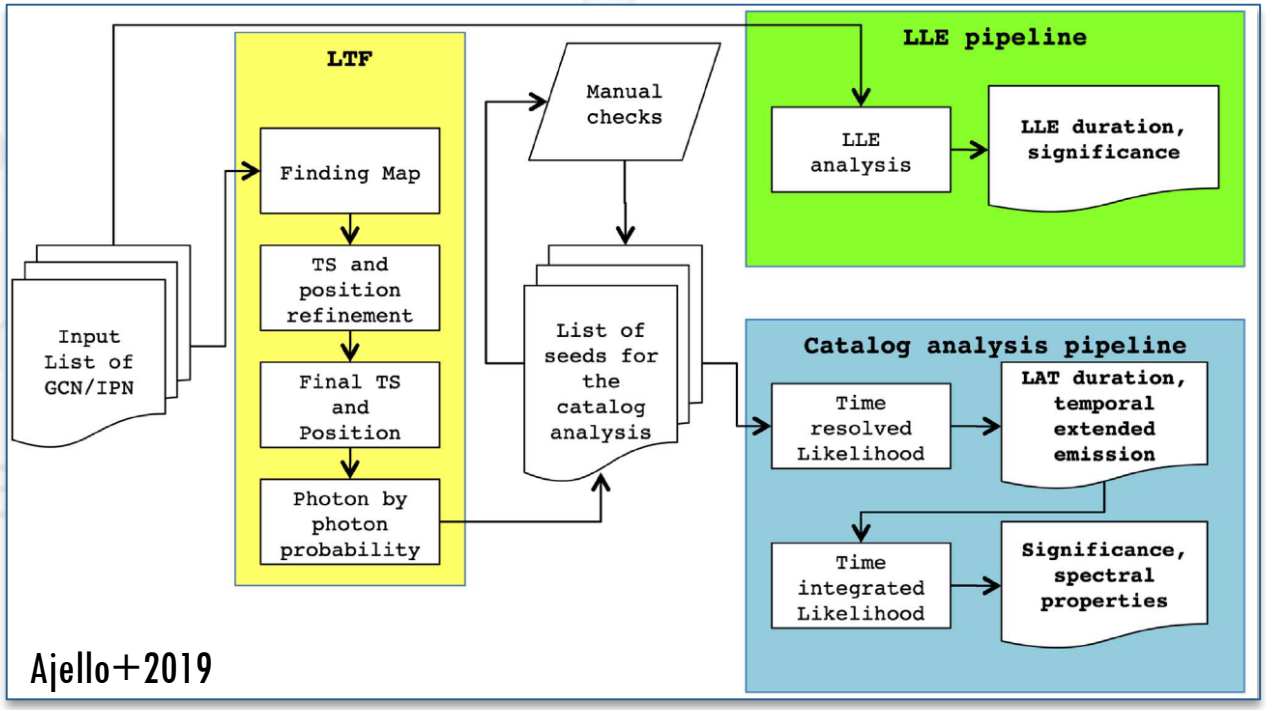


The second LAT GRB Catalog - 2FLGC

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
  - New detection algorithm: 50% improvement
  - Using Pass8 data: 10% improvement

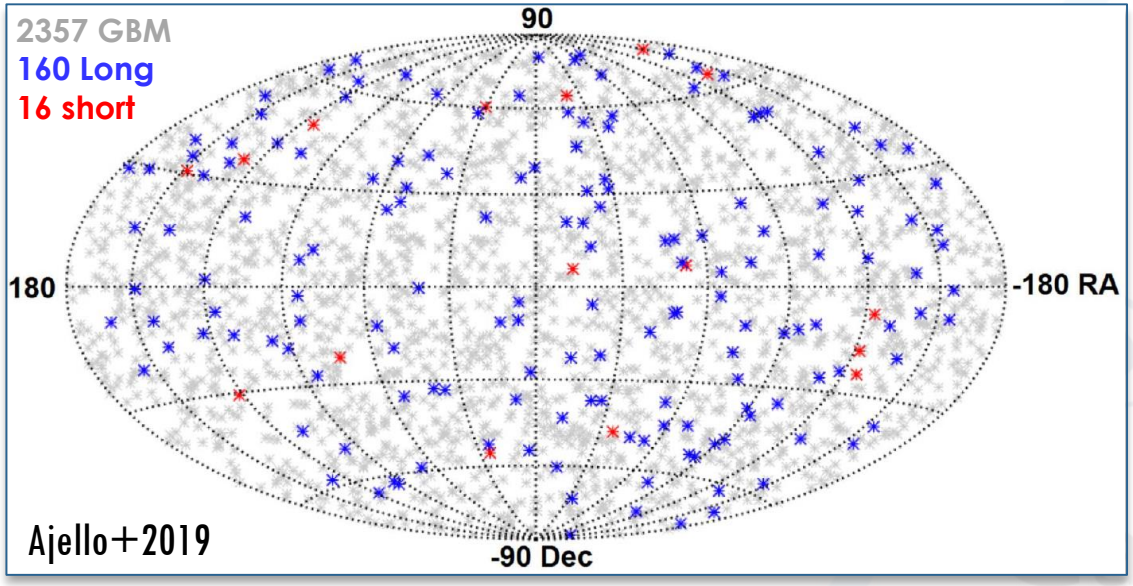


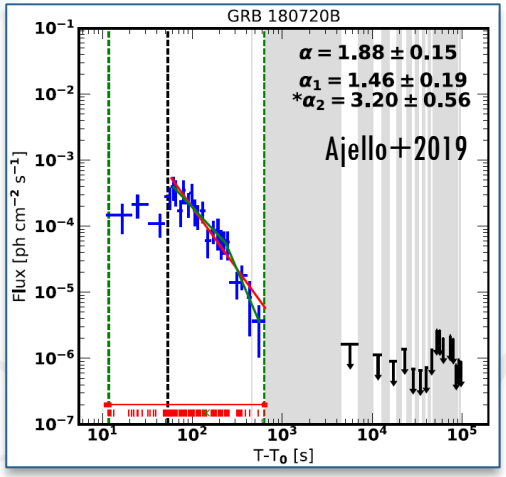


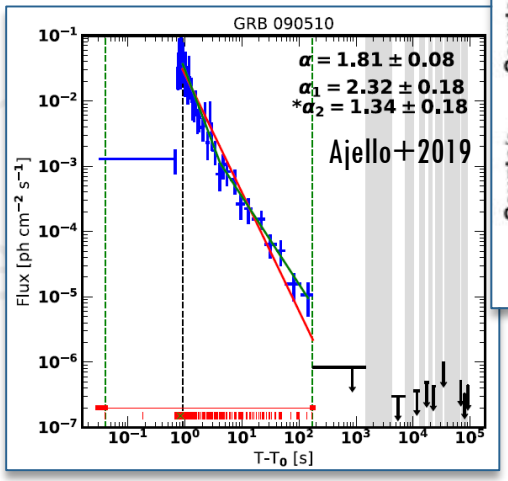
GRB detections

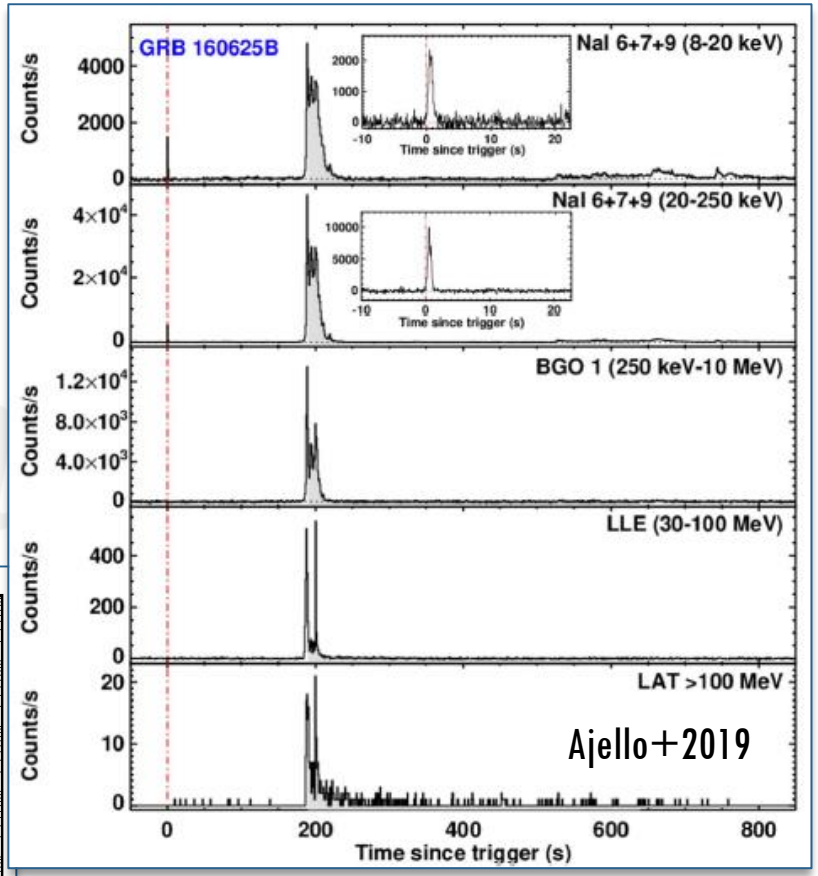
186 LAT detections – 169 **long (90%)**, 17 **short (10%)**

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







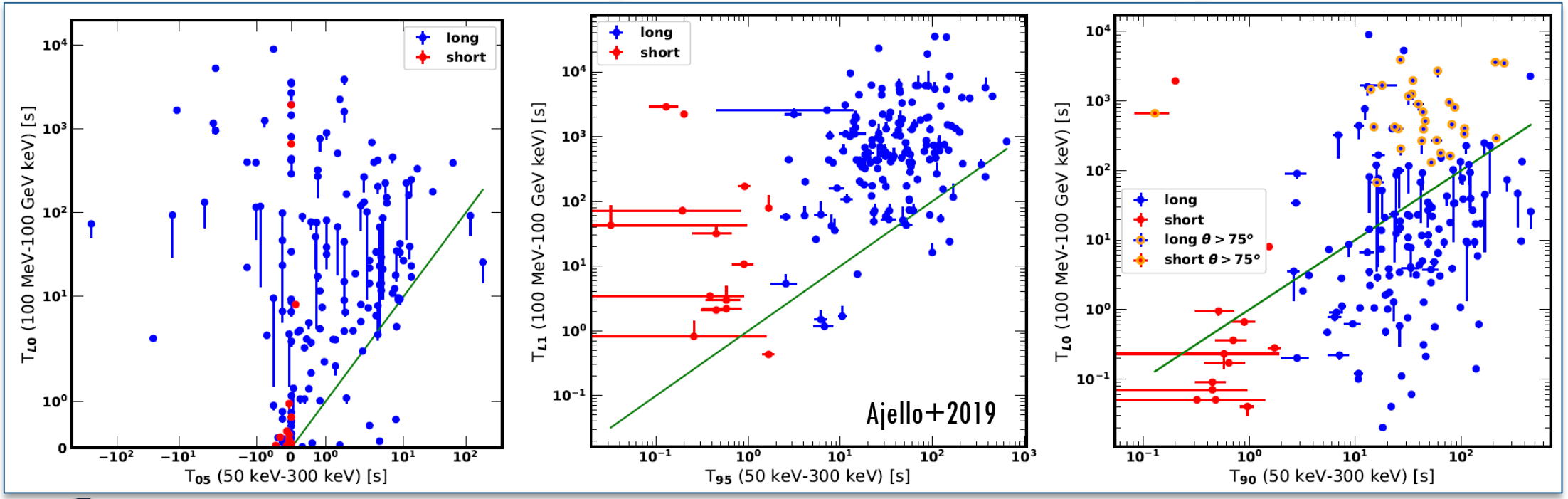


→ **176 joint detection with GBM**

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

Temporal properties (1)

- **GRB HE duration definitions**
  - T_{90} : Canonical GRB duration measured by GBM **[50 – 300 keV]**
    - $T_{90} = T_{95} - T_{05}$
  - T_{L100} : **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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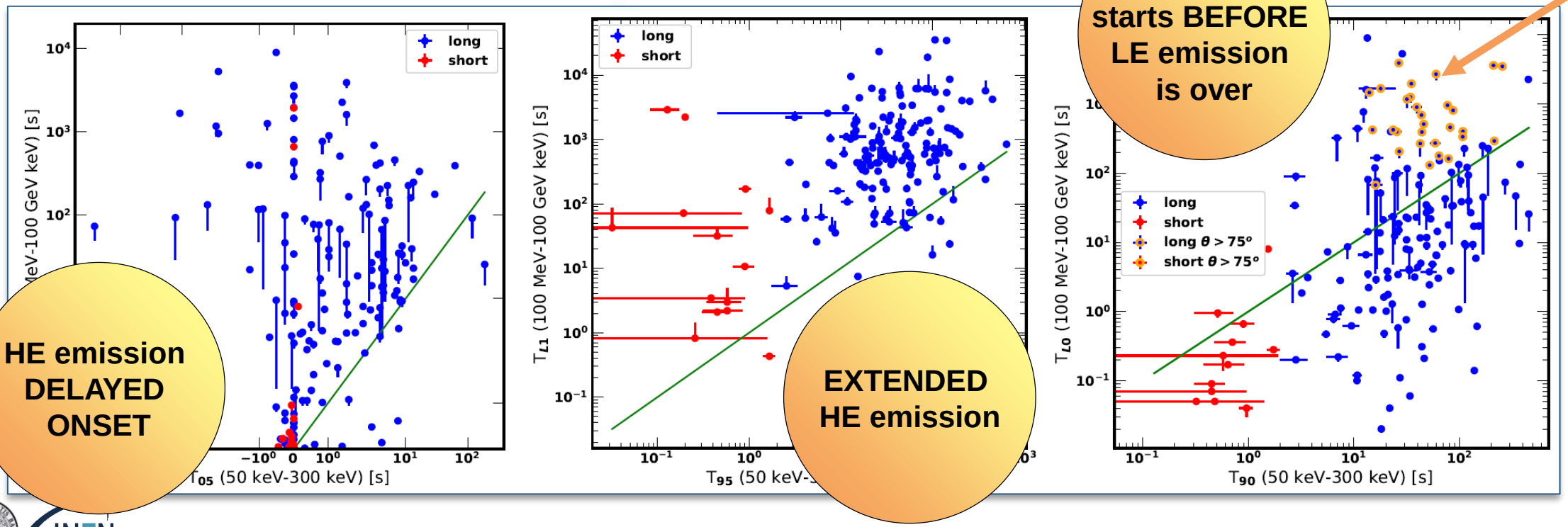
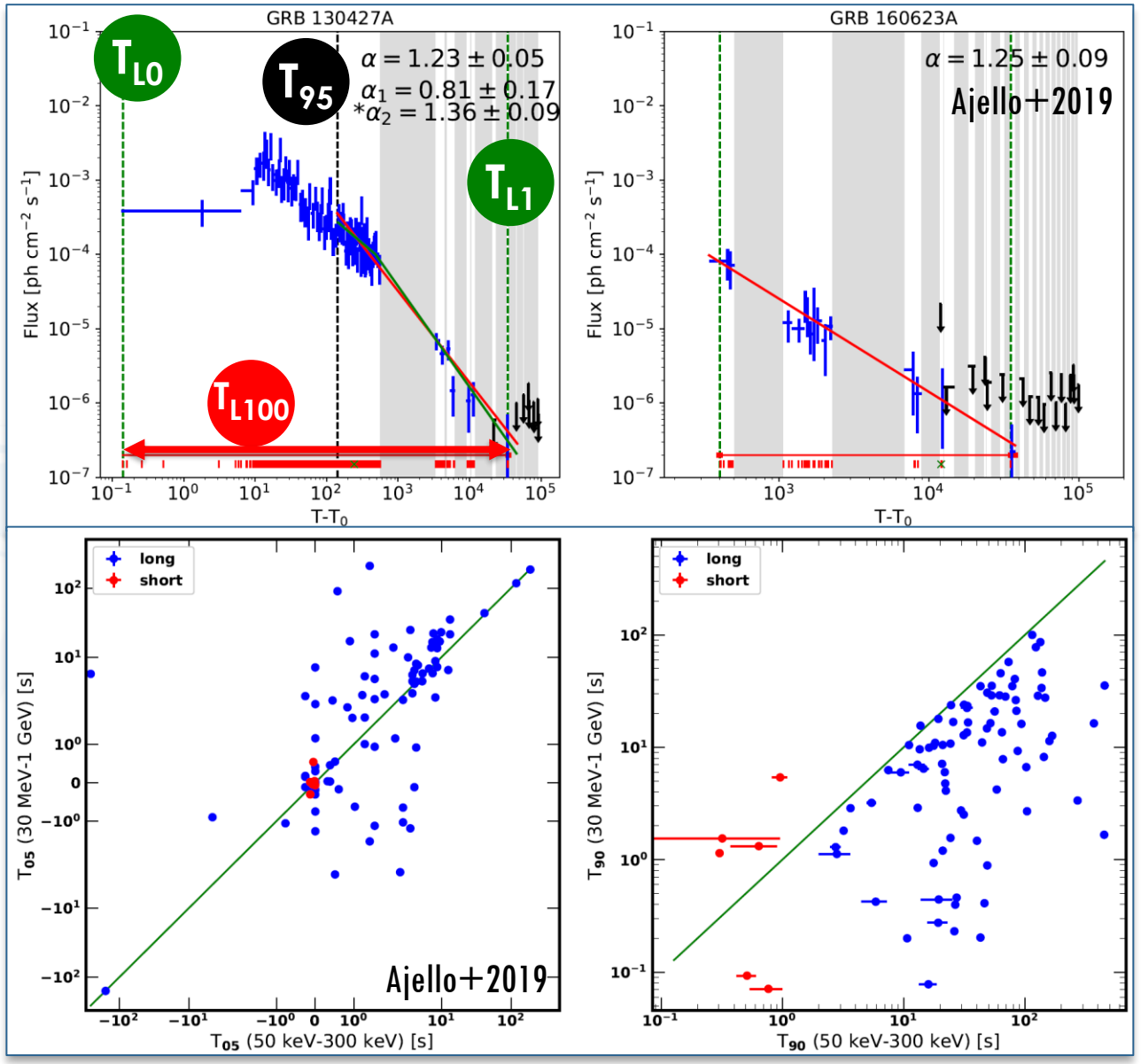


Temporal properties (2)

- **Highlights:**
  - Longest bursts
  1. GRB 130427A
     - T_{L100} = 34 ks
  2. GRB 160623A
     - T_{L100} = 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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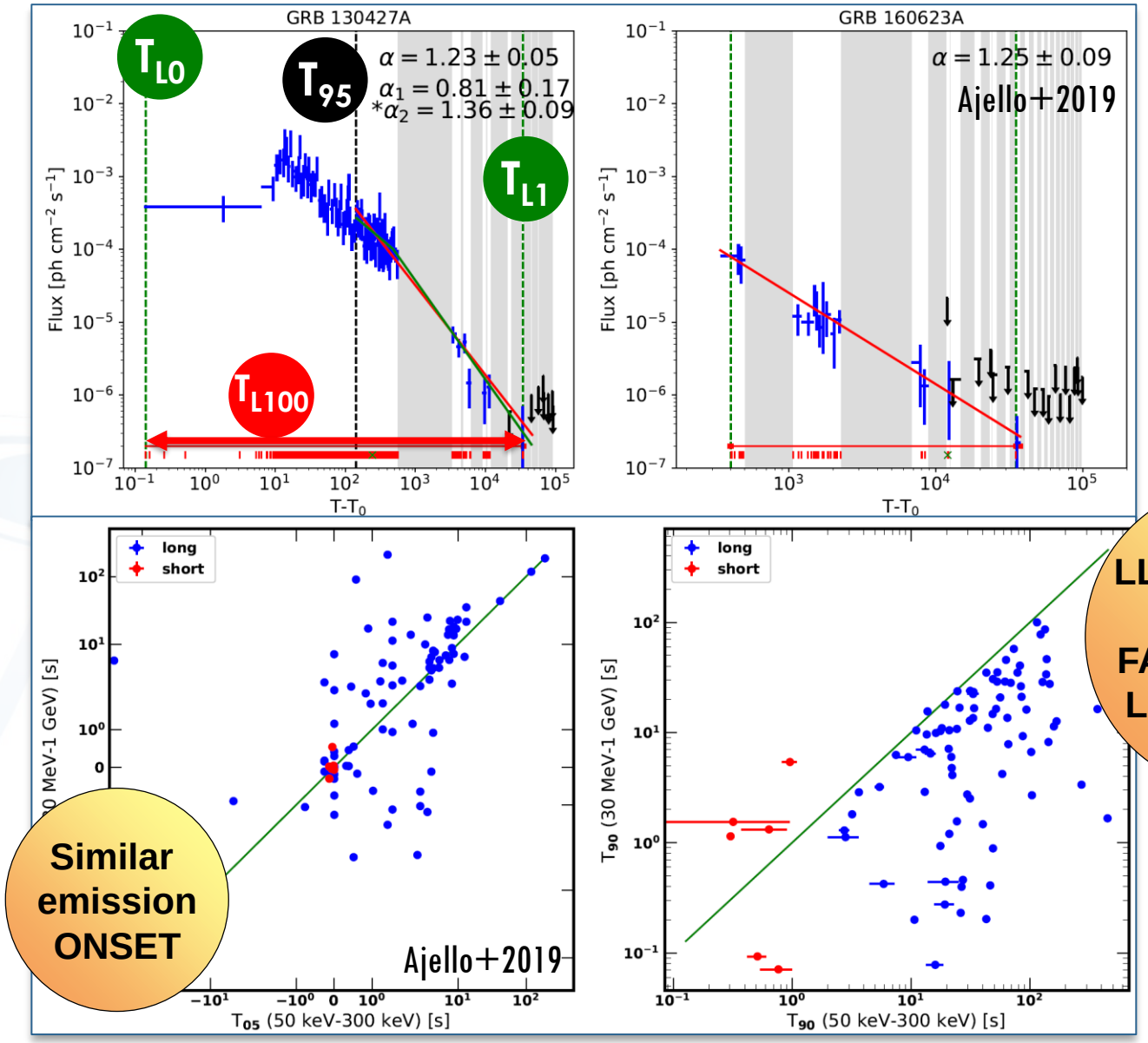
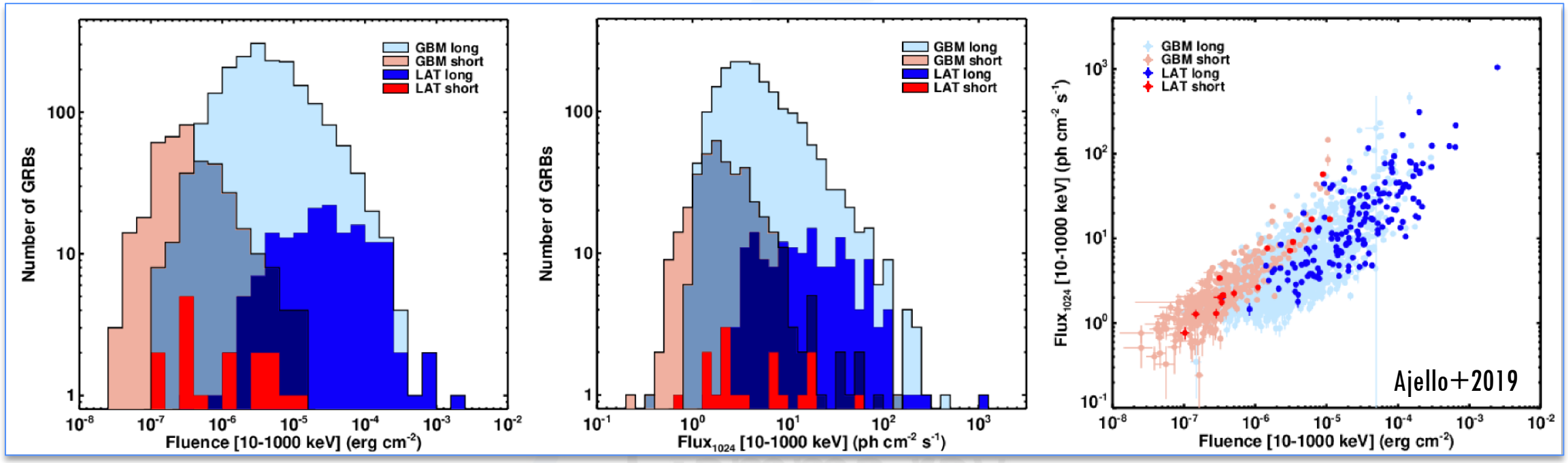


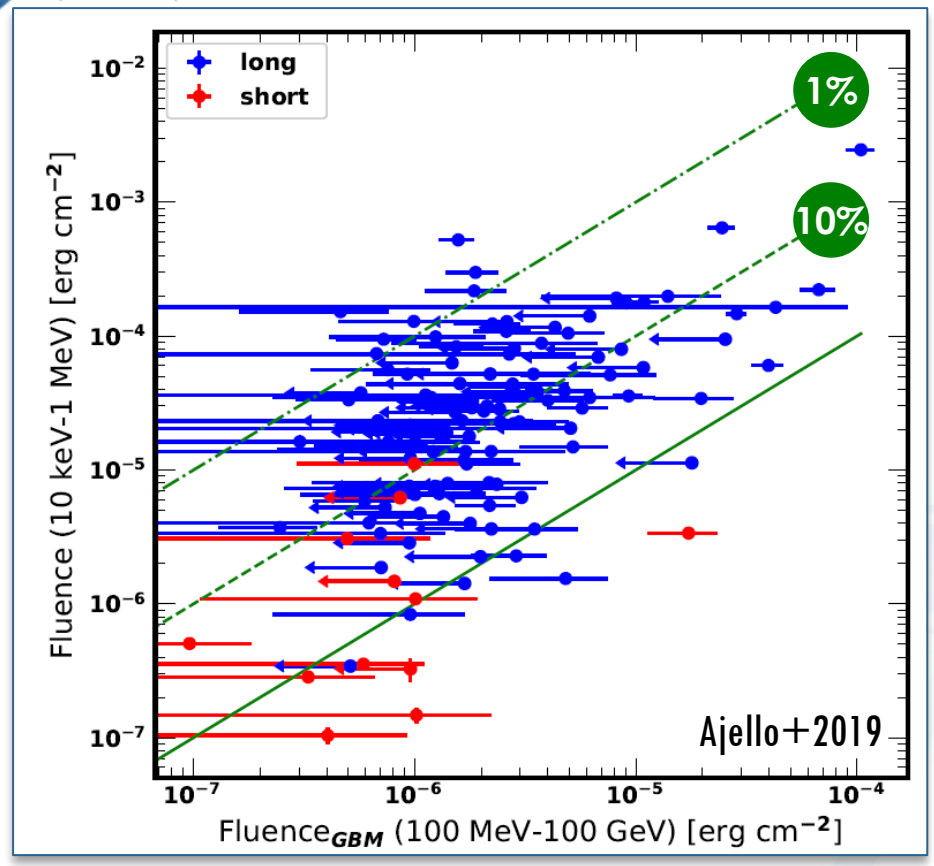
Energetics (1)

- Comparison of LE properties of LAT-detected GRBs with 10 yr GBM bursts (~2400 GRBs)



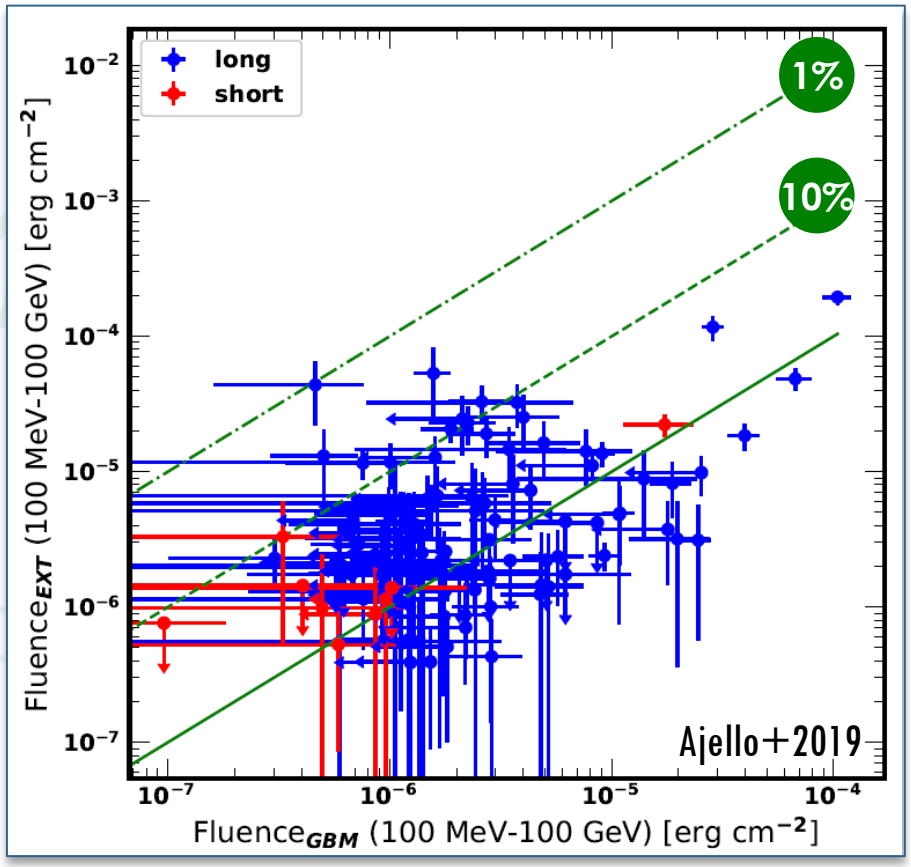
- Distribution of short and long bursts are different
- LAT tends to sample brighter bursts
  - BUT: MUCH LARGER SPREAD now than in the first LAT catalog!
  - We now detect HE emission also from weak GBM bursts!

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!**

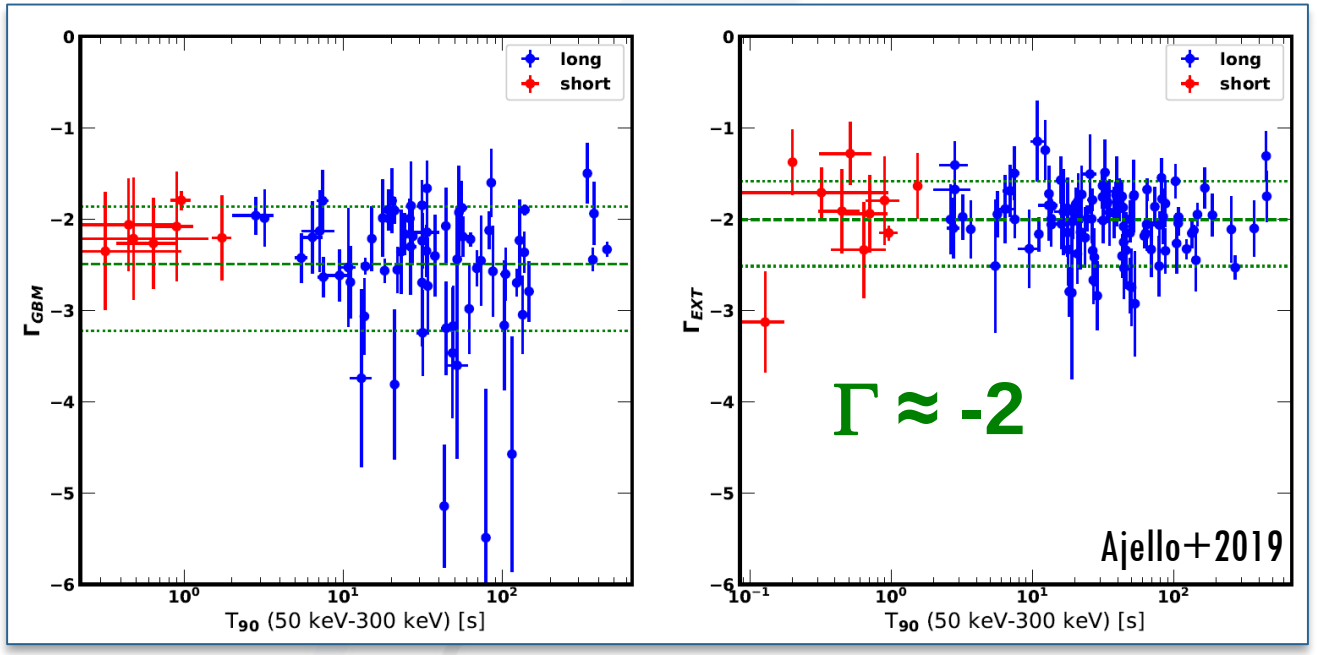


- Prompt vs late times (**"EXT"** time window)
  - HE fluence comparable

➔ **Equal contribution to energy budget**

Energetics (3)

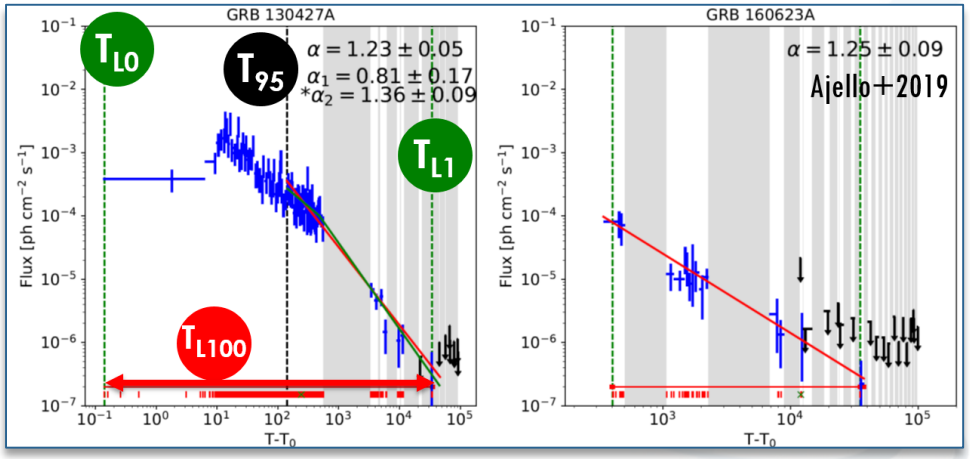
Photon index Γ vs duration in the prompt and late time windows



- **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



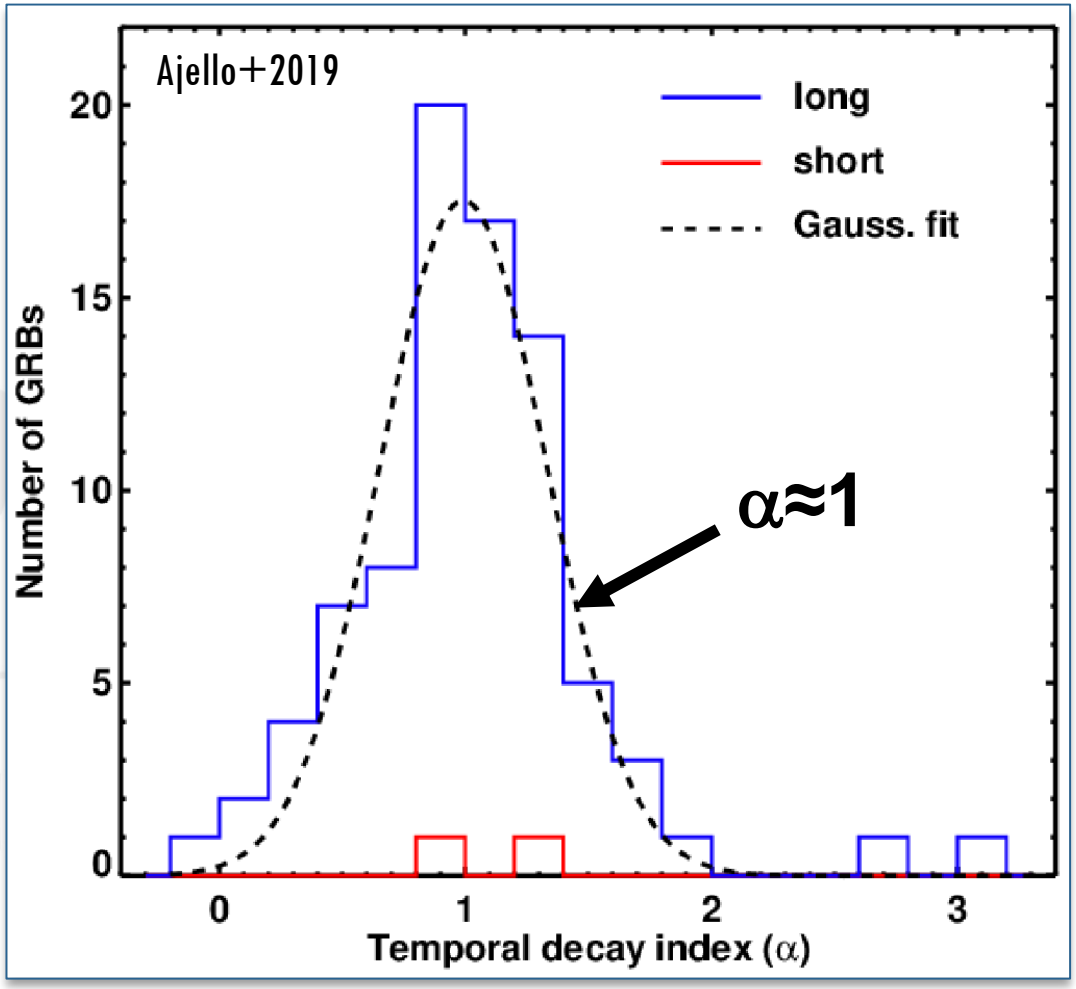
  - **Simple and broken PL fits**

$$F(t) = F_0 \left(\frac{t}{T_0}\right)^{-\alpha}$$

$$F(t) \propto t^{-p} \begin{cases} p = \alpha_1 & \text{for } t < T_b \\ p = \alpha_2 & \text{for } t \geq T_b, \end{cases}$$

  - **12 bursts best fit with BPL**

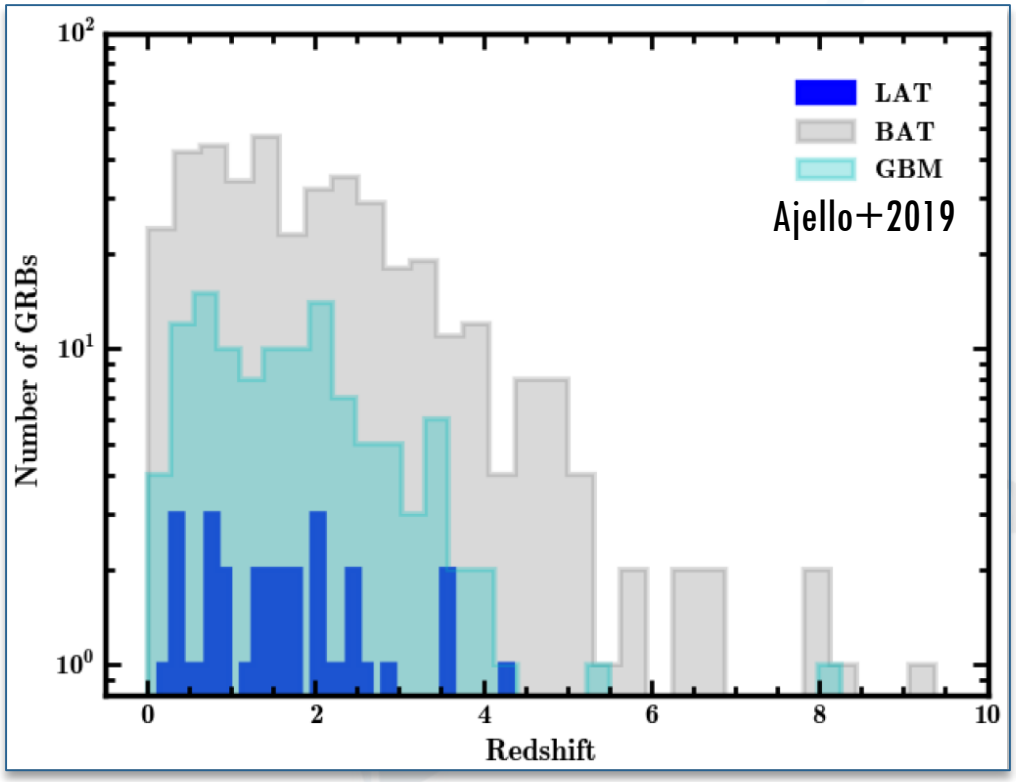
➔ **Compatible with 1FLGC, but better constrained!**

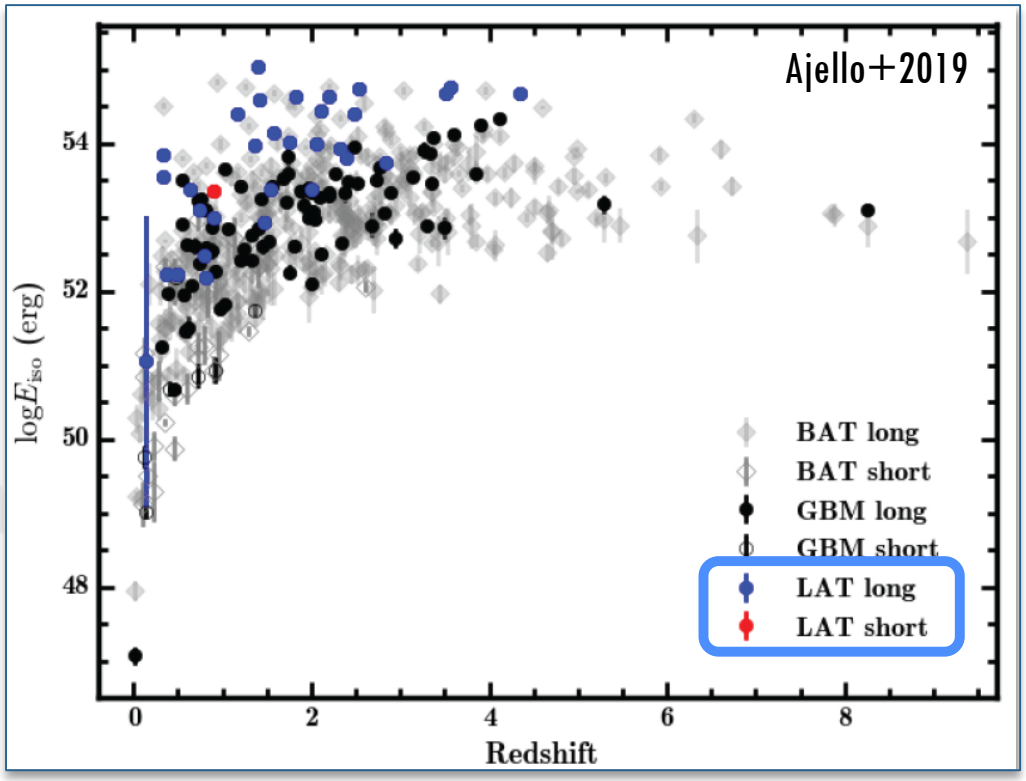


The LAT redshift sample

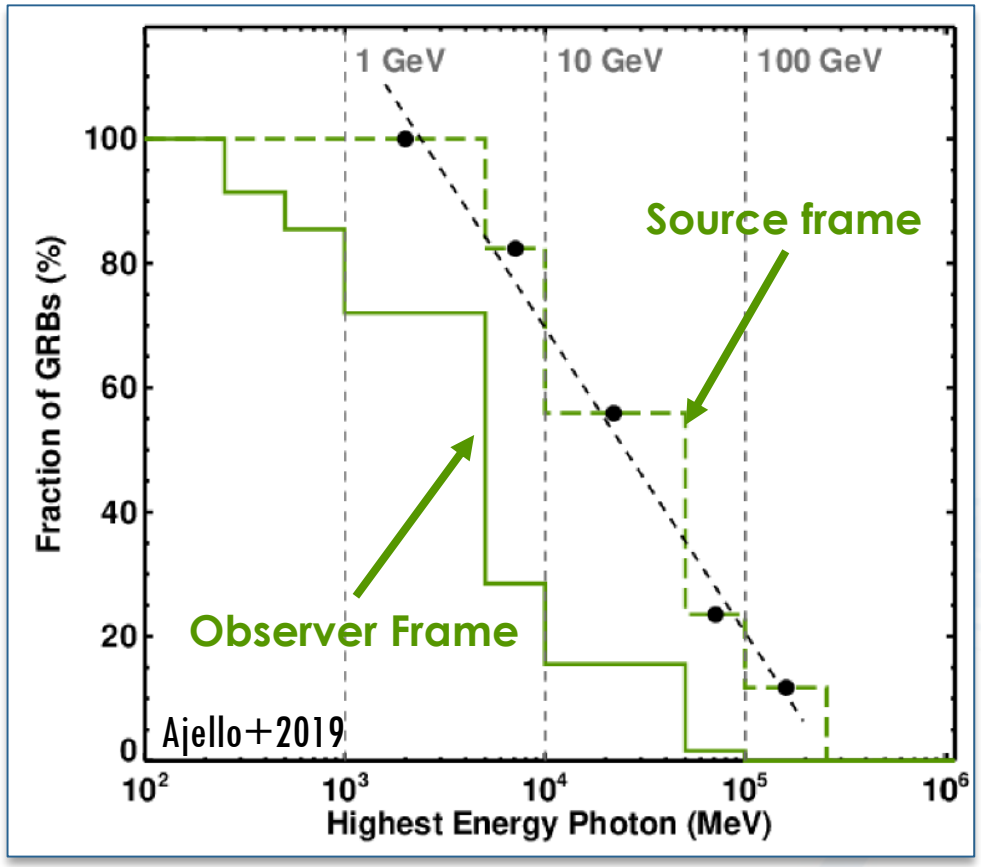
- **34 GRBs (33 long and 1 short)** have an **estimated redshift**
  - Study of properties in the **source frame**
    - ➔ Comparing with ***Swift*** **and GBM samples** we detect **brighter bursts!**

E_{iso} **[1 keV – 10 MeV]**

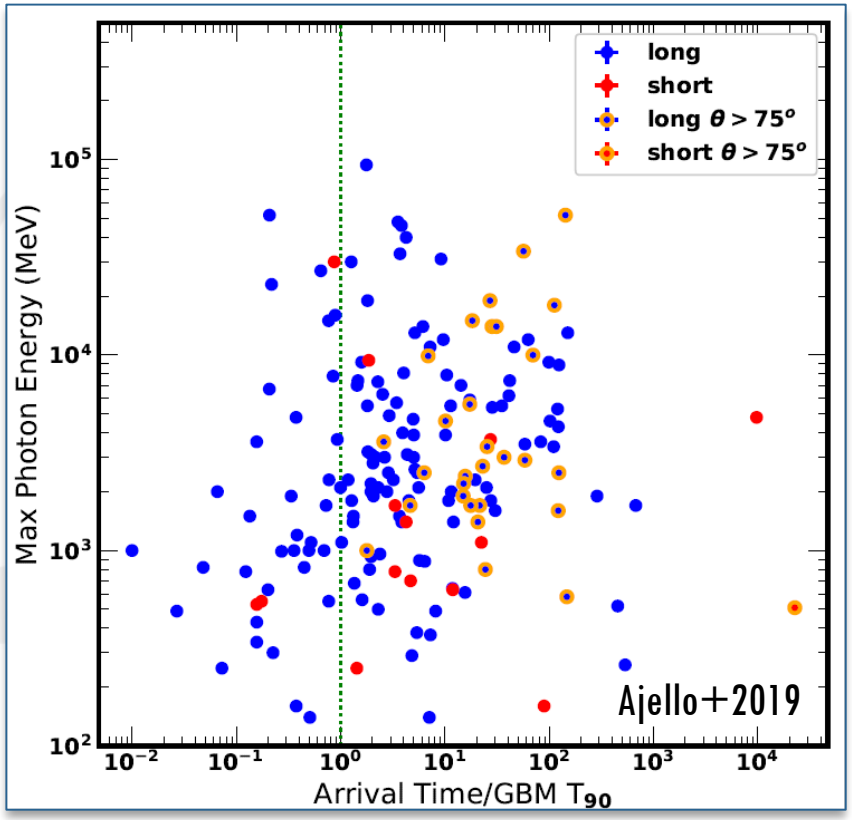




Highest-energy photons from GRBs



- **<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 LE emission is over
  - BUT: Highest energies can be produced either **very quickly** or **very late** ➔ challenge for the models!

Interpretation

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

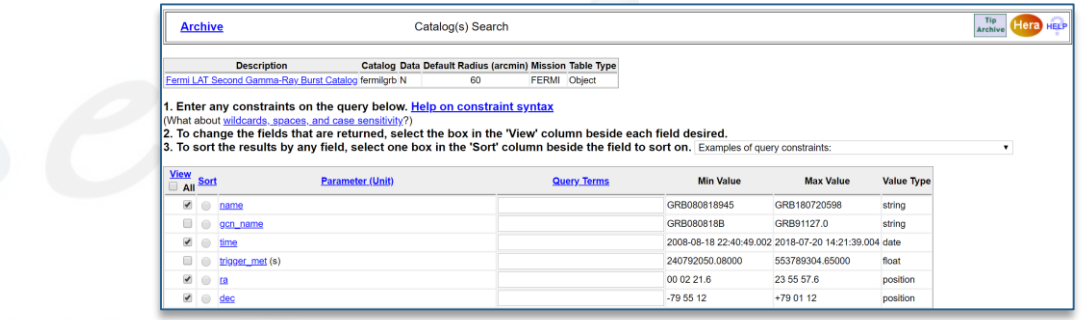
Conclusion

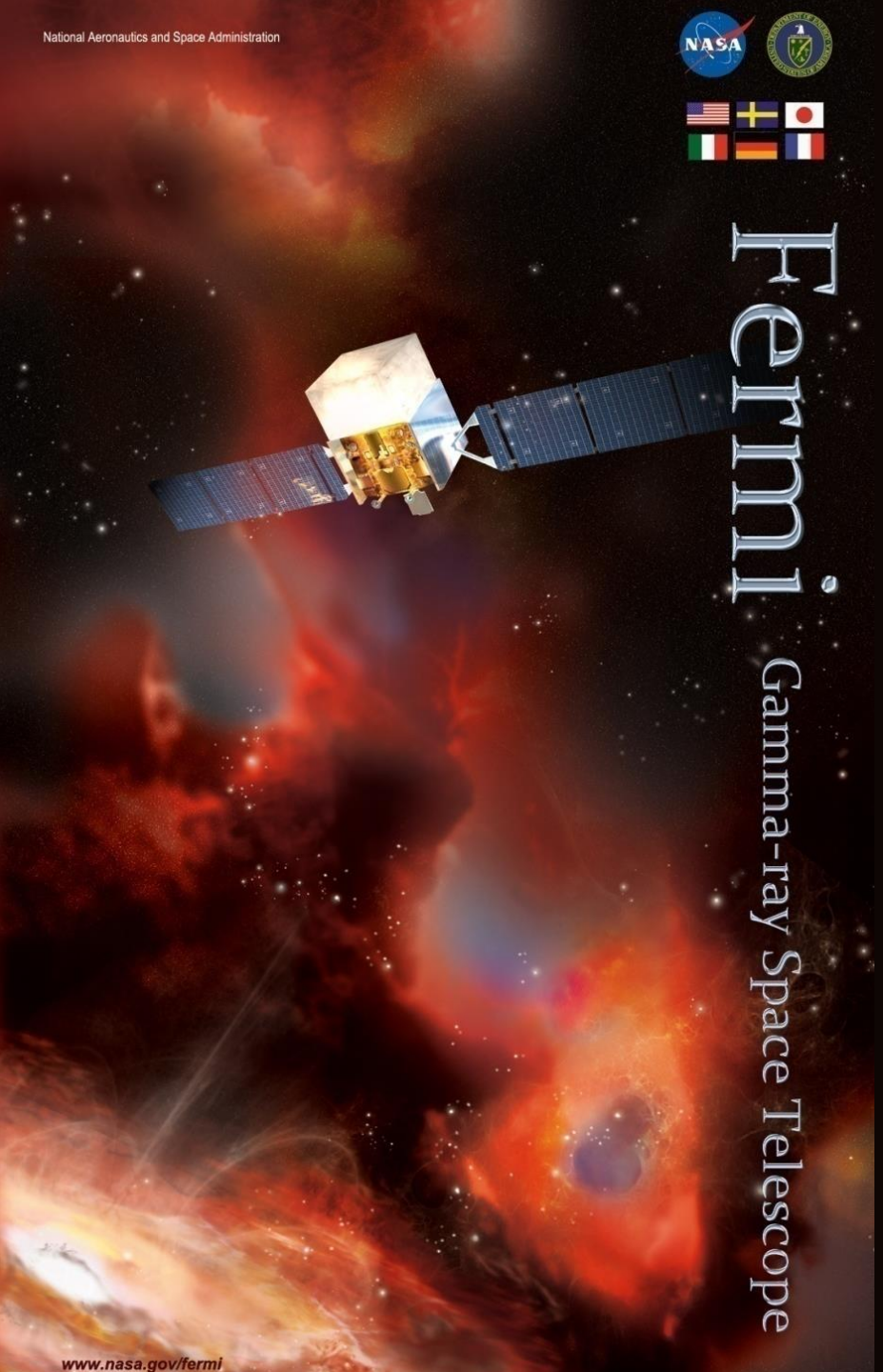
- **More things** we did **not** mention now, but you can find in the paper:
  - A lot (!!!) of **tables and figures**
  - Discussion of **prospects for GRB detections at VHE** (with CTA)
  - LAT short GRBs and implications for **gravitational wave** counterparts observations

- Paper published on June 13, 2019:
  Ajello+2019, ApJ 878, 52,
- doi: 10.3847/1538-4357/ab1d4e

- LAT FITS files **made publicly available:**
  - **HEASARC**
  - **Glast.Stanford.edu**

- More **follow-up papers** to come:
  - Stay tuned!!!



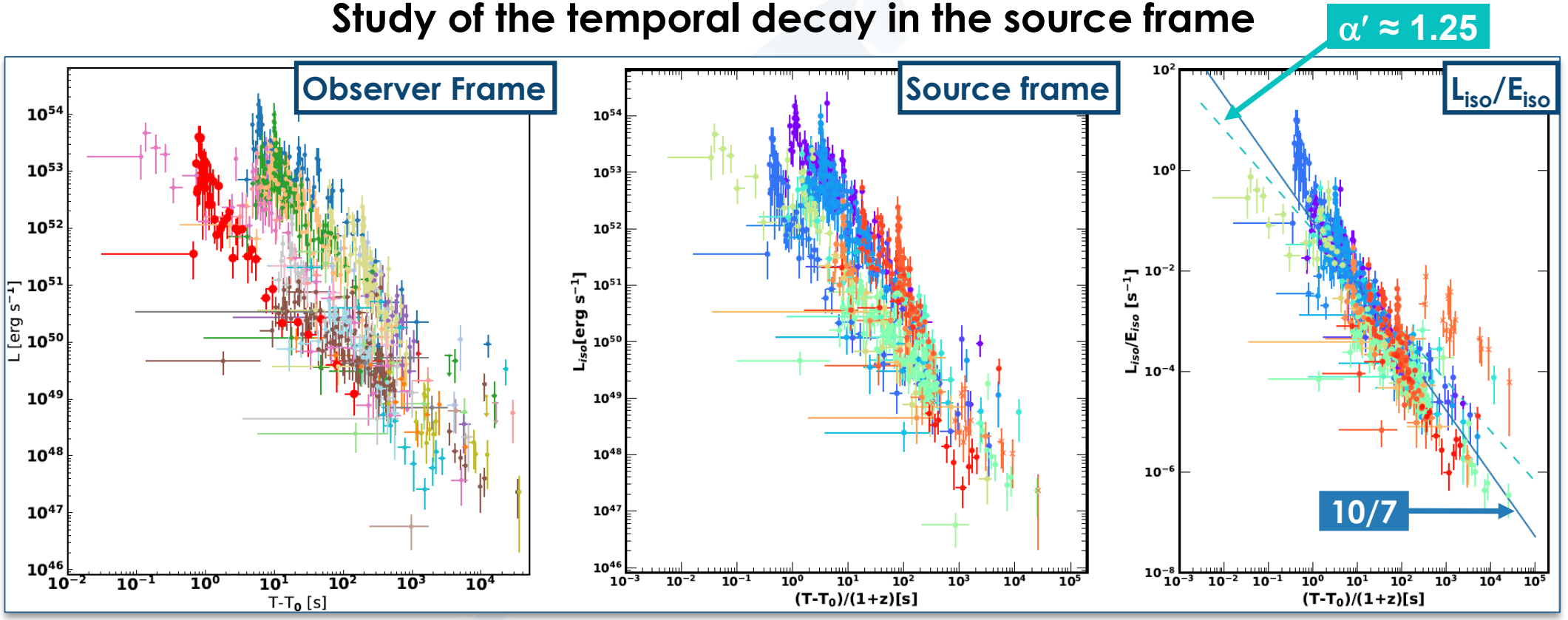


Backup slides

Fermi Gamma-ray Space Telescope

The LAT redshift sample

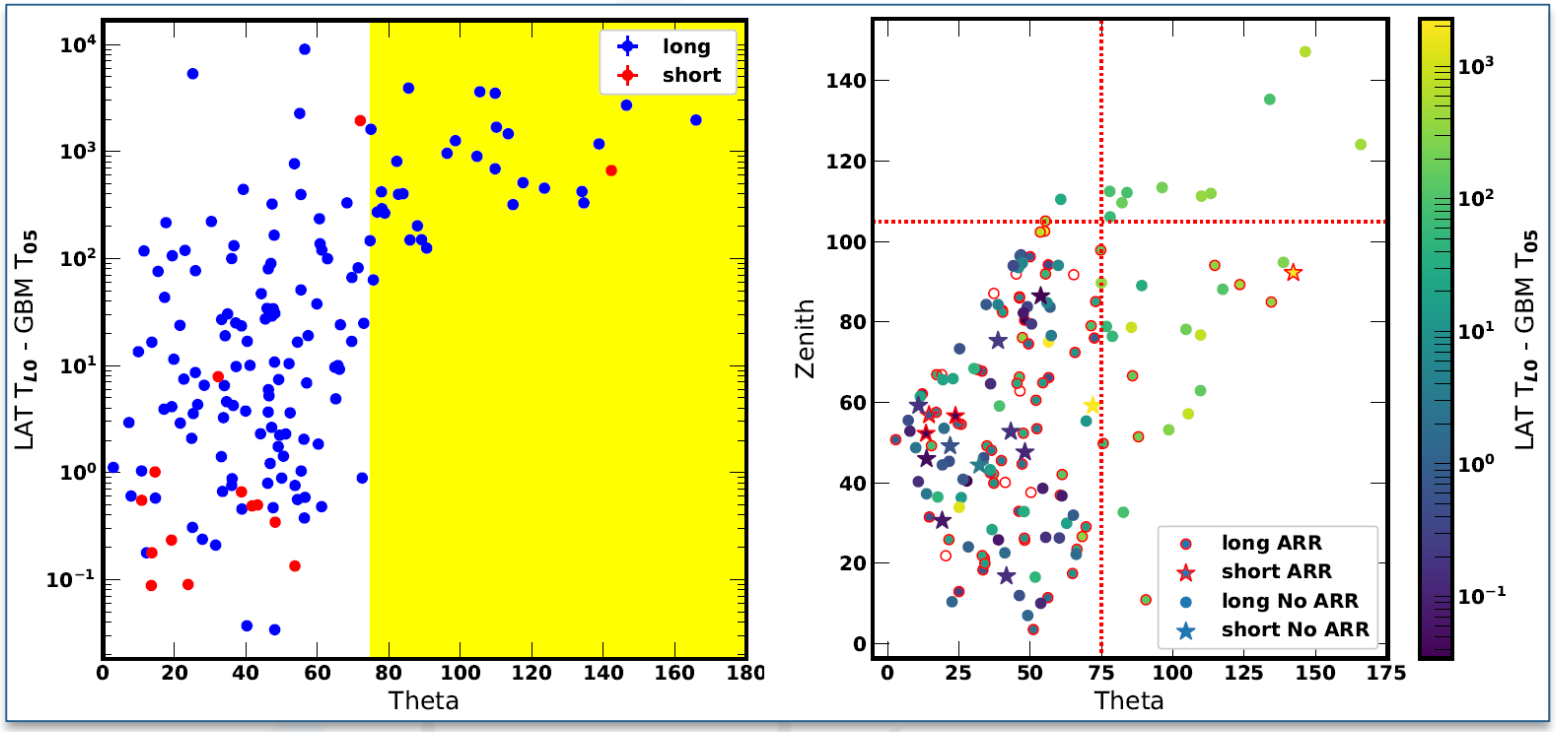
Study of the temporal decay in the source frame



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

Temporal properties

- **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**

Energetics

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!