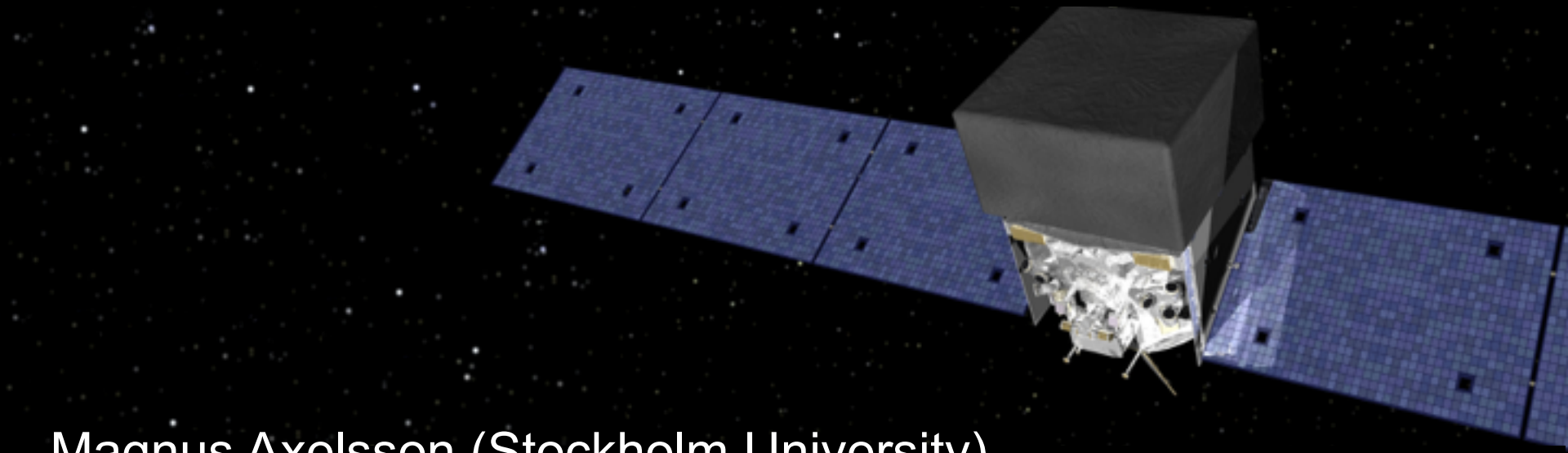
Fermi-LAT observations of Gamma-Ray Bursts

Report from NEWS secondment to the University of Tokyo



Magnus Axelsson (Stockholm University)
Elisabetta Bissaldi (INFN Bari & Politecnico di Bari)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 734303

Summary of secondments

- **Magnus Axelsson**: total 7 months
- **Elisabetta Bissaldi**: started 1 month secondment Oct 2019

- Work on *Fermi*-LAT analysis, focused on GRBs and GW follow-ups
  - Corresponding authors of the 2nd Fermi-LAT GRB catalog

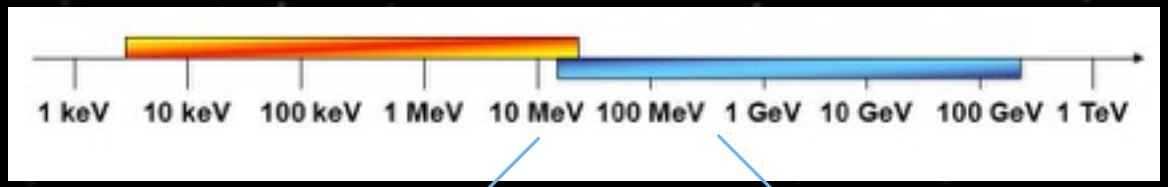
- The *Fermi*-LAT catalog is the most comprehensive compilation of high-energy (>100 MeV) emission from GRBs, and the detection pipeline developed forms an important preparation for the search for GW counterparts.

- It is also complementary to the 4FGL catalog, searching for sources seen on longer timescales - GRBs typically last only minutes to hours.

Fermi

LAT
~20 GRBs/yr

GBM
~250 GRBs/yr

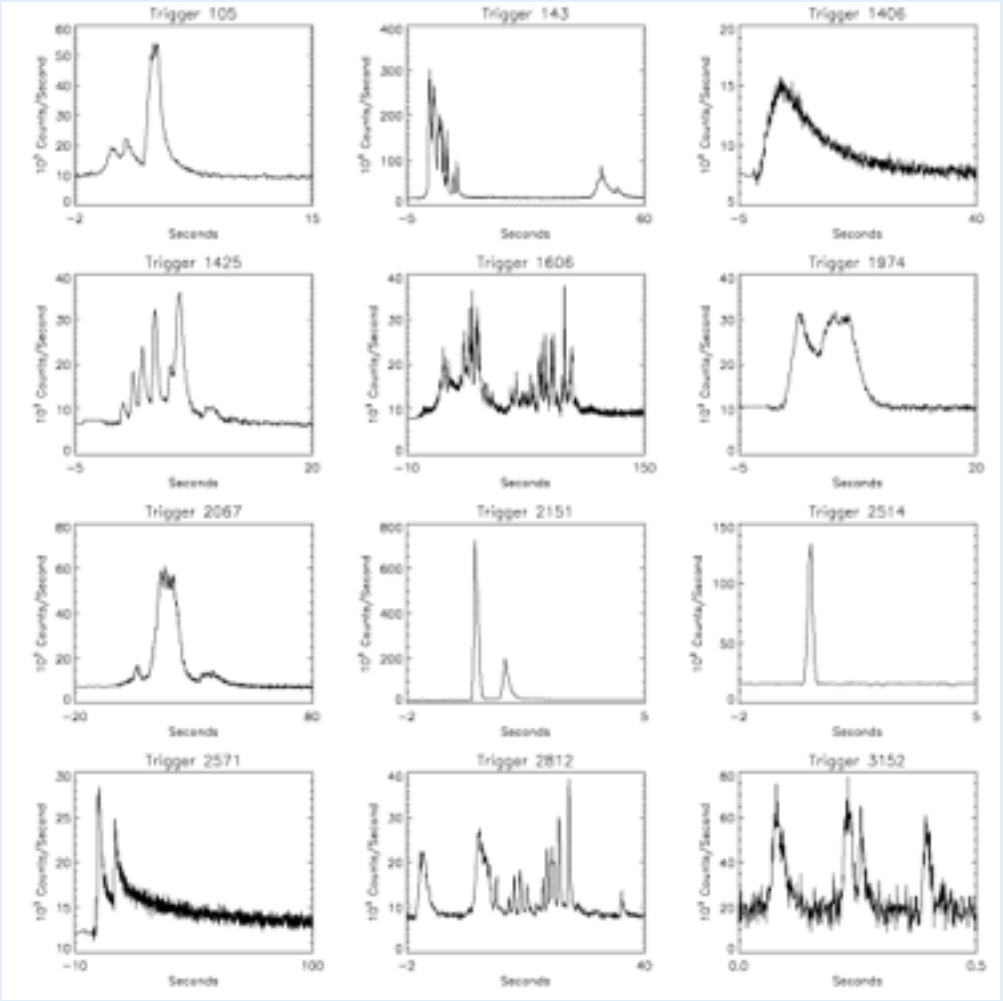


LAT LLE

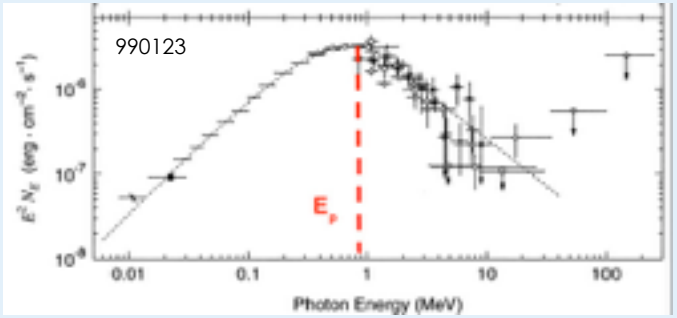
The challenging study of GRBs

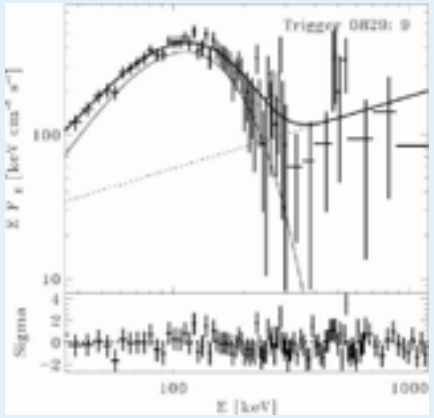
- "When you've seen one gamma-ray burst, you've seen one gamma-ray burst"

BATSE light curves



Spectra





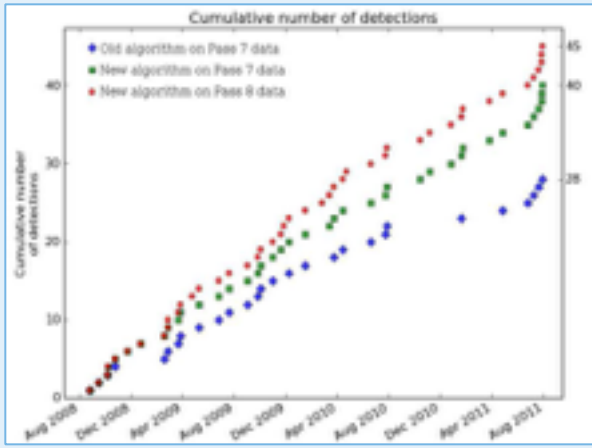
Population studies help to identify common properties

2nd catalog (2FLGC) analysis pipeline

- Time period: August 2008 to 2018 (10 years)
- Search for emission from 3044 GRBs triggered by other instruments (GBM, Swift, Integral, AGILE, IPN)
- Detection algorithm searching five time windows, from 10 s to 10 ks (LTF: Vianello et al. 2015).
- Every detection analysed by a standardized analysis pipeline.

Compared with the 1FLGC

- New detection algorithm: 50% improvement
- Using Pass8 data: 20% improvement

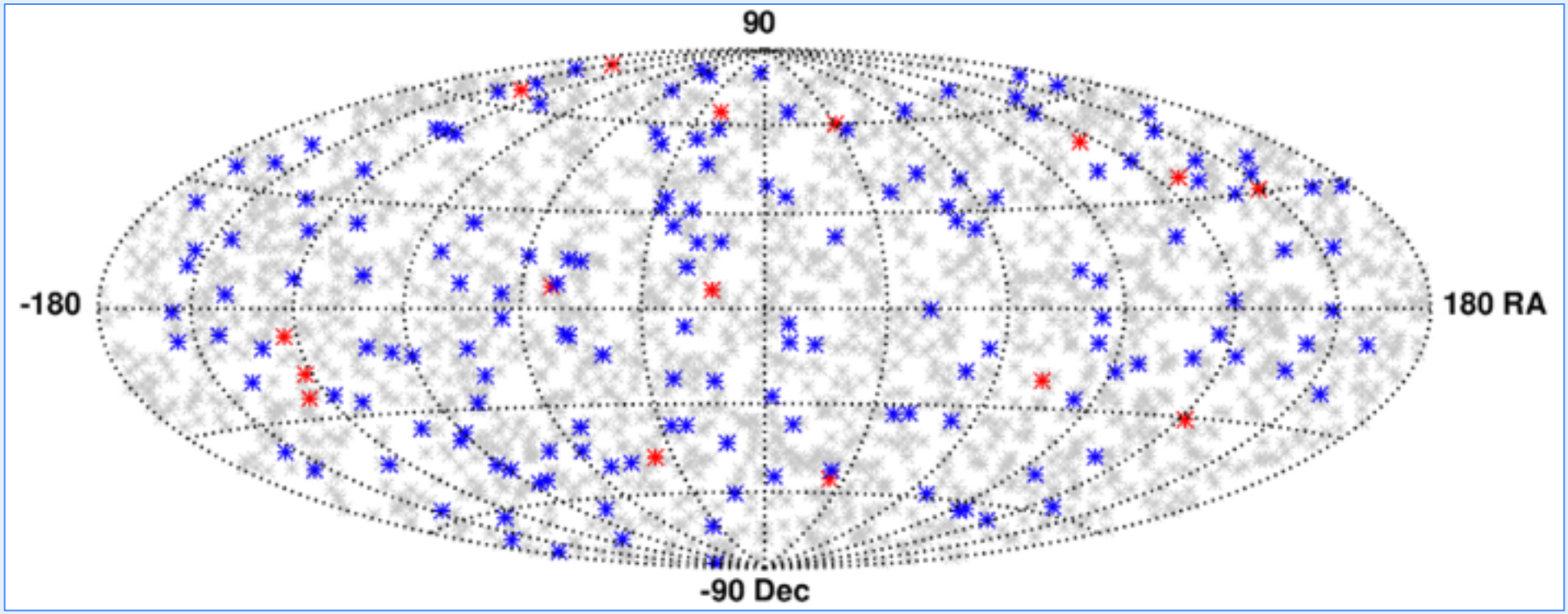


Vianello+15

A first step for the GW follow-up searches, and complementary to the 4FGL catalog analysis!

GRB detections

- **186 LAT** detections (169 **long**, 17 **short**)
  - **91 LLE** GRBs (85 long, 6 short), with **17 LLE only** GRBs (15 long, 2 short)



  - 176 joint detections with GBM (160 long, 16 short)
    - 2 Swift-BAT, 8 IPN
  - 34 GRBs have redshift measurements

Temporal properties (1)

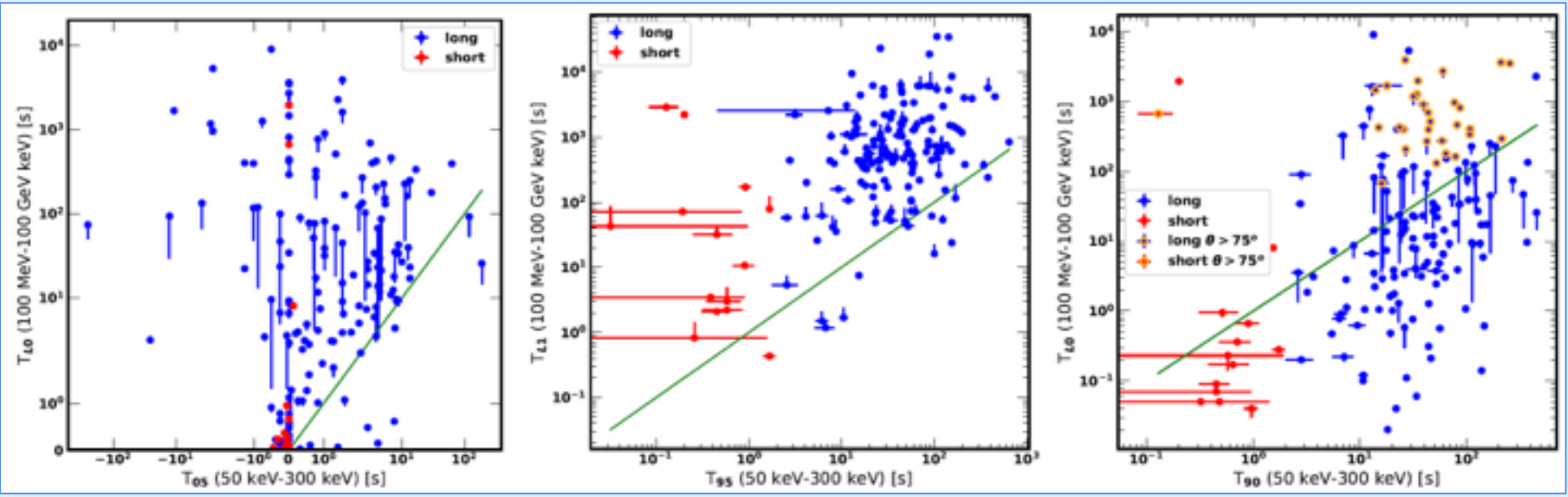
- **GRB duration definitions**

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)



Temporal properties (1)

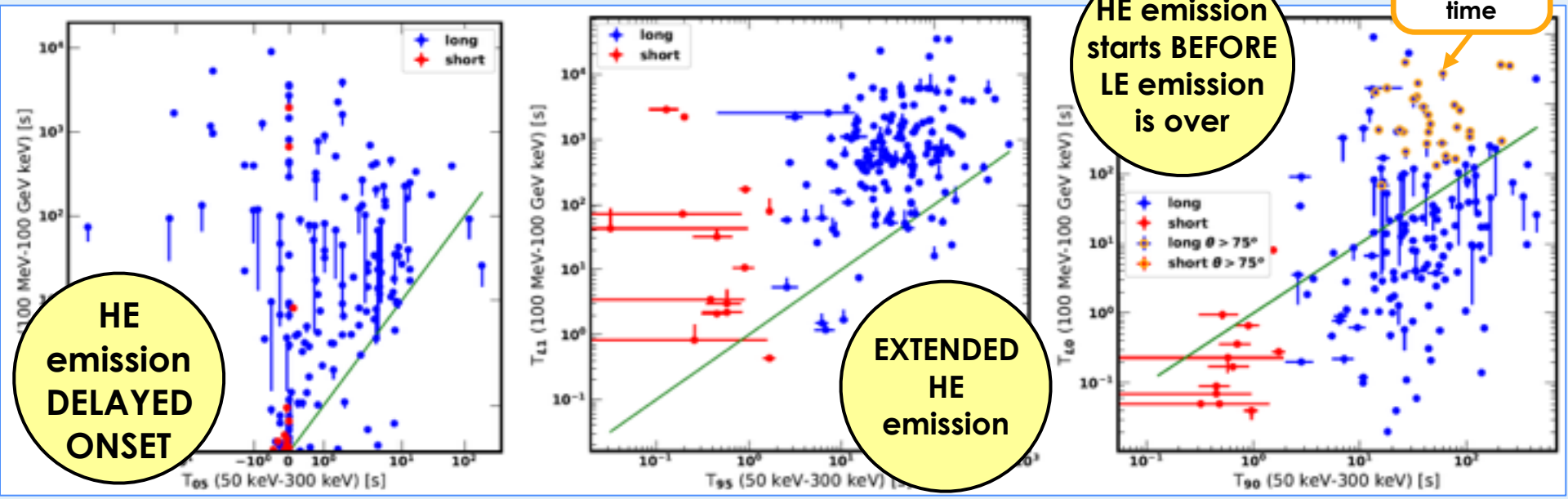
- **GRB duration definitions**

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)



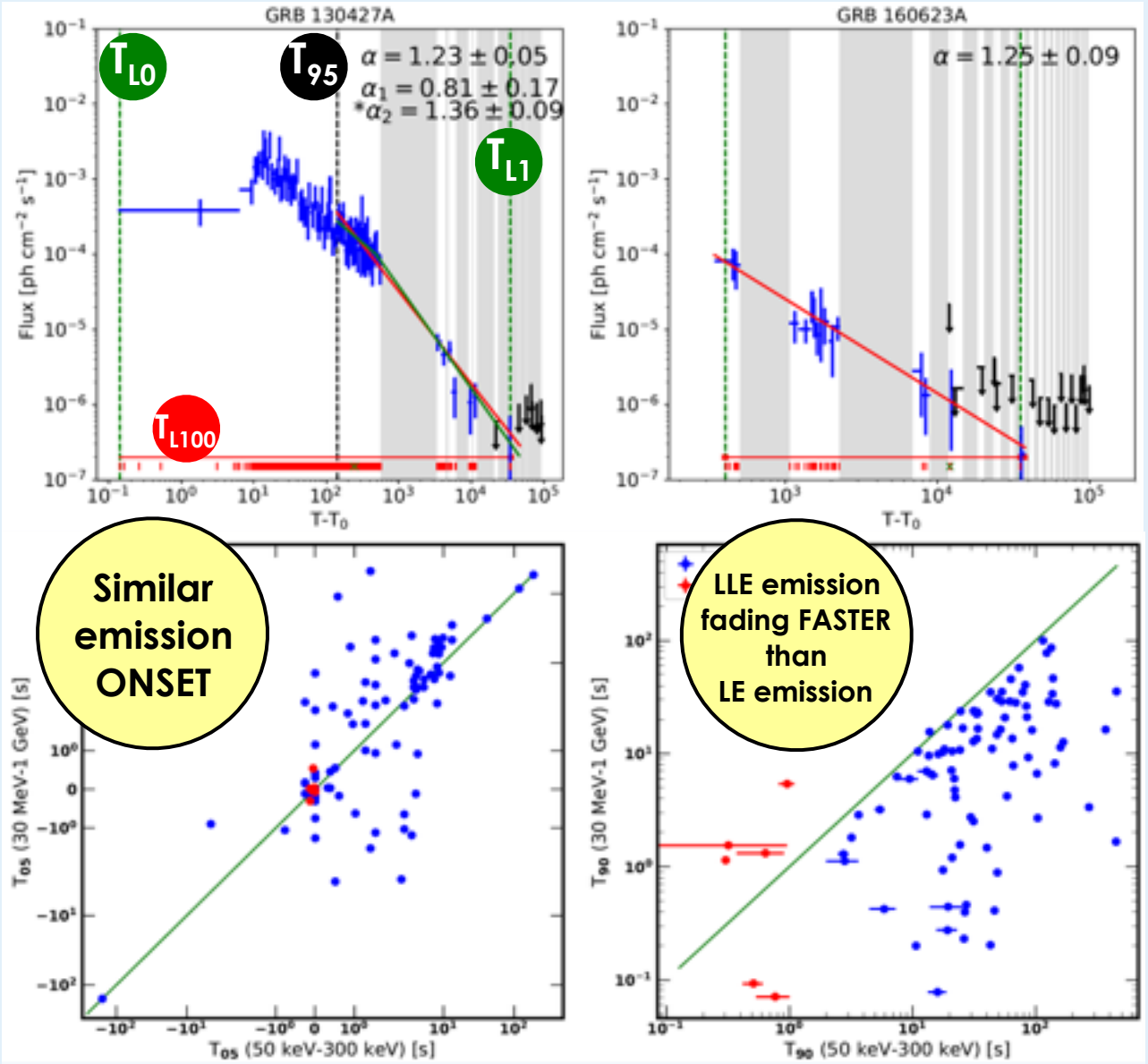
Temporal properties (2)

Highlight:
Longest bursts

1. GRB 130427A
   T_{L100} = 34 ks
2. GRB 160623A
   T_{L100} = 35 ks

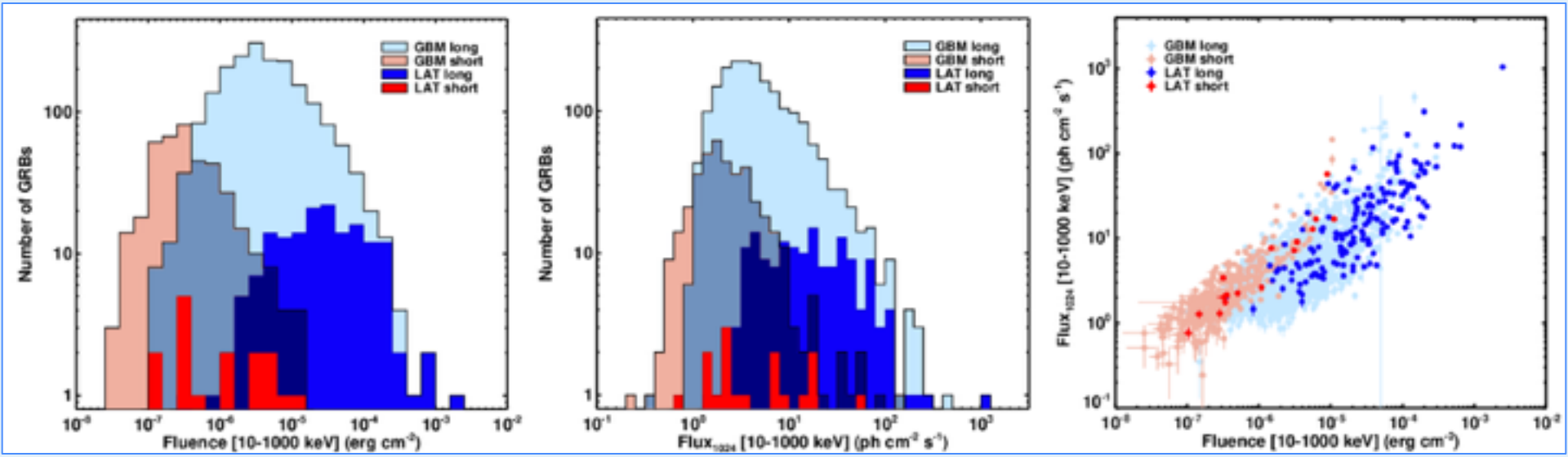
LLE bursts

- [**30 MeV – 1 GeV**]
- Definition of duration similar to the GBM
- Behavior similar to low-energy emission



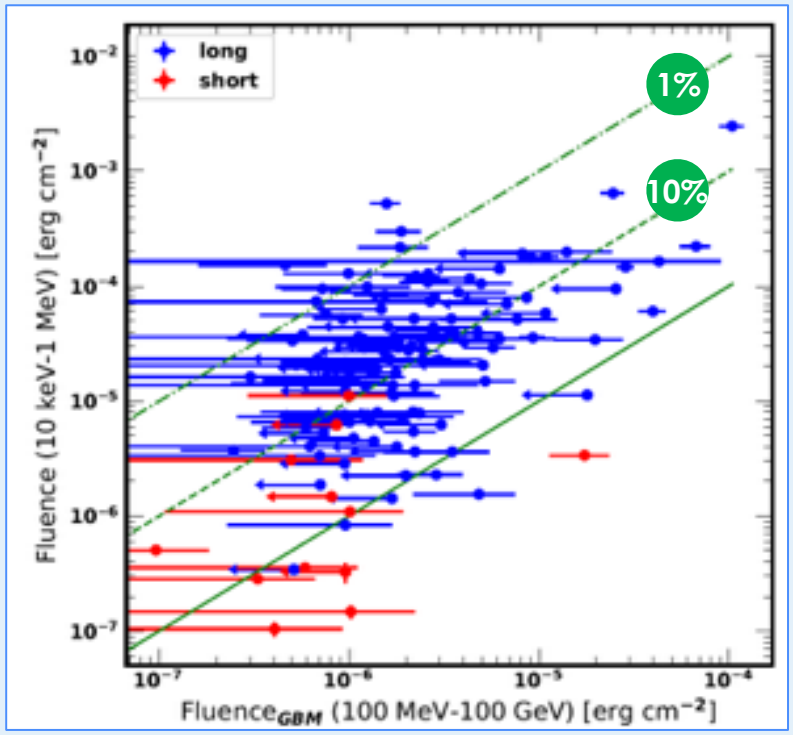
Energetics (1)

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

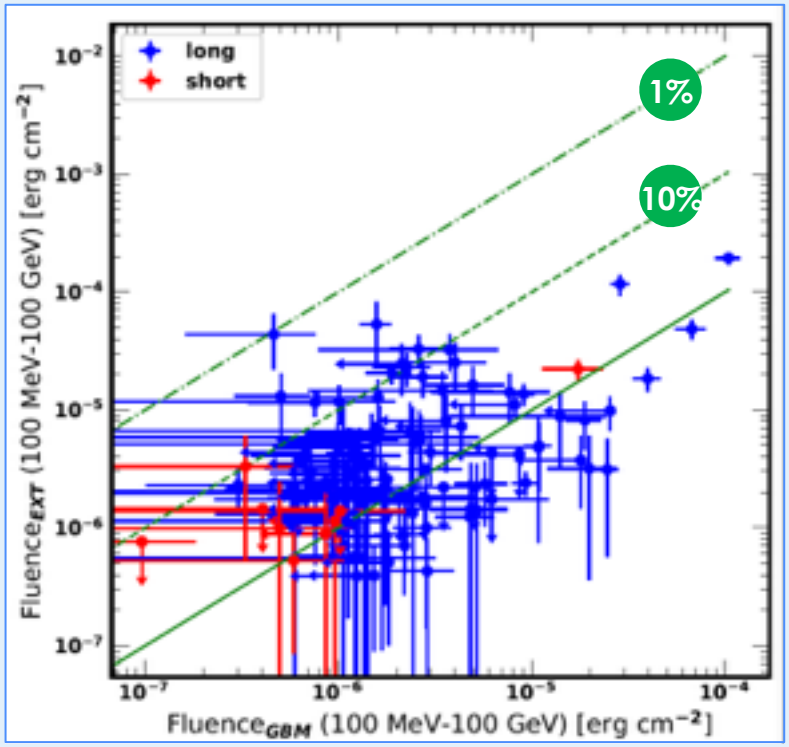


- Distribution of short and long bursts are **different**
- LAT tends to sample brighter bursts
  - BUT: **MUCH LARGER SPREAD** now than in the first LAT catalog!
  - We now detect HE emission also from **weak GBM bursts**!

Energetics (2)



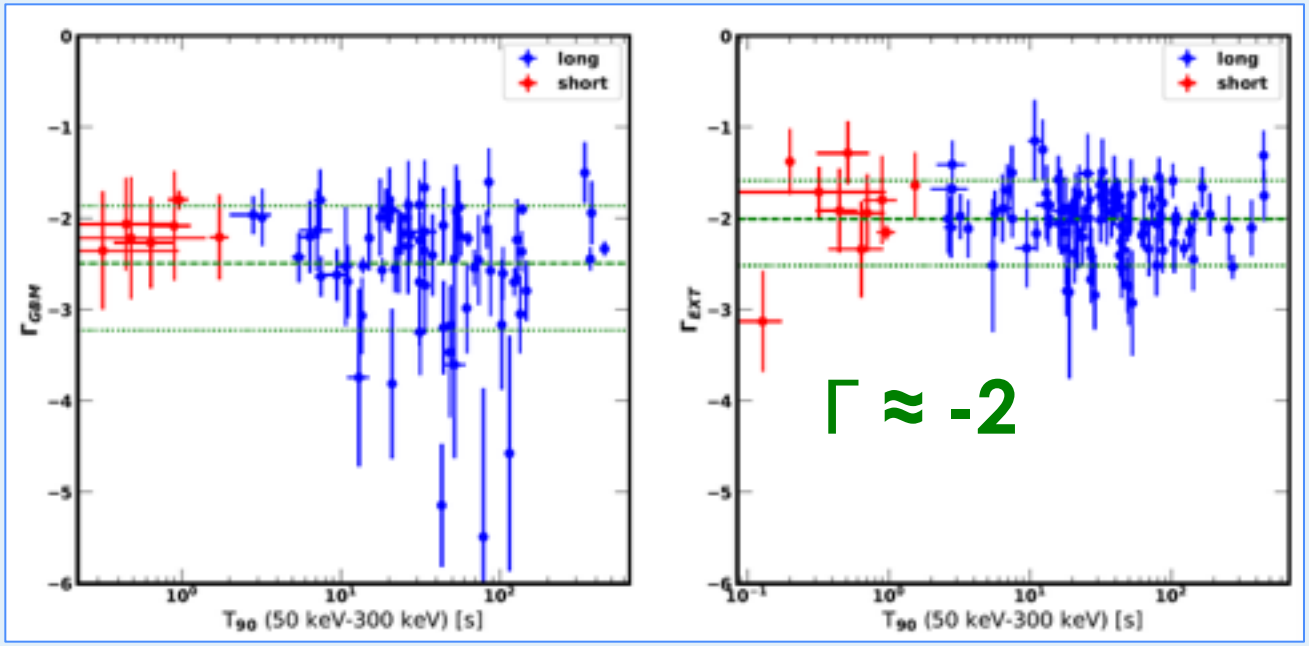
- GBM (10-1000 keV) fluence is >10 x larger than LAT (100 Mev-100 GeV) fluence
  - The majority of the burst energy is emitted at lower energies!



- In the LAT energy range, the fluence at late times is comparable to the prompt phase

Energetics (3)

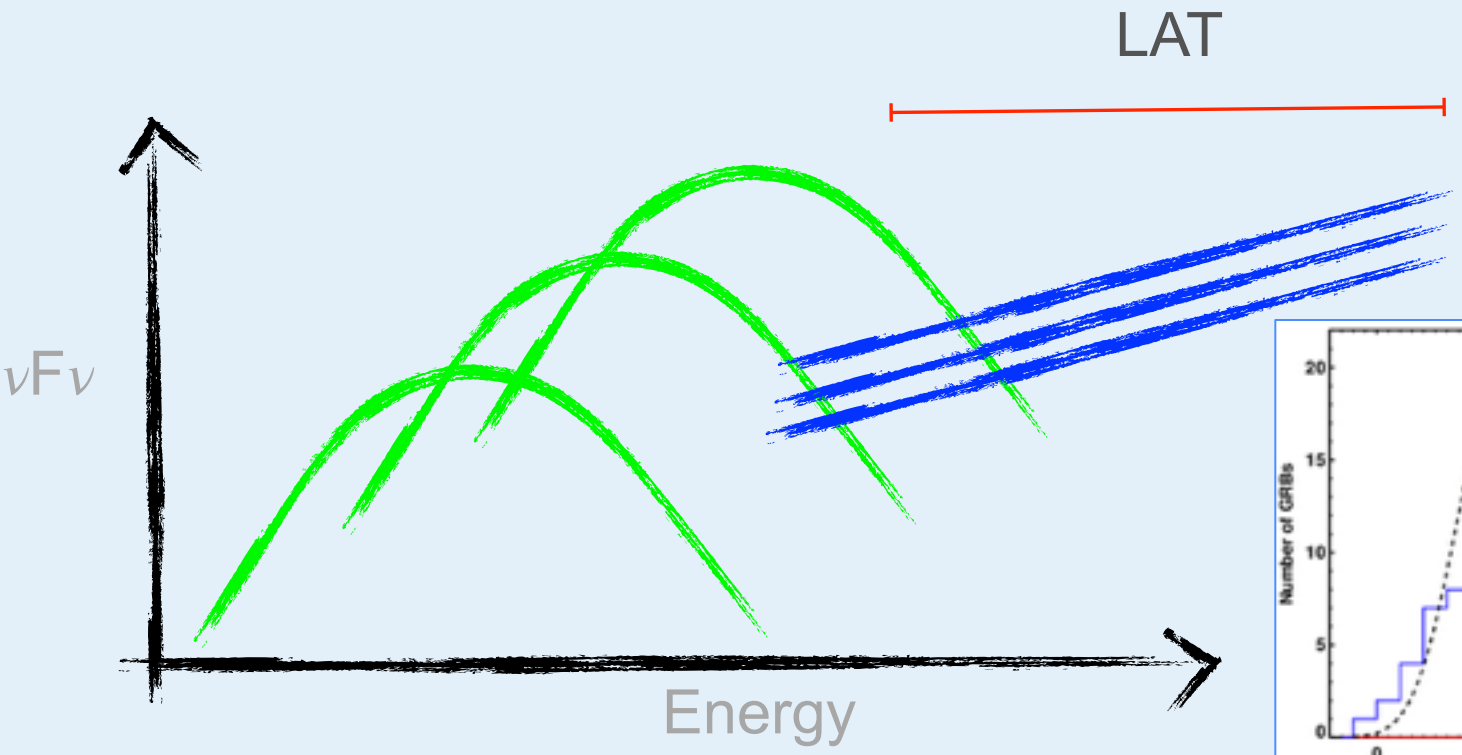
Photon index Γ vs duration in the prompt and late time windows



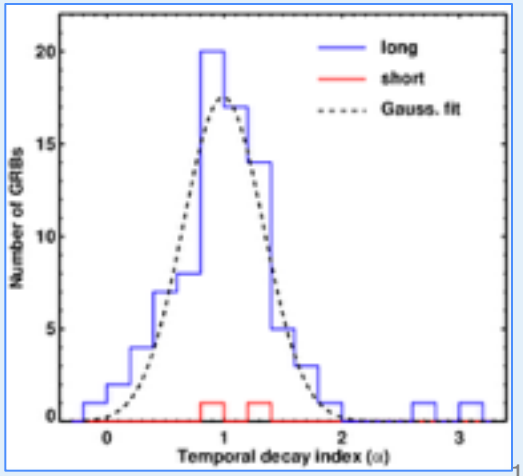
- No sign of correlation
  - Slightly **harder** at late times
- **Same component at work** in the LAT energy range the whole time
  - Is it the **same emission**? Possible **contamination** from the component that dominates in the **10-1000 keV** GBM energy range

What does this mean?

- Strong spectral evolution at low energies
- High-energy emission fairly stable
- Very different temporal behaviour at low and high energies
- Separate emission components!
- LAT component an “early afterglow”?



Temporal decay ~-1

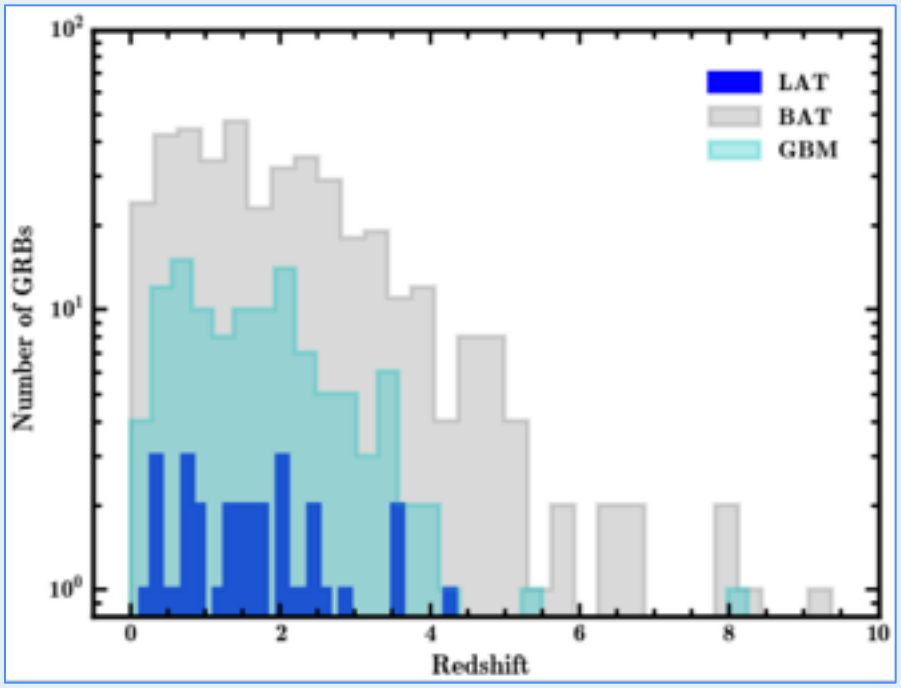


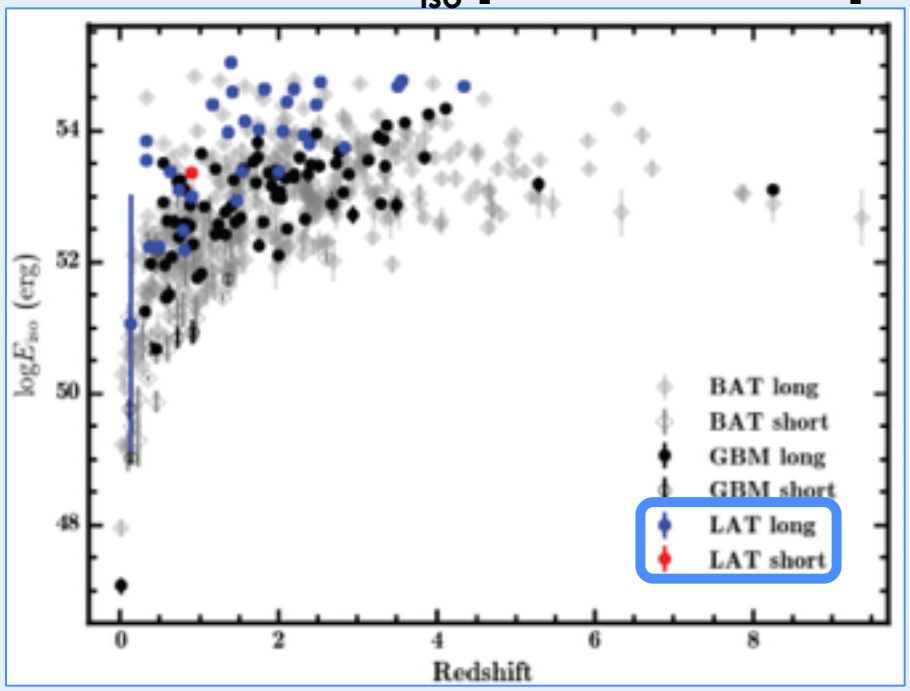
The LAT redshift sample

- **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!**

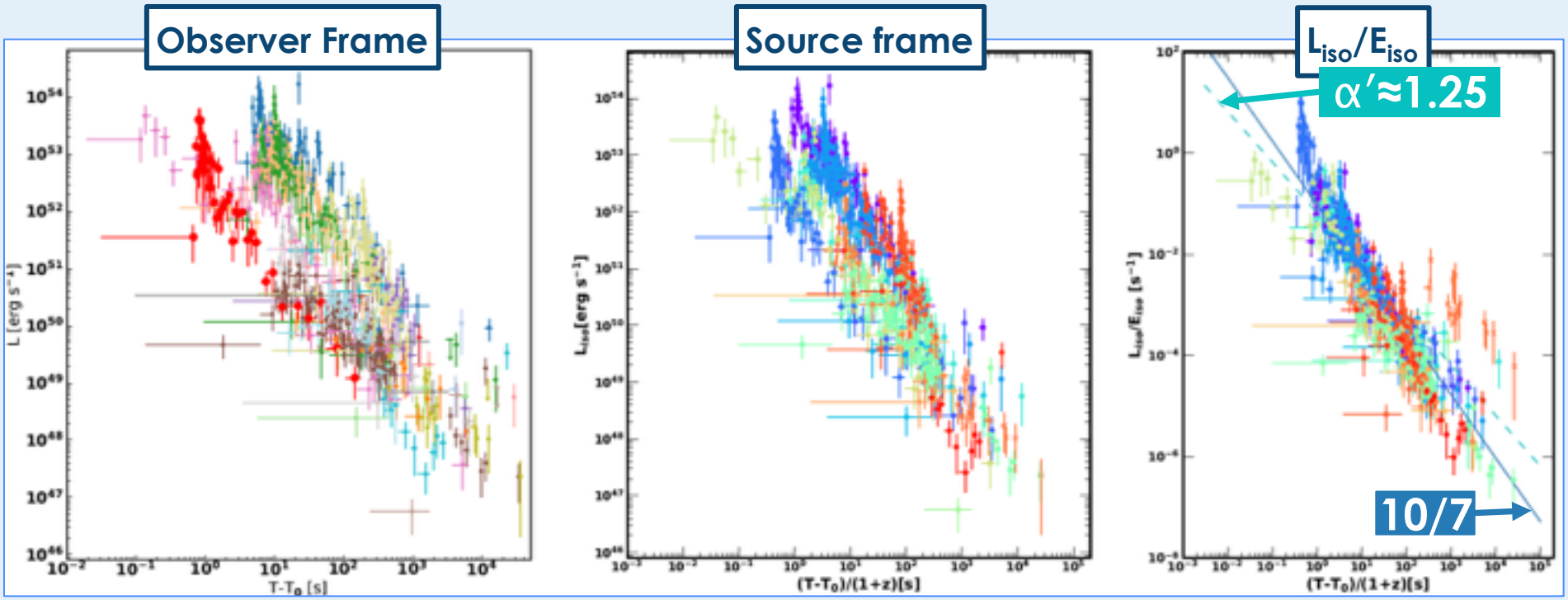
E_{iso} [1 keV – 10 MeV]





The LAT redshift sample

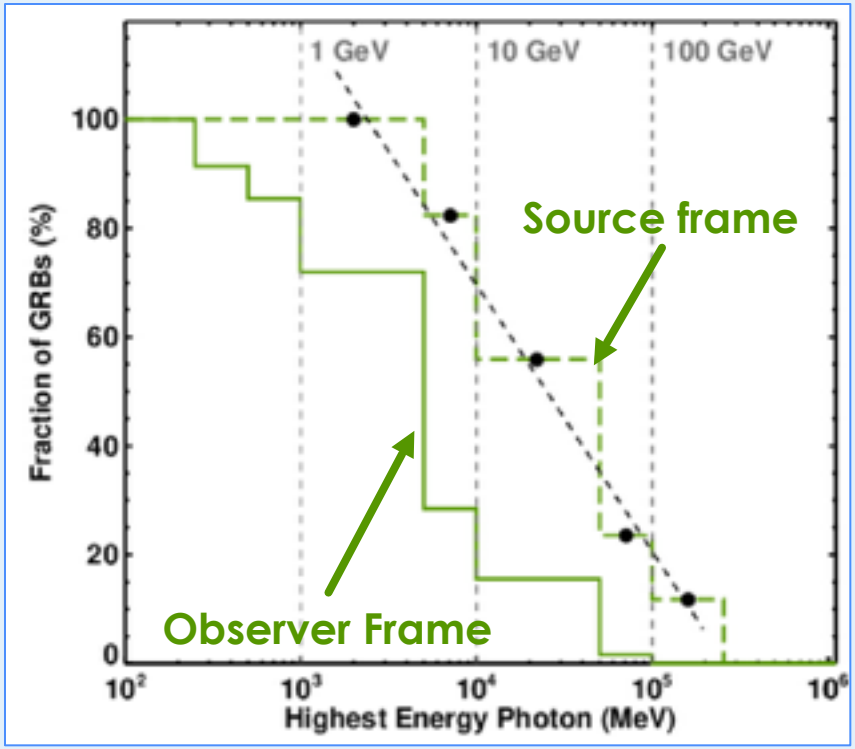
- Study of the temporal decay in **the source frame**

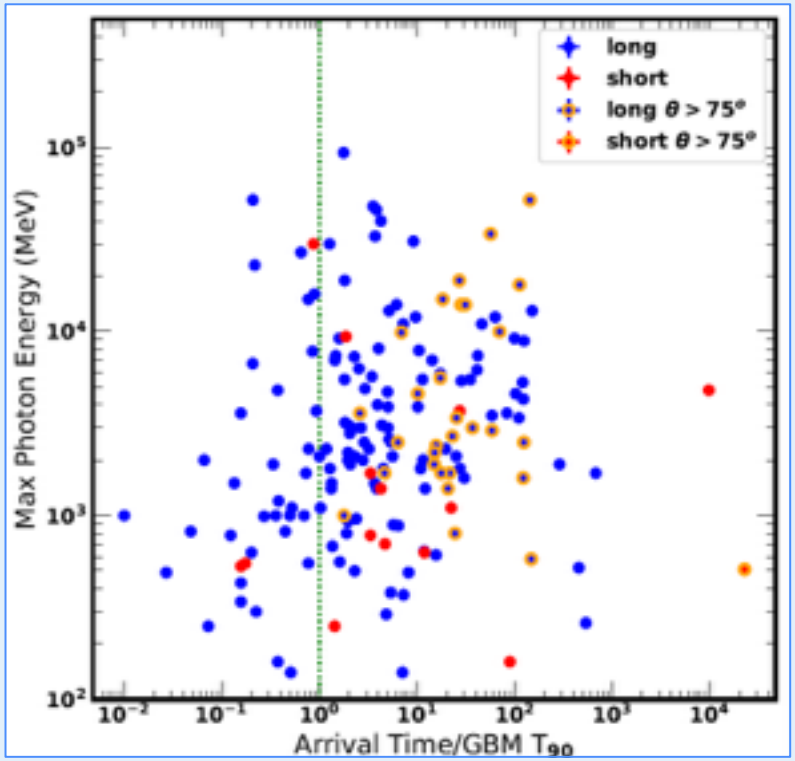


- For each correction, the **spread is reduced** and all points seem to **line up**
  (Ghisellini et al. 2010, Nava et al. 2014)
  - *In the rightmost plot: division by* ***E_{iso}*** *(proxy for* ***total energy budget****)*
    - ***Fit result*** *shown together with* ***theoretical*** *expectation*

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!

Conclusion

- GRBs can be seen across the electromagnetic spectrum - and with GW
- The LAT catalog is the largest compilation of high-energy detections
  - A lot of tables and figures
  - Discussion of prospects for GRB detections at VHE (with CTA)
  - Lays groundwork for GW follow-up searches
- 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**
- Probe emission physics, but also have wider impact, e.g., the extragalactic background light and Lorentz invariance
- Combined GW-EM observations of (short) GRBs strengthen both fields, and give important scientific return

Plans for continuing secondments

- Highest probability of a joint GW-EM detection is for a NS-NS merger
  - This is expected to produce a short GRB (cf. GRB170817)

➡ Studies of the subsample of short GRBs seen by LAT
  - Joint GBM+LAT spectral fits of the prompt emission phase
  - Studies of the cut-off energy and detectability

➡ Studies of the subset of GRBs with known redshift
  - Studies of rest-frame properties
  - Highest-energy photons
  - Emission mechanisms