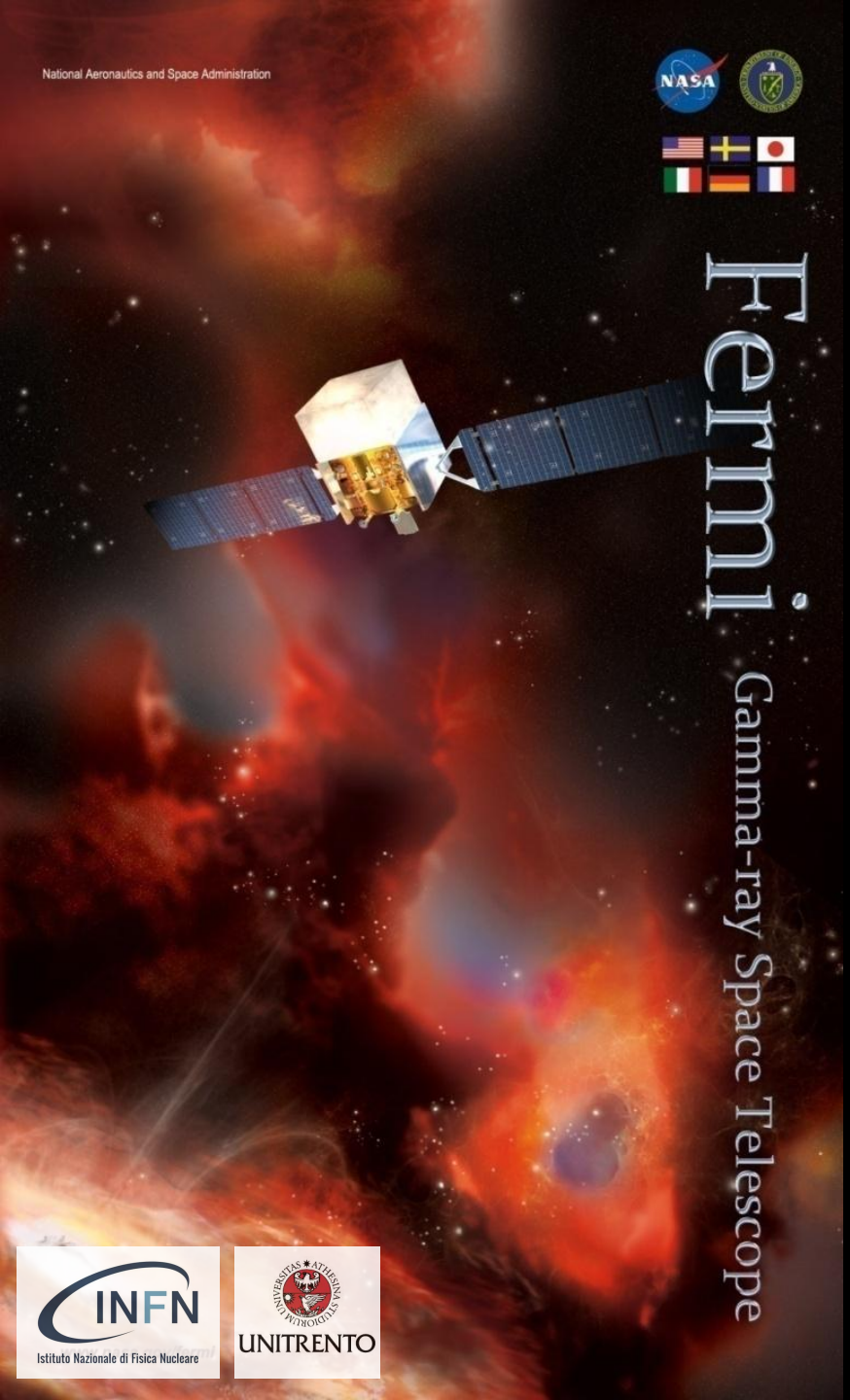


Towards a joint time-resolved systematic analysis of GRBs

Aldana Holzmann Airasca[1, 2];
Elisabetta Bissaldi [2, 3]; Francesco Longo [4],
Nicola Omodei [5]
on behalf of the *Fermi-LAT* and *Fermi-GBM*

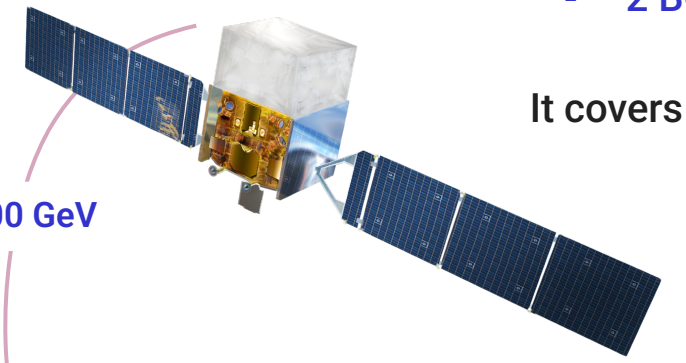
[1] University of Trento, [2] INFN Bari, [3] Politecnico di Bari,
[4] University of Trieste and INFN Trieste, [5] Stanford University

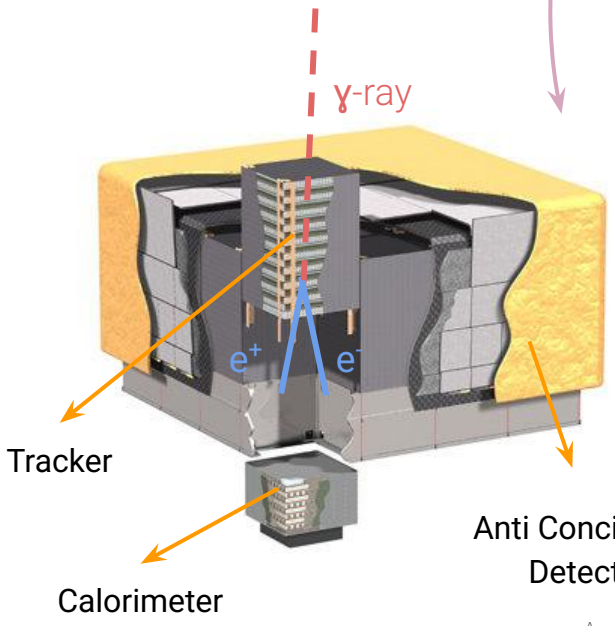
The Fermi mission: LAT and GBM

The Fermi-LAT is a pair conversion telescope covering an energy range between

~ 20 MeV - > 300 GeV

- LLE range: **30 MeV - 100 MeV**
- LAT standard range: **100 MeV - > 300 GeV**



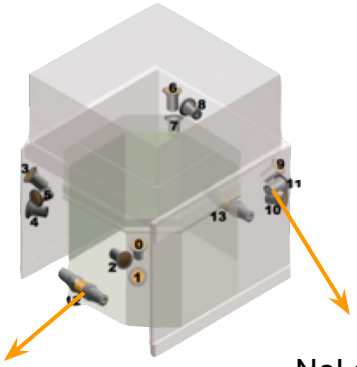


The Fermi-GBM is composed of:

- **12 NaI scintillator detectors and**
- **2 BGO calorimeters.**

It covers an energy range between

8 keV - 40 MeV



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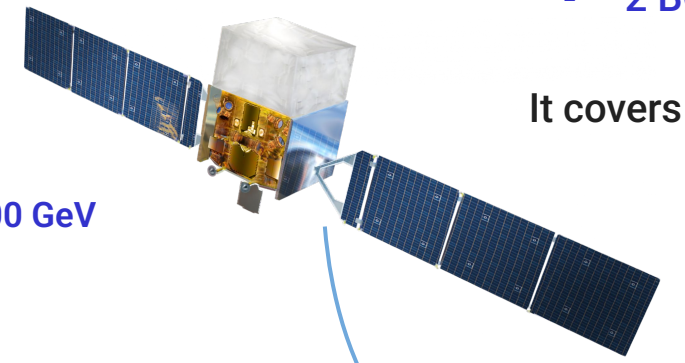

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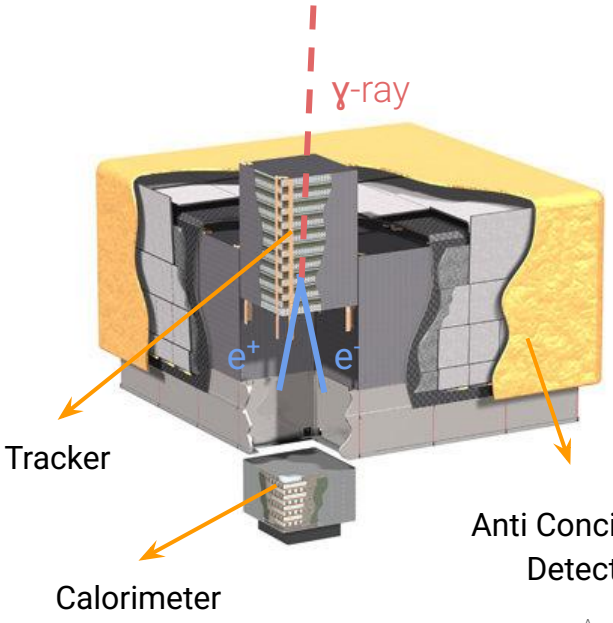
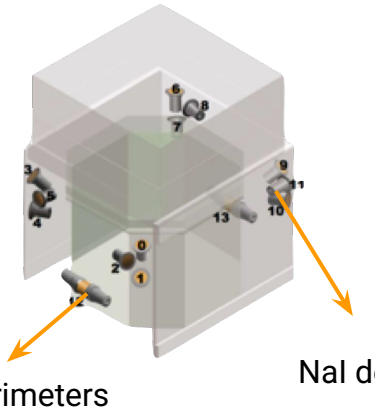


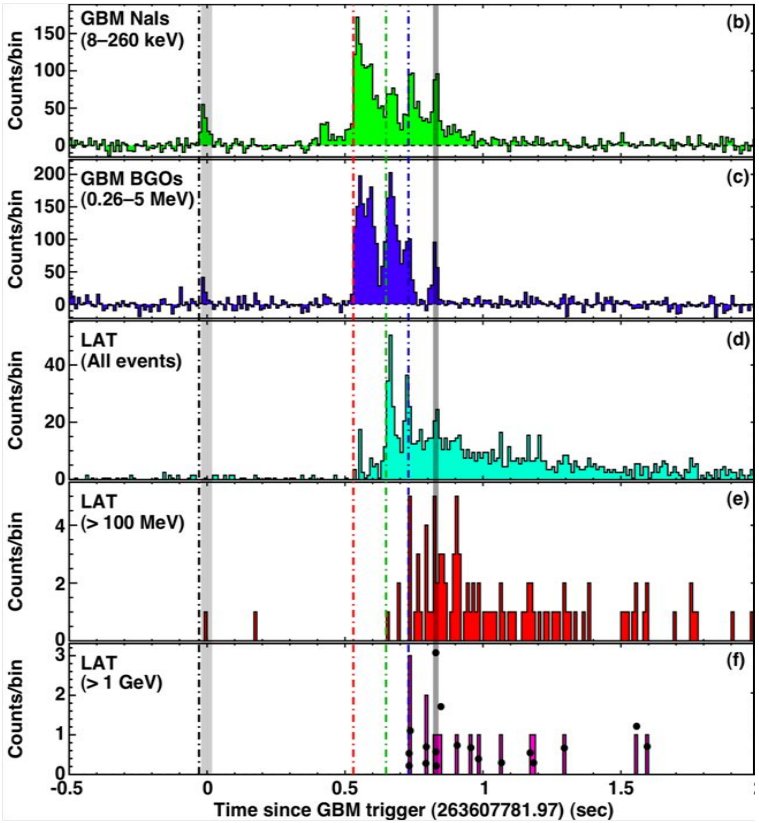


Gamma-ray Bursts (GRBs)

GRBs are the most energetic and luminous explosions observed in the universe, with its main emission in the gamma-rays band.

These bursts have two main phases:

- The prompt emission, a short flash of high-energy photons lasting from milliseconds to minutes.
- The afterglow, a longer-lasting multiwavelength emission.



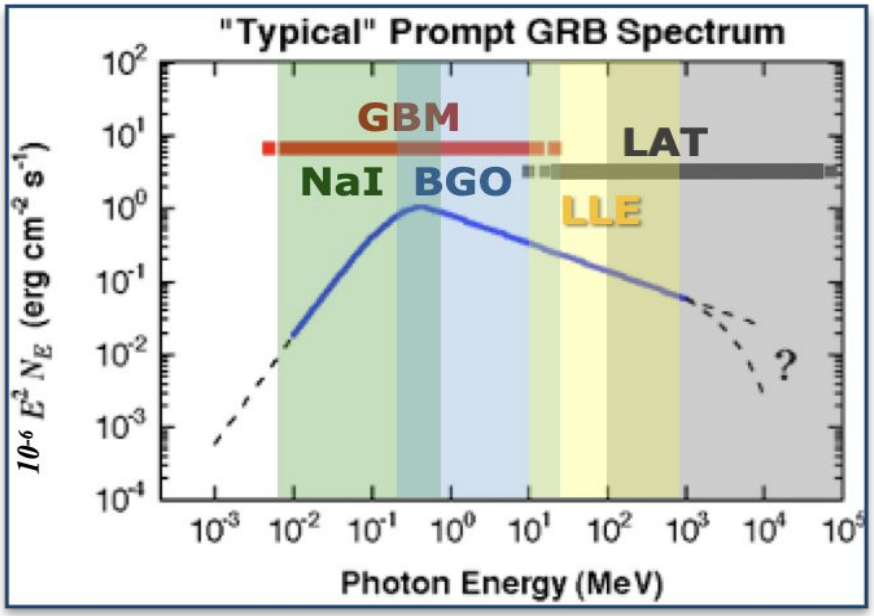
Light curve of GRB 090510 (Ackermann et al. 2010)

Spectral characteristics of GRBs

GRB continuum spectrum is non-thermal, with most of the luminosity emitted in the energy range ~100 keV to ~10 MeV

The spectrum is "typically" well fitted with phenomenological *Band* (1993) function:

$$K \times \begin{cases} \left(\frac{E}{E_{\rm piv}}\right)^{\alpha} \exp\left[-\frac{E(2+\alpha)}{E_{\rm peak}}\right] & \text{if } E \leq E_{\rm break} \\ \left(\frac{E}{E_{\rm piv}}\right)^{\beta} \exp(\beta-\alpha)\left[\frac{E_{\rm peak}(\alpha+\beta)}{E_{\rm piv}(2+\alpha)}\right]^{\alpha-\beta} & \text{otherwise} \end{cases}$$



(Fermi LAT collaboration 2008)

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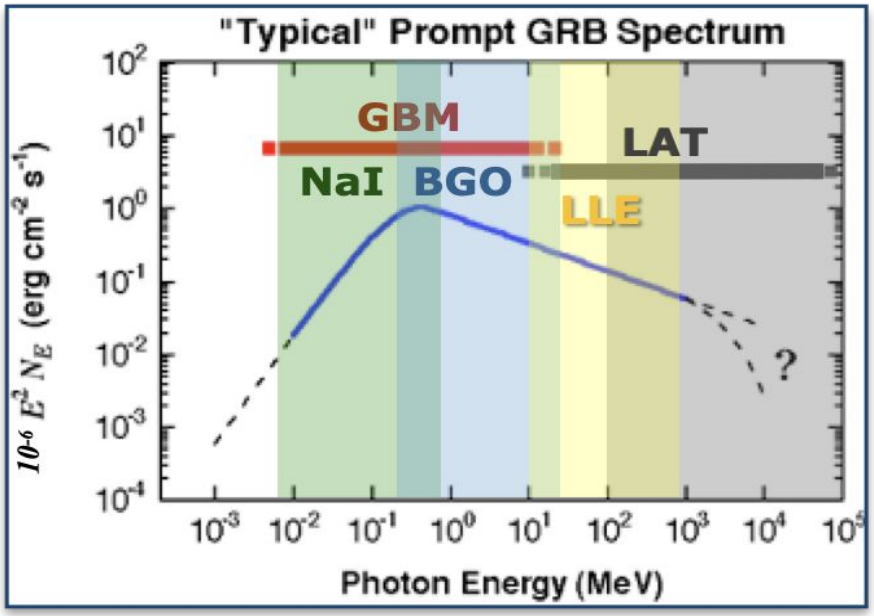

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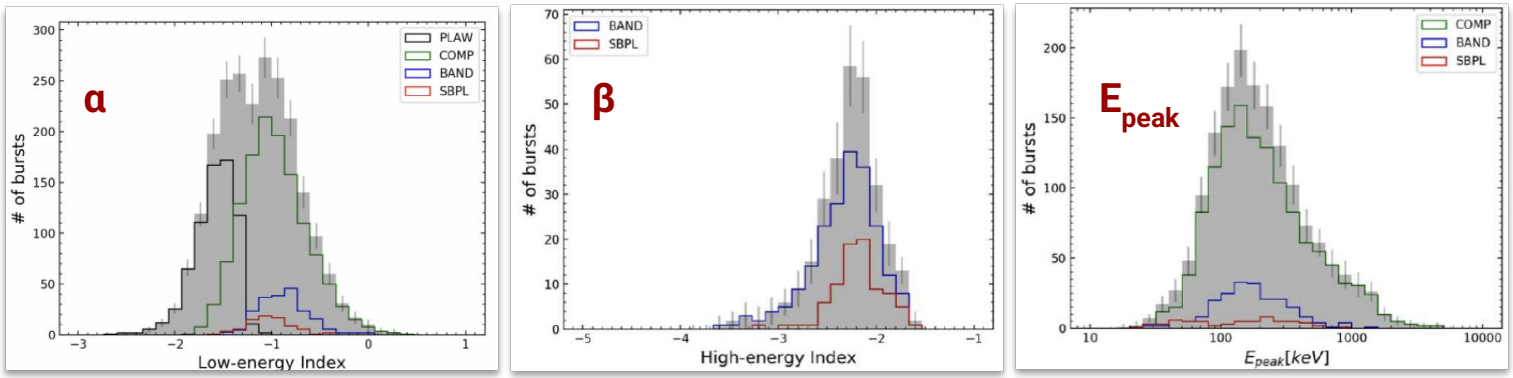

Distribution of spectral parameters (Poolakkil et al. 2021)

Past population studies

Population studies can help to identify common properties, since there are no two identical GRBs!

Past systematic studies:

- **1 joint LAT-GBM time-integrated spectral catalog** (Ackerman et al. 2013)
- **1 LAT only GRB catalog** (Ajello et al. 2019)
- **5 GBM only catalogs were published:**
  - **4 GBM GRB spectral catalogs, last one in 2018** (Poolakkil et al. 2021)
  - **1 GBM GRB time-resolved catalog** (Xu et al. 2016)

~ 40 papers dedicated to individual GRBs

Joint systematic time-integrated and time-resolved analysis of the 16 years of mission is yet to be done

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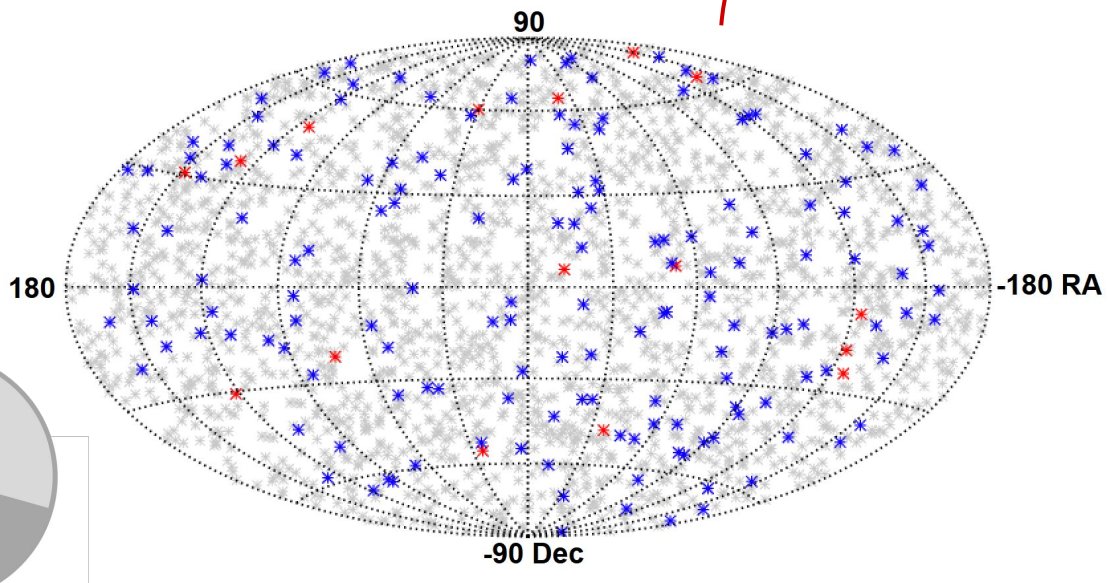
Fermi GRBs, some numbers

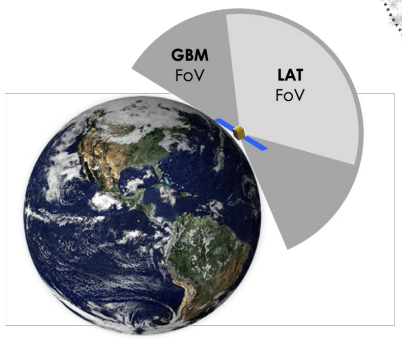
Yearly GBM observes ~ 250 GRBs while LAT ~15 bursts

To date:

- **GBM-triggered GRBs are > 4000**
- **LAT-detected only 271 events**

~ 23% of them are short and
~ 77% are long





Sky distribution of GBM-triggered and LAT-triggered GRBs, from 07-2008 to 07-2018 (Ajello et al. 2019)

Sample selection and analysis

The sample selection was performed considering the first 17 years of data (from August 2008 to September 2025). The total sample has 271 bursts.

The refined selection was considering that:

- The event shall have a significant signal in the 20 - 100 MeV energy range or
- The selection was considering that the arrival of the first LAT photon should fall inside the main emission measured by GBM (T_{90}).

189 bursts meet the criteria

Workflow of the systematic analysis

For each event we chose the time intervals for the analysis as:

- T_{90} $^{+50\%}_{-20\%}$ **for long GRBs**
- $T_{90} \pm 1$ s **for short GRBs**

The bins are created with the Bayesian Block method using the brightest NaI detector

Only bins with a S/N ratio > 5σ are considered

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8 spectral models are tested on each bin

All models with relative errors < 50% are consider GOOD models

The BEST model is chosen based on the BIC criteria (Chand et al, 2018.) **wrt the Comptonized model:**

$$\Delta\mathrm{BIC} = \mathrm{BIC}_{\mathrm{Comp.}} - \mathrm{BIC}_{\mathrm{Model\ X}} < 6$$

Band model

$$K \times \begin{cases} \left(\frac{E}{E_{\mathrm{piv}}}\right)^{\alpha} \exp\left[-\frac{E(2+\alpha)}{E_{\mathrm{peak}}}\right] & \text{if } E \leq E_{\mathrm{break}} \\ \left(\frac{E}{E_{\mathrm{piv}}}\right)^{\beta} \exp(\beta-\alpha)\left[\frac{E_{\mathrm{peak}}(\alpha+\beta)}{E_{\mathrm{piv}}(2+\alpha)}\right]^{\alpha-\beta} & \text{otherwise} \end{cases}$$

SBPL model

$$K\left(\frac{E}{E_{\mathrm{break}}}\right)^{\alpha}\left[1+\frac{E}{E_{\mathrm{break}}}^{\frac{1}{\Delta}}\right]^{(\beta-\alpha)\Delta}$$

ISSM model

$$K\left[1-\frac{E_{\mathrm{peak}}}{E_{\mathrm{ref}}}\left(\frac{2+\beta}{2+\alpha}\right)\right]^{\alpha-\beta}\left(\frac{E}{E_{\mathrm{ref}}}\right)^{\alpha}\left[\frac{E}{E_{\mathrm{ref}}}-\frac{E_{\mathrm{peak}}}{E_{\mathrm{ref}}}\frac{(2+\beta)}{(2+\alpha)}\right]^{\beta-\alpha}$$

Comptonized model

$$K\left(\frac{E}{E_{\mathrm{ref}}}\right)^{\alpha}\exp-\frac{(\alpha+2)E}{E_{\mathrm{peak}}}$$

Power-law model

$$K\frac{E}{E_{\mathrm{piv}}}^{\alpha}$$

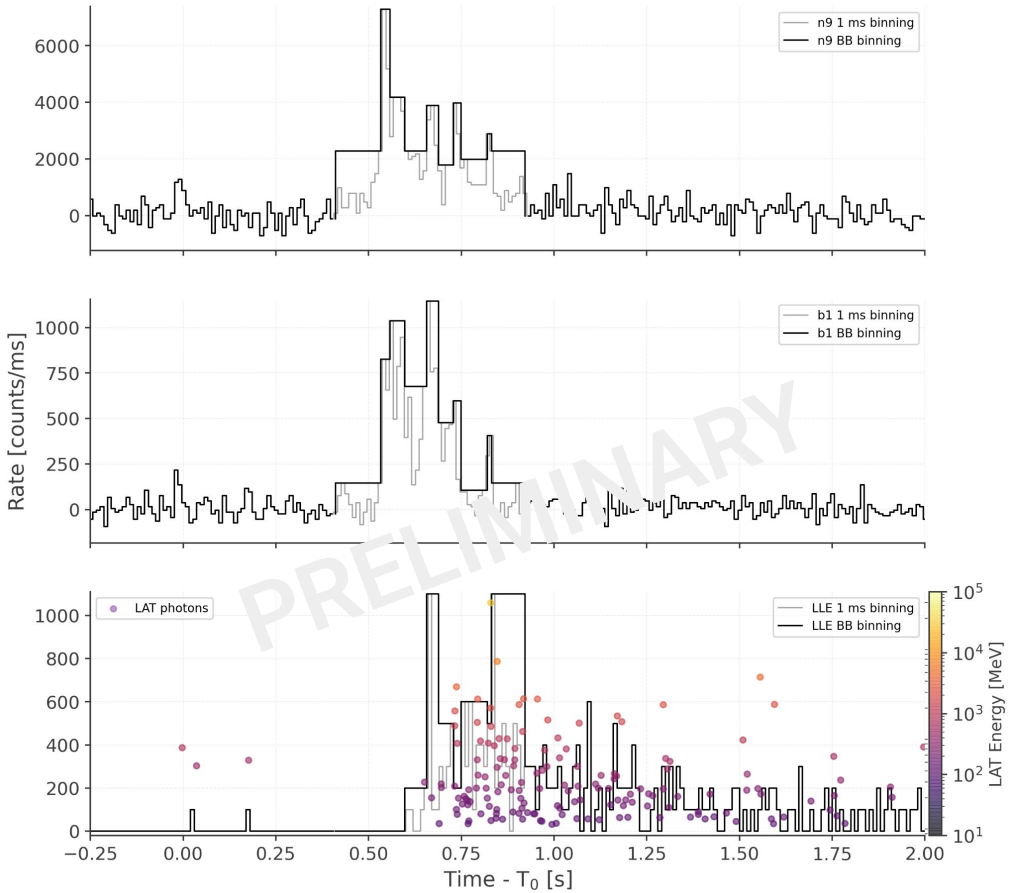
+

Black body

$$K\frac{E^2}{\exp(\frac{E}{\mathrm{kT}})-1}$$

Example of the analysis: GRB 090510

Total time interval used: T_0 - 1.05 s - T_0 + 1.91 s. **Divided into 10 bins**



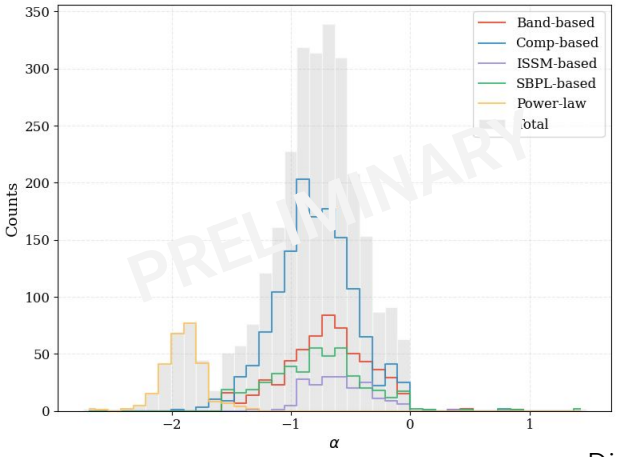
Light-curve of NaI, BGO and LLE. LAT photons are overlapped in LLE light curve

Time interval	Best fit func.
0.41 - 0.53 s	Compt.
0.53 - 0.56 s	Compt.
0.56 - 0.60 s	Compt.
0.60 - 0.66 s	Compt.
0.66 - 0.69 s	Band
0.69 - 0.73 s	Band
0.73 - 0.75 s	Band
0.75 - 0.82 s	Band+BB
0.82 - 0.83 s	SBPL
0.83 - 0.92 s	Pwl

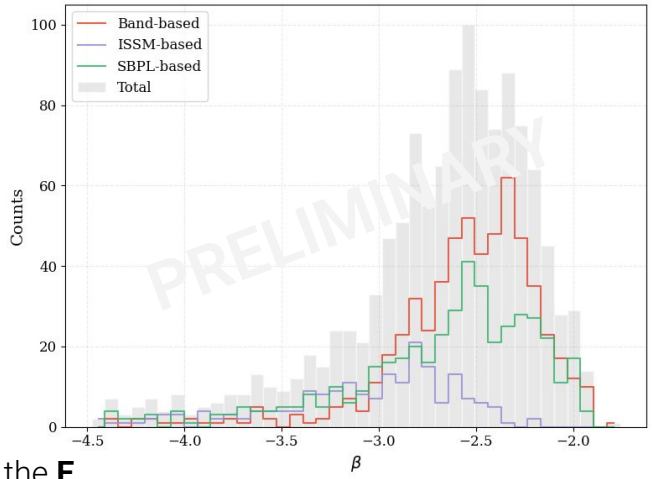
Preliminary distributions BEST sample

The total amount of analysed bins is 3270

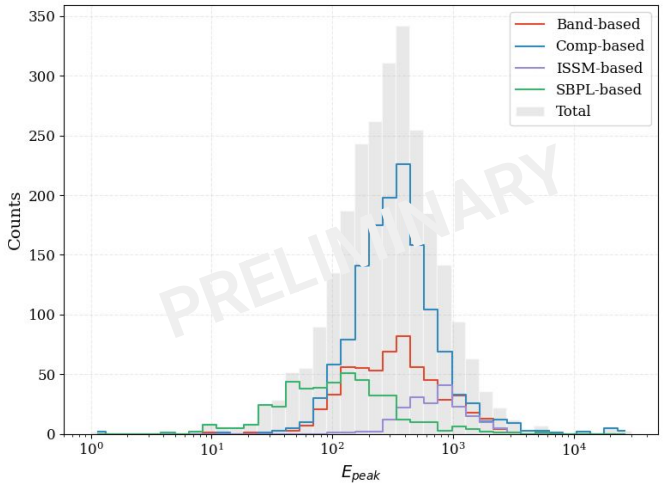
Distribution of the **α** index



Distribution of the **β** index



Distribution of the **E_{peak}**



Some preliminary general results

PRELIMINARY

Data set	Low-energy index	High-energy index	$E_{\rm peak}$ [keV]	$E_{\rm break}$ [keV]
Systematic analysis BEST	$-0.79^{+0.35}_{-0.47}$	$-2.58^{+0.33}_{-0.52}$	300^{+410}_{-190}	280^{+350}_{-150}

	Data Set	Low-energy Index	High-energy Index	$E_{\rm peak}$ (keV)	$E_{\rm break}$ (keV)
				Fluence Spectra	
GBM 10 years cat.	Poolakkil et al. 2021	$-1.08^{+0.45}_{-0.44}$	$-2.20^{+0.26}_{-0.29}$	180^{+307}_{-88}	107^{+88}_{-49}
GBM 4 years cat.	Gruber et al. (2014)	$-1.08^{+0.43}_{-0.44}$	$-2.14^{+0.27}_{-0.37}$	196^{+336}_{-100}	103^{+129}_{-63}
GBM 2 years cat.	Goldstein et al. (2012)	$-1.05^{+0.44}_{-0.45}$	$-2.25^{+0.34}_{-0.73}$	205^{+359}_{-121}	123^{+240}_{-80}
BATSE cat.	Kaneko et al. (2006)	$-1.14^{+0.20}_{-0.22}$	$-2.33^{+0.24}_{-0.26}$	251^{+122}_{-68}	204^{+76}_{-56}

Results of the distribution of spectral parameters (Poolakkil et al. 2021)

Conclusions and future perspectives

- **We have two systematic pipelines one for time-resolved and one for time-integrated.**
- **Time-resolved on 189 events, preliminary results and distribution of parameters appear to be reasonable**

To-do list:

- **Identify and study bursts that show an extra spectral components.**
- **Analyse how the results of the GBM only time-resolved analysis changes when adding LAT data** (work in progress in collaboration with D. Depalo and E. Bissaldi).
- **In depth study of the spectral evolution of the parameters, with particular interest in seeing if the firsts bins of the long GRBs are similar to the short events.**

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