Systematic time resolved analysis of gamma-ray bursts detected by Fermi-GBM

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Fermi Gamma-ray Space Telescope

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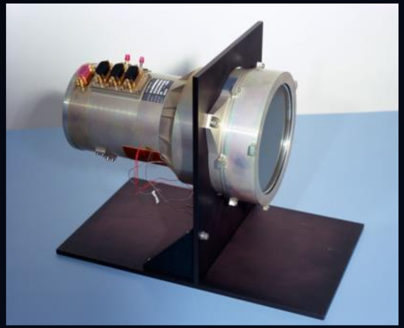
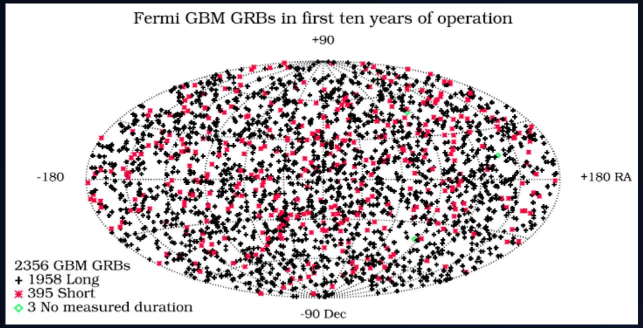
DIPARTIMENTO INTERATENEO DI FISICA

INTRODUCTION

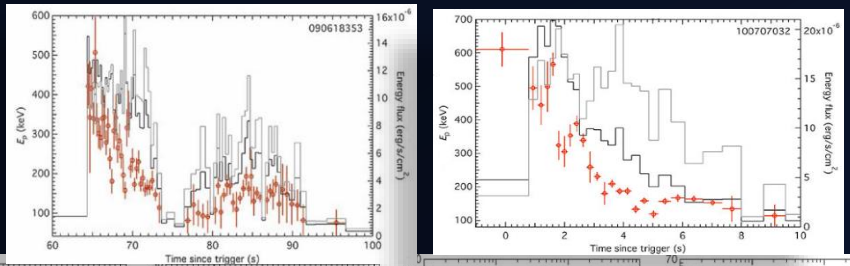
- During the last 17 years, the Fermi GBM has been the most prolific GRB detector ever, with more than 4000 observed GRBs to date.
- So far, only 1 time-resolved spectral catalog has been published (Yu et al. 2016), which covers the first 4 years of the mission (81 events).
- Here we present a systematic time-resolved analysis of a subsample of bright GRBs.

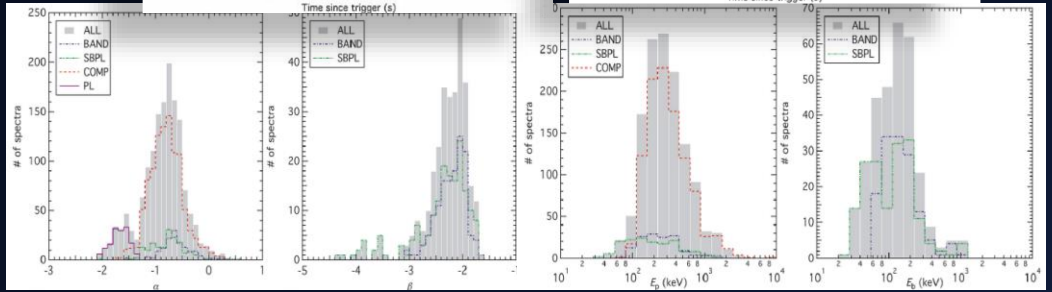


Von Kienlin + 2020



Yu + 2016





NEW PIPELINE

Old analysis: 4-years time resolved spectral catalog (2016)

- Software used for the analysis: RMFIT v4.3BA3
- Binning method: signal-to-noise ratio

Current analysis (2025)

- Python-based data tools: Gamma-ray Data Tools[1,2]
- Binning method: Bayesian Blocks

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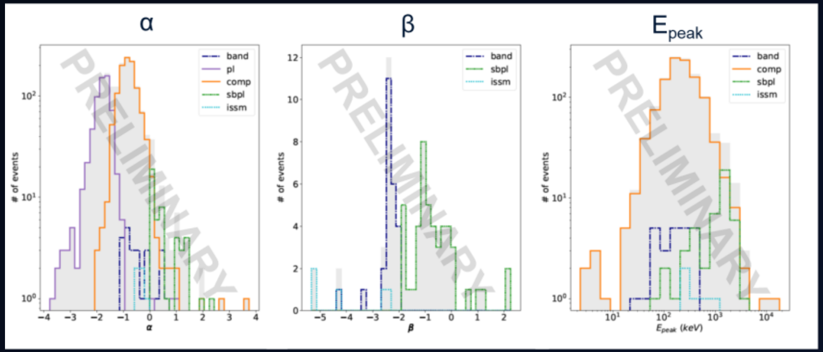
1. https://astro-gdt.readthedocs.io/en/latest/index.html#gdt-core
2. https://astro-gdt.readthedocs.io/projects/astro-gdt-fermi/en/latest/index.html

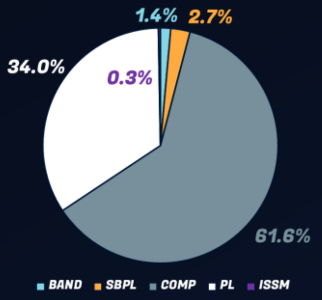
BURST SELECTION CRITERIA

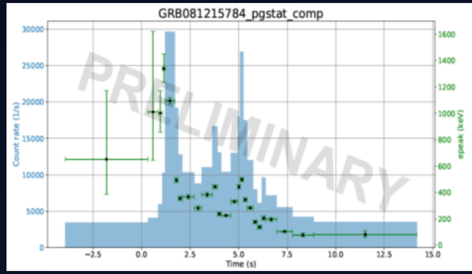
At least one of these criteria must be satisfied:

- Energy fluence $f > 5 \cdot 10^{-6}$ erg cm^{-2}
- Peak photon flux $F_p > 15$ photons cm^{-2} s^{-1} (in either 64 or 1024 ms binning timescales)



First test of the pipeline in 2023: 20 of the brightest GRBs from the entire mission lifetime





Second test in 2024: subsample of bright GRBs from 2008 to 2010 (results presented at the 11th Fermi Symposium, 5th Gravi-gamma-nu workshop and IFAE 2025)

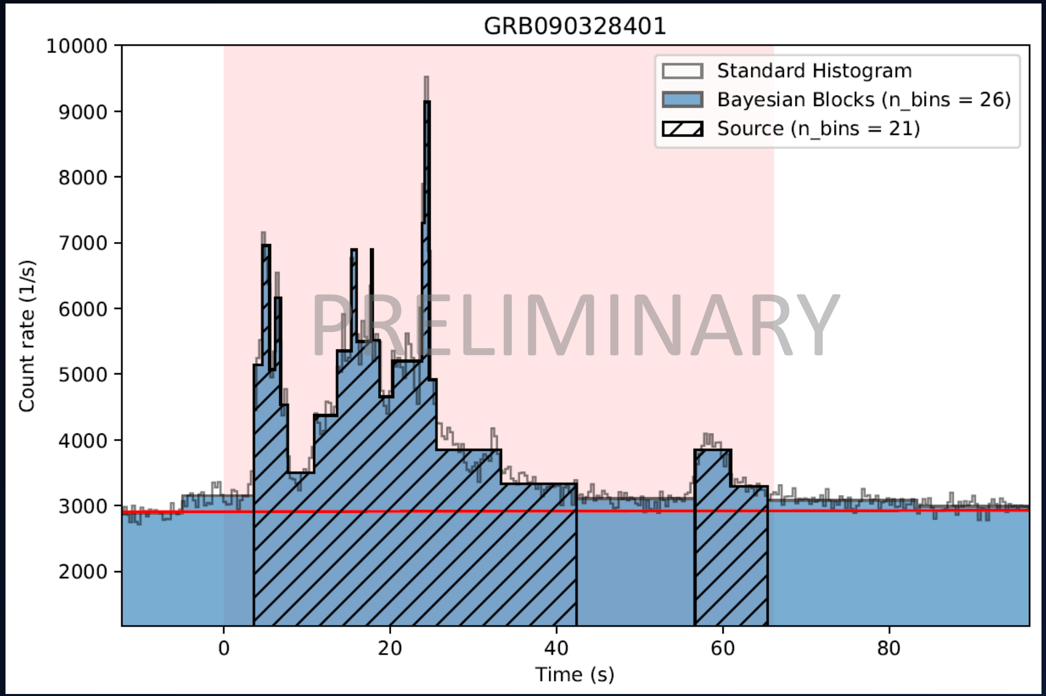
Current test: all the bursts detected by GBM in the first 6 years of the mission (1413 triggers from July 11, 2008 to July 14, 2014).
The bright subsample analyzed consists of 572 events (47 short).

BAYESIAN BLOCKS

The Bayesian Blocks algorithm* has been applied on each event using only the TTE file from the brightest NaI detector (energy range 8 – 900 keV).

- Algorithm applied to a smaller time interval (to reduce computation time)
- Events with T90 < 0.3 s are not divided using BB algorithm but we use a fixed bin width of 16 ms

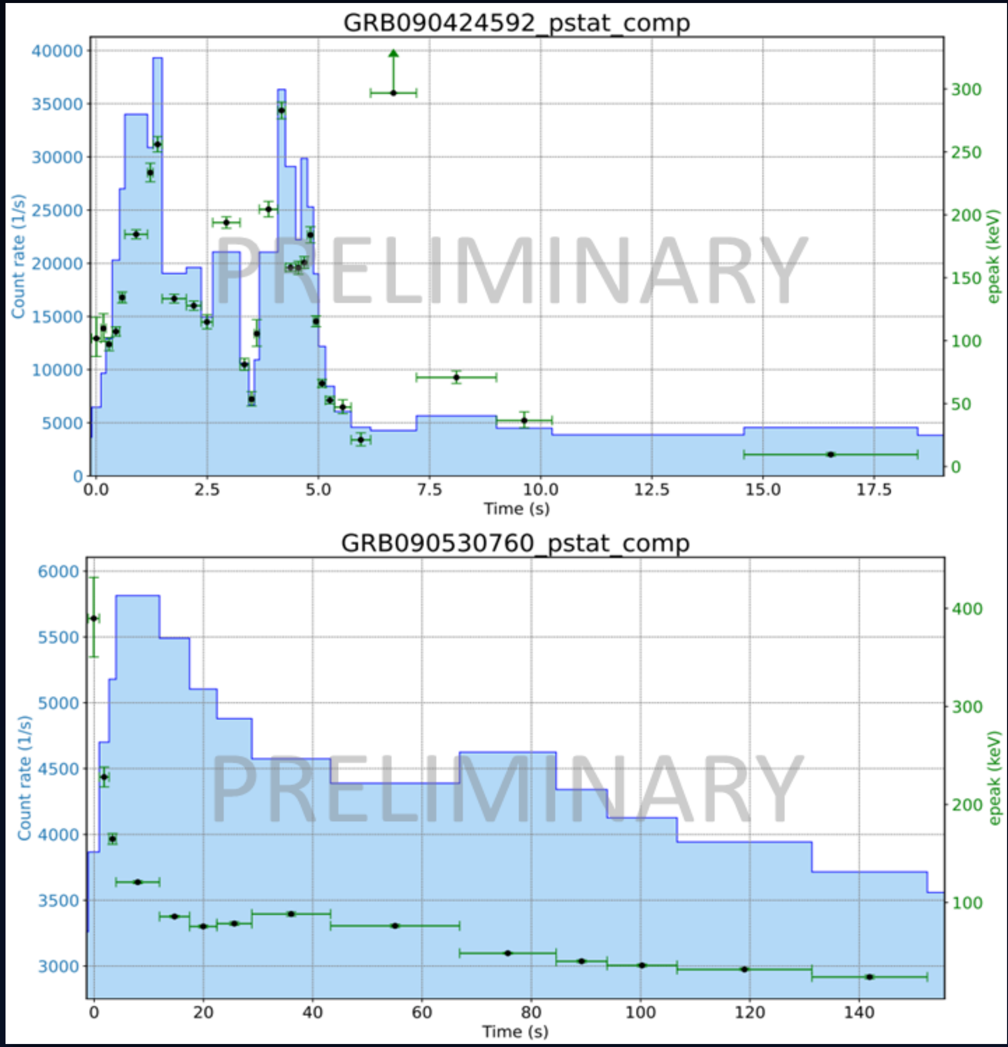
Only GRBs with 3 or more bins for which signal is above 5 sigma significance over the background (red line fitted with an order 2 polynomial) are selected for next phase.



*Parts of codes from 3ML framework
https://github.com/threeML/threeML

GOOD FITS

- 419 GRBs (35 short) survived the BB cut
- 4975 total intervals have been fitted with 4 models:
  - Power-Law (PL)
  - Cutoff Power-Law (COMP)
  - Band function (BAND)
  - Smoothly-Broken Power-Law (SBPL)
- A fitted model is considered GOOD if:
  - $\sigma_\alpha < 0.2$
  - $\sigma_\beta < 1.0$
  - $\sigma_A/A < 0.2$
  - $\sigma_E/E < 0.4$ (both E_{peak} and E_{break})



BEST FITS

For each interval fitted, among all the GOOD models, the BEST model is chosen as the one with the lowest value of the BIC (Bayesian Information Criterion):

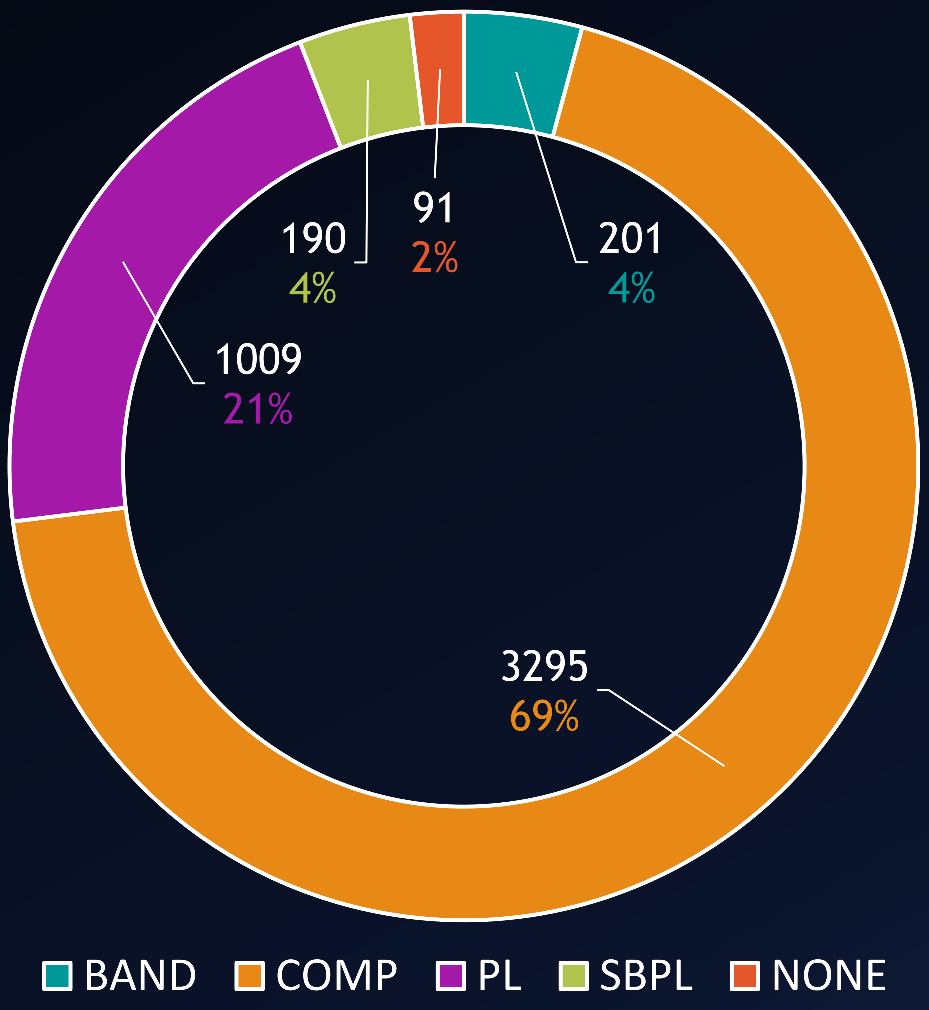
$$BIC = k \ln n - 2 \ln \mathcal{L}$$

where:

k = number of free parameters

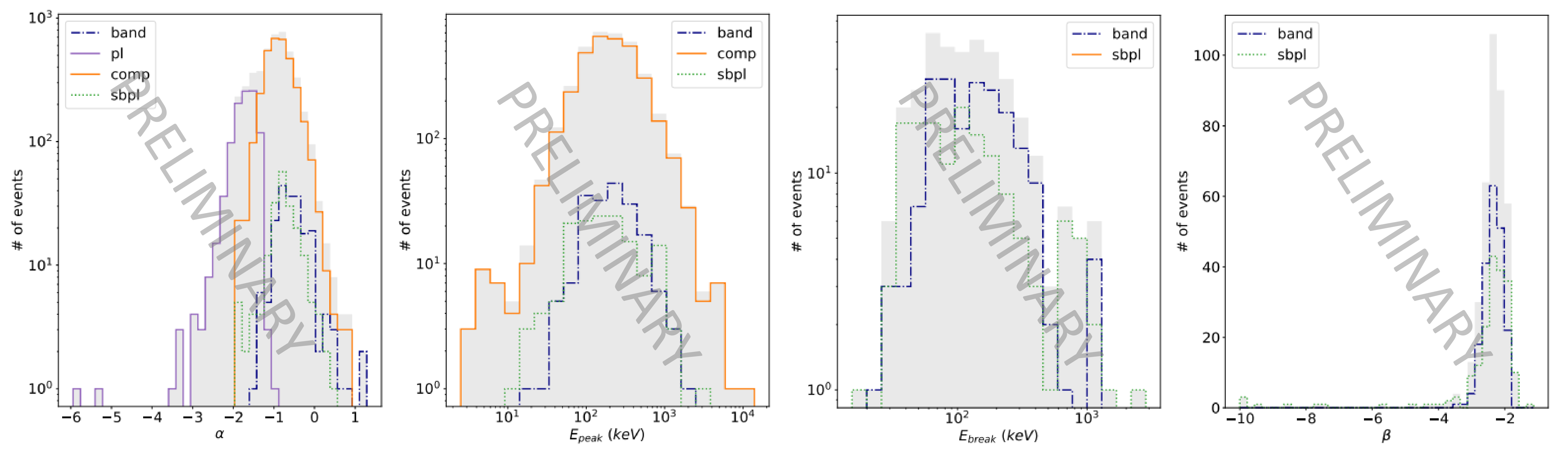
n = sample size

$\mathcal{L}$ = likelihood function



PARAMETER DISTRIBUTIONS

- α peak at ~ -0.9 (but PL values are lower, peaking around -1.7)
- E_{peak} and E_{break} mean values ~ 200 keV, E_{break} values generally lower
- β values show a peak around -2.2 ÷ -2.3



SUMMARY

- Automation of the time-resolved analysis pipeline through python based API
- Bayesian Blocks algorithm for meaningful binning
- Test of the pipeline on a subsample of GRBs from 2008-2014
- GOOD and BEST model selection

TO-DO LIST

- Errors and bugs fixing
- Additional studies on very short events
- Extending the sample up to 2024

THANKS FOR YOUR ATTENTION!

BACKUP

DETECTORS AND ENERGY CHANNELS

- Detector masks from the spectral catalog (max 3 NaI and 1 BGO)
- NaI energy range: 8 – 900 keV
- BGO energy range: 250 keV – 40 MeV

BACKGROUND FITTING

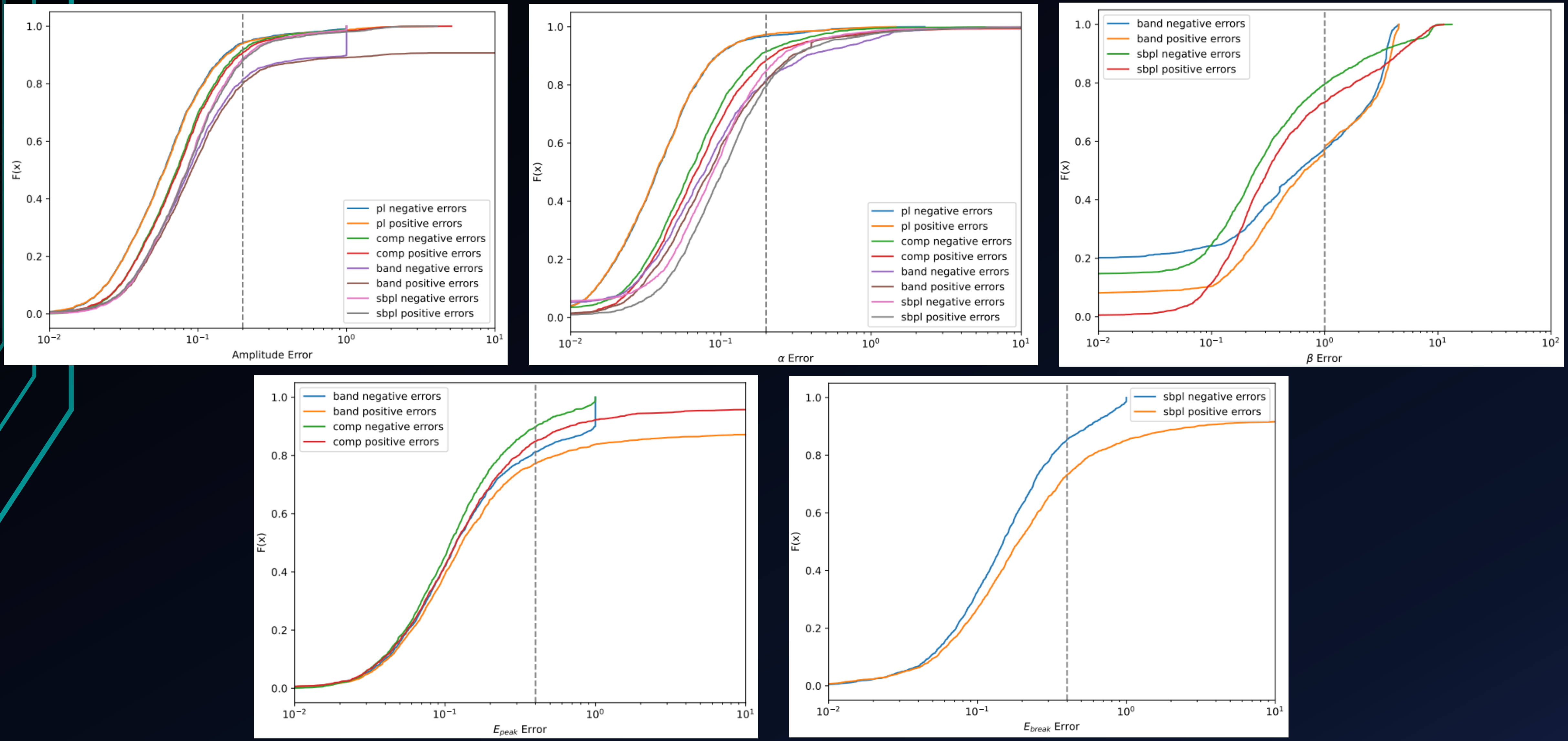
In some cases, the order of the polynomial is lower than 2.

MODELS USED

All bins fitted in the source intervals with 4 models:

- Power-Law (PL) -> free parameters: A, α
- Cutoff Power-Law (COMP) -> free parameters: A, α, E_{peak}
- Band function (BAND) -> free parameters: A, α, E_{peak}, β
- Smoothly-Broken Power-Law (SBPL) -> free parameters: A, α, E_{break}, β

CUMULATIVE ERROR DISTRIBUTIONS



E_{PEAK} AND E_{BREAK} IN BAND AND SBPL

The BAND model has only E_{PEAK} as one of its parameters, while SBPL has only E_{BREAK}. However, there are some formulas that allow us to calculate E_{BREAK} for BAND and E_{PEAK} for SBPL (Kaneko et al. 2006).

- BAND's E_{BREAK}: $$E_b = \left(\frac{\alpha-\beta}{\alpha+2}\right)\frac{E_p}{2} + 4$$
- SBPL's E_{PEAK} : $$E_p = 10^x E_b, \qquad x = \Delta \tanh^{-1}\left(\frac{\alpha+\beta+4}{\alpha-\beta}\right)$$

(only valid if $\alpha \geq -2$ and $\beta \leq -2$)