GRAN SASSO SCIENCE INSTITUTE
SCHOOL OF ADVANCED STUDIES
Scuola Universitaria Superiore

Istituto Nazionale di Fisica Nucleare

Study of the prompt emission of Gamma-ray Bursts

Samanta Macera, 3rd year PhD student

Advisors:

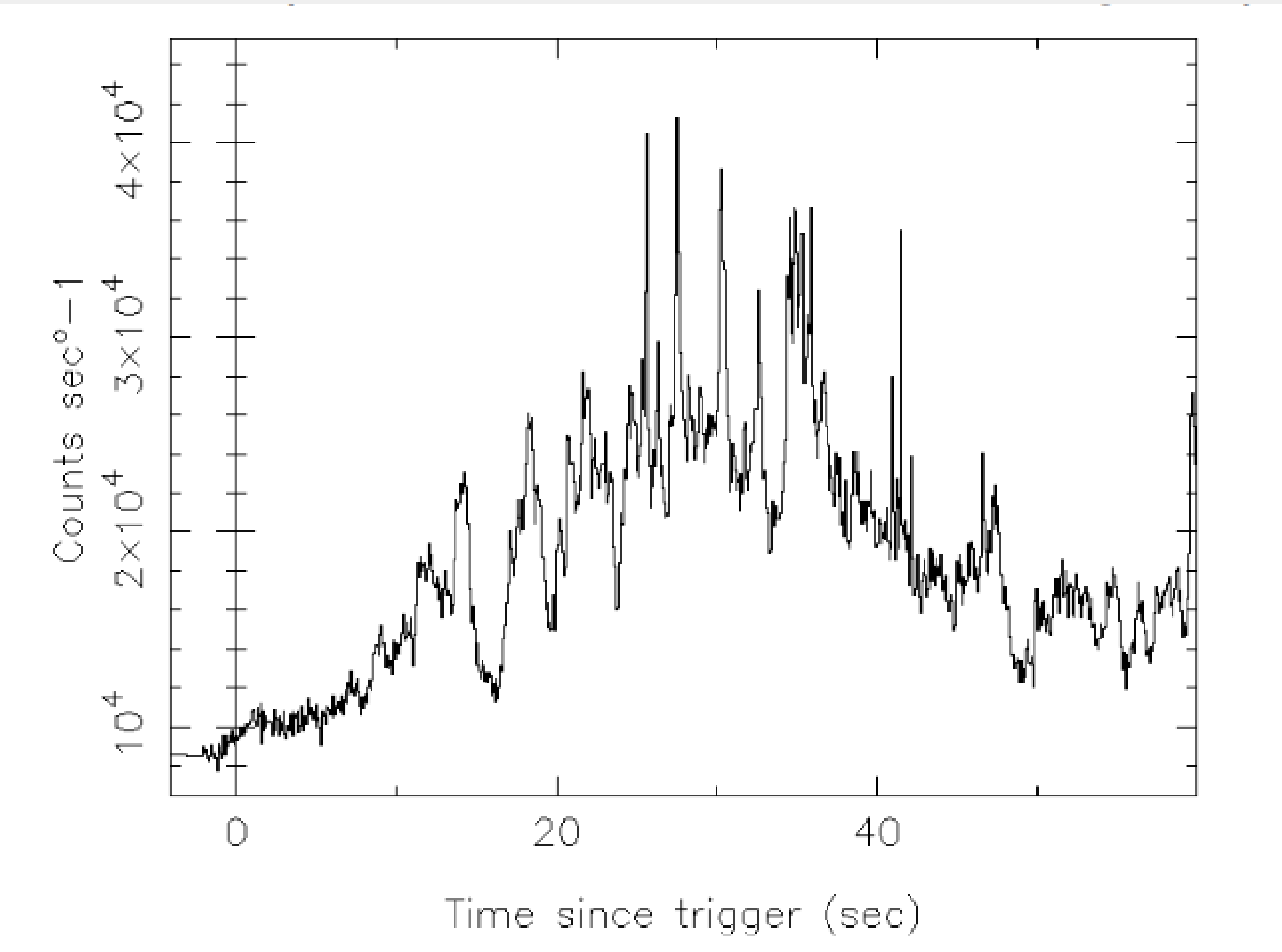
Dr. Gor Oganesyan
Dr. Biswajit Banerjee

Prompt emission of GRBs

1. Prompt emission at GeV energies
2. Modelling of the thermal component in prompt spectra
3. Early X-ray emission in GRBs

Prompt emission

Lightcurve



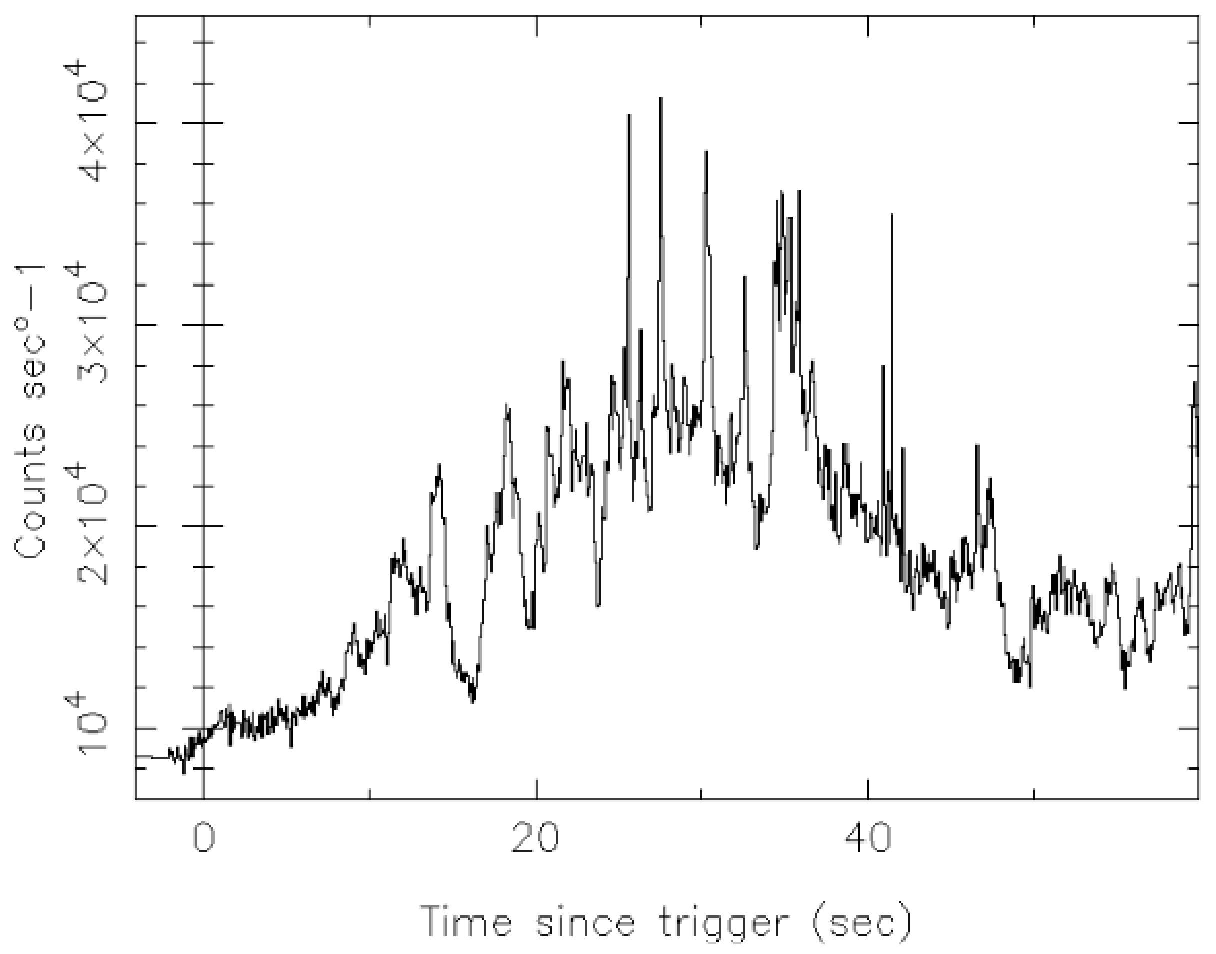
Sari and Piran, 1997

- Burst of MeV photons
- Energy $E_{iso}{\sim}10^{50} - 10^{54} erg$
- Duration 0.1 – 1000 s
- Variability 0.01 – 1 s

→ Internal dissipation of an ultrarelativistic jet

Prompt emission

Lightcurve



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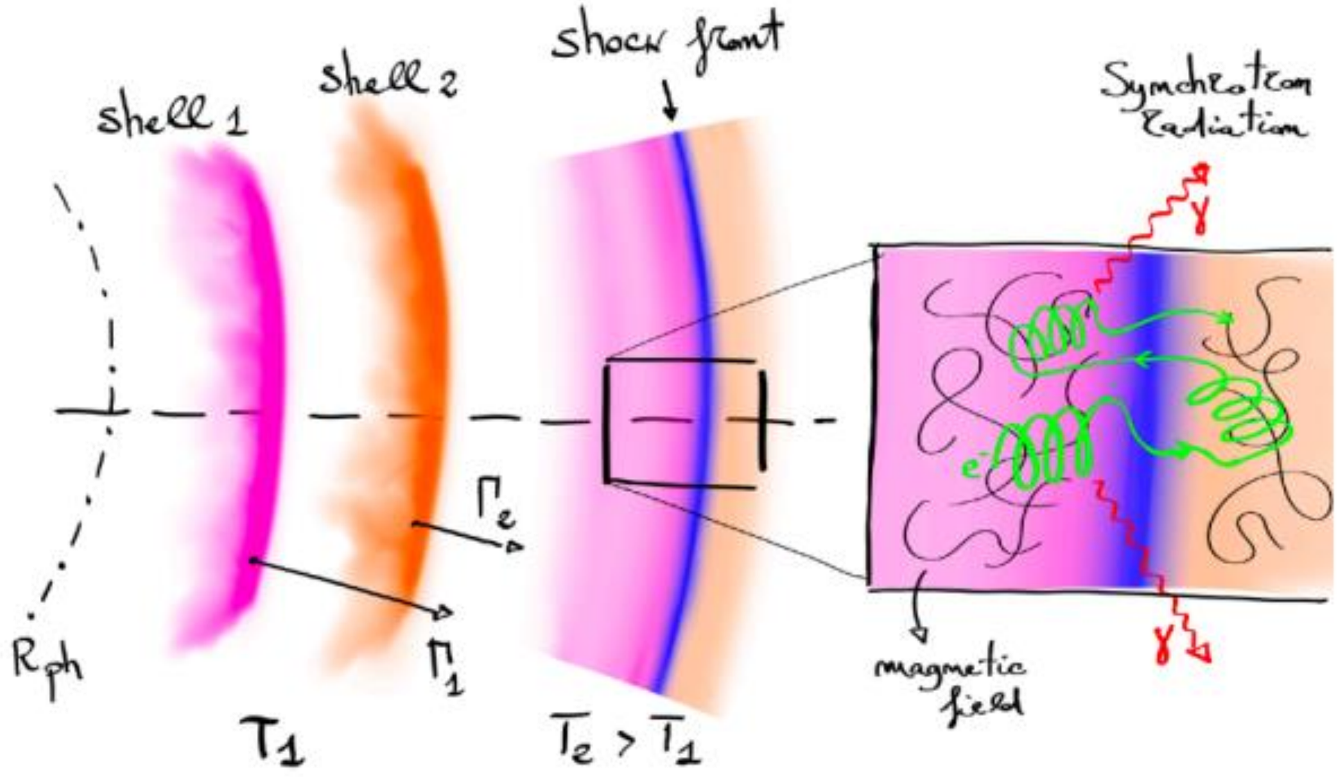
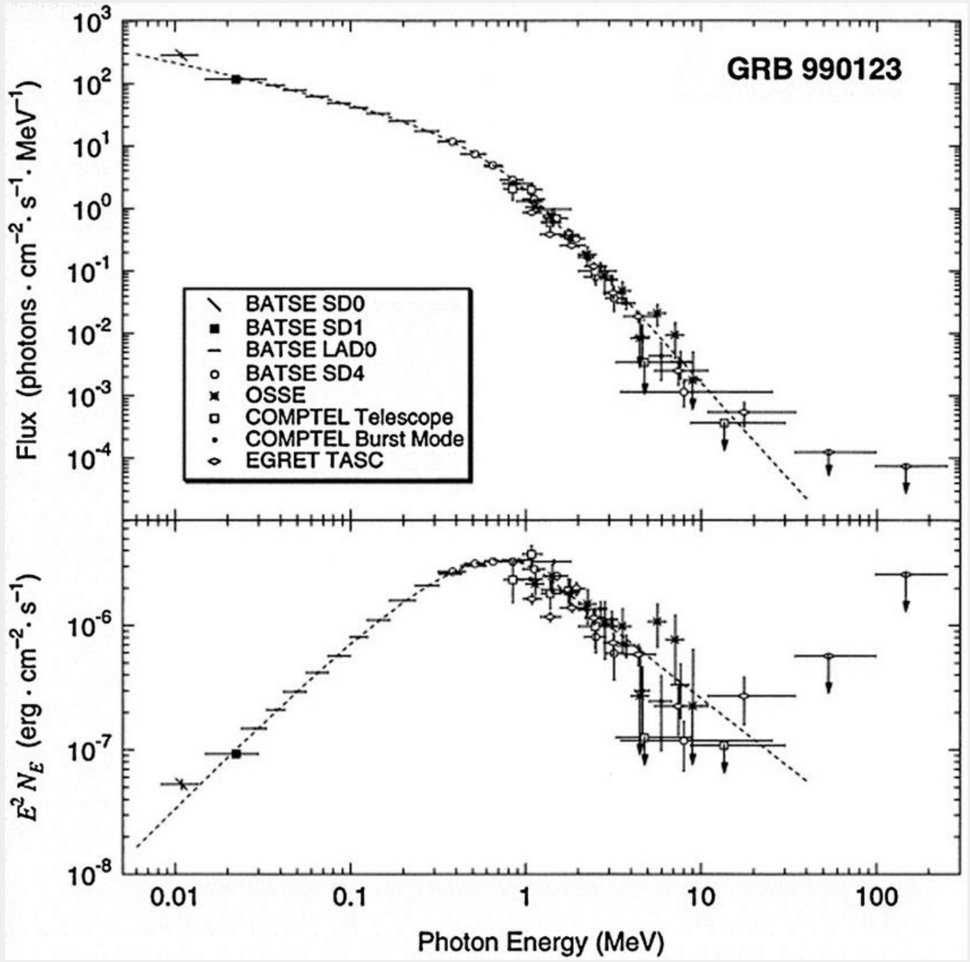


Sketch by Samuele Ronchini

State-of-art

Band Model

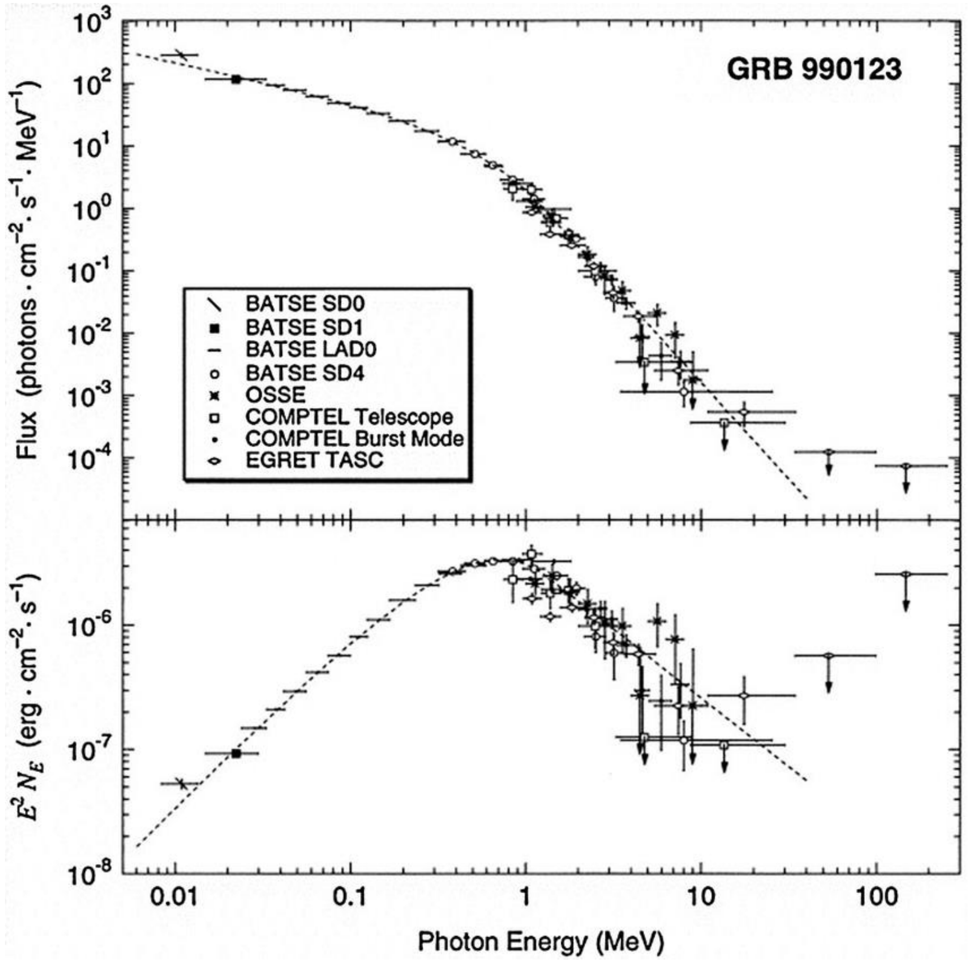


Briggs et al, 1999

Peak energy 100 keV – 1 MeV

State-of-art

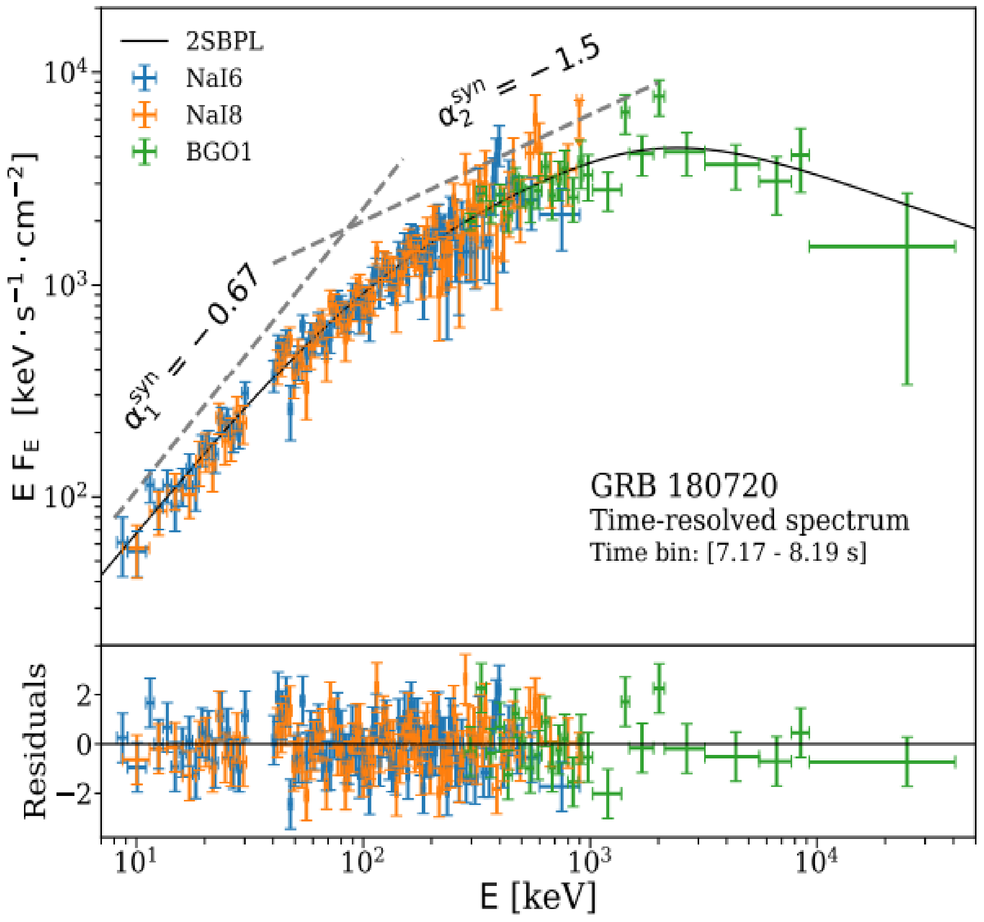
Band Model



Briggs et al, 1999

Peak energy 100 keV – 1 MeV

Spectral breaks



Oganesyan et al, 2017-2018
Ravasio et al, 2019

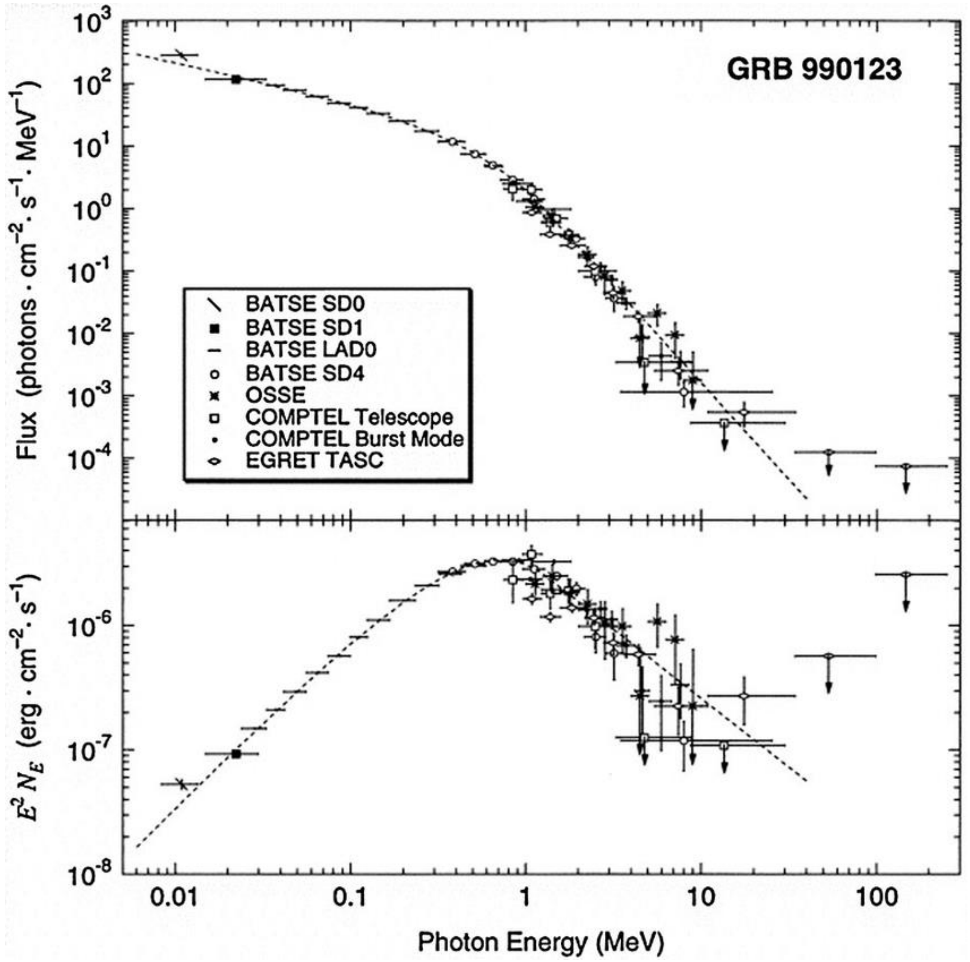
Low energy breaks empirically consistent with Synchrotron

State-of-art

Band Model

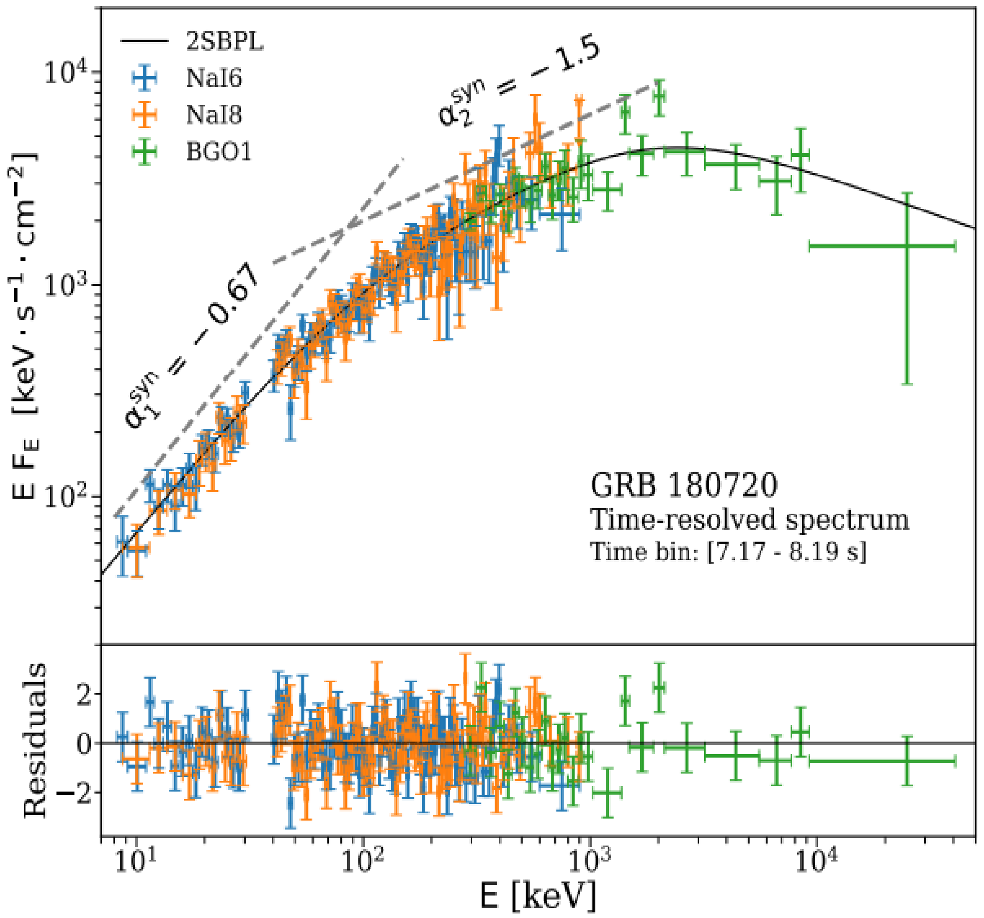
Spectral breaks

Synchrotron



Briggs et al, 1999

Peak energy 100 keV – 1 MeV



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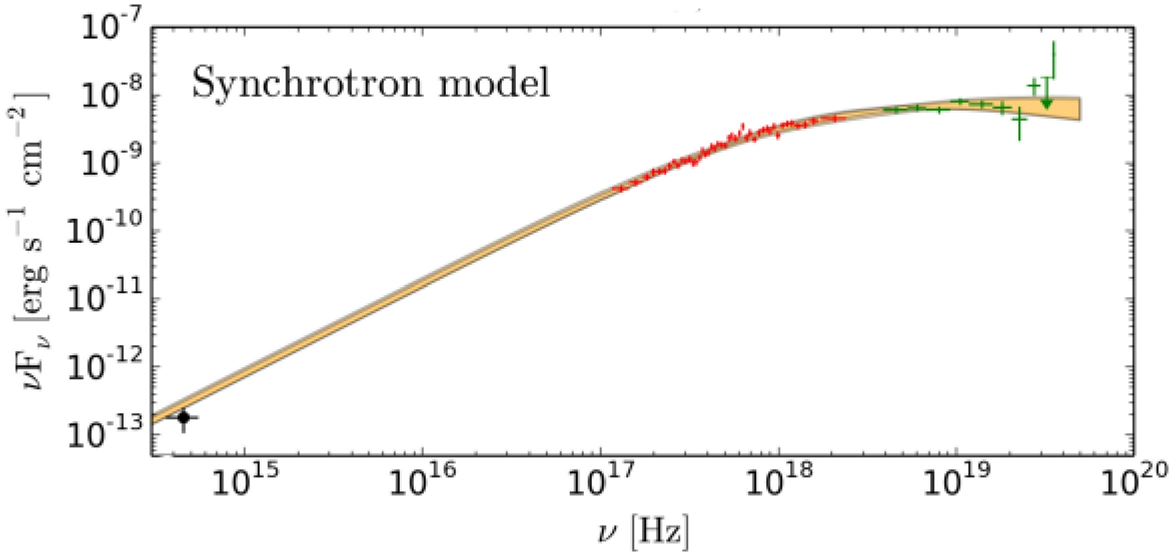
Low energy breaks empirically consistent with Synchrotron

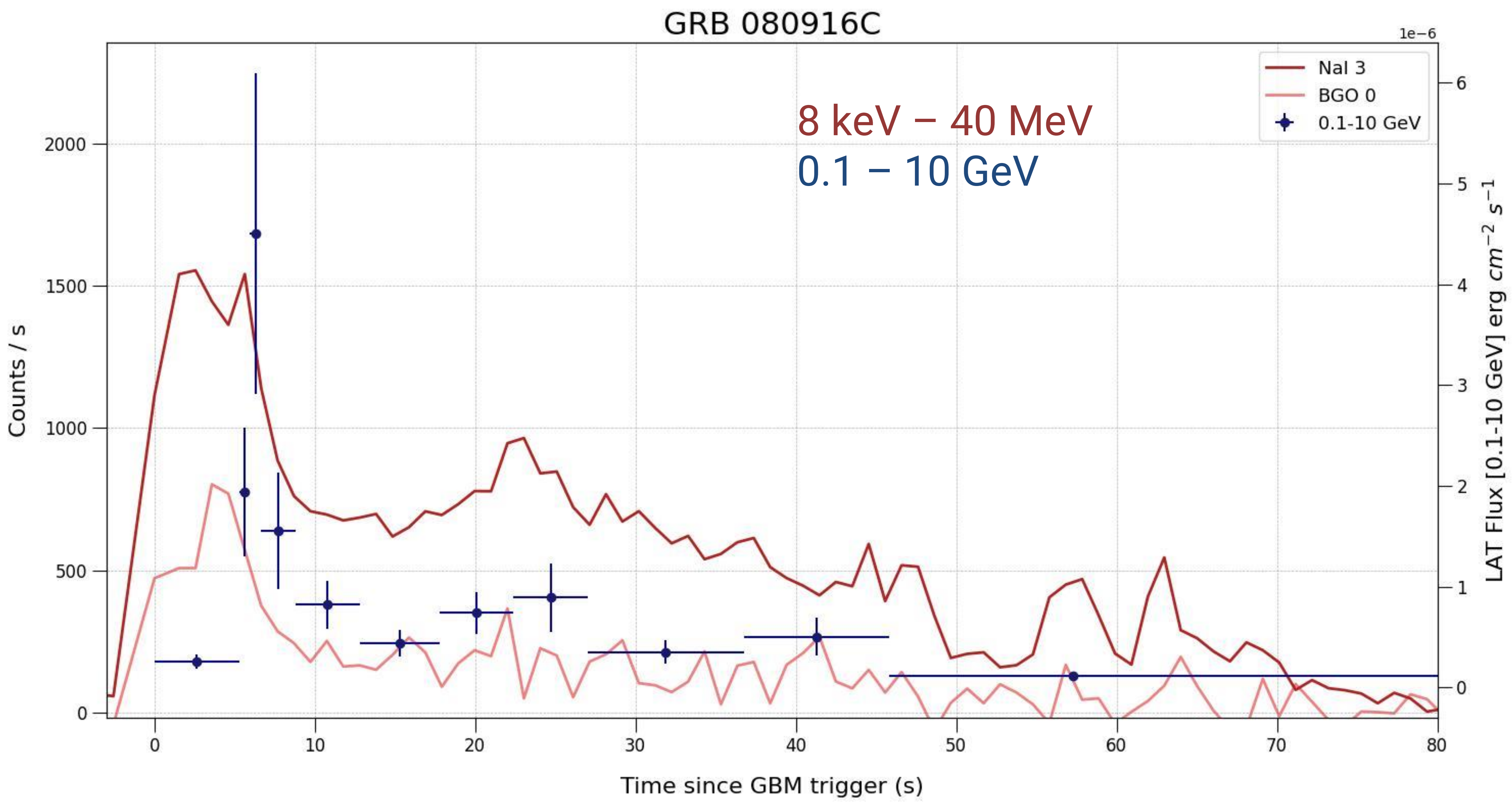


Oganesyan et al, 2019

From optical to MeV: synchrotron predicts the optical flux

Burgess et al 2020

Zhang et al 2020, ...



- High energy emission is delayed

  [Tajima et al. 2009 for GRB080916C]
  [Abdo et al. 2009 for GRB090902B]

- For some GRBs early GeV emission follows variability of prompt

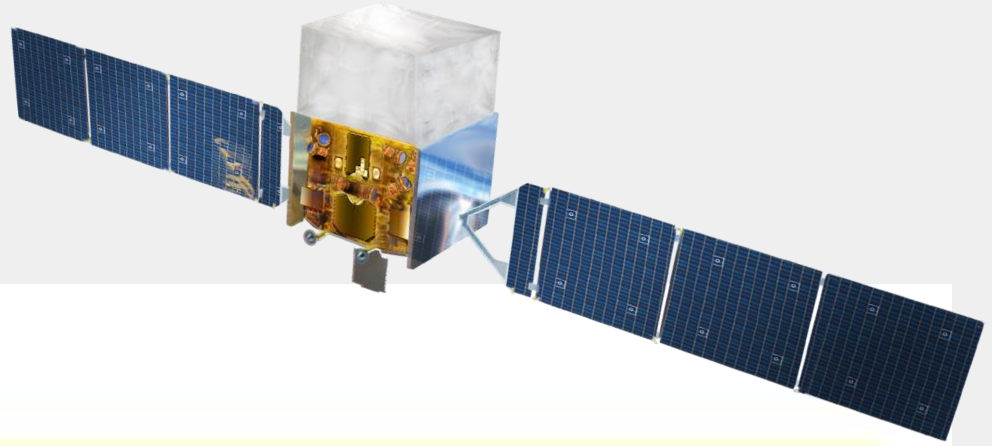
  [Zhang et al. 2011]

- Early Afterglow or Prompt origin?

  [Ghisellini et al. 2009, Kumar & Barniol Duran, 2009, Maxham et al 2011]

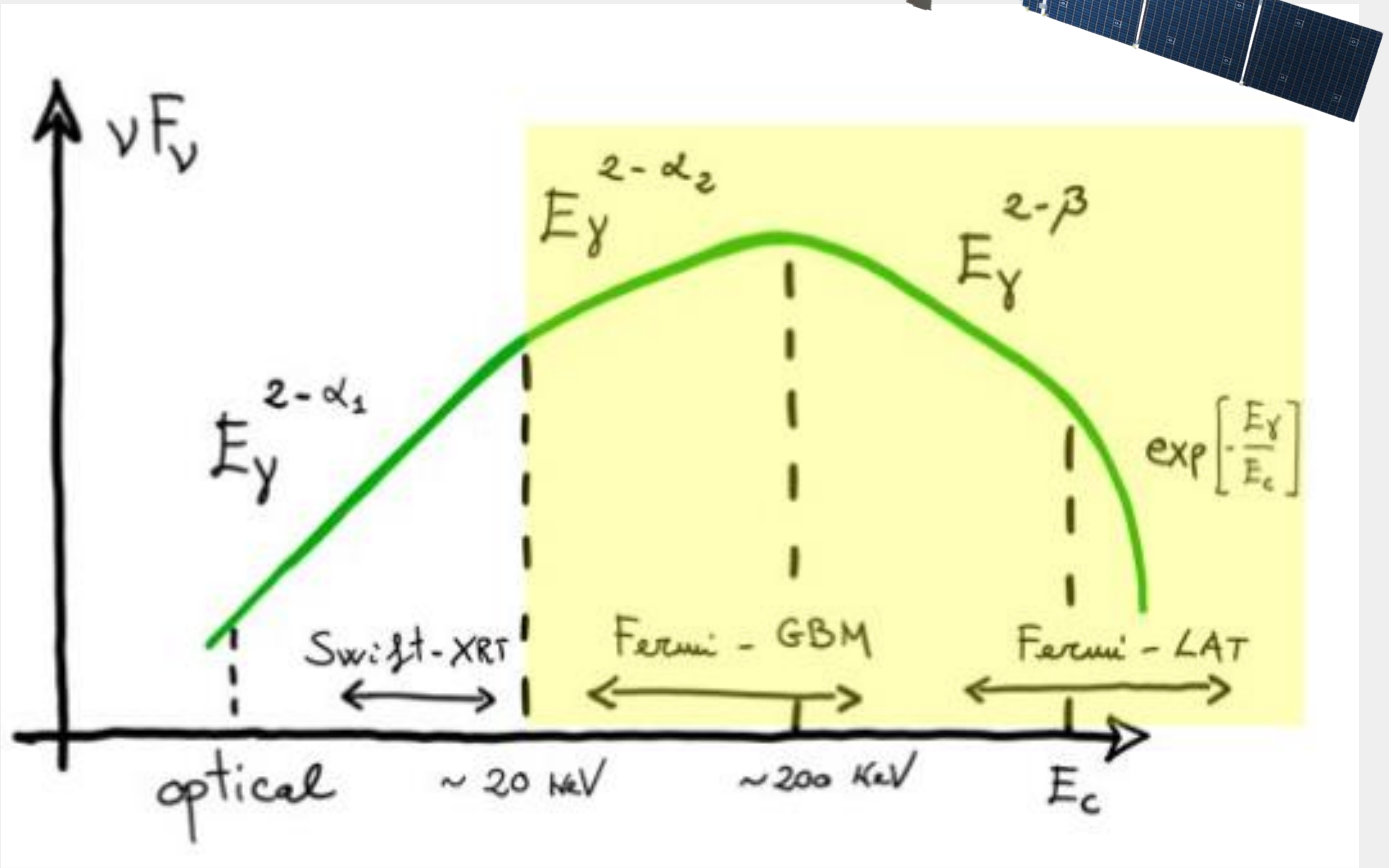
Prompt emission at higher energies

High energy emission simultaneous with the prompt phase



Prompt emission at high energies

Extension of the spectrum up to GeV

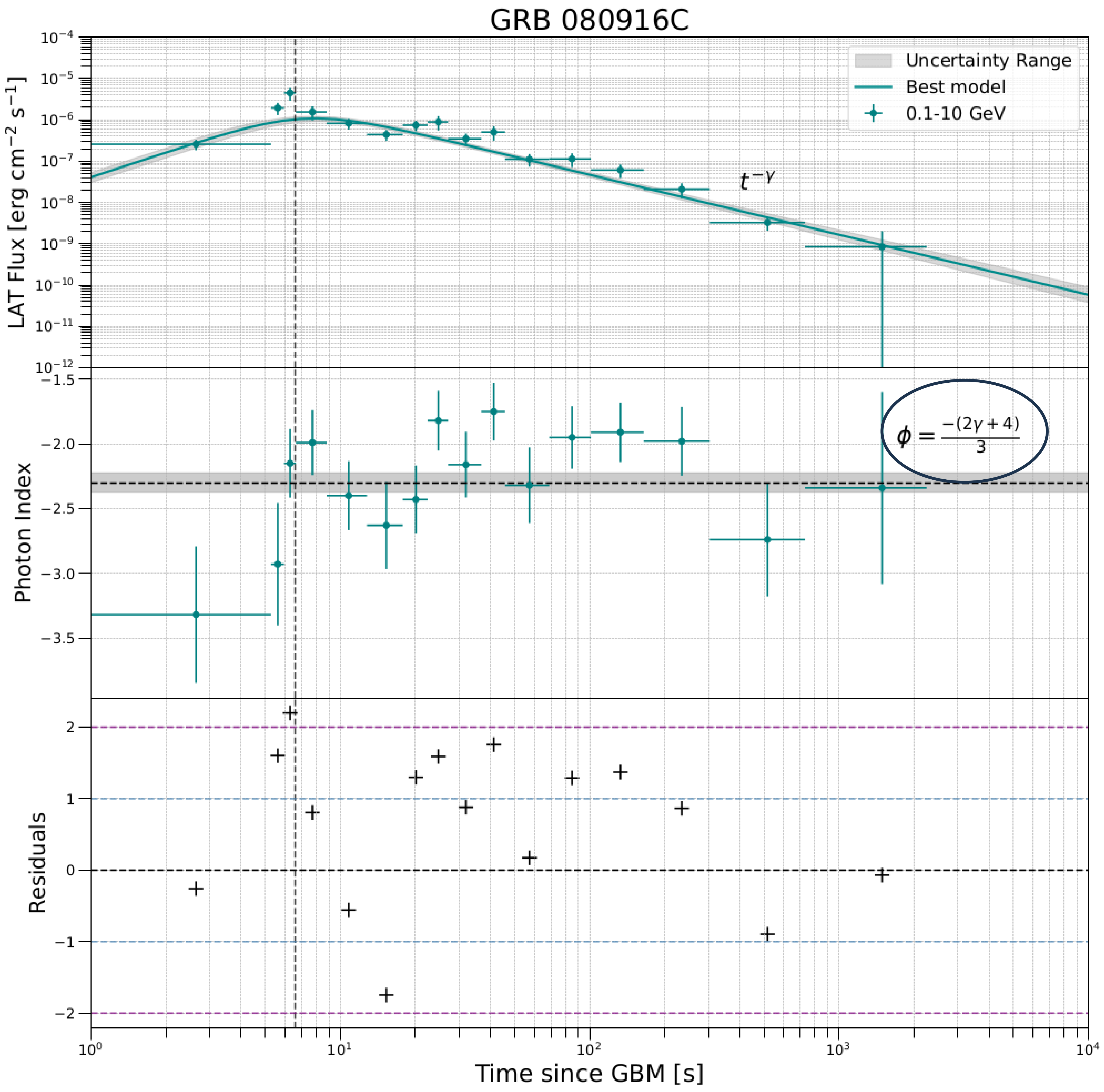


Fermi/GBM	LLE (LAT-low-energy)	Fermi/LAT
8 keV – 40 MeV	30 MeV – 100 MeV	100 MeV to > 300 GeV

Timing analysis

→ Does the emission follow the afterglow LC time-evolution?

Spectral analysis needed



Sample Selection

At least three significant temporal bins (>5 σ detection) simultaneous with Fermi-GBM

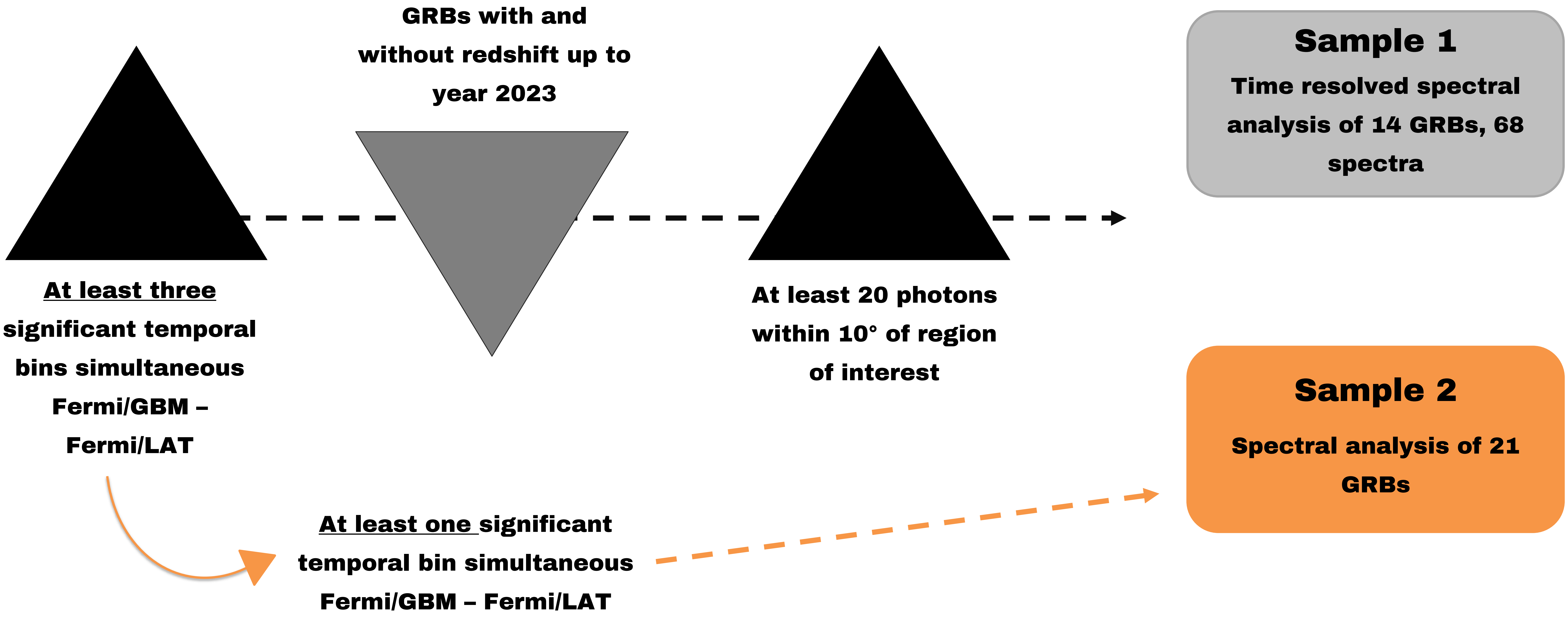
GRBs with and without redshift up to year 2023

At least 20 photons within 10° of region of interest around the GRB location

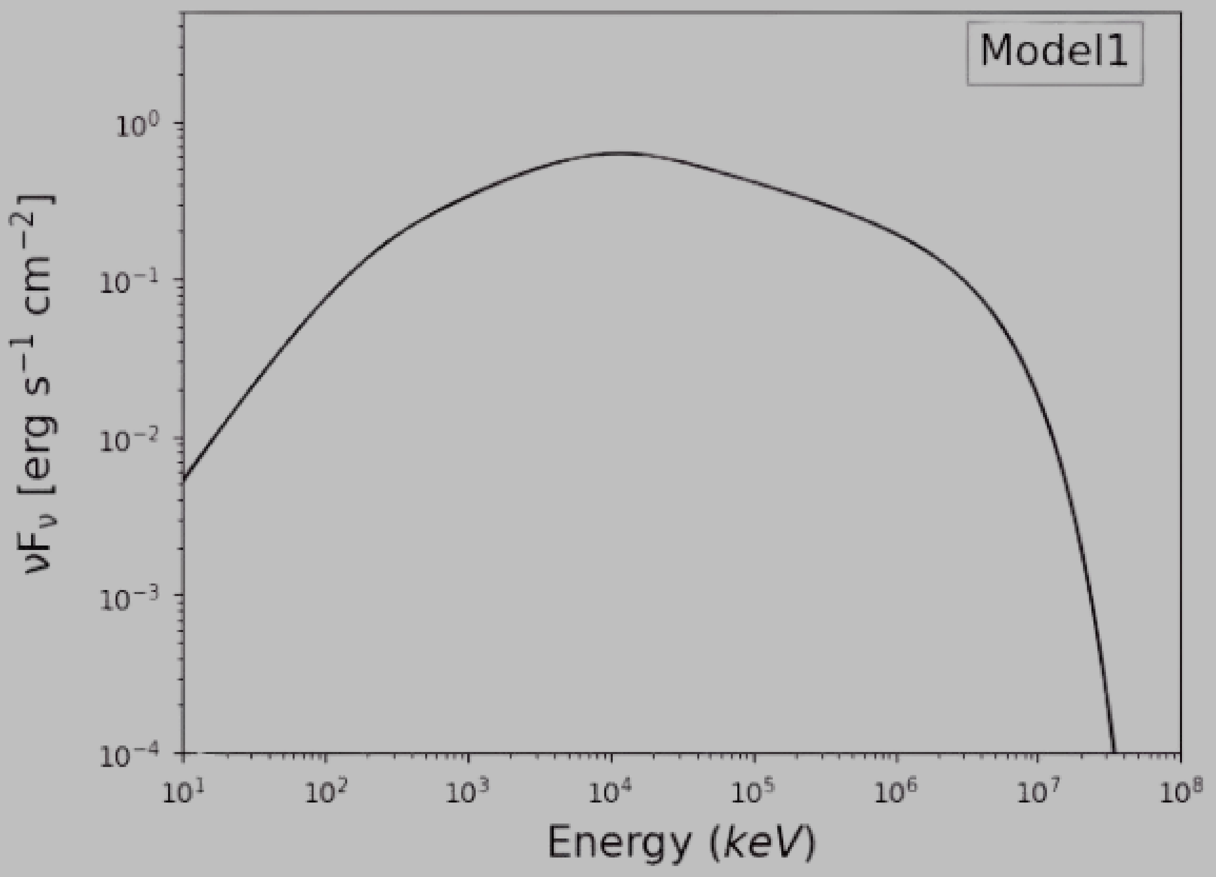
Sample 1

Time resolved spectral analysis of 14 GRBs, 80 spectra

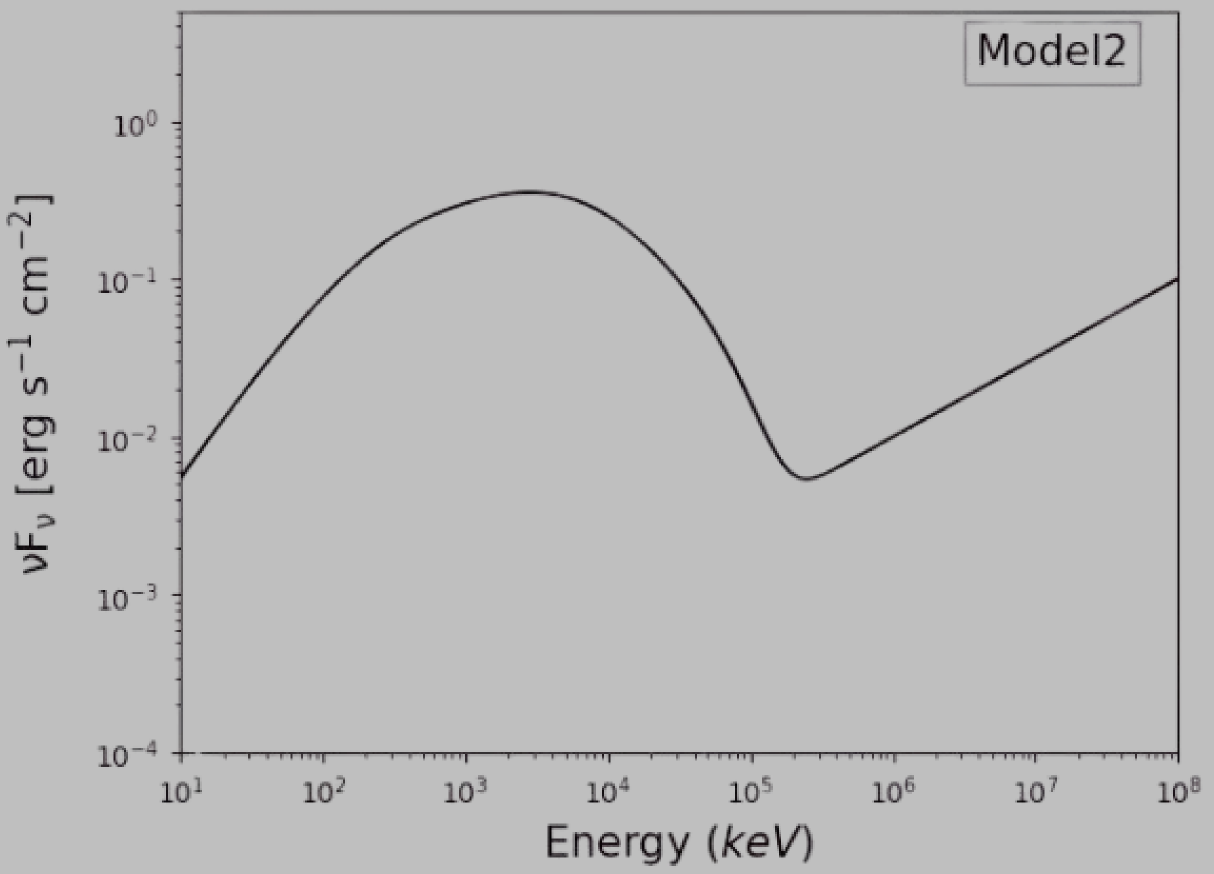
Sample Selection



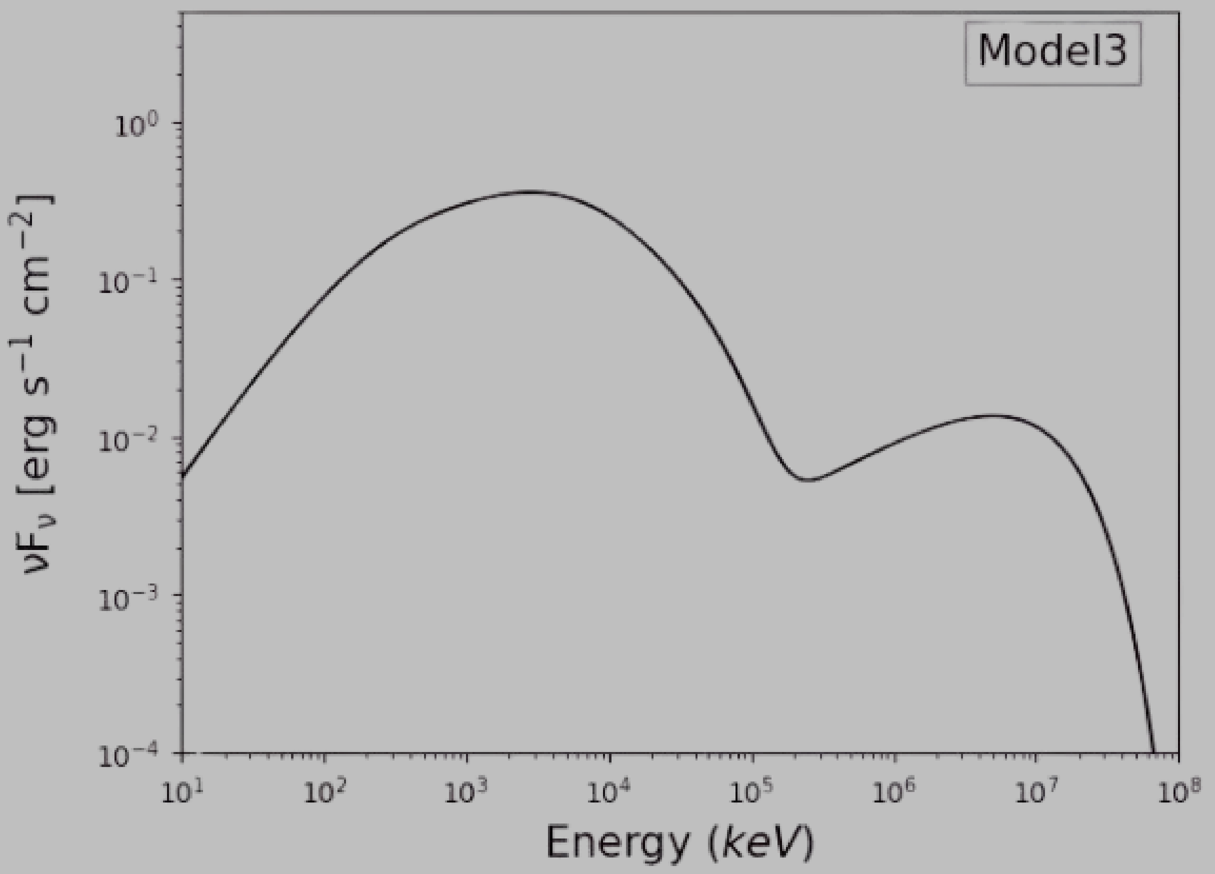
Models Tested



Synchrotron with high energy cutoff



Synchrotron with a power law



Synchrotron with a cutoff power law

35 GRBs analysed, 89 Spectra

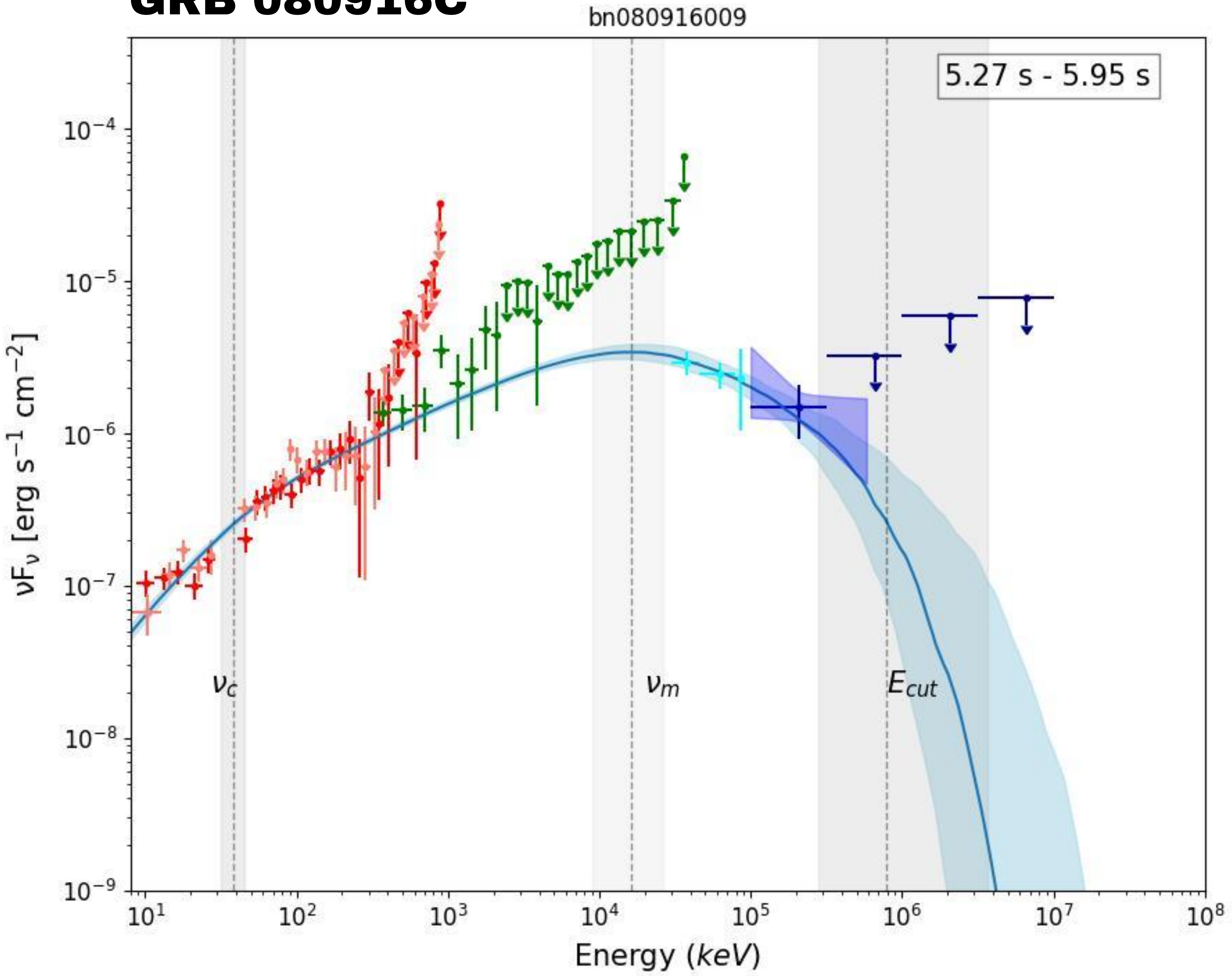
01 70 spectra and 32 GRBs best fitted with pure synchrotron

02 18 spectra and 3 GRBs best fitted with synchrotron + power-law

03 1 spectrum best fitted with synchrotron + cutoff power-law

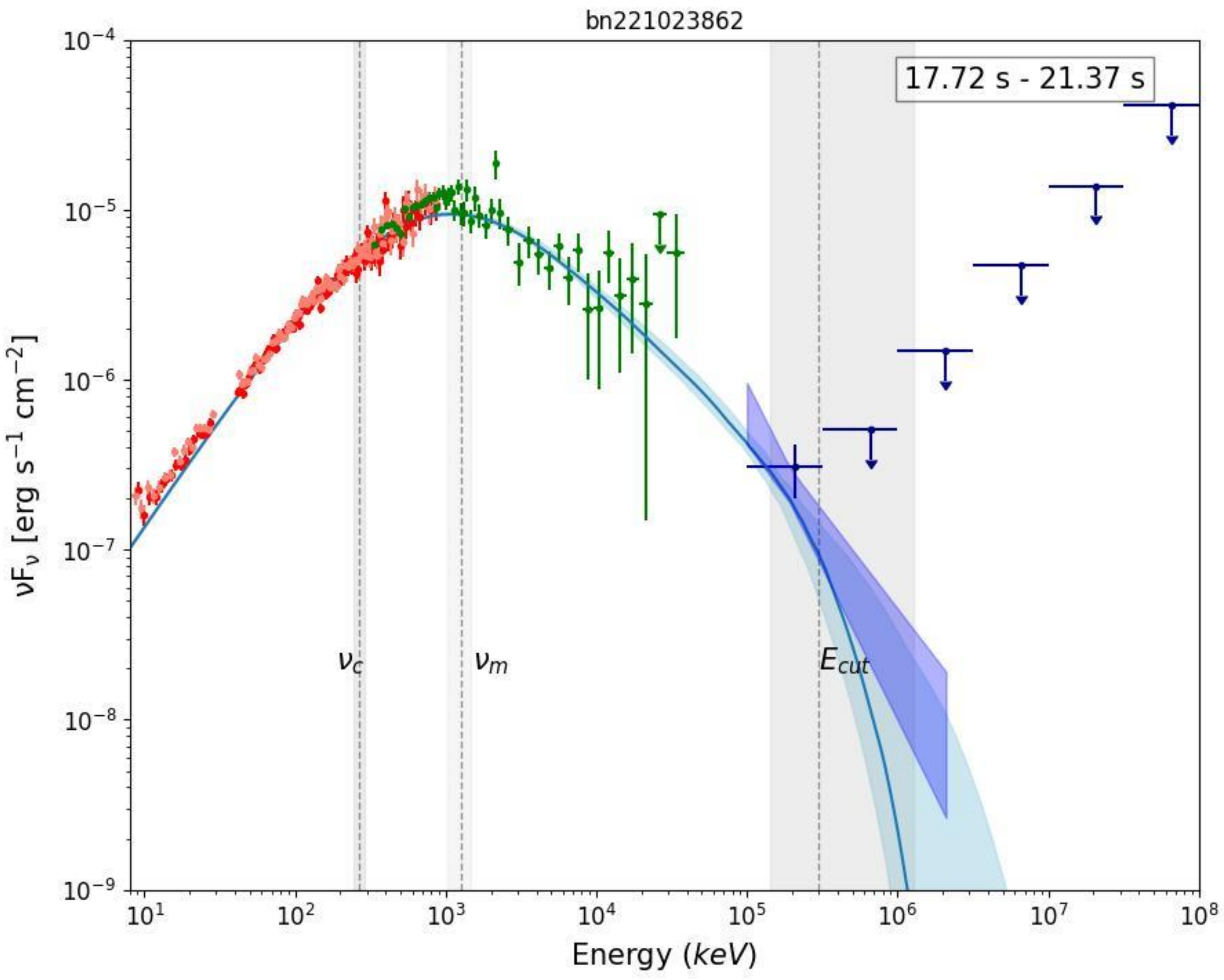
Model 1

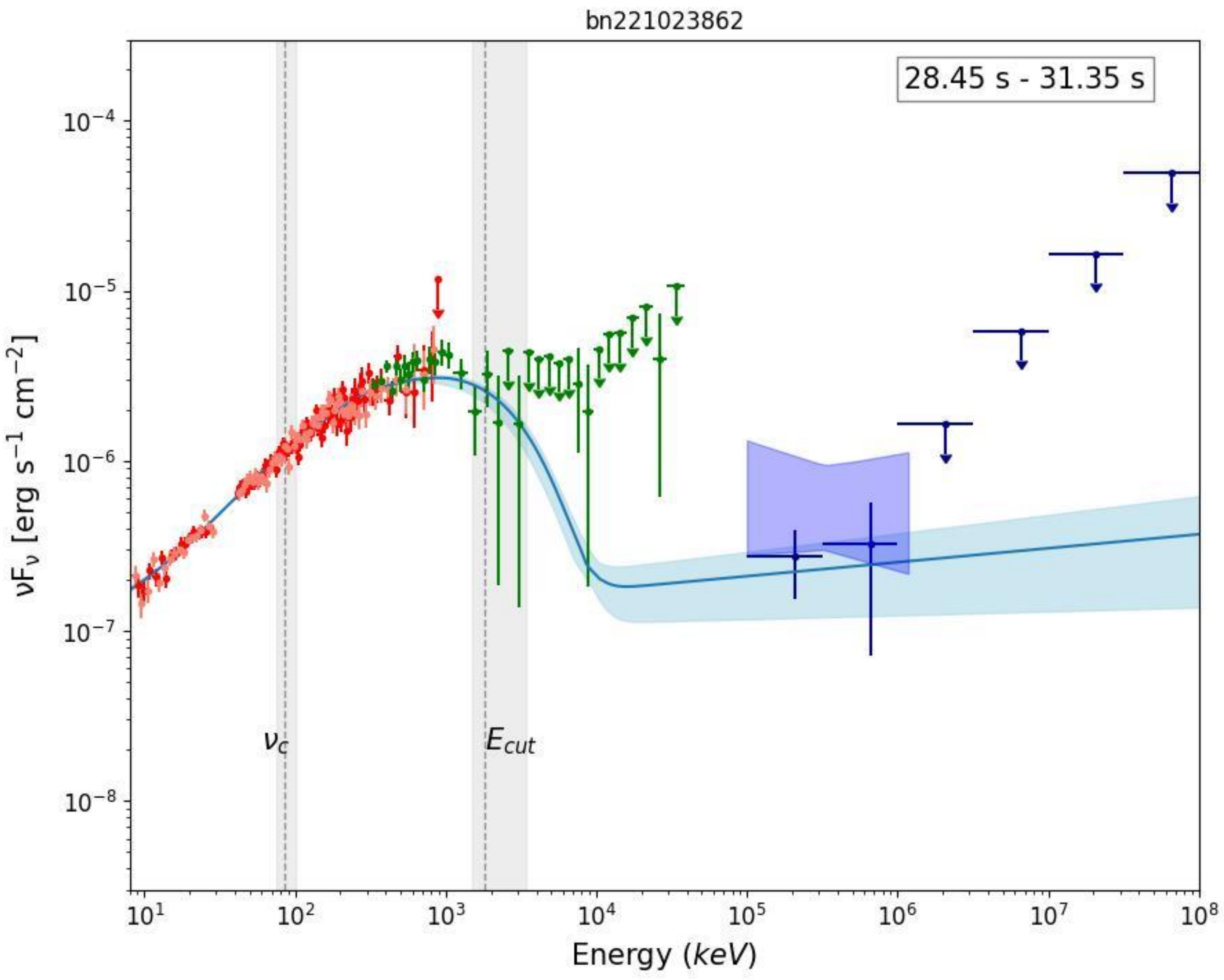
GRB 080916C



Model 2

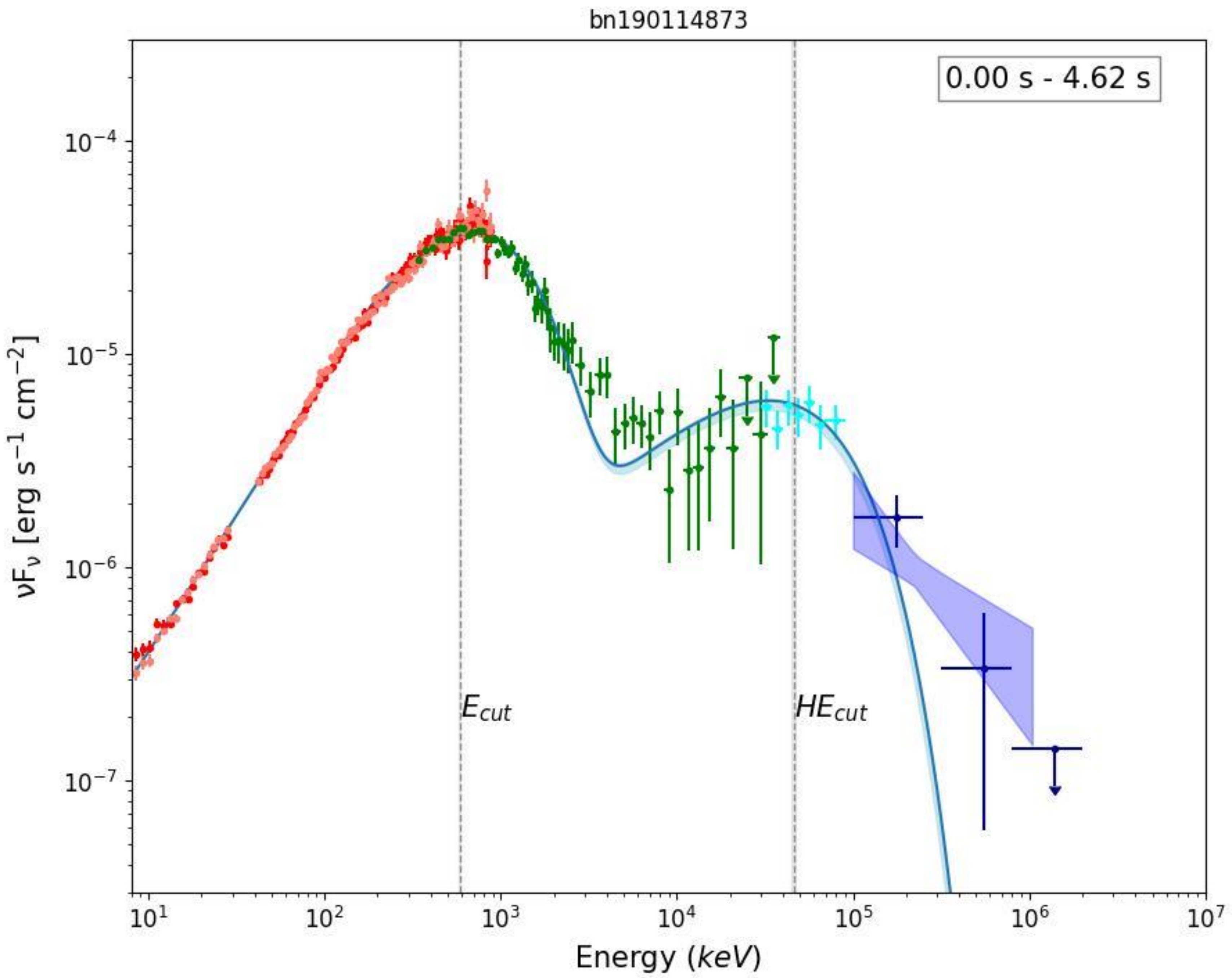
GRB 221023A



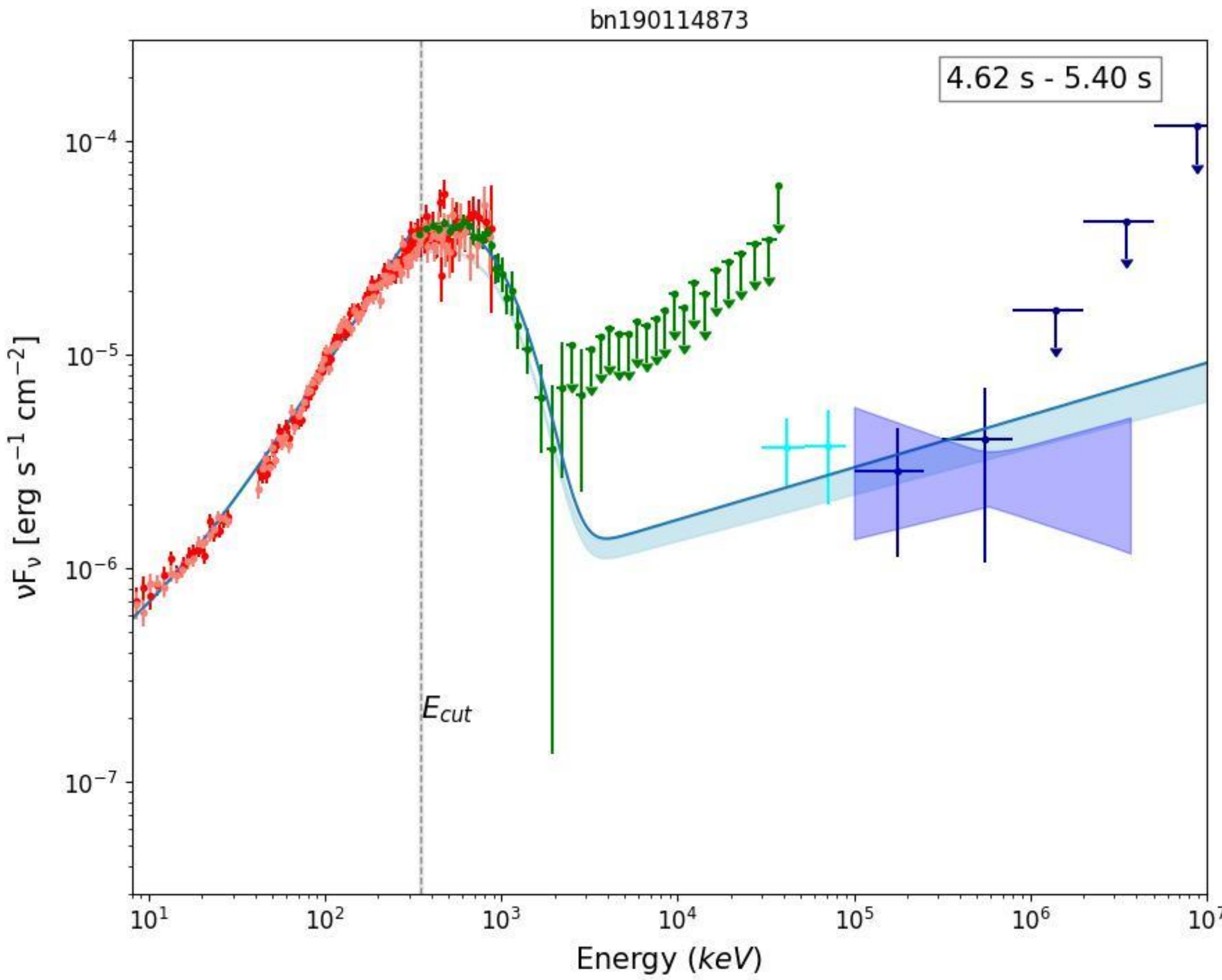


Model 3

GRB 190114C

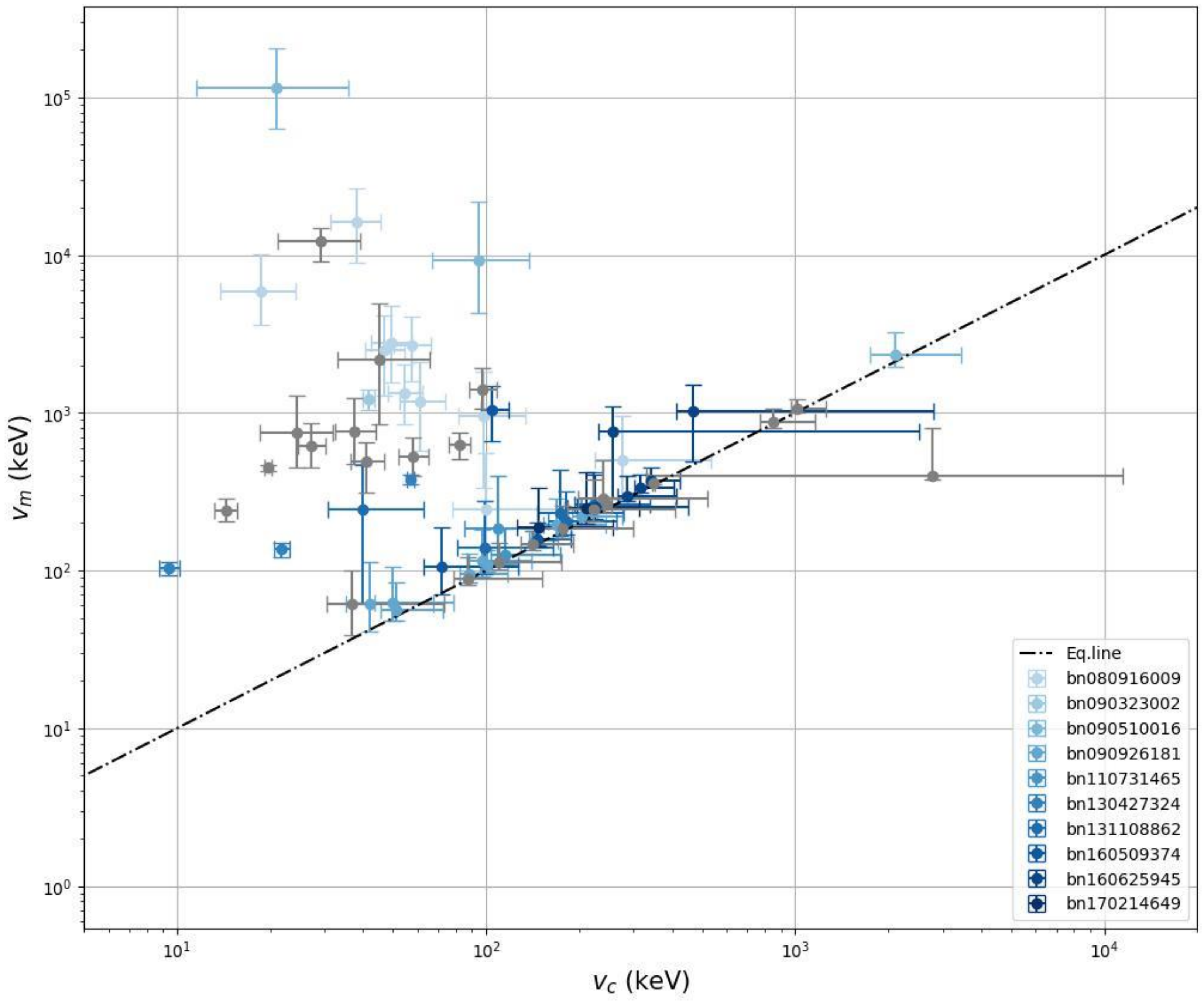


Model 2

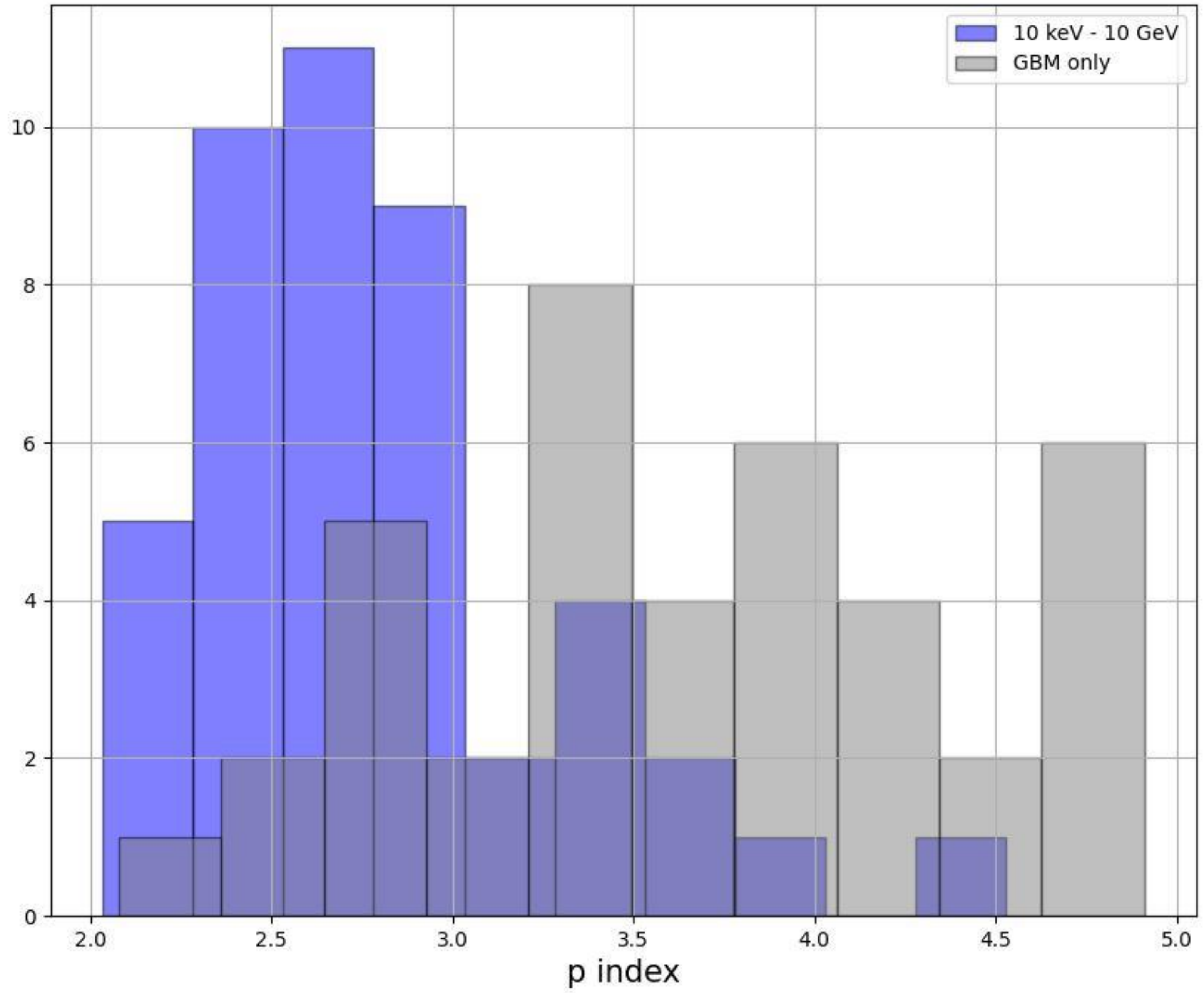


Parameter space

$\nu_c \; vs \; \nu_m$

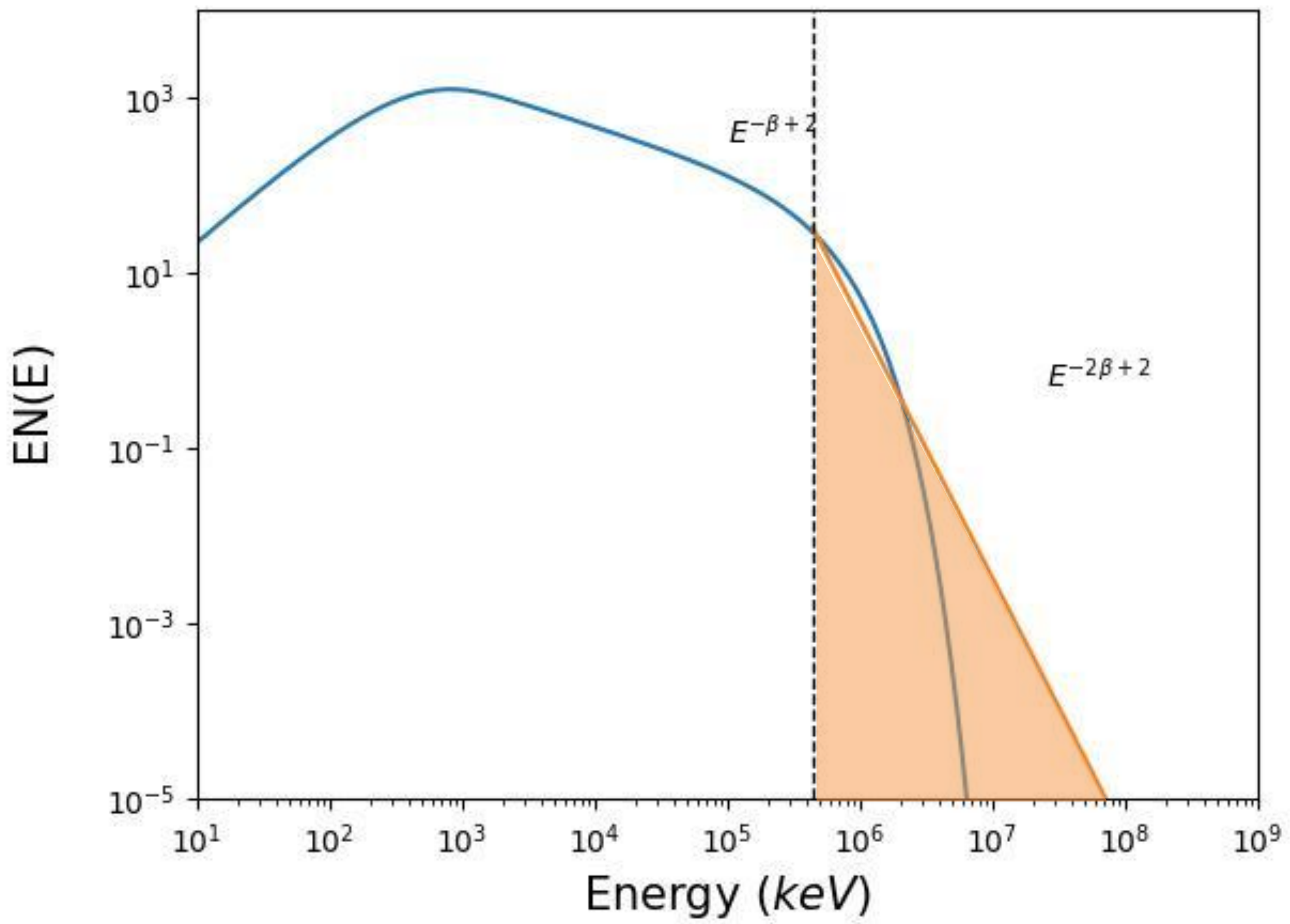


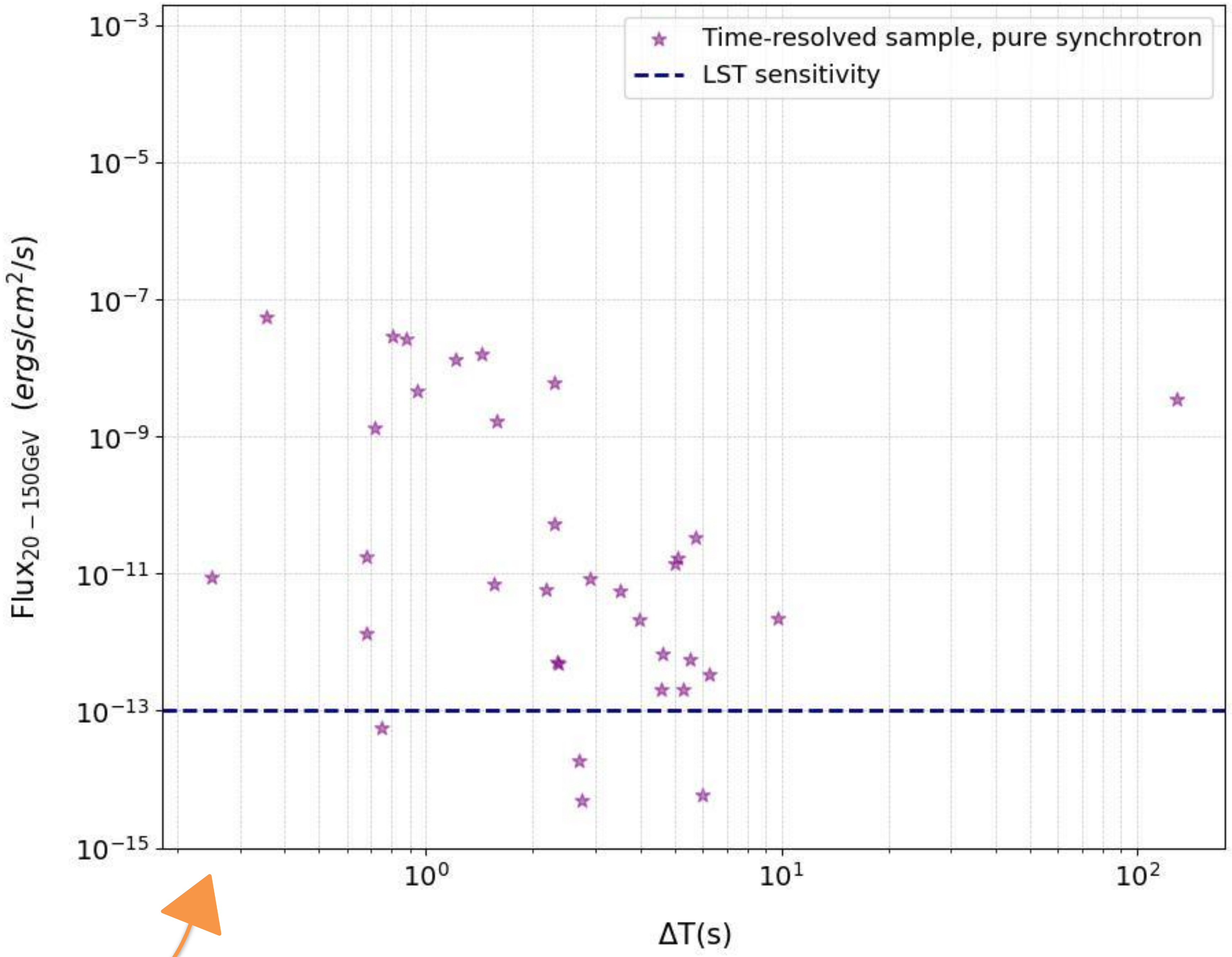
Distribution of p index $\frac{dN}{d\gamma} \propto \gamma^{-p}$



Extension to very-high-energies

Above the threshold for pair-production
→ Spectrum should evolve like $E^{-2\beta}$





If we know the cutoff energy, we can extrapolate the flux expected at LST energies (**20-150 GeV**)

MAGIC Telescope and LST have a slew time of $\sim 20\ s$

CONCLUSIONS

- ❑ Synchrotron prompt spectra are broad, covering the energy range 8 kev-10 GeV → A possible second component (if present) should appear at VHE

- ❑ Second power law component is very rare; with Fermi/LAT data it is difficult to resolve in time
  → VHE can help in understanding the nature and the physics of this component

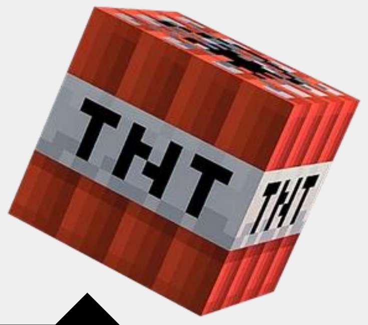
- ❑ High-energy data help in constraining the slope of the particle distribution function, (i.e. the acceleration mechanism)

→ Macera S., Banerjee B., Mei A., Oganesyan G., Branchesi M., in preparation

Thermal component in prompt emission spectra

In collaboration with: Lara Nava, Om Sharan Salafia, Giancarlo Ghirlanda

Thermal-Non Thermal model (TNT)



- Standard Fermi shock acceleration → Maxwellian component expected
- Previous studies focus mainly on the afterglow emission

Normalization

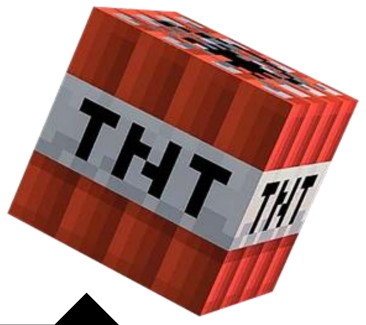
Non-thermal component

$$\frac{dN^{NT}}{d\gamma} = A_p \left(\frac{\gamma}{\gamma_m}\right)^{-p} \longrightarrow \int_{\gamma_m}^{\gamma_M} \frac{dN^{NT}}{d\gamma}\, d\gamma = \zeta_{NT} N_{tot} \qquad \int_{\gamma_m}^{\gamma_M} \frac{dN^{NT}}{d\gamma}\, \gamma\, d\gamma = \epsilon_{e,NT} \frac{m_p}{m_e} (\Gamma - 1) N_{tot}$$

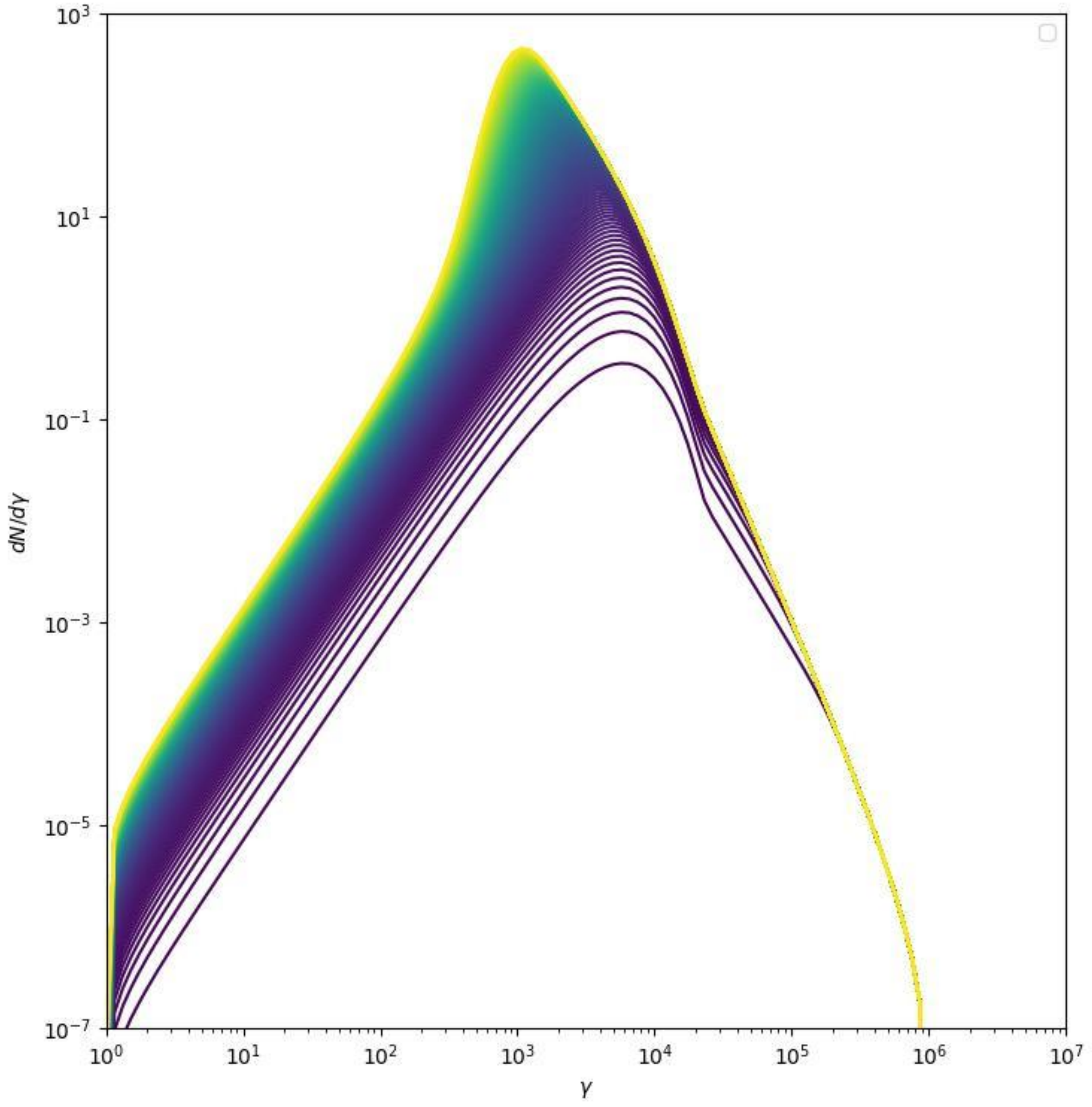
Maxwellian component

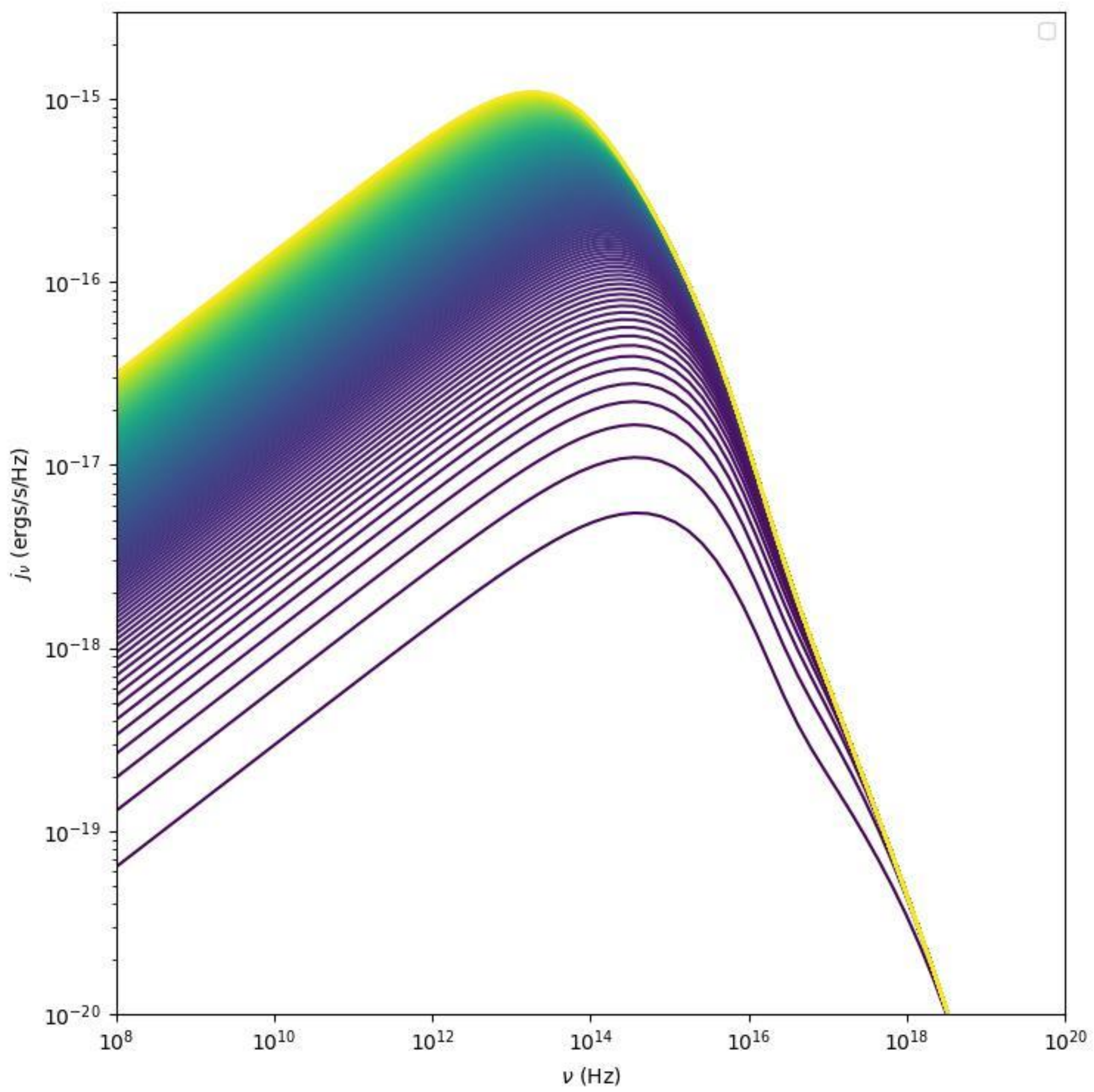
$$\frac{dN^{th}}{d\gamma} = N \frac{\gamma\sqrt{\gamma^2 - 1}\, e^{-\gamma/\gamma_{th}}}{\gamma_{th} K_2(1/\gamma_{th})} \longrightarrow \int_{1}^{\gamma_m} \frac{dN^{th}}{d\gamma}\, d\gamma = (1 - \zeta_{NT}) N_{tot} \qquad \int_{1}^{\gamma_m} \frac{dN^{th}}{d\gamma}\, \gamma\, d\gamma = \epsilon_{e,th} \frac{m_p}{m_e} (\Gamma - 1) N_{tot}$$

Thermal-Non Thermal model (TNT)



$$\frac{\partial N}{\partial \gamma}(\gamma,t) = \frac{\partial}{\partial \gamma}\left[N(\gamma,t)\frac{\partial \gamma}{\partial t}\right] + Q(\gamma,t) \longrightarrow j_\nu = \frac{1}{4\pi}\int \frac{\partial N}{\partial \gamma}P_\nu(\gamma)d\gamma$$





- Evolve the PDF until complete cooling
- Create a table model
- Fit a selected sample of GRBs

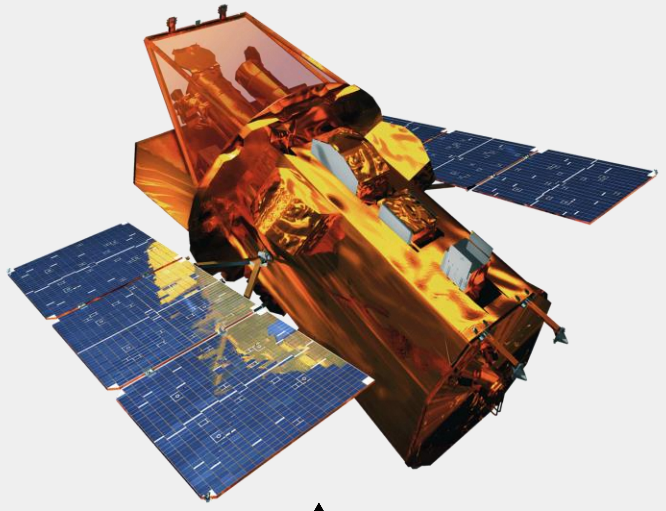
… In progress!

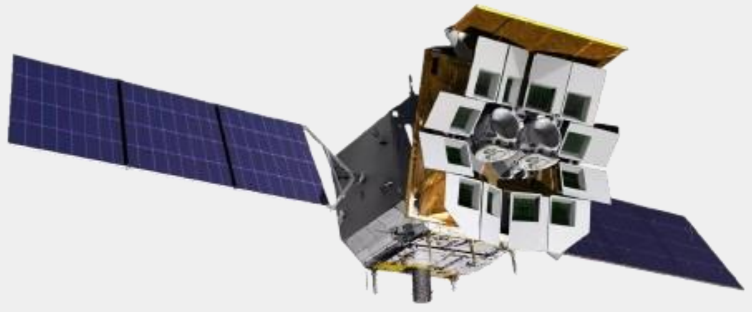
GRB prompt emission in X-rays

In collaboration with Annarita Ierardi and Pawan Tiwari

GRB prompt emission in X-rays

GRB prompt photons trigger MeV
(or even hard X-rays) instruments





Swift Satellite
(2004 - on)

BAT (10 – 150 keV)
→ 100° x 60°
XRT (0.5 – 10 keV)
→ 0.4° x 0.4°

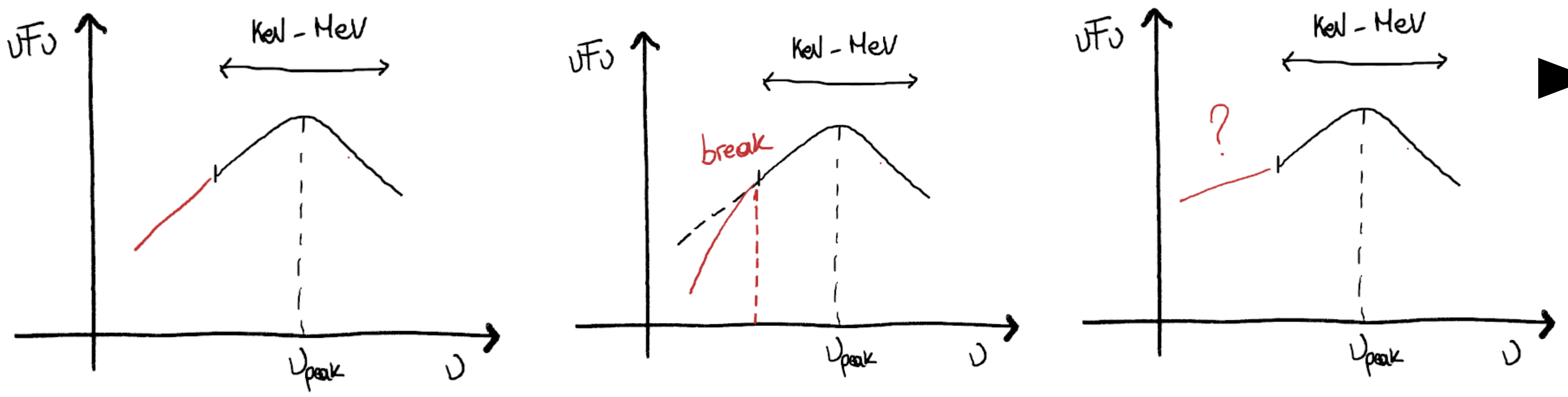
XRT Slew time ~ 1 min
→ Difficult to catch
prompt emission

Einstein Probe
(2024 - on)

WXT → 60° x 60°
FXT → 1° x 1°
0.5 – 4 keV

GRB prompt emission in X-rays

Why early X-ray observation?

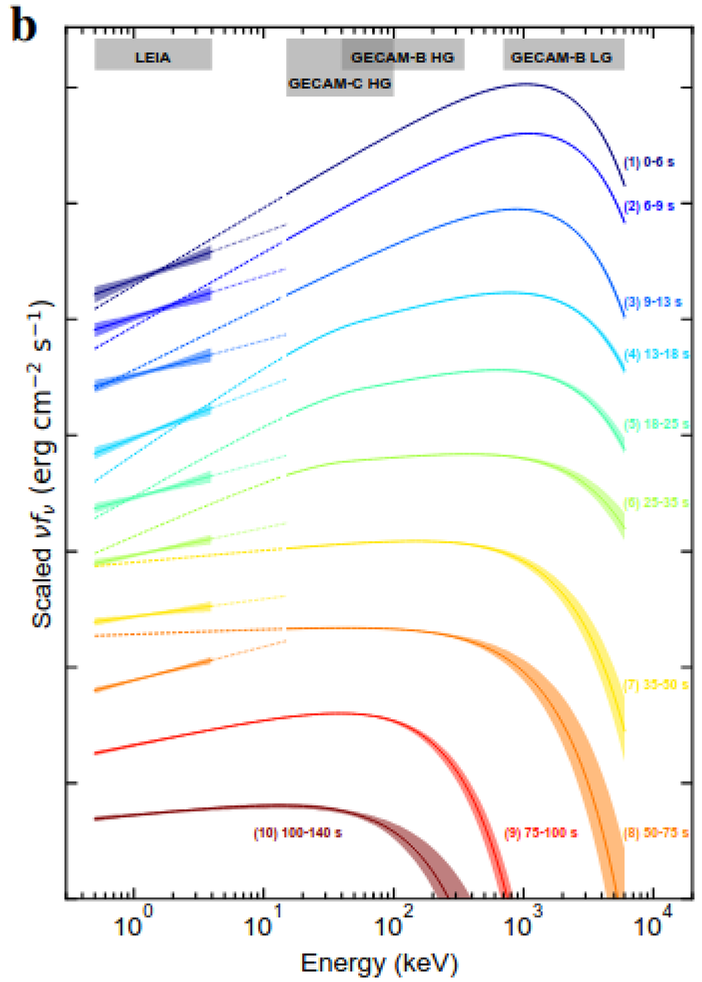


- Spectral breaks in prompt spectrum
  - Additional components?
  - Study of GRBs at high z
    - Progenitors

GRB prompt emission in X-rays

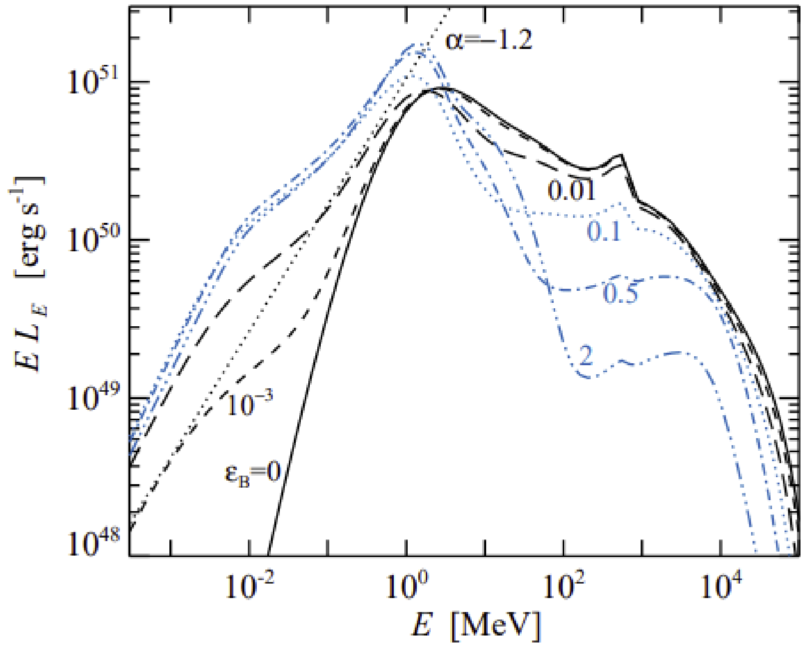
Why early X-ray observation?

Detection of excess in soft X-rays from LEIA satellite
→ Magnetar?



Sun et al, 2024

Softening of the spectrum in magnetized jets



Vurm, Beloborodov and Poutanen, 2011

- Spectral breaks in prompt spectrum
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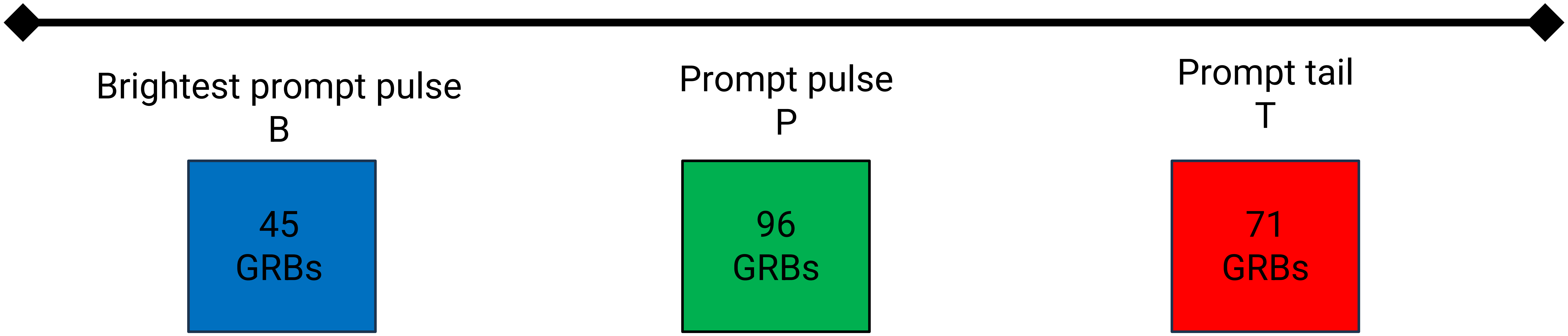
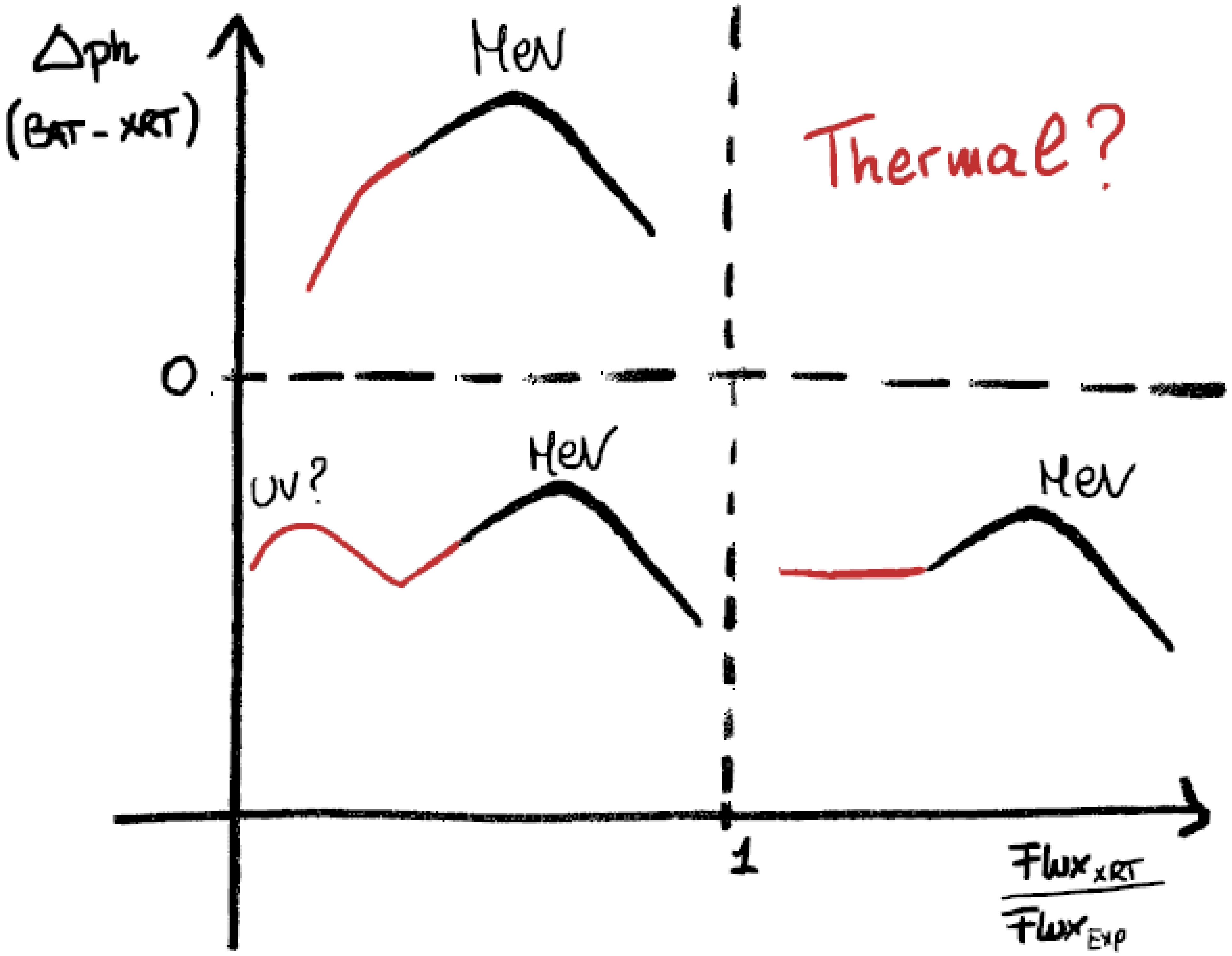
  - Study of GRBs at high z
    - Progenitors

Swift/ BAT + *Swift*/ *XRT* analysis

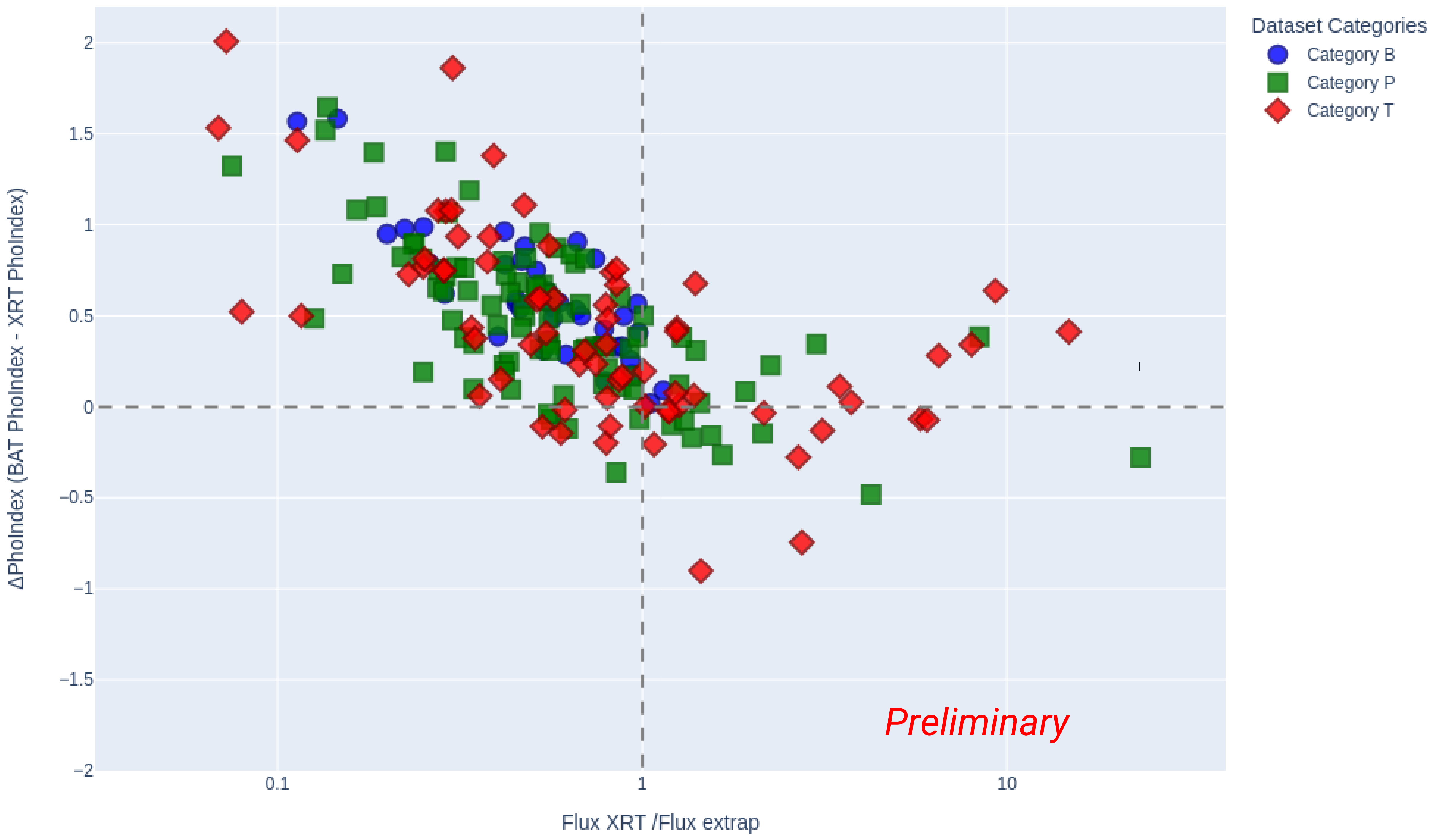


- Independent spectral analysis of BAT + XRT data → photon index and flux
- From BAT results, extrapolate and compute the expected flux in XRT and EP energy ranges

Swift/ BAT + *Swift*/ *XRT* analysis



Swift/ BAT + *Swift*/ *XRT* analysis



Conferences and schools

- ISTW2022, October 2022, online, **contributed talk**.
- GRAWITA Meeting, 3-4 November 2022, Bologna.
- Engrave Workshop, 6-8 February 2023, Garching.
- Astri and LHAASO Workshop, 7-8 March 2023, Milan.
- Einstein Telescope Symposium, 8-12 May 2023, Cagliari.
- GRB50, 28-30 August 2023, Warrenton (USA), **contributed talk**.
- IFPU Workshop, 19-23 Feb 2024, Trieste, **contributed talk**.
- CTAO Science Symposium, 15-18 April, Bologna, **contributed talk**.
- The 3rd Nanjing GRB Conference, 21-25 May 2024, Suzhou (China), **contributed talk**.
- Gravi-gamma-nu workshop, 9-11 Oct, Bari, **contributed talk**.

Schools:

- Transient Universe, 30 May - 9 June 2023, Cargése.
- Nordic Winter School on Multimessenger Astrophysics, 28 Jan - 2 Feb 2024, Norway.

★ Macera, S. et al. "High-Energy spectral component of the prompt emission of GRBs", in preparation.

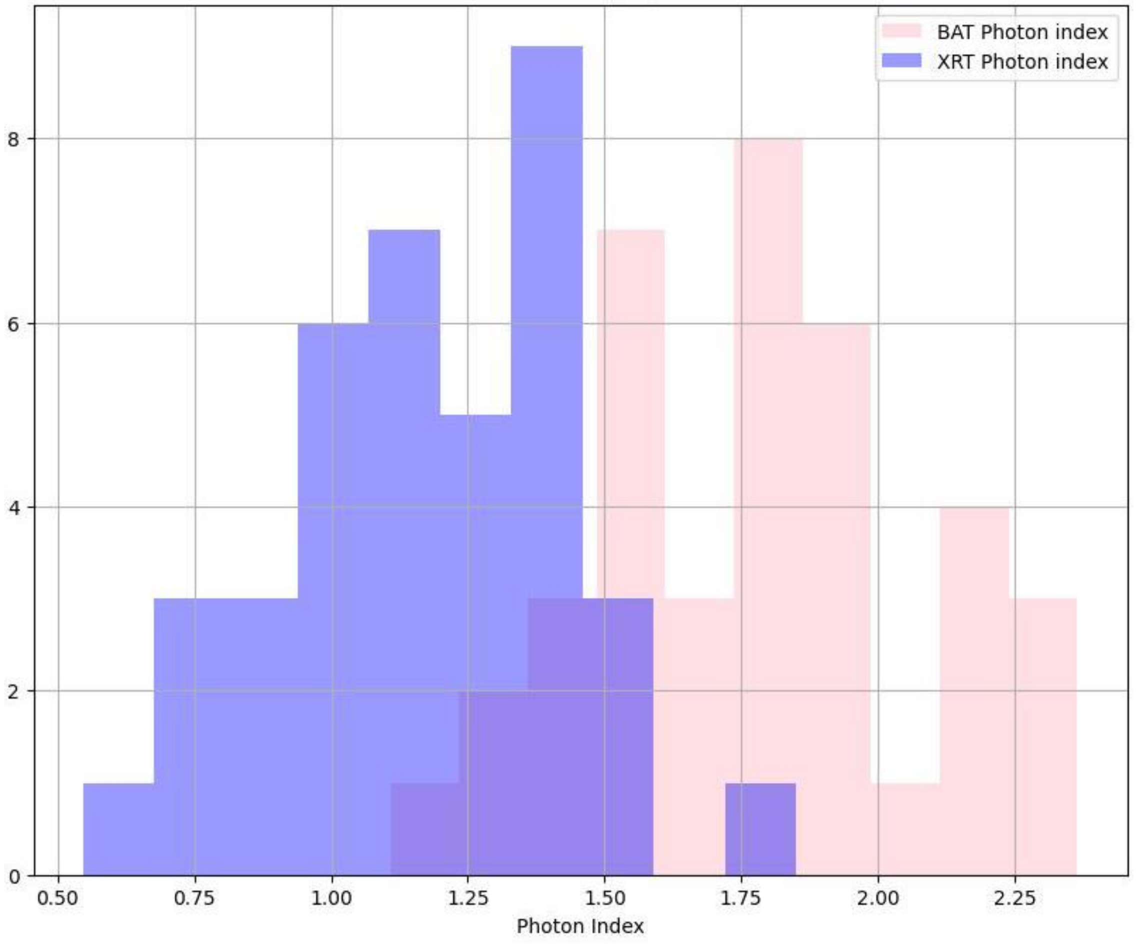
★ Banerjee, B., Macera, S., De Santis, A. L., Mei, A., Tissino, J., Oganesyan, G., ... and Branchesi, M. (2024). Camelidae on BOAT: observation of a second spectral component in GRB 221009A. arXiv:2405.15855.

★ Mei, A., Oganesyan, G., and Macera, S. (2024). Gamma-ray burst spectral-luminosity correlations in the synchrotron scenario. arXiv:2409.08341

THANK YOU!

Swift/ BAT + *Swift/ XRT* analysis

B



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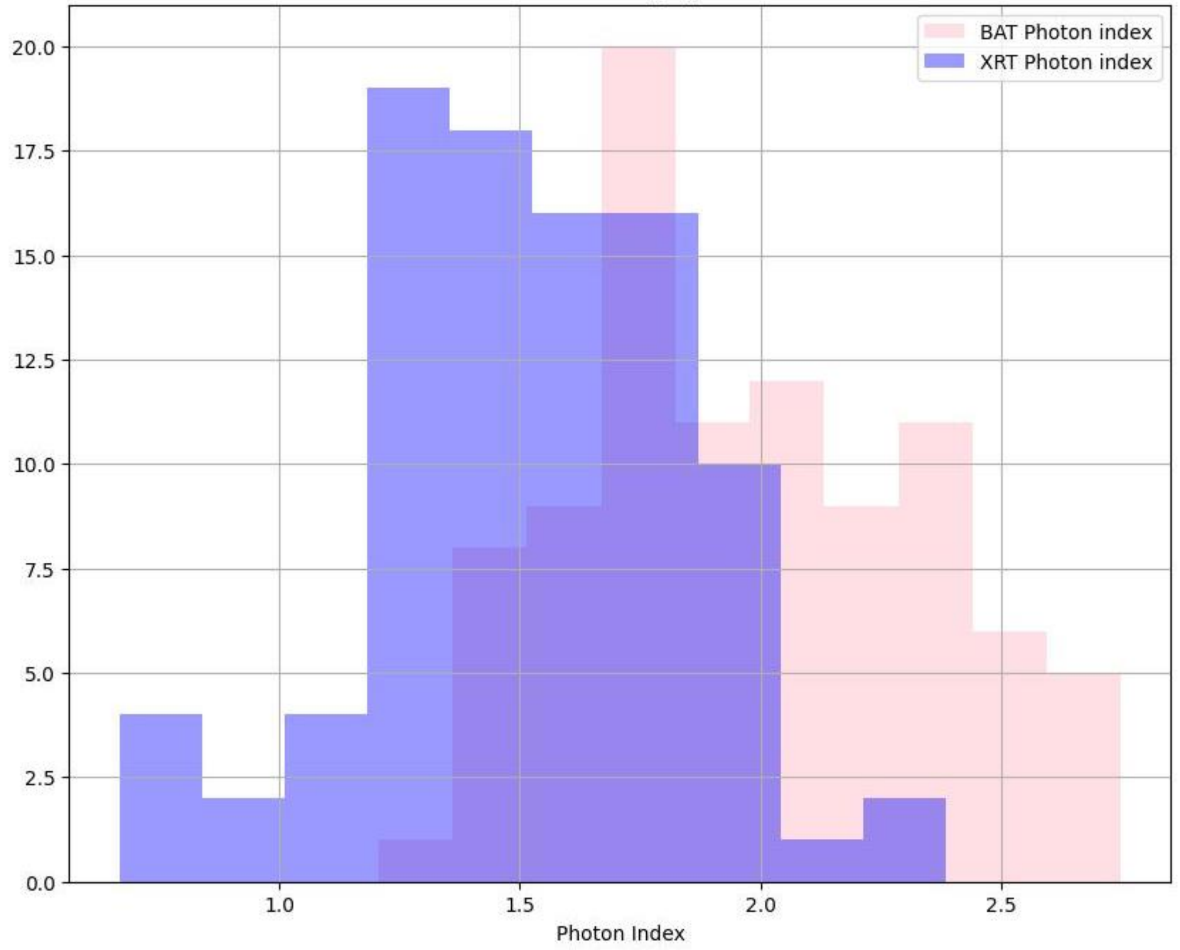

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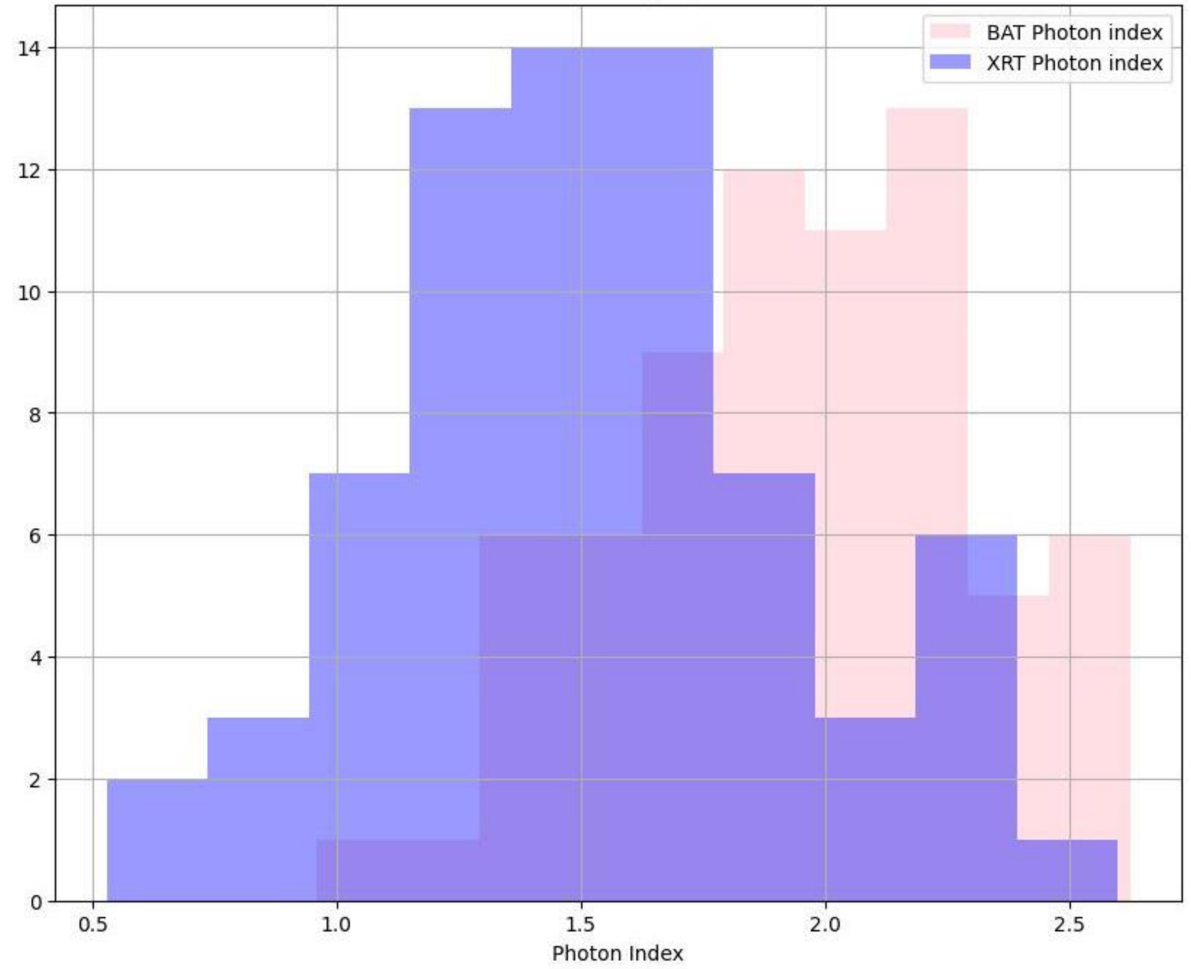

Preliminary results