Probing Particle Acceleration in Gamma-ray Burst Afterglows Through Novel MeV Correlation

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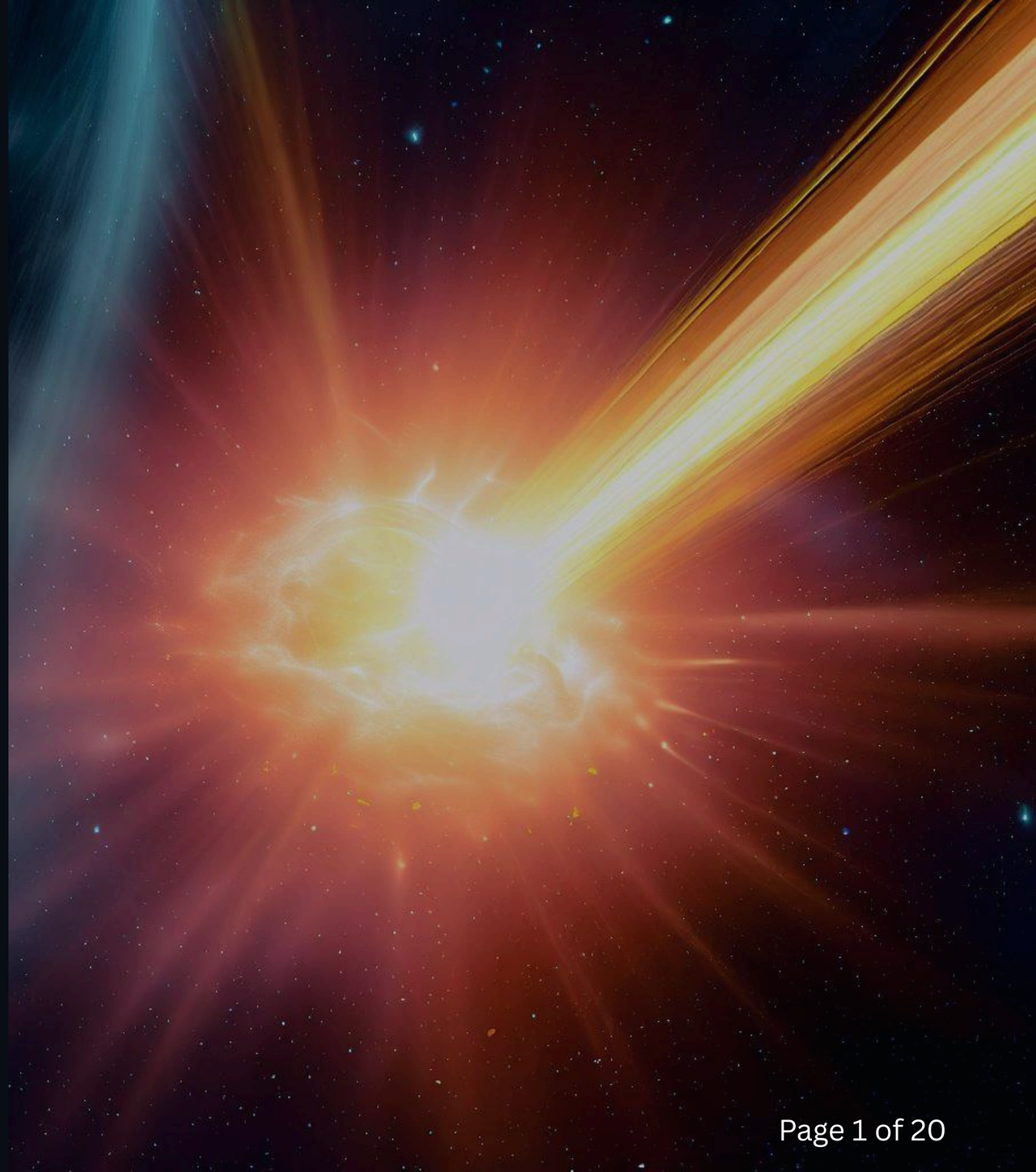


Gamma-ray burst Afterglow

Energy of the blastwave

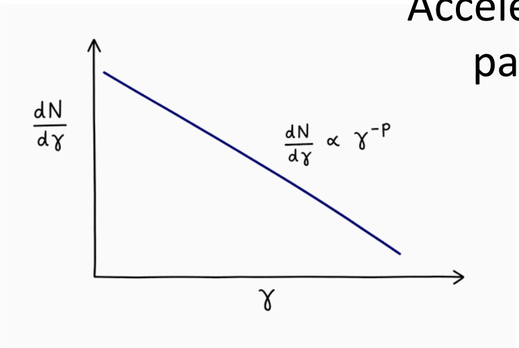
Prompt Emission

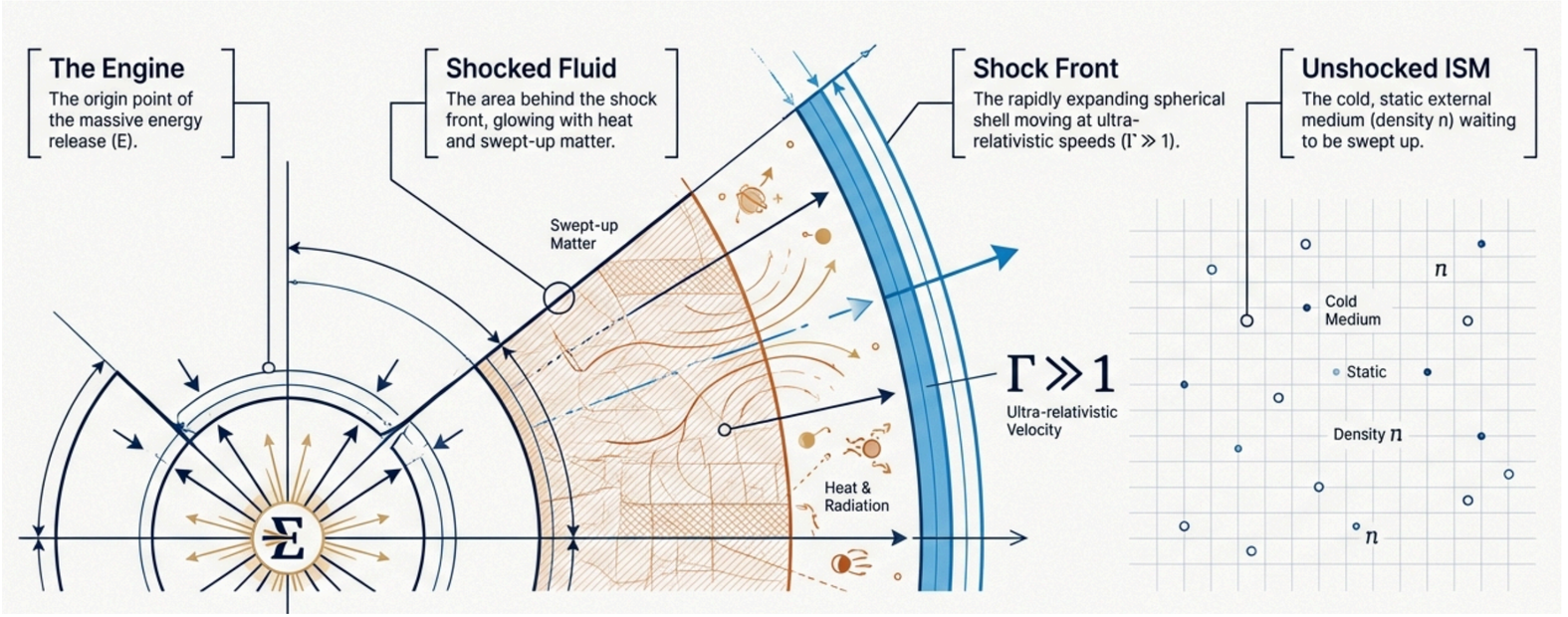
E_{prompt}

Residual energy shocks the medium

E_{kin}

Accelerates the particles





AI Generated

Why probe MeV Afterglow?

Radio	LIMITATION	Gets self-absorbed during early afterglow
Optical	CONTAMINATED	Contamination by reverse shocks and prompt emission
X-rays	CONTAMINATED	Contamination by flares and prompt emission
MeV BACKGROUND DOMINATED	GOOD WINDOW	Good for observing early afterglow
GeV	GOOD WINDOW	Good for observing early afterglow
TeV	LIMITATION	Good observation potential, but gets absorbed by EBL

Pawan Tiwari's Talk

TeV GRBs and the MeV-GeV gap

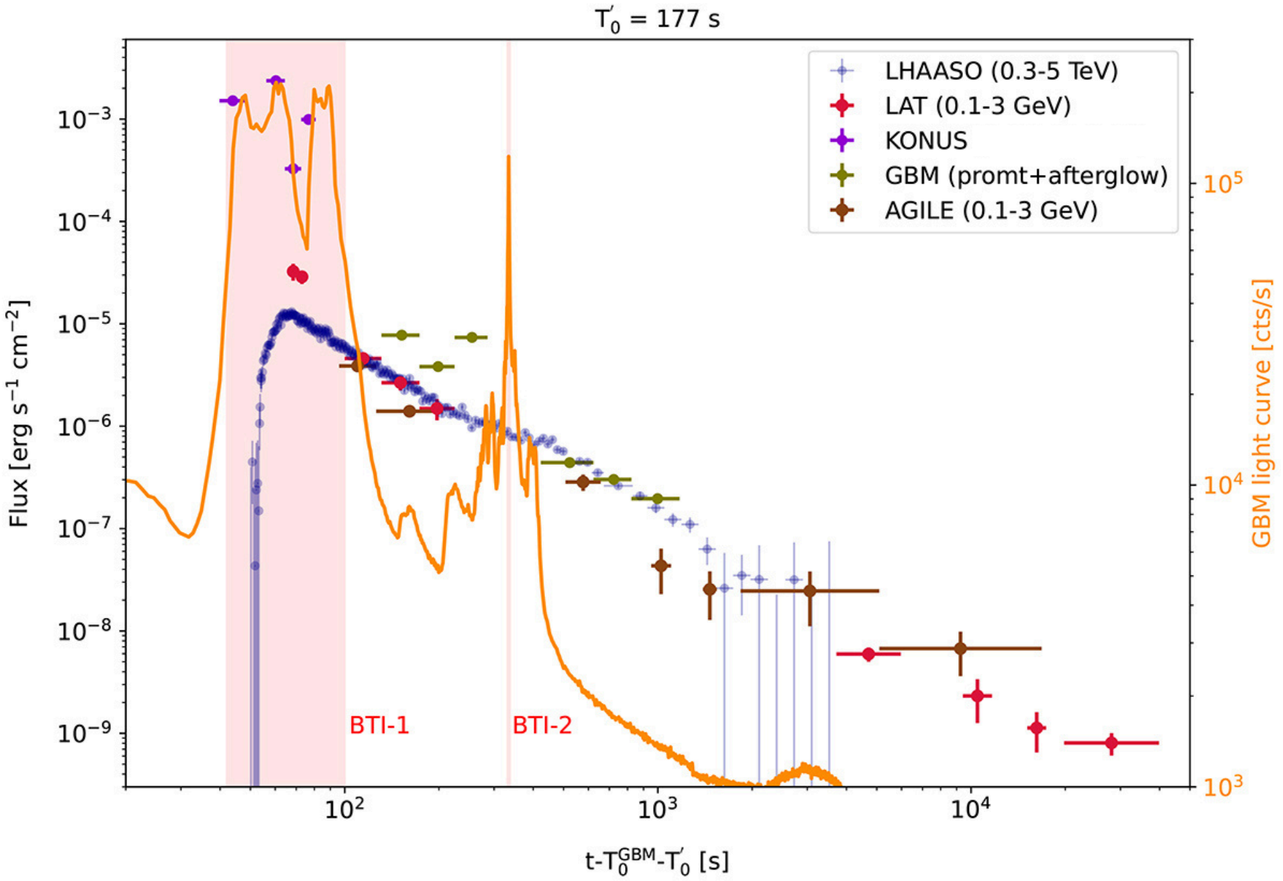
GRBs	Time ($t-T_0$)	0.2 keV — 10 keV — 100 keV — 1 MeV — 100 MeV — 10 GeV — 100 GeV — 1 TeV
GRB 180720B	~10 hr	? ? ? ? H.E.S.S.
GRB 190114C	68–110 s	XRT GBM BAT ? LAT (~5σ) MAGIC@20
	110–180 s	XRT GBM BAT ? LAT (~5σ)
GRB 190828A	4.3–7.9 hr	XRT ? ? LAT (U.L.) H.E.S.S.
	27.2–31.9 hr	XRT ? ? LAT (U.L.)
GRB 201216C	60–1.2 ks	XRT ? ? LAT (U.L.) MAGIC@20

XRT | BAT | GBM | LAT | IACTs

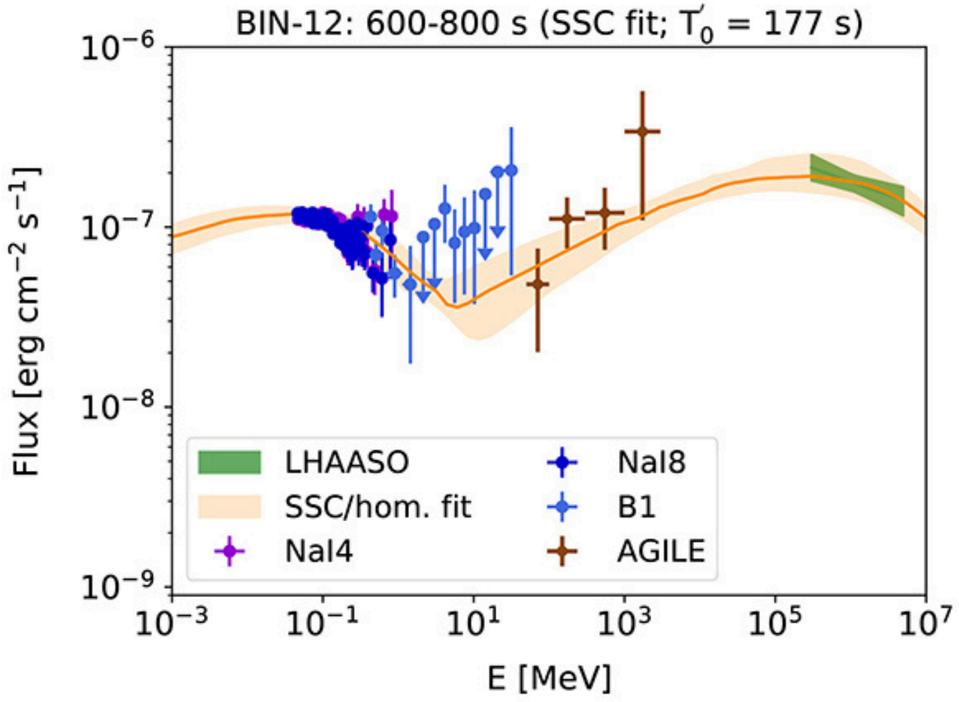
MAGIC Collaboration:
Nature v. 575, p. 455–458 (2019) and
Nature v. 575, p. 459–463 (2019)
H.E.S.S. collaboration, Nature, 2019
H.E.S.S. collaboration, Science, 2021
MAGIC Collaboration, MNRAS, 2024

GRB 221009A; BOAT (Brightest Of All Time*)

Banerjee, B., et al.: A&A, 701, A68 (2025)



Parameters	Priors	Posteriors
$\log_{10}(B)$ [G]	(-5; 2)	$-1.3^{+0.8}_{-0.4}$
$\log_{10}(\gamma_m)$	(0; 5)	$1.5^{+0.9}_{-1.0}$
$\log_{10}(\gamma_{max})$	(4; 8)	$6.3^{0.1}_{-0.2}$
$\log_{10}l_e$	(-7; -1)	$-2.8^{+0.6}_{-0.4}$
p	(2; 3)	$2.6^{+0.1}_{-0.4}$
$\log_{10}D$	(1; 4)	$2.5^{+0.1}_{-0.3}$



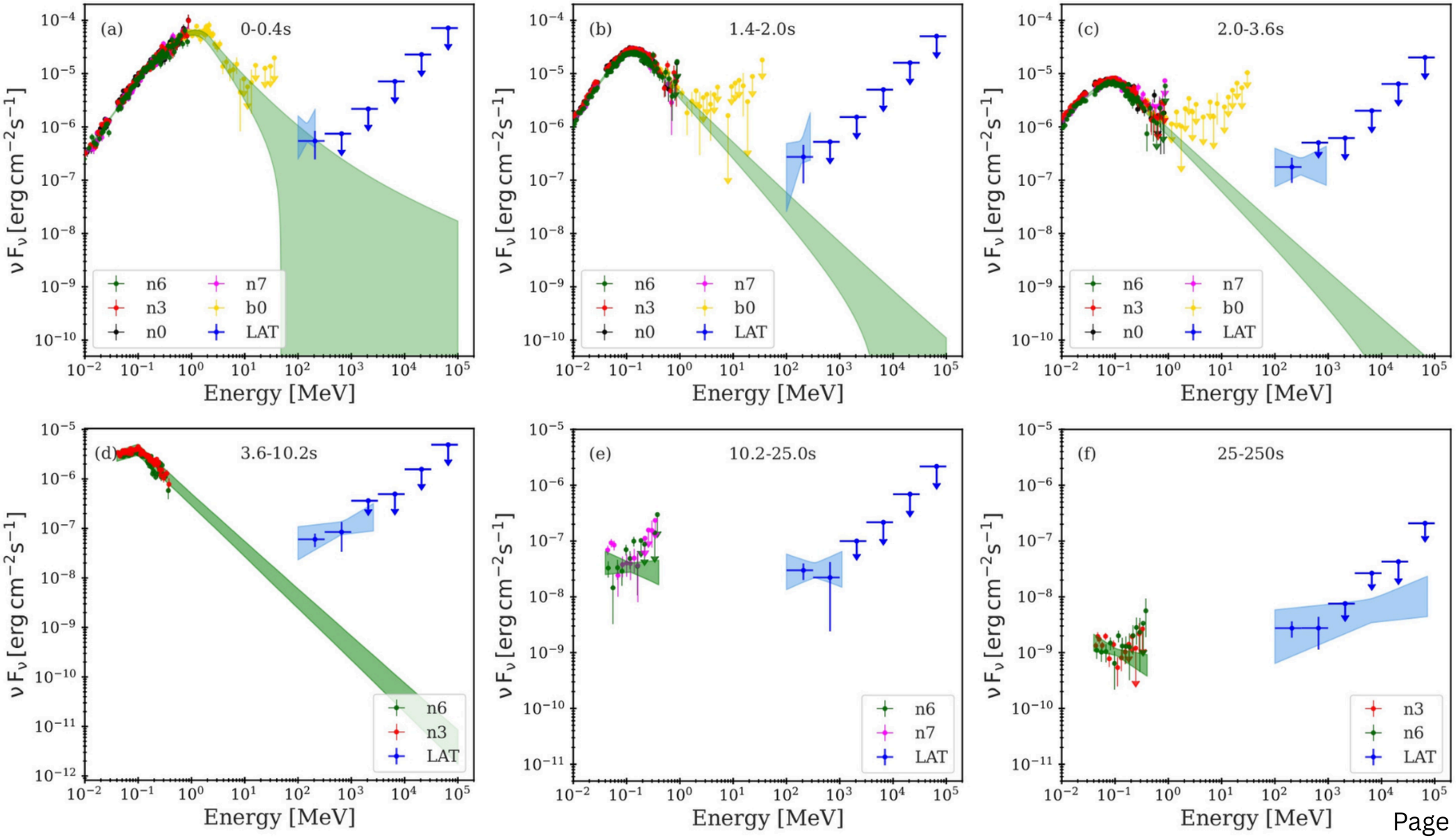
LHAASO Collaboration, Science (2023); Tavani et al 2023,ApJL 956 L23, 2023; Bissaldi et al 2023: https://pos.sissa.it/444/847/ ;Frederiks et al 2023 ,ApJL, 949, L7 (2023); Lesage et al 2023, ApJL 952 L42 ; *Burns et al 2023, ApJL 946 L31

GRB 230812B: MeV afterglow

Mohnani, S., et al.: A&A, 705, A227 (2026)

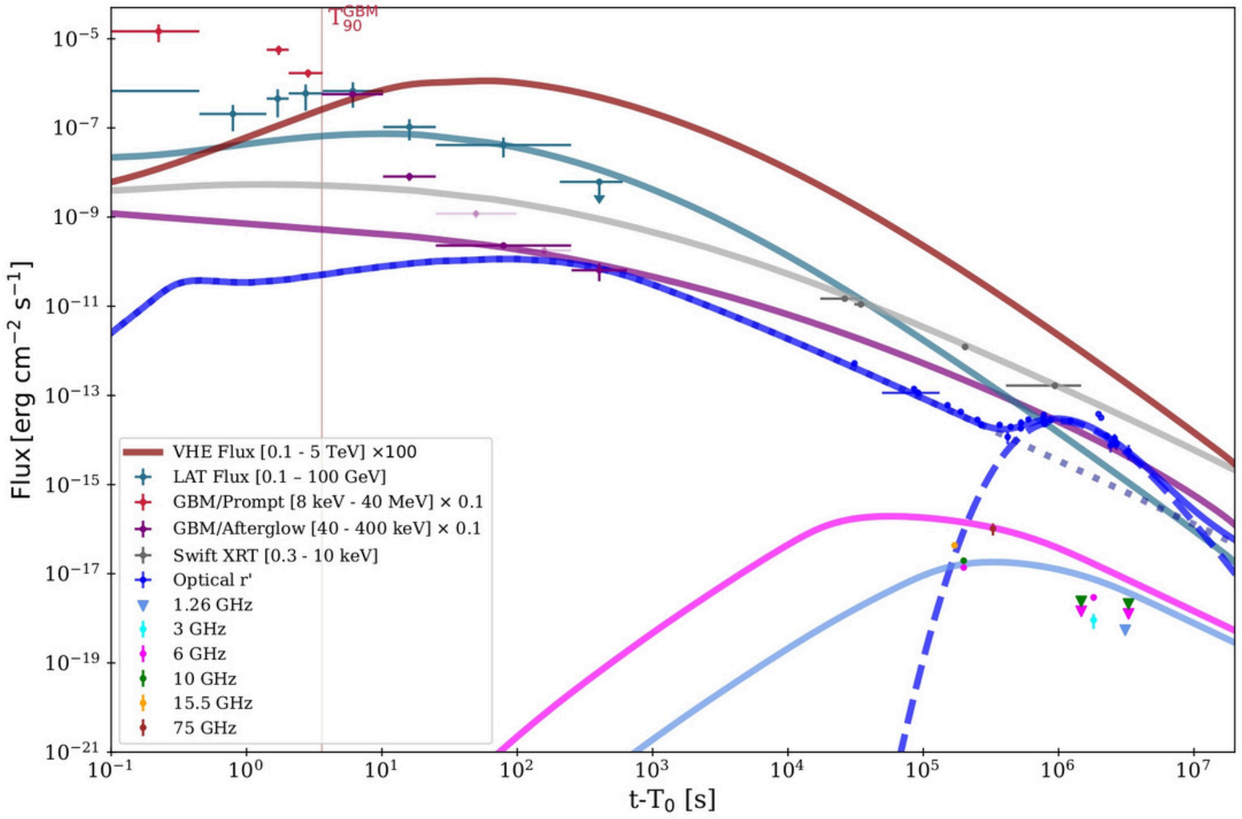
Prompt

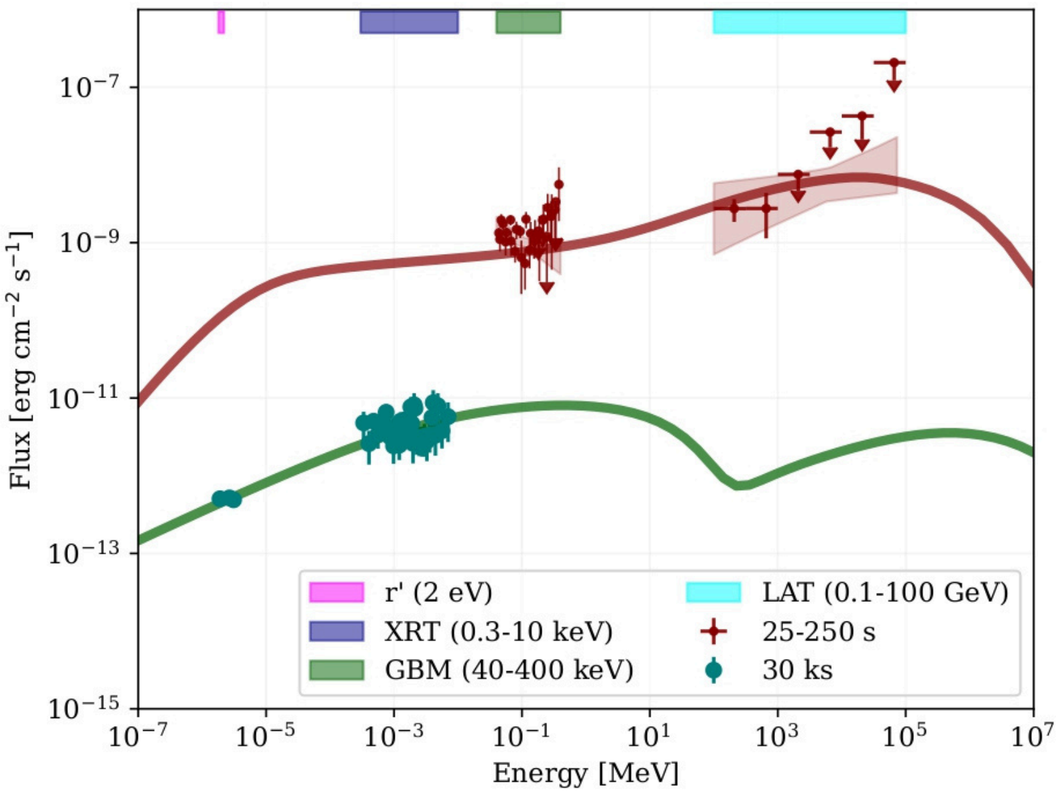
Afterglow



GRB 230812B: SSC component

Mohnani, S., et al.: A&A, 705, A227 (2026)

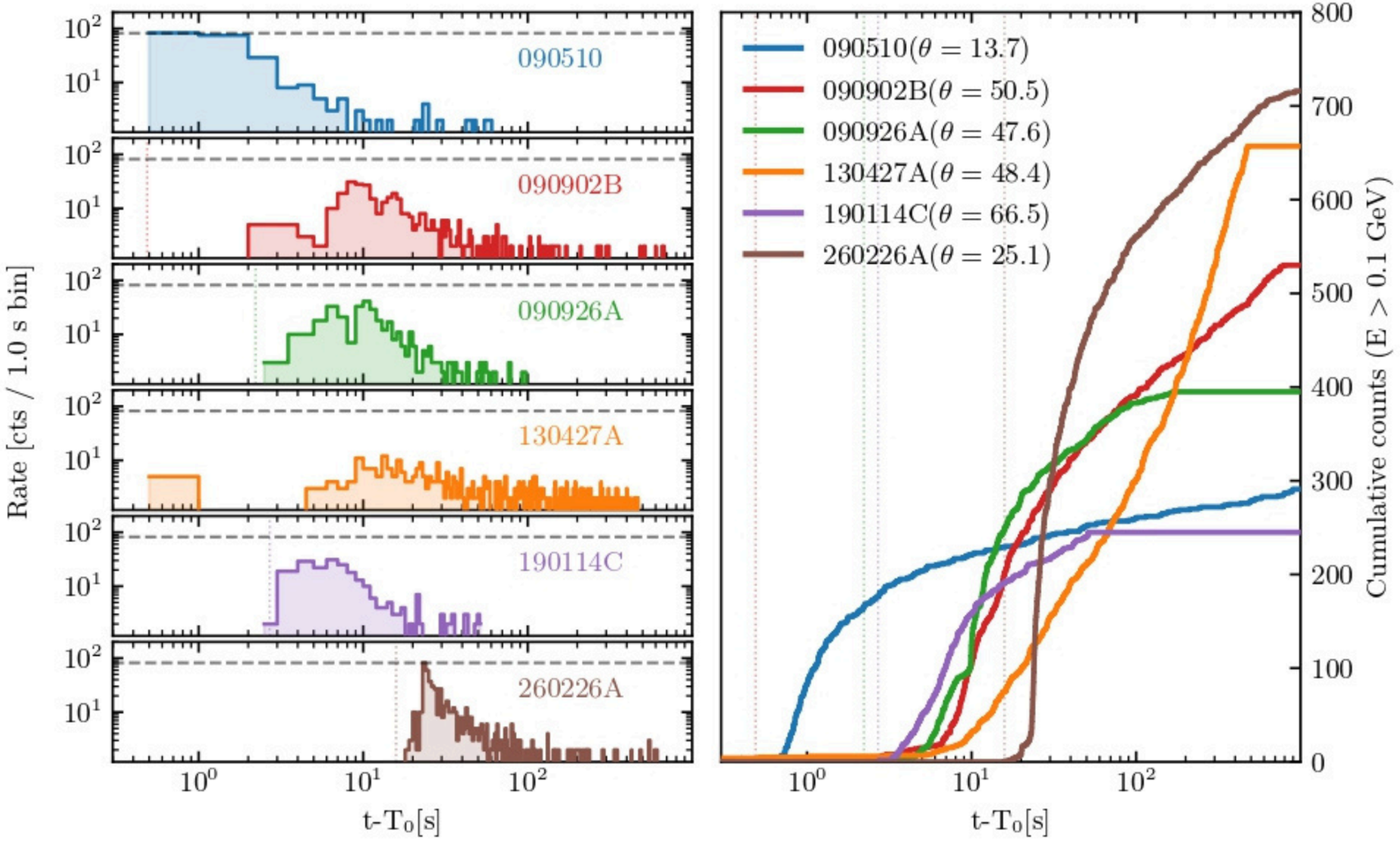




Both early and late-time afterglow data are consistent with sync+SSC external fwd shock scenario

GRB 260226A : The ultra-fast afterglow

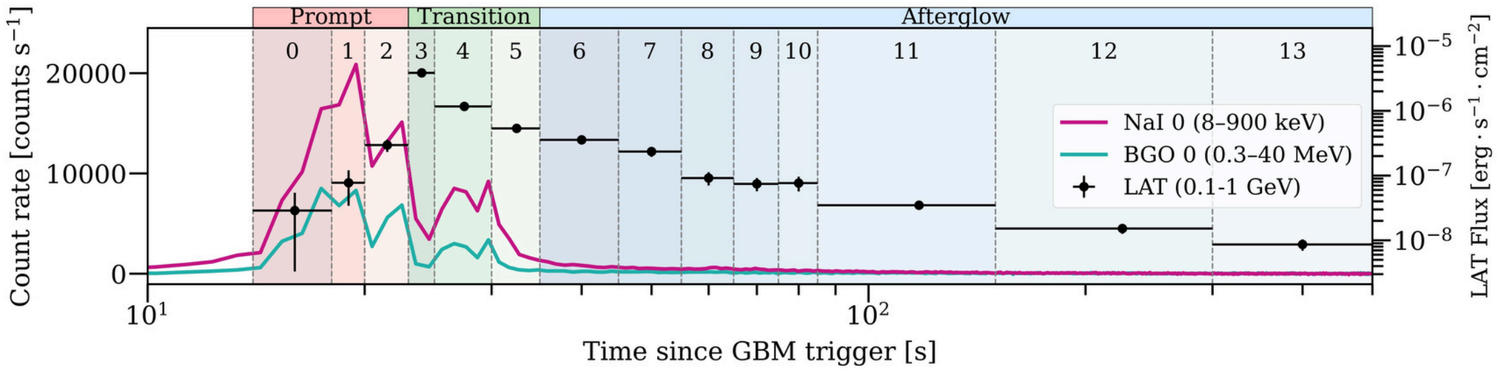
Banerjee, B., et al.(2026)

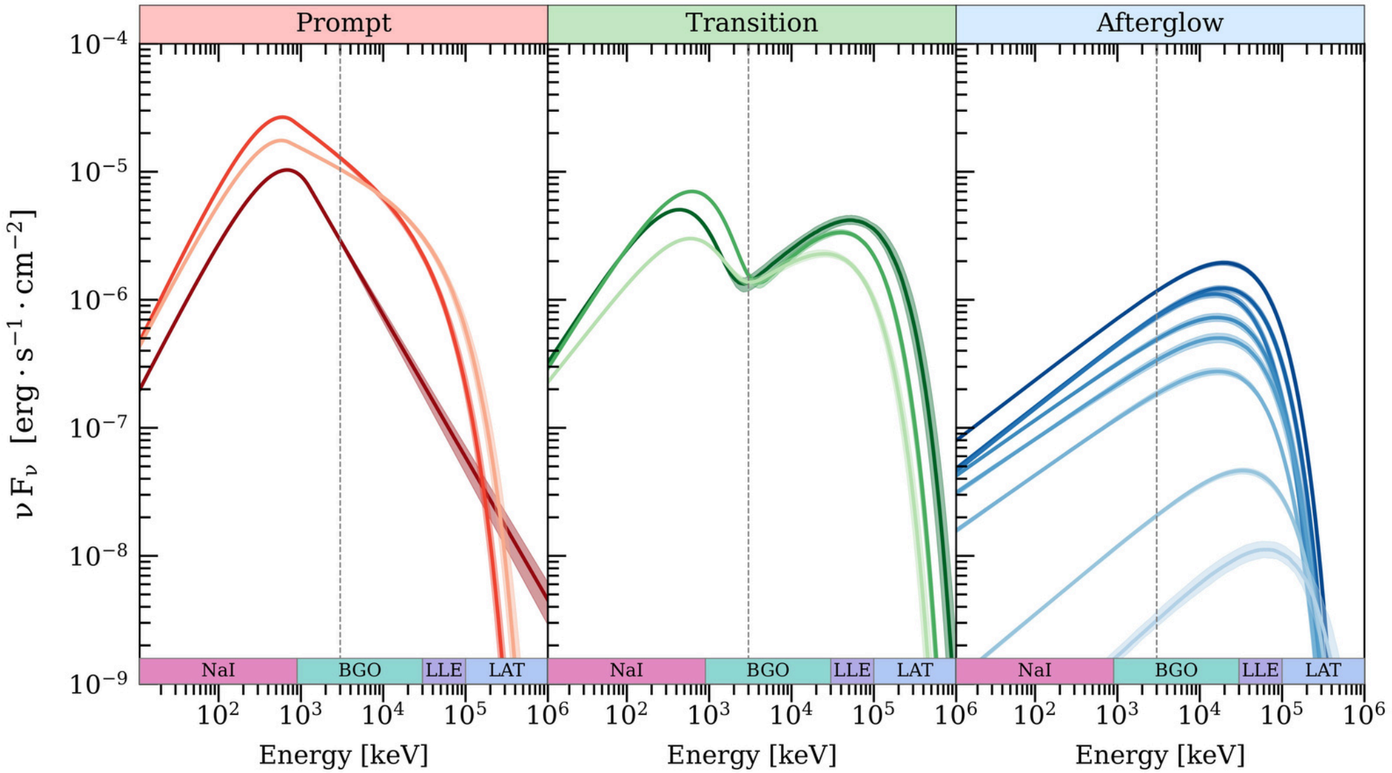


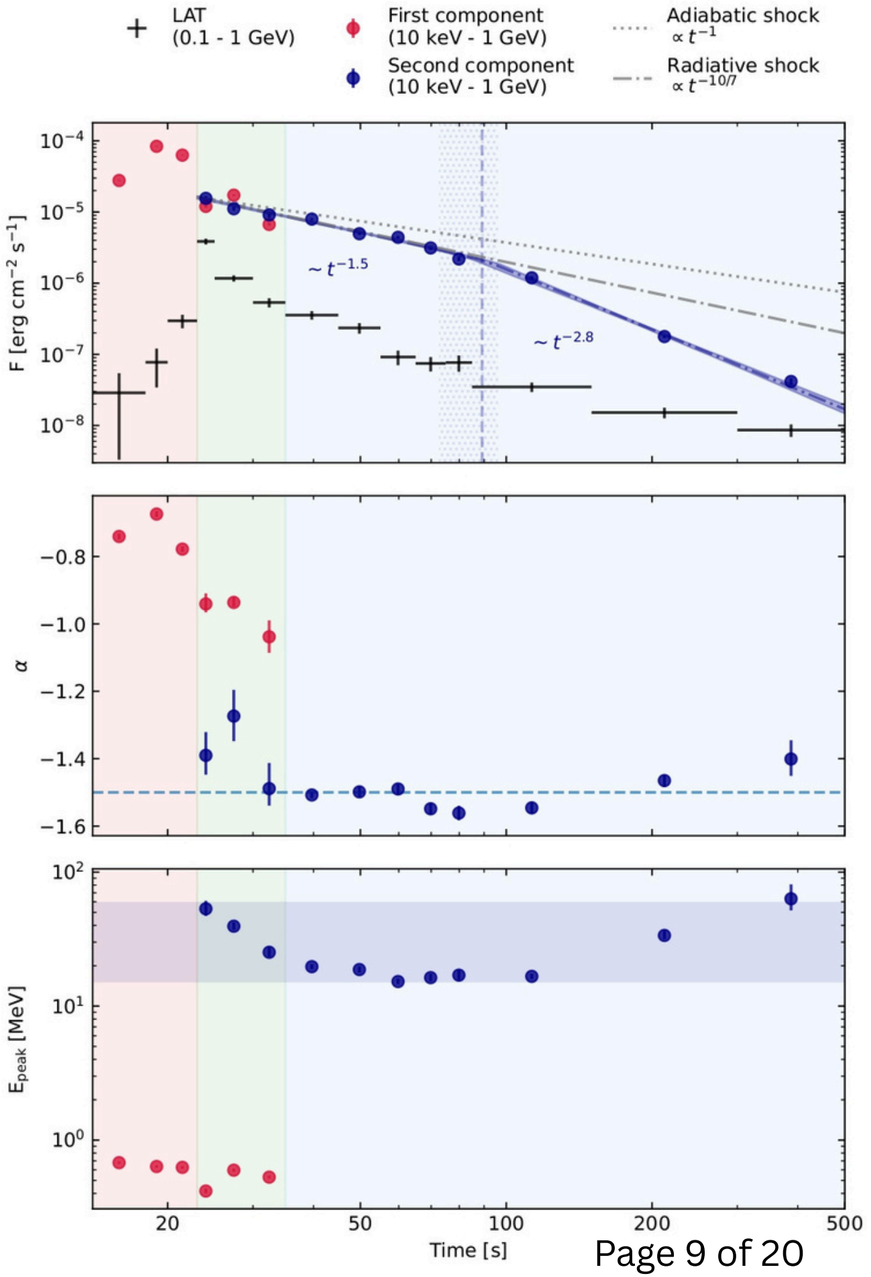
- GBM + KONUS detection
- Triggered Fermi/LAT independently from GBM (2nd GRB after 090510A)
- LAT emission until 1.5 ks. Poor localization (~0.5°)
- No Xray, optical data
- No localisation to search for optical counterpart, host, and hence no redshift

GRB 260226A : The ultra-fast afterglow

Banerjee, B., et al.(2026)

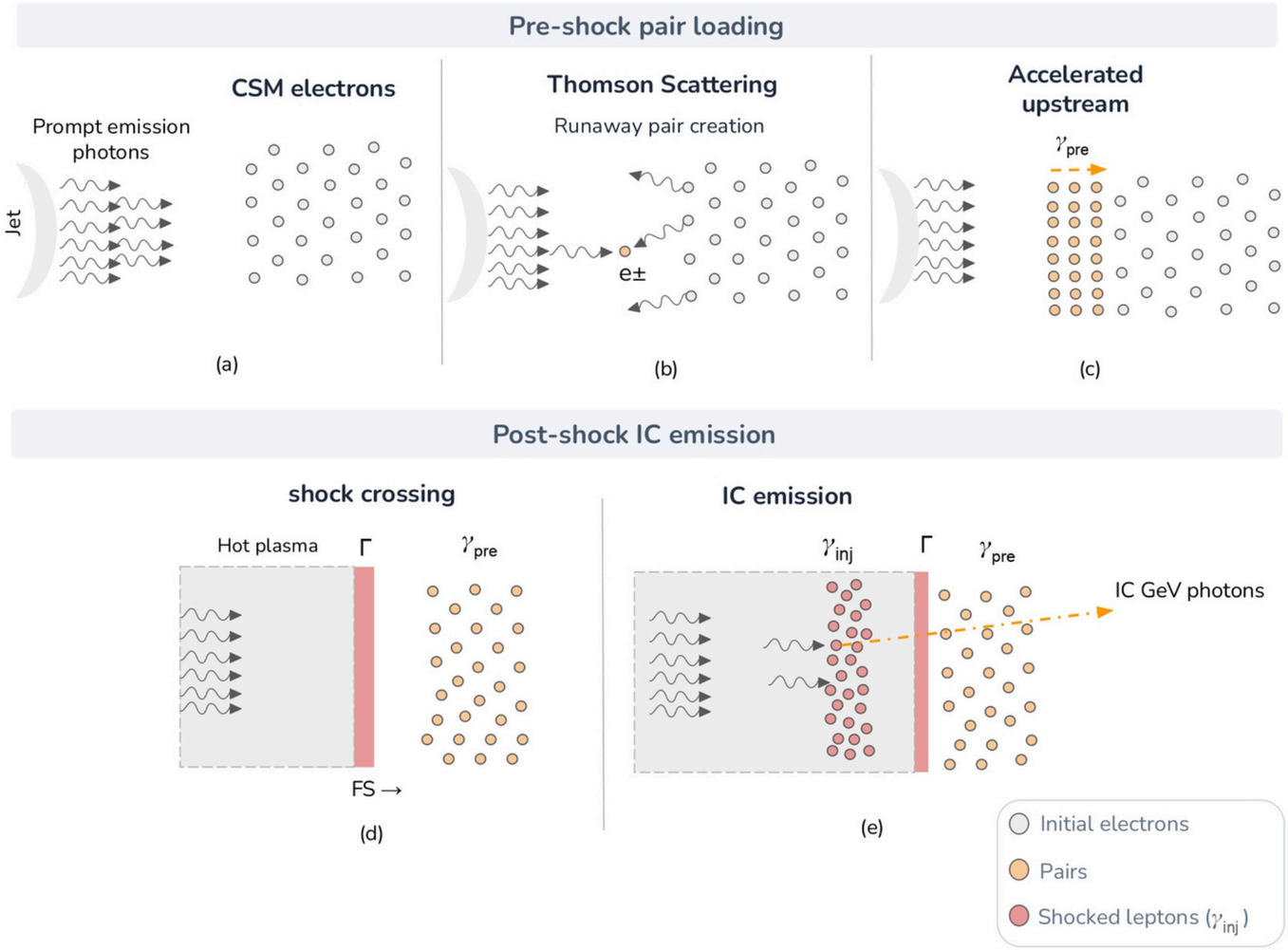


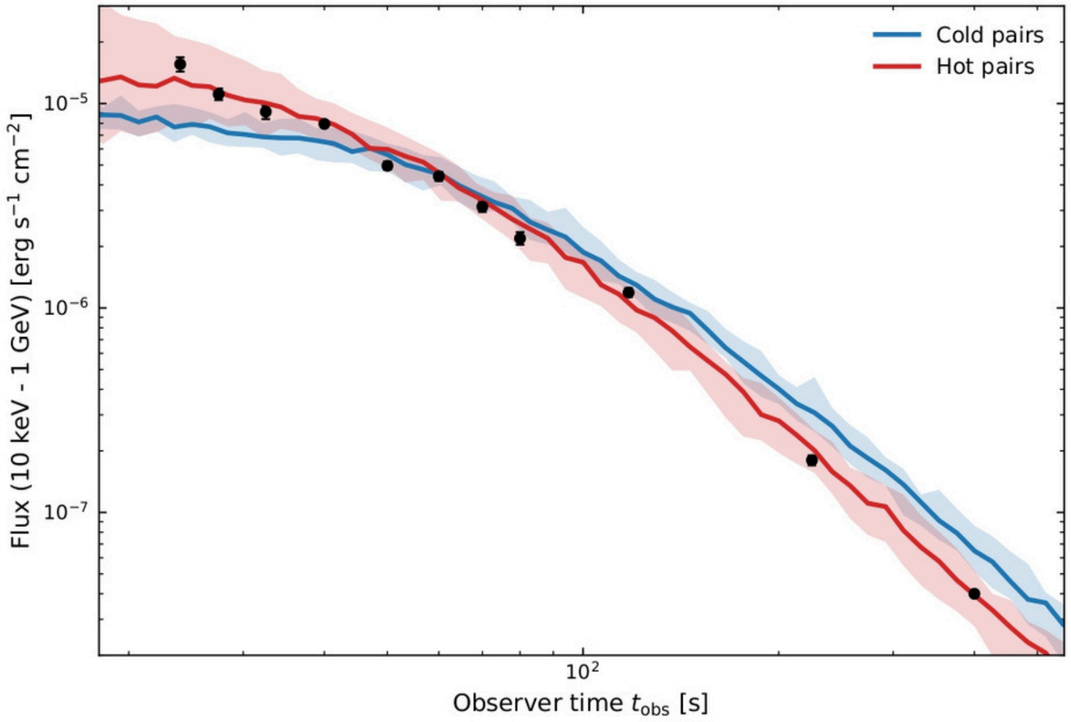




GRB 260226A : The ultra-fast afterglow

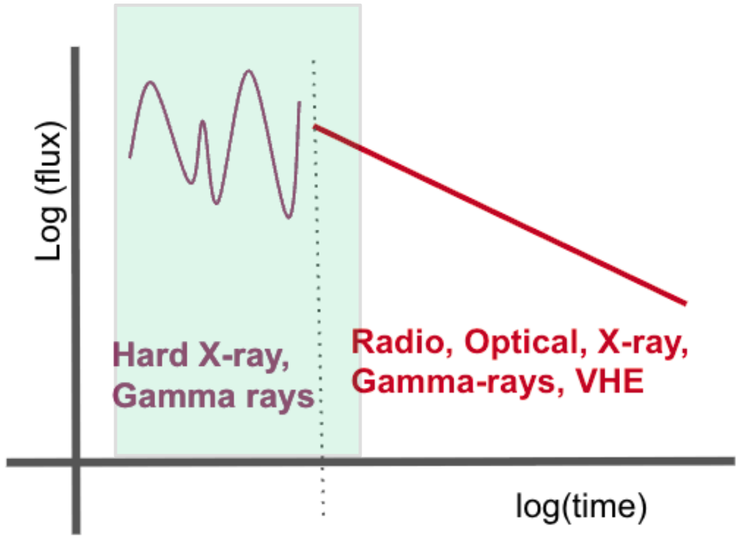
Banerjee, B., et al.(2026)



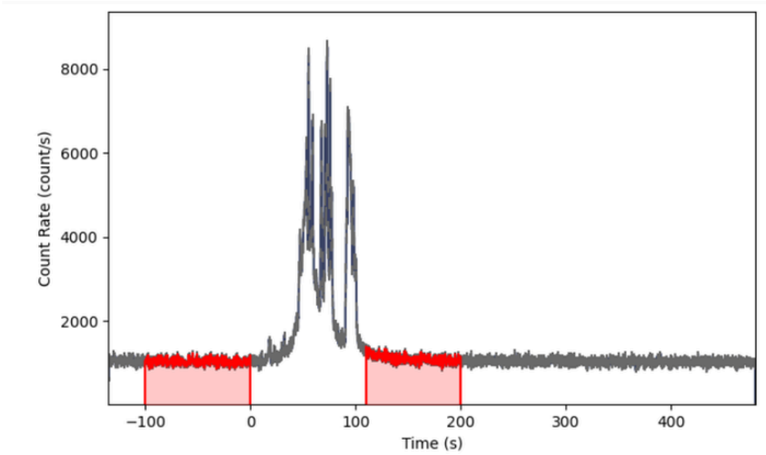


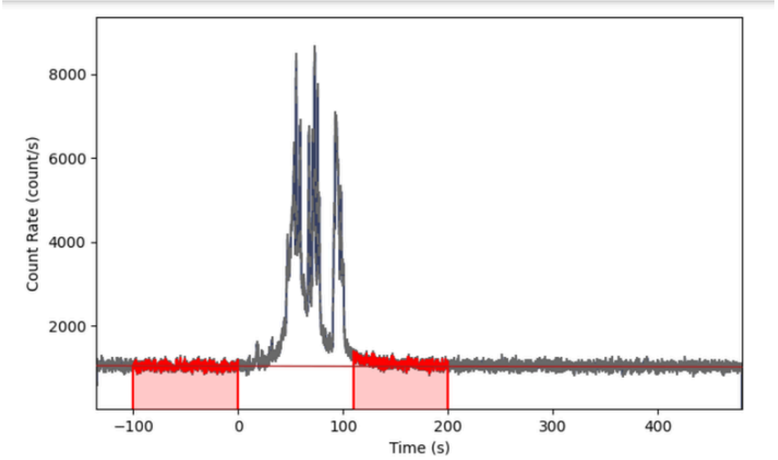
Systematic characterization of early afterglow

GRB emission

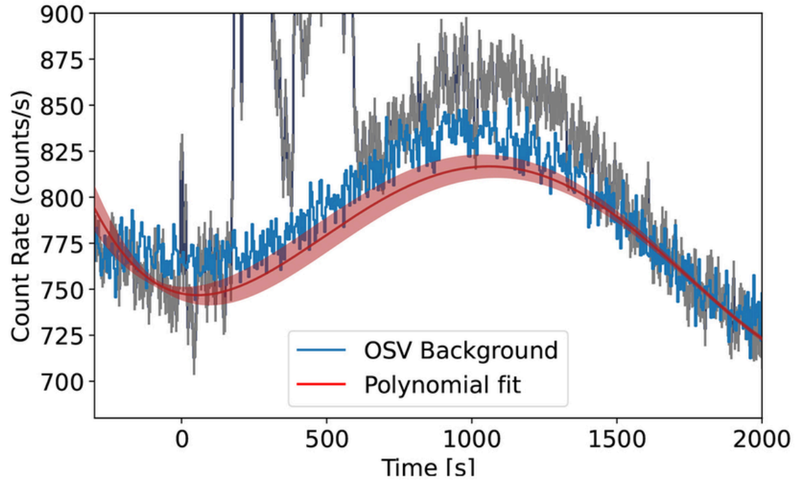


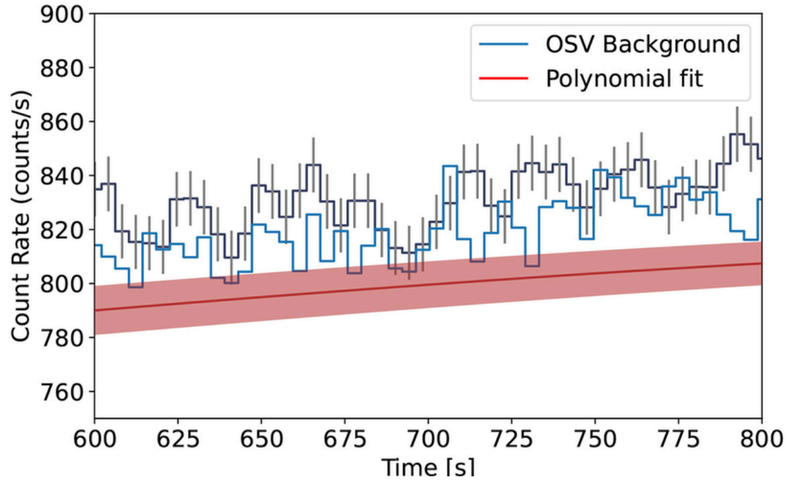
Conventional background subtraction (useful for bright prompt)





Orbital background subtraction (useful for faint afterglow)





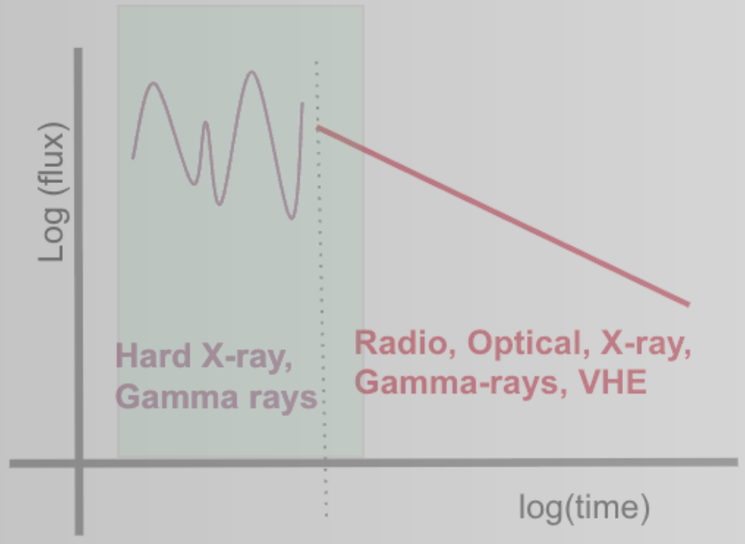
[Fitzpatrick, G., et al 2011]

https://github.com/LudovicoAlt/py3

[Banerjee, B., et al.: A&A, 701, A68 (2025)]

Systematic characterization of early afterglow

GRB emission



Collect bright GBM-detected GRBs

Sort by Fluence

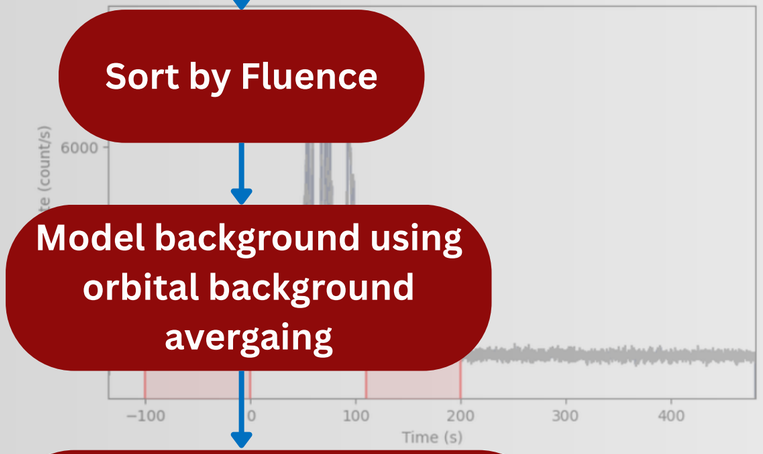
Model background using orbital background avergaing

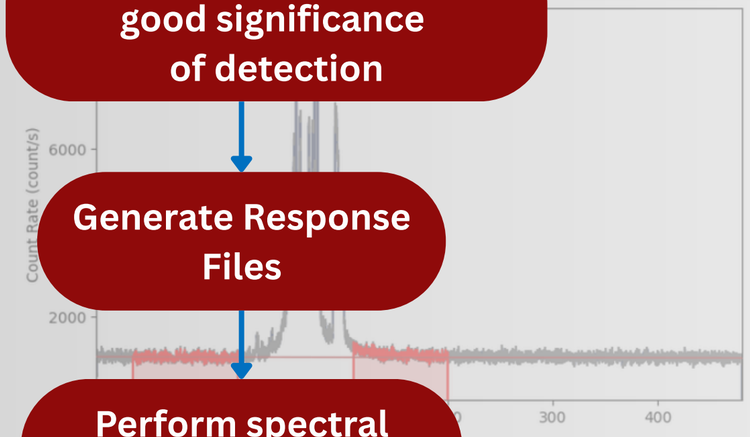
Identify the time-bins with good significance of detection

Generate Response Files

Perform spectral analysis in the most sensitive energy range

und subtraction
nt prompt)





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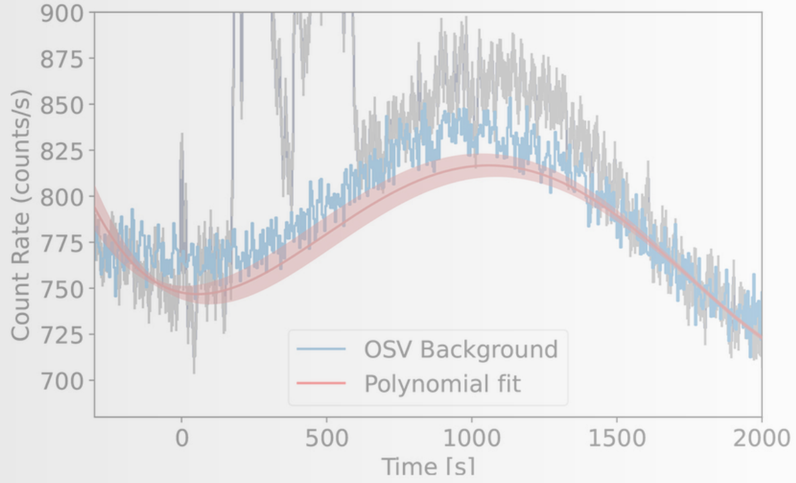
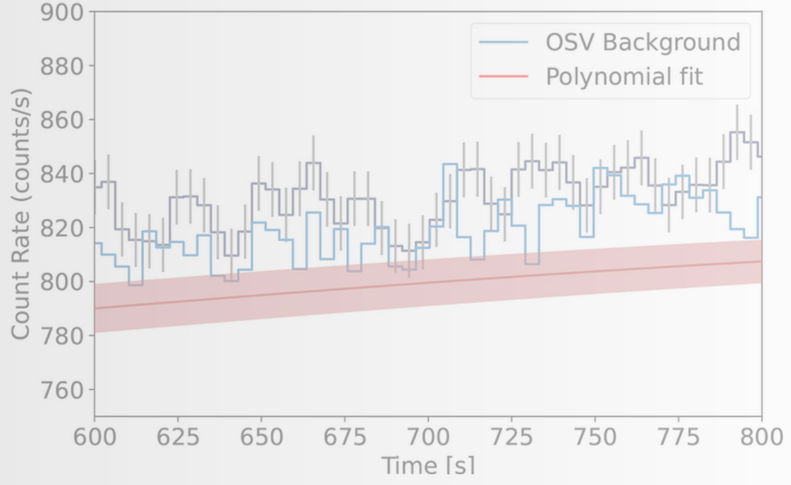
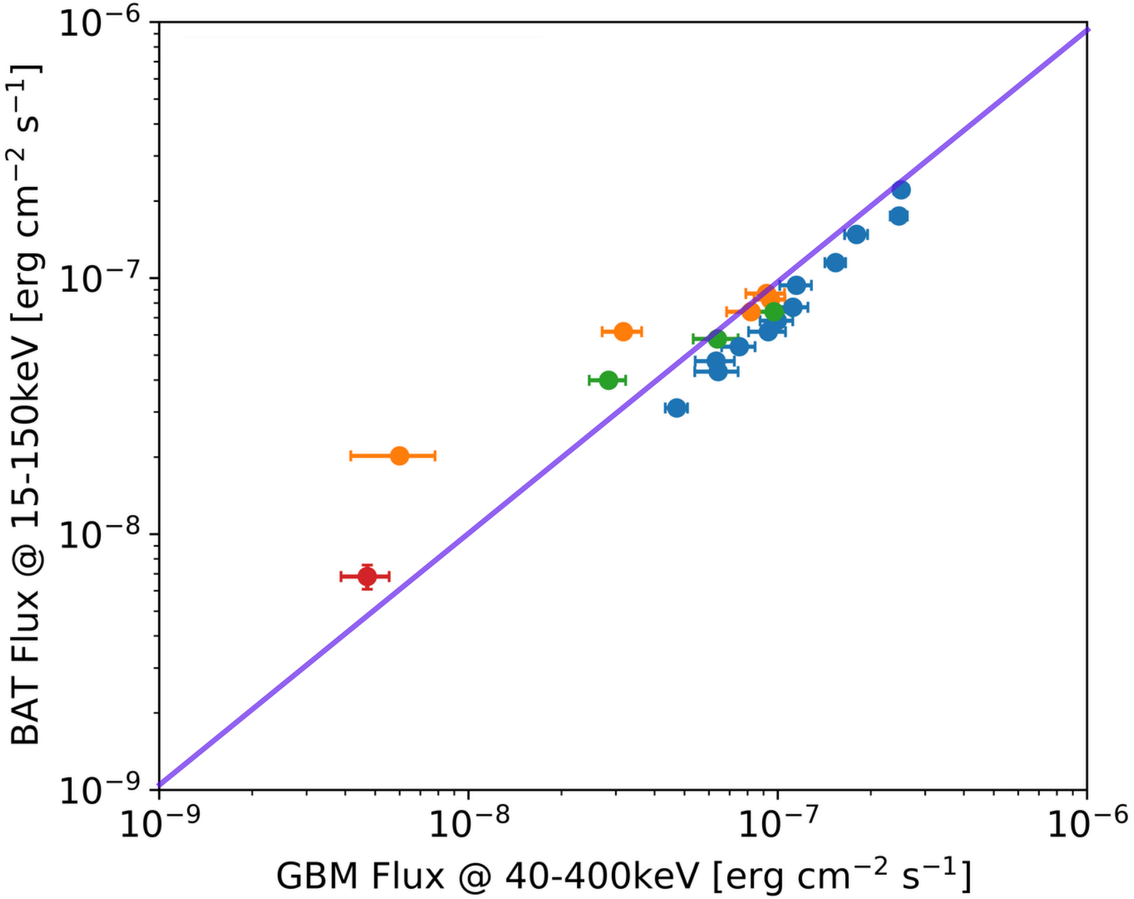
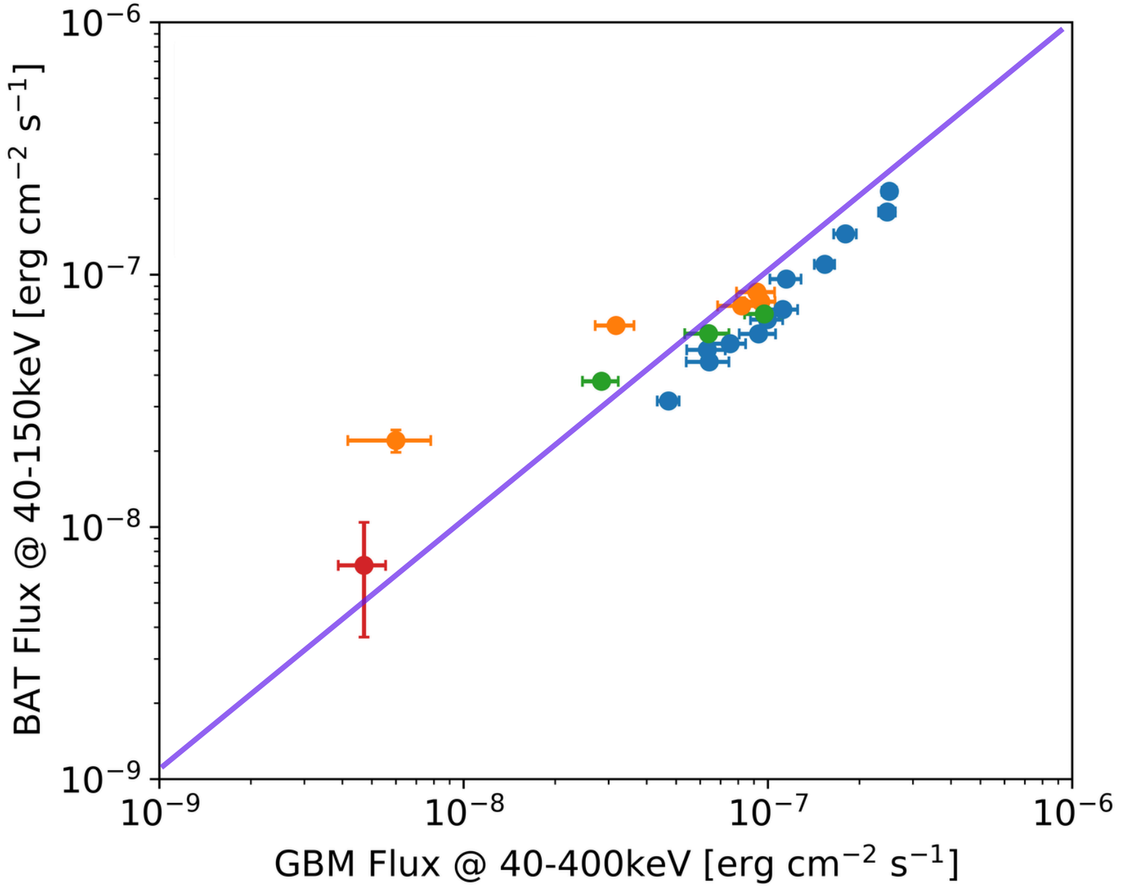


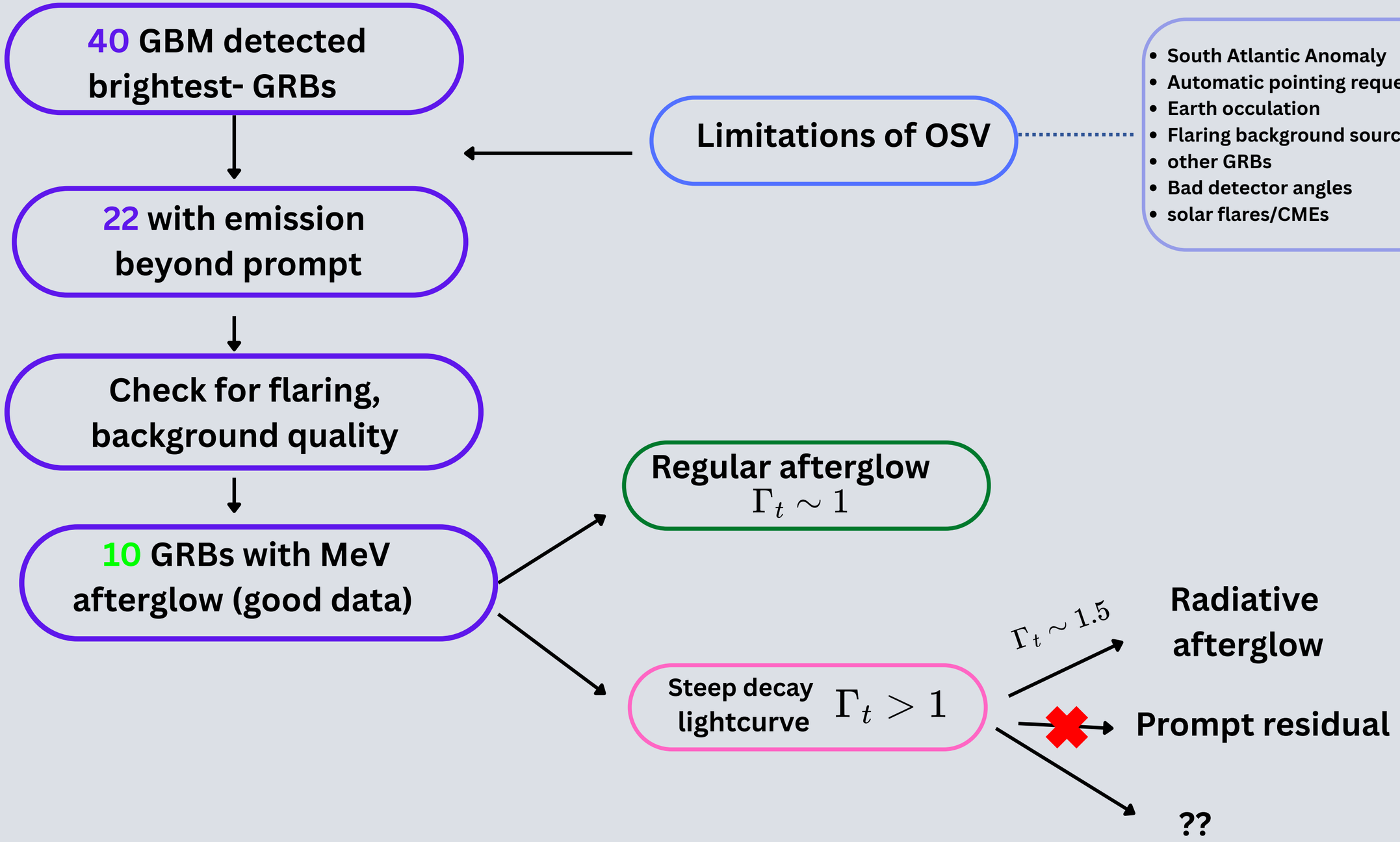


Banerjee, B., et al.: A&A, 701, A68 (2025)

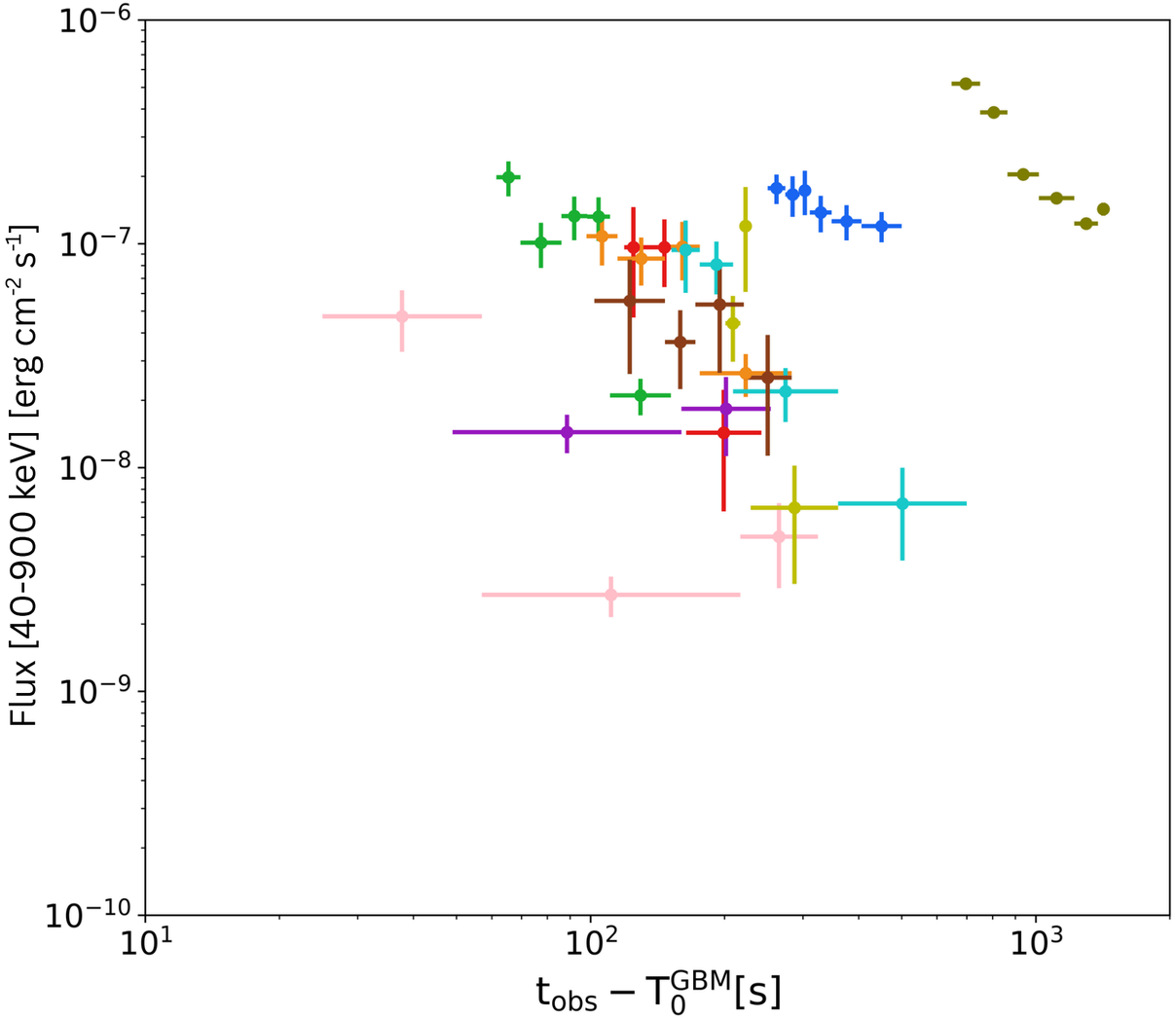
Validating the osv method

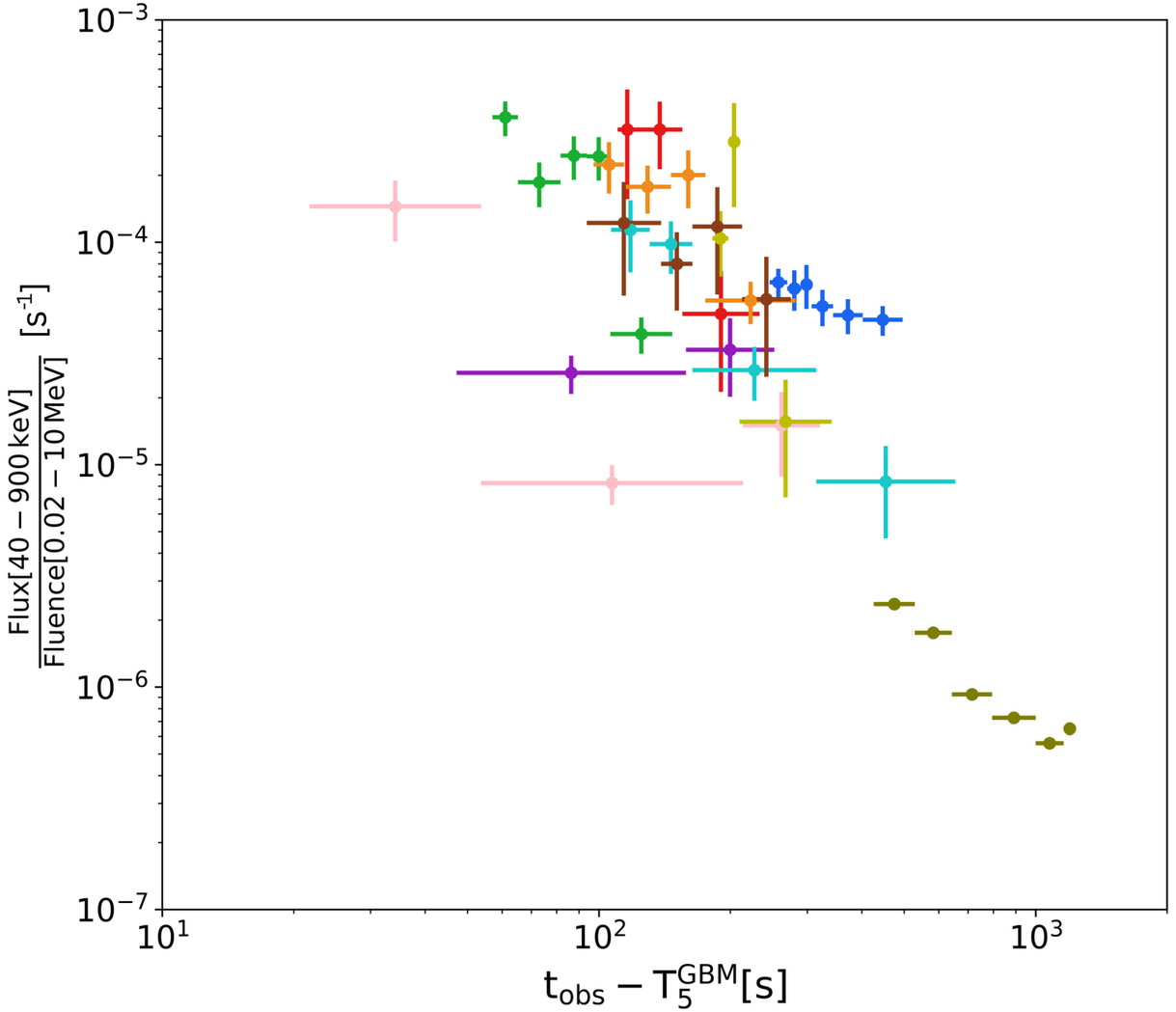


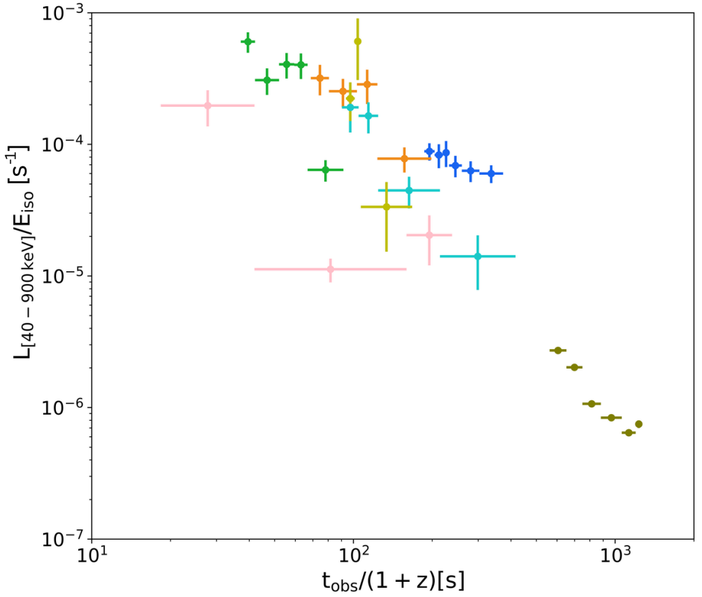


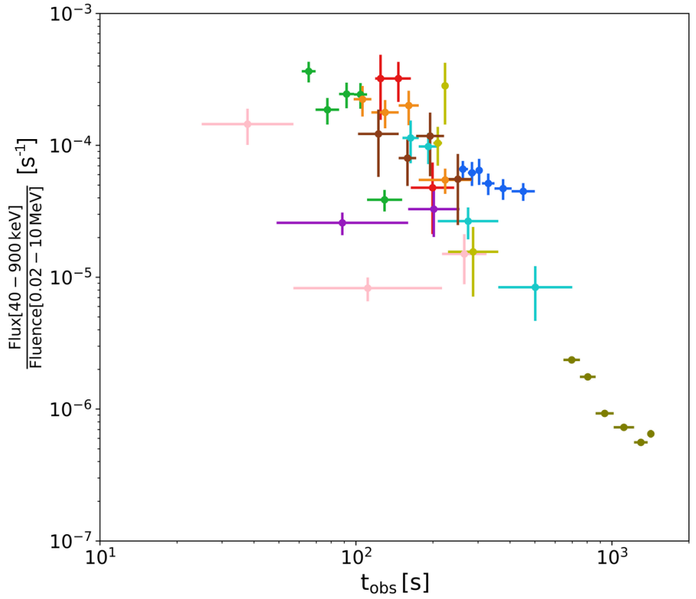

40 GBM detected brightest- GRBs
22 with emission beyond prompt
Check for flaring, background quality
10 GRBs with MeV afterglow (good data)
Limitations of OSV
South Atlantic Anomaly
Automatic pointing requests
Earth occulation
Flaring background sources
other GRBs
Bad detector angles
solar flares/CMEs
Regular afterglow
$\Gamma_t \sim 1$
Steep decay lightcurve
$\Gamma_t > 1$
$\Gamma_t \sim 1.5$
Radiative afterglow
Prompt residual
??

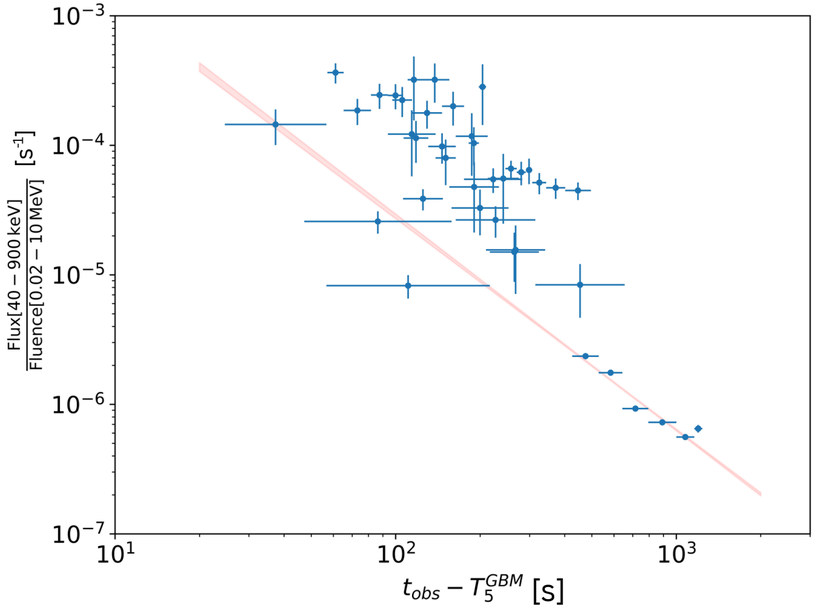
MeV afterglow

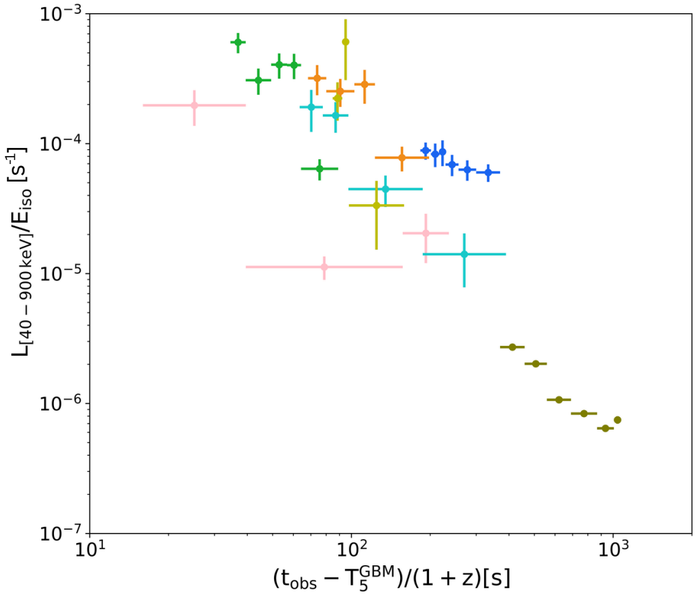


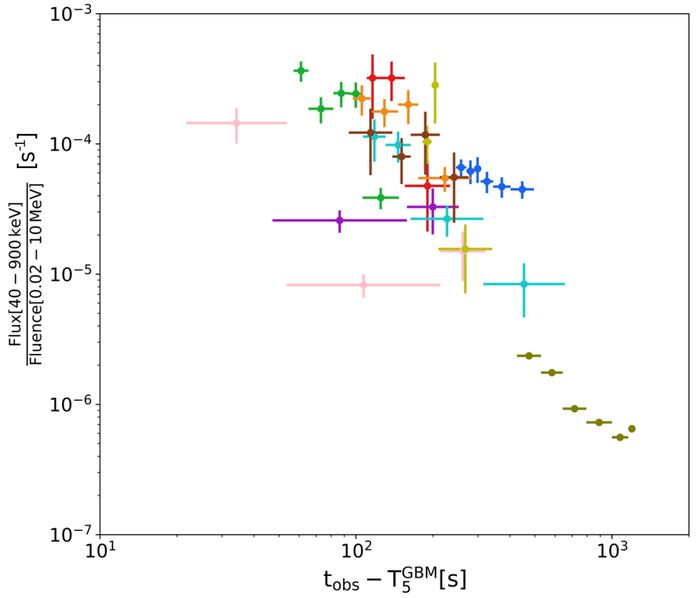



$L_{[40-900\,keV]}/E_{iso}$ [s^{-1}]
$t_{obs}/(1+z)$[s]


$\frac{Flux[40-900\,keV]}{Fluence[0.02-10\,MeV]}$ [s^{-1}]
t_{obs} [s]


$\frac{Flux[40-900\,keV]}{Fluence[0.02-10\,MeV]}$ [s^{-1}]
$t_{obs} - T_5^{GBM}$ [s]


$L_{[40-900\,keV]}/E_{iso}$ [s^{-1}]
$(t_{obs} - T_5^{GBM})/(1+z)$[s]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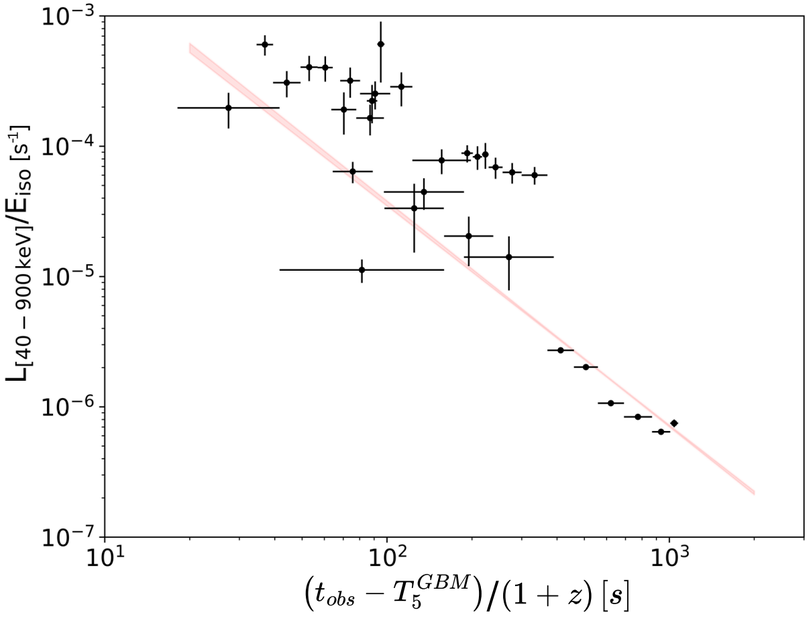
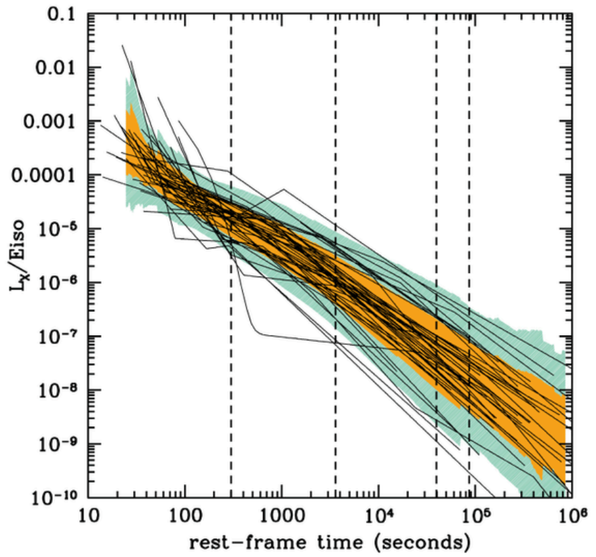
$t_{obs} - T_5^{GBM}$[s]


$L_{[40-900\,keV]}/E_{iso}$ [s^{-1}]
$(t_{obs} - T_5^{GBM})/(1+z)$ [s]

General Trends in GRBs Afterglow

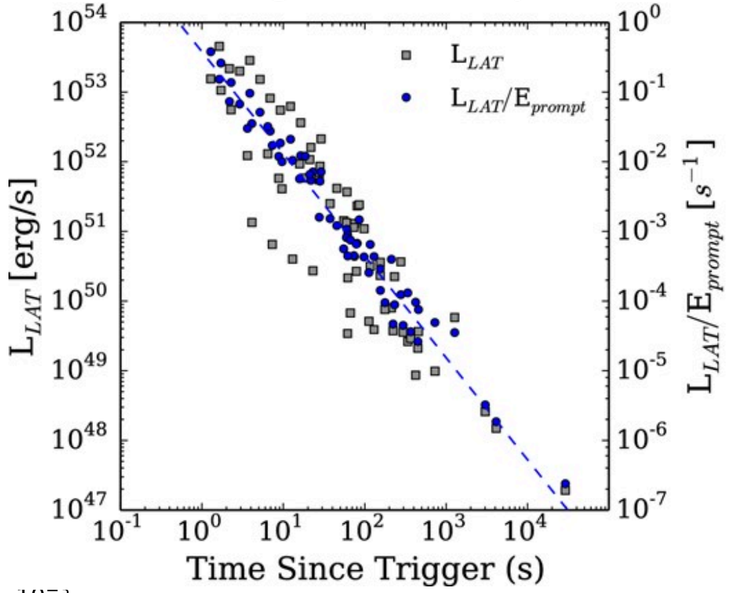
X-rays (*2*-10 keV)

D'Avanzo et al 2012

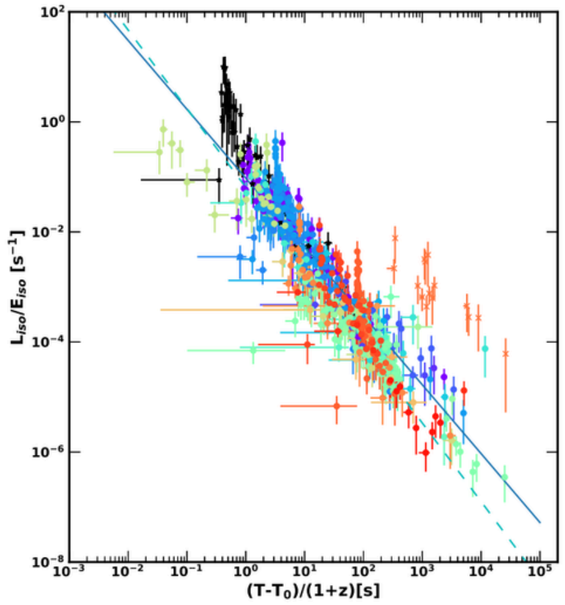


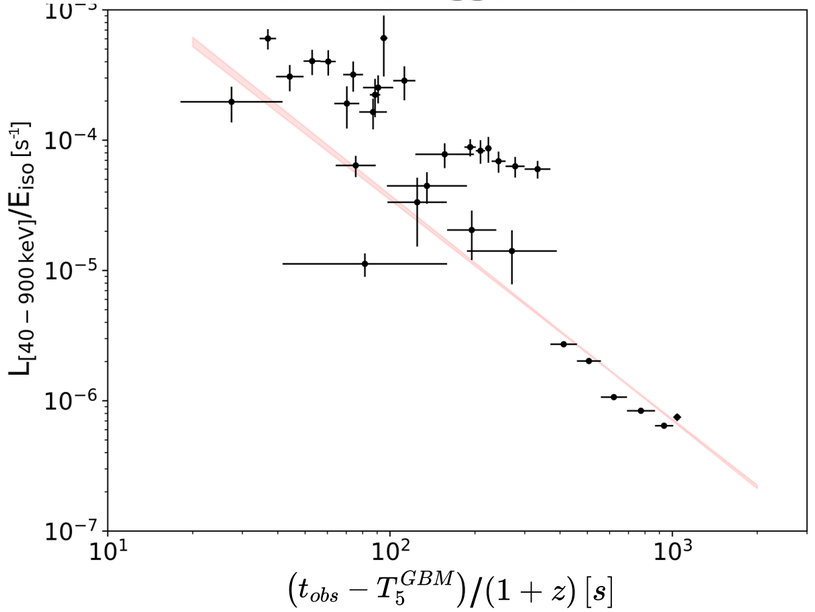
HE gamma-rays

Nava et al. 2014



LAT collaboration. 2019





→ Strong correlation between E_{PROMPT} and afterglow luminosity in X-rays and GeV

L/E_{iso} Temporal decay index

→ LAT = 1.25 ± 0.03
(LAT collaboration. 2019

→ GBM (40-900keV) = 1.7+0.02
(This work)

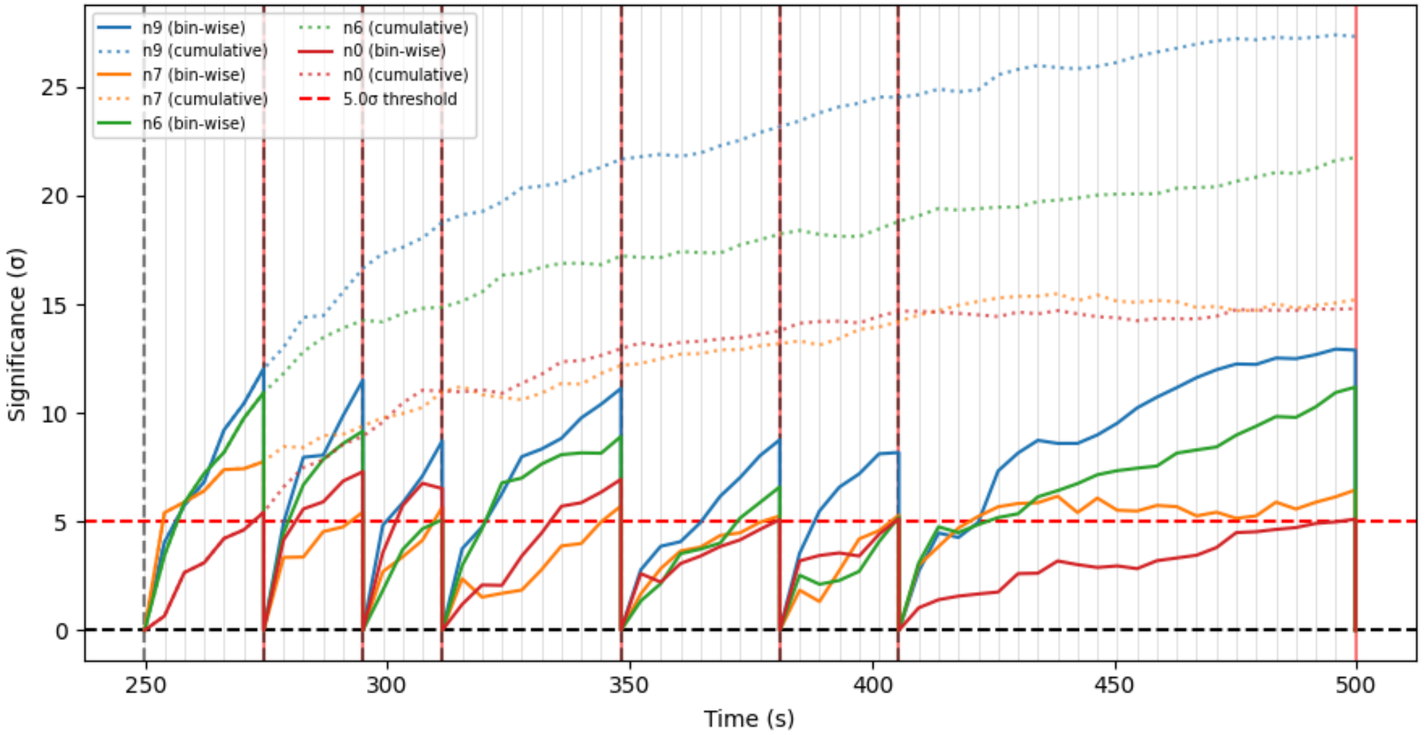
Key takeaways

- The MeV band is crucial to understanding the transition from prompt to Afterglow and remains largely unexplored due to background-dominated instruments.
- The brightest burst GRB 221009A showed the first-ever detection of MeV afterglow in the early phase, capturing the spectral turnover.
- Thanks to MeV afterglow extraction via OSV, a complete broadband modelling of GRB230812B revealed a spectral component consistent with an SSC external forward shock.
- The MeV-GeV observations from the early afterglow phase of GRB 260226A show the steepening of the light-curve, suggesting the external inverse Compton emission in a pair-enriched medium.
- A systematic characterisation of early afterglow in the MeV band helps in understanding the transition from the prompt to the afterglow phase of GRBs and the formation of the external shock.
- The MeV afterglow from the population of high-fluence GRBs shows a trend in L/E_{iso} vs T_{rest} similar to the existing correlation in X-rays and the high-energy gamma-ray band.

Thank you

Backup Slides

Selection of time-bins



Li & Ma Significance Formula

$$S = \sqrt{2\left[N_{\text{on}} \ln\left(\frac{1+\alpha}{\alpha} \cdot \frac{N_{\text{on}}}{N_{\text{on}}+N_{\text{off}}}\right) + N_{\text{off}} \ln\left((1+\alpha)\cdot\frac{N_{\text{off}}}{N_{\text{on}}+N_{\text{off}}}\right)\right]}$$

- N_{on} = Number of events in the ON (signal) region
- N_{off} = Number of events in the OFF (background) region
- α = Exposure ratio (ratio of ON to OFF exposure)
- S = Significance (in standard deviations, σ)

S is the statistical significance of the excess assuming Poisson statistics.