Minutes-long Soft X-ray Prompt Emission from a Compact Object Merger

A Short GRB Counterpart EP250704a Detected by Einstein Probe

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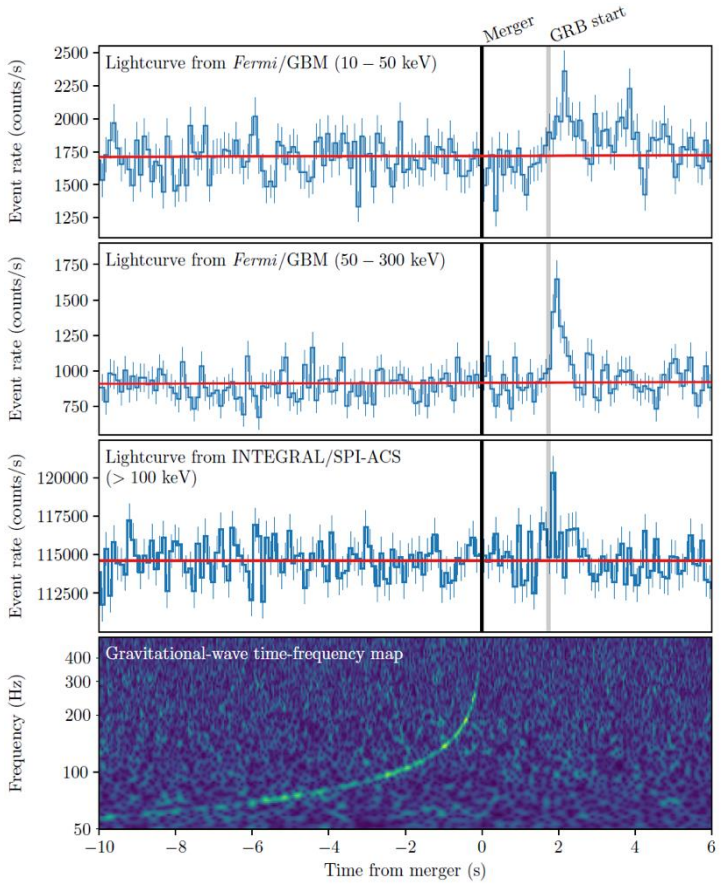
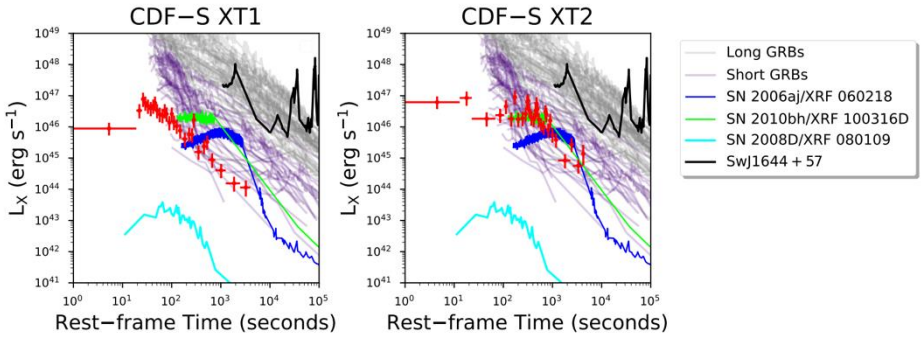
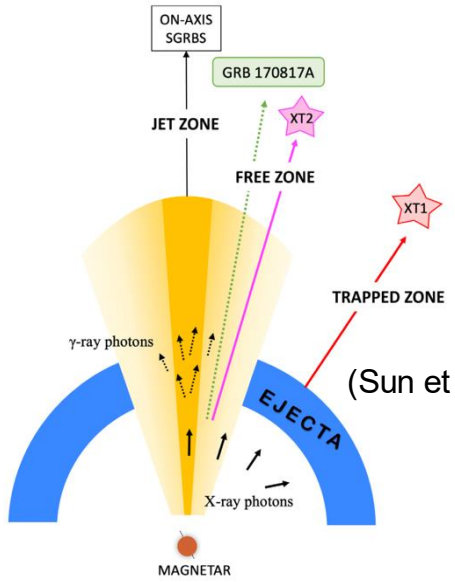
Compact object merger counterpart



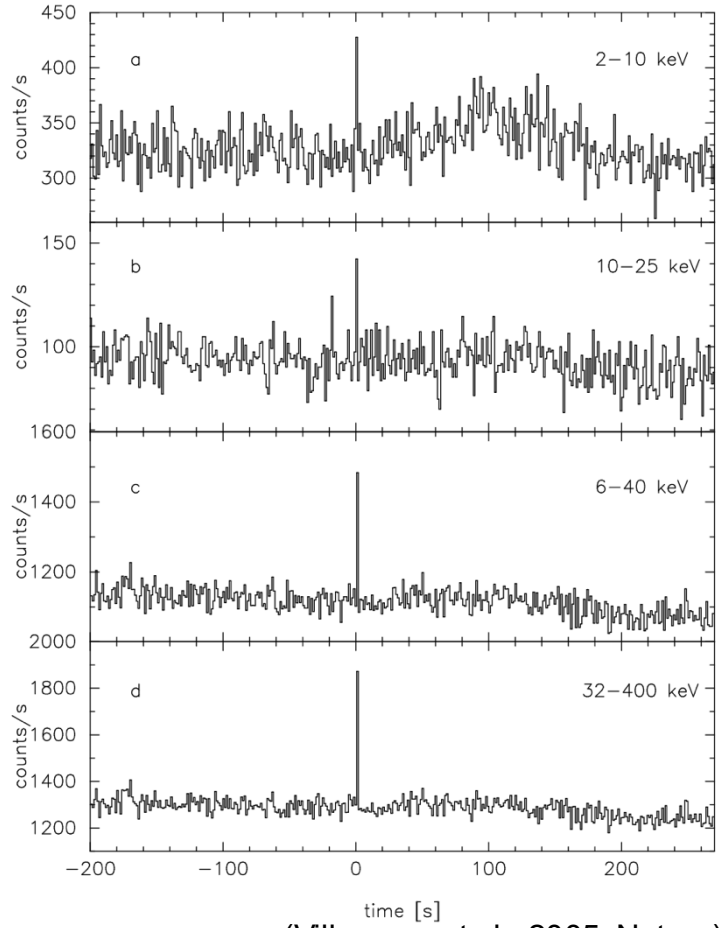
GRB 170817A and GW170817
(Abbott et al., 2017, ApJL)



(Quirola-Vásquez et al., 2025, A&A)



(Sun et al., 2019, ApJ)



(Villasenor et al., 2005, Nature)

confirm the **NS merger – short GRB** paradigm

two EFXT candidates of magnetar-powered X-ray emission following BNS mergers
origin remains unsettled (Quirola-Vásquez et al.)

GRB 050709 displayed a long-soft X-ray component after the short spike
yet explained as **the afterglow onset**

Discovery of EP250704a / GRB 250704B

Trigger Timeline

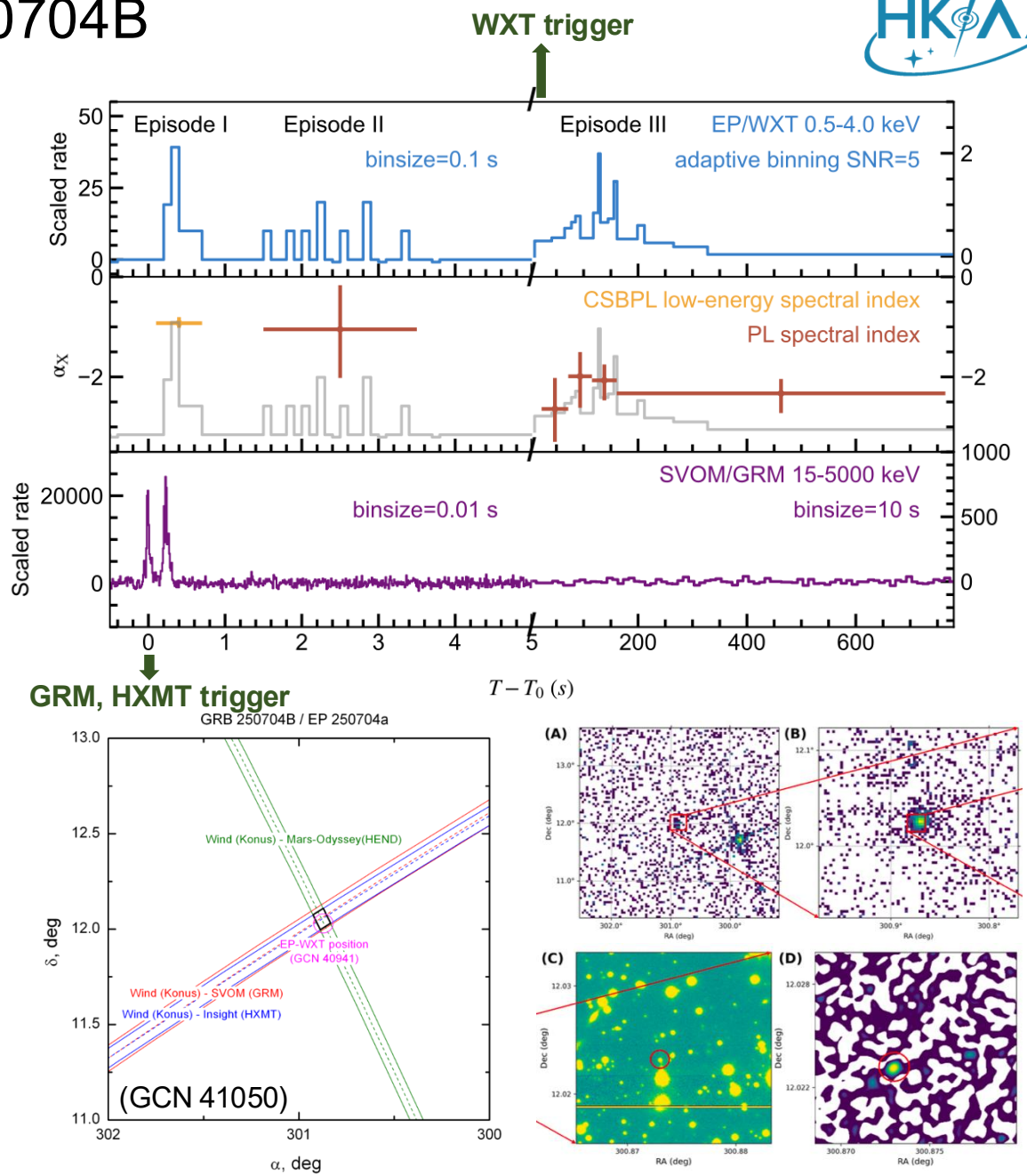
- **EP-WXT:** 2025-07-04T08:16:52 **(~ T_0 + 25 s)**
- **SVOM-GRM:** 2025-07-04T08:16:27.10 **(T_0)**
- **Insight-HXMT:** 2025-07-04T08:16:27.10 **(T_0)**
- **Konus-Wind*:** 2025-07-04T08:16:31.045

Position

- **EP-WXT:** (300.872, 12.030) 3 arcmin error circle
- **EP-FXT:** (300.8719, 12.0231) 10 arcsec error circle
- **IPN:** (300.880, 12.053) 19 sq. arcmin error box

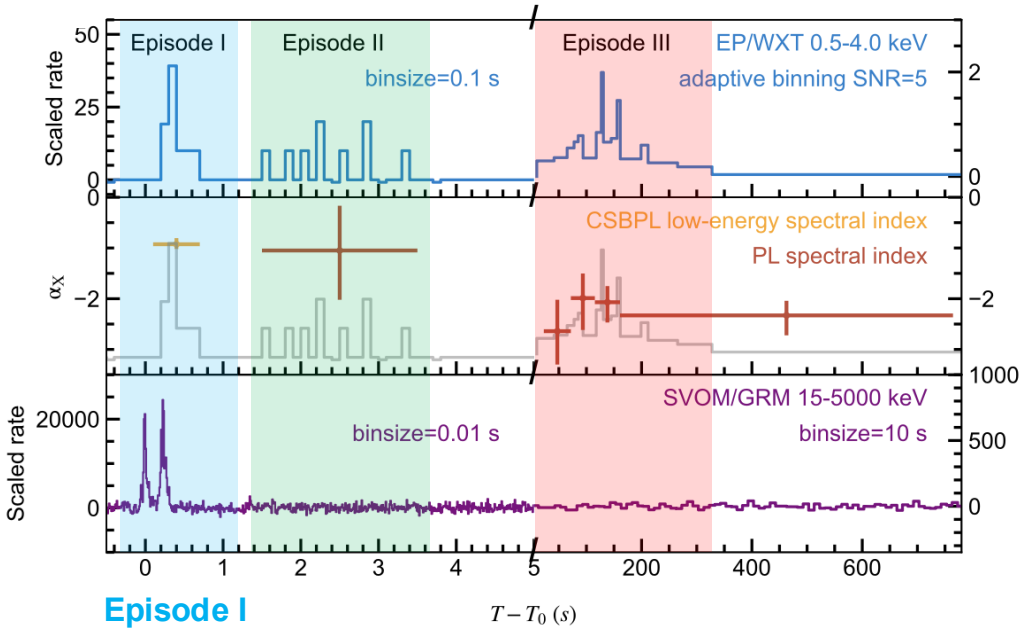
Multiwavelength Follow-up

- **X-ray:** EP-FXT (automatic follow-up in 3.3 min), XRT
- **Optical:** SVOM-VT, GRANDMA, GTC, etc.; VLT ***z* ~ 0.661**
- **Radio:** MeerKAT, VLA



*at Earth-Sun L1 Lagrange point

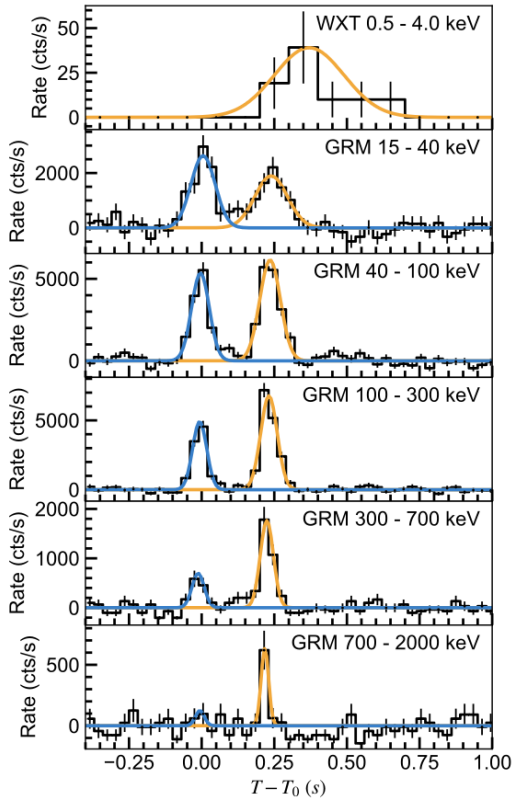
Episodes of EP250704a / GRB 250704B

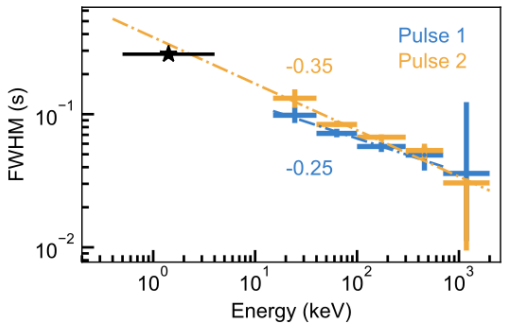


Episode I
(~ 0.5 s)
initial X-ray hard spike
gamma-ray double spikes

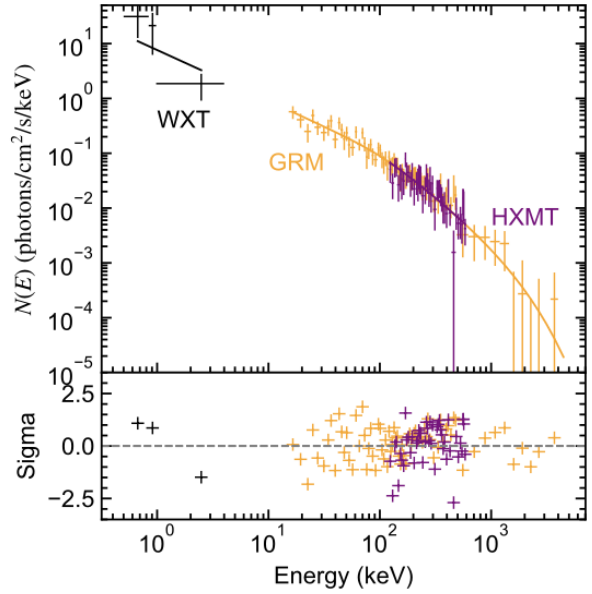
Episode II
(~ 3 s)
extended X-ray hard bump
no gamma-ray

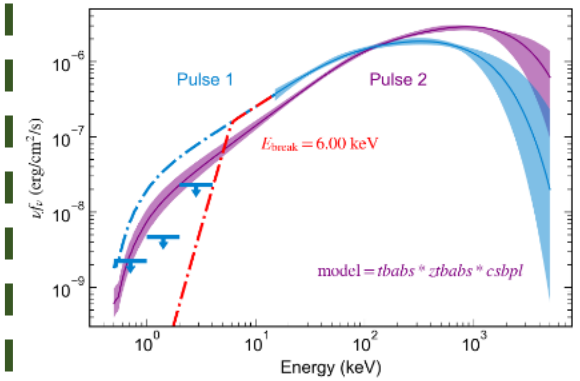
Episode III
(~ 540 s)
X-ray soft bump
no gamma-ray





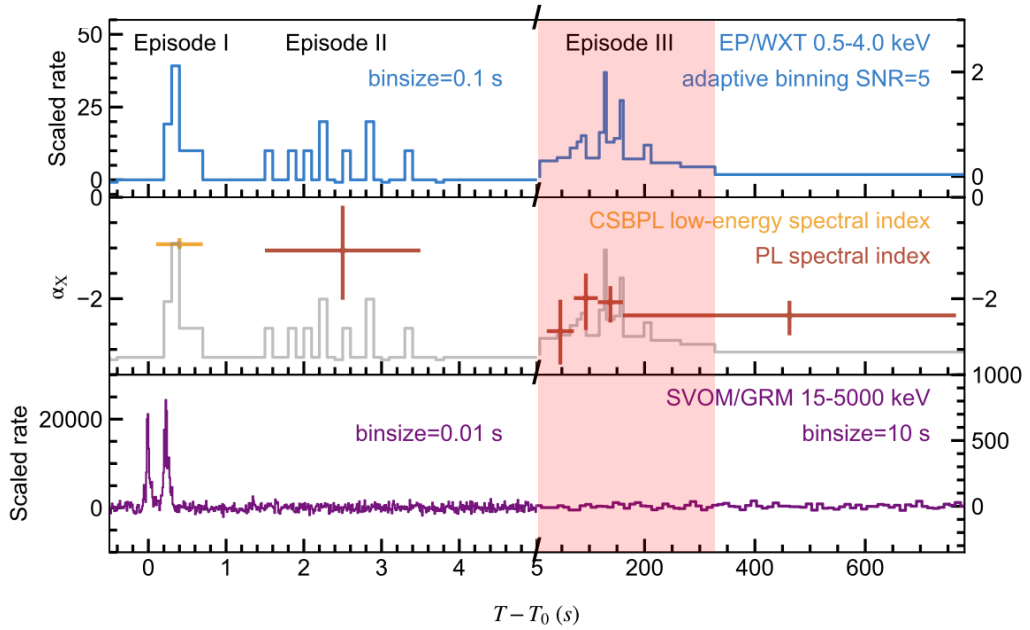
temporal and spectral consistency of the X-ray spike and gamma-ray 2nd pulse in Episode I



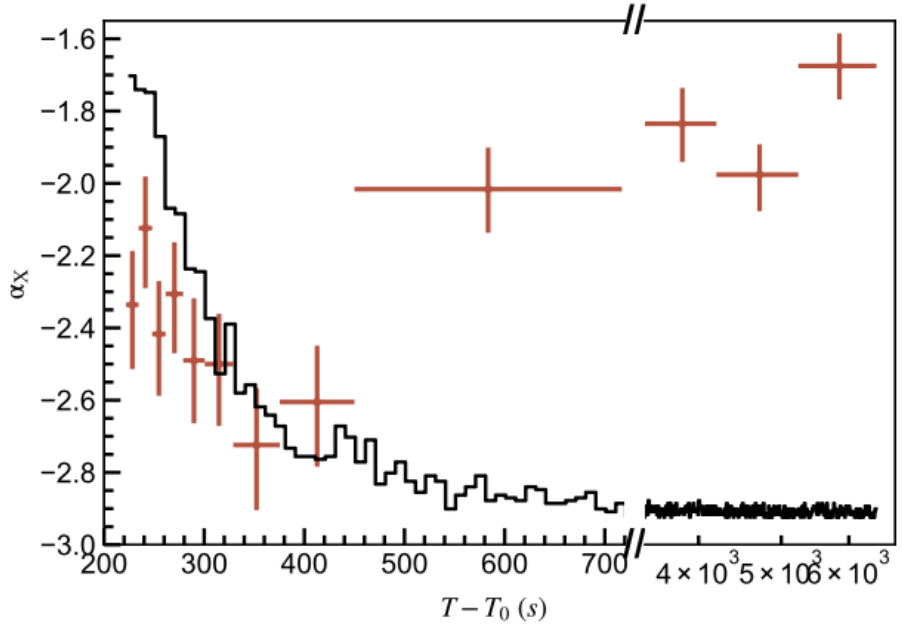


a spectral break is invoked to explain the lack of Pulse 1 in X-ray band

Episodes of EP250704a / GRB 250704B

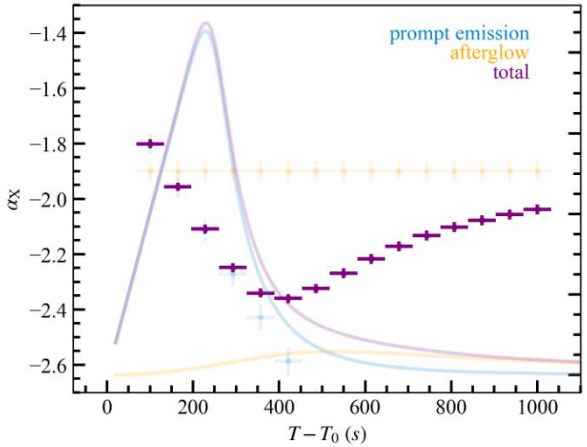


Episode III (~ 540 s): WXT light curve showing rapid variability ($\Delta t/t \lesssim 0.1$)



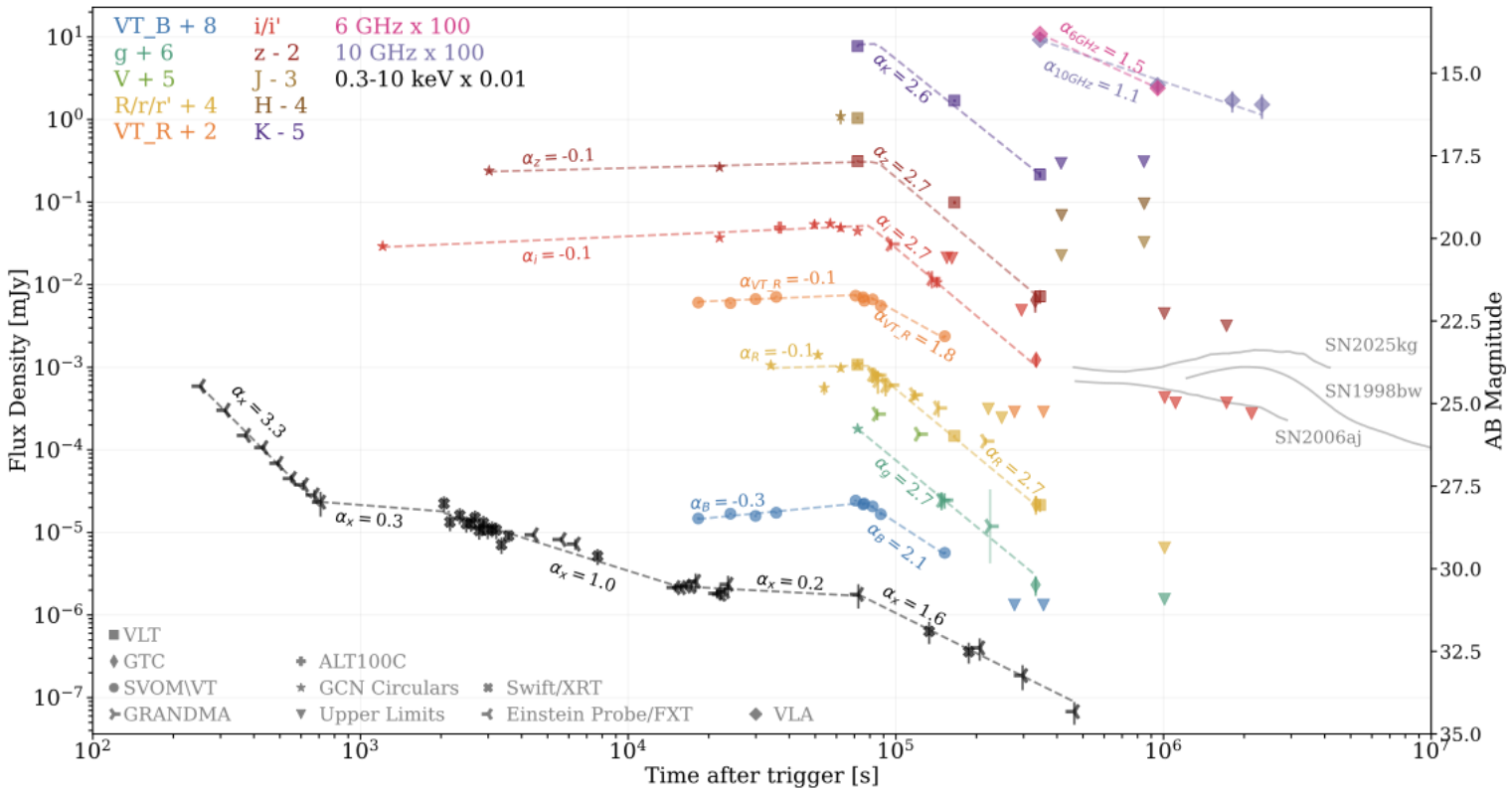
Episode III (~ 540 s): FXT spectra displaying evolving pattern

The extended soft X-ray bump (Episode III) is attributed to the long-lasting, engine-powered emission, followed by the afterglow emission dominating at ~ 400 s.

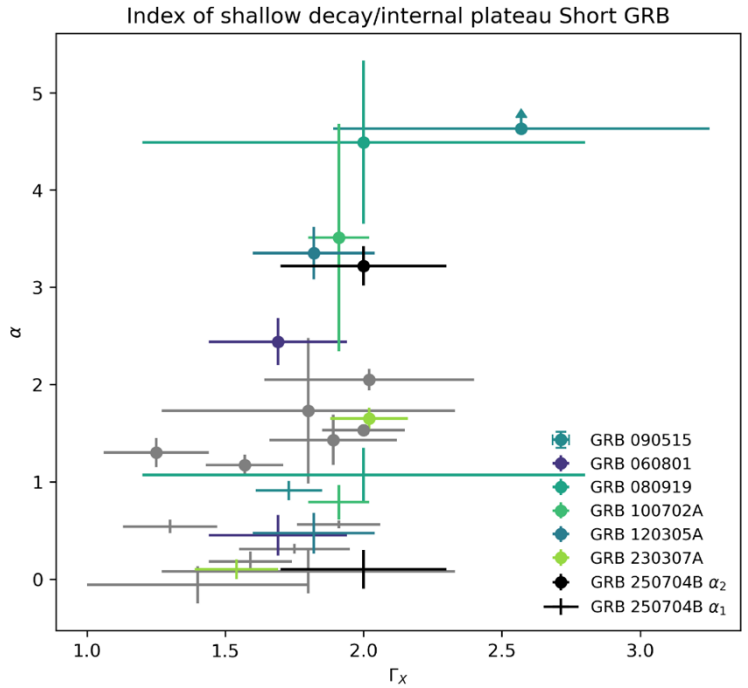


(Yin et al., 2025, ApJL)

Afterglow of EP250704a / GRB 250704B



the shallow X-ray decay and the slow optical rise require sustained energy injection

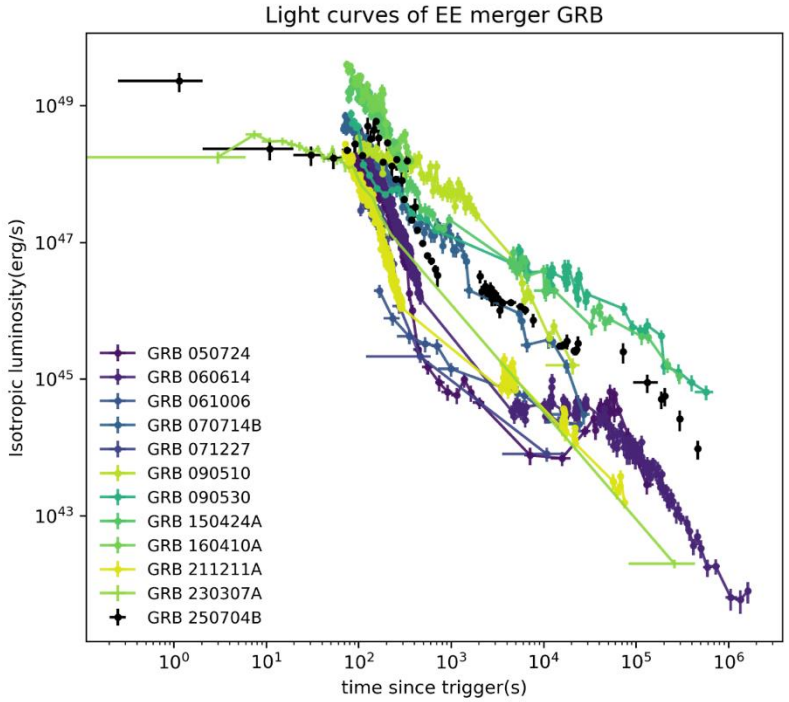


temporal and spectral indices are comparable to early X-ray light curves of short GRBs attributed to internal plateaus

The merger remnant is most likely a long-lived magnetar, which remained active well beyond the gamma-ray phase.

Minutes-long Soft X-ray Prompt Emission Counterpart

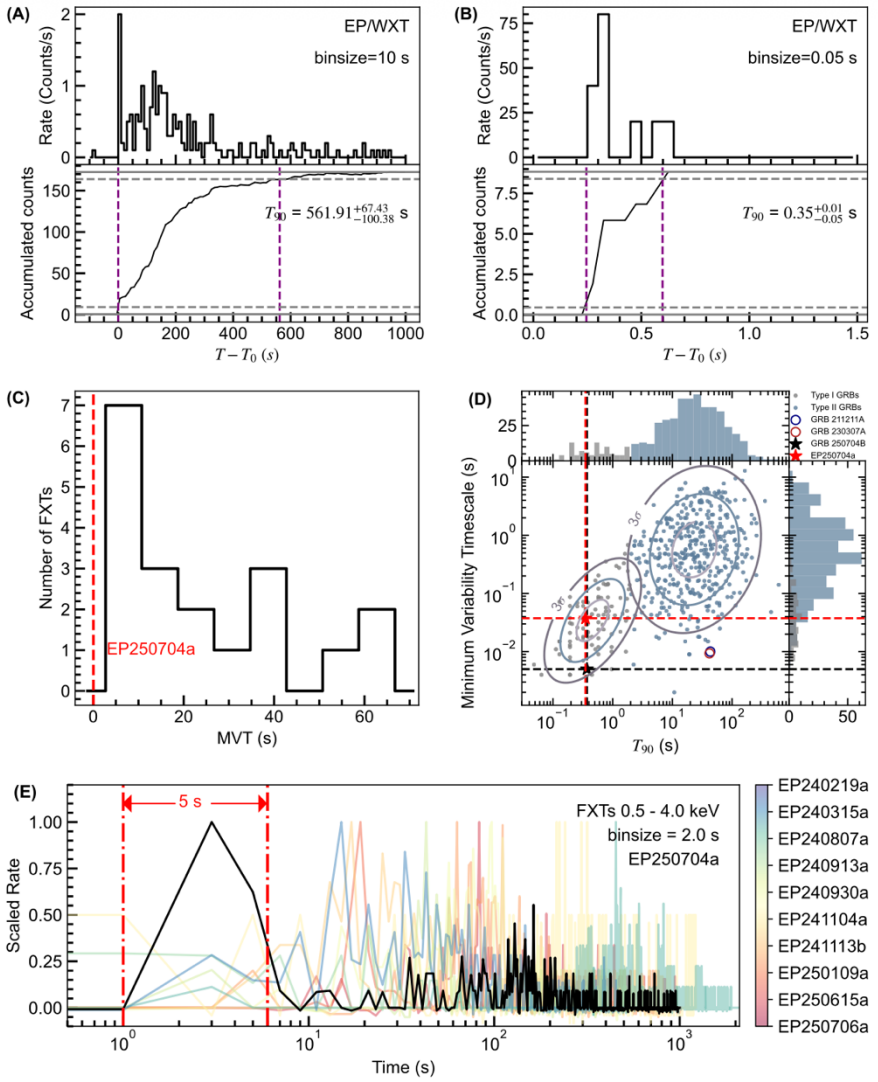
Among merger-driven bursts samples:



Spectral Constraint:
long-lasting prompt emission in merger-driven bursts has been identified only in short GRBs with extended emission and rare long GRBs with hybrid properties in gamma-ray band (≃10–15%)

Temporal Constraint:
Swift only caught the final decaying tails of the X-ray plateaus, the onset, temporal profile and short-term variability were not observed due to the slew time gap

Among fast X-ray transient samples:



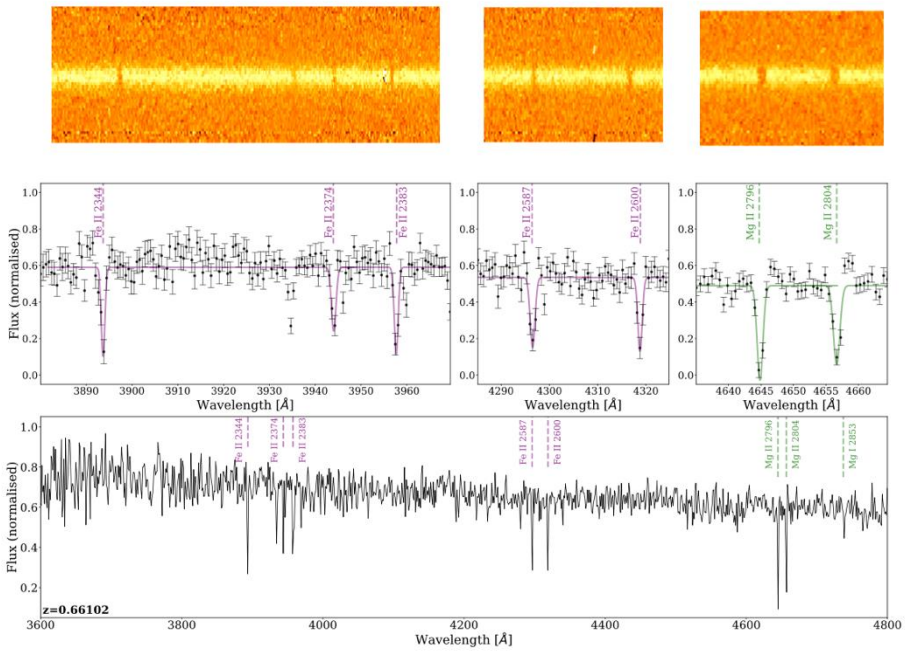
Implications and Conclusions

- Had EP250704a been monitored solely in gamma-rays, only the 0.4-s spike would have been detected.
- Detectability of the minutes-long soft prompt emission bump with Swift/BAT becomes feasible at $z \lesssim 0.08$. This is not the typical distance scale of short GRBs, localized by Swift at $z \gtrsim 0.1$.
- The long-lasting X-ray emission is likely a common feature of merger-driven bursts and a promising electromagnetic counterpart to gravitational wave sources.

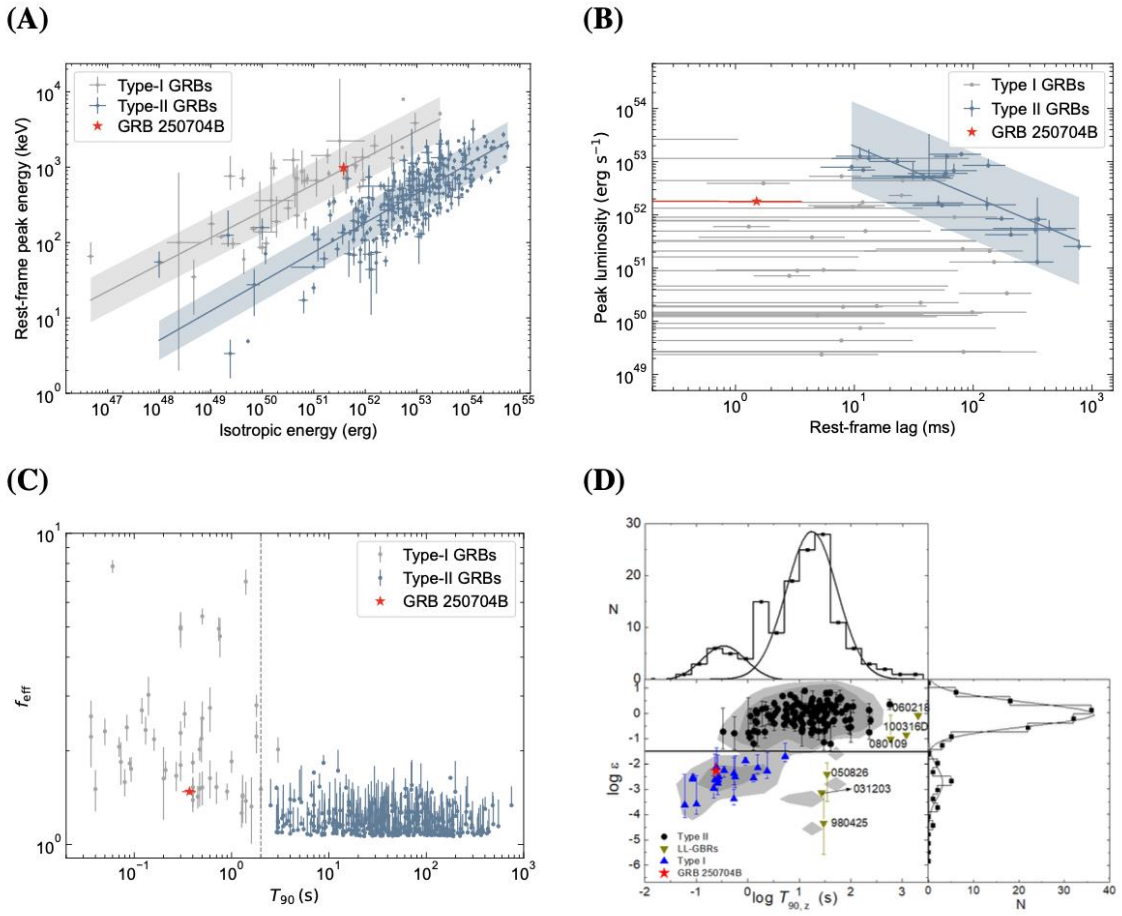
Observed Properties	EP250704a/GRB 250704B
Soft X-ray [0.5–4 keV]:	
Total duration (s)	$561.91^{+67.43}_{-100.38}$
Spike duration (s)	$0.35^{+0.01}_{-0.05}$
EE spectral index α	-2.30 ± 0.23
EE flux (erg cm^{-2} s^{-1})	$2.16^{+0.22}_{-0.19} \times 10^{-10}$
EE fluence (erg cm^{-2})	$1.61^{+0.16}_{-0.14} \times 10^{-7}$
EE luminosity (erg s^{-1})	$2.61^{+0.27}_{-0.23} \times 10^{47}$
EE Isotropic energy (erg)	$1.93^{+0.20}_{-0.17} \times 10^{50}$
Gamma-ray [10–1000 keV]:	
Trigger time	2025-07-04 08:16:27.100
Duration (s)	0.37 ± 0.06
Effective amplitude	1.48 ± 0.03
Minimum variability timescale (ms)	5
Rest-frame spectral lag*(ms)	$2.5^{+3.5}_{-2.5}$
Spectral index α_1	$-0.78^{+0.31}_{-0.27}$
Spectral index α_2	$-1.46^{+0.22}_{-0.21}$
Break energy E_b (keV)	$55.85^{+57.13}_{-26.47}$
Peak energy E_p (keV)	$588.84^{+91.93}_{-122.18}$
Peak flux (erg cm^{-2} s^{-1})	$1.23^{+0.03}_{-0.03} \times 10^{-5}$
Total fluence (erg cm^{-2})	$3.15^{+0.17}_{-0.21} \times 10^{-6}$
Peak luminosity (erg s^{-1})	$1.80^{+0.06}_{-0.07} \times 10^{52}$
Isotropic energy (erg)	$3.79^{+0.20}_{-0.25} \times 10^{51}$
Afterglow:	
Redshift	0.66102 ± 0.00011
Associations:	
Kilonova	Not detectable at z=0.661
Supernova	Ruled out: SN2025kg, SN1998bw, SN2006aj

Thank you.

Merger Origin of EP250704a / GRB 250704B



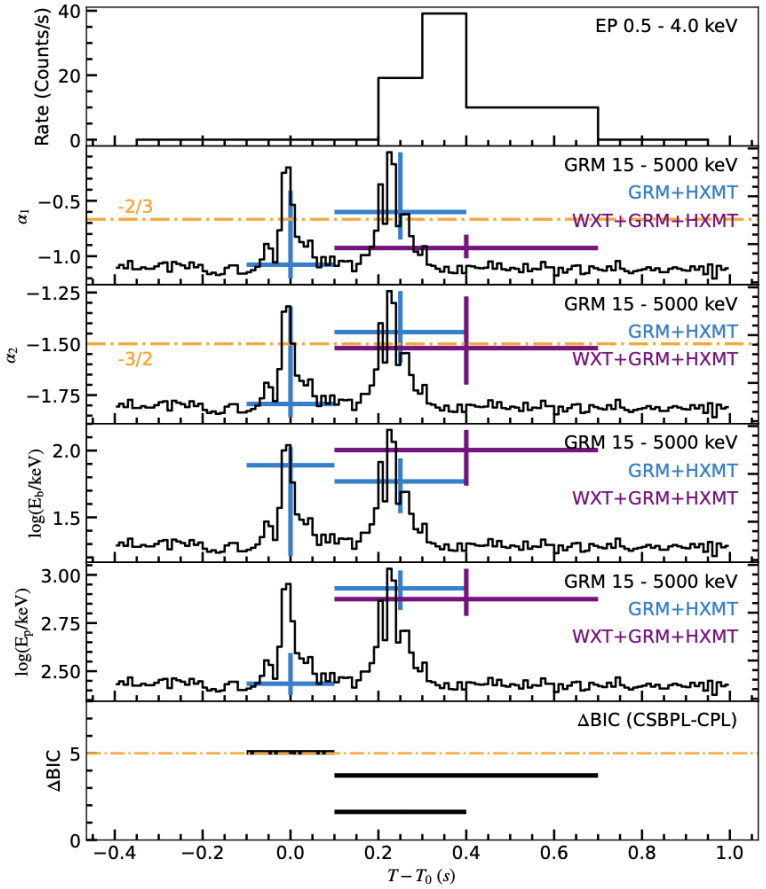
Multiple absorption lines at a common redshift of z = 0.66102 are imprinted on the afterglow light. At such distance, our deep optical limits from GTC rule out a bright supernova, making a collapsar origin unlikely.



The relationship of the observation properties from prompt emission of EP250704a/GRB 250704B classifying it as a Type-I GRB.

Spectral Fittings of EP250704a / GRB 250704B

t1 (s)	t2 (s)	CPL model α	E_p	log$A$	stat/dof	BIC	CSBPL model E_b	E_p	α_1	α_2	log$A$	stat/dof	BIC
			(photons cm^{-2} s^{-1} keV^{-1})				(keV)	(keV)			(photons cm^{-2} s^{-1} keV^{-1})		
-0.10	0.10	$-1.27^{+0.10}_{-0.09}$	$334.97^{+43.48}_{-35.05}$	$-0.96^{+0.04}_{-0.04}$	160.08/87	173.58	$77.62^{+28.54}_{-61.41}$	$272.27^{+121.28}_{-34.04}$	$-1.08^{+0.67}_{-0.12}$	$-1.79^{+0.47}_{-0.07}$	$1.28^{+0.21}_{-0.77}$	156.13/85	178.63
0.10	0.40	$-1.08^{+0.07}_{-0.08}$	$626.61^{+87.88}_{-59.07}$	$-1.04^{+0.03}_{-0.03}$	190.26/120	204.69	$58.75^{+28.75}_{-24.79}$	$851.14^{+203.25}_{-194.99}$	$-0.60^{+0.54}_{-0.25}$	$-1.44^{+0.20}_{-0.15}$	$0.38^{+0.39}_{-0.73}$	182.25/118	206.31
-0.10	0.40	$-1.13^{+0.06}_{-0.06}$	$489.78^{+57.24}_{-35.84}$	$-0.99^{+0.02}_{-0.03}$	163.85/128	178.48	$55.85^{+57.13}_{-26.47}$	$588.84^{+91.93}_{-122.18}$	$-0.78^{+0.31}_{-0.27}$	$-1.46^{+0.22}_{-0.21}$	$0.75^{+0.40}_{-0.41}$	156.73/126	181.11
0.10	0.70	$-1.05^{+0.06}_{-0.05}$	$613.76^{+59.21}_{-59.14}$	$-1.04^{+0.03}_{-0.03}$	194.83/123	209.34	$100.93^{+41.96}_{-46.35}$	$748.17^{+328.30}_{-135.82}$	$-0.93^{+0.12}_{-0.09}$	$-1.52^{+0.25}_{-0.18}$	$0.88^{+0.15}_{-0.17}$	188.88/121	213.06



$t1$ (s)	$t2$ (s)	PL Model α_X	log$A$ (photons cm^{-2} s^{-1} keV^{-1})	pgstat/dof	BIC
1.50	3.50	$-1.05^{+0.88}_{-0.97}$	$-1.80^{+1.61}_{-1.85}$	0.19/1	2.39
22.76	71.77	$-2.64^{+0.62}_{-0.66}$	$-5.83^{+1.22}_{-1.36}$	4.28/4	7.87
71.77	115.29	$-1.99^{+0.49}_{-0.63}$	$-4.45^{+0.92}_{-1.26}$	5.87/3	9.08
115.29	160.80	$-2.07^{+0.32}_{-0.40}$	$-4.64^{+0.62}_{-0.78}$	12.28/10	17.25
160.80	764.50	$-2.33^{+0.29}_{-0.39}$	$-6.08^{+0.56}_{-0.78}$	11.11/16	16.89
22.76	764.50	$-2.30^{+0.23}_{-0.23}$	$-5.75^{+0.46}_{-0.46}$	174.26/39	181.68
222.00	234.50	$-2.34^{+0.15}_{-0.18}$	$-5.65^{+0.28}_{-0.34}$	58.83/57	66.98
234.50	248.00	$-2.12^{+0.14}_{-0.17}$	$-5.29^{+0.27}_{-0.31}$	49.25/58	57.43
248.00	261.50	$-2.42^{+0.15}_{-0.17}$	$-5.86^{+0.28}_{-0.32}$	51.46/56	59.58
261.50	279.00	$-2.31^{+0.14}_{-0.16}$	$-5.75^{+0.26}_{-0.30}$	40.87/55	48.96
279.00	300.50	$-2.49^{+0.17}_{-0.17}$	$-6.21^{+0.33}_{-0.34}$	45.98/56	54.1
300.50	329.00	$-2.50^{+0.14}_{-0.17}$	$-6.34^{+0.25}_{-0.33}$	62.13/56	70.25
329.00	375.50	$-2.72^{+0.16}_{-0.18}$	$-6.97^{+0.30}_{-0.35}$	49.12/56	57.25
375.50	450.00	$-2.60^{+0.16}_{-0.18}$	$-7.12^{+0.30}_{-0.36}$	68.94/55	77.03
450.00	717.00	$-2.02^{+0.11}_{-0.12}$	$-6.36^{+0.21}_{-0.24}$	65.42/78	74.18
3460.00	4196.50	$-1.83^{+0.10}_{-0.11}$	$-6.67^{+0.18}_{-0.20}$	122.06/107	131.44
4196.50	5234.50	$-1.98^{+0.08}_{-0.10}$	$-7.00^{+0.16}_{-0.20}$	129.85/126	139.55
5234.50	6464.00	$-1.68^{+0.09}_{-0.09}$	$-6.45^{+0.17}_{-0.18}$	151.30/145	161.28

Afterglow Modeling of EP250704a / GRB 250704B

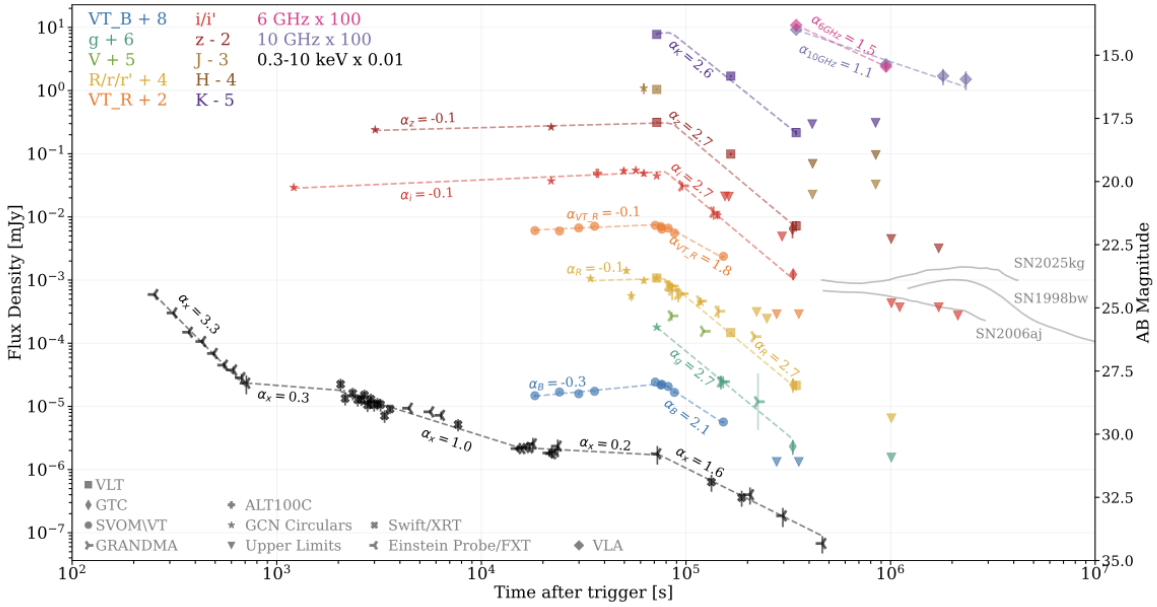


Table S4: Distributions of MCMC-Fitted Parameters with PyFRS.

Parameter	Unit	Prior Type	Parameter Bound	Posterior Value
$\log_{10}(E_{k,iso})$	erg	log − uniform	$[51, 55]$	$52.62^{+0.08}_{-0.09}$
$\log_{10}(\Gamma_0)$	1	log − uniform	$[1, 3]$	$1.51^{+0.05}_{-0.06}$
$\log_{10}(n_{18})$	cm^{-3}	log − uniform	$[-4, 0]$	$-2.96^{+0.41}_{-0.34}$
θ_j	degree	uniform	$[0, 15]$	$3.08^{+0.48}_{-0.34}$
p	1	uniform	$[2.01, 2.9]$	$2.39^{+0.01}_{-0.01}$
$\log_{10}(\epsilon_e)$	1	log − uniform	$[-3, 0]$	$-0.82^{+0.09}_{-0.07}$
$\log_{10}(\epsilon_B)$	1	log − uniform	$[-5, -0.3]$	$-1.06^{+0.19}_{-0.24}$