中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

中国科学院大学
University of Chinese Academy of Sciences

A new subclass of gamma-ray burst originating from compact binary merge

arXiv: 2407.02376

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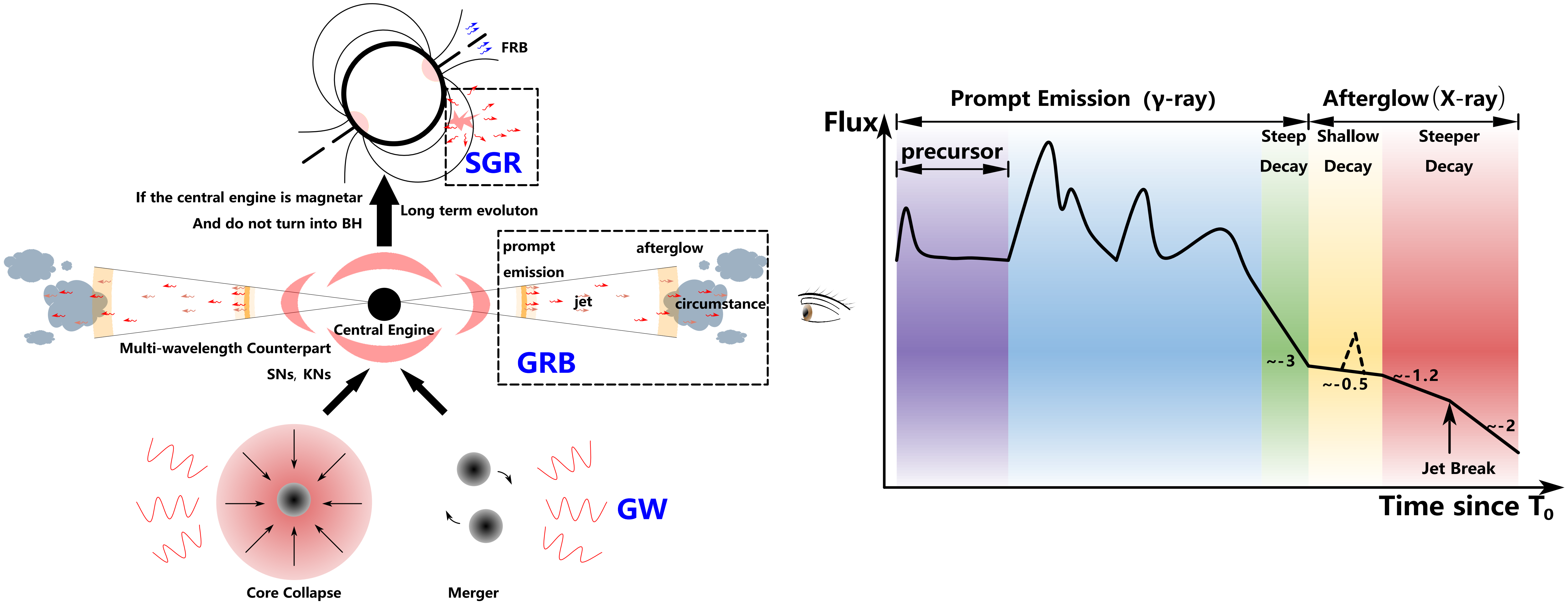
Institute of High Energy Physics (IHEP)

2024-07-03

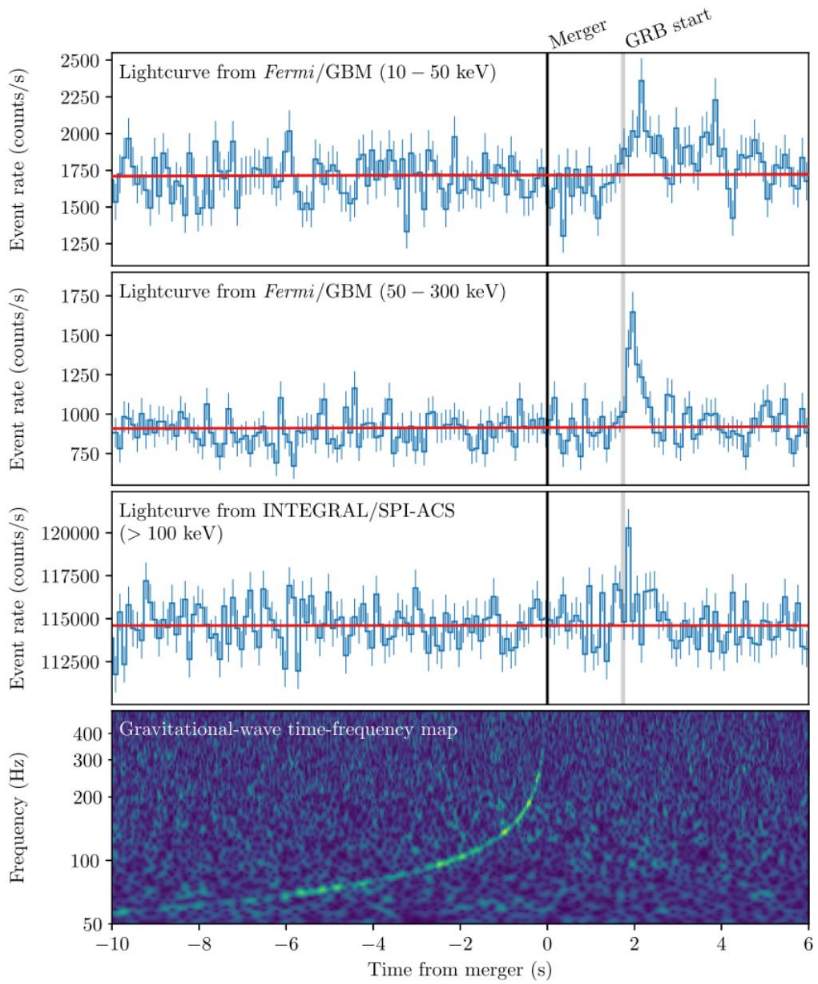
GECAM

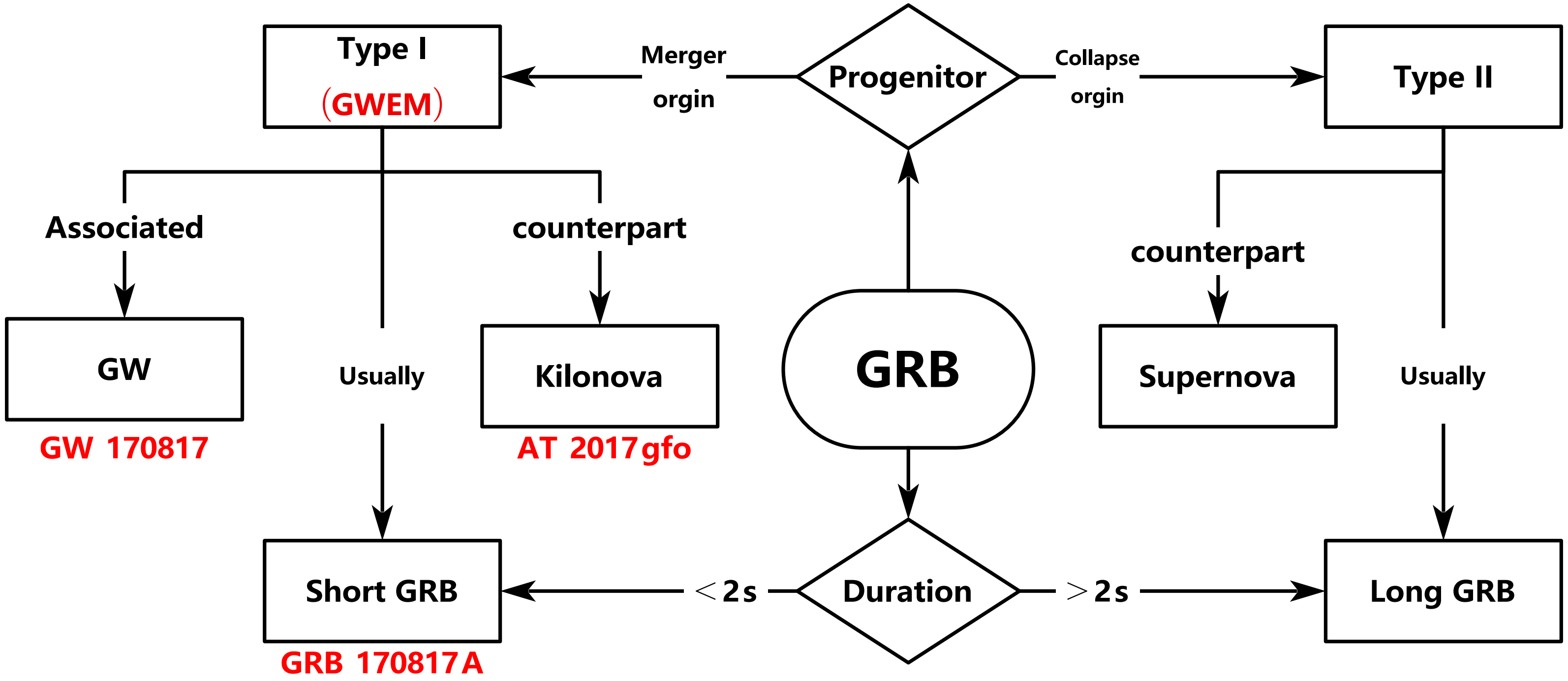
KLPA
中国科学院粒子天体物理重点实验室
KEY LABORATORY OF PARTICLE ASTROPHYSICS, CAS

The classification of GRB



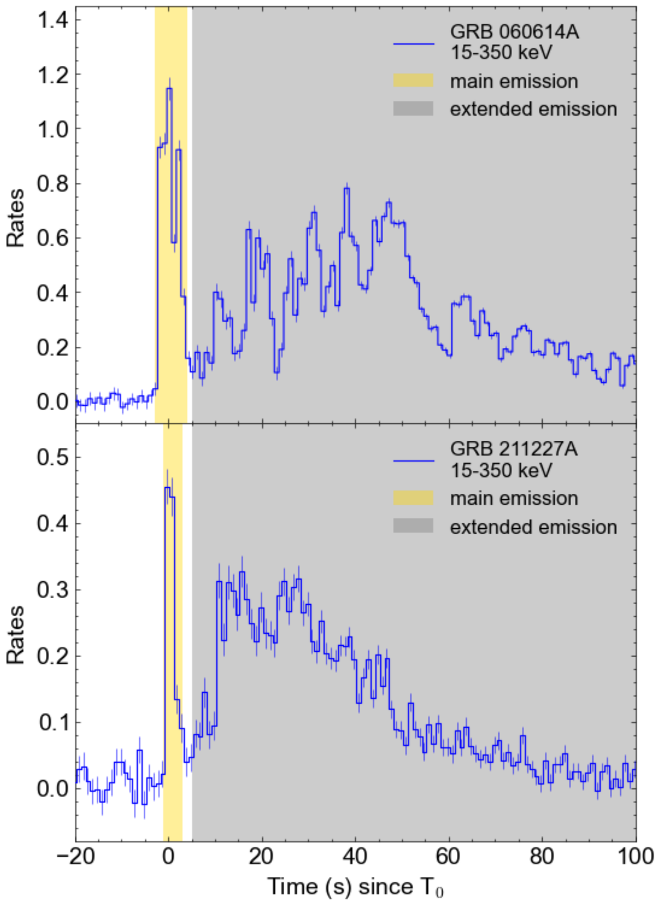
The classification of GRB



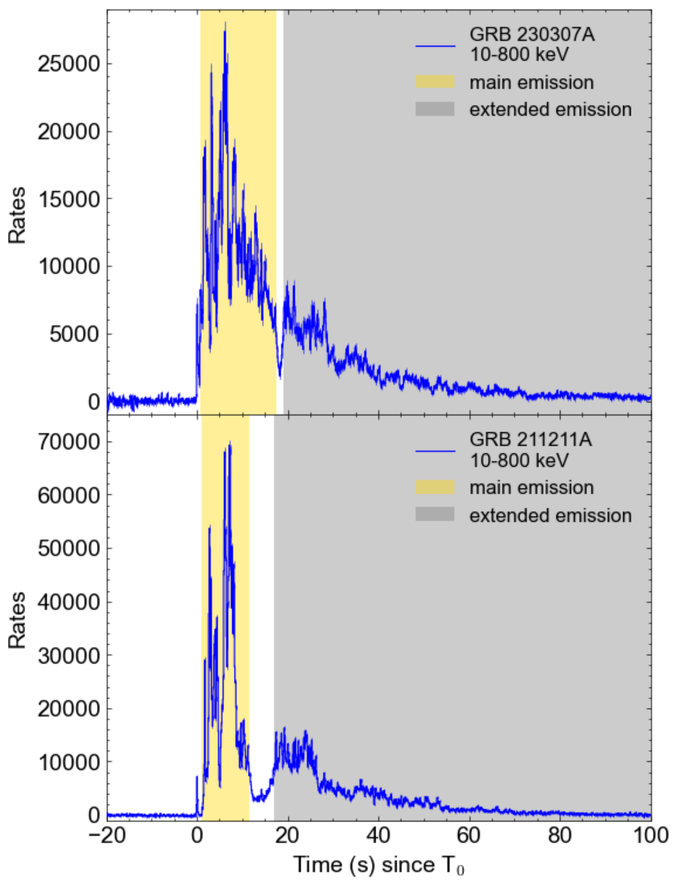


B.P. Abbott, et al., APJL, 2017

“Long(duration)” short GRB

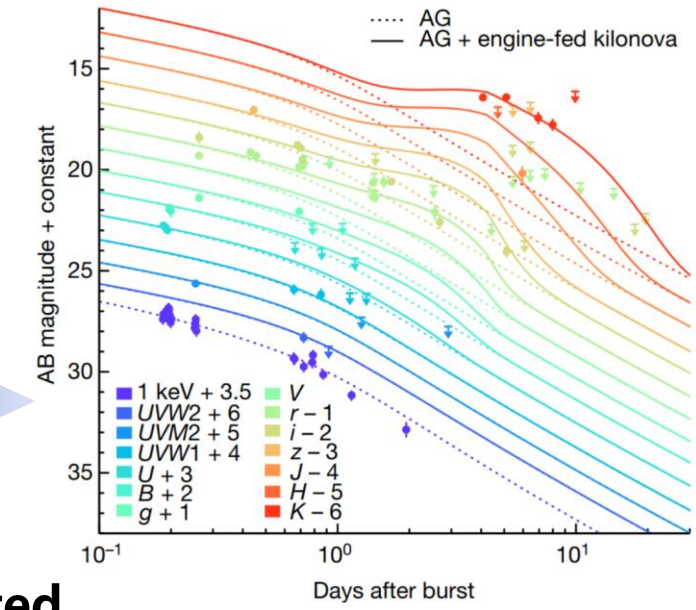


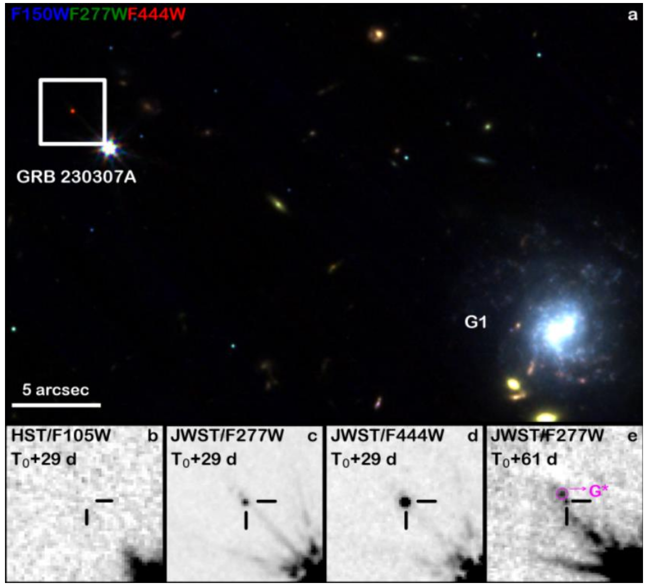
Short-Hard main emission
+
Long-Soft extended emission



Precursor (?)
+
Long-Hard main emission
+
Long-Soft extended emission

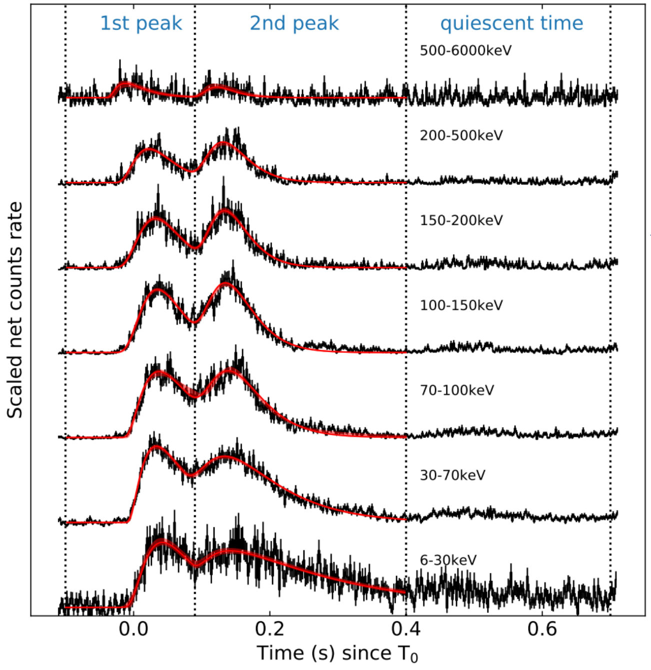
associated with KN

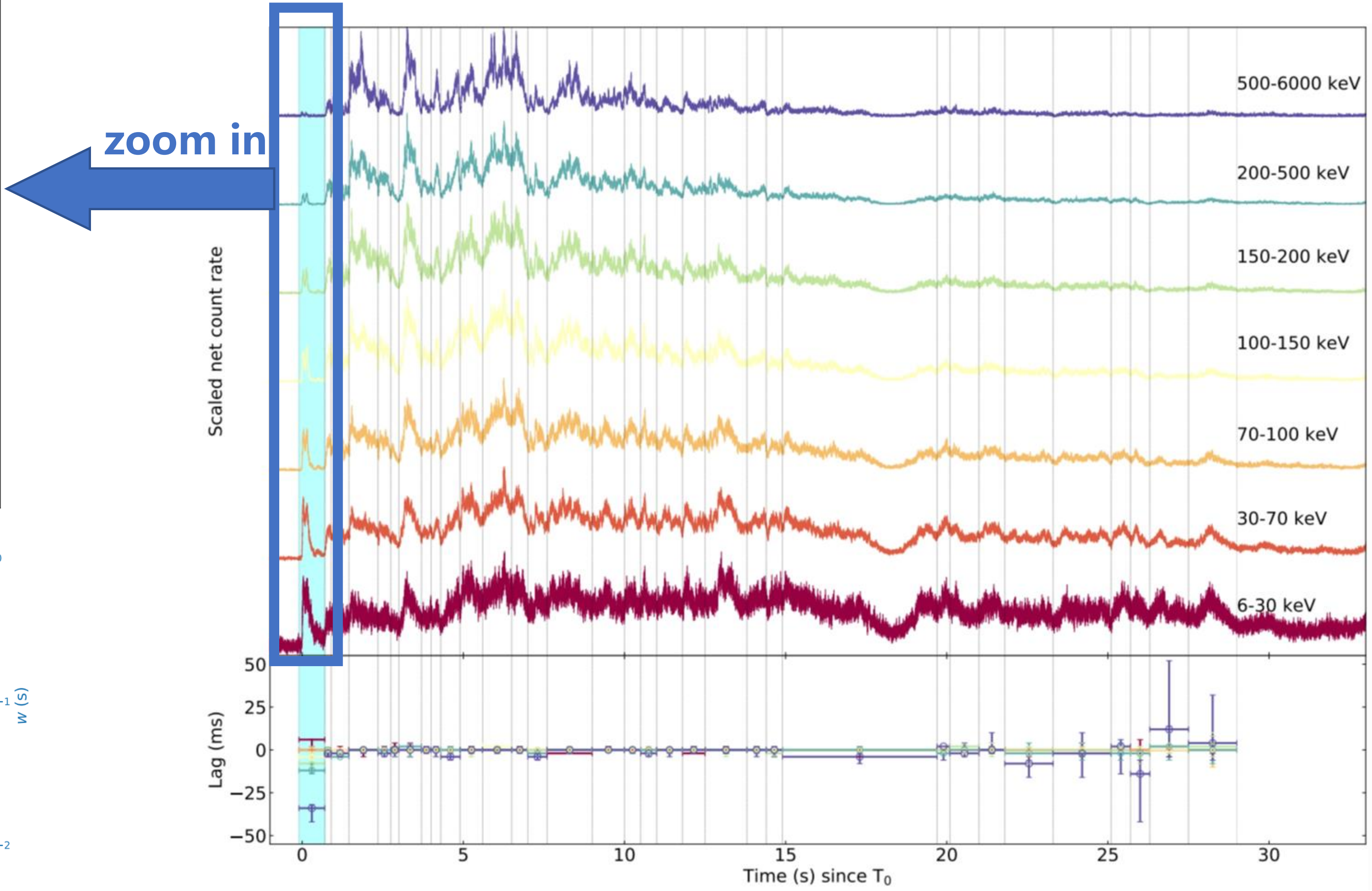


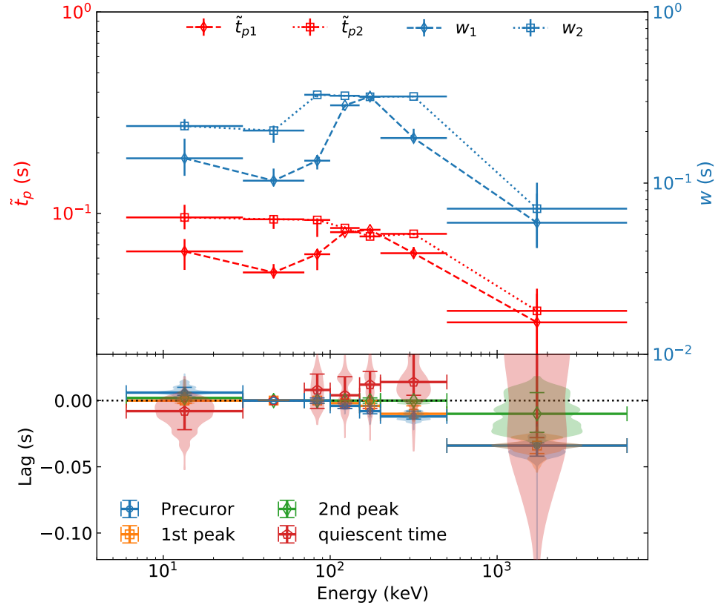


Jun Yang, et al., Nature, 2022
Yuhan Yang, et al., Nature, 2024

Identification of precursor in GRB 230307A

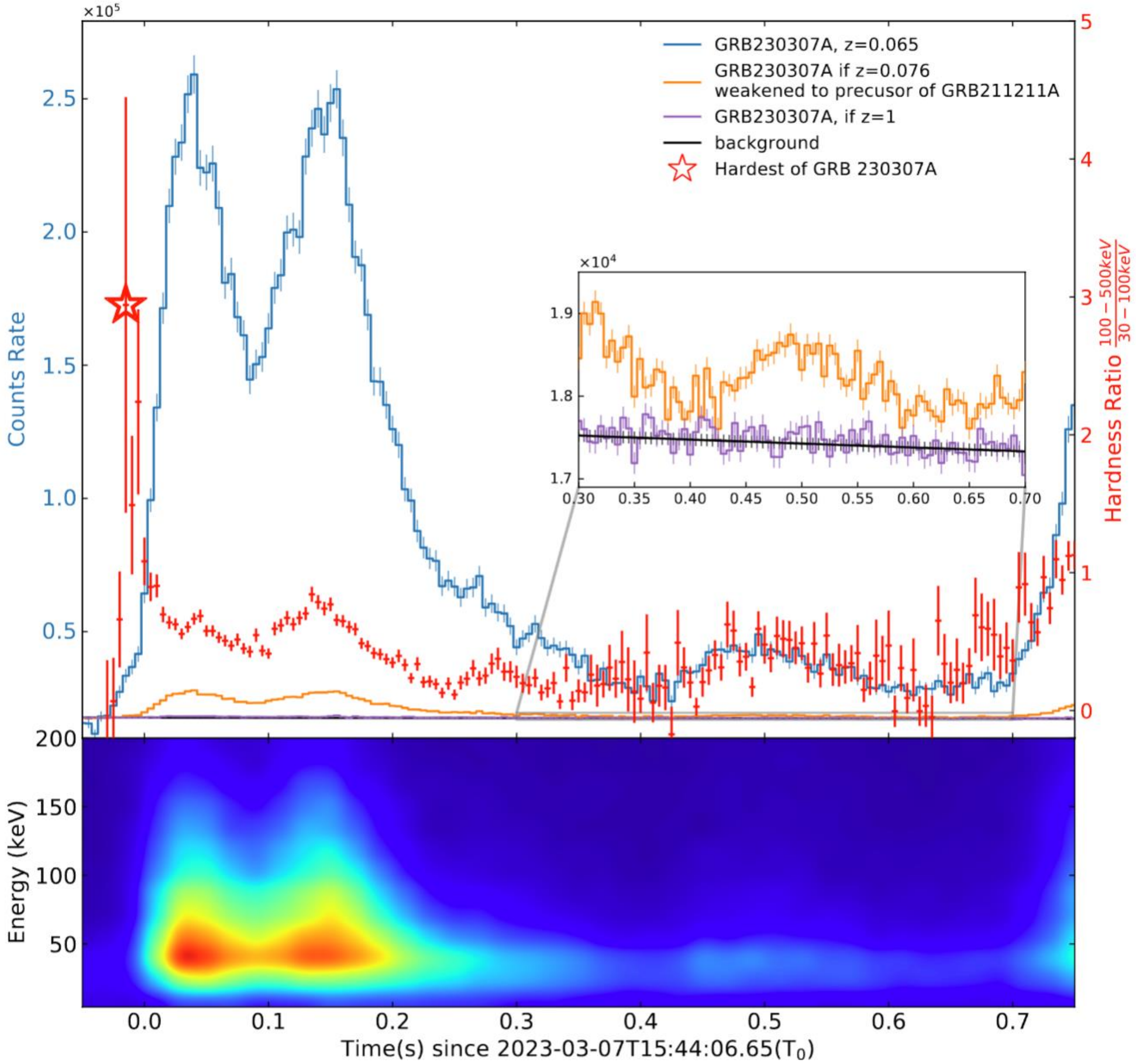


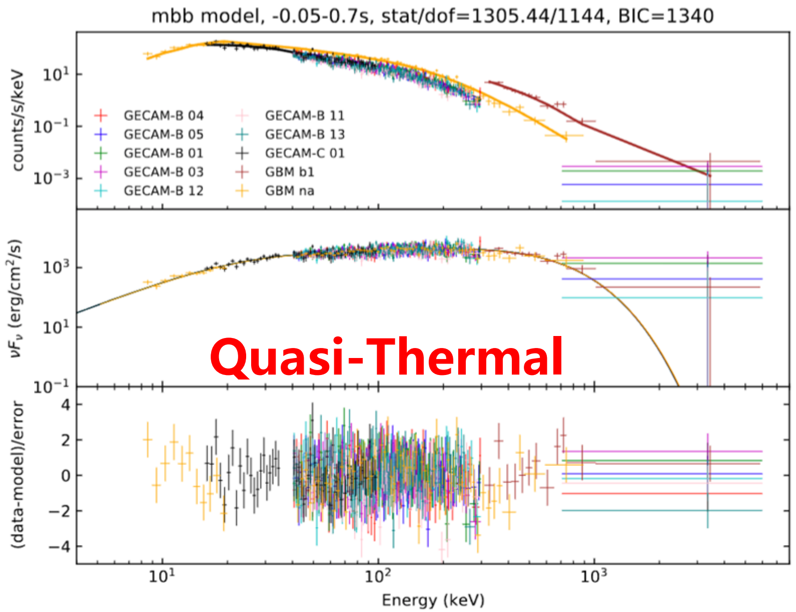




Only the the first peak of first pulse has spectral lag

Identification of precursor in GRB 230307A

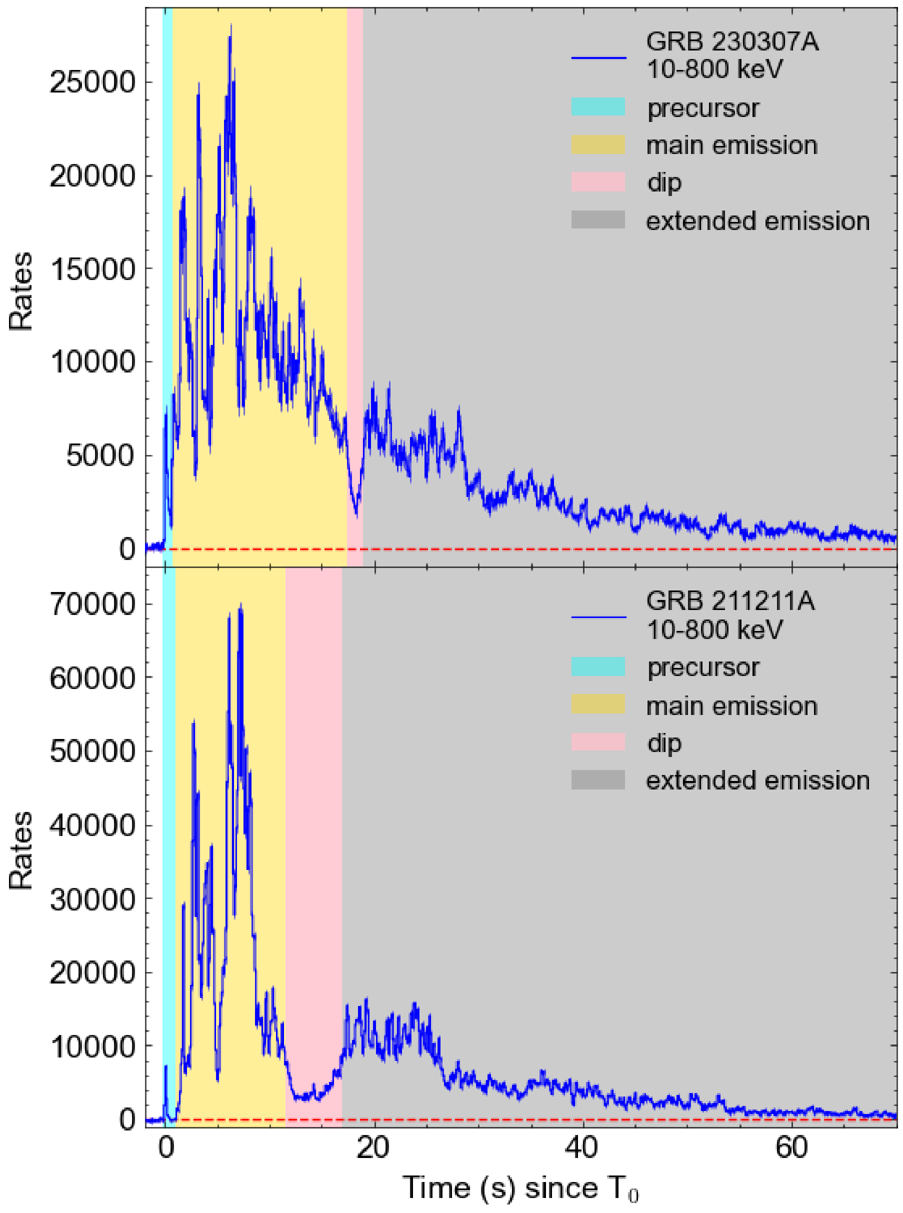




redshift	0.5	1
SNR of 1 GRD	0.73	0.13
SNR of 25 GRD	0.37	0.07
SNR of 1 NaI	0.62	0.11

If the burst is farther away, a quiescent period will exist.

Two special event



properties	GRB 230307A	GRB 211211A
duration	long	long
original	merger	merger
precursor	yes	yes
Main emission	Yes	Yes
Extended emission (dip structure)	Yes	yes

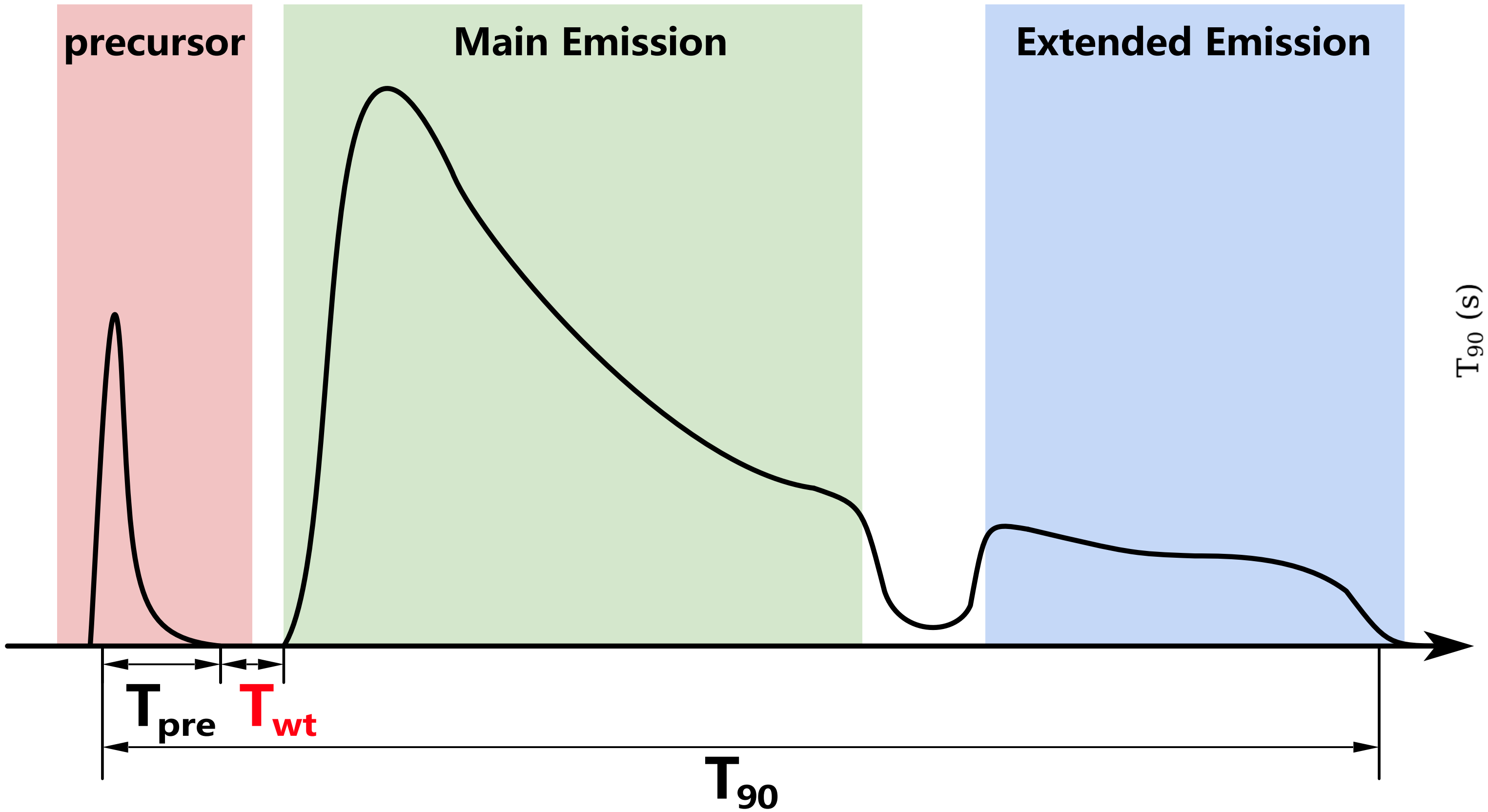
Type IL GRB

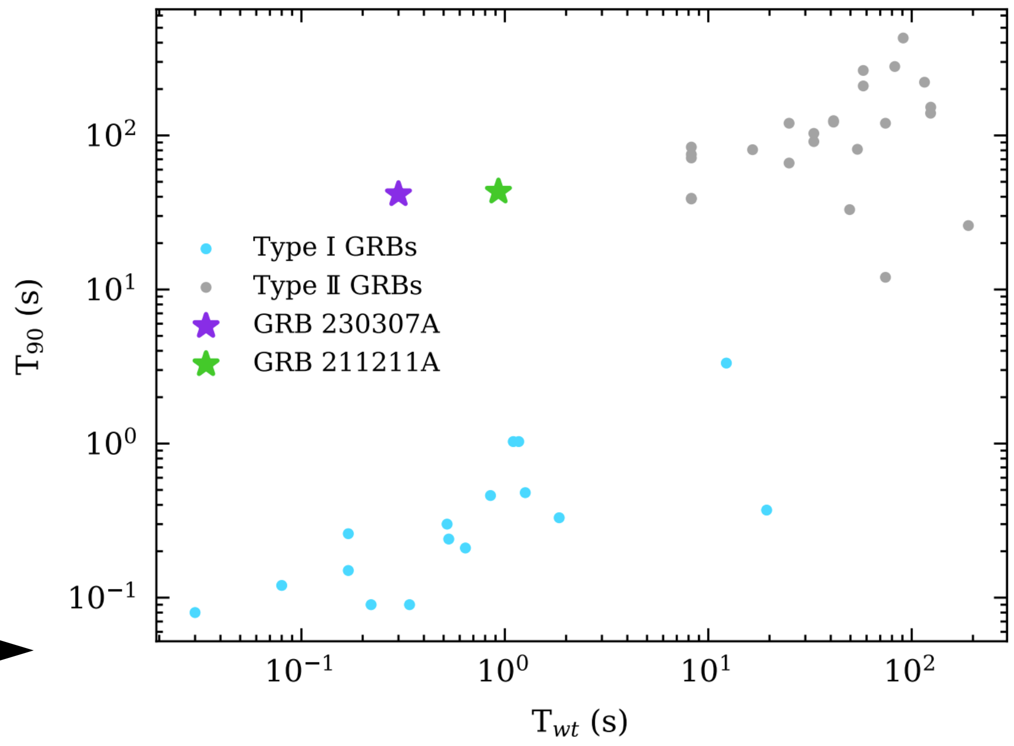
Three-episode burst pattern

① a precursor followed by a short quiescent (or weak emission) period

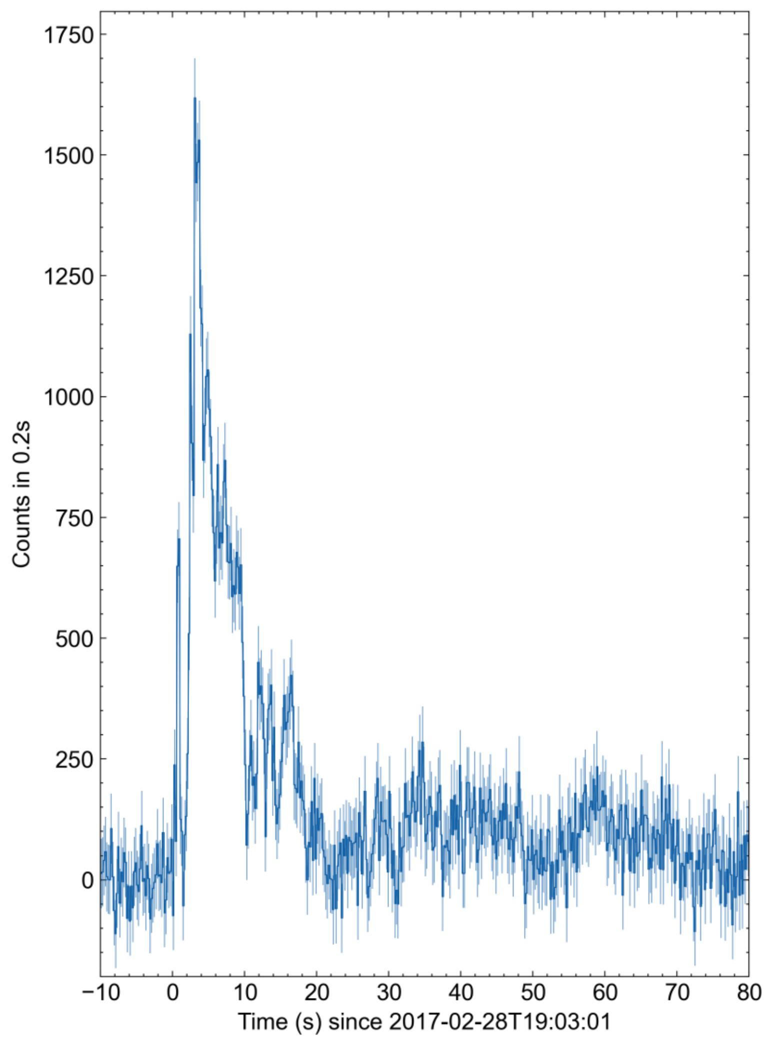
② a long-duration main emission

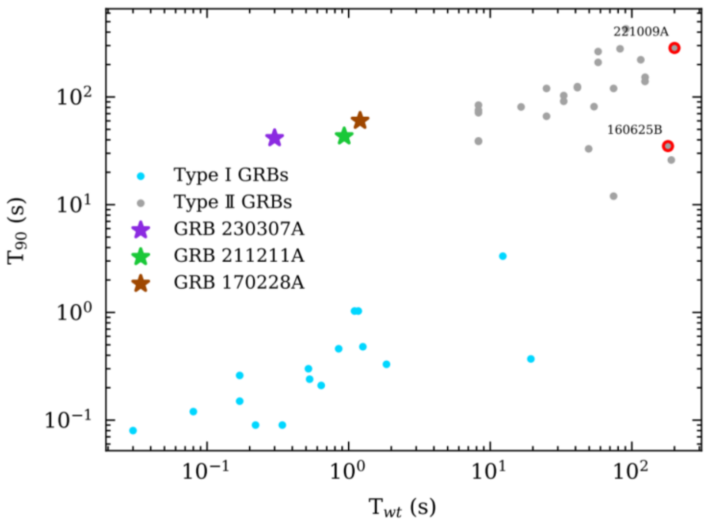
③ an extended emission

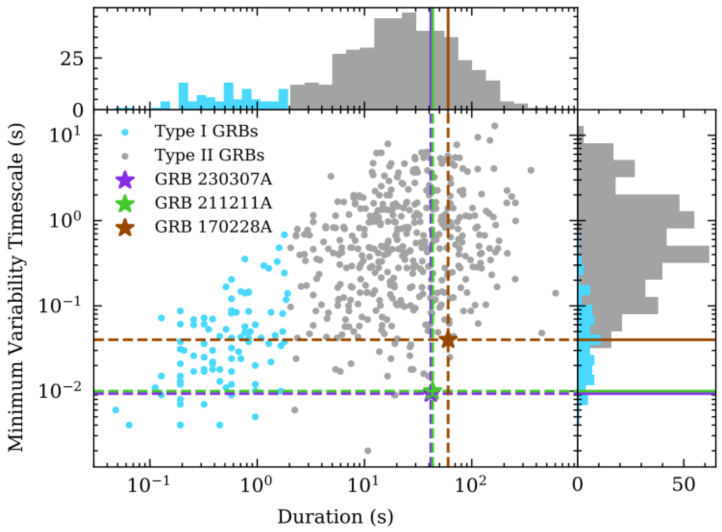


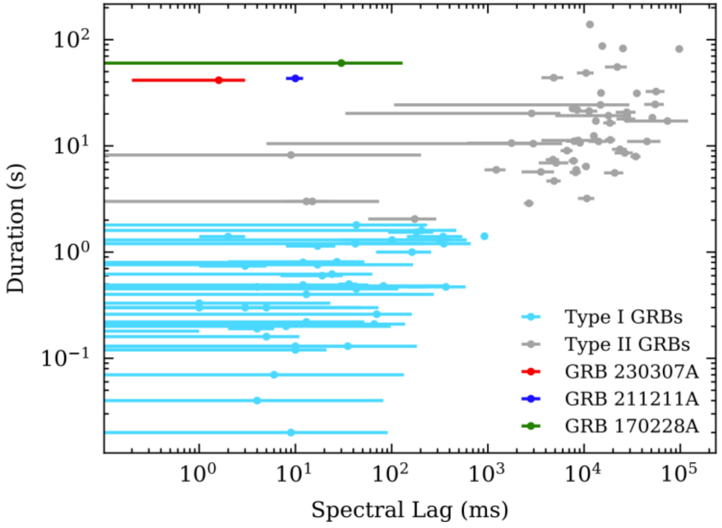


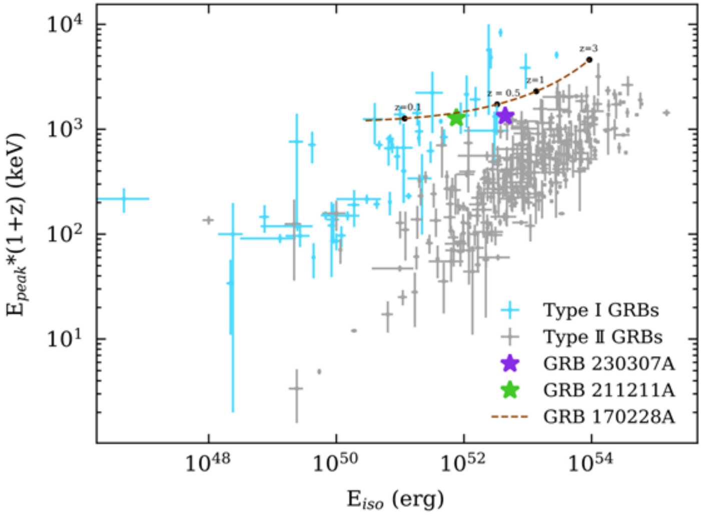
GRB 170228A





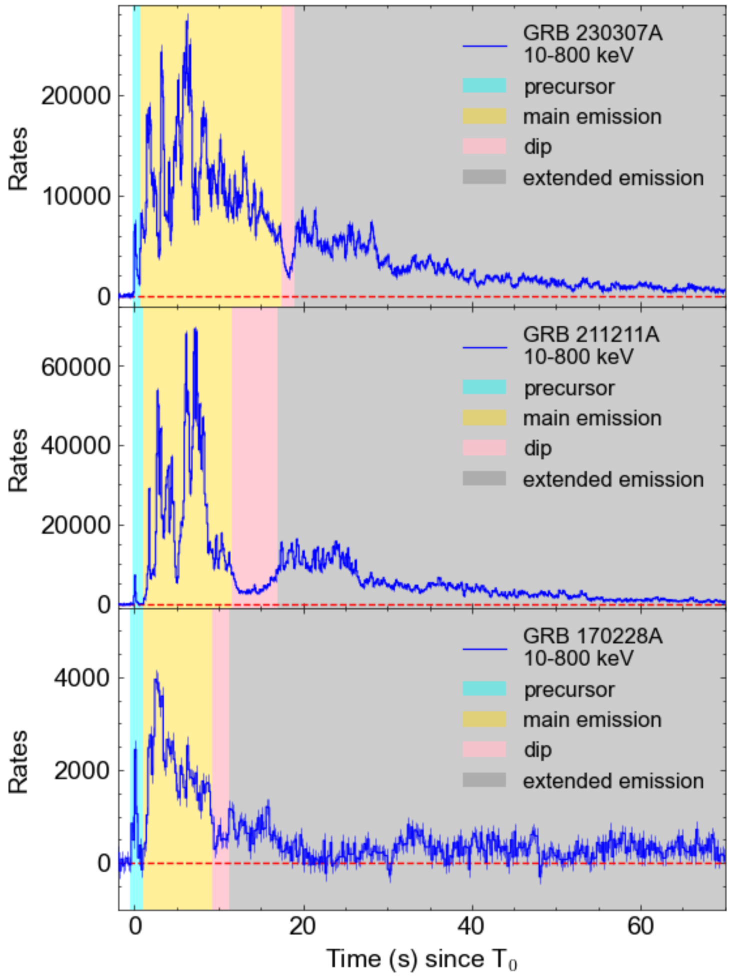


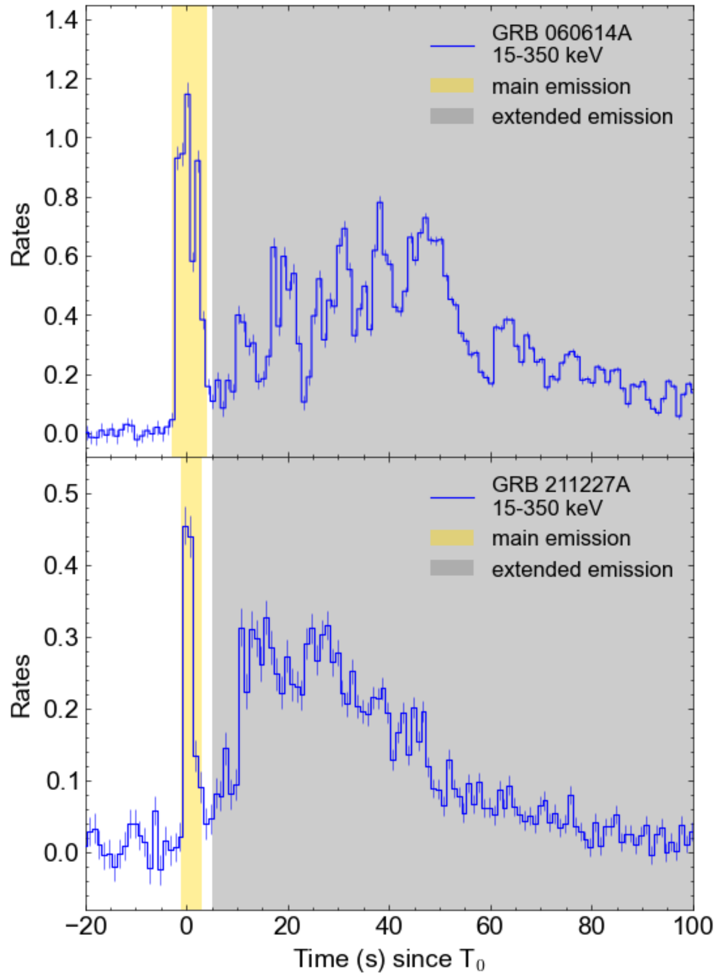


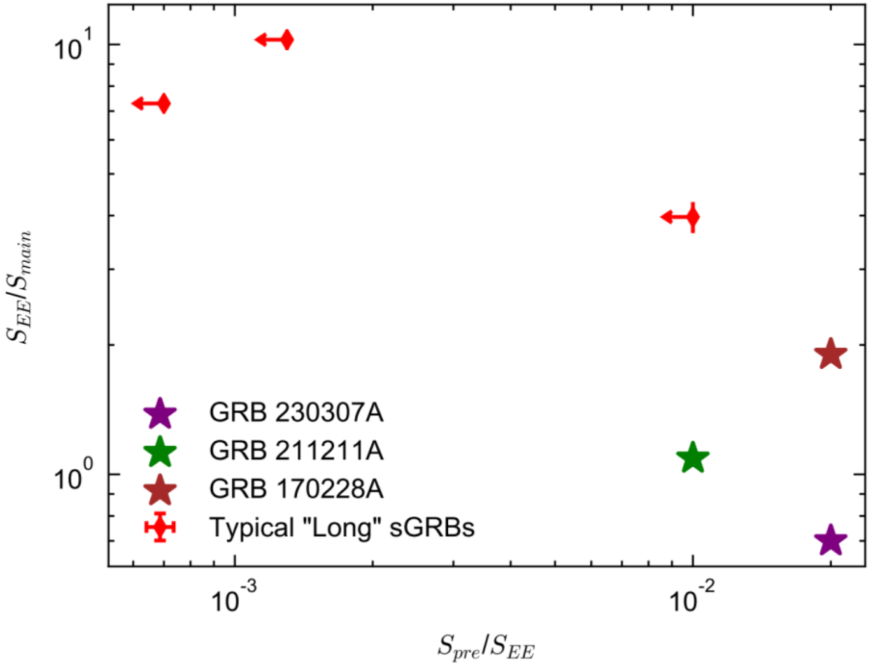


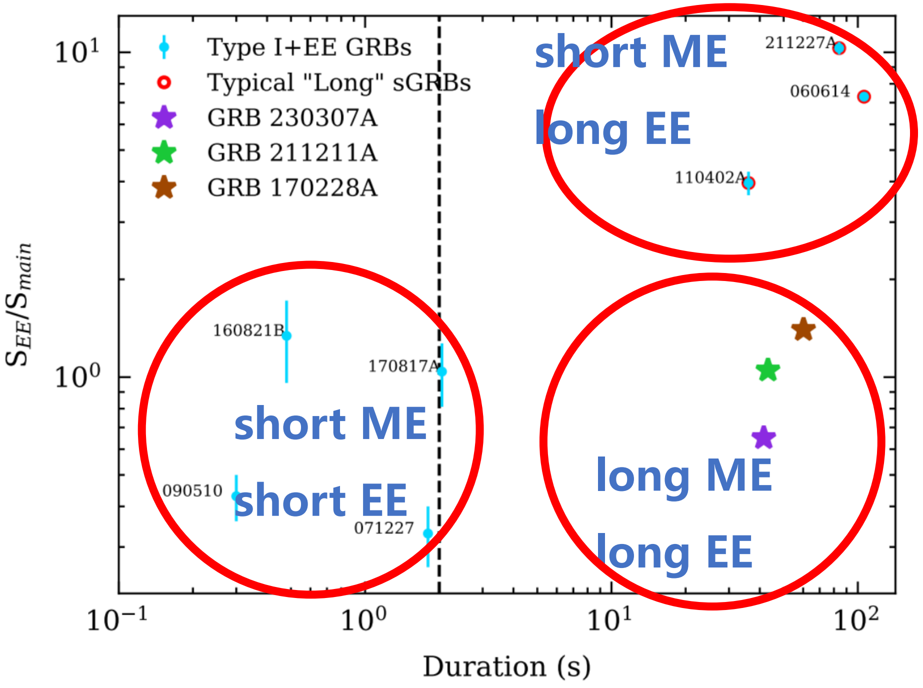
The prompt emission properties are consistent with a merger origin

Type IL GRB & classic "Long" sGRB



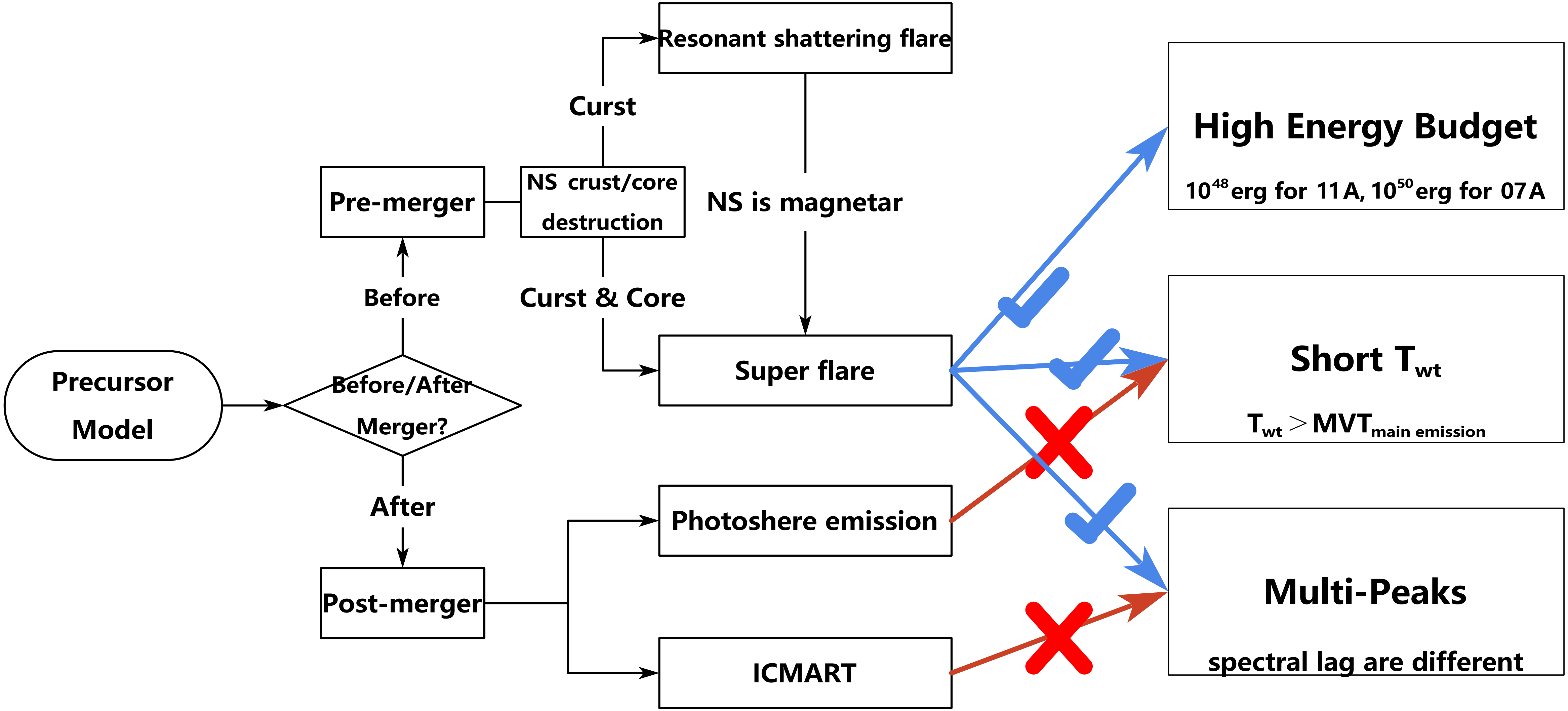






The energy allocation are different

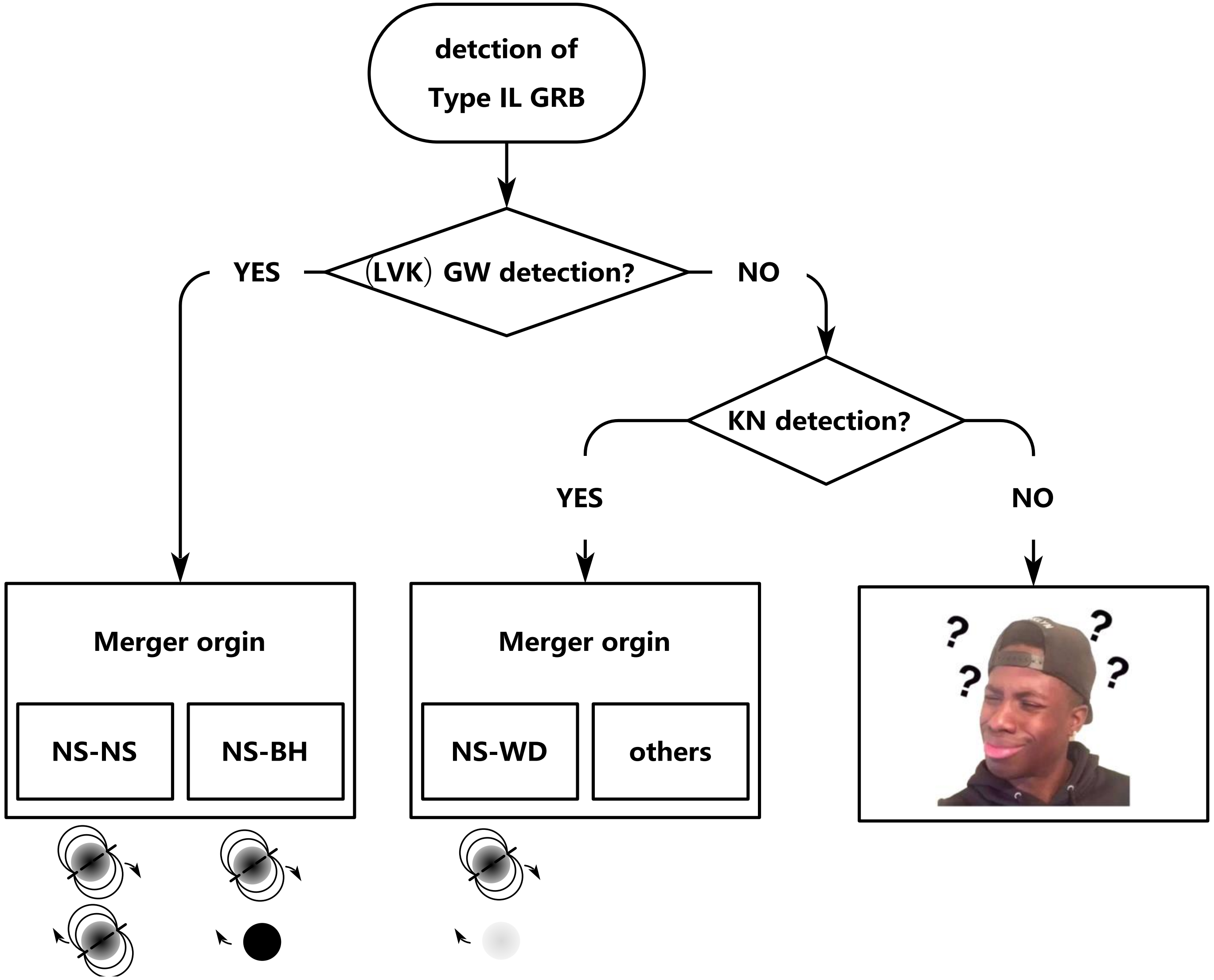
Precursor model

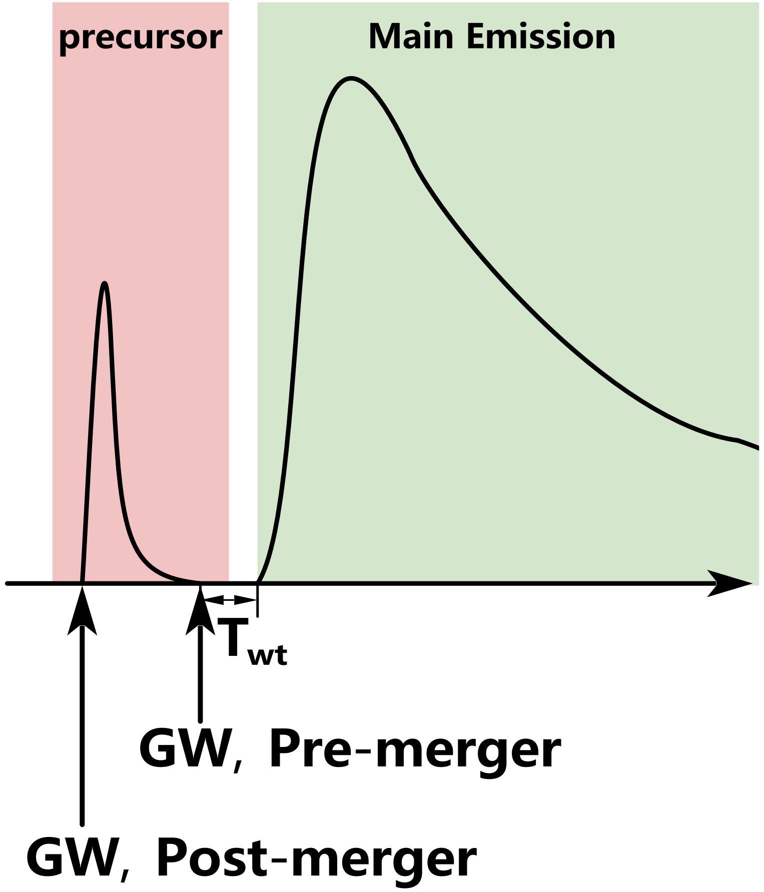


10 years, 3 type IL GRB in ~400 sGRB with an occurrence rate about 1%

same as the proportion of magnetars in NSs

Type IL GRB & classic “Long” sGRB





Jun Yang, et al., Nature, 2022
Zhen Zhang, et al., ApJL, 2022
Yanzhi Meng, et al., ApJ, 2024
Junping Chen, et al., submitted

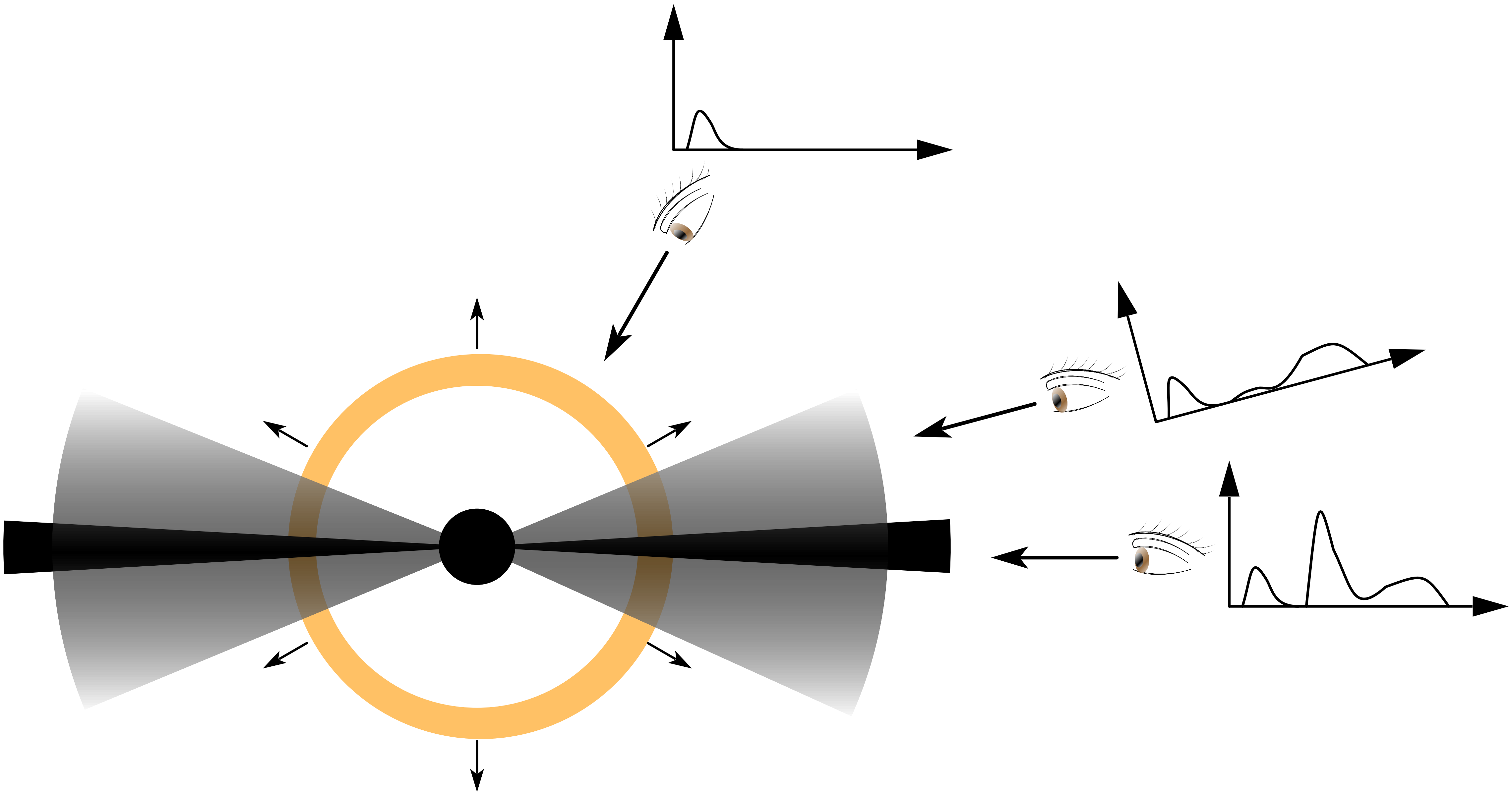
Summary

- The first pulse of GRB 230307A is a bright quasi-thermal precursor
- GRB 211211A and GRB 230307A belong to a new subclass of merger-origin GRB, type IL GRB
- A good candidate, GRB 170228A, is found by the burst pattern of type IL GRB
- The energy allocation of type IL GRB are different from classic "Long" sGRB
- Occurrence rate if type IL GRB is the same as the proportion of magnetars in NSs

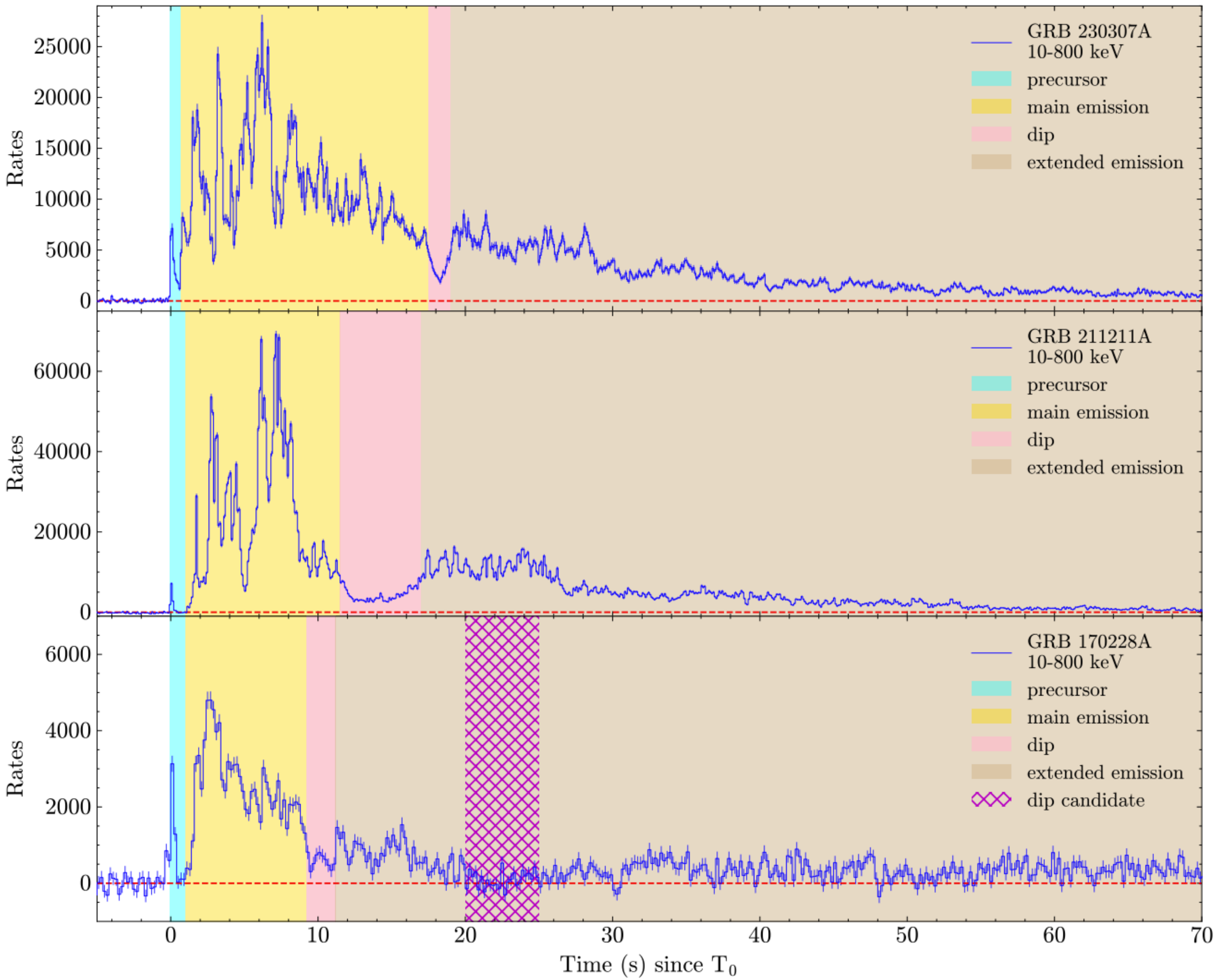
Thanks!

Your comments and suggestions are appreciated!

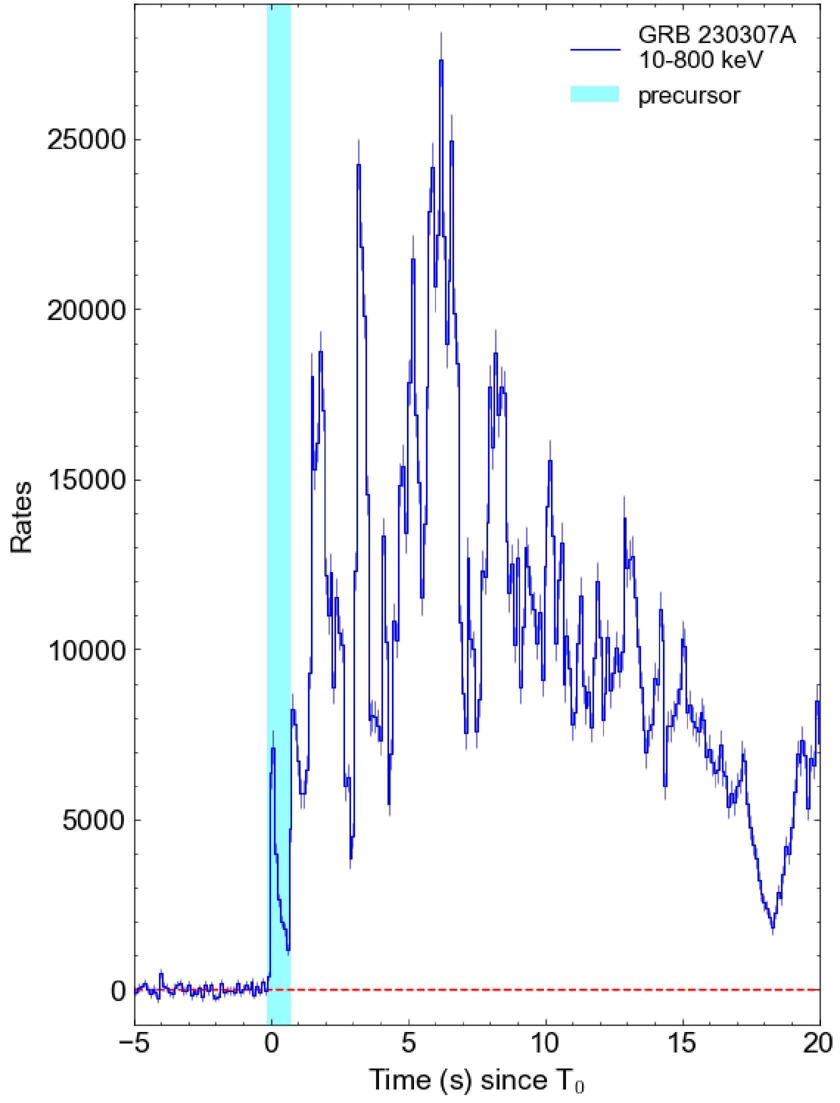
Backup



About the DIP

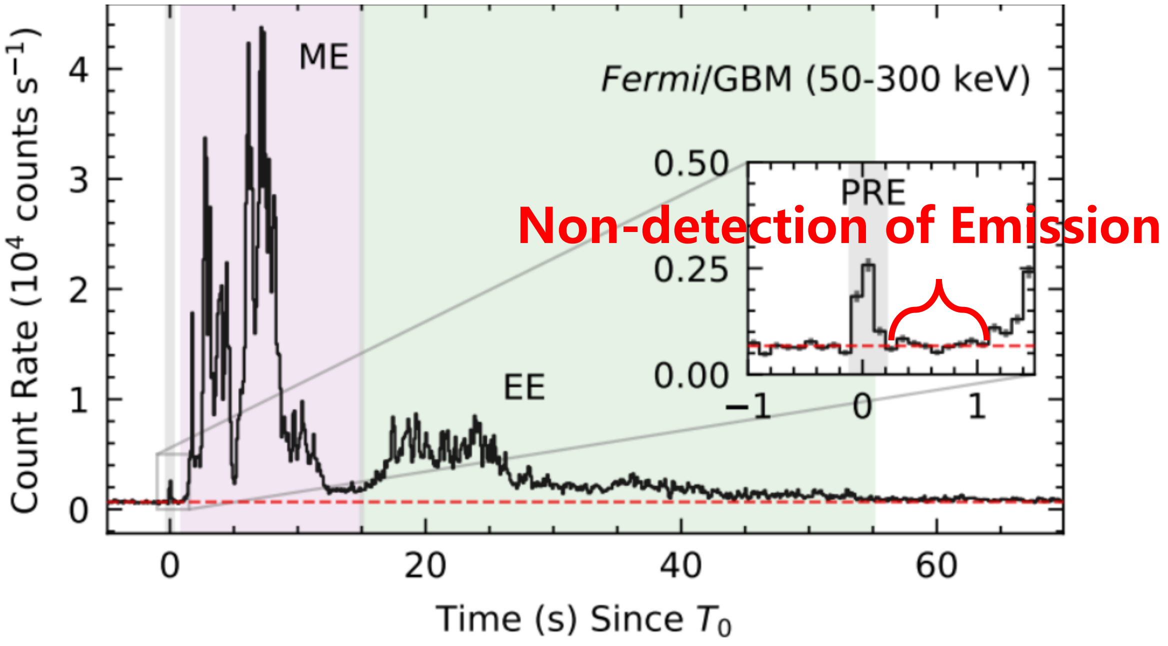


Is the first pulse of GRB 230307A is a precursor ?



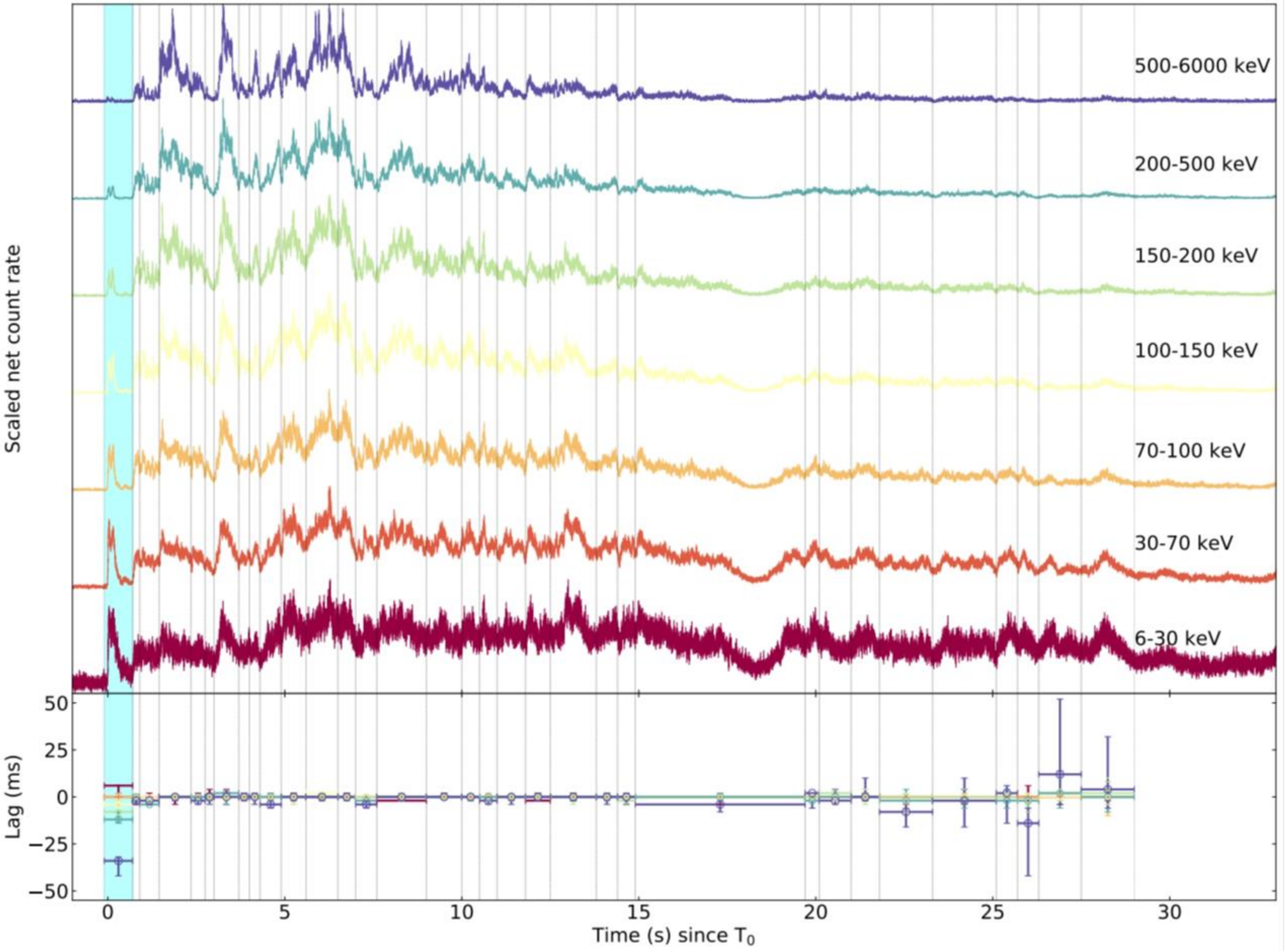
Reasons for not considering this as a precursor:

- **extremely bright, E_{iso}~1.3×10^{50} erg**
- **multiple, well-defined peaks**
- **no quiescent period**



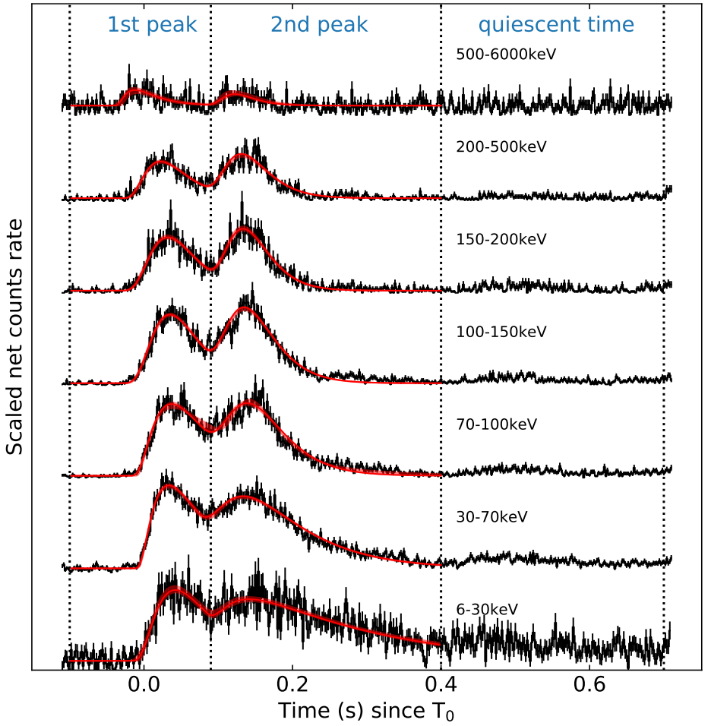
Shuo Xiao, et al., APJ, 2024

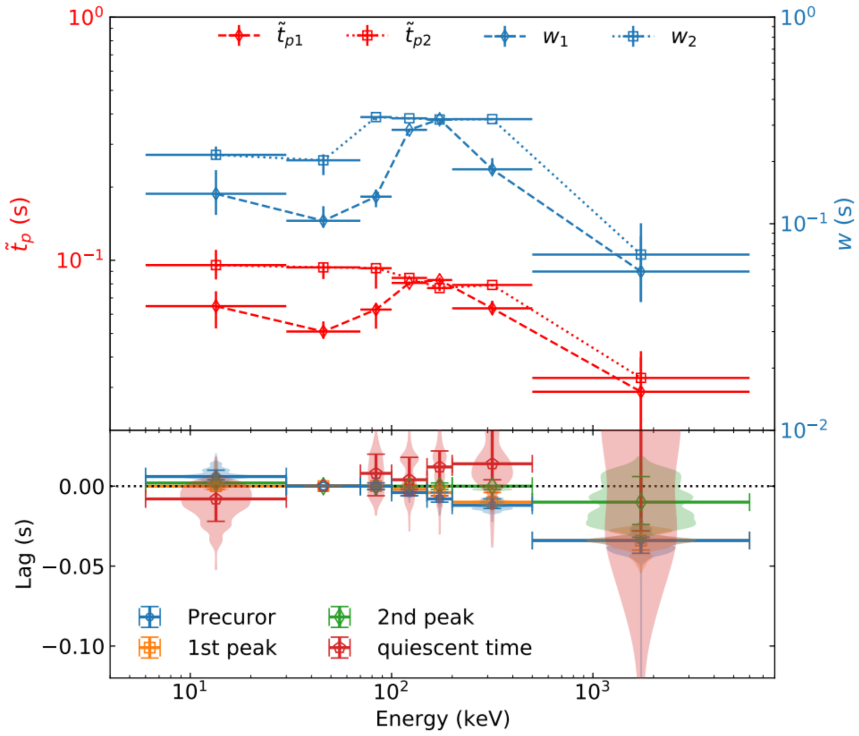
Evidence from lightcurves

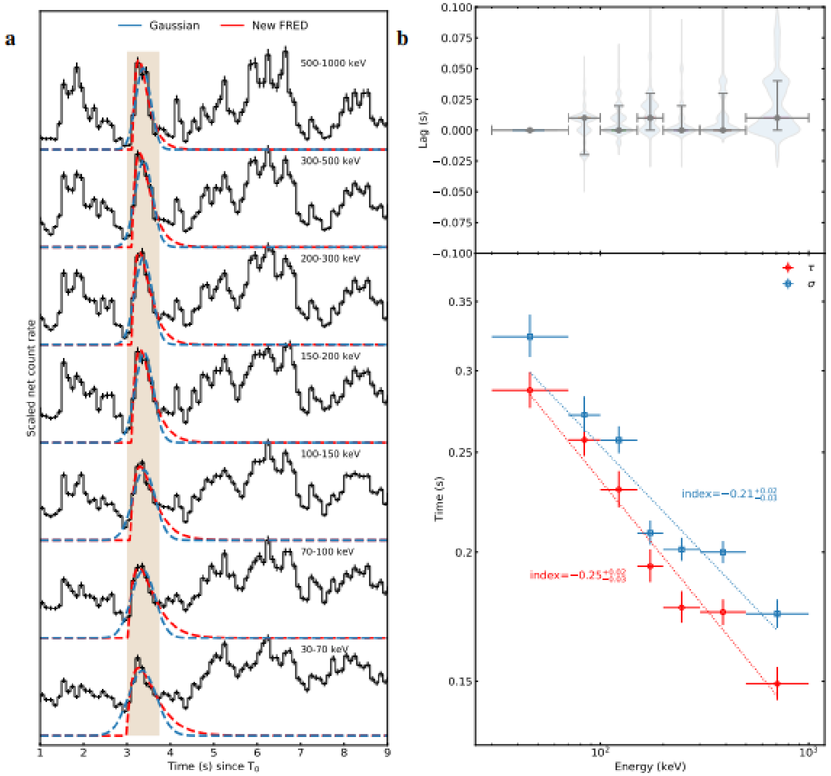


Only the first pulse has spectral lag

Evidence from lightcurves



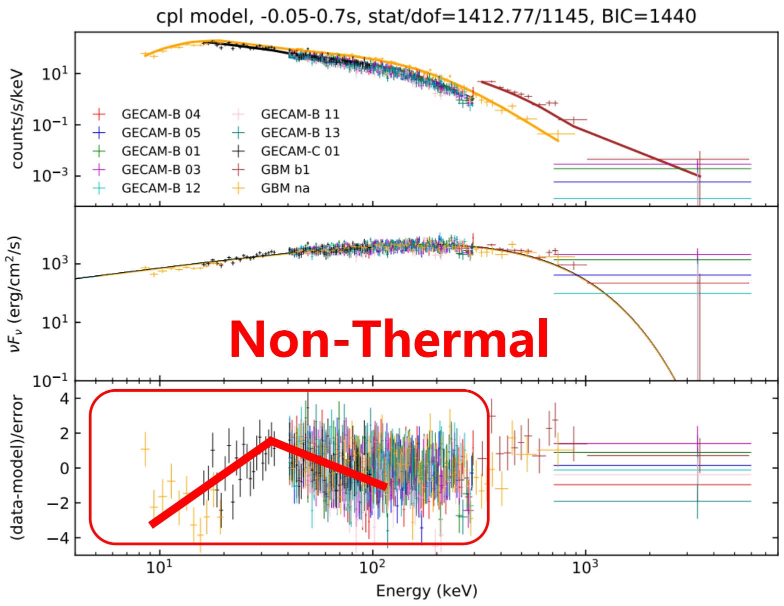


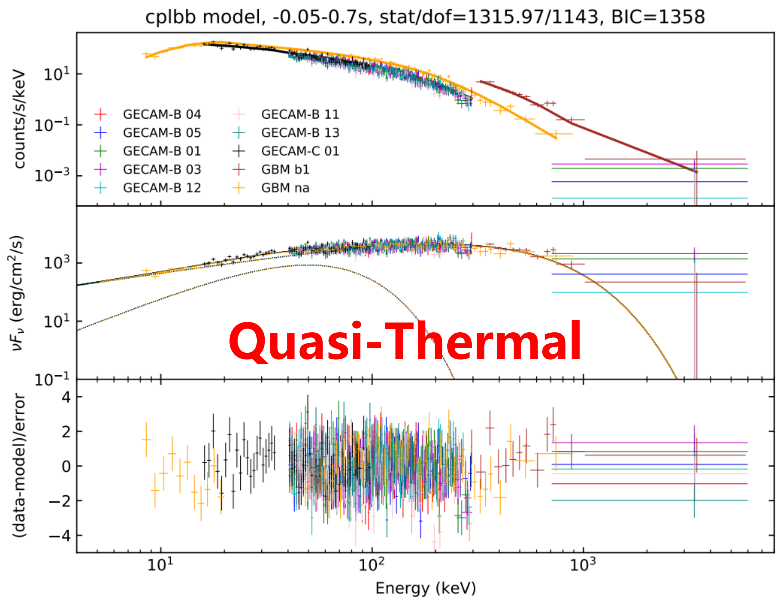


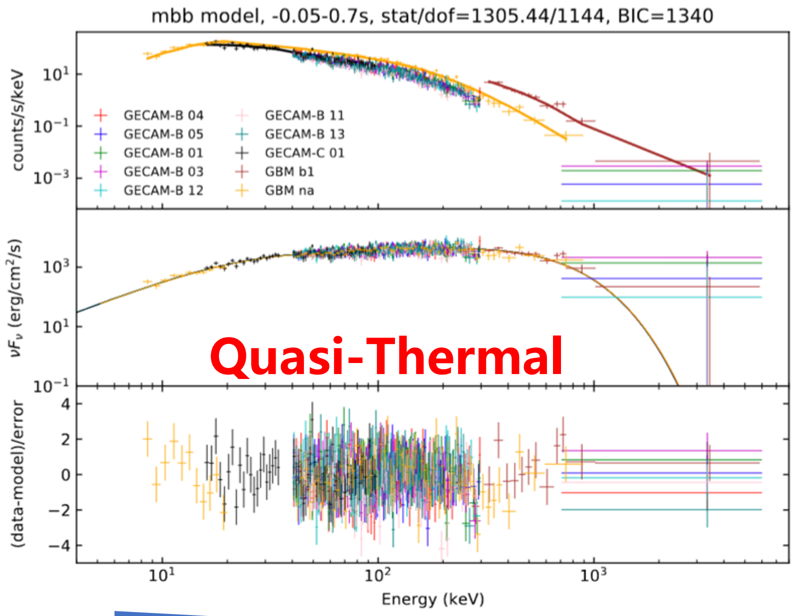
- **The spectral lag is only contributed by the first peak**
- **The FRED peak have no energy dependency**

Shuxu Yi, Chenwei Wang, et al., submitted

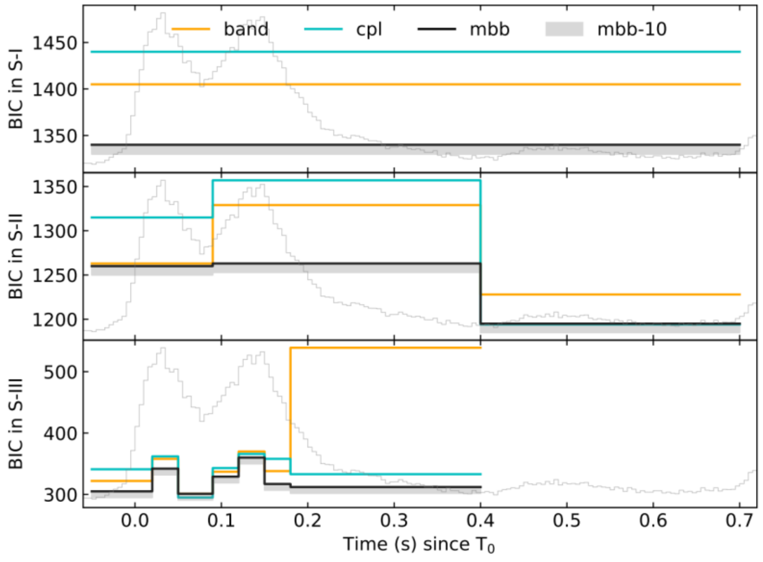
Evidence from spectra





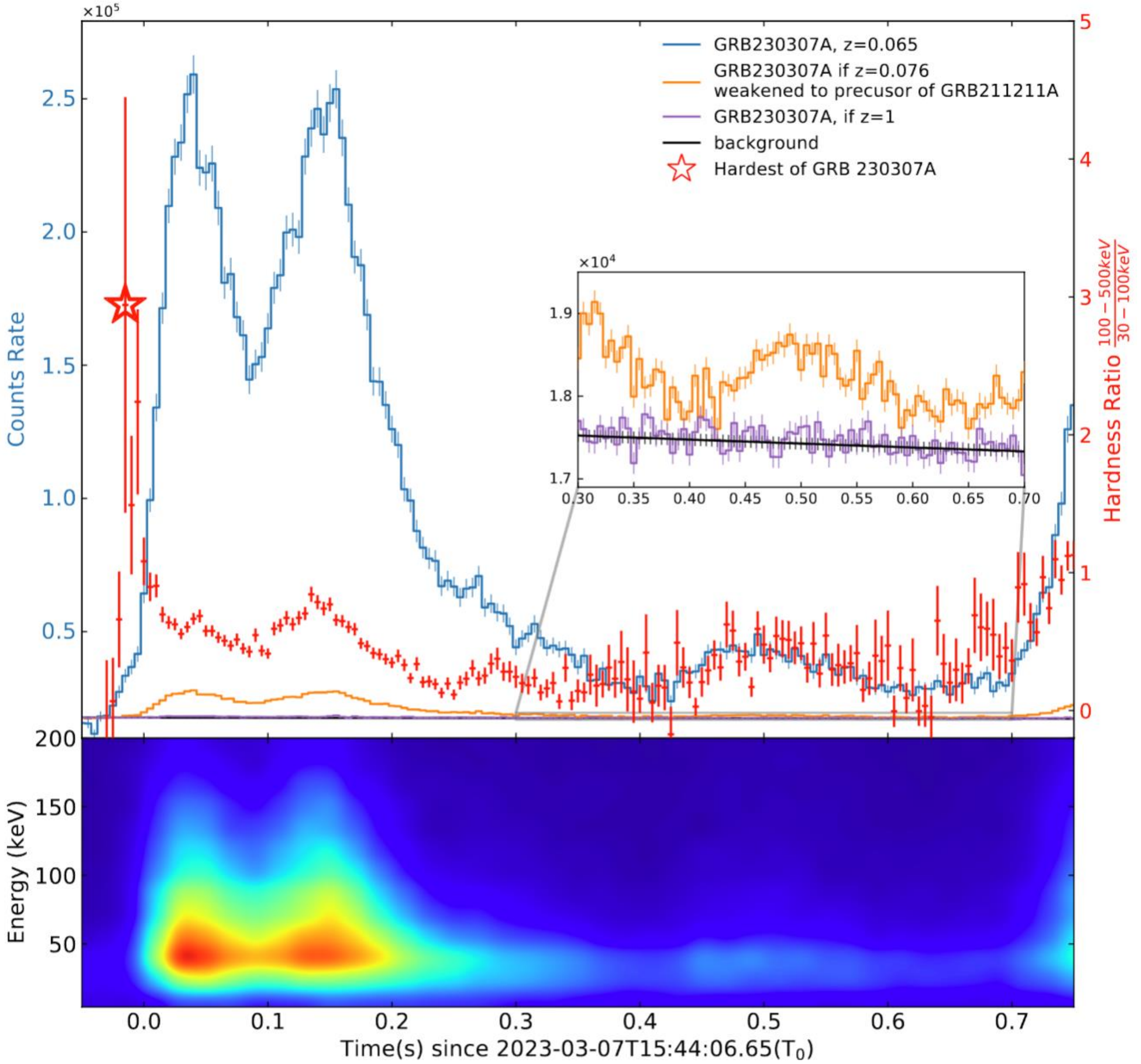


BETTER



In three epoch of time-resolve spectra, mBB is always the best model

Evidence from quiescent period



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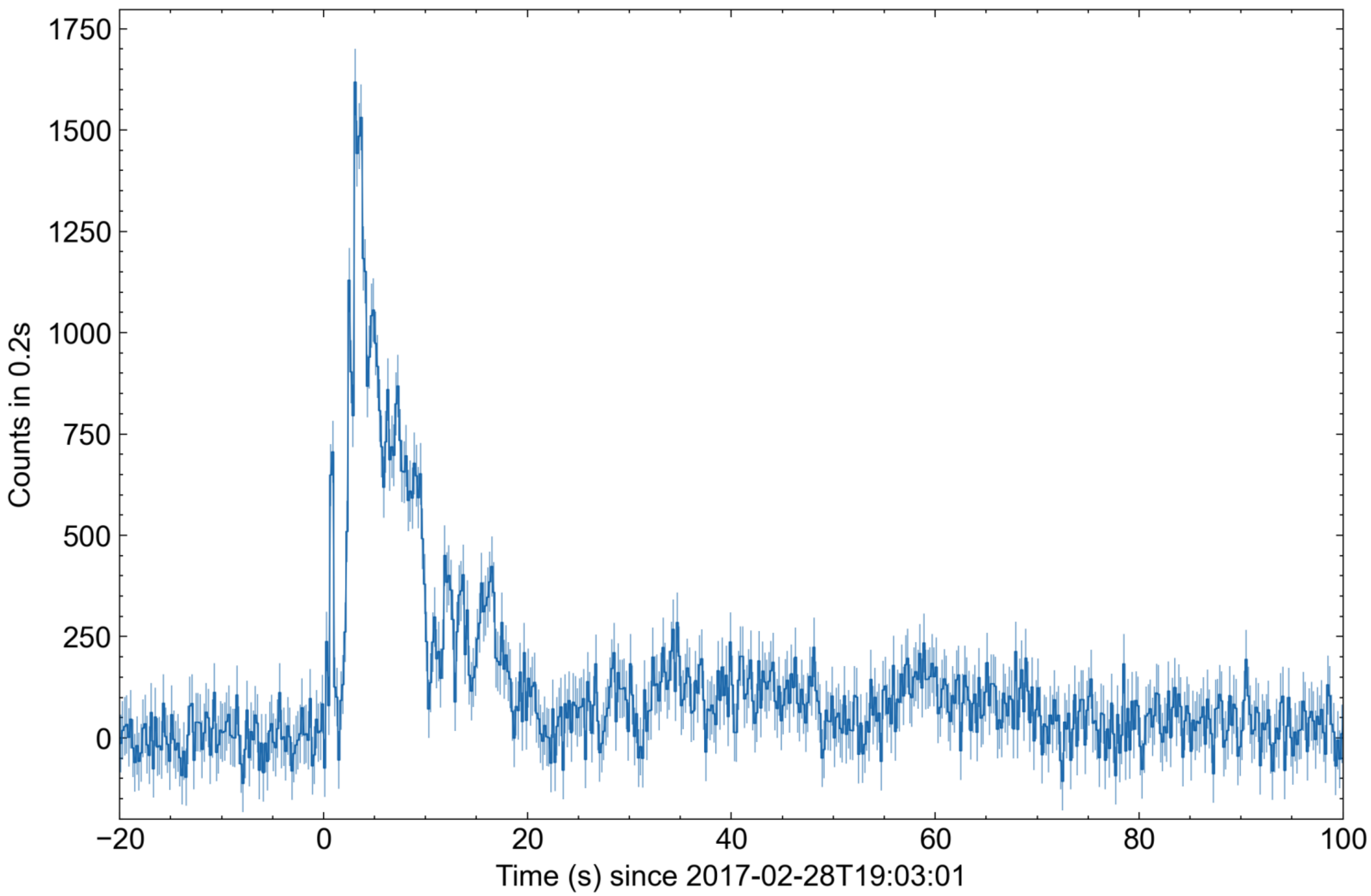
a quiescent period will exist.



1750
1500
1250
1000
750
500
250
0
Counts in 0.2s
−20
0
20
40
60
80
100
Time (s) since 2017-02-28T19:03:01

The lightcurve of prompt emission

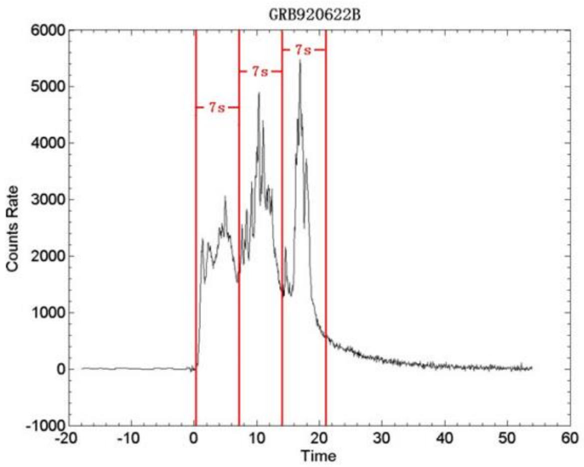
Profiles of GRB prompt emission

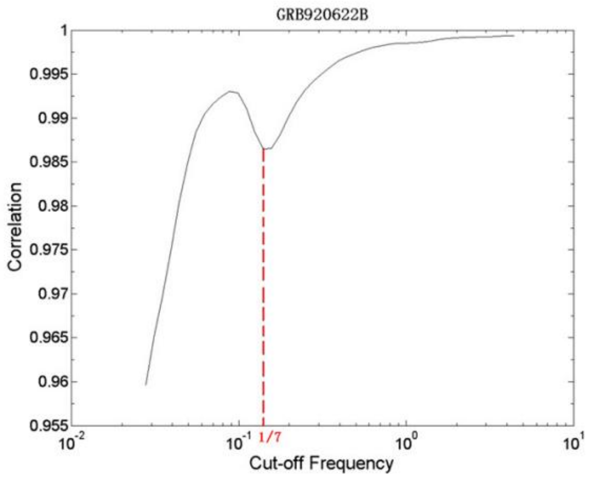
① single pulse or spike events

② smooth,either single or multiple, well-defined peaks

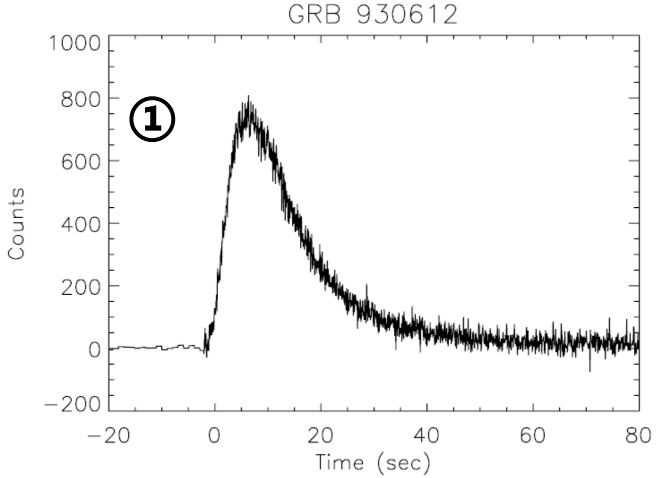
③ distinct, well-sparated episodes of emission

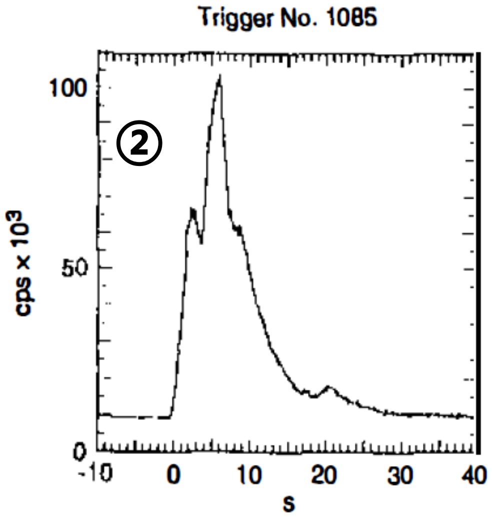
④ very erratic, chaotic, and spiky bursts

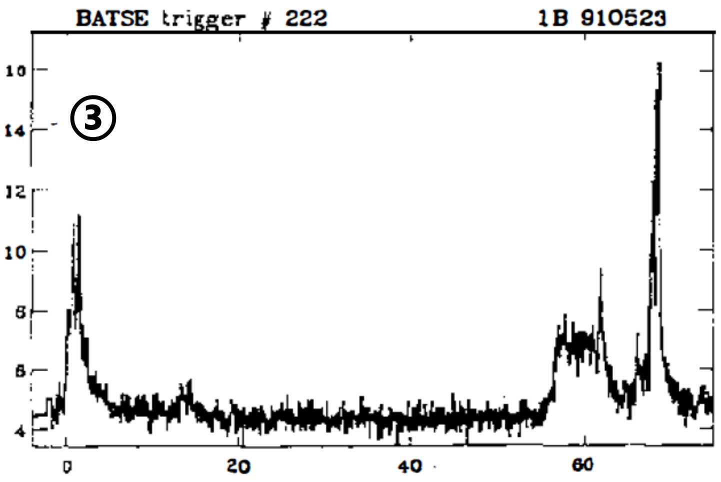


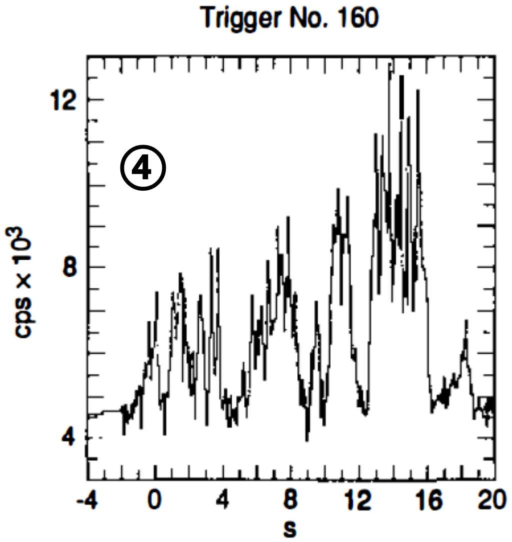


Some GRB lightcurves show two kind of time variability









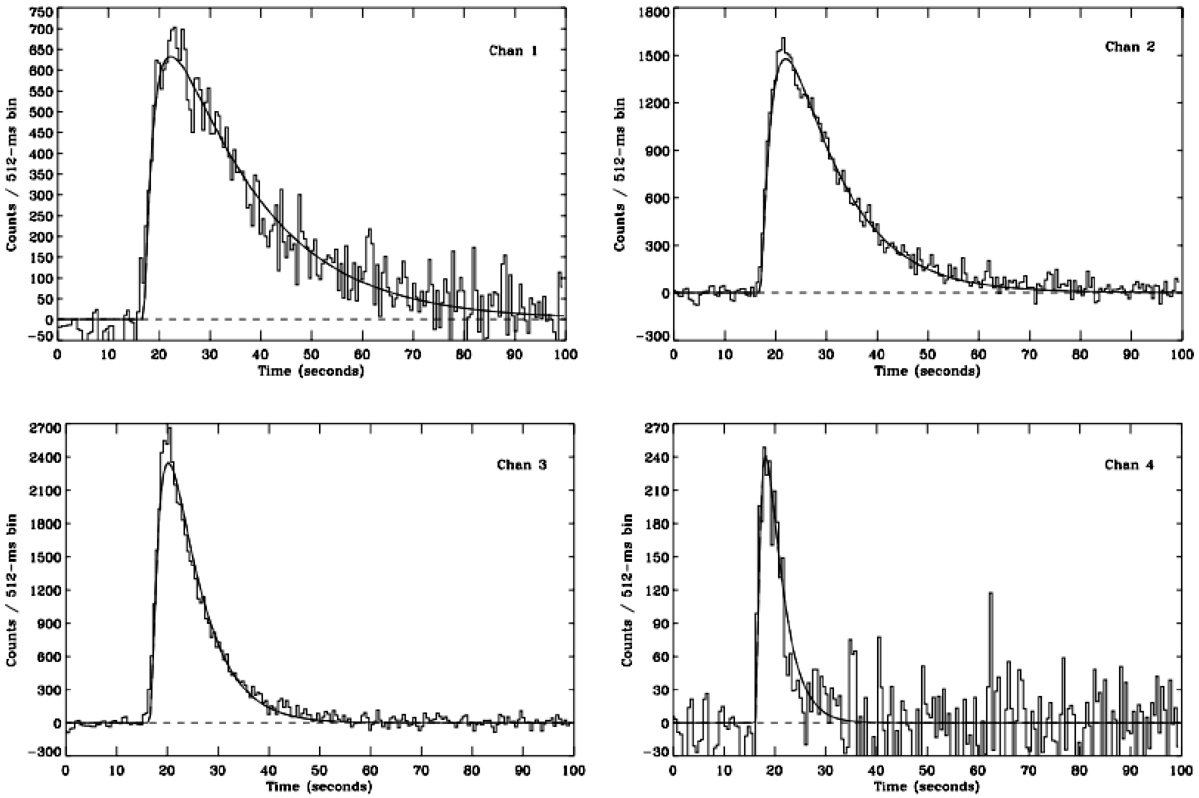
Gerald J. Fishman and Charles A. Meegan, ARAA, 1995
He Gao, Binbin Zhang and Bing Zhang, APJ, 2012

FRED shape pulse

Fast Rise and Exponential Decay

A typically asymmetric pulse have FRED shape

- $$L \propto \begin{cases} \exp\left(-\left(\frac{|t-t_{max}|}{\sigma_r}\right)^{\nu}\right), t < t_{max} \\ \exp\left(-\left(\frac{|t-t_{max}|}{\sigma_d}\right)^{\nu}\right), t > t_{max} \end{cases}$$
- $$L \propto \frac{1}{\exp\left(\frac{\tau_r}{t-t_s} + \frac{t-t_s}{\tau_d}\right)}$$
- $$L \propto \left(\frac{t+t_s}{t_p+t_s}\right)^{r}\left[\frac{d}{d+r} + \frac{r}{r+d}\left(\frac{t+t_s}{t_p+t_s}\right)^{r+1}\right]^{-\frac{r+d}{r+1}}$$



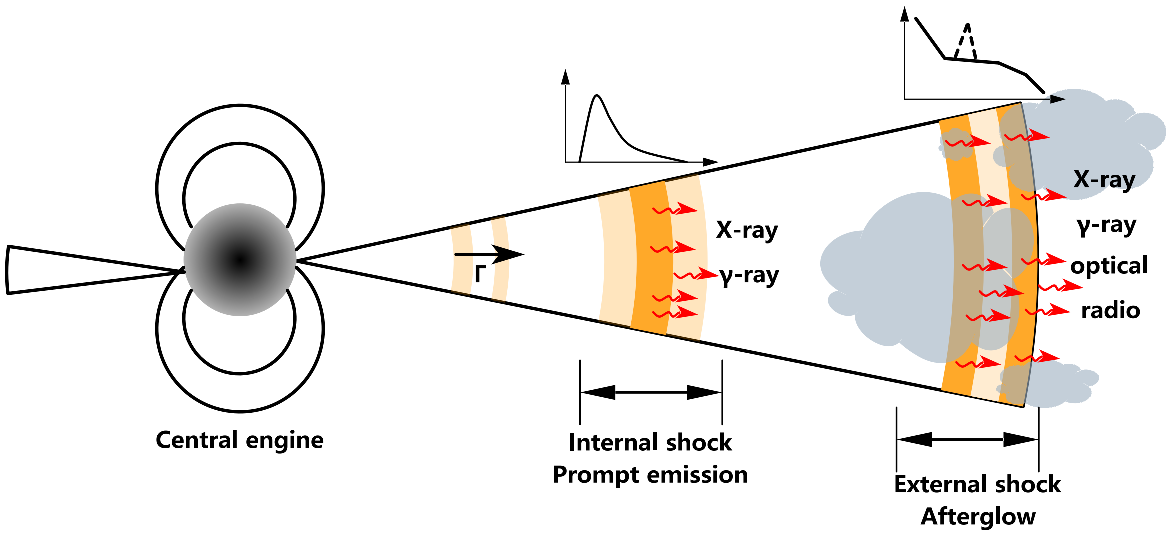
In general, FRED pulses shows spectral lag like:

- **softer-wider**
- **softer-later**

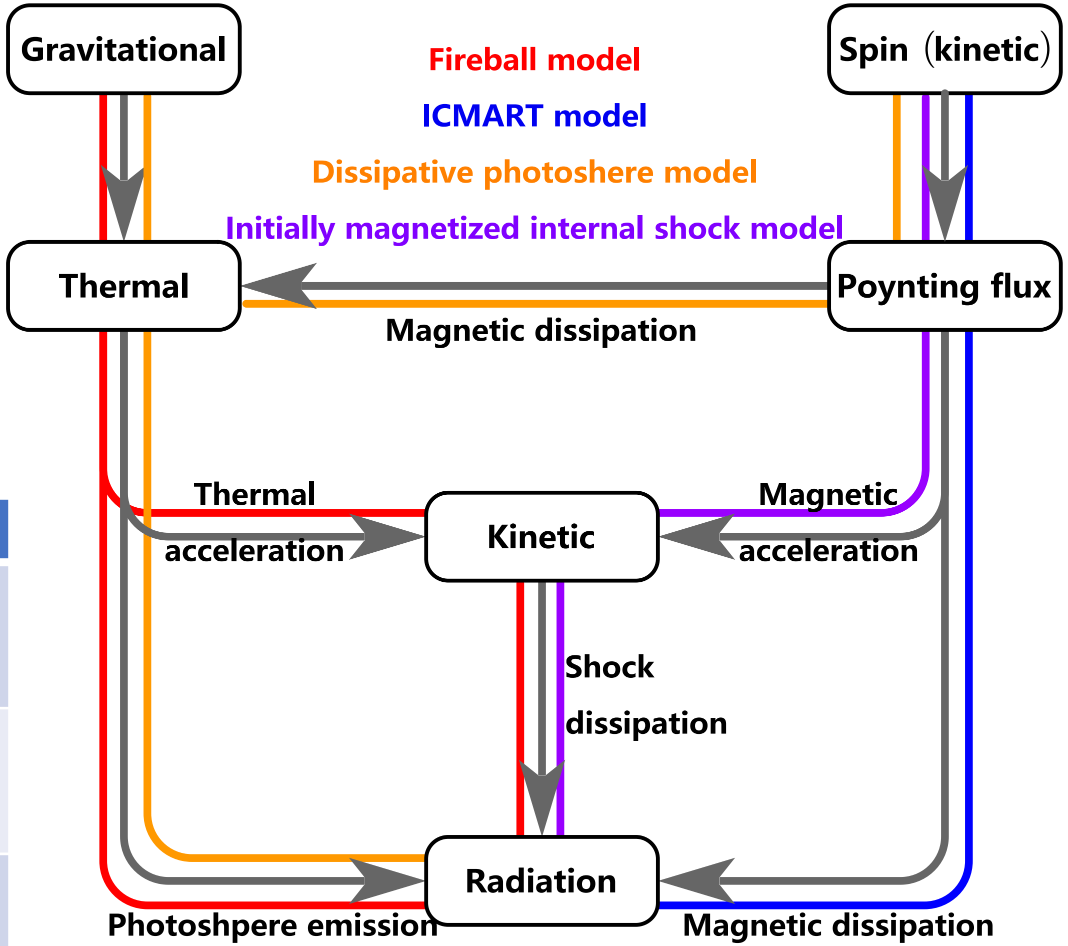
Pulse width $w(E) \propto E^{-\alpha}$, α~0.3-0.4

Norris, et al., APJ, 1996
Dan kocevski, Felix Ryde and Edison Liang, APJ, 2003
Norris, et al., APJ, 2005

Pulse in different model



	Internal Shock	ICMART
Dominating energy	Kinetic energy	Magnetic energy
Particle acceleration	Shock acceleration	Local turbulenc induced magnetic reconnection
Lightcurve profile	One shock, one pulse	One mini-jet, one spike

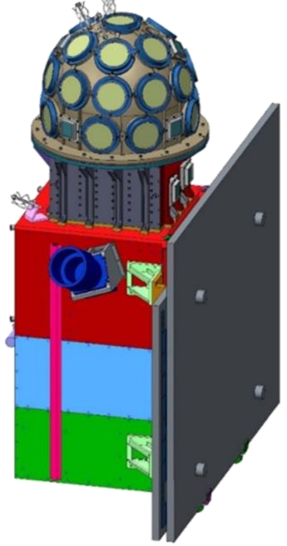


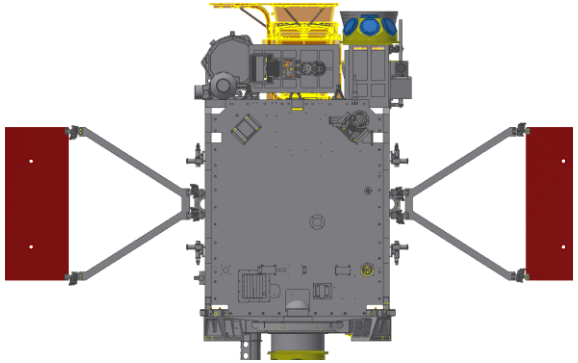
Reprocessed from The Physics of Gamma-Ray Bursts, Zhang, 2018

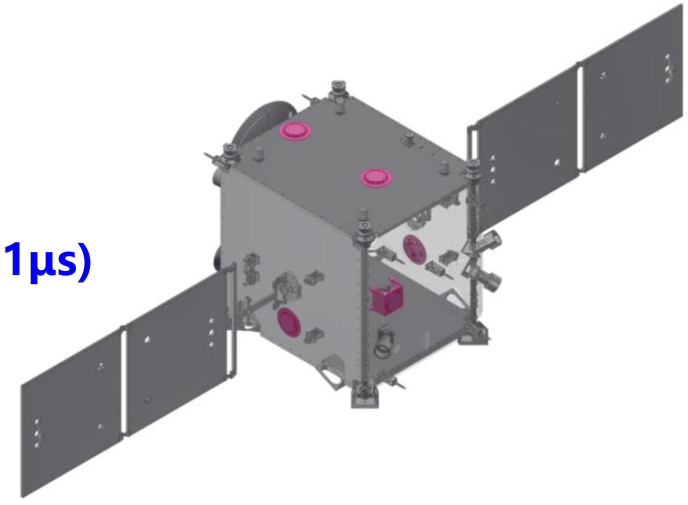
GECAM & HEBS & GTM

Gravitational wave high-energy Electromagnetic Counterpart All-sky Monitor
High Energy Burst Searcher
Gamma-ray Transient Monitor

GECAM series	launch time	orbit
GECAM-A/B	2020-12-10	LEO, ~600 kM
GECAM-C (HEBS)	2022-07-27	SSO, ~500 kM
GECAM-D (GTM)	2024-03-13	DRO, ~380,000 kM







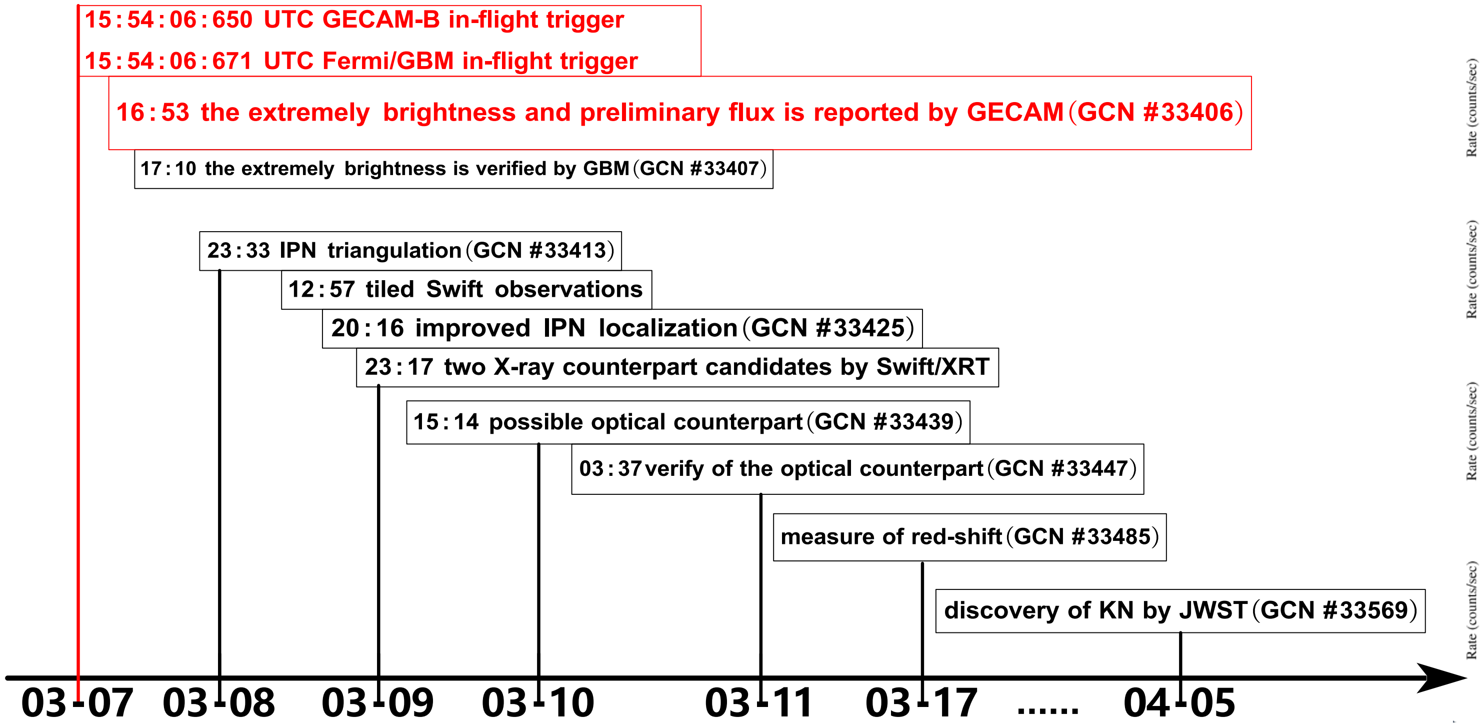
Main payload：GRD and CPD

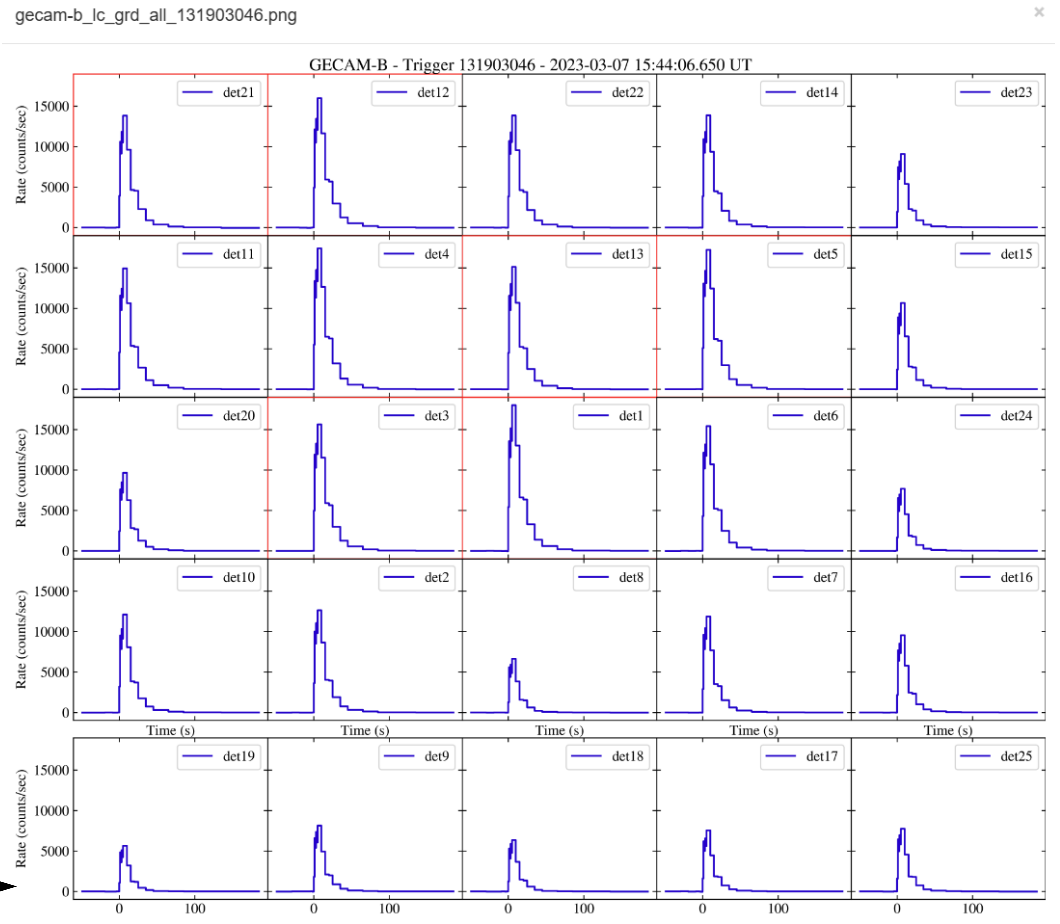
- GECAM-A/B: 25 $LaBr_3$ GRDs，8 CPDs
- GECAM-C: 6 $LaBr_3$ GRDs，6 NaI GRDs，2 CPDs
- GECAM-D: 5 NaI GTPs(i.e. GRDs)

GECAM is designed to have the highest time resolution among GRB monitors (0.1μs)

Shuo Xiao, et al., MNRAS, 2022
Shuo Xiao, et al., APJS, 2023

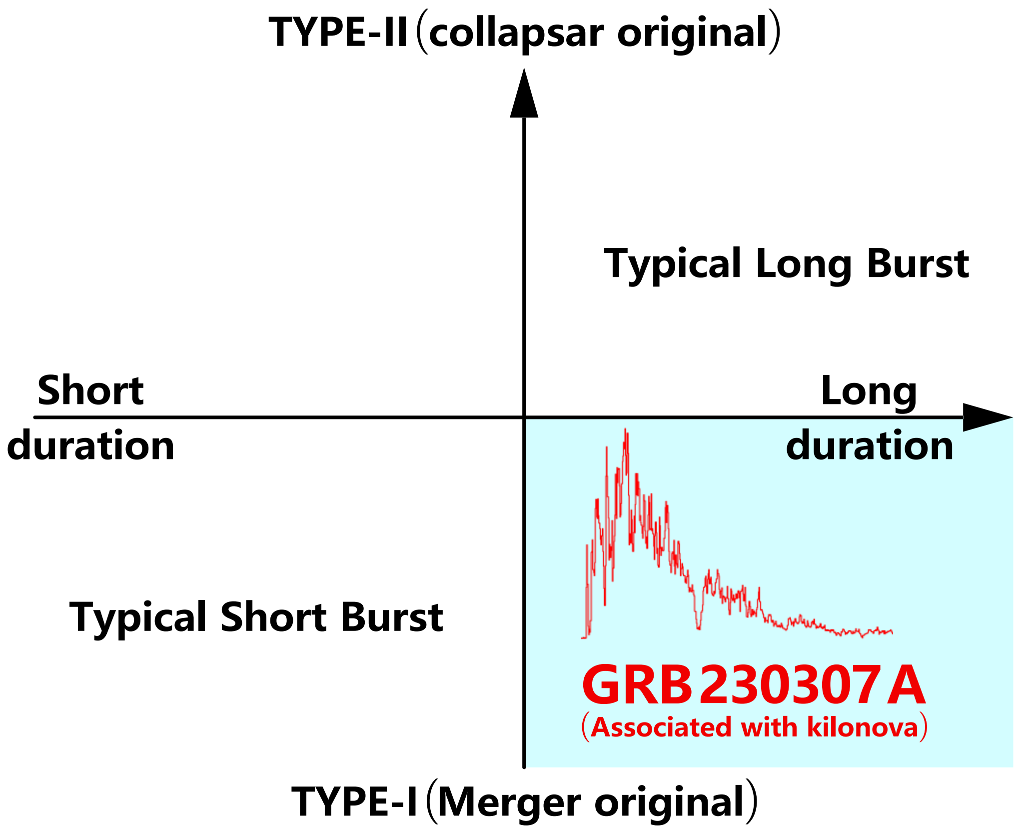
Overview of GRB 230307A





- The lightcurve from BeiDou navigation system shows a roughly FRED shape
- GECAM-B firstly reported that this is an extremely bright GRB leading a global observation campaign to this event
- Both GECAM-B & GECAM-C have high quality observation data, neither of them suffered from data saturation

Overview of GRB 230307A

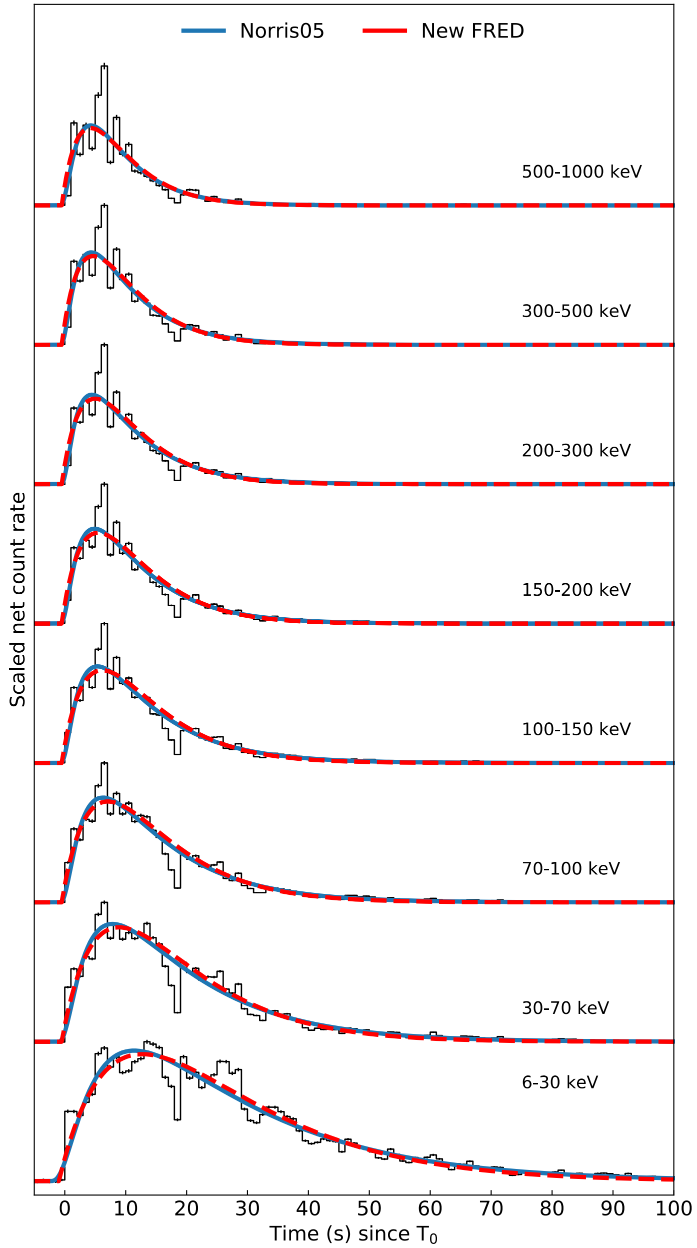


	Type I	Type II	GRB 230307A
origin	merger	collapsar	merger
γ-ray duration	short	long	long
E_{peak} vs E_{iso} Amati relation	harder	softer	harder
MVT	short	long	short
Spectral lag	small	large	small
host galaxy offset	large	small	large

The extremely brightness of GRB 230307A provide an laboratory to test the dissipative processes of GRB!

Hui Sun, et al., submitted, 2023
Andrew J. Levan, et al., Nature, 2023

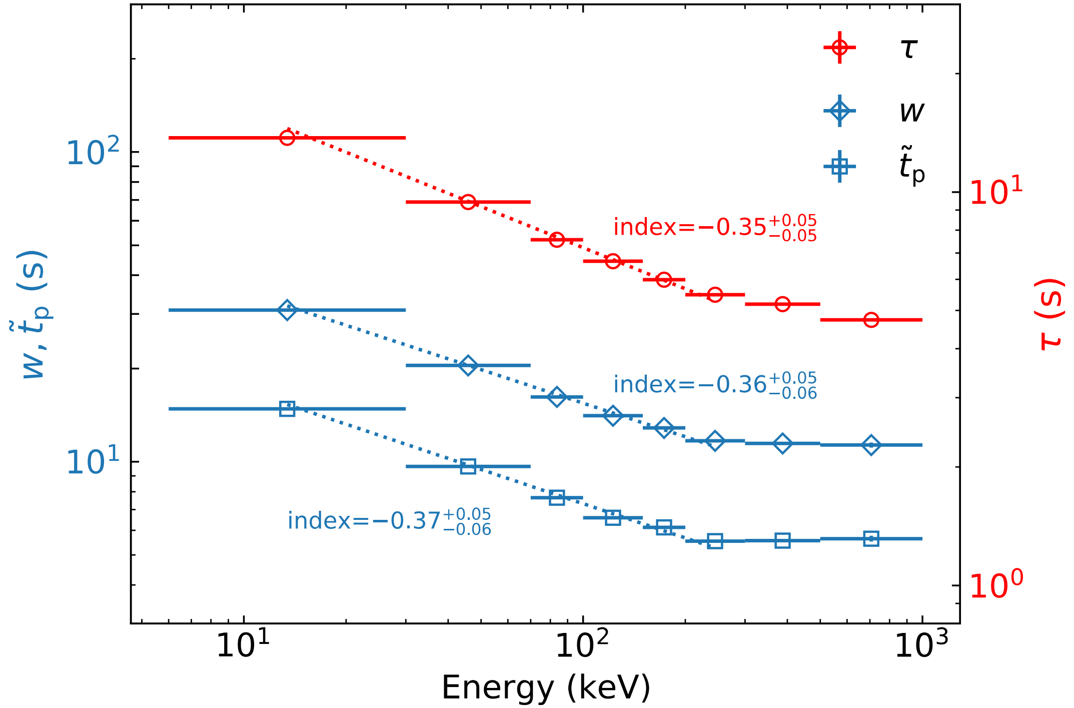
The lightcurve in multi-E bands act as a single pulse



Well fitted by $L \propto \frac{1}{\exp\left(\frac{\tau_r}{t-t_s} + \frac{t-t_s}{\tau_d}\right)}$ **(Norris05)**

$\text{Width} \equiv \tau_r + \tau_d$

$t_p \equiv t_s + \sqrt{\tau_r \cdot \tau_d}$

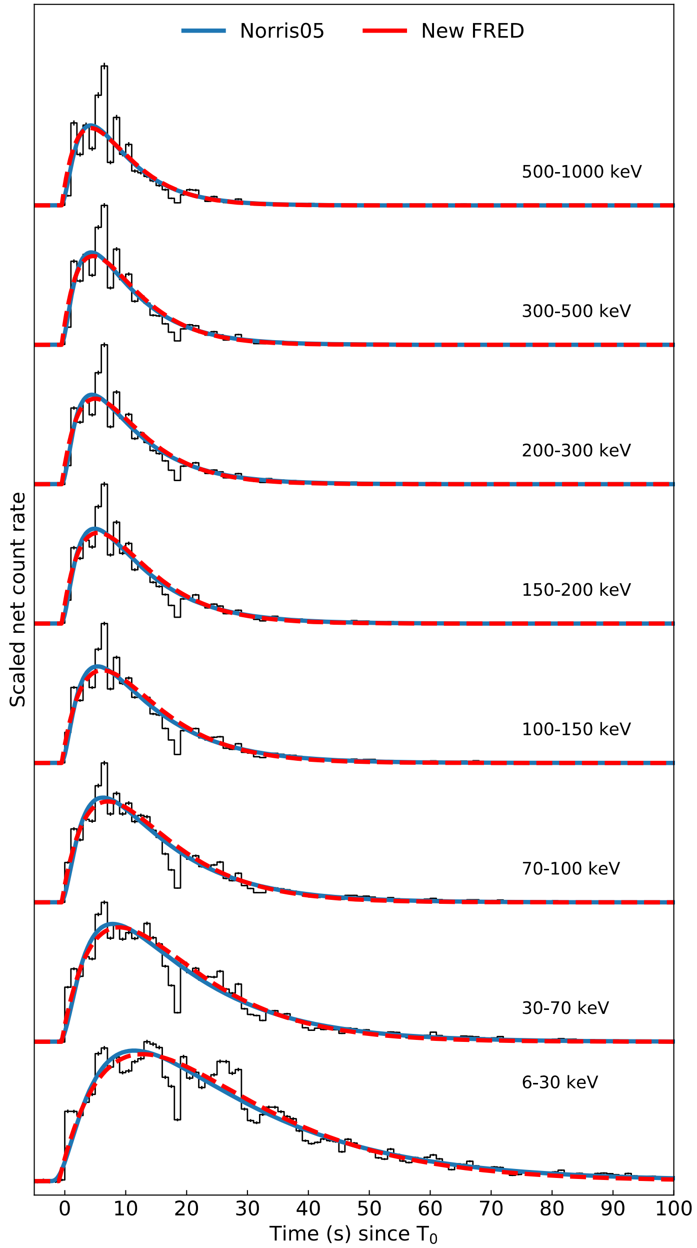


Self-similarity: W and t_p follow the same E dependency

New FRED formulation with one less dof

$$L \propto \frac{t-t_s}{\tau_E} \exp\left(-\frac{t-t_s}{\tau_E}\right)$$

Self-similarity of the pulse

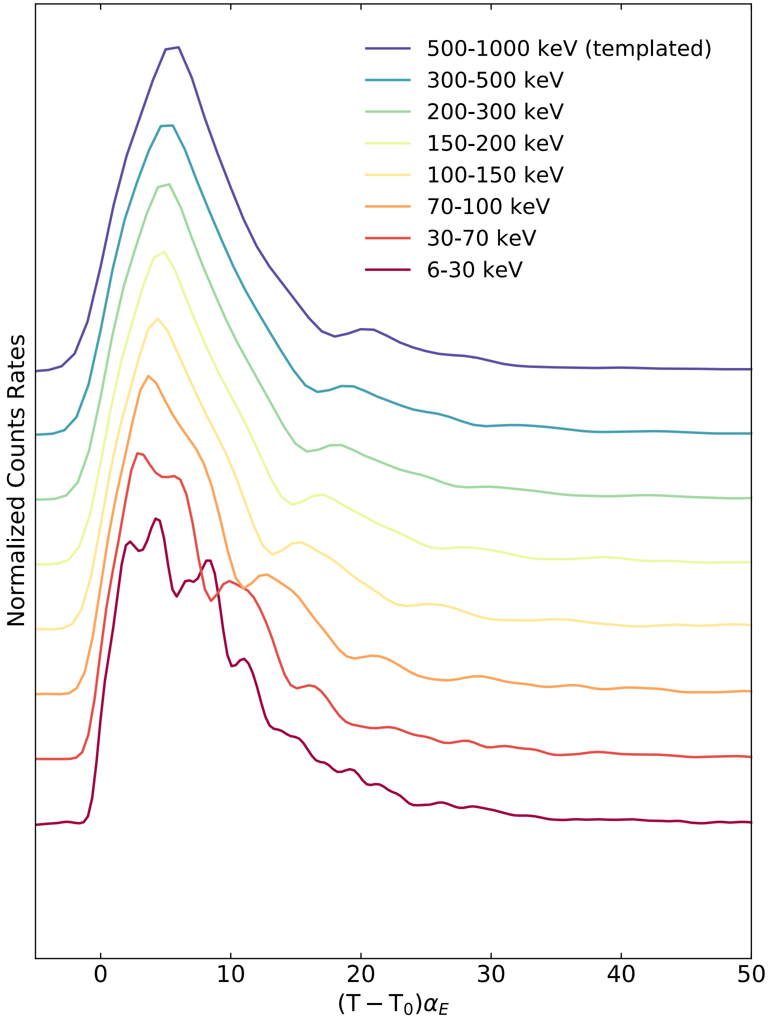


Well fitted by new FRED $L \propto \frac{t-t_s}{\tau_E} \exp\left(-\frac{t-t_s}{\tau_E}\right)$

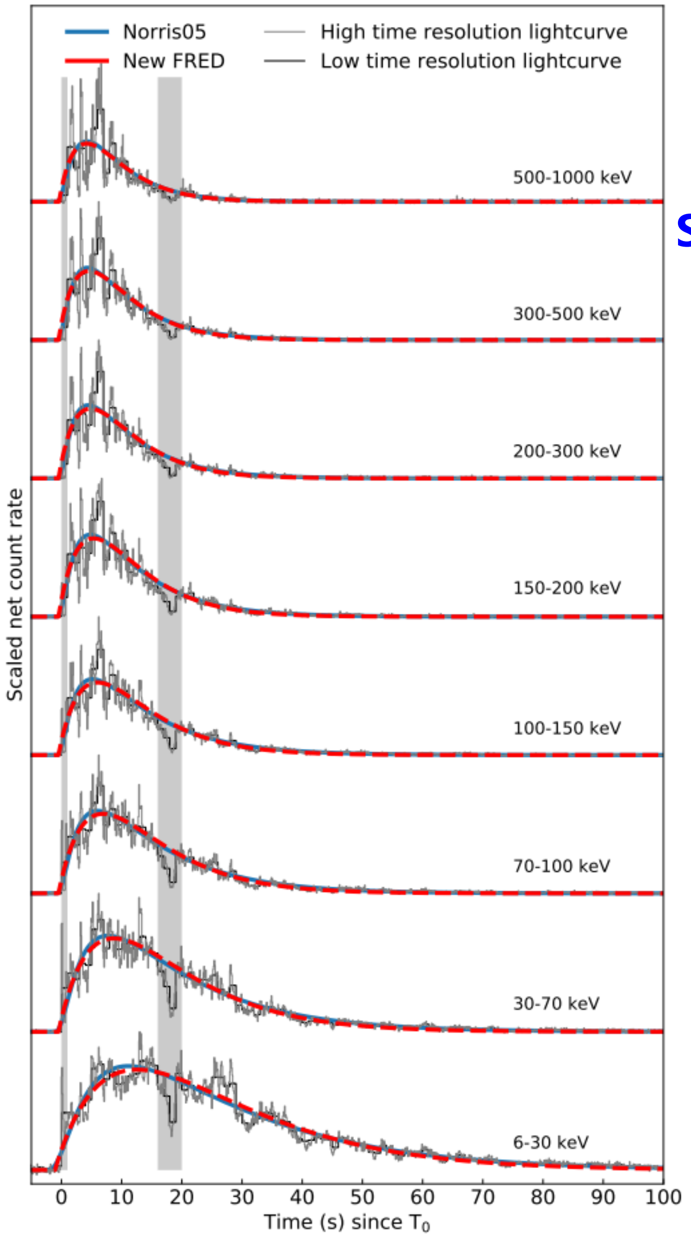
The profile can be aligned by linear stretch

"Stretch" in time

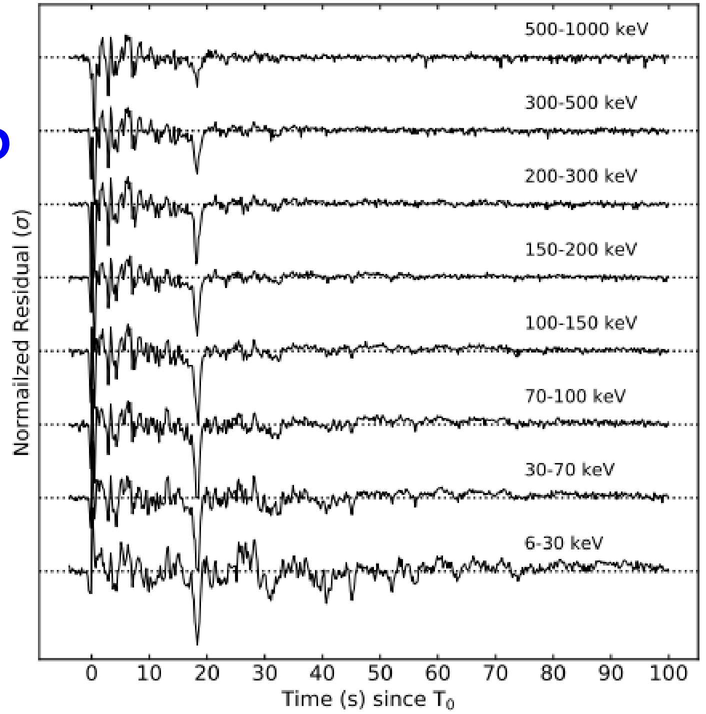
$$\alpha_E = \left(\frac{E}{E_0}\right)^{0.35}$$

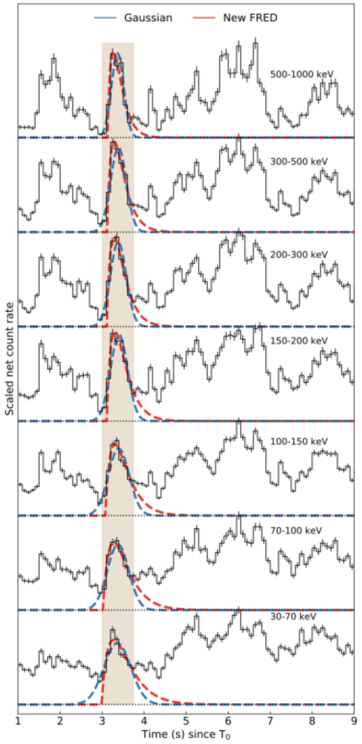


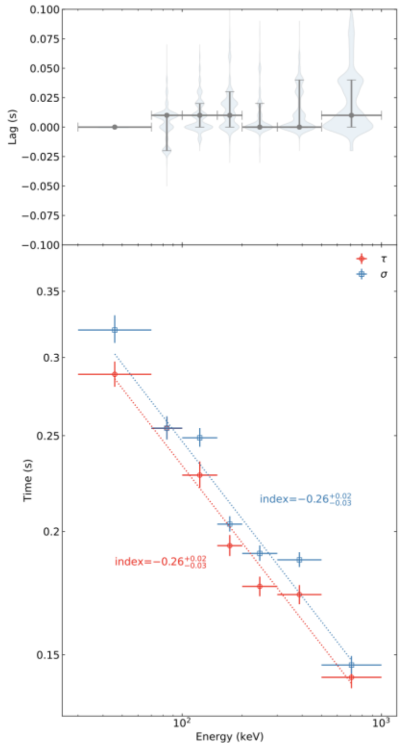
Fast component



Subtracted FRED







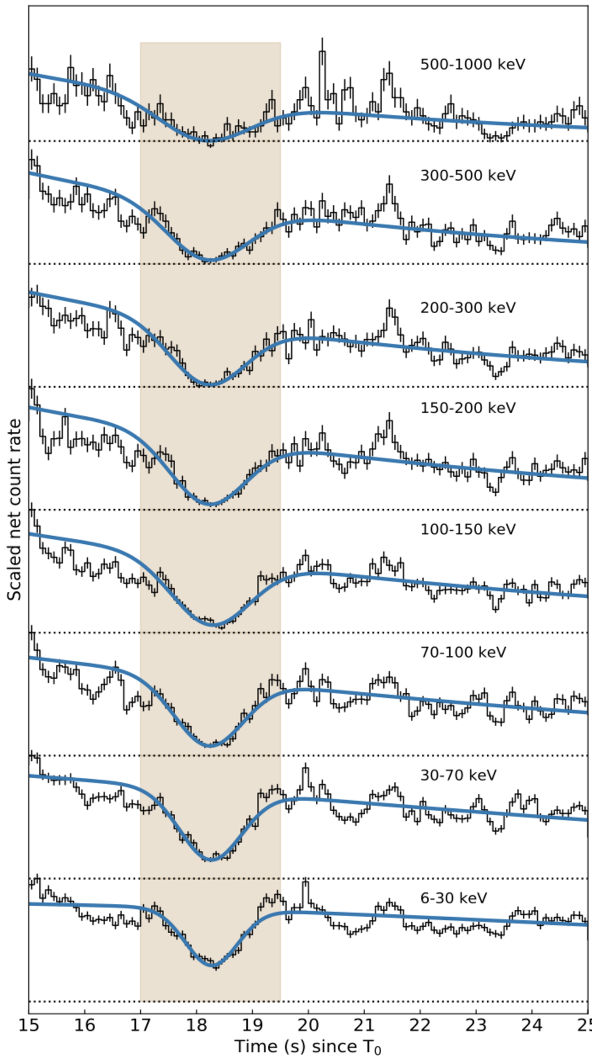
- **The fast components are well aligned!**
- **The fast components are self-similarity**

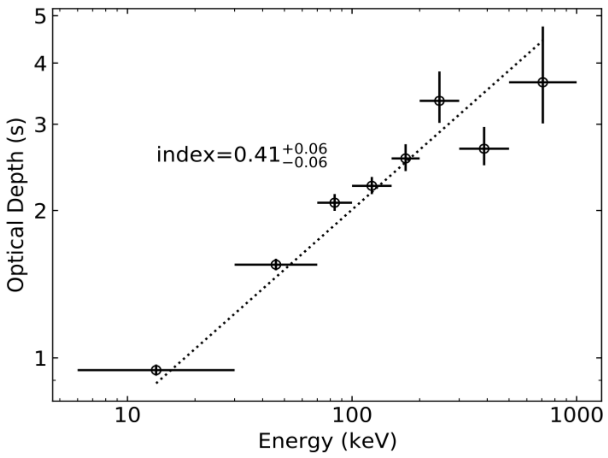
Overall lightcurve= Elementary Slow component + Fast components?

or

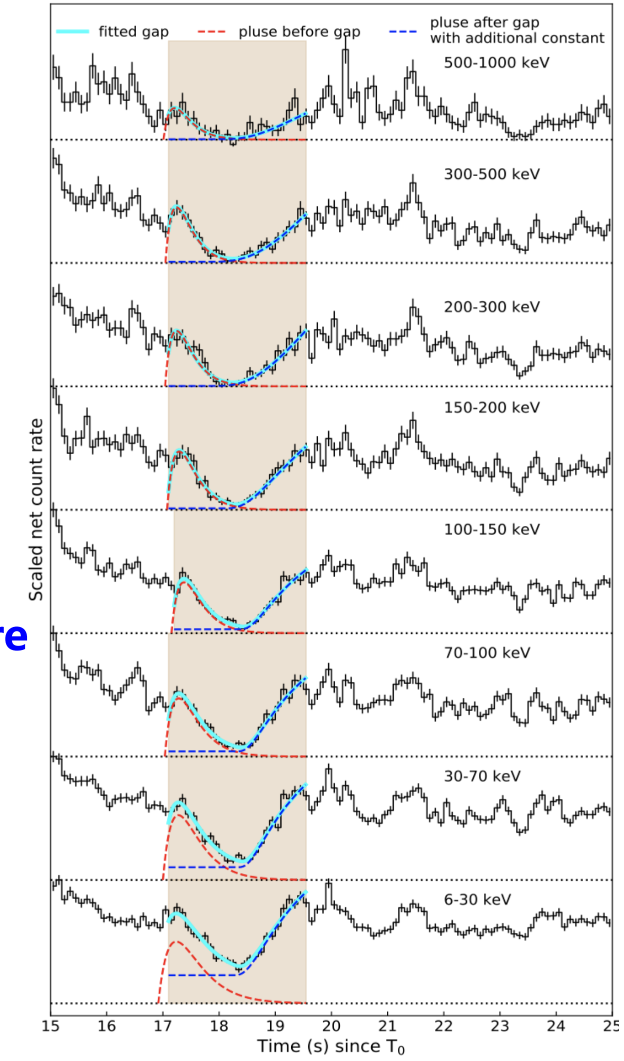
Slow component = ΣFast components ?

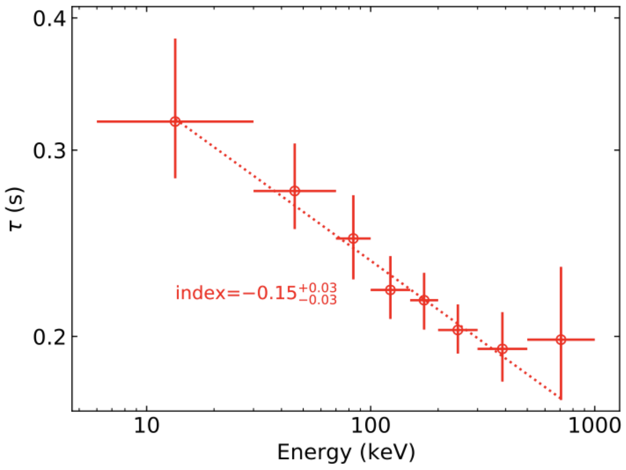
“DIP” or “GAP” ?





The effective optical depth cannot be absorption feature





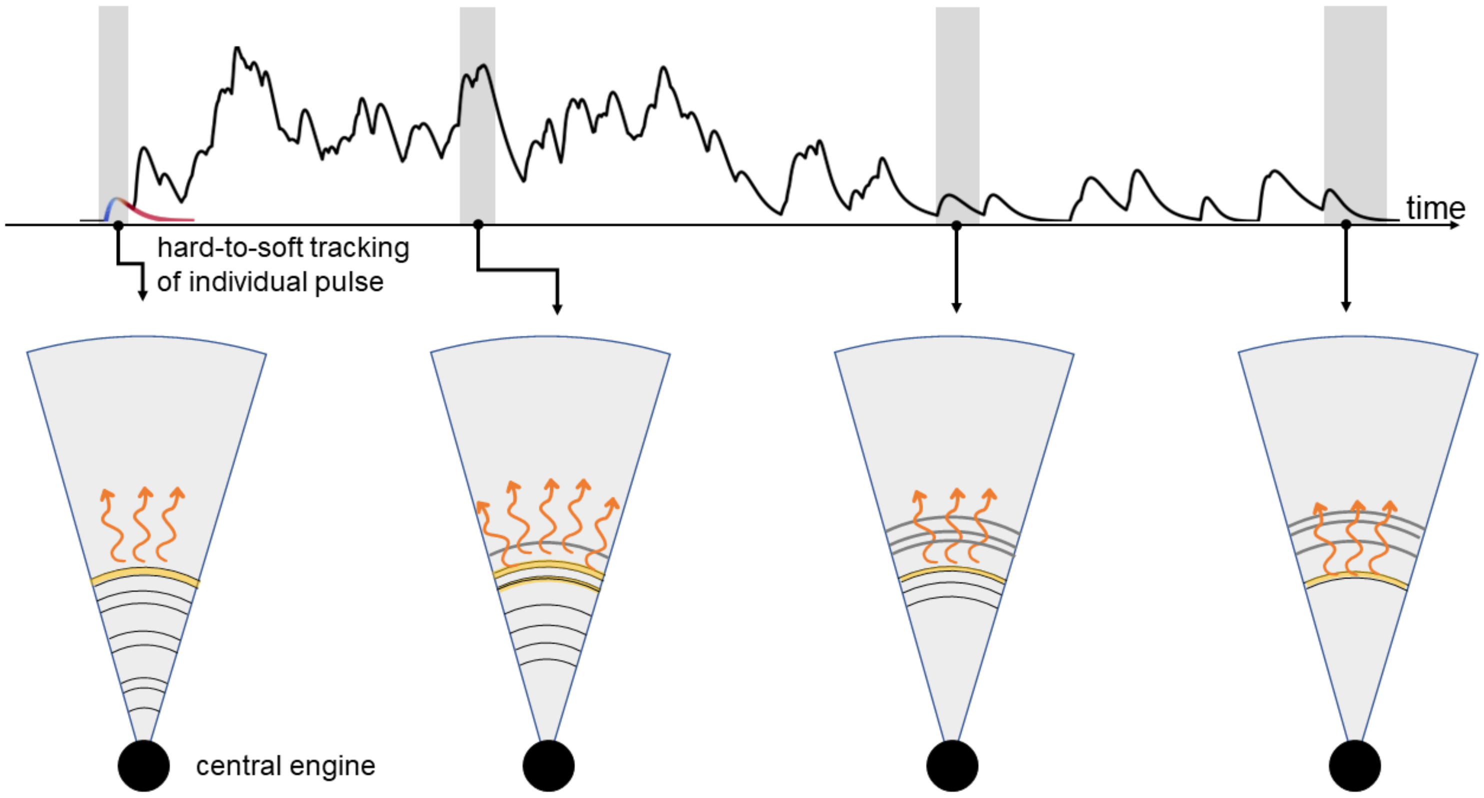
The left part of the dip have the same behavior of a typical single pulse

Overall lightcurve= Elementary Slow component + Fast components?

or

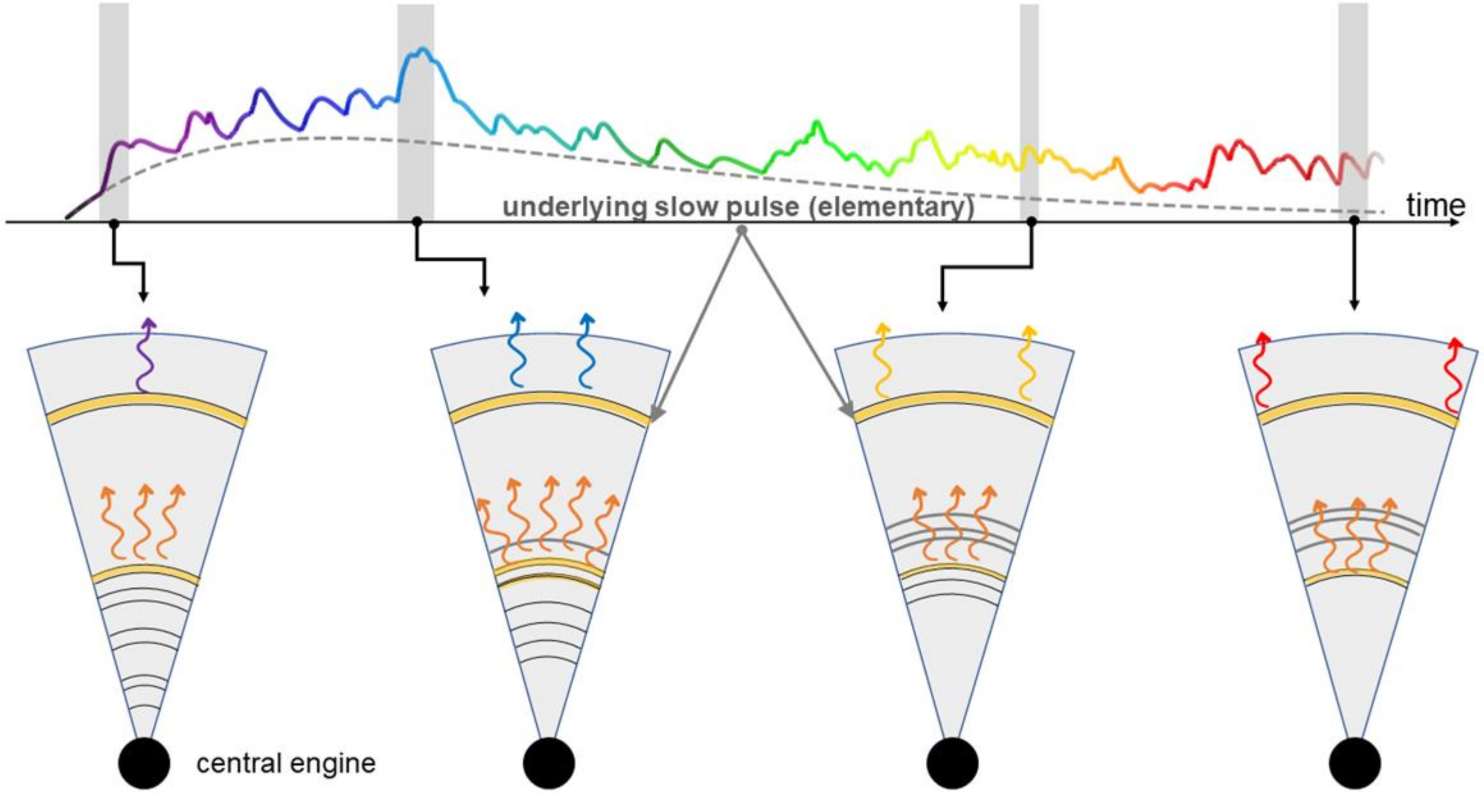
Slow component = ΣFast components ? (√)

With the standard IS scenario (IS-caseA)



- **There is no underlying elementary slow pulse**
- **Σ Fast components = typical broad pulse， R_{IS}~$(3\times10^{14}$cm$)(\Gamma/100)^2(\delta t/1s)$**
- **advantage: can produce dip structure**
- **disadvantage: no overall shape-E dependence**

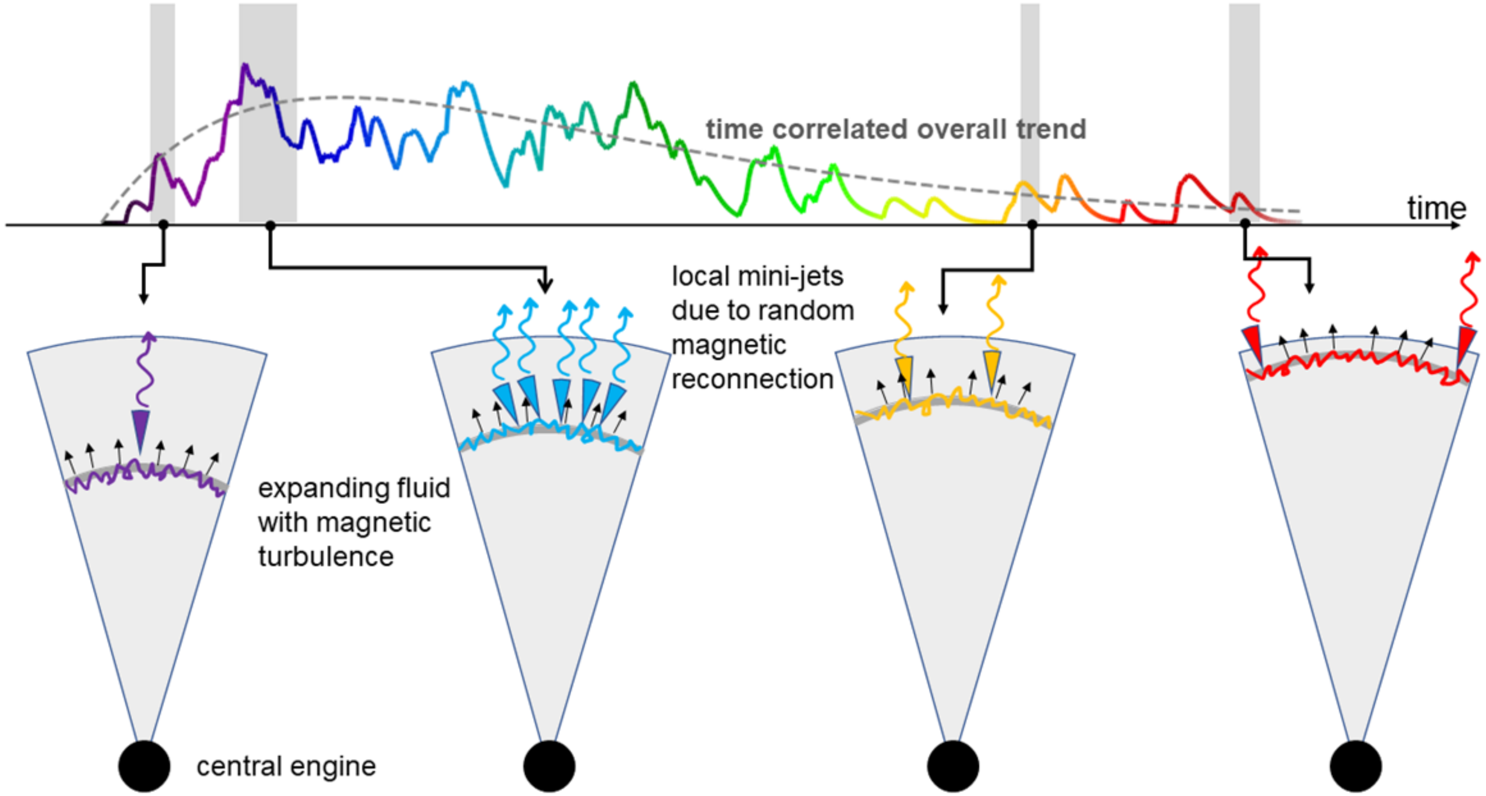
With an variant IS scenario (IS-caseB)



- There is an underlying elementary slow pulse
- Fast components: R_{IS}~$(3\times10^{14}cm)(\Gamma/100)^2(\delta t/1s)$

  Slow components: R_2~$(1.2\times10^{16}cm)(\Gamma/100)^2(\Delta t/40s)$
- advantage: overall shape-E dependence
- disadvantage: cannot produce dip structure

With the ICMART scenario



- There is no underlying elementary slow pulse
- Σ Fast components = typical broad pulse， $R_{ICMART} \sim (1.2\times10^{16}\text{cm})(\Gamma/100)^2(\Delta t/40\text{s})$
- advantage: overall shape-E dependence and can produce dip structure

Simulation result