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

# Evidence of mini-jet emission in a large emission zone from a magnetically-dominated gamma-ray burst jet

arXiv:2310.07205 submitted

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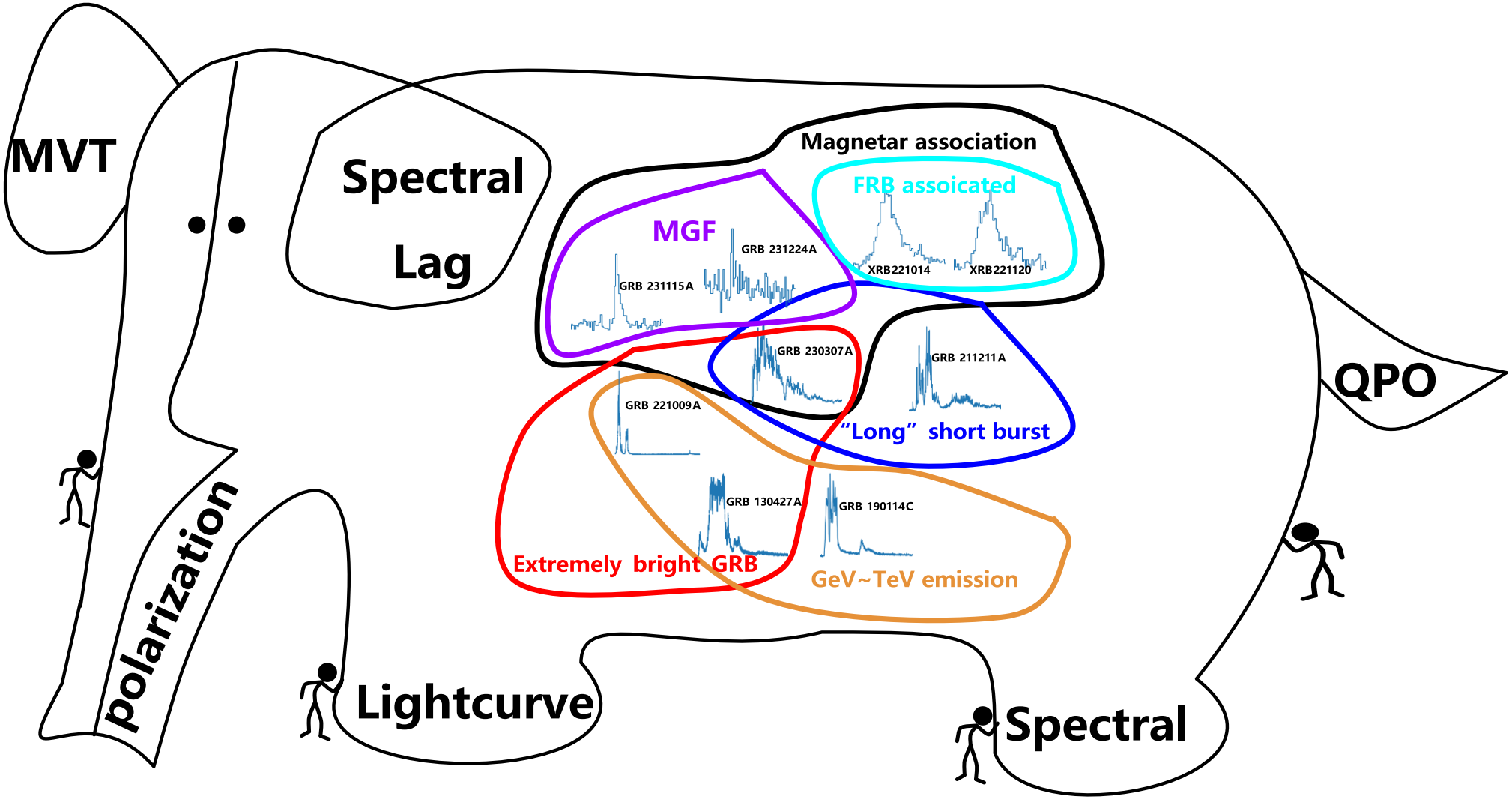
**Institute of High Energy Physics (IHEP)**
**2024-05-21**

GECAM

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

# The prompt emission of GRB



# The lightcurve of prompt emission

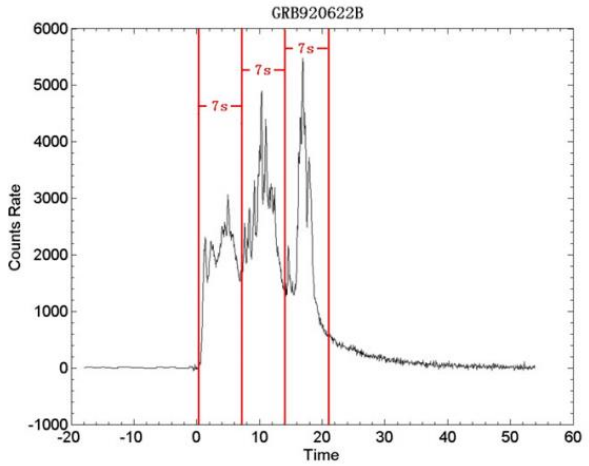
**Profiles of GRB prompt emission**

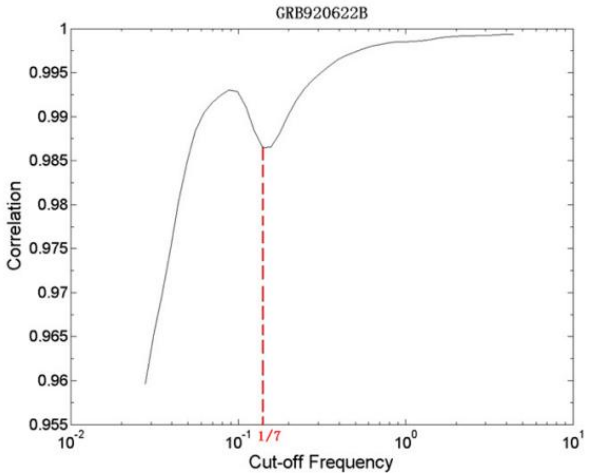
① **single pulse or spike events**

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

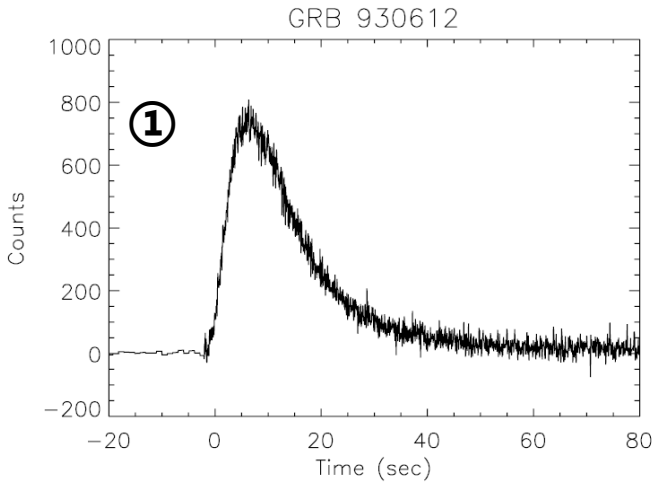
③ **distinct, well-sparated episodes of emission**

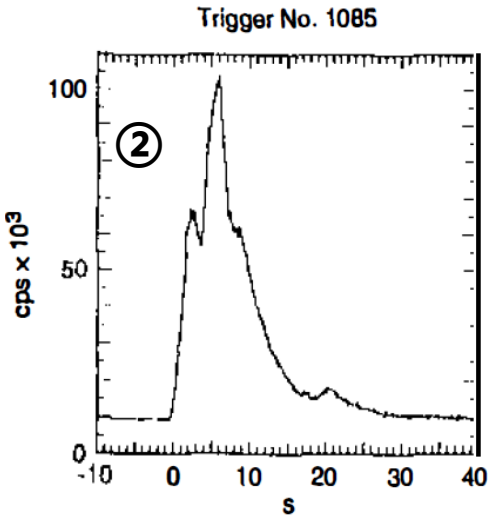
④ **very erratic, chaotic, and spiky bursts**

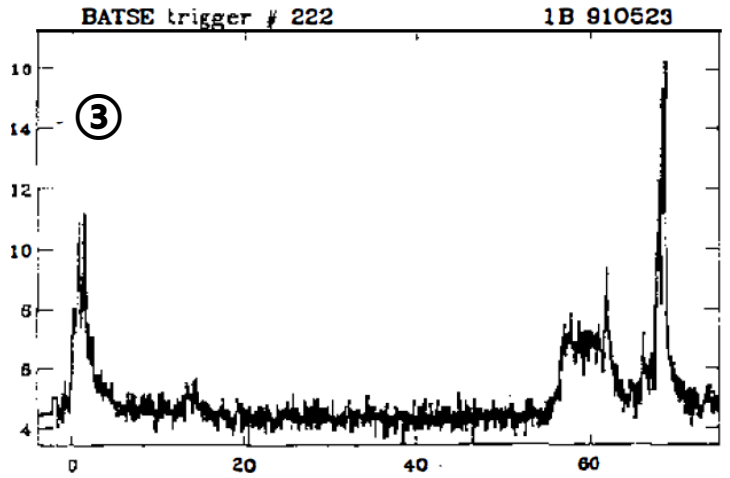


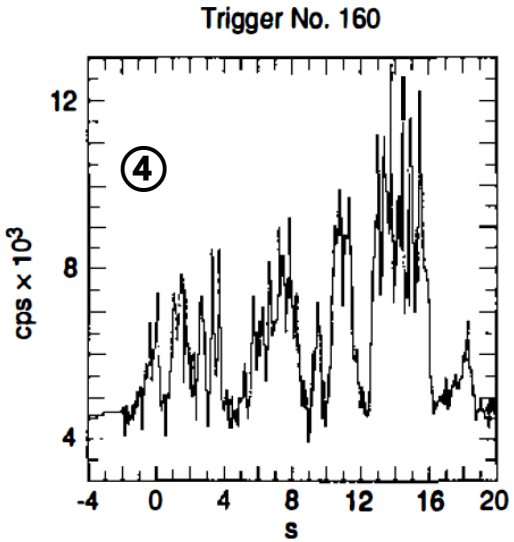




**Some GRB lightcurves show two kind of time variability**



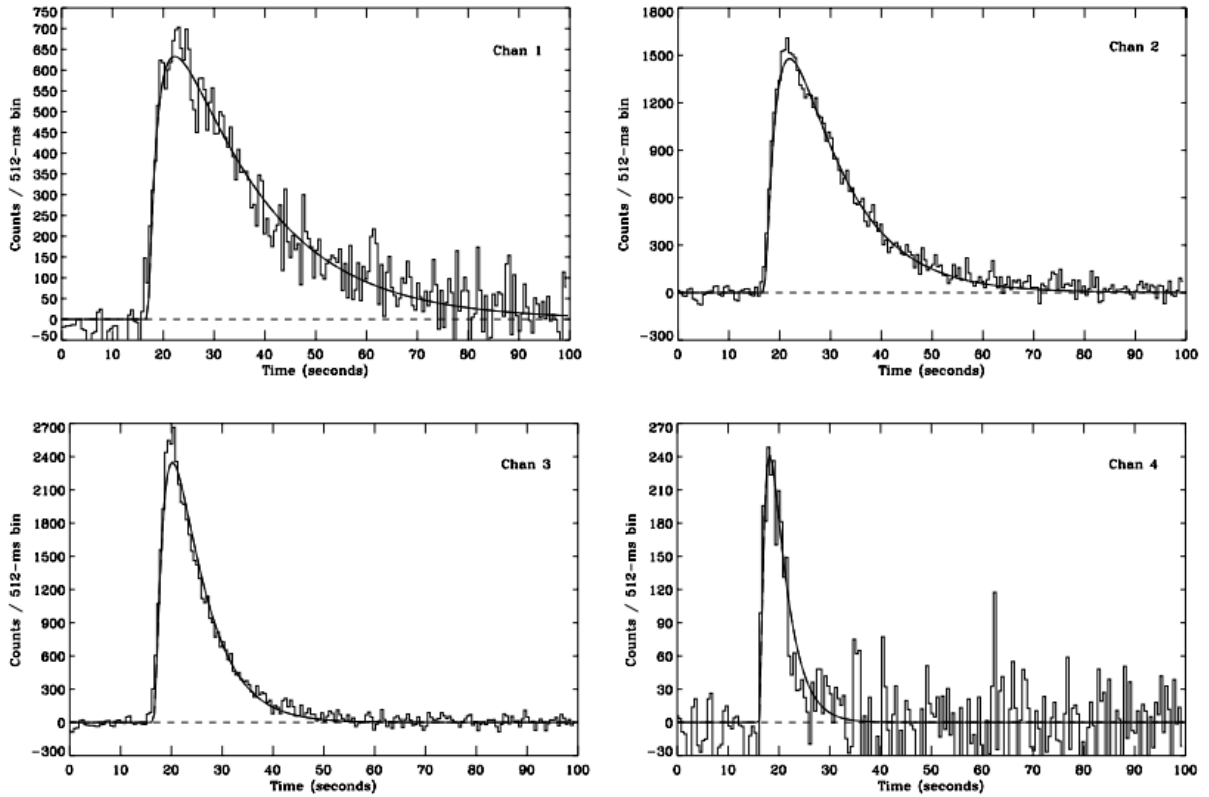

Gerald J. Fishman and Charles A. Meegan, ARAA, 1995
He Gao, Binbin Zhang and Bing Zhang, APJ, 2012

# FRED shape pulse

## Fast Rise and Exponential Decay

**A typically asymmetric pulse have FRED shape**

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



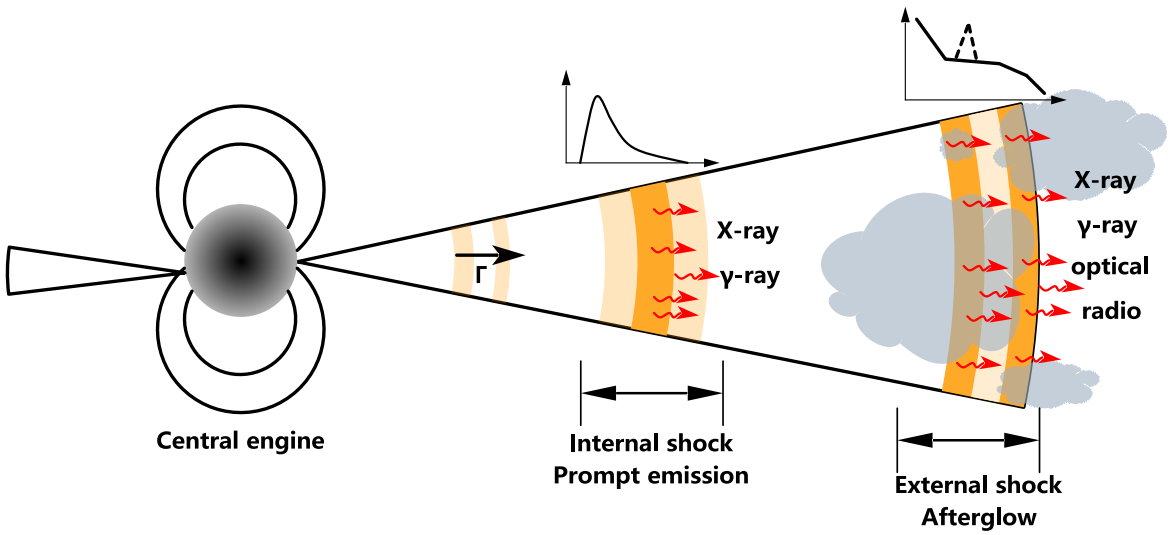

**In general, FRED pulses shows spectral lag like:**

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

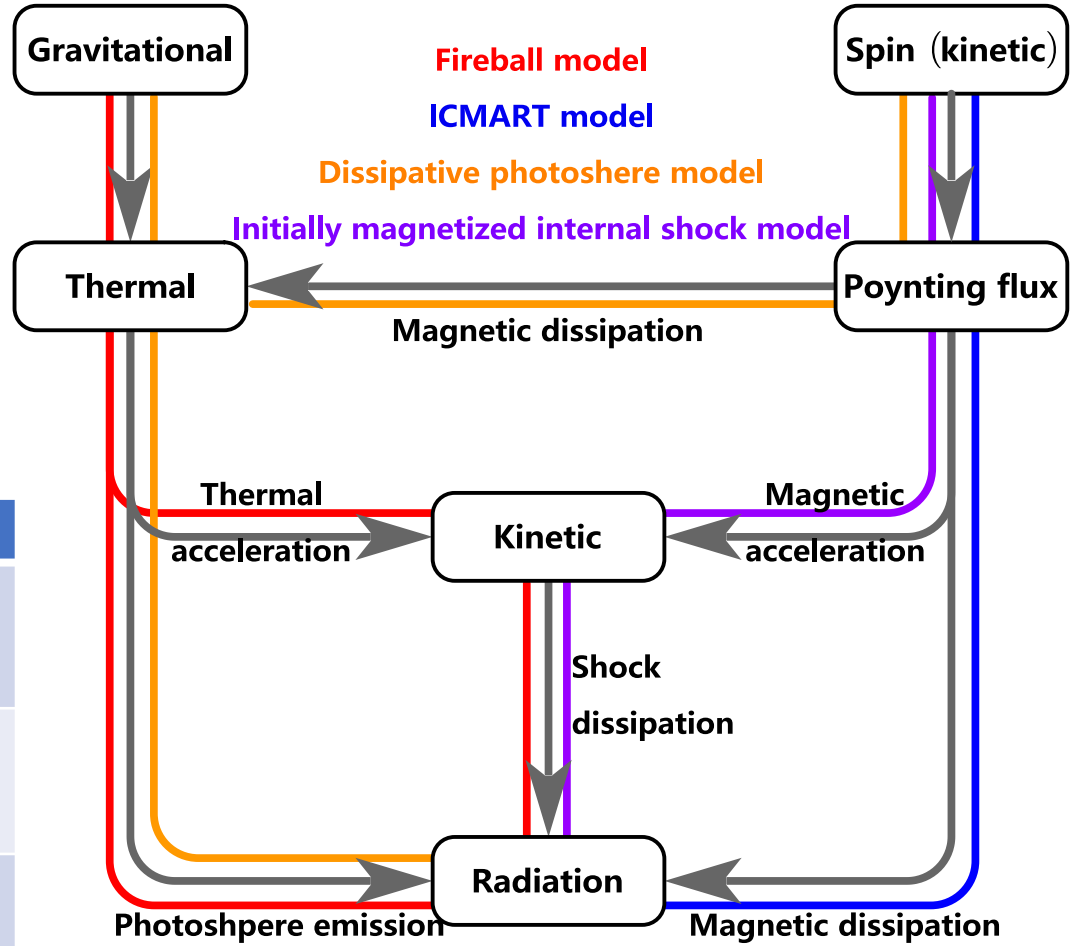
**Pulse width $w(E) \propto E^{-\alpha}$, $\alpha$~0.3-0.4**


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 |

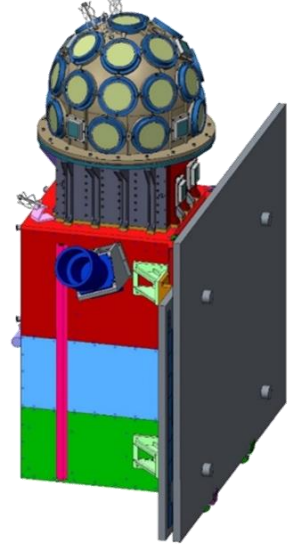


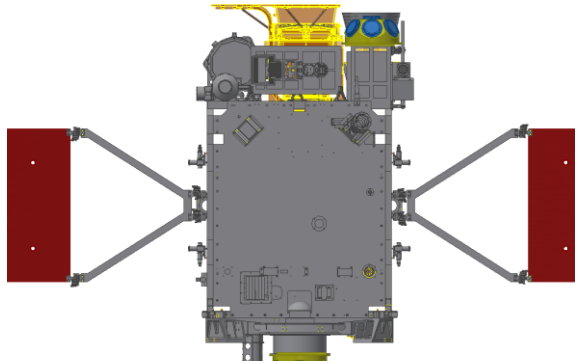

Reprocessed from The Physics of Gamma-Ray Bursts, Zhang, 2018

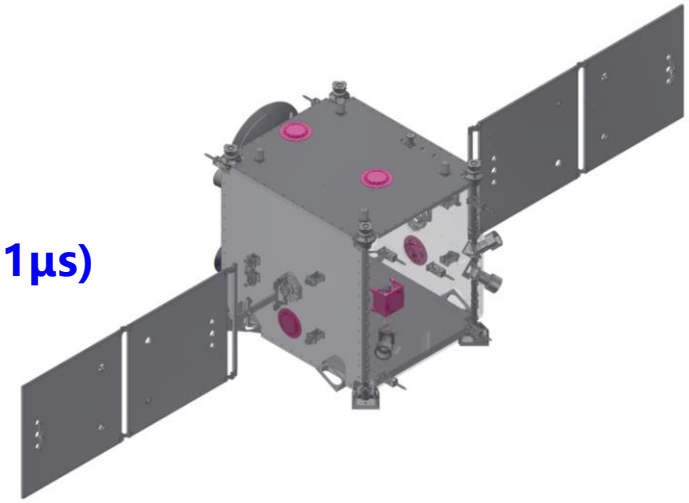
# GECAM & HEBS & GTM

**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 |







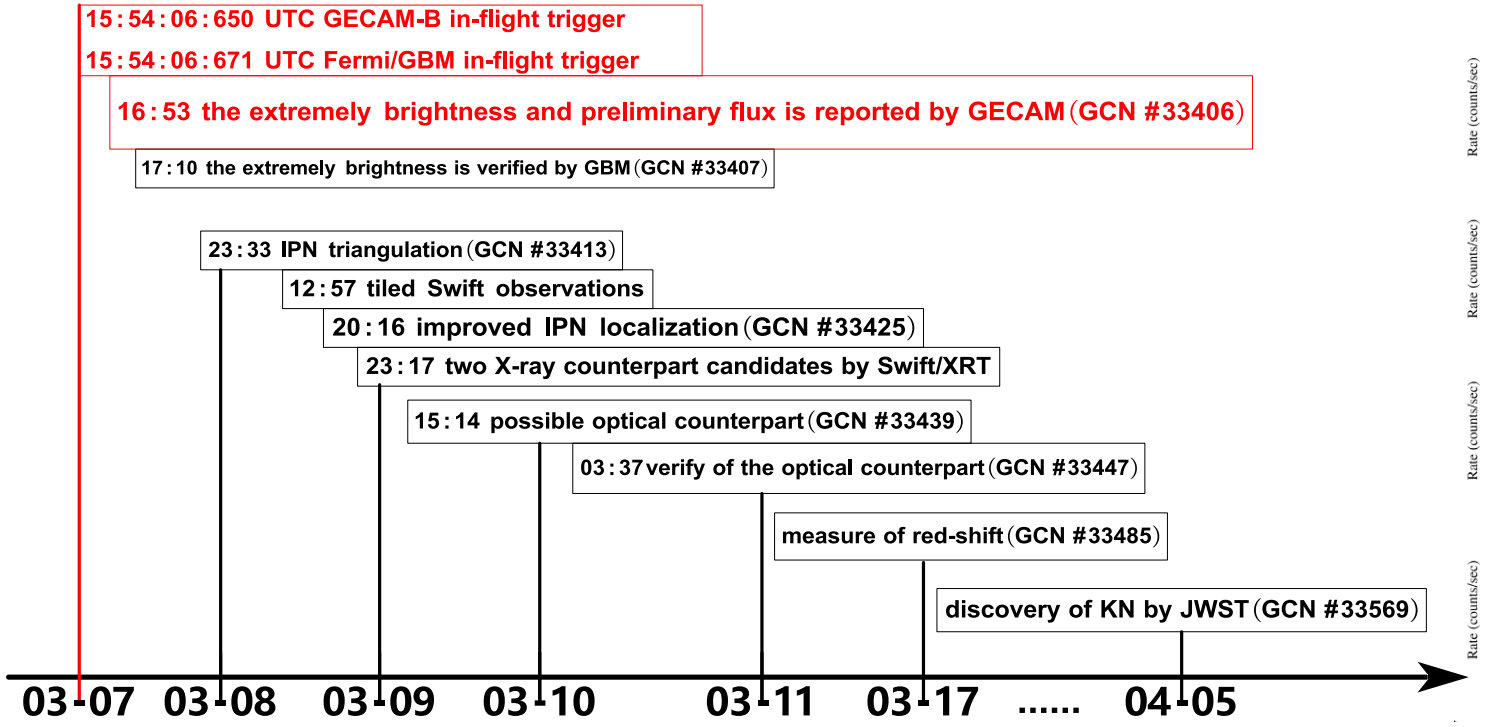
**Main payload: GRD and CPD**

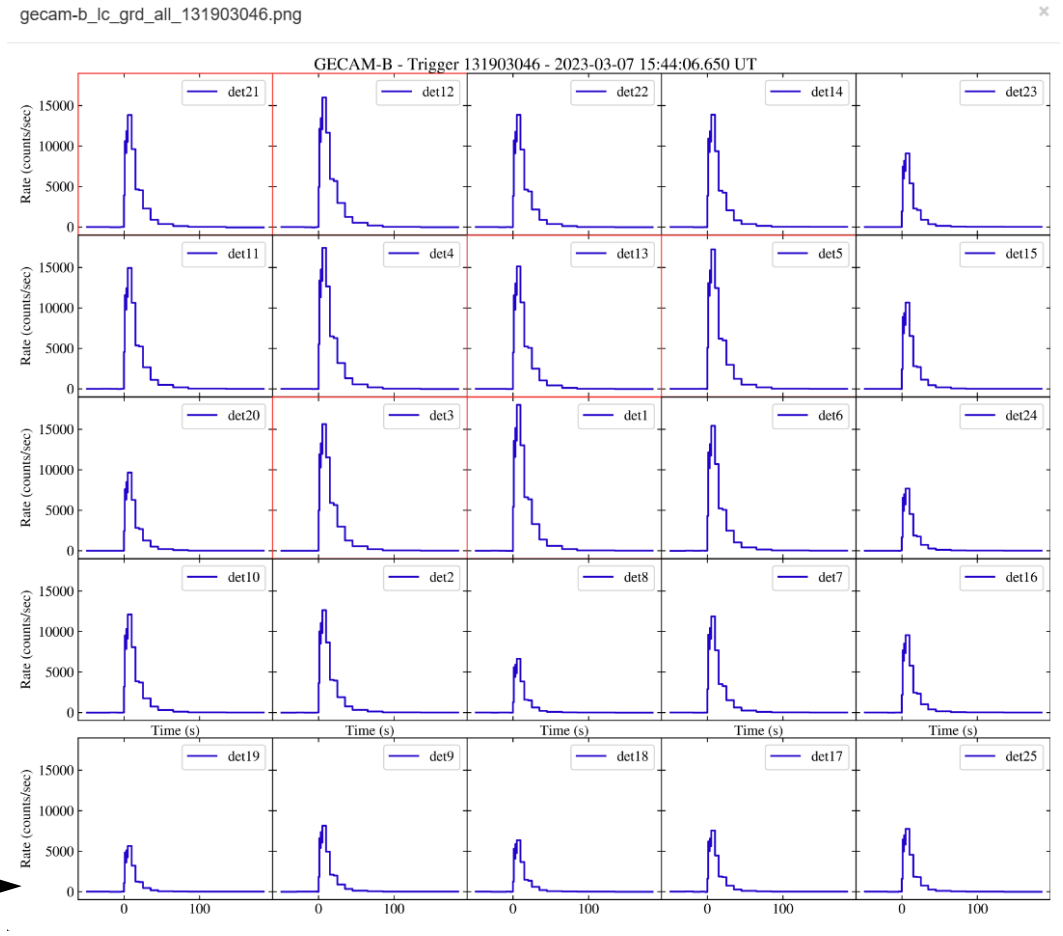
- **GECAM-A/B: 25 $LaBr_3$ GRDs, 8 CPDs**
- **GECAM-C: 6 $LaBr_3$ GRDs, 6 NaI GRDs, 2 CPDs**
- **GECAM-D: 5 NaI GTPs(i.e. GRDs)**

**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

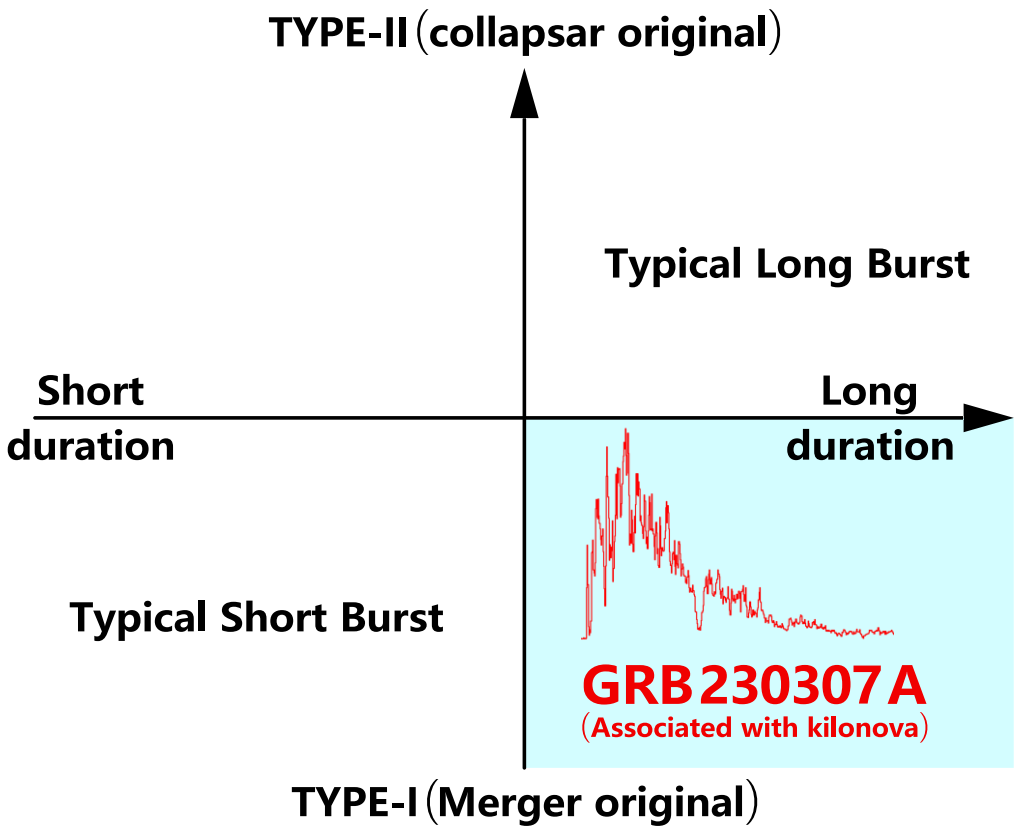
# Overview of GRB 230307A




- 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

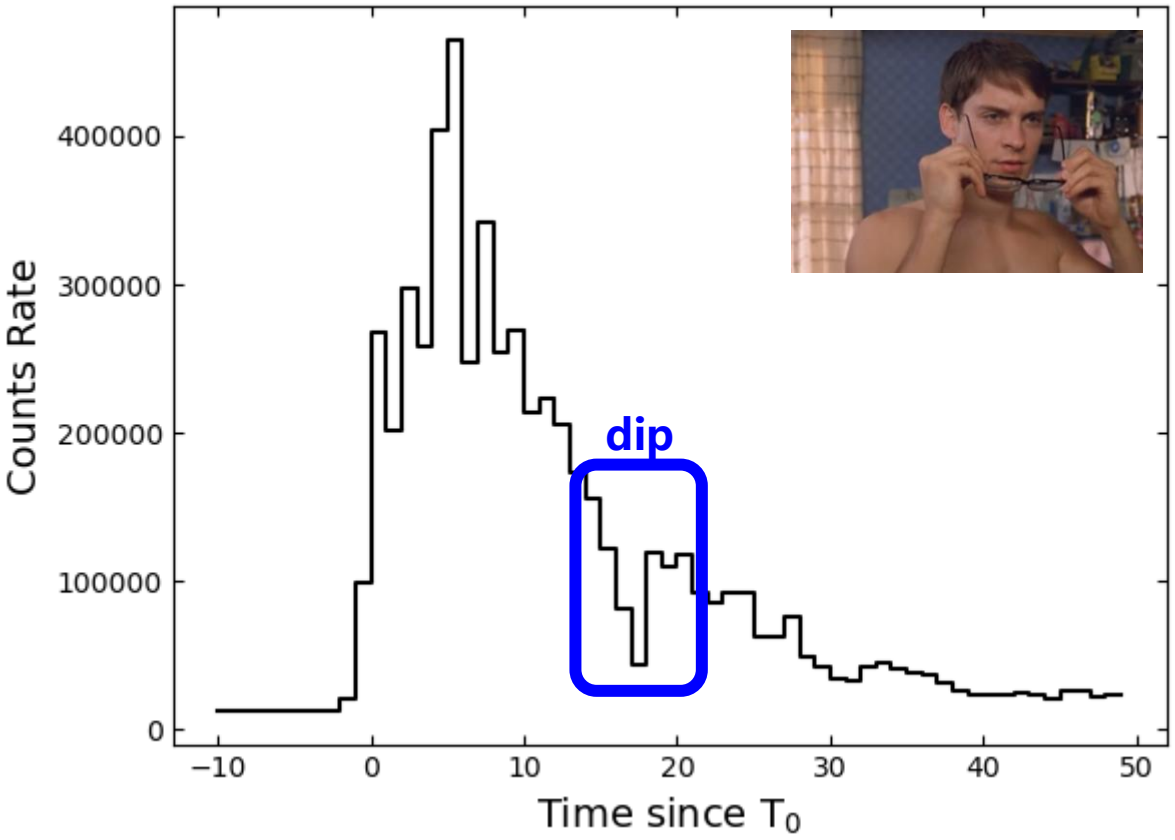


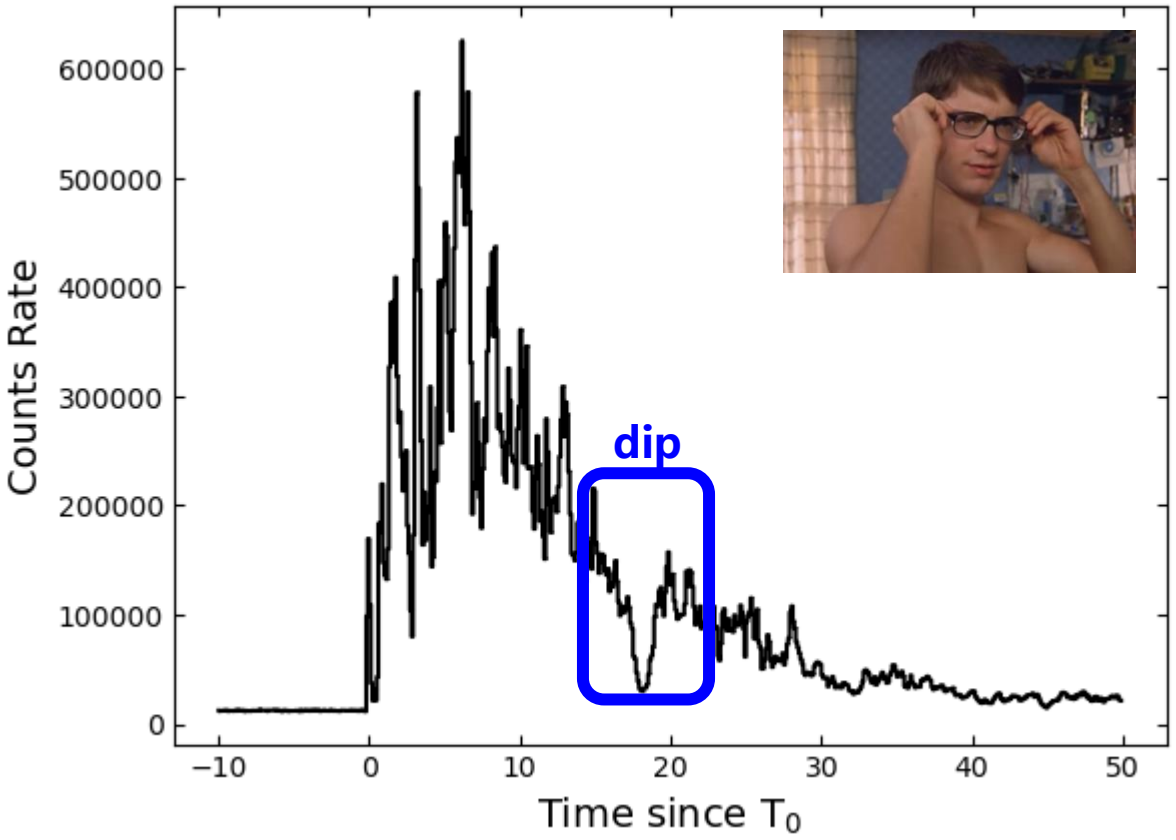

| | Type I | Type II | GRB 230307A |
|---|---|---|---|
| origin | merger | collapsar | merger |
| γ-ray duration | short | long | long |
| $E_{peak}$ vs $E_{iso}$ Amati relation | harder | softer | harder |
| MVT | short | long | short |
| Spectral lag | small | large | small |
| host galaxy offset |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

# Overview of GRB 230307A

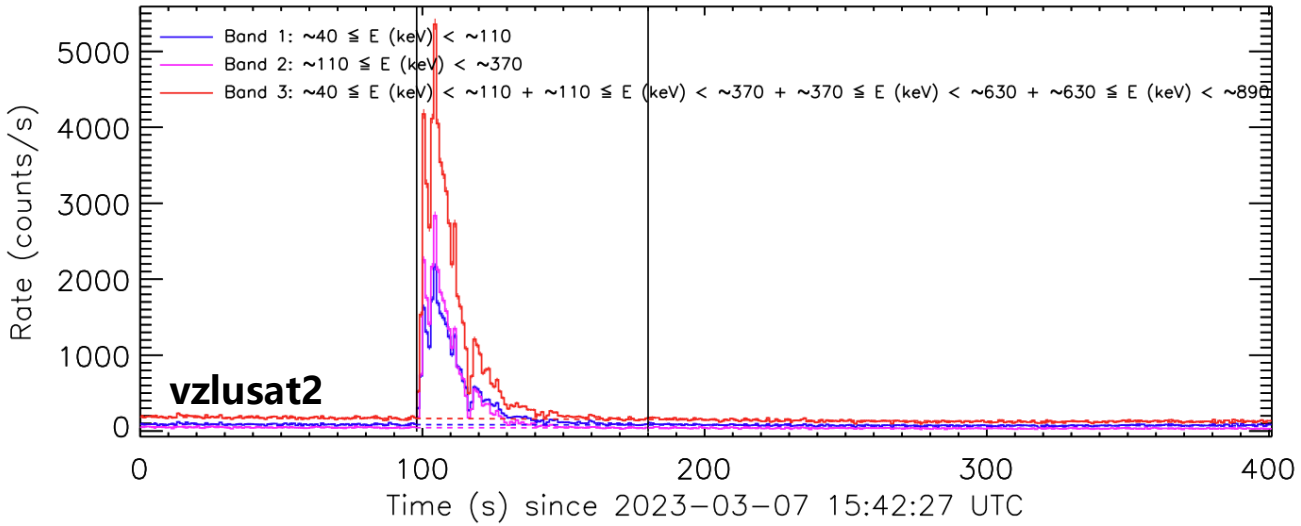


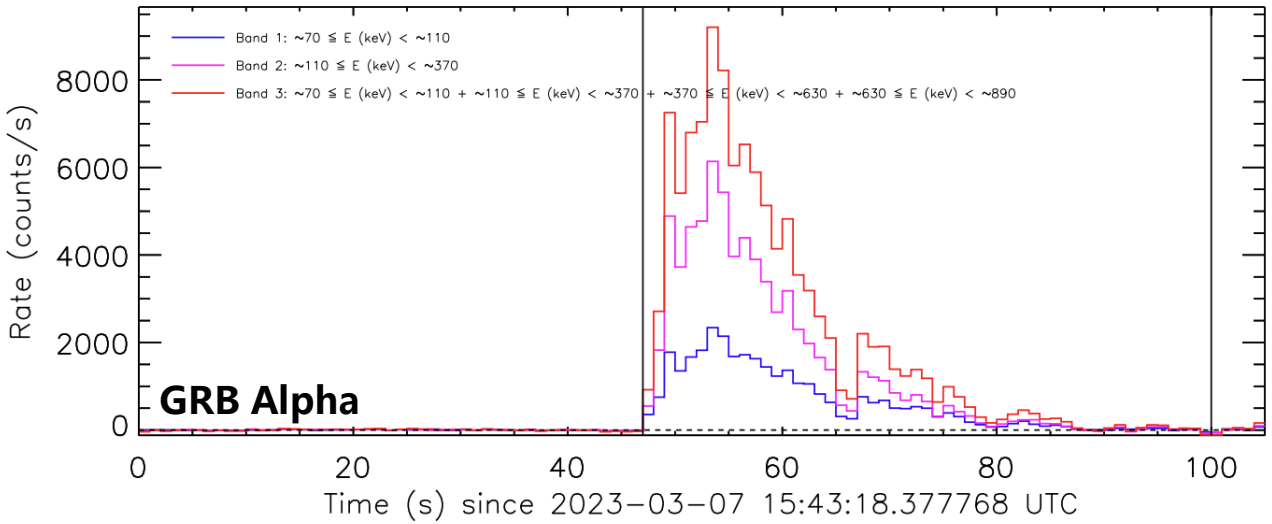



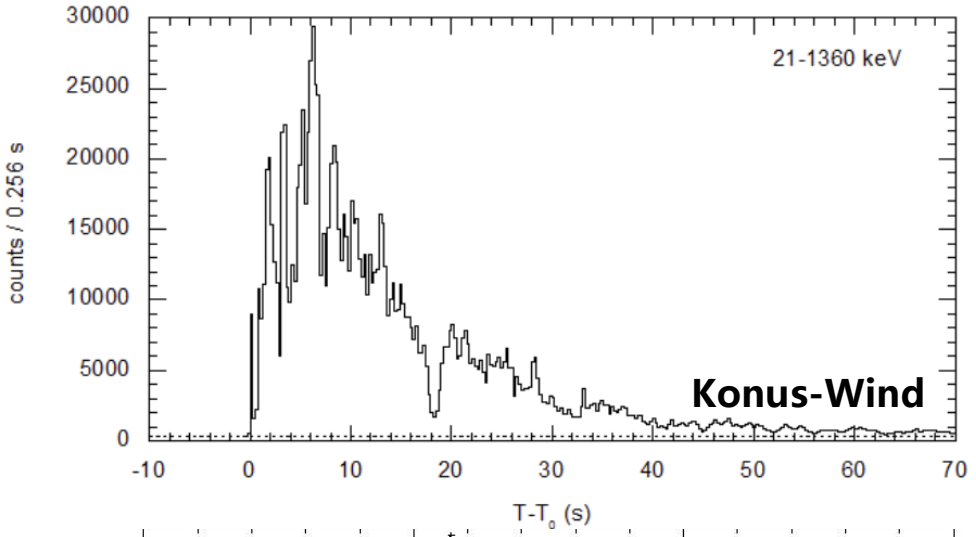

**Several features:**

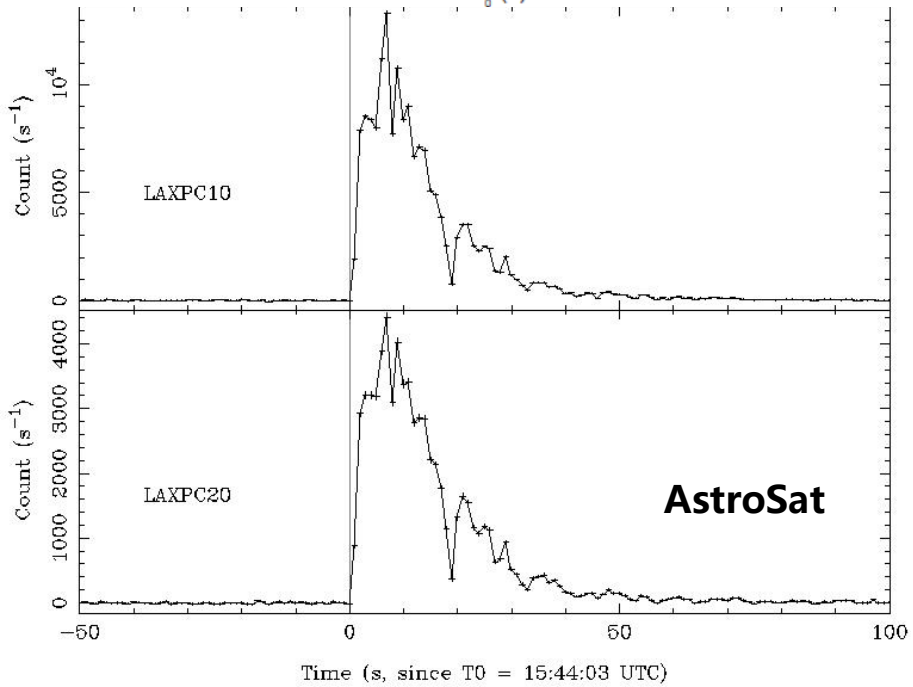
- **An overall FRED shape, especially in low time resolution lightcurve(slow component)**
- **Many spike in high time resolution lightcurve (fast component)**
- **A precursor and a significant dip**

# FRED & Dip across mission

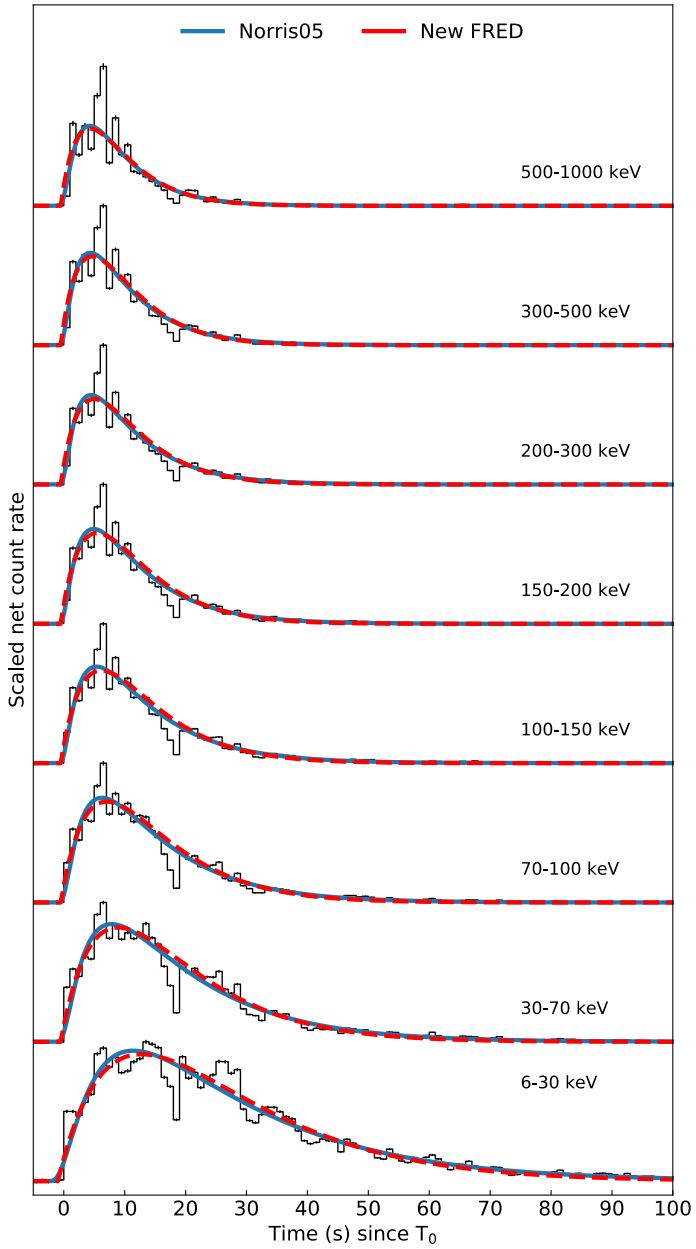


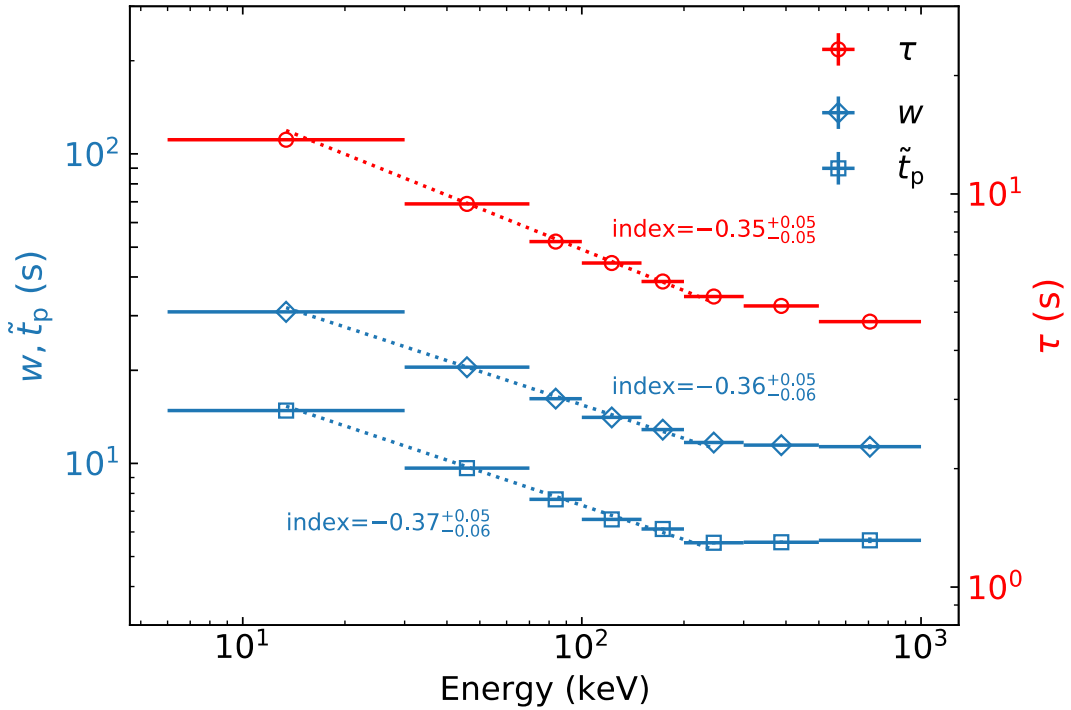
# The lightcurve in multi-E bands act as a single pulse




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

**Width** $\equiv \tau_r + \tau_d$

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

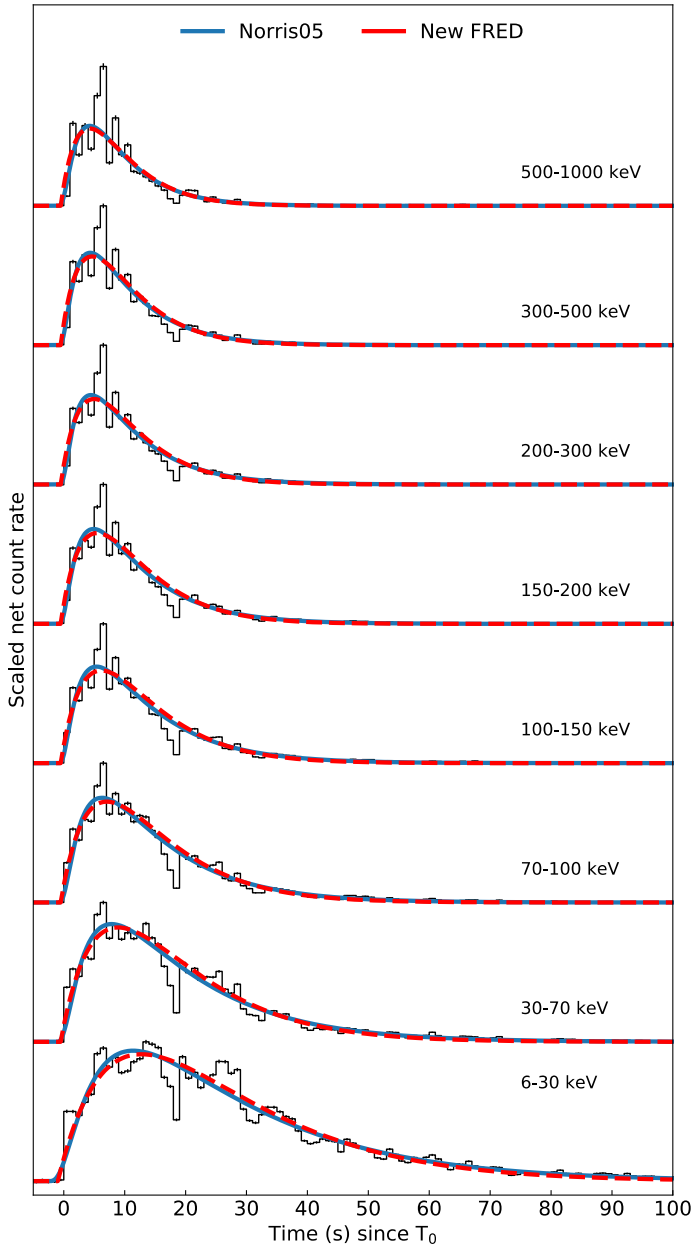



## Self-similarity: W and $t_p$ follow the same E dependency

**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

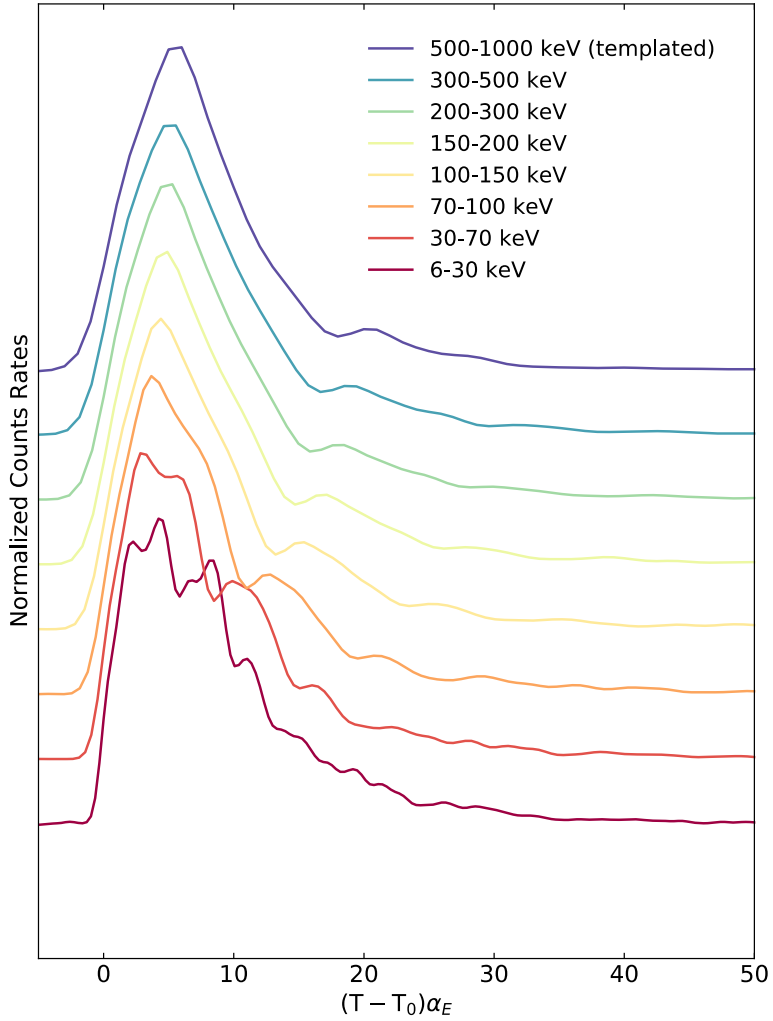



**Well fitted by new FRED** $L \propto \frac{t - t_s}{\tau_E} \exp\left(-\frac{t - t_s}{\tau_E}\right)$

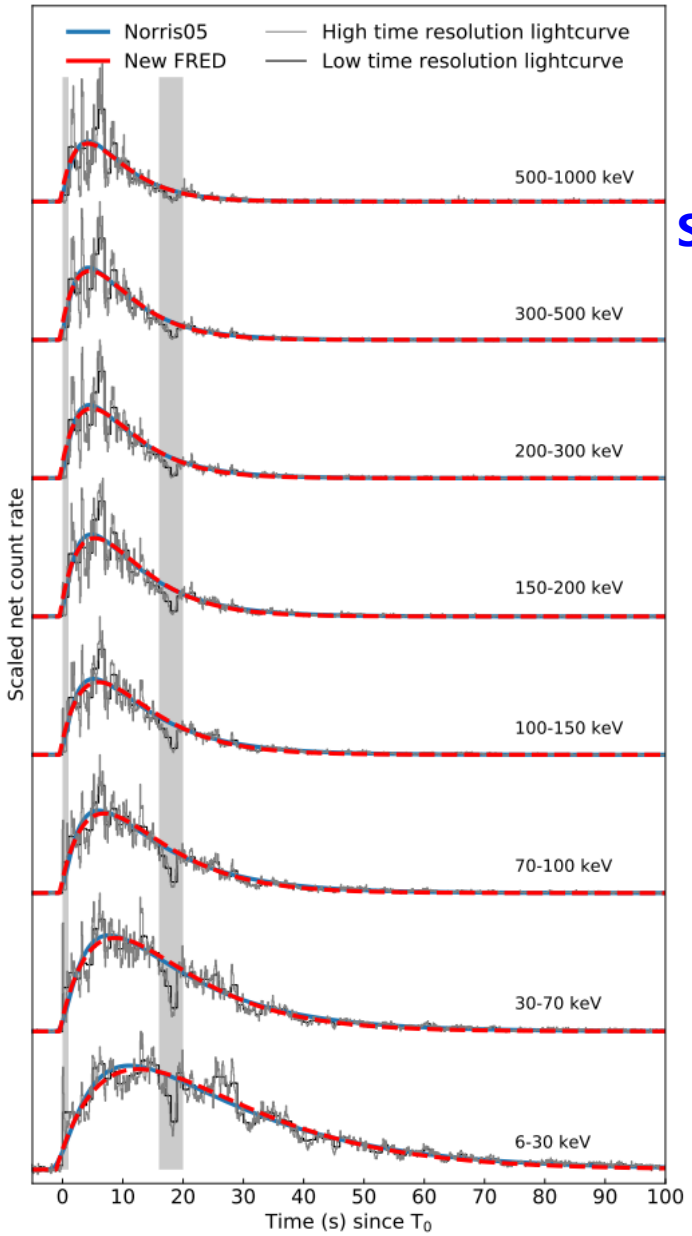
**The profile can be aligned by linear stretch**

**"Stretch" in time**

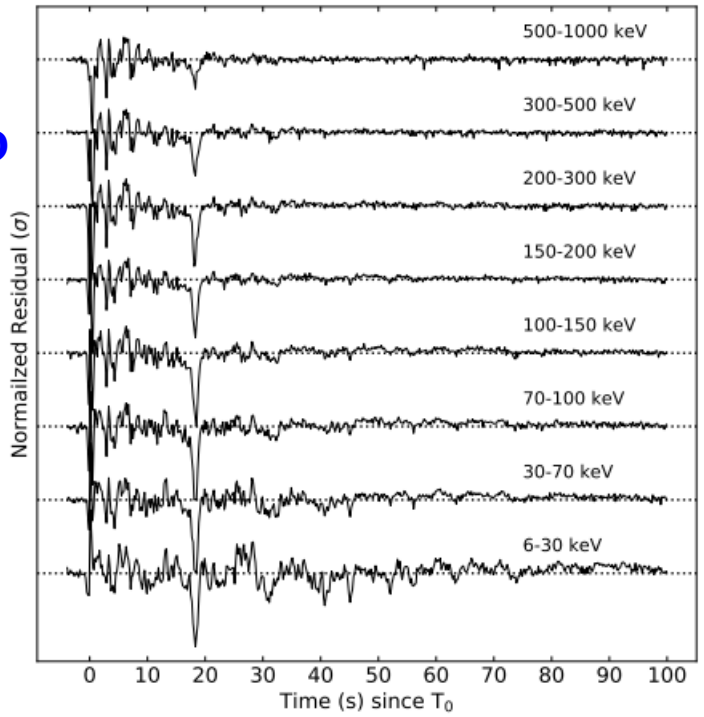
$$\alpha_E = \left(\frac{E}{E_0}\right)^{0.35}$$

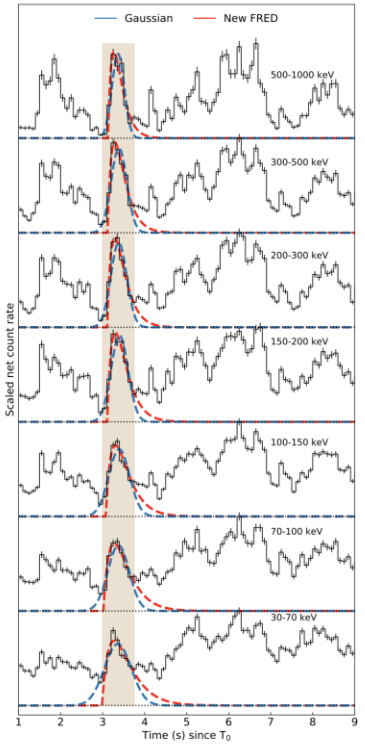


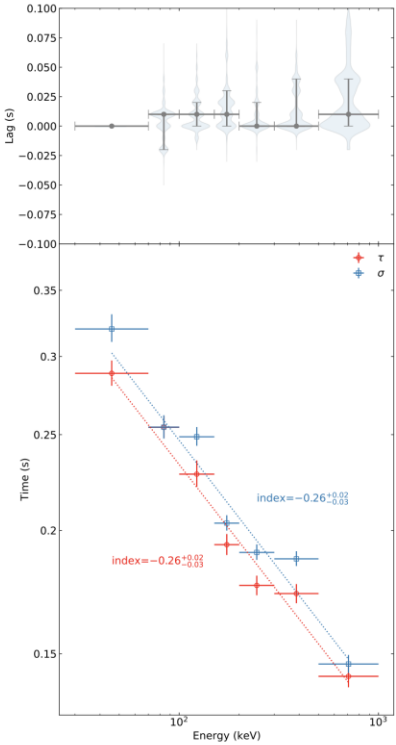
# Fast component




Subtracted FRED



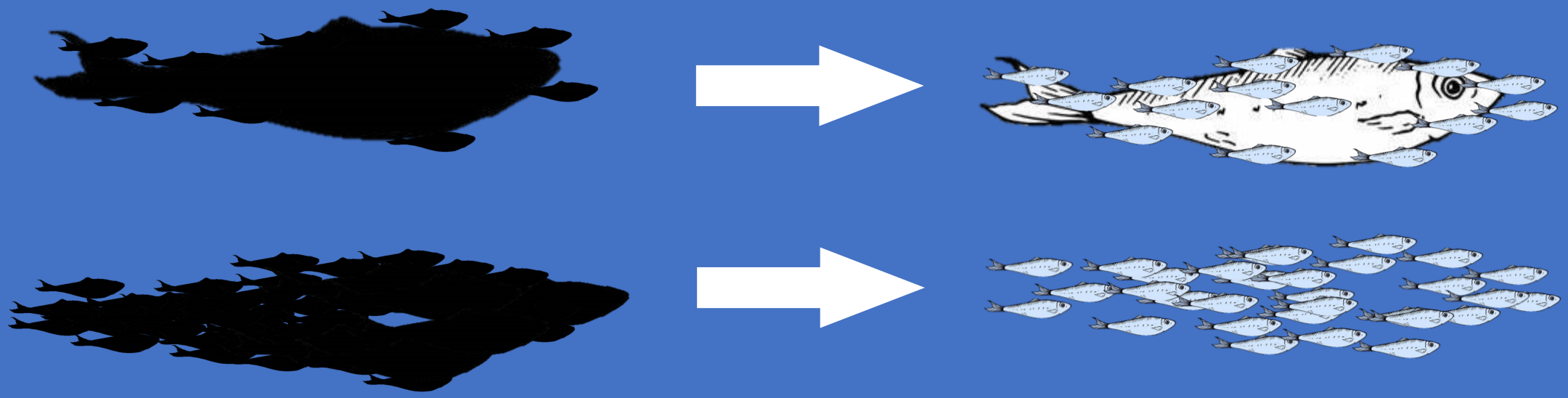

- The fast components are well aligned!
- The fast components are self-similarity

**Overall lightcurve= Elementary Slow component + Fast components?**

**or**

**Slow component = ΣFast components ?**

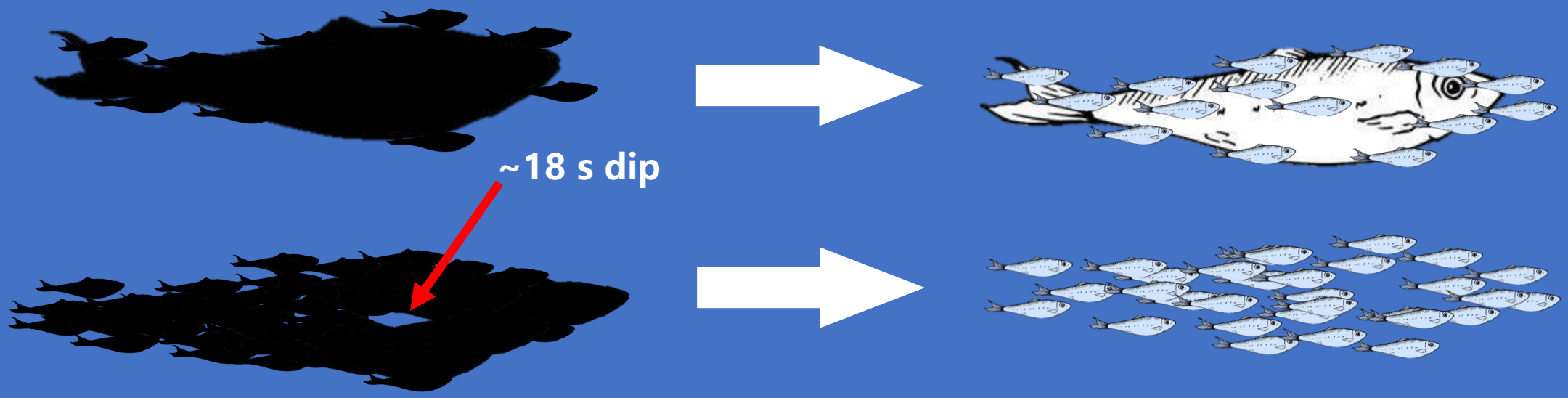
# An analogy



**How to identify the shadow is :**

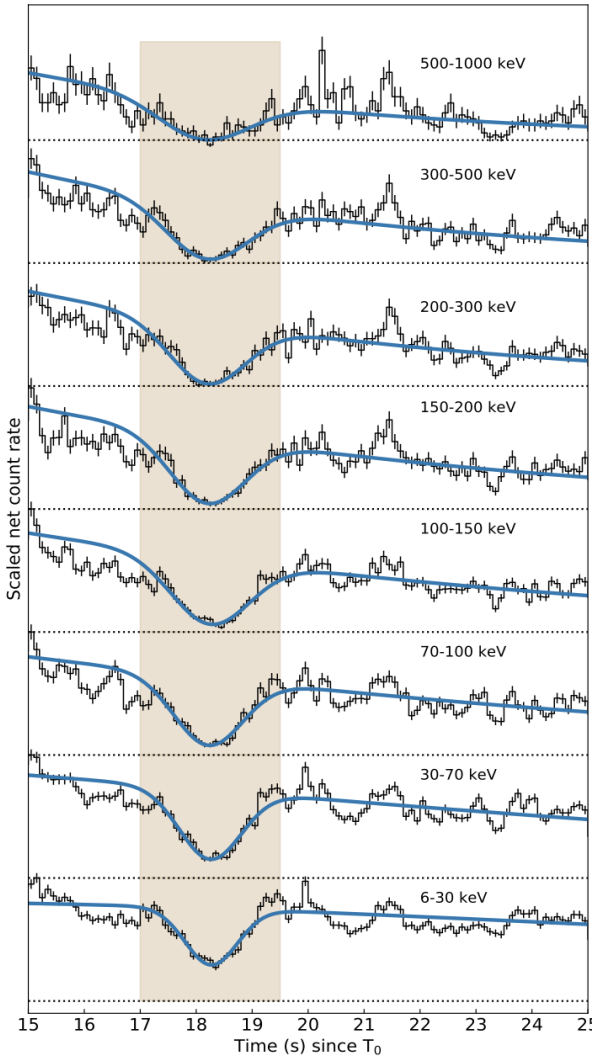
- **a big mother fish with many baby fishes**
- **a school of small fishes**

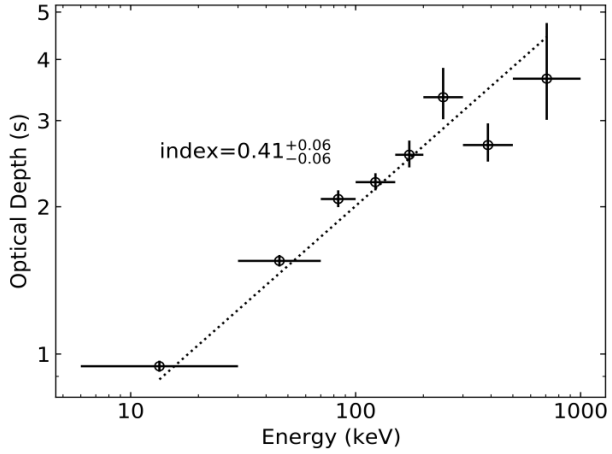
# An analogy



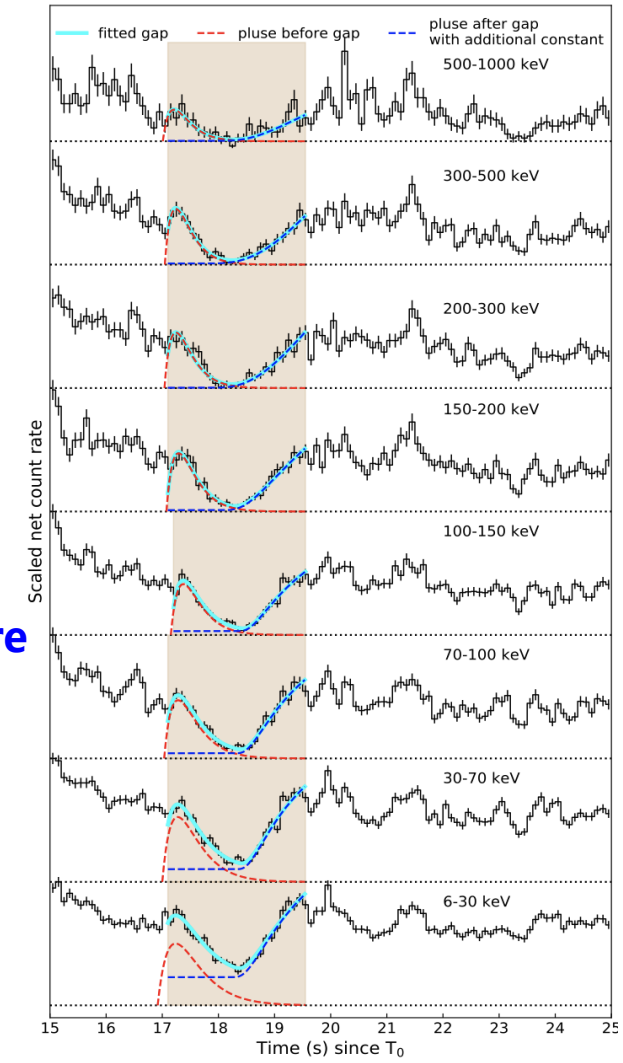

**No underlying big mother fish,**
**but the school of baby fishes coordinate themselves to mimic one big fish**

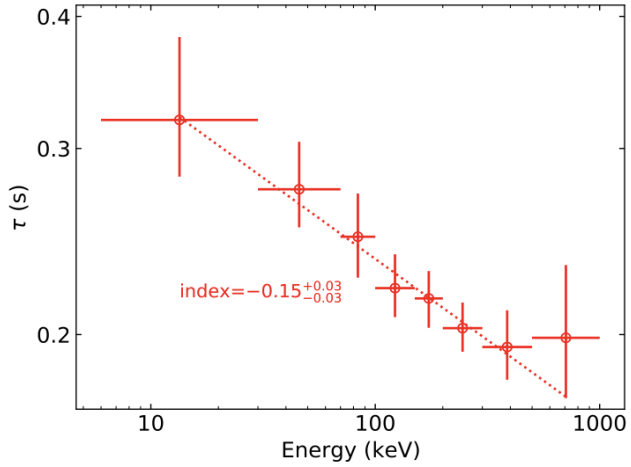
# “DIP” or “GAP” ?




**The effective optical depth cannot be absorption feature**



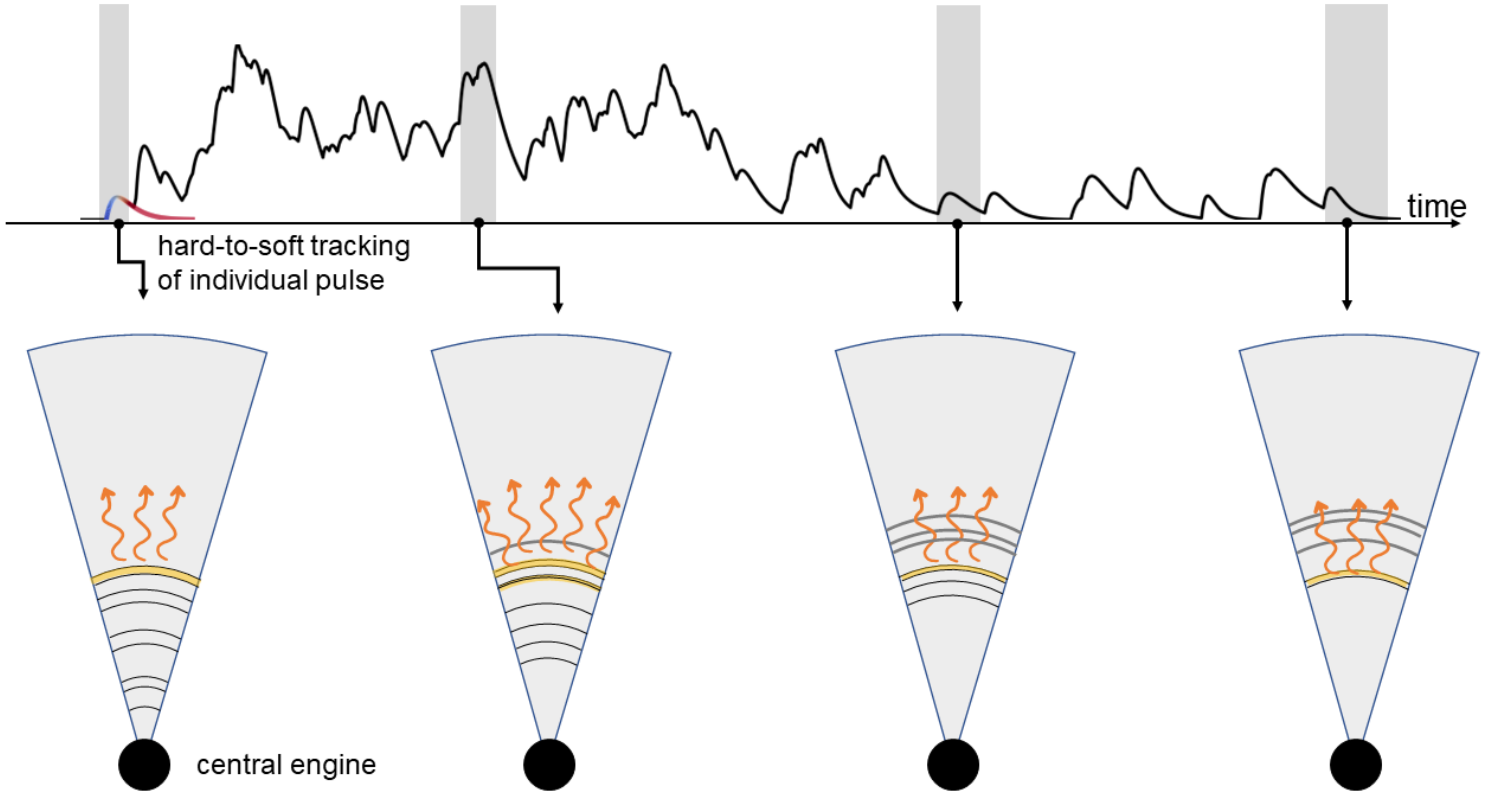

**The left part of the dip have the same behavior of a typical single pulse**

**Overall lightcurve= Elementary Slow component + Fast components?**

**or**

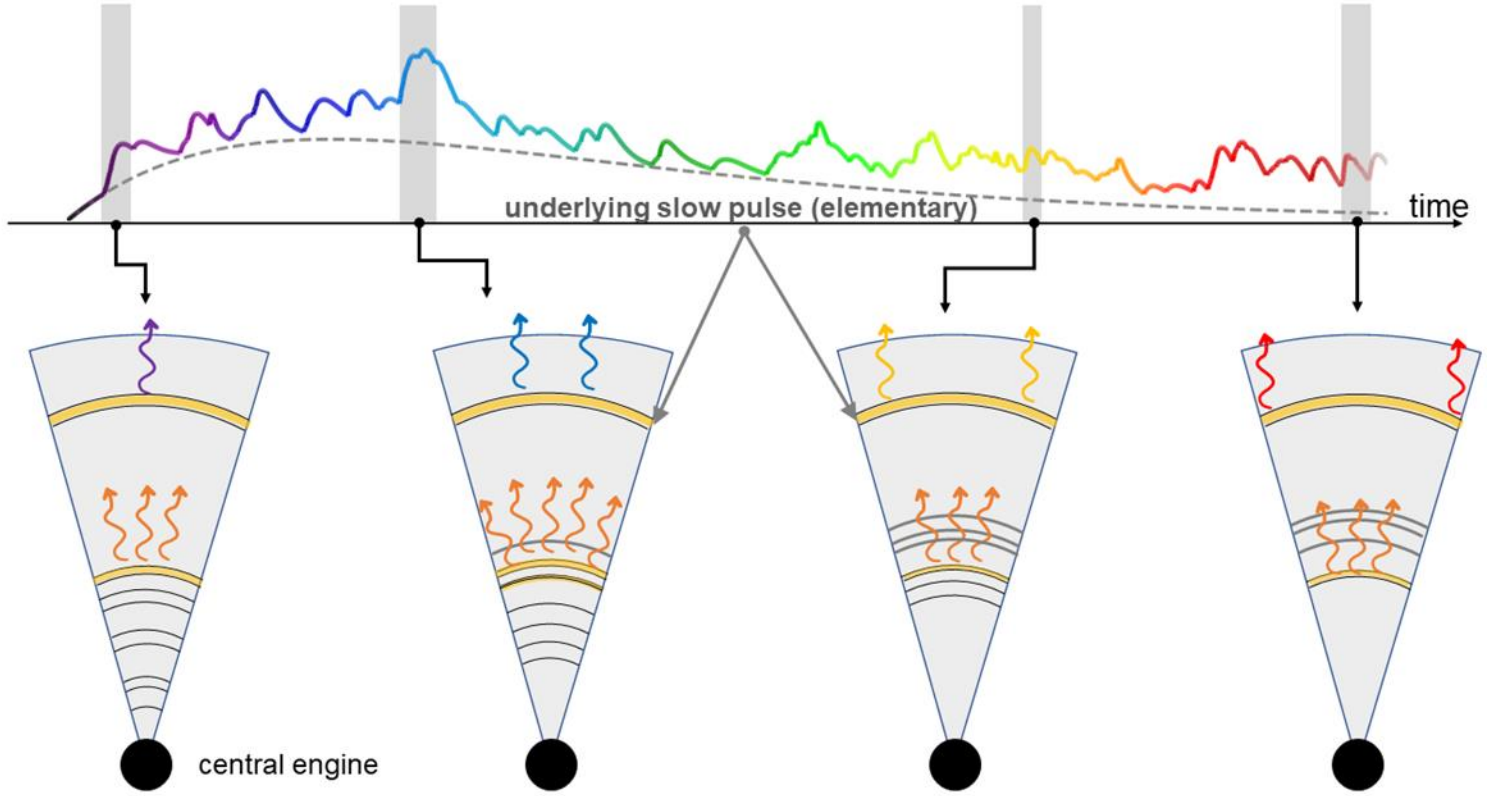
**Slow component = ΣFast components ? (√)**

# With the standard IS scenario (IS-caseA)




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

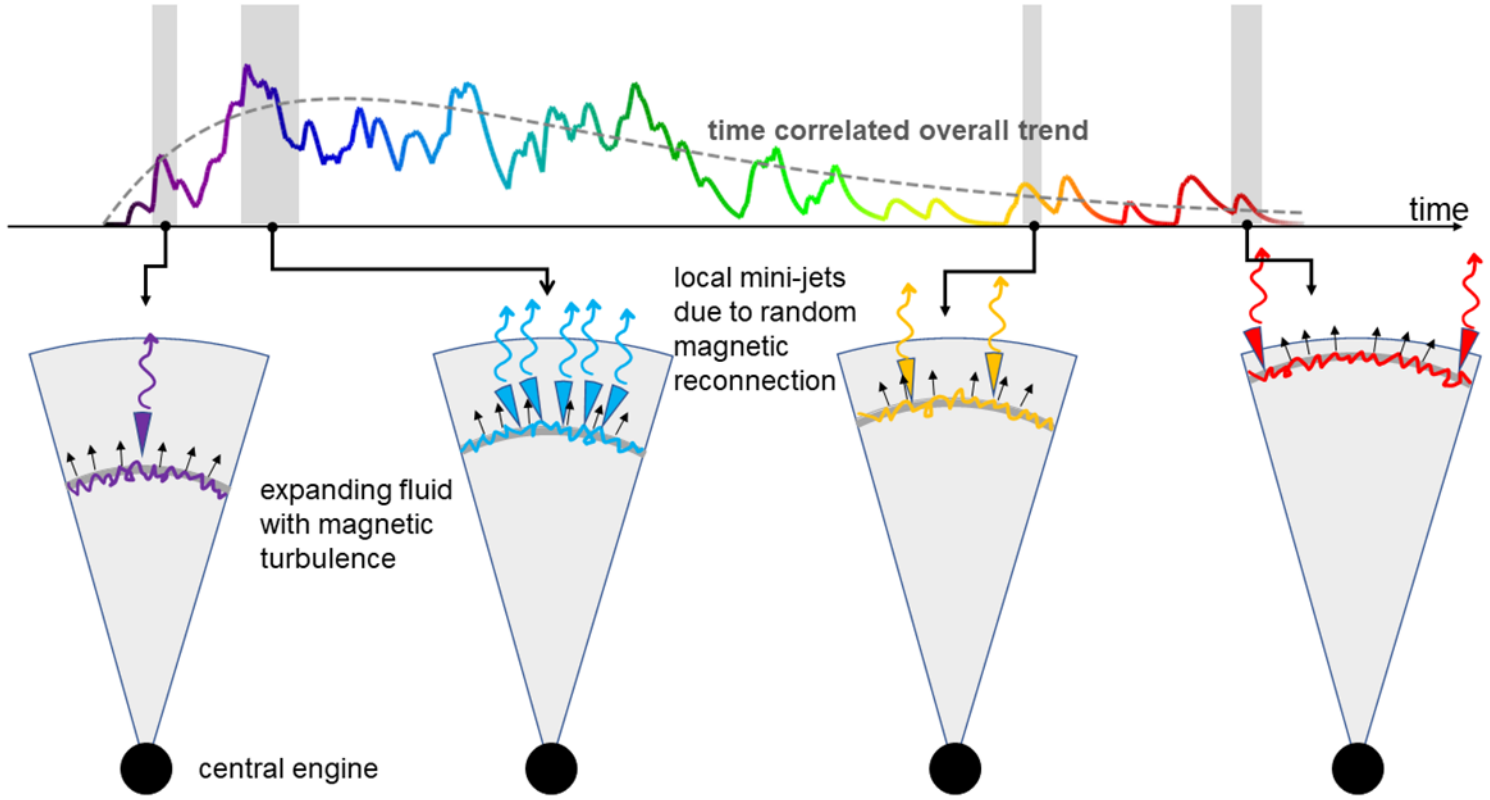
# With an variant IS scenario (IS-caseB)




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

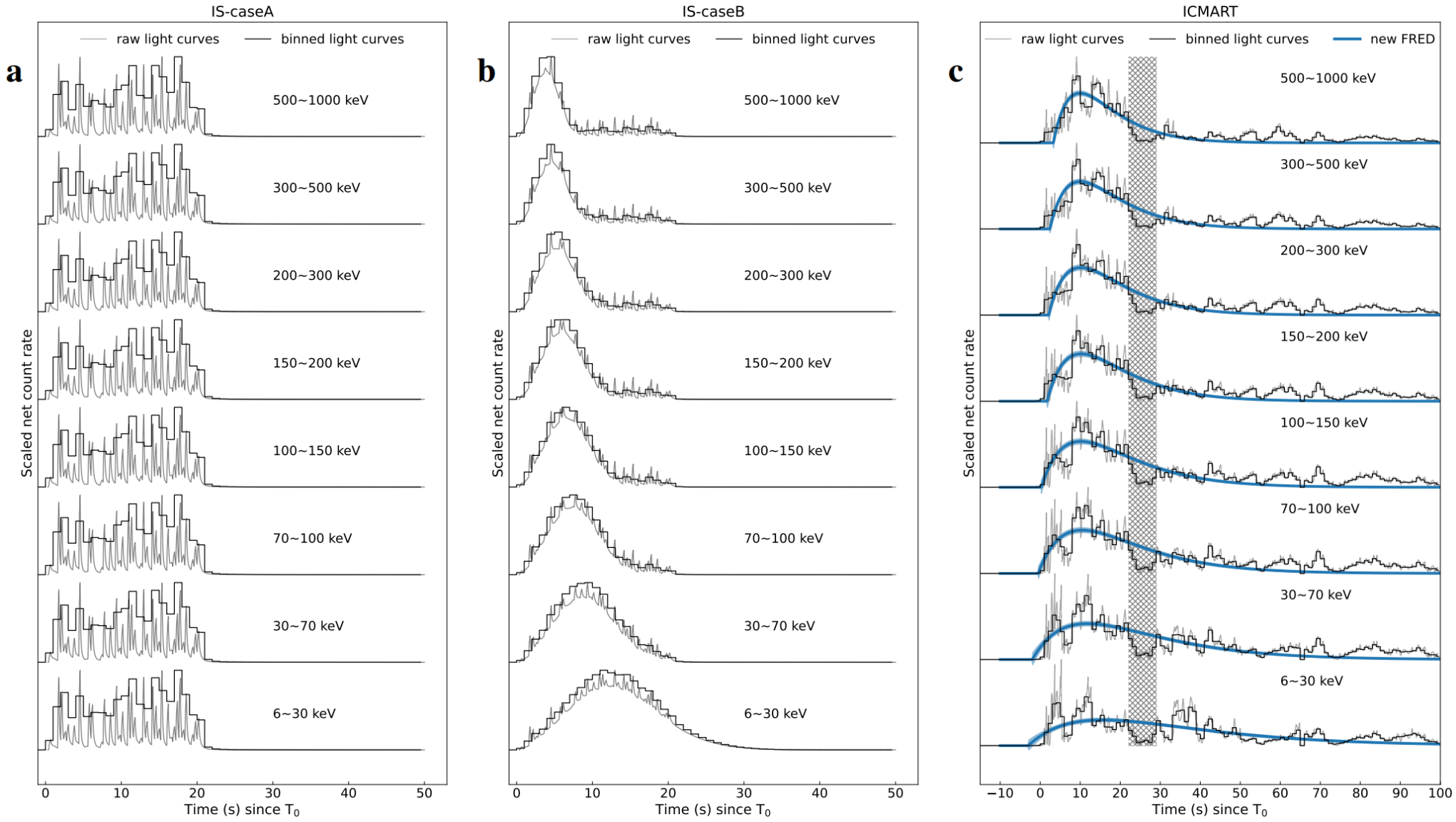
  Slow components: $R_2\sim(1.2\times10^{16}\mathrm{cm})(\Gamma/100)^2(\Delta t/40\mathrm{s})$
- advantage: overall shape-E dependence
- disadvantage: cannot produce dip structure

# With the ICMART scenario

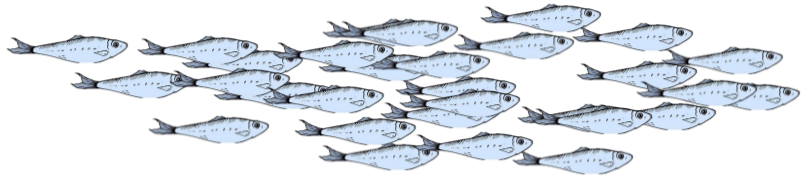



- **There is no underlying elementary slow pulse**
- **Σ Fast components = typical broad pulse，$R_{ICMART}$~$(1.2\times10^{16}cm)(\Gamma/100)^2(\Delta t/40s)$**
- **advantage: overall shape-E dependence and can produce dip structure**

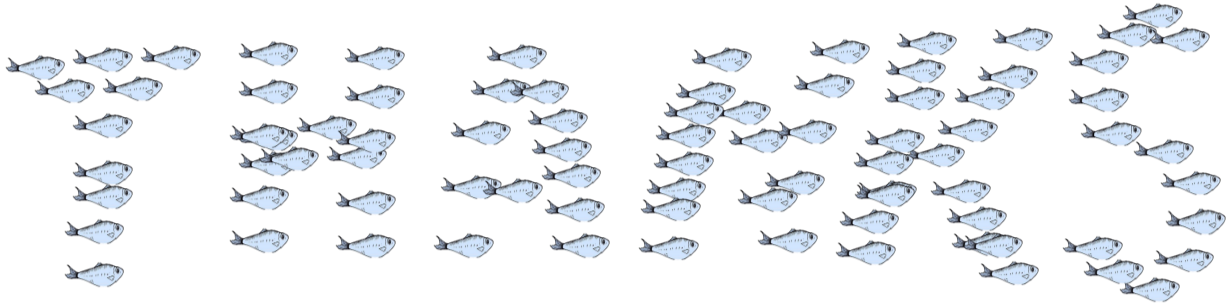
# Simulation result



# Summary



- Overall light curve of GRB 230307A is a broad FRED pulse with classic shape-E dependence
- The broad FRED pulse is assembled by many fast pulses, with self-similarity
- The “dip” structure in GRB 230307A could be explained by a “gap”
- ICMART is more favored than IS model in GRB 230307A
- provide strong evidence for a Poynting-flux-dominated jet composition of this bright GRB



**Comments and suggestions are welcome**

# Backup

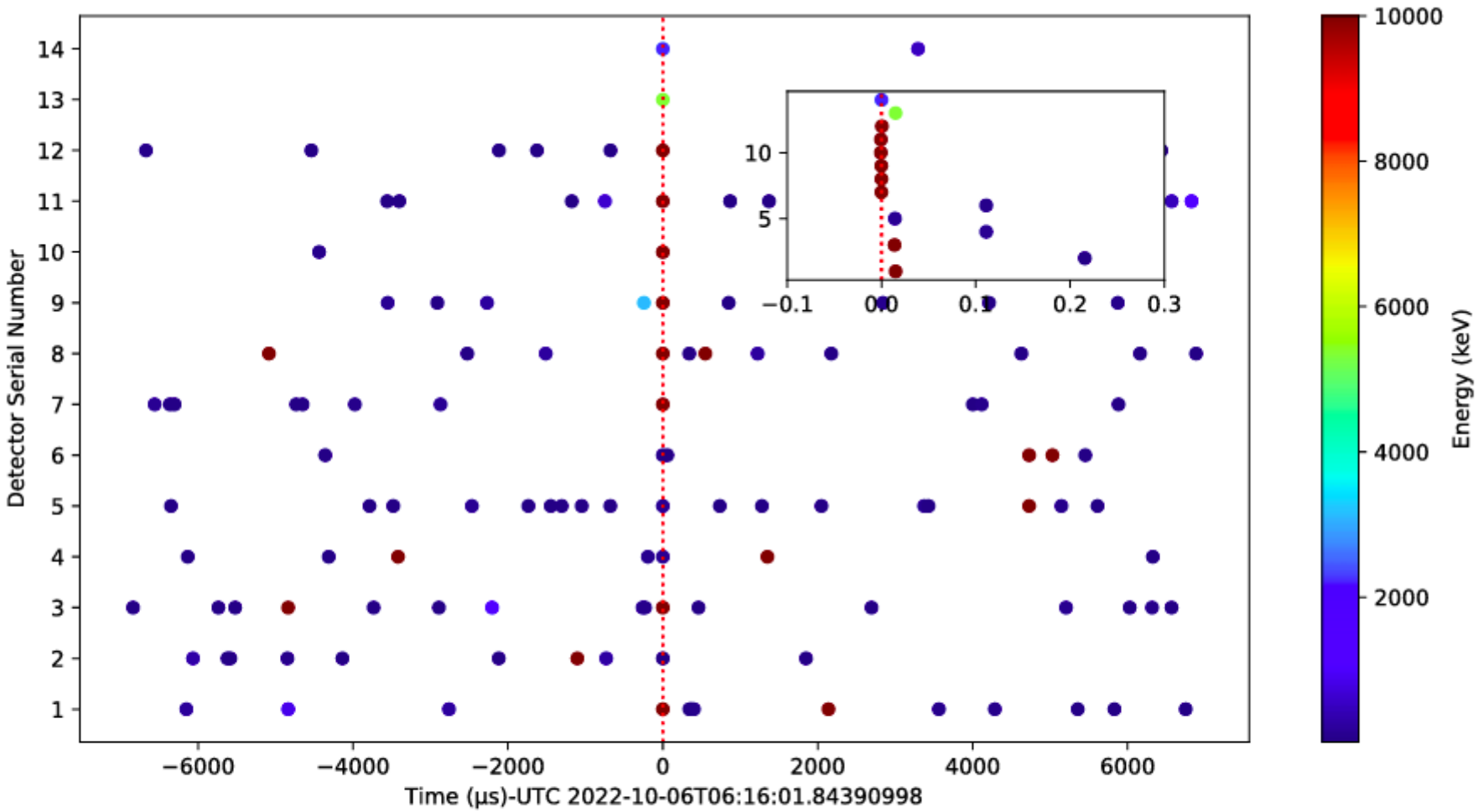



**Figure 1.** An illustration of the secondary particles produced by cosmic rays hitting the satellite and observed by all 14 detectors on board GECAM-C simultaneously at UTC 2022-10-06T06:16:01.84390998 (red dotted line). The vertical coordinate represents the detector serial number: 1 to 12 represent GRDs, whereas 13 and 14 represent CPDs. The different colors represent different energies; note that there are eight GRDs recorded with energies higher than 10,000 keV due to the very high energy of the cosmic rays. Note their time difference is less than 0.3 $\mu$s.