



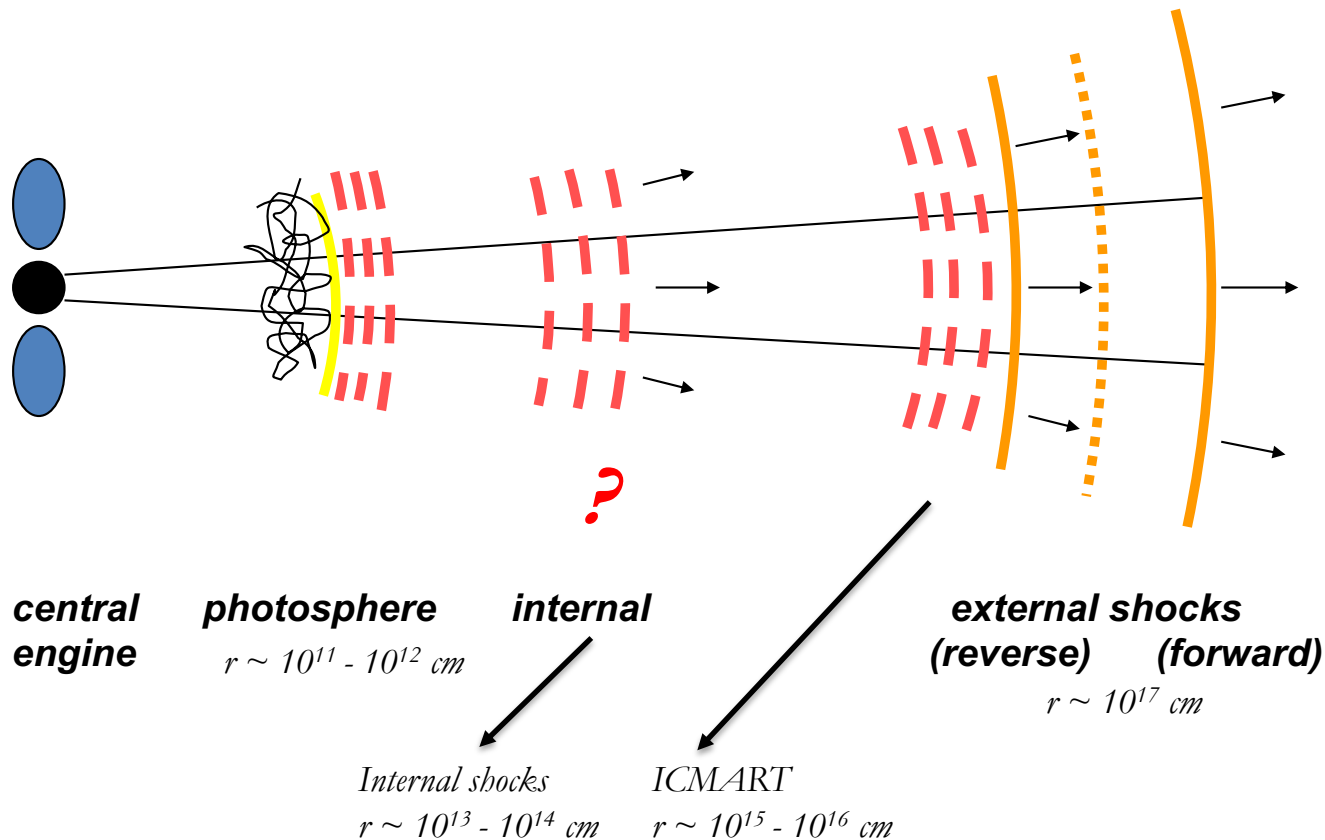
How far from the central engine are the GRBs produced?

Donggeun Tak

With

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Unsolved question in GRB physics

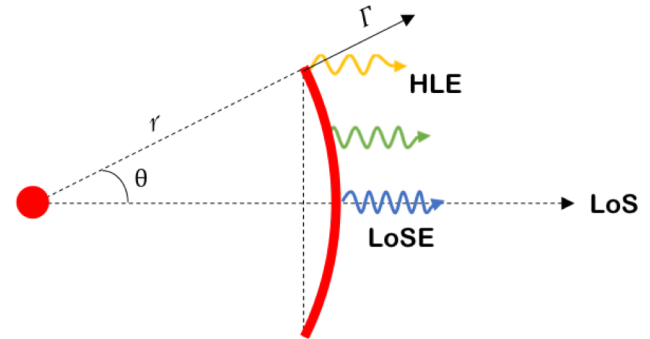


- **Where** is (are) the dissipation radius (radii)?

$$r \sim 2c\Gamma^2 t_{\text{obs}}$$



- **Gamma-ray bursts (GRBs) are attributed to collimated relativistic jets.**
 - **The geometry of the outgoing shell plays an important role in forming the observed temporal and spectral shapes.**

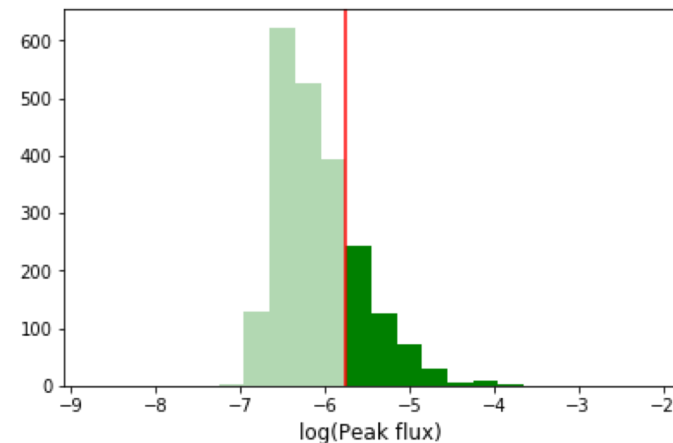
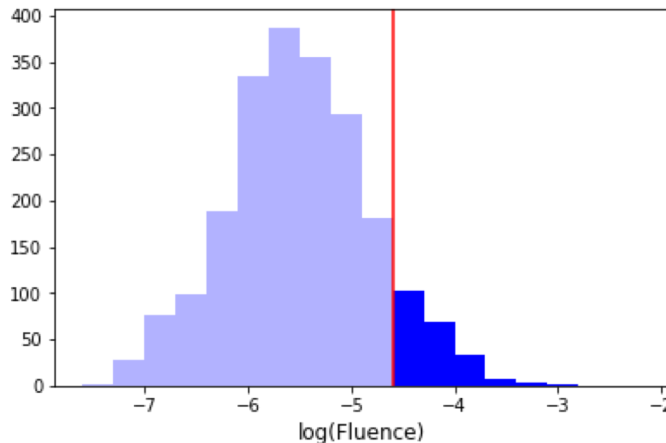


- **The signature of HLE has not been clearly identified previously in the prompt phase of GRBs.**
 - **Complicated temporal features (e.g., overlap of pulses)**
 - **Multiple spectral components (e.g., thermal and non-thermal)**
- **The HLE theory expects the relation between F_{ν, E_p} and E_p ,**

$$F_{\nu, E_p} \propto E_p^2$$



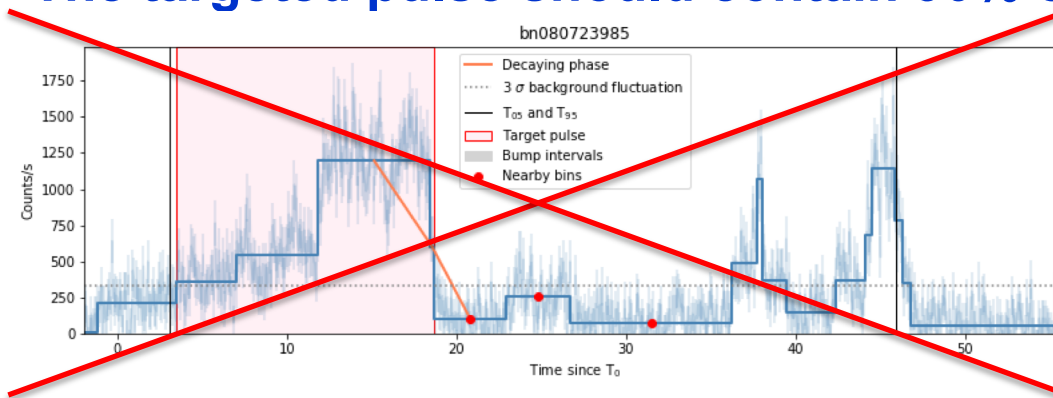
- We select a sample of bright broad-pulses of Fermi-GBM GRBs from the years 2008 – 2017.
- Among 2157 GRBs, we choose bright GRBs with fluence and peak flux cuts.
 - $\log_{10}(\text{Fluence}) \geq -4.6$ (Fluence $\geq 2.5 \times 10^{-5}$ erg cm⁻²)
 - $\log_{10}(\text{Peak flux}) \geq -5.75$ (Peak flux $\geq 1.8 \times 10^{-5}$ erg cm⁻²s⁻¹)



- Our sample consists of 175 GRBs (~ 8.1 %).

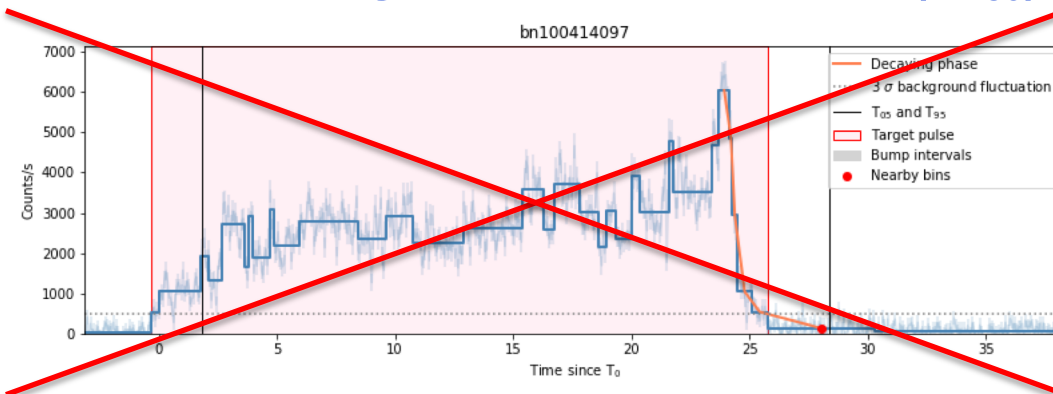


- To minimize fluctuations from the background and overlap of pulses, we impose five criteria.
 - The targeted pulse should contain 90% of the GRB fluence.



Bright pulse

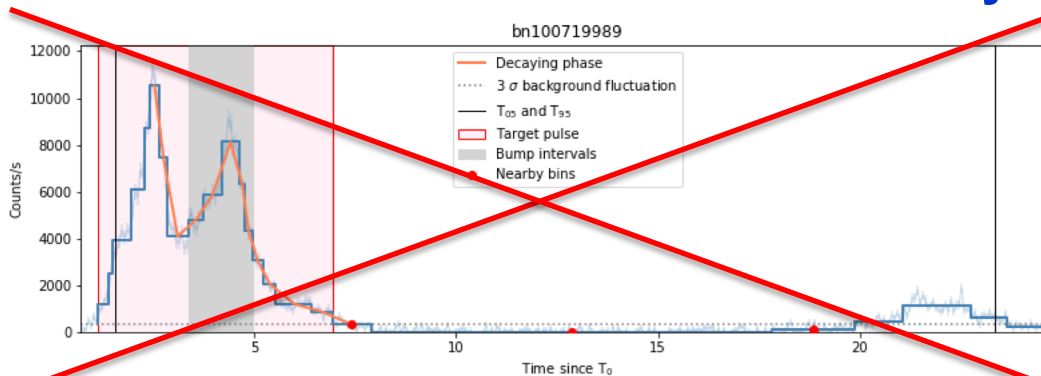
- The decaying phase time interval (T_{decay}) should be longer than the rising phase time interval (T_{rise}).



FRED pulse

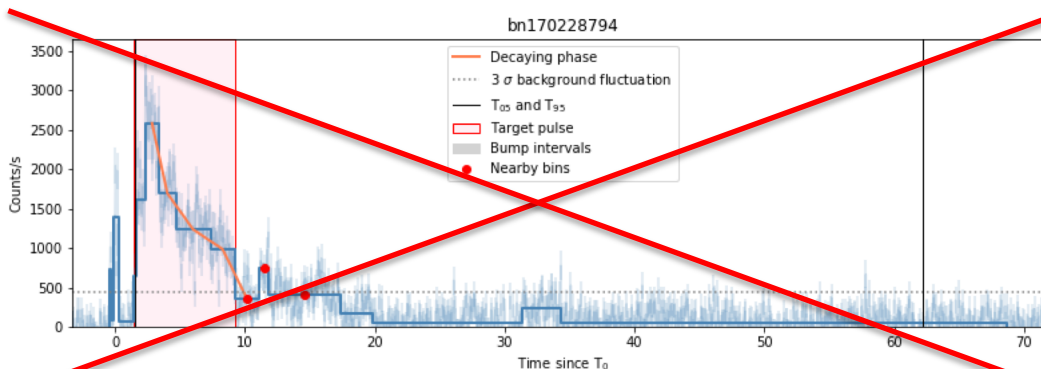


- The number of bumps (N_{bumps}) should be zero during the decaying phase.
- If a bump exists, the total duration of the bump (T_{bump}) should be shorter than 1/4 of the decaying phase time.



Clean pulse

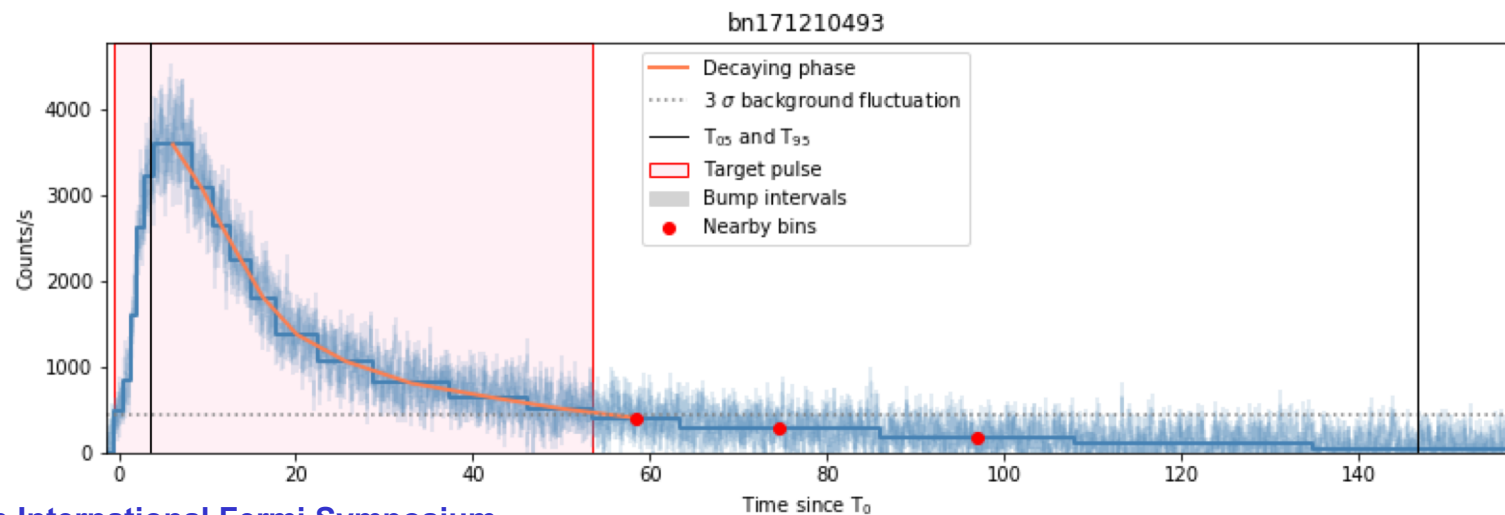
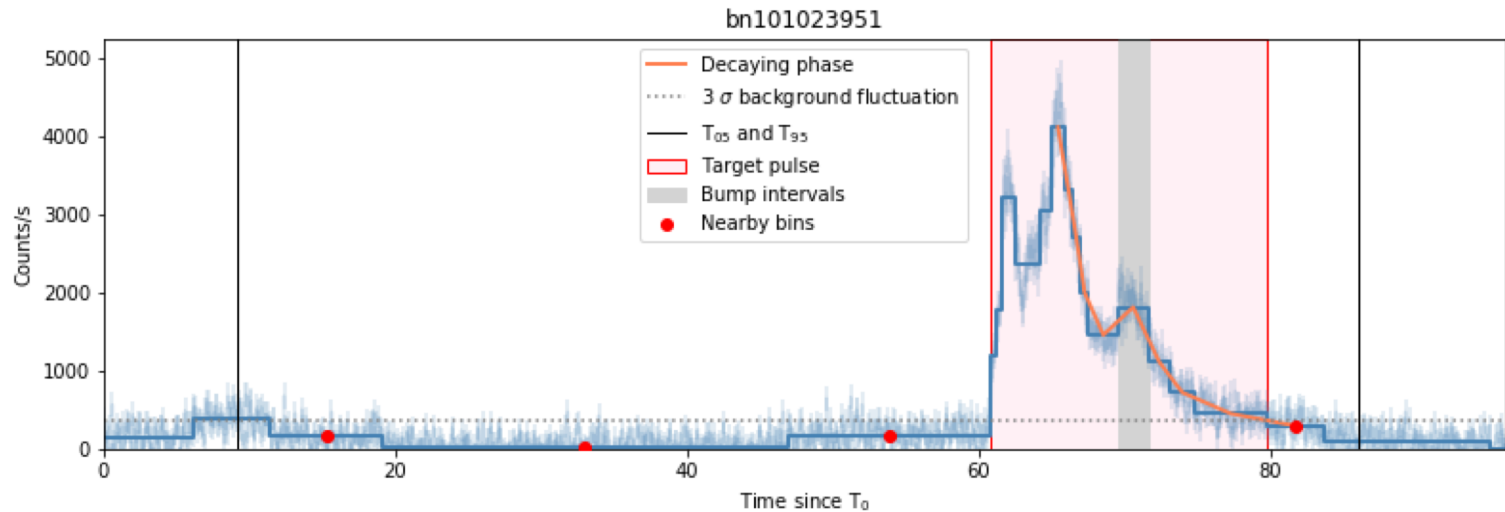
- The pulse should not overlap any nearby pulses.



Isolated pulse



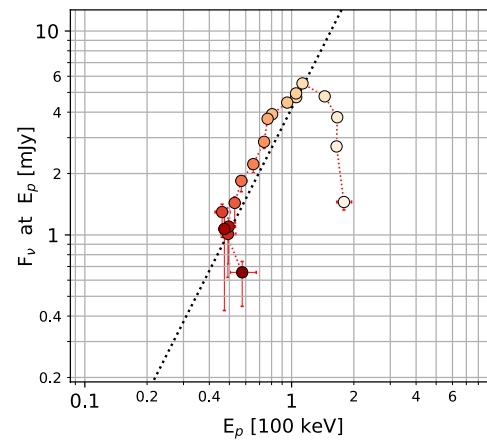
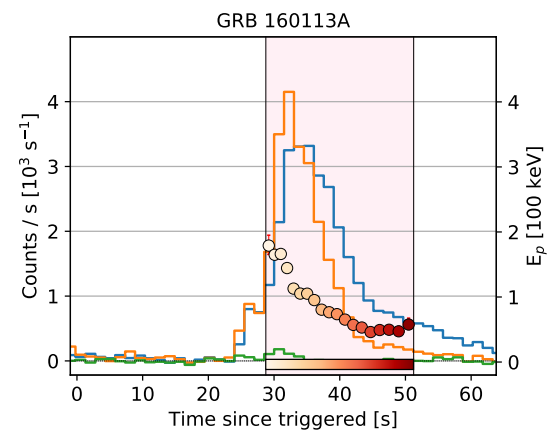
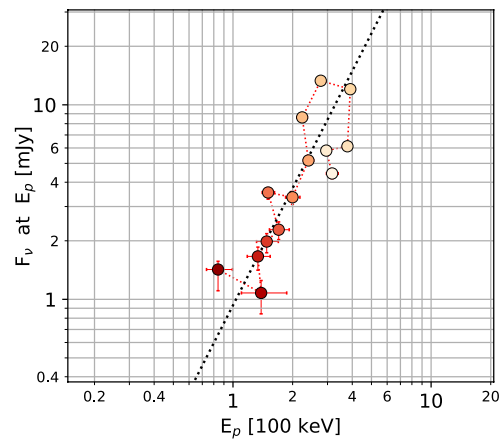
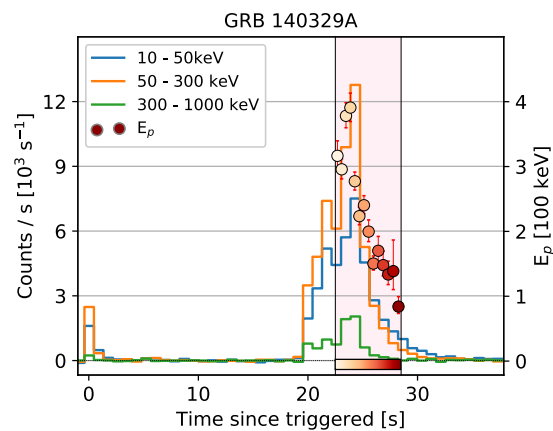
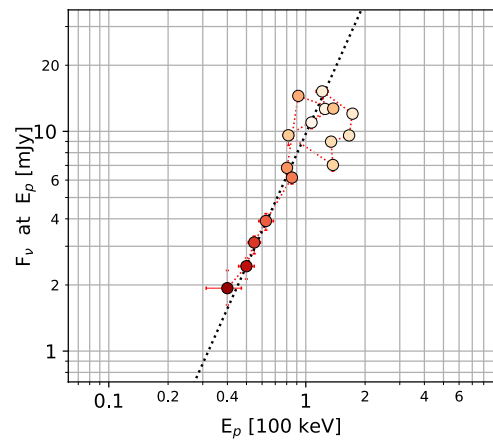
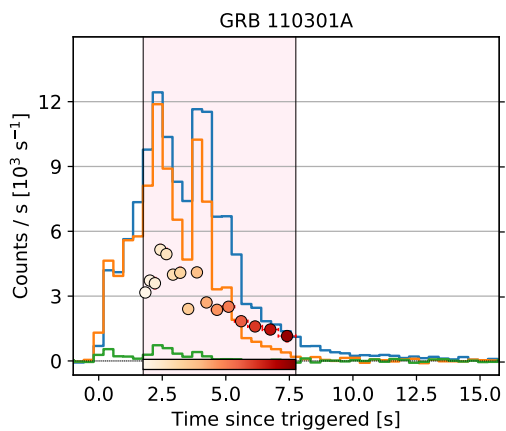
- Examples of "Good" cases





- **Sample size: 32 GRBs**
- **GBM dataset: use Nals + BGOs (8 keV to 40 MeV)**
 - **listed in “Scat Detector Mask” (GBM catalog)**
- **Spectral analysis tools**
 - **rmfit: background estimation**
 - **polynomial fit for time intervals before and after the targeted pulse.**
 - **Xspec: spectral fitting**
 - **Test a simple power law (PL), a cutoff power law, and the Band function.**
 - **The best-fit is determined by comparing PG-stat and dof.**
- **The decaying phase of a broad-pulse is divided into logarithmic equal time bins.**

Spectral analysis result





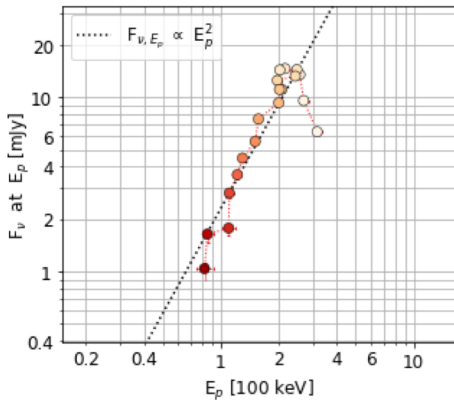
- We test the existence of the HLE evidence by fitting the HLE relation with χ^2 for all possible combination of data points.

$$F_{\nu, E_p} \propto E_p^2$$

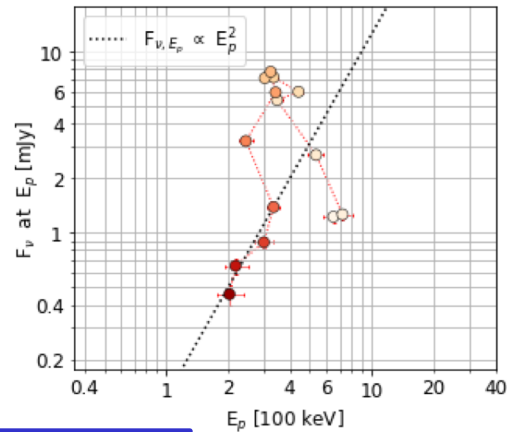
- We use at least 4 points.
- For the combination of data points with $\chi_v^2 < 2$, we fit the HLE relation again with letting the exponent free.

$$F_{\nu, E_p} \propto E_p^\delta$$

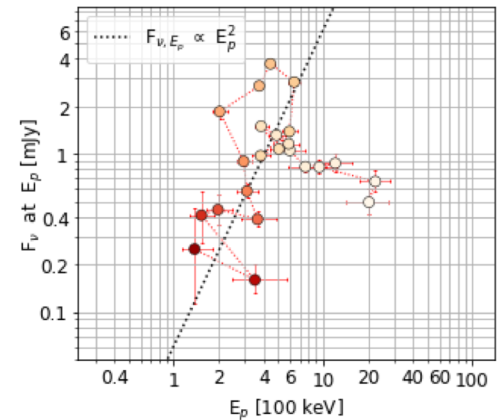
- If the HLE expected index is within 1 σ ($\delta - 2 < \sigma_\delta$), we conclude that a pulse shows the HLE signature.
- The HLE signature is found in 18 broad pulses.



HLE signature

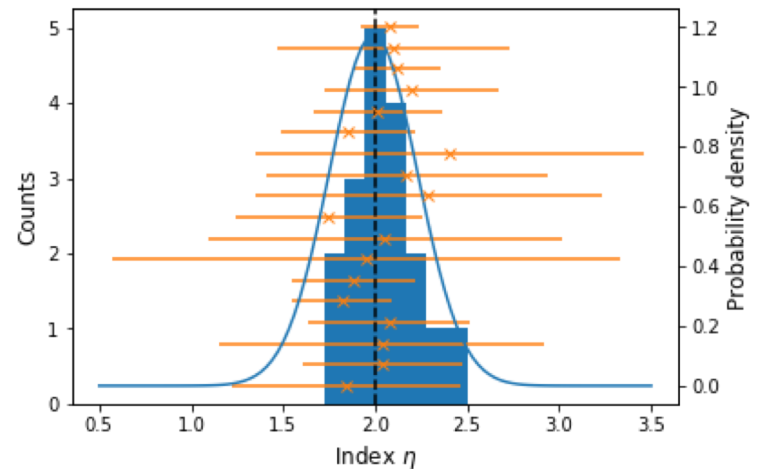


No evidence



- The distribution of δ values from 18 pulses is well-described by a Gaussian function.

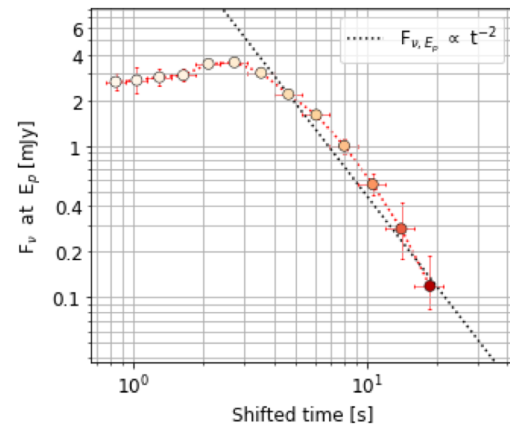
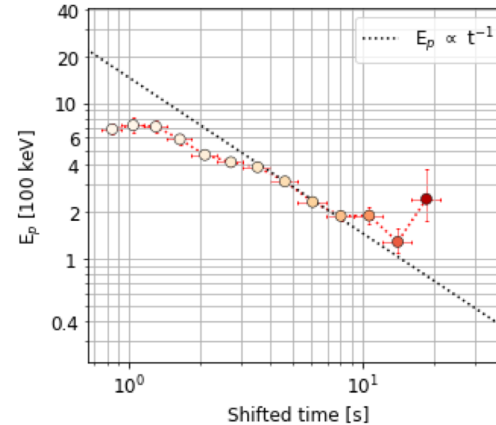
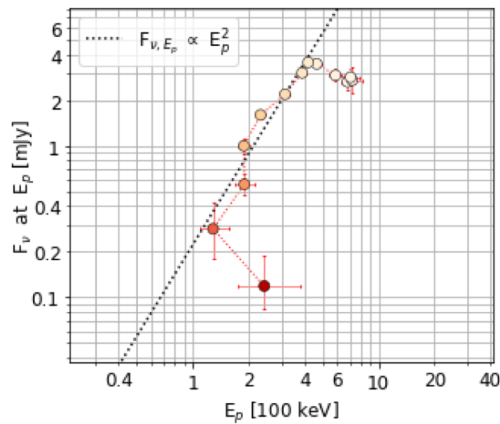
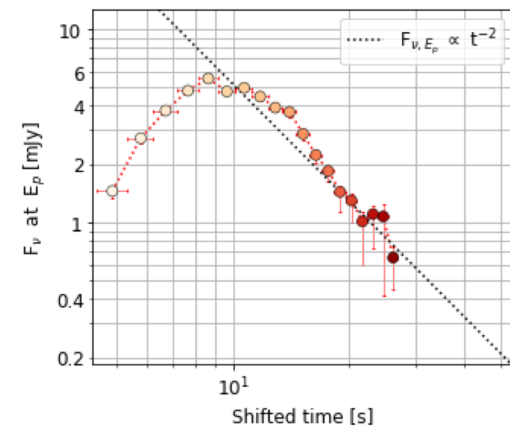
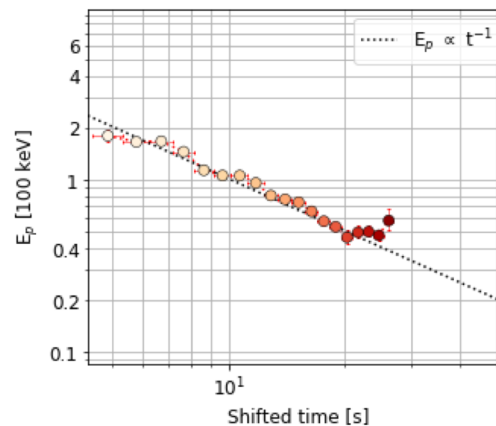
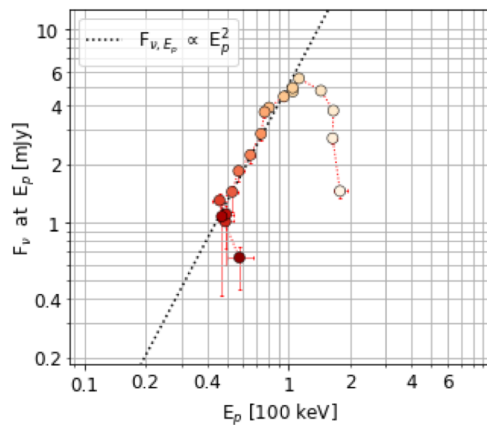
- Median: $2.04^{+0.16}_{-0.16}$
- Width: $0.42^{+0.25}_{-0.16}$





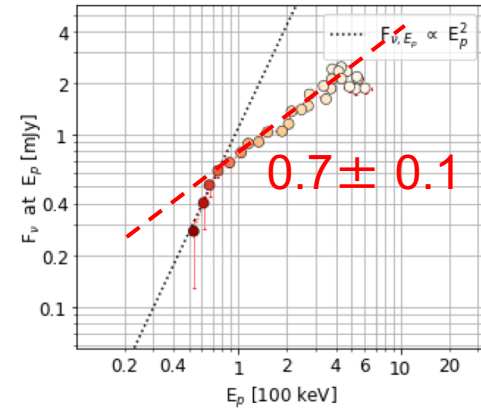
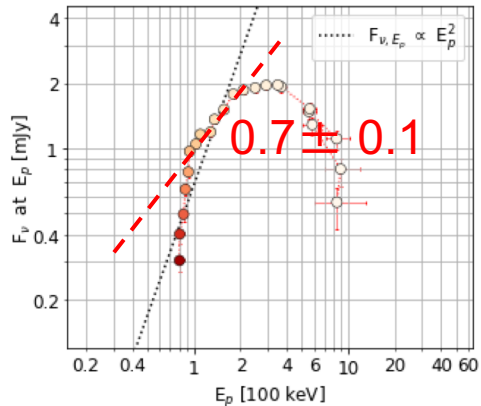
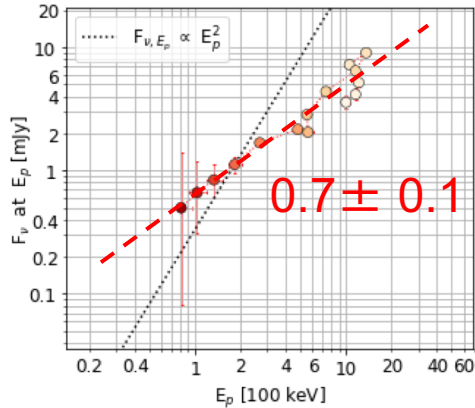
- Many pulses, which show the HLE signature, satisfy other HLE relations,

$$E_p \propto t_{\text{obs}}^{-1} \quad \text{and} \quad F_{\nu, E_p} \propto t_{\text{obs}}^{-2}$$





- Three cases showing a slope with index of 0.7.



- This value is equivalent to 1.7 in the equation,

$$\nu F_{\nu, E_p} \propto E_p^{1.7}$$

which is consistent with other observational results.
(e.g., Borgonovo & Ryde, 2001; Shenoy et al., 2013)

- This slope may result from a different physical origin.



- We analyzed GBM GRBs from the years 2008-2017 (2157).
 - Fluence and peak flux cuts
 - Temporal criteria
- Among 32 broad pulses in 32 GRBs, 18 pulses shows the signature of HLE in the decaying phase.
 - δ is distributed as a Gaussian function with median and width of 2.04 and 0.42, respectively.
- This implies that the gamma-ray emitting region of those GRBs with the HLE signature is located at $\sim 10^{16}$ cm from the central engine.