Connecting Multi-Pulse GRB Prompt Pulse Shape And Emission Mechanisms

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Abstract

- We study the individual pulse shapes in a Multi-pulse Gamma ray Burst (GRB) and its relation with the underlying emission mechanism.
- A novel pulse shape model was introduced to quantify the asymmetry and evolution of pulse shapes.
- Time-resolved spectroscopy with maximum likelihood analysis was performed and spectra fitted with Band Function using threeML package (Vianello et al. 2015).
- The pulse shape evolves during the burst, initially tending to be predominantly symmetric, while later pulses have more FRED-like lightcurve.
- A moderately positive correlation between pulse shape and the low energy spectral shape α indicates an evolution in emission mechansim from thermal to nonthermal in nature.

Introduction

The X-ray and γ-ray light curves of the prompt phase of GRBs exhibit diverse behaviour, often with multiple pulses. For a complete picture, we are considering the individual pulse shapes, spectrum and correlation between multiple pulses.

- The temporal pulse shape is often considered as a Fast Rise Exponential Decay (FRED).
- A novel pulse shape model implemented on the FERMI/GBM bursts to ascertain the general variations in pulse shape over multi-pulsed bursts.
- α - proxy for the emission mechanism (e.g., photospheric or synchrotron), becomes progressively softer for each pulse in a multi-pulse GRB. This, along with changes in pulse shape over a burst, offers insights into the jet's emission mechanisms and radii.

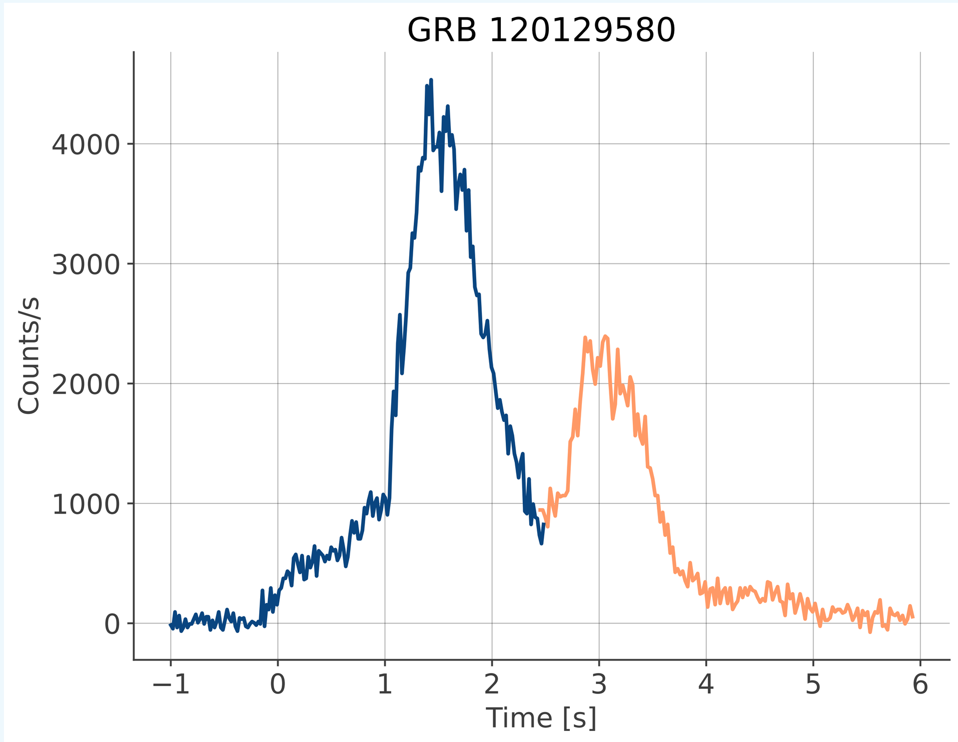

Figure 1: First pulse spans from **-0.7s to 2.5s** and the second pulse from **2.5s to 4s**. The pulse number is defined as the order in which a pulse appears in a burst

Sample selection

We select **22** multi-pulsed GRBs with **61** individual pulses from the Fermi/Gamma-Ray Burst Monitor. A pulse selection example is shown in Figure 1. The samples follow the given criteria:

- Each pulse is defined if the count-rate at the start and end of the pulse are at most **50%** of the peak count-rate or equal to the background levels.
- The shape function goodness of fit $\mathbf{r^2 \geq 0.7}$.
- The temporal binning of the pulse interval is performed via Bayesian block, and the significance of at least two bins must be $\mathbf{S \geq 20}$.

Novel Pulse Shape Model

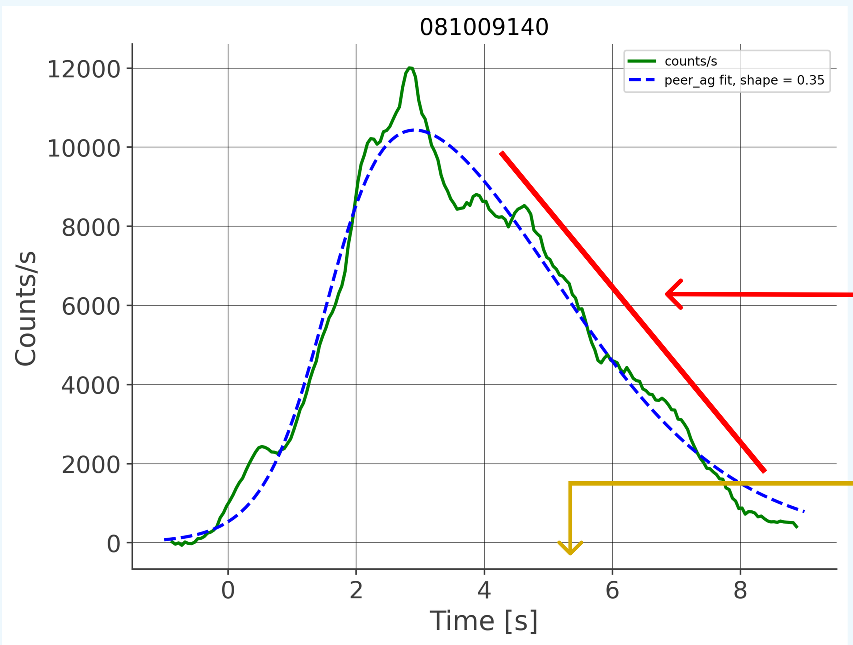

Figure 2a : The novel pulse function fit for the prompt light curve of GRB 081009 (bn 08109140). Here, the pulse shape parameter $\phi = 0.35$, the pulse shape is **FRED-like**.

$$I(t) = \frac{A}{4} \times \left[1 - tanh\left(\frac{1}{s_r}(t - r_r)\right)\right] \times \left[1 + tanh\left(\frac{1}{s_l}(t - r_l)\right)\right]$$

Pulse shape, $\phi = \frac{s_l}{s_r}$

Here, $\mathbf{s_l}$, $\mathbf{s_r}$ are the rise (left) and decay (right) slopes of the lightcurve, and $\mathbf{r_l}$, $\mathbf{r_r}$ are the half-time of the lightcurve rise and fall. Five degrees of Freedom of the function enables one to capture the rise and decay phases of the lightcurve independently.

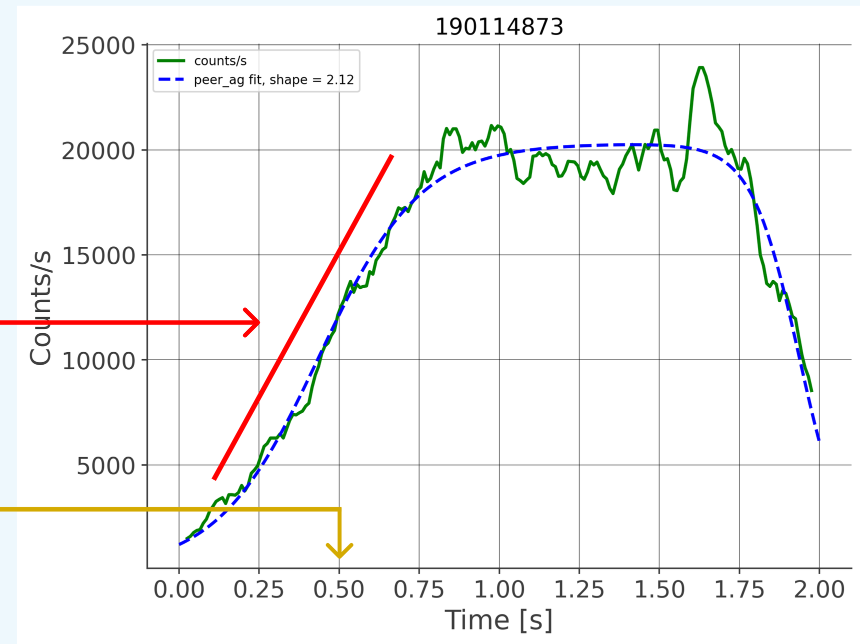

Figure 2b : The novel pulse function fit for the prompt light curve of GRB 190114 (bn 190114873). Here, the pulse shape parameter $\phi = 2.12$, and the pulse shape is **Symmetric-like**.

Results

Pulse Shape Studies

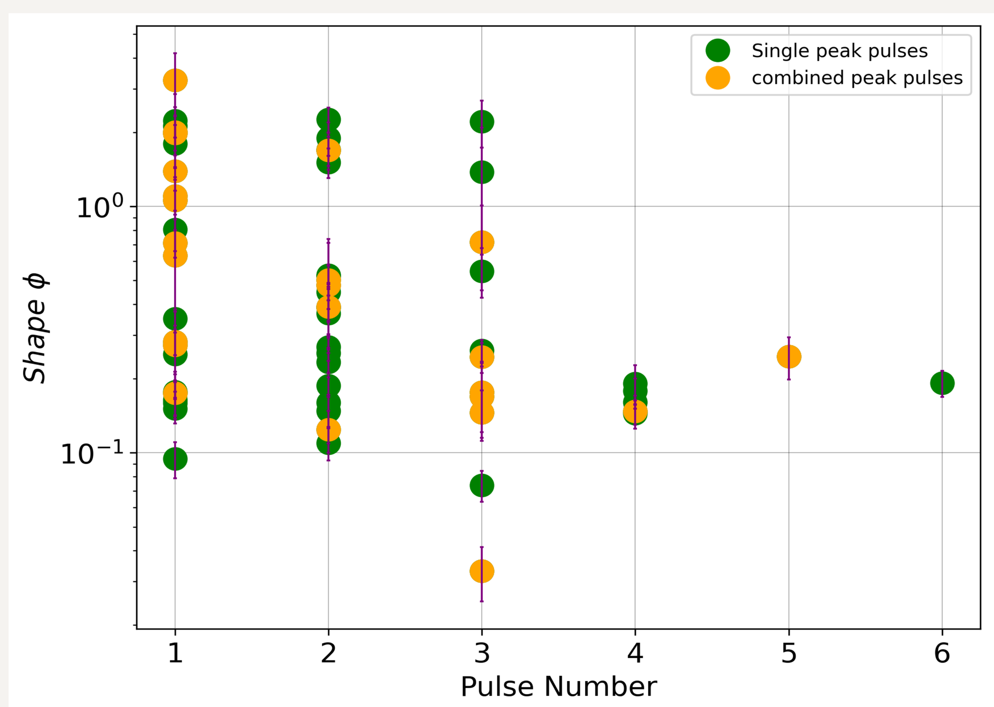

Figure 3 : Pulse shape vs pulse number. Pulses with shape $\boldsymbol{\phi \leq 0.3}$ are **FRED-like**, and shape $\boldsymbol{\phi \geq 1}$ are **Symmetric-like**. The pulse shape changes over time with the pulse number.

- **Temporal pulse shape changes from symmetric-like to FRED-like as burst evolves.**
- 9/22 ~ **41%** of the first pulses have shape function ≥ 1, indicating that they are nearly symmetric. However, the picture changes for later (2nd, 3rd) pulses: only 5/21 ~ **24%** and 2/11 ~ **18%** have shape ≥ 0.7 respectively.
- Shape - pulse number of pulses in a burst shows a moderate Spearman anti-correlation coefficient r_s = -0.34.
- Trend between the hardest value of α (α_{max}) with the ϕ parameter given by Spearman correlation r_s = 0.23.
- **Indication that Symmetric-like pulses may have harder α_{max} values compared to FRED-like pulses.**
- 31% of the pulses lie between the α_{max} bounds of fast cooling and slow cooling synchrotron. **67%** of the pulses lie between the bounds of slow cooling synchrotron and Non-dissipative photospheric (NDP) emission.

Spectral Shape - Pulse Shape

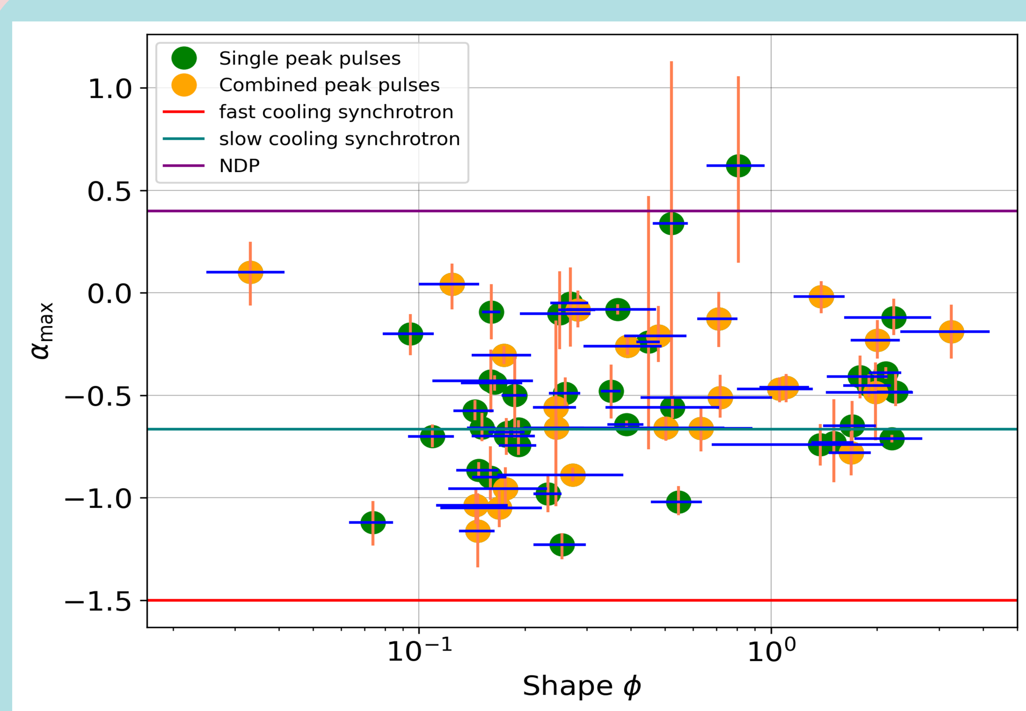

Figure 4 : α_{max} vs pulse shape with the α bounds of fast cooling **(-3/2)**, slow cooling synchrotron **(-2/3)** along with NDP emission **(0.4)**. α_{max} tends to become harder as shape symmetry increases.

Conclusions

- The initial pulses are more symmetric-like, and later pulses are more FRED-like. Furthermore, the symmetric-like pulses tend to have harder α_{max} values than the FRED-like pulses. **This indicates that the emission mechanism at different radii is likely changing throughout the burst from thermal to non-thermal.**
- Temporal symmetry detected in pulse shapes using our novel pulse function. This means rise and decay timescales are similar in these pulses. **This may be explained by the photospheric emission, as the photons that are emitted below the photosphere diffuse through the plasma until they escape, causing a more symmetric pulse structure.** Also from the timescales, indication that the typical **Lorentz factor of GRBs in our sample maybe only a few tens.**

References

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