The correlated variation of the GRB intensity and the spectral shape

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Correlations between spectral parameters during the prompt phase: 9 years of GBM observations

*Clue for the physics of the emission mechanism*

- Time-resolved spectral analysis
- Individual pulses with > 5 high SNR bins
- Bayesian analysis
Correlations between spectral parameters during the prompt phase: 9 years of GBM observations

*Clue for the physics of the emission mechanism*

9 years of GBM observations yielded 38 single pulses with 577 spectra

Analysis performed with 3ML (Vianello+15)

Band function and a cutoff power law were used

*See David Yu’s poster! Yu et al., online soon*
Results and comparison to the GBM catalogue (Yu et al. 2016)

1. $\alpha$-distribution

(Yu et al. 2016)

This work

Distribution of $\alpha_{\text{max}}$

$\langle \alpha \rangle = -0.802 \pm 0.312$

$\langle \alpha \rangle = -0.79 \pm 0.43$

2. Cutoff power law the “best” model
Consistent with Yu et al. (2016)

68% of pulses have $\alpha_{\text{max}} > -0.67$

Ghirlanda+02 found 44%
Results and comparison to the GBM catalogue (Yu et al. 2016)

3. $\beta$-distribution

$\beta$ is softer for the pulses in out sample
Spectral correlations over individual pulses
Correlation between energy flux and $\alpha$

Crider+97  
Ghirlanda+02  
Lloyd-Ronning+02
Posterior distribution of fits

\[ F(t) = F_0 e^{k \alpha(t)} \]
While $E_p - \alpha$ and $E_p - F$ show a variety of behaviours, the $F - \alpha$ correlation is similar in most bursts.

The data points move along a single track in the $F - \alpha$ plane.

$$F(t) = F_0 \ e^{k \alpha(t)}$$

Typical value $k \sim 3$
Qualitative explanation: Emission from the photosphere

Intensity and shape of the spectrum depends on

- the heating
- photon production efficiency

\( \tau \sim 10 \) Photosphere

\( \tau \sim 1 \)

\( \tau_w \sim 100 \)

Wien radius

Epk established
Saturated Comptonisation
(photon production rate)

sub-peak slope develops (\( \alpha \))
Unsaturated Comptonisation

Dissipation by oblique shocks (Meszaros&Rees05)
turbulence (Zrake+18)
B-fields (Giannios+04)

Beloborodov13
Fireball model: Lorentz factor

\[ \eta = \frac{L}{\dot{M}c^2} \]

Position of the saturation radius

Acceleration

Coasting

\[ \Gamma = \text{const} = \eta \]

\[ \Gamma \propto r \]

\[ r_S \]

\[ r \text{ [cm]} \]
Thermal pressure dominates

$E_K << E_{rad}$

1. Luminous
2. Thermal spectra
(Small dissipation compared to $E_{rad}$)

$E_K << E_{rad}$

1. Weak emission
2. Spectral broadening
(Dissipation of $E_K$ can easily modify spectrum)

Rees & Meszaros05; Pe’er+06; Giannios06, 08; Ioka+07; Beloborodov10; Lazzati+11; Vurm+13, Vianello+17
Summary photospheric scenario

Acceleration:  
- narrow spectra  
- bright emission

Coasting:  
- broader spectra  
- weaker emission

Variation in $\frac{r_{\text{ph}}}{r_s}$:
\[
\frac{r_{\text{ph}}}{r_s} = \frac{L \sigma_T}{4 \pi m_p c^3 \eta^2 \Gamma^2 r_0} \propto \frac{L}{r_0} \eta^{-4}
\]

\[\eta = \Gamma\]

Lopez-Camara+14

100707032

Acceleration

Coasting

Flux (erg s^{-1} cm^{-2})

\(\alpha\)

10^{-8} to 10^{-4}
Spectral correlations over individual pulses

$E_p - \alpha$

$F - E_p$

$F - \alpha$

$\frac{r_{ph}}{r_s}$
Conclusions:

- Time resolved pulses in GBM: 67% have $\alpha_{\text{max}} > -0.67$
- Subphotospheric emission, with dissipation and a varying entropy.

\[ \eta = \frac{L}{\dot{M}c^2} \]

Intense, narrow spectra
weak, broad spectra

- Physical models should be used in spectral analyses
e.g., Baring+95, Ghirlanda+02, Ahlgren+15, Vianello+18, Burgess+18