Pulse spectral evolution of GRBs: implication as standard candle

Rupal Basak and A. R. Rao

Department Of Astronomy and Astrophysics
Tata Institute of Fundamental Research (TIFR), Mumbai

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Outline

1. Aim: Towards a full pulse description
2. Simultaneous description: I(t, E)
   - Hard-to-soft evolution
   - An exciting result: $E_{peak,0} - E_{\gamma,iso}$ correlation
   - Alternative Spectral evolution
3. Conclusions and Future works

Towards a full pulse description

- A GRB shows complicated temporal structure, $I(t)$. This can be simplified by assuming pulse structures.
- Each pulse can be described in time $[I(t)]$ and energy $[I(E)]$ by empirical laws.
- By simple assumptions of the empirical description, we will show that a simultaneous description $[I(t, E)]$ is possible, and from ***these assumptions only***, various quantities can be ***derived and compared*** with the data.
- One of the very exciting results of this description is finding a ***new correlation*** of a spectral parameter with pulse energy. But, as a physical description is essential for using GRBs as cosmological tool, we shall explore other physical models.

Models we have used

Pulse light curve: Exponential model (Norris et al. 2005)

$$I(t) = A_n \lambda\, exp\left\{-\frac{\tau_1}{t-t_s} - \frac{t-t_s}{\tau_2}\right\} = A_n f_n\left(t, \tau_1, \tau_2, t_s\right)$$

Pulse spectrum: Band model (Band et al. 1993)

$$I(E) = A_b f_b\left(E, \alpha, \beta, E_{peak}\right)$$

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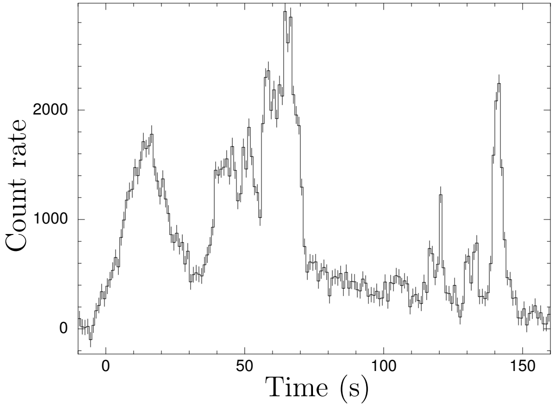
Pulse spectrum: Band model (Band et al. 1993)

$$I(E) = A_b f_b\left(E, \alpha, \beta, E_{peak}\right)$$

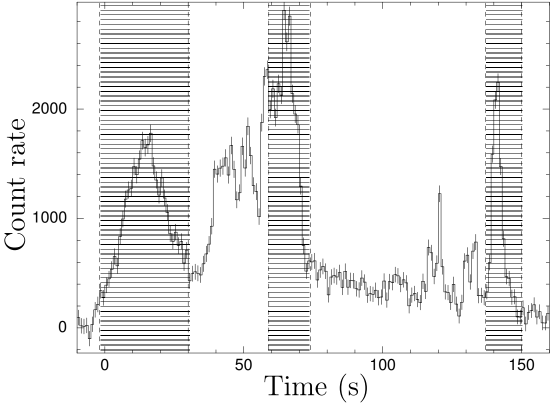
An example

- GRB 090323:



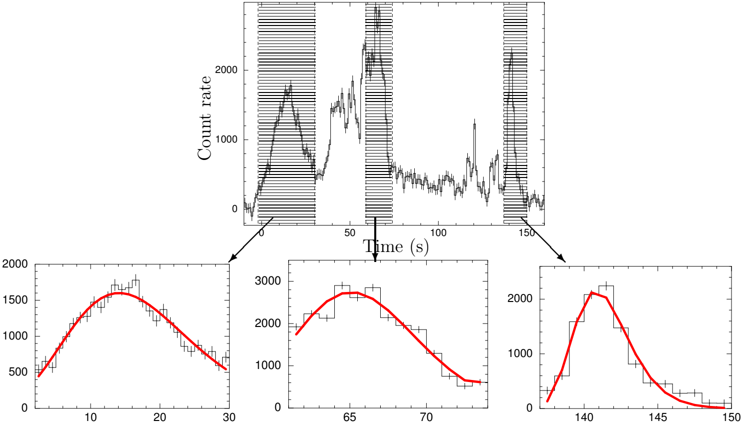
An example

- GRB 090323:



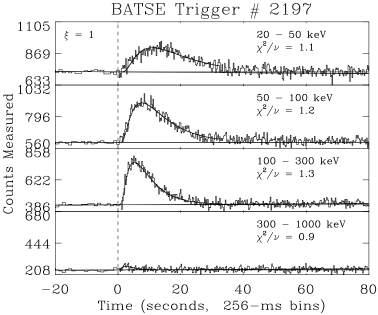
An example

- GRB 090323 pulses fitted with Norris model:

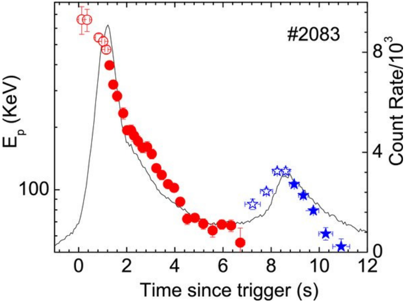


Pulse spectral evolution

Nemiroff (2012; MNRAS 419, 1650)



Lu, Hou and Liang et al. (2010; ApJ, 720, 1146)



Questions

- Can we use all these to get a full description of a pulse, $I(t, E)$, which is simultaneous in time and energy?
- How do the derived parameters compare with the data?
- What new insight does it give in terms of correlation studies?
- How correct are the basic assumptions? Are there any alternative physical models?

Assumptions of the model

- **Norris model** for light curve, integrated over energy
- **Band model** for time integrated spectrum
- Connection: E_{peak} of Band model follows the time evolution given by **Liang and Kargatis (1996)**:

Liang and Kargatis model

$$E_{peak}(t) = E_{peak,0} exp\left[-\phi(t)/\phi_0\right]$$

where $\phi(t)$ is the fluence up to time t from the start of the pulse

- The normalization factors (A_n and A_b) are connected

Model parameters

Norris model parameters:

- τ_1 ✓
- τ_2 ✓
- t_s ✓

Band model parameters:

- α ✓
- β ✓
- E_{peak}

Normalization parameters:

- A_n ✓
- A_b ✓

LK96 model parameters:

- $E_{peak,0}$
- ϕ_0

Xspec table model

$$(1)\ I(t) = A_n f_n(t, \tau_1, \tau_2)$$

$$(2)\ I(E) = A_b f_b(E, \alpha, \beta, E_{peak}(t, E_{peak,0}, \phi_0))$$

$$(3)\ \phi(t) = \int_{t_s}^{t} I(t')dt'$$

$$(4)\ E_{peak}(t) = E_{peak,0}\ exp\left(-\frac{\phi(t)}{\phi_0}\right)$$

XSPEC table model

- Taking a grid of guess values for the model parameters, $E_{peak,0}$ and ϕ_0, a 2 parameter table model can be generated by integrating the 3D pulse model over **time.**
- Use the table model in XSPEC to get the parameters $E_{peak,0}$, ϕ_0 and norm by χ^2 minimization along with the nominal 90% confidence level error

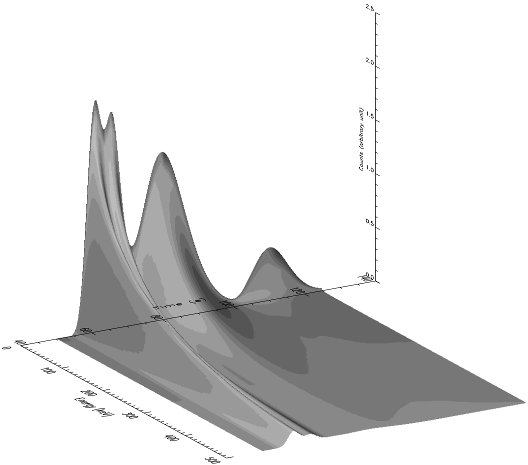
Derived parameters: how accurate?

- Once $E_{peak,0}$ and ϕ_0 is known, we have the full description of the pulse . Various timing parameters can be derived:

1. Integrate over desired **energy channels** to get light curves in those energy channels.
2. Width, spectral lag etc. can be derived and checked with the data.

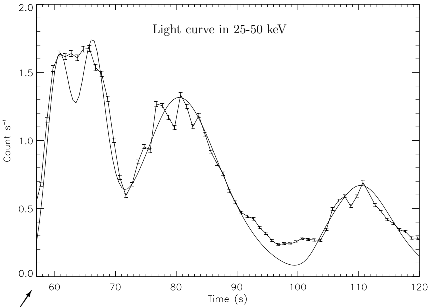
An example

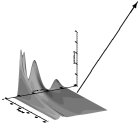
GRB 090618 (Basak & Rao 2012a, ApJ, 745, 76)



An example

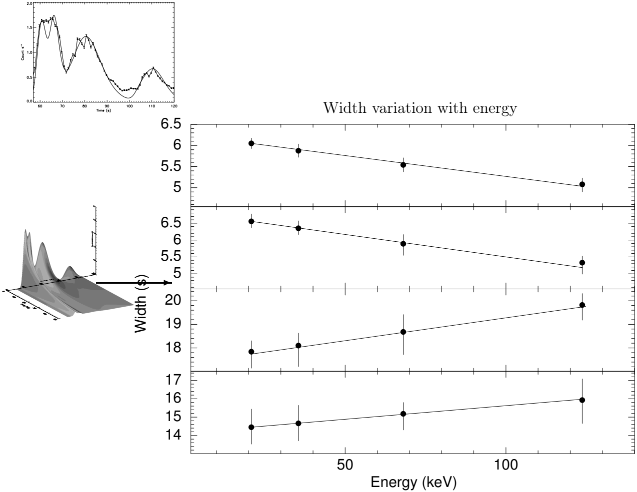
The light curve of GRB 090618: 25-50 keV



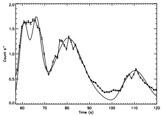


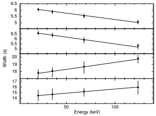
An example

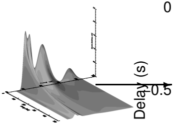
Pulse width variation with energy

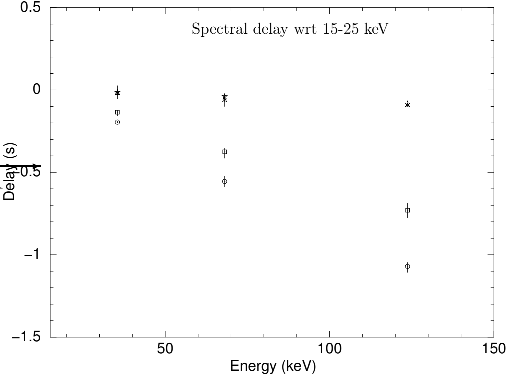


An example
Spectral Delay

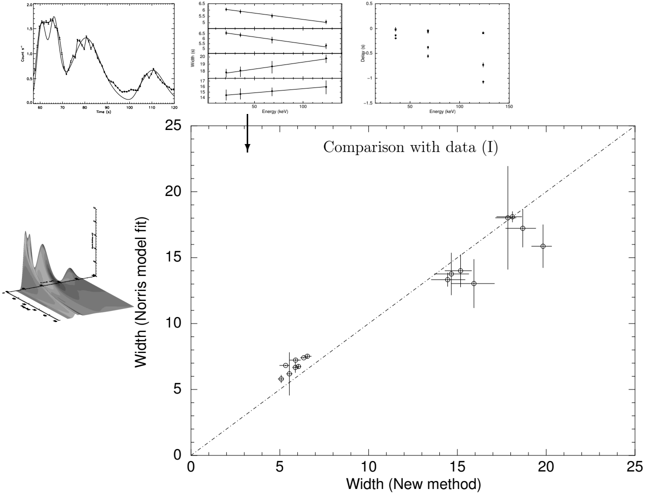




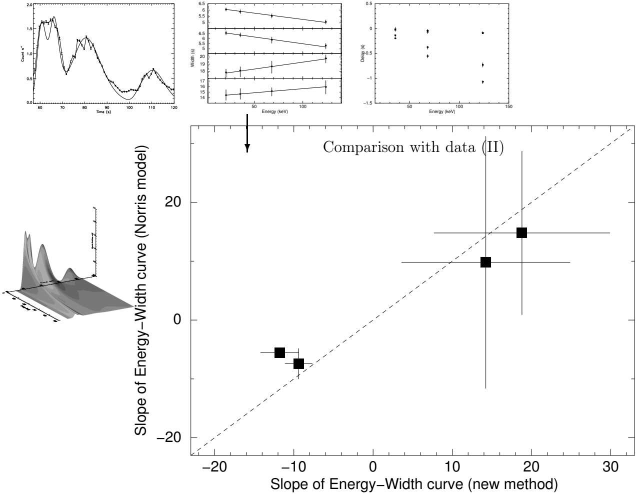




An example
Comparison of width



An example
Comparison of slope



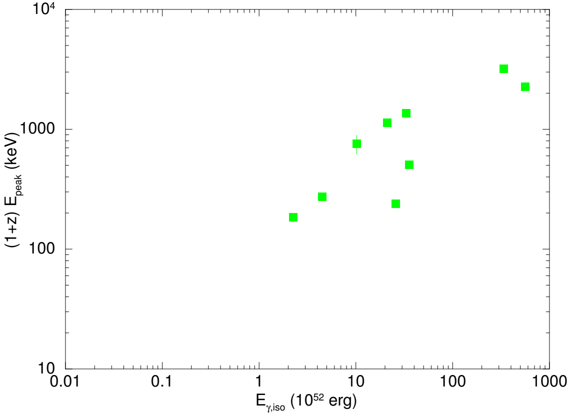
Comment on the empirical model

The fact that the derived parameters are comparable with the actual data gives us confidence that the empirical description is correct. Note that, **NO such assumptions of lag, width variation with energy etc. were made in the original model.**

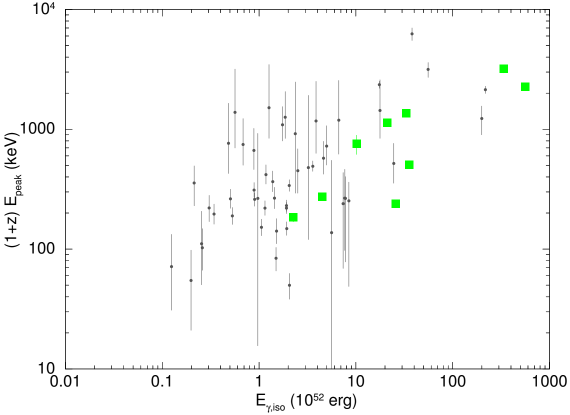
An exciting result: $E_{peak,0} - E_{\gamma,iso}$ correlation

We choose all Fermi/GBM GRBs with measured redshift till the end of July 2009 (The same sample used by Ghirlanda et al. 2010 for time-resolved spectral study). We use our model on the individual pulses of these GRBs

Correlation b/w $E_{\gamma,iso}$ and time integrated E_{peak}

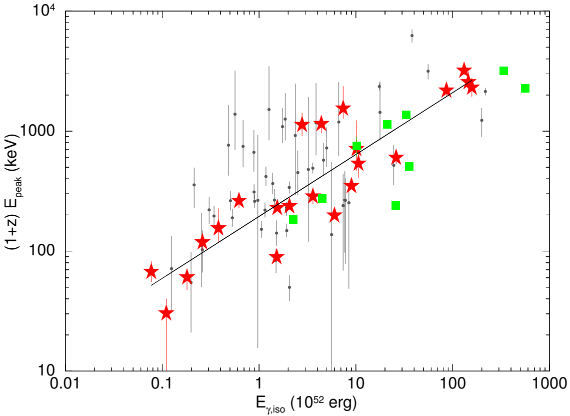


Correlation b/w $E_{\gamma,iso}$ and time resolved E_{peak}



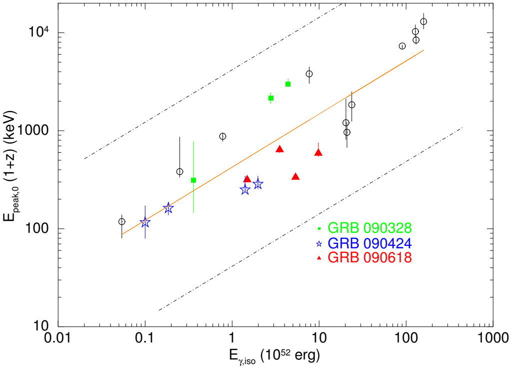
Correlation b/w $E_{\gamma,iso}$ and pulse-wise E_{peak}

Basak & Rao 2012b, ApJ, 749, 132



Correlation b/w $E_{\gamma,iso}$ and pulse-wise $E_{peak,0}$

Basak & Rao 2012b, ApJ, 749, 132



Statistical results			
Meth.[a]	ρ	P	σ_{int}
I	0.80	9.6×10^{-3}	0.22 ± 0.07
II	0.37	9.5×10^{-3}	
III	0.89	2.9×10^{-8}	0.24 ± 0.05
IV	0.96	1.6×10^{-12}	0.29 ± 0.04

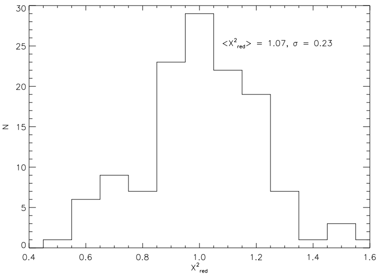
[a]I: time-integrated $E_{peak} - E_{\gamma,iso}$
II: time-resolved $E_{peak} - E_{\gamma,iso}$
III: Pulse-wise $E_{peak} - E_{\gamma,iso}$
IV: Pulse-wise $E_{peak,0} - E_{\gamma,iso}$

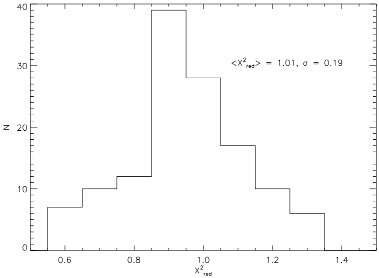
Alternative Spectral evolution

- As pulses are **building blocks** of the GRBs, we select from the Nava catalogue (Nava et al. 2011), Fermi GRBs having single or at least separable pulses
- We select only **long duration** ($T_{90} > 15$ s) and **bright** ($fluence > 10^{-6} erg\ \ cm^{-2}$) GRBs to facilitate time resolved spectral study
- Total 11 GRBs. We fit Band and Blackbody+Powerlaw (Ryde 2004) to the individual time-resolved data

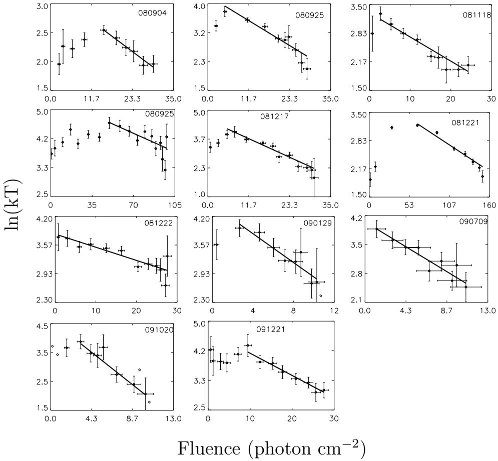
Comparison of Band and BBPL fit

χ^2_{red} of the fits





kT-fluence relation



kT-fluence relation

- The E_{peak} of Band model follows the LK96 model:

Liang and Kargatis model

$$E_{peak}(t) = E_{peak,0} exp\left[-\phi_{Band}(t)/\phi_{Band,0}\right]$$

where $\phi_{Band}(t)$ is the fluence till t from the start time

- kT holds similar relation with fluence:

kT-fluence relation

$$kT(t) = kT_0 exp\left[-\phi_{BB}(t)/\phi_{BB,0}\right]$$

where $\phi_{BB}(t)$ is the running fluence of BB component

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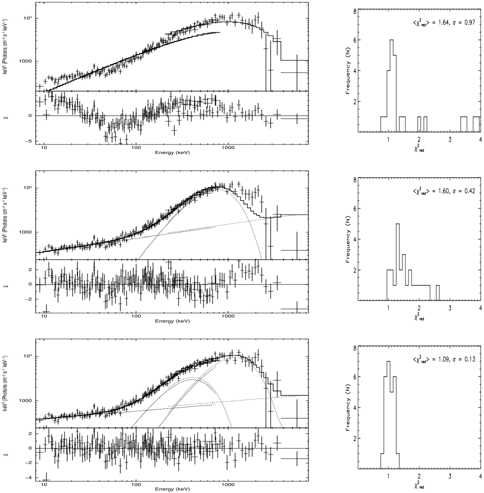
Comment

The description is consistent at the later part. What about the beginning of the pulse. Temperature sometime shows increment !! Is there another component which is affecting the kT variation?

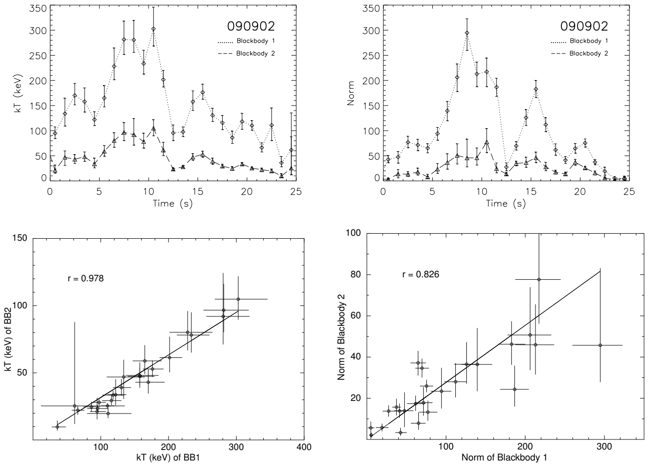
Speculation of multiple component

The case of GRB 090902B

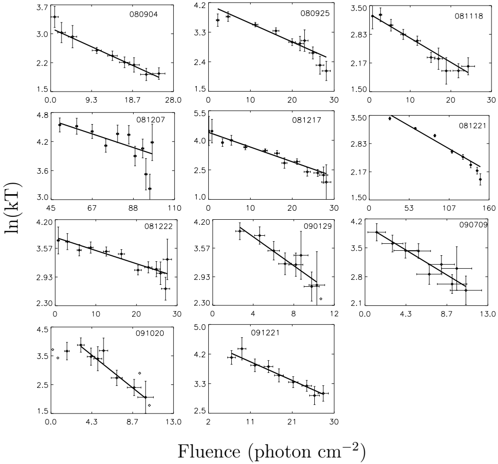


Speculation of multiple component

The case of GRB 090902B



Using this information to our sample



Conclusions

- The simultaneous timing and spectral description of the prompt emission of GRB pulse is developed. The model correctly predicts the other parameters in the time domain e.g., width (and its broadening effect), delay etc.
- The parameter $E_{peak,0}$ shows much better correlation with $E_{\gamma,iso}$ than other such correlations
- There are evidences of alternative spectral descriptions, e.g., BBPL. If double BB is forced, the variation of temperature is throughout or at least constant till the break.
- Future works: This can be used for a set of redshift measured GRB to get an even better correlation. Once a very good correlation is obtained, the corresponding model parameter can be used as a proxy of **redshift.** Each pulse of a GRB can be used which gives further constraint.