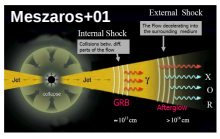
Nature of thermal emission from the photosphere of GRB jet

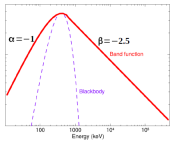
Rupal Basak[1], A. R. Rao[2], R. Misra[3], D. Bhattacharya[3],W. Kłużniak[1], R. Moderski[1]

[1] Nicolaus Copernicus Astronomical Center, Warsaw, Poland, [2] Tata Institute of Fundamental Research, Mumbai, India, [3] IUCAA, Pune, India

Abstract: A GRB is an explosive event marking the formation of a compact object, most probably a stellar mass blackhole. The radiation is believed to be an optically thin synchrotron emission from electrons accelerated in a highly relativistic jet launched by the central compact object. The evidences in favour of this scenario are the non-thermal spectral shape extending out to very high energies, and the observation of an achromatic jet-break. However, there are now mounting evidence in favour of an additional thermal component in the spectrum. Recently, we have found an evidence of two blackbody emission in stead of a single blackbody emission in various cases e.g., GRBs with single pulses, separable pulses, GRBs with high energy (GeV) emission. We shall show (i) various such cases specially highlighting some recent results obtained by using focusing X-ray detectors like *Swift*/XRT, *NuSTAR* and *Chandra* along with the traditional GRB detectors like *Swift*/BAT, *Fermi*/GBM. (ii) We propose that various components of our spectral model possibly originate from a stratified GRB jet. Finally, we discuss the future directions in understanding the nature of the thermal emission.

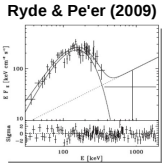
Background and Motivation





Kaneko+06

Ryde & Pe'er (2009)



Low energy index, α

"Facts"

1. Distance scale: cosmological
Redshift: ~400/1400 (Swift era)

2. Phenomenon: Two phase.
i. Prompt emission
ii. Afterglow

3. Geometry: Possibly jet.
Achromatic break and energy.
"Missing jet-break" in Swift era

4. Progenitor:
long (**collapsar**),
short (compact object **mergers**).
Supernova (SN) association,
also host, environment etc.
Two Long bursts with no SN

5. Radiation process:
Prompt emission debated
Rapid spectral evolution,
Poor resolution of GRB detectors

- Prompt emission spectrum is generally fitted with empirical **Band function** (Band+93). Phenomenological representation of synchrotron emission?
- Problem: **Synchrotron line of death** - photon index of the spectrum restricted below -1.5.
- Additional thermal component. **blackbody+powerlaw (Ryde 2004)** or **BBPL model**

We study the radiation process, specifically that of the prompt emission, and investigate the nature of the thermal component

Take-home Message

- The thermal component shows an evidence of two smoothly evolving balckbodies.
- Origin: spine-sheath jet. Also incorporates a part of the non-thermal emission

Sample*:

- 090902B: A GRB with high signal-to-noise data (**Rao+14**)
- 090618: Overlapping BAT-XRT observation (**Basak & Rao 2014, ApJ sub**)
- 130925A: Ultra-long GRB with NuSTAR observation (**Basak & Rao 2014, ApJ sub**)

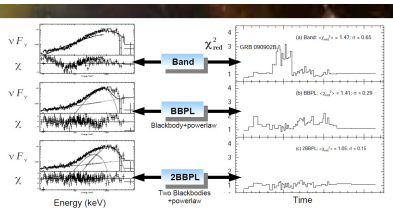
* also see **Basak & Rao 2013, ApJ, 768, 187** and **Basak & Rao 2013, ApJ 775, 31**

1. GRB 090902B

GRB 090902B: second brightest burst in the *Fermi* era (after 130427A). Variable light curve. Also detected by *Fermi*/LAT in GeV energies.

Time-resolved spectra fitted with Band and BBPL shows unacceptable residual. 2BBPL model provides a good fit.

χ^2_r of 2BBPL fit is the best for all time bins

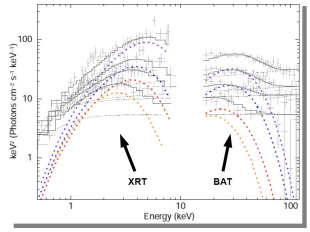


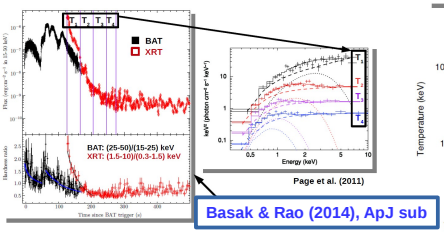
Rao, Basak et al. (2014), RAA

2. GRB 090618

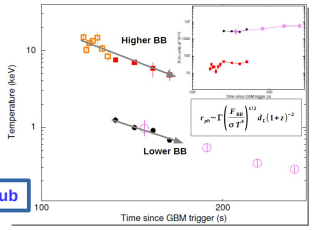
One of the brightest burst with several pulses during the prompt emission. Thermal emission is seen in the early phase of the precursor pulse.

XRT observation starts at 125 s, during the falling part of the final pulse. Page et al. (2011) found a thermal component in the XRT data. Using a simultaneous BAT and XRT data and a finer time interval, we find two blackbody emission.





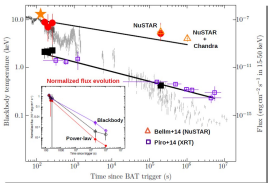
Basak & Rao (2014), ApJ sub



3. GRB 130925A

An ultra-long burst with prompt emission lasting for ~2h. Observed with focusing instruments e.g., Chandra and NuSTAR.

Piro et al. (2014) find a blackbody emission (0.3-1 keV) throughout the burst. Bellm et al. (2014) find a blackbody emission at a higher temperature (3-5 keV). We show that both the blackboy emissions are present. Both the components are detected only when a wider energy coverage is available.



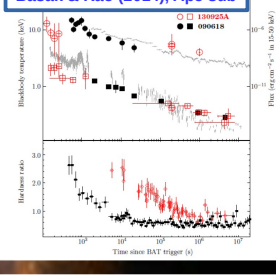
GRB 130925A vs. GRB 090618:

Comparison of 130925A, an ultra-long burst with 090618, a typical long burst. Time axis of the later is stretched arbitrarily.

- Upper panel: kT evolution of the two blackbodies.
- Lower panel: Hardness ratio (ratio of counts in 1.5-10 keV to that of 0.3-1.5 keV)
- **Slower evolution of ultra-long GRB.** Crude estimates: accretion timescale from free-fall time scale

$$t_{acc} \sim t_{ff} \approx 10^4 R_{12}^{3/2} M_{50}^{-1/2} s$$

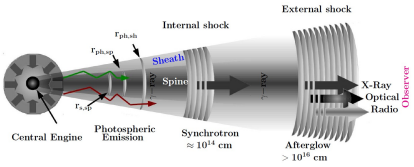
Basak & Rao (2014), ApJ sub



Origin of 2BBPL: a spine-sheath jet

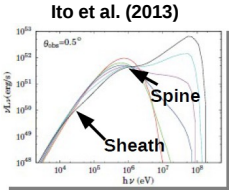
Stratified jet in various objects

- GRB: Mészáros & Rees 01, Ramirez-Ruiz+02, Zhang+03, 04
- BL Lac: Ghisellini+05, 08
- Cyg X-1: Szostek & Zdziarski 07



Basak & Rao (2014), ApJ sub

Ito et al. (2013)



➔ Naturally explains two blackbodies

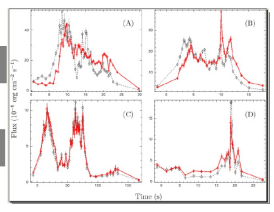
➔ Additional cut-off power-law due to inverse-Compton of photons crossing the spine-sheath boundary.

Outlook and Future directions

- Modification of **jet break signature.** The break due to the sheath can occur at much later epoch and requires sensitive observation.
- Sheath can form (i) either due to the interaction of GRB jet with the envelop of the progenitor, or (ii) due to selective collimation of protons compared to neutrons in a magnetic jet. Requires a detailed study. Short bursts will be interesting.
- Various processes of producing the **non-thermal component.**

High GeV emission

Low GeV emission



Basak & Rao (2013), ApJ

- Early observation with focusing detectors (like NuSTAR). **Writing ToO proposals.** We have collected a sample of 78 GRBs with BAT-XRT overlap in the final phase. 16 have known host. Comprehensive study of the environmental impact on the radiation. Analysis in progress.
- Developing a **spine-sheath model** and implement the synthetic spectrum in **XSPEC**. Measure the physical quantities like the Lorentz factor, and find the actual photospheric radius.
- Grant proposal with WK, RM –- members of H.E.S.S. consortium. One of the major aims: Observation of GRBs at TeV energies and constrain models.

Major conclusions:

- Smoothly evolving blackbodies (BBs) are found in the pulses of GRBs during the prompt emission phase.
- Two BBs are also found in the afterglow data. High significance. Possibly a tail emission of the prompt phase.
- Radiation mechanism in ultra-long GRBs is possibly similar as long GRBs with longer time scale.
- Our finding is consistent with a spine-sheath structure of GRB jet.

Contact:
rupal@camk.edu.pl
rupal.basak@gmail.com

N. Copernicus Astronomical Center of Polish Academy of Science, Warsaw