Detection of Thermal Spectral Component in the Prompt Emission of GRBs

by

Sylvain Guiriec

University of Alabama in Huntsville

NASA Marshall Space Flight Center

V. Connaughton, M. Briggs, M. Burgess, A. Goldstein, J. McEnery & N. Omodei

F. Daigne, F. Ryde & P. Mészáros

On behalf of the Fermi GBM Collaboration

(Submitted to ApJL, arXiv: 1010.4601)

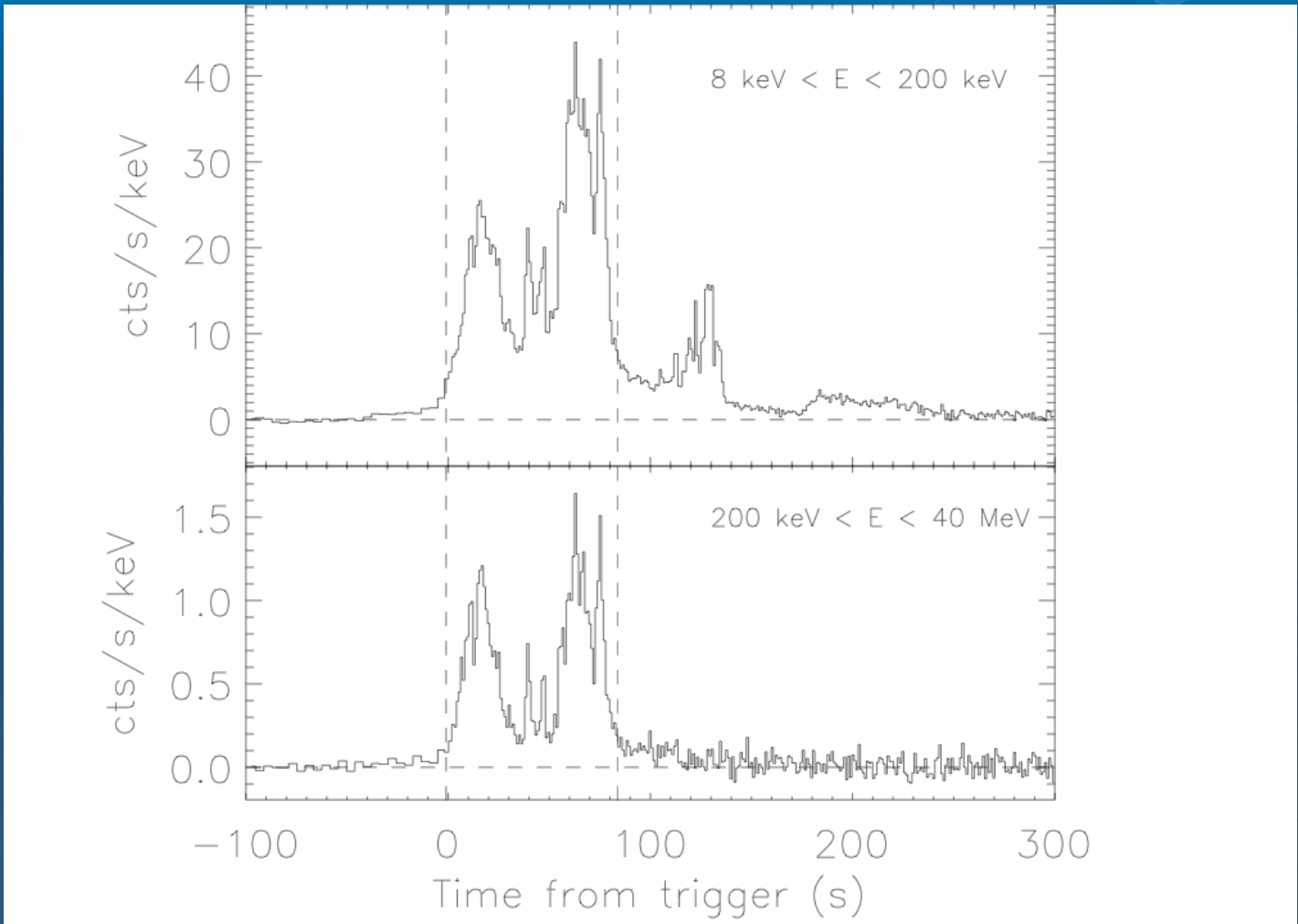
Fermi Gamma-ray Space Telescope

GRB Conference - Annapolis, USA - Monday, November 1st 2010

Outline

- Our show case, GRB 100724B
- Simultaneous fit of thermal and non-thermal components in the time-integrated spectrum
- Evolution of the black body during the prompt emission
- Interpretation of a weak thermal component
- Perspectives

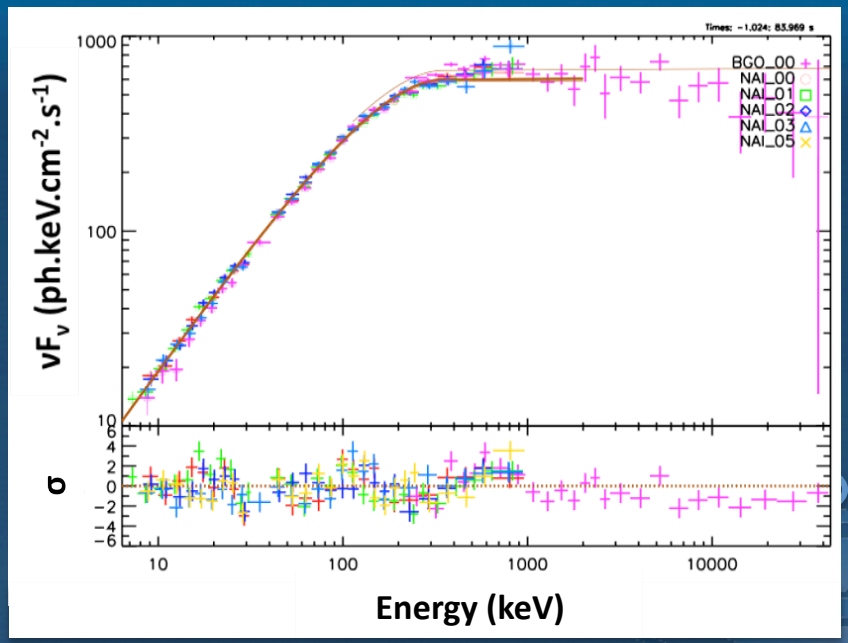
GRB 100724B Observation : an Usual Burst ?



- **GRB 100724B: large fluence.**
- **Duration T_{90}≈111s (50-300 keV).**
- **Multi-peak light curve with various intensity.**
- **No redshift measured for this GRB.**

Time-Integrated Spectral Analysis

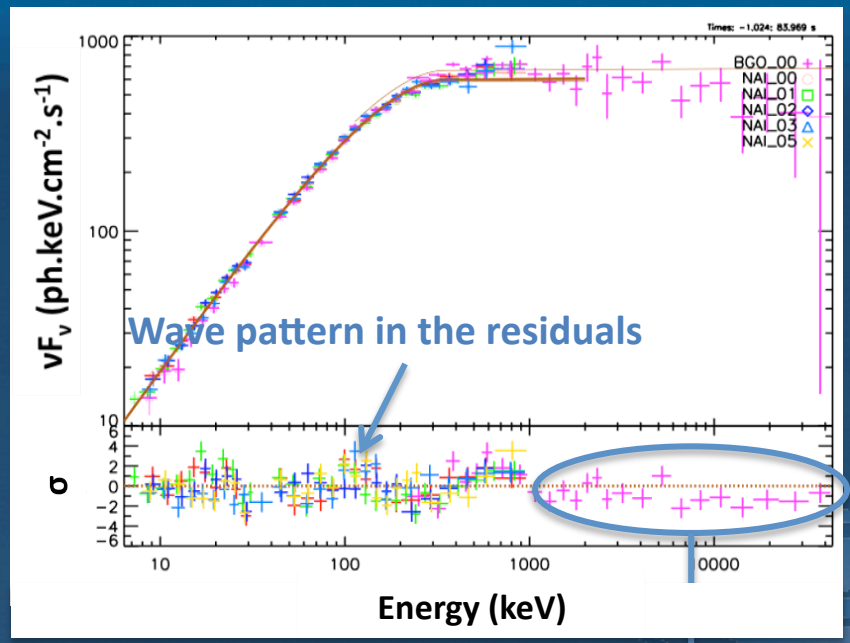
vF_v - Band



- GRB 100724B not correctly fit with Band only (pattern in the fit residuals and systematic deviation at high energy) => Band only is not correct. Additional component ?

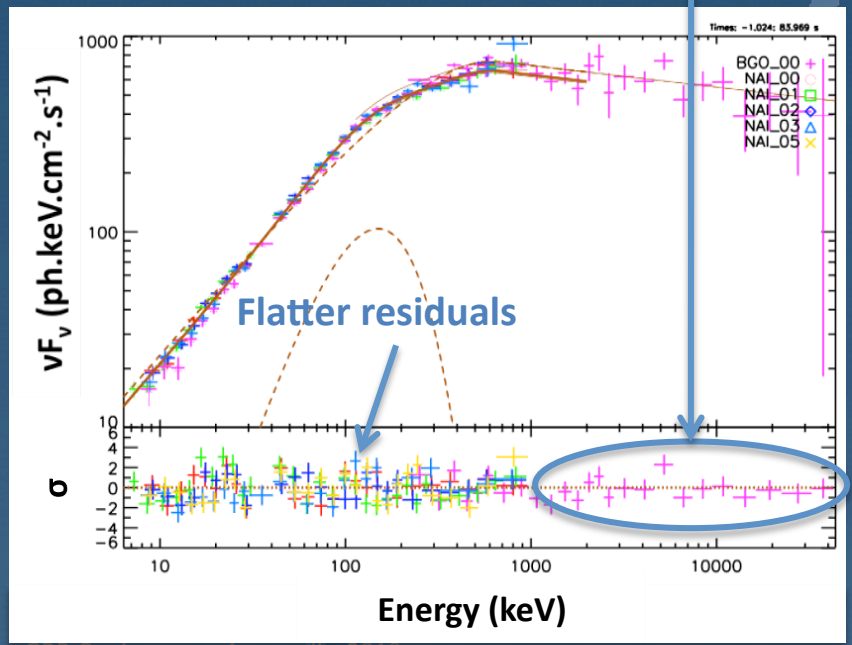
Time-Integrated Spectral Analysis

vF_v - Band



- GRB 100724B not correctly fit with Band only (pattern in the fit residuals and systematic deviation at high energy) => Band only is not correct. Additional component ?

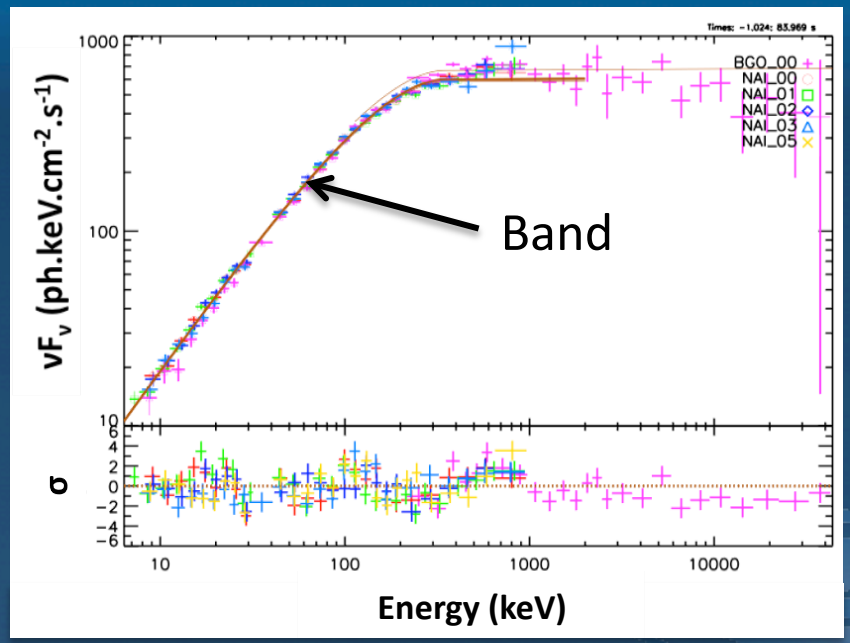
vF_v - Band + BB



- Band+BB improves significantly the fit reducing the residuals patterns and making residuals better and the HE consistent with the model. BB remains a weak component.

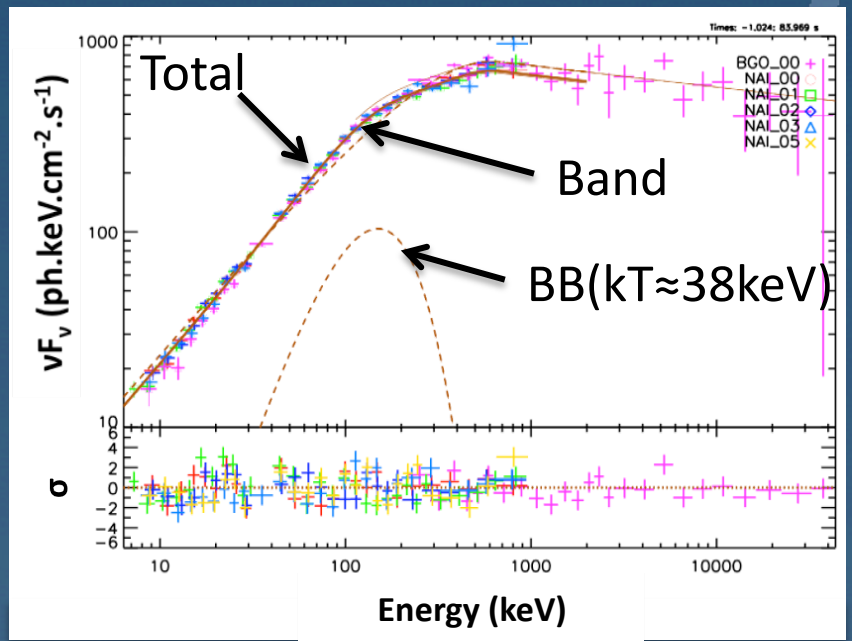
Time-Integrated Spectral Analysis

vF_v - Band



- GRB 100724B not correctly fit with Band only (pattern in the fit residuals and systematic deviation at high energy) => Band only is not correct. Additional component ?

vF_v - Band + BB



- Band+BB improves significantly the fit reducing the residuals patterns and making residuals better and the HE consistent with the model. BB remains a weak component.

Time-Integrated Spectral Analysis

Is BB the best model to fit the spectral deviation from the Band function ?
=> Test of various model combinations with the Band function.

Models	Standard Model			Additional Models									
	Band			BB	Compt		Band			Gaussian		PL	Cstat/dof
	E_{peak} keV	α	β	kT keV	E_{peak} keV	index	E_0 keV	α	β	Centroid	log_{10}FWHM	index	
Band	352 ±6	-0.67 ±0.01	-1.99 ±0.01										1133/704
Band+BB	615 ±29	-0.90 ±0.02	-2.11 ±0.02	38.14 ±0.87									1038/702
Band+Compt	708 ±48	-0.94 ±0.02	-2.13 ±0.02		164 ±7	+0.81 ±0.20							1039/701
Band+Band	716 ±48	-0.94 ±0.02	-2.13 ±0.02				60 ±7	+0.76 ±0.21	<-5				1039/700
Band +Gaussian	403 ±8	-0.75 ±0.01	-2.02 ±0.01							103 ±2	0.25 ±0.03		1060/701
Band+PL	341 ±9	-0.63 ±0.05	-1.99 ±0.01									-1.93 ±1.59	1131/702

Time-Integrated Spectral Analysis

- Band+BB improve the Band-only fit by 95 units of Castor Cstat.
- The BB temperature in the time-integrated spectrum is kT≈38 keV.
- With Band+BB, E_{peak} significantly shifted towards higher energy.
- With Band+BB, α and β are steeper (with BB, α values could be consistent with synchrotron emission).

Models	Standard Model			Additional Models									
	Band			BB	Compt		Band			Gaussian		PL	Cstat/dof
	E_{peak} keV	α	β	kT keV	E_{peak} keV	index	E_0 keV	α	β	Centroid	$\log_{10}$FWHM	index	
Band	**352 ±6**	**-0.67 ±0.01**	**-1.99 ±0.01**										**1133/704**
Band+BB	**615 ±29**	**-0.90 ±0.02**	**-2.11 ±0.02**	**38.14 ±0.87**									**1038/702**
Band+Compt	708 ±48	-0.94 ±0.02	-2.13 ±0.02		164 ±7	+0.81 ±0.20							1039/701
Band+Band	716 ±48	-0.94 ±0.02	-2.13 ±0.02				60 ±7	+0.76 ±0.21	<-5				1039/700
Band +Gaussian	403 ±8	-0.75 ±0.01	-2.02 ±0.01							103 ±2	0.25 ±0.03		1060/701
Band+PL	341 ±9	-0.63 ±0.05	-1.99 ±0.01									-1.93 ±1.59	1131/702

Time-Integrated Spectral Analysis

- Band+Band and Band+Compt fit equally well the spectrum than Band+BB but with more d.o.f. Band+BB is prefered.
- The parameters of the Band function are identical for the 3 combinations.
- The index and α of the additional Compt and Band function are compatlble with +1 => Compatibility with Planck function => BB.

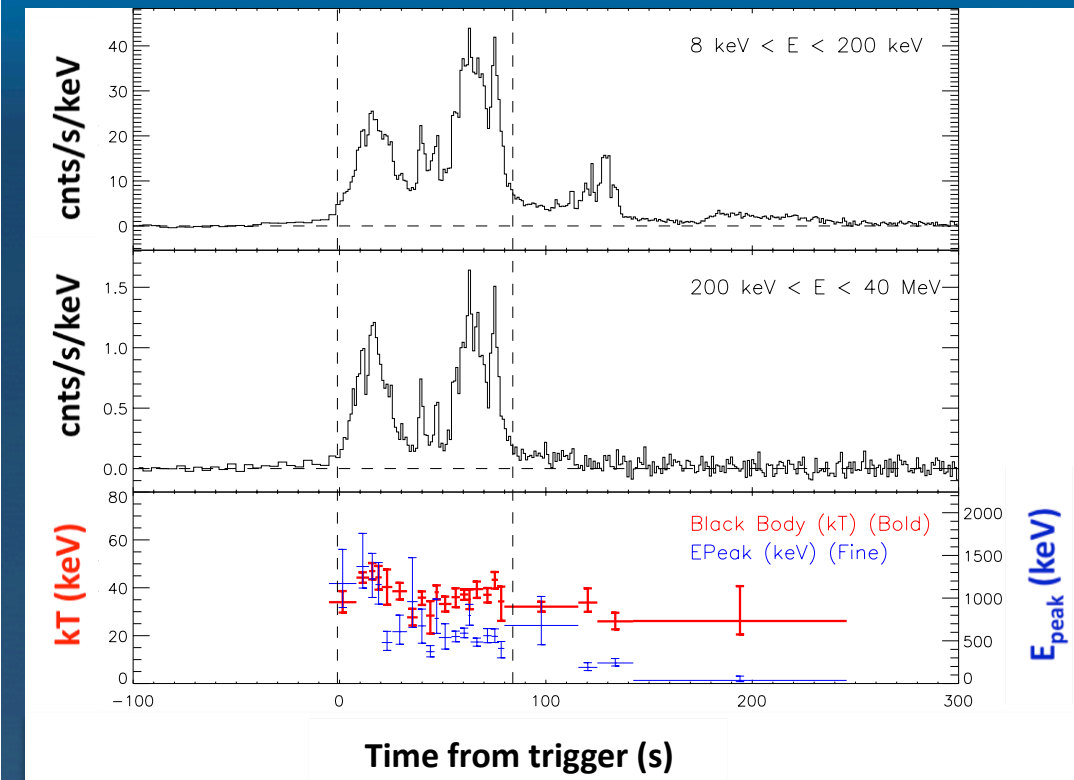
Models	Standard Model			Additional Models									
	Band			BB	Compt		Band			Gaussian		PL	Cstat/dof
	E_{peak} keV	α	β	kT keV	E_{peak} keV	index	E_0 keV	α	β	Centroid	log_{10}FWHM	index	
Band	352 ±6	-0.67 ±0.01	-1.99 ±0.01										1133/704
Band+BB	615 ±29	-0.90 ±0.02	-2.11 ±0.02	38.14 ±0.87									1038/702
Band+Compt	**708 ±48**	**-0.94 ±0.02**	**-2.13 ±0.02**		**164 ±7**	**+0.81 ±0.20**							**1039/701**
Band+Band	**716 ±48**	**-0.94 ±0.02**	**-2.13 ±0.02**				**60 ±7**	**+0.76 ±0.21**	**<-5**				**1039/700**
Band +Gaussian	403 ±8	-0.75 ±0.01	-2.02 ±0.01							103 ±2	0.25 ±0.03		1060/701
Band+PL	341 ±9	-0.63 ±0.05	-1.99 ±0.01									-1.93 ±1.59	1131/702

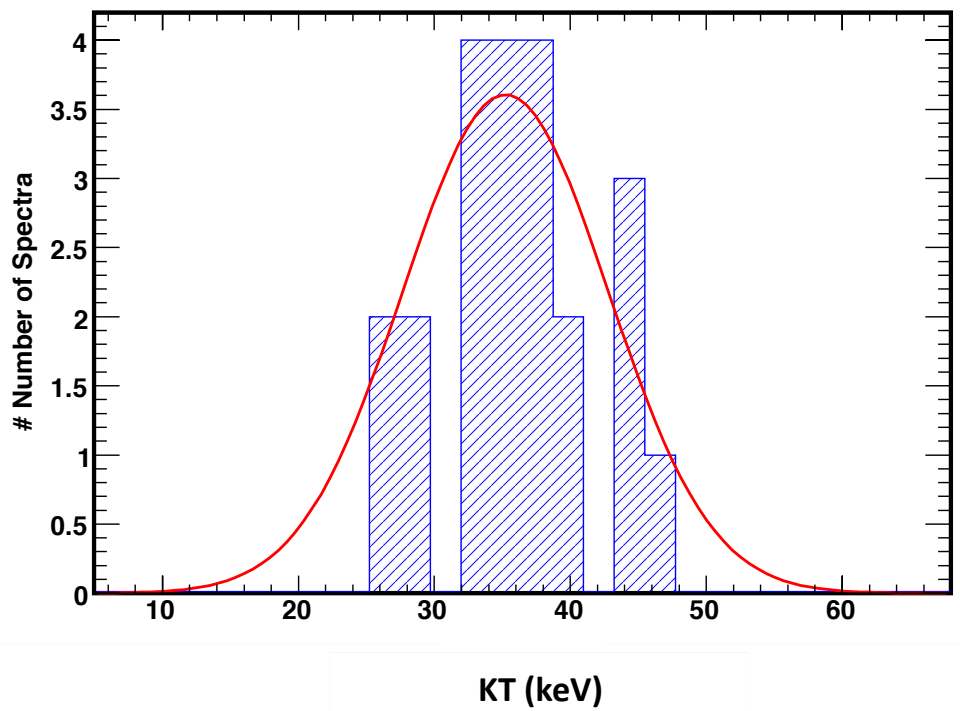
Time-Integrated Spectral Analysis

- Evaluation of the significance of Band+BB over Band-only with simulation
  - → 20000 synthetic spectra.
  - → 1 synthetic spectrum = (Band model + real background) + Poissonian fluctuation
  - → Each synthetic spectrum is fit with Band and Band+BB.
- → Probability that the fit improvement using BB is due to statistical fluctuation is $<5.10^{-5}$
- → First clear simultaneous detection of a thermal and non-thermal component !!!

Models	Standard Model			Additional Models									
	Band			BB	Compt		Band			Gaussian		PL	Cstat/dof
	E_{peak} keV	α	β	kT keV	E_{peak} keV	index	E_0 keV	α	β	Centroid	$\log_{10}$FWHM	index	
Band	352 ±6	-0.67 ±0.01	-1.99 ±0.01										1133/704
Band+BB	**615 ±29**	**-0.90 ±0.02**	**-2.11 ±0.02**	**38.14 ±0.87**									**1038/702**
Band+Compt	708 ±48	-0.94 ±0.02	-2.13 ±0.02		164 ±7	+0.81 ±0.20							1039/701
Band+Band	716 ±48	-0.94 ±0.02	-2.13 ±0.02				60 ±7	+0.76 ±0.21	<-5				1039/700
Band +Gaussian	403 ±8	-0.75 ±0.01	-2.02 ±0.01							103 ±2	0.25 ±0.03		1060/701
Band+PL	341 ±9	-0.63 ±0.05	-1.99 ±0.01									-1.93 ±1.59	1131/702

Time-Resolved Spectral Analysis





- Time-resolved spectroscopy using Band+BB with time intervals with enough signal to have good constraints on the Band function parameters.
- E_{peak} follows the usual trend: E_{peak} tracks the light curves and global soft-hard-soft evolution. Large variation amplitude for E_{peak}.
- BB temperature kT remains mostly constant with a possible cooling trend.
- Maximum of the kT distribution consistent with the value obtained from the fit of the integrated-spectrum.

Interpretation

- Low correlation between E_{peak} and kT and kT~constant

  → Thermal emission most likely from photospheric origin

- The observables kT≈38 keV, F_{BB}≈2.6 x 10-7 erg/s/cm^2 and F_{BB}/F_{tot}≈0.04 allow determination of physical properties of the outflow and its photosphere.

  → Assuming a redshift of 1 :

  $\Gamma \approx 325\ \xi^{1/4}\ f_{NT}^{-1/4}$

  $R_{ph} \approx 5.6 \times 10^{11}\ \text{cm}\ \xi^{-3/4}\ f_{NT}^{-1/4}$

  $R_0 \approx 1.2 \times 10^{7}\ \text{cm}\ \xi^{-1}\ f_{NT}^{3/2}$

  (Low dependency on the redshift)

- For extreme efficiency of the internal shocks $f_{NT} \approx 1$, these values are in agreement with what is expected from the standard fireball model.
- For a more realistic efficiency $f_{NT} \approx 0.1 - 0.5$:
  $R_0 \approx$ (3.6 - 40 km) ξ^{-1} < innermost stable orbit radius for a 5-10 $M_\odot$ black hole (44-89 km for non-rotating, 22-43 km for highly-rotating).
- $f_{NT} \approx 1$ or $R_0 \approx$ (3.6 - 40 km) => challenging for the standard fireball model. → Solution if the flow highly magnetized, f_{NT} replaced by $(1+\sigma)\ f_{NT}$ with $\sigma>1$
- Pure Poynting flux ($\sigma=\infty$) probably excluded.

Interpretation

- The BB component could be a solution to the “line of death” probleme :
  α steeper => Band compatible with synchrotron emission.

- The BB component could lead to steeper β for Band
  => Could solve the discrepency between the expected nb of GRBs detected at HE based on extrapolation of β and the real number of GRBs observed at HE.

Perspectives

- GRB 100724B is a show case to exhibits the simultaneous existence of a thermal and non-thermal component because it is a very bright and simple case.

- Most GBM GRBs are consistent with a possible BB component in addition to the Band function but very often :

  → GRBs are too faint to reach a significant detection threshold.

  → Difficulties to separate the BB component from the non thermal emission because right on top of each other.

  → Lots of GRBs have multi-components.

- Band+BB fit better the data of previous instruments.

- The door is open to fit physical model in GRB prompt emission (see M. Burgess presentation).

=> Much more to come very soon !!!

BACKUP