The Photosphere in GRBs: Lessons learned from *Fermi*

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On behalf of the Fermi GBM and LAT teams

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VETENSKAP OCH KONST

Oskar Klein centre

Bottom line:

- *Fermi* confirms BATSE results on thermal emission in (at least) a fraction of GRBs

- Many GRBs have a 'double hump' spectra and the Band function cannot model their shapes.

- *Fermi* provides evidence of subphotospheric heating (*Photosphere* $\not\leftrightarrows$ *Planck function*)

We need time resolved spectroscopy!

Should there be thermal emission in GRBs?

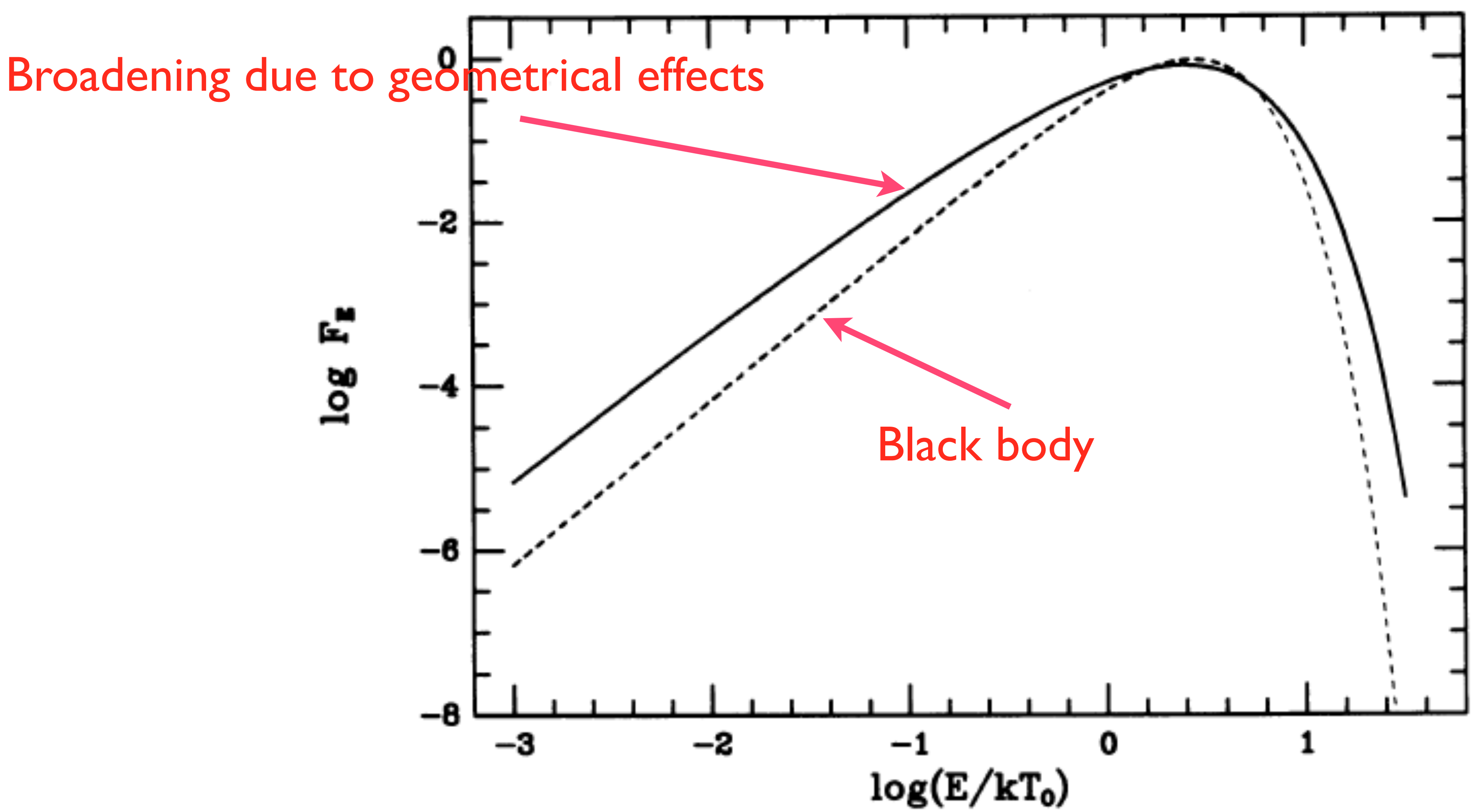
1986: Thermal emission from the fireball

Variability >~10 ms
Cosmological distances
Observed Flux: ~10^{-7} - 10^{-4} erg cm^{-2} s^{-1}
Typical observed energy: <~ MeV

→ Fireball model, high optical depths

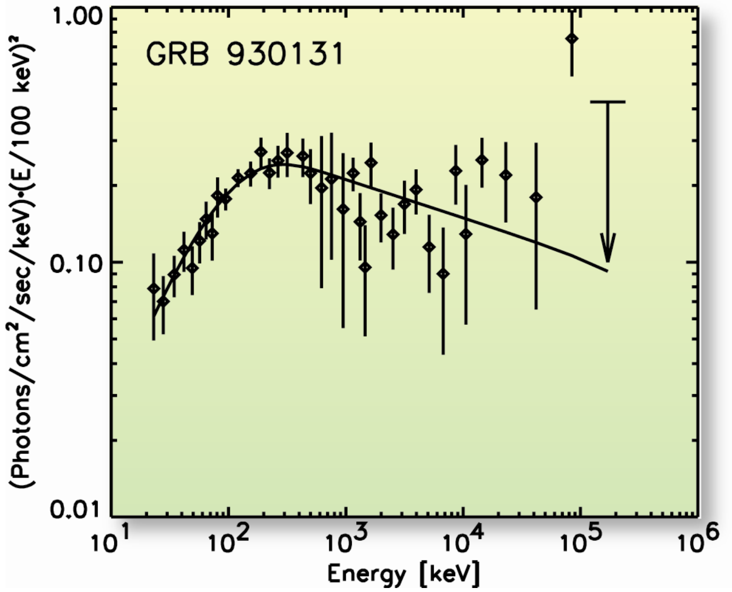
→ Strong thermal component expected ~1 MeV and at 10^{12} cm

Goodman (1986), Paczyński (1986), Thomson (1994) etc.

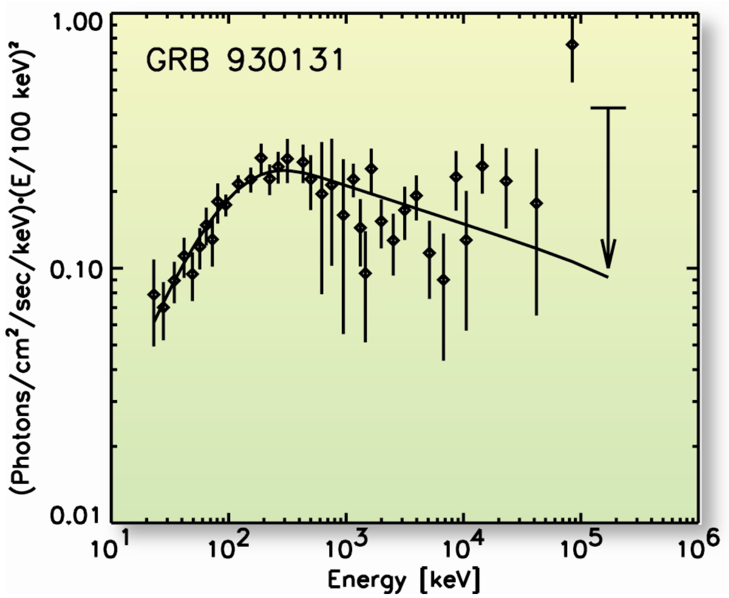


Paczyński 1986, ApJL, 308, 47

FIG. 1.—*Solid line*: energy distribution of the flux received by a distant observer at rest with respect to the center of mass of the fluid. The vertical scale in arbitrary units. (*Dashed line*): corresponding distribution for a blackbody at the initial temperature of the fluid.



Observed spectra are *not* Planck spectra



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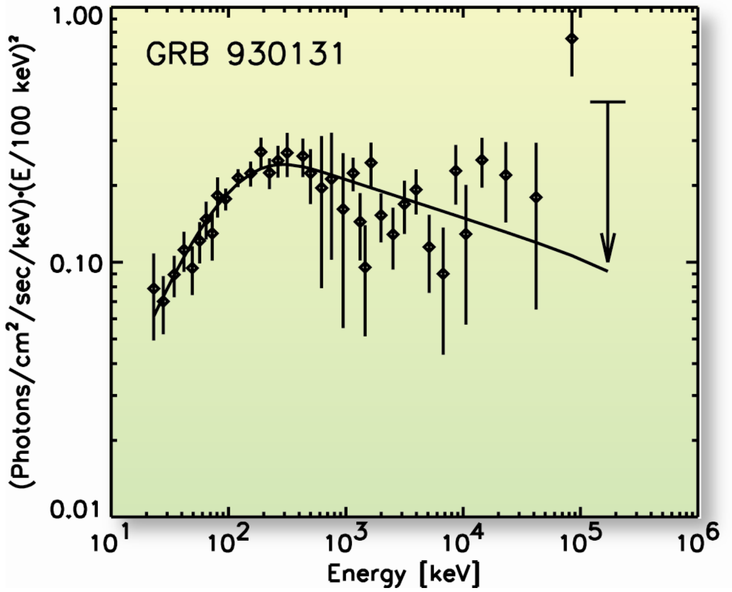
Solution?

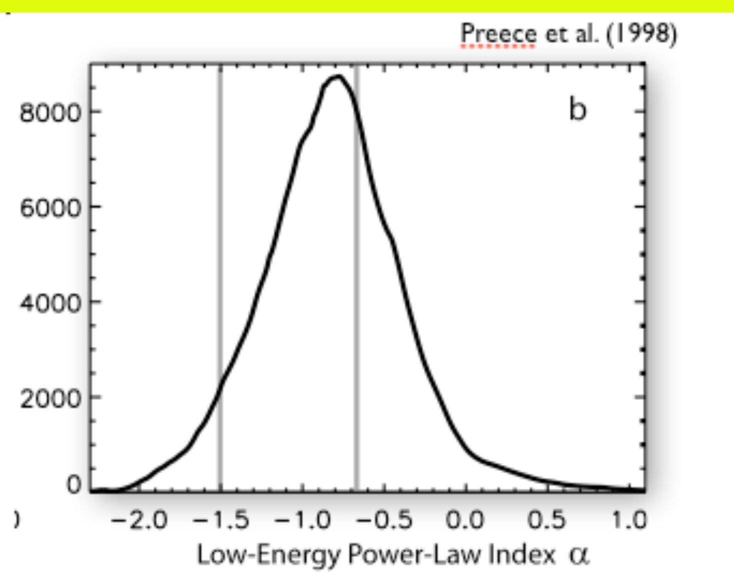


Observed spectra are *not* Planck spectra

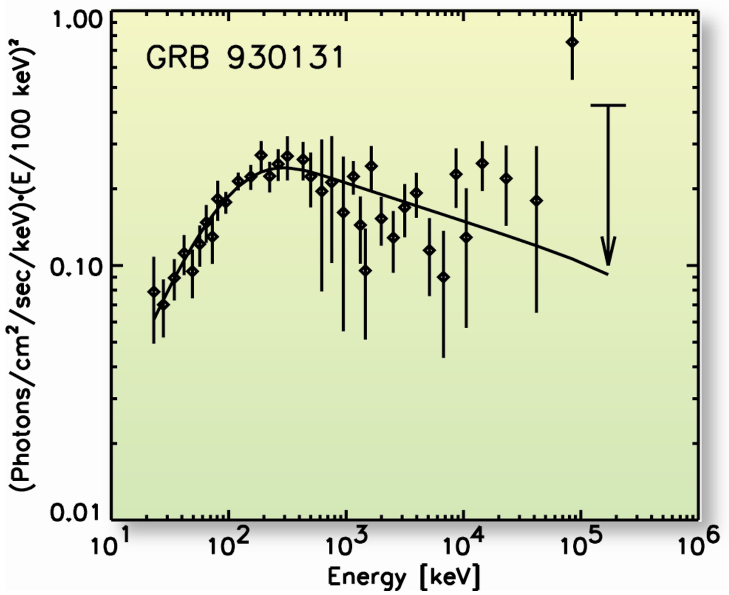
Solution?

Optically thin
synchrotron emission
in internal shocks; jitter radiation, IC

- Line of death
- shock acceleration
- efficiency of internal shocks



Slope of cooling spectrum $\alpha = -1.5$



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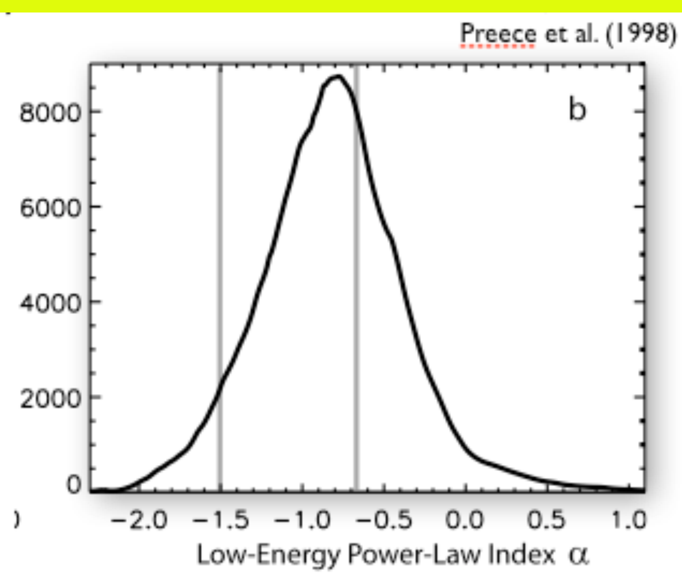
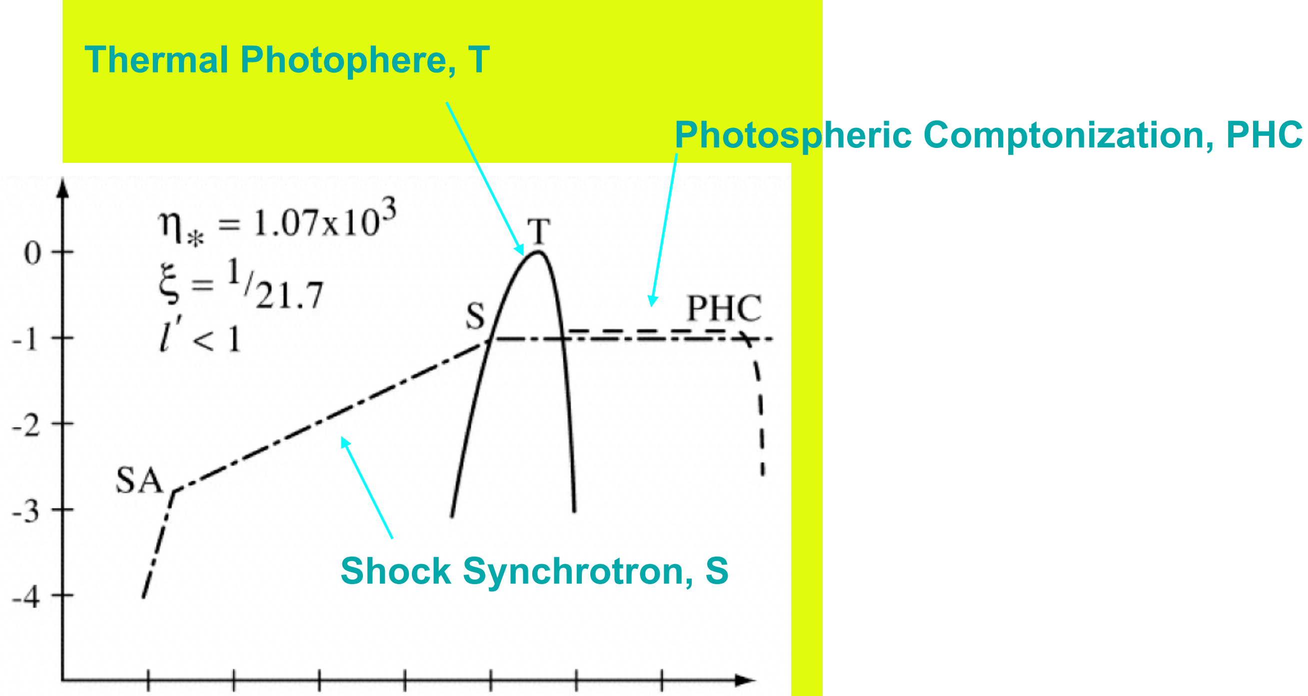
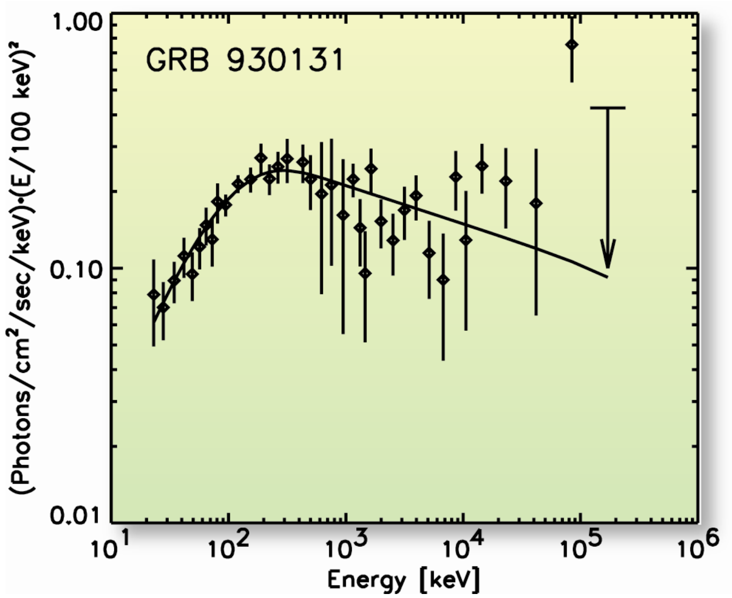


Slope of cooling spectrum $\alpha = -1.5$

Multiple spectral components (e.g. Mészáros et al. 2002) - *Veres talk*





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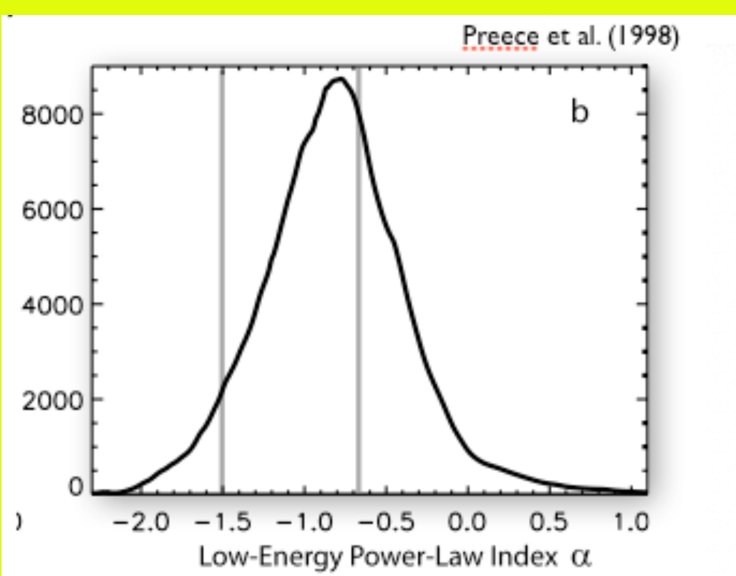

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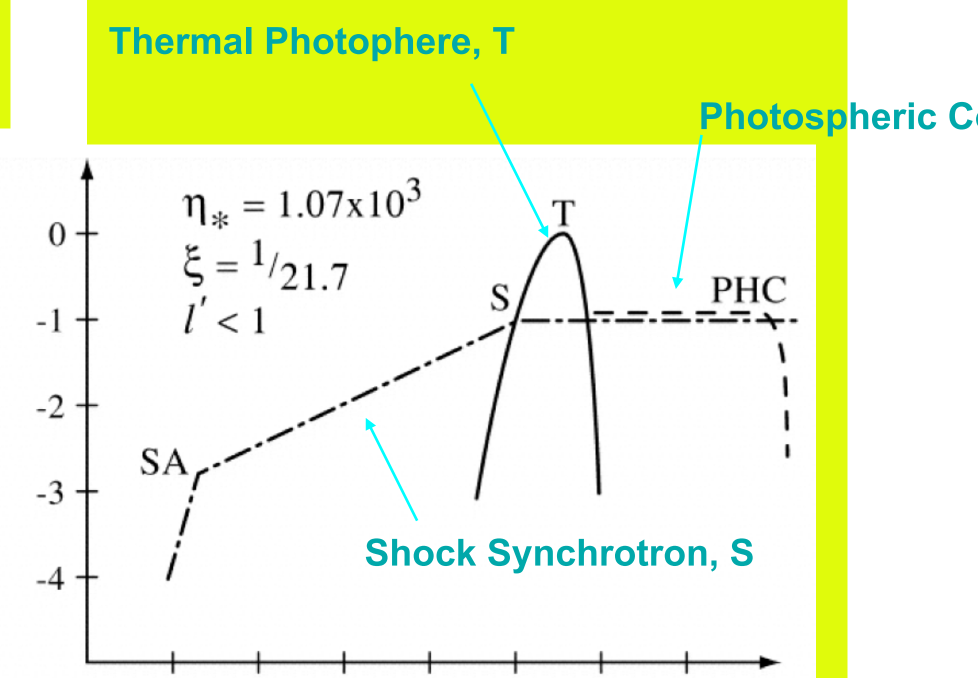
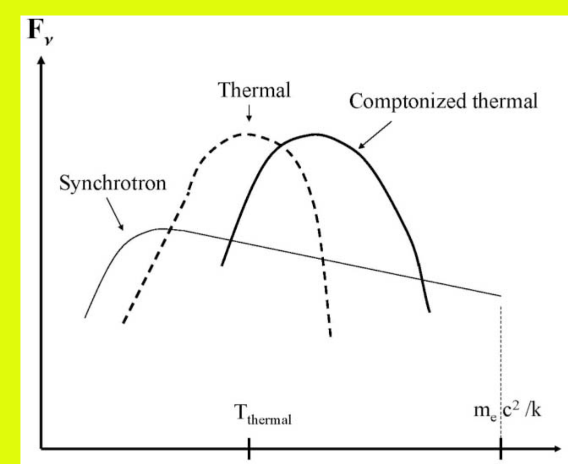


The emission from the photosphere is **not Planckian** - *Lazzati's talk*

- Subphotospheric dissipation (Rees & Mészáros 2005, Pe'er et al 2006 Daigne & Mochkovitch (2002), Giannios (2007) and Lazzati (2009), Beloborodov 2011)

- Geometrical effects (Pe'er 2008)



CGRO BATSE ERA (1994-2000)

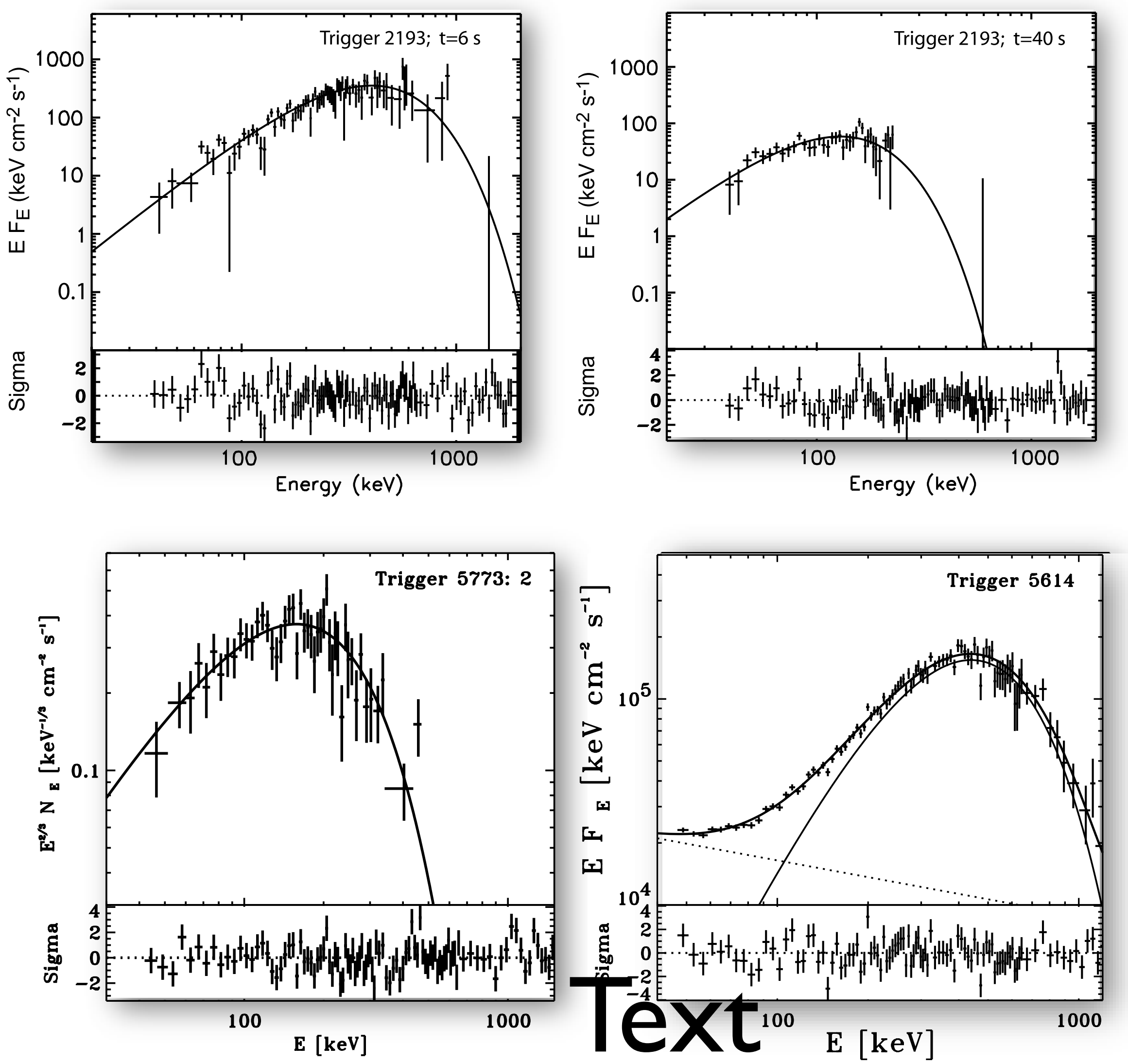
Photospheric emission in BATSE bursts

Spectra from temporally resolved pulses observed by BATSE over the energy range 20-2000 keV.

Spectral fit: Black body combined with a power law:

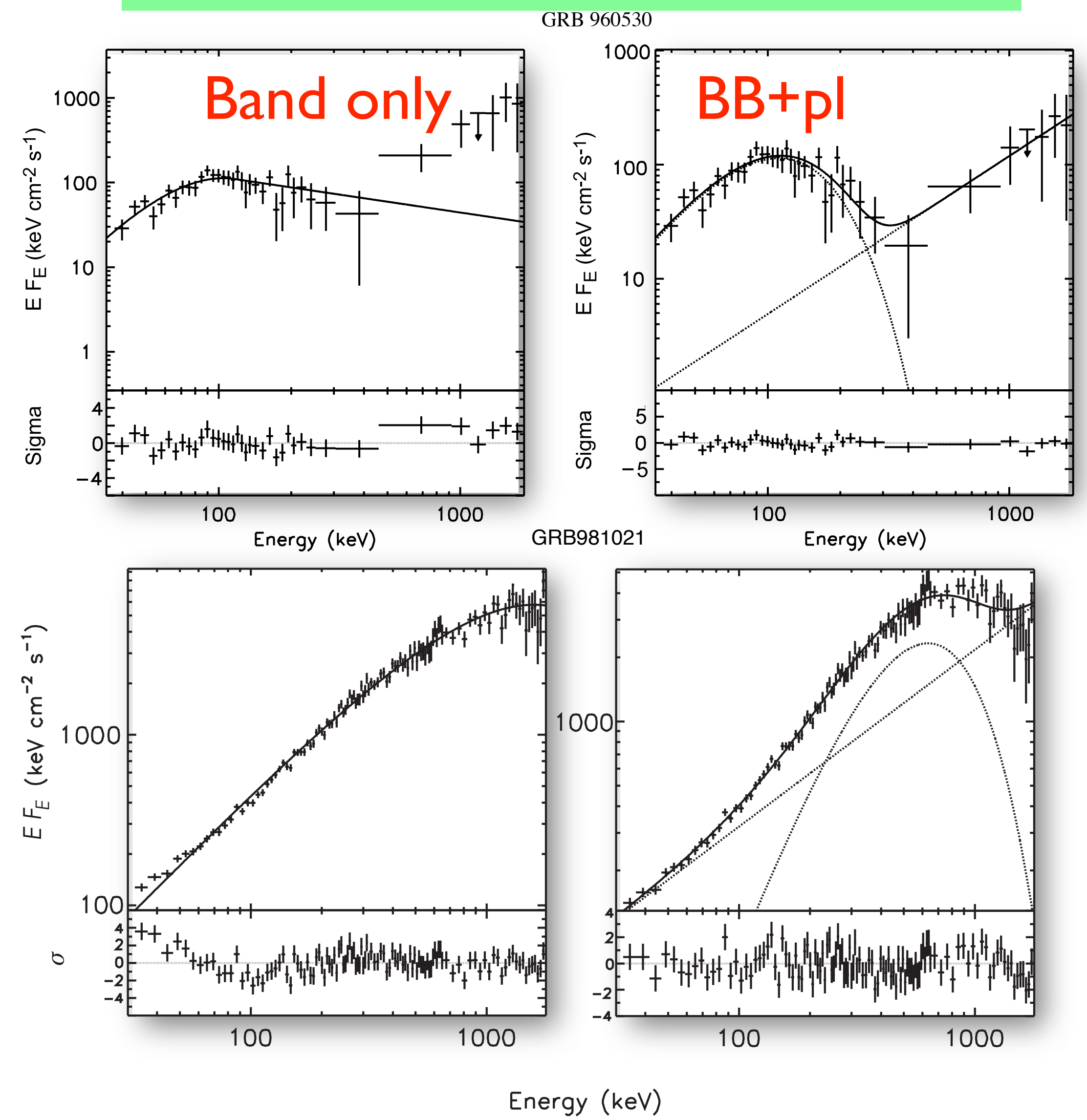
$$N_{\mathrm{E}}(E,t) = A(t)\ \frac{E^2}{exp[E/kT(t)]-1} + B(t)\ E^s$$

Photosphere (Planck function)



Ryde 2004
(see also Ghirlanda et al. 2003)

Additional non-thermal emission



EGRET TASC peak at *Ep* = 1600 keV

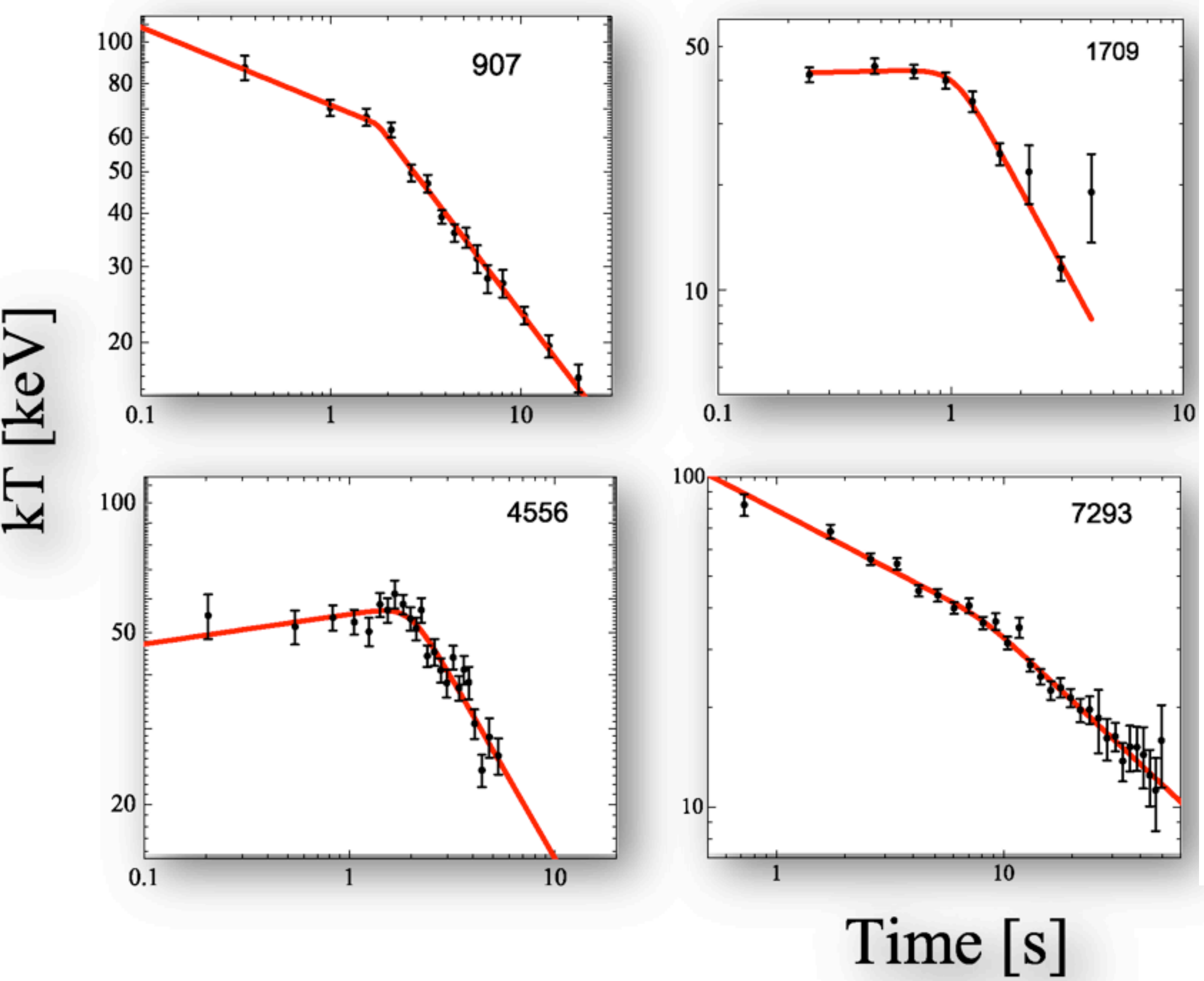
Ryde 2005

CGRO BATSE ERA (1994-2000)

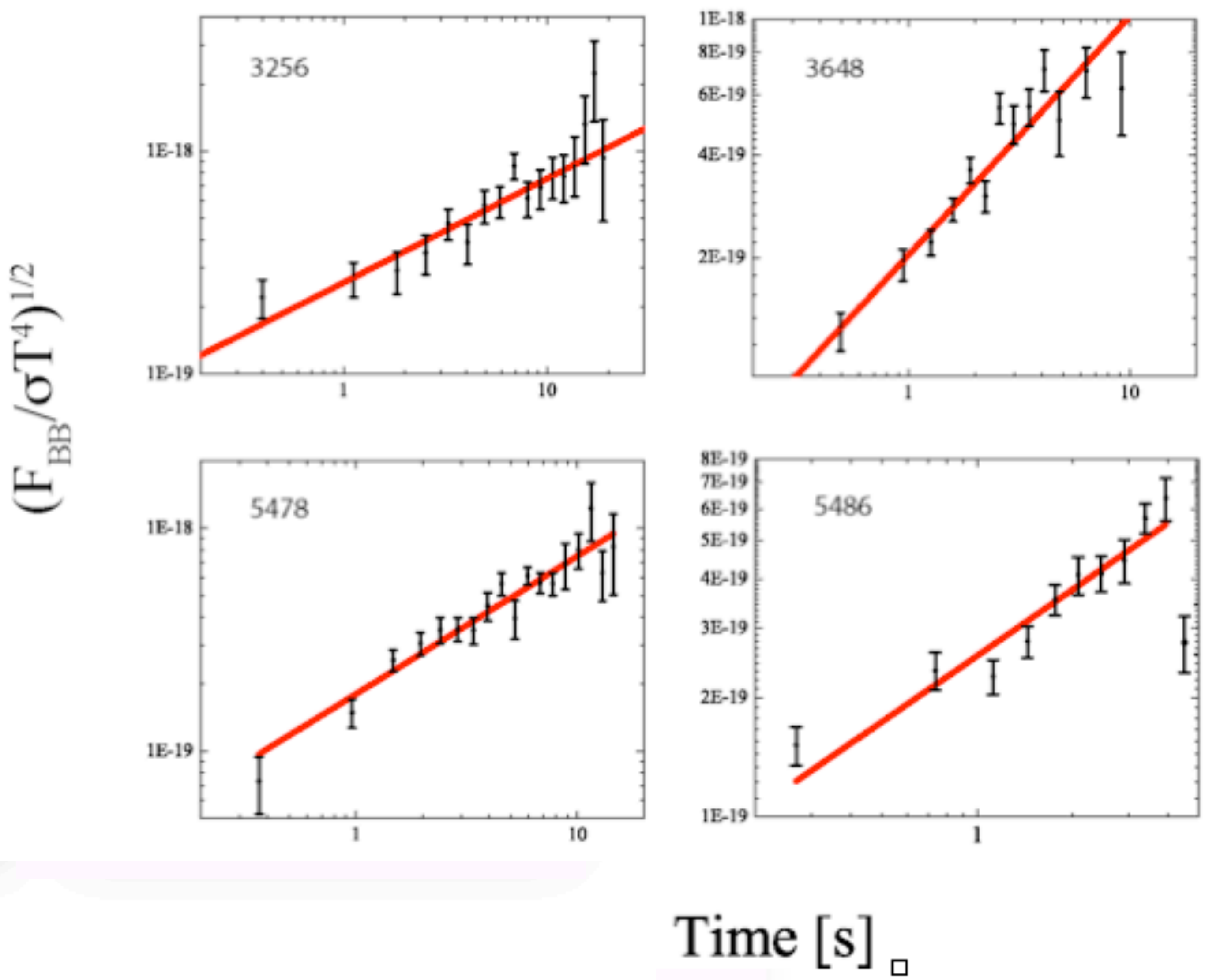
The spectral peak is due to a peaked thermal component. *Behavior of the thermal component:*

$$F(t) = A(t)\,[kT]^4\,\pi^4/15$$

Temperature Evolution *kT*



Evolution of the normalization, *A(t)*



Ryde & Pe'er 2009

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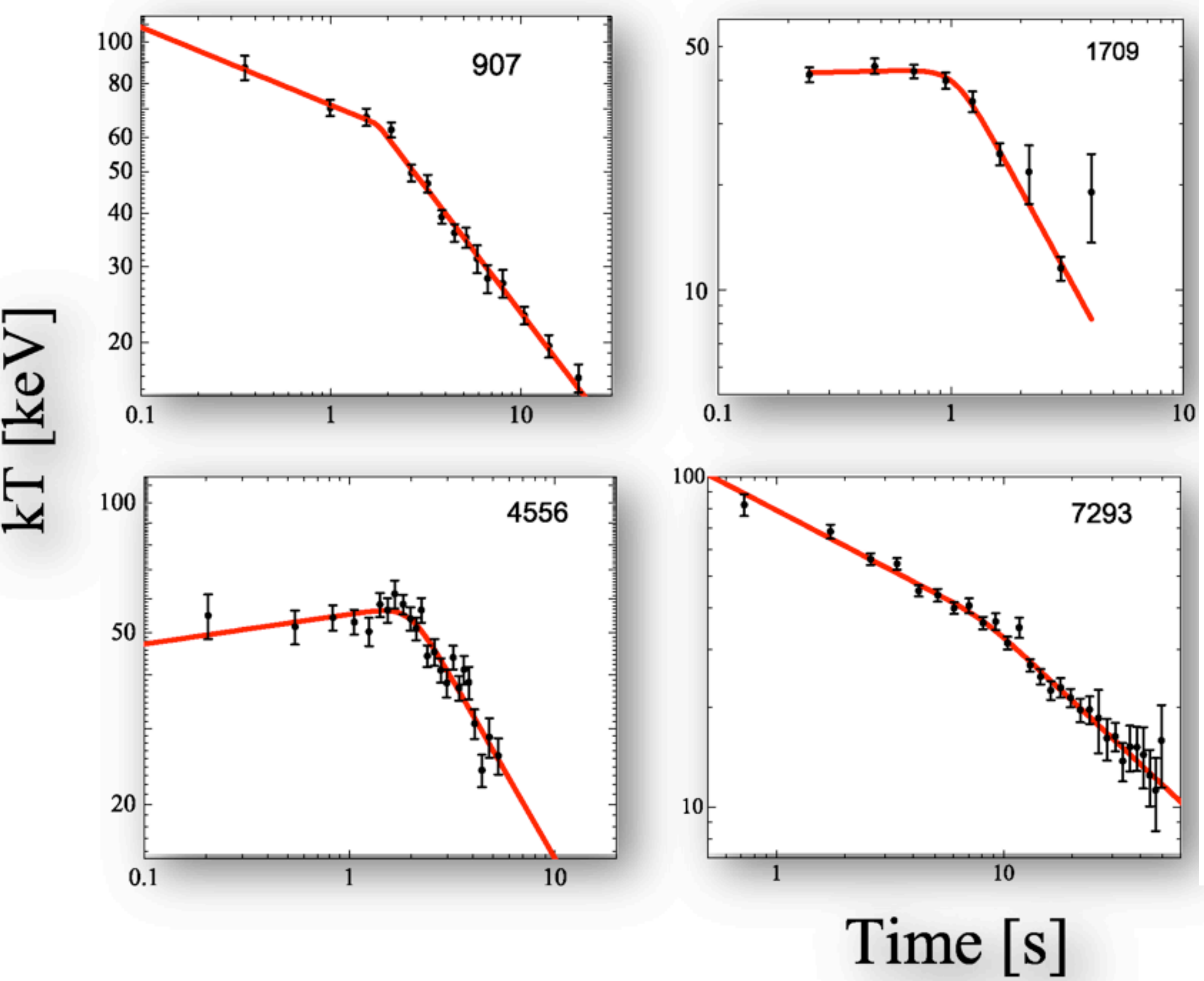

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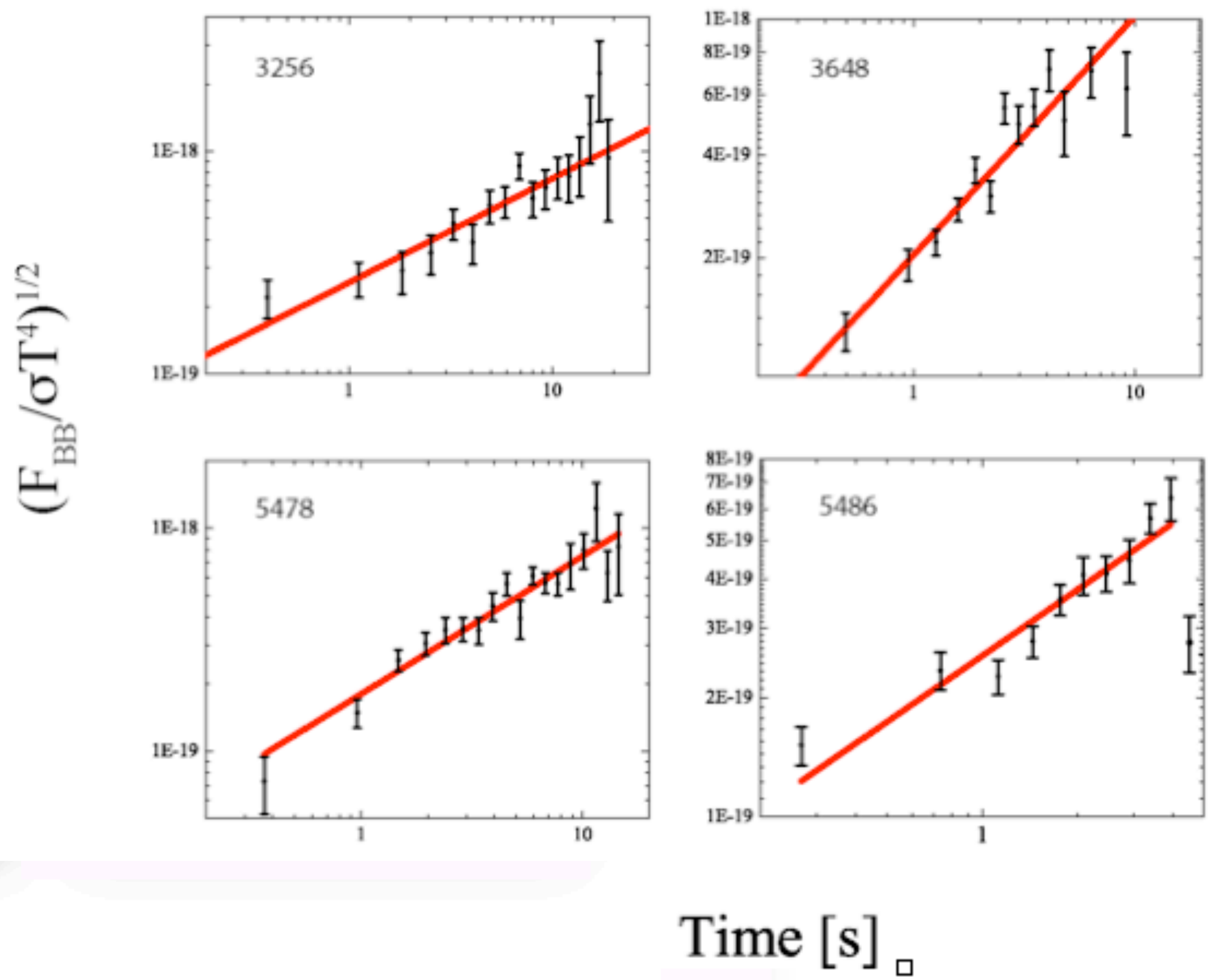
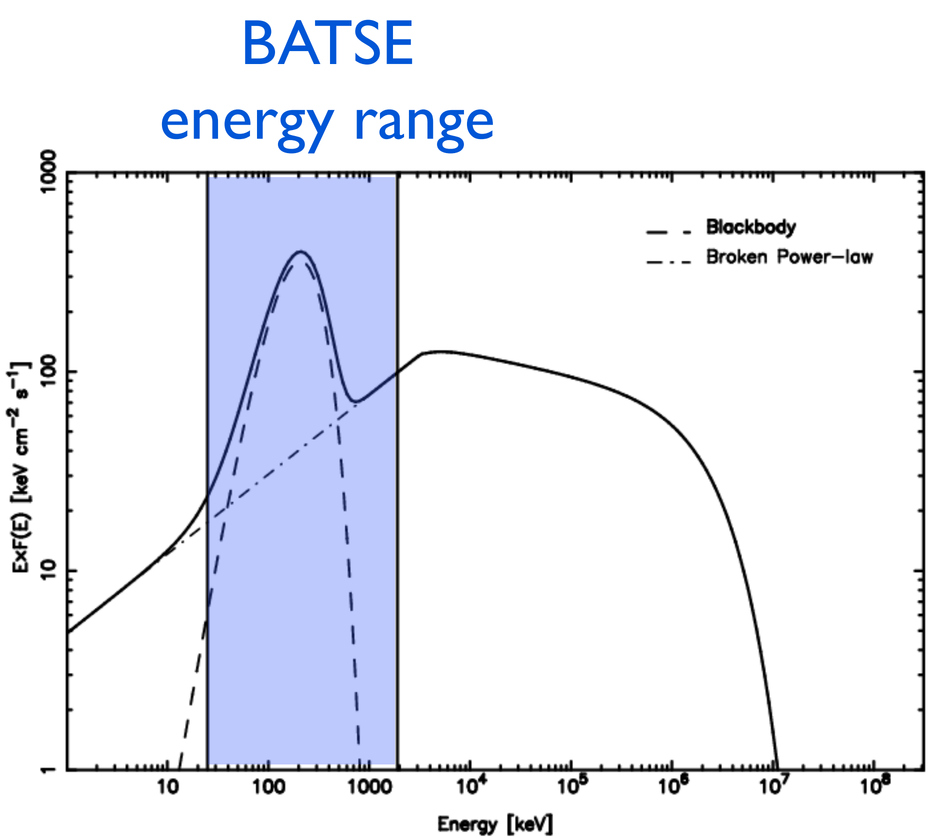


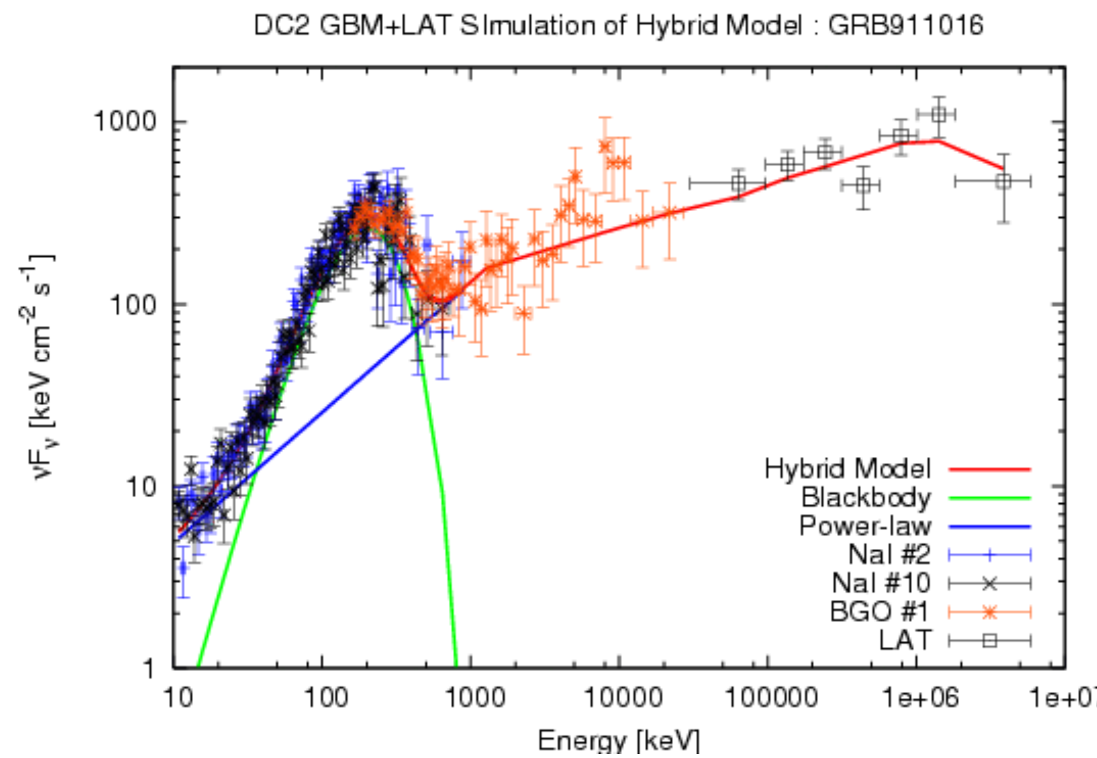
Distinct recurring behavior

Ryde & Pe'er 2009

Predictions for *Fermi* based on BATSE results

Simulations using prelaunch models of the response: gtobsim



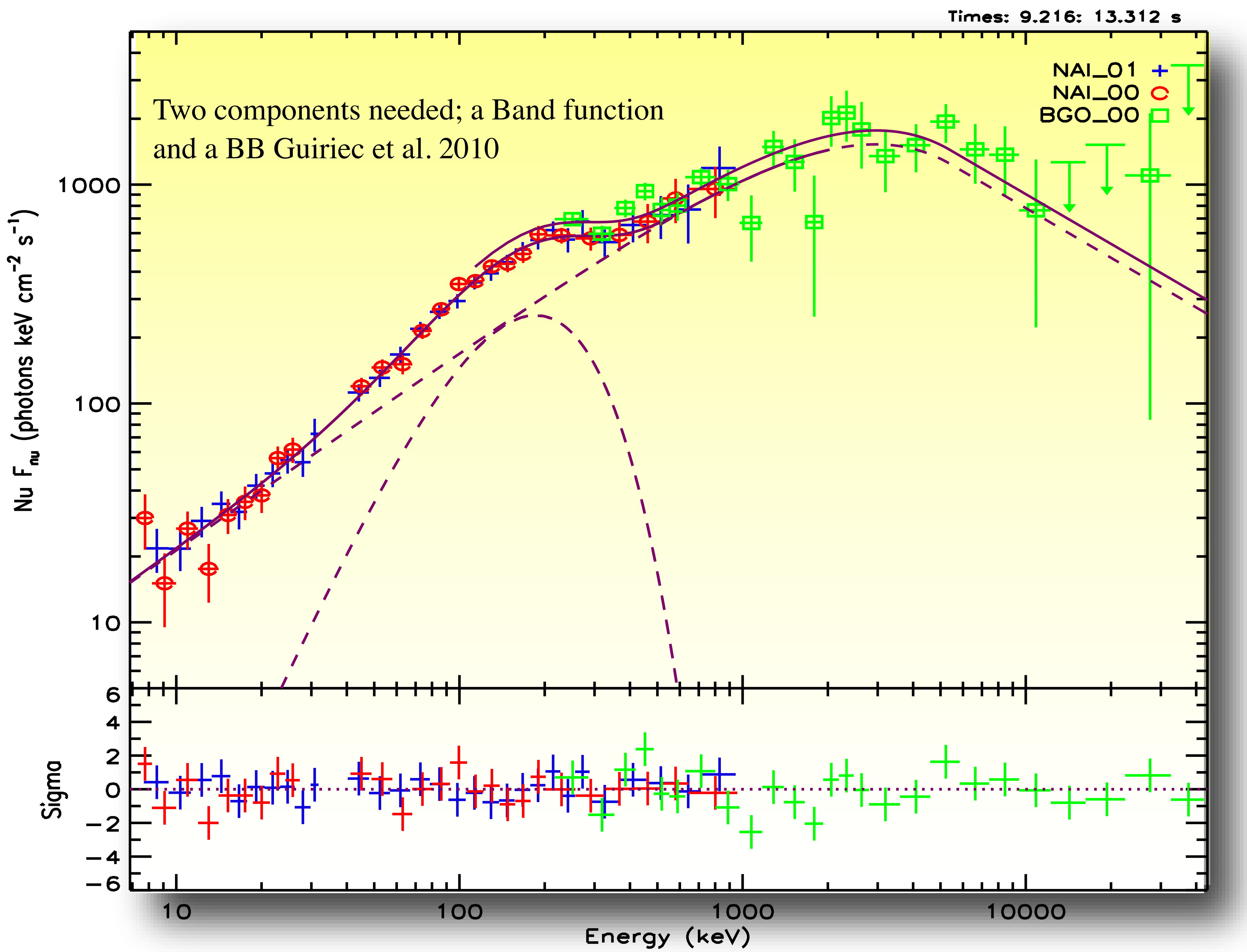


Battelino, Ryde, Omodei, & Longo (2007)

Predictions for *Fermi* based on BATSE results

Simulations using prelaunch models of the response: gtobsim

GRB100724B



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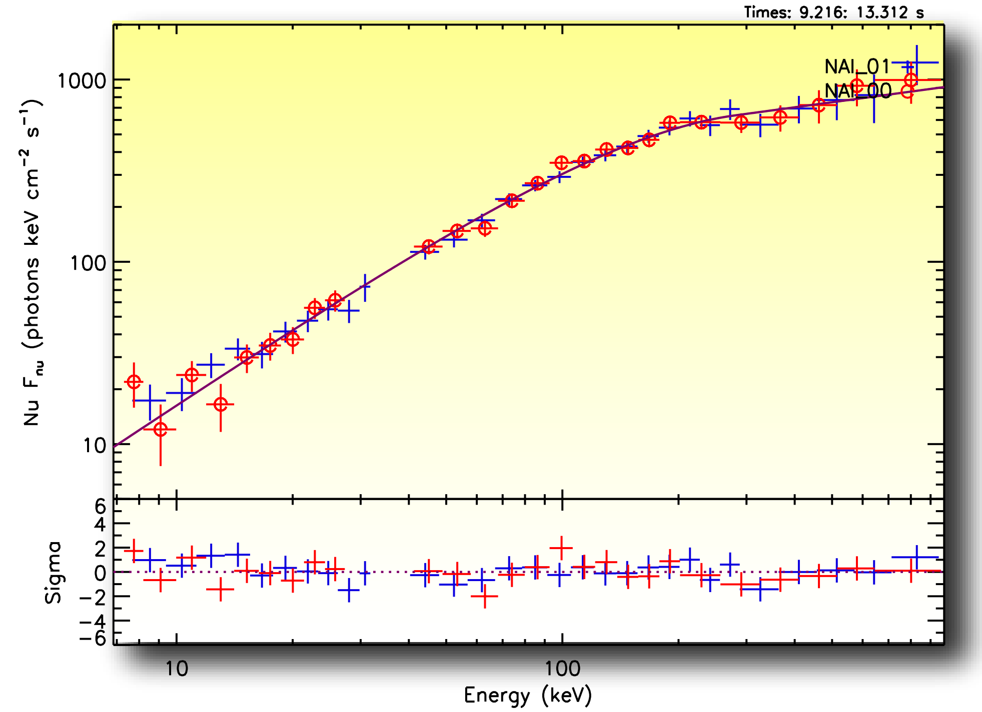
Photosphere in GRB100724B

Guiriec+10

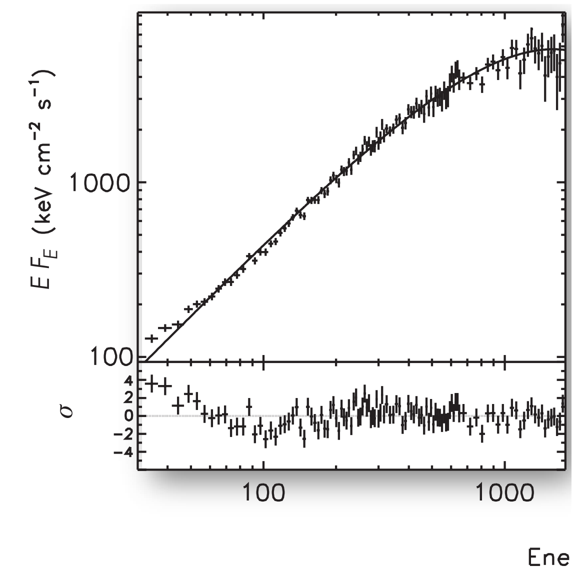
Limiting the band width to 8 keV - 1500 keV (Comparing the BATSE fits)

Band model

NaI
Band

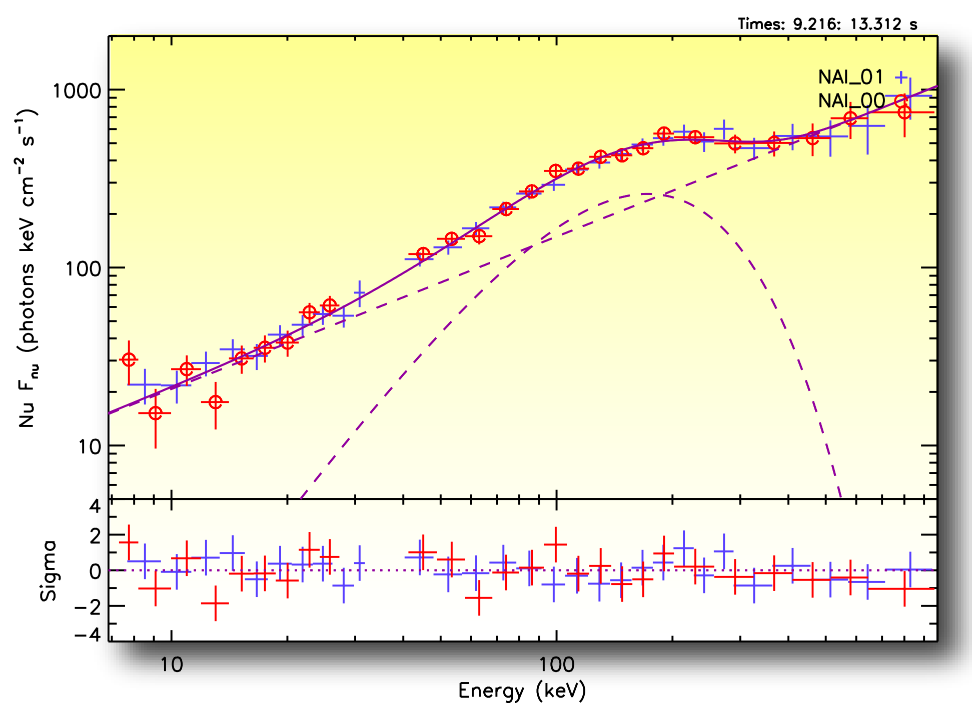


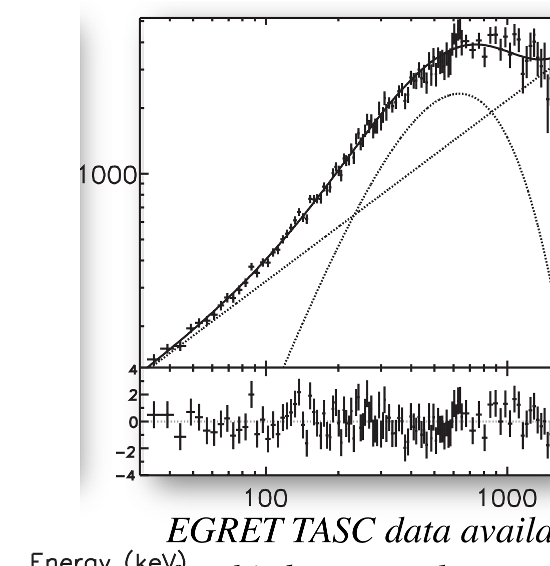
CGRO BATSE fits of GRB981021 (Ryde & Pe'er 2009)



BB+pl model

NaI
BB+pl





EGRET TASC data available for this burst; peak energy = 1600 keV

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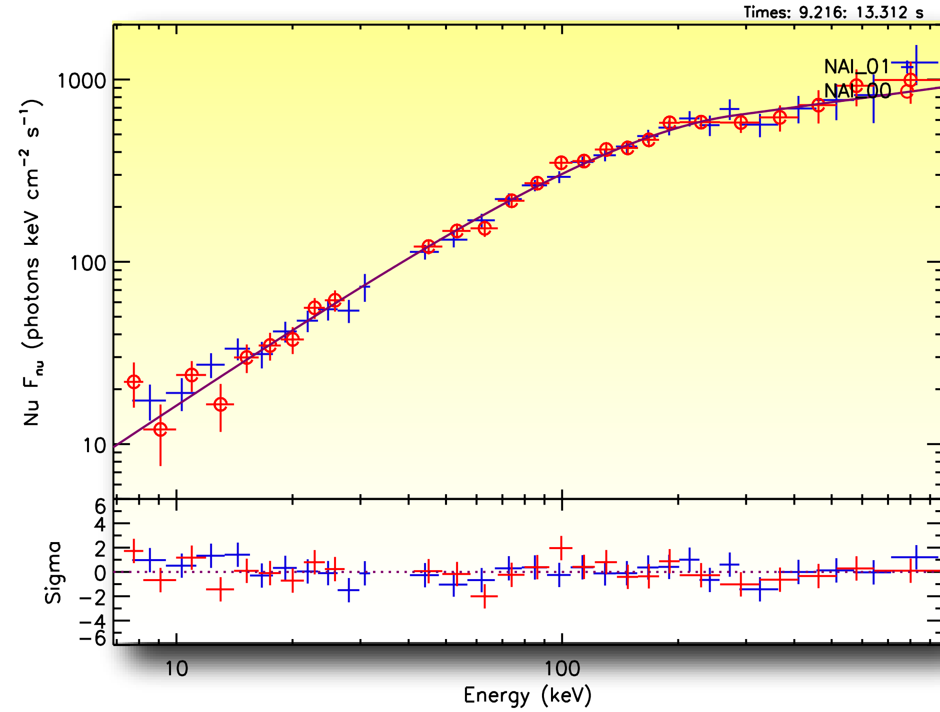

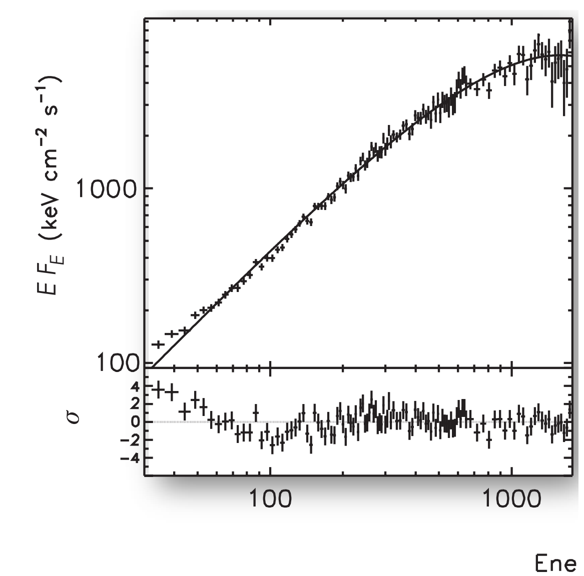

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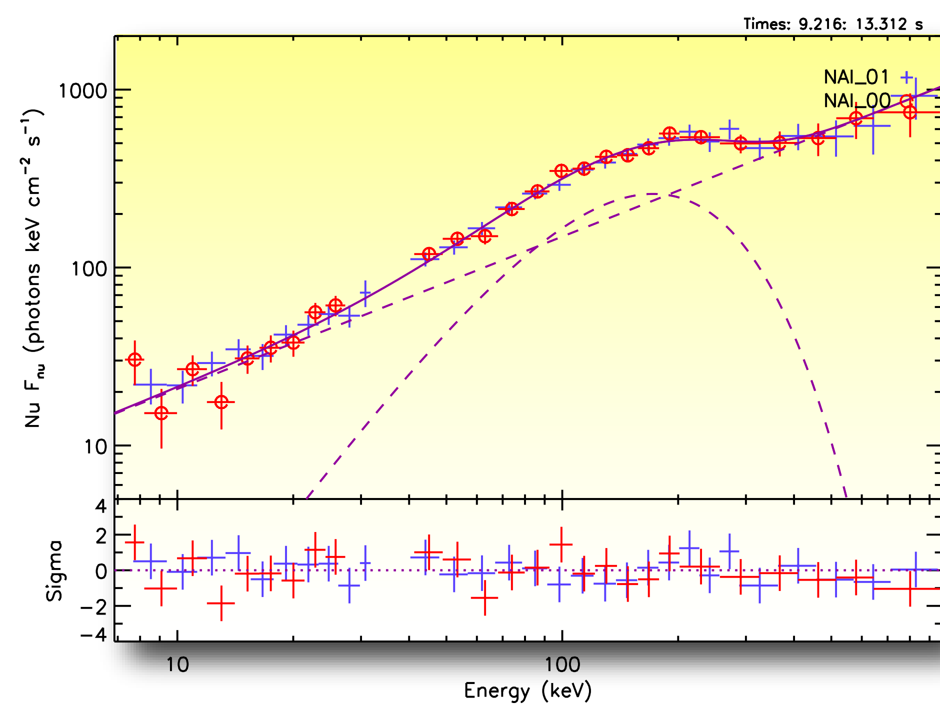

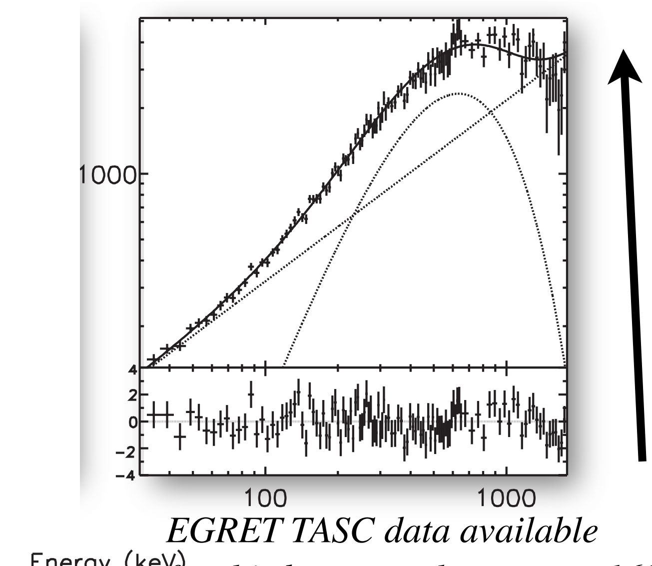

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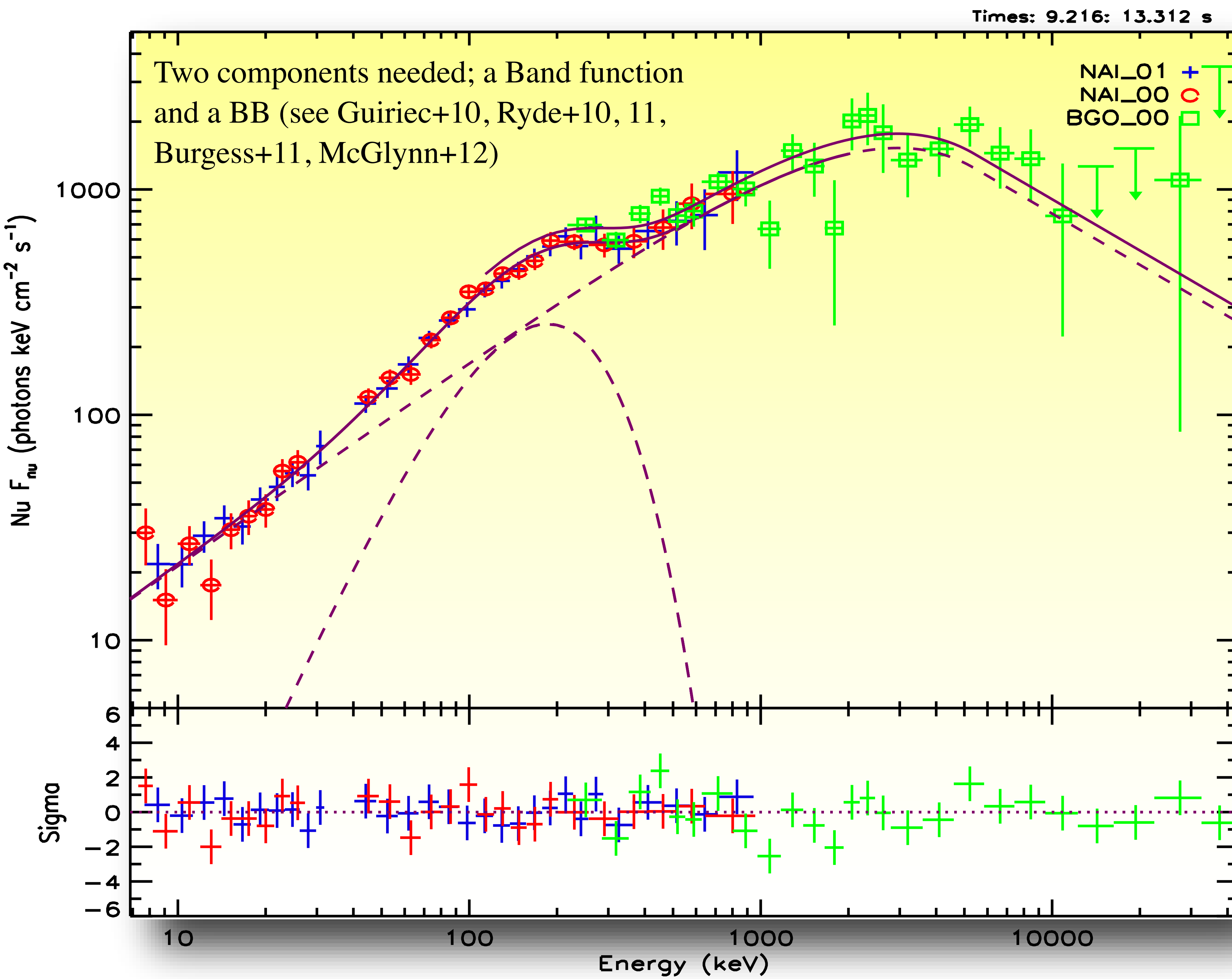
Photosphere in GRB100724B

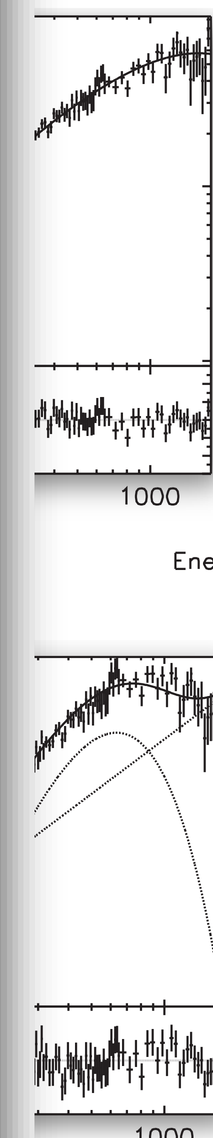
Guiriec+10

ts)

of GRB981021

)



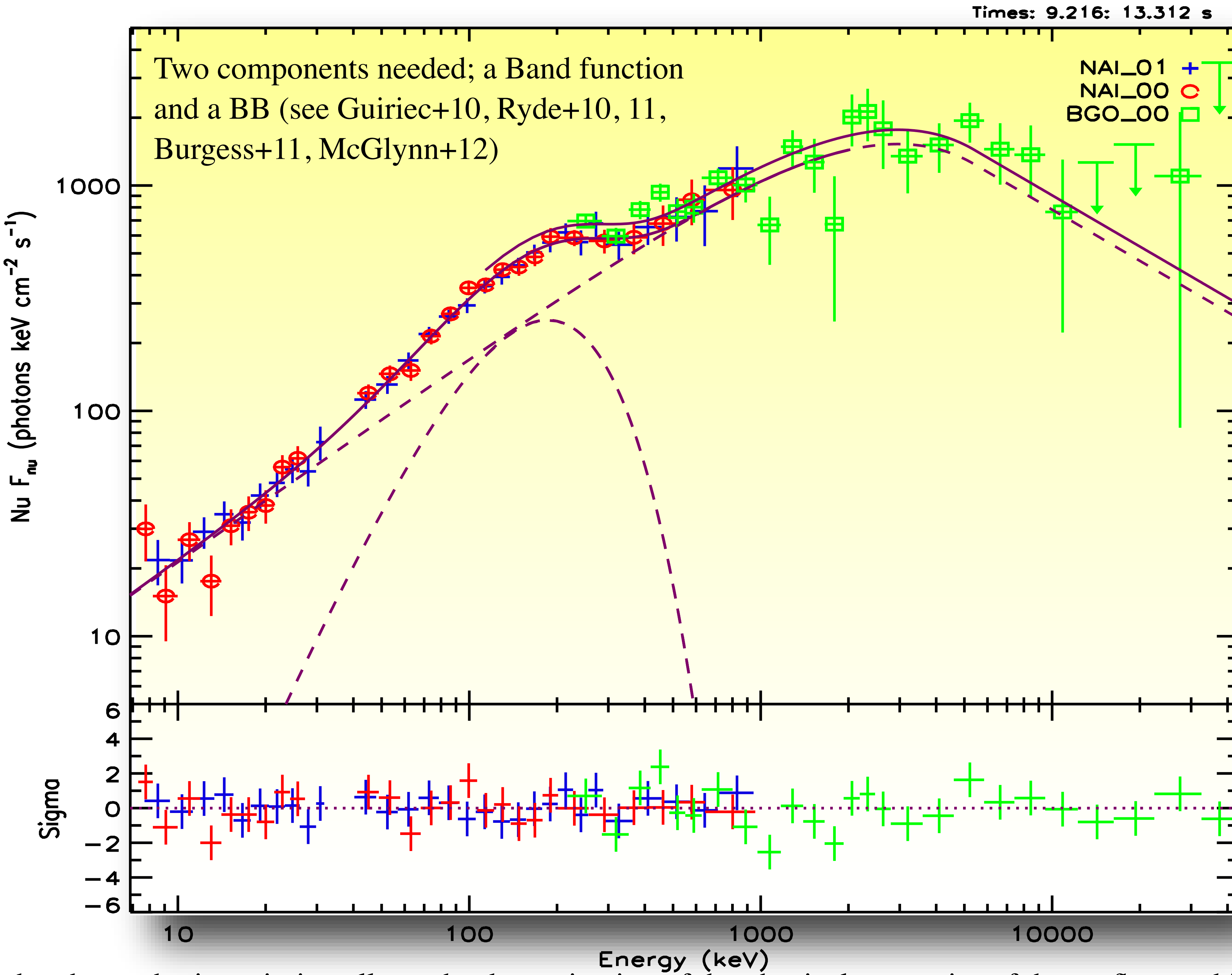


data available

peak energy = 1600 keV

Photosphere in GRB100724B

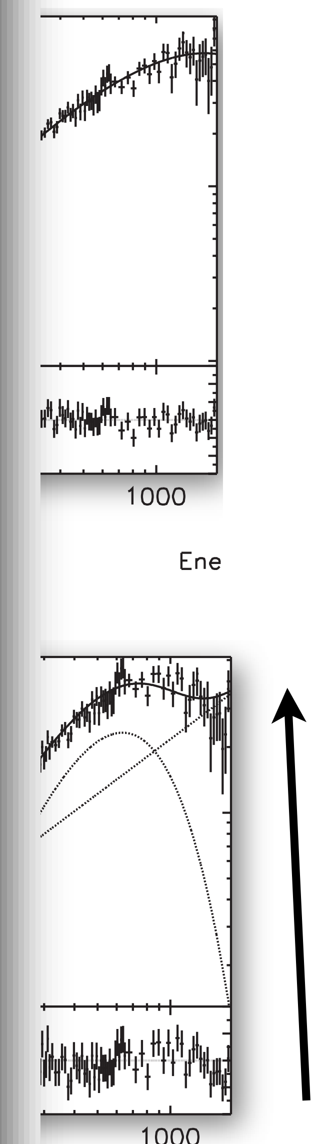
Guiriec+10



ts)

of GRB981021

)



data available

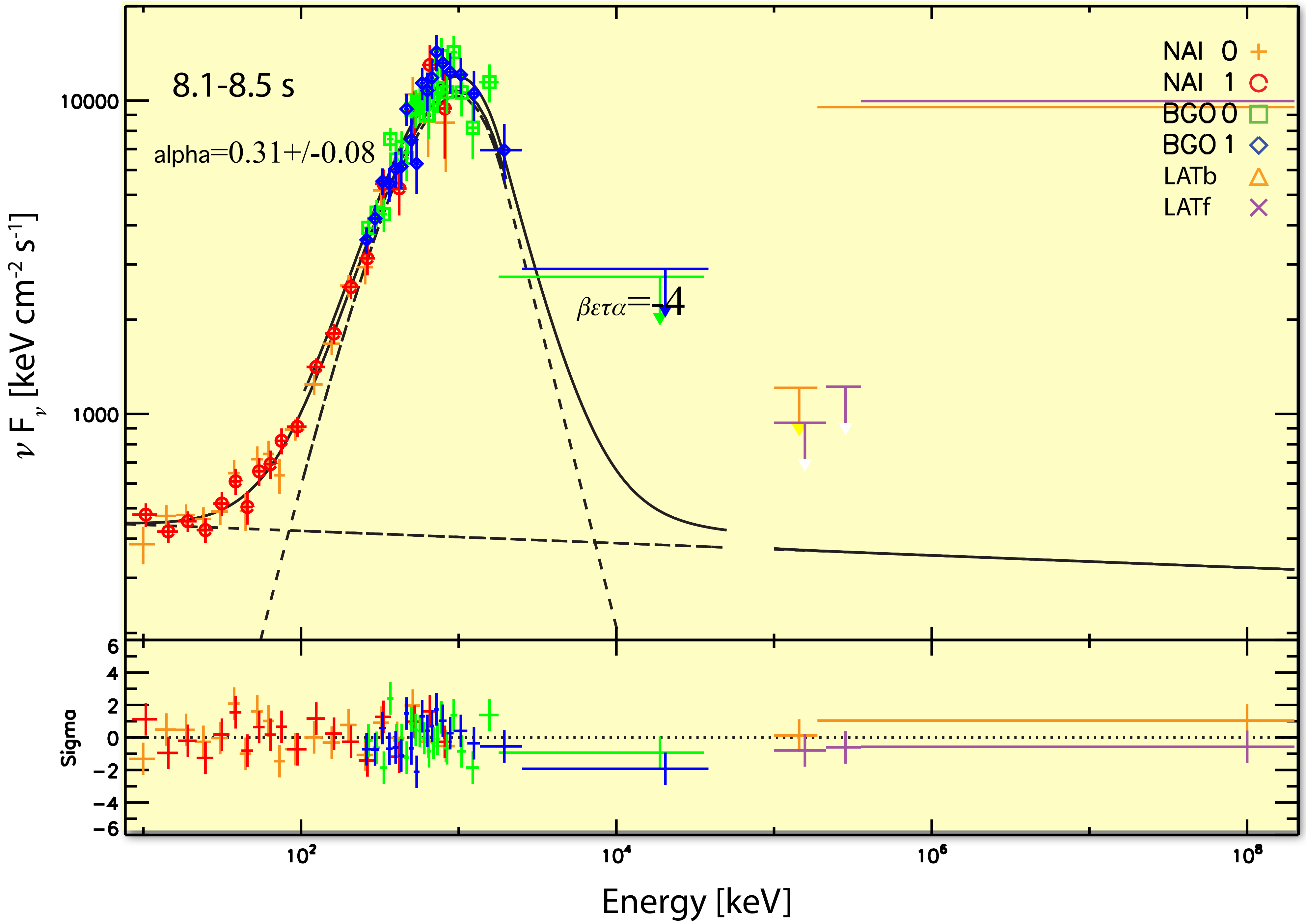
peak energy = 1600 keV

Having identified the photospheric emission allows the determination of the physical properties of the outflow and its photosphere Pe'er+07, Daigne+07.

In this case we find that the bulk Lorentz factor $\Gamma \sim 325$ and photospheric radius $R_{\rm ph} \simeq 5.6 \times 10^{11}$ cm

Fermi Era 2008-

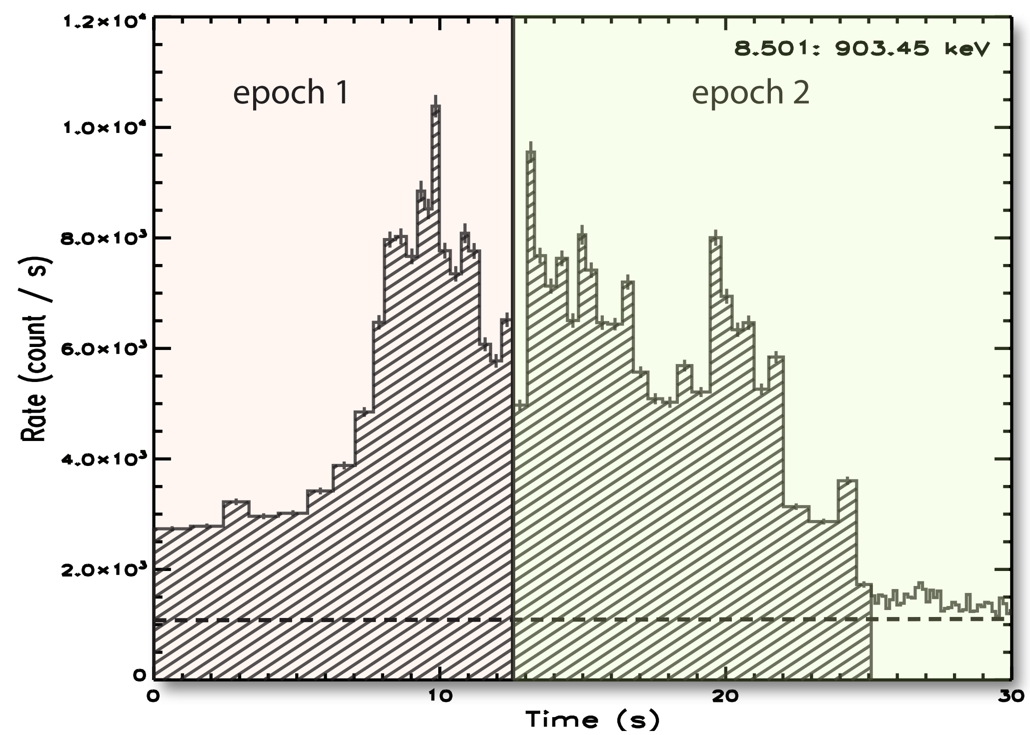
Photosphere in GRB090902B

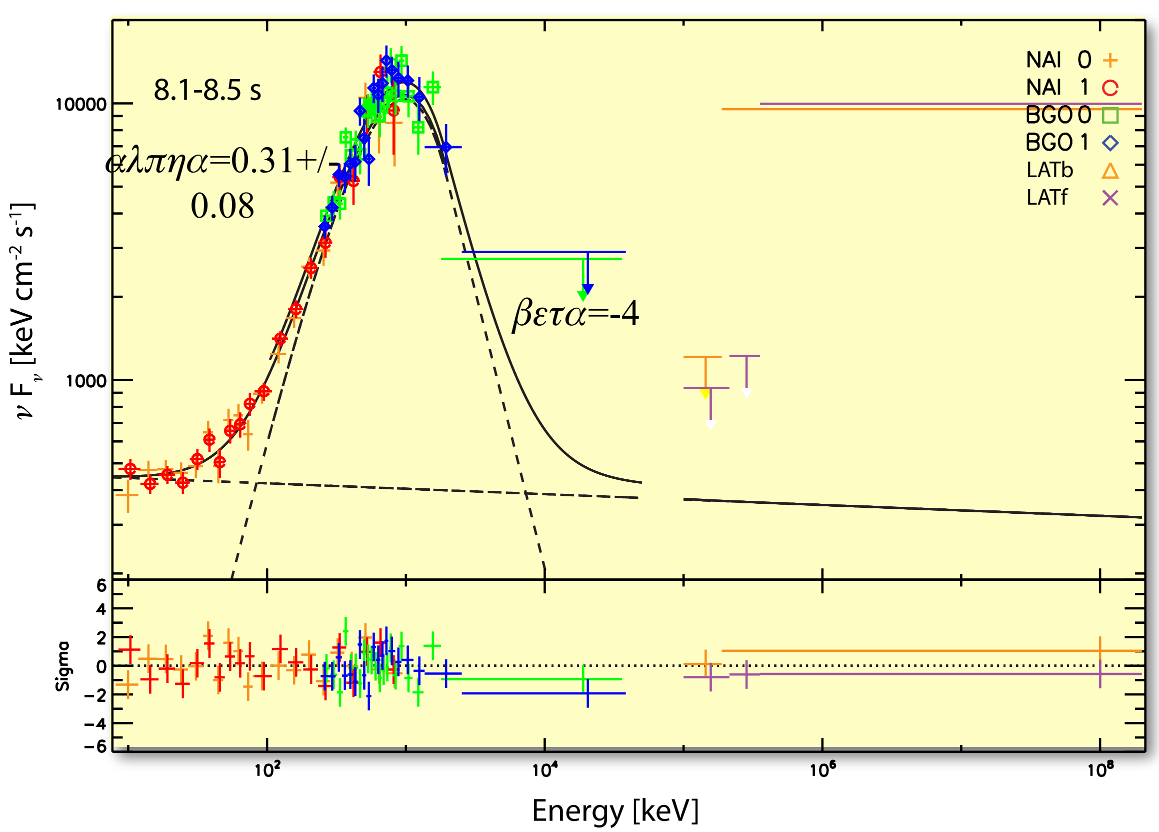


$$\Gamma = 750 \qquad R_{\rm ph} = (1.1 \pm 0.3) \times 10^{12}\, Y^{1/4}\ \rm cm$$

Ryde et al. 2010

Photosphere in GRB090902B





Ryde et al. 2011

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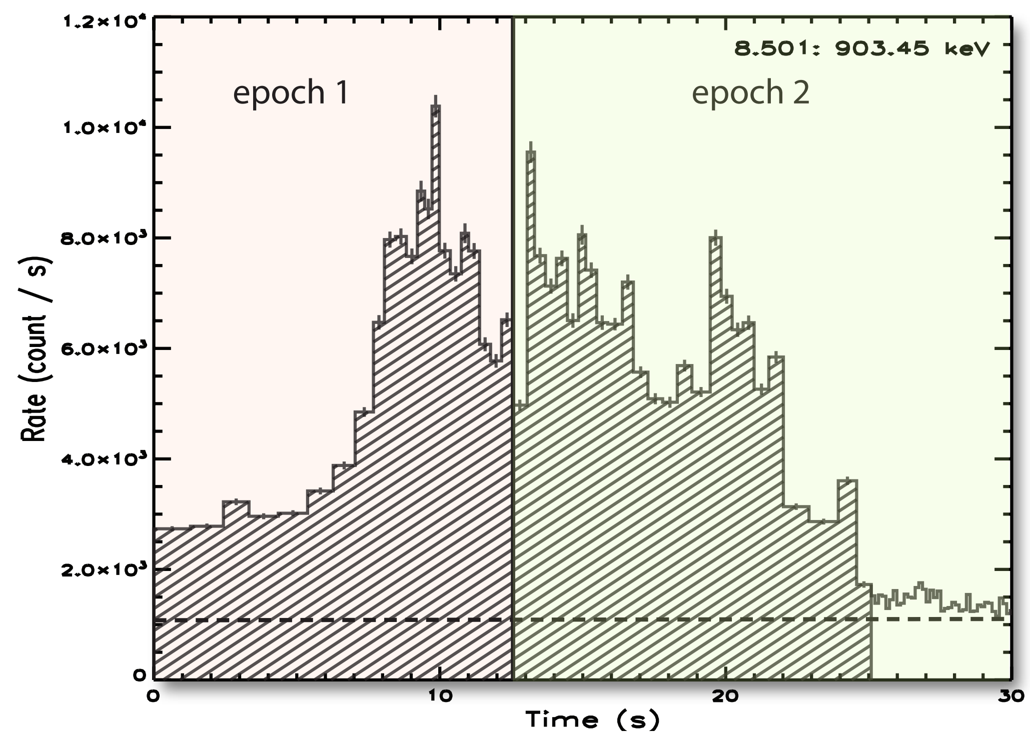
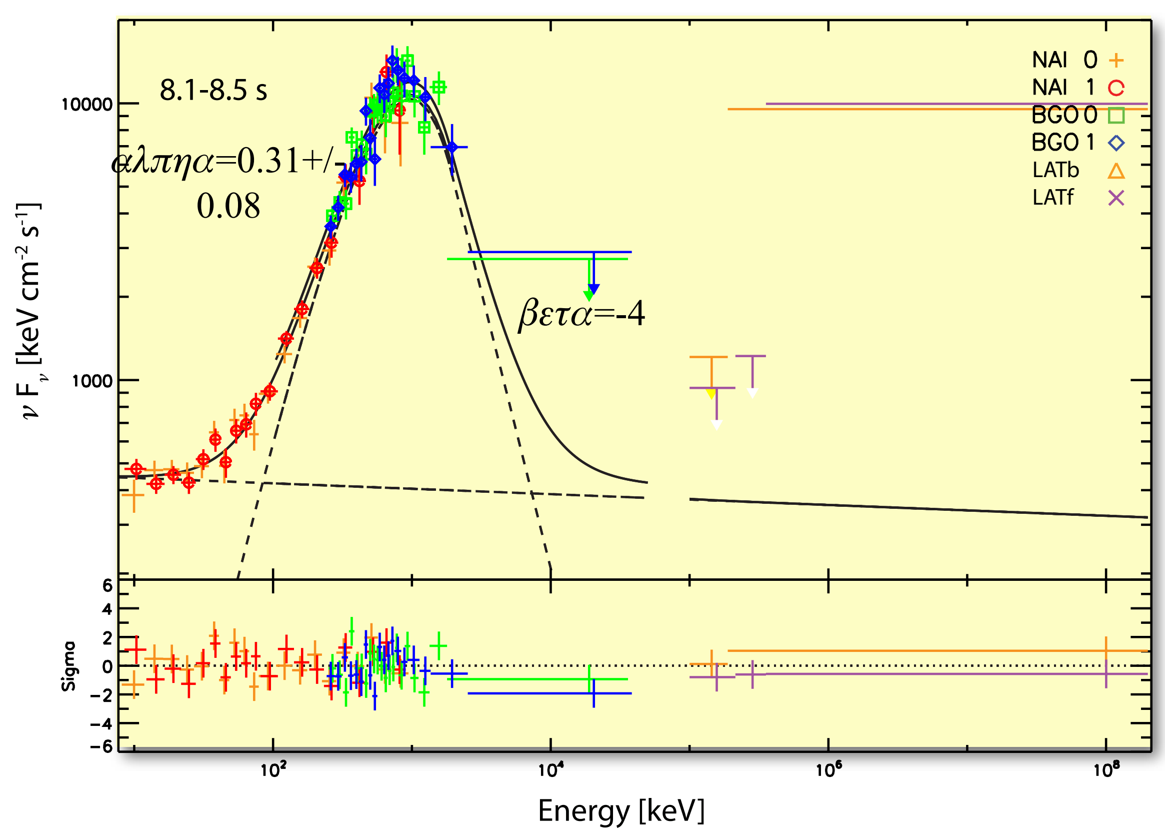
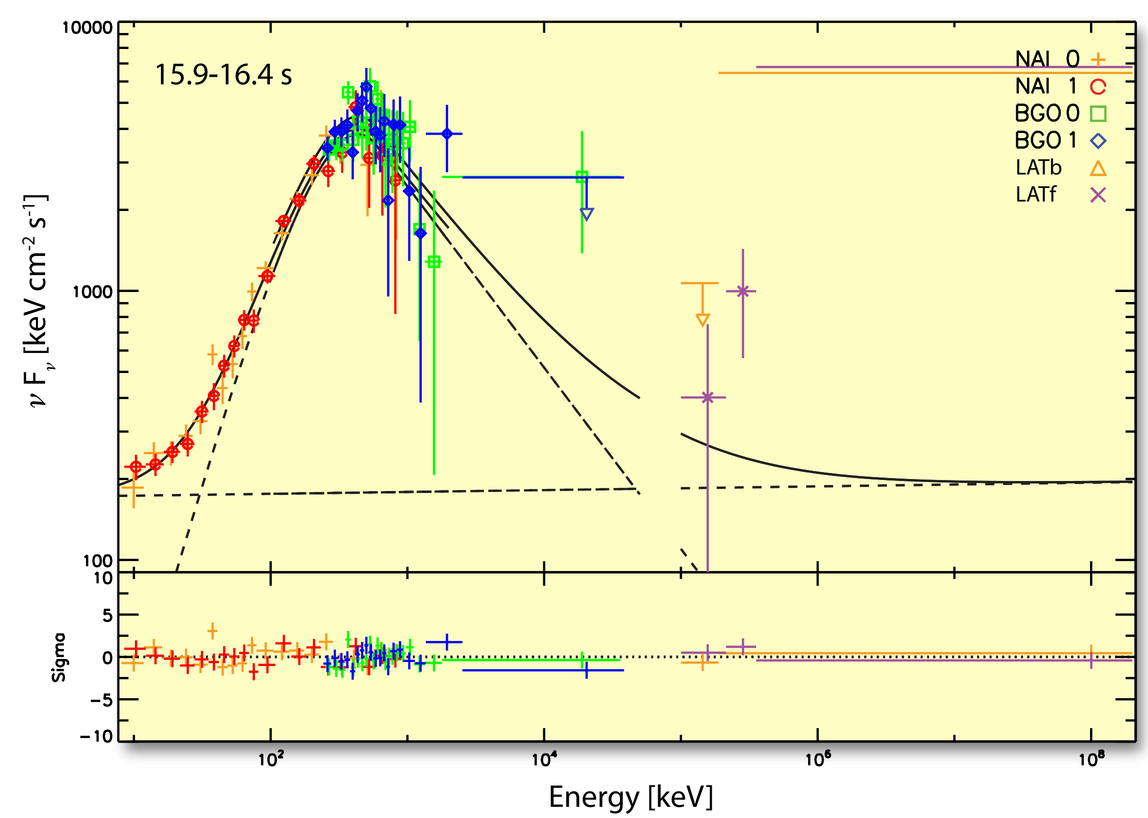




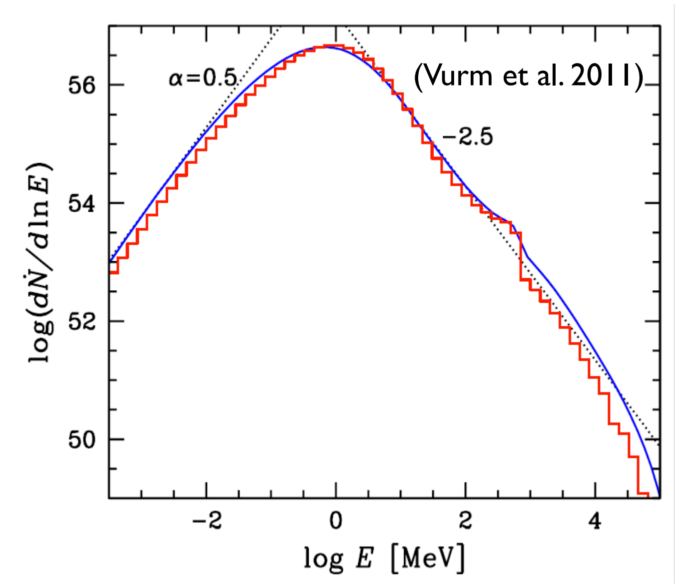


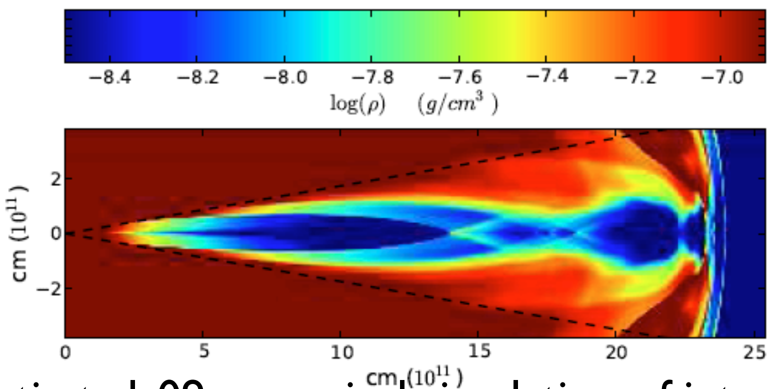
Ryde et al. 2011

Modification of Planck spectrum

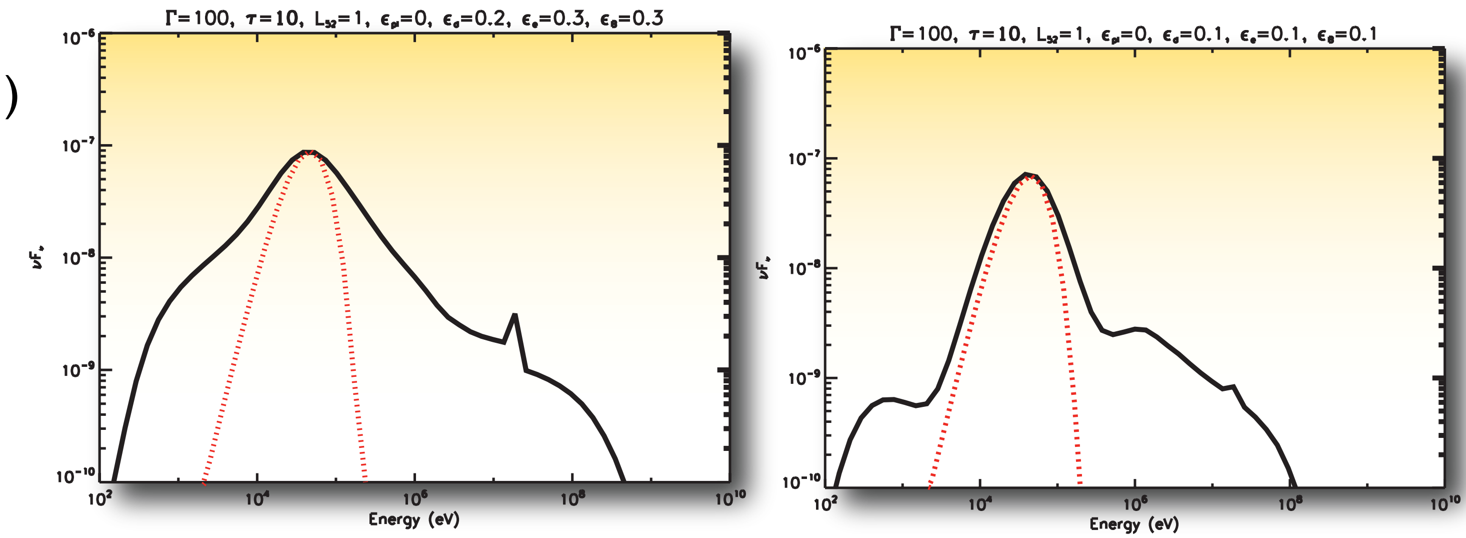
Idea: a heating mechanism below
the photosphere modifies the Planck spectrum
Rees & Meszaros 2005

- Internal shocks
  (Peer, Meszaros, Rees 06, Toma+10, Ioka10)
- Magnetic reconnection
  (Giannions 06, 08)
- Weak / oblique shocks
  (Lazzati, Morsonoi & Begelman 11, Ryde & Peer 11)
- Collisional dissipation
  (Beloborodov 10, Vurm, Beloborodov & Poutanen 11)





Lazzati et al. 09 numerical simulation of jet propagation.
See also Mizuta 11,Toma11



Nymark et al. 2011, Pe'er et al. 2006

Emission from the photosphere is NOT seen as Planck !

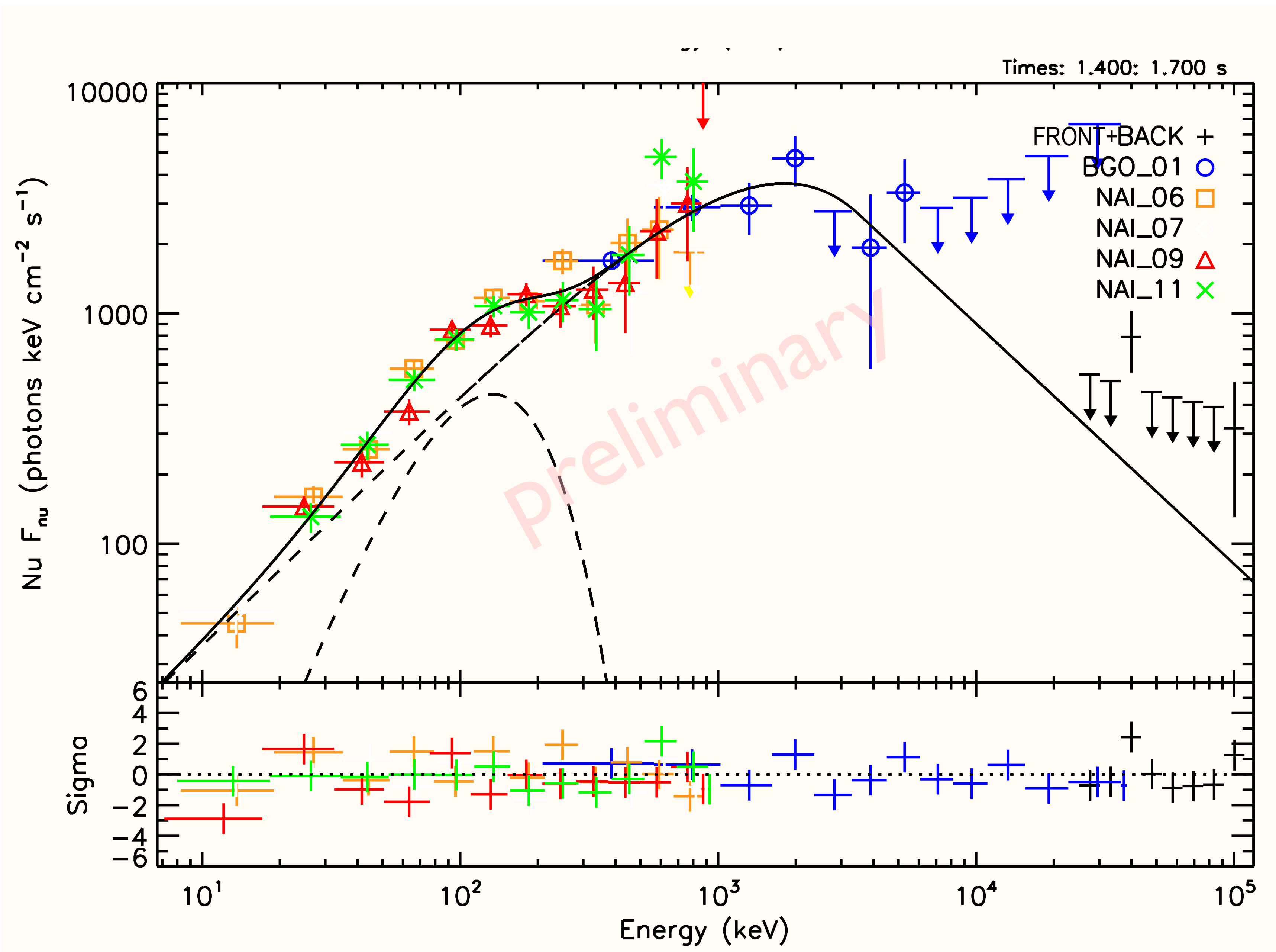
Fermi Gamma-ray Space Telescope

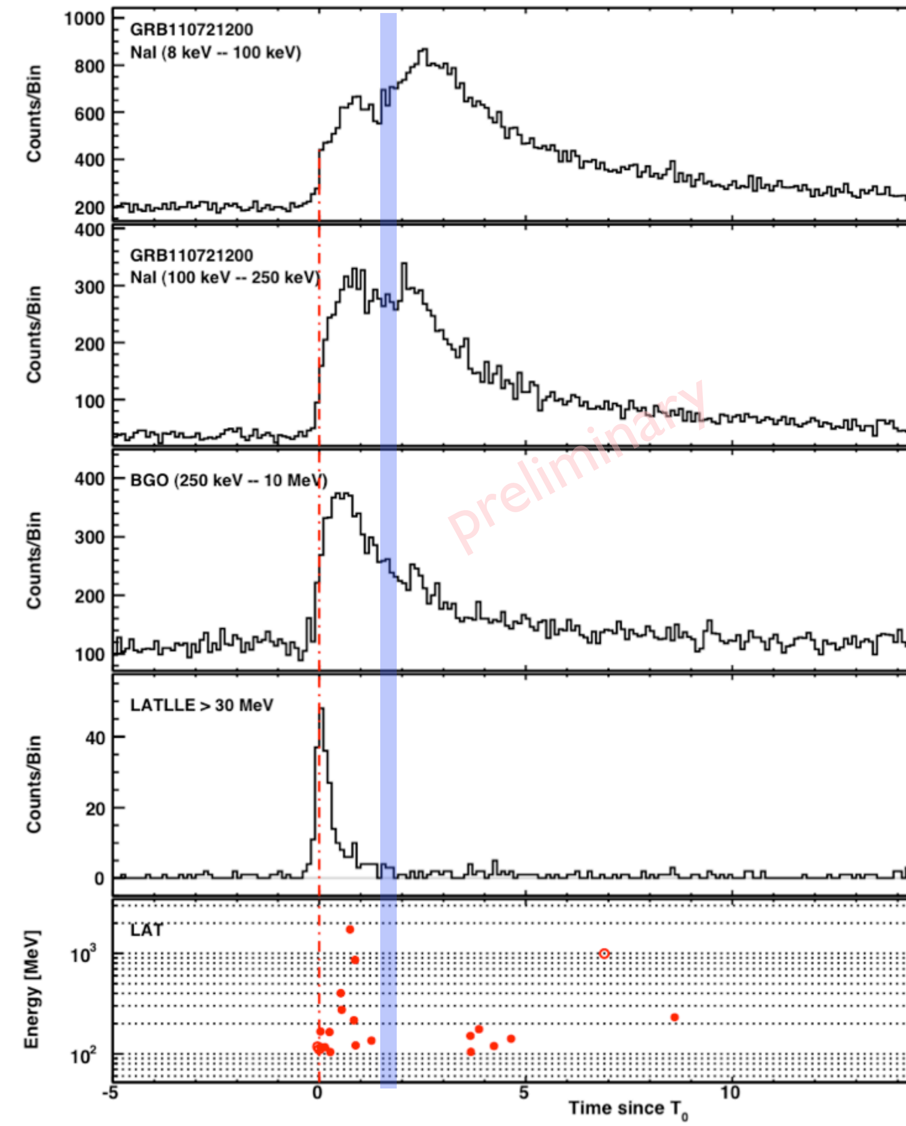
GRB 110721A

(Fermi collaboration, in prep.)

Time resolved spectra consists of two peaks, one at 100 keV and one at ~ MeV

Time resolved spectrum:



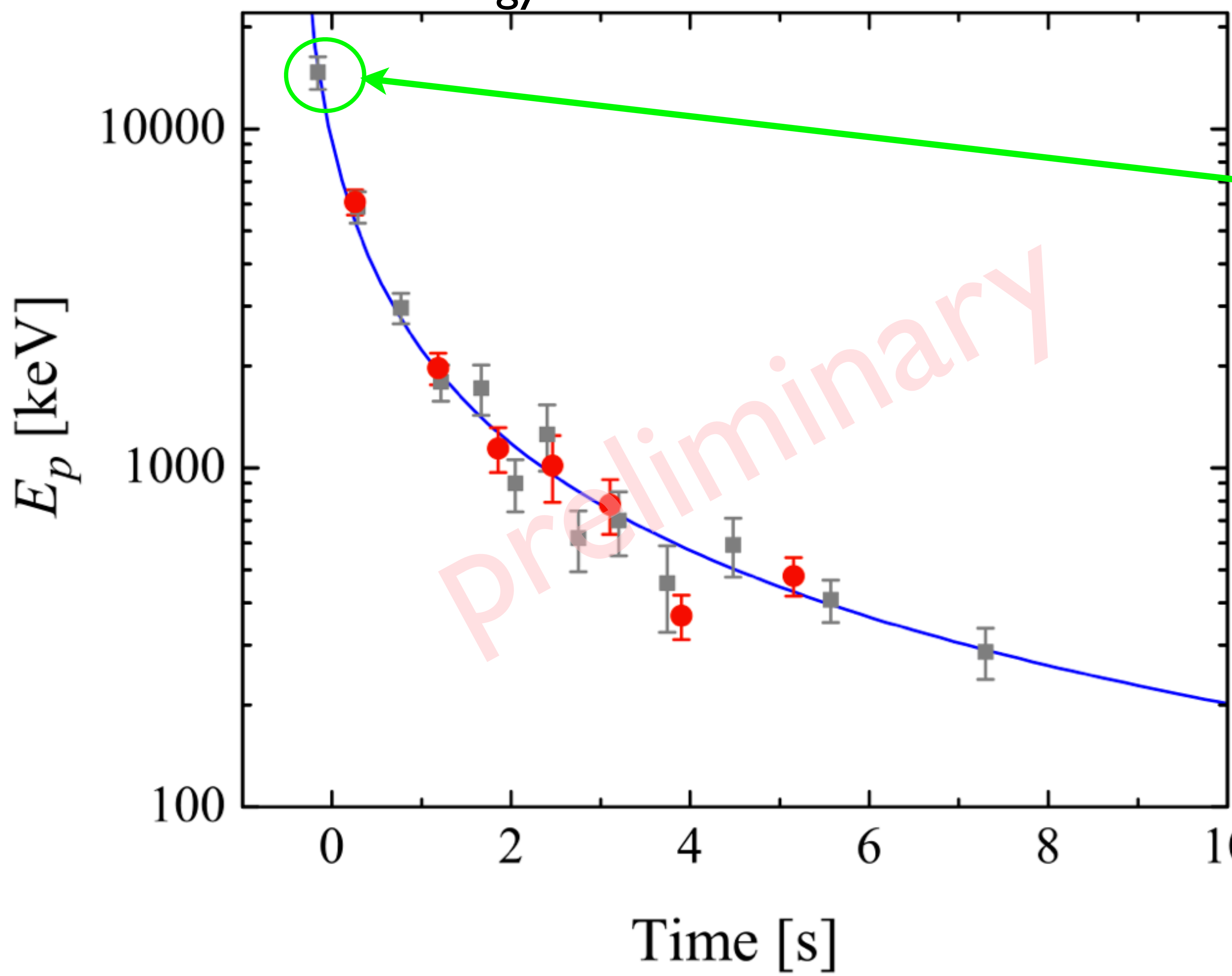


Best fit model:
Band function +
Planck function

GRB 110721A

Exceptionally high peak energy 15 MeV during initial time bin [-0.32: 0 s]

Peak energy evolution as a function of time



$\alpha = -0.81^{+0.07}_{-0.06}$

$\beta = -4.1^{+0.4}_{-0.7}$

$E_{\rm pk} = 15.2^{+1.3}_{-1.2}$ MeV

Importance of BGO and LLE data!

$$E_p = A_{\rm pl}(t - t_0)^p$$

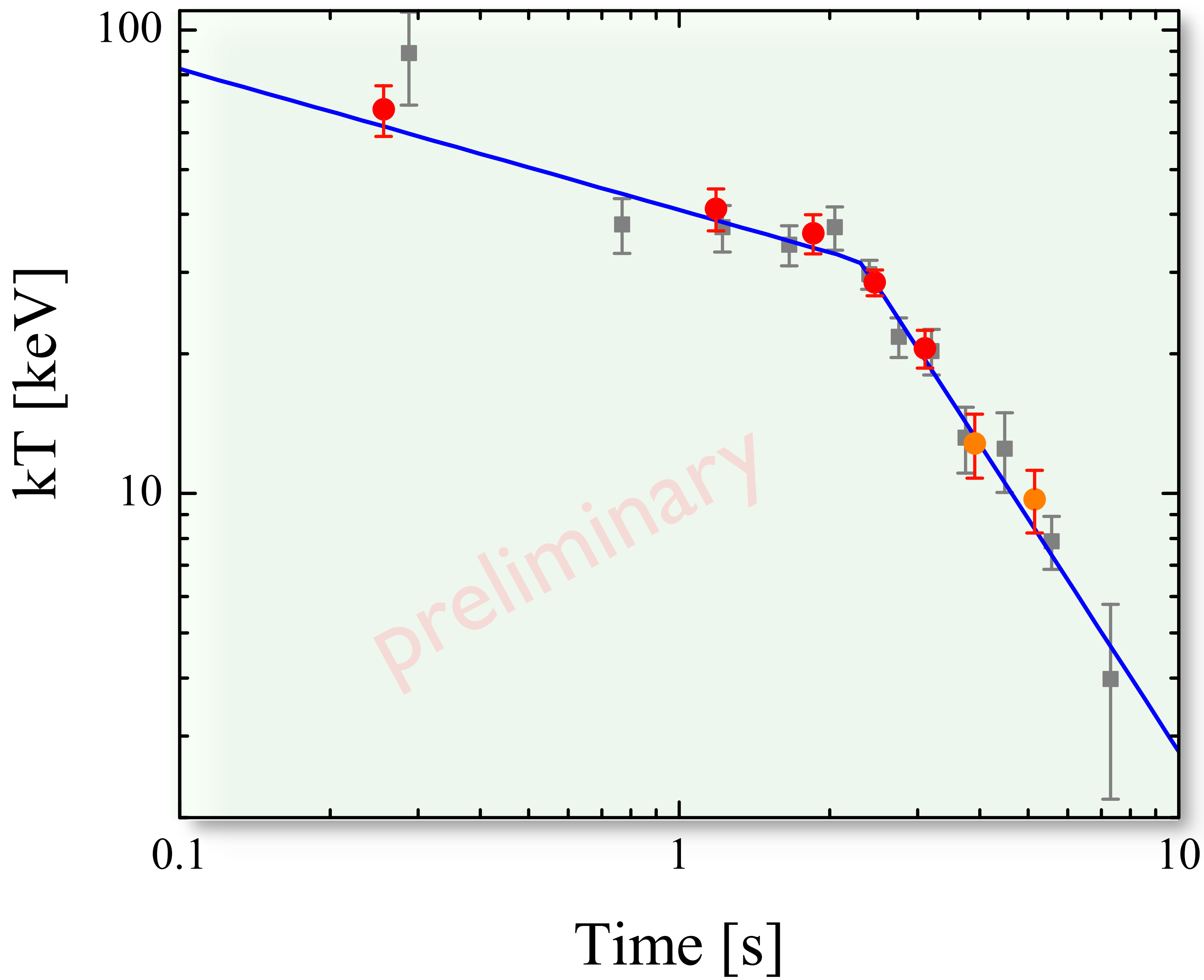
$p = 1.89 \pm 0.35$

$t_0 = -0.8 \pm 0.3$ s

cf. Lloyd & Petrosian (1998)

GRB 110721A

Significant temperature evolution



Red points: >5 *σιγμα* detection of a extra (blackbody) component

Orange points ~3 *σιγμα* detection of a extra (blackbody) component

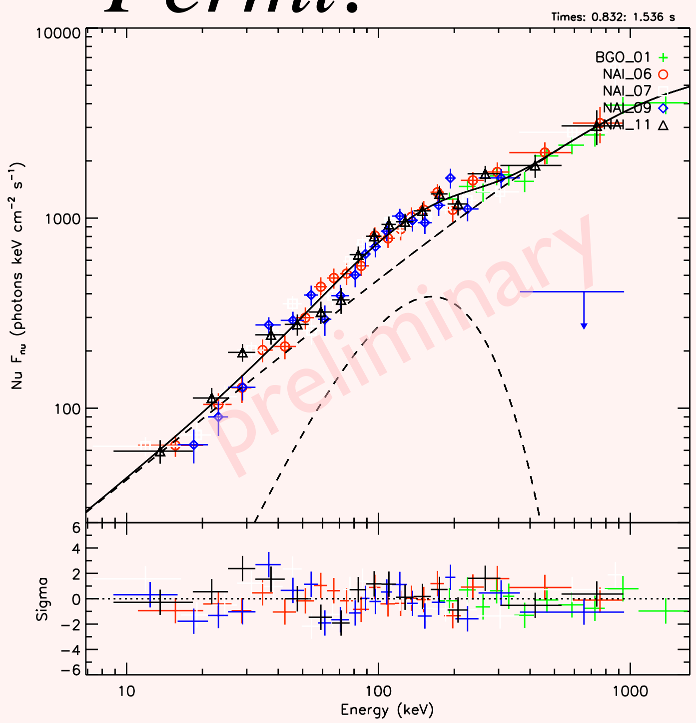
Grey points: higher time resolution gives lower significance in each bin. However the characteristic trend is confirmed.

Evolution different from *Ep* and normalization!

In this case: $\Gamma \sim 210$ and $R_{\rm ph} = (5.7 \pm 0.8) \times 10^{11}$ cm

Comparison to BATSE analysis:

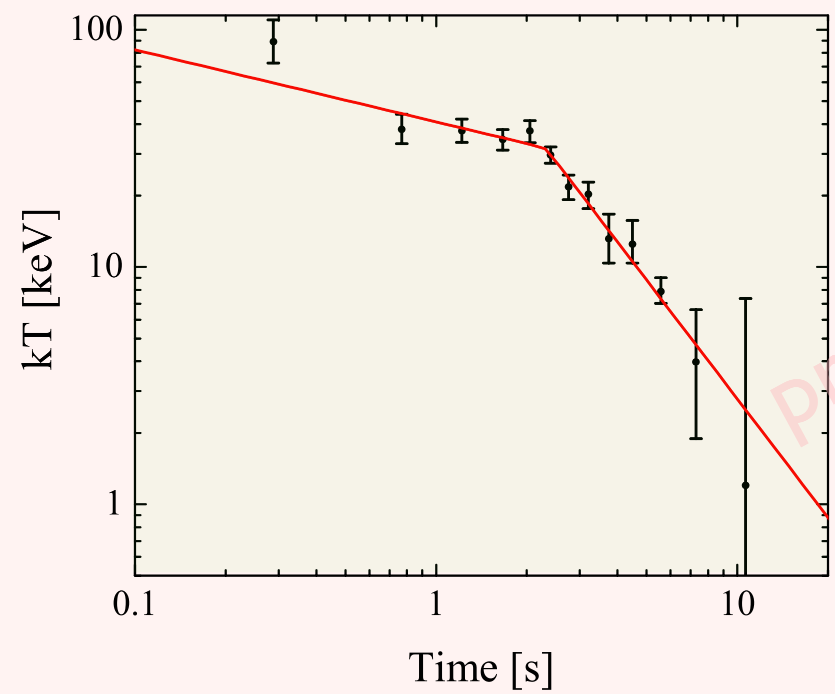
Fermi:

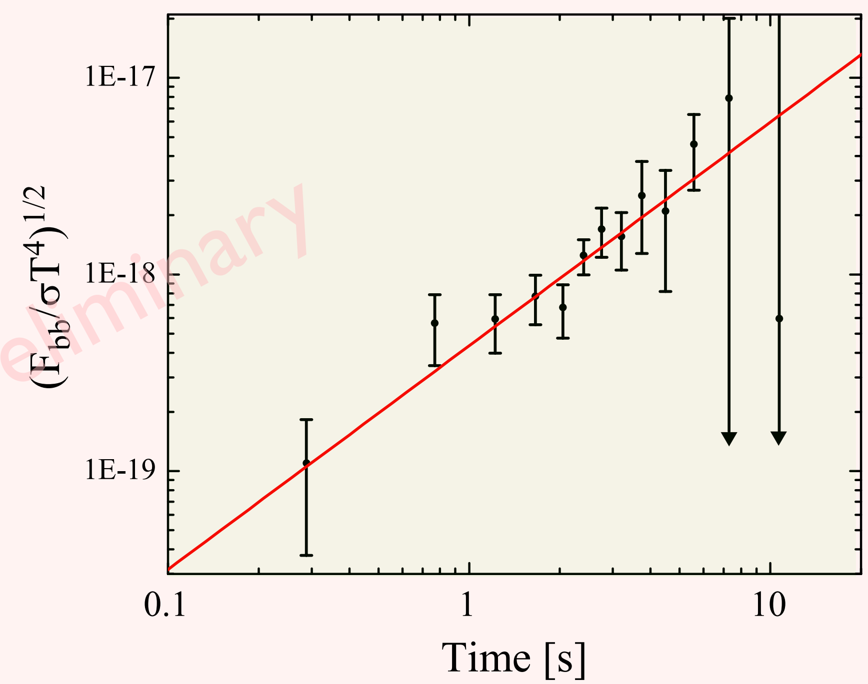


Temperature

GRB110721

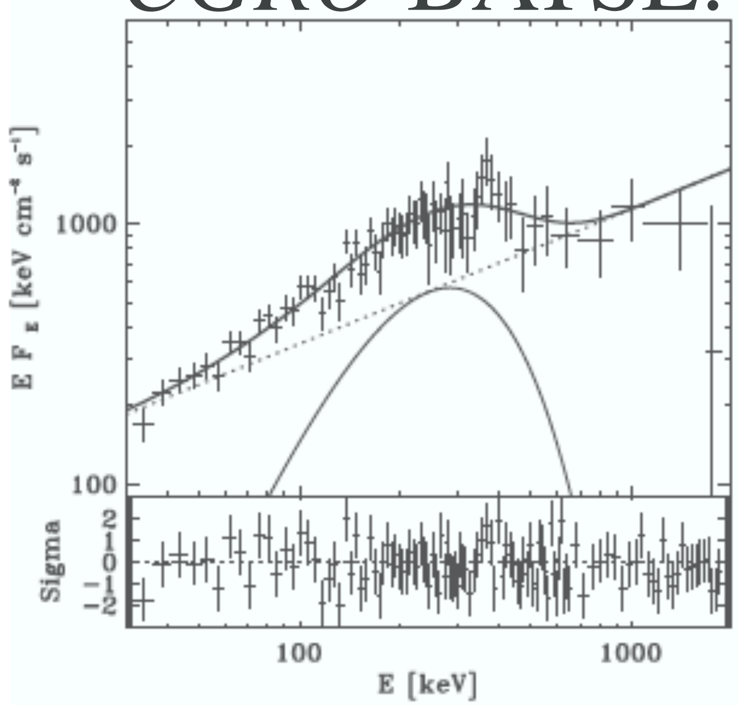
Normalization

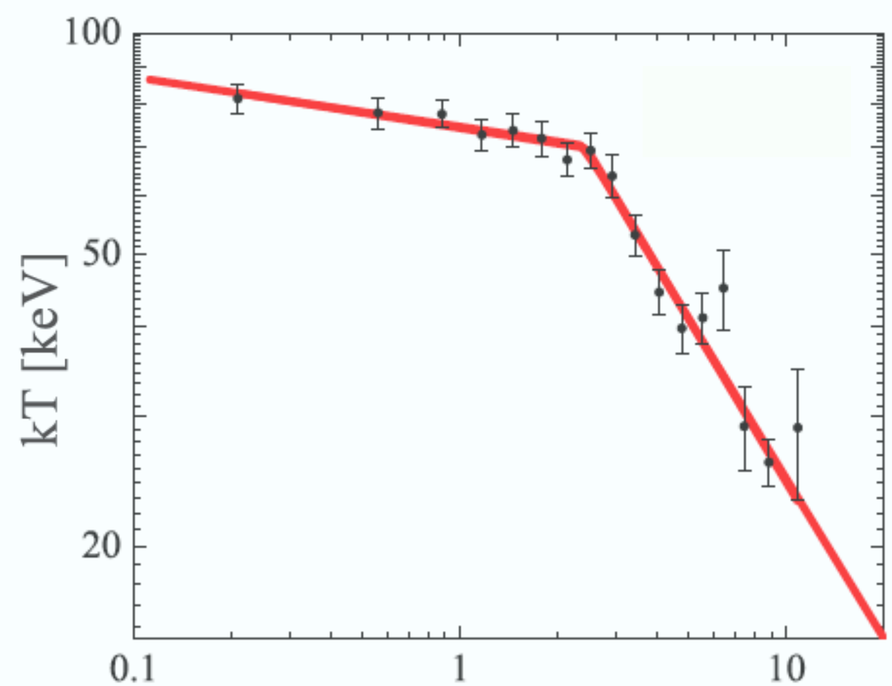


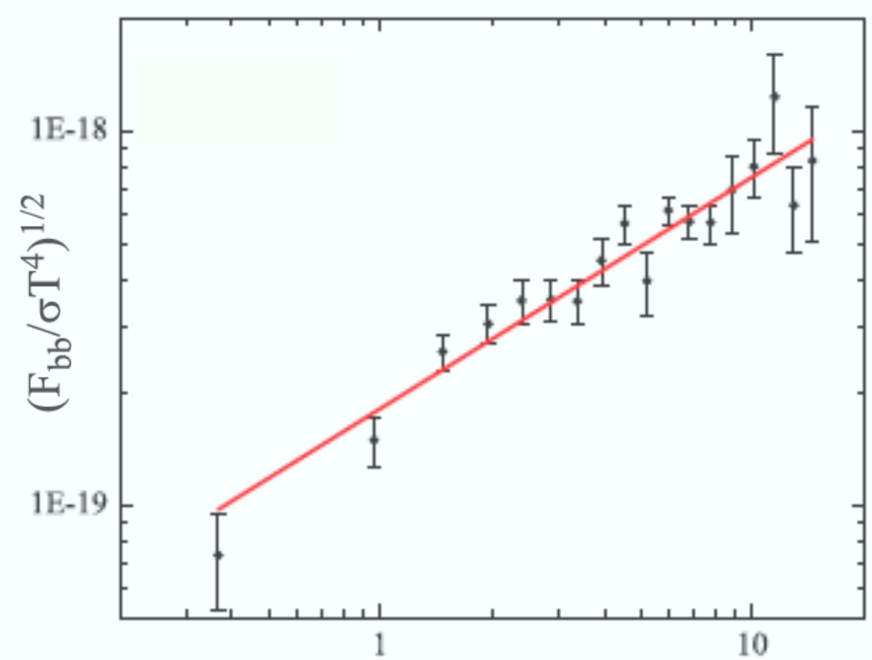


Fermi collab. in prep.

CGRO BATSE:







Ryde & Pe'er (2009)

Conclusions

- *Fermi* confirms BATSE results on thermal emission in GRBs

- Many GRBs have a **'double humped' spectra** and the Band function cannot model their shapes. *(Guiriec+10,12, Ryde+10, 11, Burgess+11, McGlynn+12, Fermi coll.+12)*

- The **addition of a blackbody** spectrum improves the fit in many cases, and follows well-defined characteristics.

- The spectrum emerging from the photosphere does **not need to be a Planckian**. It can be broadened due to subphotospheric dissipation.

- The inclusion of the blackbody is the first step towards an **understanding the physical origin** of the prompt emission: The Band function does not provide it.