Varying faces of photospheric emission in gamma-ray bursts

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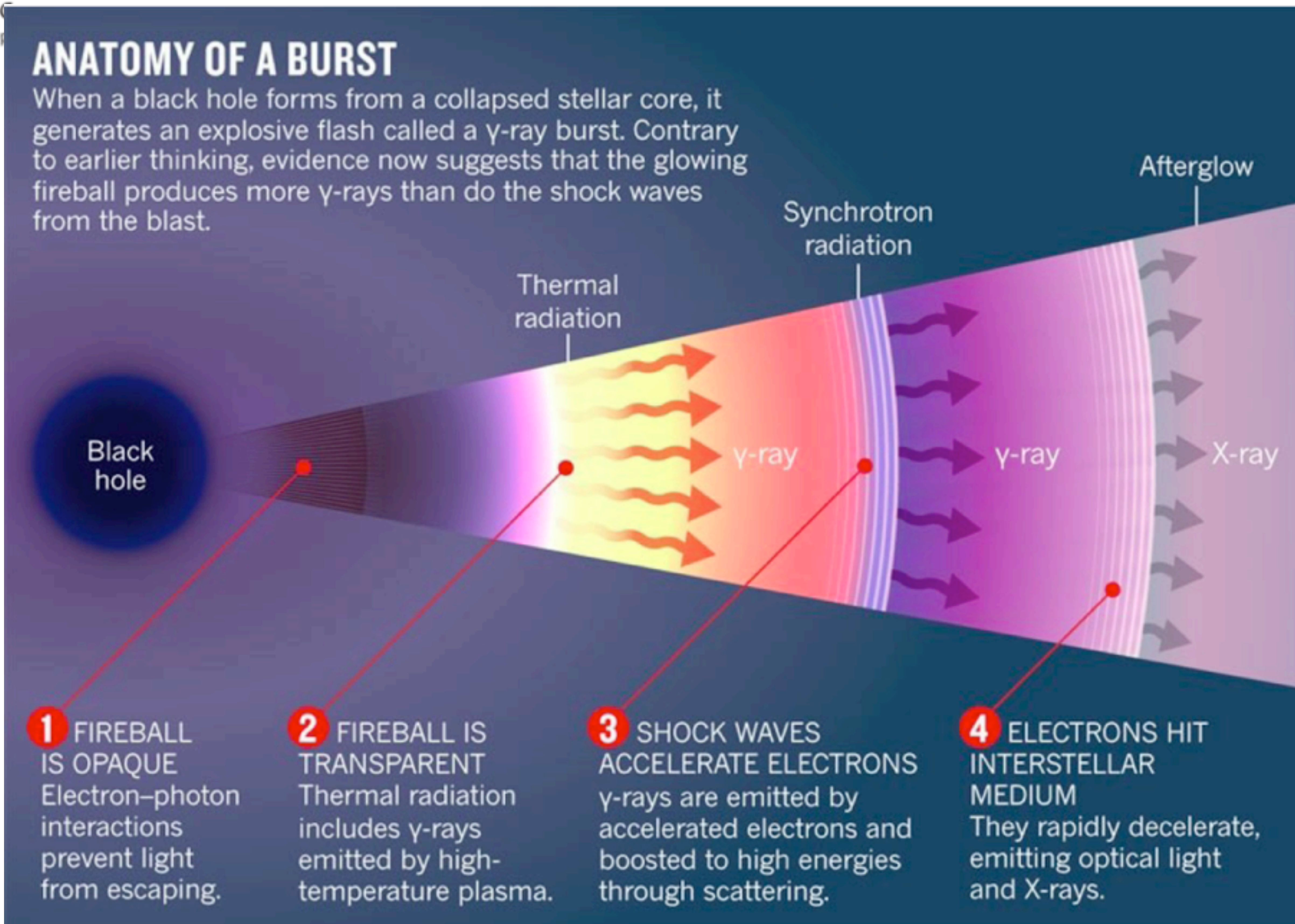
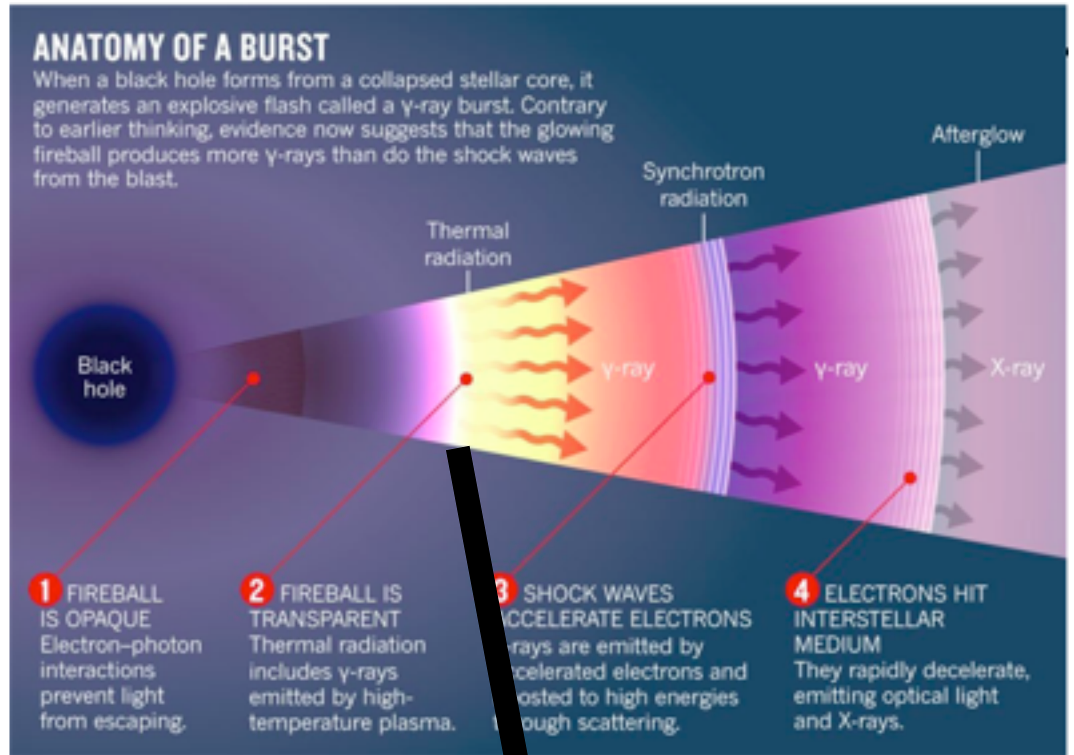
On behalf of the *Fermi* GBM and LAT teams

5th *Fermi* Symposium, Nagoya, Japan (Oct 20-24, 2014)

Basic framework: the fireball model





Paczyński 1986:

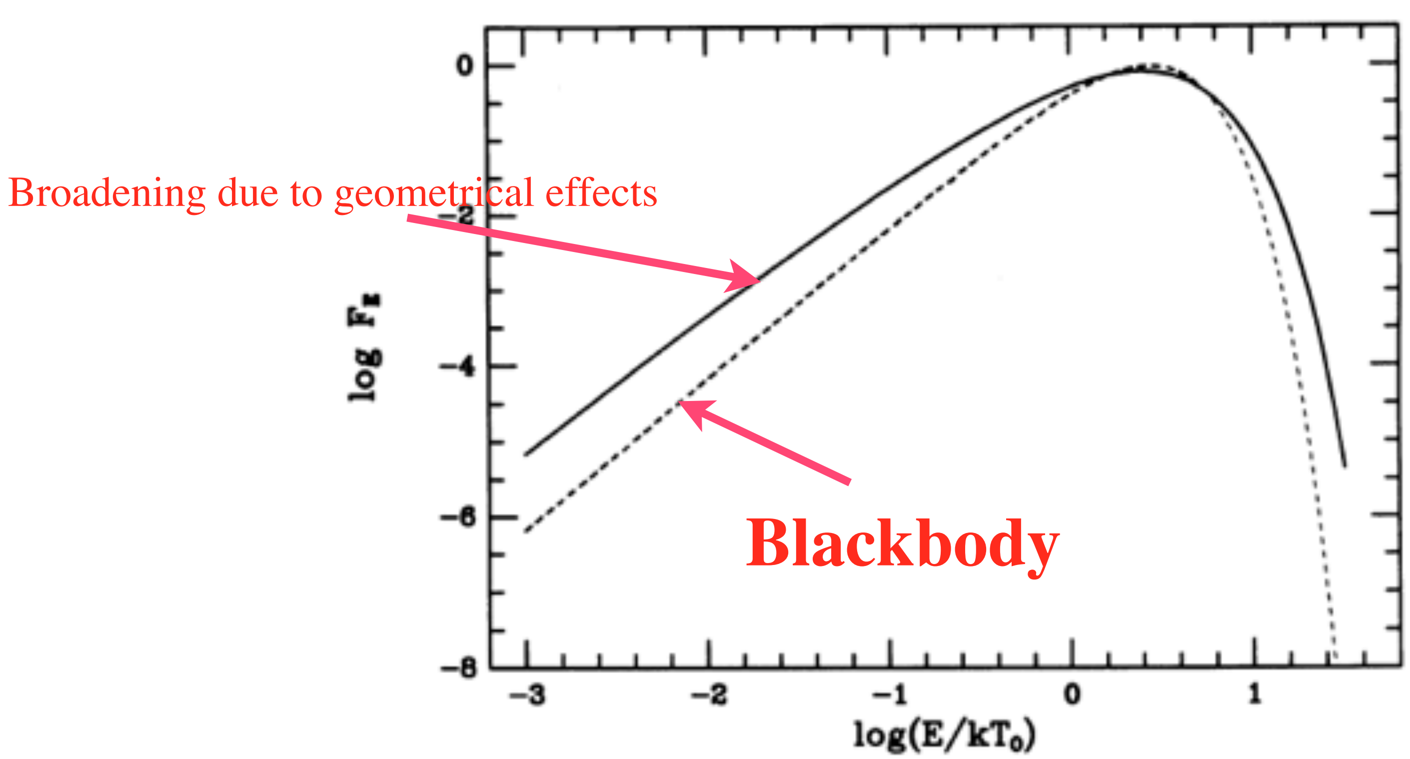


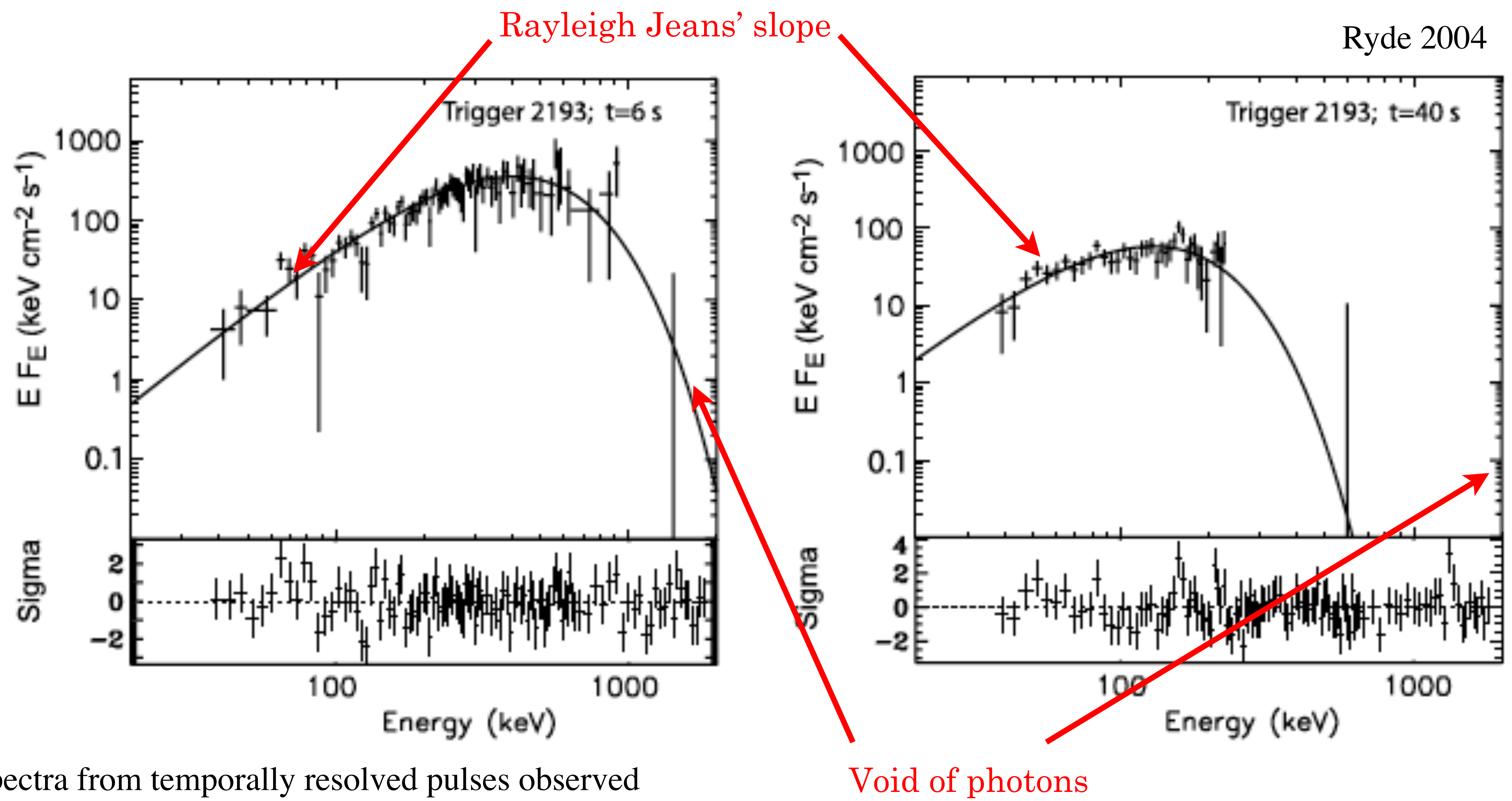
FIG. 1.—*Solid line*: energy distribution of the flux received by a distant observer at rest with respect to the center of mass of the fluid. The vertical scale is in arbitrary units. (*Dashed line*): corresponding distribution for a blackbody at the initial temperature of the fluid.

Paczyński 1986, ApJL, 308, 47

Single Planck function bursts

Compton Gamma-Ray Observatory

GRB930214



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

- **Ryde (2004):** Blackbody throughout the pulse
- **Ghirlanda et al. (2003):** Blackbody in initial phase of burst

Single Planck function bursts

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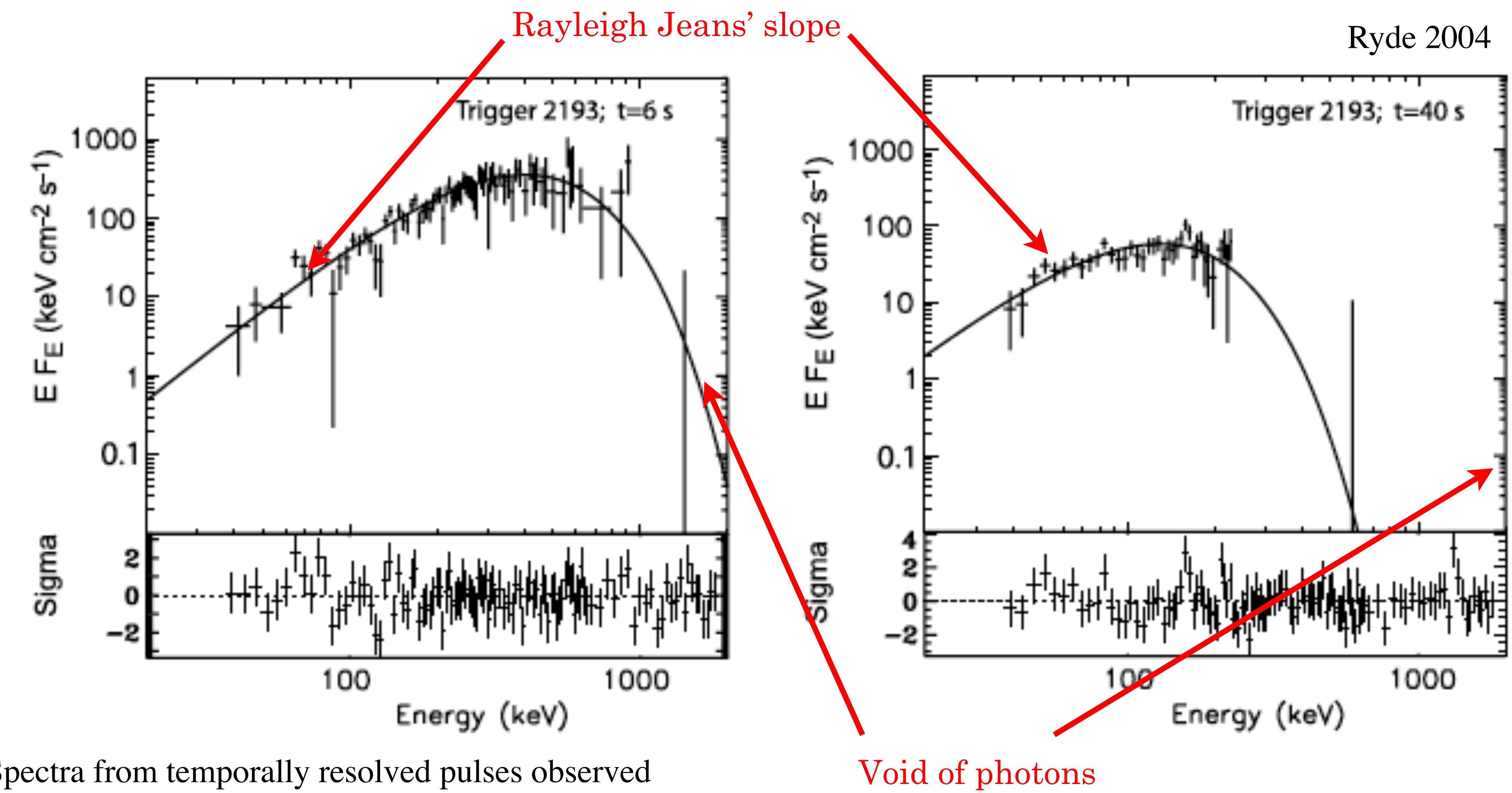

Spectra from temporally resolved pulses observed by BATSE over the energy range 20-2000 keV.

CGRO BATSE: 6 observed bursts out of 2200

- **Ryde (2004):** Blackbody throughout the pulse
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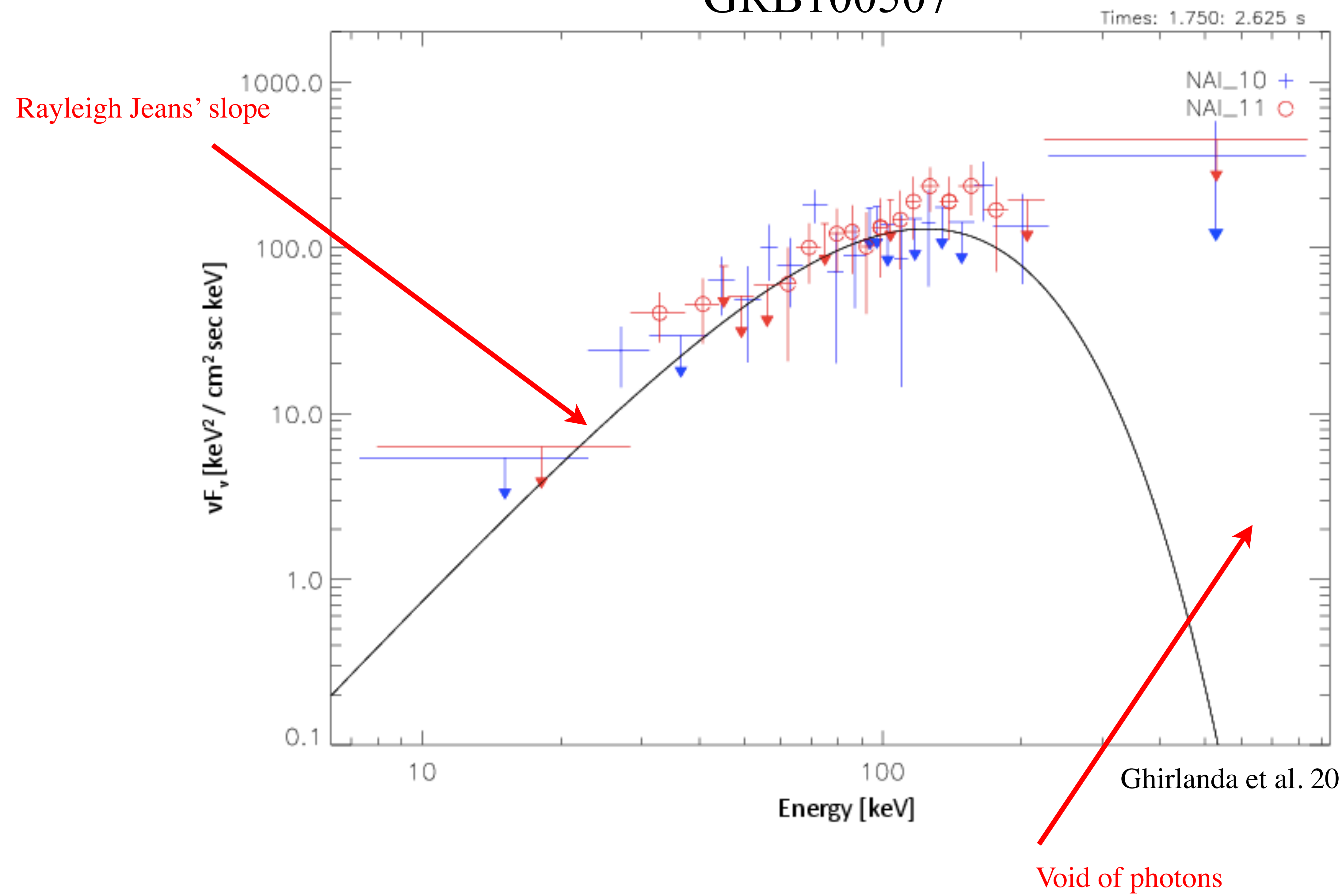
Single Planck function bursts

Fermi Gamma Ray Space Telescope

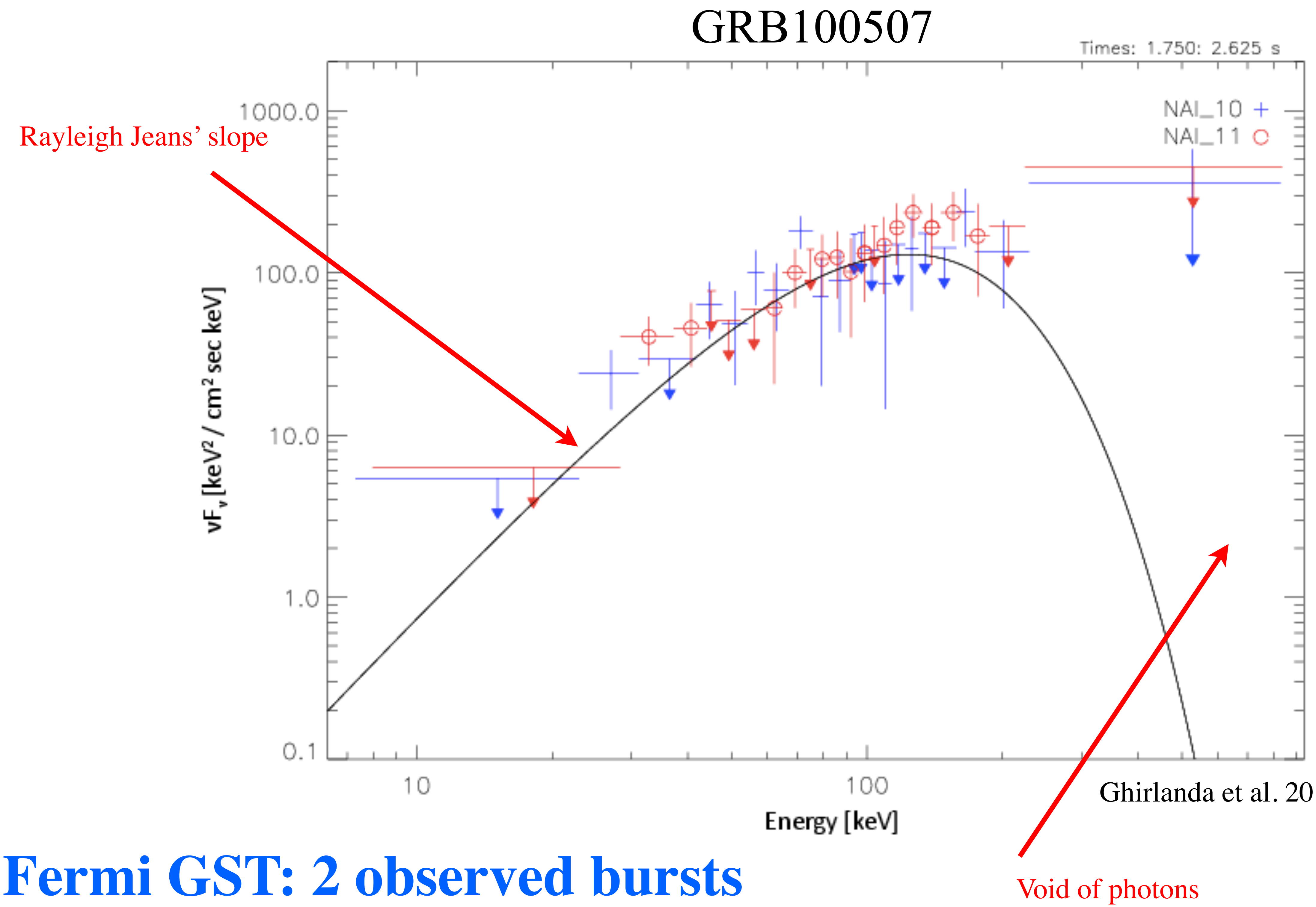
GRB100507



Ghirlanda et al. 2013

Single Planck function bursts

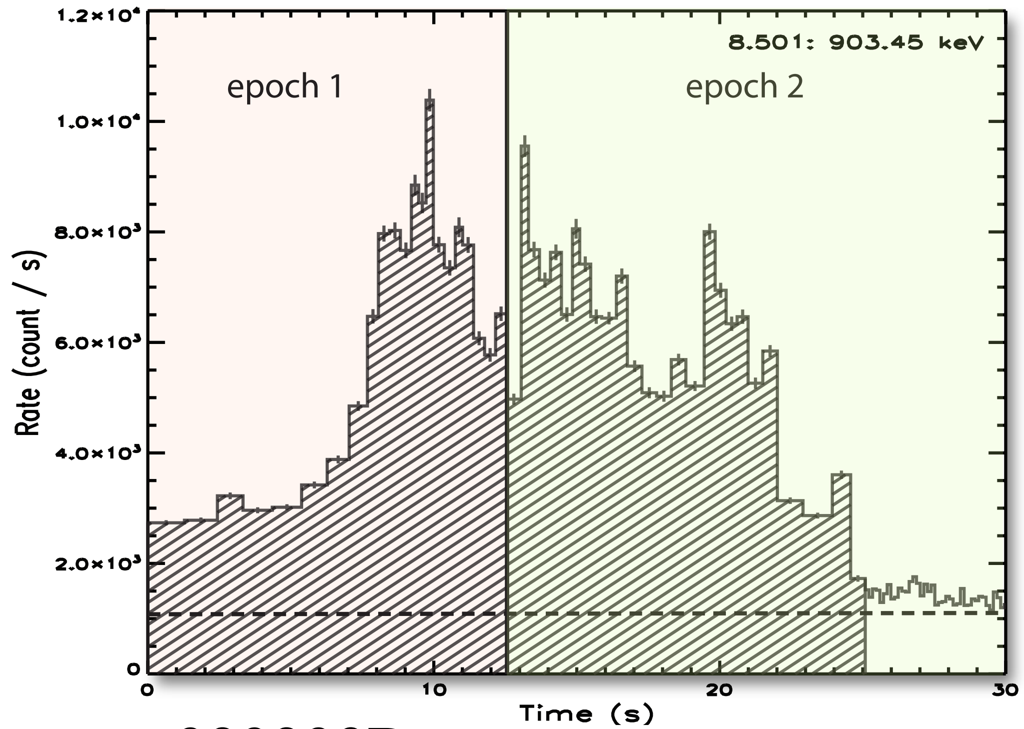
Fermi Gamma Ray Space Telescope



Ghirlanda et al. 2013

Fermi GST: 2 observed bursts out of 1400

Narrow “BB-like” components



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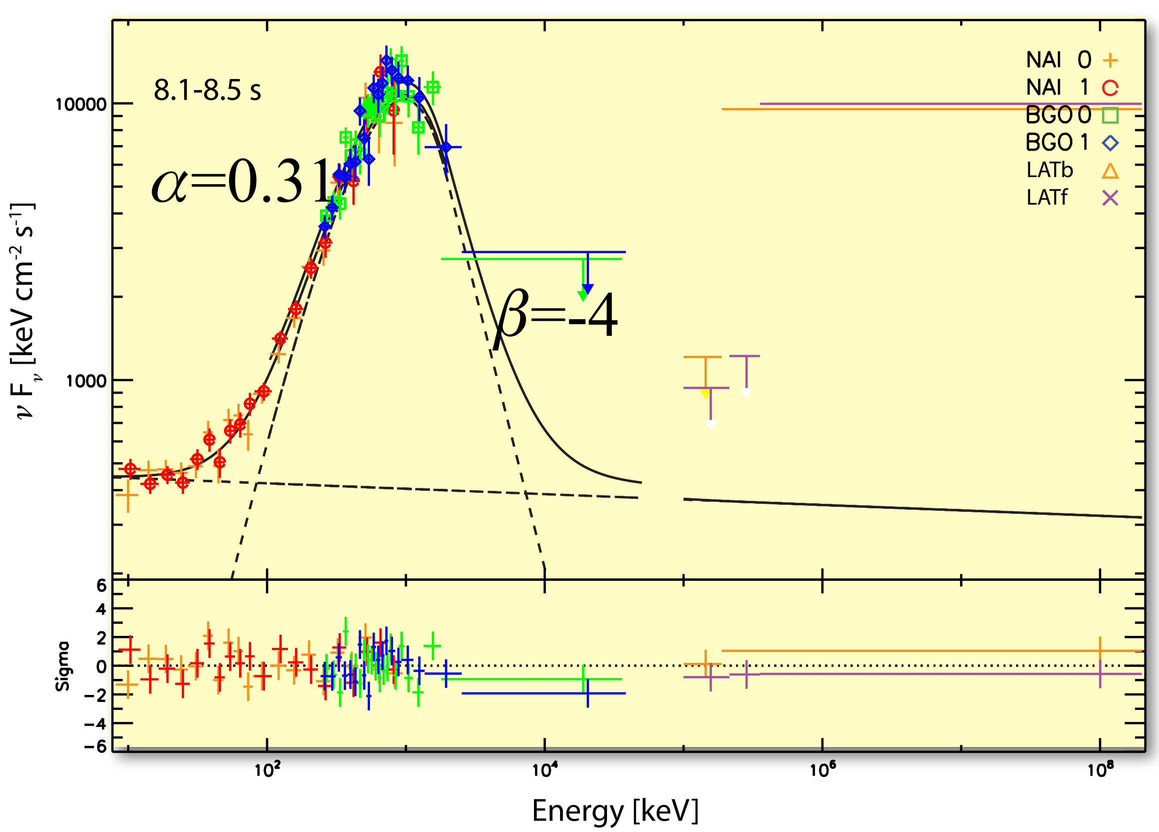

Ryde et al. 2011

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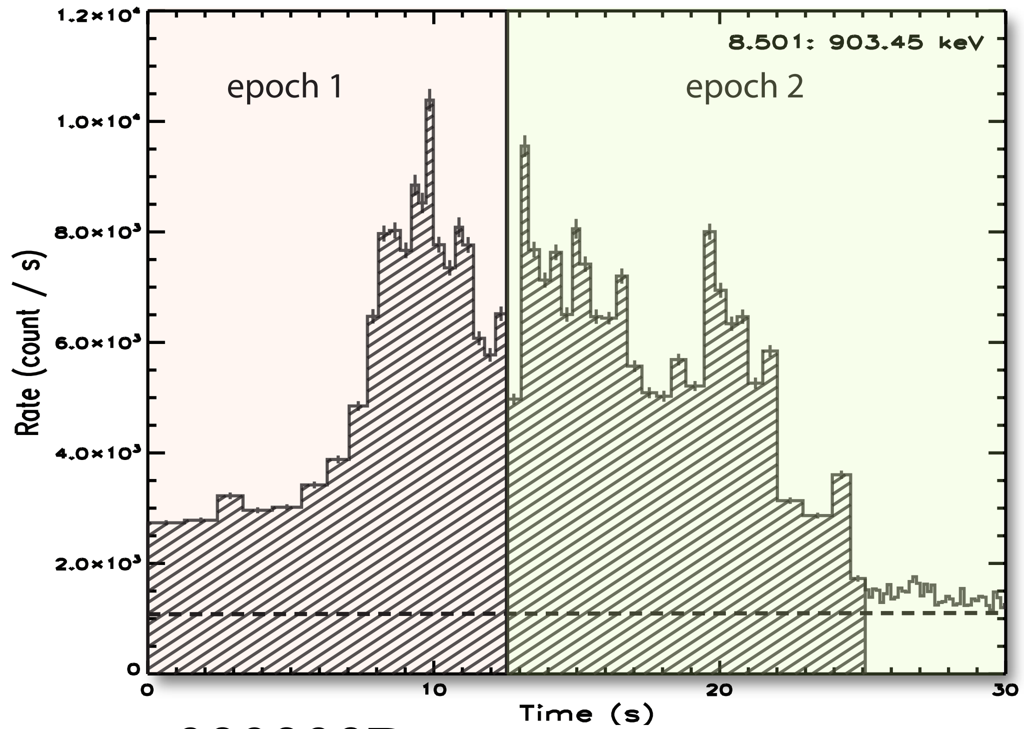

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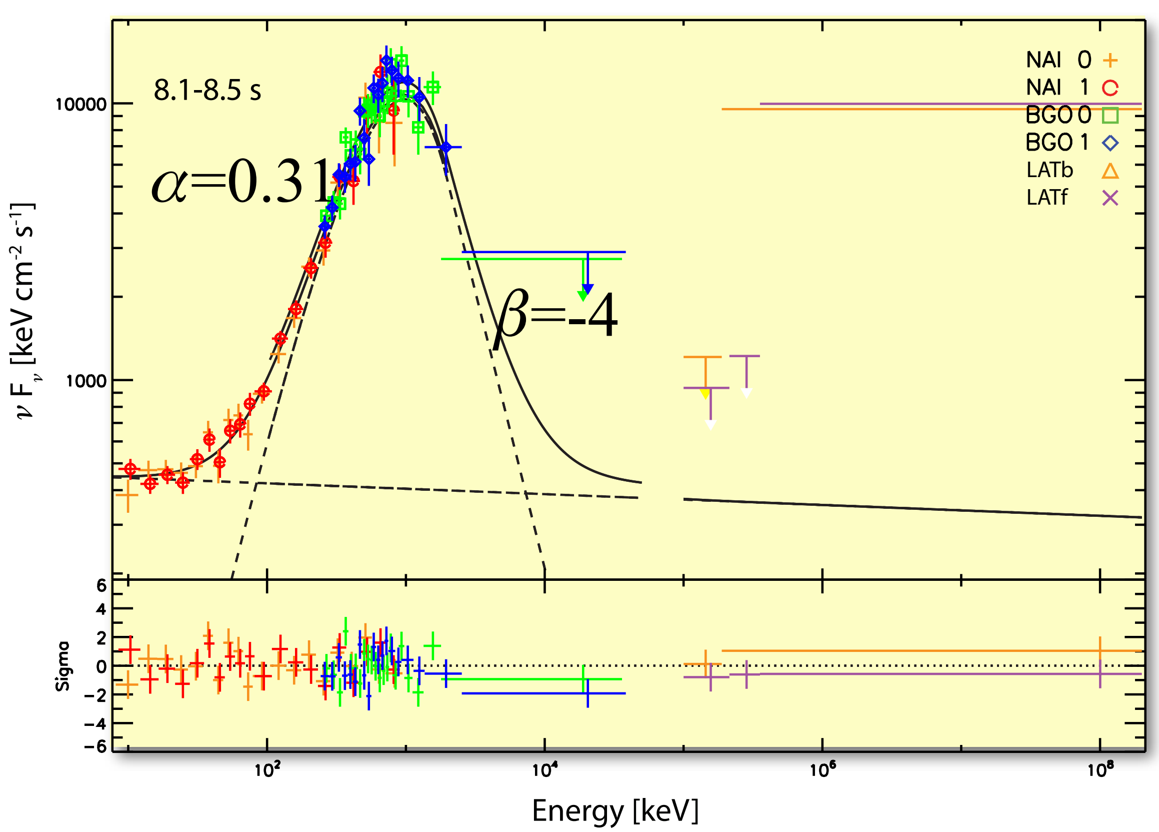
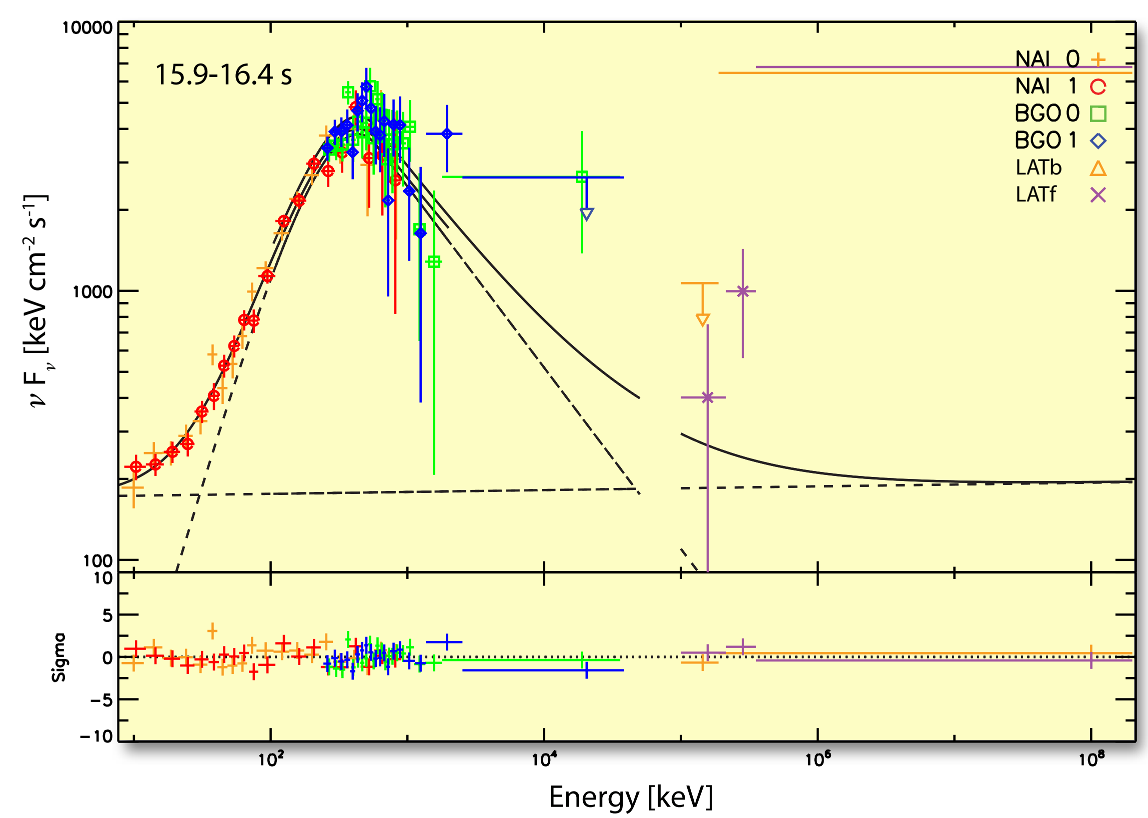




Ryde et al. 2011

What do these bursts tell us?

1. Jet photosphere is detected! Photosphere has an effect on the formation of the GRB spectra.

2. Some spectra are pure blackbodies → strong theoretical implications!

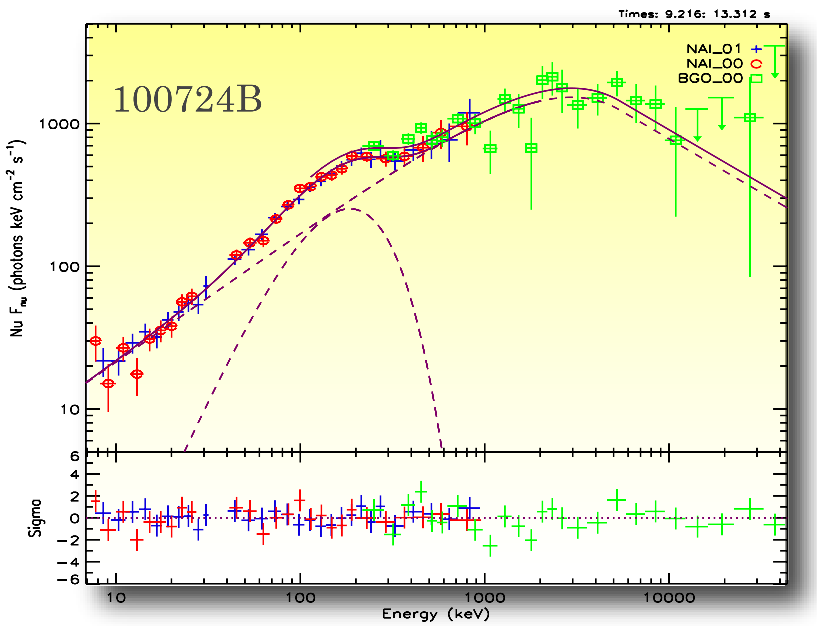
3. Some spectra are slightly broader than a BB → broadening mechanisms

4. Typical spectra are not this kind

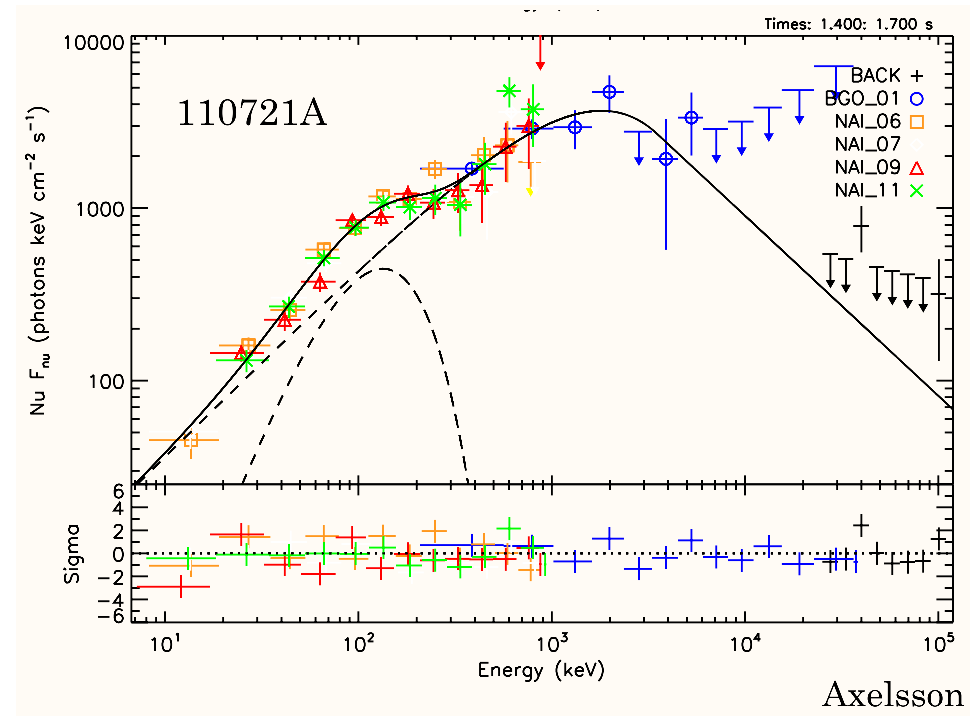
5. Motivation to search for blackbodies in the spectra

Examples of multi-peaked spectra observed by *Fermi*:

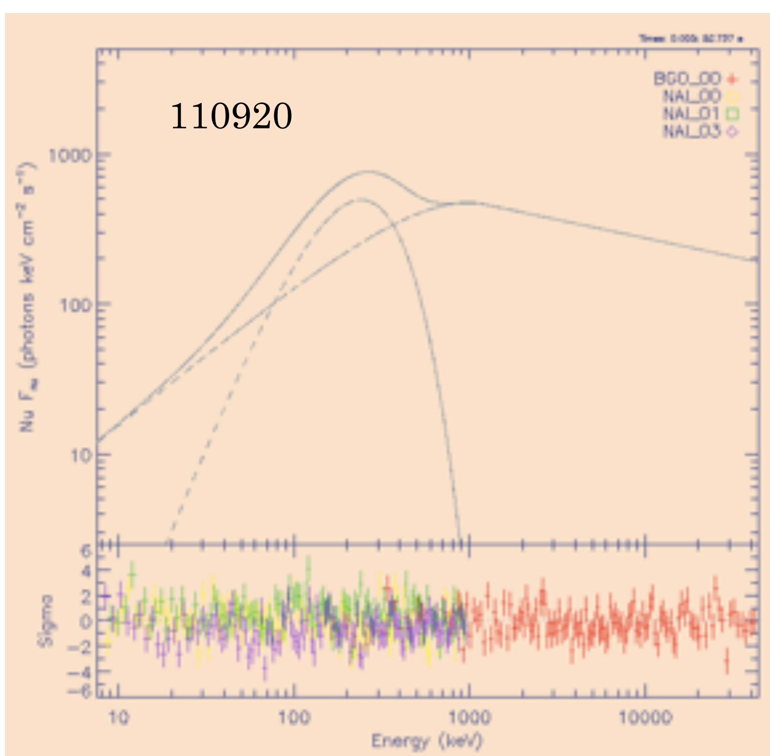
The photospheric component is modelled by a Planck function.
Is expected to be broadened to some extent.



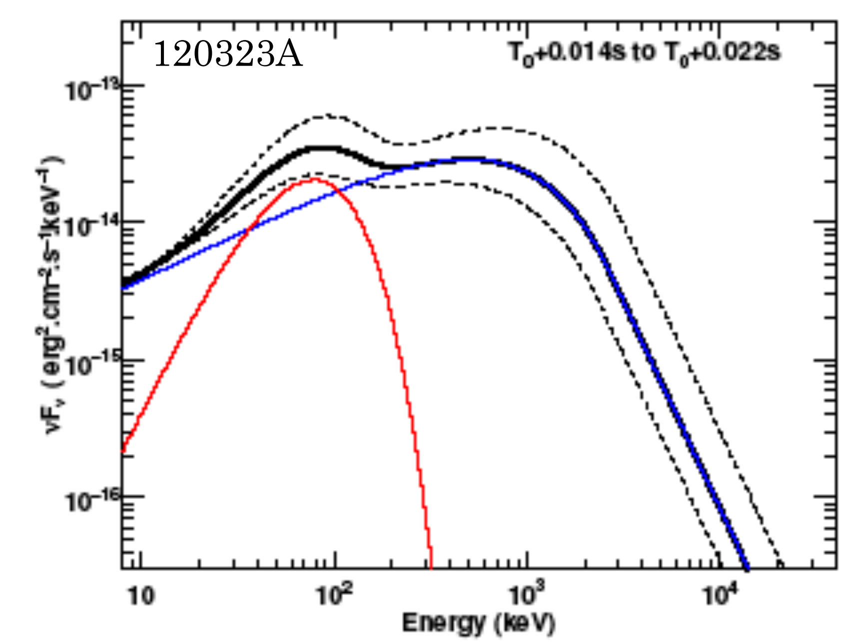
Guiriec et al. 2011



Axelsson et al. 2012



McGlynn et al. 2012

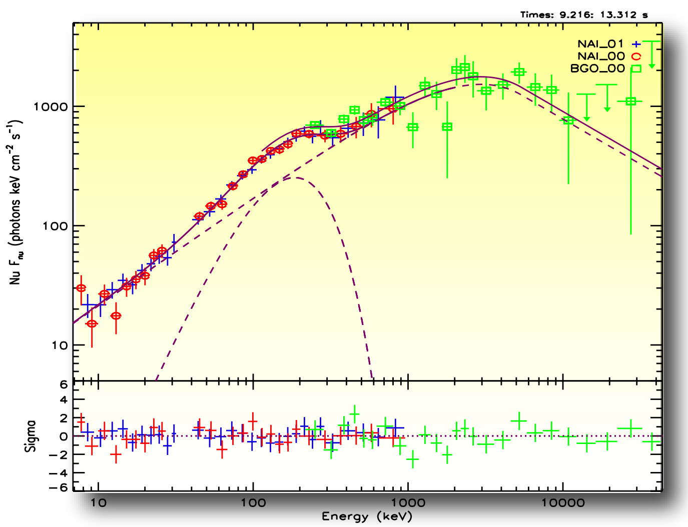


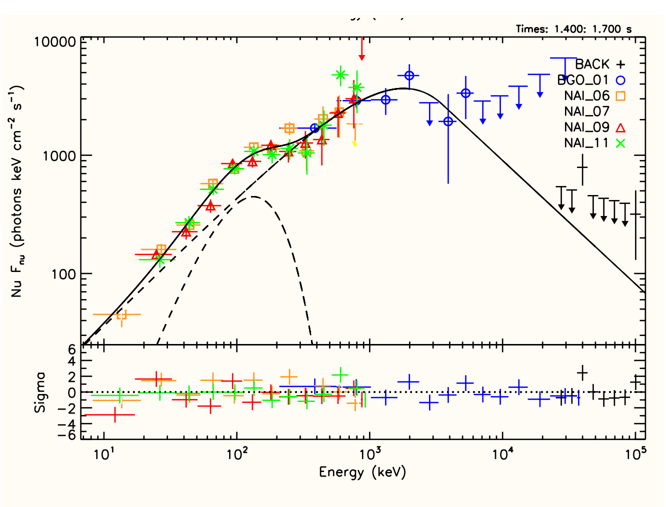
Guiriec et al. 2013

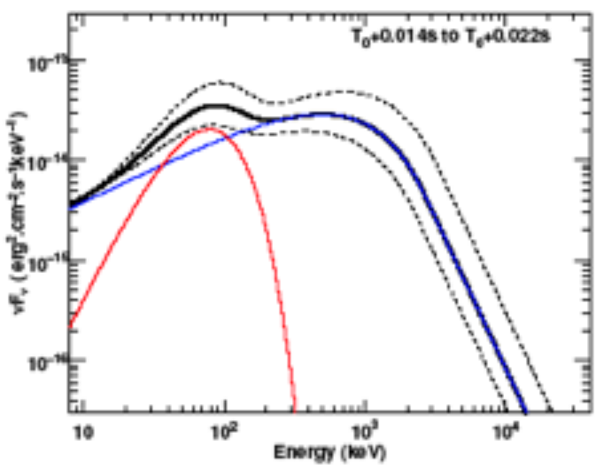
<u>Two component spectra:</u> Blackbody component typically 5-10% of total flux.
But much higher some cases.

Two component spectra

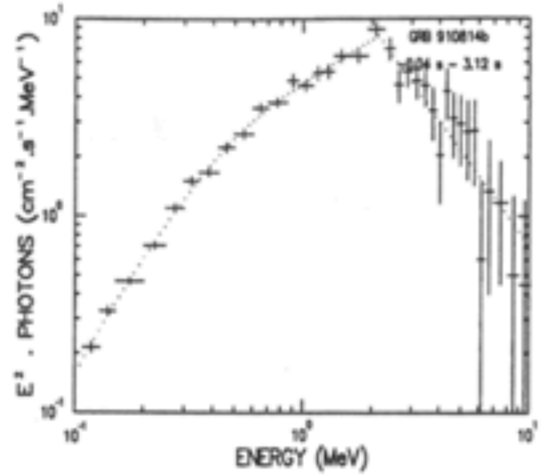
Fermi

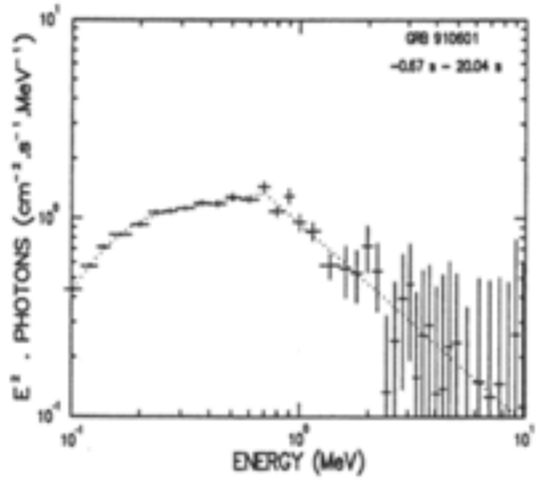


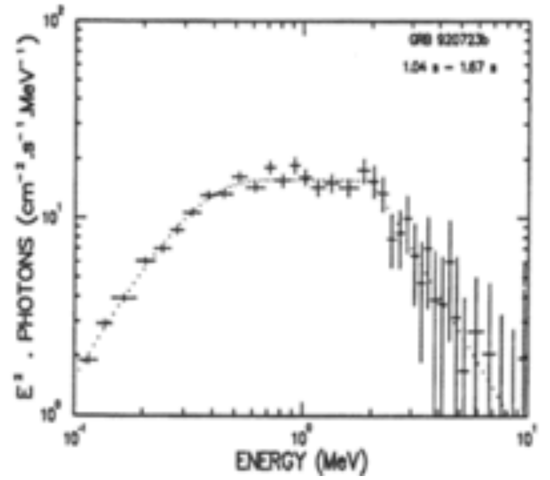




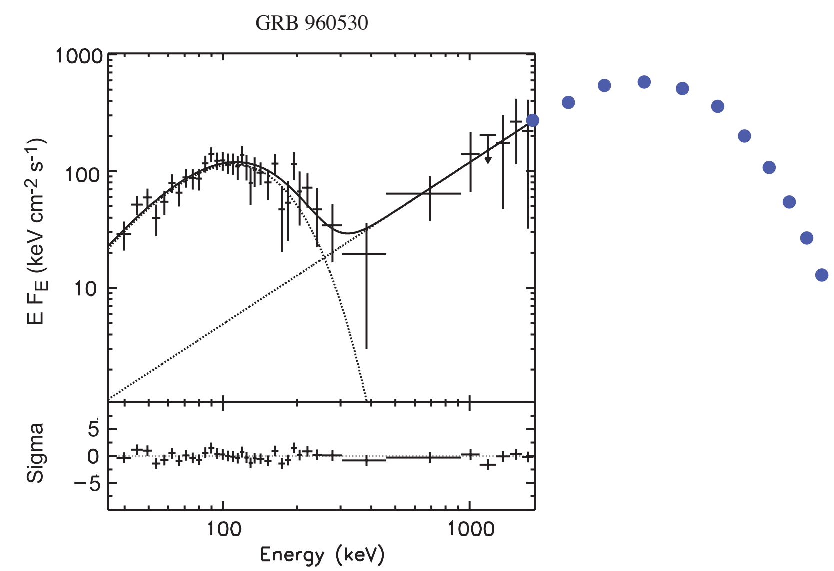
Fregate

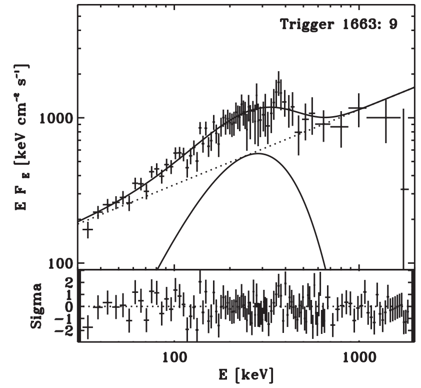


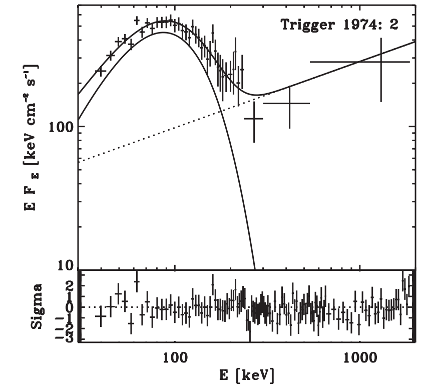


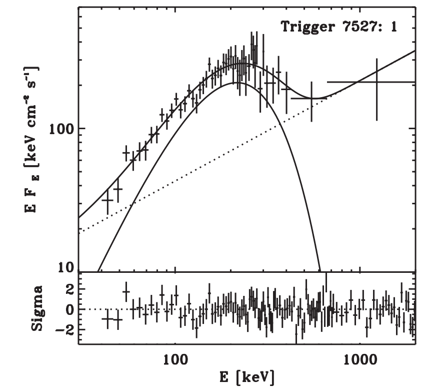


CGRO



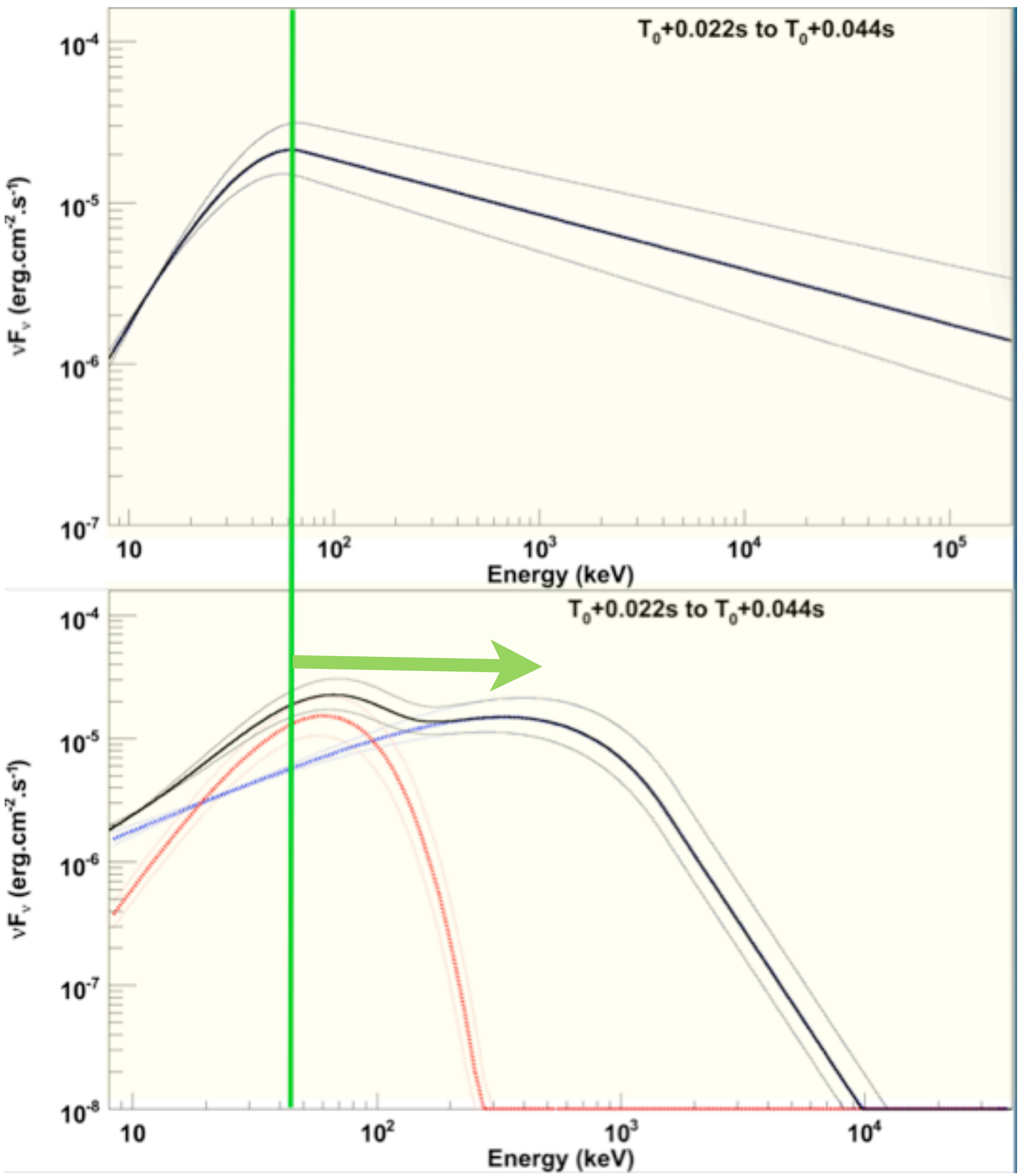






Fermi Gamma-ray Space Telescope

GRB120323A



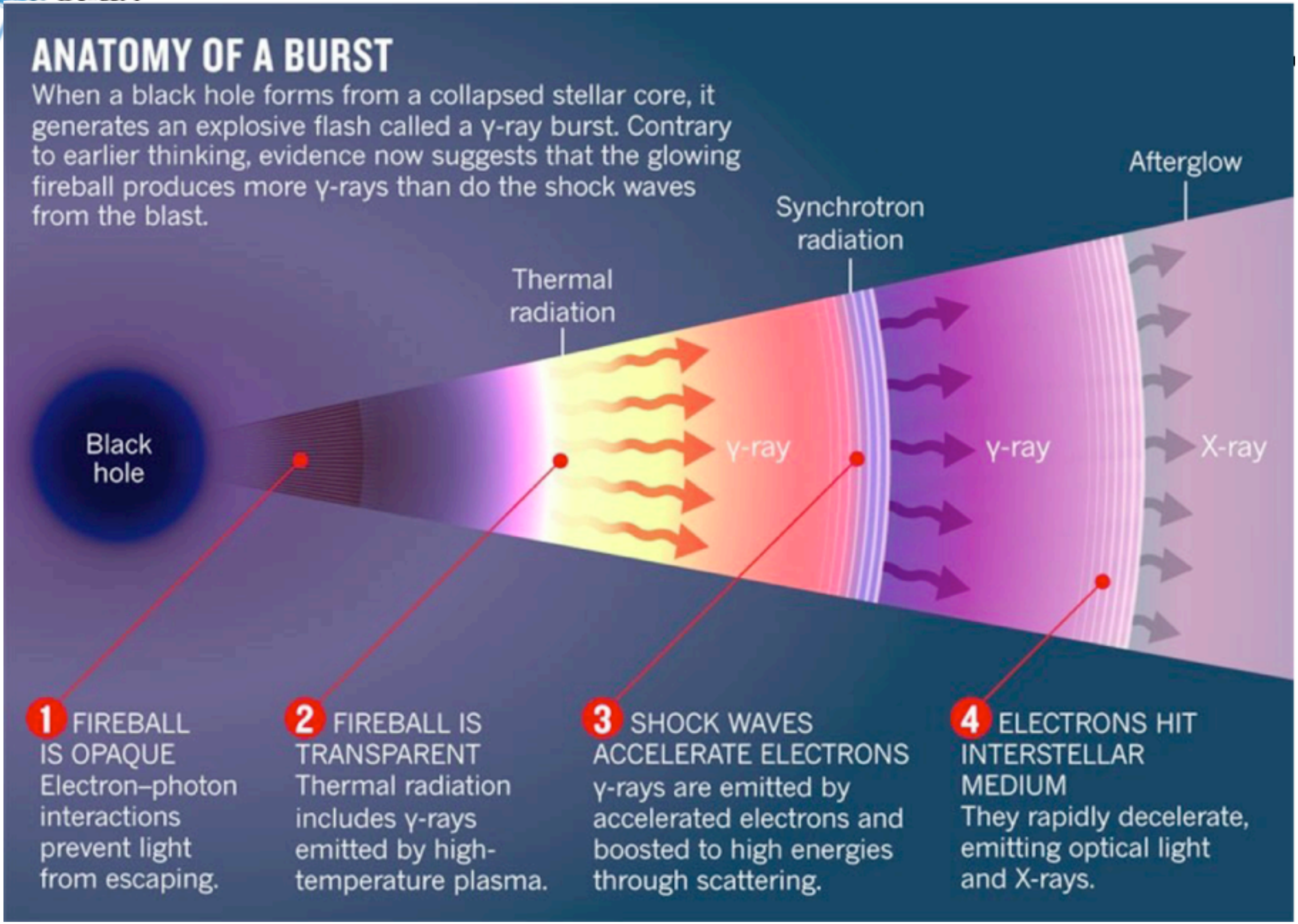
Guiriec et al. 2013

Changes the interpretations!

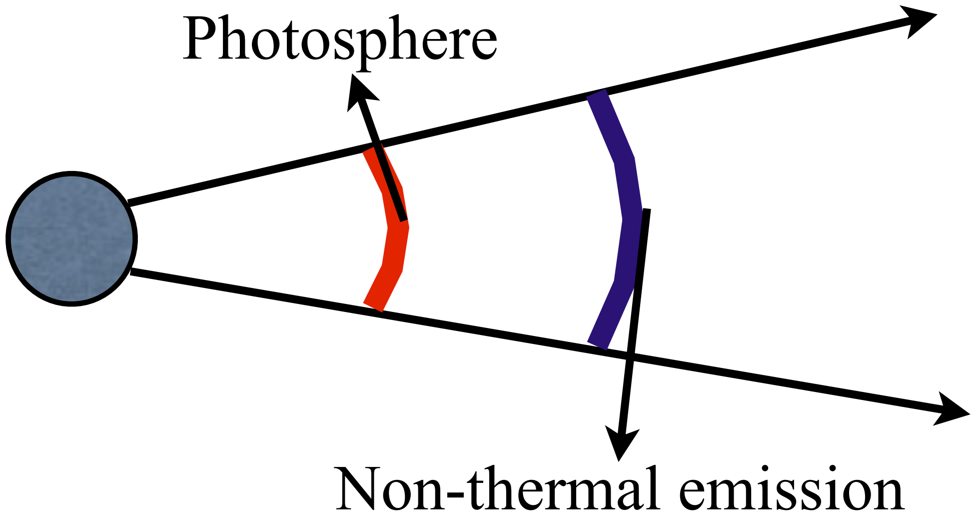
1. Change in Epeak
2. Change in alpha (synchrotron?)
3. Change in emission zones

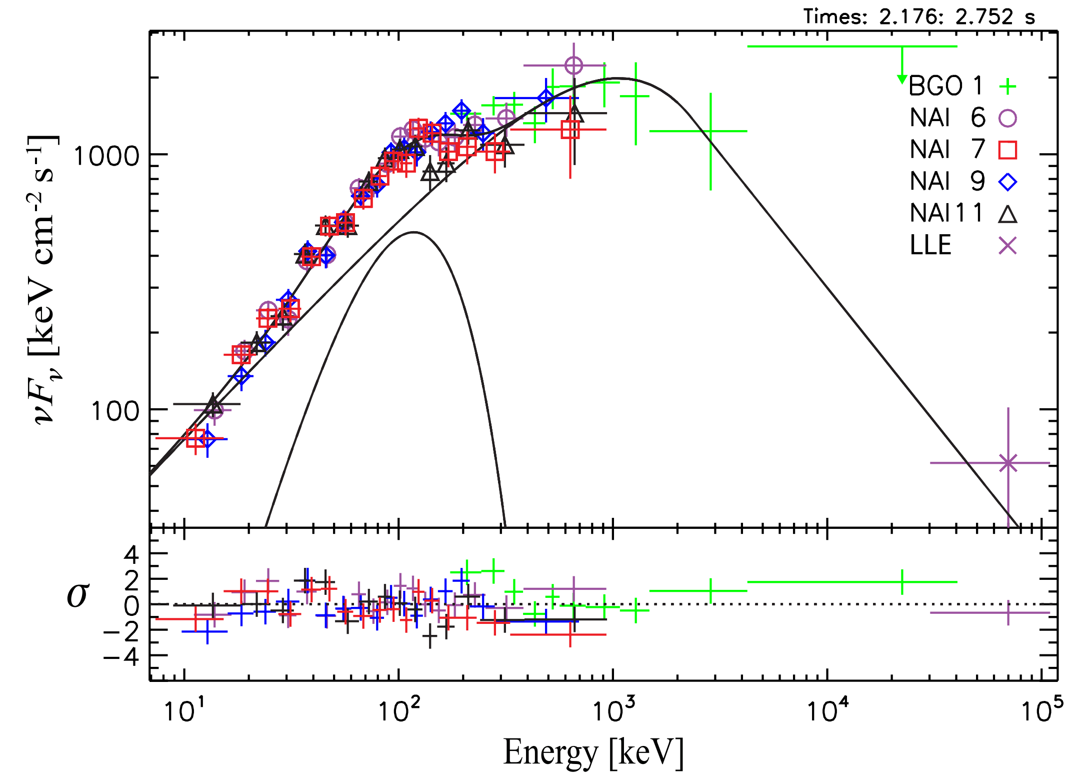
Fermi Gamma-ray Space Telescope

Interpretation 1: Multiple Emission Zones



Two emission zones - model





Photosphere
(No dissipation below) → Thermal component - Planck function (BB)

Above photosphere
(Optically thin) → Non-thermal component - Band function
synchrotron, ICMART...

<u>2 zone emission, various realisations</u>

If below the saturation radius - strong black body
If above saturation radius - adiabatic cooling

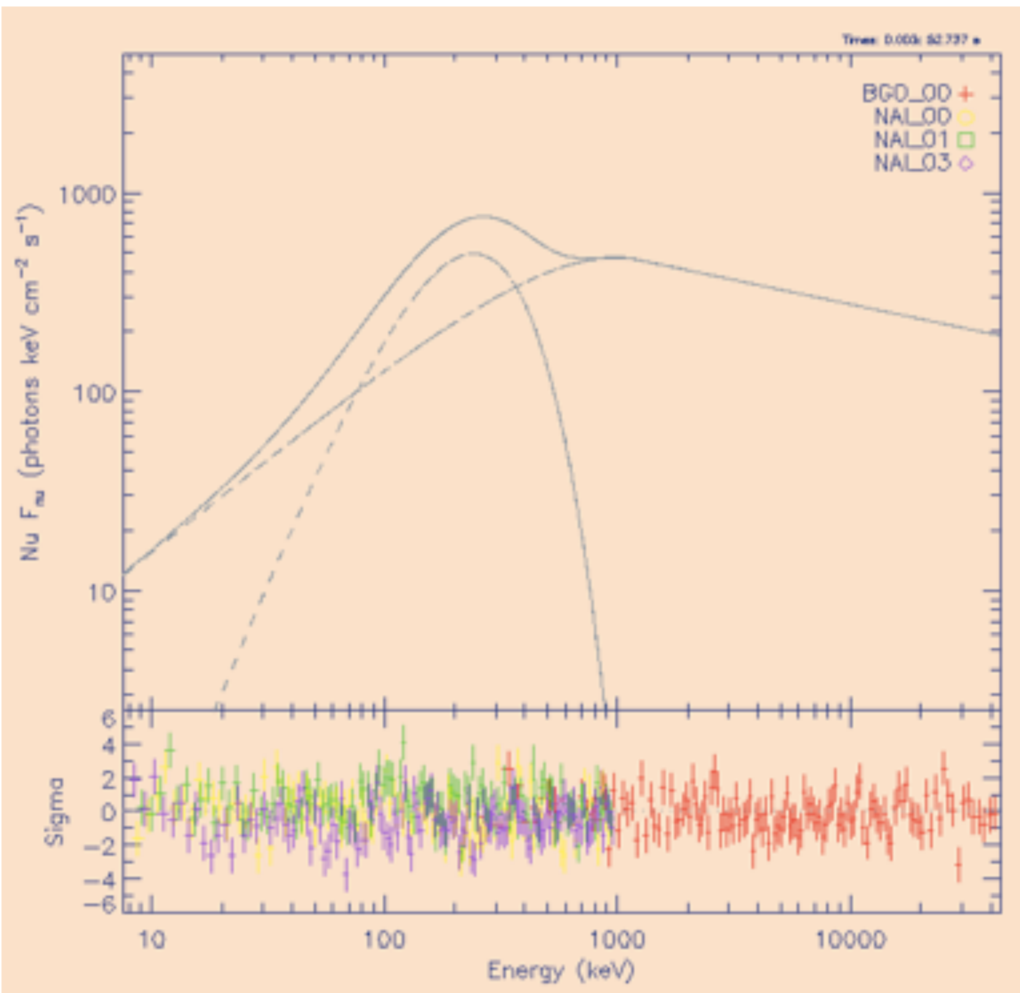
$$\left(\frac{r_{\rm ph}}{r_{\rm s}}\right)^{-2/3} = \frac{F_{\rm BB}}{F_{\rm NT}},$$

Magnetisation of the jet allows the ratio to vary (Daigne et al. 2013)

GRB110920

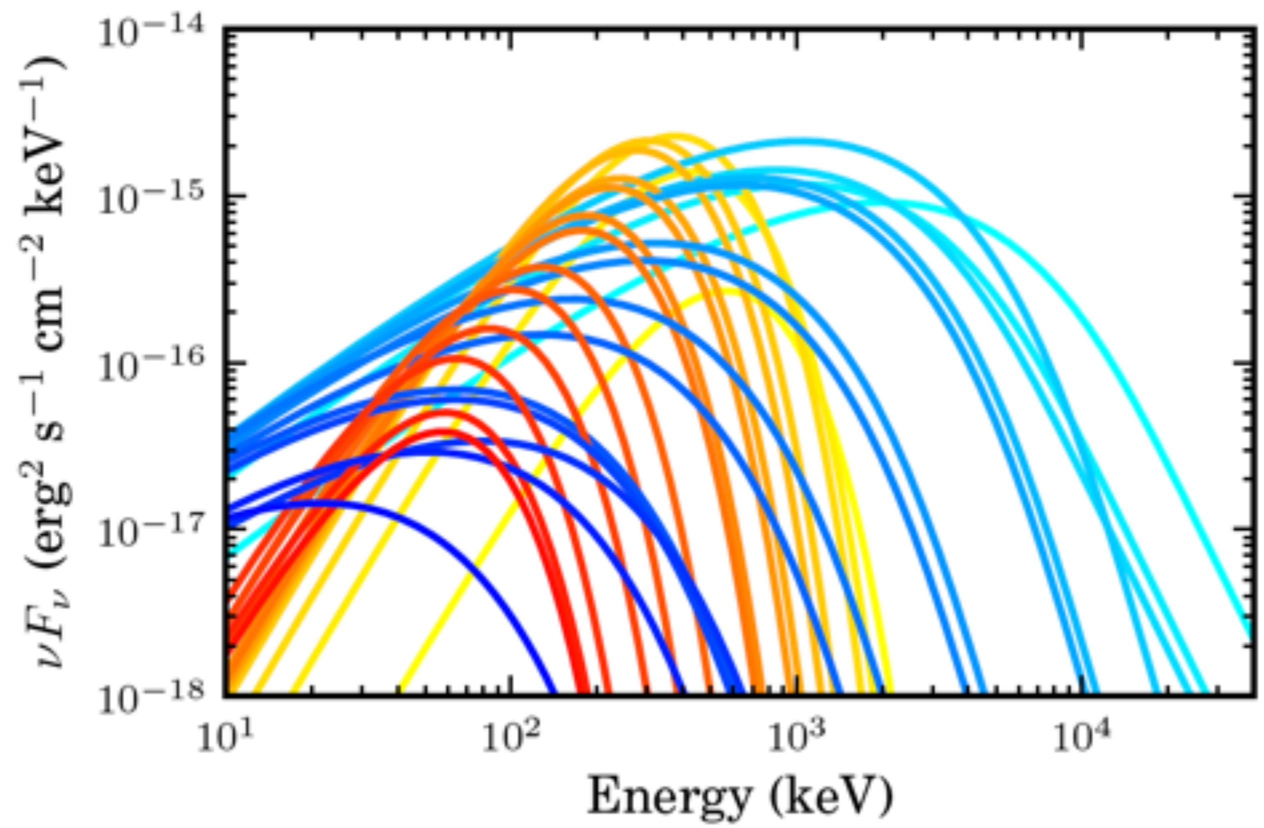
Two component fit

Band + BB



McGlynn et al. 2012

Synchrotron + BB

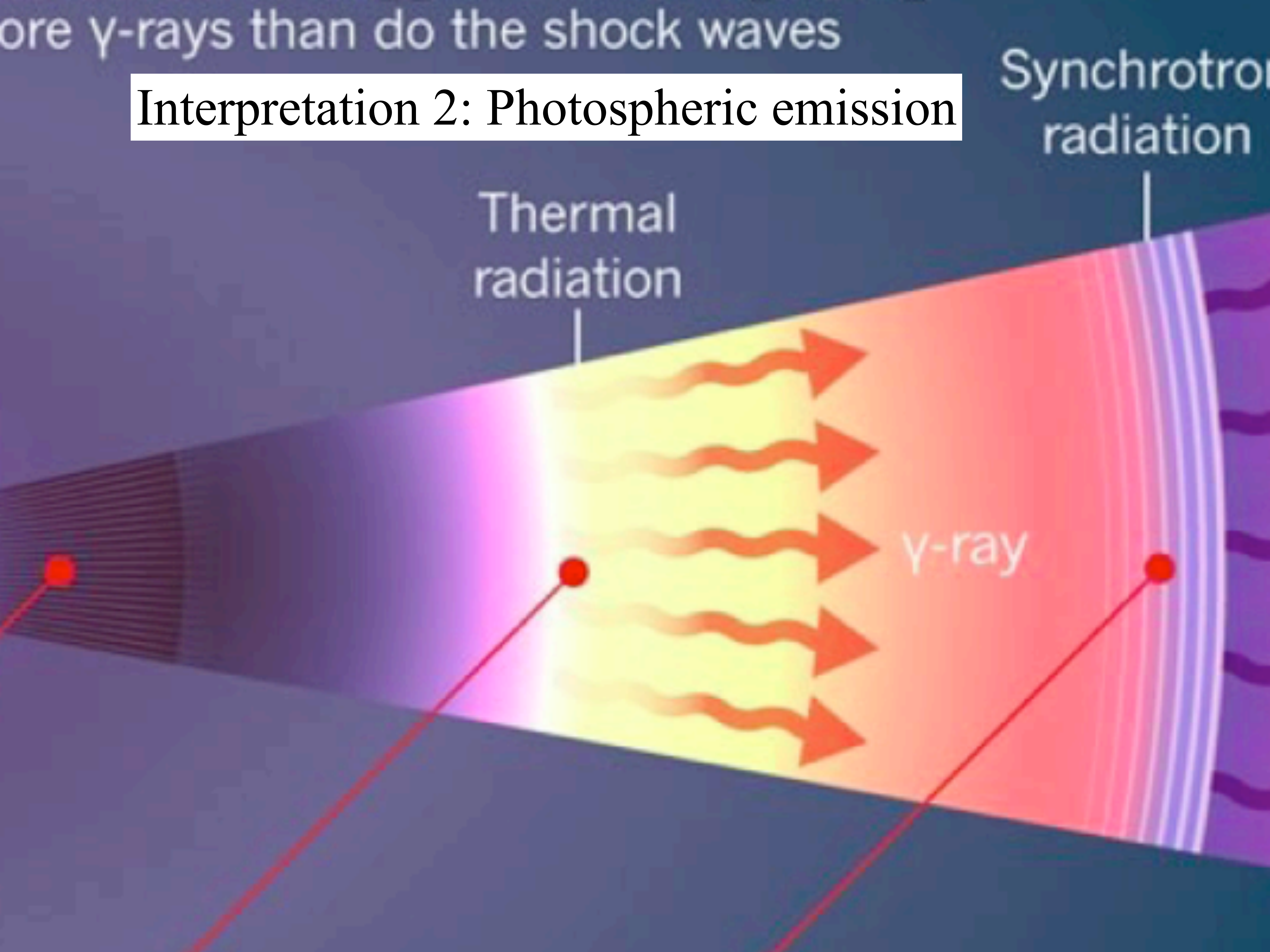


Burgess et al. 2014

Not a general solution!

Talk and poster by Michael Burgess

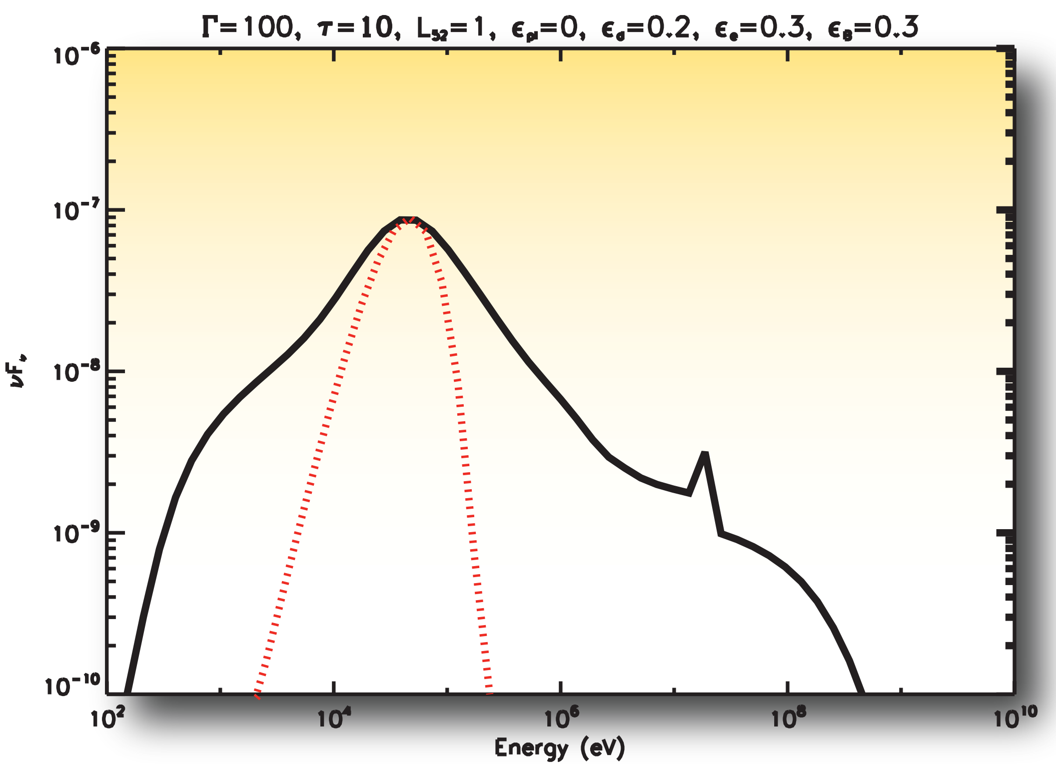
Interpretation 2: Photospheric emission



Modification of Planck spectrum

Heating mechanism below the photosphere modifies the Planck spectrum

- Internal shocks
  (Peer, Meszaros, Rees 06, Ryde+10, 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)

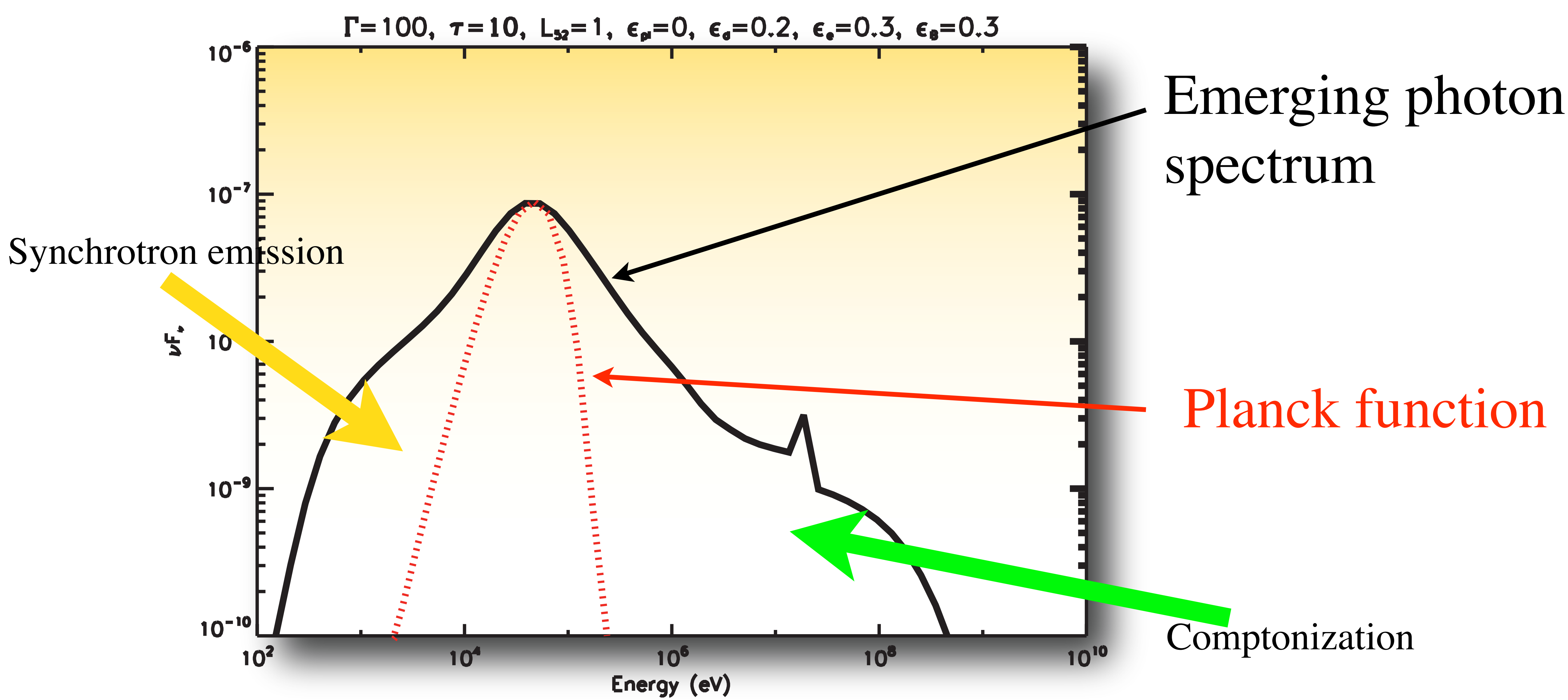


Emission from the photosphere is NOT seen as Planck !

Modeling with subphotospheric dissipation

- Our code (by Pe'er & Waxman 2004) solves the kinetic equations for internal shocks
- Includes cyclo/synchrotron emission, SSA, Compton scattering (direct/inverse), pair production, pair annihilation

Dissipation at optical depth $\tau = 10$



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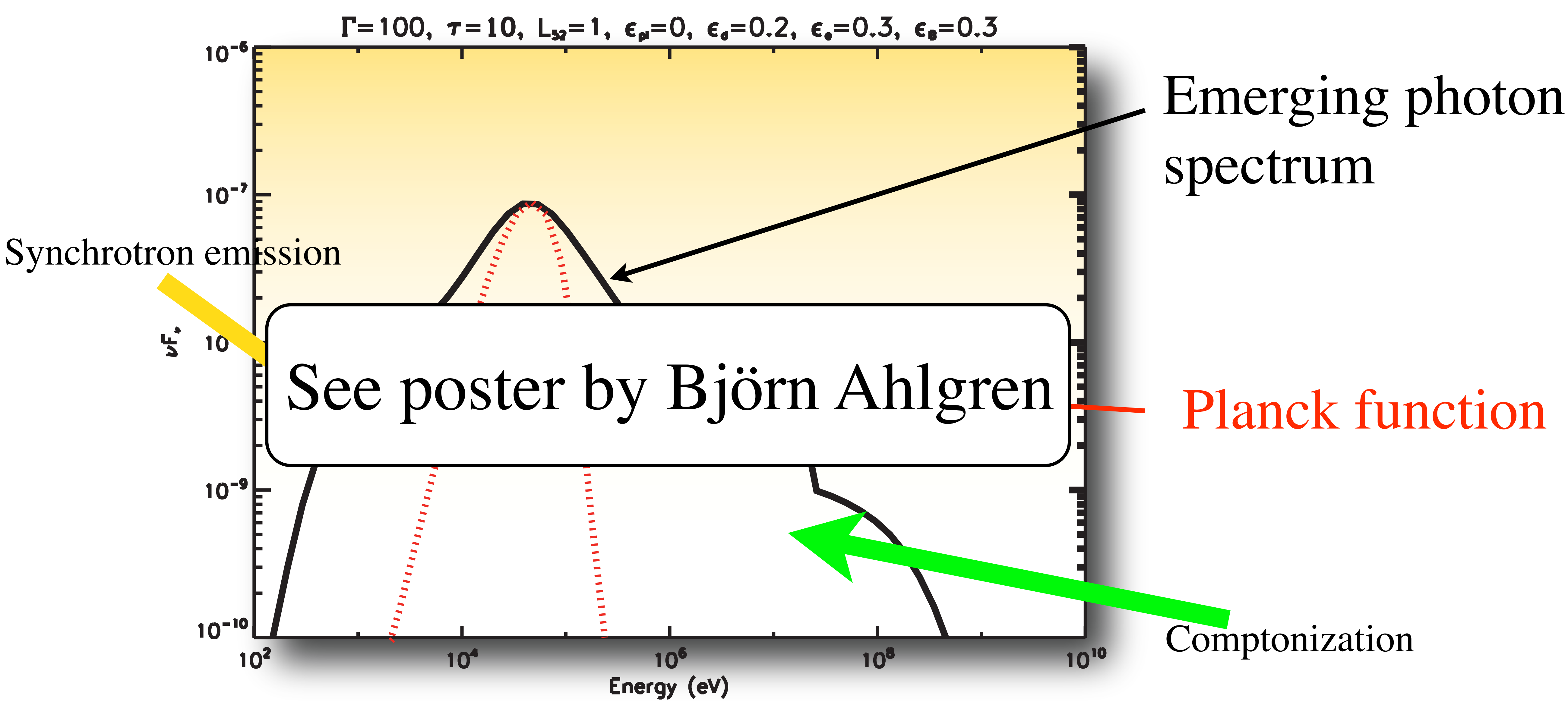
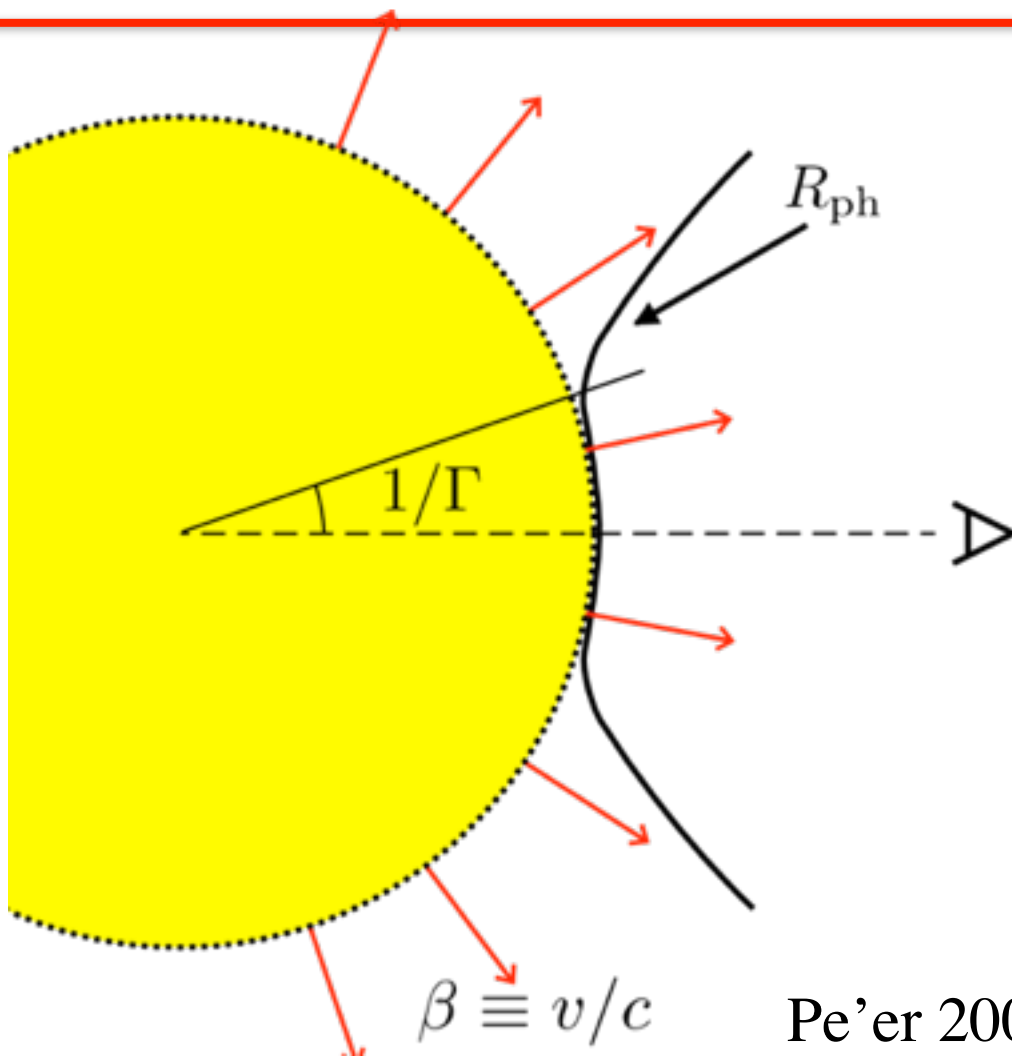
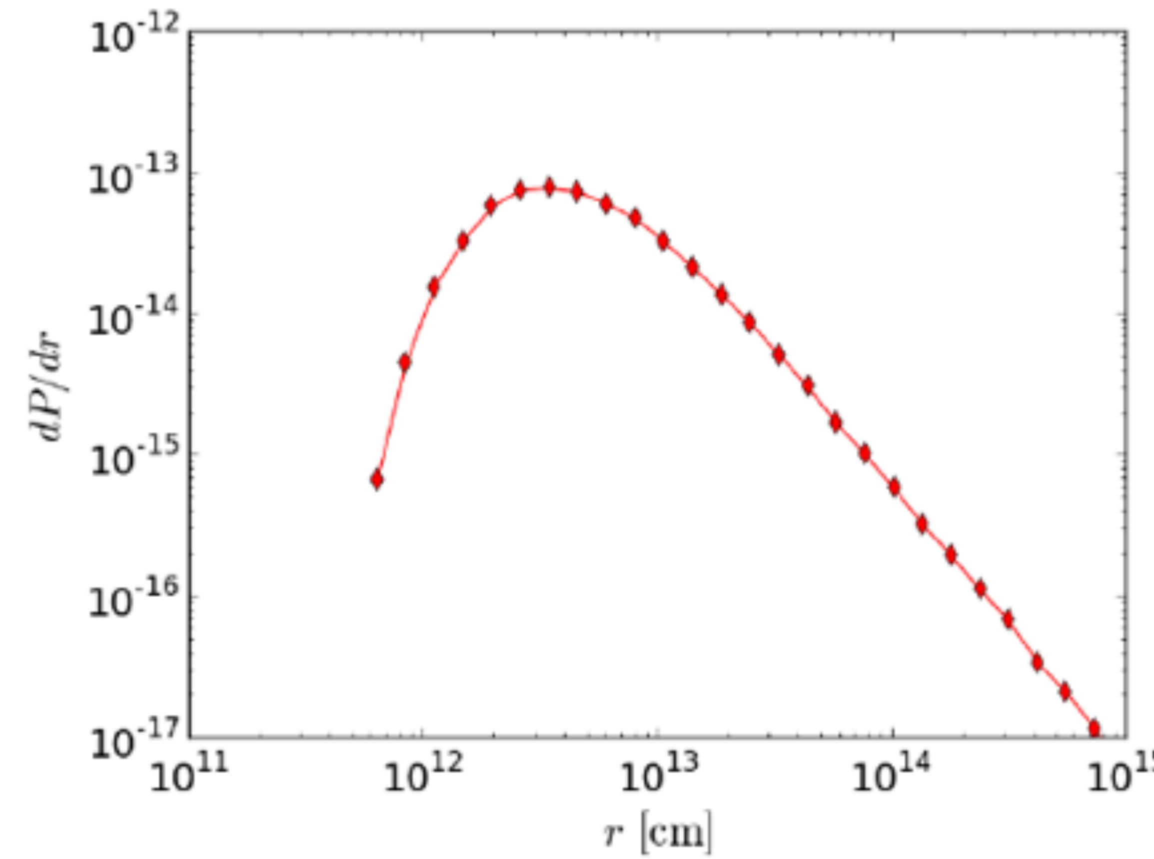


Modification of Planck spectrum

Geometrical broadening: 'photosphere' is NOT a single radius, but is 3-dimensional





Pe'er 2008; Pe'er & Ryde 2011   Lundman, Peer, Ryde 2012

'Limb darkening' in relativistically expanding plasma: emission from photosphere is NOT seen as Planck!

Modification of Planck spectrum

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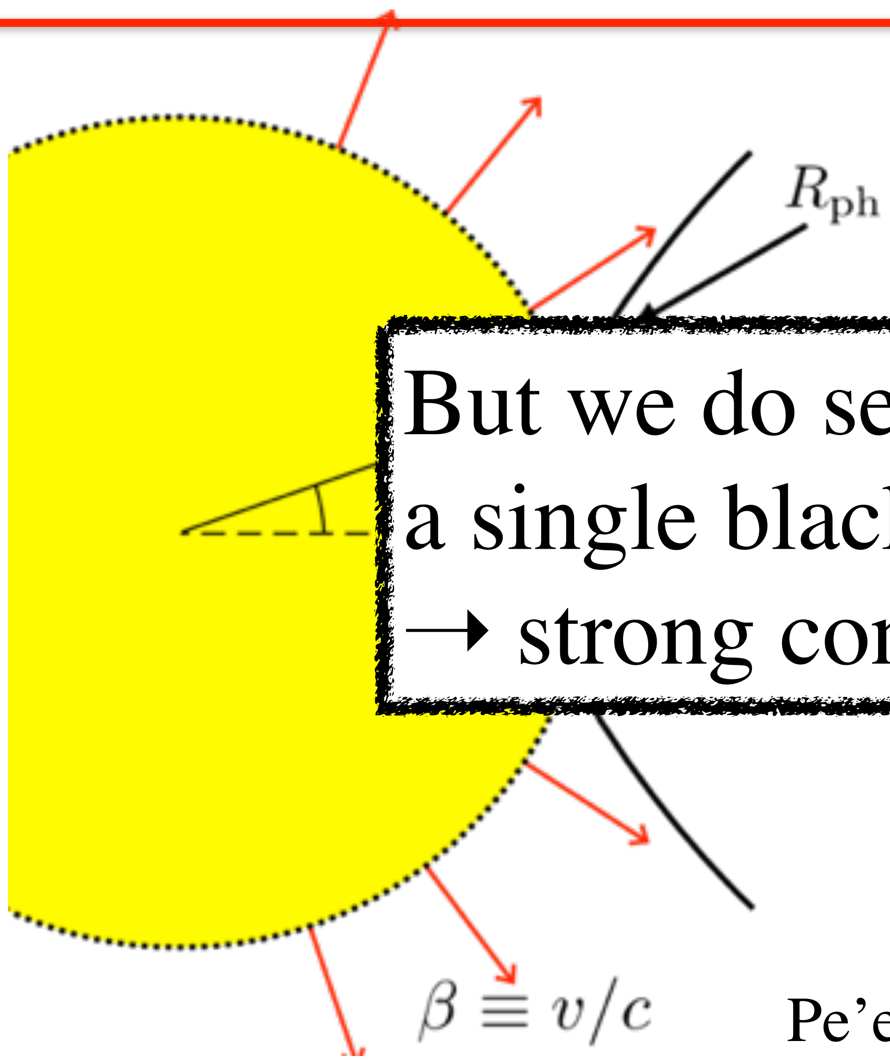
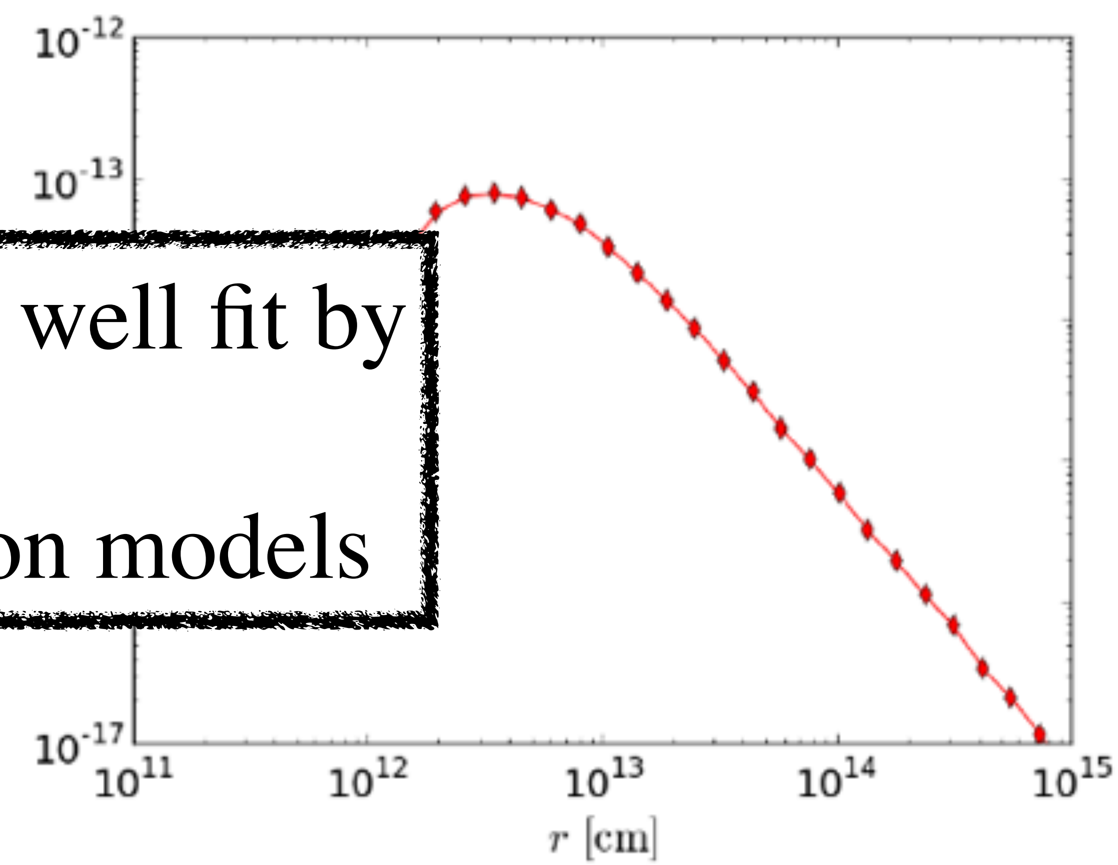


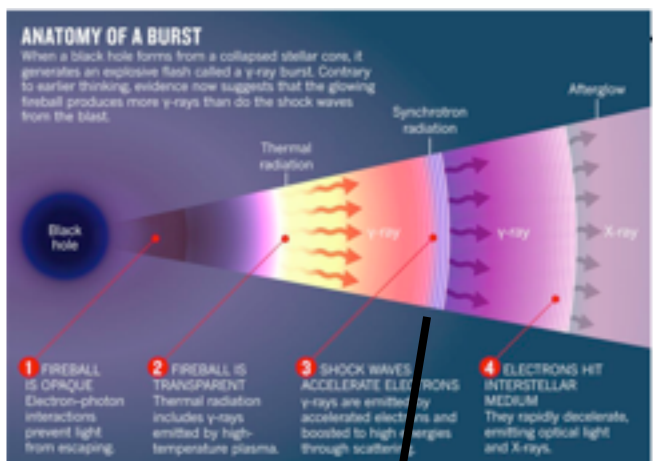


But we do see spectra well fit by a single blackbody!
→ strong constraints on models

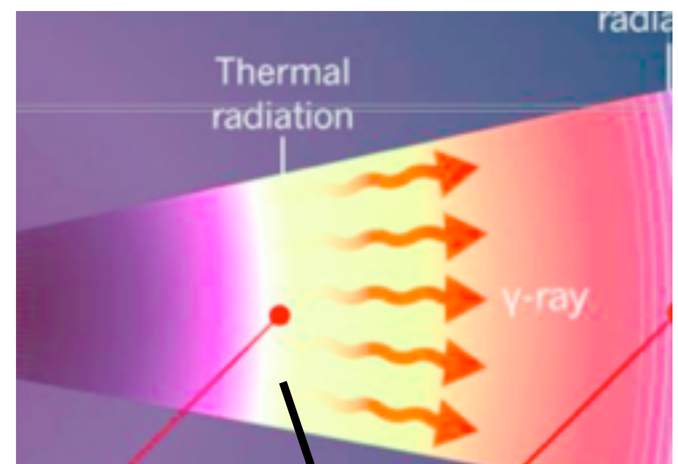
Pe'er 2008; Pe'er & Ryde 2011 Lundman, Peer, Ryde 2012

'Limb darkening' in relativistically expanding plasma: emission from photosphere is NOT seen as Planck!

Possible observable to discriminate between interpretations: *Polarisation*



Synchrotron emission easily polarised



Is the photosphere polarised?

Polarisation from the photosphere

- Polarized emission in range **0-40% expected** (depending on viewing angle and jet structure)
- **Only** a change in pol. angle of **90º** is possible (due to jet axisymmetry)
- If jet is wide, most obs. see low polarization (few percent)
- Correlations expected between spectrum and polarization

Lundman, Pe'er, & Ryde 2014

Conclusions

The jet photosphere is important for the understanding of GRB emission.

Most GRB spectra do not look thermal (i.e., Planckian).

Many GRBs have multiple components.

Interpretations: 1. Multi zone emission
2. Pure photospheric emission

Polarisation measurements are important!