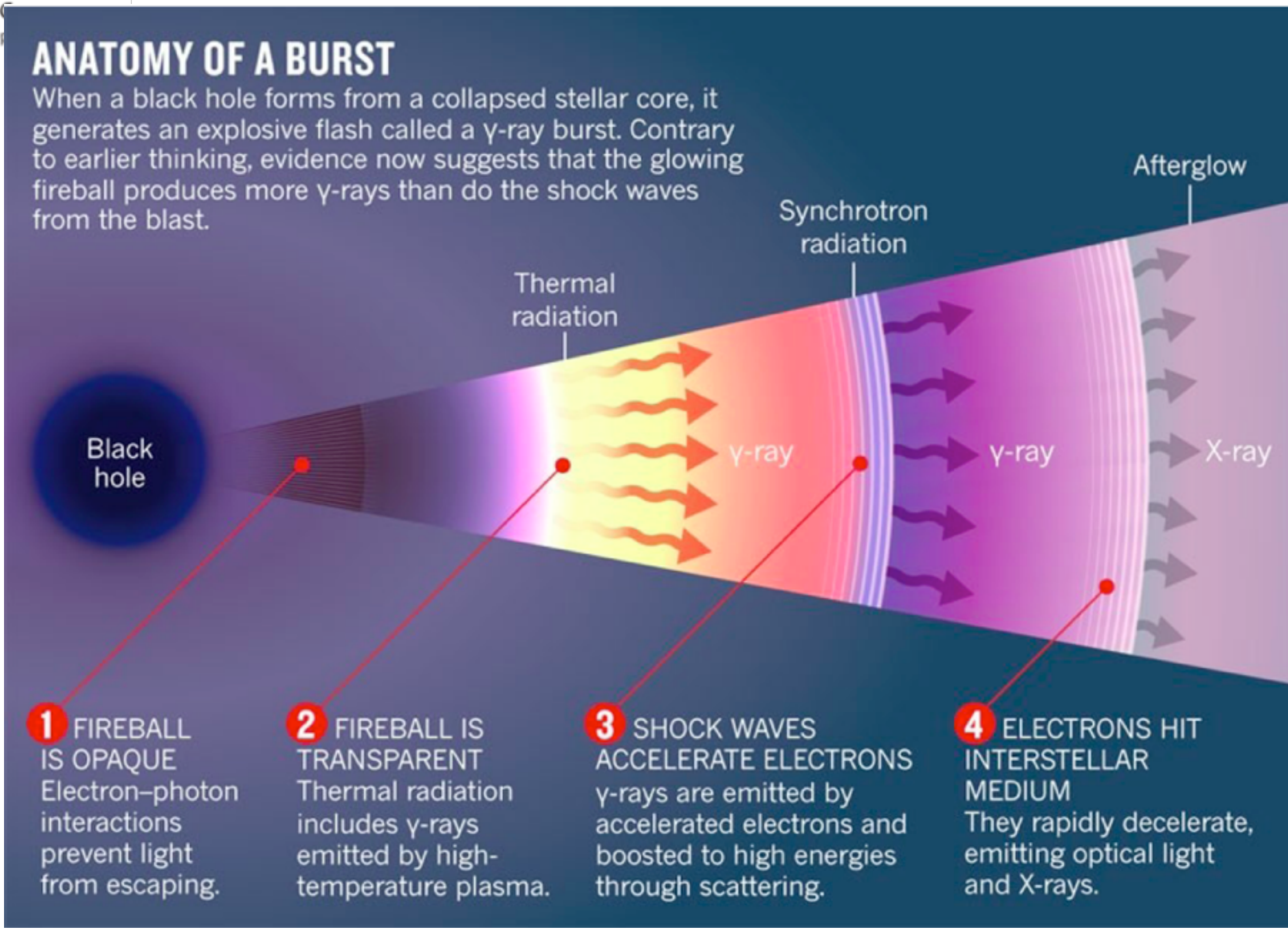
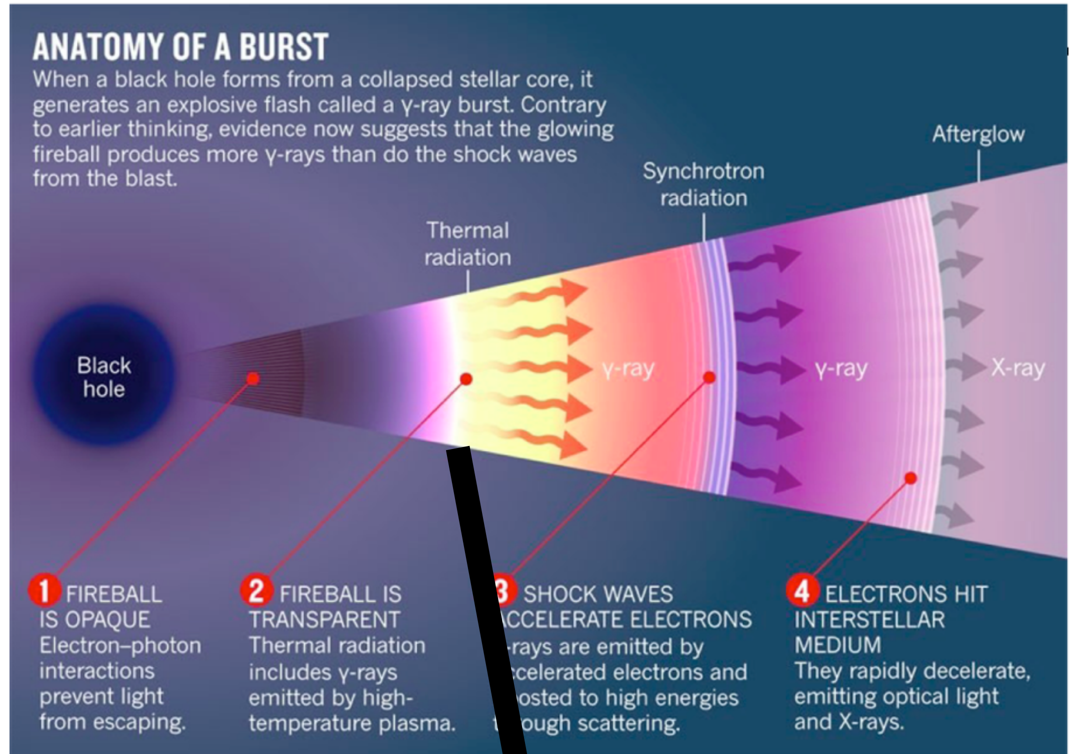
Varying faces of photospheric emission

Magnus Axelsson
Tokyo Metropolitan University

on behalf of the Fermi LAT (and SPHiNX) collaboration(s)

Basic framework: the fireball model





Paczyński 1986:

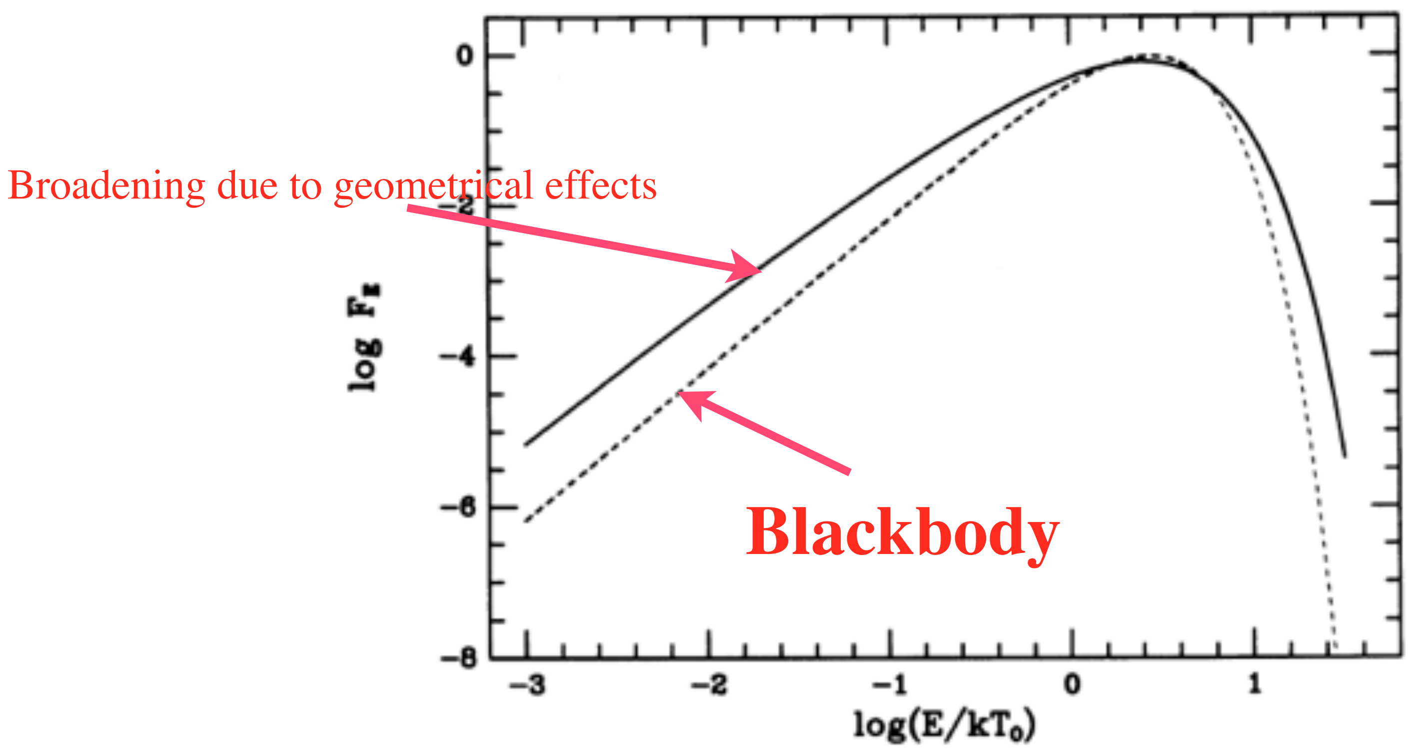
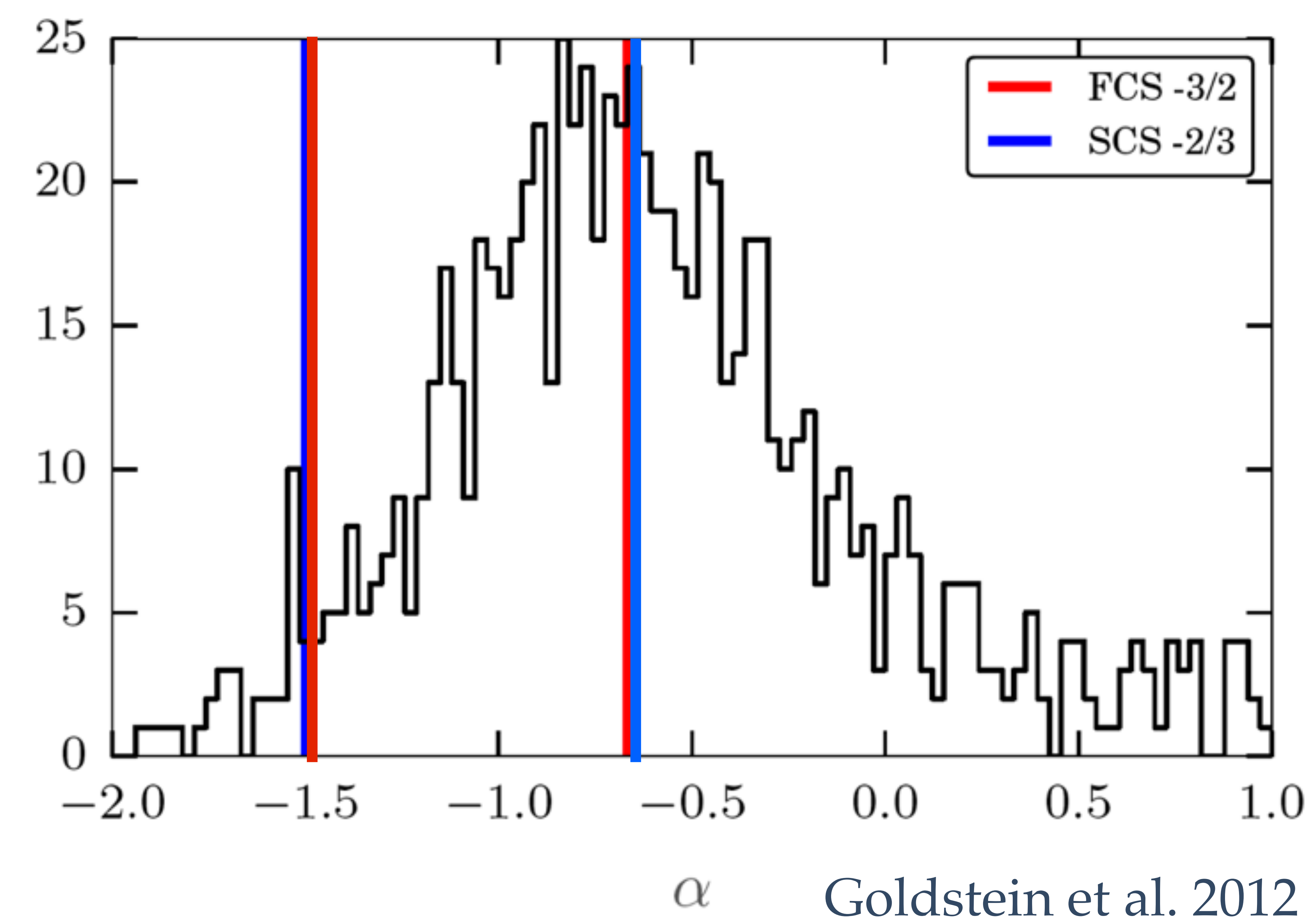


FIG. 1.—*Solid line*: energy distribution of the flux received by a distant observer at rest with respect to the center of mass of the fluid. The vertical scale is in arbitrary units. (*Dashed line*): corresponding distribution for a blackbody at the initial temperature of the fluid.

Paczyński 1986, ApJL, 308, 47

Line of death of synchrotron emission

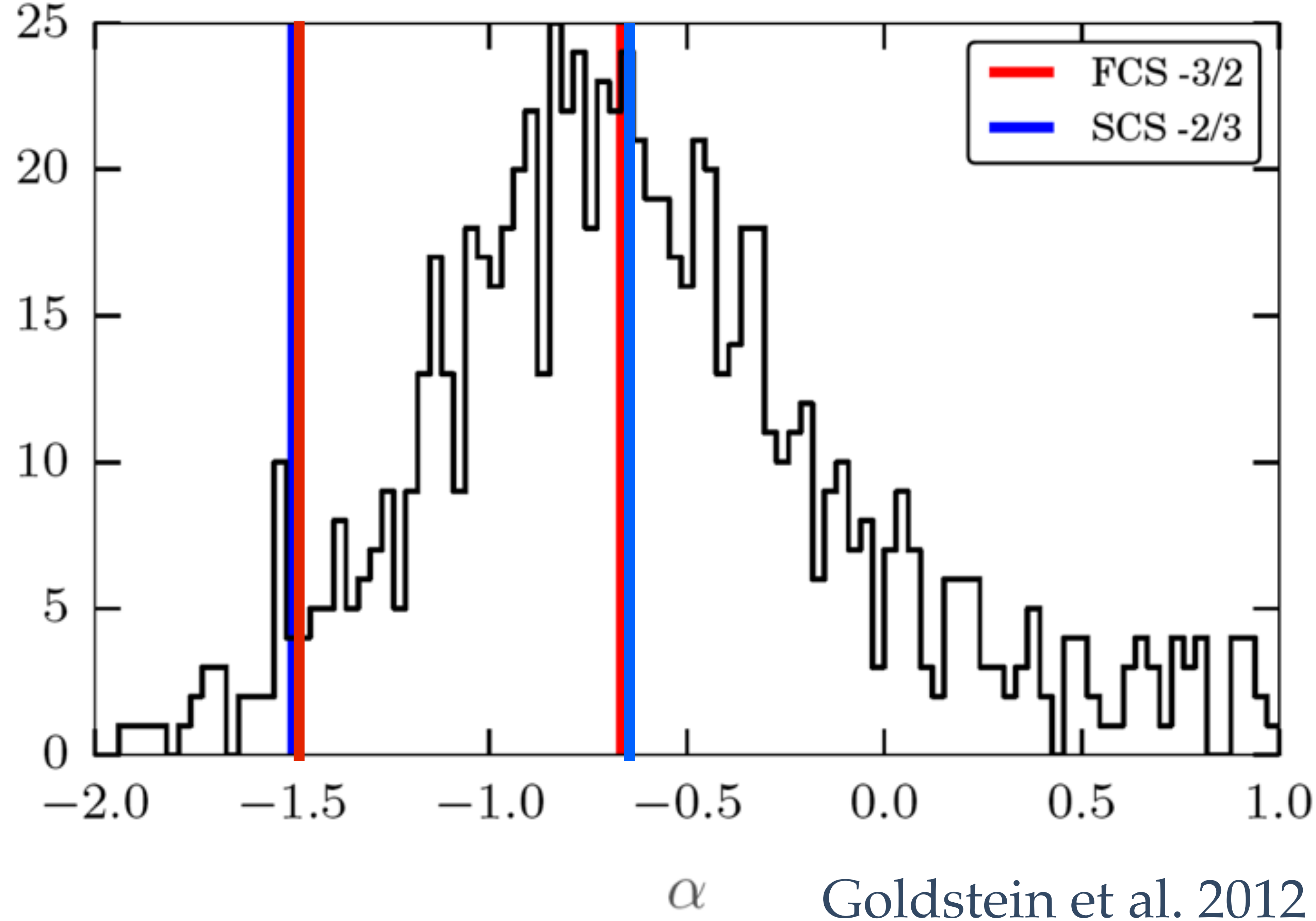
Preece et al. 98



Goldstein et al. 2012

Line of death of synchrotron emission

Preece et al. 98

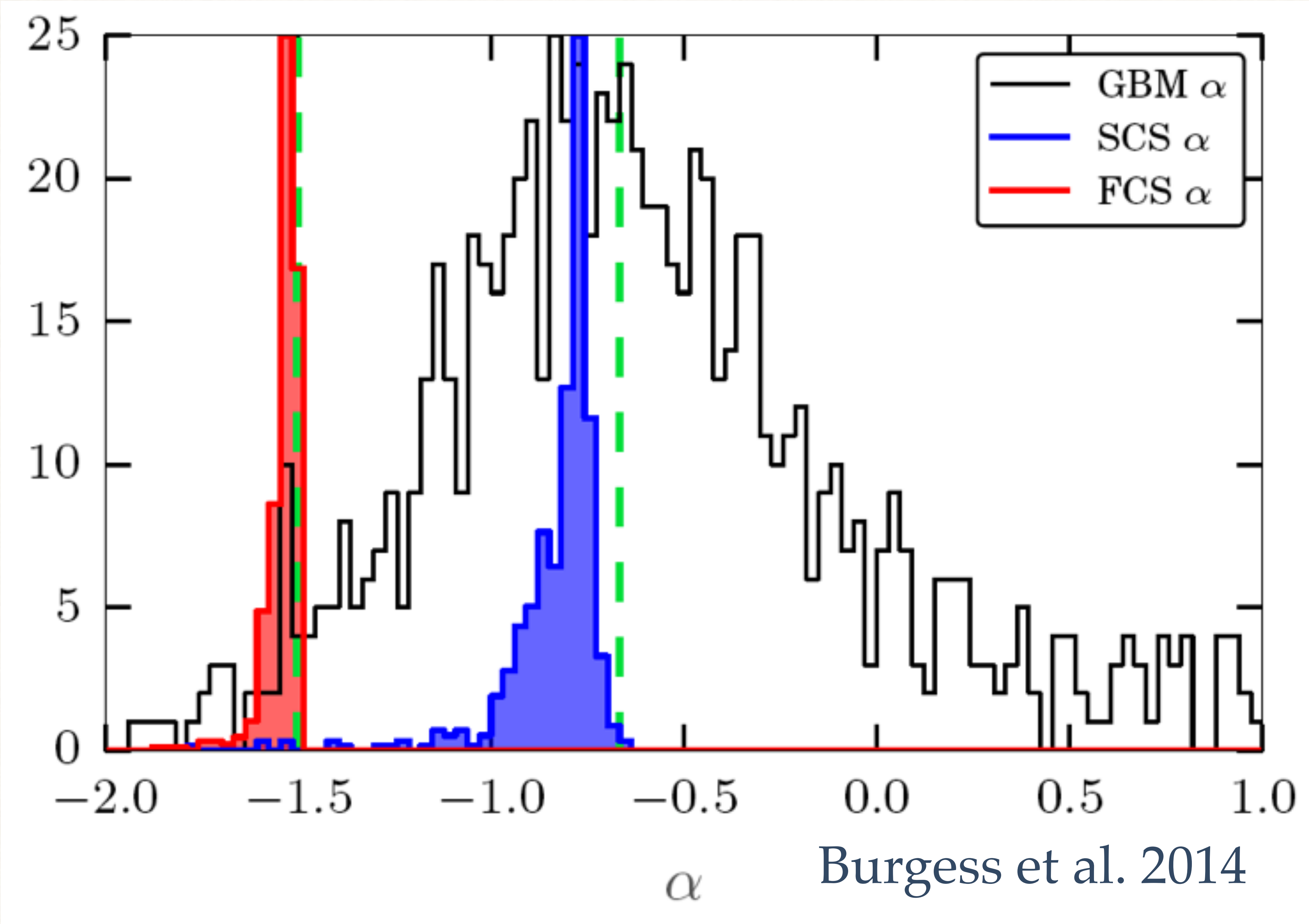


Goldstein et al. 2012

Synchrotron emission is not well represented by the Band function

Line of death of synchrotron emission

Preece et al. 98



Synchrotron emission is not well represented by the Band function

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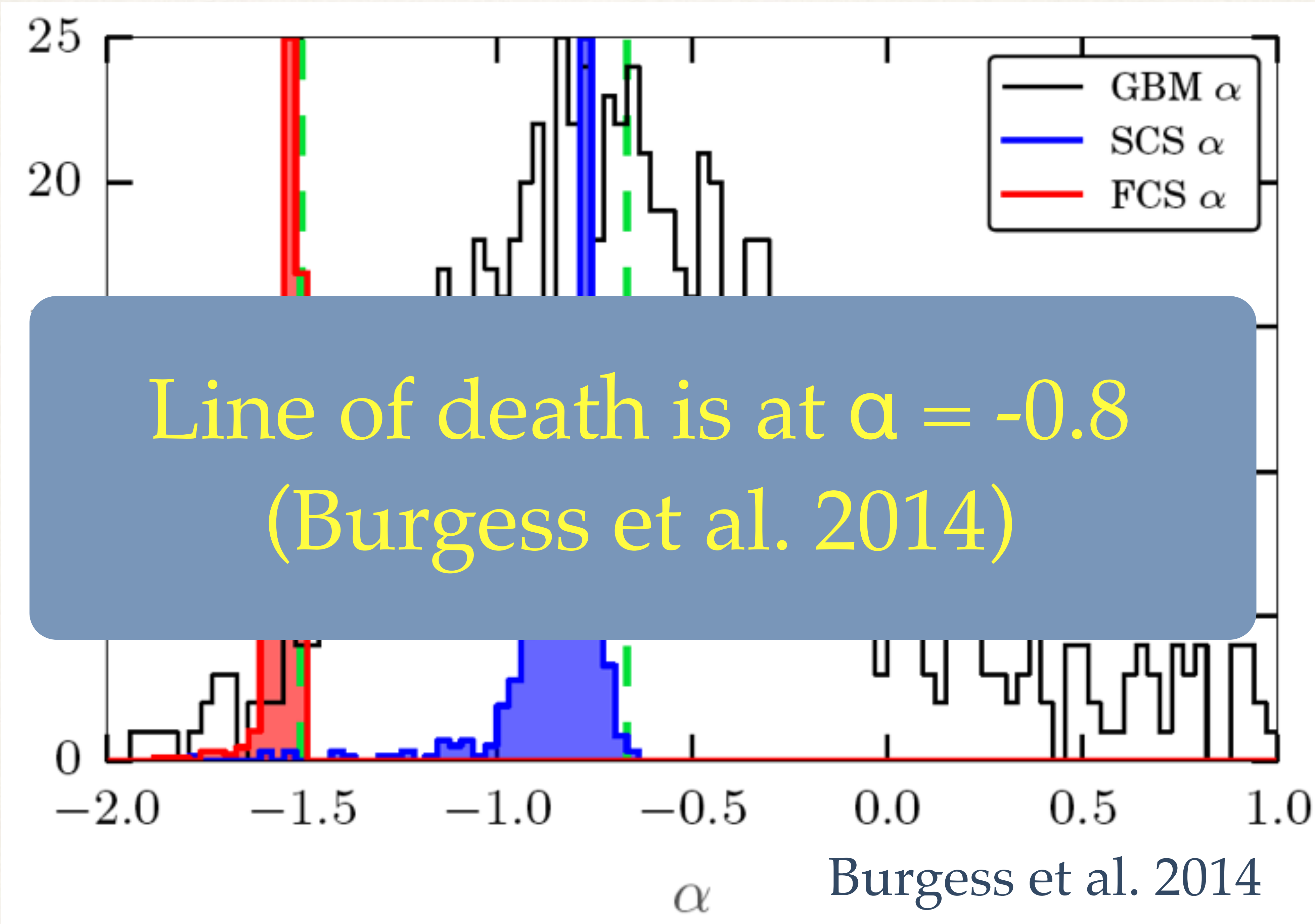
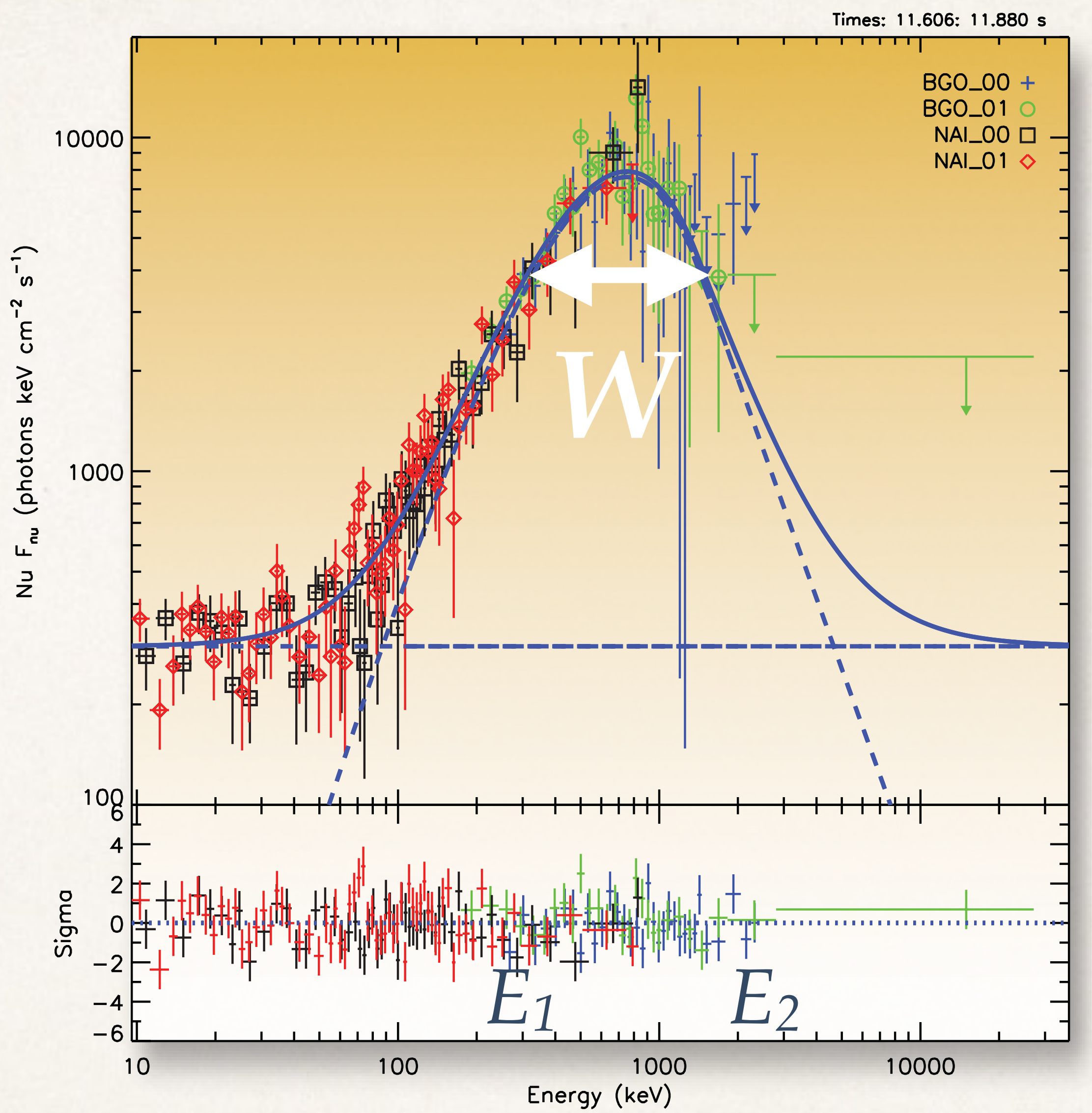


Line of death is at α = -0.8
(Burgess et al. 2014)

Synchrotron emission is not well represented by the Band function

Width of GRB spectra

W= FWHM



$$W = \log\left(\frac{E_2}{E_1}\right)$$

Width of GRB spectra

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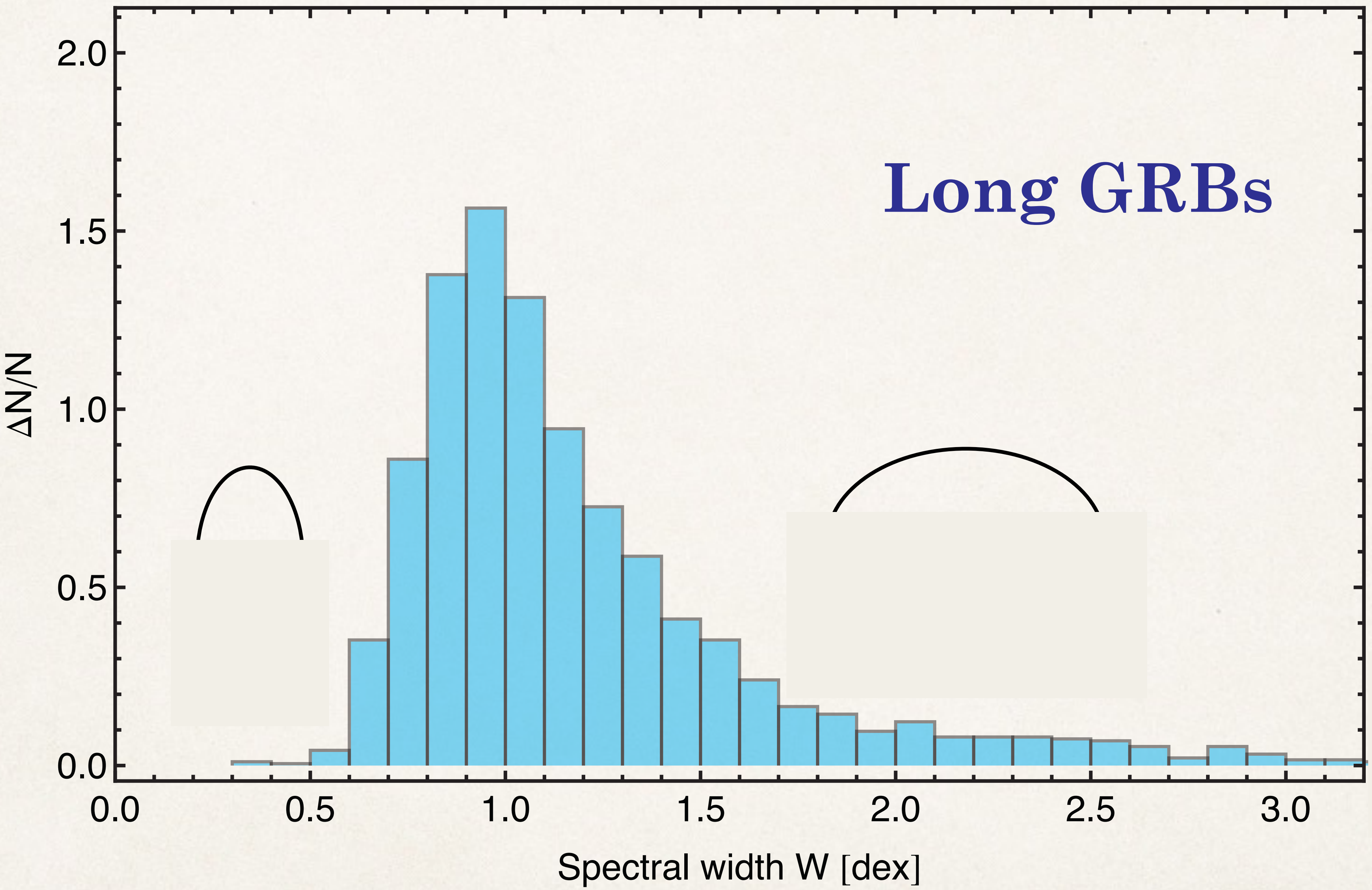
Peak flux spectra of 1970 CGRO/BATSE and 943 Fermi/GBM



Axelsson et al. 2015

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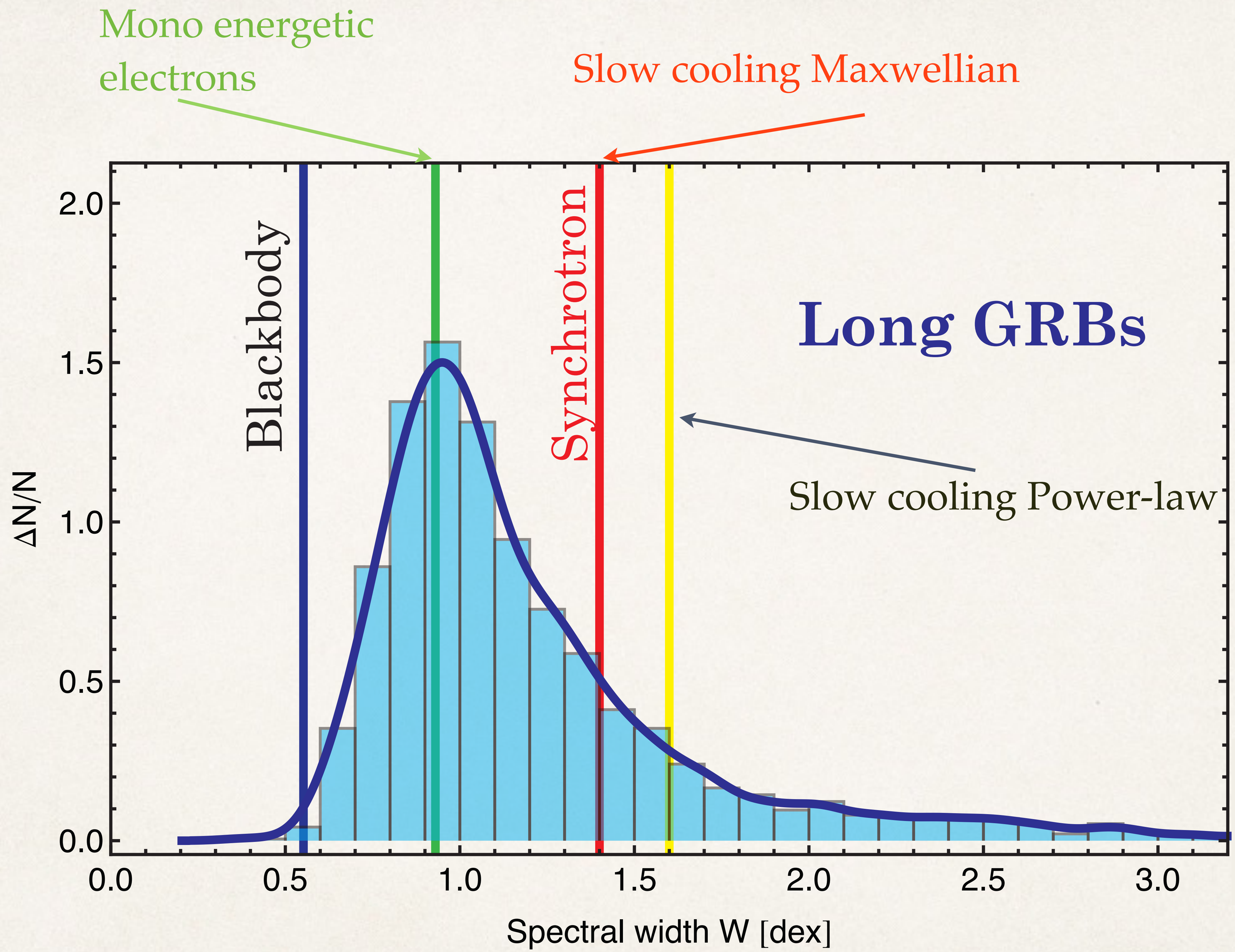

Axelsson et al. 2015

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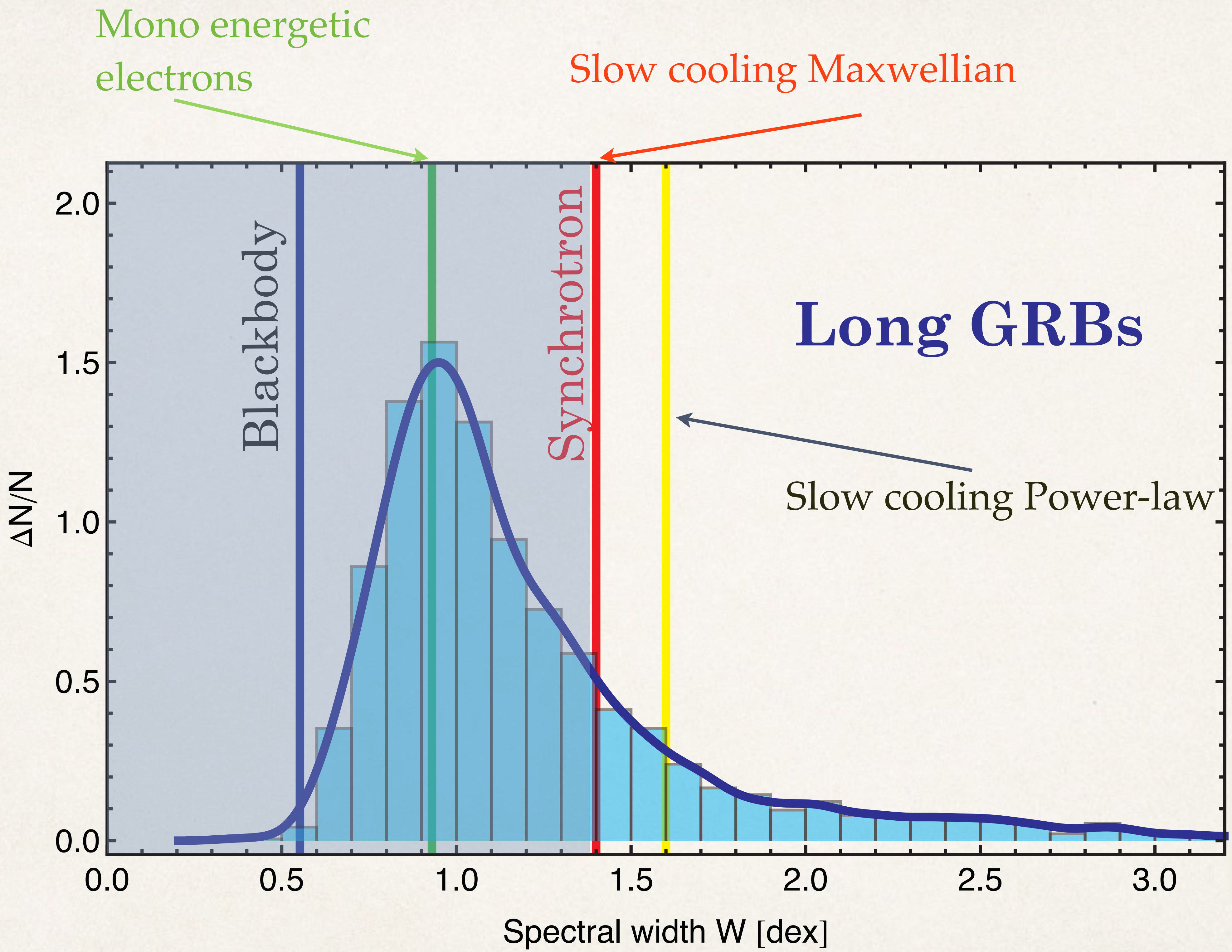

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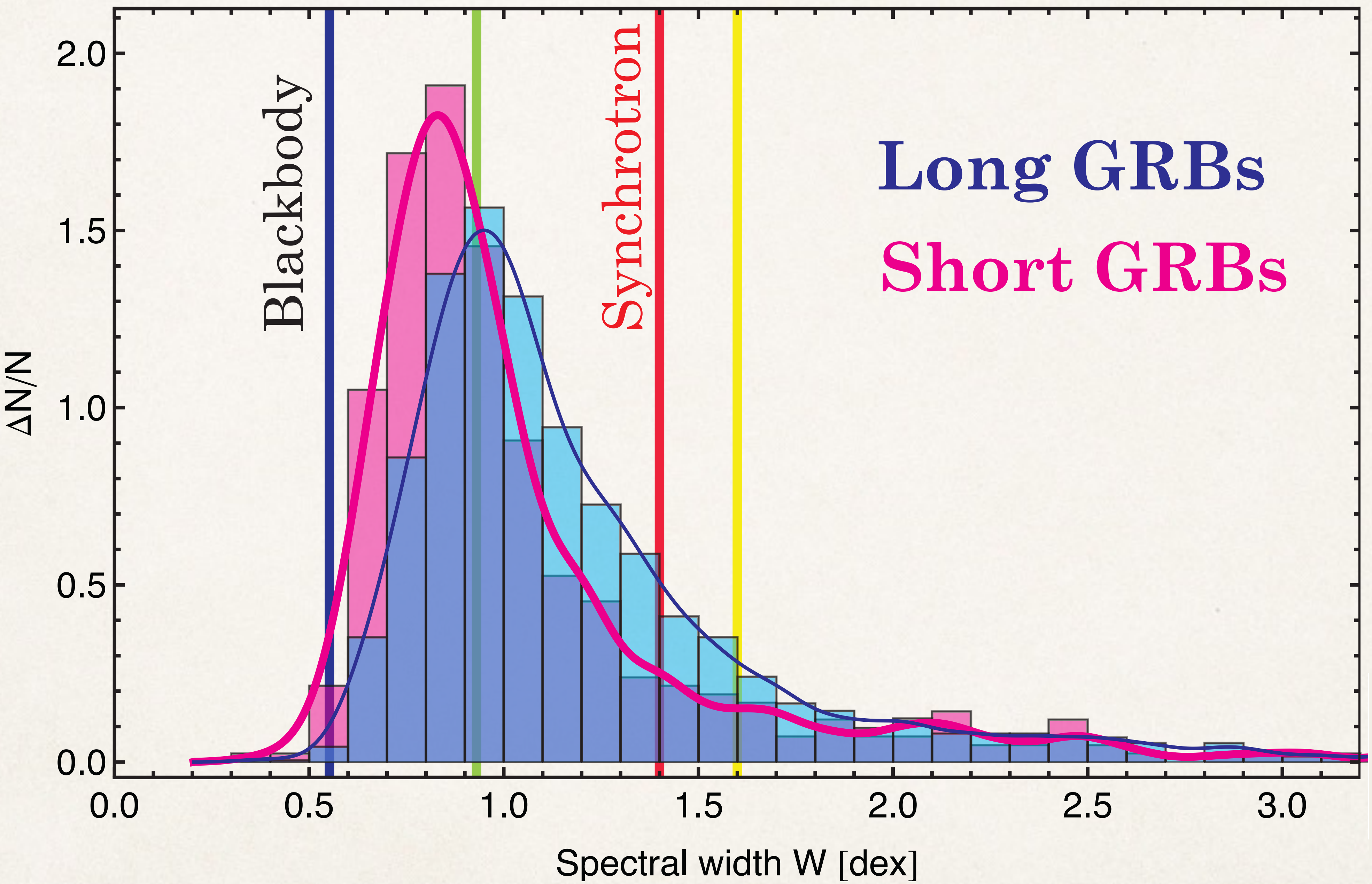

Axelsson et al. 2015

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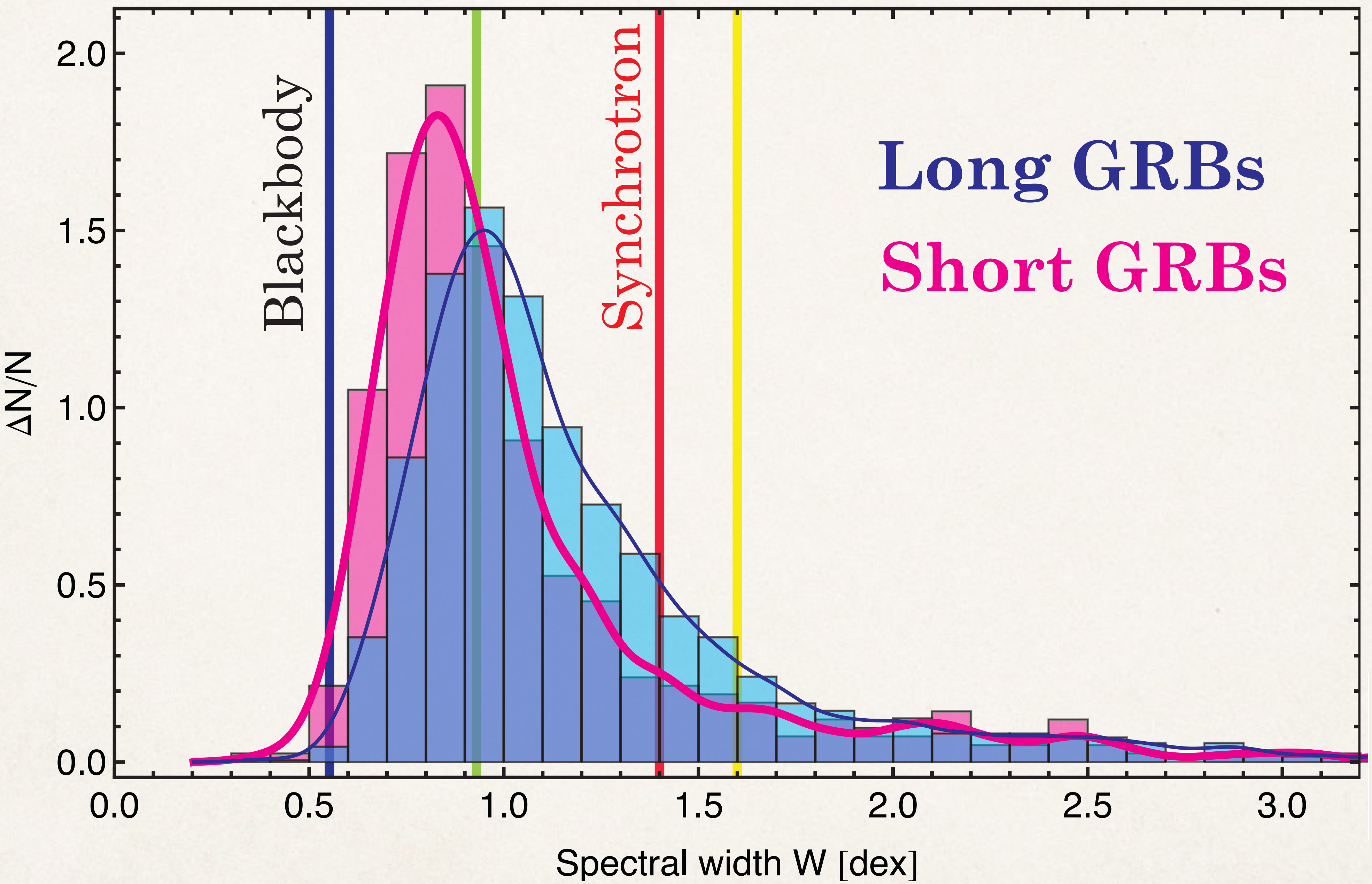

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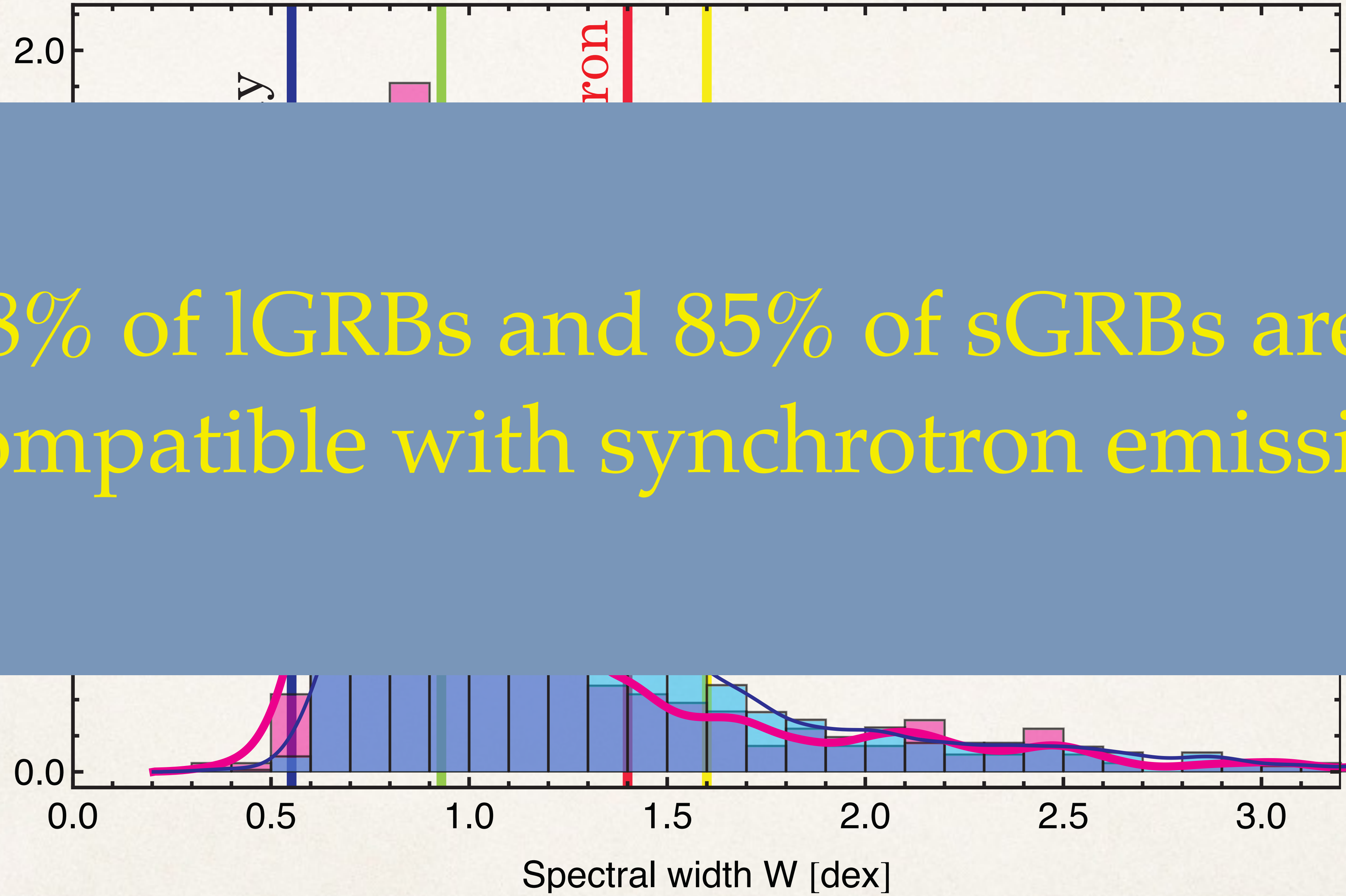


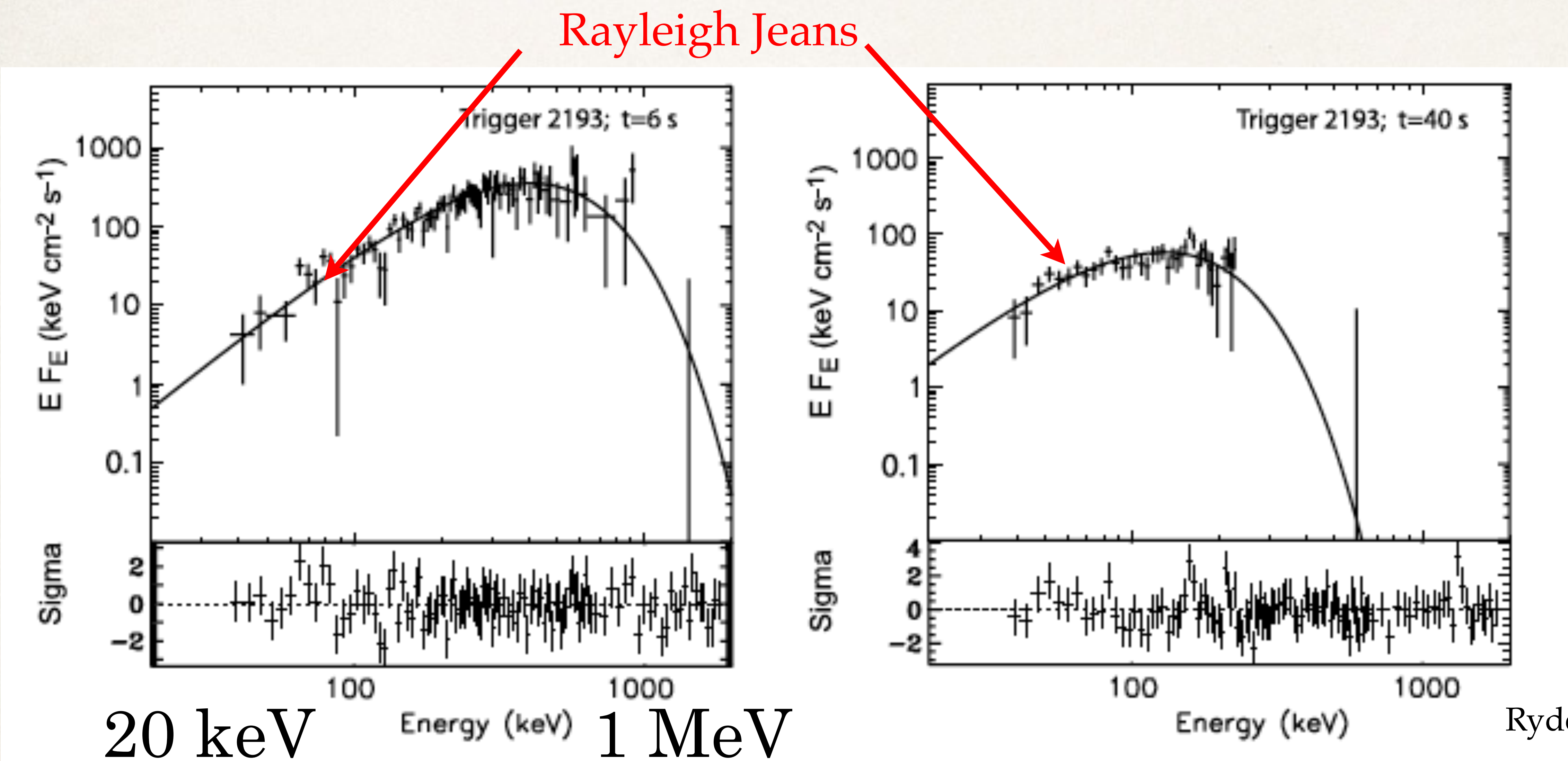
78% of lGRBs and 85% of sGRBs are incompatible with synchrotron emission

Axelsson et al. 2015

Single Planck function bursts

Compton Gamma-Ray Observatory

GRB930214



Ryde 2004

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

Single Planck function bursts

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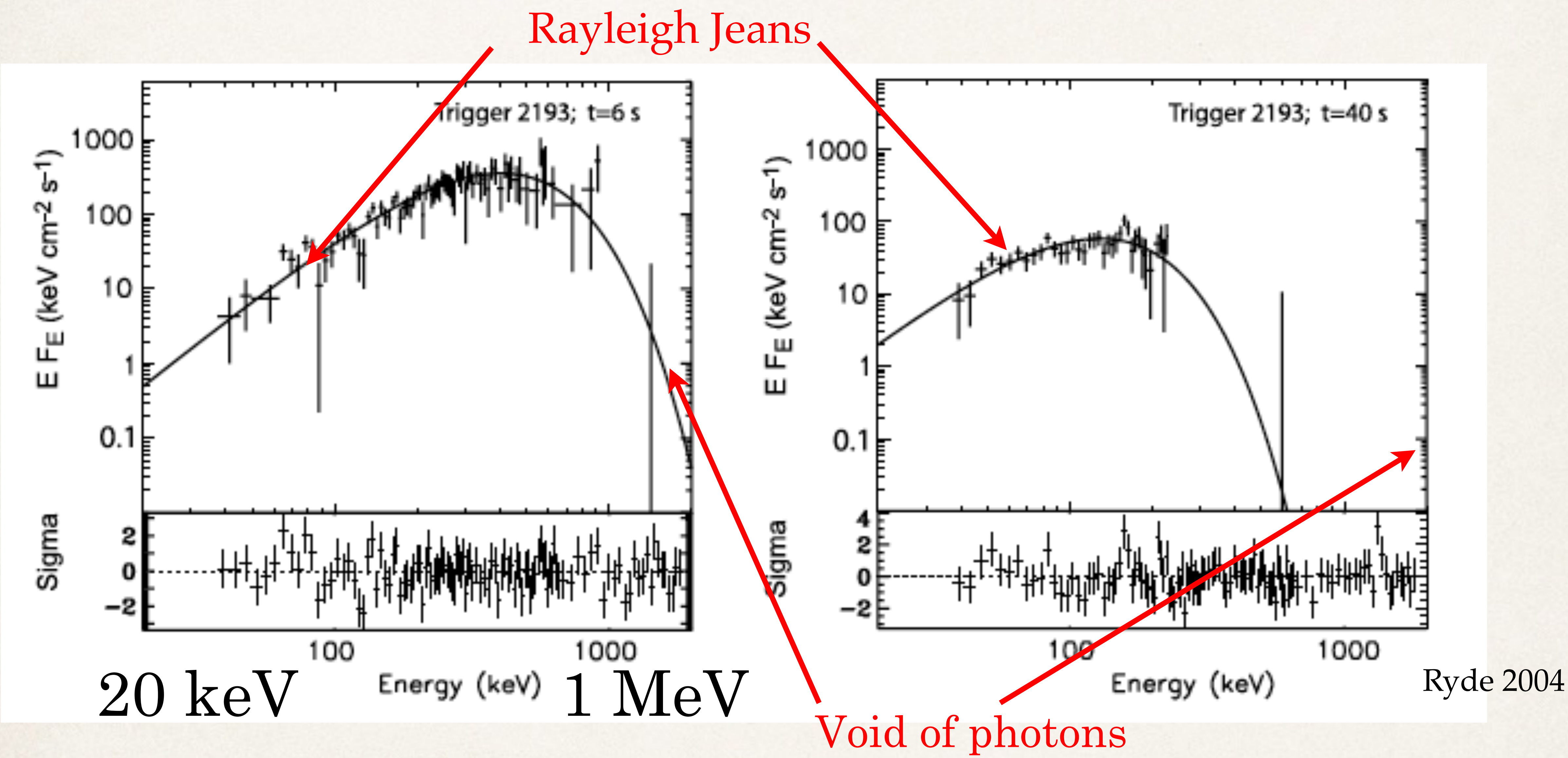

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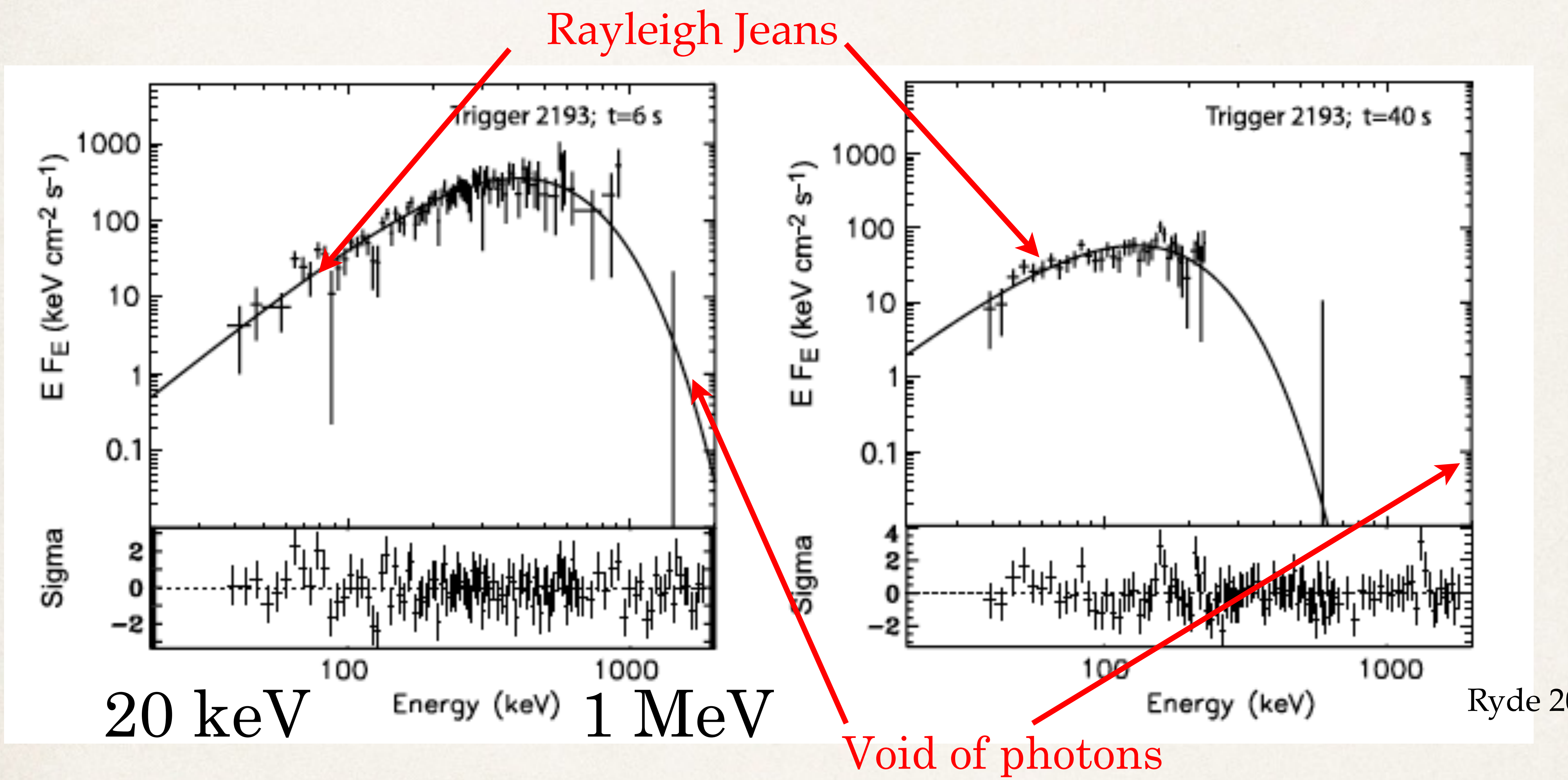

Ryde 2004

CGRO BATSE: 6 observed bursts out of 2200

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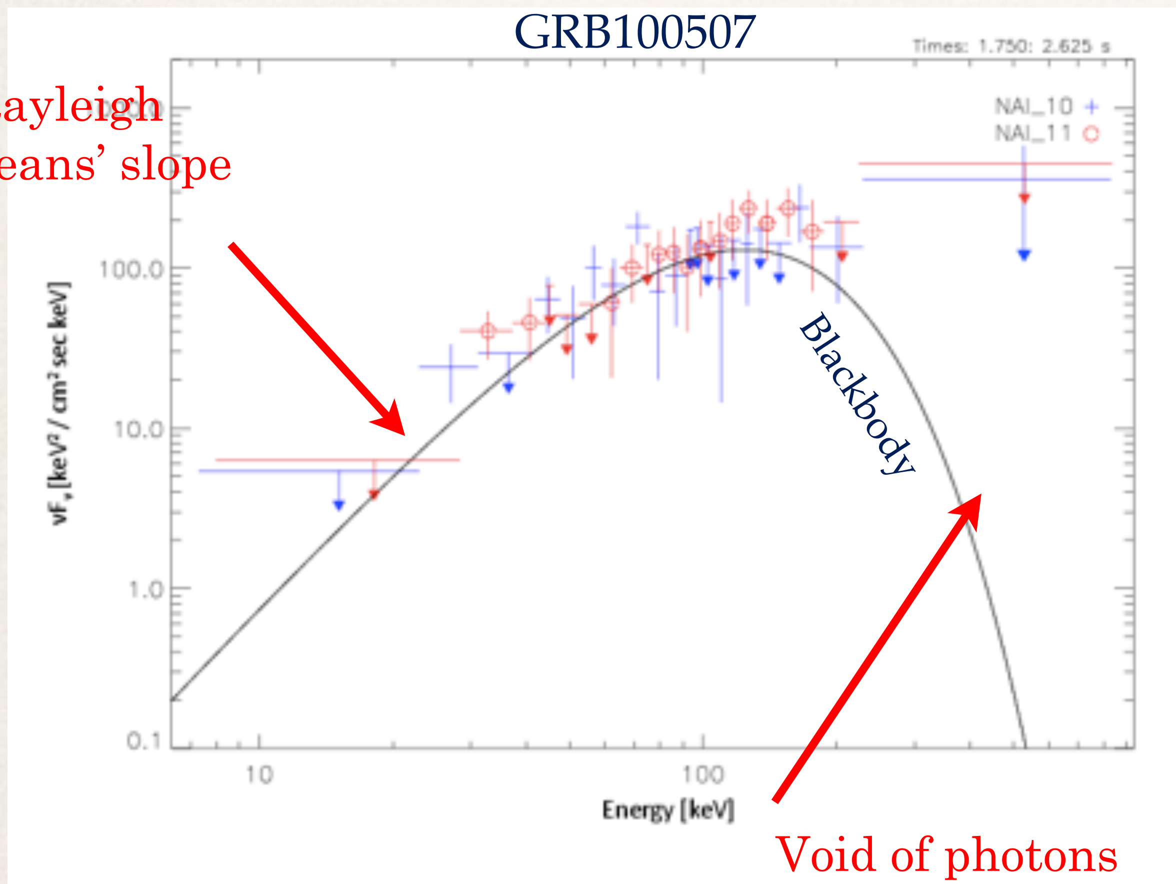
Single Planck function bursts

Fermi Gamma Ray Space Telescope

Rayleigh
Jeans' slope



Ghirlanda et al. 2013

Rayleigh
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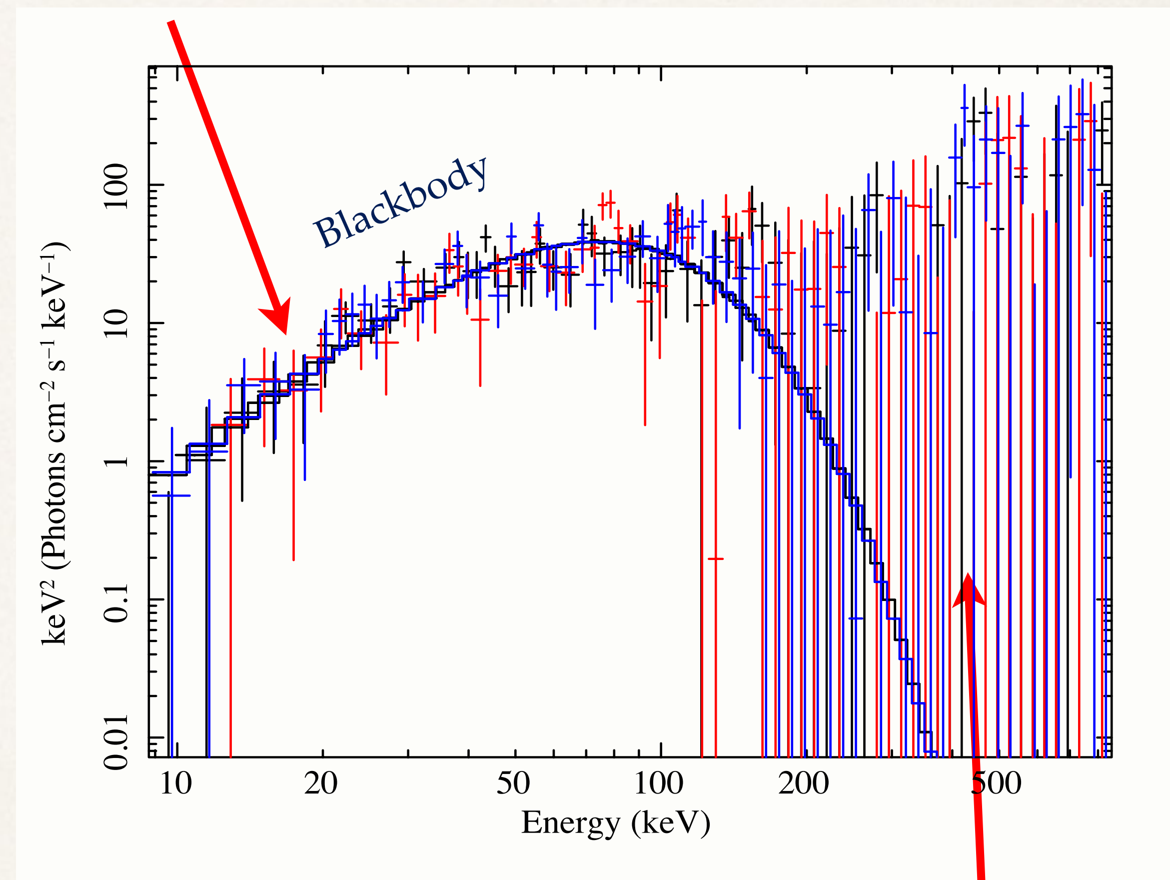


Larsson et al. 2014

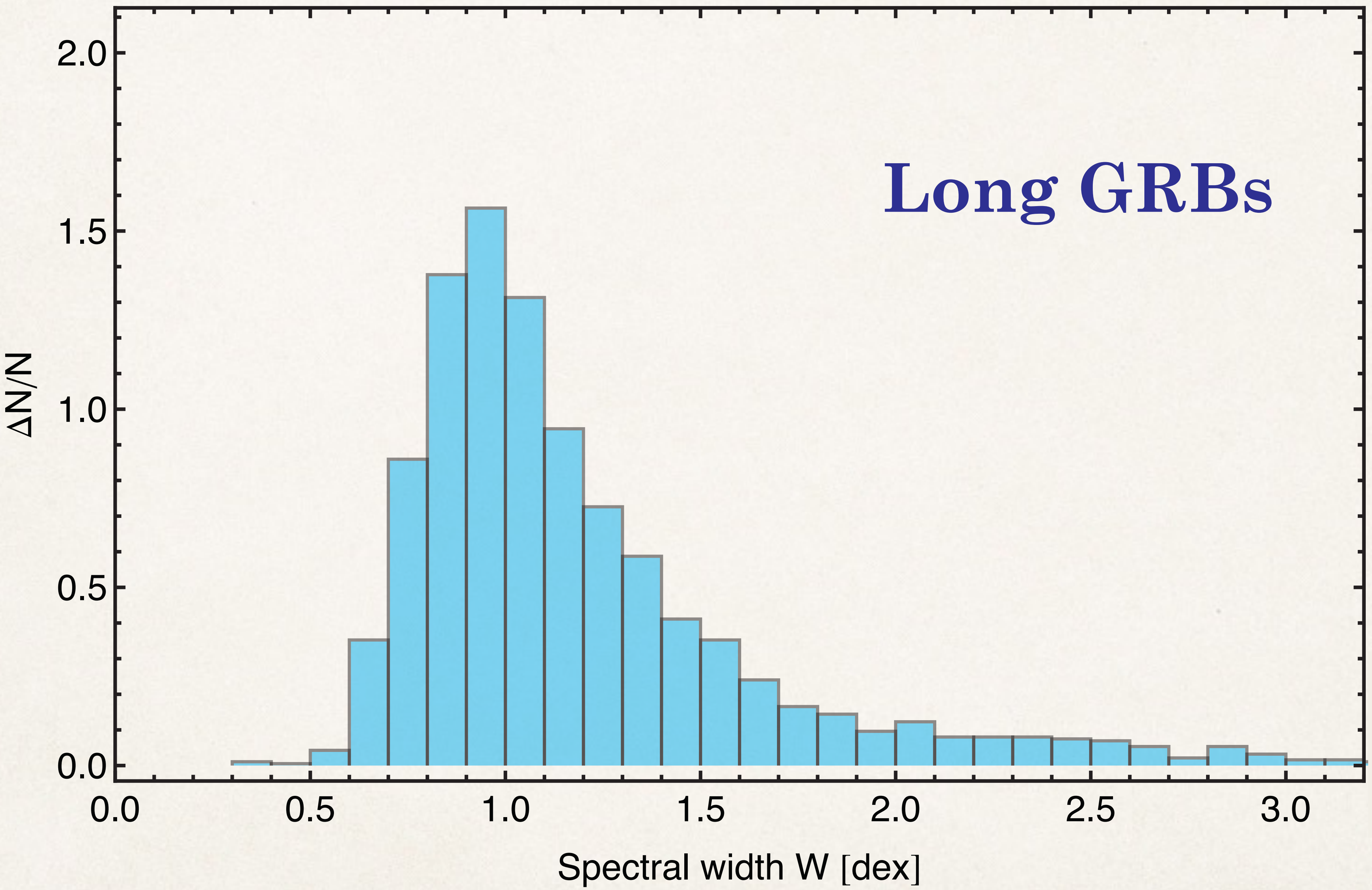
Void of photons

Fermi: 2 pure BB (out of 1400)

Width of GRB spectra

$$W = \log\left(\frac{E_2}{E_1}\right)$$

Peak flux spectra of 1970 CGRO/BATSE and 943 Fermi/GBM



Axelsson et al. 2015

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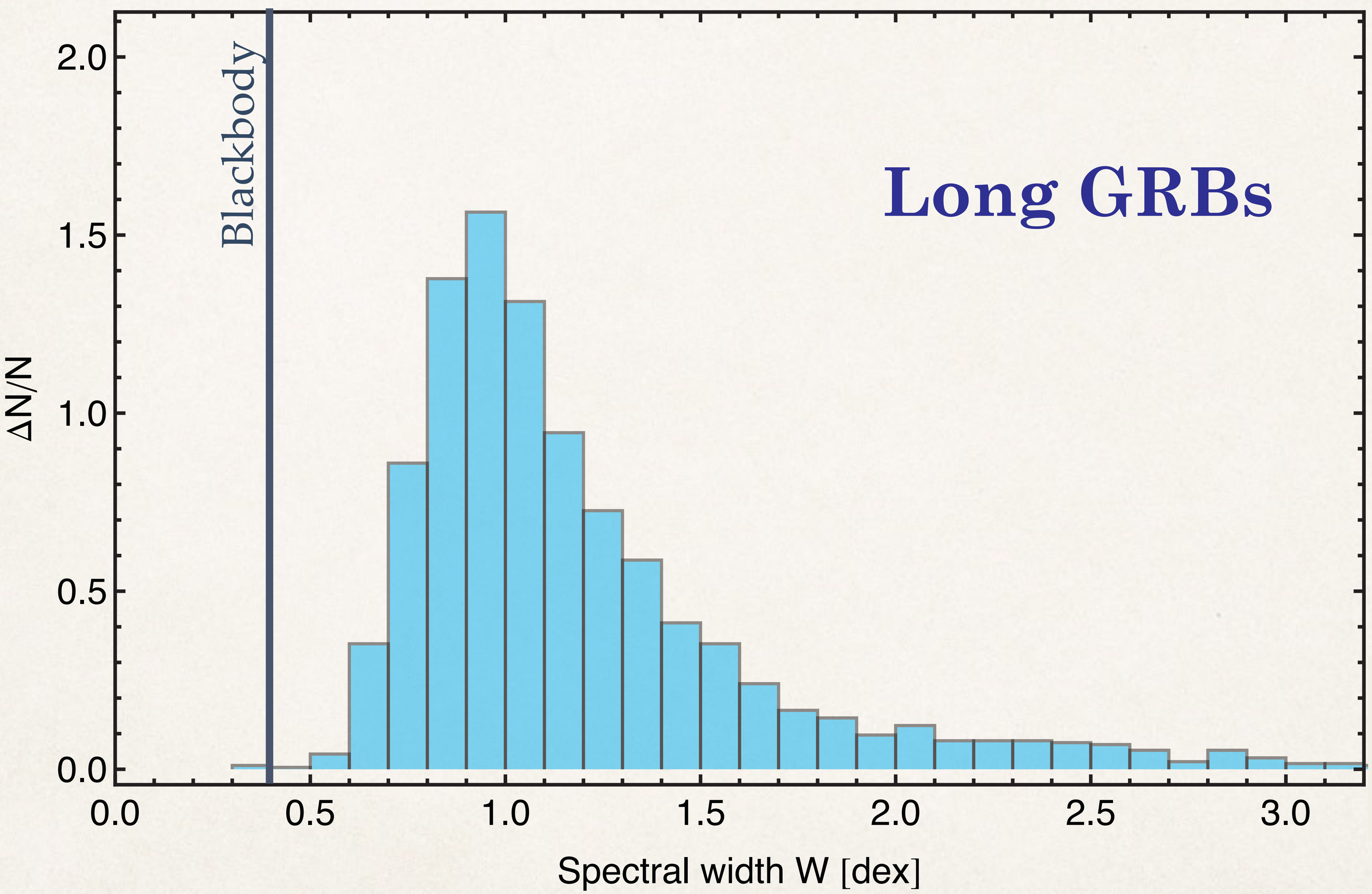

Axelsson et al. 2015

How can we explain the data?

Problem:

- 0.3% are pure blackbodies during the whole burst

- 78% are narrower than the synchrotron function

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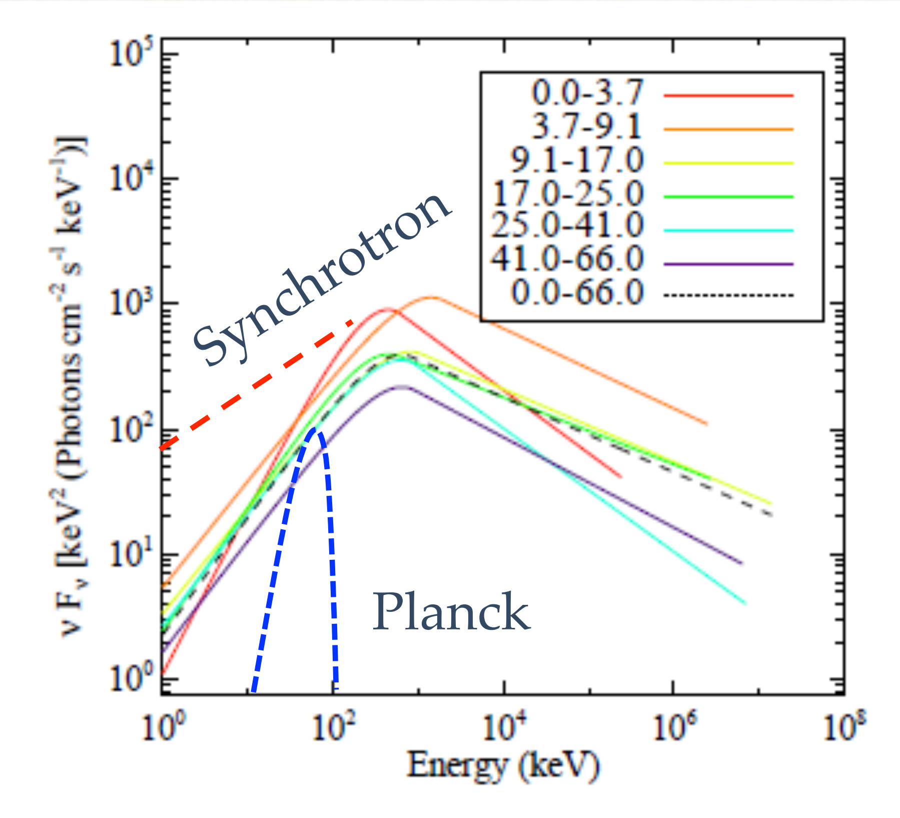
Problem:

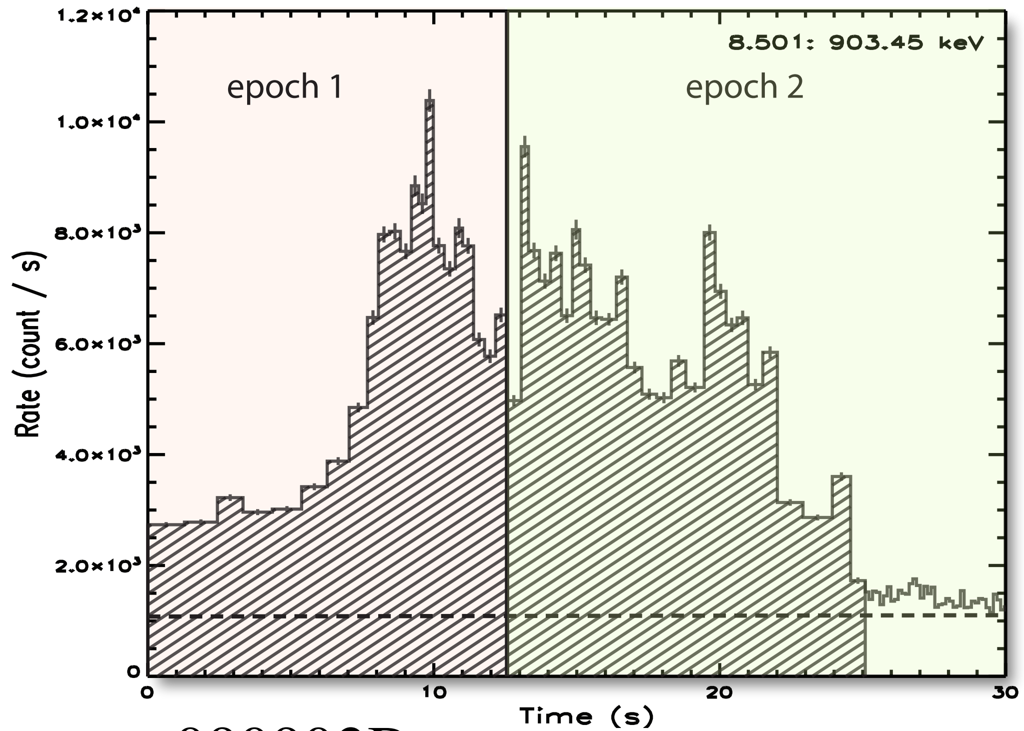
- 0.3% are pure blackbodies during the whole burst

- 78% are narrower than the synchrotron function

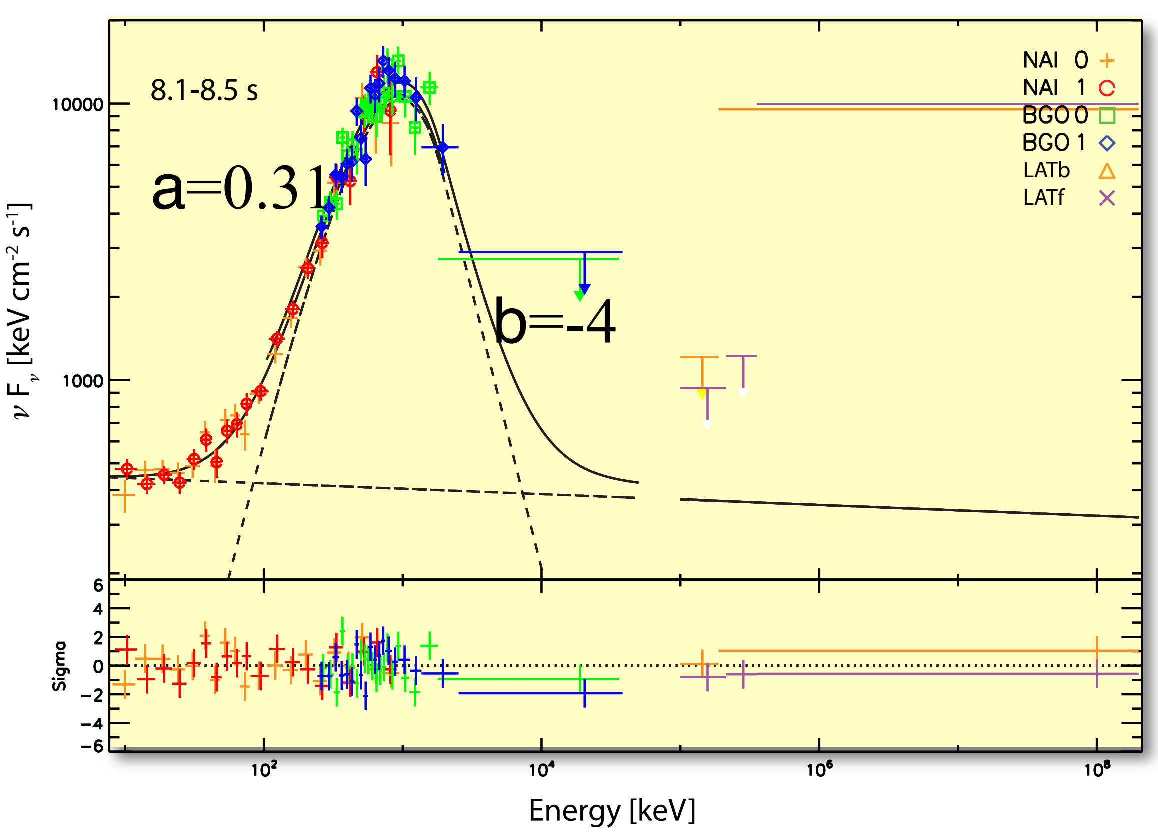
The Planck spectrum can be broadened, but the synchrotron emission cannot be made narrower.



Narrow “BB-like” components



090902B



Ryde et al. 2011

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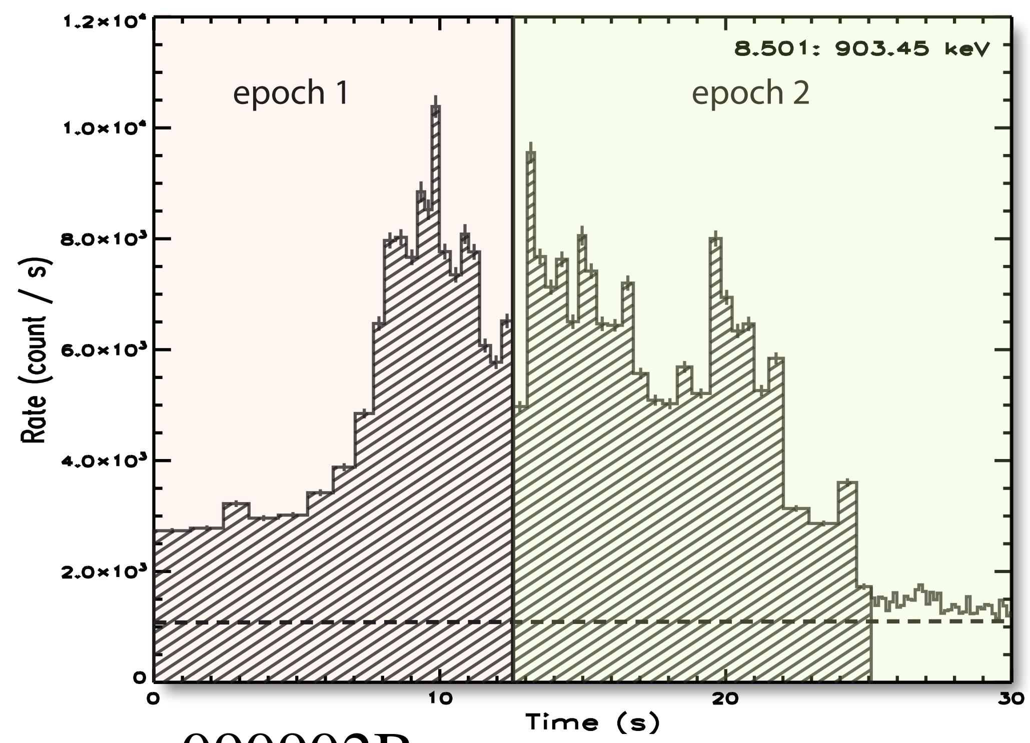

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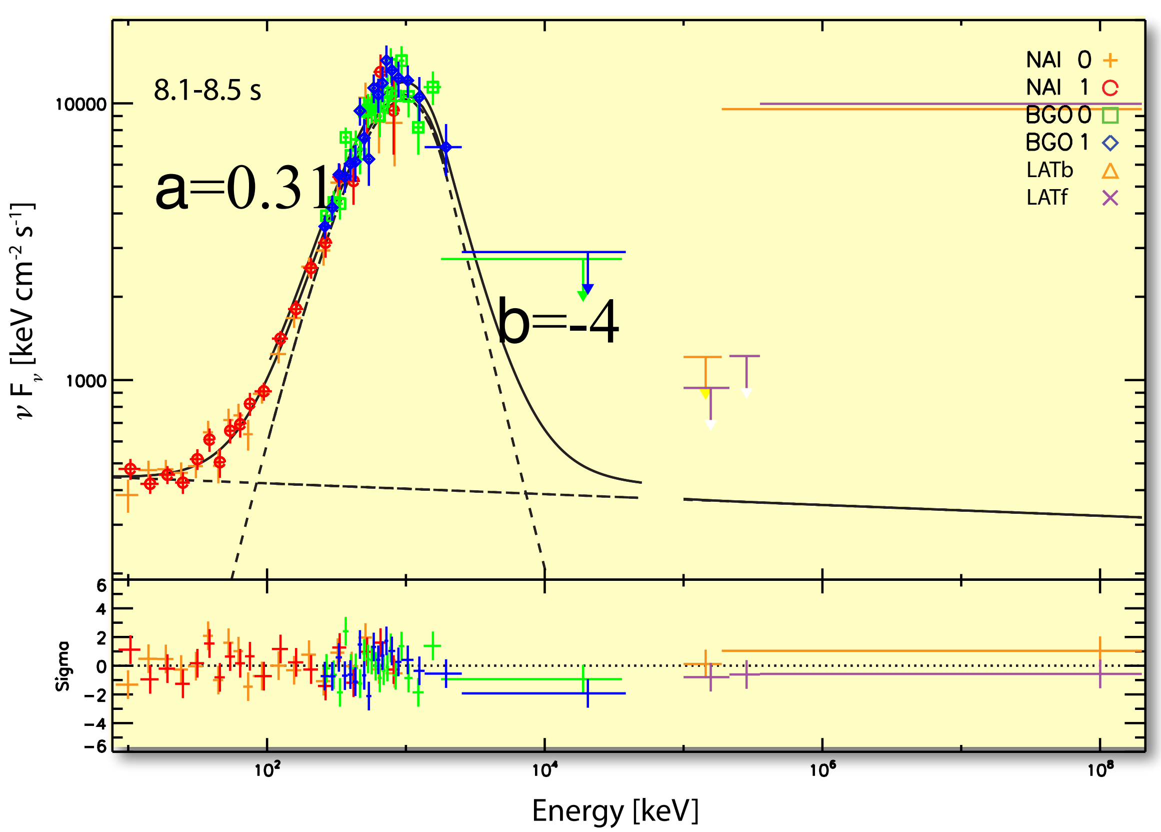
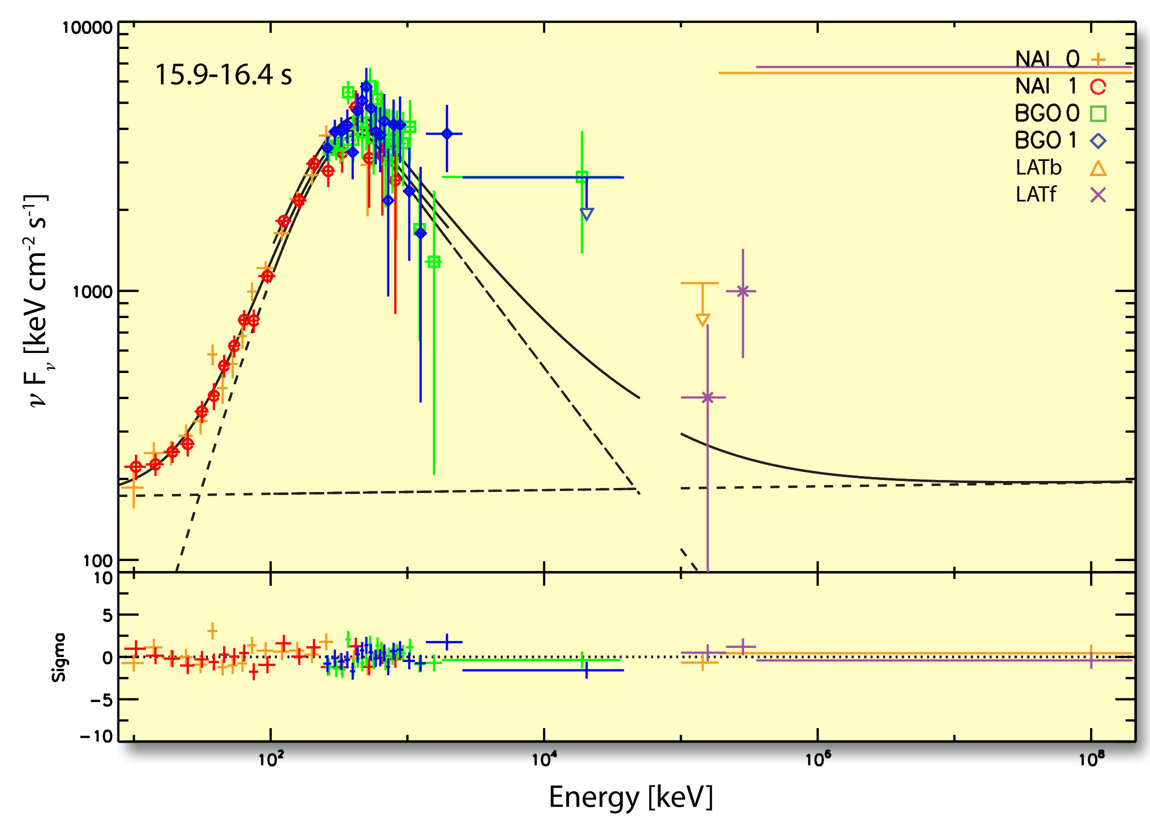




Ryde et al. 2011

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!

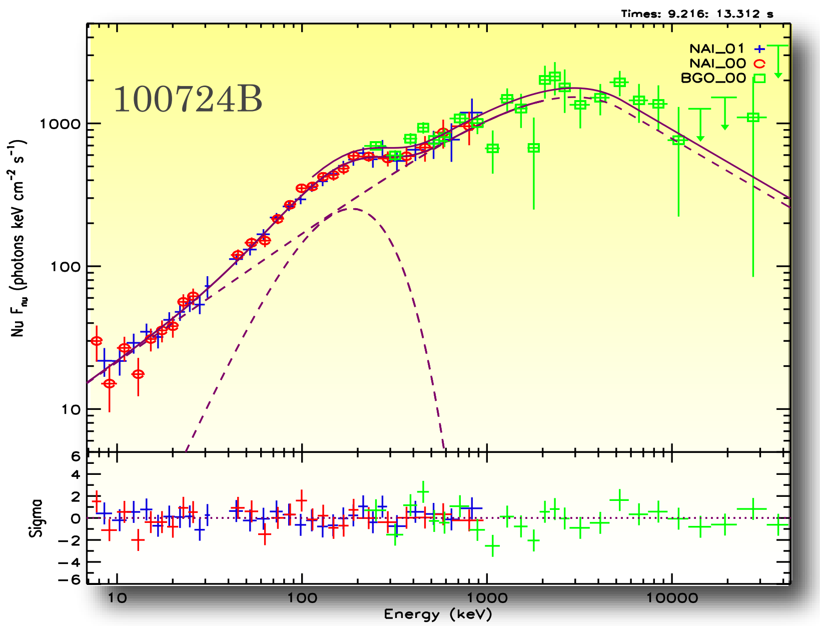
3. Typical spectra are not this kind

4. Most spectra are broader than a BB -> broadening mechanisms

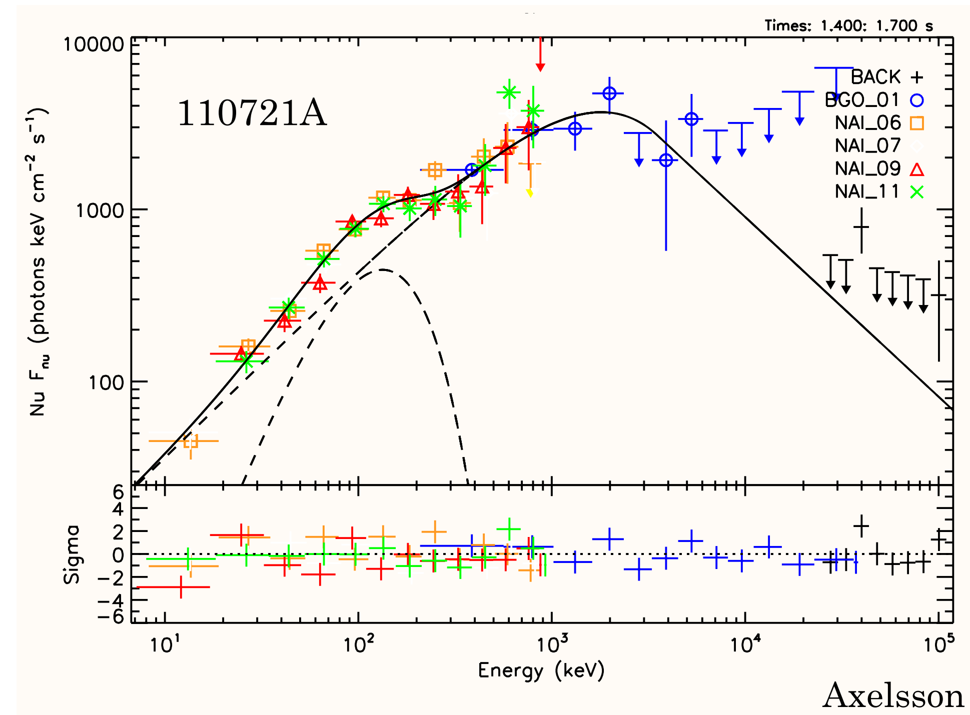
5. Motivation to search for photospheric emission

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

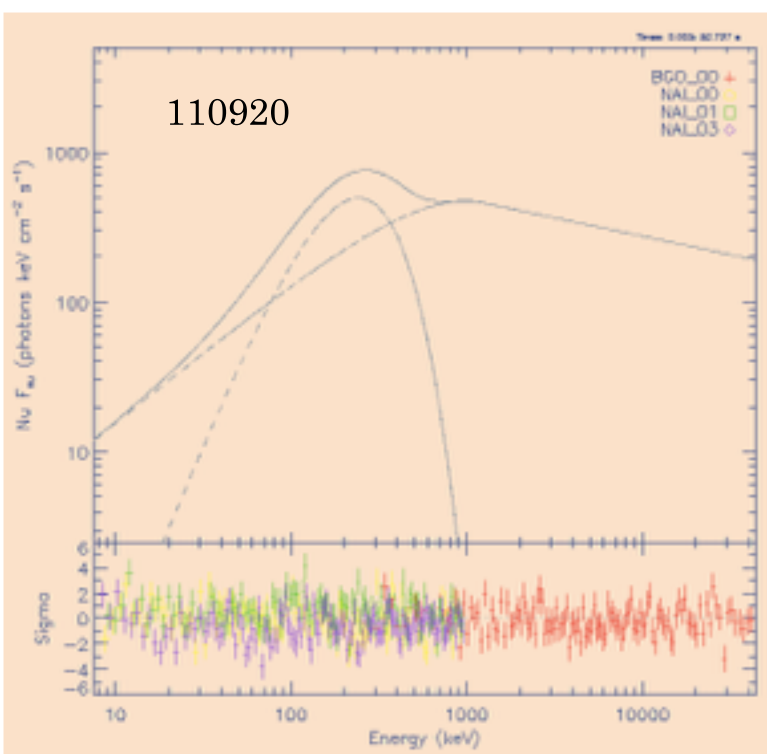
The photospheric component is modelled by a Planck function.
Is expected to be broadened to some extent.



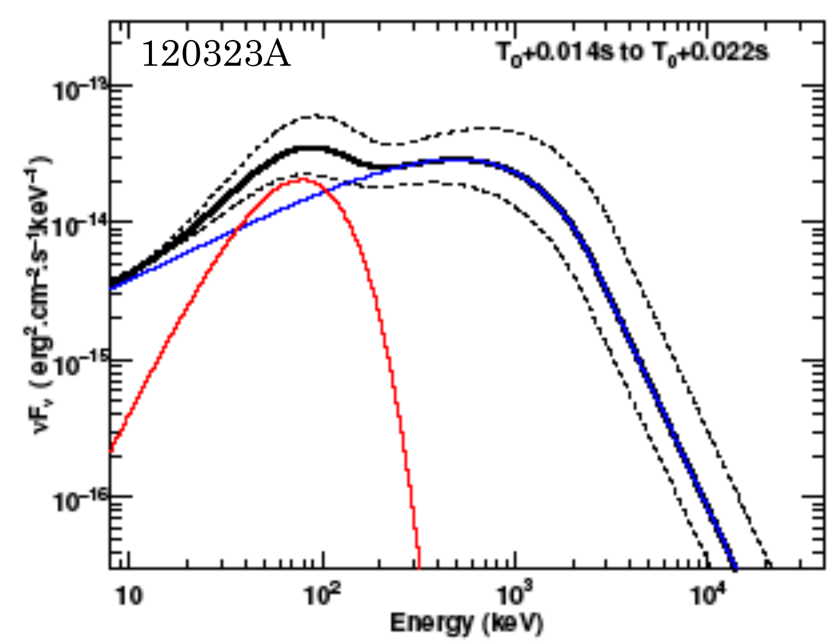
Guiriec et al. 2011



Axelsson et al. 2012



McGlynn et al. 2012

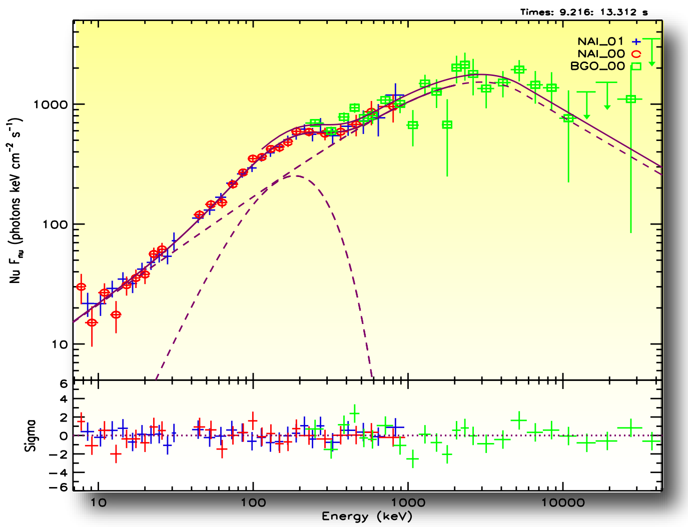


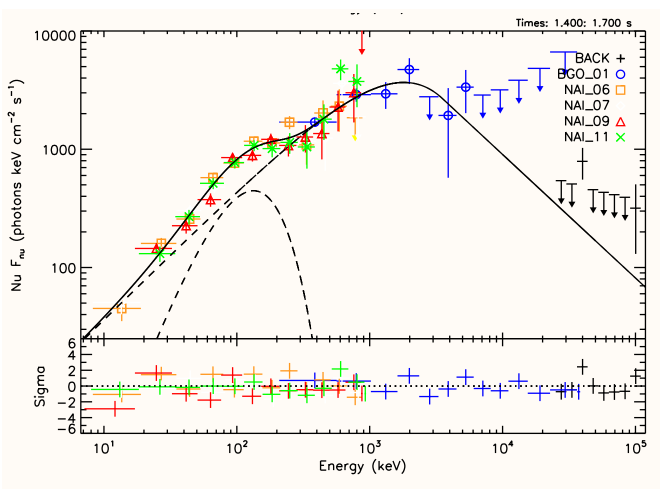
Guiriec et al. 2013

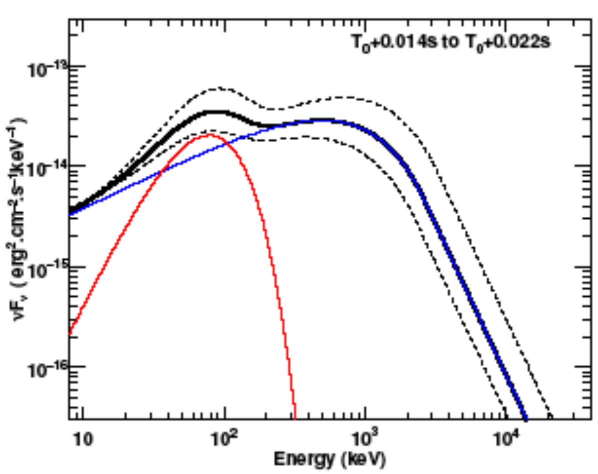
Two component spectra: Blackbody component typically 5-10% of total flux.
But much higher some cases.

Two component spectra

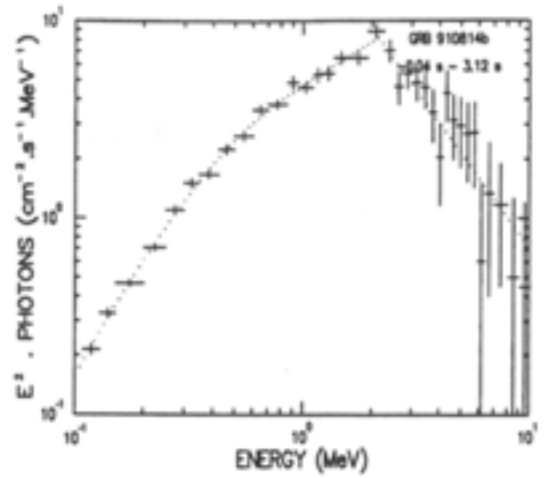
Fermi

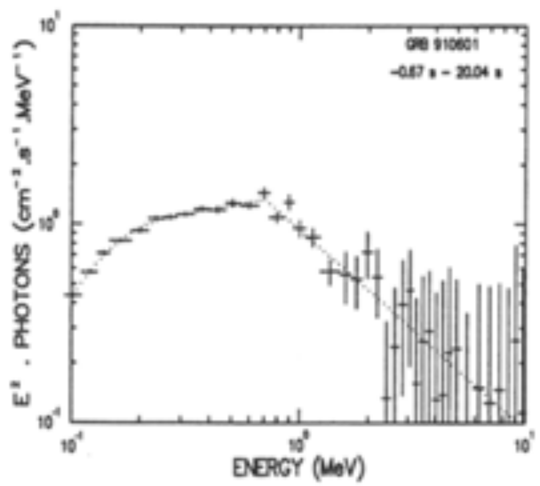


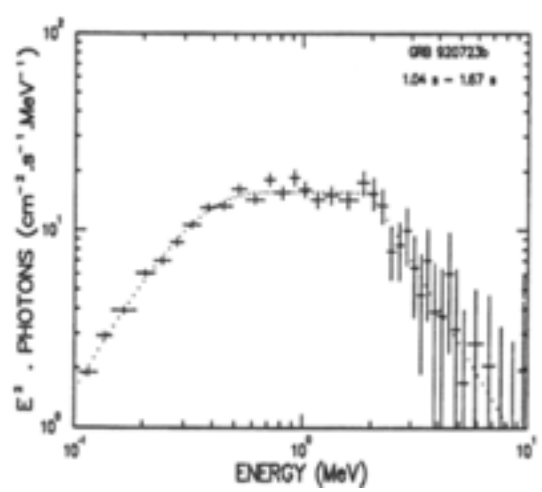




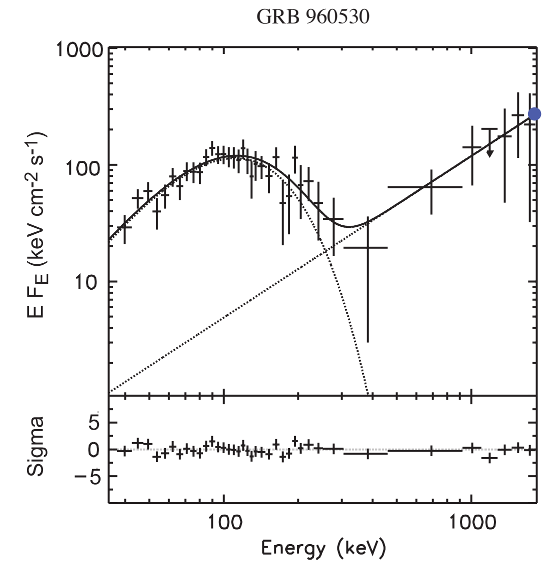
Fregate

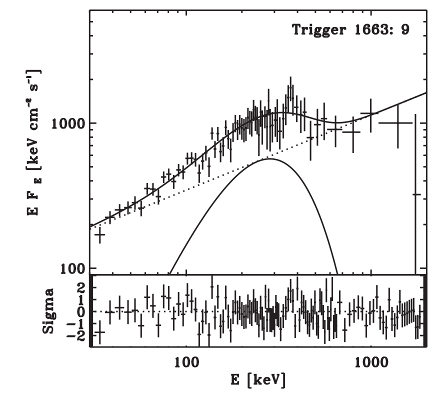


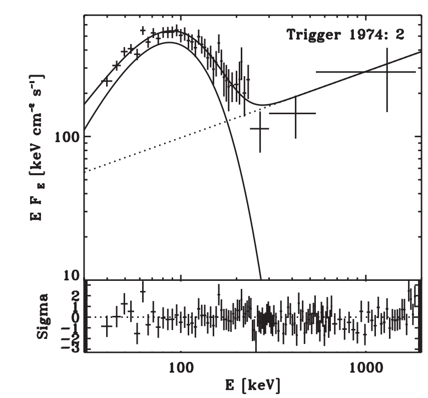


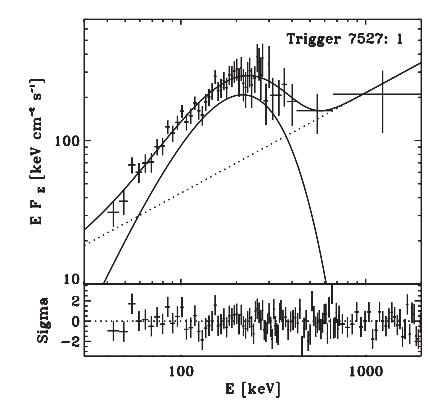


CGRO





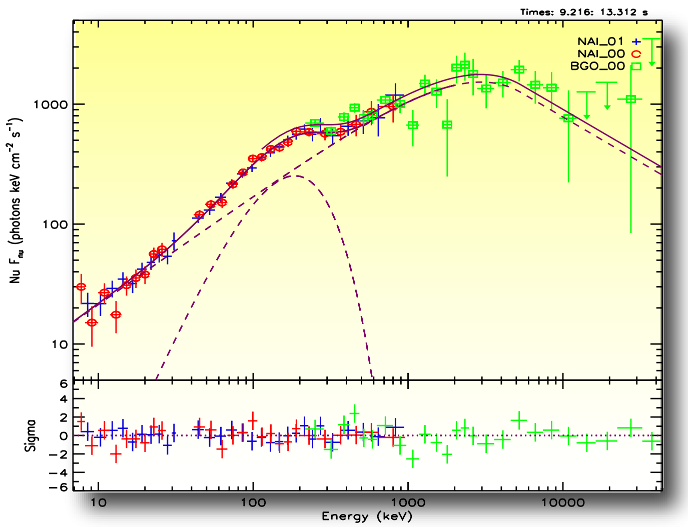


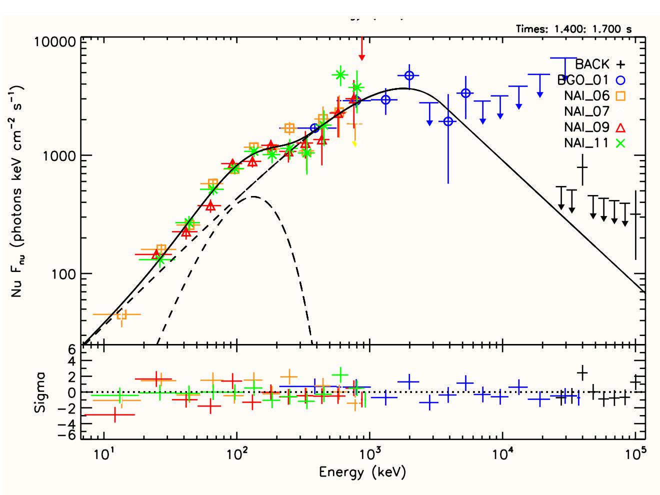


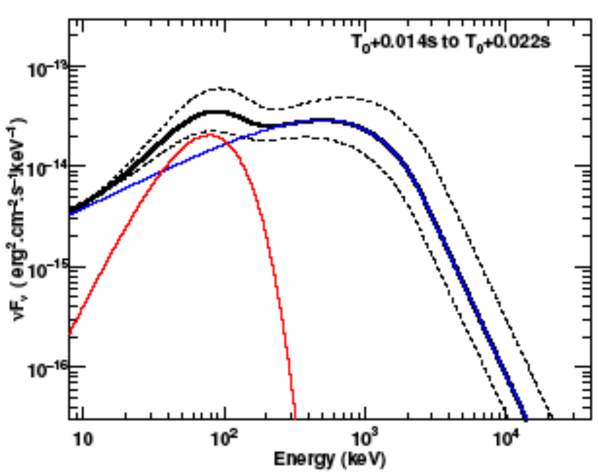
Fermi Gamma-ray Space Telescope

Two component spectra

Fermi







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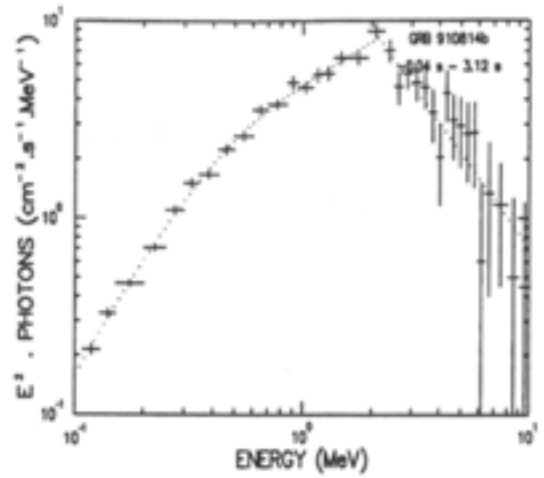
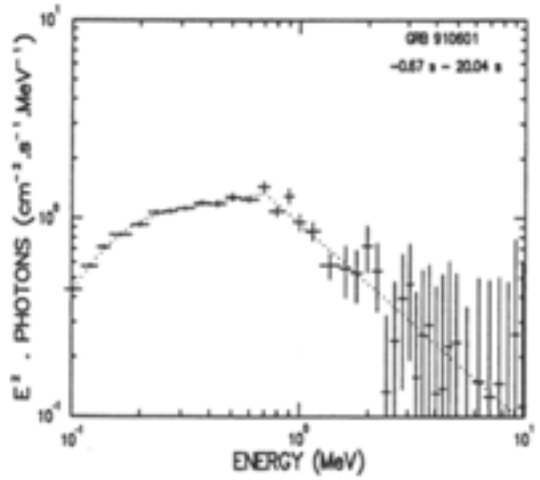
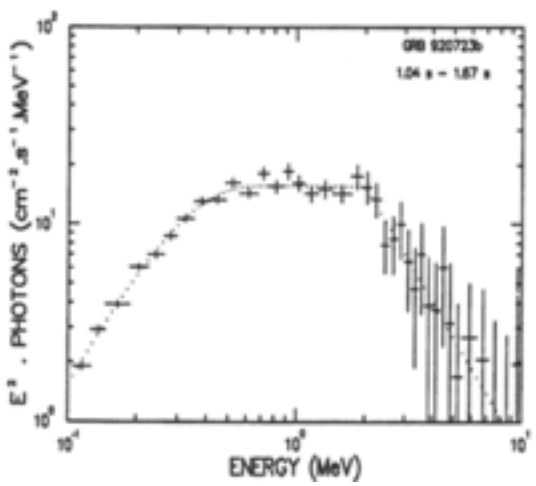
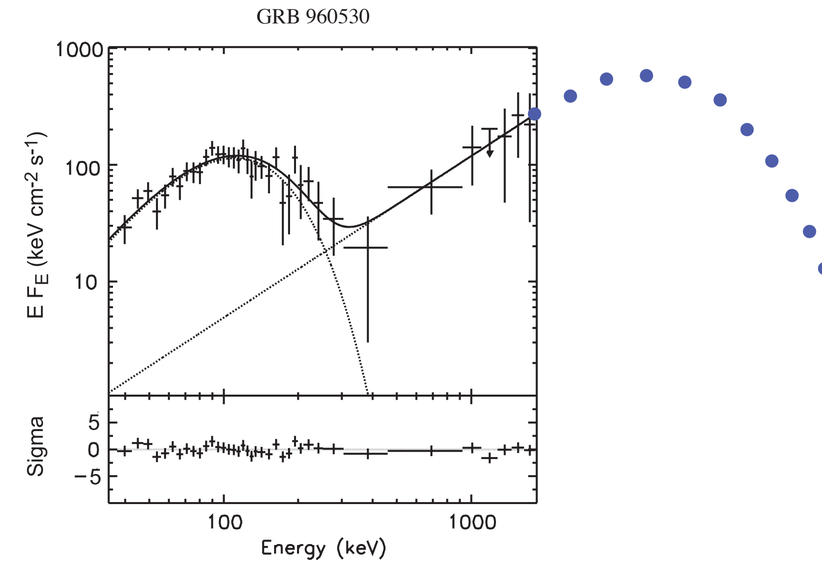
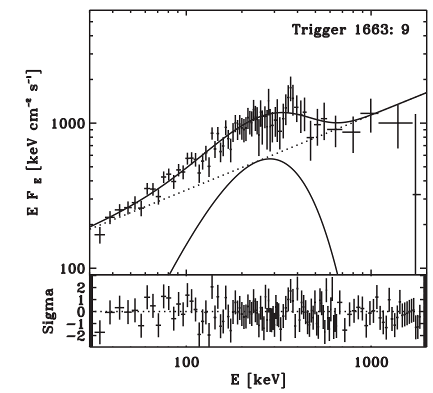


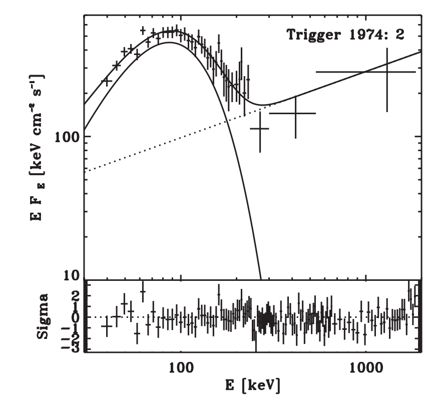


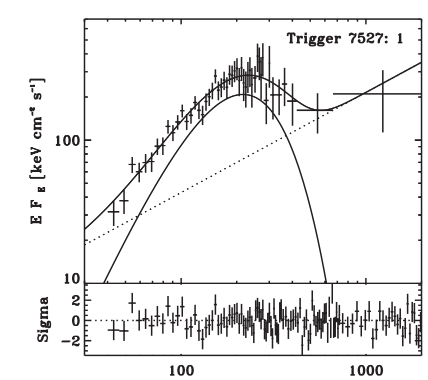


CGRO







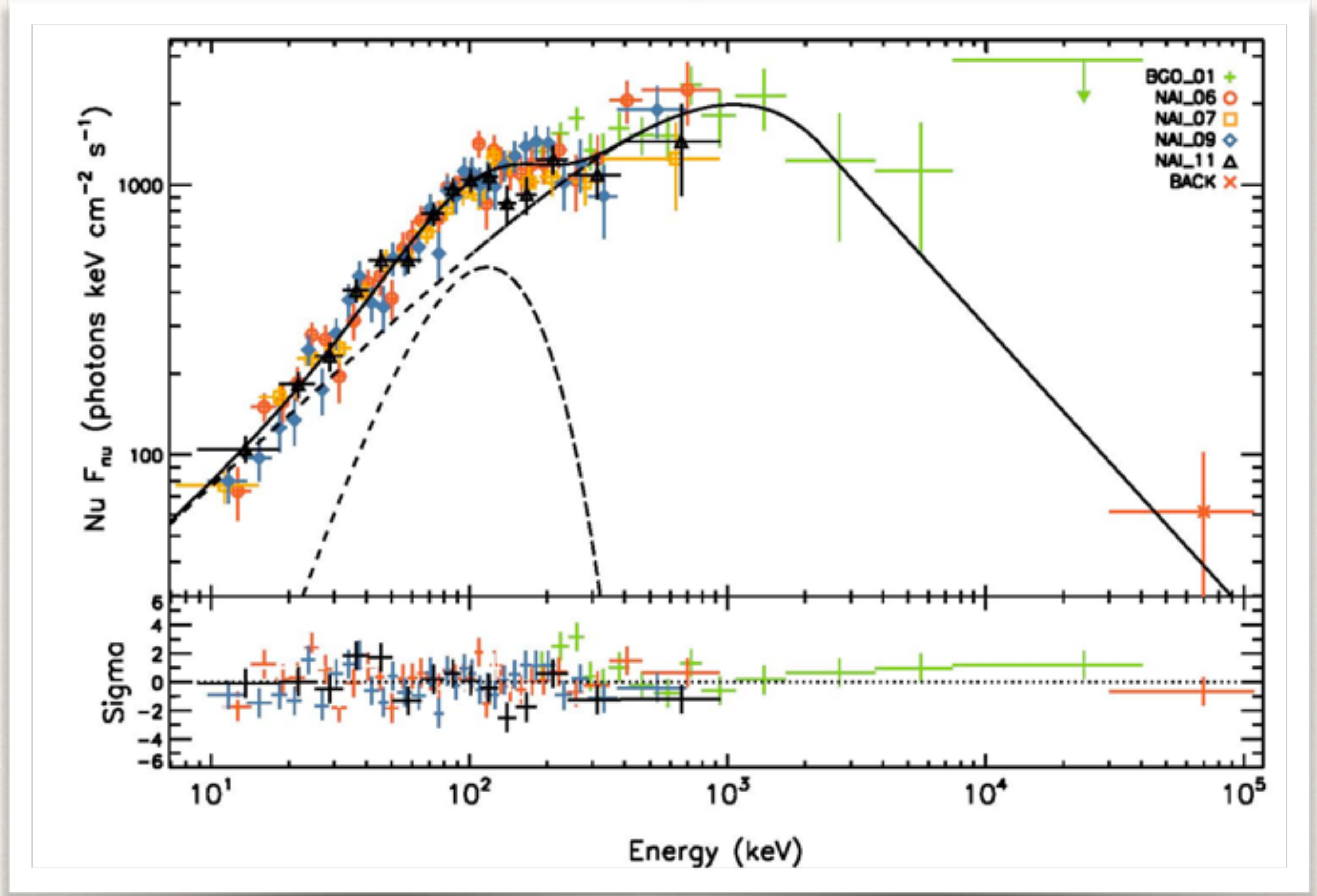


Fermi Gamma-ray Space Telescope

Single Planck function bursts

Fermi Gamma Ray Space Telescope

Axelsson+ 12



Single Planck function bursts

Fermi Gamma Ray Space Telescope

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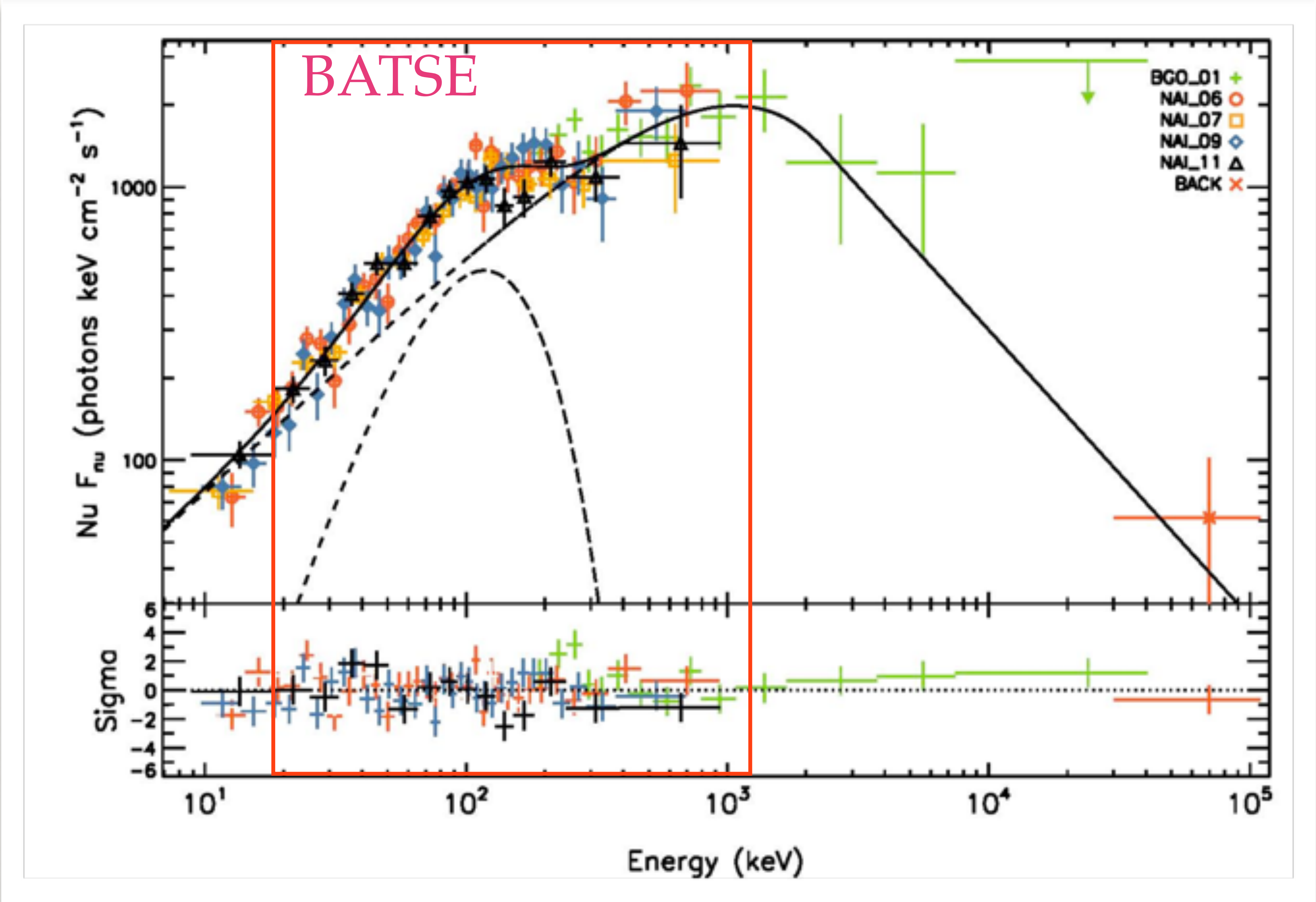

Single Planck function bursts

Fermi Gamma Ray Space Telescope

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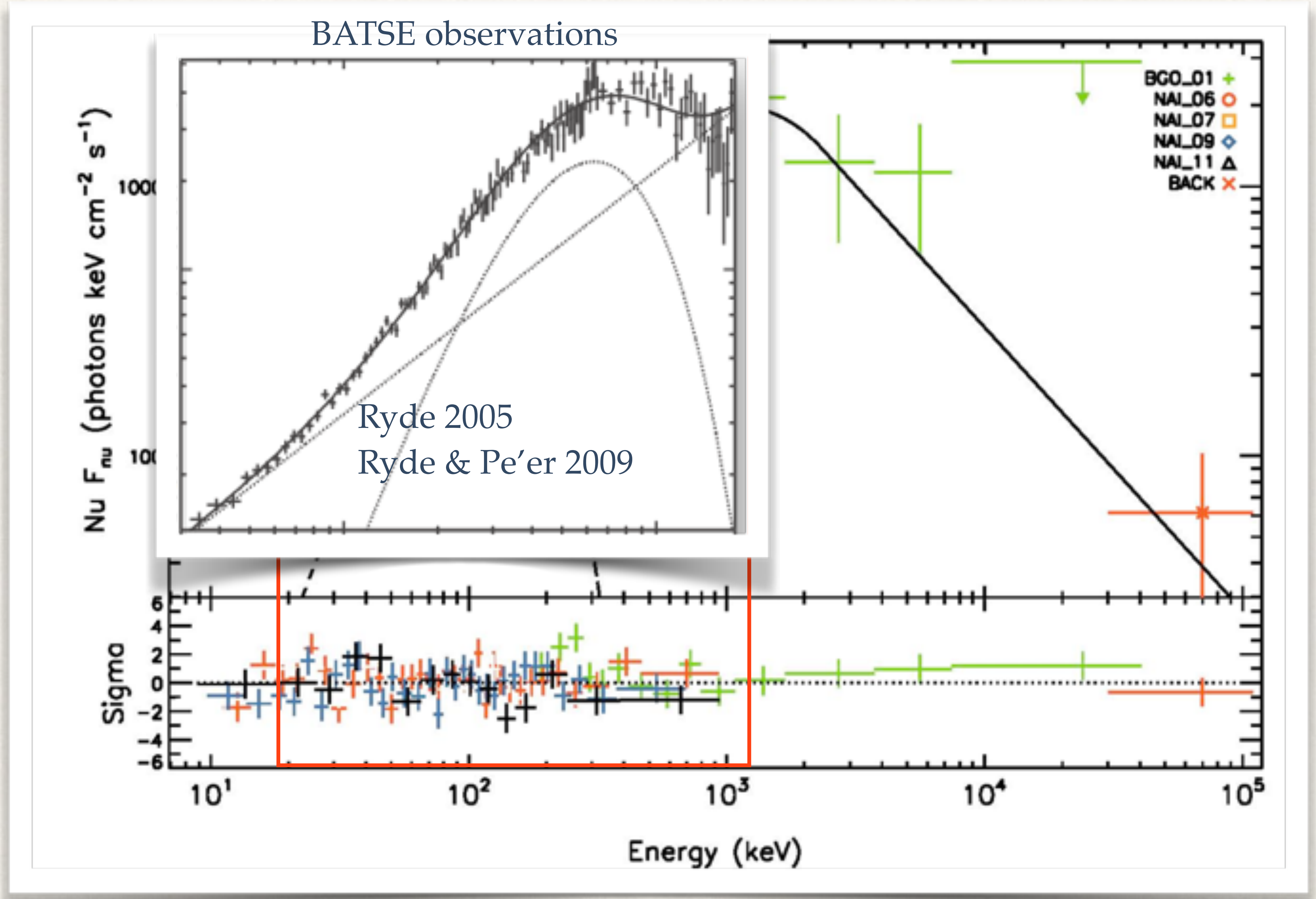
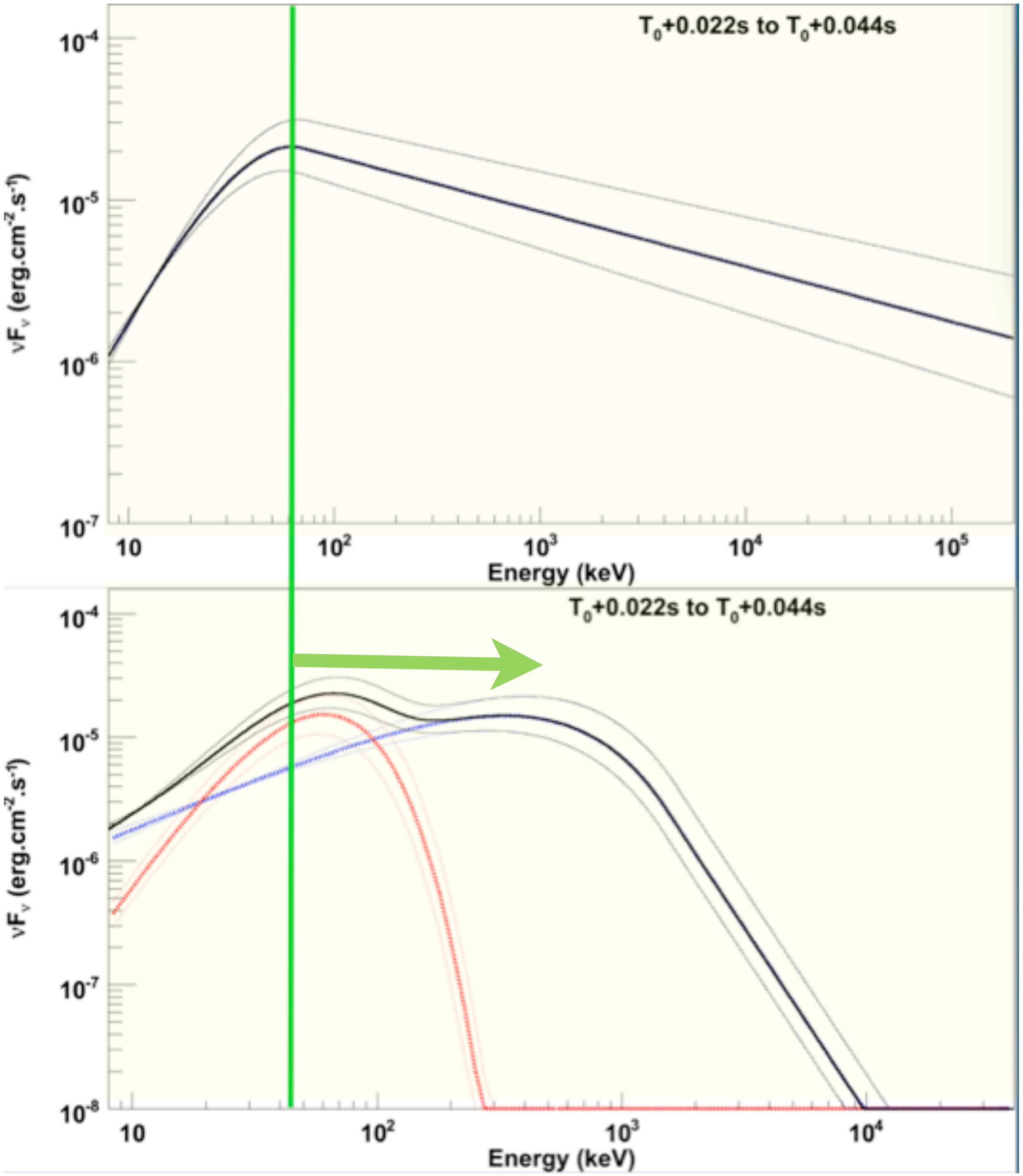


Multiple components in the *short* burst GRB120323A

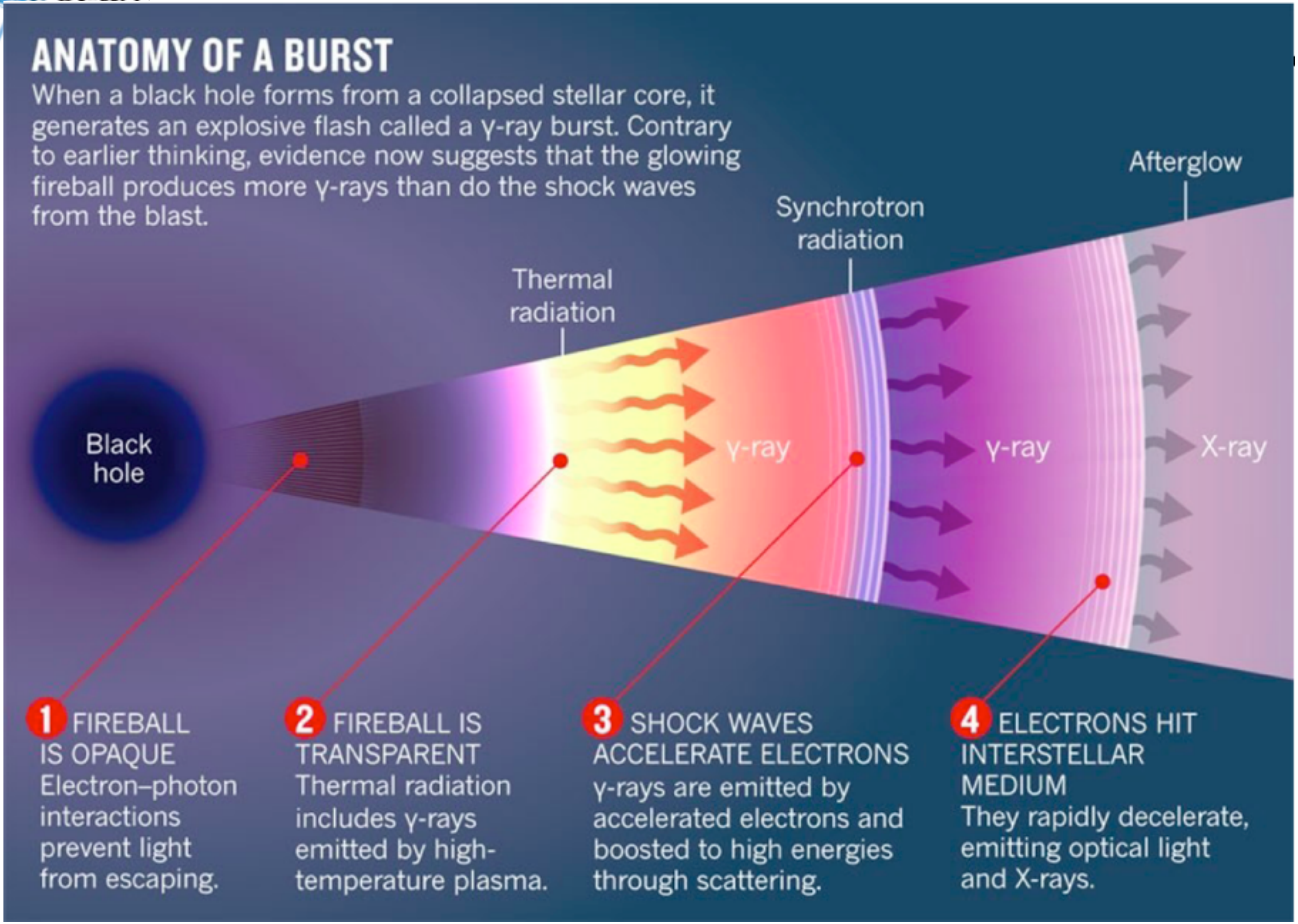


Guiriec et al. 2013

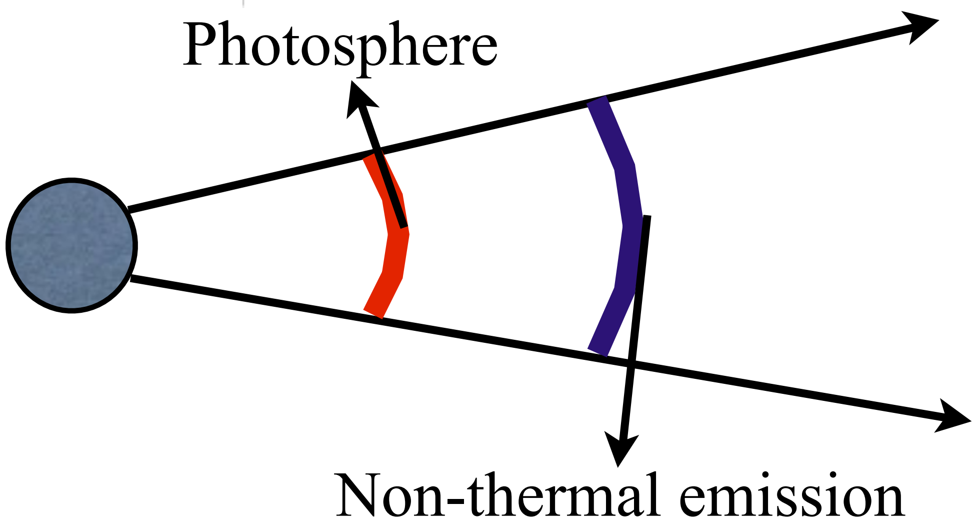
Changes the interpretations!

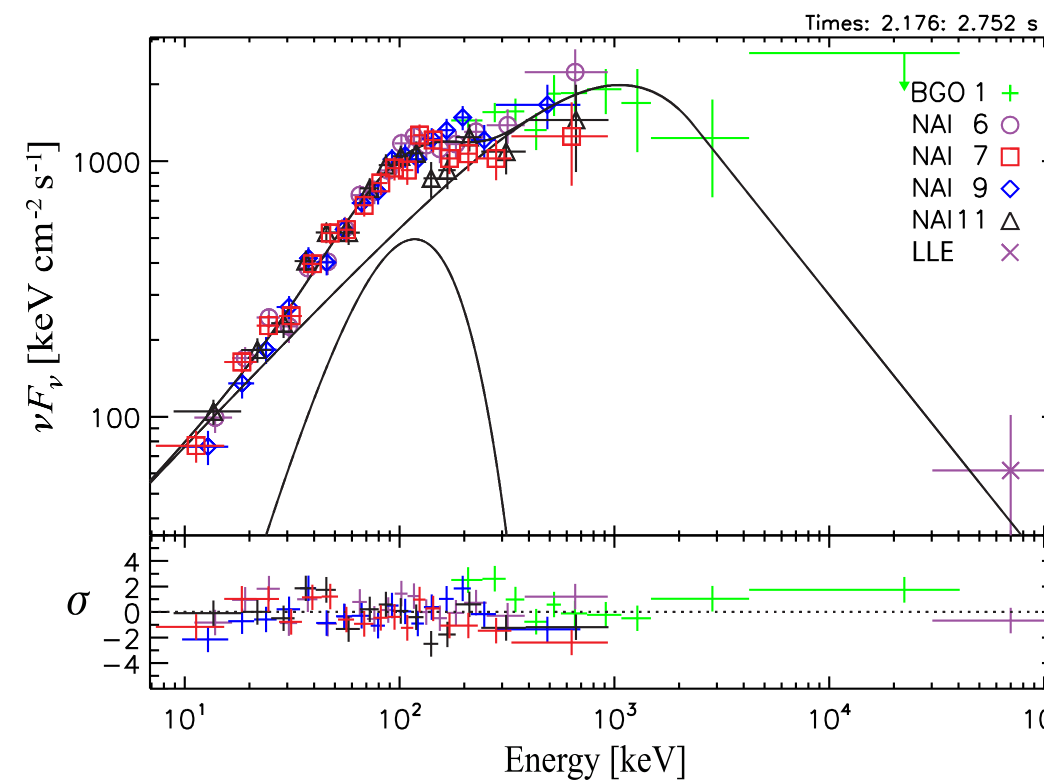
1. Change in Epeak
2. Change in alpha (synchrotron?)
3. Change in emission zones

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...

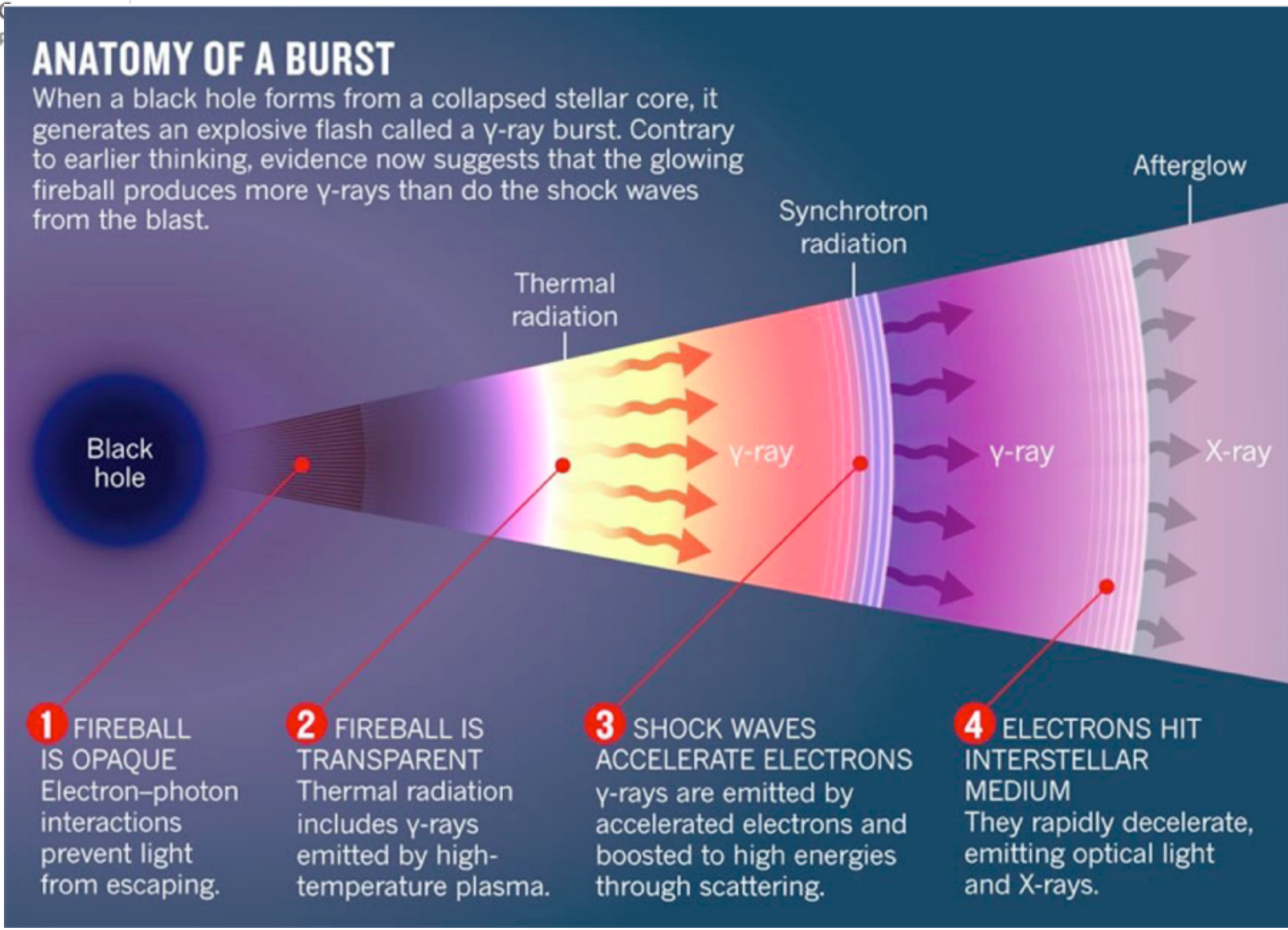
<u>2 zone emission, various realisations</u>

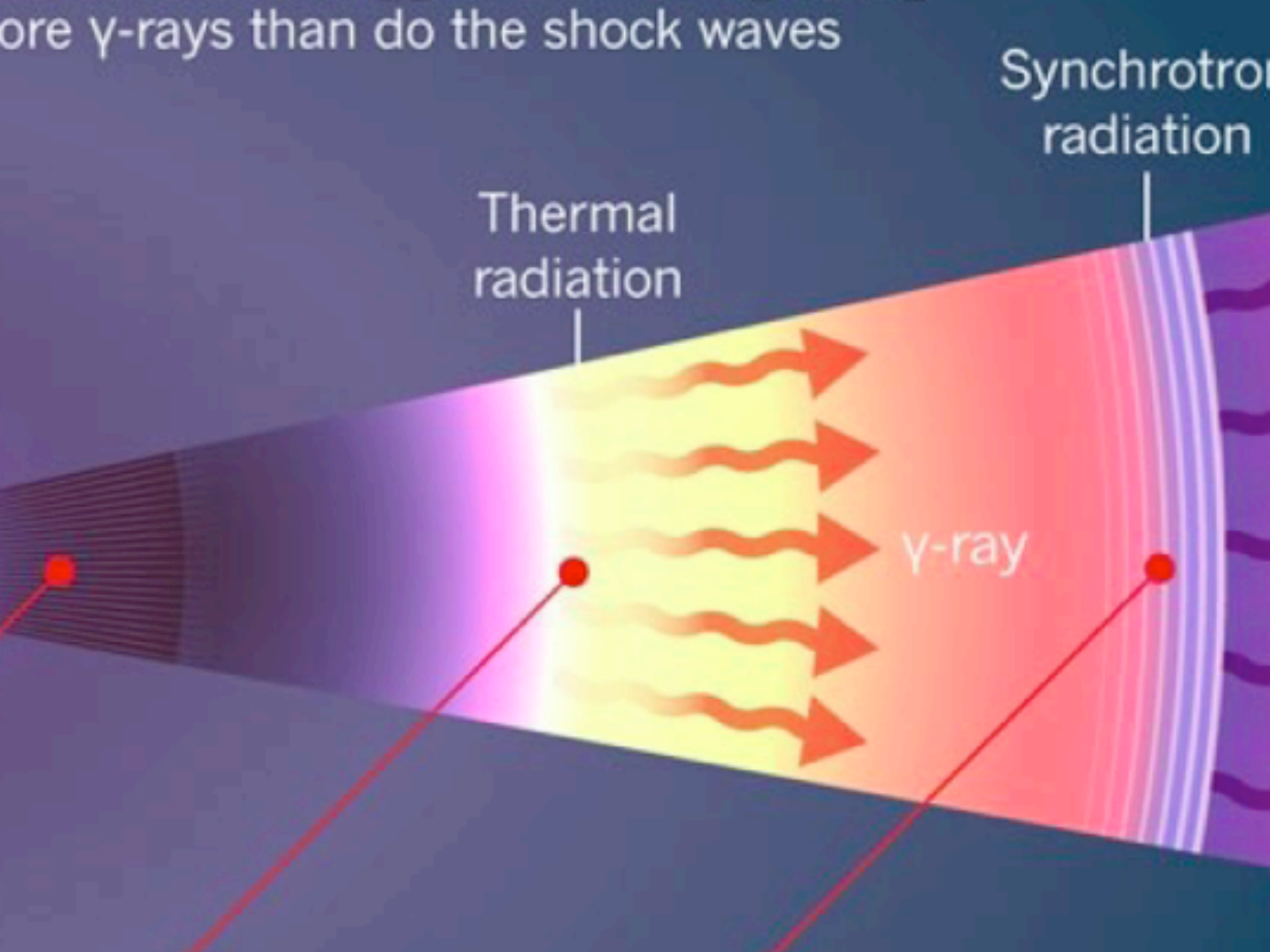
If below the saturation radius - strong black body
If above saturation radius - adiabatic cooling

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

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

Interpretation 2: Photospheric emission

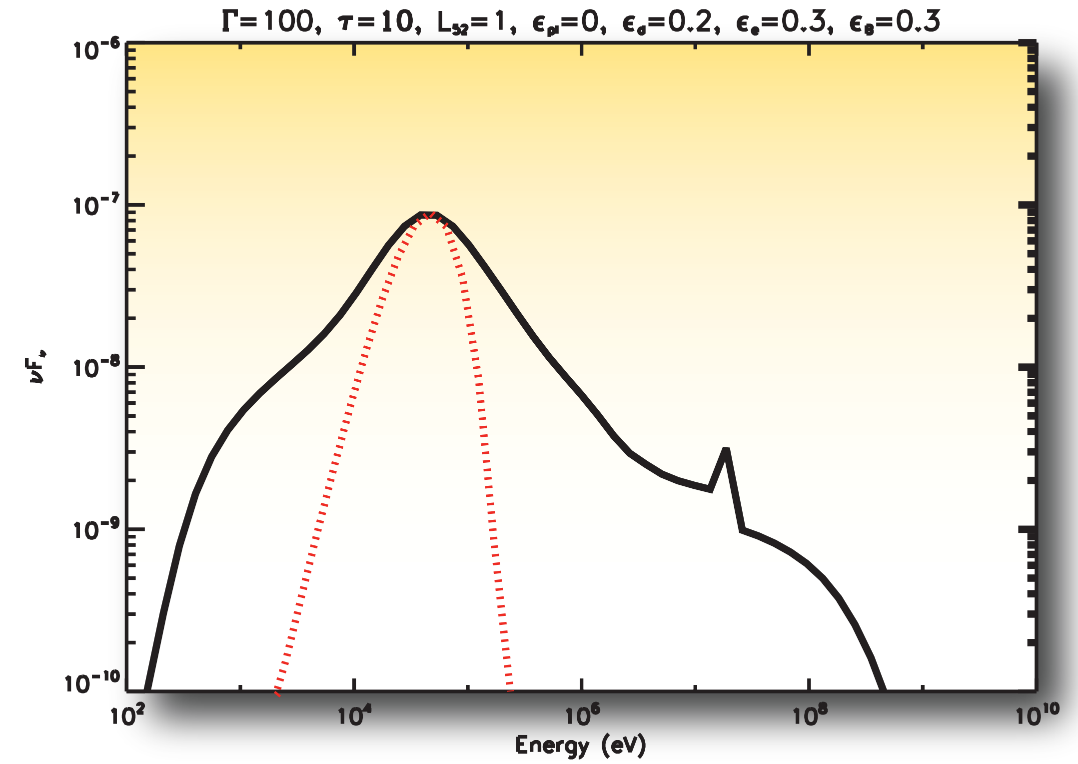



γ-rays than do the shock waves
radiation
Thermal
radiation
γ-ray

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)

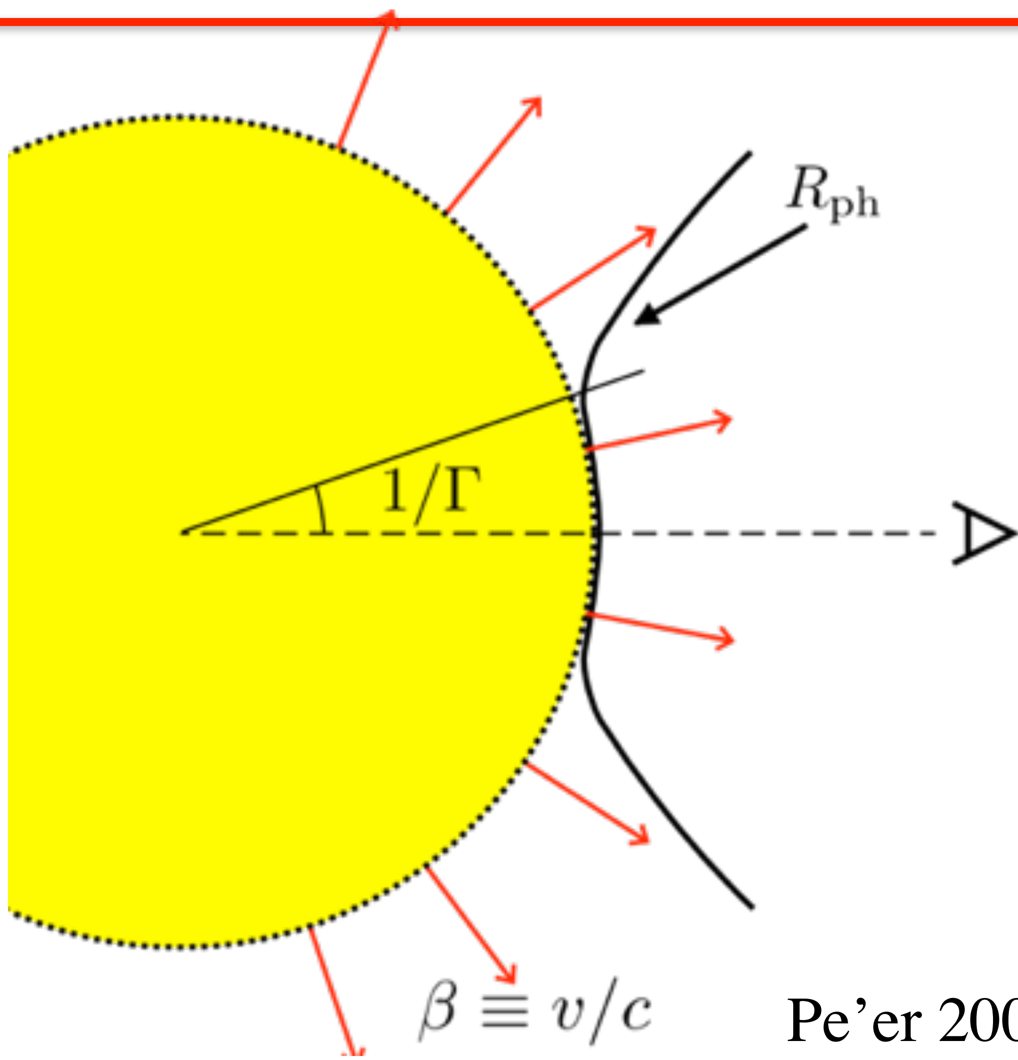


Emission from the photosphere is NOT seen as Planck !

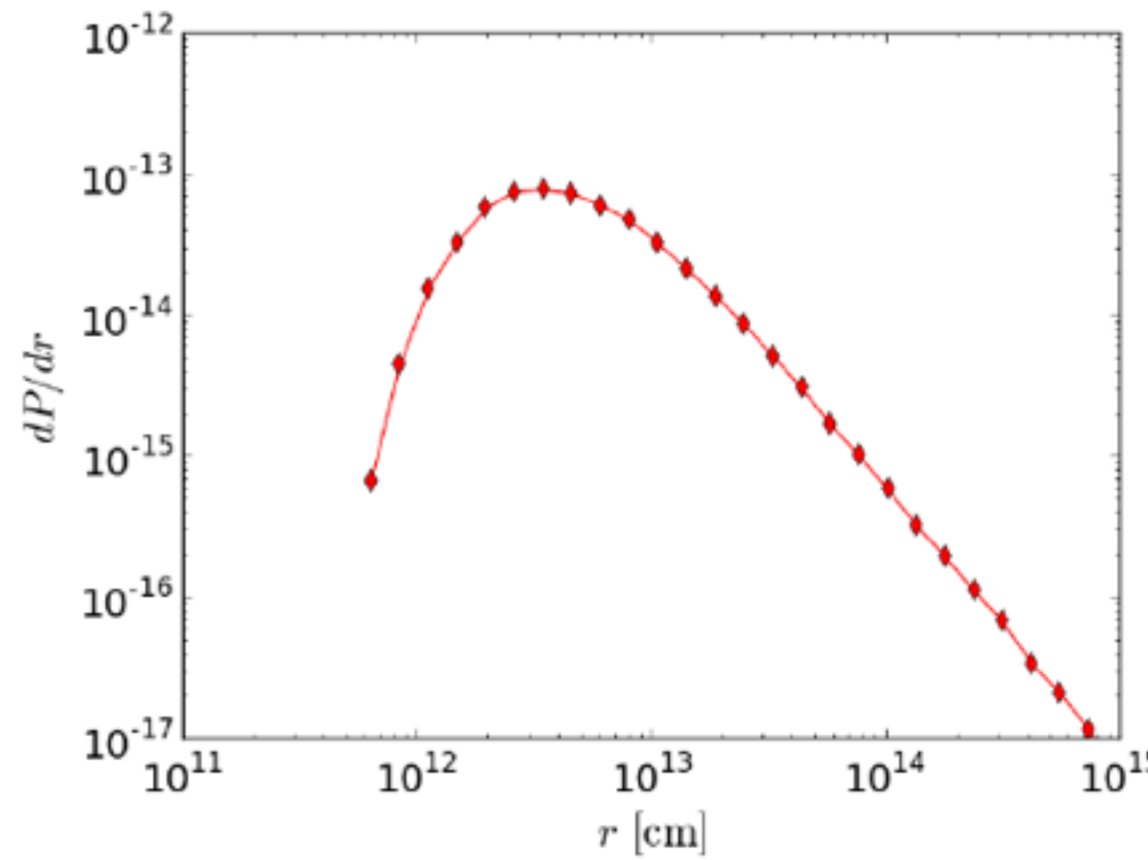
Fermi Gamma-ray Space Telescope

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!

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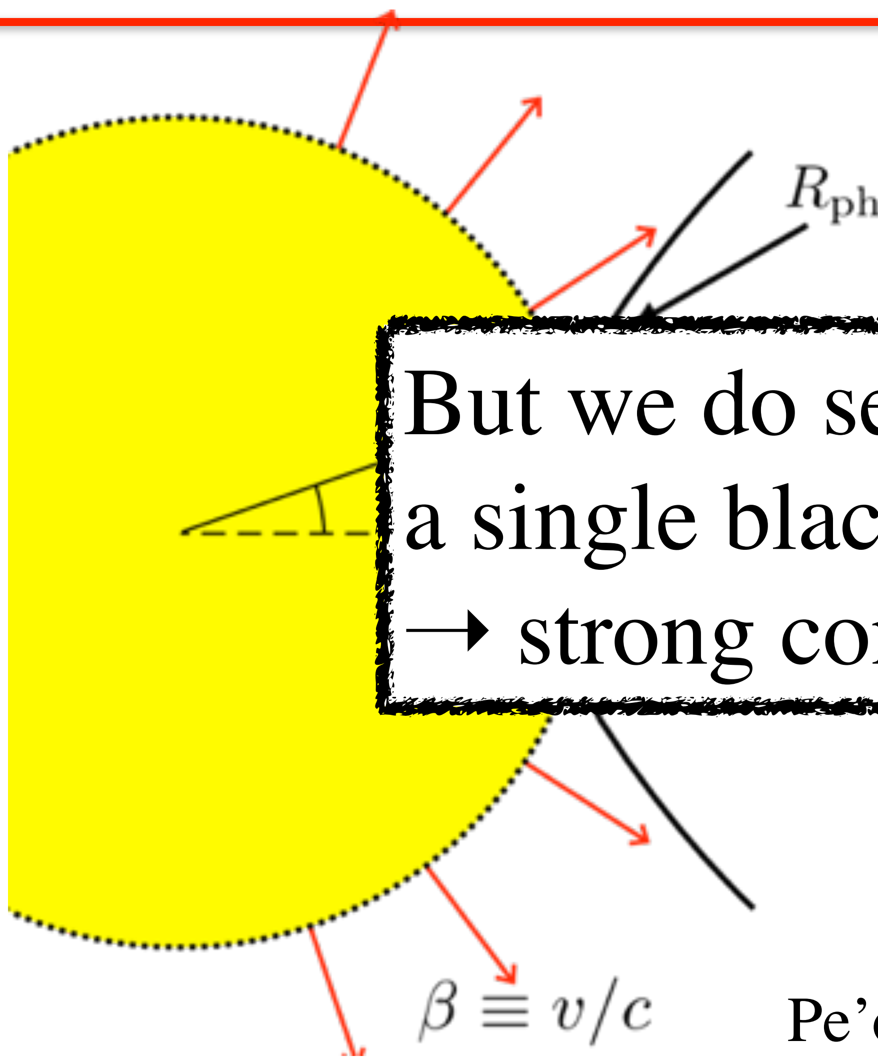
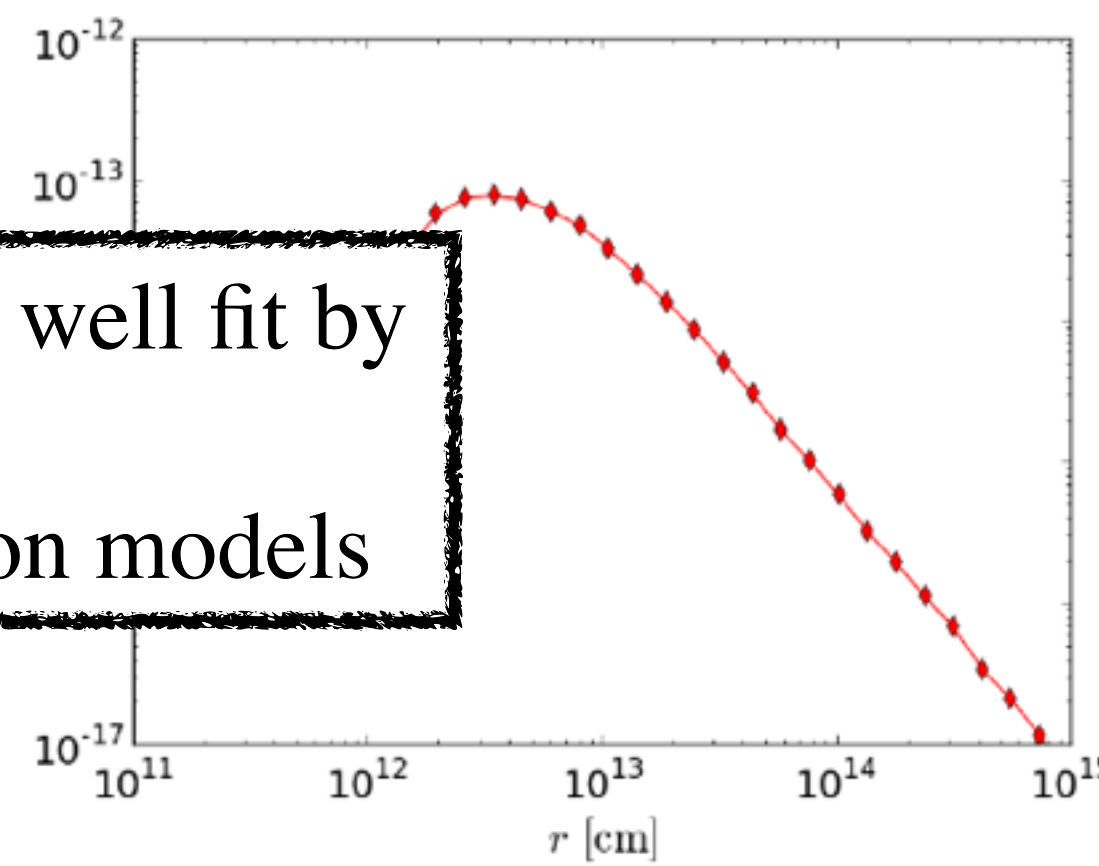


But we do see spectra well fit by a single blackbody!
→ strong constraints on models



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

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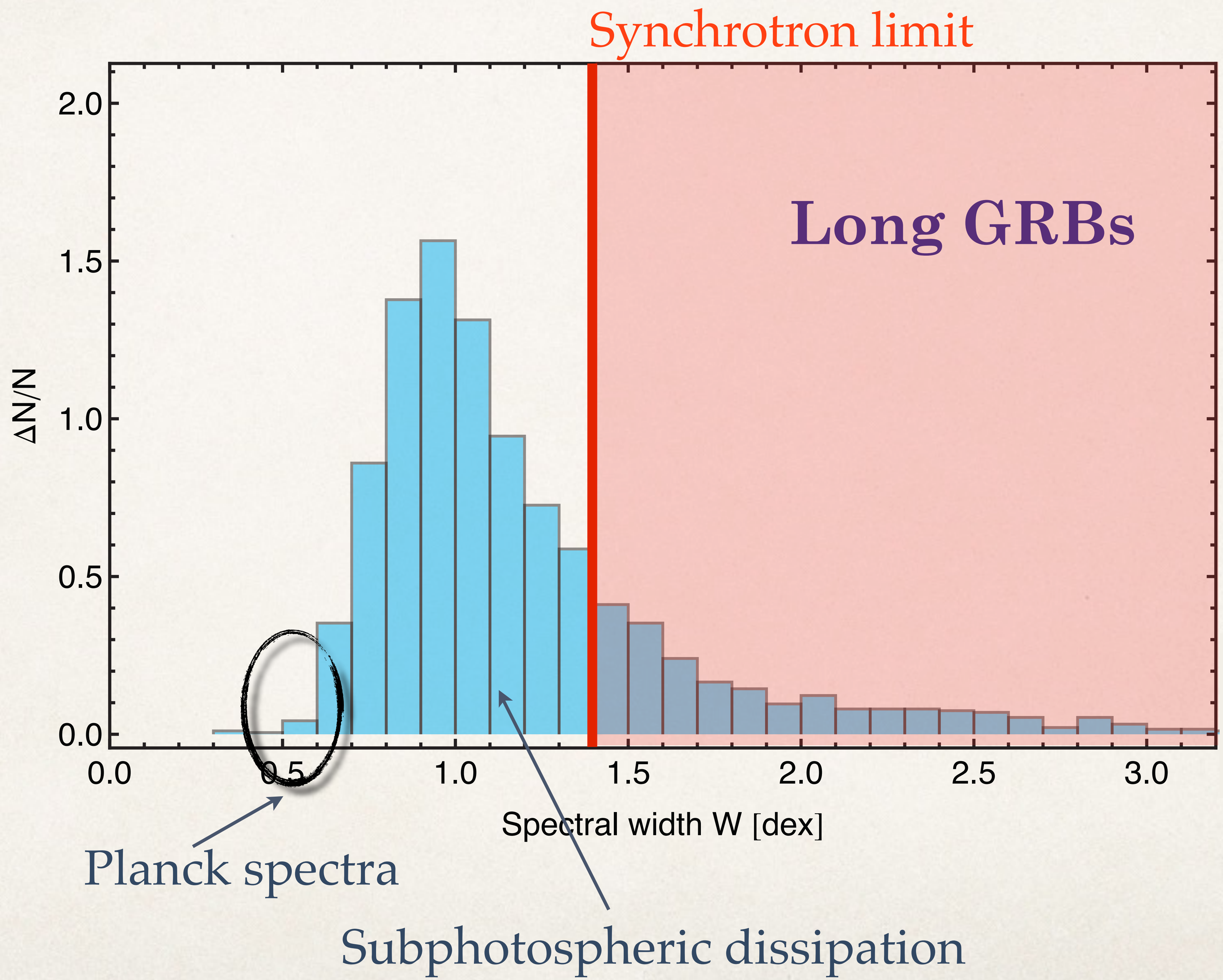
Width of GRB spectra

$$W = \log\left(\frac{E_2}{E_1}\right)$$



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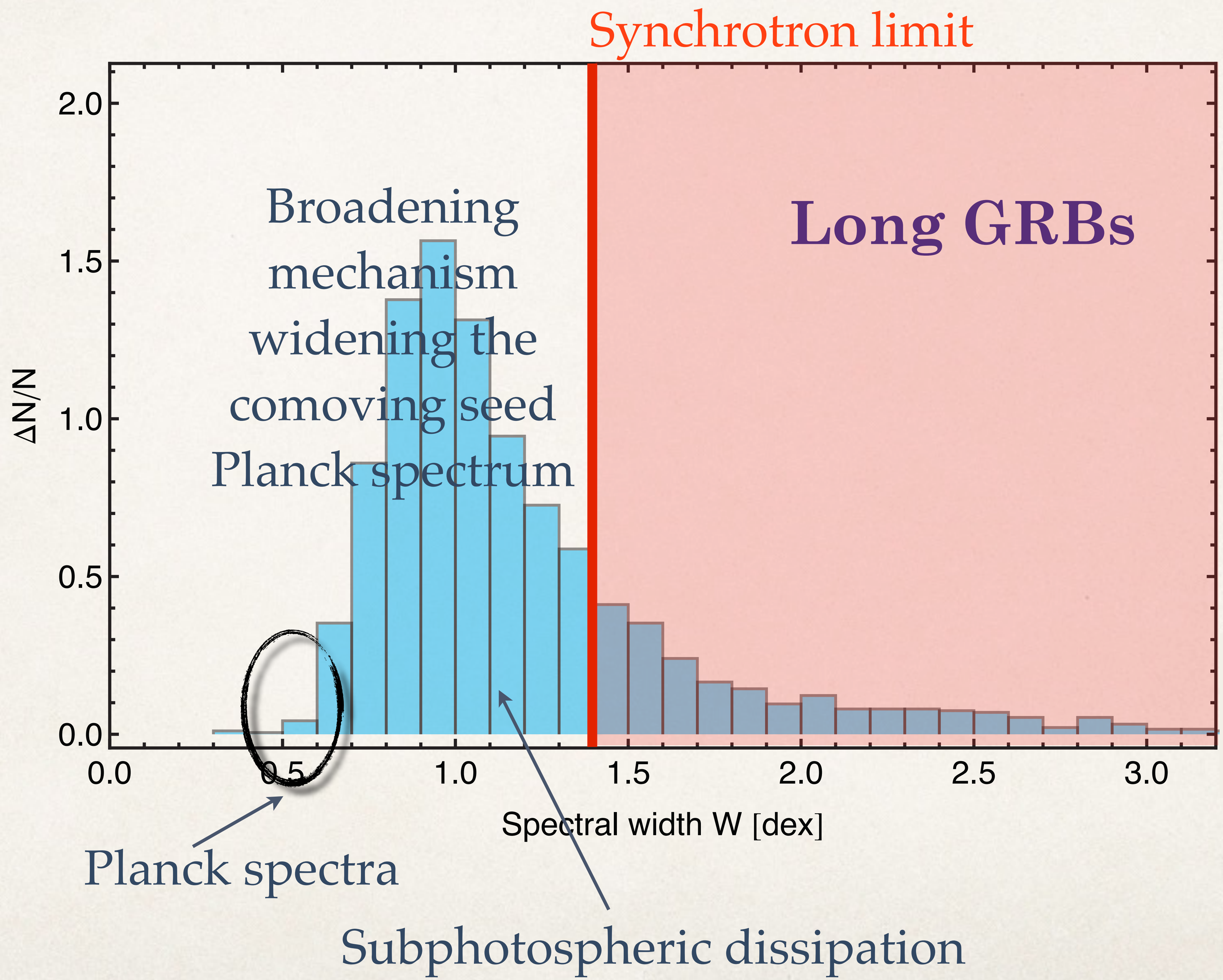
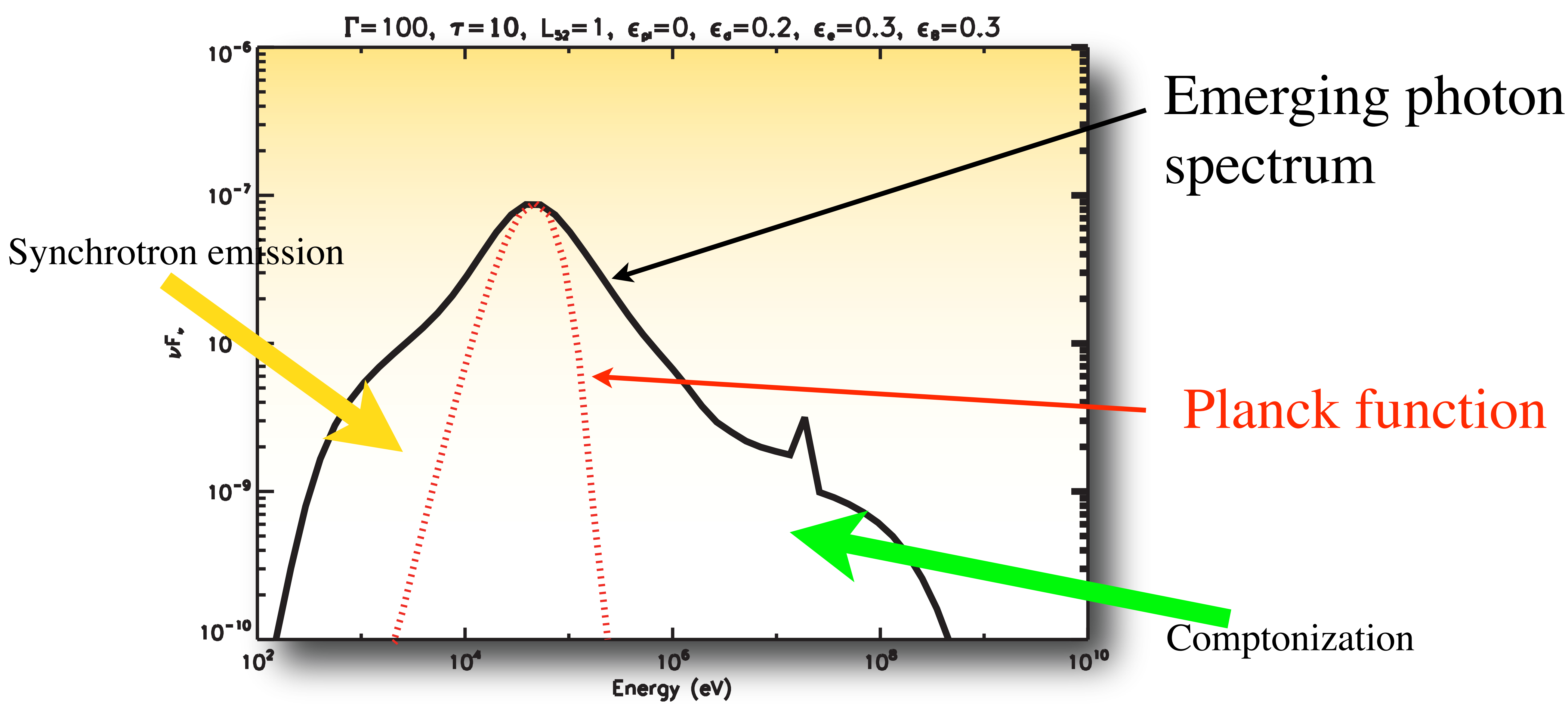


Modeling with subphotospheric dissipation

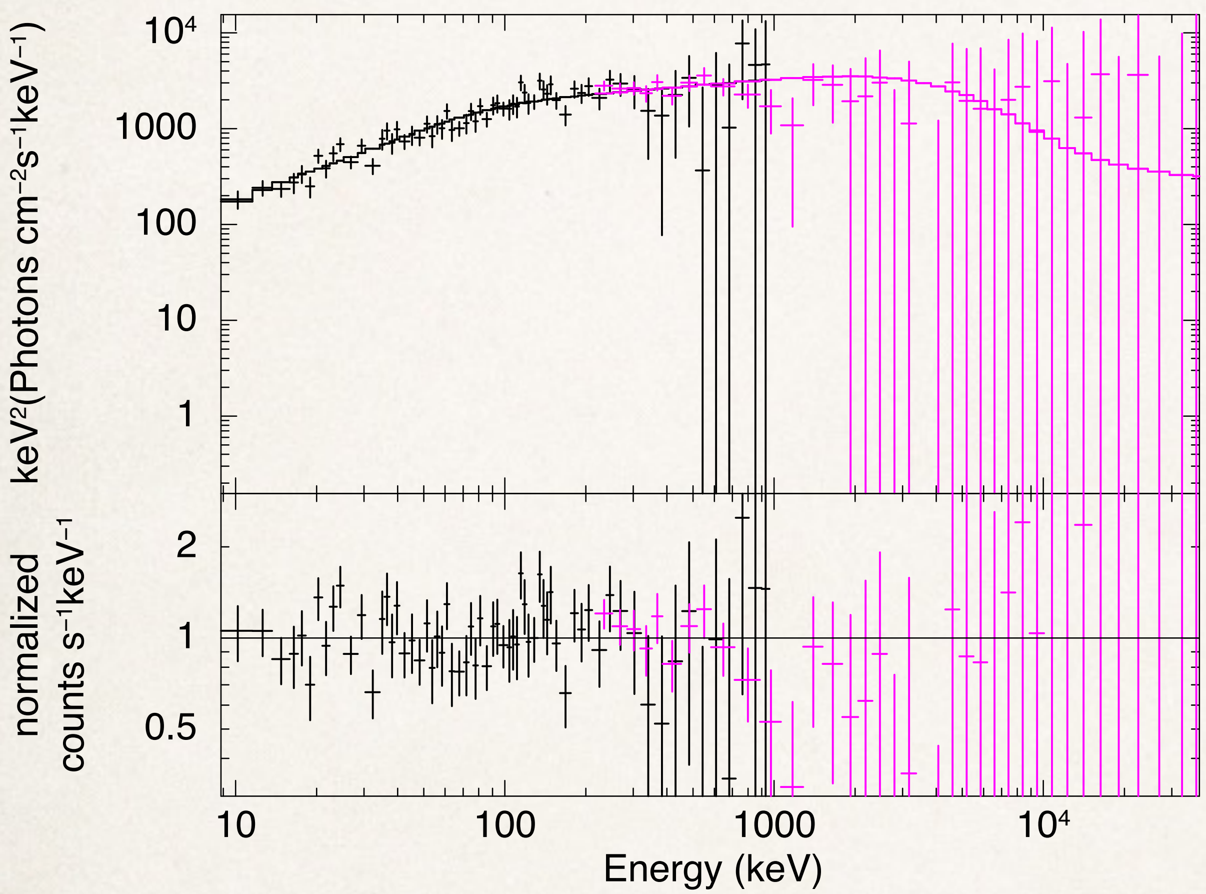
- Our code (by Pe'er & Waxman 2004) solves the kinetic equations for internal shocks
- Includes cyclo/synchrotron emission, SSA, Compton scattering (direct/inverse), pair production, pair annihilation

Dissipation at optical depth $\tau = 10$



Physical modelling of subphotospheric dissipation

GRB090618



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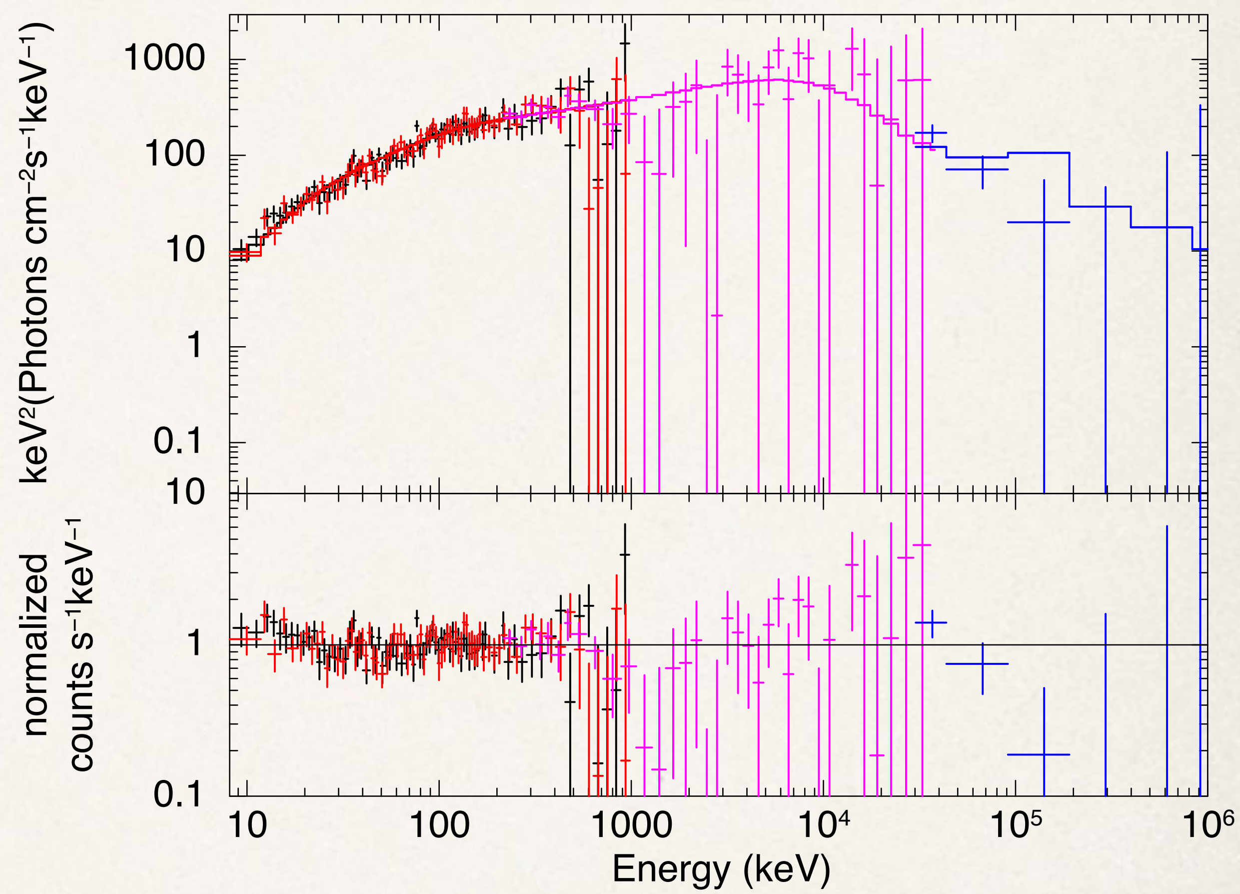
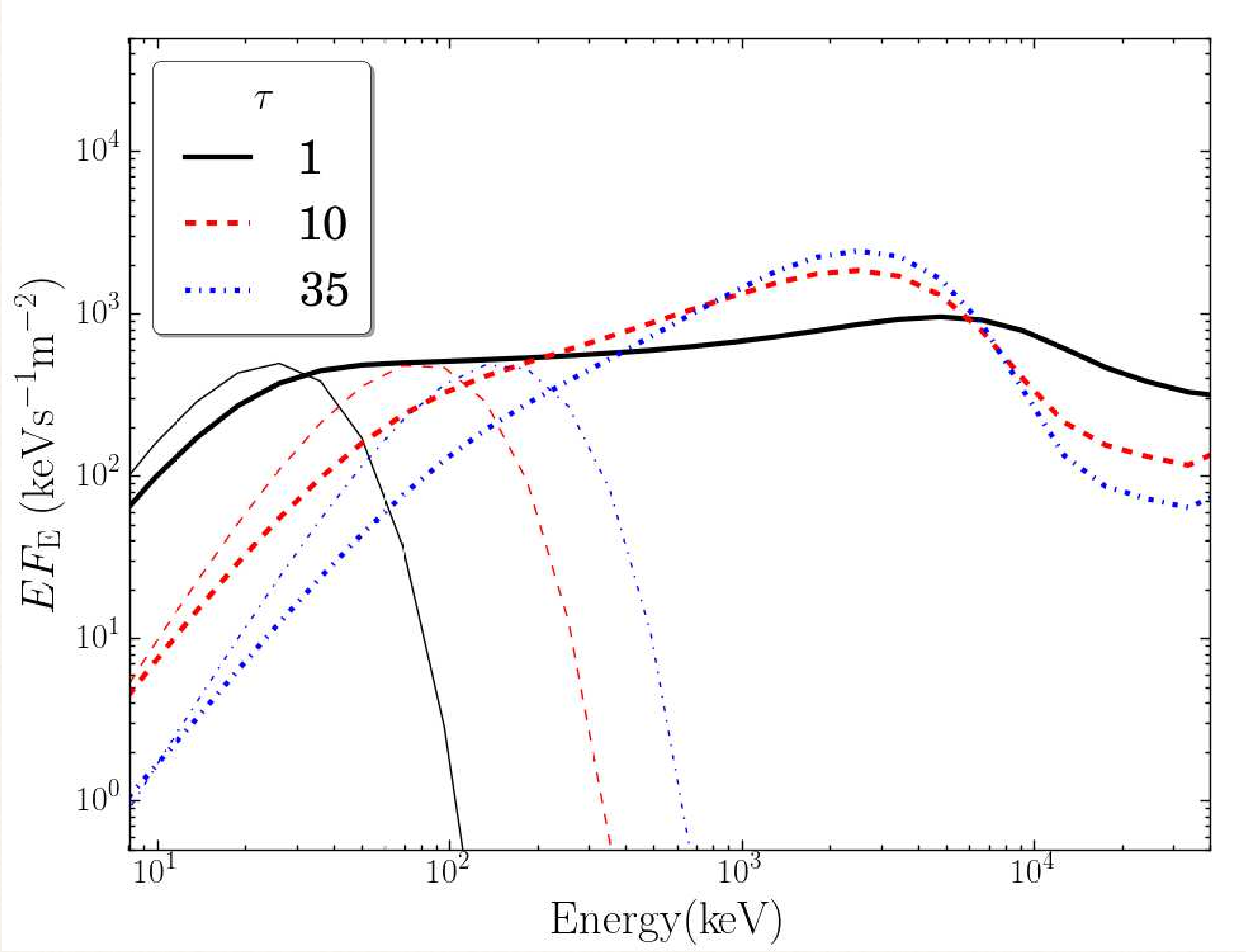


Fits are of comparable quality to Band fits - but fully physical!

Ahlgren et al. (2015)

Model spectra

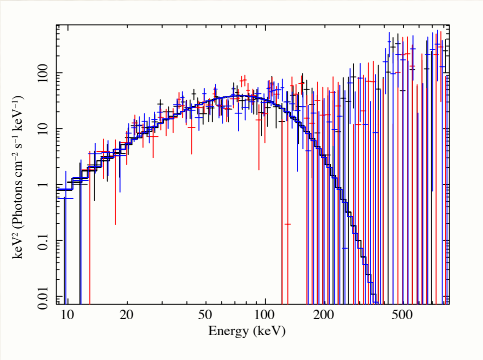


Physically motivated model can produce a variety of spectra!

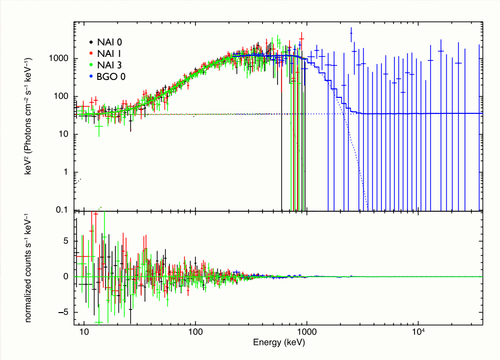
Conclusions

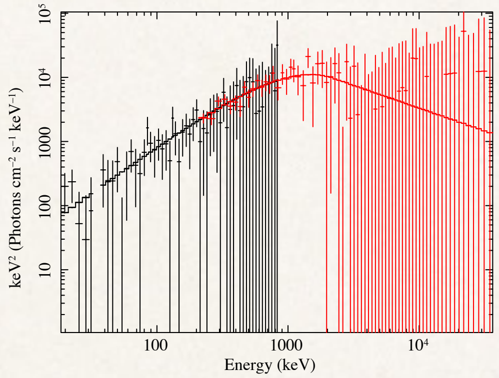
- Line of death for synchrotron α=-0.8
- 80% of GRBs are inconsistent with the *width* of synchrotron
- Varying faces of the jet photosphere:

Blackbody

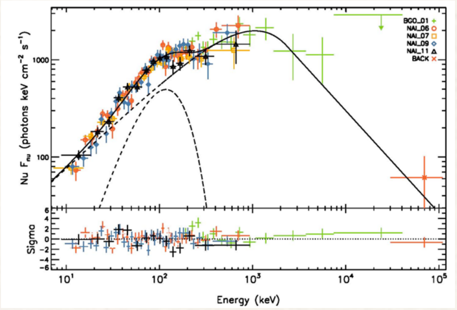


Subphotospheric dissipation





Two emission zones



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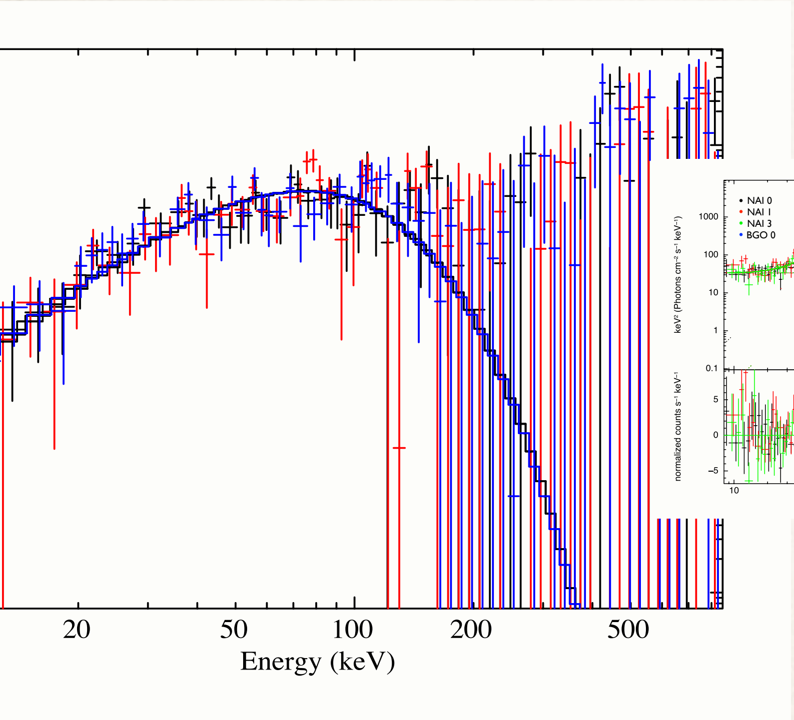

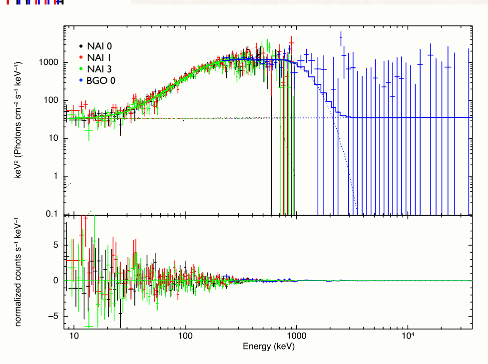

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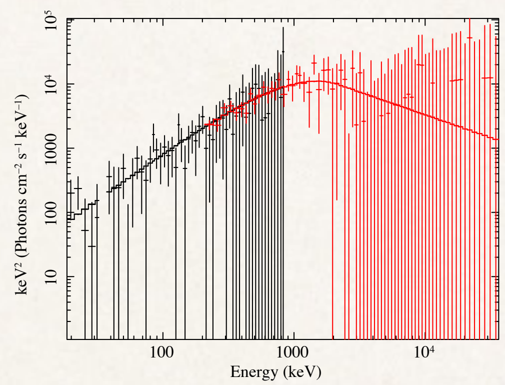

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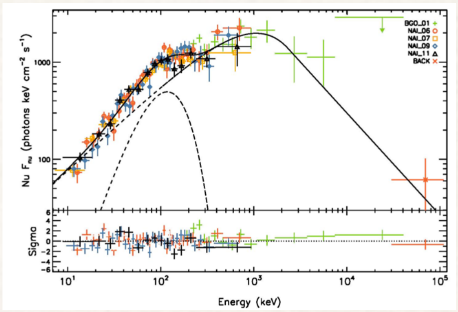

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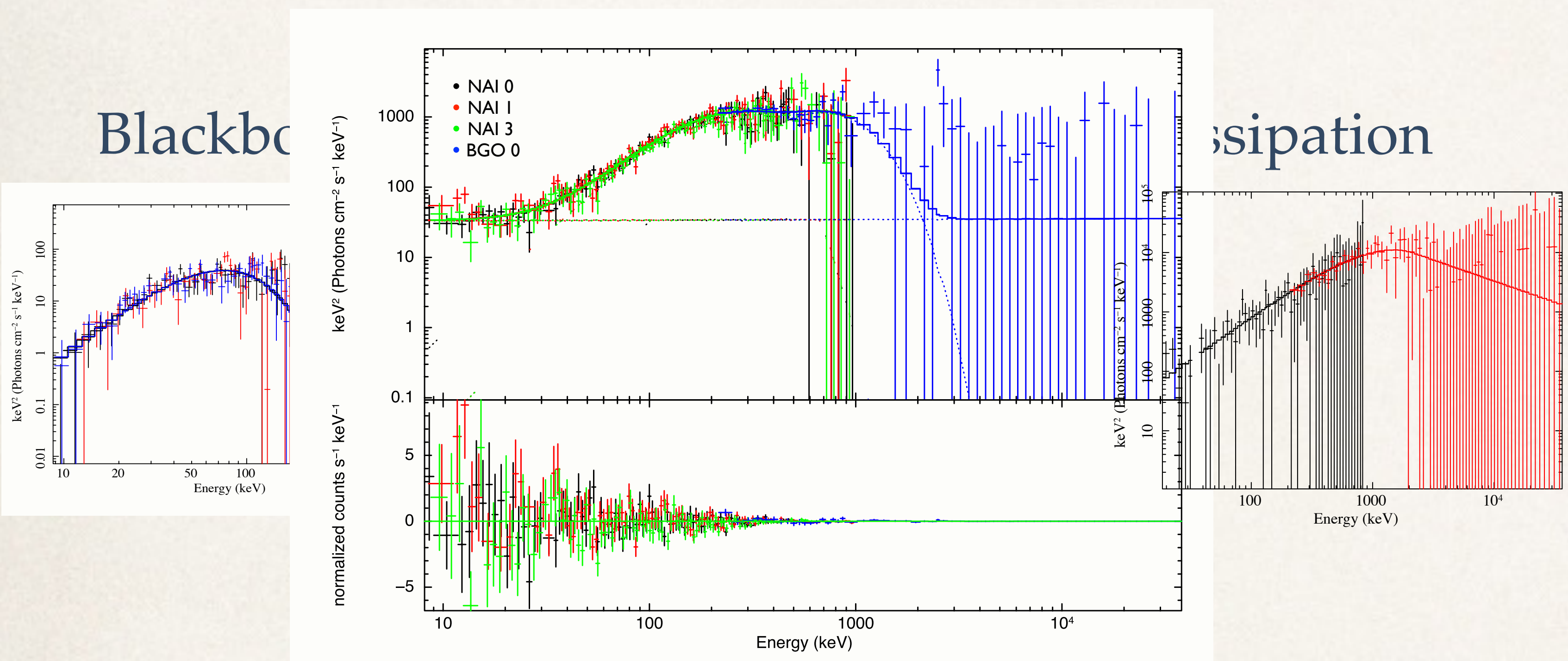

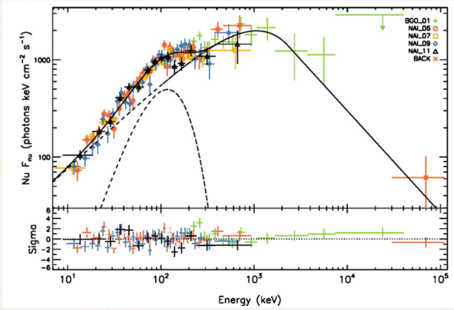

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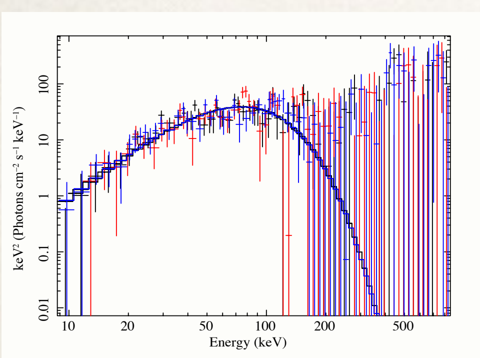

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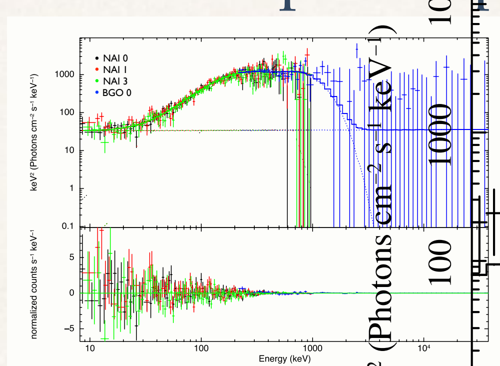

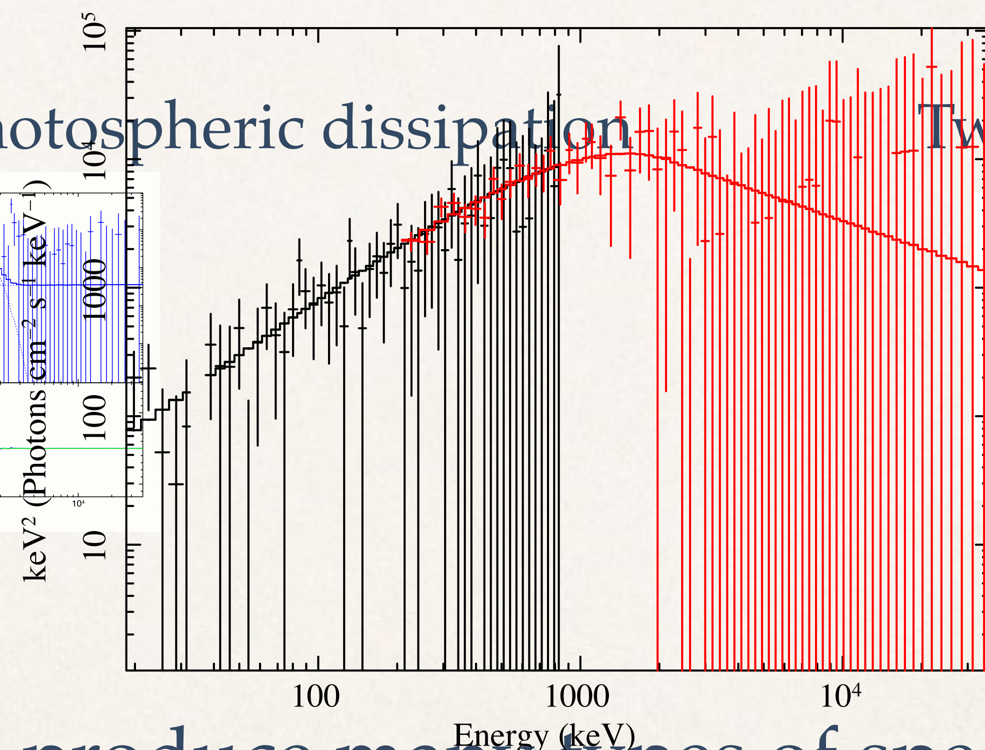

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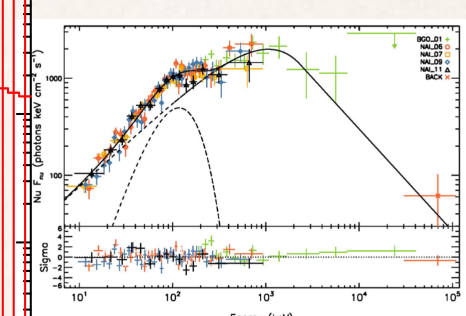

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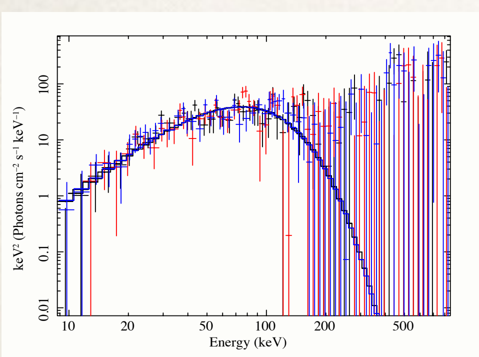
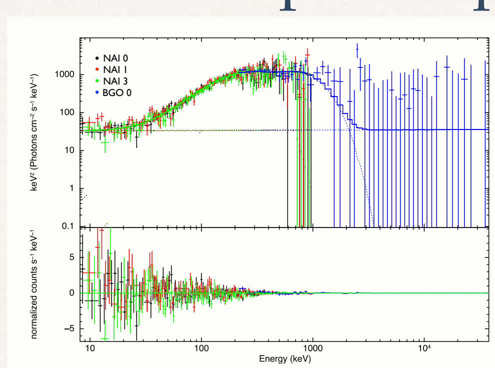
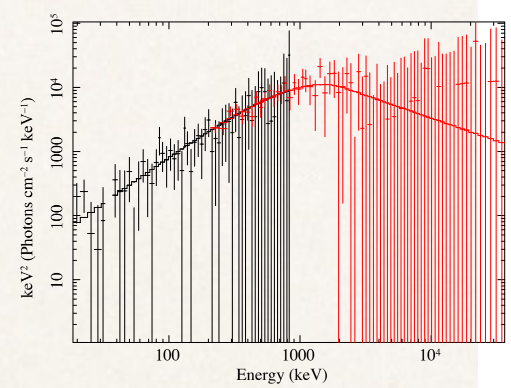
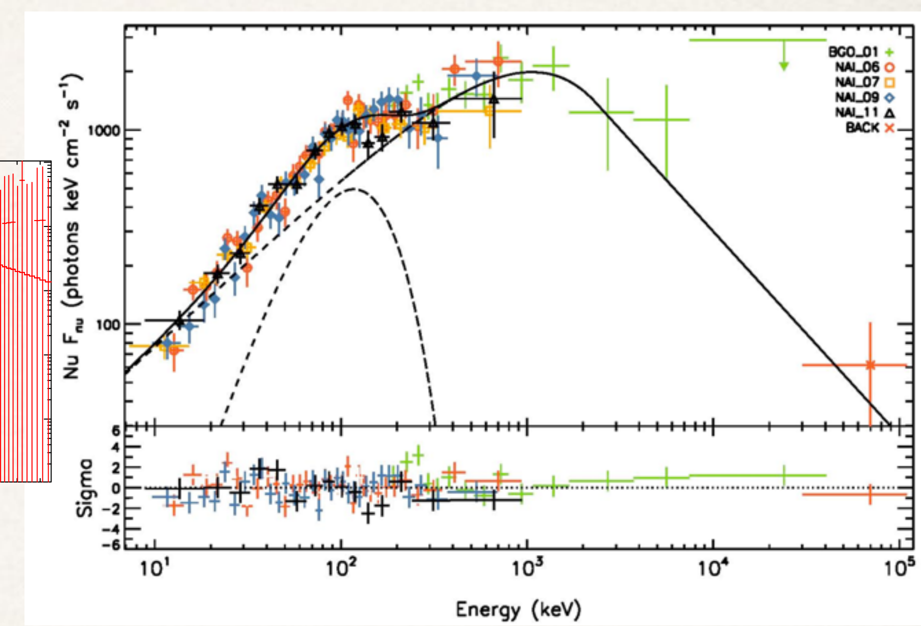


Subphotospheric dissipation







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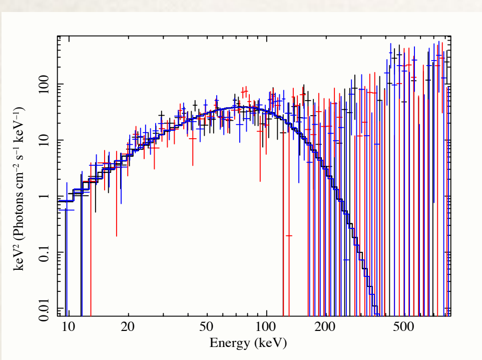

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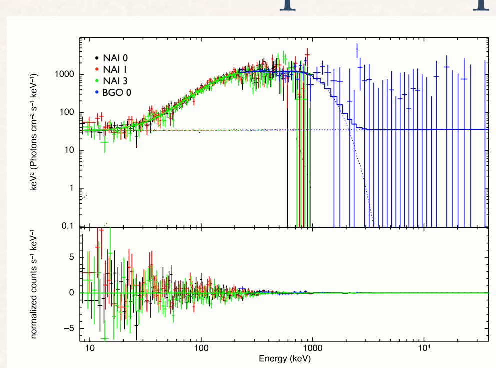

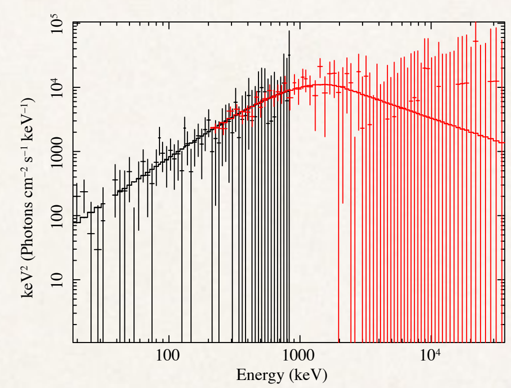

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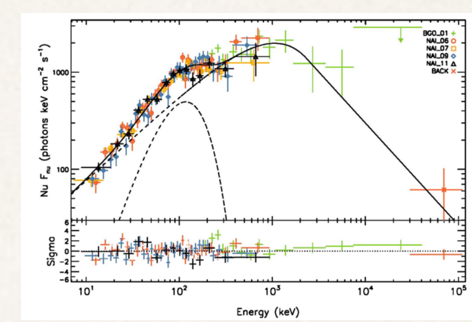

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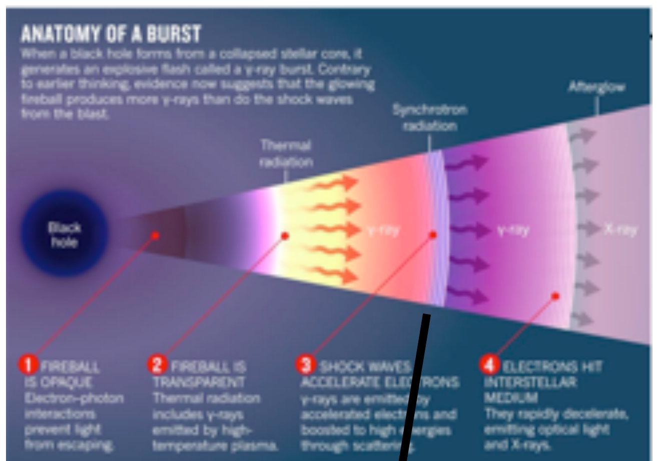
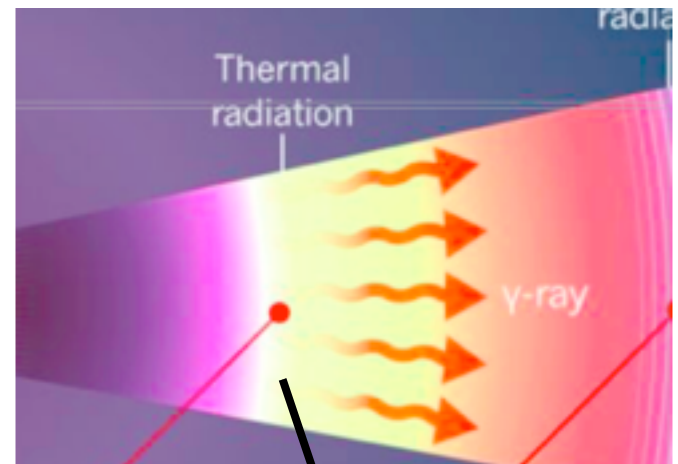
Observable to discriminate between interpretations: *Polarisation*



Synchrotron emission easily polarised



Is the photosphere polarised?

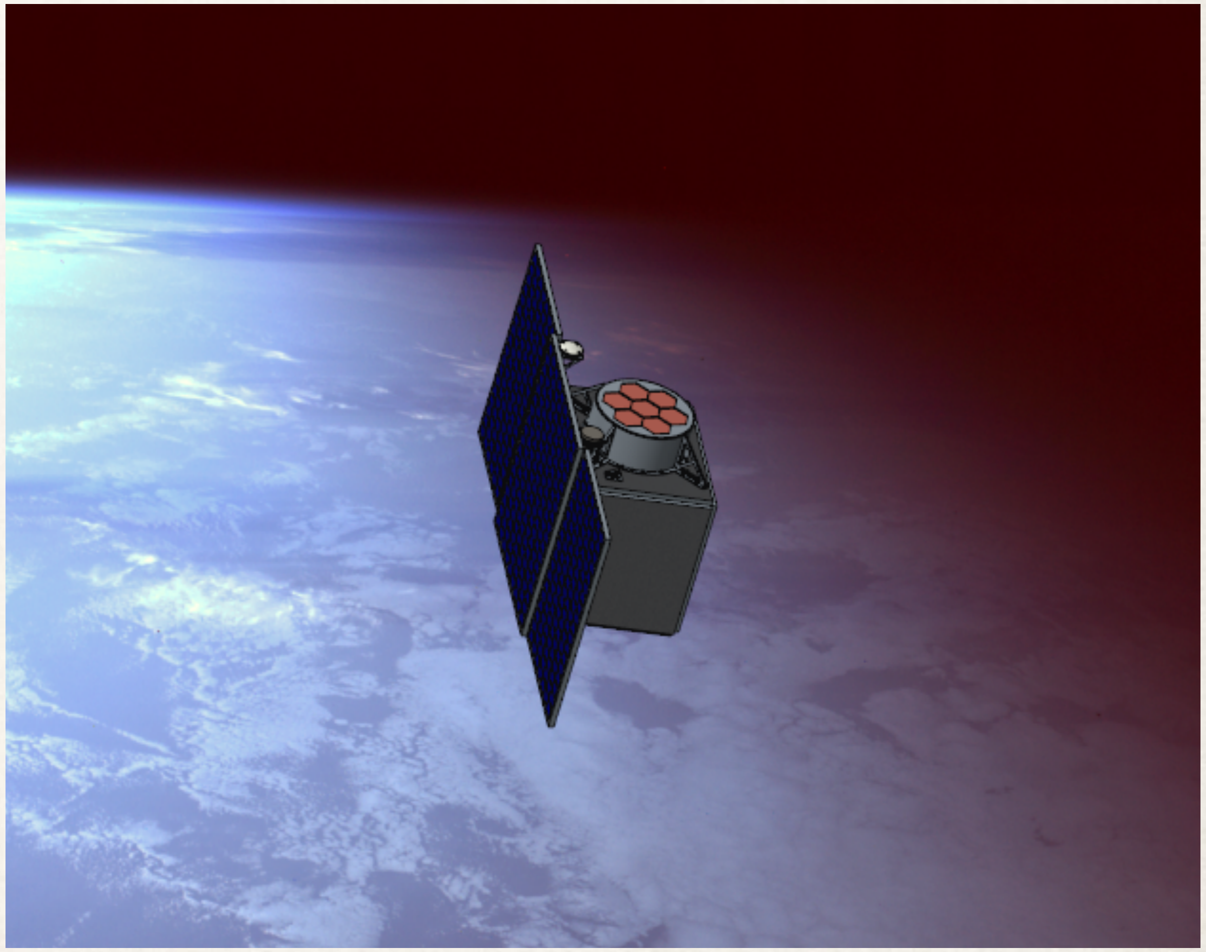
Polarisation from the photosphere

- 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

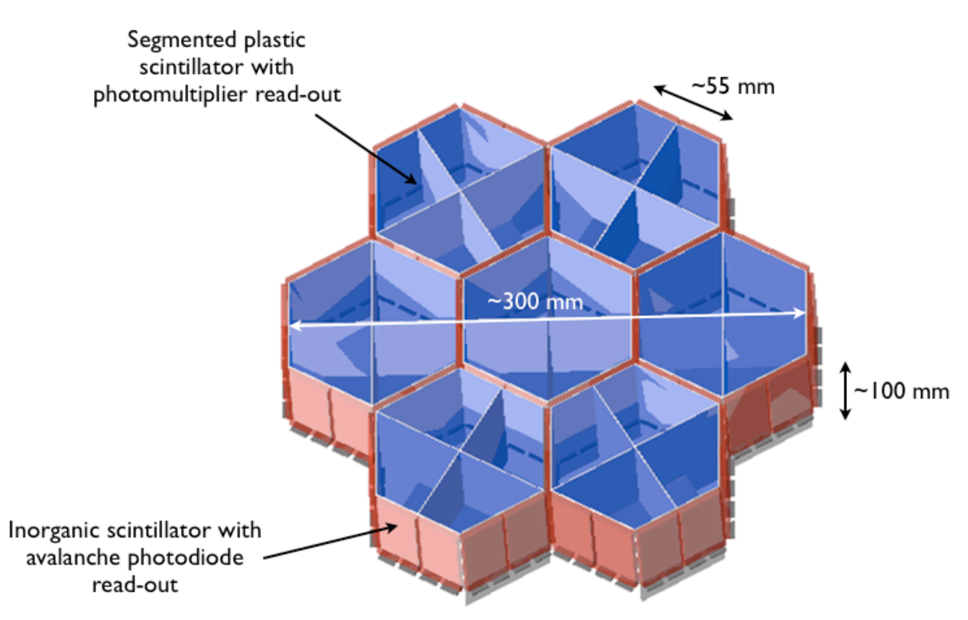
Segmented Polarimeter for High-eNergy X-rays (SPHiNX)

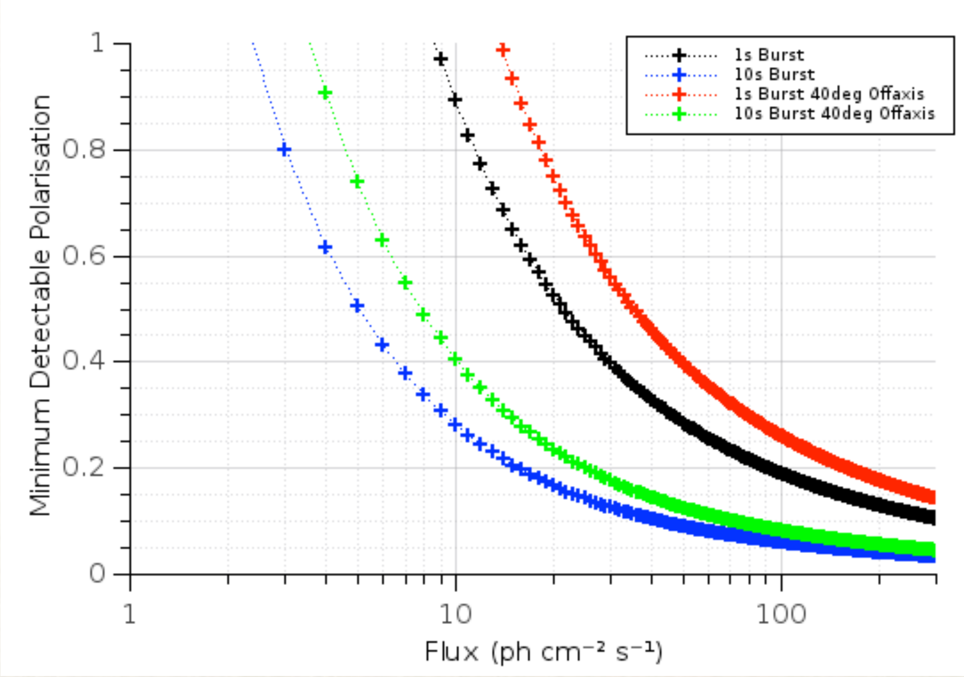
- Proposed mission to measure polarisation in GRBs
- Science goals are to determine jet structure including:
    - Magnetisation
    - Structure (axisymmetric, fragmented…)
    - Emission processes



SPHiNX

- Compton scattering polarimeter
- Plastic scintillators for scattering and inorganic (BGO, CsI) scintillators for absorption.
- Segmented symmetric design, hexagonal elements to minimize systematics.
- Coincidence and multilayer metal shield to reduce background

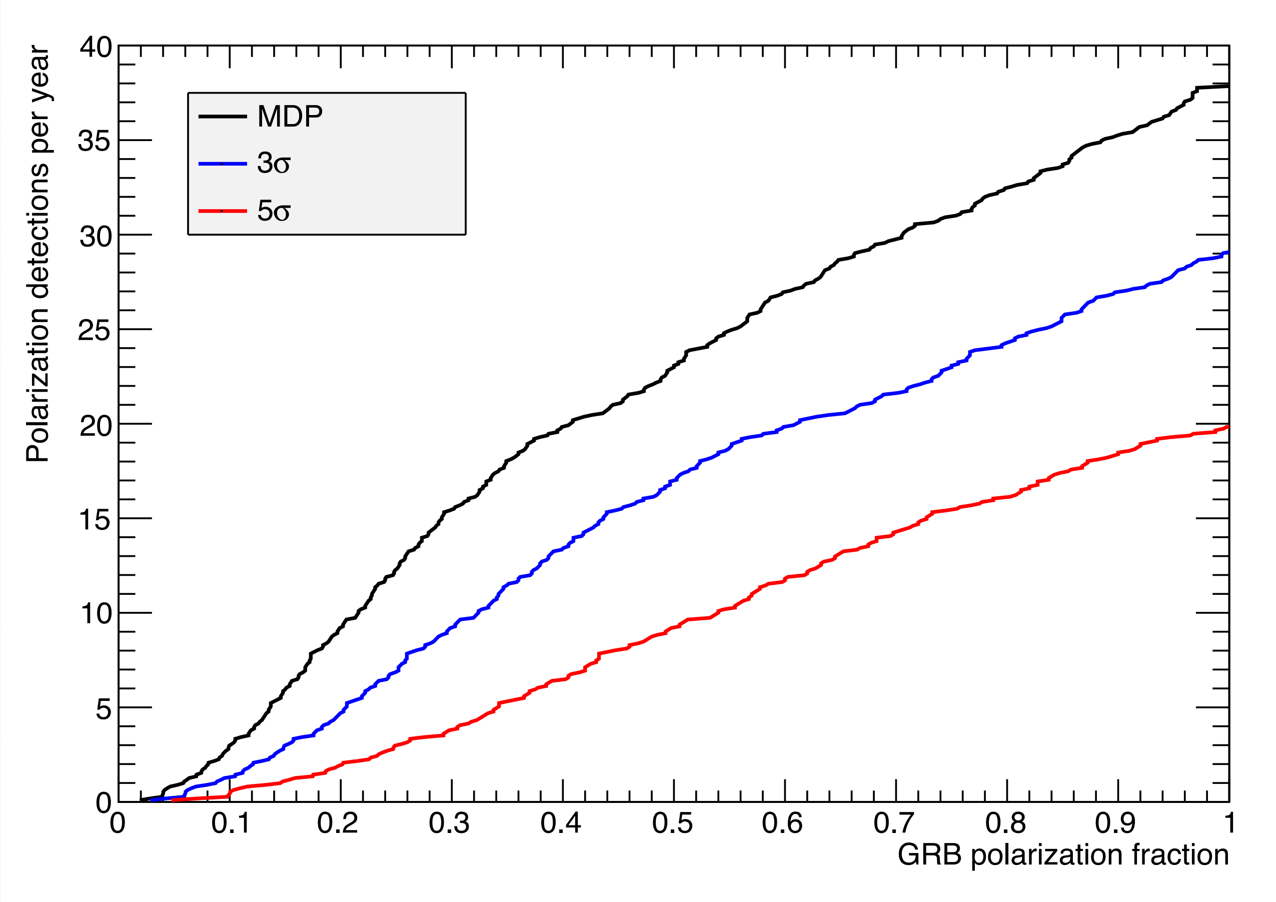




SPHiNX

- Energy band: 30 - 300 keV
- FoV: 120 degrees
- Effective area: 95 cm^2
- Lifetime: 2 years
- MDP of 13.5% for the brightest GAP burst
- Determine polarization degree to ~5%, angle to a few degrees

Yearly detections



Thank you!