Onset of particle acceleration during the prompt phase of GRBs

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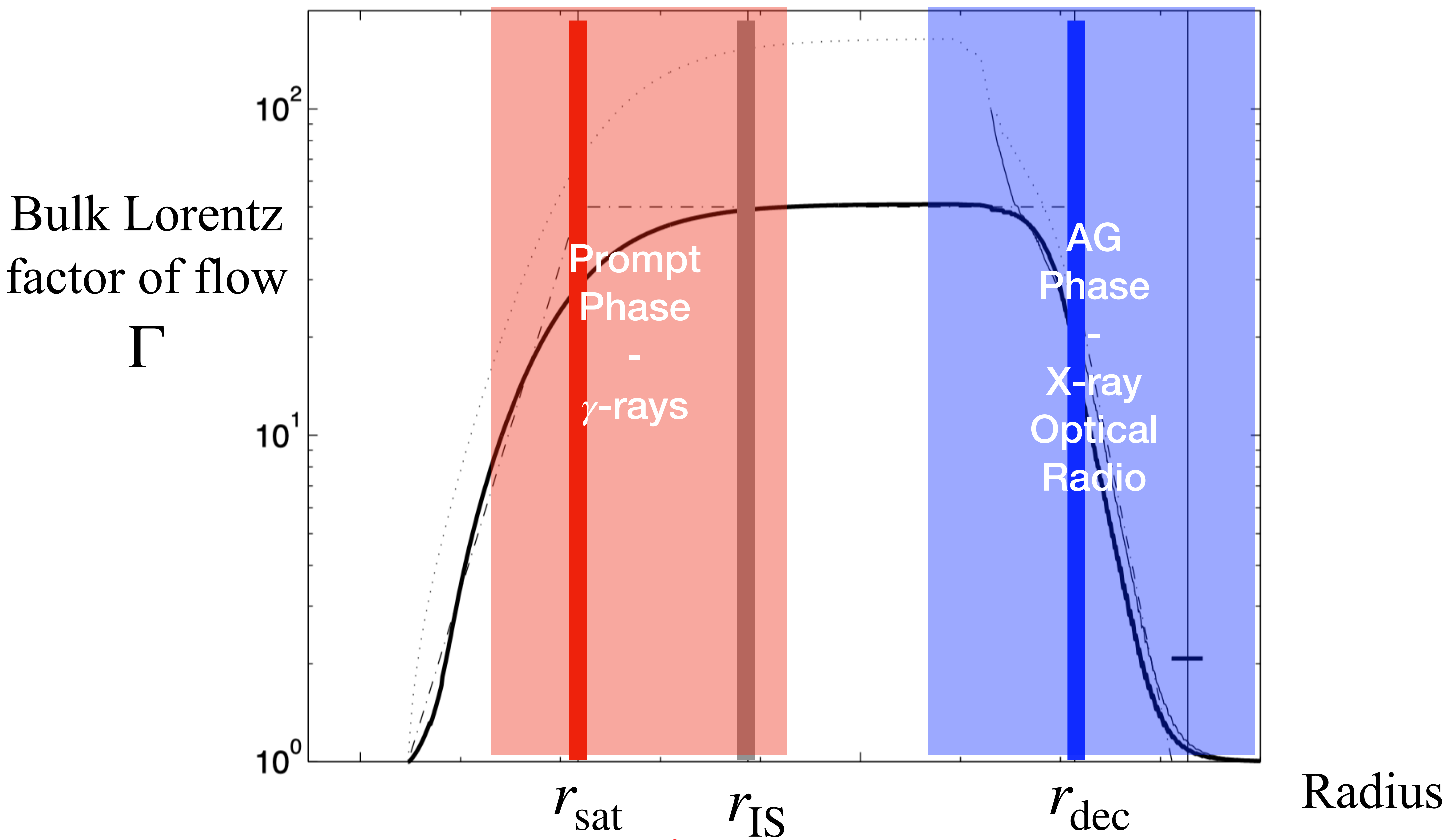
Fireball model of gamma-ray bursts

Saturation radius   Internal shock   External shocks



$r_{sat} = 10^9$cm

$r_{IS} = 10^{13}$cm

$\Gamma \sim 300$

$r > 4 \times 10^{15}\,\Gamma_2^{-2}$ cm   (wind)

$r > 10^{17}\,\Gamma_2^{-2/3}$ cm   (ISM)

$\Gamma \sim 30$

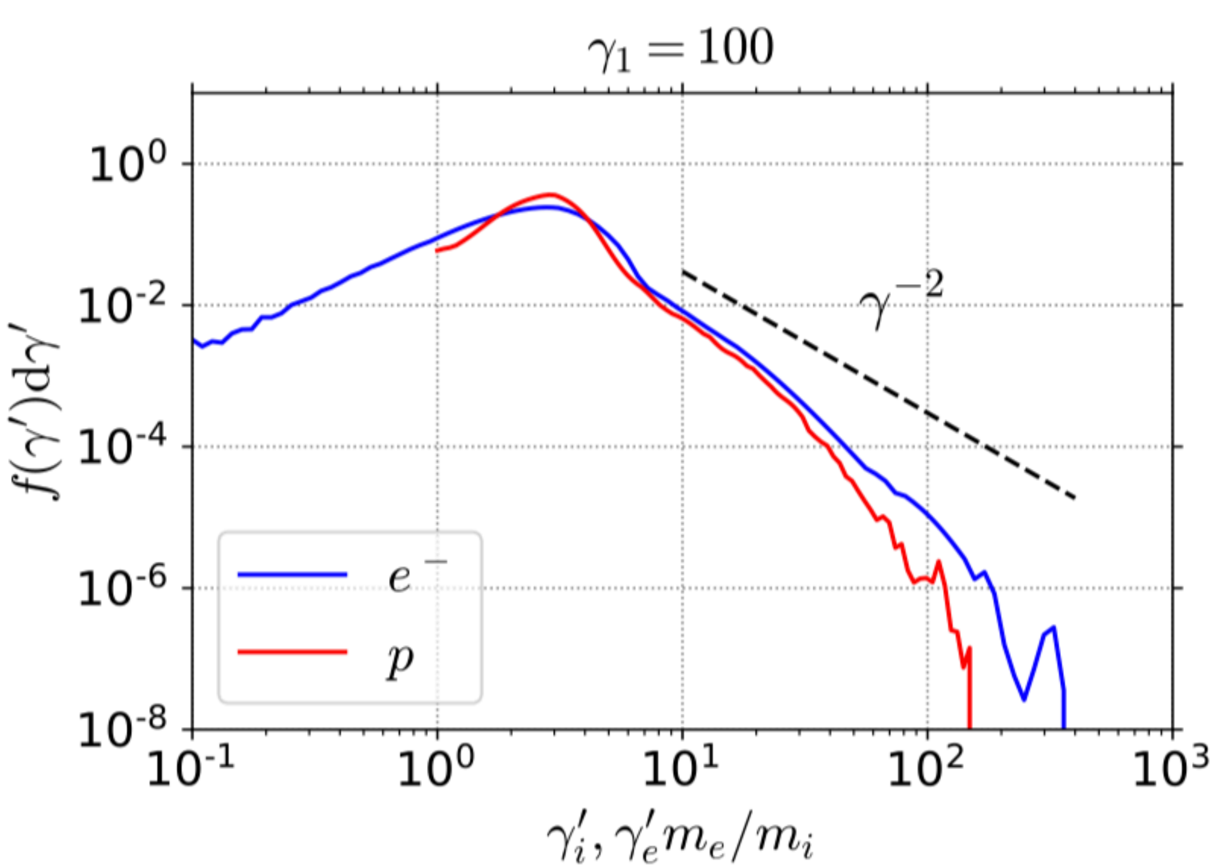
GRB Afterglow phase

Well established to be synchrotron emission (Rees & Mészáros 97, Sari+98)

Particle acceleration in relativistic, collisionless shocks with $\Gamma \sim 10 - 50$ (e.g. Tavani 96; Wijers & Galama 99)

Theory:

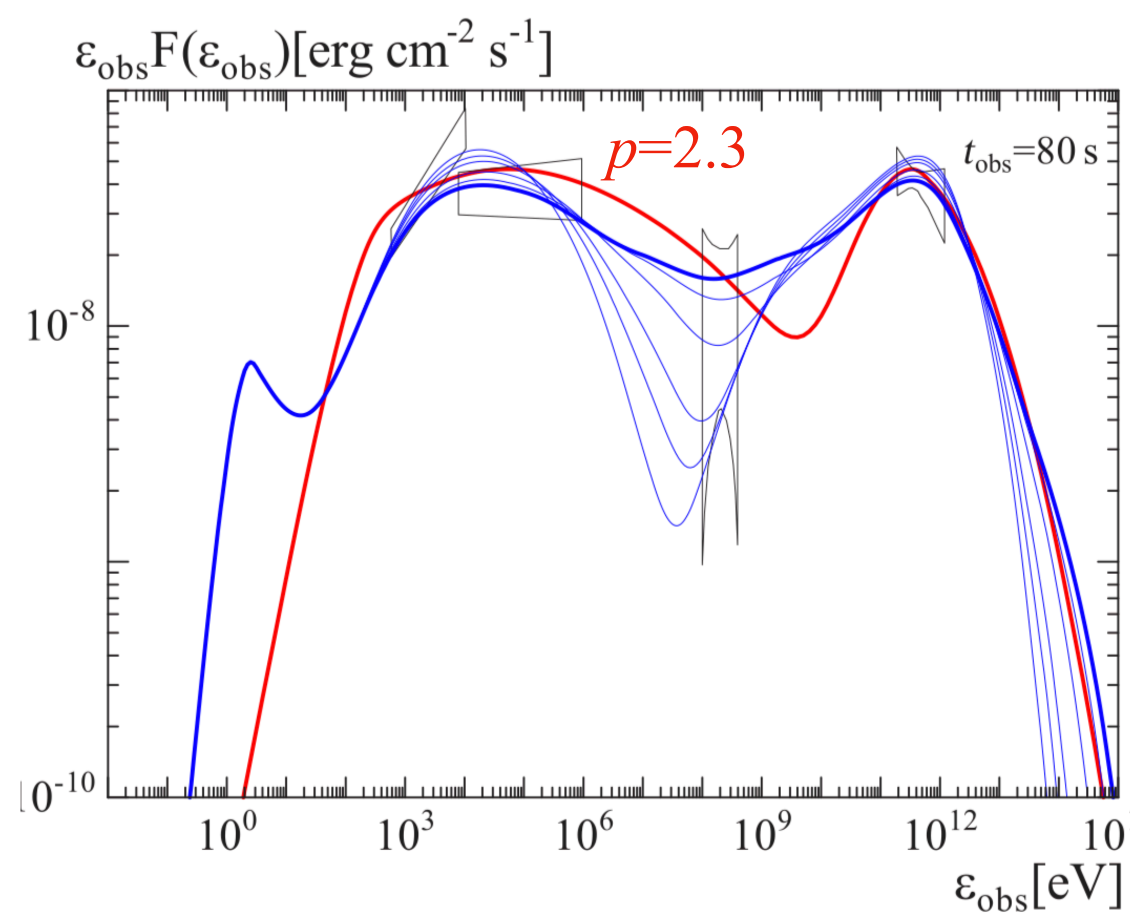
Lemoine & Pelletier 11,13; Kumar15; Plotnikov+18
PIC simulations (Spitkovsky 08, Sironi+11)



Iwamoto+22

Observations:

Example GRB190114C at 80s



Asano+22

GRB Prompt phase

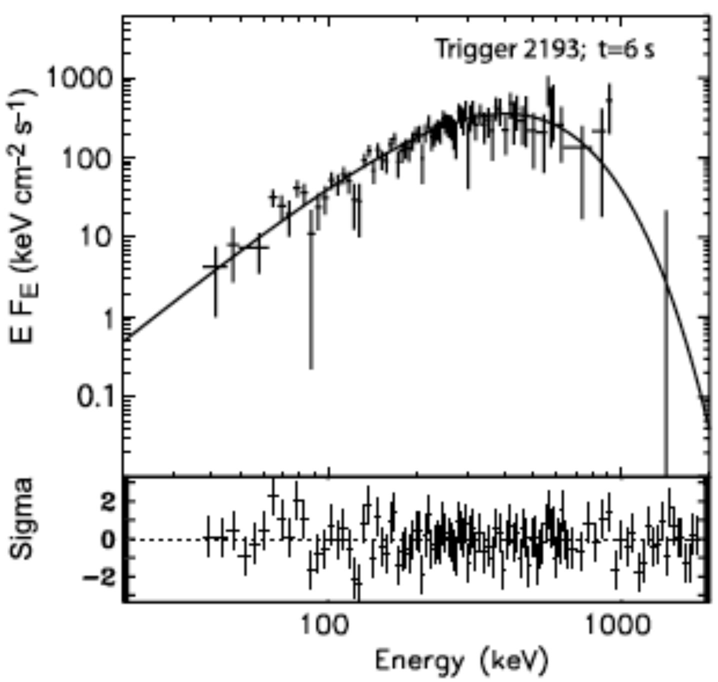
Not yet fully established

A few per cent of all spectra are quasi-Planckian

$\Longrightarrow$

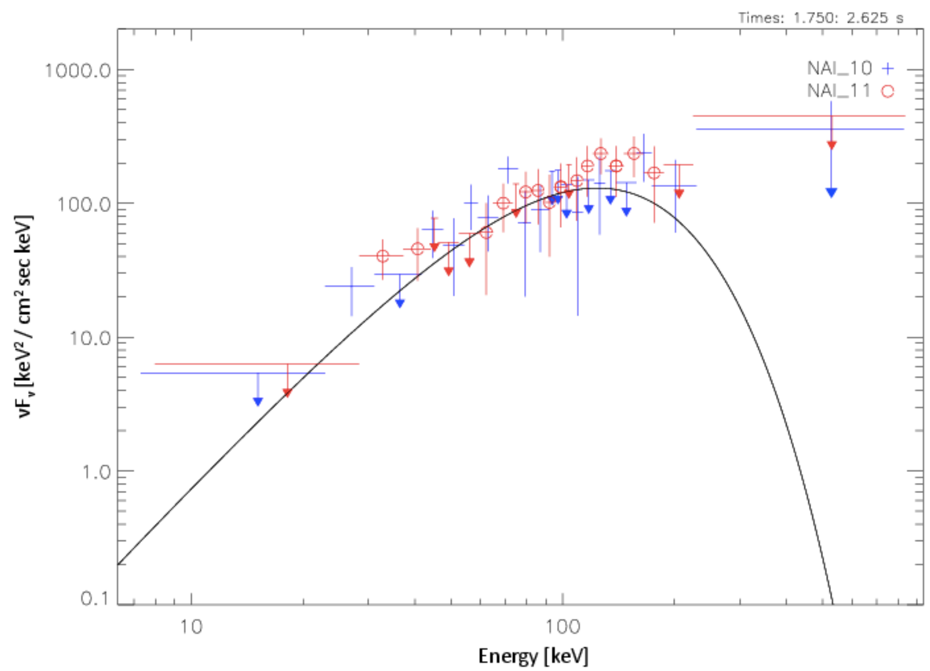
Observed photopheric spectra

CGRO/BATSE



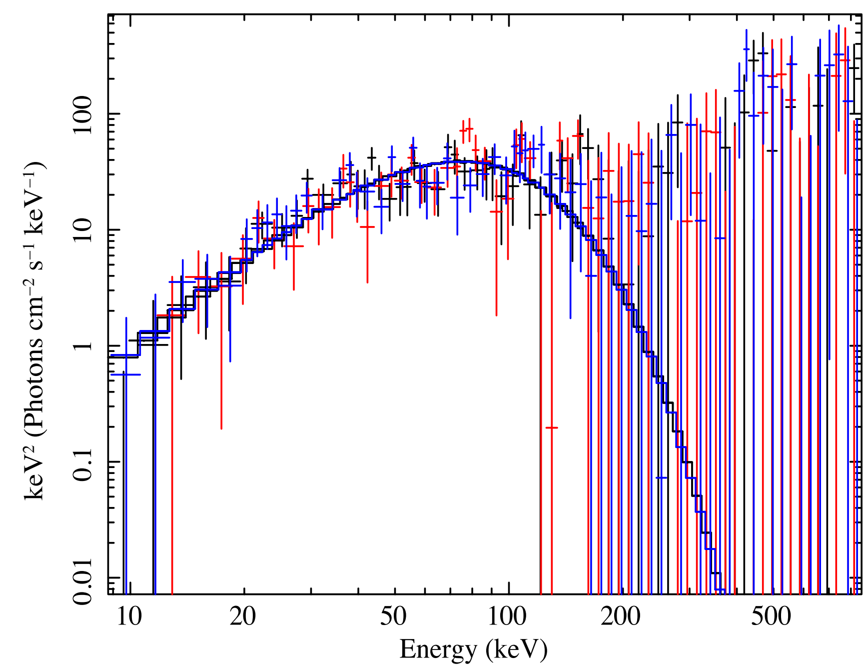
Ryde 04

Fermi/GBM



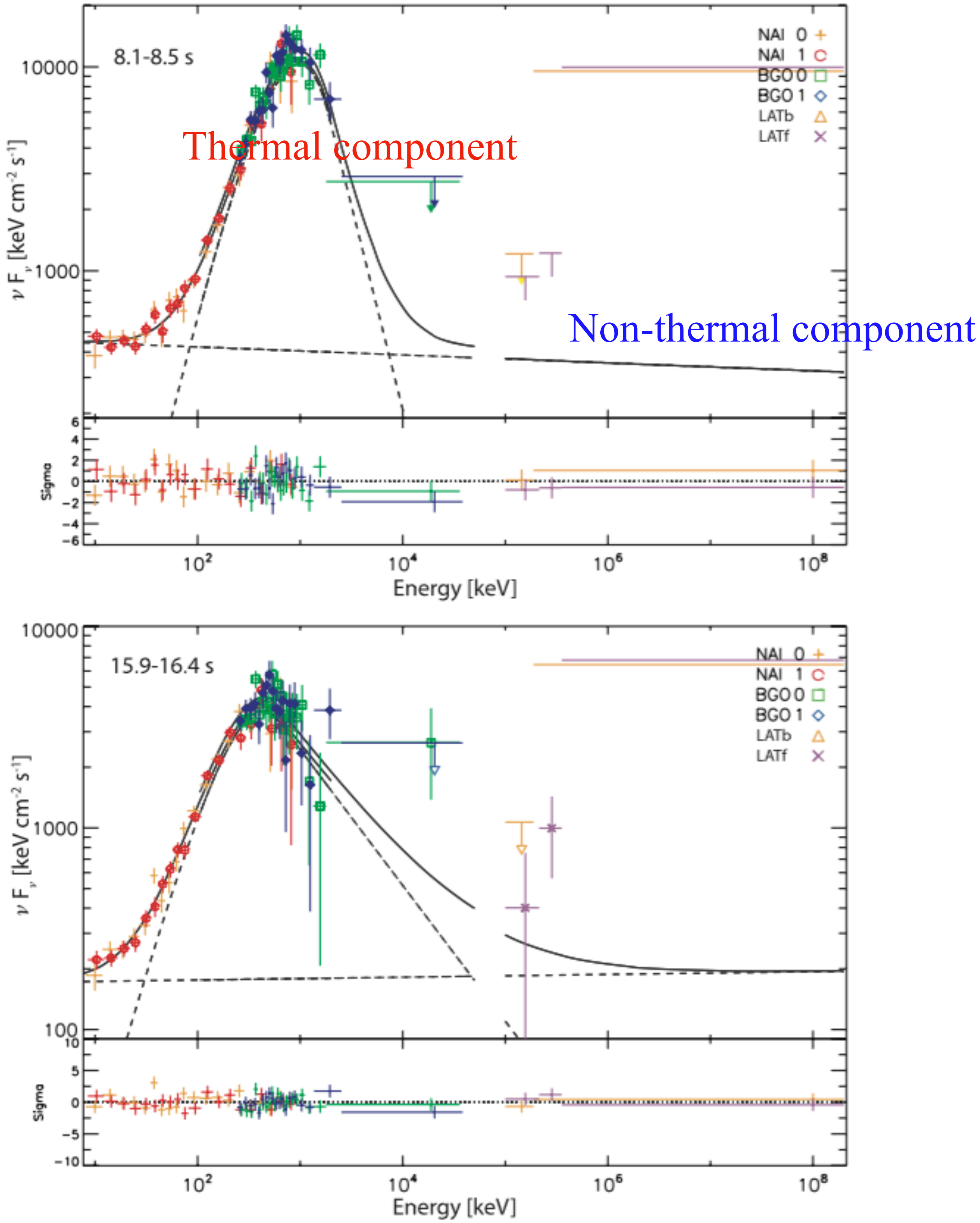
Ghirlanda+10

Fermi/GBM

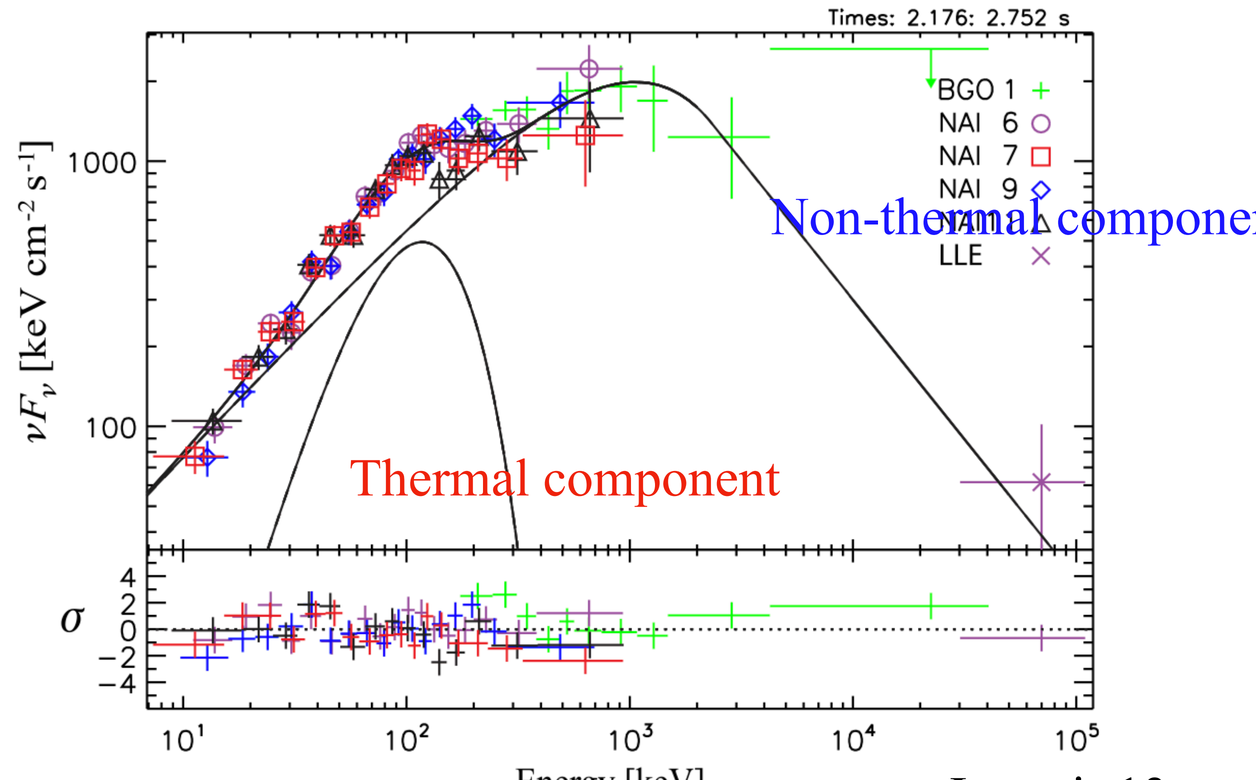


Larsson+15

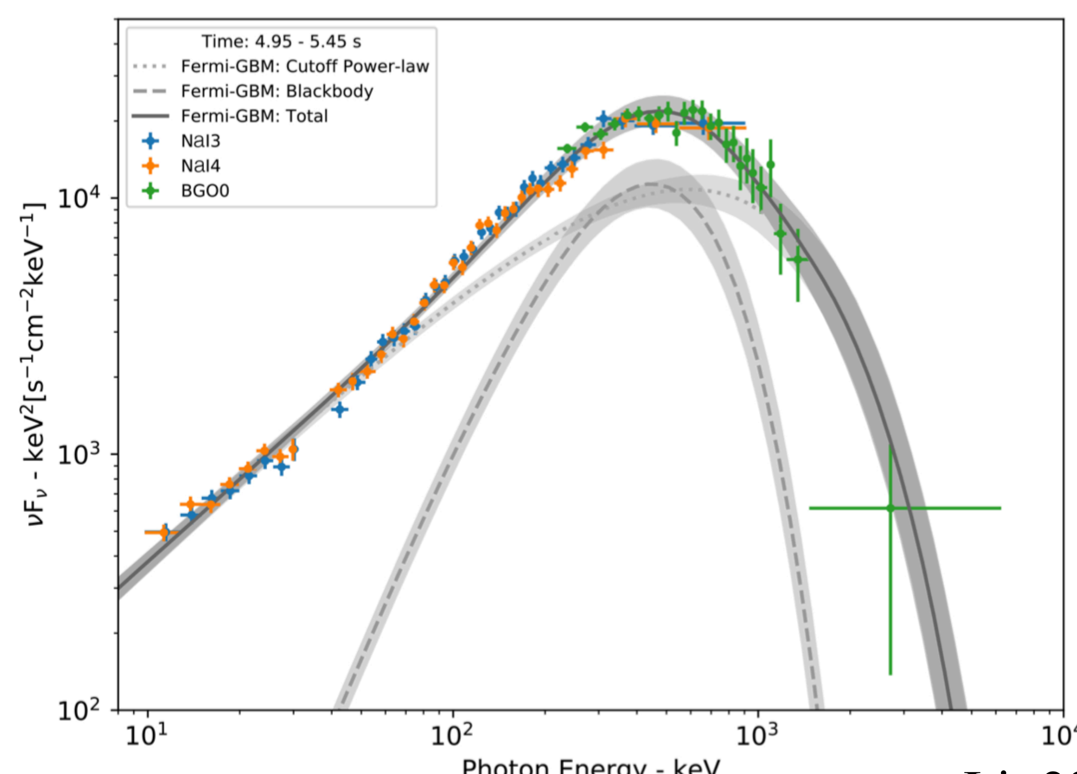
Others have multiple spectral components



Ryde+10



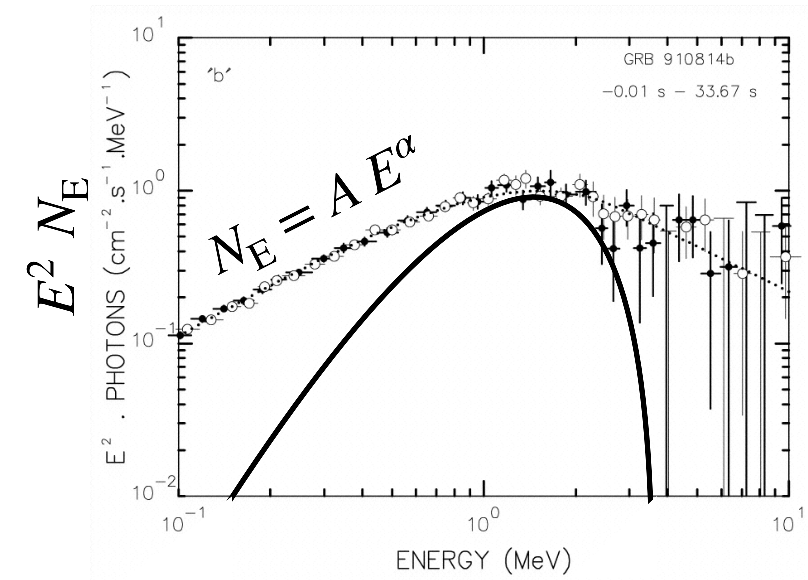
Iyyani+13



Li+22

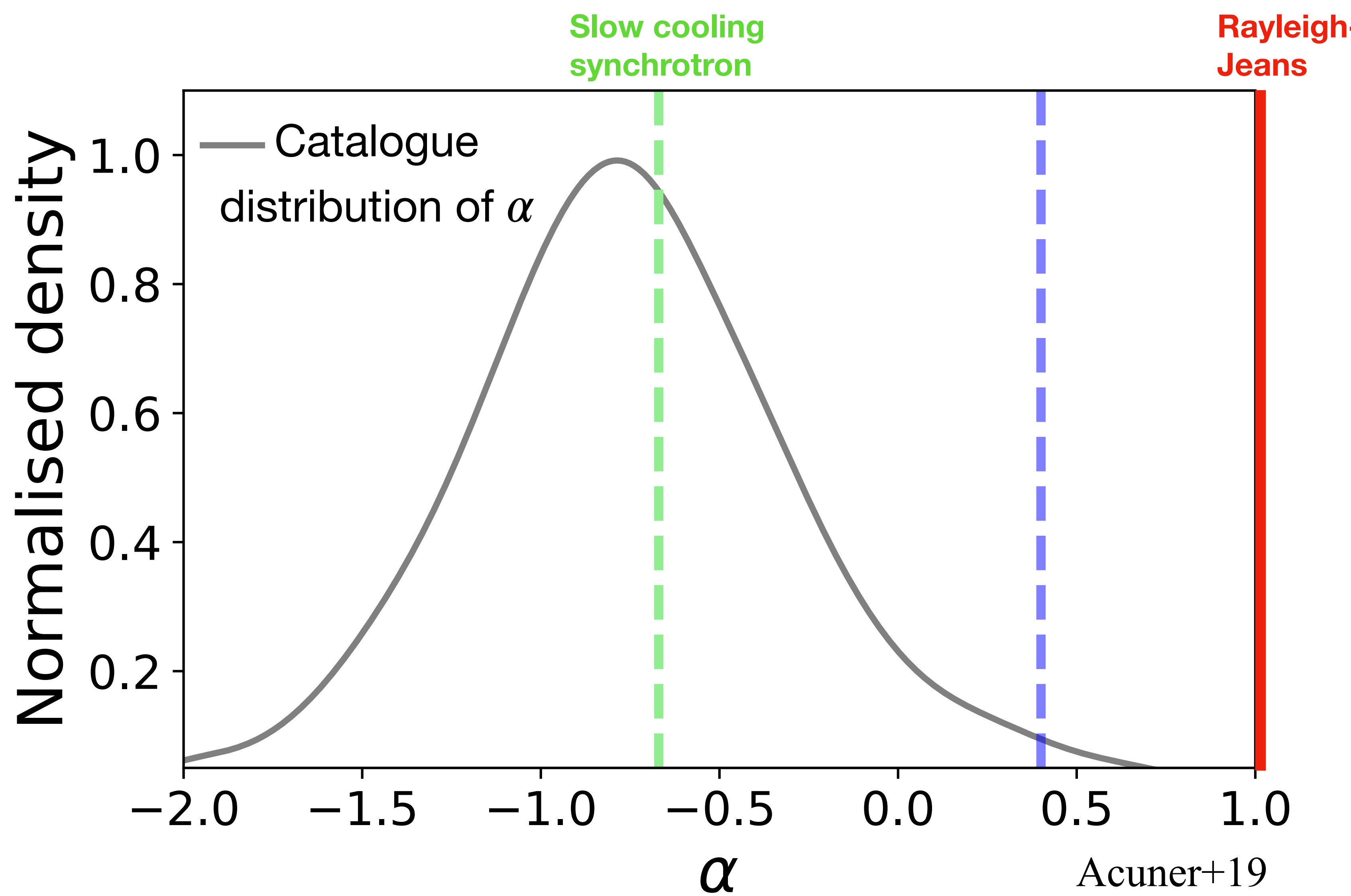
Distribution of prompt emission spectral shapes

Typical gamma-ray spectrum



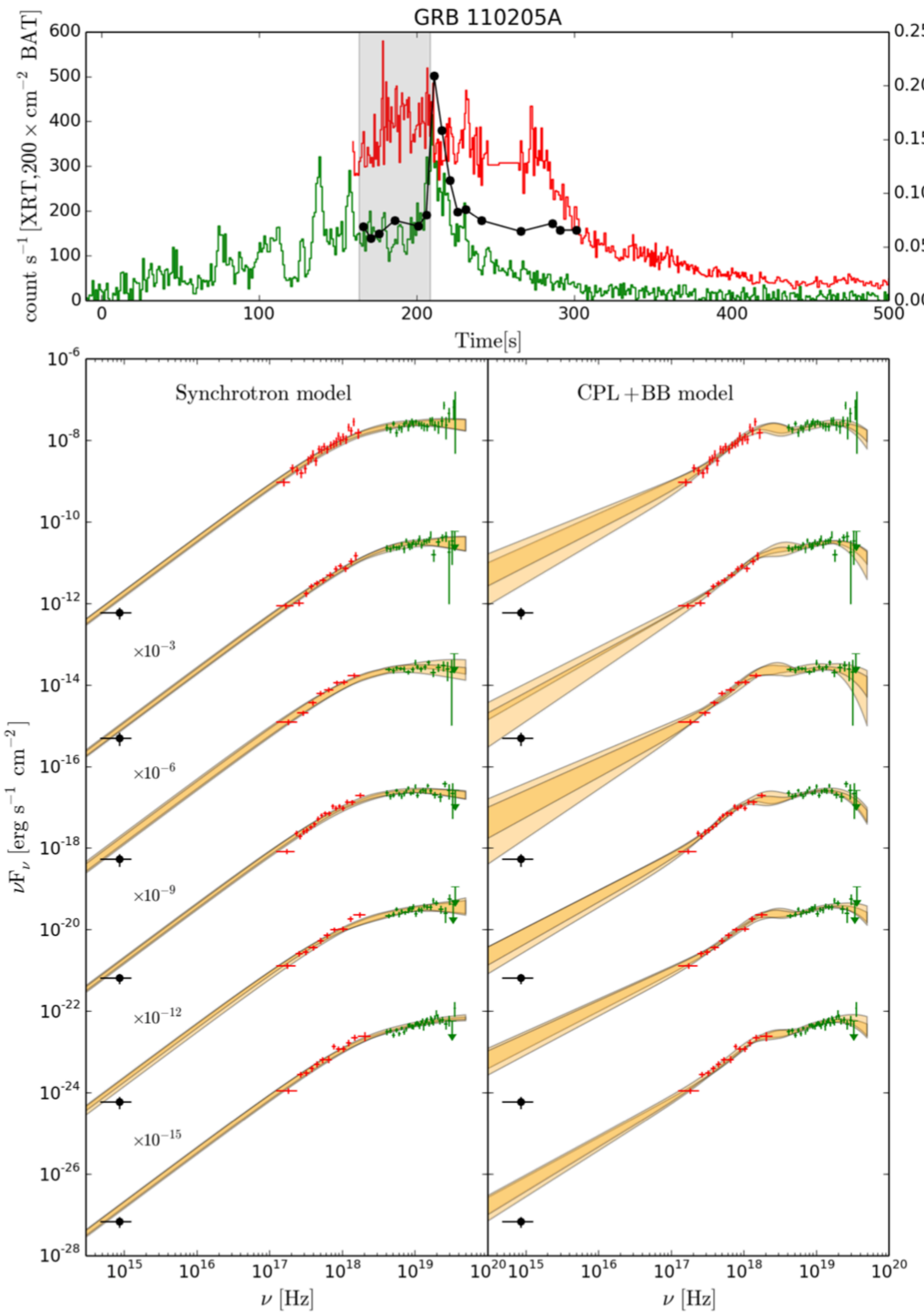
Current α-distribution

2300 GRBs observed
By Fermi/GBM

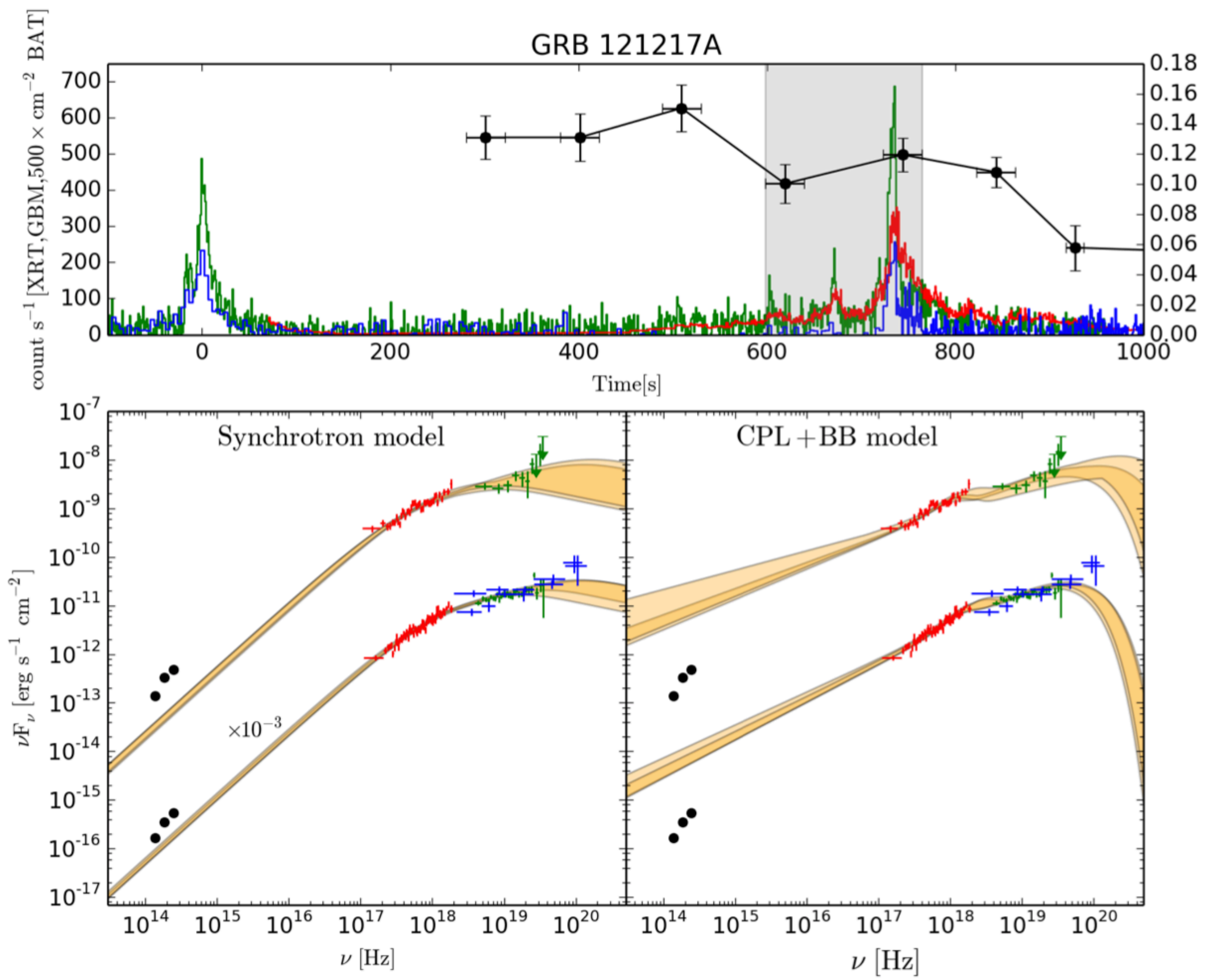


Acuner+19
Burgess+17

Synchrotron emission during the prompt phase



Oganesyan+17, 18, 19; Ravasio+19, 20; Burgess+20



Large Lorentz factors and large emission radii

Conclusion:

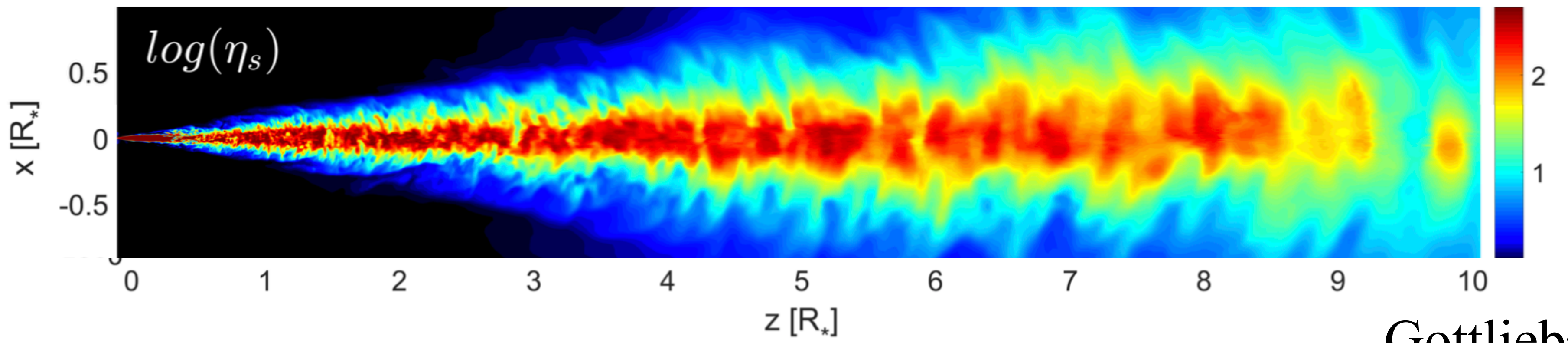
Both photospheric and synchrotron emission expected *and observed* during the prompt phase

1. Clustering analysis of the full Fermi/GBM catalogue indicates that (Acuner & Ryde 2019):
   - 1/3 synchrotron emission
   - 2/3 photospheric

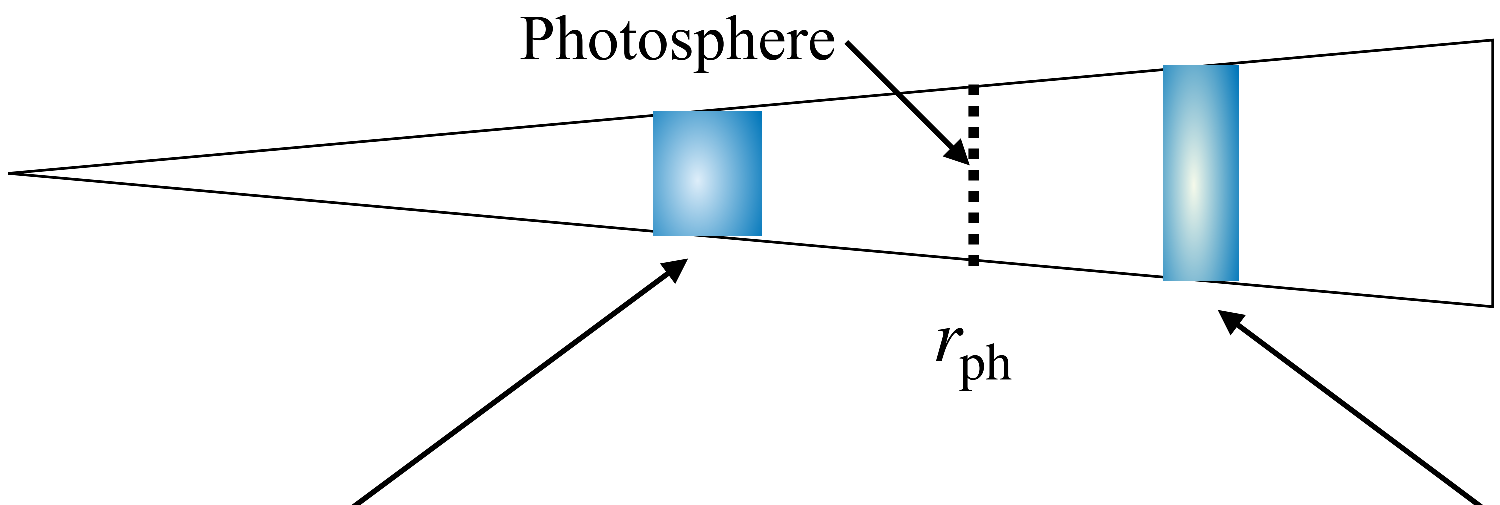
2. Later pulses in multiples GRBs are more synchrotron-like (Li+21)

Particle acceleration during the prompt phase?

Dissipation $\epsilon_d(r)$



Gottlieb+19



$$r_{ph} \sim \frac{L\sigma_T}{4\pi m_p c^3 \Gamma^3}$$

Subphotospheric dissipation
Radiation mediated shocks

No particle acceleration

Optically thin dissipation
Collisionless shocks

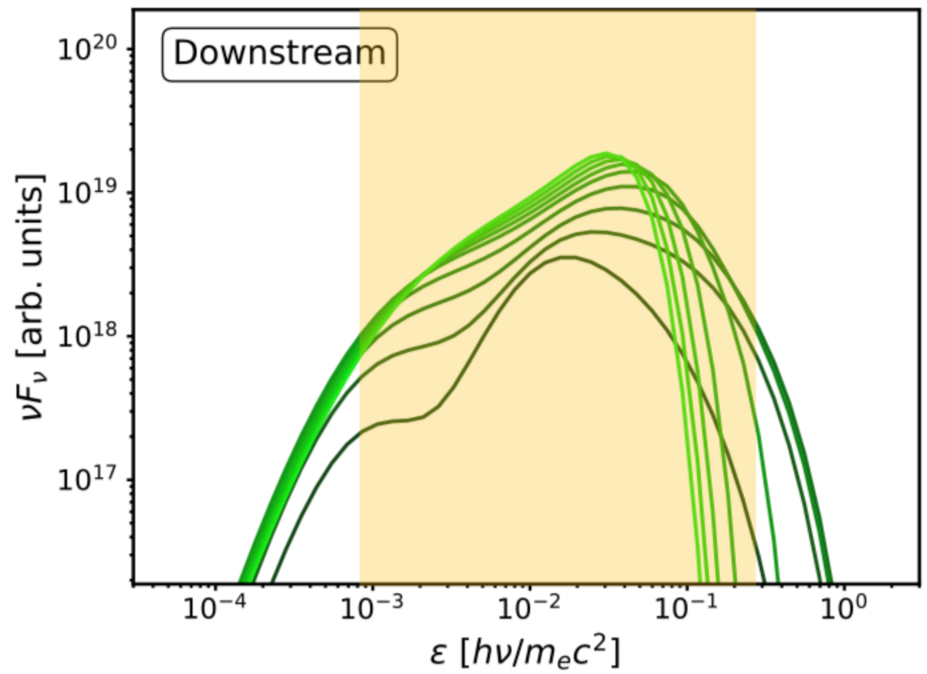
Particle acceleration possible

To study particle acceleration during the prompt phase in GRB synchrotron emission must be identified first

It is difficult to unambiguously identify synchrotron emission

Subphotospheric dissipation can also produce broad spectra (Rees+05, Pe'er+06, Giannios+06)

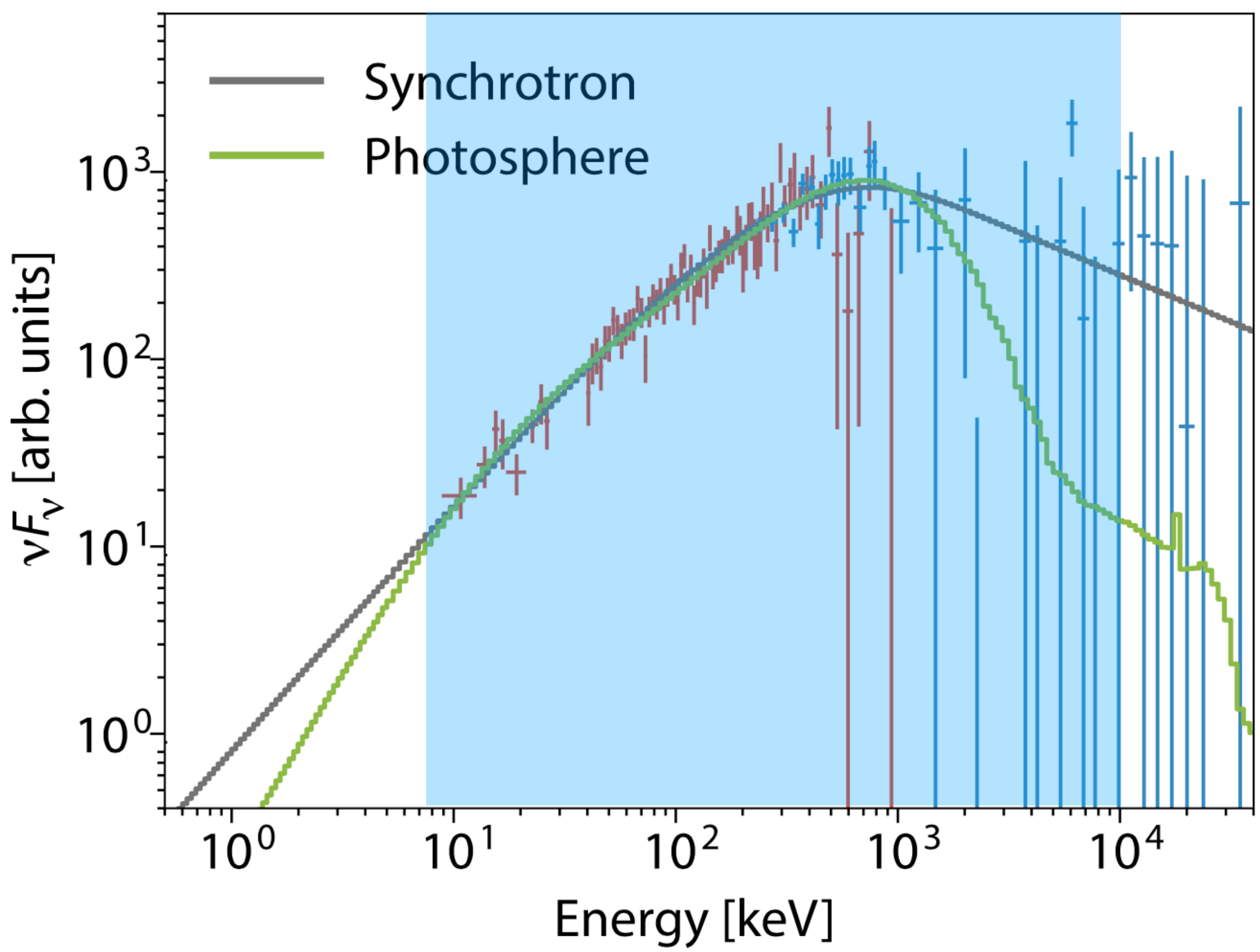
Radiation mediated shock spectra
Photospheric emission



Samuelsson & Ryde 22

Synthetic SPD spectra fitted with a synchrotron model (Acuner+20)

Fermi/GBM



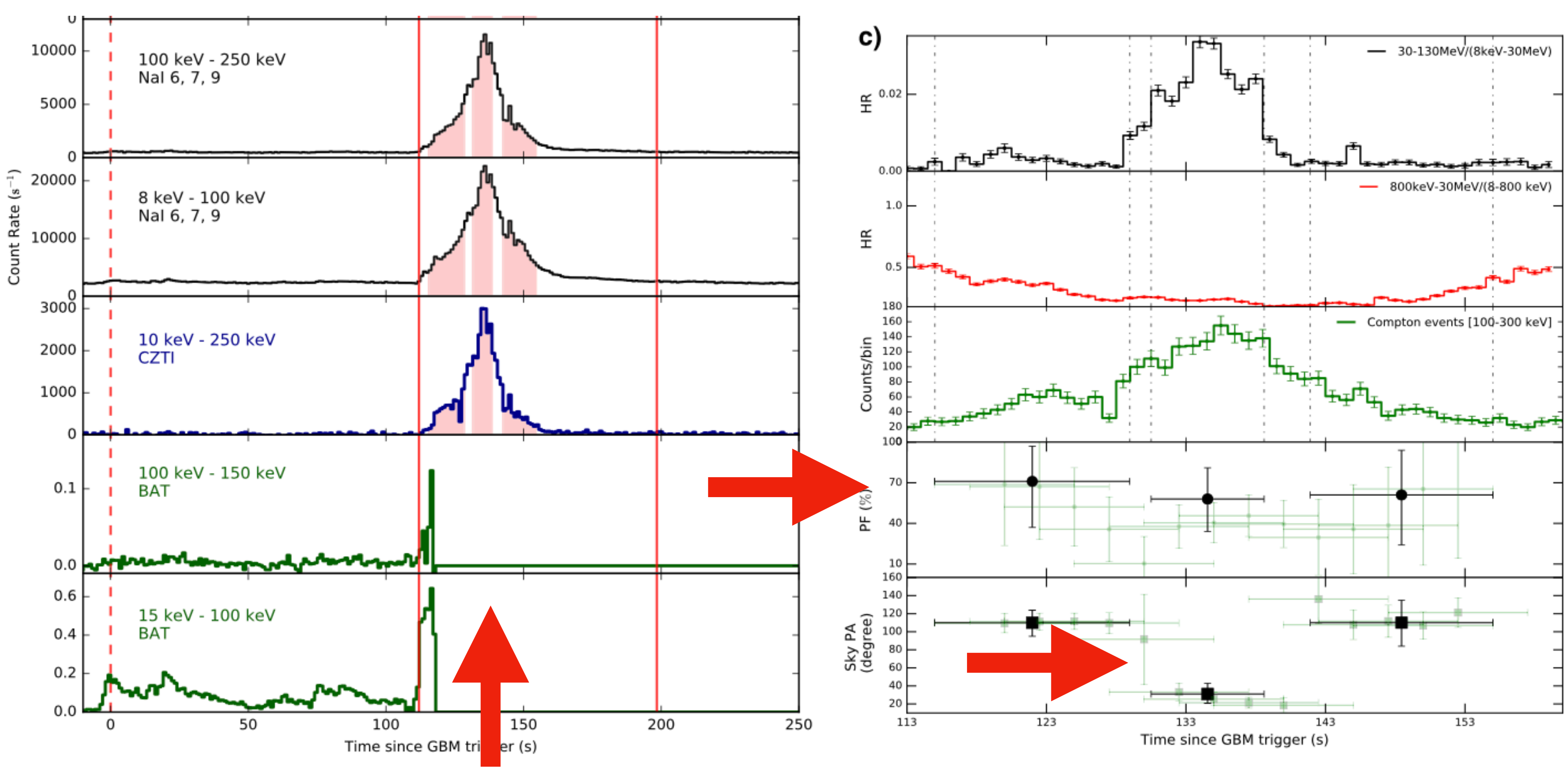
See also Gill+20

To study particle acceleration during the prompt phase in GRB synchrotron emission must be identified first

If a synchrotron model is fitted to a RMS spectrum the conclusion will be invalid

1. Broad energy range (optical, X-ray, γ-ray)
2. Secondary information

Example: GRB160821A: A clear case of synchrotron emission



Sharma+19; Ravasio+19; Gill+20

Synchrotron emission during the prompt phase

Time-varying Polarized Gamma-Rays from GRB 160821A: Evidence for Ordered Magnetic Fields

Vidushi Sharma[1], Shabnam Iyyani[1], Dipankar Bhattacharya[1], Tanmoy Chattopadhyay[2,3], A. R. Rao[1,4], E. Aarthy[5], Santosh V. Vadawale[5], N. P. S. Mithun[5], Varun. B. Bhalerao[6], Felix Ryde[7,8], and Asaf Pe'er[9,10]

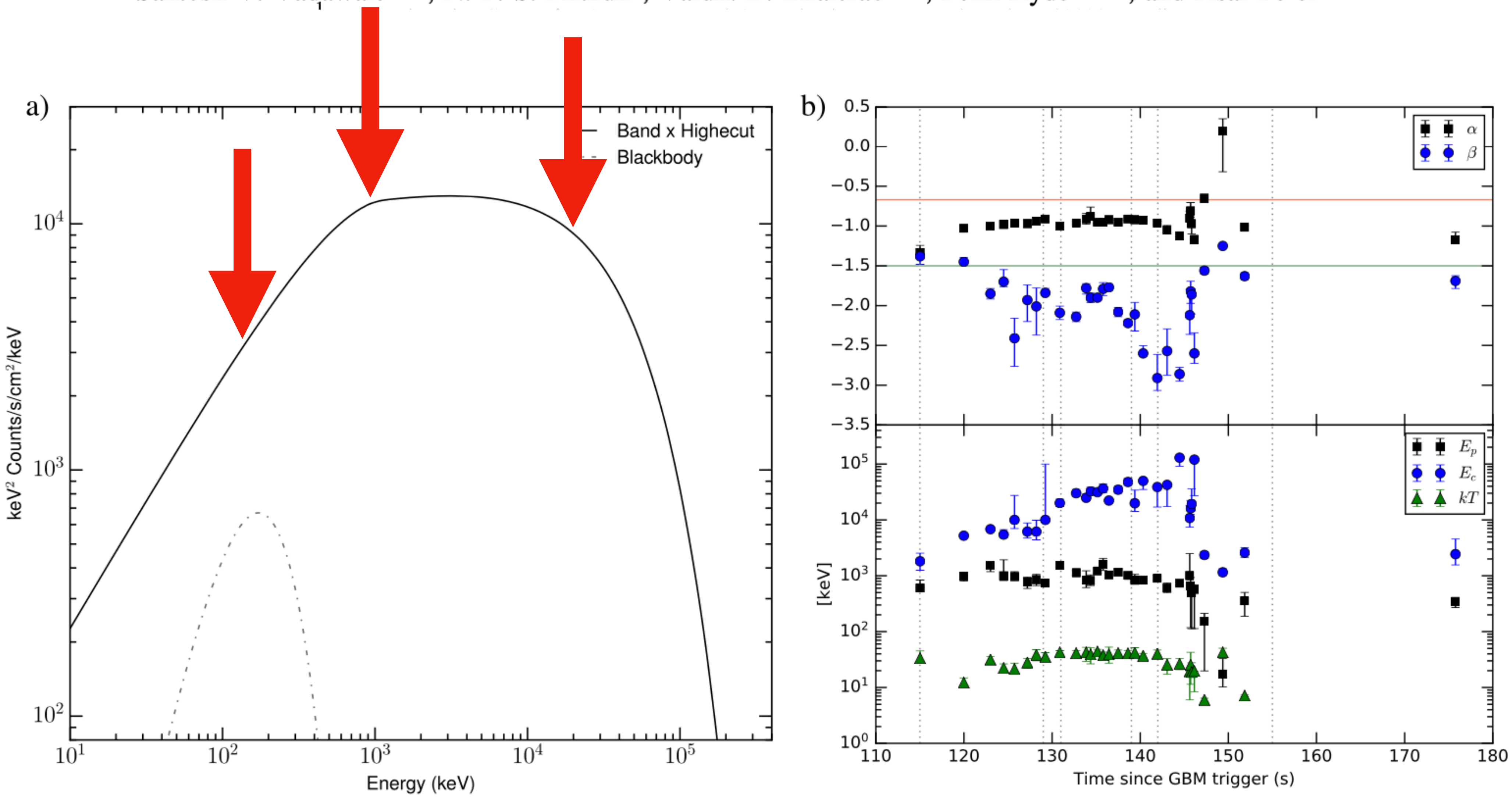
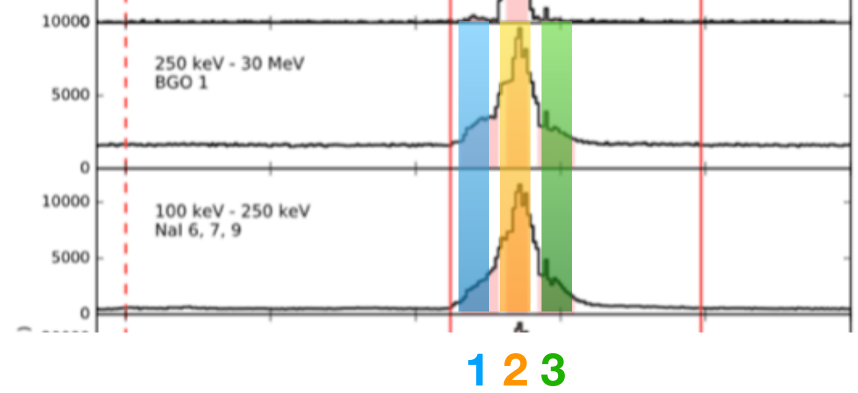


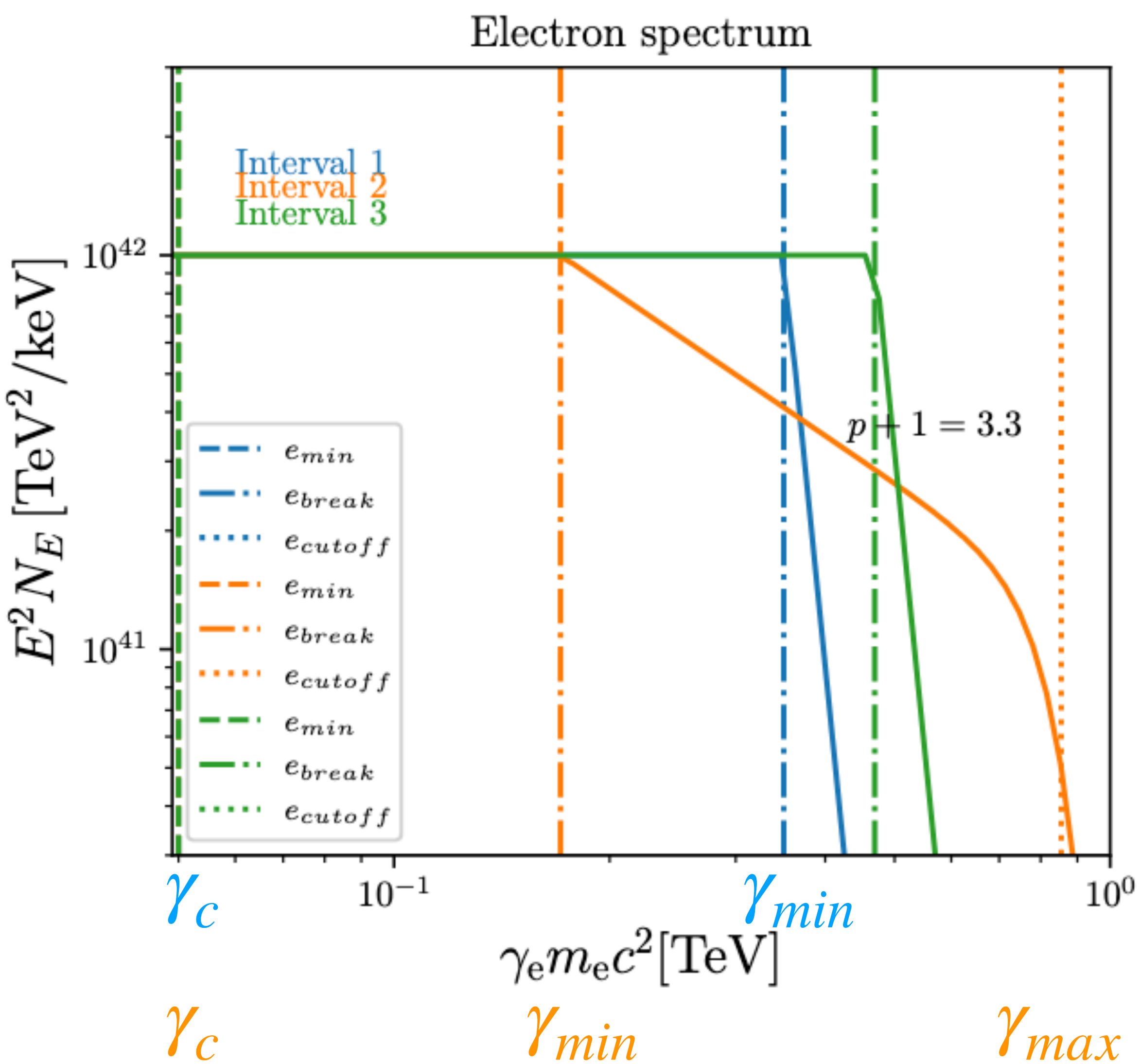
Figure 4. Panel (a): the νF_ν plot of the best-fit model, Band × Highecut (solid black line) + blackbody (BB; dashed–dotted black line), fitted to the brightest time interval, i.e., 134.59–135.71 s. Panel (b): the upper section shows the time evolution of α (black squares) and β (blue circles) of the Band function. The green and red horizontal lines in the upper section mark the photon index of $\alpha = -1.5$ and $\alpha = -0.67$, corresponding to the fast and slow cooling synchrotron emissions, respectively. In the lower section, the time evolution of the Band E_p (black squares), the high-energy cutoff E_c (blue circles), and the temperature of the BB component kT (green triangles) are shown. The three time intervals of polarization study are shown in dotted vertical black lines across the two panels.

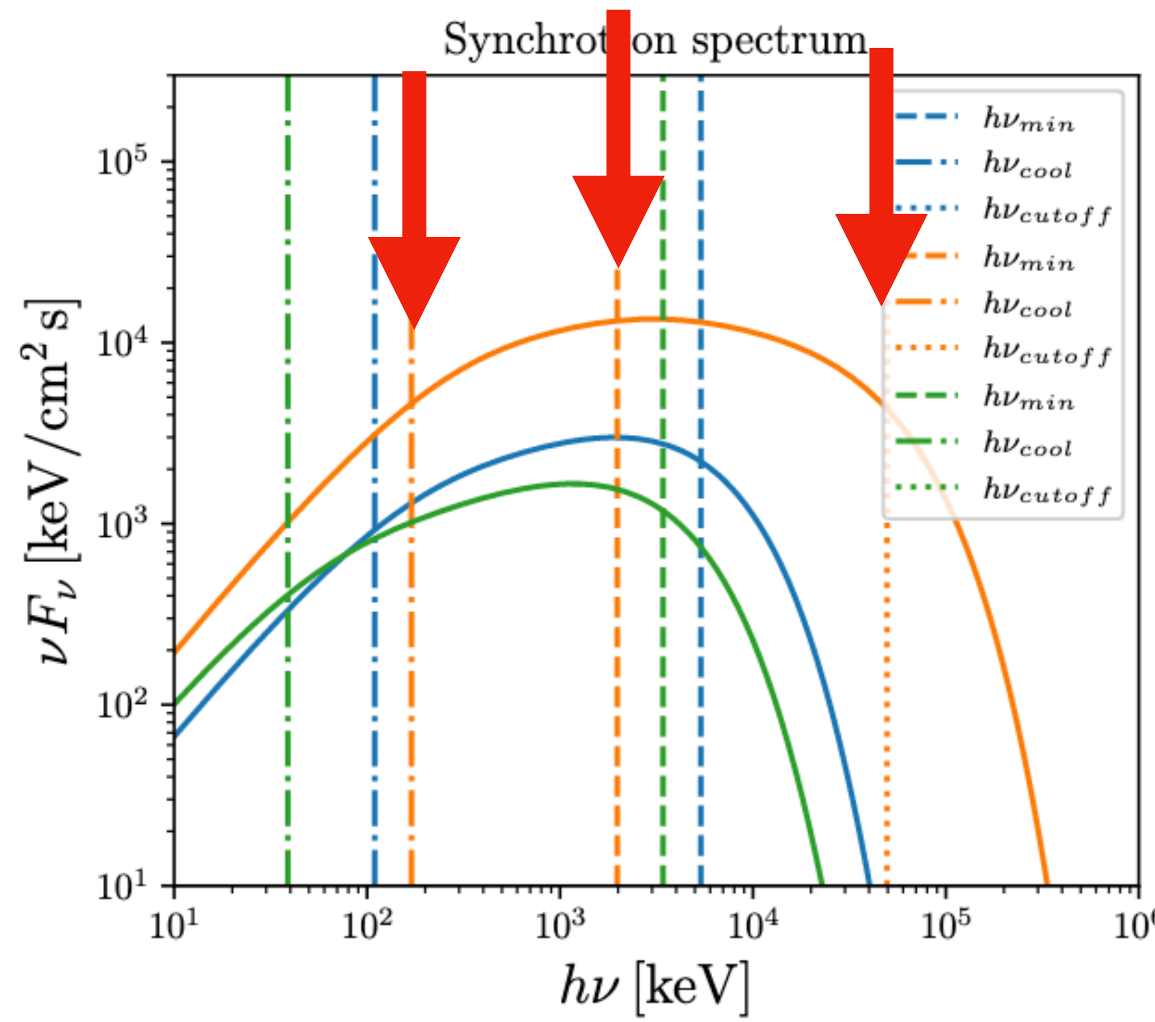
See also Ravasio+19

Synchrotron fits of 160821A

Ryde+22, *ApJL*, 932, L15

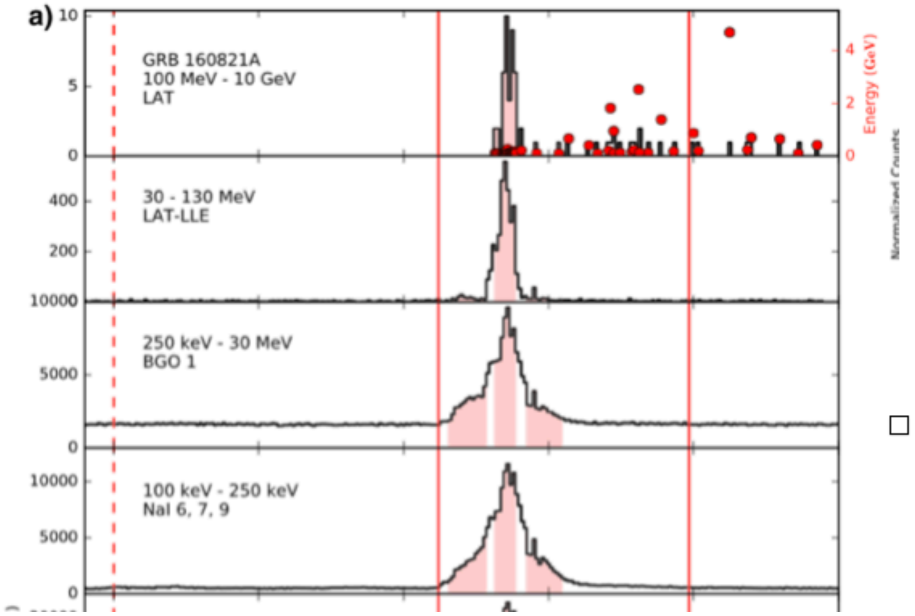


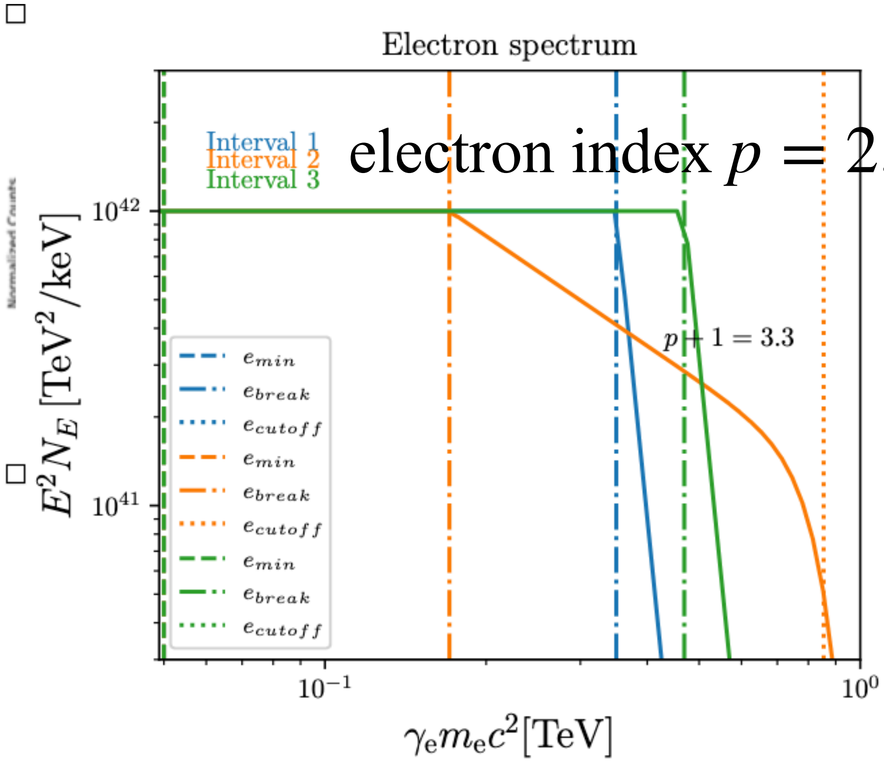




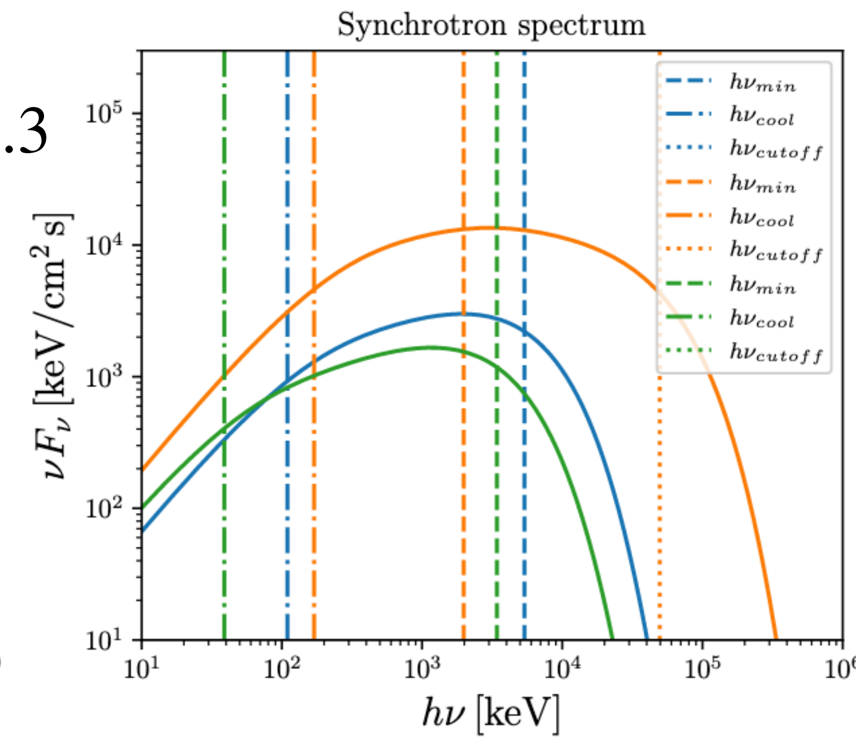
"Onset of particle acceleration during the prompt phase in gamma-ray bursts as revealed by synchrotron emission in GRB160821A"

The giant flare during the prompt phase in GRB160821A





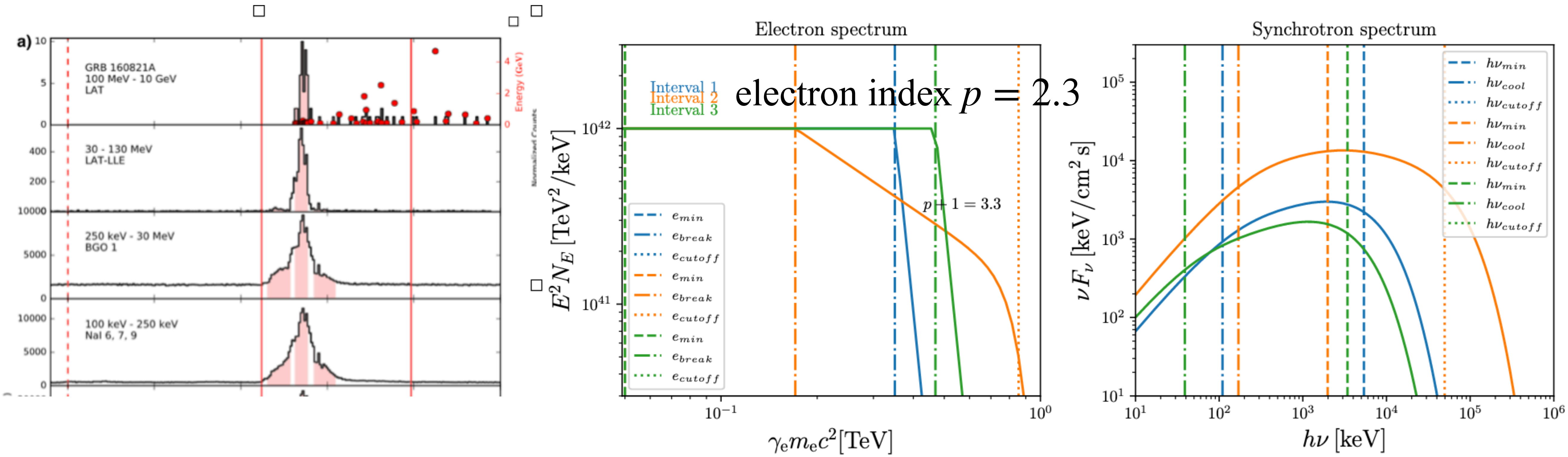
electron index $p = 2.3$



Onset of particle acceleration during the prompt phase in GRBs.

Particle acceleration at a collisionless shock at $\Gamma \sim 300$

The giant flare during the prompt phase in GRB160821A



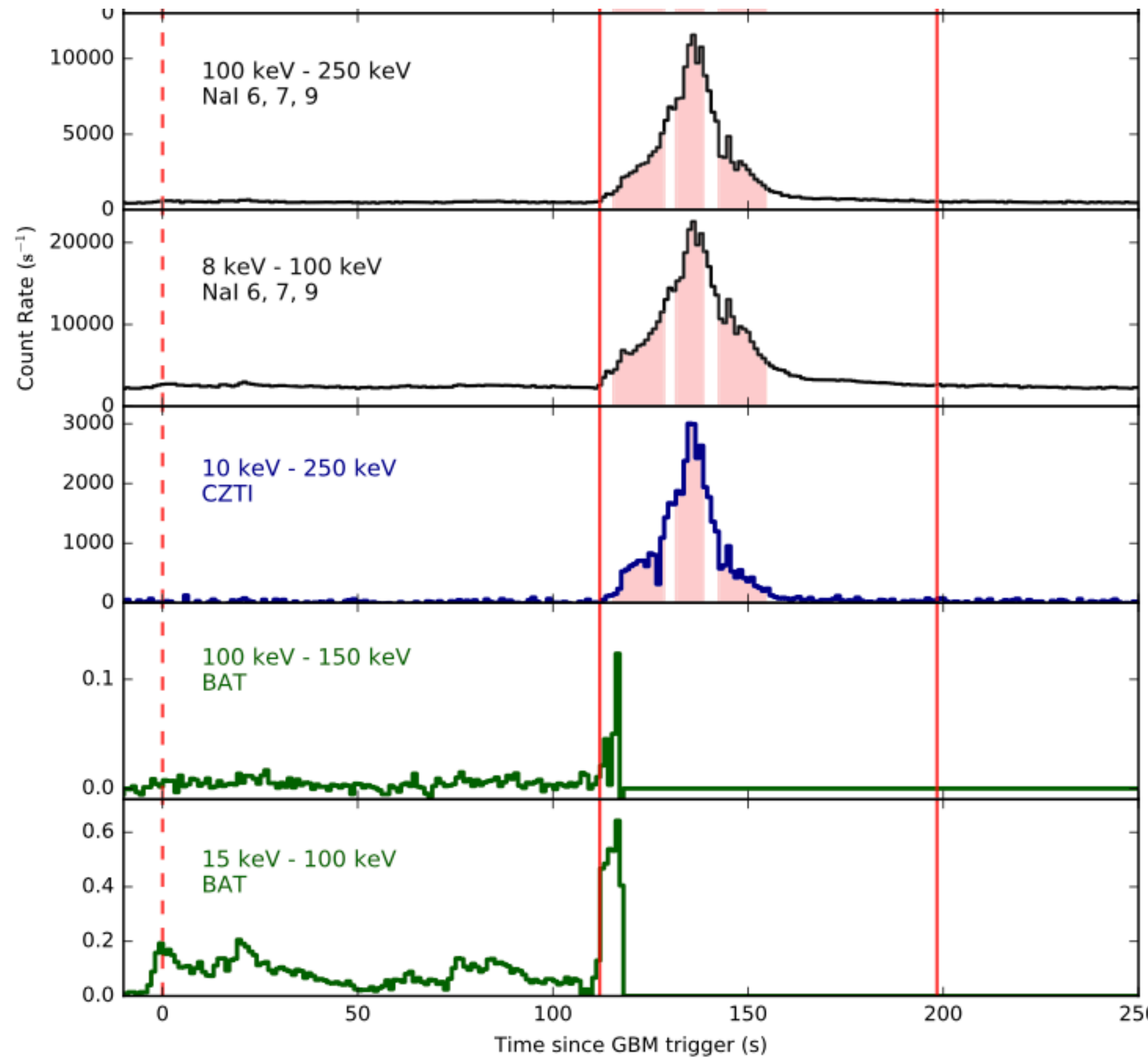
Onset of particle acceleration during the prompt phase in GRBs.

Particle acceleration at a collisionless shock at $\Gamma \sim 300$

What causes the onset of particle acceleration?
What are the physical parameters of the flow?

Scenario:

GRB160821A



Variability time scale of flare $\sim 10\,\mathrm{s}$ is much shorter than expected from the afterglow

$\Longrightarrow$

The flare at 135s is not part of the afterglow

Internal shock
Collision between shells

The fluence makes GRB160821A one of the brightest GRBs observed by Fermi:
Internal shocks are very inefficient

Efficient synchrotron emission requires large difference in Lorentz factors
$\Longrightarrow$ Pre existing ring of circumburst matter

Efficient synchrotron emission requires large difference in Lorentz factors
$\Longrightarrow$ Pre existing ring of circumburst matter

A&A 559, A52 (2013)

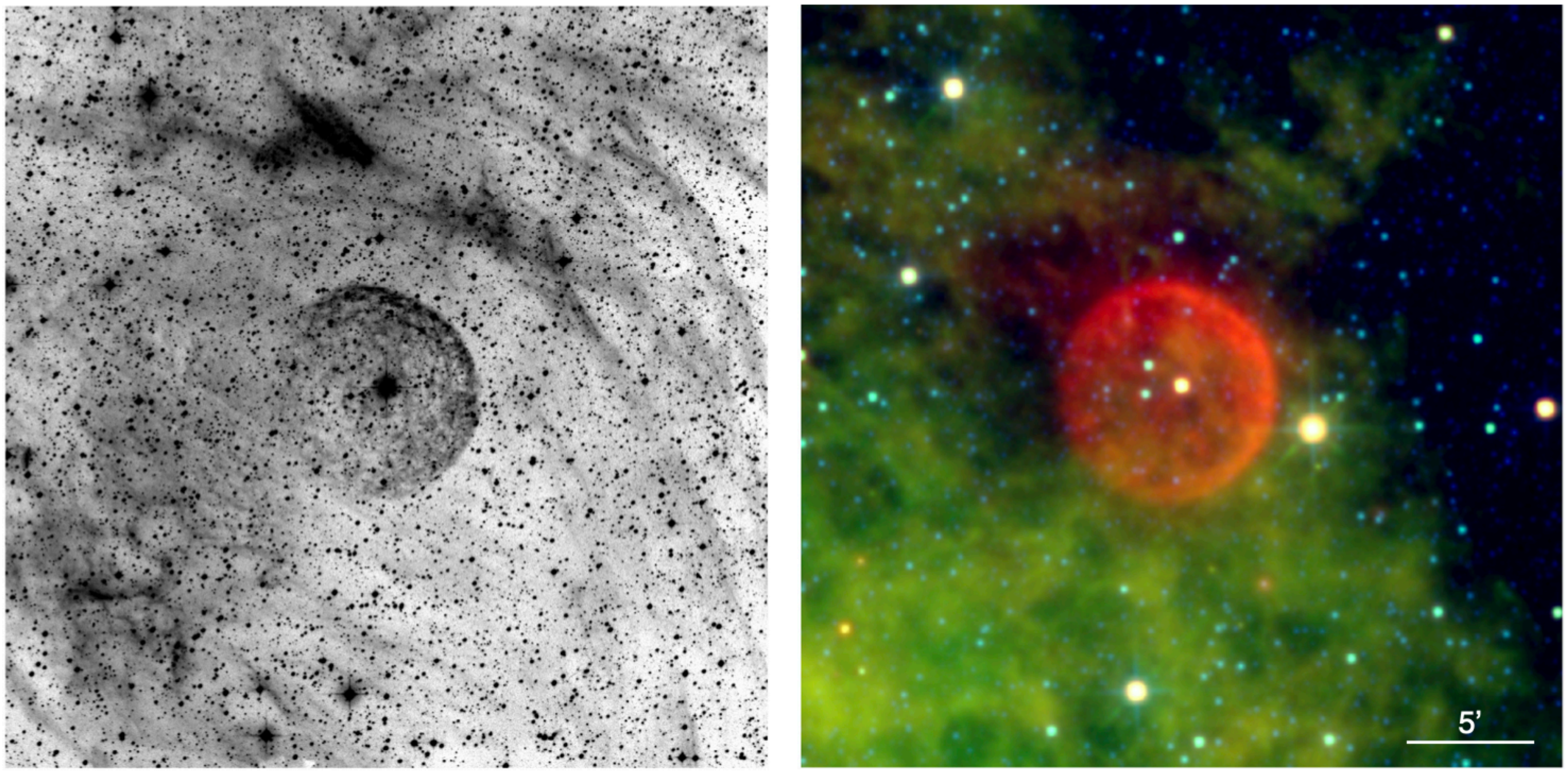
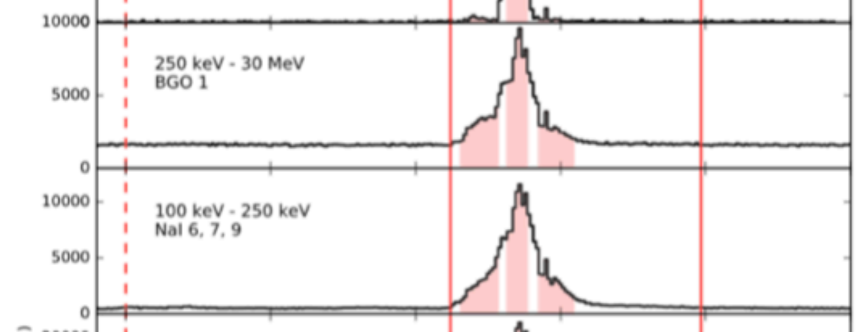


Fig. 1. *Left*: narrow-band Hα image of the WR nebula around WR 16 taken from the Super COSMOS Sky Survey (Parker et al. 2005). *Right*: color-composite mid-infrared WISE W2 4.6 μm (blue), W3 12 μm (green), and W4 22 μm (red) picture of the WR nebula around WR 16. The central star, WR 16, is located at the center of each image. North is up, east to the left.

Wolf Rayet ring nebulae:
- radius ~1pc
- 1/3 of galactic WR stars have WR ring nebulae

(Chu 1981; Marston 1997; Crowther 2007)

Synchrotron emission in 160821A



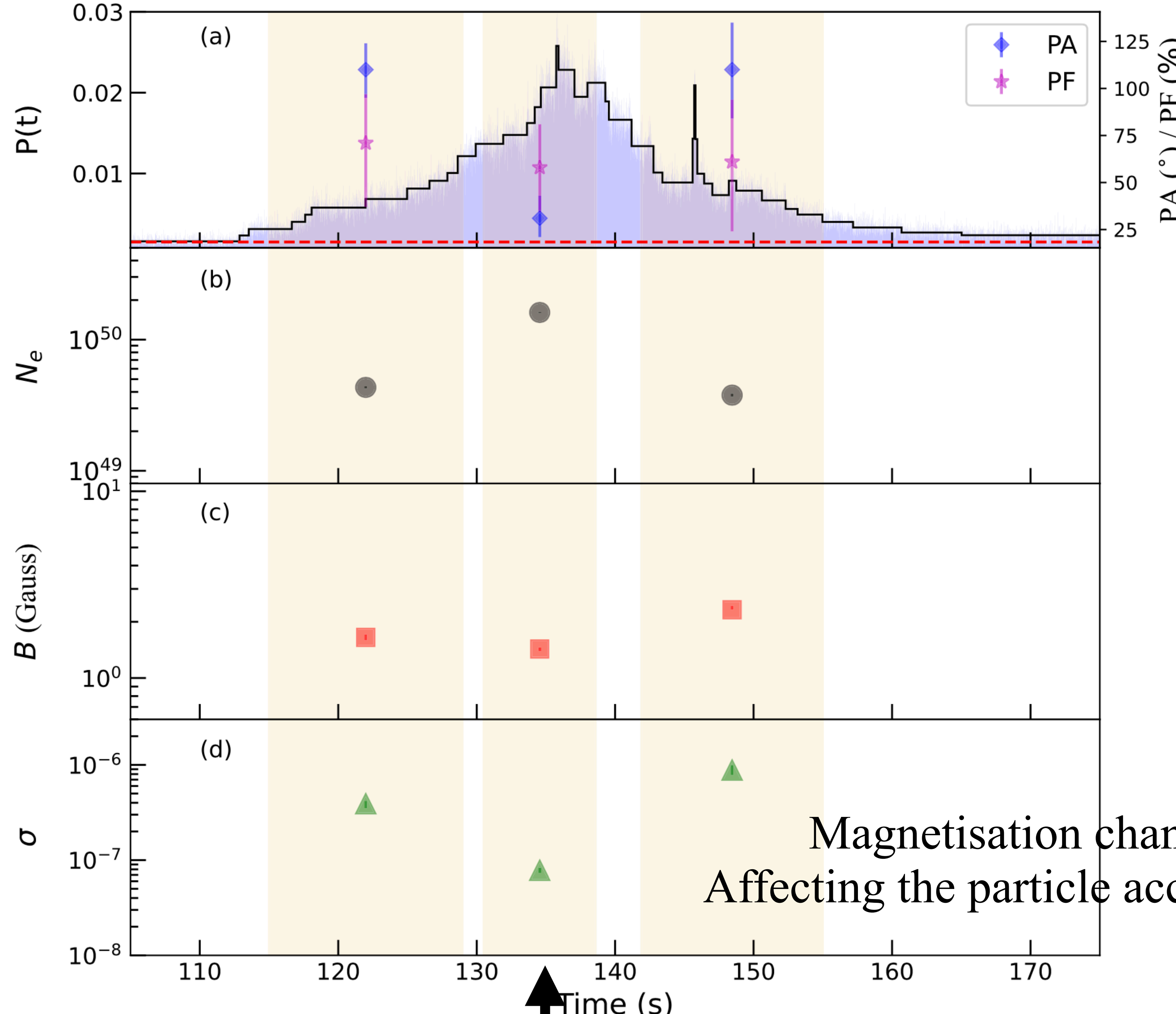
Assuming $\Gamma = 300$

Radiating number of particles

Magnetic field strength
in the down stream

Magnetisation

$$\sigma = B'^2/4\pi\Gamma n' m_p c^2$$

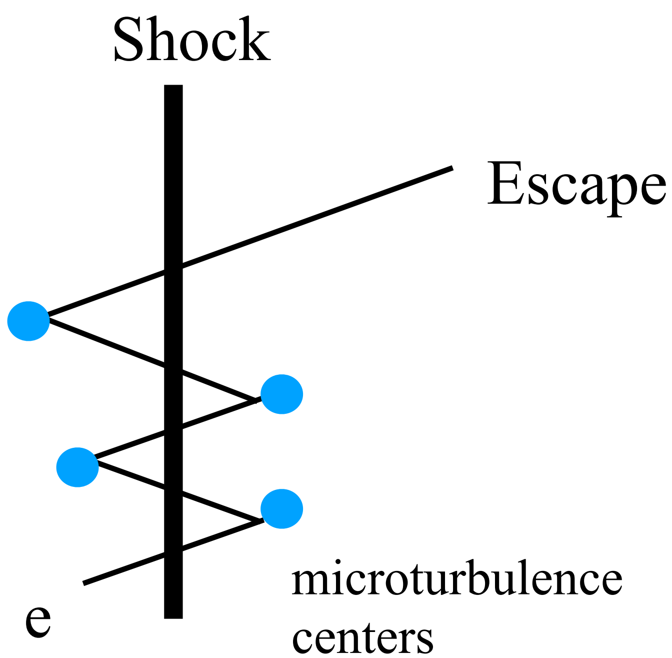


Magnetisation changes
Affecting the particle acceleration

Particle acceleration
Change in polarisation angle

We find that the magnetisation changes affecting the particle acceleration

Fermi acceleration
Collisionless shock
Microturbulence centers



Microturbulence centers cannot form if the magnetisation is above a critical value (Lemoine & Pelletier 10, Pelletier+17, Plotnikov+18)

The critical value of the magnetisation for the onset of Fermi acceleration, σ_c

$\sigma_c \sim 0.1\ \Gamma_r^{-2} = 10^{-5}\ (\Gamma/100)^{-2}$

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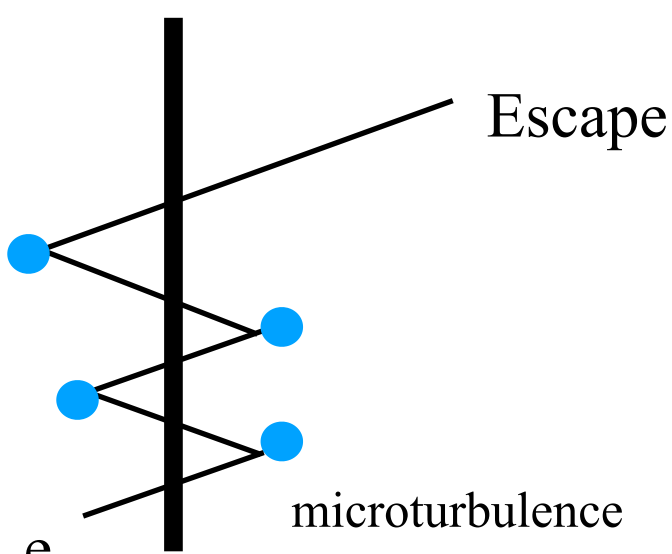

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The critical value of the magnetisation for the onset of Fermi acceleration, σ_c

$\sigma_c \sim 0.1\ \Gamma_r^{-2} = 10^{-5}\ (\Gamma/100)^{-2}$

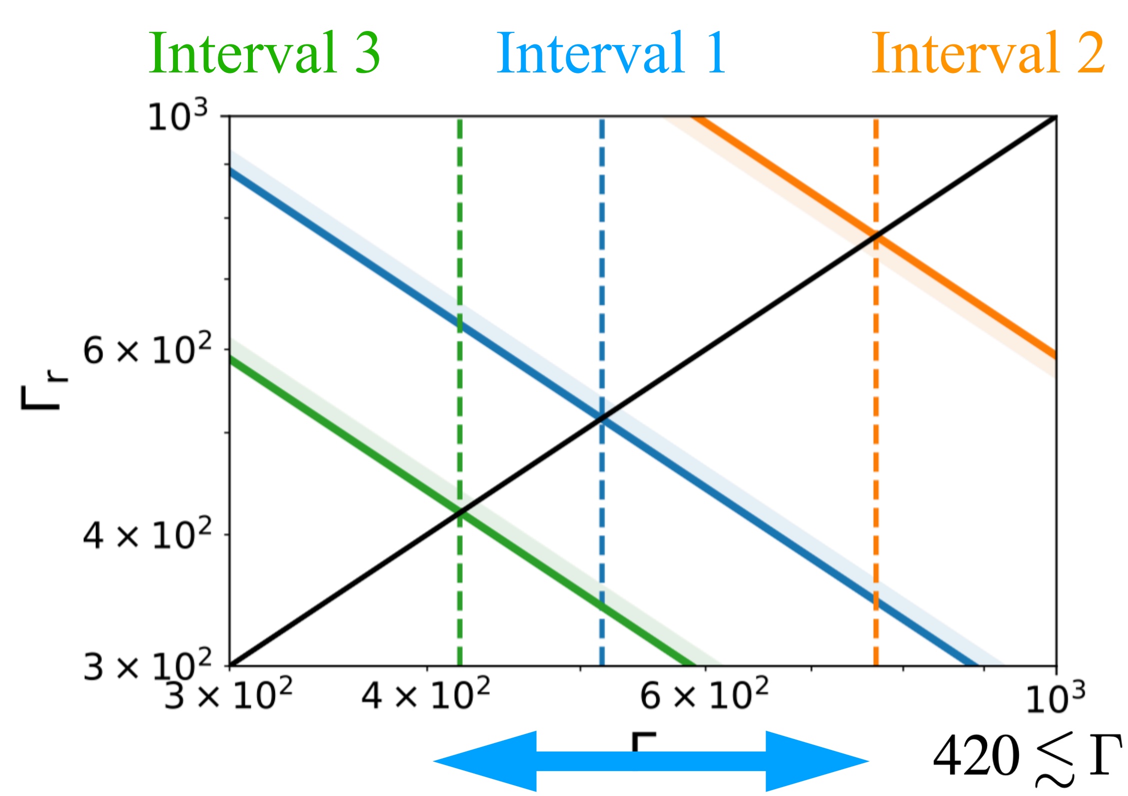
Did the magnetisation pass the critical value in GRB160821A? (see Lemoine & Pelletier 11)

Γ is a priori unknown:

Measured σ depends on assumed Γ

Critical σ_c depends on assumed Γ

Find the range of Lorentz factors that satisfy the requirement



$420 \lesssim \Gamma \lesssim 770$

Conclusions

Need to identify emission mechanism!

1. Both photospheric and optically-thin synchrotron emission is observed during the prompt phase

2. Synchrotron emission is clearly identified in GRB160821A

3. Onset of particle acceleration occurs during the prompt phase $\Gamma \sim 600$

4. Related to the magnetisation

5. Independent way to determine the bulk Lorentz factor Γ

6. Which plasma instabilities develop and dominate at large Lorentz factors, affecting particle acceleration? Confront theory with observations.