The origin of prompt emission in Gamma-Ray Bursts

recent findings and physical implications

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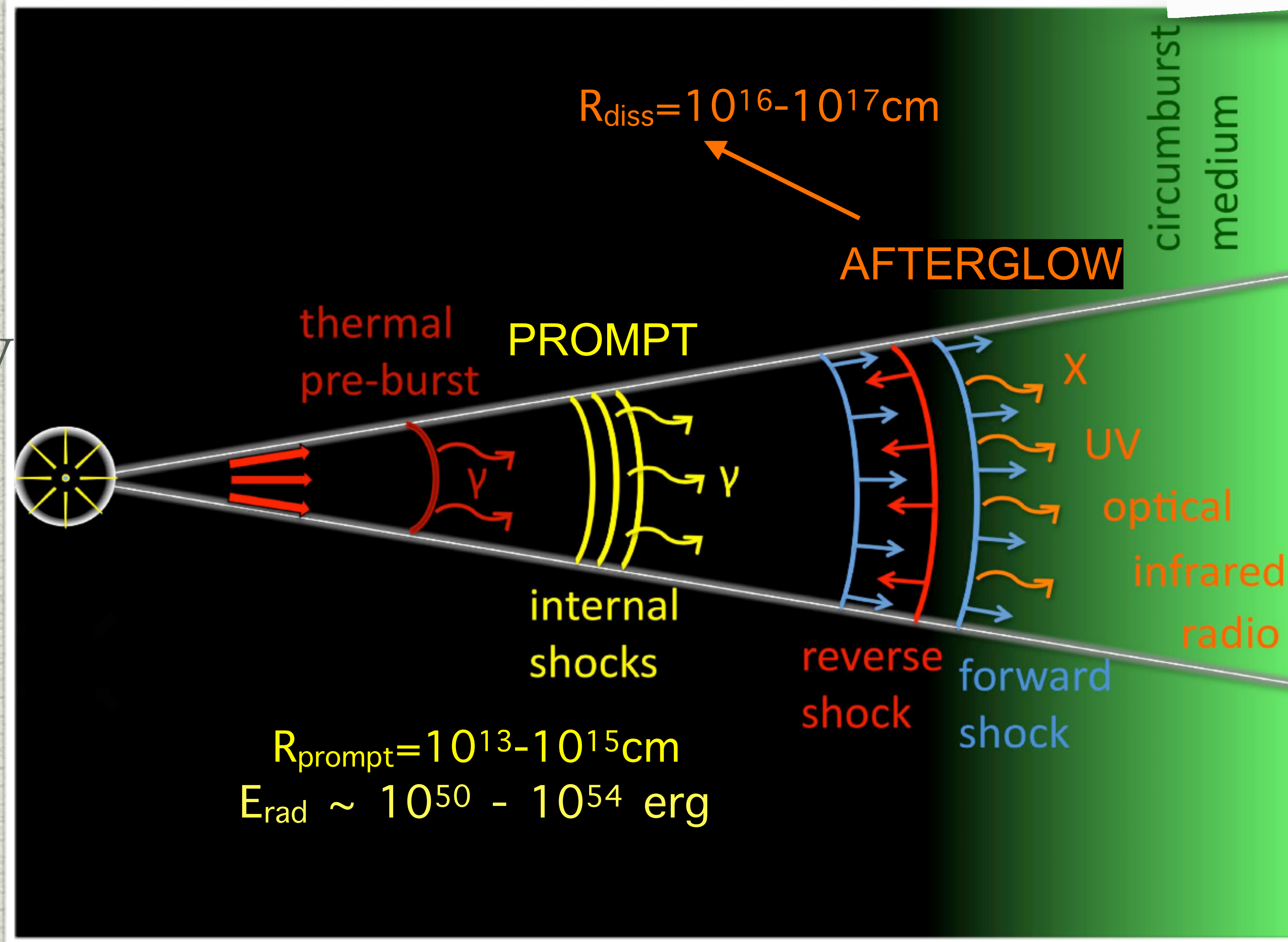
GRBs: the standard model

Bernardini's talk tomorrow

PROMPT

- 10 keV- 10 MeV
- < 1s to 10^3 s
- non-thermal spectra



AFTERGLOW

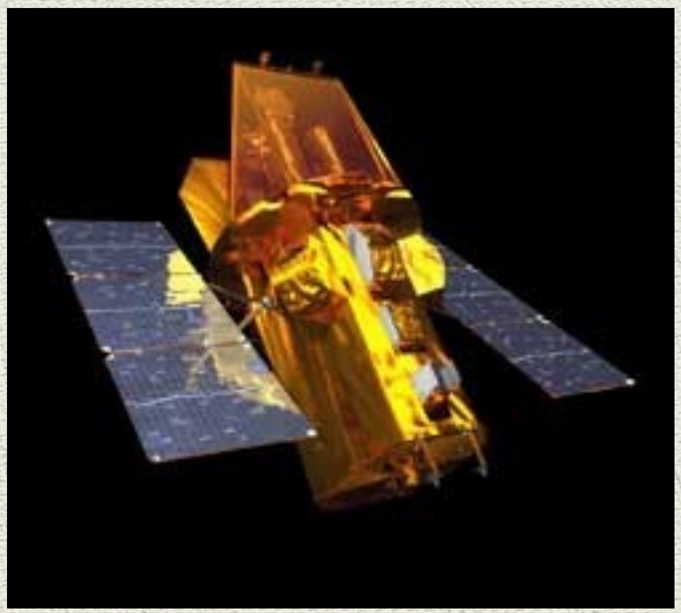
- softX, OT, radio
- weeks, months
- flux PL decay in time

Dar's talk tomorrow

Most important instruments for GRB prompt emission studies

CGRO/**BATSE**: prompt emission in the range 20 keV - 2 MeV from **2700** GRBs

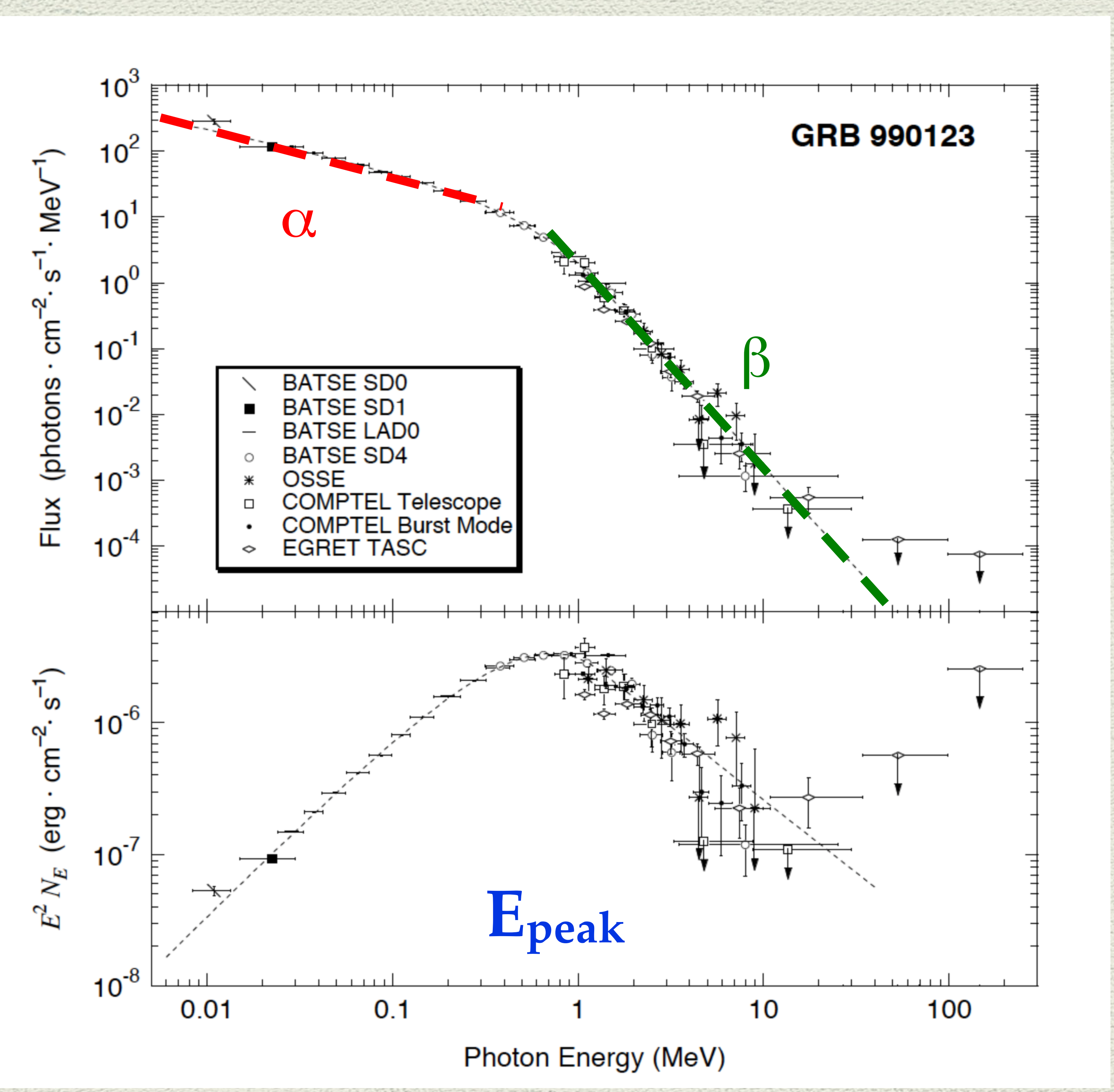
Fermi/**GBM**: prompt emission in the range 8 keV- 20 MeV from **2200** GRBs



The Neil Gehrels Swift Observatory

Swift/**BAT**: 15-150 keV from **1200** GRBs

The typical GRB prompt spectrum



Typical values

$\alpha \sim -1$

$\beta \sim -2.5$

$E_{peak} \sim$ few keV - few MeV

Prompt emission:
possible energy reservoirs

- **thermal** energy radiated at the photosphere (Mészáros & Rees 2000; Daigne & Mochkovitch 2002; Giannios & Spruit 2007; Pe'er 2008; Beloborodov 2010)

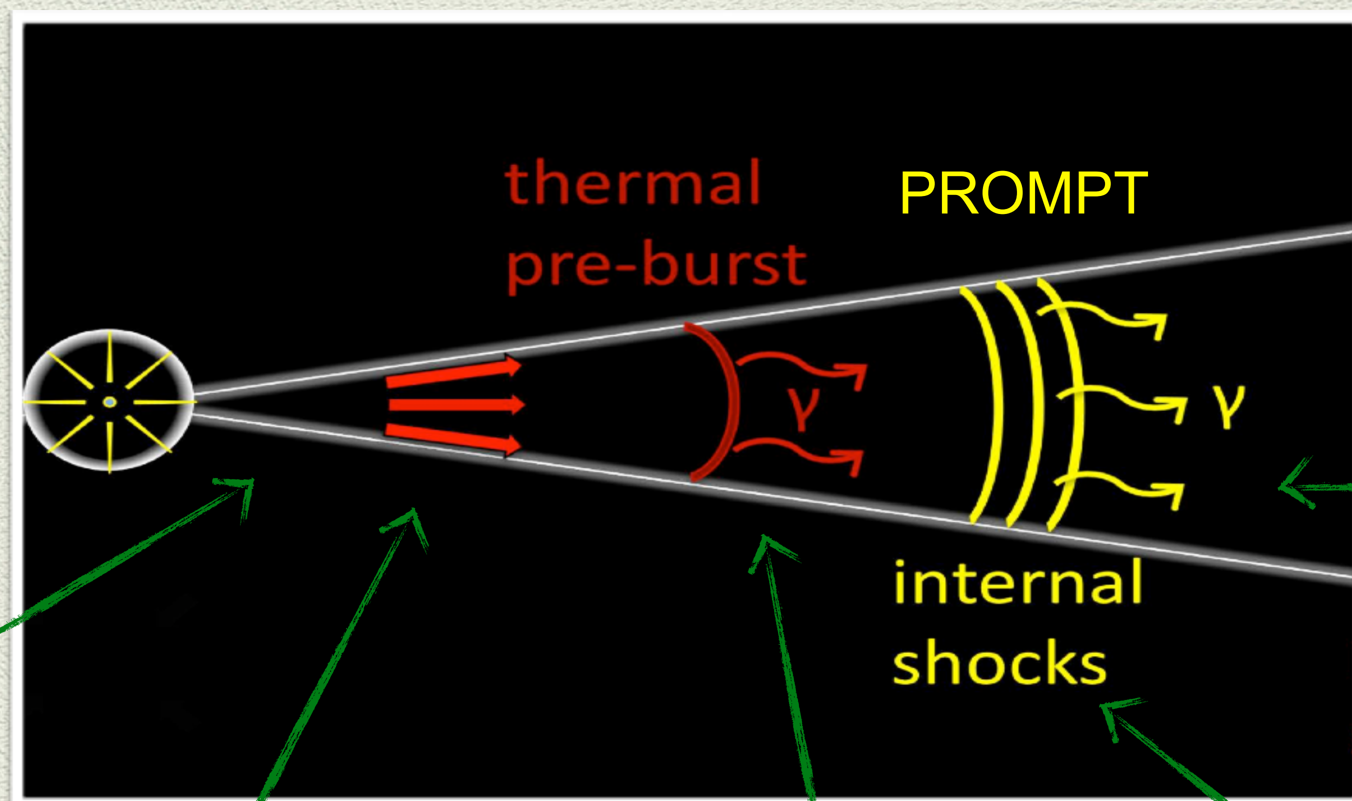
- **kinetic** energy that can be extracted by shock waves propagating within the outflow and then radiated by shock-accelerated electrons (internal shocks, Rees & Mészáros 1994; Kobayashi et al. 1997; Daigne & Mochkovitch 1998)

- **magnetic** energy that can be dissipated via the reconnection of field lines and then radiated by shock-accelerated electrons (Thompson 1994; Meszaros & Rees 1997; Spruit et al. 2001; Drenkhahn & Spruit 2002; Lyutikov & Blandford 2003; Giannios & Spruit 2005)

Prompt emission:

standard model

- **kinetic** energy



energy is initially in radiation

gradually transformed into kinetic

photosphere: a fraction of the thermal can be radiated away

at larger radii: shocks dissipate kinetic energy into internal energy

accelerated electrons radiate synchrotron

Prompt emission: processed thermal photons

- **thermal** energy radiated at the photosphere

nearly thermal seed photons

+

energetic electrons

photons undergo multiple scatterings with more energetic electrons and increase their energy

Prompt emission:

magnetic models

- **magnetic** outflow (Poynting-flux-dominated).

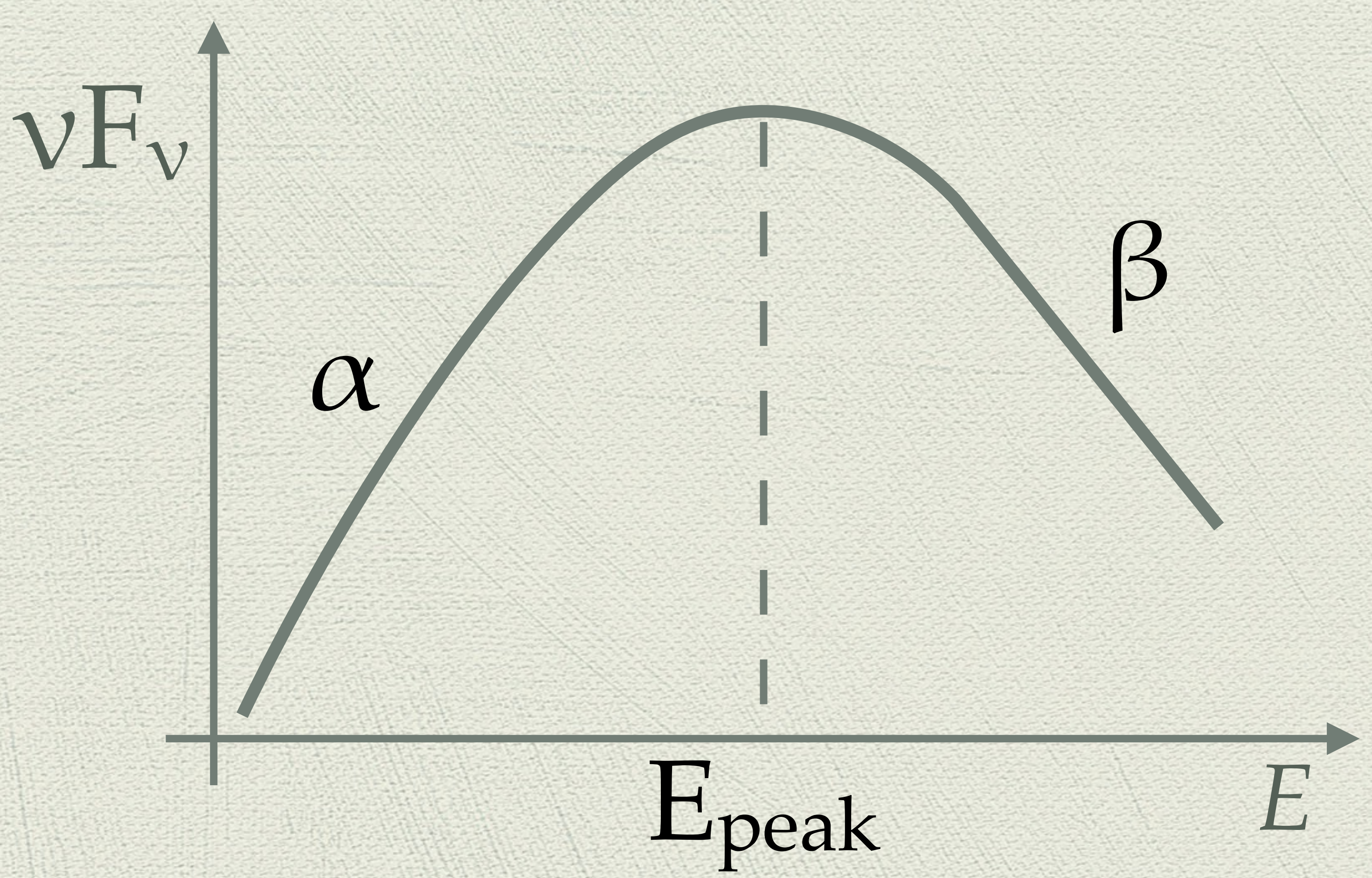
ICMART model Zhang and Yan (2011)
multiple internal collisions can entangle magnetic field and trigger reconnection events, converting a fraction of magnetic energy to radiation. Rapid variability can be produced even if $R>10^{15}$cm

Prompt emission observations

Inconsistency
with synchrotron radiation:
the alpha problem

Typical prompt spectral shape and fitting models

Typical GRB prompt spectrum

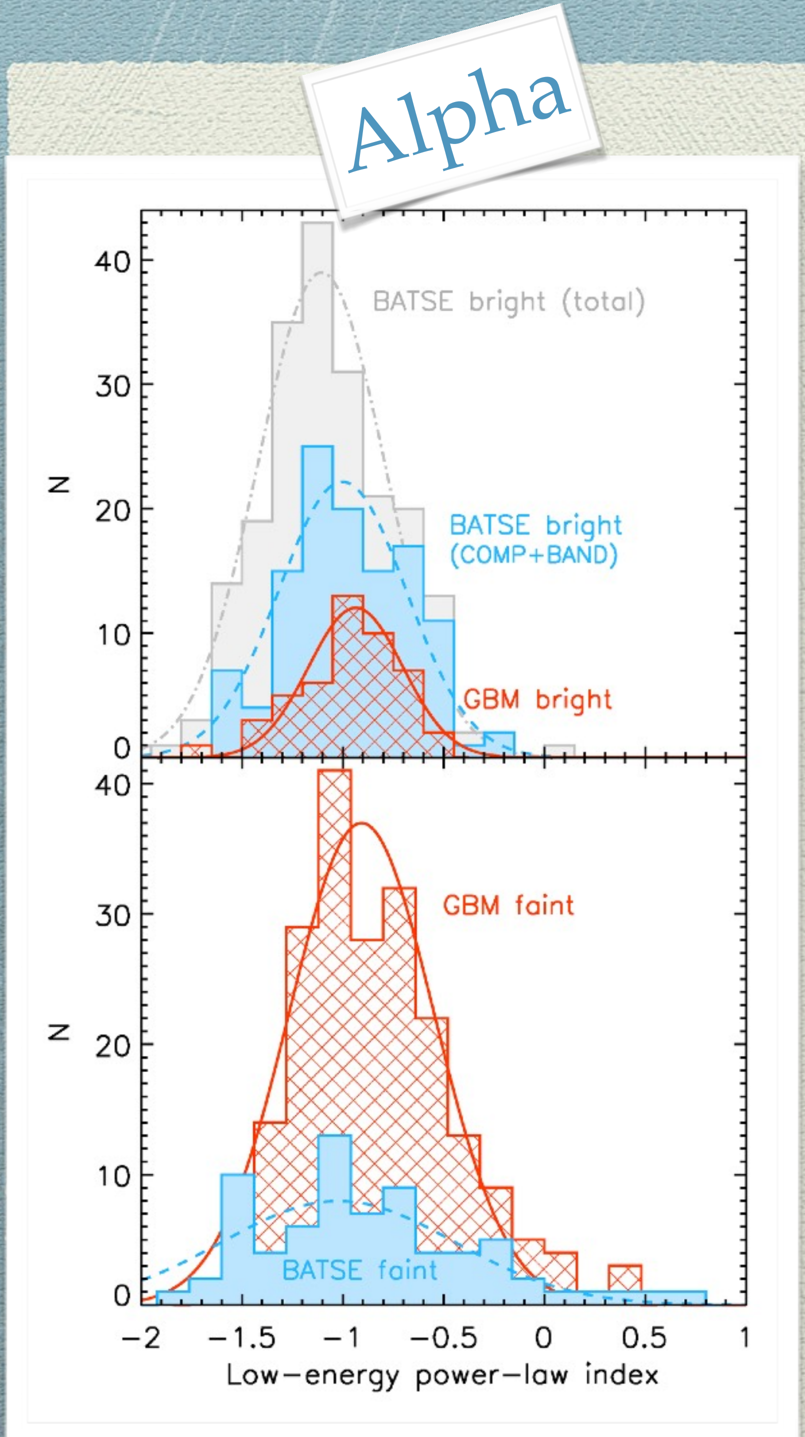


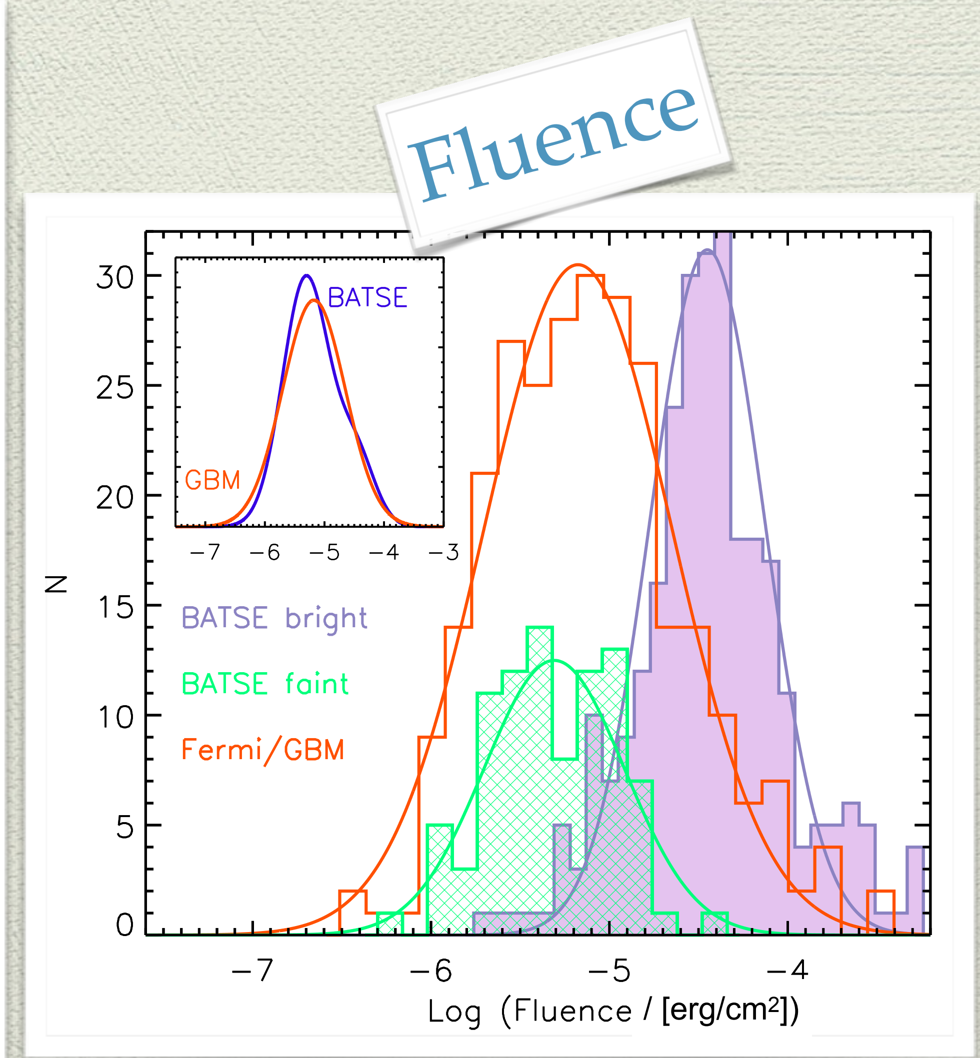
Fitting models

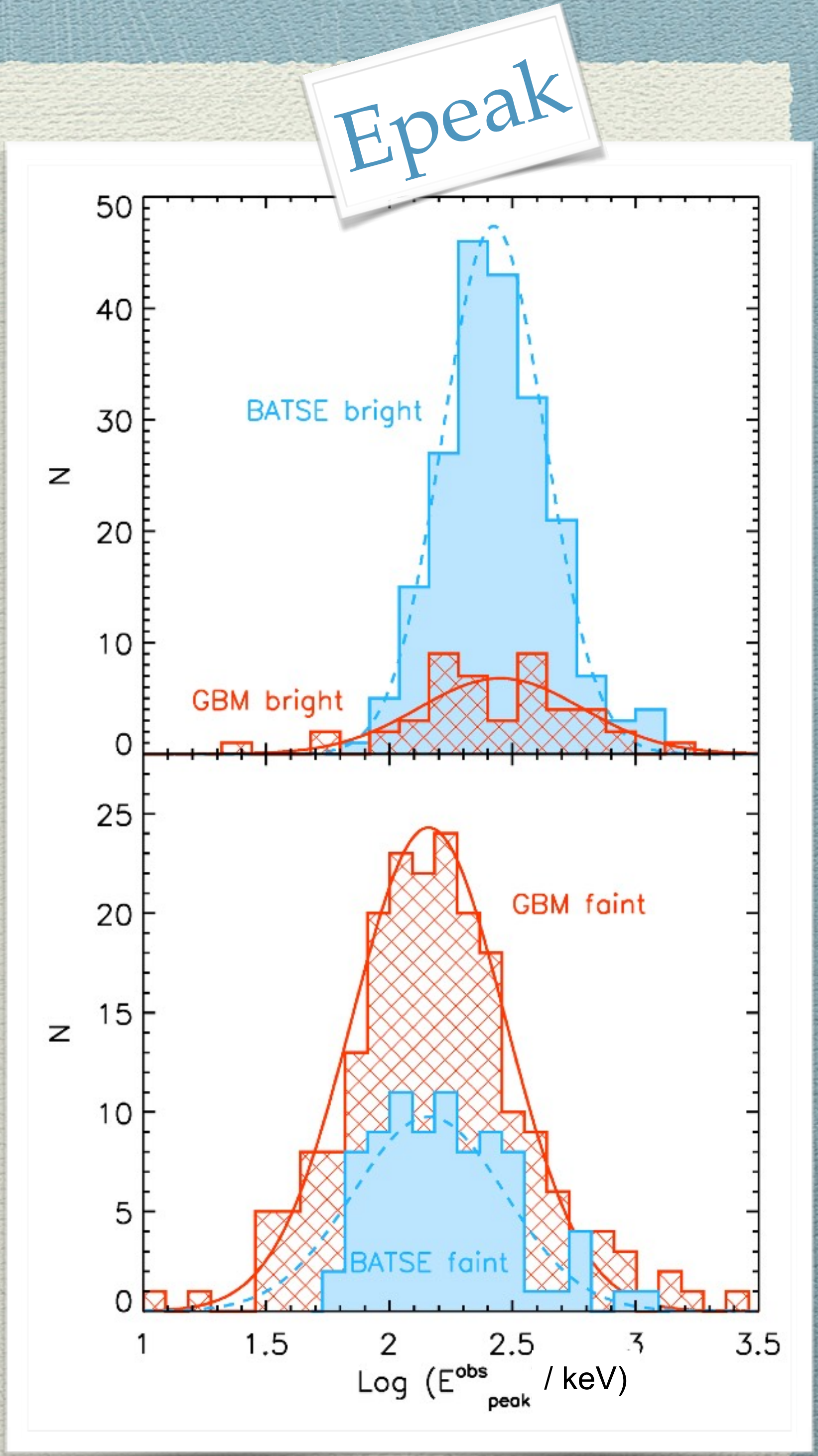
Standard models include the following **empirical** functions:

- Band model
- Smoothly broken PL
- CPL
- PL

The phenomenological picture

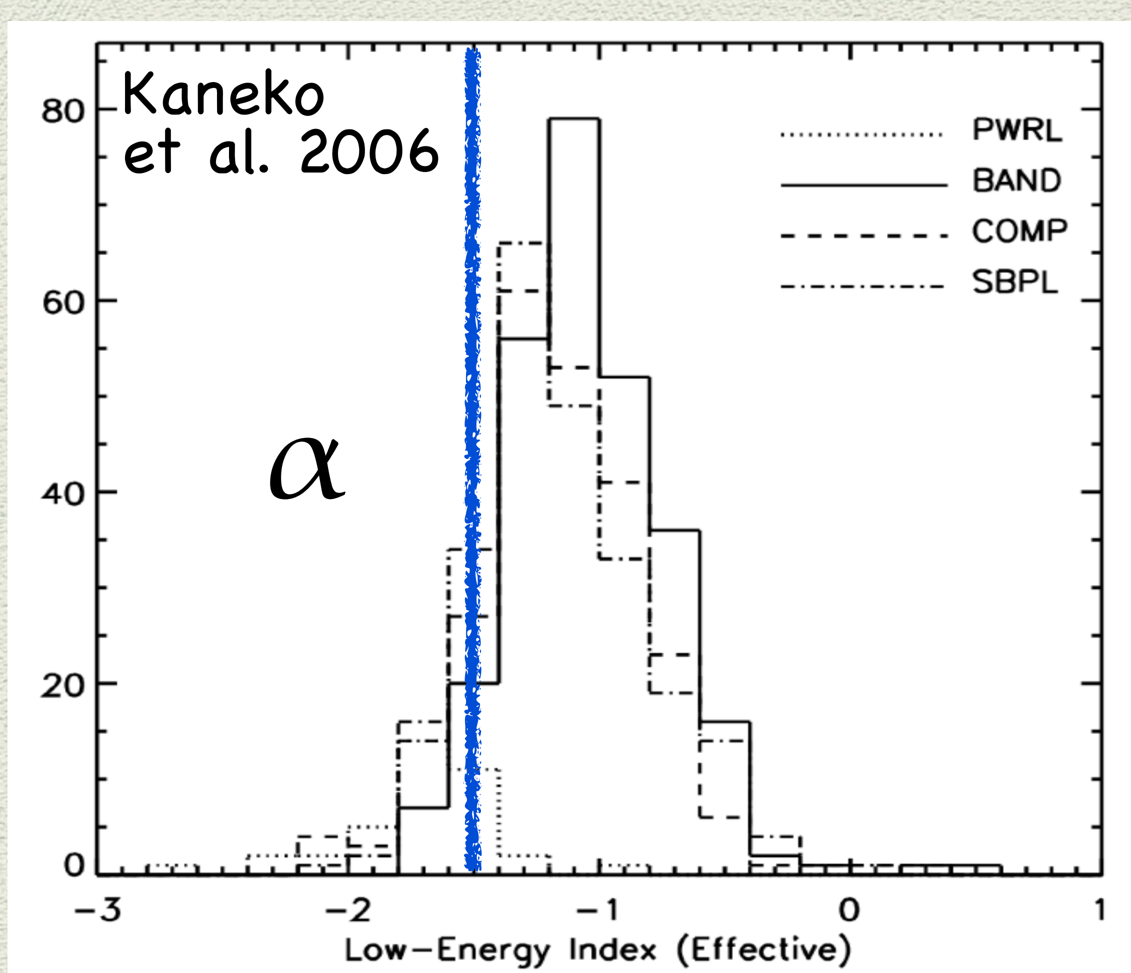




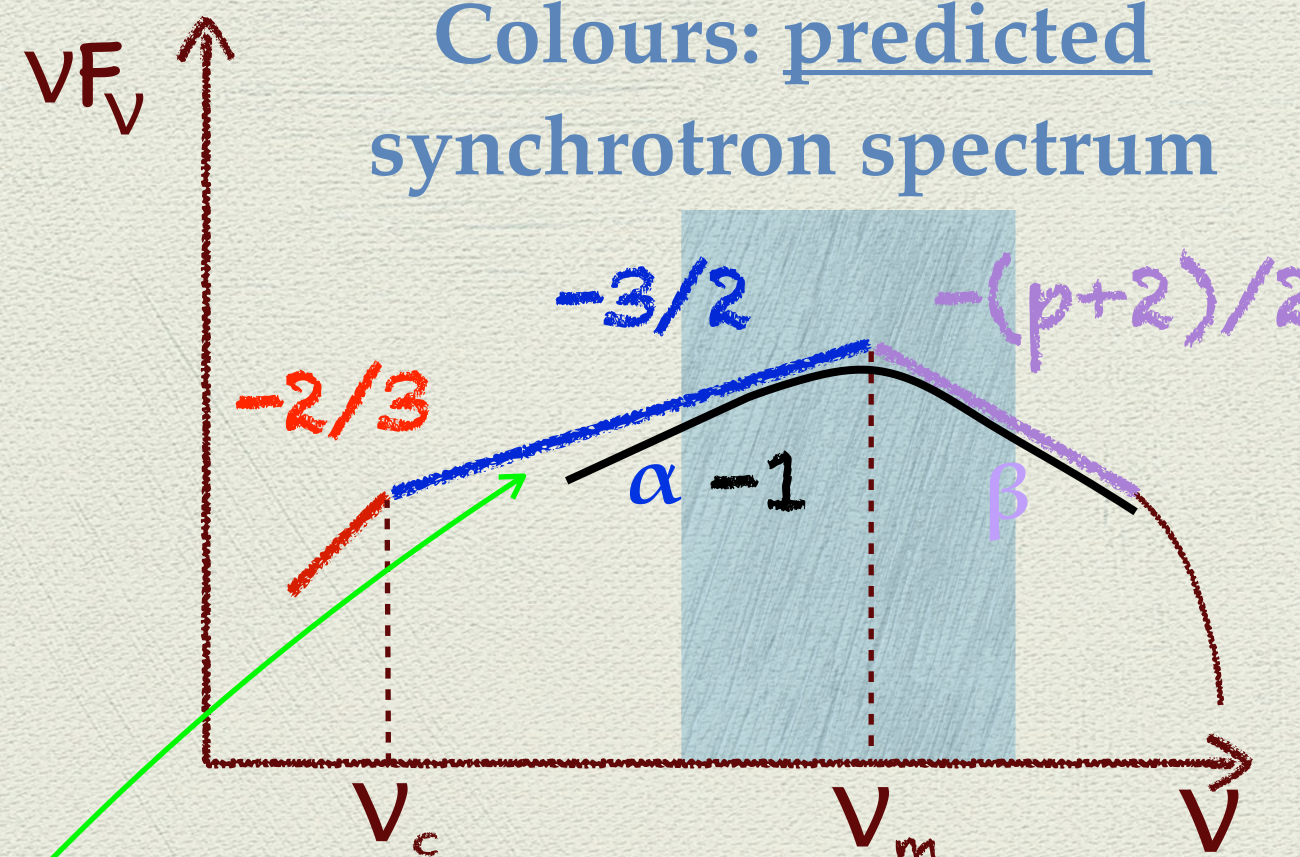


Nava et al., 2011

Inconsistency with synchrotron interpretation



Preece at al. 1998



Colours: predicted synchrotron spectrum

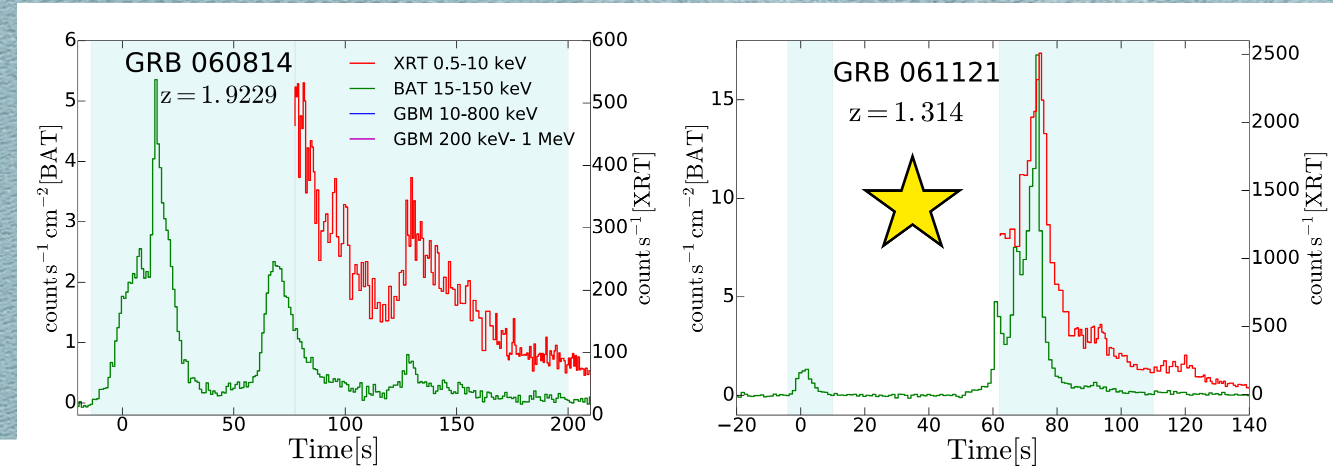
Black: typical observed prompt spectrum

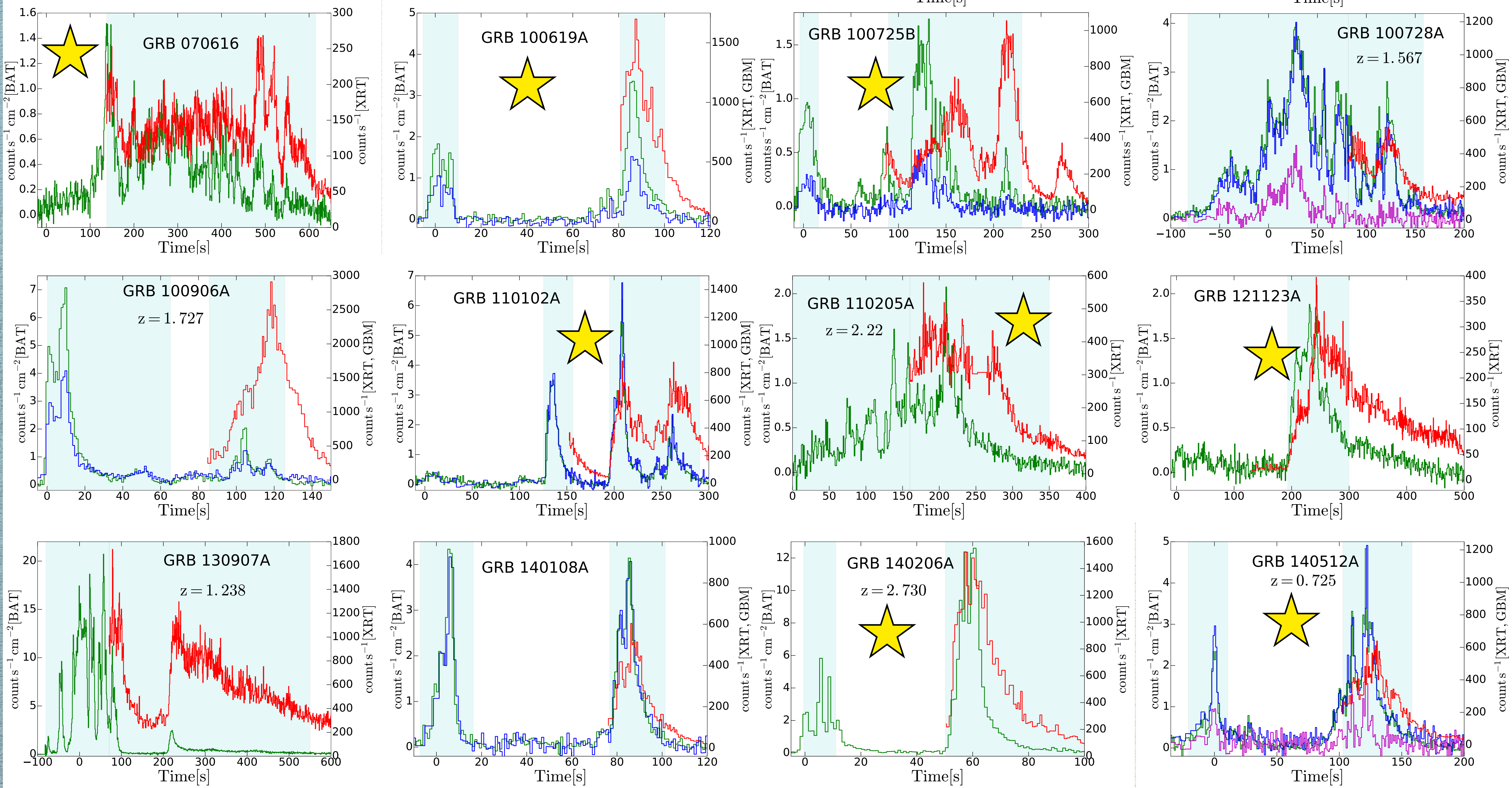
Problem is at low energies: let's look at XRT prompt data

Recent progresses

Light curves

red = XRT **blue = GBM/NaI**
green = BAT **purple = GBM/BGO**





Oganesyan, Nava, Ghirlanda, Celotti, 2017, ApJ

The Sample

GRBs with BAT+XRT simultaneous observations of the prompt emission

We found **34 GRBs** with prompt BAT+XRT observations and large S/N to allow spectral analysis

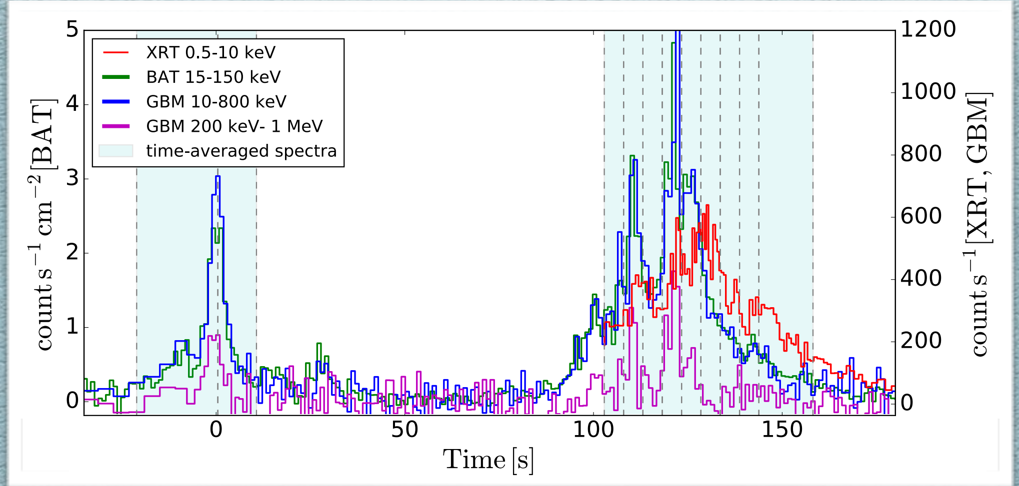
Results can be found in:

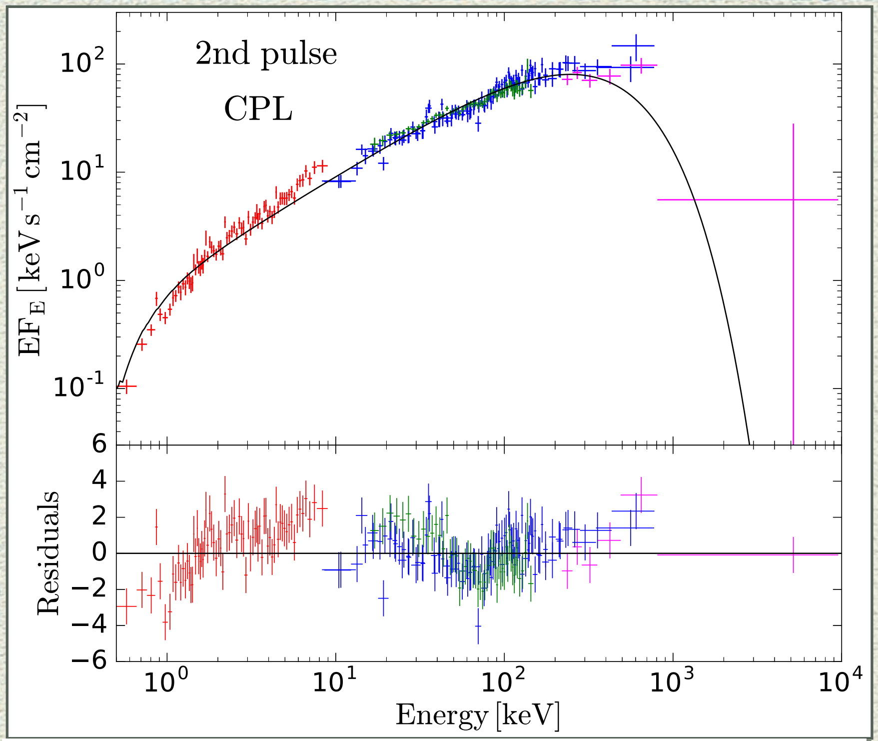
Oganesyan's talk tomorrow

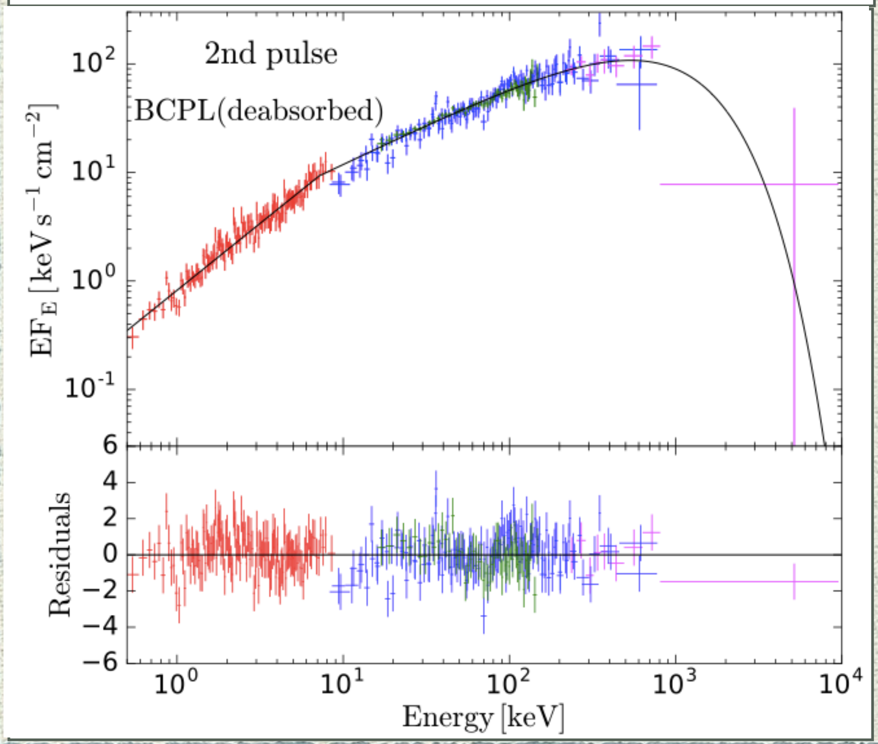
1. 14 are bright enough to allow time-resolved analysis
   Oganesyan, Nava, Ghirlanda, Celotti, 2017, ApJ

2. additional 20: only time-integrated analysis
   Oganesyan, Nava, Ghirlanda, Celotti, in press, arXiv:1710.09383

Example of spectral fit including XRT data GRB 140512A







CPL (Cutoff PL) model:

$\chi^2_{red} = 1.28$ (d.o.f. = 480)

> 8σ improvement

CPL + break at low energy:

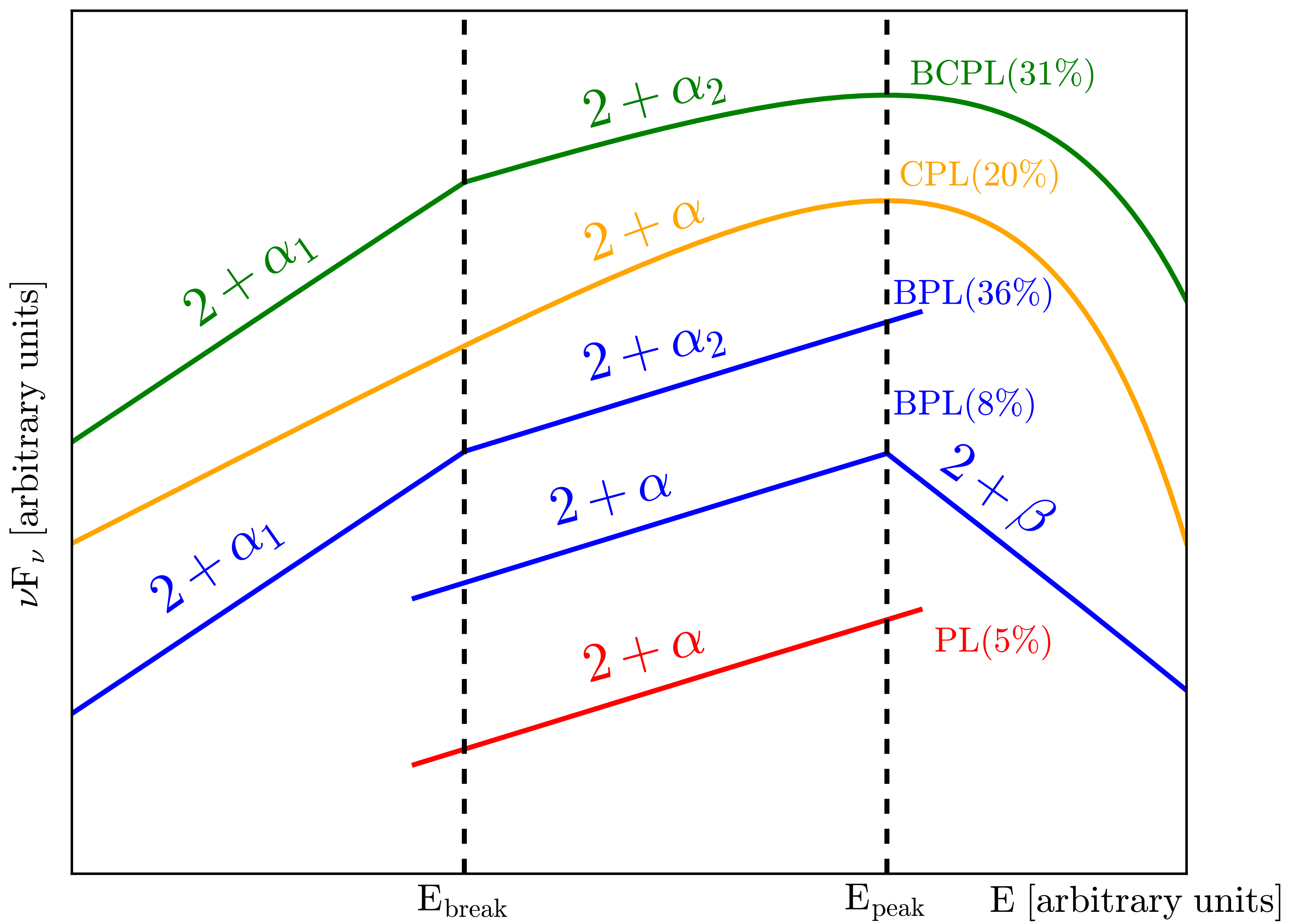
$\chi^2_{red} = 0.93$ (d.o.f. = 478)

$E_{break} = (7.2 \pm 1)$ keV

$E_{peak} = (532 \pm 150)$ keV

Spectral models

we fit all these models to all spectra in the sample



Spectral models

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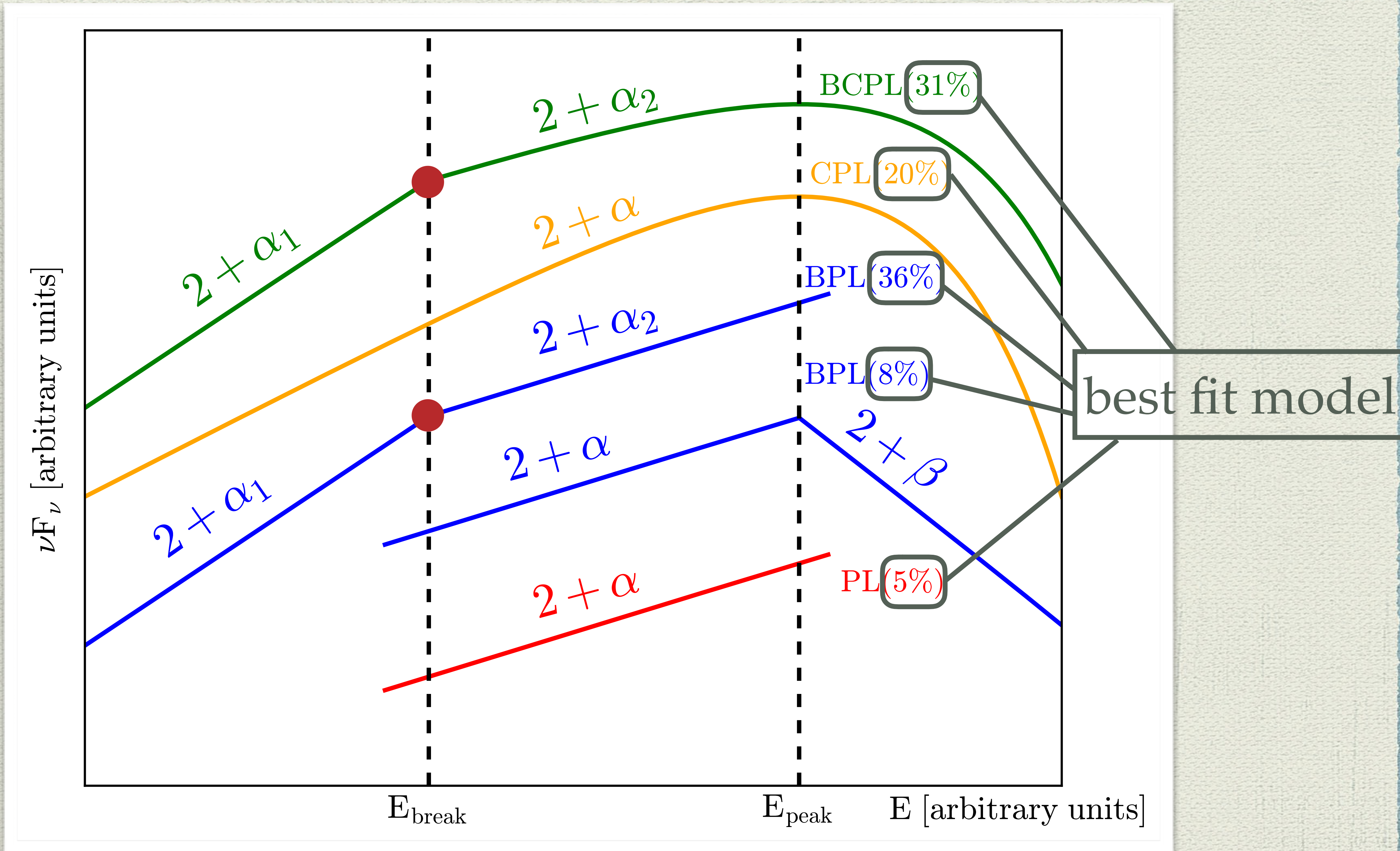
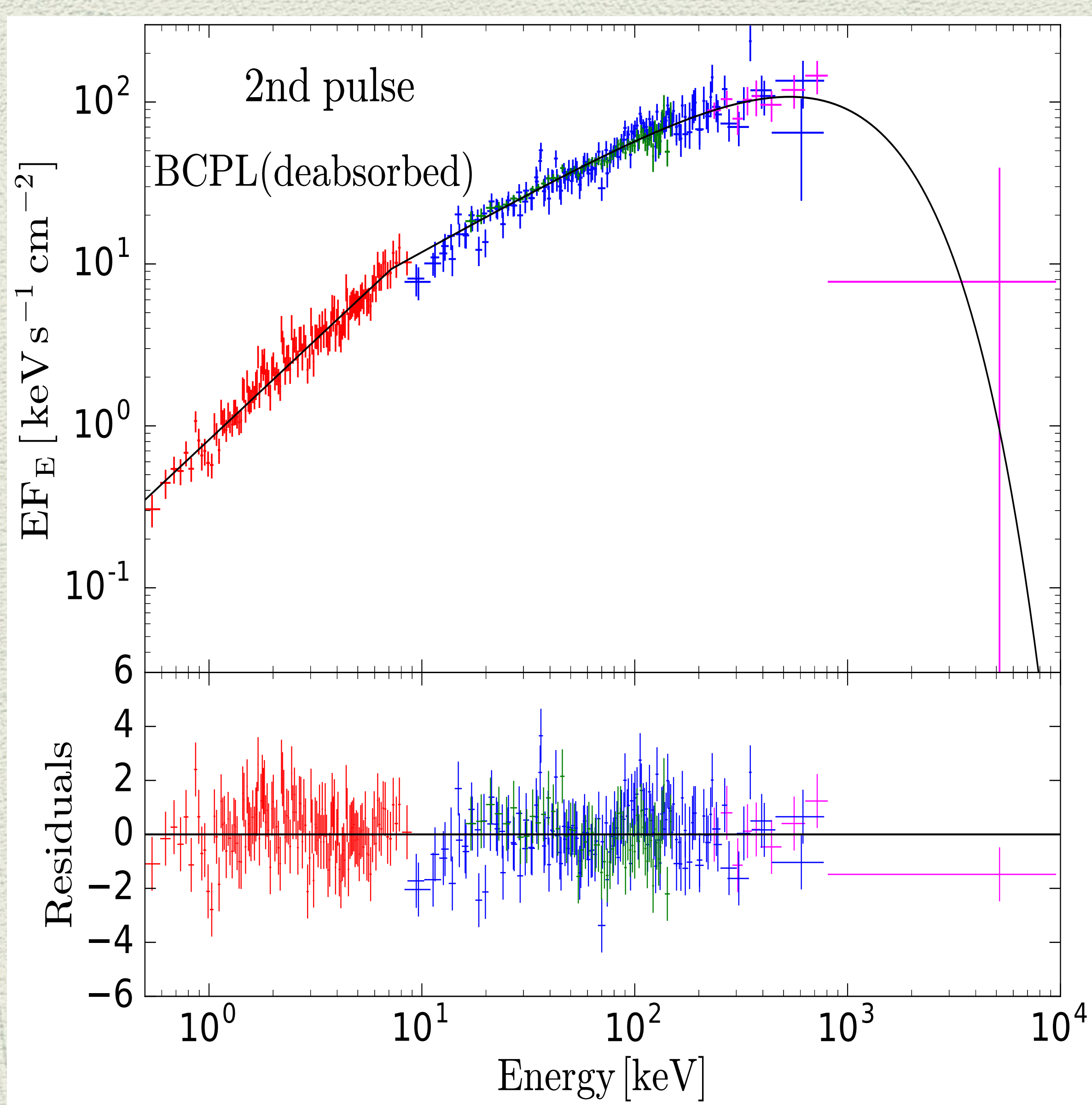
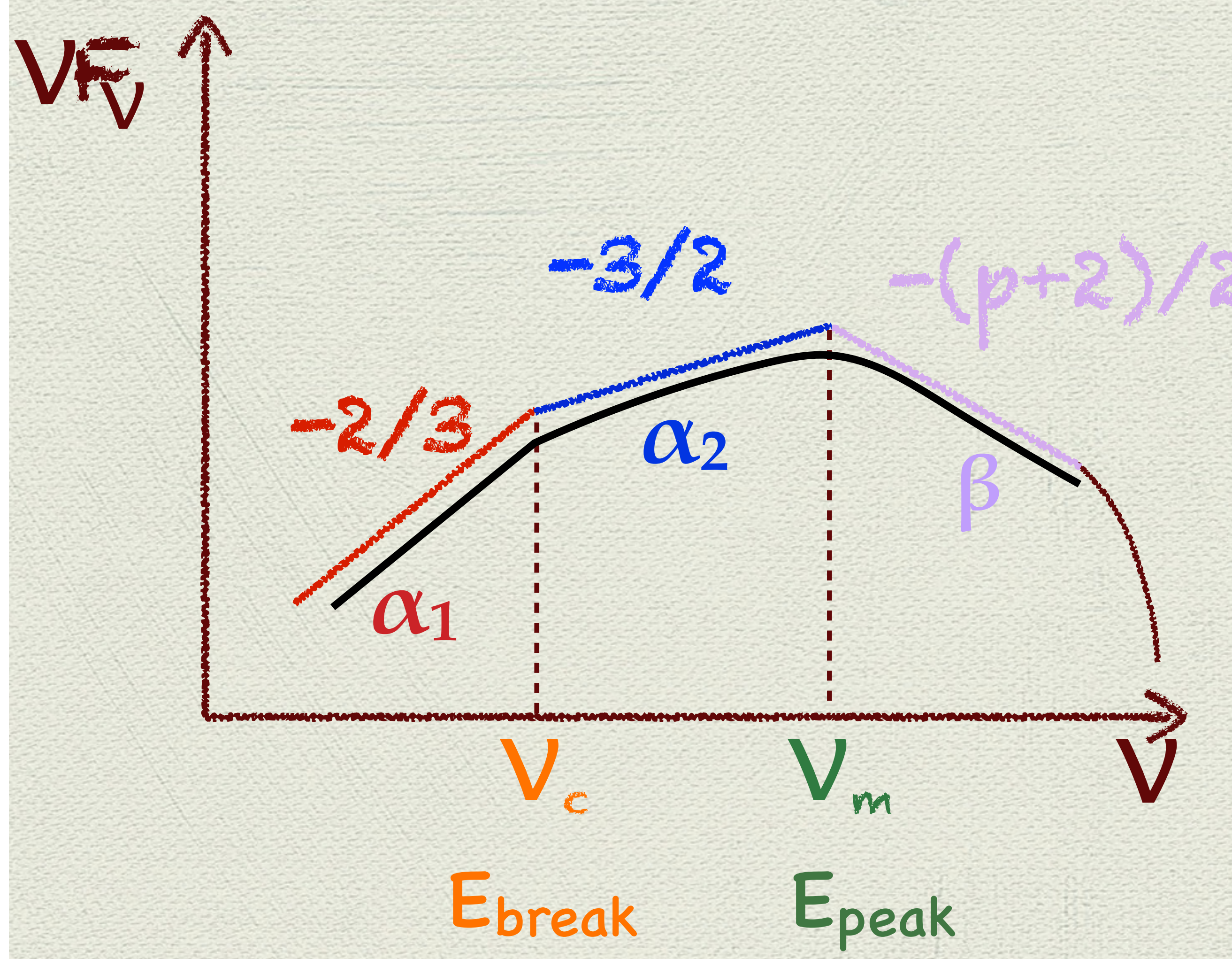


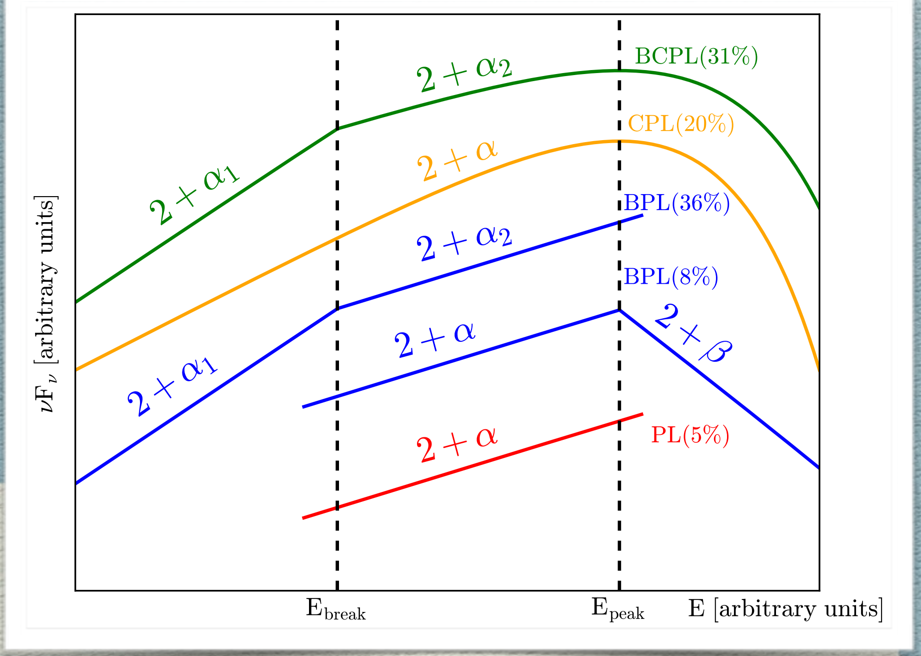
Comparison between observed spectral shape and synchrotron spectrum

Oganesyan, Nava, Ghirlanda, Celotti, 2017, ApJ

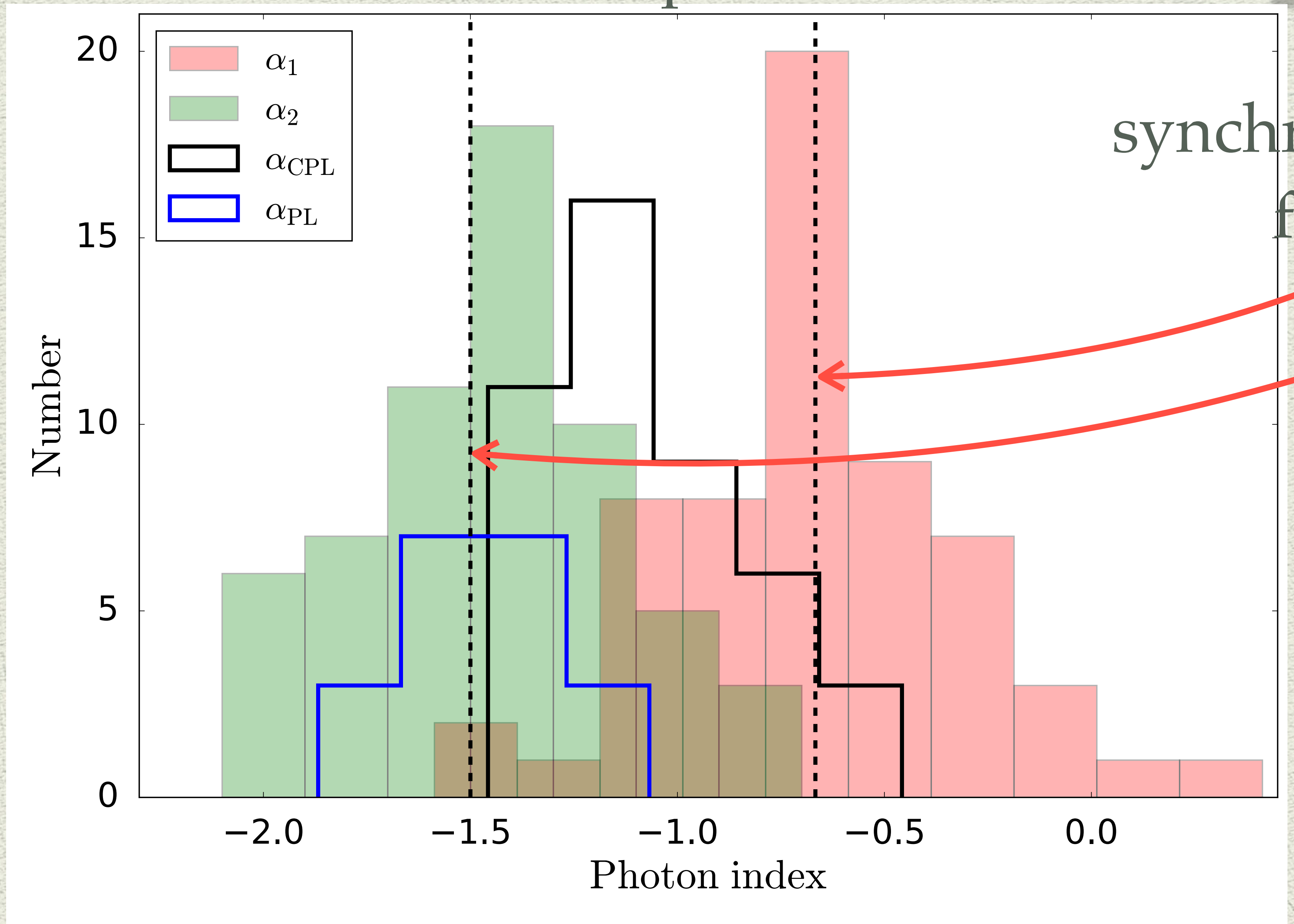




Spectral fit: full sample time resolved analysis



Distribution photon indices



synchrotron predictions for α_1 and α_2

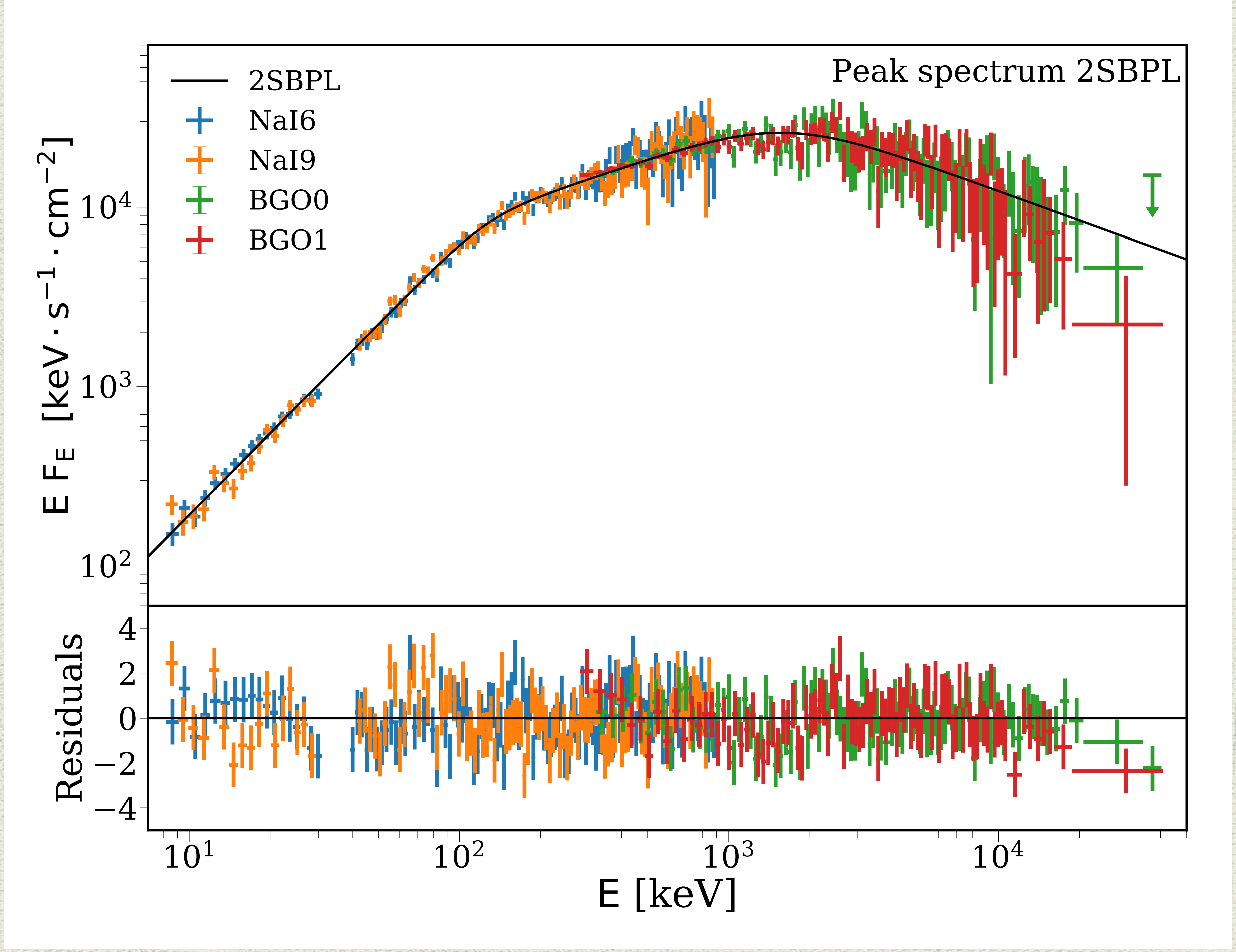
Oganesyan, Nava, Ghirlanda, Celotti, 2017, ApJ

Spectral low-energy breaks in *Fermi*/GBM GRBs

Spectral breaks in Fermi bursts?

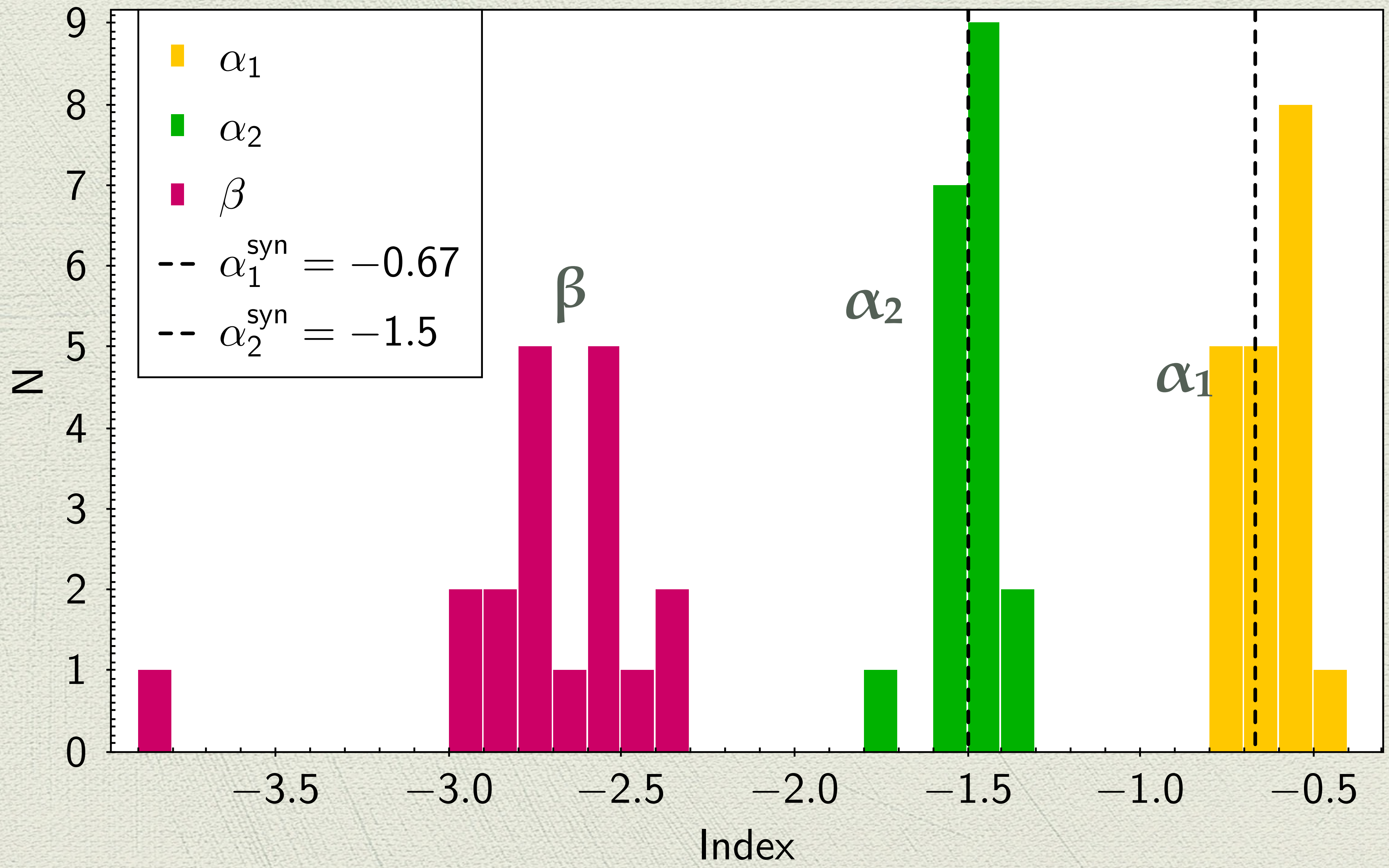
Ravasio,…, LN et al., 2018, A&A, 613A, 16

GRB 160625B



GBM GRB 160625B
time-resolved analysis

Photon indices



Ravasio,…, LN et al., 2018, A&A, 613A, 16

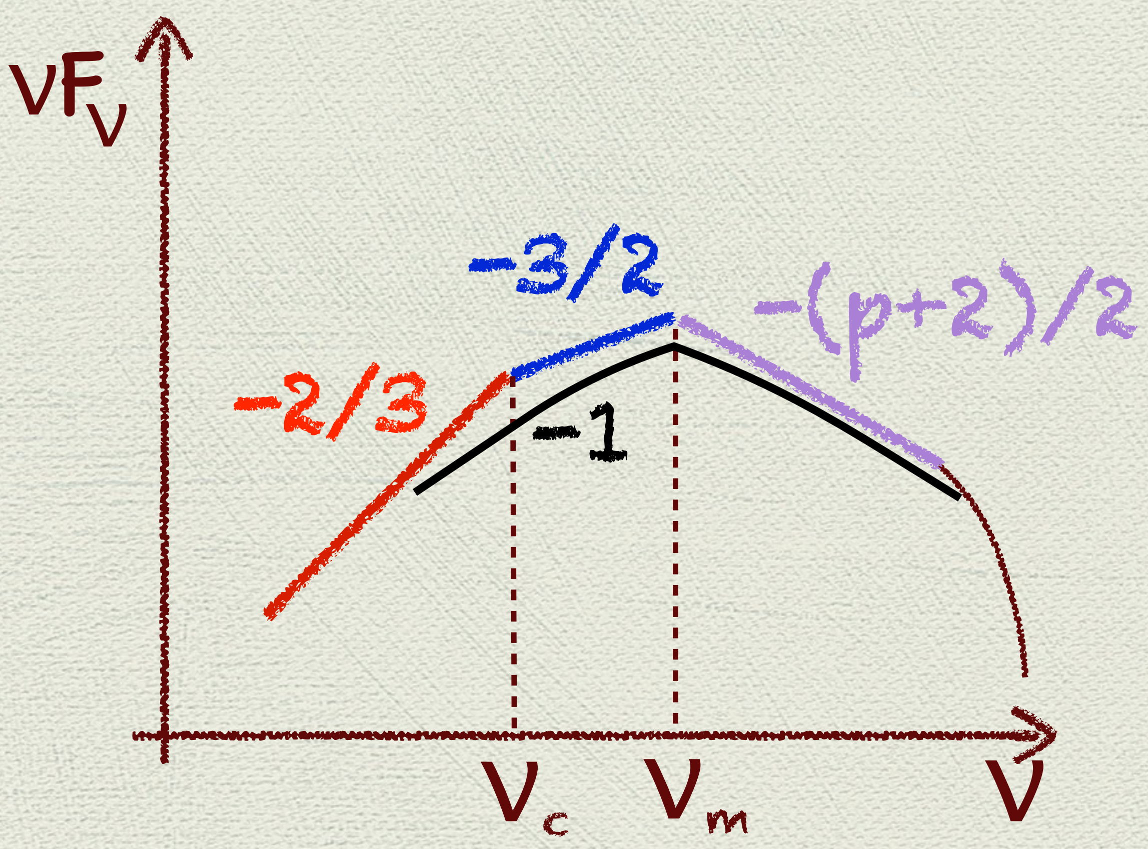
More on low-energy spectral breaks in Fermi/GBM GRBs

A spectral analysis of the **10 brightest long GBM** GRBs is in progress. Preliminary results show that **most of them** require a fitting model including a break (15-100 keV) and an additional, hard power-law below the break

Ravasio et al., 2018, in preparation

Chand's talk tomorrow

Are we observing synchrotron radiation in moderately fast cooling regime?



This situation has been already considered by
theoretical models
moderately fast cooling regime
first invoked to explain
spectra as hard as -2/3:

$\nu_c \sim \nu_m$

Derishev 2007
Kumar & McMahon 2008
Daigne et al. 2011
Beniamini & Piran 2013,2014
Uhm & Zhang 2014

Are we observing synchrotron radiation in moderately fast cooling regime?

R

Γ (bulk motion)

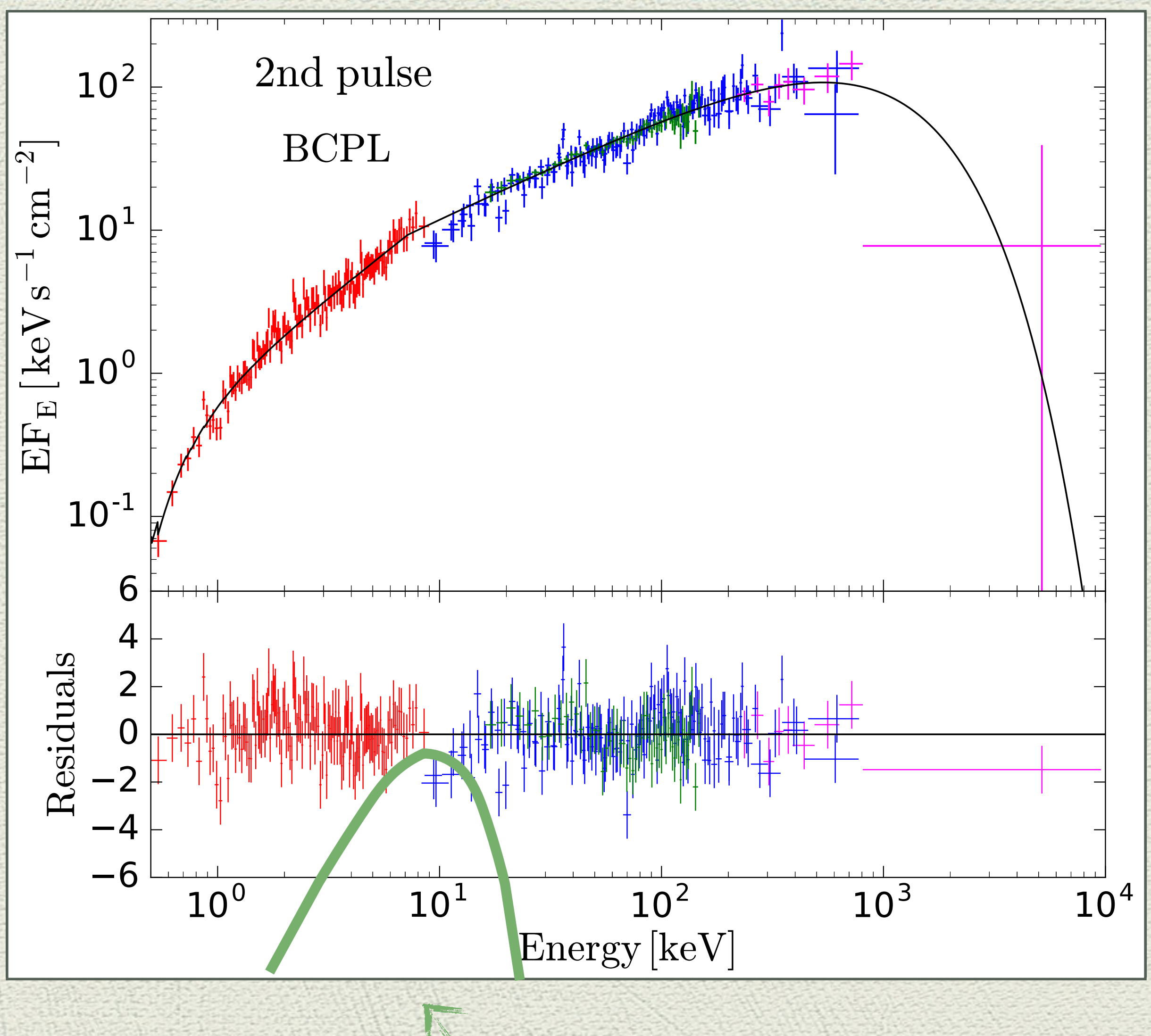
N, γ (electrons) + $\nu_c \sim \nu_m$ $\Rightarrow$

B (magnetic field)

large **R**~10^{16}cm
small **B'**~10-100 G
large **Γ** > 500
large $\gamma_m > 10^{4-5}$

Derishev 2007
Kumar & McMahon 2008
Daigne et al. 2011
Beniamini & Piran 2013,2014
Uhm & Zhang 2014

Breaks or BB components?



Page et al., 2011
Starling et al 2011, 2012
Guiriec et al. 2011, 2015,2016, 2017;
Axelsson et al. 2012
Peng et al., 2014
Valan et al., 2018

Thermal component

Breaks or BB components?

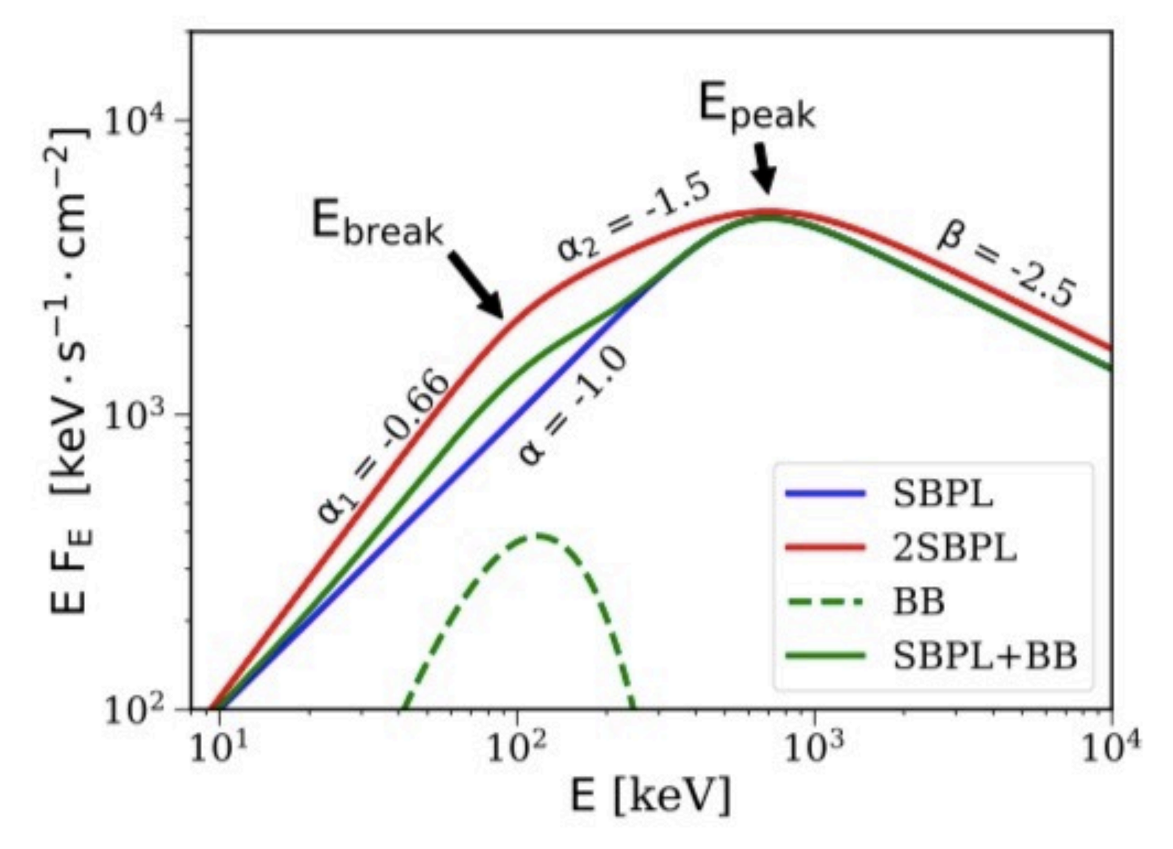
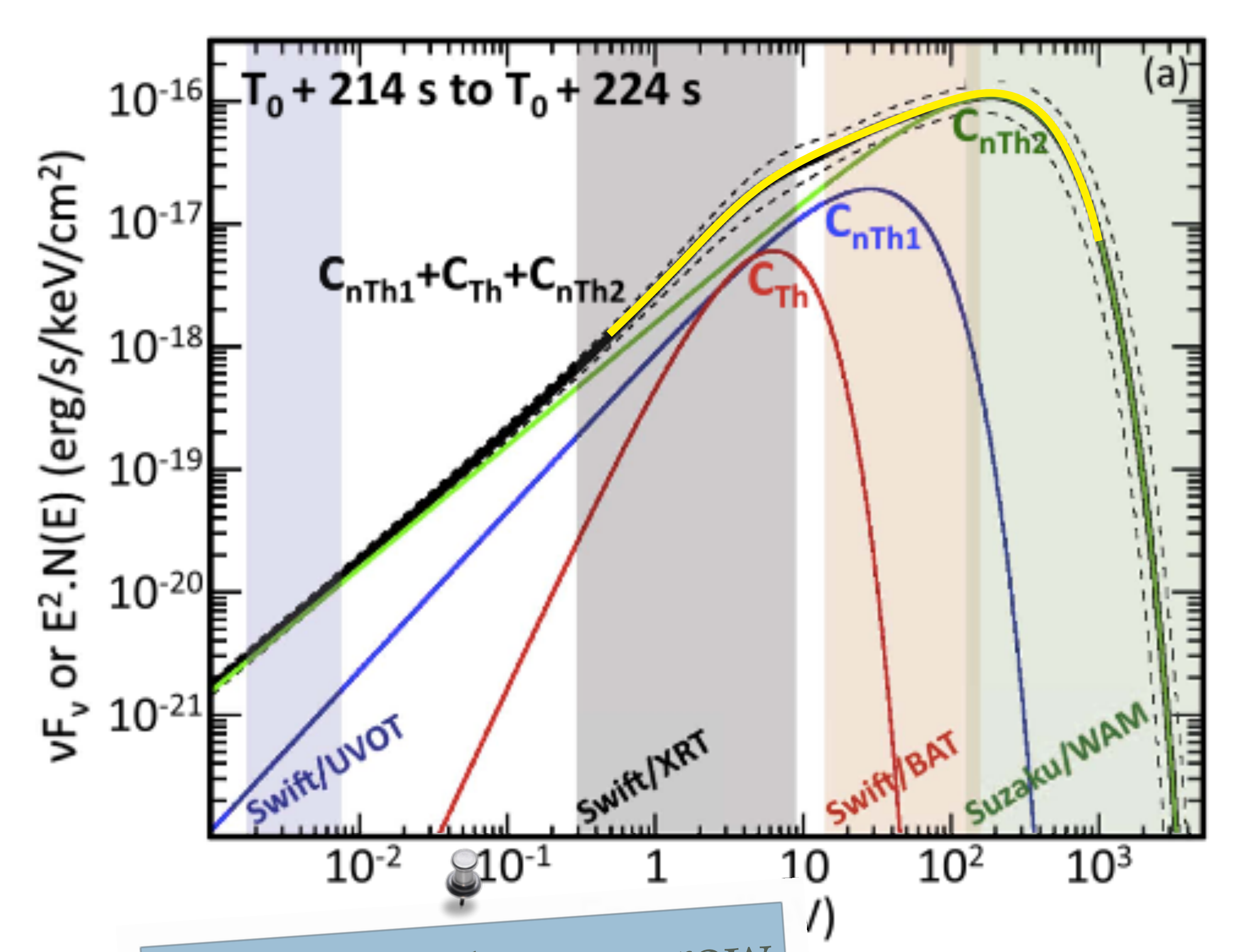


Fig. 2. Comparison between the SBPL model (blue curve), SBPL+BB (green solid curve), and 2SBPL (red curve). Normalizations are arbitrary.



Guiriec's talk tomorrow

Ravasio,…, LN et al., 2018, A&A, 613A, 16

Guiriec et al., 2016 GRB 110205A

Summary

- Band model not sufficient to properly characterize prompt emission spectra [Guiriec + 11,13,15,16,17] [Burgess+14] [Yu + 2015]
- inclusion of third power-law segment at low energies (<1-100 keV) often improves the fit [Oganesyan+ 17,18] [Ravasio+17]
- the photon indices are consistent with expectations from synchrotron radiation [Oganesyan+ 17,18] [Ravasio+17]
- within a synchrotron interpretation: moderately fast cooling implies relatively small magnetic fields and large radii