GRB prompt emission spectra in the keV-MeV range

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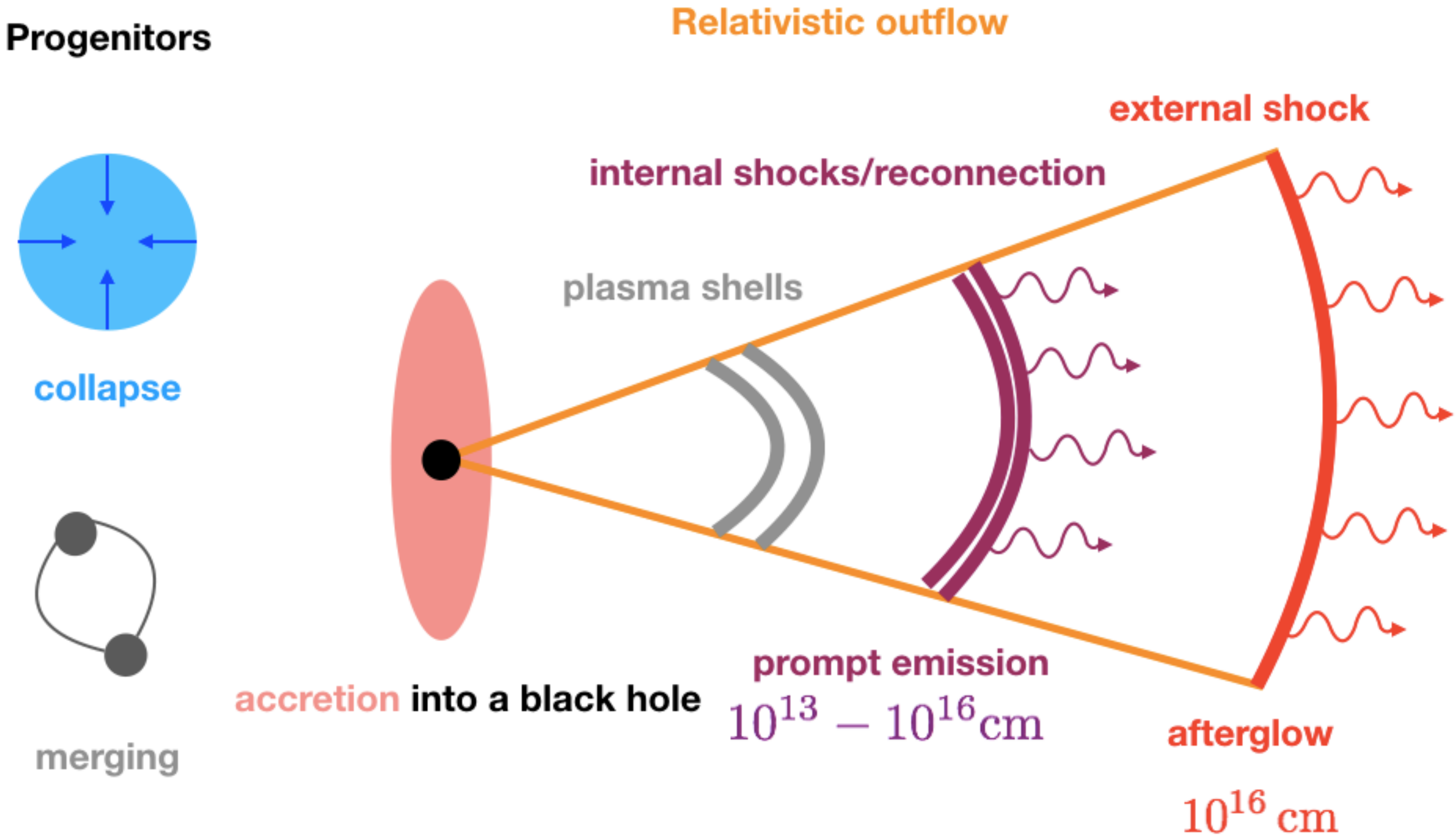

Progenitors
Relativistic outflow
external shock
internal shocks/reconnection
plasma shells
collapse
merging
accretion into a black hole
prompt emission
$10^{13} - 10^{16}$cm
afterglow
10^{16} cm

OPEN QUESTIONS

- location of the emission region

somewhere between 10^{13} and 10^{16} cm

- jet composition

baryonic vs magnetic dominated

- acceleration of particles

shocks vs magnetic reconnection

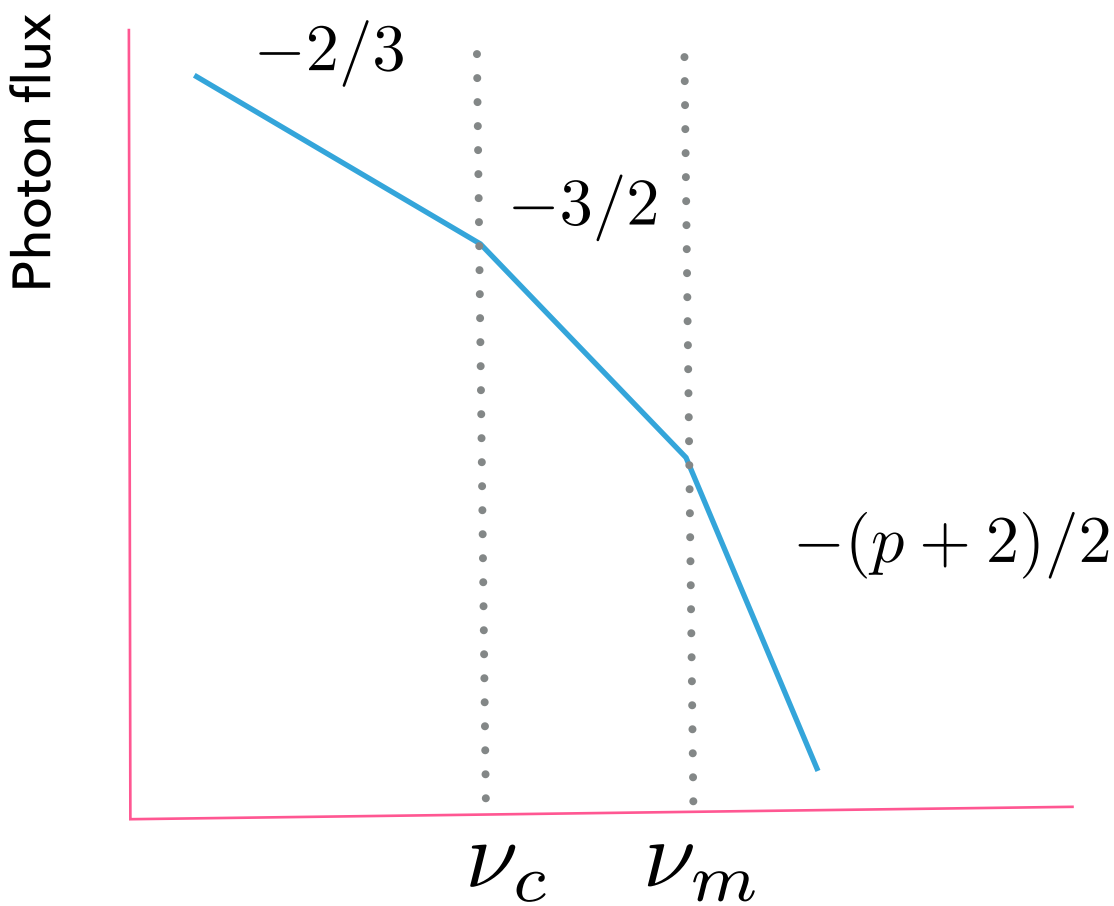
- radiative processes

SYNCHROTRON-LIKE SPECTRA

$$t_{syn} = \frac{6\pi m_e c}{\sigma_T B^2 \gamma} \rightarrow \gamma_c = \frac{6\pi m_e c}{\sigma_T B^2 t_{dyn}} \qquad t_{dyn} = \frac{R}{c\Gamma_*}$$

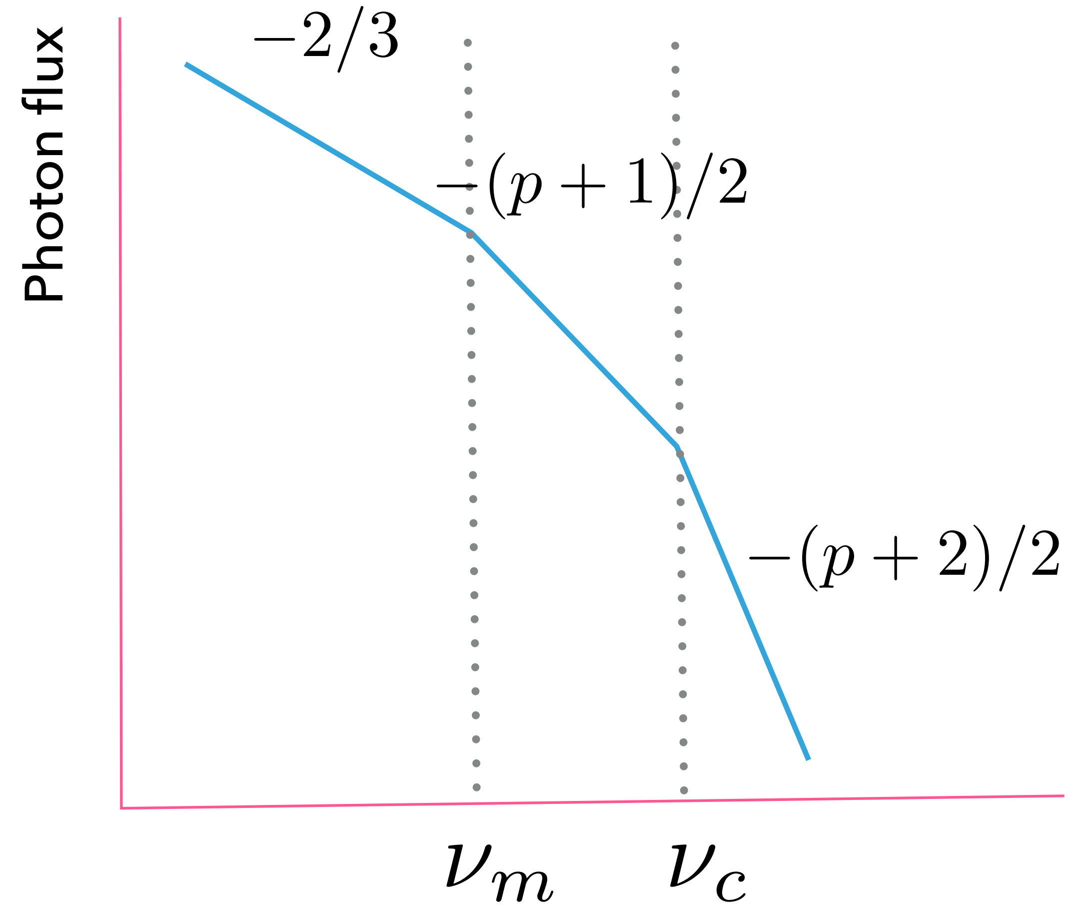
$$N_\gamma \propto \gamma^{-p}, \gamma > \gamma_m$$

Sari et al (1998)



fast cooling

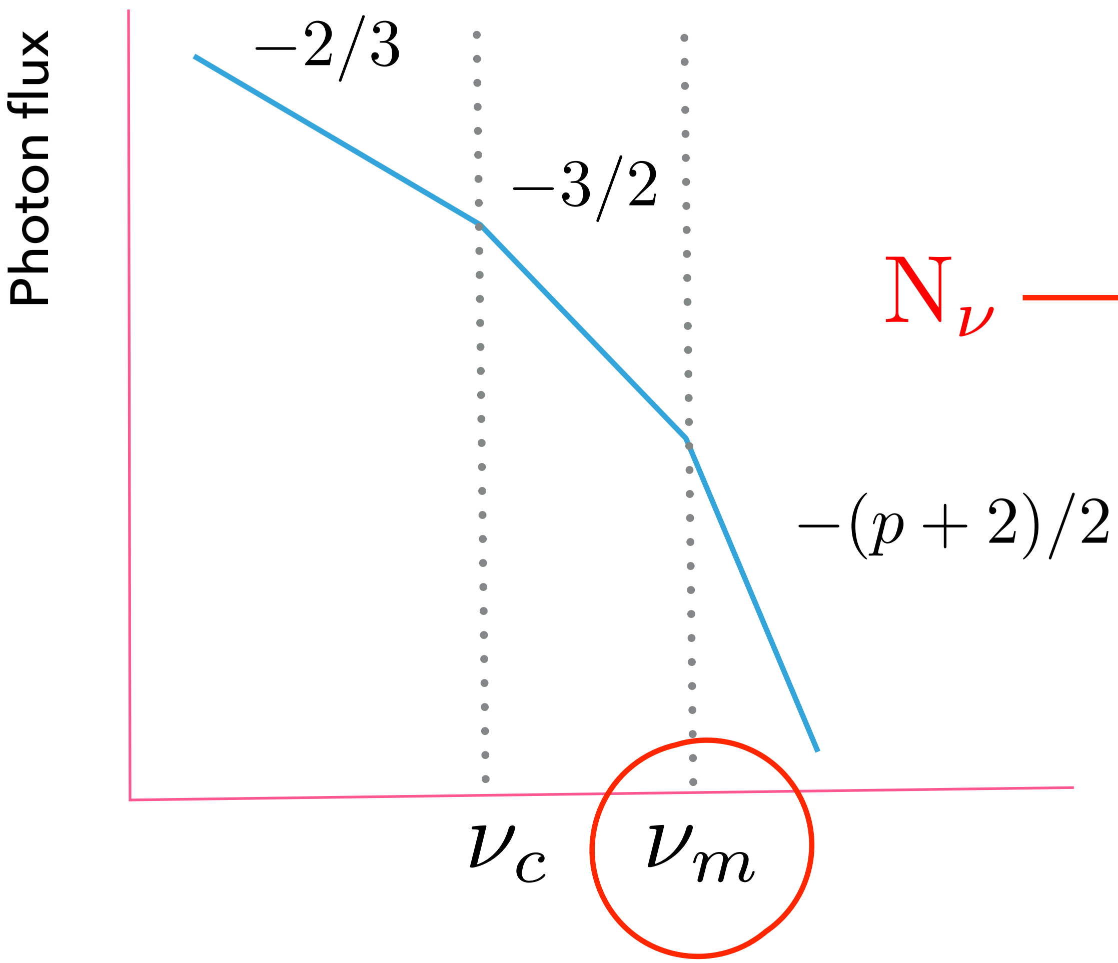
$$\gamma_c << \gamma_m$$



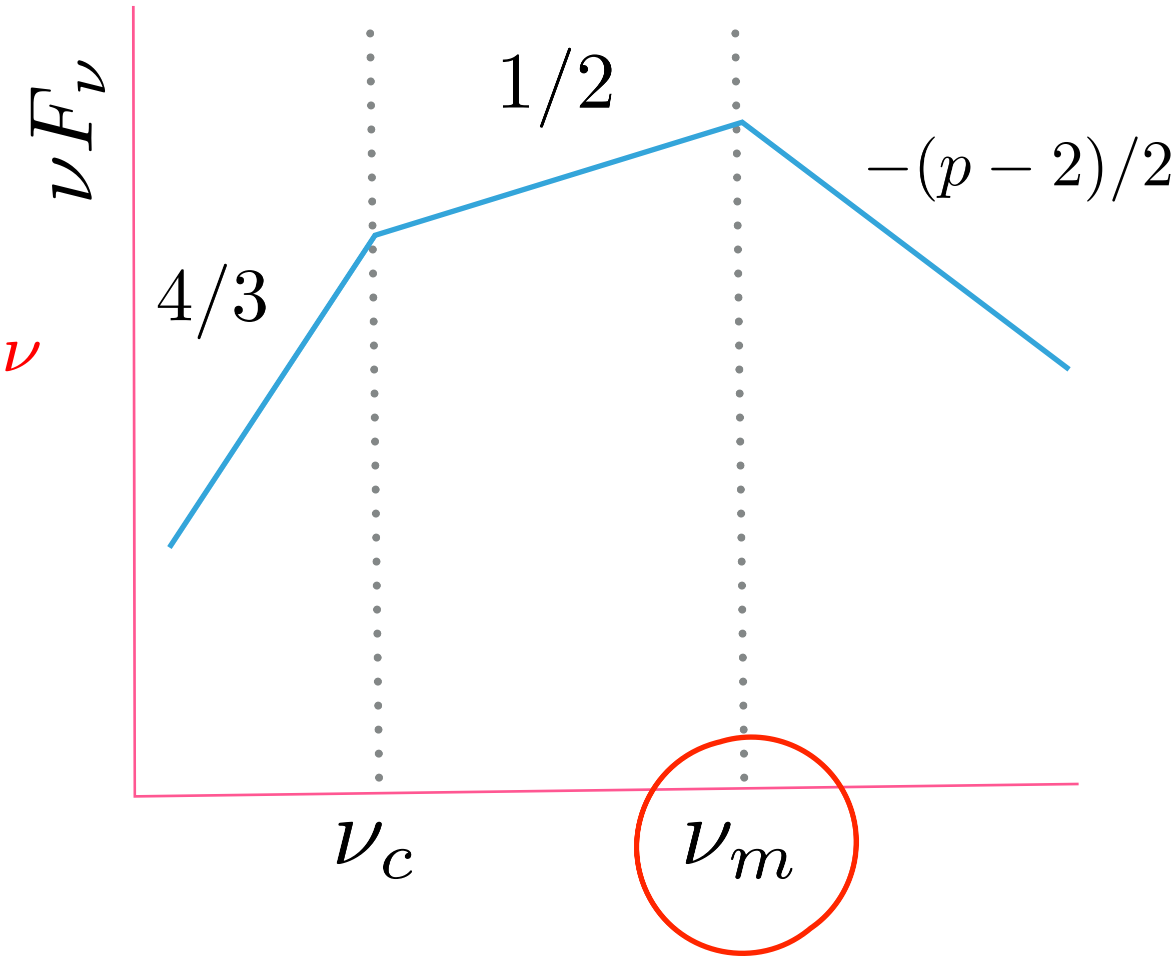
slow cooling

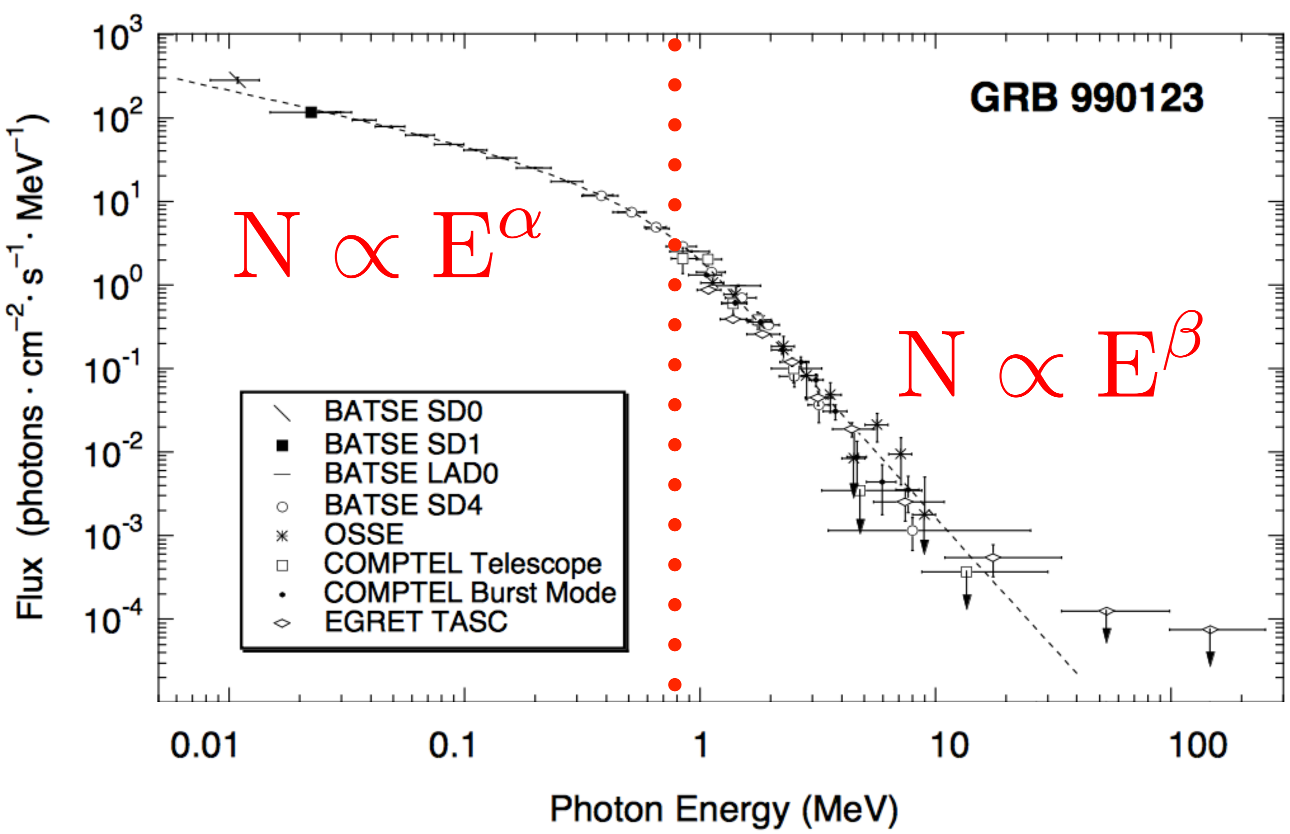
$$\gamma_c > \gamma_m$$

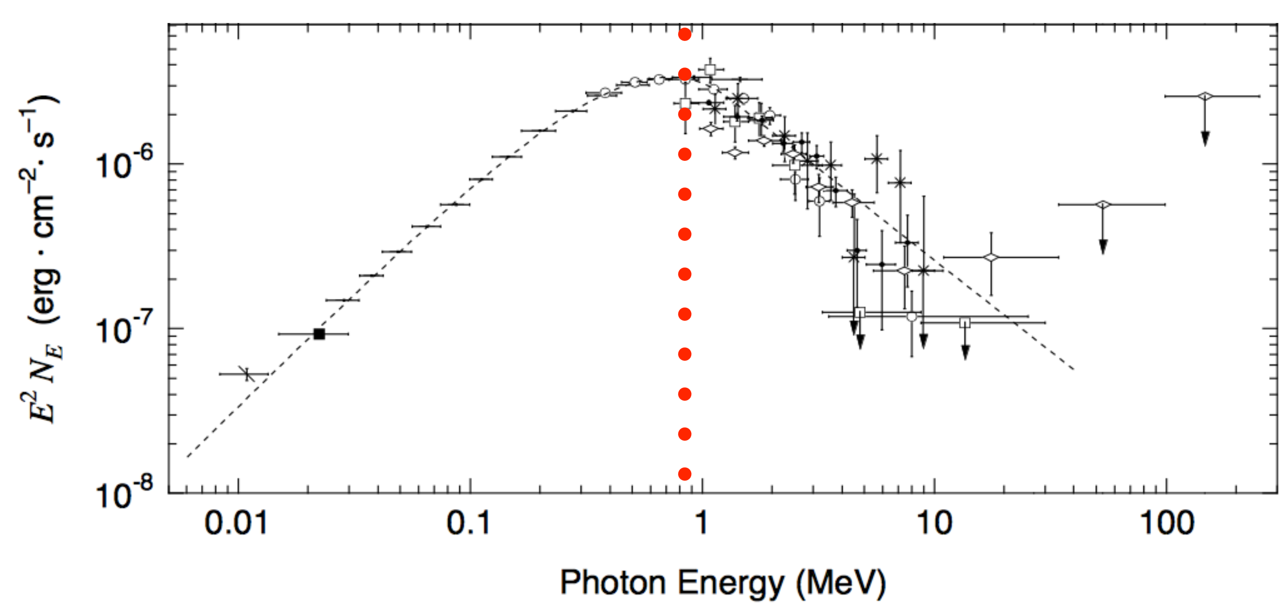
SYNCHROTRON SPECTRA IN FAST COOLING REGIME



$$N_\nu \longrightarrow \nu F_\nu$$







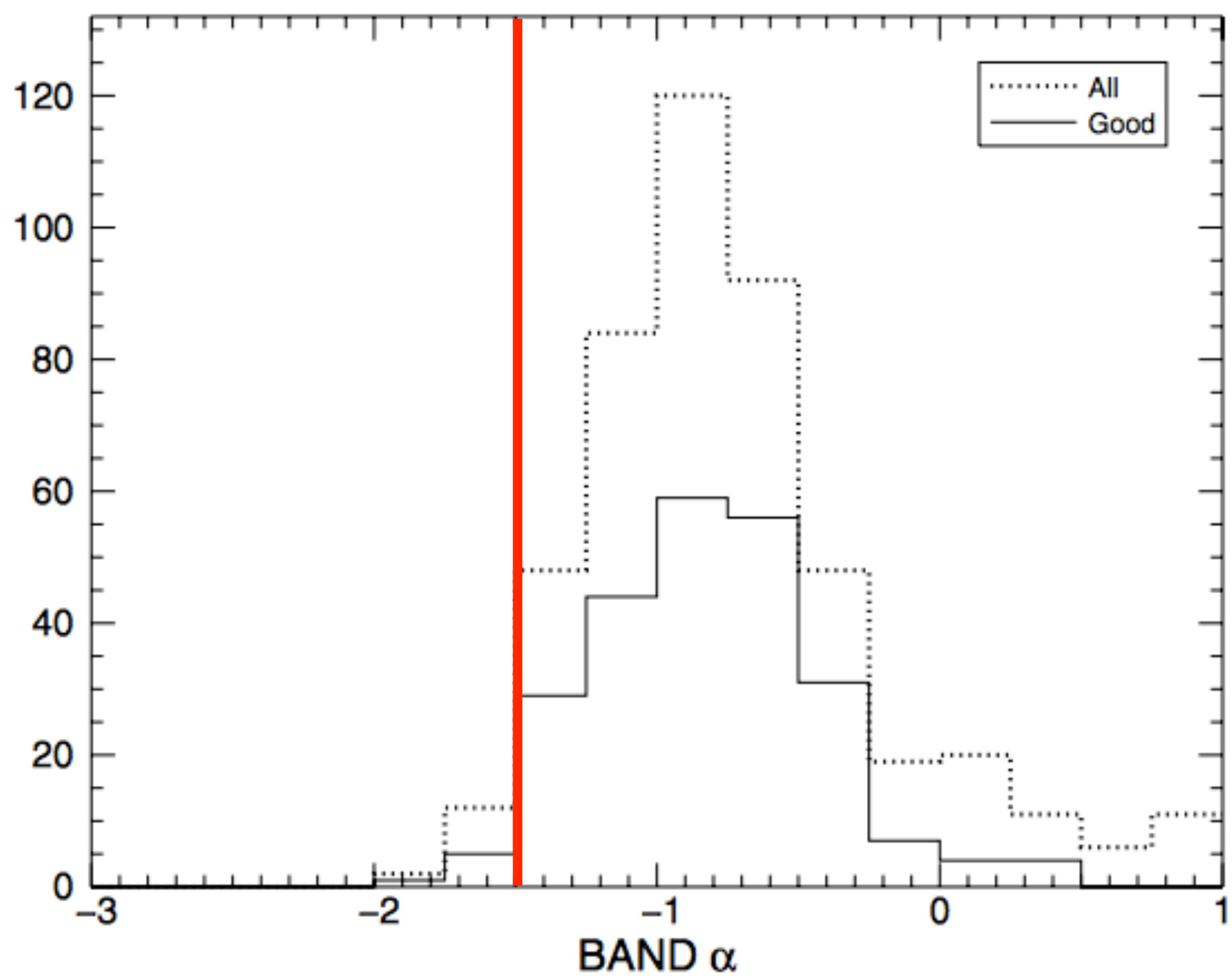
$$\alpha \sim -1 \qquad \beta \sim -2.5$$

SYNCHROTRON LINE OF DEATH

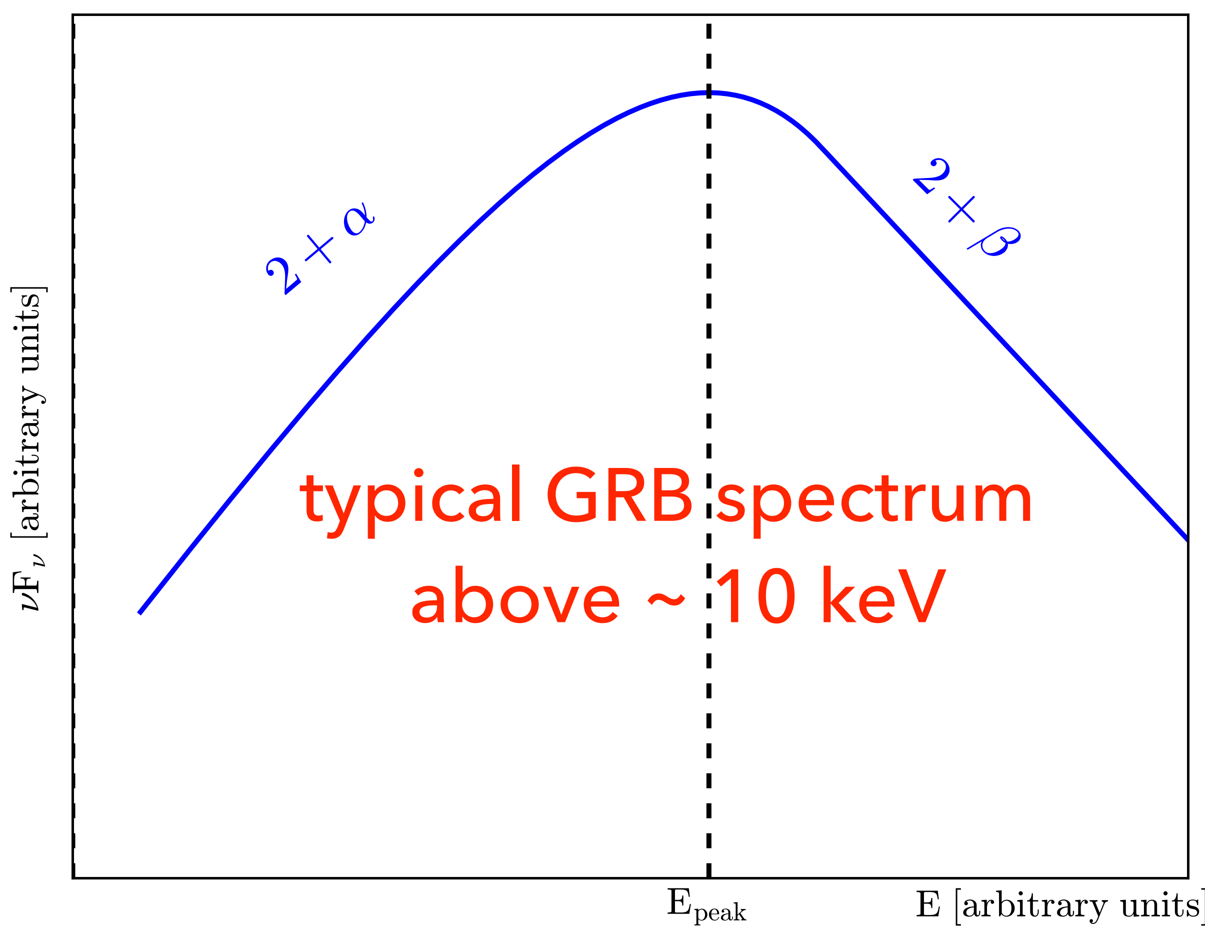
most prompt spectra, in the literature, are not consistent with fast cooling synchrotron spectrum

$$\alpha \sim -1 \qquad \beta \sim -2.5$$

$-3/2$



2nd Fermi catalog



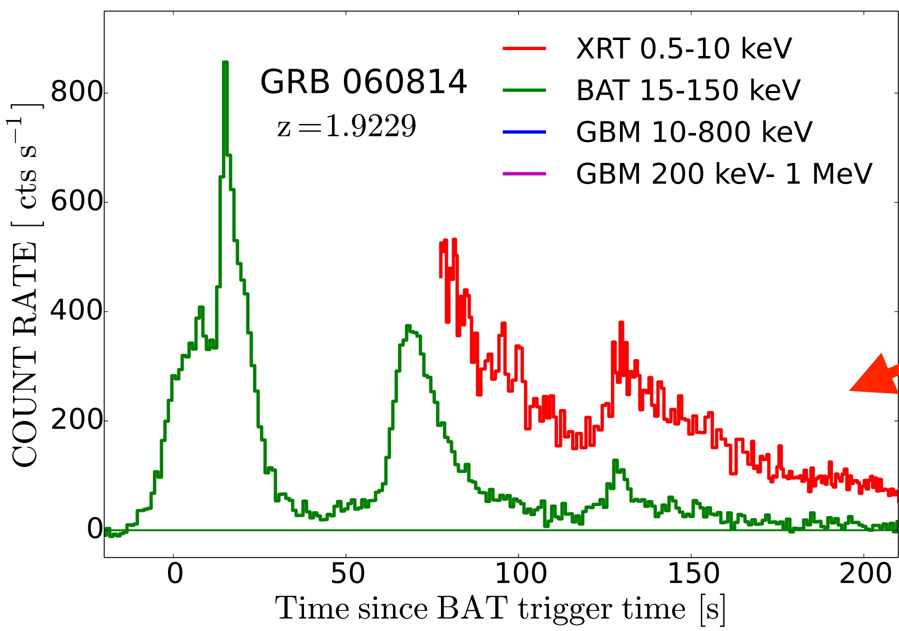
MOTIVATION

EXTEND THE STUDY OF PROMPT EMISSION SPECTRA DOWN TO LOWER ENERGIES

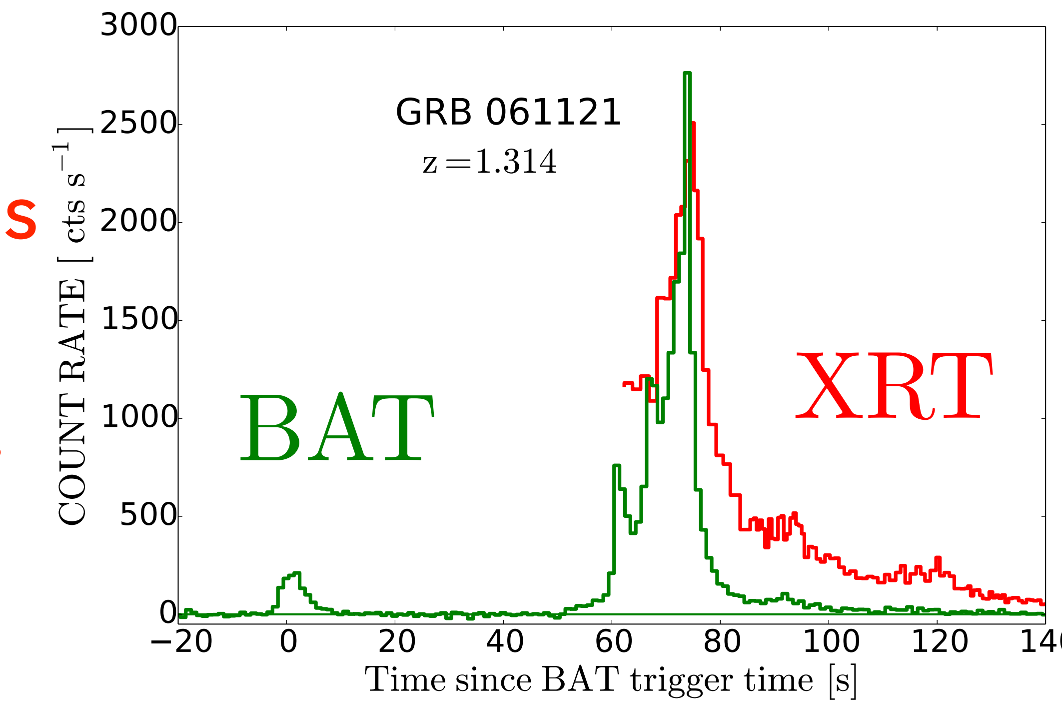
SWIFT/XRT	+	SWIFT/BAT	+	Fermi/GBM
0.5-10 keV		15-150 keV		8 keV-1 MeV

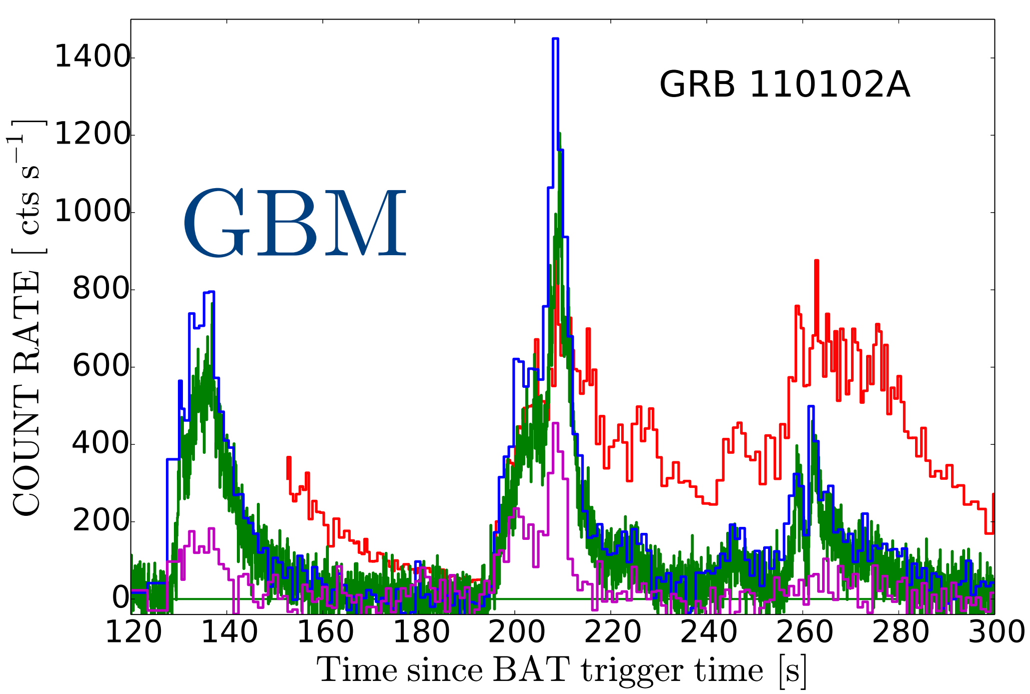
XRT + BAT + GBM SAMPLE   14 GRBs with 128 TIME-RESOLVED SPECTRA

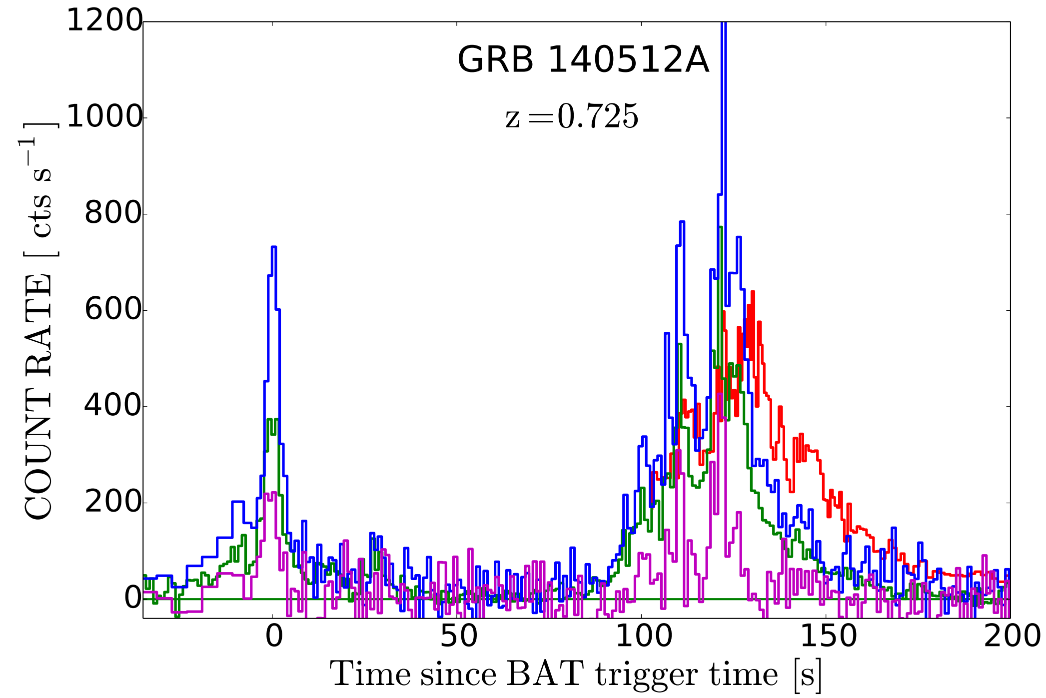
Light curve examples



Swift/XRT observations during the prompt!

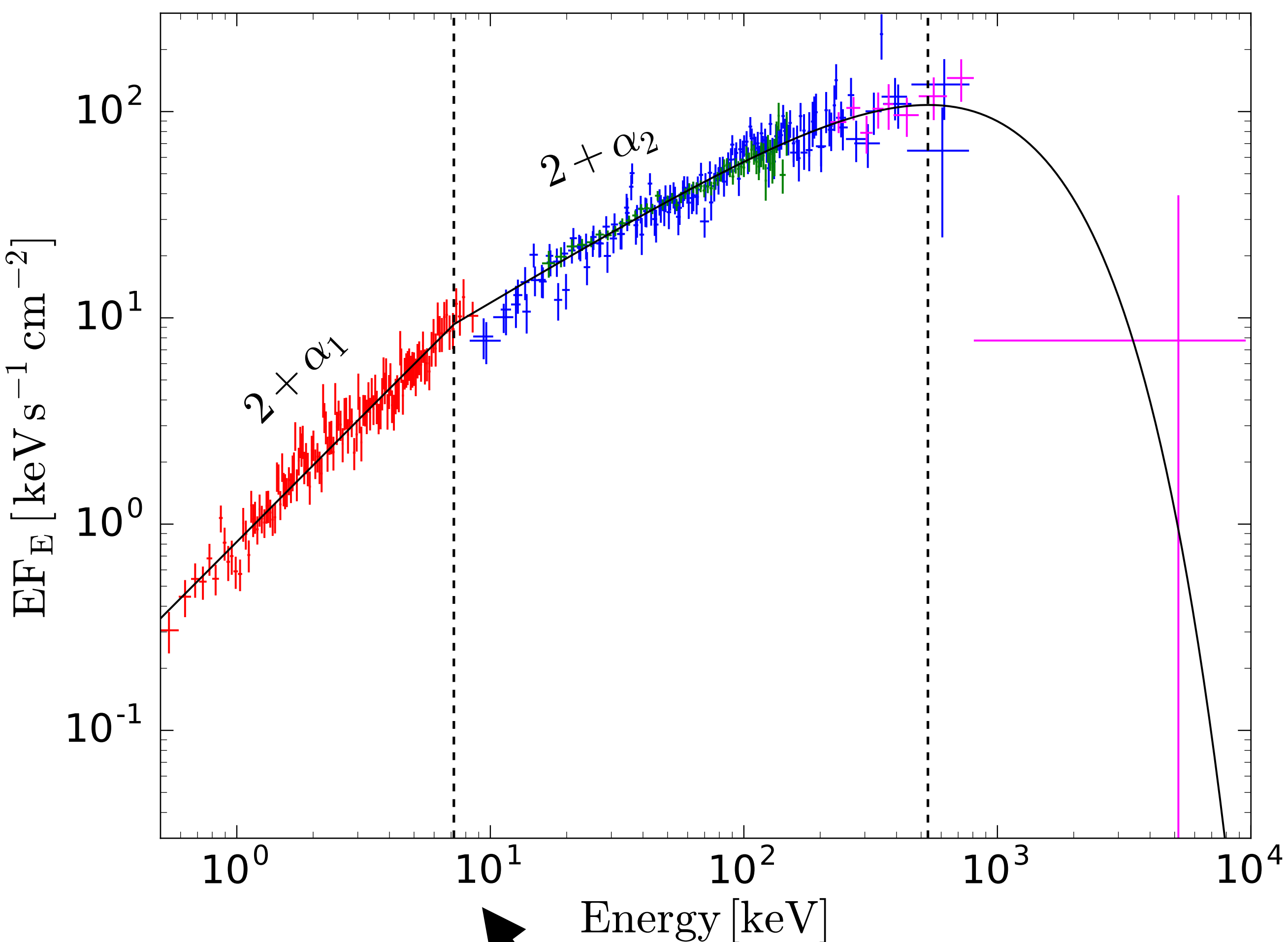


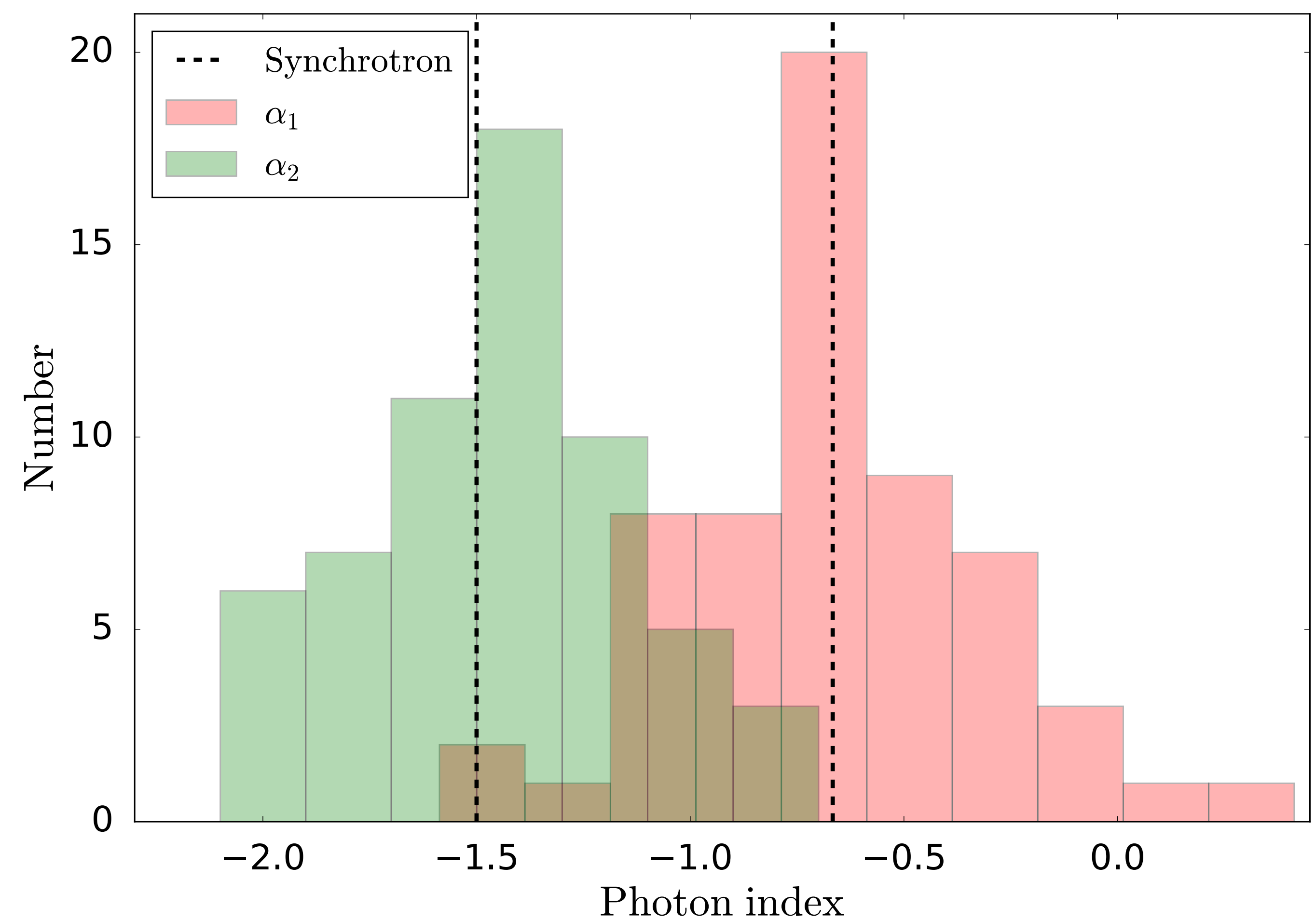




SWIFT/XRT + SWIFT/BAT + Fermi/GBM

0.5-10 keV + 15-150 keV + 8 keV-40 MeV





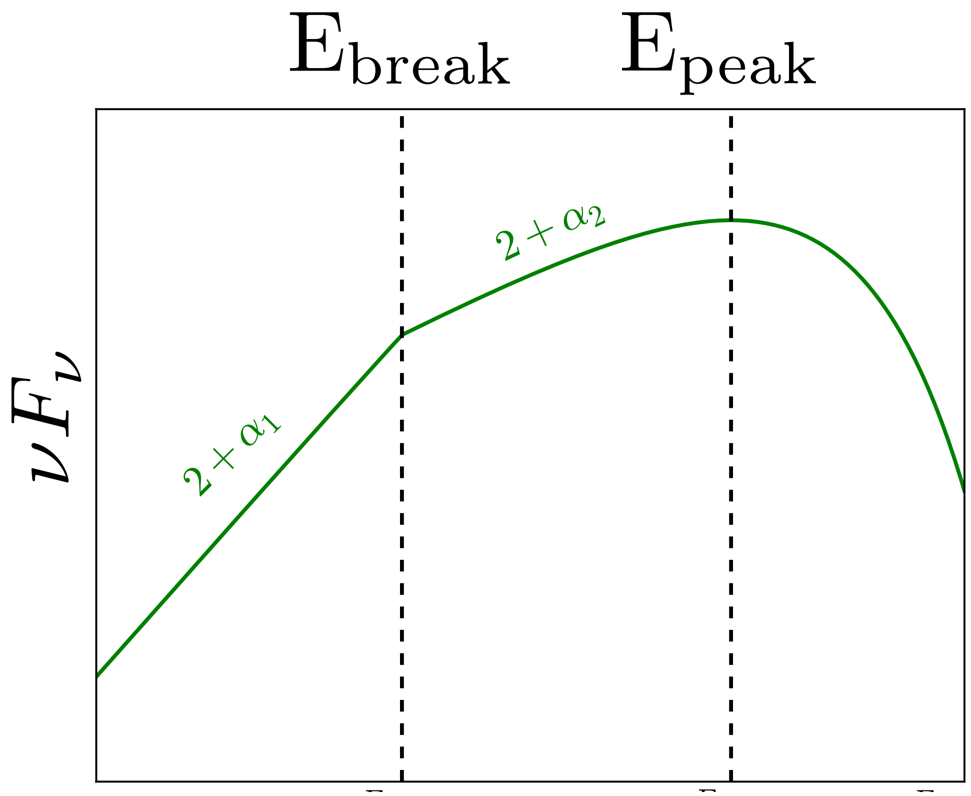
$\mathrm{E_{break}}$

cooling frequency?

mean values are in agreement with synchrotron spectrum

DISTRIBUTION OF PEAK/BREAK ENERGIES

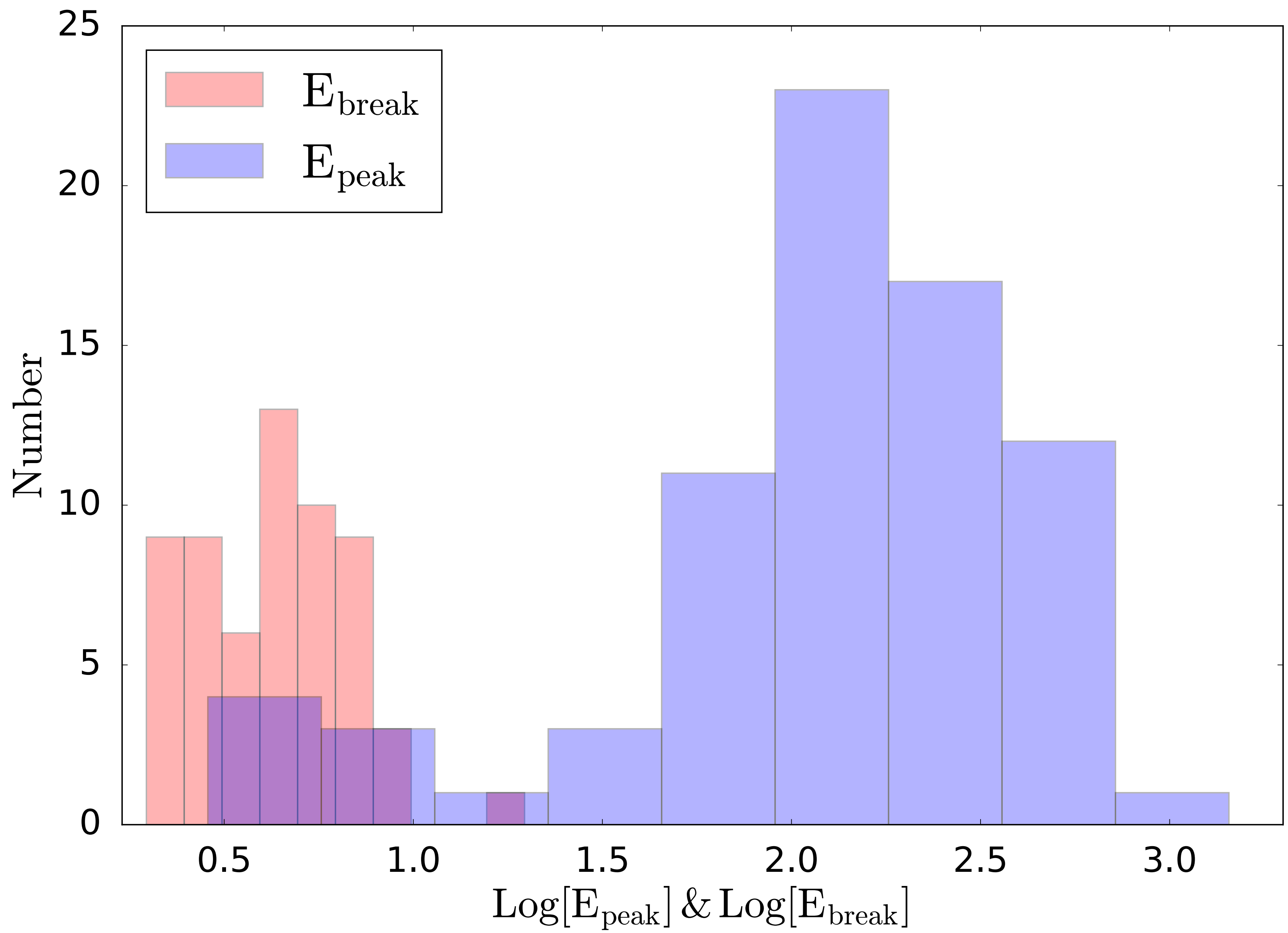
A spectral break is found for 67% of time-resolved spectra



$$\langle E_{break} \rangle = 4.3 \text{ keV}$$

$$\langle E_{peak} \rangle = 126 \text{ keV}$$

$$E_{peak}/E_{break} \sim 30$$



MAIN FINDINGS OF THE TIME-RESOLVED SPECTROSCOPY

- A spectral **break** at soft X-rays is found for 67% time-resolved spectra
- Photon indices are **consistent with synchrotron** radiation scenario
- The typical ratio is $\frac{\mathrm{E_{peak}}}{\mathrm{E_{break}}} \sim 30$. This regime has been considered before ('moderately fast cooling')
- We gave the first time observational evidence in support of this scenario

Oganesyan, G., Nava, L., Ghirlanda, G., & Celotti, A. 2017, ApJ, 846, 137

THE MICROPHYSICAL PARAMETERS OF MARGINALLY FAST COOLING SYNCHROTRON REGIME

$$\nu_c \sim \nu_m$$

$\Gamma \geq 300$ large bulk Lorentz factors

$B \sim 10\ G$ weak magnetic fields

$R \geq 3 \times 10^{16}\ cm$ large radii (excludes wind-like solutions for the ISM)

$\gamma_m \sim 10^5$ only small fraction of electrons should be accelerated

Kumar & McMahon (2008) F. Daigne et al (2011) Beniamini & Piran (2013)

TOWARDS LARGER SAMPLE OF PROMPT EMISSION WITH XRT OBSERVATIONS

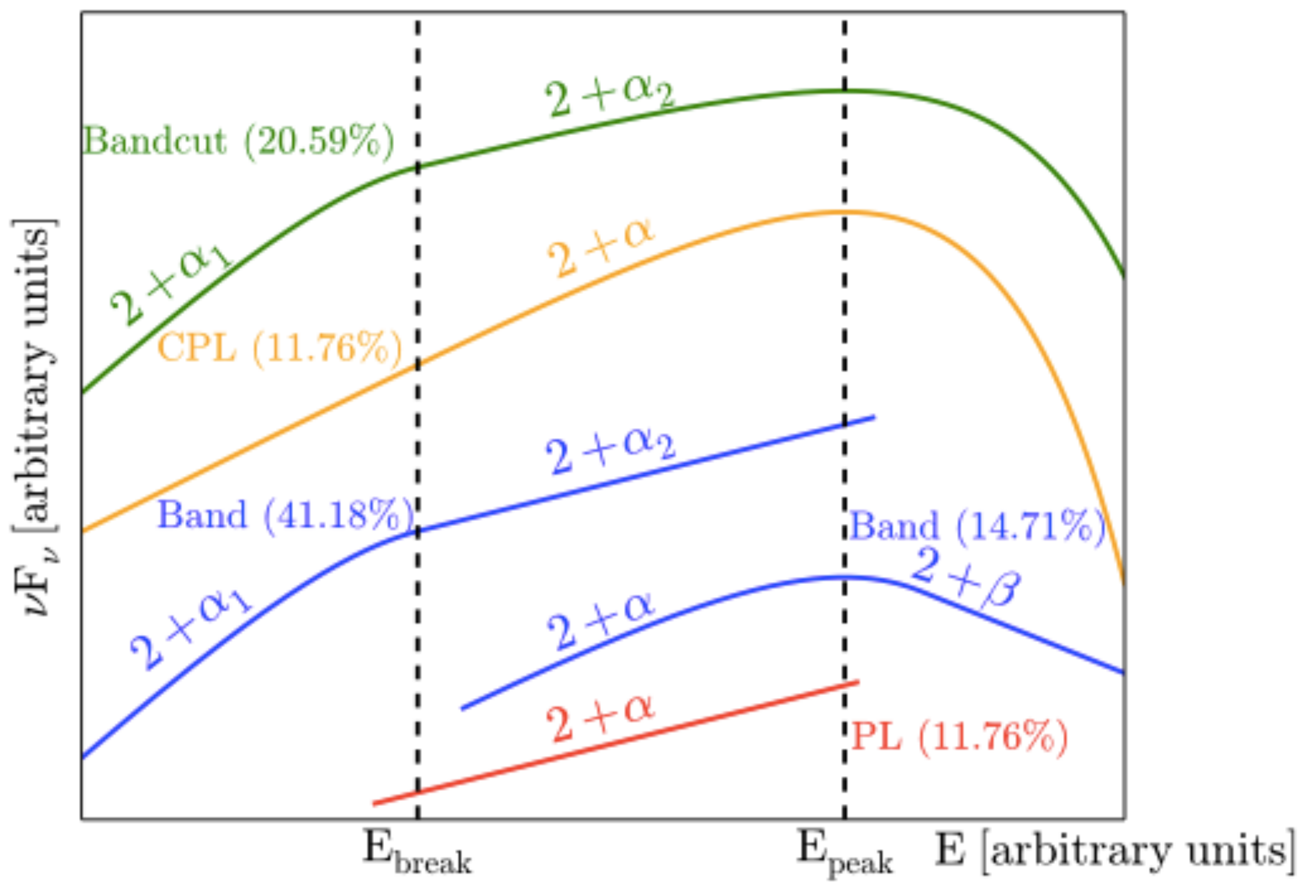
- 34 GRBs with XRT+BAT(+GBM) observations
- "Time-averaged" spectral analysis in the available joint time-slices
- Search for the breaks
- When do we observe the breaks?

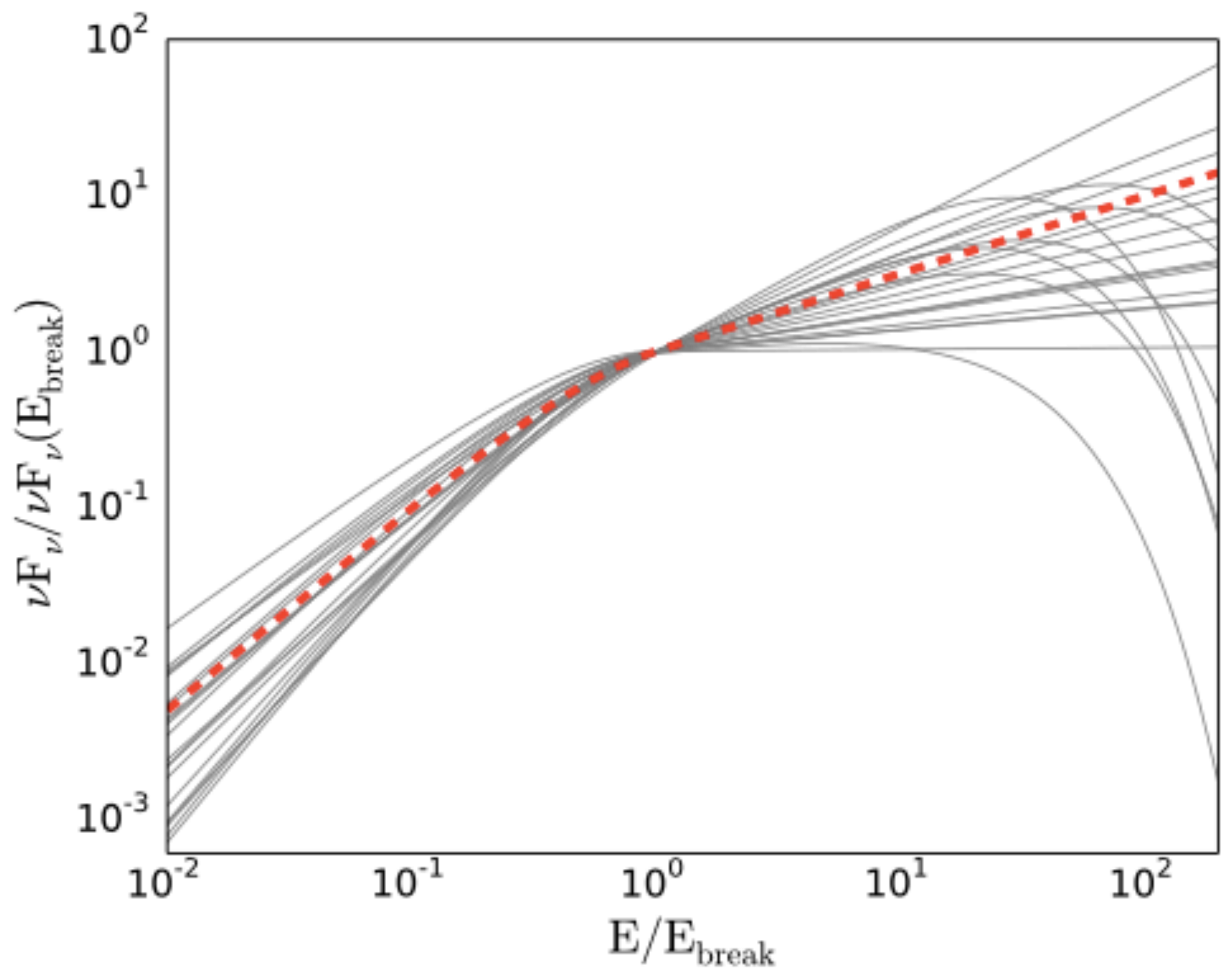
Oganesyan, G., Nava, L., Ghirlanda, G., & Celotti, A. 2018, A&A (in press)

TOWARDS BIGGER SAMPLE OF PROMPT EMISSION WITH XRT OBSERVATIONS

Results are confirmed in a larger sample

Tested models

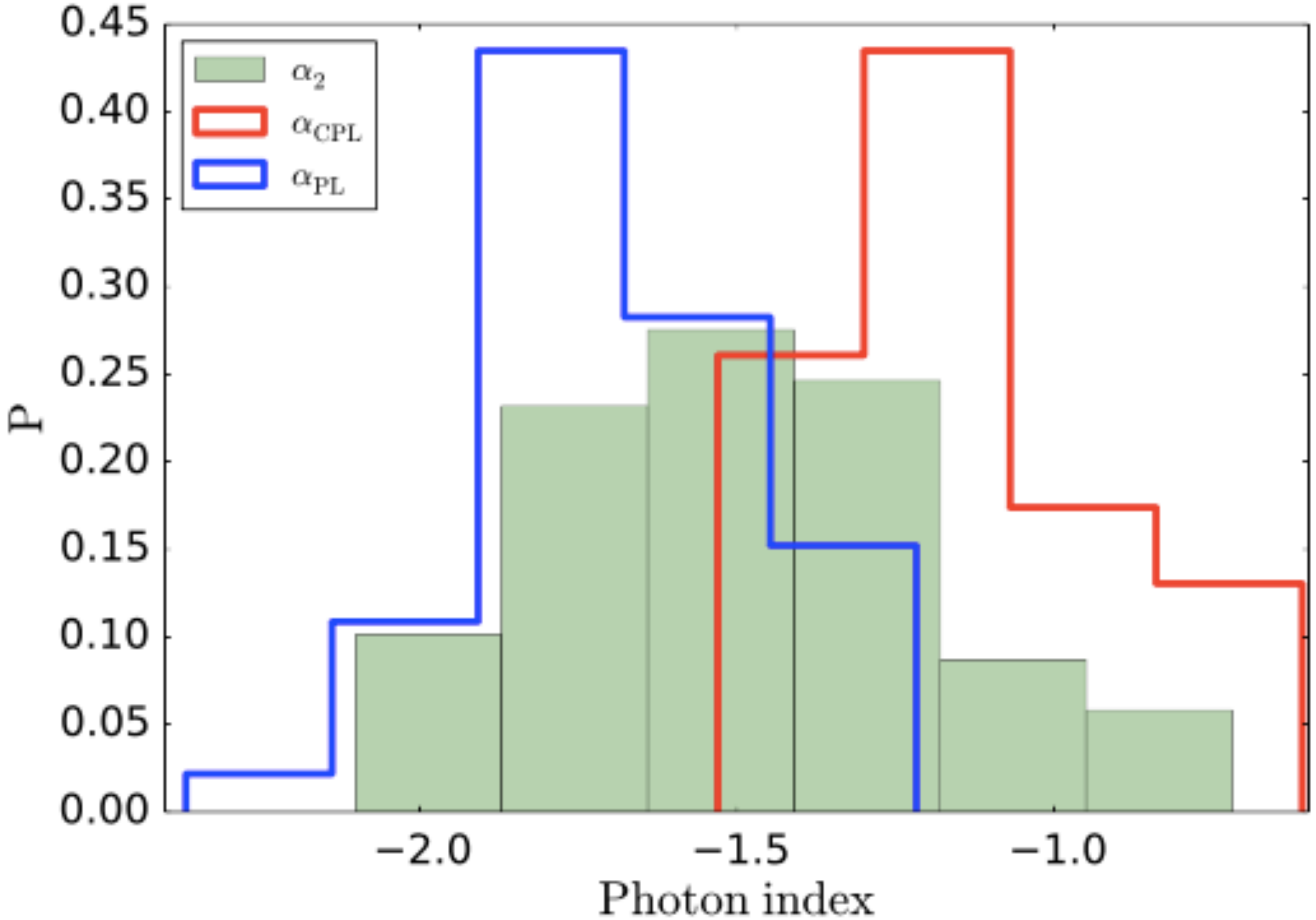


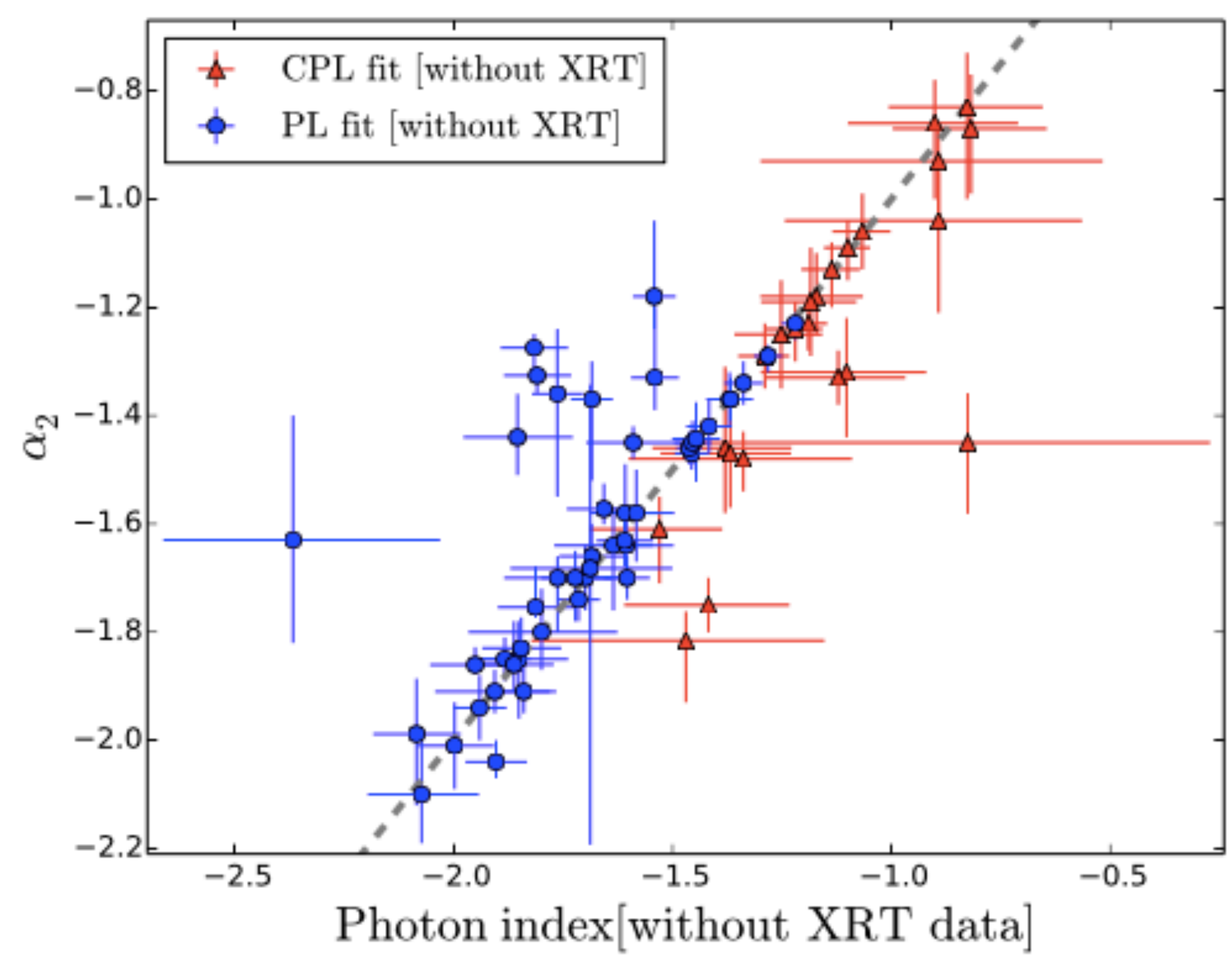


TOWARDS BIGGER SAMPLE OF PROMPT EMISSION WITH XRT OBSERVATIONS

Why spectra without break have typical shape -1 ?

Is this a real shape or it is a bias due to the lack of low-energy observations?





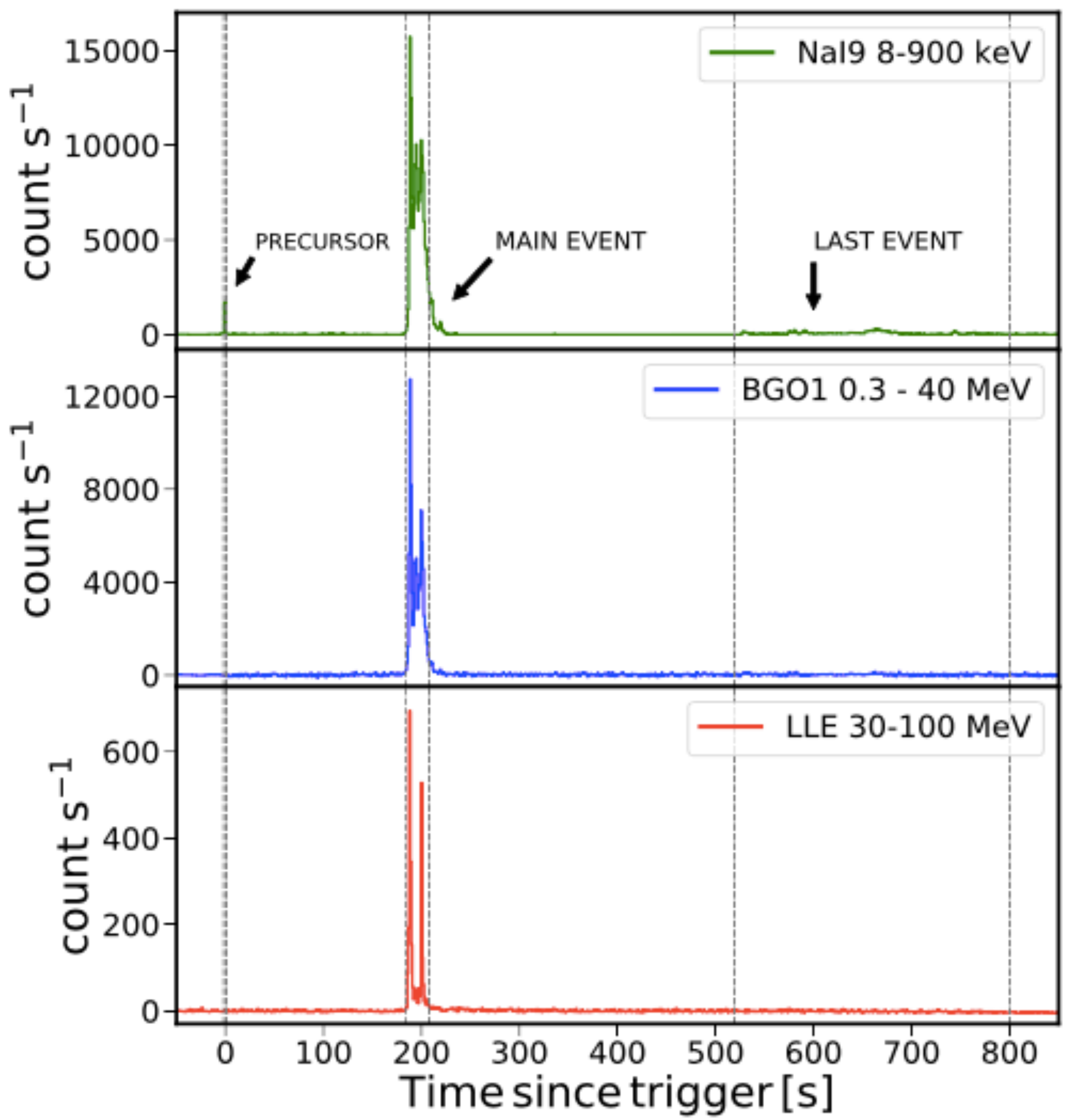
MAIN FINDINGS OF THE "TIME-AVERAGED" SPECTRAL ANALYSIS

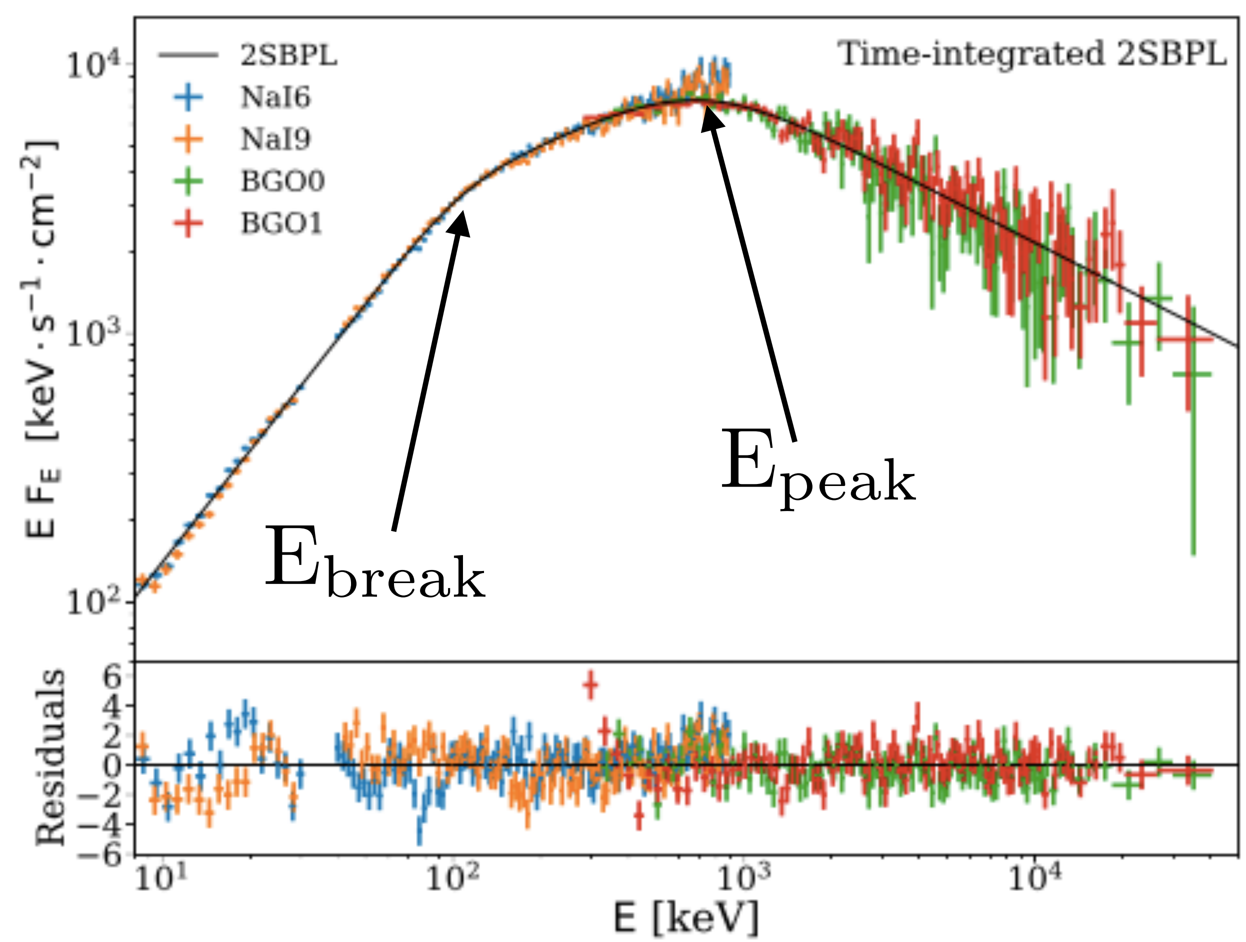
- Confirmation of **the breaks in more than 50% prompt emission spectra**
- No significant difference between properties of spectra with/without breaks
- Best fit parameters of spectra without X-ray data are consistent with previous studies

Oganesyan, G., Nava, L., Ghirlanda, G., & Celotti, A. 2018, A&A (in press)

BRIGHT FERMI GRB 160625B

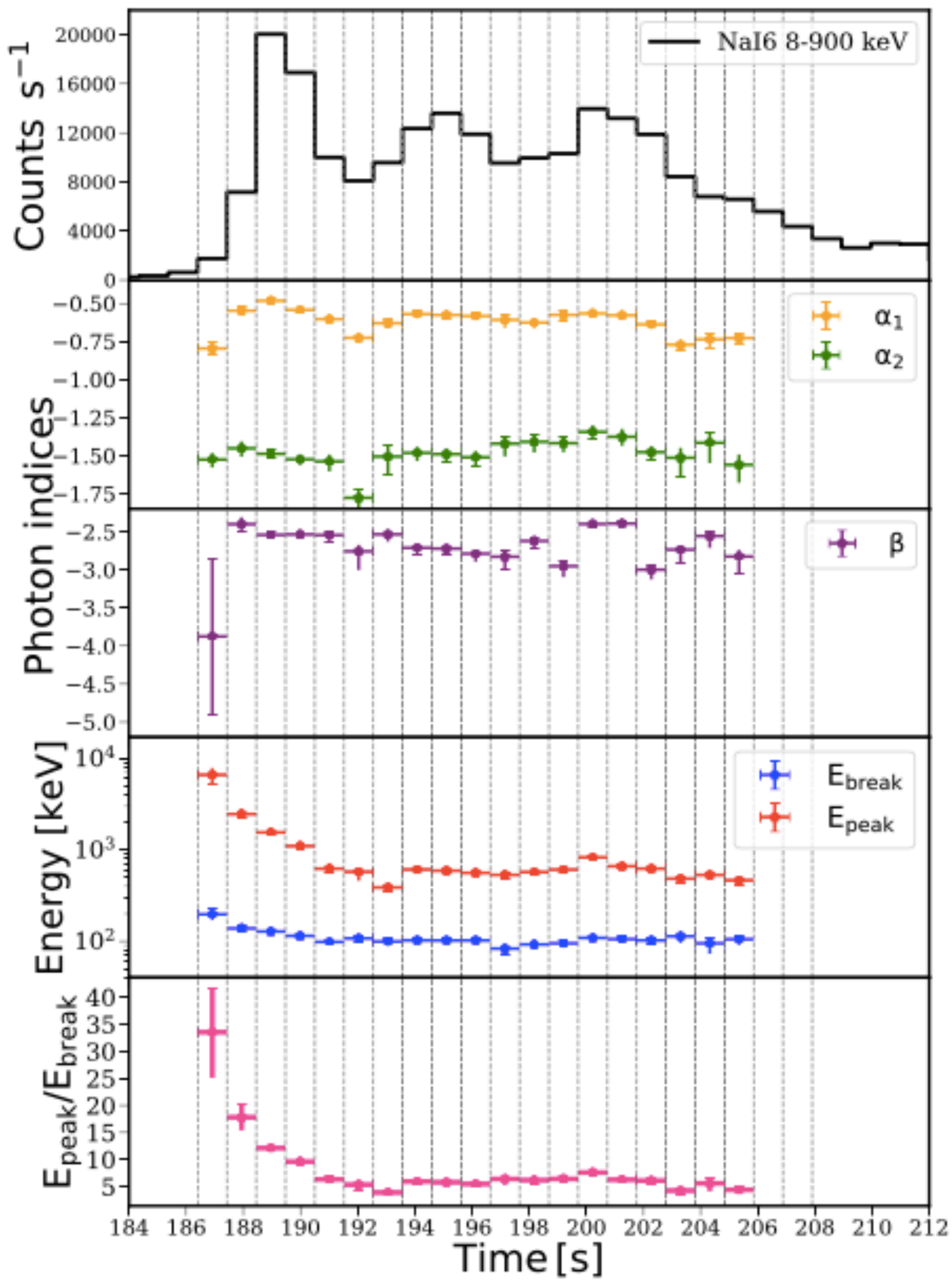
Ravasio M. E., Oganesyan G., Ghirlanda G., Nava L. et al., A&A, 613, A16,11



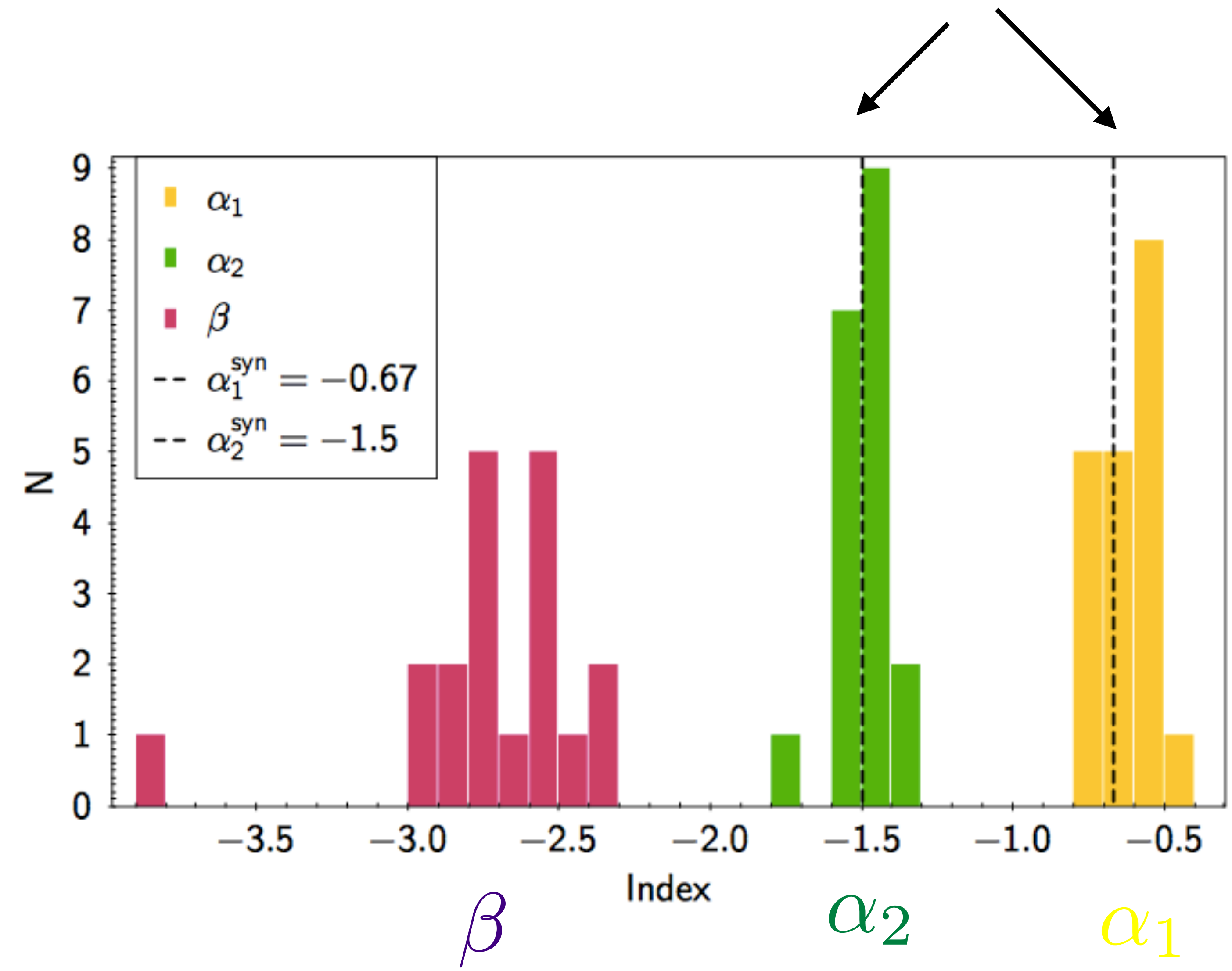


BRIGHT FERMI GRB 160625B

TIME-RESOLVED ANALYSIS



SYNCHROTRON



DISTRIBUTION OF PHOTON INDICES

COMPETING MODELS

SYNCHROTRON-BASED

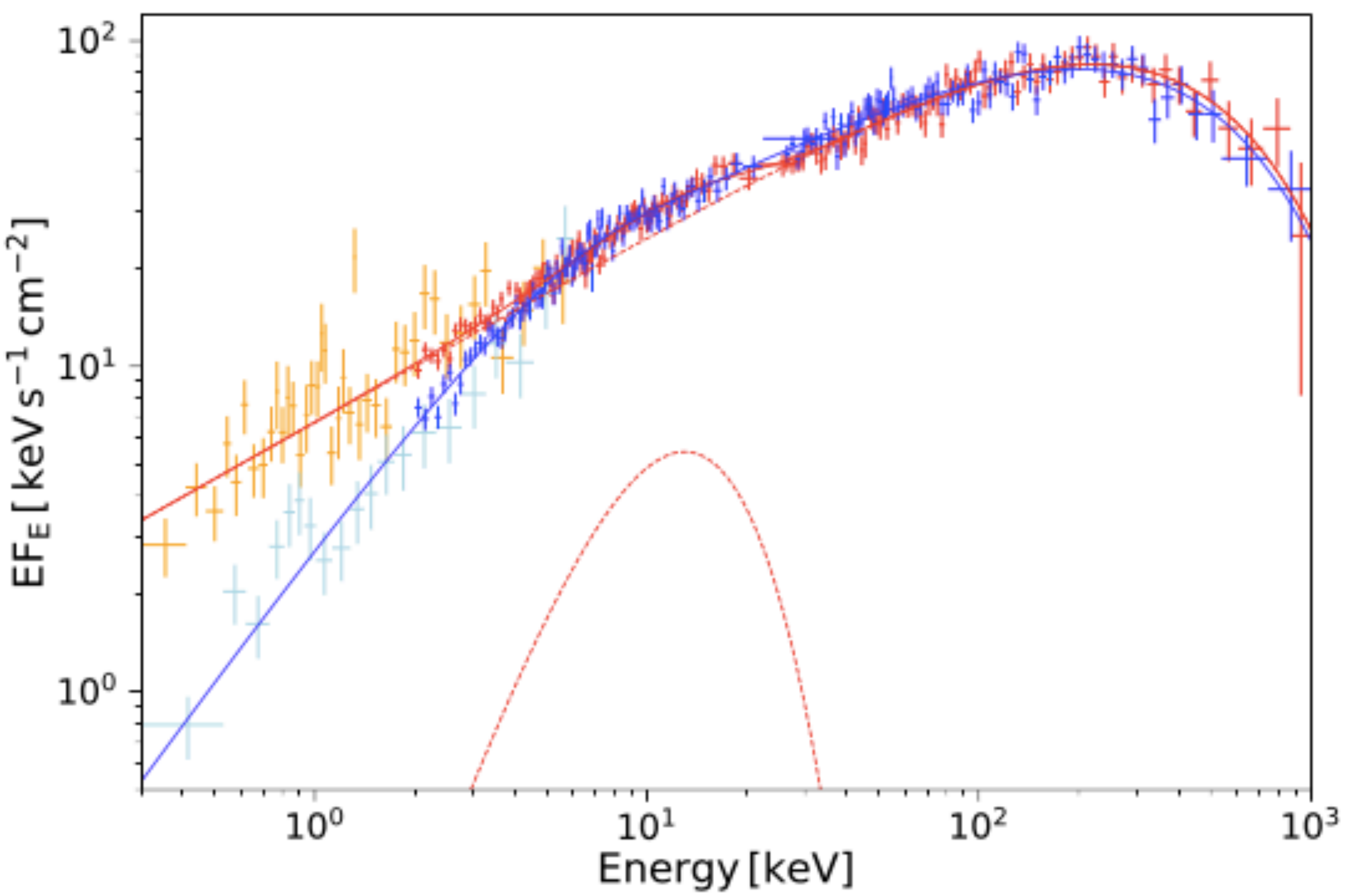
- inverse Compton in Klein-Nishina regime (Nakar et al. 2009, Daigne et al. 2011)
- marginally fast cooling synchrotron (Kumar & McMahon 2008, Daigne et al. 2011, Beniamini & Piran 2013)
- anisotropic magnetic field (Uhm & Zhang 2014)
- anisotropic pitch angles (Medvedev 2000)

ALTERNATIVES

- Comptonization
- Thermal components

WHAT TO DO AND HOW TO DISTINGUISH?

- Test of realistic synchrotron model
- Optical prompt emission
- Future wide-field X-ray missions (SVOM, THESEUS,ISS-TAO)



Nava L. et al.: The THESEUS contribution to GRB prompt emission

PROMPT OPTICAL EMISSION

SYNCHROTRON FIT TO 0.5 KEV-40 MEV SPECTRA

↓

PREDICTION OF OPTICAL FLUX

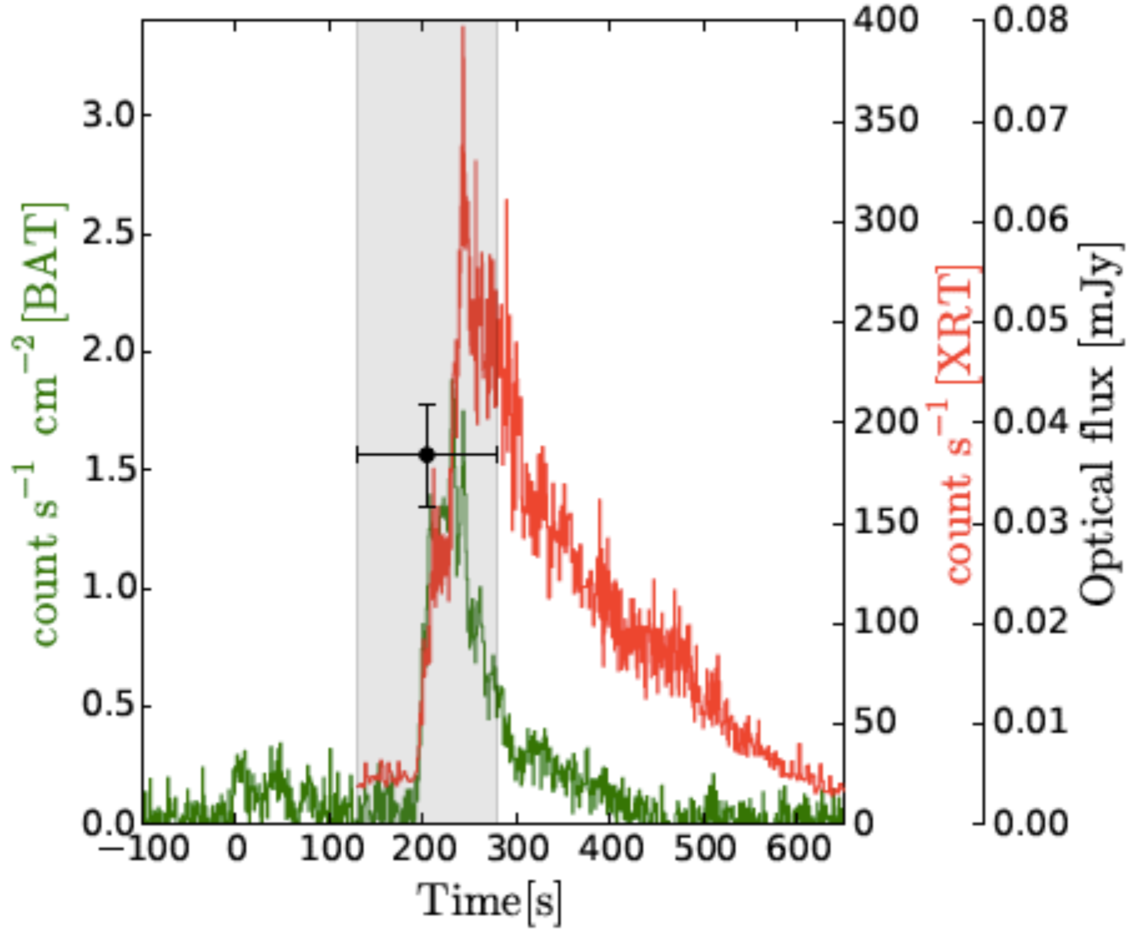
↓

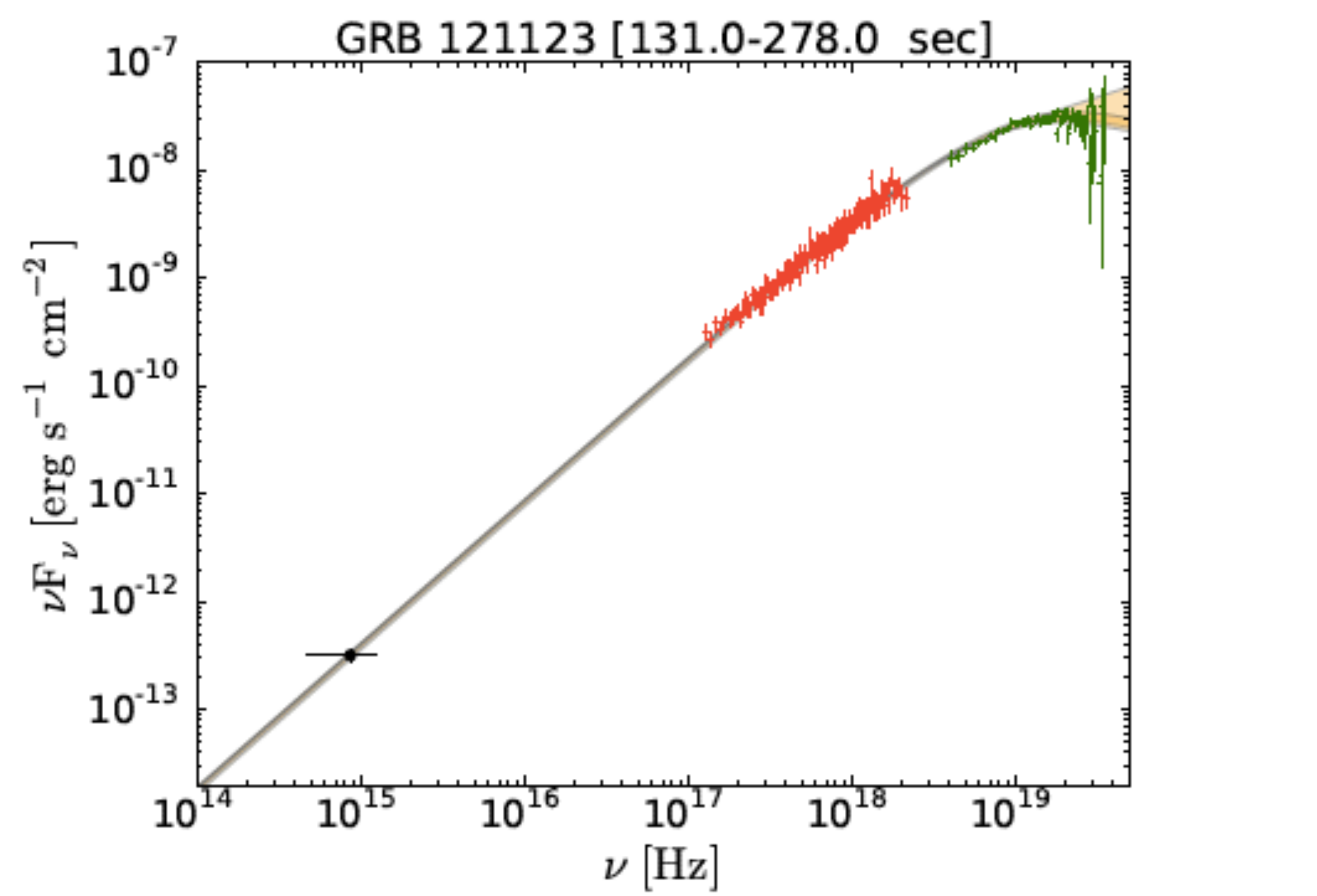
COMPARISON WITH OPTICAL OBSERVATIONS

PROMPT OPTICAL DATA : 21 GRBS (OUT OF 34), 56 TIME-RESOLVED SPECTRA

PROMPT OPTICAL EMISSION - CONSISTENCY

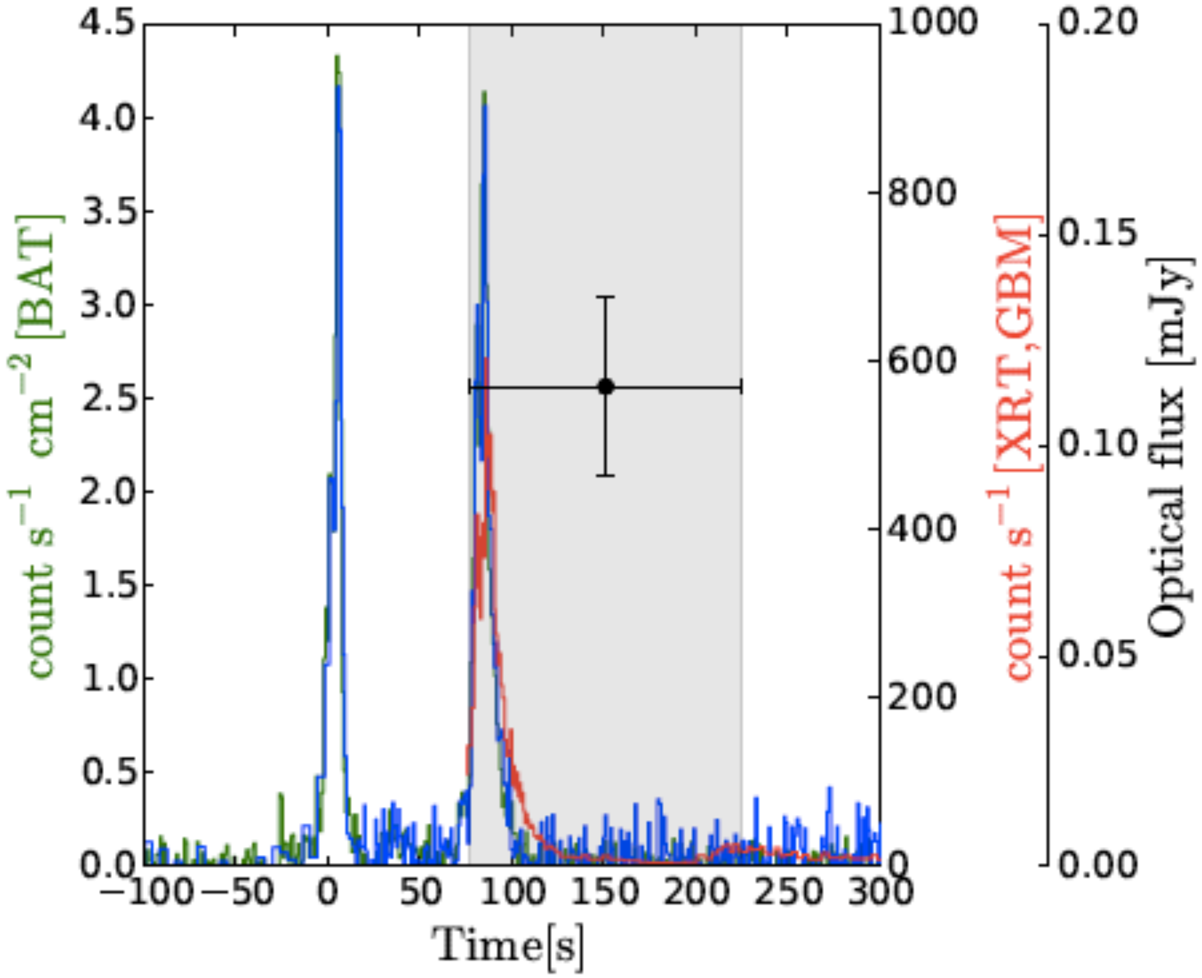
50% OF CASES

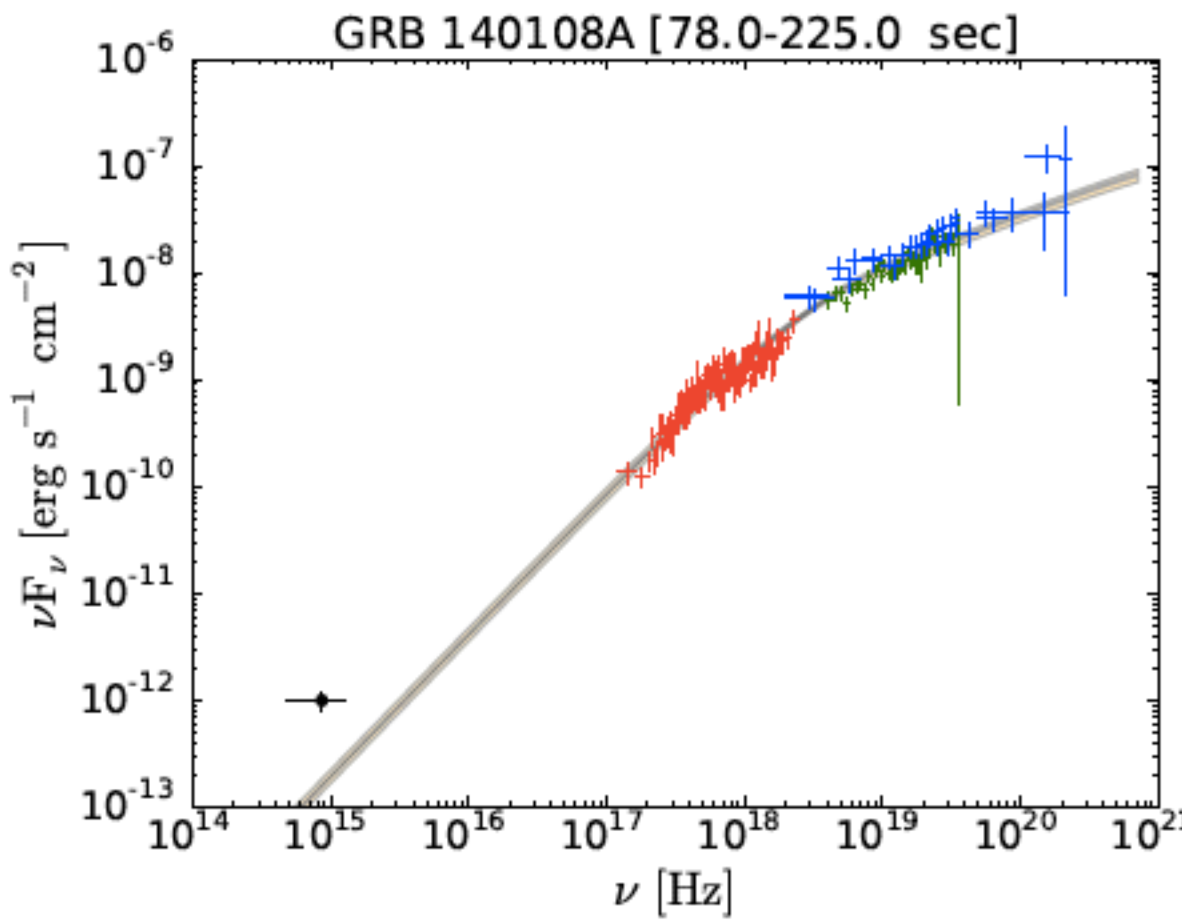




PROMPT OPTICAL EMISSION - UNDER-PREDICTION

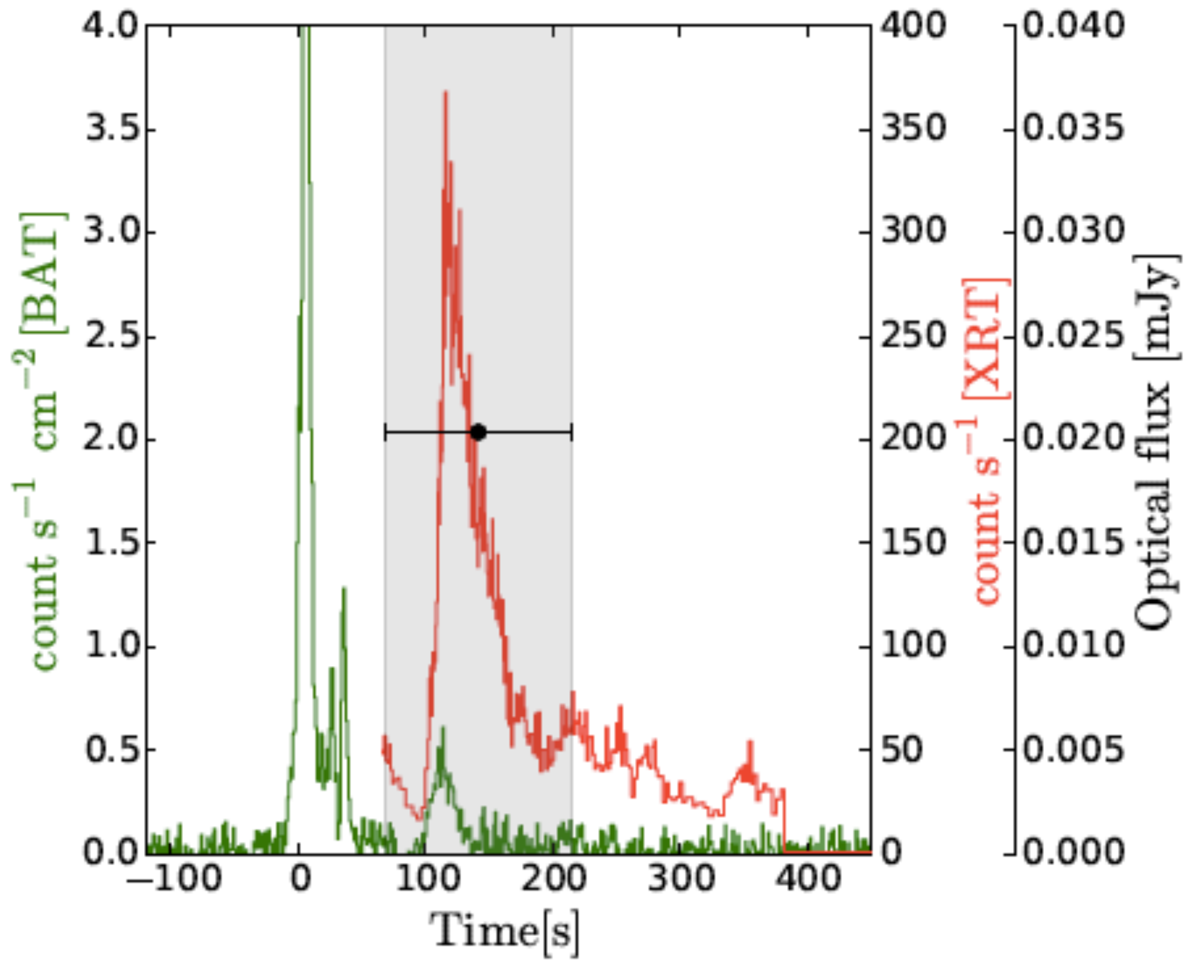
32% OF CASES

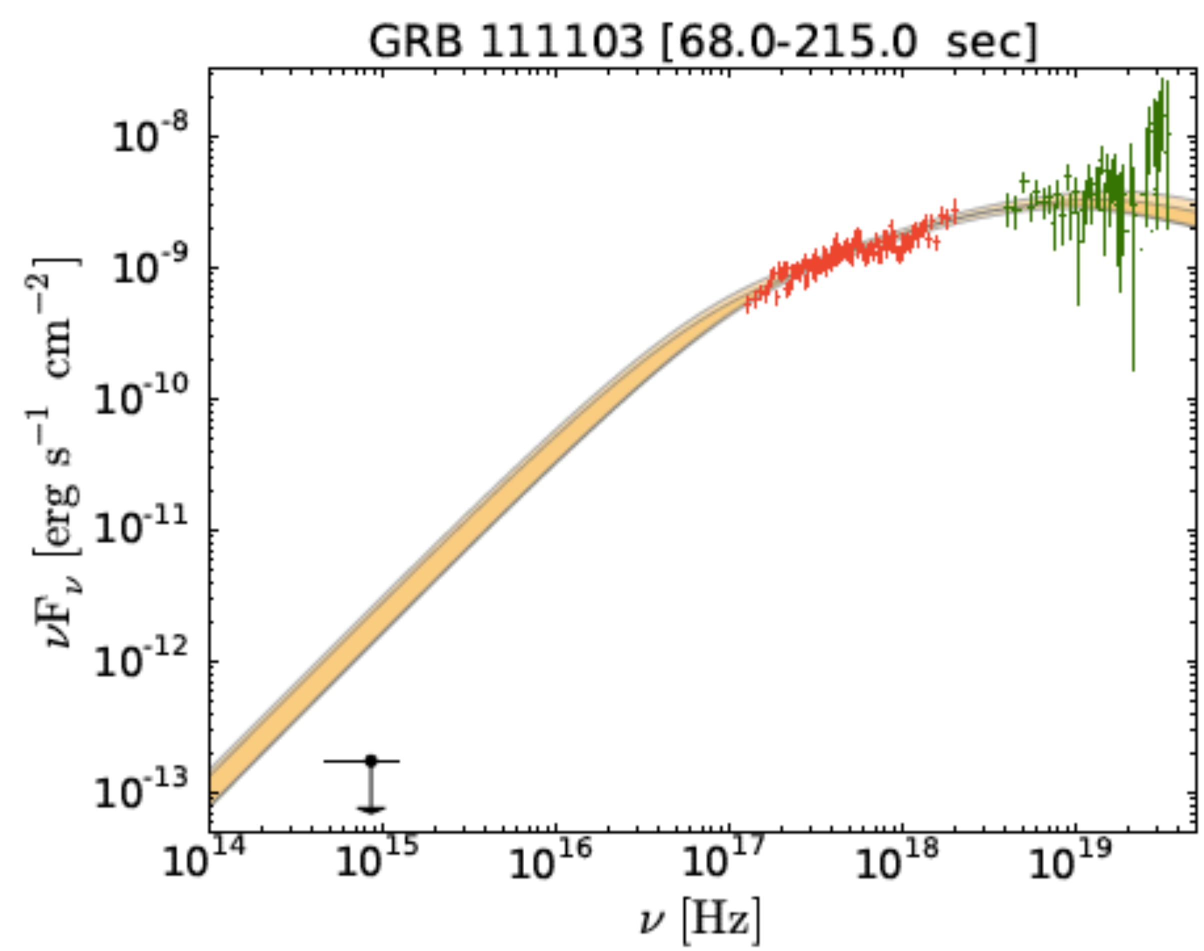




PROMPT OPTICAL EMISSION - OVER-PREDICTION

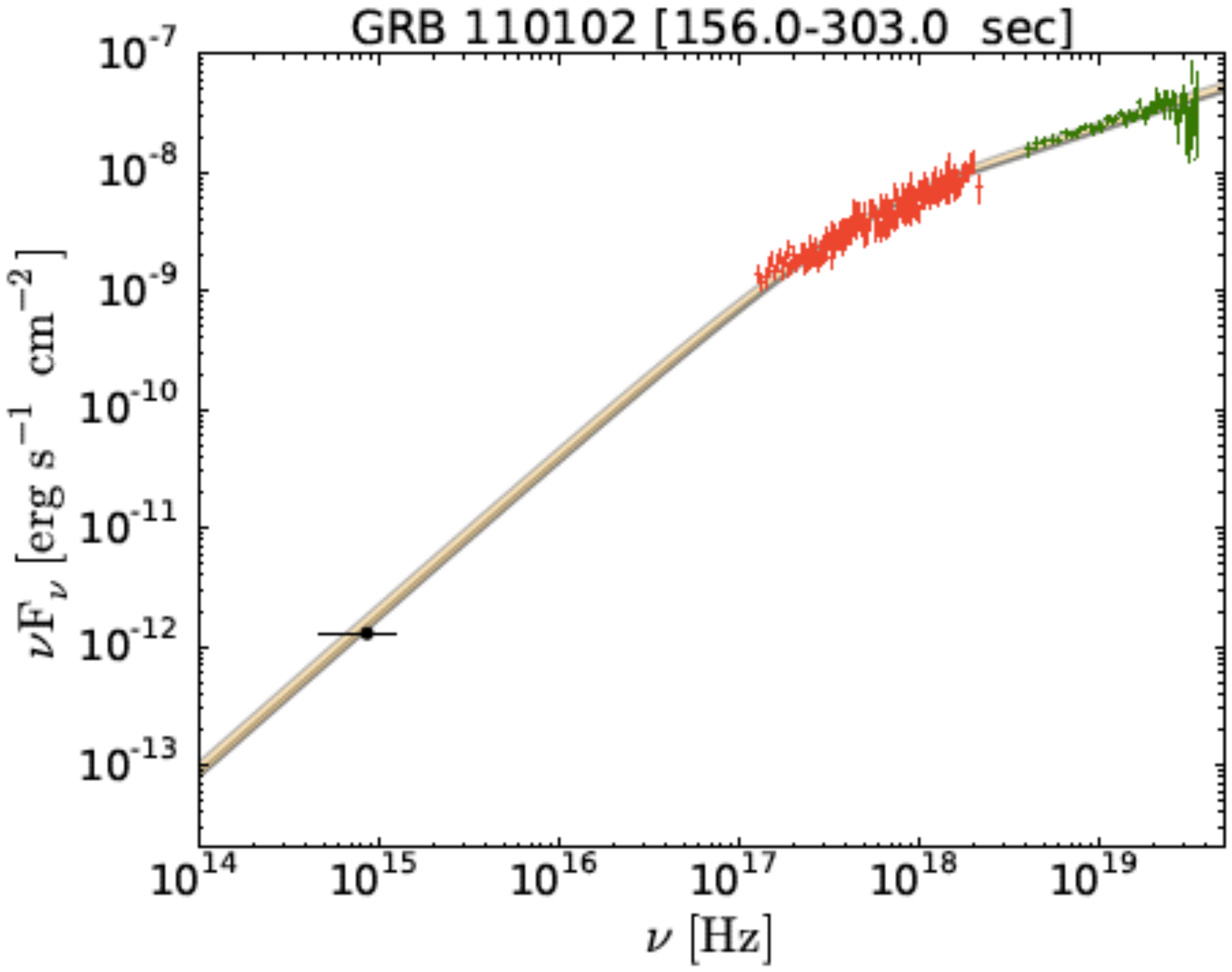
18% OF CASES

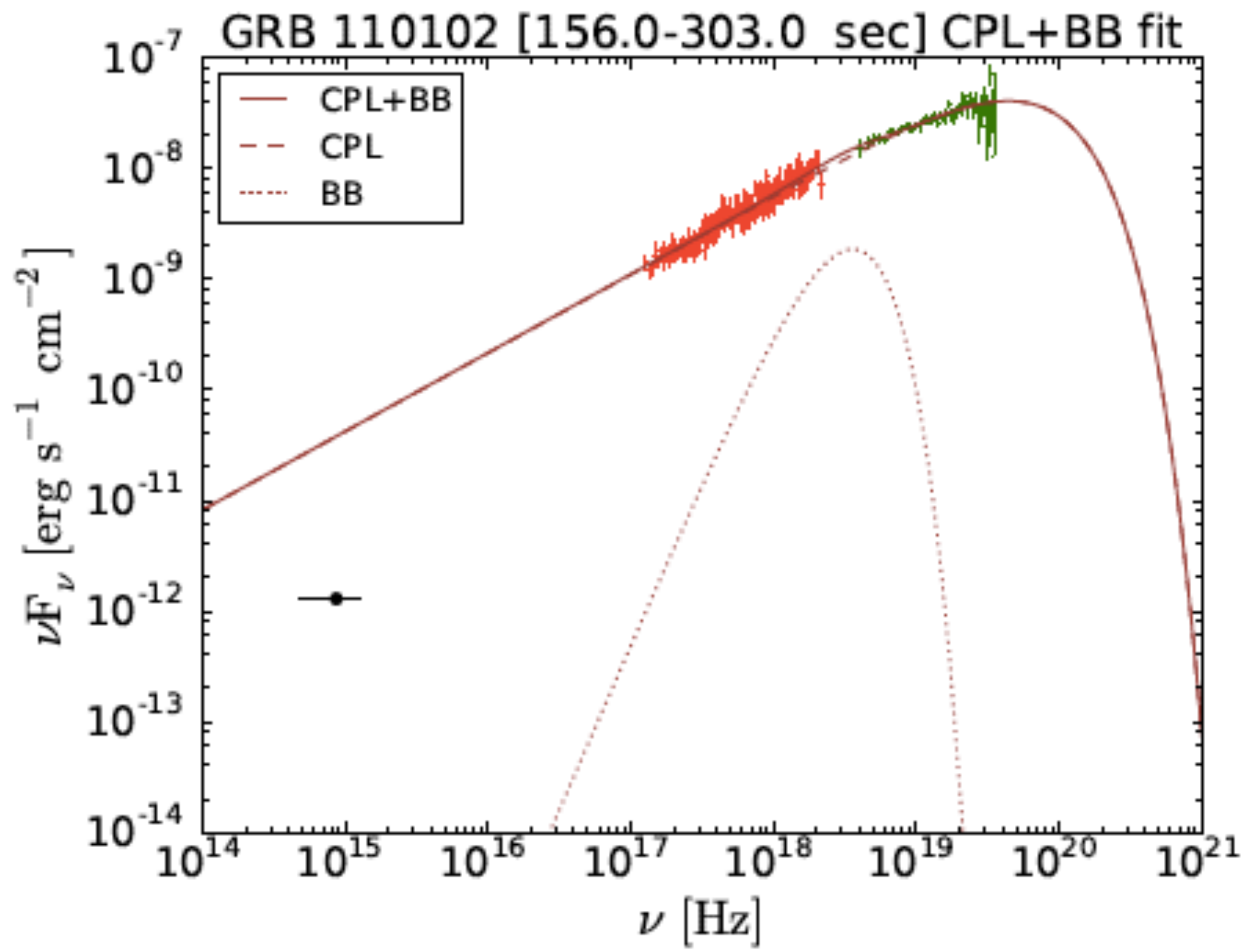




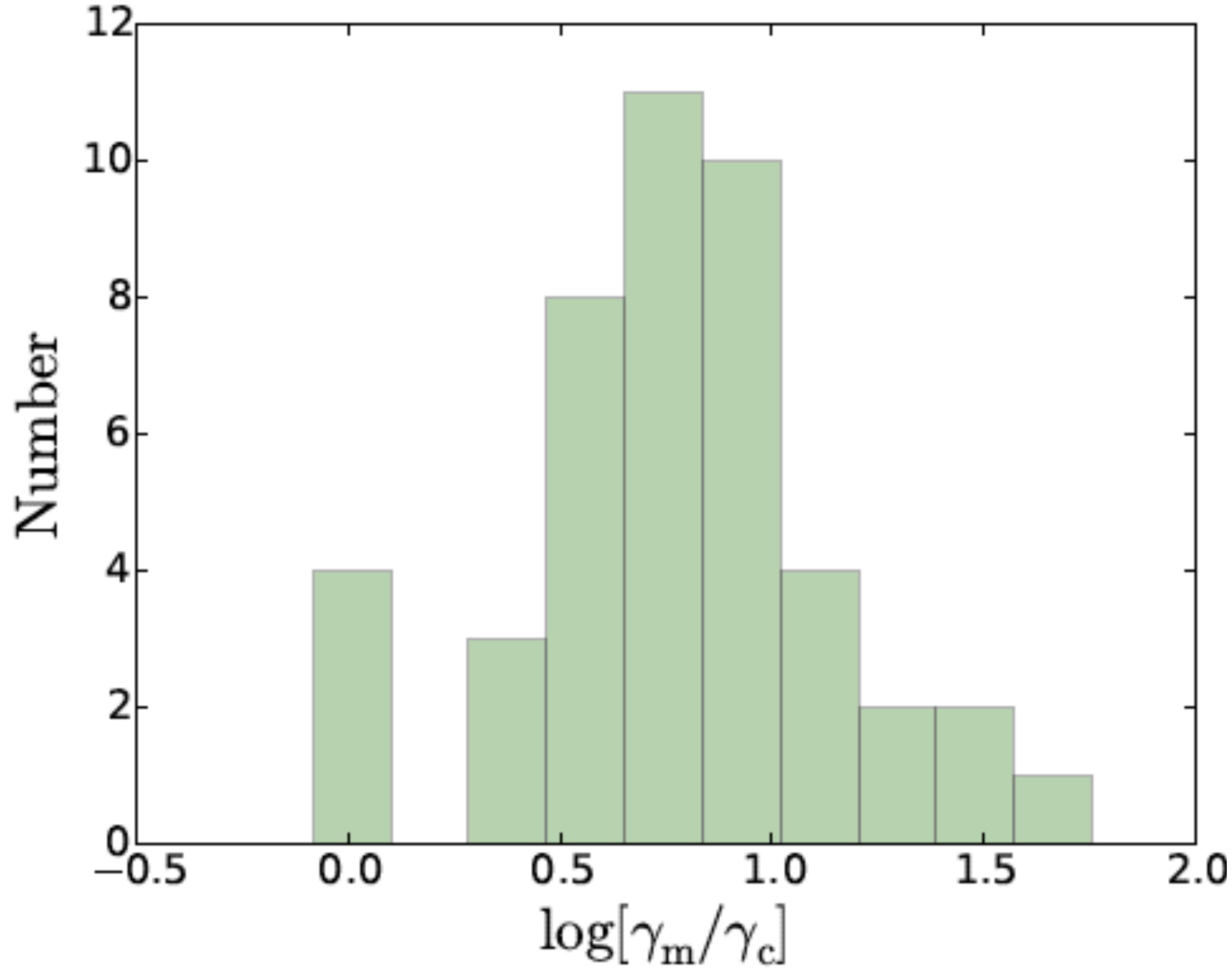
PROMPT OPTICAL EMISSION - BB COMPONENTS

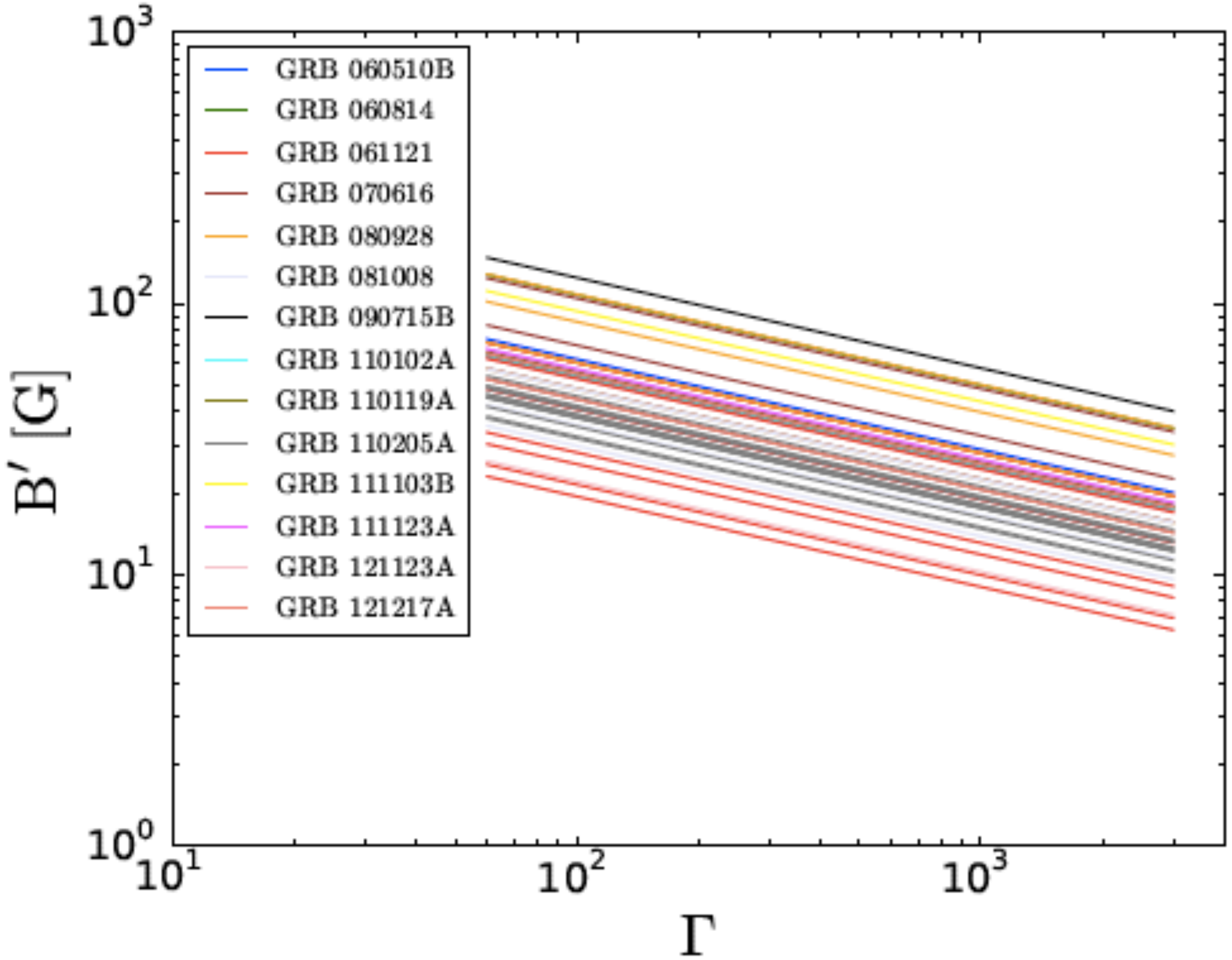
OVER-PREDICTION





SYNCHROTRON FITS - CONSTRAINS





CONCLUSIONS AND FUTURE PERSPECTIVES

- Presence of low-energy breaks in prompt emission spectra
- Marginally fast cooling synchrotron scenario is preferred
- Prompt optical emission is consistent in 50% of cases
- Strict constrains on the prompt emission region

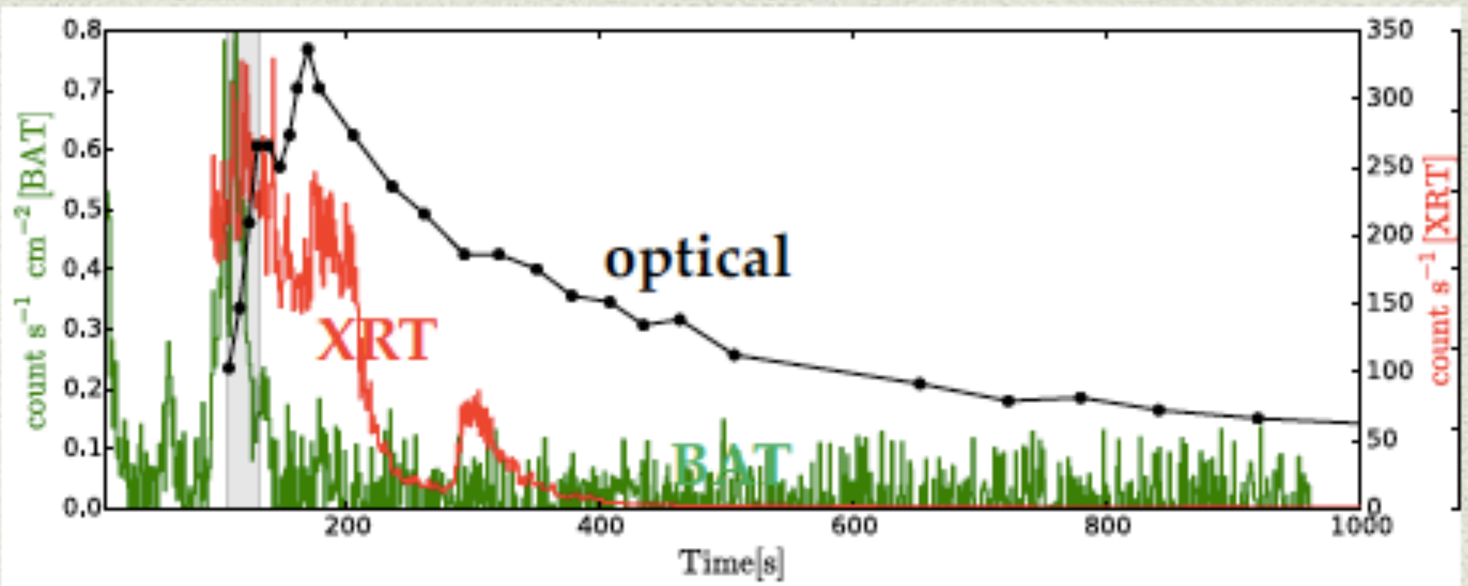
If internal shocks, can the magnetic field be so low?

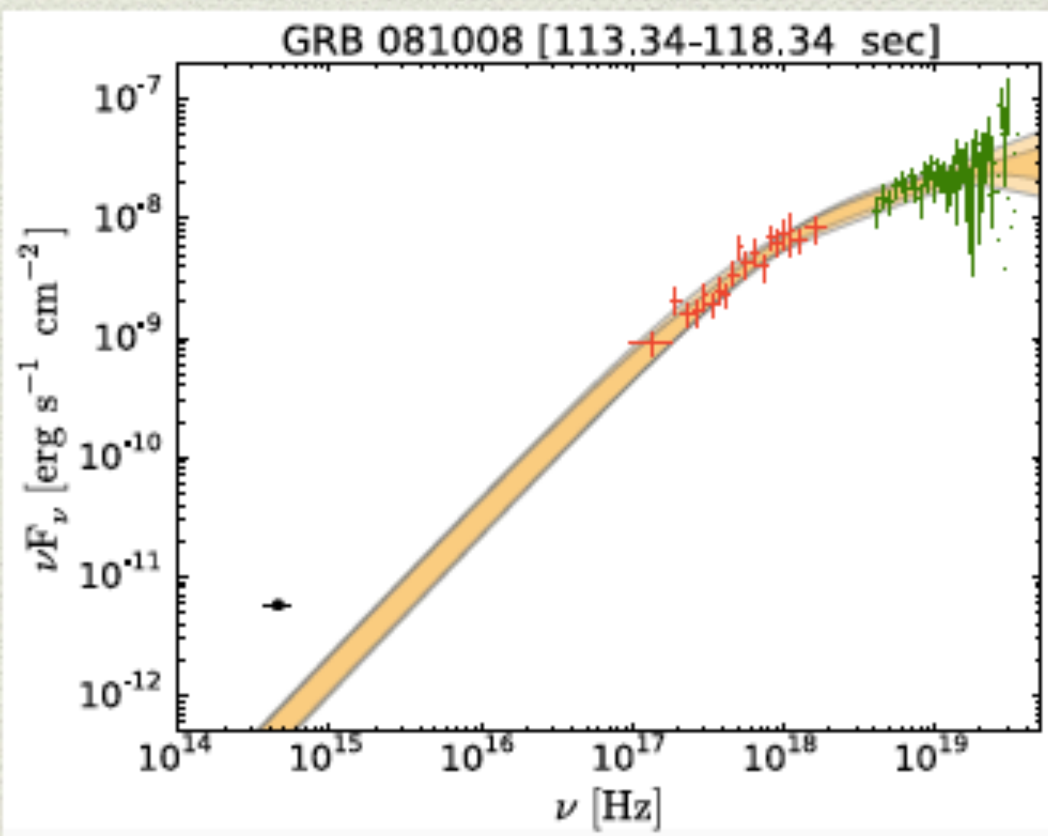
Is magnetic reconnection a solution?

Thank you!

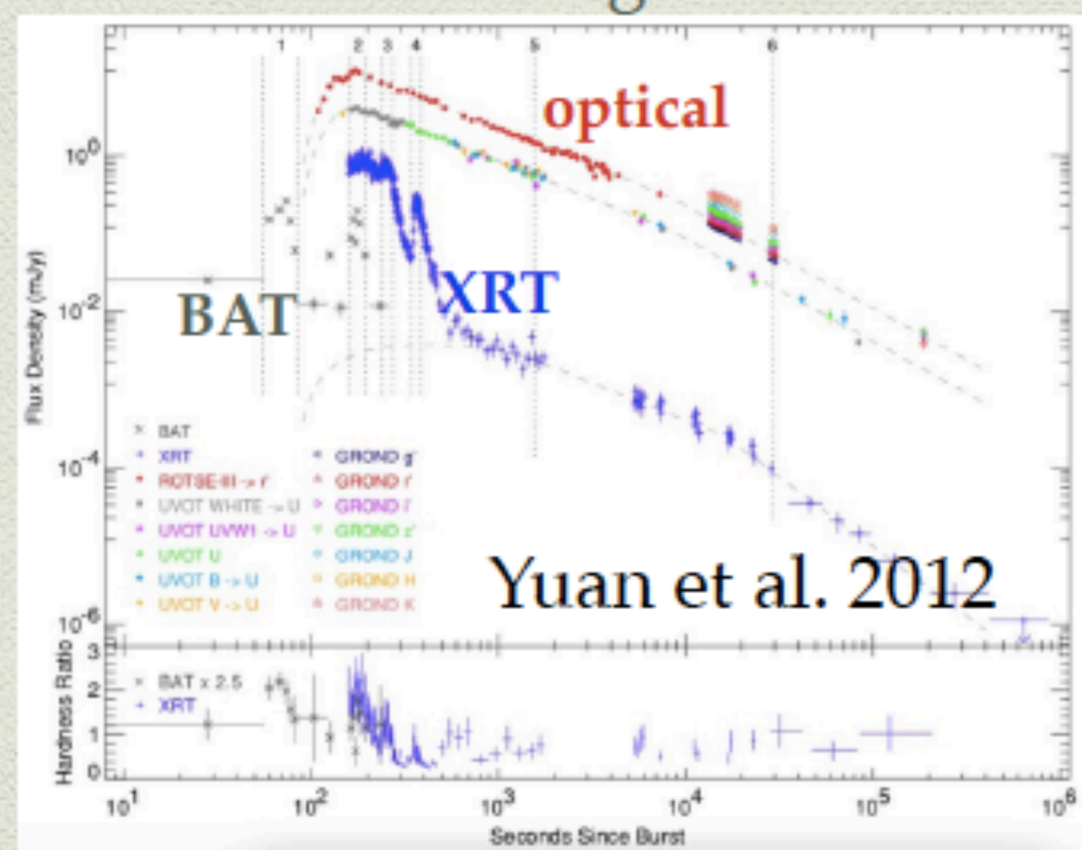
Optical simultaneous data
(+ from empirical model to synchrotron model)

Oganesyan et al., 2018, in preparation





lightcurves in log scale and on a much longer timescale



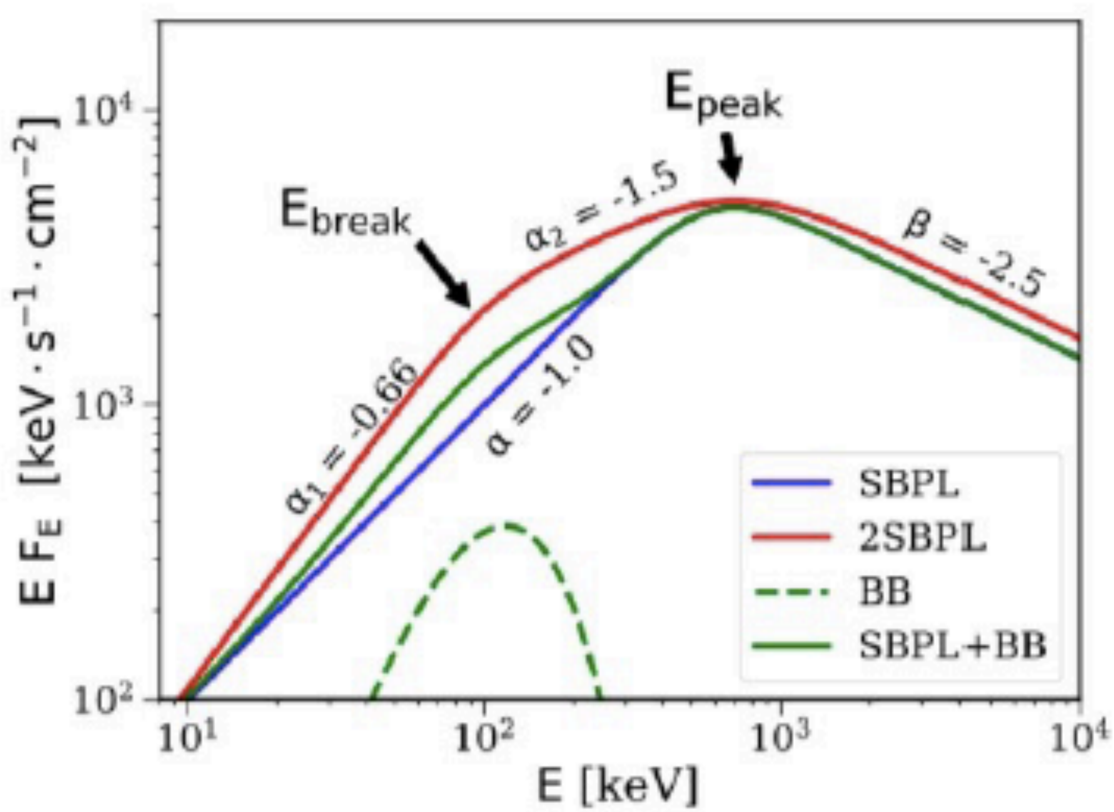


Fig. 2. Comparison between the SBPL model (blue curve), SBPL+BB (green solid curve), and 2SBPL (red curve). Normalizations are arbitrary.

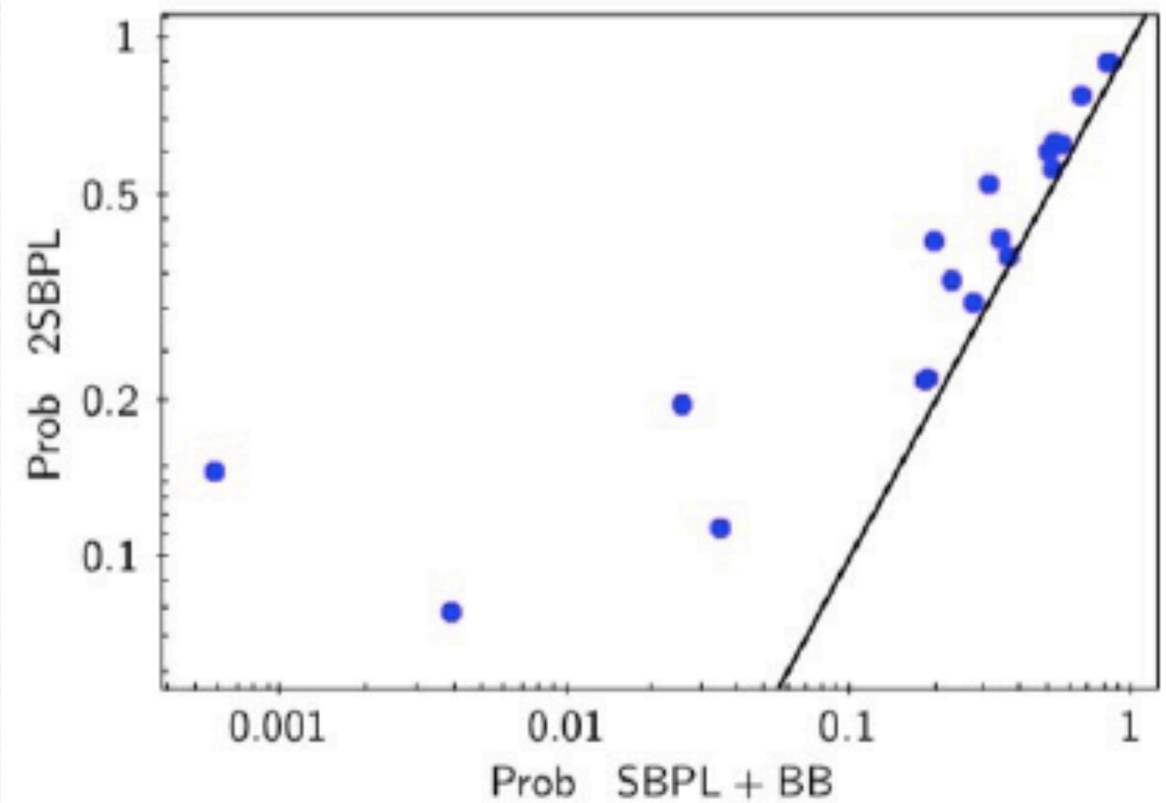


Fig. 5. Fit probability for time-resolved spectra: comparison between fits performed with a 2SBPL model (y-axis) and with a SBPL+BB model (x-axis). The two models have the same number of degrees of freedom. The equality line is shown as a solid black line.

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

Is a bad estimate of the N_H causing the low-energy breaks ?

Oganesyan, Nava, Ghirlanda, Celotti, 2017, ApJ

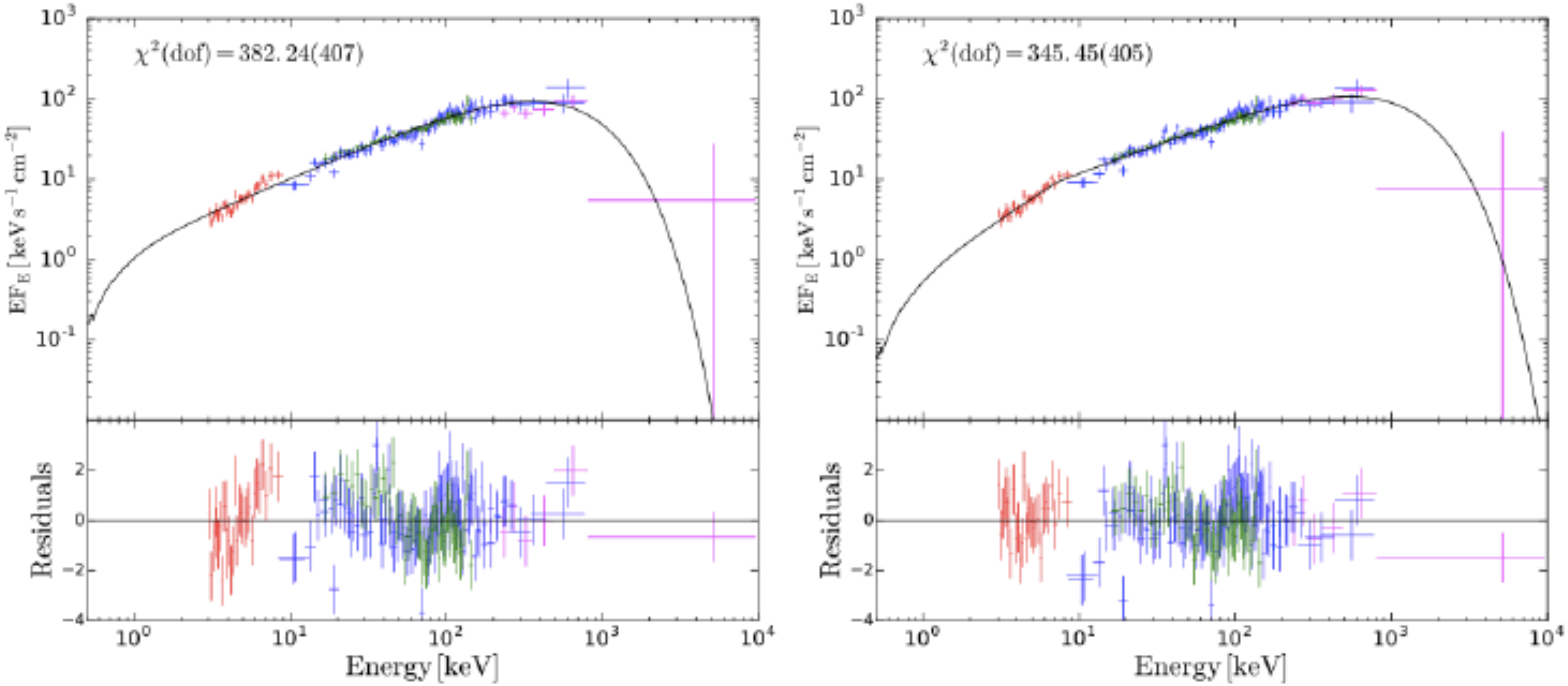


Figure 11. Time-integrated spectrum of GRB 140512A during the second pulse, fitted by CPL (left) and BCPL (right) models when data below 3 keV are excluded. The improvement of the chi-square (reported in the upper-left corner of each panel) when the low-energy break is added is significant at 6.1σ, according to the F-test.

Is an underestimate of *pile-up* causing the low-energy breaks ?

Oganesyan, Nava, Ghirlanda, Celotti, 2017, ApJ

Table 4. Results of the test performed to verify the possible effects of pile-up on the presence of a break energy in the XRT energy range. The test is applied to one time-resolved spectrum of GRB 140512A (from 128.46 to 133.58s). The first column reports the maximum rate of the light curve after the central region of the source has been excluded. Columns 2-5 list the χ^2 (d.o.f.) of the four different spectral models. Models that differ from each other for the presence of a break (i.e. PL vs BPL and CPL vs BCPL) are compared in the last two columns, where the significance of the F-test is reported.

Rate [cts/s]	PL	CPL	BPL	BCPL	F_{PL-BPL}	$F_{CPL-BCPL}$
120	412.97 (228)	243.89 (227)	217.09 (226)	210.95 (225)	1.11e-16 (8.4)	8.14e-08 (5.4)
90	264.89 (220)	224.17 (219)	216.90 (218)	211.05 (217)	3.45e-10 (6.3)	1.44e-03 (3.2)
70	253.40 (218)	218.80 (217)	213.14 (216)	207.45 (215)	7.67e-09 (5.8)	3.26e-03 (2.9)

GRB 140512A: time resolved

Oganesyan, Nava, Ghirlanda, Celotti, 2017, ApJ