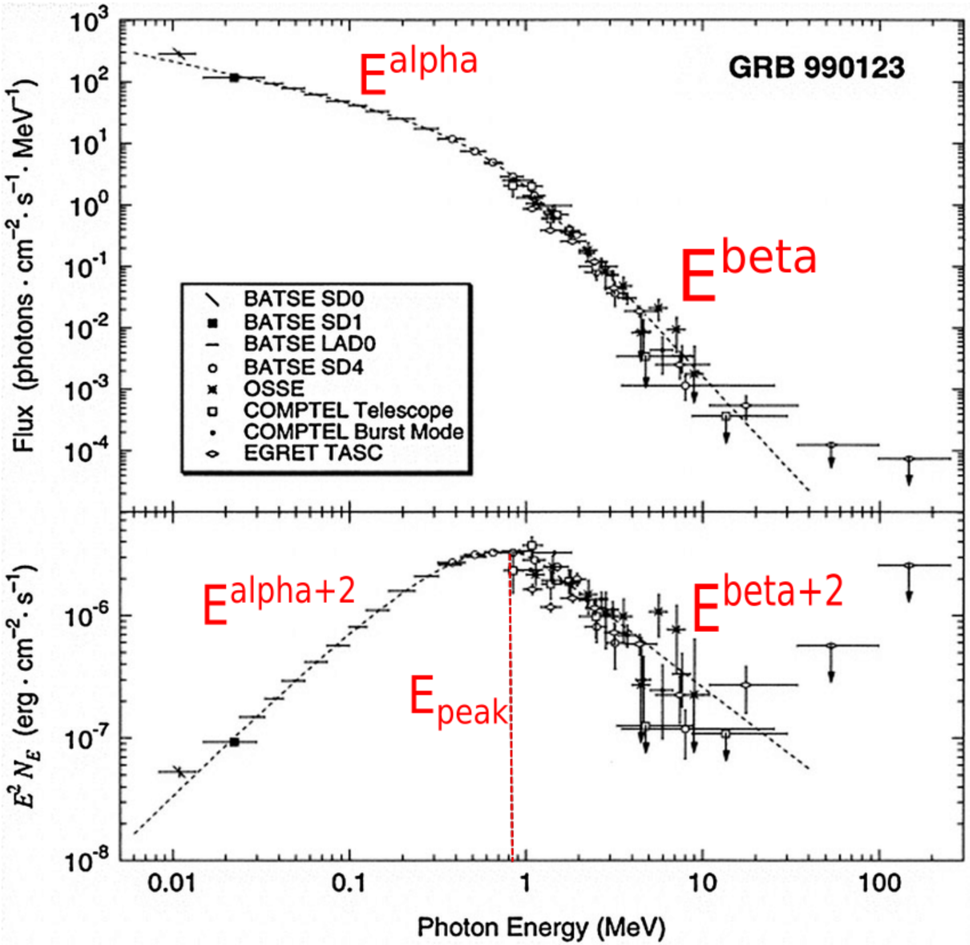
GRB prompt emission spectra: the synchrotron revenge

Maria Edvige Ravasio
PhD Student
University of Milano-Bicocca
INAF – Astronomical Observatory of Brera – Merate

In collaboration with
Giancarlo Ghirlanda, Gabriele Ghisellini, Lara Nava, Gor Oganesyan

Yamada Conference LXXI: Gamma-ray Bursts in the Gravitational Wave Era 2019
30/10/2019 - Yokohama, Japan

Typical observed GRB prompt spectrum



From Briggs et al., 1999

-Non-thermal spectrum

-Band function **(Band et al., 1993)** **works most of the time** (sometimes a power-law or a cut-off power-law is all that could be constrained, depending also from the energy range covered by the instrument)

Open problem of the GRB prompt emission

What is the radiative process responsible for the prompt emission?

- Non-thermal spectrum
- Accelerated electrons in a magnetized region

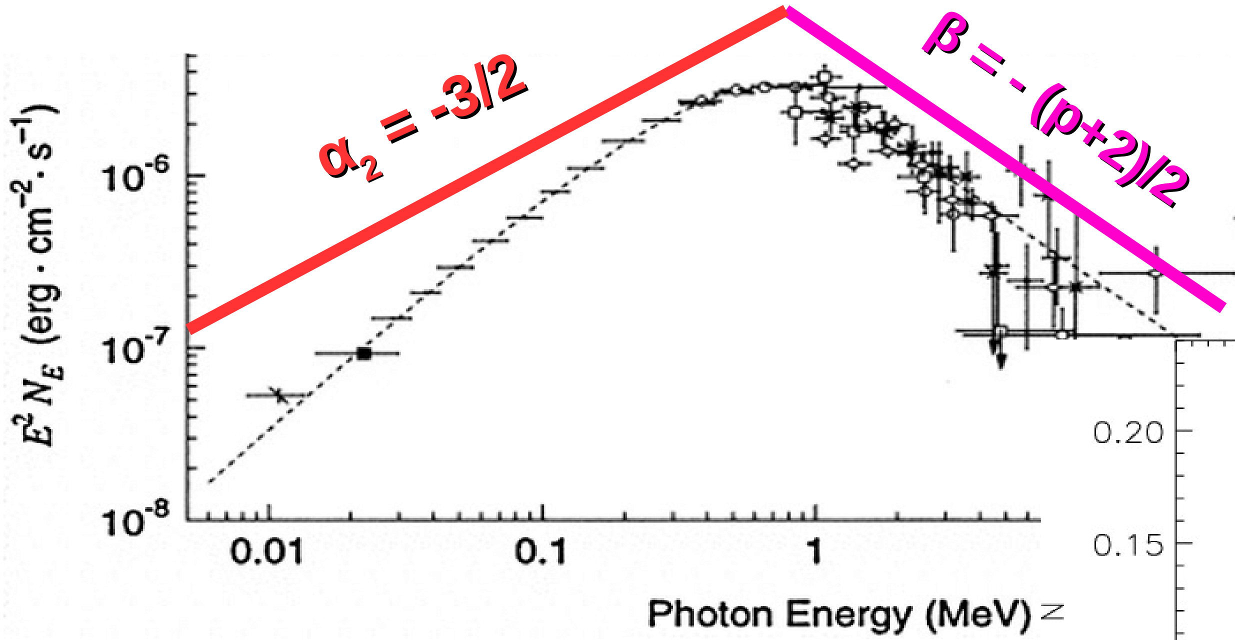
→ Synchrotron?

Rees & Mészaros 1994
Sari et al. 1996, 1998

Synchrotron prediction for prompt spectrum - fast cooling regime

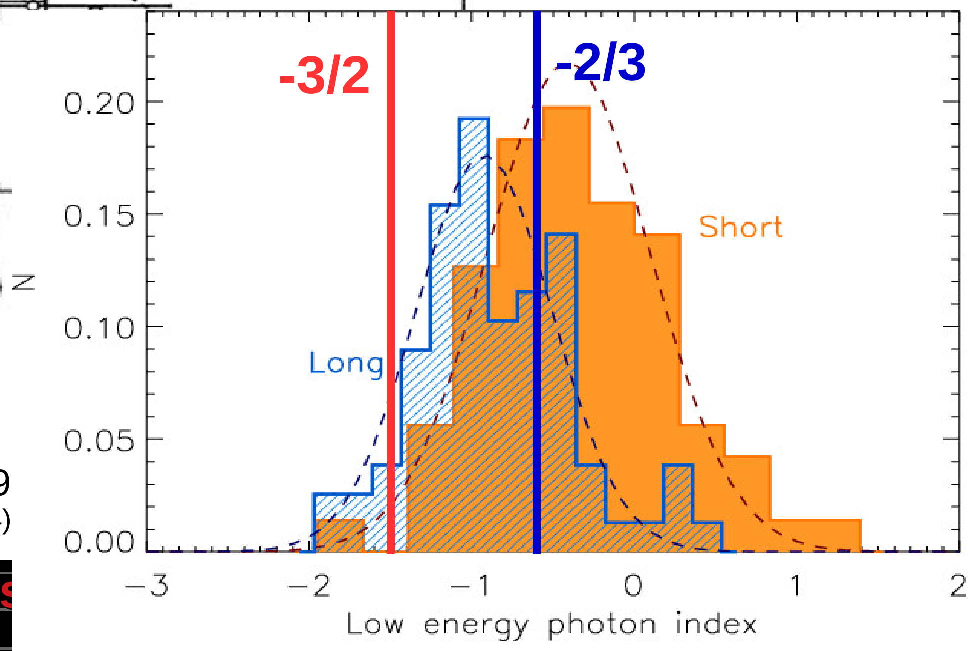
Theoretical predictions

Sari & Piran 1997
Preece 1998
Ghisellini 2000



From Ghirlanda et al., 2009
(see also Preece 1998, Kaneko 2006, Nava 2011, Goldstein 2012, Gruber 2014)

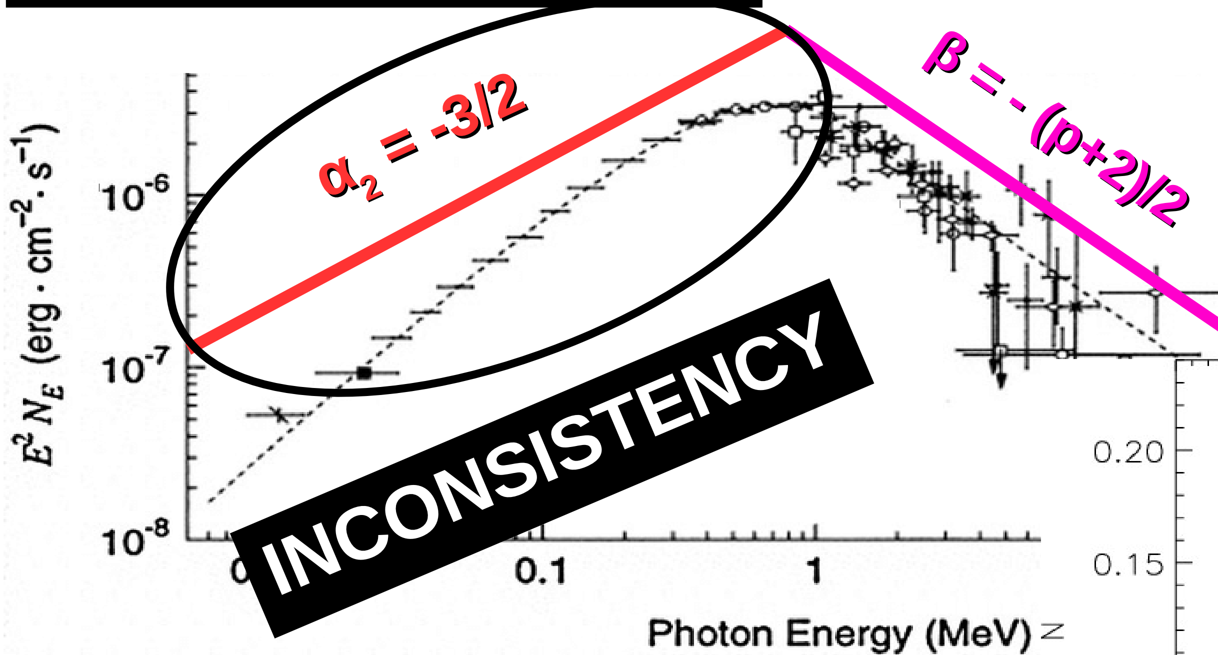
Observed slopes



Synchrotron prediction for prompt spectrum - fast cooling regime

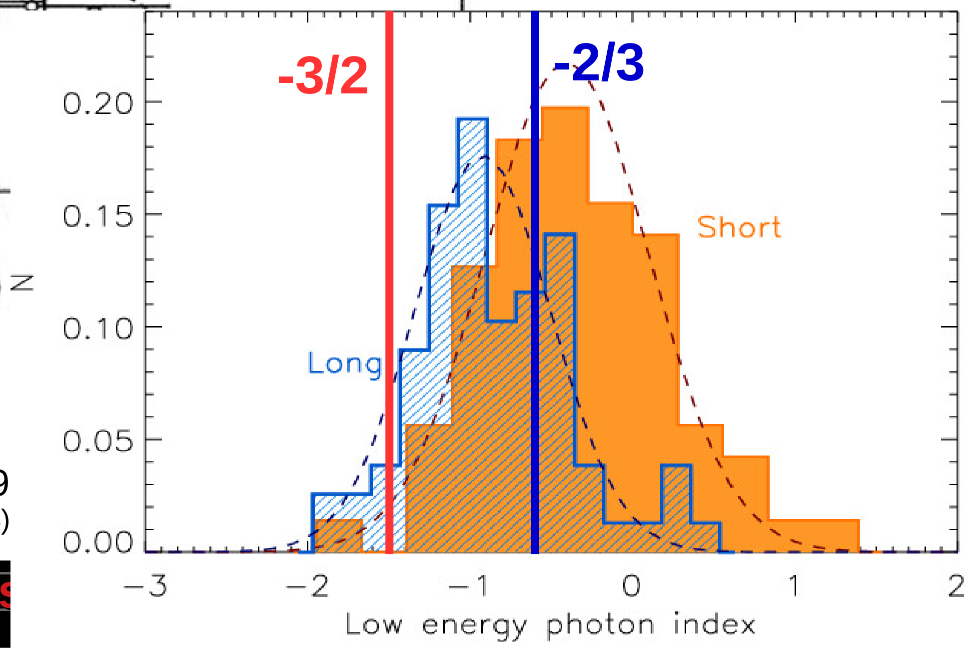
Theoretical predictions

Sari & Piran 1997
Preece 1998
Ghisellini 2000

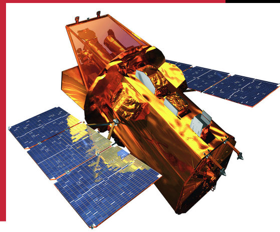


From Ghirlanda et al., 2009
(see also Preece 1998, Kaneko 2006, Nava 2011, Goldstein 2012, Gruber 2014)

Observed slopes



Recent hints from Oganesyan et al., 2017, 2018

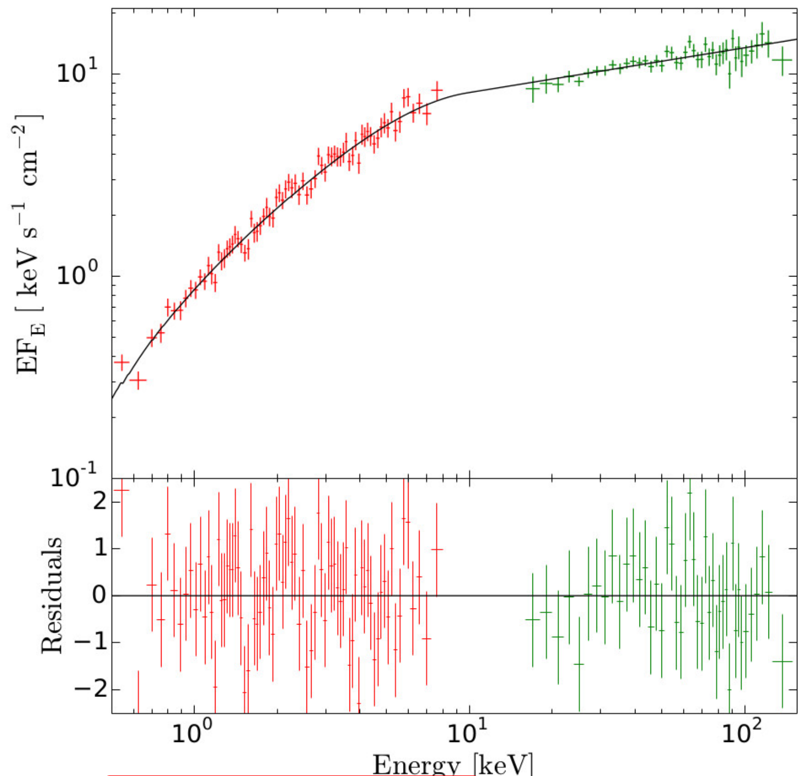


34 long GRBs observed simultaneously with XRT and BAT (Swift satellite)

- 62% of the prompt spectra display a break between 2 and 30 keV

- the spectral indices are $\langle\alpha_1\rangle = -0.66 \pm 0.35$ and $\langle\alpha_2\rangle = -1.46 \pm 0.31$

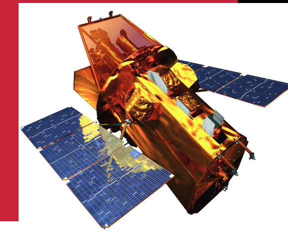
Consistent with synchrotron prediction!



XRT (0.3 – 10 keV)

BAT (15 – 150 keV)

Recent hints from Oganesyan et al., 2017, 2018

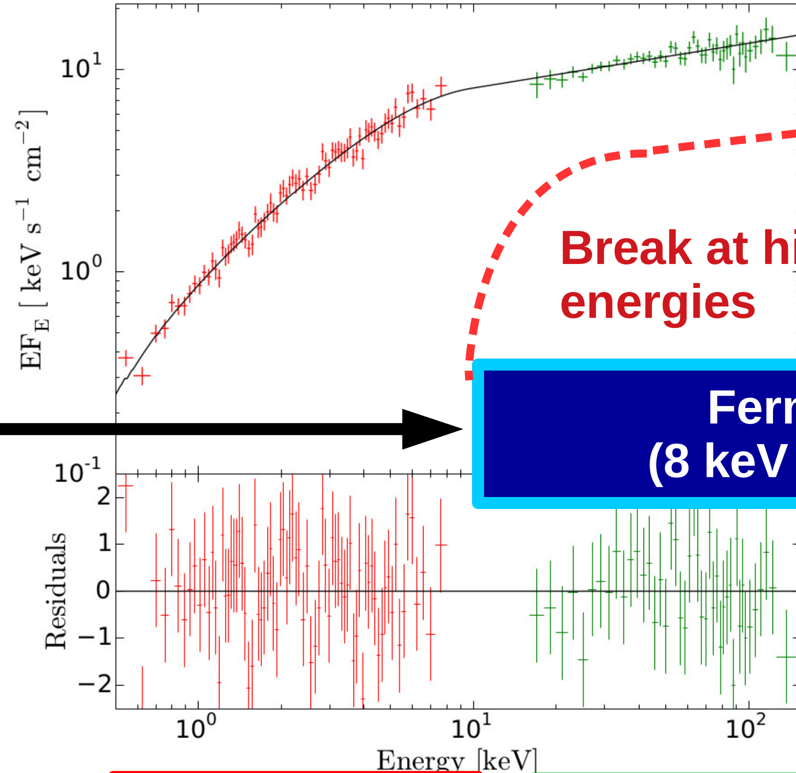


34 long GRBs observed simultaneously with XRT and BAT (Swift satellite)

- 62% of the prompt spectra display a break between 2 and 30 keV

- the spectral indices are $\langle\alpha_1\rangle = -0.66 \pm 0.35$ and $\langle\alpha_2\rangle = -1.46 \pm 0.31$

Consistent with synchrotron prediction!

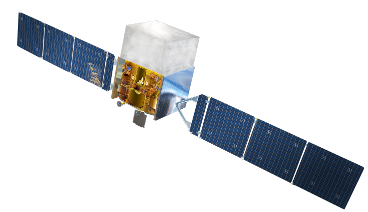


XRT (0.3 – 10 keV)

BAT (15 – 150 keV)

Break at higher energies ?

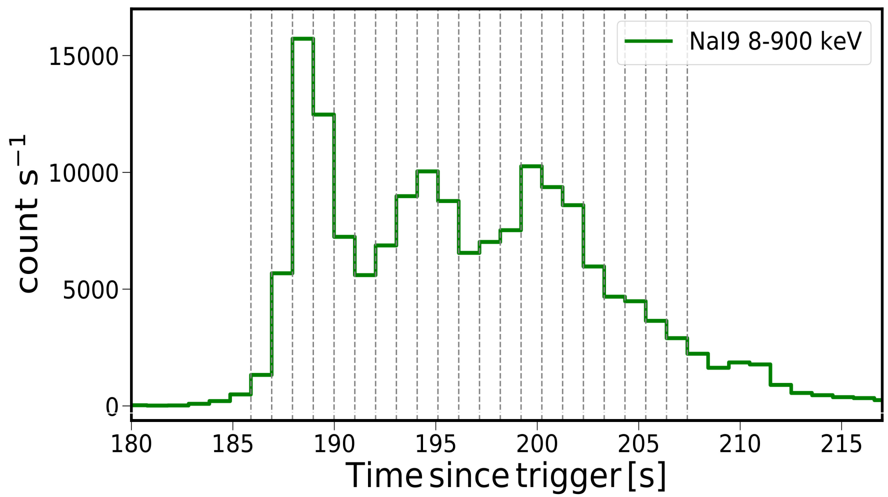
Fermi/GBM (8 keV – 40 MeV)

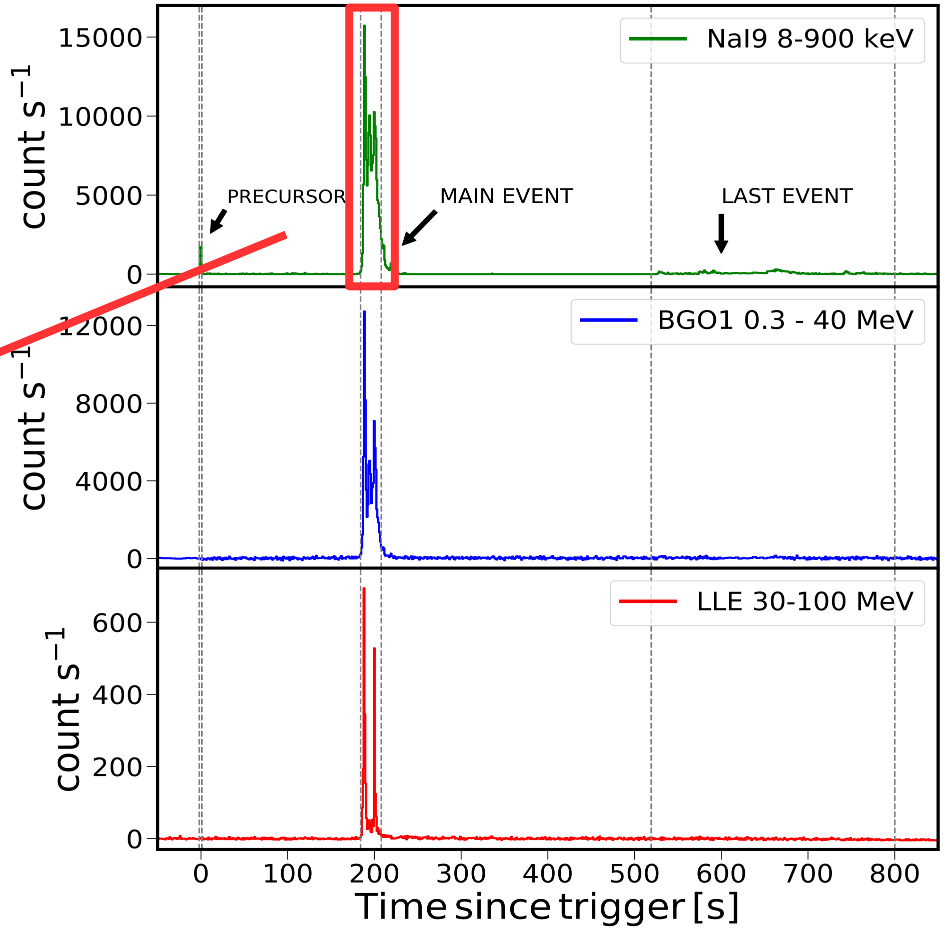


GRB 160625B

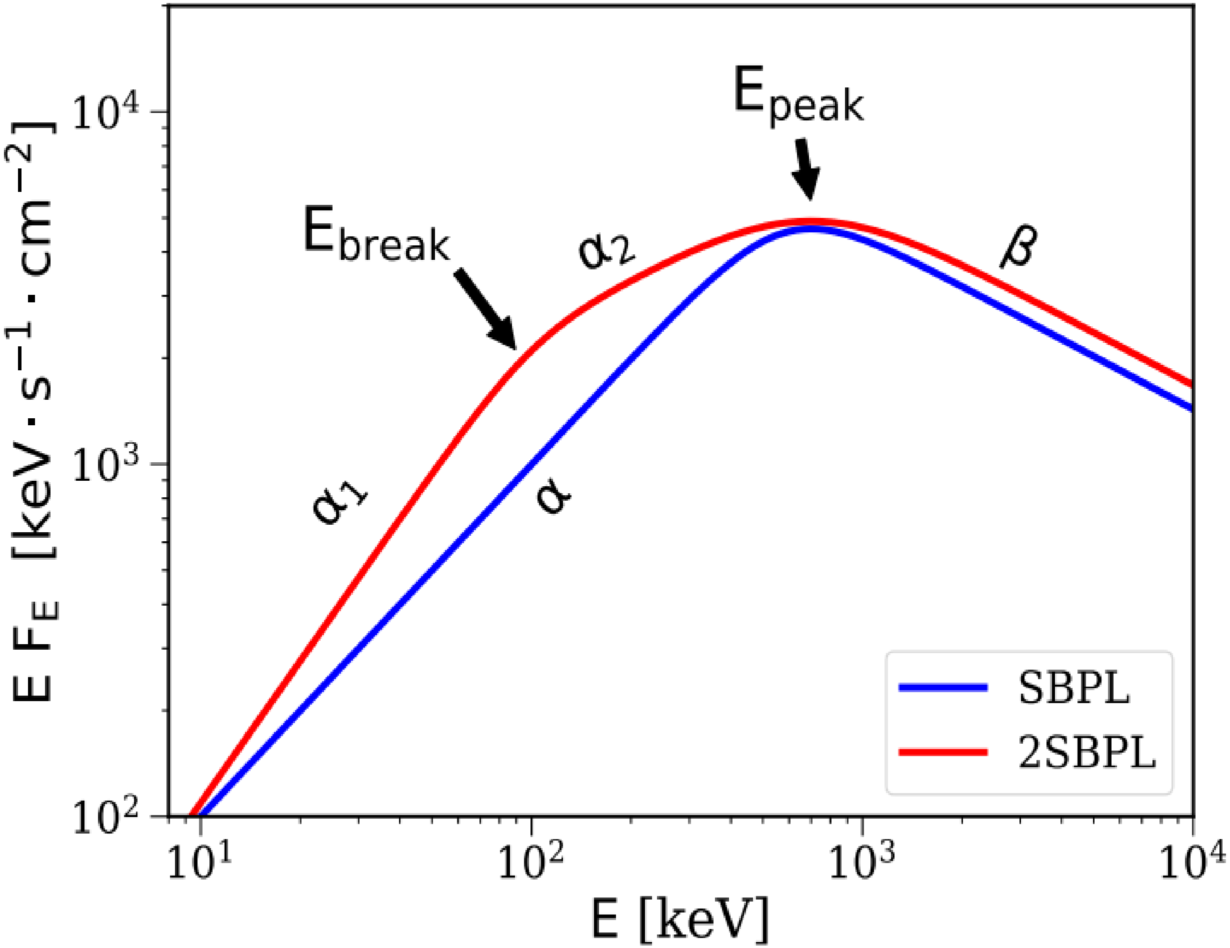
Racusin et al GCN#19580 (LAT)
Burns et al GCN#19581 (GBM)

- **The GBM light curve consists of 3 distinct emission episodes**
- **Fluence = 5.7 x 10^{-4} erg/cm^2**
- **z = 1.406**
- **We performed a time-resolved analysis on the main event**





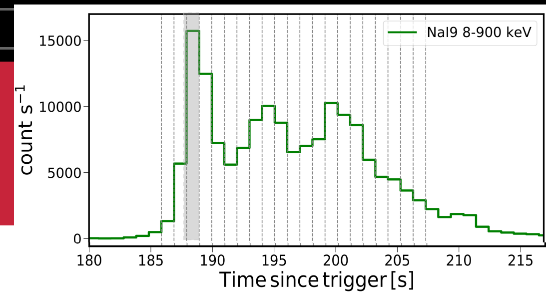
Comparison of the fitting functions



Model independent analytical function

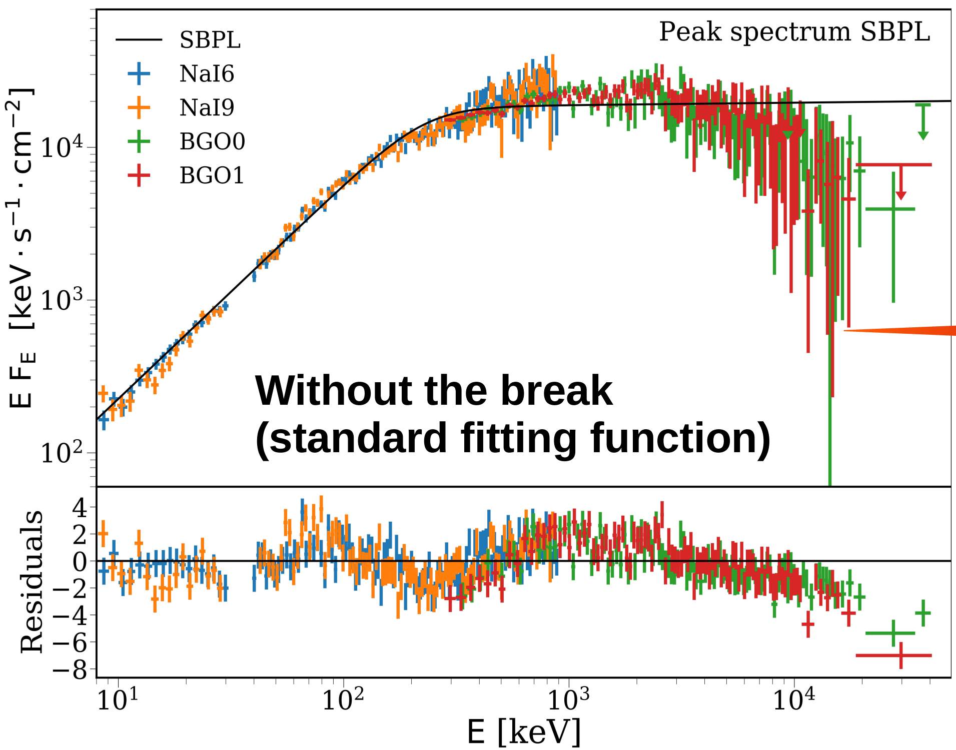
- **three power-laws, allowing for the presence of another spectral break**

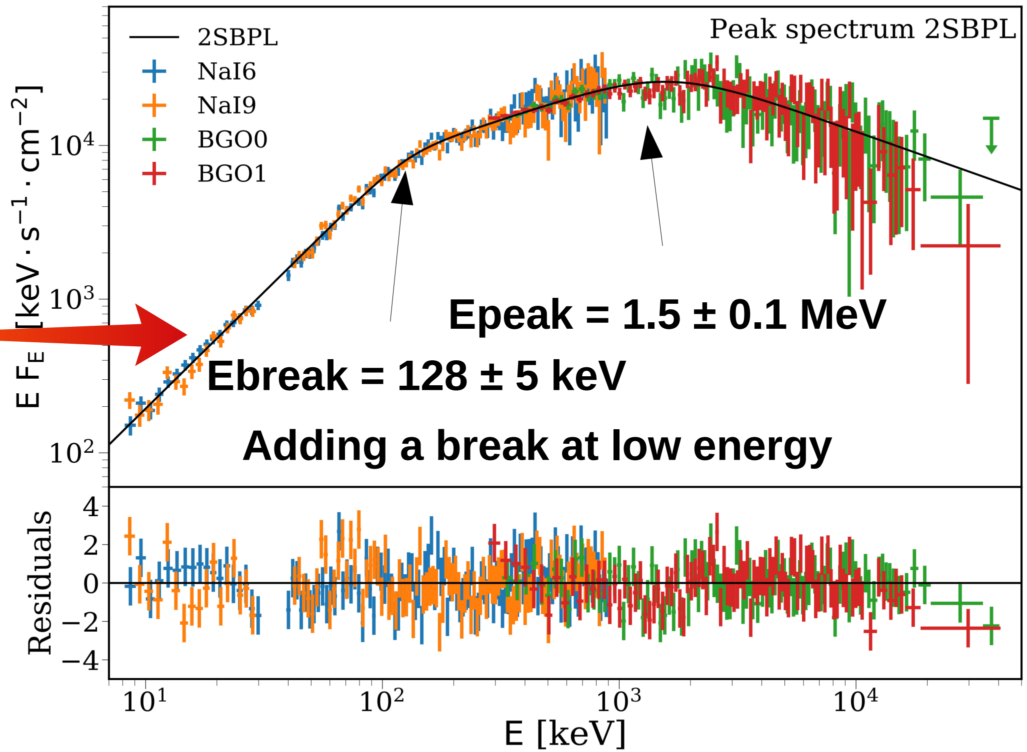
GRB 160625B



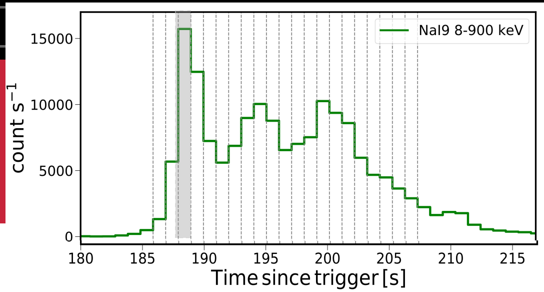
Ravasio et al., 2018, A&A

Adding a break at low energy → the fit significantly improves! σ(F-test) > 8σ



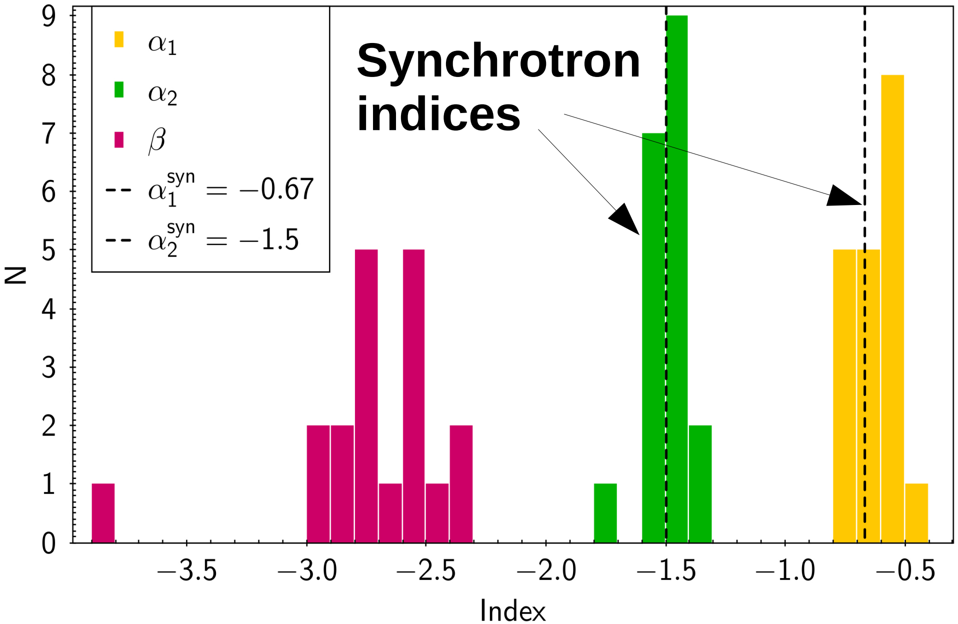


GRB 160625B

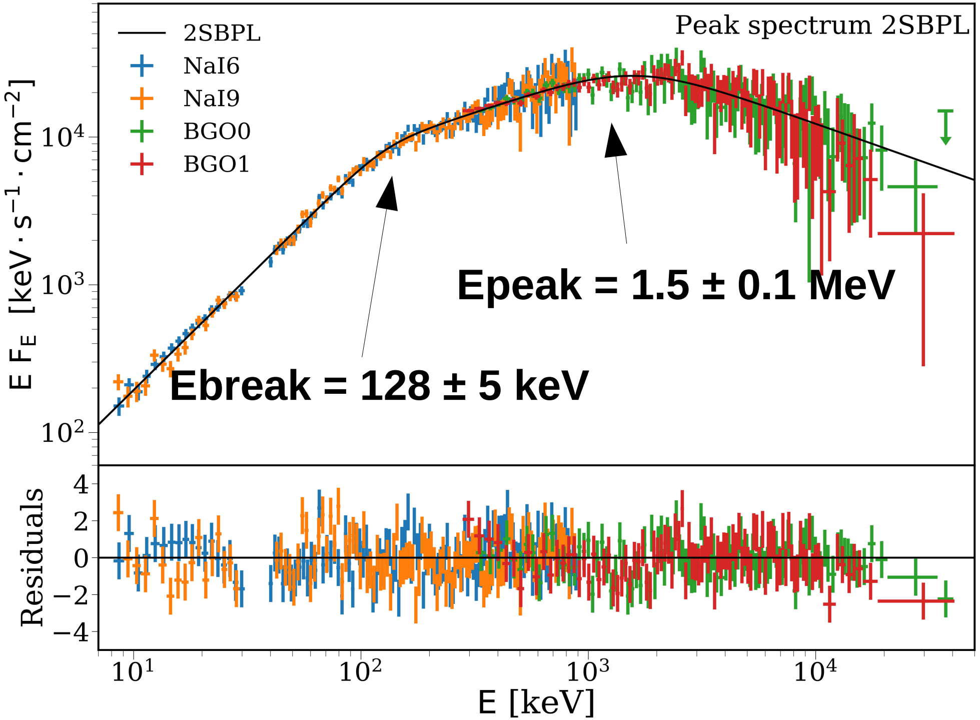


Ravasio et al., 2018, A&A

Adding a break at low energy → the fit significantly improves! σ(F-test) > 8σ



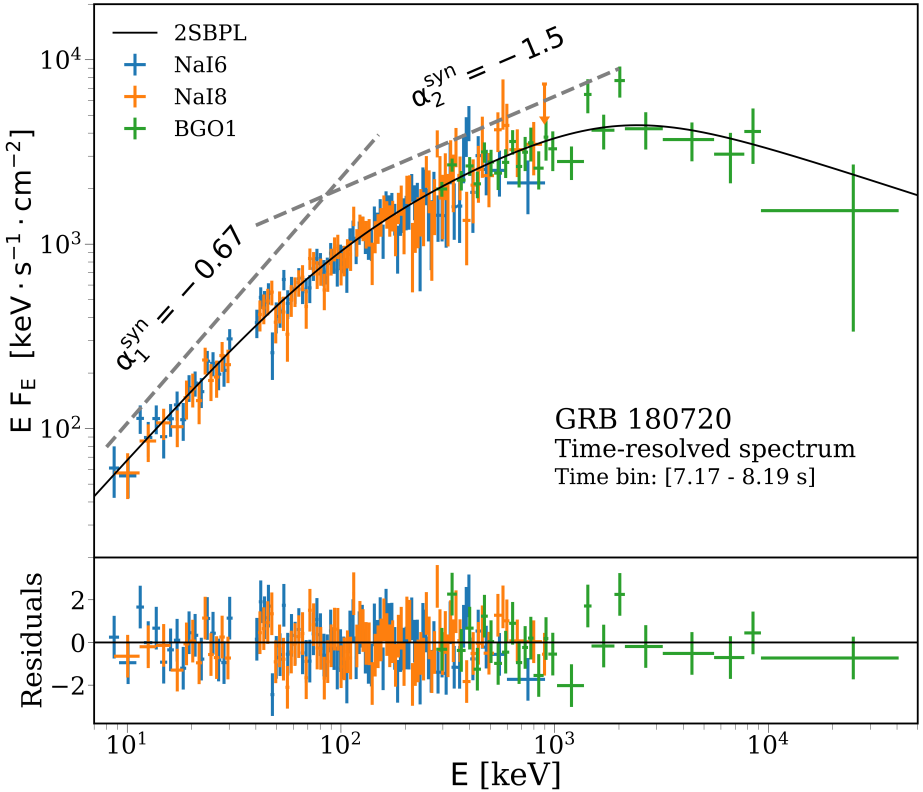
DISTRIBUTION OF THE SPECTRAL INDICES from the time-resolved analysis



→ synchrotron consistency also found by Zhang et al. 2018

Selection of the candidates

Ravasio, Ghirlanda, Nava & Ghisellini, 2019, A&A



We selected the **brightest events** in the Fermi/GBM Catalogue

10 LONG BRIGHTEST GRBs
(over 2227 long GRBs detected by GBM)

{NEW}

10 SHORT BRIGHTEST GRBs
(over 442 short GRBs detected by GBM)

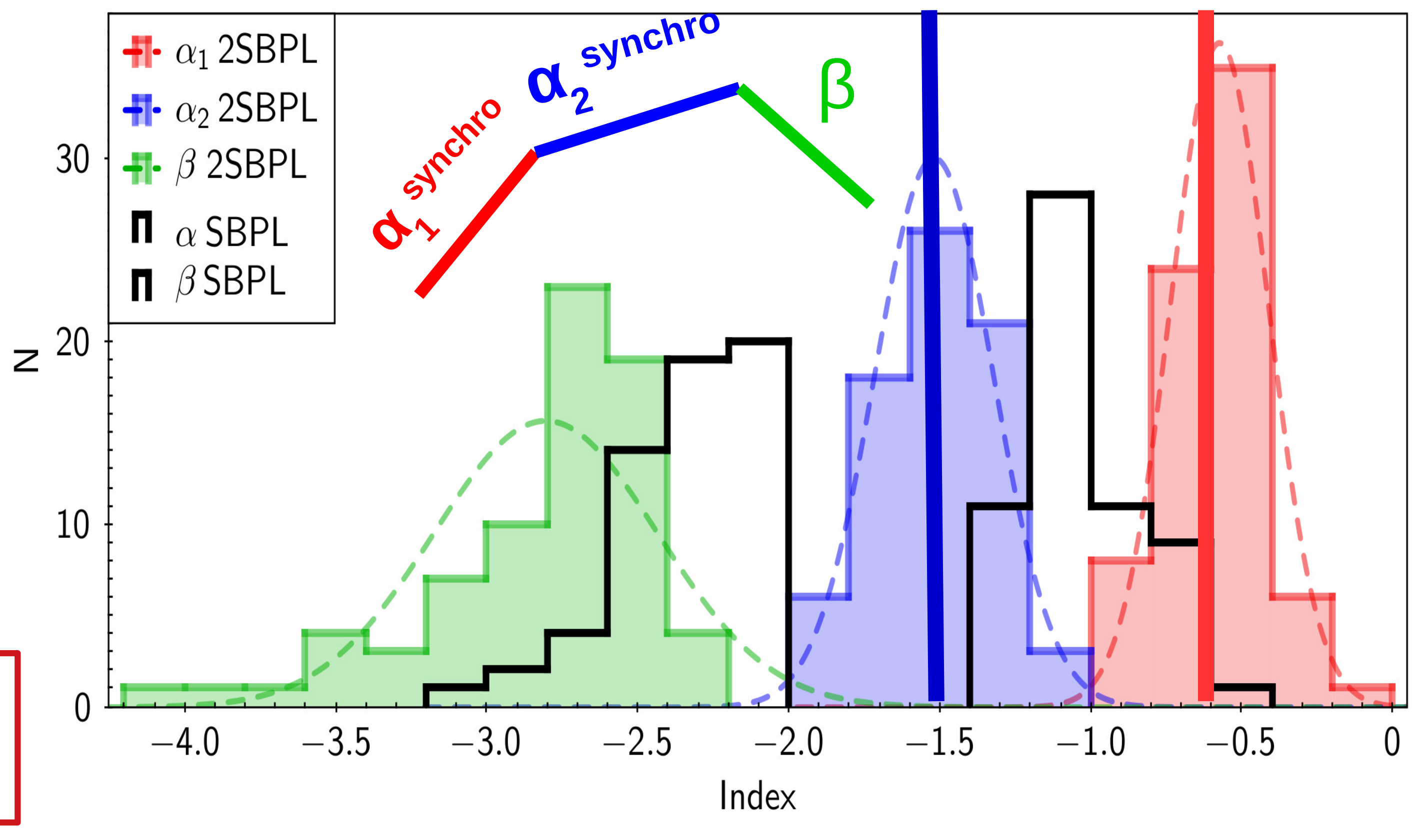
Results of the time-resolved spectral analysis

10 LONG GRBs

BREAK FOUND IN 8/10 GRBs

In most of the time resolved spectra (139/199, **~ 70%**) the best fit model is the 2SBPL function

$\langle\alpha_1\rangle$ = -0.58 (0.16)
$\langle\alpha_2\rangle$ = -1.52 (0.20)



Single break function → $\langle\alpha\rangle$ = -1.02 (0.19)

Results of the time-resolved spectral analysis

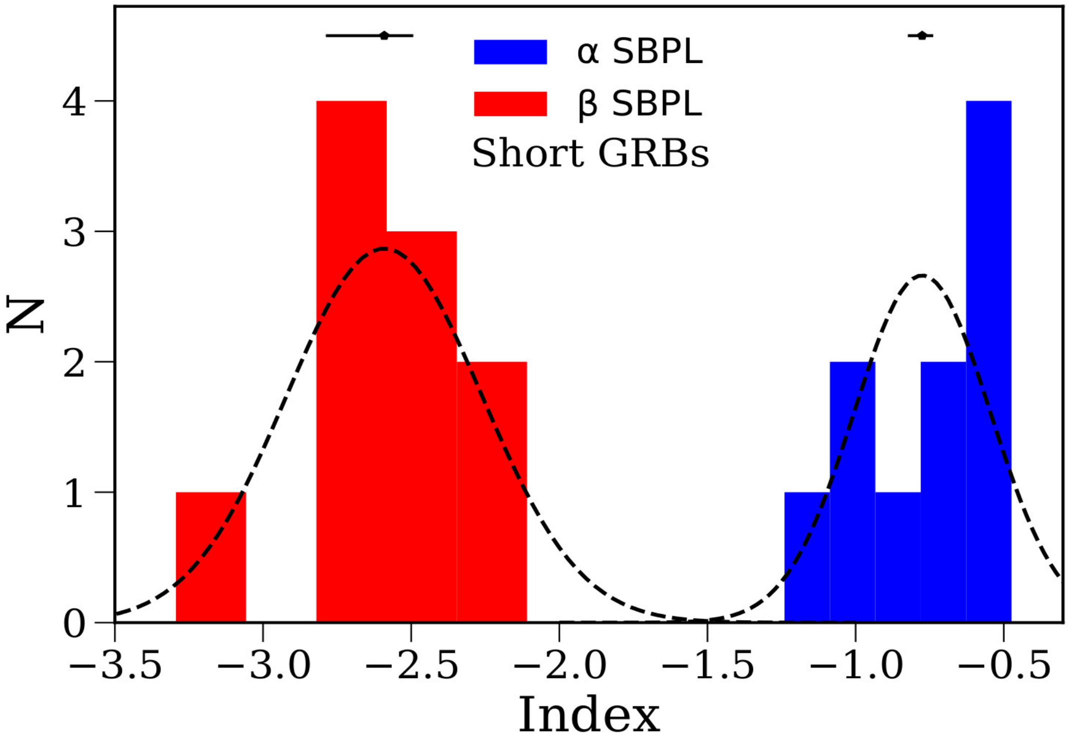
10 SHORT GRBs

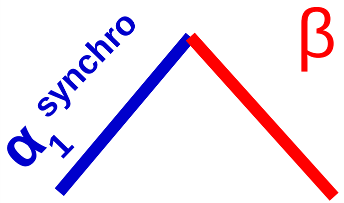
↓

NO ADDITIONAL BREAK!

↓

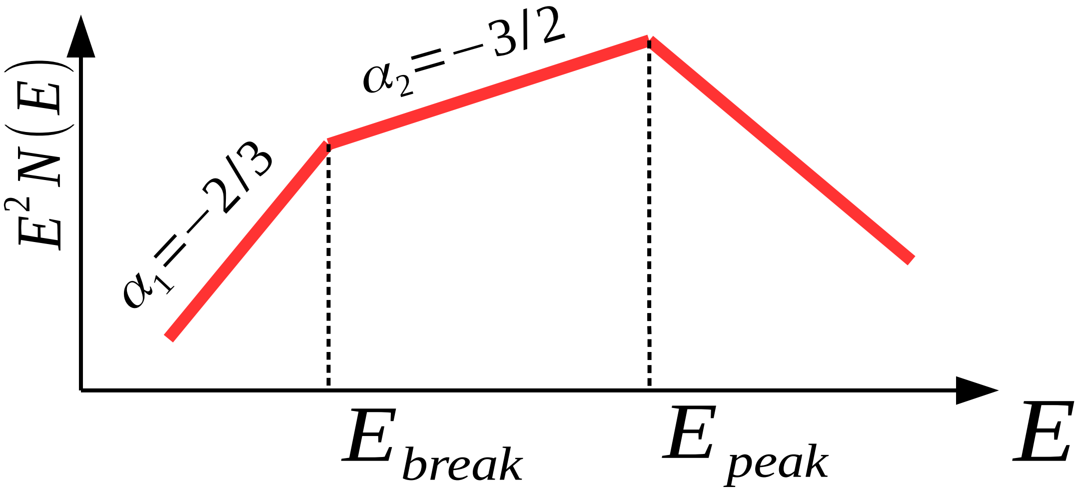
<α> = −0.78 (0.23)





- **It seems to exist only one component below the peak energy**
- **Consistent within 1σ with the synchrotron value α = -2/3**

Theoretical implications

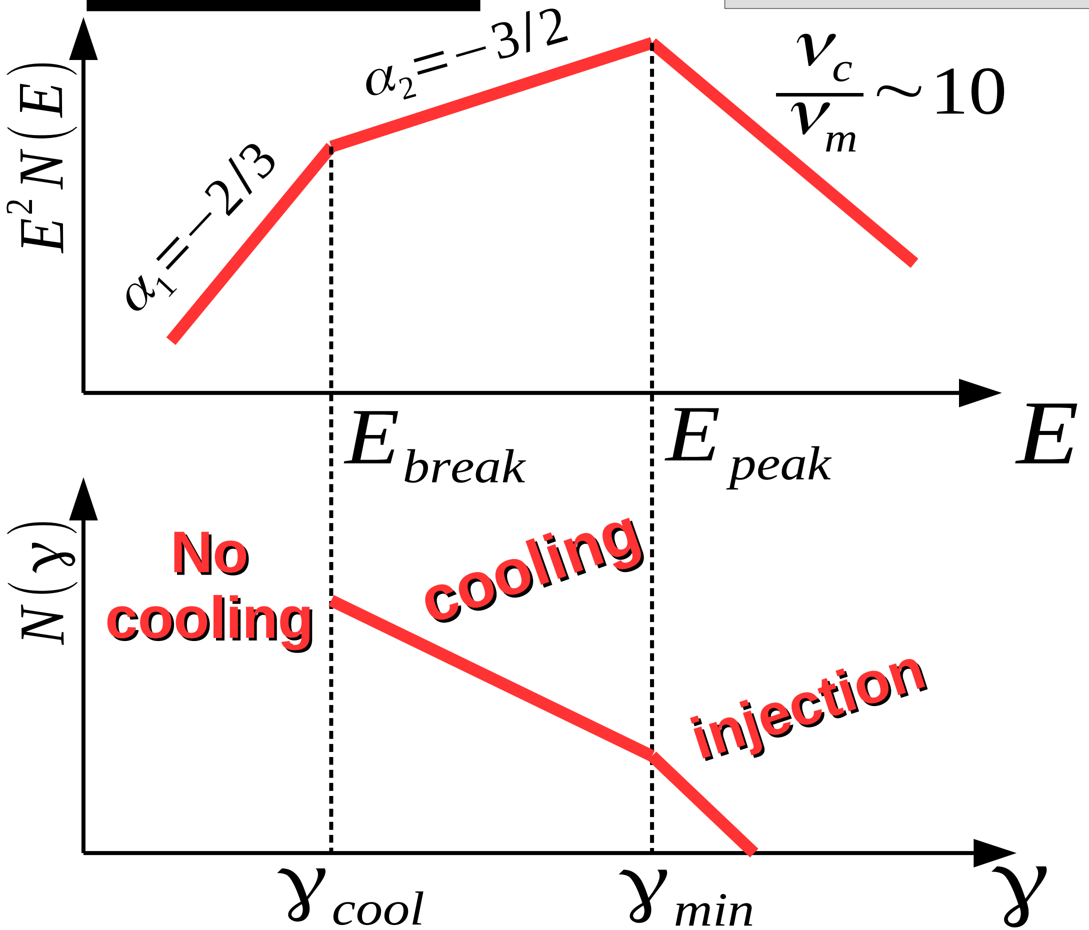


Theoretical implications

LONG GRBs

Marginally fast cooling regime

(Kumar & McMahon 2008, Daigne 2011, Beniamini & Piran 2013)



E_{break} → **synchrotron cooling frequency**

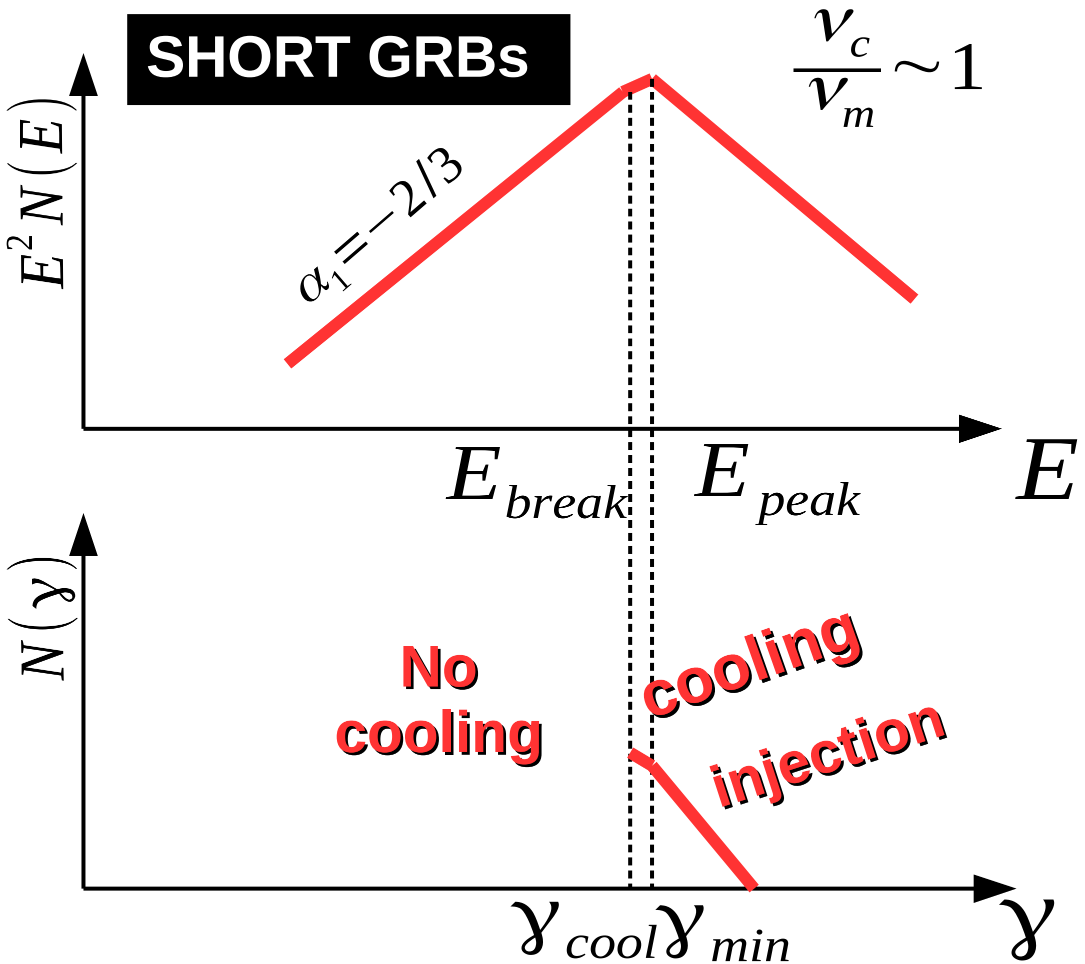
$$t_{cool}^{obs} = \frac{6\pi m_e c}{\sigma_T \gamma_e B^2} \frac{1+z}{\Gamma} \sim 1\,s$$

$$\gamma_e^2 \sim \frac{1+z}{\Gamma} \frac{2\pi m_e c}{e B} \nu_{syn}$$

At the emitting region

$$B \sim 10\, \Gamma_2^{-1/3} \nu_{syn,100\,keV}^{-1/3}\, Gauss$$

Theoretical implications



E_{break} → **synchrotron cooling frequency**

$$t_{cool}^{obs} = \frac{6\pi m_e c}{\sigma_T \gamma_e B^2} \frac{1+z}{\Gamma} \sim 1\,s$$

$$\gamma_e^2 \sim \frac{1+z}{\Gamma} \frac{2\pi m_e c}{e B} \nu_{syn}$$

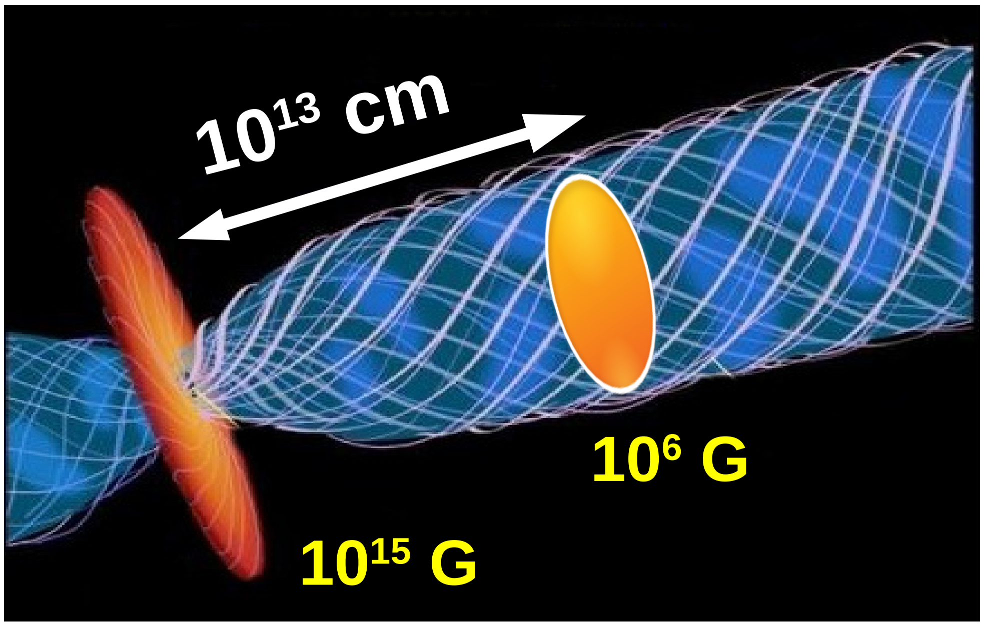
At the emitting region

$$B < 10\, \Gamma_2^{-1/3} \nu_{syn,100\,keV}^{-1/3}\ Gauss$$

Theoretical implications

Interpreting the observed E_{break} as the synchrotron cooling frequency → **B ~ 10 Gauss**

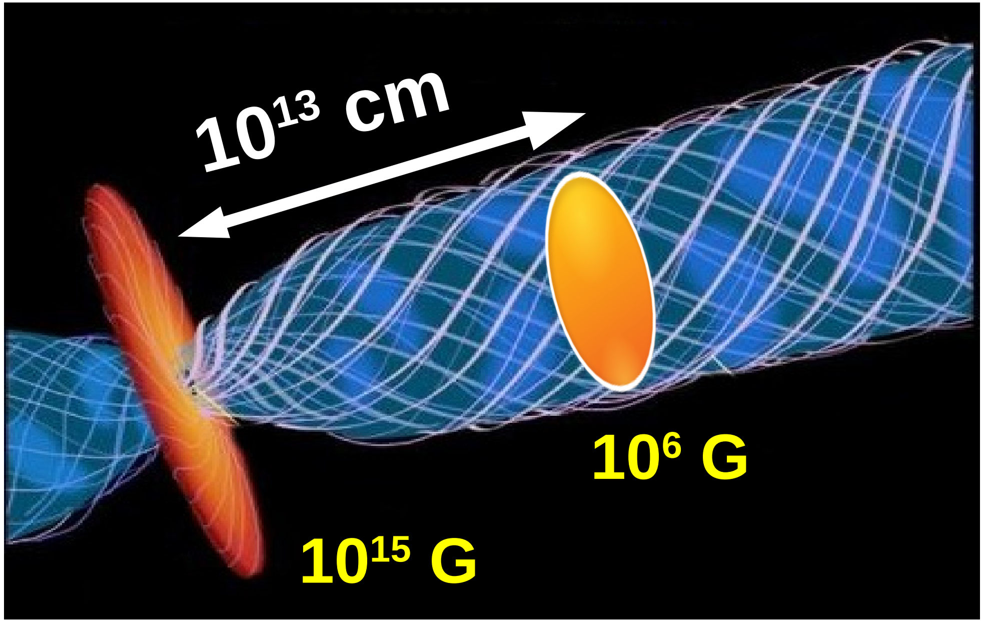
GRB Standard Model:

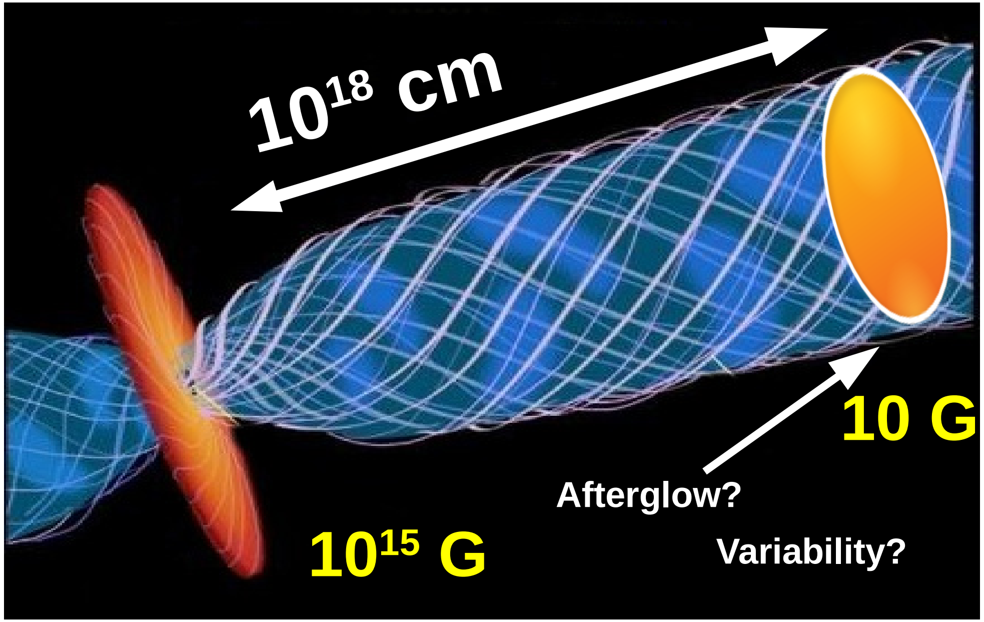


Theoretical implications

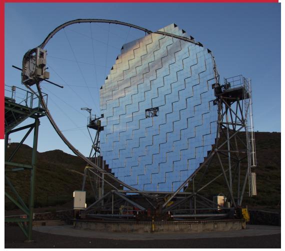
Interpreting the observed E_{break} as the synchrotron cooling frequency → **B ~ 10 Gauss**

GRB Standard Model:





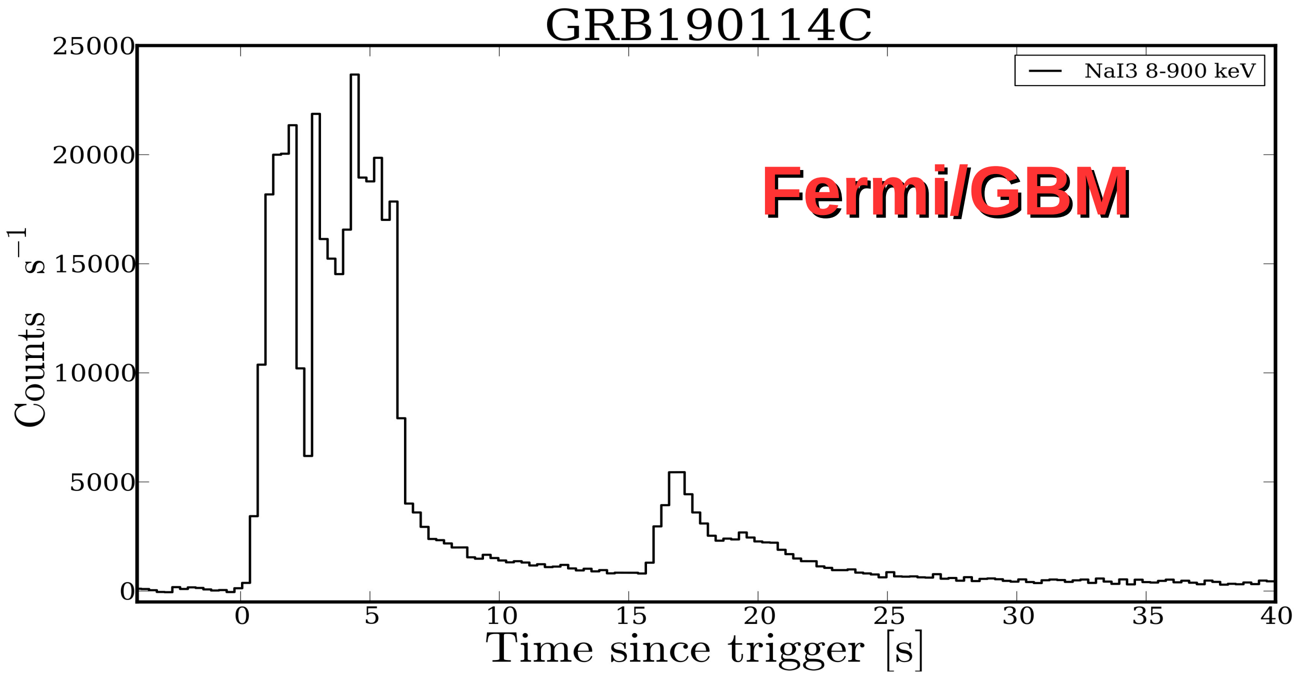
GRB 190114C: the first GRB detected at VHE



Mirzoyan et al. GCN #23701: MAGIC detects the GRB 190114C in the TeV energy domain

Hamburg et al. GCN #23707: GRB 190114C: Fermi GBM detection

- **We analyze its spectral evolution detected by Fermi/GBM between 10 keV and 40 MeV**

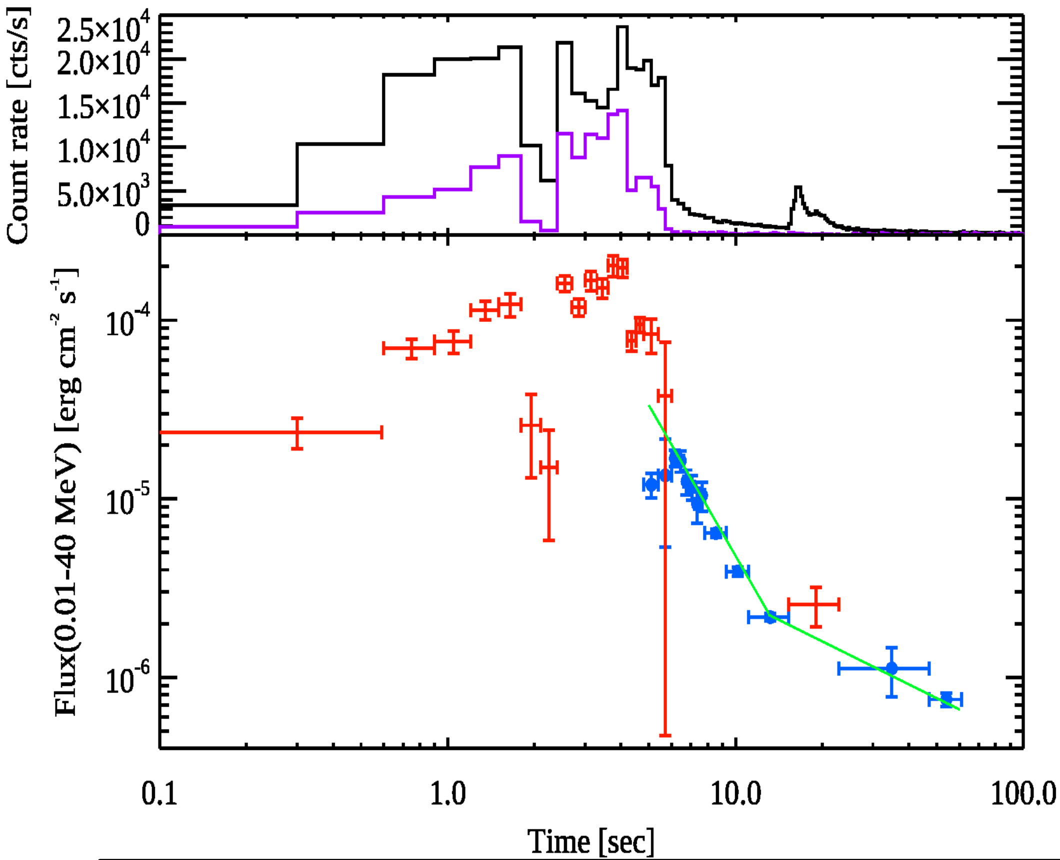


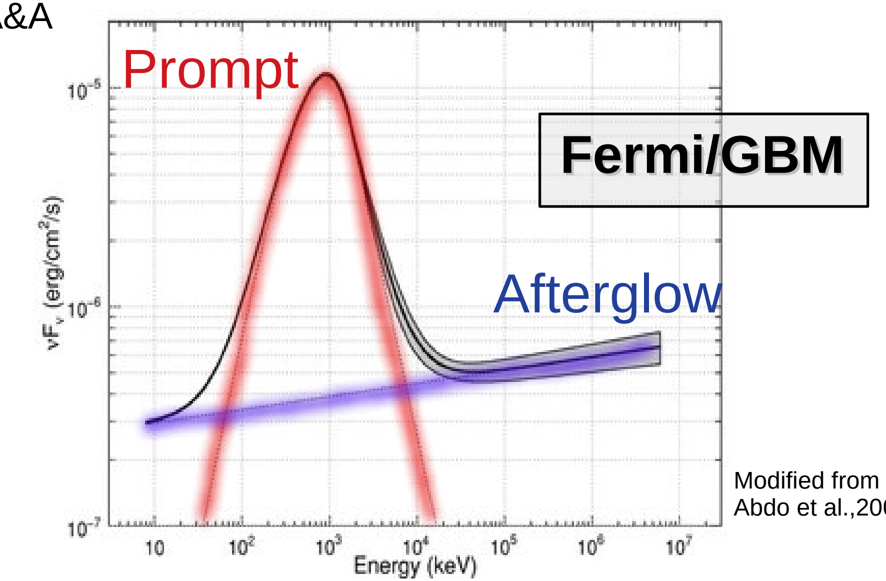
- **Fifth brightest GRB ever observed by Fermi**

- **T90= 116 s**
- **z = 0.42**
  (Selsing et al. 2019)

Spectral analysis of GRB 190114C

Ravasio M.E., Oganesyan G., Salafia O.S., et al., 2019, A&A





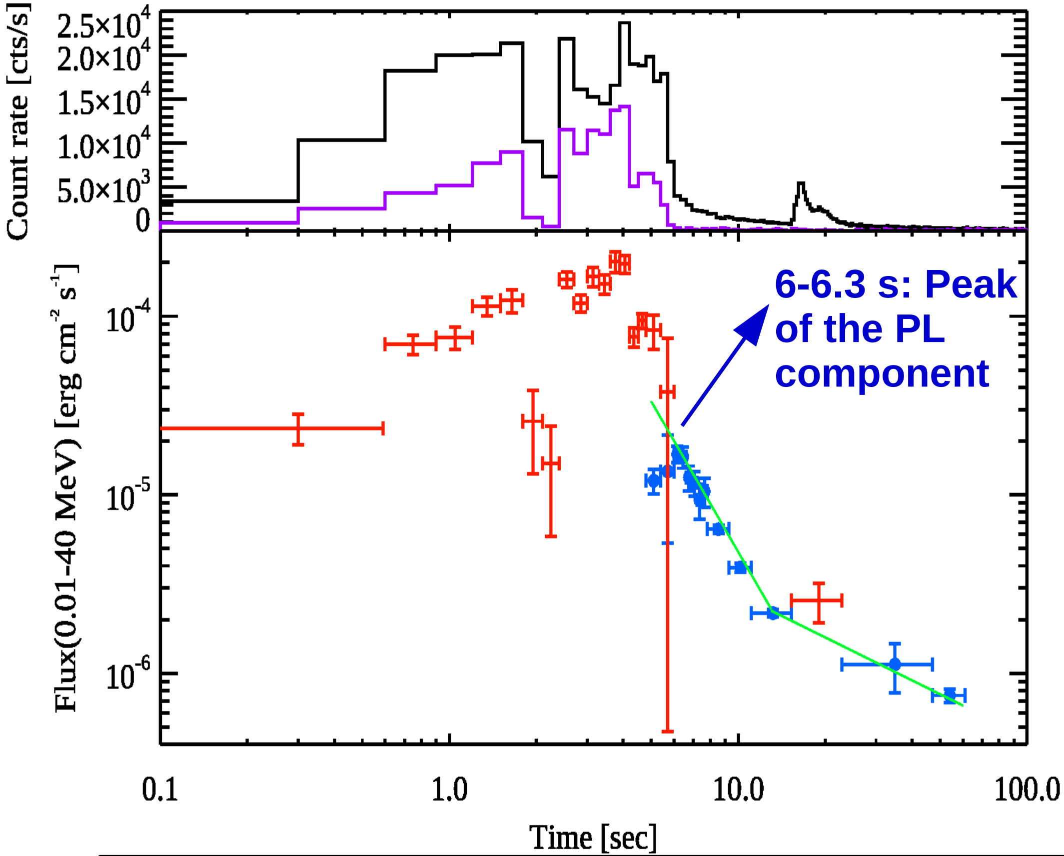
Modified from Abdo et al.,2009

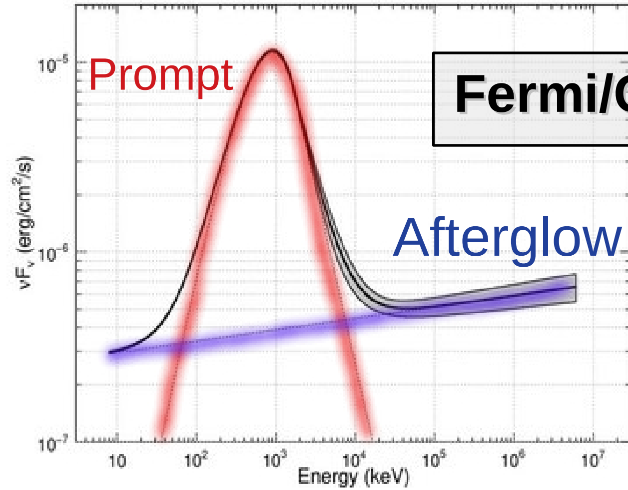
Evidence of compresence of **prompt** and **afterglow** in the GBM energy range

- The first 4 s of the burst show a typical prompt emission spectrum, fit by a standard fitting function with typical parameters
- Starting from 4 s post-trigger, we find an additional non-thermal component, fit by a **power-law with spectral index** $\Gamma_{PL} \sim -2$ peaking at 6 s

Spectral analysis of GRB 190114C

Ravasio M.E., Oganesyan G., Salafia O.S., et al., 2019, A&A





Modified from Abdo et al.,2009

Evidence of compresence of **prompt** and **afterglow** in the GBM energy range

Estimate of the bulk Lorentz factor Γ_0 from the peak of the afterglow lightcurve (using equation from Nava et al., 2013):

$$\Gamma_0 \sim 700$$

Homogeneous medium with density $n_0 = 1\, cm^{-3}$

$$\Gamma_0 \sim 130$$

Wind medium with: $\dot{M}_w = 10^{-5} M/yr$, $v_w = 10^2 km/s$

Summary

- Strong **observational evidences** in both Swift and Fermi GRBs in favour of the **synchrotron origin of GRBs spectra**

Oganesyan et al. 2017, 2018
Ravasio et al., 2018, 2019

↳ Well supported by the **optical data** and by the **direct fit of the synchrotron model**

Oganesyan et al., 2019
Burgess et al. 2019
Ronchi et al., 2019
[submitted]

Summary

- Strong **observational evidences** in both Swift and Fermi GRBs in favour of the **synchrotron origin of GRBs spectra**

Oganesyan et al. 2017, 2018
Ravasio et al., 2018, 2019

↳ Well supported by the **optical data** and by the **direct fit of the synchrotron model**

Oganesyan et al., 2019
Burgess et al. 2019
Ronchi et al., 2019 [submitted]

- Identifying E_{break} as the synchrotron cooling frequency → **B ~ 10 Gauss**
(marginally fast cooling regime)

Summary

- Strong **observational evidences** in both Swift and Fermi GRBs in favour of the **synchrotron origin of GRBs spectra**

Oganesyan et al. 2017, 2018
Ravasio et al., 2018, 2019

Well supported by the **optical data** and by the **direct fit of the synchrotron model**

Oganesyan et al., 2019
Burgess et al. 2019
Ronchi et al., 2019
[submitted]

- Identifying E_{break} as the synchrotron cooling frequency → **B ~ 10 Gauss** **(marginally fast cooling regime)**

- Next step: **Find the reason why!** It's time for more theoretical efforts!

Summary

- Strong **observational evidences** in both Swift and Fermi GRBs in favour of the **synchrotron origin of GRBs spectra**

Oganesyan et al. 2017, 2018
Ravasio et al., 2018, 2019

Well supported by the **optical data** and by the **direct fit of the synchrotron model**

Oganesyan et al., 2019
Burgess et al. 2019
Ronchi et al., 2019 [submitted]

- Identifying E_{break} as the synchrotron cooling frequency → **B ~ 10 Gauss (marginally fast cooling regime)**

- Next step: **Find the reason why!** It's time for more theoretical efforts!

GRB 190114C

- Evidence of **transition from prompt to afterglow** in the GBM energy range

- **Estimate of bulk Lorentz factor** Γ_0 (150 – 700) from the peak in the afterglow lightcurve

- **Waiting for the MAGIC spectrum** to give crucial information about the origin of the entire high energy spectrum!

Thanks for your attention!