Synchrotron footprints in GRB prompt emission spectra

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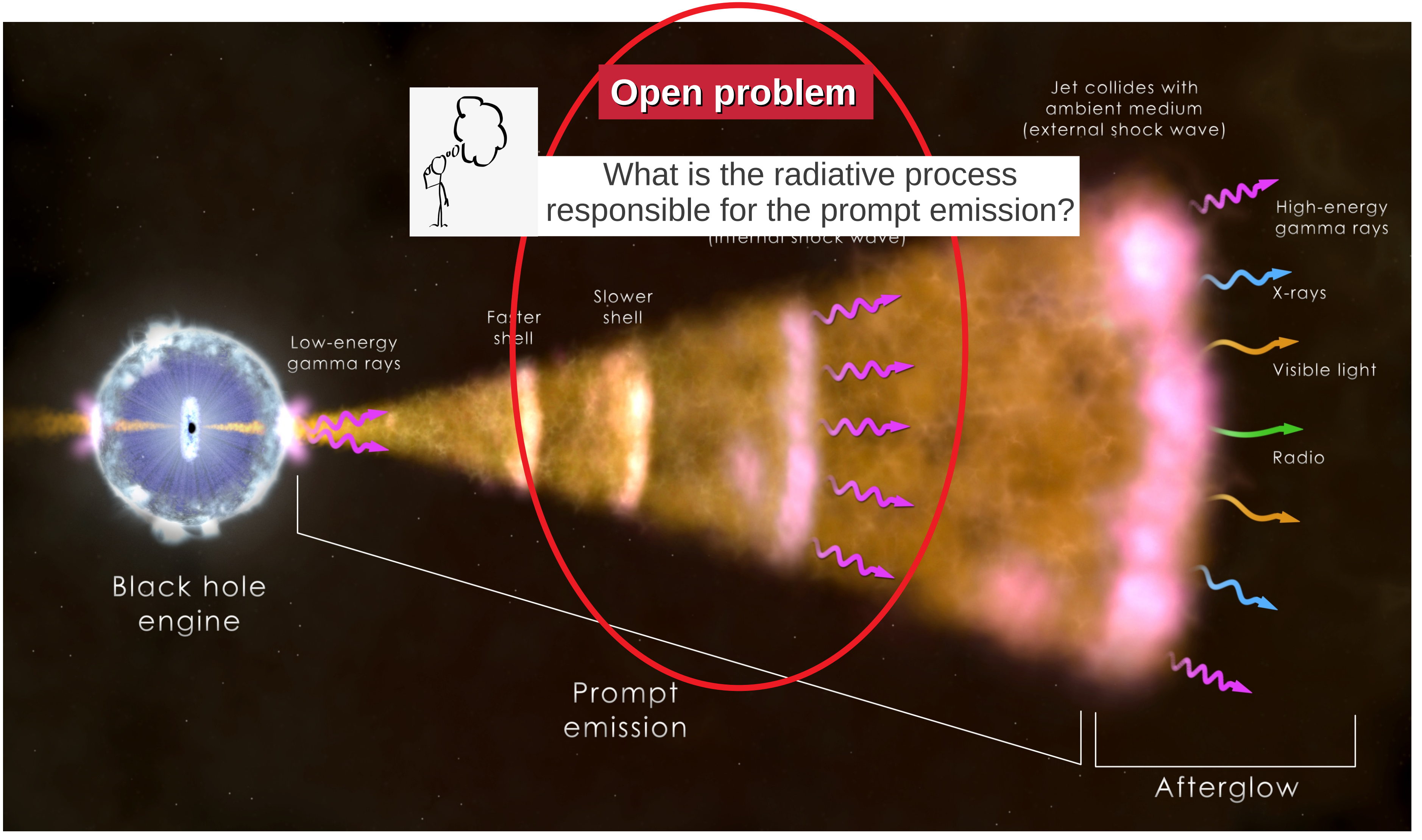
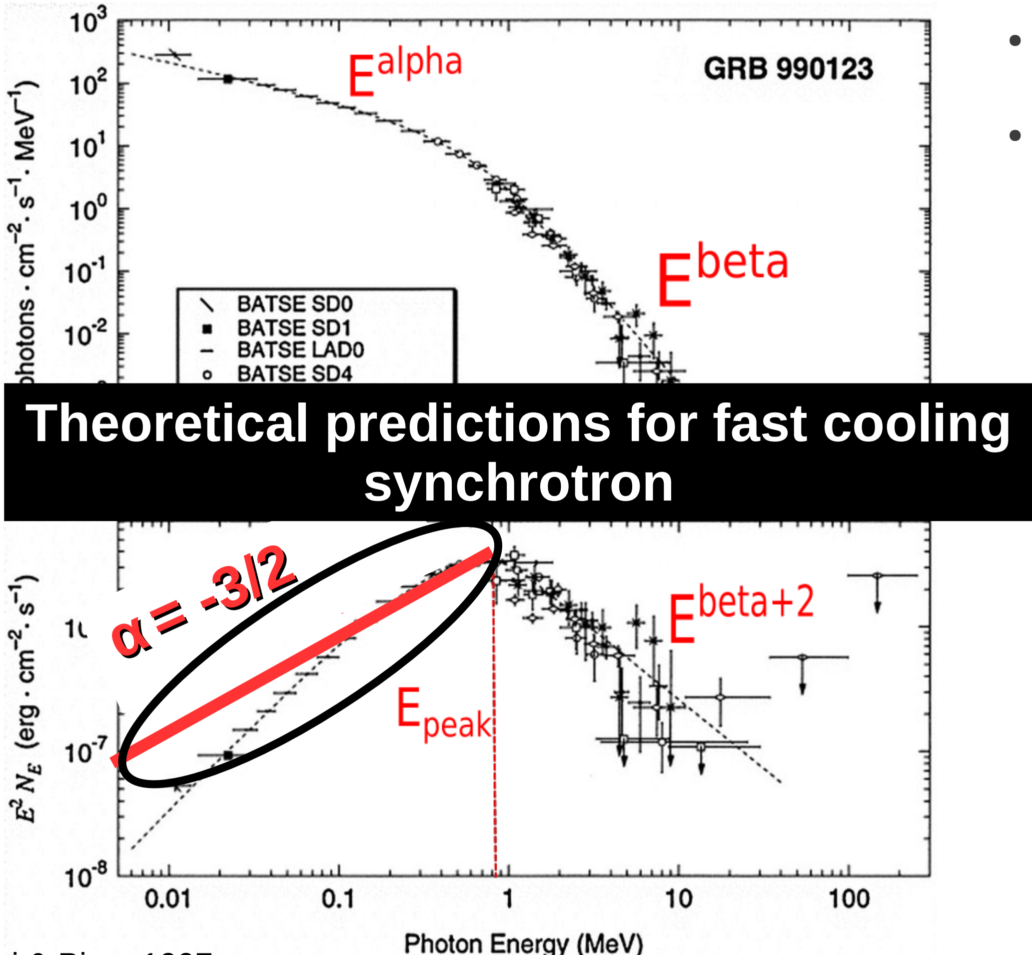
Gamma-Ray Burst: standard model



Typical observed GRB prompt spectrum

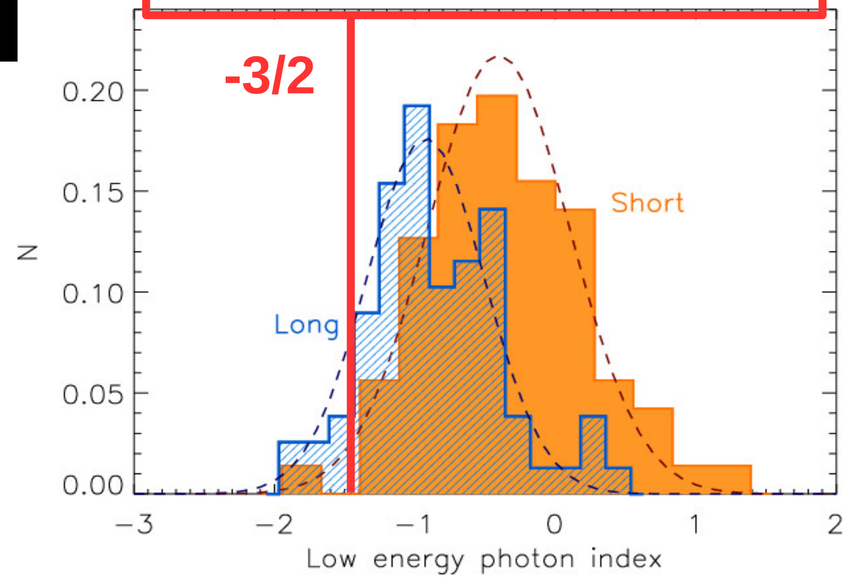


Sari & Piran 1997
Preece 1998
Ghisellini 2000

- **Non-thermal spectrum**
- **Band function (Band et al., 1993) satisfactory fits most of the spectra**

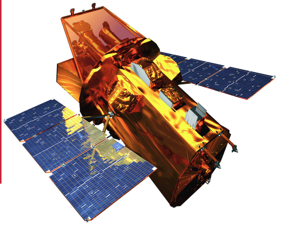
Observed slopes

LONG GRBs: <α> ~ -1
SHORT GRBs: <α> ~ -0.4



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

Recent hints from the observations



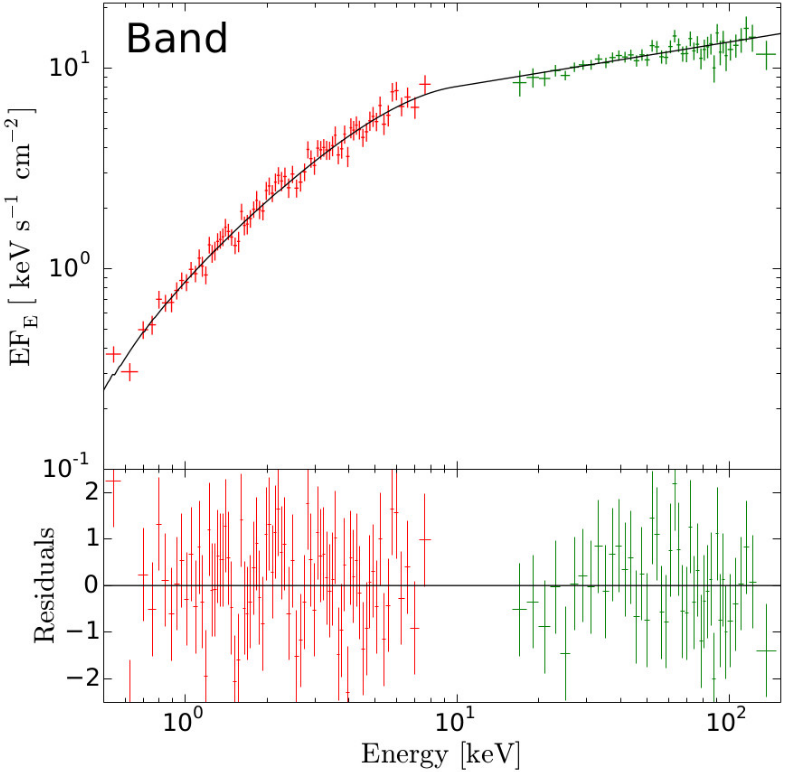
34 long GRBs observed simultaneously with XRT and BAT (Swift satellite)

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

- the spectral indices are $<\alpha_1> = -0.51 \pm 0.29$ and $<\alpha_2> = -1.54 \pm 0.26$

Consistent with synchrotron prediction!

Oganesyan et al., 2017,2018



XRT (0.3 – 10 keV)

BAT (15 – 150 keV)

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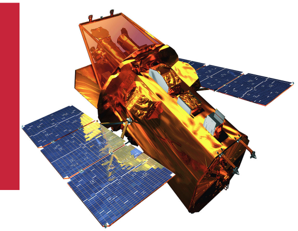

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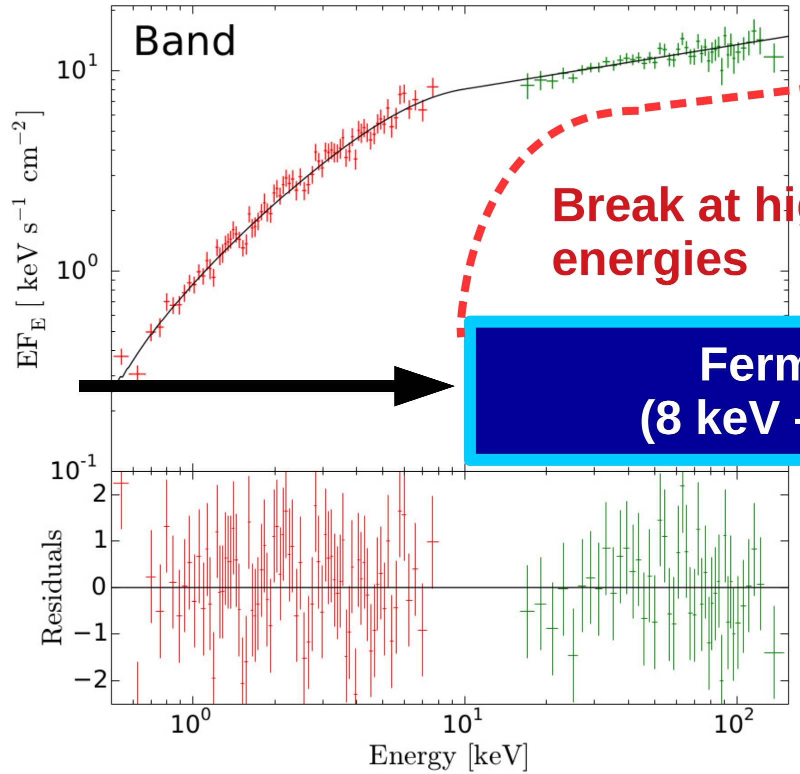
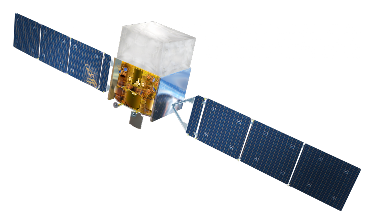


Break at higher energies ?

Fermi/GBM (8 keV – 40 MeV)

XRT (0.3 – 10 keV)

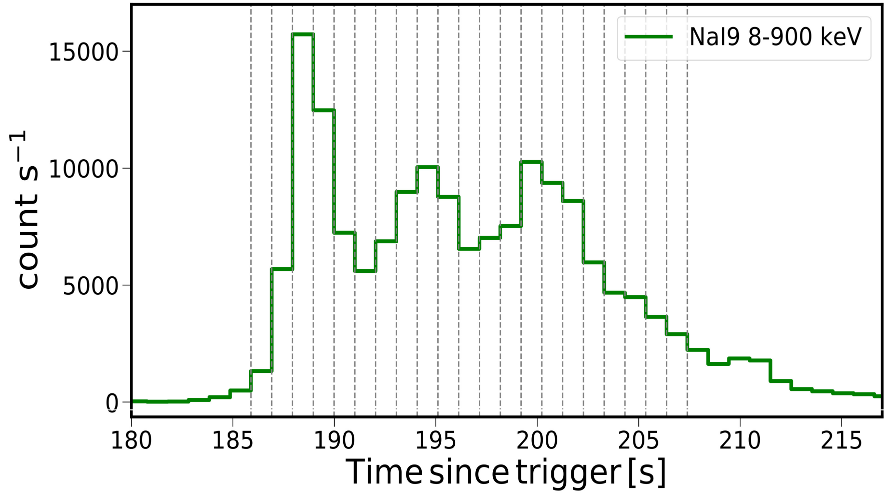
BAT (15 – 150 keV)

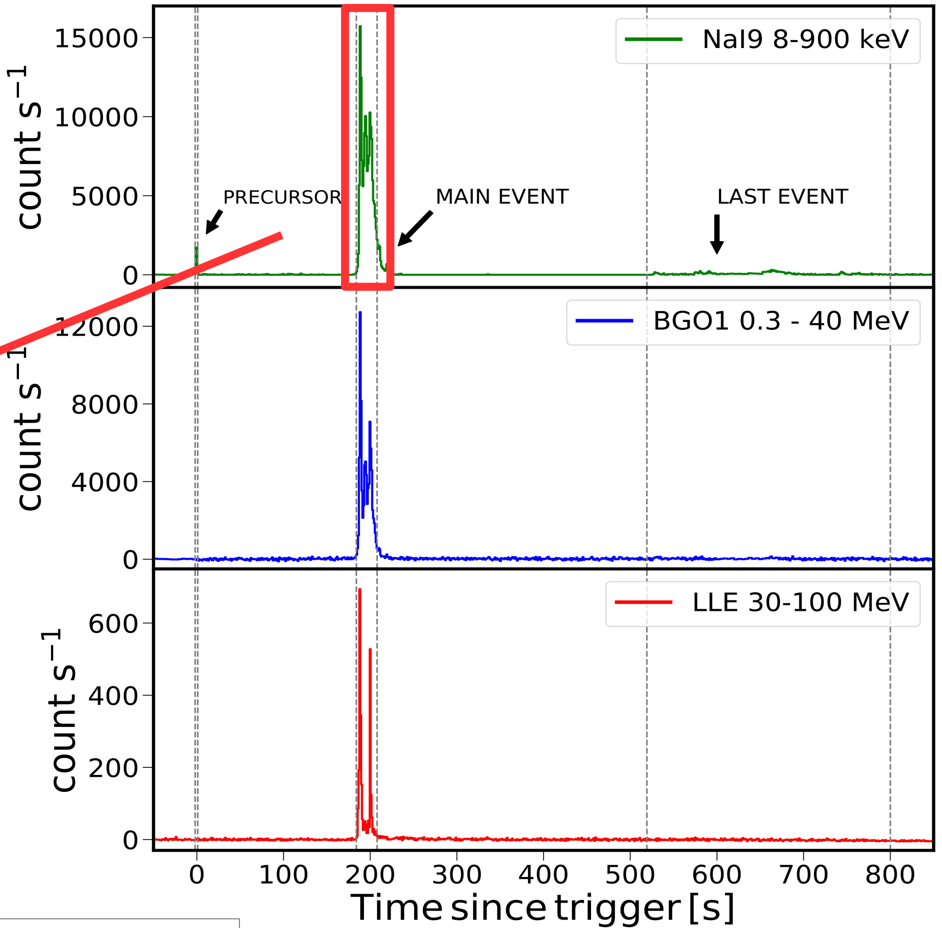


The case of GRB 160625B

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

- **One of the brightest burst ever detected by Fermi/GBM (Fluence = 5.7 x 10^{-4} erg/cm^2)**
- **z = 1.406**
- **We performed a time-resolved analysis on the main event**

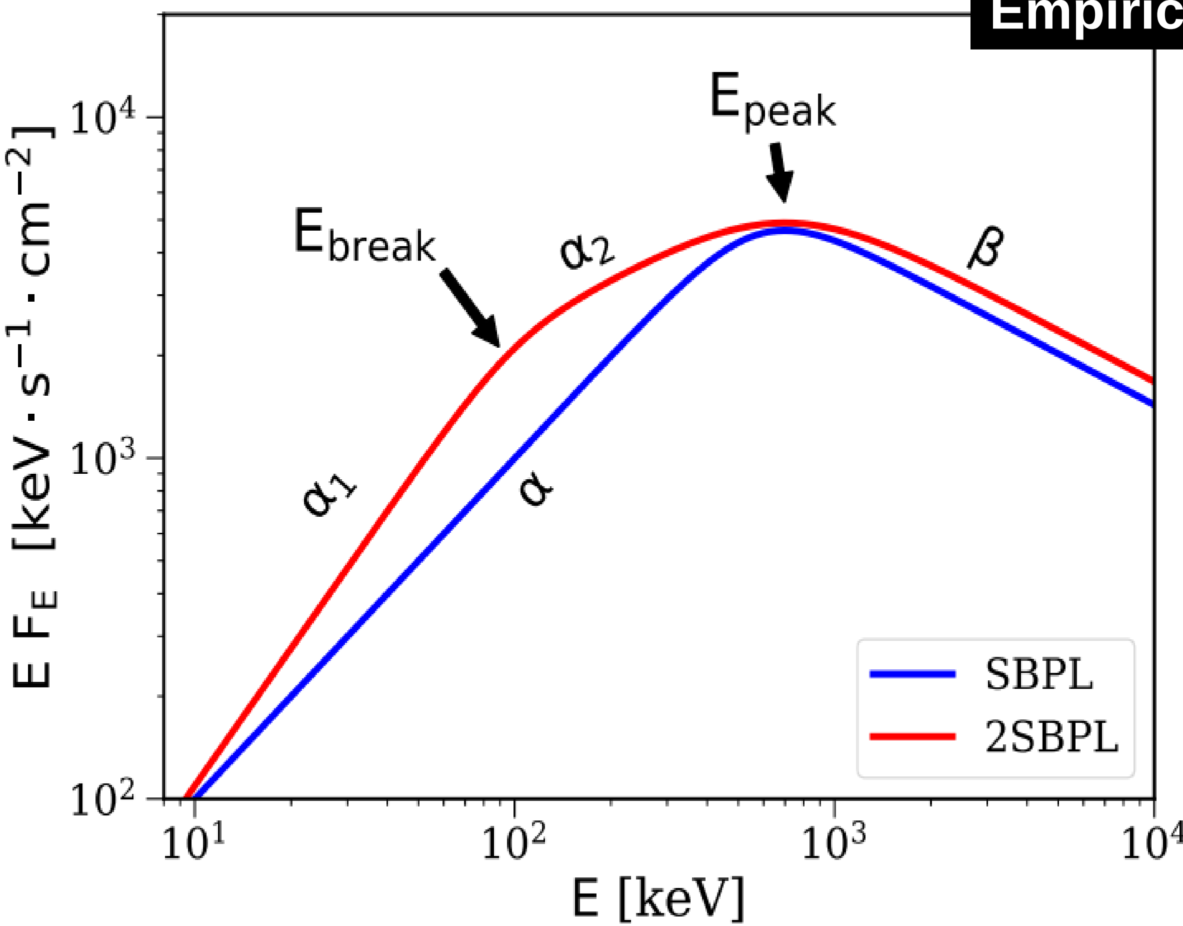




Ravasio et al., 2018, A&A

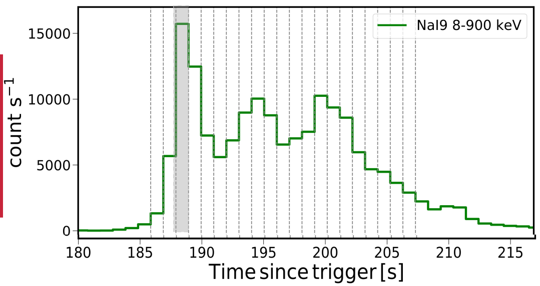
Comparison of the fitting functions

Empirical functions

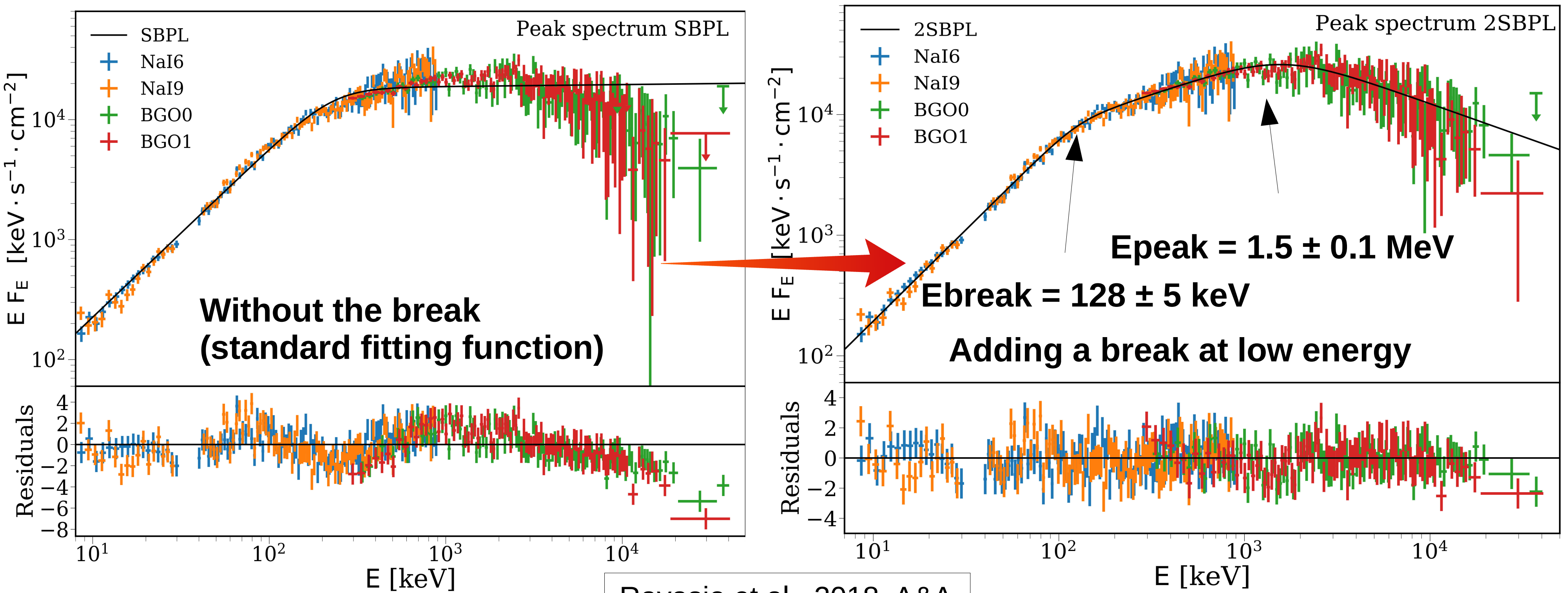


- **three power-laws, allowing for the presence of another spectral break**

GRB 160625B



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



Ravasio et al., 2018, A&A

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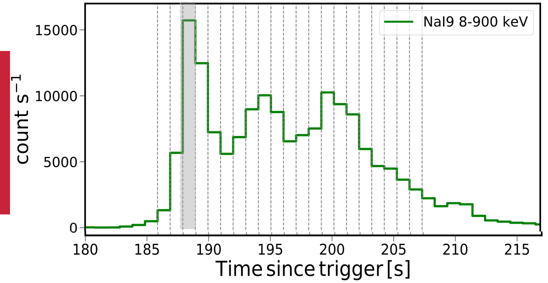

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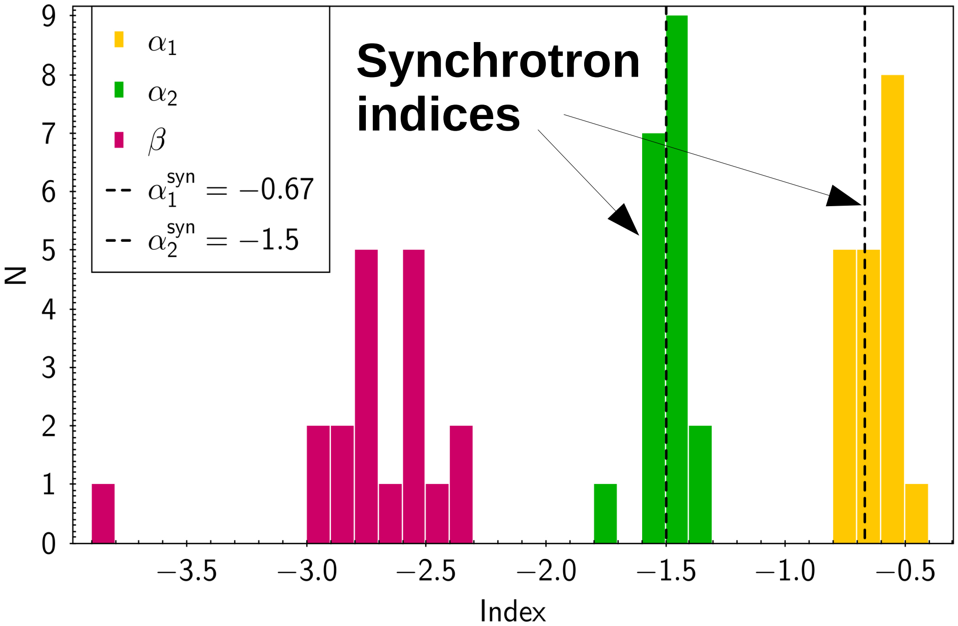
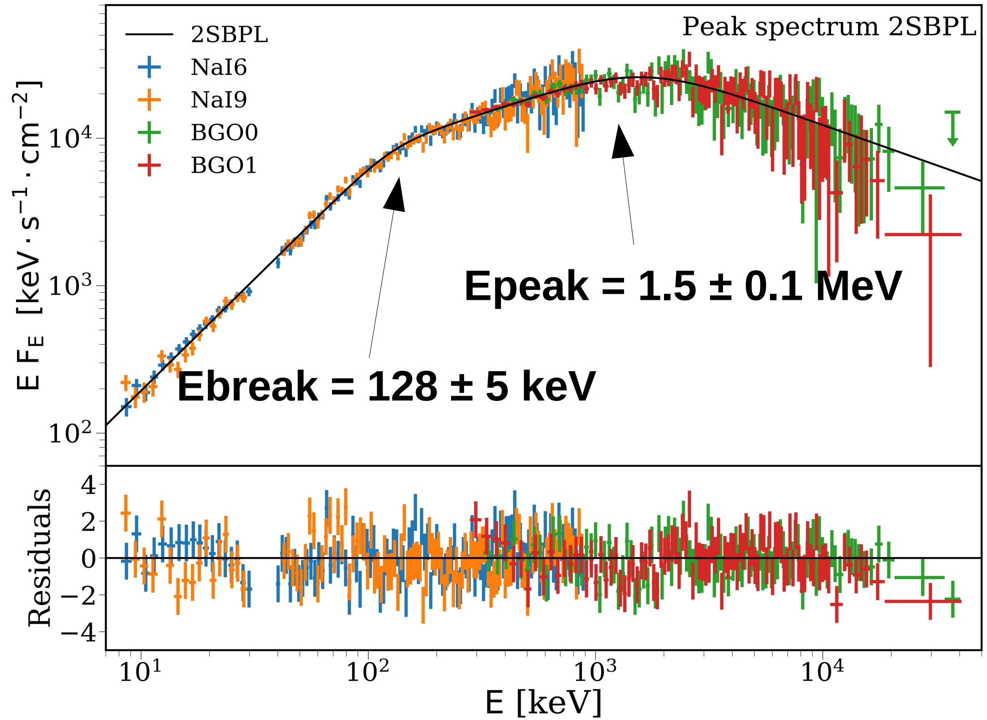


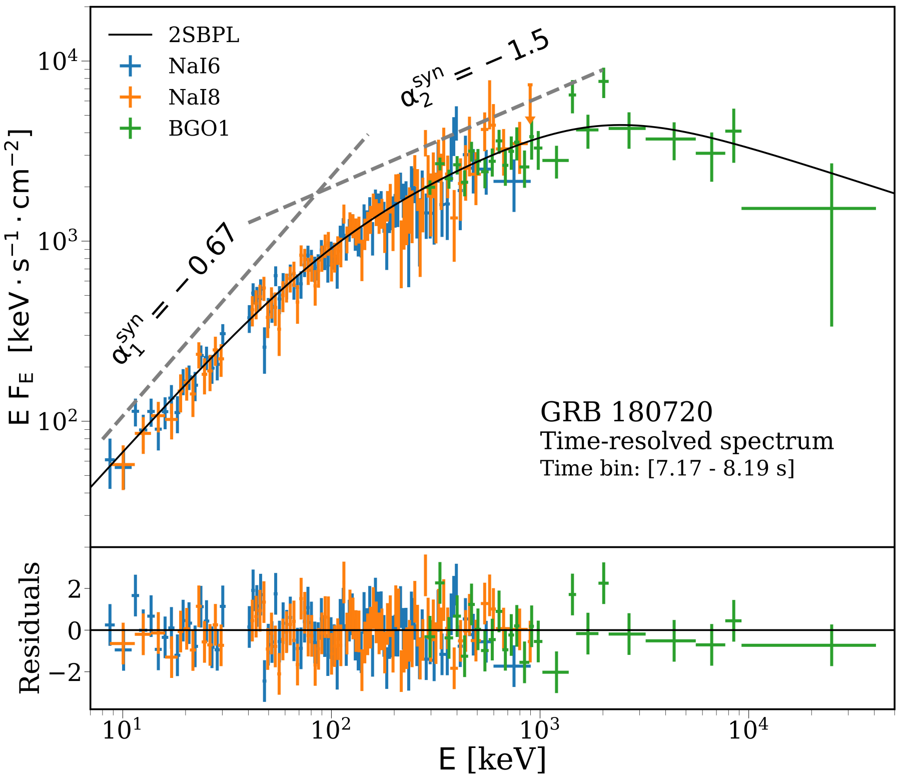


DISTRIBUTION OF THE SPECTRAL INDICES
from the time-resolved analysis

Ravasio et al., 2018, A&A

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 2194 long GRBs detected by GBM)

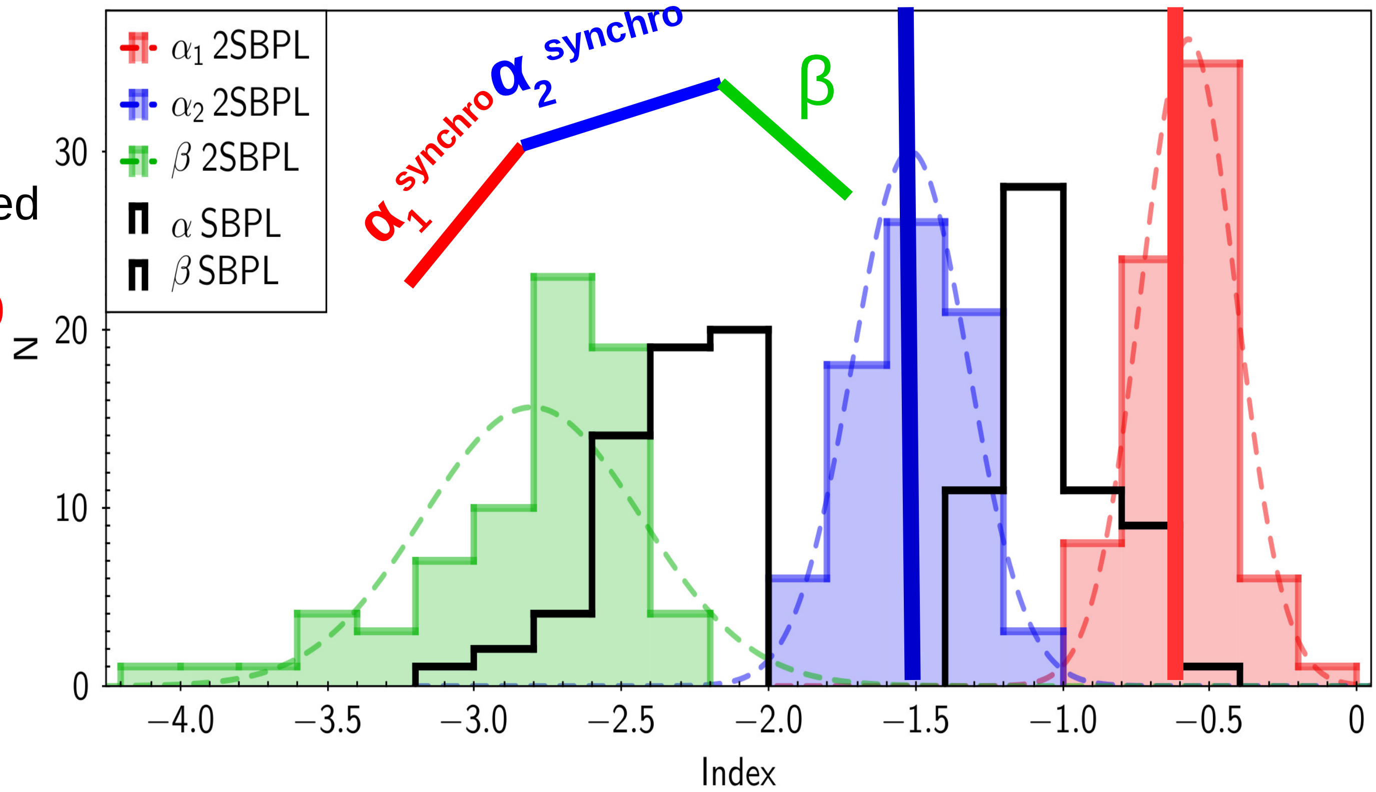
10 SHORT BRIGHTEST GRBs {NEW}
(over 439 short GRBs detected by GBM)

Results of the time-resolved spectral analysis

10 LONG GRBs

- 70% of the 199 time-resolved spectra analyzed show a **break** between **10 and 300 keV**
- the **spectral indices** are consistent with synchrotron predictions

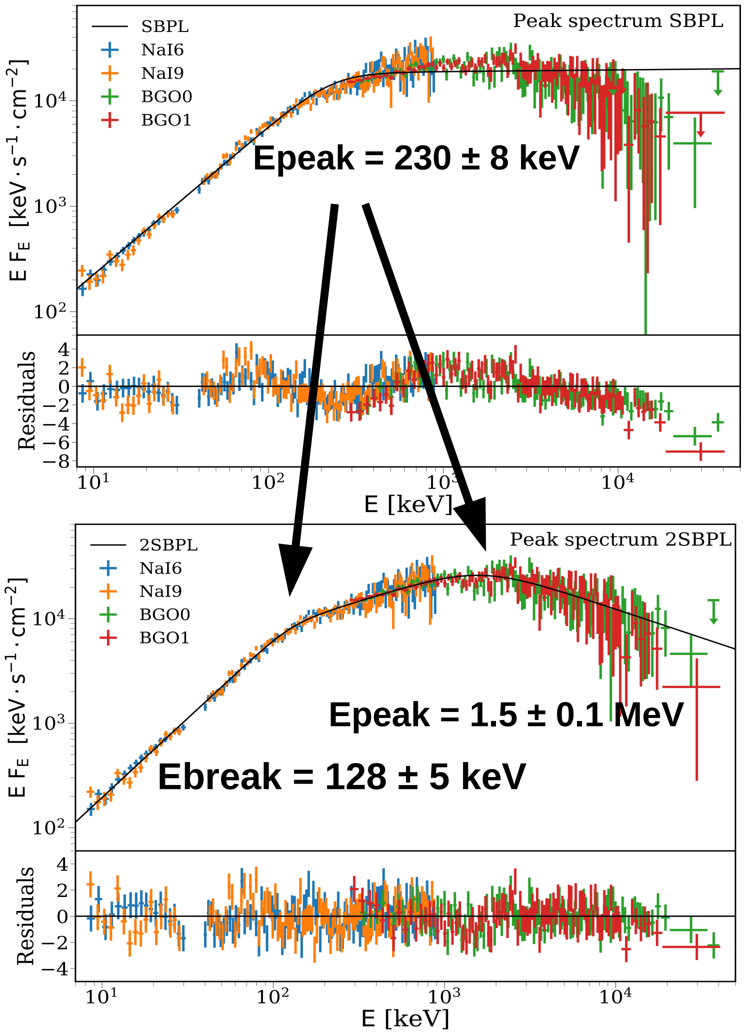
<α₁> = -0.58 (0.16)
<α₂> = -1.52 (0.20)



Single break function → <α> = -1.02 (0.19)

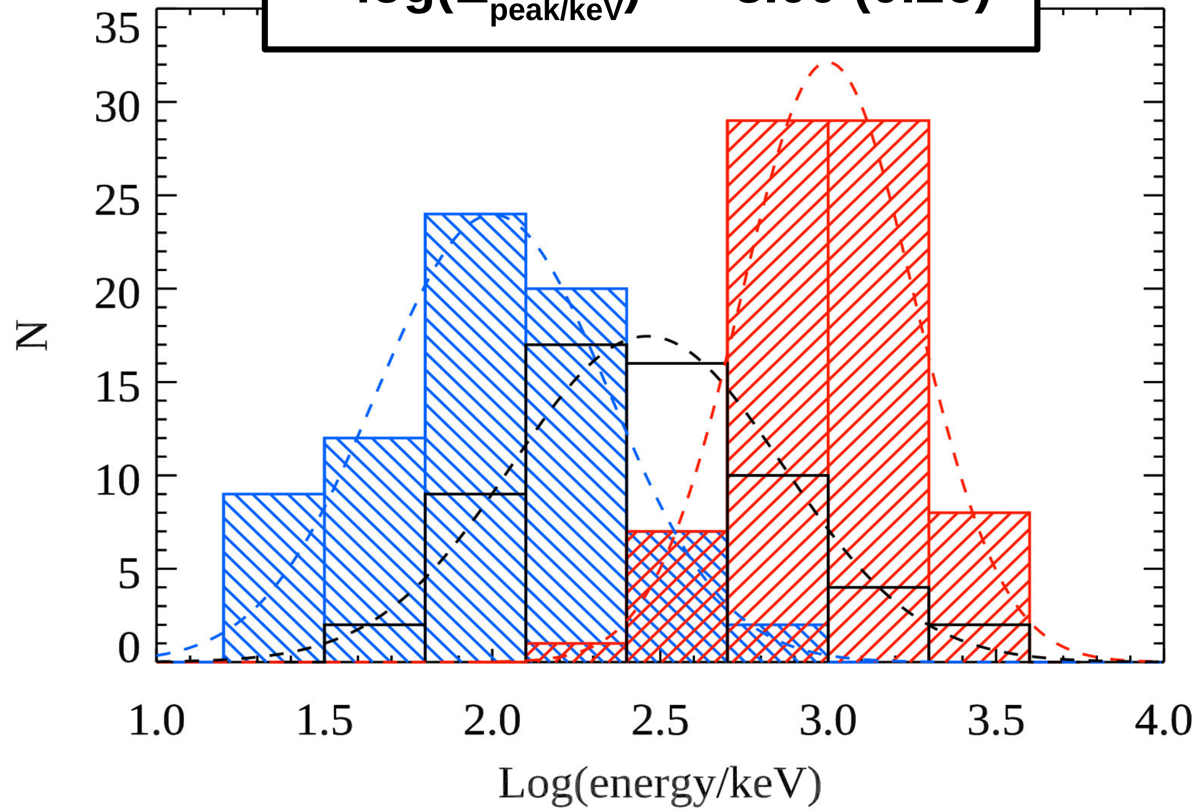
Ravasio et al., 2019, A&A

Results of the time-resolved spectral analysis



$<\log(E_{break/keV})> = 2.00\ (0.34)$

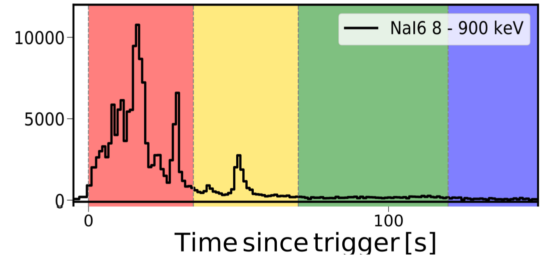
$<\log(E_{peak/keV})> = 3.00\ (0.26)$

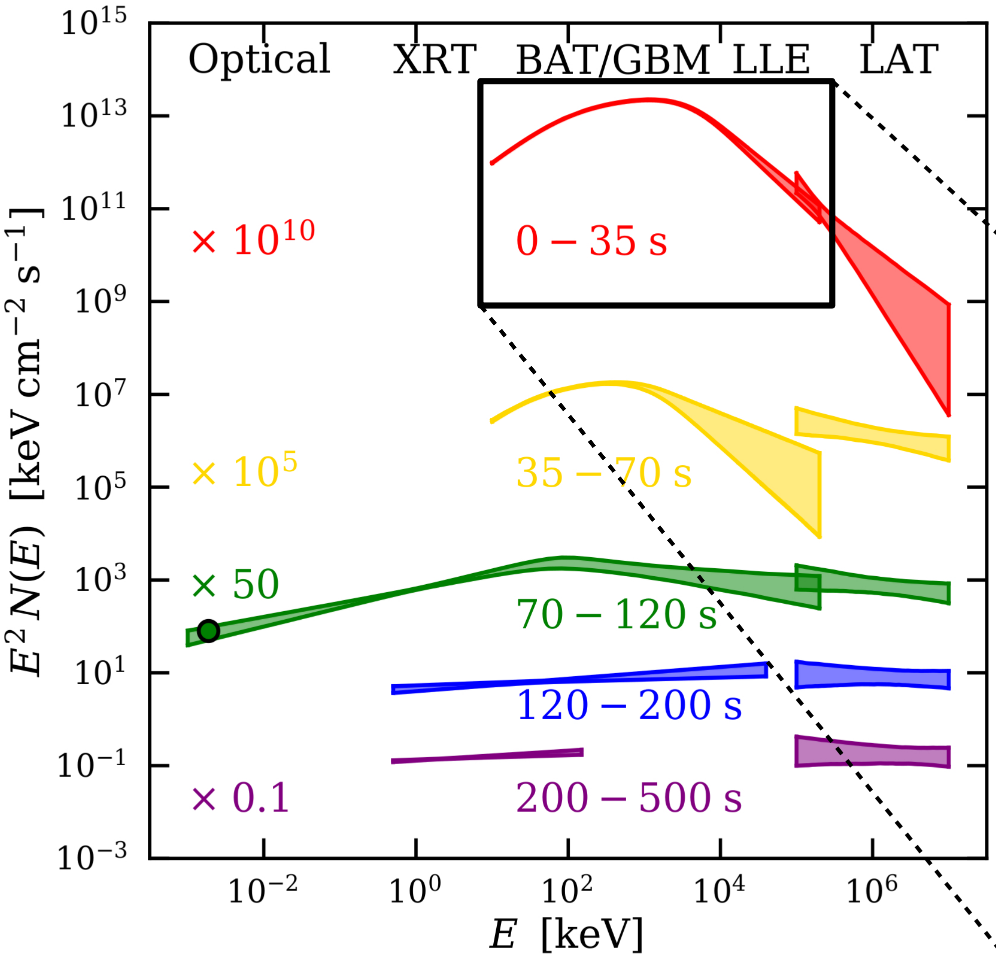


Single break function → $<\log(E_{peak/keV})> = 2.46\ (0.40)$

Ravasio et al., 2019, A&A

The spectral evolution of GRB 180720B

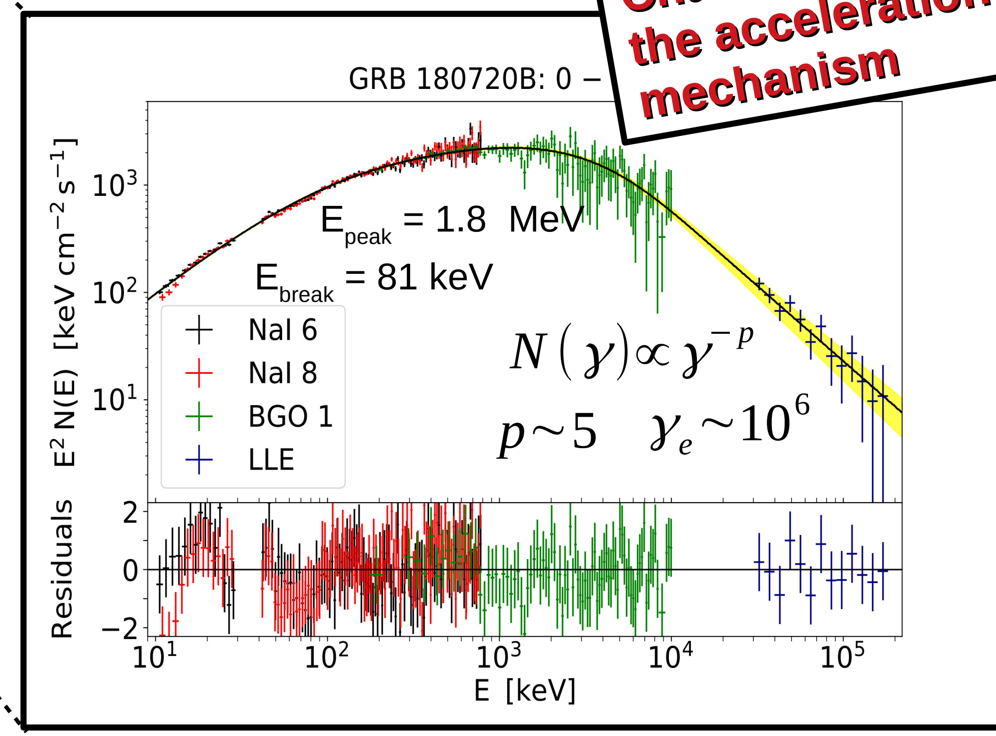




Ronchi M., Fumagalli F., **Ravasio M.E.** et al, 2020, A&A

→ We directly fit with a synchrotron model

Challenge for the acceleration mechanism



→ see also synchrotron model fit by Burgess et al. 2020

Results of the time-resolved spectral analysis

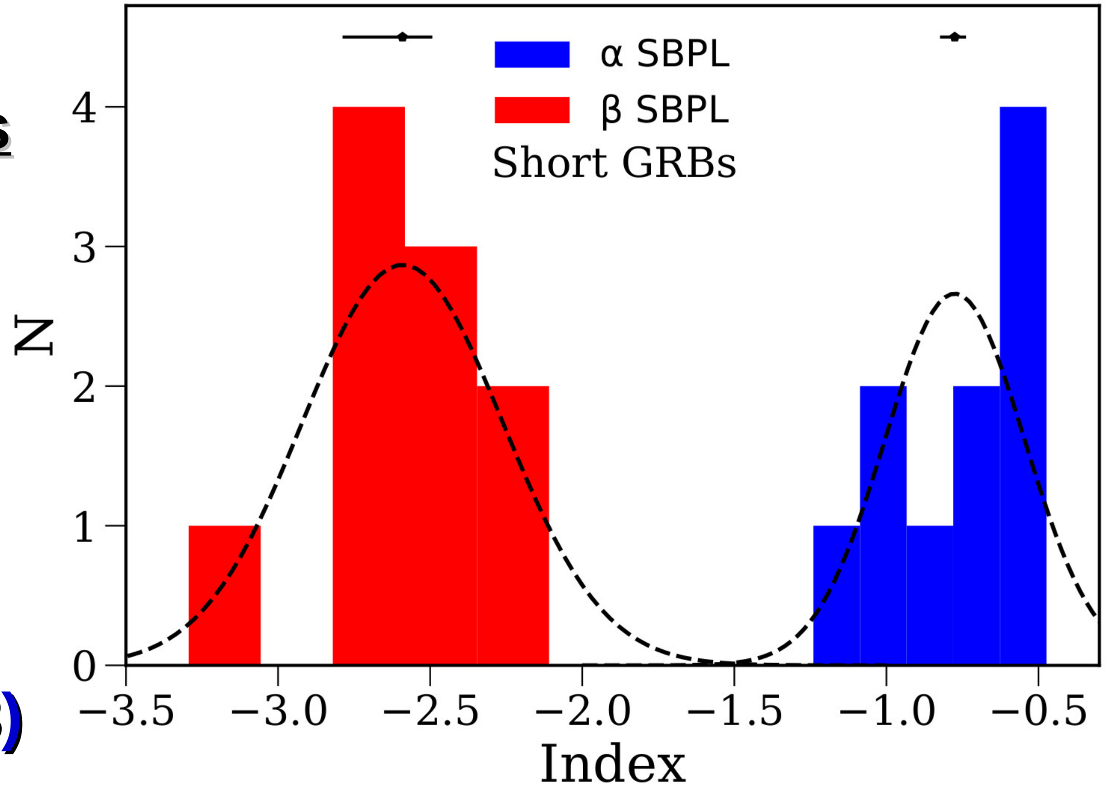
<u>10 SHORT GRBs</u>

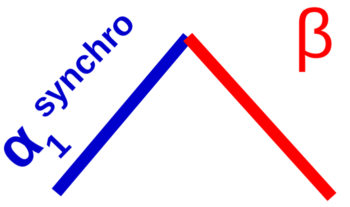
↓

NO ADDITIONAL BREAK!

↓

$\langle\alpha\rangle = -0.78\ (0.23)$

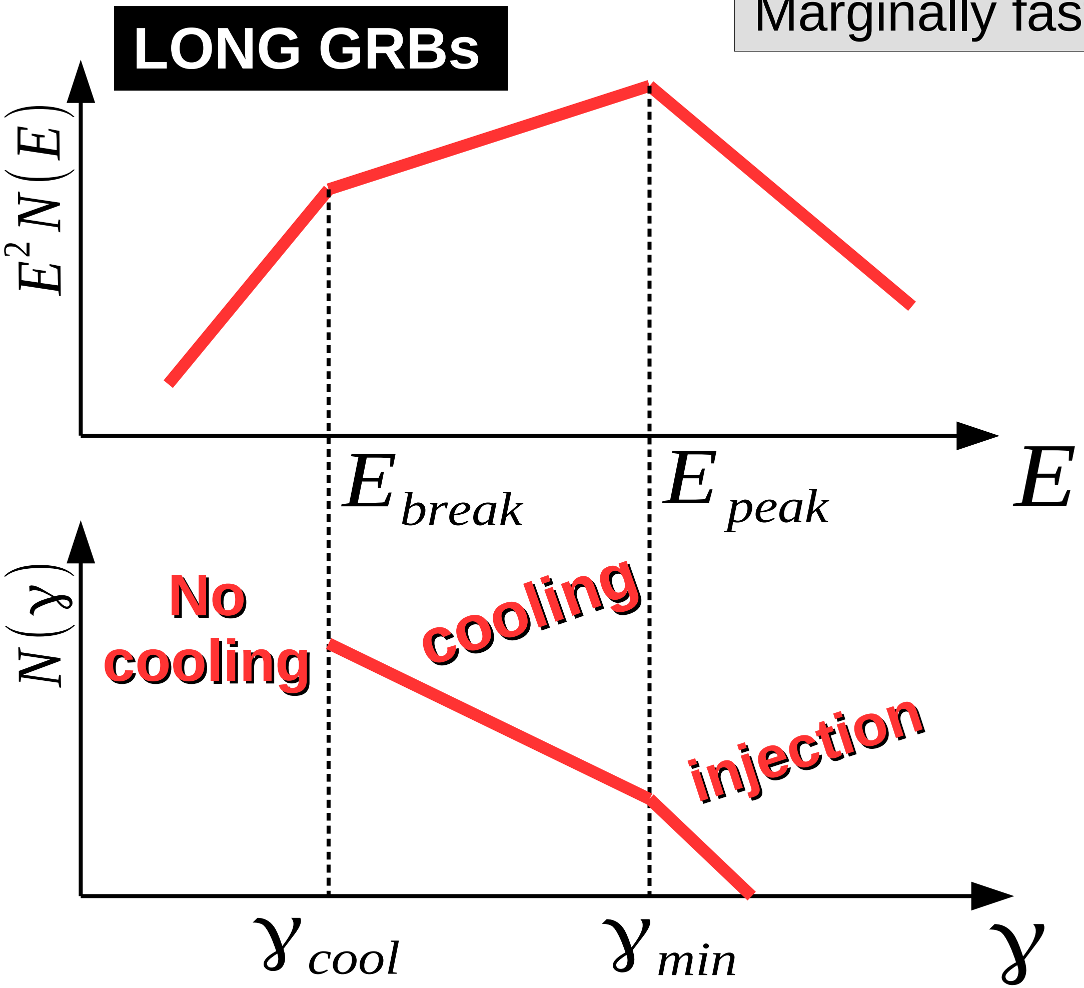




- **It seems to exist only one component below the peak energy**
- **Consistent within 1σ with the synchrotron value α = -2/3**

Ravasio et al., 2019, A&A

Theoretical implications



Marginally fast cooling regime

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

Interpreting E_{break} as the synchrotron cooling frequency

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

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

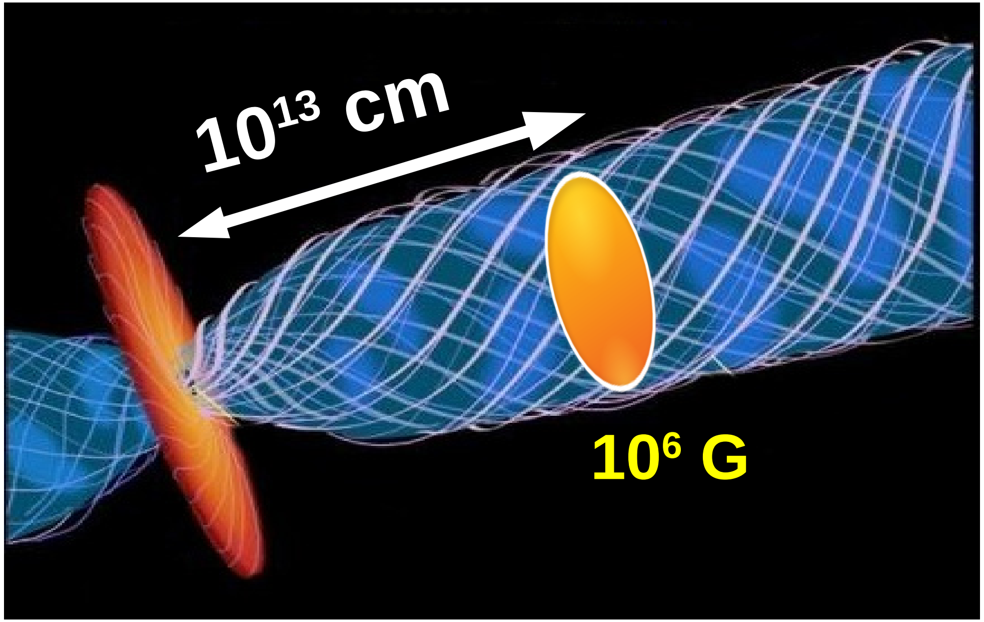
At the emitting region

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

Theoretical implications

B ~ 10 Gauss

GRB Standard Model:



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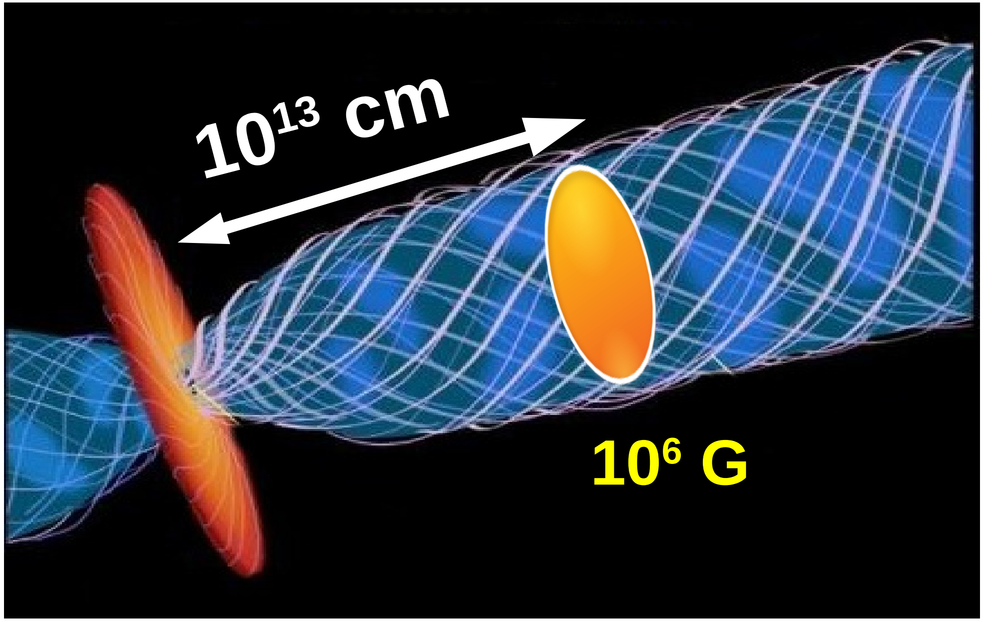

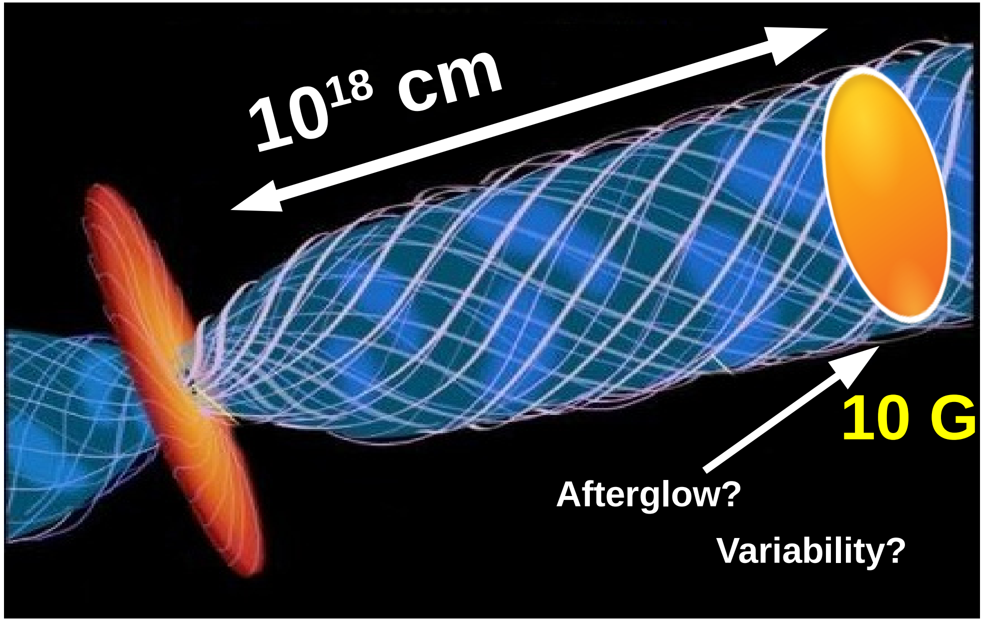

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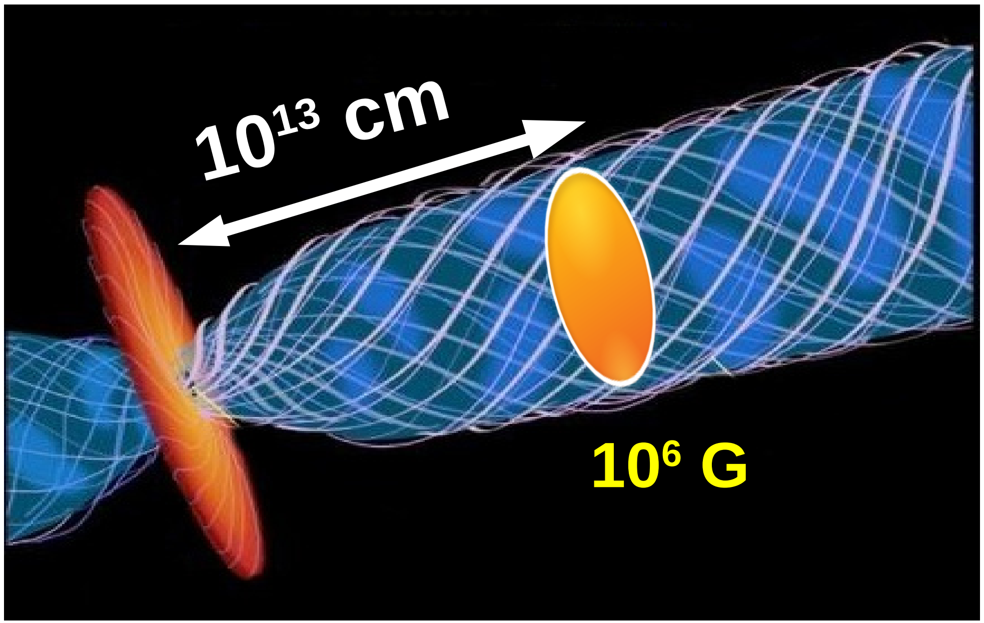
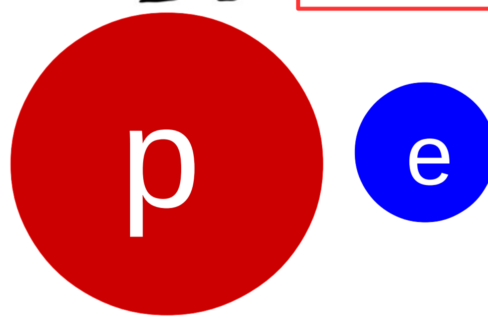


Ghisellini et al., A&A, 2020

A possible solution: the prompt emission may be produced by synchrotron from **protons** rather than electrons



Switching roles

These new results could be explained by synchrotron emission from **protons** rather than electrons

Ghisellini et al., A&A, 2020

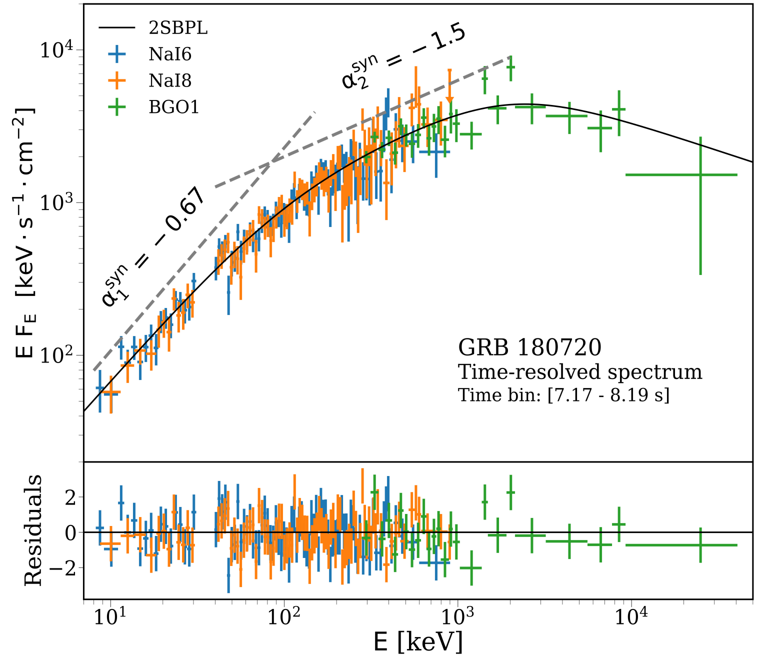
For typical parameters of the emitting region (**B′~10⁶ G**):

Electrons ⟶ $t^{obs}_{cool,e} \sim 10^{-7} s$ Too short!!

Protons ⟶ $t^{obs}_{cool,p} \sim t^{obs}_{cool,e} \left(\frac{m_p}{m_e}\right)^{5/2} \sim 1.44 \times 10^8 \; t^{obs}_{cool,e}$

Much longer!! ~1 s

⟶ They become efficient emitters



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It can explain:

- $\nu_{cool} \sim 100\, keV$ ✓
- a standard B′~10^6 G ✓
- still keeping the emitting region at R ~10^{13} cm ✓
- accounting for a short variability timescale ✓

...still under investigation
(see also Florou et al. 2021)

Summary

- Strong **observational evidences** (**Oganesyan et al. 2017,2018, Ravasio et al., 2018, 2019)** in both Swift and Fermi data in favour of the **synchrotron origin of GRBs spectra**

  → Well supported by the **optical data** and by the **direct fit of the synchrotron model** (Oganesyan et al., 2019, Ronchi et al., 2020, Burgess et al. 2020)

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- Identifying E_{break} as the synchrotron cooling frequency → **marginally fast cooling regime**

In the leptonic scenario

B ~ 10 Gauss

In the hadronic scenario

B ~ 10^6 Gauss

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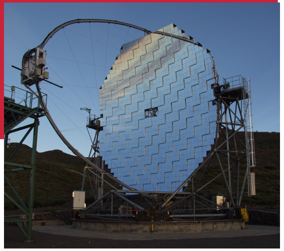
- Next step: **Think!** It's time for more theoretical efforts

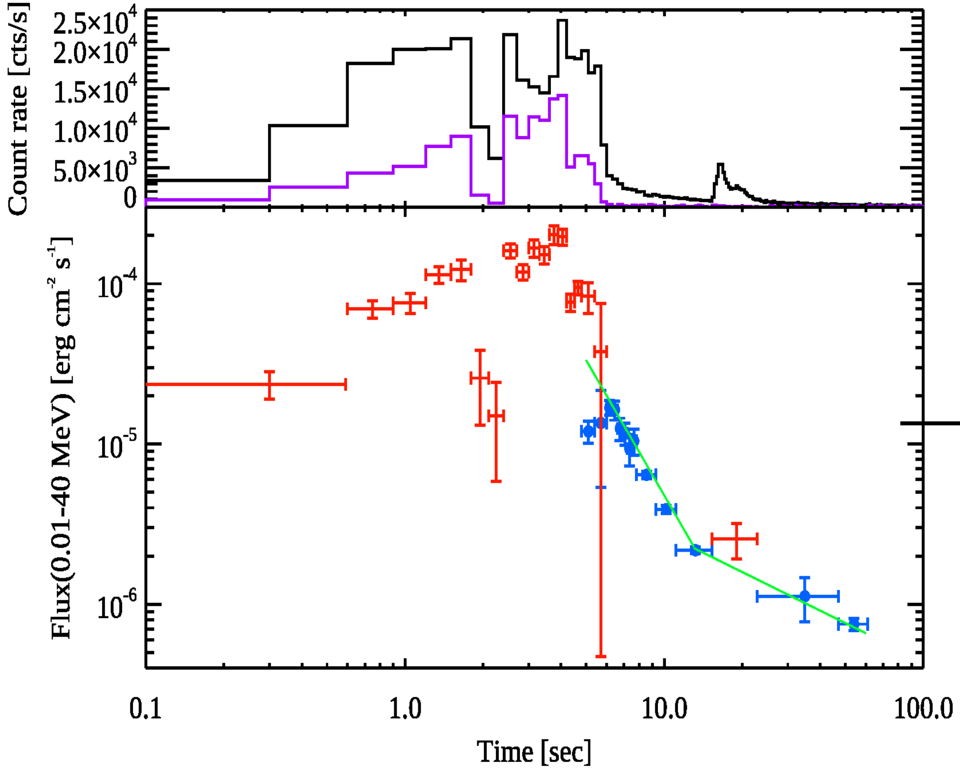
Thanks for your attention

GRB 190114C: from prompt to afterglow



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

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



Poster Session
Gamma-ray Bursts/SN/Instrumentation

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

Ravasio M.E., et al., 2019, A&A