New insights into the physics of GRB prompt emission from high energy observations

In collaboration with:
Dr. Giancarlo Ghirlanda
Dr. Lara Nava
Dr. Gabriele Ghisellini
Dr. Gor Oganesyan

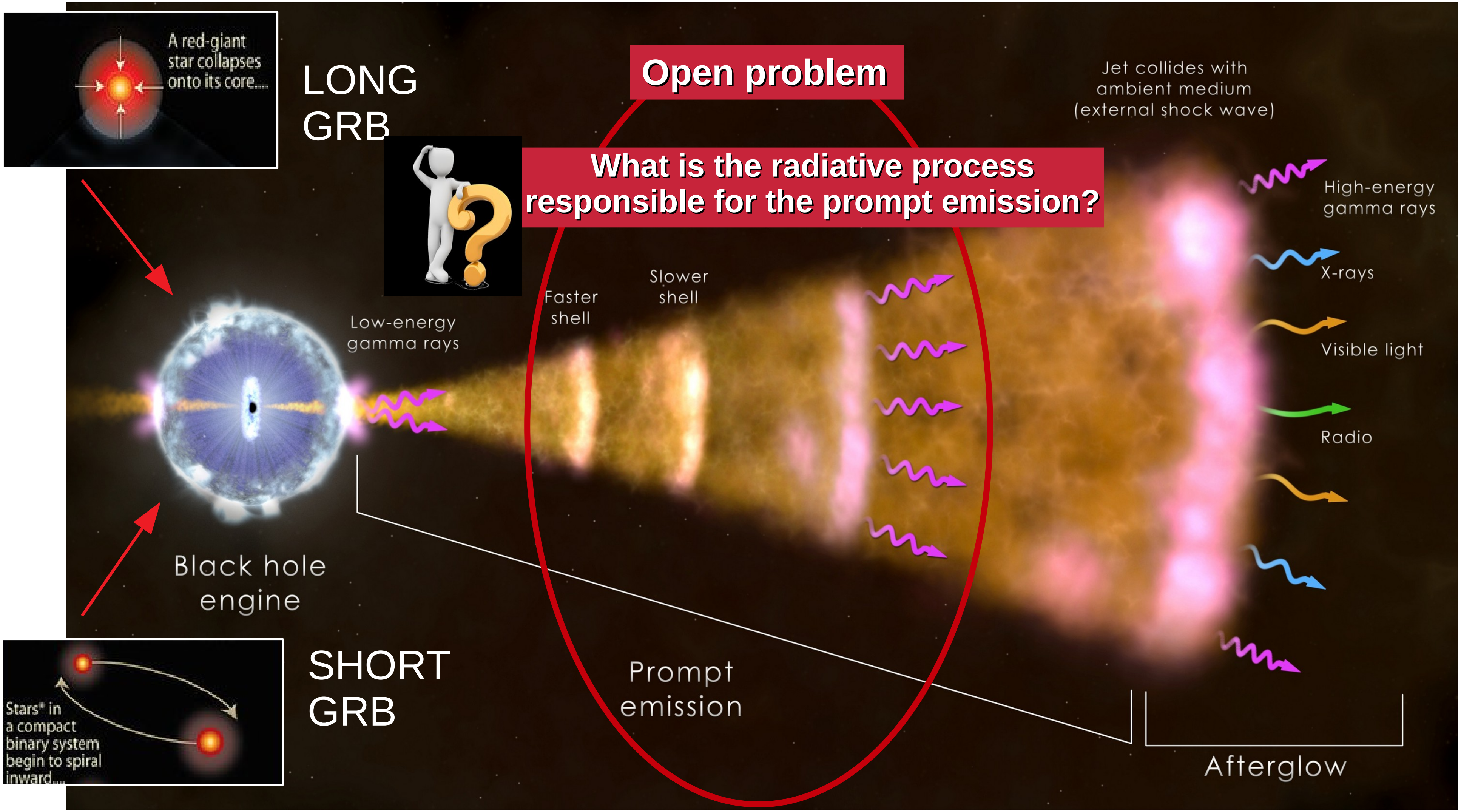
Radboud Universiteit Nijmegen

Maria Edvige Ravasio
Radboud University
INAF - Astronomical Observatory of Brera

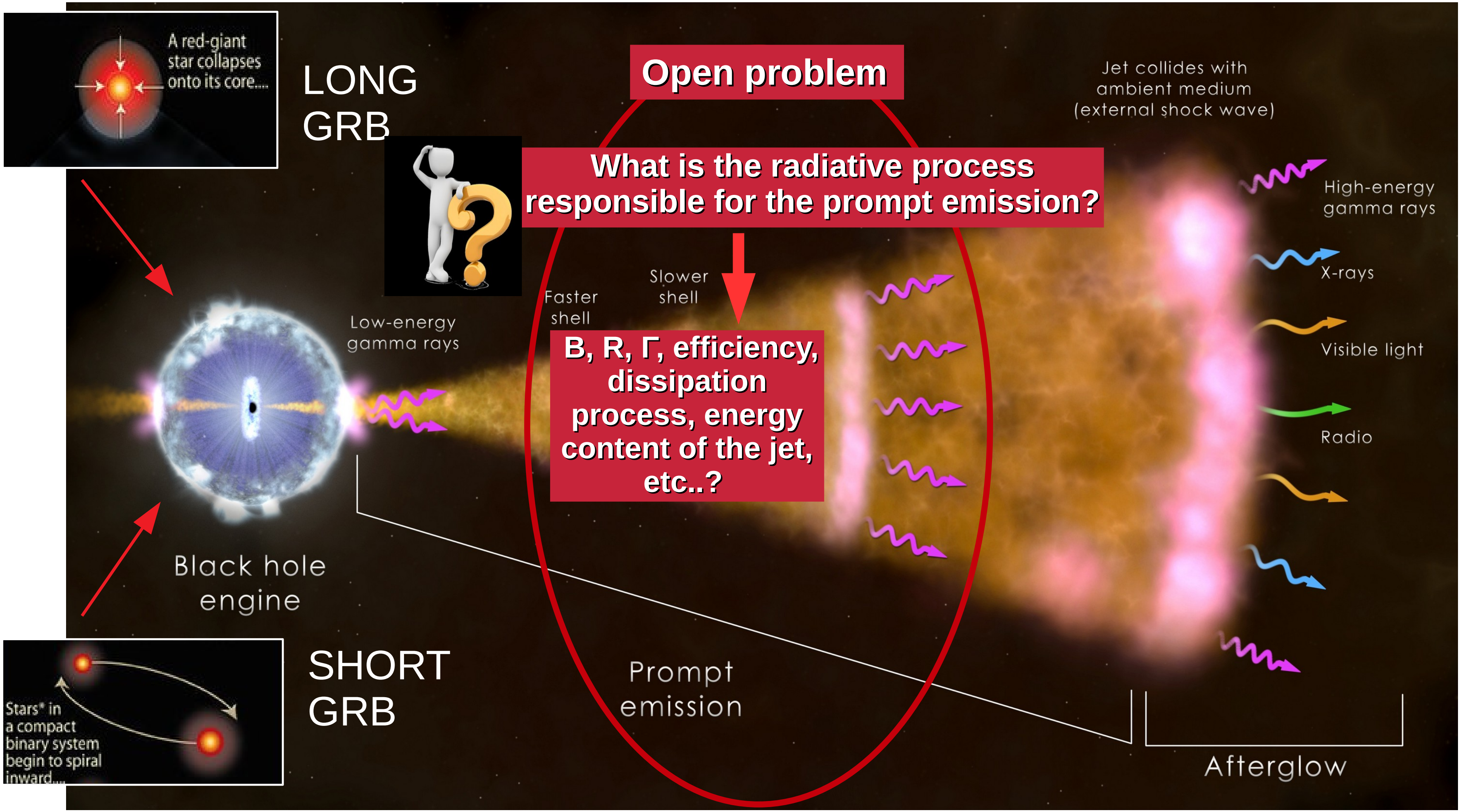
GRBV – 12/09/2022

INAF
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

Gamma-Ray Burst: standard model

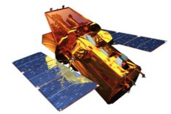


Gamma-Ray Burst: standard model



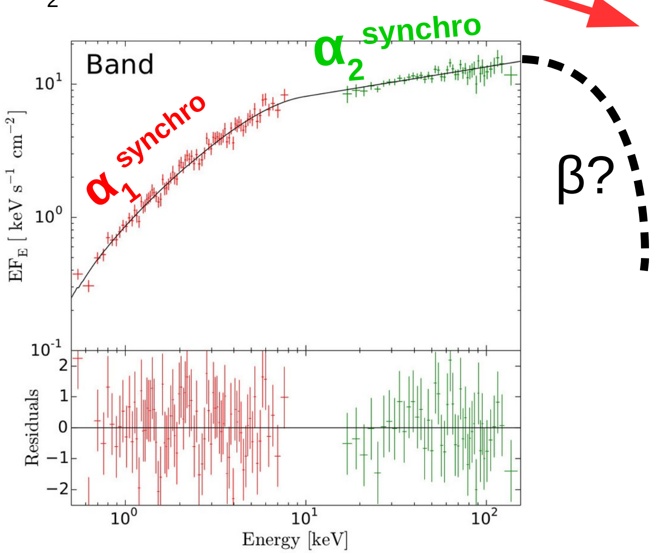
Recent hints from the observations

Oganesyan et al., 2017, ApJ
Oganesyan et al., 2018, A&A



Analyzing 34 **long GRBs** down to the X-rays:

- 62% of the prompt spectra display a **break** between **2 and 30 keV**
- the **spectral indices** are $\langle\alpha_1\rangle = -0.51 \pm 0.29$ and $\langle\alpha_2\rangle = -1.54 \pm 0.26$



XRT
(0.3 – 10 keV)

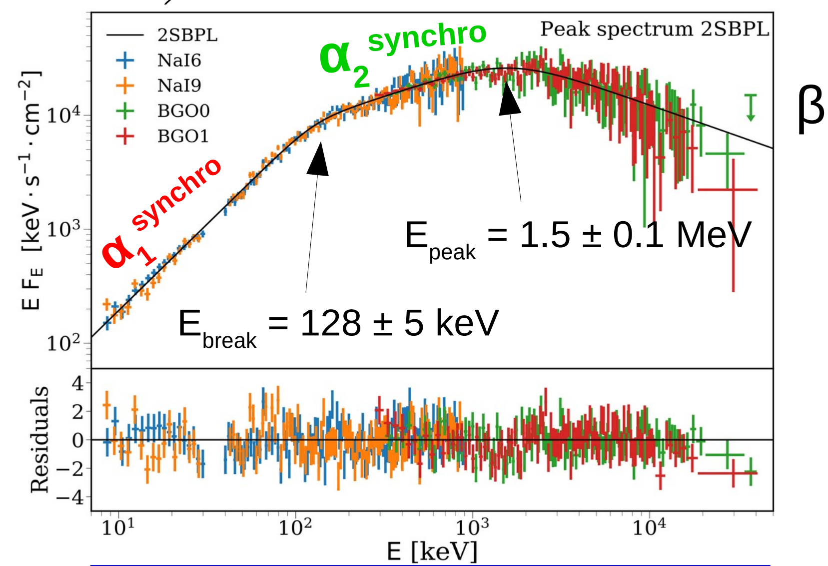
BAT
(15 – 150 keV)

Consistent with synchrotron predictions!

Ravasio et al., 2018, A&A
Ravasio et al., 2019, A&A

Analyzing 10 **long GRBs** at γ-ray energies:

- 70% of the prompt spectra display a **break** between **20 and 300 keV**
- the **spectral indices** are $\langle\alpha_1\rangle = -0.58 \pm 0.16$ and $\langle\alpha_2\rangle = -1.52 \pm 0.20$



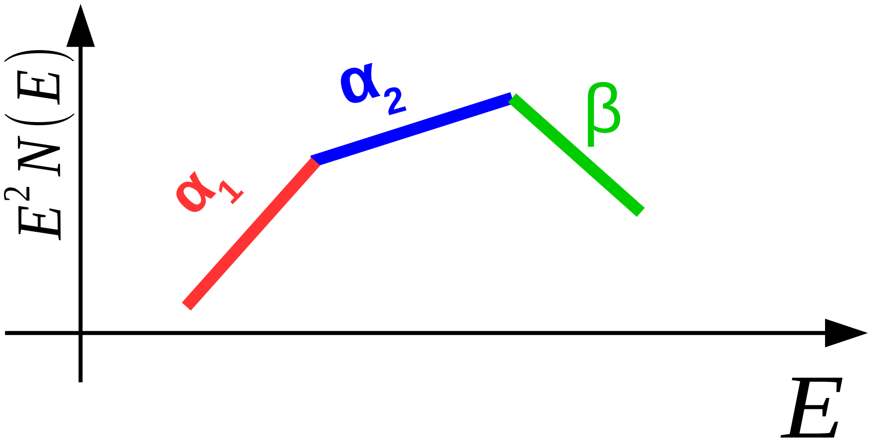
Fermi/GBM
(8 keV – 40 MeV)

Recent hints from the observations

Ravasio et al., 2019, A&A

LONG GRBs

TWO BREAKs

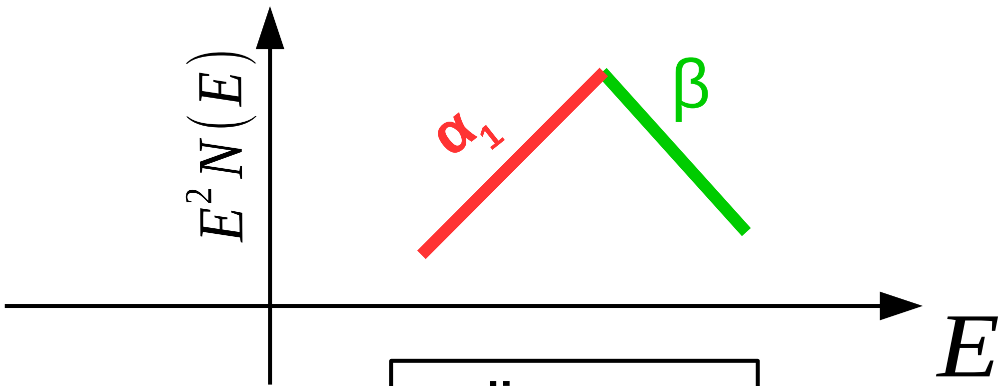


$\langle\alpha_1\rangle$ = -0.58 (σ= 0.16)

$\langle\alpha_2\rangle$ = -1.52 (σ= 0.20)

SHORT GRBs

NO ADDITIONAL BREAK



α_2 disappears

$\langle\alpha_1\rangle$ = −0.78 (σ=0.23)

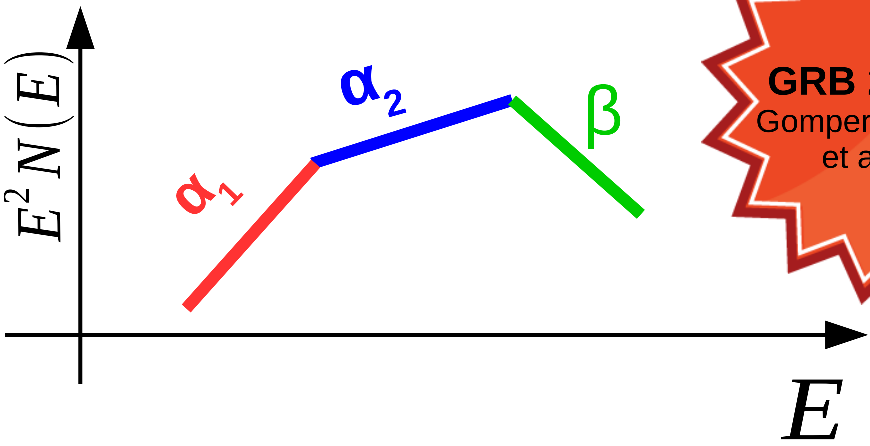
- In **both cases**, photon indices from empirical fits **consistent with synchrotron predictions** ✓
- Direct **test of the synchrotron model** with data [Ronchi M., Fumagalli F., **Ravasio M.E.** et al, 2020, A&A ; Oganesyan et al. 2019 ; Burgess et al. 2020] ✓

Recent hints from the observations

Ravasio et al., 2019, A&A

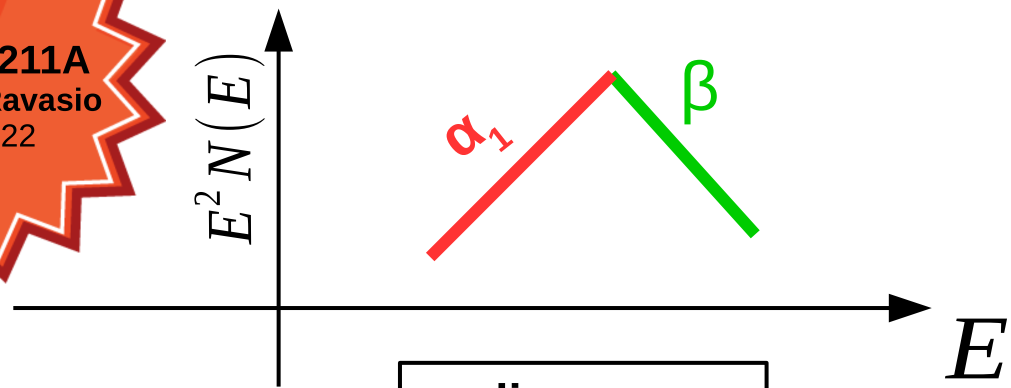
LONG GRBs

TWO BREAKs



SHORT GRBs

NO ADDITIONAL BREAK



α_2 disappears

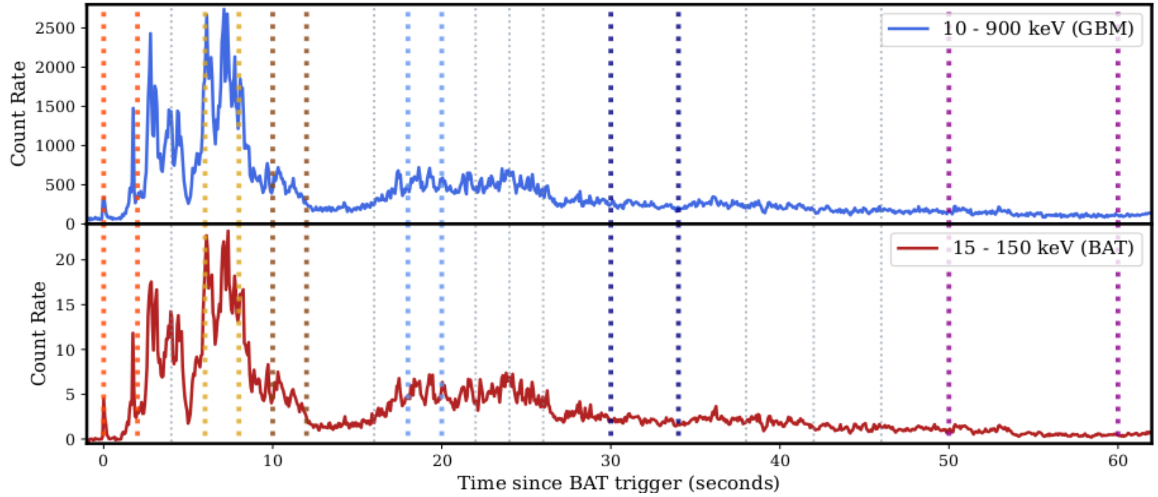
$\langle\alpha_1\rangle = -0.58$ ($\sigma = 0.16$)

$\langle\alpha_2\rangle = -1.52$ ($\sigma = 0.20$)

$\langle\alpha_1\rangle = -0.78$ ($\sigma = 0.23$)

- In **both cases**, photon indices from empirical fits **consistent with synchrotron predictions** ✓
- Direct **test of the synchrotron model** with data [Ronchi M., Fumagalli F., **Ravasio M.E.** et al, 2020, A&A ; Oganesyan et al. 2019 ; Burgess et al. 2020] ✓

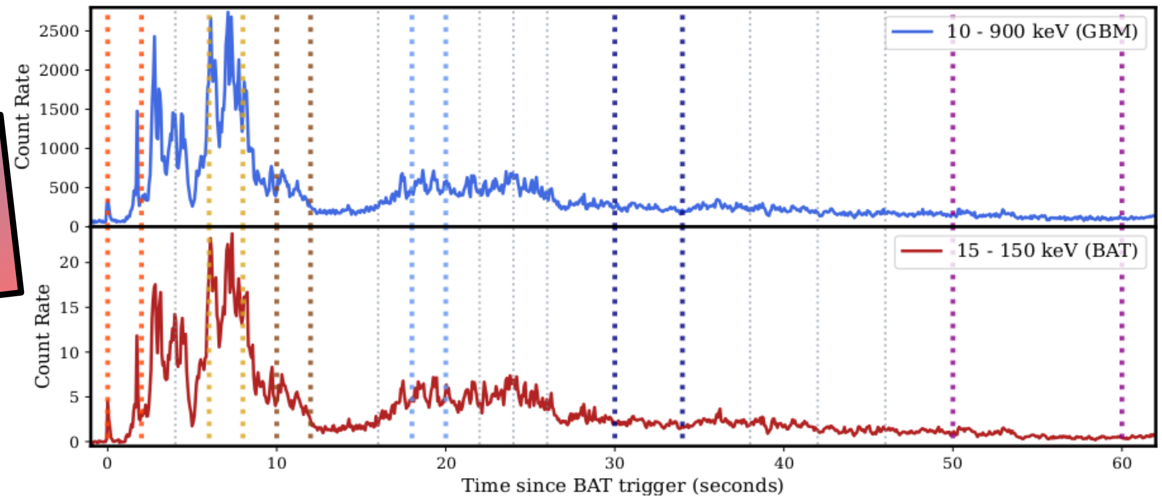
GRB 211211A: long GRB with a kilonova



[Rastinejad et al, (...)
Ravasio et al, 2022,
submitted to Nature]

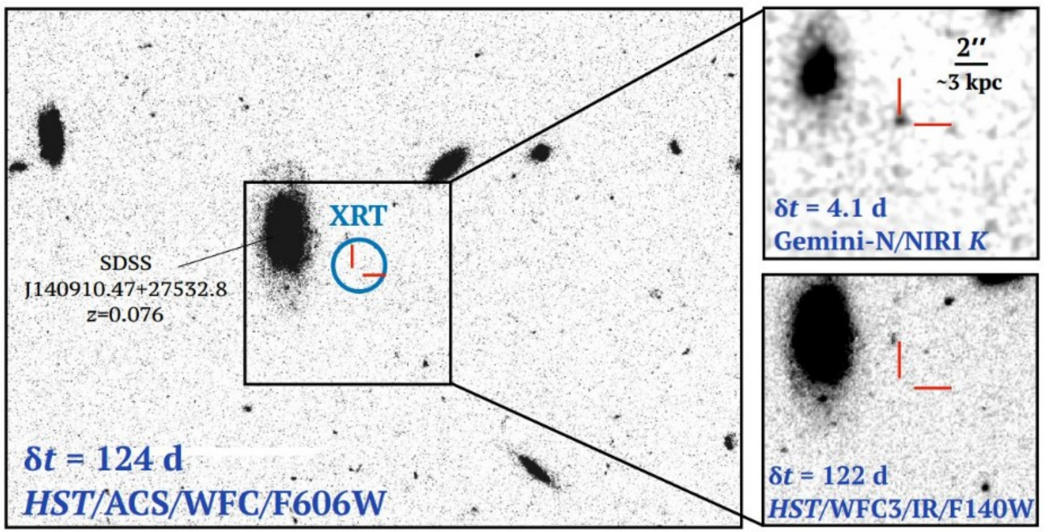
GRB 211211A: long GRB with a kilonova

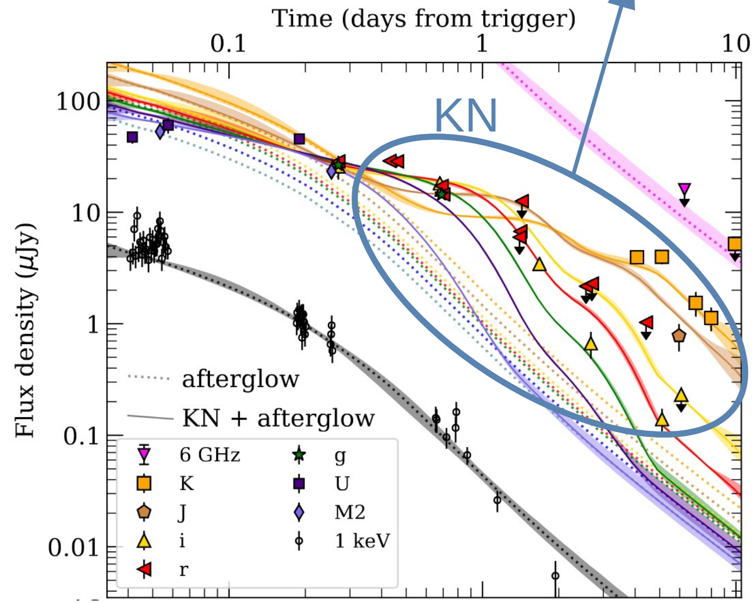
Late GeV emission!
Talk by Alessio Mei
tomorrow at 10:20



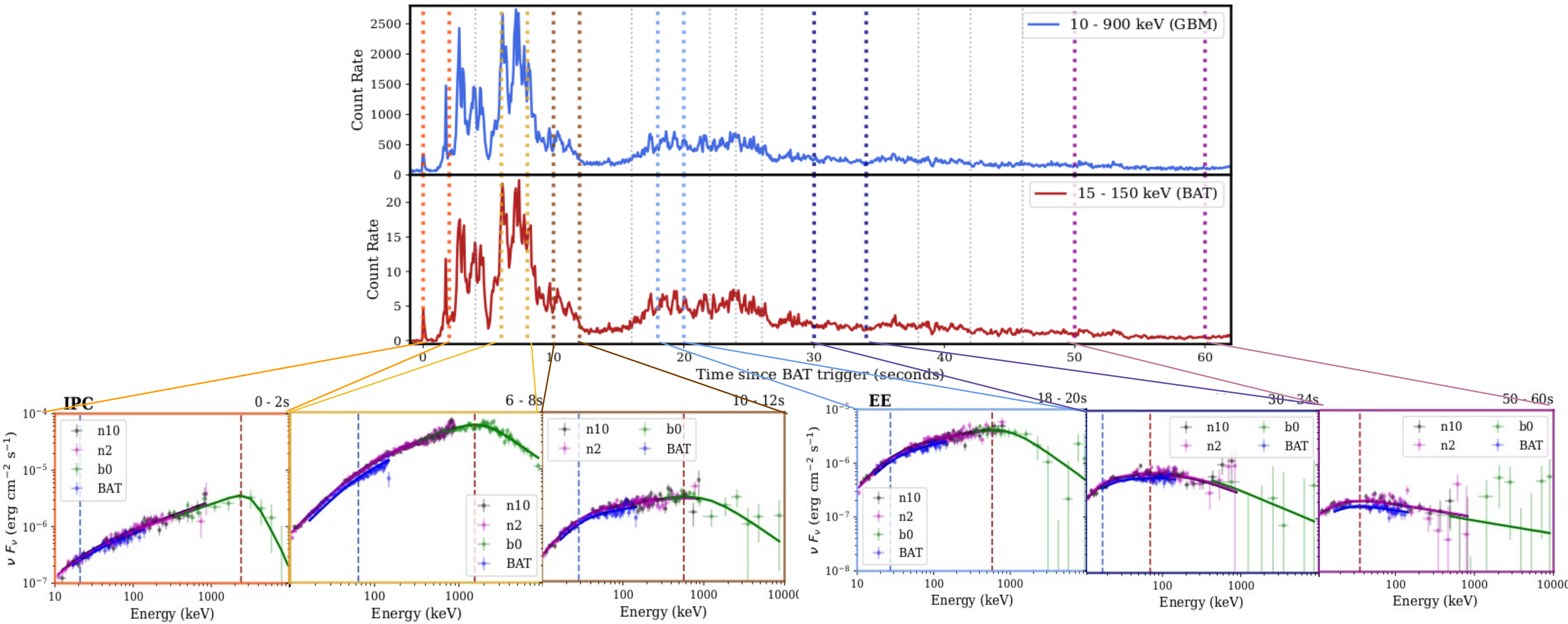
[Rastinejad et al, (...)
Ravasio et al, 2022,
submitted to Nature]

Infrared data in excess (~3mag) wrt afterglow model





GRB 211211A: long GRB with a kilonova

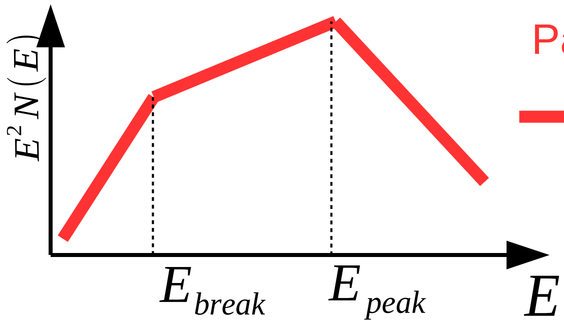


Both ν_{cool} and ν_{min} evolving from gamma- to X-rays

→ **First time synchrotron cooling** found in a **merger-driven GRB!**

[Gompertz, **Ravasio** et al, 2022, under revision by Nature Astronomy]

Theoretical implications



Particles do not cool completely!

$$\frac{\nu_{min}}{\nu_{cool}} \sim 1 - 10$$

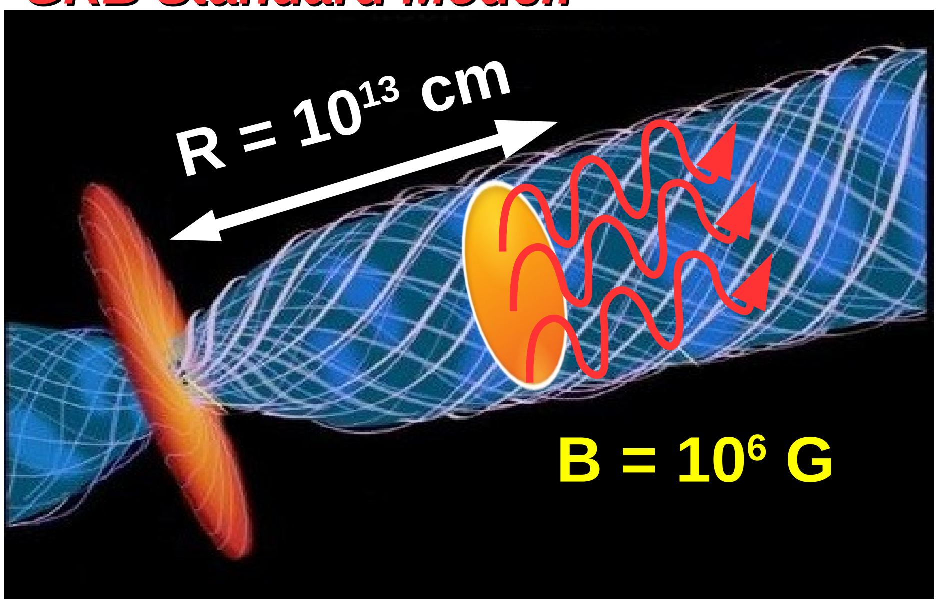
Marginally fast cooling regime

[Kumar & McMahon 2008, Daigne 2011, Beniamini & Piran 2013]

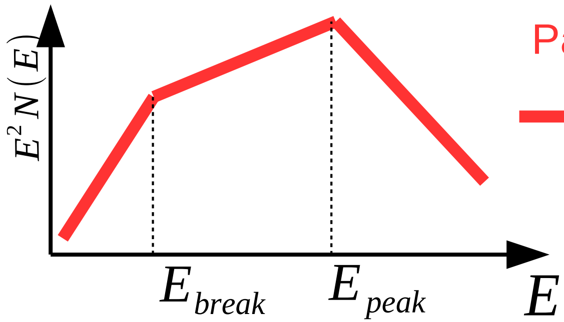
At the emitting region

$$B' \sim 10\ \Gamma_2^{-1/3} {\nu_{100\,\mathrm{keV}}^{\mathrm{obs}}}^{-1/3} {t_{1s}^{\mathrm{obs}}}^{-2/3}\ \mathrm{G}$$

GRB Standard Model:



Theoretical implications



Particles do not cool completely!

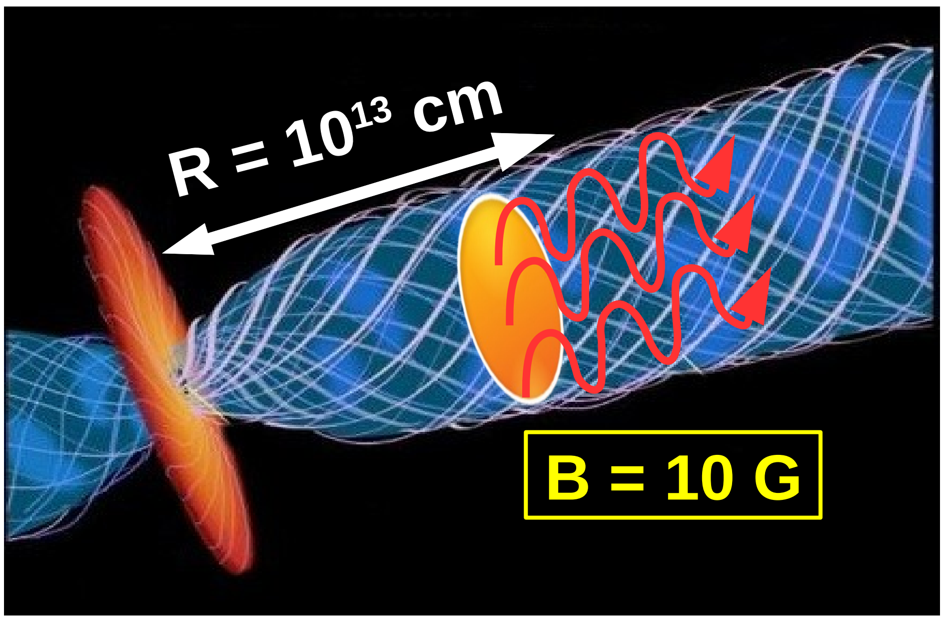
$$\to \frac{\nu_{min}}{\nu_{cool}} \sim 1 - 10$$

Marginally fast cooling regime

[Kumar & McMahon 2008, Daigne 2011, Beniamini & Piran 2013]

At the emitting region

$$B' \sim 10 \;\; \Gamma_2^{-1/3} \, {\nu_{100\,\mathrm{keV}}^{\mathrm{obs}}}^{-1/3} \; {t_{1s}^{\mathrm{obs}}}^{-2/3} \;\; \mathrm{G}$$



Consequences of a low magnetic field in the leptonic scenario:

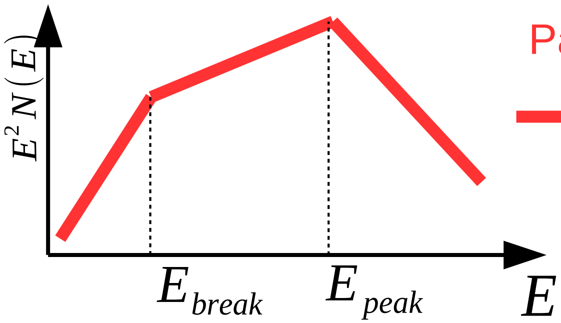
→ R ~ 10^{13} - 10^{14} cm

(standard model)

$$\frac{U'_{rad}}{U'_B} = \frac{L_C}{L_{Syn}} \uparrow$$

Not observed!

Theoretical implications



Particles do not cool completely!

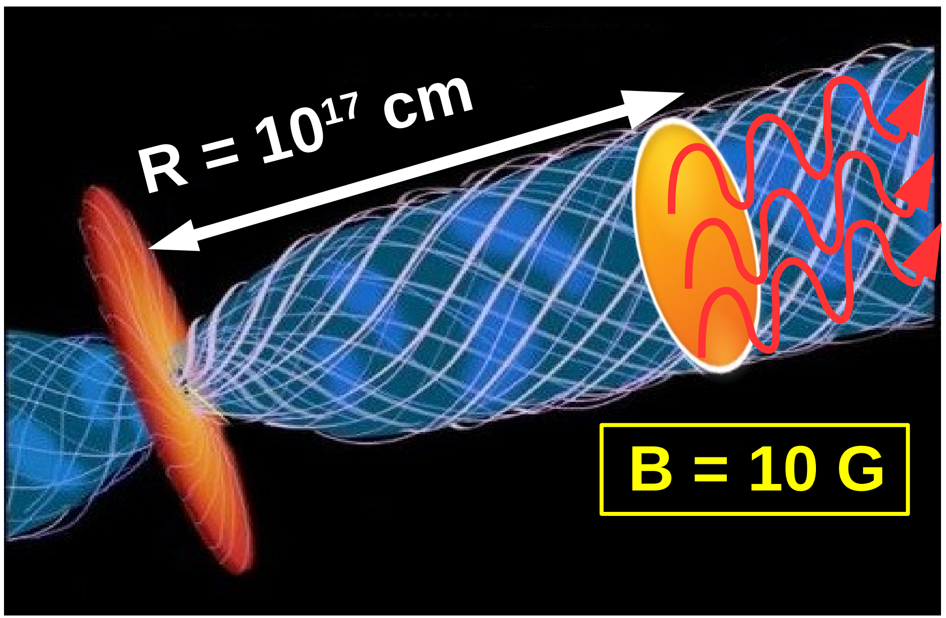
$$\frac{\nu_{min}}{\nu_{cool}} \sim 1 - 10$$

Marginally fast cooling regime

[Kumar & McMahon 2008, Daigne 2011, Beniamini & Piran 2013]

At the emitting region

$$B' \sim 10 \;\; \Gamma_2^{-1/3} \nu_{100\,\mathrm{keV}}^{\mathrm{obs}\;-1/3} \;\; t_{1s}^{\mathrm{obs}\;-2/3} \;\; \mathrm{G}$$



Consequences of a low magnetic field in the leptonic scenario:

→ R ~ 10^{13} - 10^{14} cm

(standard model)

$$\frac{U'_{rad}}{U'_B} = \frac{L_C}{L_{Syn}} \uparrow$$

Not observed!

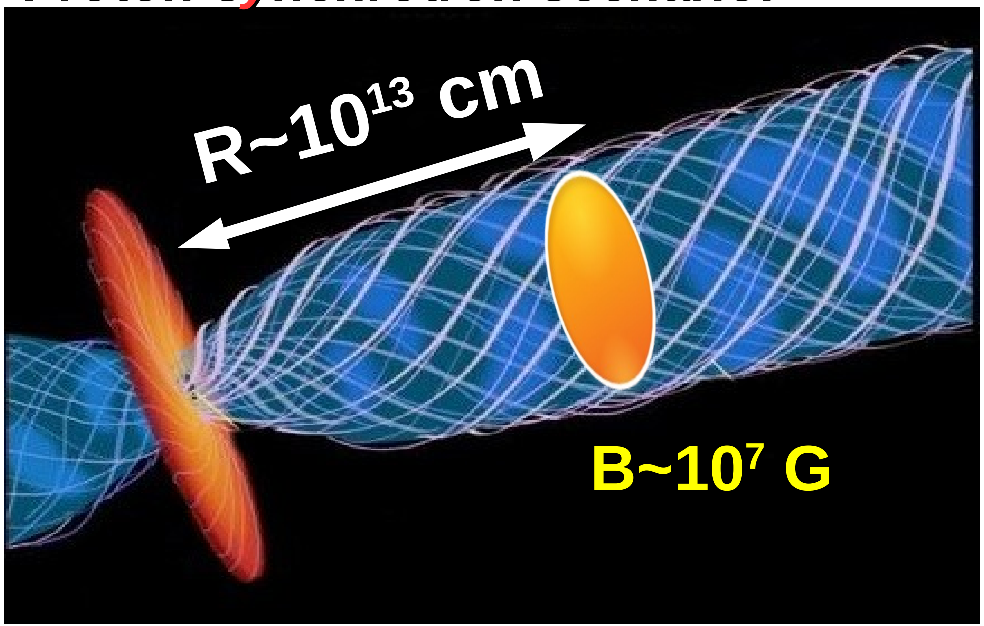
→ R ~ 10^{16} - 10^{17} cm

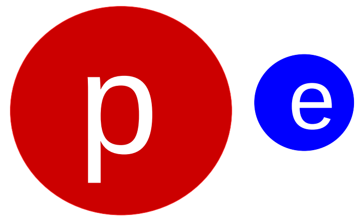
- Variability timescale?? → very large Γ
- Afterglow??

Theoretical implications

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

Proton-synchrotron scenario:





Ghisellini et al., A&A, 2020

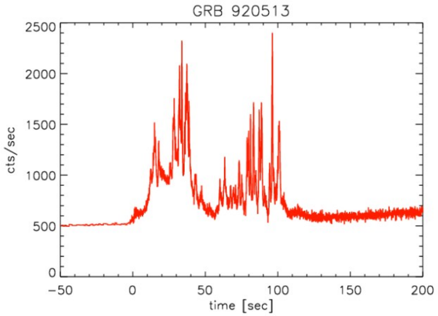
Require higher magnetic field of **$B \sim 10^7$ G** in a ‘standard’ emitting region at **$R \sim 10^{13}$** cm with ‘standard’ bulk Lorentz factors **$\Gamma \sim 10^2$**

...still under investigation
(see Florou et al. 2021, Bégué, Samuelsson, Pe'er 2021)

High energy observation

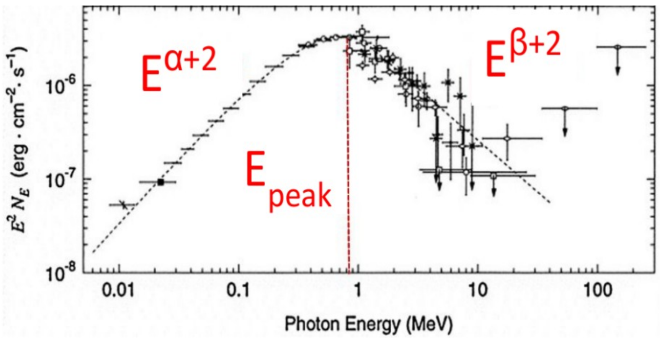
GRBs as relativistic sources

- The variability timescales δt imply that the source is compact

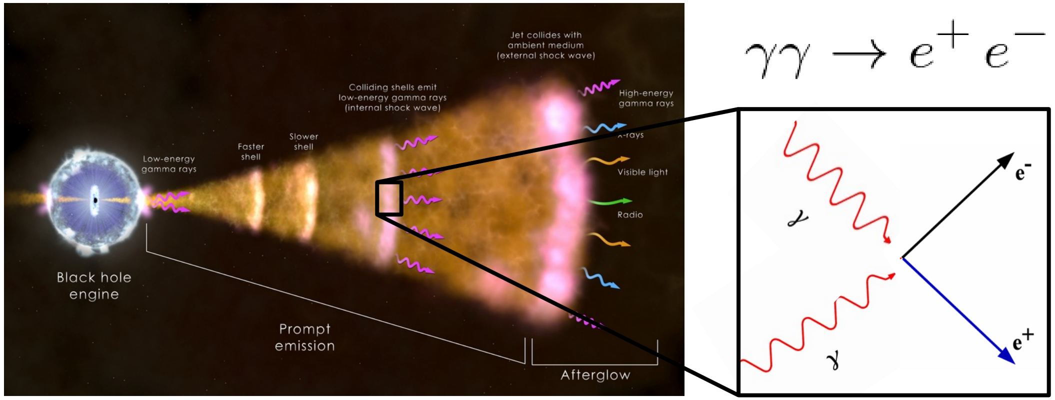


$$R \sim c\,\delta t$$

- The spectrum is non-thermal and made by high energies photons



$$\gamma\gamma \rightarrow e^+ e^-$$



If the emitting matter is **moving relativistically with a bulk Lorentz factor Γ**

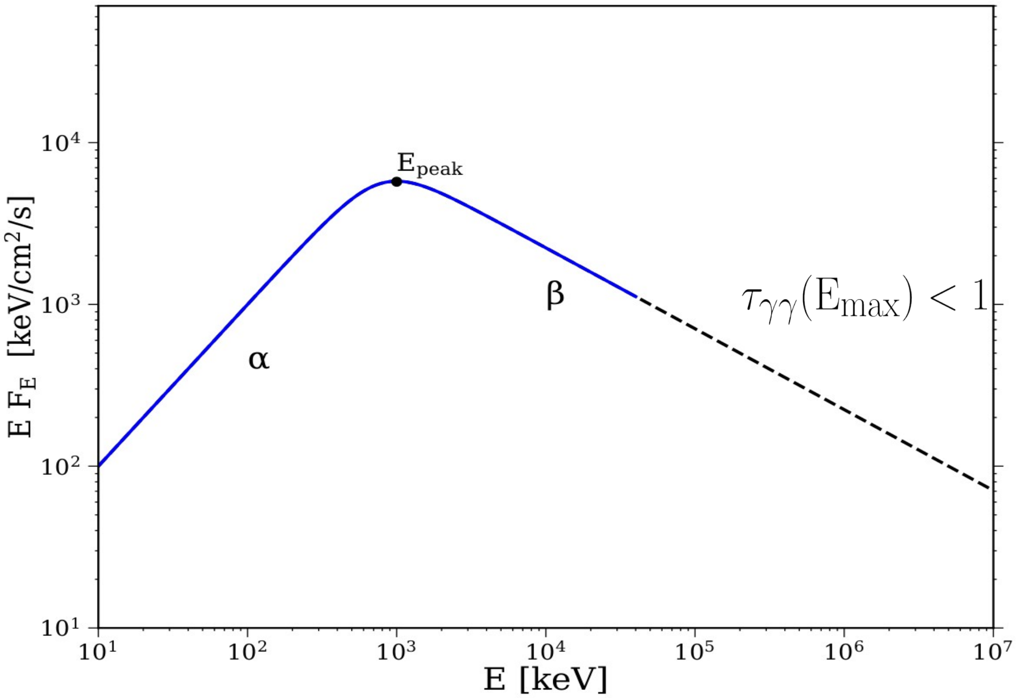
$$\tau_{\gamma\gamma} \propto \Gamma^{-2-2\beta} < 1$$

$$\longrightarrow \Gamma > 100$$

for typical parameters
(t_{var} = 10 ms, E_{iso} = 10^{52} erg, beta=-2.5, z=2)

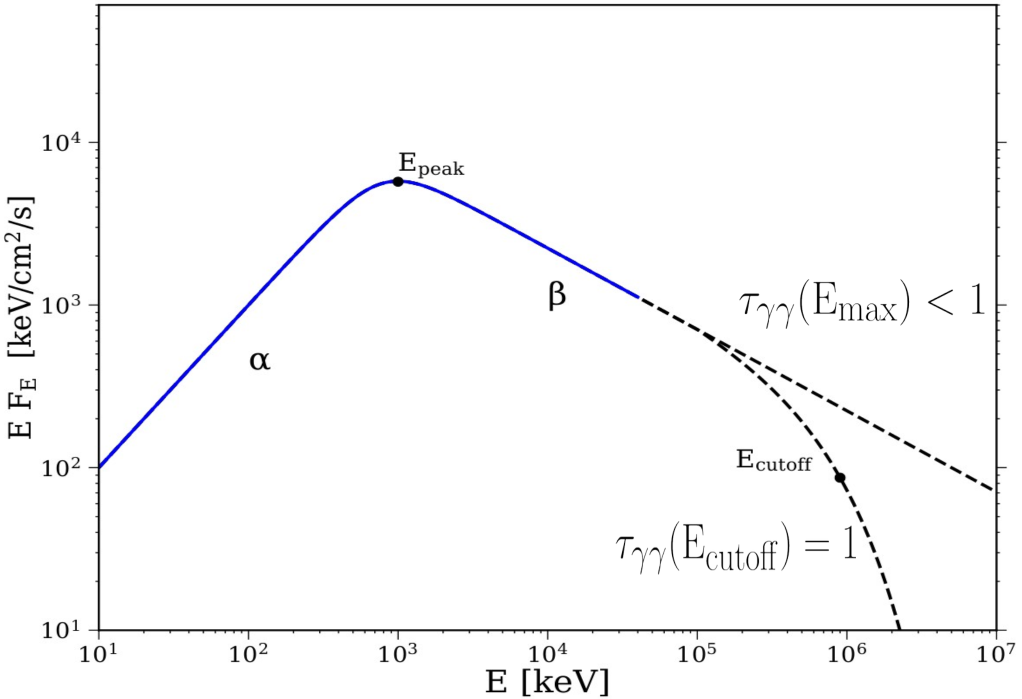
[Piran 1999]
[Lithwick & Sari 2001]

Searching for compactness signature in Fermi data



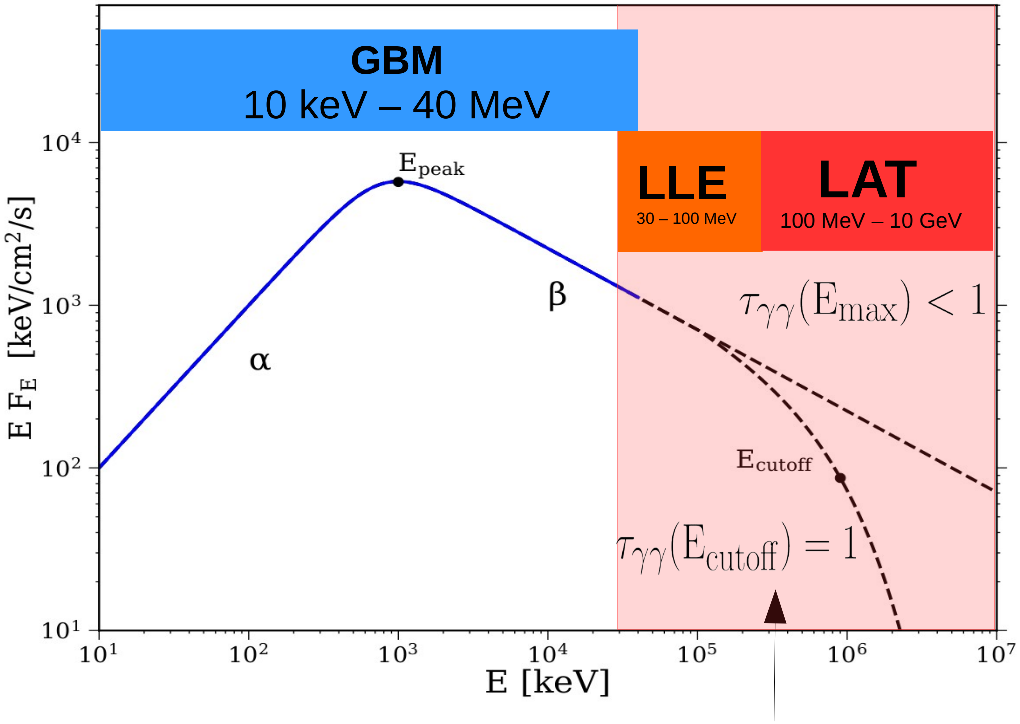
Ravasio et al., in prep.

Searching for compactness signature in Fermi data

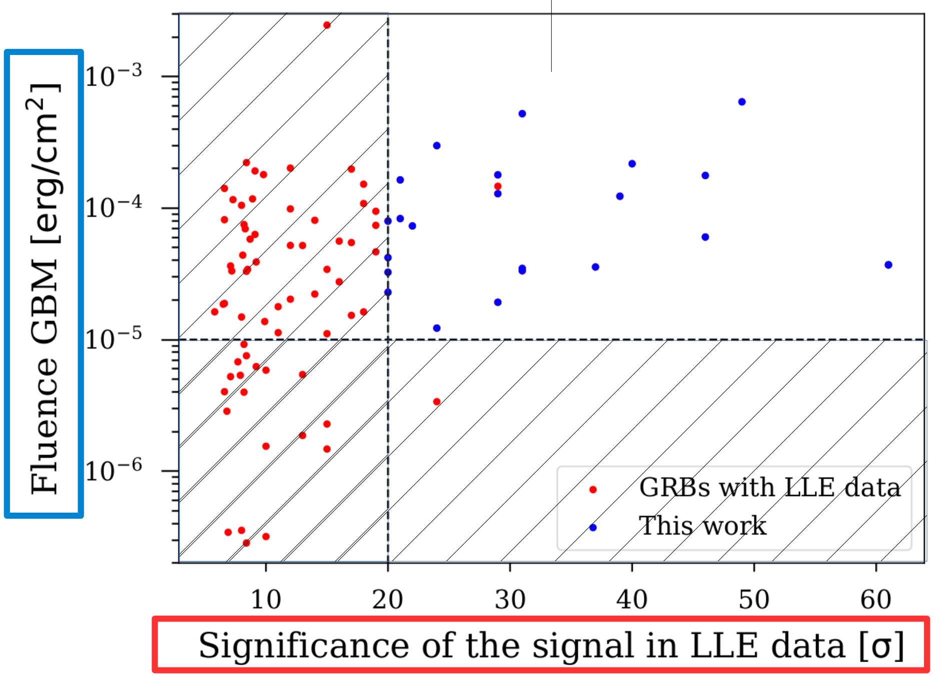


Ravasio et al., in prep.

Searching for compactness signature in Fermi data



Sample: **22 GRBs with optimal photon statistic both at low and at high energies**

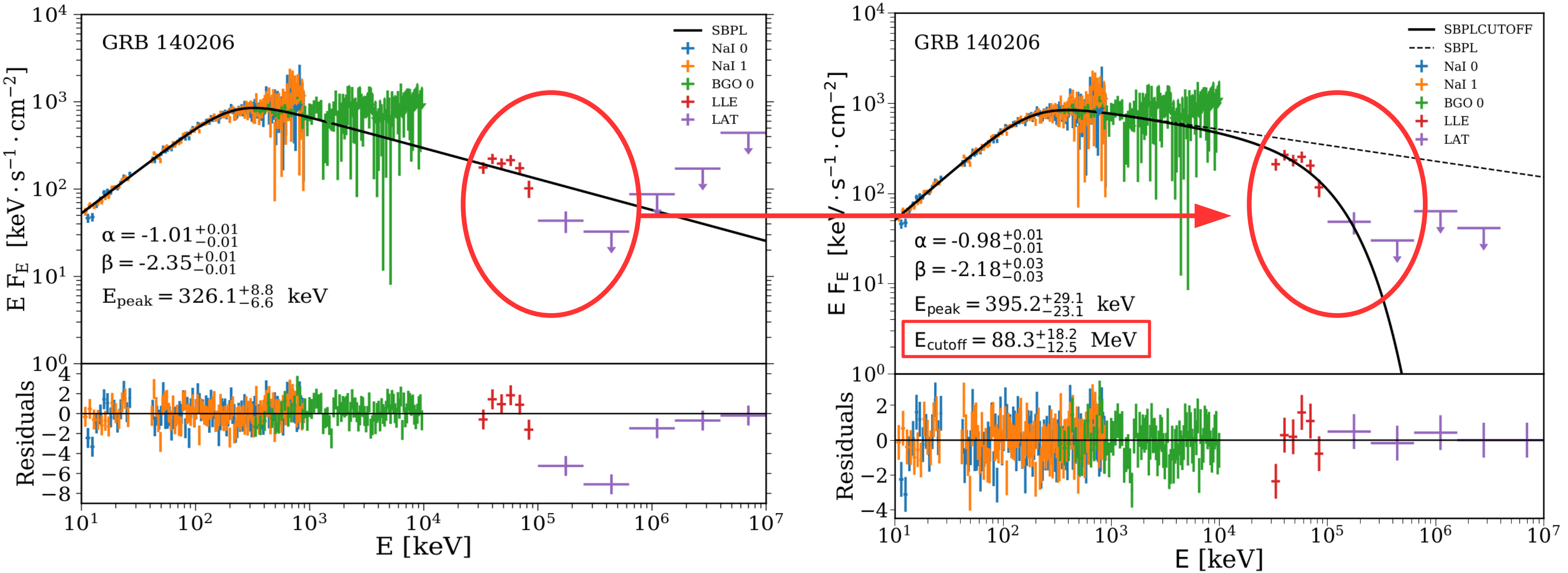


AIM: systematically characterize the high-energy part of prompt emission spectra to estimate Γ

Ravasio et al., in prep.

Results of the joint analysis: high-energy cutoff

→ in **10/22 bursts**, the spectral data significantly required the presence of an **exponential cutoff at high energies**, with **E$_{cutoff}$** between ∼ **14 and 298 MeV**

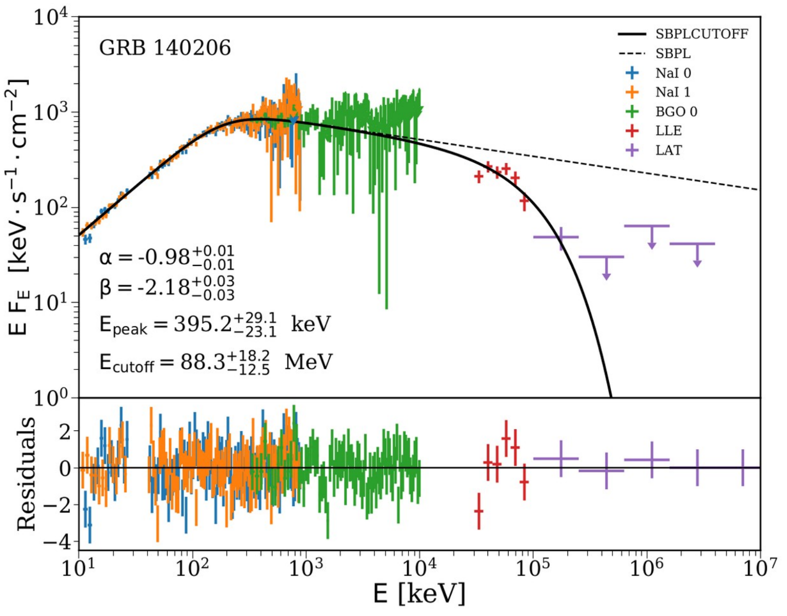


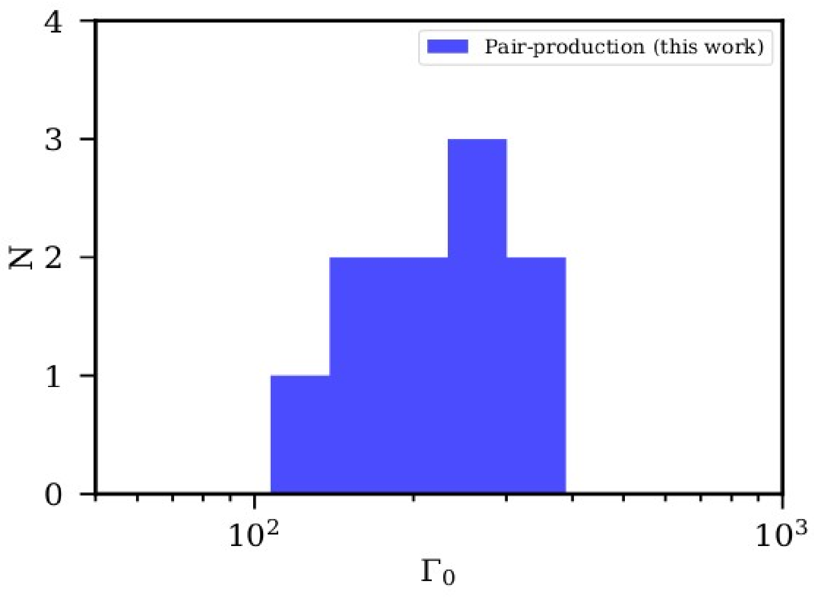
Ravasio et al., in prep.

Theoretical interpretation: pair-production

Interpreting the cutoff as the **sign of the opacity to pair-production** and assuming t_{var} = 0.1 s for each burst

$$140 \leq \Gamma \leq 330$$





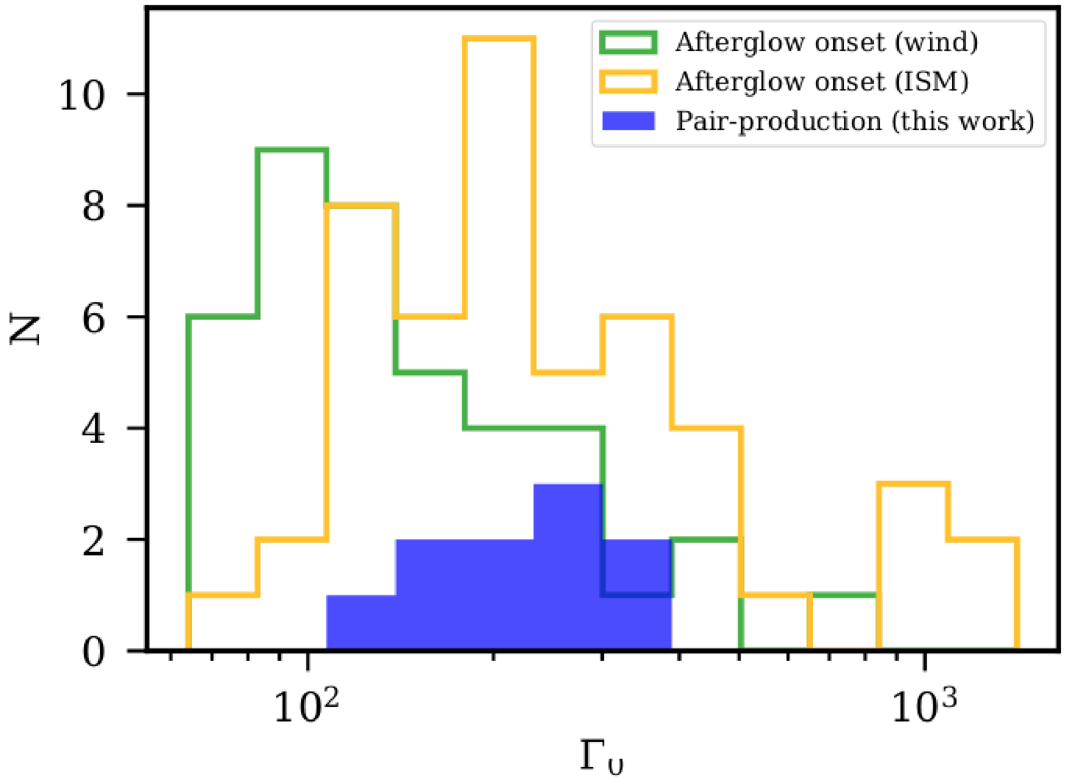
Consistent with values derived from the same opacity argument applied in a few bursts present in the literature

[e.g. Ackermann et al., 2012, Tang et al. 2015, Vianello et al., 2018]

Ravasio et al., in prep.

Pair-production & afterglow onset

Ravasio et al., in prep.



$$140 \leq \Gamma \leq 330$$

consistent with the distributions of Γ derived from the afterglow deceleration peak

[Ghirlanda et al. 2018]

But we can go beyond the comparison of the Γ values...

Inferring the distance R from the central engine

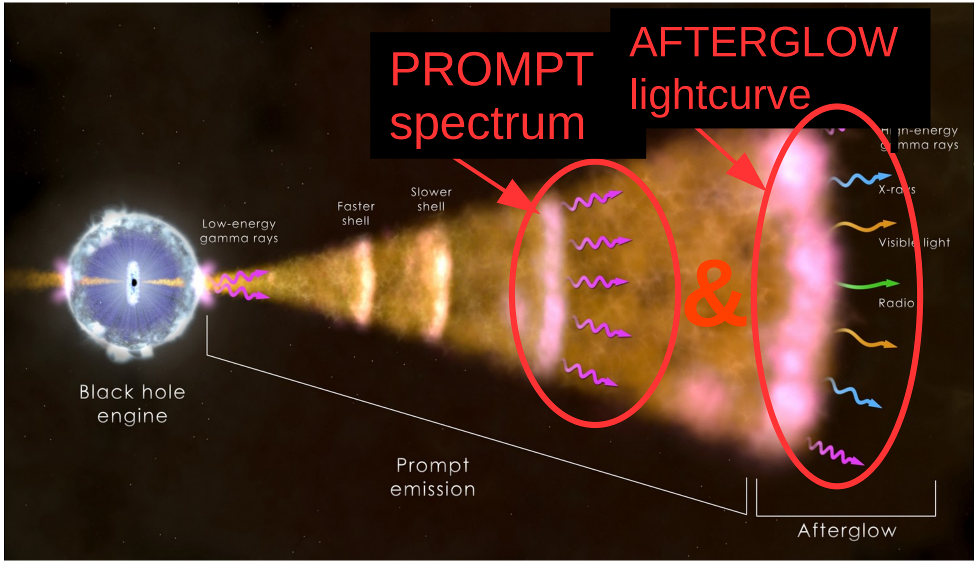
Ravasio et al., in prep.

$$\begin{cases} Compactness \\ Afterglow\ onset \end{cases}$$

$$\begin{cases} \tau_{\gamma\gamma}(\Gamma, \mathrm{R}) \leq 1 \\ \Gamma\ \ onset \end{cases}$$

Combining the two methods →

$$R \propto L_{\mathrm{iso}} \frac{E_{\mathrm{cutoff}}^{\beta_e}}{E_{\mathrm{peak}}^{1-\beta_e}} \Gamma^{-2-2\beta_e}$$



Method to restrict the parameter space for the prompt emission

Inferring the distance R from the central engine

$$\begin{cases} Compactness \\ Afterglow\ onset \end{cases}$$

Ravasio et al., in prep.

$$\begin{cases} \tau_{\gamma\gamma}(\Gamma, R) \leq 1 \\ \Gamma \quad onset \end{cases}$$

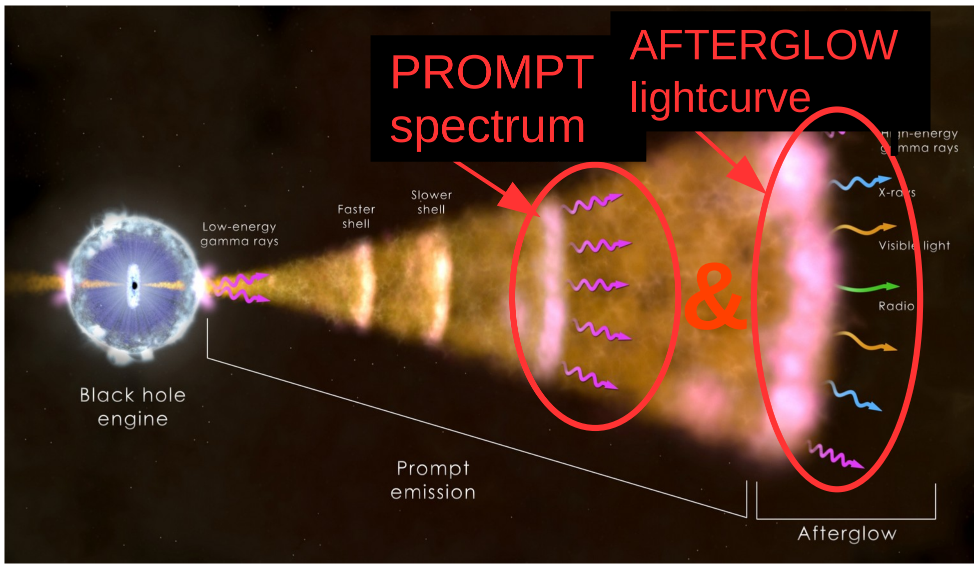
Combining the two methods →

$$R \propto L_{iso} \frac{E_{cutoff}^{\beta_e}}{E_{peak}^{1-\beta_e}} \Gamma^{-2-2\beta_e}$$

PRELIMINARY

$$R > 10^{13} - 10^{15} cm$$

For the only 2 GRBs of the sample with measured afterglow onset time (but without cutoff)



Method to restrict the parameter space for the prompt emission

Inferring the distance R from the central engine

$$\begin{cases} Compactness \\ Afterglow\ onset \end{cases}$$

Ravasio et al., in prep.

$$\begin{cases} \tau_{\gamma\gamma}(\Gamma, \mathrm{R}) \leq 1 \\ \Gamma \quad onset \end{cases}$$

Combining the two methods →

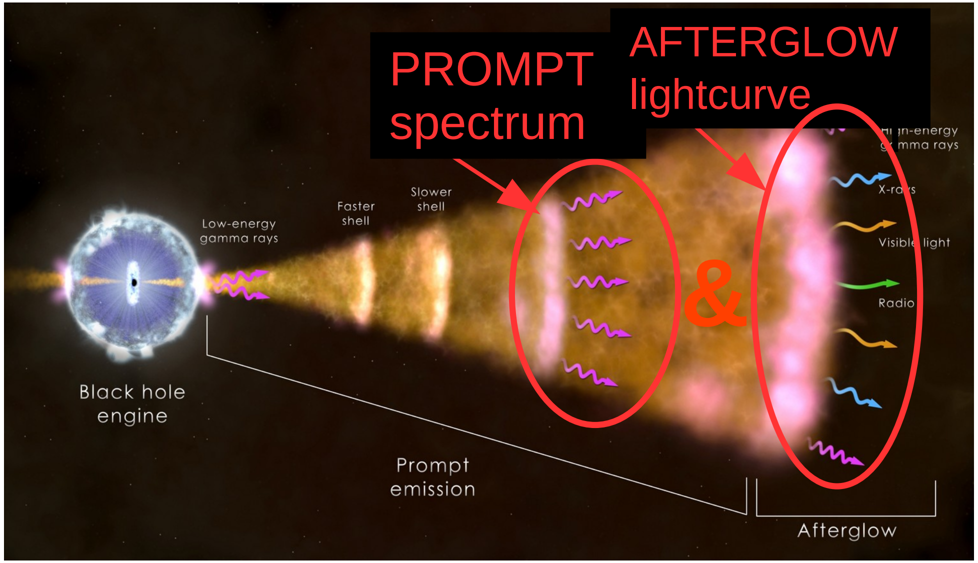
$$R \propto L_{\rm iso} \frac{E_{\rm cutoff}^{\beta_e}}{E_{\rm peak}^{1-\beta_e}} \Gamma^{-2-2\beta_e}$$

PRELIMINARY

$$R > 10^{13} - 10^{15} cm$$

For the only 2 GRBs of the sample with measured afterglow onset time (but without cutoff)

Apply to every GRB with:
→ Γ from the afterglow
→ prompt emission spectrum up to LAT energies



Method to restrict the parameter space for the prompt emission

STAY TUNED!

Inferring the distance R from the central engine

Ravasio et al., in prep.

$$\begin{cases} Compactness \\ Afterglow\ onset \end{cases}$$

$$\begin{cases} \tau_{\gamma\gamma}(\Gamma, \mathrm{R}) \leq 1 \\ \Gamma\ \ onset \end{cases}$$

Combining the two methods →

$$R \propto L_{\mathrm{iso}} \frac{E_{\mathrm{cutoff}}^{\beta_e}}{E_{\mathrm{peak}}^{1-\beta_e}} \Gamma^{-2-2\beta_e}$$

PRELIMINARY

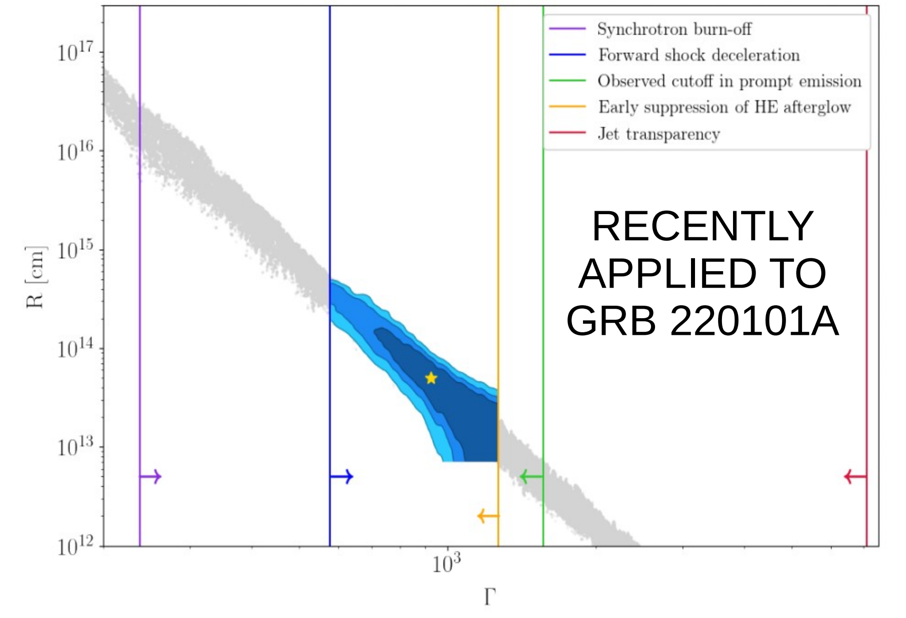
$$R > 10^{13} - 10^{15} cm$$

For the only 2 GRBs of the sample with measured afterglow onset time (but without cutoff)

Γ = 929 ± 231
logR = 13.69 ± 0.5

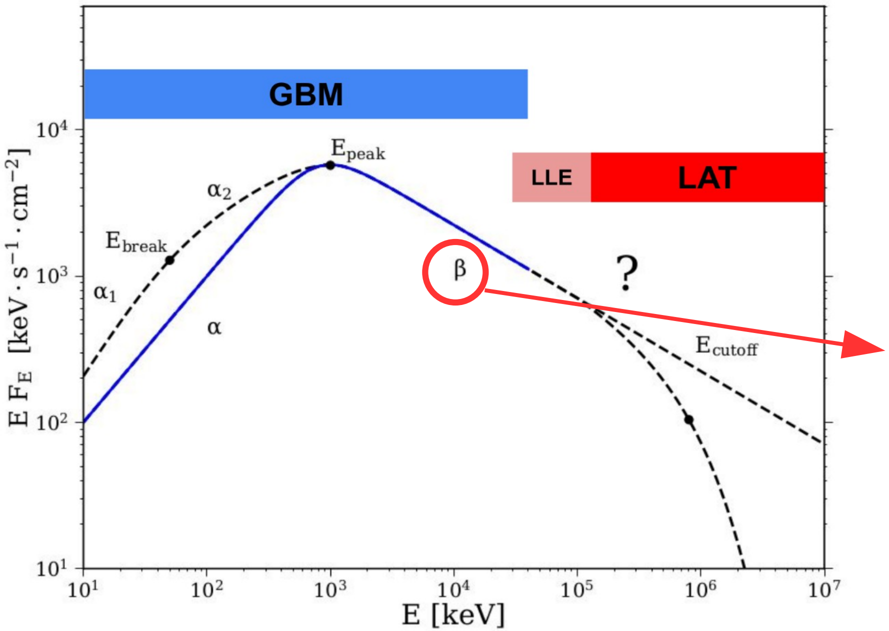
favouring the proton-sync scenario!

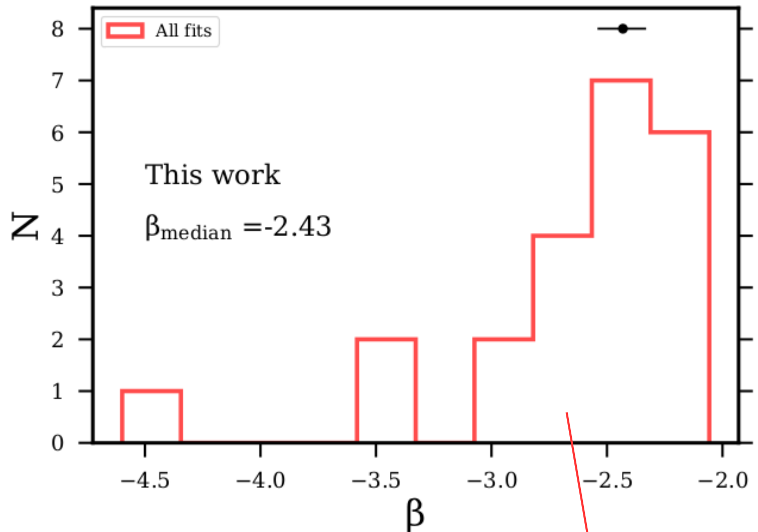
[Mei, Oganesyan, Tsvetkova, **Ravasio** et al., 2022]

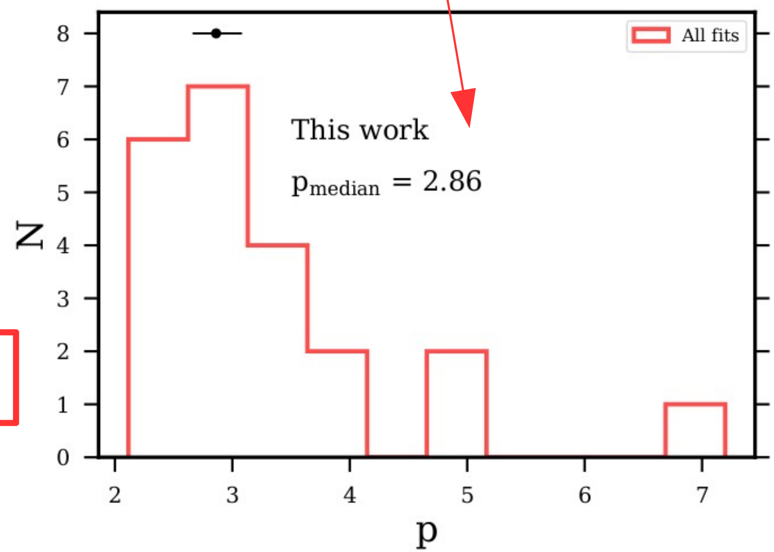


Method to restrict the parameter space for the prompt emission

Results of the joint analysis: high-energy slope







- distribution of p is quite **broad**
- extending towards **steep values**

Useful for theory of acceleration process

Ravasio et al., in prep.

Conclusion

- GRB Prompt emission: → Is it synchrotron? It looks like synchrotron, it smells like synchrotron, BUT…

In the leptonic scenario

B ~ 10 Gauss

Hard to reconcile with the standard model

In the hadronic scenario

B ~ 10^7 Gauss

Feasible but limited parameter space

Conclusion

- GRB Prompt emission: → Is it synchrotron? It looks like synchrotron, it smells like synchrotron, BUT…

In the leptonic scenario

B ~ 10 Gauss

Hard to reconcile with the standard model

In the hadronic scenario

B ~ 10^7 Gauss

Feasible but limited parameter space

- High-energy: → Γ from compactness (independent from the radiative process)

$$140 \leq \Gamma \leq 330$$

→ Slope of the particles distribution

Conclusion

- GRB Prompt emission: ⟶ Is it synchrotron? It looks like synchrotron, it smells like synchrotron, BUT…

In the leptonic scenario	In the hadronic scenario
B ~ 10 Gauss	**B ~ 10^7 Gauss**
Hard to reconcile with the standard model	Feasible but limited parameter space

- High-energy: → Γ from compactness (independent from the radiative process)

$$140 \lesssim \Gamma \lesssim 330$$

→ Slope of the particles distribution

- **High energy prompt spectra** + **afterglow lightcurves** → **distance R**

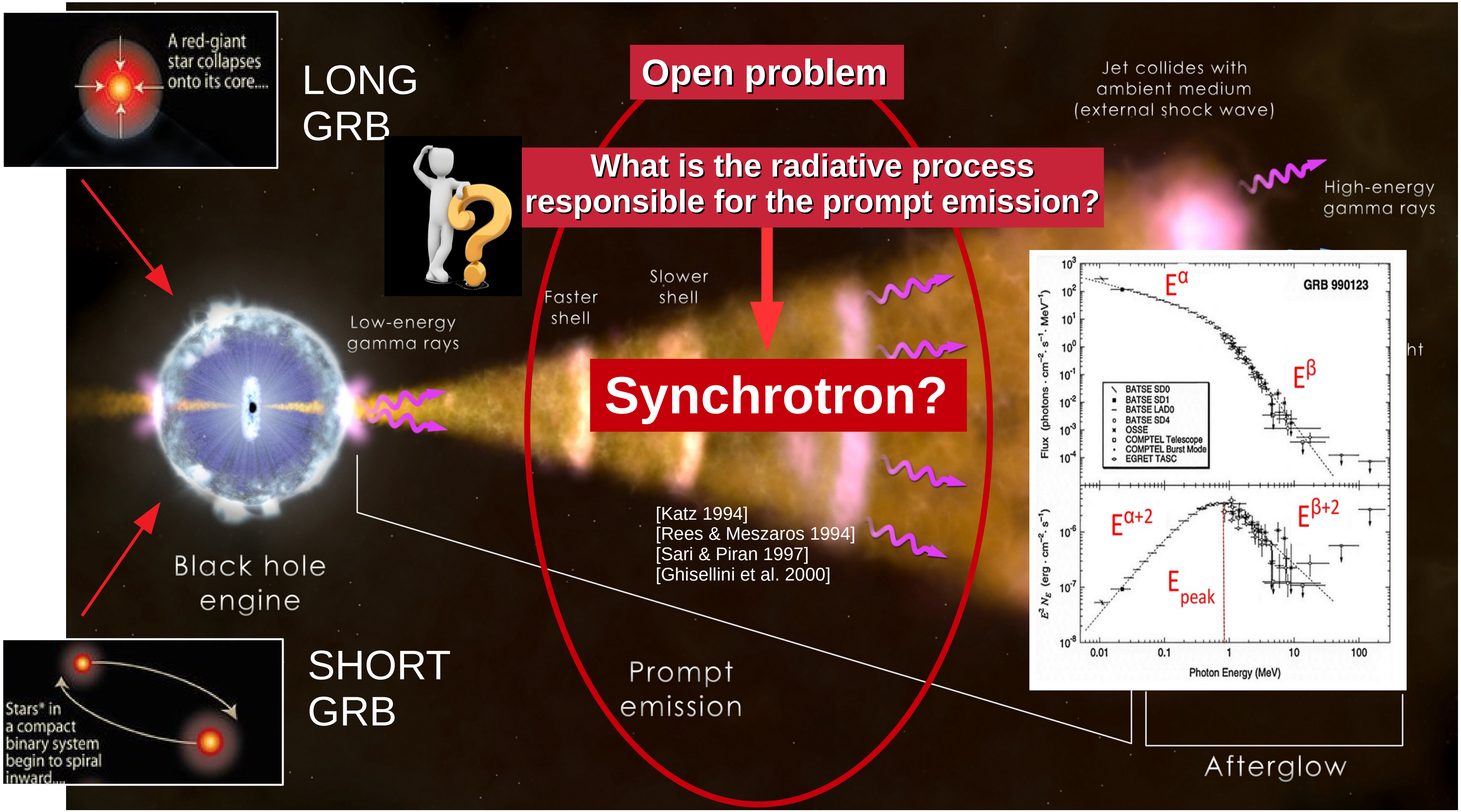
- more **HE** and **VHE** observations needed to fully uncover the prompt GRB parameter space

Ravasio et al., in prep.

Thanks for your attention

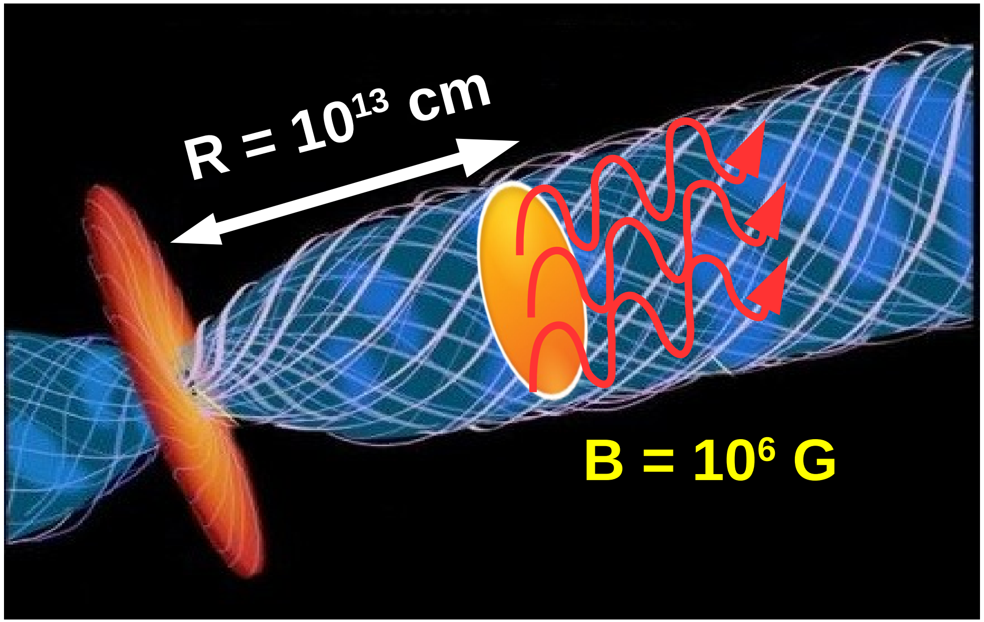
Back-up slides

Gamma-Ray Burst: standard model

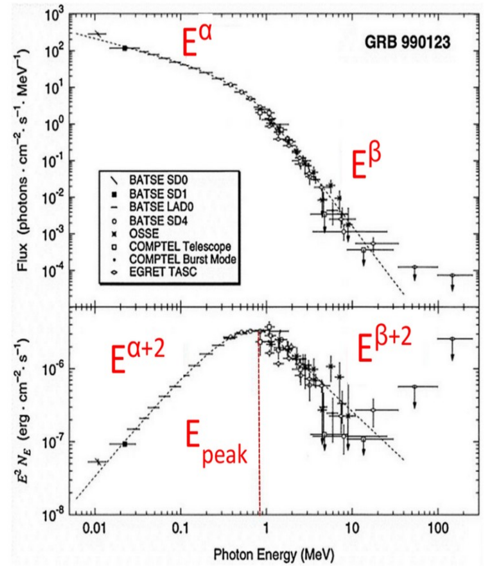


Theoretical expectations

GRB Standard Model:



- observed non-thermal spectrum

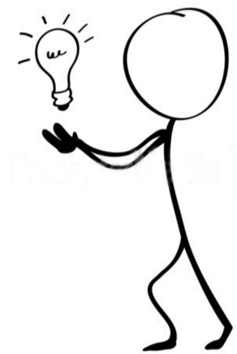


[Briggs et al., 1999]

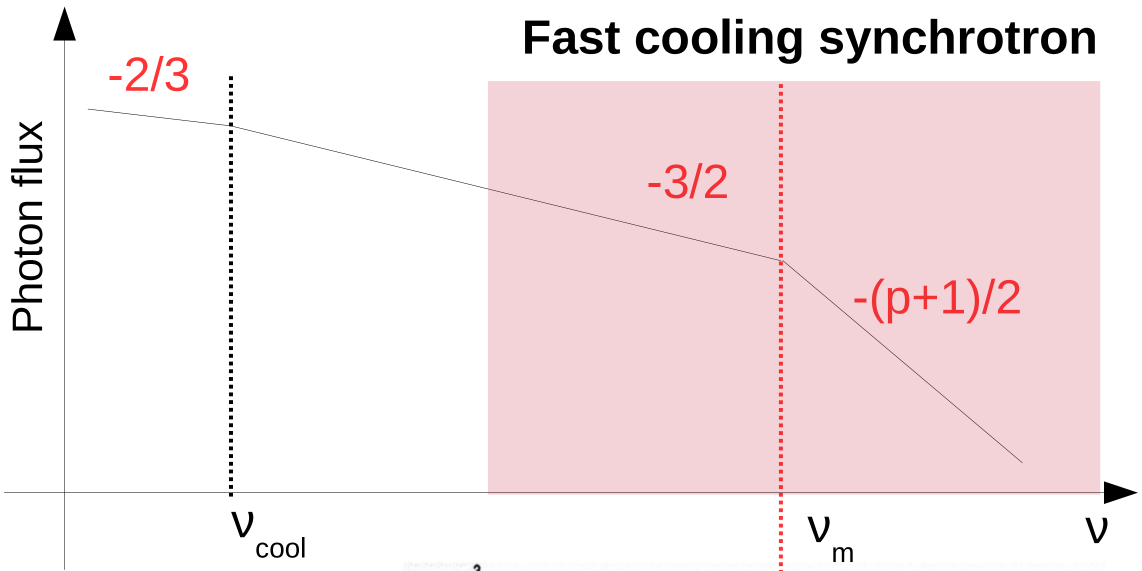
- accelerated electrons in a magnetized region

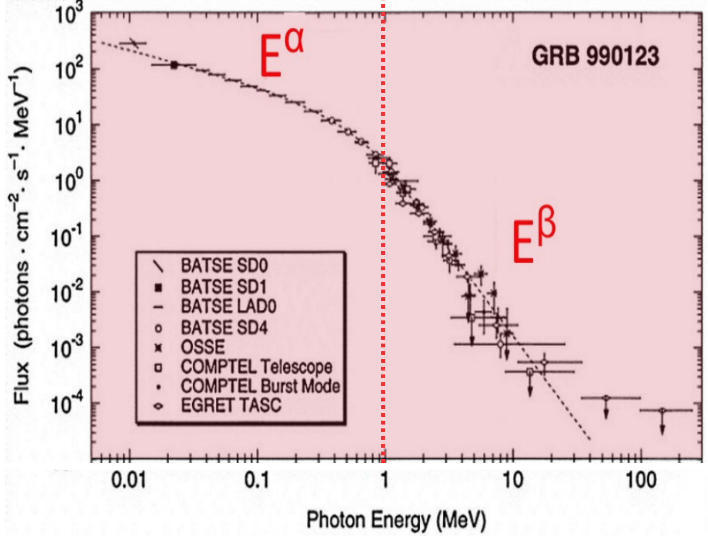
Synchrotron?

[Katz 1994]
[Rees & Meszaros 1994]
[Sari & Piran 1997]
[Ghisellini et al. 2000]



Theoretical expectations



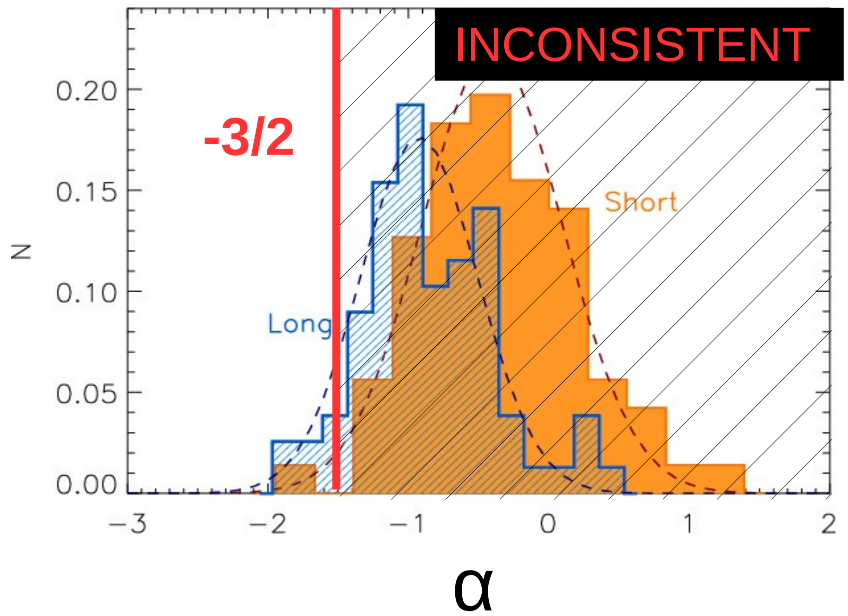


[Briggs et al., 1999]

[Ghisellini et al. 2000]

Observed slopes

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



[Ghirlanda et al., 2009]
[see also Preece 1998, Kaneko 2006, Nava 2011, Goldstein 2012, Gruber 2014]

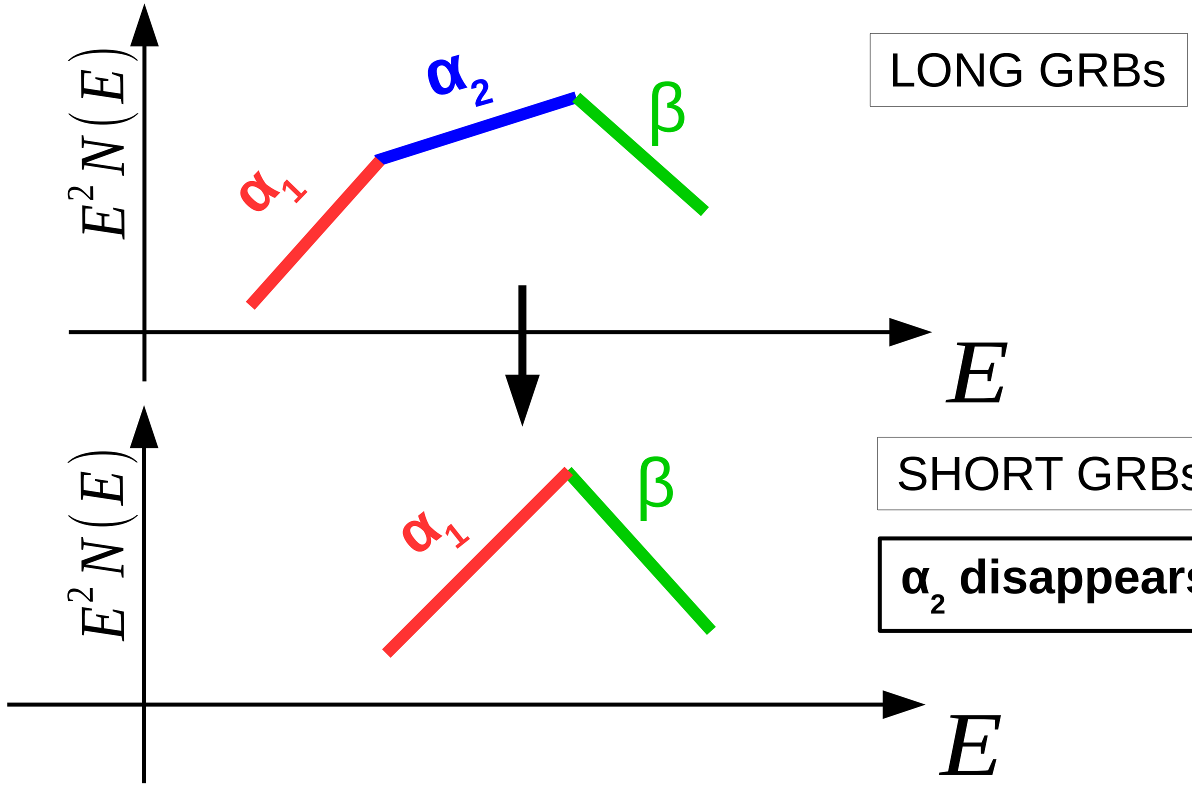
Recent hints from the observations

Ravasio et al., 2019, A&A

10 brightest SHORT GRBs detected by Fermi/GBM

↓

NO ADDITIONAL BREAK!



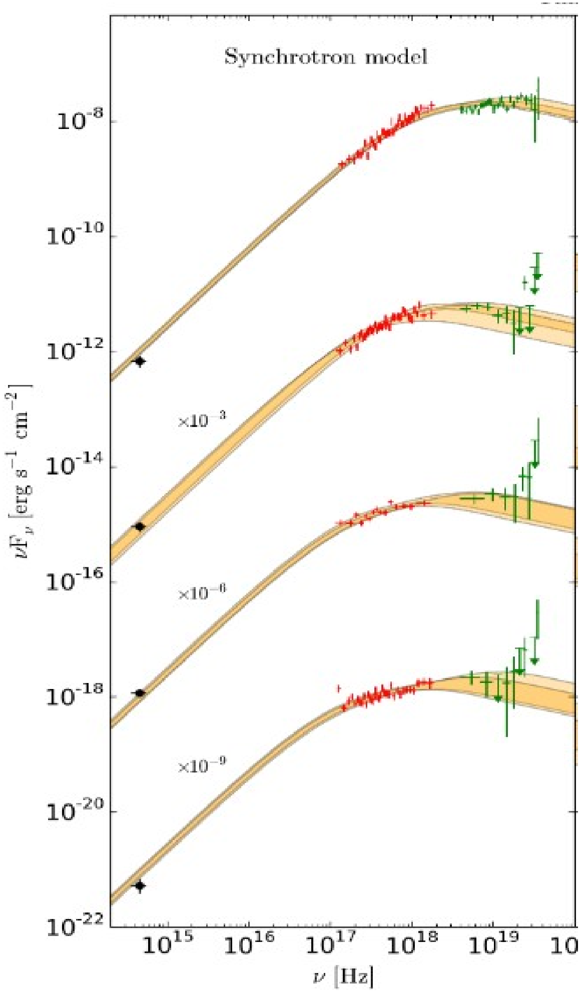
α_2 disappears

$\langle\alpha_1\rangle = -0.78$ (σ=0.23)

Consistent with the synchrotron value -2/3

[→ but the long merger-driven GRB 211211A shows two breaks, see Gompertz, **Ravasio** et al. 2022]

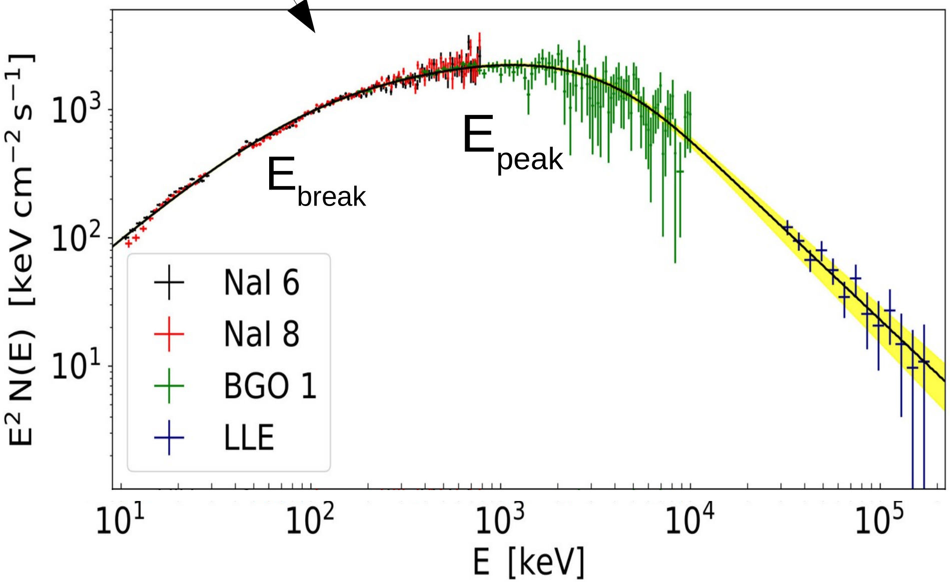
Recent hints from the observations



Oganesyan et al., 2019

Synchrotron model successfully fits the spectral data

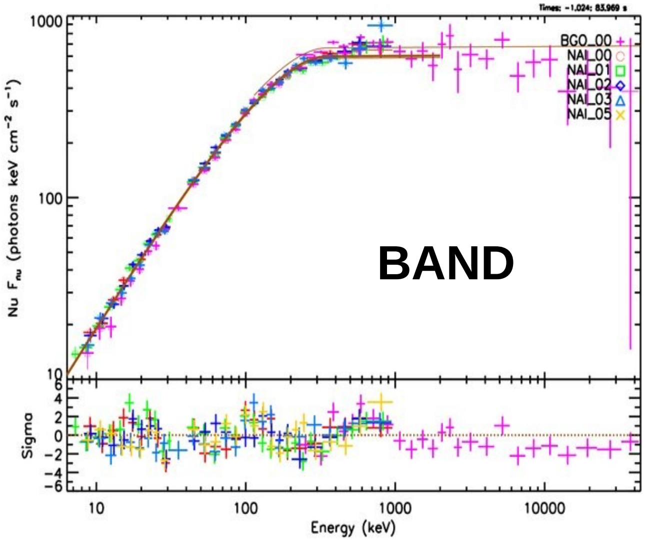
GRB 180720B

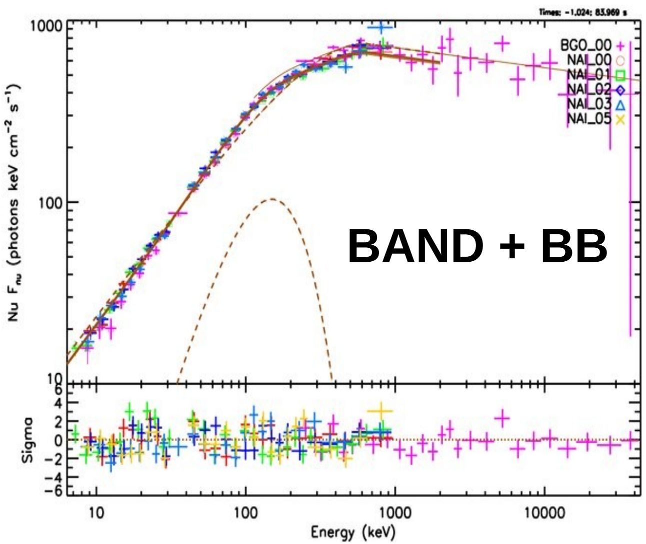


Ronchi M., Fumagalli F., **Ravasio M.E.** et al, 2020, A&A

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

Multi-component models: the addition of a blackbody





The spectrum could be a **combination of thermal and non-thermal emission**

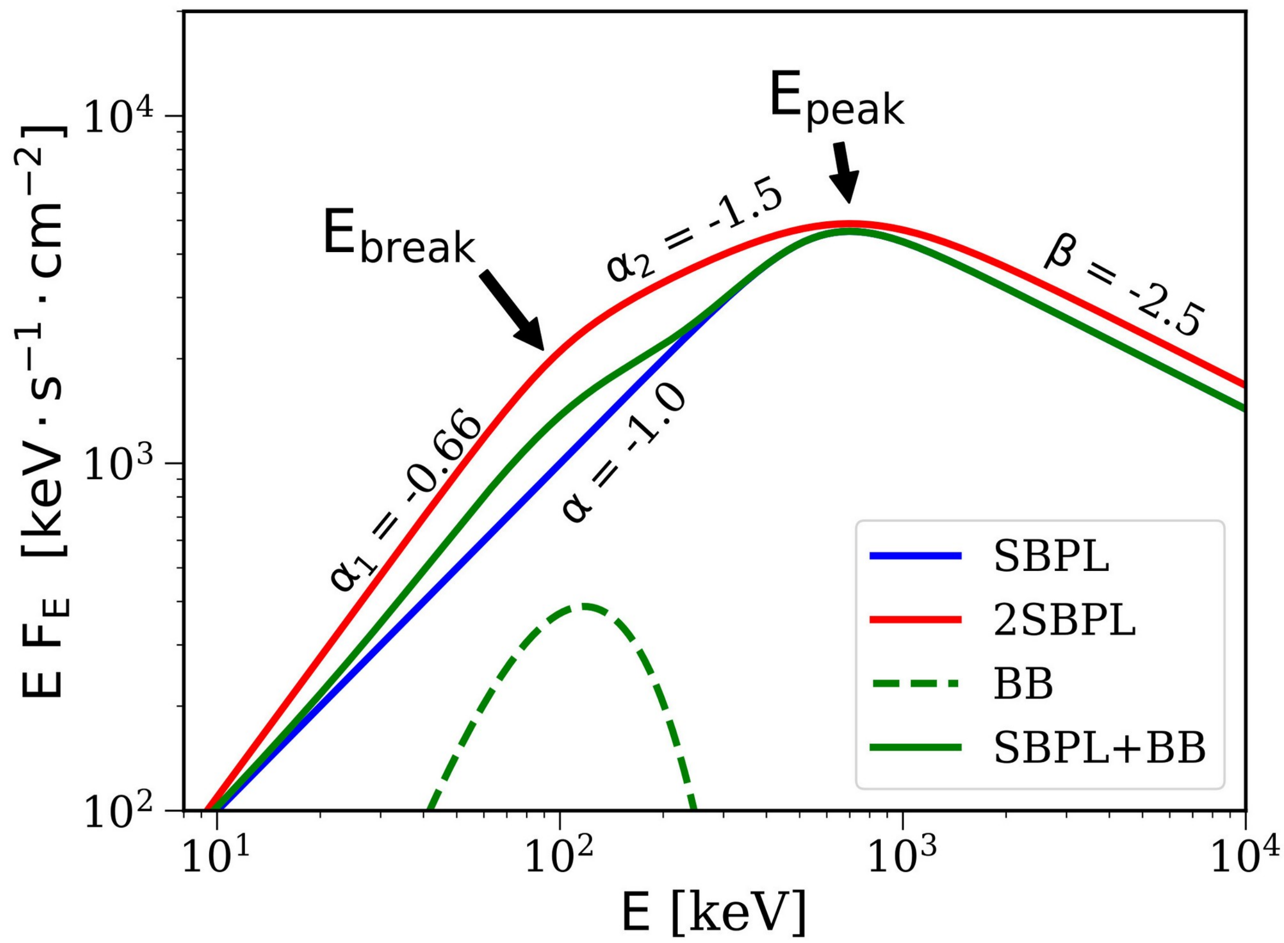
Physically motivated as the emission from the fireball photosphere, demonstrated to be present in few cases (Ghirlanda et al., 2003)

The addition of a blackbody (BB) can produce a **hardening** of the low energy part of the spectrum

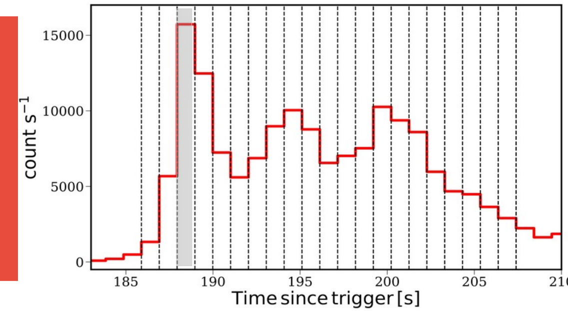
→ **The addition of a BB has been widely used in literature**
(Ryde et al. 2010, Guiriec et al. 2011,2013,2015, 2016, 2017)

E.g. from Guiriec et al. 2011

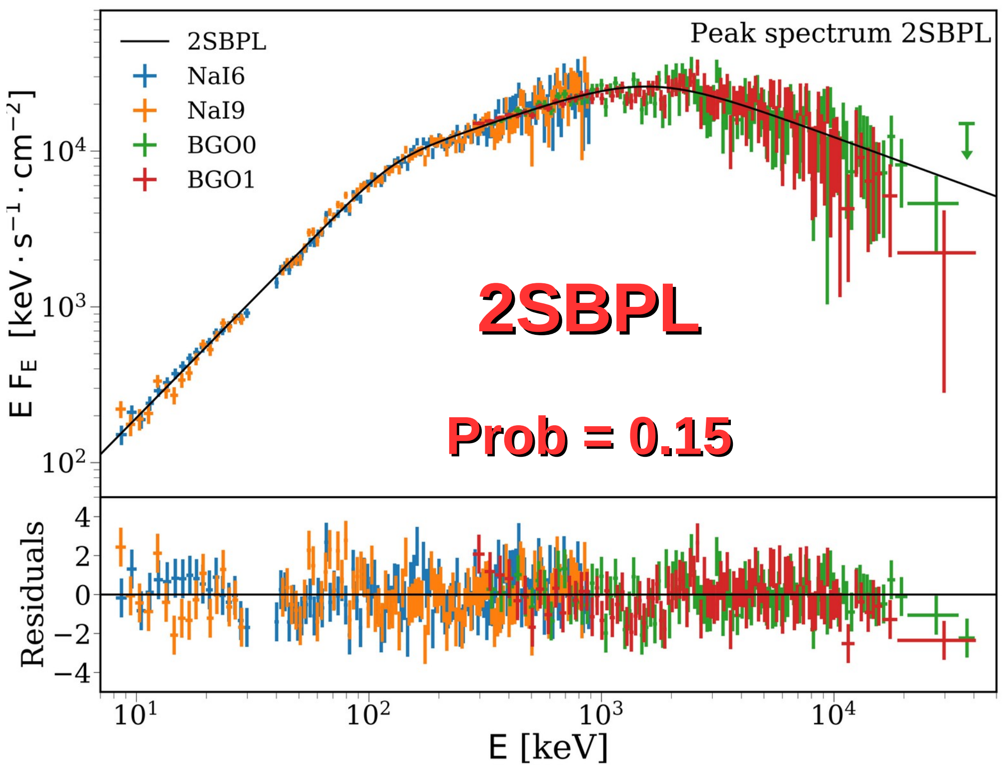
Comparison of the fitting functions

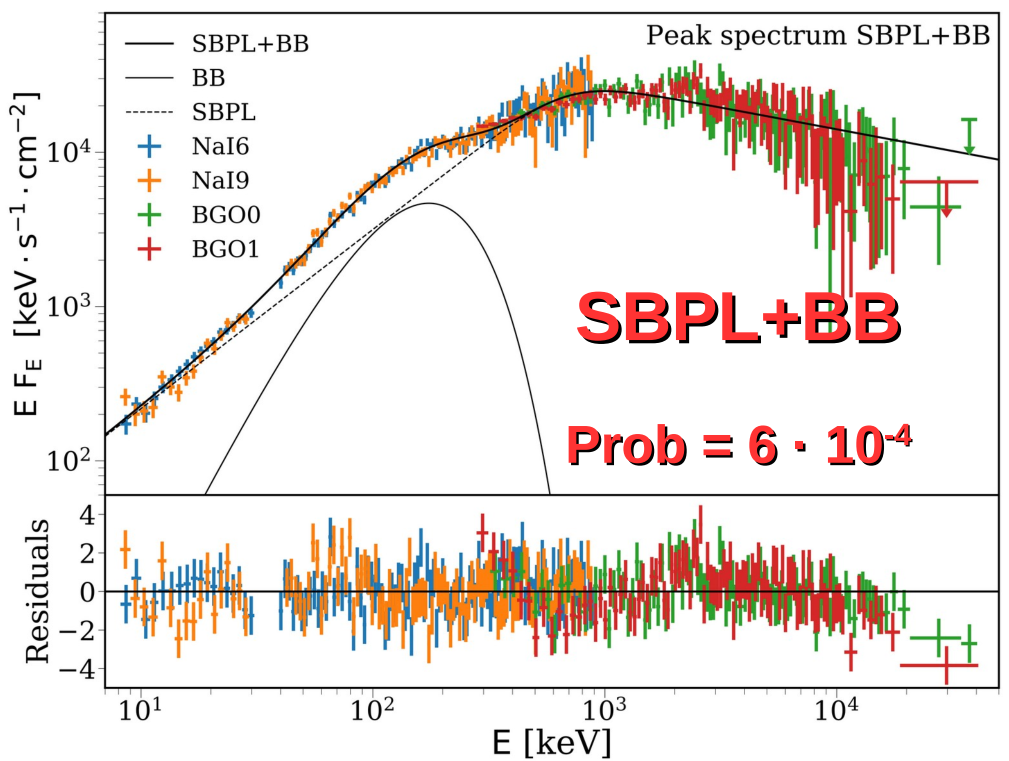


GRB160625B: time-resolved analysis



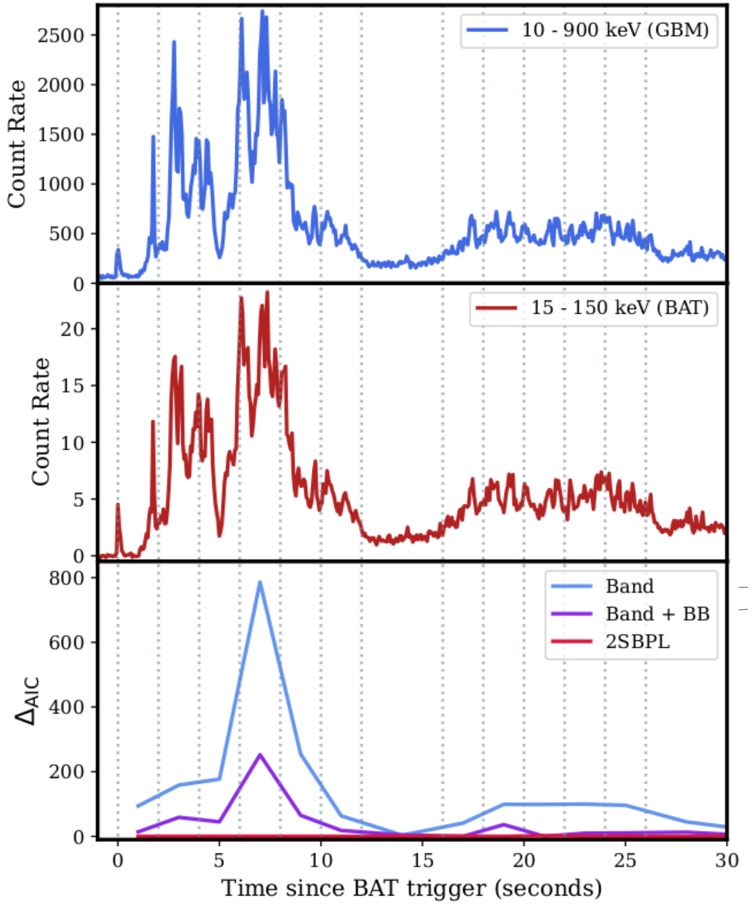
Comparison between competing models: One- vs Two-Component

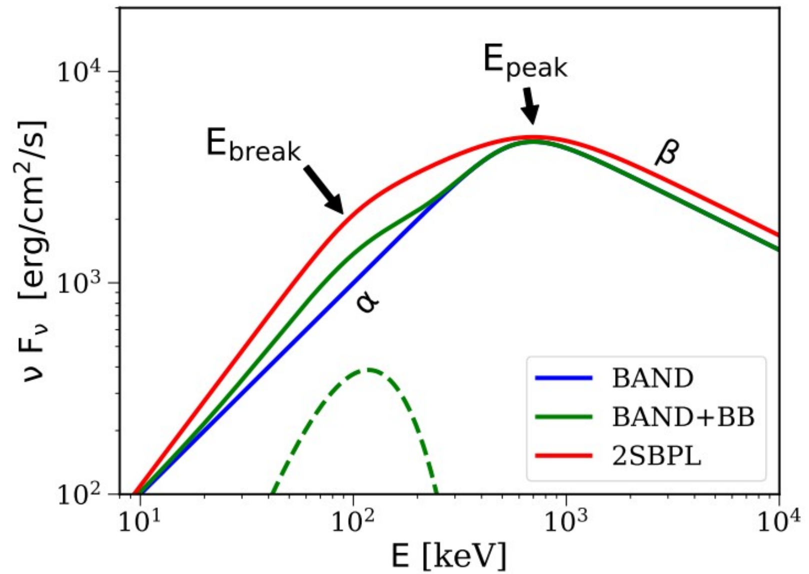




GRB 211211A: long GRB with a kilonova

- Time-resolved analysis with 2 s time resolution of Swift and Fermi data
- Tested: Band, Band+BB, 2SBPL

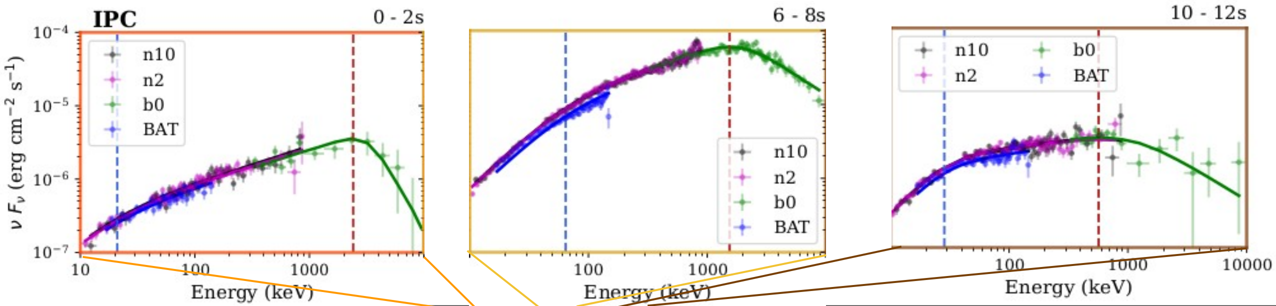


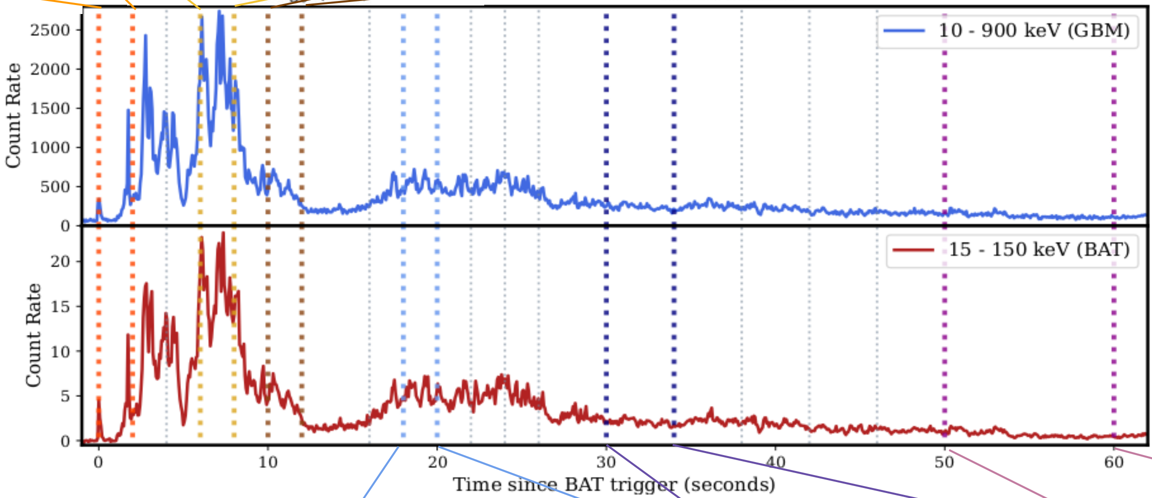


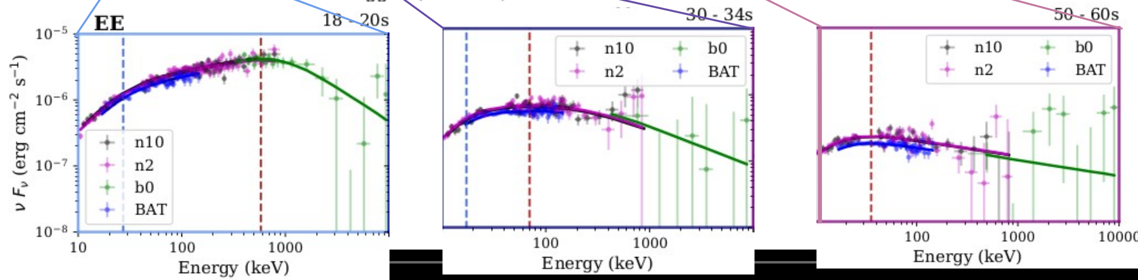
→ Both strongly disfavored, especially in the brightest pulses

[Gompertz, **Ravasio** et al, 2022, submitted to Nature Astronomy]

Recent hints from the observations







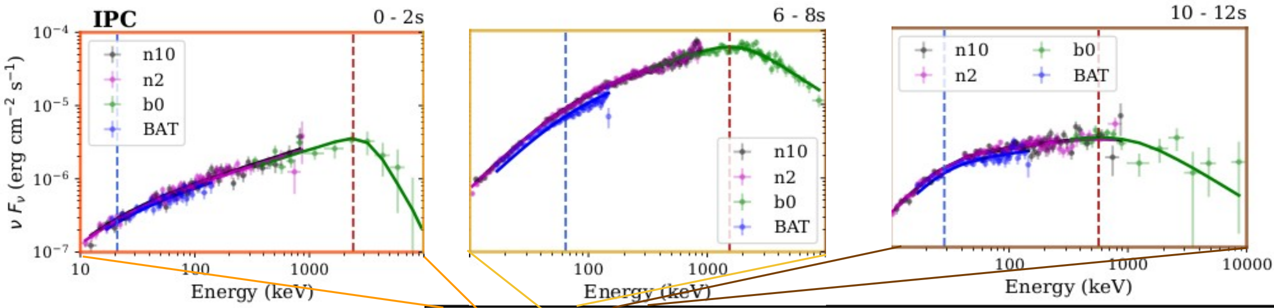
GRB 211211A
long GRB
with a KN

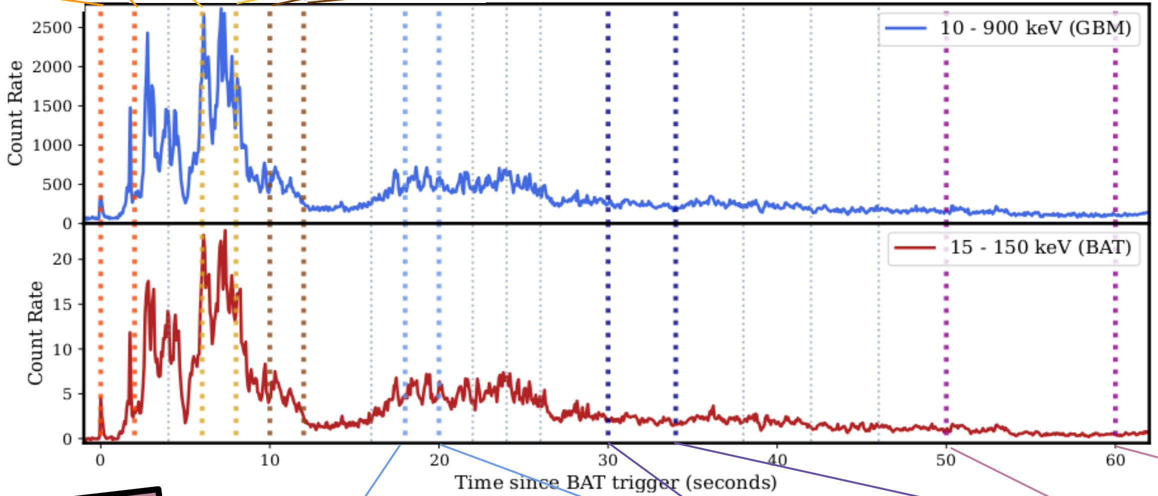
[Rastinejad et al, (...) **Ravasio** et al, 2022, submitted to Nature]

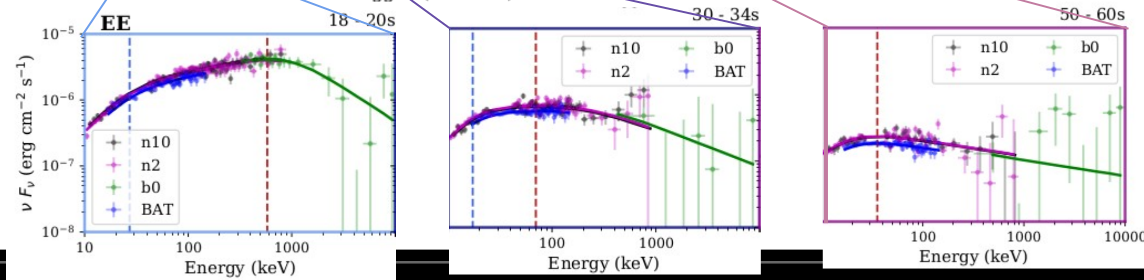
→ **First time synchrotron cooling** found in a **merger-driven GRB!**

[Gompertz, **Ravasio** et al, 2022, submitted to Nature Astronomy]

Recent hints from the observations







GRB 211211A
long GRB
with a KN

[Rastinejad et al, (...) **Ravasio** et al, 2022, submitted to Nature]

→ **First time synchrotron cooling** found in a **merger-driven GRB!**

[Gompertz, **Ravasio** et al, 2022, submitted to Nature Astronomy]

Late GeV emission
Talk by Alessio Mei
tomorrow at 10:20

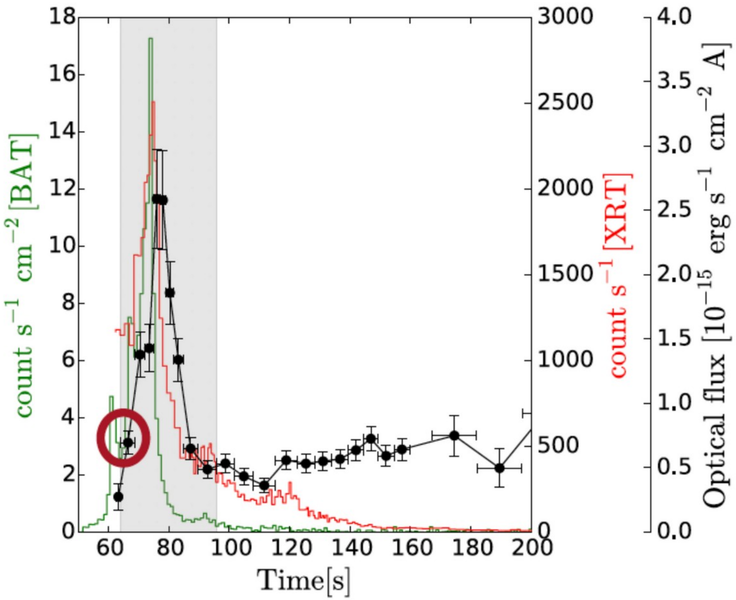
Comparison with the BB: the optical emission

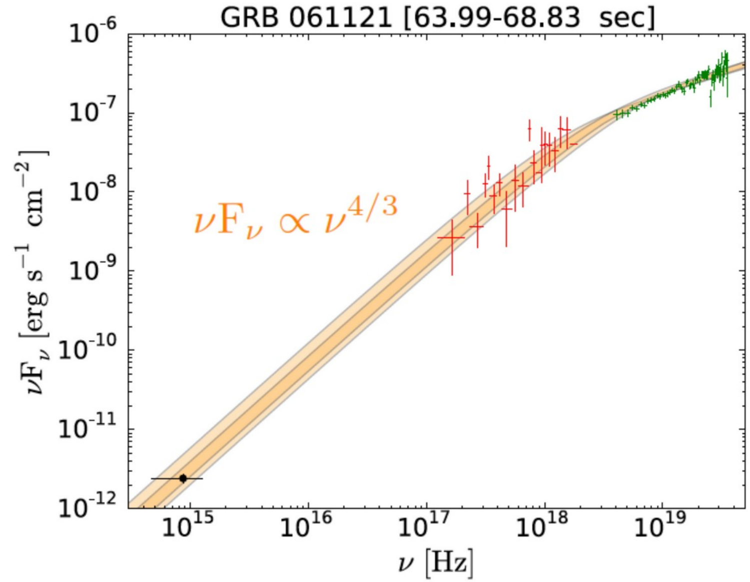
Oganesyan, Nava, Ghirlanda, Melandri & Celotti, 2019

21 GRBs, 56 TIME-RESOLVED SPECTRA

Fit the synchrotron model
to XRT+BAT (+GBM) spectra

Prediction of the
optical flux





Optical data + XRT [0.5 – 10 keV] + BAT [15 – 150 keV]

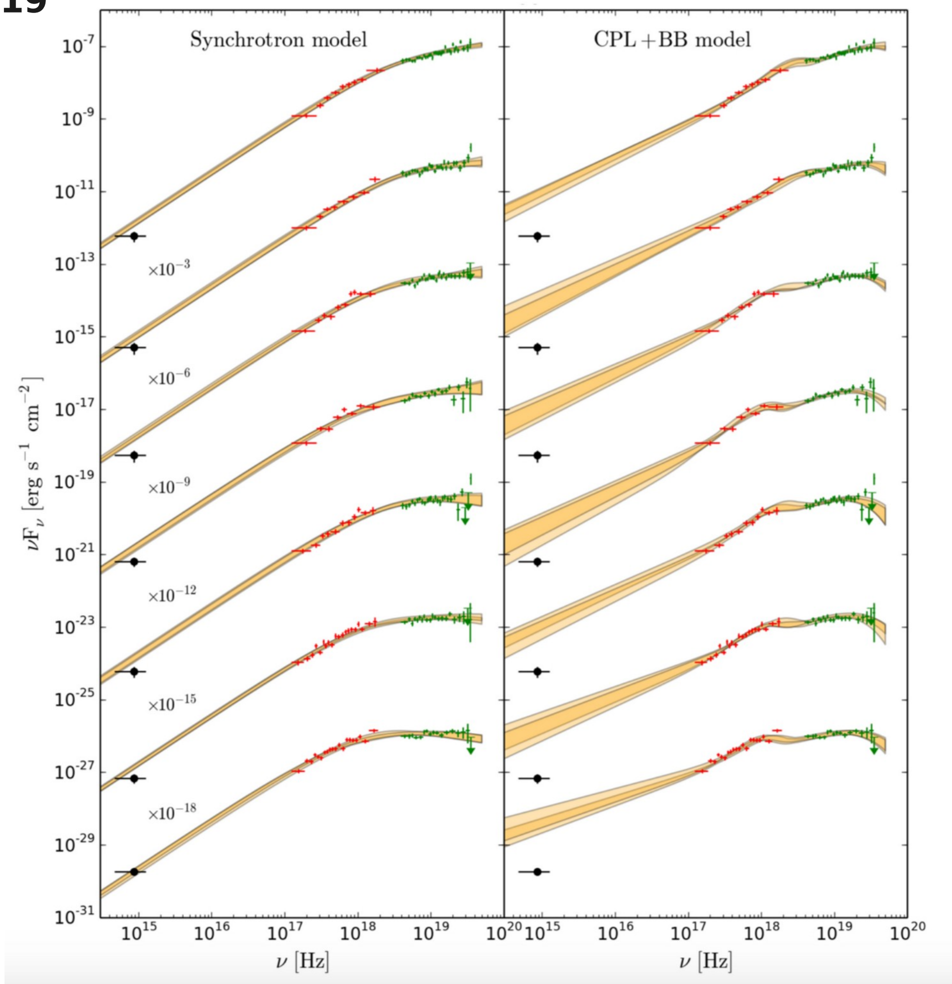
Comparison with the BB: the optical emission

Oganesyan, Nava, Ghirlanda, Melandri & Celotti, 2019

~ 90 % of spectra are inconsistent with CPL+BB model!

Synchrotron model is preferred

GRB 110205A



Recap from observations

What we have learnt:

- Long GRB → additional spectral break (both in *Swift* and *Fermi* bursts) ✓
- Short GRB → no additional break (possible only with *Fermi* bursts) ✓

- In both cases, photon indices from empirical fits **consistent with synchrotron predictions** ✓

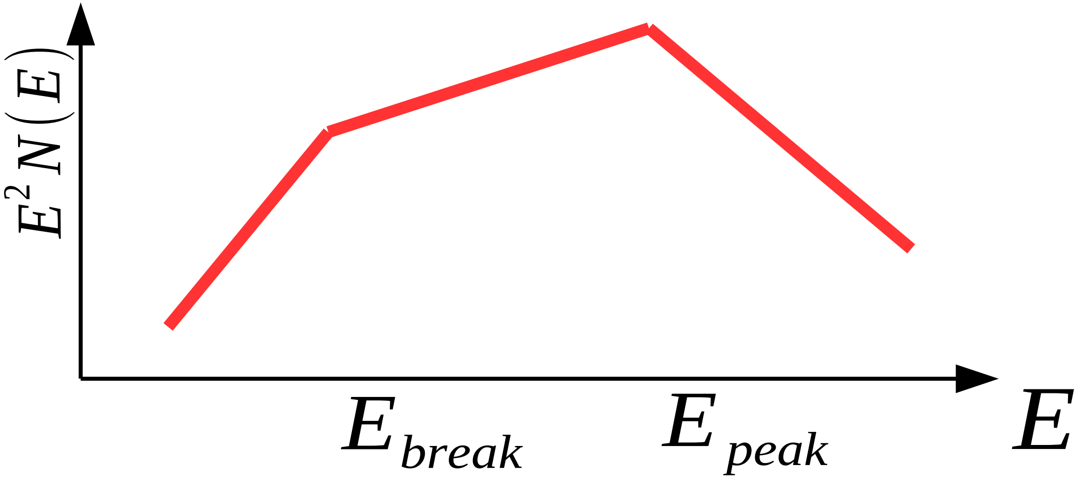
[Oganesyan et al. 2017,2018 ; **Ravasio et al., 2018, 2019**]

- Direct test of the synchrotron model with data ✓

[Ronchi M., Fumagalli F., **Ravasio M.E.** et al, 2020, A&A ; Oganesyan et al. 2019 ; Burgess et al. 2020]

Theoretical implications

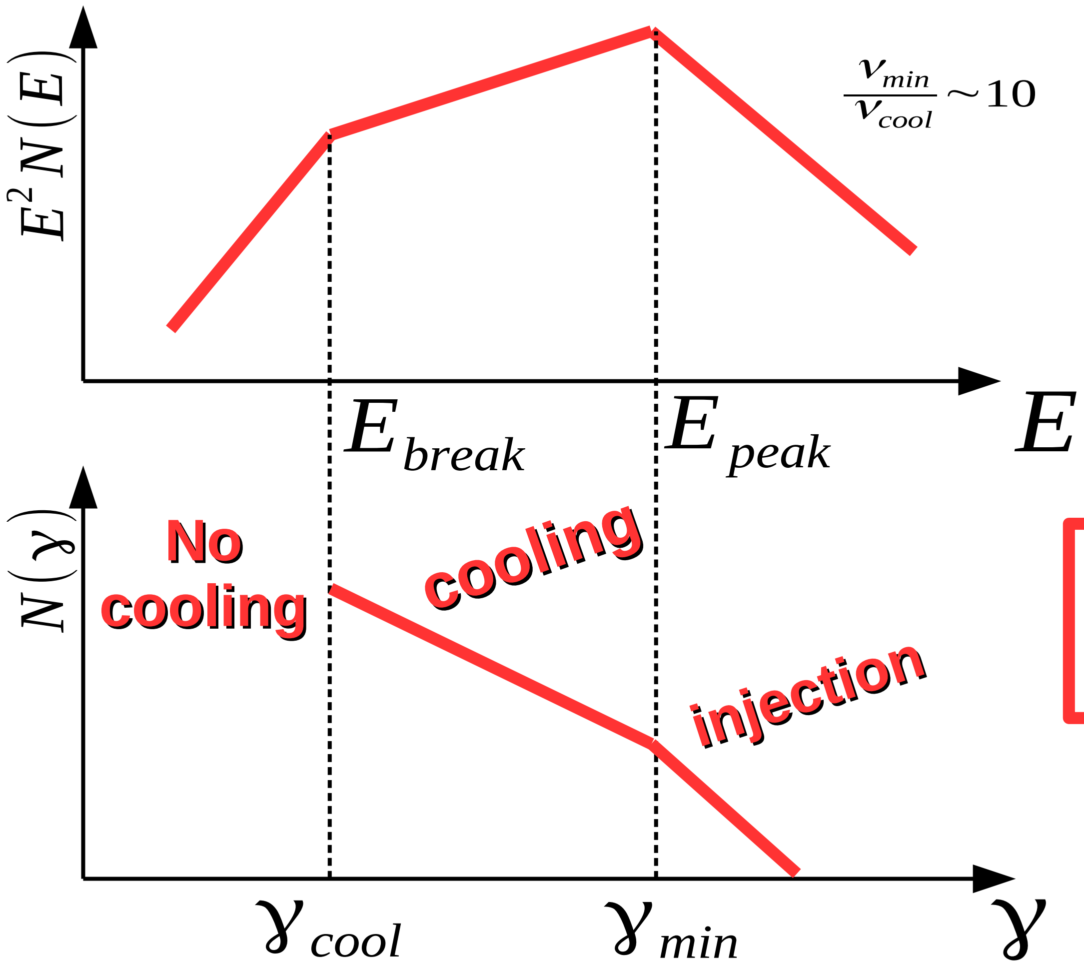
Marginally fast cooling regime



Theoretical implications

Marginally fast cooling regime

[Kumar & McMahon 2008, Daigne 2011, Beniamini & Piran 2013]



Interpreting E $_{break}$ as the synchrotron cooling frequency

$$t_{\rm cool}^{\rm obs} = \frac{6\pi m_e c}{\sigma_T \gamma'_e B'^2} \frac{(1+z)}{\Gamma}$$

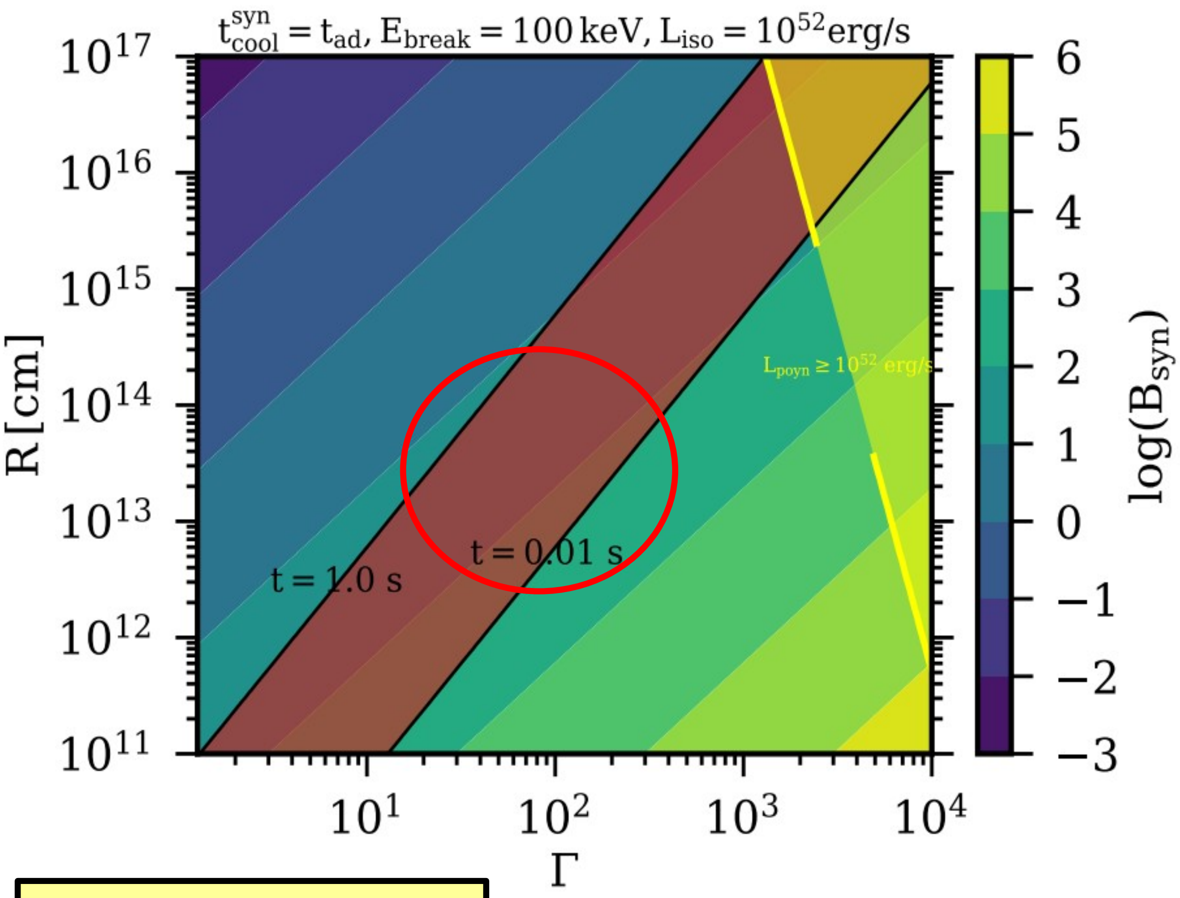
$$\gamma_e'^2 = \frac{3\pi m_e c}{2eB'} \frac{(1+z)}{\Gamma} \nu^{\rm obs}$$

At the emitting region

$$B' \sim 10 \;\; \Gamma_2^{-1/3} \nu_{100\,\rm keV}^{\rm obs\;\;-1/3} \;\; t_{1s}^{\rm obs\,-2/3} \;\; {\rm Gauss}$$

Ravasio et al., 2019, A&A

Theoretical implications



Ravasio et al., in prep.

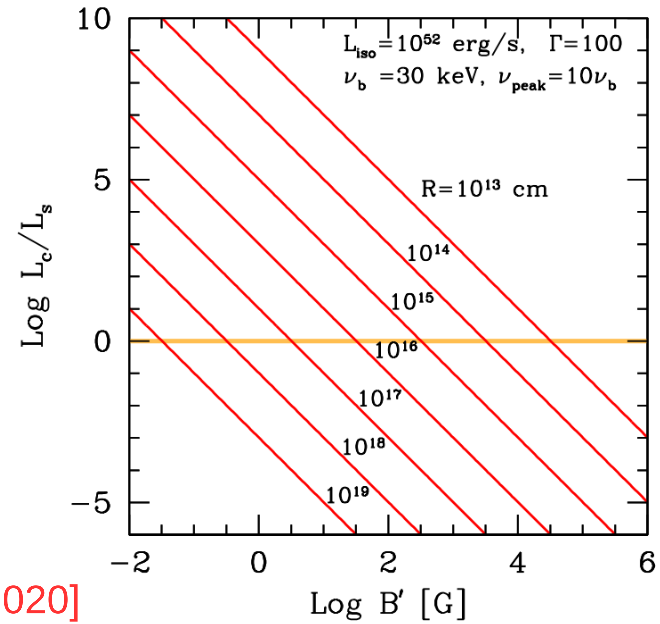
Consequences of a low magnetic field in the leptonic scenario:

→ R ~ 10^{13} - 10^{14} cm

(standard model)

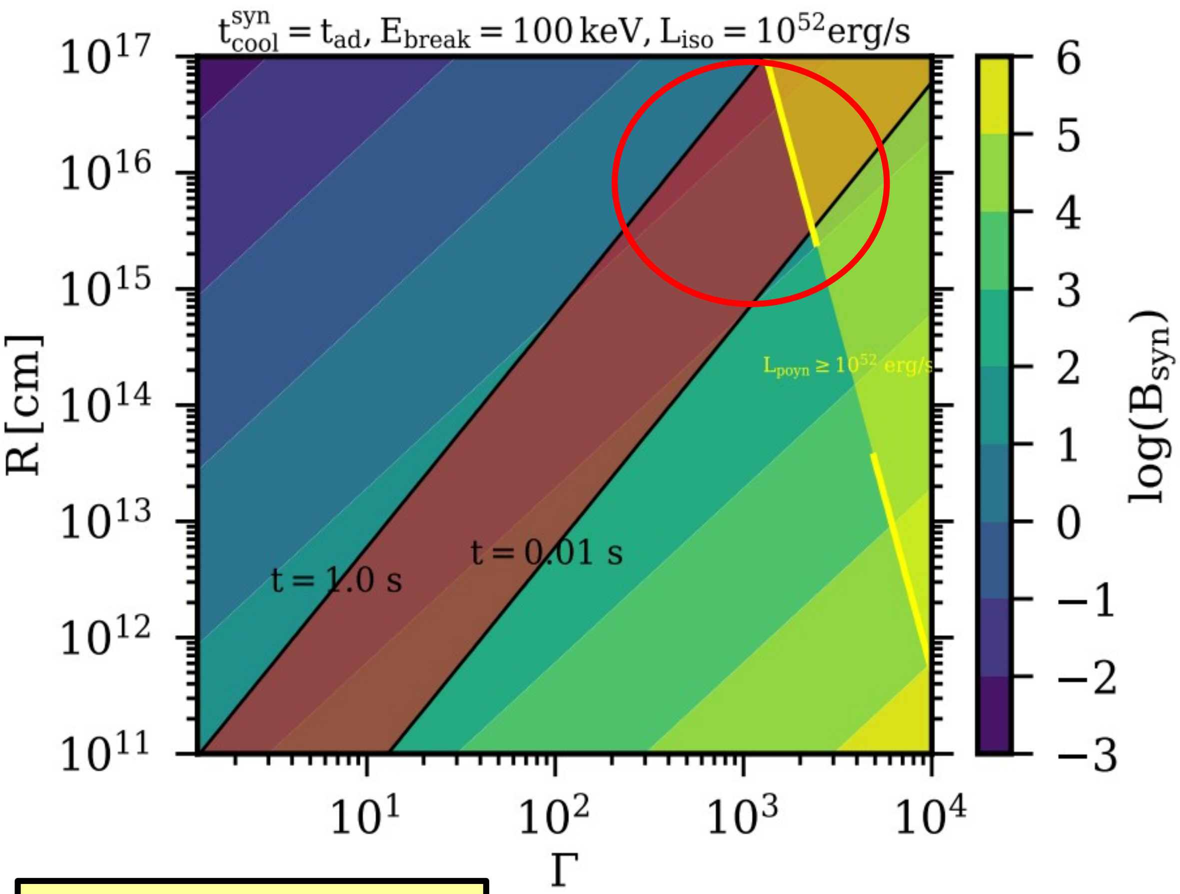
$$\frac{U'_{rad}}{U'_B} = \frac{L_C}{L_{Syn}}$$ ↑

Not observed!



[From Ghisellini et al., 2020]

Theoretical implications



Ravasio et al., in prep.

Consequences of a low magnetic field in the leptonic scenario:

→ R ~ 10^{13} - 10^{14} cm

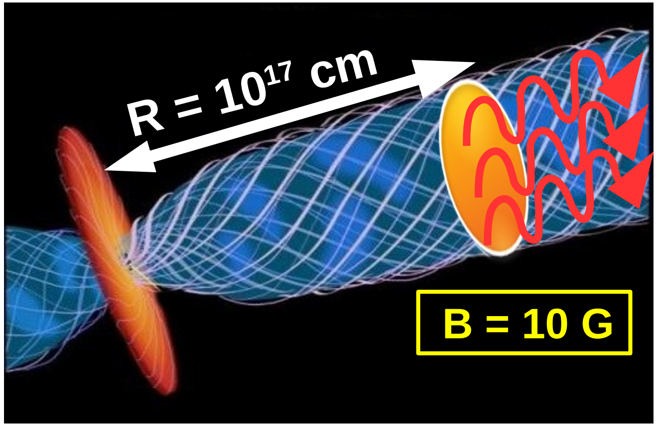
(standard model)

$$\frac{U'_{rad}}{U'_B} = \frac{L_C}{L_{Syn}} \uparrow$$

Not observed!

→ R ~ 10^{16} - 10^{17} cm

- Variability timescale?? → very large Γ
- Afterglow??



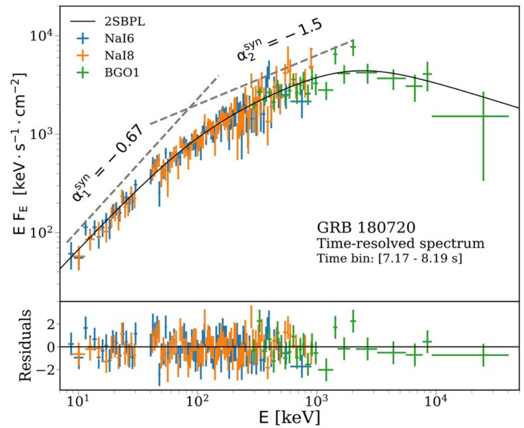
Switching roles: synchrotron from protons

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!!**
(we should see a complete cooling, namely index = -3/2 below the peak)



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!! ~1-10 s

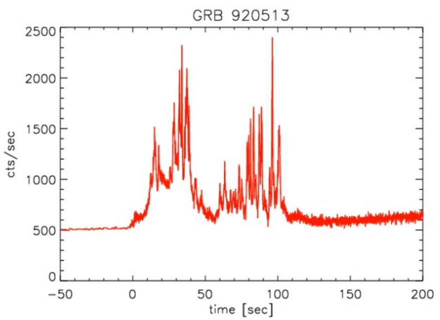
↓

We need a higher magnetic field of B~10^7 G in a 'standard' emitting region at R~10^{13} cm

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

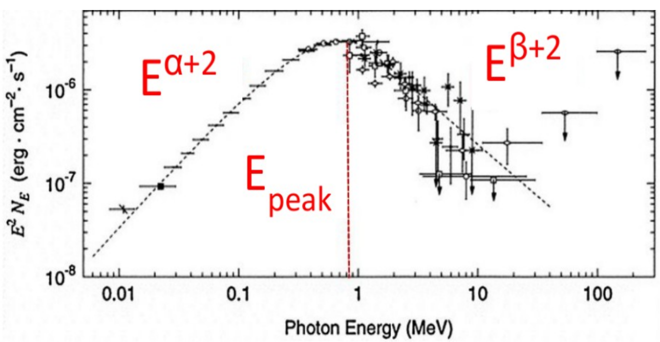
GRBs as relativistic sources

- The variability timescales δt imply that the source is compact

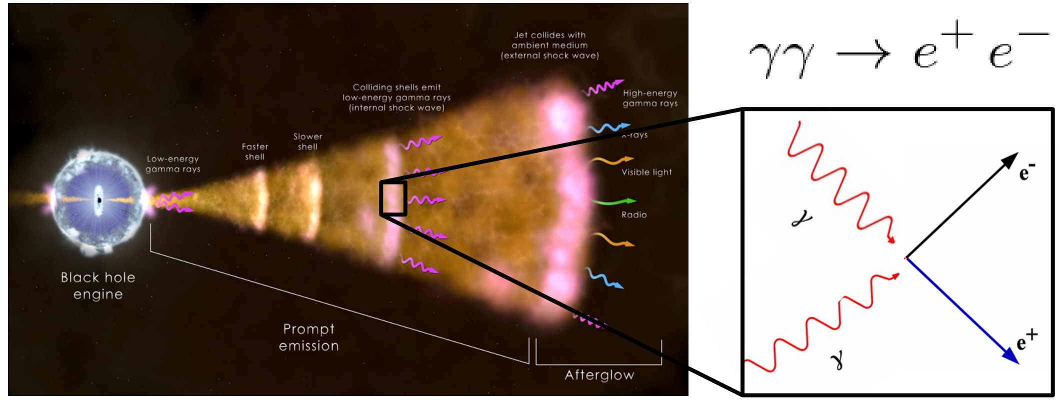


$$R \sim c\,\delta t$$

- The spectrum is non-thermal and made by high energies photons



$$\gamma\gamma \rightarrow e^+ e^-$$



→ The optical depth for pair-production

$$\tau_{\gamma\gamma} \approx \frac{f_{e\pm}\sigma_T 4\pi d^2 F}{\bar{E}_\gamma c^2 \delta t} \longrightarrow \tau_{\gamma\gamma} \sim 10^{15}$$

for typical parameters

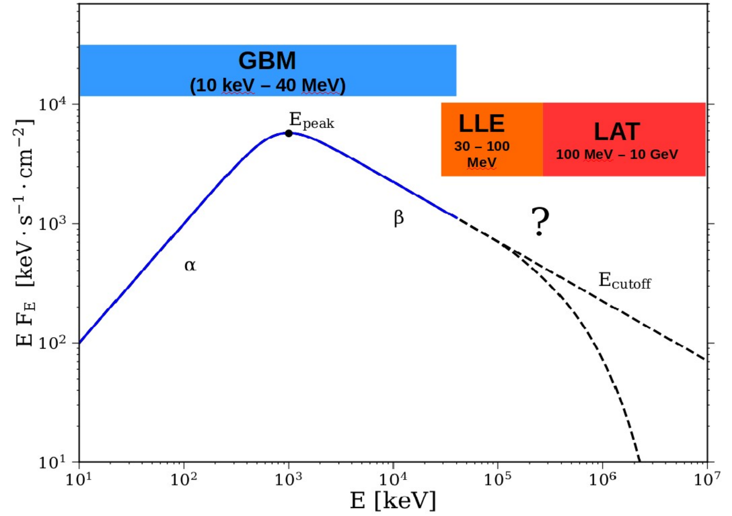
(t_{var} = 10 ms, E_{iso} = 10^{52} erg, beta=-2,5, z=2)

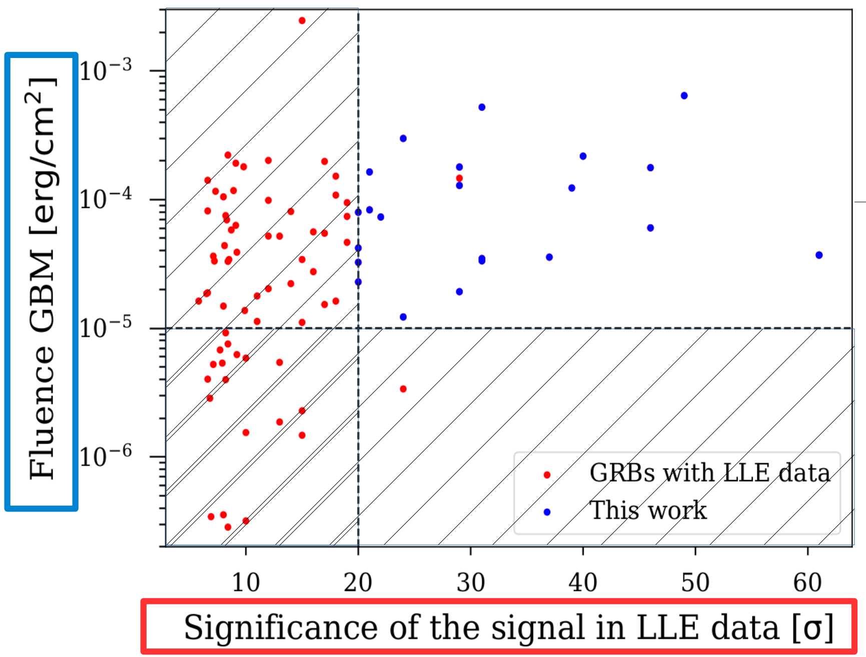
→ inconsistent with observations!
('compactness problem', Piran 1999)

Selection of the sample

- Sample of GRBs whose prompt emission has been detected up to GeV energies

91 GRBs that show emission in the range 30-100 MeV (LLE data available)





Sample: **22 GRBs with optimal photon statistic both at low and at high energies**

Ravasio et al., in prep.

Inferring the distance R from the central engine

$$\begin{cases} Compactness \\ Afterglow\ onset \end{cases}$$

$$\begin{cases} \tau_{\gamma\gamma}(\Gamma, \mathrm{R}) \leq 1 \\ \boxed{\Gamma}\ \ onset \end{cases}$$

Combining the two methods →

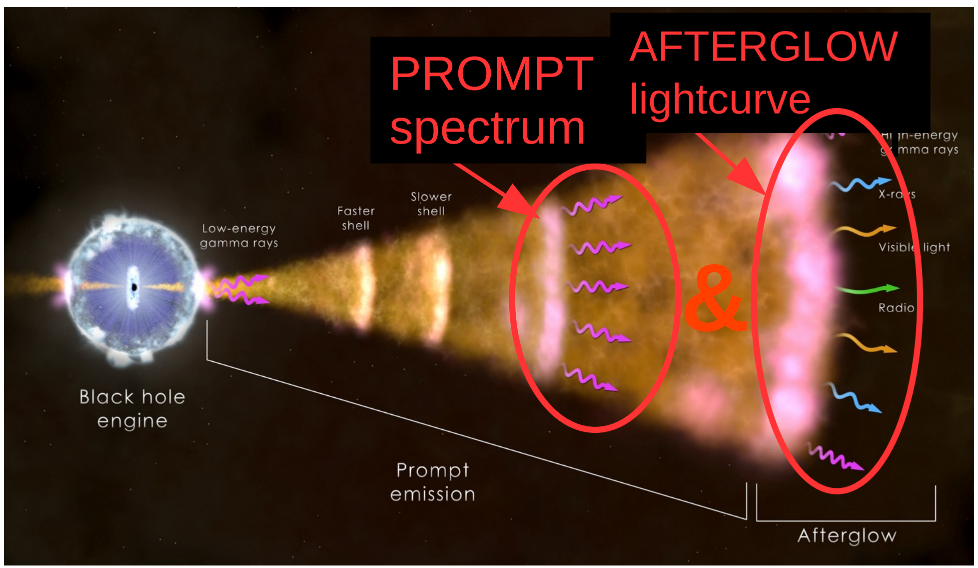
For the only 2 GRBs of the sample with measured afterglow onset time (but without cutoff):

$$\boxed{R} > 10^{13} - 10^{15} cm$$

PRELIMINARY

Apply to every GRB with:
→ Γ from the afterglow
→ prompt emission spectrum up to LAT energies

Ravasio et al., in prep.



Method to restrict the parameter space for the prompt emission

Inferring the distance R from the central engine

$$\begin{cases} Compactness \\ Afterglow\ onset \end{cases}$$

Ravasio et al., in prep.

For the only 2 GRBs of the sample with measured afterglow onset time (but without cutoff):

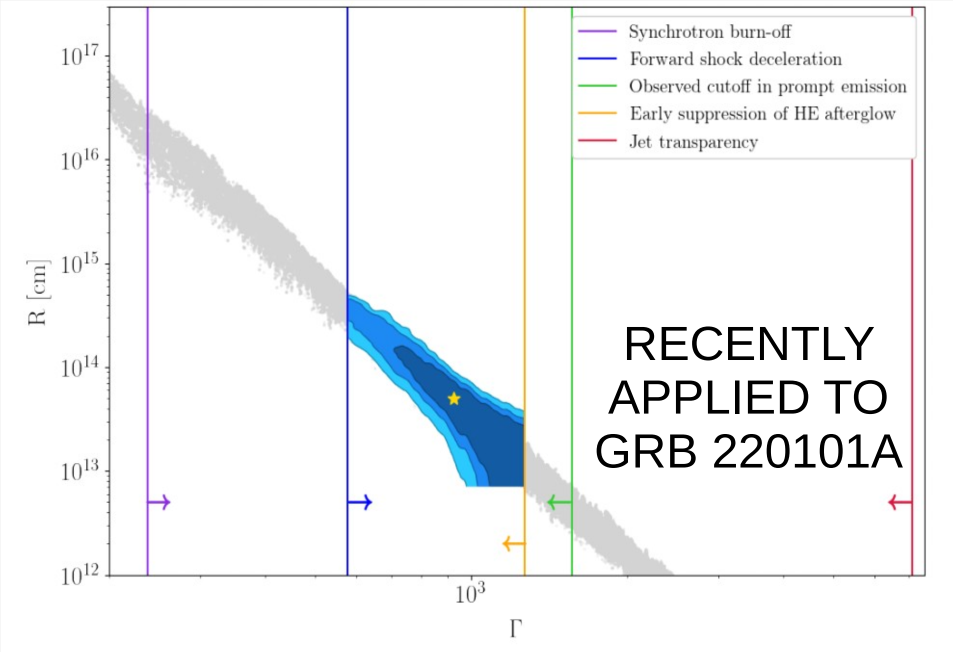
$$\begin{cases} \tau_{\gamma\gamma}(\Gamma, \mathrm{R}) \leq 1 \\ \boxed{\Gamma}\ \ onset \end{cases}$$

Combining the two methods →

$$\boxed{R} > 10^{13} - 10^{15} cm$$

PRELIMINARY

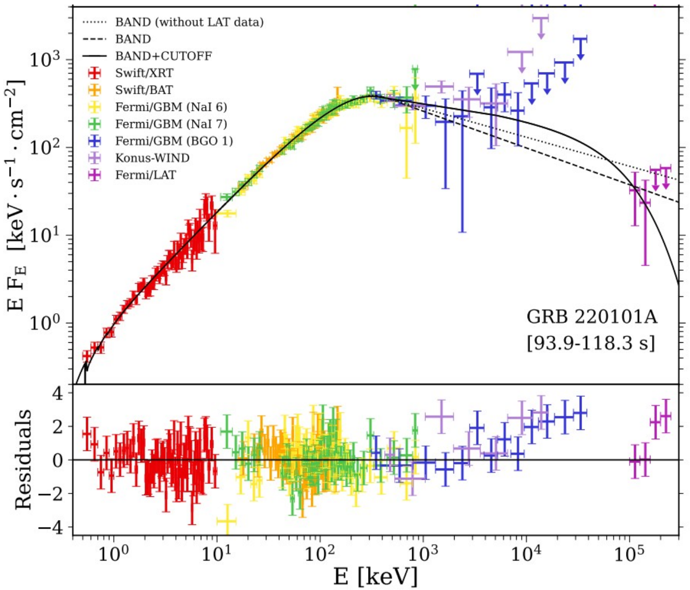
Γ = 929 ± 231
logR = 13.69 ± 0.5

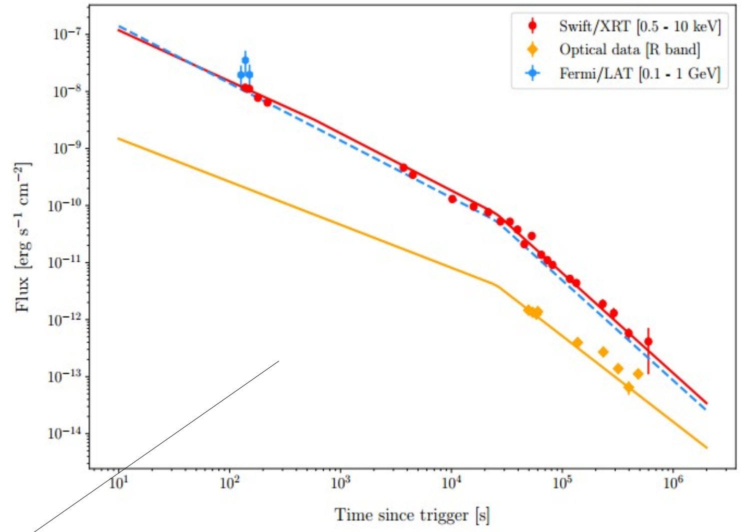


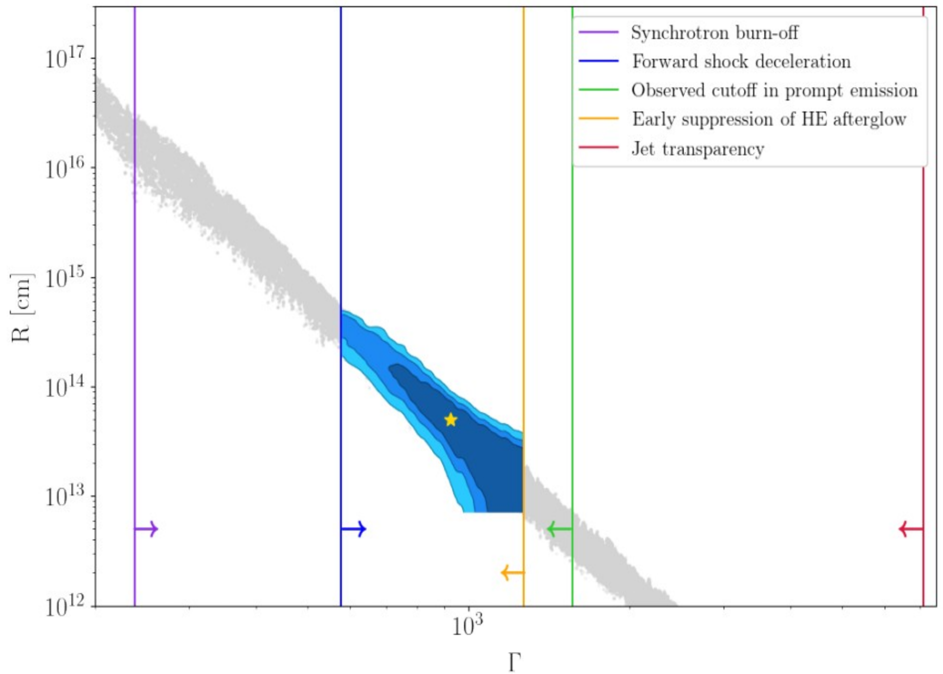
Method to restrict the parameter space for the prompt emission

favouring the proton-sync scenario!

[Mei, Oganesyan, Tsvetkova, **Ravasio** et al., 2022]



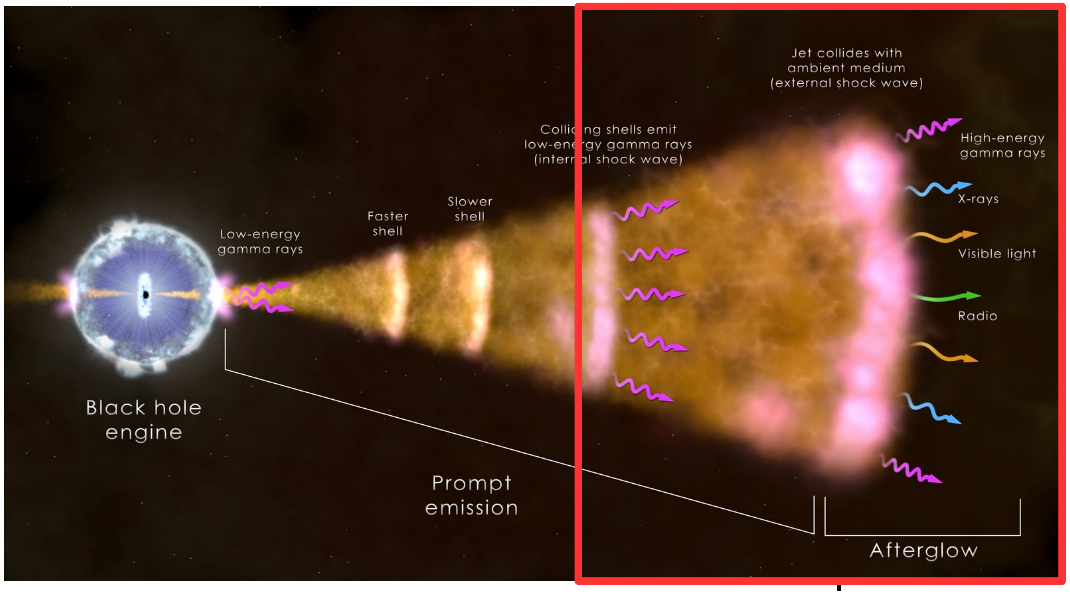


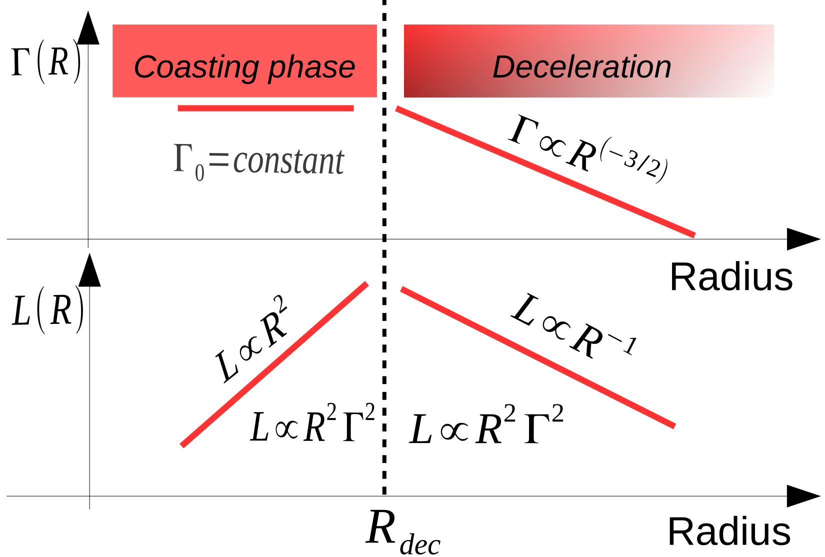


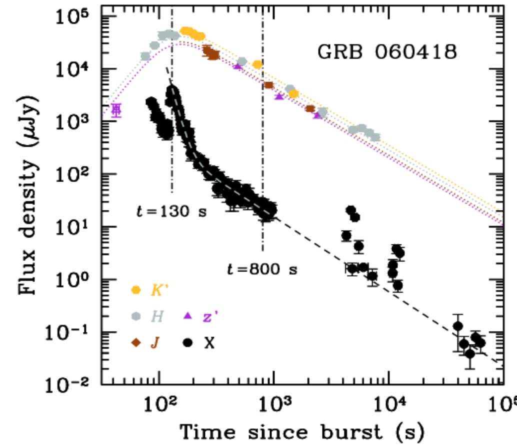
→ the spectral cutoff in **GRB 220101A** together with the afterglow observations allow to put tight constrains on the R-Γ parameter space

[Mei, Oganesyan, Tsvetkova, **Ravasio** et al., 2022]

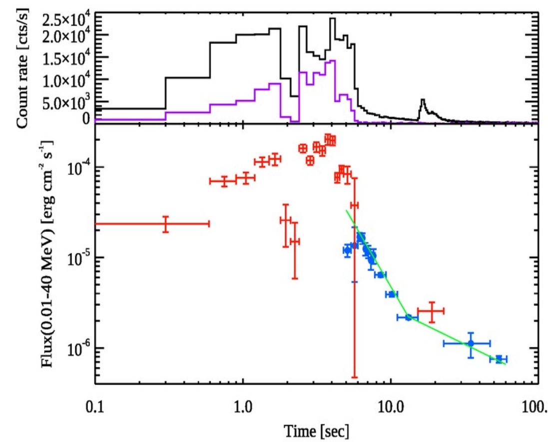
Deceleration of the jet: observational features







NIR and X-ray light curves of GRB 060418 [Molinari et al., 2007]



Fermi/GBM (keV-MeV) light curve of the prompt (red) and afterglow (blue) emission of GRB 190114C

[Ravasio et al. 2019]

Deceleration of the jet: observational features

From the **peak of the afterglow lightcurve**, it is possible to derive an **estimate of Γ**, that depends on:

Homogeneous ISM

$$\Gamma \propto \left(\frac{E_{\rm iso}}{\eta n_0 m_{\rm p} c^5}\right)^{\frac{1}{8}} t_{\rm p,z}^{-\frac{3}{8}}$$

- time of the peak
- blast wave kinetic energy
- density of the circumburst medium

Wind ISM

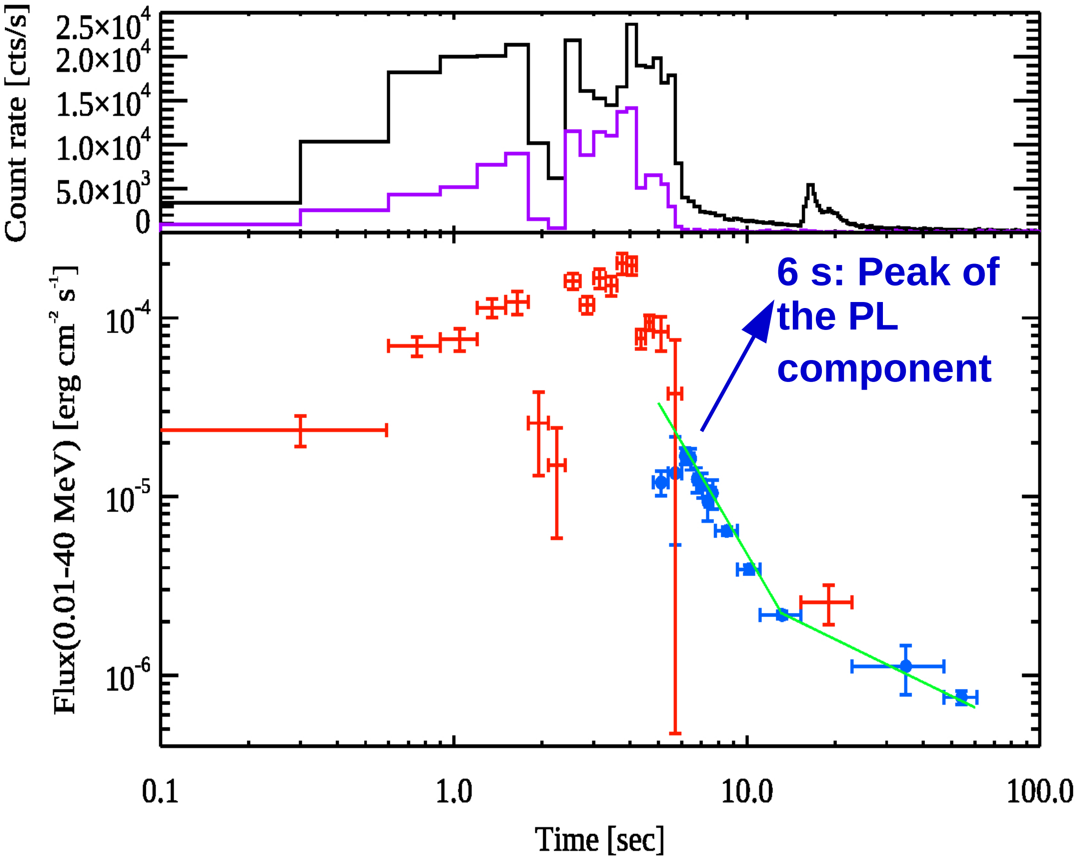
$$\Gamma \propto \left(\frac{E_{\rm iso}}{\eta n_0 m_{\rm p} c^3}\right)^{\frac{1}{4}} t_{\rm p,z}^{-\frac{1}{4}}$$

Bulk Lorentz factor Γ of GRBs is on average 300 and extends from ~30 to ~1000

[Ghirlanda et al.. 2018]

Spectral analysis of GRB 190114C

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



→ **We interpret the power-law component as due to the afterglow emission of the burst**

→ **Estimate the bulk Lorentz factor** Γ :

[from Nava et al., 2013]

$$\Gamma \sim 700$$

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

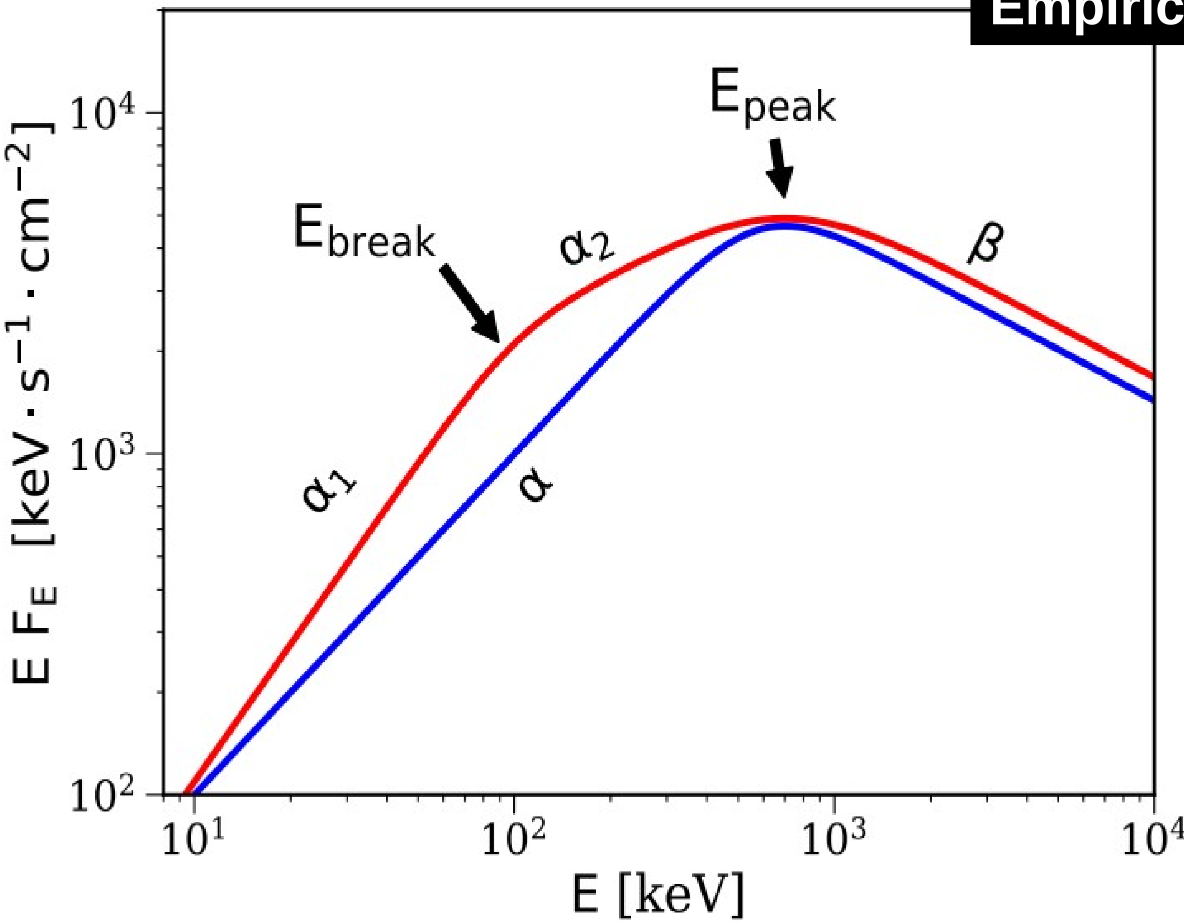
$$\Gamma \sim 130$$

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

Ravasio et al., 2019, A&A

Comparison of the fitting functions

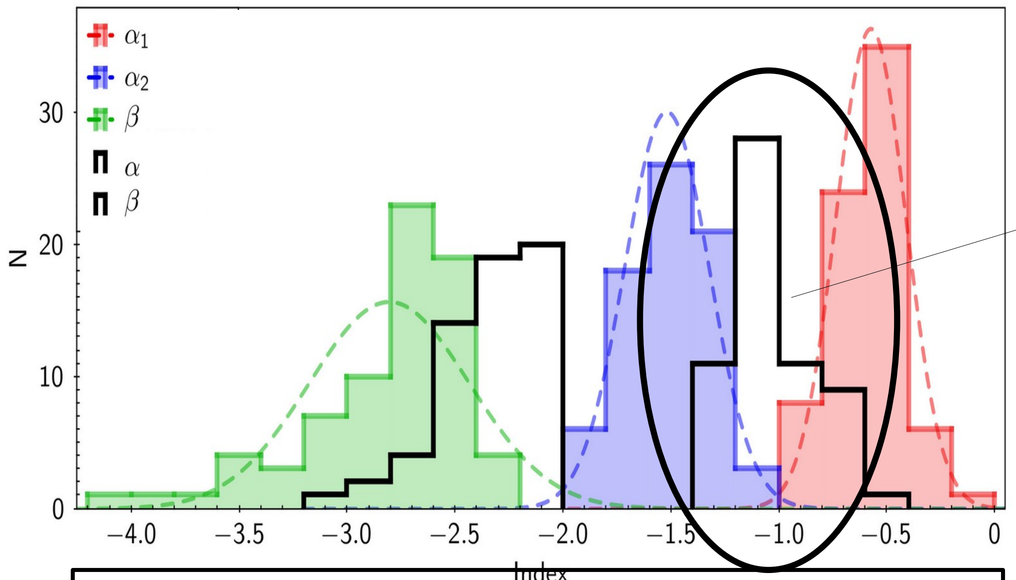
Empirical functions



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

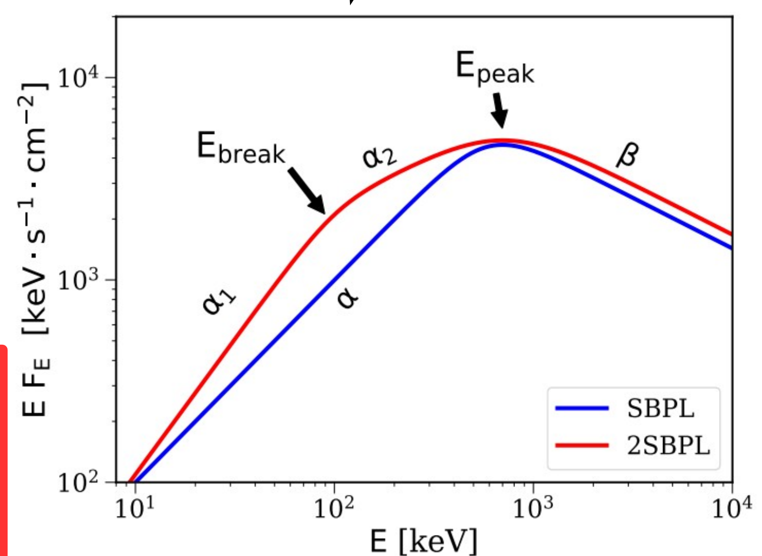
Ravasio et al., 2018, A&A

Comparison of the fitting functions



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

Is this the result of fitting with only one powerlaw below the peak?



Yes
→ S/N and the position of the break in the instrument band can prevent its detection

Toffano, Ghirlanda, Nava, Ghisellini, **Ravasio**, Oganesyan et al. 2021, A&A

Observational biases hiding the low energy break

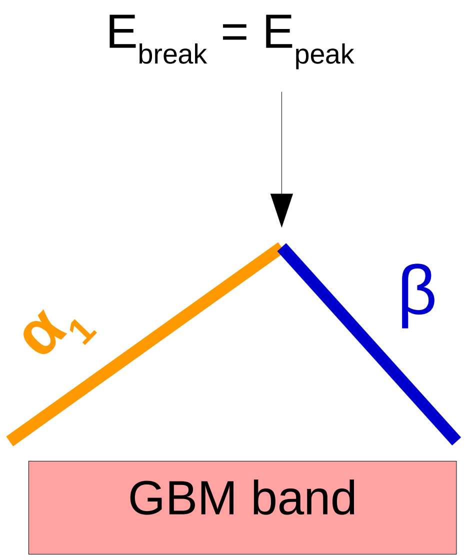
→ We investigated this issue through both data analysis and simulation

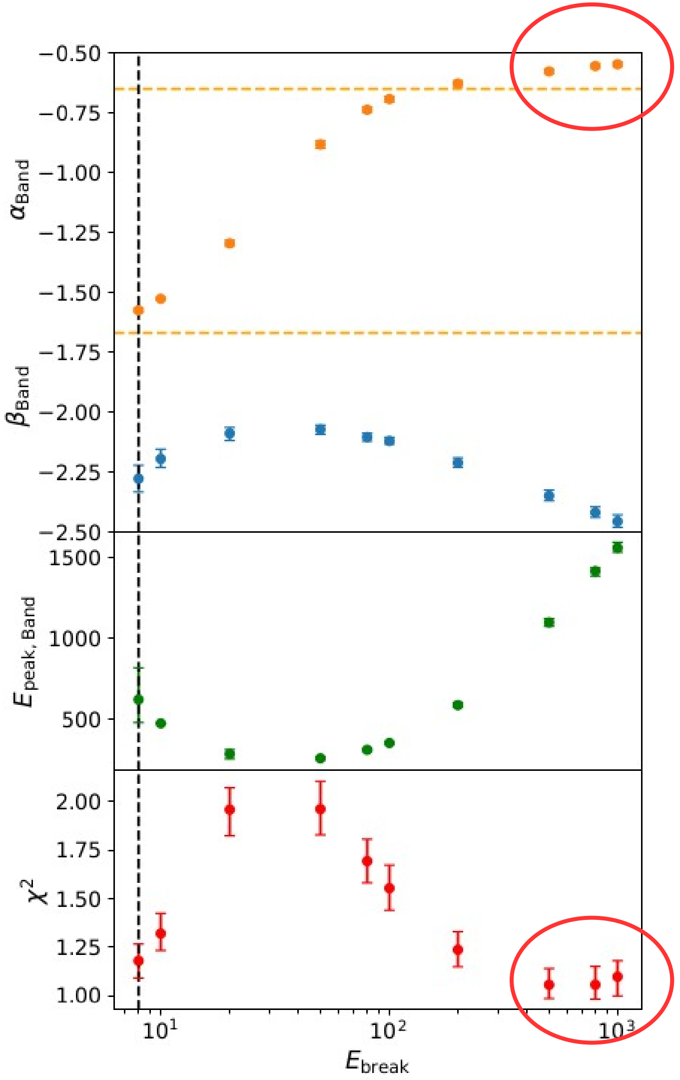
- We analyzed a sample of 31 GRBs spectra with high fluence and high peak energy
- We confirm the presence of a statistically significant low-energy break in 12 cases

Toffano, Ghirlanda, Nava, Ghisellini, Ravasio et al. 2021 A&A

- Through spectral simulations we investigated if bursts without an evident break can still have it at the limits of the spectral energy range
- Our results suggest that the low-energy break could be a more common feature, but hidden behind the intrinsic shape of the Band function
- α_{Band} could be a proxy for the position of the break

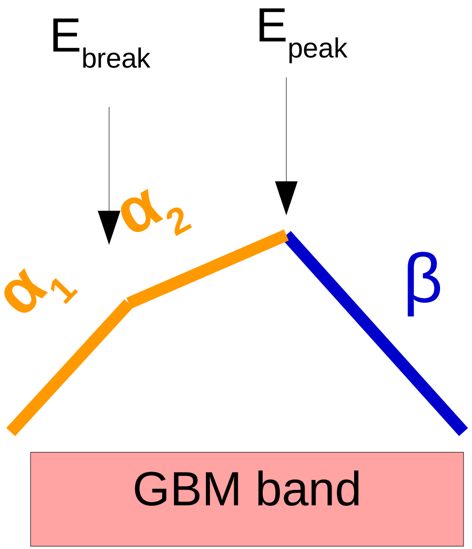
Observational biases hiding the low energy break

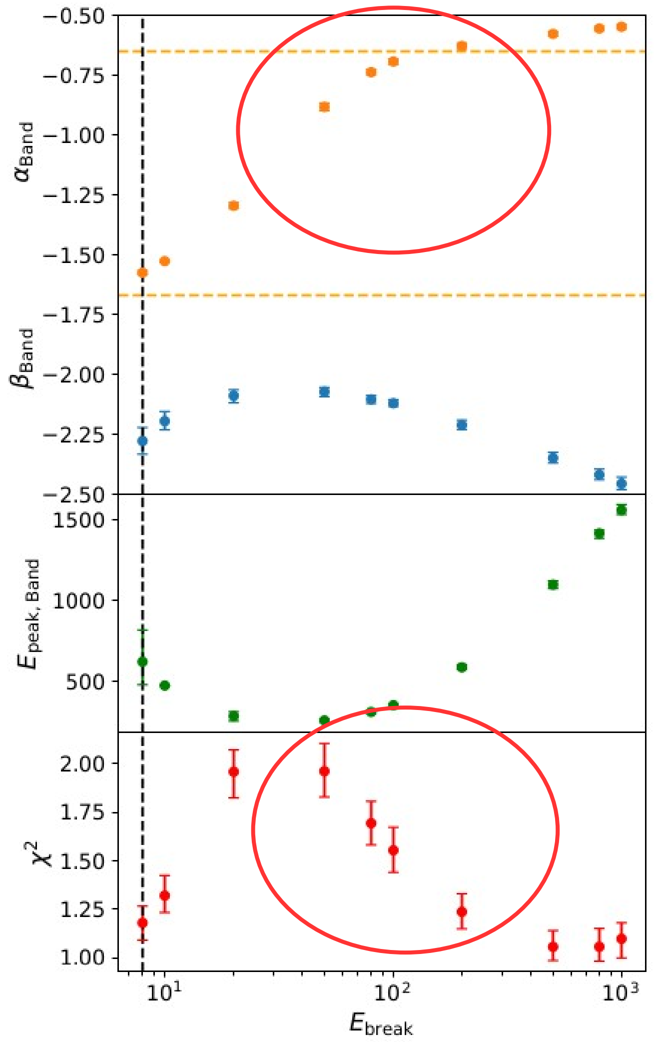




Toffano, Ghirlanda, Nava, Ghisellini, Ravasio et al. 2021 A&A

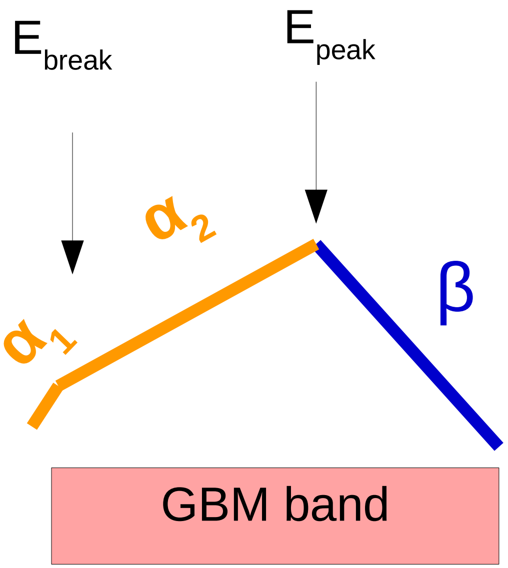
Observational biases hiding the low energy break

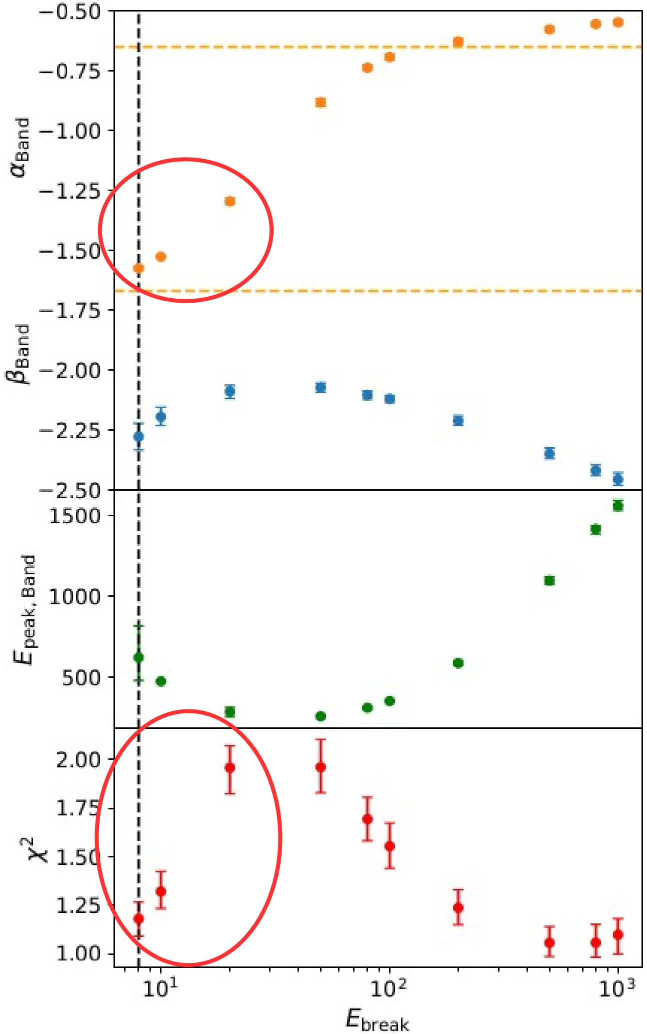




Toffano, Ghirlanda, Nava, Ghisellini, Ravasio et al. 2021 A&A

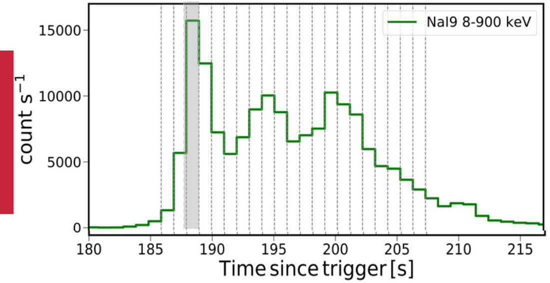
Observational biases hiding the low energy break



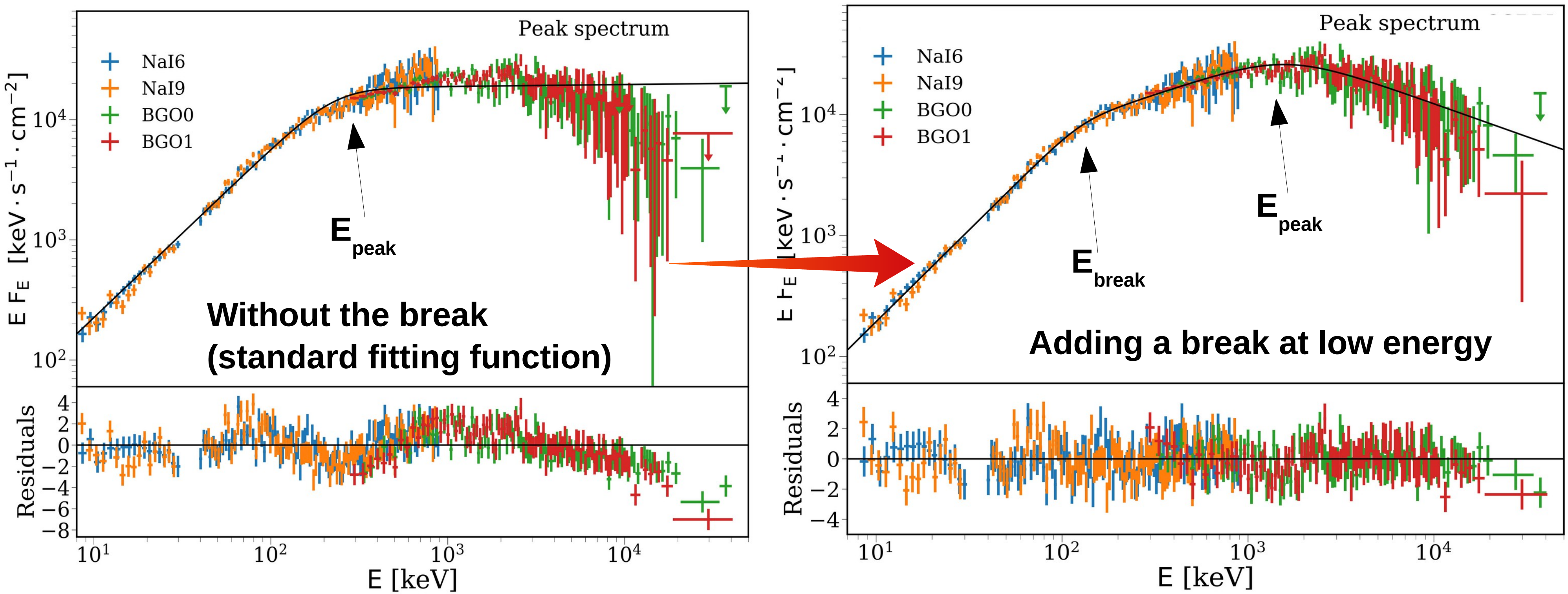


Toffano, Ghirlanda, Nava, Ghisellini, Ravasio et al. 2021 A&A

GRB 160625B

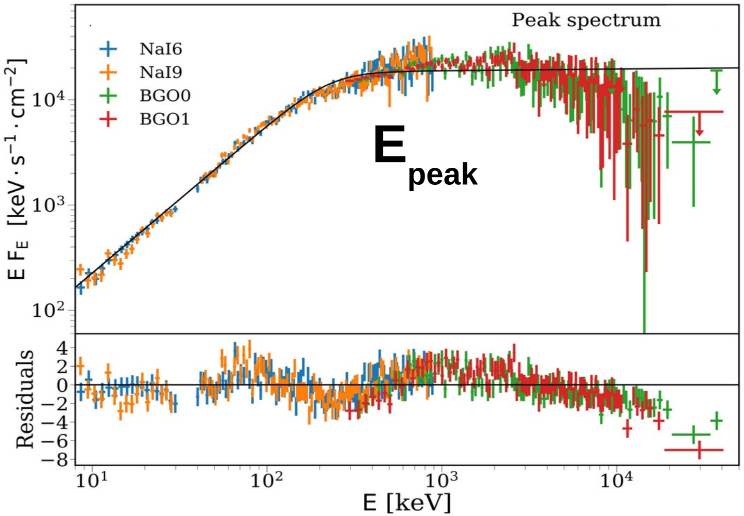


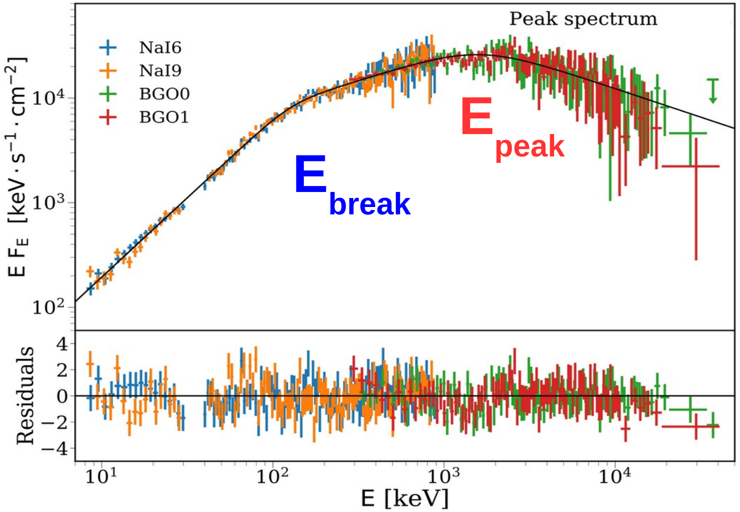
Adding a break at low energy → the fit significantly improves! σ(F-test) > 8σ

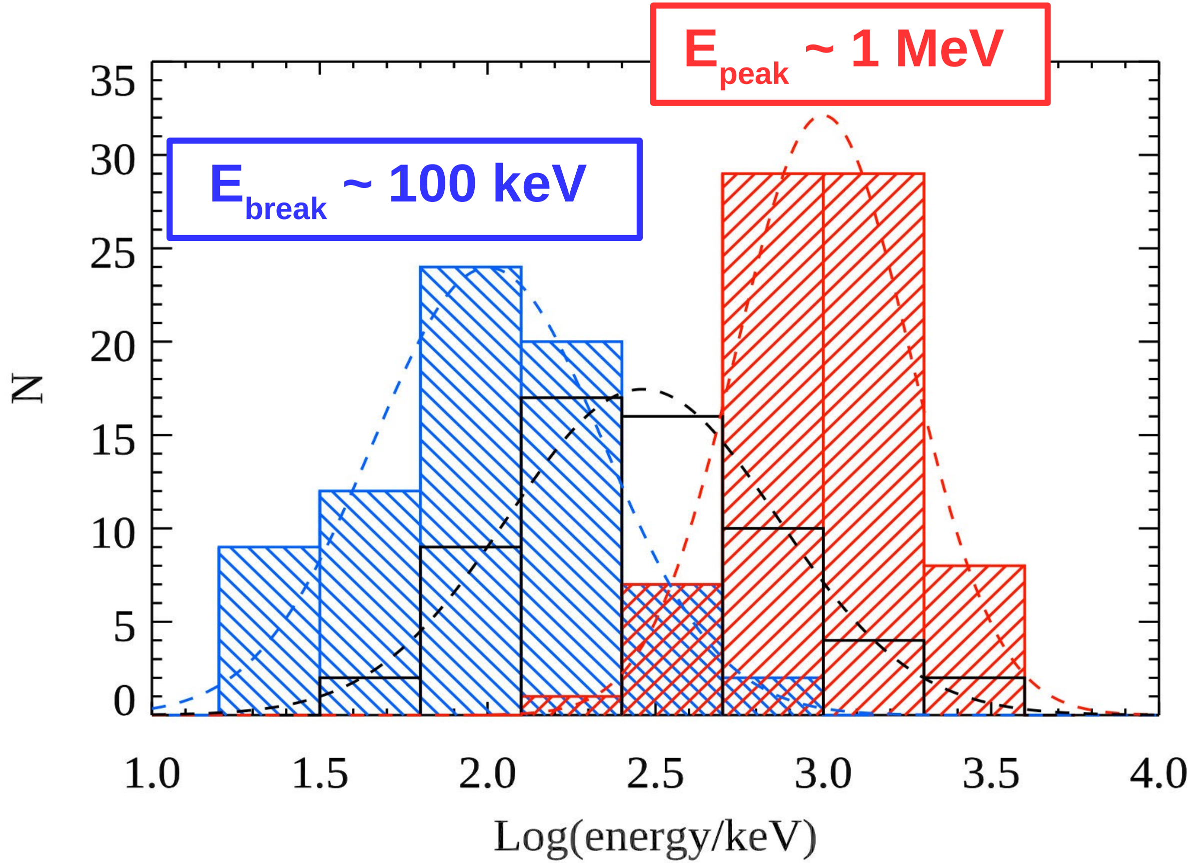


Ravasio et al., 2018, A&A

Results of the time-resolved spectral analysis



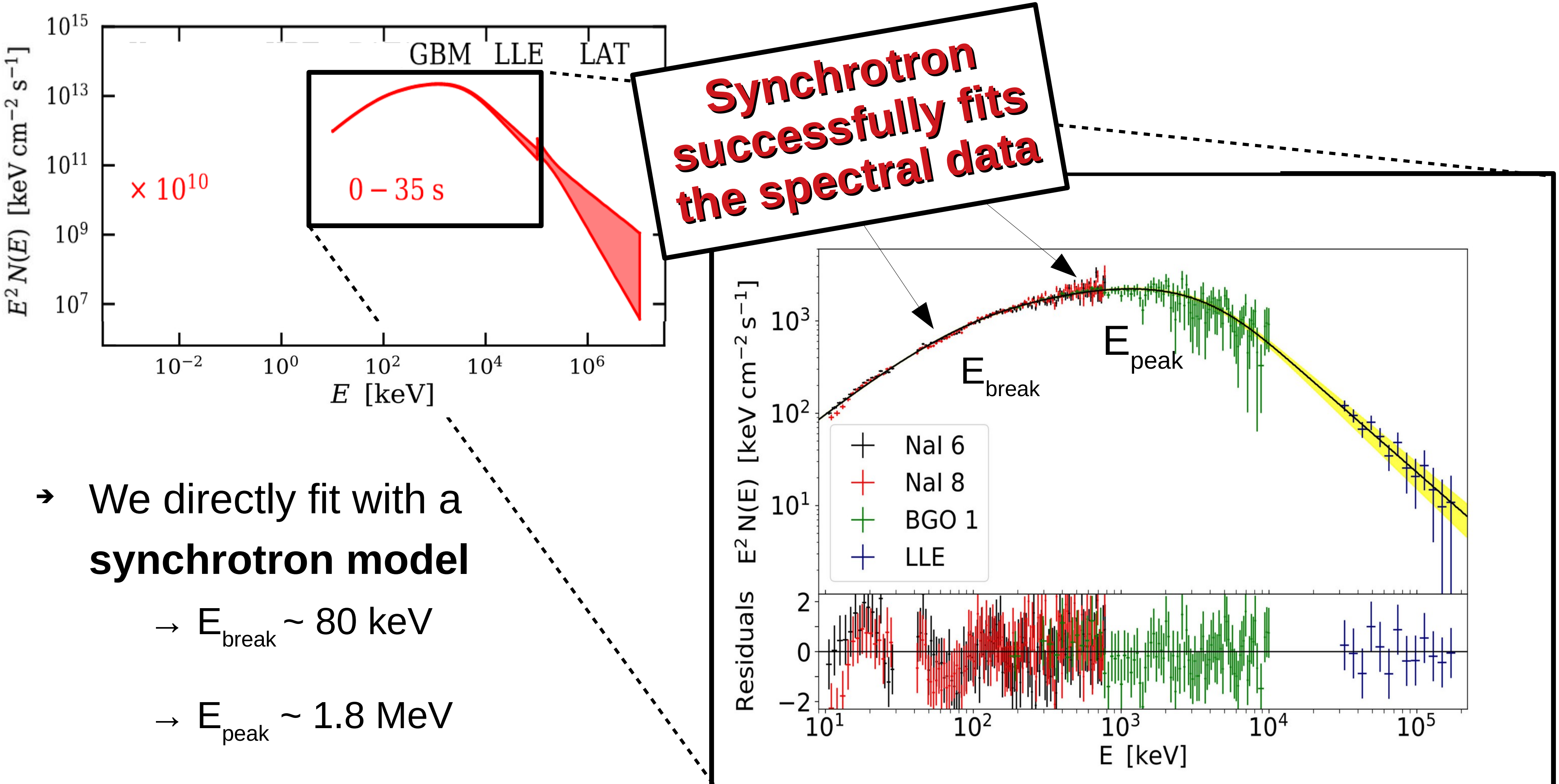




Single break function → E_{peak} ~ 300 keV

Ravasio et al., 2019, A&A

The synchrotron modeling of GRB 180720B

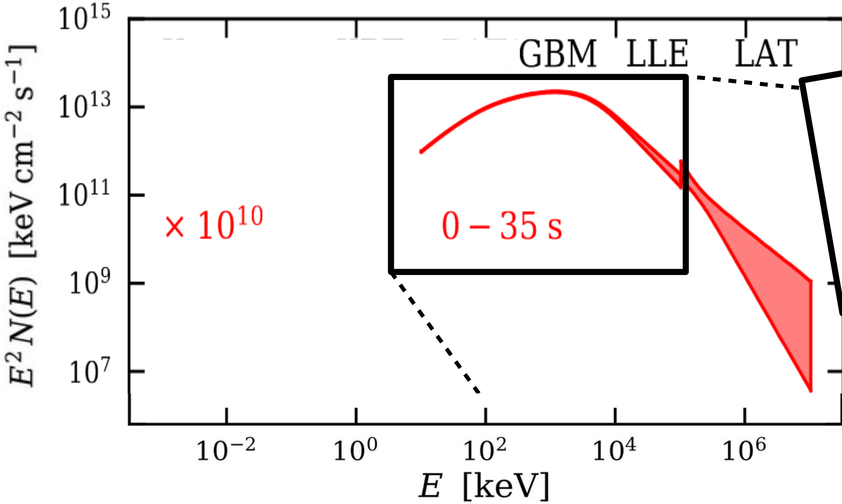


- We directly fit with a **synchrotron model**
  - → E_{break} ~ 80 keV
  - → E_{peak} ~ 1.8 MeV

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

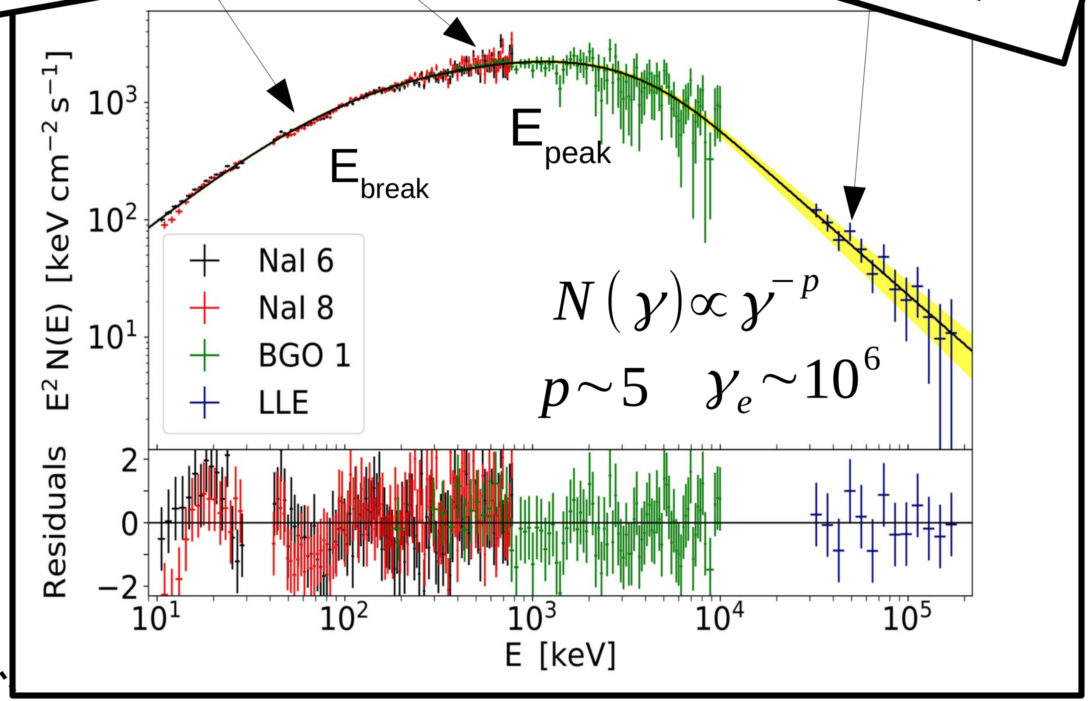
→ see also synchrotron model fit by Oganesyan et al. 2019 and Burgess et al. 2020

The synchrotron modeling of GRB 180720B



Synchrotron successfully fits the spectral data

Challenge for the acceleration mechanism



- We directly fit with a **synchrotron model**
  - → $E_{break} \sim 80$ keV
  - → $E_{peak} \sim 1.8$ MeV

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

→ see also synchrotron model fit by Oganesyan et al. 2019 and Burgess et al. 2020

Conclusion

- Strong **observational evidences** in both Swift and Fermi data in favour of the **synchrotron origin of GRBs spectra** [Oganesyan et al. 2017,2018,2019; **Ravasio et al., 2018, 2019;** Ronchi et al., 2020, Burgess et al. 2020]

In the leptonic scenario

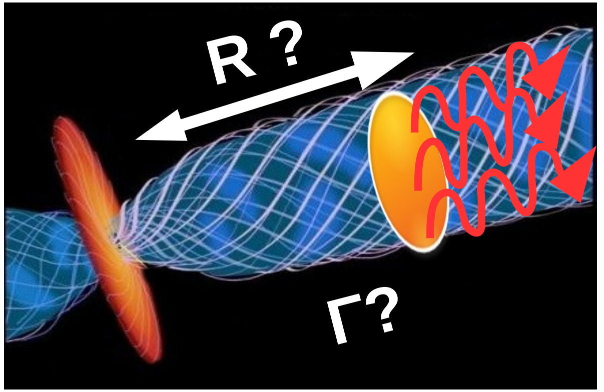
B ~ 10 Gauss

Hard to reconcile with the standard model

In the hadronic scenario

B ~ 10^7 Gauss

Feasible but limited parameter space



Conclusion

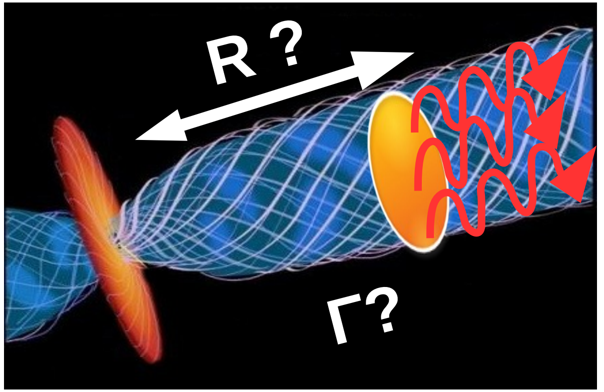
- Strong **observational evidences** in both Swift and Fermi data in favour of the **synchrotron origin of GRBs spectra** [Oganesyan et al. 2017,2018,2019; **Ravasio et al., 2018, 2019;** Ronchi et al., 2020, Burgess et al. 2020]

In the leptonic scenario
B ~ 10 Gauss

Hard to reconcile with the standard model

In the hadronic scenario
B ~ 10^7 Gauss

Feasible but limited parameter space



- High-energy: → Γ from compactness (independent from the radiative process)

$$140 \leq \Gamma \leq 330$$

Ravasio et al., in prep.

Conclusion

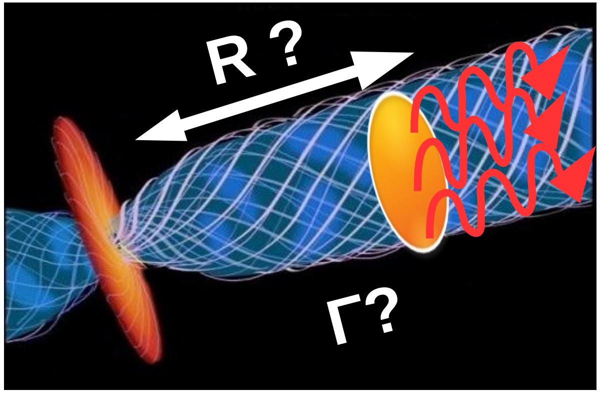
- Strong **observational evidences** in both Swift and Fermi data in favour of the **synchrotron origin of GRBs spectra** [Oganesyan et al. 2017,2018,2019; **Ravasio et al., 2018, 2019;** Ronchi et al., 2020, Burgess et al. 2020]

In the leptonic scenario
B ~ 10 Gauss

Hard to reconcile with the standard model

In the hadronic scenario
B ~ 10^7 Gauss

Feasible but limited parameter space



- High-energy: → Γ from compactness (independent from the radiative process)

$$140 \leq \Gamma \leq 330$$

- **high energy prompt spectra** + **afterglow lightcurves** → **distance R** **~ 10^{13} – 10^{15} cm**

- more **HE** and **VHE** observations needed to fully uncover the prompt GRB parameter space

Ravasio et al., in prep.