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GW group

Recent progresses in understanding the nature of gamma-ray burst production mechanism

Gor Oganesyan

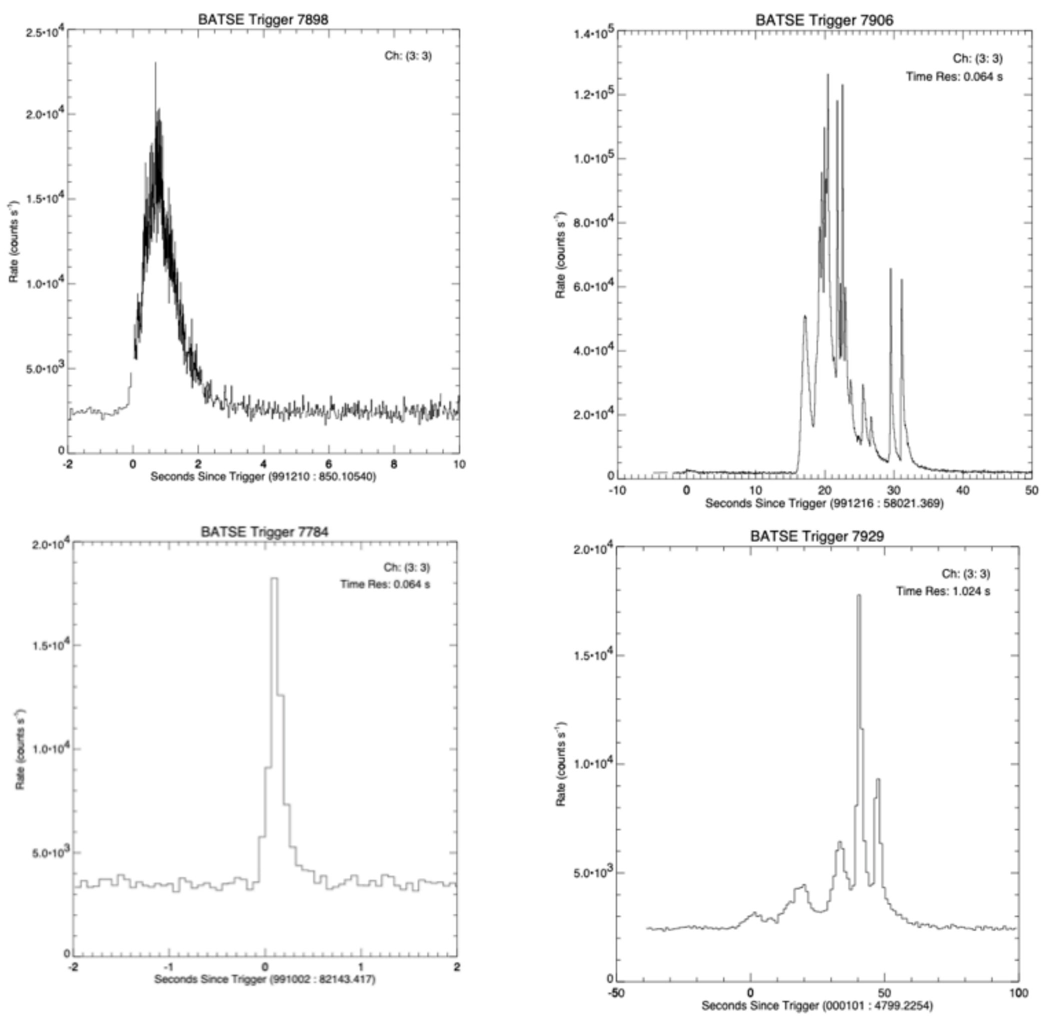
24 June 2021
PLUS collaboration

what are γ-ray bursts?

extragalactic sources (z up to 9.4 for now)

prompt emission

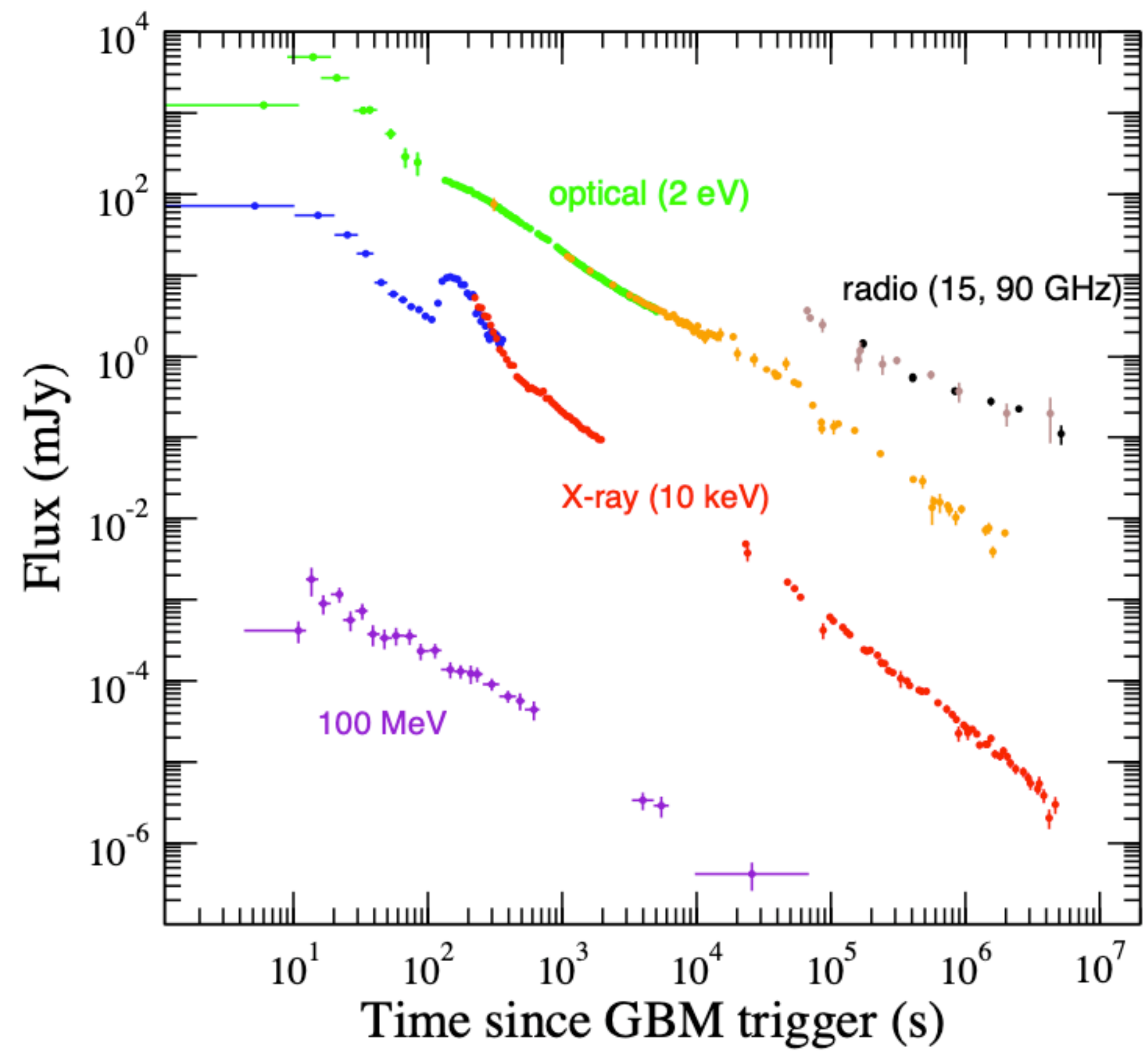
GRB lightcurves (100-300 keV) from BATSE catalog



band 10 keV - 10 MeV
total duration 0.1 s - 1000s
variability 0.01-1 s
total energy 1E51-1E54 erg

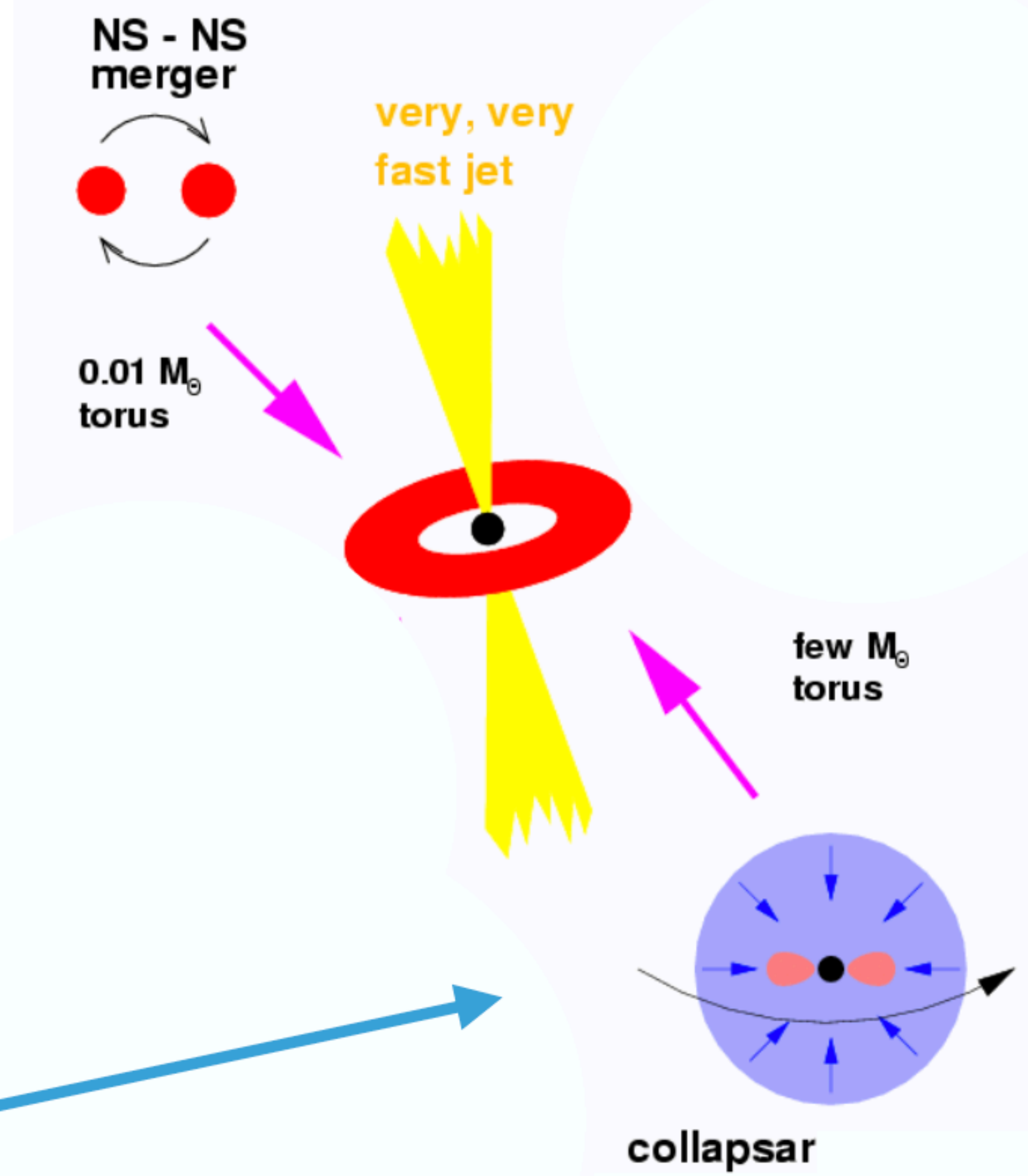
afterglow

GRB 130427A Panaitescu et. al. 2013



Progenitors of short and long GRBs

SHORT GRBs



LONG GRBs

we are quite comfortable with the progenitors

Open questions?

many!

prompt emission

where and how is it produced?

jet launching mechanism

composition of the jet

acceleration processes

which jets are successful?

central machine of GRB

black hole vs magnetar

GRBs from first stars?

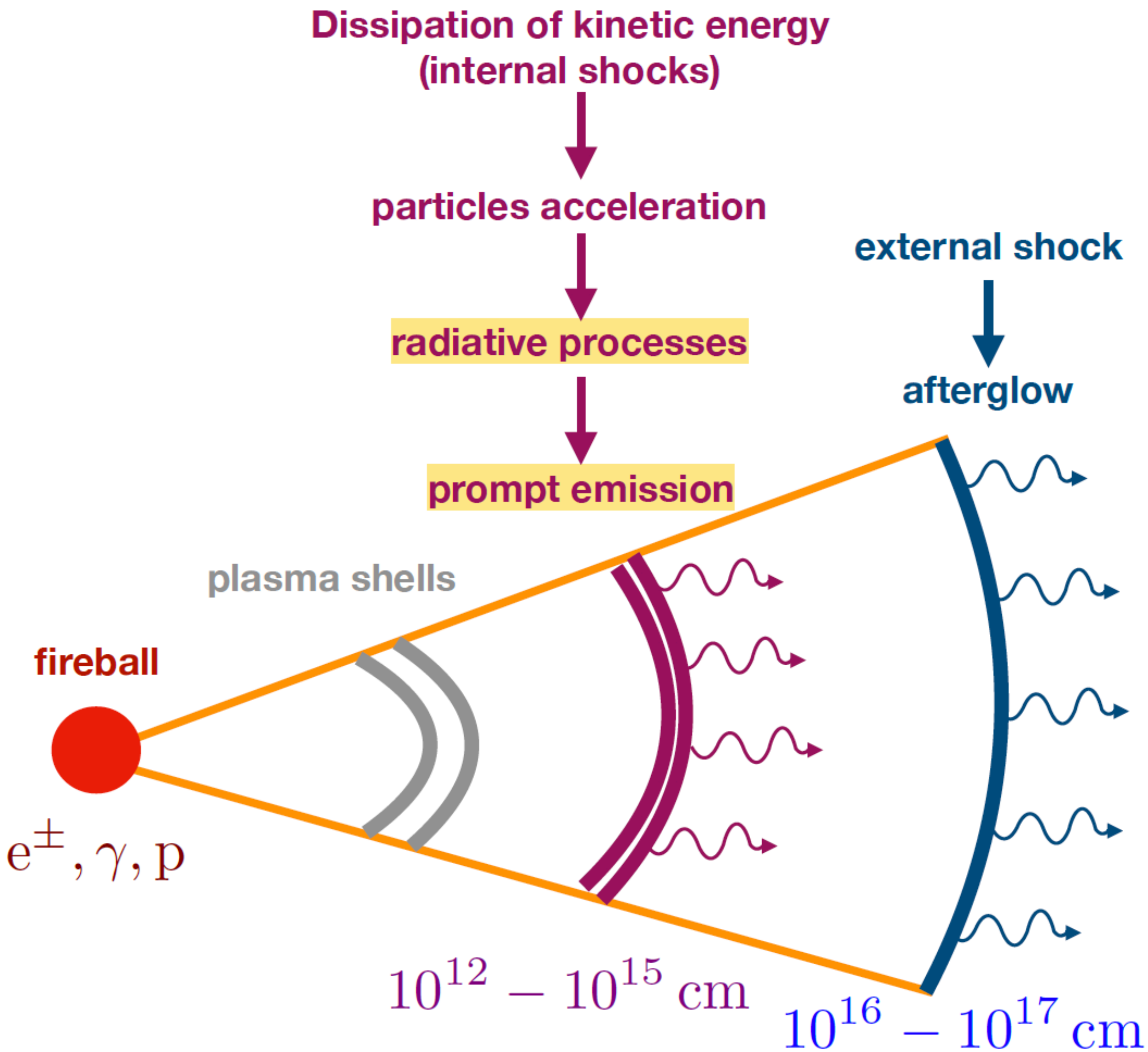
...

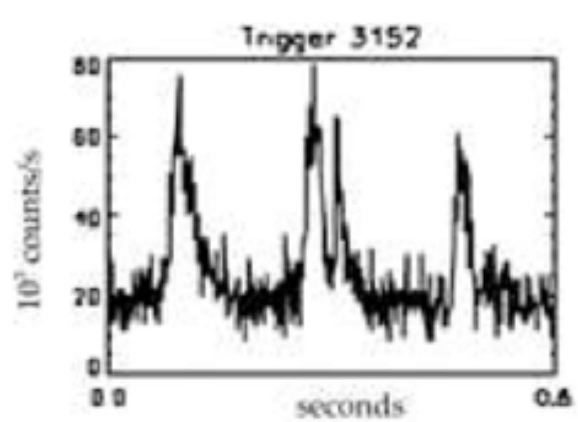
Electromagnetic Counterparts of Compact Binary Mergers

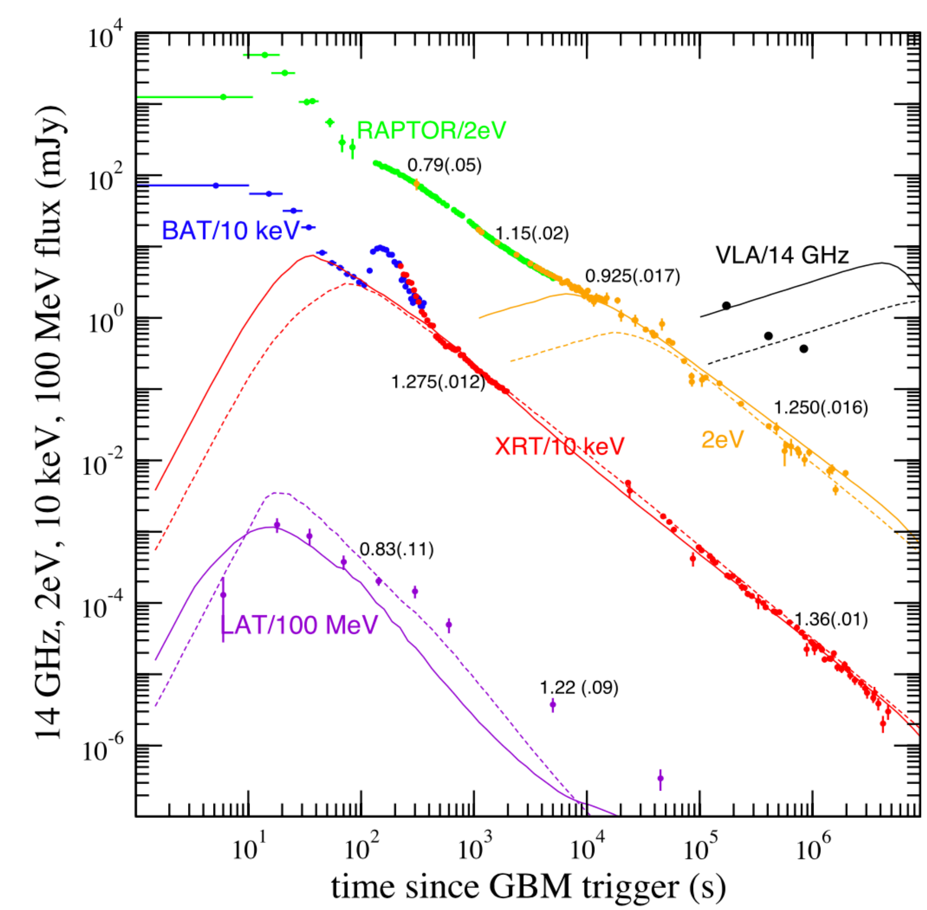
Stefano Ascenzi, Gor Oganesyan, Marica Branchesi, Riccardo Ciolfi

The first detection of a binary neutron star merger through gravitational waves and photons marked the dawn of multi-messenger astronomy with gravitational waves, and it greatly increased our insight in different fields of astrophysics and fundamental physics. However, many open questions on the physical process involved in a compact binary merger still remain and many of these processes concern plasma physics. With the second generation of gravitational wave interferometers approaching their design sensitivity, the new generation under design study, and new X-ray detectors under development, the high energy Universe will become more and more a unique laboratory for our understanding of plasma in extreme conditions. In this review, we discuss the main electromagnetic signals expected to follow the merger of two compact objects highlighting the main physical processes involved and some of the most important open problems in the field.

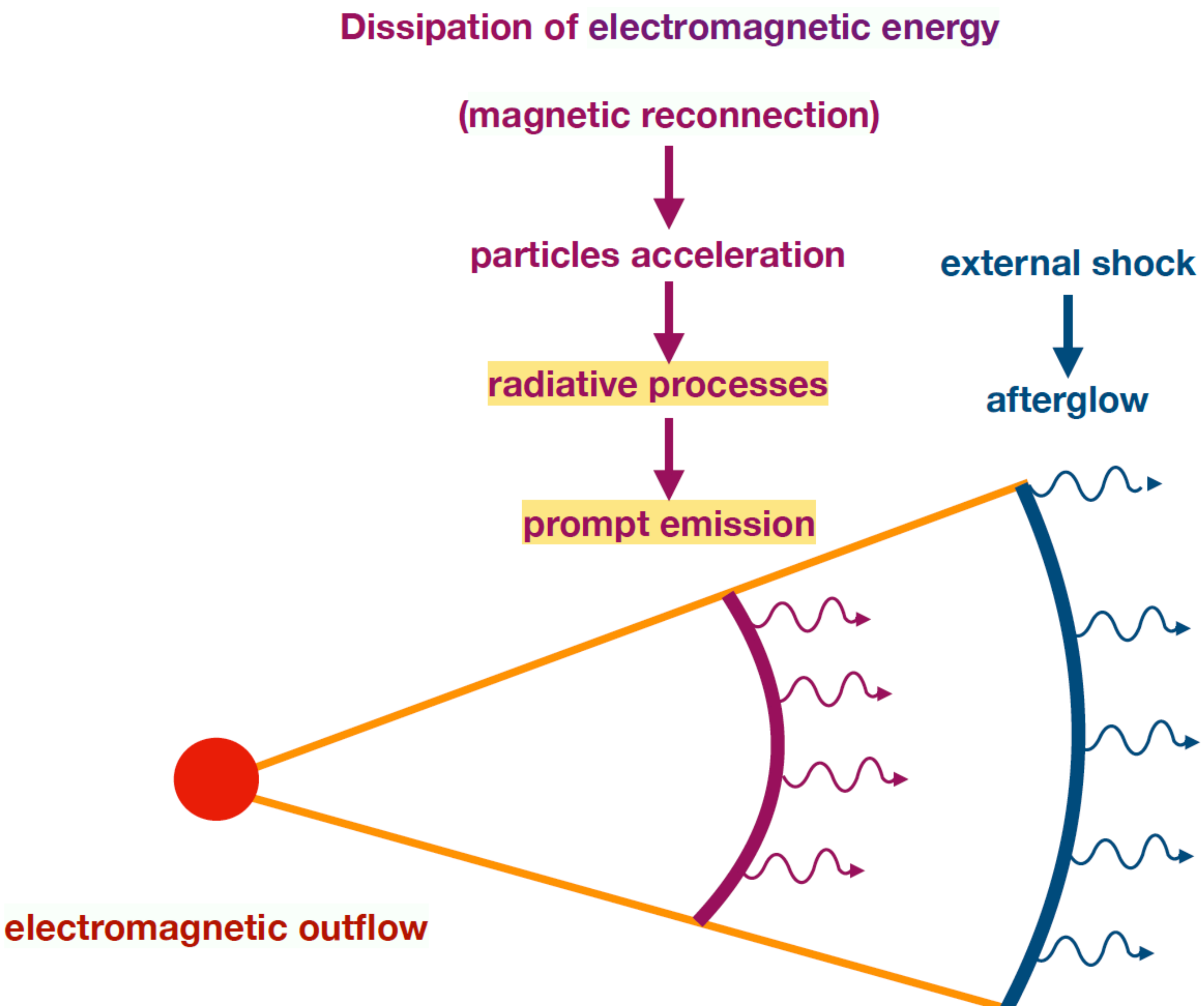
“standard theory”

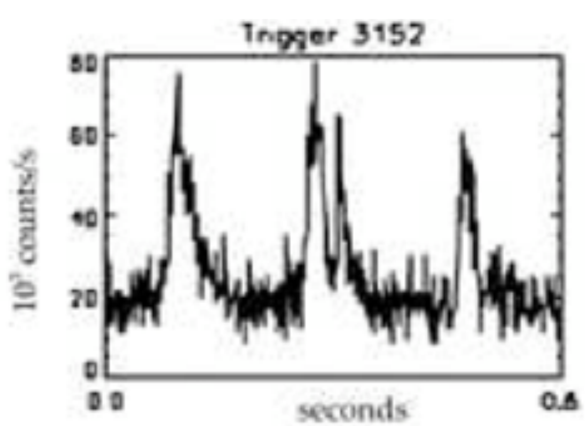


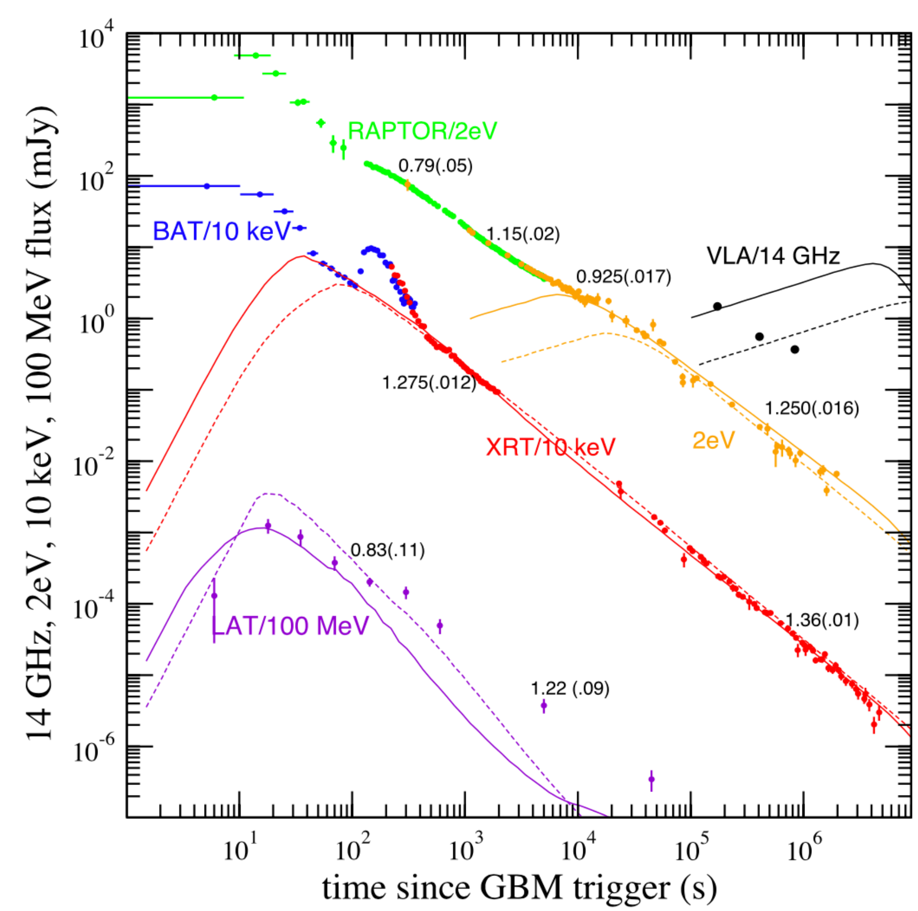




“another standard theory”

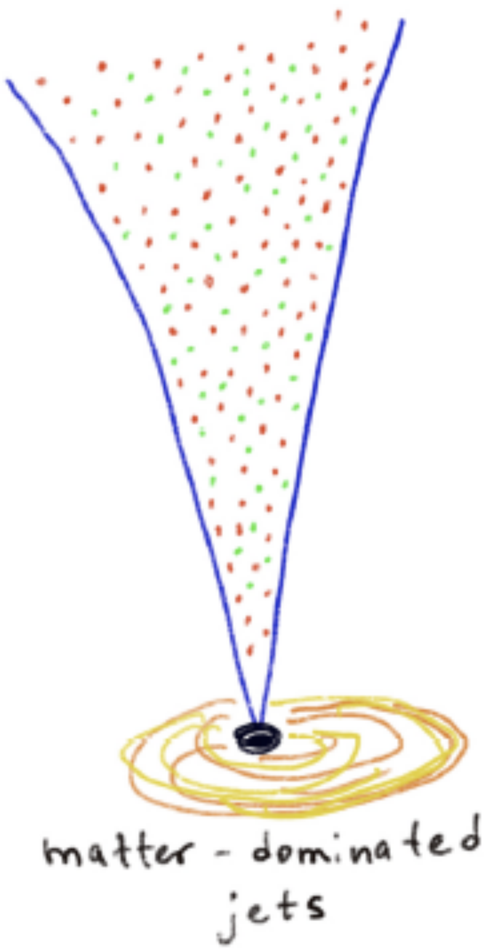


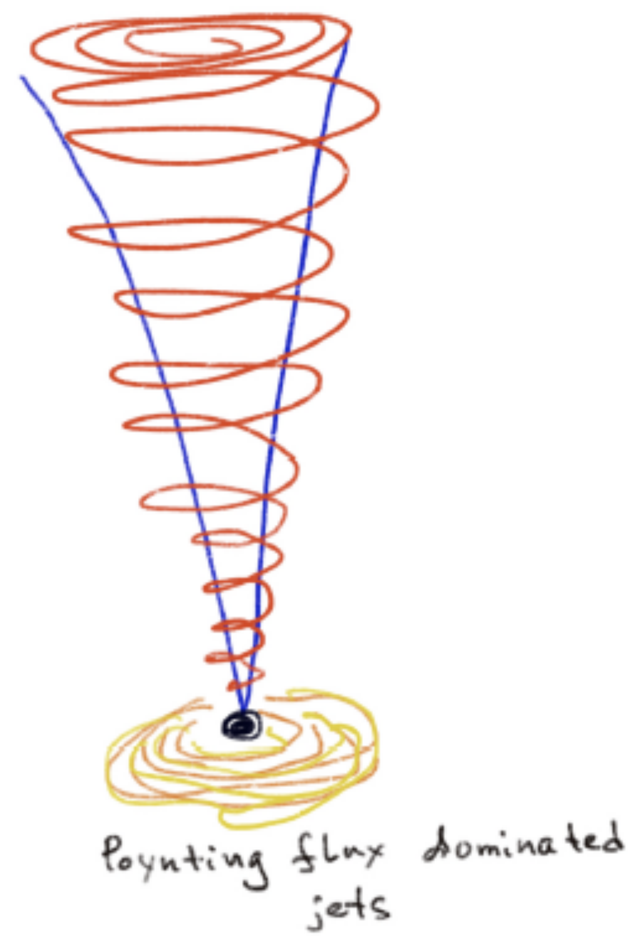




GRB prompt emission: open problems

jet composition



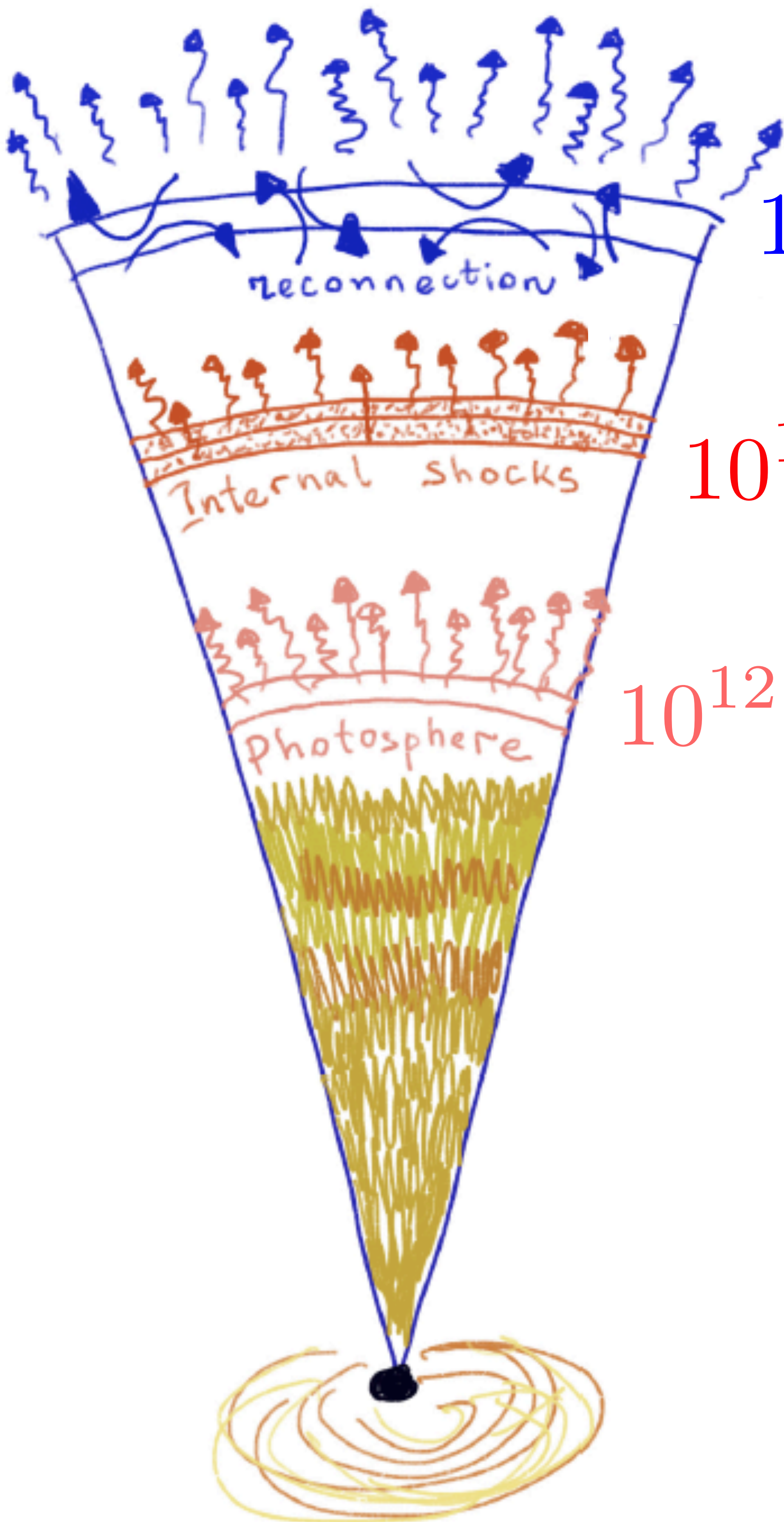


Cavallo & Rees 1978
Paczýnski 1986
Goodman 1986
Shemi & Piran 1990

Usov 1992
Thompson 1994
Mészáros & Rees 1997
Lyutikov & Blandford 2003

GRB prompt emission: open problems

dissipation and radiation mechanisms



$10^{16}\mathrm{cm}$

Drenkhahn & Spruit 2002,
Lyutikov & Blandford 2003,
Zhang & Yan 2011

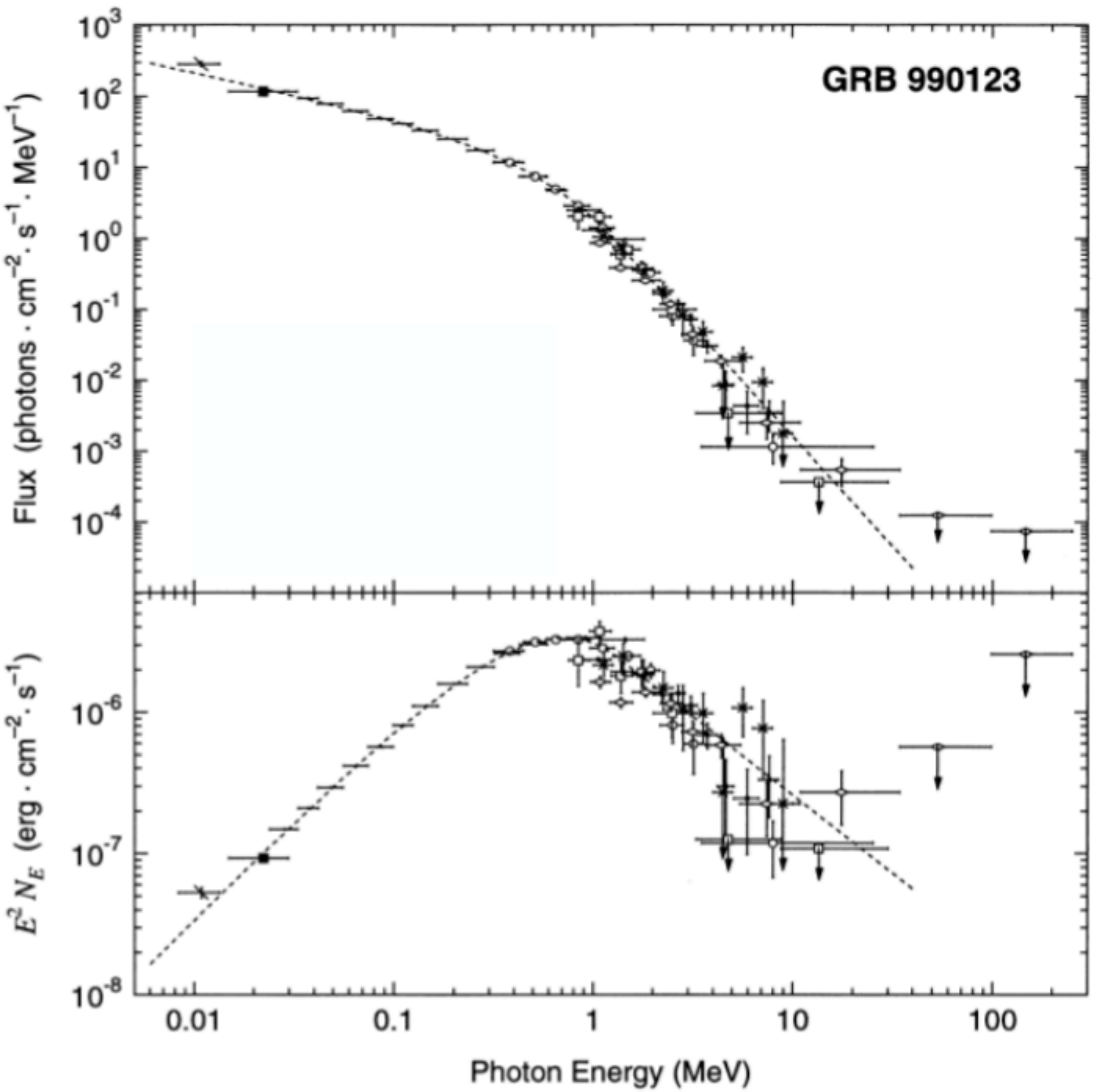
$10^{14}\mathrm{cm}$

Narayan et al. 1992, Rees & Mészáros 1994

$10^{12}\mathrm{cm}$

Thomson 1994, Ghisellini & Celotti 1999,
Mészáros & Rees 2000, Pe'er et al. 2006

the mystery of the prompt emission spectra



Briggs et al. 1999

observed non-thermal spectra

what is it?

accelerated electrons
in
magnetic field

synchrotron?

Rees & Mészáros 1994
Sari et al. 1996, 1998

fast cooling regime

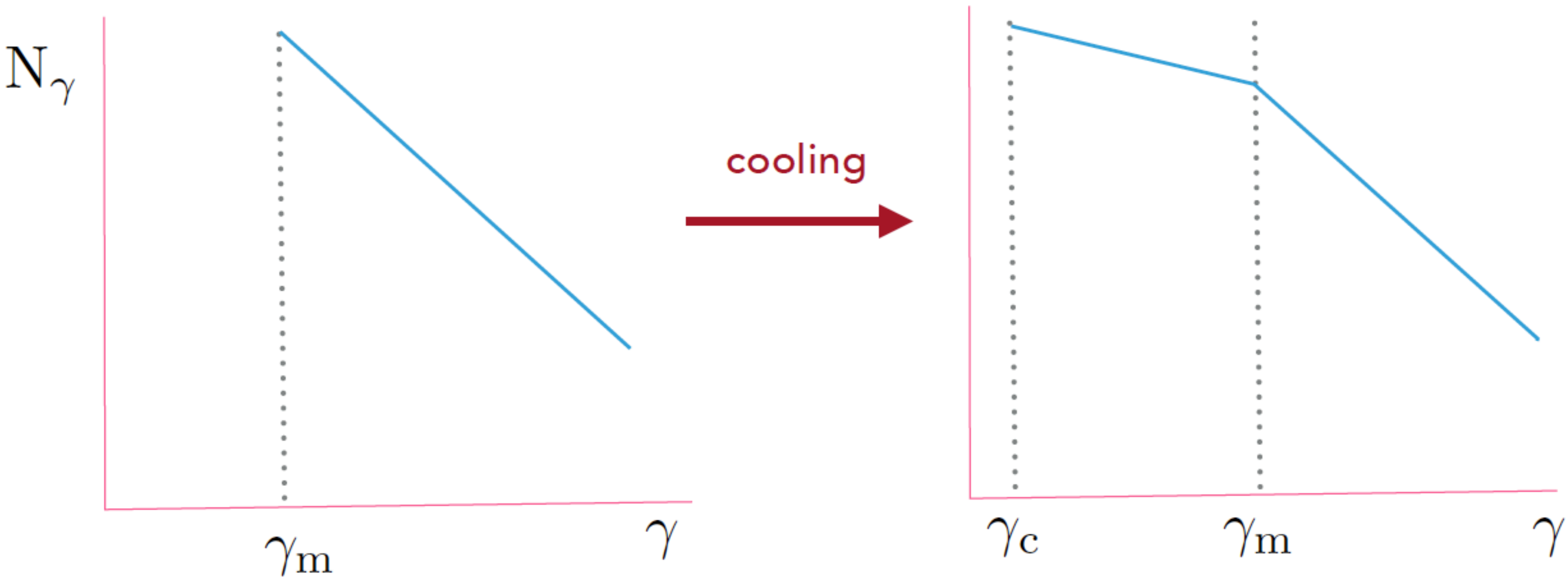
Preece et al. 1998
Ghisellini et al. 2000

The expectations

accelerated electrons

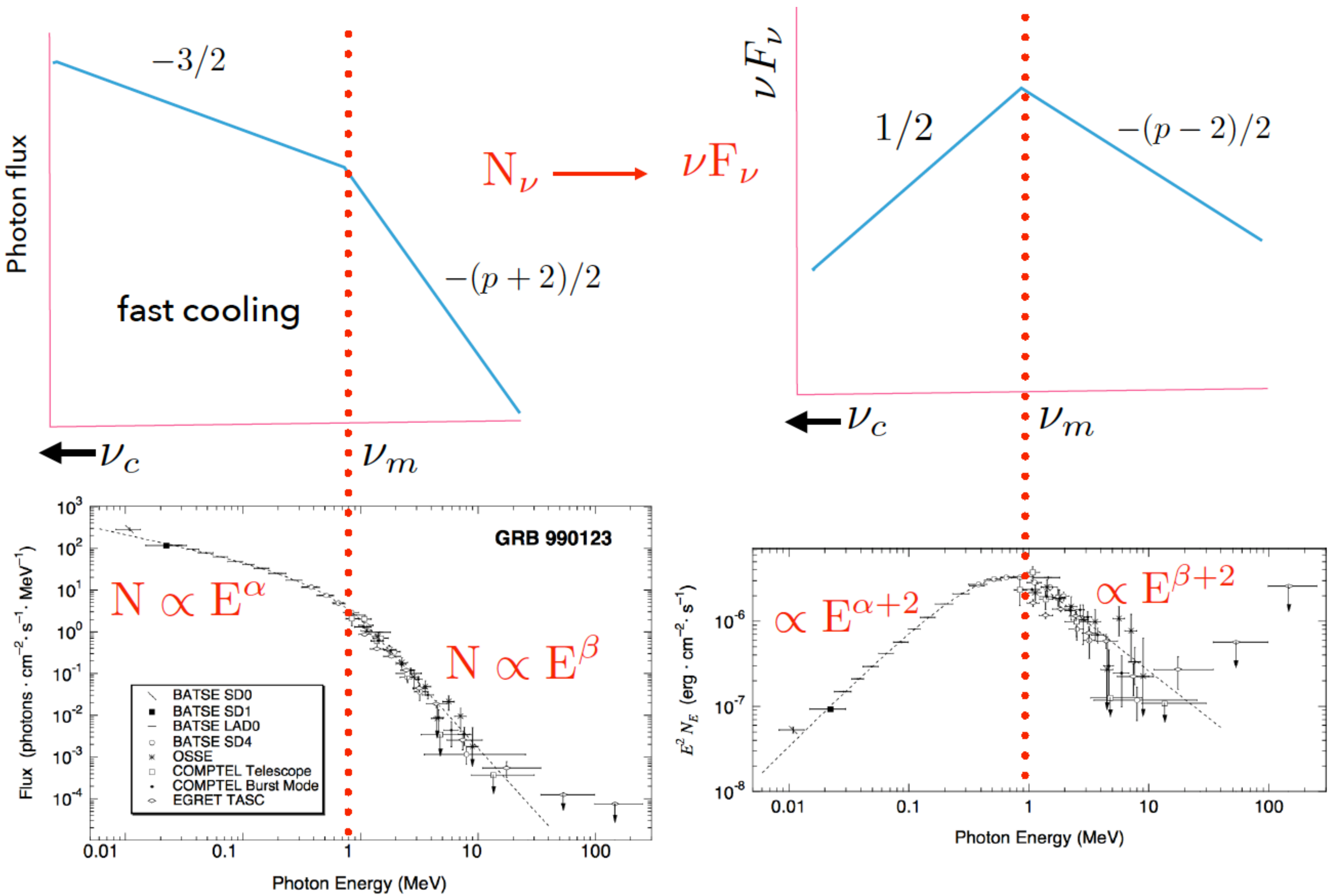
$$N_\gamma \propto \gamma^{-p}, \gamma > \gamma_m$$

$$\mathrm{t_c} = \frac{\gamma \mathrm{m_e c^2}}{\mathrm{P_{syn}}} = \frac{6\pi \mathrm{m_e c^2}}{\sigma_\mathrm{T} \mathrm{B}^2 \gamma} \rightarrow \gamma_\mathrm{c} = \frac{6\pi \mathrm{m_e c}}{\sigma_\mathrm{T} \mathrm{B}^2 \mathrm{t_{dyn}}}$$



$$\mathrm{t_{dyn}} \sim \mathrm{R/c\Gamma^2} \longleftrightarrow \mathrm{t_c}$$

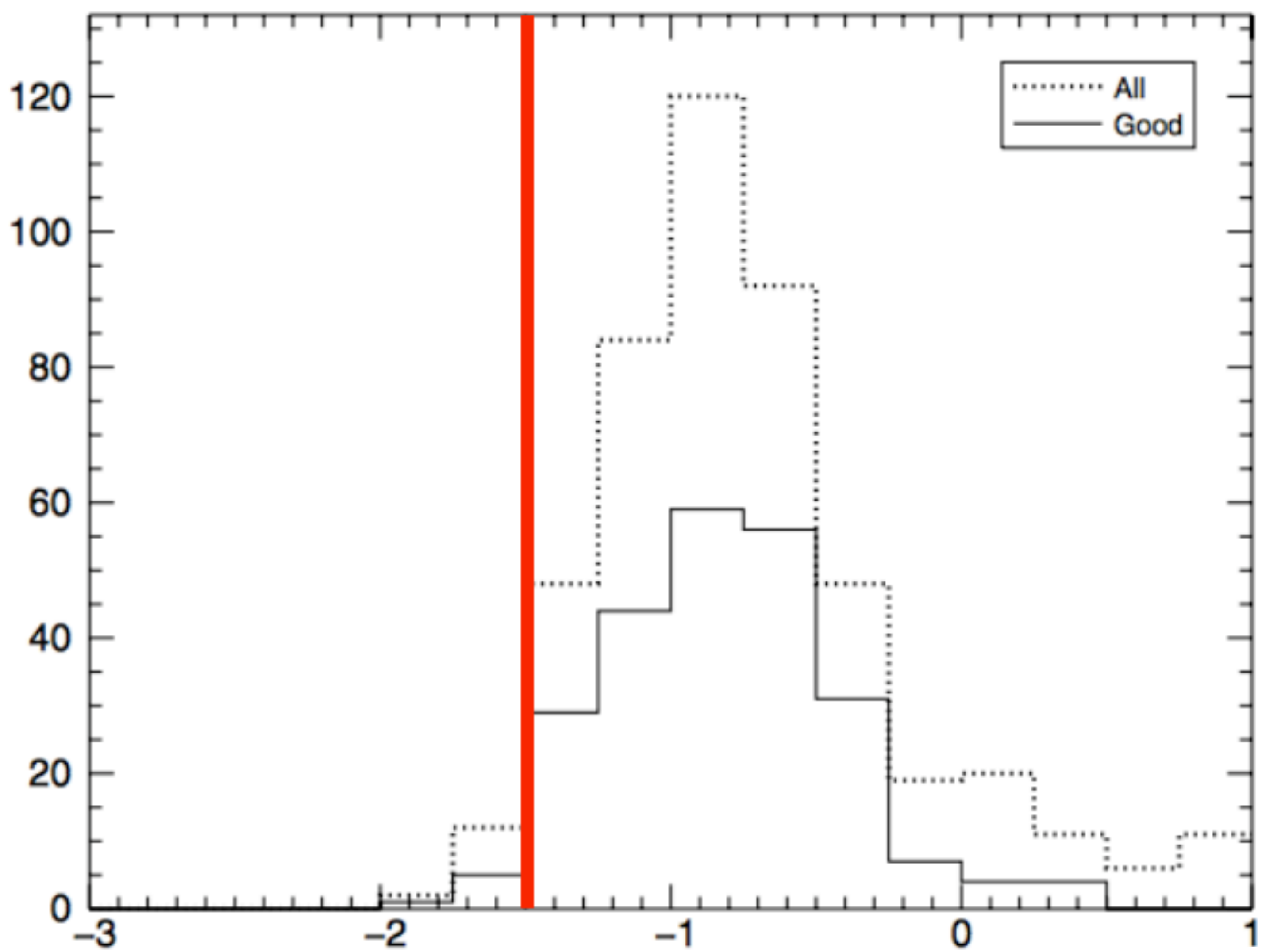
the expectations



the reality

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

$-3/2$



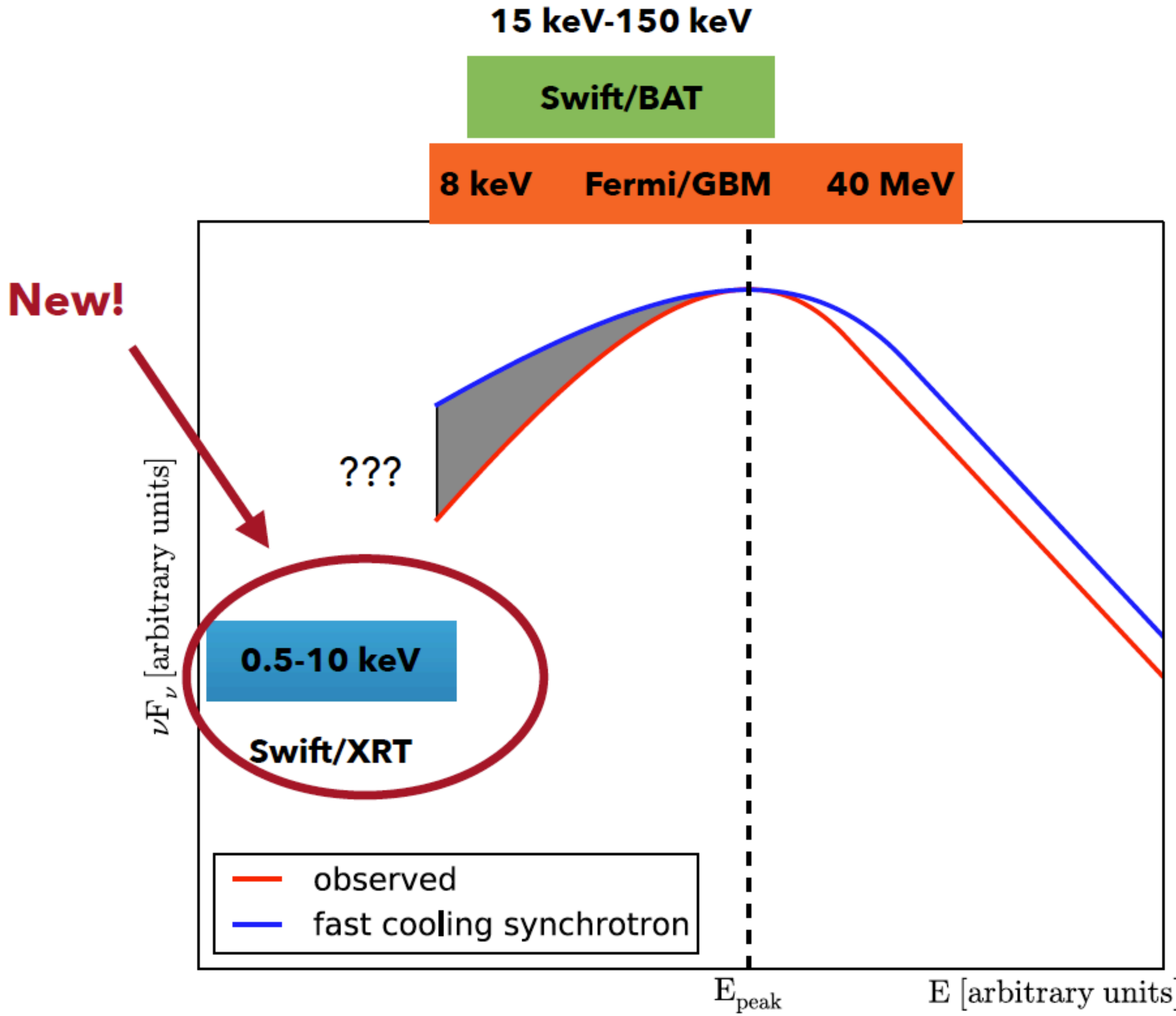
α

2nd Fermi catalog

$\alpha \sim -1$

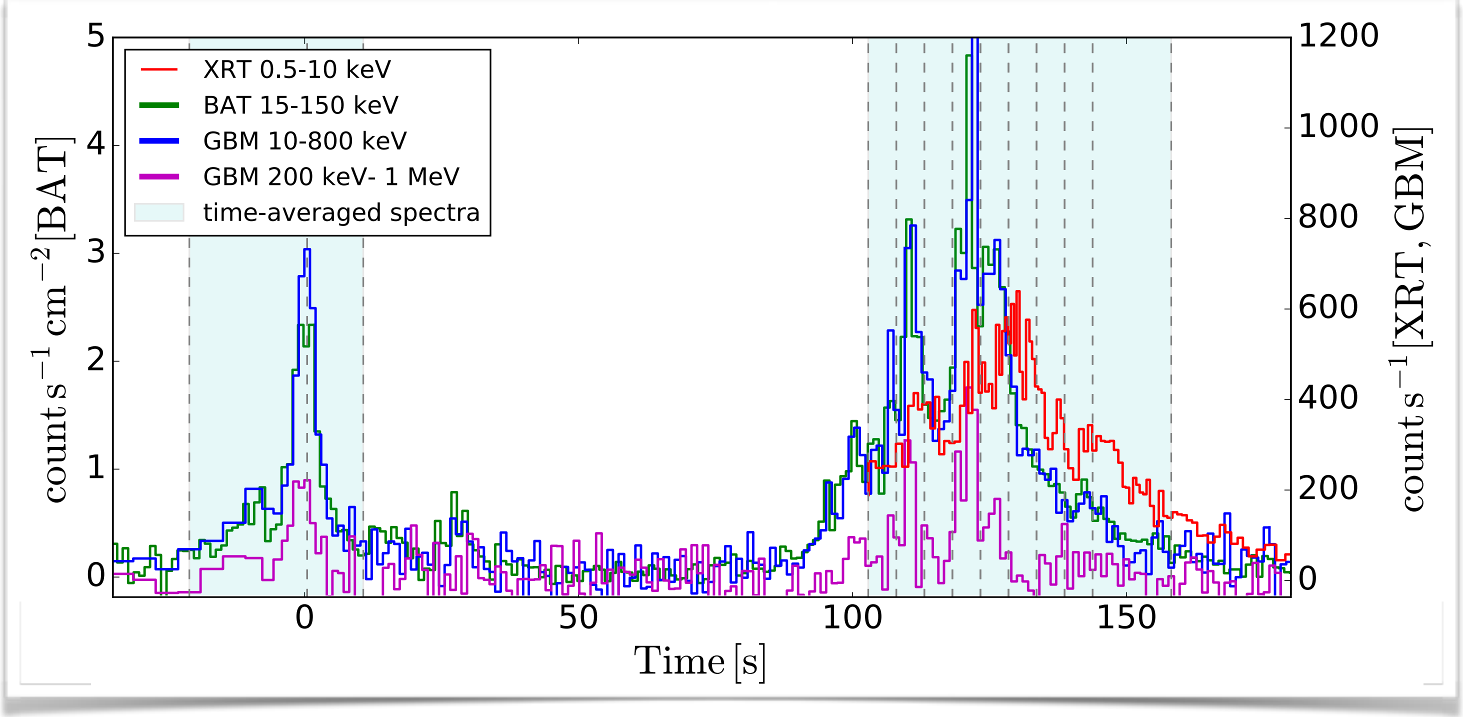
Preece et al. 1998
Ghisellini et al. 2000
Frontera et al. 2000
Ghirlanda et al. 2002
Kaneko et al. 2006
Nava et al. 2011

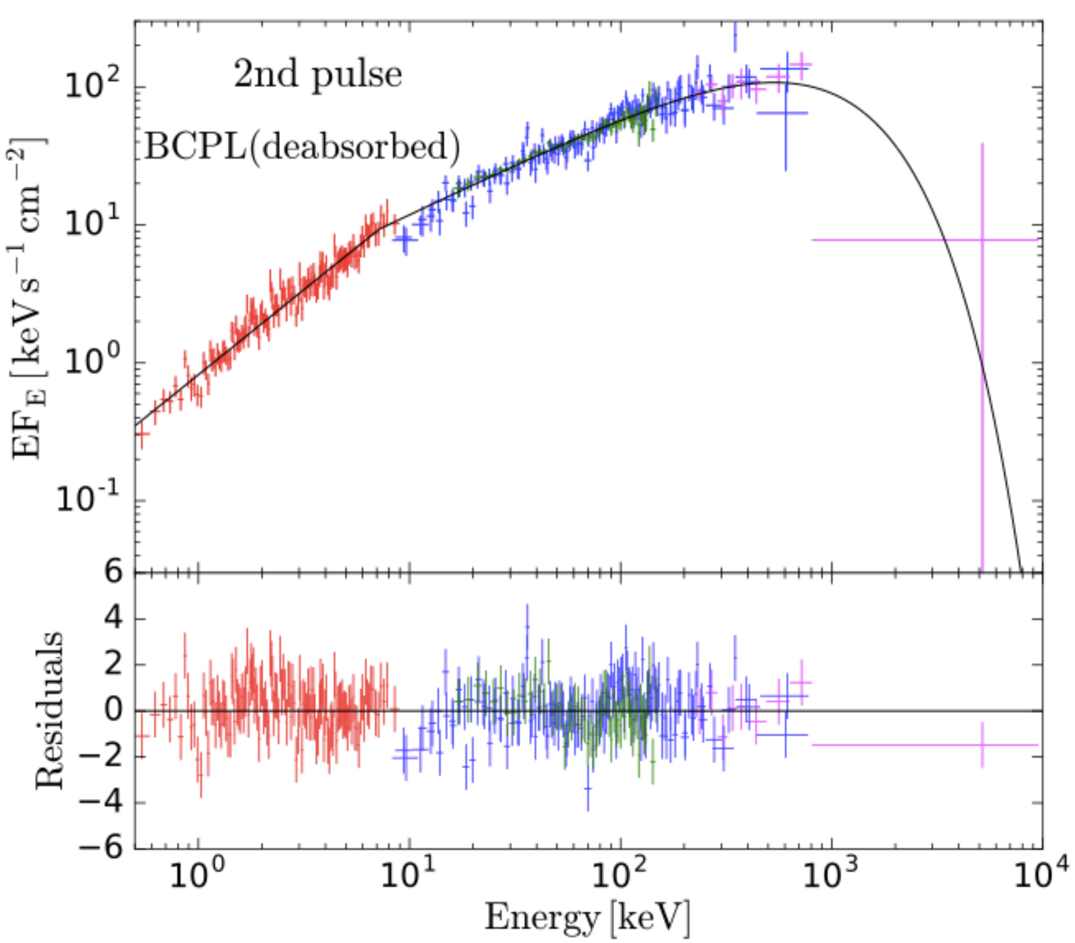
Low-energy look at the problem

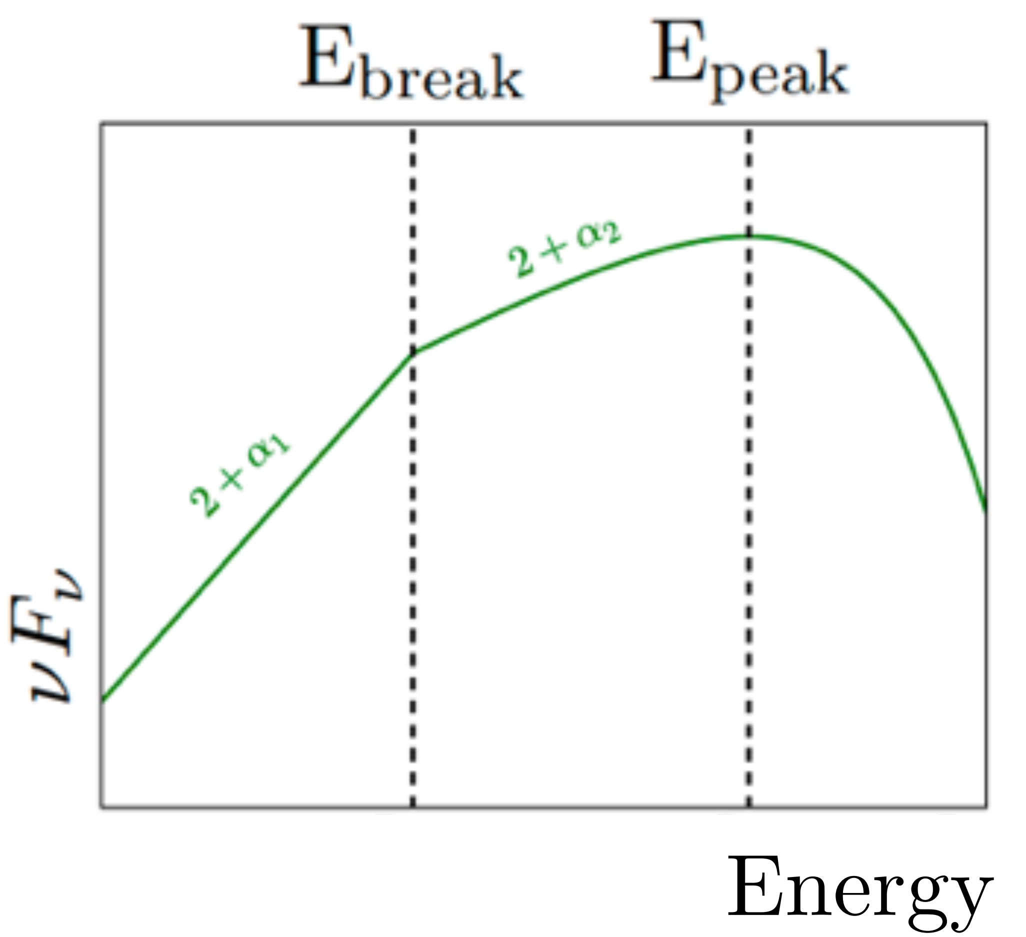


Oganesyan et al. 2017,2018

Low-energy look at the problem

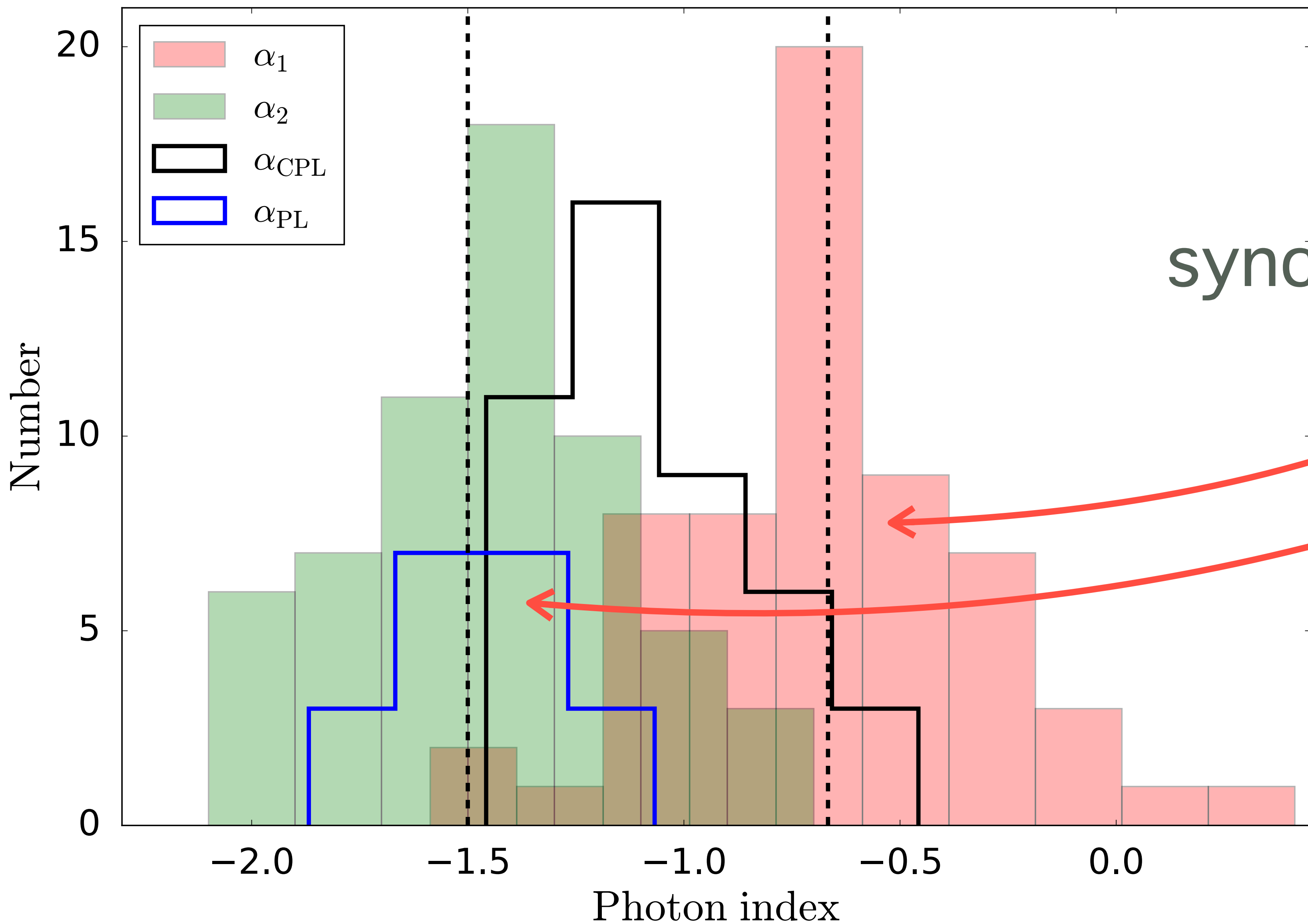






Low-energy look at the problem

synchrotron origin is suggested from the empirical fits



synchrotron predictions for α_1 and α_2

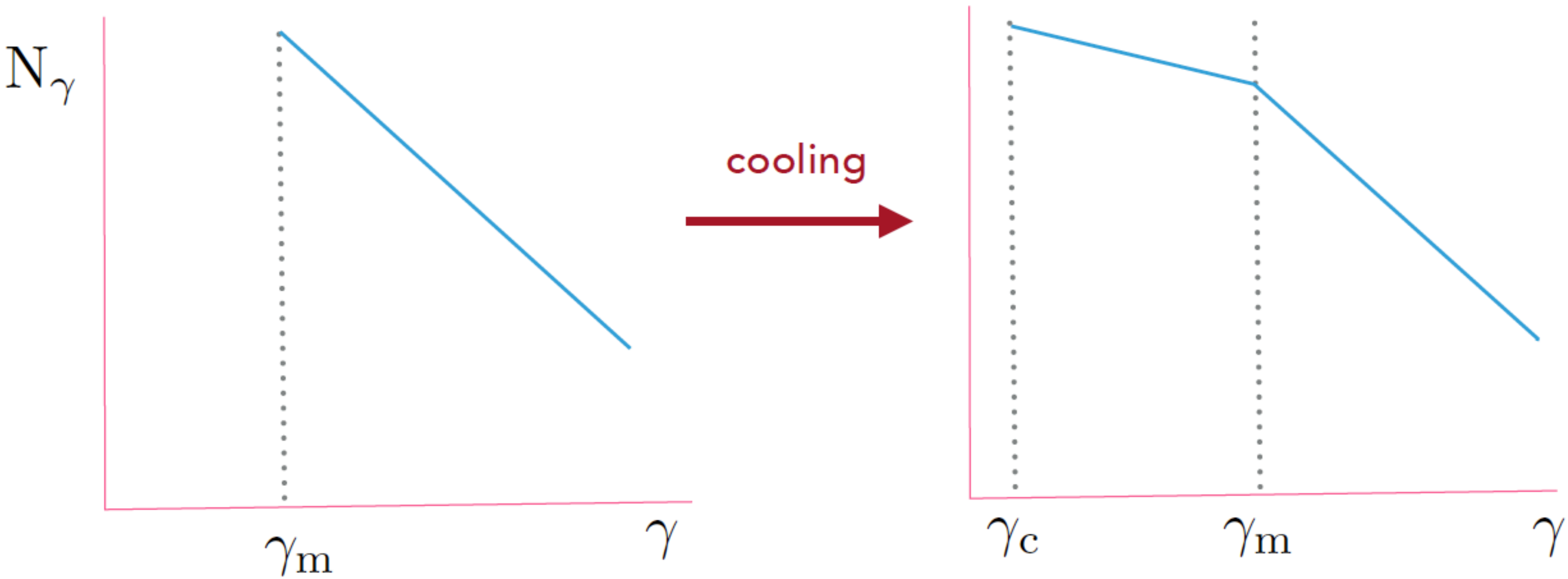
Oganesyan et al. 2017,2018

The expectations

accelerated electrons

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

$$\mathrm{t_c} = \frac{\gamma \mathrm{m_e c^2}}{\mathrm{P_{syn}}} = \frac{6\pi \mathrm{m_e c^2}}{\sigma_\mathrm{T} \mathrm{B}^2 \gamma} \rightarrow \gamma_\mathrm{c} = \frac{6\pi \mathrm{m_e c}}{\sigma_\mathrm{T} \mathrm{B}^2 \mathrm{t_{dyn}}}$$

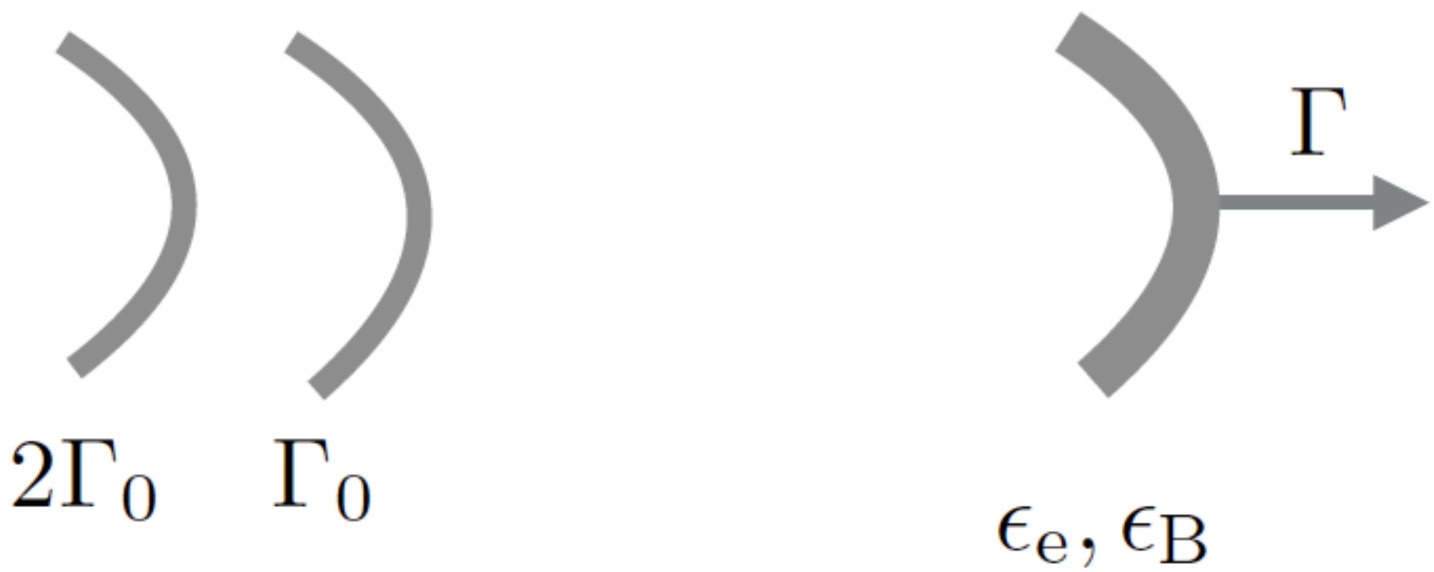


$$\mathrm{t_{dyn}} \sim \mathrm{R/c\Gamma^2} \longleftrightarrow \mathrm{t_c}$$

The expectations

which regime?

Internal shocks



$$t_c = \frac{\gamma m_e c^2}{P_{syn}} \frac{1+z}{\Gamma} \sim 1.1 \times 10^{-5} \frac{\epsilon_B^3 \Gamma_2}{E^2_{2,peak[keV]}(1+z)} s << t_{obs}$$

Ghisellini, Celotti and Lazzati 2000

[fast cooling regime]

What we have learnt

- **There is a low-energy break in the GRB spectra**

- **The break could be the synchrotron cooling frequency**
  Oganesyan et al. 2017,2018; Ravasio et al. 2018,2019

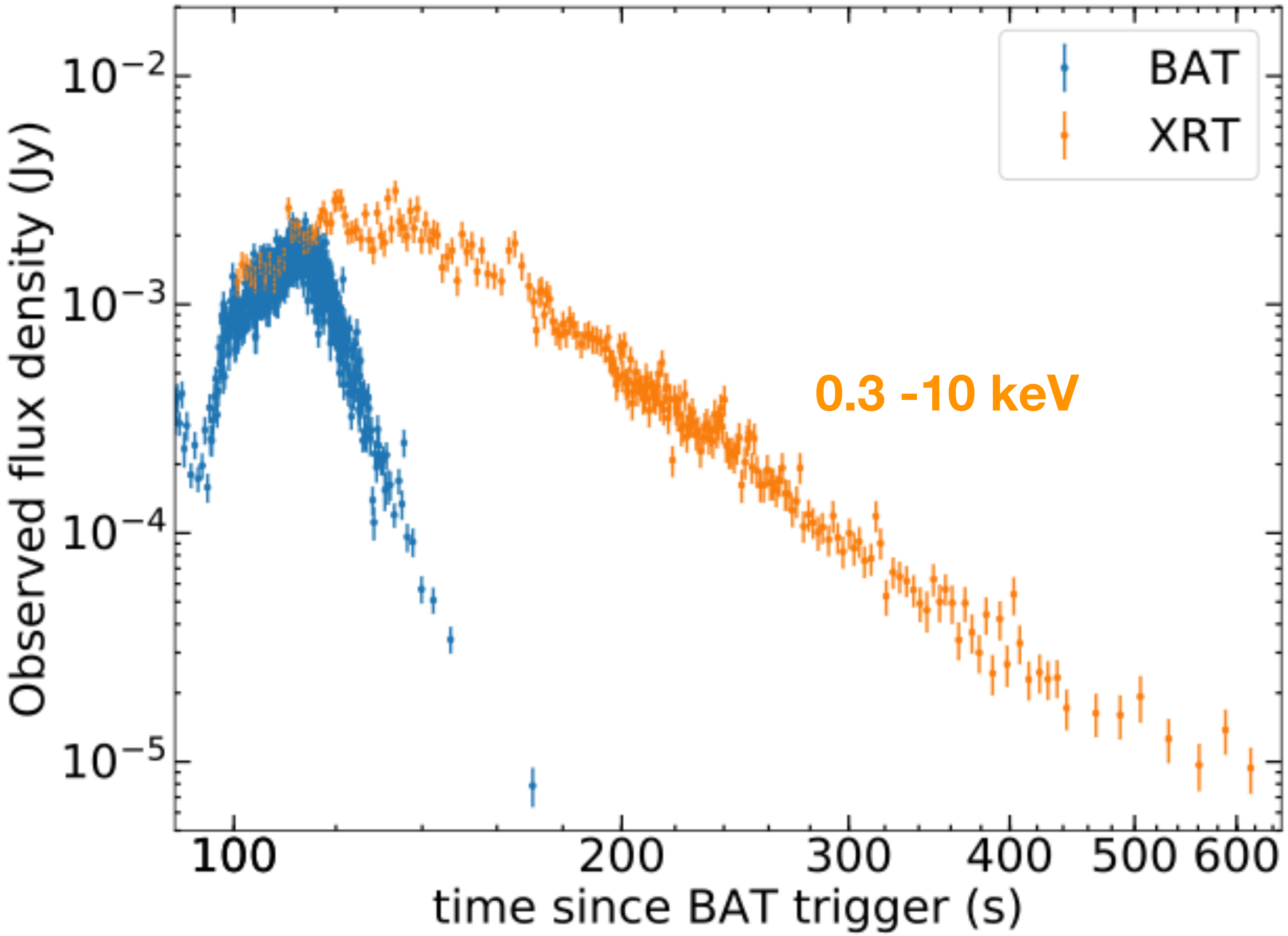
- **Synchrotron model fits the (considered) data**
  Oganesyan et al. 2019; Burgess et al. 2020

see B. Zhang 2020, Nature Astronomy, for a brief discussion

Models that could work

- re-acceleration/heating of electrons
  Kumar & McMahon 2008; Asano & Terasawa 2009; Beniamini & Piran 2014; Beniamini et al. 2018;
- noticeable decay of the magnetic field
  Pe'er & Zhang 2006; Derishev 2007; Zhao et al. 2014; Uhm & Zhang 2014; Zhang et al. 2016
- proton synchrotron model
  Ghisellini et al. 2020

X-ray steep decay as diagnostics of the GRB emission side

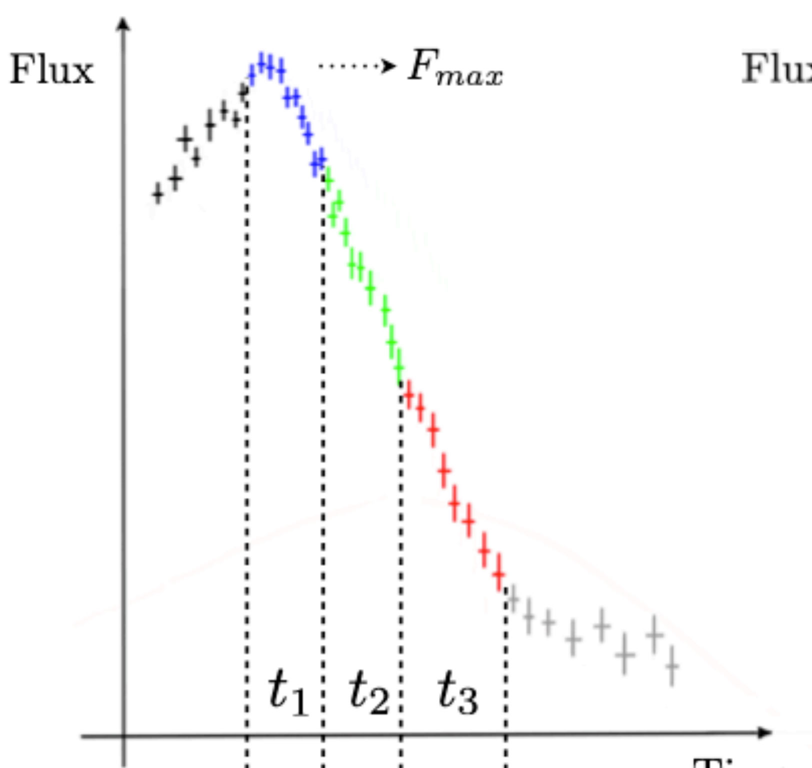


Ronchini, Oganesyan, Branchesi et al. Nature Comm.,2021

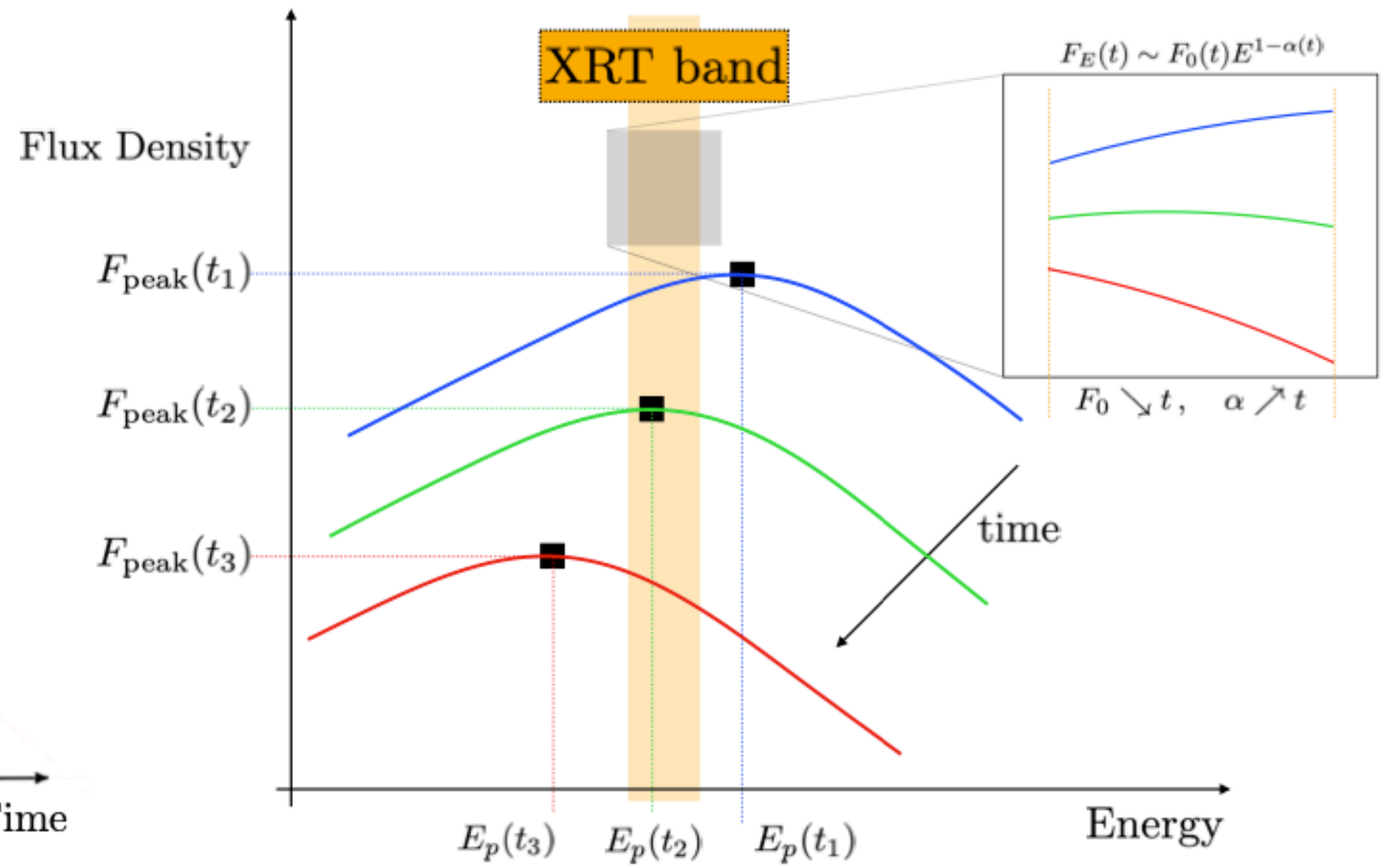
Prompt emission

Prompt tail

X-ray steep decay as diagnostics of the GRB emission side



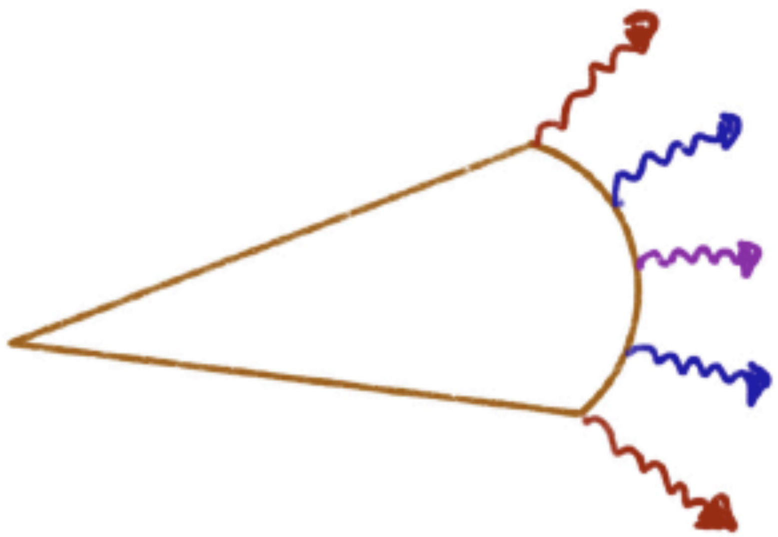
0.3 -10 keV

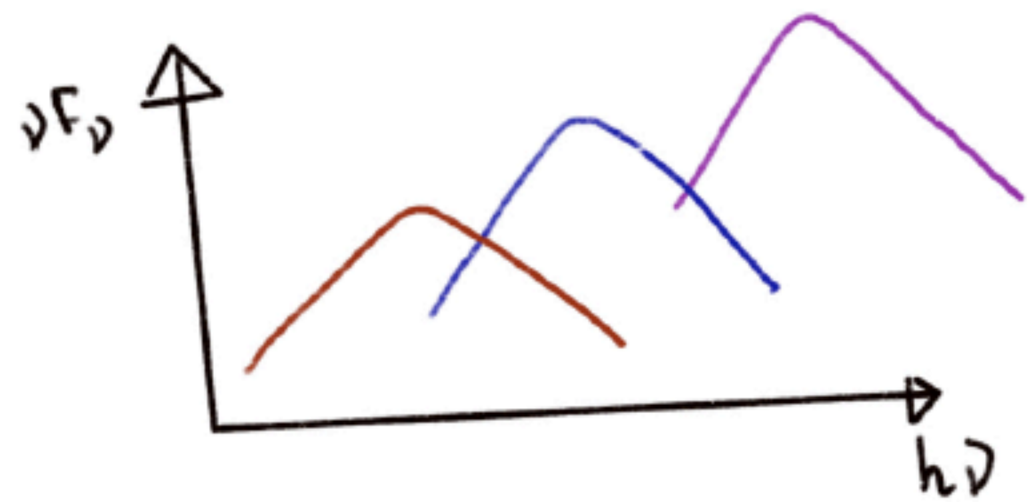


Ronchini, Oganesyan, Branchesi et al. Nature Comm.,2021

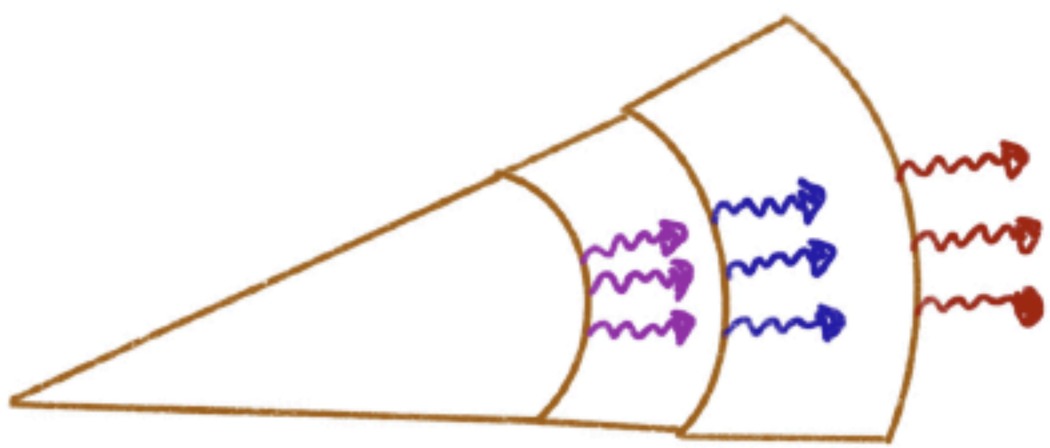
X-ray steep decay as diagnostics of the GRB emission side

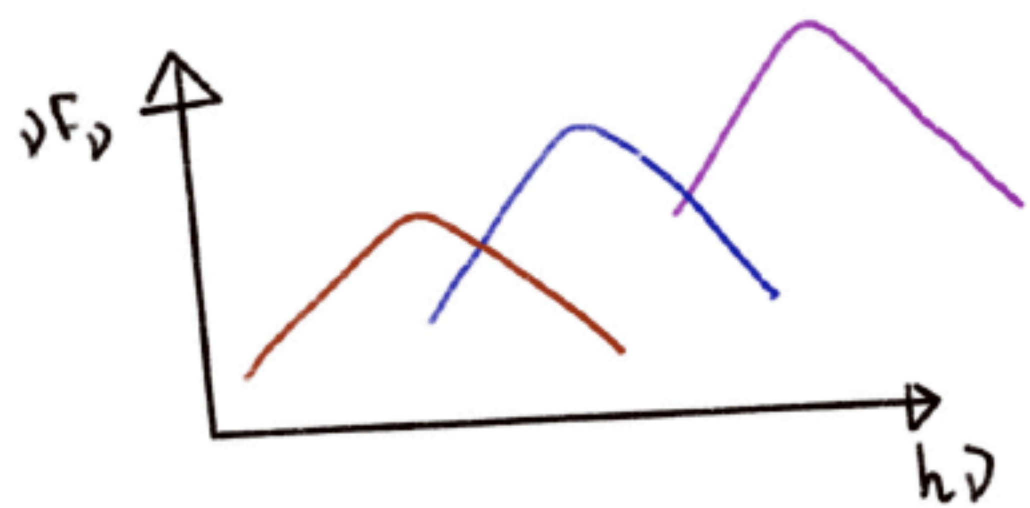
Efficient cooling —> we observe the high latitude emission





Inefficient cooling —> we observe the adiabatic cooling





Ronchini, Oganesyan, Branchesi et al. Nature Comm.,2021

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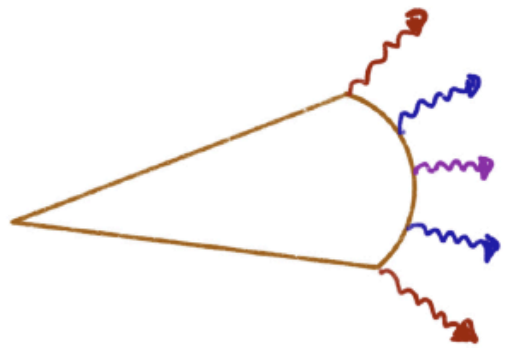

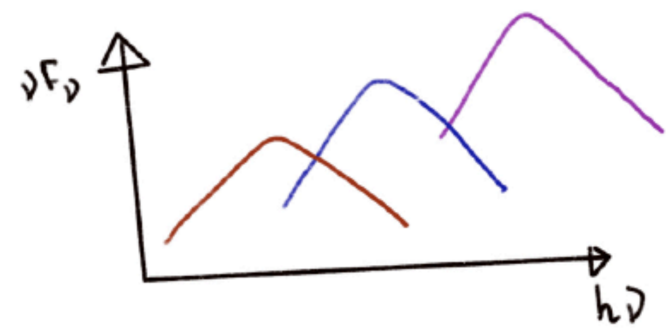

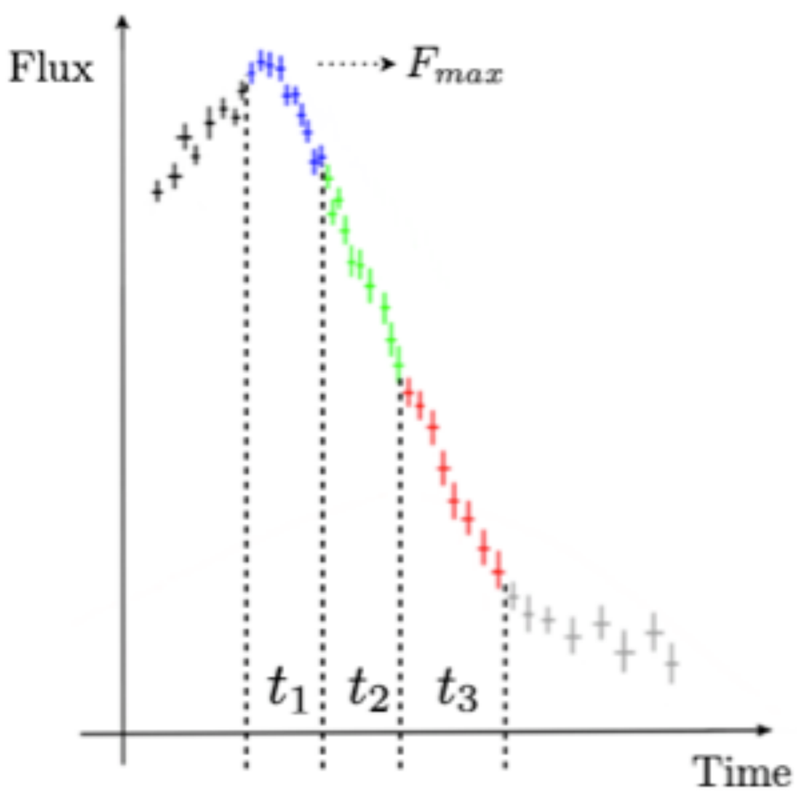

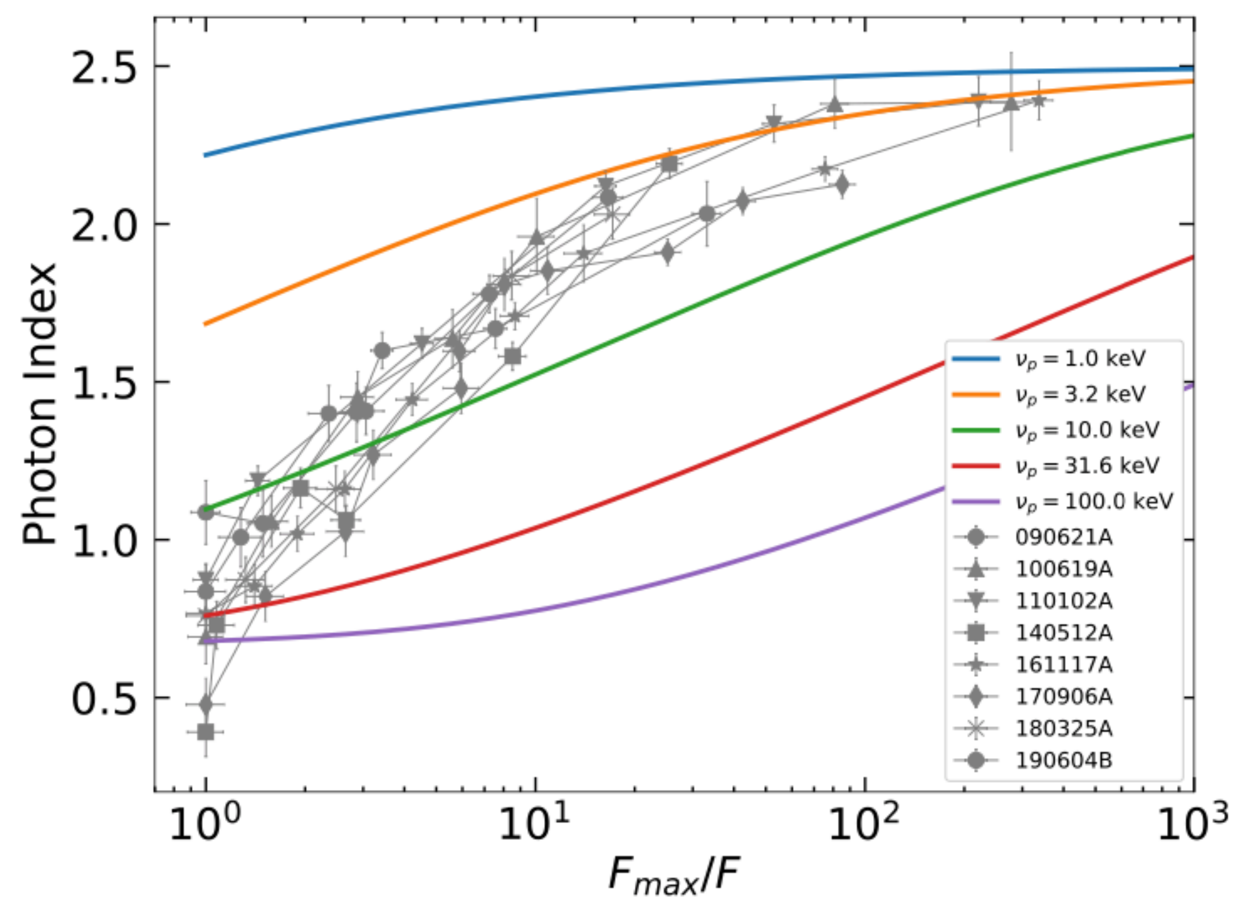

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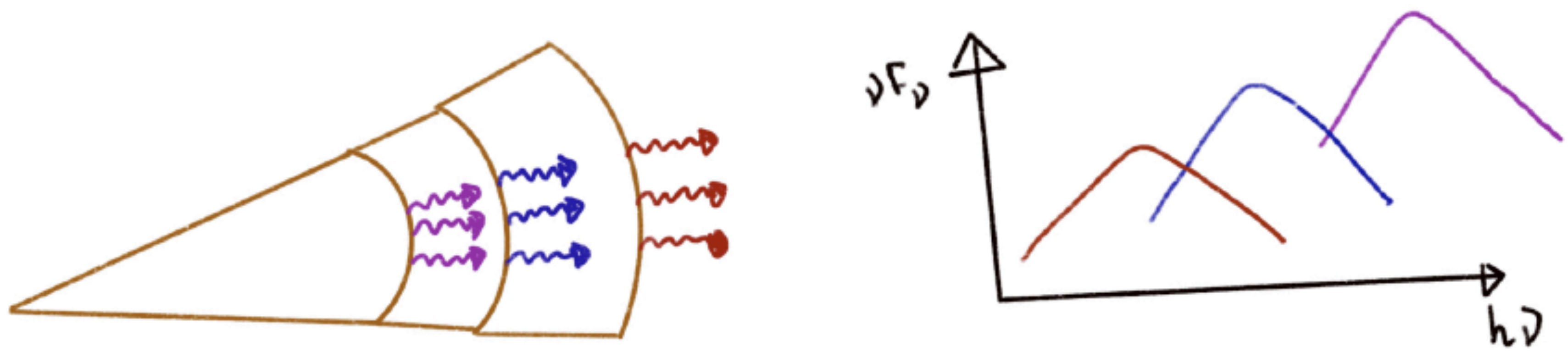


Conservation of

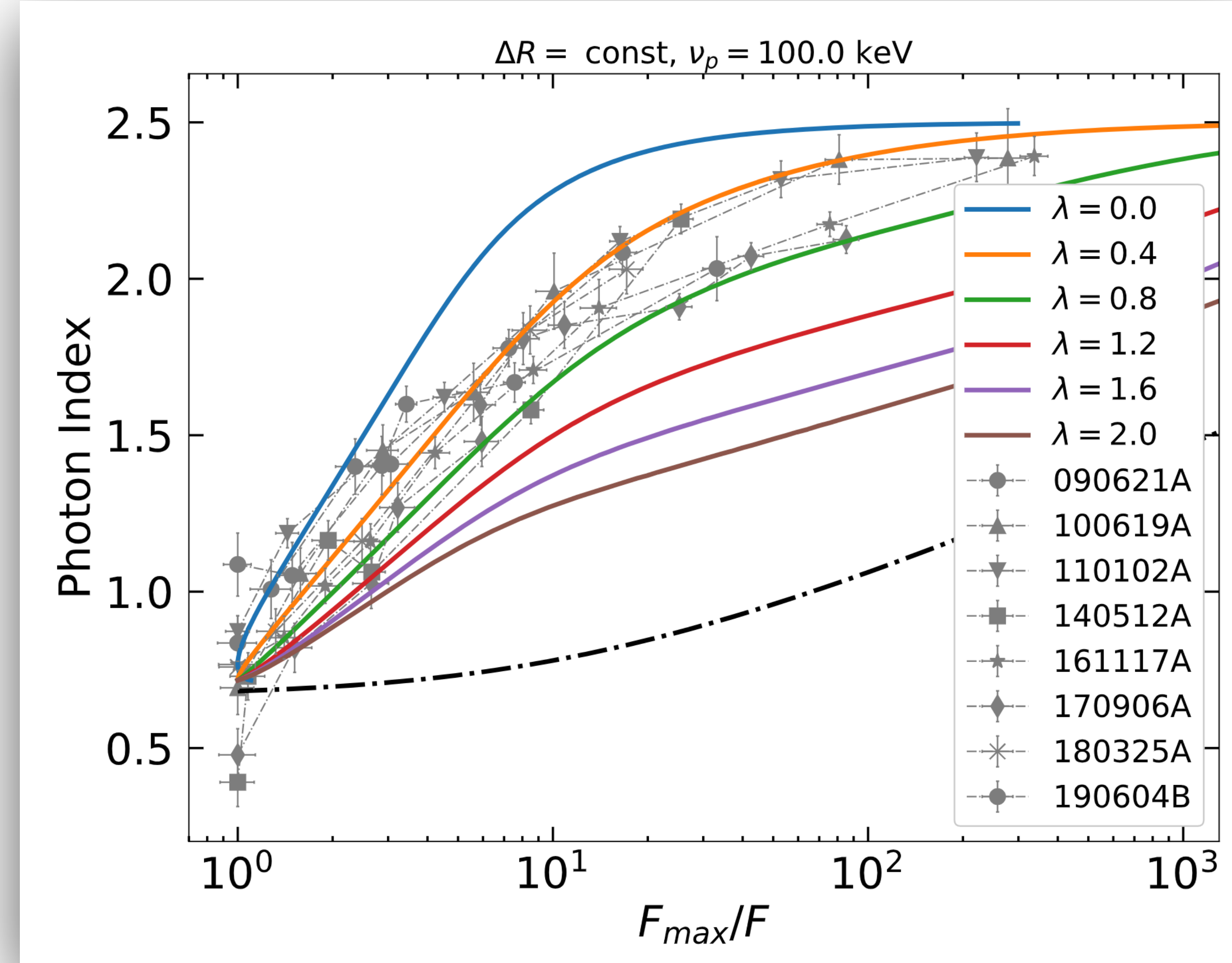
$$\langle\gamma\rangle^3 V' = \text{ const}$$

For a synchrotron

$$\nu_p \propto \langle\gamma\rangle^2 B \qquad F_\nu(\nu_p) \propto B$$

Prescription for B

$$B = B_0\left(\frac{R}{R_0}\right)^{-\lambda}$$



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- Synchrotron model fits the (considered) data
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+ **now**

Ronchini et al. 2021 —-> adiabatic cooling

Models that could work

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  Ghisellini et al. 2020
- re-acceleration/heating of electrons
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Thank you!