GRAN SASSO SCIENCE INSTITUTE
CENTER FOR ADVANCED STUDIES
INFN

INFN

GRB prompt emission

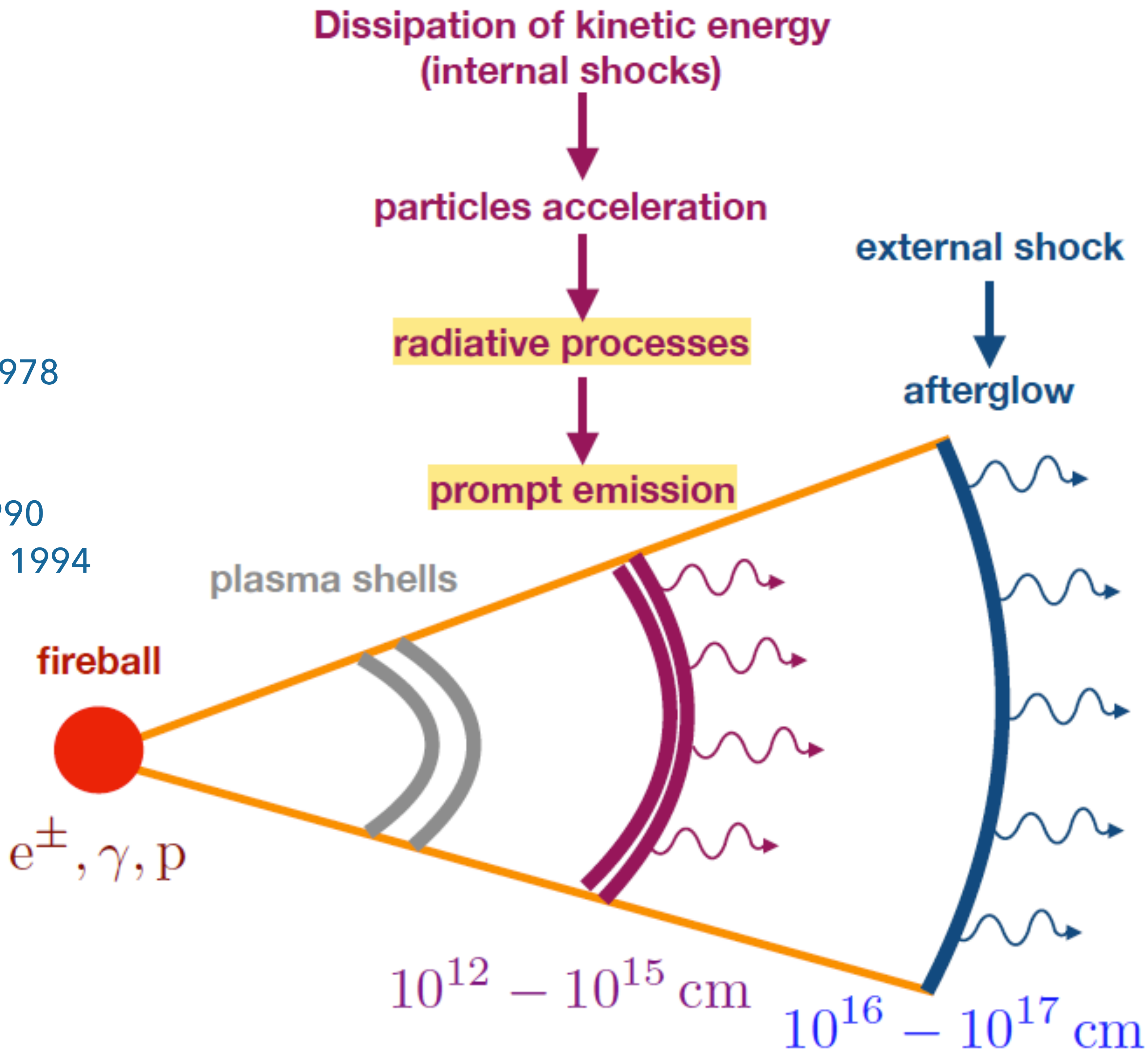
Gor Oganesyan

in collaboration with

Lara Nava, Giancarlo Ghirlanda, Annalisa Celotti,
Maria E. Ravasio, Andrea Melandri, Gabriele Ghisellini

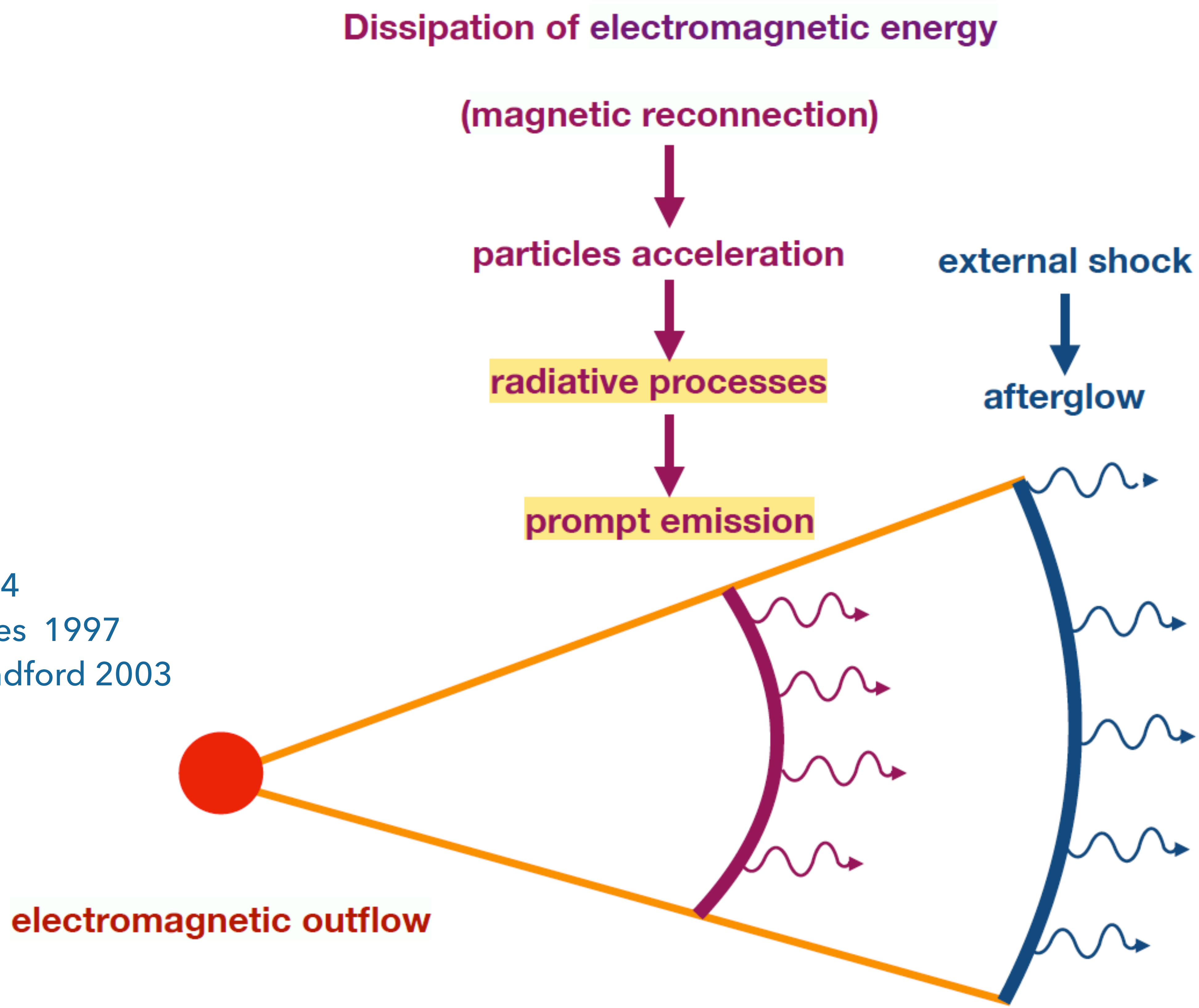
The model

Cavallo & Rees 1978
Paczýnski 1986
Goodman 1986
Shemi & Piran 1990
Rees & Meszaros 1994



The model

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



The unknowns

- radiative processes

unestablished

- location of the emitting region

somewhere between $10^{12}\mathrm{cm}$ and $10^{15}\mathrm{cm}$

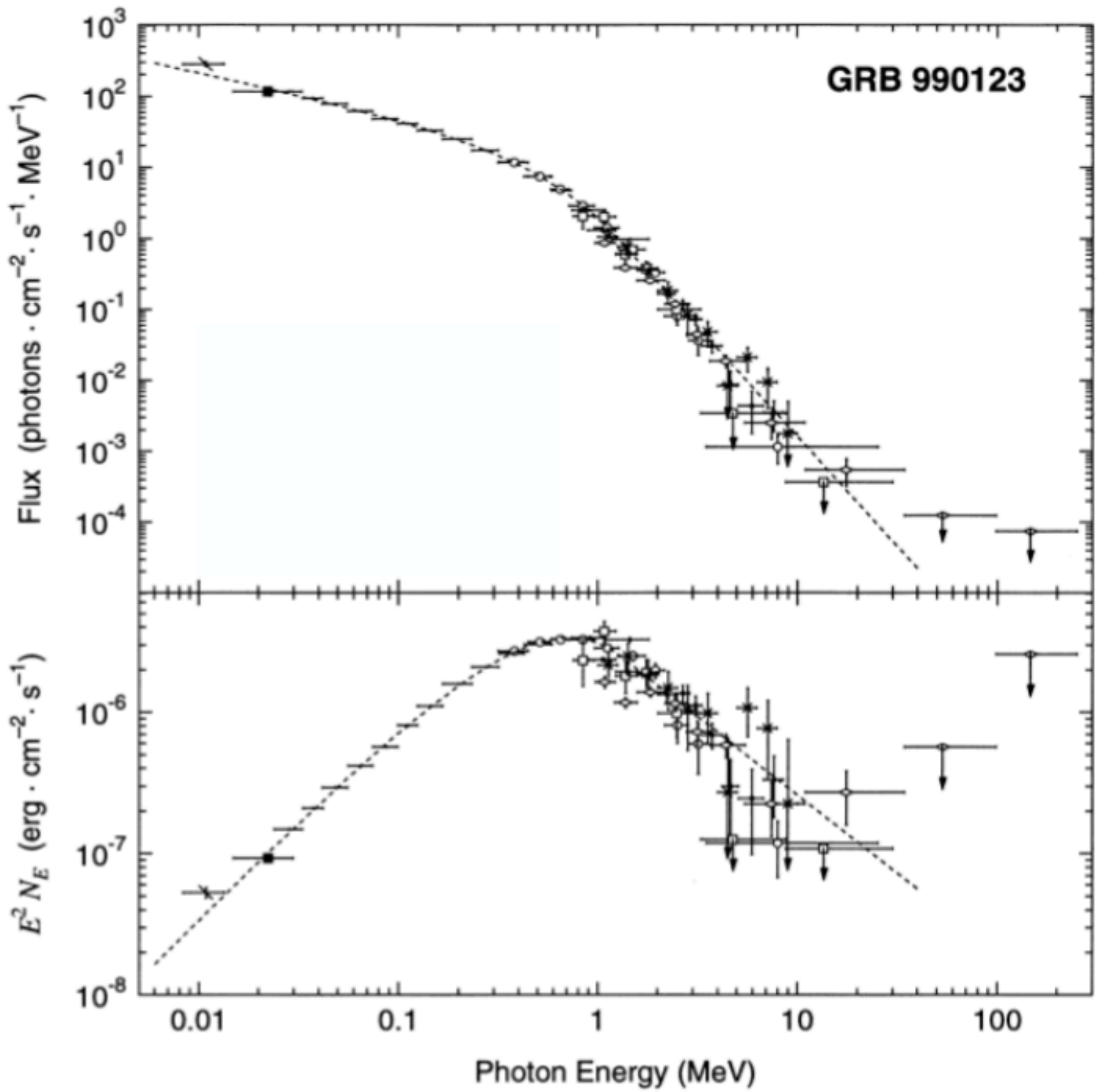
- acceleration mechanism

shocks vs magnetic reconnection

- jet composition

baryonic vs EM

The problem



Briggs et al. 1999

observed non-thermal spectra

what is it?

accelerated electrons
in
magnetic field

synchrotron?

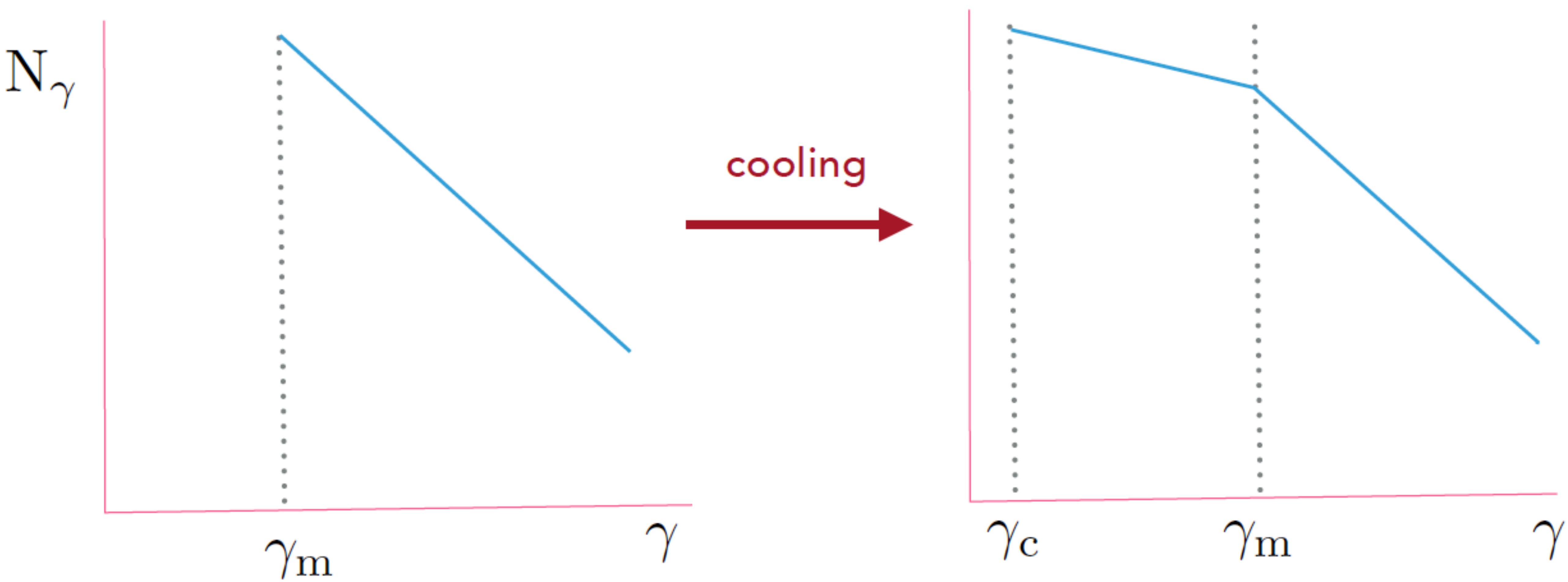
Katz 1994
Rees & Meszaros 1994
Sari et al. 1996, 1998

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?

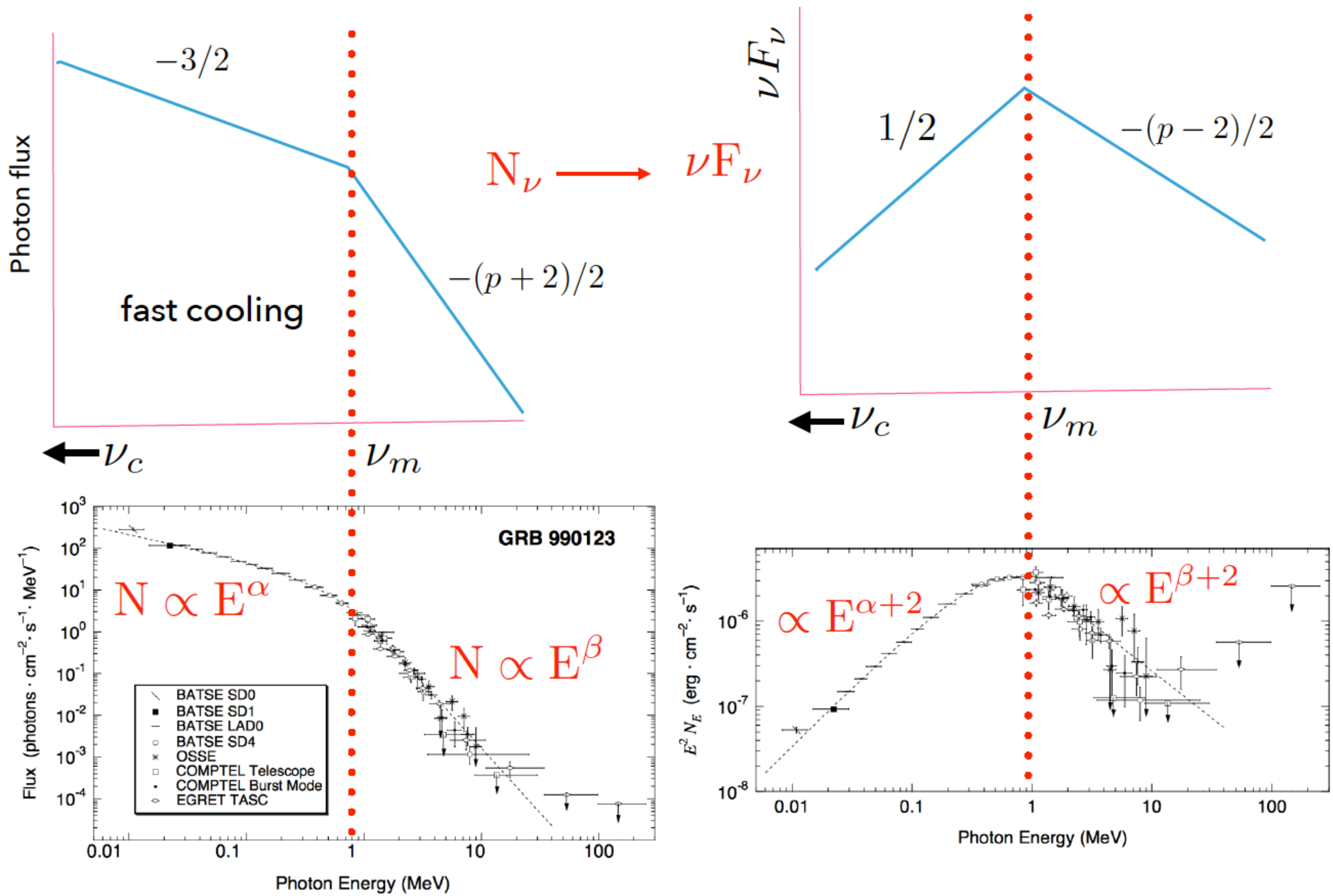
Internal shocks

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

Ghisellini, Celotti and Lazzati 2000

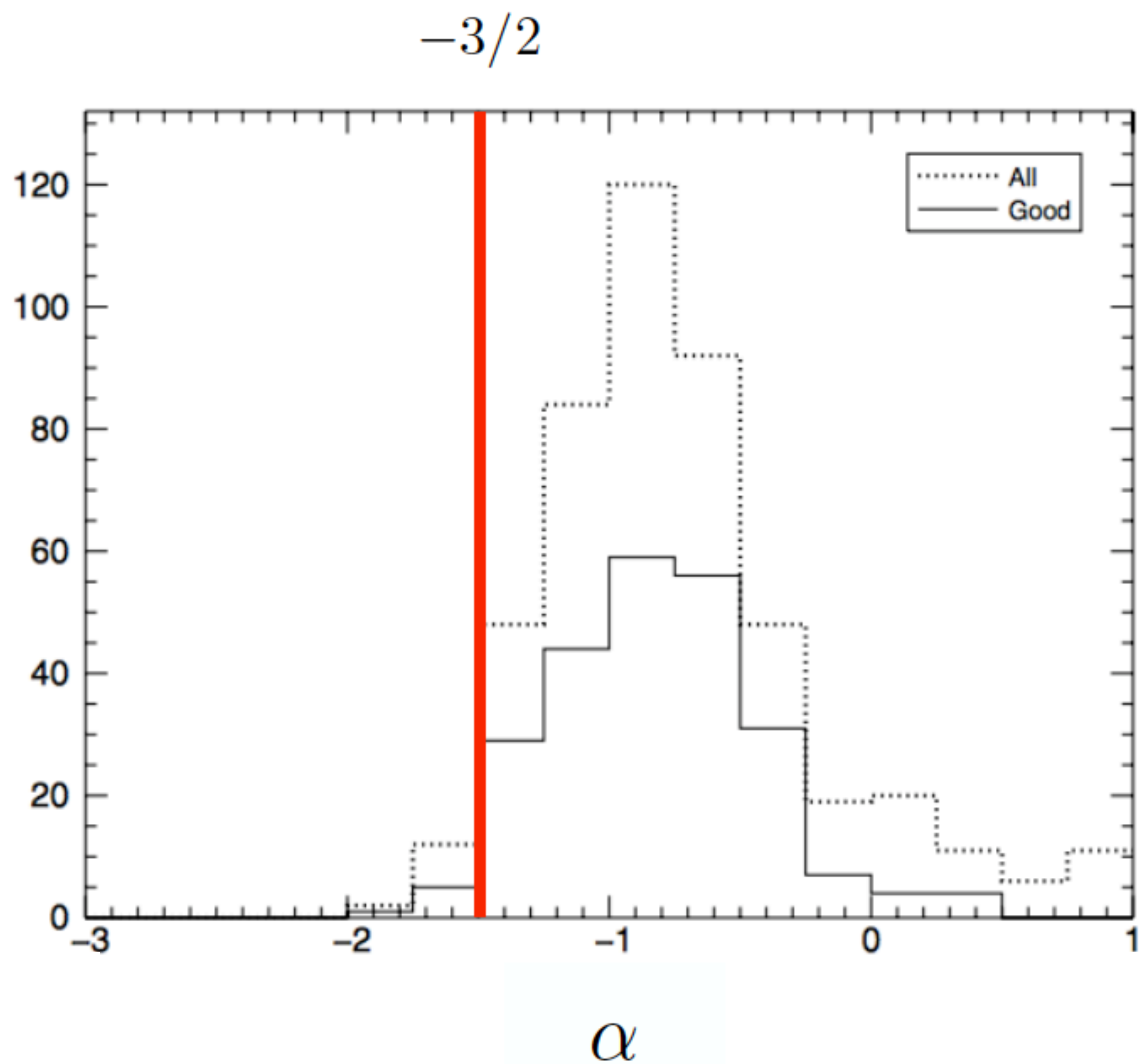
[fast cooling regime]

The expectations



The problem

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



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

Solutions [synchrotron based]

prevent electrons from fast cooling via synchrotron [marginally fast cooling]

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

how?

- decay of the magnetic field within the emitting region

  Pe'er & Zhang 2006, Derishev 2007, Zhao 2014 + more

- continuous acceleration/heating/re-acceleration

  Asano & Terasawa 2009, Xu et al. 2018, Beniamini et al. 2018

electrons cool via IC in KN regime

Derishev et al. 2001, Nakar et al. 2009, Daigne et al. 2011

self-absorption/anisotropy of electrons' pitch angles

Lloyd & Petrosian 2000, Medvedev 2000

synchrotron self-Compton model

Piran et al. 2009 for the criticism

Solutions [alternatives]

photospheric models
Thompson 1994, Liang et al. 1997, Ghisellini & Celotti 1999, Meszaros & Rees 2000, +

+

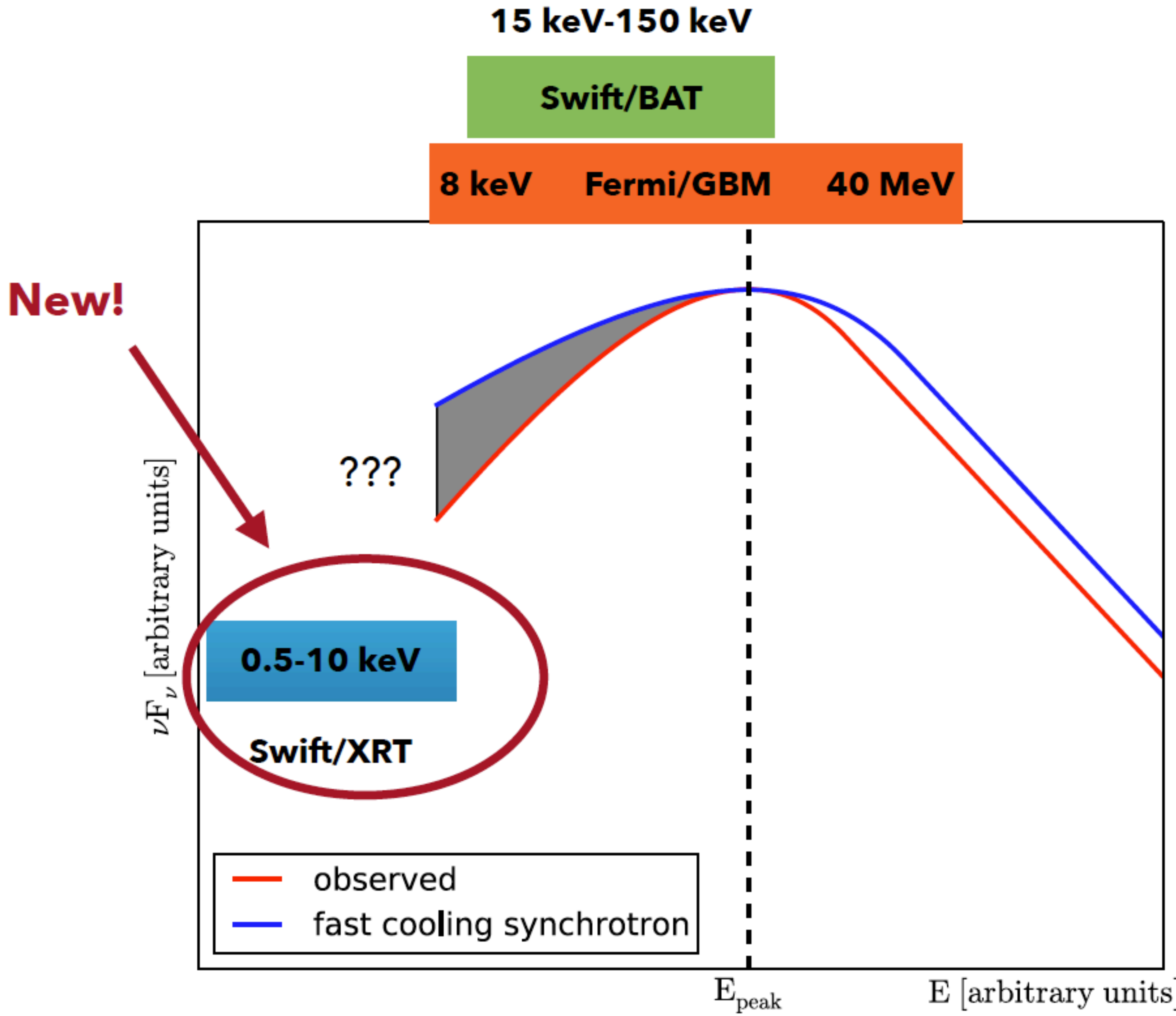
many claims of the BB components in the prompt emission spectra
Ryde & Pe’er 2009, Guiriec 2011, Ghirlanda et al. 2013 +

today in Prompt emission 3 session

The photospheric origin of the Yonetoku relation in gamma-ray bursts

by Hirotaka Ito

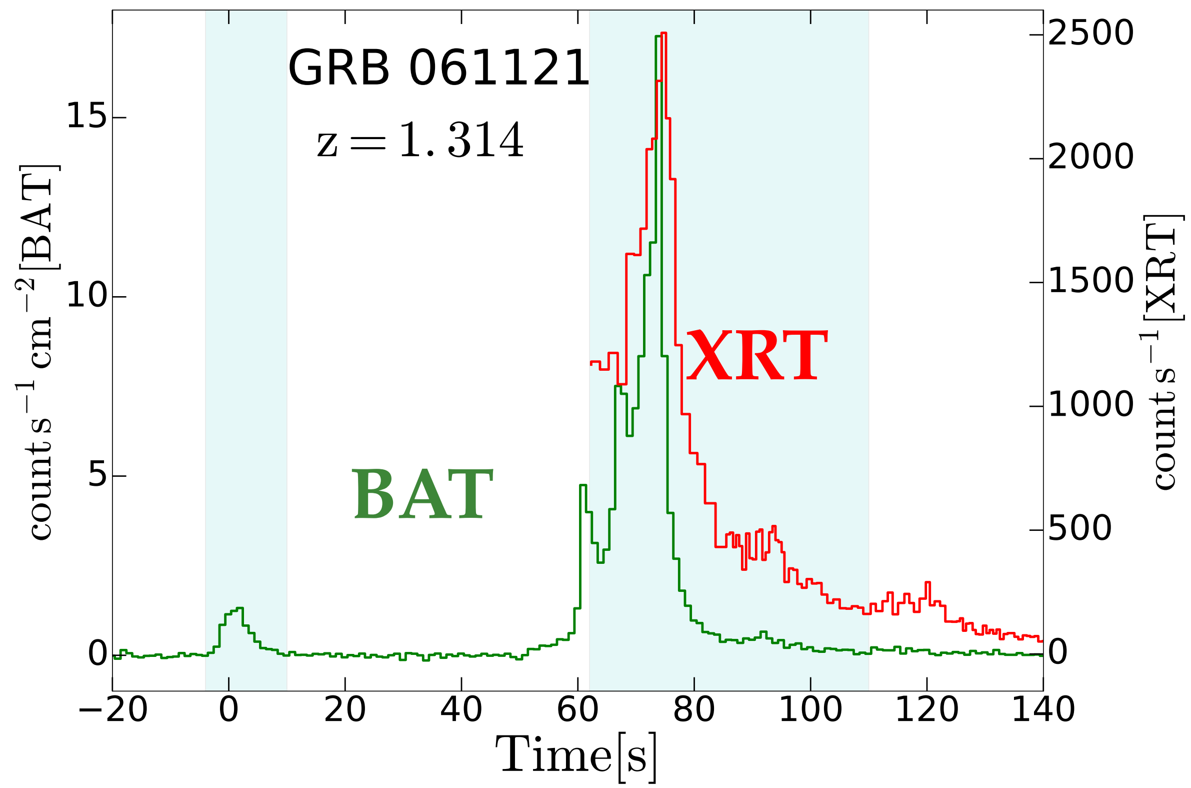
Recent progresses [X-ray view on the problem]



Oganesyan et al. 2017,2018

Recent progresses [X-ray view on the problem]

34 GRBs with prompt **BAT+XRT** observations & **large S/N** to allow spectral analysis

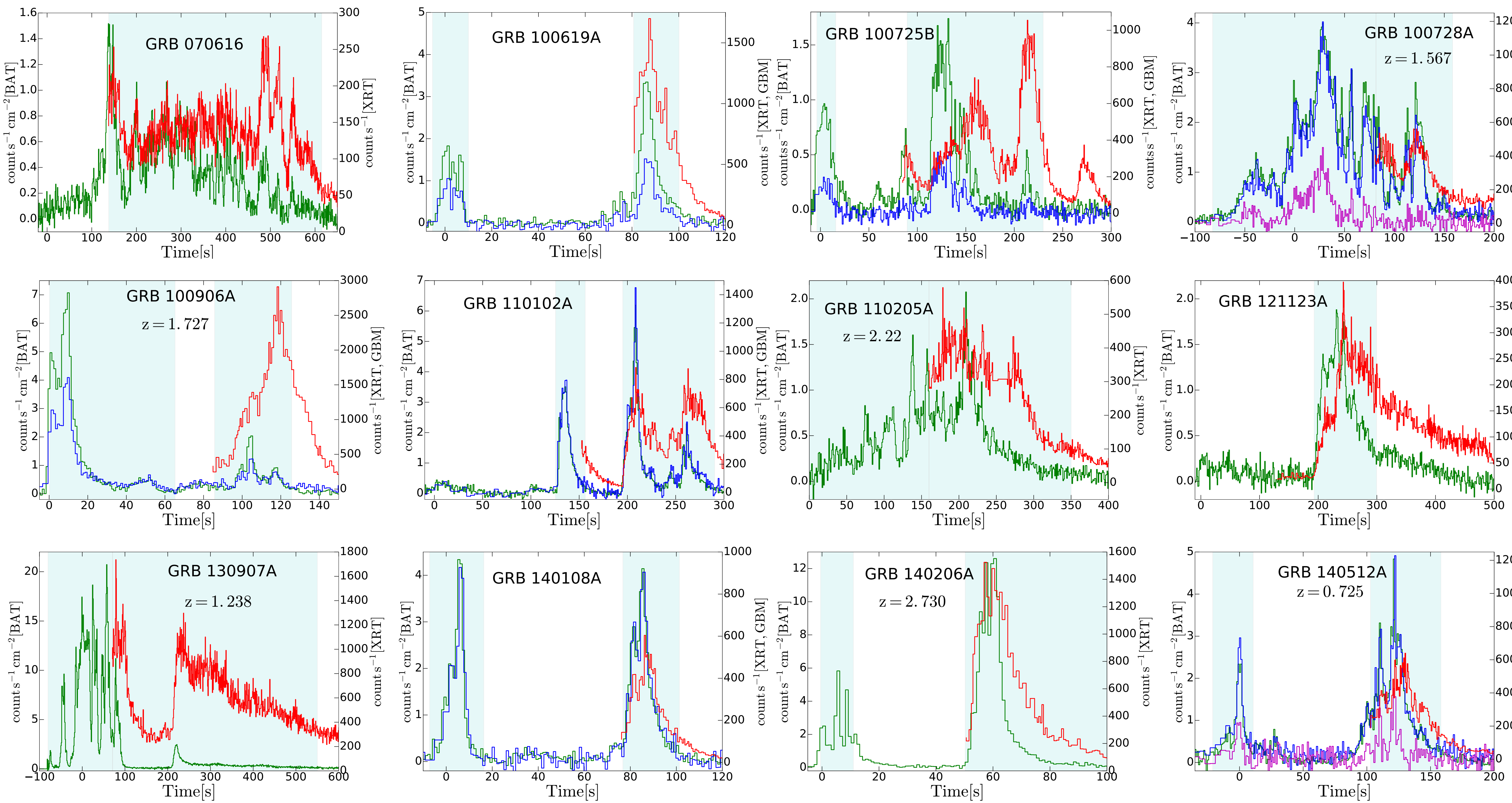


Results can be found in:

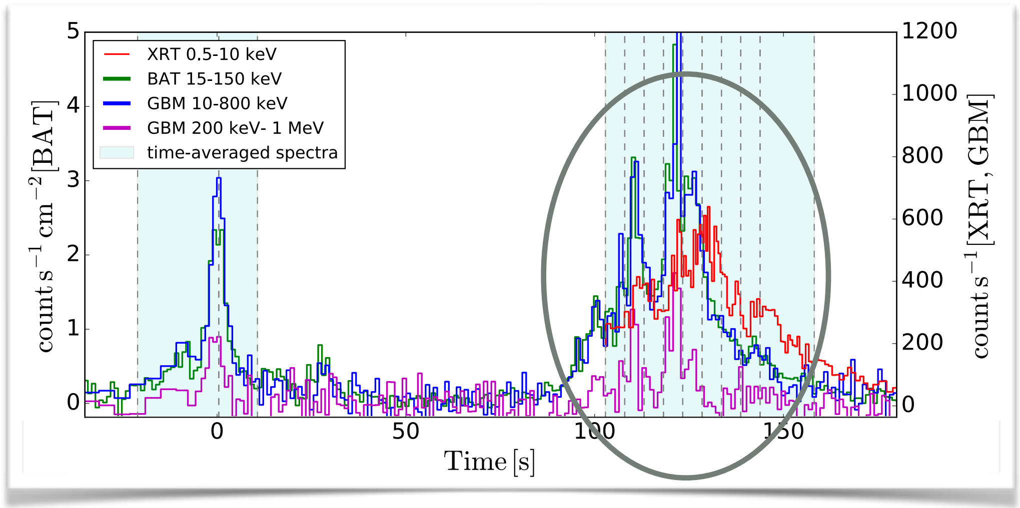
1. 14 are bright enough to allow time-resolved analysis
   Oganesyan, Nava, Ghirlanda, Celotti, 2017, ApJ
2. additional 20: only time-integrated analysis
   Oganesyan, Nava, Ghirlanda, Celotti, 2018, A&A

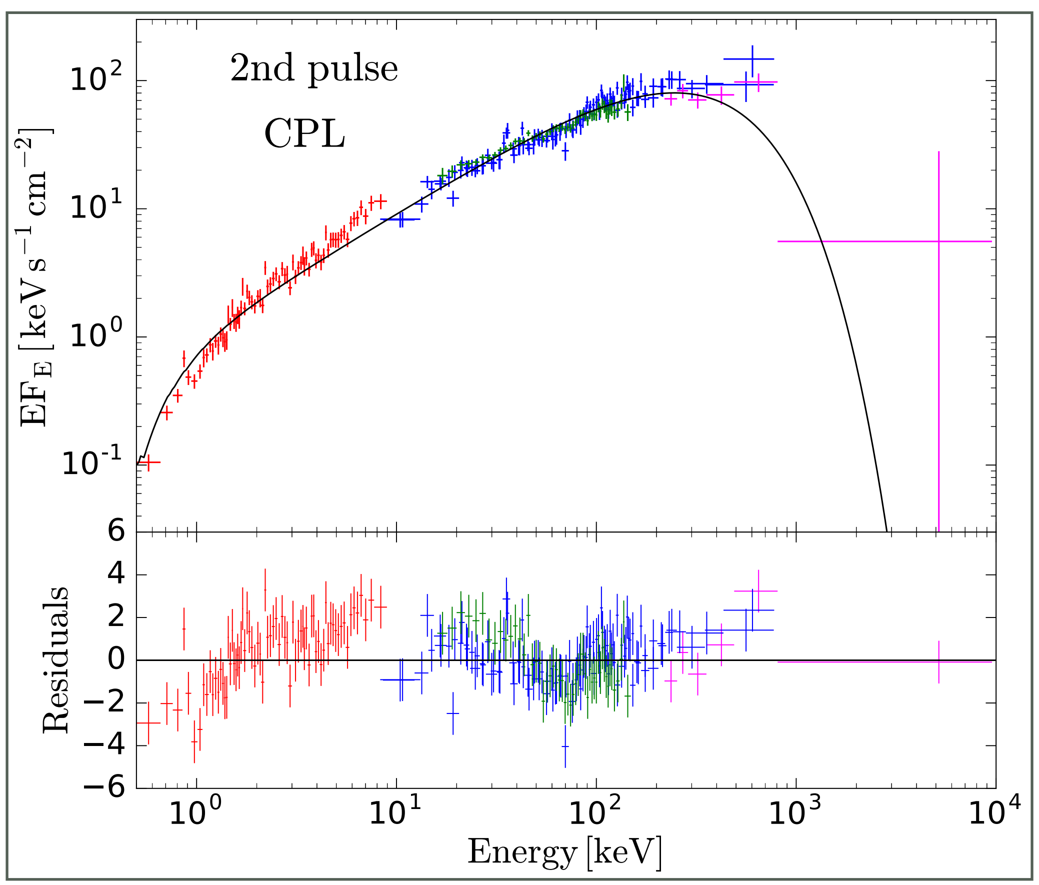
Recent progresses [X-ray view on the problem]

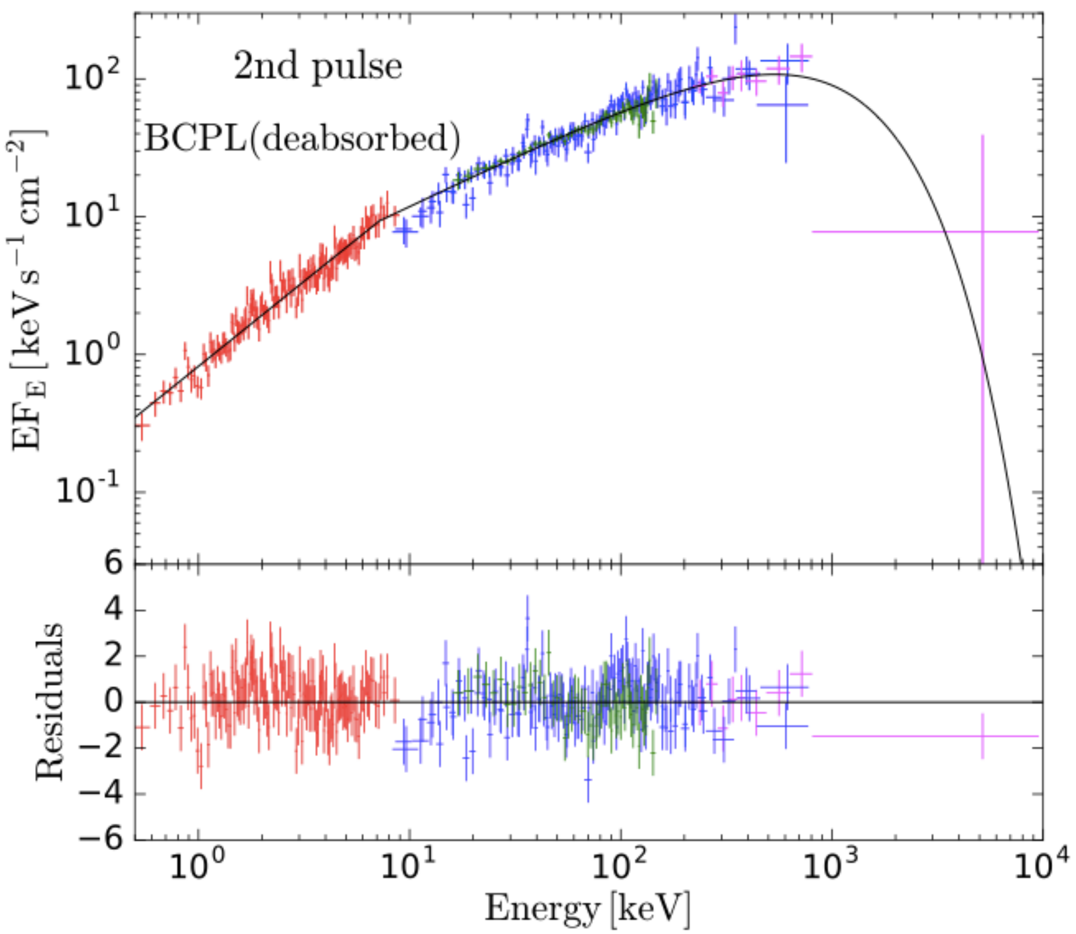
red = XRT (0.5-10 keV) blue = GBM/NaI (8 keV - 1 MeV)
green = BAT (15-150 keV) purple = GBM/BGO (200 keV - 40 MeV)



Recent progresses [X-ray view on the problem]

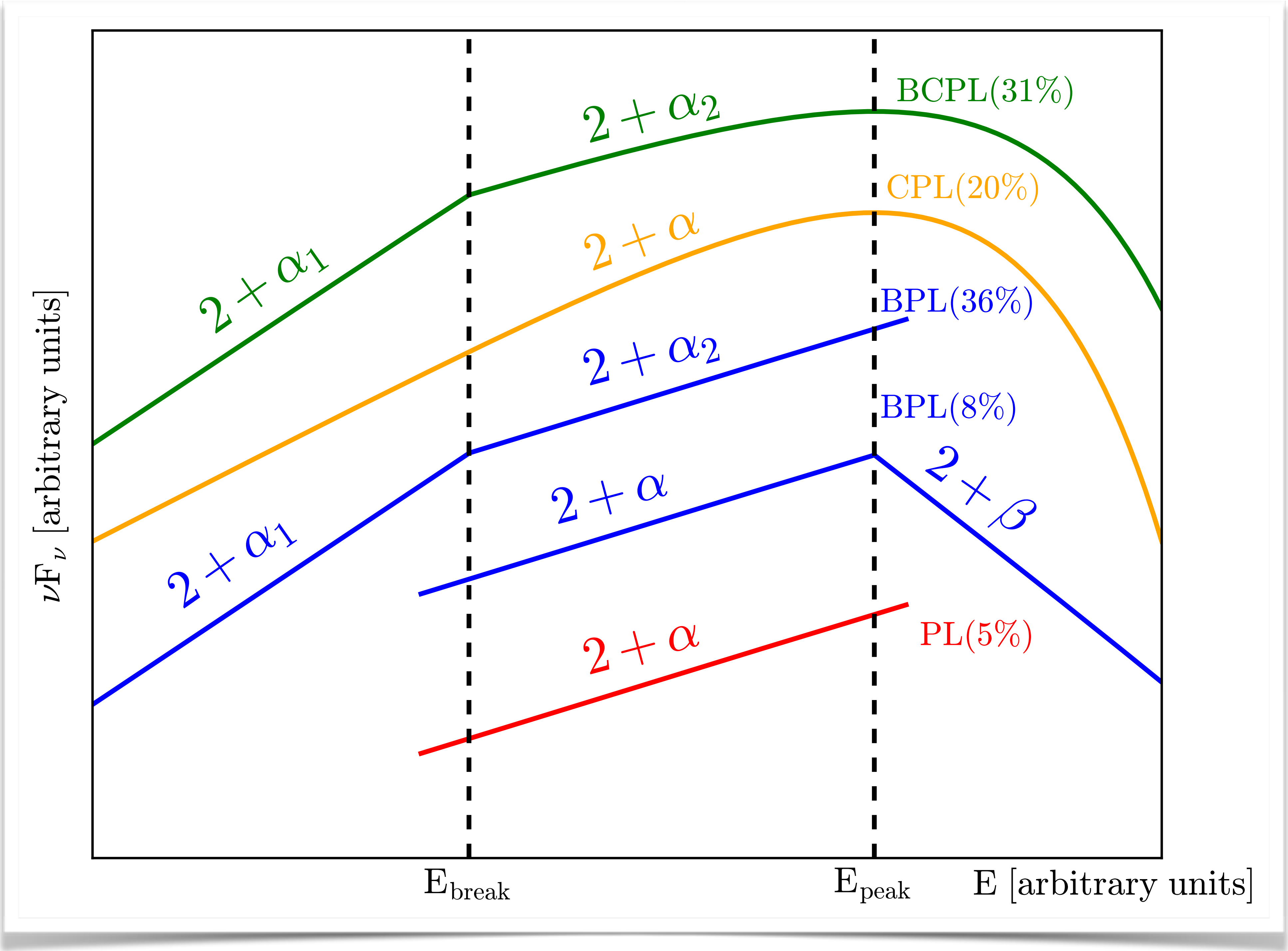






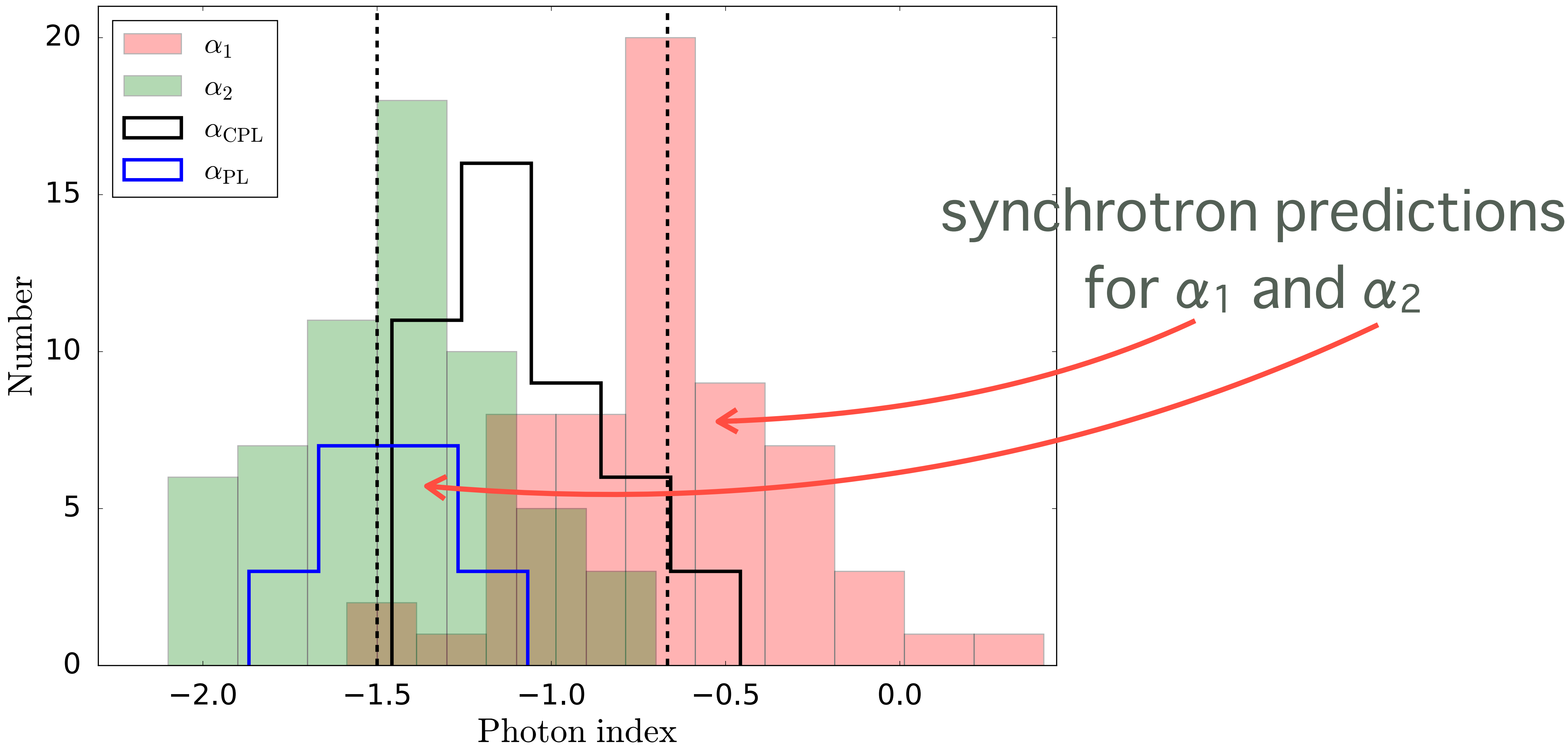
Recent progresses [X-ray view on the problem]

most of the spectra require a break



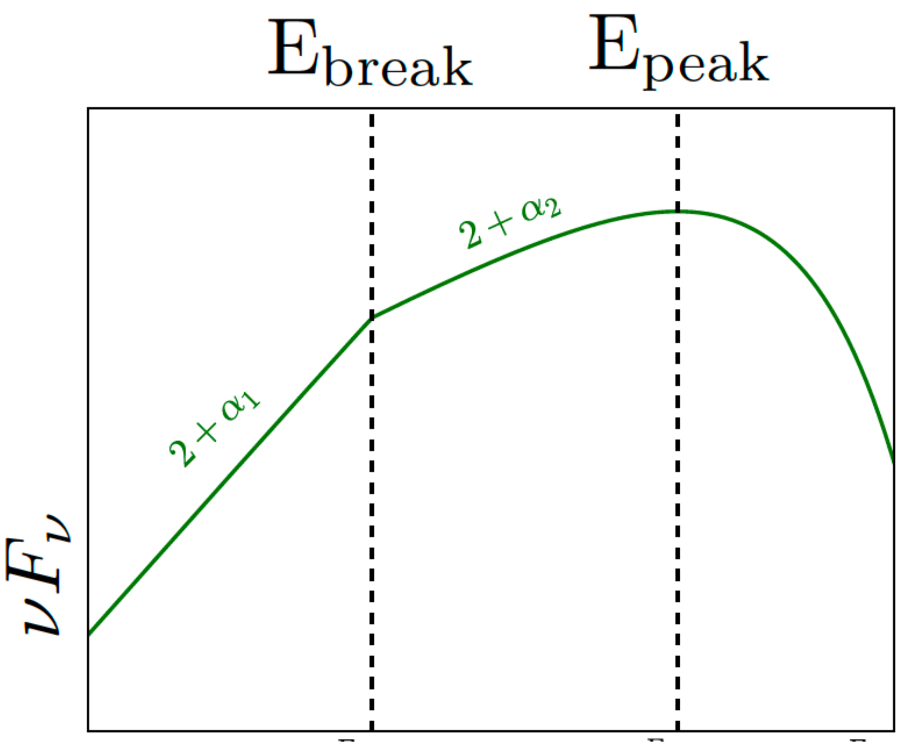
Recent progresses [X-ray view on the problem]

synchrotron origin is suggested from the empirical fits



Oganesyan et al. 2017,2018

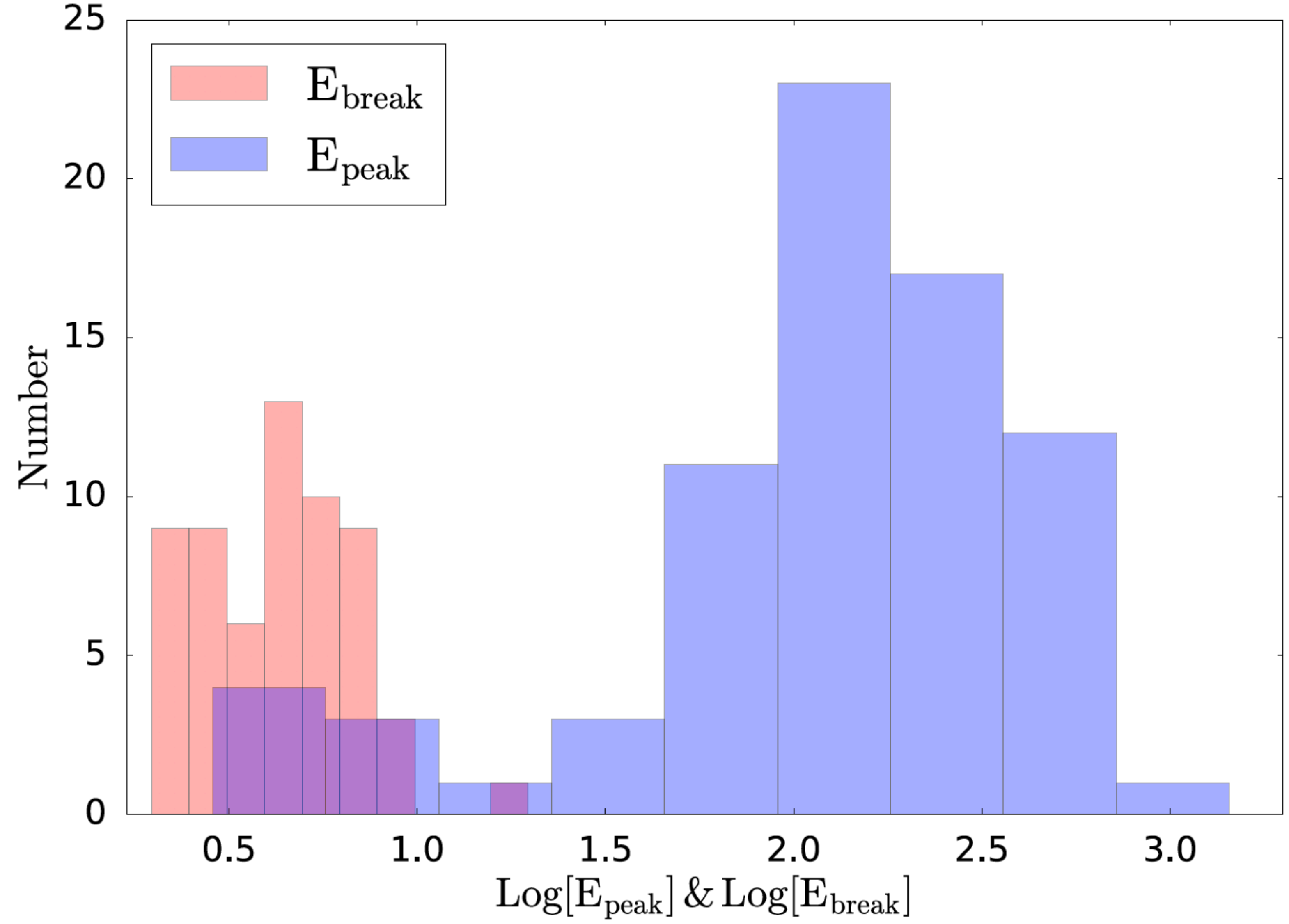
Recent progresses [X-ray view on the problem]



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

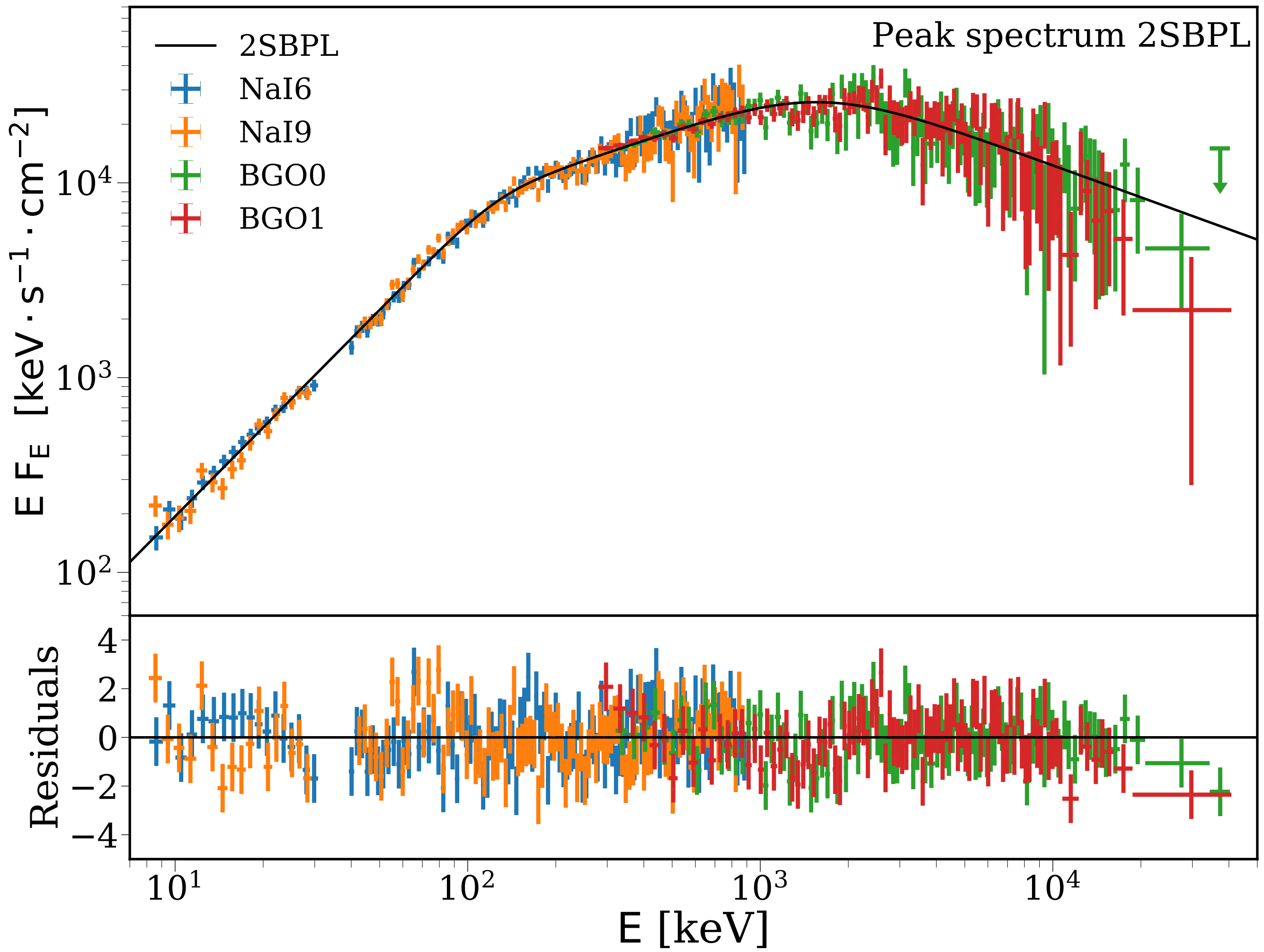
$$\langle E_{peak} \rangle = 126 \text{ keV}$$

$$E_{peak}/E_{break} \sim 7 - 175$$



Oganesyan et al. 2017,2018

Recent progresses [bright Fermi GRBs]



today in Prompt emission 2 session

GRB prompt emission spectra: the synchrotron revenge

by Maria E. Ravasio

Recent progresses [direct test of the synchrotron model]

!!!Strong motivation to test the synchrotron data vs keV-MeV data!!!

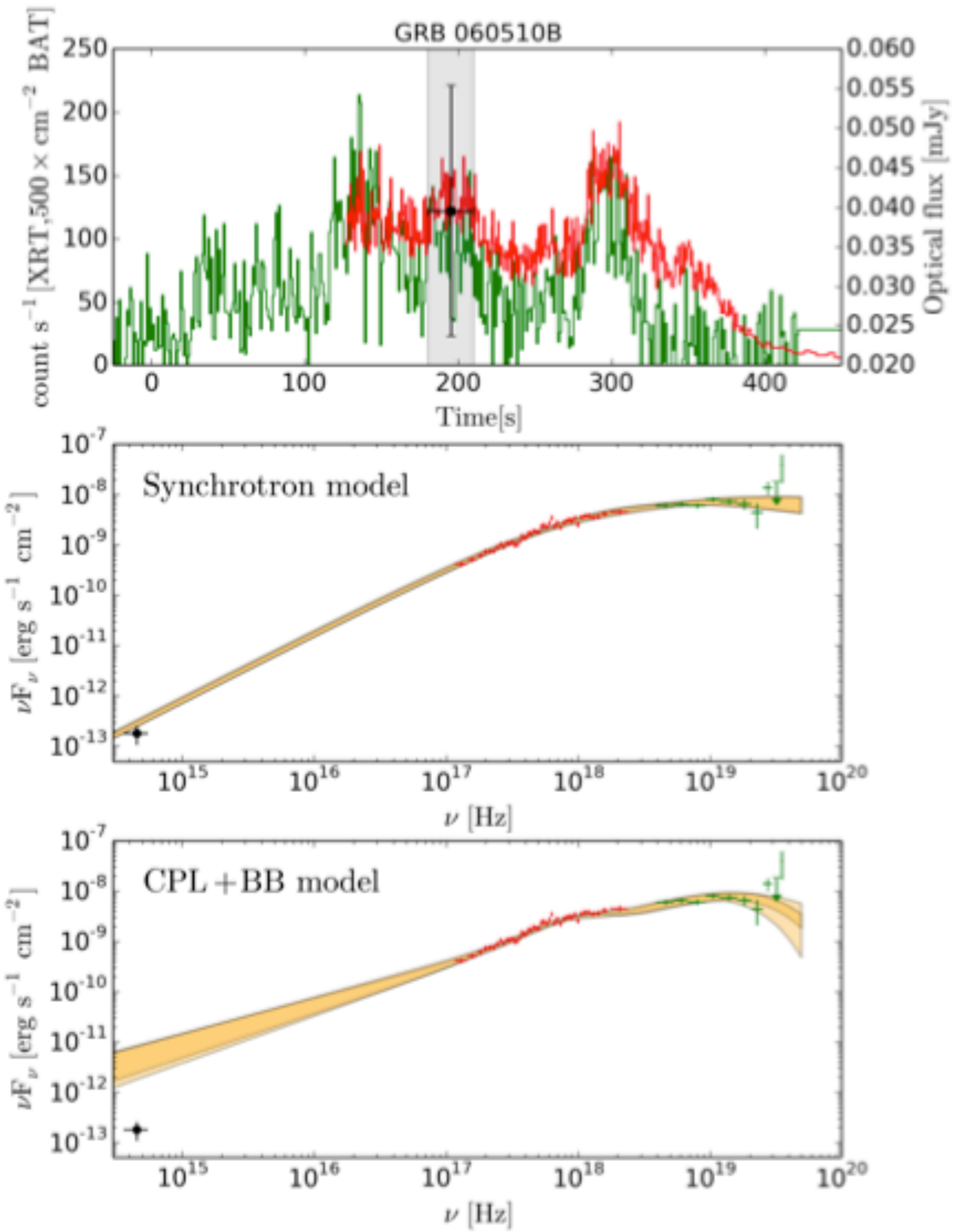
+

early optical data as a critical test for the 1/3 tail of the synchrotron model

rarely applied to the data
Tavani 1996, Lloyd & Petrosian 2000, Burgess et al. 2011,2013; Zhang et al. 2016, 2018

more recently for single-pulsed Fermi GRBs (today in prompt emission 2 session)
Burgess et al. 2018

Recent progresses [early optical emission]



21 GRBs, 56 time-resolved spectra

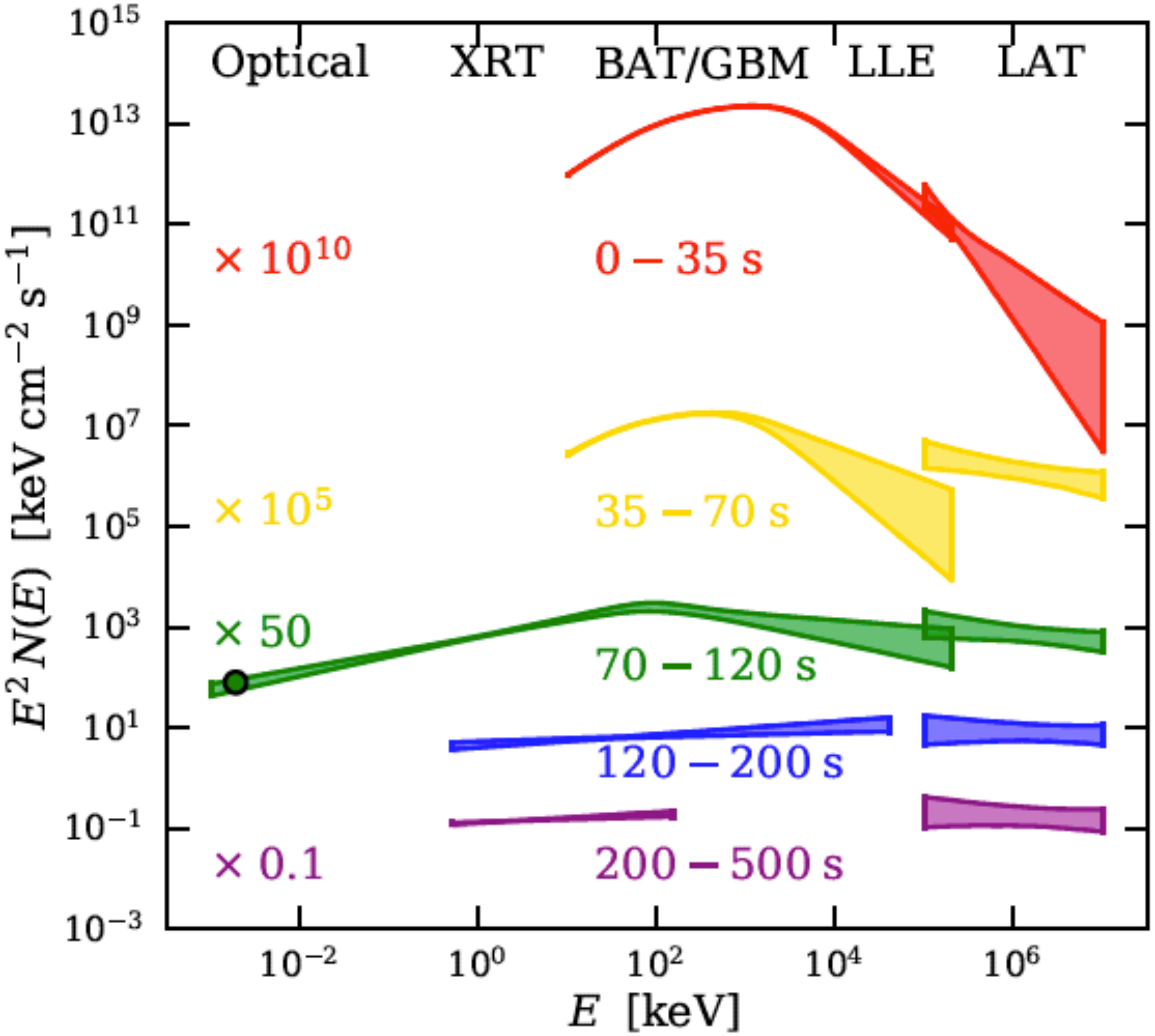
synchrotron fits the data 0.5-150 keV (1 MeV)
marginally fast cooling regime is confirmed

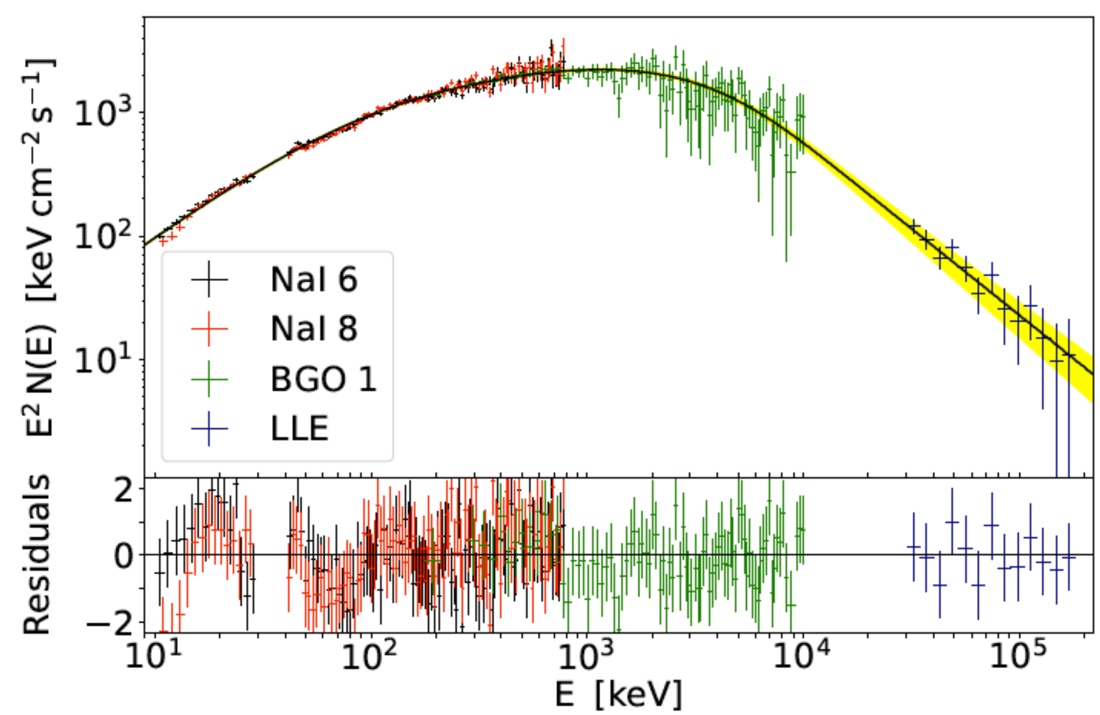
optical data is consistent with synchrotron
and inconsistent with non-thermal+BB
in absence/presence of early afterglow

today in prompt emission 2 session

Oganesyan et al. 2019

Recent progresses [from optical to LAT and beyond]





$$N(\gamma) \propto \gamma^{-5} \quad \gamma_e \sim 10^6$$

challenge for the acceleration mechanism!

Ronchi, Fumagalli, Ravasio, Oganesyan et al. , in preparation

Recent progresses [summary]

presence of spectral breaks at 4-100 keV
associated with the synchrotron
spectral shapes suggest synchrotron origin

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

synchrotron model CAN fit the prompt emission spectra
in the marginally fast cooling regime
from optical to ~sub-MeV range

Oganesyan et al. 2019

2 component thermal + non-thermal empirical model
is excluded from the optical data

very soft spectra of accelerated electrons are required

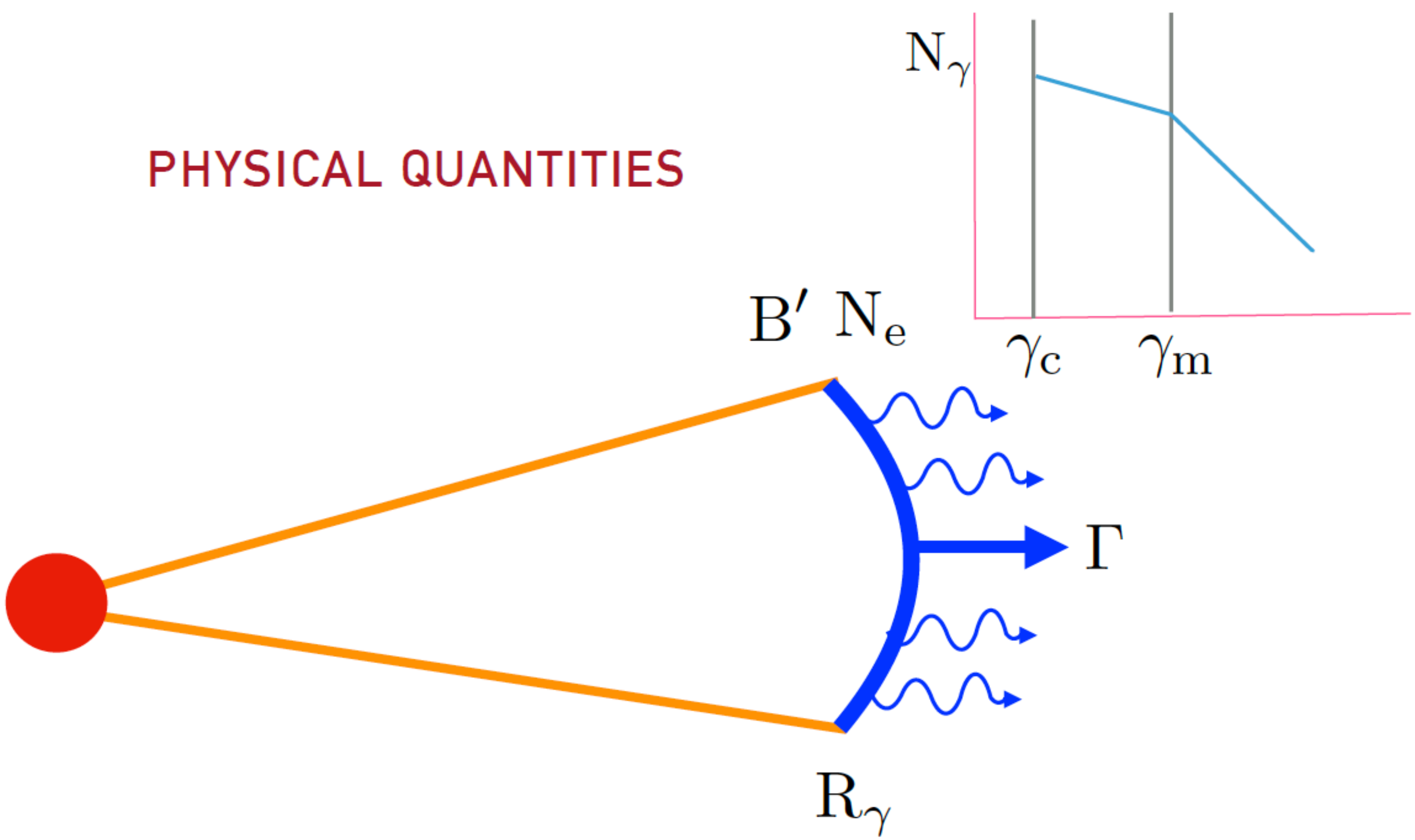
$$N(\gamma) \propto \gamma^{-5}$$

Physical parameters for the synchrotron model

MEASURED PARAMETERS

ν_c	$F_\nu(\nu_c) = F_c$	γ_m/γ_c

PHYSICAL QUANTITIES



Physical parameters for the synchrotron model

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

$\Gamma \geq 300$ large bulk Lorentz factors

$\mathrm{B}' \sim 10\,\mathrm{G}$ weak magnetic fields

$\nu_c \sim \nu_m$

$R \geq 3 \times 10^{16}\ cm$ large radii

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

what can naturally produce it?

re-acceleration?

in-homogenous magnetic field?

More…

- polarisation measurements

- temporal resolution

HERMES

- low-energy spectral information

THESEUS, SVOM

- VHE detections

H.E.S.S, MAGIC, CTA

Thank you!