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ISTITUTO NAZIONALE DI ASTROFISICA
ISTITUTO DI ASTROFISICA E PLANETOLOGIA SPAZIALI DI ROMA

Gamma Ray Bursts

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1. MeV emission - prompt emission mechanism
2. GeV emission - (mainly) afterglow component
3. GRBs at VHE

Poster highlights

Will CTA detect Gamma Ray Bursts?

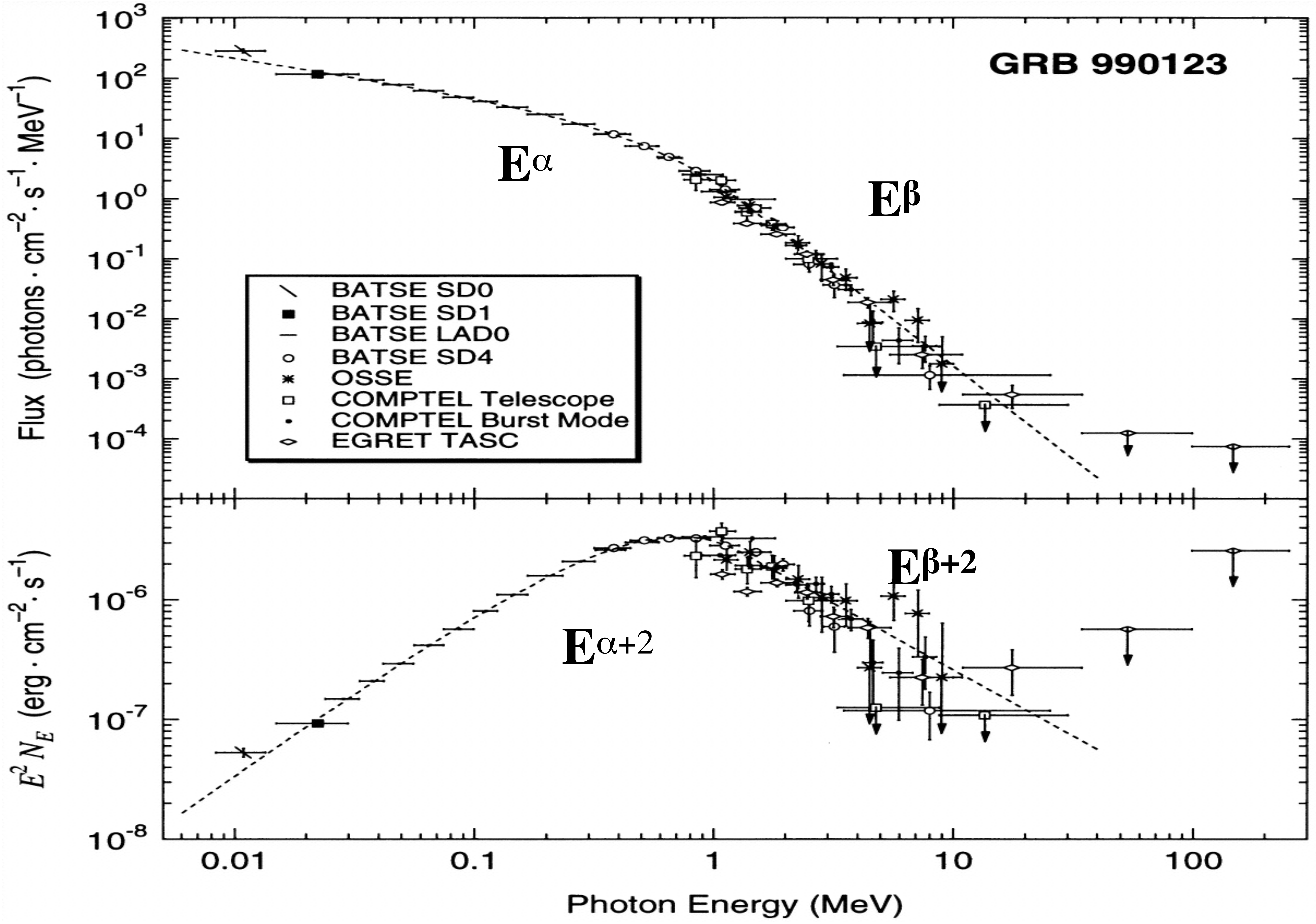
- 190114C!
- E. L. Riuz Valasco talk!

Gamma Ray Bursts

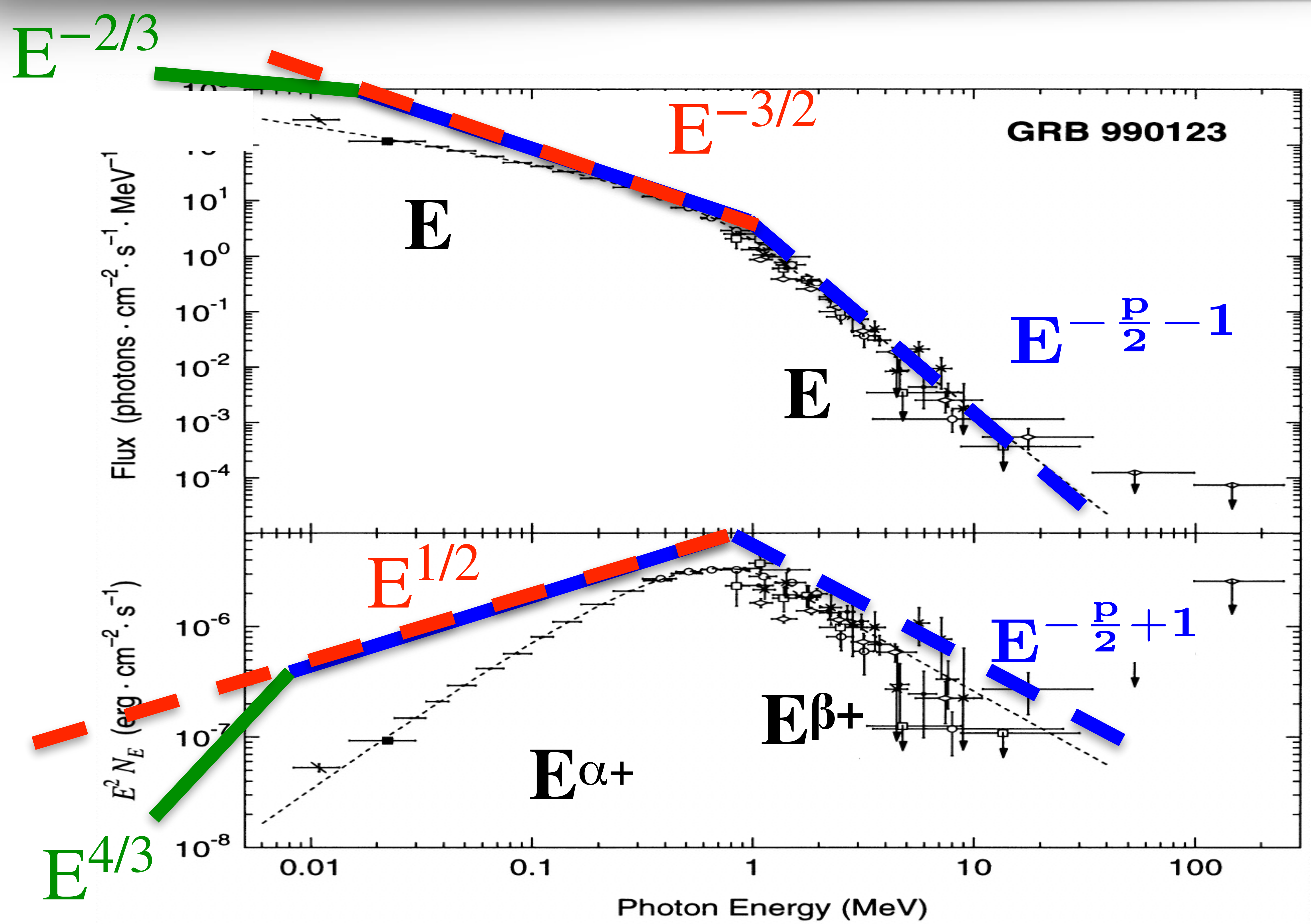
Isotropic equivalent energy 10^{52} erg/s ; z=0.01-9.3; single or double stellar origin

Poster: C. D. Y. Moore et al.
"Magnetar powered GRBs"

Prompt γ-ray emission: how it appears



Prompt γ-ray emission: should be synchrotron



Prompt should be synchrotron [Rees & Meszaros 1994; Katz 1994; Tavani 1996; Sari et al. 1996, 1998]

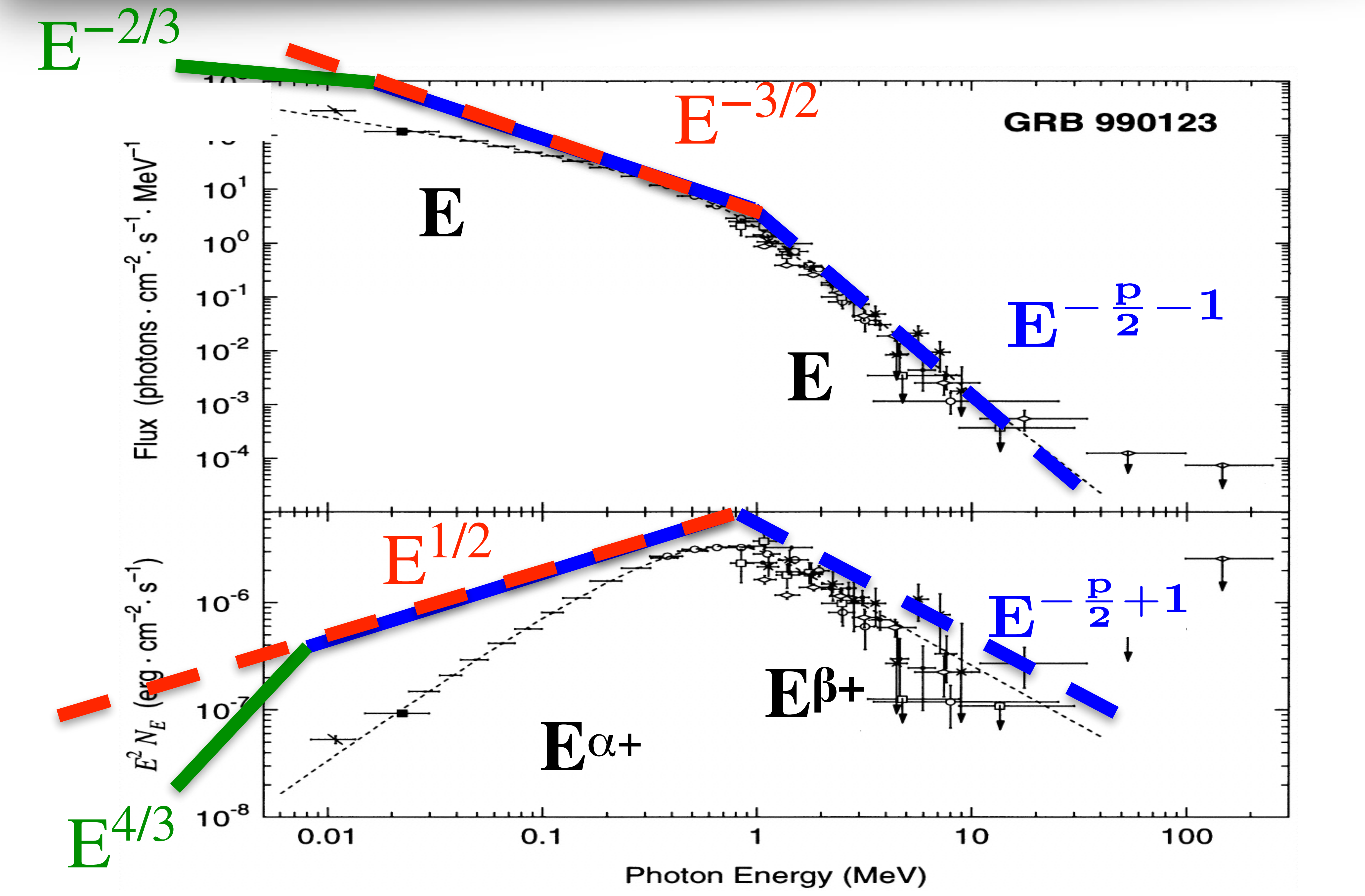
$T_{cool} \sim 10^{-7}$ sec << $T_{dyn} \sim R/2c\Gamma^2$
[e.g. Ghisellini et al. 2000]

→ $E^{-3/2}$ ($E<E_{peak}$)

Below the cooling frequency

→ $E^{-2/3}$

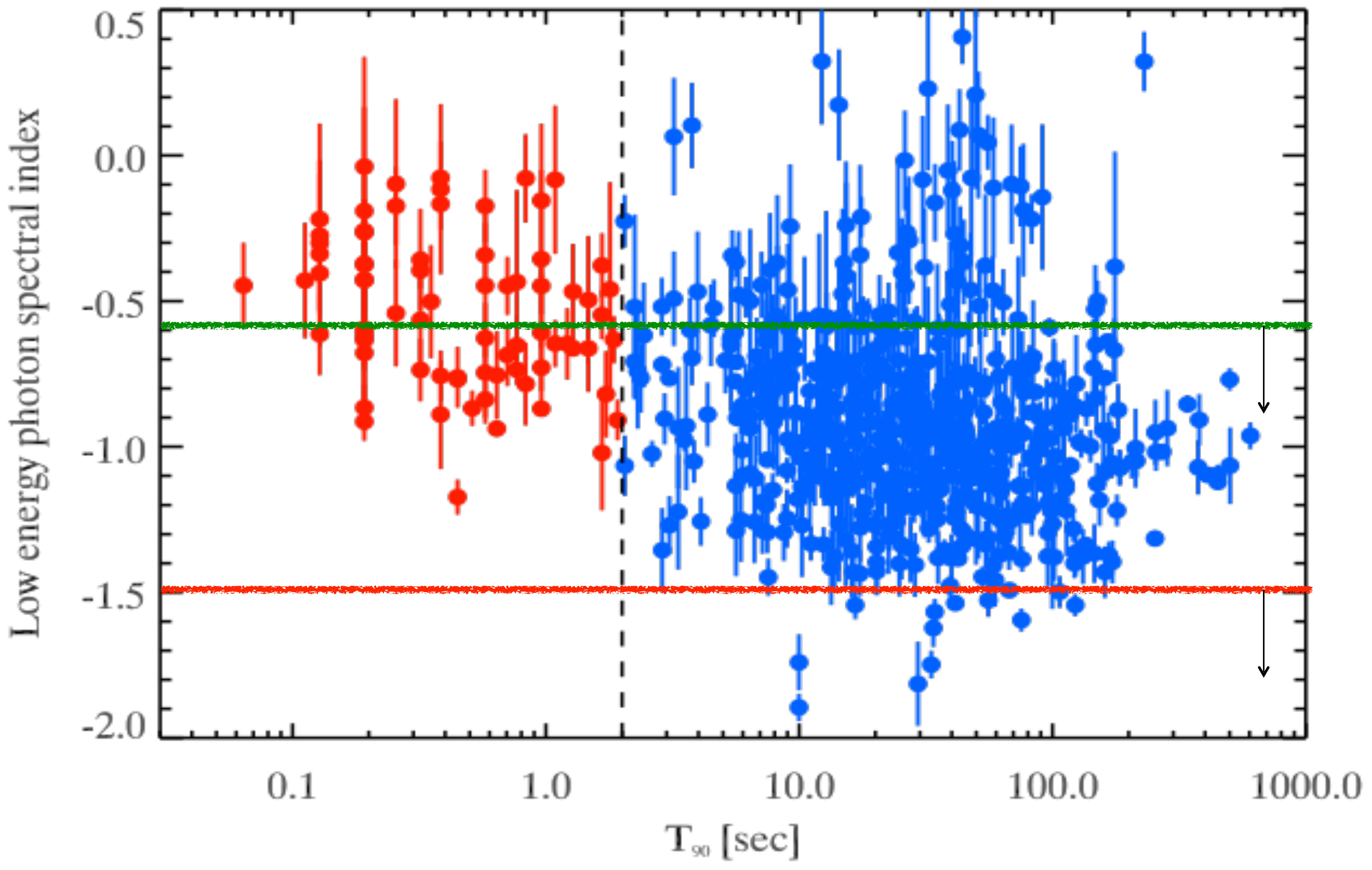
Prompt γ-ray emission: doesn't look synchrotron



Prompt should be synchrotron [Rees & Meszaros 1994; Katz 1994; Tavani 1996; Sari et al. 1996, 1998]

Prompt desn't look like synchrotron [Preece et al. 1998; Ghirlanda et al. 2002; Kaneko et al. 2006; Frontera et al. 2006; Vianello et al. 2008; Gruber et al. 2014].

Fermi GBM spectral catalog
[Gruber+2014; von Kienlin+2014; Bhat+2016]



1. **Inconsistency of spectral slopes**

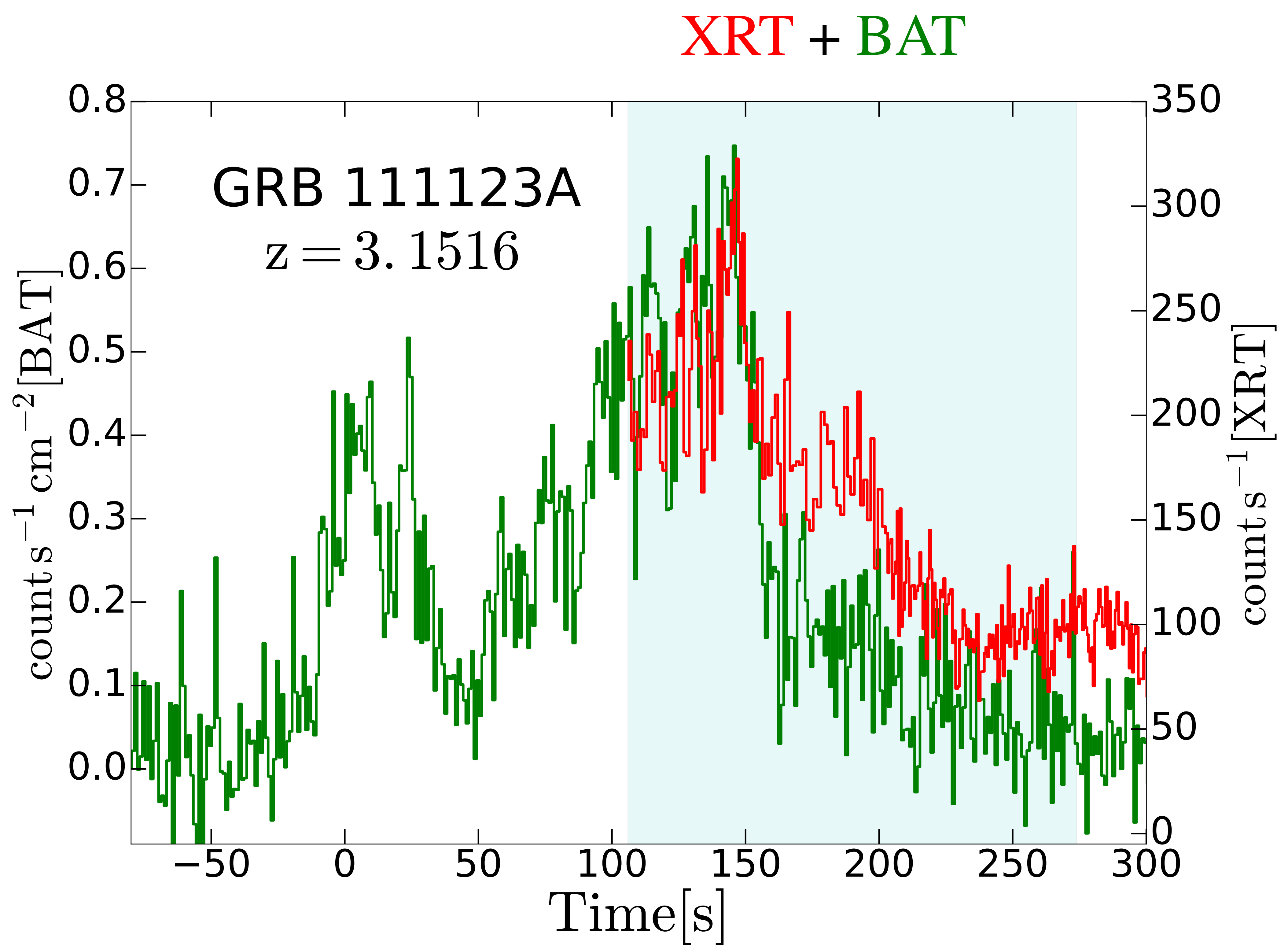
2. Spectral peak too narrow compared to synchrotron

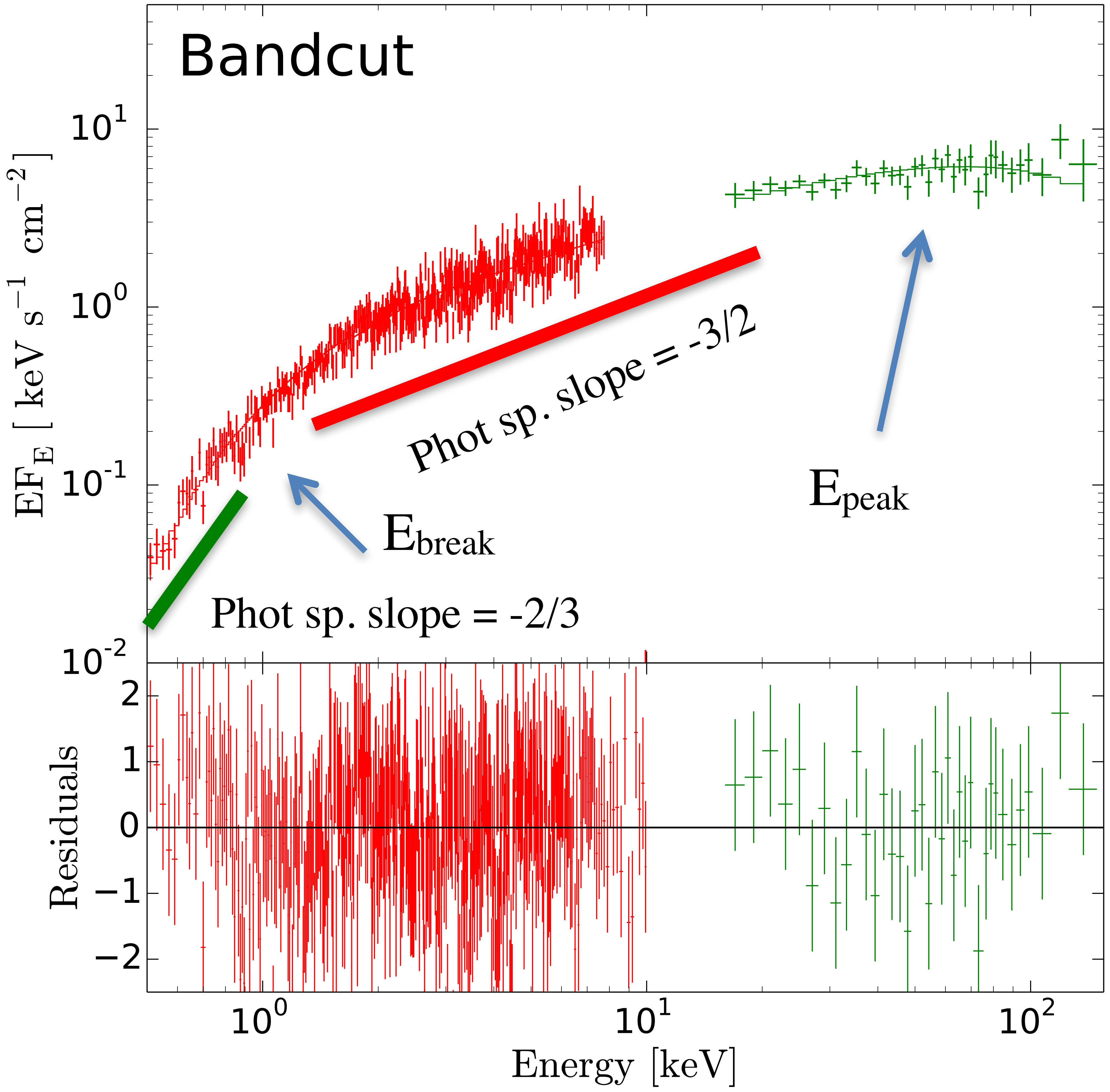
Prompt γ-ray emission: does look like synchrotron !

Modify theory to match observations → Look deeper into the data

Oganesyan et al. 2017: 14 bright GRBs detected by Swift

Oganesyan et al. 2017a: 34 GRBs detected by Swift (14 with Fermi GBM data)



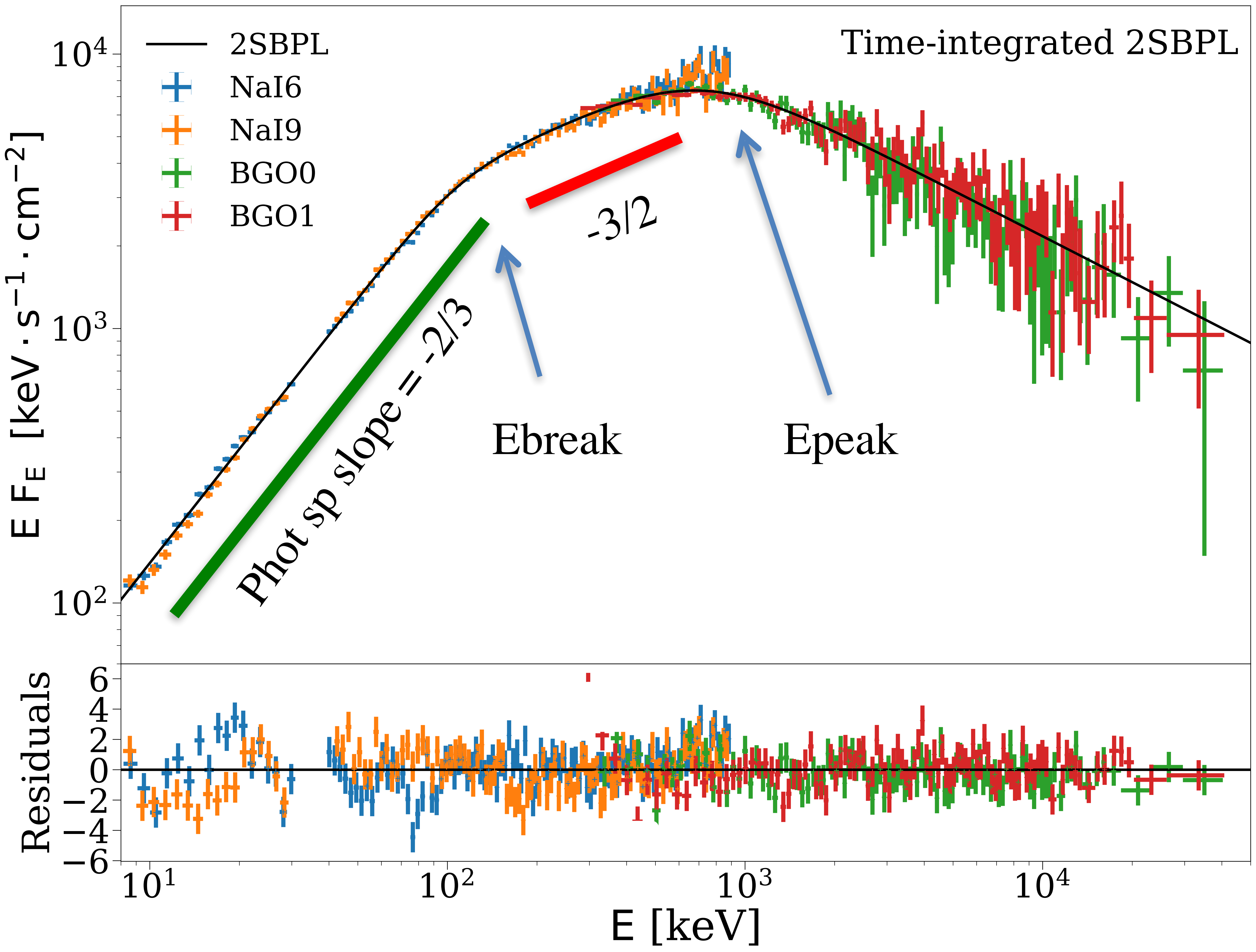


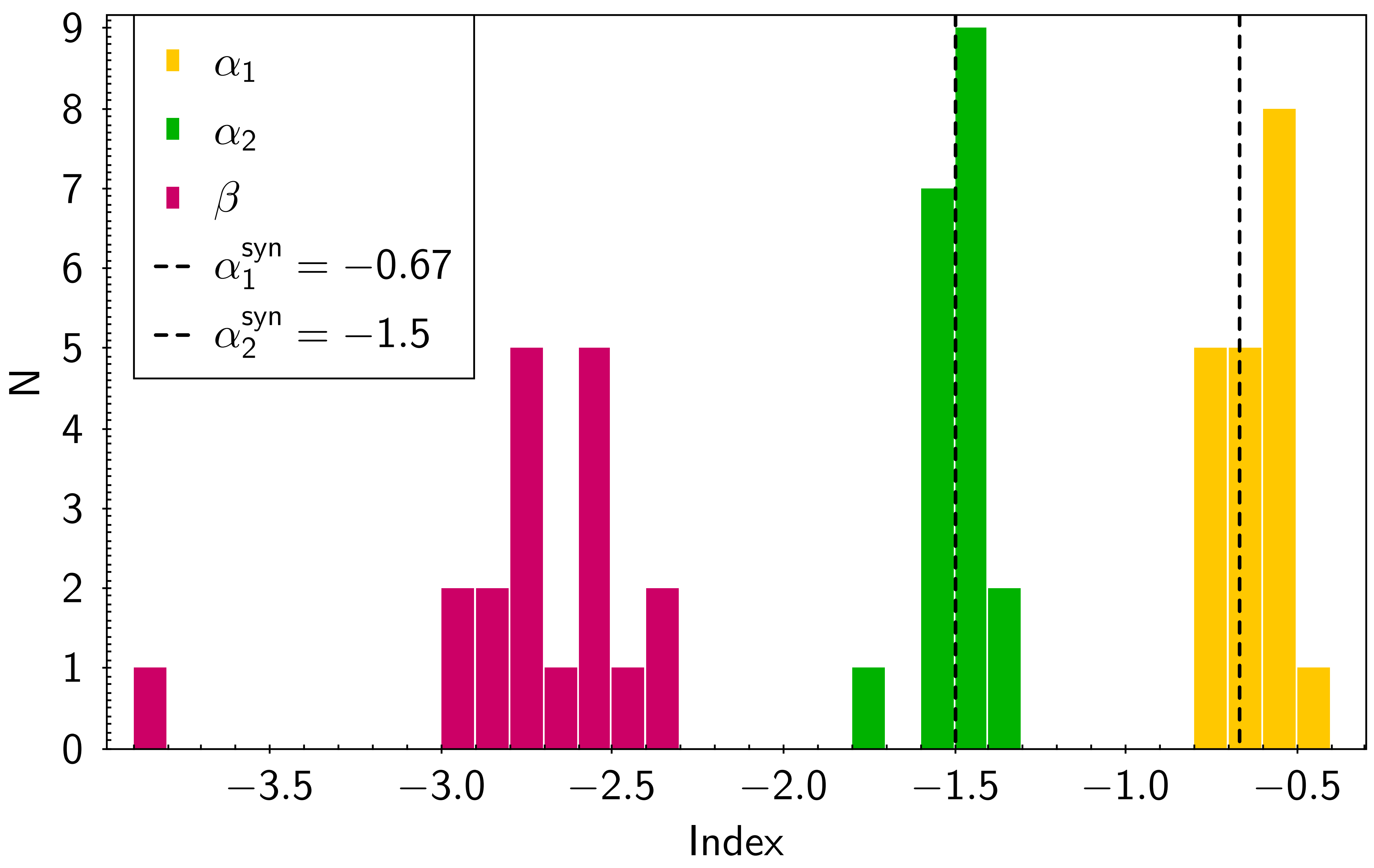
62% of GRBs

- ✓ Show two spectral breaks (new: low energy break 3-20 keV)
- ✓ The average photon indices below and above the break are -2/3 and -3/2

Prompt γ-ray emission: does look like synchrotron !!

Fermi/GBM → GRB 160625 [Ravasio et al. 2018]

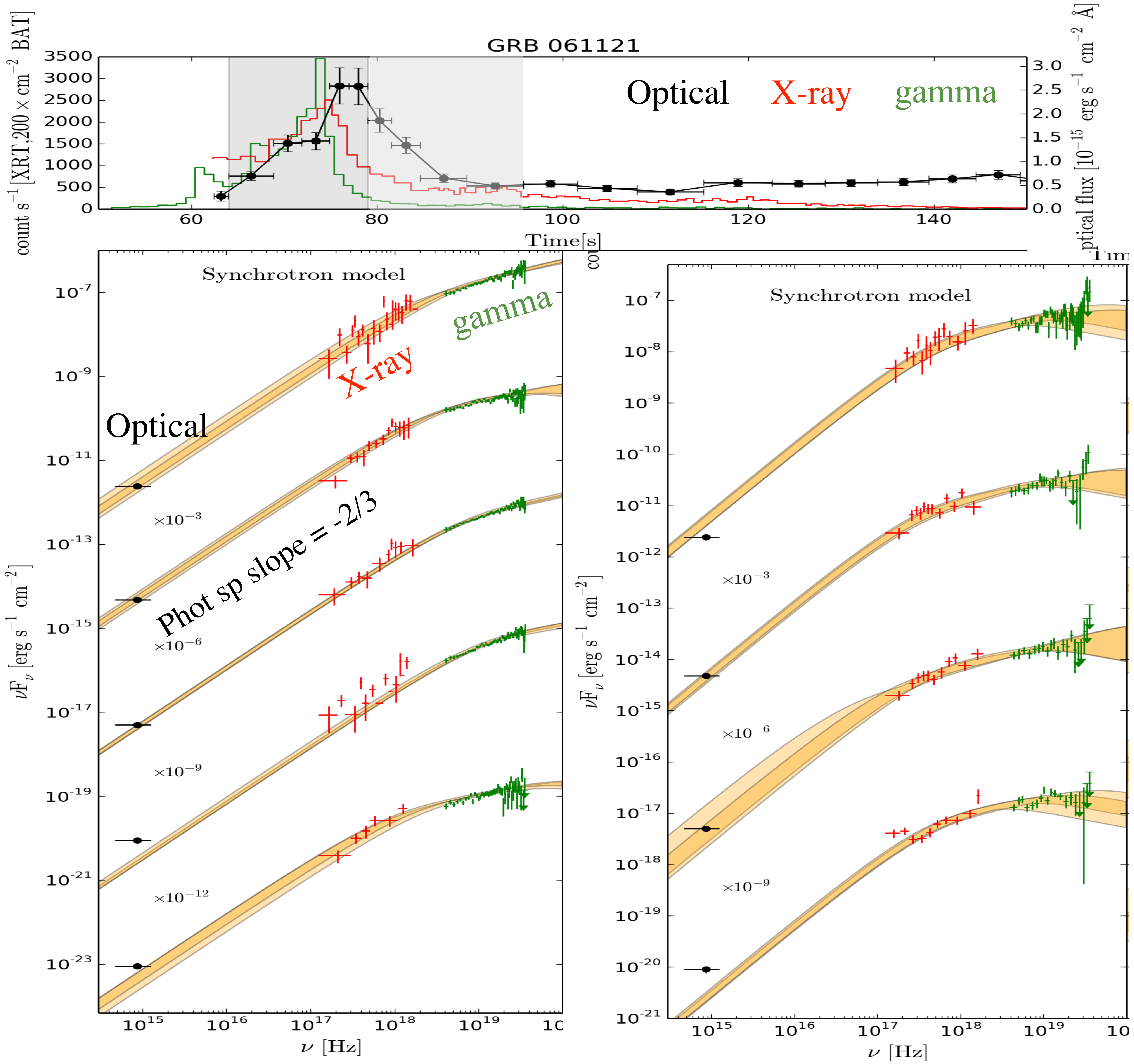




- Confirmed with 10 brightest Fermi GRBs (Ravasio et al. 2019) - empirical function
- Single peaked Fermi events (Burgess et al 2018; Oganesyan et al. 2019) - synchrotron emission

Prompt γ-ray emission: does look like synchrotron !!!

Oganesyan et al. 2019: 21 GRBs with optical-X-Gamma-ray spectra

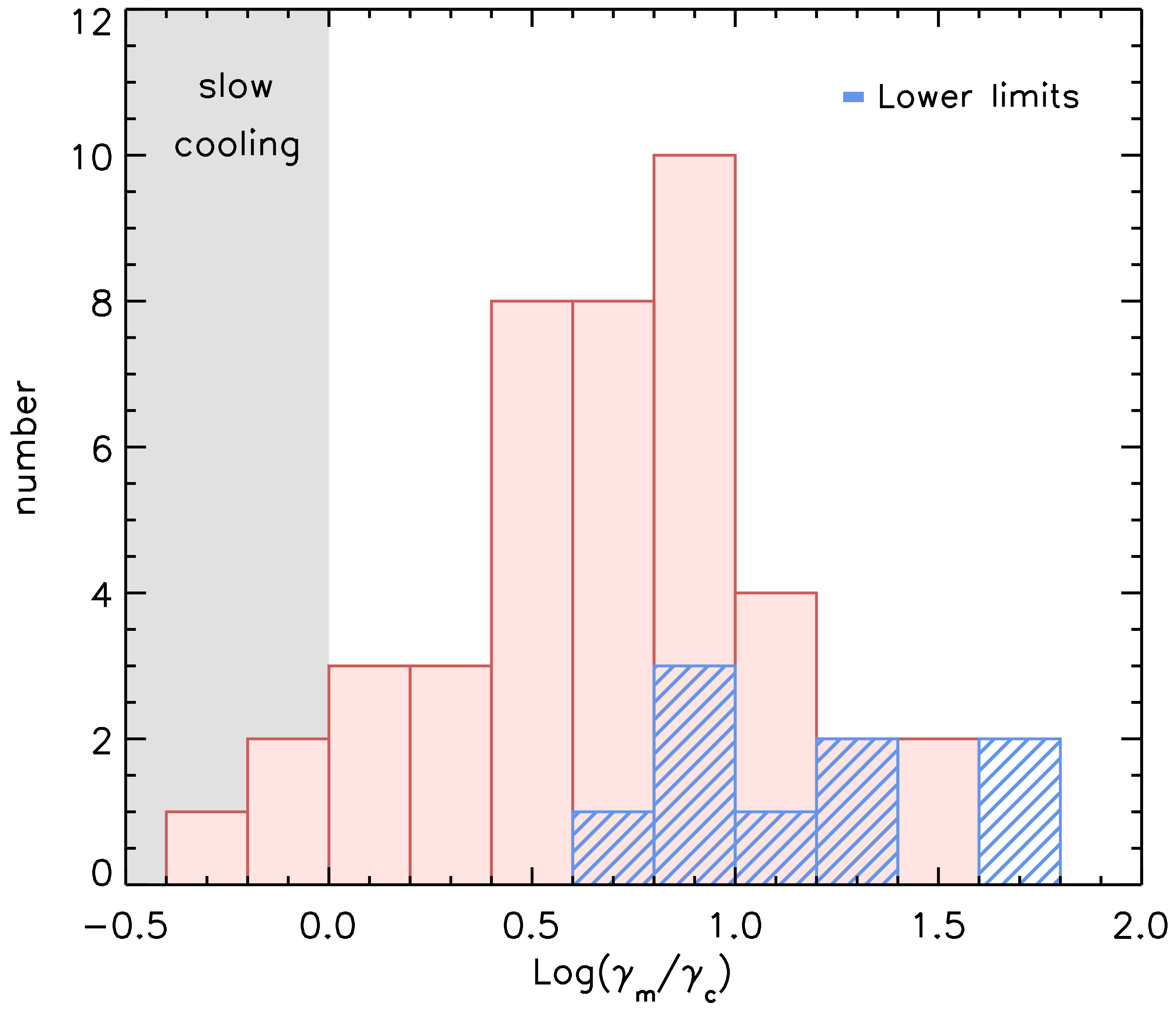


GRB061121, GRB080928, GRB110205A

- Synchrotron consistent from Optical to gamma -rays
- Optical to 1 keV is single component
- Optical exclude thermal (BB) + non-thermal components

Prompt γ-ray emission is synchrotron: parameter space

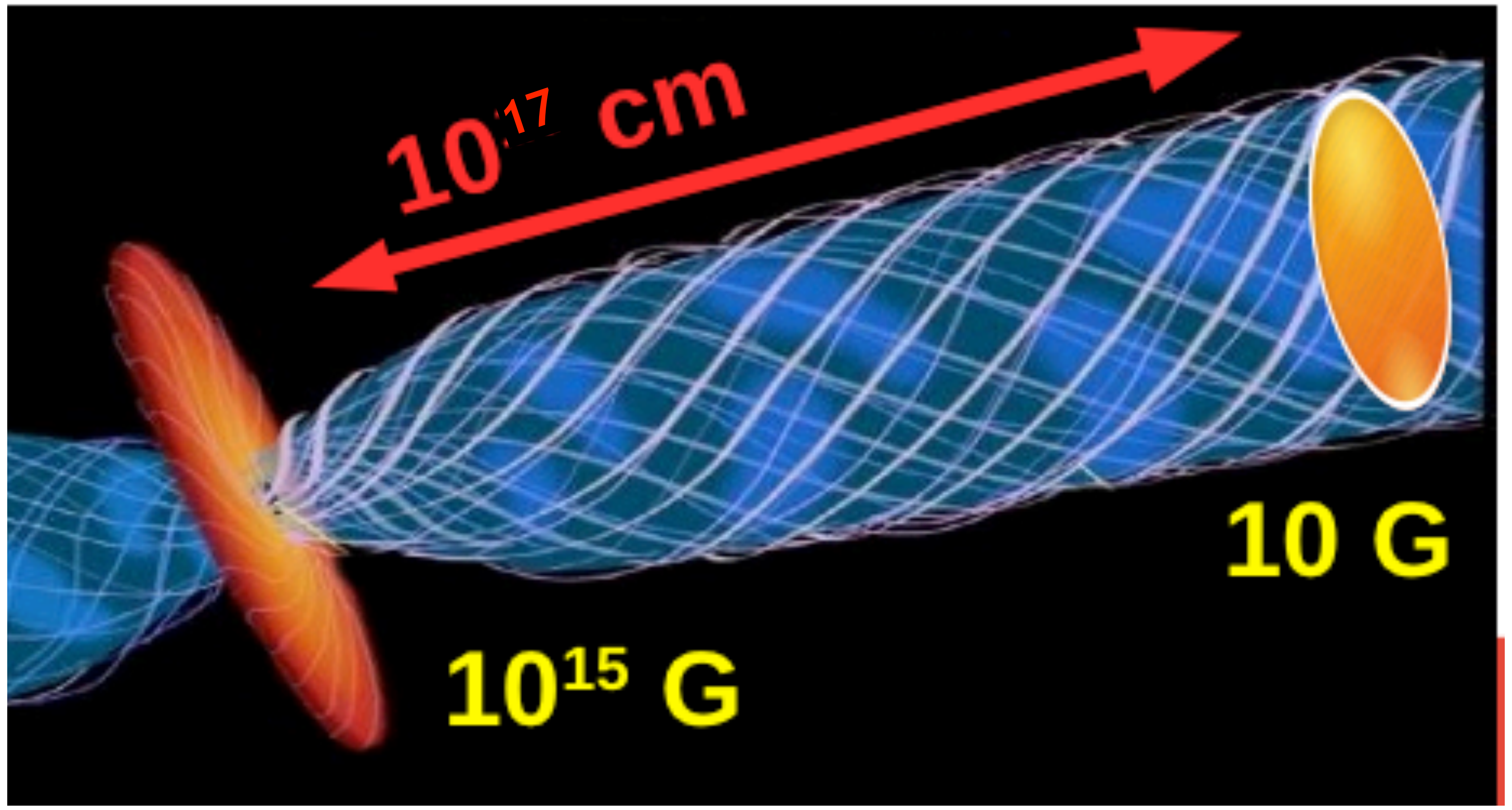
Oganesyan et al. 2019



$\Gamma_0 > 500$

$5\,\mathrm{G} < B' < 30\,\mathrm{G}$

10^{16} cm $< R_{\rm diss} < 10^{17}$ cm

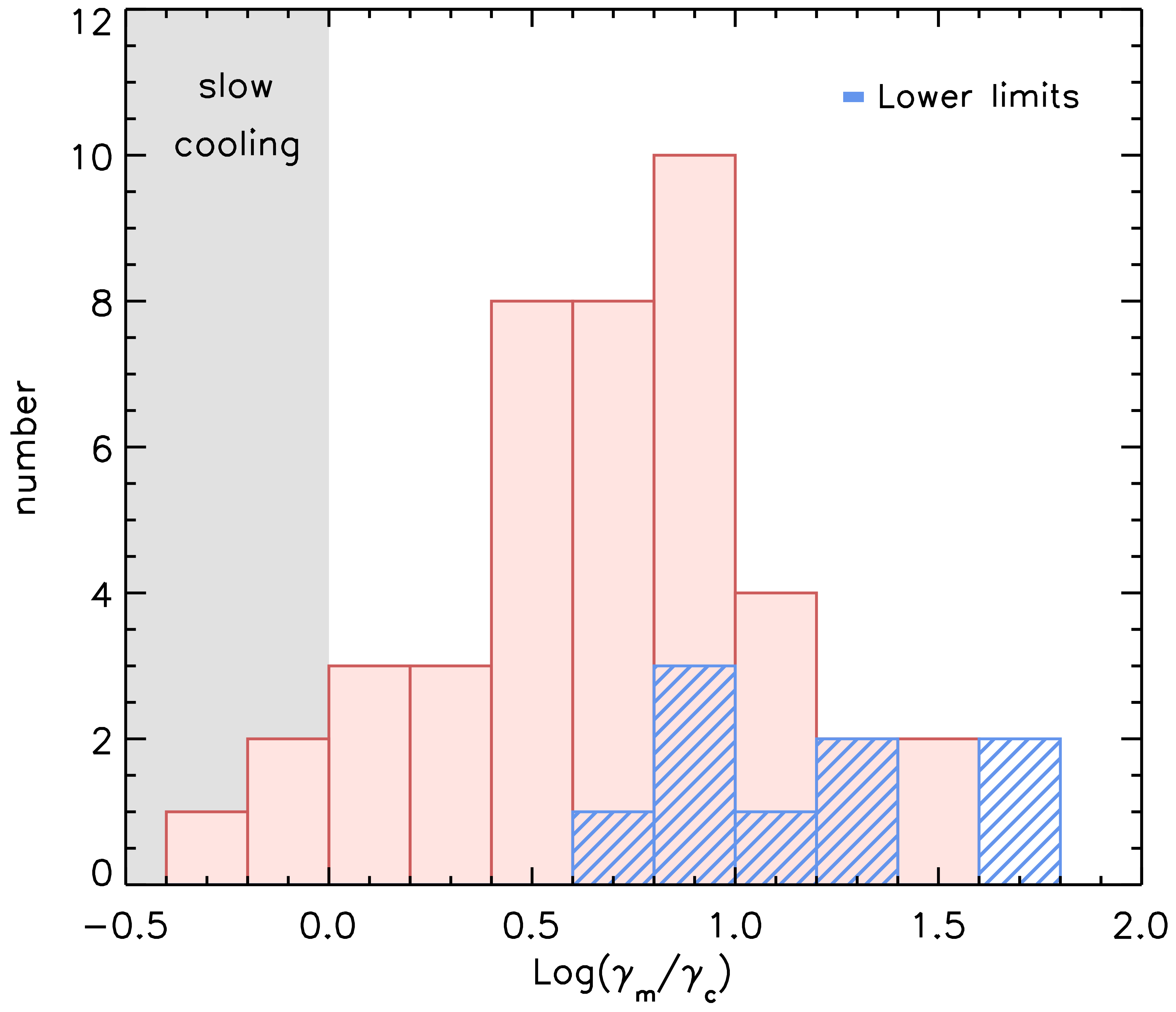


PB1: compactness required for variability

PB2: If mini jets then IC would dominate

Prompt γ-ray emission is synchrotron: parameter space

Oganesyan et al. 2019



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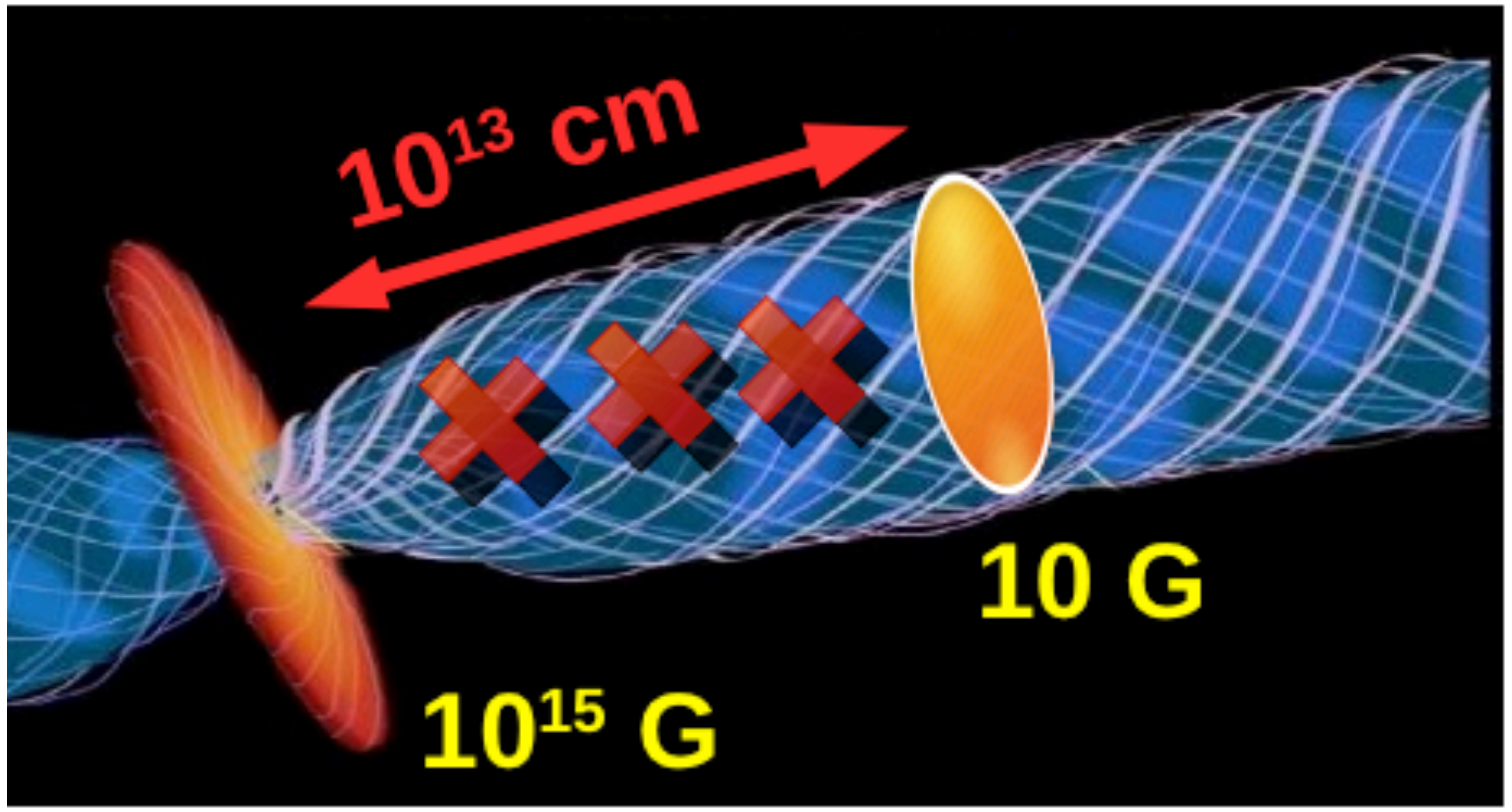


PB1: IC would dominate

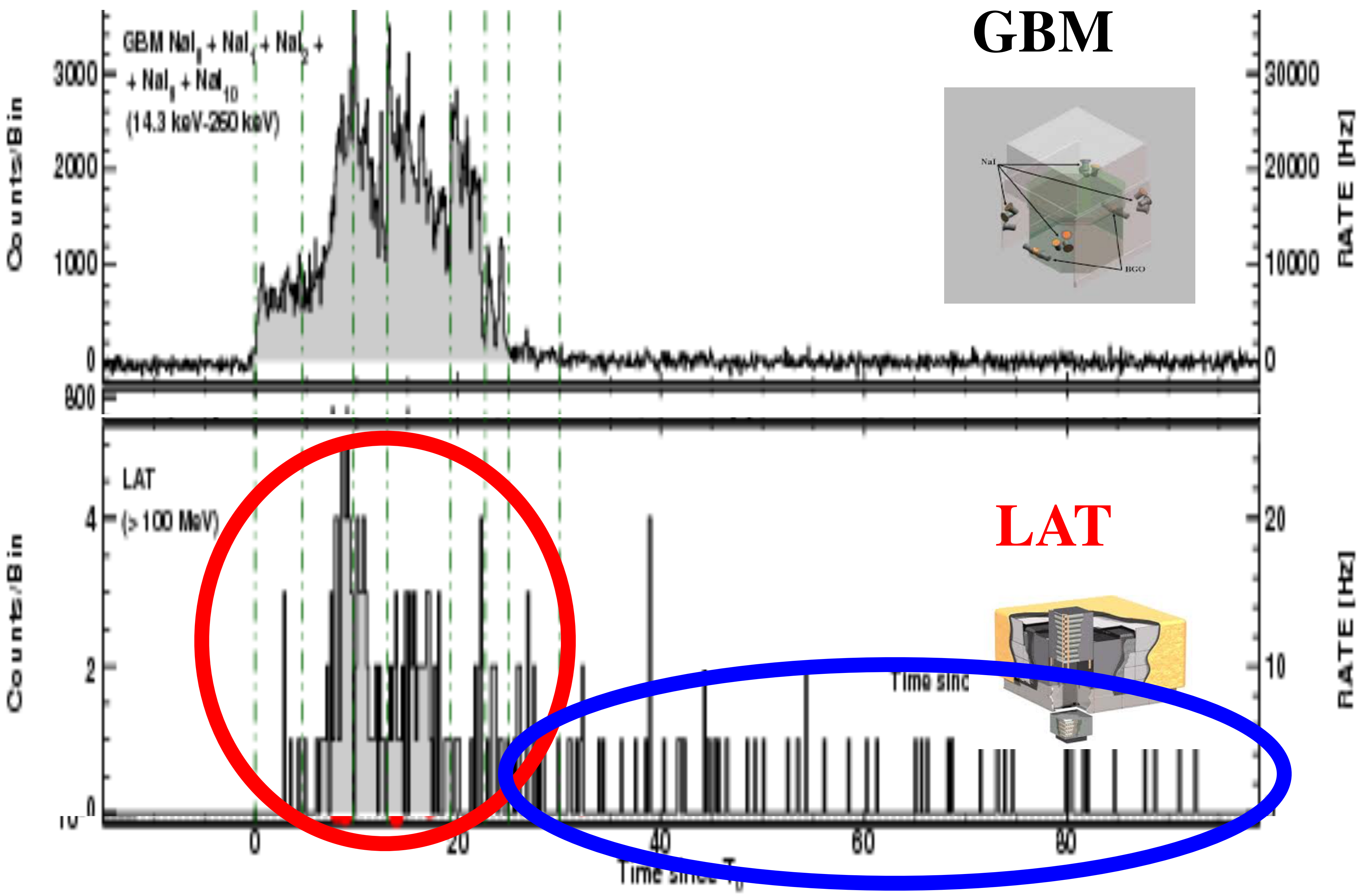
GeV emission of GRBs: origin?

PROMPT = Internal dissipation

141 GRBs @ 12/2017 →~ 15 LAT GRBs yr[-1]
9% are Short
[e.g. Ackermann+2013]

Poster: Bissaldi et al.
“New LAT GRB catalog”

Poster: Fana Dirisra et al.
“LAT GRBs with z & Cosmology”



EARLY PHASE

EXTENDED EMISSION

PROMPT or AFTERGLOW?
[Internal or External?]

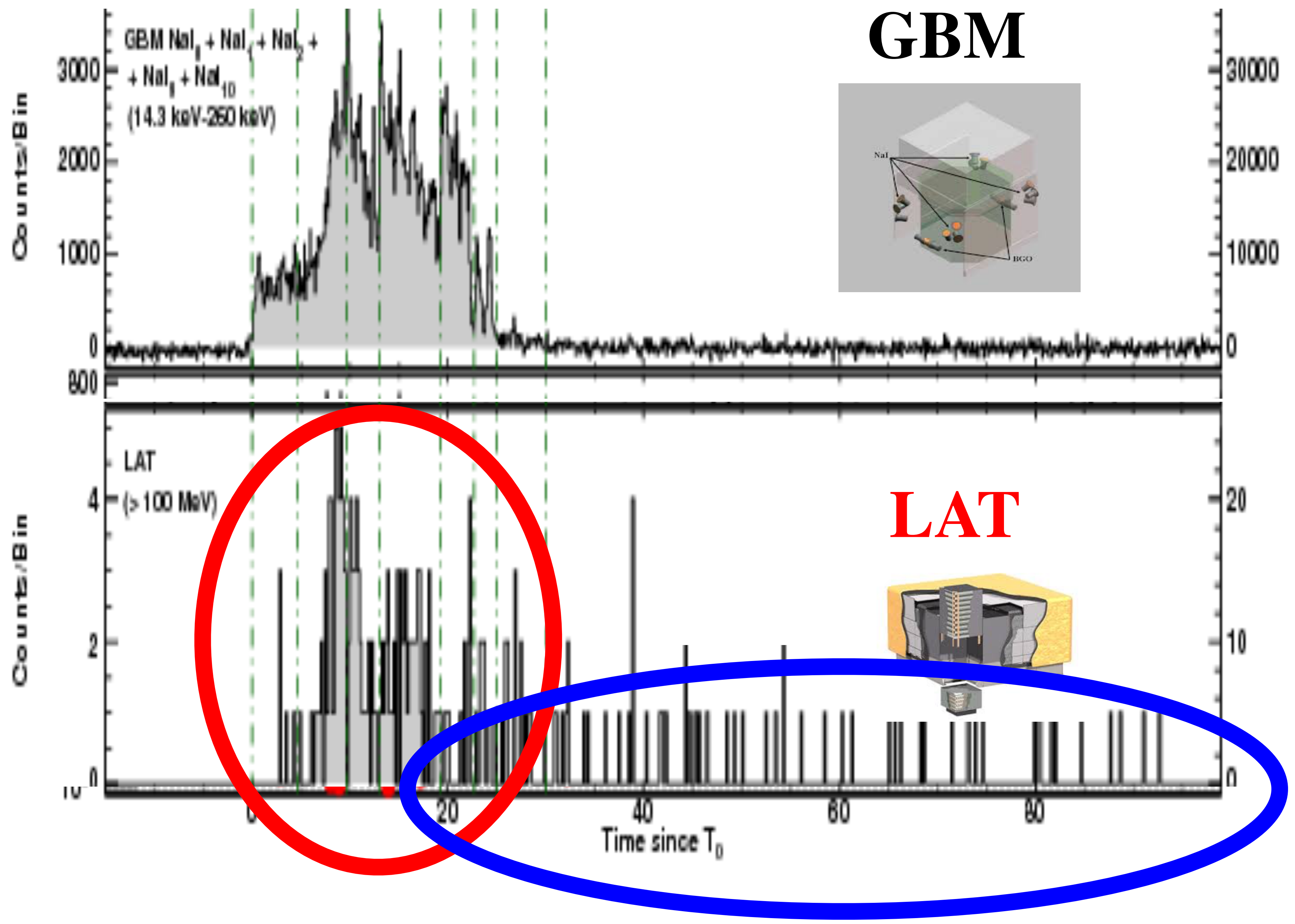
GeV emission of GRBs: two phases …

[in individual GRBs detected by Fermi (e.g. Abdo+2010) and in the Fermi LAT catalog: Ackermann+2013]

EARLY PHASE

DELAY

VARIABILITY



EXTENDED EM

LONGER

SMOOTH DECAY (no Variability)

GeV emission of GRBs: two phases …

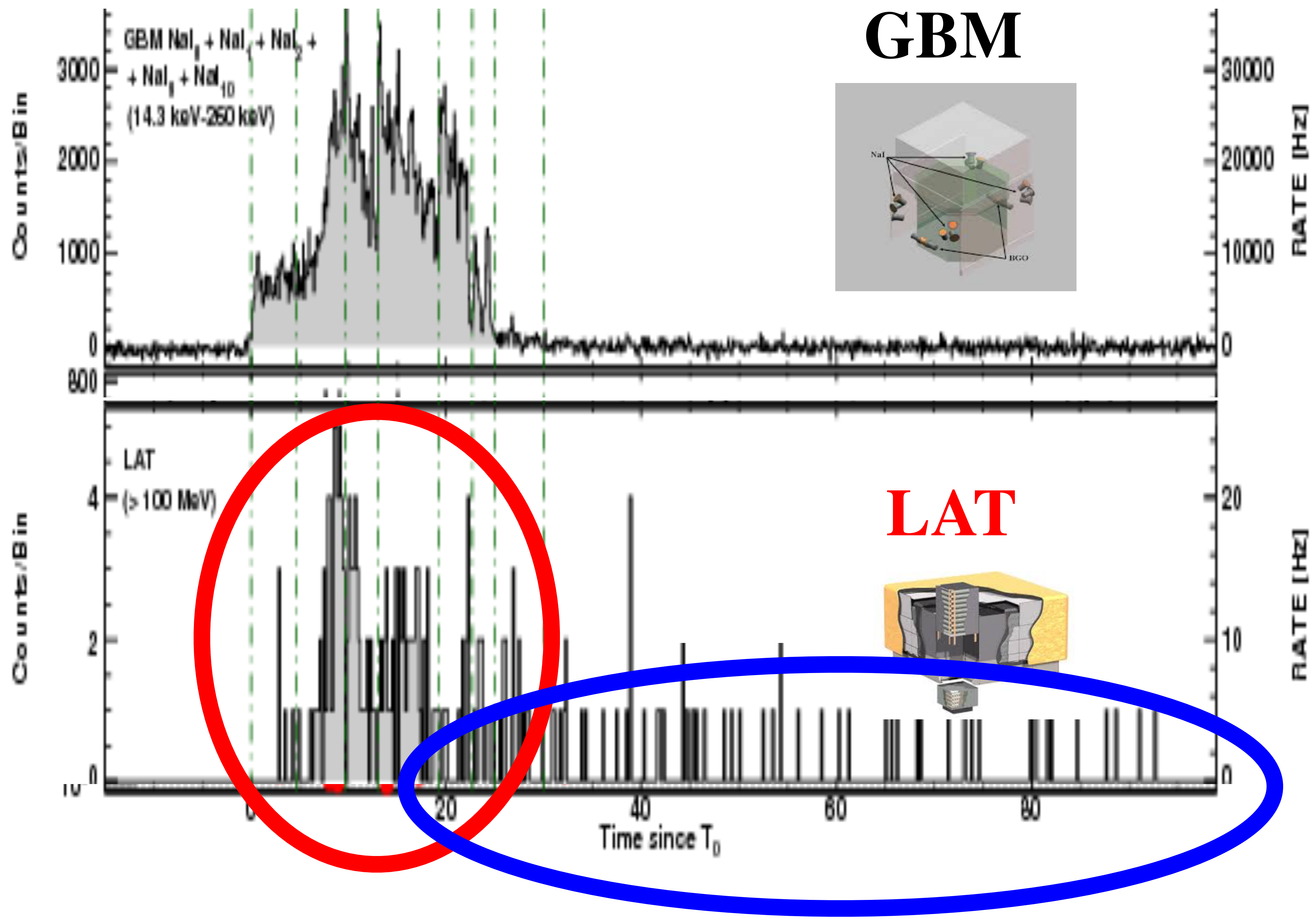
[in individual GRBs detected by Fermi (e.g. Abdo+2010) and in the Fermi LAT catalog: Ackermann+2013]

EARLY PHASE

DELAY

VARIABILITY

SPECTRAL CONSISTENCY

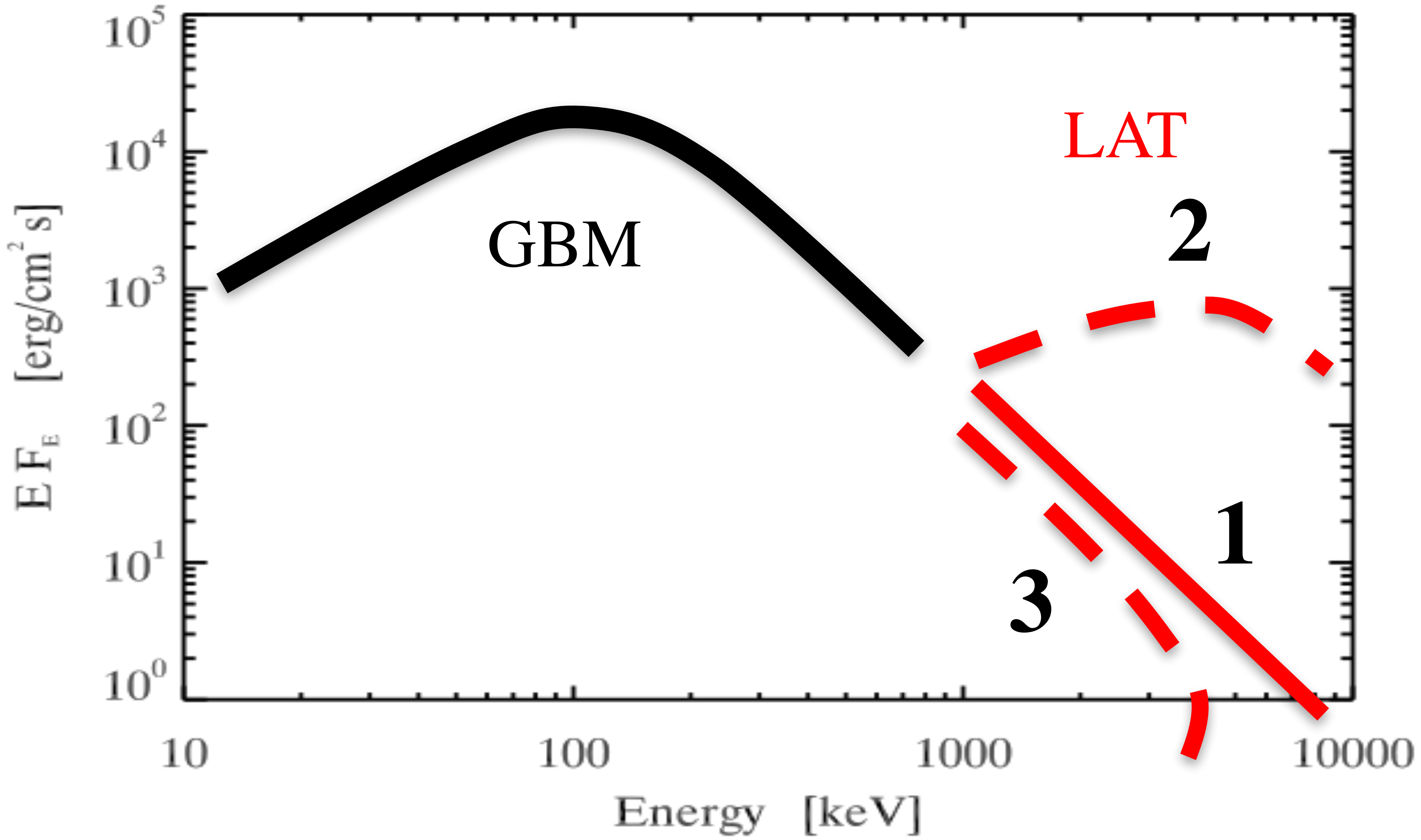


EXTENDED EM

LONGER

SMOOTH DECAY (no Variability)

> GeV emission (not always) spectrally consistent with extrapolation of GBM spectrum



GeV emission of GRBs: two phases …

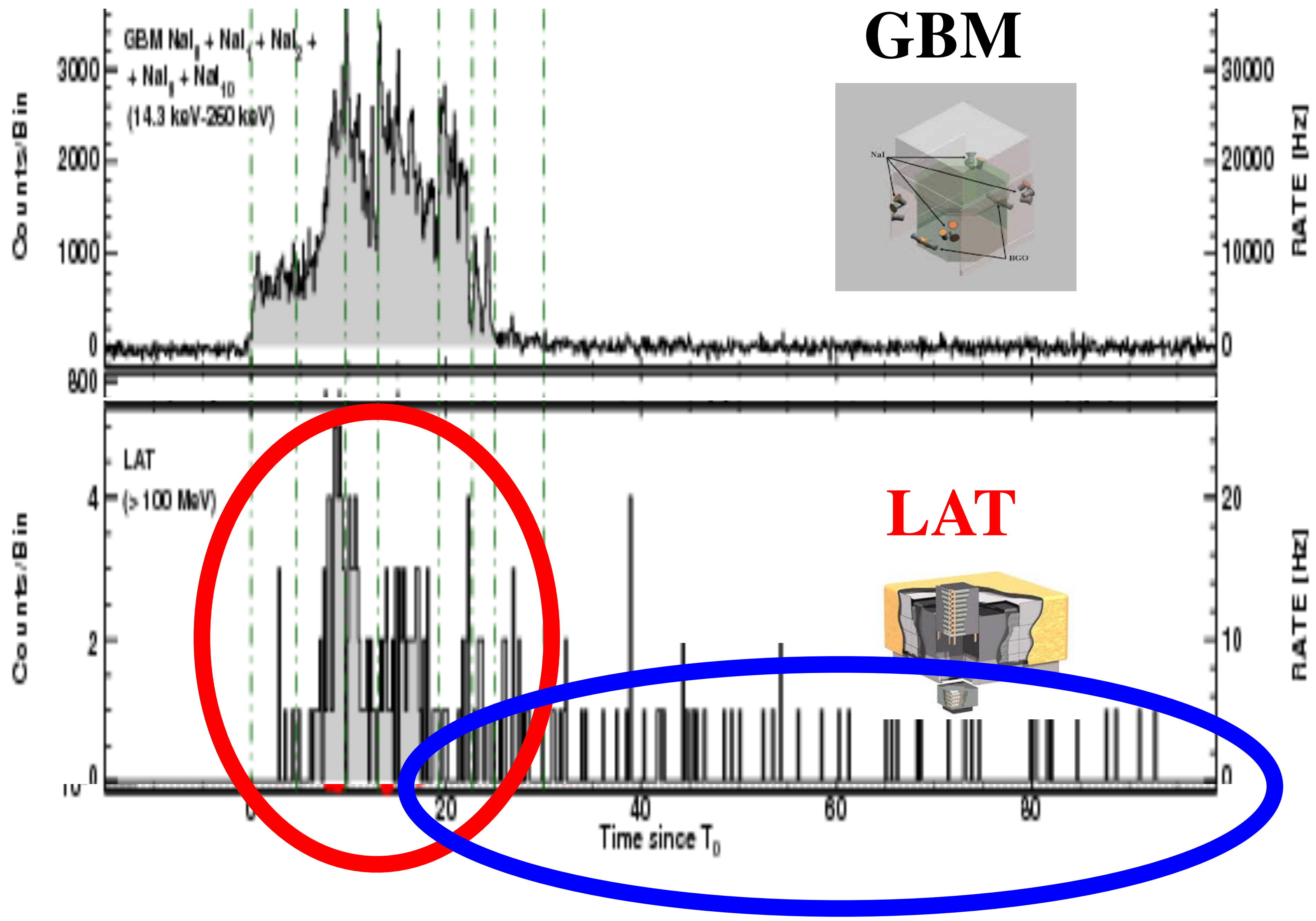
[in individual GRBs detected by Fermi (e.g. Abdo+2010) and in the Fermi LAT catalog: Ackermann+2013]

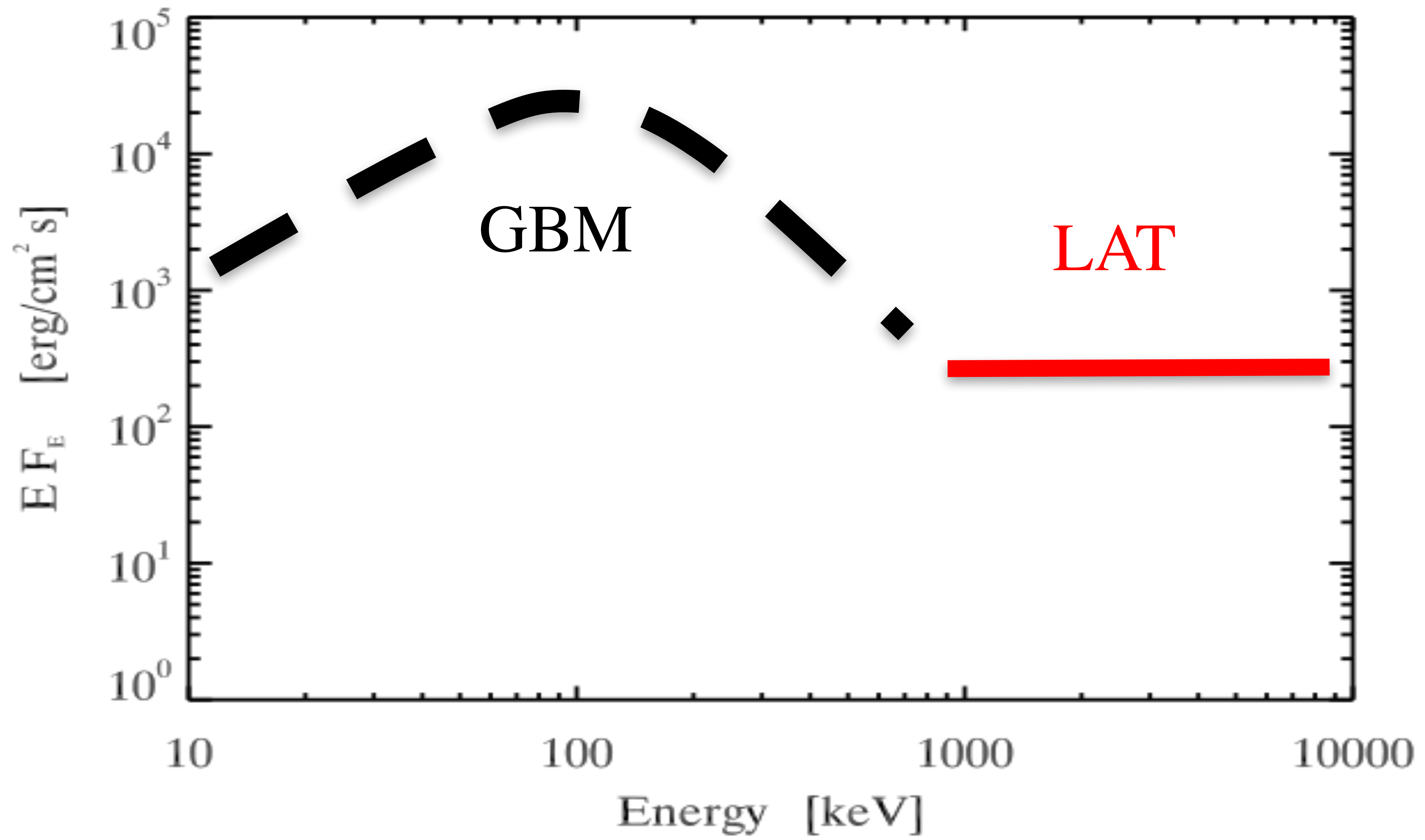
EARLY PHASE

DELAY

VARIABILITY

SPECTRAL CONSISTENCY





EXTENDED EM

LONGER

SMOOTH DECAY (no Variability)

SPECTRALLY HARDER

Poster: Bissaldi et al.
“New LAT GRB catalog”

GeV emission of GRBs: two phases … two zones

[in individual GRBs detected by Fermi (e.g. Abdo+2010) and in the Fermi LAT catalog: Ackermann+2013]

EARLY PHASE

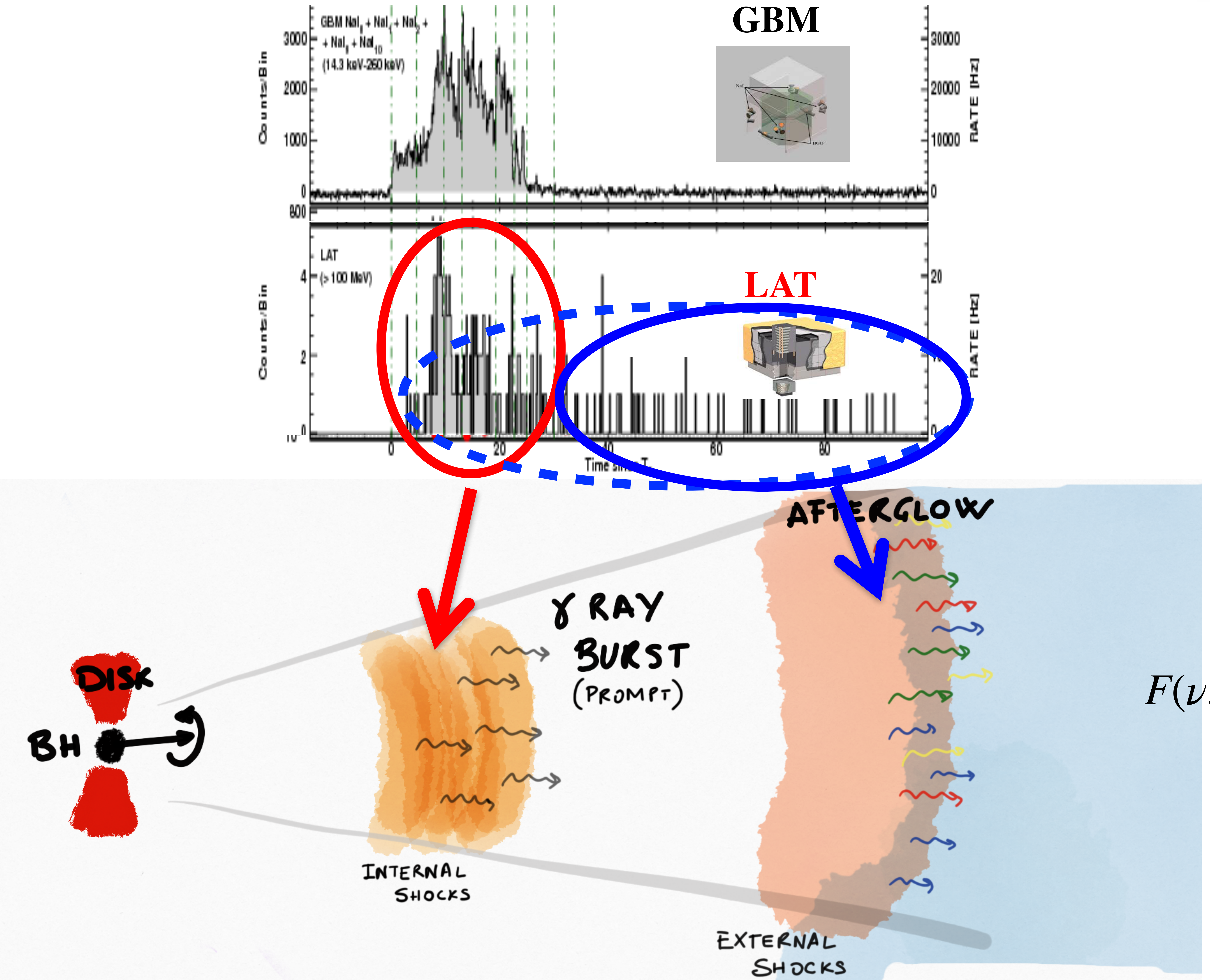
DELAY

VARIABILITY

SPECTRAL CONSISTENCY

PROMPT
Synchrotorn @
Internal shocks

Most likely coexistence of prompt and early afterglow



EXTENDED EM

LONGER

SMOOTH DECAY
(no Variability)

SPECTRALLY HARDER

AFTERGLOW
Synchrotorn @
External shocks

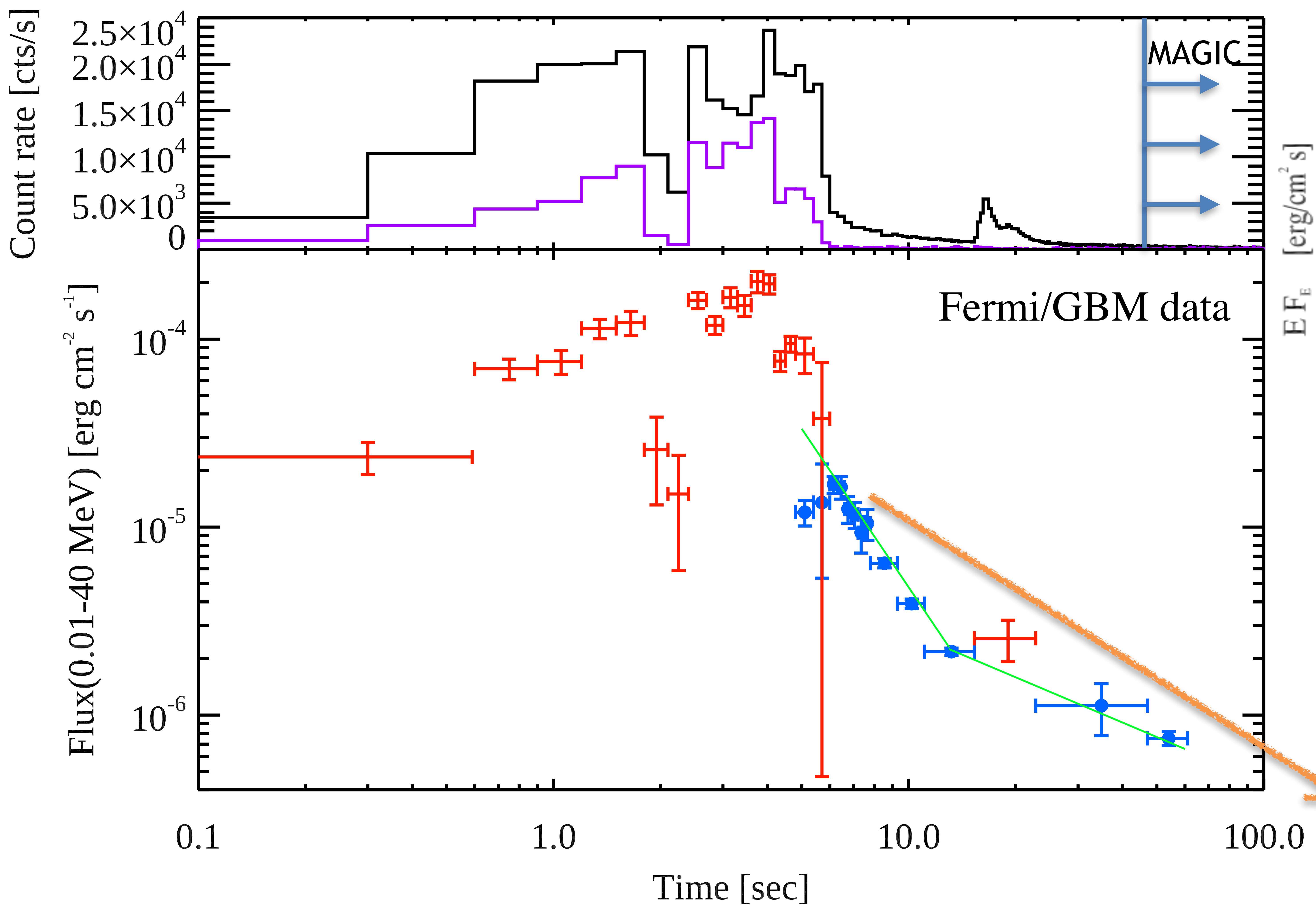
$$F(\nu, t) \propto \nu^{-p/2} t^{-(3p-2)/4}$$

$$\nu > [\nu_m, \nu_c]$$

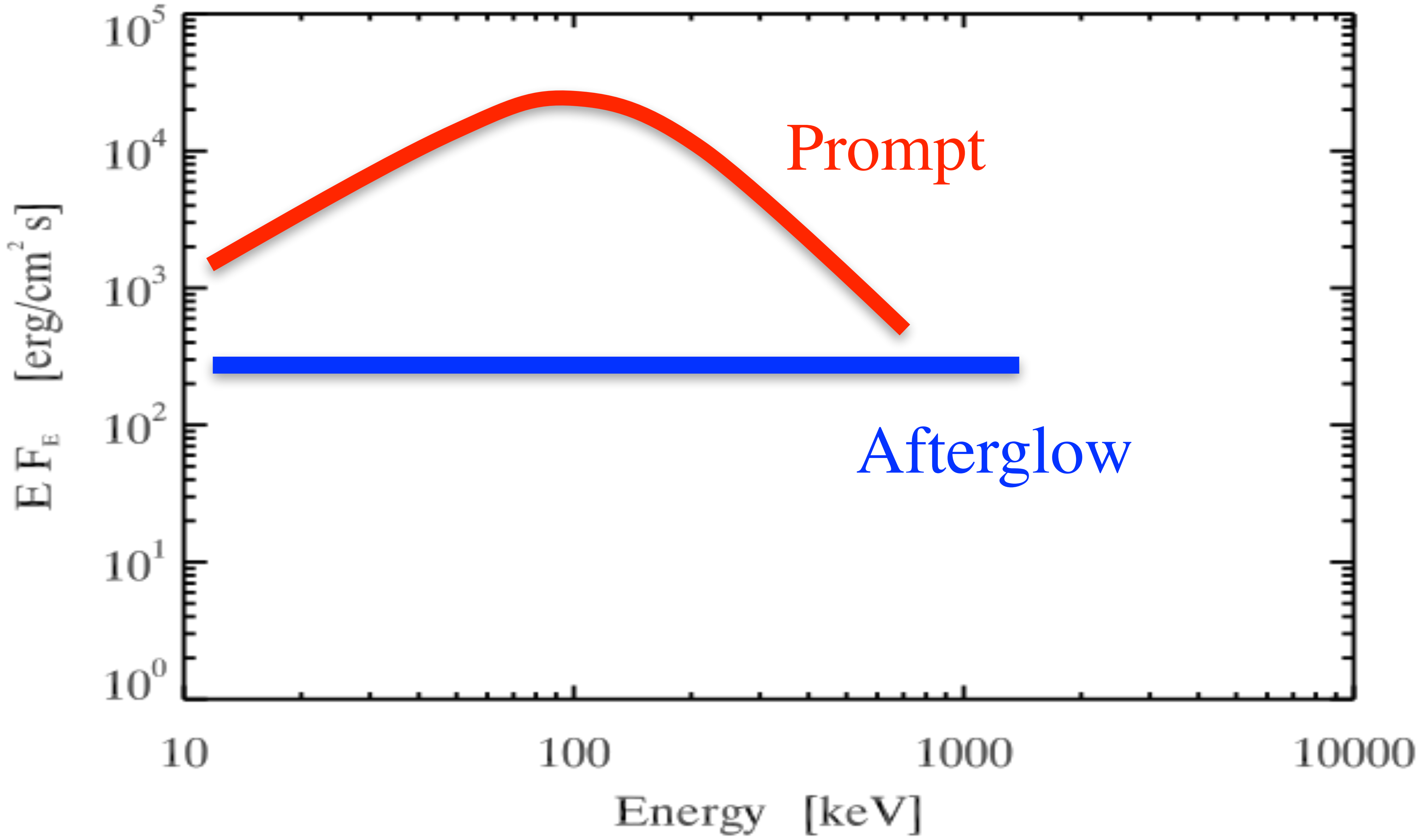
p<-2

The “Magical” GRB 190114C

190114C the first GRB significantly detected by MAGIC (Mirzoyan+2019)



The rise and fall of the afterglow [Ravasio et al. 2019]



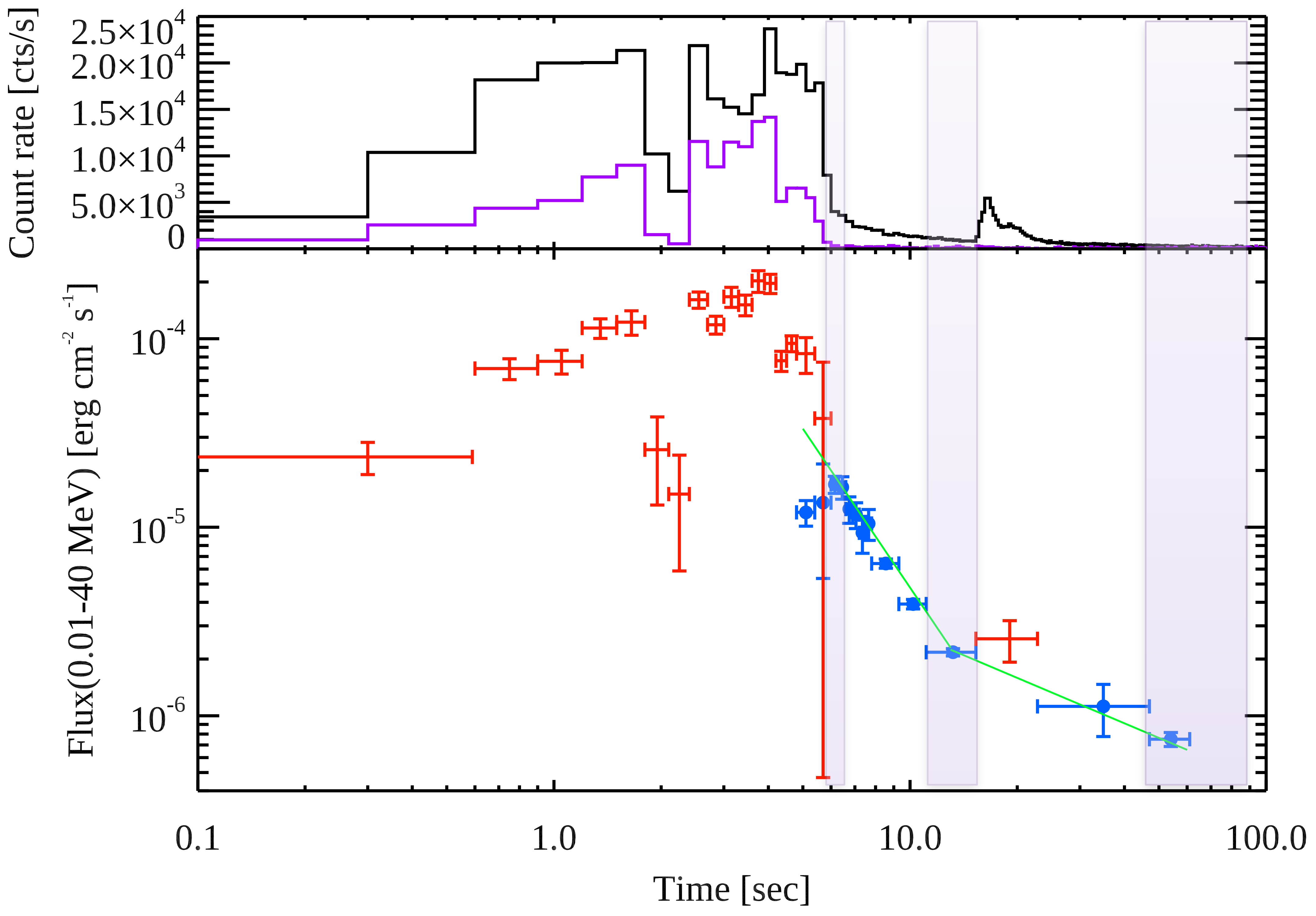
(time resolved) evidence of compresence of PROMPT and AFTERGLOW IN THE KEV-MEV (GBM) SPECTRUM

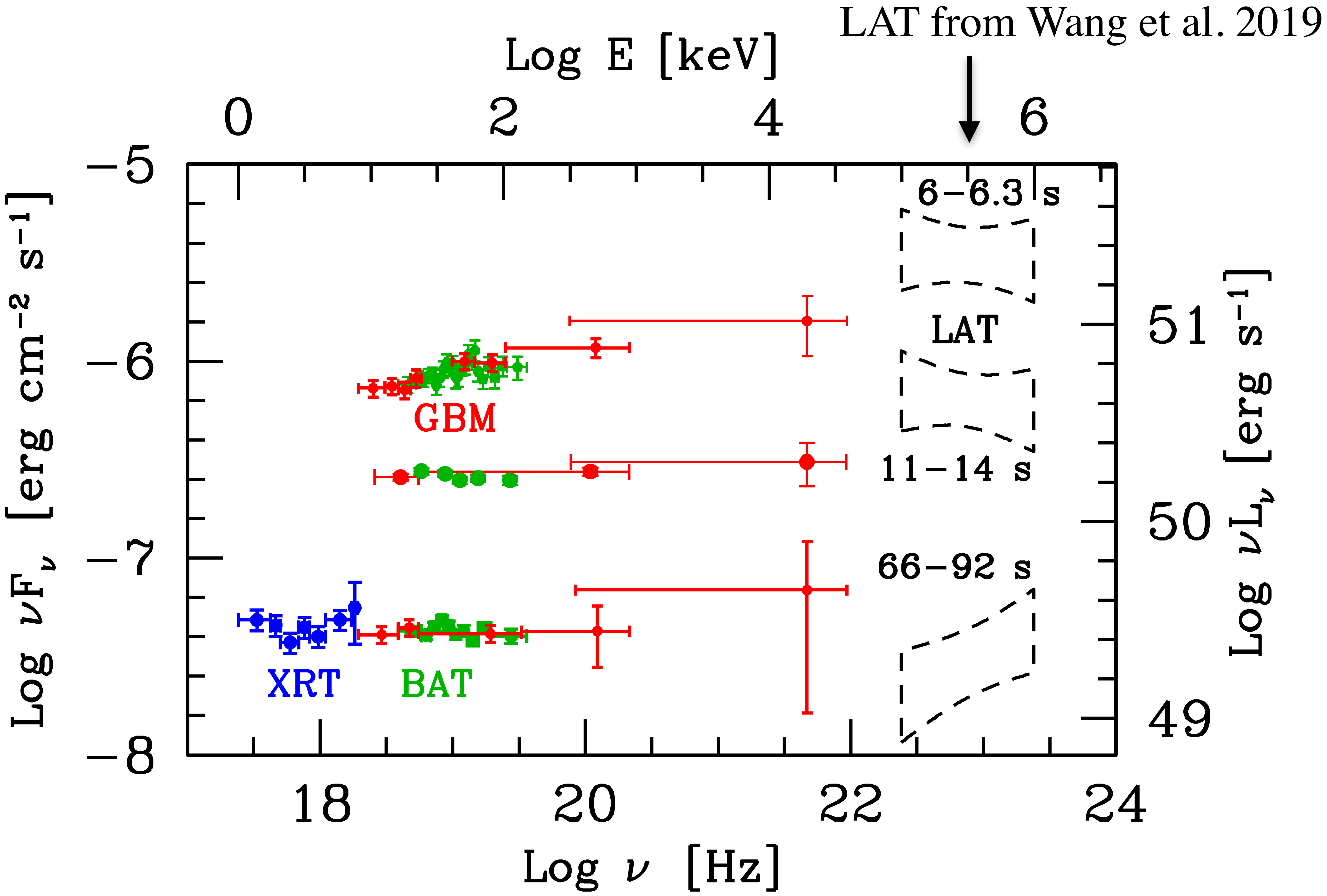
Afterglow peak —> Bulk Lorenz factor

$$\Gamma_0 \sim 500$$

190114C the first GRB significantly detected by MAGIC (Mirzoyan+2019)

The rise and fall of the afterglow
[Ravasio et al. 2019]





POpulation SYnthesis Theory Integrated Very high Energy emission (POSYTIVE)

CTA detection and follow up of GRBs

PHYSICALLY BASED APPROACH

POpulation SYnthesis

LONG & SHORT

Theory Integrated code for Very high Energy emission

PROMPT + AFTERGLOW

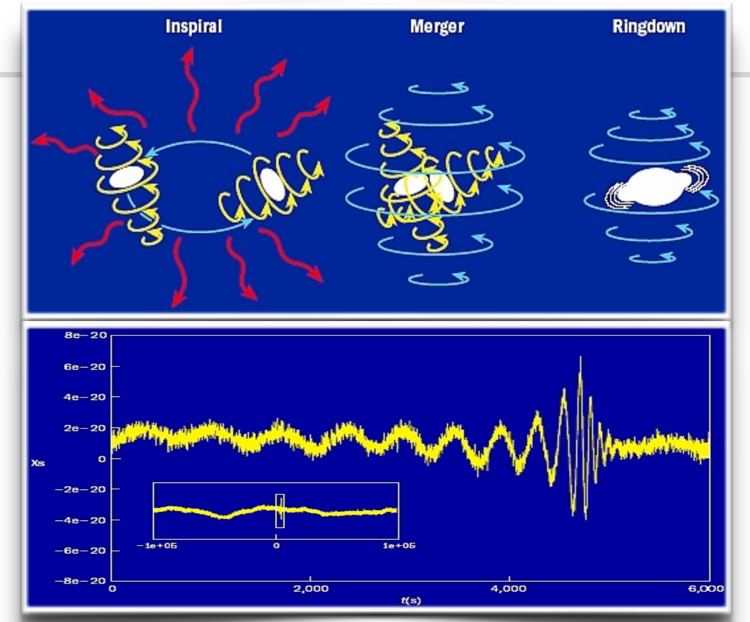
POSYTIVE

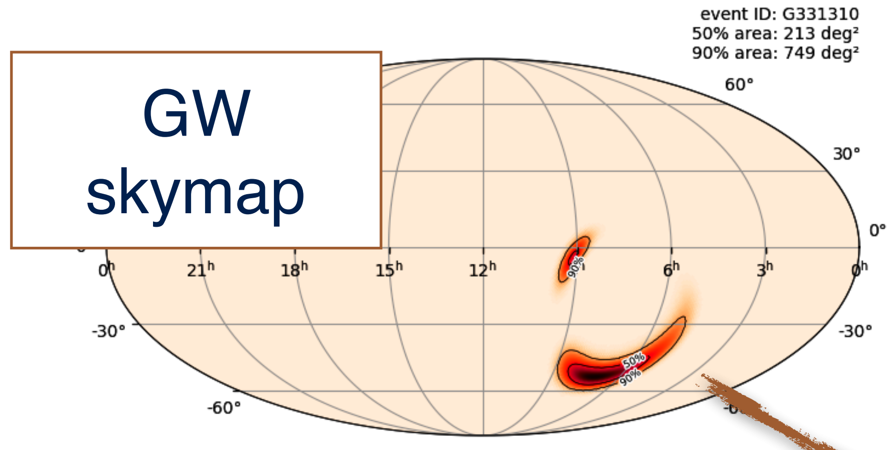
$P[E_{tot}, z, \Gamma, T, n_e, \phi(\gamma), B, p, \vartheta_{jet}, \vartheta_{view} \ldots]$

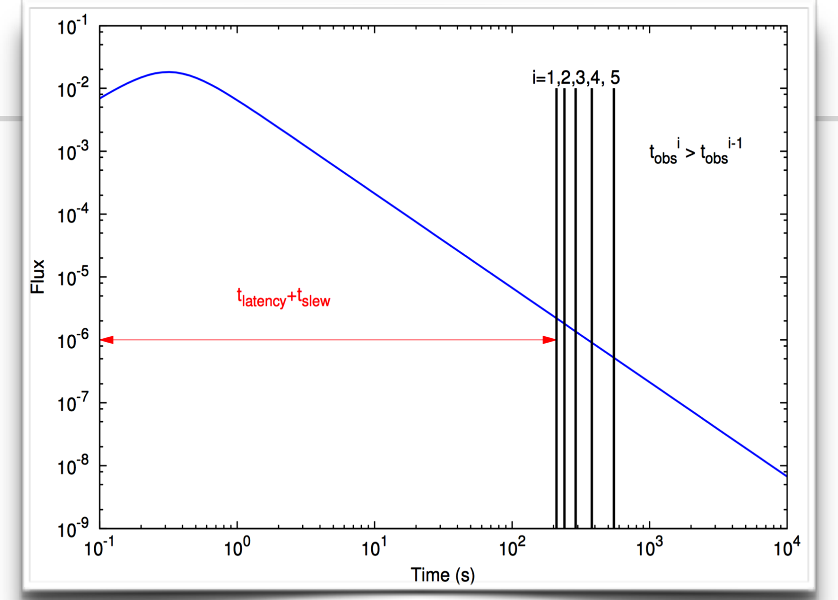
G. Ghirlanda, L. Nava, F. Longo, Z. Bosnjak, M G. Bernardini, S. D. Vergani, F. Schussler, Q. Piel, A. Carosi, E. Bissaldi, T. Stoclarzyk, P. D'Avanzo, S. Inoue, P. O'Brien, A. Melandri, I. Sadeh … … … …

CTA detections of GW counterparts

- **Simulation of mergers** and GW signal in local universe

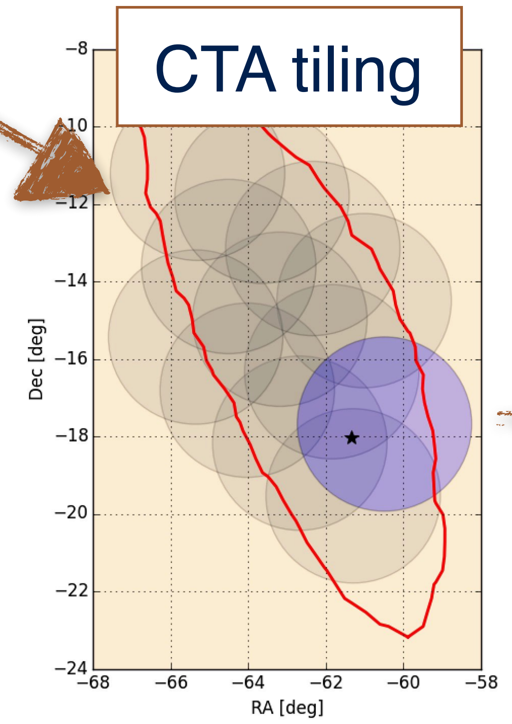


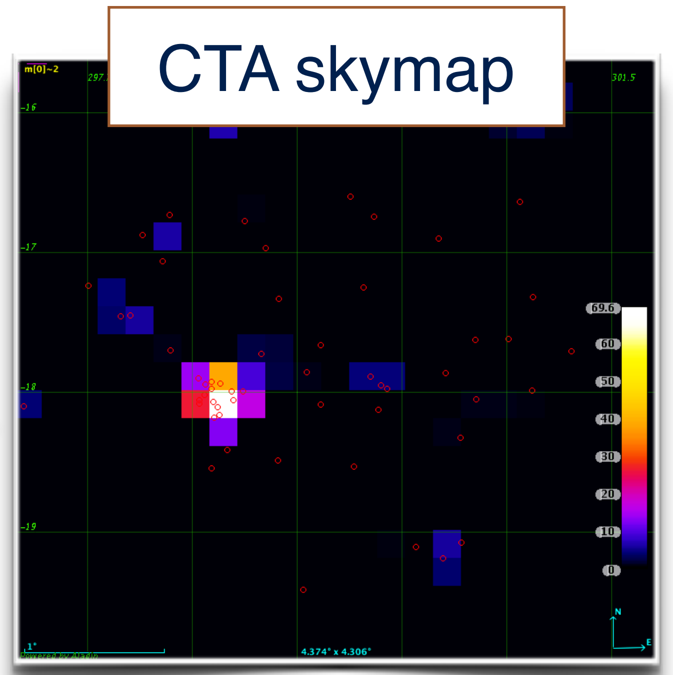




- **Phenomenological model** of VHE emission, from short-GRB templates
- Off-axis emission

- **CTA observing strategy**



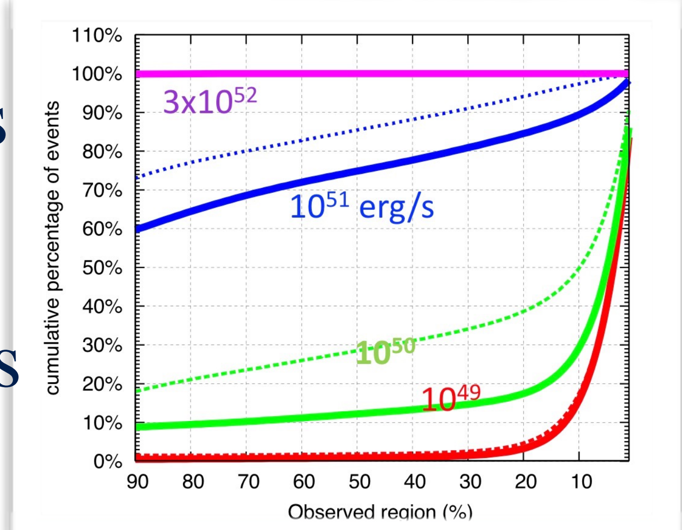


- **Simulation of CTA** response (IRFs, EBL)

Expected Results

✓ Joint GW-CTA detection rates and coverage

✓ Optimal observation strategies



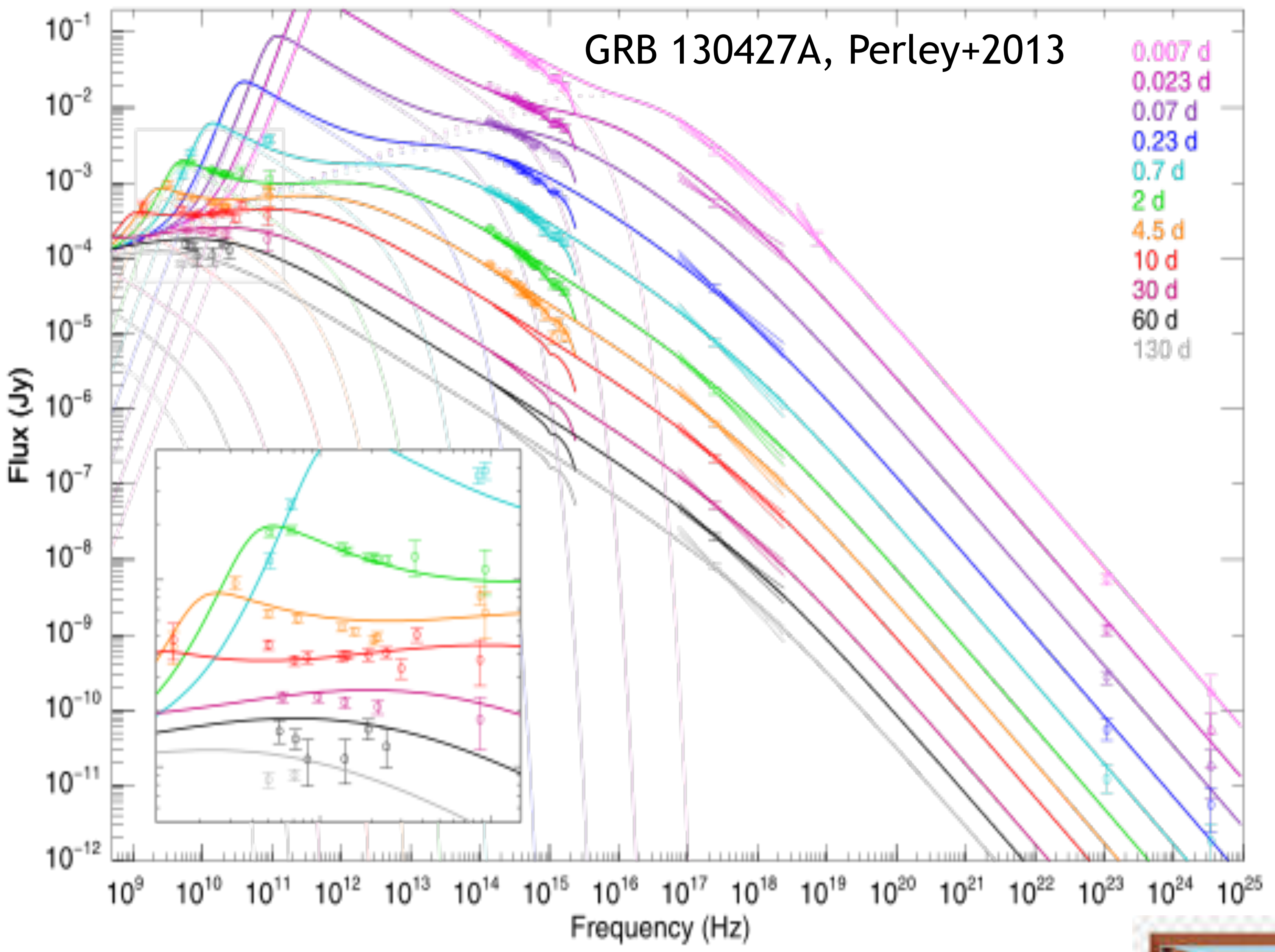
A joint effort of the GW-CTA team:

Alessandro Carosi, Antonio Stamerra, Barbara Patricelli, Brian Humensky, Deivid Ribeiro, Elisabetta Bissaldi Fabian Schüssler, Francesco Longo, Giulia Stratta, Julien.Lefaucheur, Lara Nava, Monica Seglar-Arroyo, Stefano Covino, Susanna Vergani, Susumu Inoue, Thomas Gasparetto, Tristano Di Girolamo and Giancarlo Cella, Massimiliano Razzano.

Poster: B. Patricelli et al. “GW counterparts @ CTA”

Gamma Ray Bursts

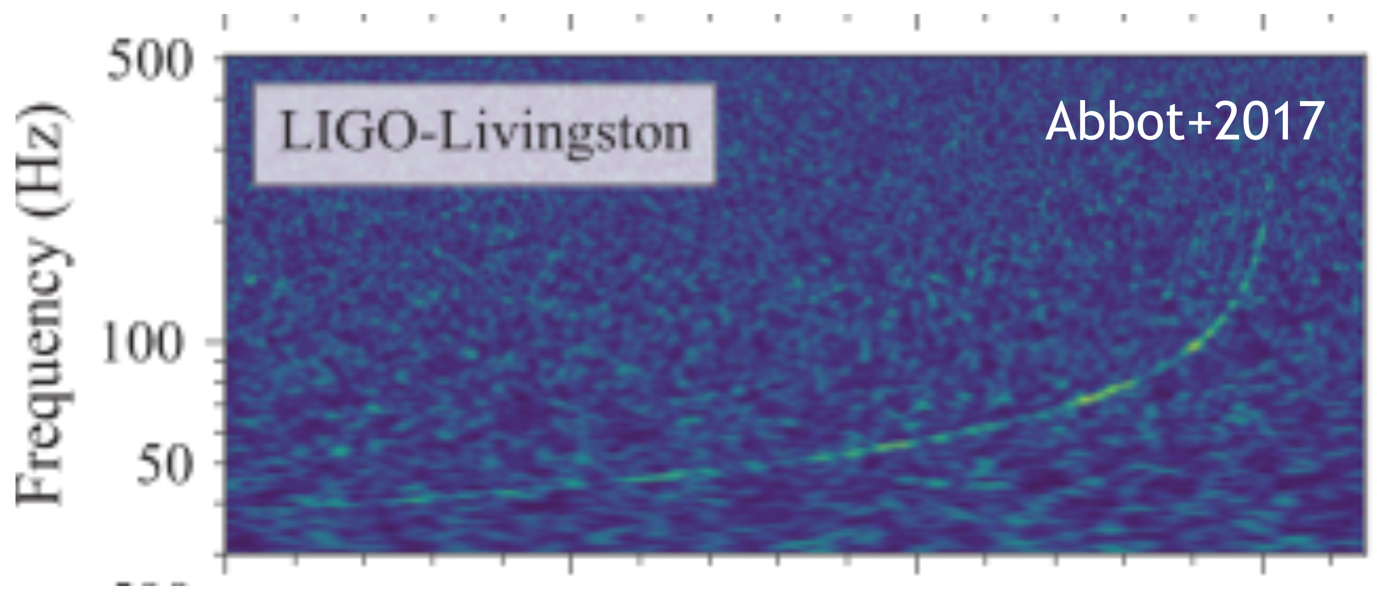
MW = Multi Wavelength

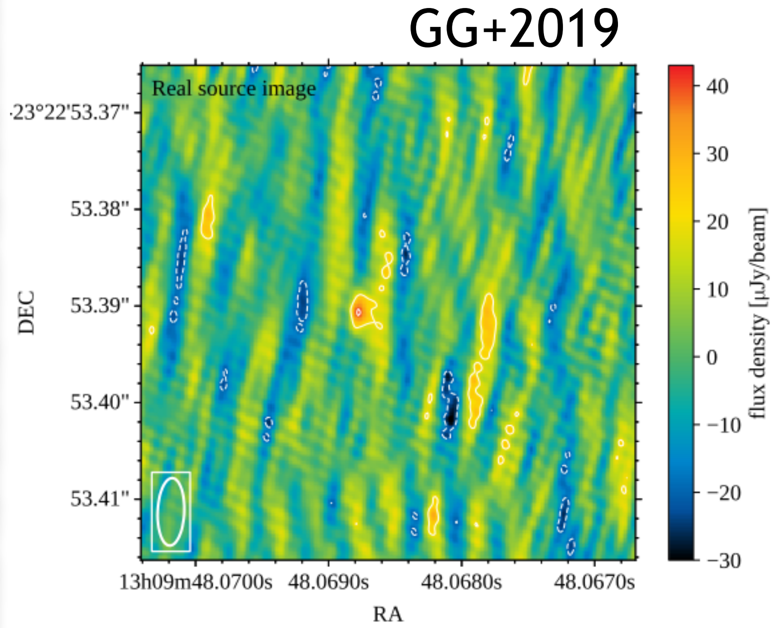


- Jet physics
- Radiative mechanism
- Envurinment

Poster: J. C. Joshi et al.
"SSC & GRB 130427A"

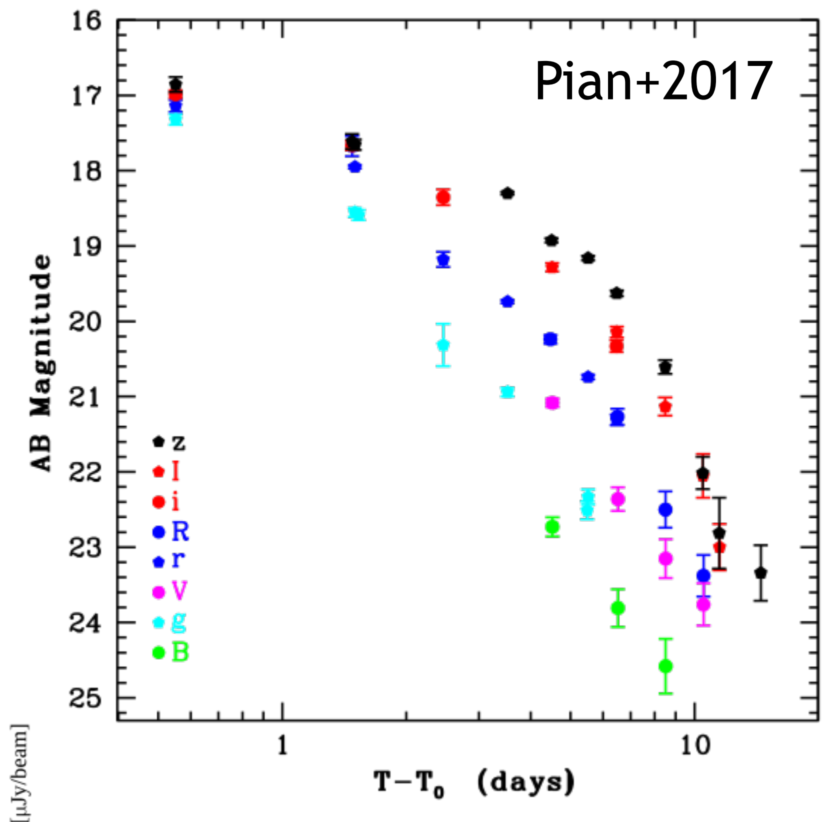
Poster: Zhang et al.
"SSC vs EC for CTA"





Jet image

Jet structure



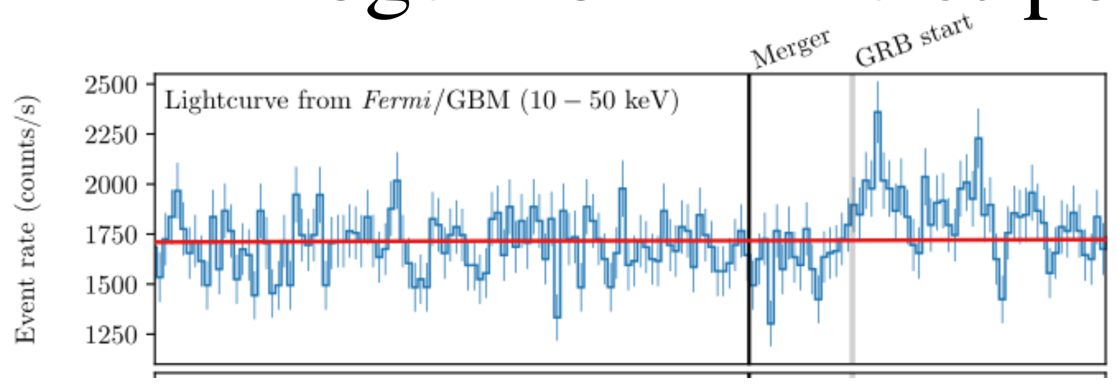
Kilonova

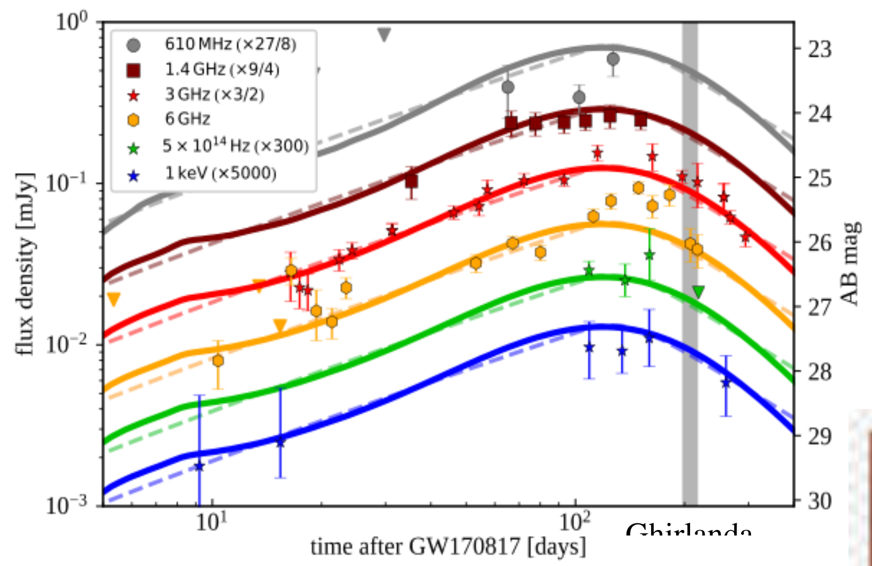
Nuc. physics

MM = Multi Messenger

GW/GRB 170817

- Jet physics
- Radiative mechanism
- Envurinment
- Progenitor nature & pop





Jet emission

Rad. proc./environ.

Radio/mm — NIR/Optical — Xray—MeV/GeV — >10 GeV

Conclusions

(1) Prompt emission spectrum (Optical/X-ray/Gamma-ray < 1MeV): moderate fast cooling synchrotron (but …)

(2) >100 MeV emission: competing prompt and afterglow (early) then afterglow (extended).

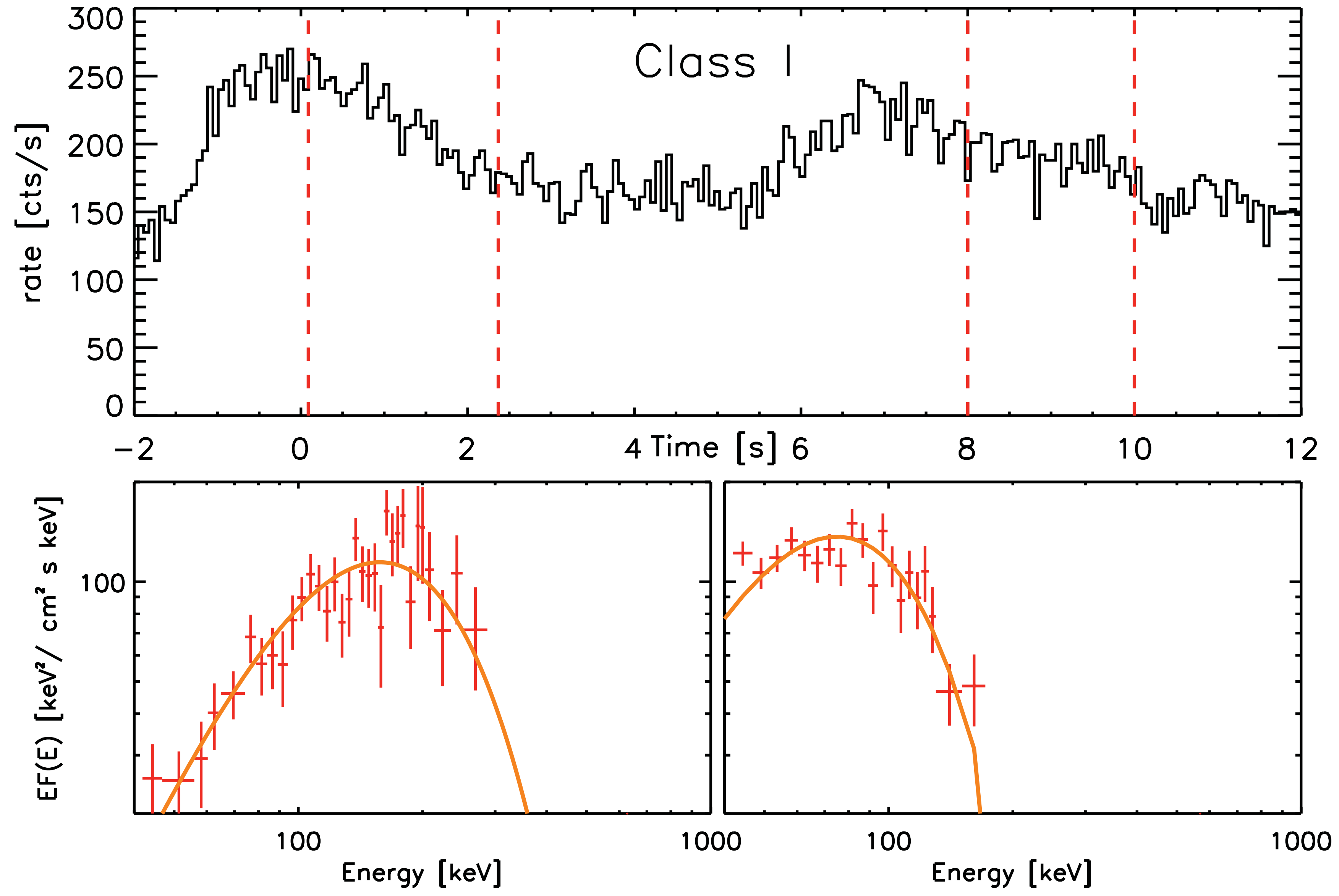
(3) 190114C shows the rise of the afterglow during prompt

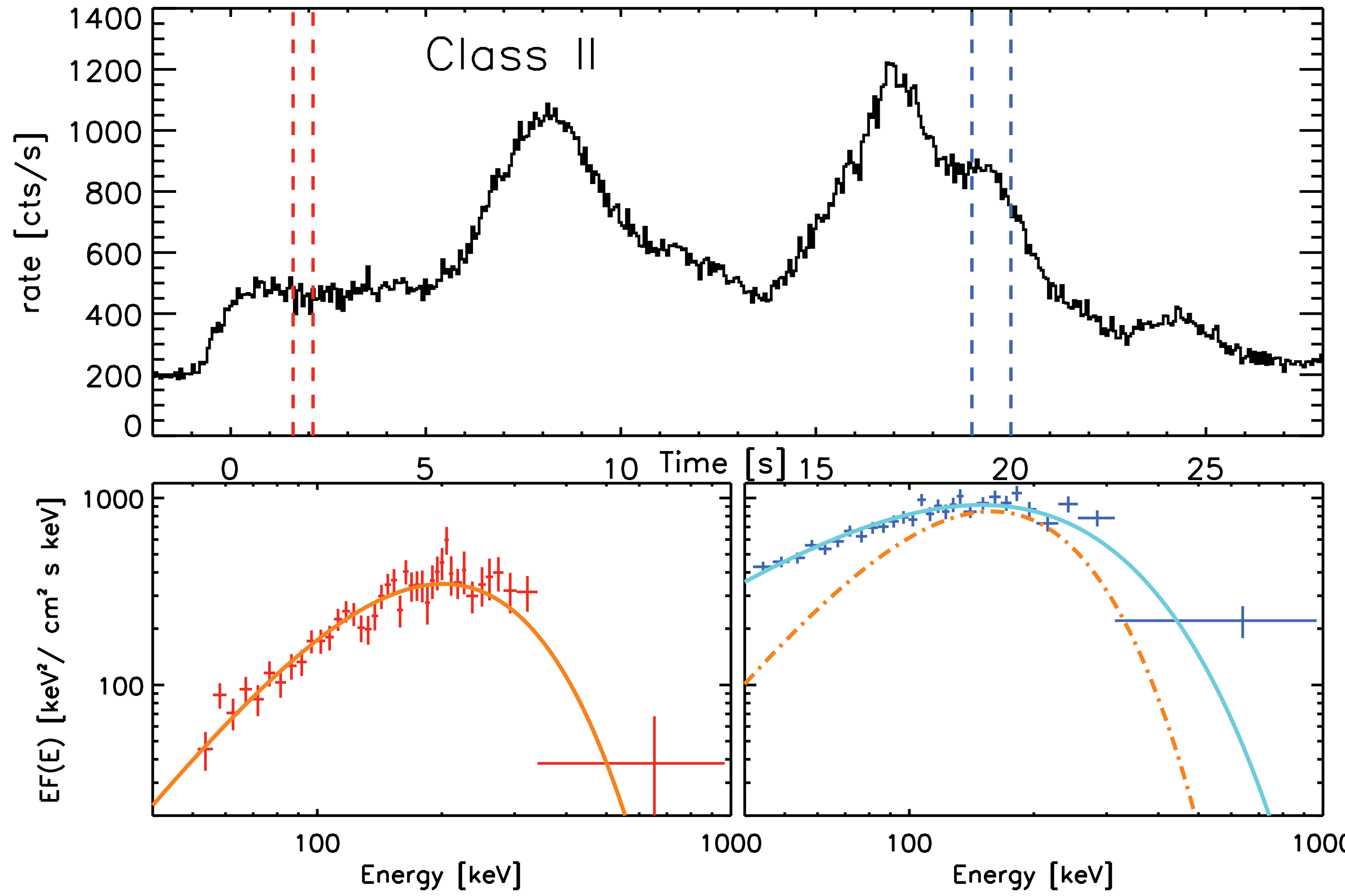
(4) CTA will unveil the GRB physics: high photon statistics

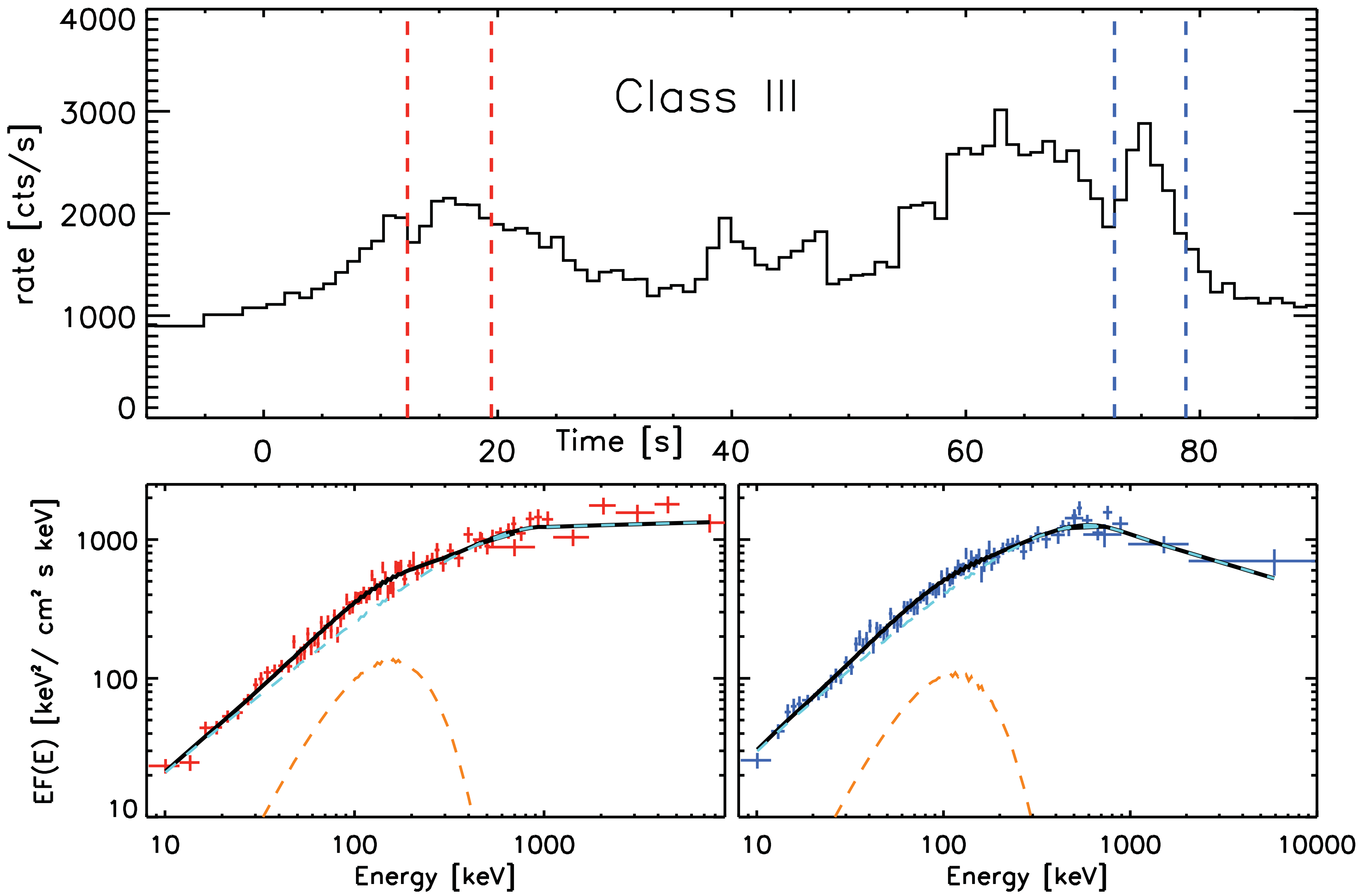
	Observable	Constrain	Impact
Prompt	Shape > nu_m cutoff(t) SSC	Bulk Lorentz factor Parameter space	Jet acceleration mechanism Prompt emission mechanism
Afterglow	Max Energy Variability (>>E) Early to extended transition	GeV-TeV emission alone MW modeling	Afterglow emission mechanism Extrinsic parameters GRB effects on the ambient
GRBs as tools	EBL cutoff		EBL
GRBs as tools	Photon(E,t)		LIV

Thermal (BB) components in Gamma Ray Burst prompt emission

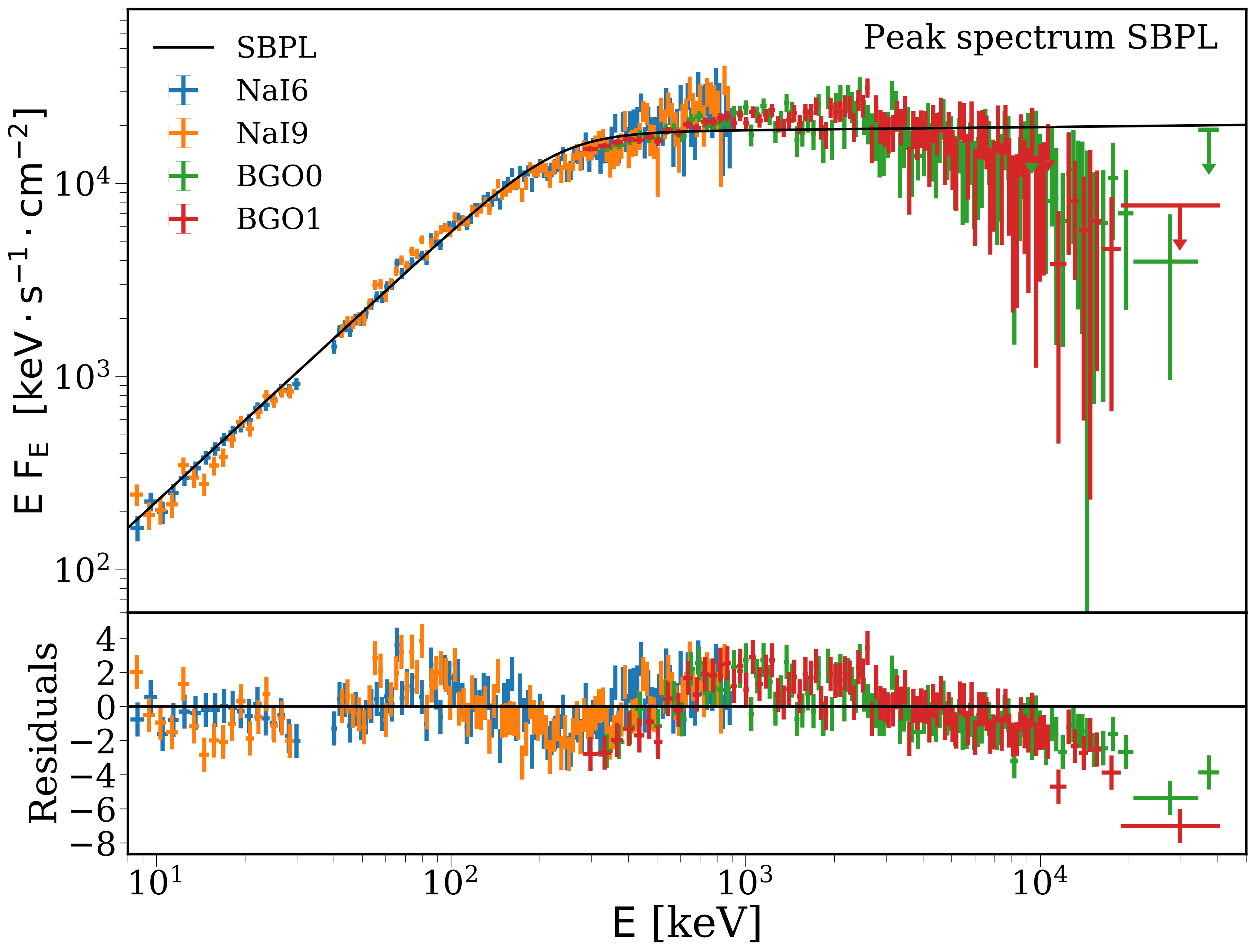
Ghirlanda et al. 2013

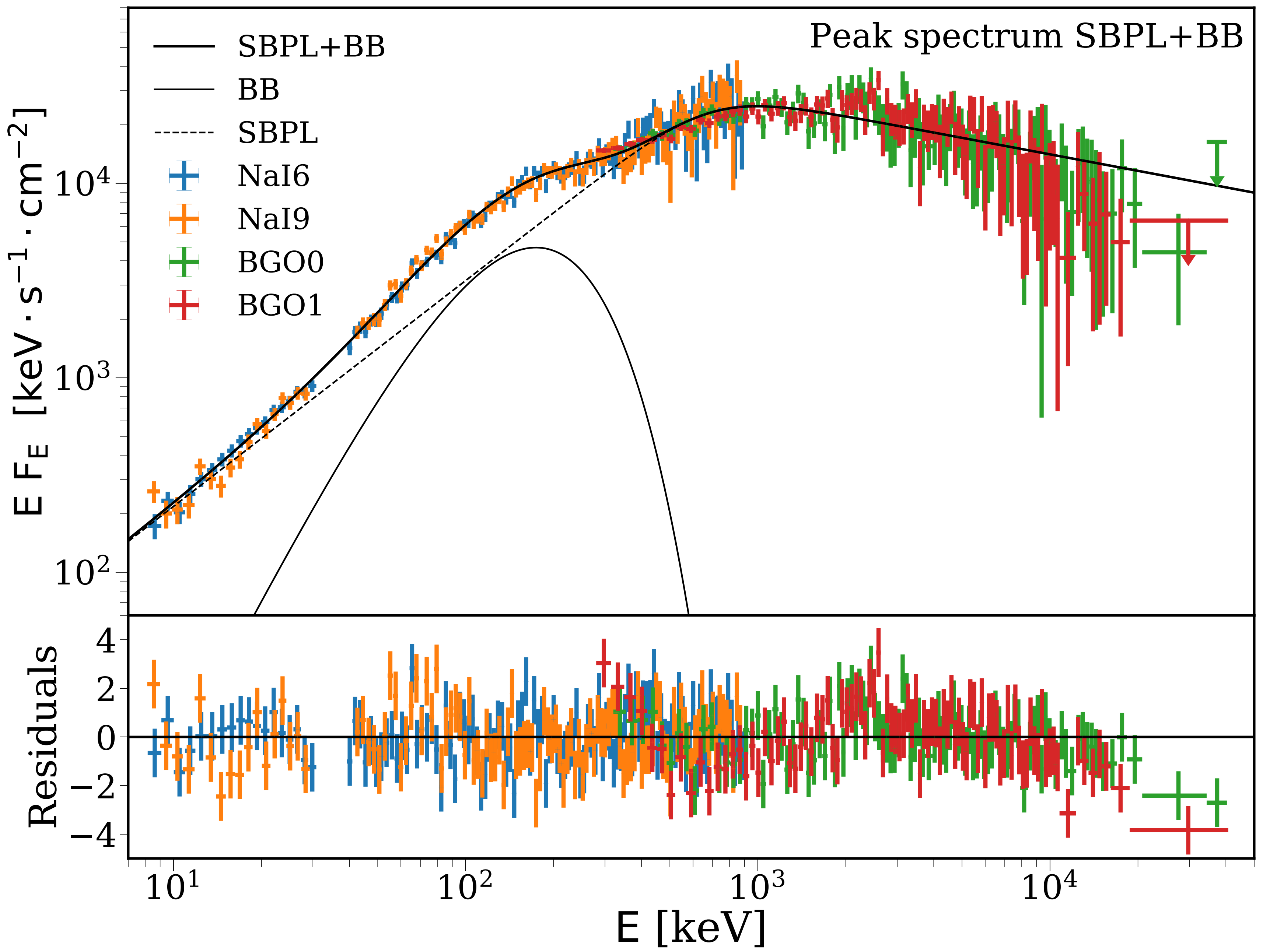


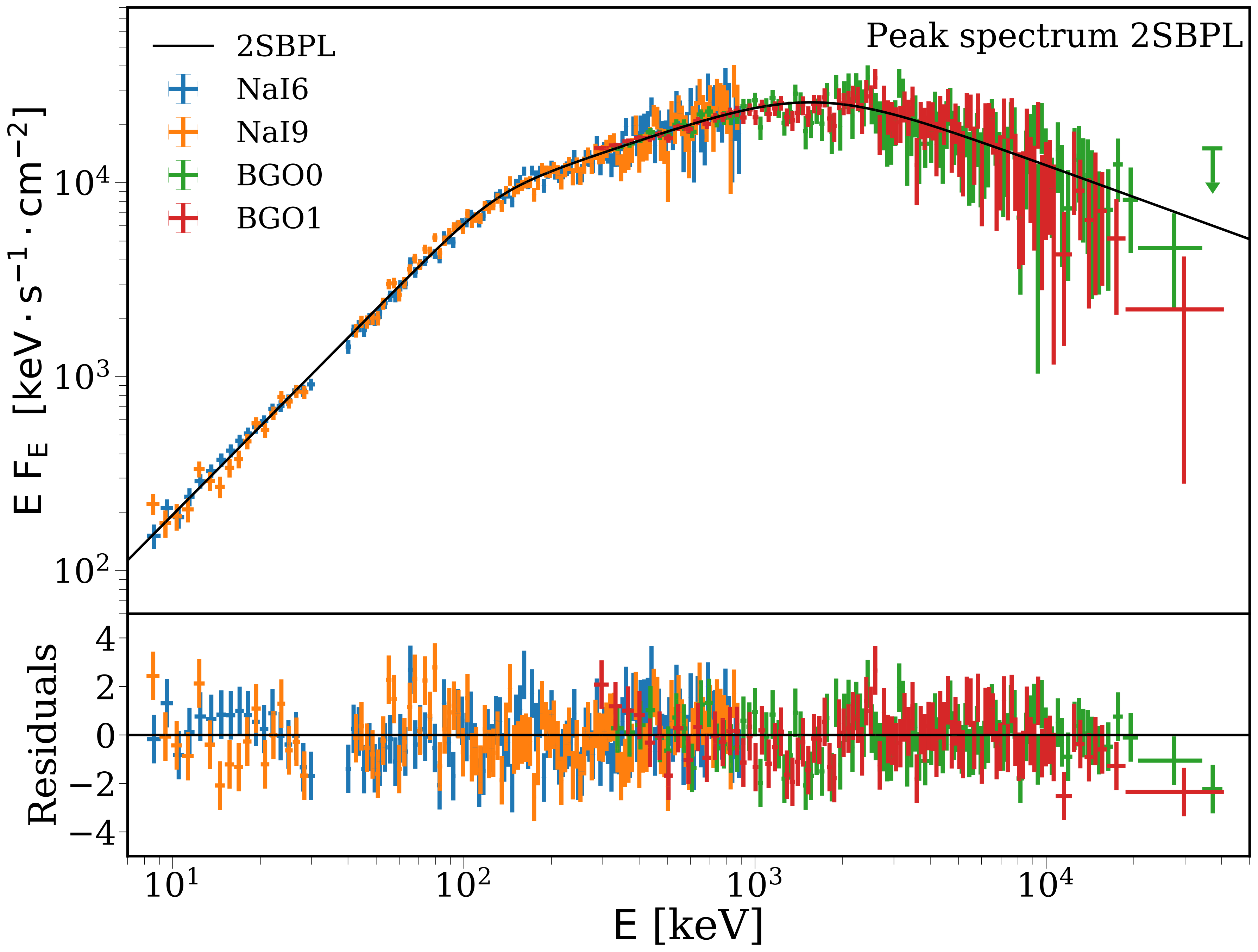




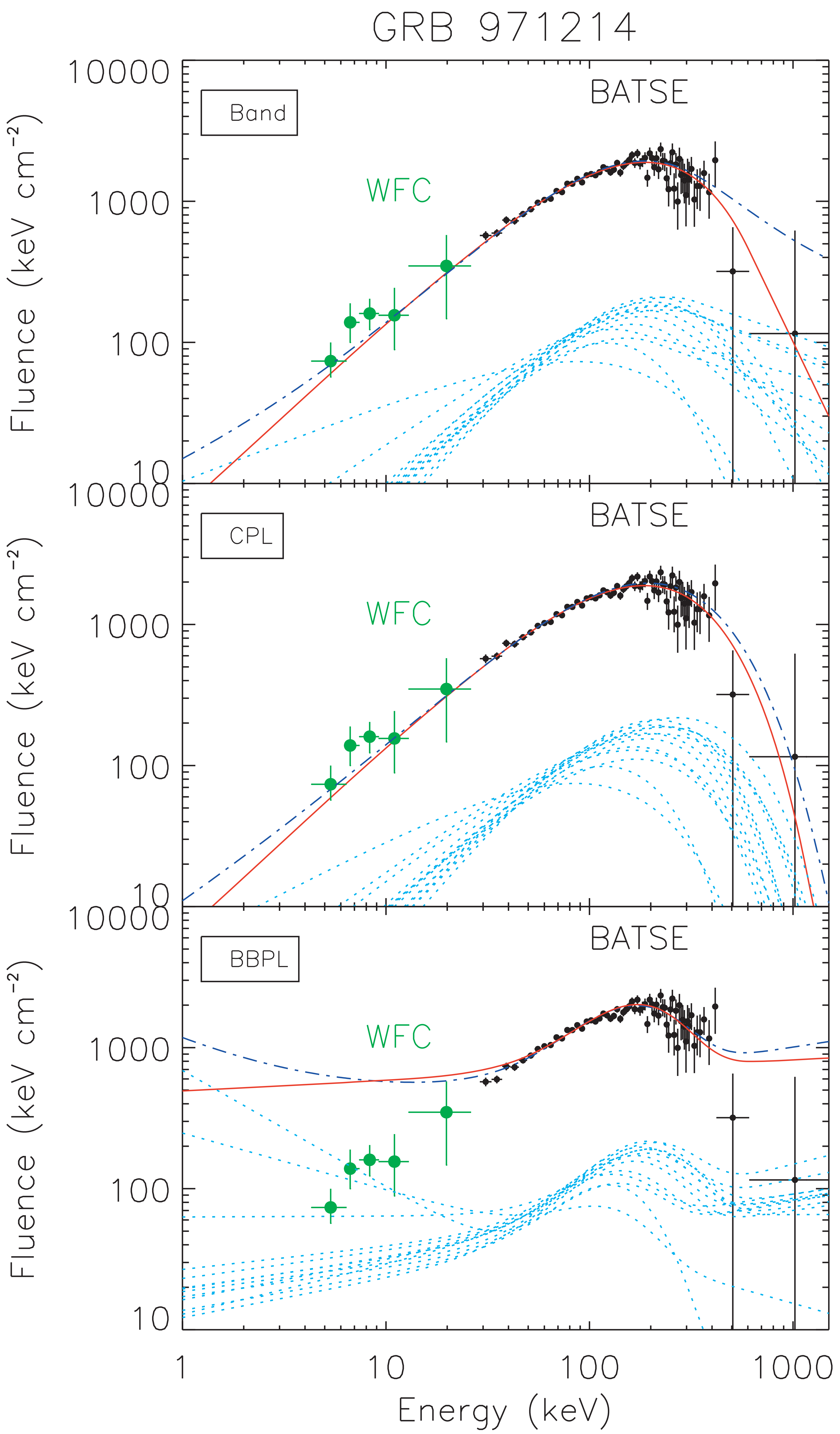
Why not before?

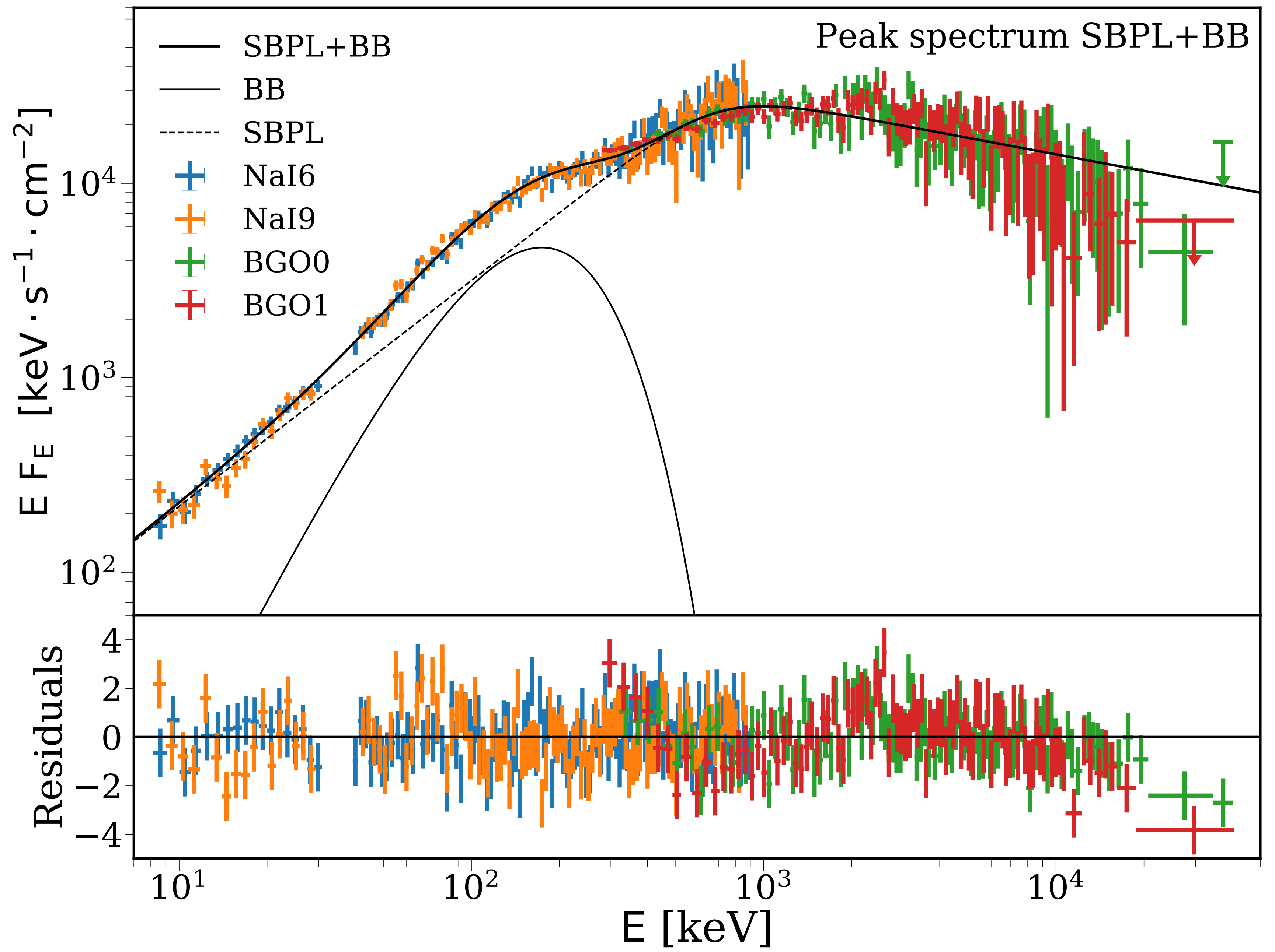


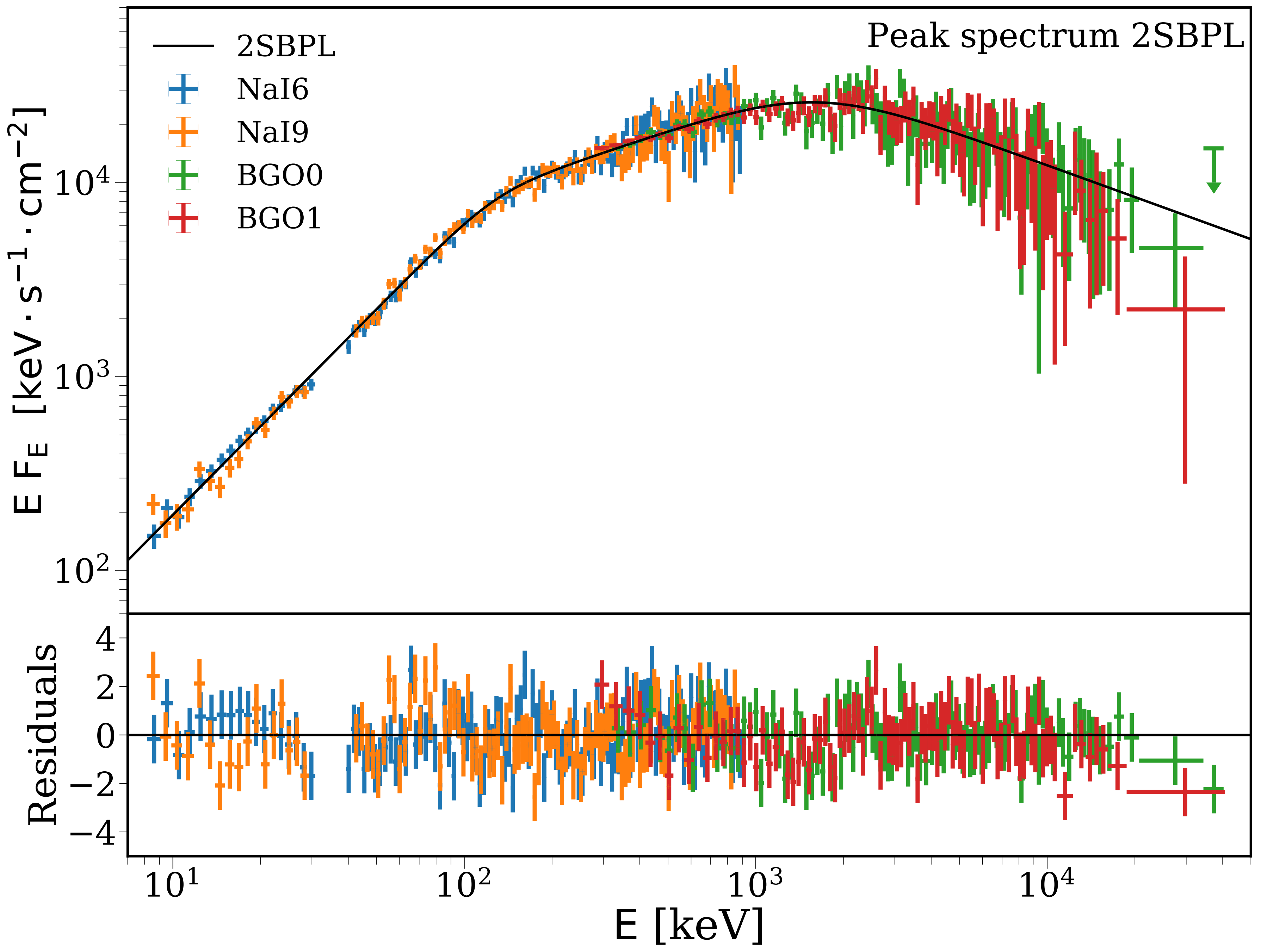




Why not before?

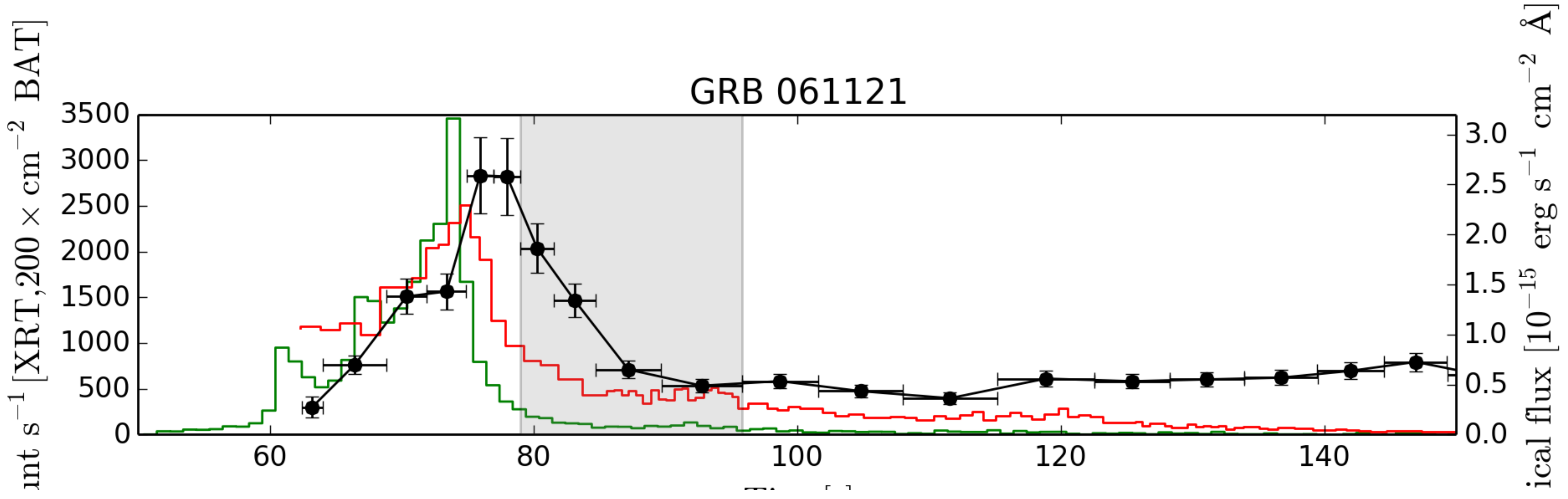


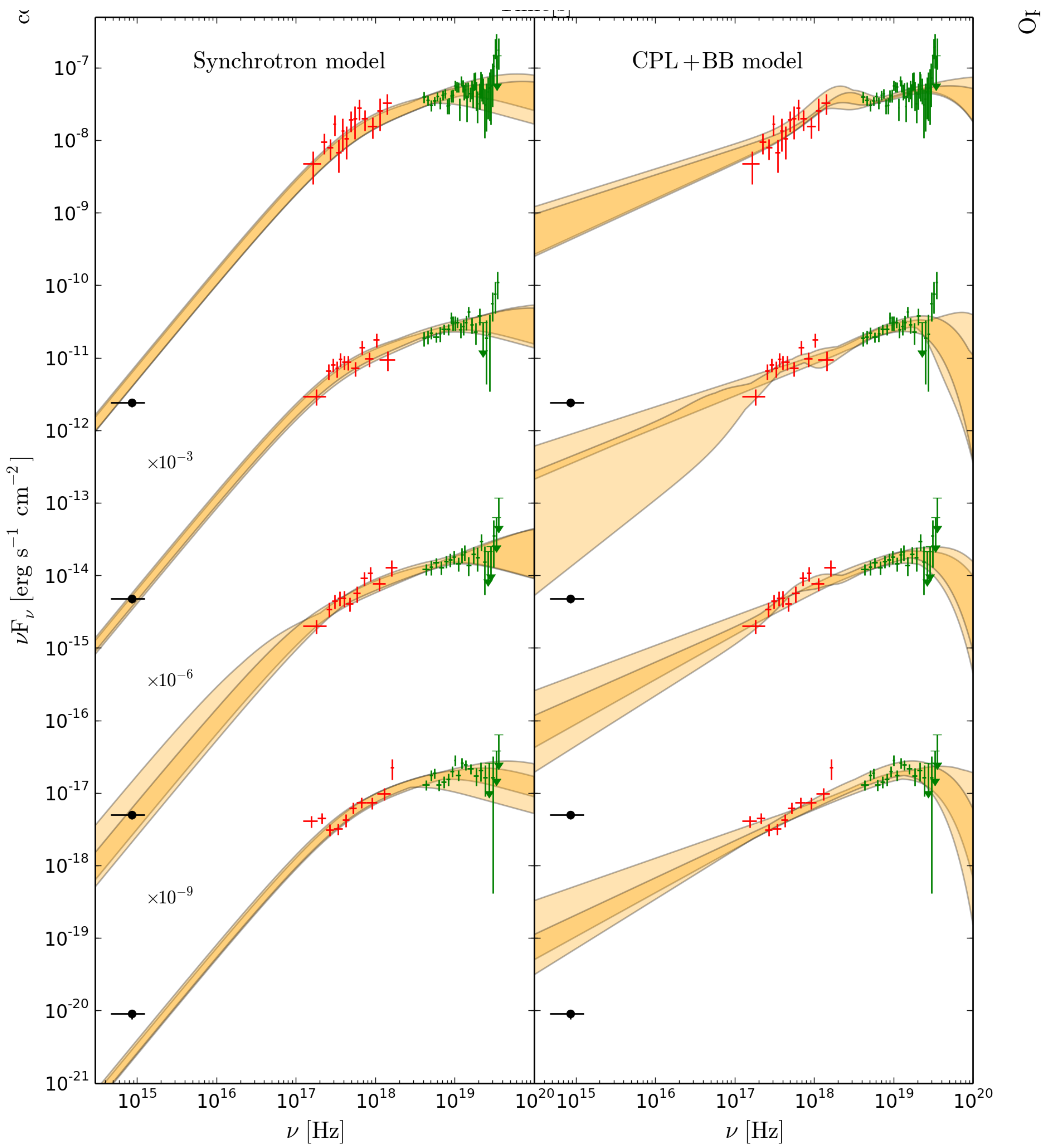




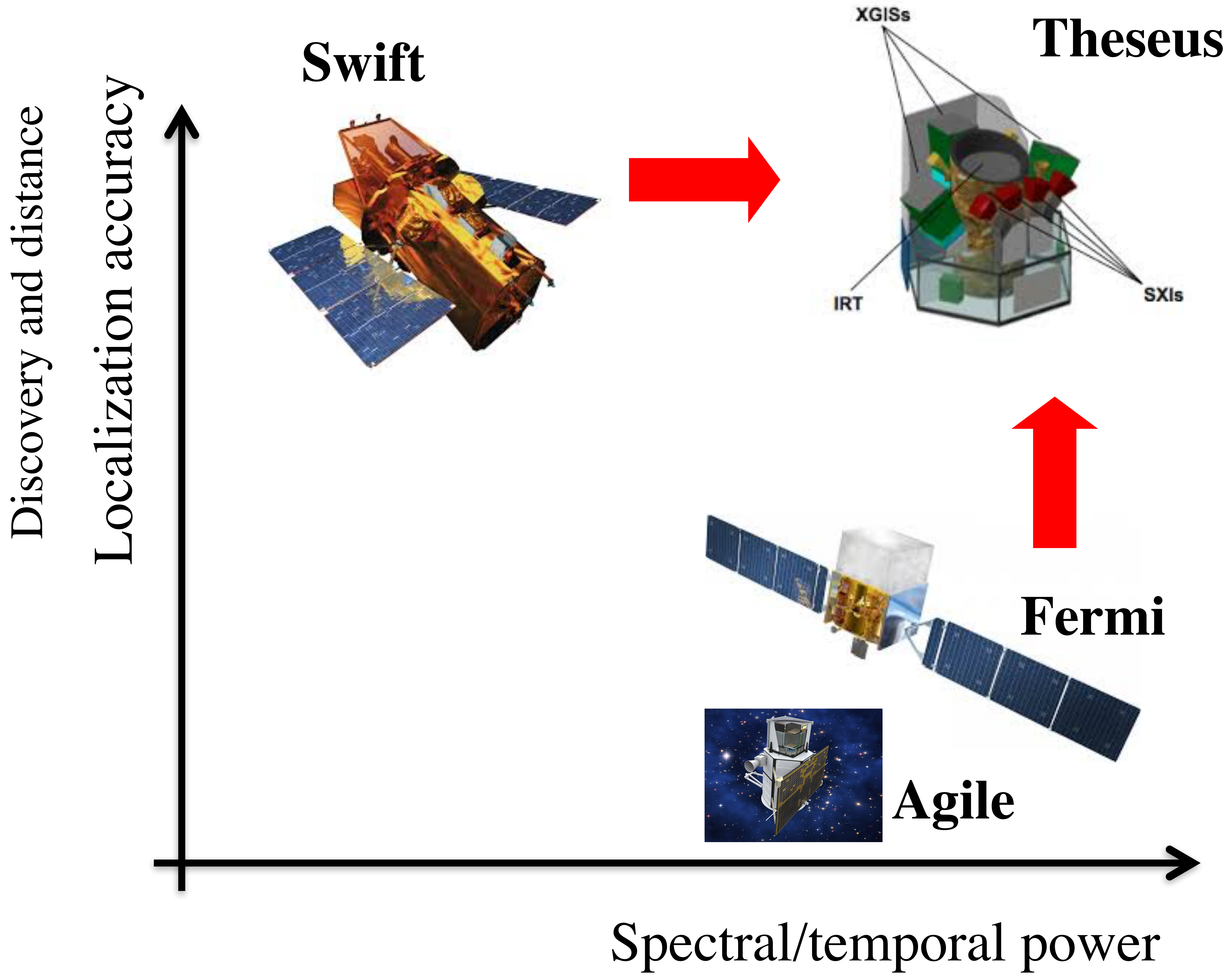
Black Boldy + Non-thermal component excluded

Oganesyan et al. 2019





What next?



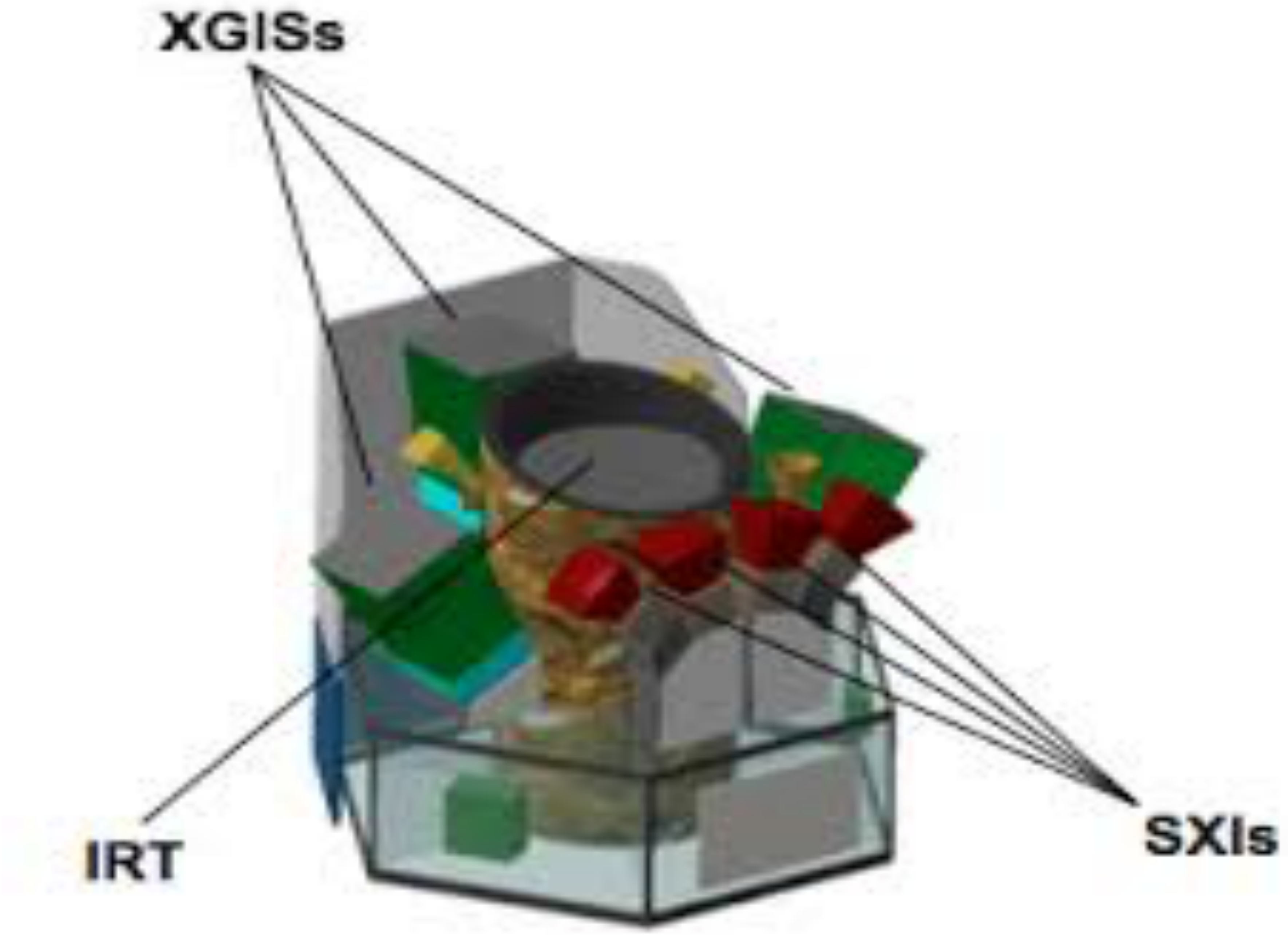
Physics behind (emission mechanisms, acceleration)

Theseus

https://www.isdc.unige.ch/theseus/mission-payload-and-profile.html?

showall=1&limitstart=

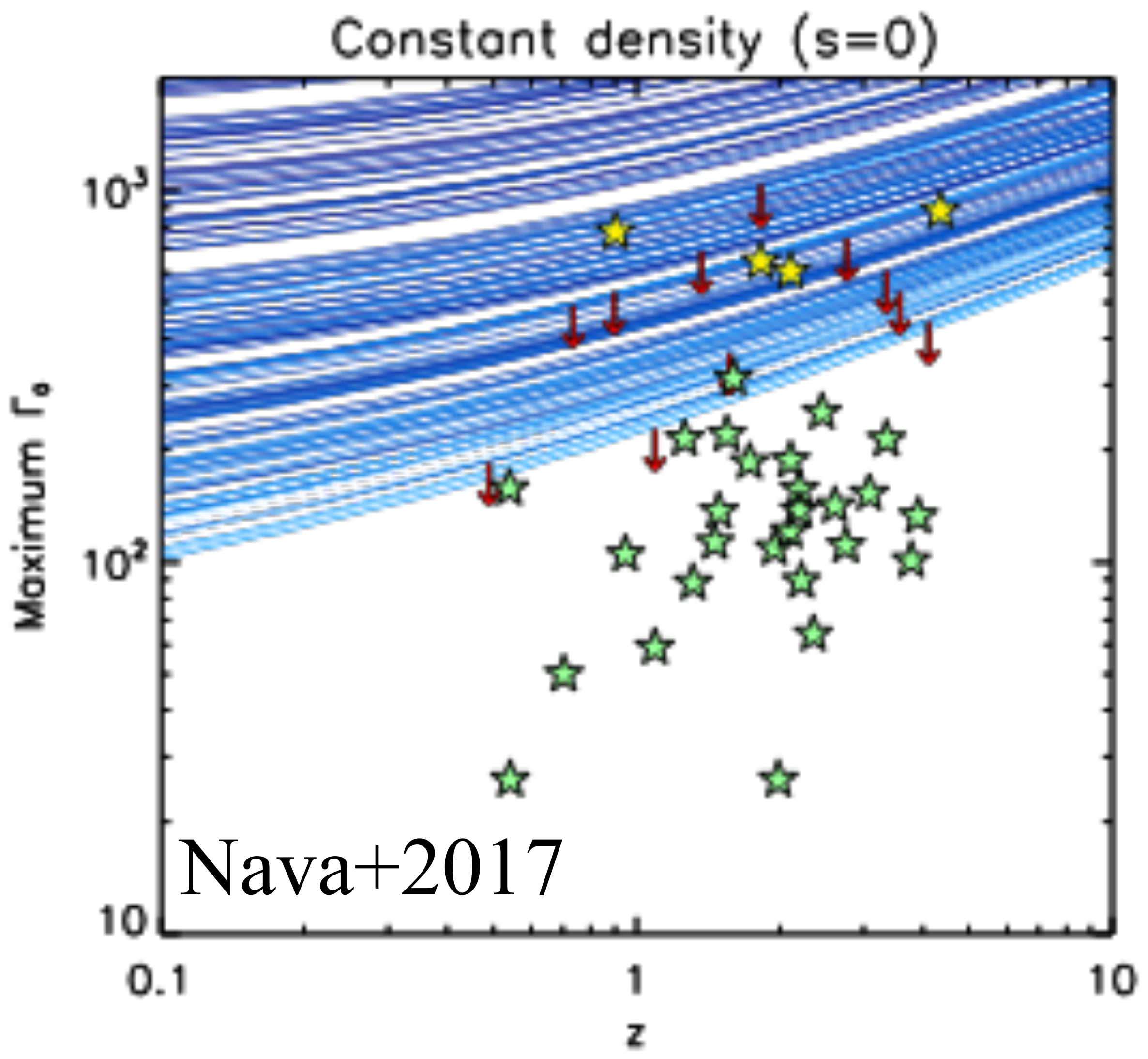
4 modules (composite Masks+Scintillators)
2keV-20MeV
<5 arcmin



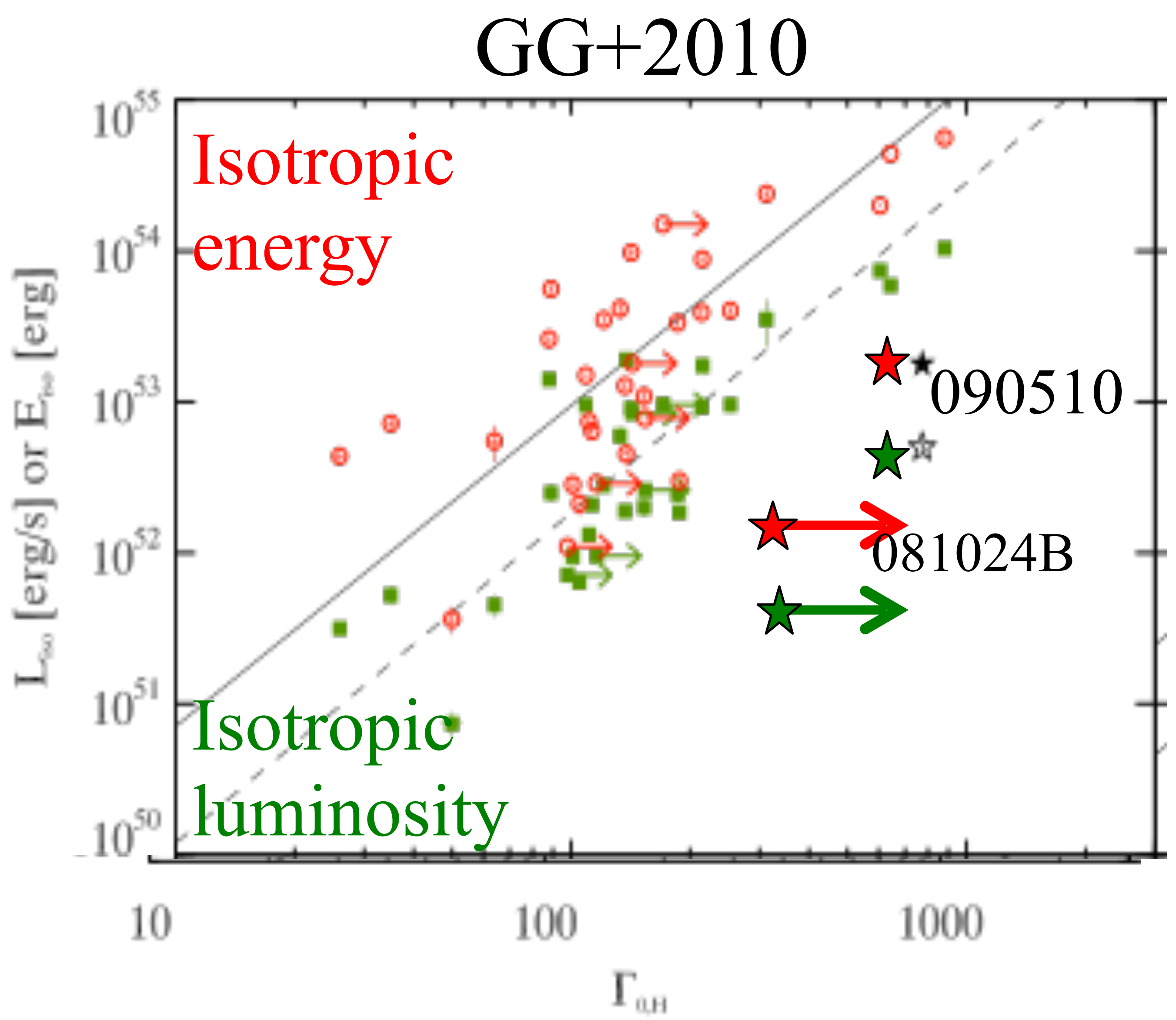
10’x10’
0.7-1.8 μm
H=20

4 modules (1sr fov each)
0.3-5 keV
<10 arsec

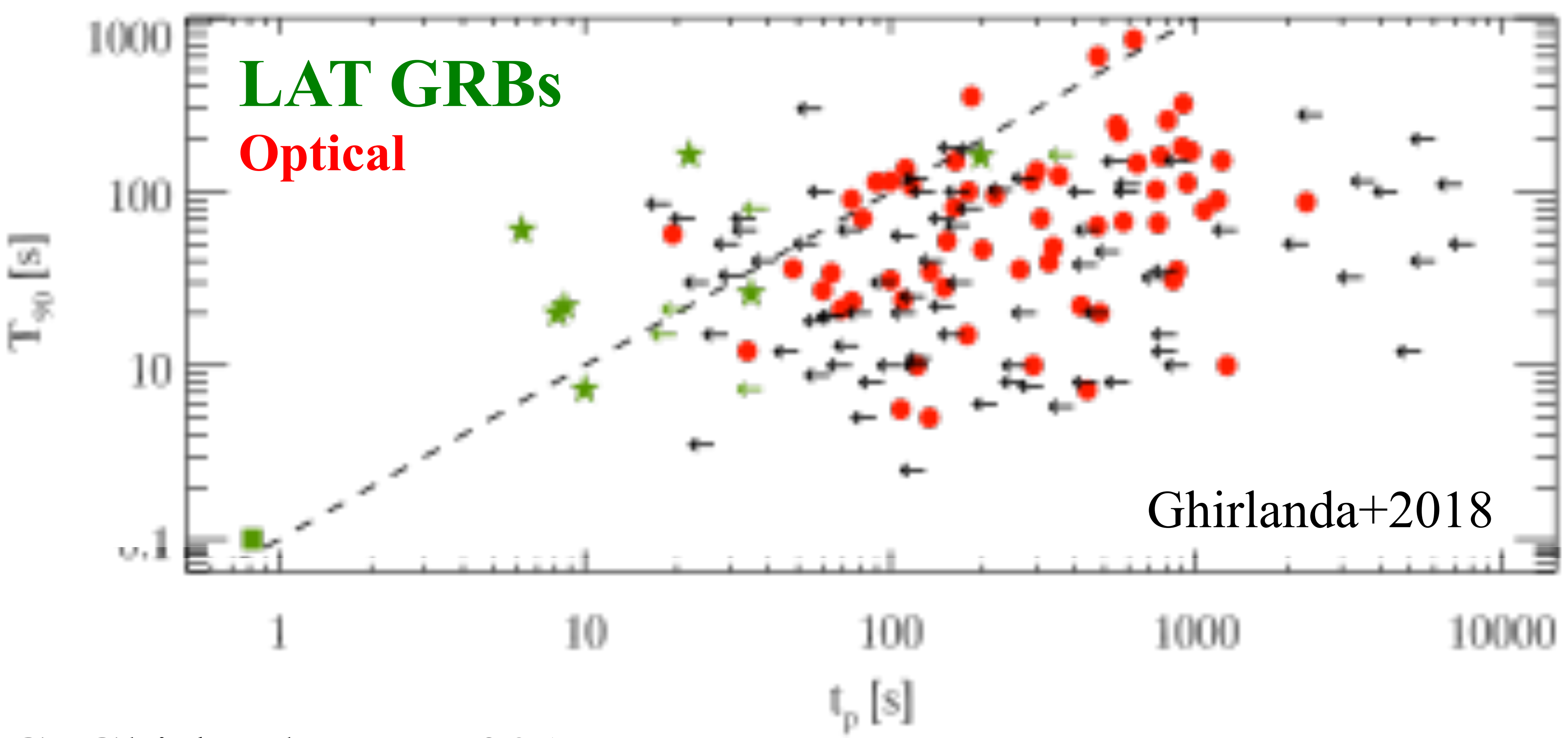
Bulk Lorentz factor

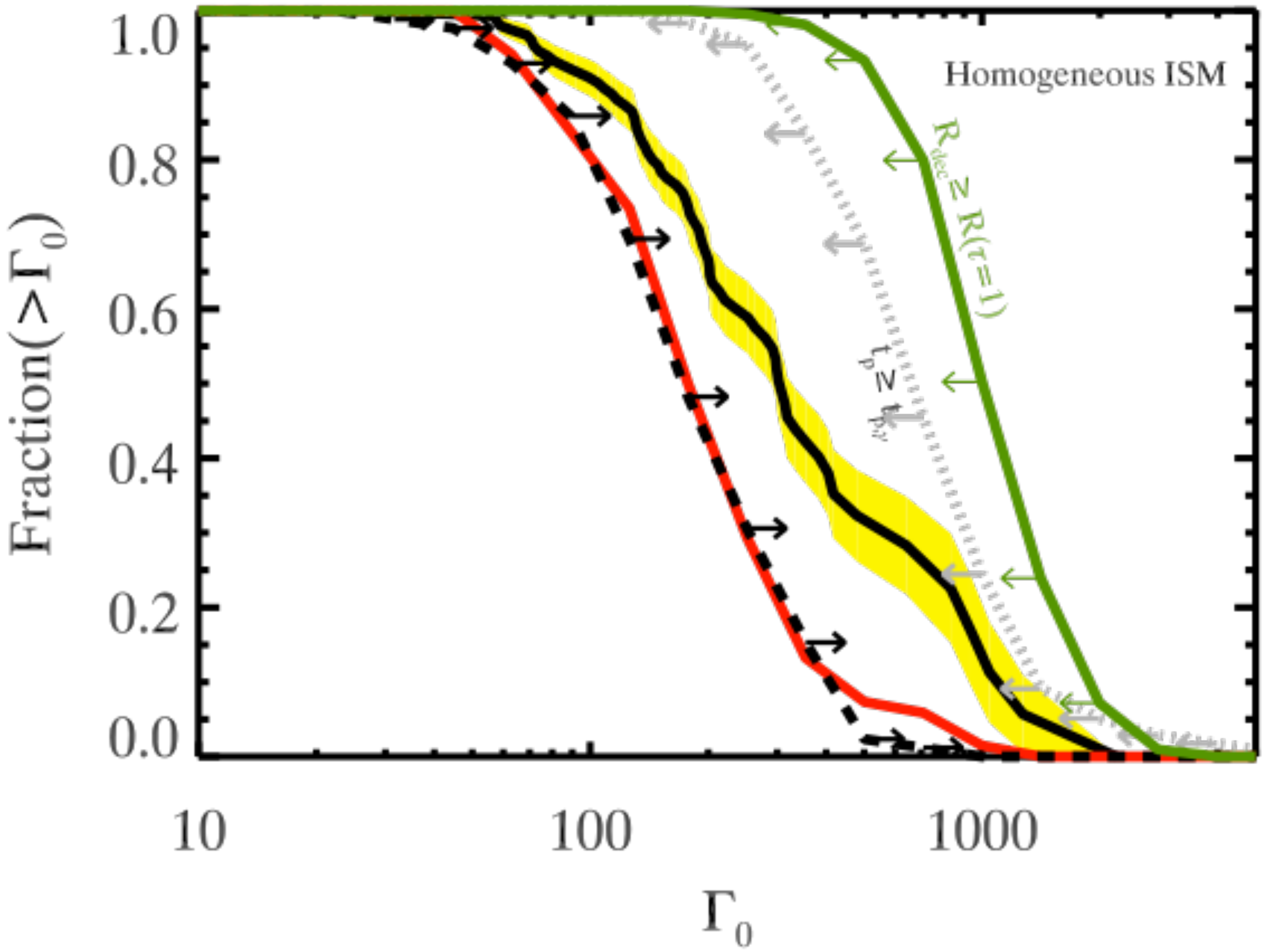


Bulk Lorentz factor and Jet opening angle could be related [e.g. McKinney 2009] [GG+2011] $\vartheta^2\Gamma$=const



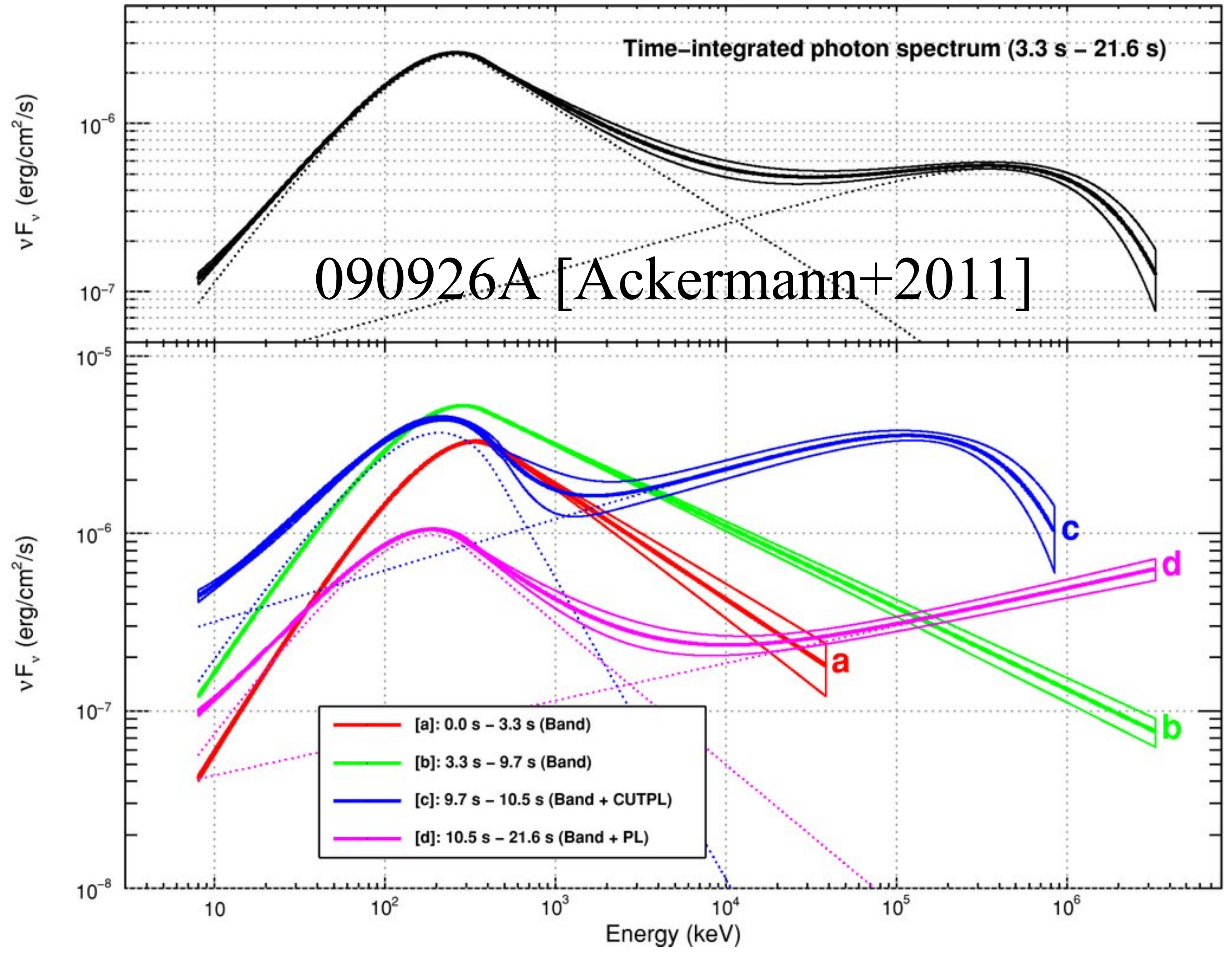
Estimate of Γ_0 from the peak of the afterglow





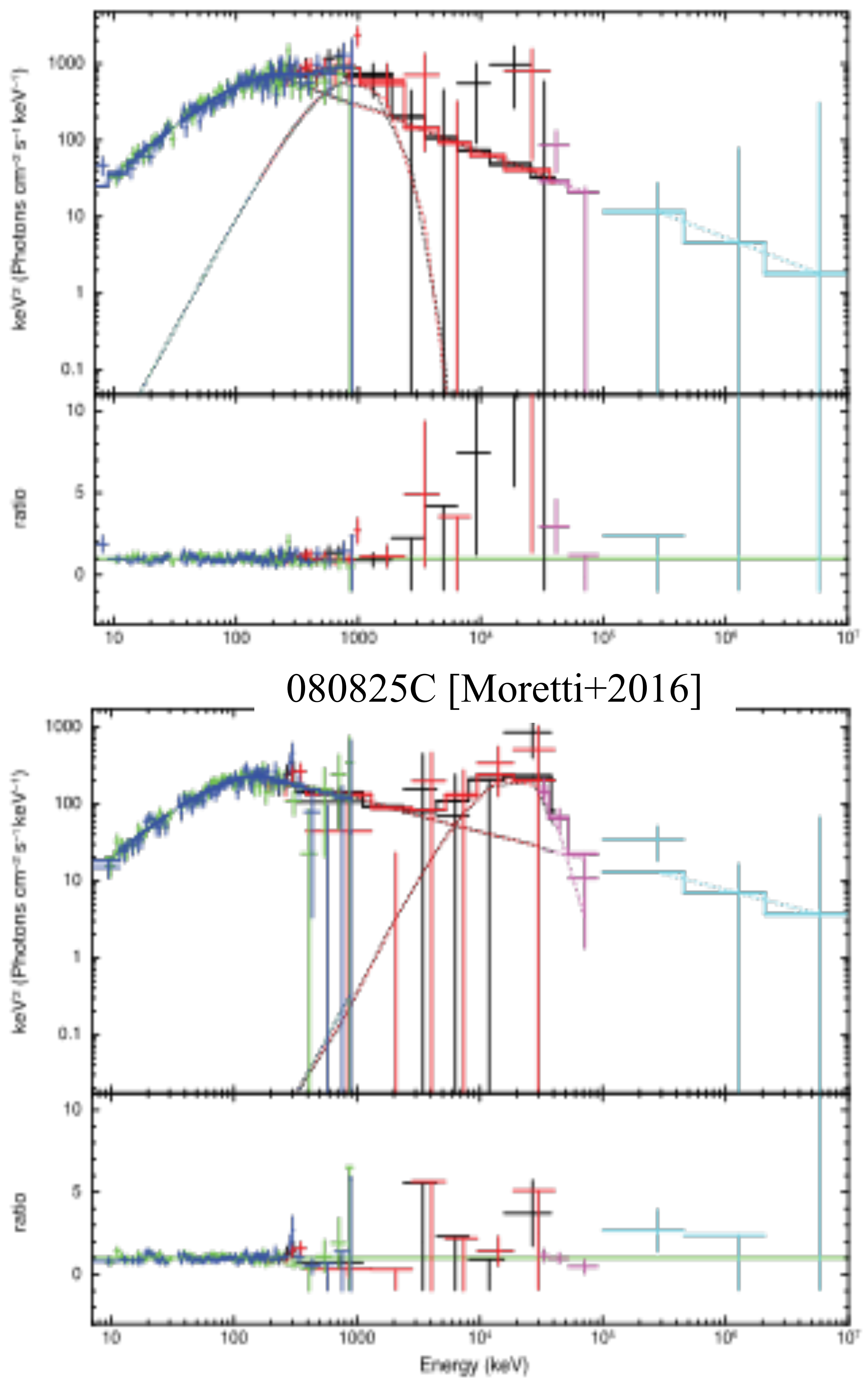
GeV emission

Transient spectral break (or cutoff?) @ 1.4 GeV



090926A [Ackermann+2011]

Additional peaked MeV component

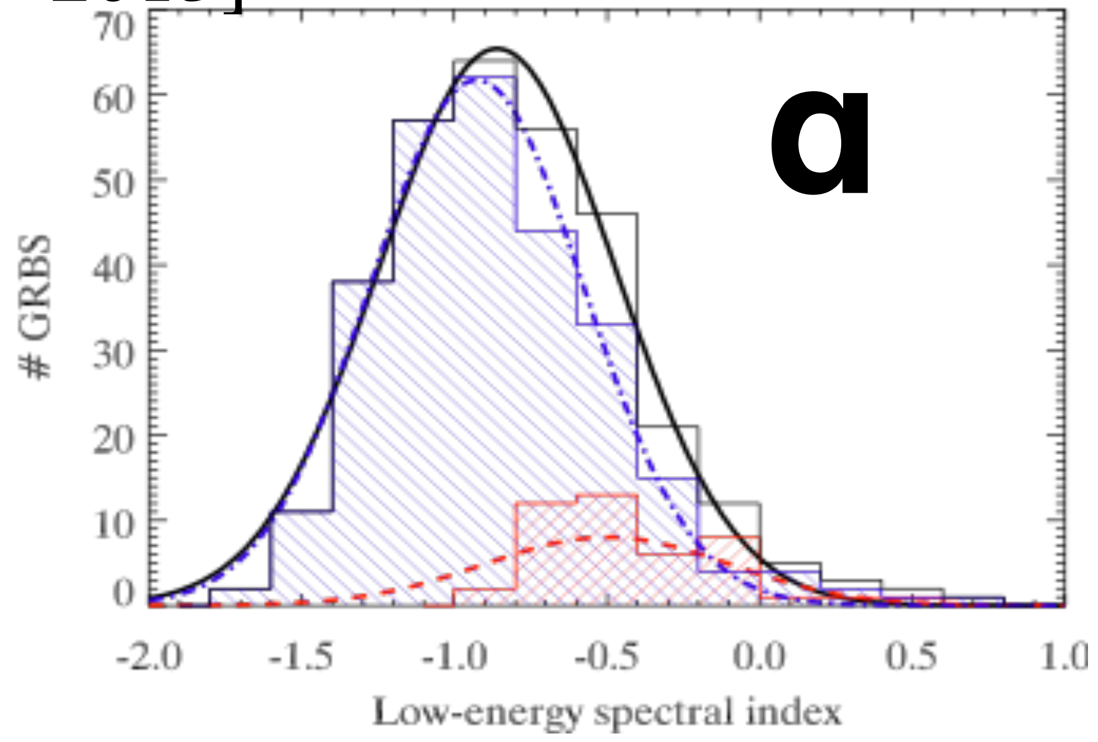


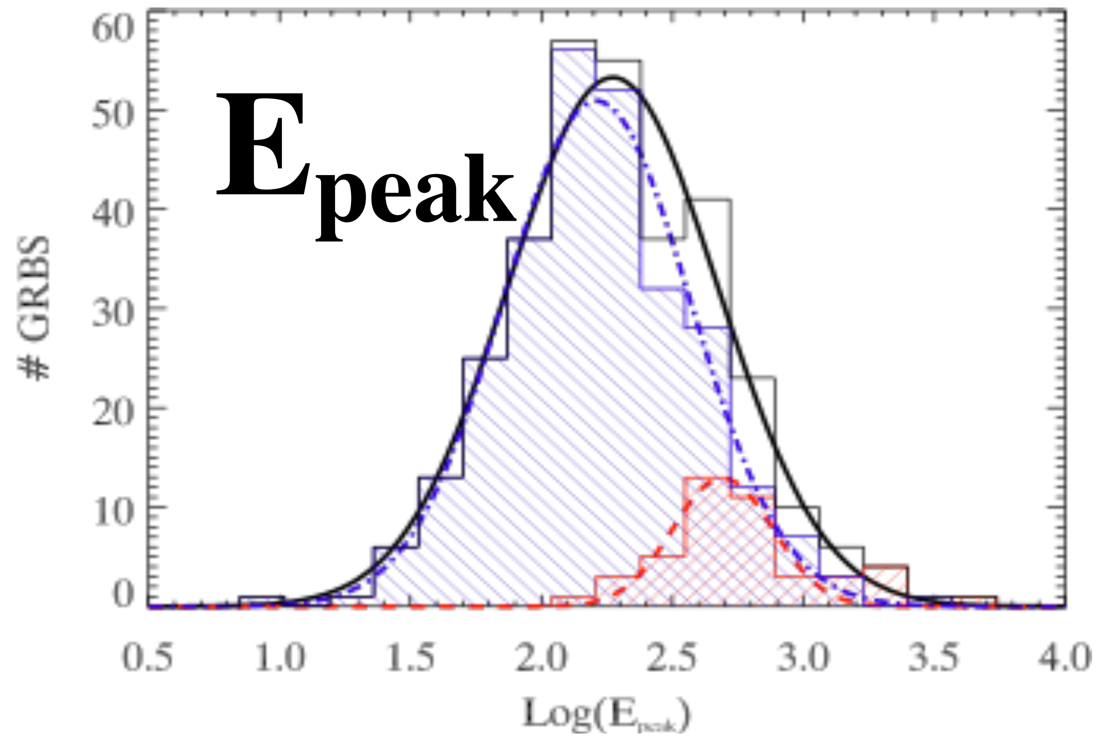
080825C [Moretti+2016]

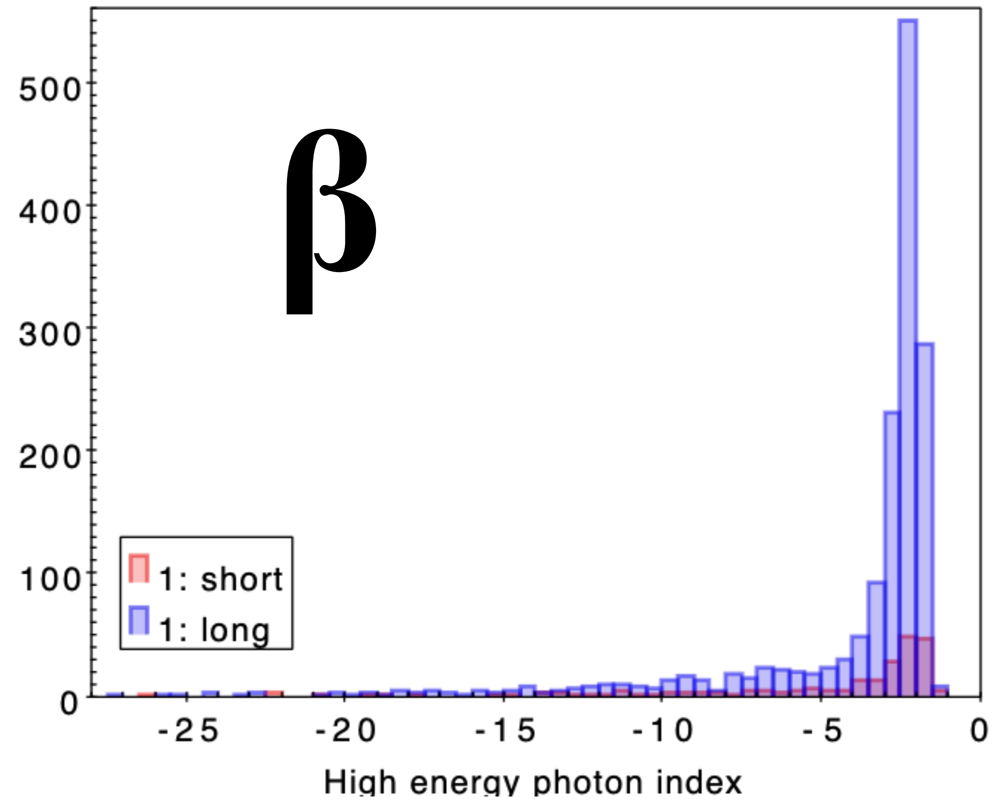
- Intrinsic apsorption
- Emission mechanism (IC in KN regime)

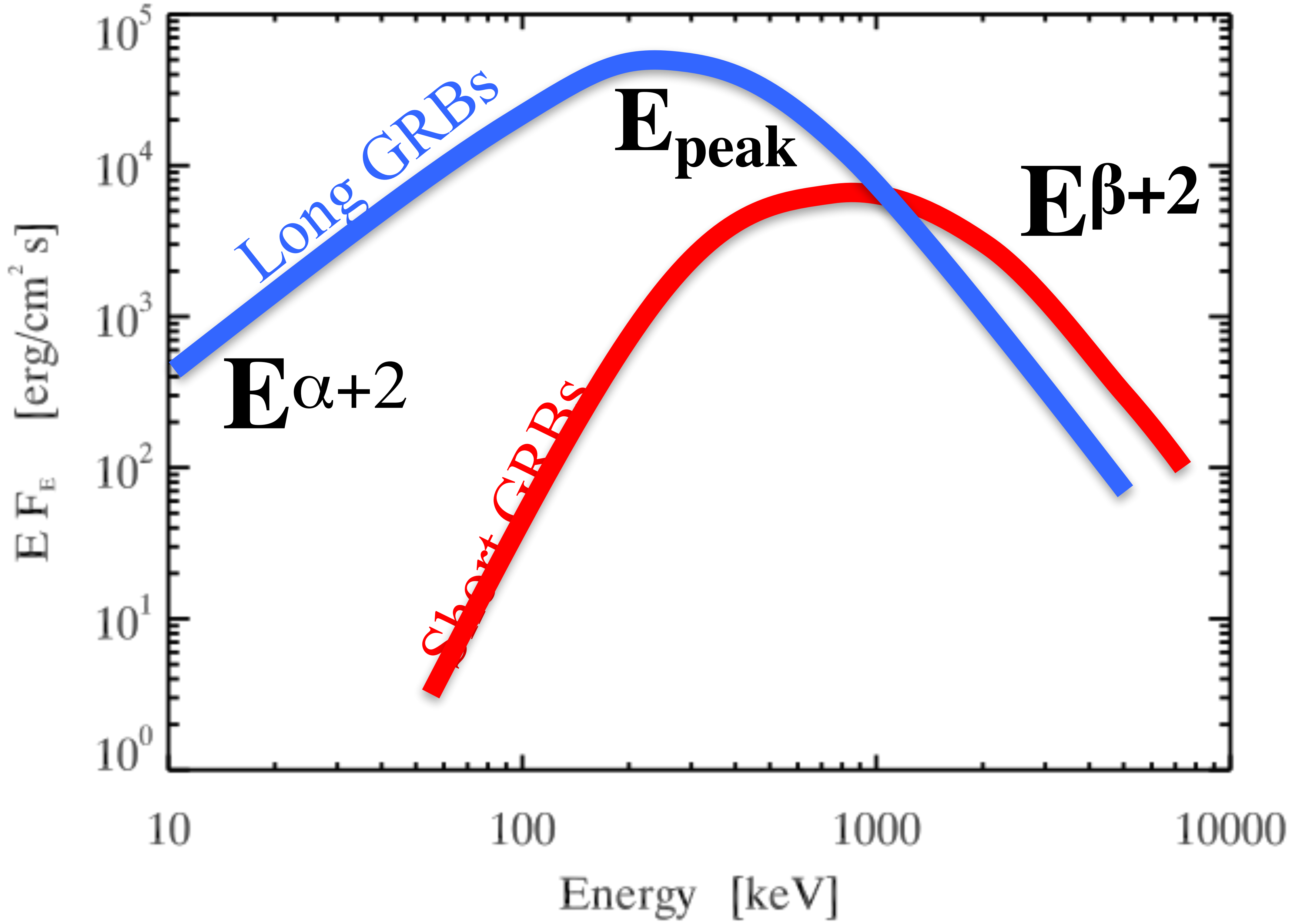
Prompt γ-ray emission: how does it look like?

BATSE-CGRO [Band+1998;Preece+2000; GG+2003], **BeppoSAX** [Frontera+2006]; **Fermi** [Goldstein+2010; Ghirlanda+2011; Nava+2011; Gruber 2014]; **Integral** [Vianello 2008]; **Swift** [Sakamoto 2013]







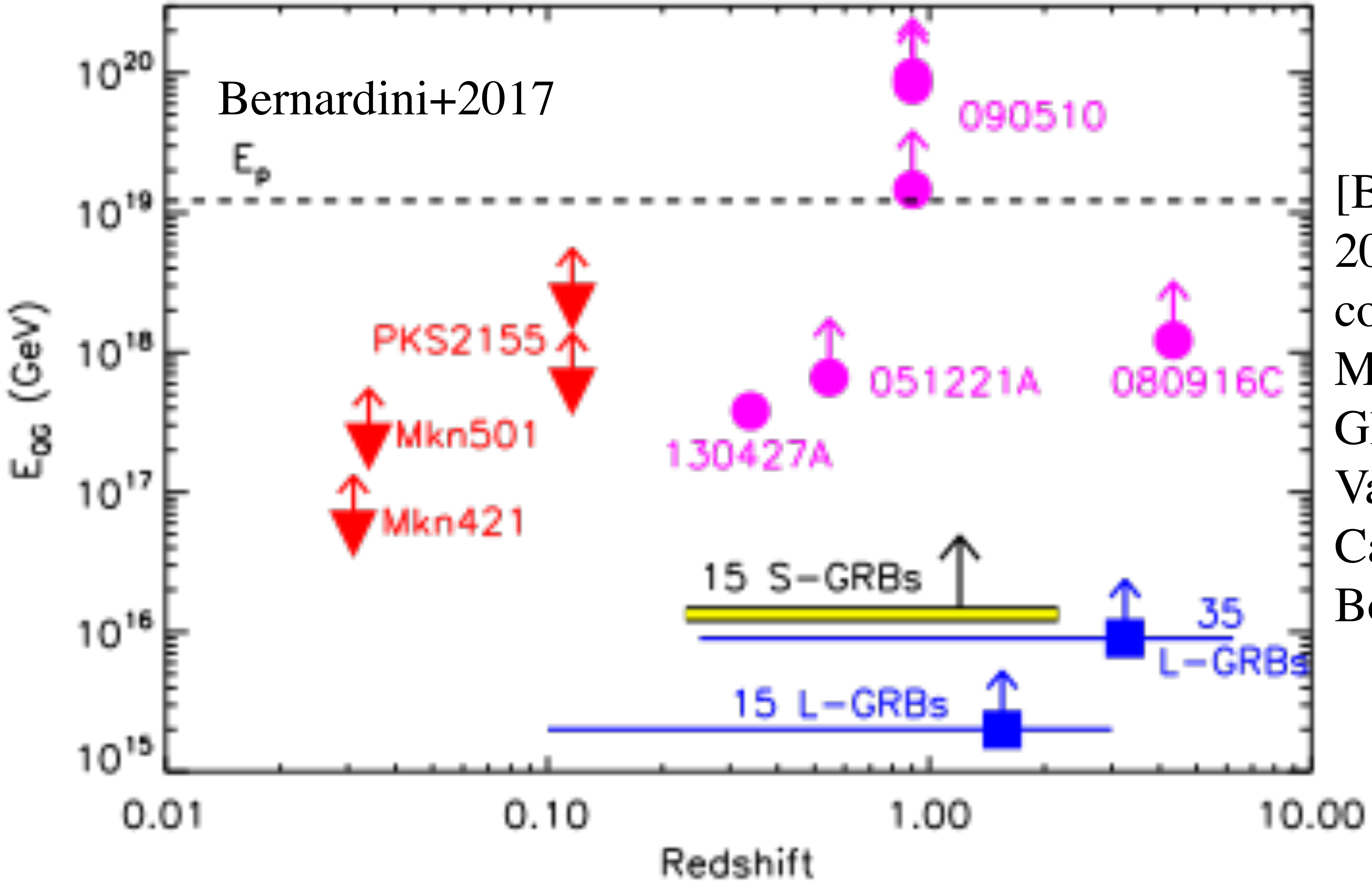


Lorentz Invariance Violation

$$E_{QG} = \frac{1}{H_0} \boxed{\frac{\Delta E}{\Delta t}} \int_0^z \frac{(1+z)}{\sqrt{\Omega_\Lambda + \Omega_m (1+z)^3}} dz$$

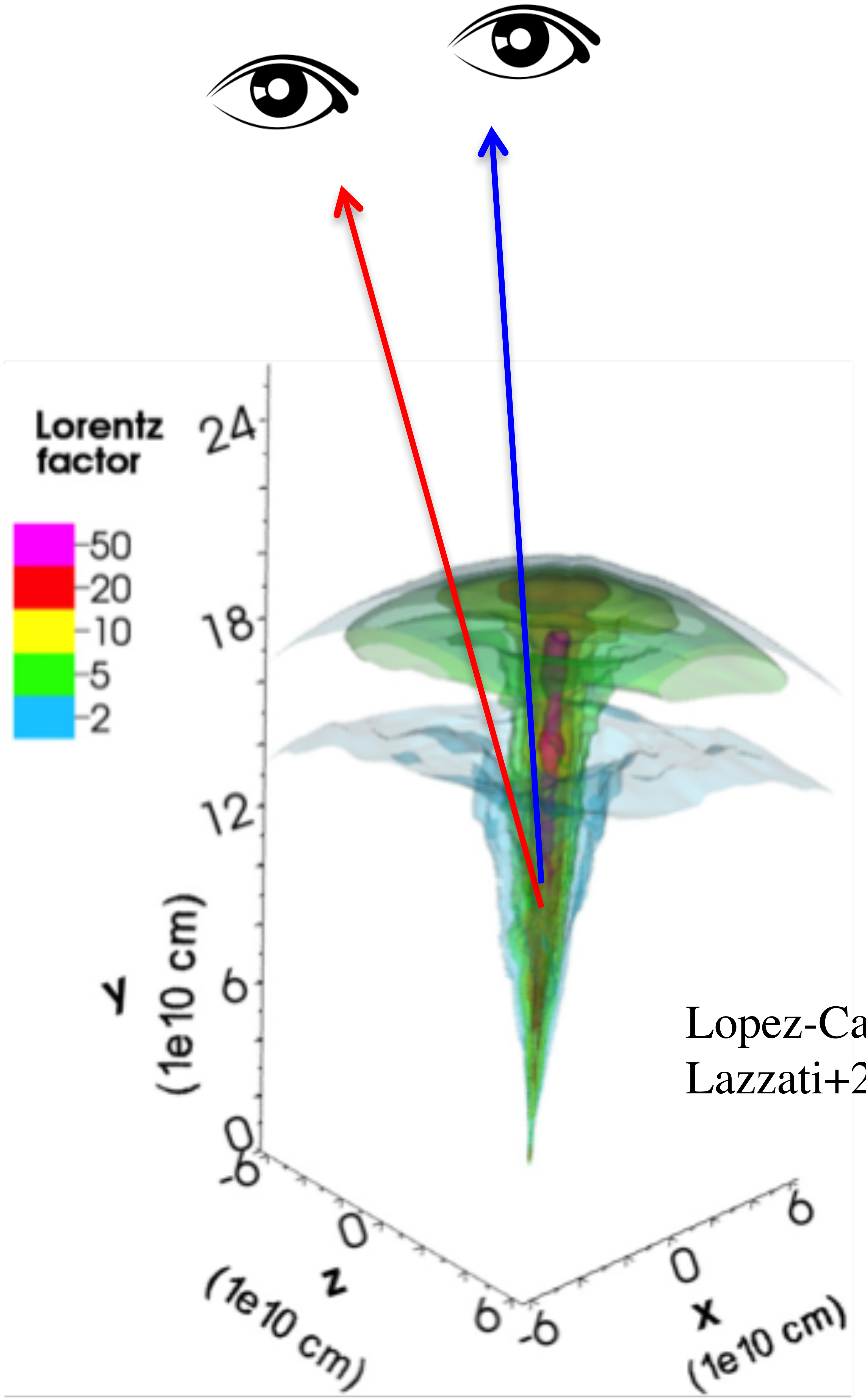
What we want to constrain

Observables



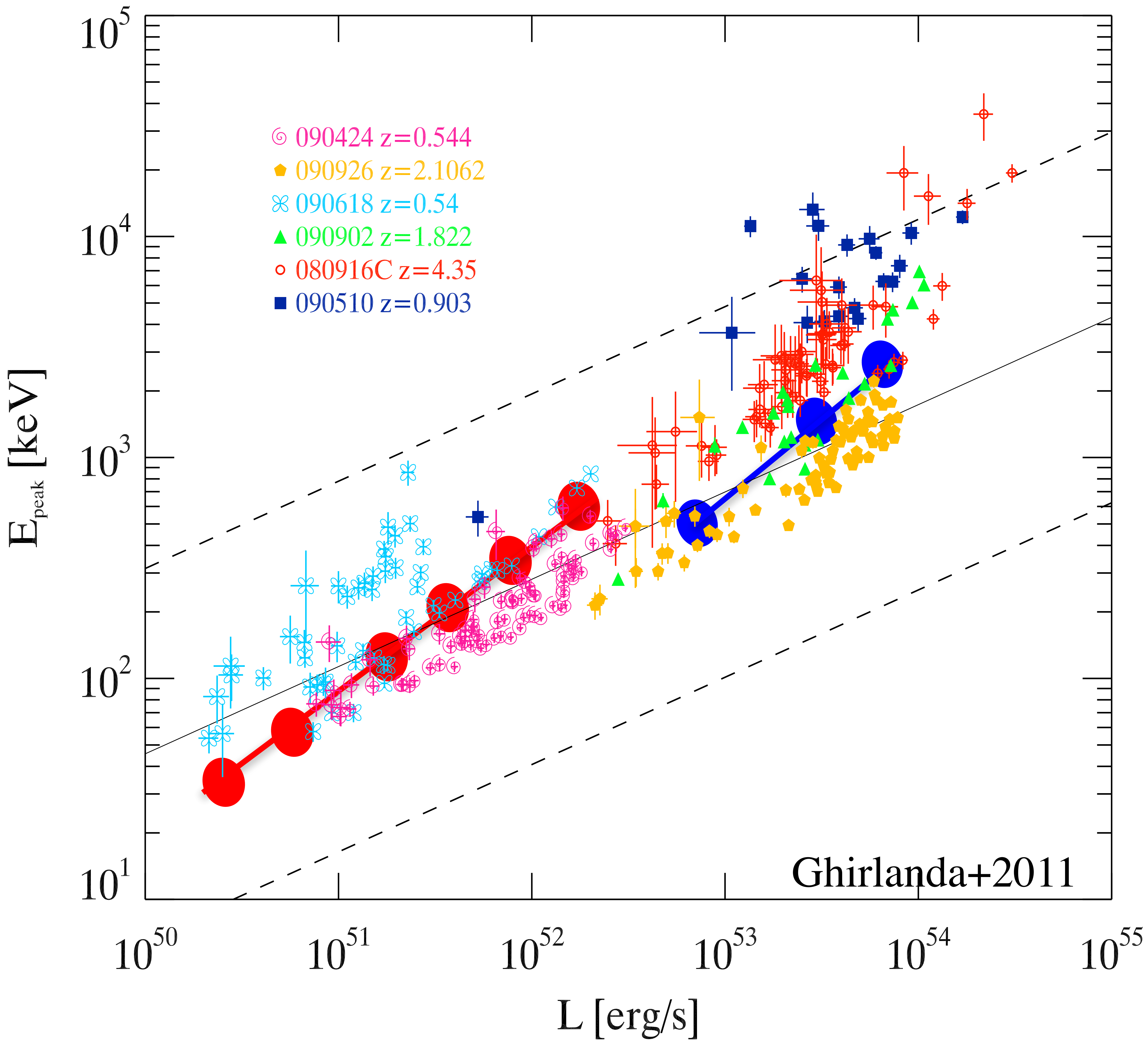
[Biller+1999; MAGIC Cool. 2008; Ahronian+2008; HESS coll. 2011; Rodrigues-Martines+2006; Abdo+2009; Ghirlanda+2010; Vasileiou+2013; Amelino-Camelia+2013; Bolmont+2008; Ellis+2008]

Prompt γ-ray emission: spectral evolution and jet structure



Lopez-Camara+2014; Lazzati+2011; 2013

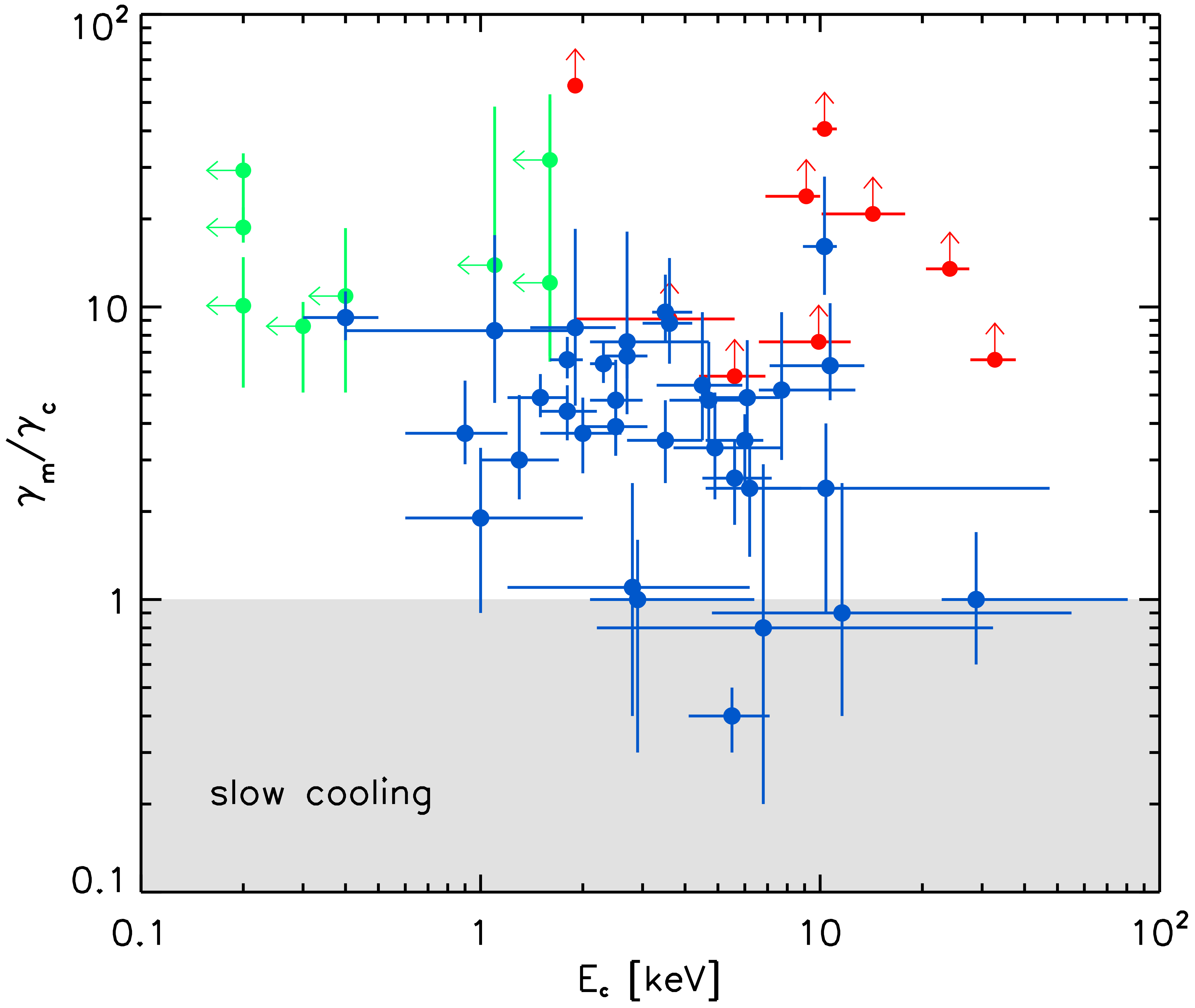
Ghirlanda+2009, 2010, 2011; Lu+2012



+ Indirect evidence of structured jet in long (Salafia et al. 2015,2016)
+ Direct evidence of structured jet in short (Mooley et al. 2018; Ghirlanda+2019)

Prompt γ-ray emission is synchrotron: "moderate" fast cooling

Oganesyan et al. 2019

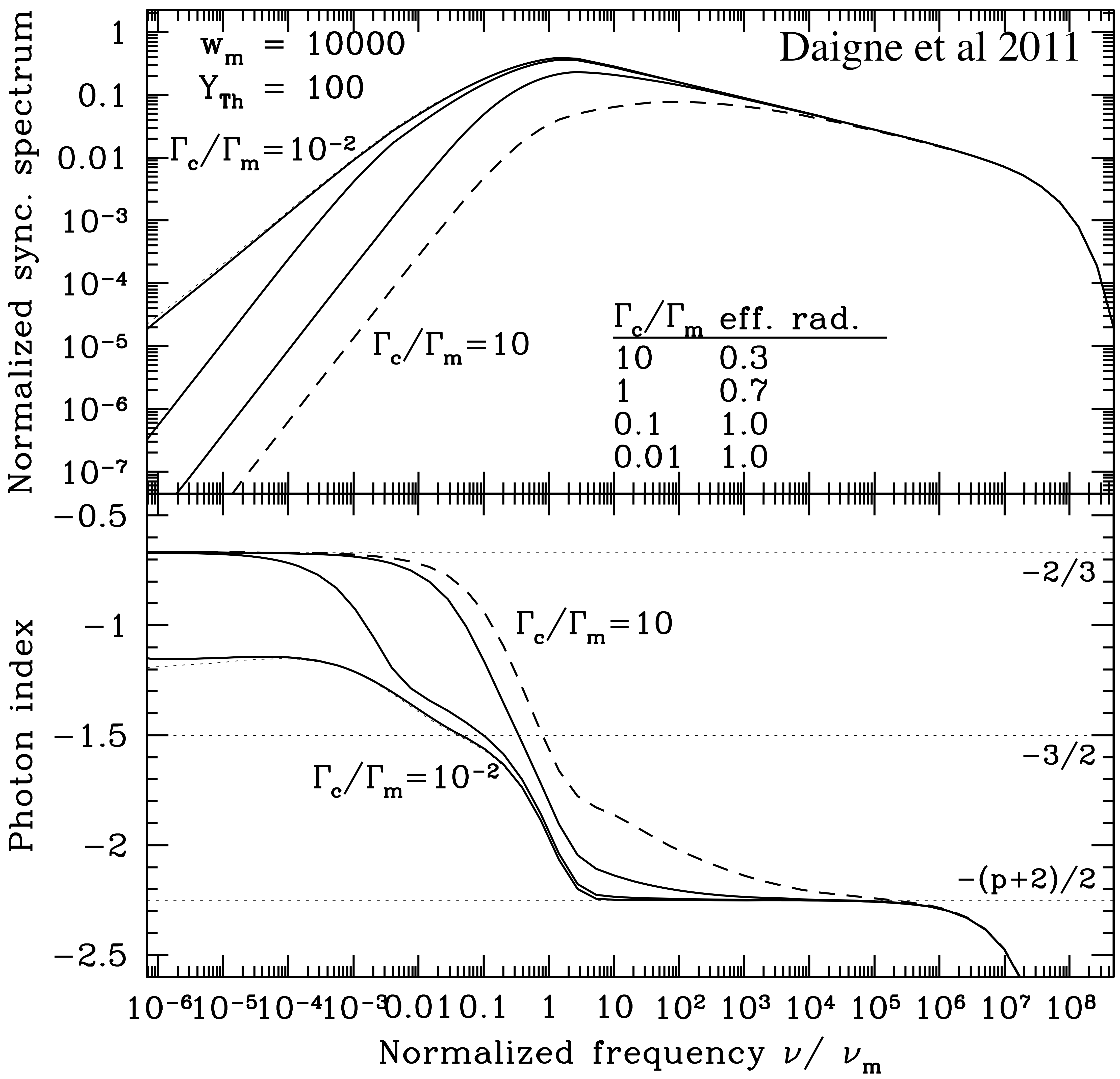


$$5\,\mathrm{G} < B' < 30\,\mathrm{G}$$

$$10^{16}\ \mathrm{cm} < R_{\rm diss} < 10^{17}\ \mathrm{cm}$$

$$\Gamma > 500$$

[Daigne+2011; Derishev+2001; Nakar+2009; Asano+2009; Kumar+2008; Beniamini+2013]



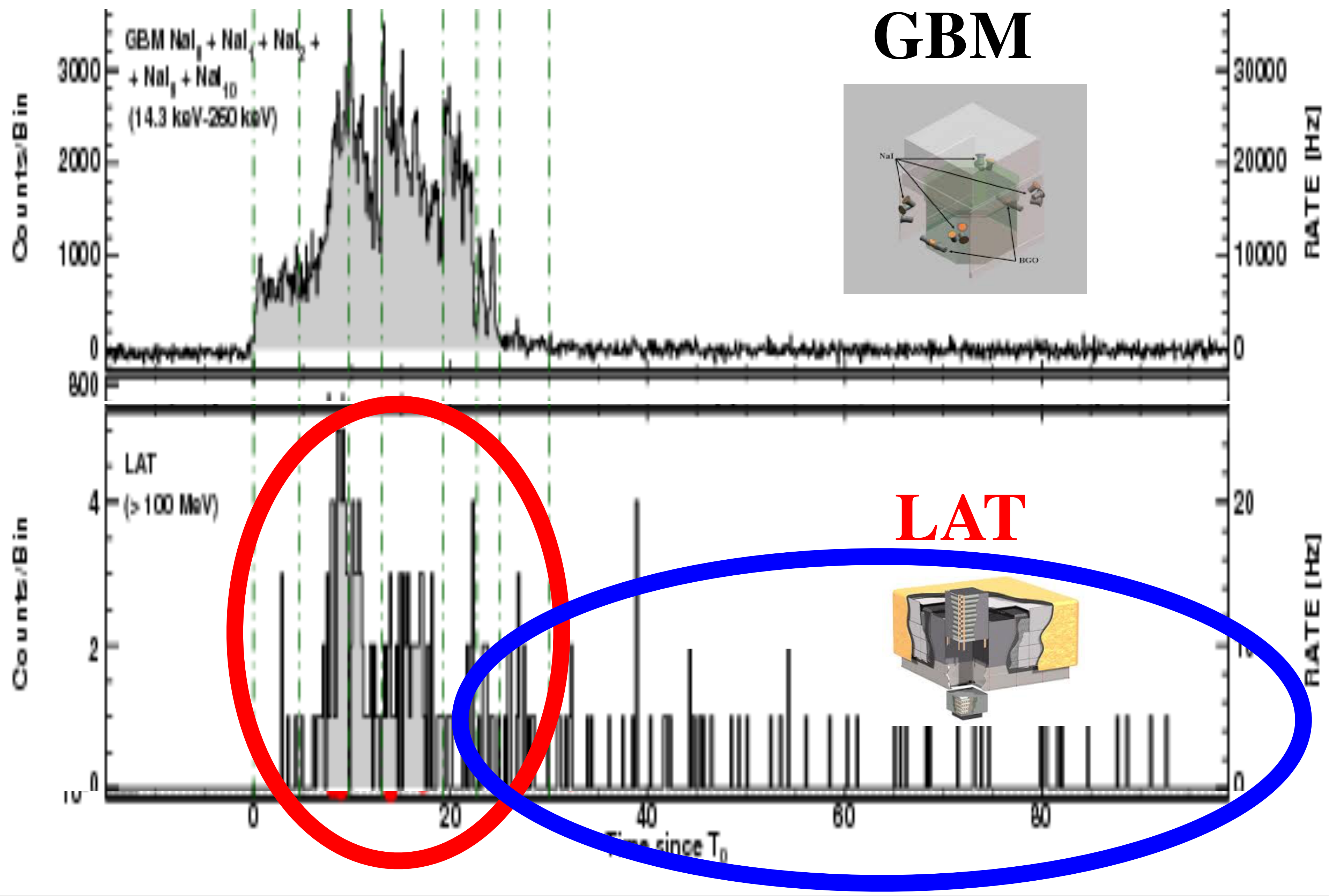
GeV emission of GRBs: some puzzles

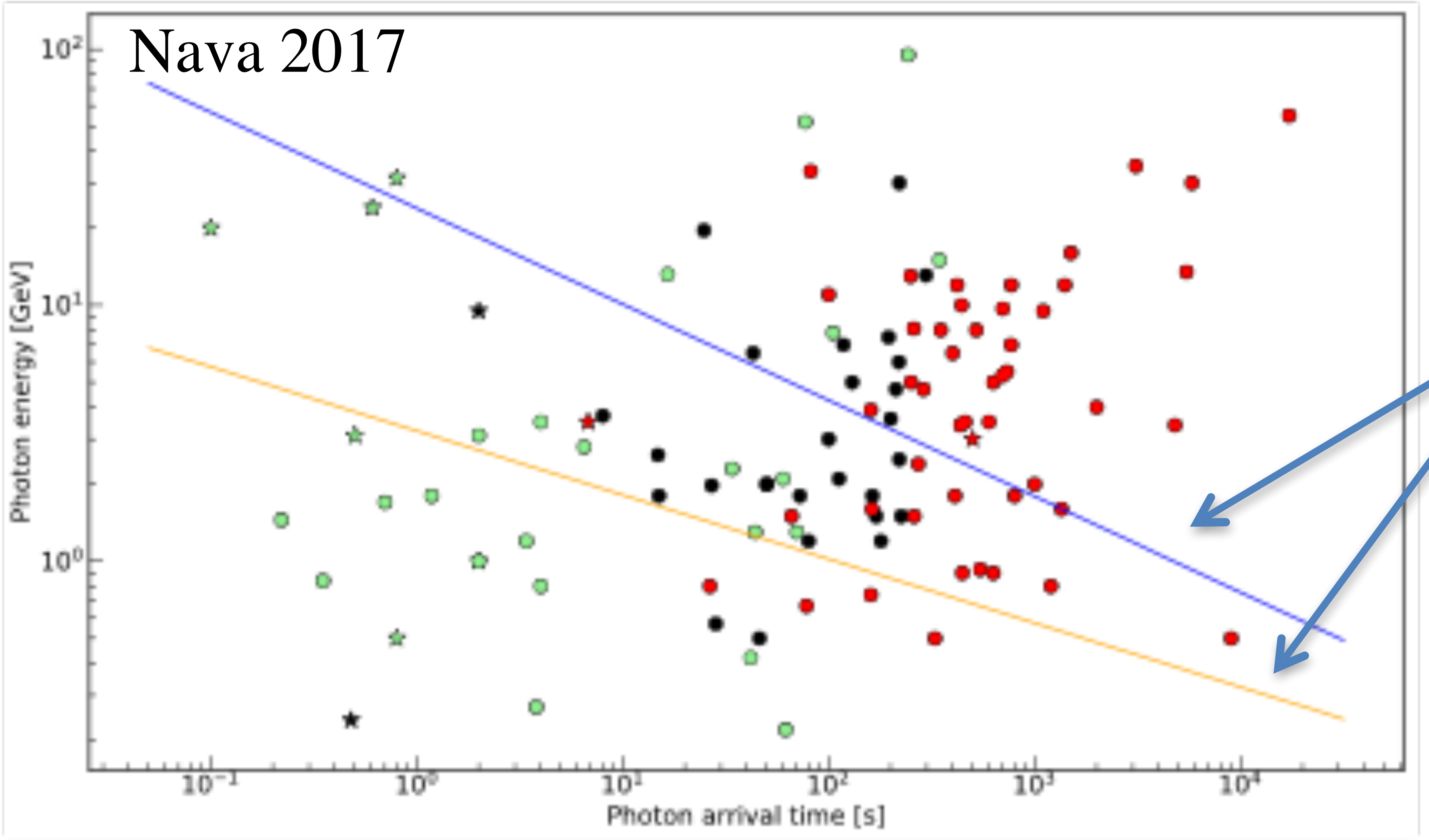
[in individual GRBs detected by Fermi (e.g. Abdo+2010) and in the Fermi LAT catalog: Ackermann+2013]

EARLY PHASE

PROMPT
Synchrotorn @
Internal shocks

DELAY





EXTENDED EM

AFTERGLOW
Synchrotorn @
External shocks

SYNCHROTRON

$$t_{\mathrm{acc}} < t_{\mathrm{cool}}$$

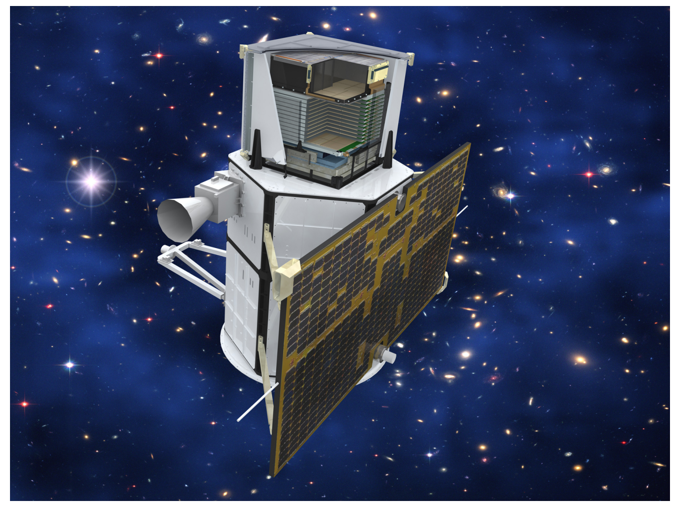
$$E^{\mathrm{max}}_{\mathrm{synch}} < \frac{50}{1+z}\Gamma(t)\ \mathrm{MeV}$$

1) Inverse Compton (External or SSC)
2) Shock physics (e.g. B decaying downstream)

GeV emission of GRBs: a brief history

SMM – GRB840805 (Share+1986)

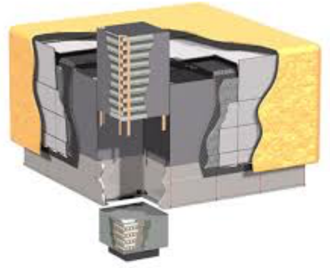
EGRET – CGRO
(6 GRBs > 100 MeV)
[Sommer+1994;
Hurley+1994;
Gonzales+2003]

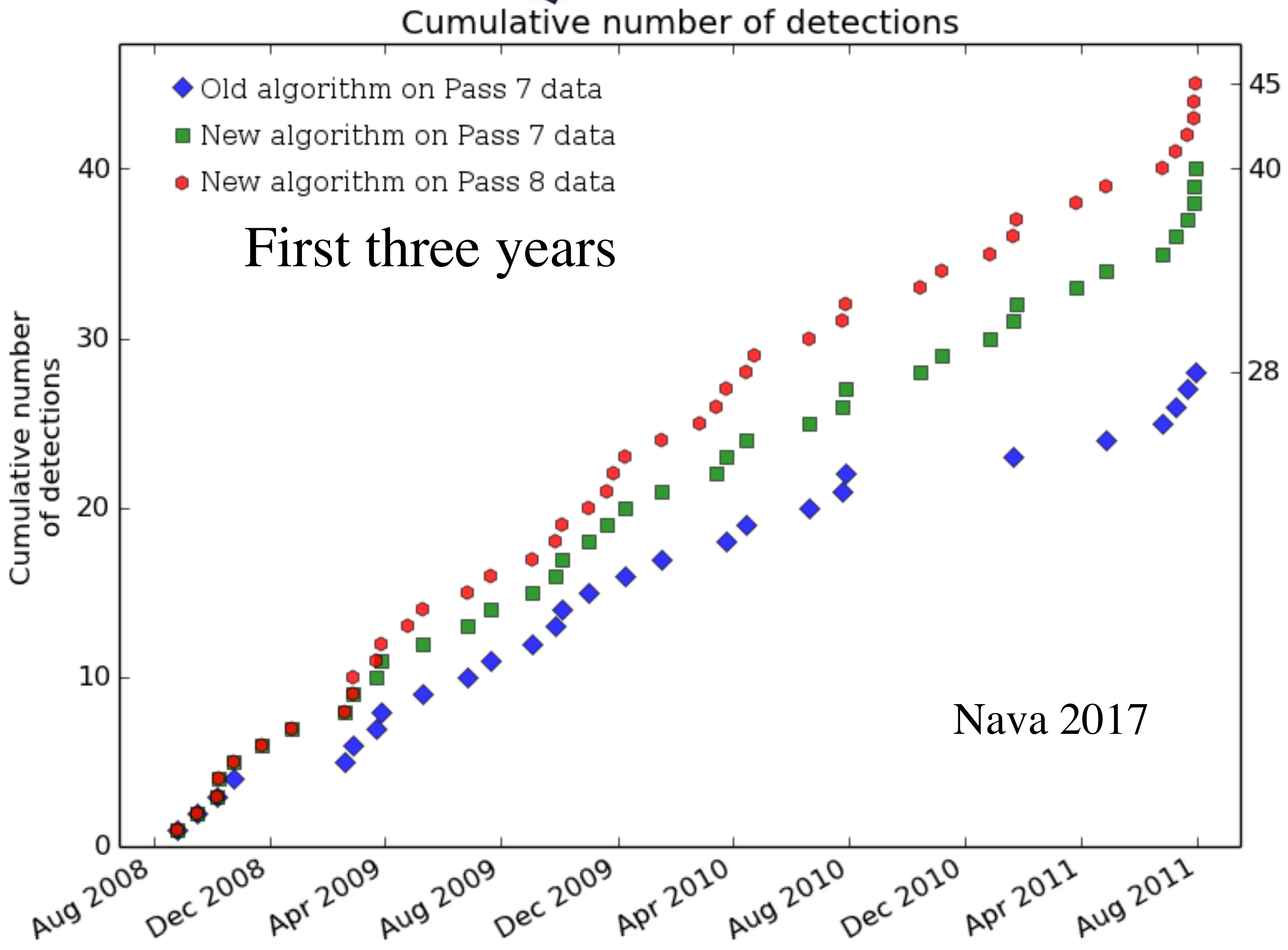


AGILE

GRB 080514 [Giuliani+2008]
090401B [Moretti+2009], 090510 [Giuliani+2009], 100724B [Del Monte+2011], 130327B [Longo+2013], 130427A [Verrecchia+ 2013], 131108A [Giuliani+2013; Giuliani+2015]

Fermi - LAT

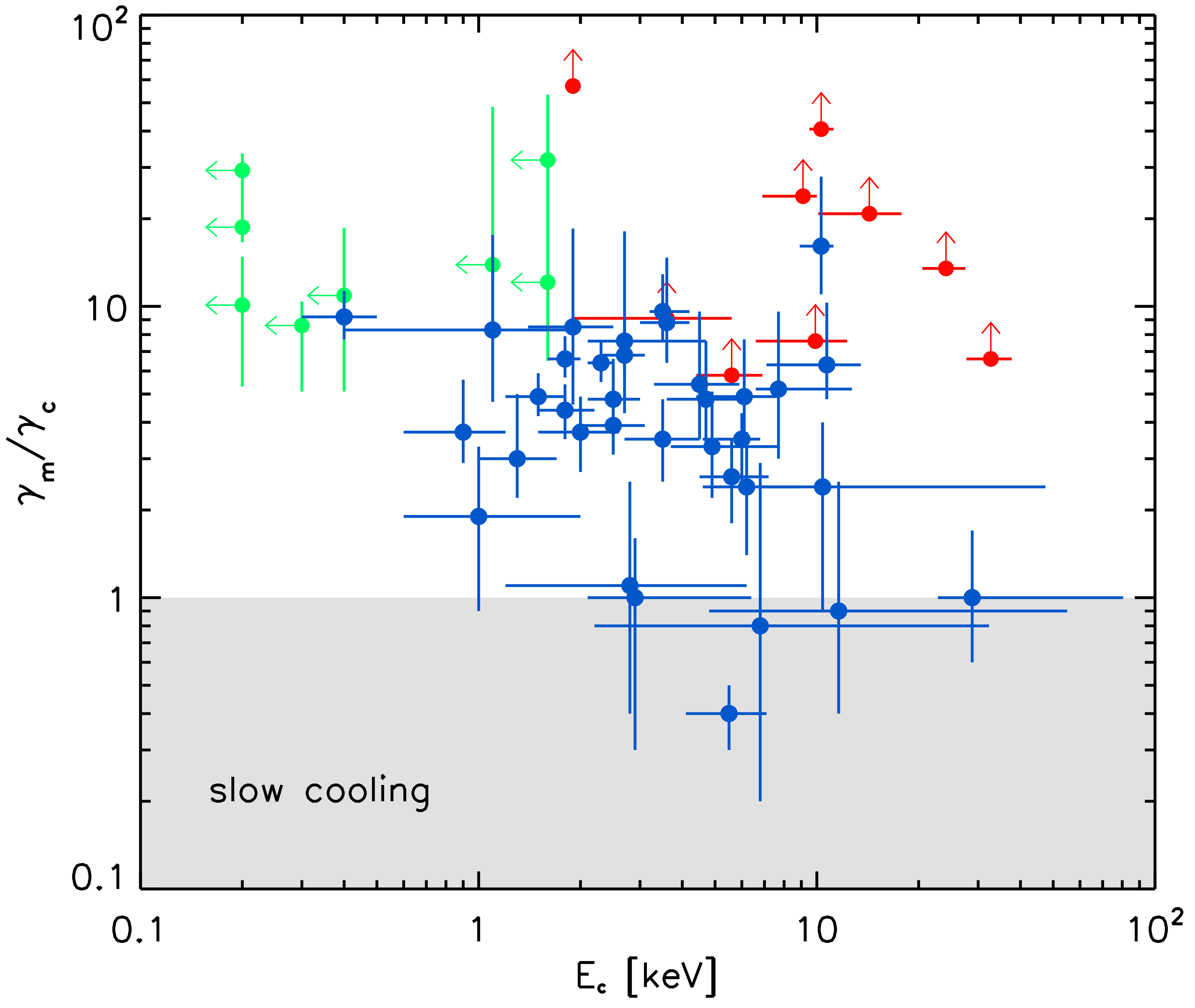




141 GRBs @ 12/2017 → ~ 15 LAT GRBs yr^{-1}
9% are Short
[e.g. Ackermann+2013]

Prompt γ-ray emission is synchrotron: "moderate" fast cooling - parameter space

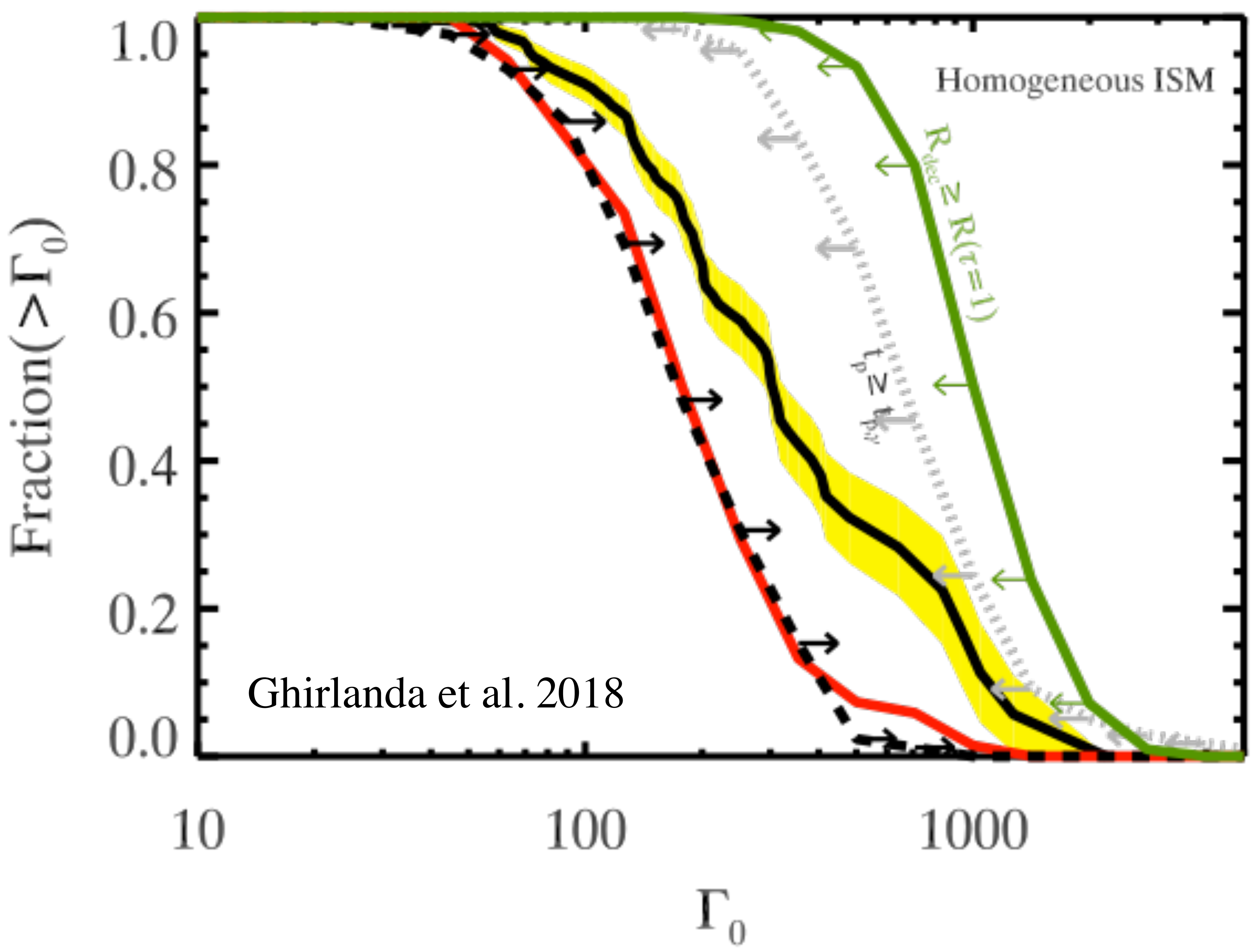
Oganesyan et al. 2019



$\Gamma_0 > 500$

$5\,\mathrm{G} < B' < 30\,\mathrm{G}$

10^{16} cm $< R_{\rm diss} < 10^{17}$ cm



GeV emission of GRBs: Early Phase

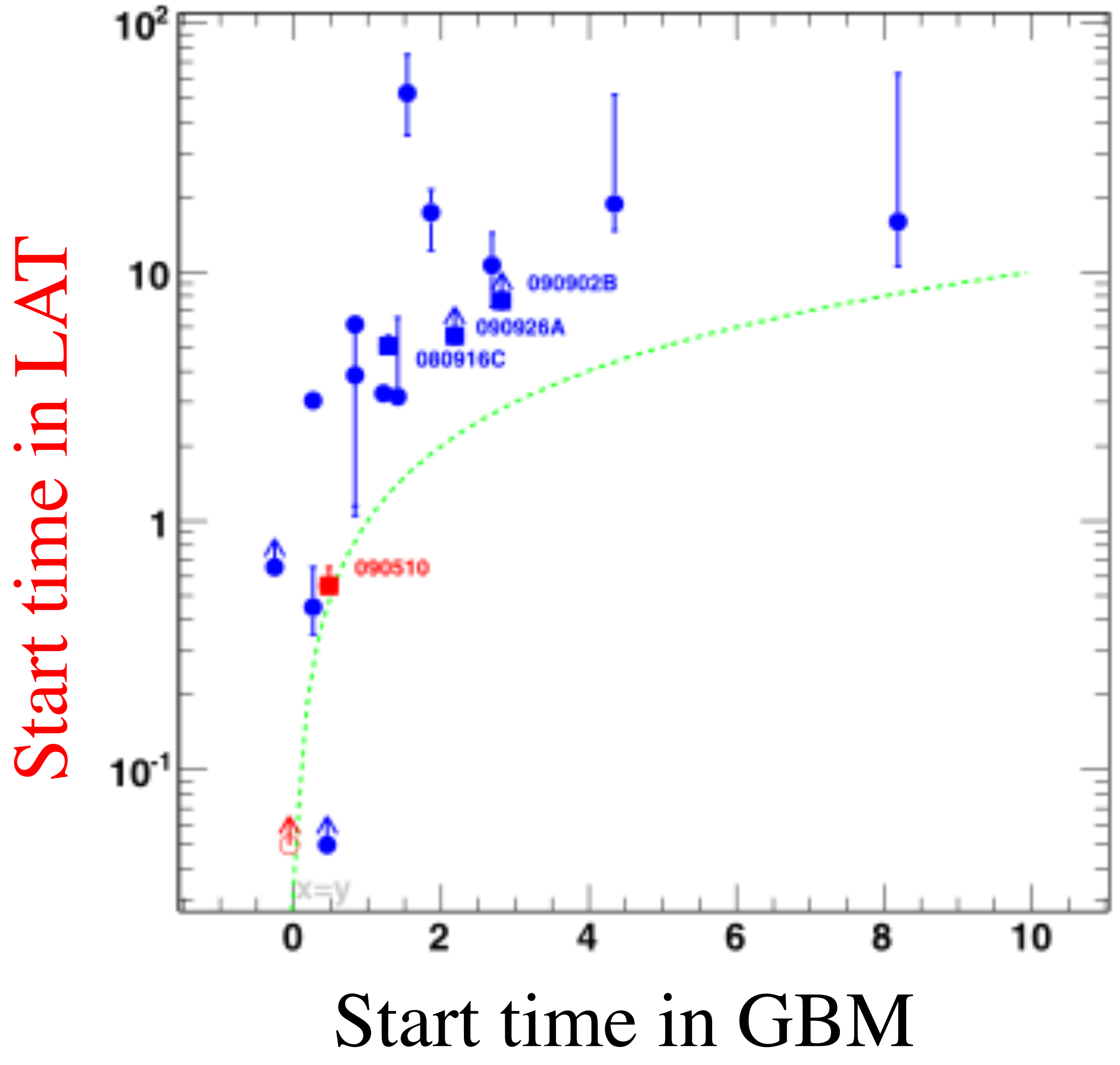
[in individual GRBs detected by Fermi (e.g. Abdo+2010) and in the Fermi LAT catalog: Ackermann+2013]

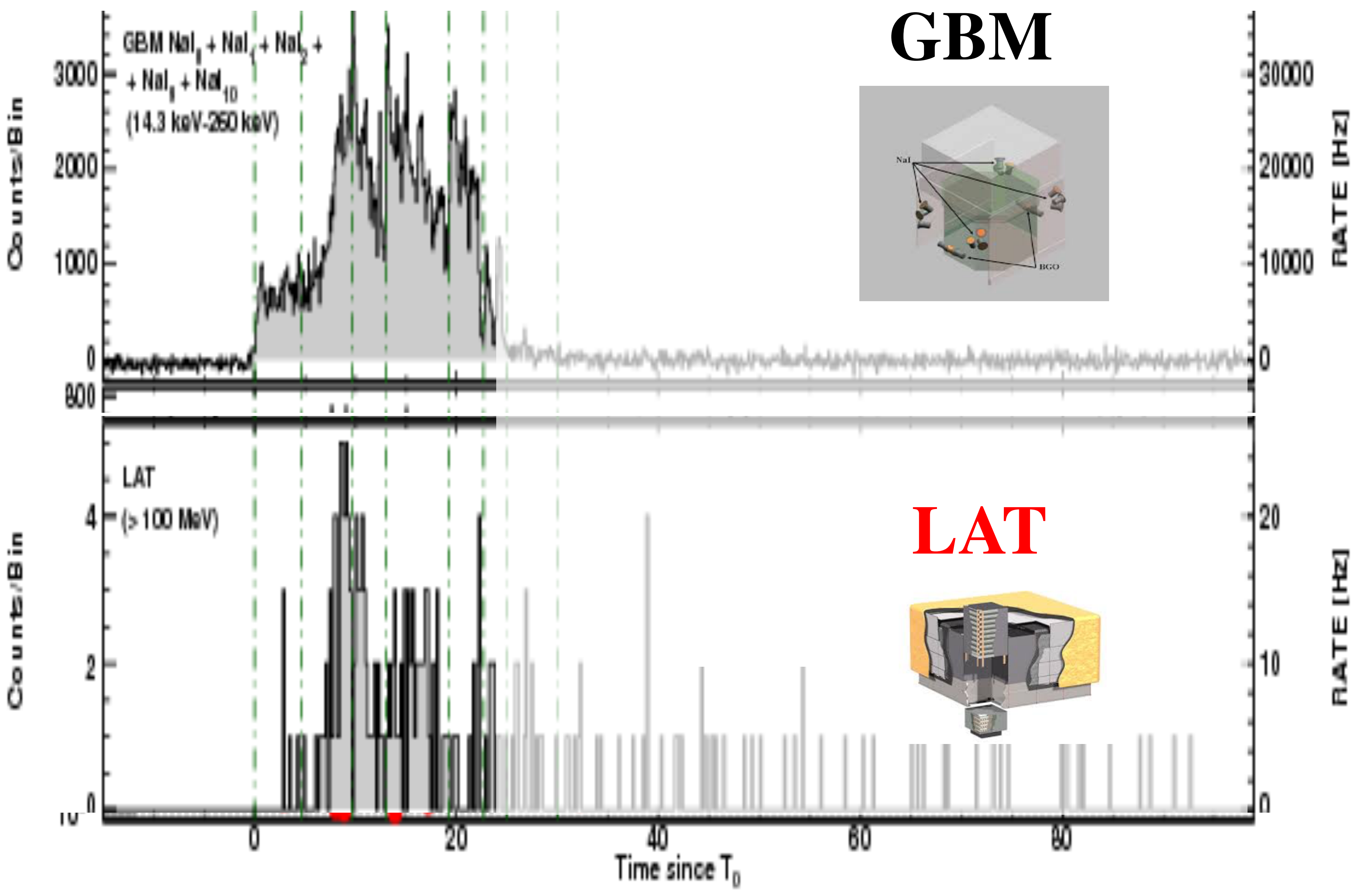
EARLY PHASE

LAT emission during prmpt (MeV emission)

DELAY

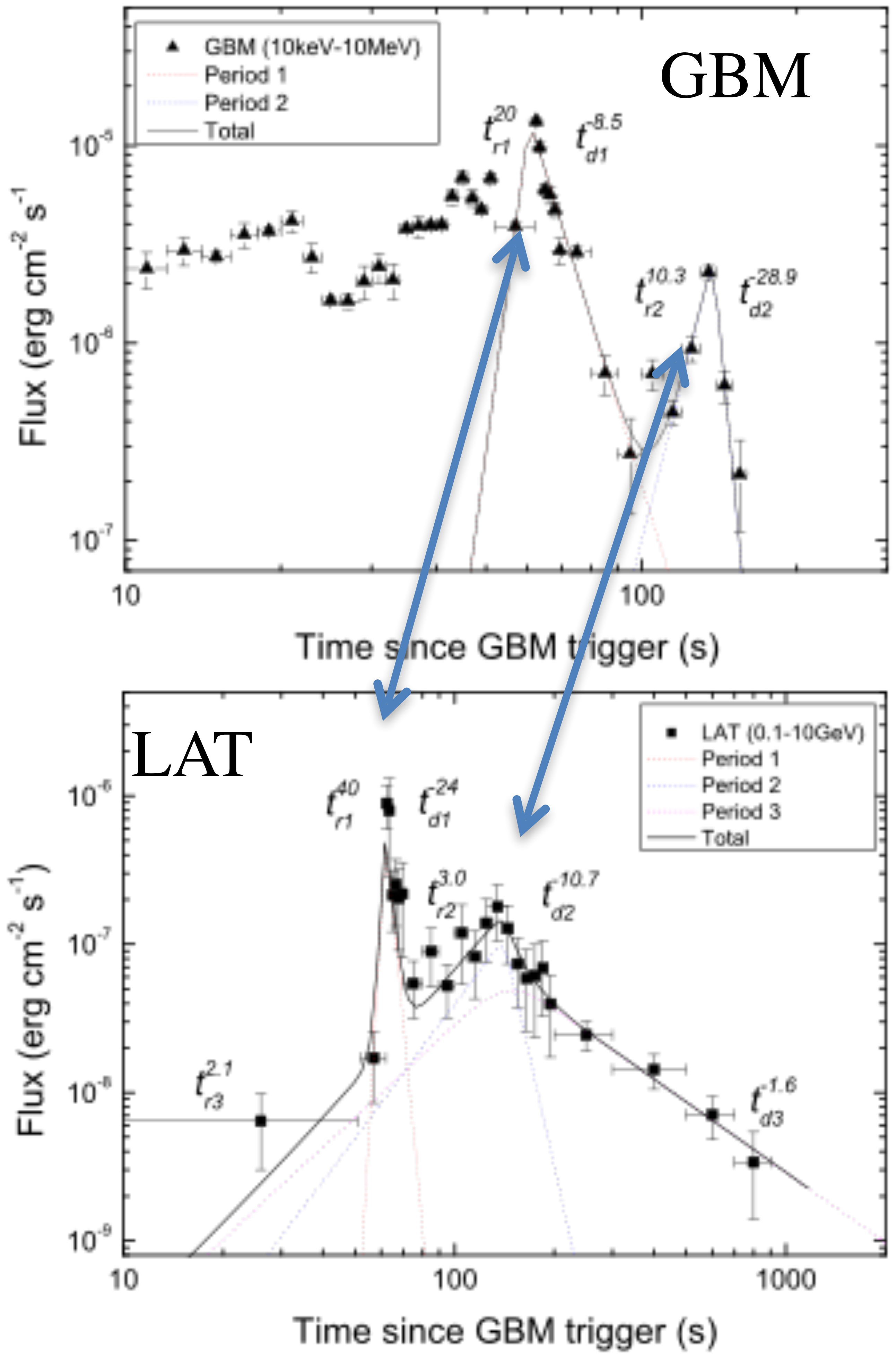
> GeV emission start time is delayed wrt < MeV





VARIABILITY

170214 (Tang+2017)



GeV emission of GRBs: Late Phase

[in individual GRBs detected by Fermi (e.g. Abdo+2010) and in the Fermi LAT catalog: Ackermann+2013]

EARLY PHASE

LAT emission during prmpt (MeV emission)

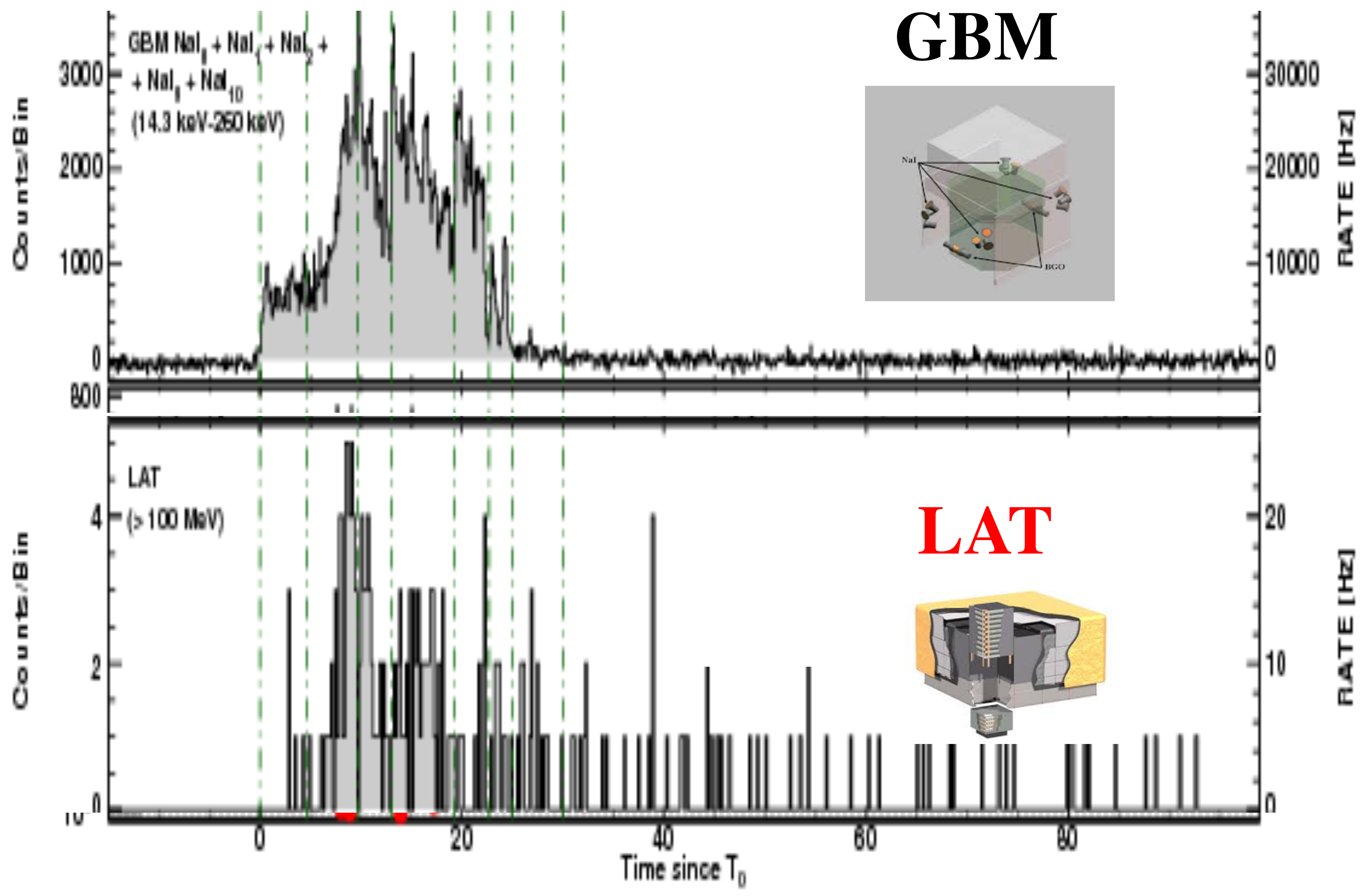
DELAY

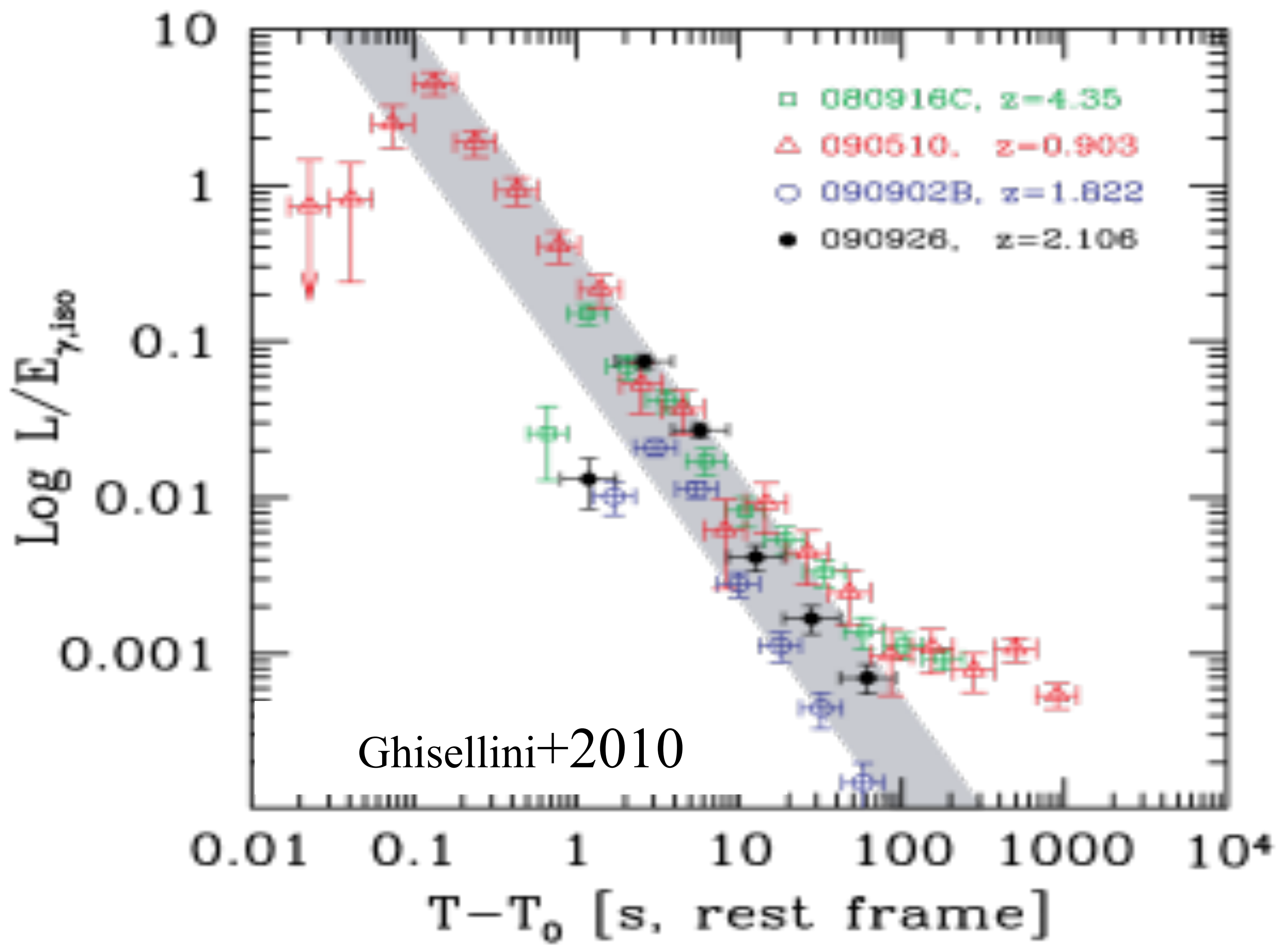
> GeV emission start time is delayed wrt < MeV

VARIABILITY

SPECTRAL CONSISTENCY

> GeV emission (not always) spectrally consistent with extrapolation of GBM spectrum





EXTENDED EM

LONGER

SMOOTH DECAY
(no Variability)

Ackermann+2010; Vianello 2012; Nava+2015

GeV emission of GRBs: Late Phase

[in individual GRBs detected by Fermi (e.g. Abdo+2010) and in the Fermi LAT catalog: Ackermann+2013]

EARLY PHASE

LAT emission during prmpt (MeV emission)

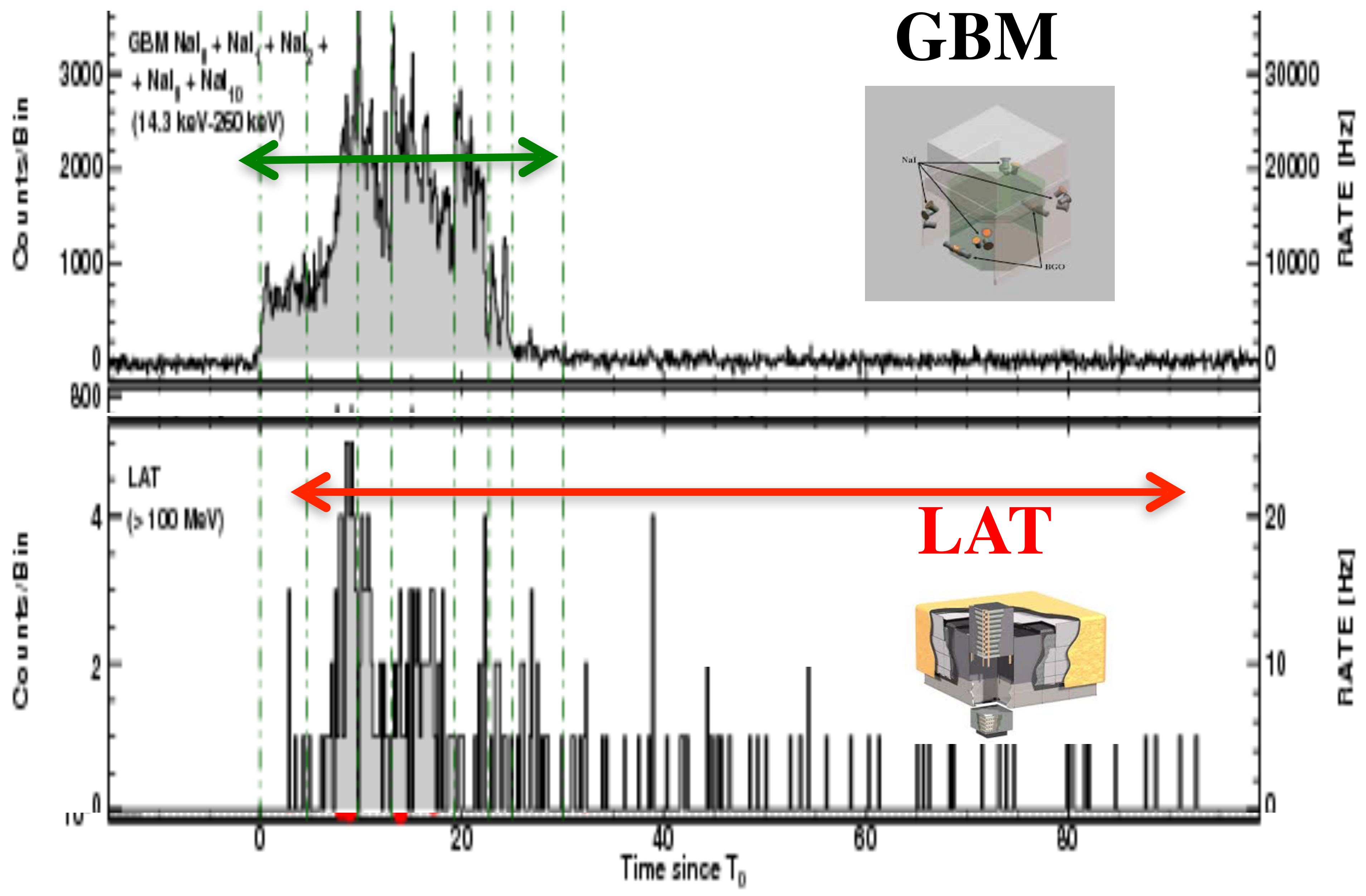
DELAY

> GeV emission start time is delayed wrt < MeV

VARIABILITY

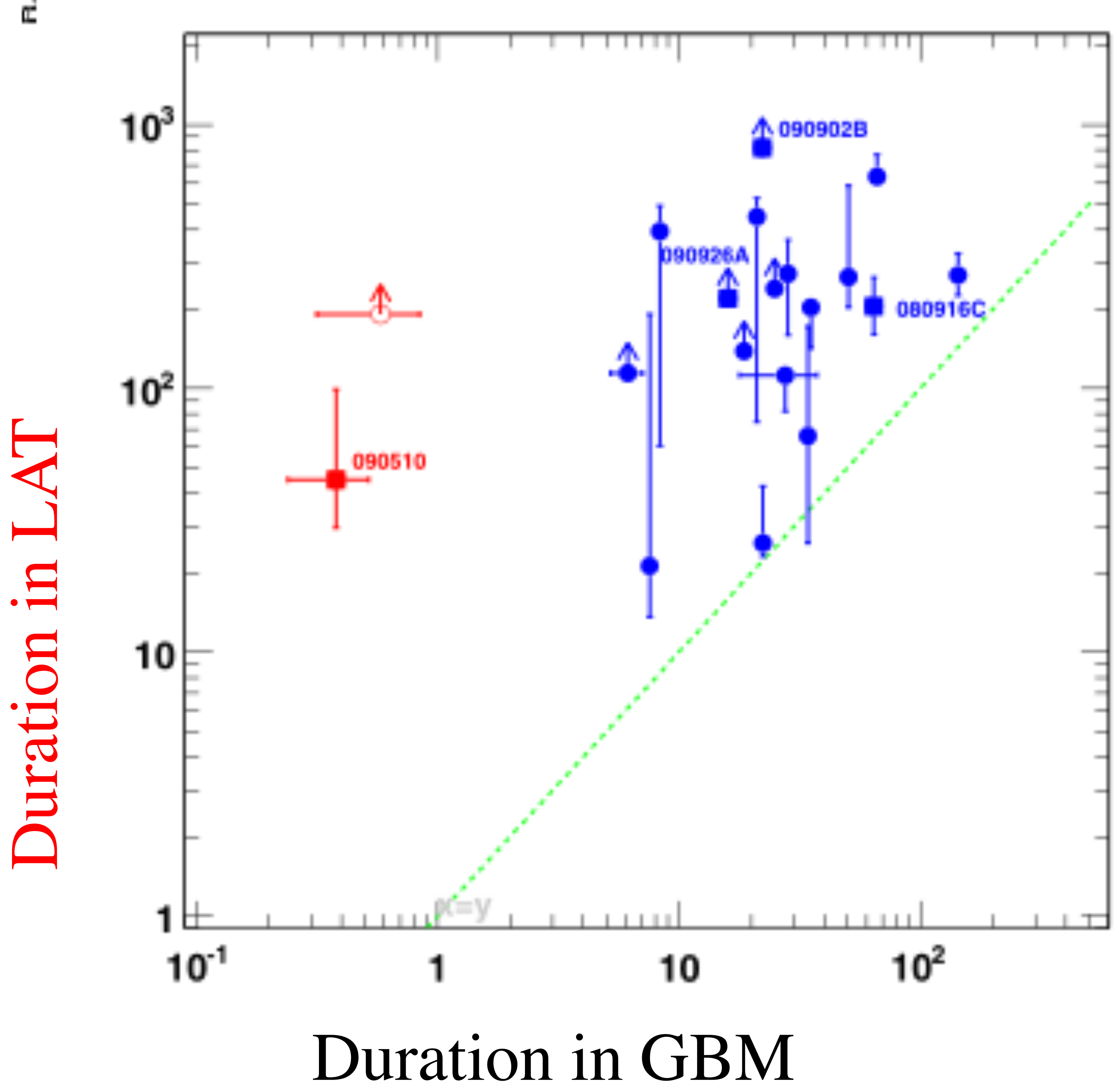
SPECTRAL CONSISTENCY

> GeV emission (not always) spectrally consistent with extrapolation of GBM spectrum



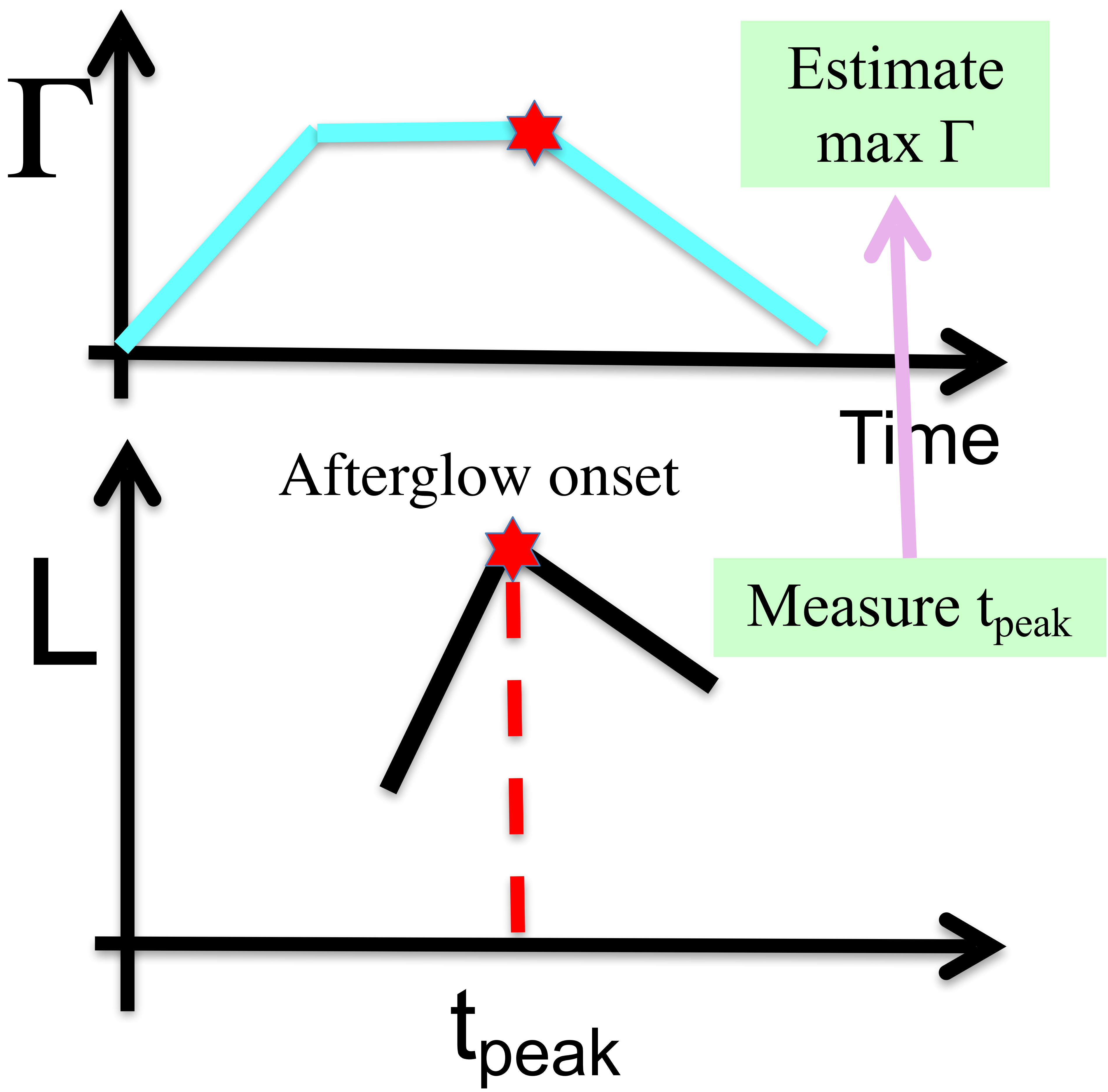
EXTENDED EM

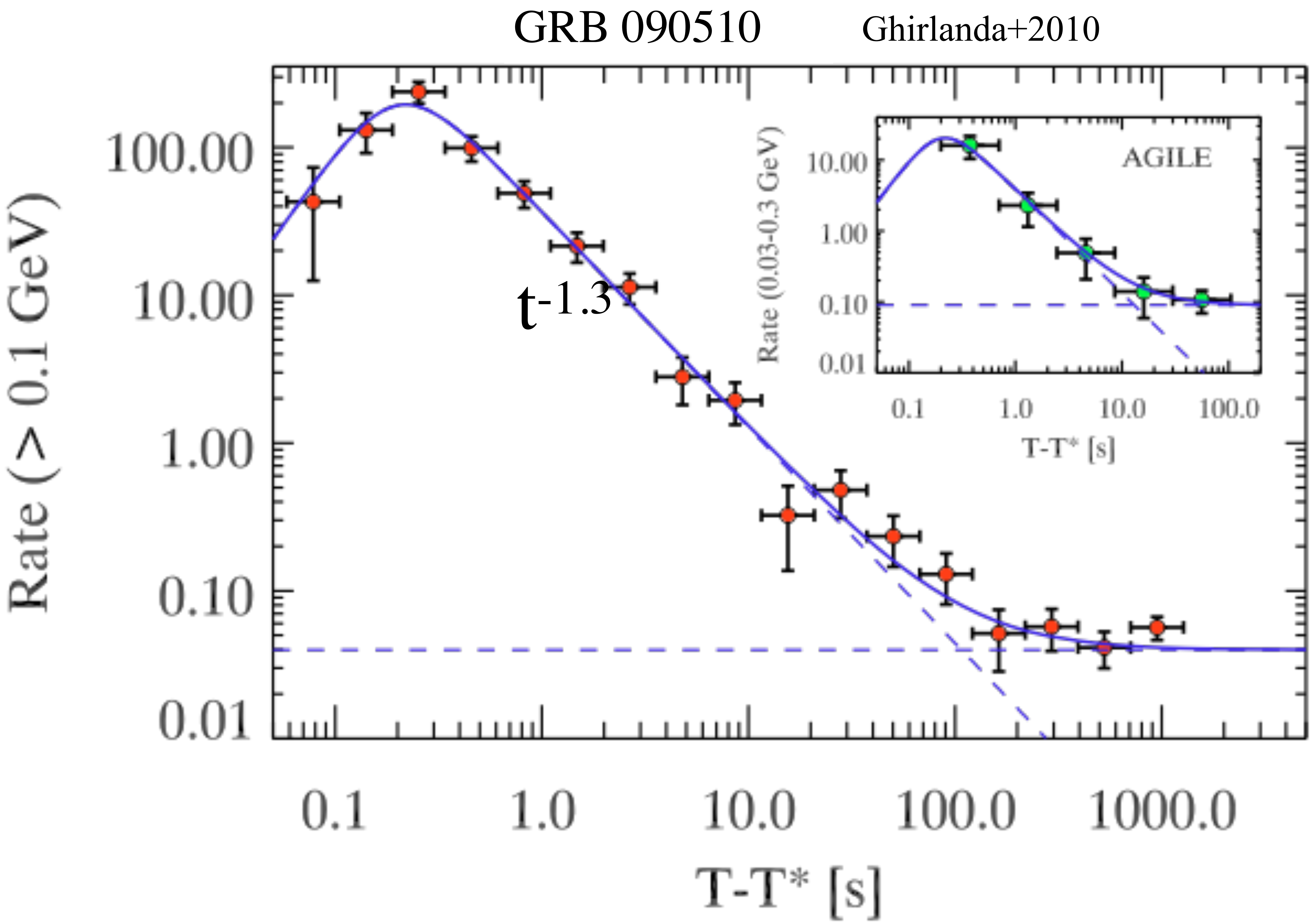
LONGER



GeV emission of GRBs: implication

[Sari&Piran 1999; … Molinari+2006; Ghirlanda+2010; Liang+2010; Longo+2012; Nava+2016, Ghrlanda+2018]

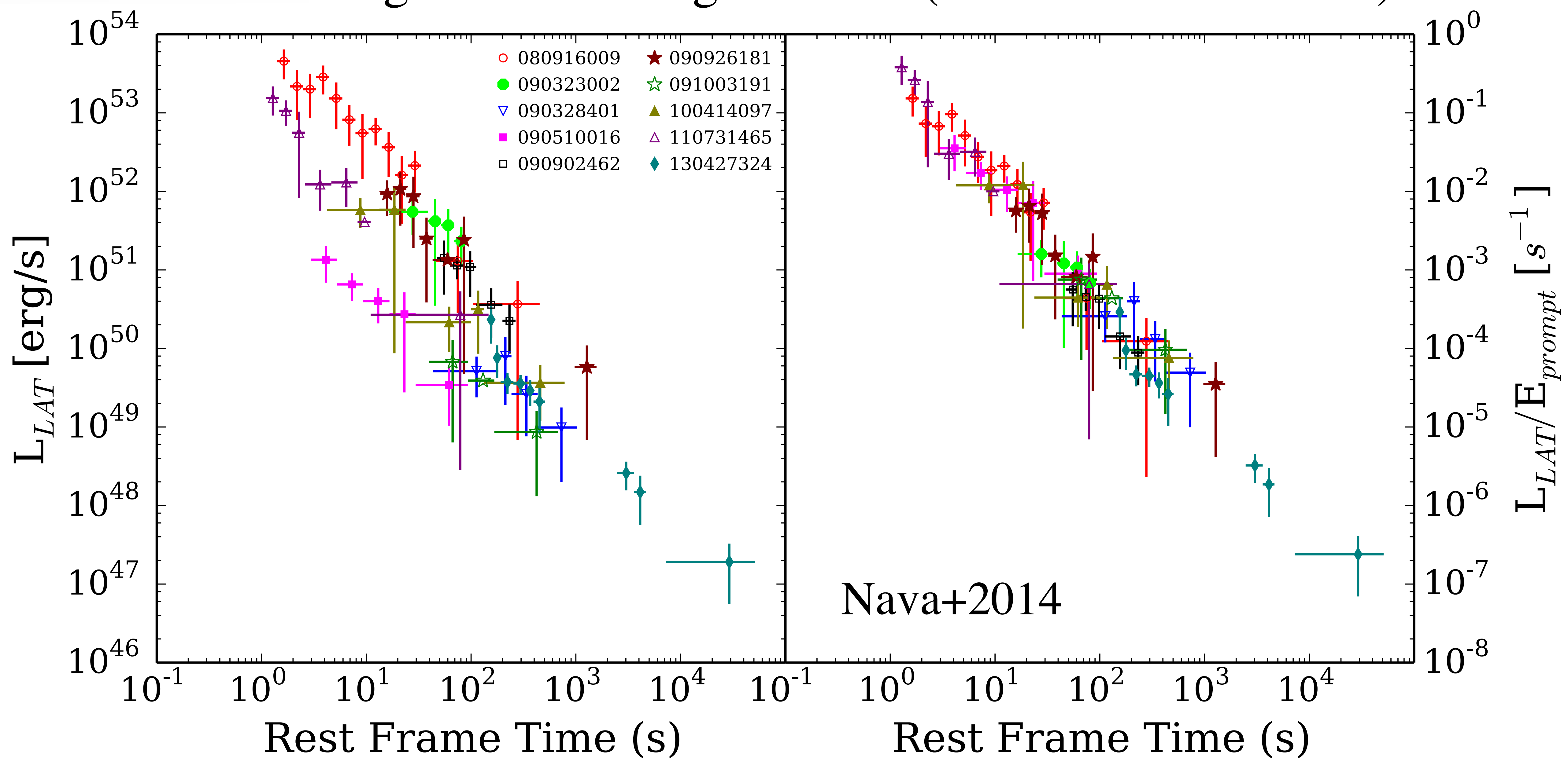




Naturally explains the delay as due to the time needed for the fireball to decelerate (larger bulk velocities earlier deceleration)

GeV emission of GRBs: implication

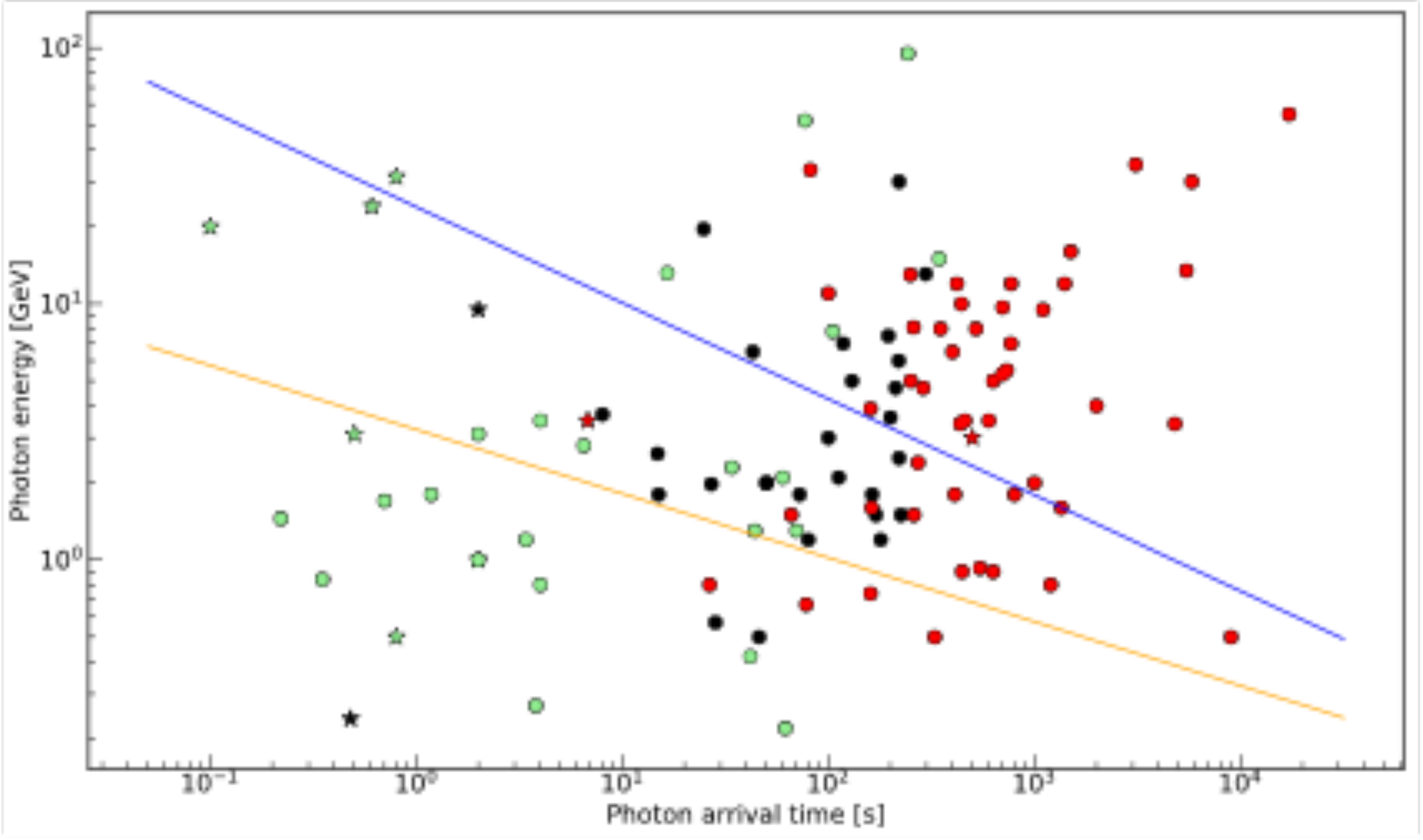
Clustering of the LAT light curves (Ghisellini et al. 2010)



Nava 2017

EXTENDED EM

AFTERGLOW



If emission > 1 GeV is $>\nu_c\ \nu_m$

"LAT"

$$\frac{L_{\nu>\nu_m,\nu_c}}{E_{\rm prompt}} \propto \frac{\epsilon_e}{\eta}$$

"GBM"

Fraction of energy in the acc electrons

Efficiency of IS

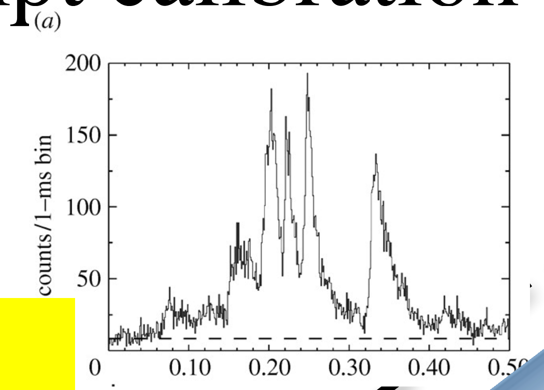
1) Inverse Compton (External or SSC)
2) Shock physics (e.g. B decaying downstream)

POpulation SYnthesis Theory Integrated Very high Energy emission (POSYTIVE)

POpulation Synthesis
G. Ghirlanda
[Ghirlanda+2012;2015; 2016]
Long and Short

PROMPT EMISSION
Z. Bosnjak
Bosnjak et al. 2009, 2014

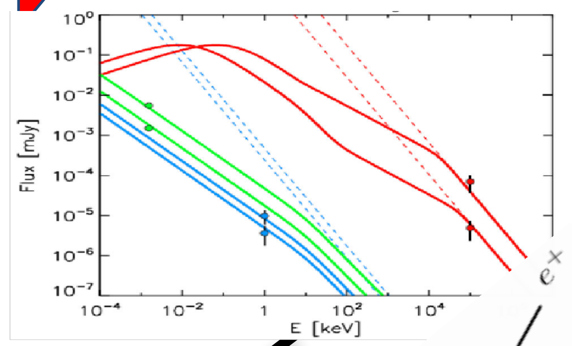
Prompt calibration

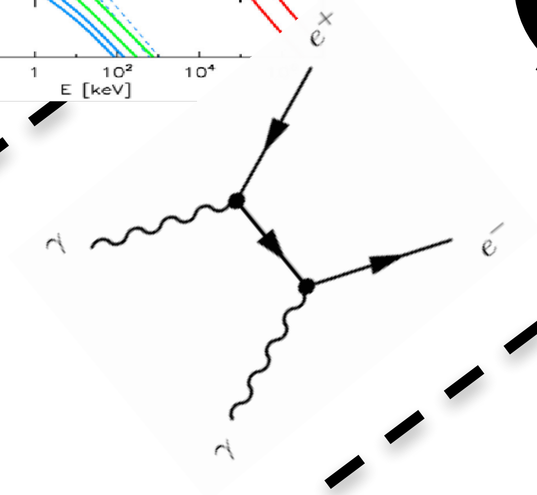


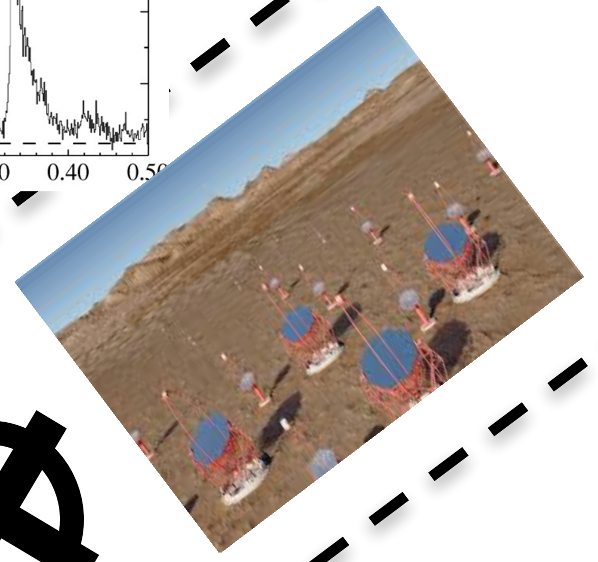
AFTERGLOW EMISSION
L. Nava
Nava et al. 2014
Beniamini, Nava et al. 2015

Afterglow calibration

Library







DETECTION SIMULATIONS
F. Longo; : T. Stolarczyk

CTOOLS; Gammapy

MW FOLLOW UP
S.D. Vergani

OBSERVABILITY
M.G. Bernardini

GRB SCIENCE CASES