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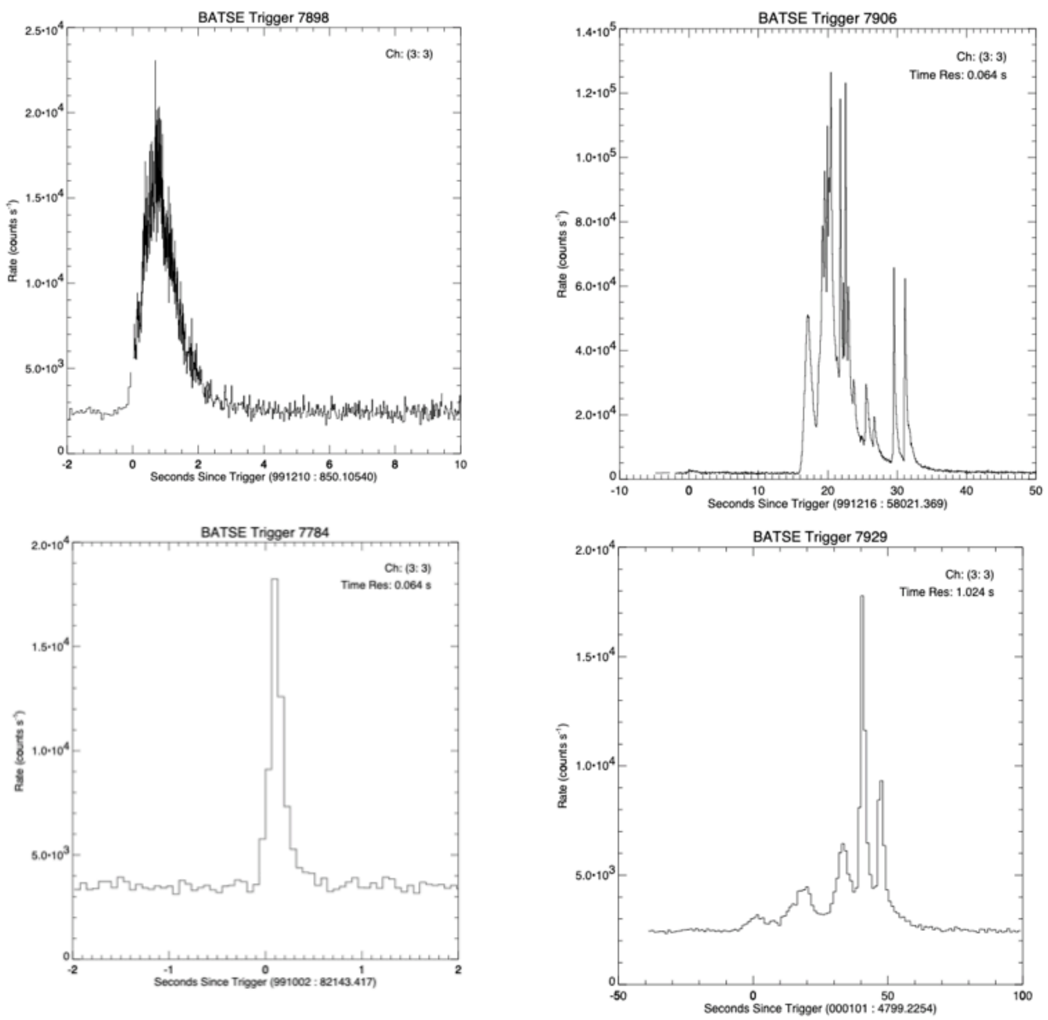
# Tests of GRB prompt emission models

Gor Oganesyan

**GRB+CE2024, Playa del Carmen, 2 December 2024**

# the problem

# γ-ray burst



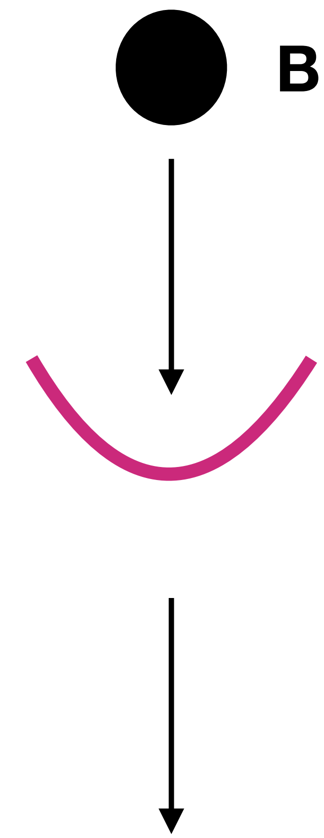

**energy (iso)** $10^{52}\, erg$

**photons ~ MeV**

**variability 0.01-1 s**

# model

**Pair fireball**



**BH** $\sim 1 - 10 M_{\odot}$

$e^{\pm}, \gamma$

$L_{\gamma} >> 10^{10} L_{Edd}$

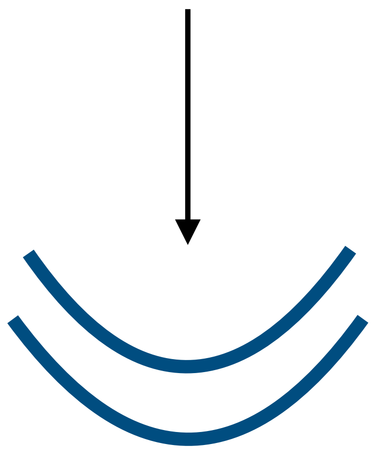
$T_{BB} \sim MeV$

Cavallo & Rees 1978
Paczýnski 1986
Goodman 1986

## model

**Baryon poisoning**

Shemi & Piran 1990
Cavallo & Rees 1978
Paczýnski 1990



$$R_{coll} \approx 2c\,\delta t\,\Gamma_s^2$$

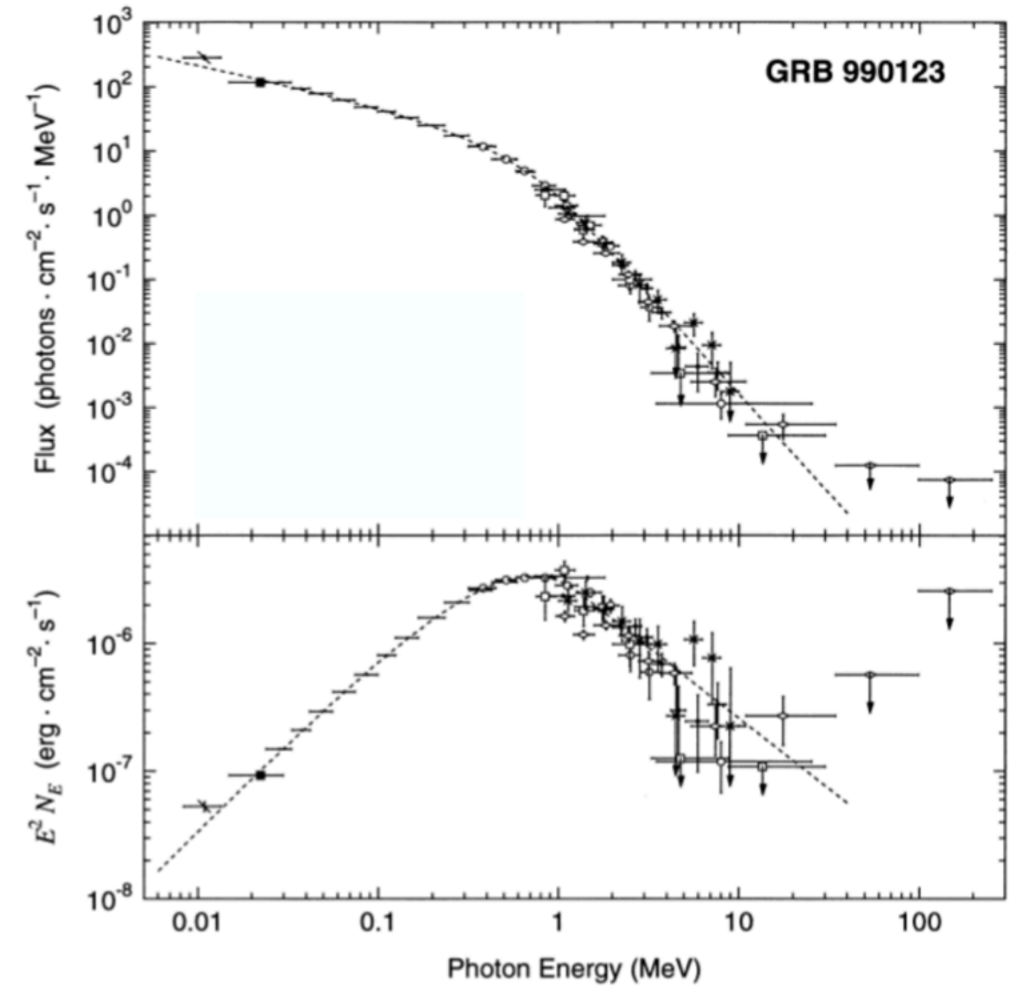
$$T_{BB} \rightarrow L_k \rightarrow L_\gamma$$

Rees & Mészáros 1994

(Narayan et al. 1992, Paczýnski & Xu 1994)

Daigne & Mochkovitch 1998

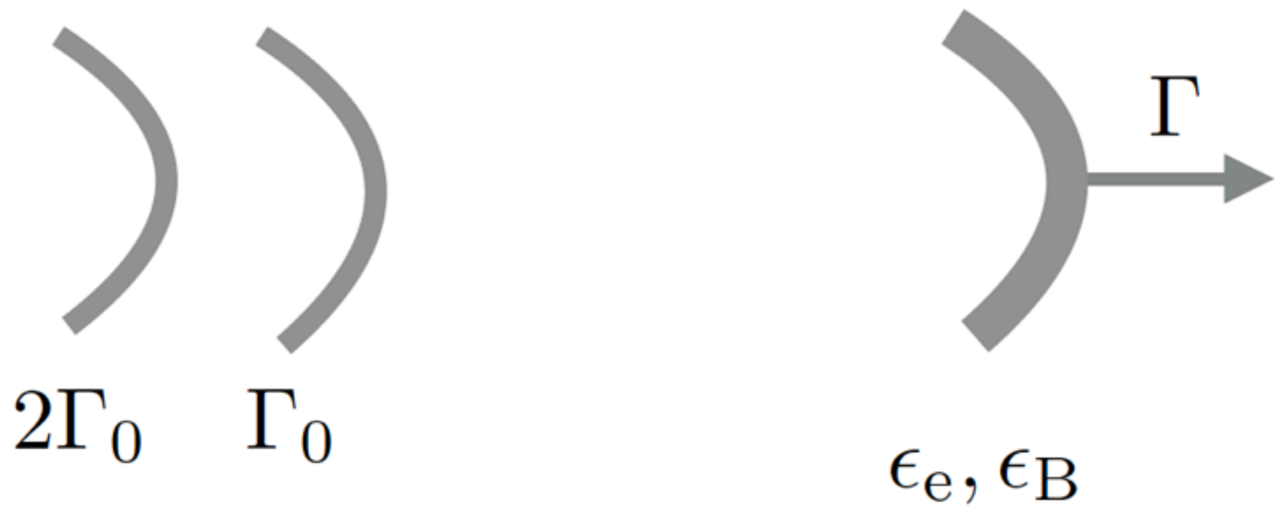
## γ-ray burst




Briggs et al. 1999

$$E_{peak} \sim 100\,keV - 1\,MeV$$

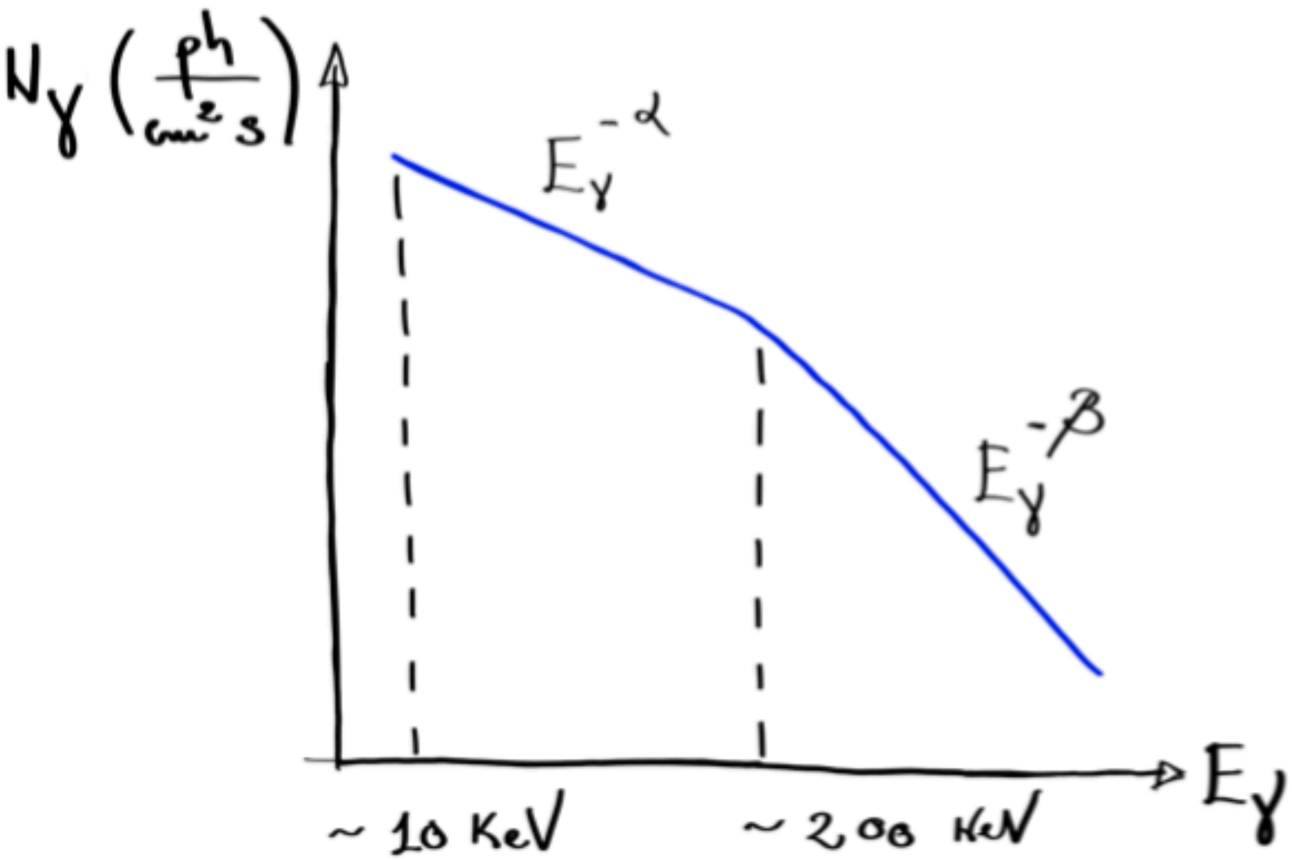
# Internal shocks beyond the photosphere - Spectra



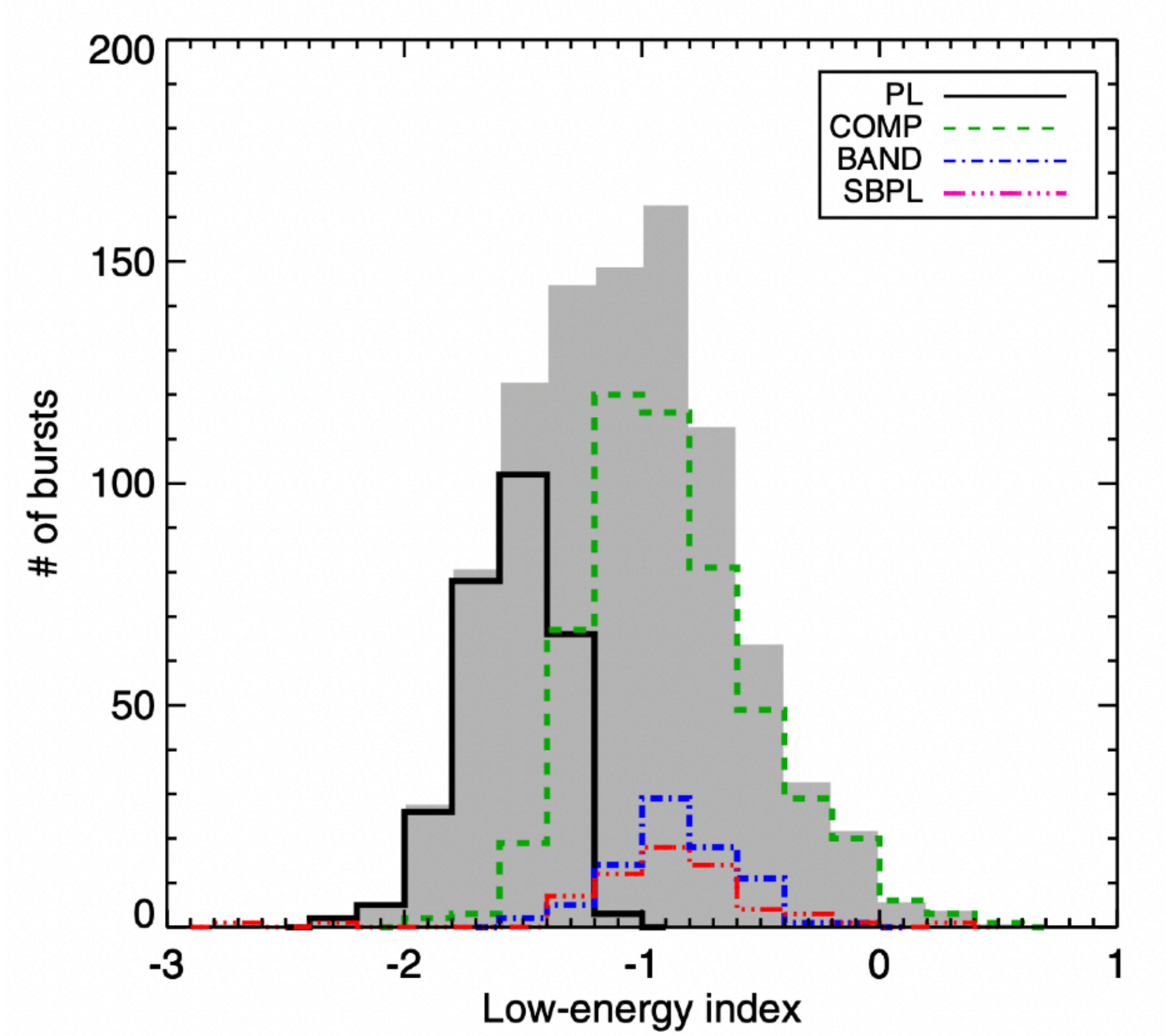

$$t_c = \frac{\gamma m_e c^2}{P_{syn}} \frac{1+z}{\Gamma} \sim 1.1 \times 10^{-5} \frac{\epsilon_B^3 \Gamma_2}{E^2_{2,peak[keV]}(1+z)} s << t_{obs}$$

Ghisellini et al. 2000

# more data - spectral index



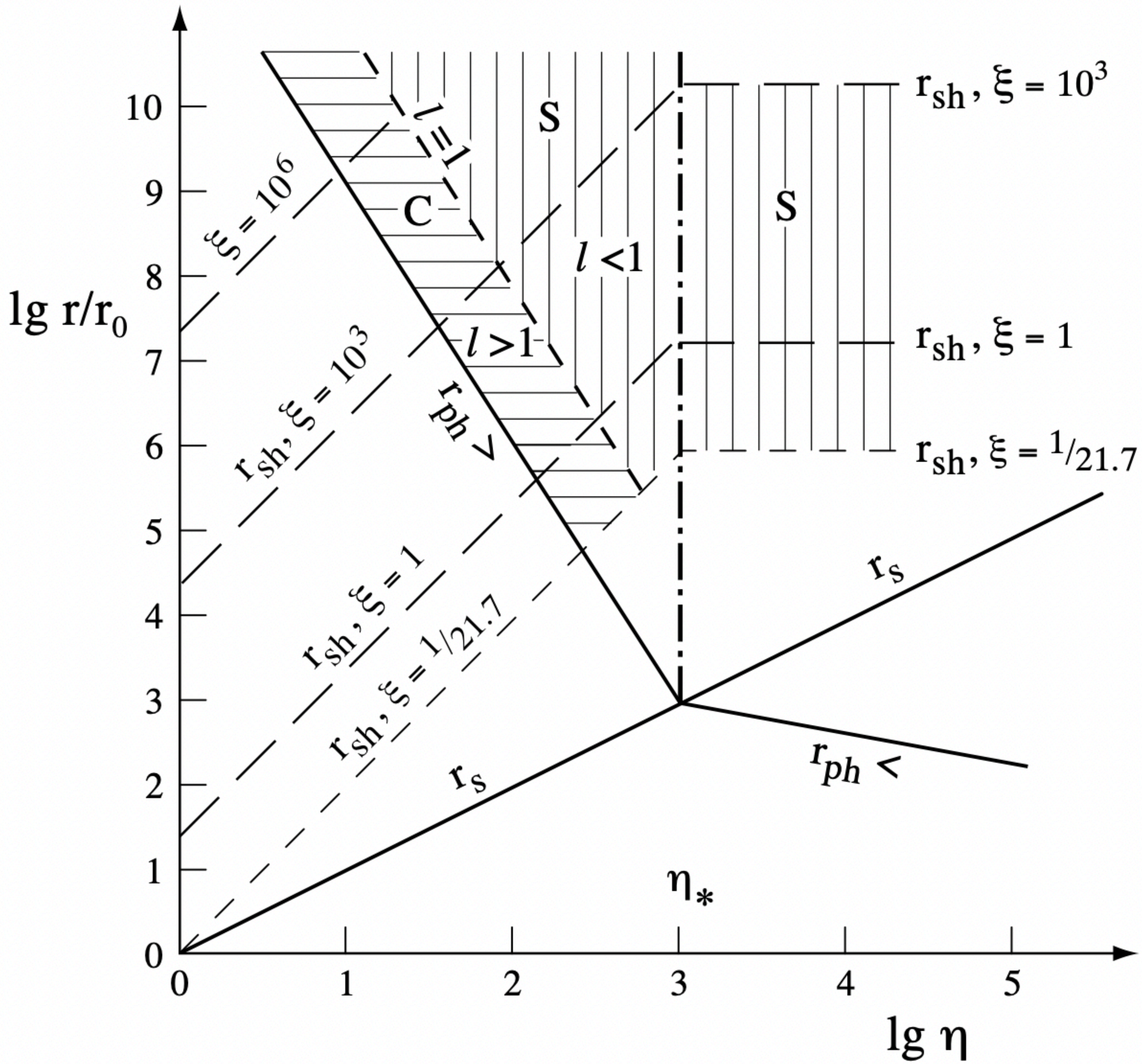

Band 1993




Gruber et al. 2018

**Problems with the opt. thin synchrotron** Crider 1997, Preece et al. 1998

# more options




Mészáros & Rees 2000

$$M_{BH} = 10 M_\odot$$

$$r_0 \approx 10^7\, cm$$

$$t_0 \approx 10^{-3}\, s$$

$$\xi = t_v / t_0$$

$$\eta = L/\dot{M}c^2$$

$$L_0 = 10^{52}\, erg\, s^{-1}$$

**C = Comptonisation**

Ghisellini & Celotti 1999

**S = Synchrotron**

$$\eta \uparrow L \uparrow = C \qquad L \downarrow = S \qquad \eta \downarrow = ph$$

# more data

## spectral-energy relations

**Amati** $E_{peak} \propto E_{iso}^{0.5}$

**Ghirlanda** $E_{peak} \propto E_{\gamma}^{0.7}$

**Yonetoku** $E_{peak} \propto L_{iso}^{0.5}$

## Thermal components

**Ghirlanda et al. 2003; Ryde 2004**

↓

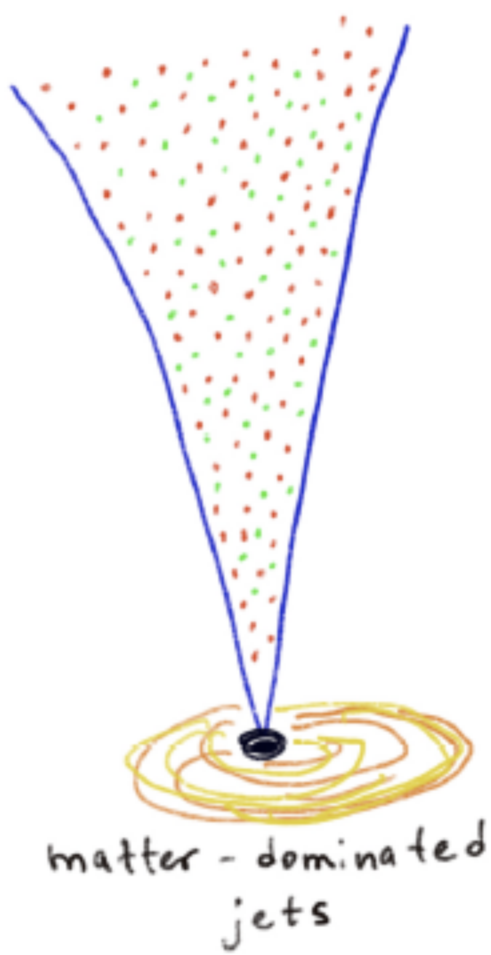
## dissipative photospheres

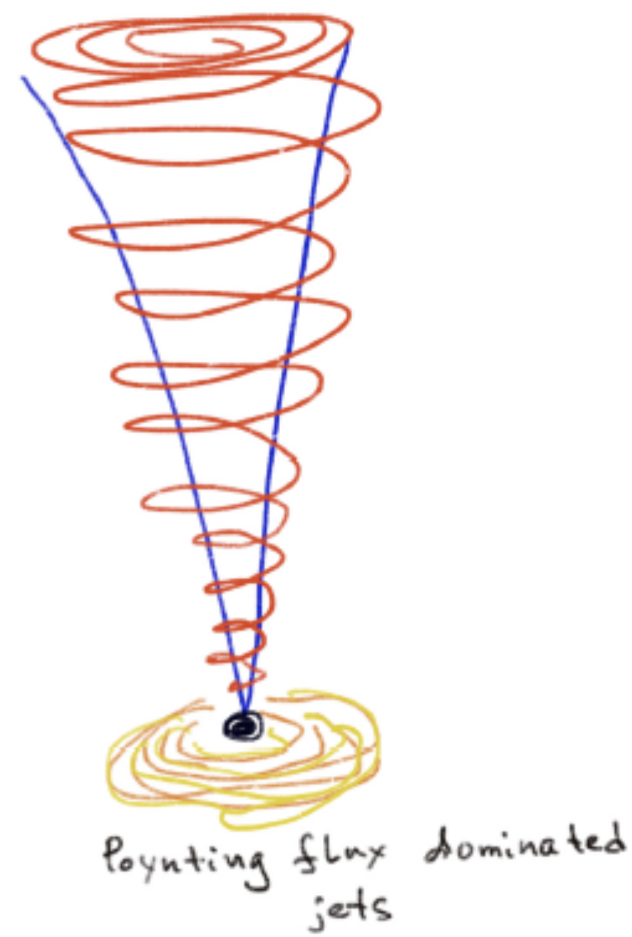
Rees & Mészáros 2005

Ghisellini & Celotti 1999
(quasi-thermal C.)

Pe'er & Waxman 2004
(opt. thick solutions)

# GRB jet mystery

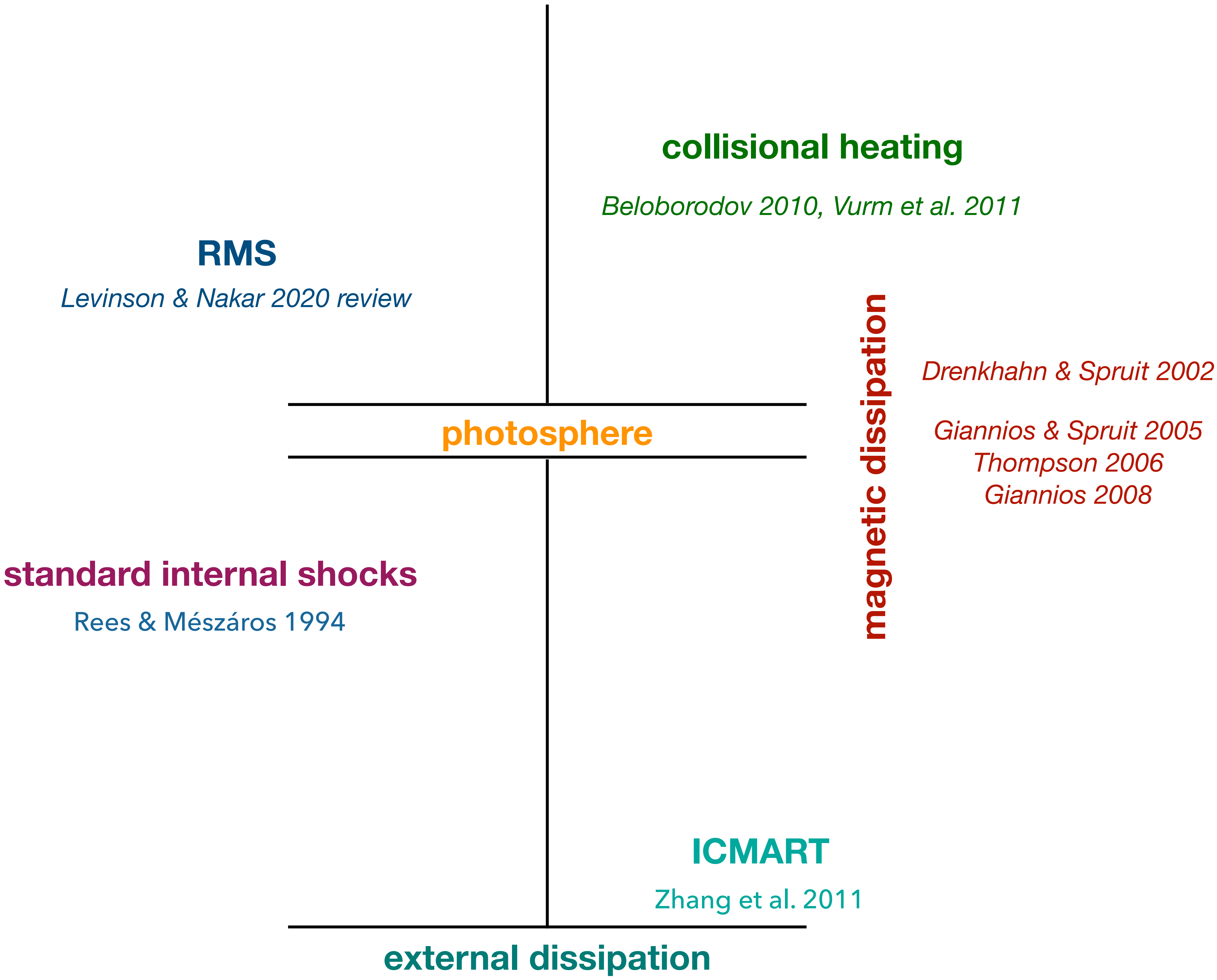


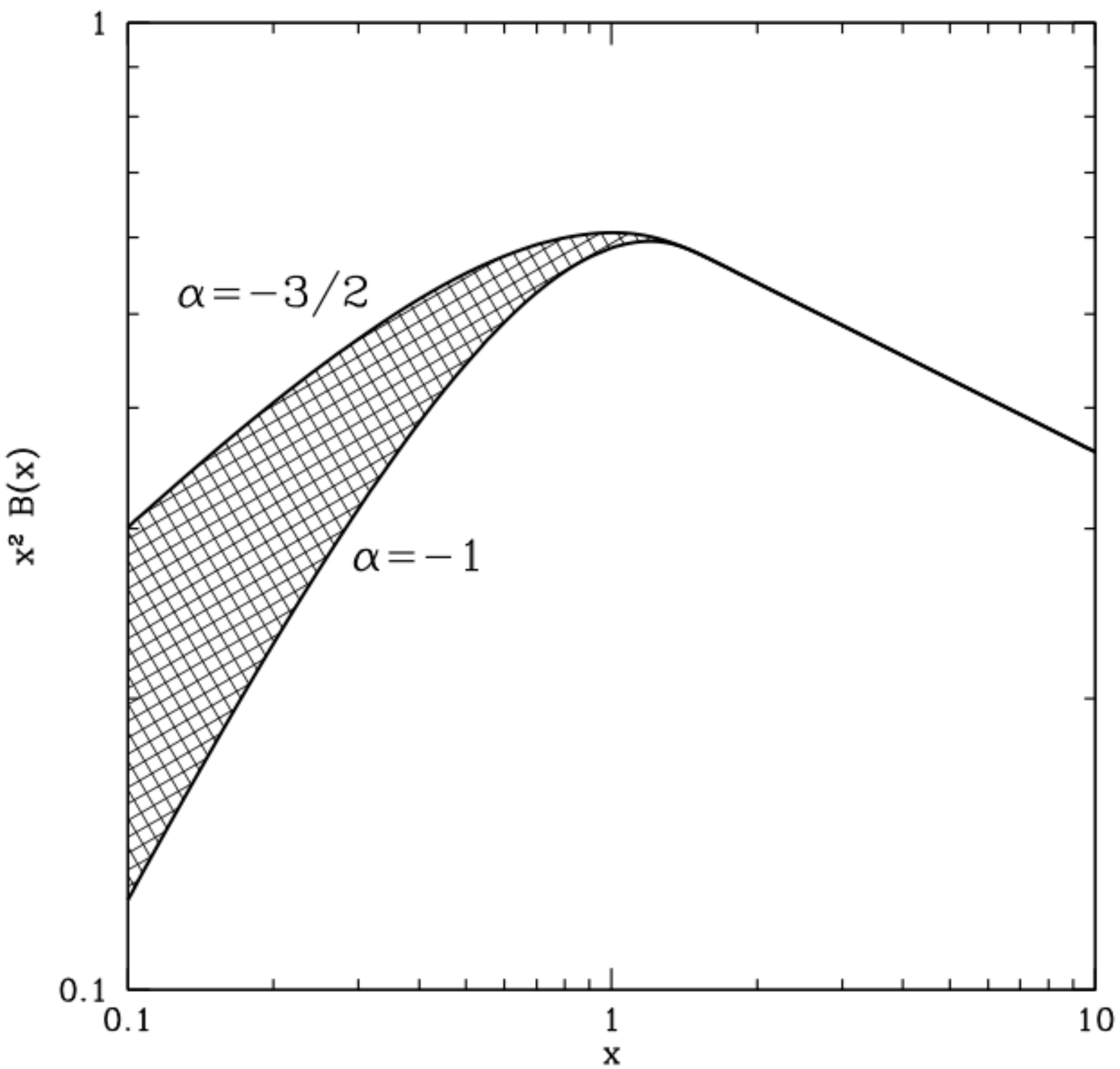

Cavallo & Rees 1978
Paczýnski 1986
Goodman 1986
Shemi & Piran 1990

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

# Possible dissipation models

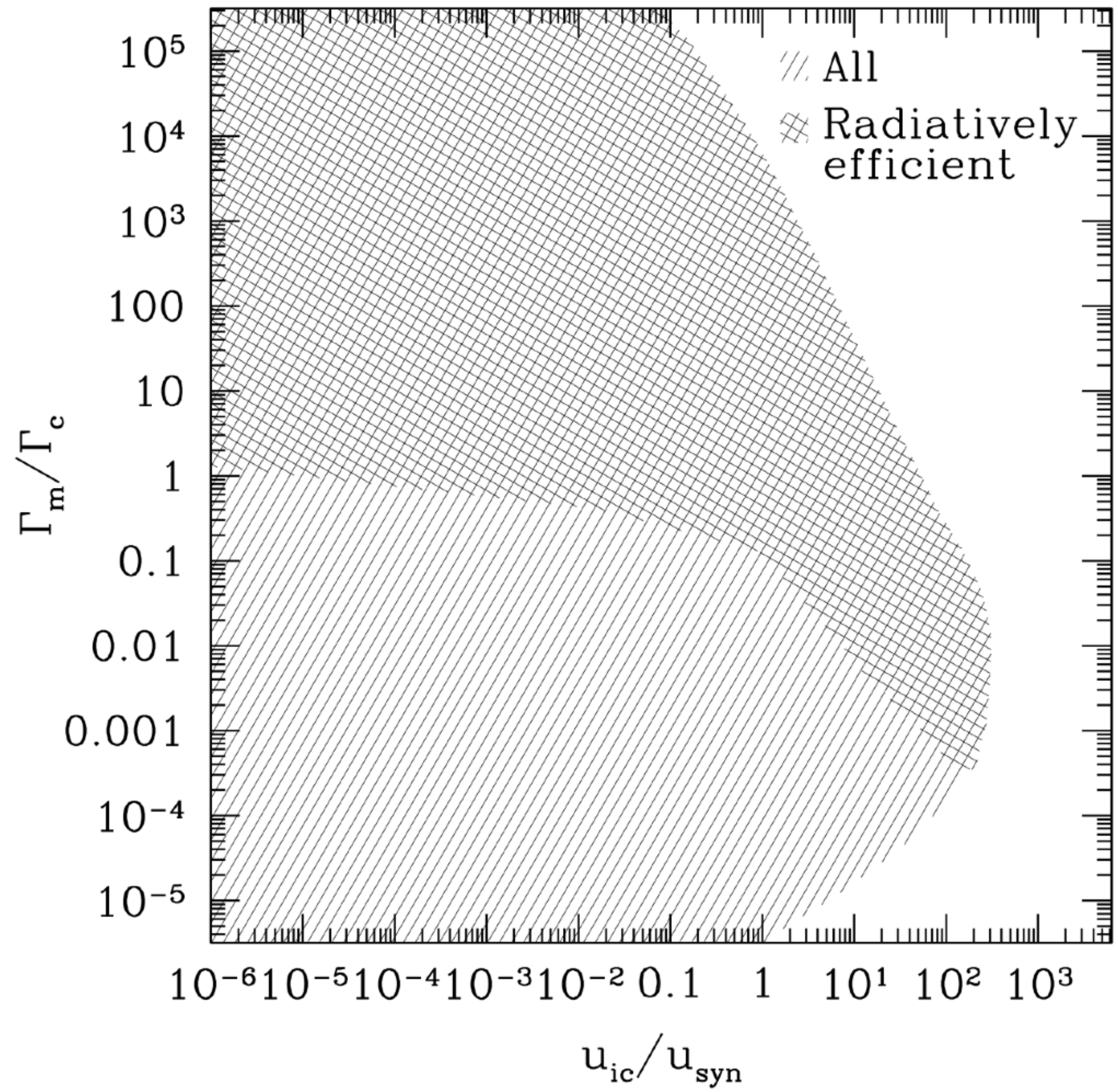


# Harder in thin synchrotron models




*Daigne et al. 2011*

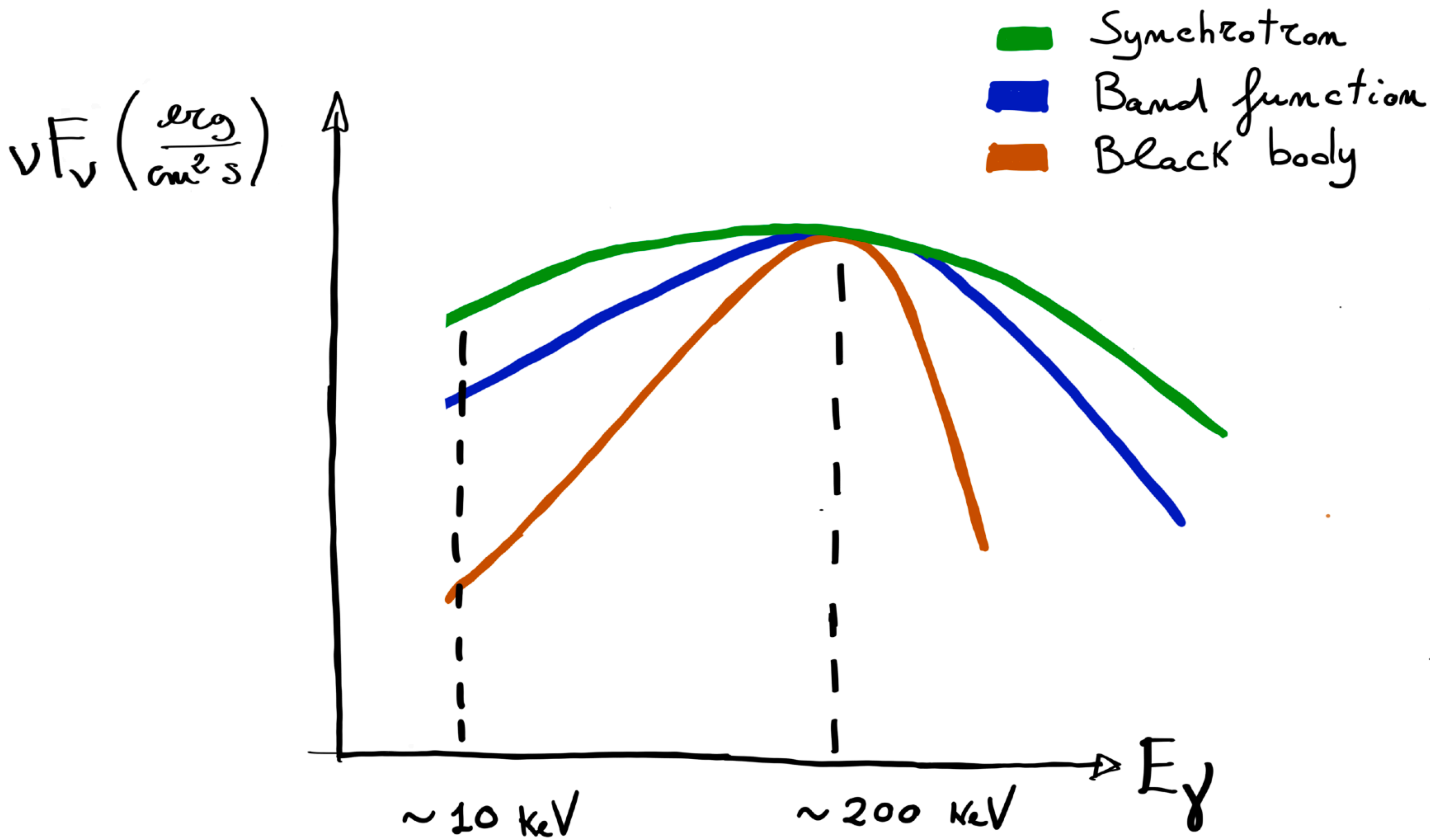
*(see Derishev et al. 2001)*




*Bošnjak et al. 2009*

**Par. space:** $R_\gamma > 10^{15}\, cm \quad \Gamma > 300 \quad \gamma_e > 10^3$ *Beniamini et al. 2013*

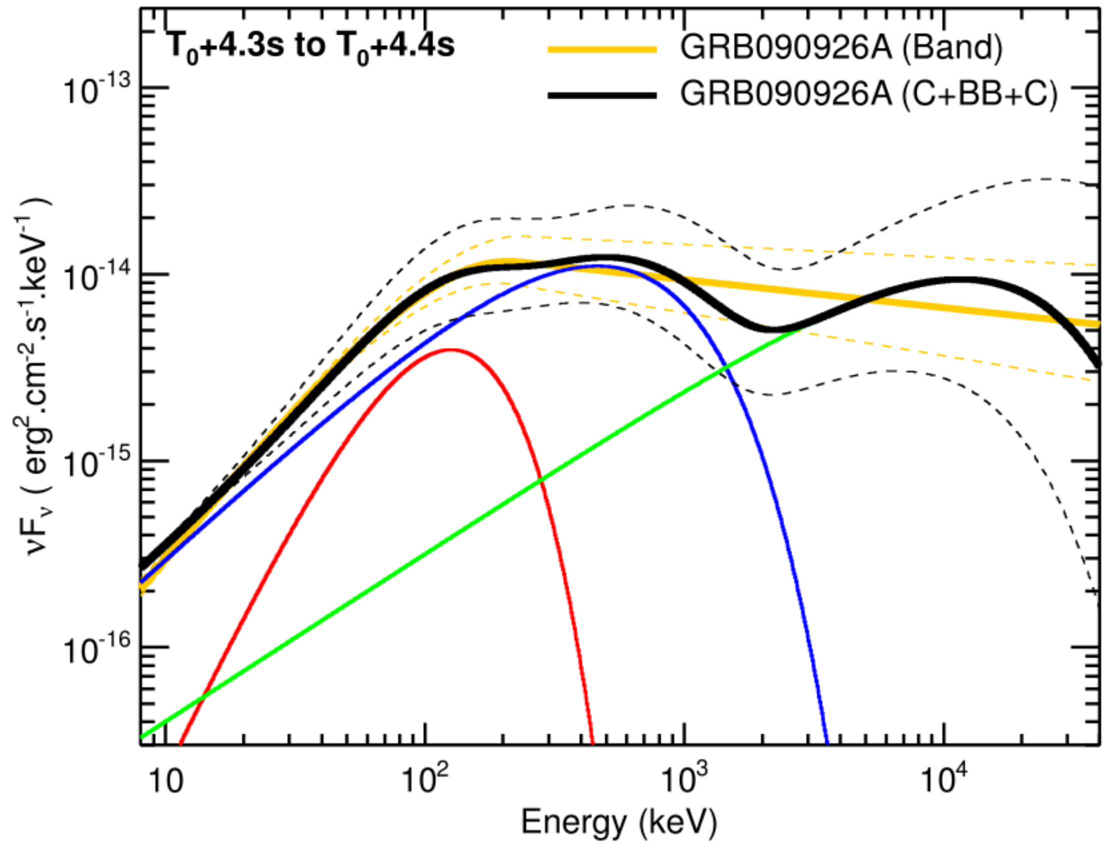
## Synchrotron vs Thermal emission



# Looking for thermal components

**multiple thermal and non-th. components**

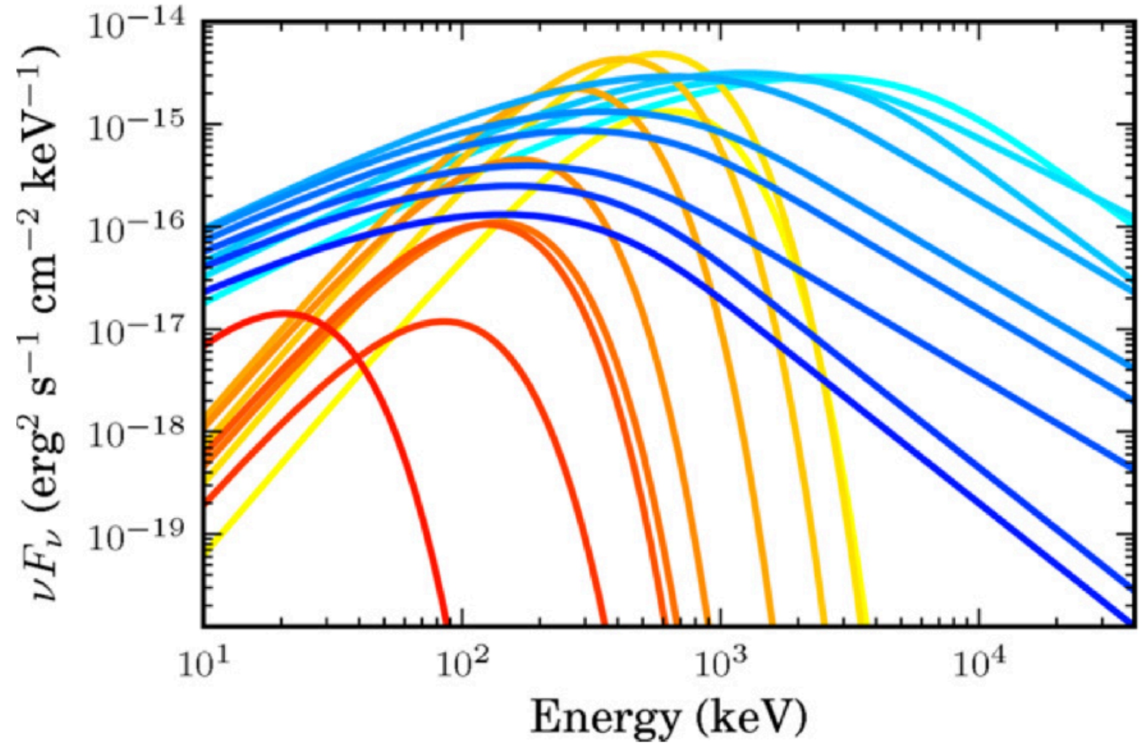
**[10 GRBs]**




*Guiriec et al. 2011-2017*

**thermal + non.th.**
**(fixed slow-cool synchrotron)**

**[9 GRBs]**

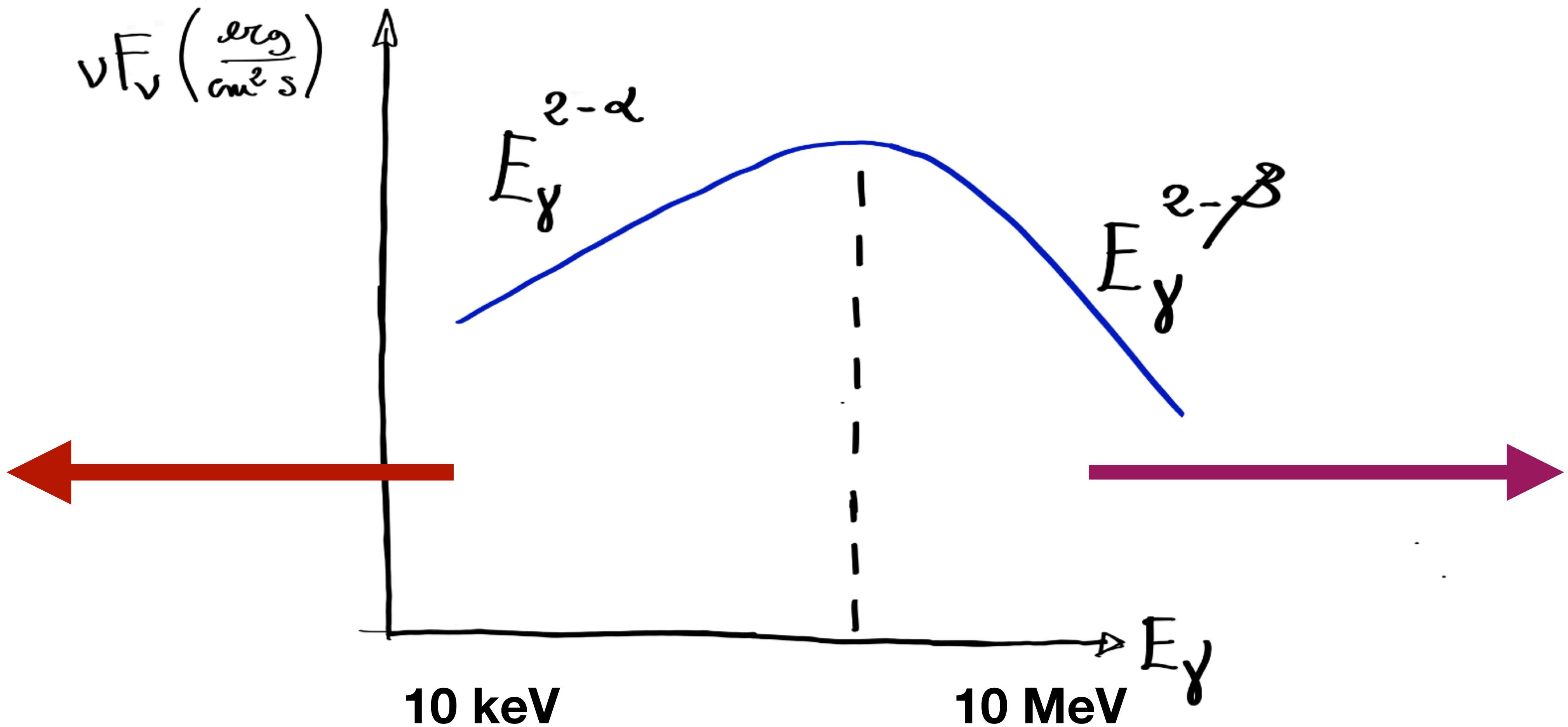



*Burgess et al. 2011-2014*

+ many authors on individual GRBs with BB components

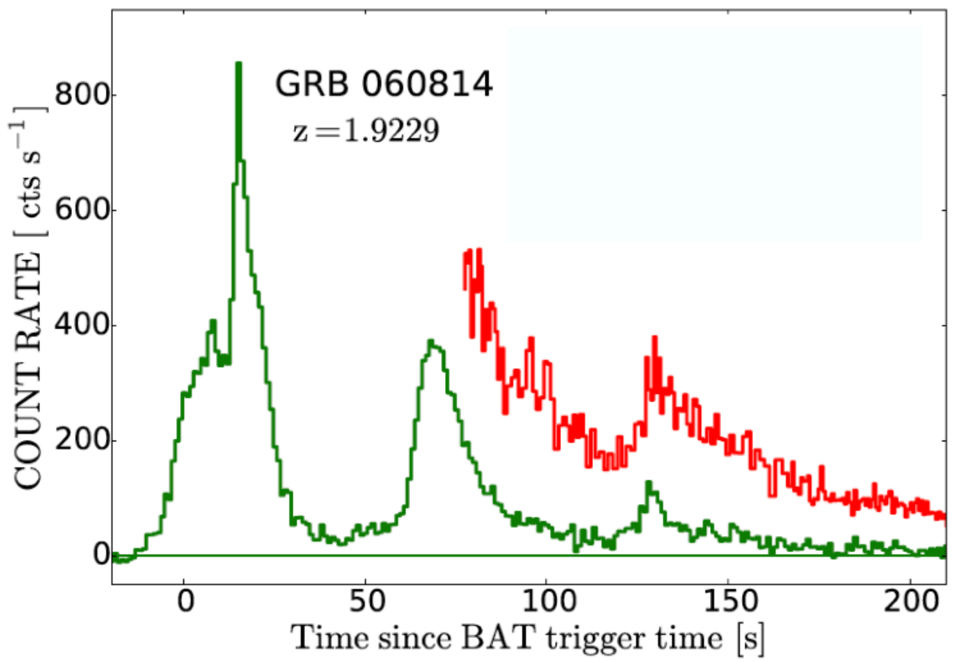
# spectral breaks

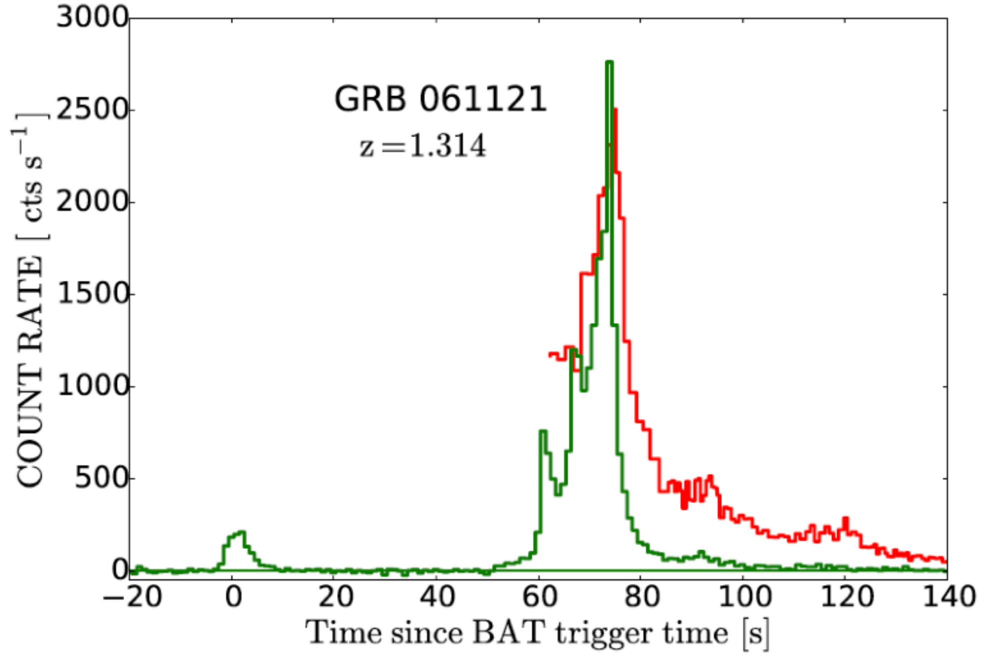
## Different ways to “solve” the problem



## Soft X-rays

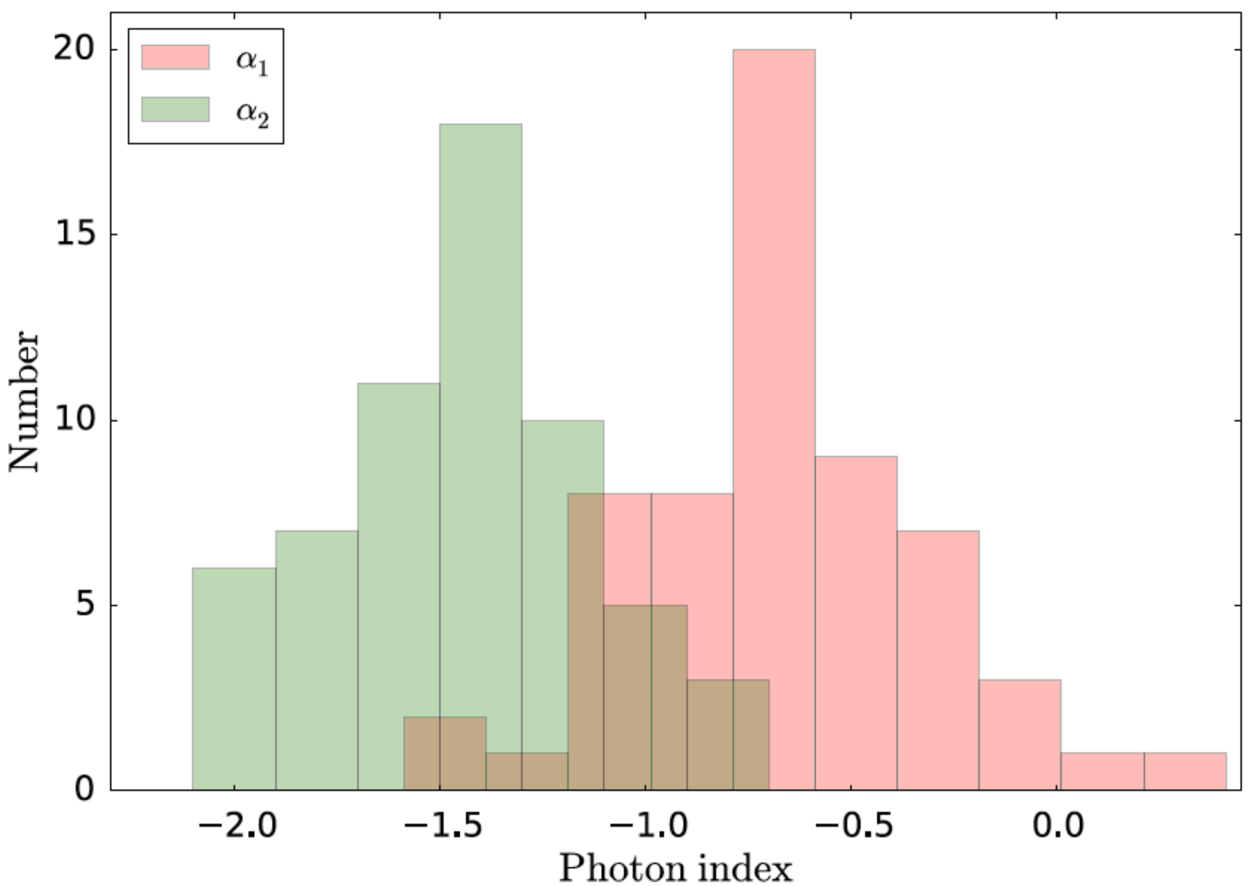
**XRT average slewing time ~ 90 s**

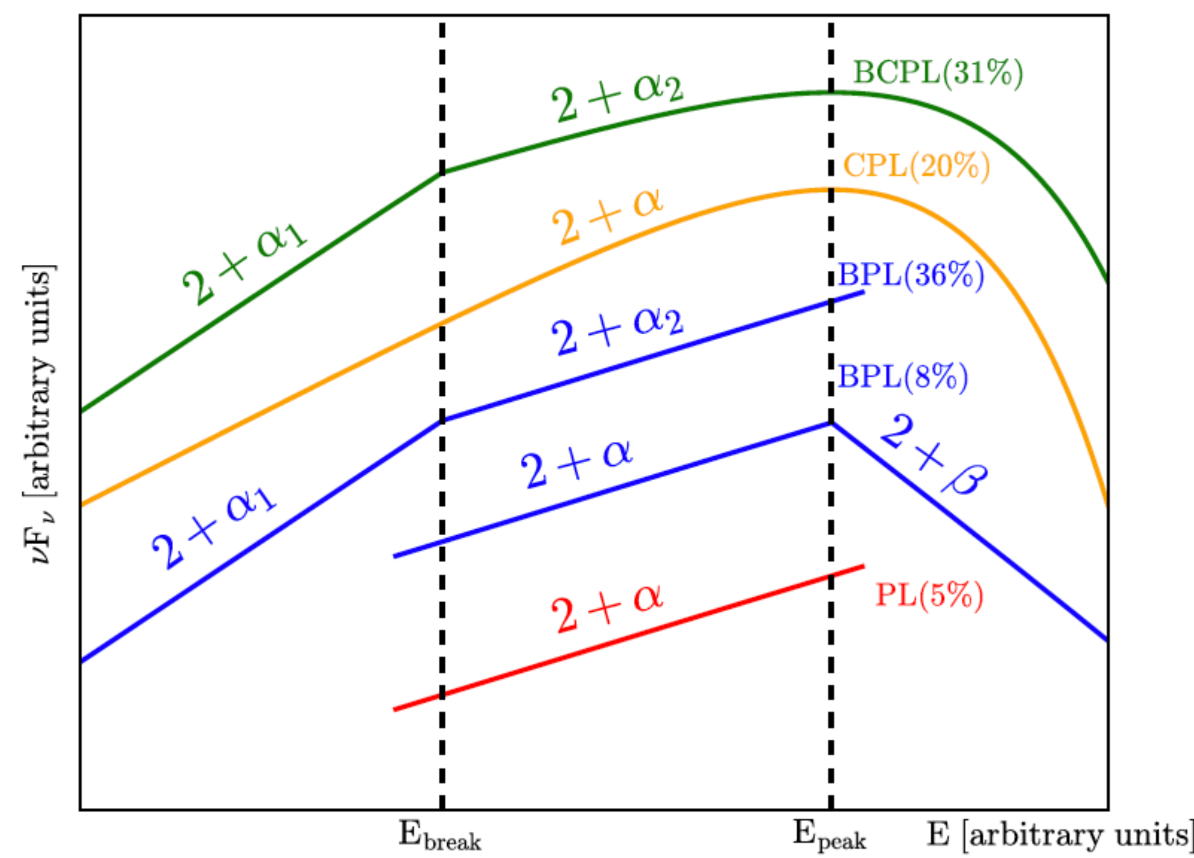



**BAT [15-150 keV] + XRT [0.5-10 keV]**

# Soft X-rays



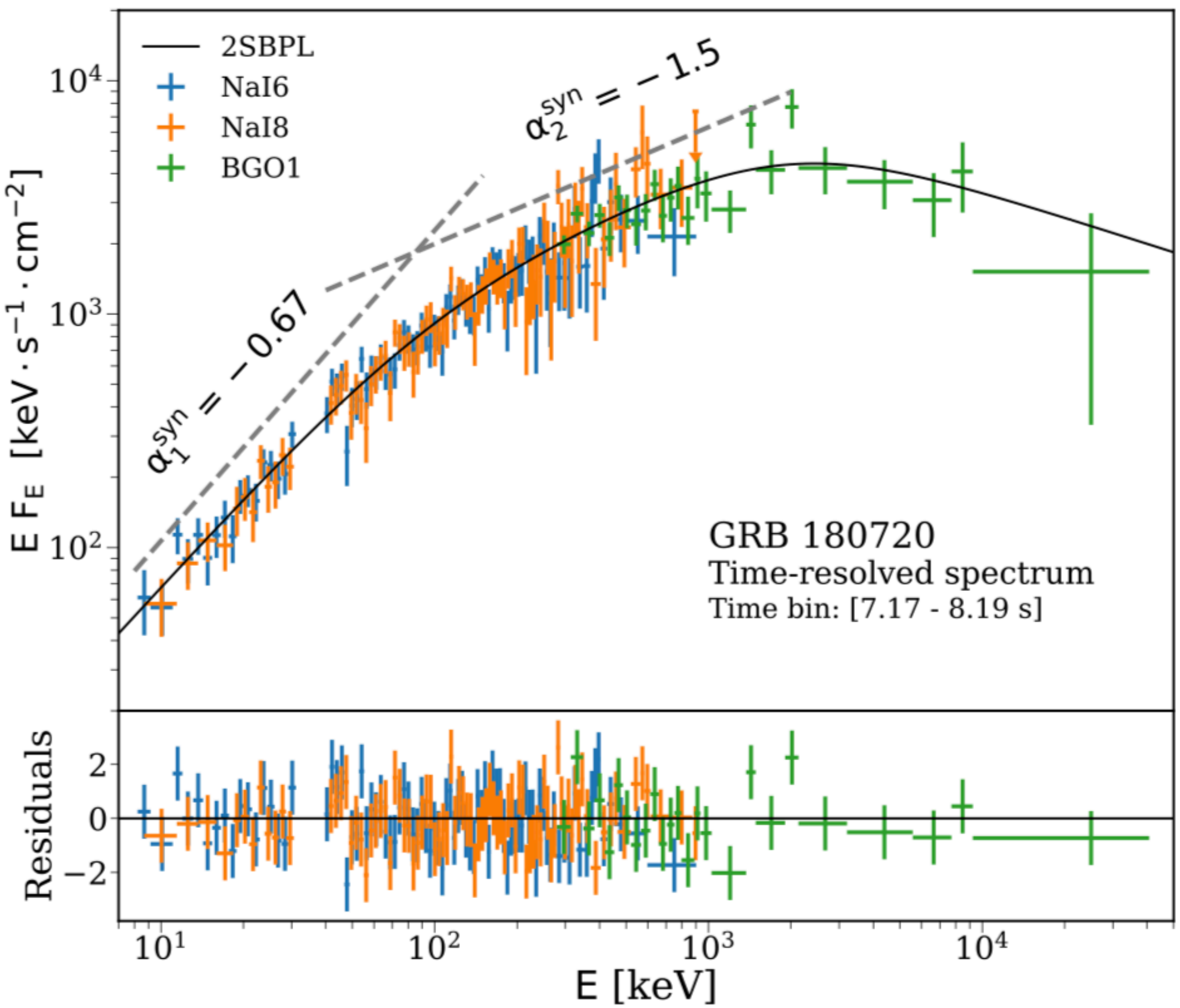

**[>30 GRBs, 120 spectra]**

**67 % of spectra require a break**

Oganesyan et al. 2017; 2018        see Zheng et al. 2012 for GRB 110205A

# Spectral breaks at hard X-rays

10 short and 10 long GRBs




**Fermi GBM**

**8 keV - 100 MeV**

**breaks for 8/10 long GRBs**

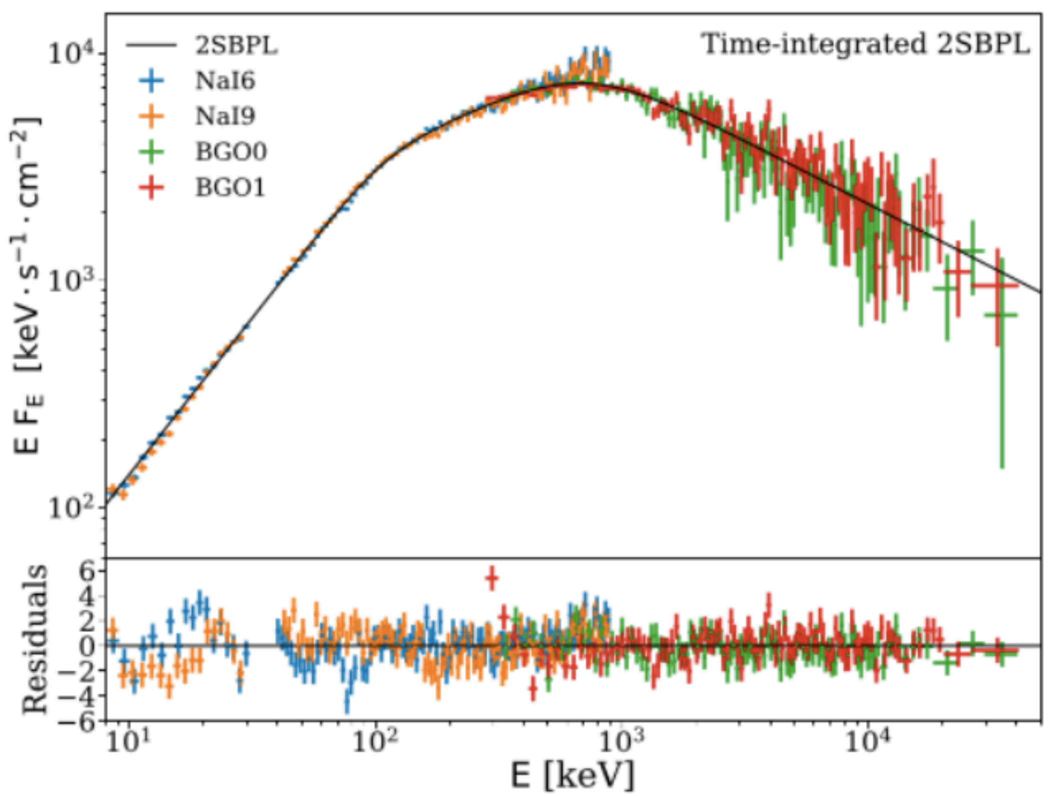
**no breaks for short GRBs**

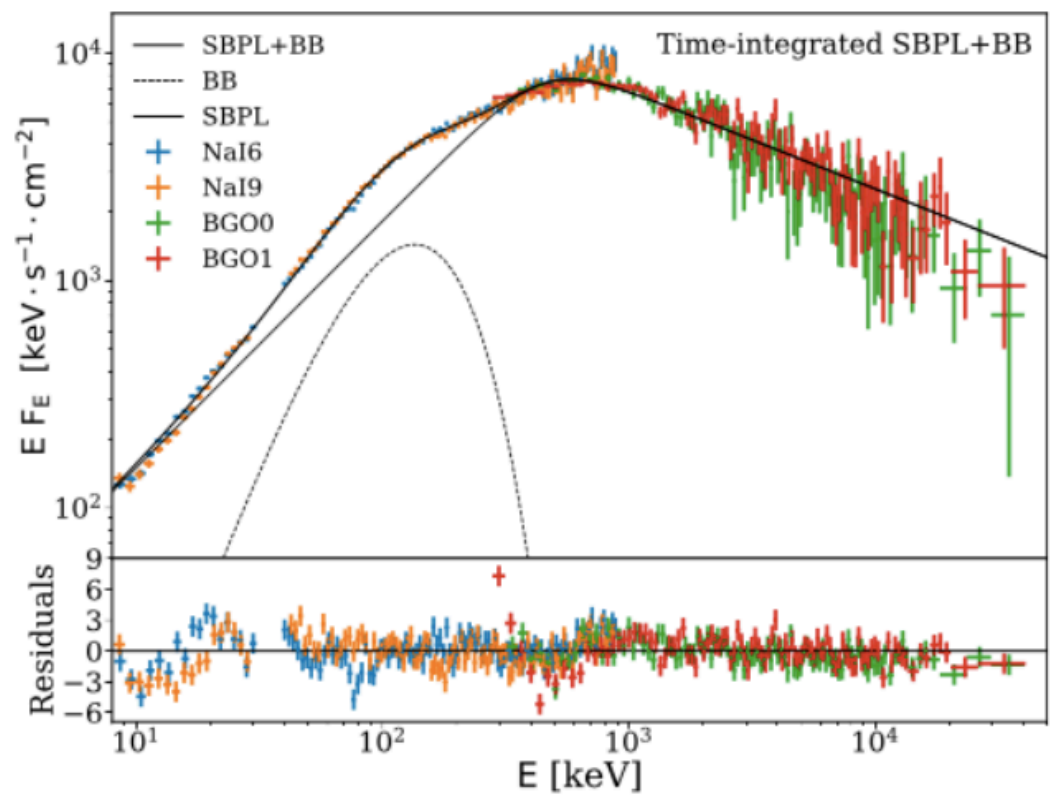
**[20 GRBs, 145 spectra]**

Ravasio et al. 2018, 2019

**Break** vs **BB component**

**Empirical models** vs **Physical models**

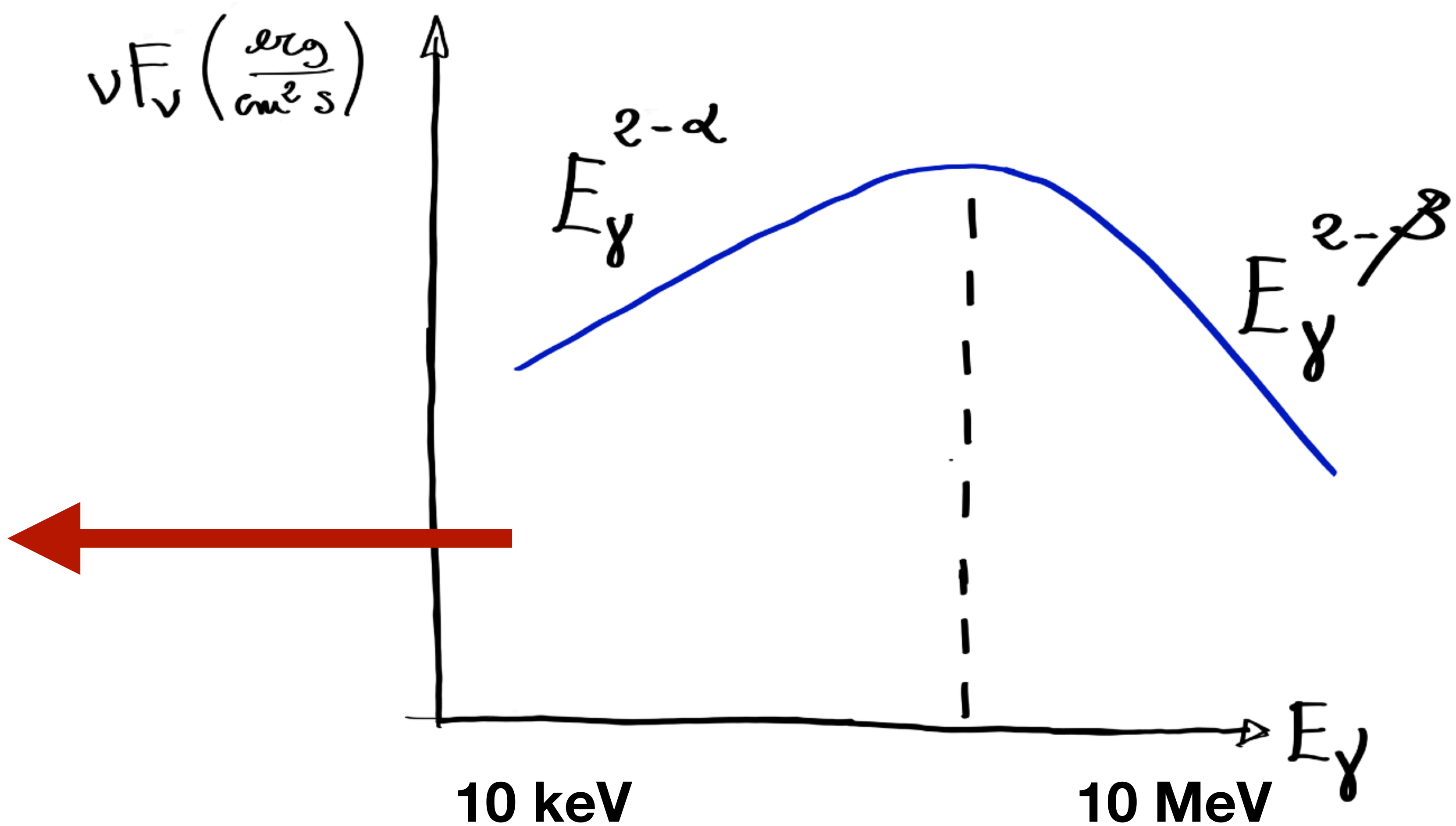



BRIGHT FERMI GRB 160625B

Ravasio et al. 2018

# Different ways to “solve” the problem



# single synchrotron vs 2 component model

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

↓

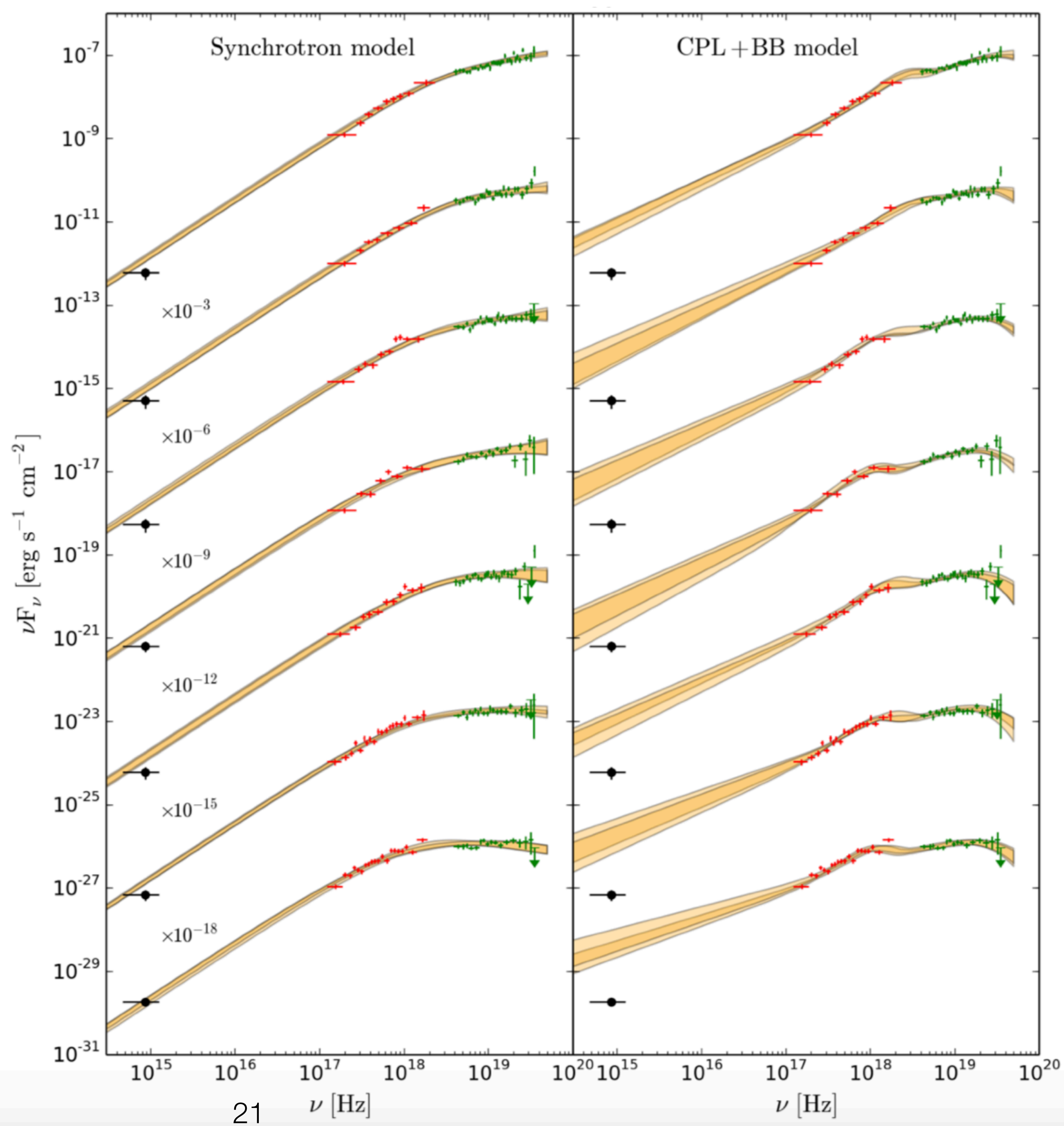
**synchrotron model is preferred**

**[21 GRBs, 52 spectra]**

Oganesyan et al. 2019

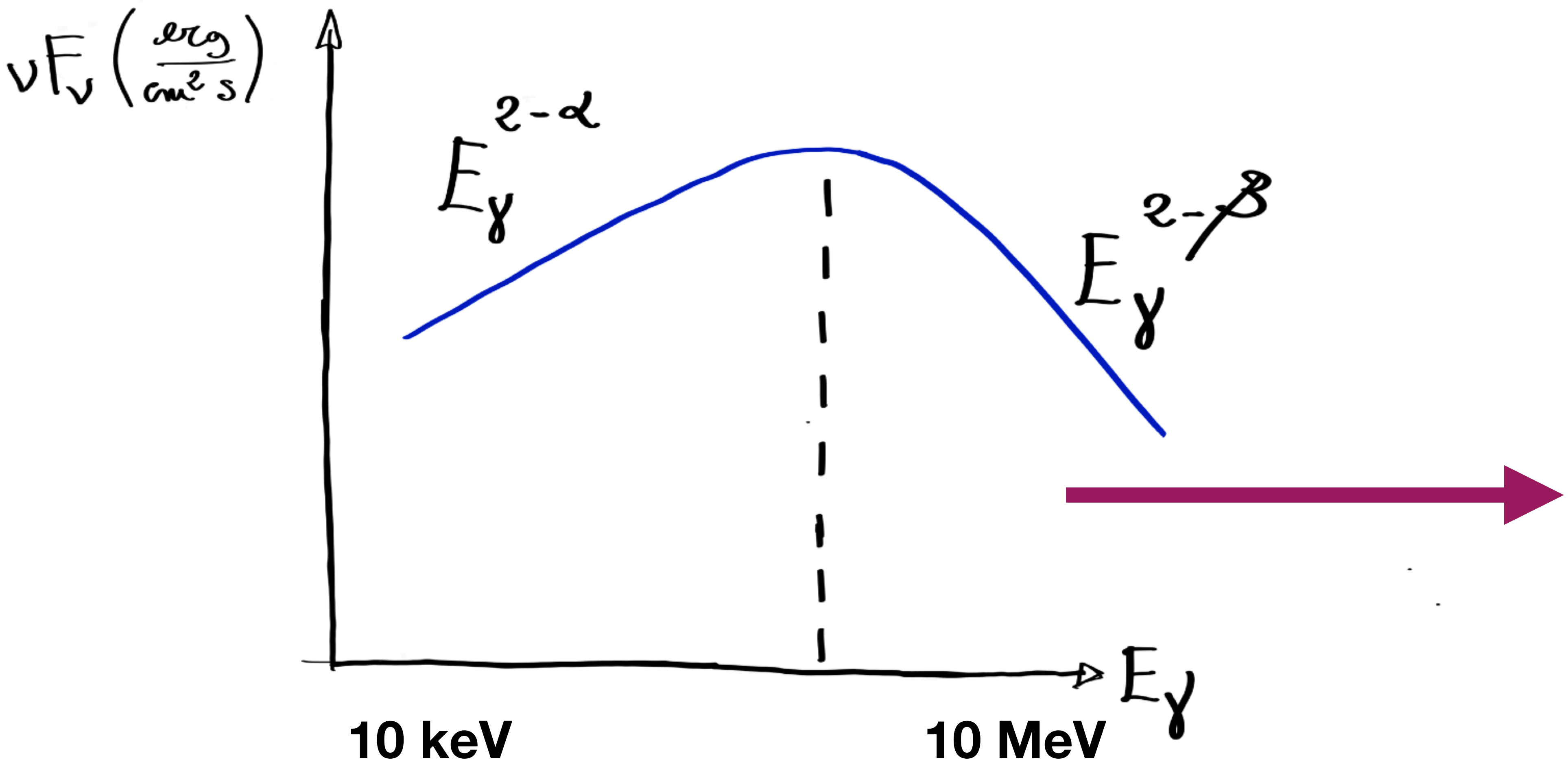
see Burgess et al. 2020

GRB 110205A



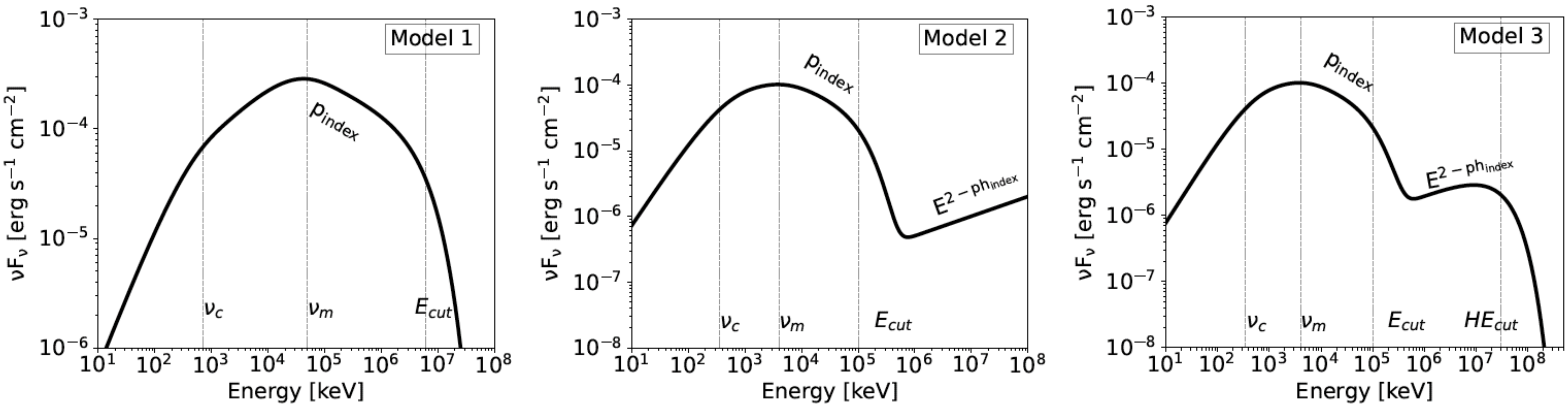
**high energy**

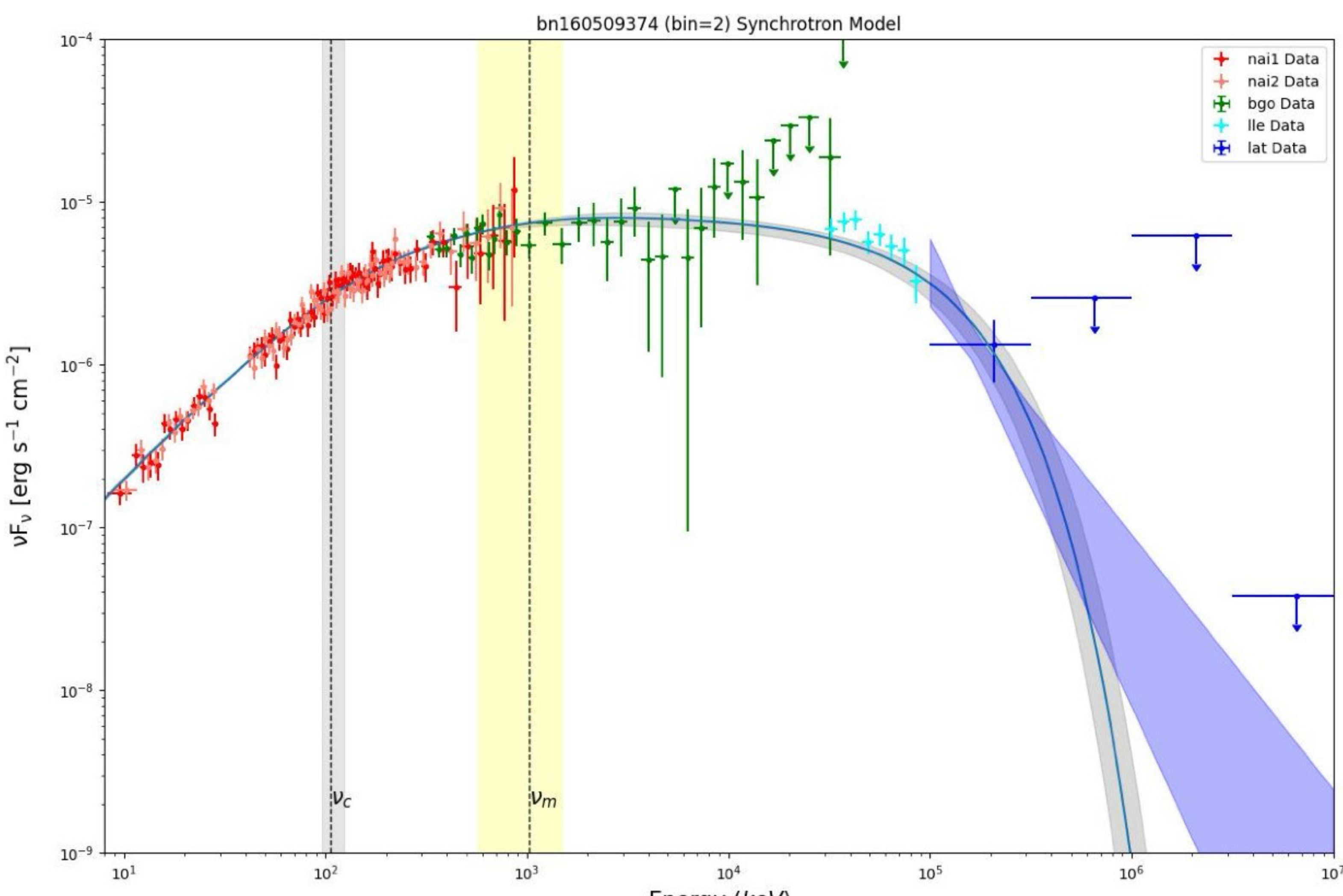
## Let's go to higher energies




Gupta & Zhang 2008, Zhang & Pe'er 2009, Hascoët + 2012 for HE softening

Vianello+ 2018, Chand+ 2020, Mei + 2022, Ravasio+ 2024
for observations



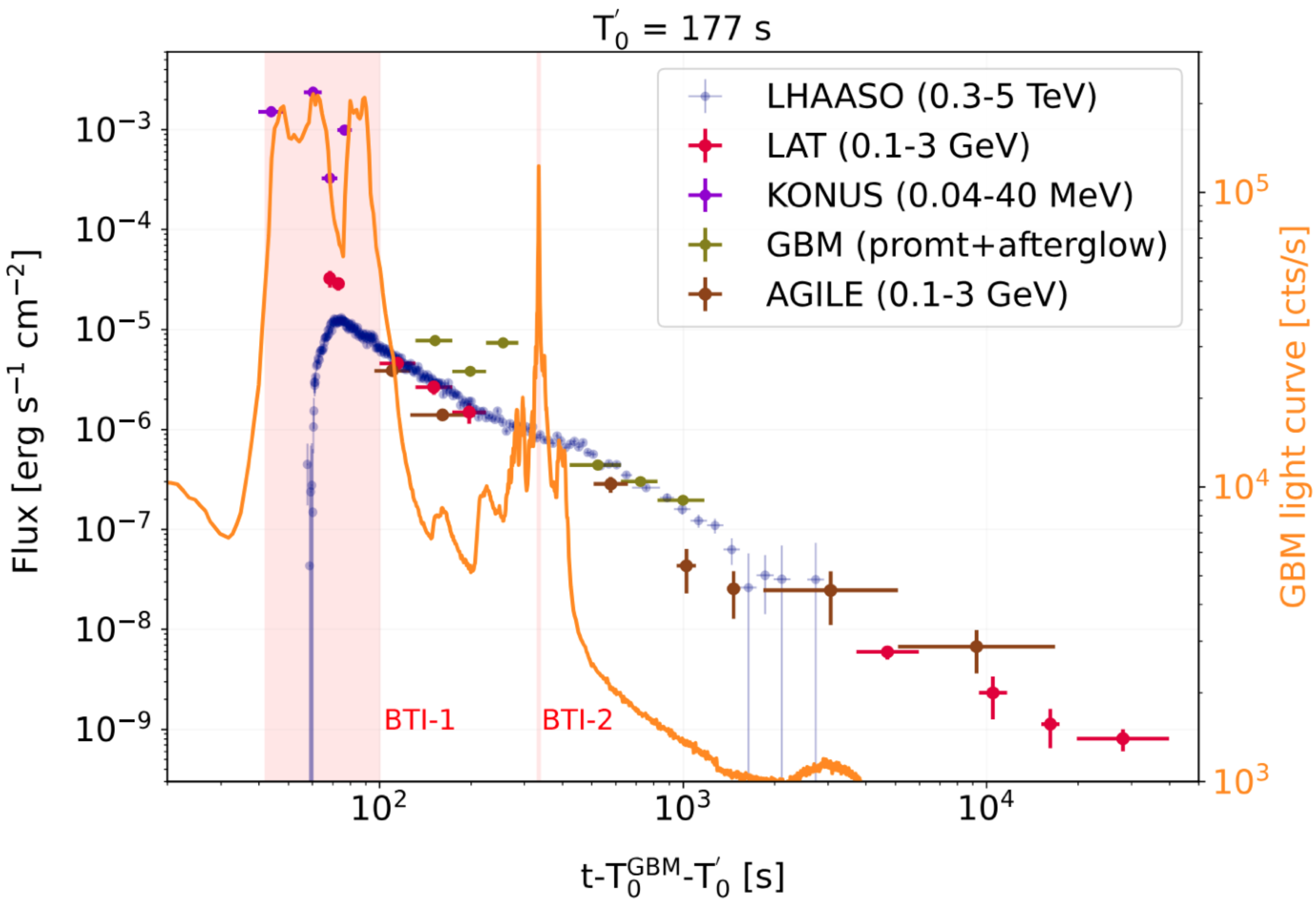

**>30 GRBs and ~ 100 spectra**

**Fermi/LAT**

Macera et al. (in preparation)

**very high energy**

# GRB 221009A - BOAT




Banerjee et al. 2024

LHAASO Collaboration, Science (2023)

Tavani et al 2023 ApJL 956 L23, 2023

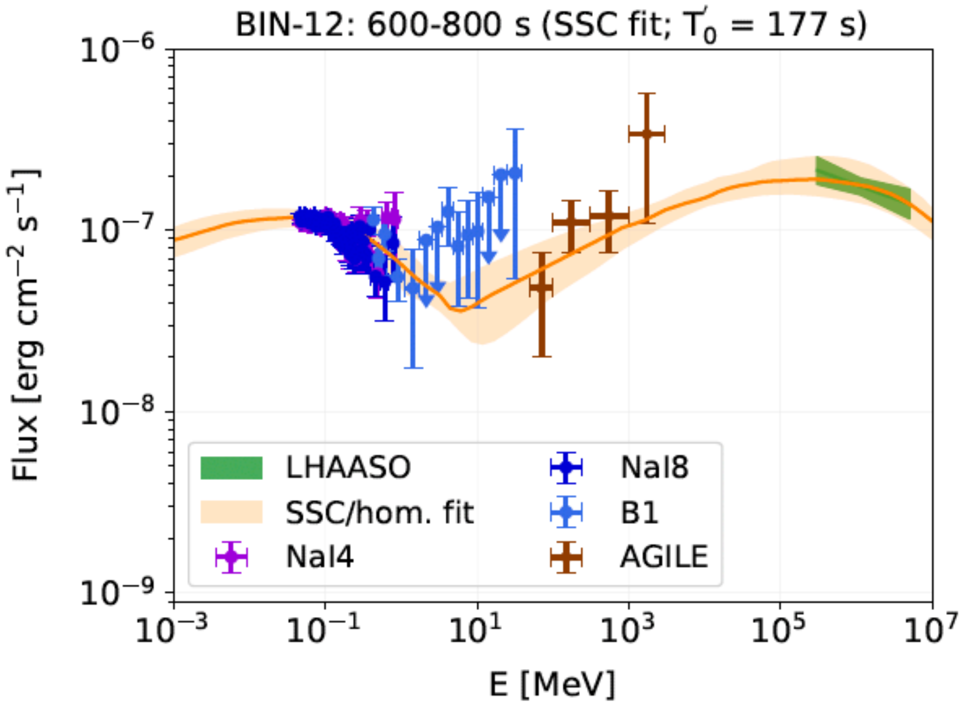
Bissaldi et al 2023

Frederiks et al 2023 ApJL, 949, L7 (2023)

Lesage et al 2023, ApJL 952 L42

Burns et al 2023, ApJL 946 L31

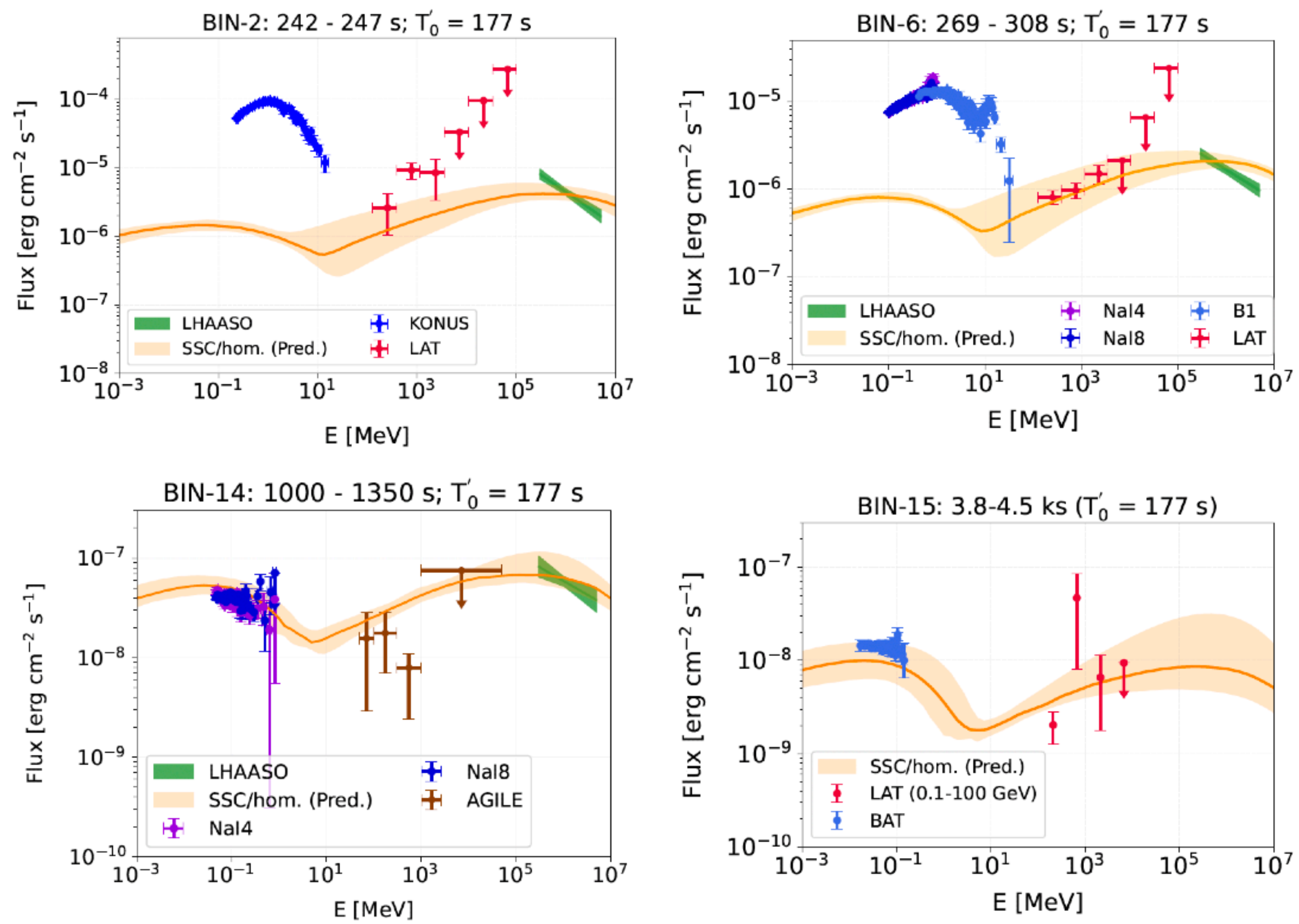
## SSC




**best model**

Banerjee et al. 2024

## BM dynamics + same microphysics




**predicted afterglow SED**

## spectral-energy relations

# more data

## spectral-energy relations

**Amati** $E_{peak} \propto E_{iso}^{0.5}$

**Ghirlanda** $E_{peak} \propto E_{\gamma}^{0.7}$

**Yonetoku** $E_{peak} \propto L_{iso}^{0.5}$

## Thermal components

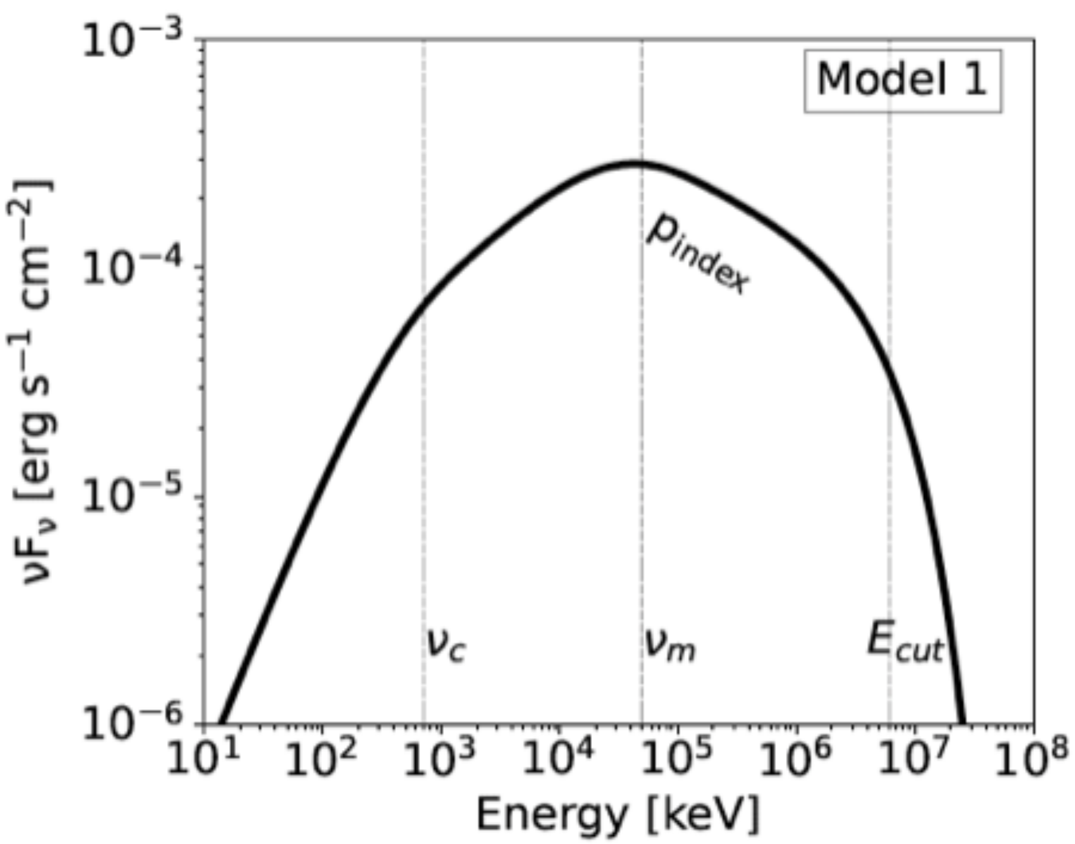
**Ghirlanda et al. 2003; Ryde 2004**

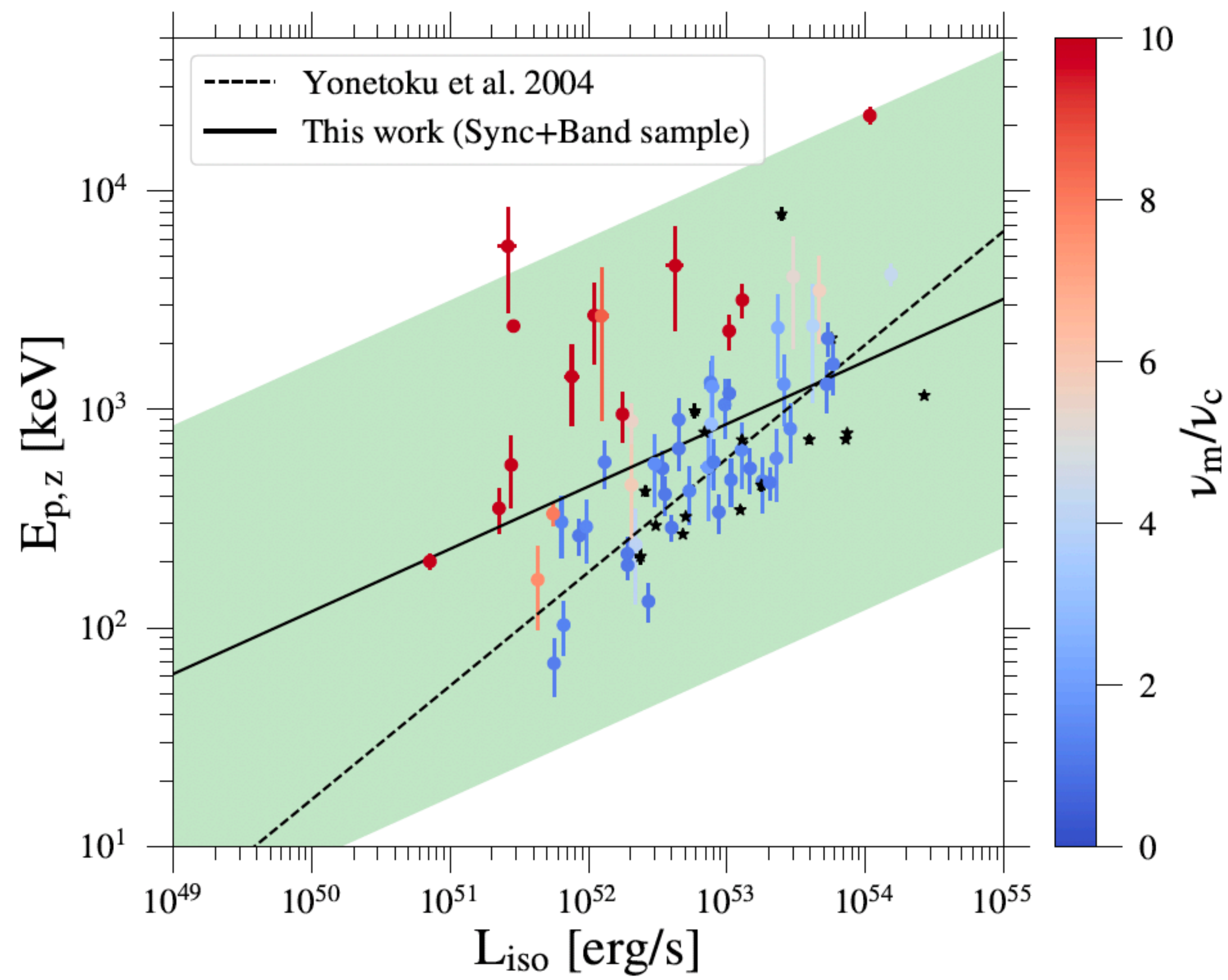
↓

# dissipative photospheres

Rees & Mészáros 2005

## spectral-energy relations



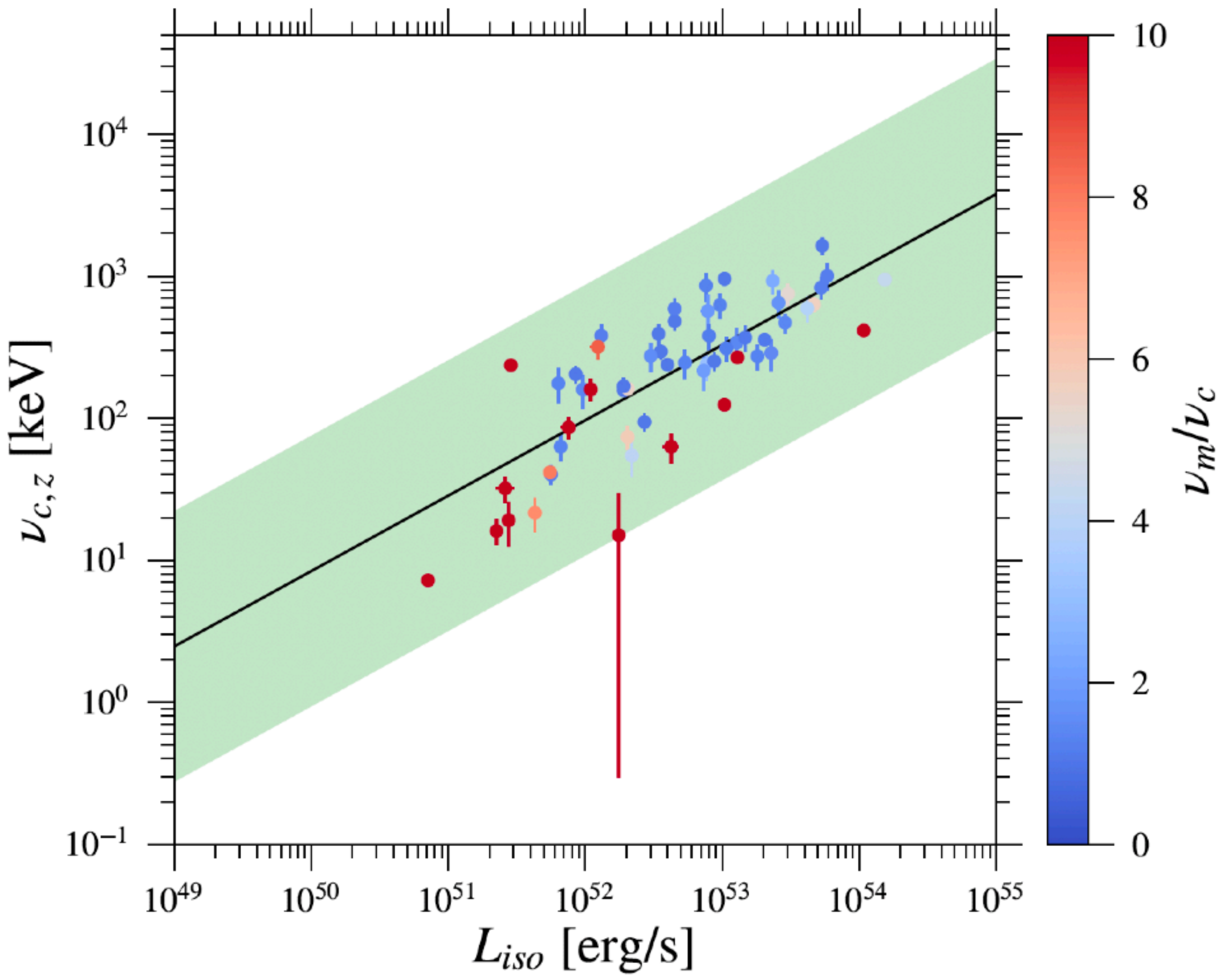



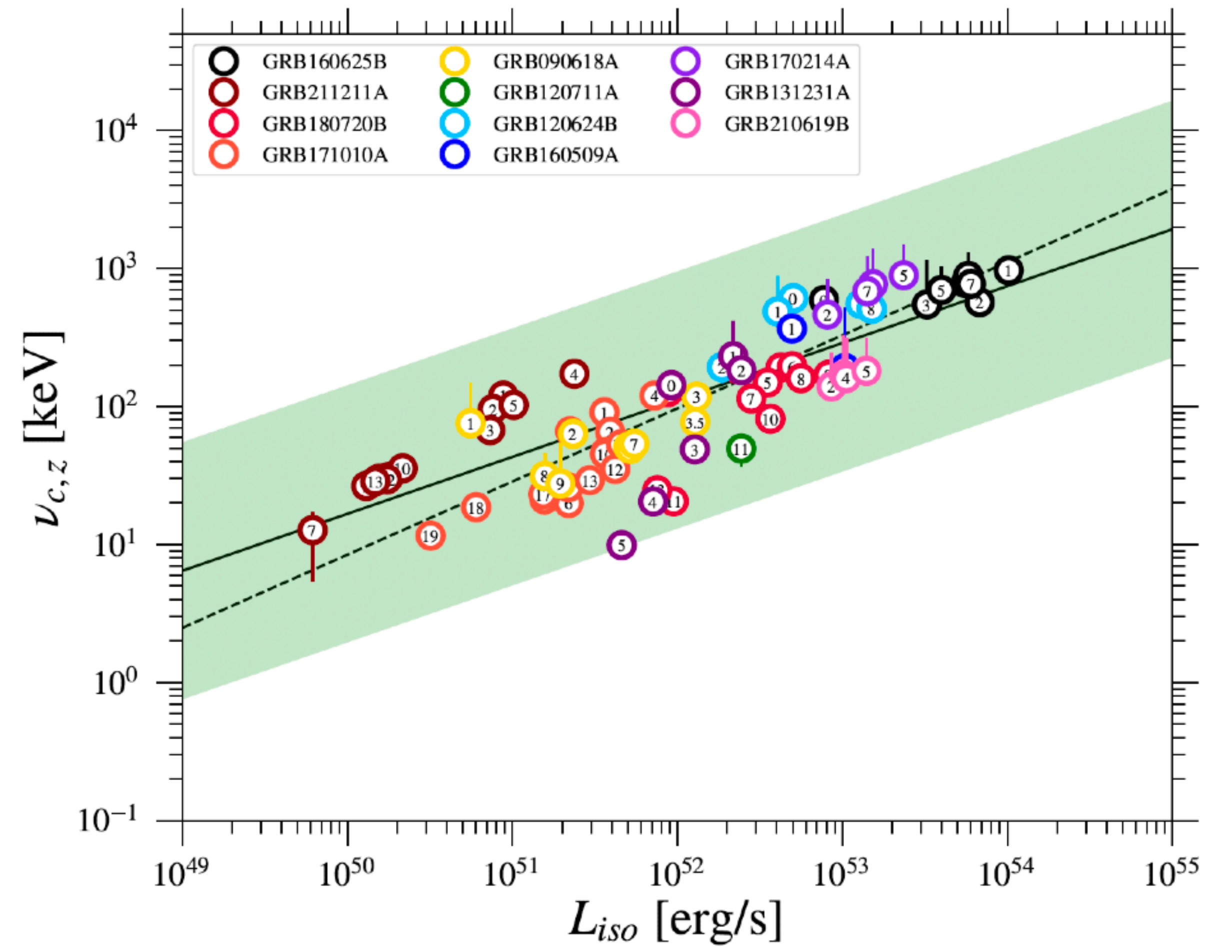

**70 GRBs**

Mei et al. (Forthcoming in A&A)

## spectral-energy relations

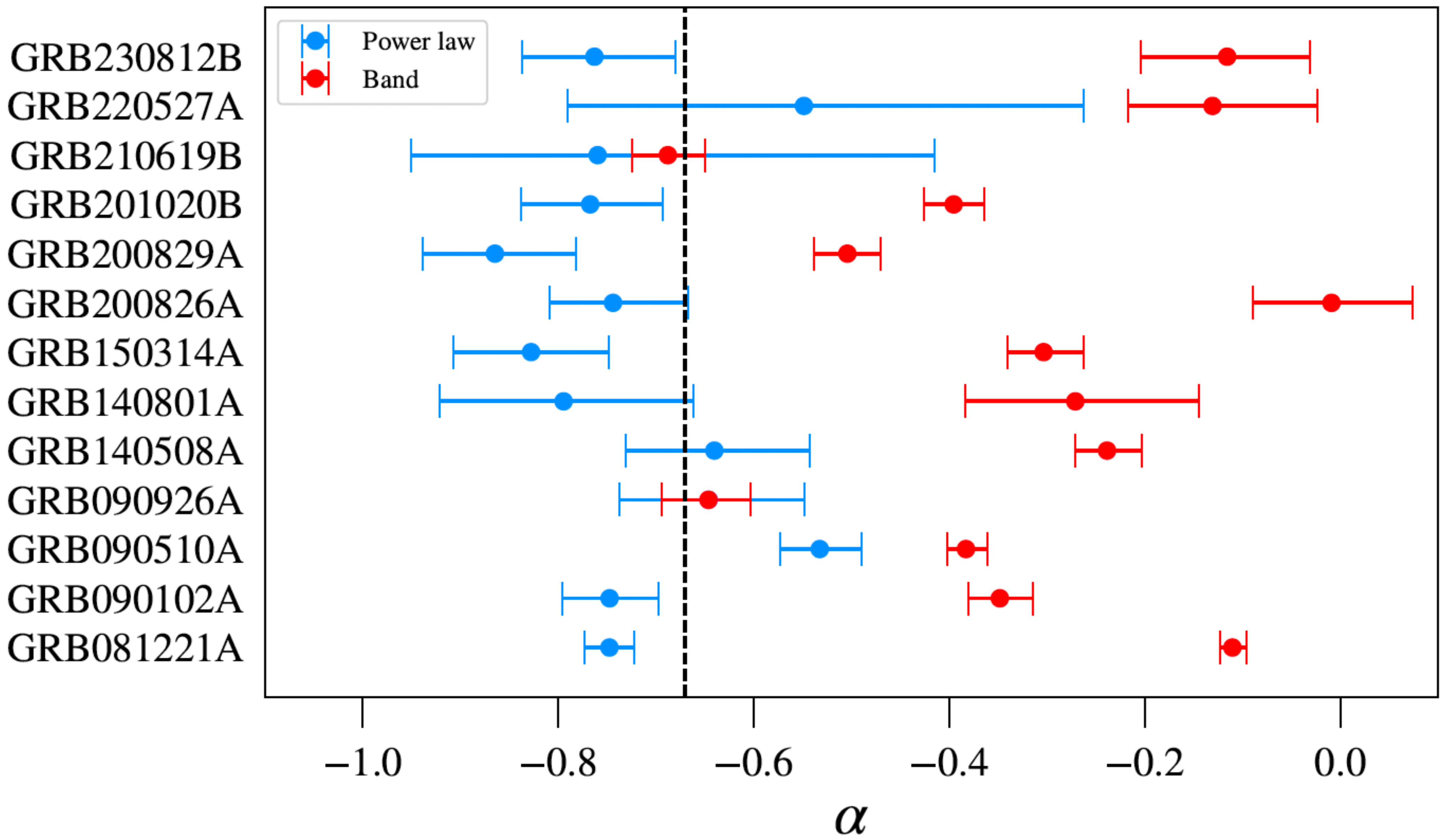
**BUT**




Mei et al. (Forthcoming in A&A)

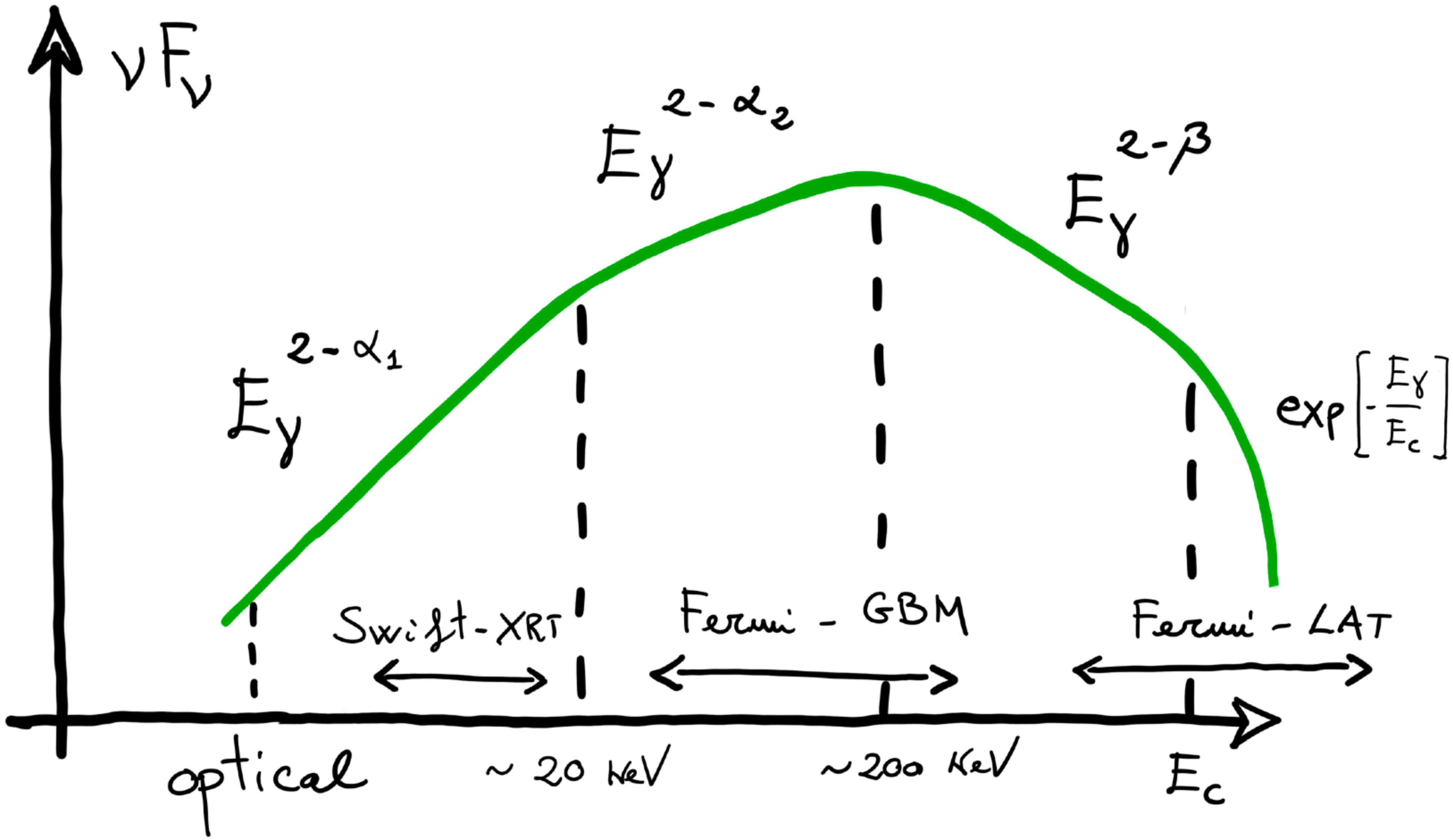
## **Hard** bursts?




**8-30 keV**

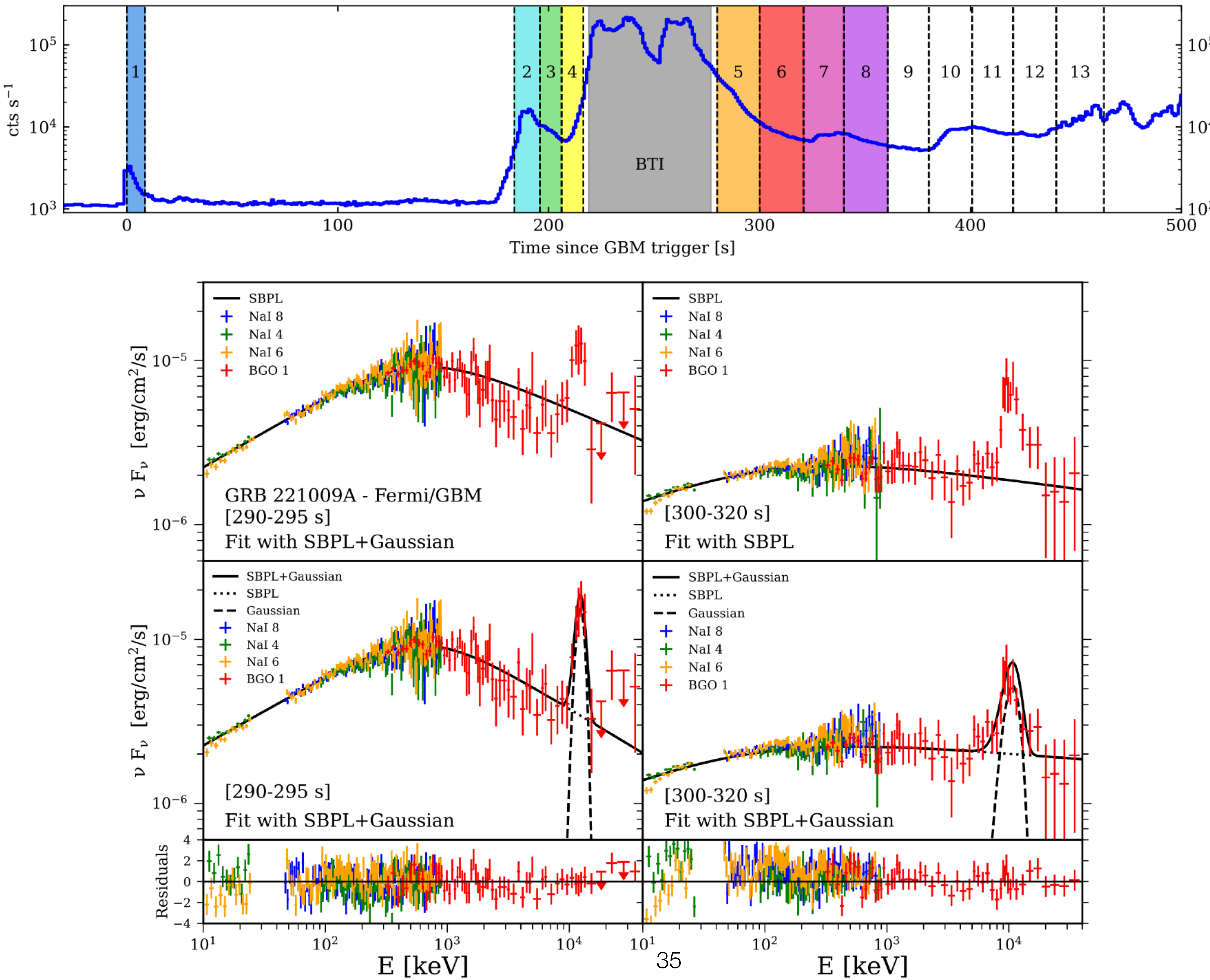
Mei et al. (Forthcoming in A&A)

## news on the prompt emission

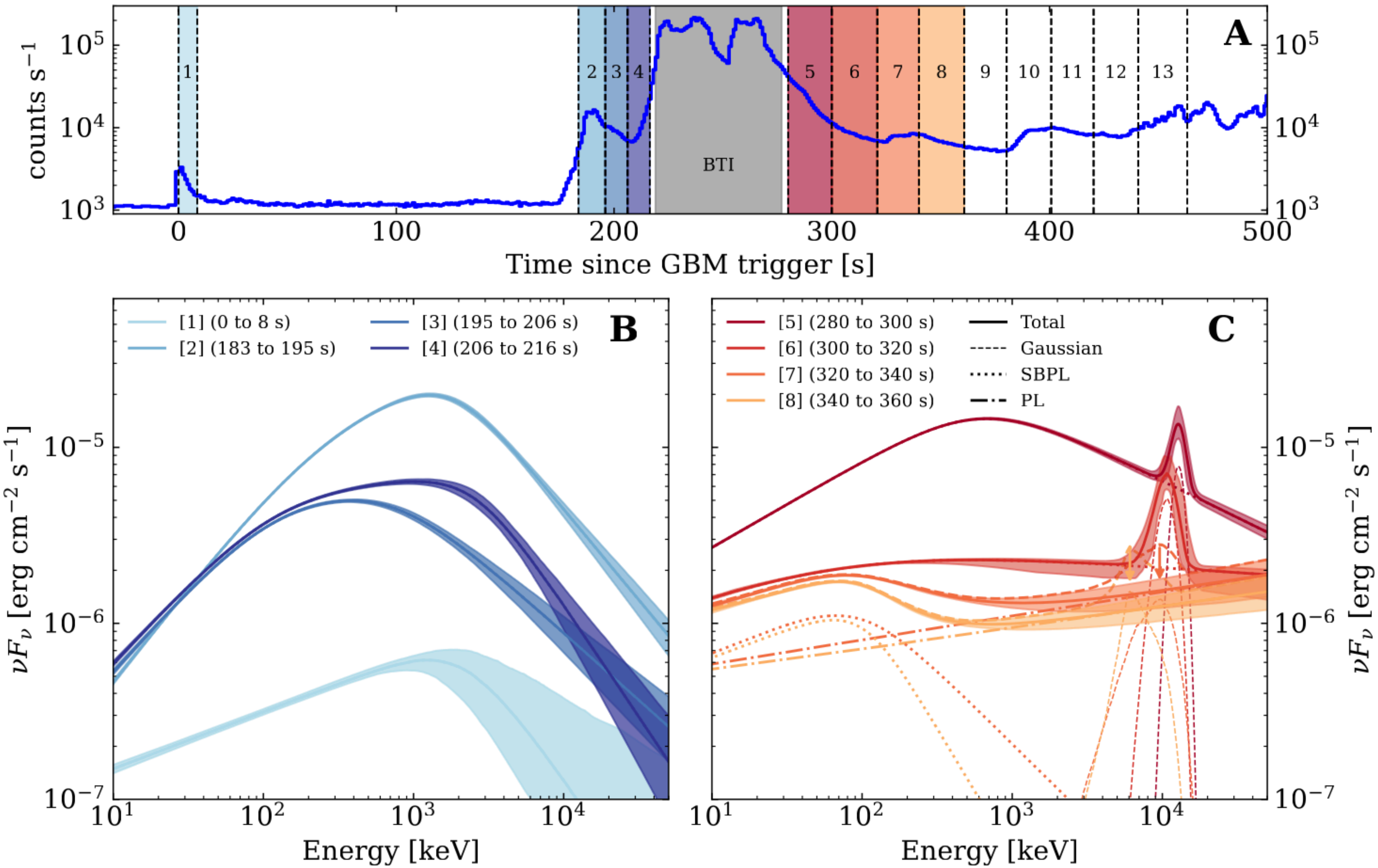



**sketch by S. Ronchini**

# 10 MeV line  Ravasio et al. 2023



# Discovery of the ~ 10 MeV line




**6 and 11 sigma post-trial**

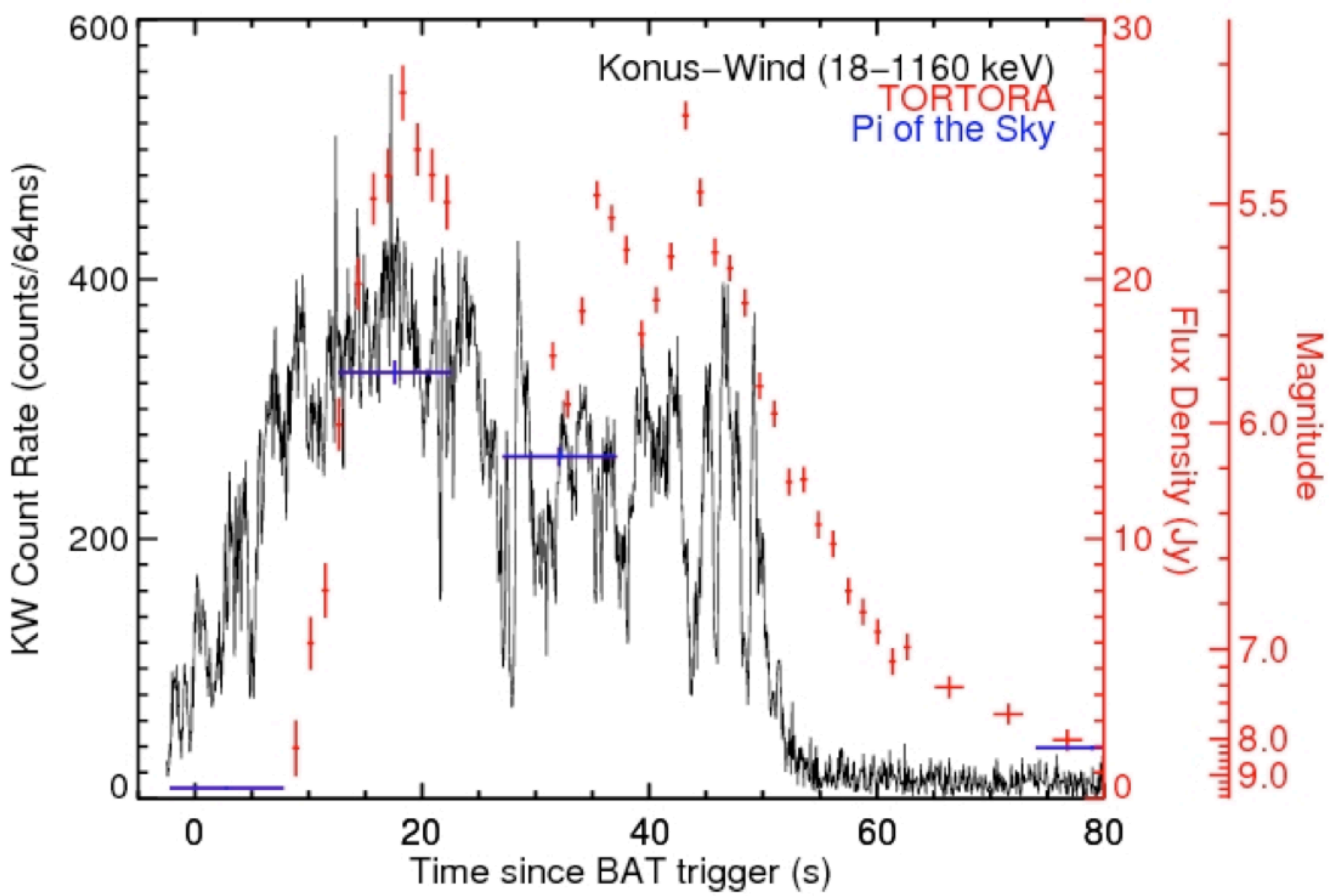
Ravasio et al. 2024, Science

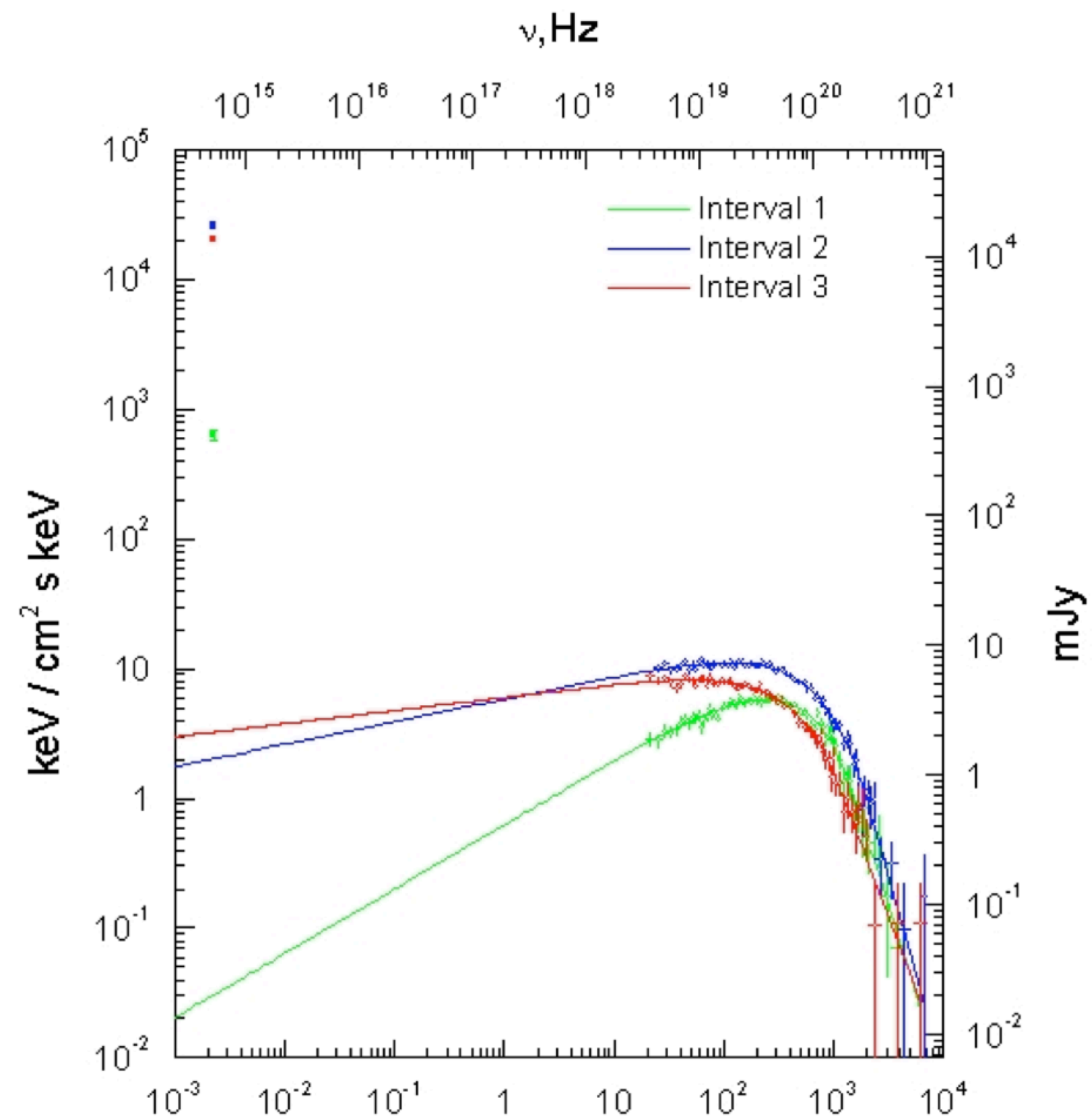
# next steps

**fast optical observations**

# The optical outliers

## Naked eye GRB 080319B, z=0.937

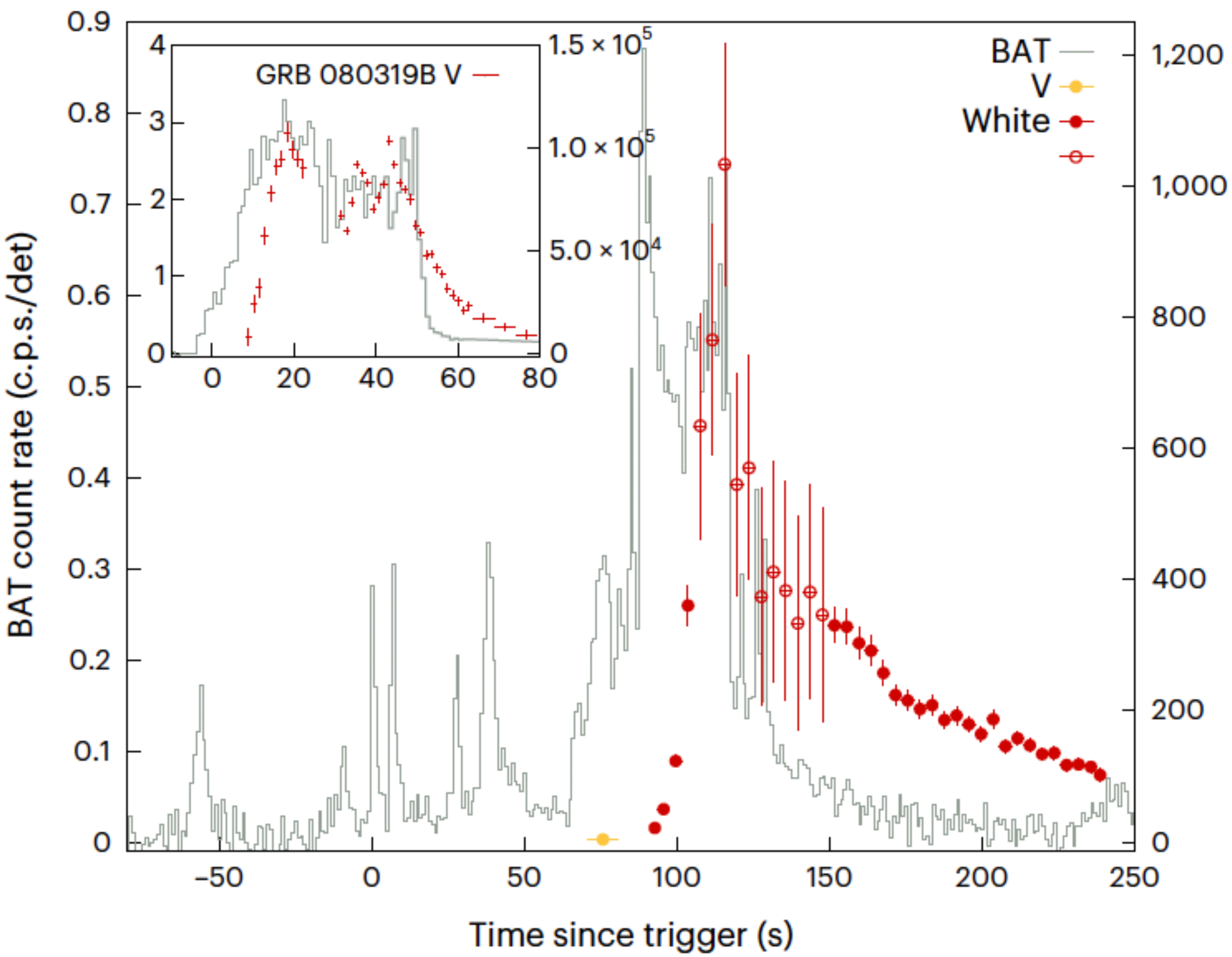


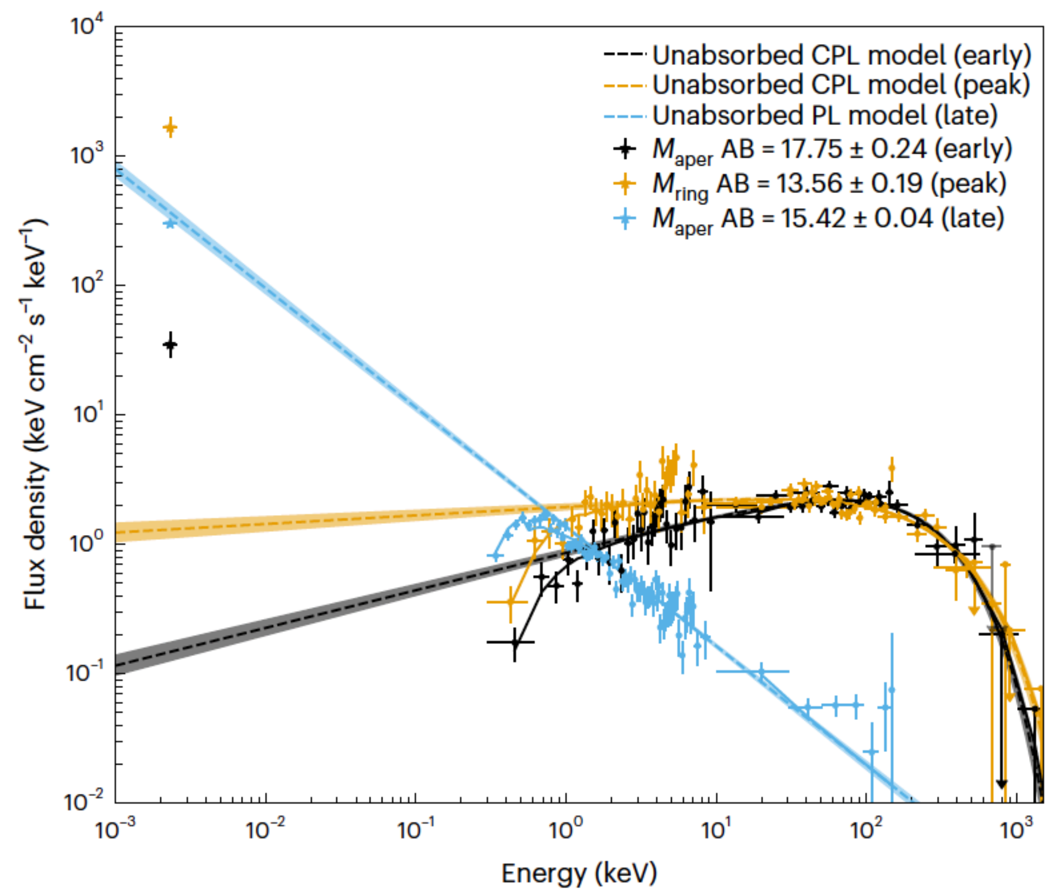




Racusin et al. 2008, Nature

# A new case

## GRB 220101A, z=4.6

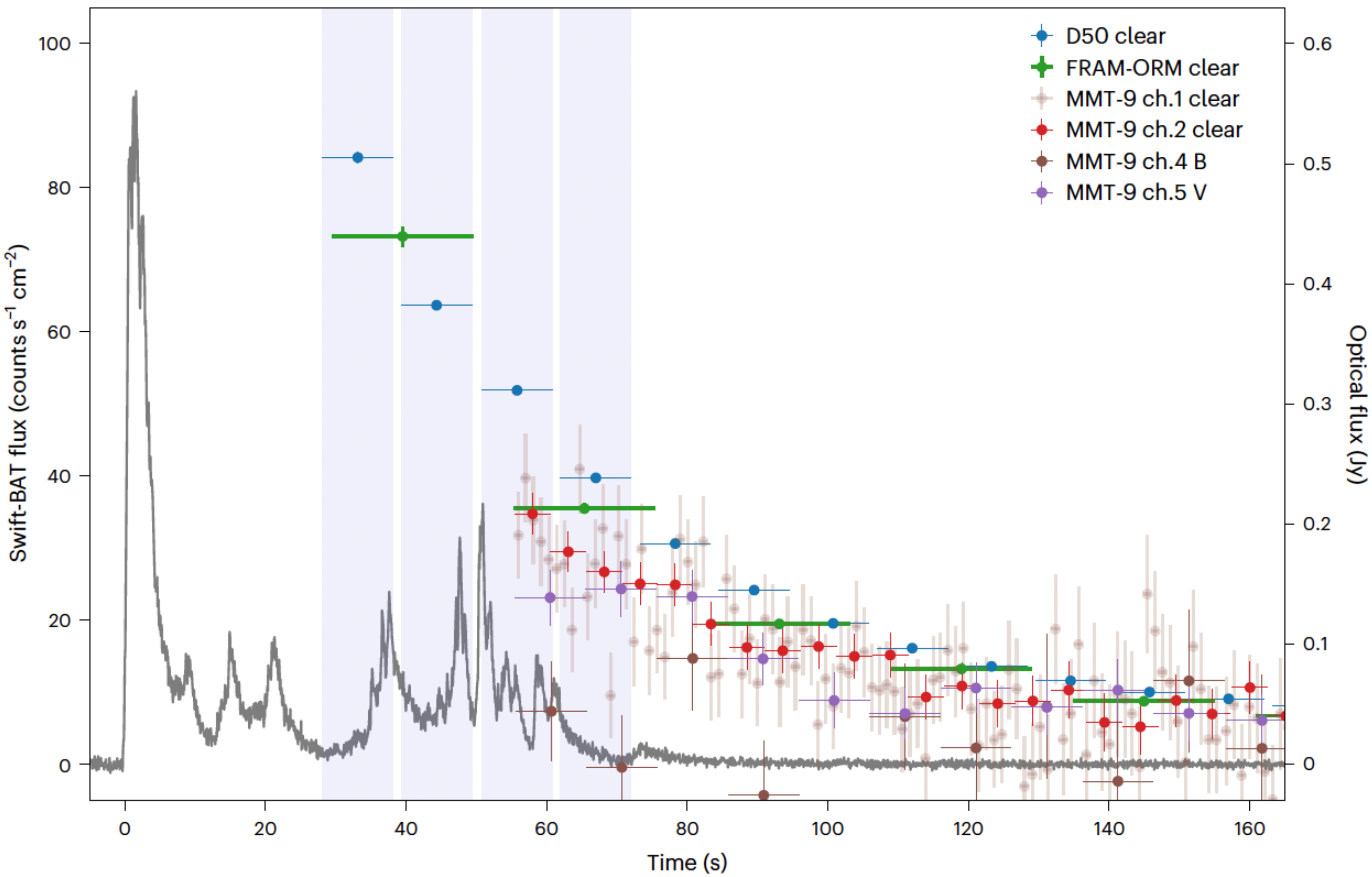



Jin et al. 2023, Nature Astronomy

# Other observables

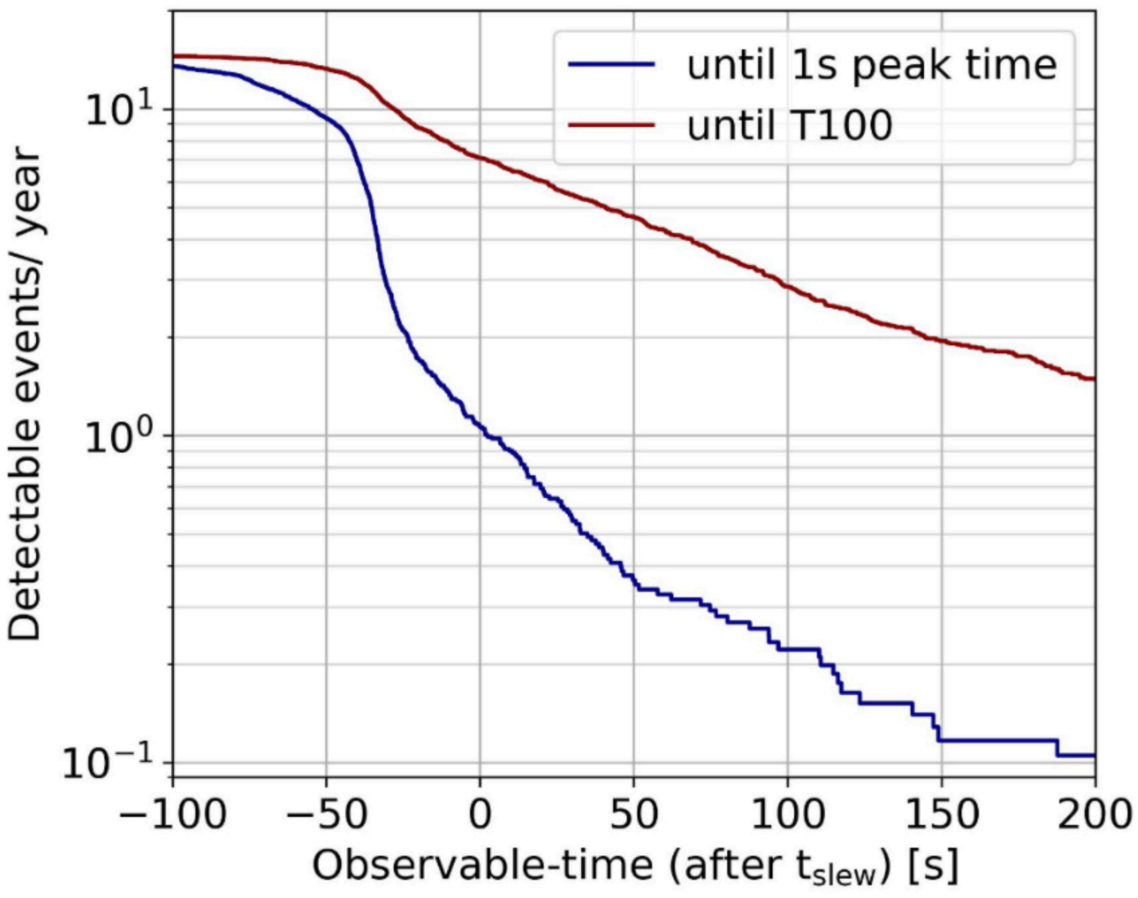
**high time-resolution in observations, but no high variability = the reverse shock**

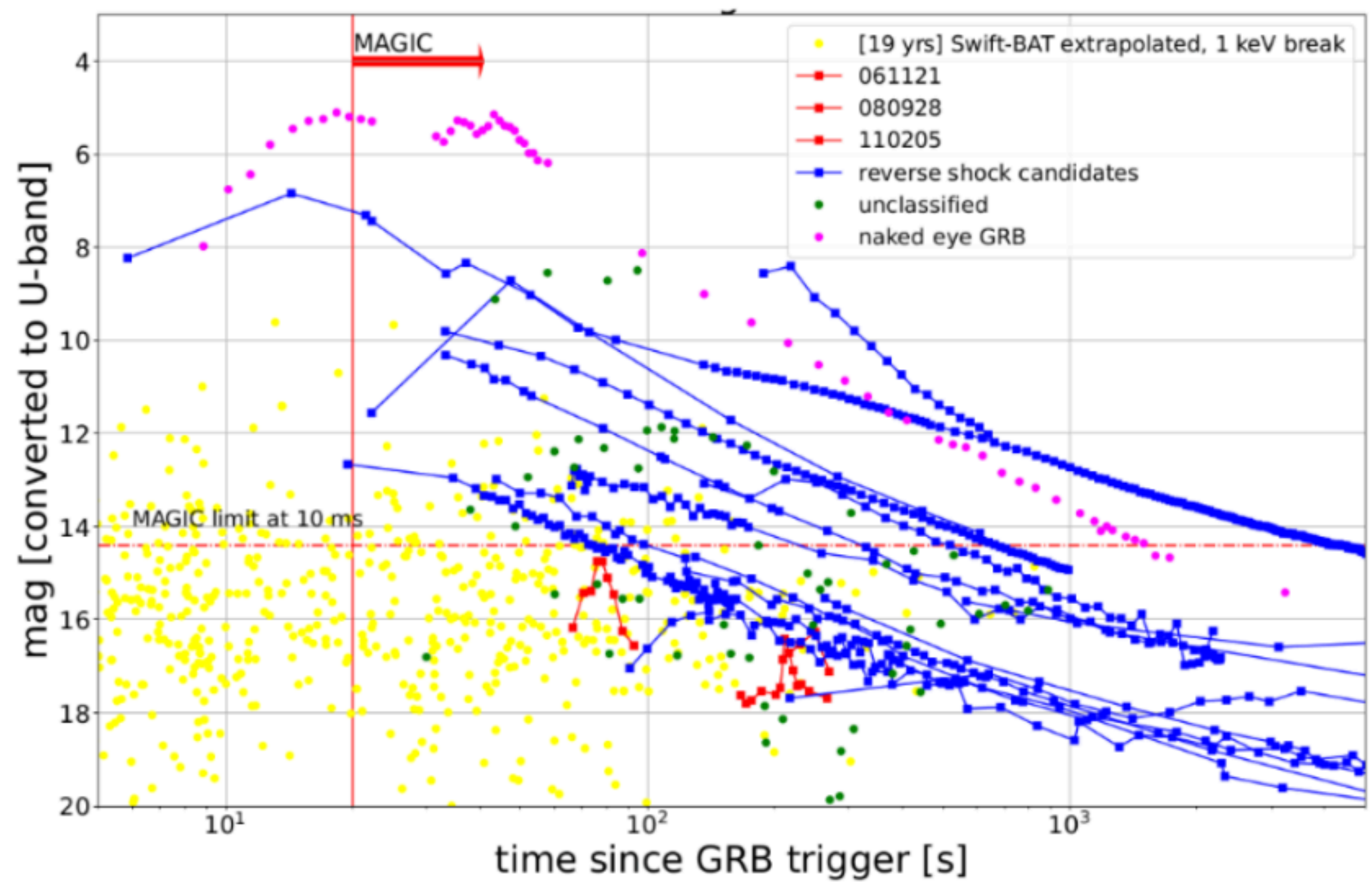



Oganesyan et al. 2023, Nature Astronomy

# Sub-second prompt optical flashes

## Fast optical transients by MAGIC

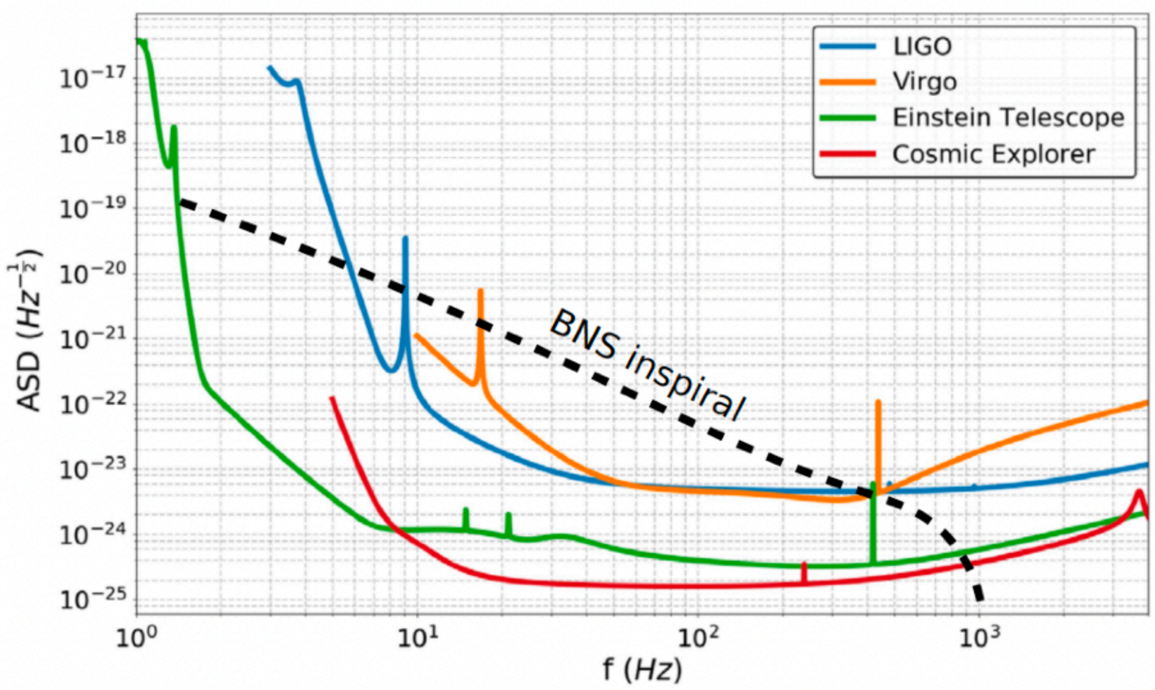


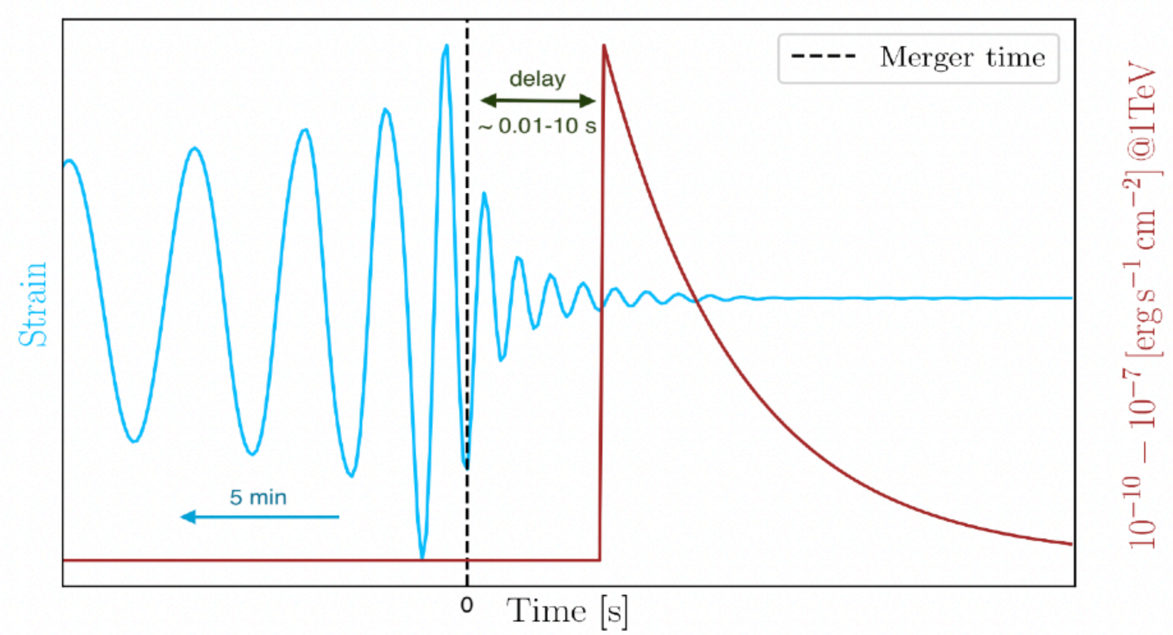



**fast VHE observations**

# VHE observations

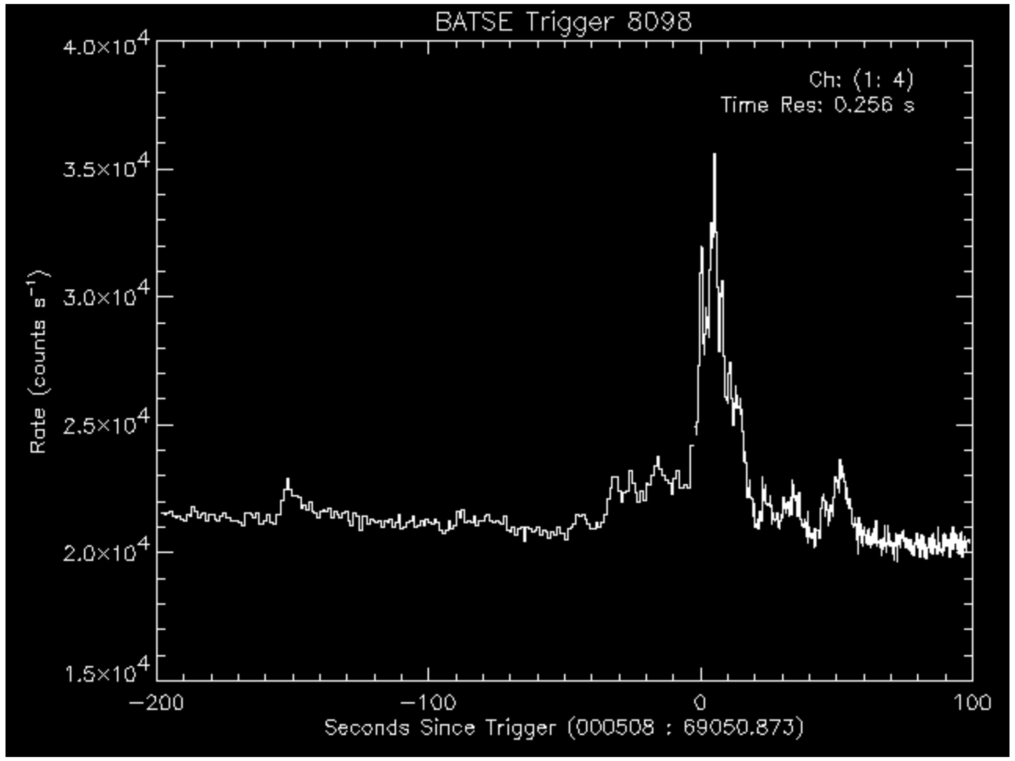
## short GRBs via GWs (inspiral phase)



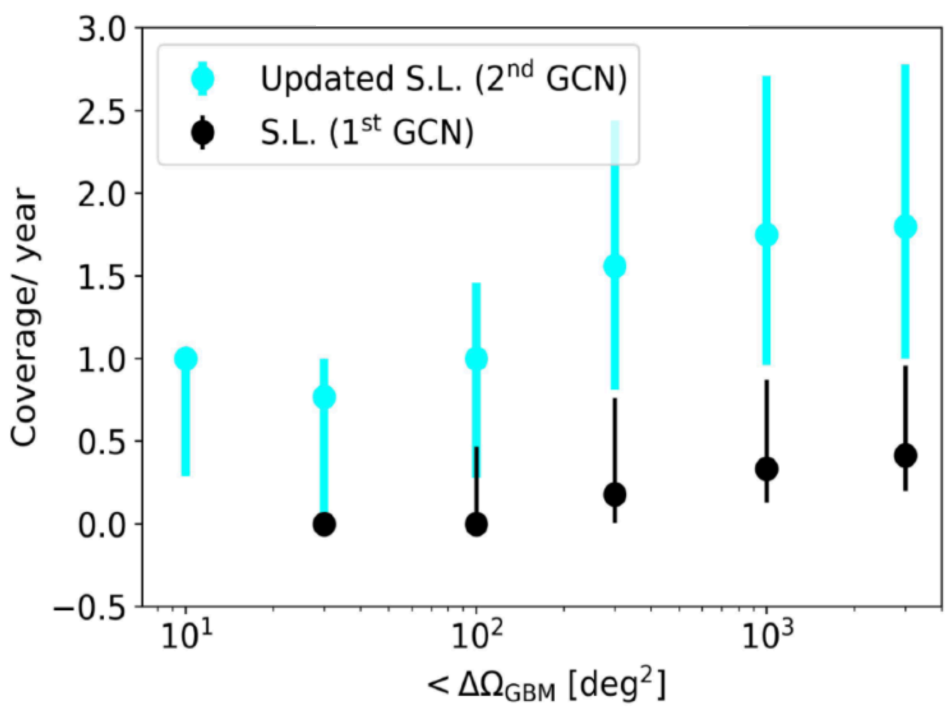




**Banerjee et al. 2023**

## long GRBs (precursors)




$$\delta t_q \sim t_{slew}$$



# Conclusions

1. The composition of GRB jets is unclear
2. Not clear where the dissipation takes place
3. Collisionless heating/magnetic dissipation/collisional heating
4. Dominant radiative cooling is not identified
    1. Low-energy breaks are common in the spectra
    2. Spectra are consistent with marginally-fast cooling synchrotron
       cooling frequency - luminosity (Mei et al. 2024)
    3. 10 MeV line is identified in the BOAT GRB
       Ravasio et al. 2024

1. We expect soft X-ray observations - Einstein Probe and SVOM
2. We may catch the prompt in the VHE gamma-rays - GWs and precursors help
   Banerjee et al. 2023
3. High time-resolution optical observations via IACTs
   Banerjee, Miceli, Berti, Carosi + efforts in MAGIC