Radiative processes in gamma-ray burst prompt emission

GOR OGANESYAN
SISSA

LARA NAVA
INAF - Osservatorio Astronomico di Trieste
INAF - Osservatorio Astronomico di Brera

GIANCARLO GHIRLANDA
INAF - Osservatorio Astronomico di Brera

ANNALISA CELOTTI
SISSA

What are GRBs?

- Cosmological distances

$$z \sim 0.01 - 9.2$$

- Energetics

$$E_{iso} \sim 10^{51} - 10^{54}\ erg$$

[emitted in 10 keV - 10 MeV]

- Duration

$$T \sim 0.1 - 1000\ sec$$

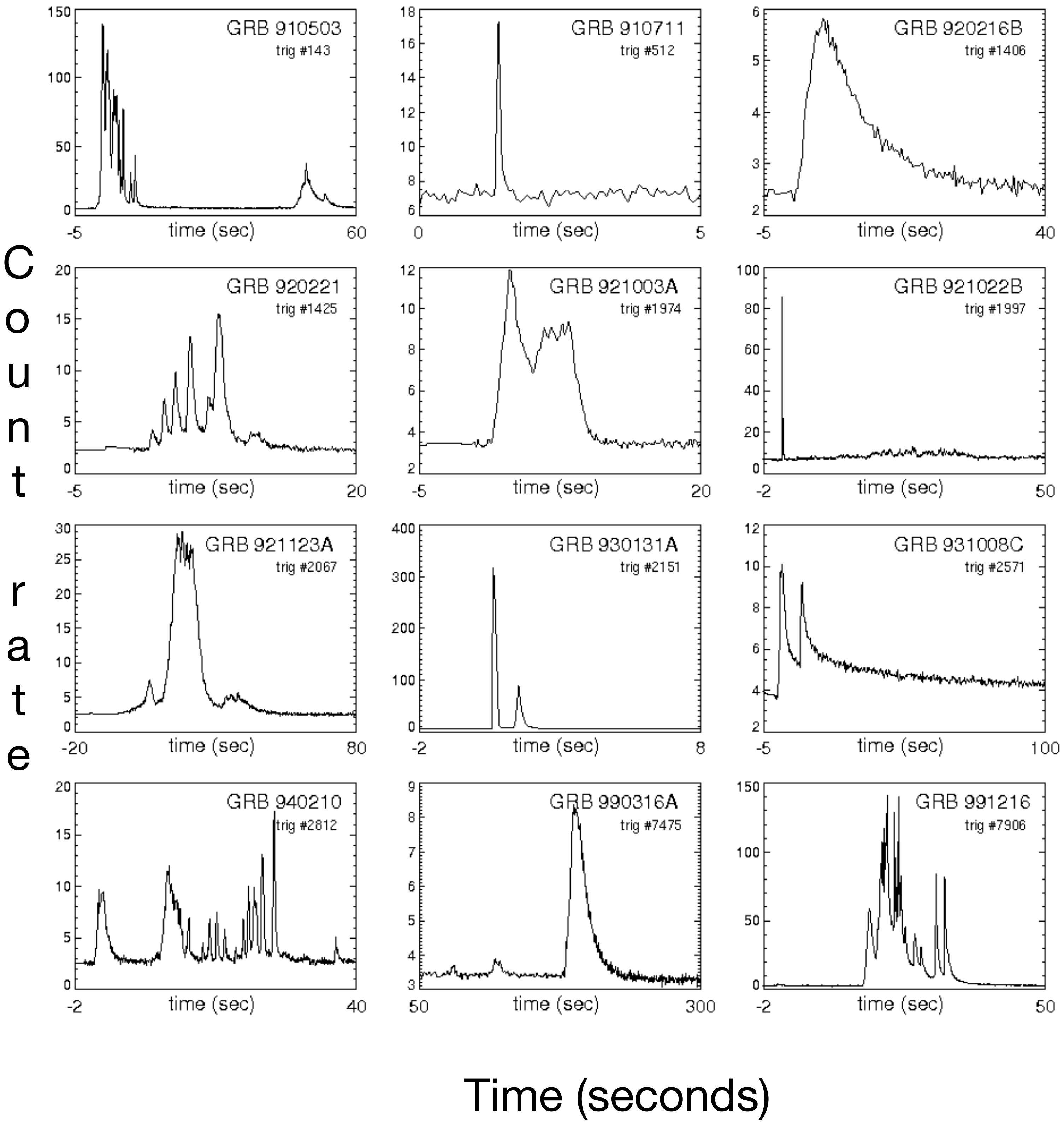
- Variability

$$\delta t \sim 10\ msec$$

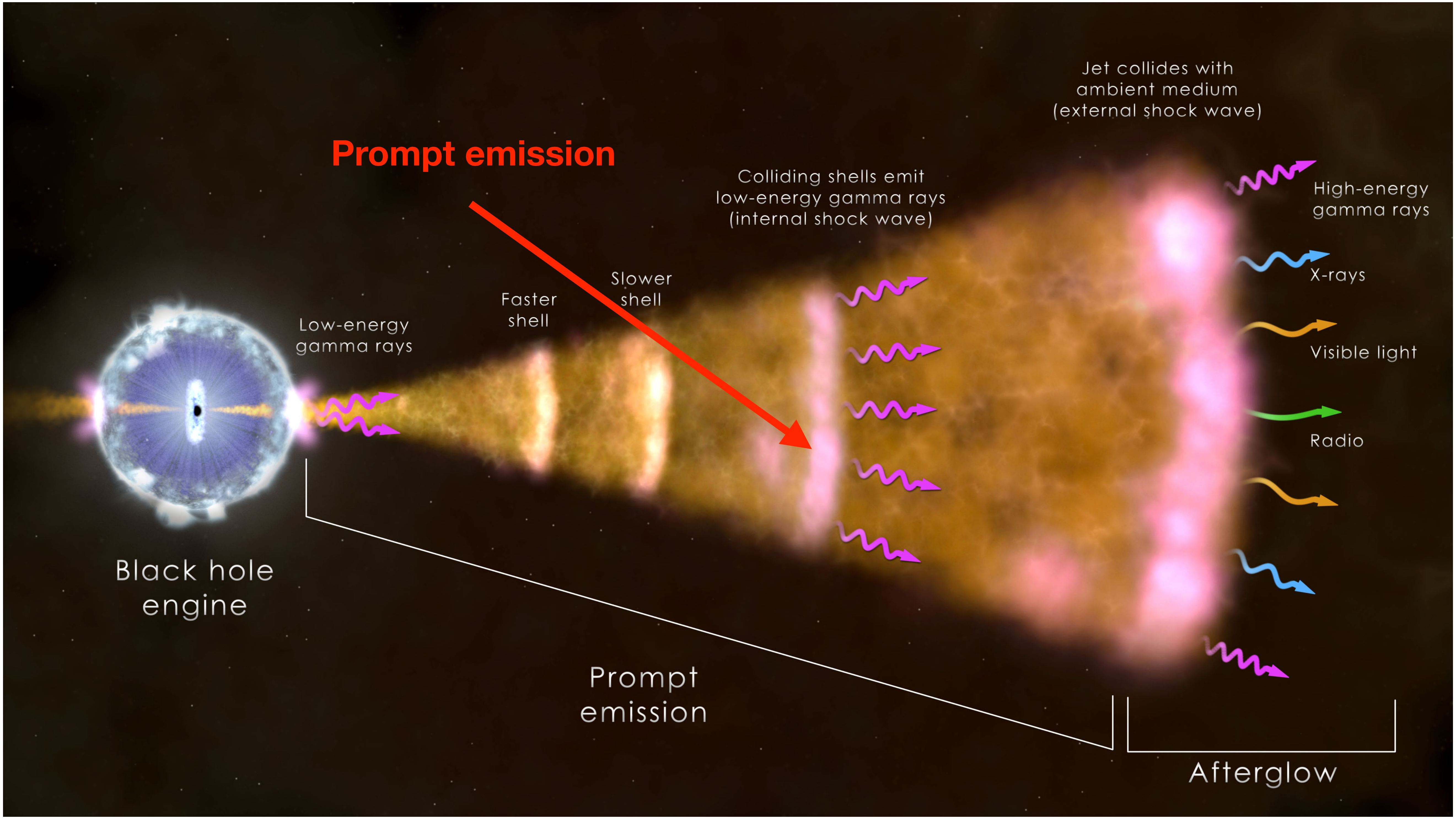
- Detection rate

$$\sim few/week$$

Examples of GRB prompt emission light-curves



What are GRBs?



Open questions

Location of the emission region (distance from BH)

somewhere between 10^{13} and $10^{17}\,\mathrm{cm}$

Jet composition

baryonic vs magnetic dominated

acceleration of particles

how the jet energy is transferred to electrons' internal energy?
in baryonic jets: shocks - in magnetic jets: reconnection events

what is the role of magnetic field in particle acceleration?

radiative processes

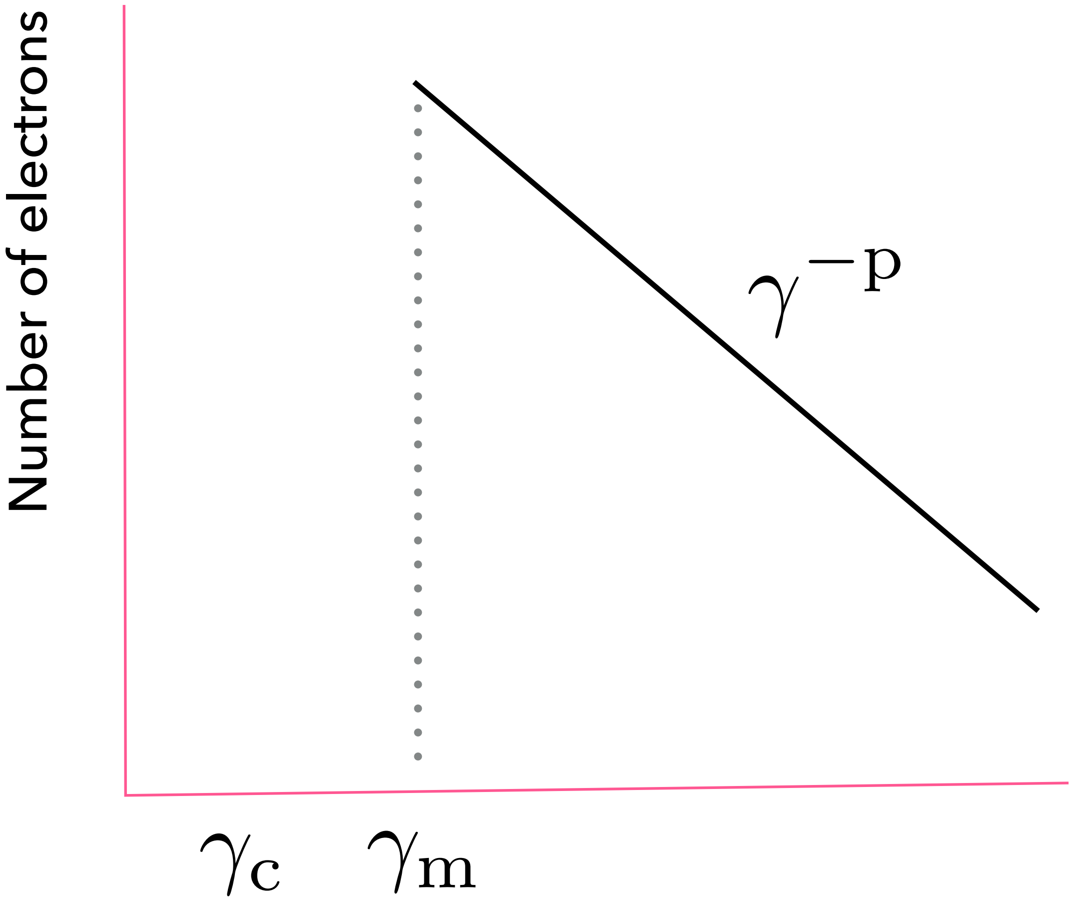
what is the mechanism through which the accelerated electrons produce radiation?

SYNCHROTRON THEORY

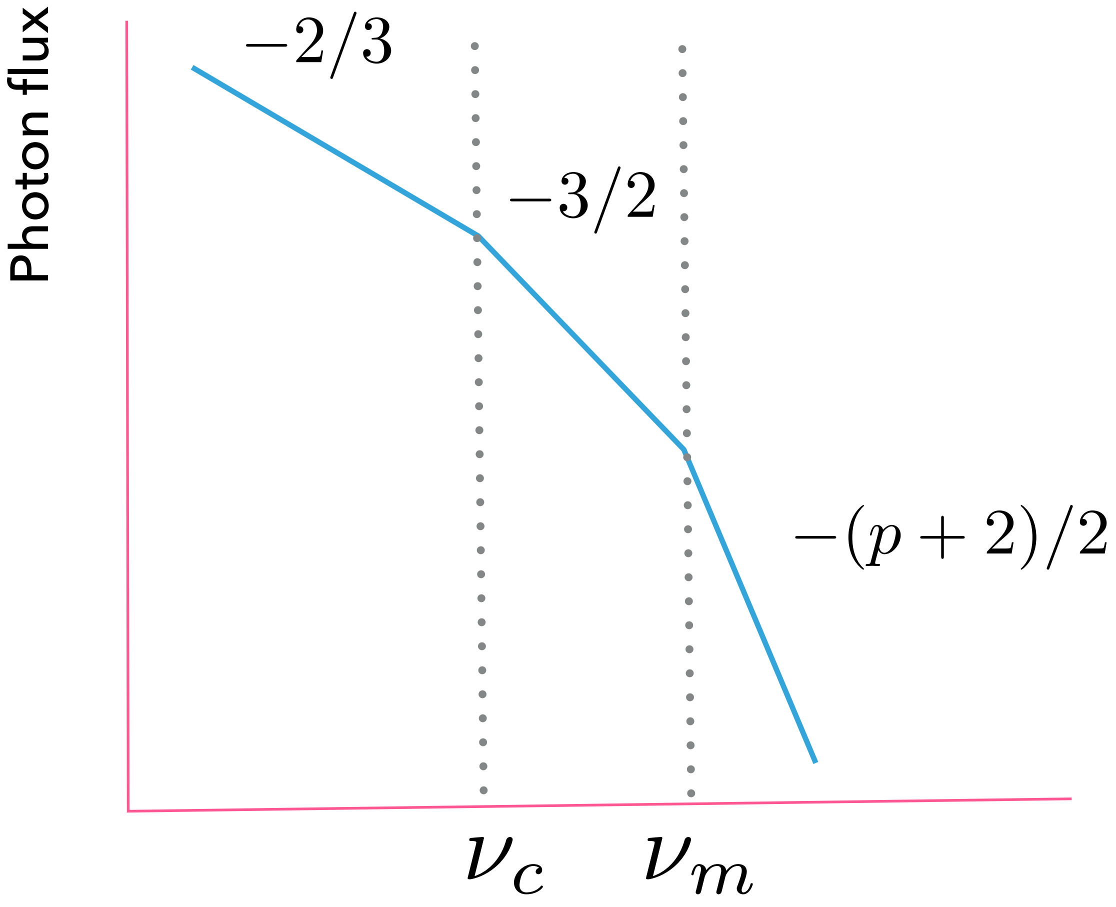
$$t_{dyn} = \frac{R}{c\Gamma_*} \qquad \gamma_c = \frac{6\pi m_e c}{\sigma_T B^2 t_{dyn}}$$

Sari et al (1998)

Energy spectrum of the accelerated electrons injected into the system



Resulting synchrotron photon spectrum

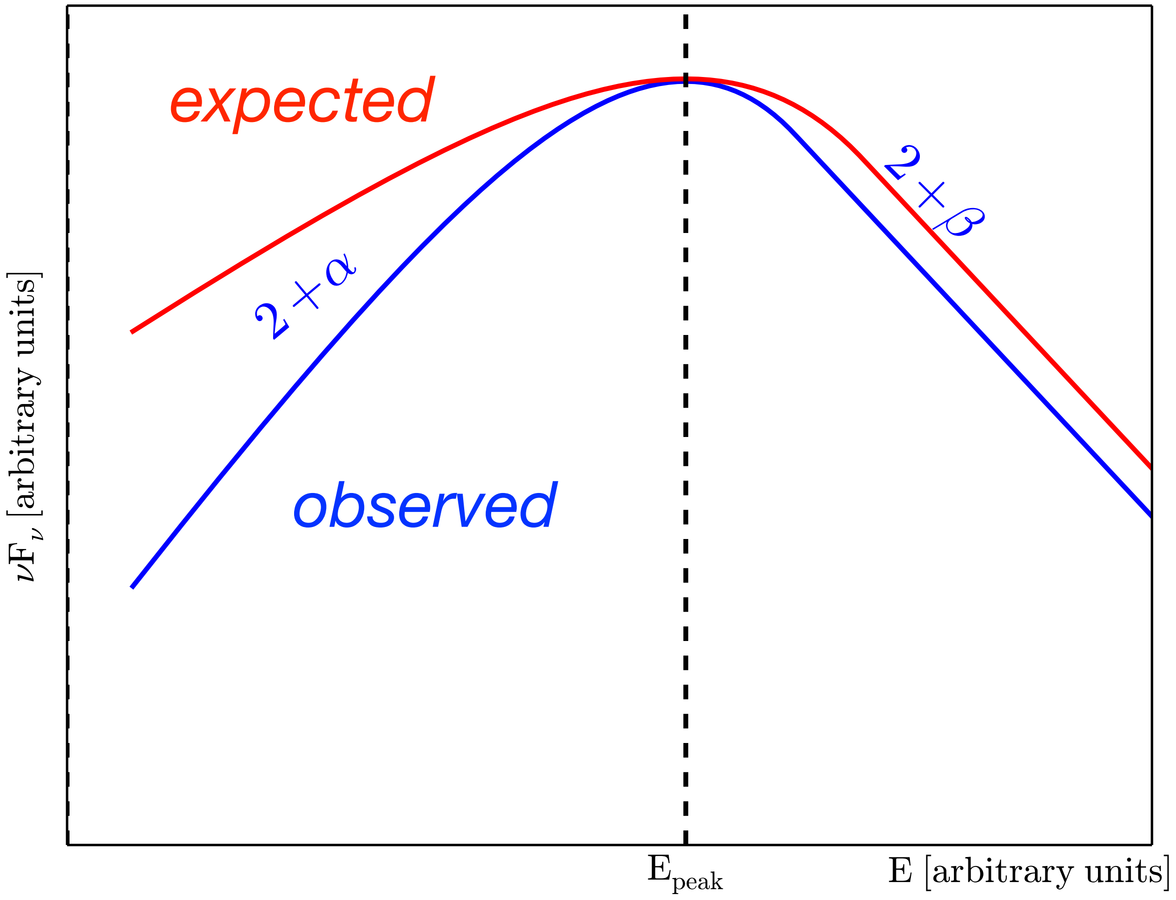


fast cooling

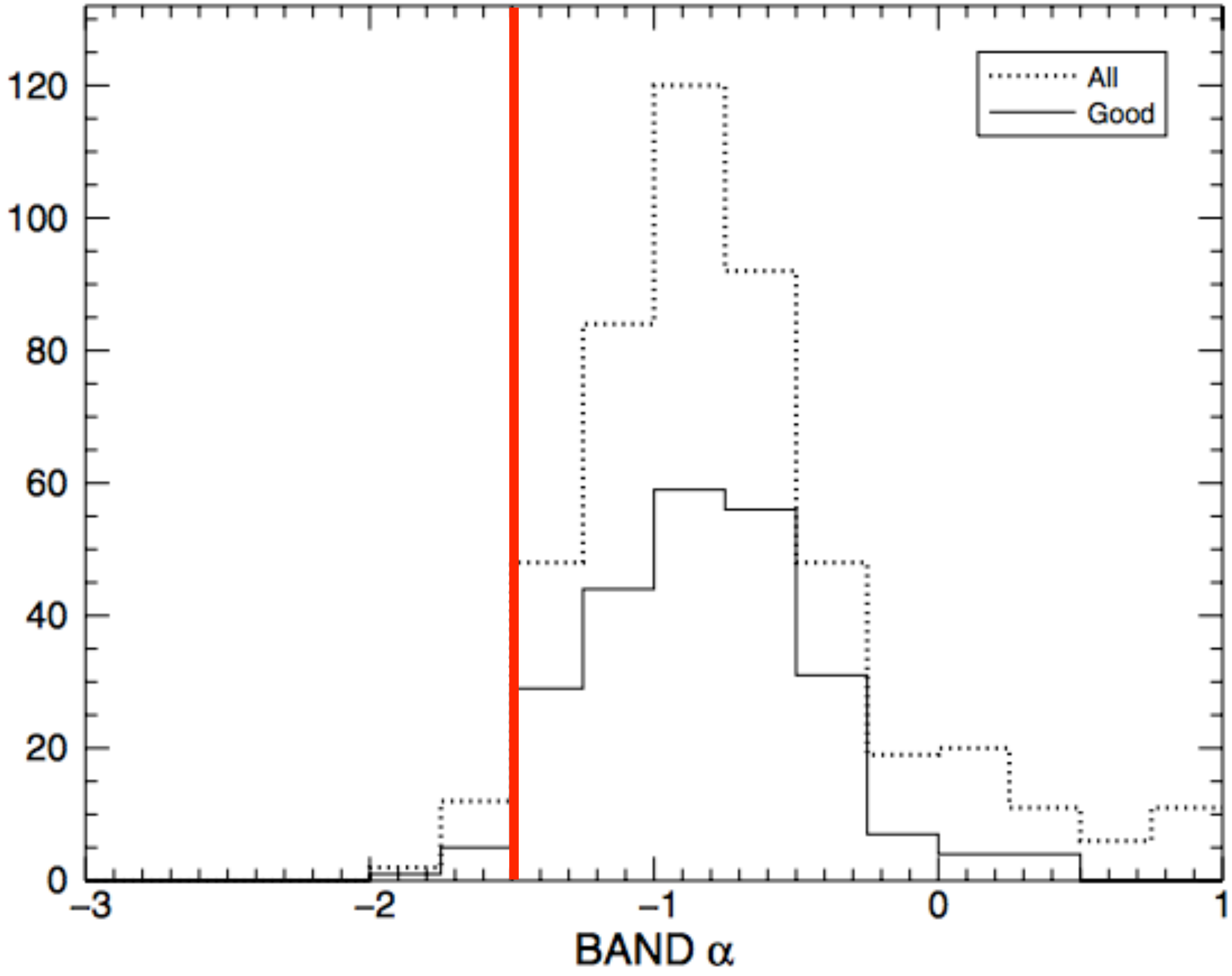
The problem: inconsistency between prompt spectra and synchrotron predictions

most prompt spectra are not consistent with fast cooling synchrotron spectrum

$$\alpha \sim -1 \qquad \beta \sim -2.5$$



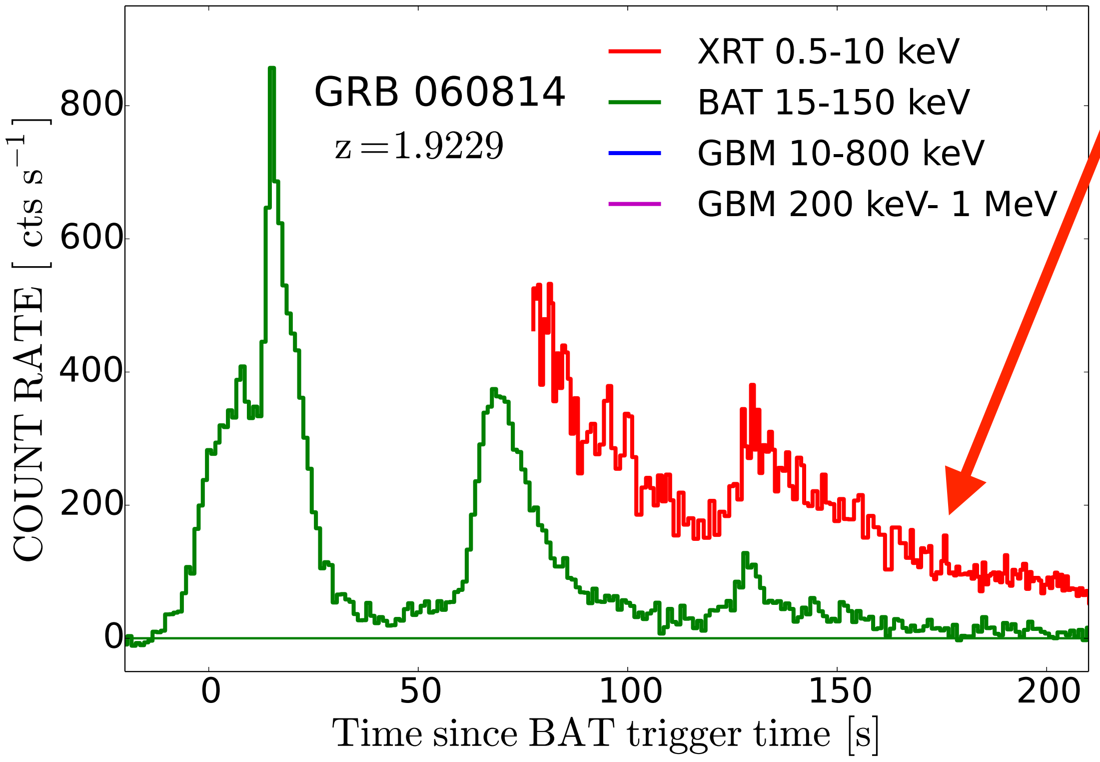
$-3/2$

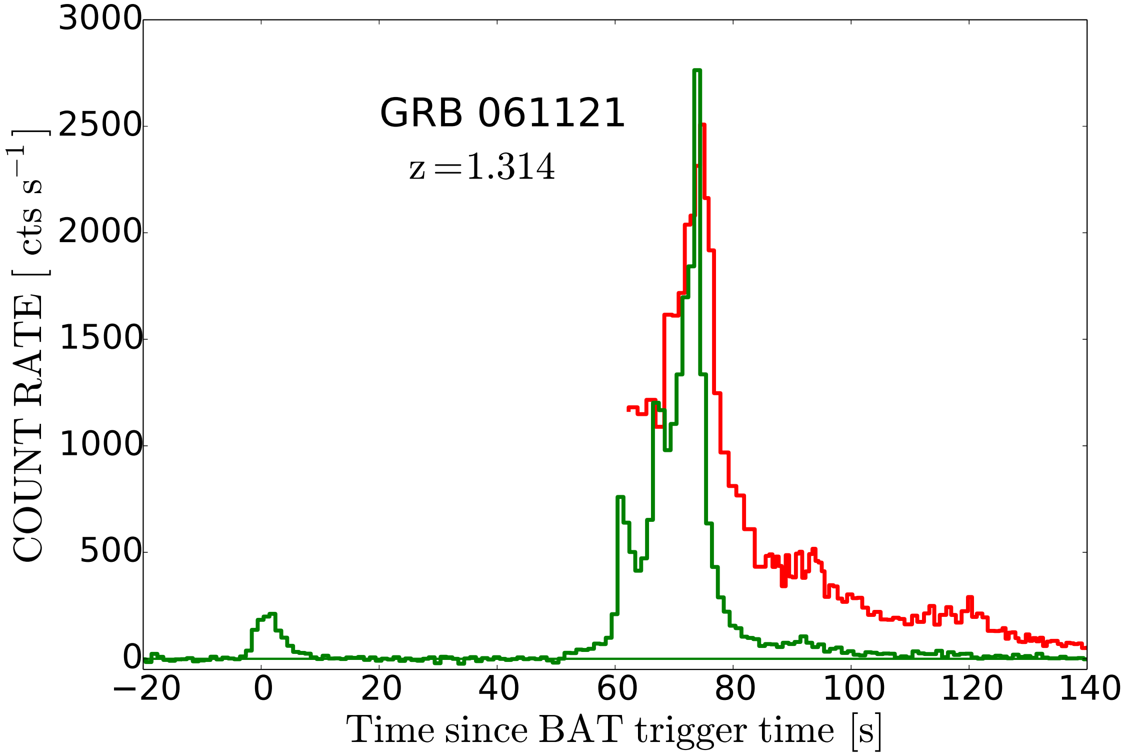


The inconsistency is at low energies (keV). How can we improve the characterization of spectra in the keV range?

Swift-XRT!

We occasionally have Swift/XRT
observations during
the prompt!

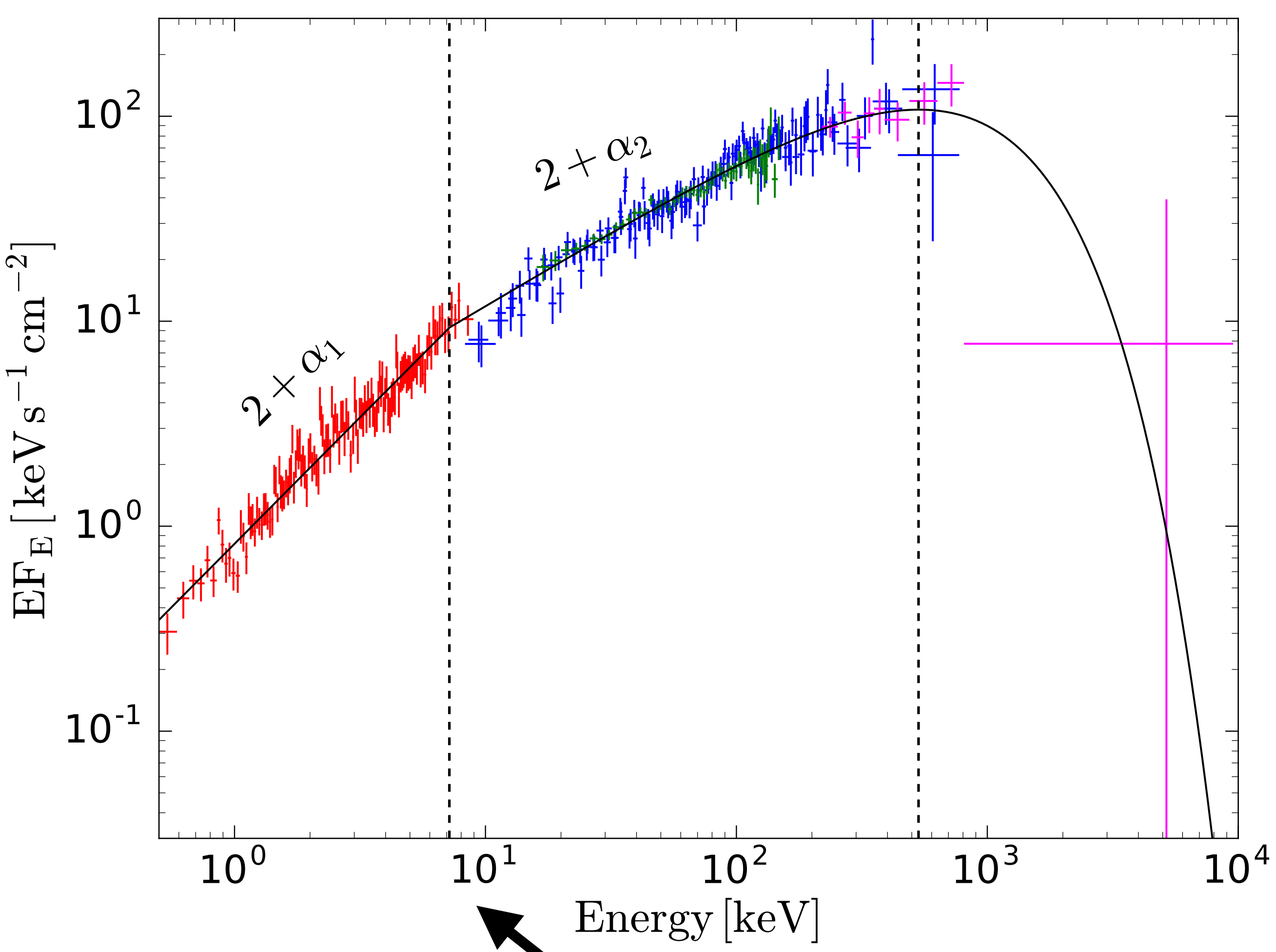




SWIFT/XRT + **SWIFT/BAT** + **Fermi/GBM**

0.5-10 keV 15-150 keV 8 keV-40 MeV

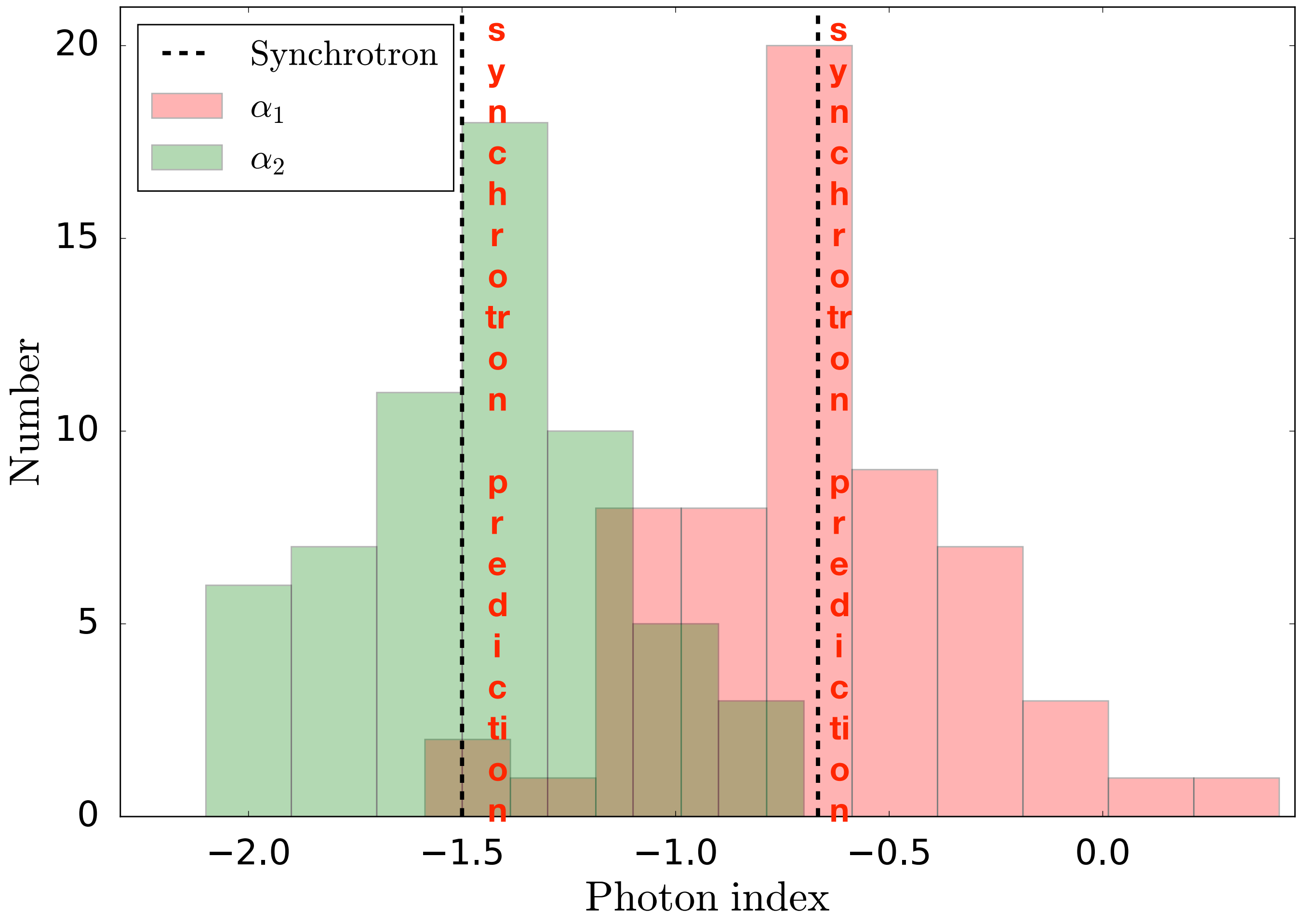
Example of 1 spectrum from 0.5 keV to 40 MeV



$\mathrm{E_{break}}$

cooling frequency?

Results from the whole sample



mean values are in agreement with synchrotron spectrum

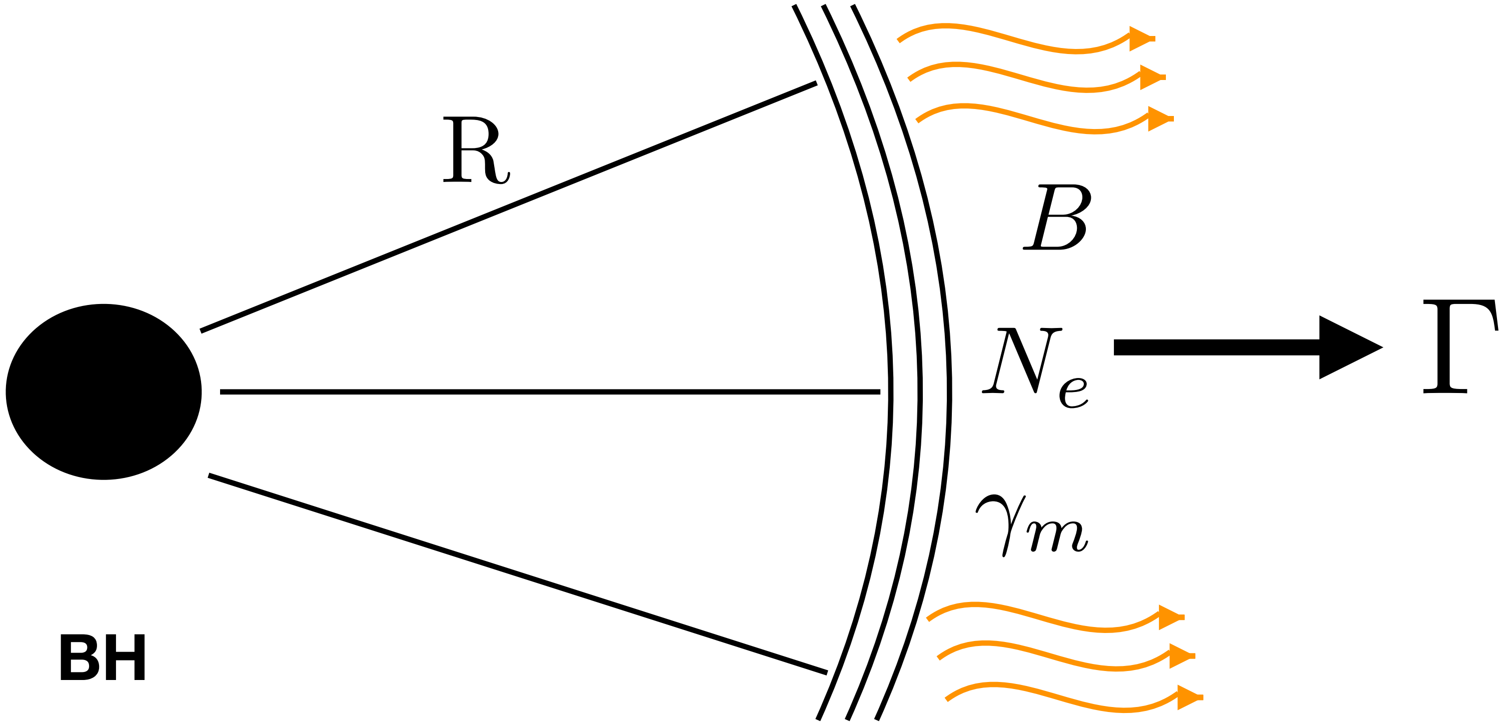
Oganesyan, G., Nava, L., Ghirlanda, G., & Celotti, A. 2017, ApJ, 846, 137

What are the consequences of our findings?

- Prompt emission is synchrotron radiation

- Location of the cooling frequency (identified here for the first time) add an important constraint on the properties of the region where the radiation is produced

$$\mathrm{B}, \mathrm{N_e}, \mathrm{R}, \Gamma, \gamma_\mathrm{m}$$



Free parameters $\mathrm{B, N_e, R, \Gamma, \gamma_m}$

+

observed quantities

$$E_p(z=1) \sim 300\ keV, t_{var} \sim 0.5\ s, L_{peak} \sim 10^{52} erg\ s^{-1}$$

+

$$\mathrm{E_b \sim 4\ keV}$$

↓ ↓ ↓

We can derive all physical parameters as a function of a single one

+

Fast cooling regime+ high radiation efficiency +avoid emission in Fermi/LAT (20 MeV - 300 GeV) + optically thin source + avoid the forward shock zone

=

$\Gamma \geq 700$ large bulk Lorentz factors $R \geq 3 \times 10^{16}\ cm$ large radii

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

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

CONCLUSIONS AND FUTURE WORK

- Low energy breaks are identified for the first time in prompt spectra.
- Large cooling frequency implies weak magnetic fields
- Strict constrains on the prompt emission region

- Are the derived values reasonable?
- Can our results be used to discriminate between the magnetic and baryonic scenario?

Thank you!