Modelling of gamma ray bursts and predictions for high-energy observations

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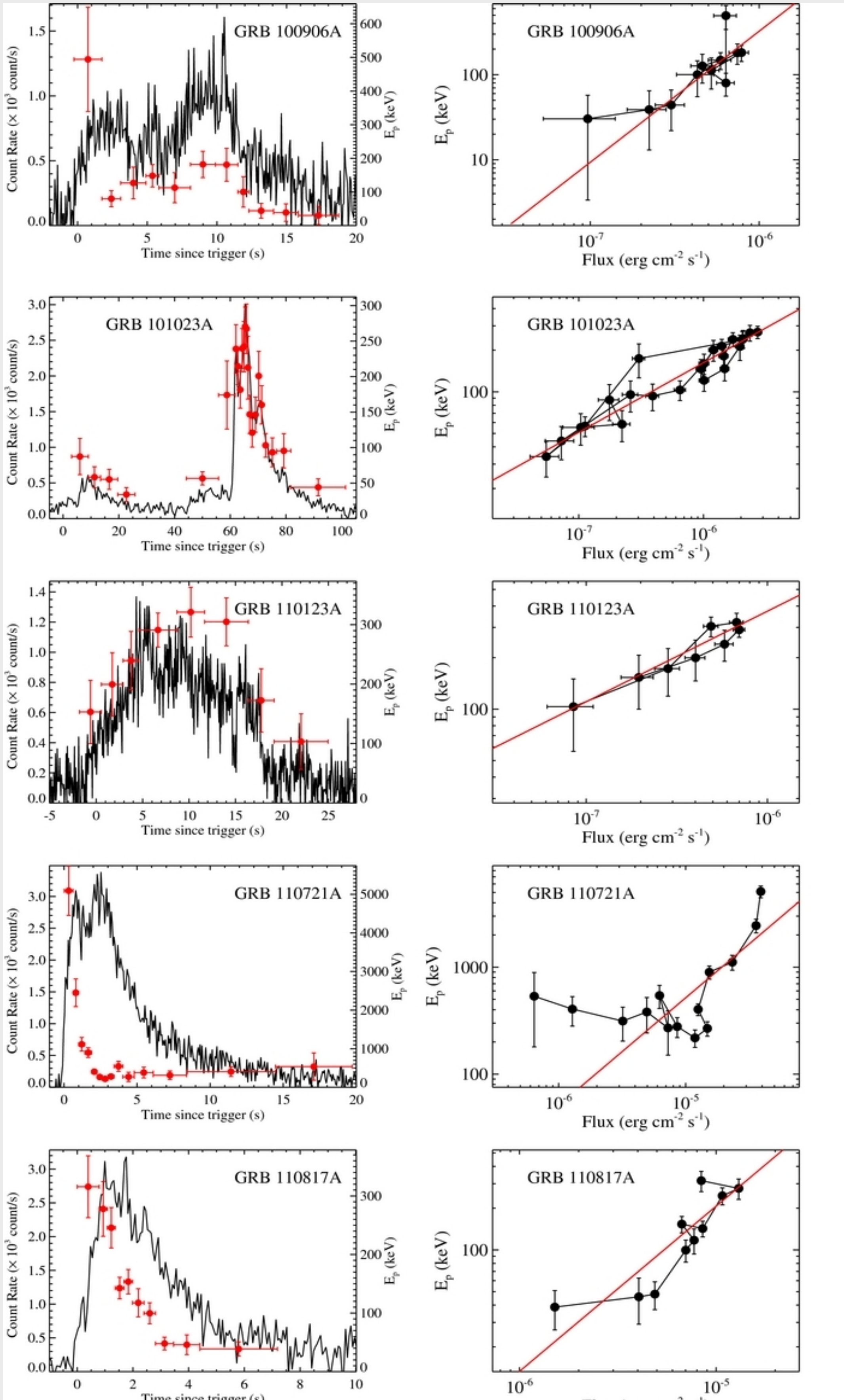
Sub-MeV emission



Ferm/GBM observations:

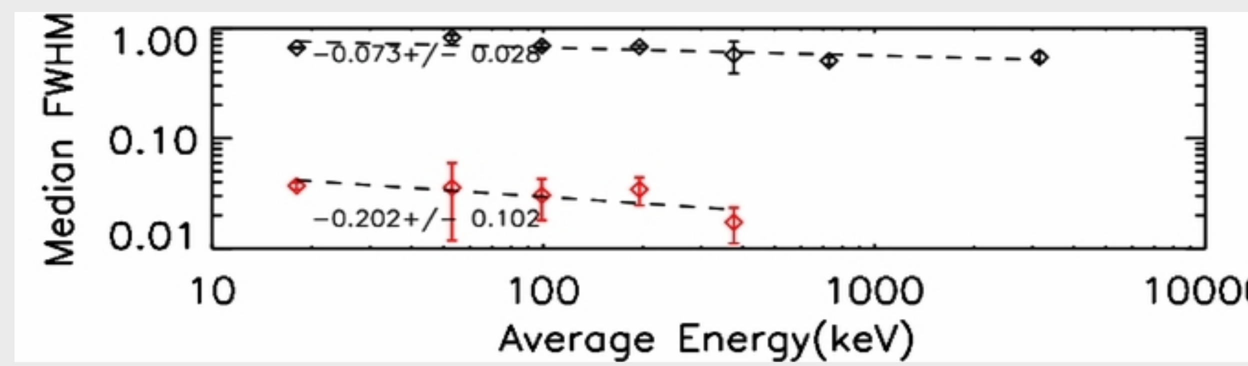
hard-to-soft evolution

hardness maximum preceding the peak of the intensity

hardness-intensity correlation: $E_{p,obs} \propto F(t)^{\kappa}$, $\kappa \simeq 0.4\text{-}1.2$

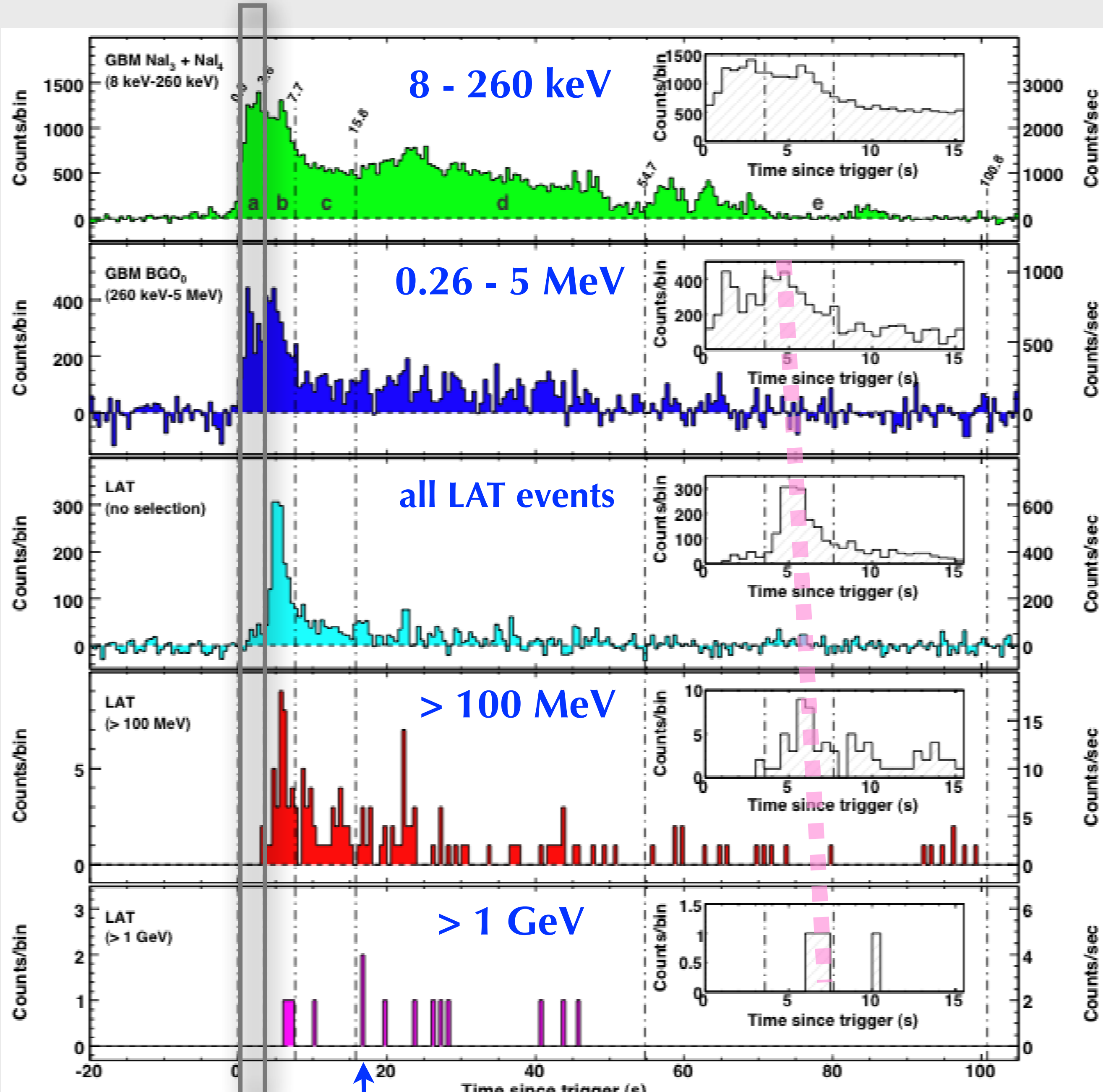
energy-dependent pulse asymmetry: $W(E_{obs}) \propto E_{obs}^{-a}$

Bhat et al. 2012



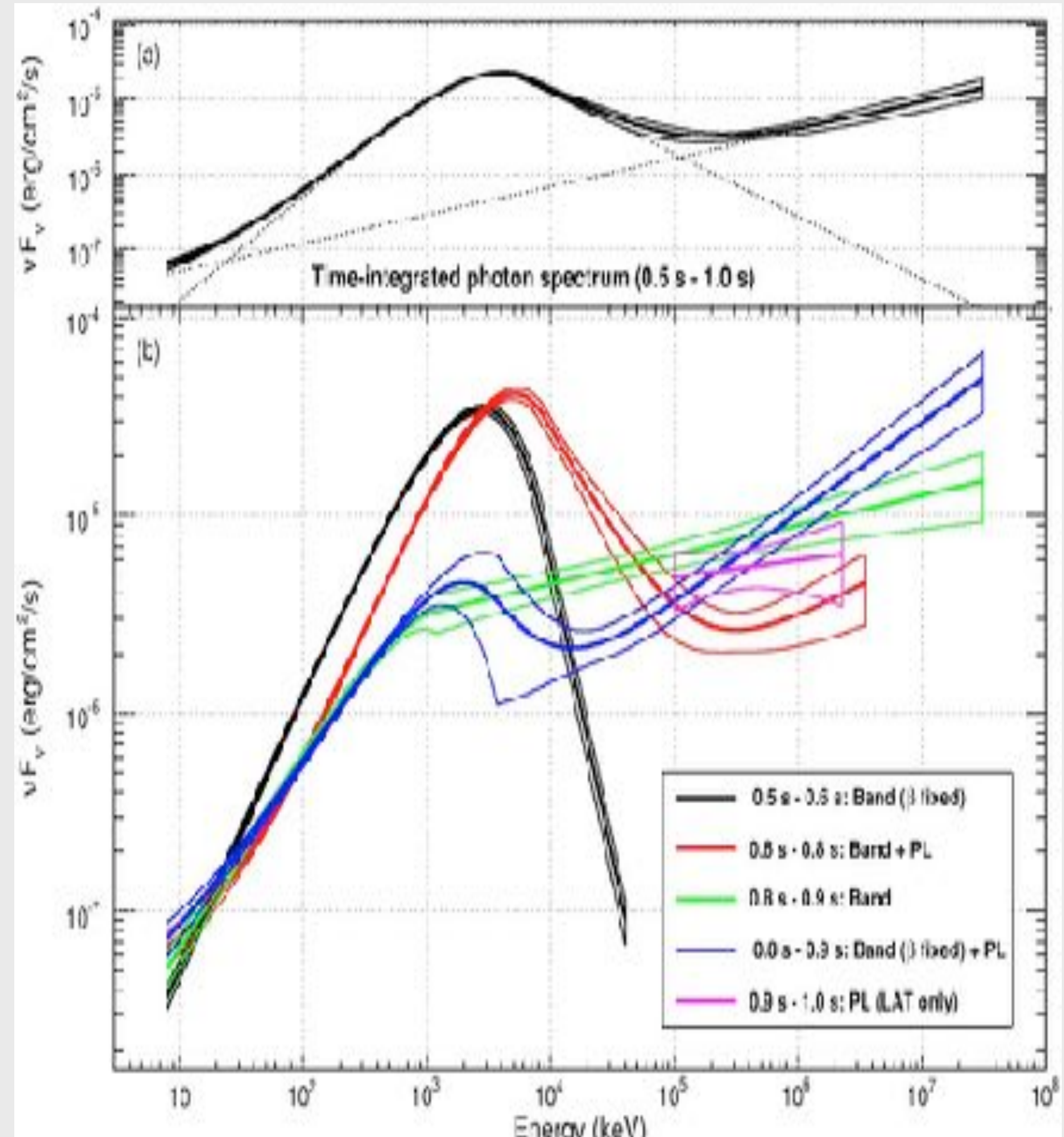
Lu et al. 2012

High energy emission



13.2 GeV photon

GRB 080916C
Abdo et al. 2008



GRB 090510
Ackermann et al. 2010

Fermi/LAT observations:

- Delayed onset of high energy (>100 MeV) emission
- **Long lived** high energy emission
- Deviation from the usual GRB spectral models: **extra component**

Very high energy emission from GRBs

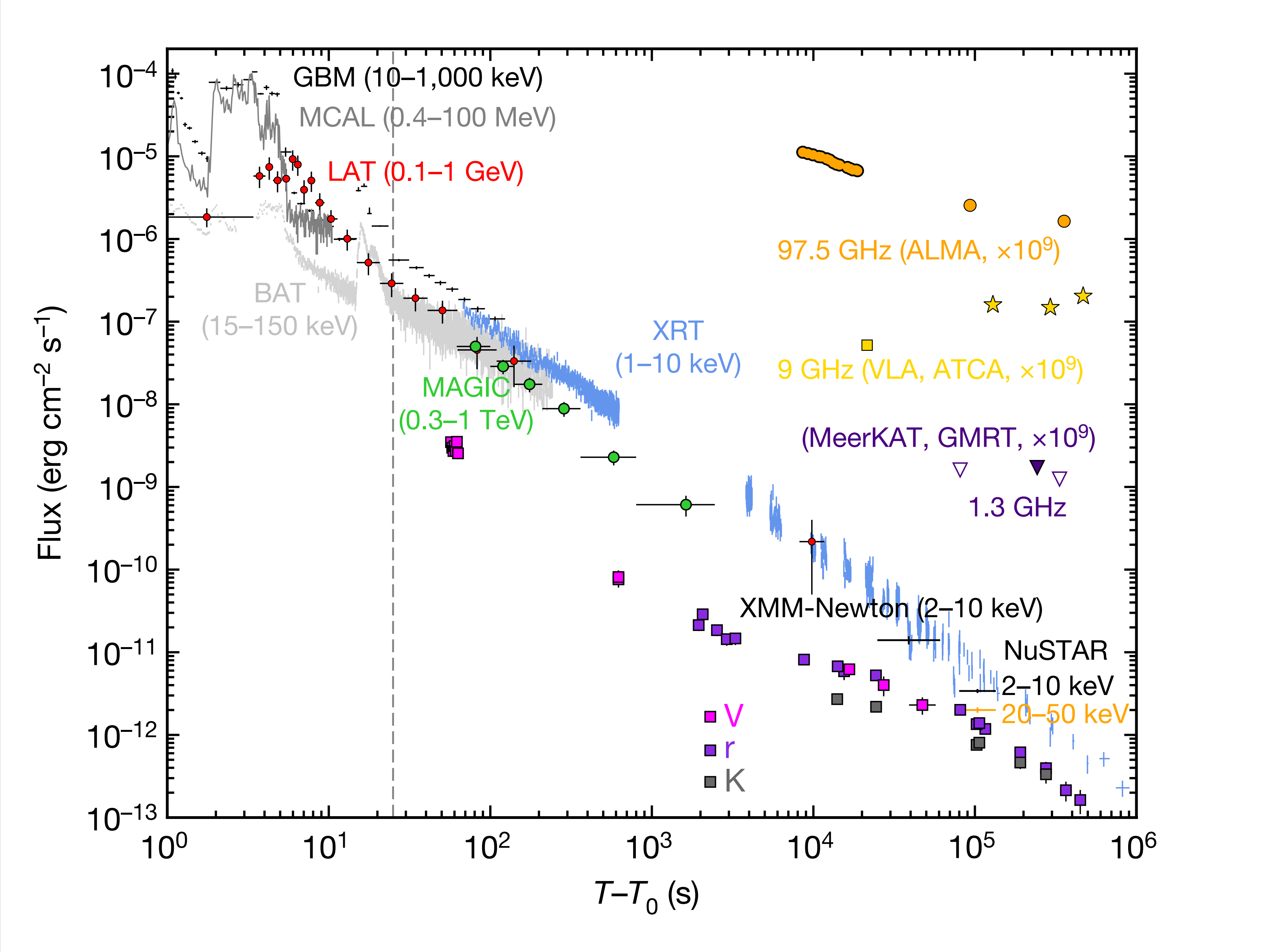
* MAGIC slew to the direction of GRB 190114C (z=0.42) about 50 s after the trigger and detected > 300 GeV photons for the first 20 min with a significance > 20 σ
(Mirzoyan 2019)

* HESS started to observe GRB 180720B (z=0.65) at about 10 hr after the burst and detected 100-440 GeV photons
(Ruiz-Velasco 2019)

* bright bursts:
Eiso = 3 x 10 ^{53} erg and 6 x 10^{53} erg
(Hamburg et al 2019; Frederiks et al. 2018)

* both GRBs have very high X-ray afterglow

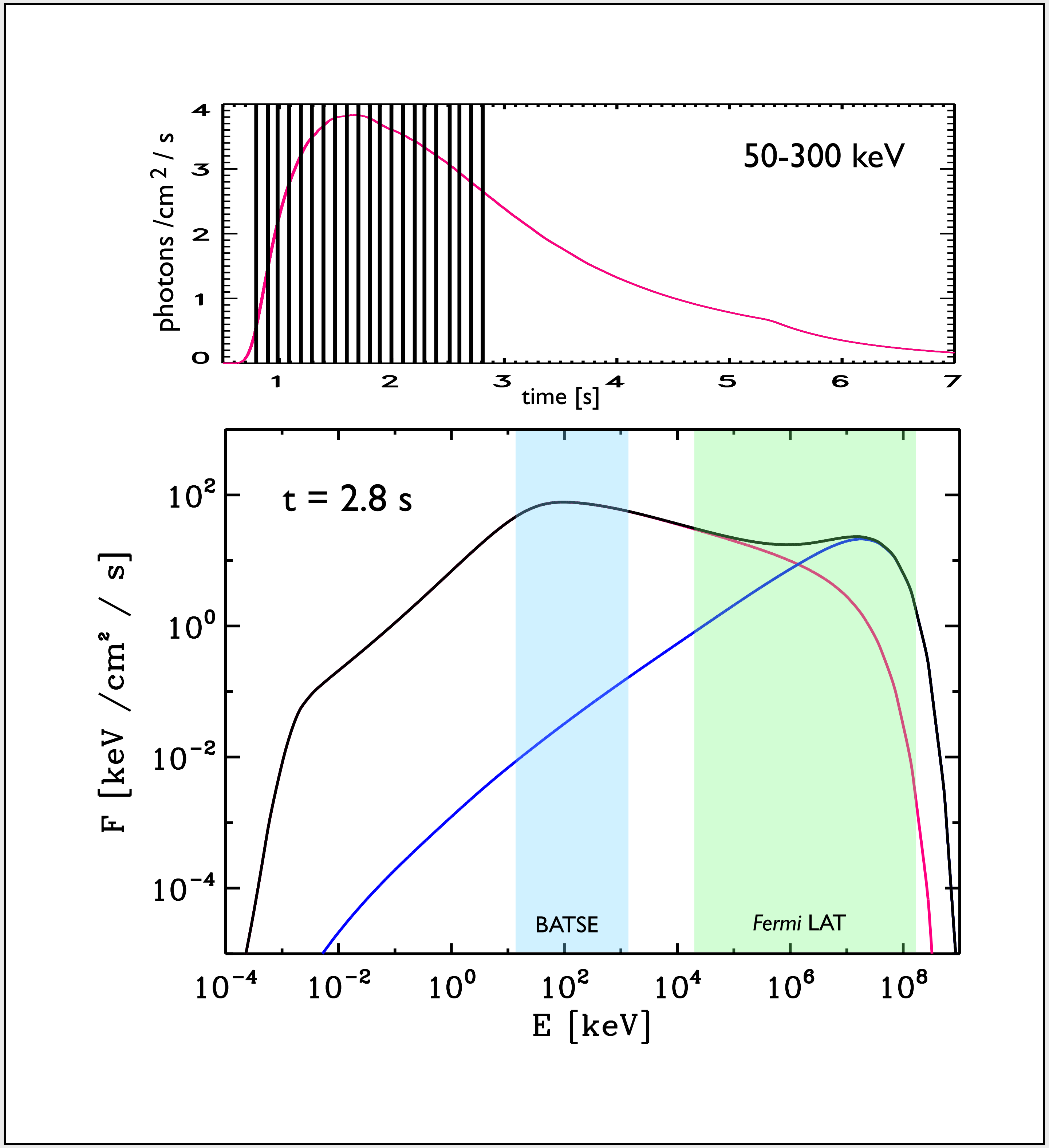
GRB 190114C



MAGIC collaboration, 2019

Observed spectra and time profiles

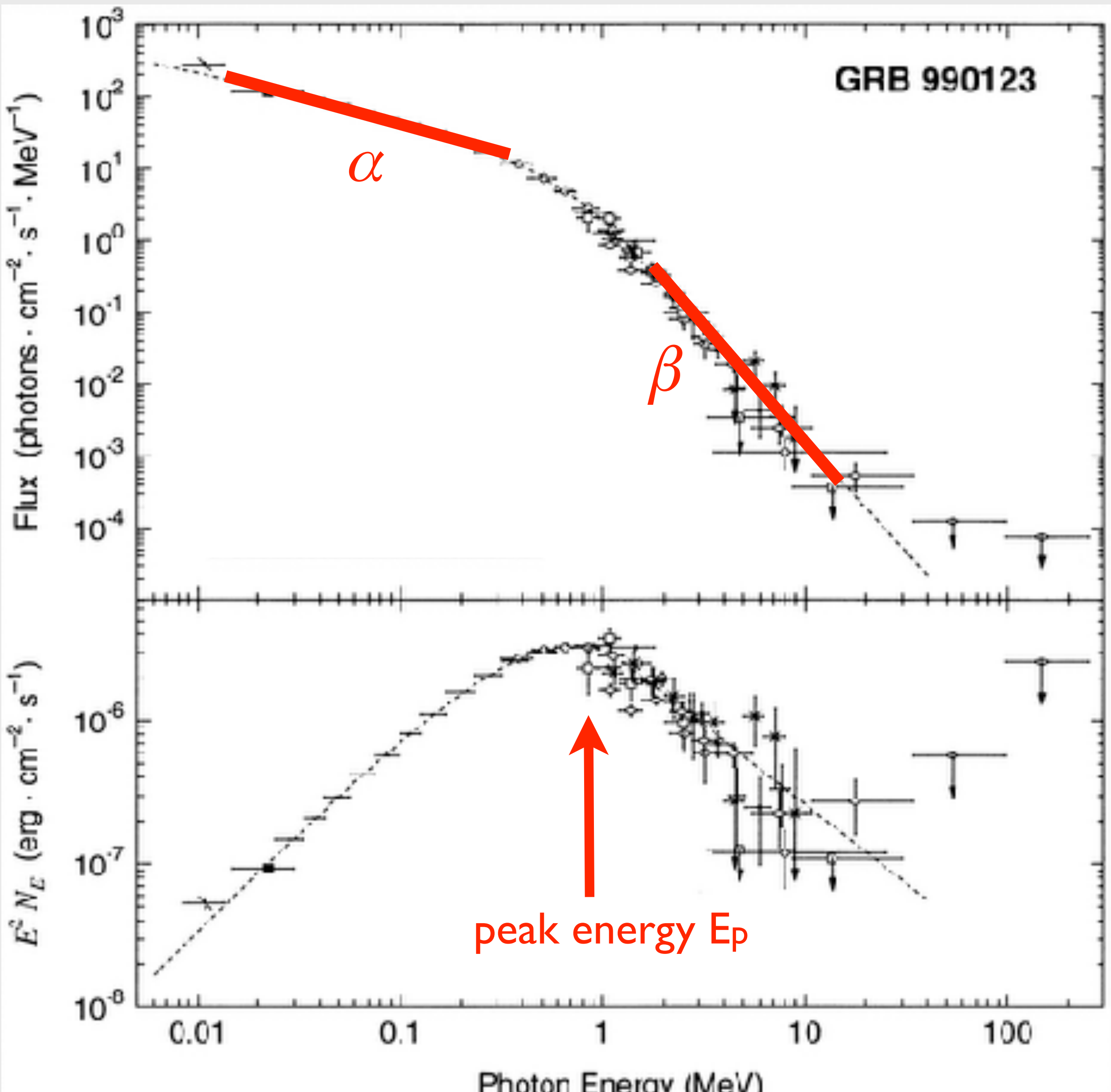
Instantaneous observed spectrum:



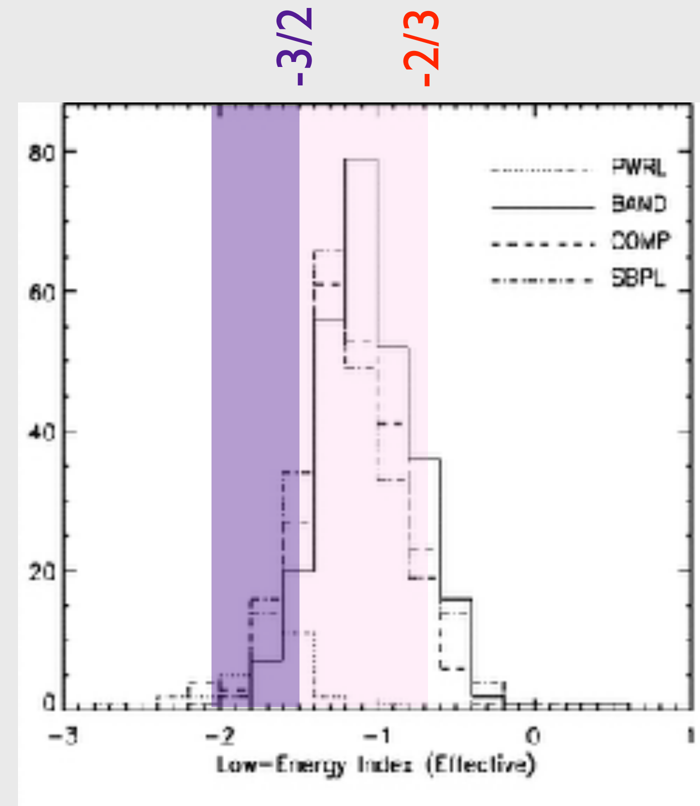
synchrotron
inverse Compton
total

Spectral properties

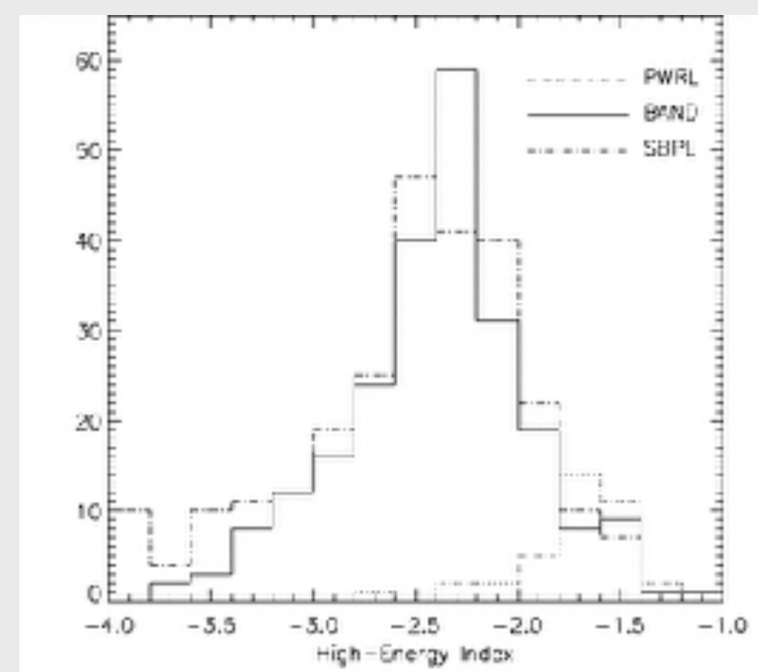
4-parameters “Band spectrum”
Ep, α, β and normalization
Band et al. 1993



Briggs et al. 1999



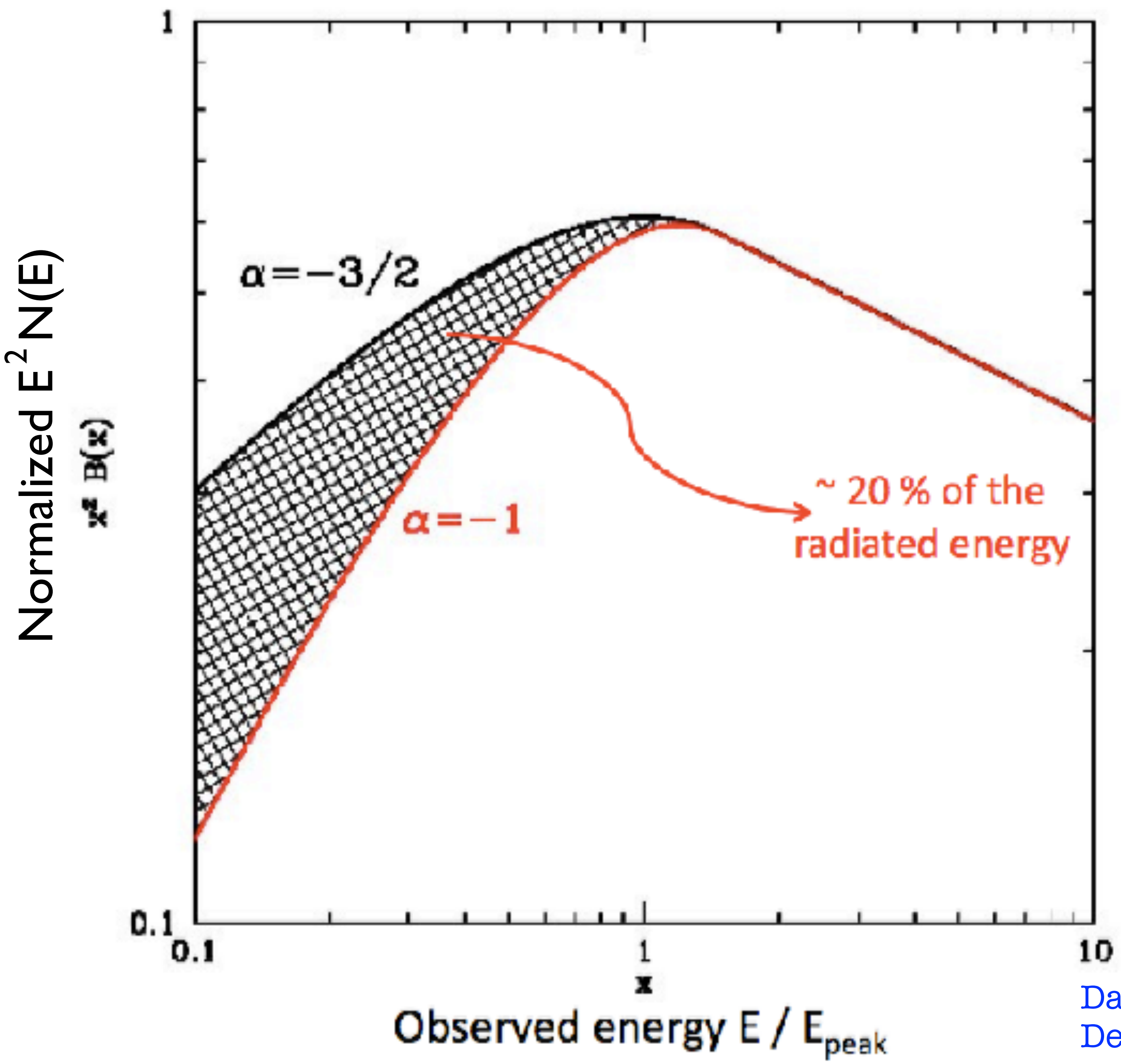
α = -1.02 ± 0.27



β = -2.35 ± 0.27

Kaneko et al. 2006

Spectral properties



Band function

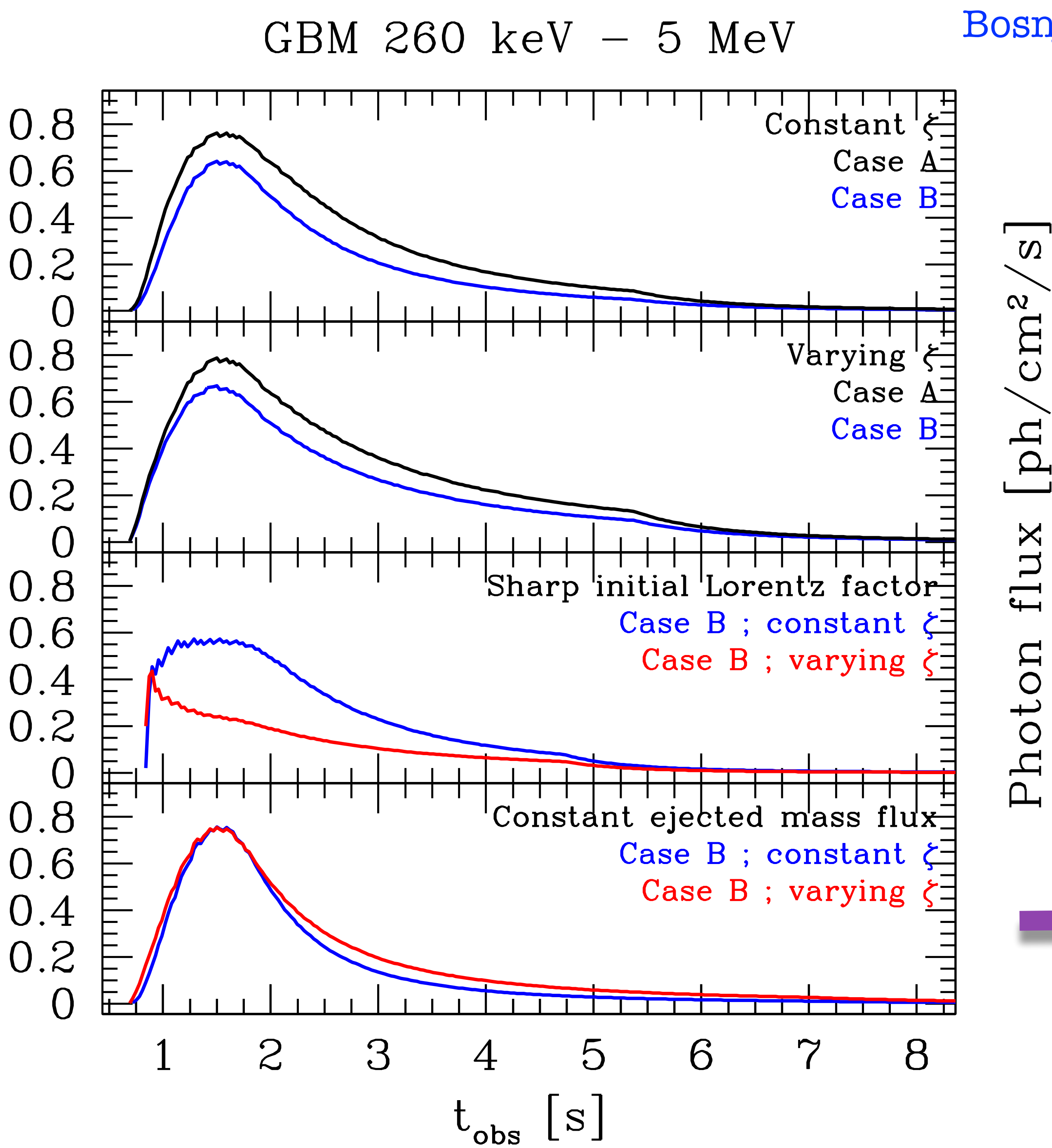
α = - 1.5 → -1
β = - 2.25

Daigne, Bosnjak & Dubus 2011
Derishev 2001

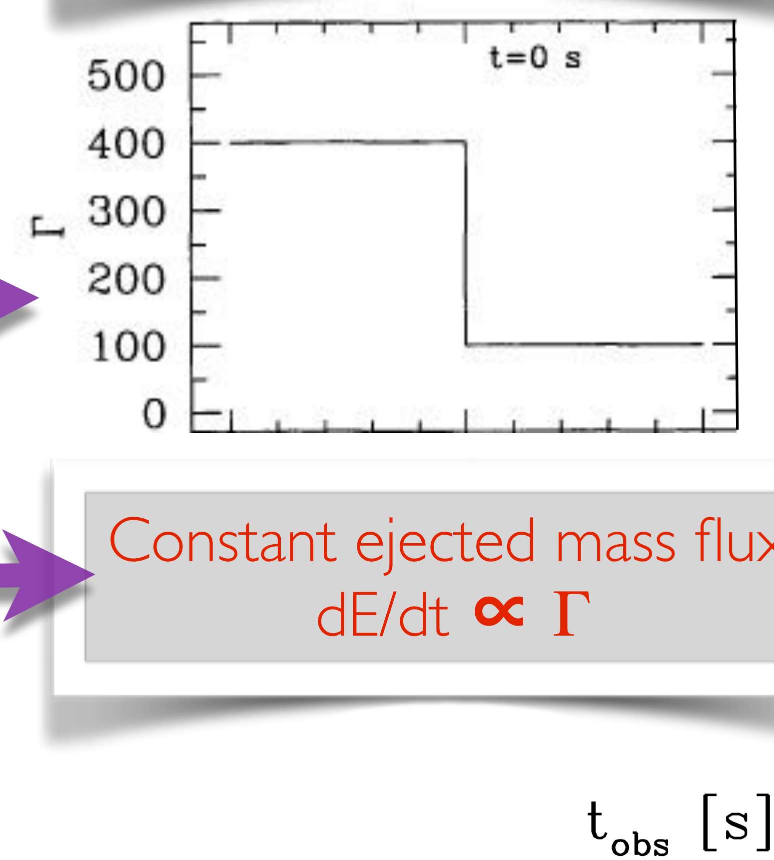
Inverse Compton scatterings in Klein-Nishina regime have an impact on the synchrotron slope

High energy emission: light curves

Bosnjak & Daigne 2014

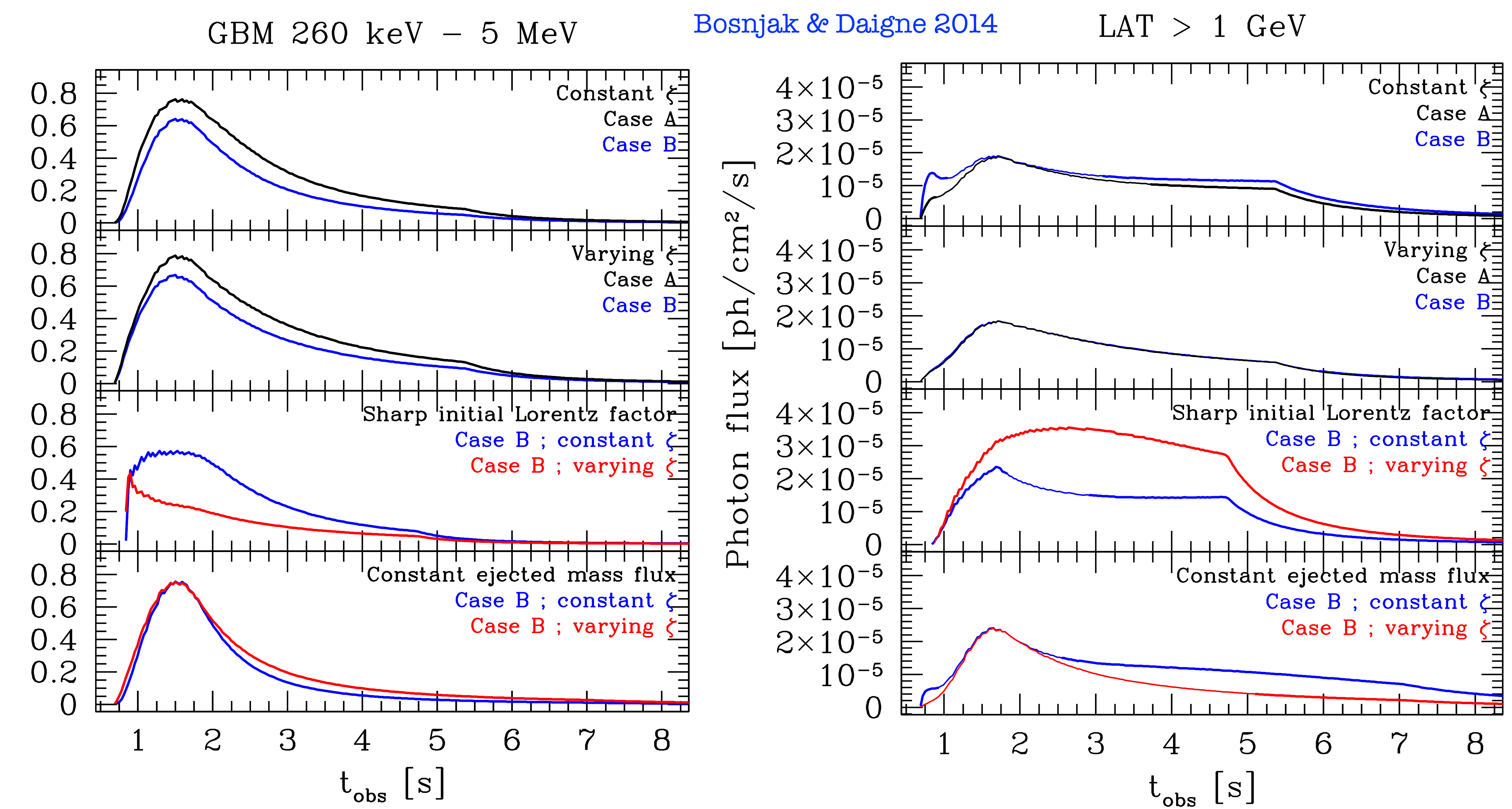


'Sharp' initial Lorentz factor:



Constant ejected mass flux:
$dE/dt \propto \Gamma$

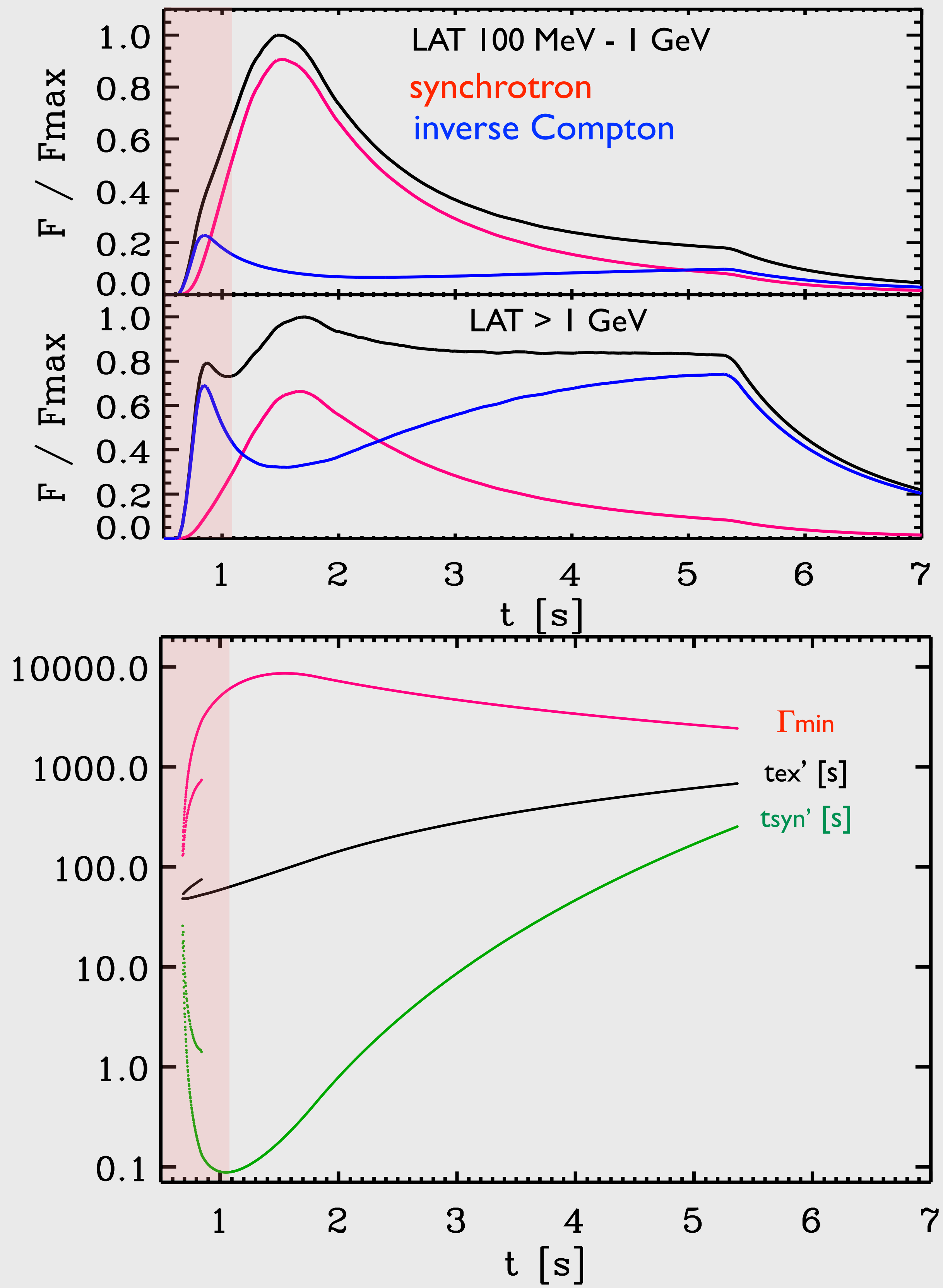
High energy emission: light curves



For the delayed arrival of >100 MeV photons in *magnetic jet model* see Bosnjak & Kumar 2012

Temporal profiles: >100 MeV range

Model: in LAT (>100 MeV) energy bands both components present, synchrotron + IC



weak shock

ε^* low

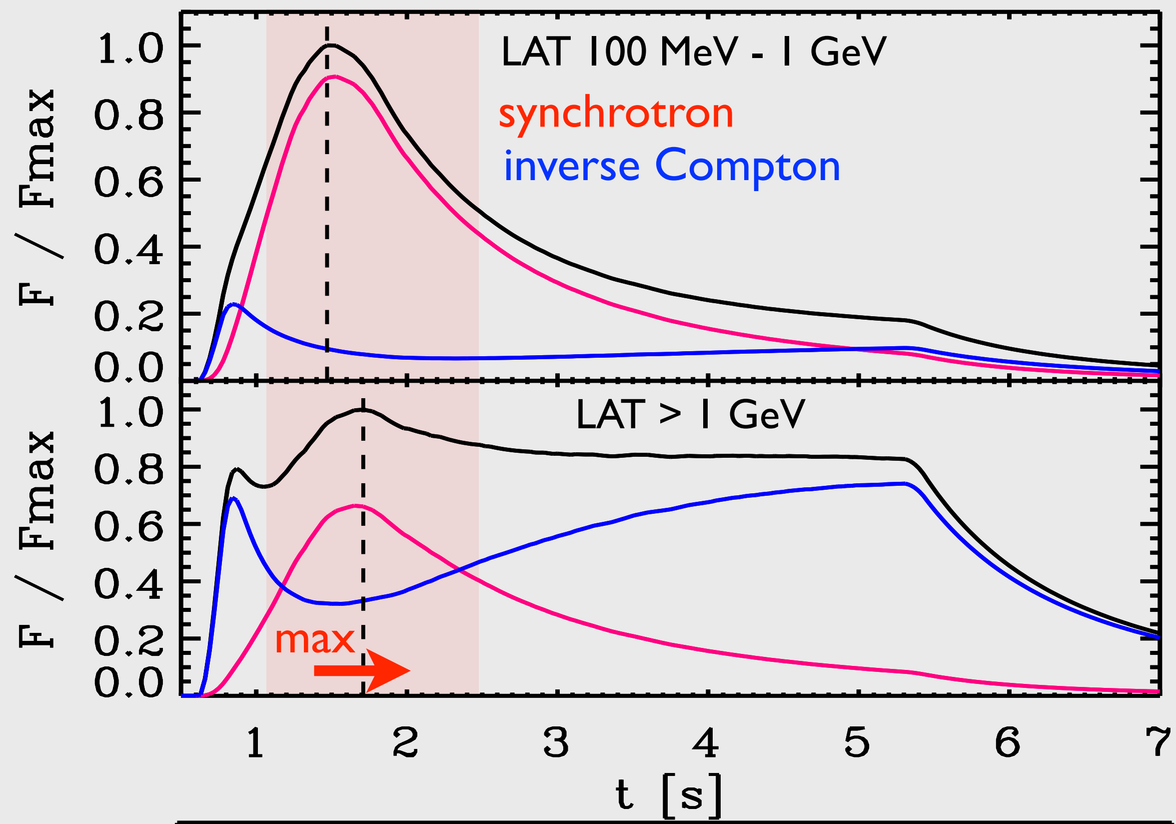
moderate $\Gamma_m \Rightarrow$ large t_{syn}'

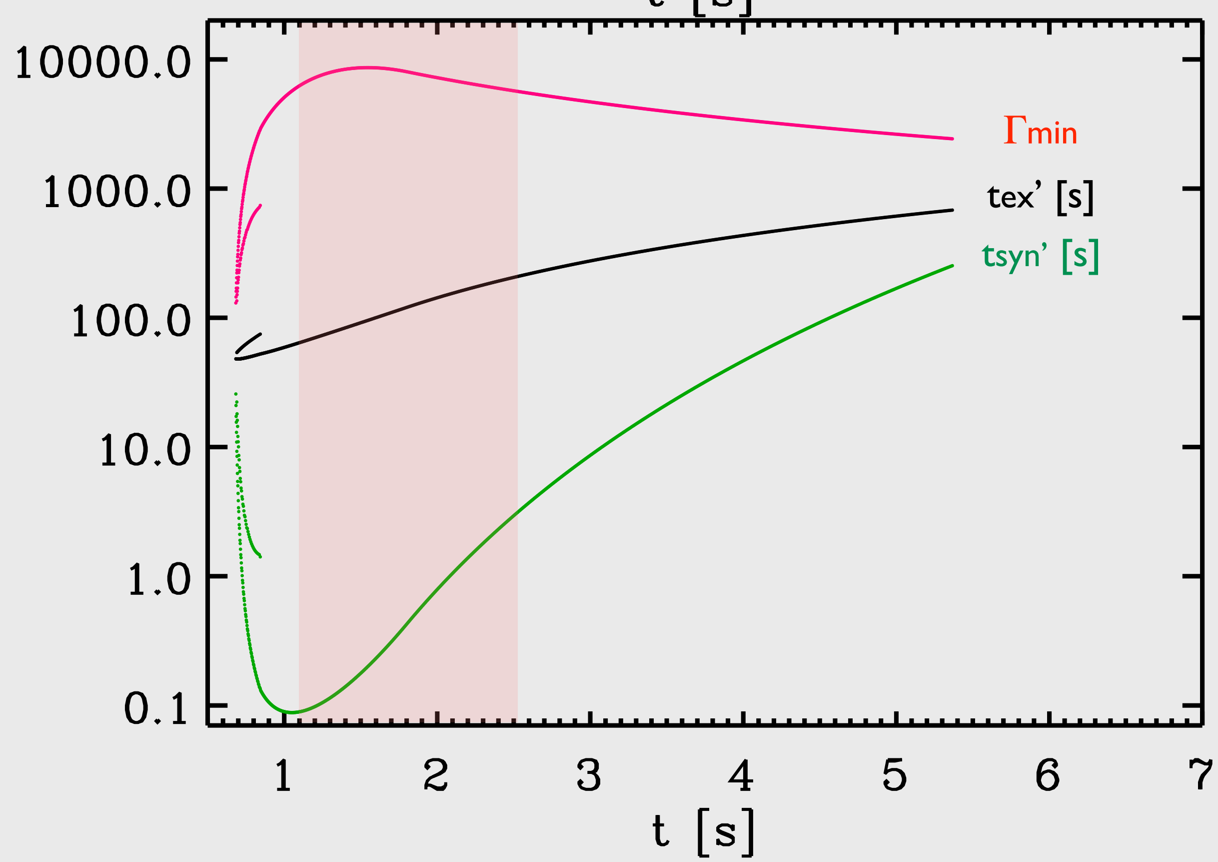
R small $\Rightarrow t_{ex}' \cong R/\Gamma^* c$ small

$t_{syn}' \leq t_{ex}' \Rightarrow$ large efficiency of IC

Temporal profiles: >100 MeV range

Model: in LAT (>100 MeV) energy bands both components present, synchrotron + IC



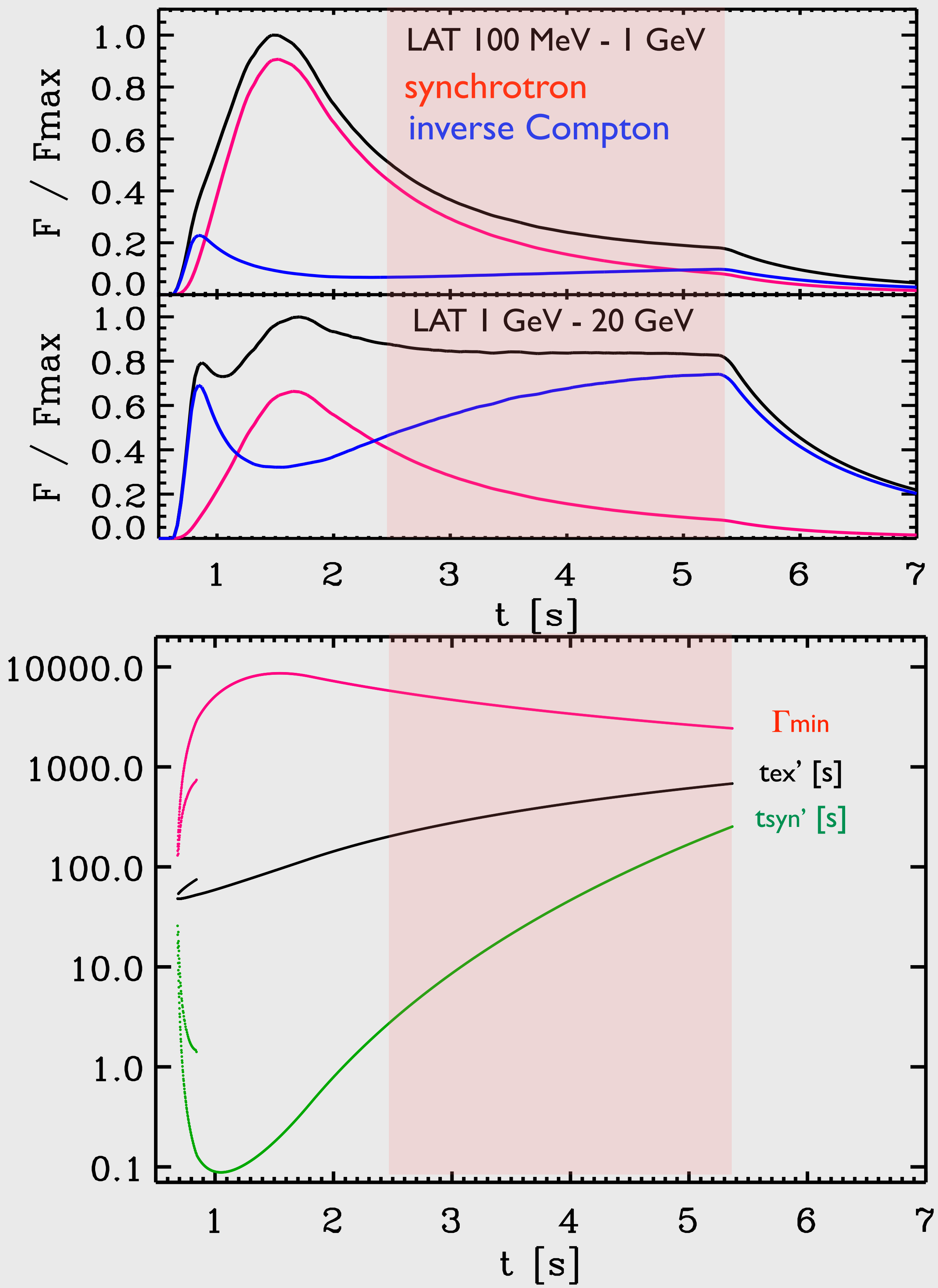


shock becomes stronger
Γm increases ⇒ tsyn' decreases
R, tex' increase
tsyn' << tex' ⇒ low efficiency of IC

dominant synchrotron component

Temporal profiles: >100 MeV range

Model: in LAT (>100 MeV) energy bands both components present, synchrotron + IC



tail of the pulse:
B decreases ⇒ tsyn' increases
tsyn' ≤ tex' ⇒ increased efficiency of IC
IC component dominant in GeV

Parameter space exploration

Parameter space of internal shocks:

(1) mean LF in the outflow $\overline{\Gamma}$

(2) contrast κ characterizing the amplitude of the variations in the initial distribution of the LFs

(3) injected kinetic power dE/dt

(4) variability timescale τ

(5) fraction of the dissipated energy which is injected in the magnetic field ε_B

(6) fraction of electrons that are accelerated ζ

Comoving frame parameters:

(1) magnetic field B’
(2) adiabatic cooling timescale $t`_{dyn}$
(3) relativistic electron density n_e
(4) shape of the initial distribution of the LF of accelerated electrons

Parameter space exploration

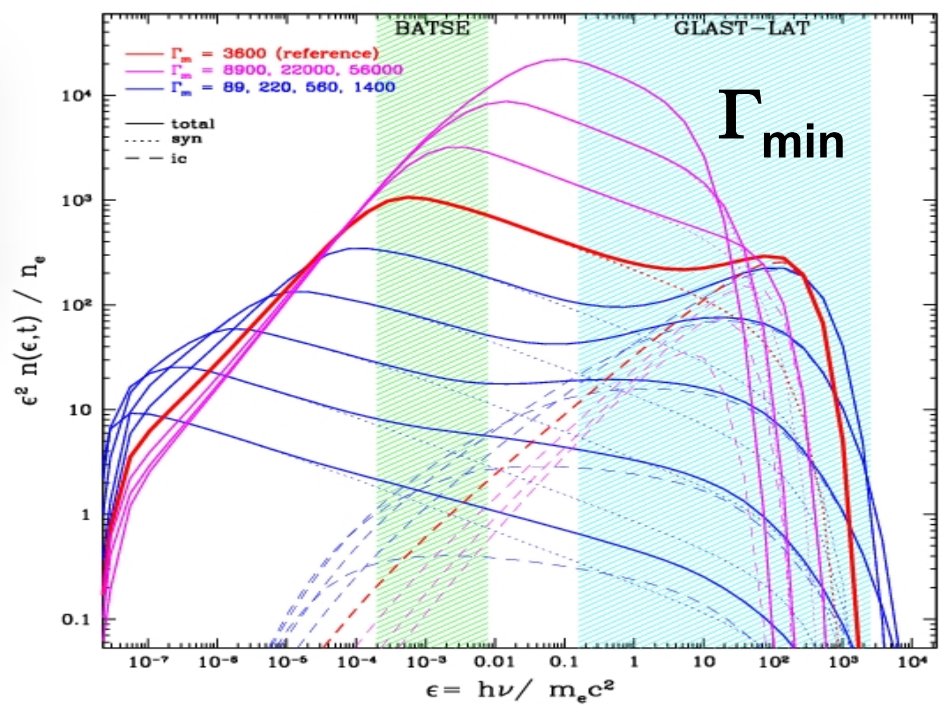
We consider the physical conditions in the shocked medium corresponding to an observer time t_{obs} close to the peak: reference case (Γ_{min} = 3600, n_e = 1.3 x $10^7 cm^{-3}$, B= 5200 G, t_{ex} = 170 s)

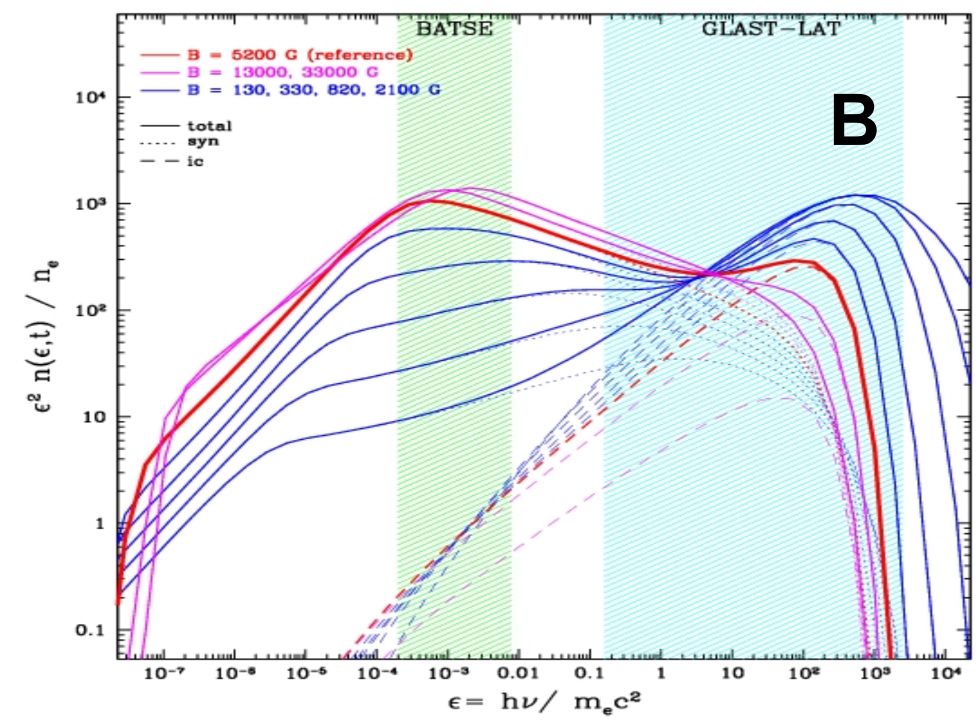
Q: how is the broad spectral shape affected by each of the parameters (Γ_{min}, n_e, B, t_{ex}) ?

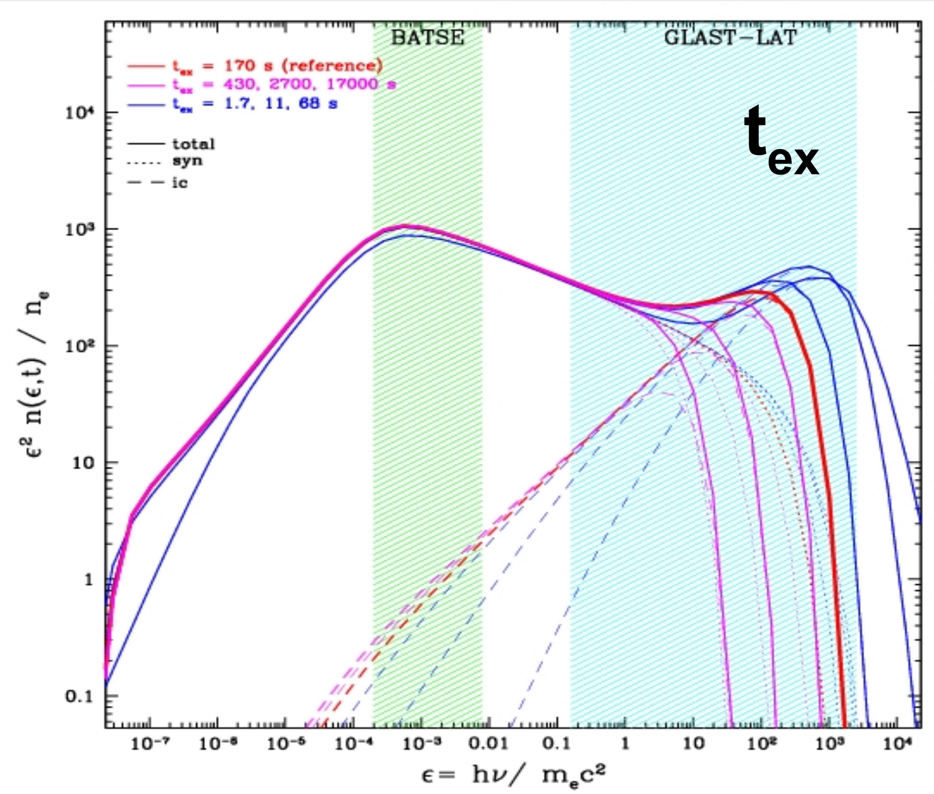
$\tau_{IC} \approx n_e\ (\sigma_T \times \text{KN corr.})\ (c \times t_{rad})$

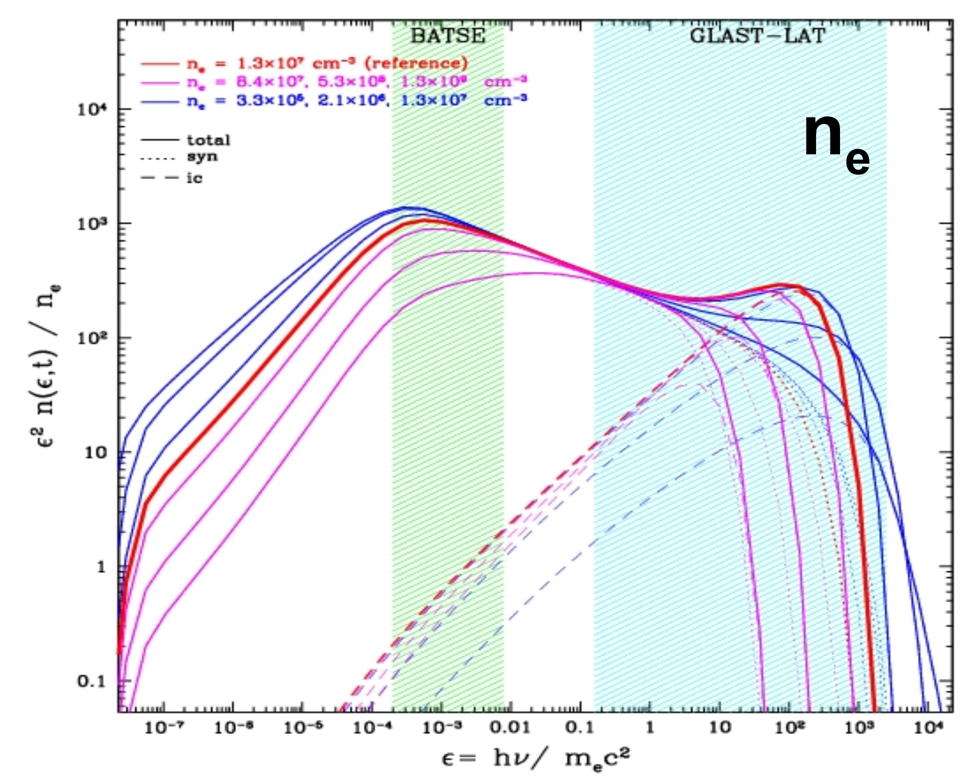
$Y \approx \tau_{IC} \times (\Gamma^2_{min} \times \text{KN corr.})$

A strong IC component is obtained when relativistic e- survive long enough for scatterings to occur (*a low Γ_{min}, a low B and a low t_{ex}, i.e. $t_{rad} \longrightarrow t_{ex}$*)







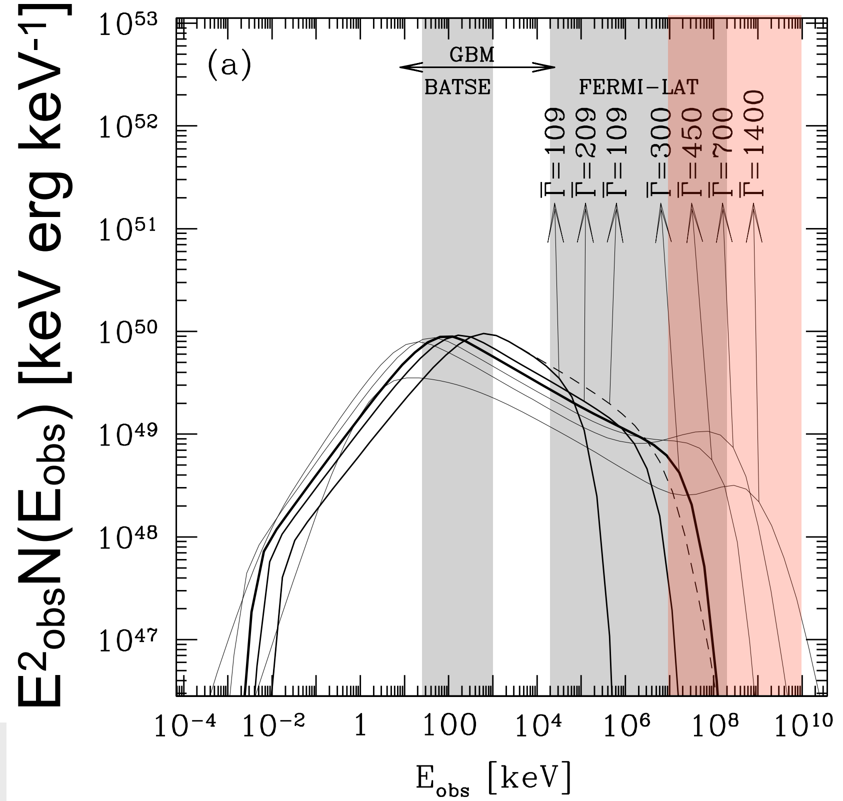


A low density n_e does not favor IC emission (τ_{IC} is too low), but a large n_e increases photon density and then the $\gamma\gamma$ annihilation

$\longrightarrow$ *IC is strongest for intermediate n_e*

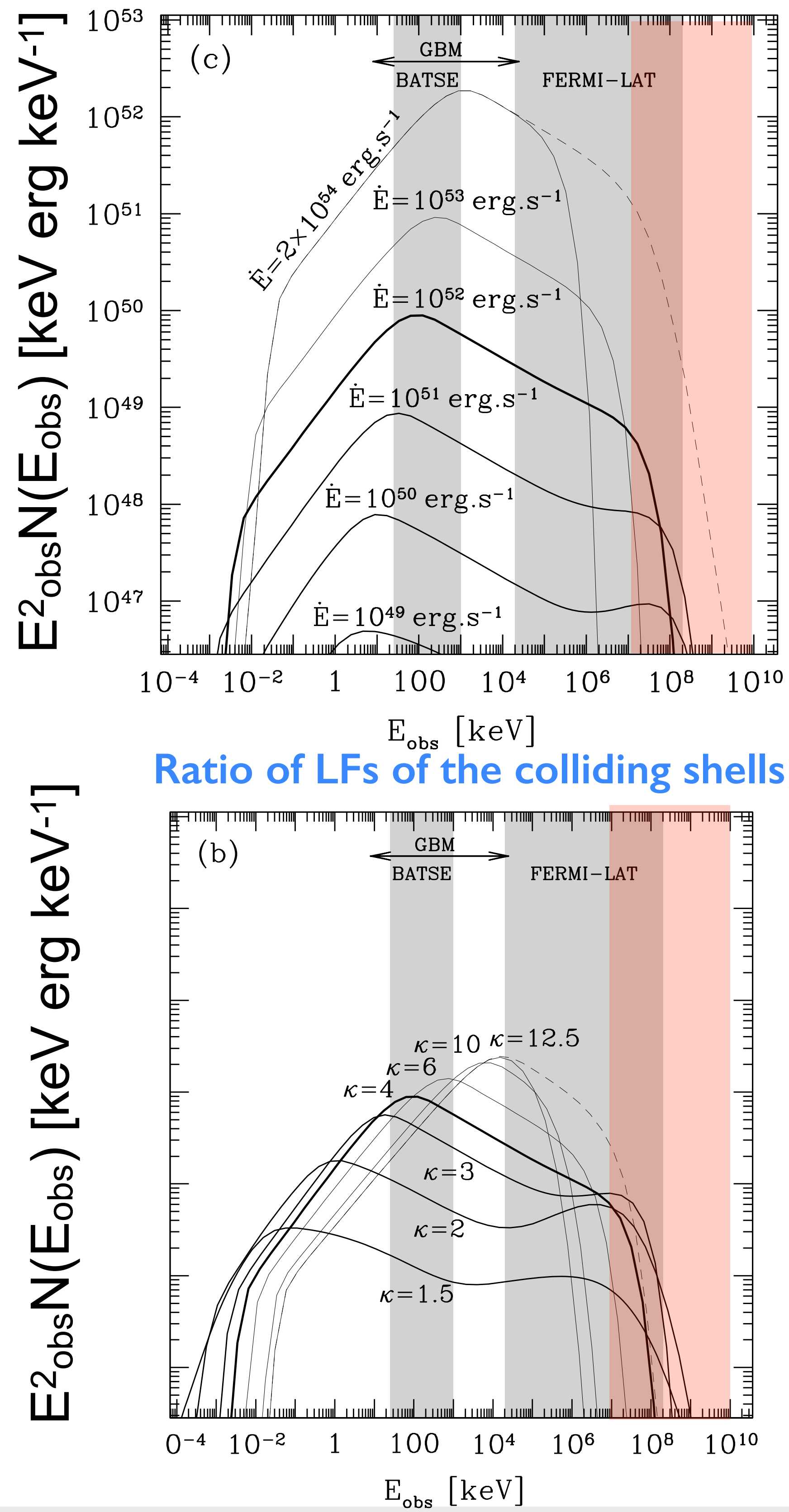
Parameter space exploration: internal shock parameters

Bulk Lorentz factor



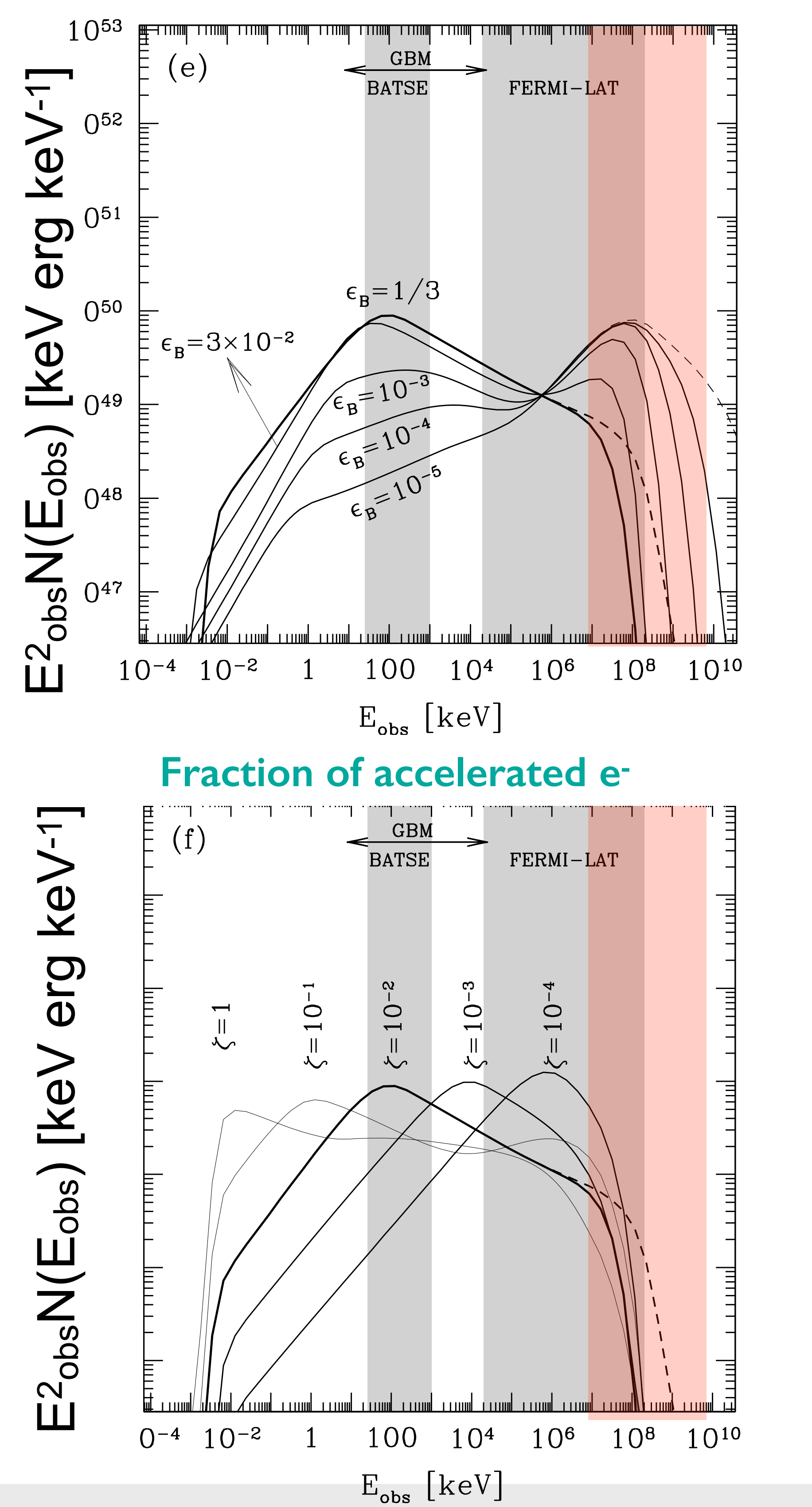
Injected kinetic power

Ratio of LFs of the colliding shells



Fraction of en. injected in MF

Fraction of accelerated e-



Two effects can limit the parameter range:

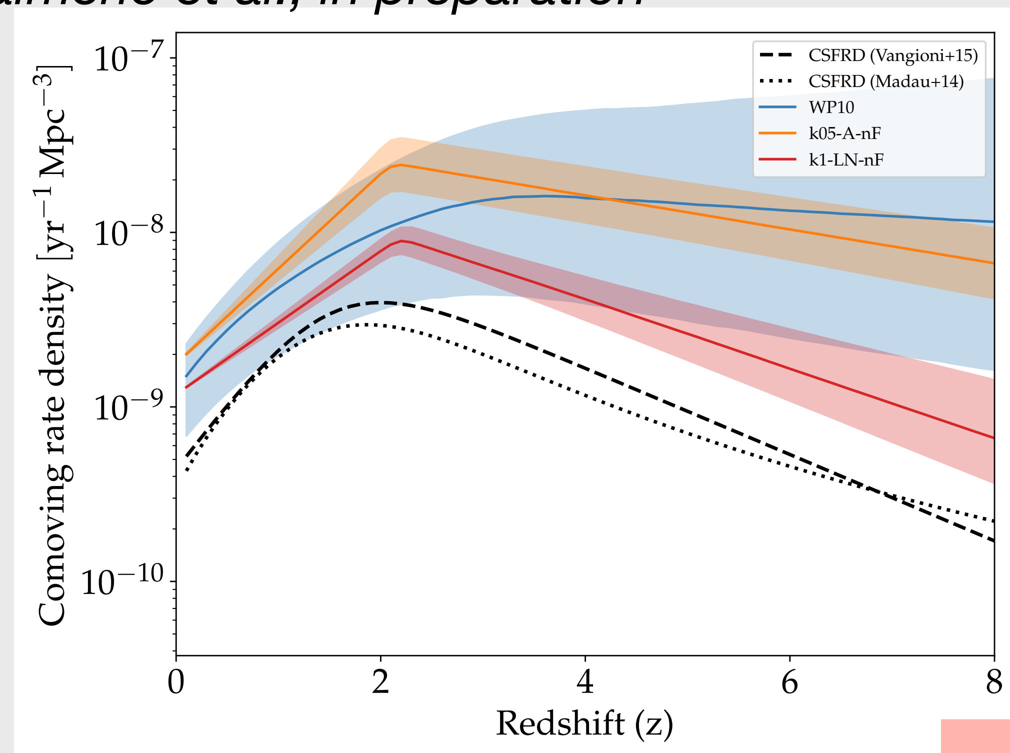
(i) electrons become radiatively inefficient ("efficiency limit") or

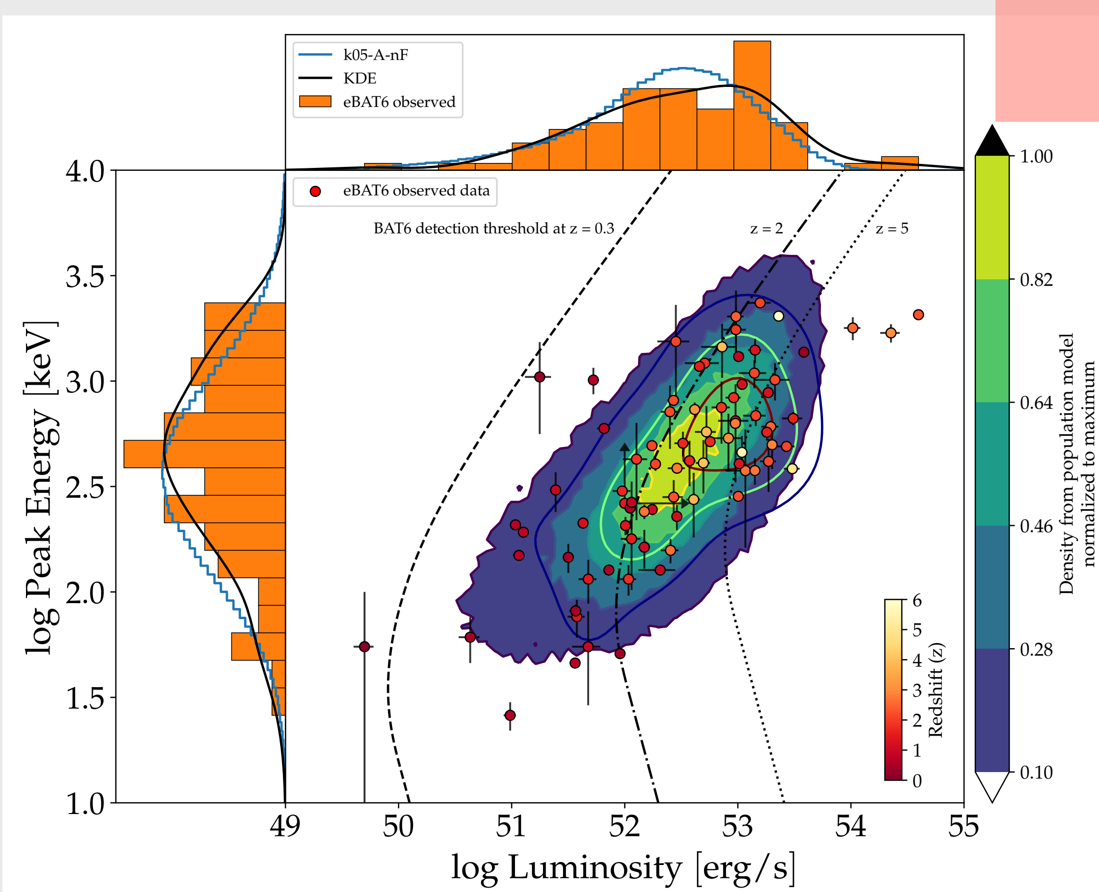
(ii) the medium becomes optically thick due to the intense production of pairs ("transparency limit").

- - - - spectrum without $\gamma\gamma$ annihilation

Parameter space exploration

Palmerio et al., in preparation





Parameter space of internal shocks:

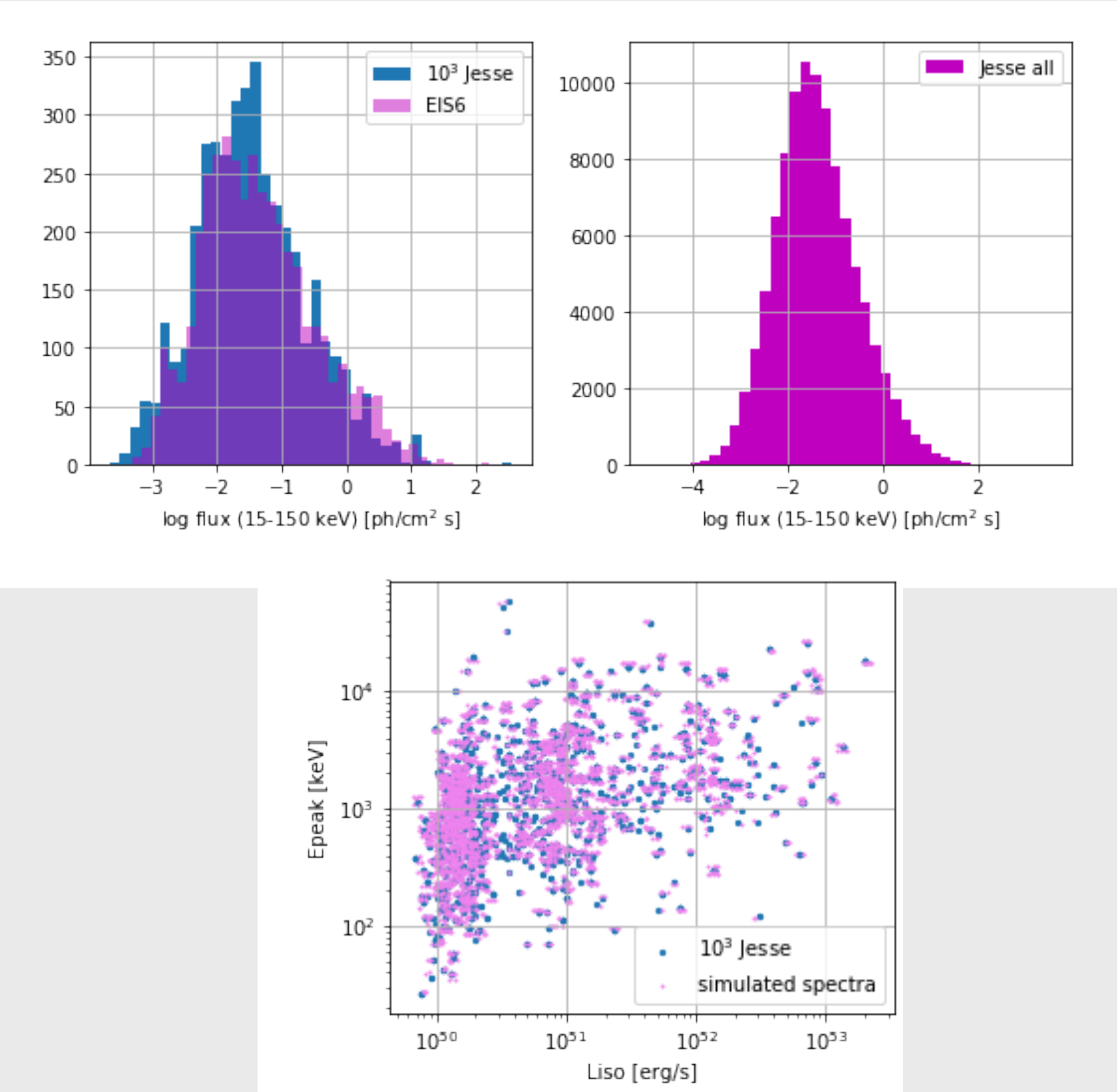
(1) log $\langle\Gamma\rangle$: 1.5 → 3
(2) log κ: 2.5 → 10
(3) dE/dt: 50 → 54
(4) log τ: −2 → 2
(5) log ε_B : -5 → -0.5
(6) log ζ: −4 → 0

Comoving frame parameters:

(1) log B': 1 → 4
(2) log t'_{dyn}: 0 → 3
(3) log n_e: 4 → 10
(4) log Γ_{min} :1.5 → 5

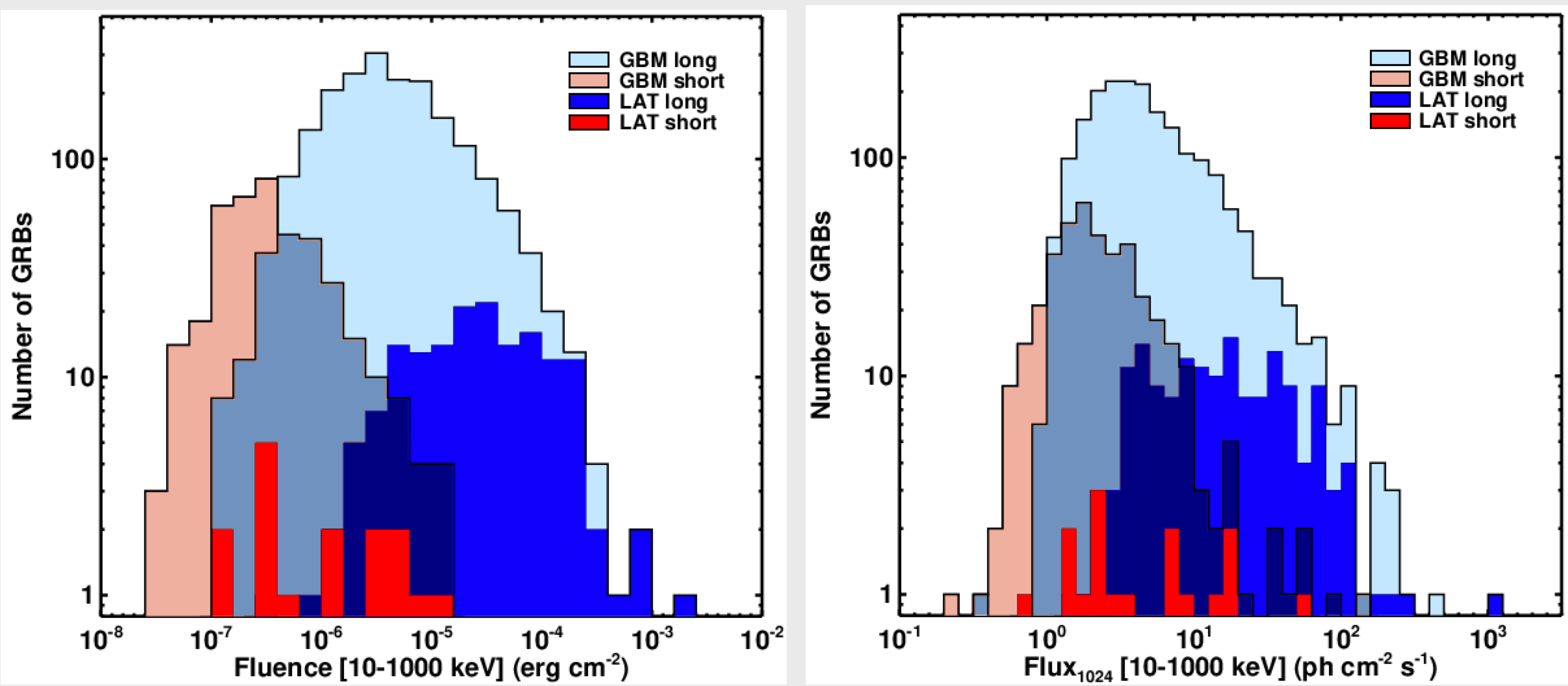
Parameter space exploration

Bosnjak, Daigne & Palmerio in preparation



Parameter space exploration

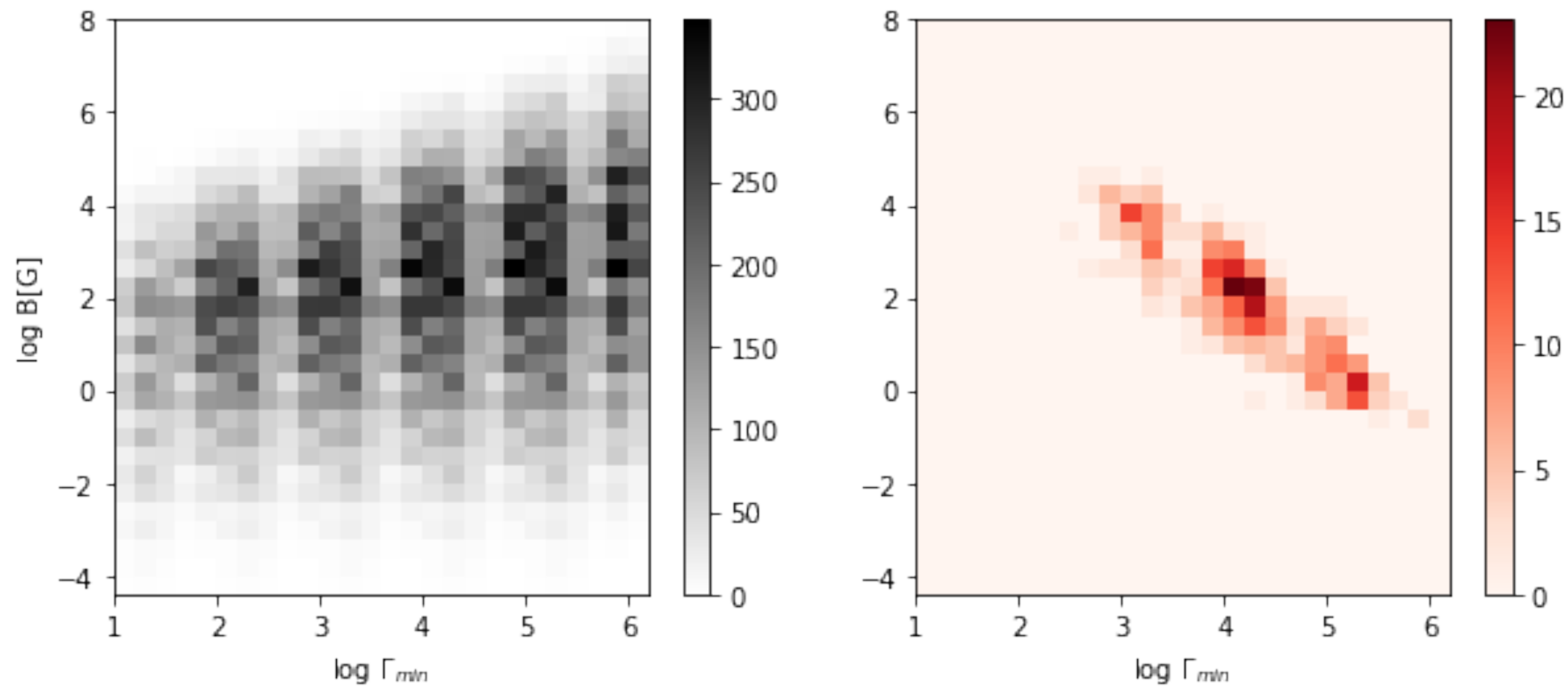
- LAT detected GRBs are among the brightest detected by the GBM
- there are a few cases of bursts that were not particularly bright in the GBM, yet were detected by LAT (e.g. short GRBs 081024 and GRB 090531)

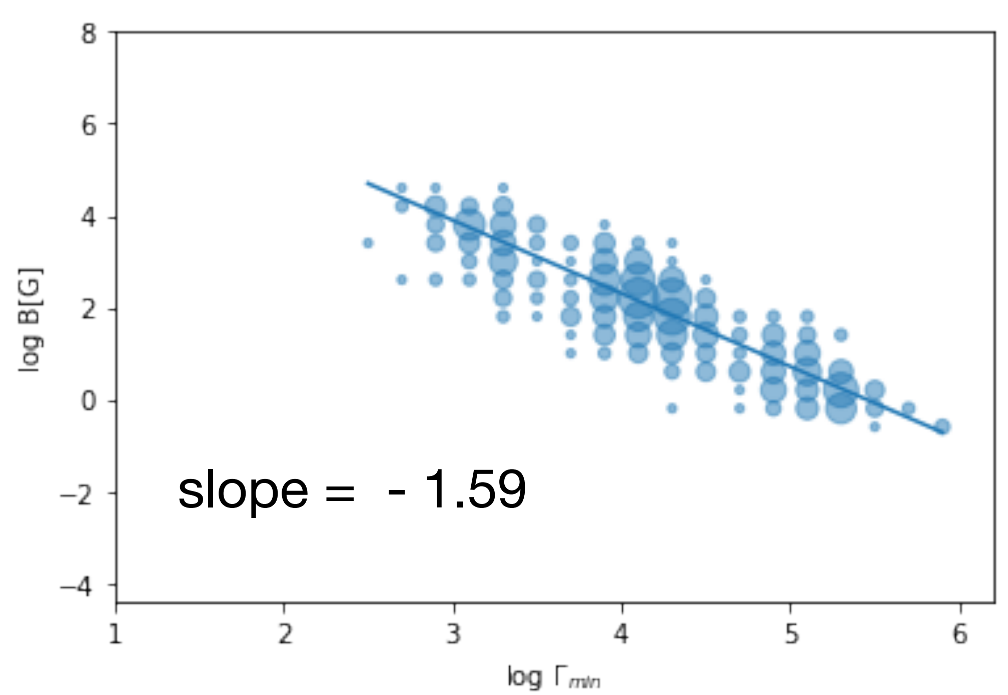


2nd Fermi LAT Catalog, 2019

Parameter space exploration

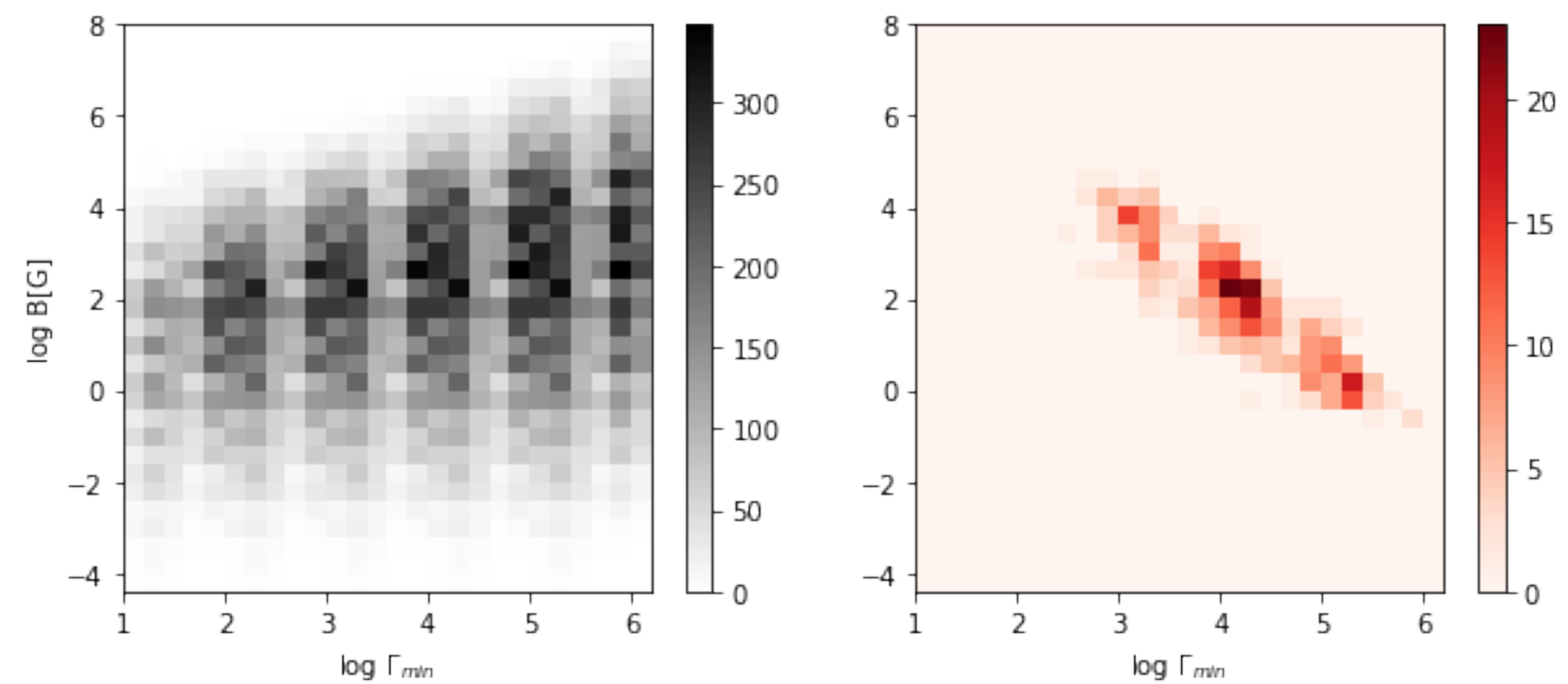
Bosnjak, Daigne & Palmerio in preparation

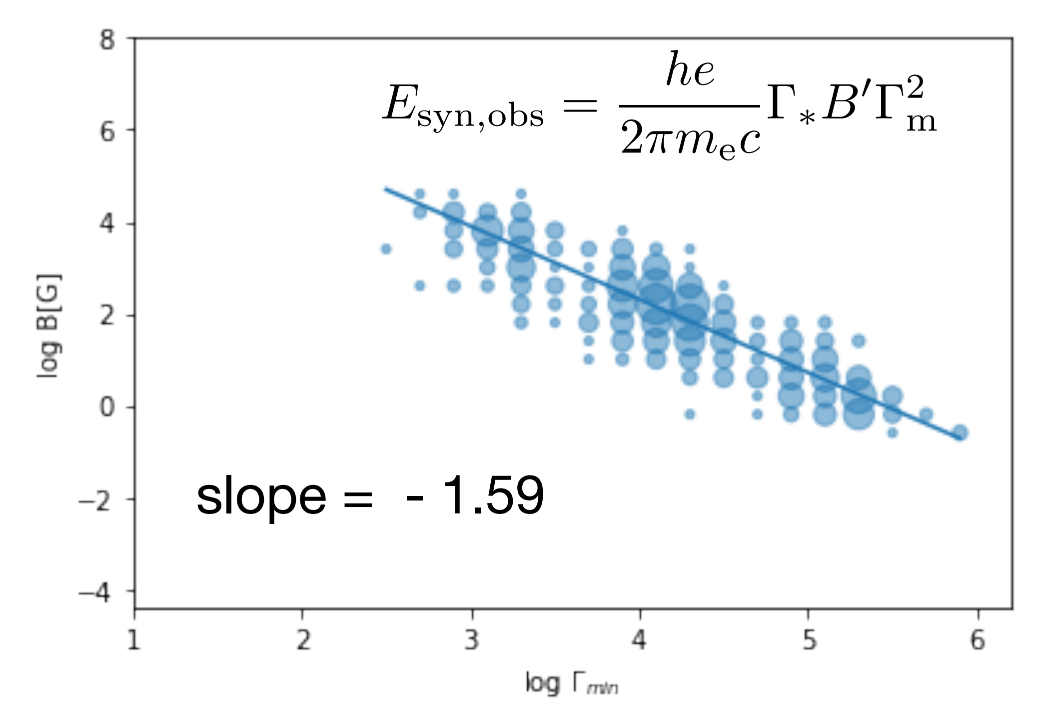


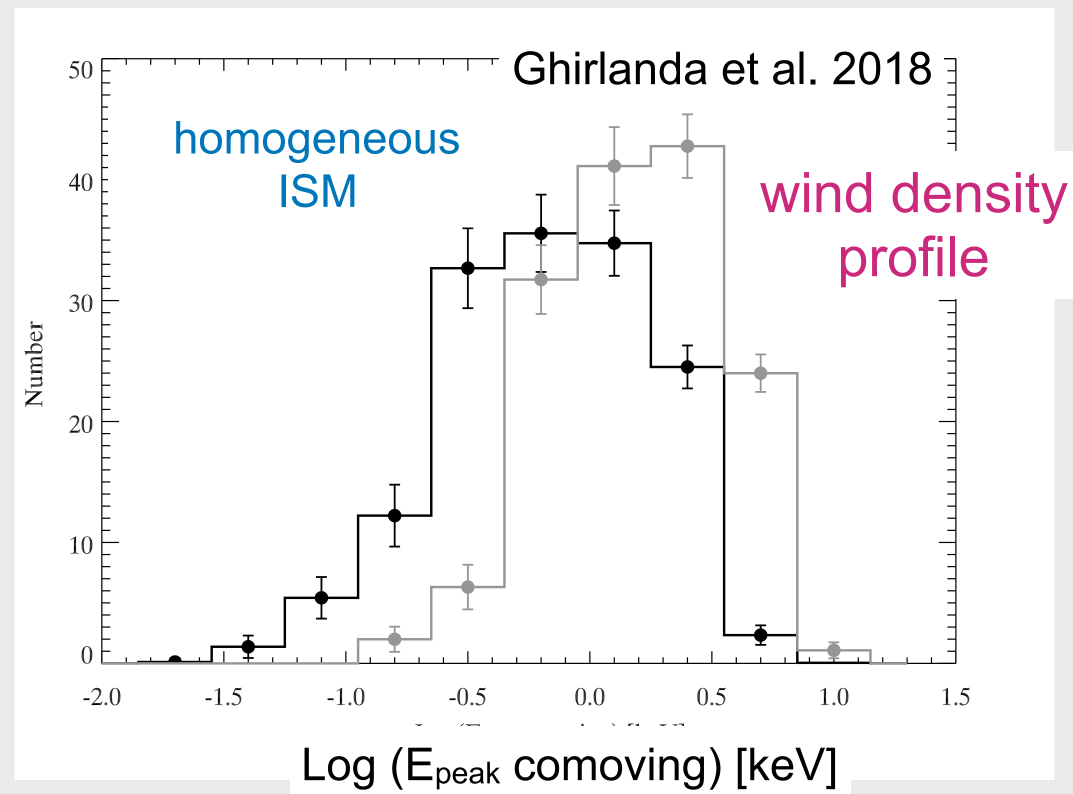


Parameter space exploration

Bosnjak, Daigne & Palmerio in preparation

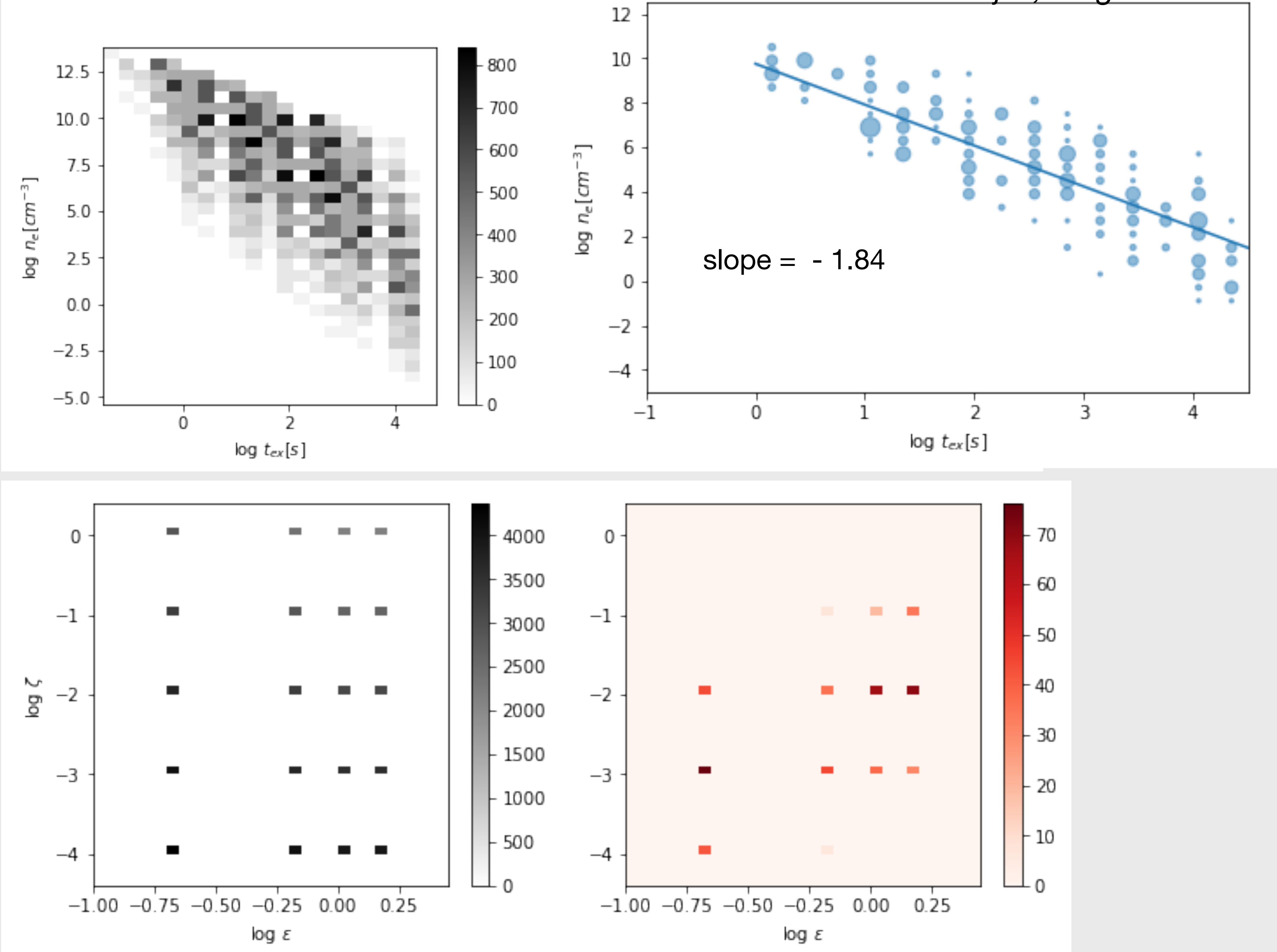






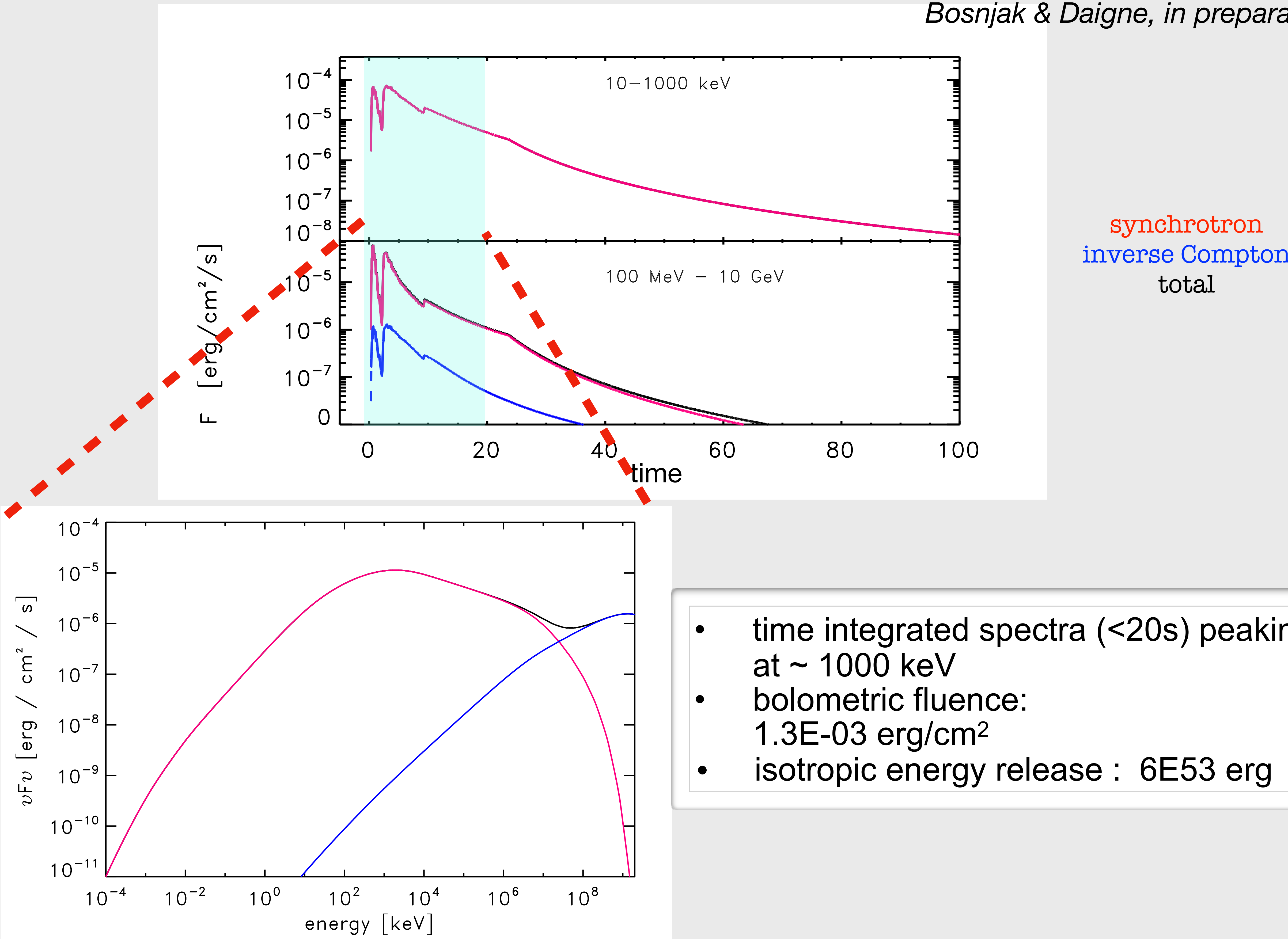
Parameter space exploration

Bosnjak, Daigne & Palmerio in preparation



Prompt emission in GRB 190114C: contribution to early MAGIC observations

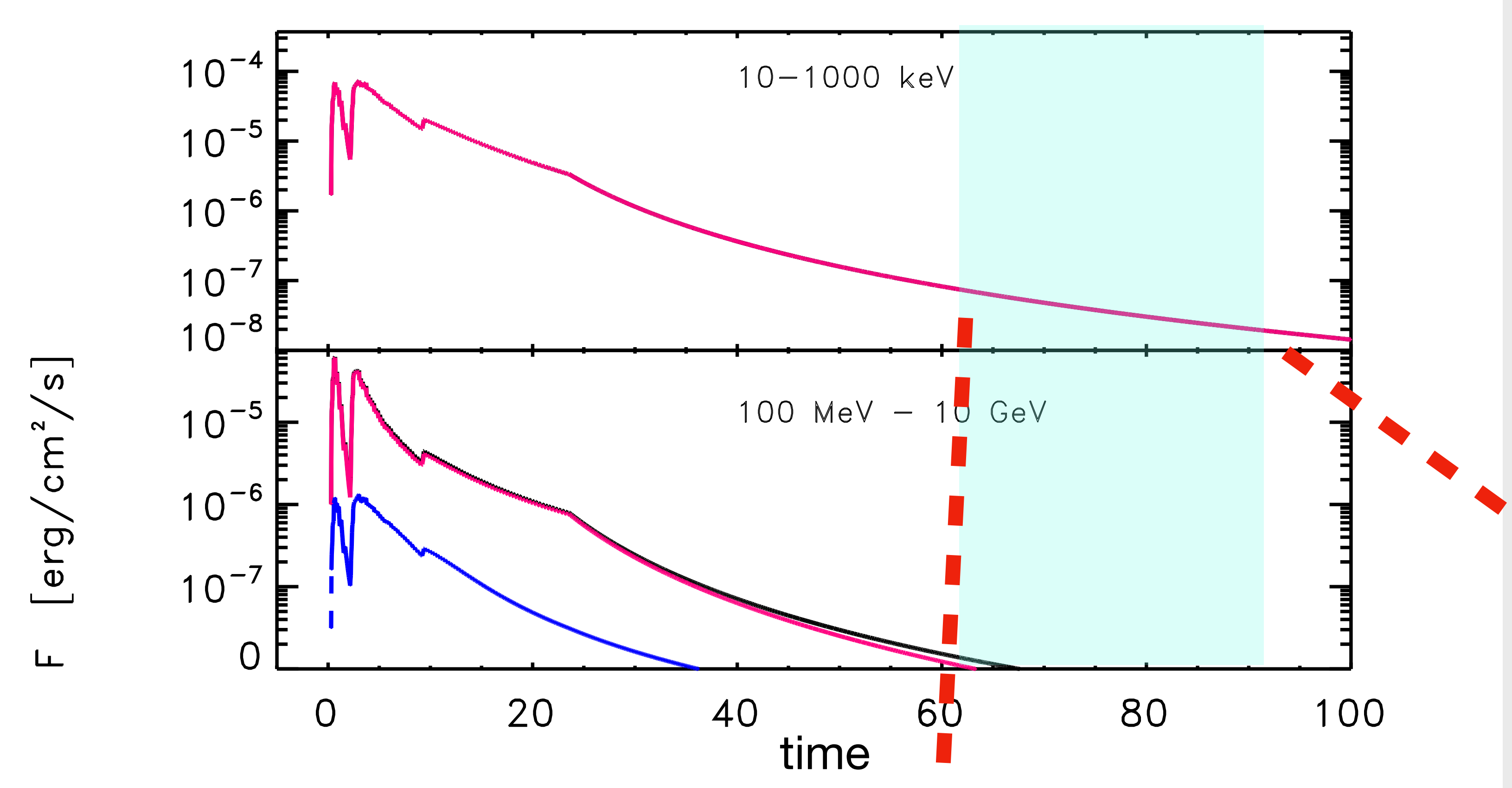
Bosnjak & Daigne, in preparation



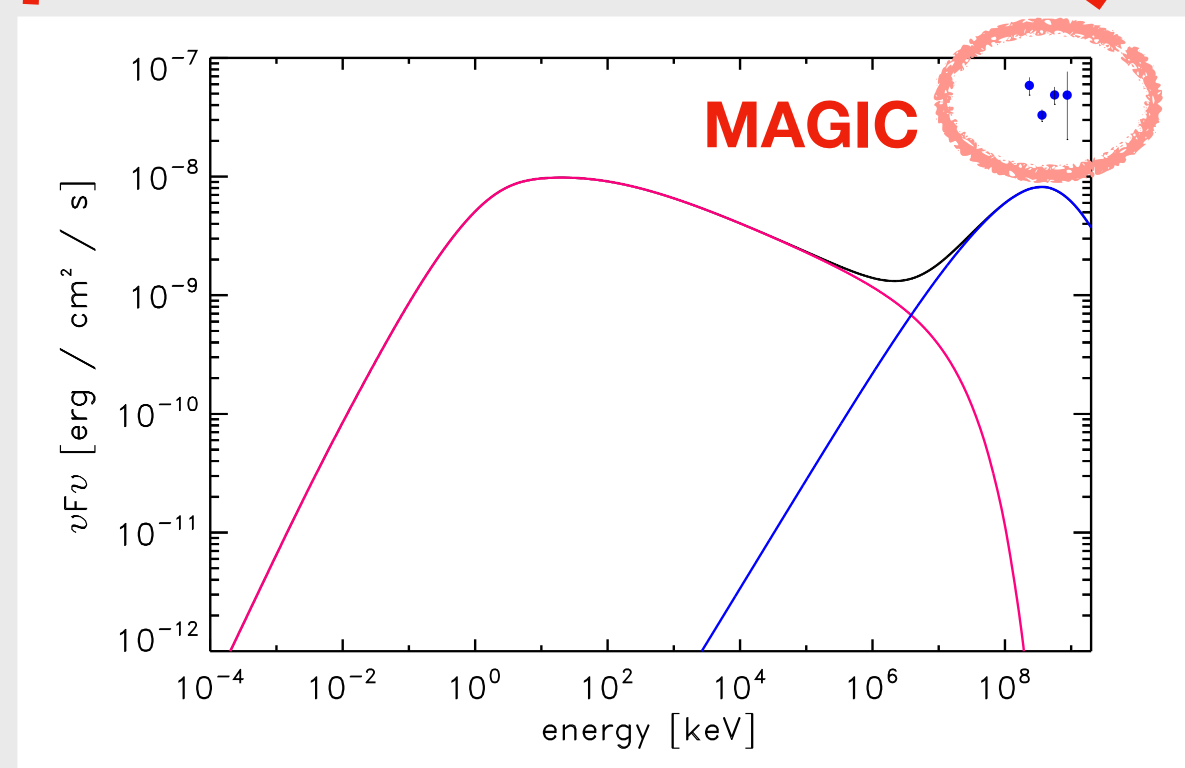
- time integrated spectra (<20s) peaking at ~ 1000 keV
- bolometric fluence: 1.3E-03 erg/cm^2
- isotropic energy release : 6E53 erg

Prompt emission in GRB 190114C: contribution to early MAGIC observations

Bosnjak & Daigne, in preparation



synchrotron
inverse Compton
total



Spectra integrated on 62-90 s

Contribution to MAGIC observations: ~20%

Summary

We are using modeling tools to compute the GRB prompt emission from internal shocks in a time-dependent way in different spectral bands, including the high-energy gamma rays, to interpret new VHE observations and make predictions for future CTA observations

Further developments:

- the radiative code is currently updated accounting for the magnetic field evolution in the downstream region;
- the high energy emission will be estimated using the new assumption on the magnetic field