The Three Spectral Components of Fermi/LAT GRBs

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Outline

- Observations
- Three Elemental Spectral Components
- Origin of GeV emission
- Summary

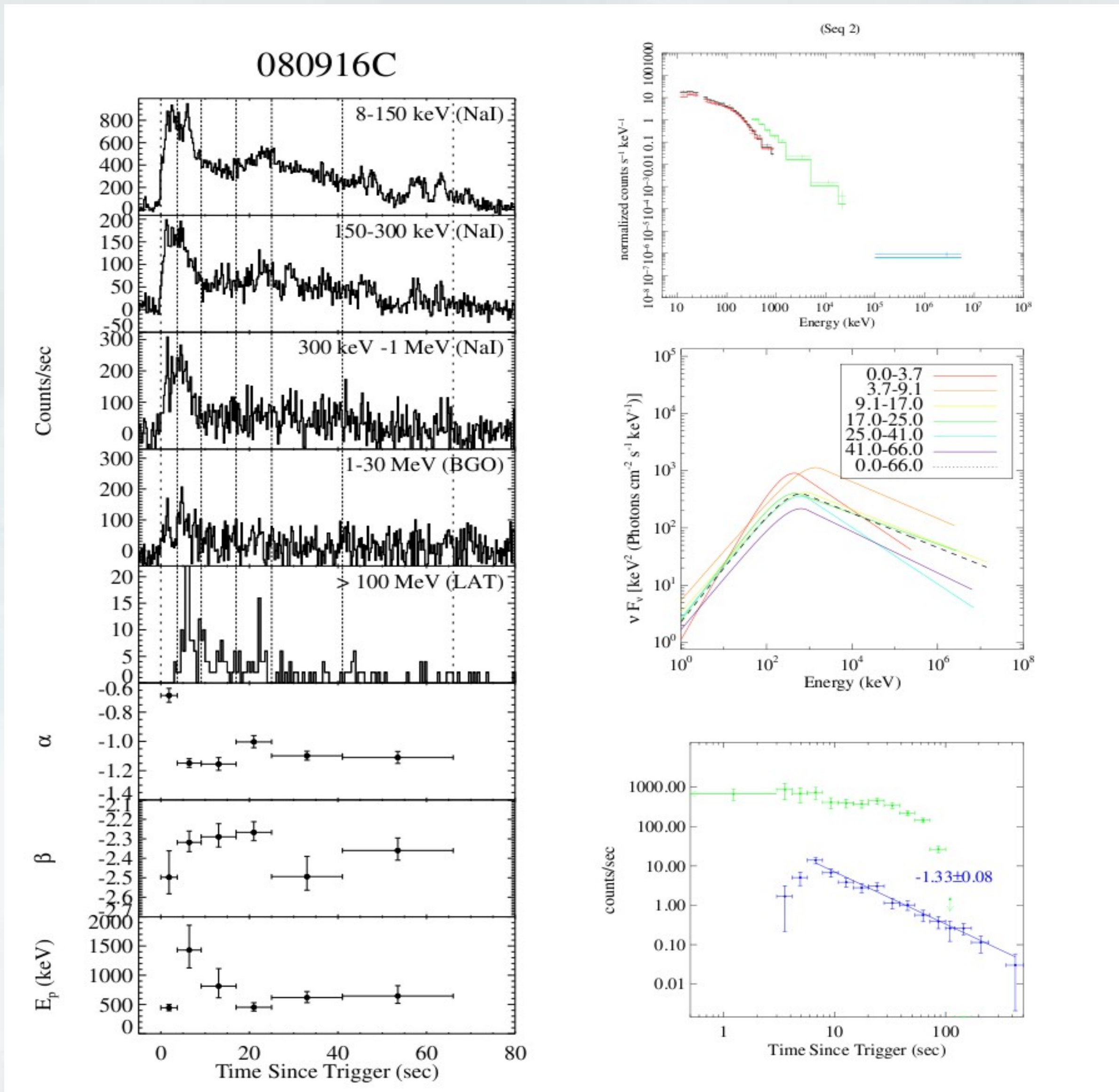
Highlights on Data Analysis :

Time-Dependent Spectral Evolution in Finest Time Resolution for All The Fermi Bursts

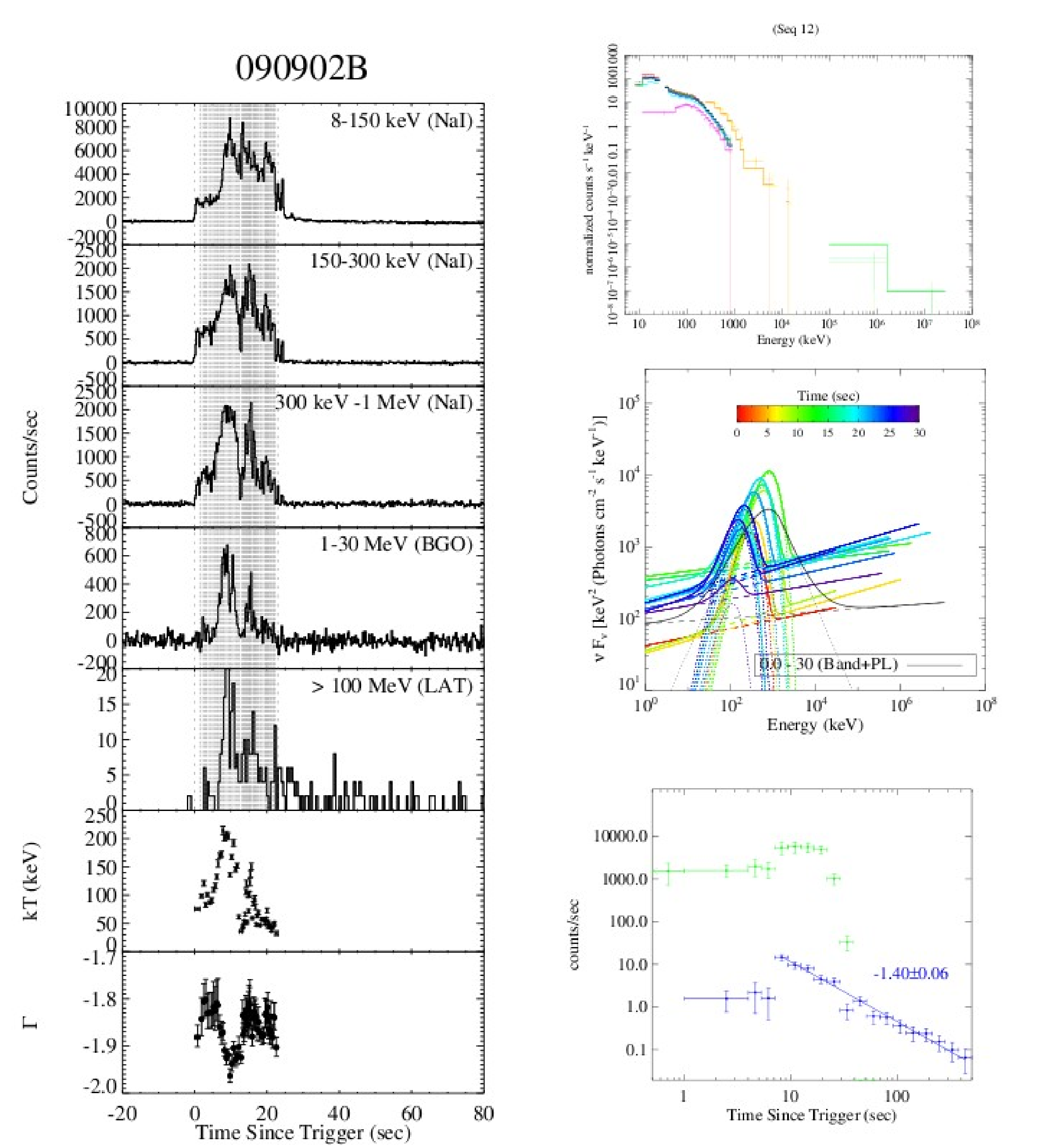
(This wok focus on LAT-only bursts)

GRB	z	dur. [sec]	E_p [keV]	$E_{\gamma,\mathrm{iso}}$ [erg]	Fluence ($1-10^4$ keV)	Spectral Type	Onset Delay	$E_{\max}$
080825C	-	22	192 ± 15	-	$4.84^{+0.59}_{-0.57} \times 10^{-5}$	BAND	Y	~ 600 MeV
080916C	4.35	66	1443^{+433}_{-303}	$5.7^{+0.54}_{-0.41} \times 10^{54}$	$1.55^{+0.15}_{-0.11} \times 10^{-4}$	BAND	Y	~ 13.2 GeV
081024B	-	0.8	1258^{+2405}_{-522}	-	$(1,61 \pm 3.8) \times 10^{-6}$	BAND	Y	~ 3 GeV
081215A	-	7.7	1014^{+140}_{-123}	-	$8.74^{+1.21}_{-0.99} \times 10^{-5}$	BAND	-	-
090217	-	32.8	552^{+85}_{-71}	-	$4.48^{+0.69}_{-0.56} \times 10^{-5}$	BAND	N	~ 1 GeV
090323	3.57	150	812^{+181}_{-143}	$> 2.89^{+6.56}_{-0.69} \times 10^{54}$	$> 1.07^{+0.24}_{-0.26} \times 10^{-5}$	BAND	N	~ 1 GeV
090328	0.736	80	756^{+85}_{-72}	$1.02^{+0.087}_{-0.083} \times 10^{53}$	$7.14^{+0.61}_{-0.58} \times 10^{-5}$	BAND	?	> 100 MeV
090510	0.903	0.3	6010^{+2524}_{-1690}	$4.47^{+4.06}_{-3.77} \times 10^{52}$	$2.06^{+1.88}_{-1.74} \times 10^{-5}$	CPL+PL	Y	~ 31 GeV
090626	-	70	362^{+47}_{-41}	-	$7.81^{+0.44}_{-0.38} \times 10^{-5}$	BAND	?	~ 30 GeV
090902B	1.822	21	207 ± 6 [BB]	$(1.77 \pm 0.01) \times 10^{52}$	$(2.10 \pm 0.02) \pm 10^{-4}$	BB+PL	Y	$33.4^{+2.7}_{-3.5}$ GeV
090926A	2.1062	~ 20	412 ± 20	$2.10^{+0.09}_{-0.08} \times 10^{54}$	$1.93^{+0.08}_{-0.07} \times 10^{-4}$	BAND	Y	$\sim$20 GeV
091003	0.8969	21.1	409^{+34}_{-31}	$7.85^{+0.73}_{-0.57} \times 10^{52}$	$3.68^{+0.34}_{-0.27} \times 10^{-5}$	BAND	N	> 150 MeV
091031	-	~ 40	567^{+197}_{-135}	-	$3.17^{+0.64}_{-0.51} \times 10^{-5}$	BAND	N	1.2 GeV
100116A	-	~ 110	1463^{+163}_{-122}	-	$7.34^{+1.42}_{-1.26} \times 10^{-5}$	BAND	N	~ 2.2 GeV
100225A	-	13 ± 3	540^{+381}_{-204}	-	$1.21^{+1.07}_{-0.57} \times 10^{-5}$	BAND	Y	~ 300 MeV
100325A	-	8.3 ± 1.9	198^{+44}_{-37}	-	$6.15^{+2.85}_{-1.81} \times 10^{-6}$	BAND	N	~ 800 MeV
100414A	1.368	26.4 ± 1.6	520^{+42}_{-39}	$5.88^{+0.69}_{-0.65} \times 10^{53}$	$1.20^{+0.12}_{-0.10} \times 10^{-5}$	BAND	N	~ 2.6 GeV

Two distinct types of GRBs

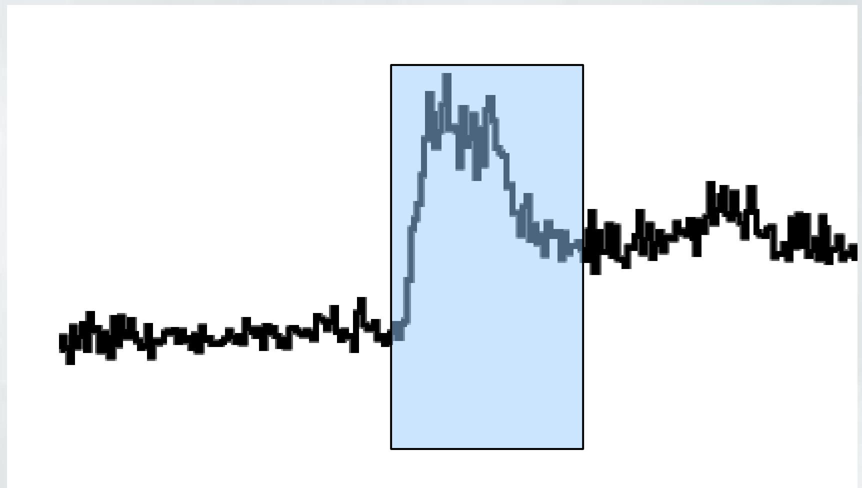


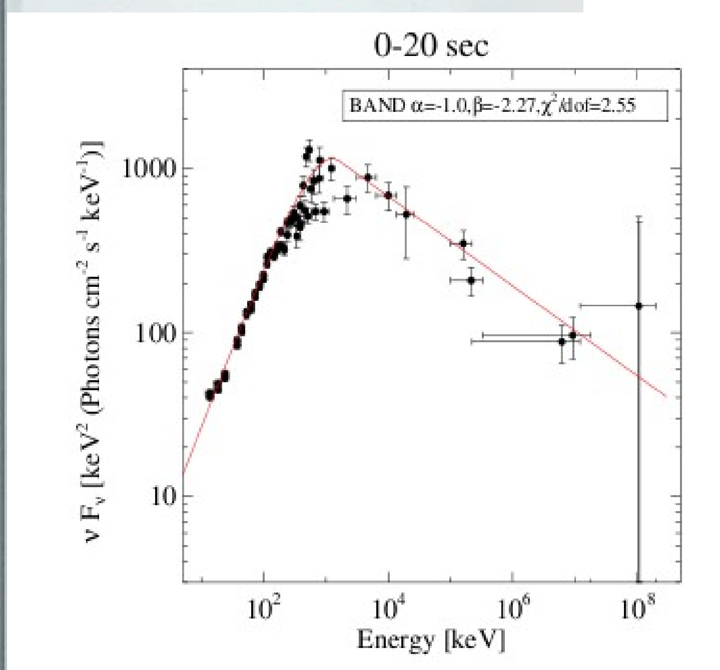
Two distinct types of GRBs



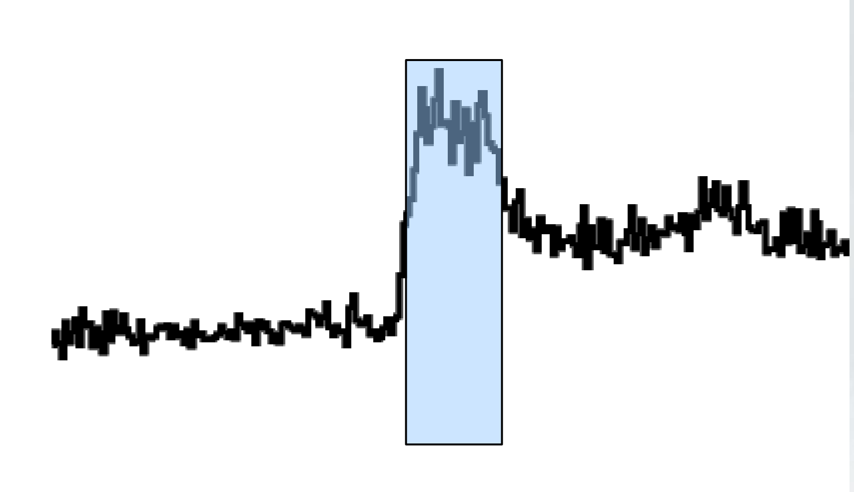
080916C:

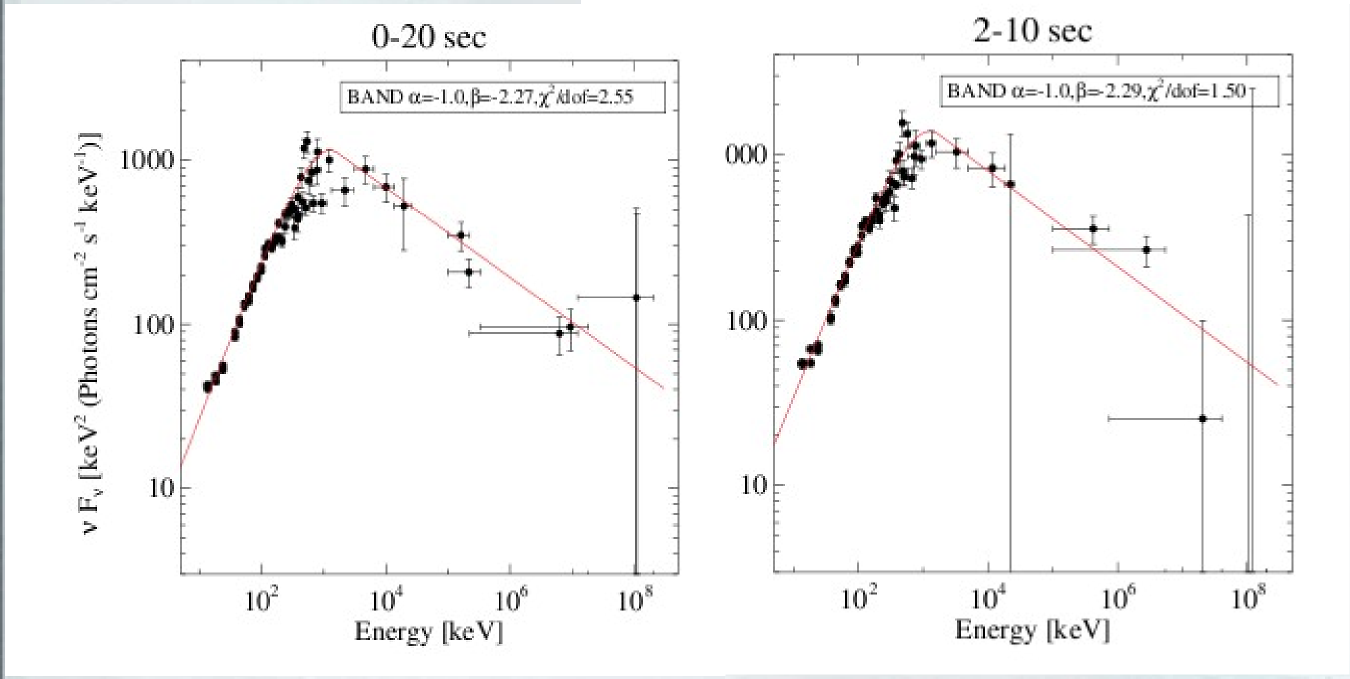
Band Function – Does NOT narrow with reducing time bins





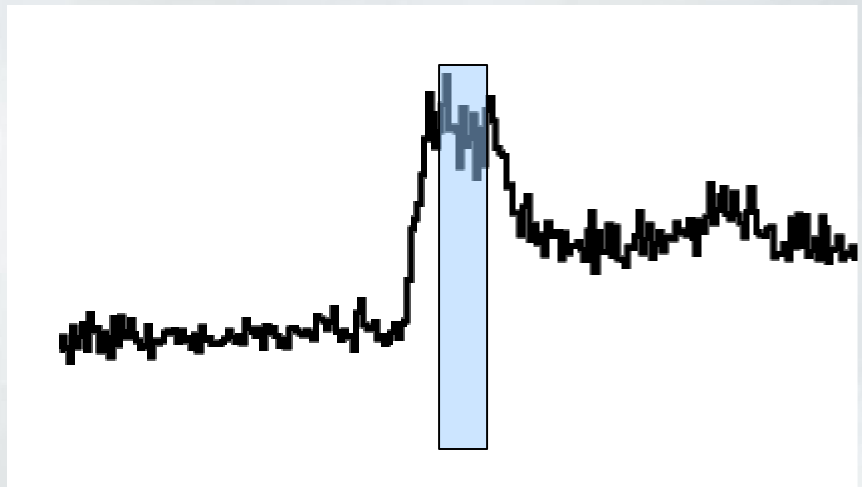
080916C

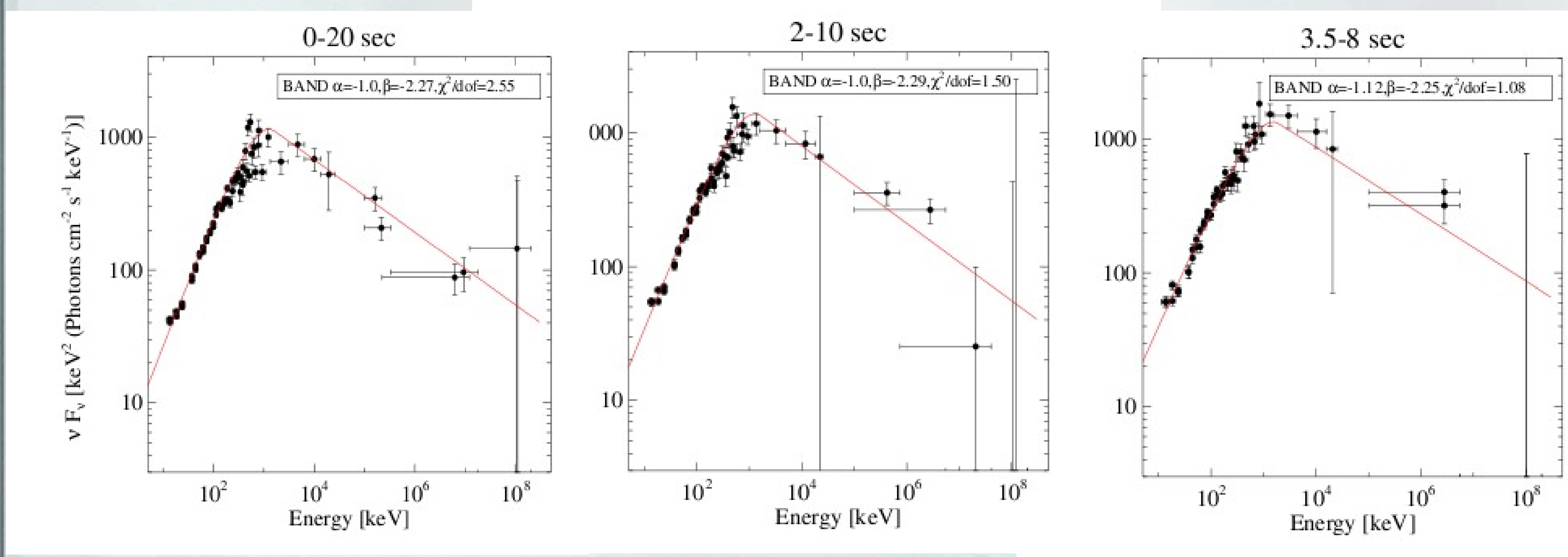




0-20 sec
BAND α=-1.0,β=-2.27,χ²/dof=2.55
ν F_ν [keV² (Photons cm⁻² s⁻¹ keV⁻¹)]
Energy [keV]
2-10 sec
BAND α=-1.0,β=-2.29,χ²/dof=1.50
Energy [keV]

080916C

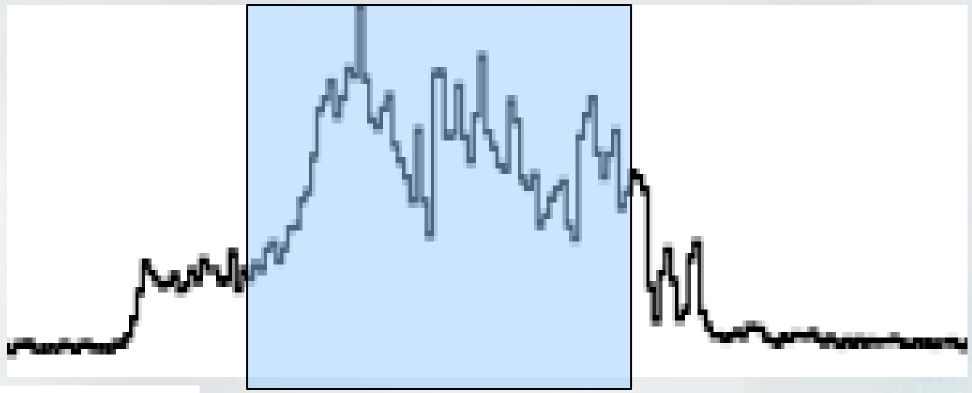


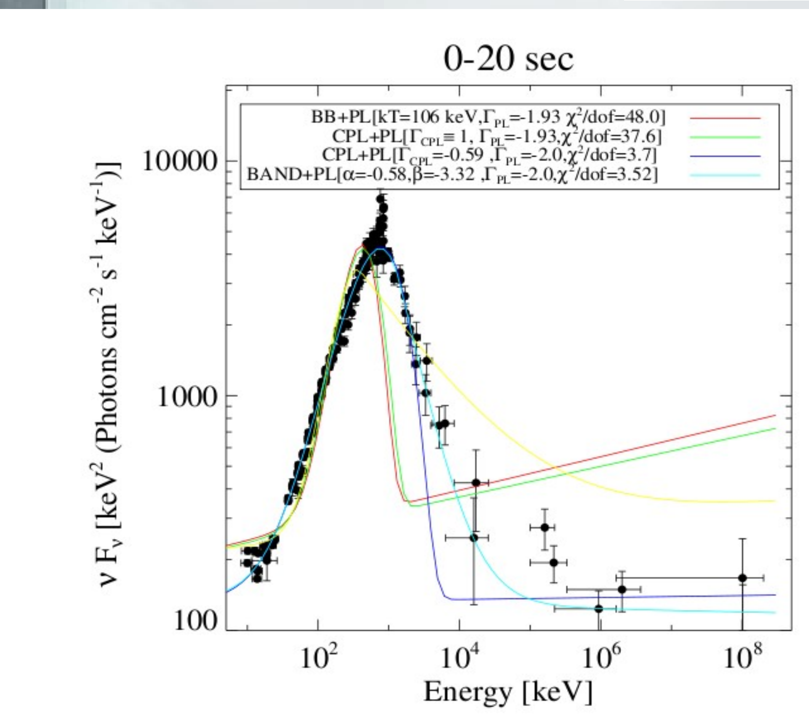


0-20 sec
BAND α=-1.0,β=-2.27,χ²/dof=2.55
ν F_ν [keV² (Photons cm⁻² s⁻¹ keV⁻¹)]
1000
100
10
10²
10⁴
10⁶
10⁸
Energy [keV]
2-10 sec
BAND α=-1.0,β=-2.29,χ²/dof=1.50
000
100
10
10²
10⁴
10⁶
10⁸
Energy [keV]
3.5-8 sec
BAND α=-1.12,β=-2.25,χ²/dof=1.08
1000
100
10
10²
10⁴
10⁶
10⁸
Energy [keV]

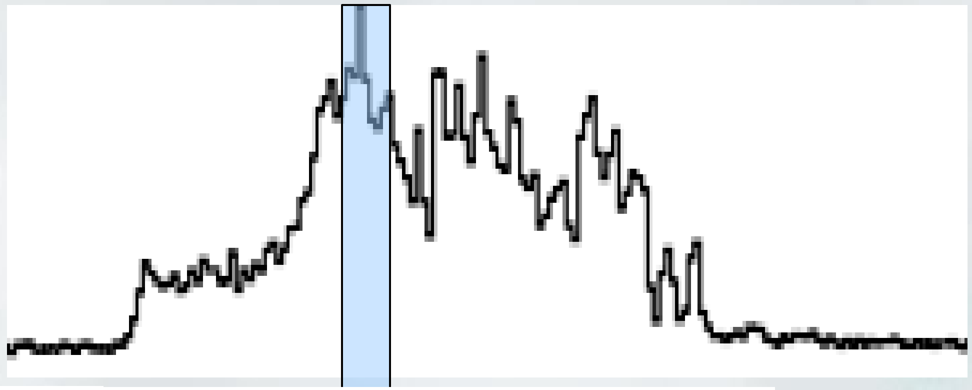
090902B

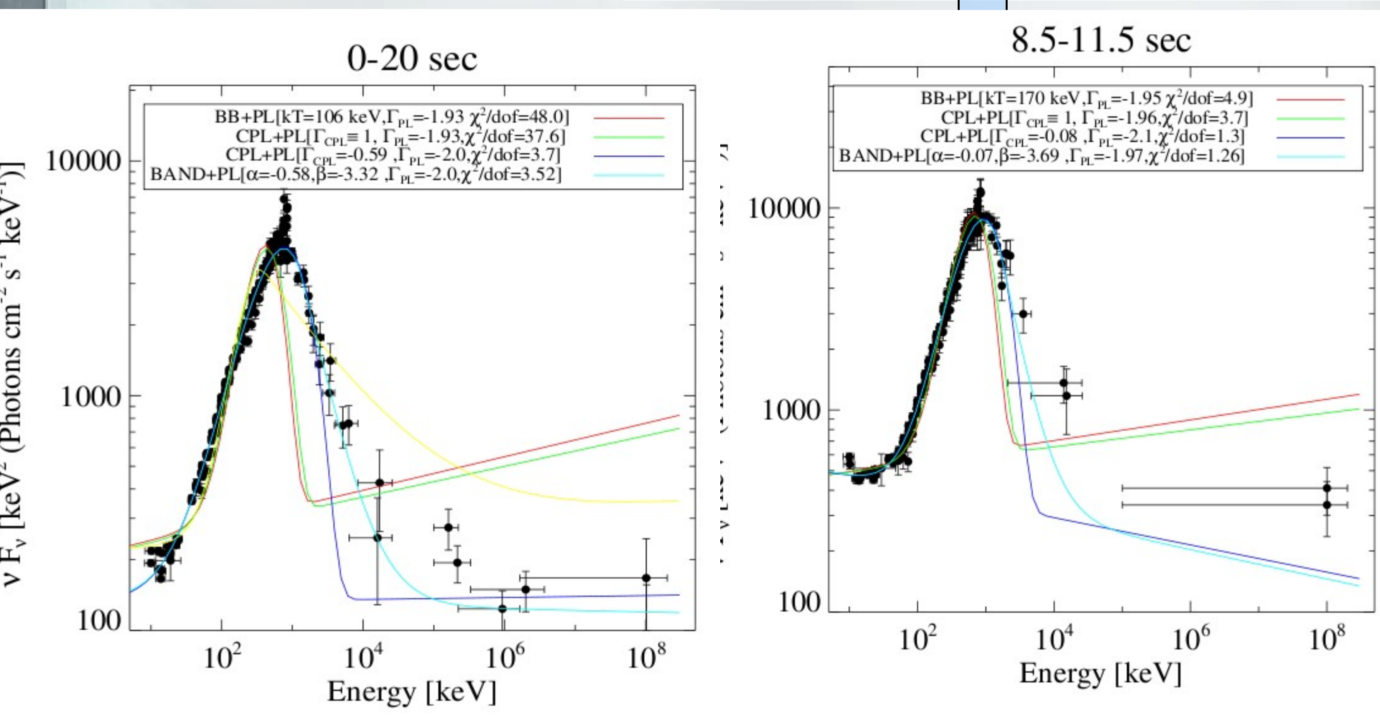
Thermal : progressively narrowing with reducing time bins and extra PL



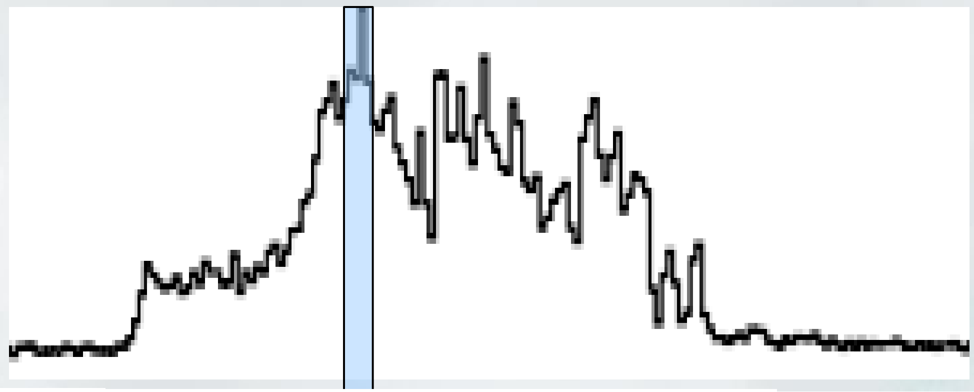


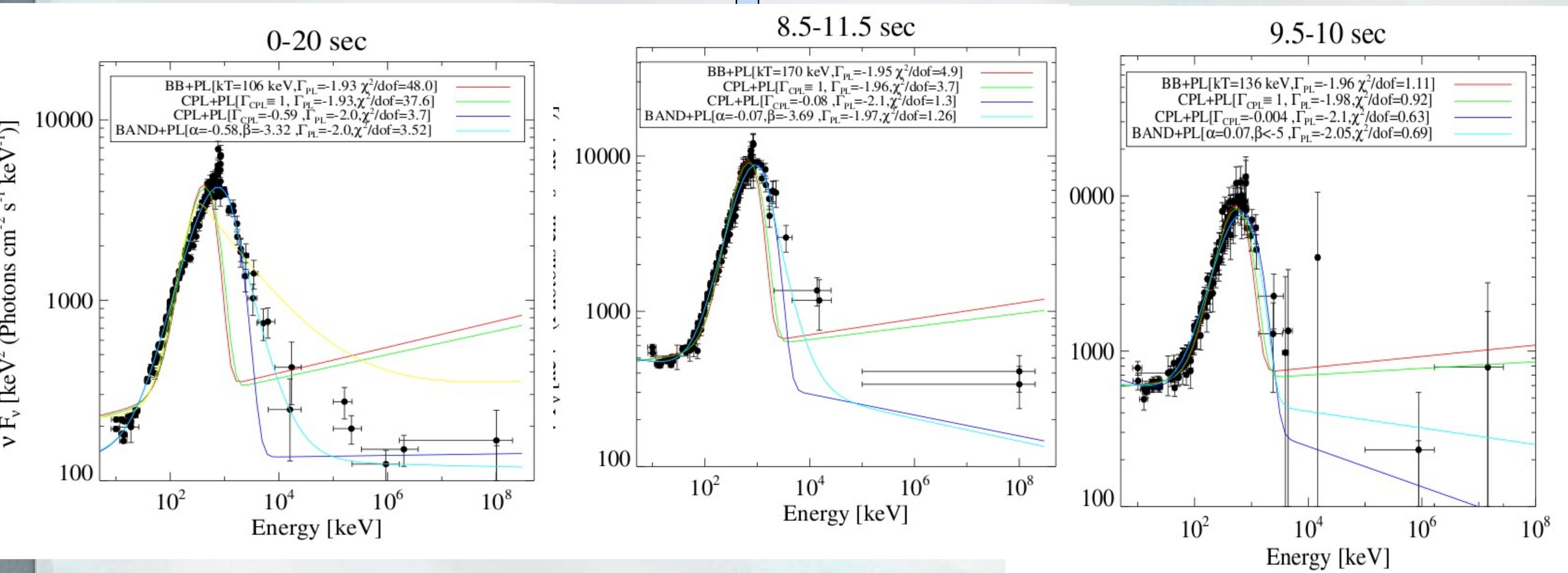
090902B




0-20 sec
BB+PL[kT=106 keV,Γ_PL=-1.93 χ²/dof=48.0]
CPL+PL[Γ_CPL≡ 1, Γ_PL=-1.93,χ²/dof=37.6]
CPL+PL[Γ_CPL=-0.59 ,Γ_PL=-2.0,χ²/dof=3.7]
BAND+PL[α=-0.58,β=-3.32 ,Γ_PL=-2.0,χ²/dof=3.52]
ν F_ν [keV² (Photons cm⁻² s⁻¹ keV⁻¹)]
10000
1000
100
10²
10⁴
10⁶
10⁸
Energy [keV]
8.5-11.5 sec
BB+PL[kT=170 keV ,Γ_PL=-1.95 χ²/dof=4.9]
CPL+PL[Γ_CPL≡ 1, Γ_PL=-1.96,χ²/dof=3.7]
CPL+PL[Γ_CPL=-0.08 ,Γ_PL=-2.1,χ²/dof=1.3]
BAND+PL[α=-0.07,β=-3.69 ,Γ_PL=-1.97,χ²/dof=1.26]
10000
1000
100
10²
10⁴
10⁶
10⁸
Energy [keV]

090902B




0-20 sec
BB+PL[kT=106 keV,Γ_PL=-1.93 χ²/dof=48.0]
CPL+PL[Γ_CPL≡ 1, Γ_PL=-1.93,χ²/dof=37.6]
CPL+PL[Γ_CPL=-0.59 ,Γ_PL=-2.0,χ²/dof=3.7]
BAND+PL[α=-0.58,β=-3.32 ,Γ_PL=-2.0,χ²/dof=3.52]
ν F_ν [keV² (Photons cm⁻² s⁻¹ keV⁻¹)]
Energy [keV]
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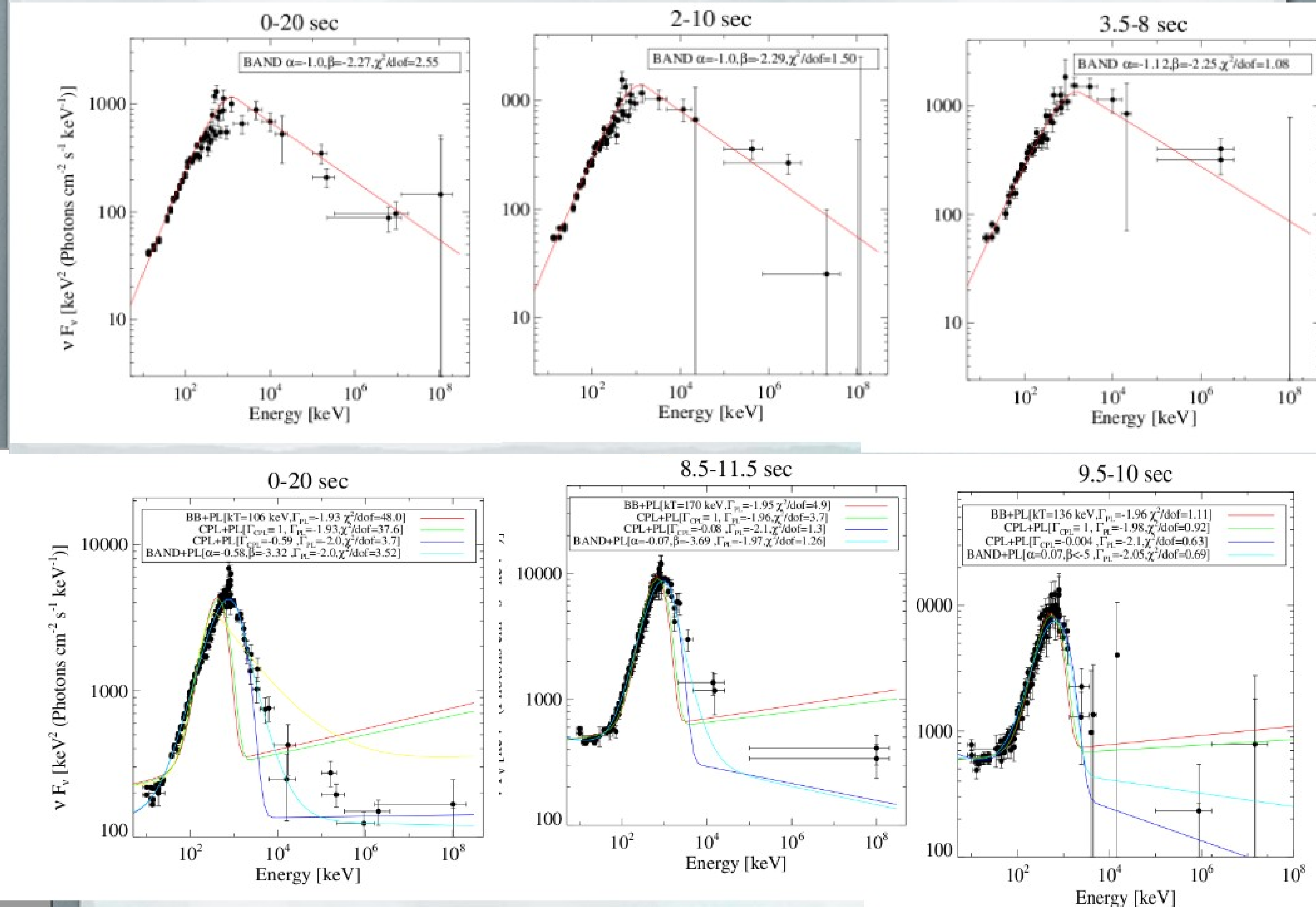
BAND+PL[α=-0.07,β=-3.69 ,Γ_PL=-1.97,χ²/dof=1.26]
Energy [keV]
9.5-10 sec
BB+PL[kT=136 keV,Γ_PL=-1.96 χ²/dof=1.11]
CPL+PL[Γ_CPL≡ 1, Γ_PL=-1.98,χ²/dof=0.92]
CPL+PL[Γ_CPL=-0.004 ,Γ_PL=-2.1,χ²/dof=0.63]
BAND+PL[α=0.07,β<-5 ,Γ_PL=-2.05,χ²/dof=0.69]
Energy [keV]



0-20 sec
BAND α=-1.0,β=-2.27,χ²/dof=2.55
2-10 sec
BAND α=-1.0,β=-2.29,χ²/dof=1.50
3.5-8 sec
BAND α=-1.12,β=-2.25,χ²/dof=1.08
ν Fν [keV² (Photons cm⁻² s⁻¹ keV⁻¹)]
Energy [keV]
0-20 sec
BB+PL[kT=106 keV,Γ_PL=-1.93 χ²/dof=48.0]
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8.5-11.5 sec
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9.5-10 sec
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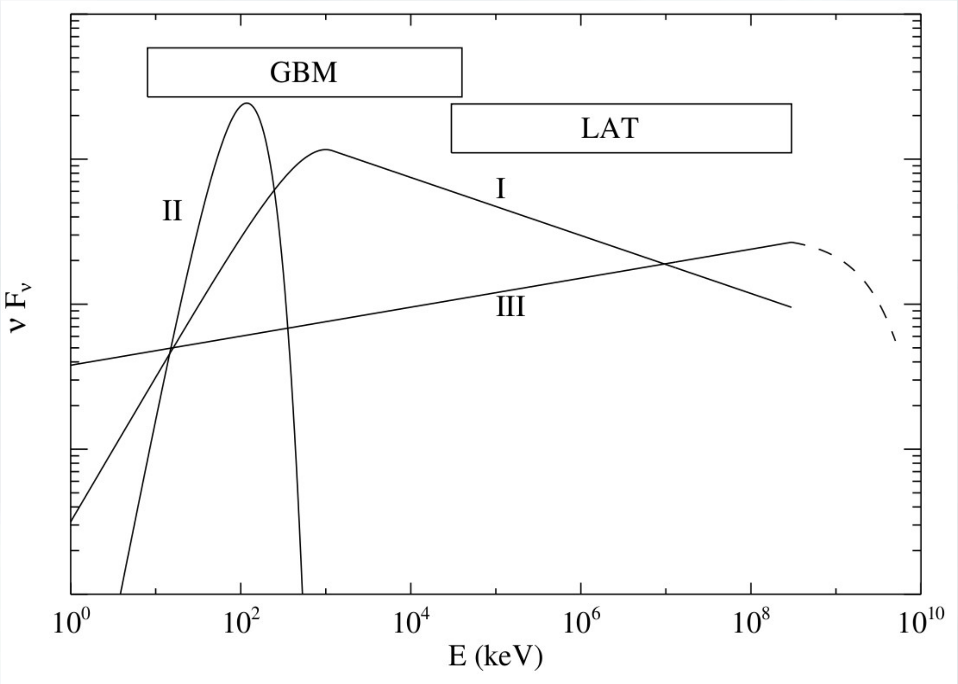
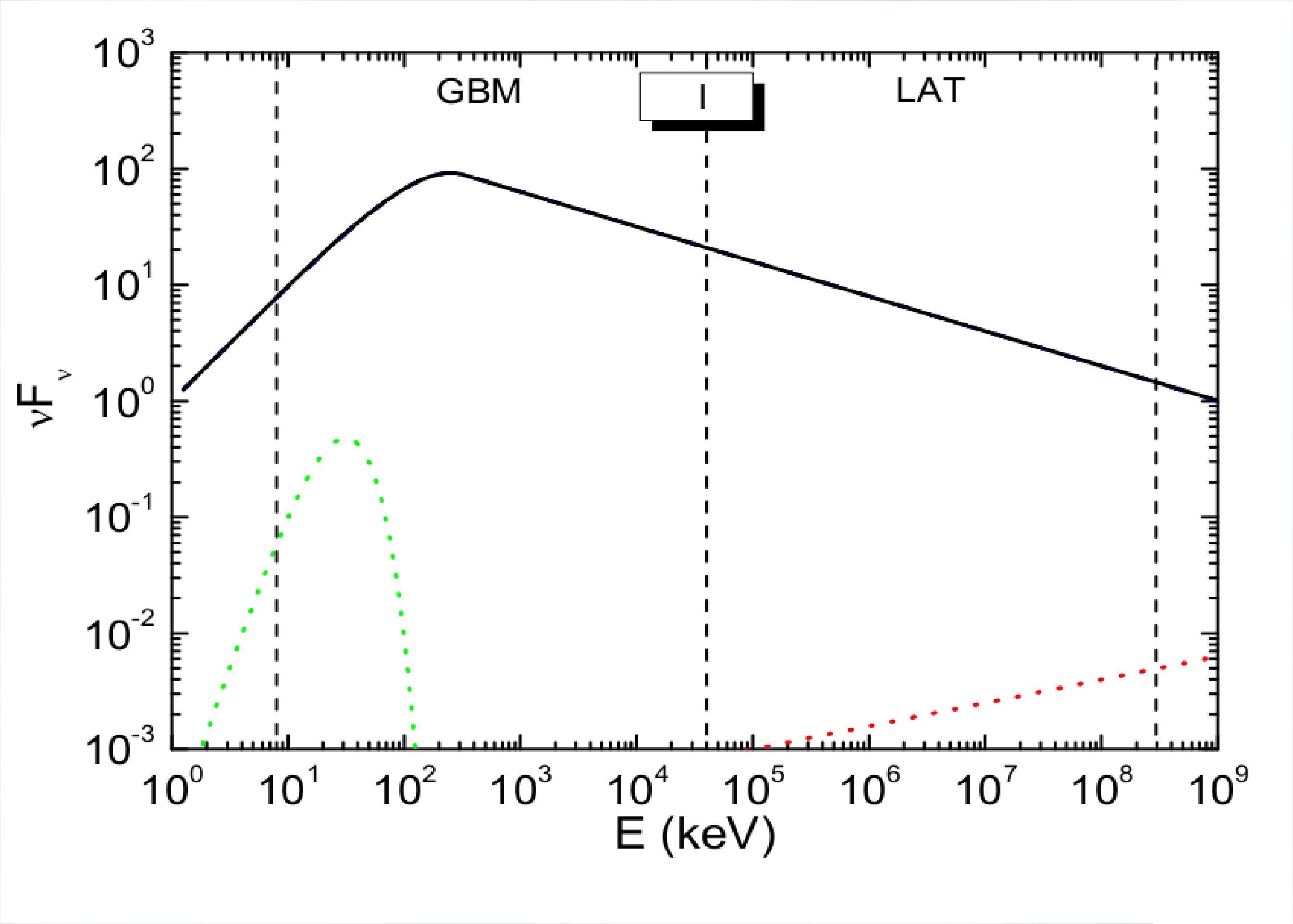
CPL+PL[Γ_CPL=-0.004 ,Γ_PL=-2.1,χ²/dof=0.63]
BAND+PL[α=0.07,β<-5 ,Γ_PL=-2.05,χ²/dof=0.69]

Three Elemental Spectral Components (Phenomenally, observationally)

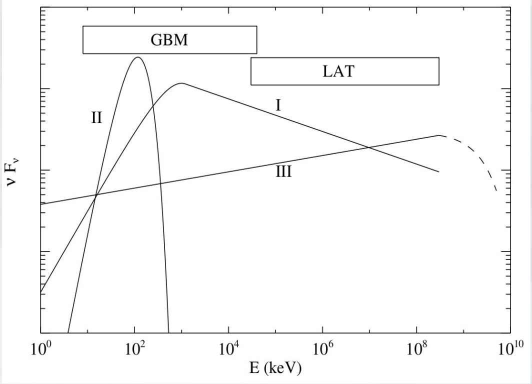
- I : Band-function component (extend up to GeV)
- II: Quasi-thermal Component
- III: extra non-thermal power law component extending to high energies.

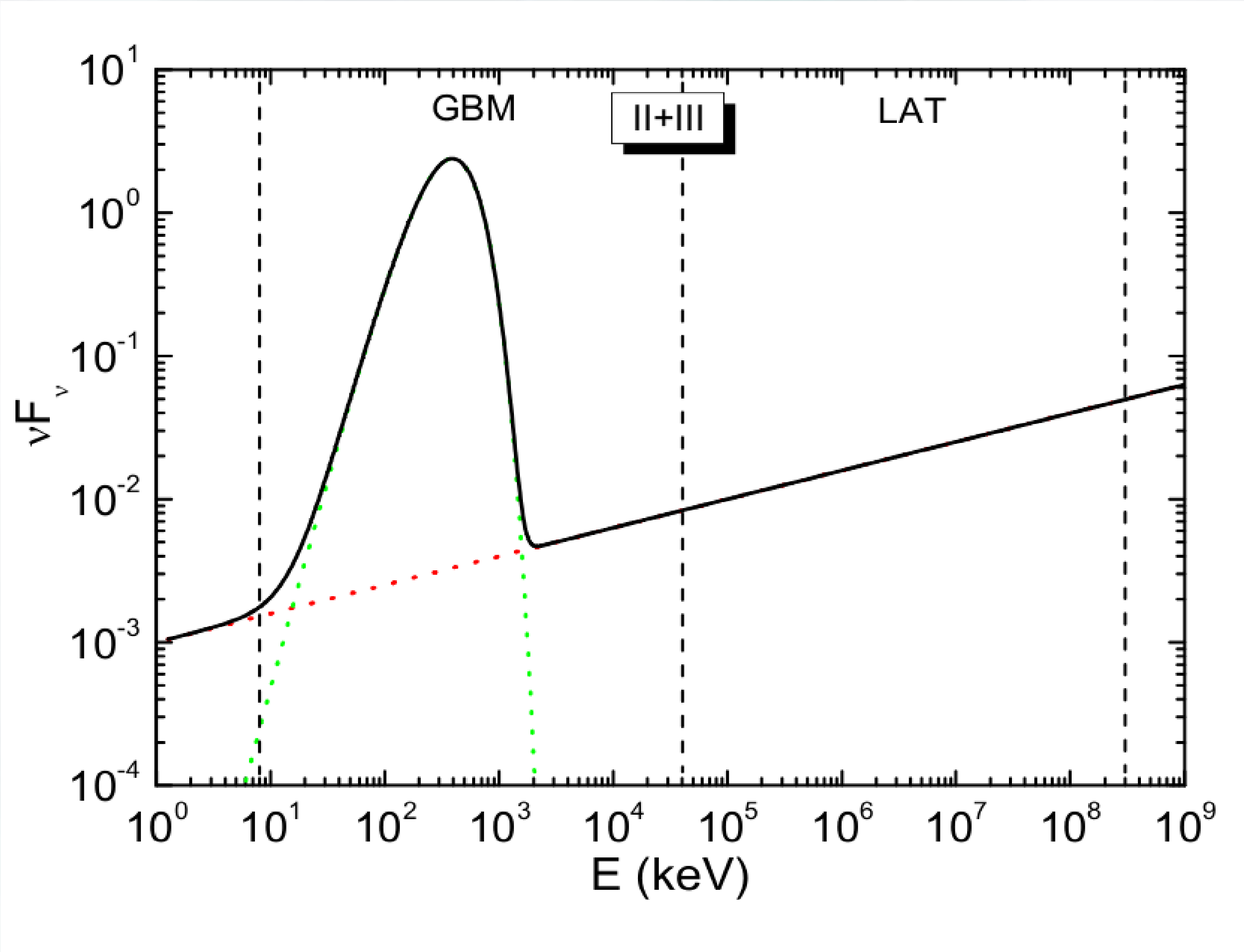


Observed spectra are combinations of the three.

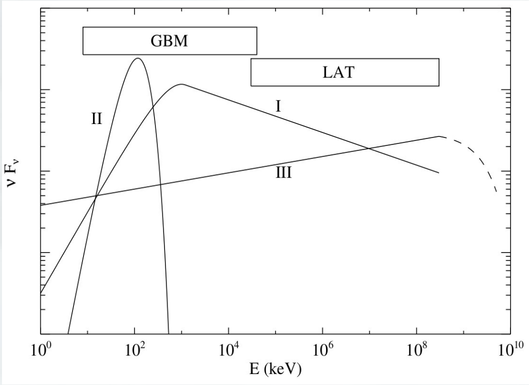


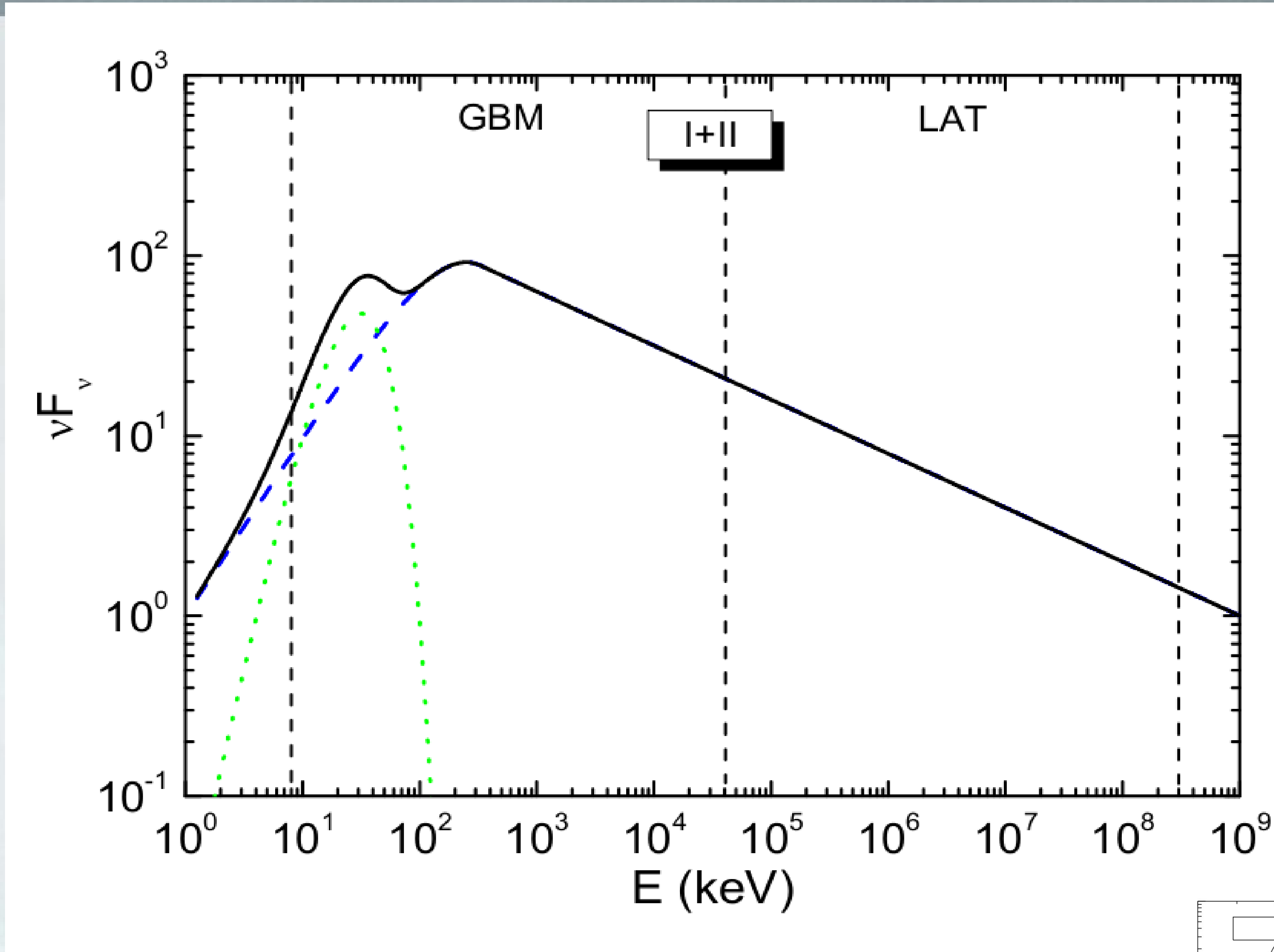
- E.g 080916C, 14 out of 17

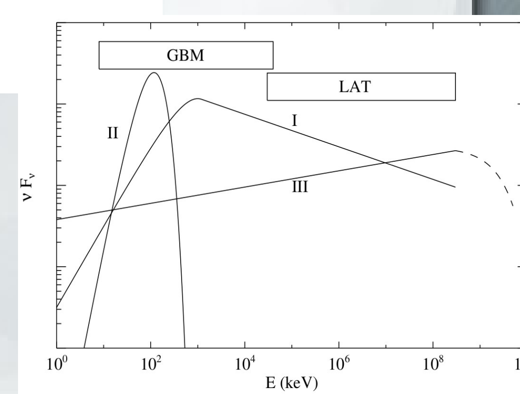




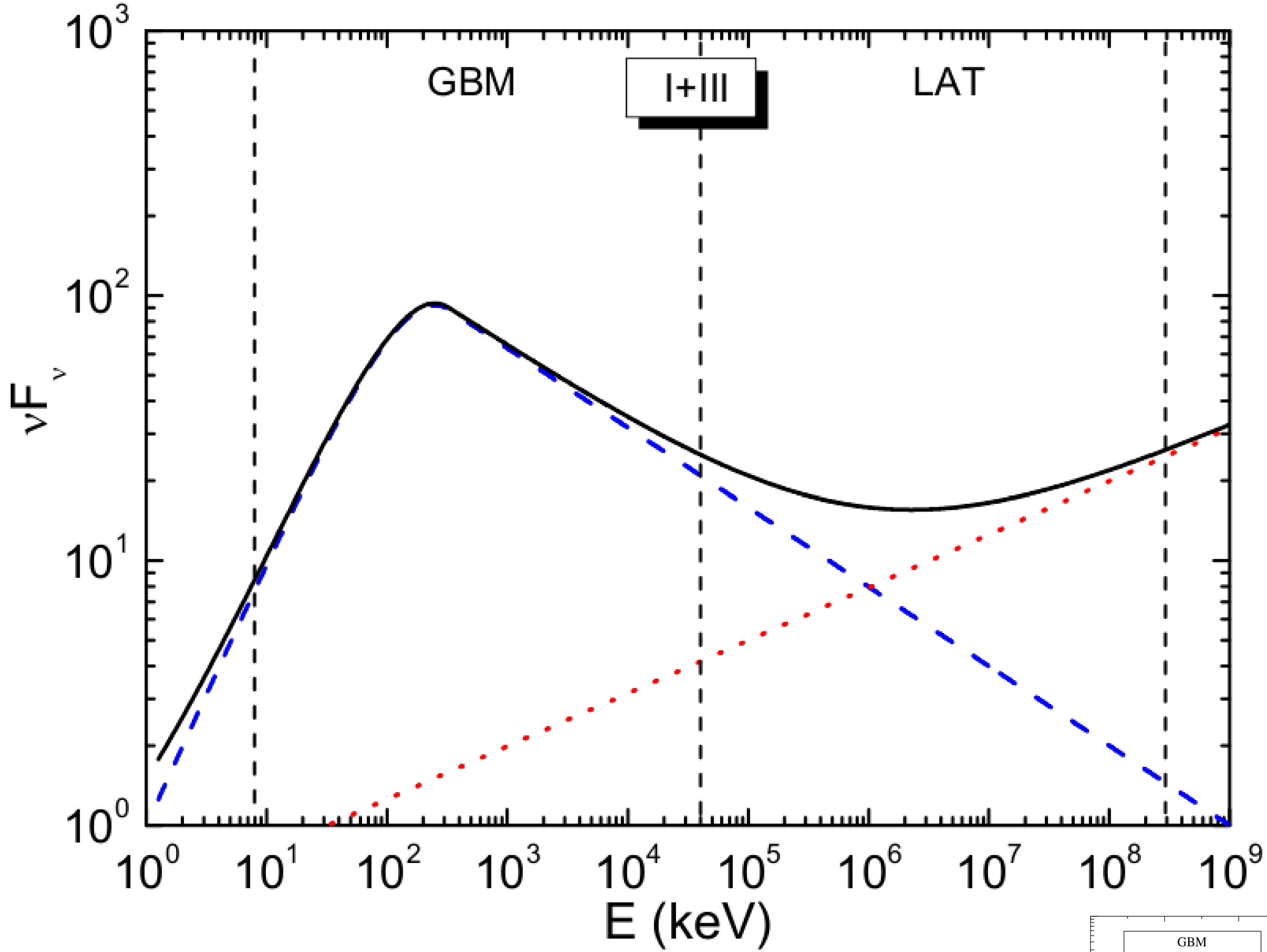
- 090902B , probably 090510

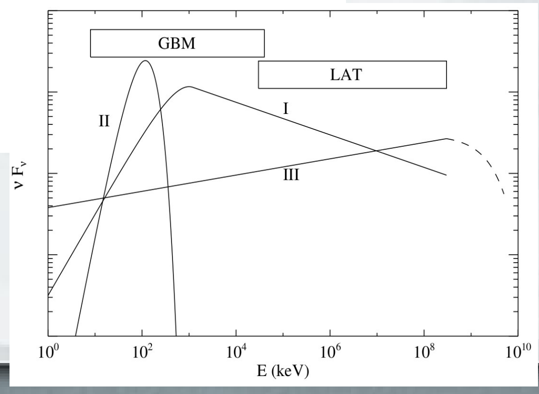


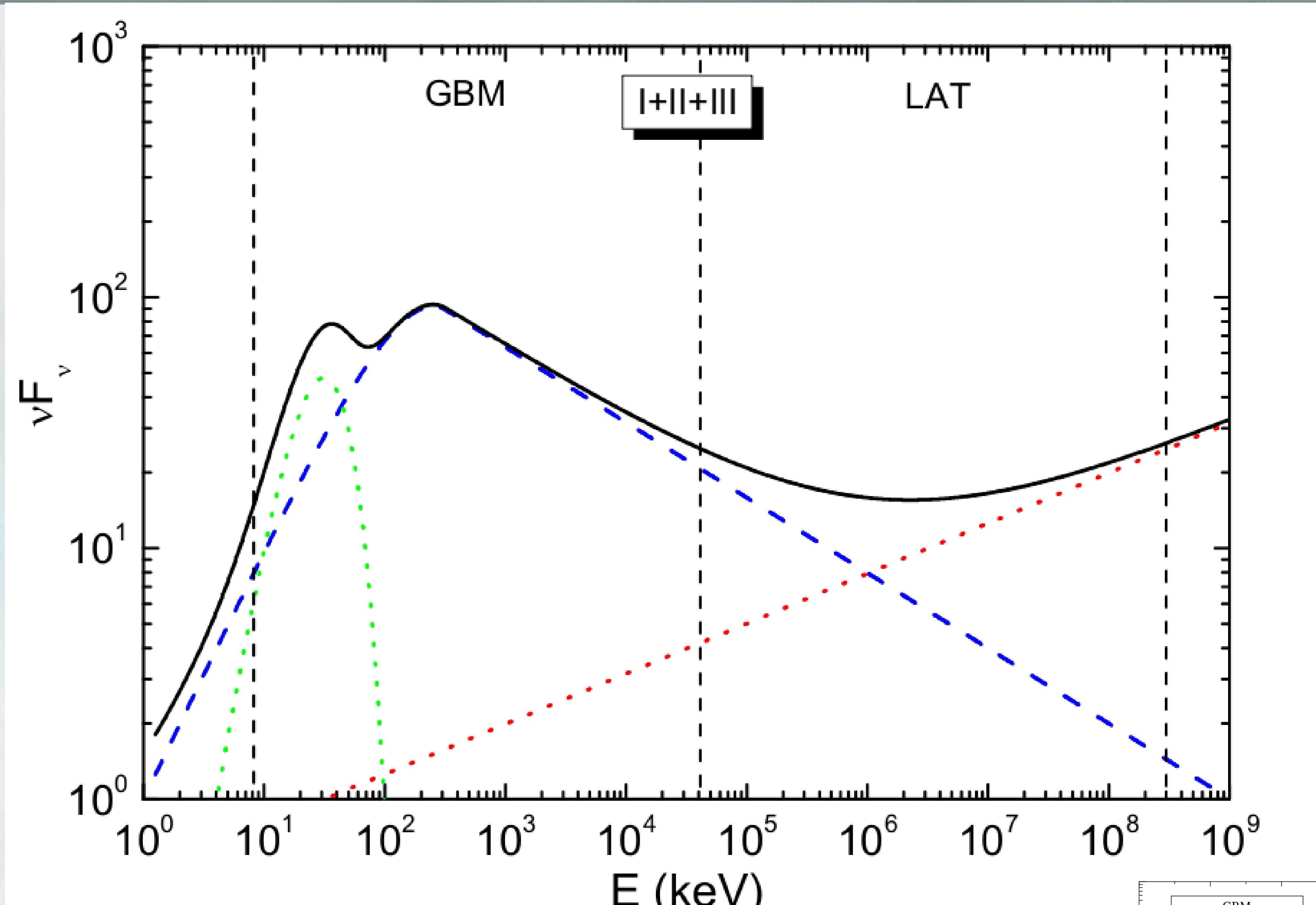


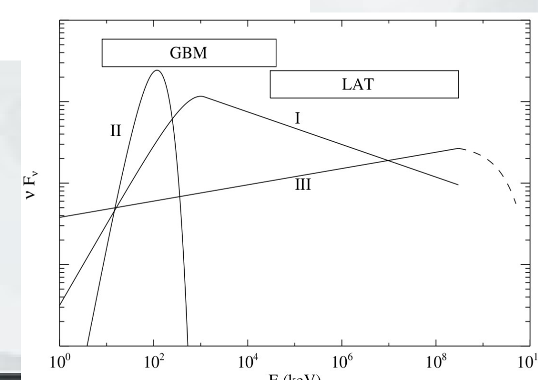


- X-Ray Excess
- 100724B , 38KeV, Sylvain Guiriec et al 2010
- 081221, 8keV, Shu-Jin Hou, 2010 , in prep

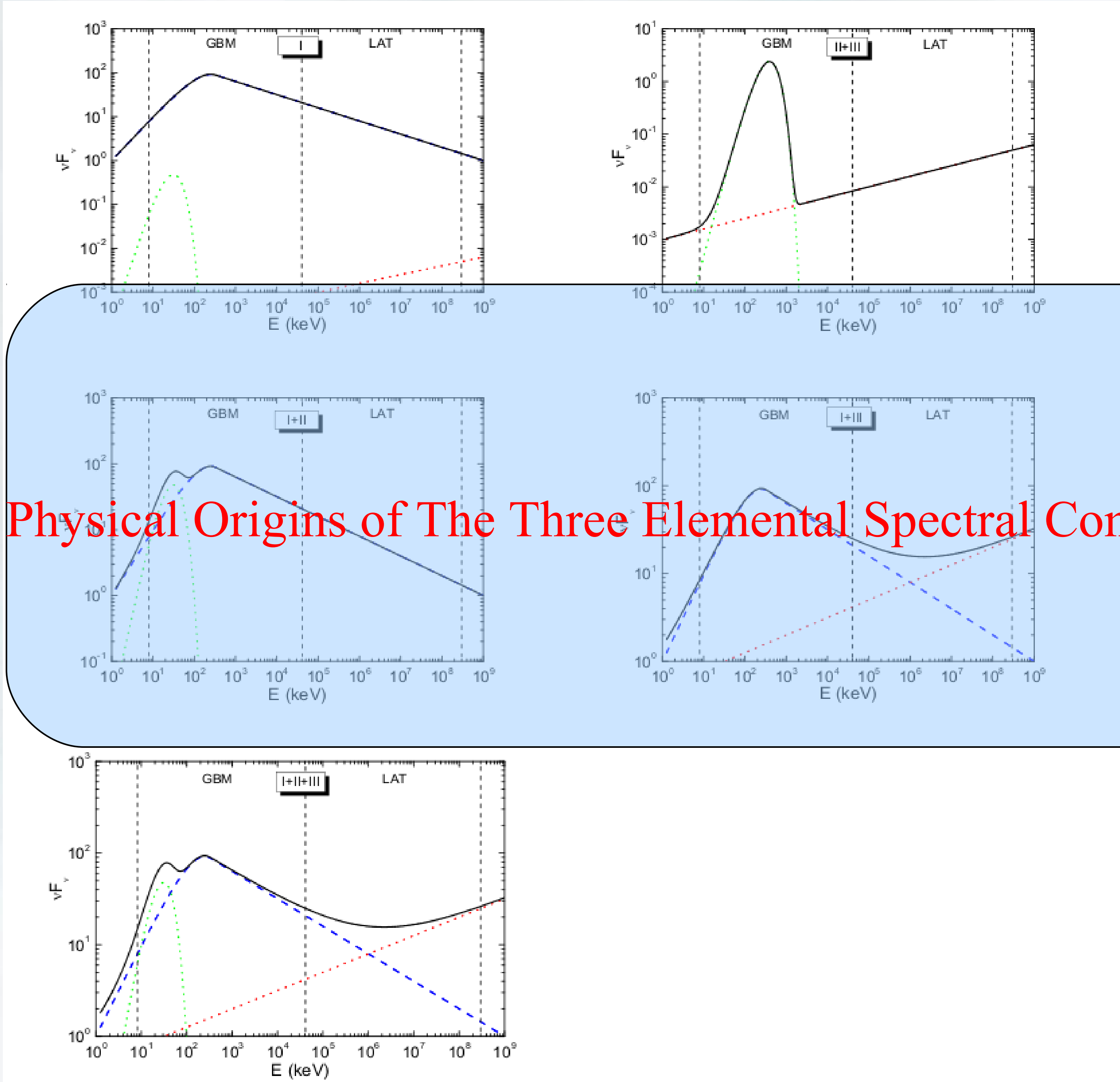

GBM
I+III
LAT
νF ν
E (keV)


GBM
LAT
I
II
III
ν F ν
E (keV)


GBM
I+II+III
LAT
νF ν
E (keV)
10^3
10^2
10^1
10^0
10^0 10^1 10^2 10^3 10^4 10^5 10^6 10^7 10^8 10^9


GBM
LAT
II
I
III
ν F ν
E (keV)
10^0 10^2 10^4 10^6 10^8 10^10

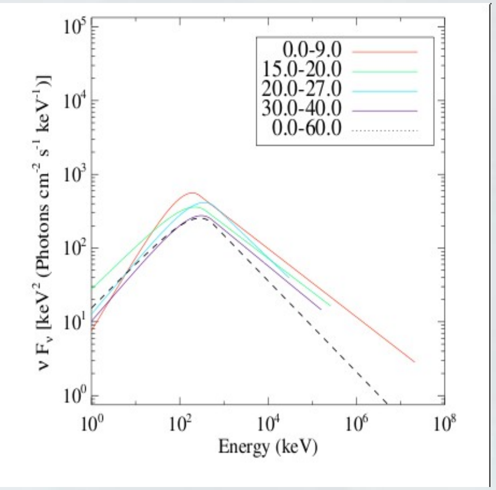
Physical Origins of The Three Elemental Spectral Components



Band Function Component

Poynting flux dominated outflow

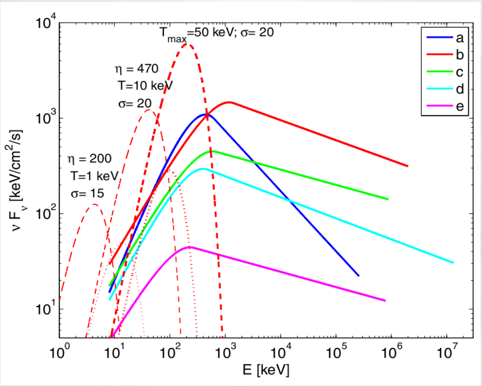
•14 out 17 bursts are fitted by Band
•Internal Non-thermal Emission
•Time-dependent Band Function in Finest time resolution
– NO photosphere thermal component
– NO second SSC bump
– NO pair-production cutoff



– 6-7 orders extension

See Bing Zhang's talk this afternoon .

Zhang & Pe'er 2009



[most energy carried in B filed , not in photons, photosphere emission is suppressed
– Compton parameter Y<<1 (because B energy density >> photon energy density, Y=U_ph/U_B<<1),so SSC suppressed (L_ssc~YL_syn)
- Poynting flux : larger emission radius reduce 2-photon annihilation opacity and increase the pair cutoff energy]

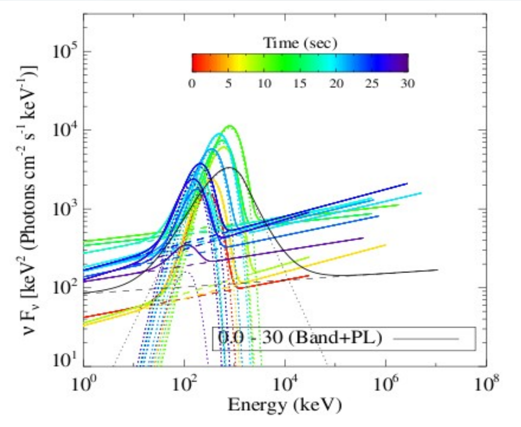
Quasi-Thermal Component

Thermal Emission from Fireball Photosphere

(Paczynski 86, Goodman 86, Pe'er 2006, Pe'er & Ryde 2010 , see talks by Pe'er, Lazzati, Beloborodov,Toma)

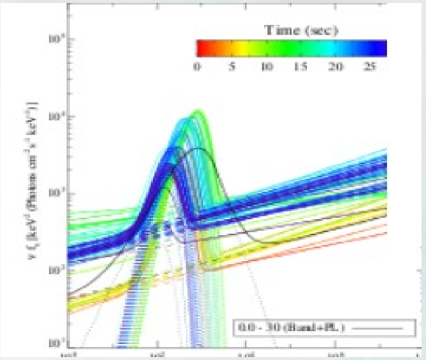
Photosphere emission when relativistic outflow turn optically thin

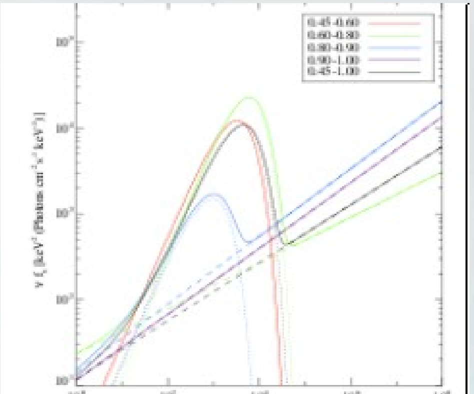
- Why “Quasi”: modified by
  1) temporal smear
  multicolor-BB (Ryde et al 2010)
  2) high-latitude emission effect
  gives \alpha=-1 (Pe'er & Ryde 2010)



Extra Simple Power law component

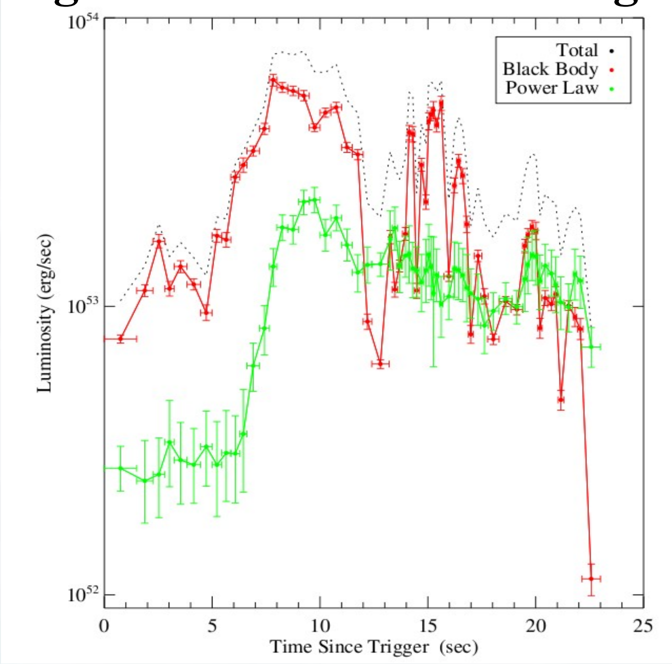
Not Straightforward





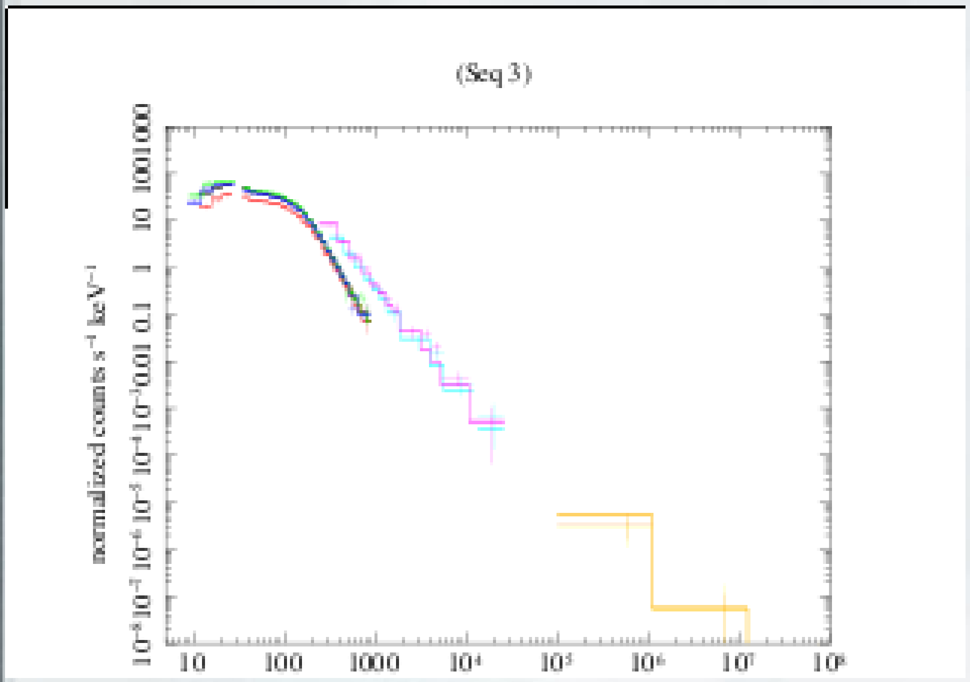
•Tracking of thermal and non-thermal suggests that they might be from the same origin

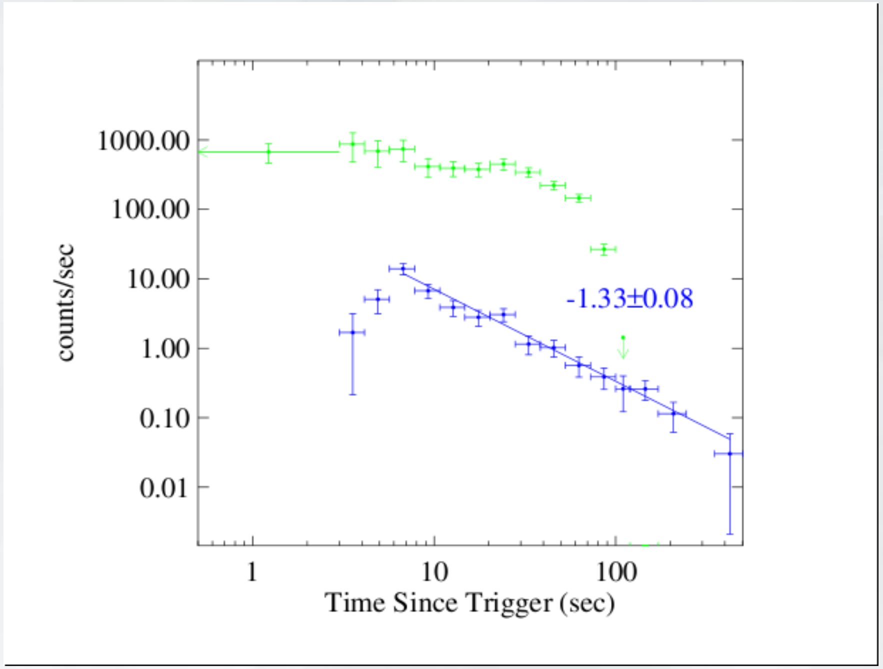
- Accompany with BB, or Band
- Extended to GeV, also existed in low energies
- NOT straightforward to expected since theoretically non-thermal GRB spectra should be curved (Pe'er et al 2006, Gupta & Zhang 2007, Asano & Terasawa 2009)
- For 090902B, it might be a combination of Syn emission (low energy dominated) and SSC and Comptonization of thermal photons (Pe'er 2010)
-



Origin of GeV Emission

A Dilemma





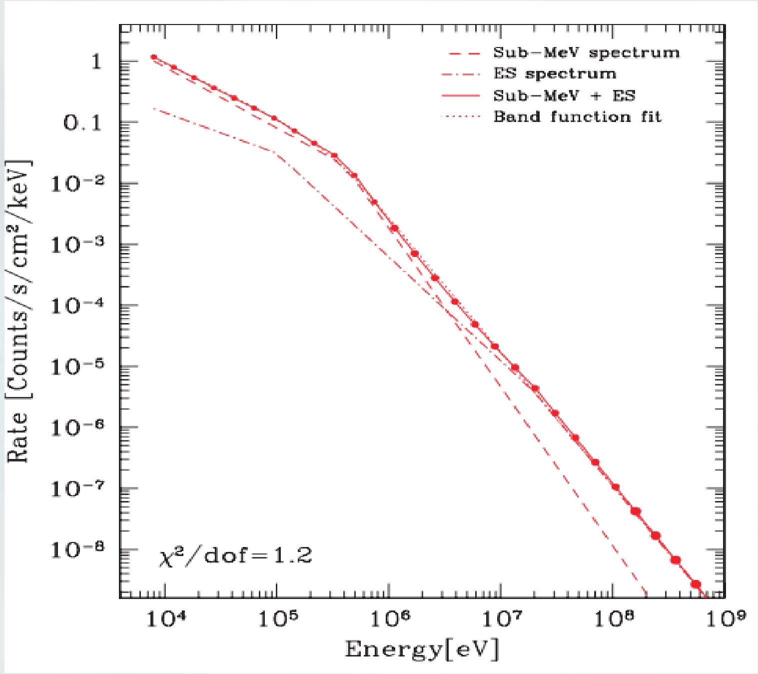
In spectral domain, one single component

In light curve domain, different components

How to solve the dilemma?

Solution 1:

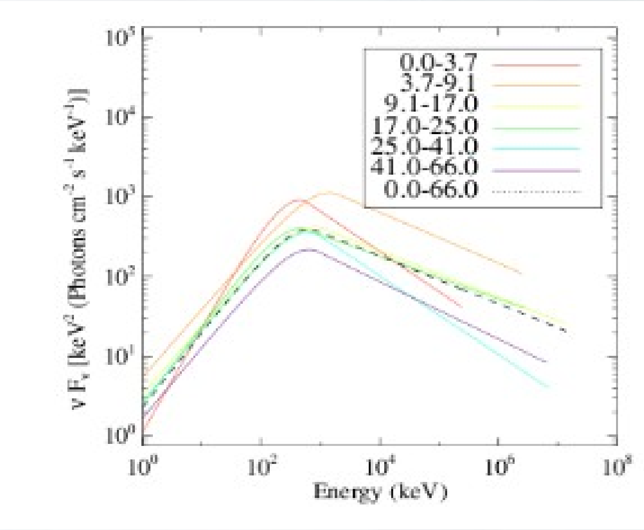
Superposition in Spectrum



Kumar, & Barniol Duran, 2010.

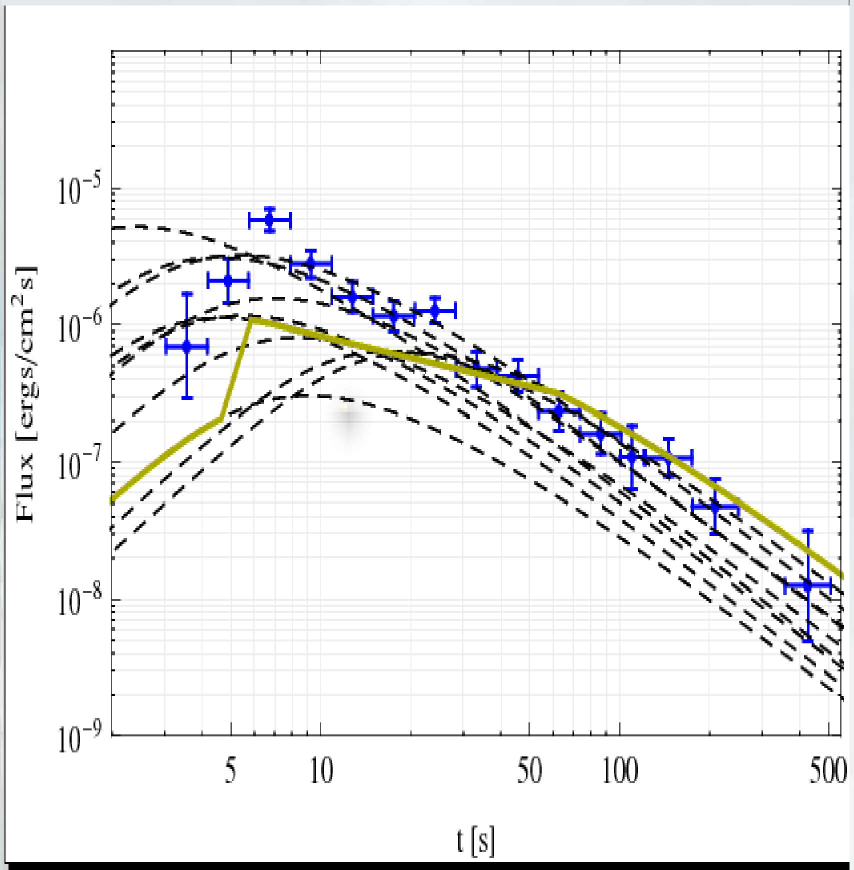
A Big Issue:

Since observation shows Band function in every time slice.
---> have to assume superpositions of external and internal components in each time slice to “make” a Band function



A Dilemma of Superpositions

Superposition in Spectrum



Plus, our simulation shows that the external shock can NOT reproduce a so steep light curve during the prompt emission phase

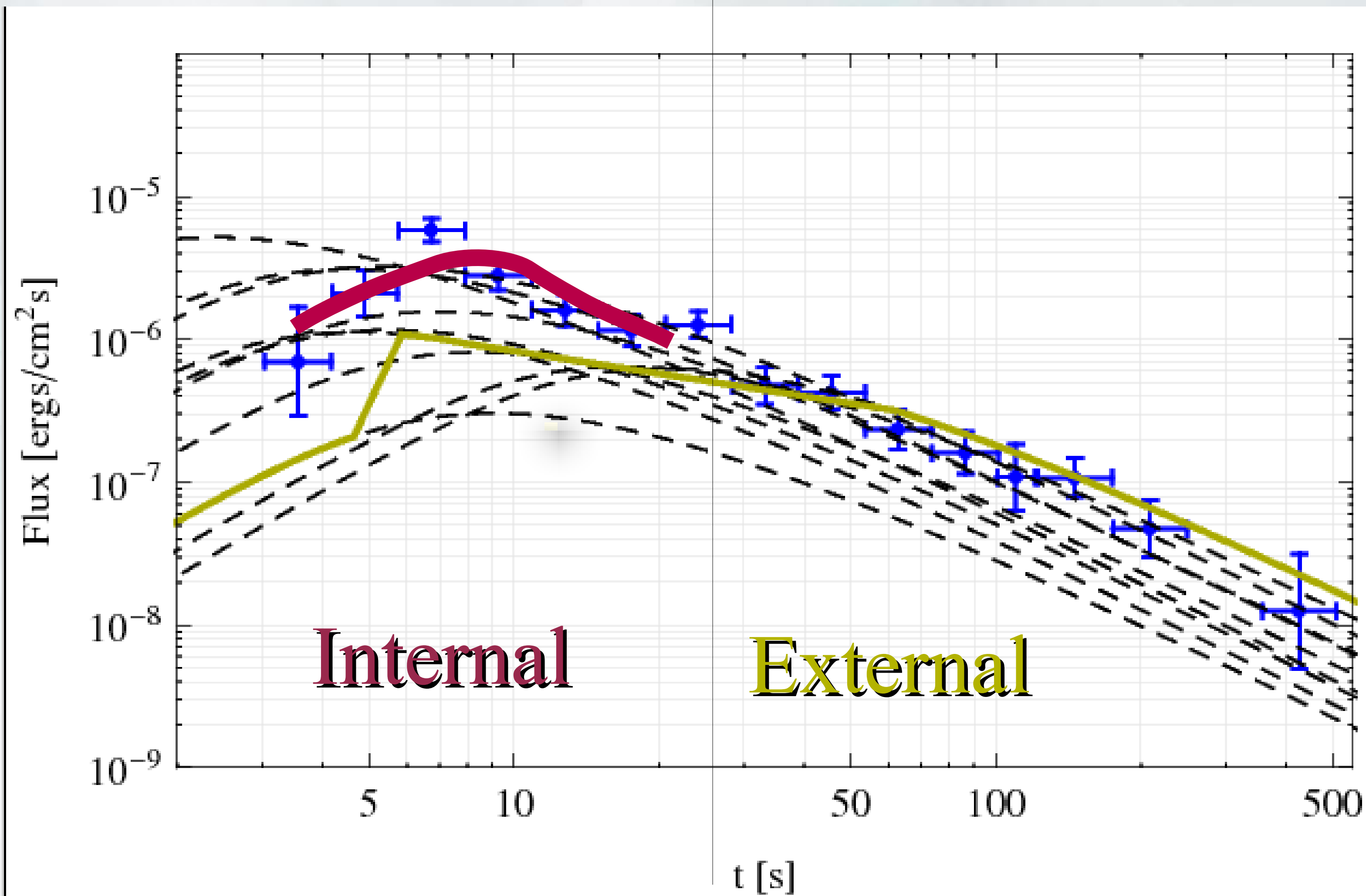
(Amanda Maxham, Bin-Bin Zhang And Bing Zhang , 2010, in prep

see Amanda Maxham's Poster 4.03 for details

Solution 2

Superposition in Light Curve

Alternatively, we propose the Long Term GeV Light Curve is the Superposition effect of internal and external components



Further Evidence for Internal Origin of Prompt GeV

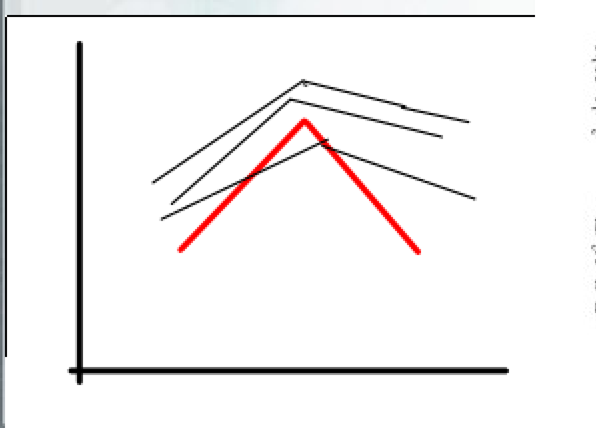
- Rough Tracking Light Curve btw GBM and LAT
- For 080916C, GeV peak Coincides the Second Peak of GBM light Curve
-

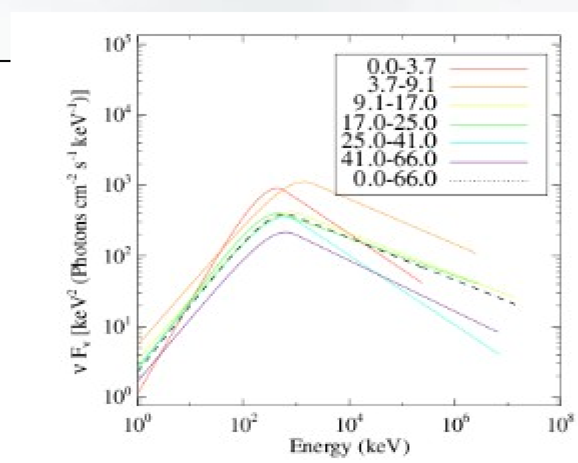
If Prompt GeV emission is internal , how to interpret the onset delay?

Possibility 1:

Change of particle acceleration Mechanism

Early on , the particle acceleration process may not be so efficient , so the electron energy spectral index is steep





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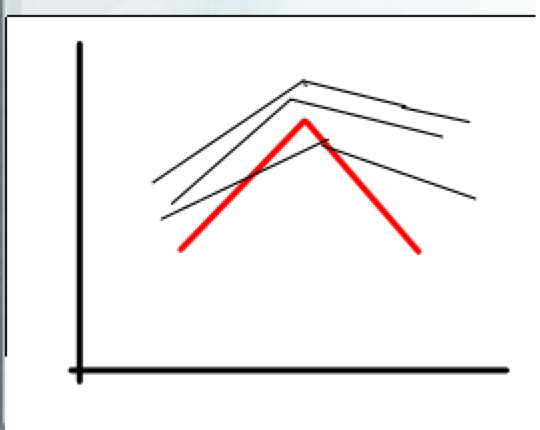
Early on , the particle acceleration process may not be so efficient , so the electron energy spectral index is steep

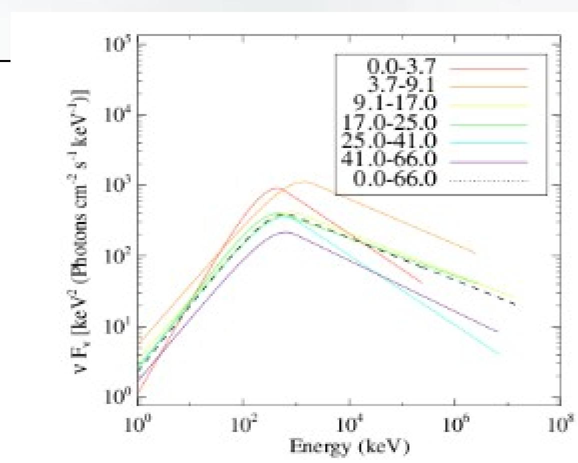
Possibility 2:

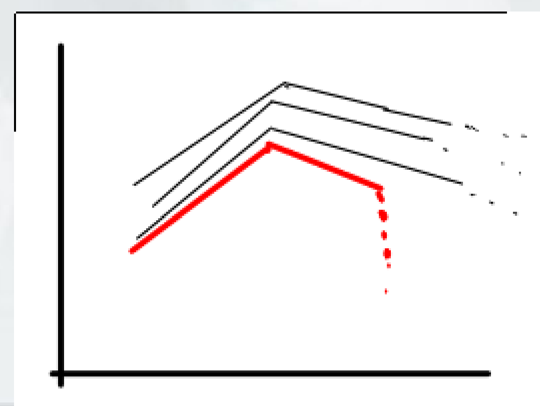
Change of Opacity

particle acceleration proces is the same, the pair-production opacity changes early on.

(supporting evidence: GBM alone spectra give similar beta with later epochs)

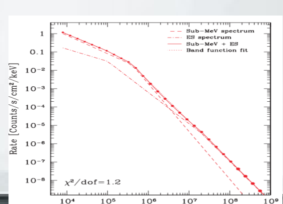






Prompt GeV emission is likely of internal origin

	Band Extended To GeV	Delay onset of LAT emission	Rough tracking behavior	Long Term Emission in LAT Band	For 080916C, GeV peak Coincides the Second Peak of GBM light Curve
Internal	✓	•up-scattered cocoon emission by IS (Toma+09) •protons Sync (Razzaque+09) •up-scattered cocoon emission by residual IS (Li 2009) •Change of Acceleration Condition •Change of Opa… ✓	✓	•superposition effect of IS and ES Light Curve Slope : require same decay slope at the transition epoch [contrived] •gradual die-off of the central engine activity ✓	✓
External	• Spectrum Slope: require IS and ES spectra mimic a same BAND function in ALL the Time Bins (Kumar & Barniol Buran 2009) [MORE contrived]	✓	✗	(but can not be that steep, during PE Amanda Maxham poster 4.03) ✓	ES Deceleration time = 2[nd] central engine activity time ← Fine Tuned Bulk Lorentz Factor --Highly contrived ✗



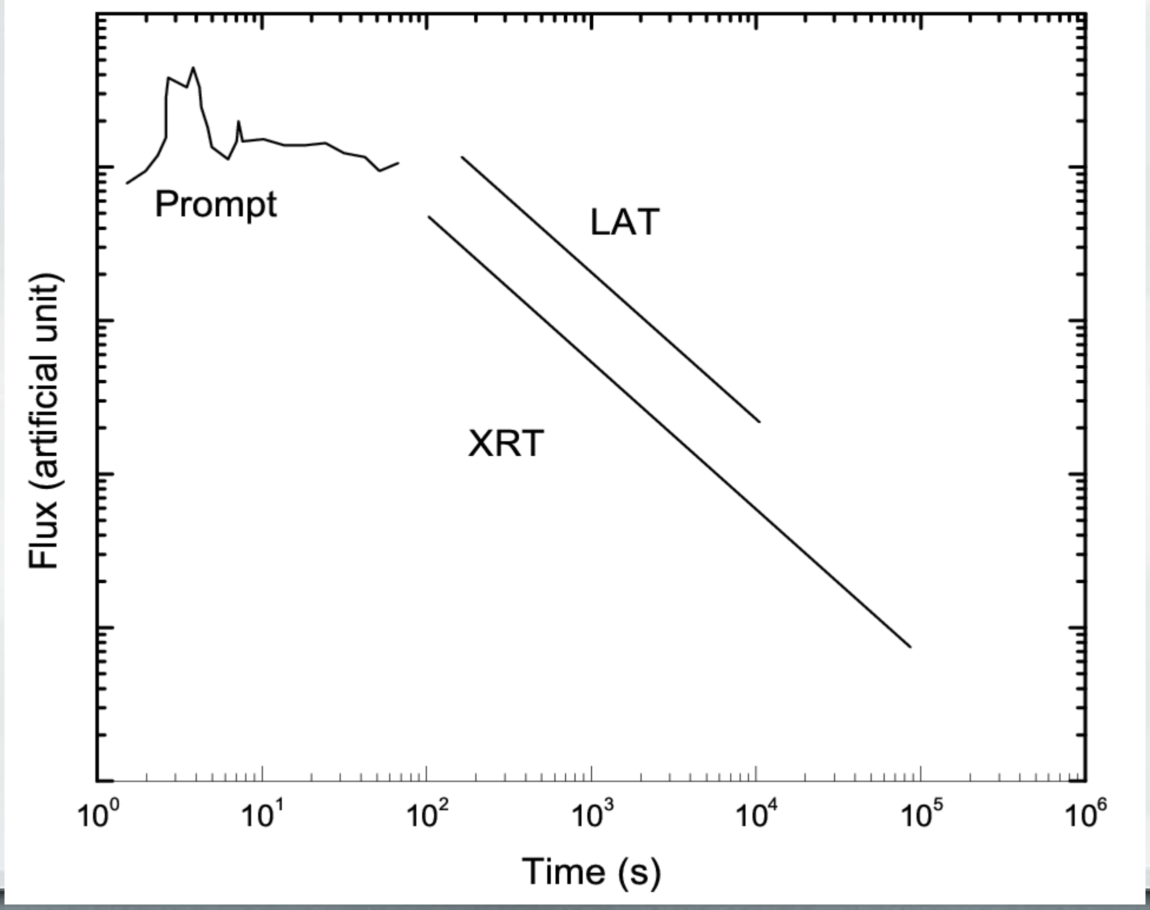
Summary

- Three Elemental Spectral Components are observed in Fermi/LAT GRBs
- Prompt GeV emission is likely of internal origin
- Further Co-triggered Bursts by Swift and Fermi will help.

Thanks!

A Judgment Test

- A bright GRB co-triggered by Fermi LAT/GBM and Swift
- External



A Judgment Test

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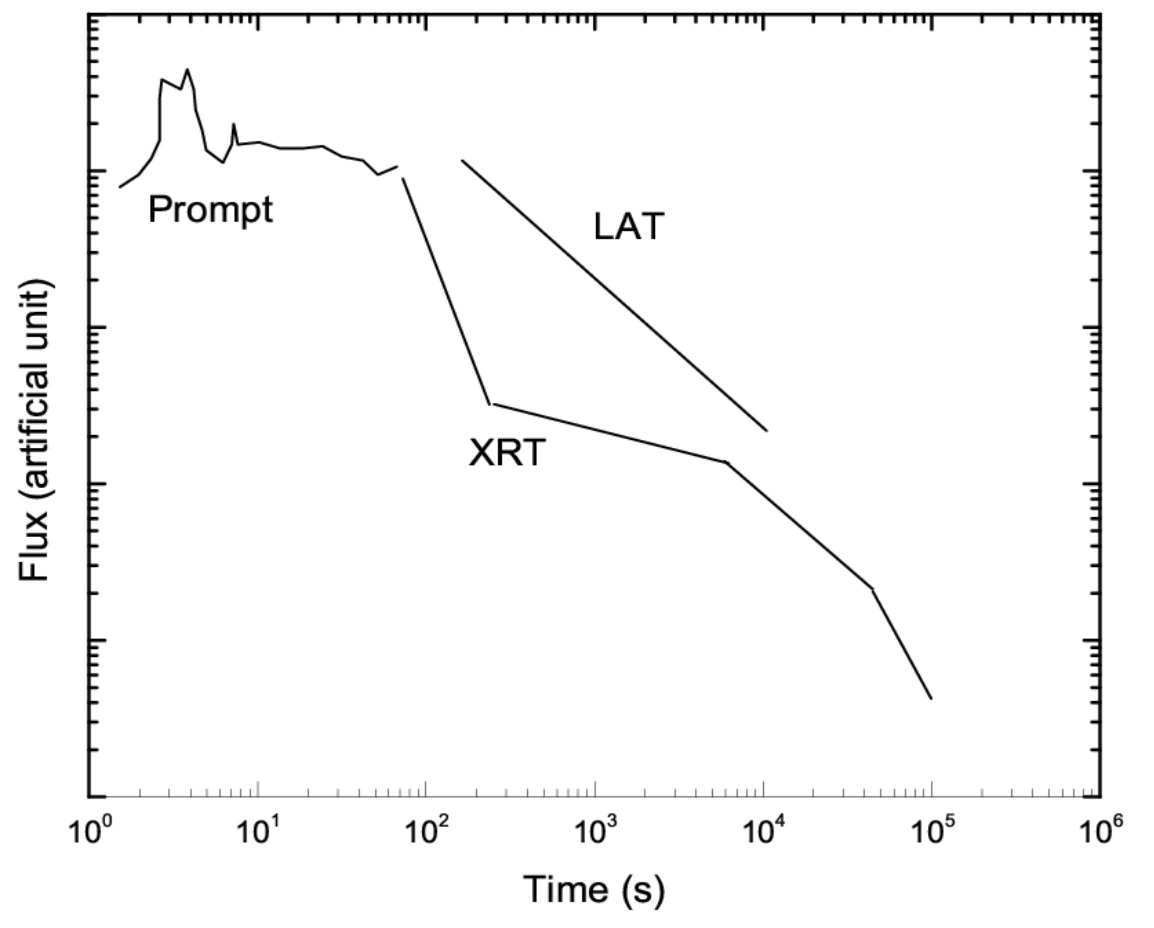
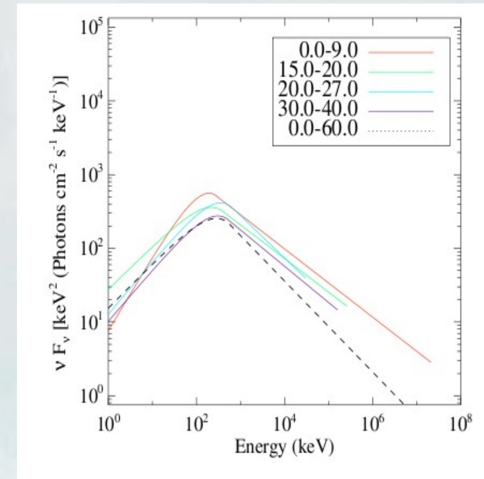
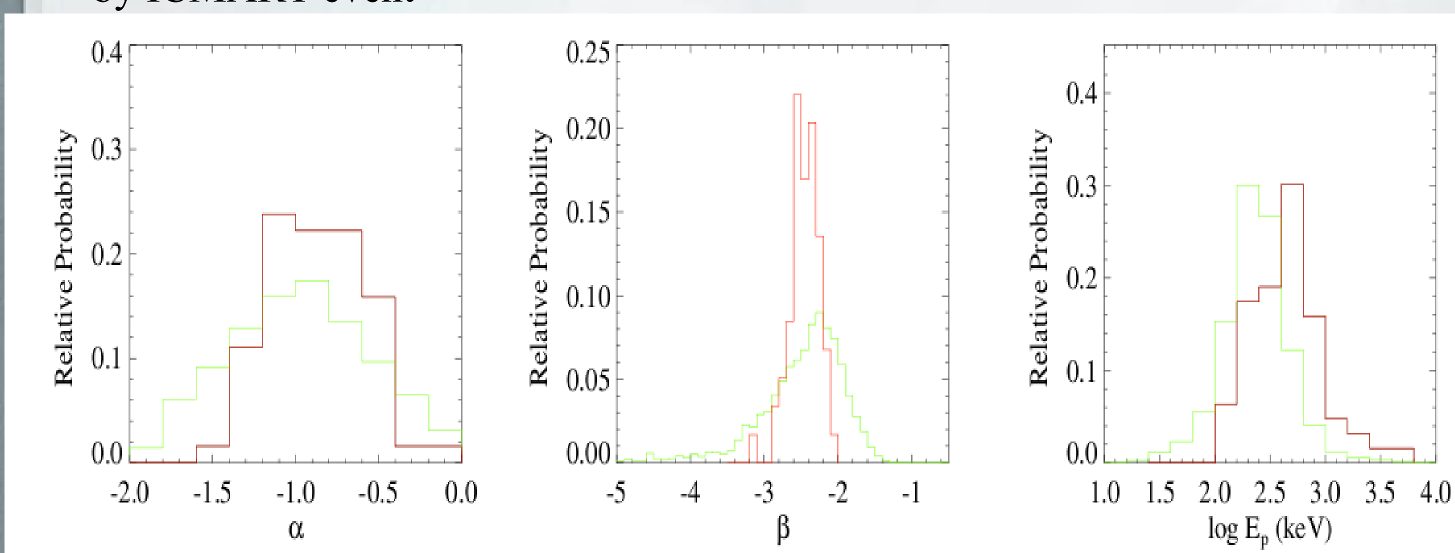


Backup slides

Band Function Component

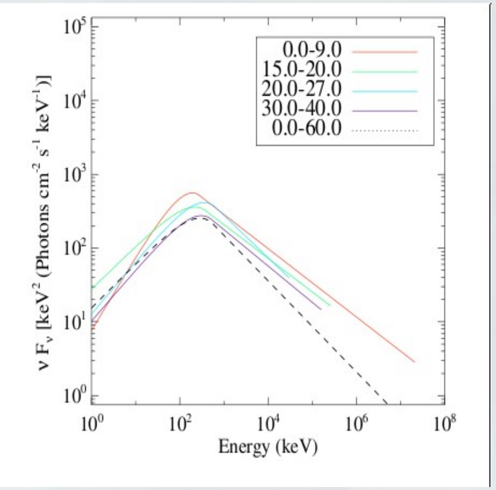


- 15 out 17 bursts are fitted by Band
- Time-dependent Band Function in Finest time resolution
- β: -2.2 , high energy PL component :
  - synchrotron
    - SSC (synchrotron self-Compton)
  - Compton up-scattering of a thermal photon source
- α : -1, hard to explain
  - syn gives -1.5
  - not simple multi-color BB effect (cf Kenji 2010)
  - high-latitude emission effect : too late
  - may still be synchrotron with bulk heating by ICMART event



$$exp\left(-\frac{\varepsilon_\gamma}{\varepsilon_\gamma^o}\right) \qquad \varepsilon_\gamma \le \varepsilon_\gamma^b \equiv (\alpha-\beta)\varepsilon_\gamma^o \tag{1}$$
$$\alpha-\beta \quad exp(\beta-\alpha)\left(\frac{\varepsilon_\gamma}{100\,\mathrm{keV}}\right)^\beta \qquad \varepsilon_\gamma \ge \varepsilon_\gamma^b \equiv (\alpha-\beta)\varepsilon_\gamma^o$$

Band Function Component



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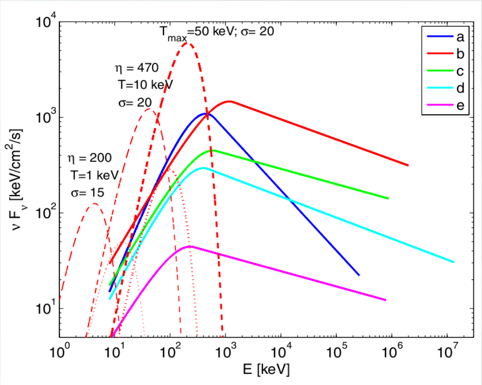
by ICMART event

– 6-7 orders extension

----> Poynting flux dominated outflow



[most energy carried in B filed , not in photons, photosphere emission is suppressed

– Compton parameter Y<<1 (because B energy density >> photon energy density, Y=U_ph/U_B<<1),so SSC suppressed (L_ssc~YL_syn)

- Poynting flux : larger emission radius reduce 2-photon annihilation opacity and increase the pair cutoff energy]

$$N_{\varepsilon_\gamma}(\varepsilon_\gamma) = \begin{cases} A_\gamma\left(\dfrac{\varepsilon_\gamma}{100\,\mathrm{keV}}\right)^{\alpha} exp\left(-\dfrac{\varepsilon_\gamma}{\varepsilon_\gamma^o}\right) & \varepsilon_\gamma \le \varepsilon_\gamma^b \equiv (\alpha-\beta)\varepsilon_\gamma^o \\ A'_\gamma\left[\dfrac{(\alpha-\beta)\varepsilon_\gamma^o}{100\,\mathrm{keV}}\right]^{\alpha-\beta} exp(\beta-\alpha)\left(\dfrac{\varepsilon_\gamma}{100\,\mathrm{keV}}\right)^{\beta} & \varepsilon_\gamma \ge \varepsilon_\gamma^b \equiv (\alpha-\beta)\varepsilon_\gamma^o \end{cases} \quad (1)$$