Multi-Component Spectral Analysis of Fermi GRBs :

a Step Forward in the Understanding of the Prompt Emission

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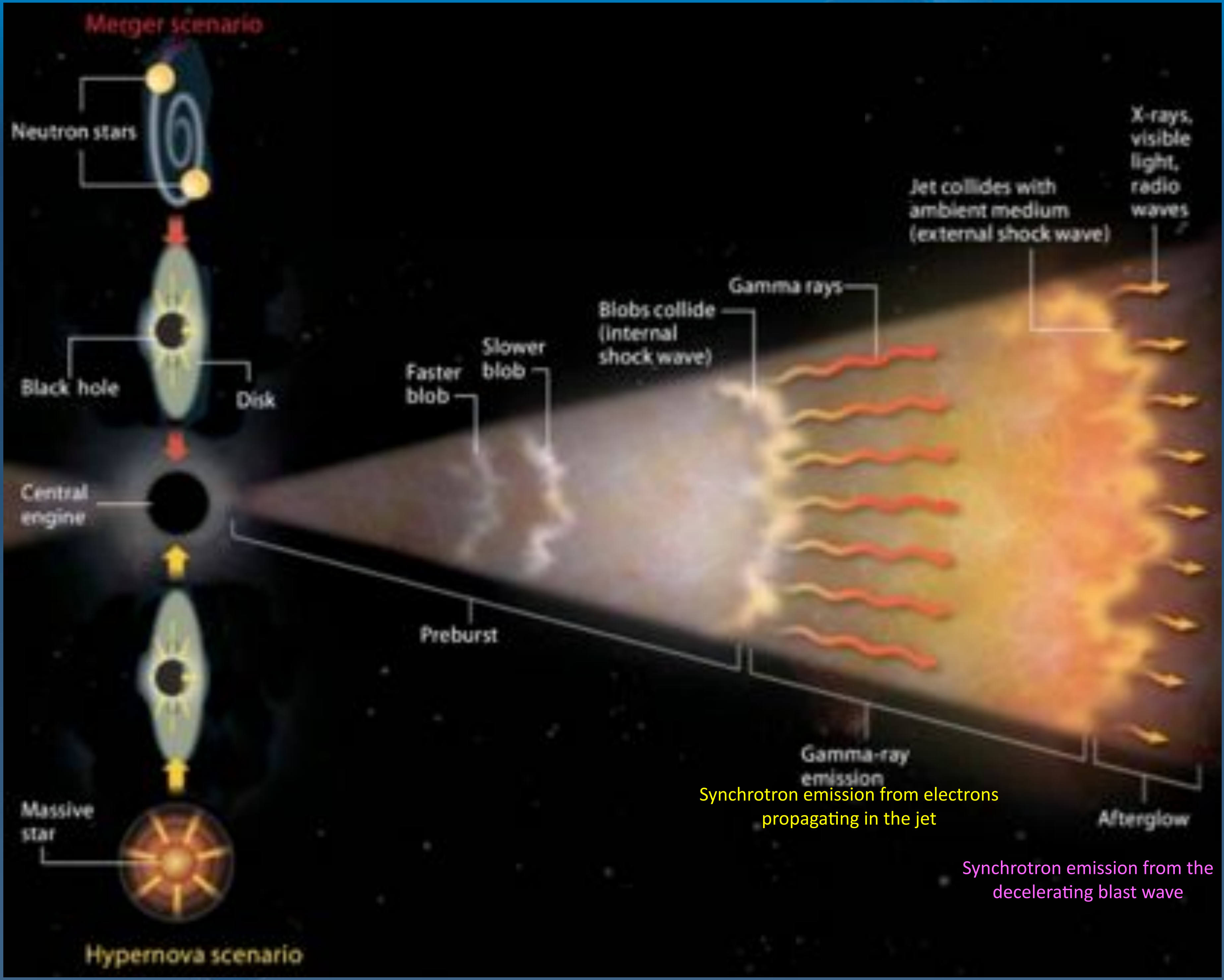
on behalf of the Fermi GBM and LAT collaborations

NASA
POSTDOCTORAL PROGRAM
Administered by Oak Ridge Associated Universities

Fermi
Gamma-ray
Space Telescope

4th Fermi Symposium, Monterey,CA, USA – October 29th, 2012

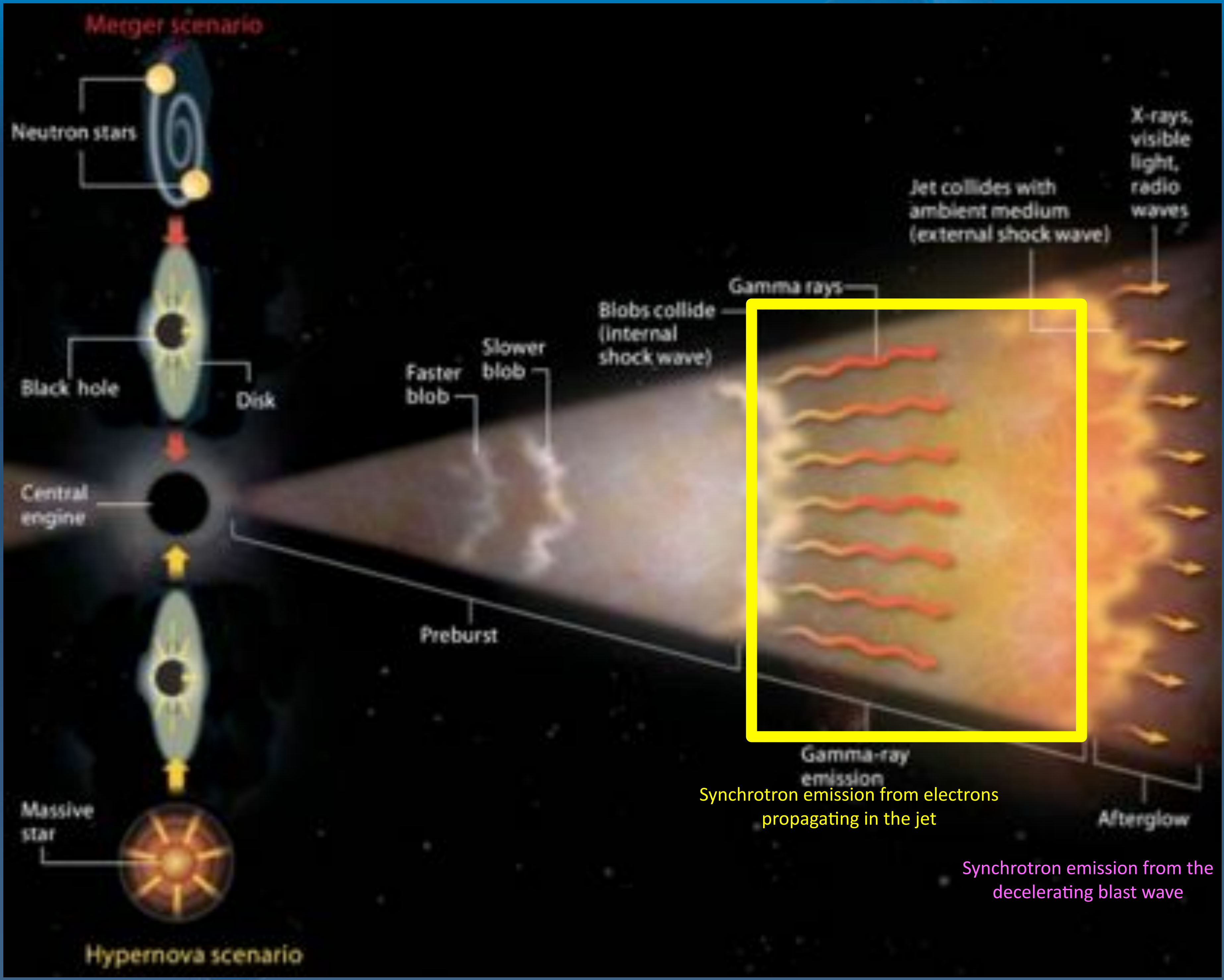
The Fireball Model



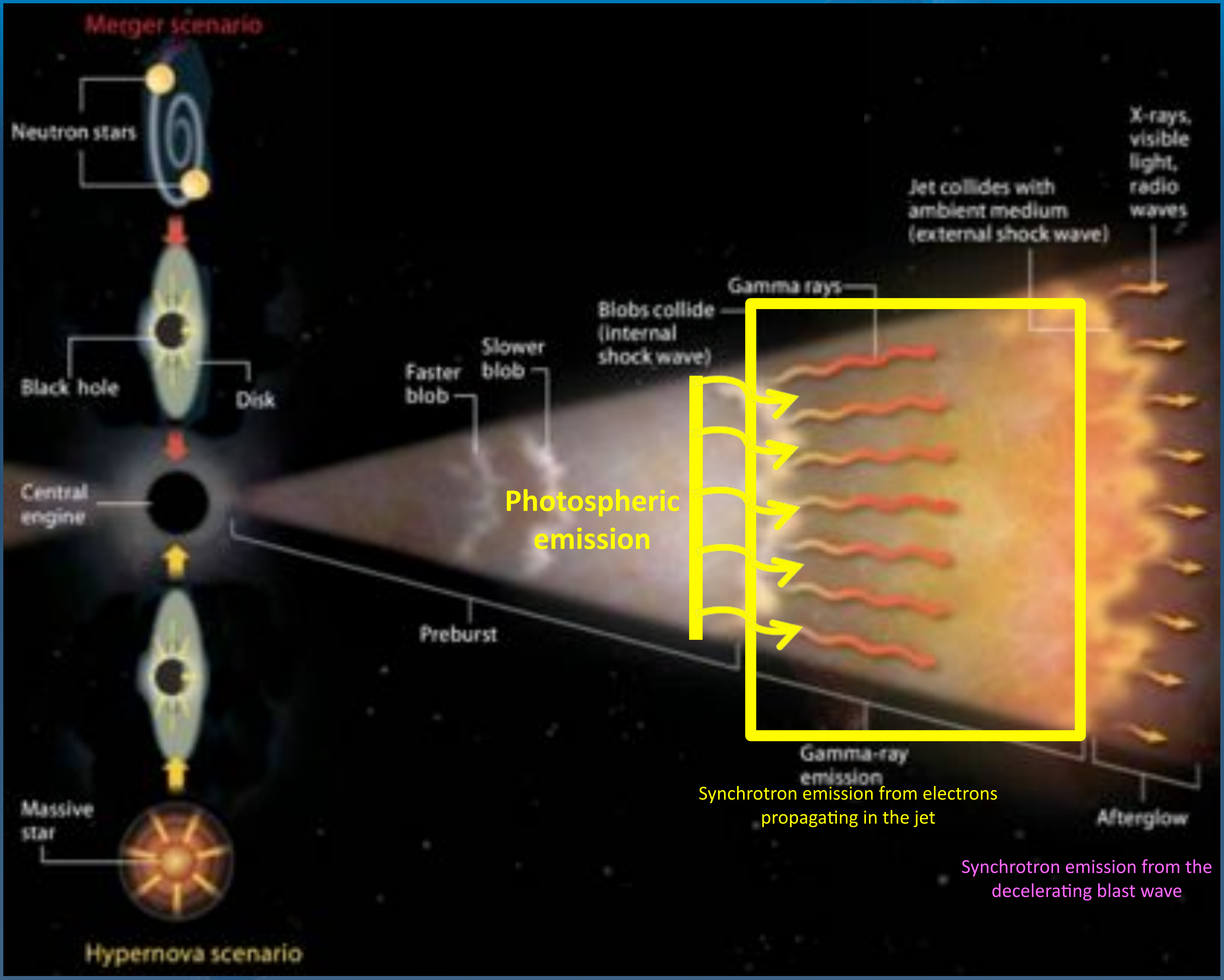
Synchrotron emission from electrons propagating in the jet

Synchrotron emission from the decelerating blast wave

The Fireball Model

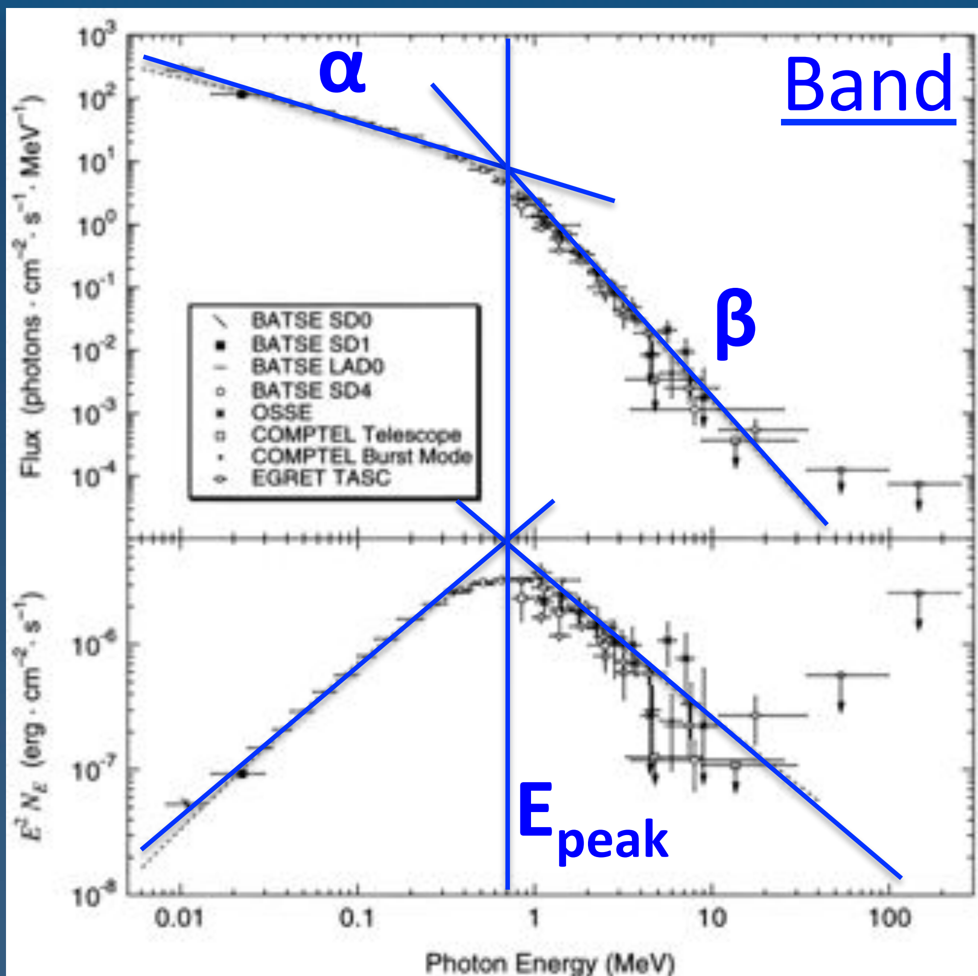


The Fireball Model

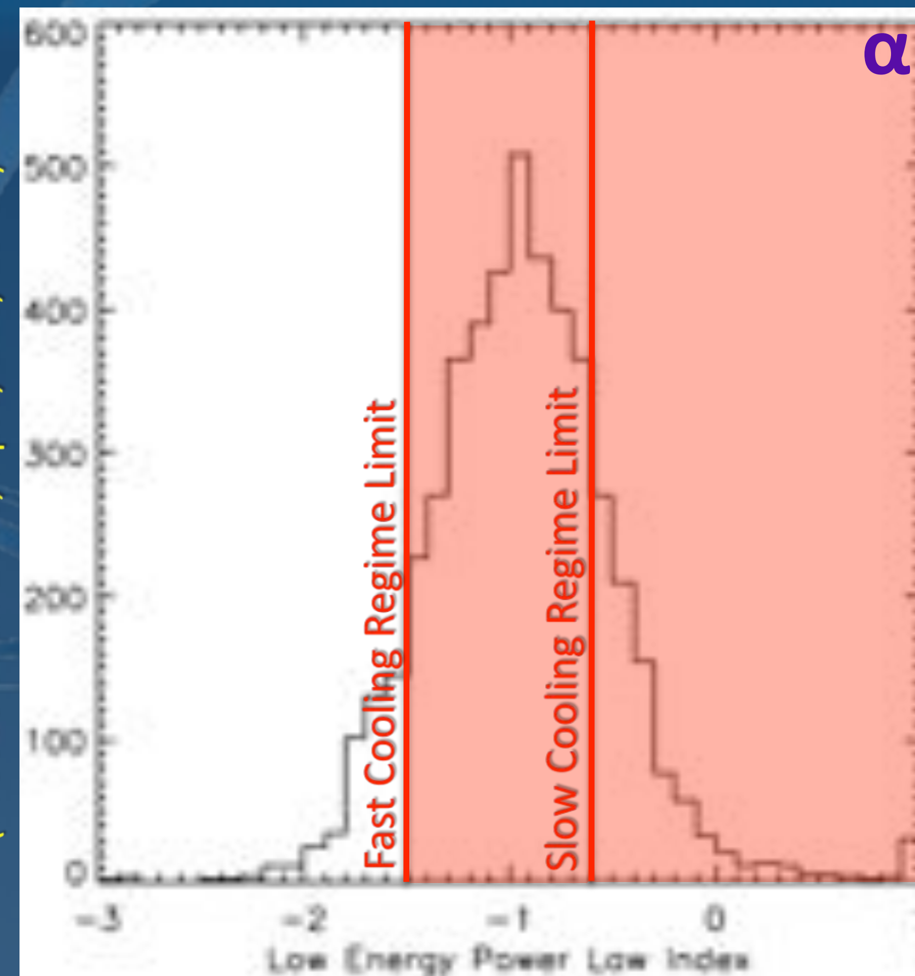


The Empirical Band Function

(Briggs et al. 1999, ApJ, 524, 82-91)



(Preece et al. 2000, ApJS, 126, 19-36)

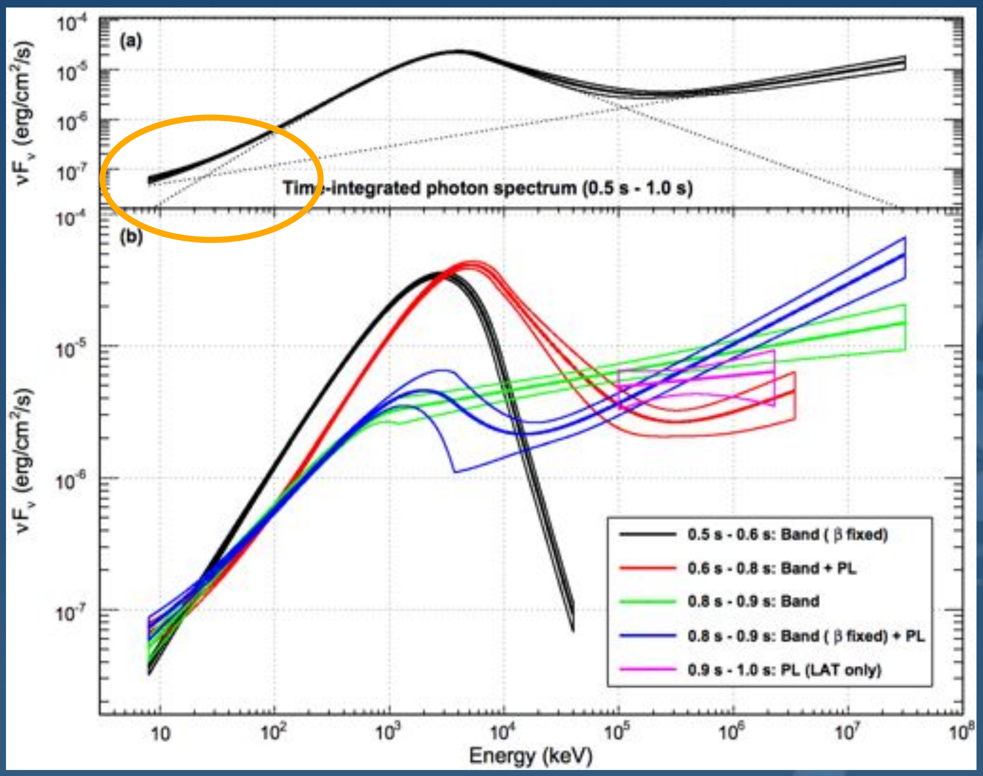


- Band usually considered synchrotron emission from e^- propagating and accelerated in the jet.
- However α often not compatible with synchrotron scenarios.

Additional Components to the Band Function

Band+PL

GRB 090510



(Ackerman et al. 2010)

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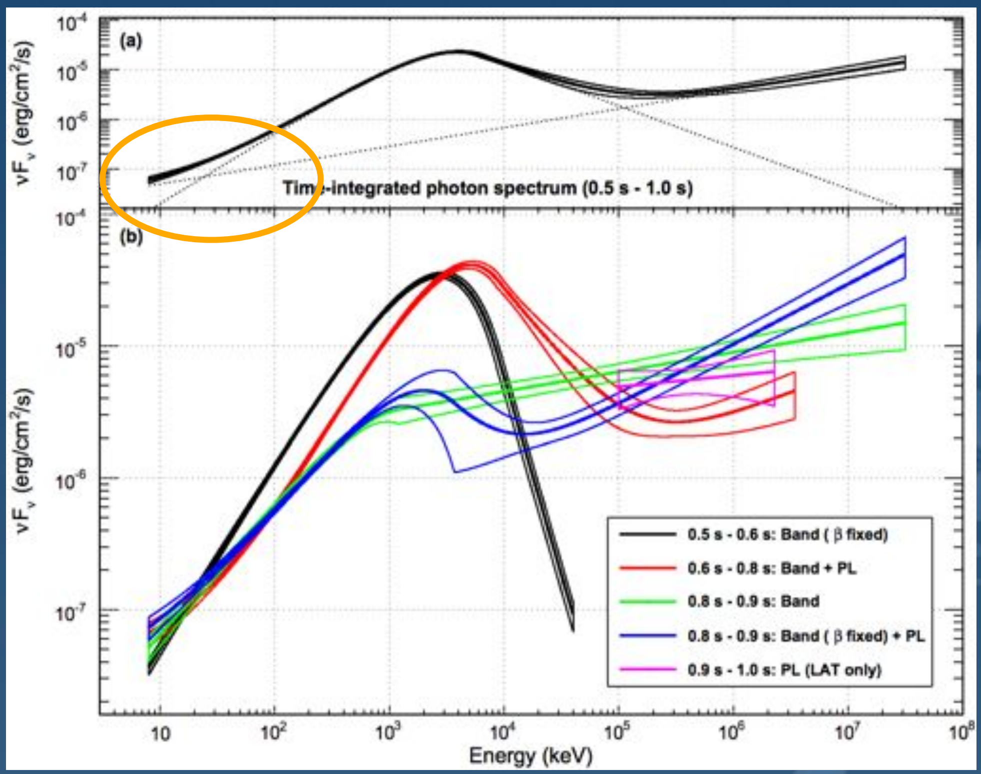
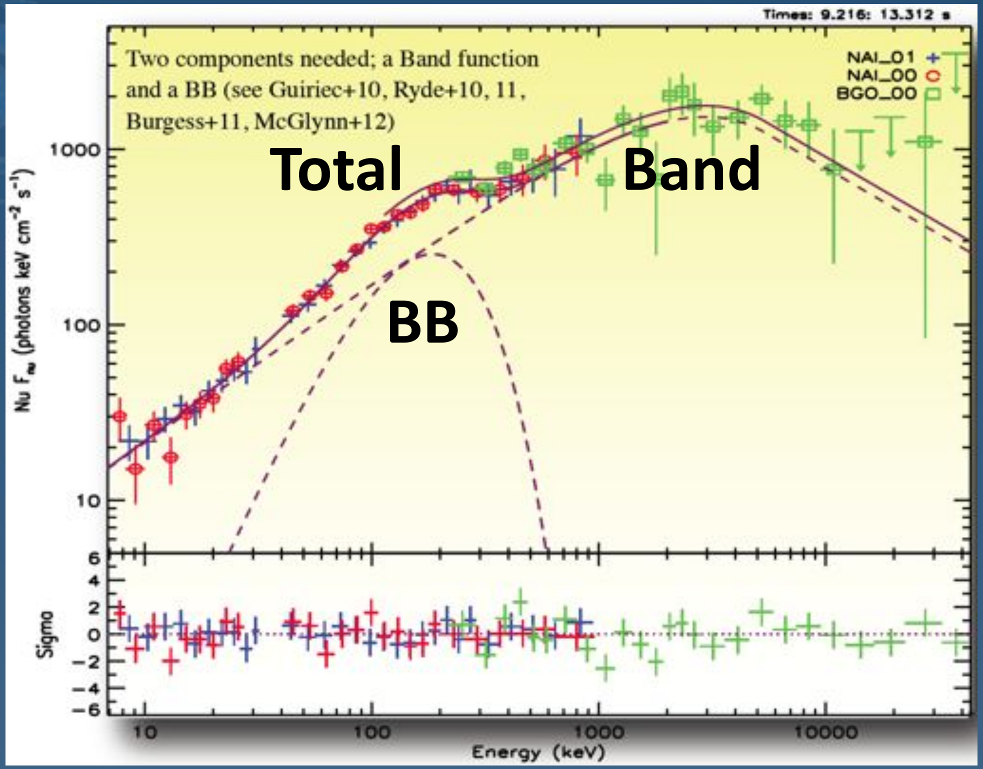
GRB 090510



(Ackerman et al. 2010)

Band+BB

GRB 100724B



(Guiriec et al. 2011)

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Band+PL

(Ackerman et al. 2010) (Ackermann et al. 2011)

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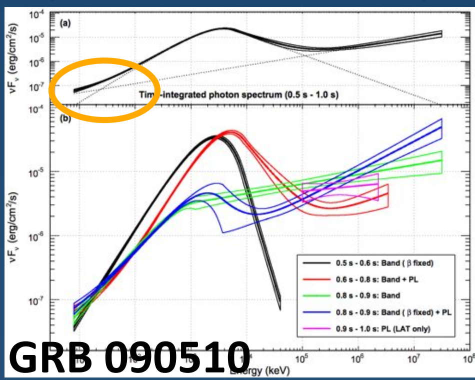

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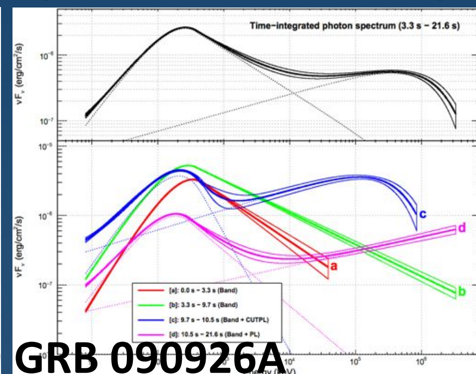

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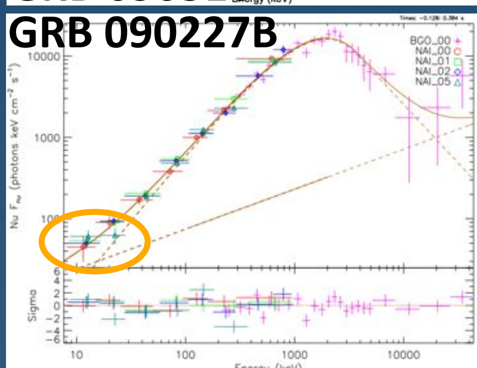

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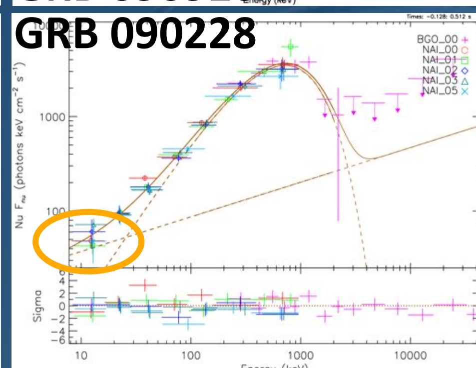
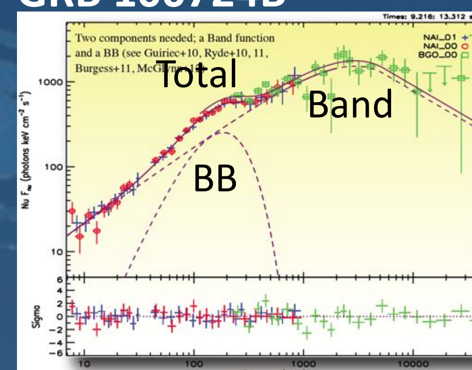


(Guiriec et al. 2010)

Band+BB

GRB 100724B



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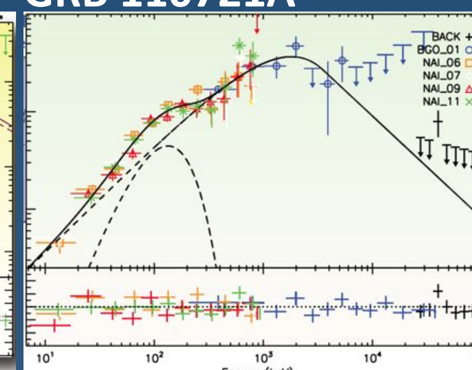
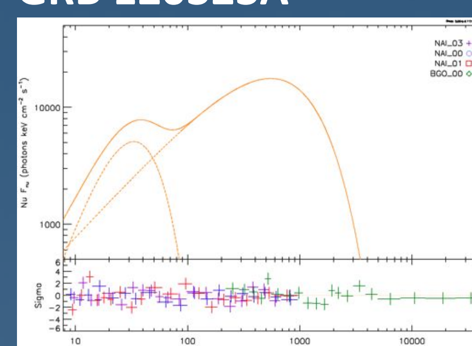
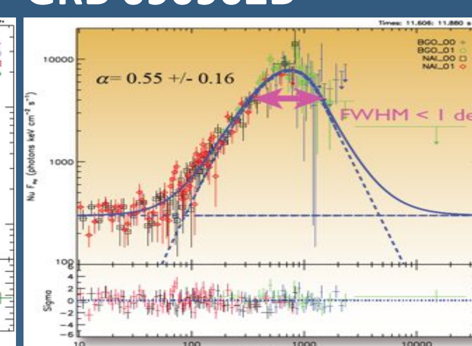


(Guiriec et al. 2011) (Axelsson et al. 2012)

GRB 120323A

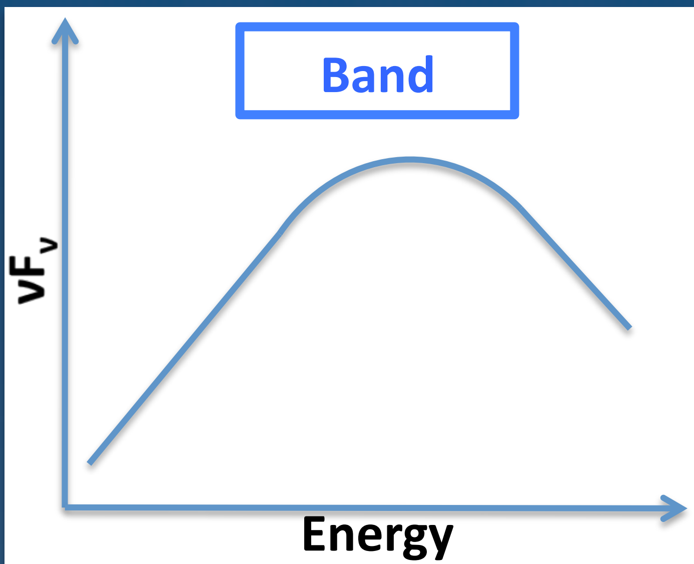


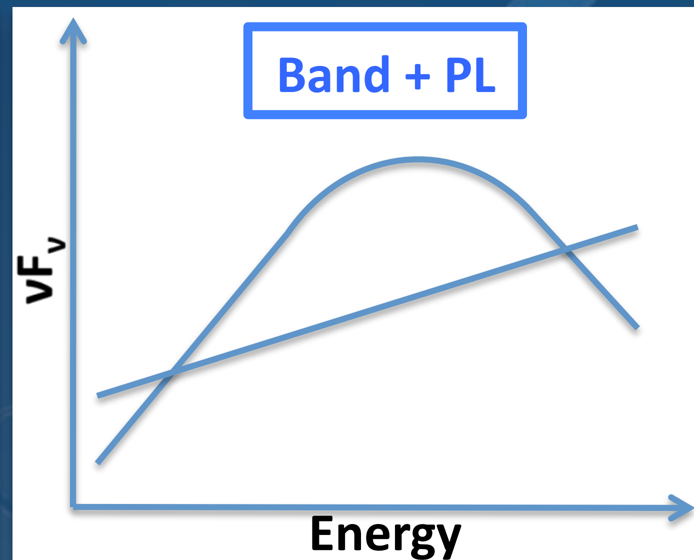
GRB 090902B

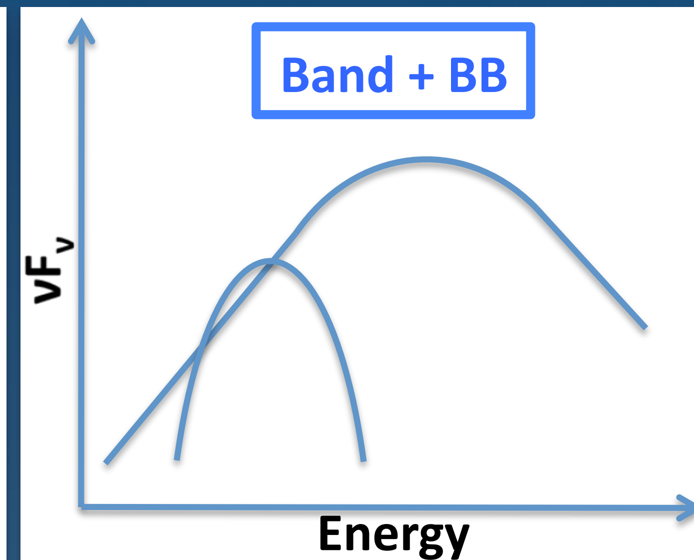


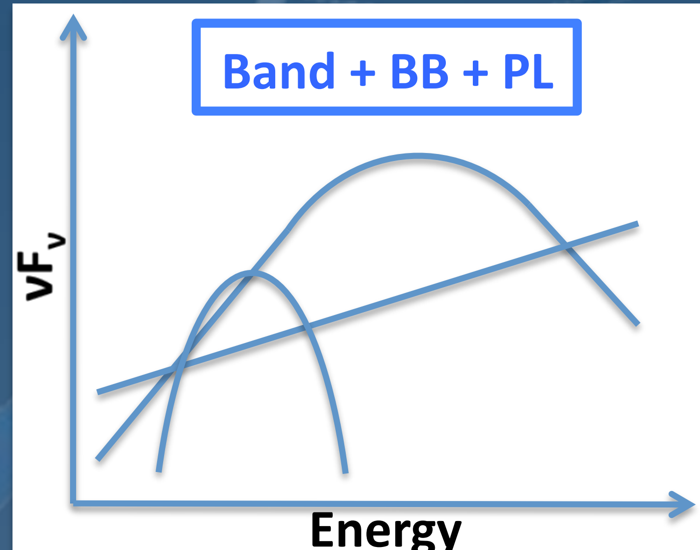
(Guiriec et al. 2012: on astro-ph tomorrow !) (Ryde et al. 2009)

Spectral Shapes









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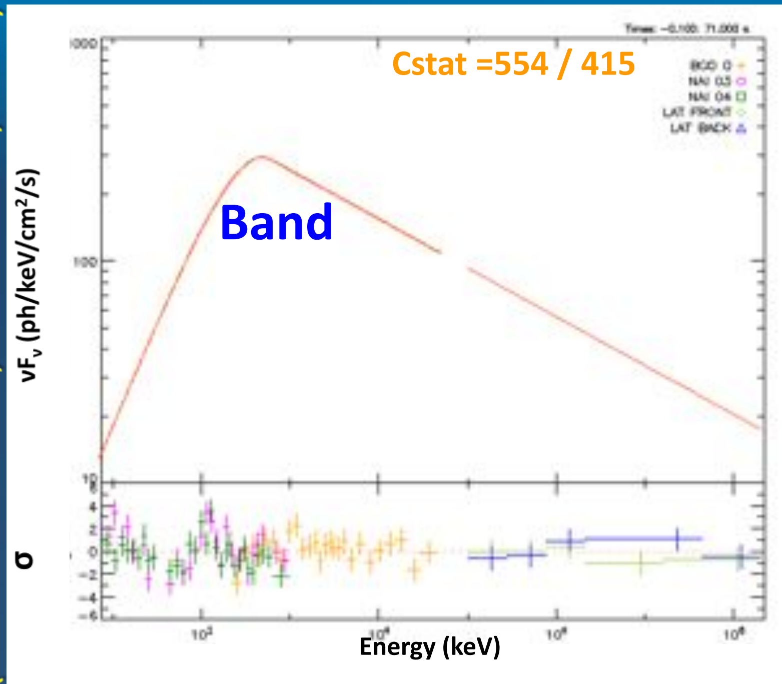
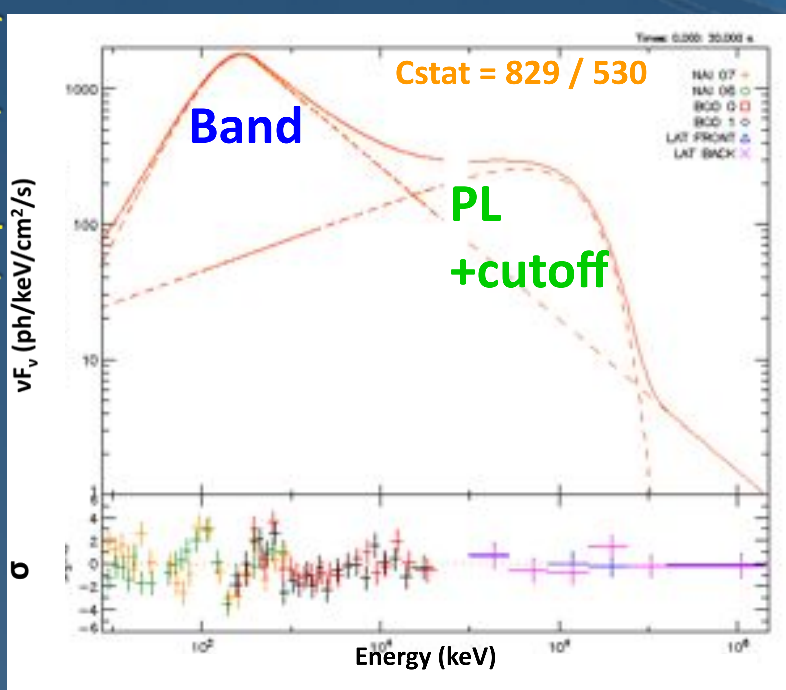
Multiple Spectral Components

GRB 080916C
(Abdo et al. 2009, Science 323, 1688)



GRB 090926A
(Ackermann et al. 2011, ApJ 725, 225)



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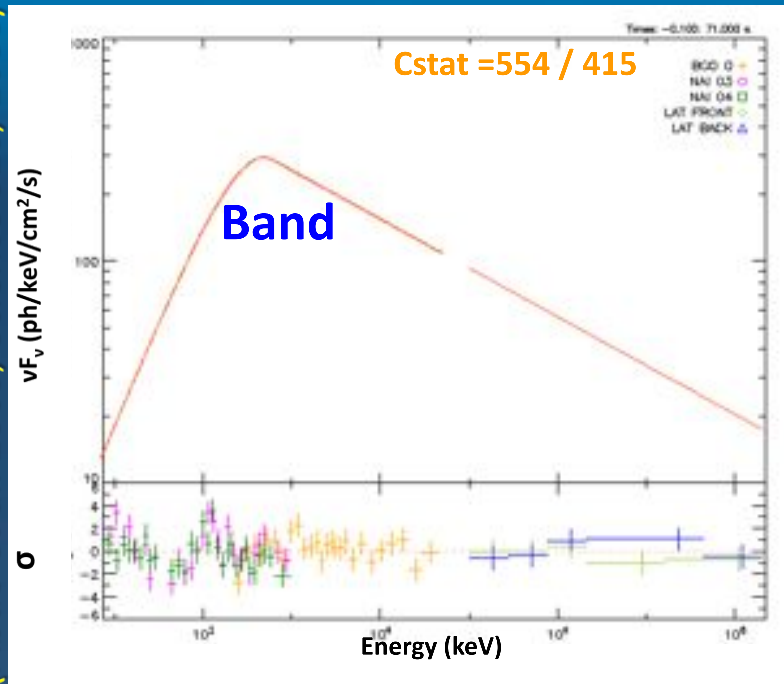

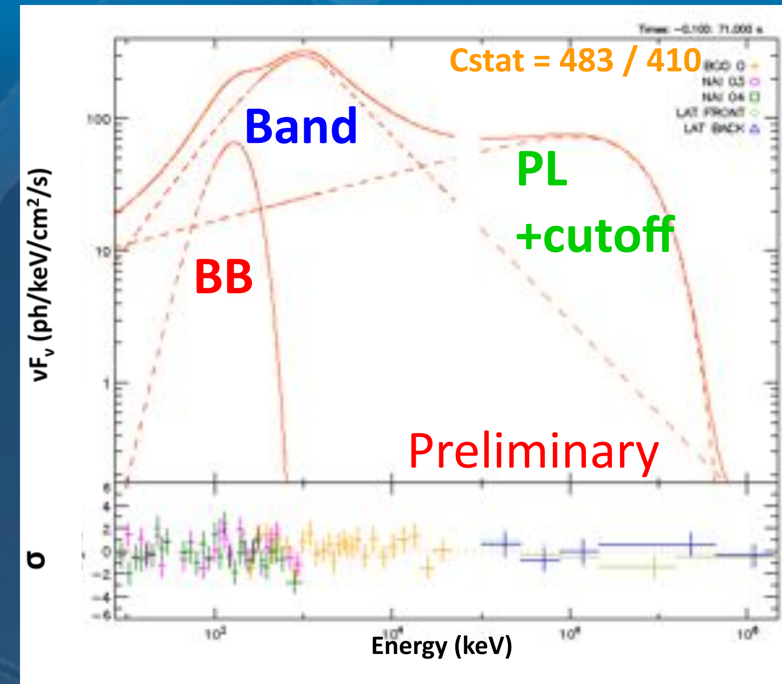

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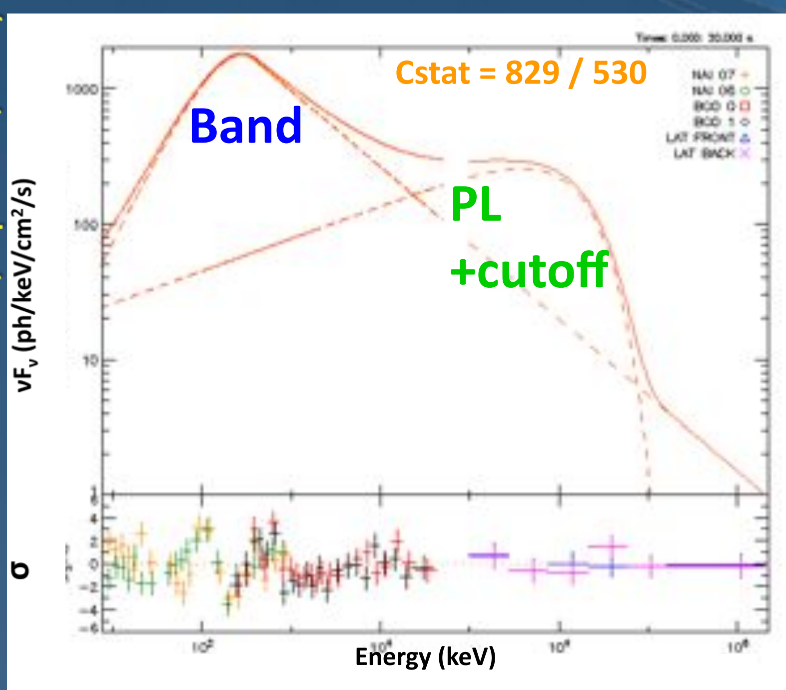
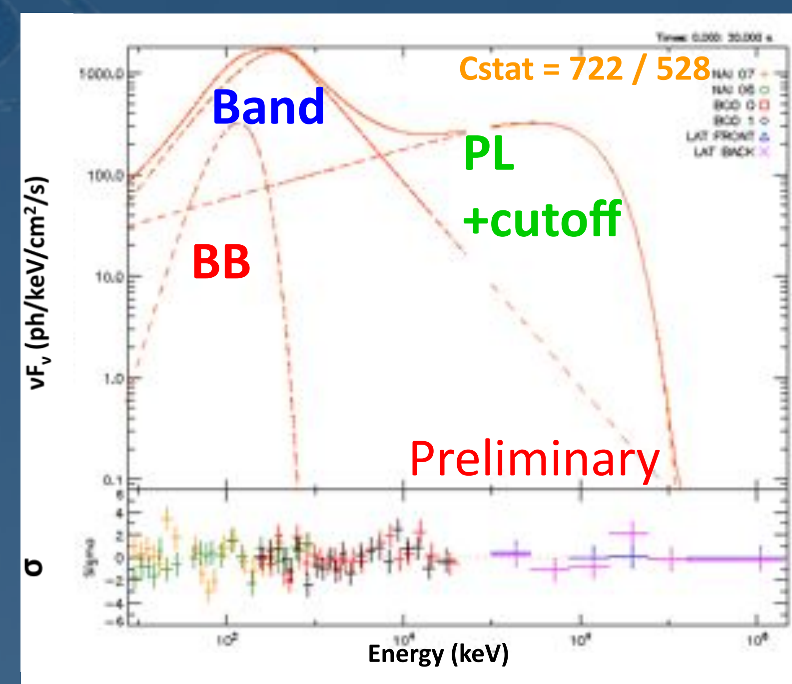
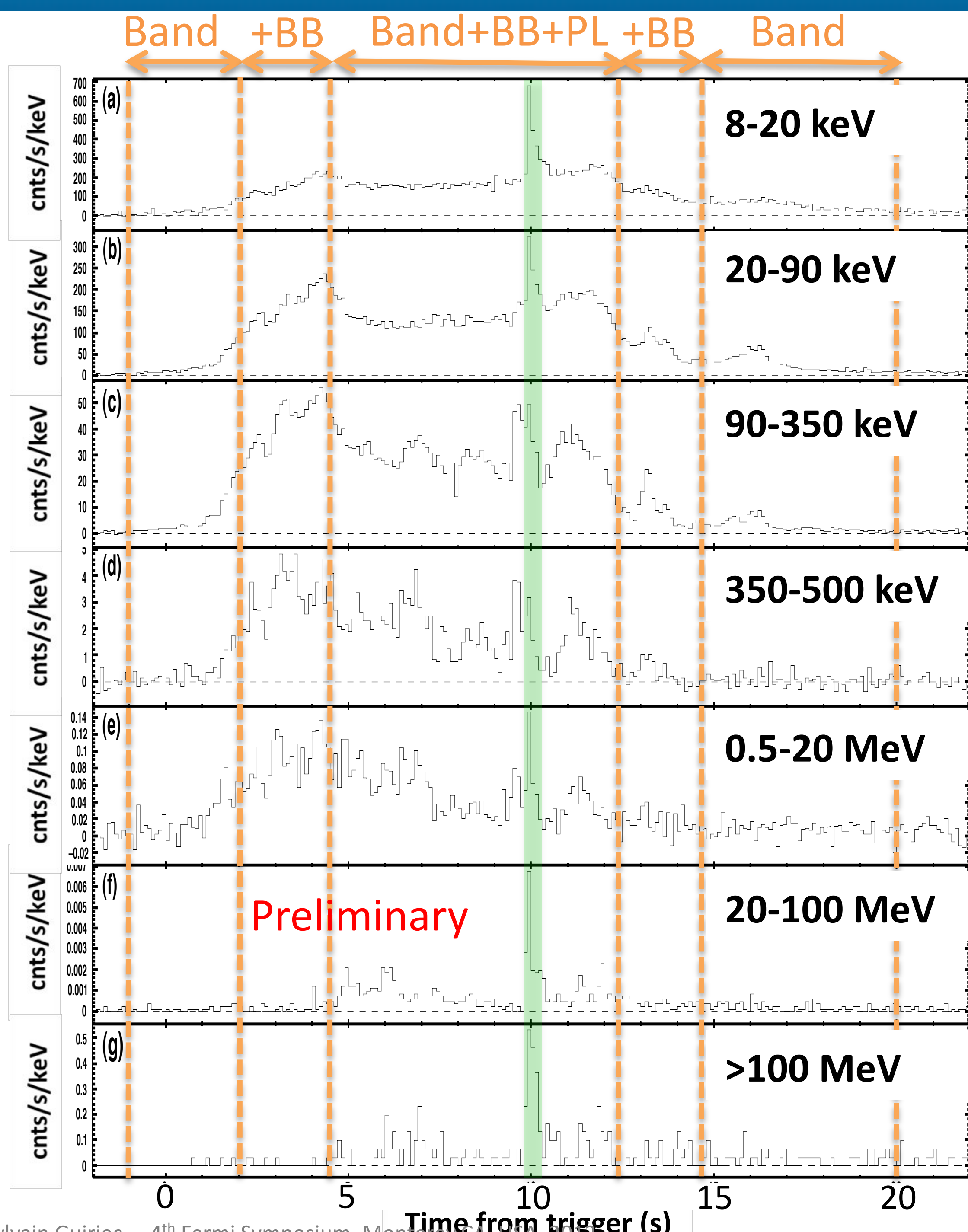
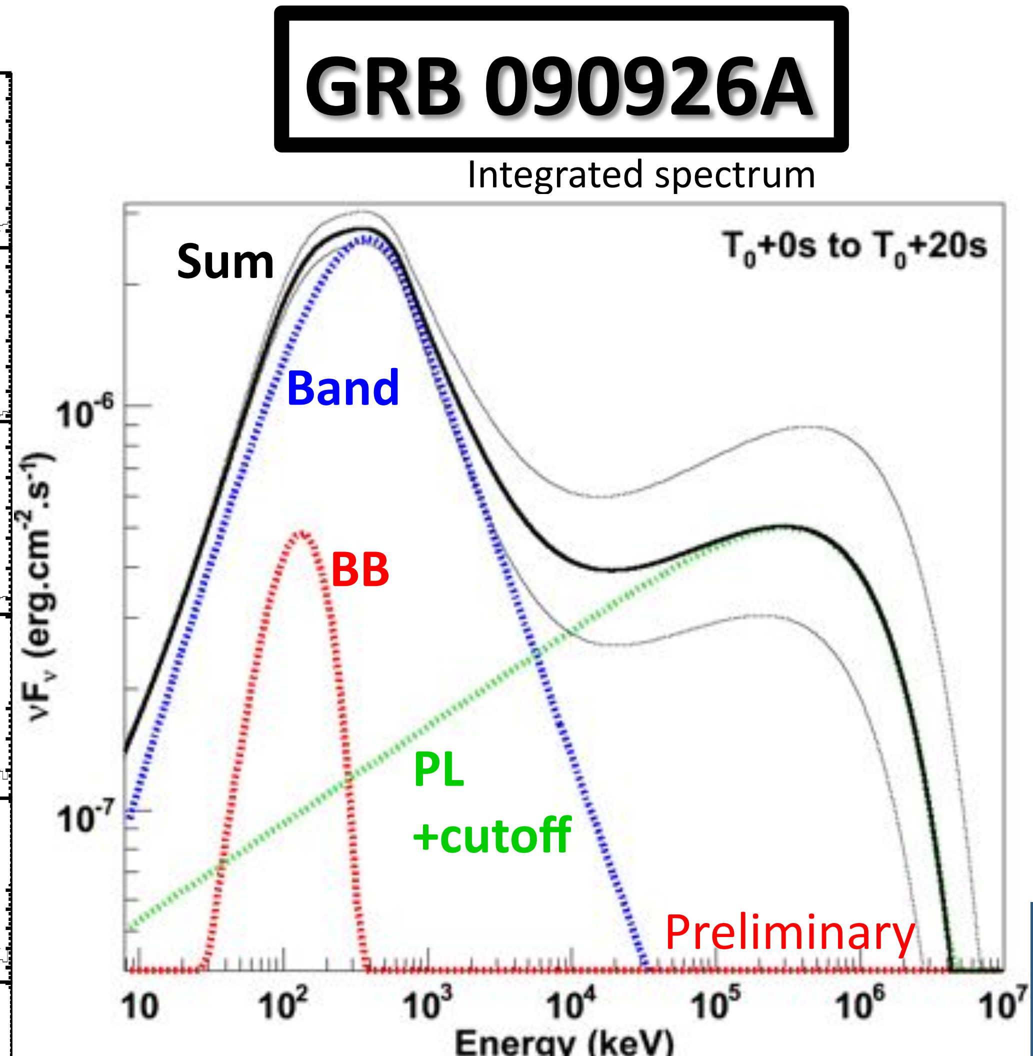




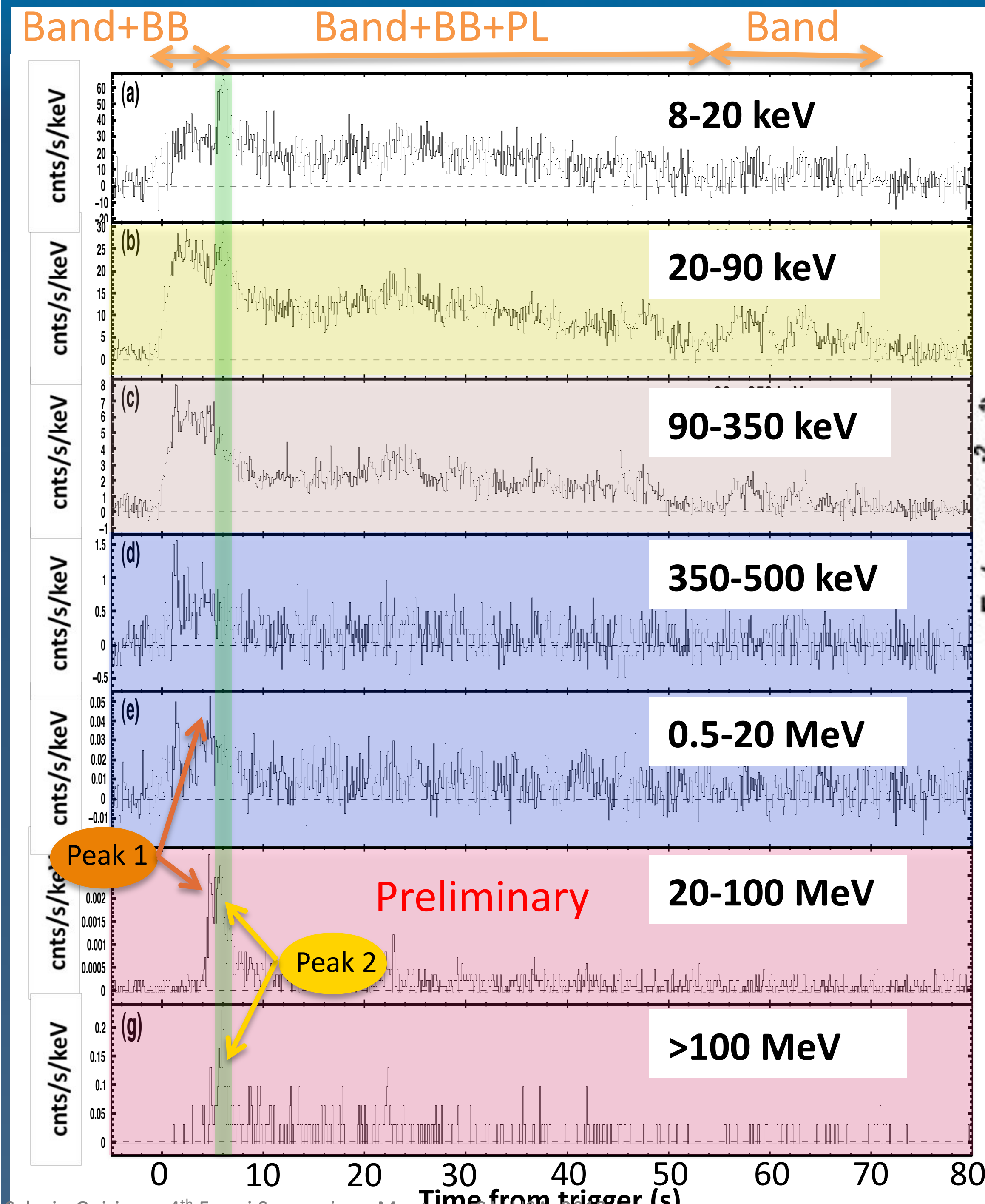
(Guiriec et al. in preparation)

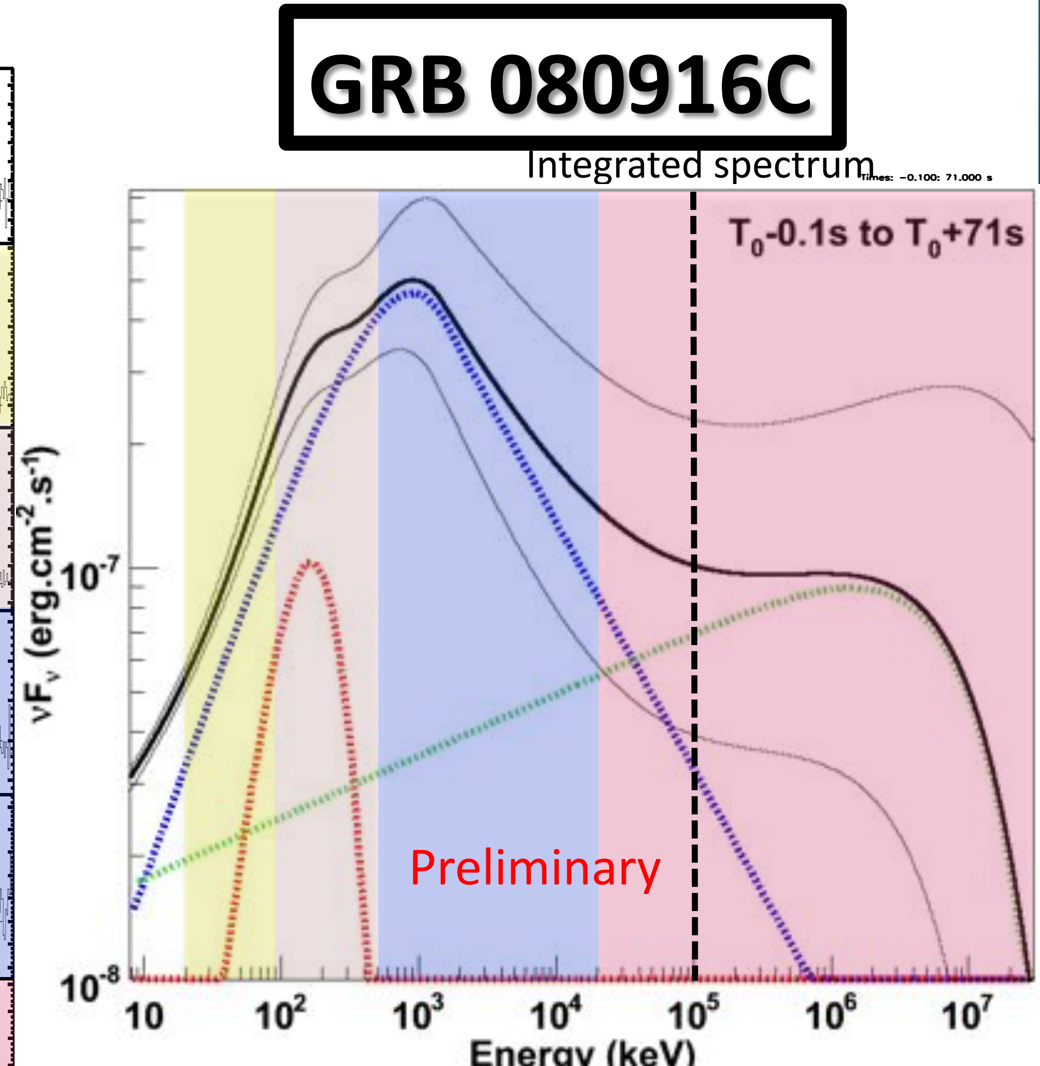
A New View of Fermi GRBs : Multi-Component Spectra



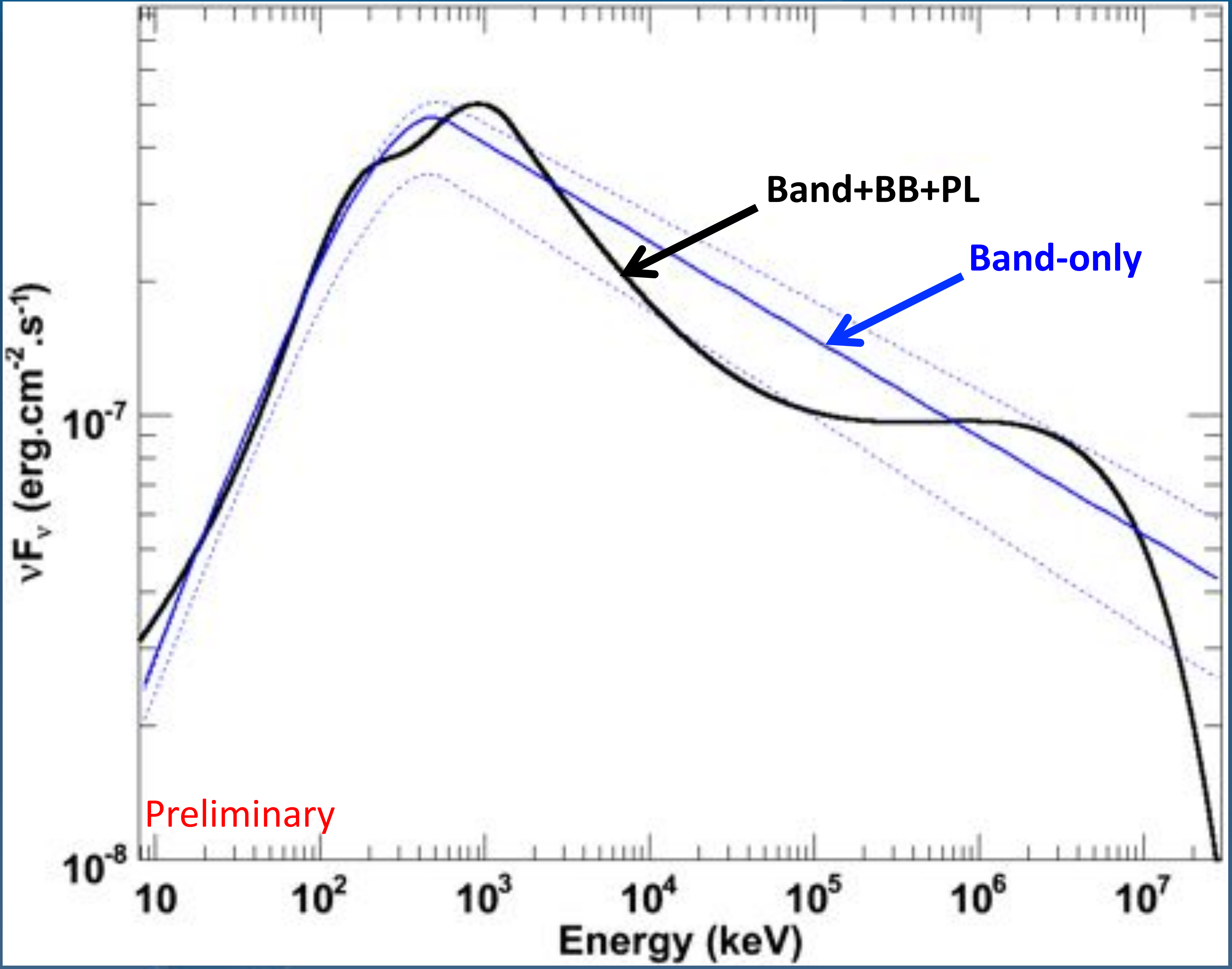


A New View of Fermi GRBs : Multi-Component Spectra





GRB080916C : Band vs Band+BB+Compt



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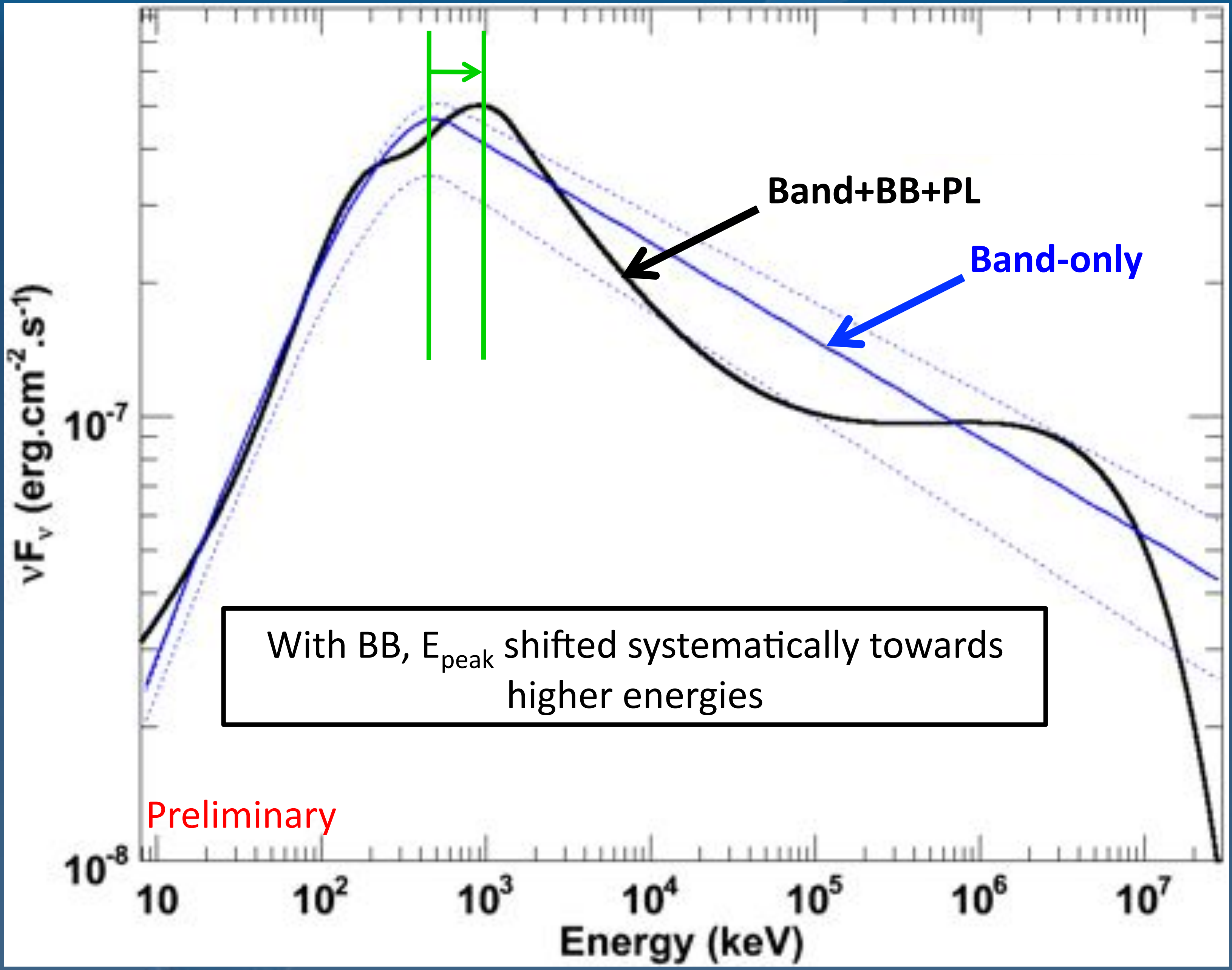

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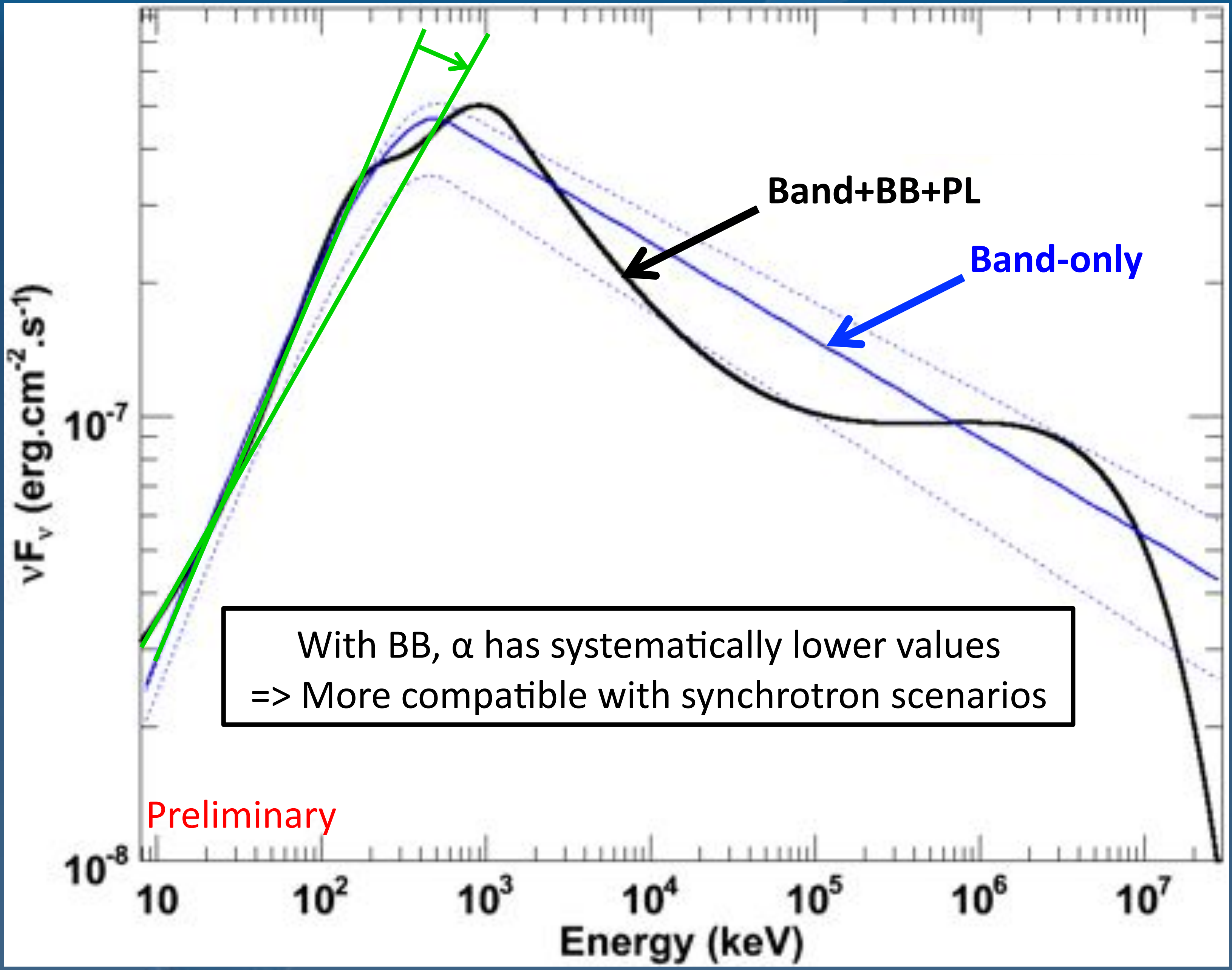

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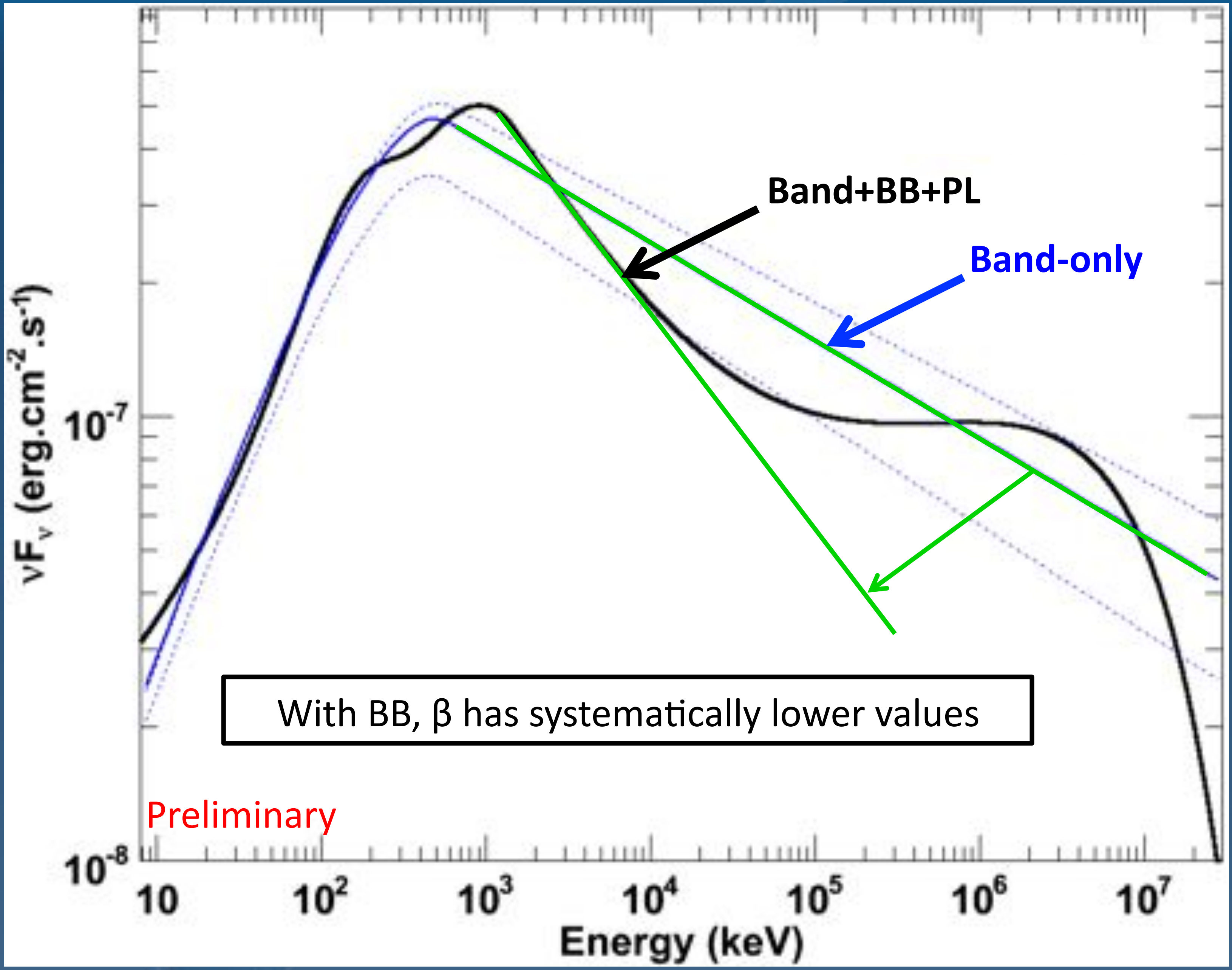
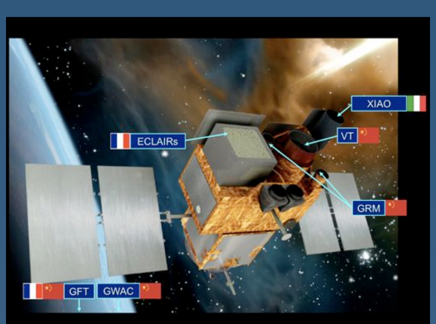


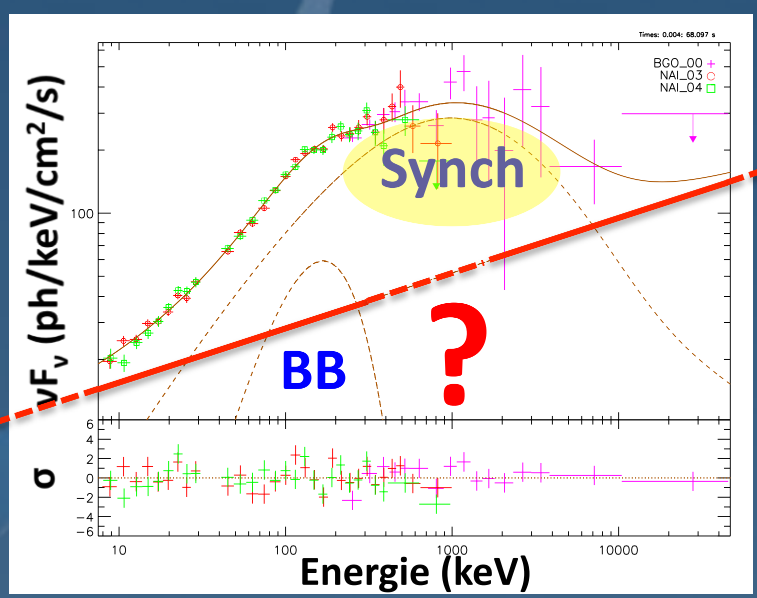
Conclusion

- Prompt emission spectra of GRBs are much more complex that the Band function usually used in the BATSE Era.
- With Fermi, we start to fit physical models to the spectra while only empirical models were used previously.
  - For the first time, we clearly identified a thermal component in addition to the non-thermal Band function.
  - Using the BB component, the Band function parameters are usually more compatible with synchrotron models.
  - Interpretation of the additional PL remains challenging for the physical models (need SVOM and CTA ?).

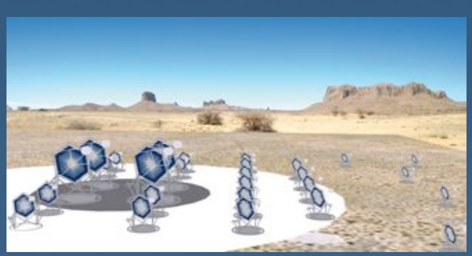
SVOM



Synchrotron + BB + PL



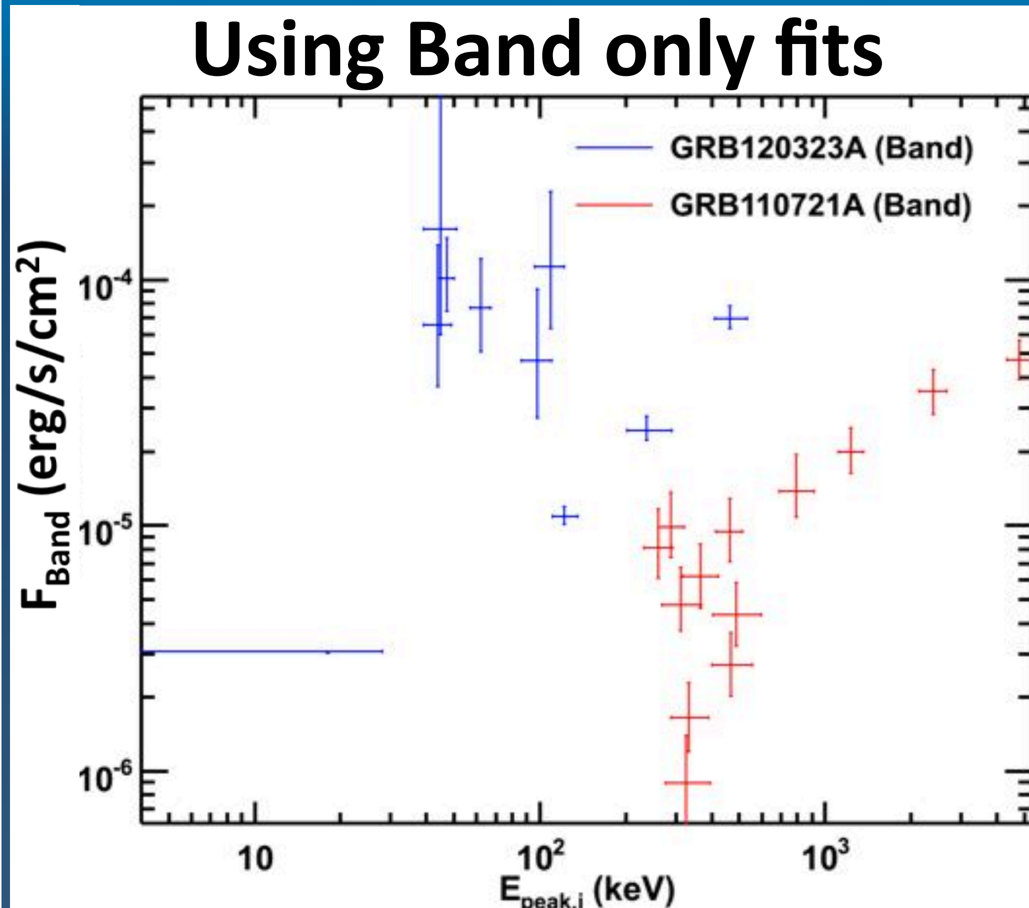
CTA



Impact of the Photospheric Emission on the Flux-E_{peak} and Luminosity-E_{peak} Relations

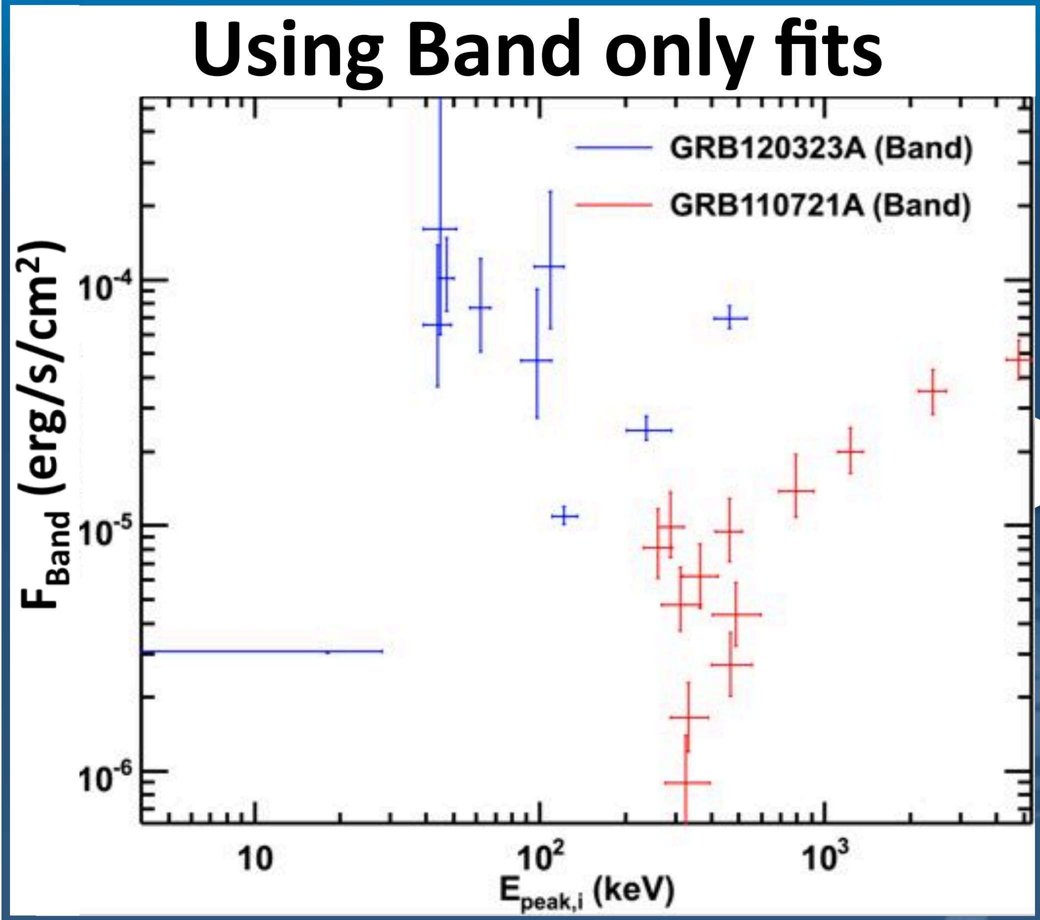
(Guiriec et al.: Submitted to ApJ and on astro-ph tomorrow !)

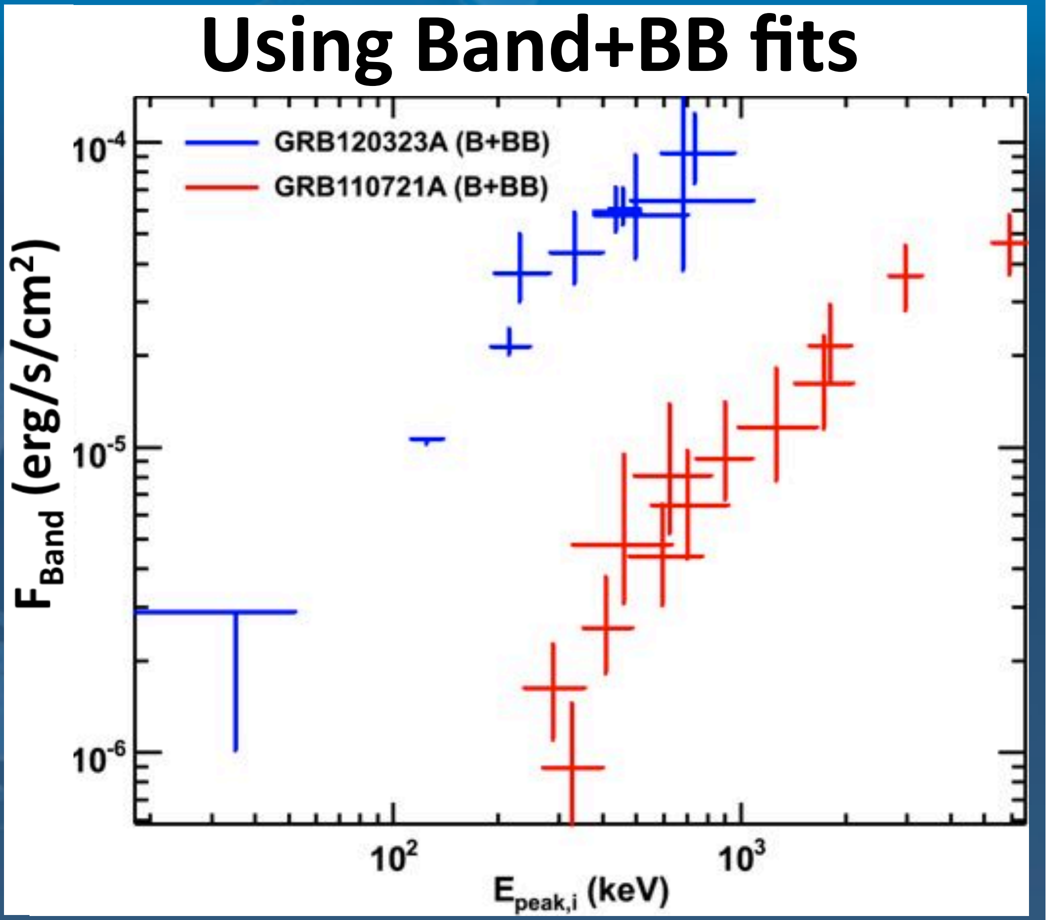
The F_{Band}-E_{peak} Relation



- When fit with Band alone, no correlation between F_{Band} and E_{peak}

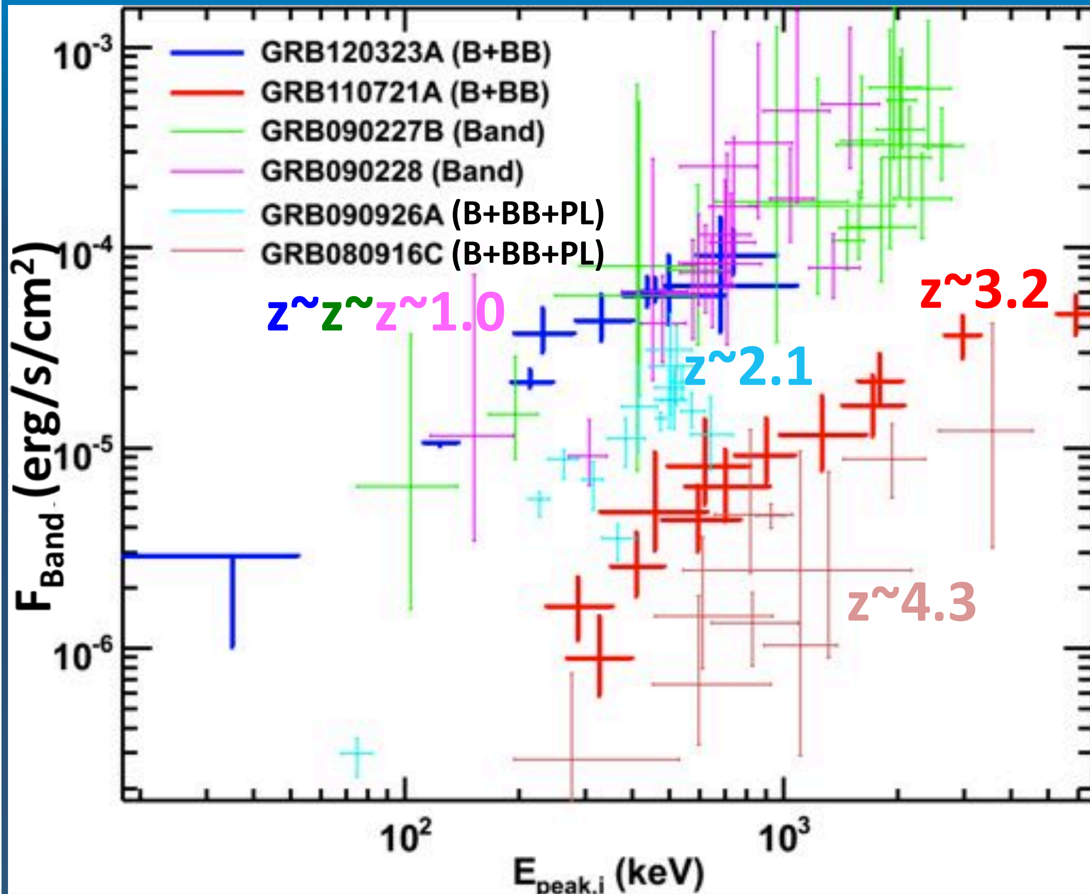
The F_{Band}-E_{peak} Relation



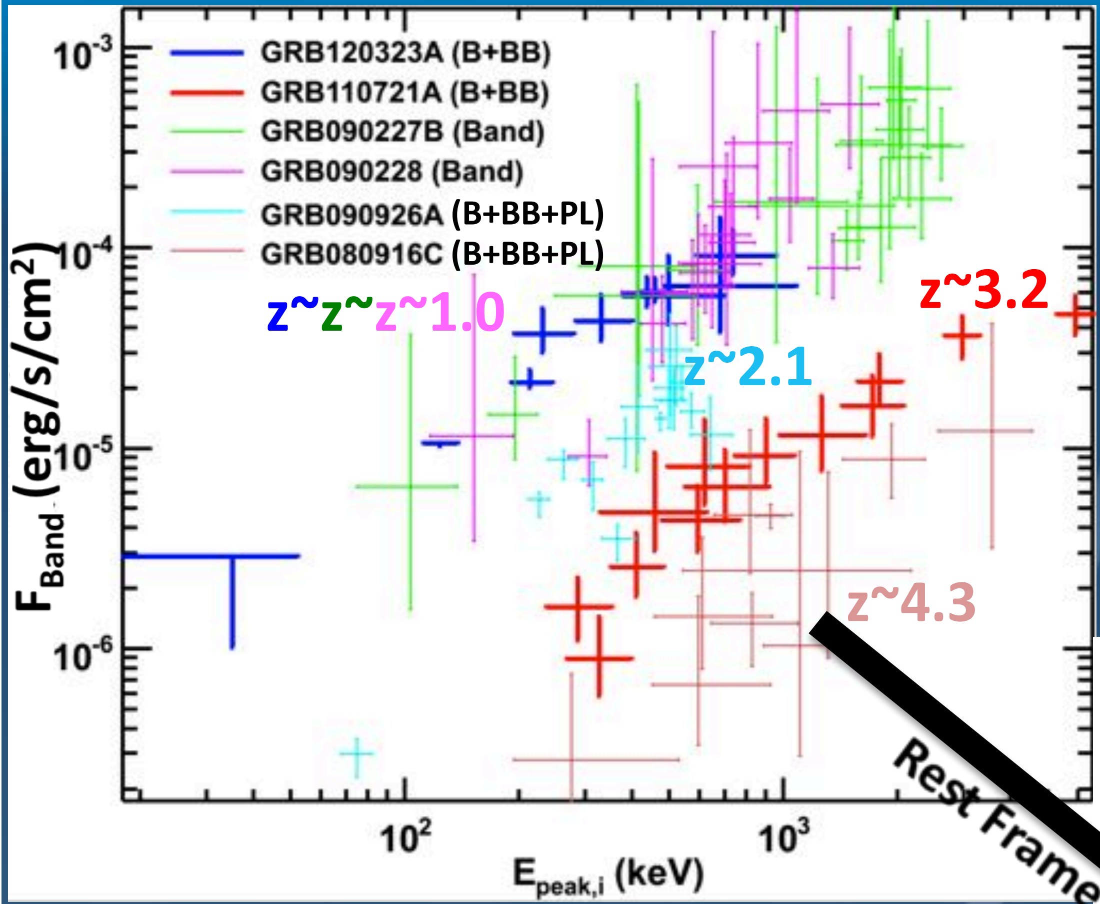


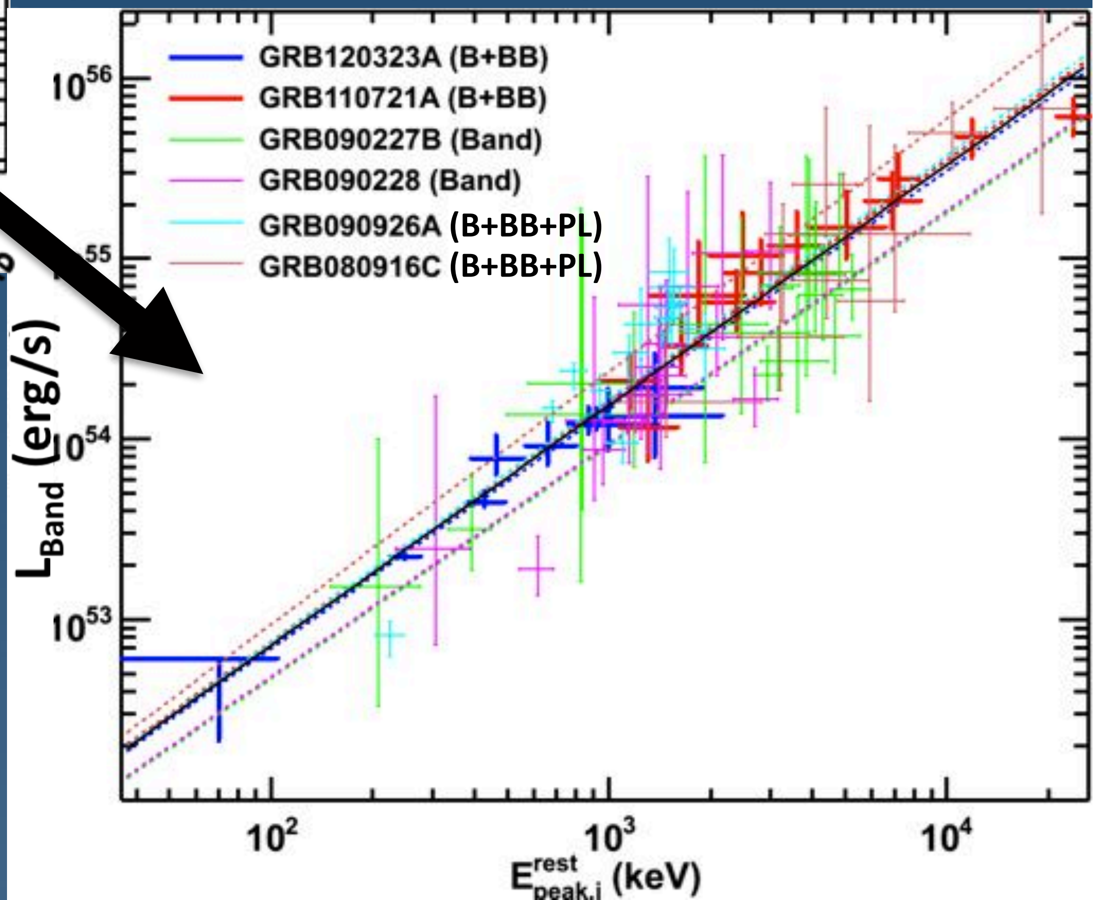
- When fit with Band alone, no correlation between F_{Band} and E_{peak}
- When fit with Band+BB, strong correlation between F_{Band} and E_{peak}
  - Reinforce the B+BB scenario
  - Why this correlation ? The emission mechanism producing the Band function must follow such a correlation.
  - Tool to discriminate between models (synch emission can explain this correl)
  - Tool to identify bursts with additional component when strong BB.

The L_{Band}-E_{peak} Relation



The L_{Band}-E_{peak} Relation

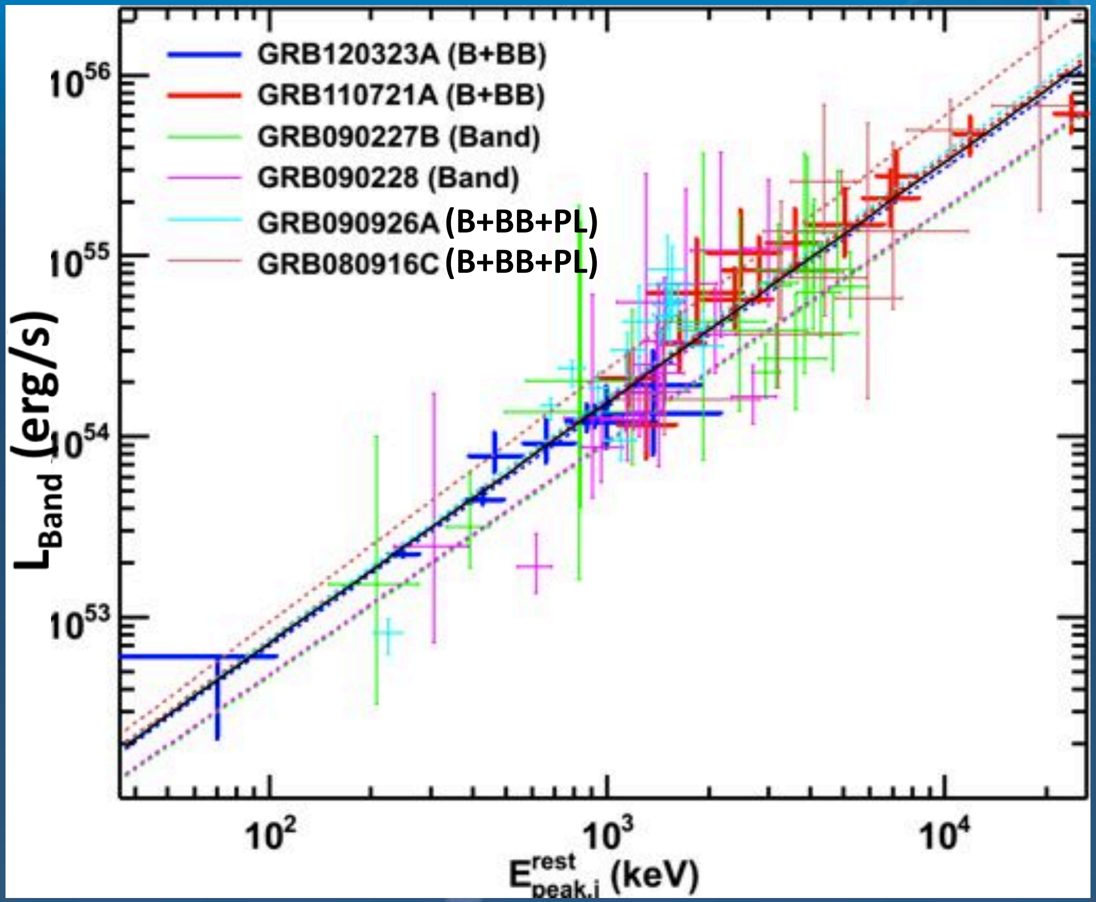




$$L_i^{Band} = (1.59 \pm 0.84) 10^{50} \; (E^{rest}_{peak,i})^{1.33 \pm 0.07} \mathrm{erg \; s^{-1}}$$

- Short and long GRBs follow the same correlation

The L_{Band}-E_{peak} Relation



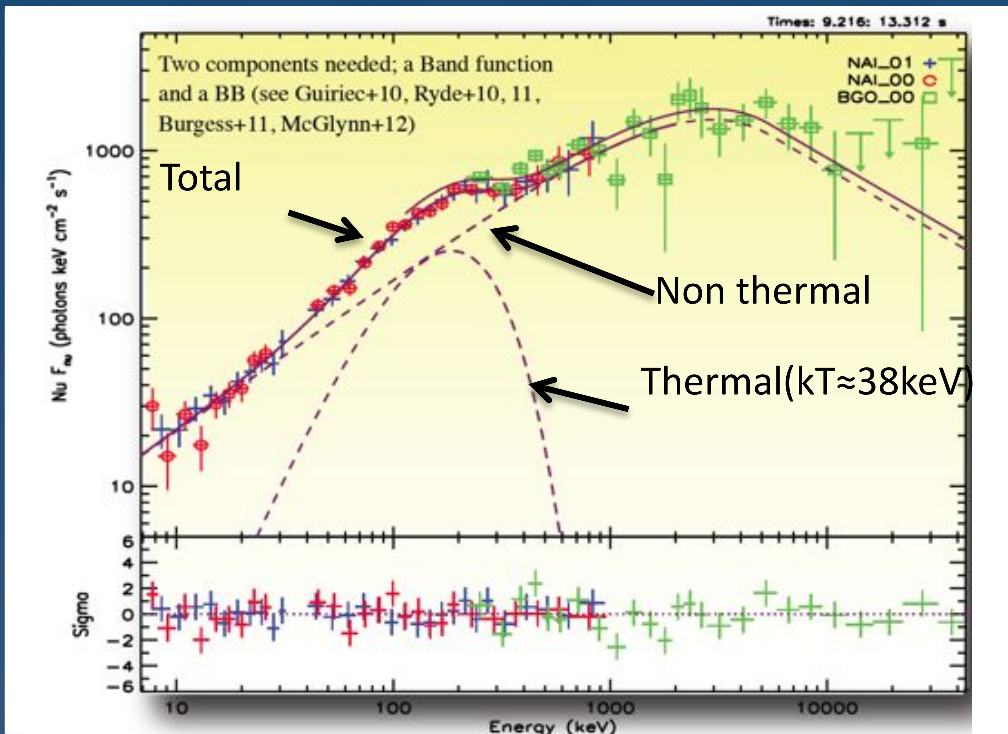
- When corrected from the redshift (source frame), data points are very well aligned
- Dispersion could be due to other parameters not included in this analysis yet.
- An intrinsic phenomenon seems to be responsible for this correlation.
- Beyond a possible identification of the emission mechanism this correlation could eventually be used as an estimator of the redshift.

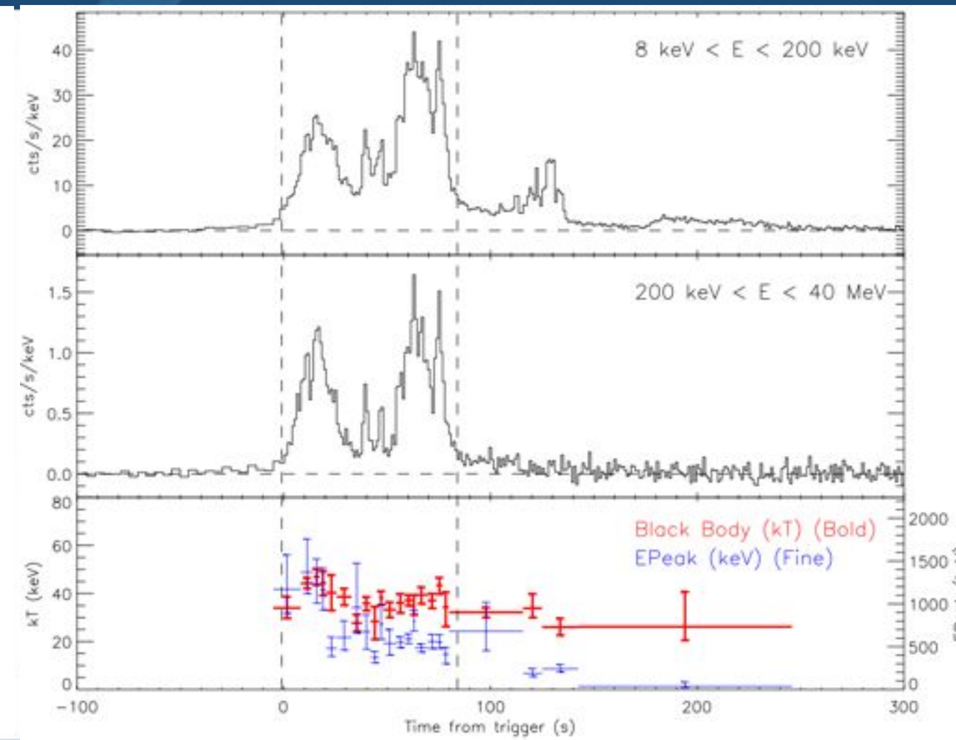
!!! LIMITED SAMPLE OF BURSTS !!!

BACKUP

Thermal Emission

GRB 100724B



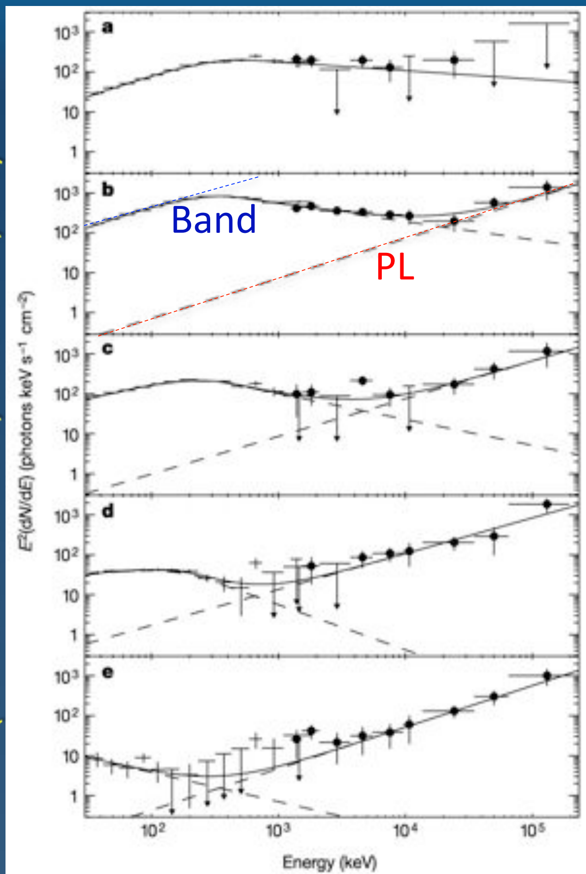


(Guiriec et al. 2011, ApJL 727, L33)

- E_{peak} and kT evolve independently.
- kT evolution : constant or slow cooling, or clear cooling.
- With BB, Band more compatible with synchrotron models.

Additional Power Law to the Band Function

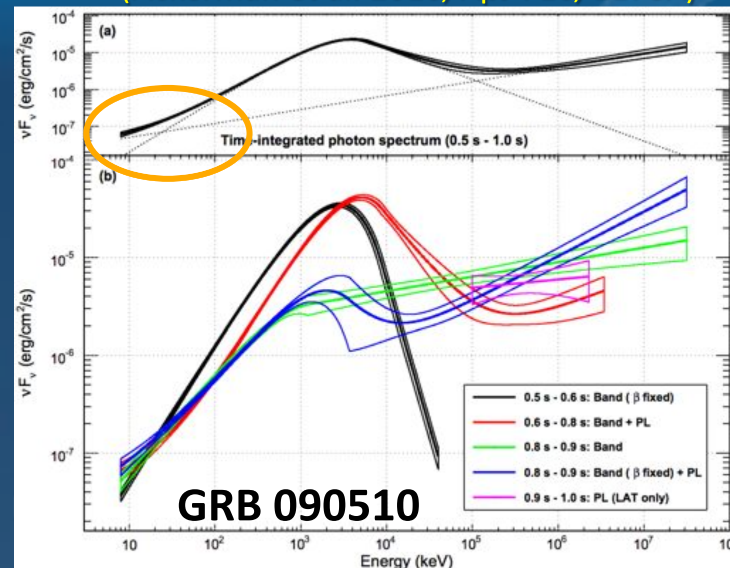
CGRO



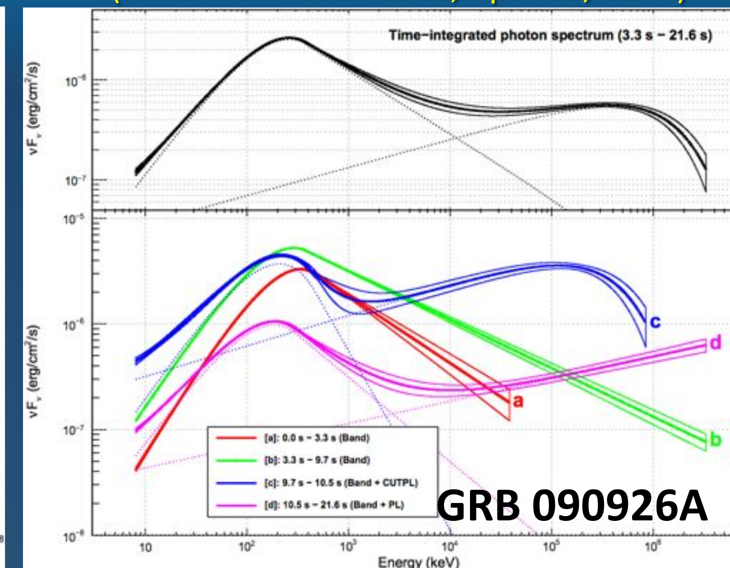
(Gonzalez et al. 2003, Nature 424, 749)

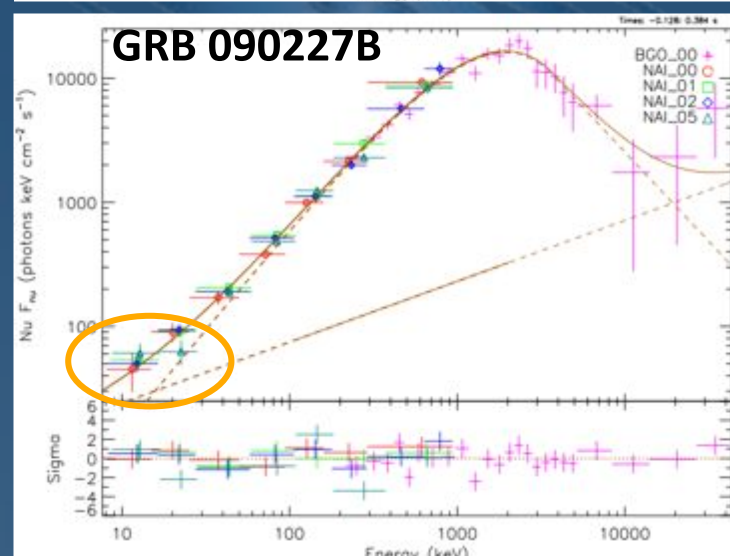
Fermi

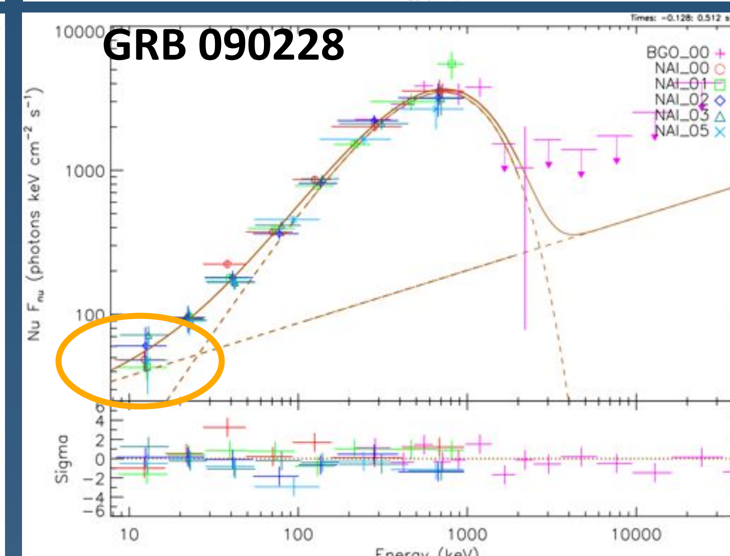
(Ackerman et al. 2010, ApJ 716, 1178A)



(Ackermann et al. 2011, ApJ 729, 114A)





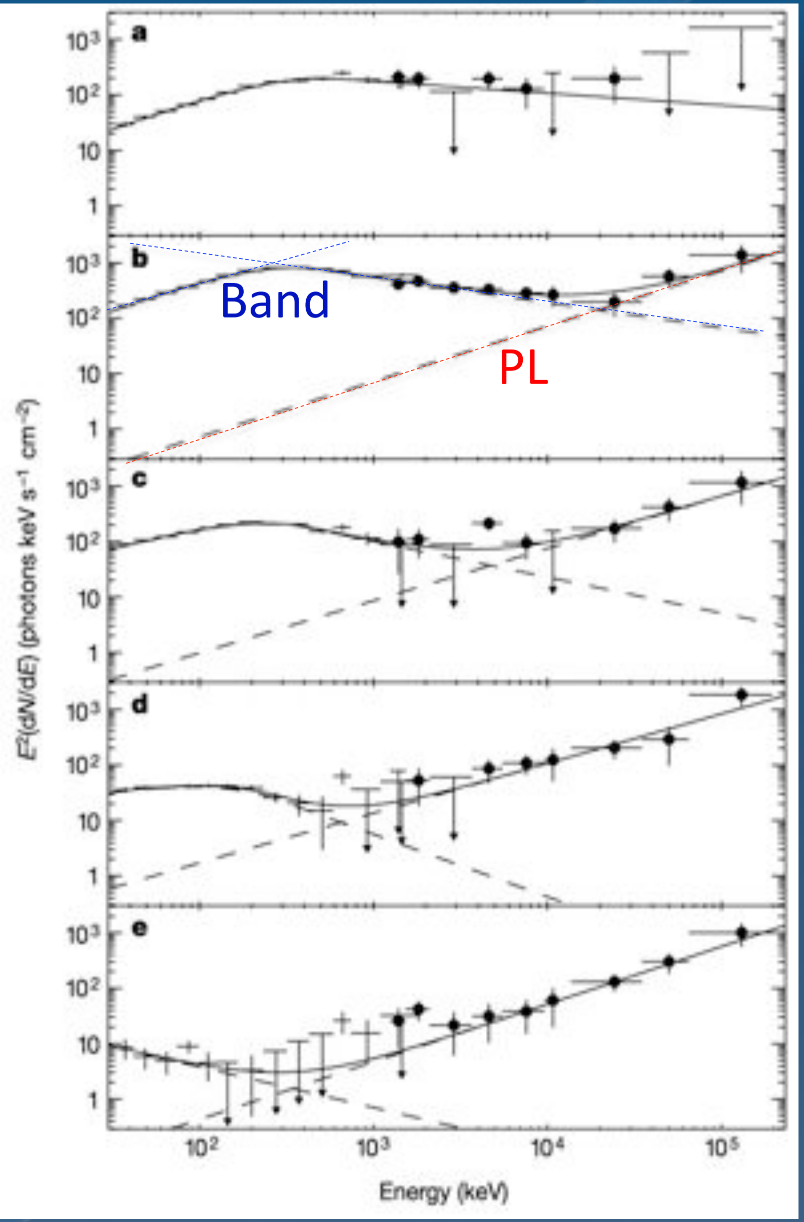


(Guiriec et al. 2010, ApJ 725, 225G)

- **Additional PL can be identified in GBM data alone.**
- **PL overpowers the Band spectrum at both low and high energy.**
- **Additional PL does not always extend to high energies.**

Deviation from the Band Function (Band+PL)

Before Fermi



(Gonzalez et al. 2003, Nature 424, 749)

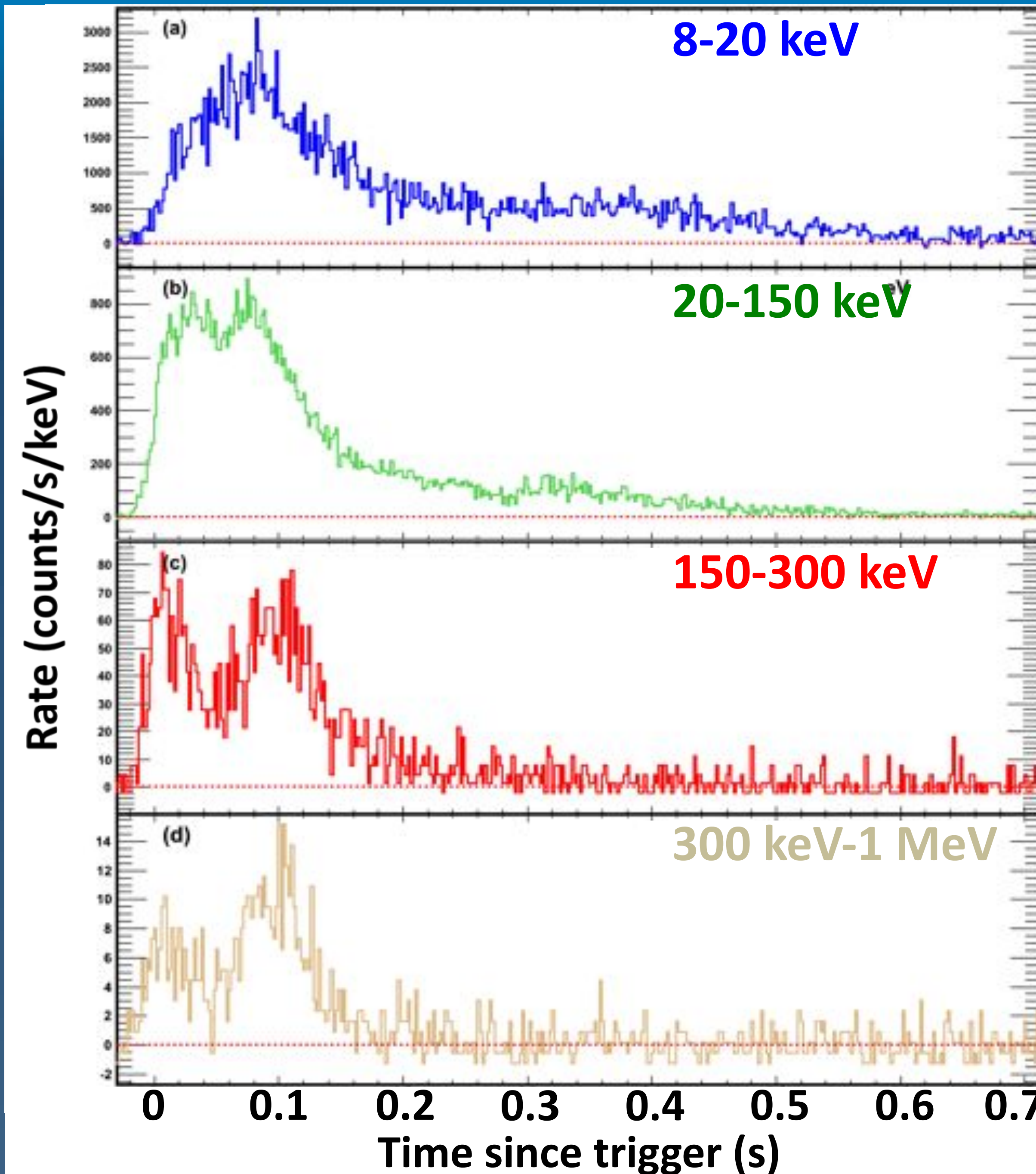
Additional PL not compatible with synchrotron emission.

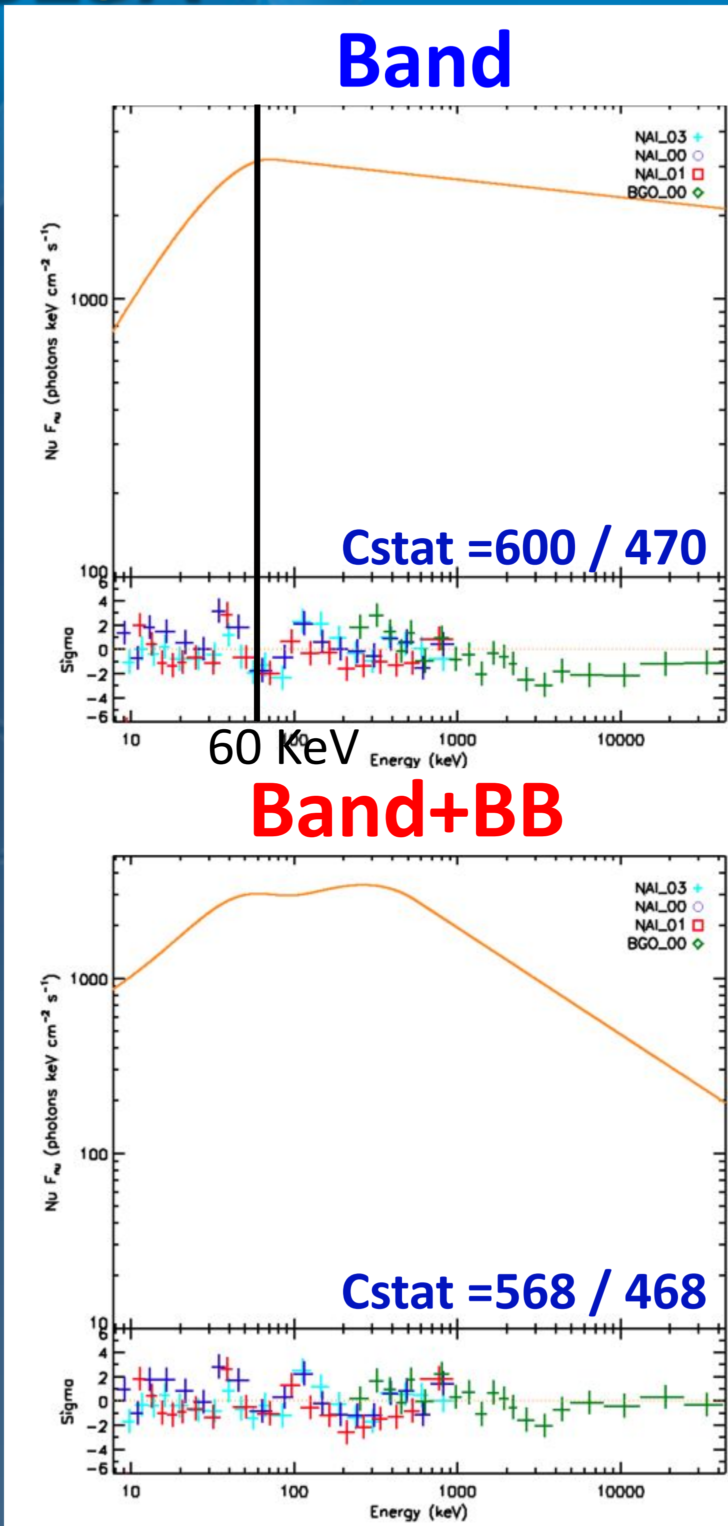
Is GRB 120323A an Unusually Soft and Intense Short GRB

Or

is it a Regular Short GRB with an Intense Additional BB Component (Photospheric) ?

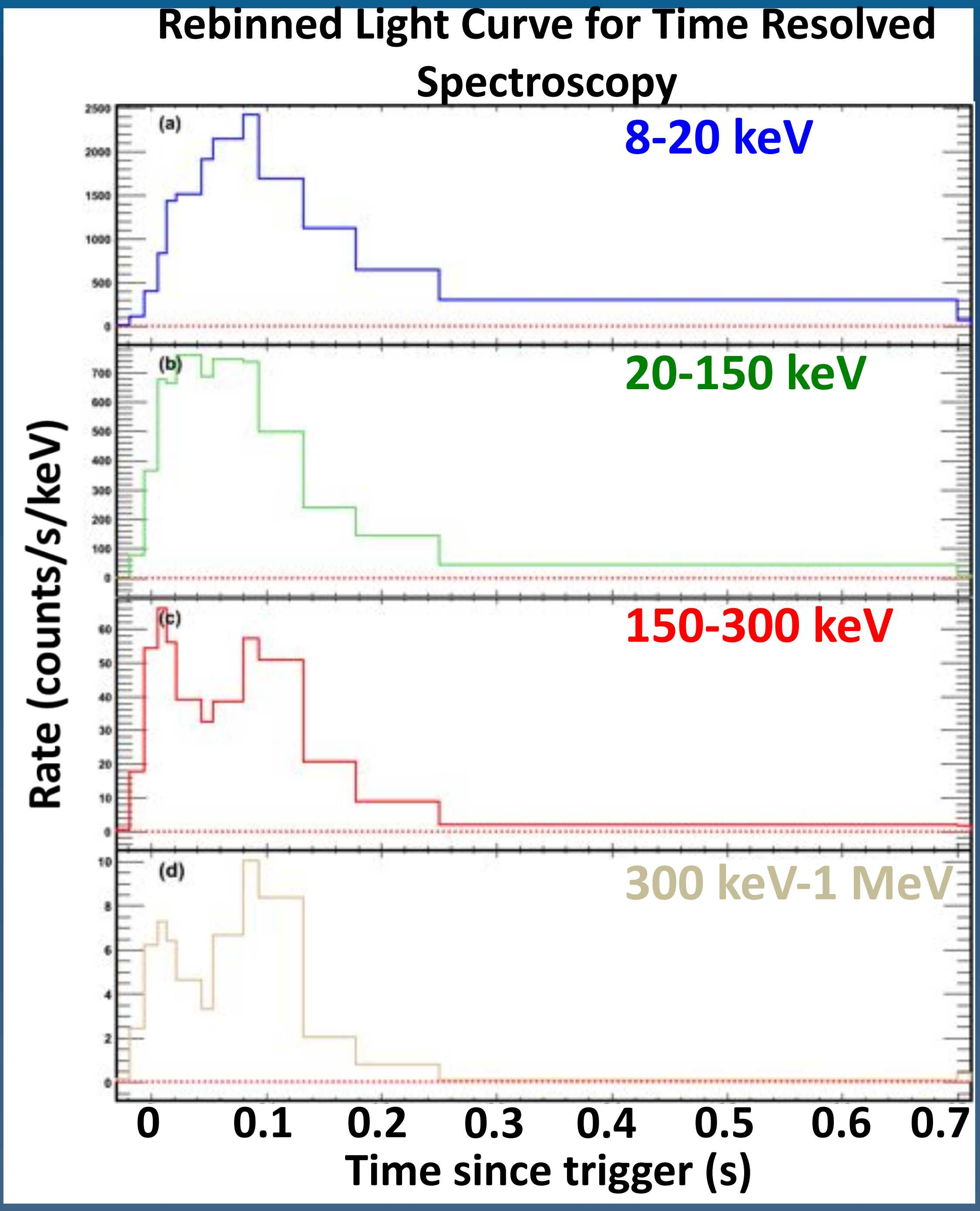
Short GRB 120323A

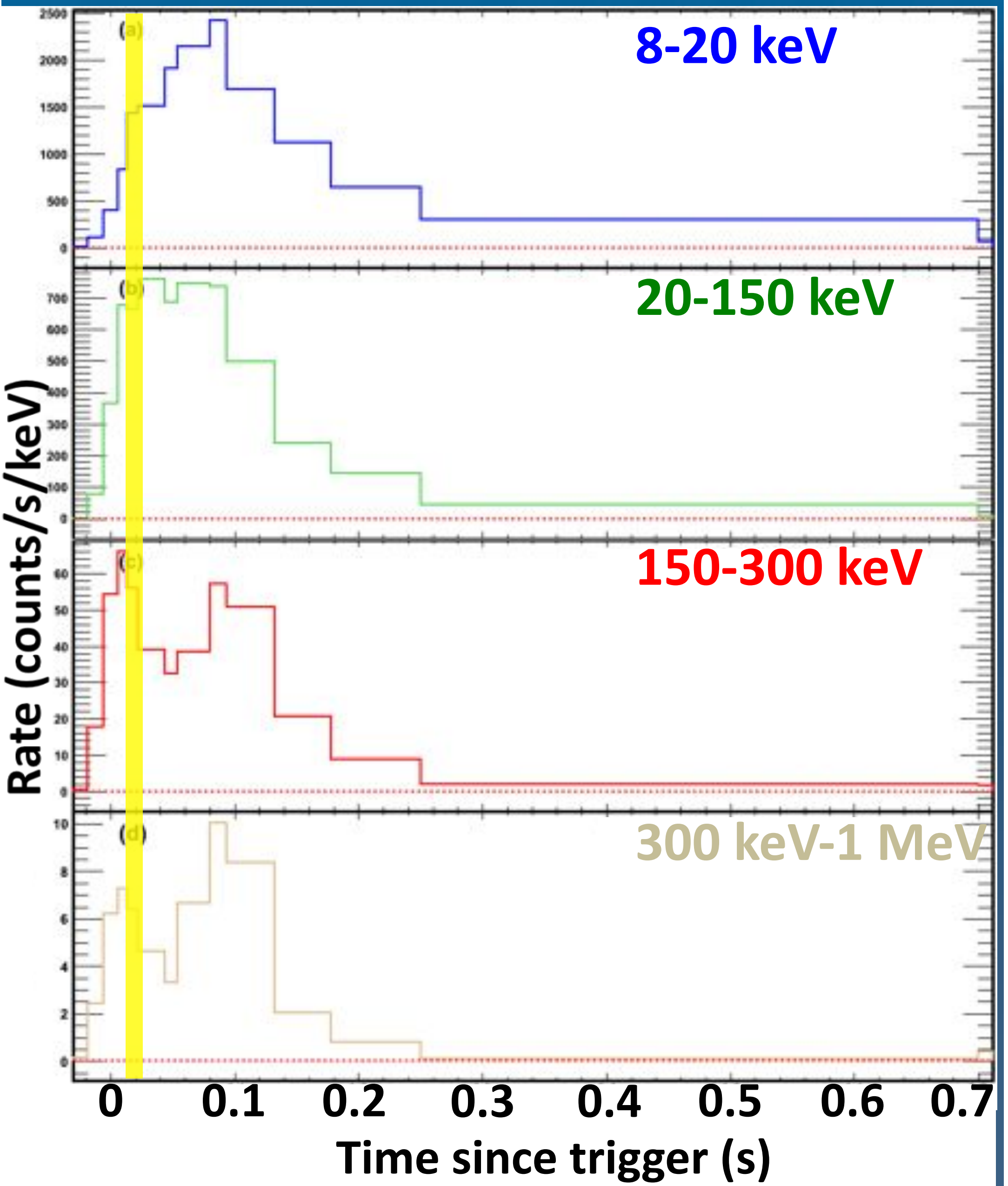




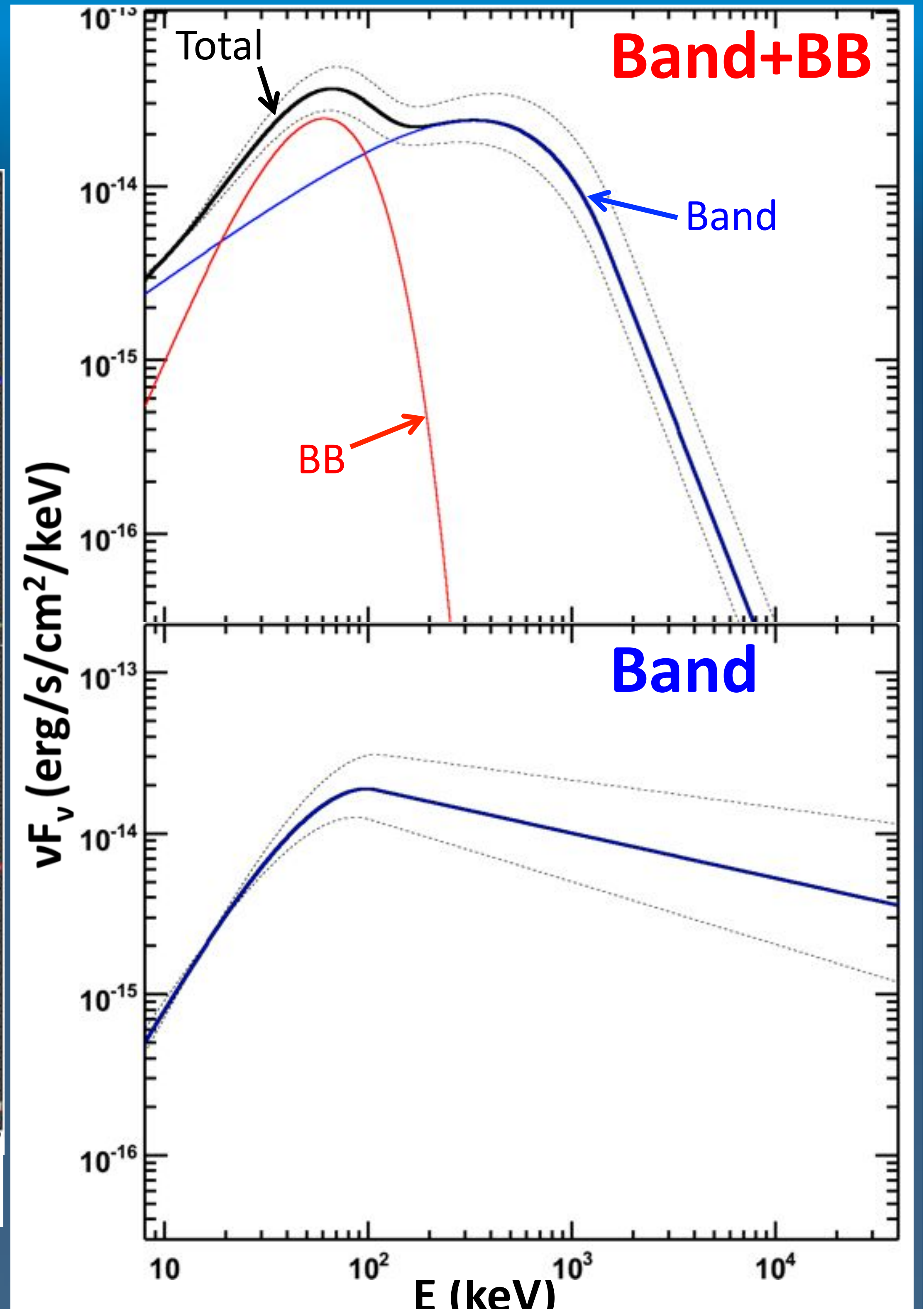
Unusually intense and soft short GRB when fit with a Band function.

An Unusually Soft Short GRB or a Regular Short GRB with an Intense Blackbody ?

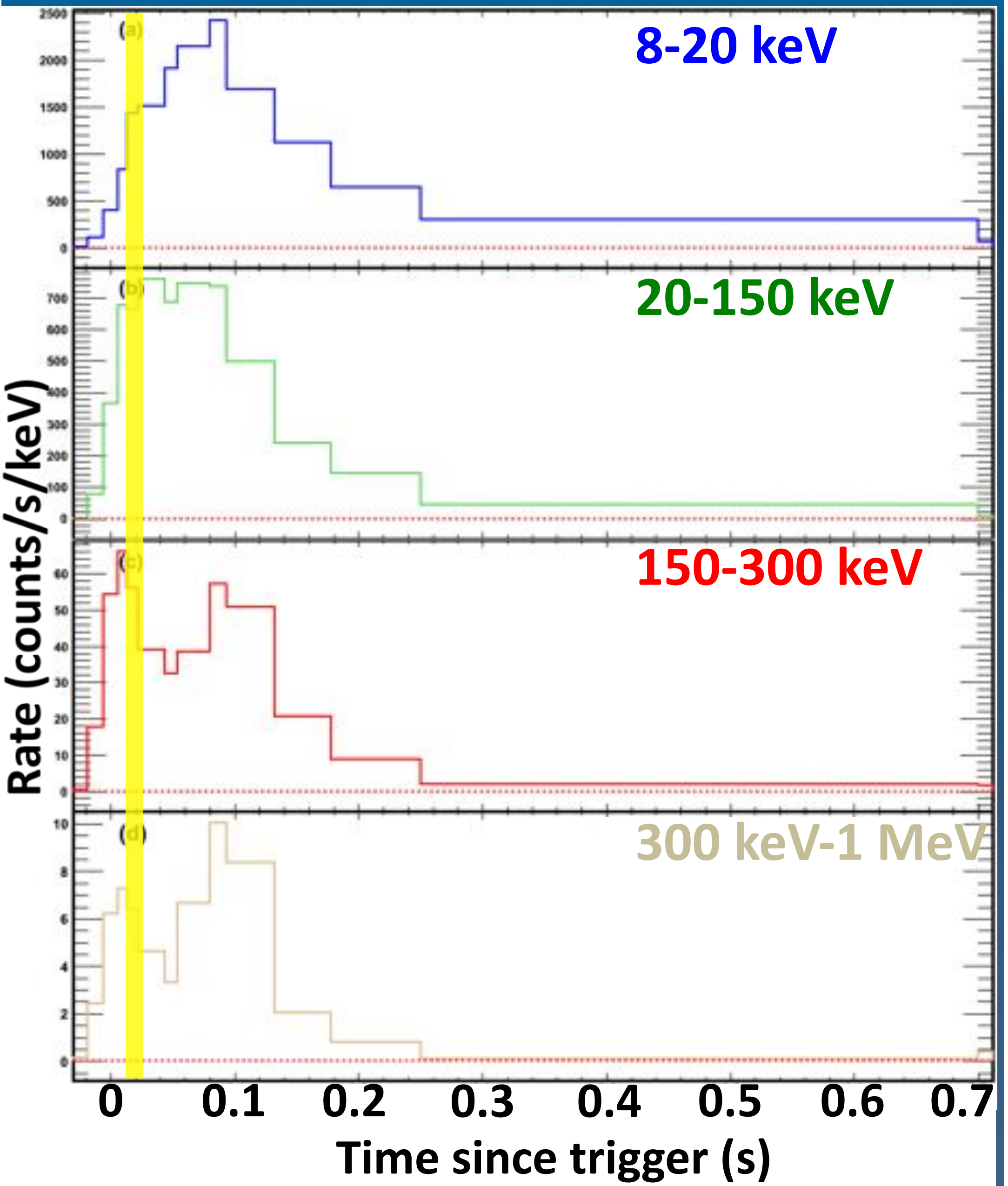


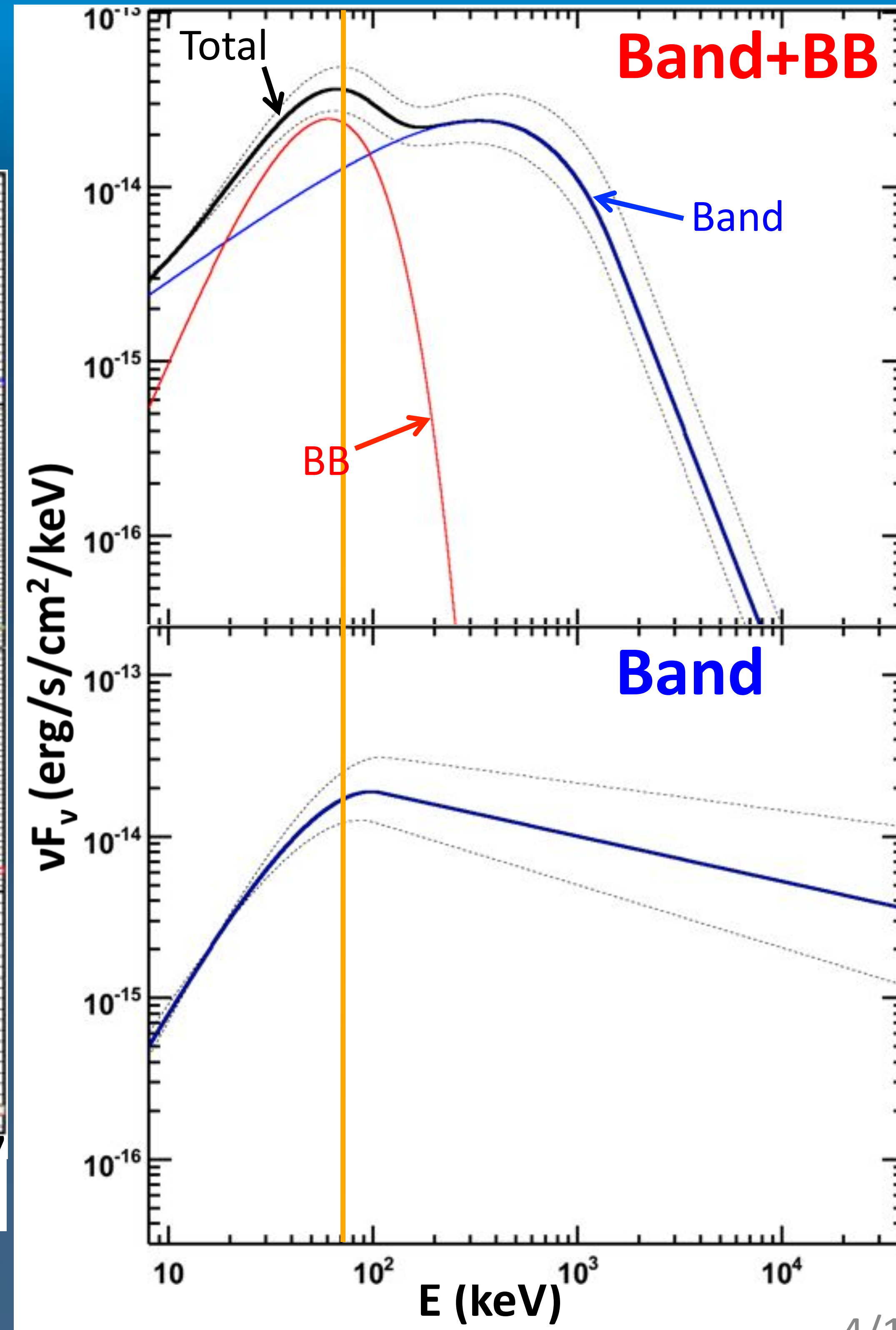


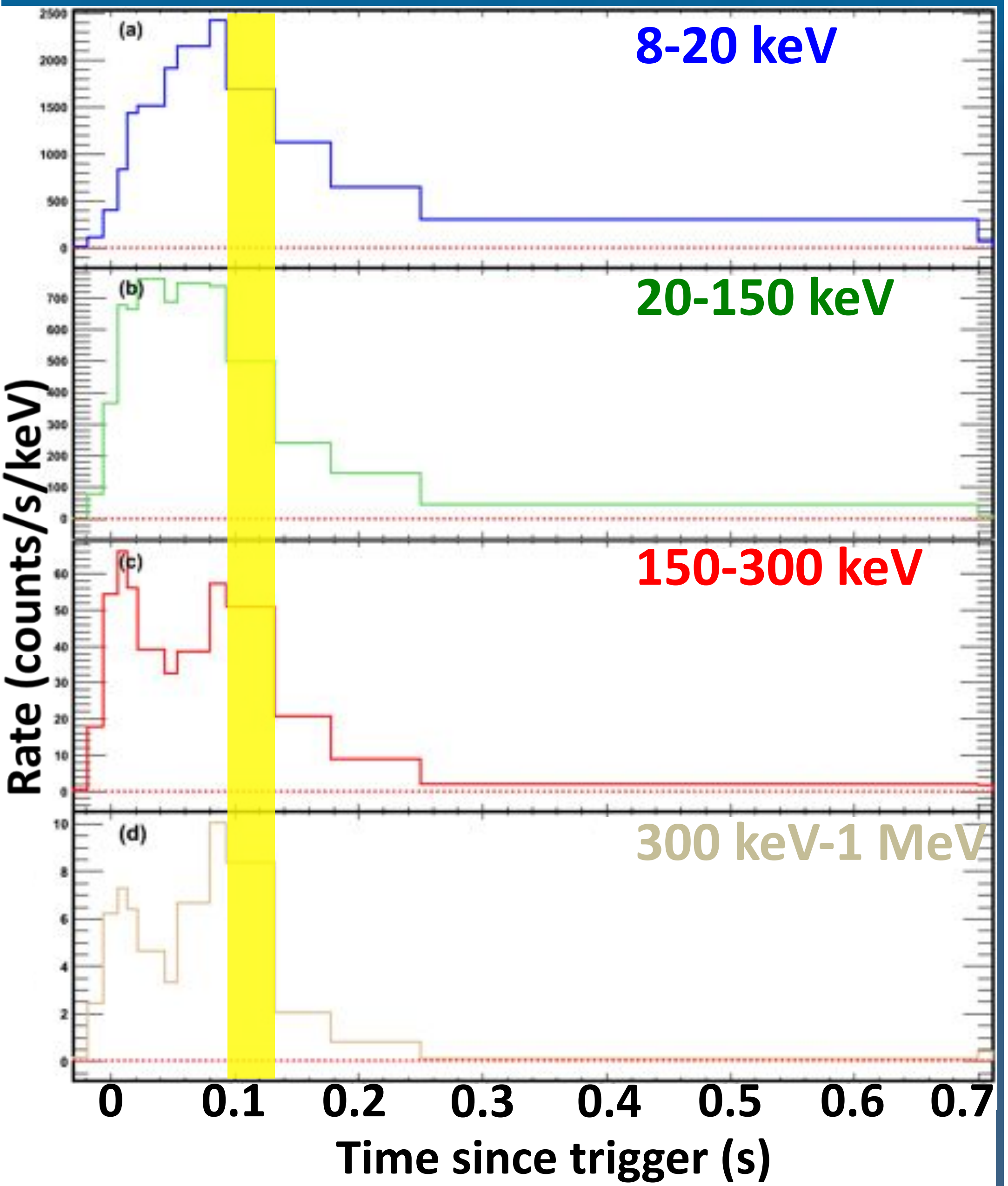
8-20 keV
20-150 keV
150-300 keV
300 keV-1 MeV
Rate (counts/s/keV)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Time since trigger (s)

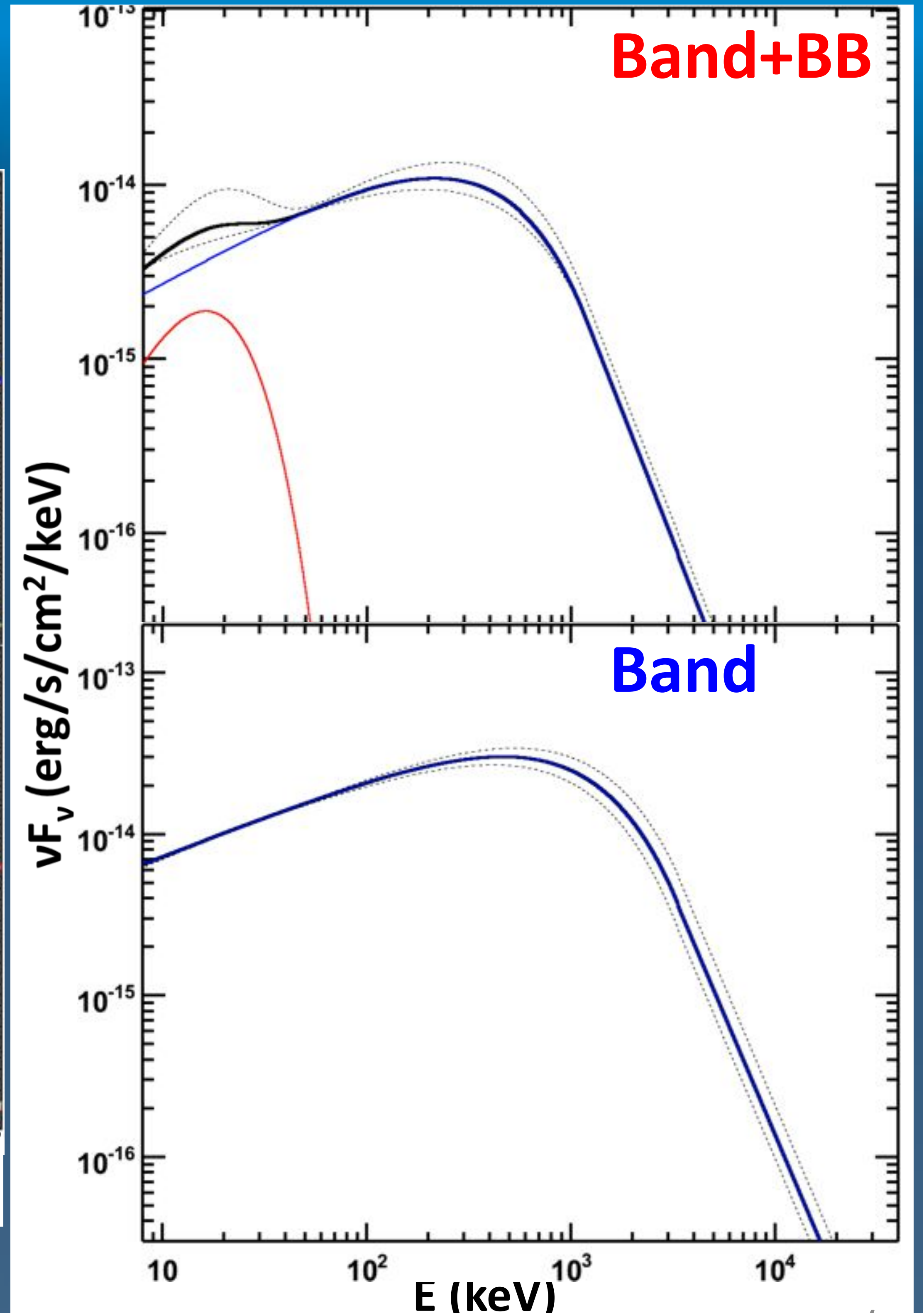


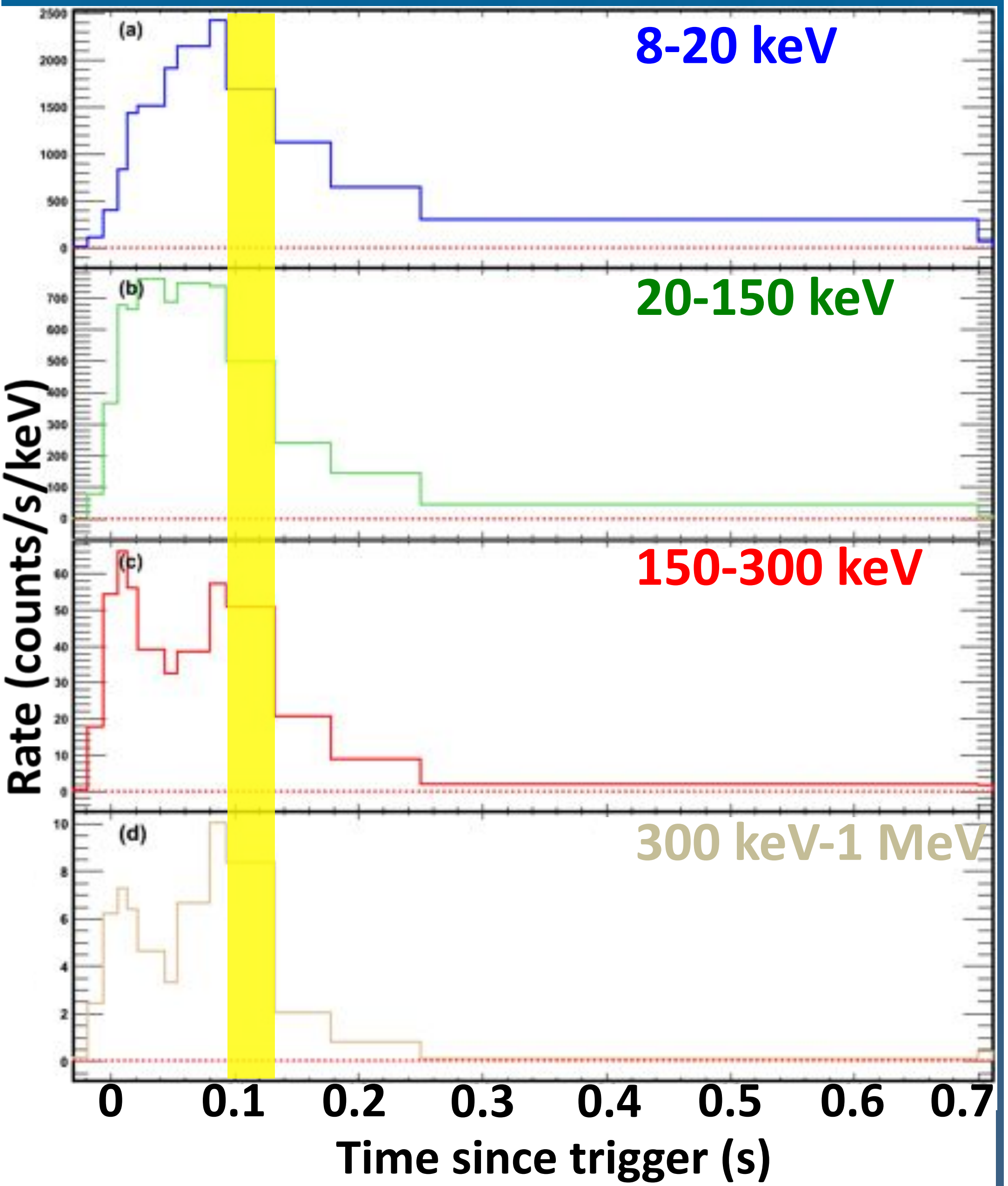
Band+BB
Total
Band
BB
Band
νF_ν (erg/s/cm^2/keV)
E (keV)


8-20 keV
20-150 keV
150-300 keV
300 keV-1 MeV
Rate (counts/s/keV)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Time since trigger (s)

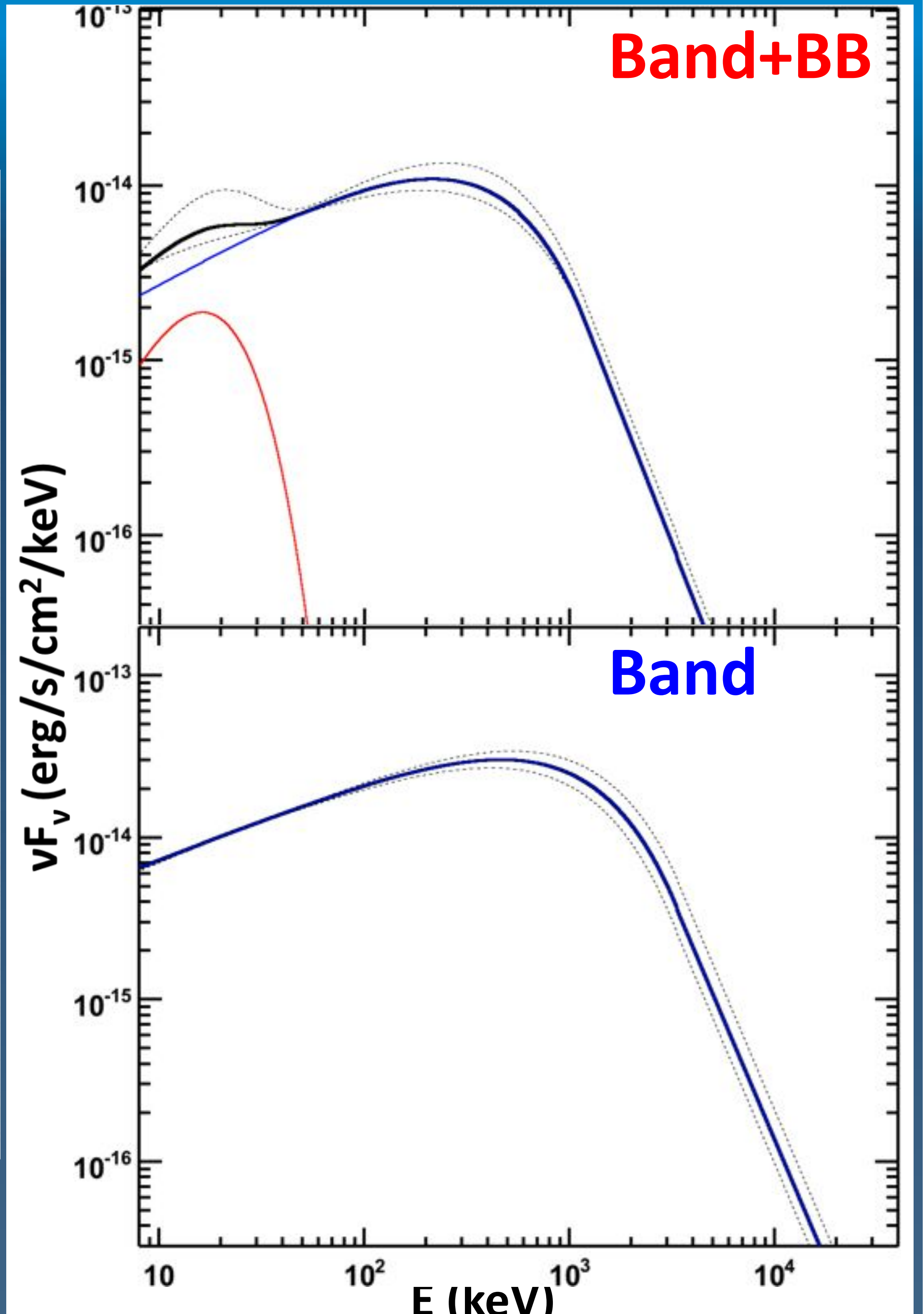

Band+BB
Total
Band
BB
Band
νF_ν (erg/s/cm^2/keV)
10^{-13}
10^{-14}
10^{-15}
10^{-16}
10
10^2
10^3
10^4
E (keV)


8-20 keV
20-150 keV
150-300 keV
300 keV-1 MeV
(a)
(b)
(c)
(d)
Rate (counts/s/s/keV)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Time since trigger (s)


Band+BB
Band
νF_ν (erg/s/cm^2/keV)
10
10^2
10^3
10^4
E (keV)

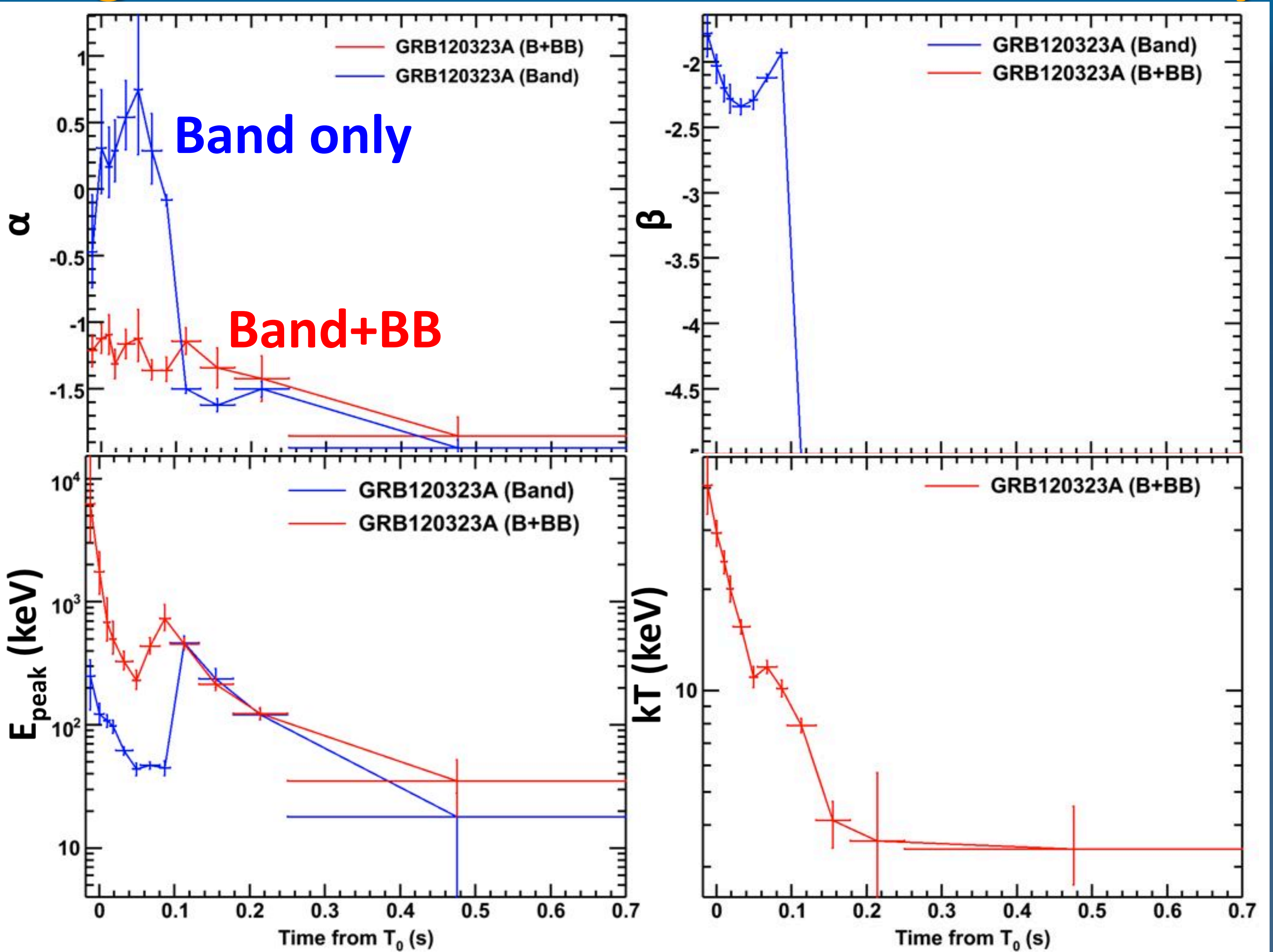


(a)
8-20 keV
(b)
20-150 keV
(c)
150-300 keV
(d)
300 keV-1 MeV
Rate (counts/s/keV)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Time since trigger (s)

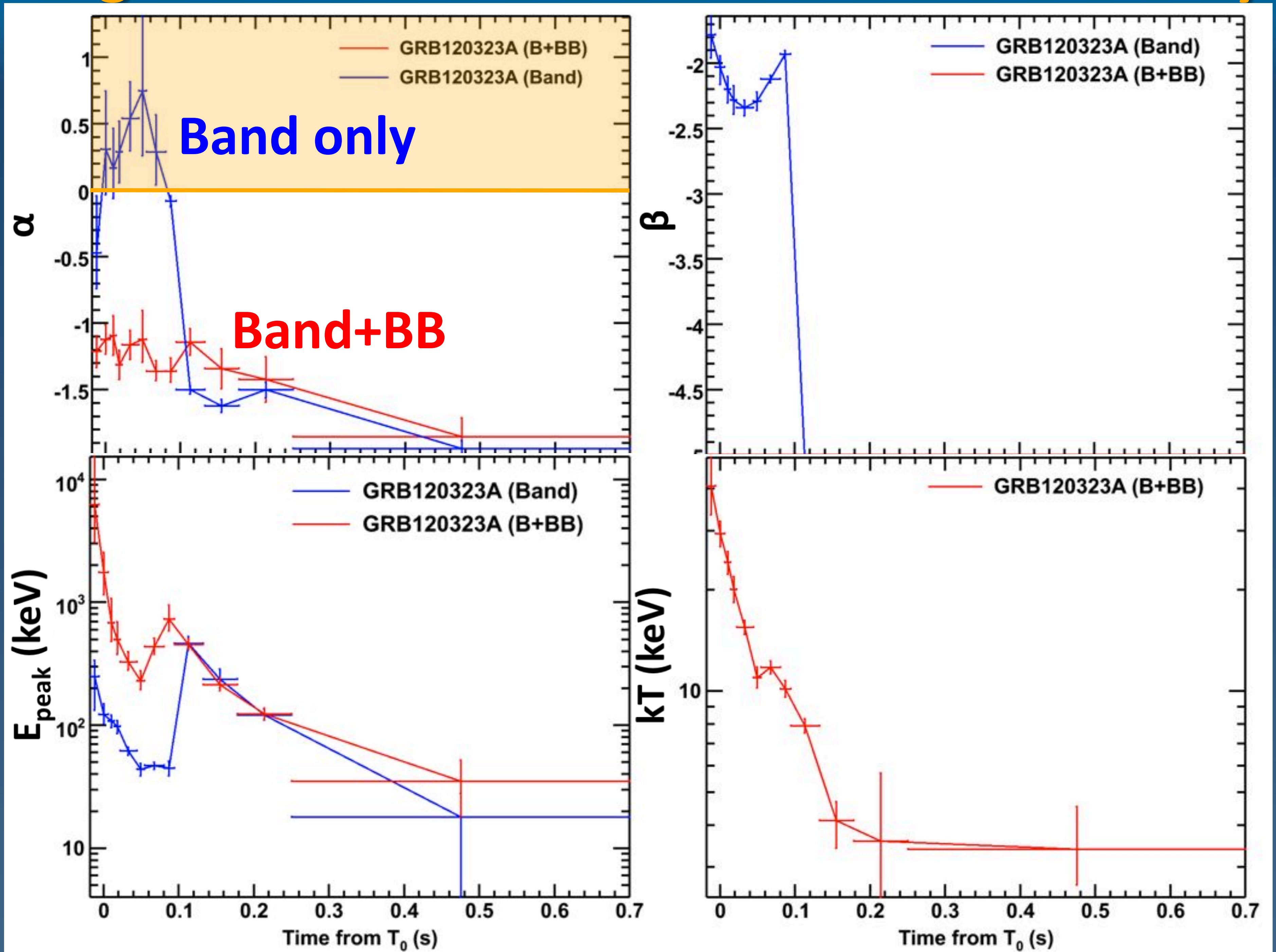


Band+BB
Band
νF$_\nu$ (erg/s/cm^2/keV)
10
10^2
10^3
10^4
E (keV)

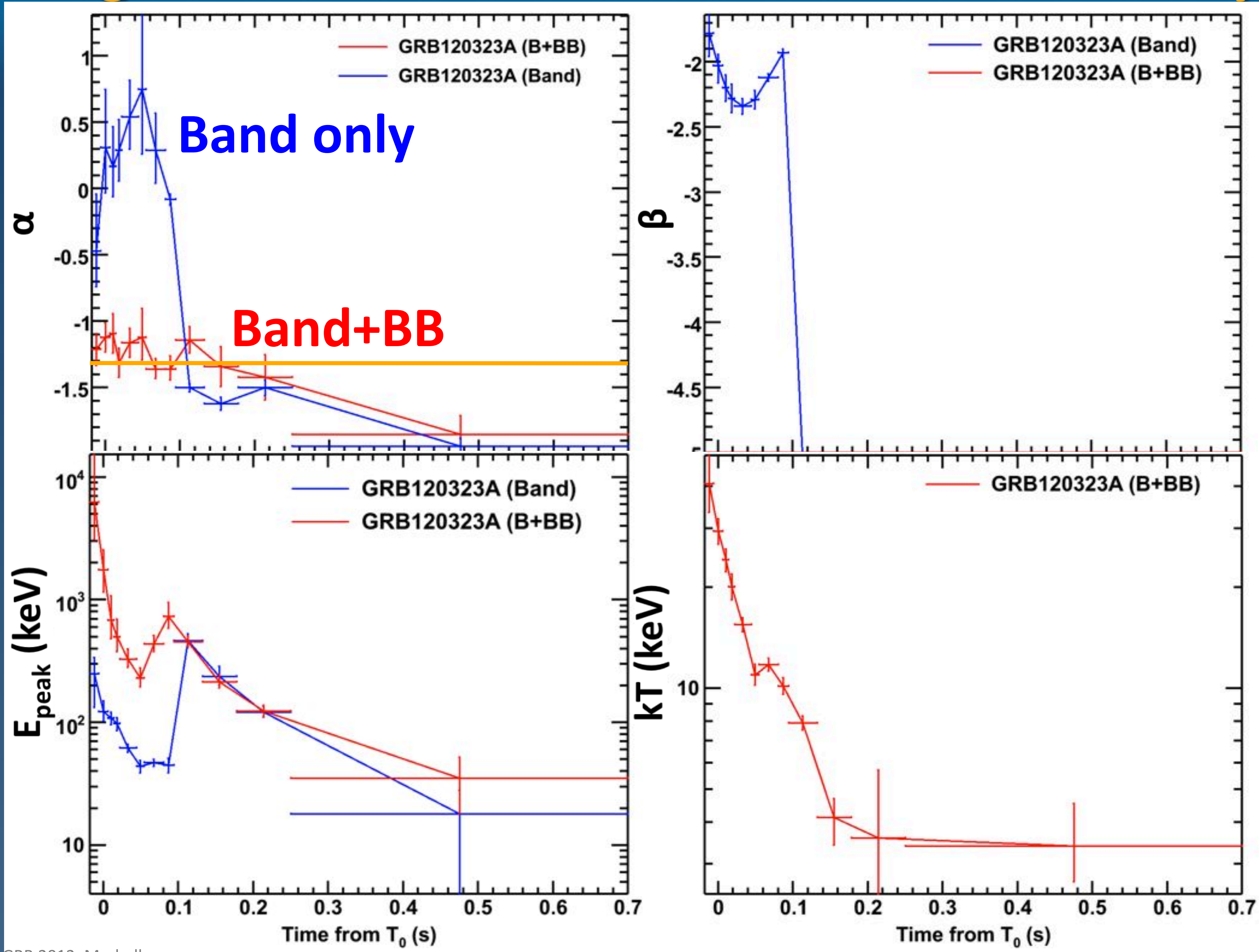
An Unusually Soft Short GRB or a Regular Short GRB with an Intense Blackbody ?



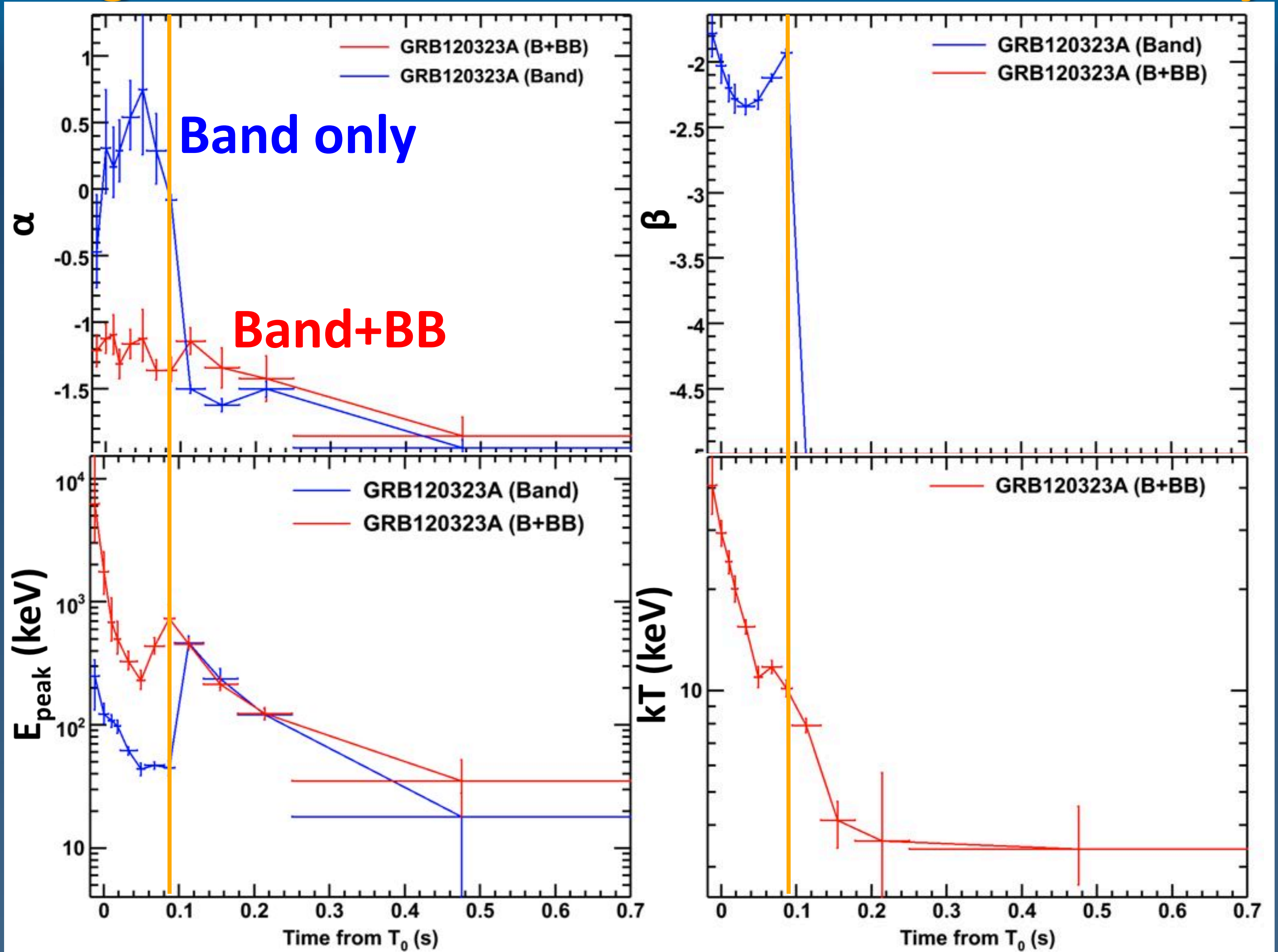
An Unusually Soft Short GRB or a Regular Short GRB with an Intense Blackbody ?



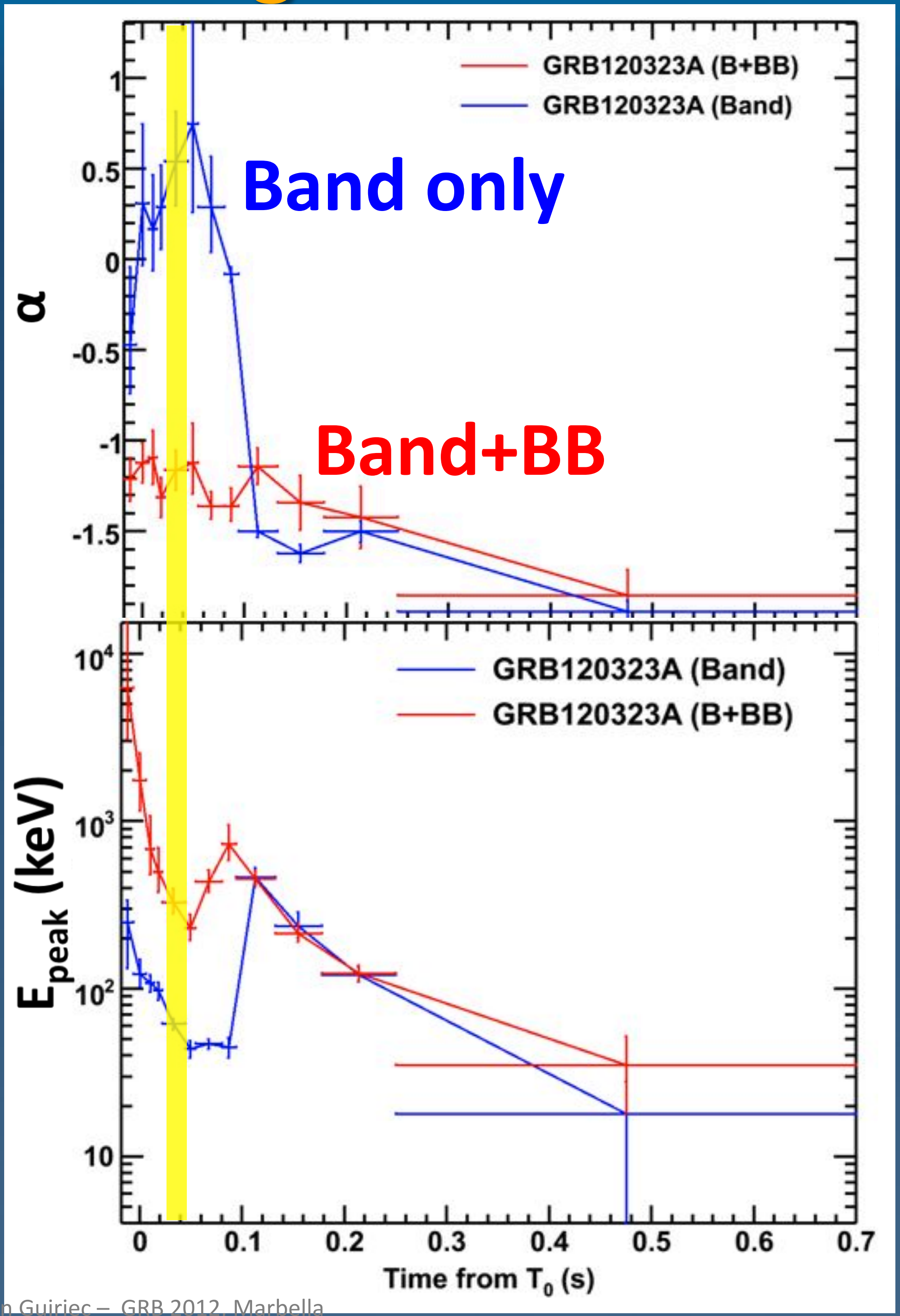
An Unusually Soft Short GRB or a Regular Short GRB with an Intense Blackbody ?

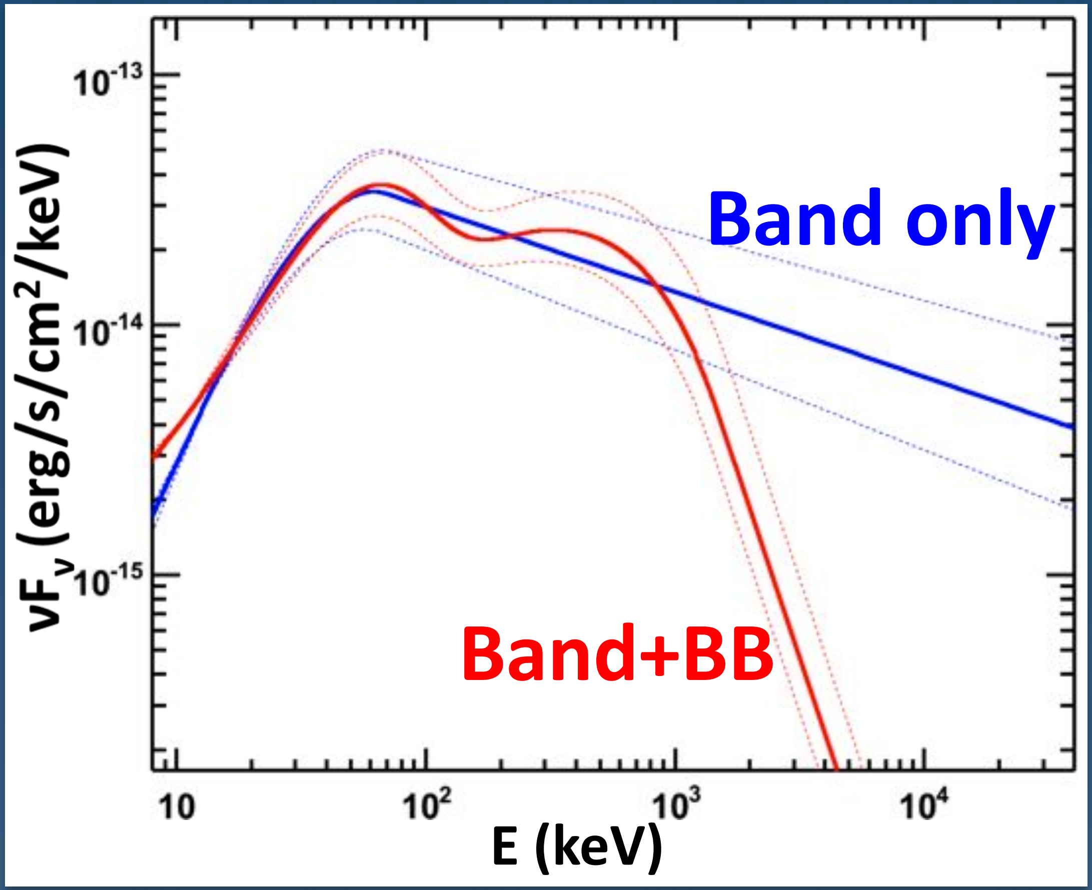


An Unusually Soft Short GRB or a Regular Short GRB with an Intense Blackbody ?

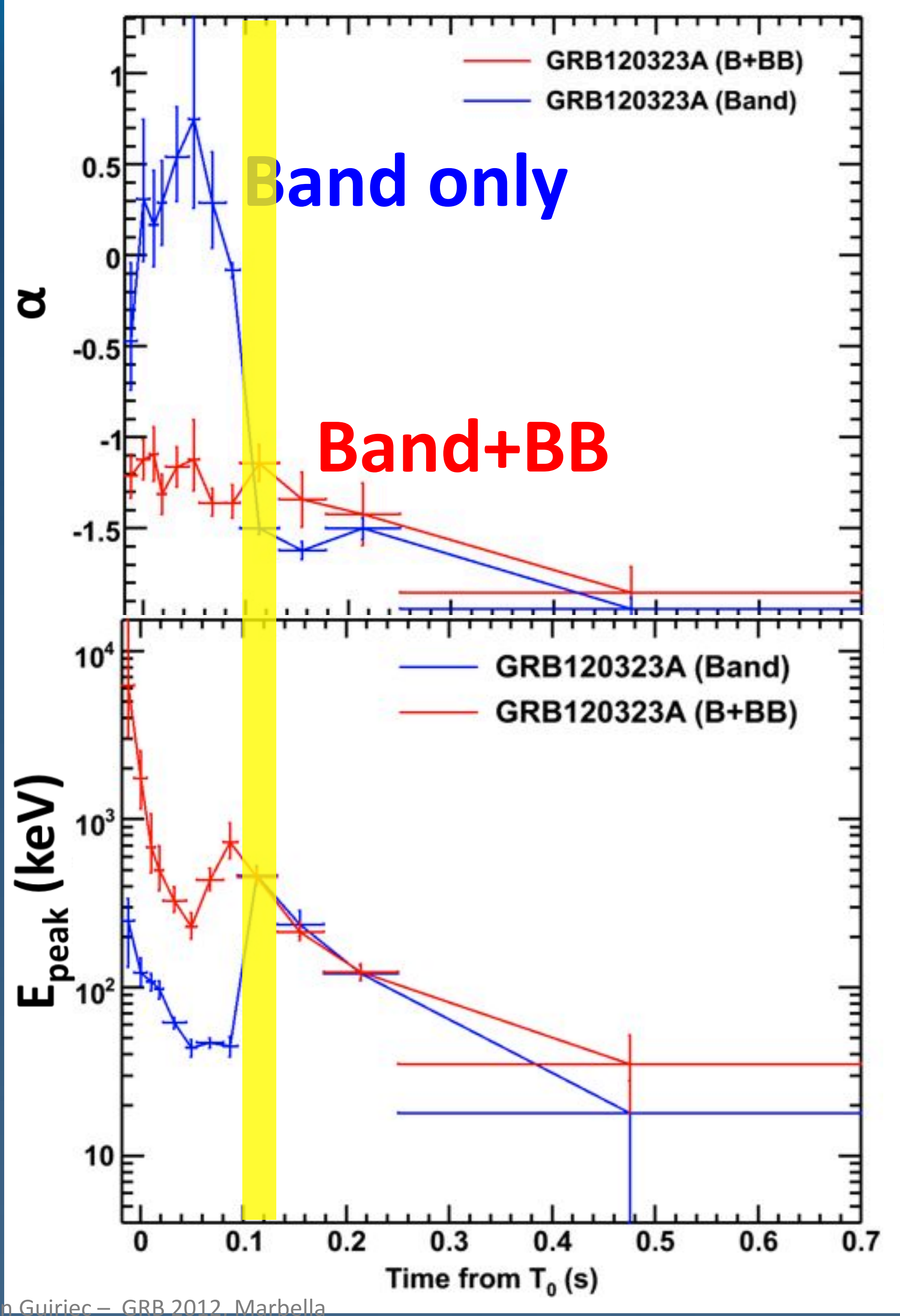


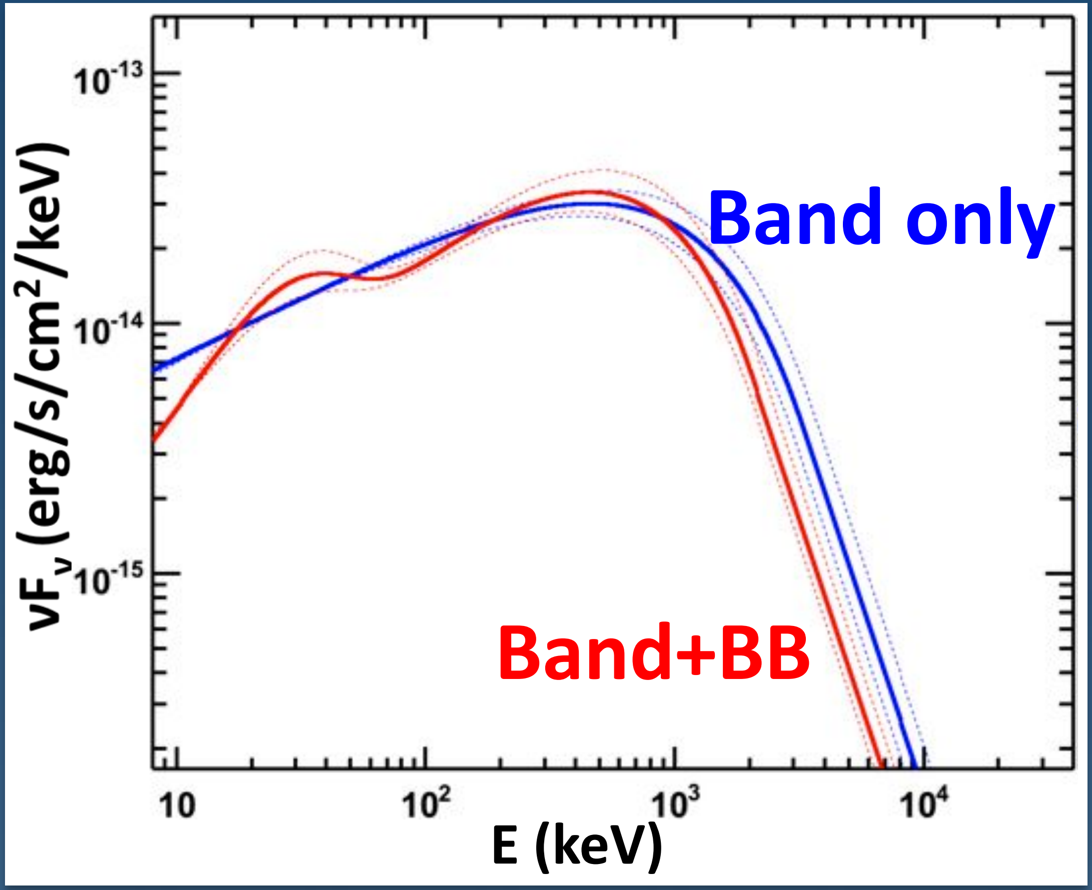
An Unusually Soft Short GRB or a Regular Short GRB with an Intense Blackbody ?





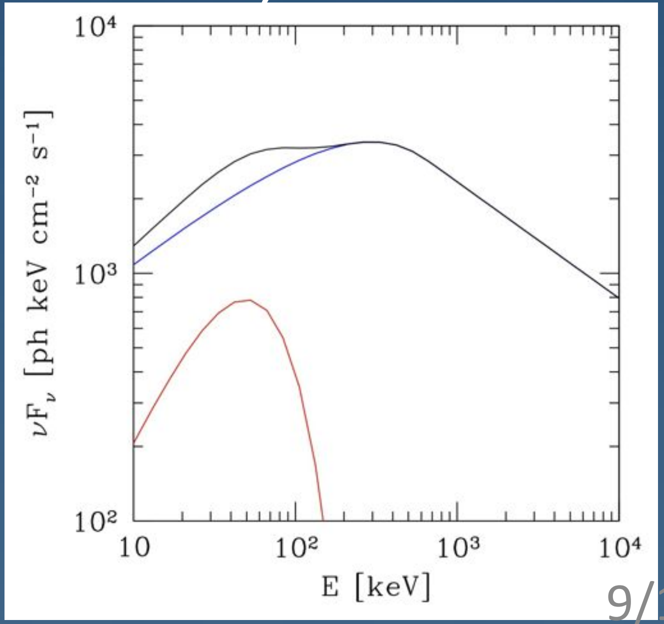
An Unusually Soft Short GRB or a Regular Short GRB with an Intense Blackbody ?





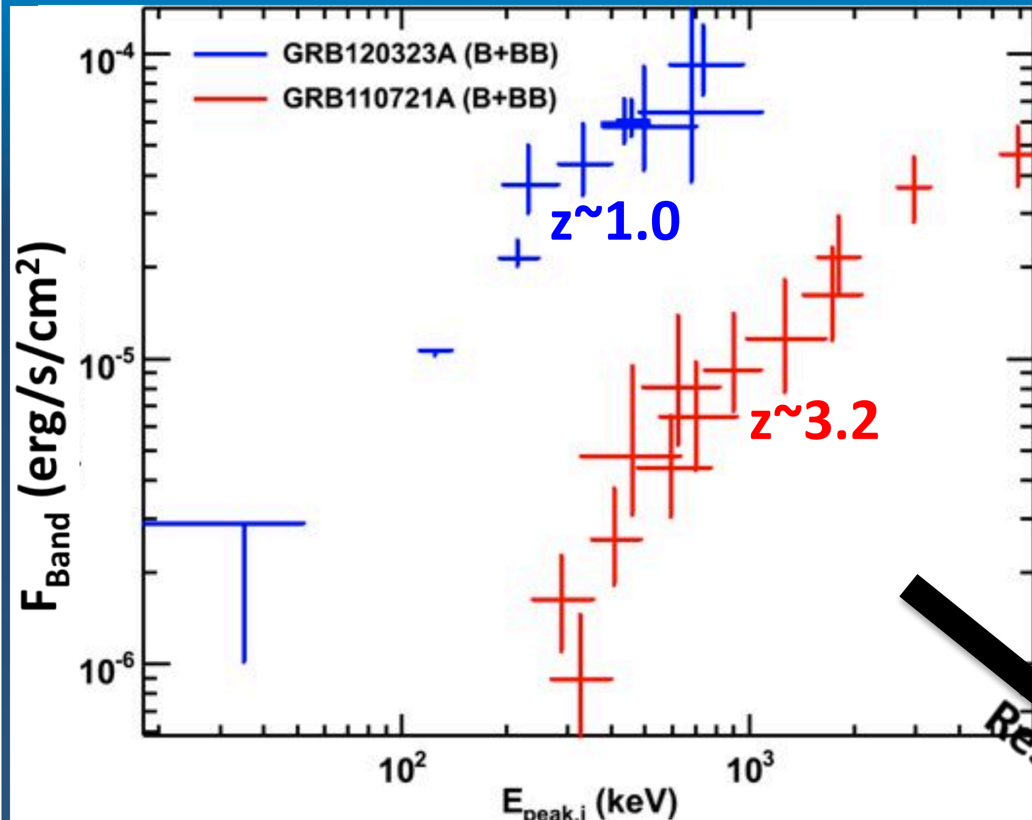
Interpretation

Band Only Scenario	Band+BB Scenario
• Photospheric origin with additional dissipative processes at the photosphere Or • Photospheric emission followed with non-thermal radiation	• Synchrotron emission in electron fast cooling regime together with subdominant photospheric emission. • Jet thermally accelerated or high magnetization close to the source and energy mostly converted into kinetic energy below the photosphere (low magnetization far from the source)

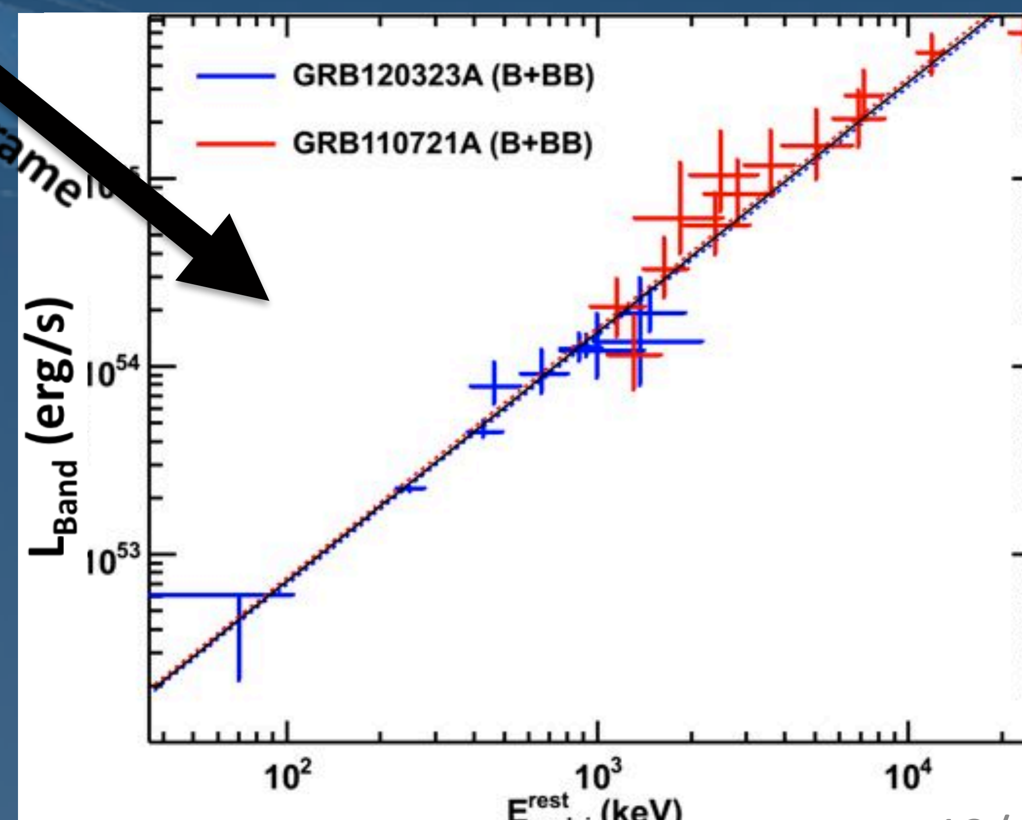


Impact of the Photospheric Emission on the Flux-E_{peak} and Luminosity-E_{peak} Relations

The L_{Band}-E_{peak} Relation



Rest Frame



$$L^{Band}_{120323A,i} = (1.57 \pm 1.26)10^{50}\ (E^{rest}_{peak,i})^{1.32 \pm 0.13} \mathrm{erg\ s^{-1}}$$

$$L^{Band}_{110721A,i} = (1.65 \pm 2.64)10^{50}\ (E^{rest}_{peak,i})^{1.34 \pm 0.19} \mathrm{erg\ s^{-1}}$$

$$L^{Band}_{i} = (1.60 \pm 0.65)10^{50}\ (E^{rest}_{peak,i})^{1.33 \pm 0.06} \mathrm{erg\ s^{-1}}$$

Conclusion

• Is GRB 120323A an unusually intense and soft short GRB, or is it a common GRB (based on its Band function) looking like softer because of an intense BB at low energy ?

→ Band+BB scenario seems to be robust.

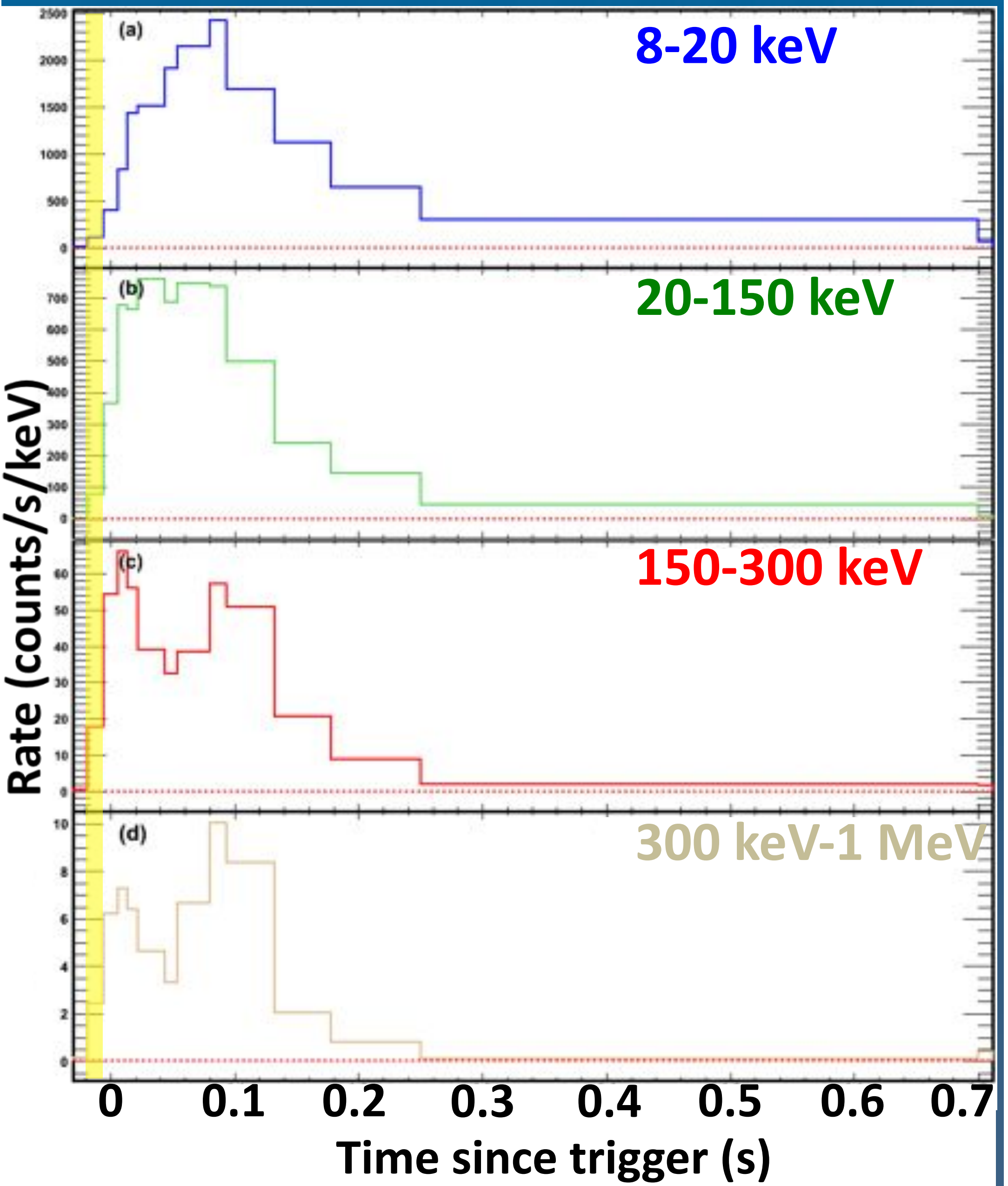
→ Band+BB could be explain by either a jet thermally accelerated or an outflow highly magnetized close to the source whose energy is converted into kinetic energy below the photosphere (and low magnetization at large radius)

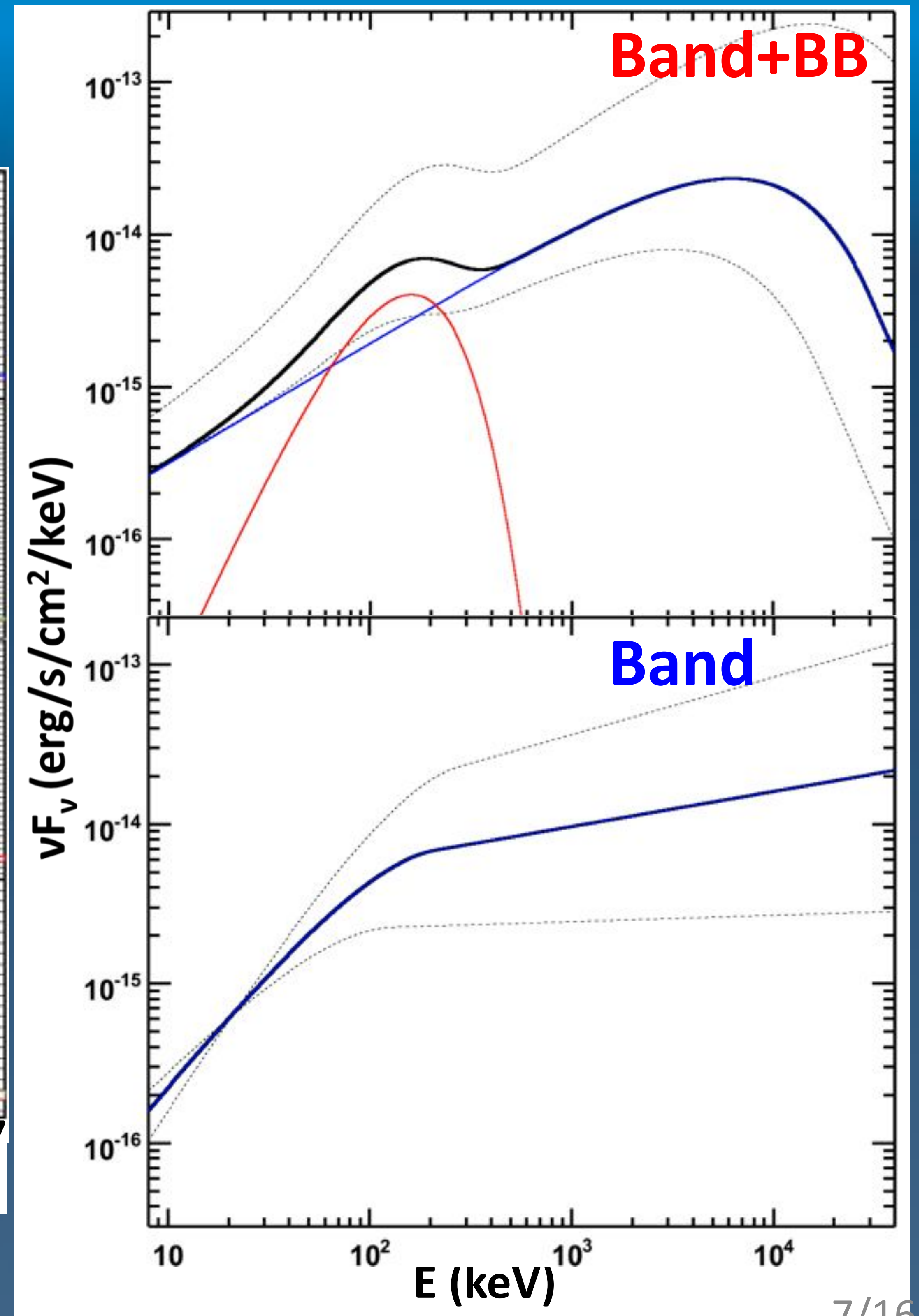
→ Band only scenario could eventually be explain with either photospheric emission only (including dissipative processes) or photospheric emission followed with a non thermal episode.

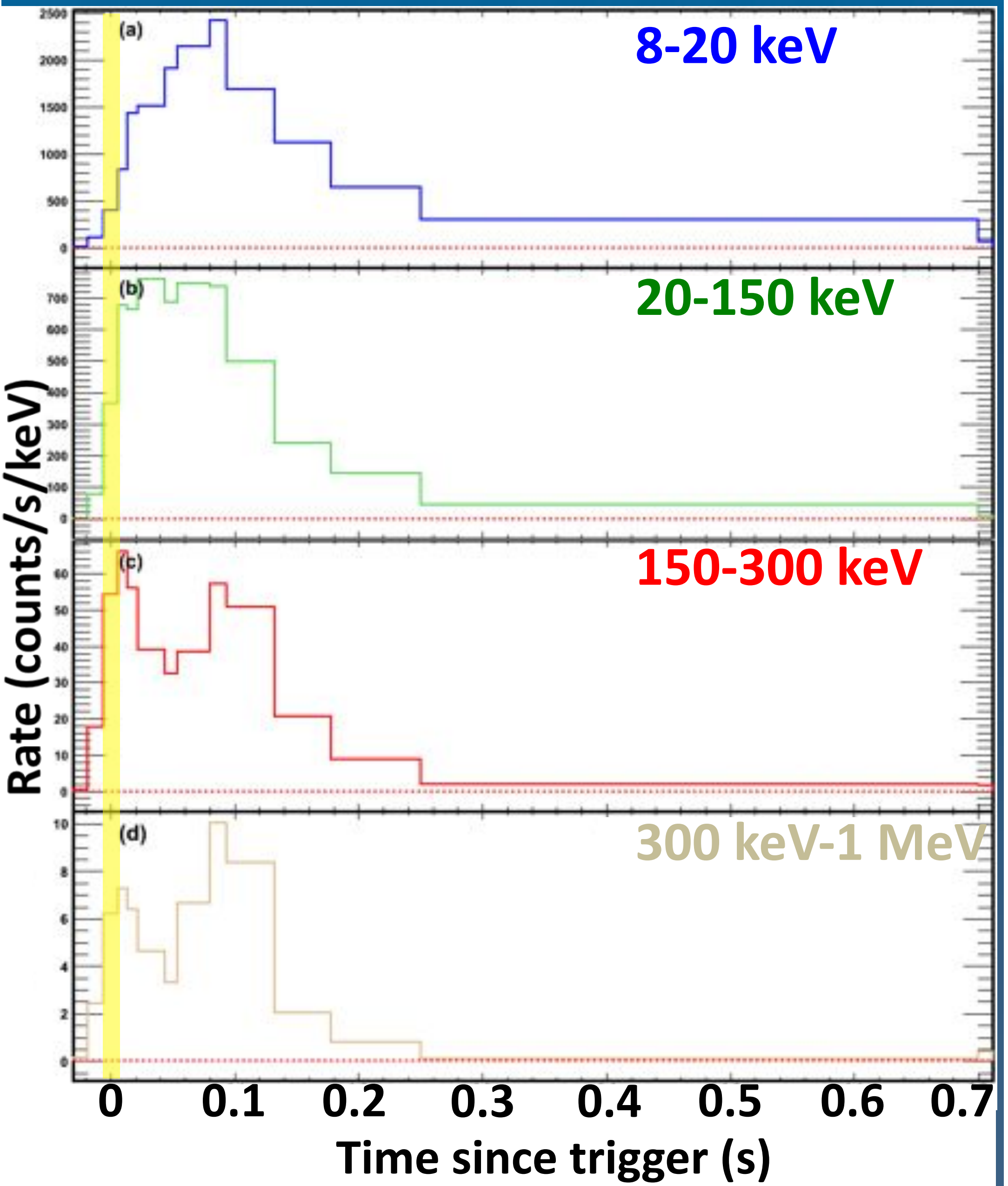
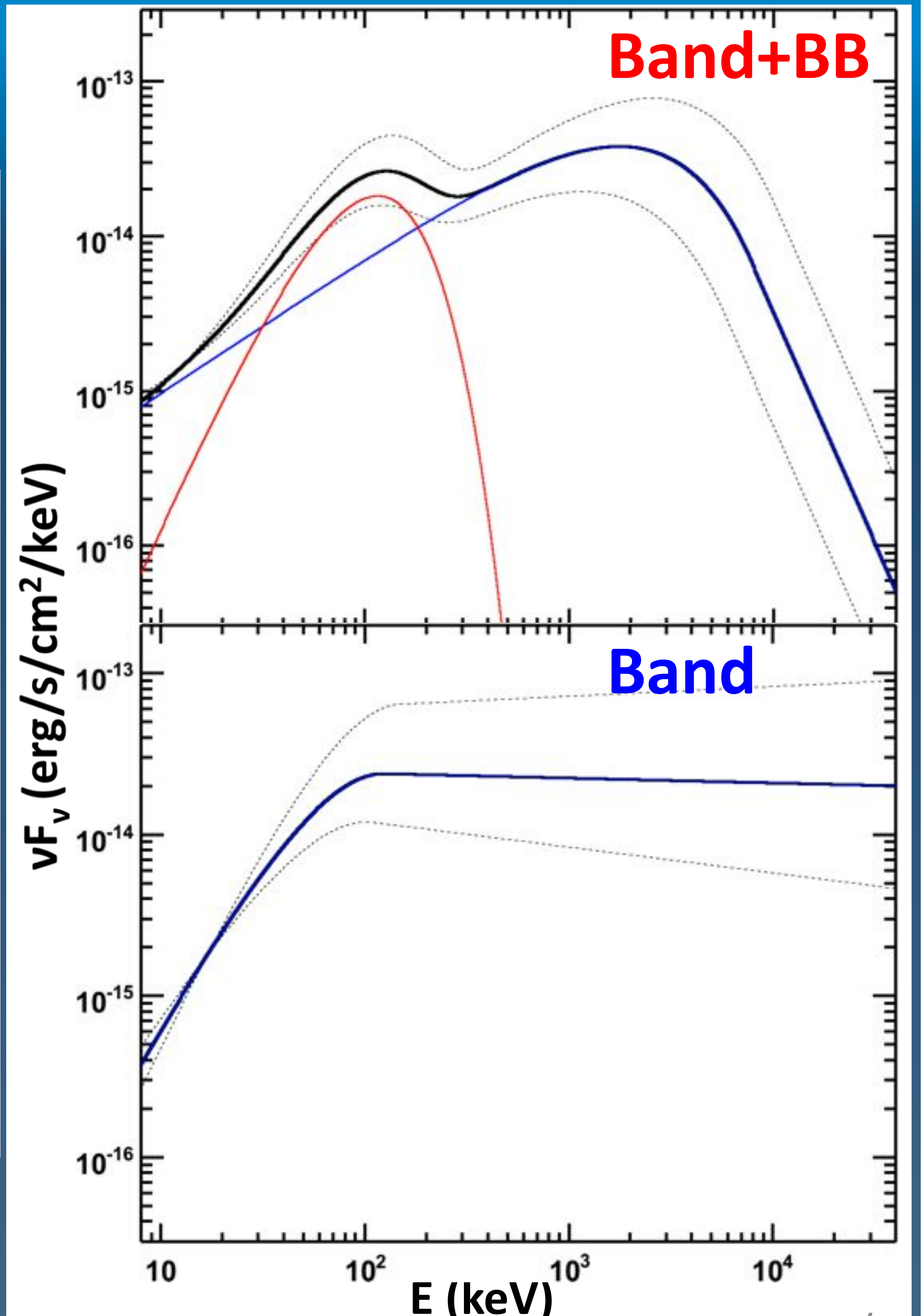
• There is apparently a strong correlation between the E_{peak} and the Luminosity (and Flux) of the Band function.

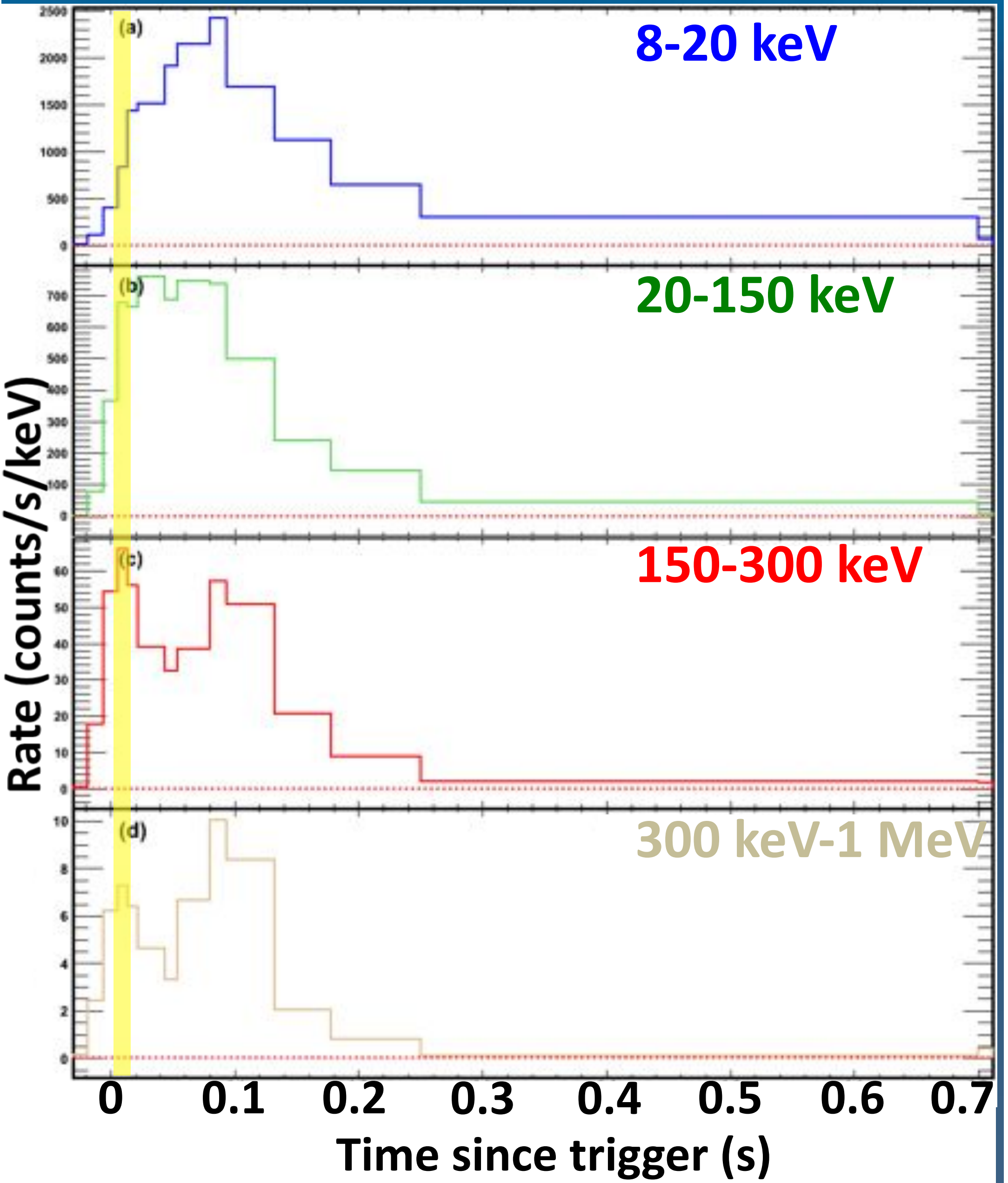
→ Possibility to discriminate between models.

→ Could eventually be used as a redshift estimator.

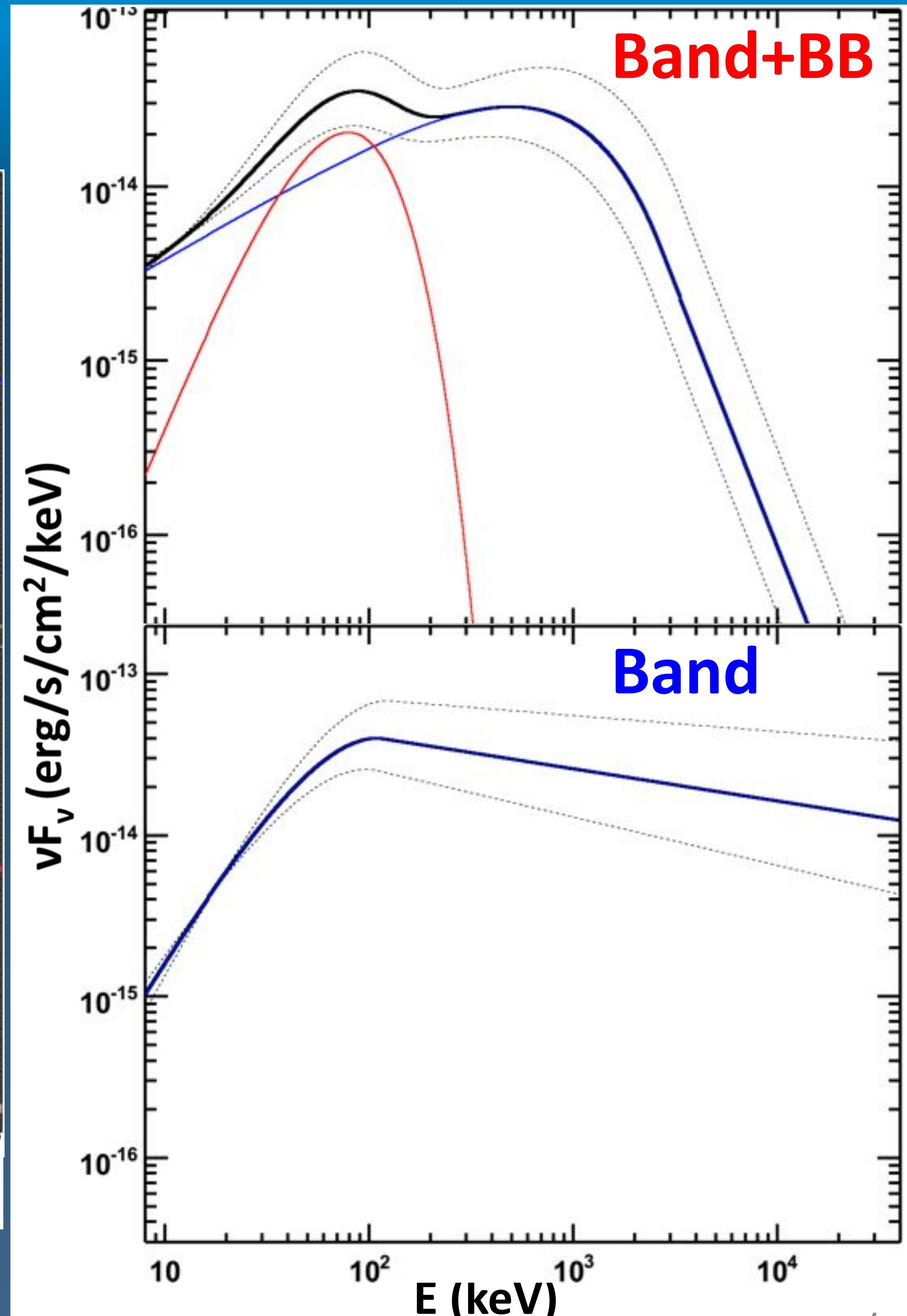

(a)
8-20 keV
(b)
20-150 keV
(c)
150-300 keV
(d)
300 keV-1 MeV
Rate (counts/s/keV)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Time since trigger (s)


Band+BB
Band
νF_ν (erg/s/cm^2/keV)
10^{-13}
10^{-14}
10^{-15}
10^{-16}
10
10^2
10^3
10^4
E (keV)

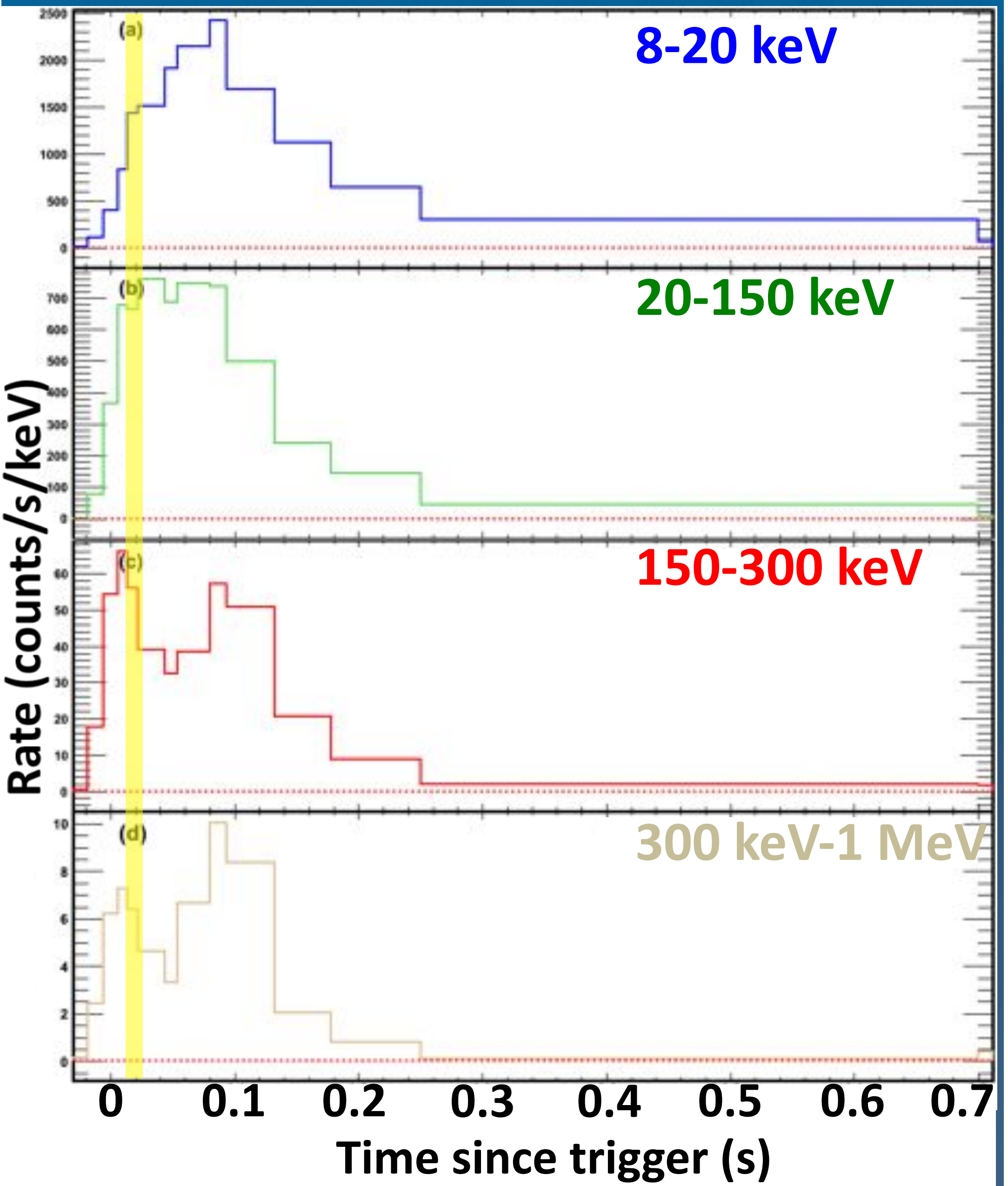

(a)
8-20 keV
(b)
20-150 keV
(c)
150-300 keV
(d)
300 keV-1 MeV
Rate (counts/s/keV)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Time since trigger (s)

Band+BB
Band
νF$_ν$ (erg/s/cm^2/keV)
10^{-13}
10^{-14}
10^{-15}
10^{-16}
10
10^2
10^3
10^4
E (keV)



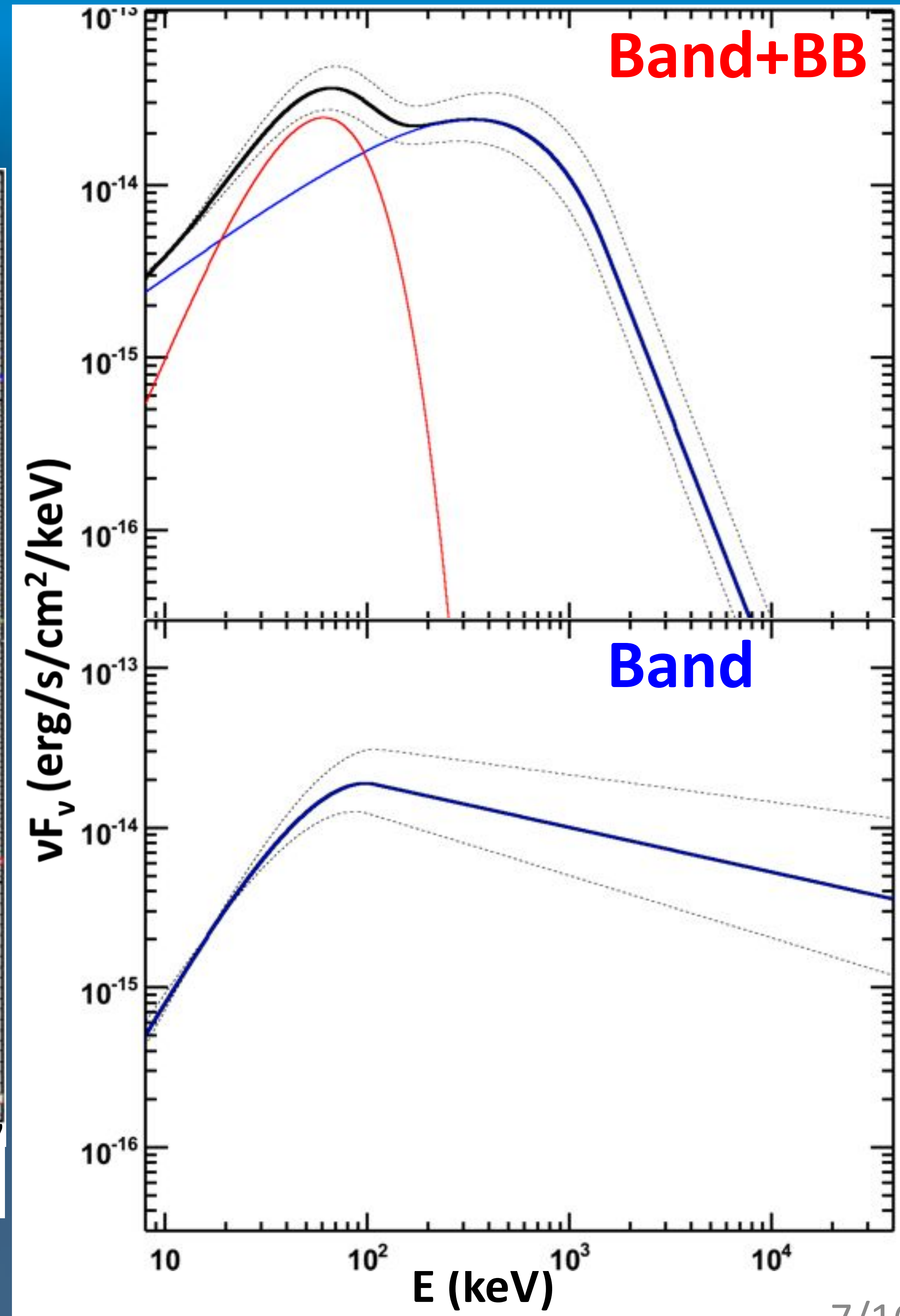
8-20 keV
20-150 keV
150-300 keV
300 keV-1 MeV
Rate (counts/s/keV)
Time since trigger (s)



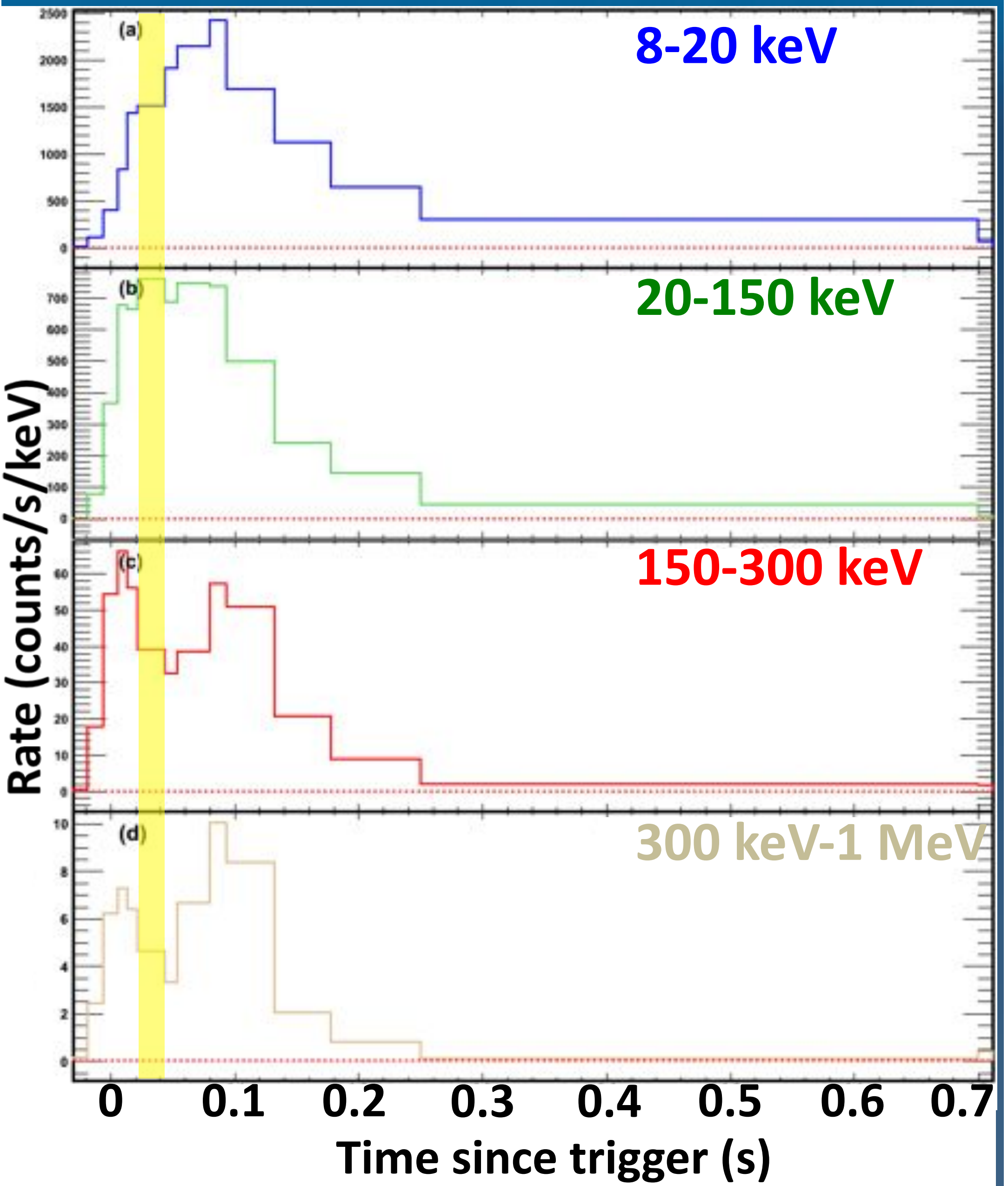
Band+BB
Band
νF$_ν$ (erg/s/cm^2/keV)
E (keV)

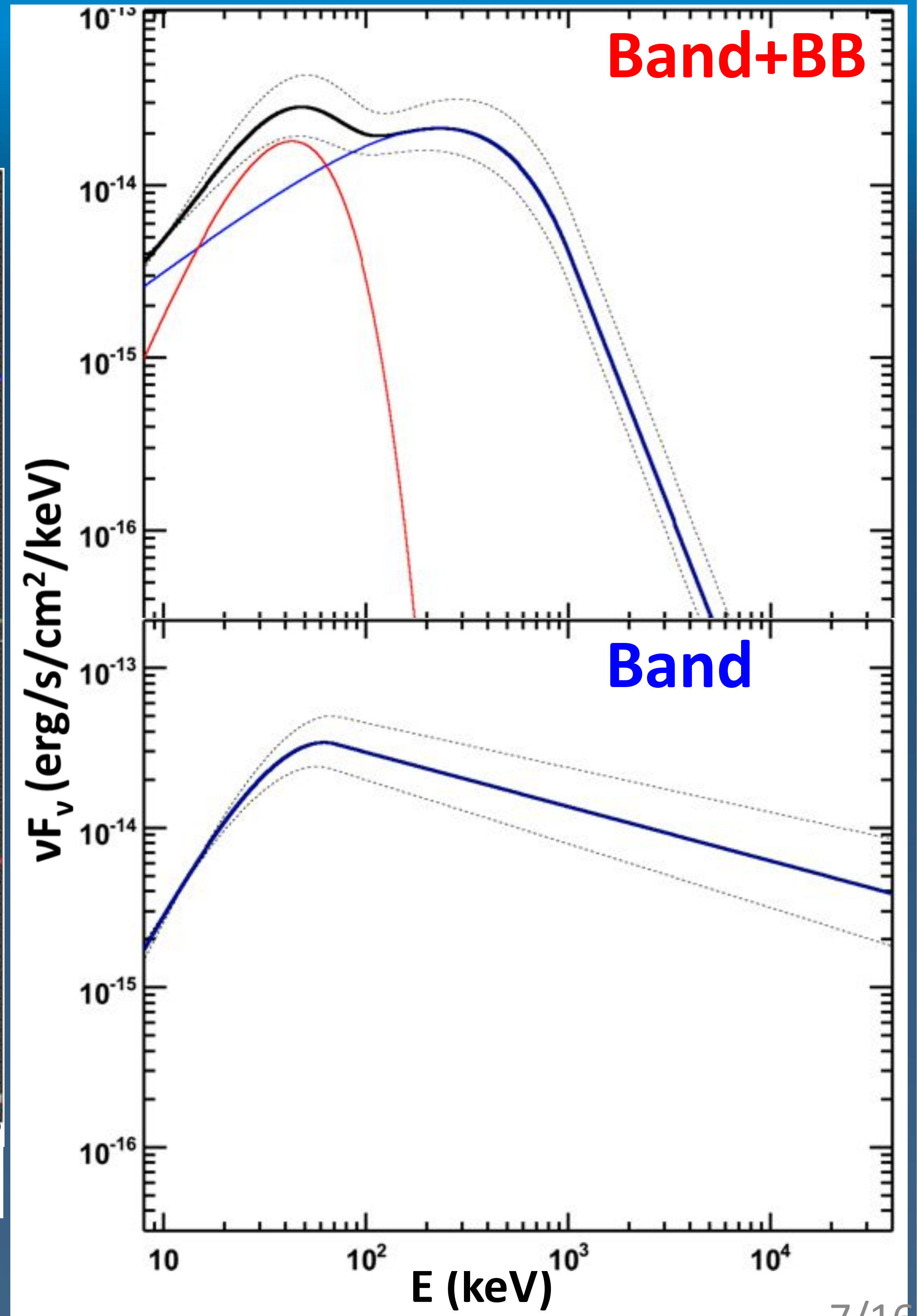


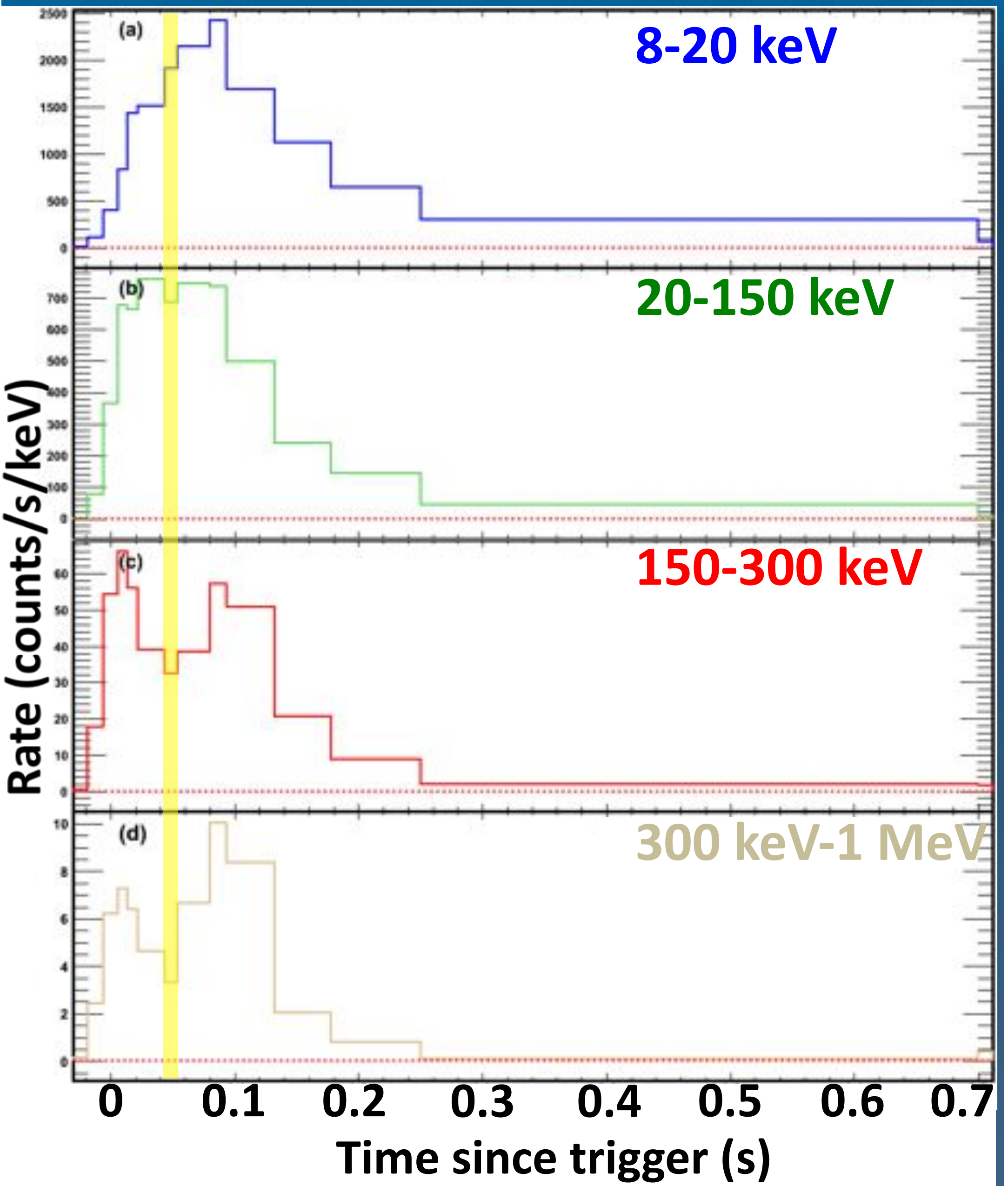
8-20 keV
20-150 keV
150-300 keV
300 keV-1 MeV
Rate (counts/s/keV)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Time since trigger (s)



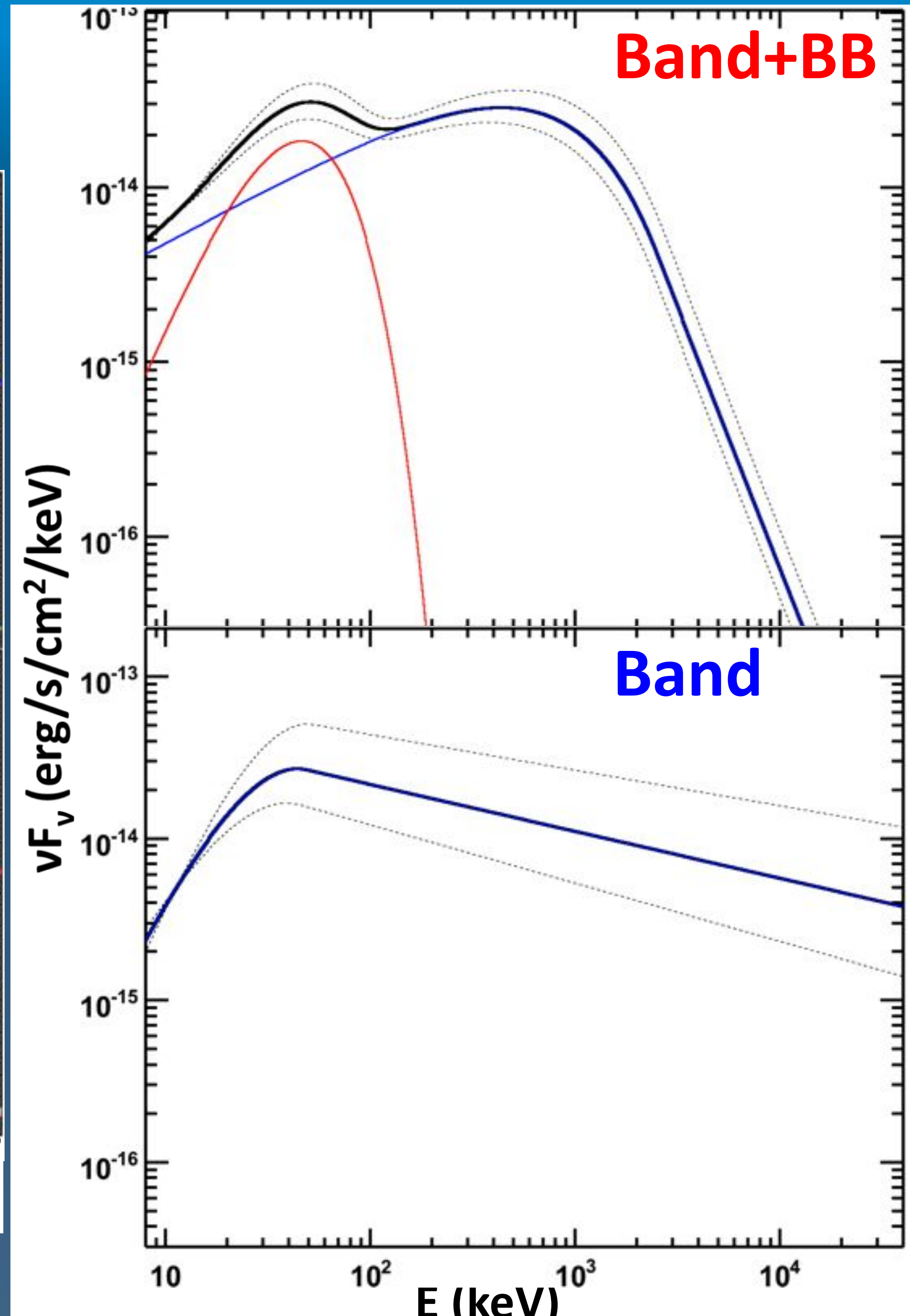
Band+BB
Band
νF_ν (erg/s/cm^2/keV)
10^{-13}
10^{-14}
10^{-15}
10^{-16}
10
10^2
10^3
10^4
E (keV)


8-20 keV
20-150 keV
150-300 keV
300 keV-1 MeV
Rate (counts/s/keV)
Time since trigger (s)

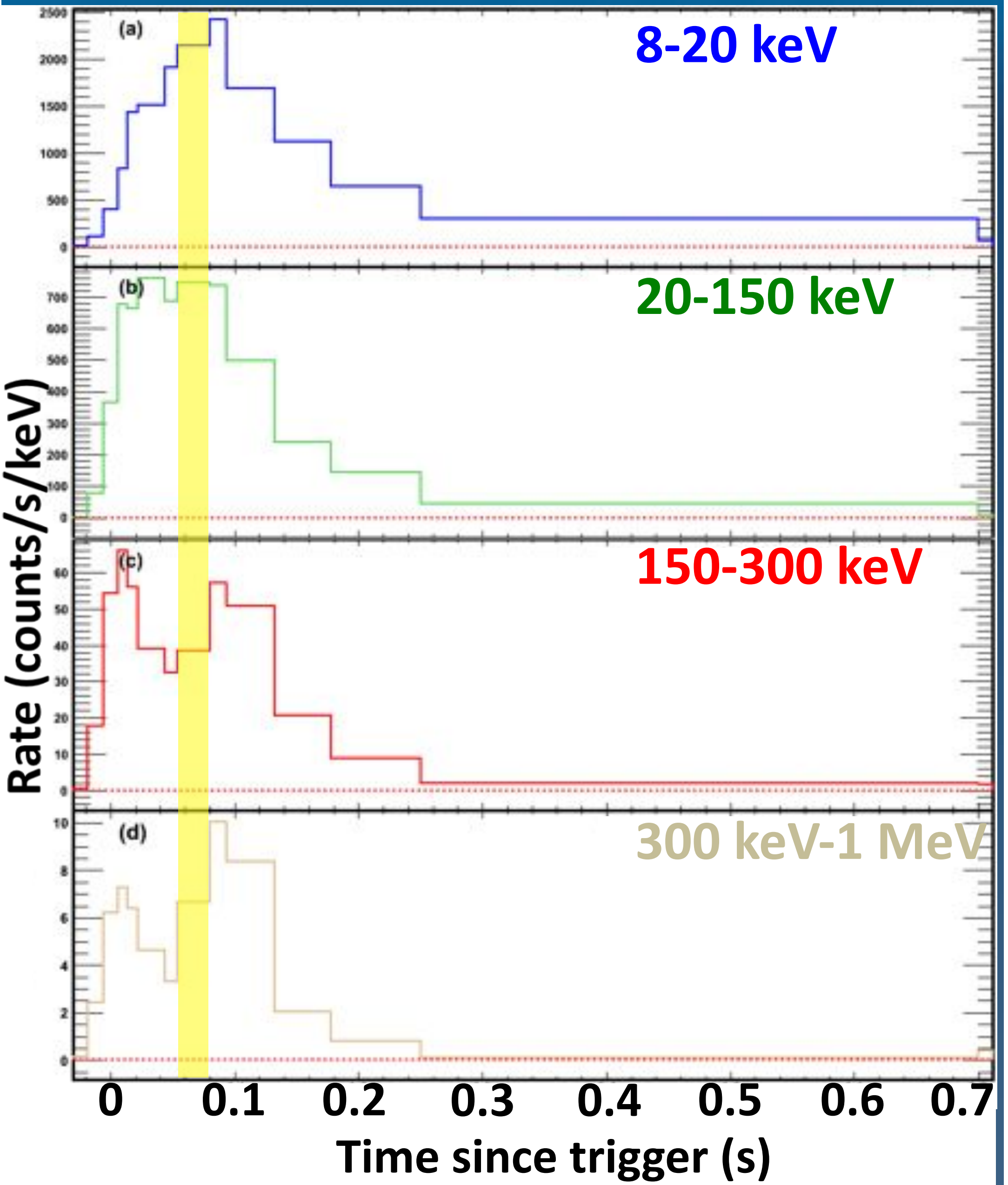

Band+BB
Band
νF_ν (erg/s/cm^2/keV)
E (keV)

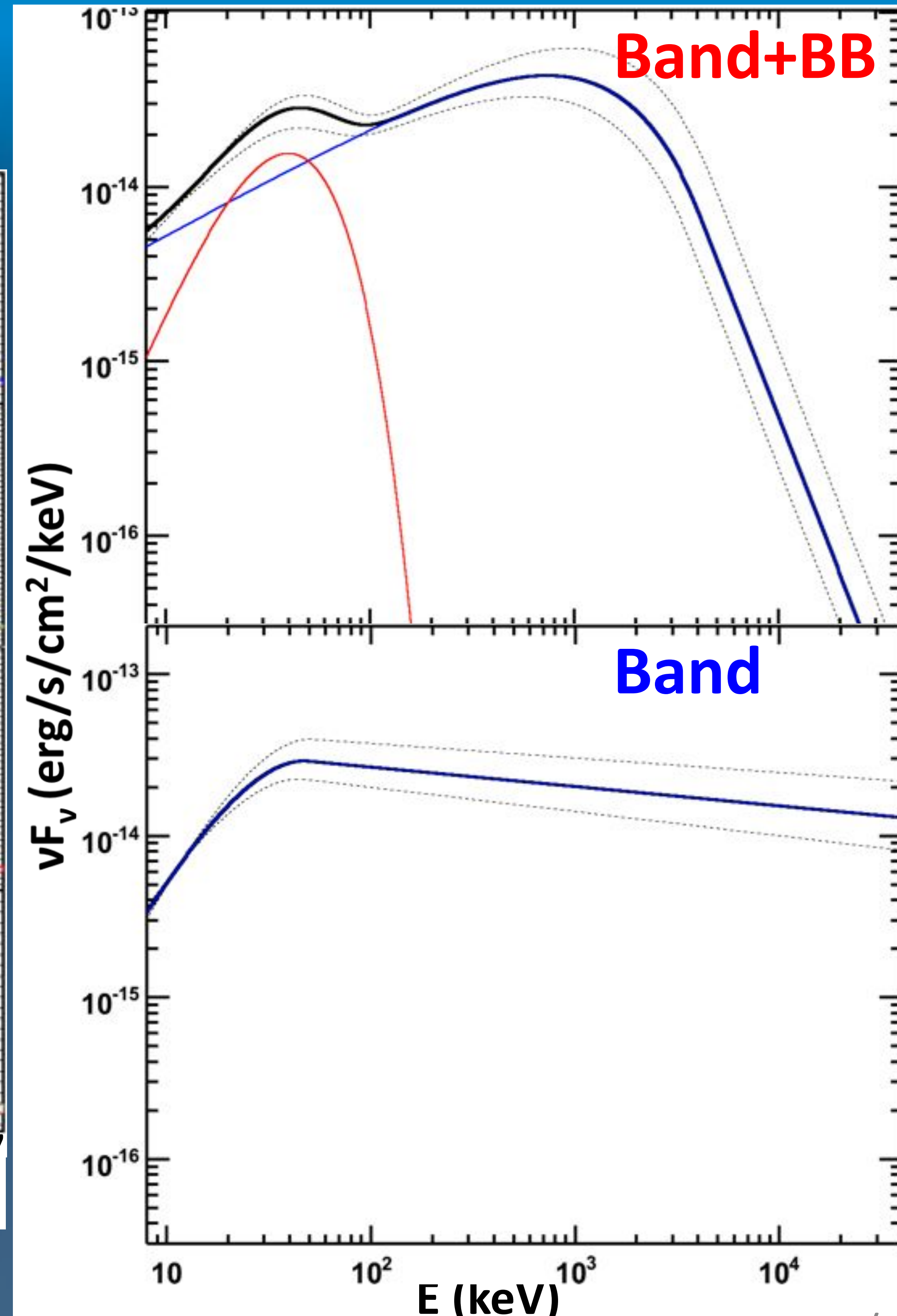


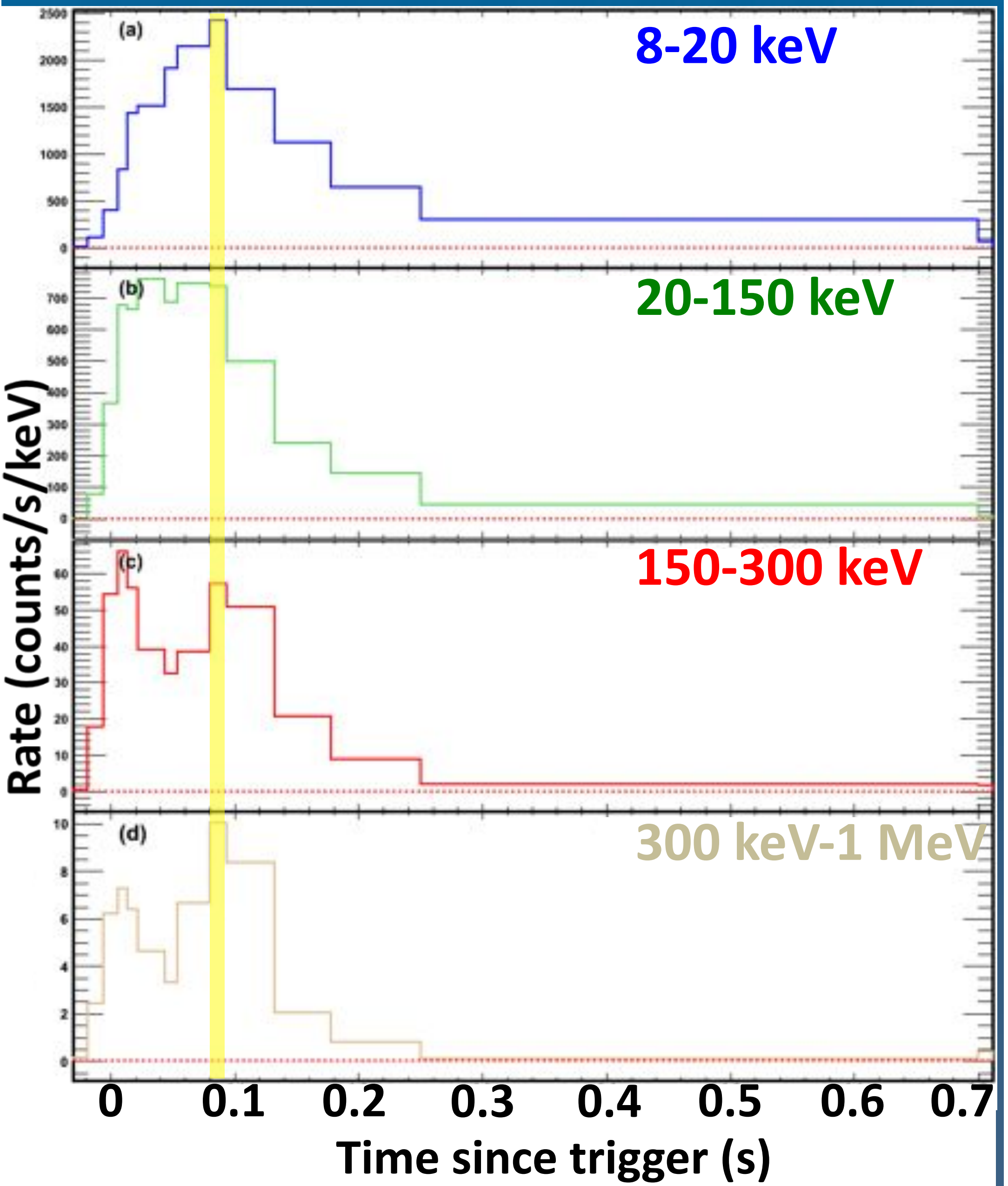
(a)
8-20 keV
(b)
20-150 keV
(c)
150-300 keV
(d)
300 keV-1 MeV
Rate (counts/s/keV)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Time since trigger (s)

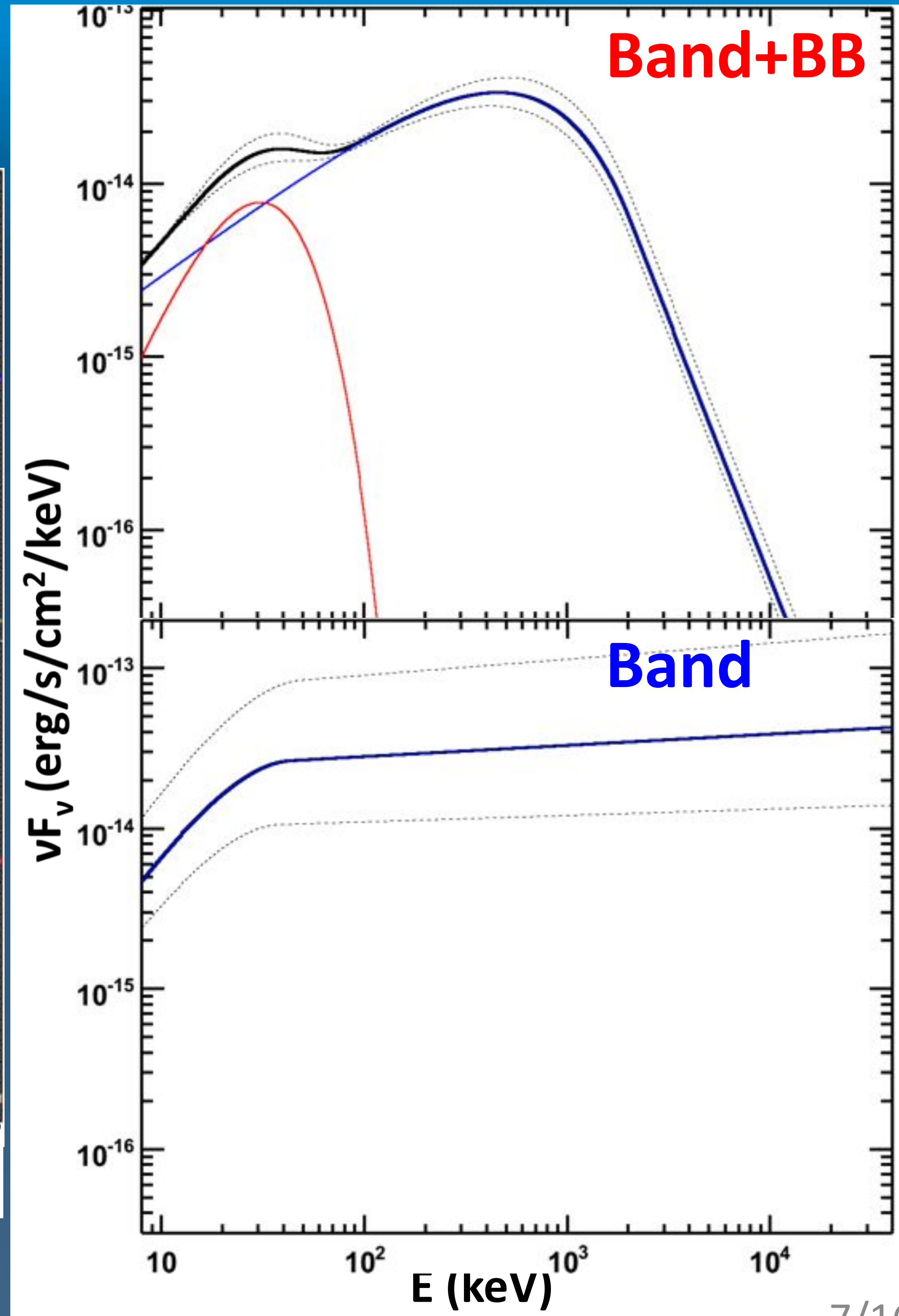


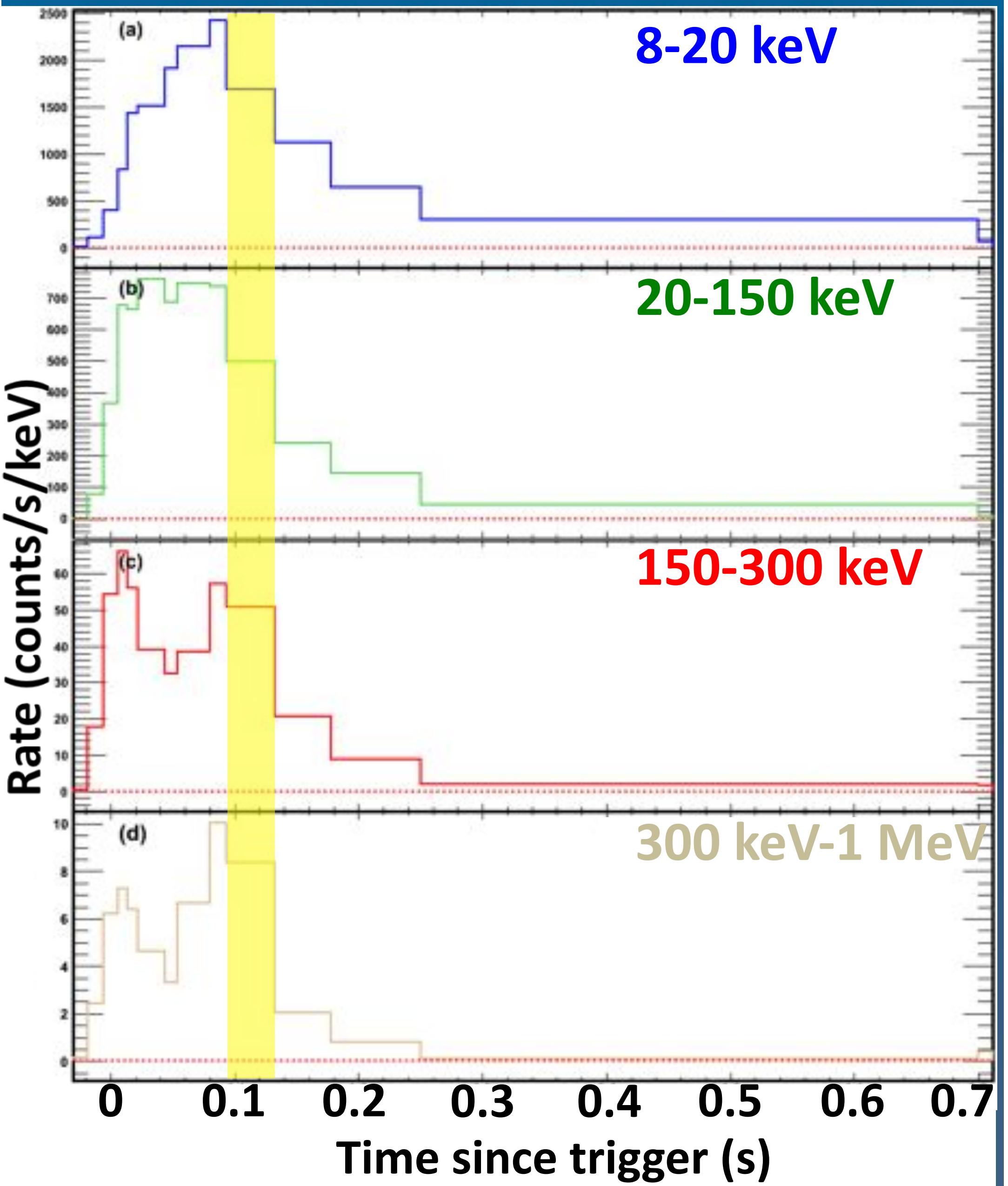
Band+BB
Band
νF_ν (erg/s/cm^2/keV)
10^{-13}
10^{-14}
10^{-15}
10^{-16}
10
10^2
10^3
10^4
E (keV)

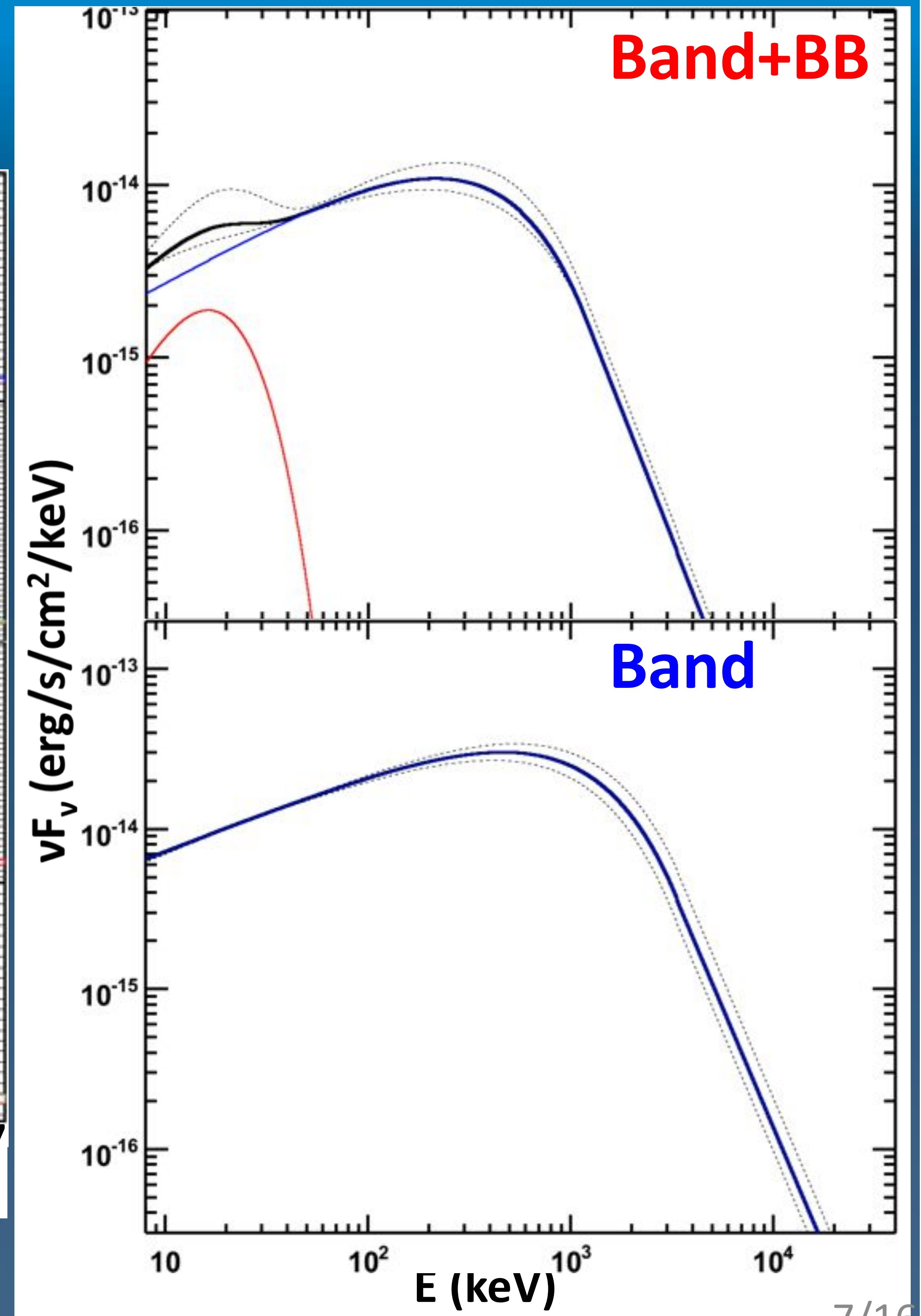

8-20 keV
20-150 keV
150-300 keV
300 keV-1 MeV
(a)
(b)
(c)
(d)
Rate (counts/s/keV)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Time since trigger (s)

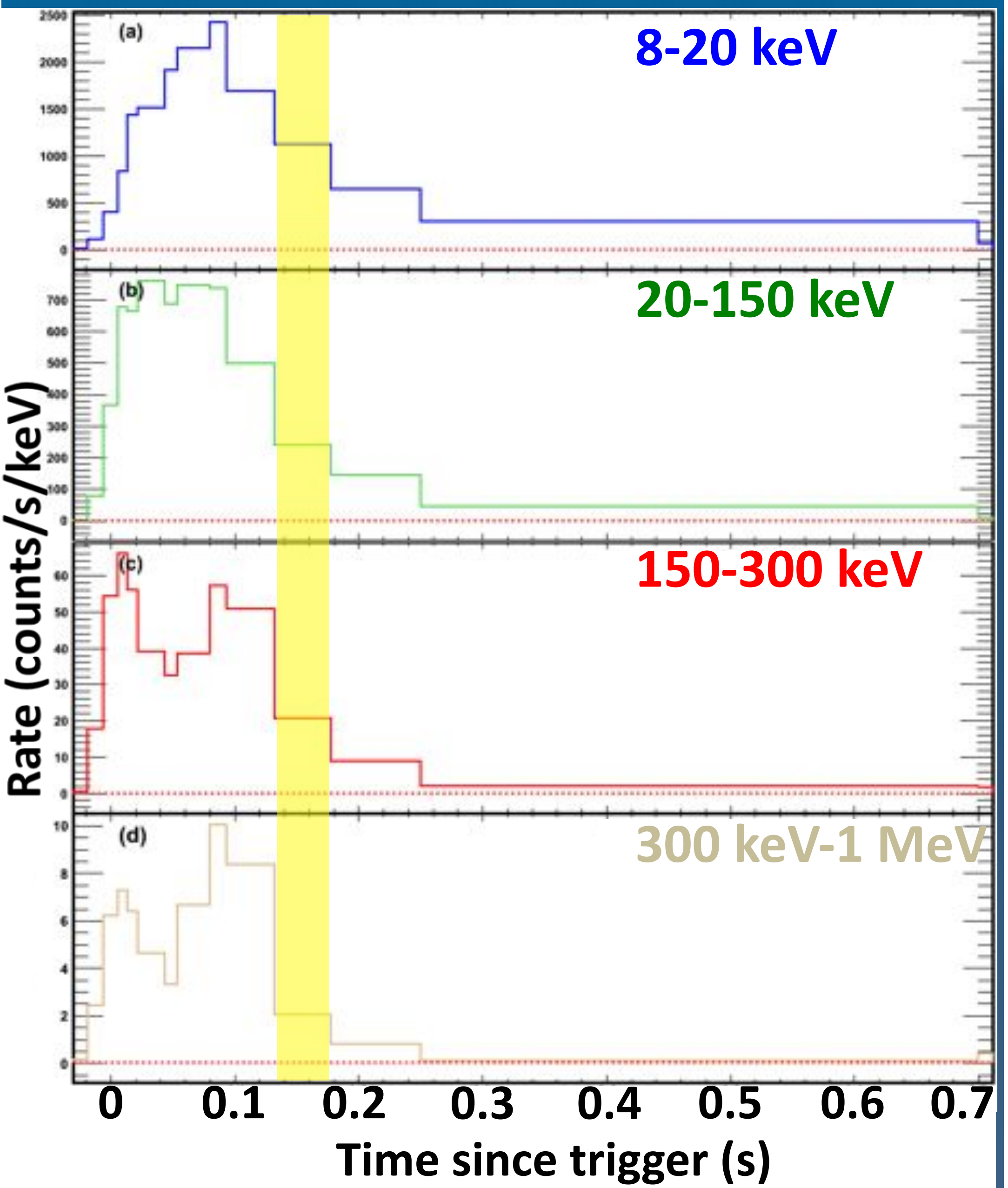

Band+BB
Band
νF_ν (erg/s/cm²/keV)
E (keV)
10
10²
10³
10⁴

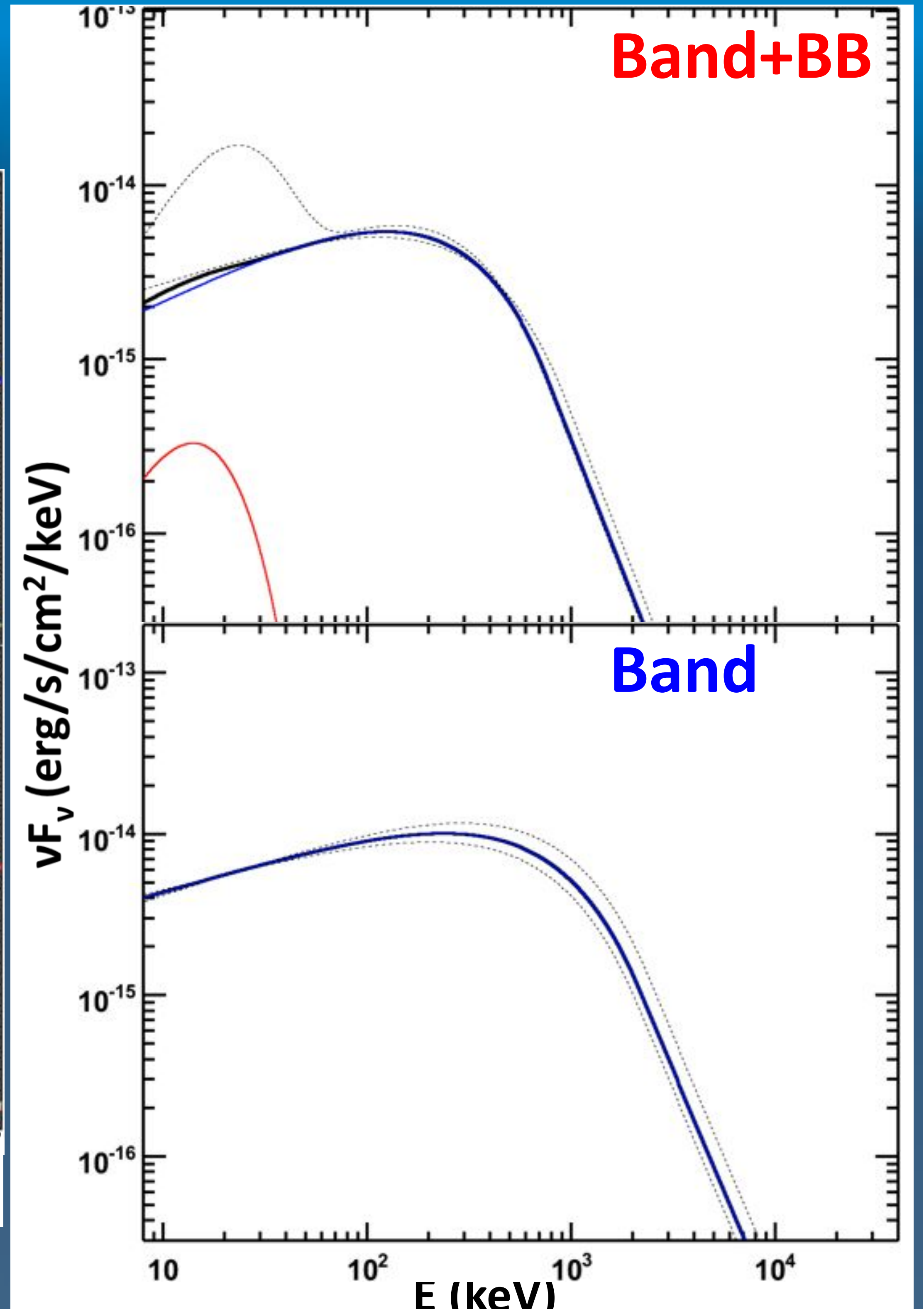

(a)
8-20 keV
(b)
20-150 keV
(c)
150-300 keV
(d)
300 keV-1 MeV
Rate (counts/s/keV)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Time since trigger (s)

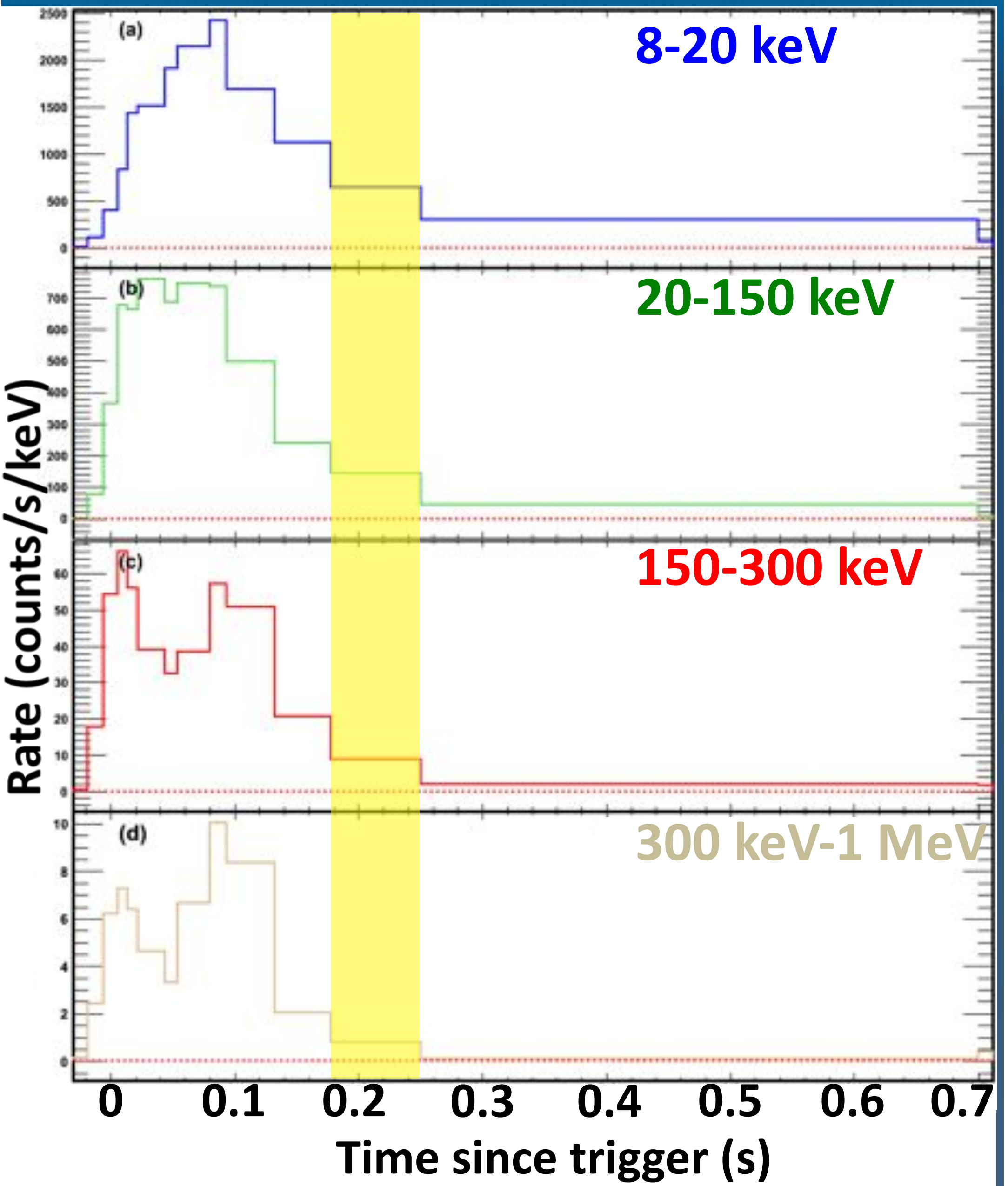

Band+BB
Band
νF_ν (erg/s/cm^2/keV)
10^{-13}
10^{-14}
10^{-15}
10^{-16}
10
10^2
10^3
10^4
E (keV)

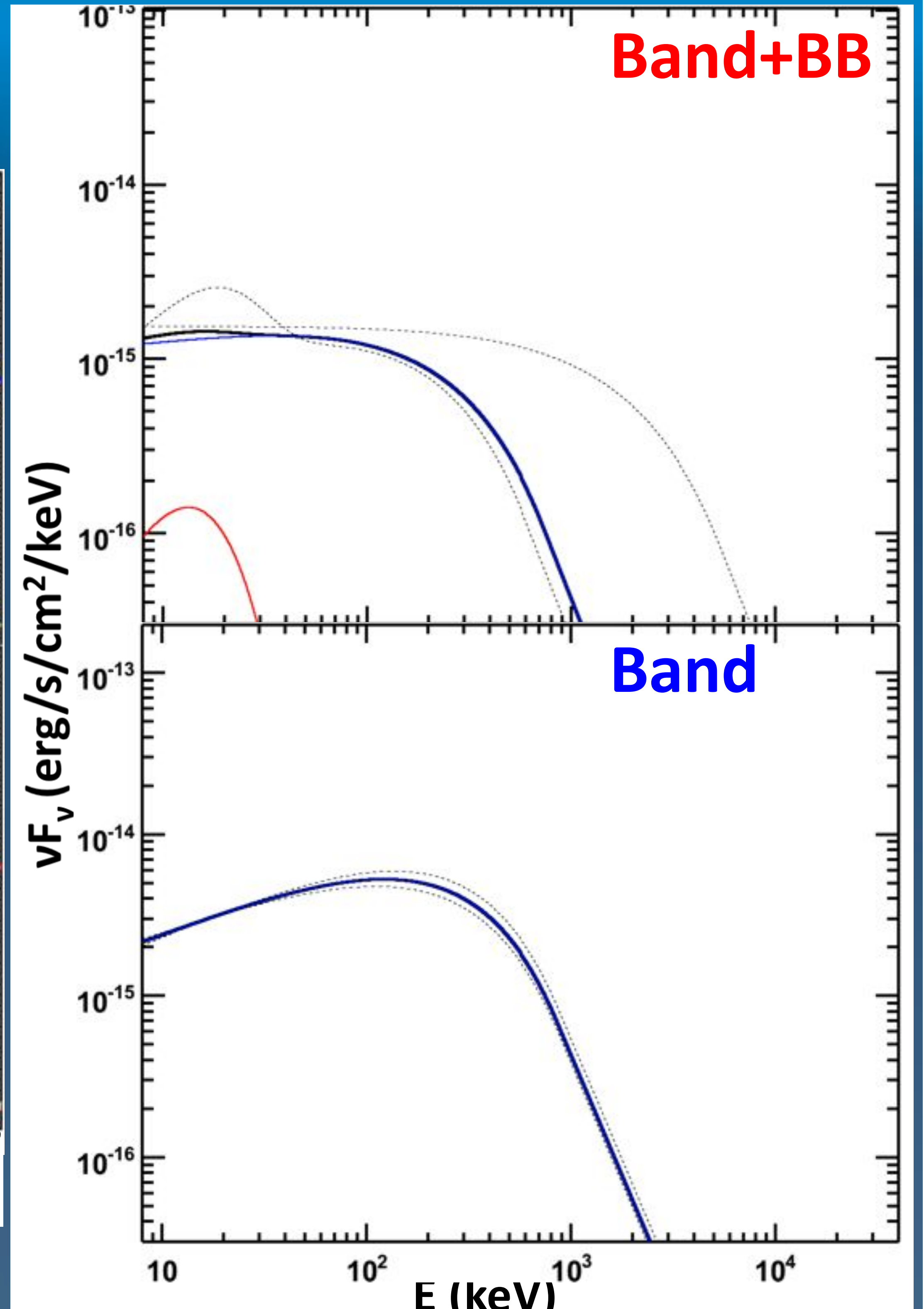

(a)
8-20 keV
(b)
20-150 keV
(c)
150-300 keV
(d)
300 keV-1 MeV
Rate (counts/s/keV)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Time since trigger (s)

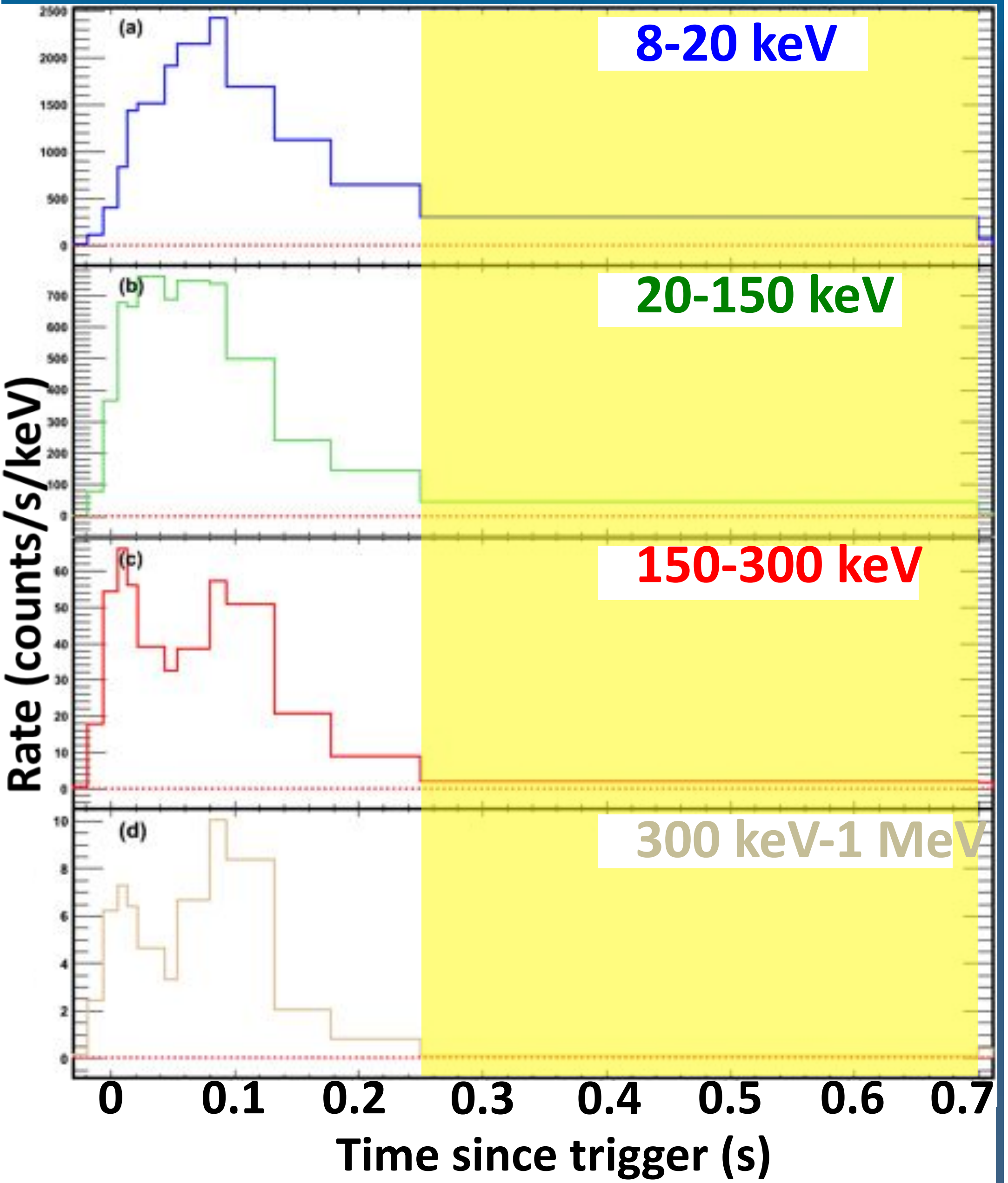

Band+BB
Band
νF_ν (erg/s/cm^2/keV)
10^{-13}
10^{-14}
10^{-15}
10^{-16}
10
10^2
10^3
10^4
E (keV)


(a)
8-20 keV
(b)
20-150 keV
(c)
150-300 keV
(d)
300 keV-1 MeV
Rate (counts/s/keV)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Time since trigger (s)

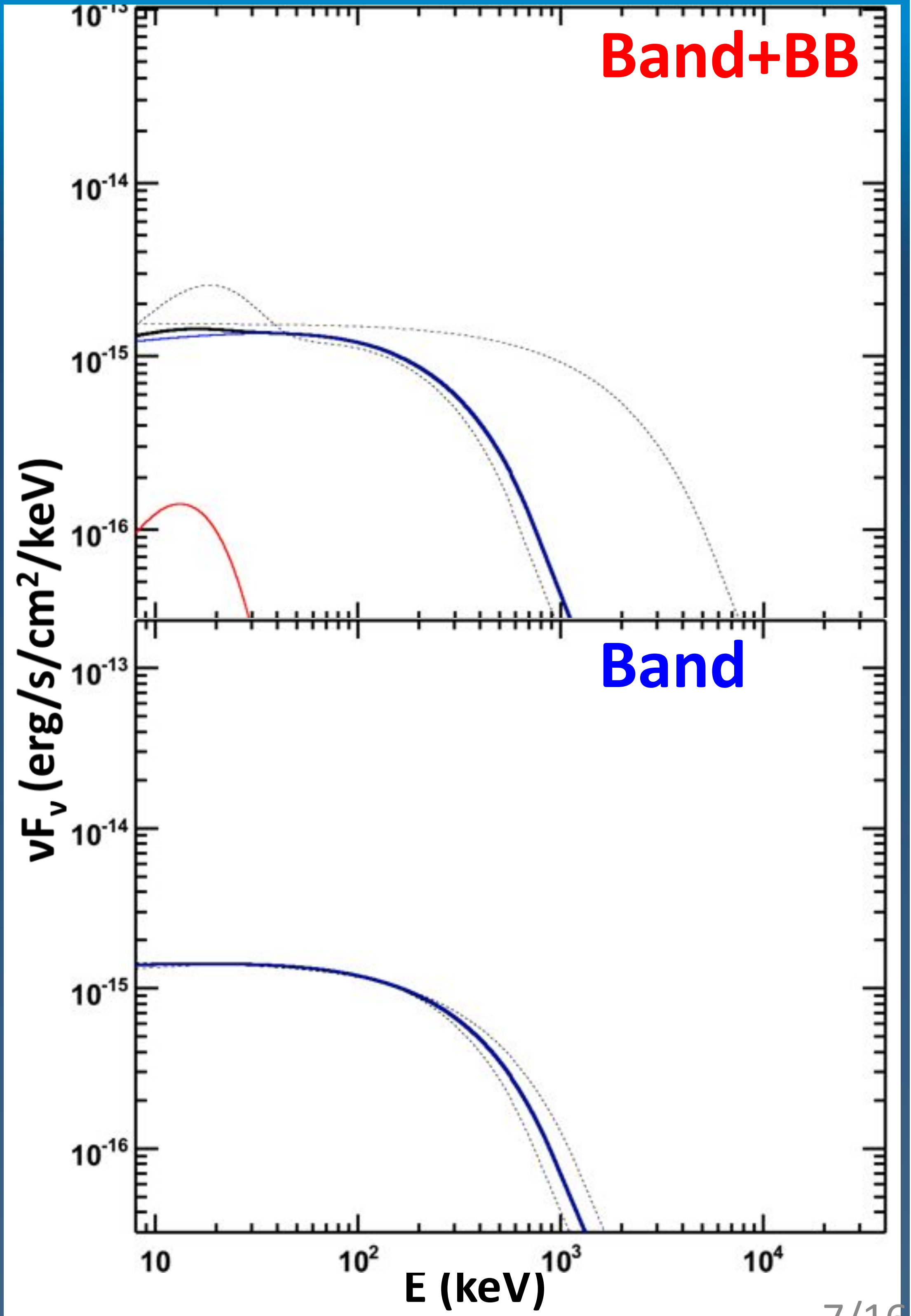

Band+BB
Band
νF_ν (erg/s/cm^2/keV)
10^{-13}
10^{-14}
10^{-15}
10^{-16}
10
10^2
10^3
10^4
E (keV)


8-20 keV
20-150 keV
150-300 keV
300 keV-1 MeV
Rate (counts/s/keV)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Time since trigger (s)

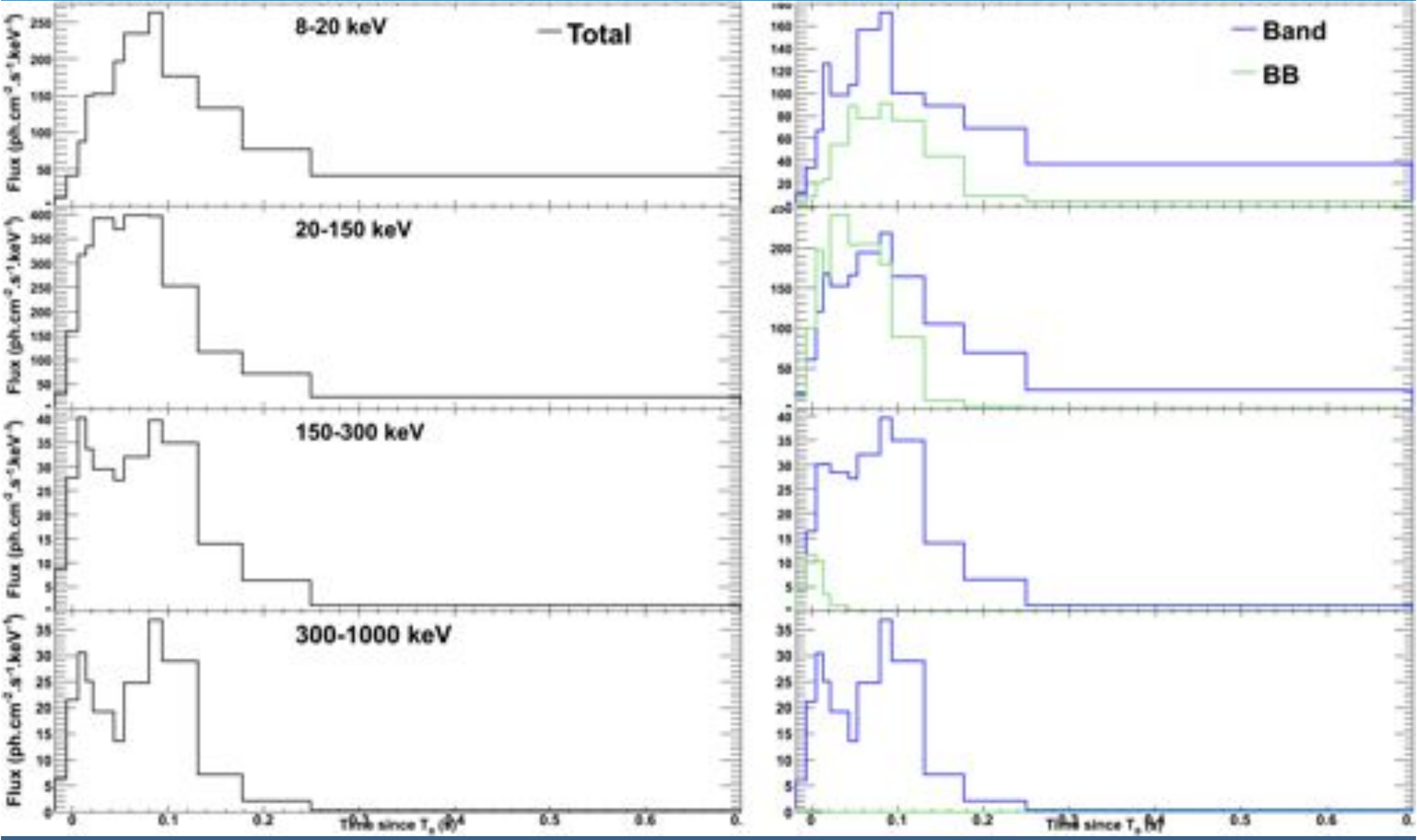

Band+BB
Band
νF_ν (erg/s/cm^2/keV)
10^{-13}
10^{-14}
10^{-15}
10^{-16}
10
10^2
10^3
10^4
E (keV)

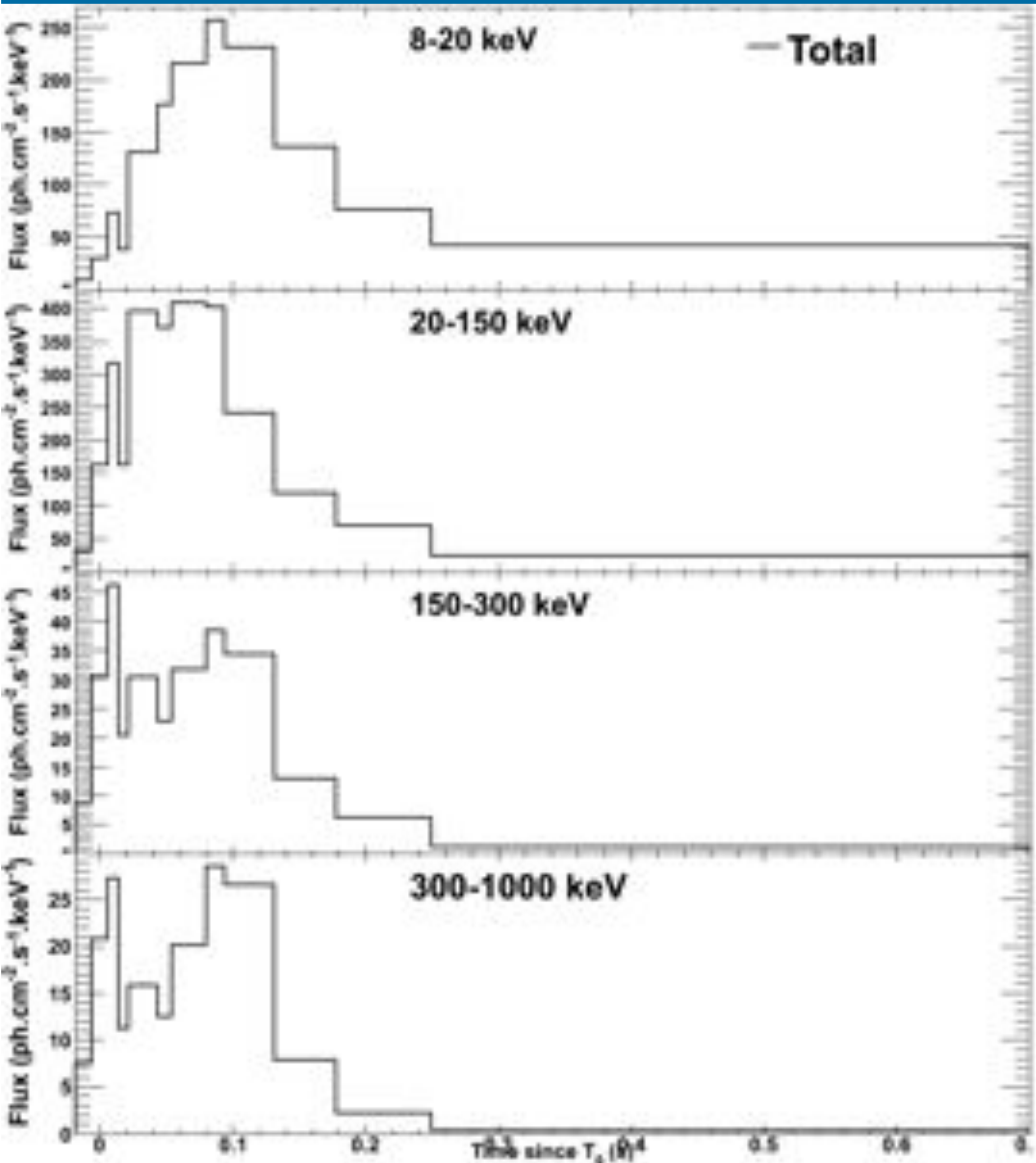


8-20 keV
20-150 keV
150-300 keV
300 keV-1 MeV
Rate (counts/s/keV)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Time since trigger (s)

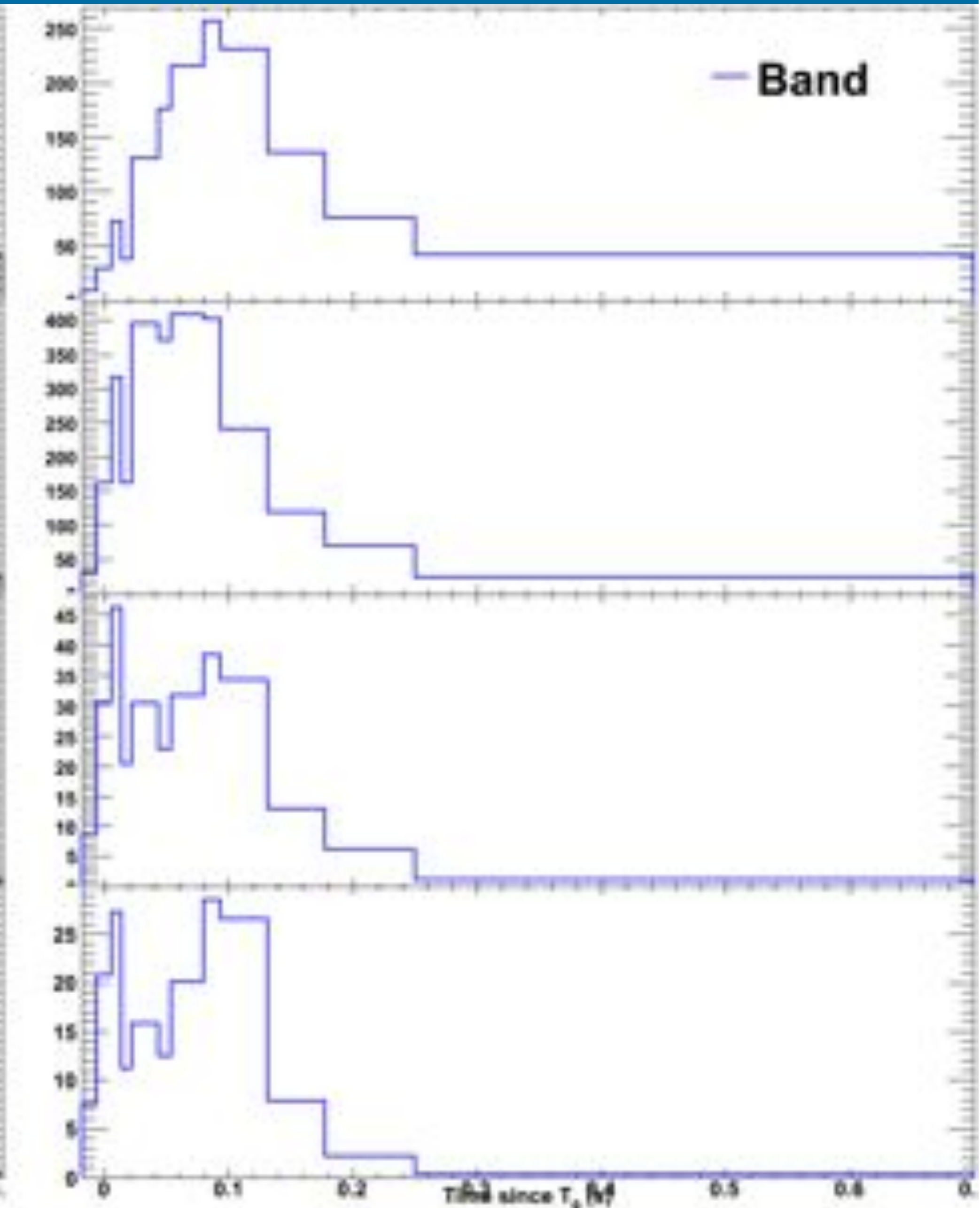


Band+BB
Band
νF_ν (erg/s/cm^2/keV)
10^{-13}
10^{-14}
10^{-15}
10^{-16}
10
10^2
10^3
10^4
E (keV)


8-20 keV
Total
20-150 keV
150-300 keV
300-1000 keV
Band
BB
Flux (ph.cm⁻².s⁻¹.keV⁻¹)
Time since T₀ (s)

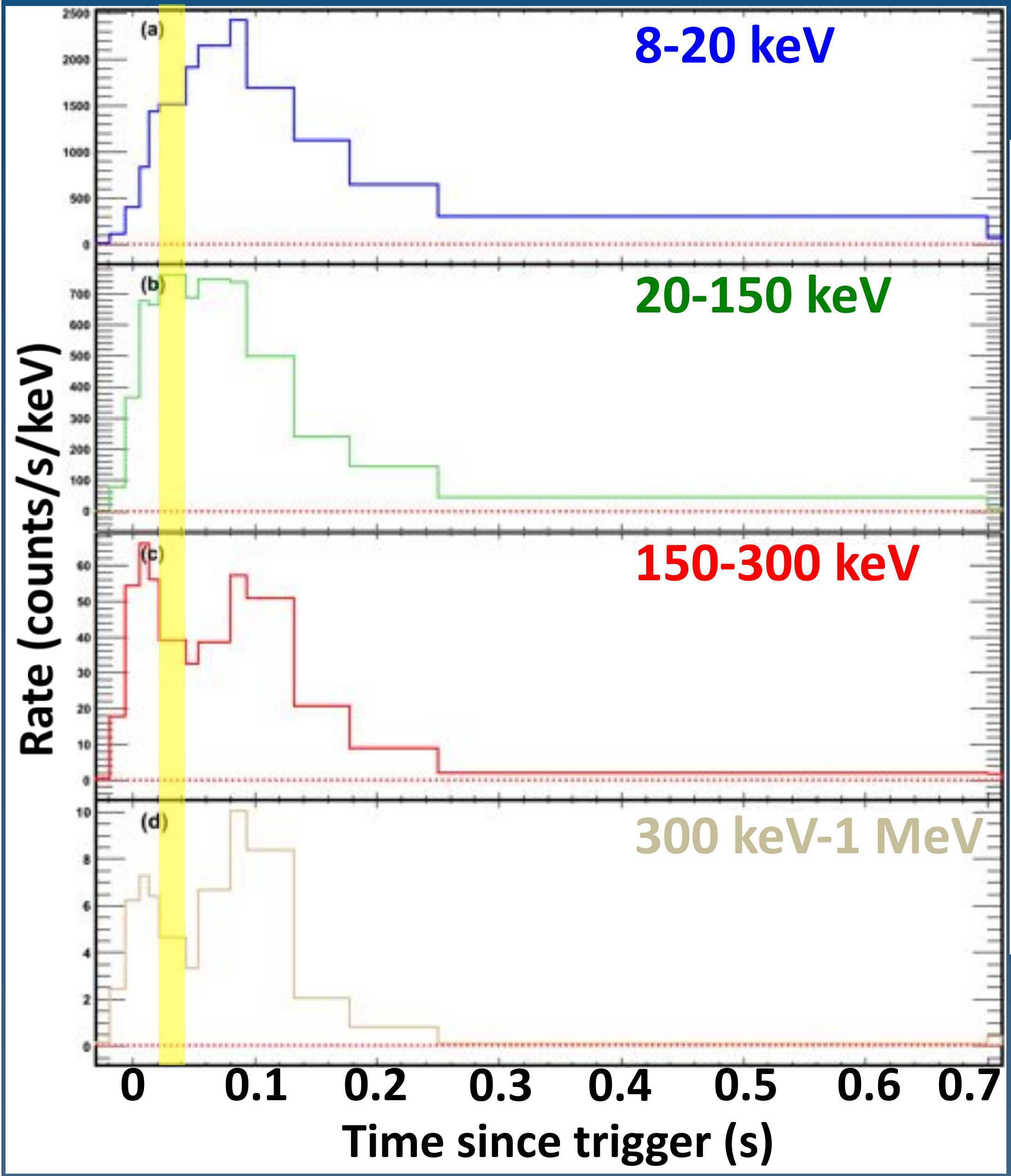


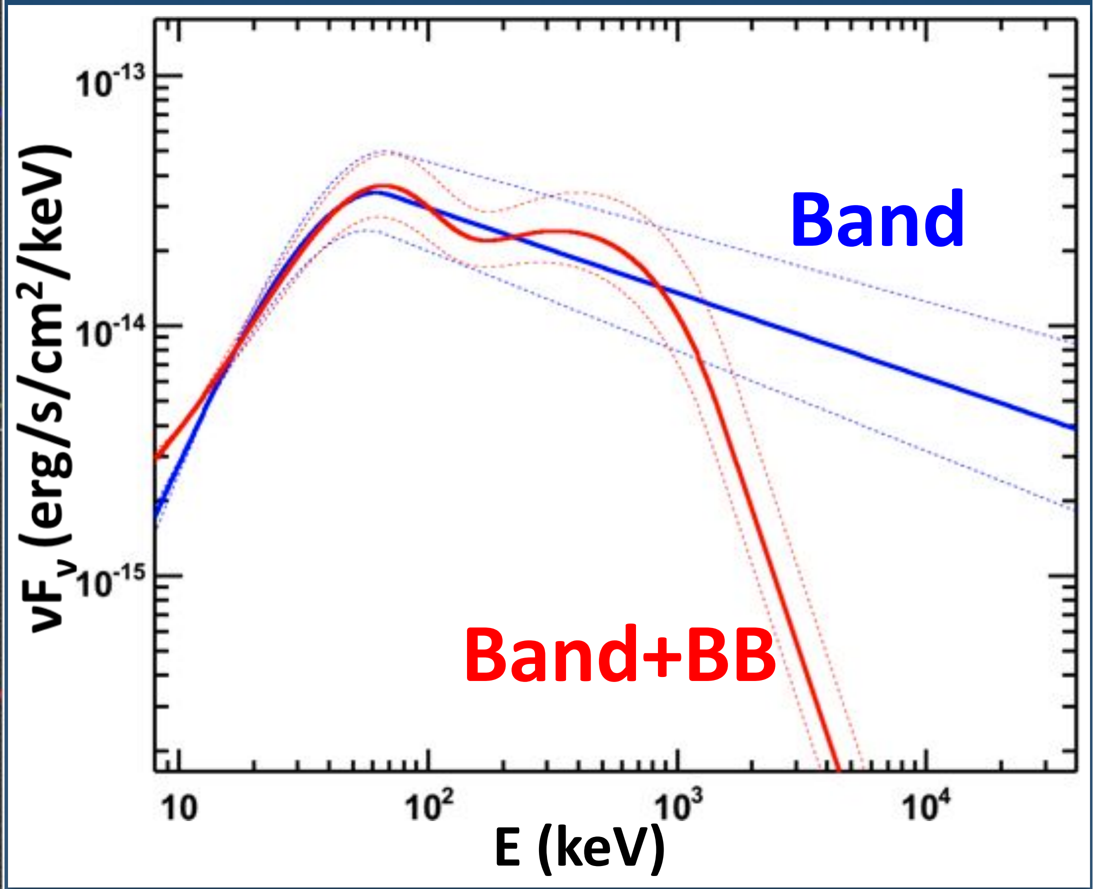
8-20 keV
Total
20-150 keV
150-300 keV
300-1000 keV
Flux (ph.cm^{-2}.s^{-1}.keV^{-1})



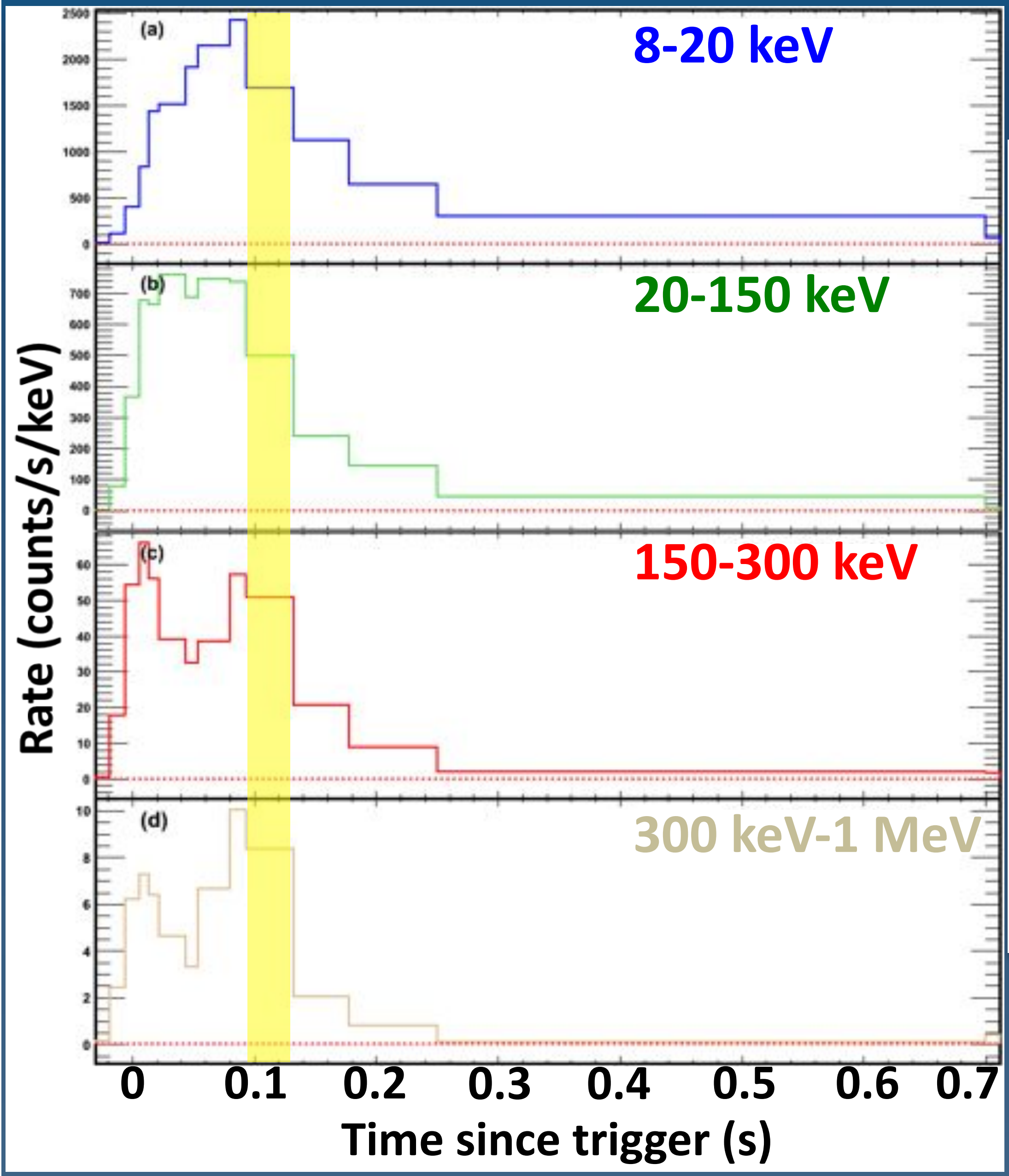
Band

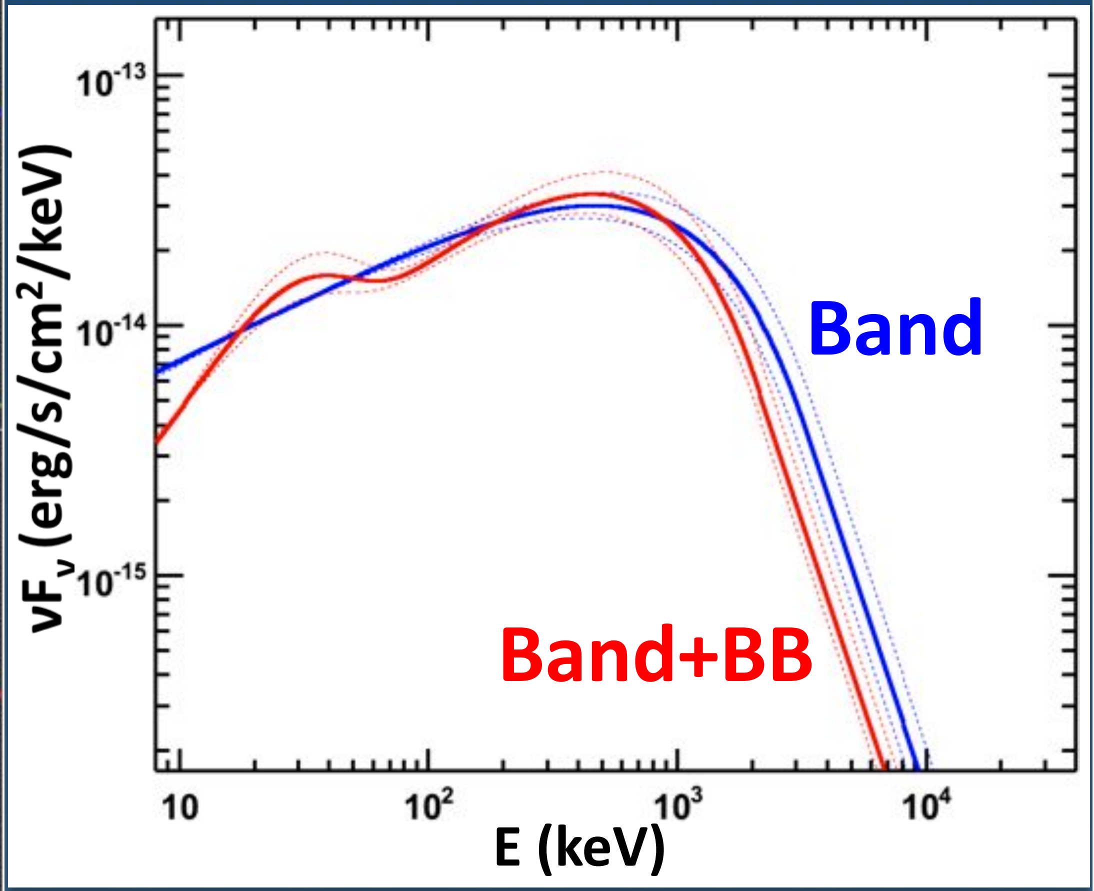
An Unusually Soft Short GRB or a Regular Short GRB with an Intense Blackbody ?



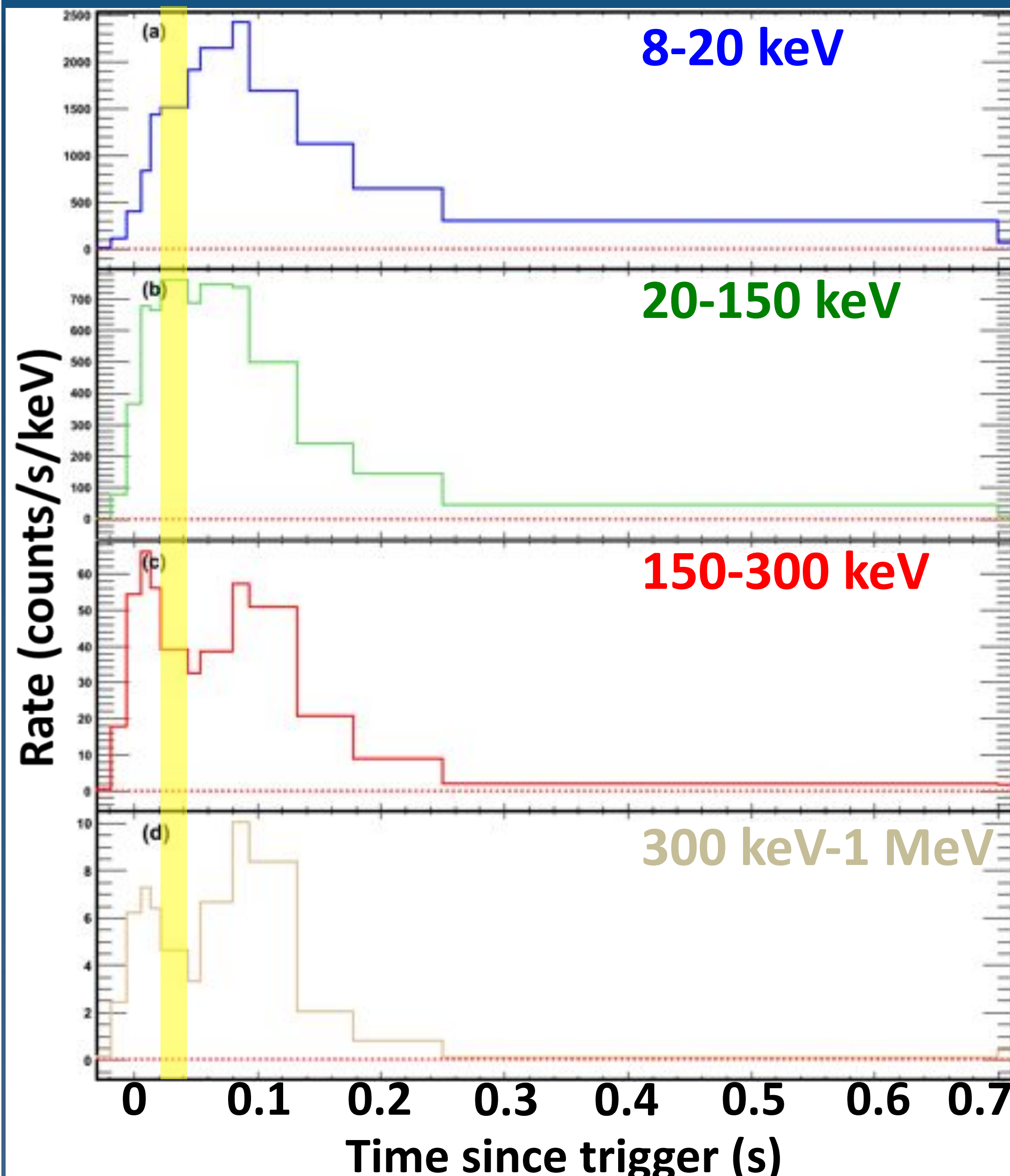


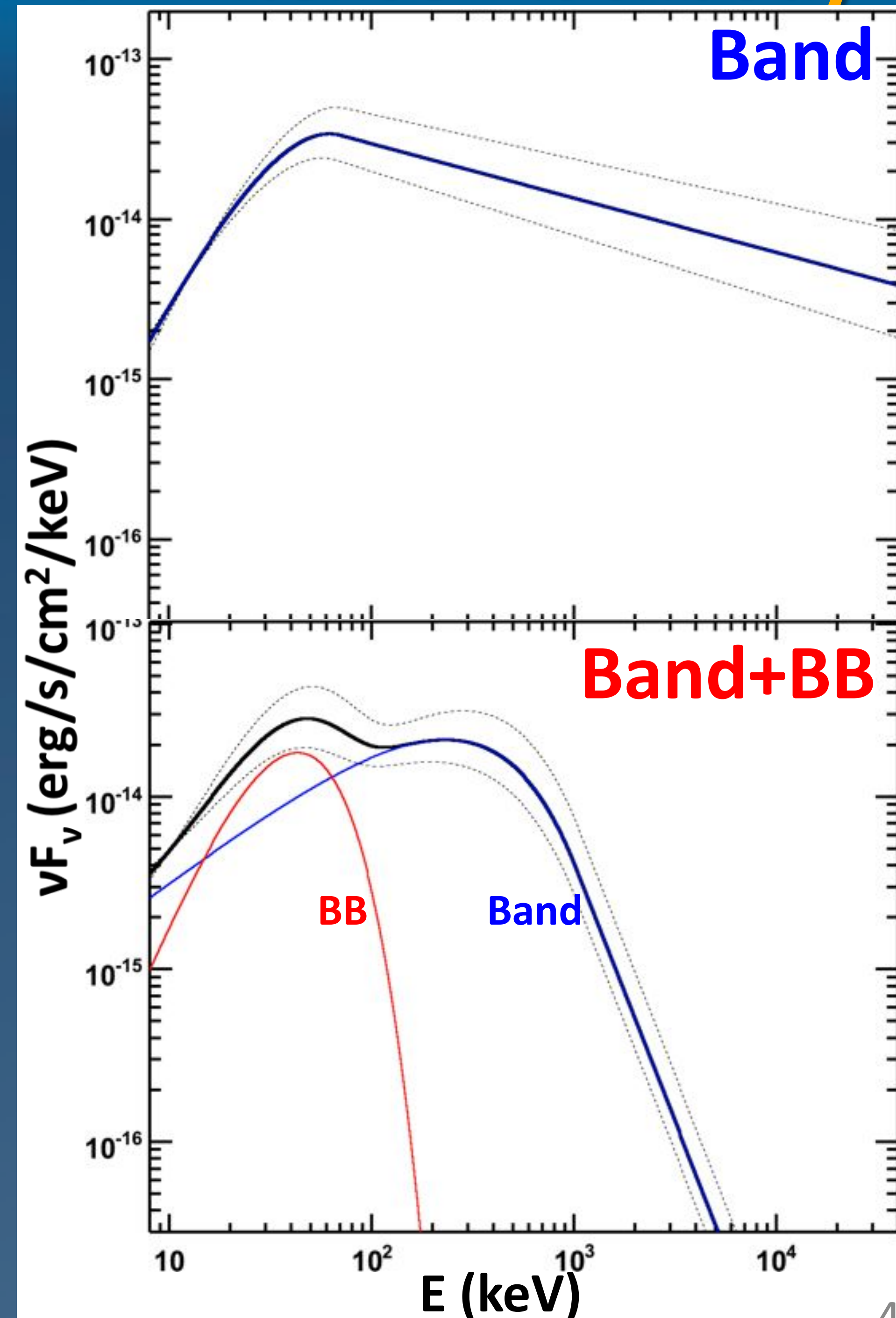
An Unusually Soft Short GRB or a Regular Short GRB with an Intense Blackbody ?



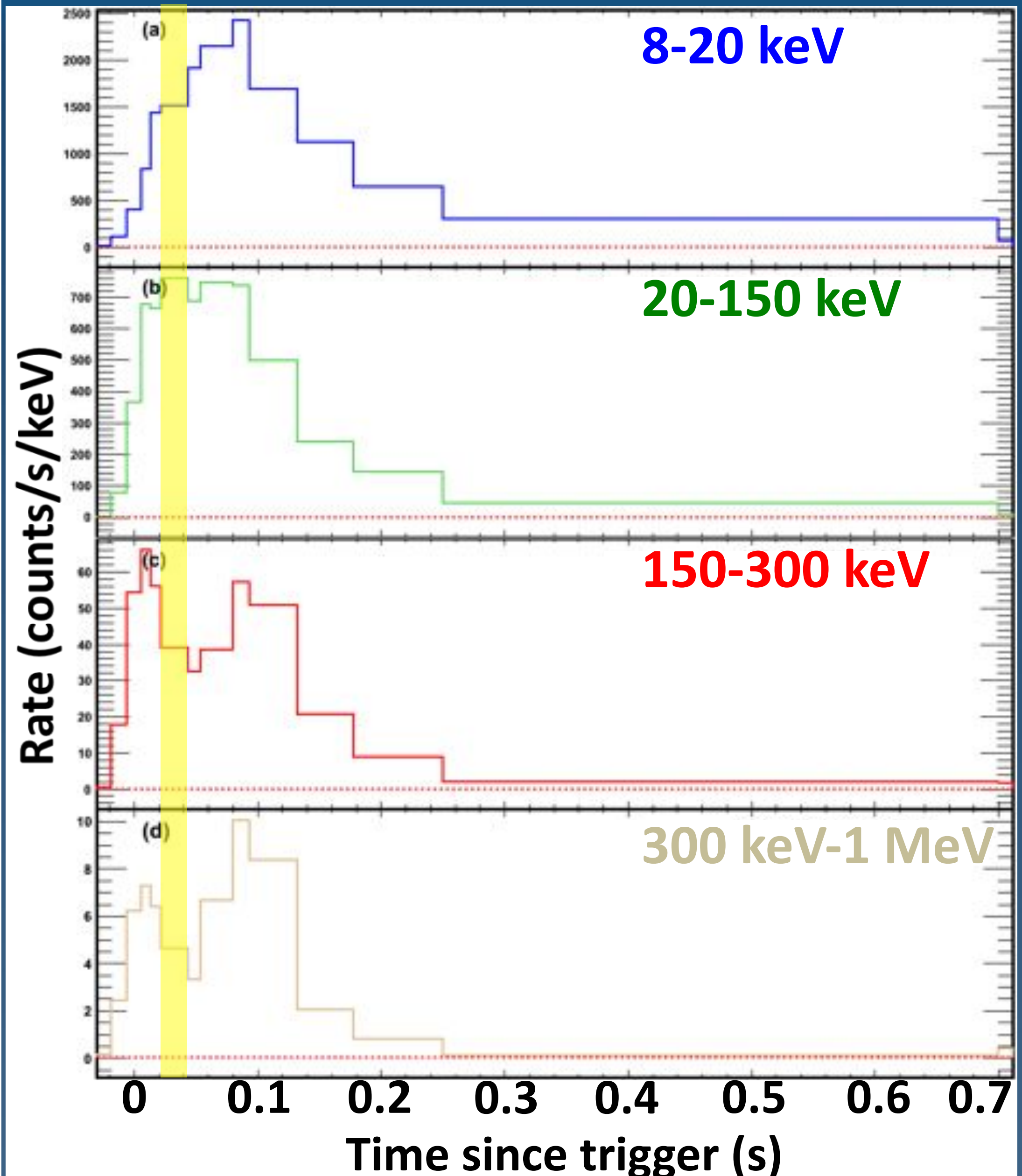


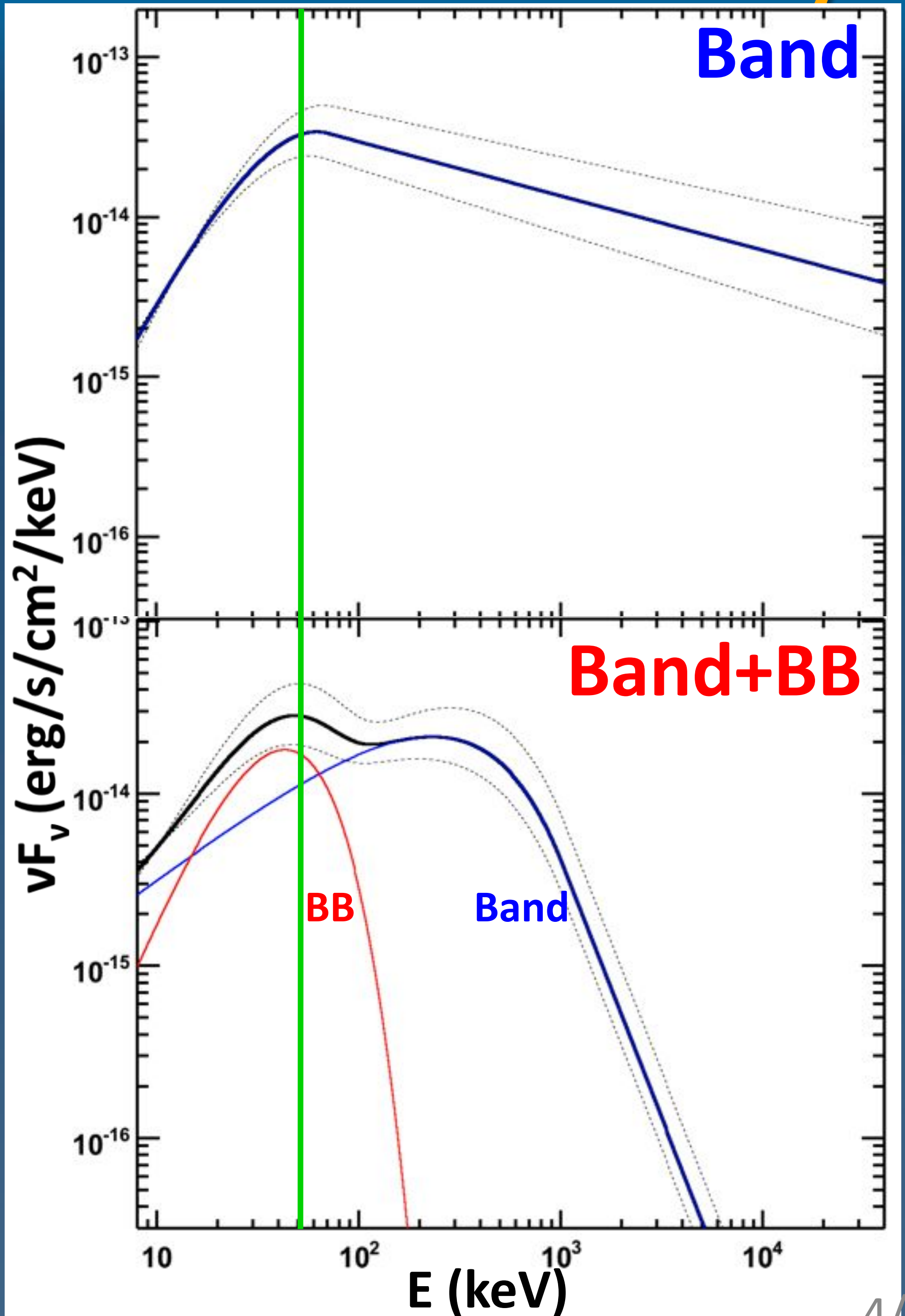
An Unusually Soft Short GRB or a Regular Short GRB with an Intense Blackbody ?



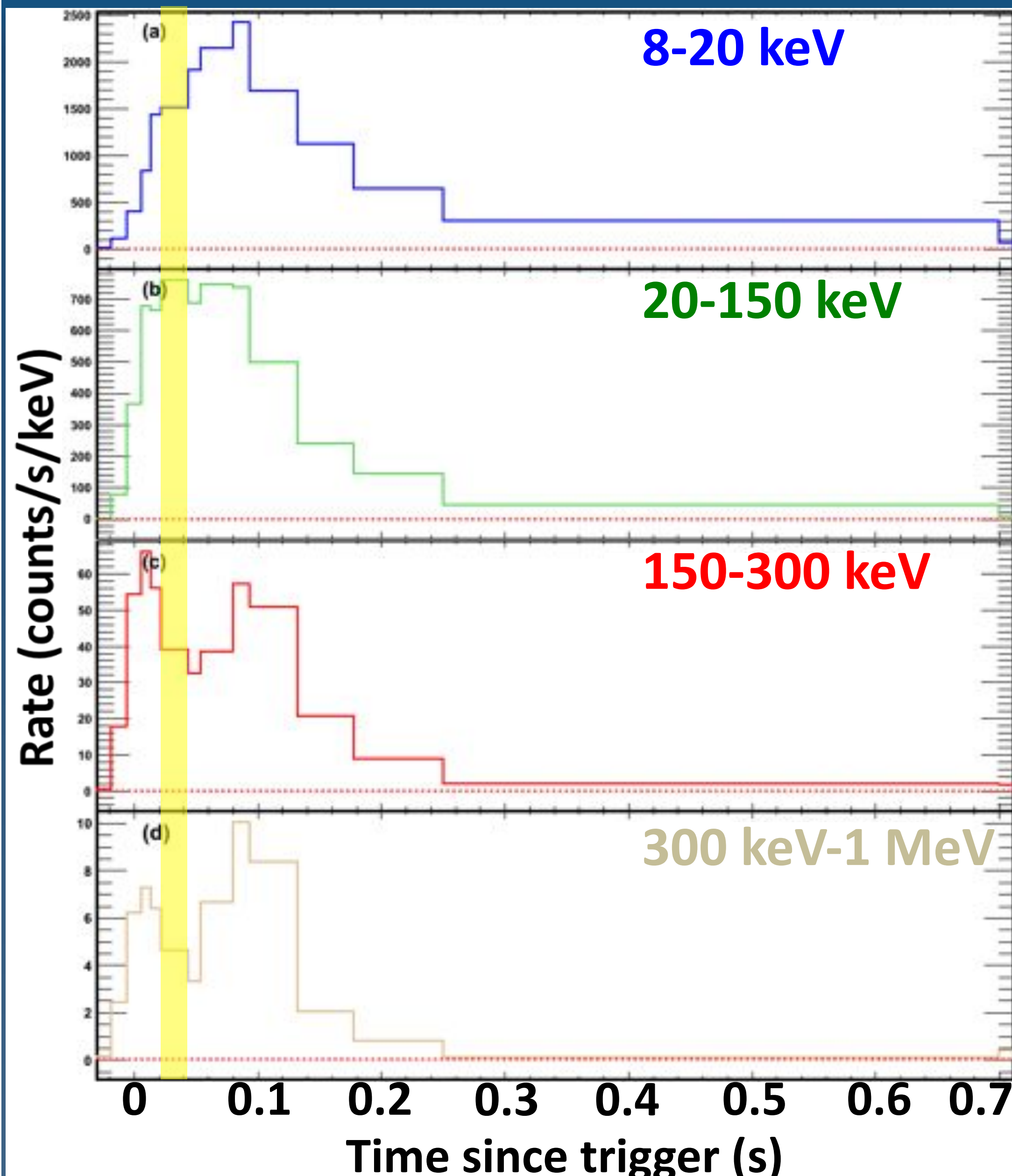


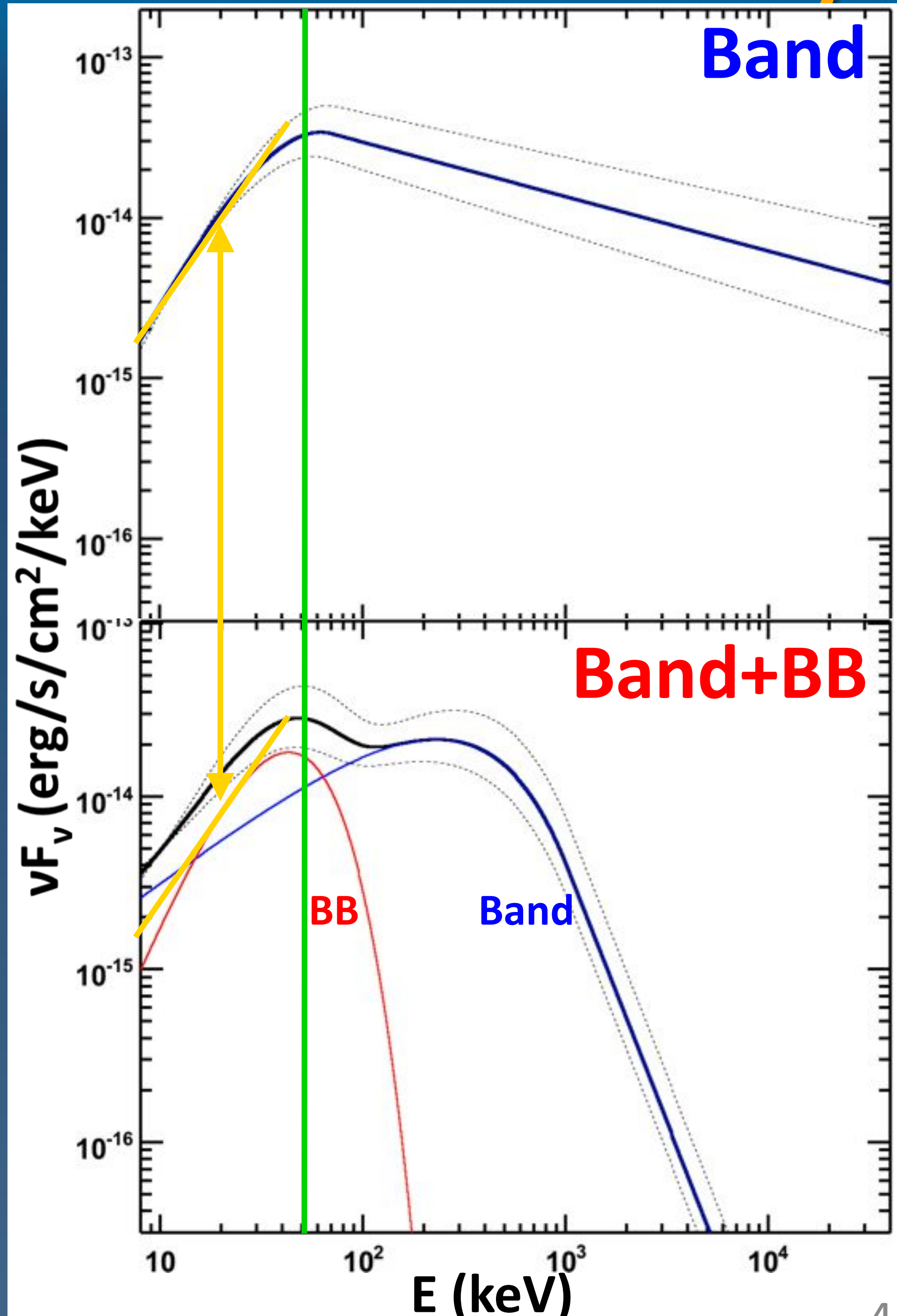
An Unusually Soft Short GRB or a Regular Short GRB with an Intense Blackbody ?





An Unusually Soft Short GRB or a Regular Short GRB with an Intense Blackbody ?





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