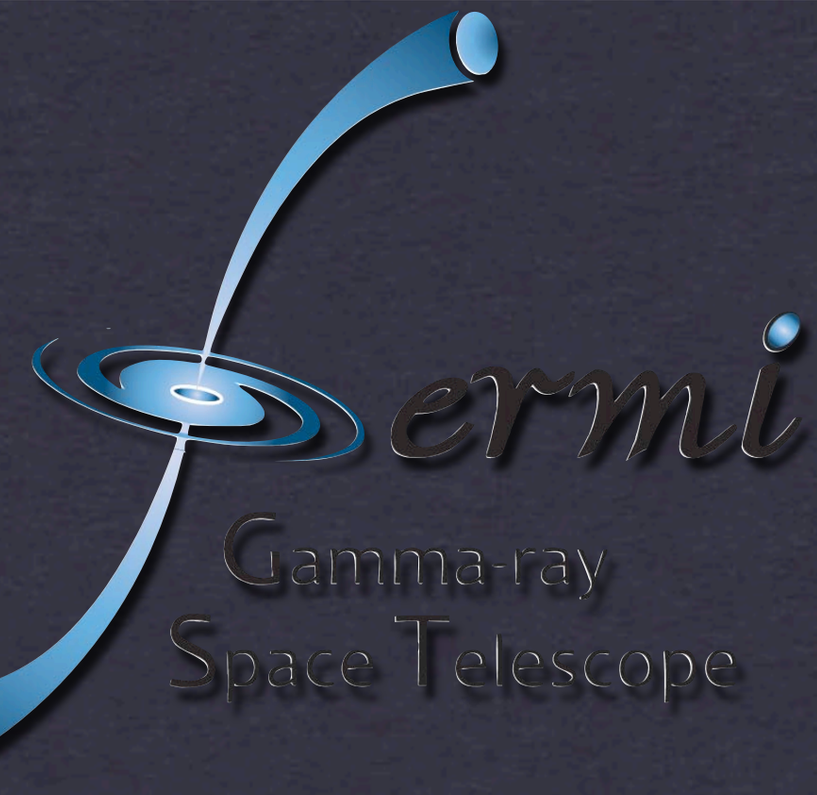


Fitting GBM Gamma-Ray Burst Spectra with Physical Emission Models

J. Michael Burgess

Rob Preece, Matthew Baring, Michael Briggs, Valerie Connaughton, Sylvain Guiriec

on behalf of the Fermi GBM Team

What We Know...

- Band's GRB function fits most GRB spectra well.
- Synchrotron spectrum appears to be inconsistent with with some fitted Band indices (Preece (1998)).
- Multi-component spectra (Gonzalez et al. (2003), Fermi LAT Team (2009-2011), Ryde (2009) Guiriec et al. (2011))
- Electron distributions from relativistic shock acceleration are well known (Baring (2011), Spikovsky (2008)).

Electron Distributions

SHOCK ACCELERATION

BARING AND BRABY (2004)

$$n_e(\gamma) = n_0 \left(\frac{\gamma}{\gamma_{\rm th}}\right)^2 e^{-\frac{\gamma}{\gamma_{\rm th}}} \Theta\left(\eta - \frac{\gamma}{\gamma_{\rm th}}\right) + \epsilon \left(\frac{\gamma}{\gamma_{\rm th}}\right)^{-\delta} \Theta\left(\frac{\gamma}{\gamma_{\rm th}} - \eta\right)$$

FAST COOLING

BLUMENTHAL & GOULD (1971)

$$\frac{\partial}{\partial t} n_e(\gamma, t) + \frac{\partial}{\partial \gamma}(\dot{\gamma} n_e(\gamma, t)) = Q_{inj}(\gamma) - \frac{n_e(\gamma, t)}{t_{esc}}$$

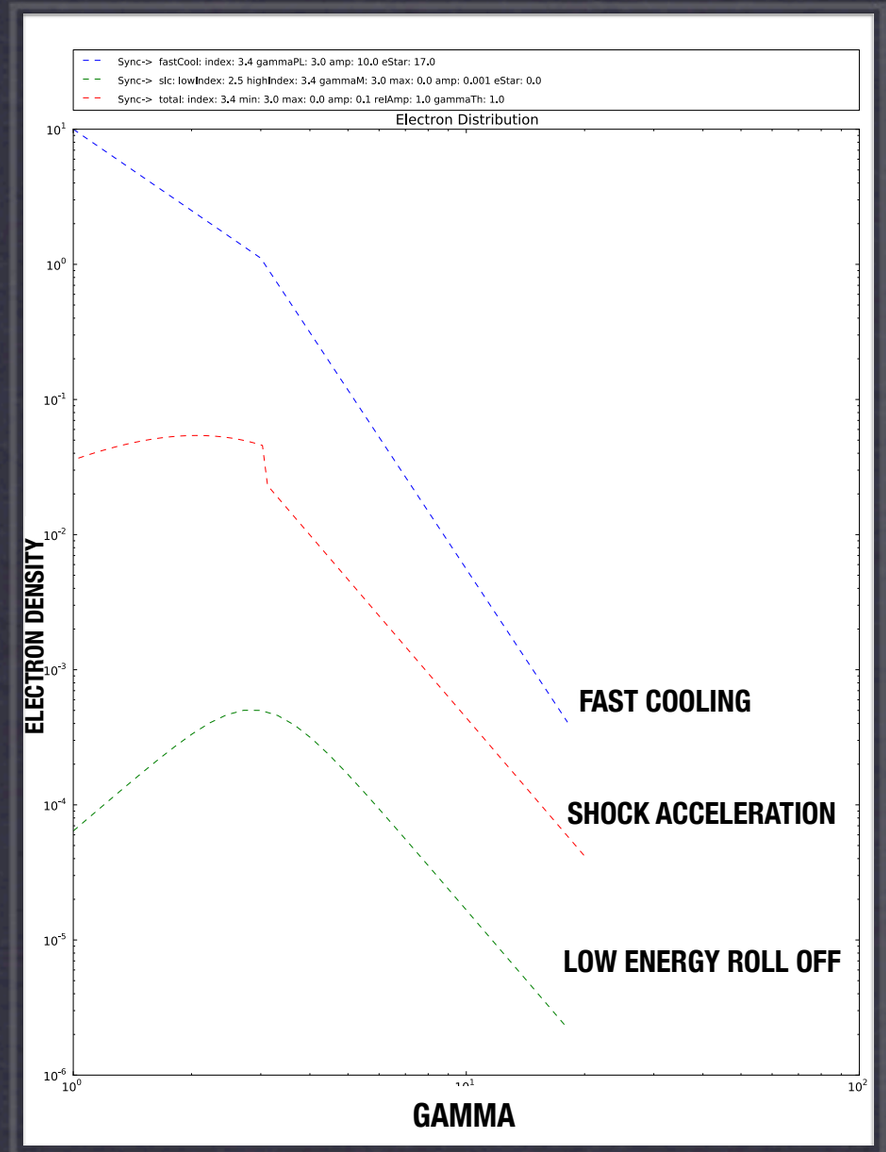
$$Q_{inj}(\gamma) = n_0(\delta - 1)\gamma_{pl}^{\delta-1}\gamma^{-\delta}\Theta(\gamma - \gamma_{pl}) \qquad \dot{\gamma} = -\frac{2}{3}\frac{r_0 c}{r_g^2}\gamma^2 \sin^2\theta$$

$$n_e^{cool}(\gamma) = n_0 \frac{3}{2}\frac{n_0 r_g^2}{r_0 c \sin^2\theta}\gamma^{-2}\left[\left(\frac{\gamma}{\gamma_{pl}}\right)^{-(\delta-1)} \Theta(\gamma - \gamma_{pl}) - \Theta(\gamma_{pl} - \gamma)\right]$$

LOW-ENERGY ROLL OFF

LLOYD & PETROSIAN (2002)

$$n_e^{rolloff}(\gamma) = n_0 \frac{(\gamma/\gamma_m)^q}{1 + (\gamma/\gamma_m)^{p+q}}$$



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ROME, ITALY

Electron Distributions

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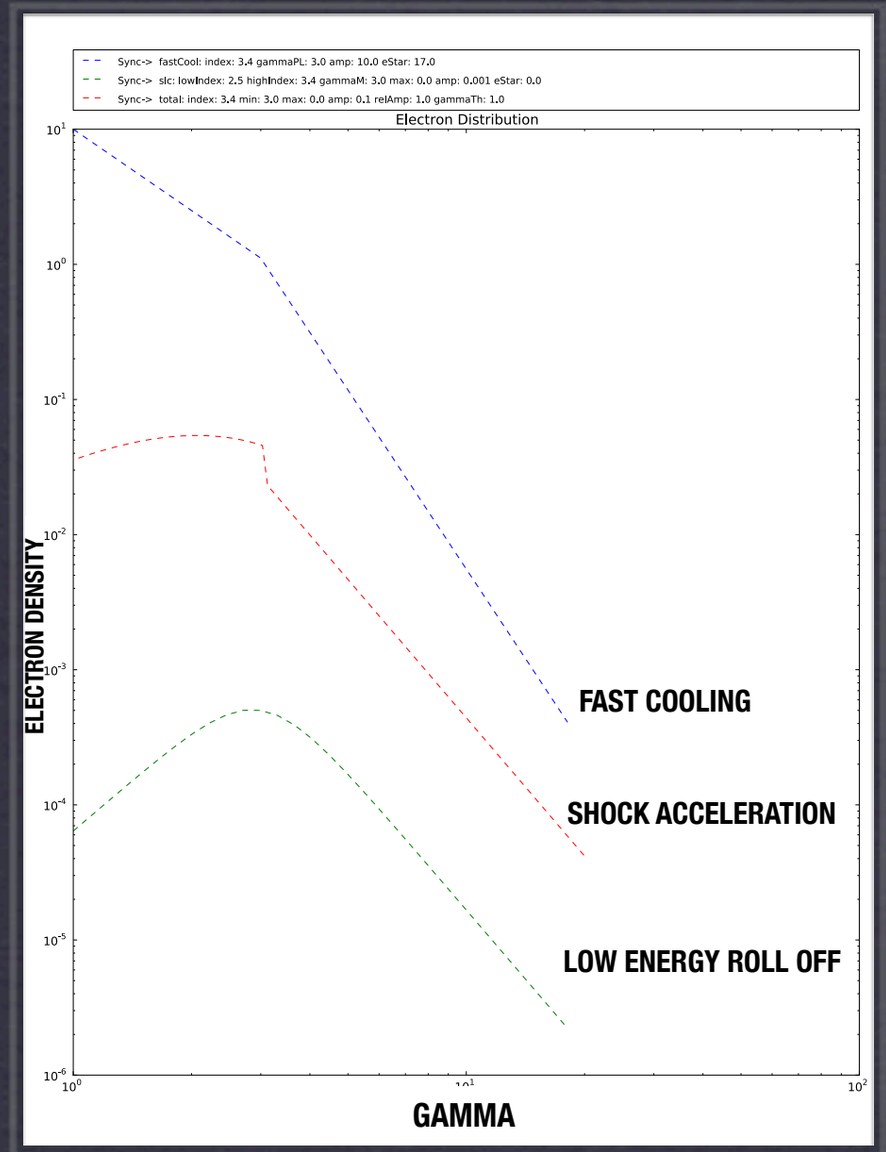

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ROME, ITALY

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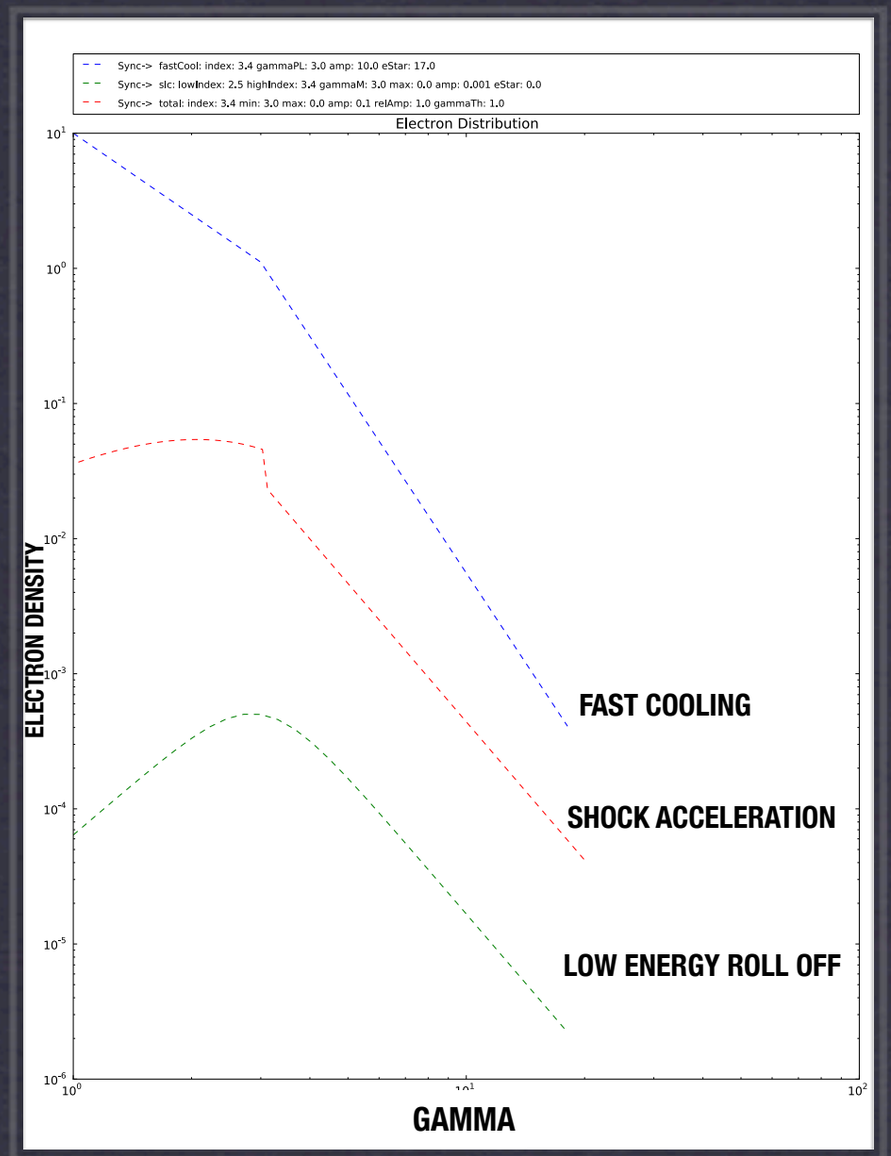

$$\frac{\mathcal{E}_\gamma}{\mathcal{E}_\star \gamma^2} \qquad \mathcal{E}_\star = \frac{3}{2}\frac{B}{B_{\rm cr}}\Gamma\,\gamma_{th}^2\, m_e c^2$$

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ROME, ITALY

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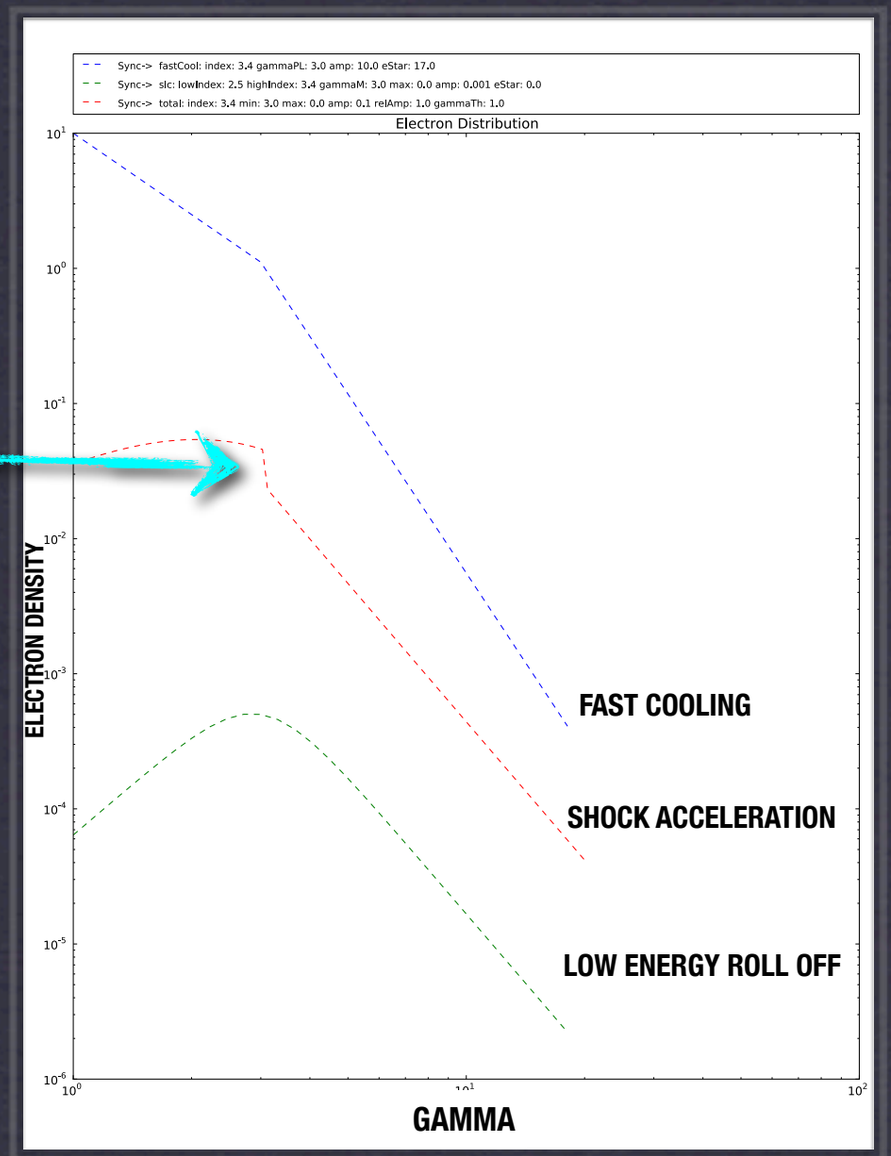

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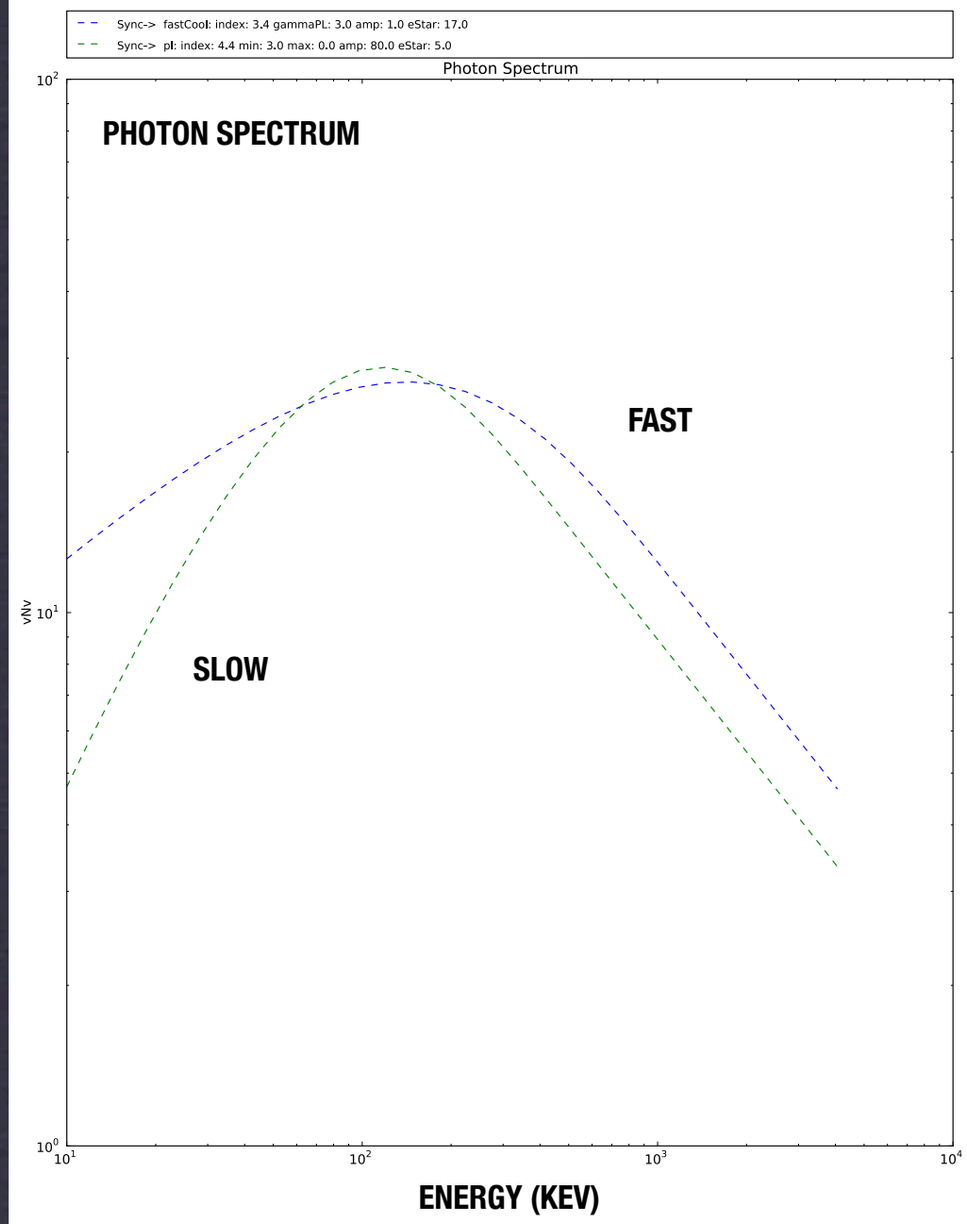

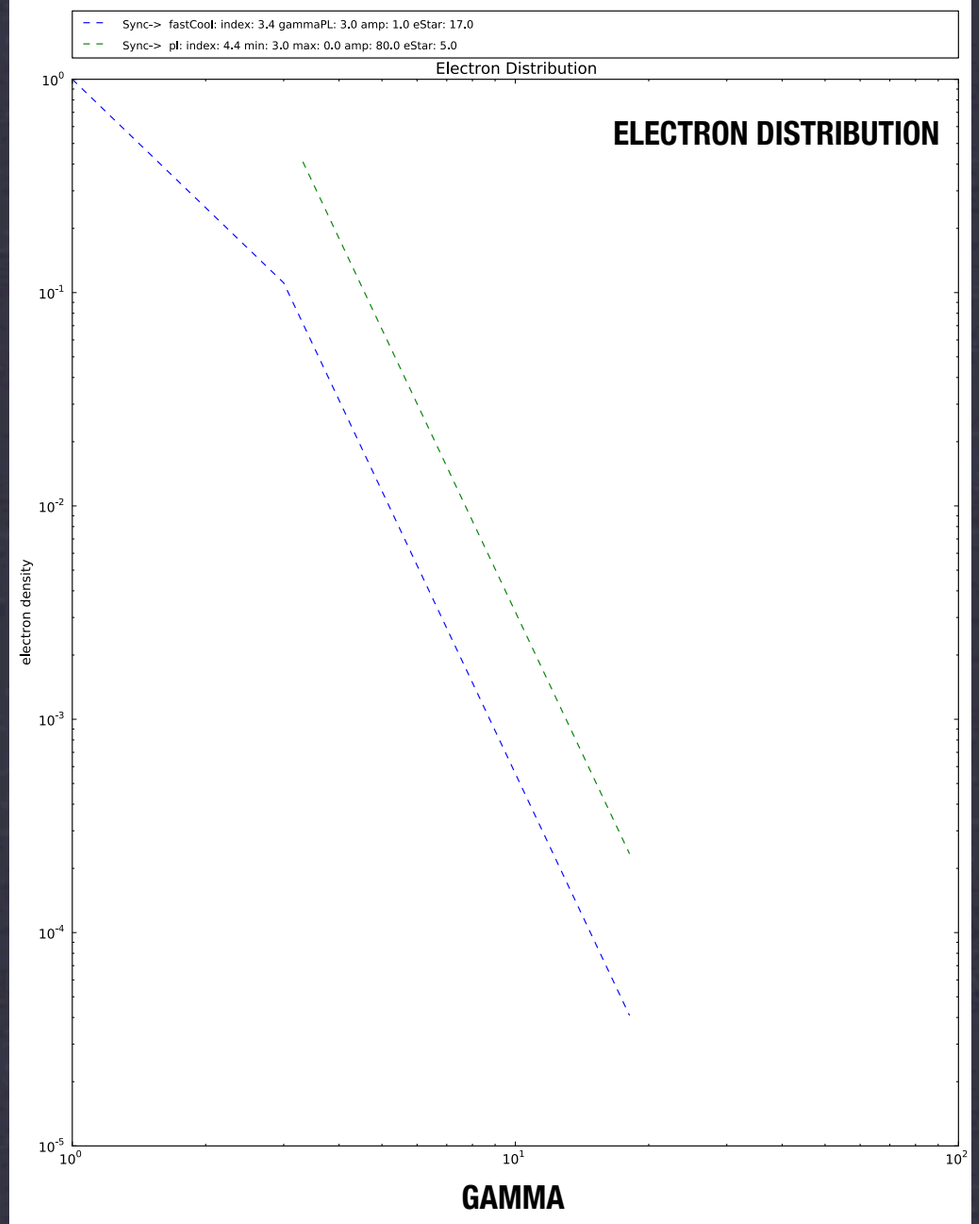

FAST OR SLOW?

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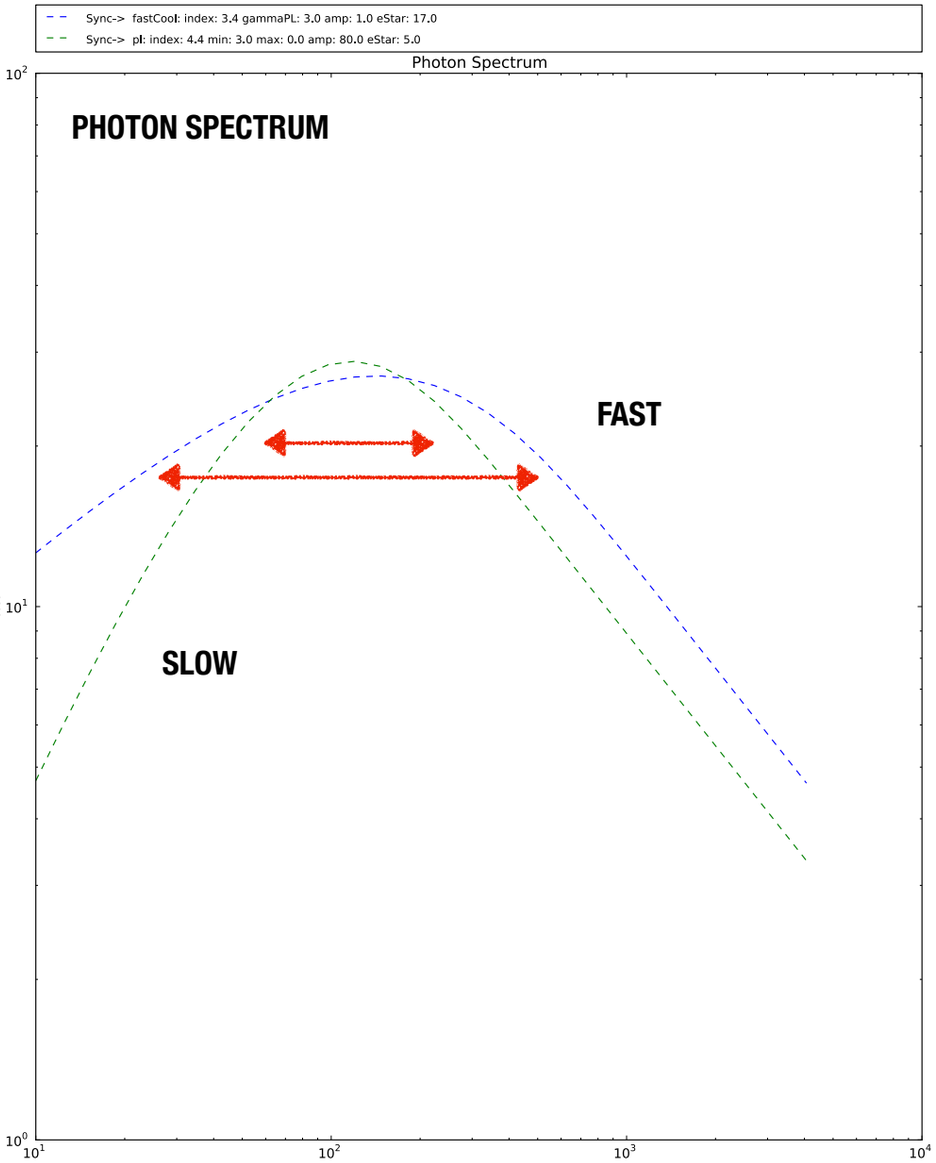
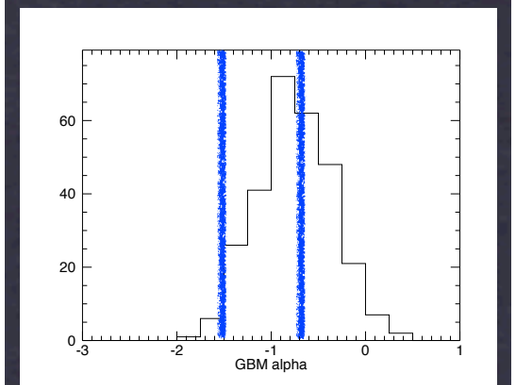
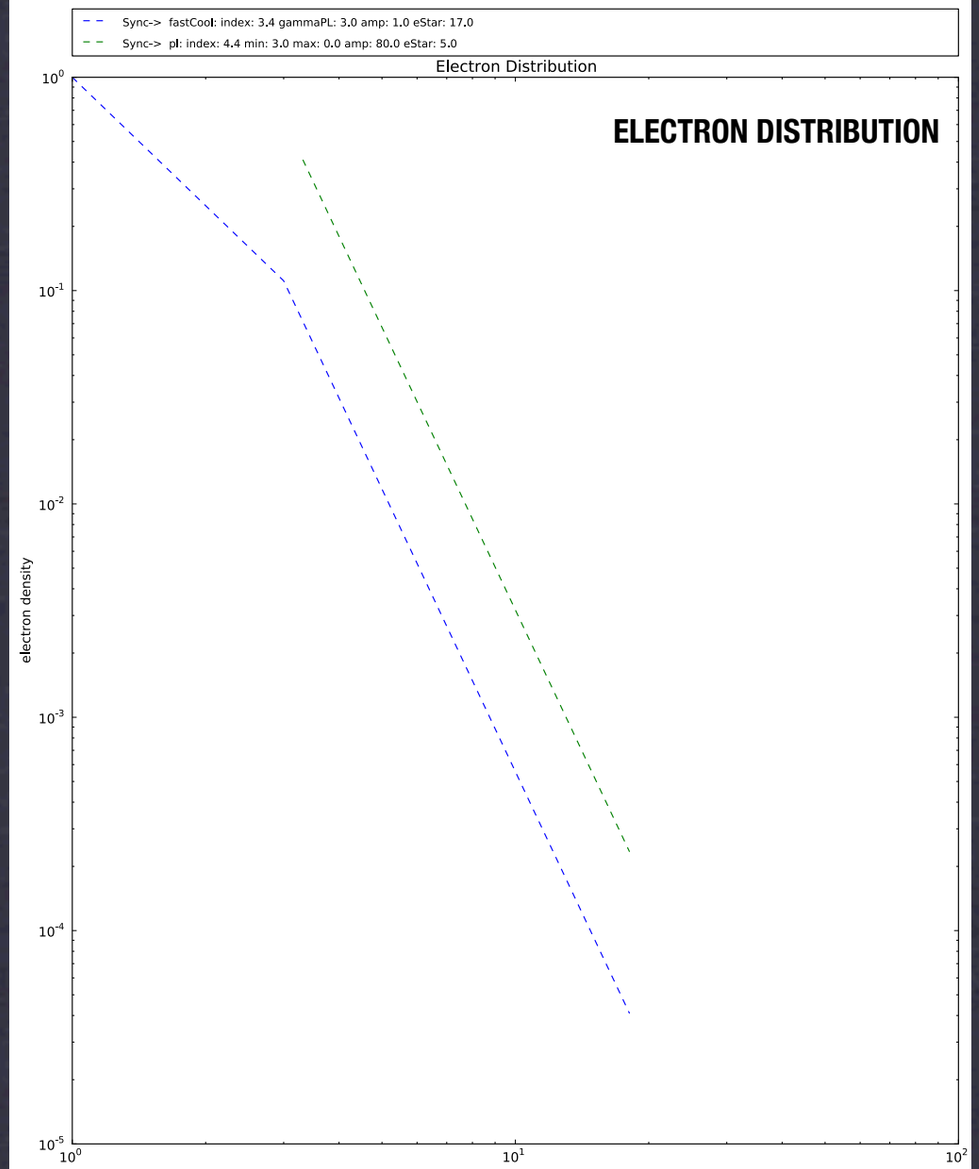




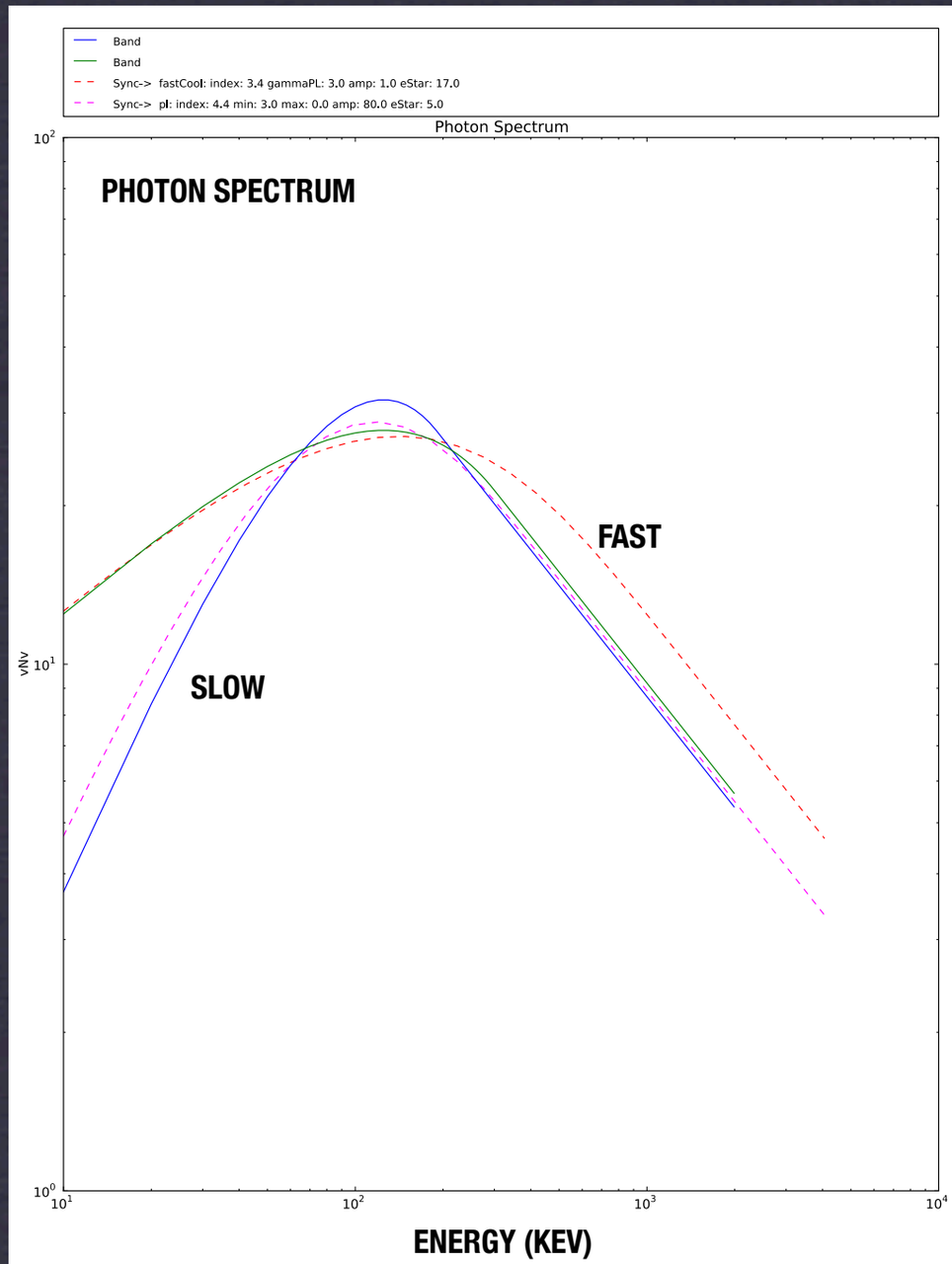
GOLDSTEIN ET. AL. (IN PREP)

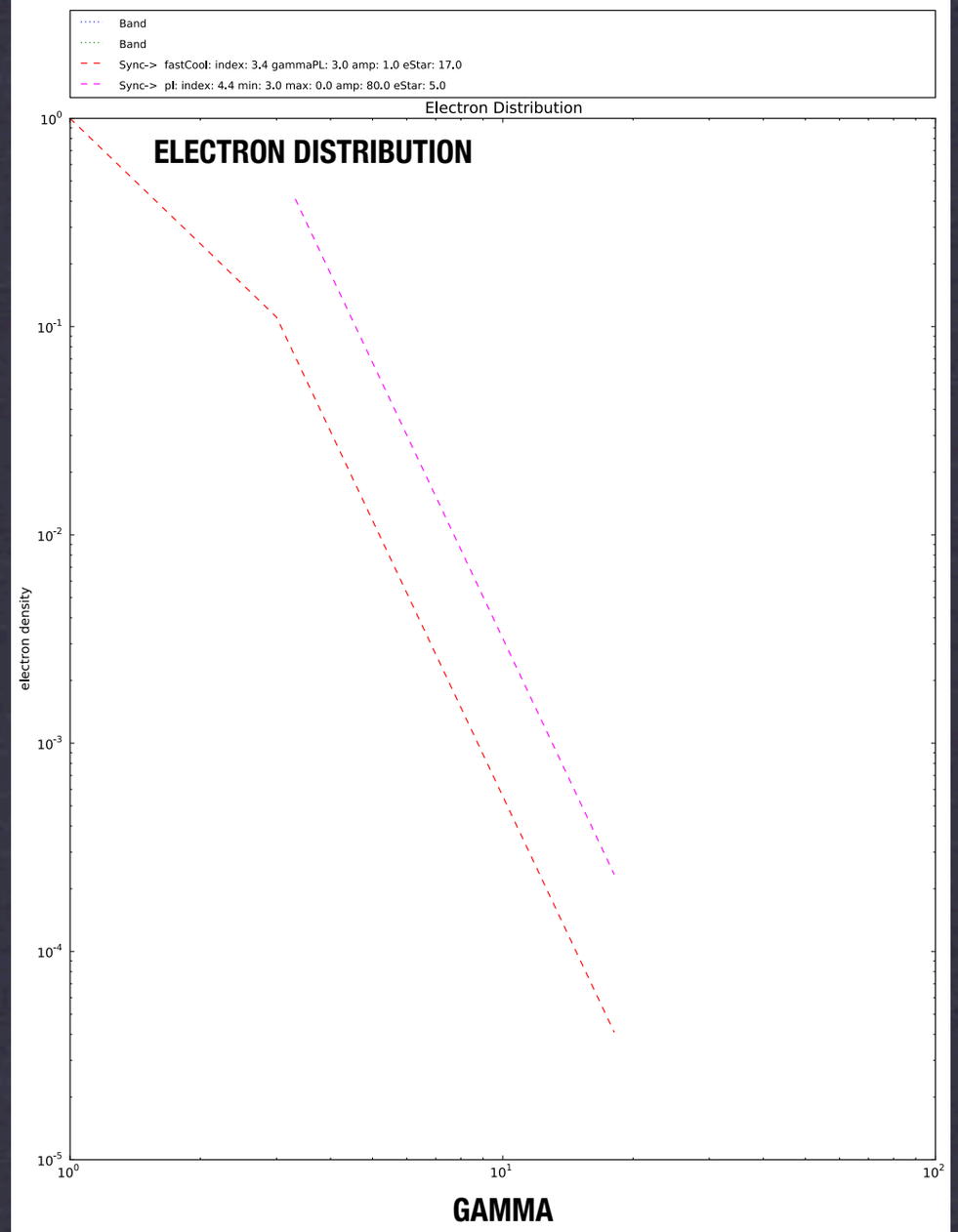


FAST OR SLOW?

FERMI SYMPOSIUM 2011

ROME, ITALY





FAST OR SLOW?

FAST SYNCHROTRON IS MUCH BROADER THAN BAND AT THE PEAK

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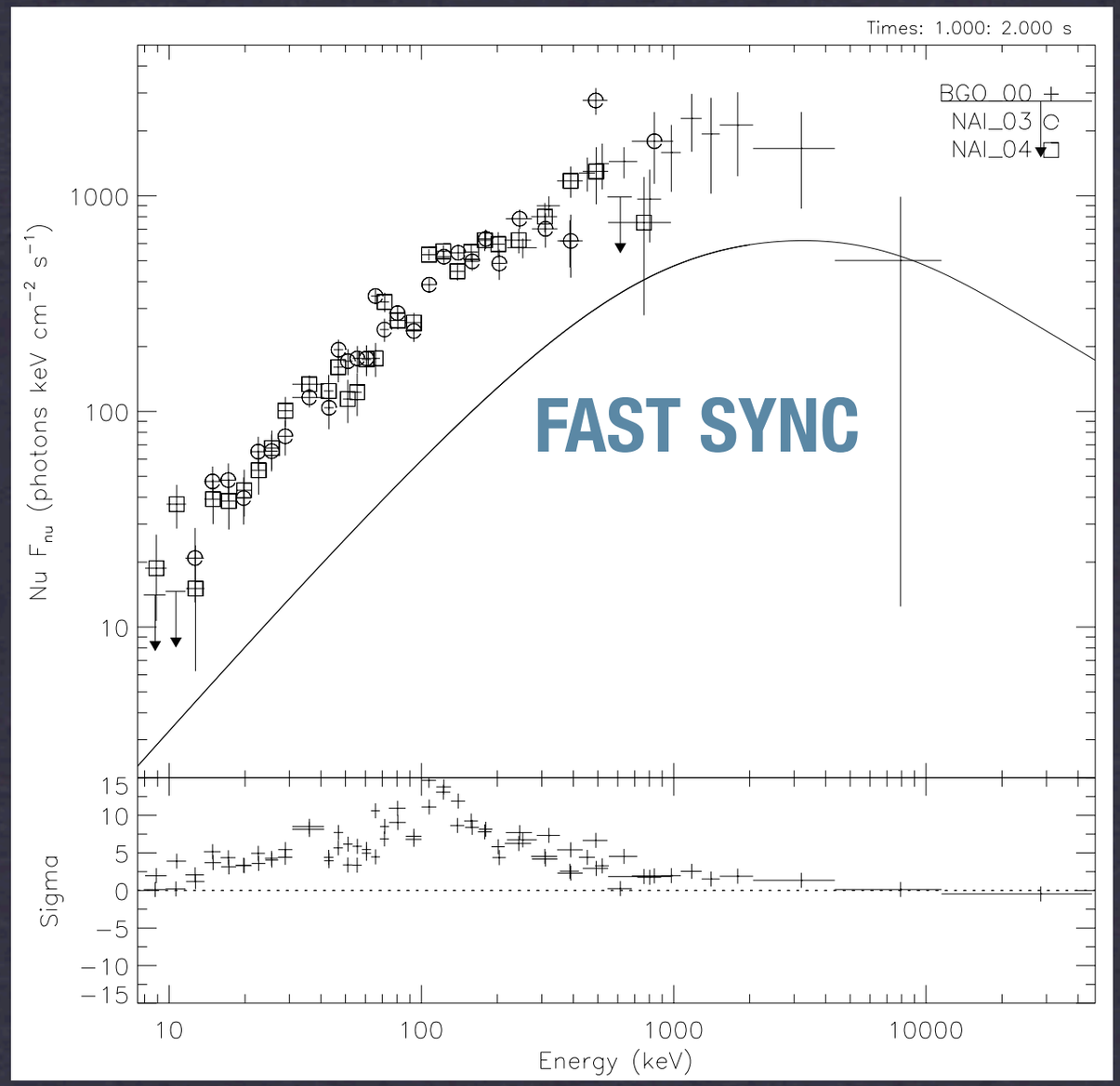
The Fast Conundrum

- Curvature is too broad to fit the prompt emission spectrum regardless of low-energy index for all bursts tried.
- Slow cooling spectrum implies electrons are being re-energized.



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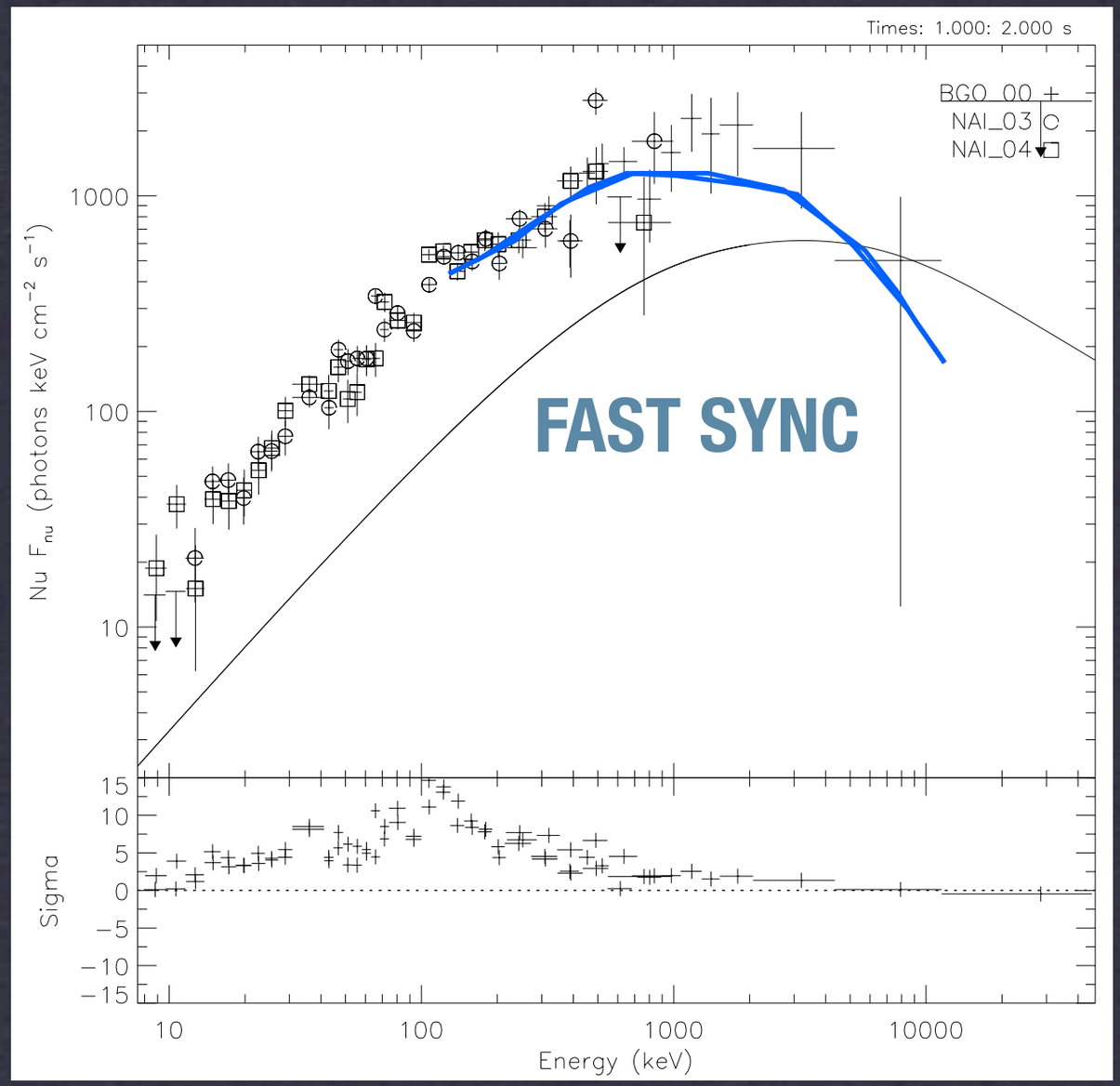
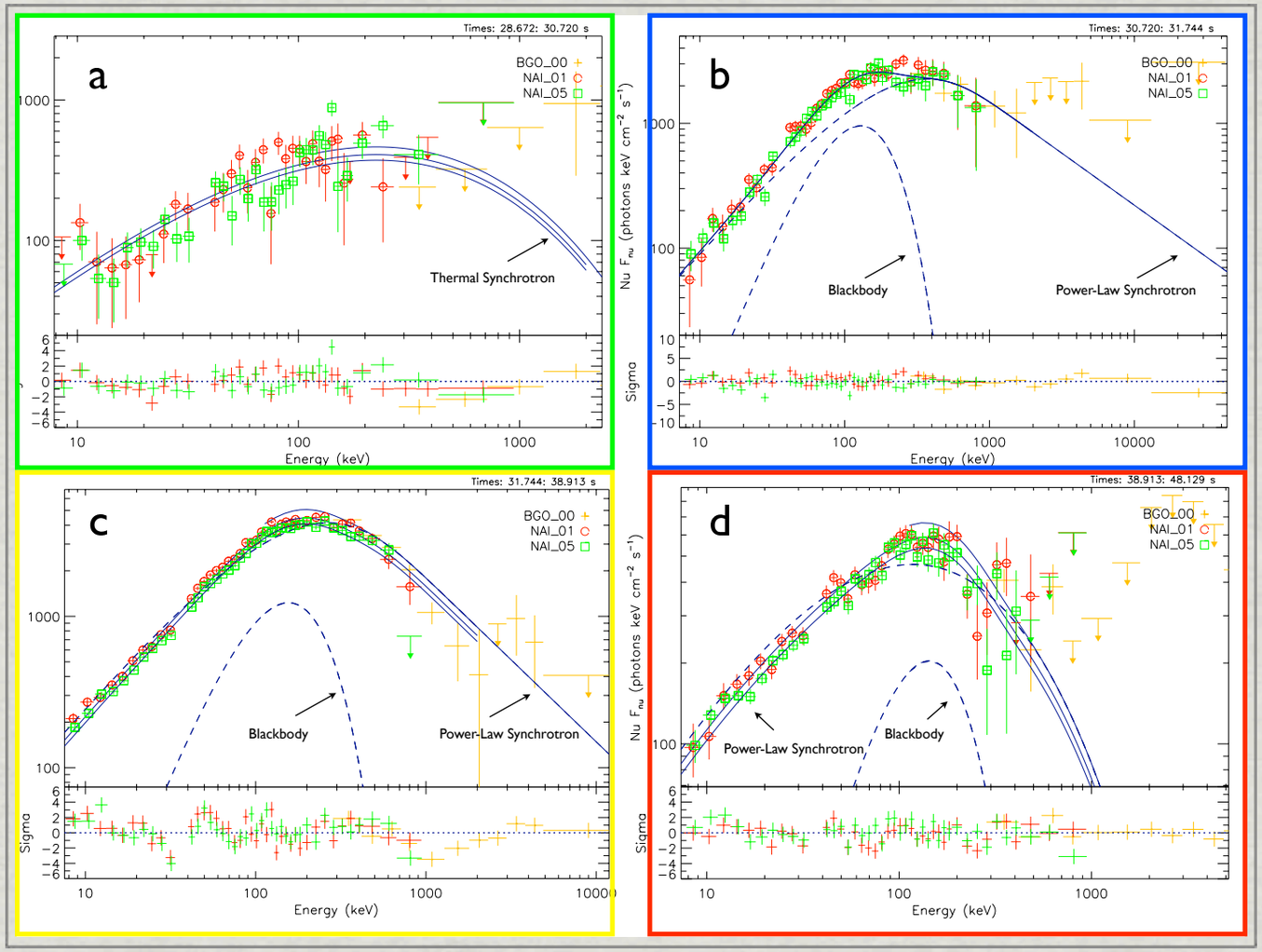
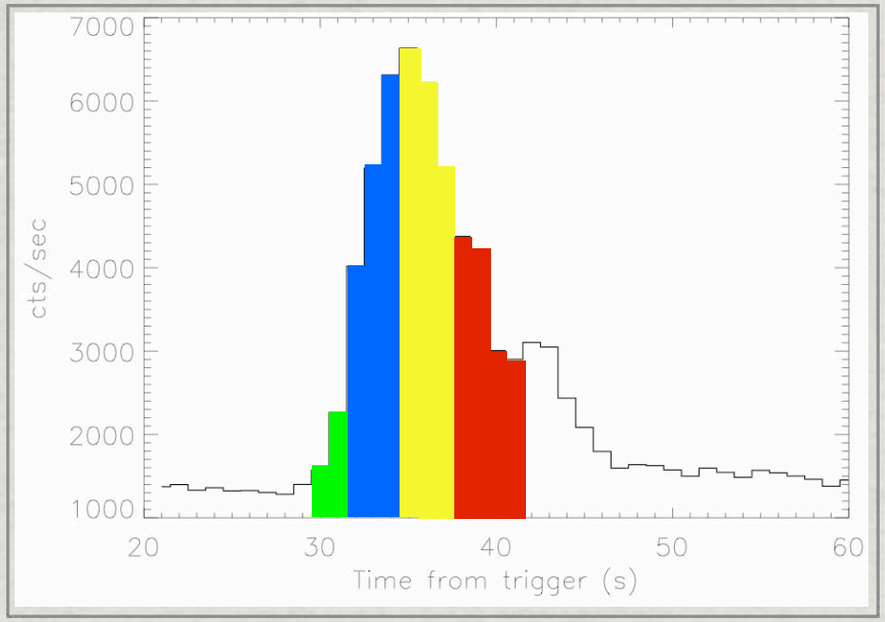


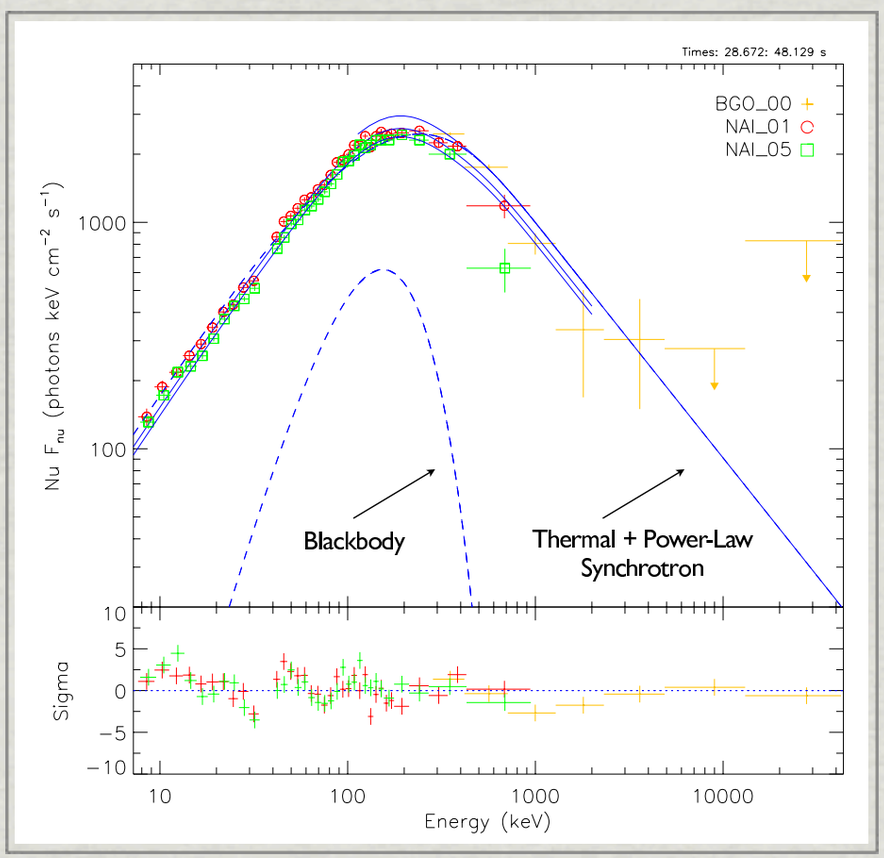
GRB090820A

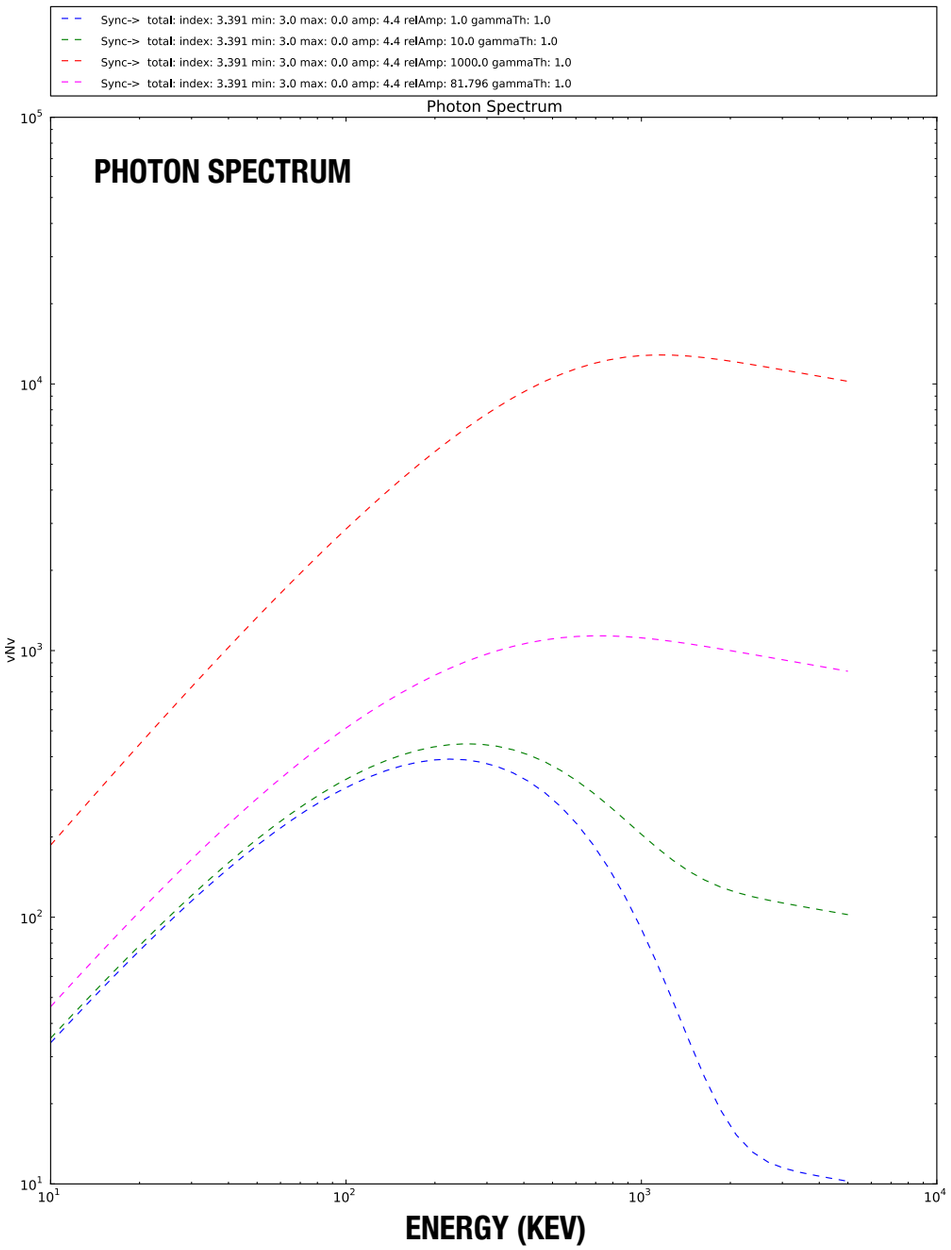
- SPECTRUM STATISTICALLY BEST DESCRIBED BY SYNCHROTRON AND AN ADDITIONAL BLACKBODY
- EXCESS OF POWER-LAW ELECTRONS IN THE DISTRIBUTION
- TIME EVOLUTION OF THE ELECTRON DISTRIBUTION

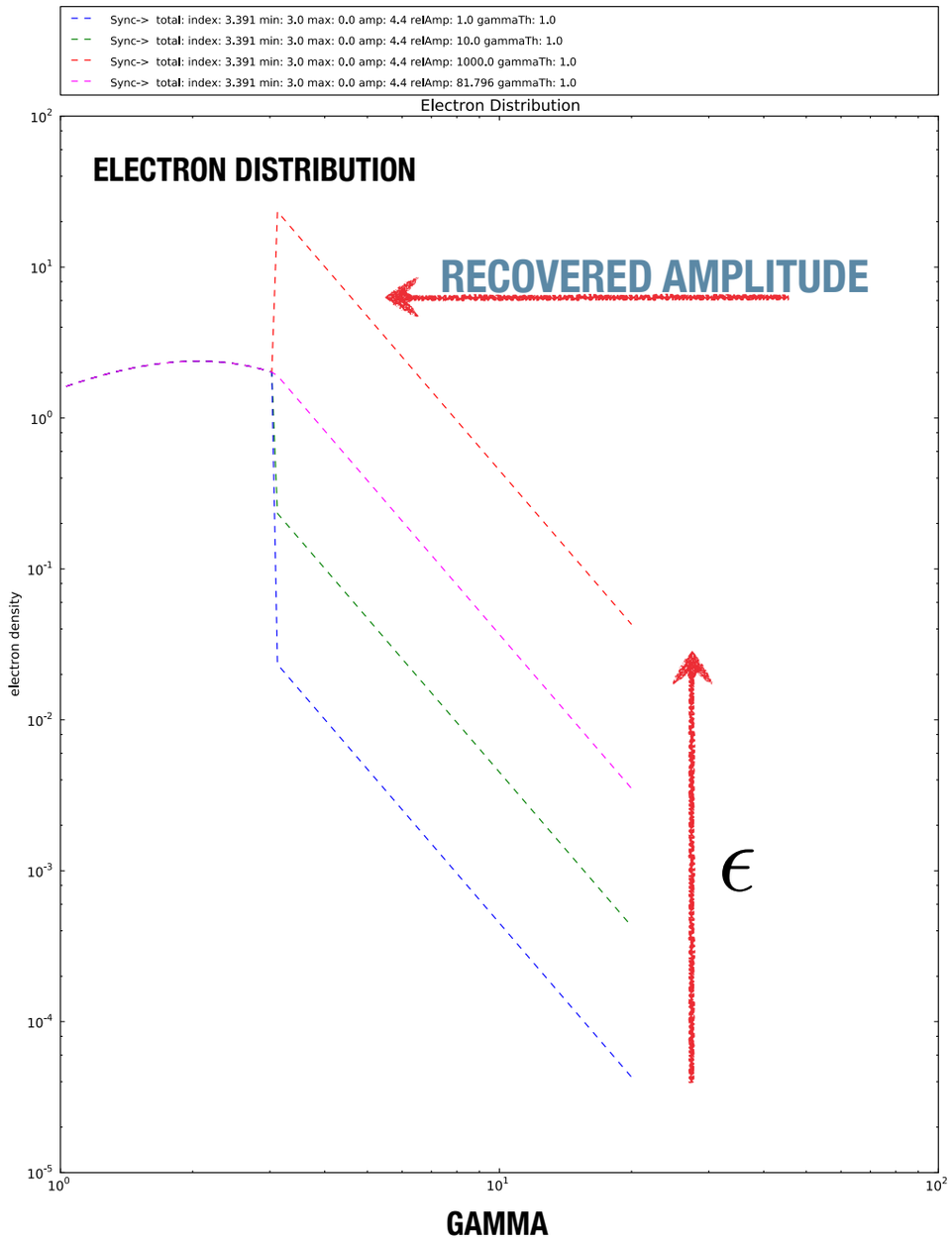


BURGESS ET AL (SUBMITTED)









WHERE IS THE MAXWELLIAN?

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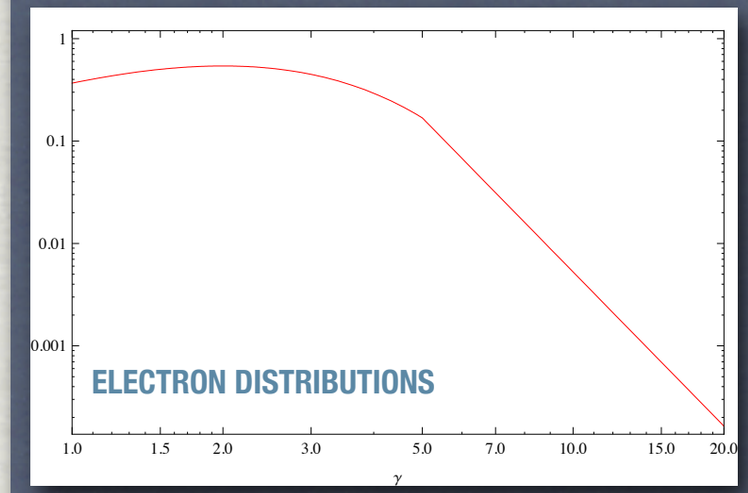
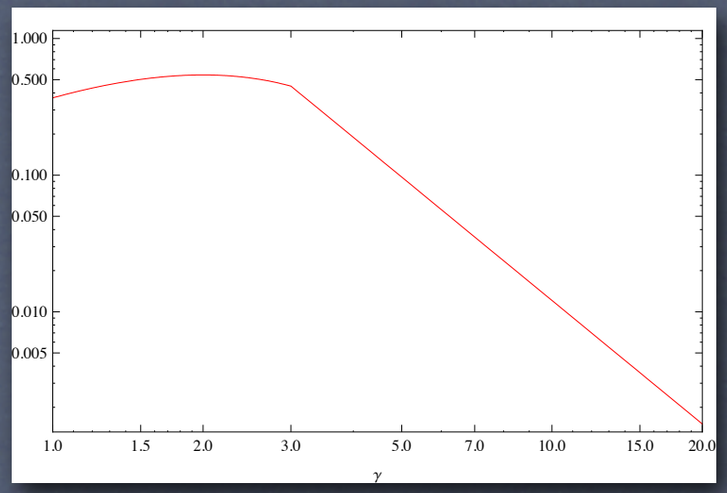
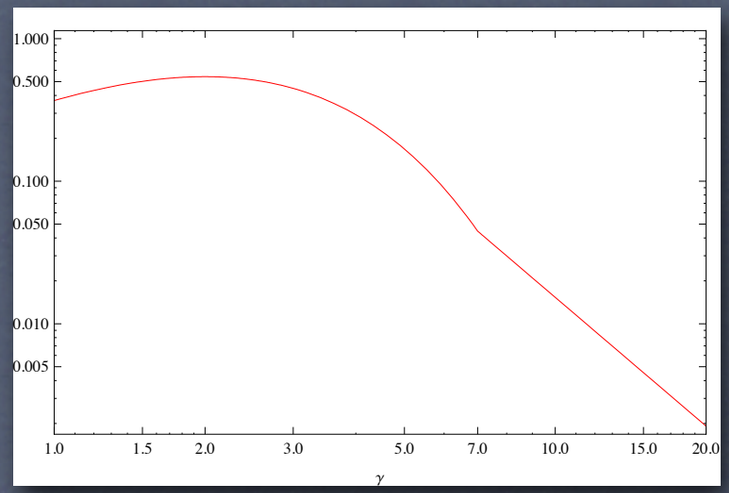
Fixing the Amplitude

$$\epsilon = \eta^{2+\delta} e^{-\eta}$$







BY FIXING THE AMPLITUDE WE ELIMINATE A PARAMETER AND RECOVER A MORE PHYSICALLY MOTIVATED SPECTRUM

Fixing the Amplitude

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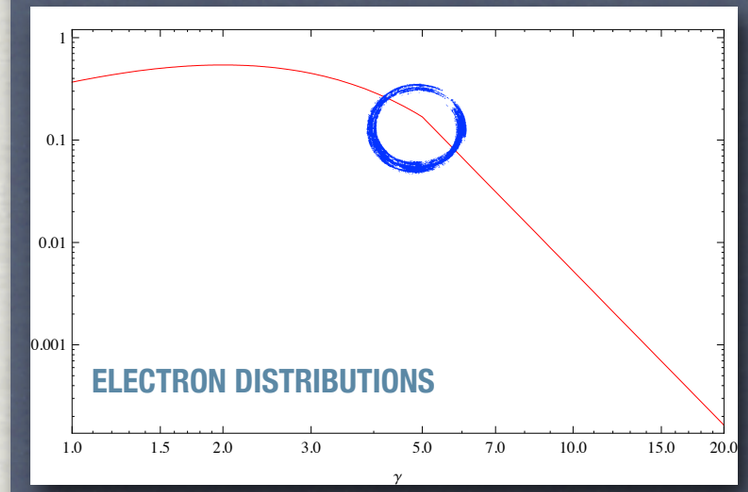

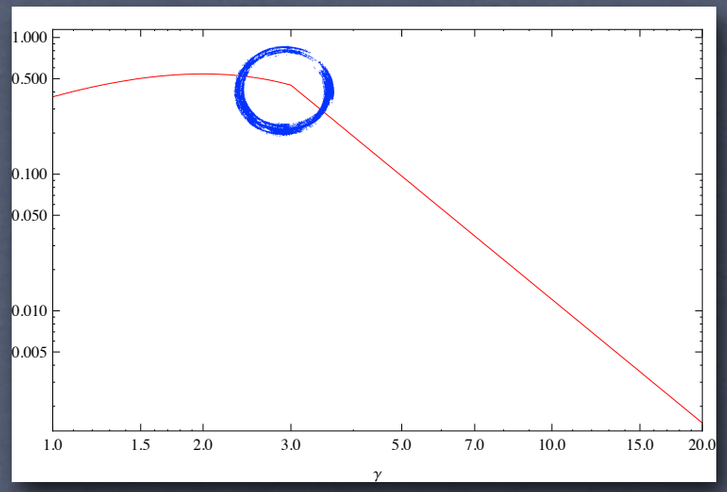

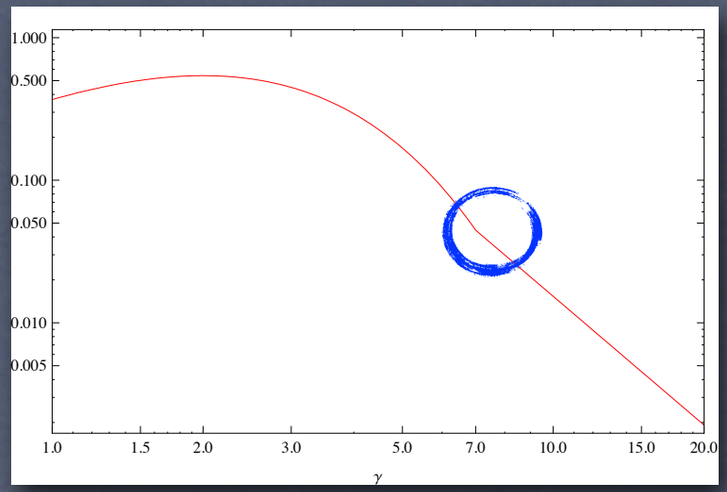

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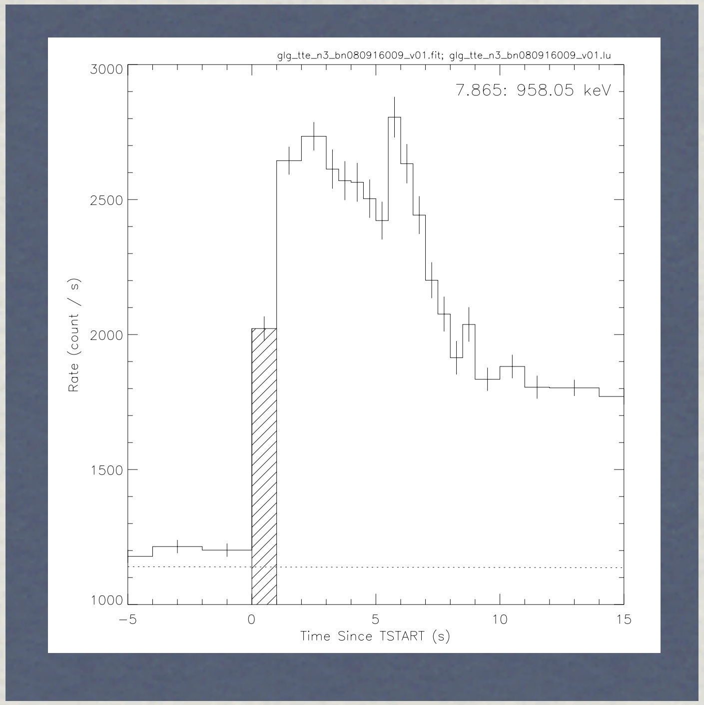
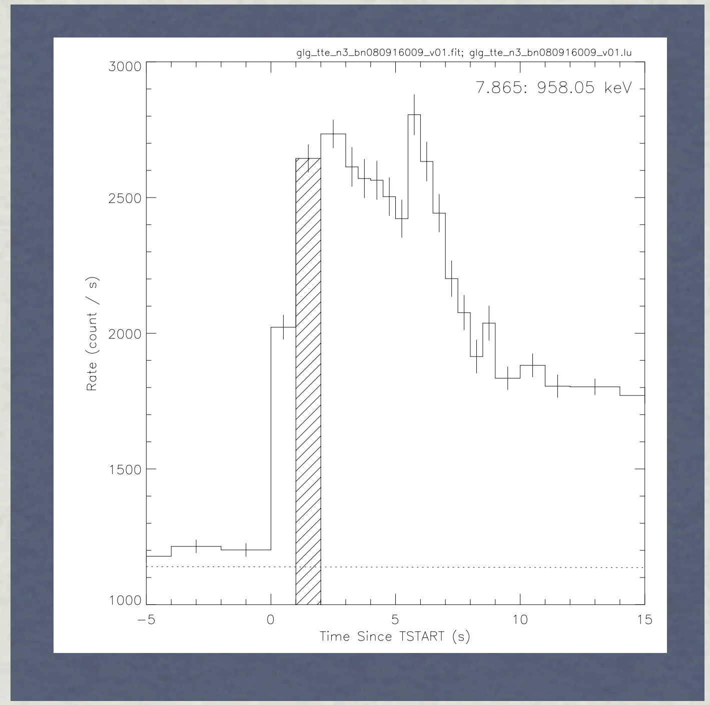
GRB080916C


glg_tte_n3_bn080916009_v01.fit; glg_tte_n3_bn080916009_v01.lu
7.865: 958.05 keV
Rate (count / s)
Time Since TSTART (s)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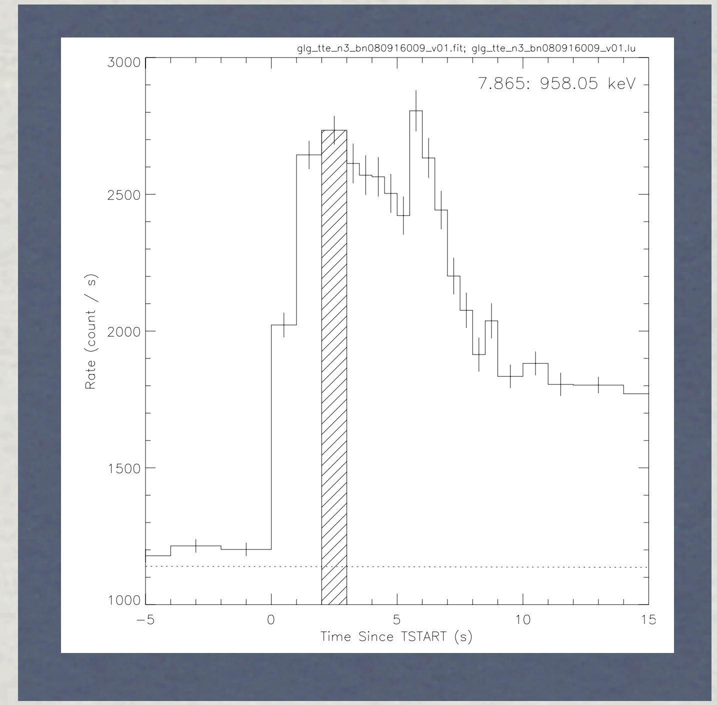
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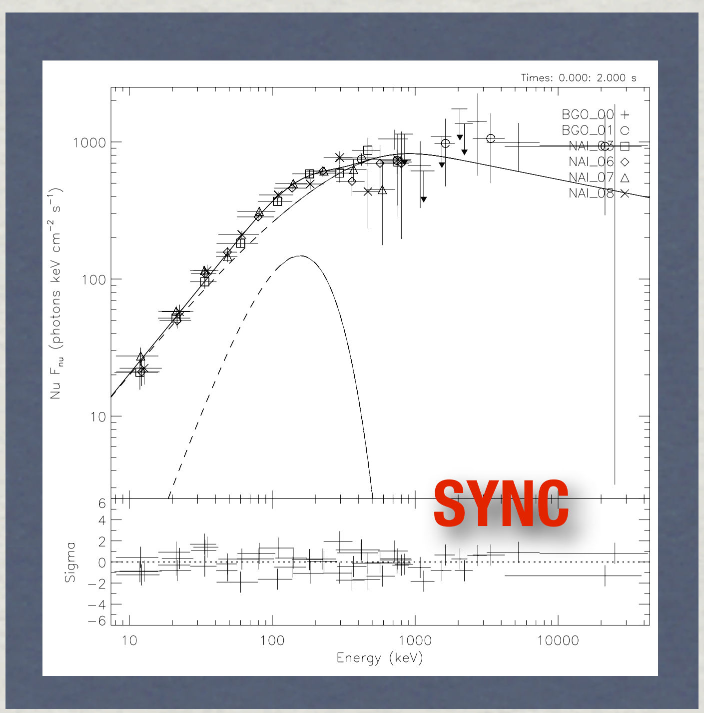
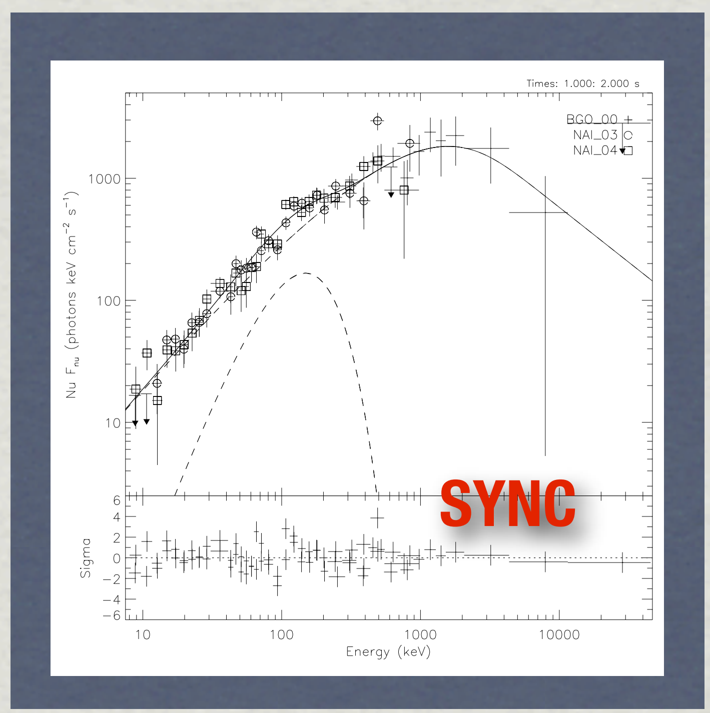
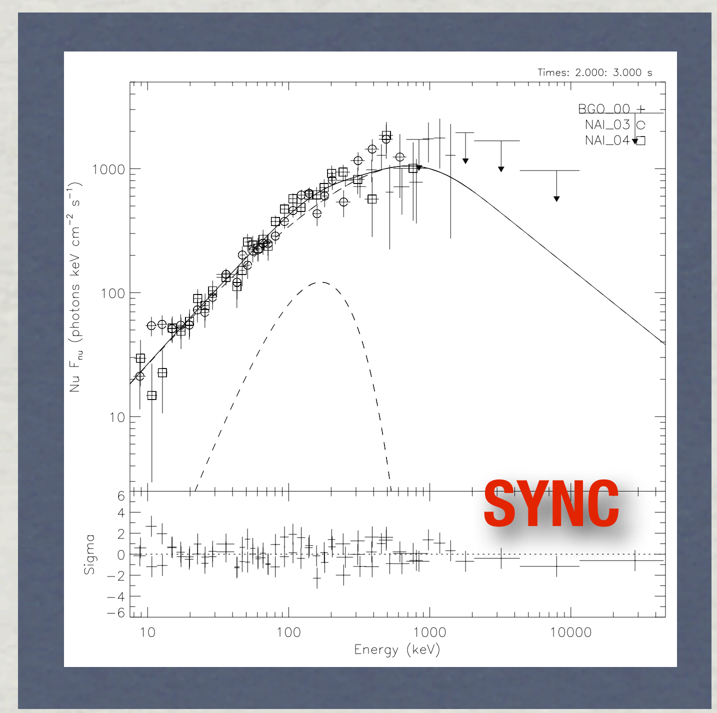
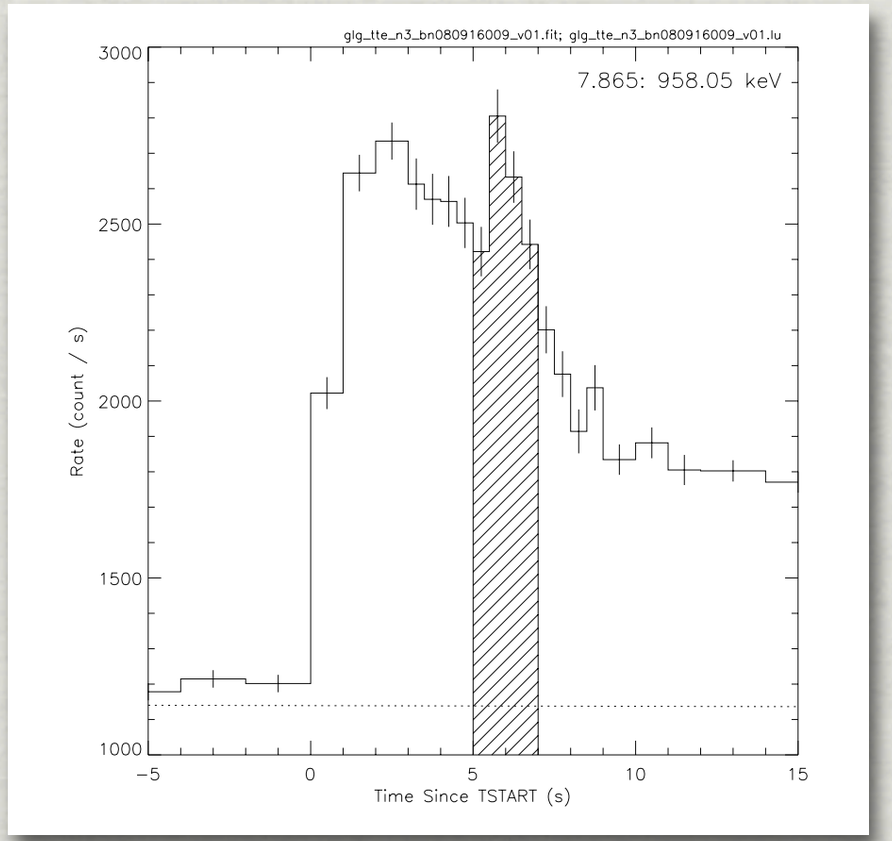
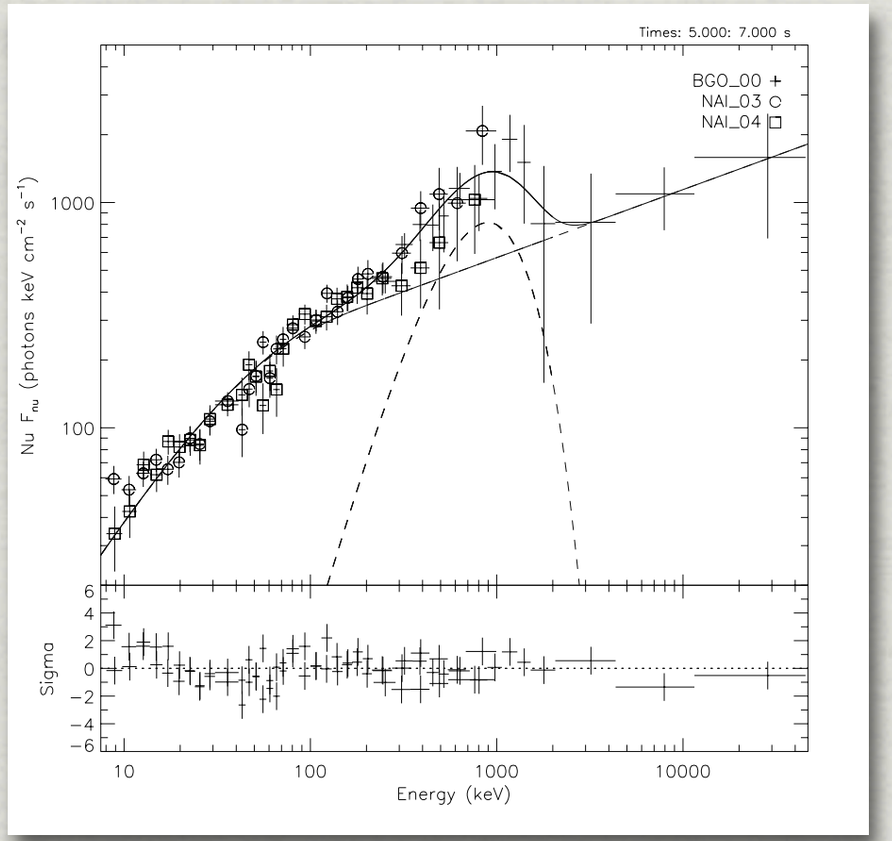

Times: 0.000: 2.000 s
Nu F_nu (photons keV cm^-2 s^-1)
Sigma
Energy (keV)
SYNC


Times: 1.000: 2.000 s
BGO_00
NAI_03
NAI_04
Nu F_nu (photons keV cm^-2 s^-1)
Sigma
Energy (keV)
SYNC


Times: 2.000: 3.000 s
BGO_00
NAI_03
NAI_04
Nu F_nu (photons keV cm^-2 s^-1)
Sigma
Energy (keV)
SYNC

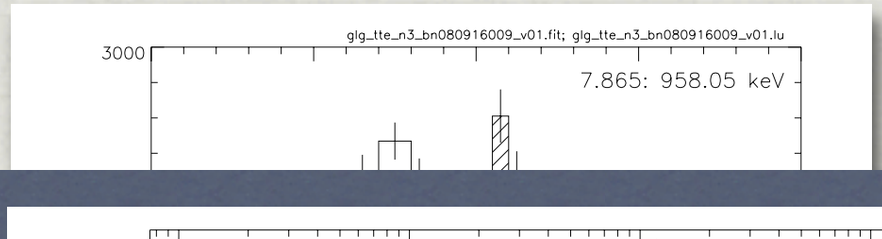


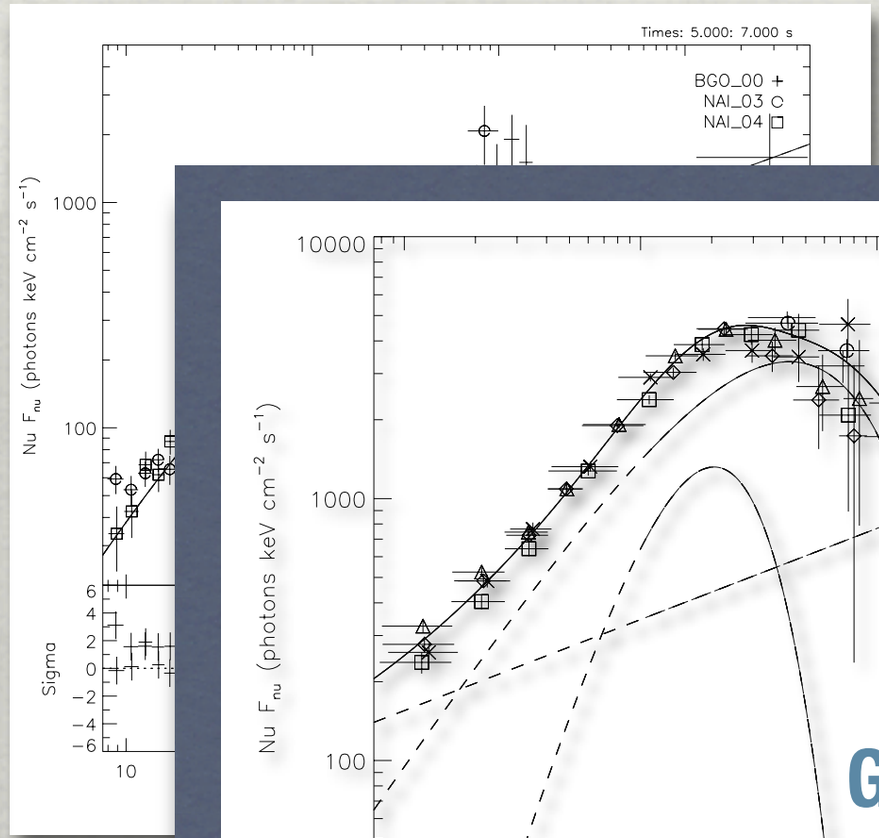


- SYNCHROTRON CEASES TO DESCRIBE THE NON-THERMAL SPECTRUM WELL.
- HIGH-ENERGY POWER-LAW CHANGES IN A NON-PHYSICAL WAY.
- INDICATION OF AN EXTRA-COMPONENT.

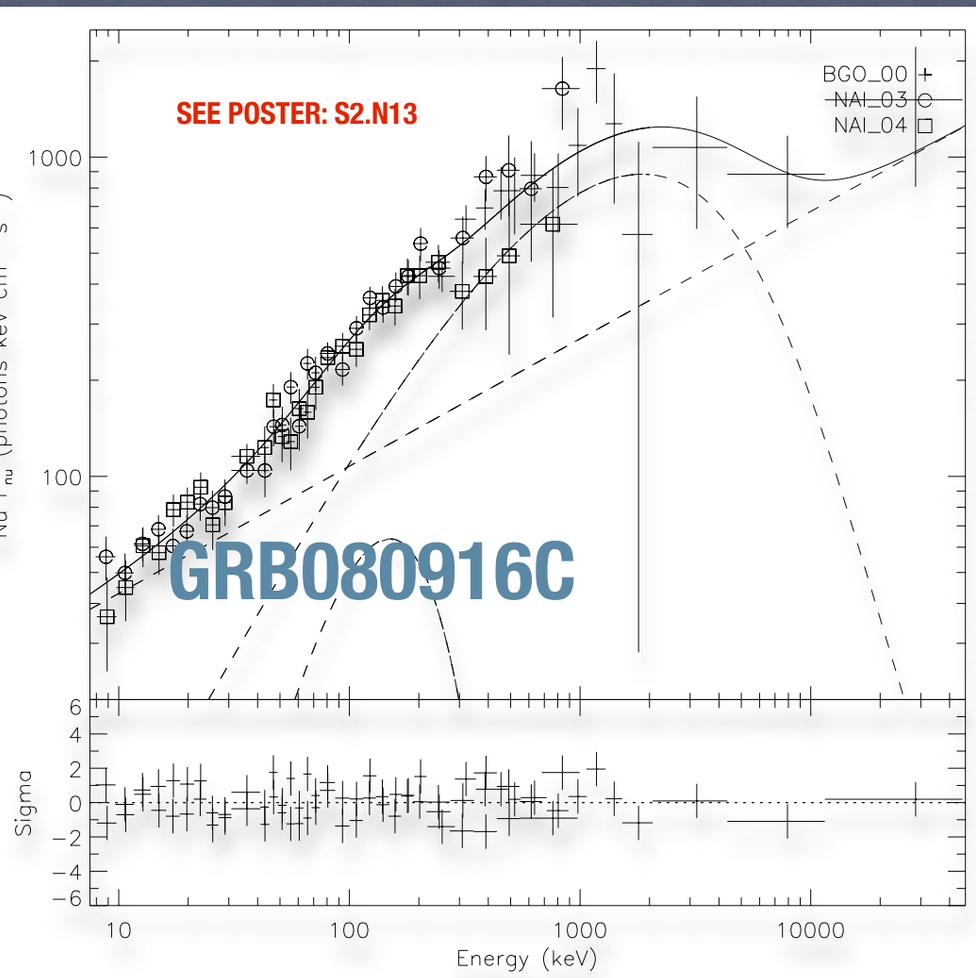
SYNCHROTRON + BB
CASTOR C-STAT = 394.07, DOF = 366

BAND + BB
CASTOR C-STAT = 375.00, DOF = 365





SEE POSTER: S2.N13



NON-PHYSICAL WAY.

- **INDICATION OF AN EXTRA-COMPONENT.**

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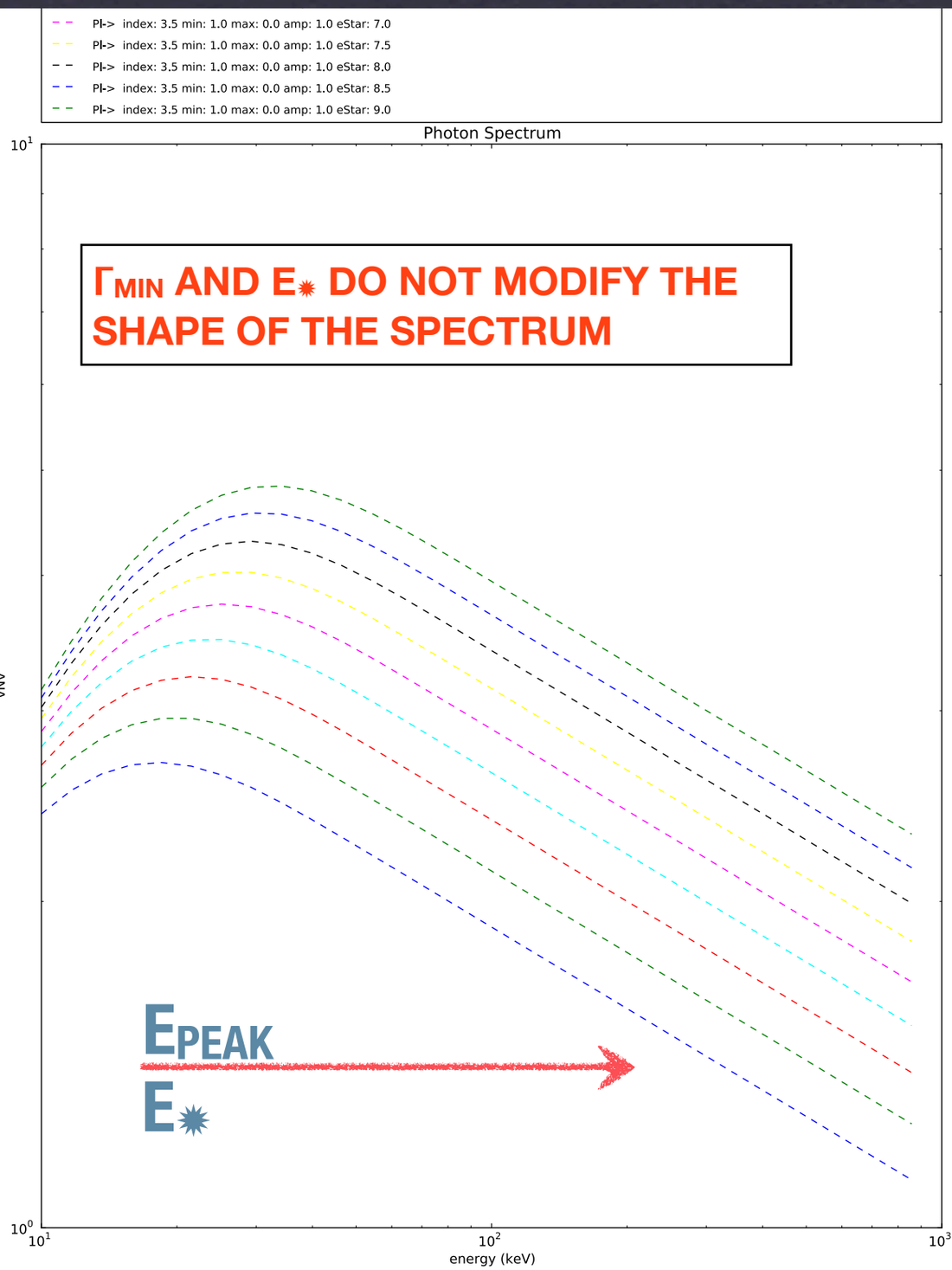
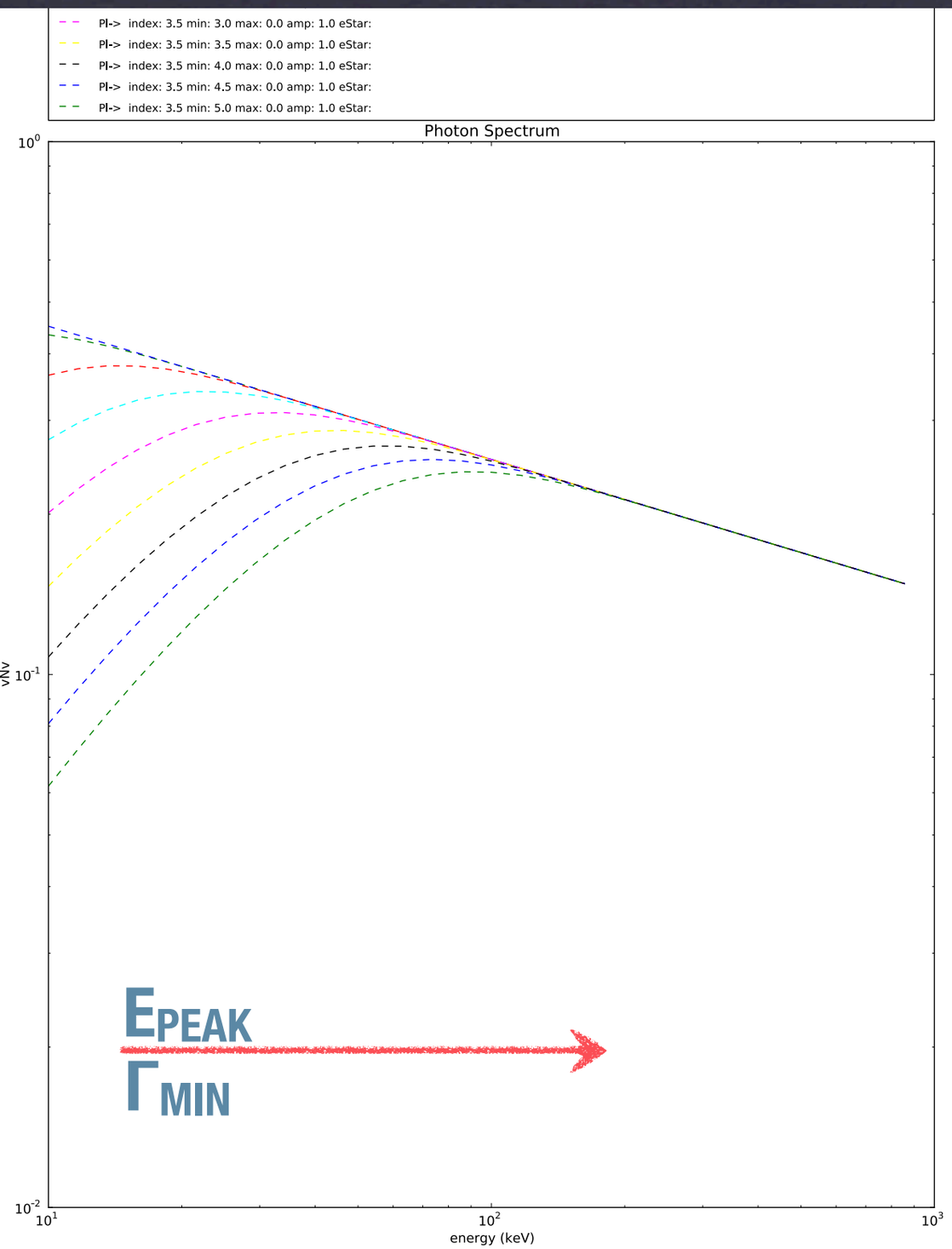
Conclusions

- Band function can be replaced by synchrotron in many cases.
- Can resolve the Maxwellian peak if we assume that the electron distribution is continuous.
- Curvature of the νF_ν peak is important when modeling spectra.
- Fast cooling synchrotron is far too broad to be the main non-thermal emission component in GRB prompt emission.
- Synchrotron fits consistent with multi-component fits attempted.
- Physical fits with other models and the high-energy component coming soon...

Backup slides



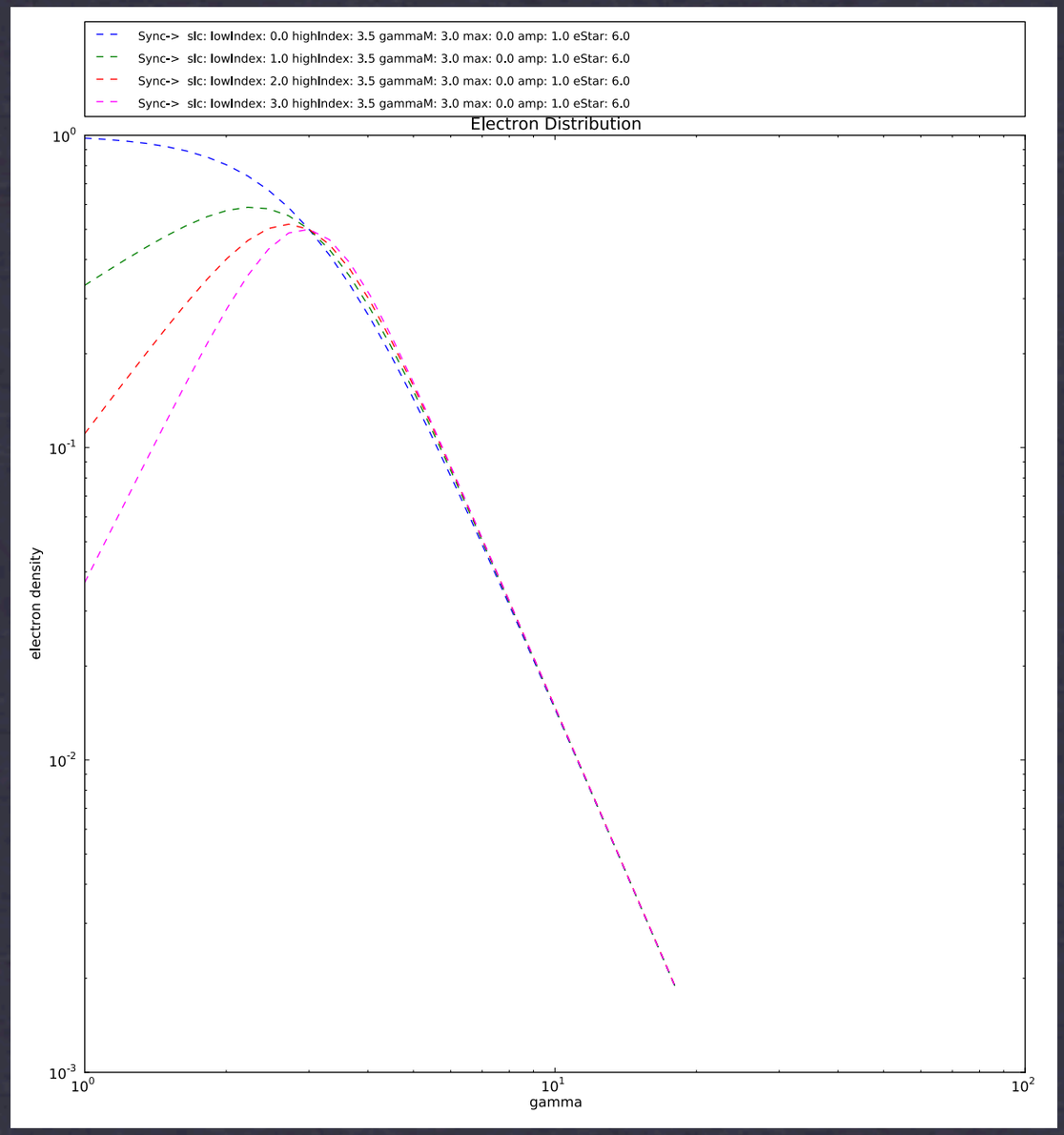


CORRELATIONS

UNABLE TO RESOLVE MINIMUM LORENTZ FACTOR AND E_* SIMULTANEOUSLY

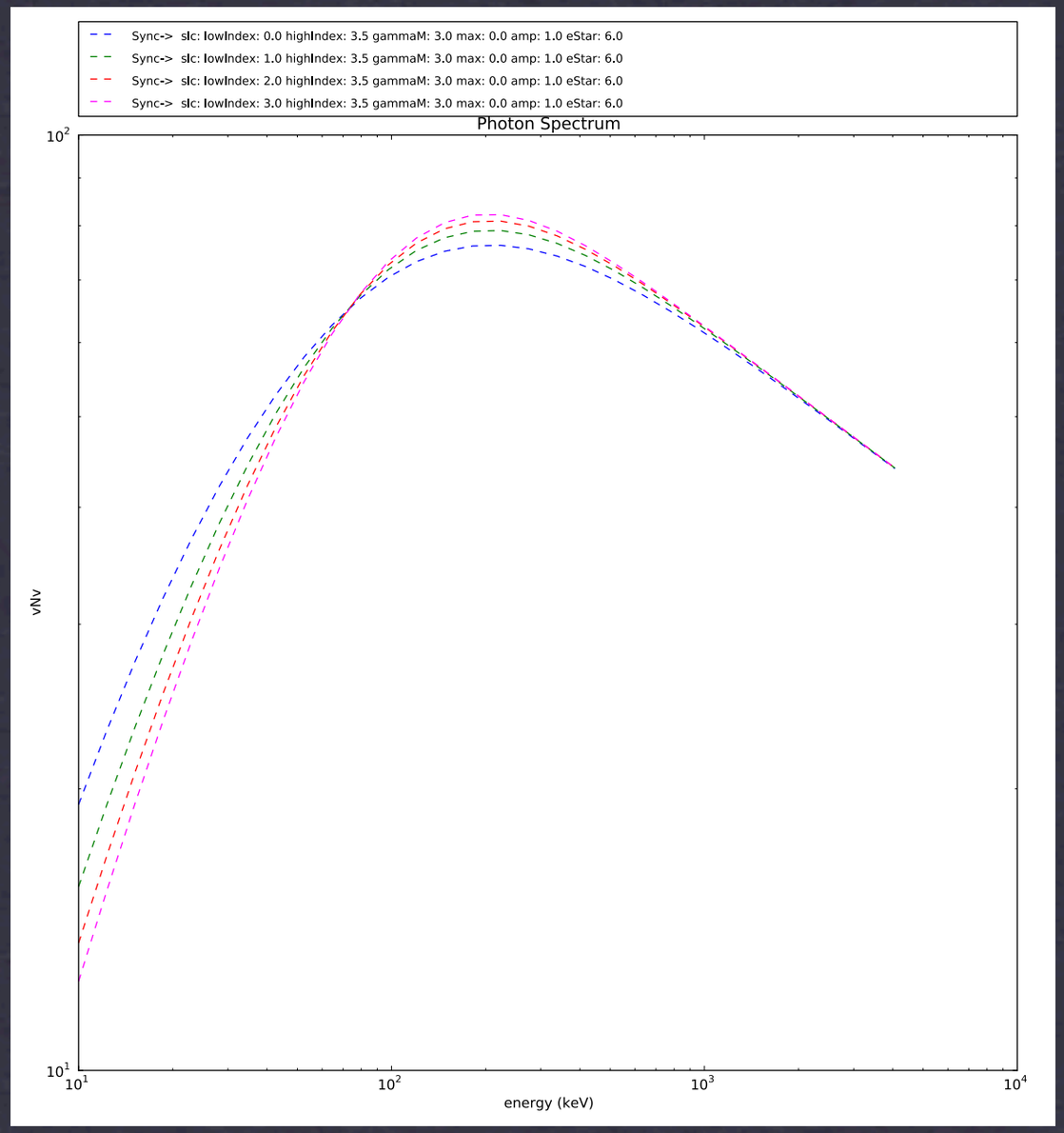
The Low-Energy Index

- Adding an extra parameter helps improve the fit however not significantly (ΔC-Stat ~ 1)
- Most parameters must be fixed to have constrained fits.

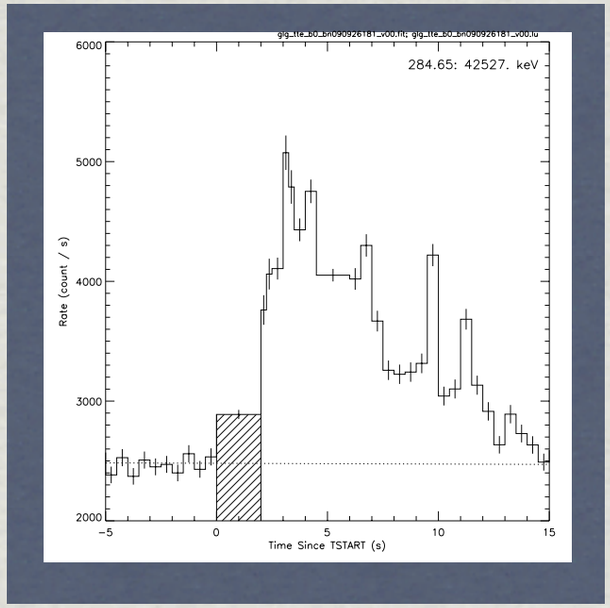


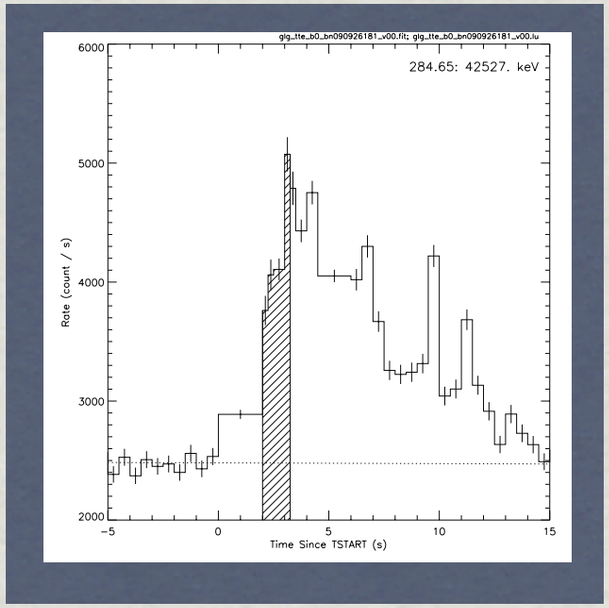
The Low-Energy Index

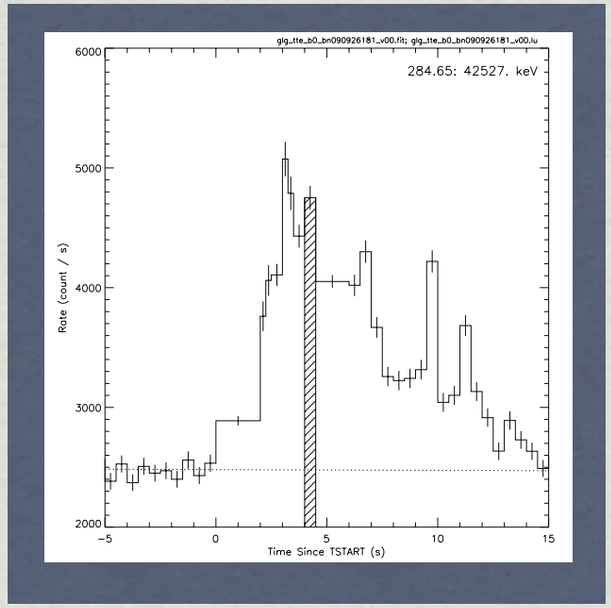
- Adding an extra parameter helps improve the fit however not significantly (ΔC-Stat ~ 1)
- Most parameters must be fixed to have constrained fits.

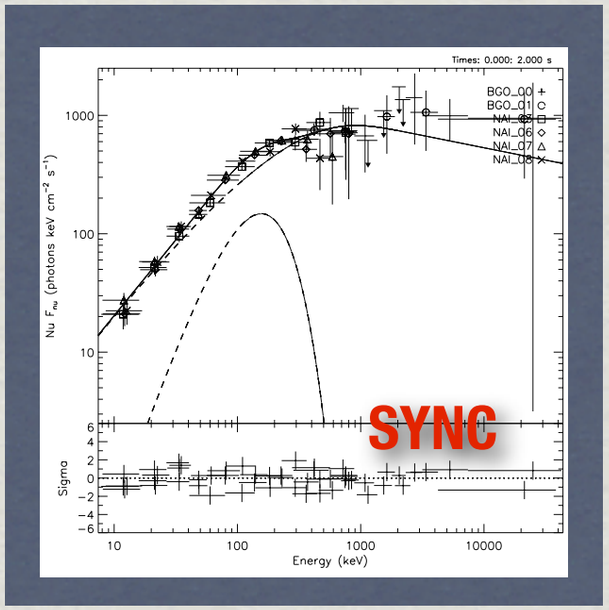


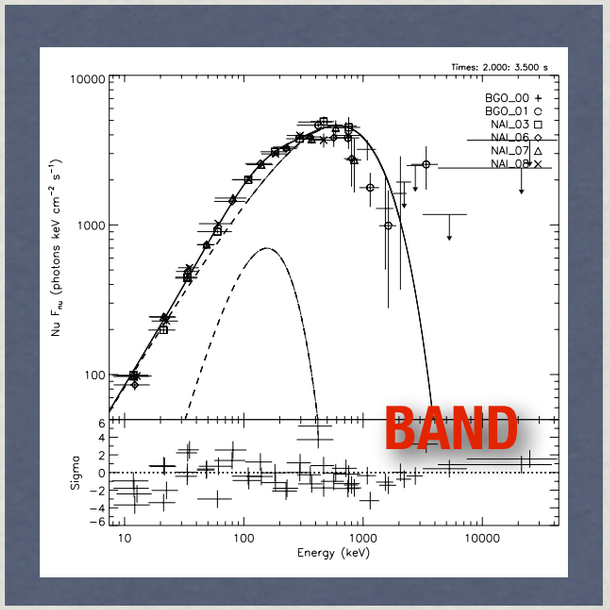
GRB090926A

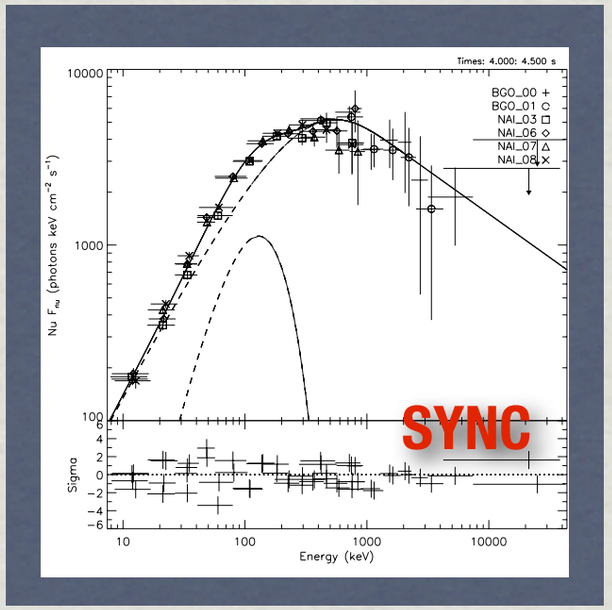

284.65: 42527. keV
Rate (count / s)
Time Since TSTART (s)


284.65: 42527. keV
Rate (count / s)
Time Since TSTART (s)


284.65: 42527. keV
Rate (count / s)
Time Since TSTART (s)


Times: 0.000: 2.000 s
BGO_00
BGO_01
NAI_03
NAI_06
NAI_07
NAI_08
Nu F_nu (photons keV cm^-2 s^-1)
Sigma
Energy (keV)
SYNC


Times: 2.000: 3.500 s
BGO_00
BGO_01
NAI_03
NAI_06
NAI_07
NAI_08
Nu F_nu (photons keV cm^-2 s^-1)
Sigma
Energy (keV)
BAND


Times: 4.000: 4.500 s
BGO_00
BGO_01
NAI_03
NAI_06
NAI_07
NAI_08
Nu F_nu (photons keV cm^-2 s^-1)
Sigma
Energy (keV)
SYNC

FIT VALUES: GRB 090926A

TERM: BAND'S GRB, EPEAK

AMPLITUDE	0.03141 +/-	0.00541 P/S-CM2-KEV
EPEAK	600.0 +/-	153. KEV
ALPHA	-0.8176 +/-	0.101
BETA	-2.143 +/-	0.131

TERM: BLACK BODY

AMPLITUDE	1.735E-05 +/-	6.20E-06 P/S-CM2-KEV
KT	35.55 +/-	4.31 KEV

==> CASTOR C-STAT = 783.07, DOF = 724

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TERM: BLACK BODY

AMPLITUDE	1.234E-05 +/-	4.41E-06 P/S-CM2-KEV
KT	39.93 +/-	3.90 KEV

TERM: TOTAL TEST SYNCHROTRON

AMPLITUDE	4.004 +/-	0.200 P/S-CM2-KEV
ENERGY CRIT	28.74 +/-	5.78 KEV
ETA	3.000 +/-	0.00
PL INDEX	3.382 +/-	0.311

==> CASTOR C-STAT = 783.19, DOF = 725

TERM: BAND'S GRB, EPEAK

AMPLITUDE	0.1809 +/-	0.00683 P/S-CM2-KEV
EPEAK	514.5 +/-	18.6 KEV
ALPHA	-0.5280 +/-	0.0310
BETA	-3.593 +/-	0.487

TERM: BLACK BODY

AMPLITUDE	0.0001476 +/-	3.74E-05 P/S-CM2-KEV
KT	26.85 +/-	2.03 KEV

==> CASTOR C-STAT = 784.10, DOF = 724

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TERM: BLACK BODY

AMPLITUDE	4.020E-05 +/-	6.02E-06 P/S-CM2-KEV
KT	46.58 +/-	1.89 KEV

TERM: TOTAL TEST SYNCHROTRON

AMPLITUDE	33.46 +/-	0.913 P/S-CM2-KEV
ENERGY CRIT	31.25 +/-	3.87 KEV
ETA	3.000 +/-	0.00
PL INDEX	4.554 +/-	0.356

==> CASTOR C-STAT = 900.14, DOF = 725

TERM: BAND'S GRB, EPEAK

AMPLITUDE	0.2760 +/-	0.0263 P/S-CM2-KEV
EPEAK	443.6 +/-	42.2 KEV
ALPHA	-0.6760 +/-	0.0551
BETA	-2.355 +/-	0.0737

TERM: BLACK BODY

AMPLITUDE	0.0002532 +/-	4.84E-05 P/S-CM2-KEV
KT	29.76 +/-	2.02 KEV

==> CASTOR C-STAT = 858.46, DOF = 724

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TERM: BLACK BODY

AMPLITUDE	0.0001957 +/-	3.29E-05 P/S-CM2-KEV
KT	33.69 +/-	1.39 KEV

TERM: TOTAL TEST SYNCHROTRON

AMPLITUDE	45.86 +/-	1.07 P/S-CM2-KEV
ENERGY CRIT	21.59 +/-	2.21 KEV
ETA	3.000 +/-	0.00
PL INDEX	3.893 +/-	0.203

==> CASTOR C-STAT = 865.87, DOF = 725