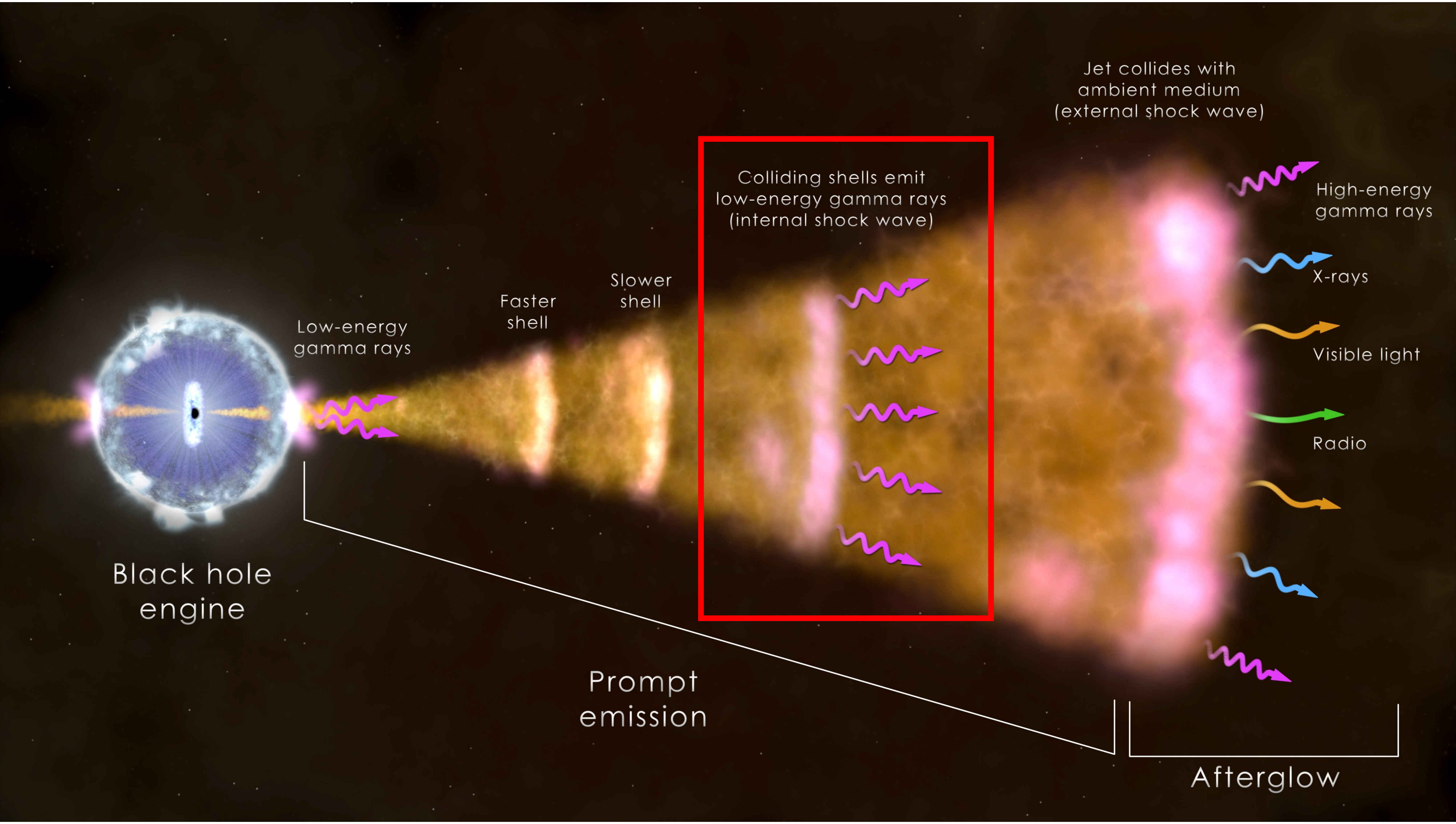
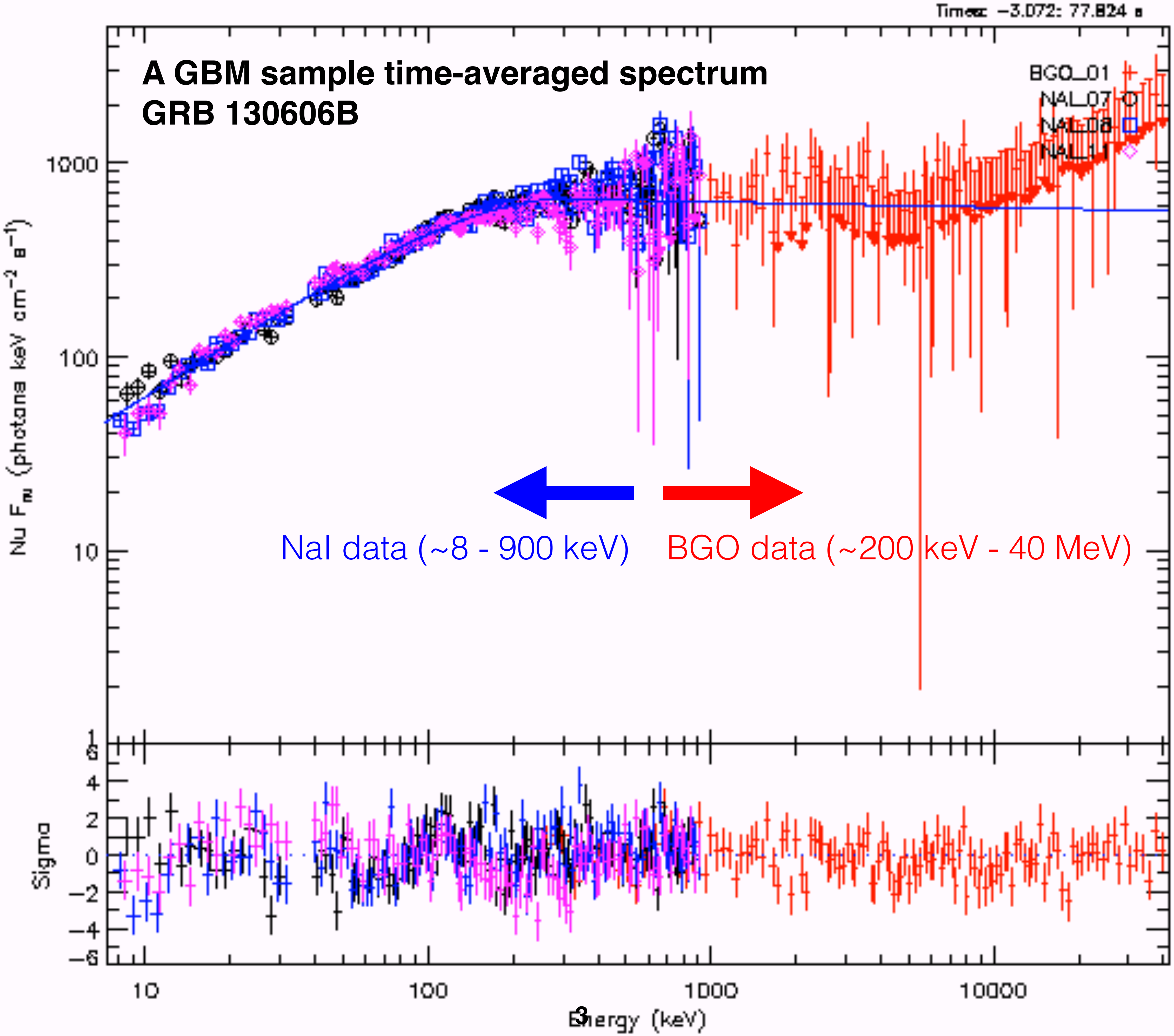
Synchrotron Cooling in the Hardest Gamma-Ray Bursts Observed by the *Fermi* Gamma-Ray Burst Monitor

Hoi-Fung Yu*^, Jochen Greiner*^, Hendrik van Eerten*,
et al. (in prep)
*Max-Planck-Institut für extraterrestrische Physik, Germany
^ *Fermi* GBM Team



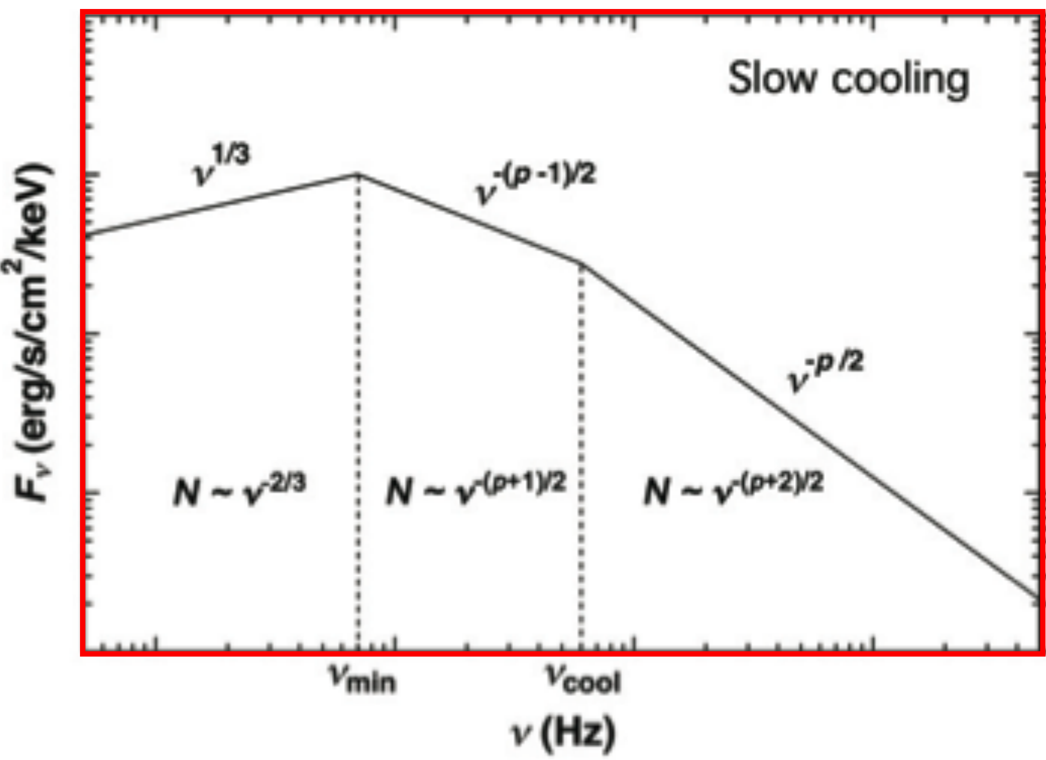
Jet collides with
ambient medium
(external shock wave)
Colliding shells emit
low-energy gamma rays
(internal shock wave)
High-energy
gamma rays
X-rays
Visible light
Radio
Slower
shell
Faster
shell
Low-energy
gamma rays
Black hole
engine
Prompt
emission
Afterglow

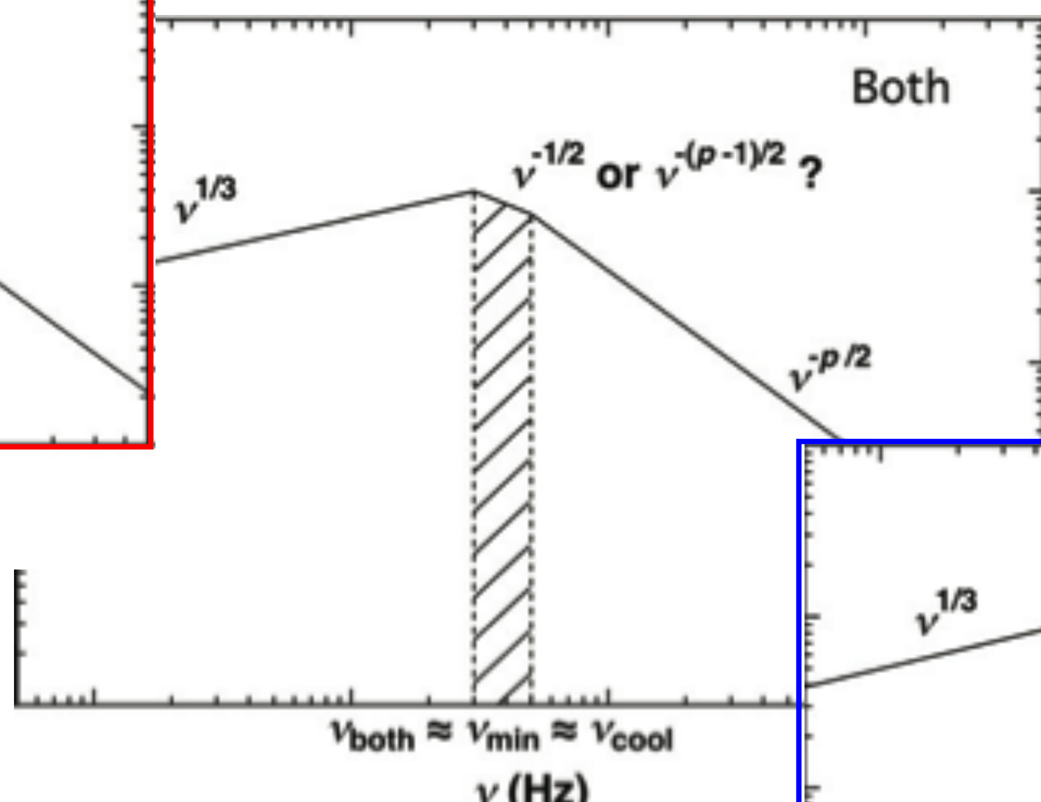


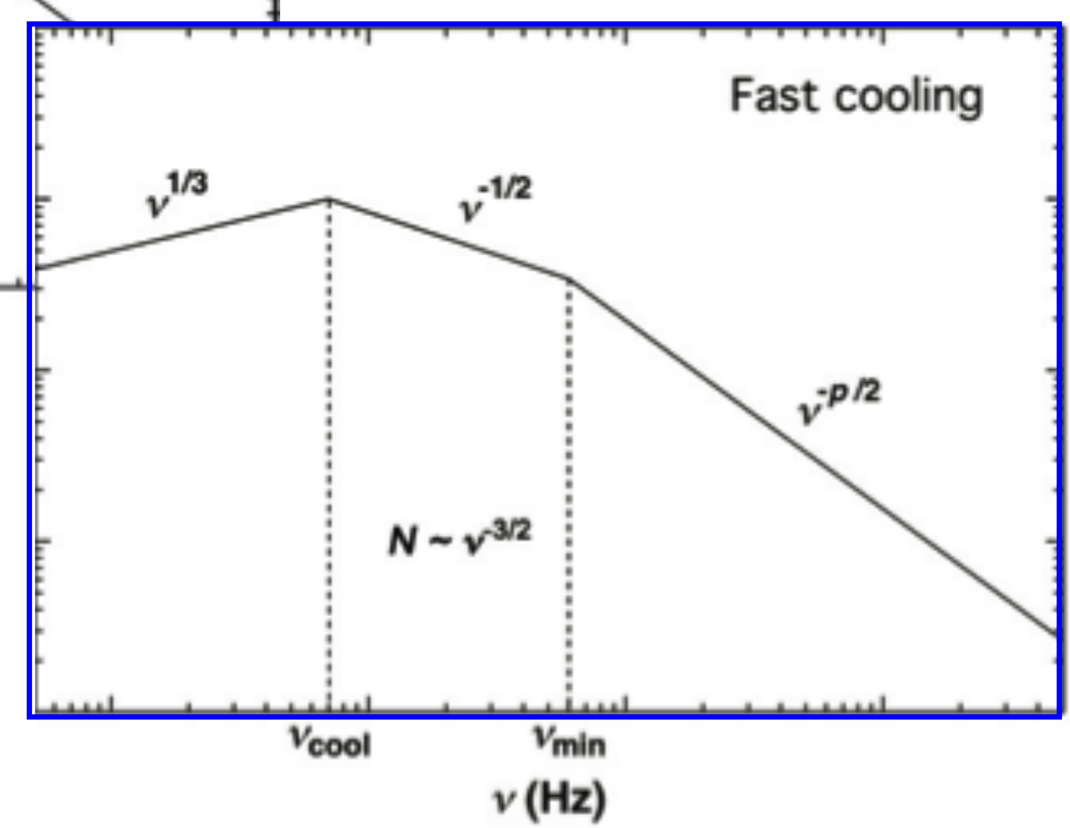
Time: −3.072: 77.824 s
A GBM sample time-averaged spectrum
GRB 130606B
BGO_01
NAL_07
NAL_08
NAL_11
NaI data (~8 - 900 keV)
BGO data (~200 keV - 40 MeV)
Nu F$_{\nu}$ (photons keV cm^{-2} s^{-1})
Sigma
Energy (keV)

Synchrotron radiation: $N(\gamma) \propto \gamma^{-p}$

$$F_{\nu,\text{slow}} \propto \begin{cases} \nu^{1/3} & \text{for } \nu_{\text{min}} > \nu, \\ \nu^{-(p-1)/2} & \text{for } \nu_{\text{cool}} > \nu > \nu_{\text{min}}, \\ \nu^{-p/2} & \text{for } \nu > \nu_{\text{cool}}, \end{cases} \qquad F_{\nu,\text{fast}} \propto \begin{cases} \nu^{1/3} & \text{for } \nu_{\text{cool}} > \nu, \\ \nu^{-1/2} & \text{for } \nu_{\text{min}} > \nu > \nu_{\text{cool}}, \\ \nu^{-p/2} & \text{for } \nu > \nu_{\text{min}}. \end{cases}$$







The empirical Band function could be fitting:

1) slow, low (lowest + middle)
2) slow, high (middle + highest)
3) fast, low (lowest + middle)
4) fast, high (middle + highest)
5) both (lowest + highest)

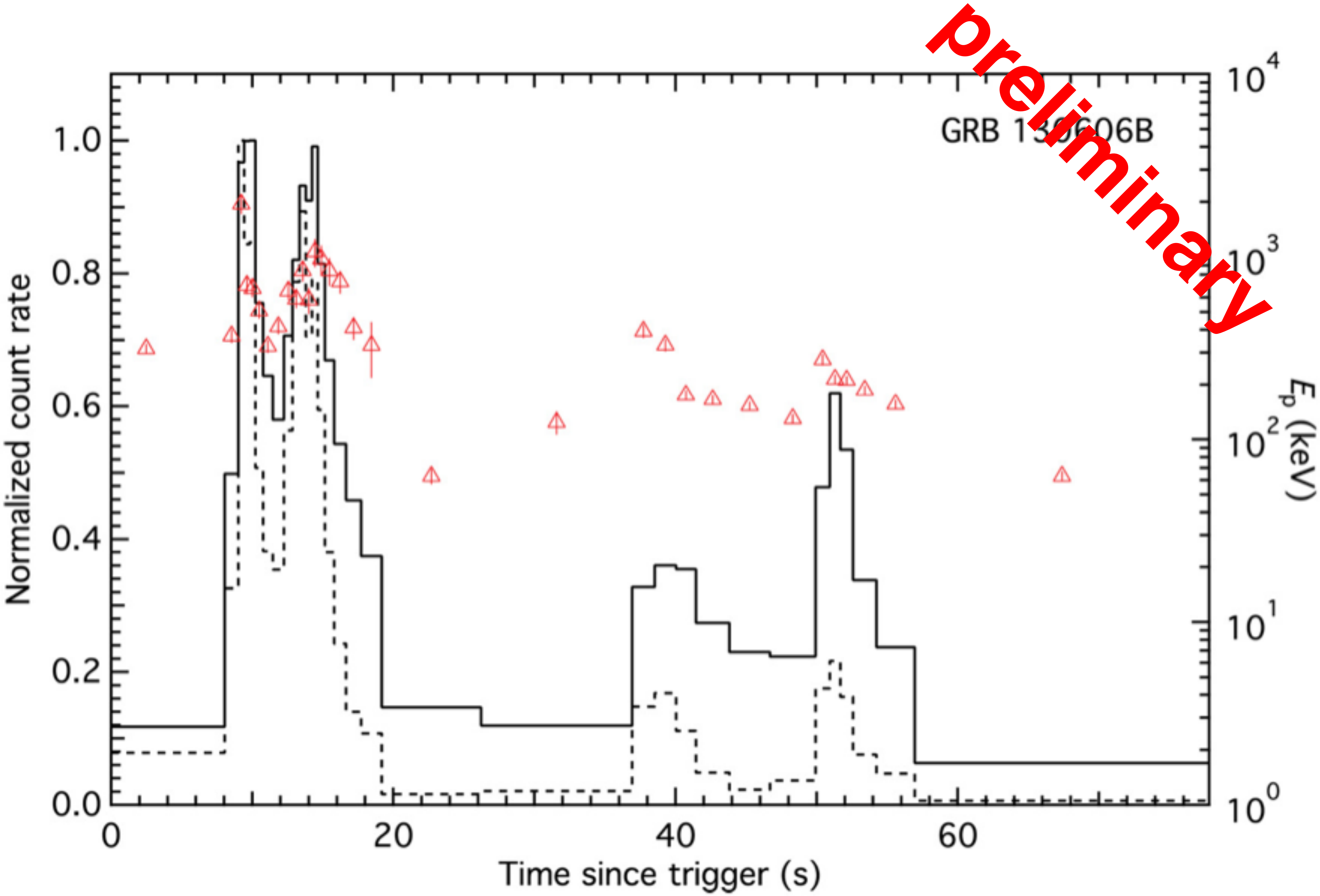
(Preece+02)

Sample cutting criteria:

1) high fluence f(1-1000keV) > 1.0×10^{-4} erg cm^{-2} AND

2) BGO signal detected above 3 MeV

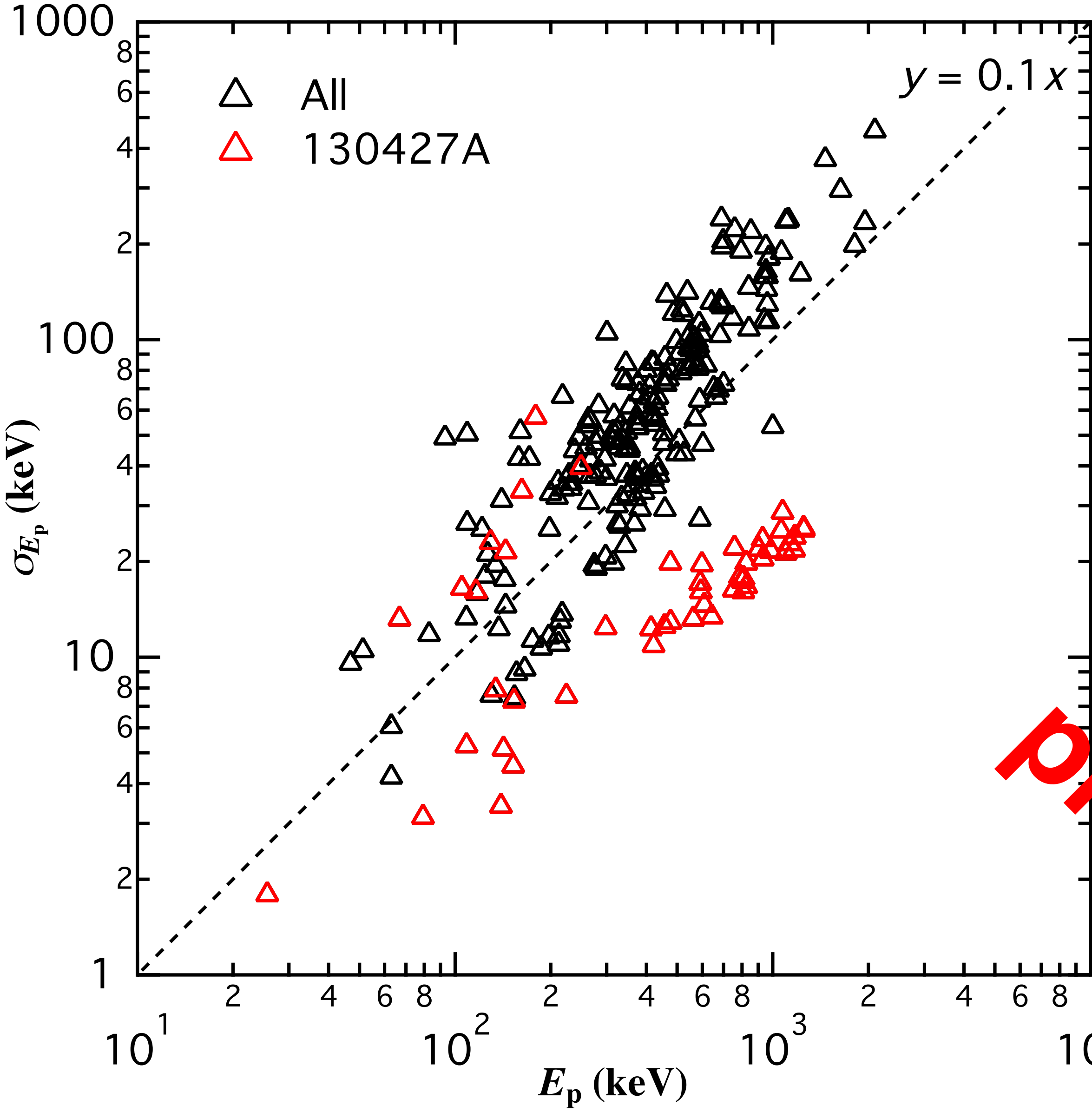
GRB Name
090902B
100724B
100826A
101123A
120526A
130427A
130504C
130606B



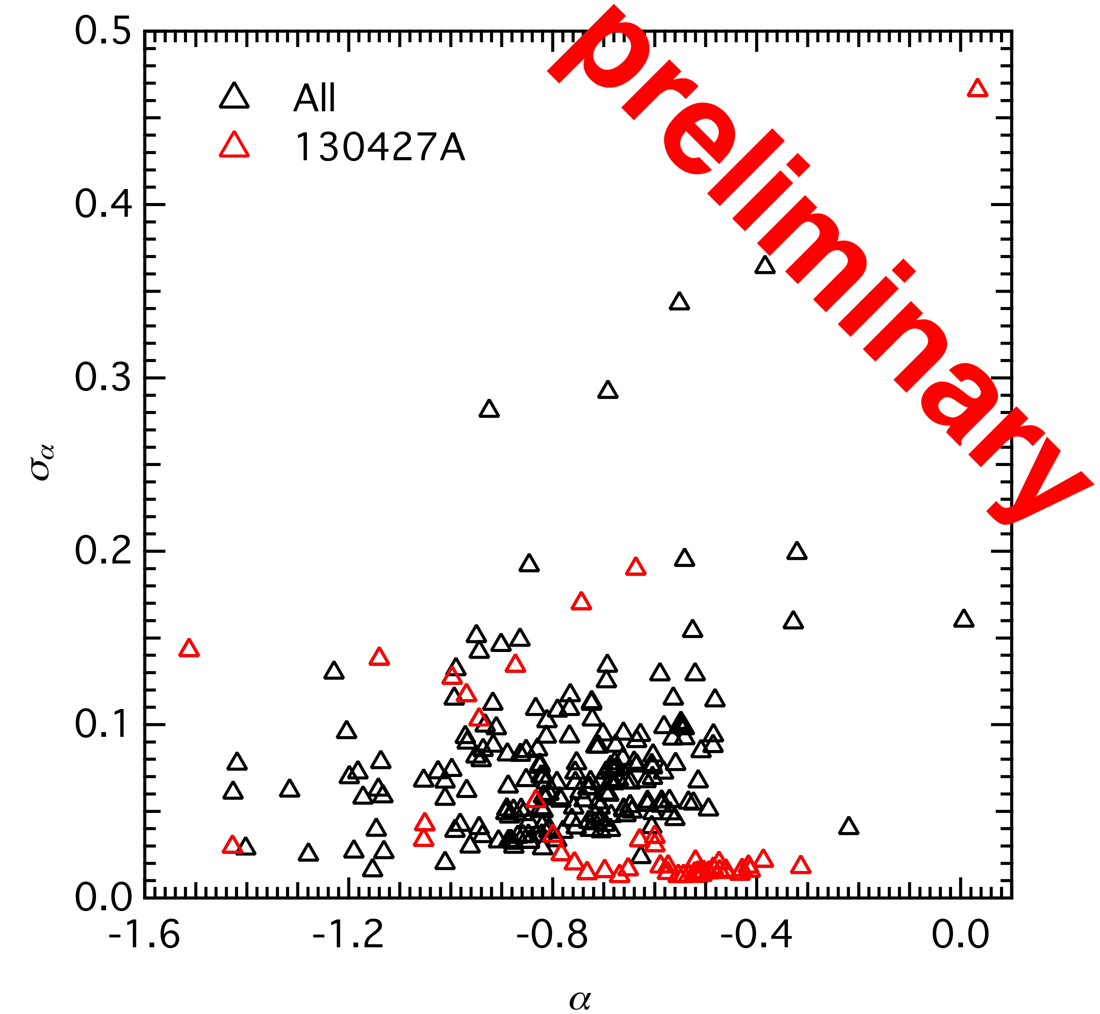
Band function fitting results:

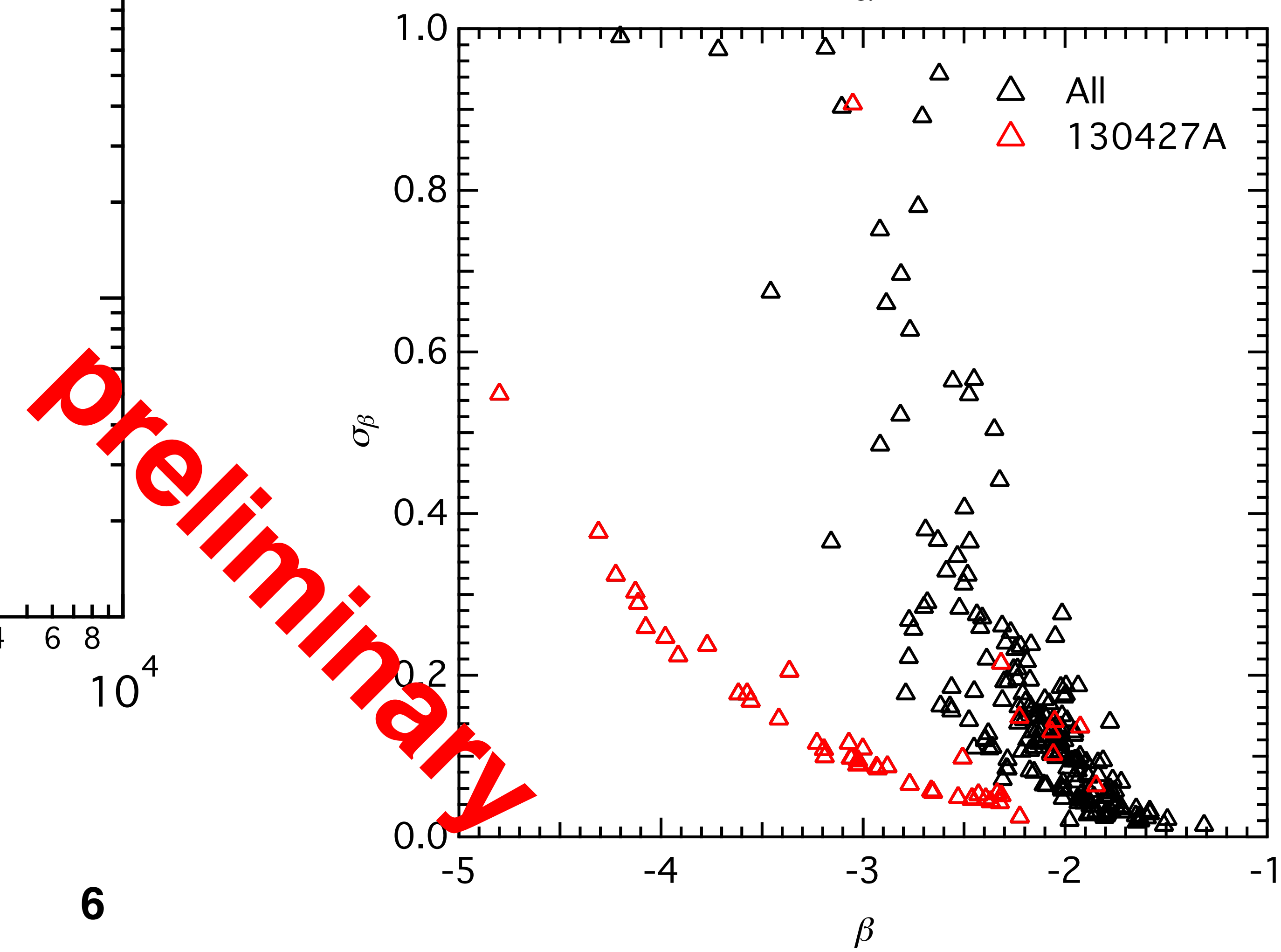
sigma_norm / norm < 1.0
sigma_Ep / Ep < 1.0
sigma_alpha < 1.0
sigma_beta < 1.0

245/314 ~ 80%



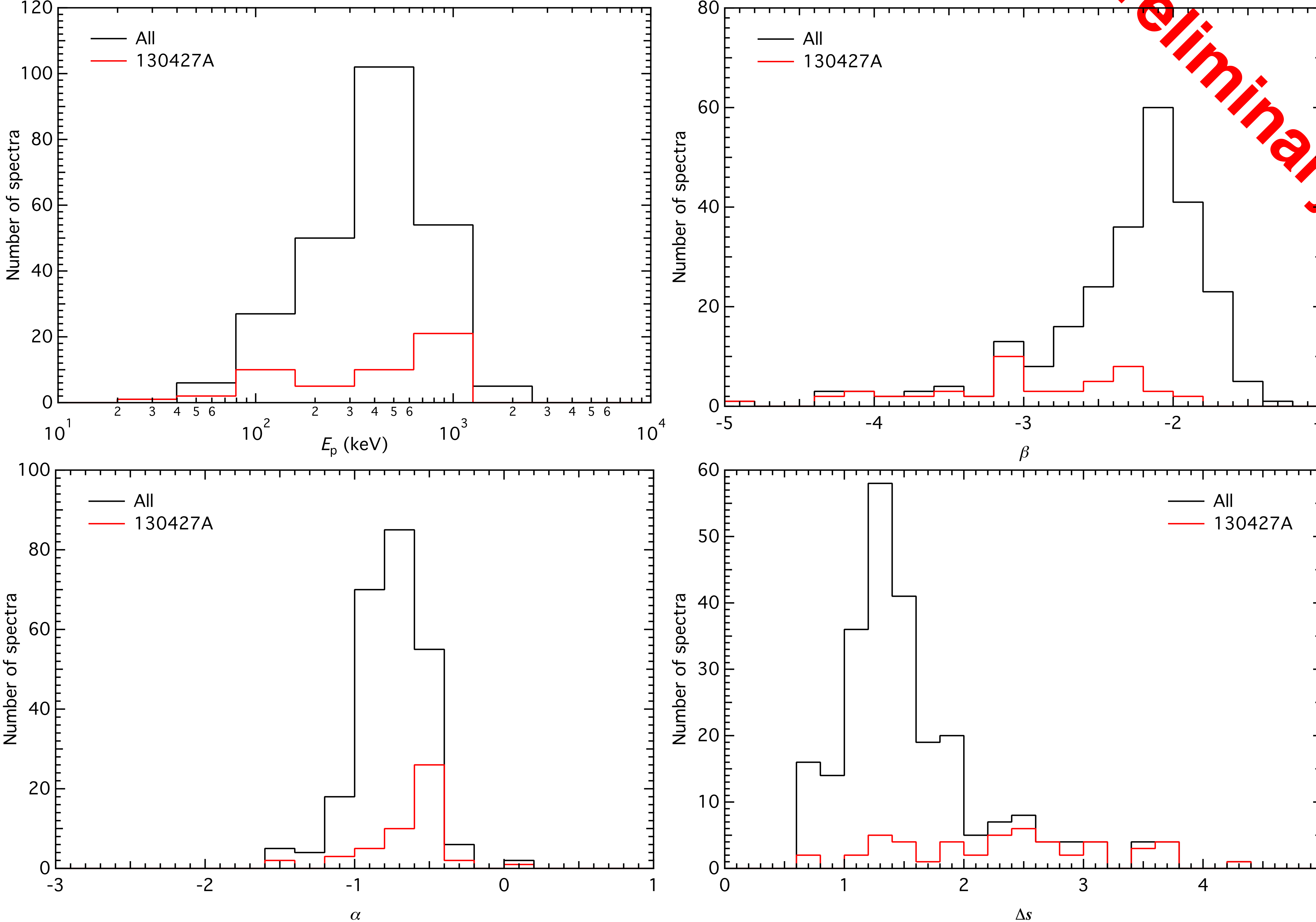
pulse-pile up in 130427A? (Preece+14)





Band function fitting results:

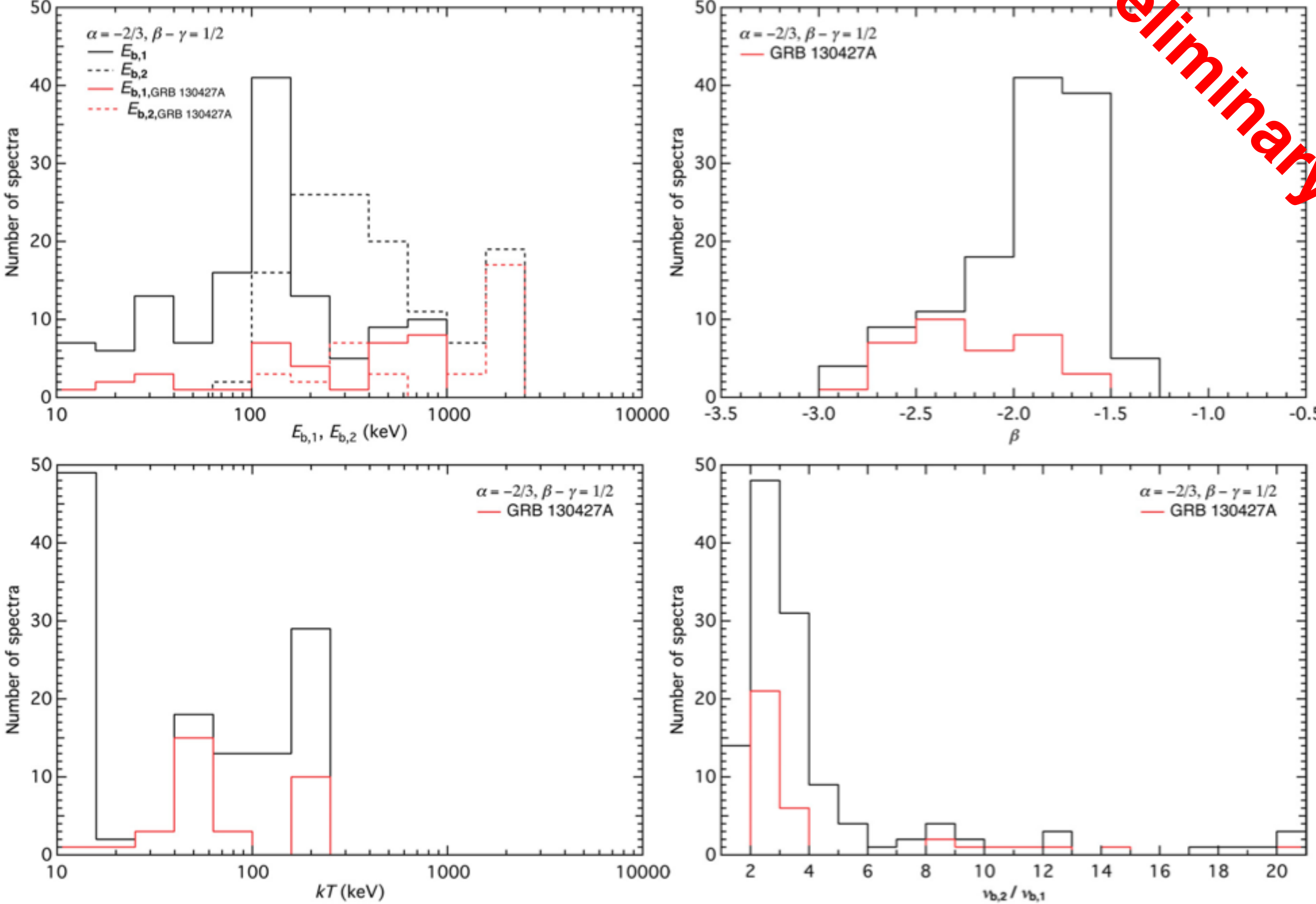
preliminary



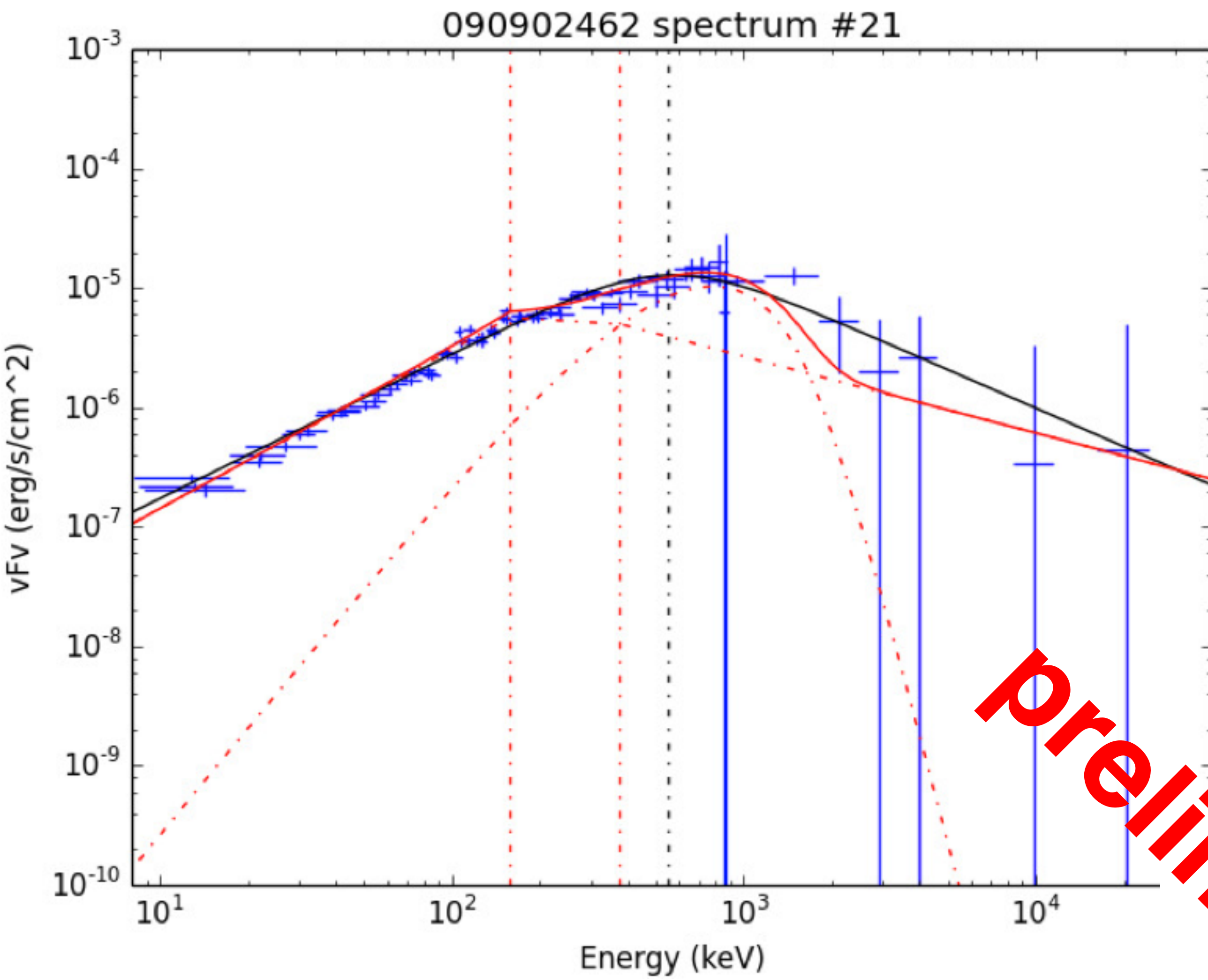
p values suggest "slow, low" or "both"

Slow-cooling toy model fitting results:

preliminary



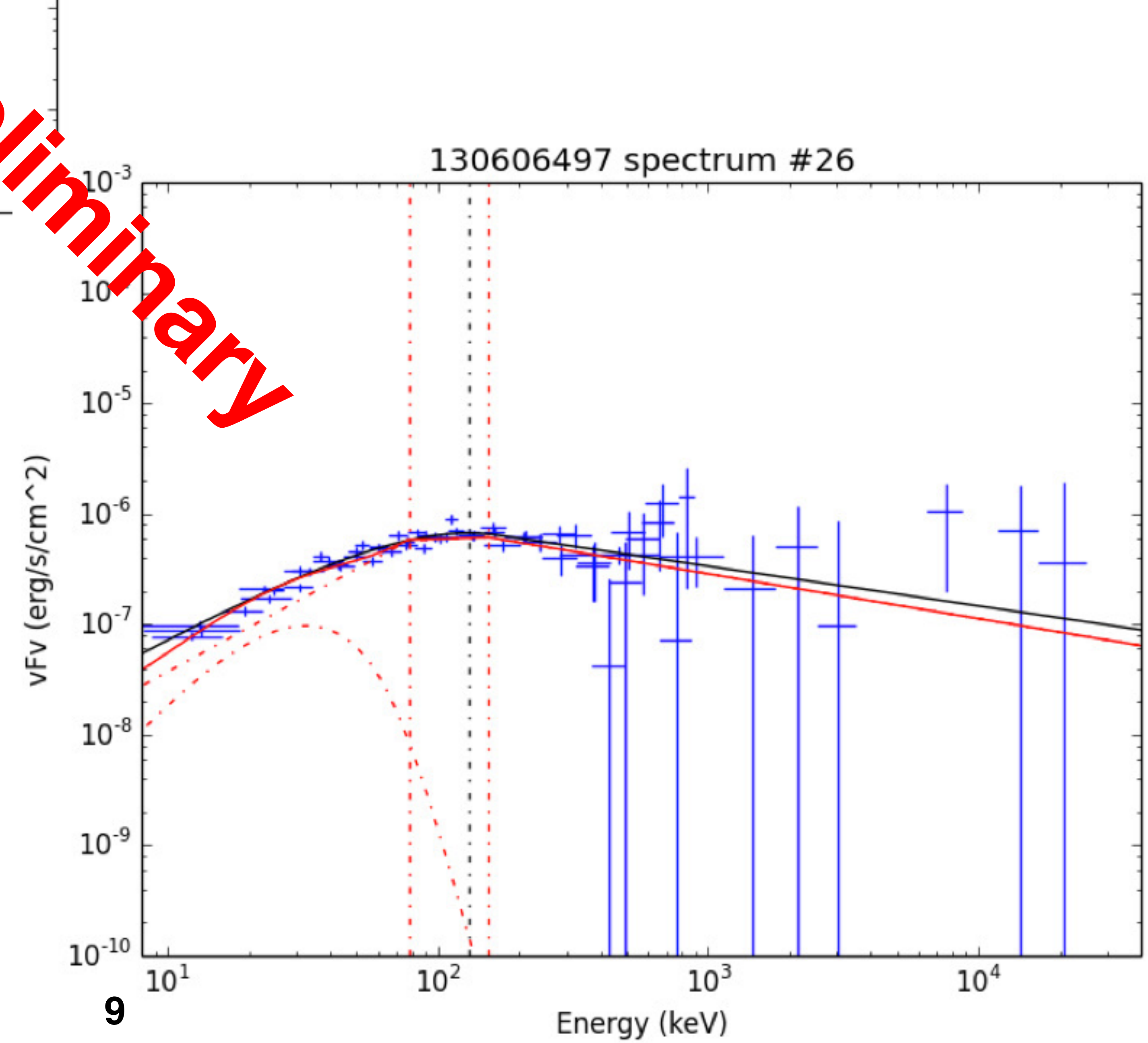
p values also suggest "slow, low" or "both"



Black: Band function

Red: slow-cooling toy model
+ blackbody component

effect of kT ~ 100 keV



effect of kT ~ 10 keV

consistent with observations for high significance sub-dominant thermal GRBs (Guiriec+11,13; Axelsson+12)

Summary

- hard bursts suggest slow-cooling is consistent (Preece+02, Burgess+14)
- Band function may be fitting both the injection and cooling breaks > fast-cooling is not to be dismissed
- triple power-law suggests small break ratios
- when fitting a Band function, a Planck function is generally unnecessary (e.g. Burgess+14)
- when fitting a triple power-law, a Planck function is generally needed, with either kT ~ 10 keV or ~ 100 keV
- time-resolved spectral analysis may disentangle the thermal and non-thermal components in the prompt phase from the averaging effects in time-averaged spectra, which will be addressed in the *Fermi* GBM GRB Time-Resolved Spectral Catalog (Yu+ in prep.)

Backup slide

preliminary

Band function:

Table 2. Electron distribution index p for different cases.

Case[a] (1)	α (2)	$p = f(\Delta s)$ (3)	$f(1.2)$ - $f(1.6)$[b] (4)	$f(1.0)$[c] (5)	$p = g(\beta)$ (6)	$g(-2.0)$ - $g(-2.4)$[b] (7)	$g(-1.7)$[c] (8)
Fast, high...	$-3/2$	$2\Delta s + 1$	3.4 - 4.2	3.0	$-2(\beta + 1)$	2.0 - 2.8	1.4
Slow, low...	$-2/3$	$2(\Delta s + 1/6)$	2.73 - 3.53	2.33	$-2\beta - 1$	3.0 - 3.8	2.4
Both..........	$-2/3$	$2(\Delta s - 1/3)$	1.73 - 2.53	1.33	$-2(\beta + 1)$	2.0 - 2.8	1.4

Notes. [a] Preece et al. (2002), Eqns. (9), (10), and (12). [b] Calculated from the ranges of peak and median values of Δs and β distributions for all eight bursts, given that $1.2 < \Delta s_{\rm peak} < 1.4$, $1.4 < \Delta s_{\rm median} < 1.6$, $-2.2 < \beta_{\rm peak} < -2.0$, and $-2.4 < \beta_{\rm median} < -2.2$. [c] Calculated from the median values of Δs and β distributions for GRB 100724B only.

Slow-cooling toy model:

According to the SYNC fitting results, there are two cases to consider: (1) the γSYNC is actually the high-energy segment in the slow cooling scenario, i.e. ν_{min} and ν_{cool} are the predicted break values; or (2) γSYNC is indeed the middle-energy segment in the slow-cooling scenario, in this case the triple power-law is just mimicking the slowly varying BAND-like models. If (1) is true, then we can take the values of the γSYNC peaks ~ −2.0 to −2.5, and we will have p ~ 2 - 3. Looking at Table 2, it can be seen that it matches nicely with the "both" case; if (2) is true, then instead comparing to γSYNC, we should compare with βSYNC in Eqn. 8, and we will have p ~ 3 - 4, which matches nicely with the "slow, low" case.

Backup slide