On the sharpness of gamma-ray burst prompt emission spectra

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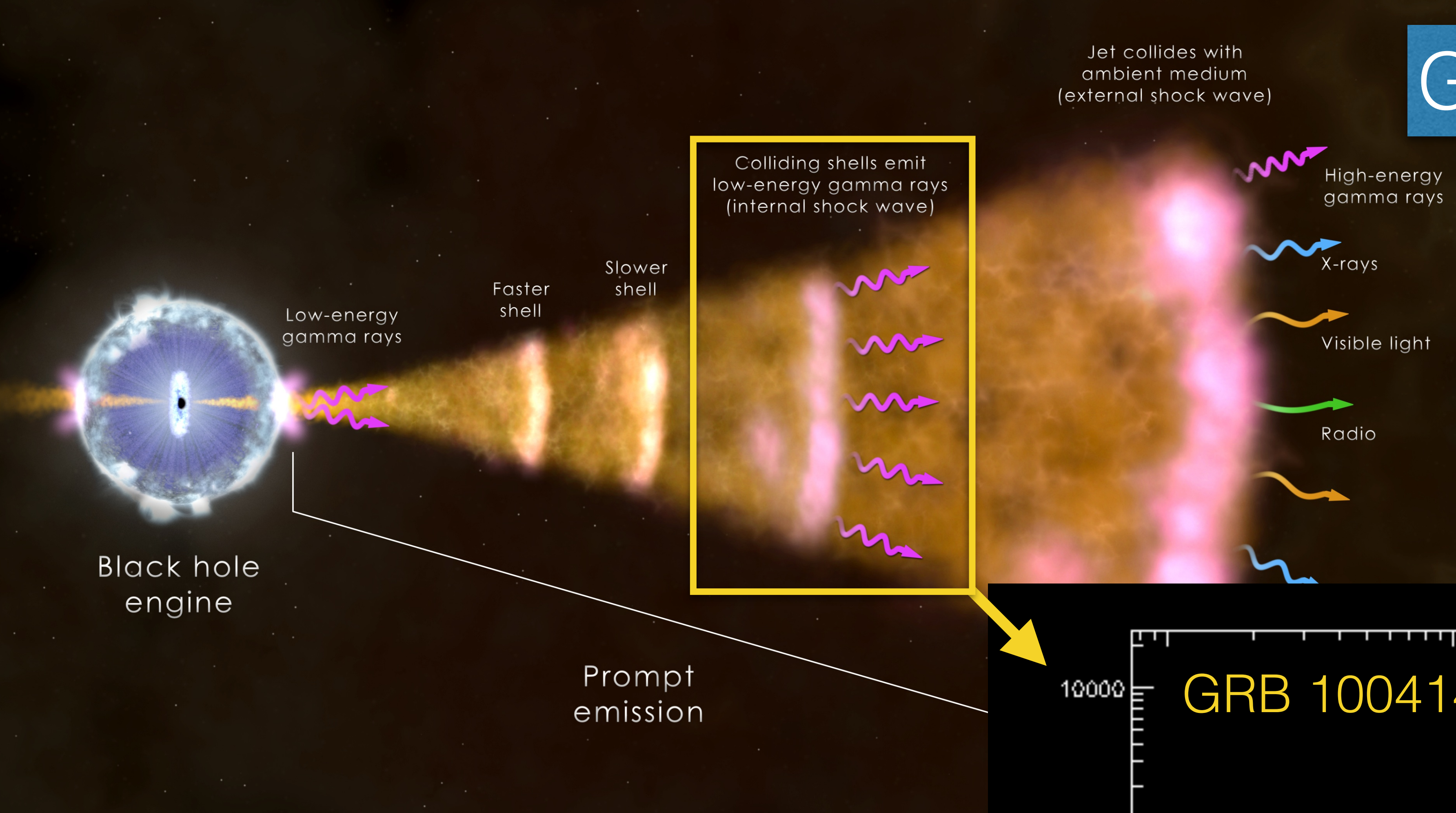
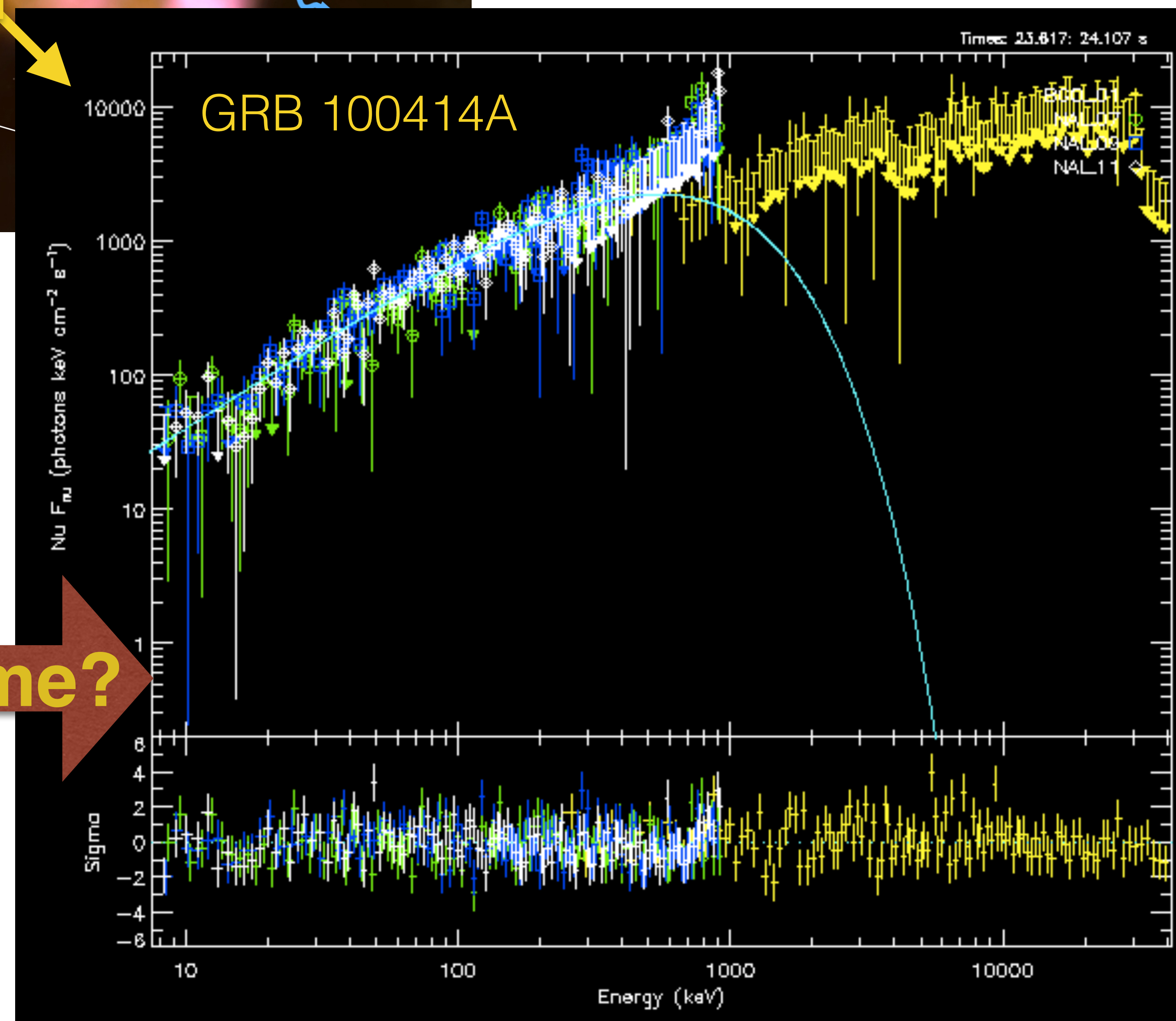
GRB prompt emission

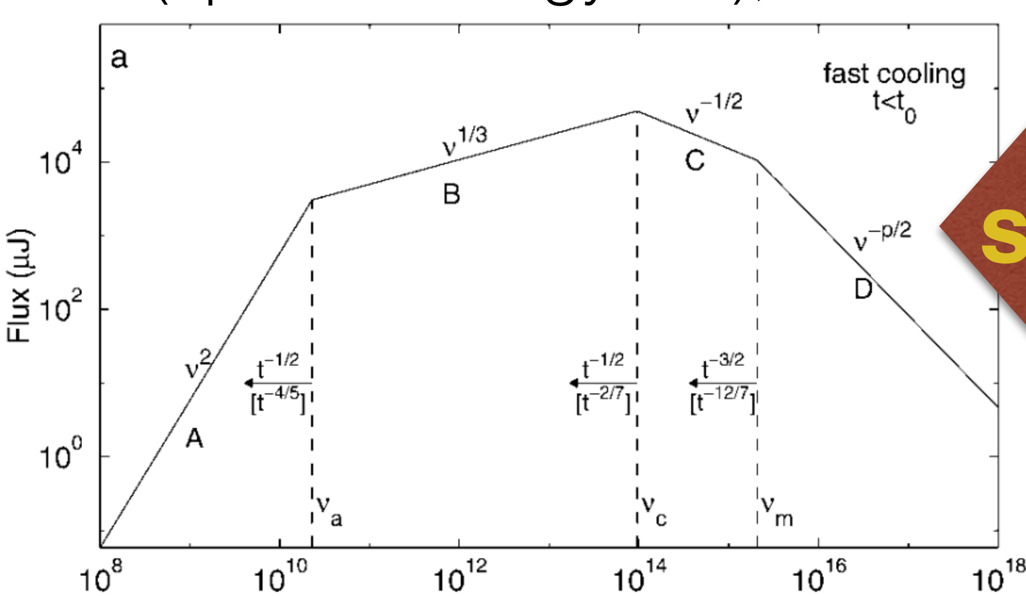


**GBM observed prompt spectrum in νF_ν (energy flux)



same?

**Afterglow synchrotron spectrum in F_ν (specific energy flux), Sari+98



This work

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The sharpness of gamma-ray burst prompt emission spectra★

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William S. Paciesas[5], and Robert D. Preece[6]

- Take the 1,802 spectra from the 1st official *Fermi* GBM GRB time-resolved spectral catalog

- Extract the spectra with a peak or break in νF_ν (energy flux) space, and re-fit them in energy domains concentrating on the peak or break position

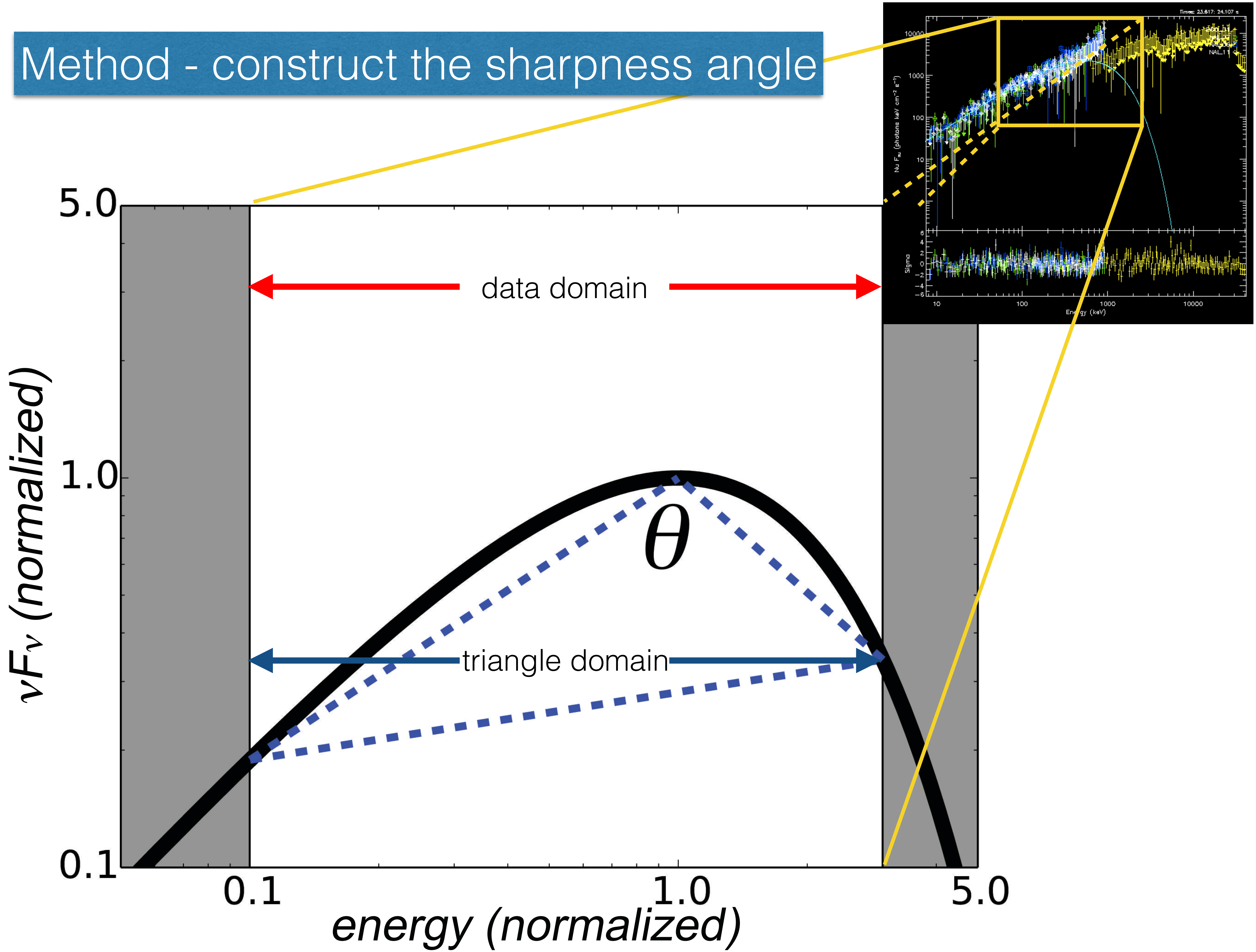
Statistics from the catalog

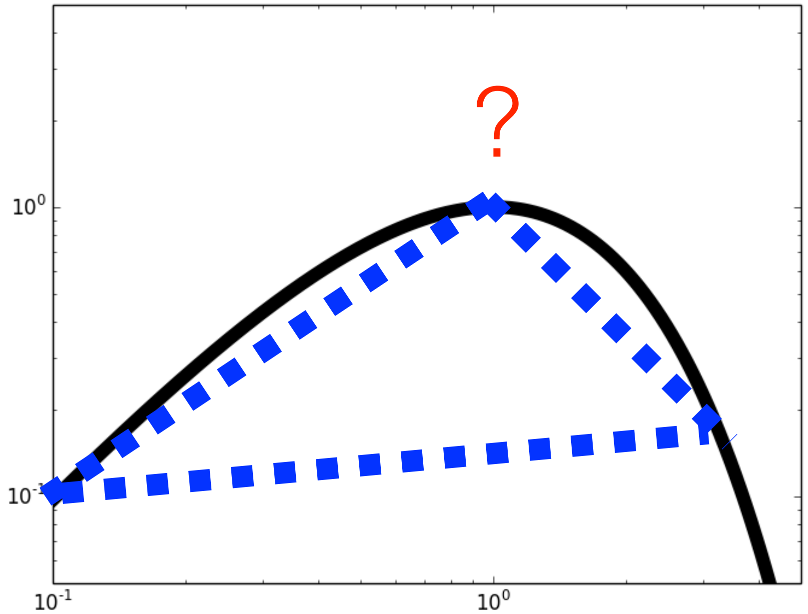
	GOOD		BEST	
Model	*N*	percentage	*N*	percentage
BAND	939	52.1%	139	9.3%
SBPL	1,201	66.6%	170	11.4%
COMP	1,276	70.8%	1,030	69.1%
PL	1,488	82.6%	152	10.2%
ALL	1,802	-	1,491	-

Yu+submitted to A&A, see poster GRB#12

** BAND and SBPL are two kinds of smoothly broken power laws, COMP is a simple power law with high-energy exponential cutoff

Method - construct the sharpness angle

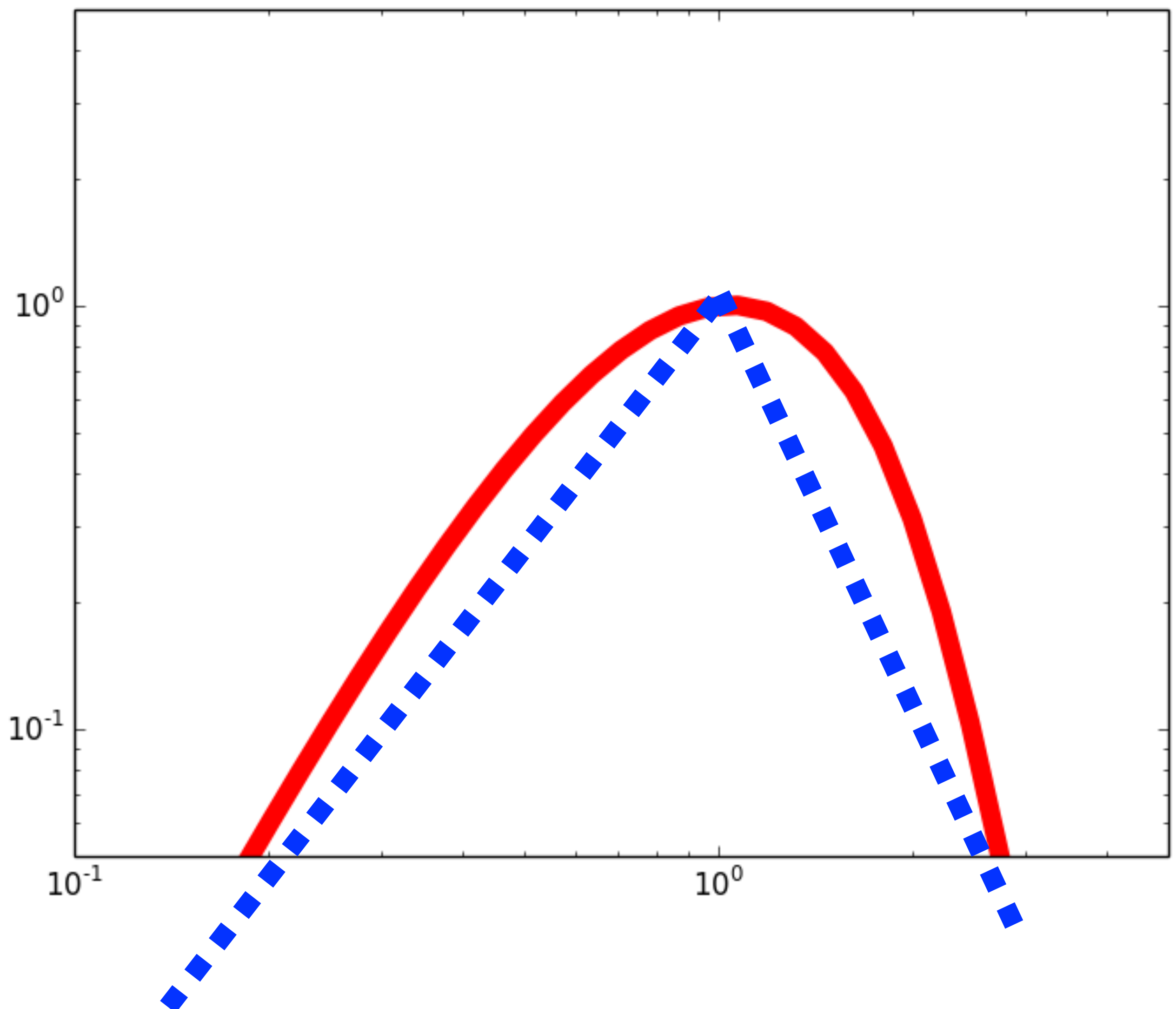




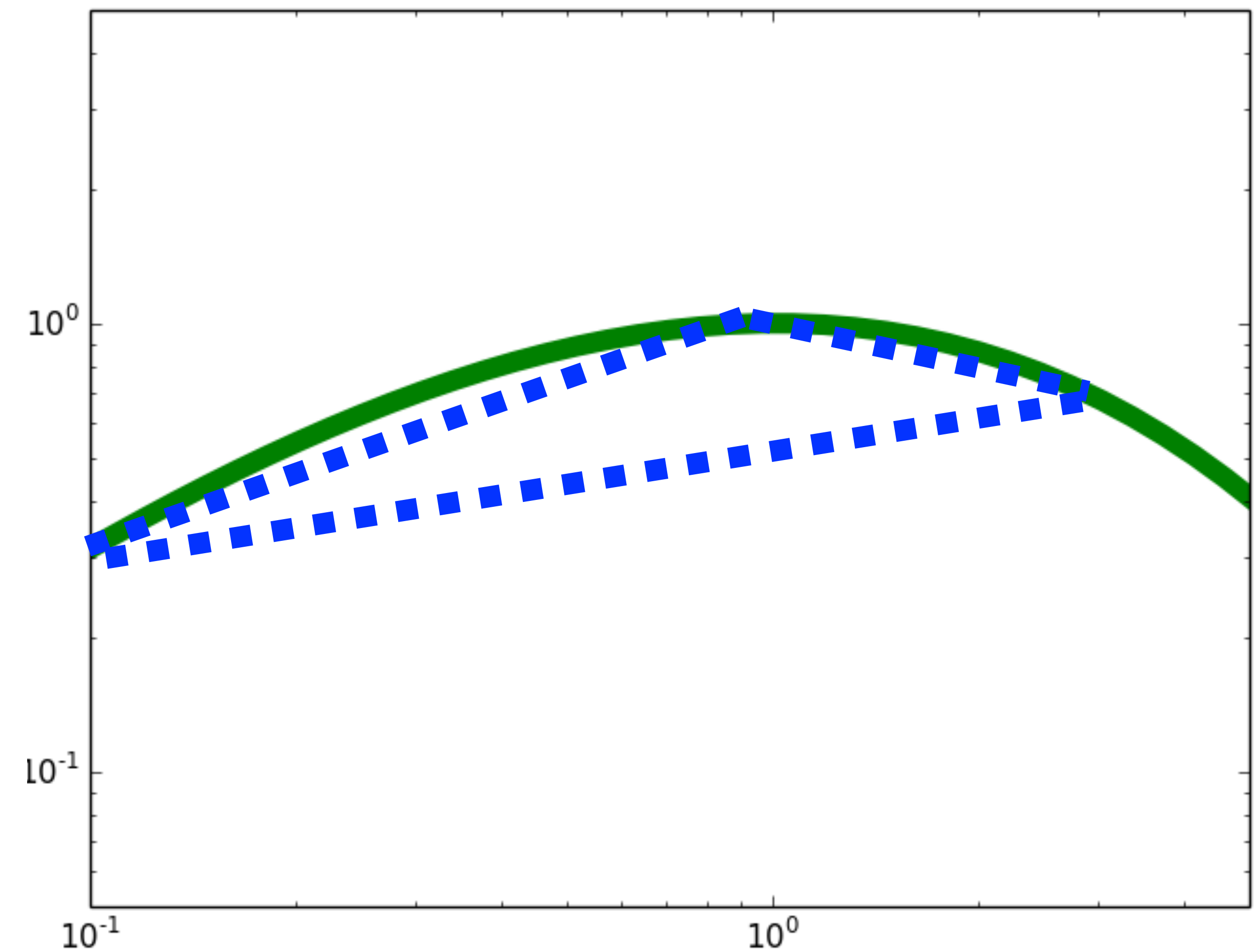
Which emission process could possibly fit the spectral curvature around the νF_ν peak?

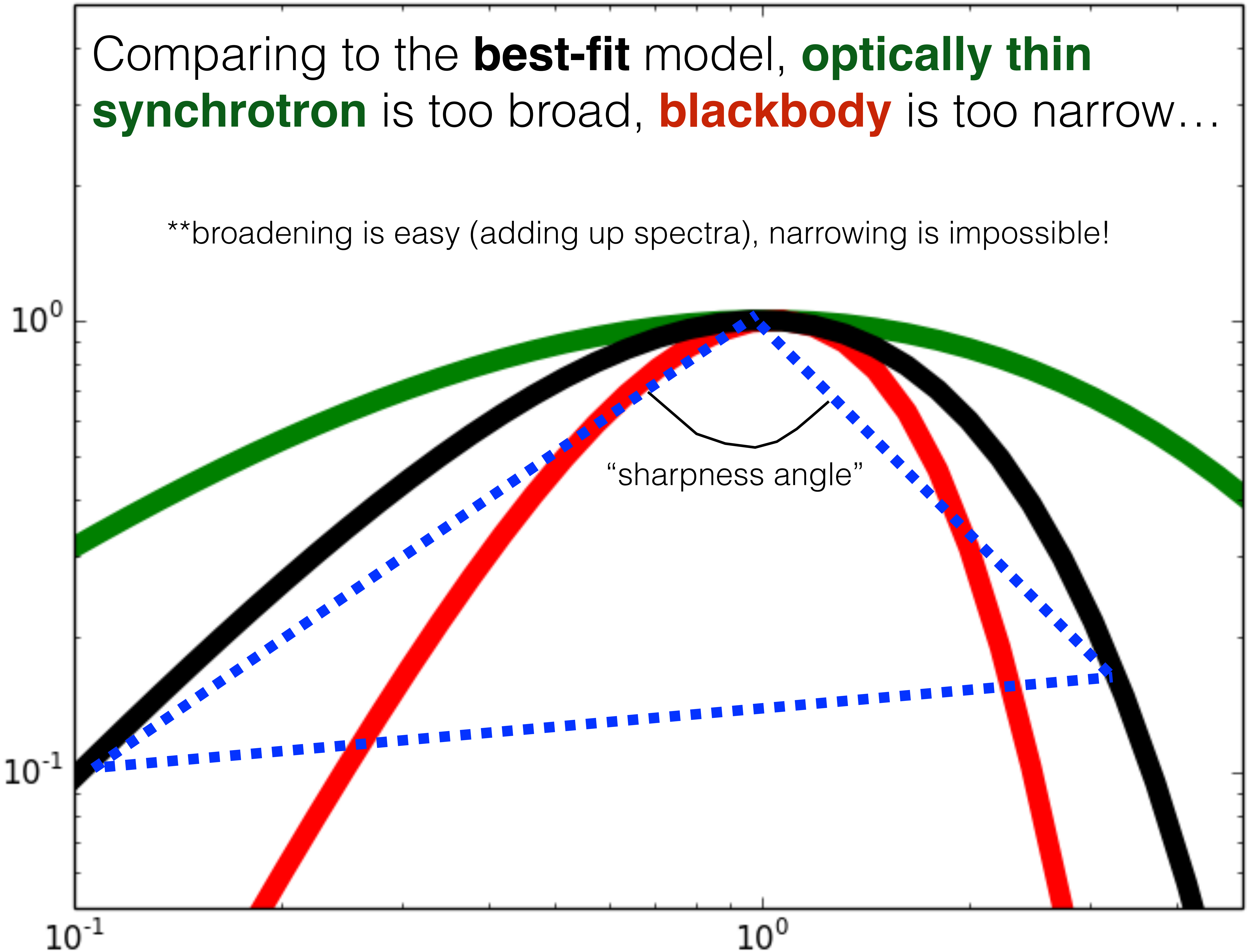
Consider two simplest processes:

Blackbody?
(Very sharp)



Optically thin synchrotron from a Maxwellian distribution of electrons?
(Sharpest physical synchrotron case)




Comparing to the **best-fit** model, **optically thin synchrotron** is too broad, **blackbody** is too narrow…
**broadening is easy (adding up spectra), narrowing is impossible!
“sharpness angle”
10^0
10^{-1}
10^{-1}
10^0

Time-resolved spectra within a single burst are not consistent with optically thin Maxwellian synchrotron…

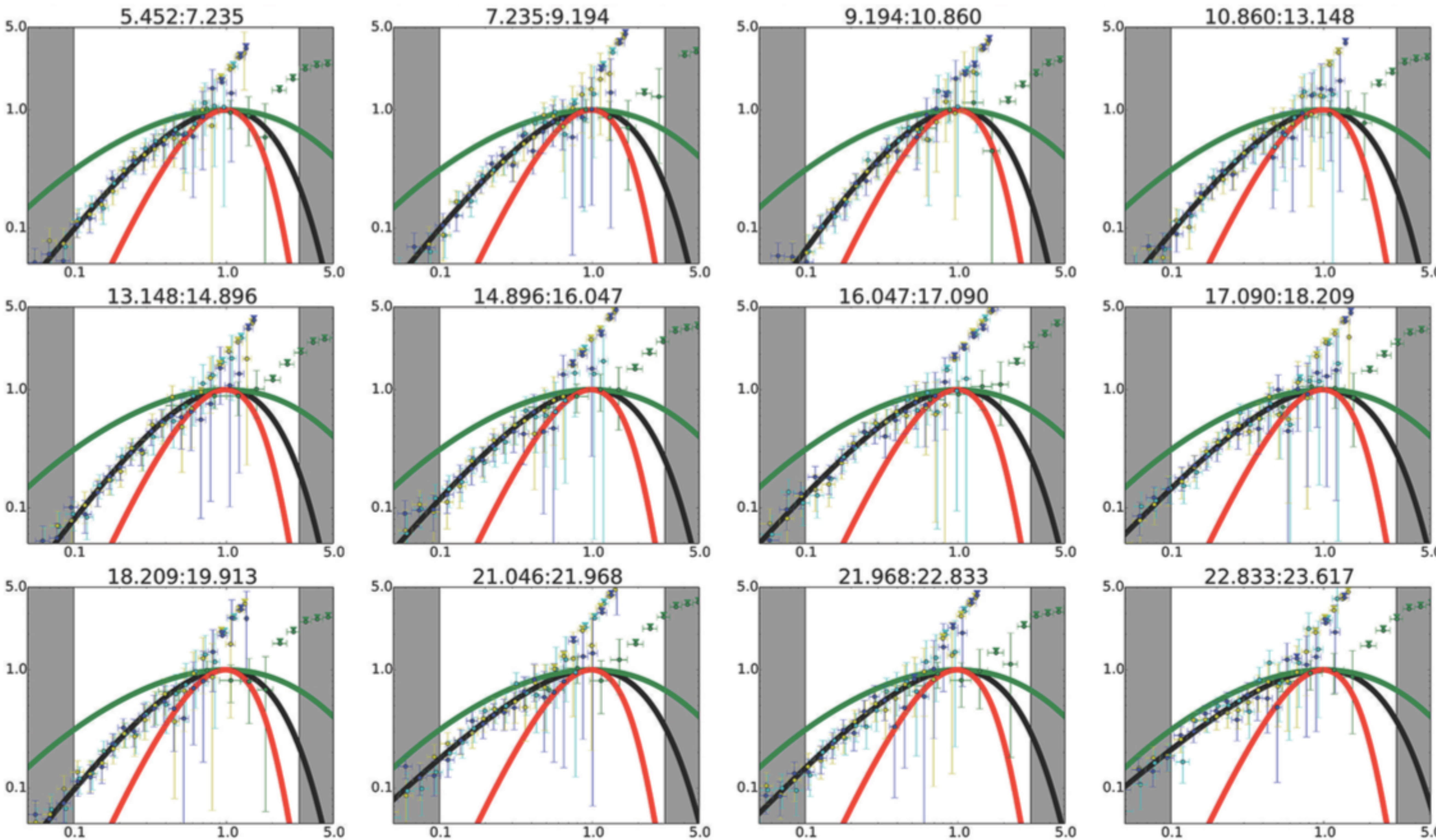
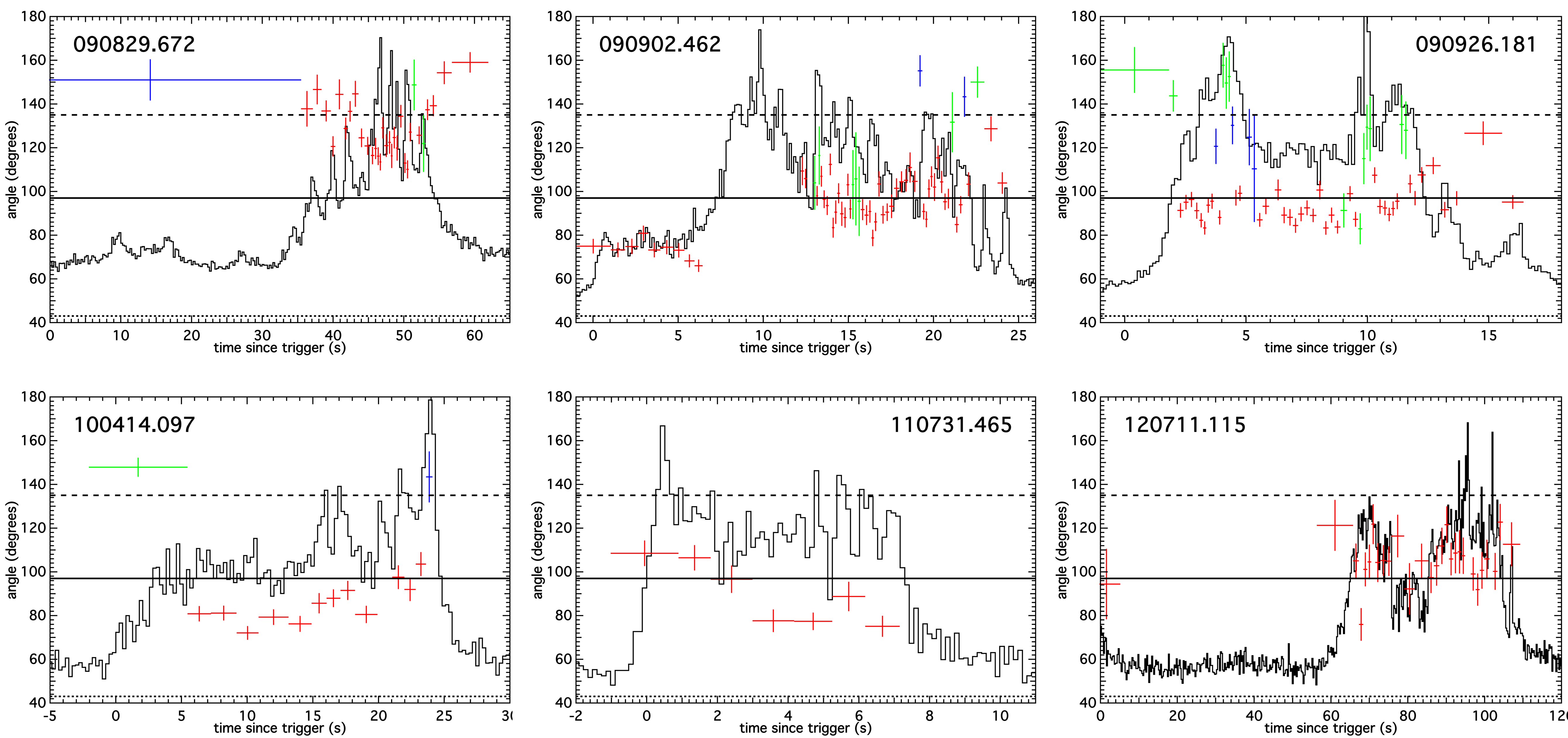


Fig. 6. Spectral evolution of GRB 100414.097 with the normalised blackbody (red), Maxwellian synchrotron (green), and the best-fit model (black) overlaid. Time evolves from top left to bottom right, and the time since trigger is labeled at the top of each snapshot spectrum, in units of seconds. The peaks of the models are all normalised to $(x, y) = (1, 1)$. Data points and the shaded regions are plotted as described in Fig. 4.

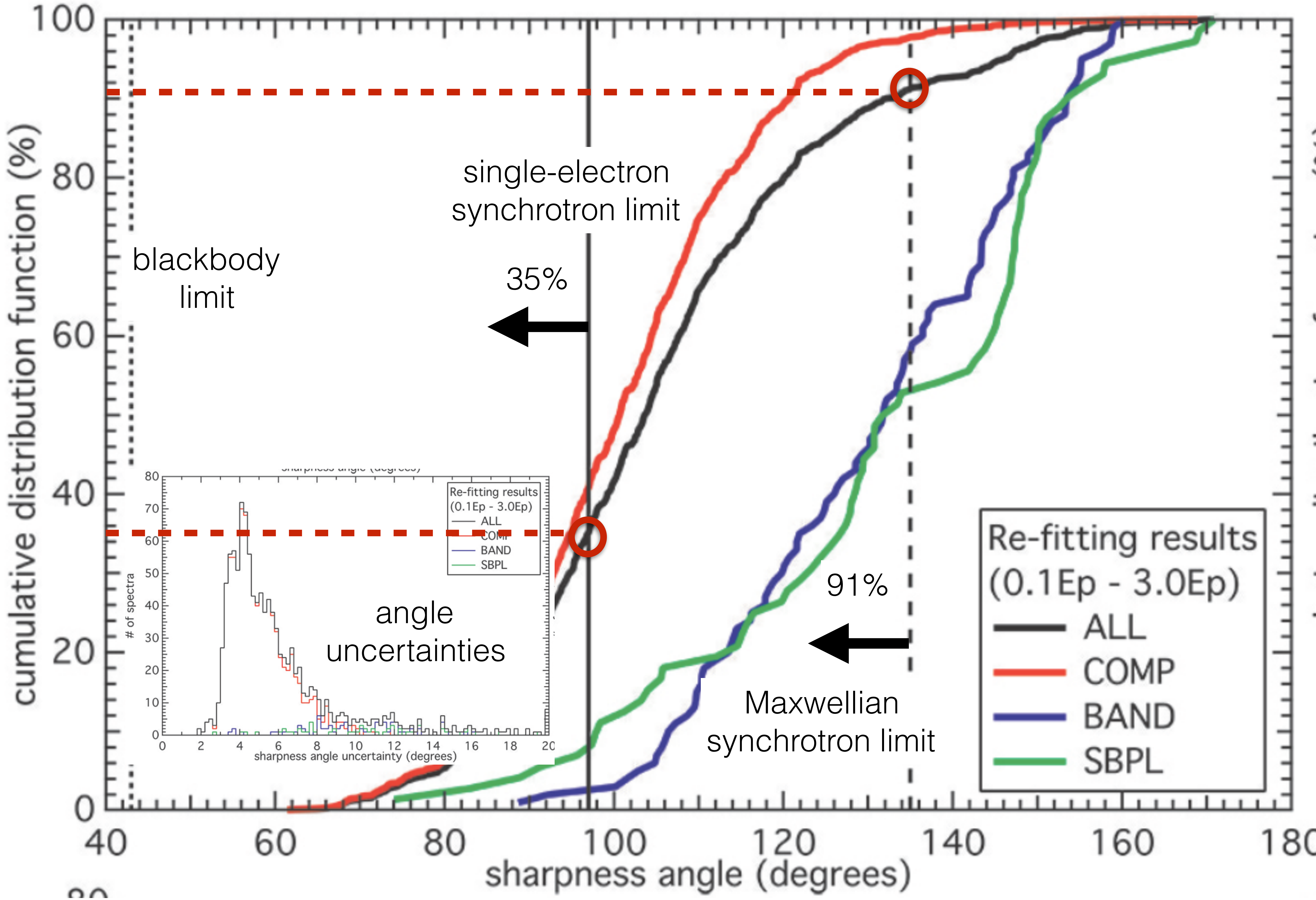
Sharpness angle evolution of 6 example bursts

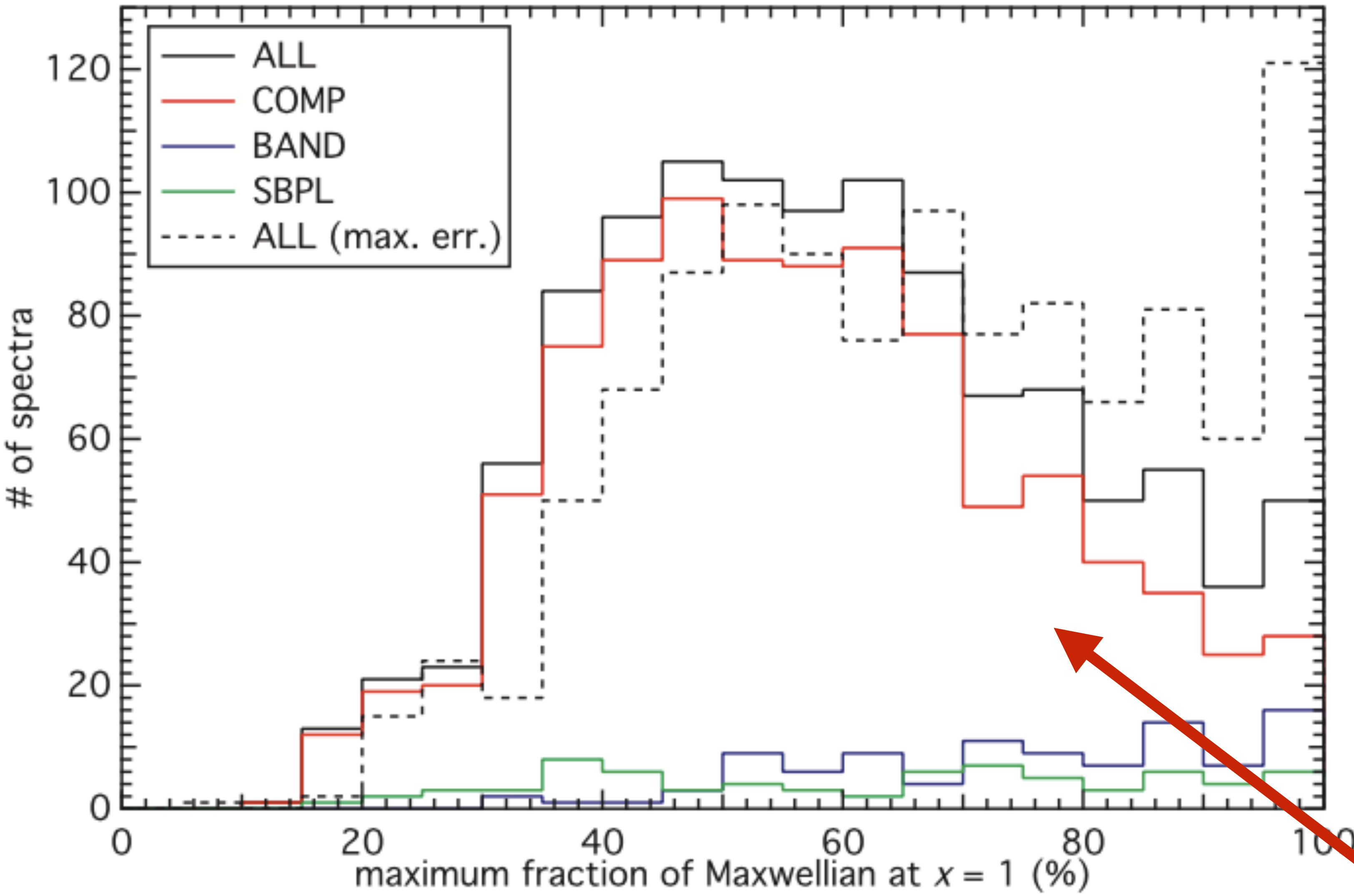
Emission models	θ (degrees)
Blackbody	43
Single-electron synchrotron	97
Maxwellian synchrotron	135
Synchrotron with $p = 2^a$	170
Synchrotron with $p = 4$	128

BAND SBPL COMP

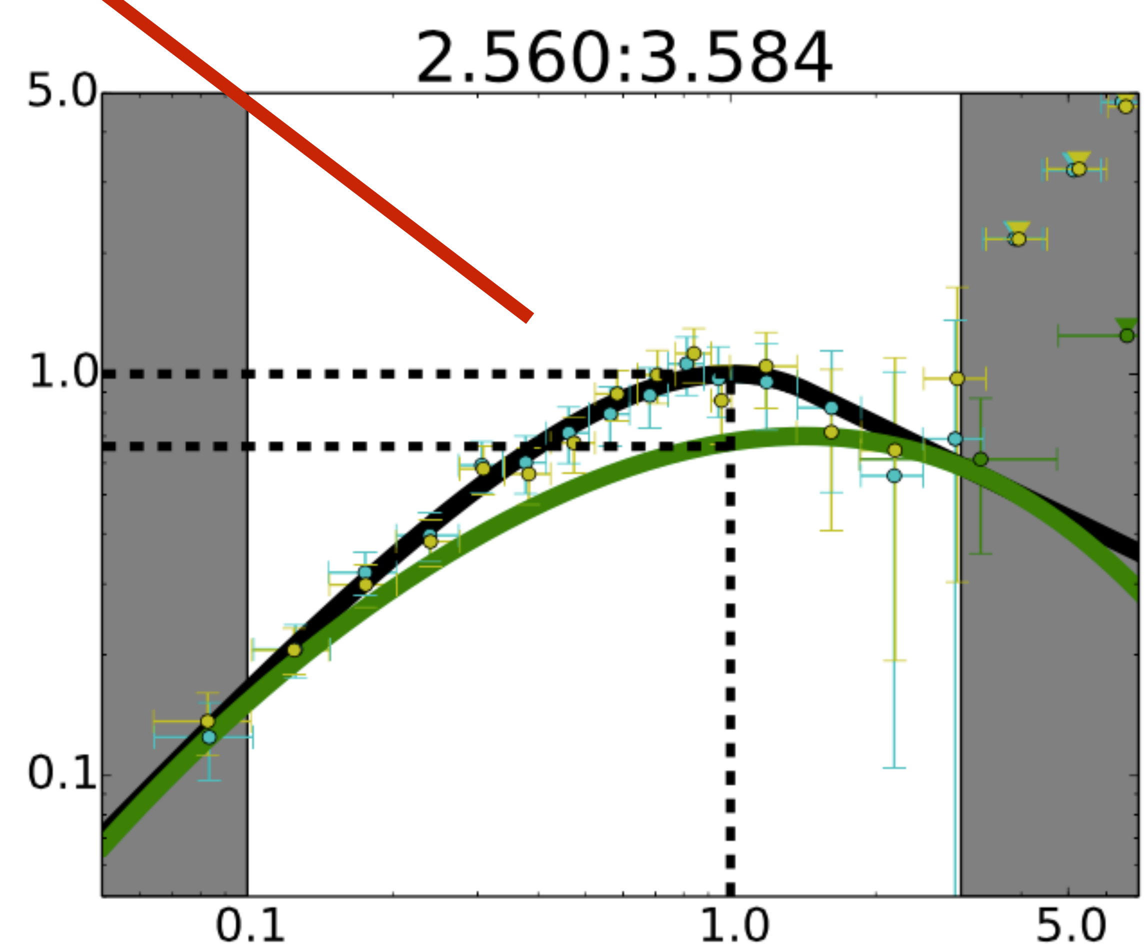


Optically thin synchrotron emission is clearly not consistent…



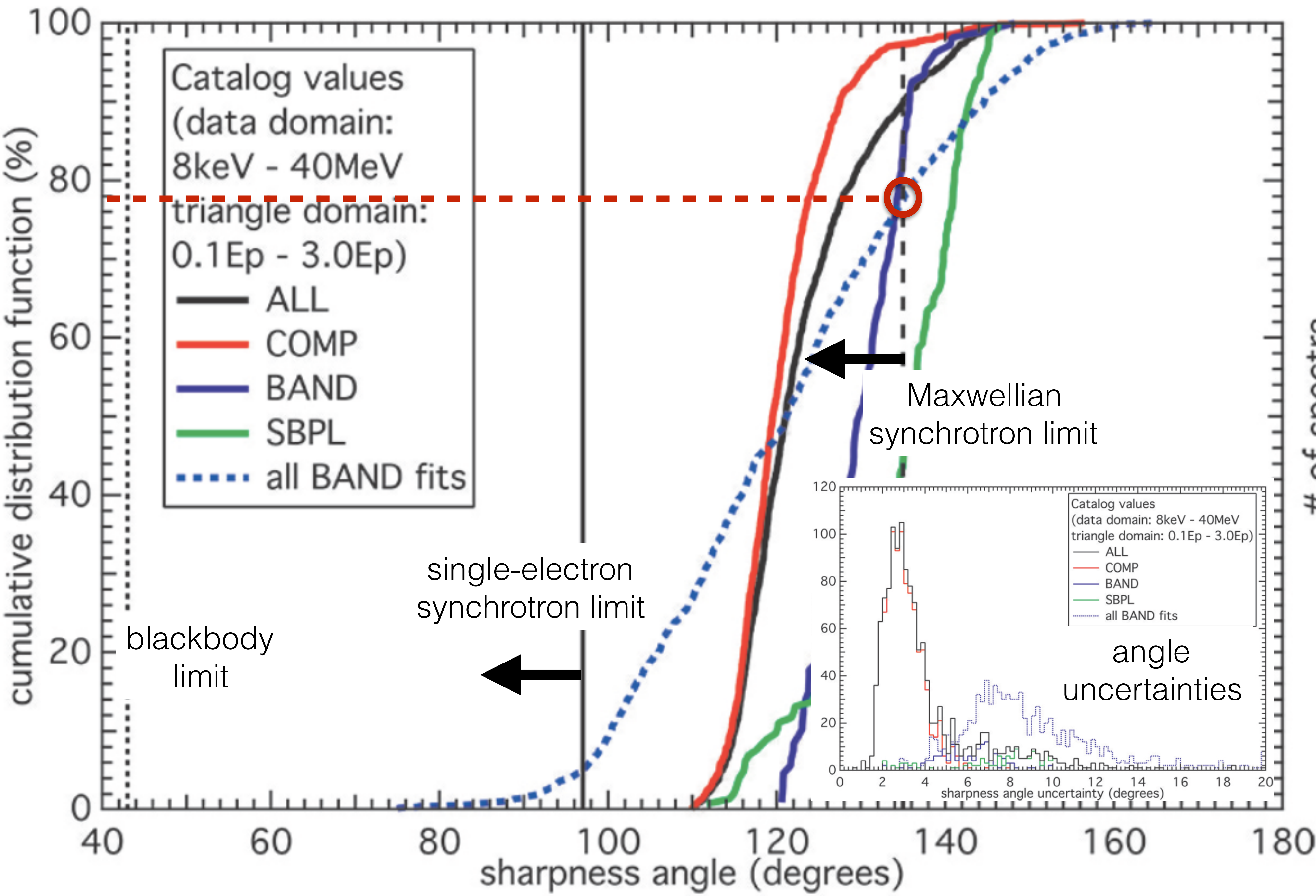


So, how much synchrotron is allowed?

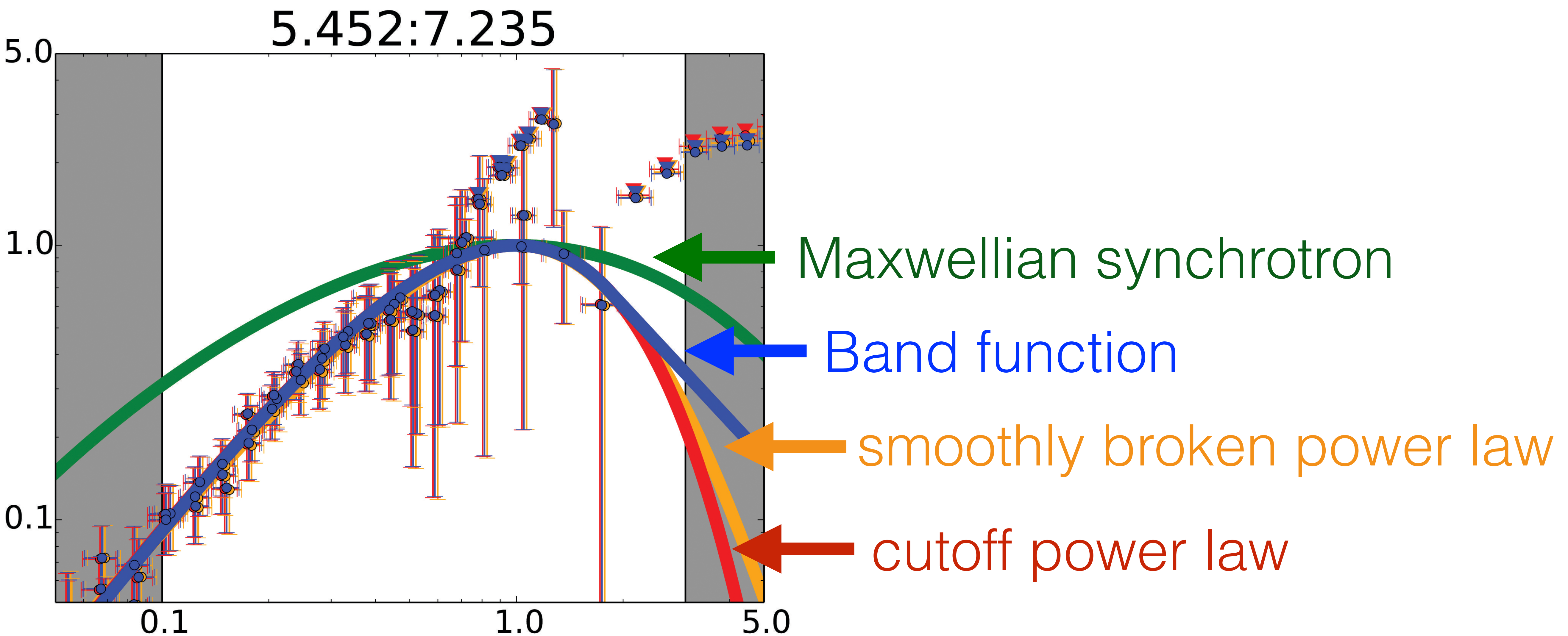


- The limiting case, single temperature Maxwellian synchrotron, can only contribute up to 58^{+23}_{-18}%.

Even if (1) the whole GBM energy range is taken to be the data domain, and (2) the Band function (typically broader than cutoff power law) is assumed…



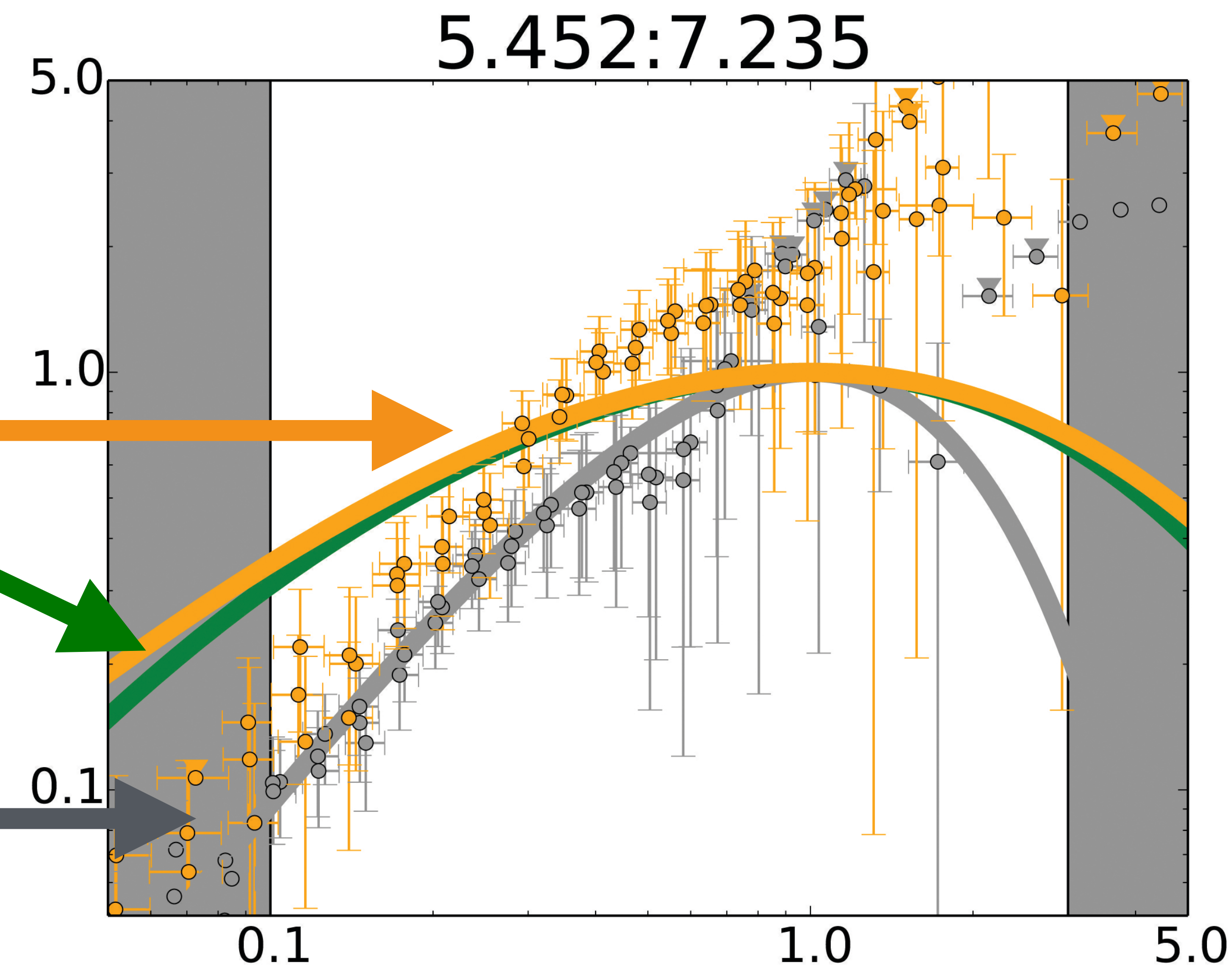
Different fitting functions comparing to the data points



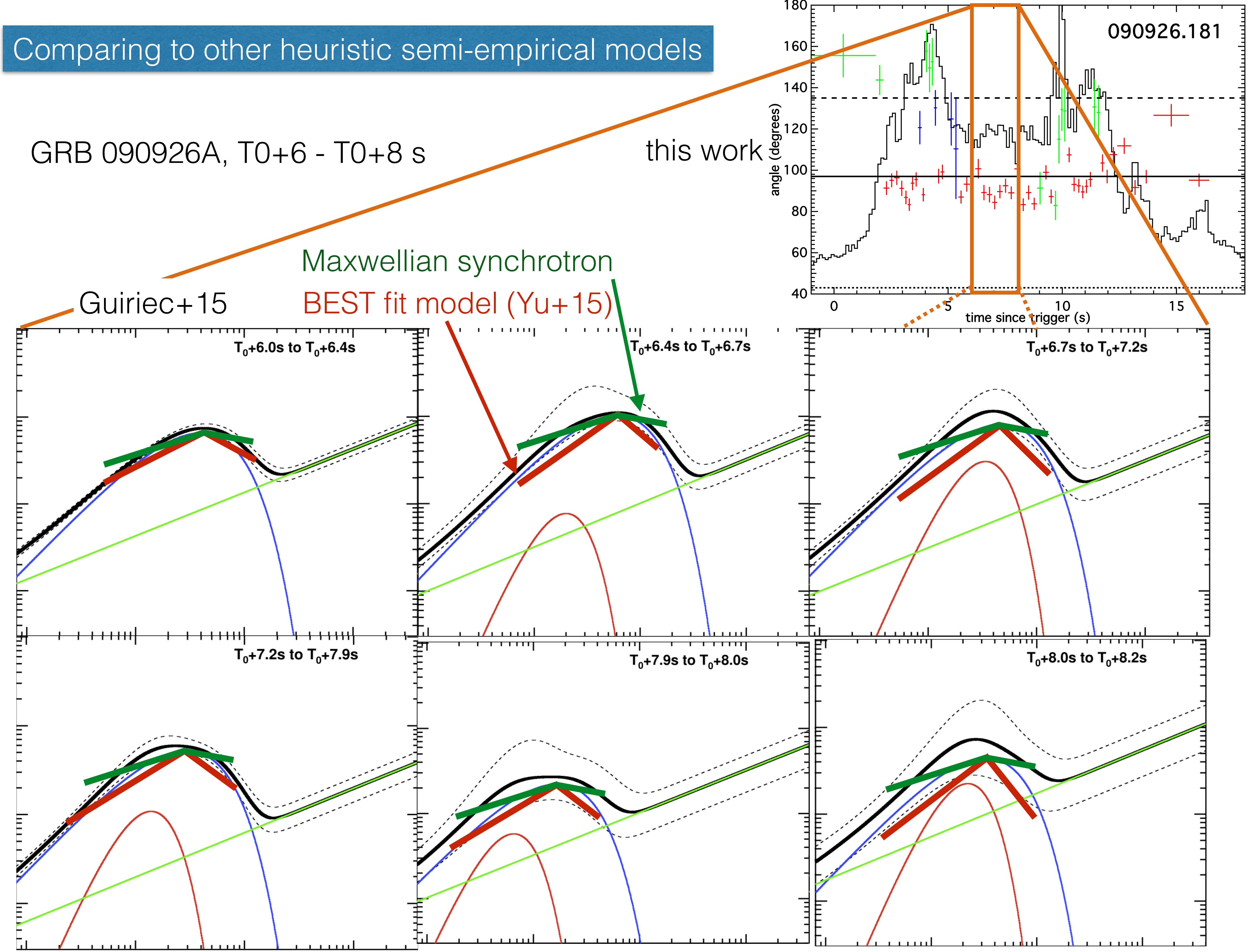
How about fitting the Maxwellian to data points?

smoothly broken power law fit
to a Maxwellian synchrotron

best-fit cutoff power law

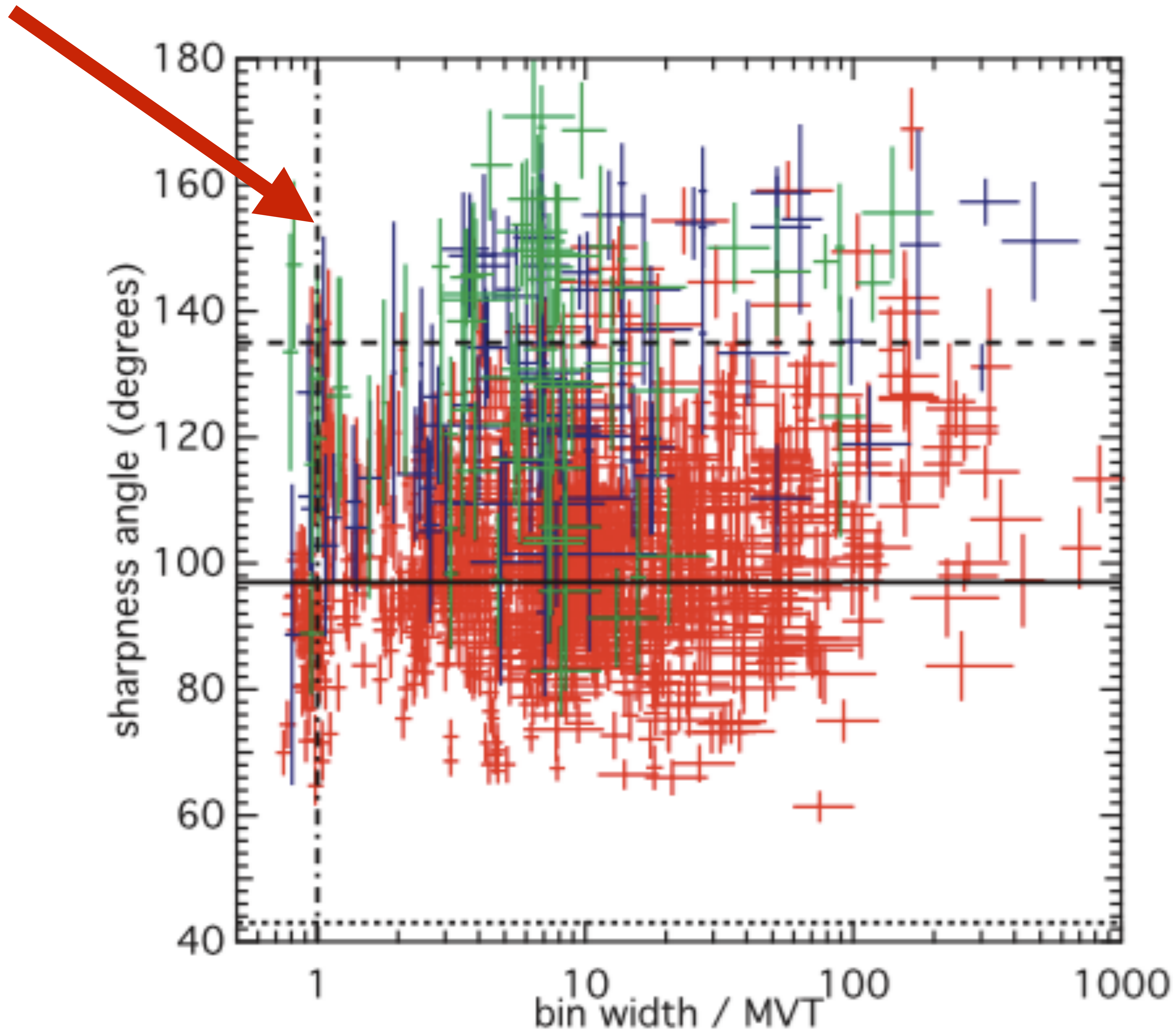


Comparing to other heuristic semi-empirical models



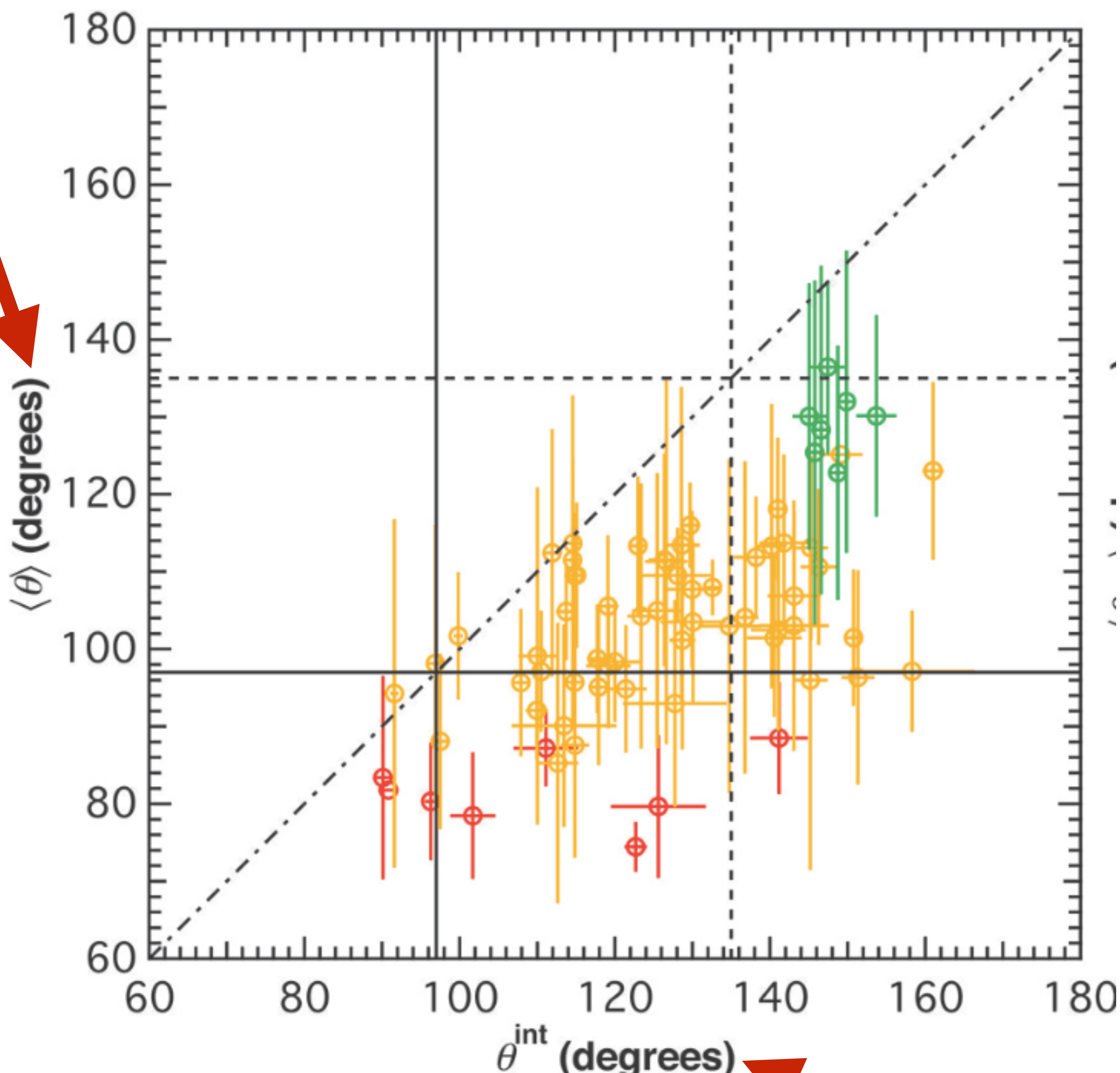
How resolved are the time-resolved spectra?

- 96% of our time-resolved time bin may still be wider than the intrinsic minimum variability time-scale (Bhat13, Golkhou+14,15)



How resolved are the time-resolved spectra?

average sharpness angle (this work)



sharpness angle computed using best-fit models from time-integrated catalog (Gruber+14)

Summary

- Optically thin synchrotron cannot explain the observed prompt spectral peaks (only contribute up to 58^{+23}_{-18}%)

- Blackbody is too sharp, however a simple distribution function of blackbodies may be constructed

- Time-integrated spectral analysis can underestimate the sharpness of the observed spectra

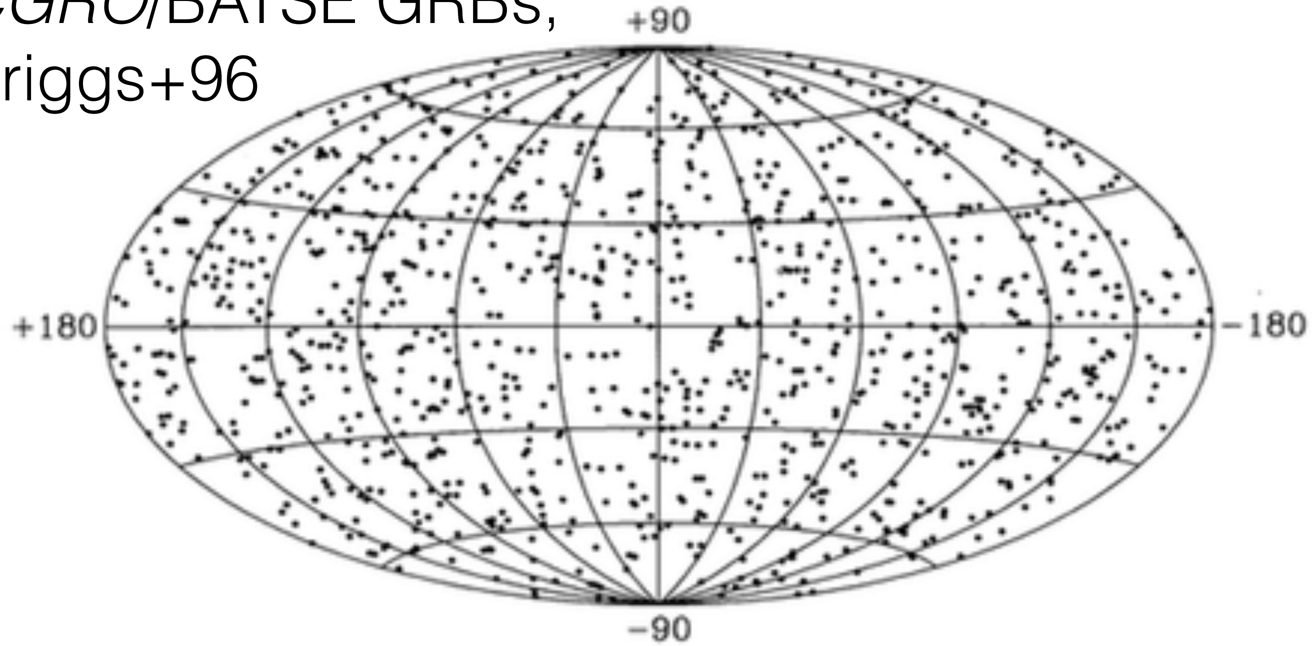
- Beloborodov (2013) argues that the Poynting-flux models shares the same problems of the synchrotron model, suggesting that the outflow is not magnetically dominated

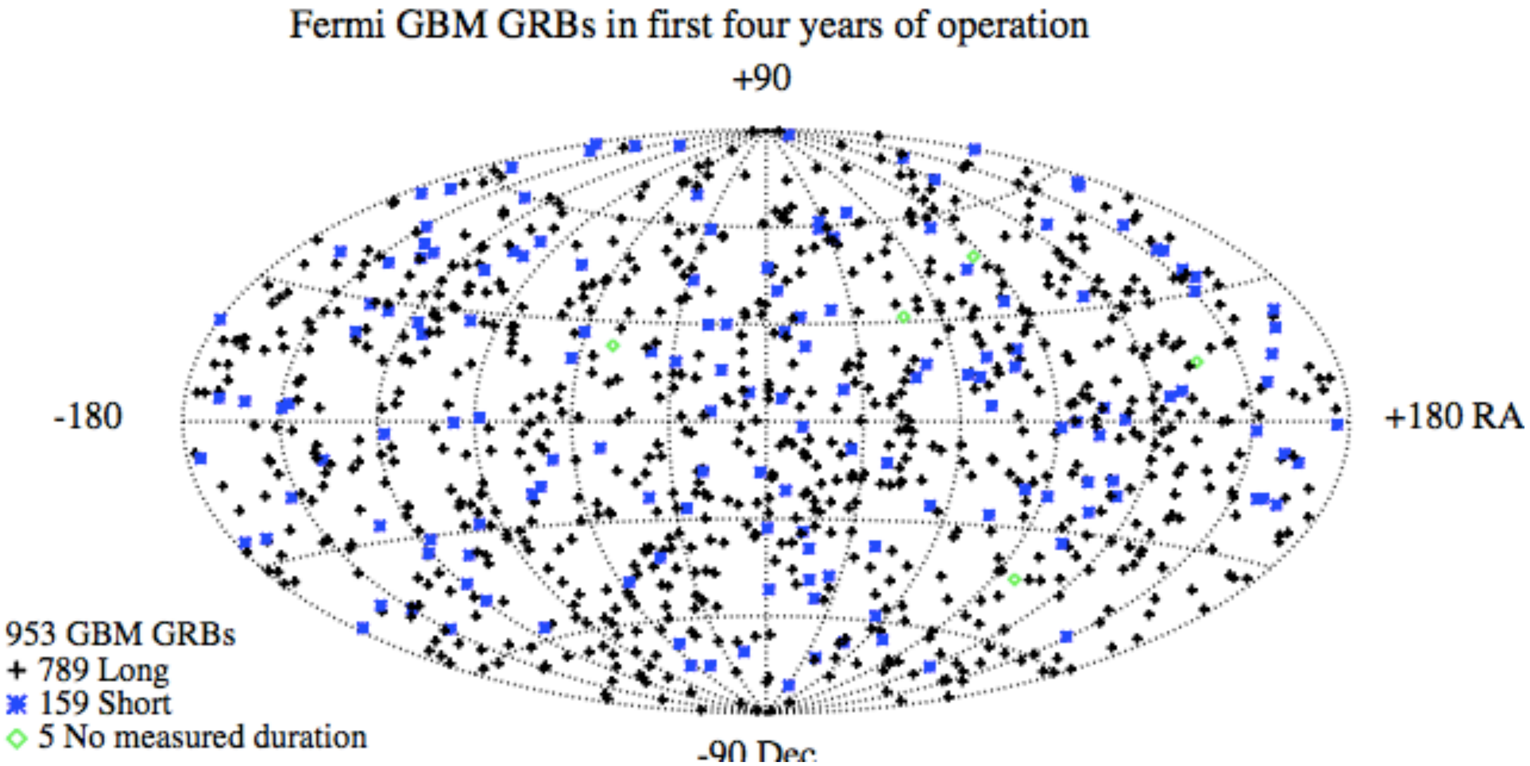
Back-up slides

GRBs are isotropically and cosmologically distributed

isotropic distribution from catalogs

CGRO/BATSE GRBs, Briggs+96

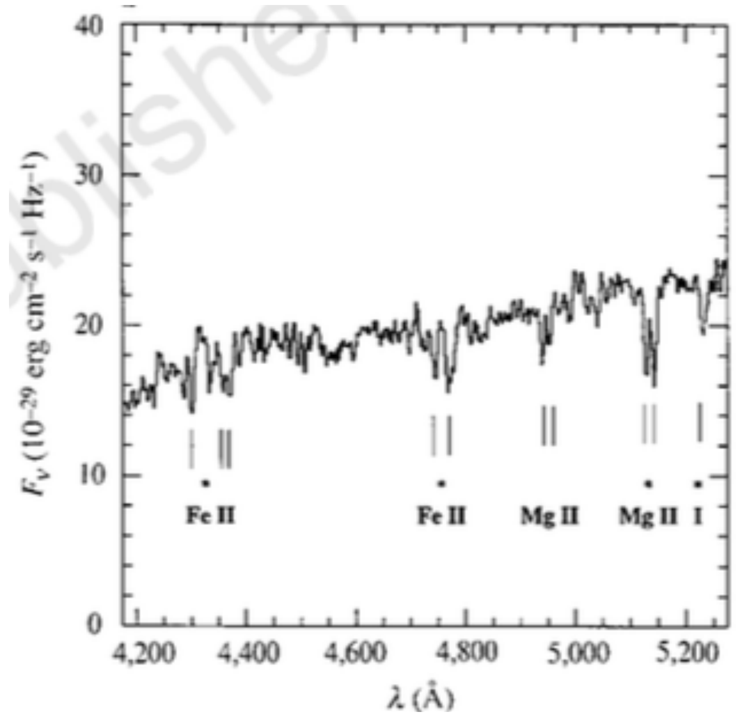


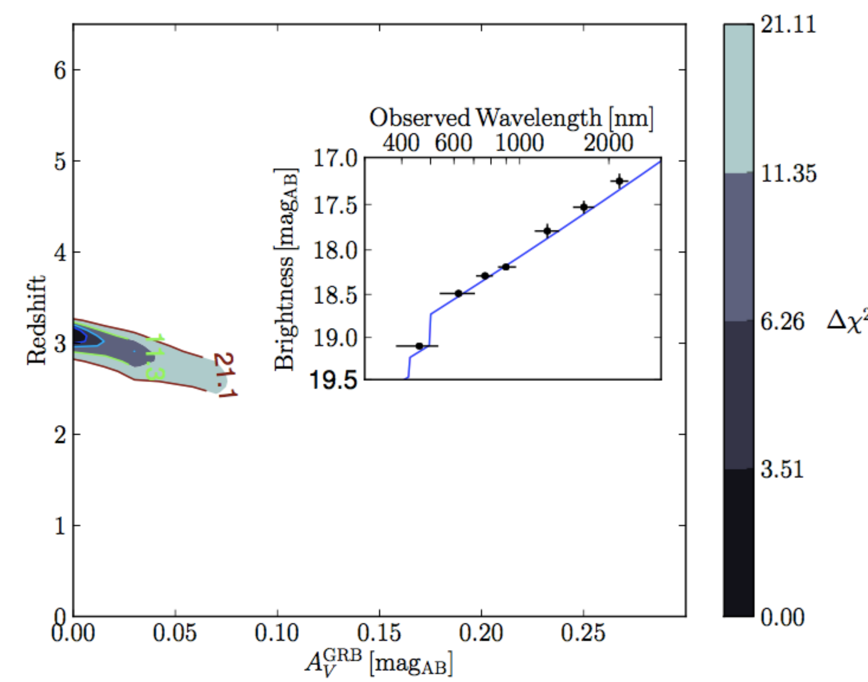


Fermi/GBM GRBs, von Kienlin+14

redshift measurements

spectroscopic, GRB 970508, Metzger+97

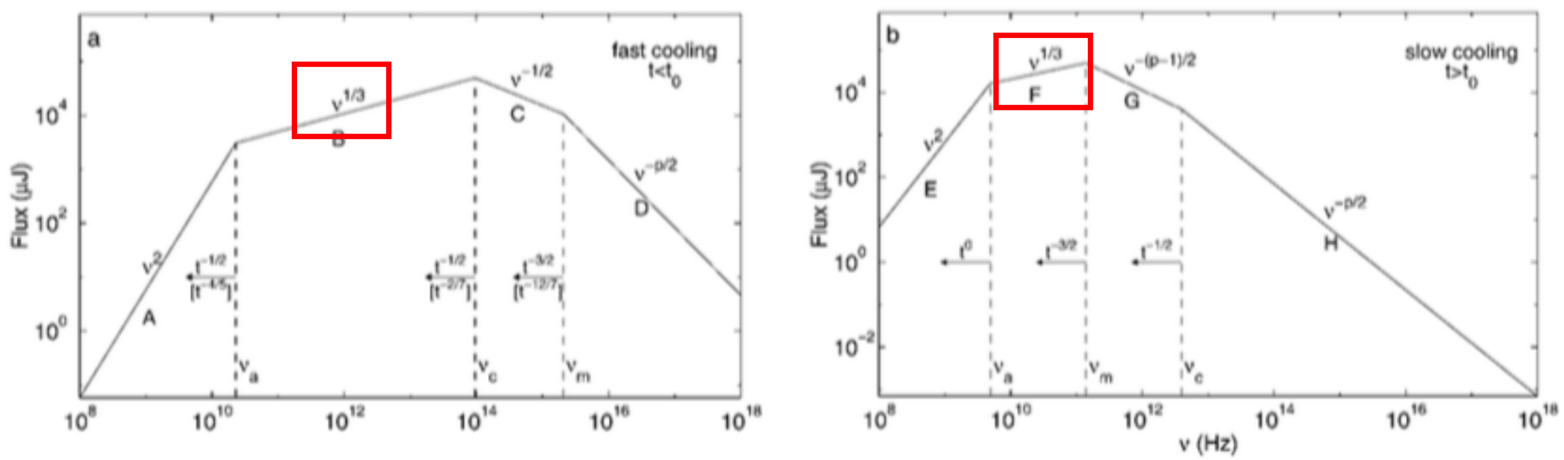




photometric, GRB 121217A, Elliott+14

Why people favor the synchrotron theory?

afterglow: synchrotron (e.g., Sari+98)



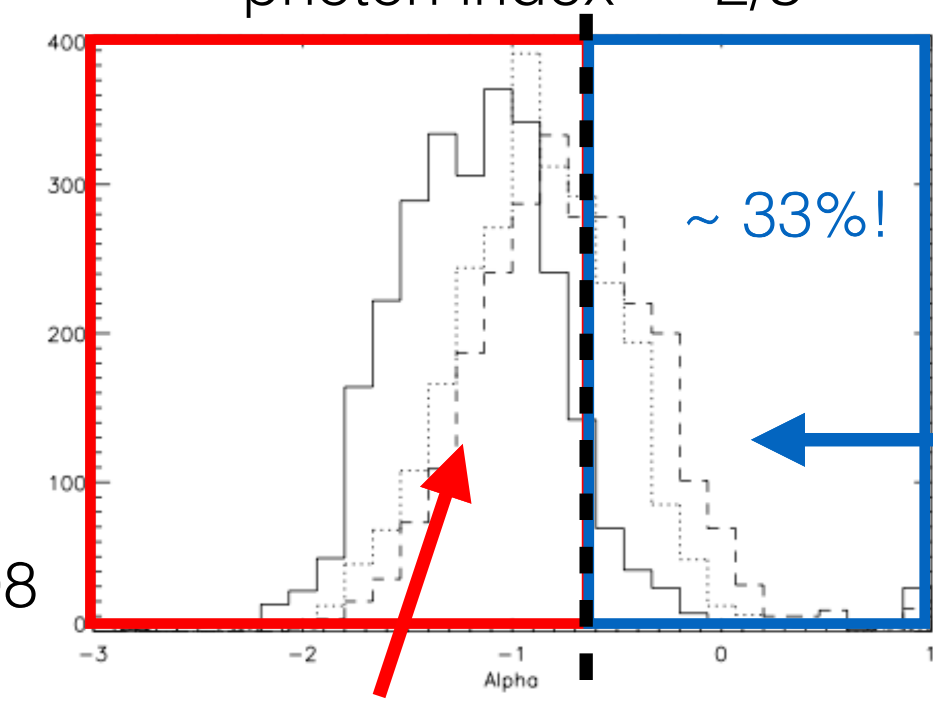
$$F_{\nu,\mathrm{slow}} \propto \begin{cases} \nu^{1/3} & \text{for } \nu_{\min} > \nu, \\ \nu^{-(p-1)/2} & \text{for } \nu_{\mathrm{cool}} > \nu > \nu_{\min}, \\ \nu^{-p/2} & \text{for } \nu > \nu_{\mathrm{cool}}, \end{cases}$$

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

prompt: also synchrotron? There is the "line-of-death" problem: spectral index = 1/3 or photon index = -2/3

**remember:
photon index + 1 = spectral index

Preece+98



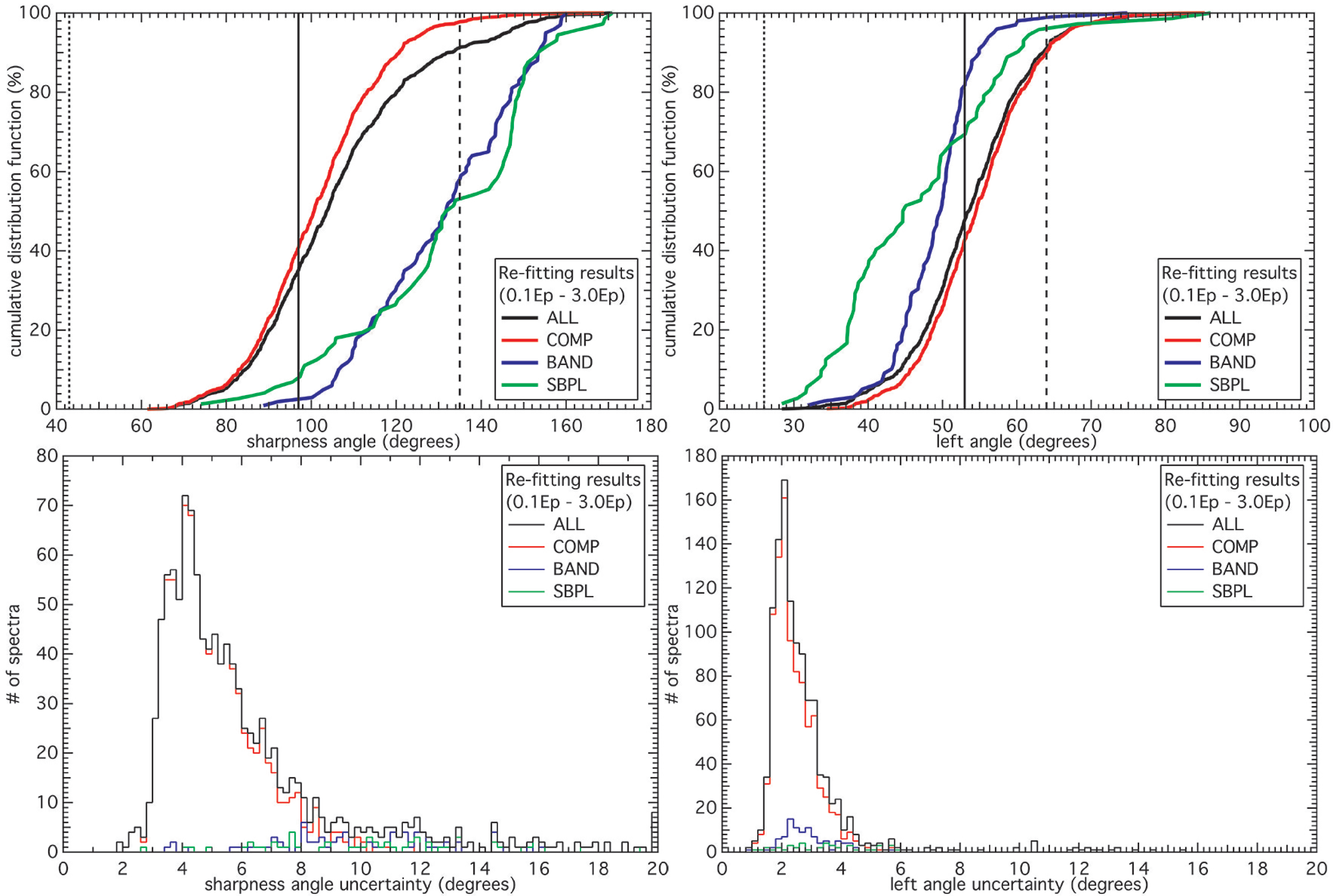
-2/3

synchrotron could explain index < -2/3

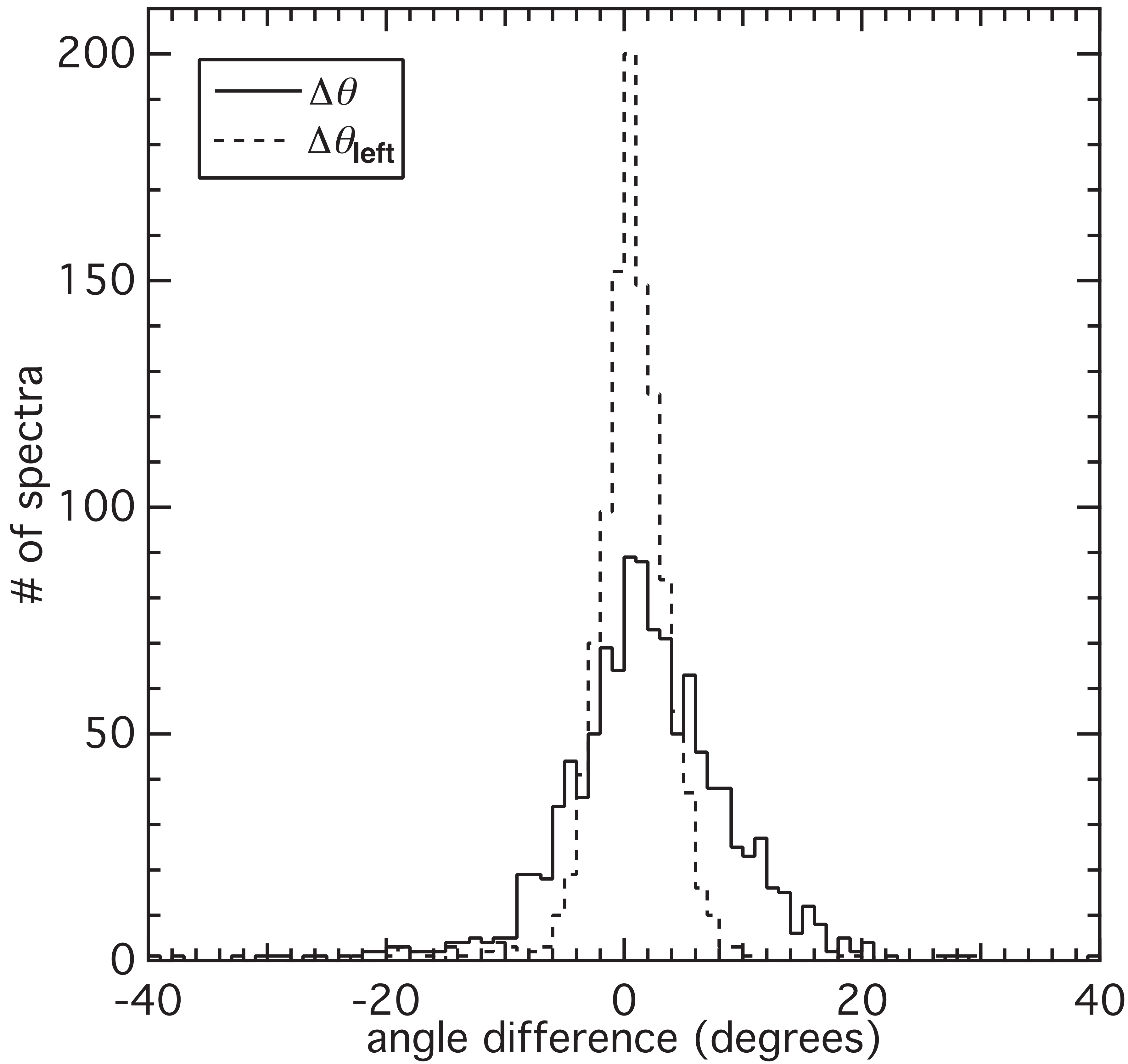
what about index > -2/3? very difficult, require extra blackbody and/or evolving B-field (Burgess+14, Yu+15)

****But all previous works have only considered the low-energy spectral slope! What about the high-energy slope and the curvature around the spectral peak/break?**

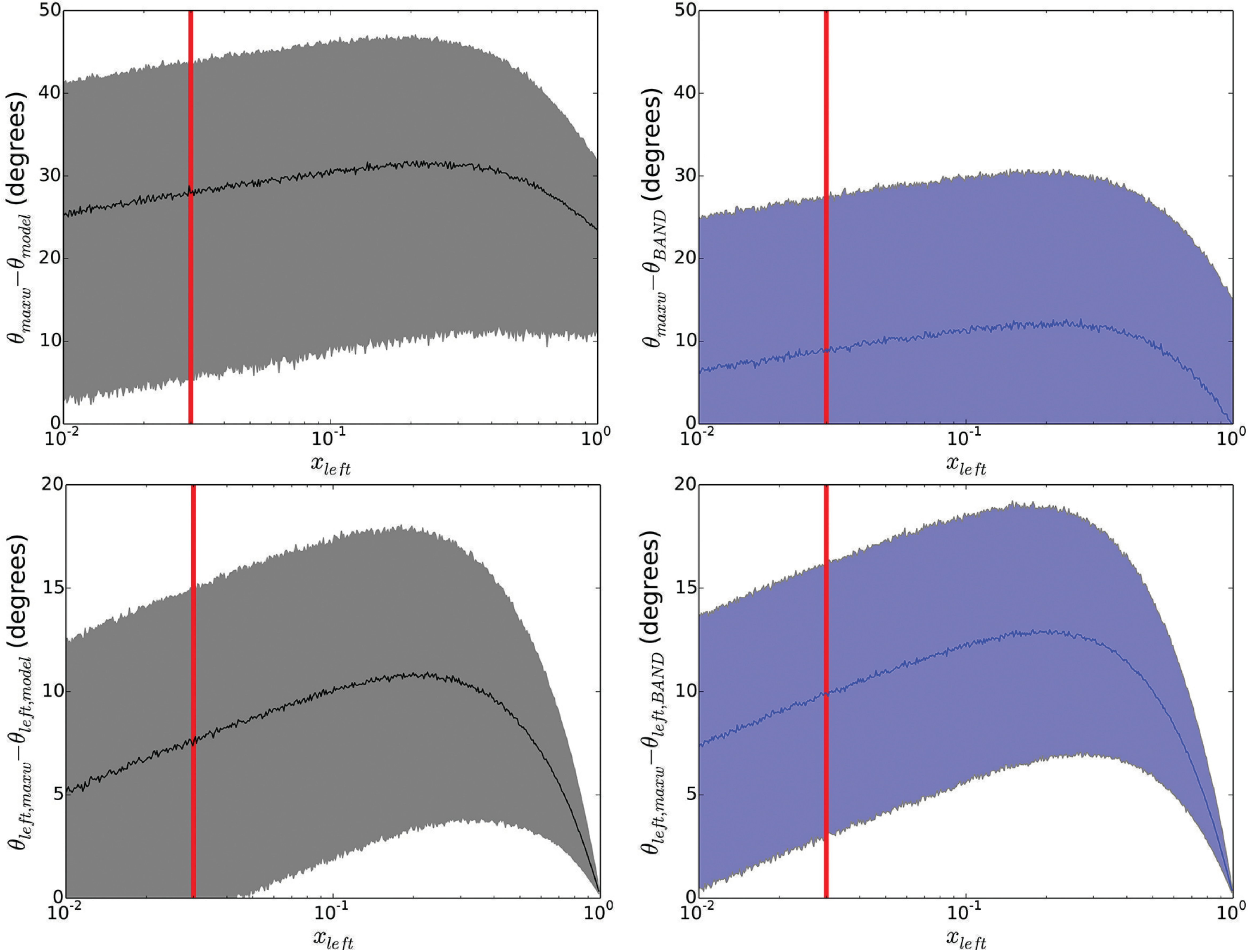
Full angle or left-hand-side angle results are consistent



Angle difference between re-fits and catalog fits



Choice of the triangle domain is a good one



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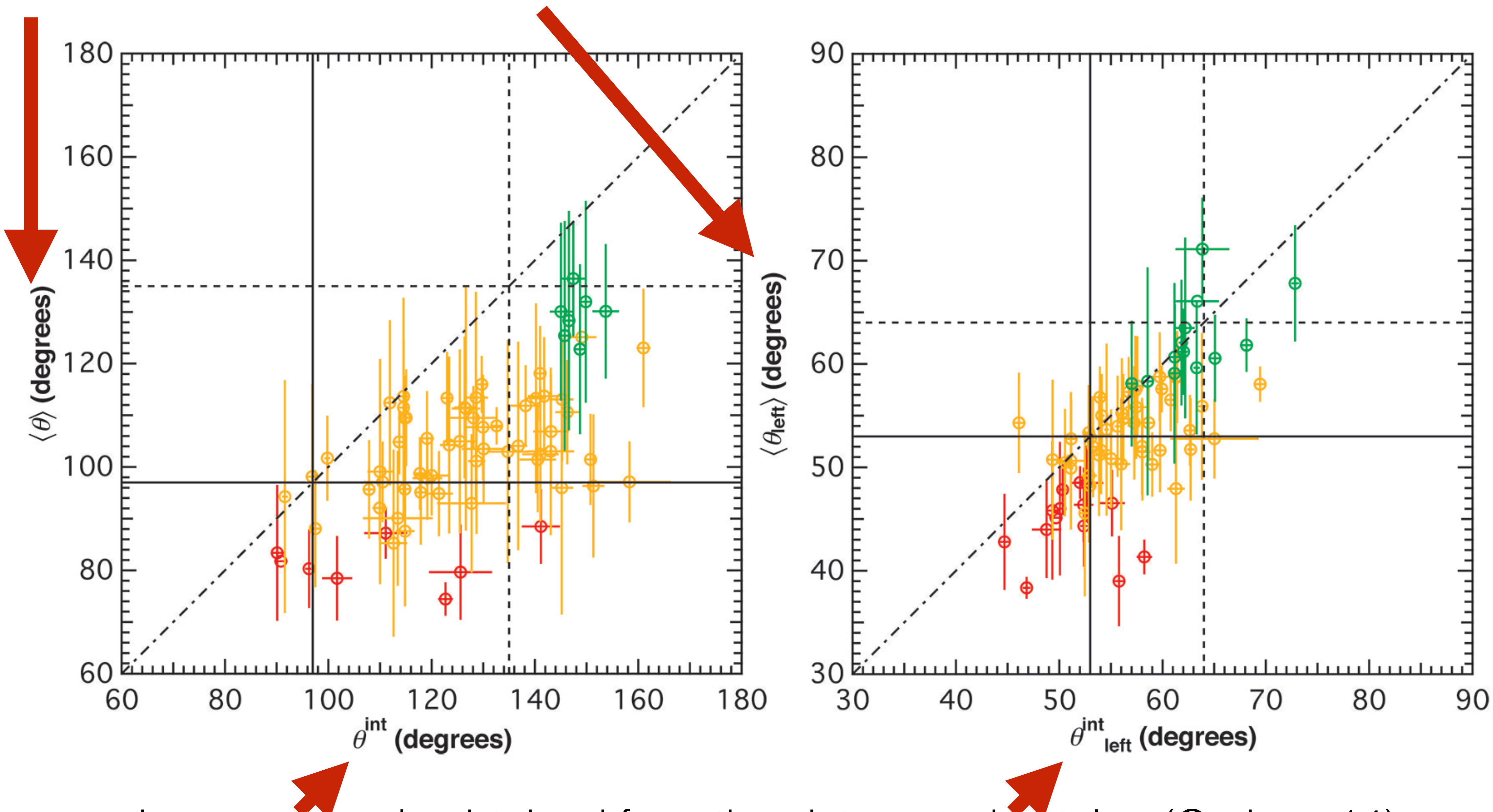
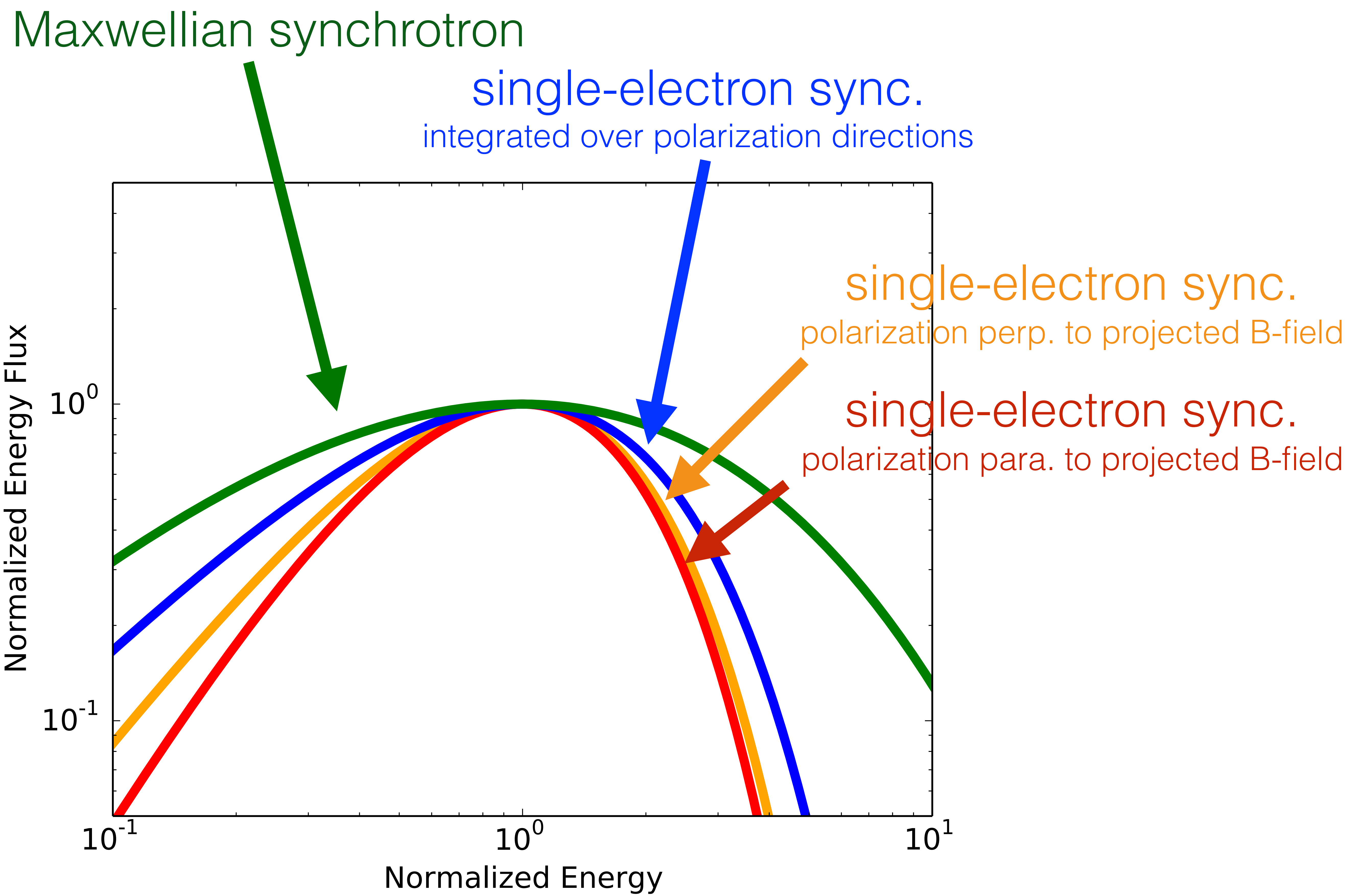
average sharpness angle (this work)

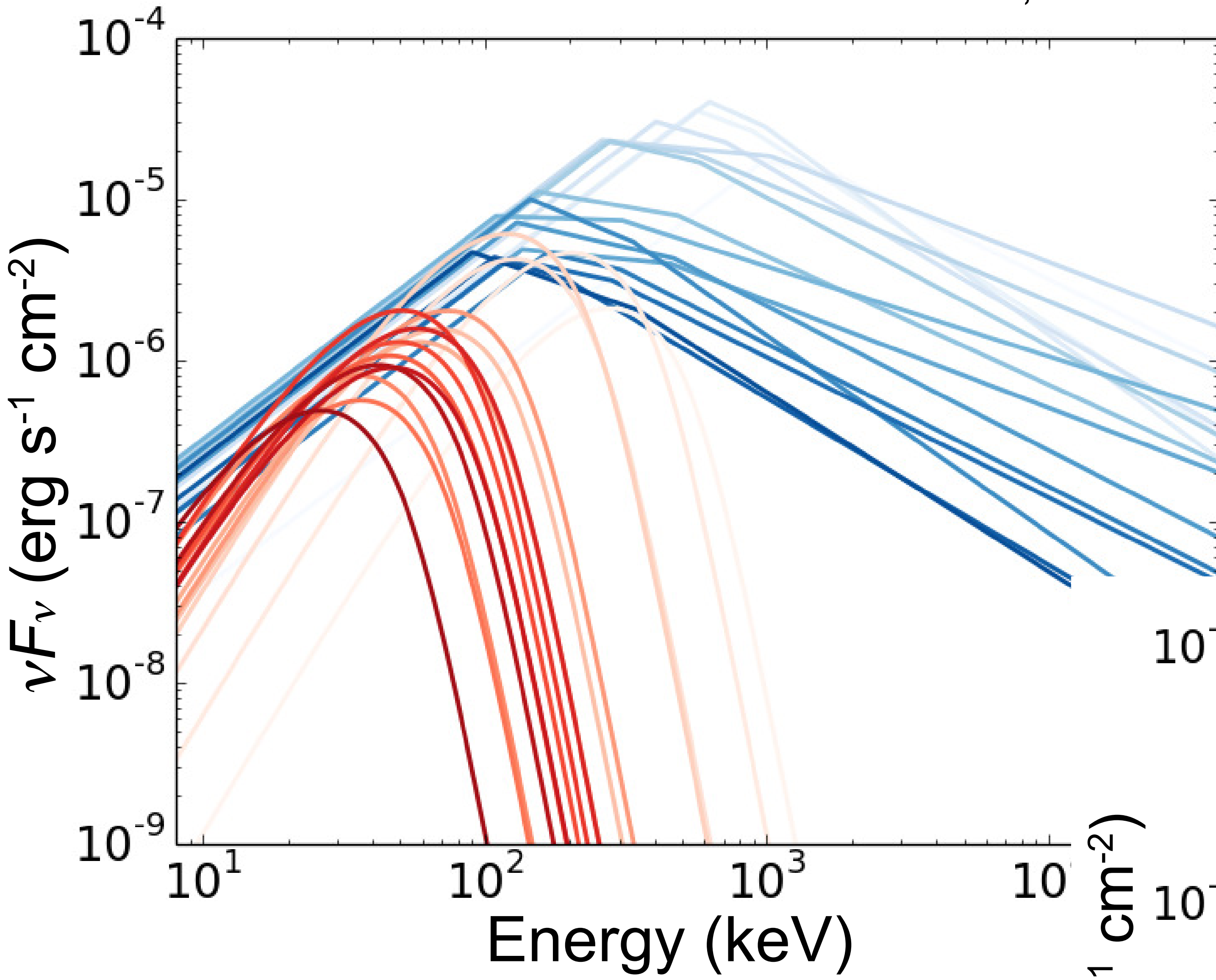


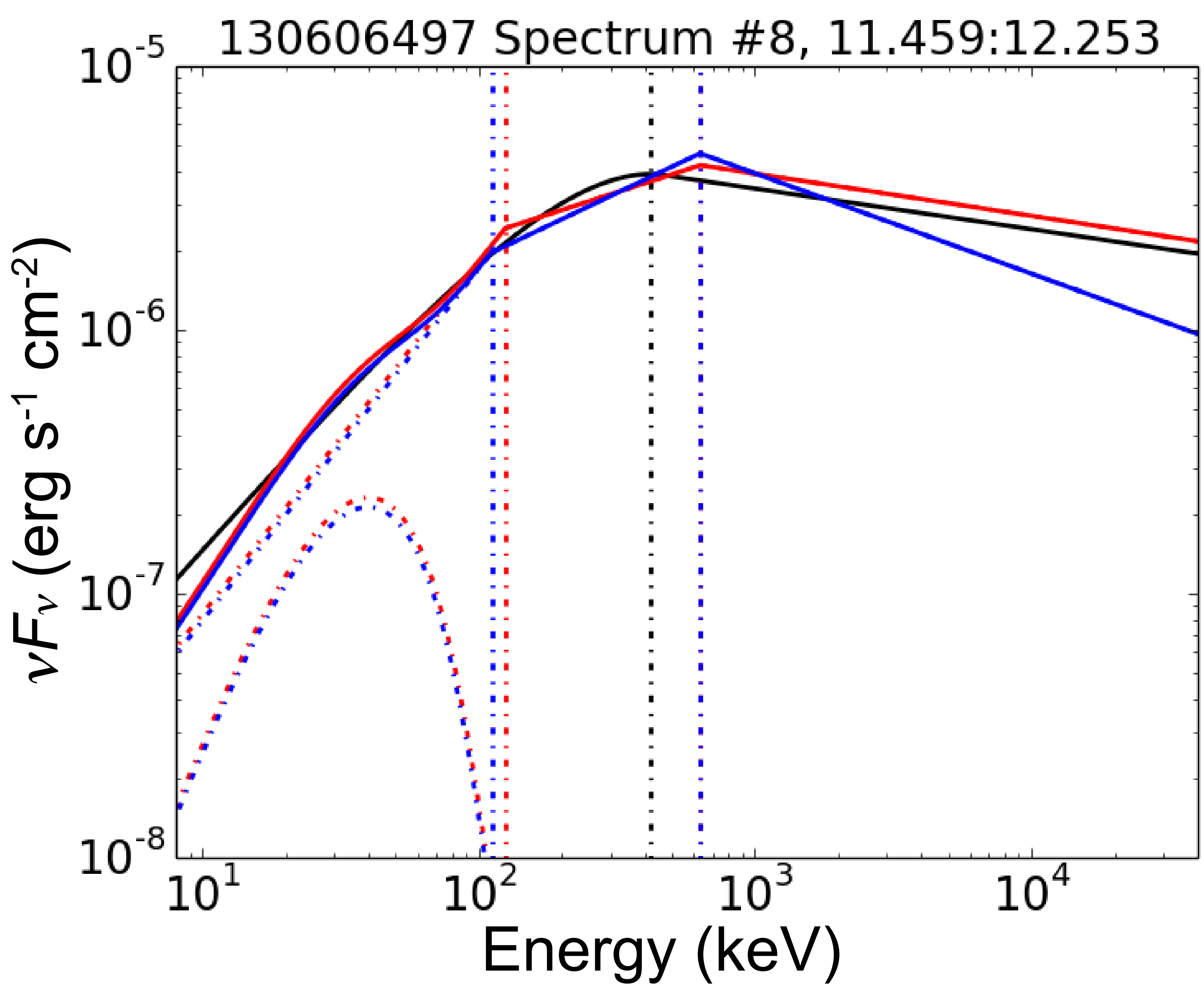
sharpness angle obtained from time-integrated catalog (Gruber+14)

Mathematical but not physical limits



Yu, Greiner, van Eerten et al., 2015, A&A, 573, A81





Yu, Preece, Greiner, et al., submitted to A&A