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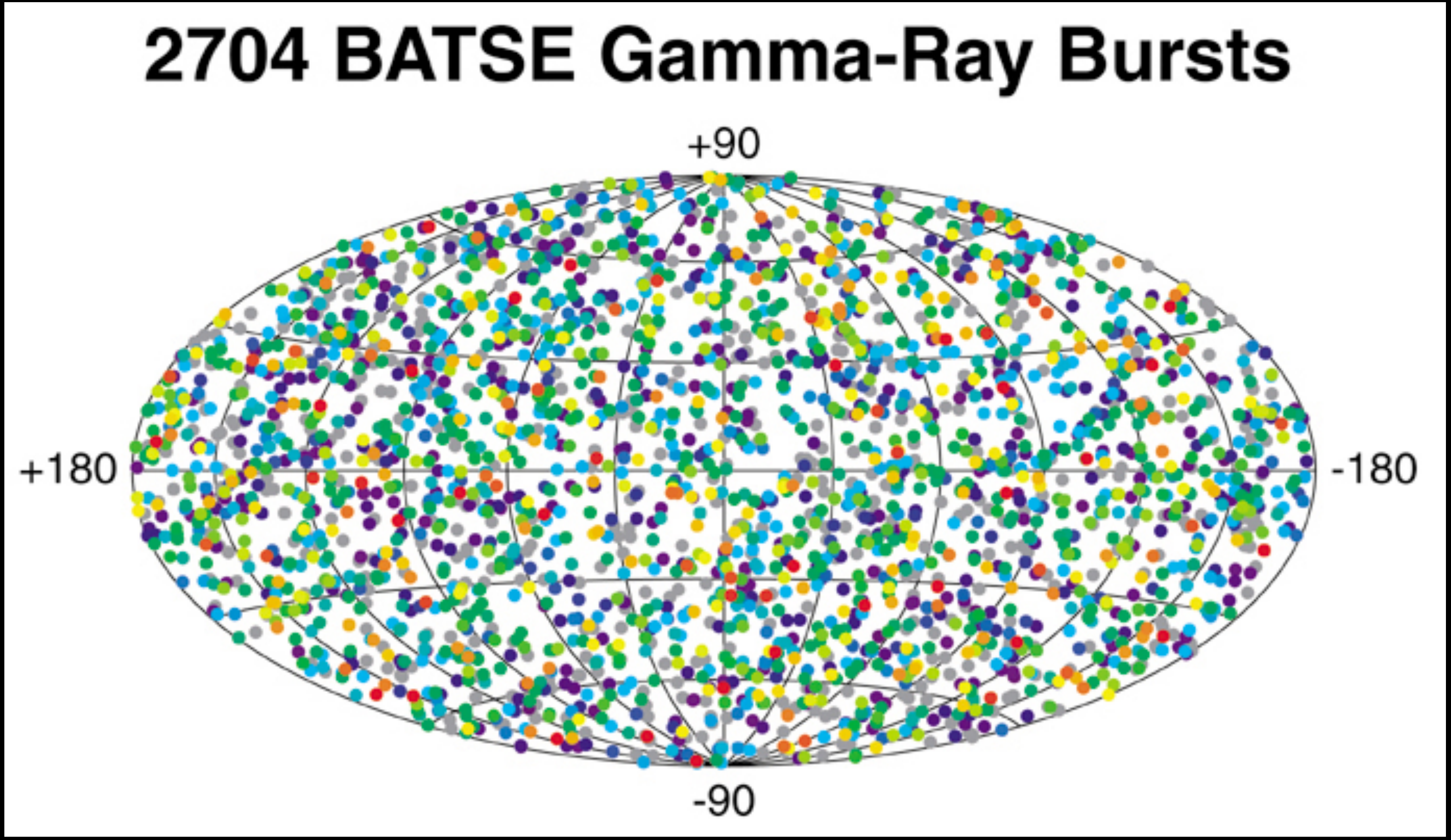
GAMMA RAY BURST OBSERVATIONS

Fermi Summer School (2015)

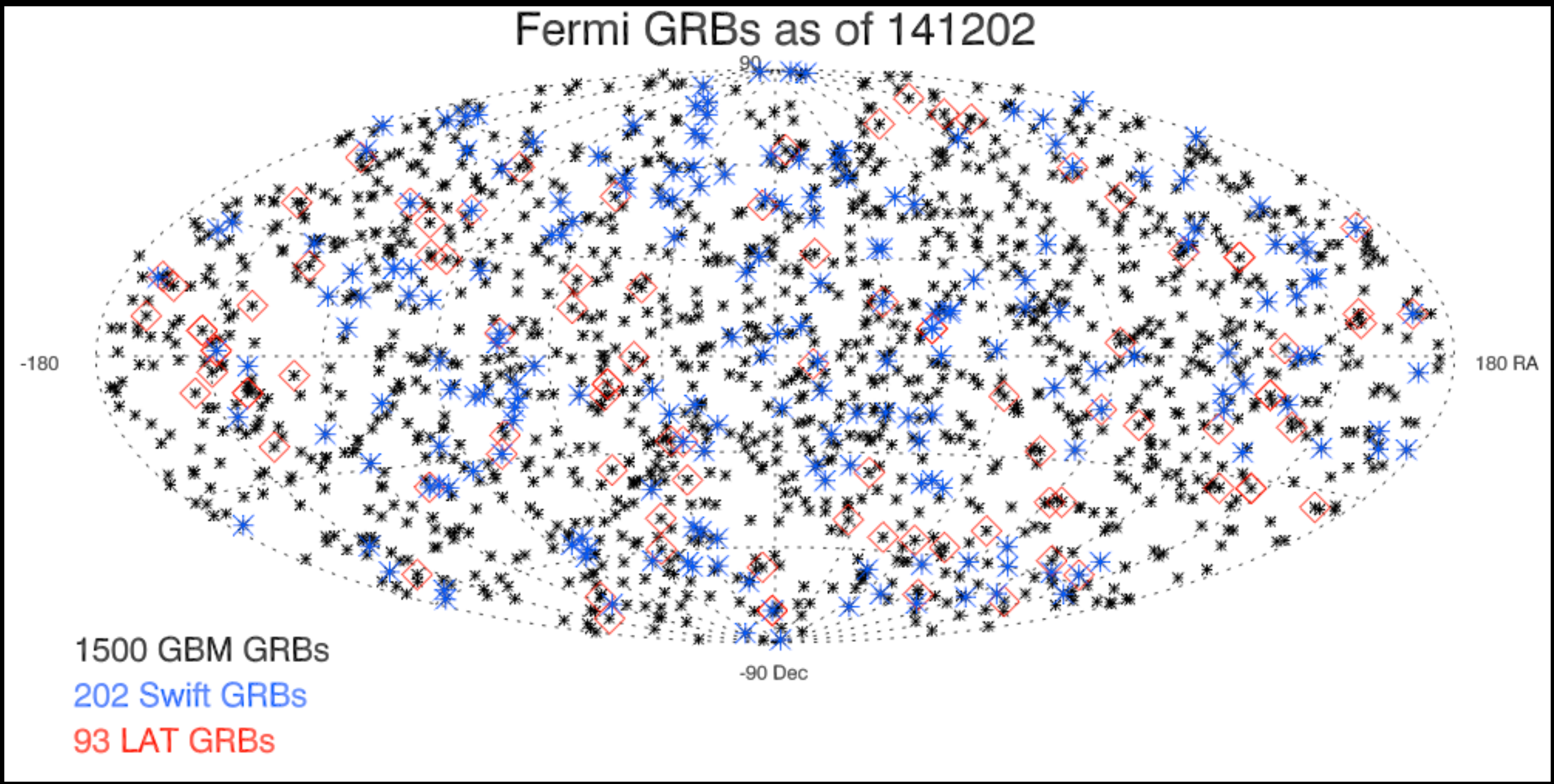
WHAT DO WE KNOW ABOUT GRBS?

- The are cosmological
- They are the most energetic sources in the Universe
- Exhibit a variety of spectral and temporal properties

COSMOLOGICAL

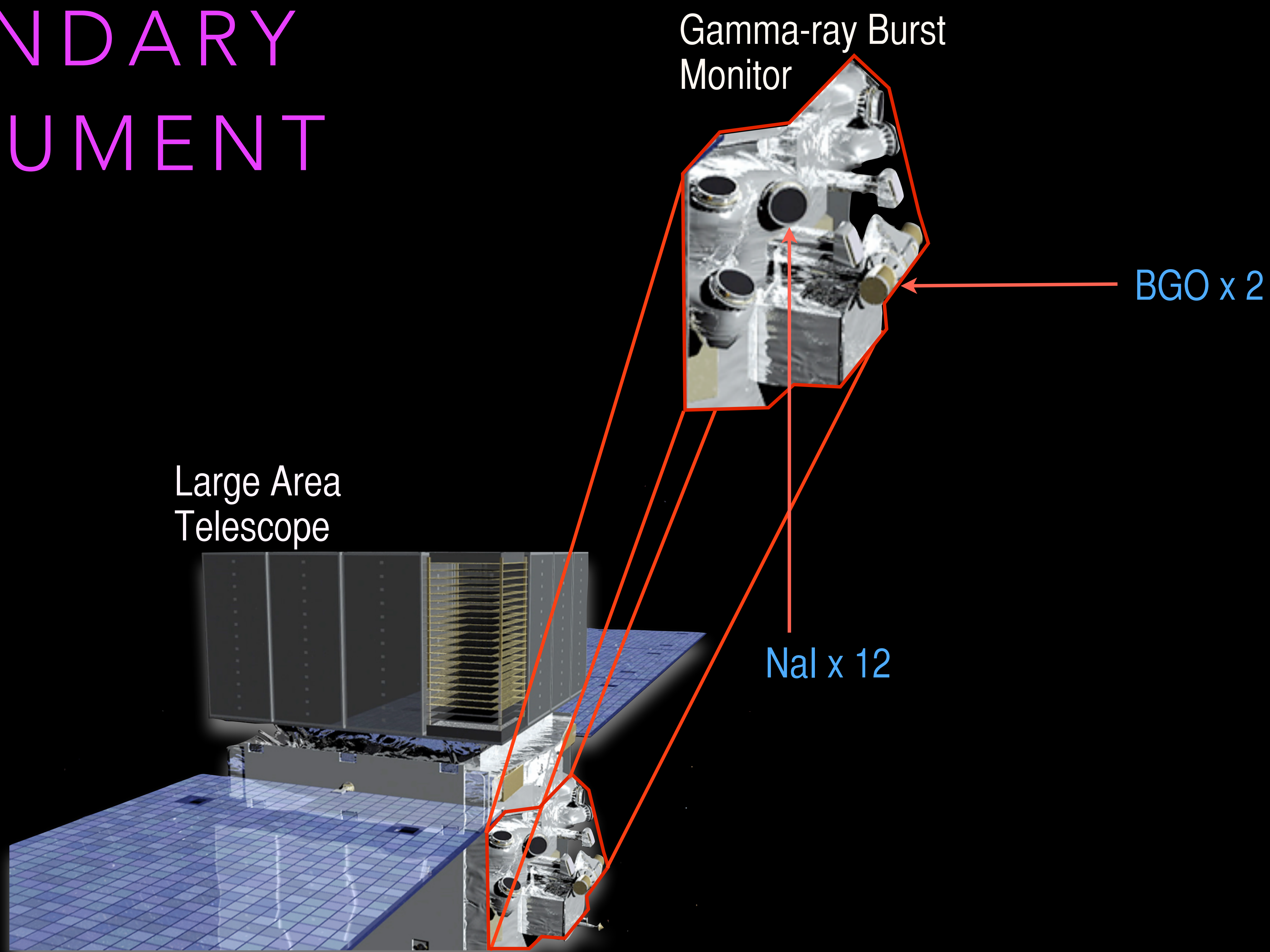


COSMOLOGICAL

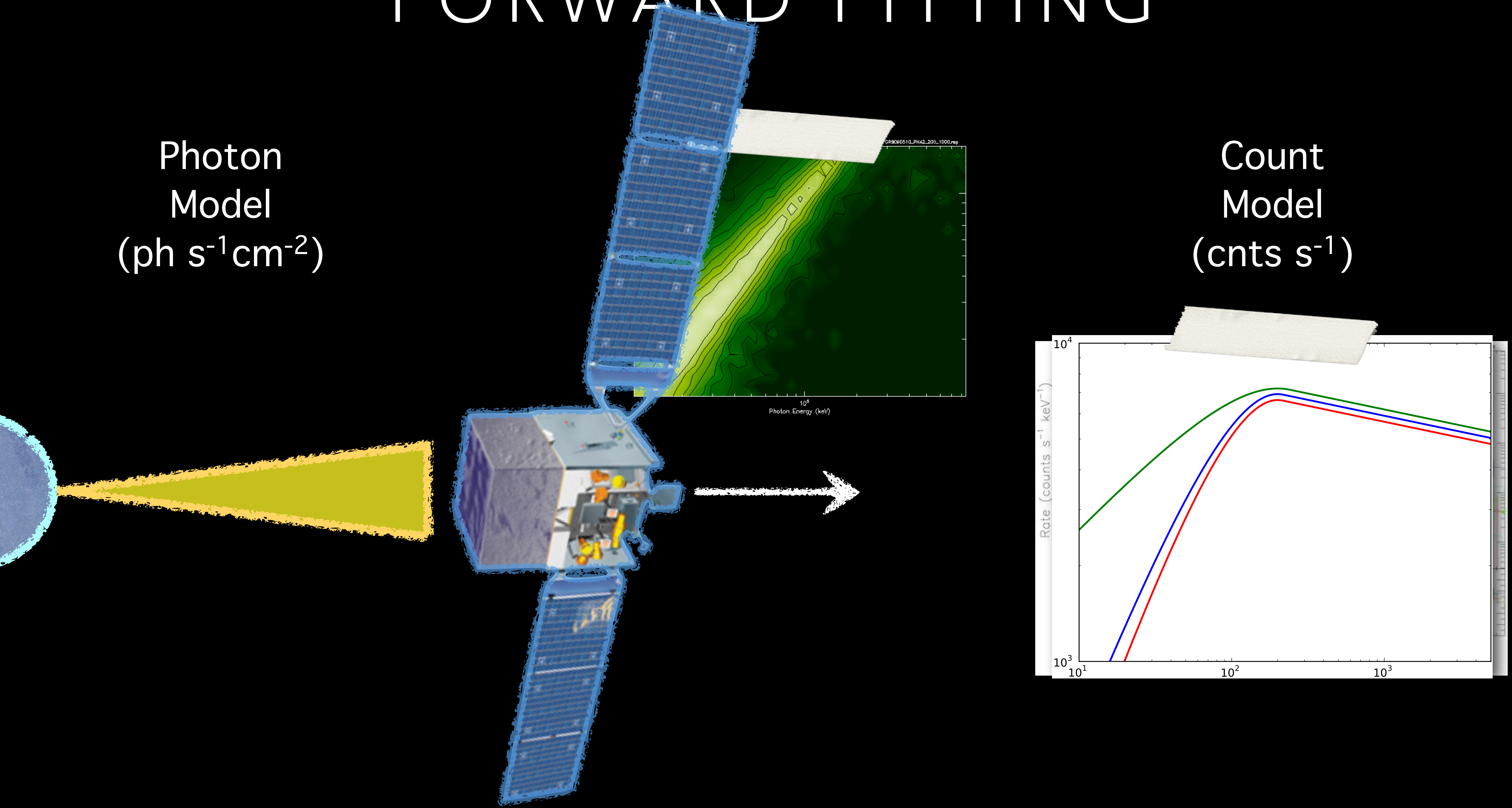


GAMMA-RAY BURST MONITOR

THE SECONDARY INSTRUMENT

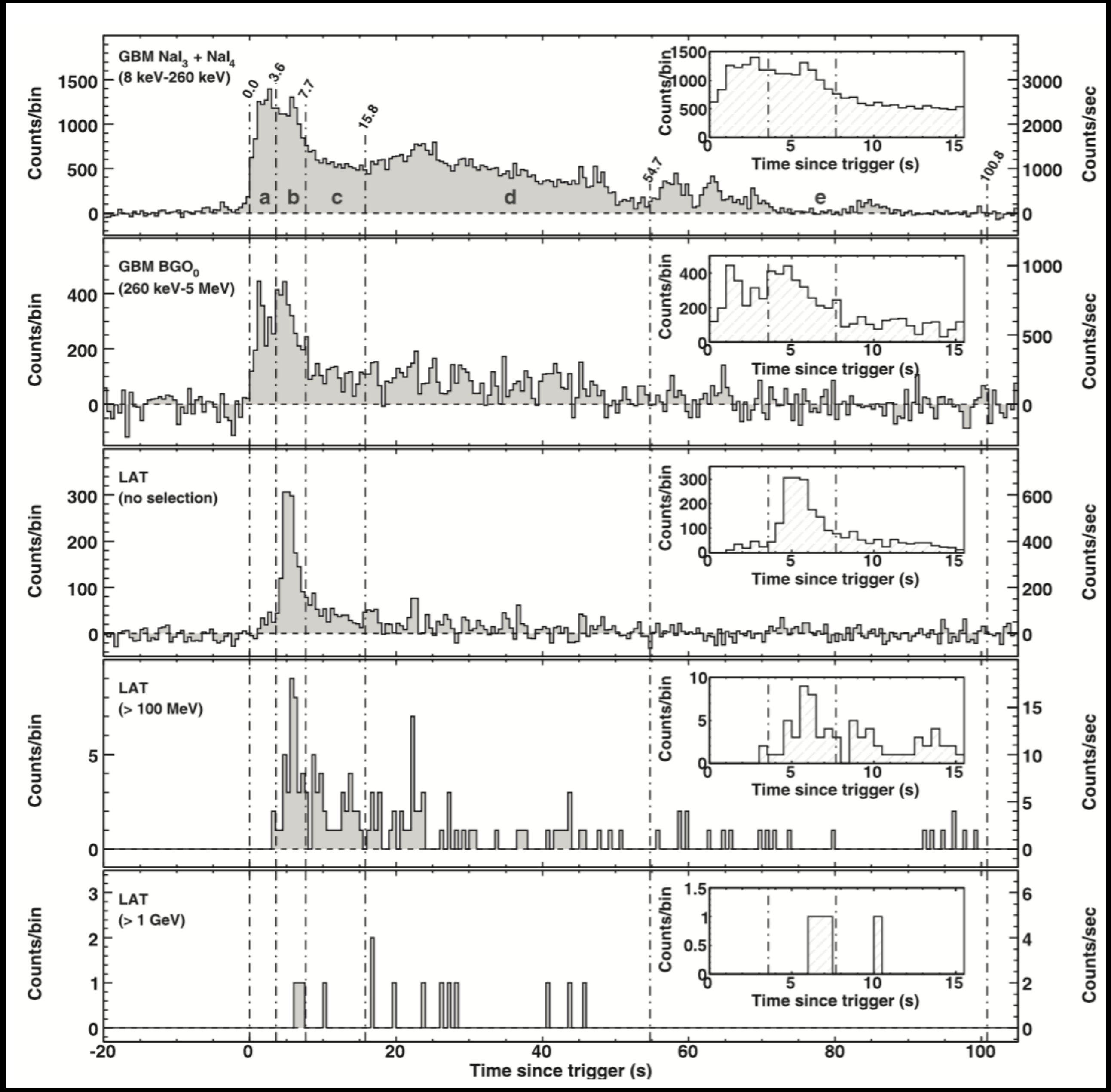


FORWARD FITTING



$$c_i = D_{ij} f_j + b_i$$

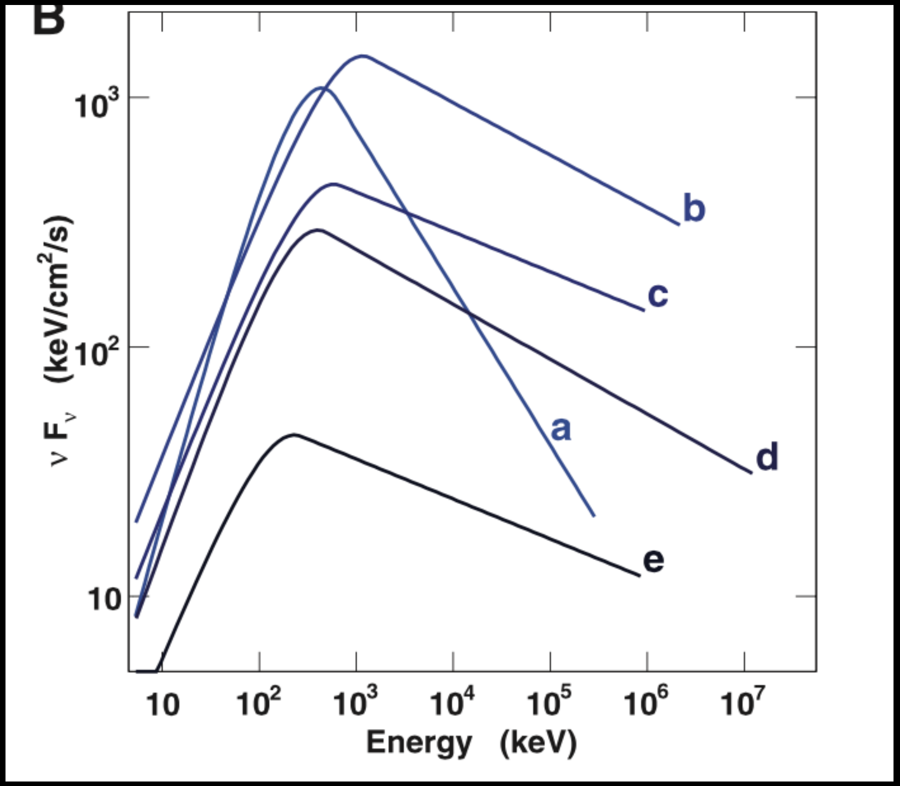
GRB 080916C



ABDO ET AL 2008

DELAYED ONSET OF HIGH-ENERGY EMISSION

PURE BAND FUNCTION



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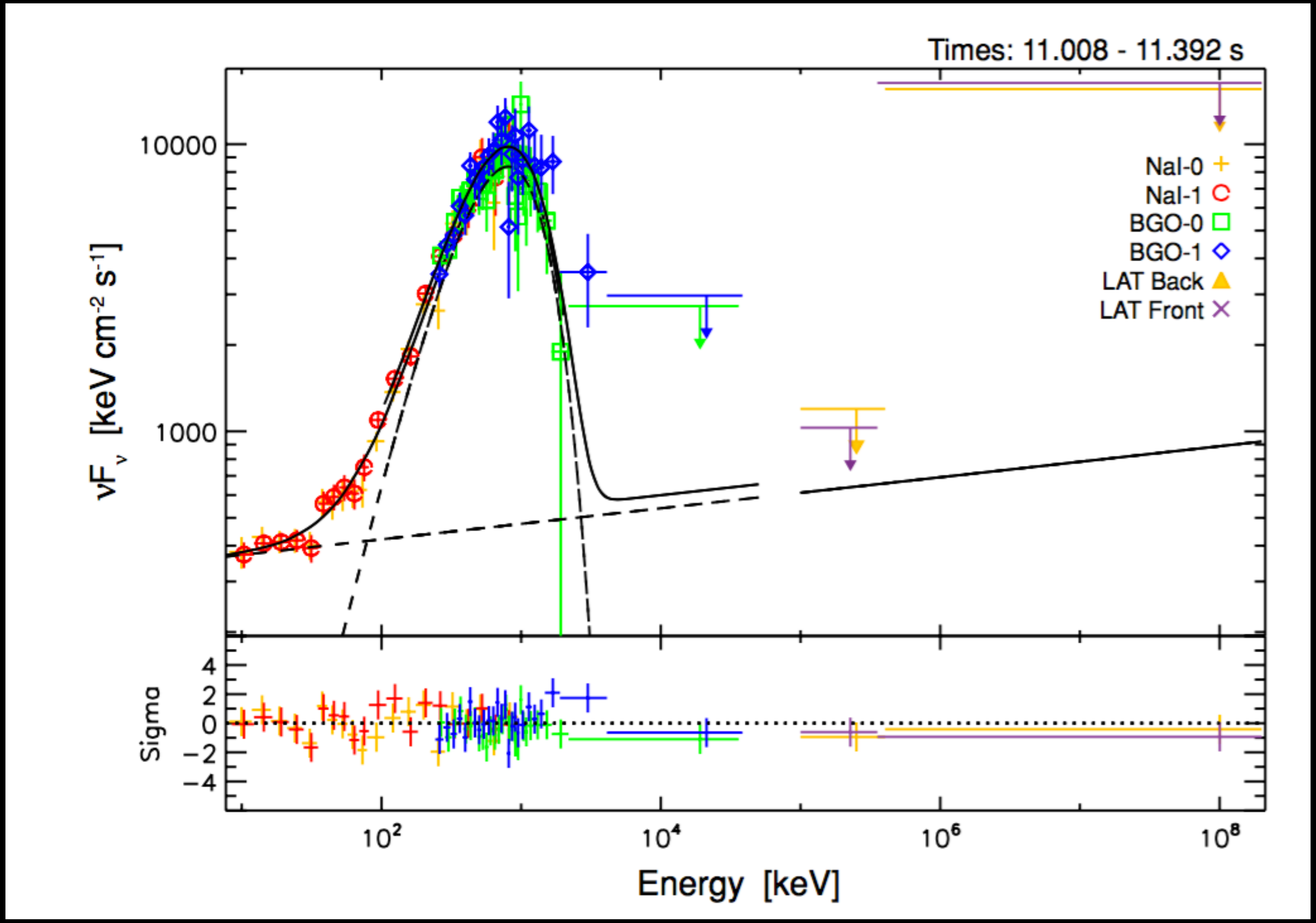
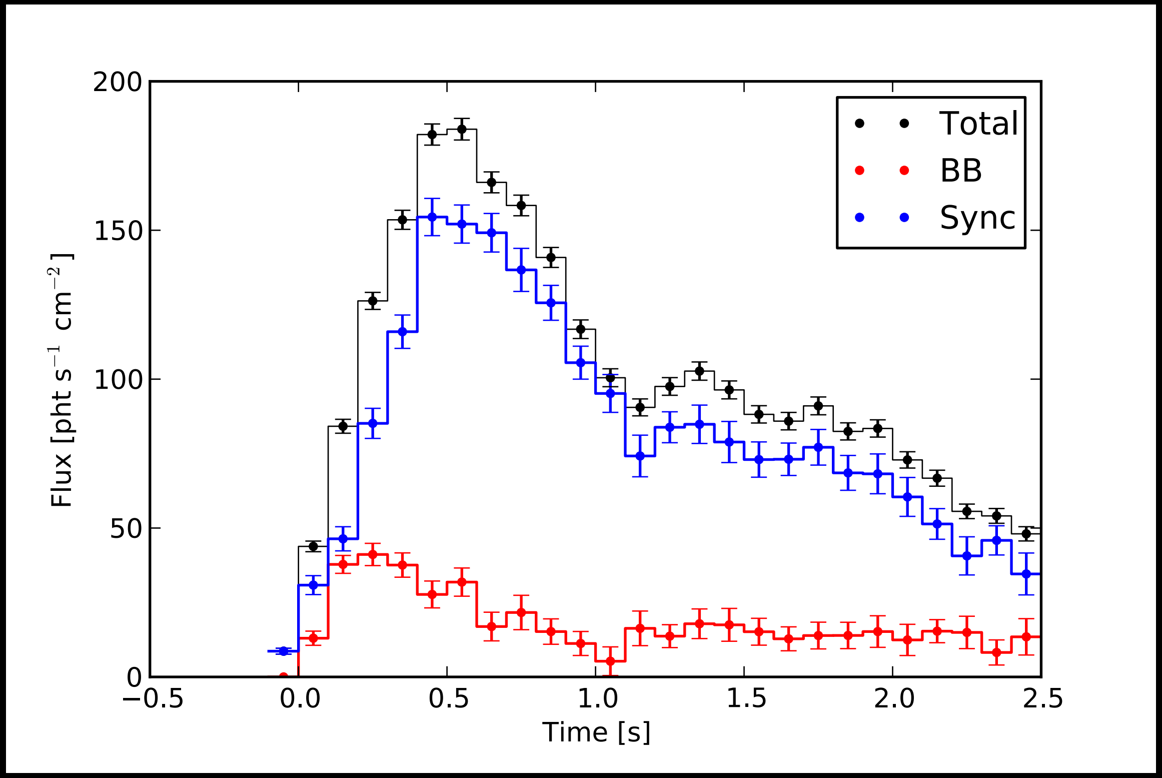


RYDE ET AL 2009

NEARLY PURE THERMAL SPECTRUM

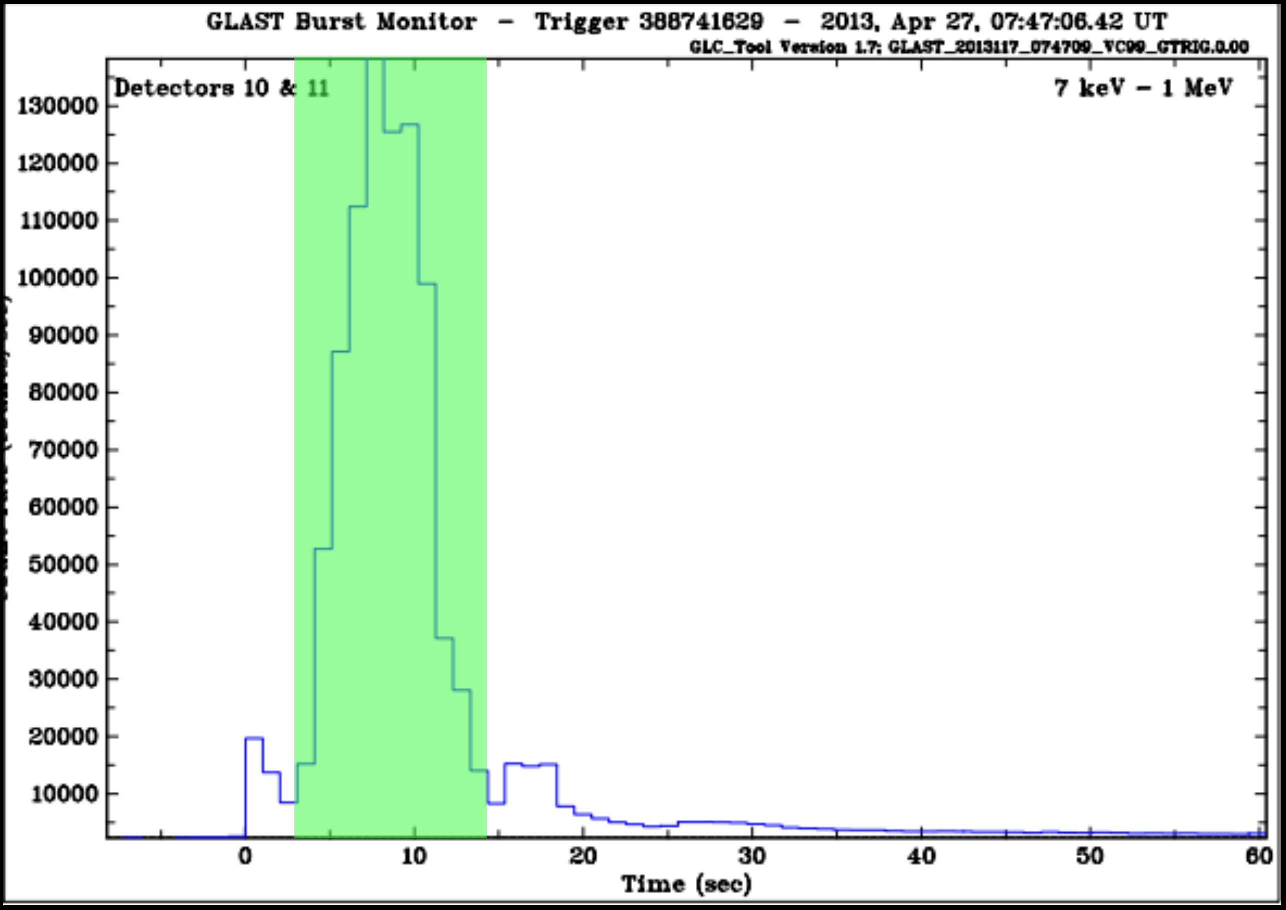
HIGH-ENERGY POWER LAW

GRB 130427A



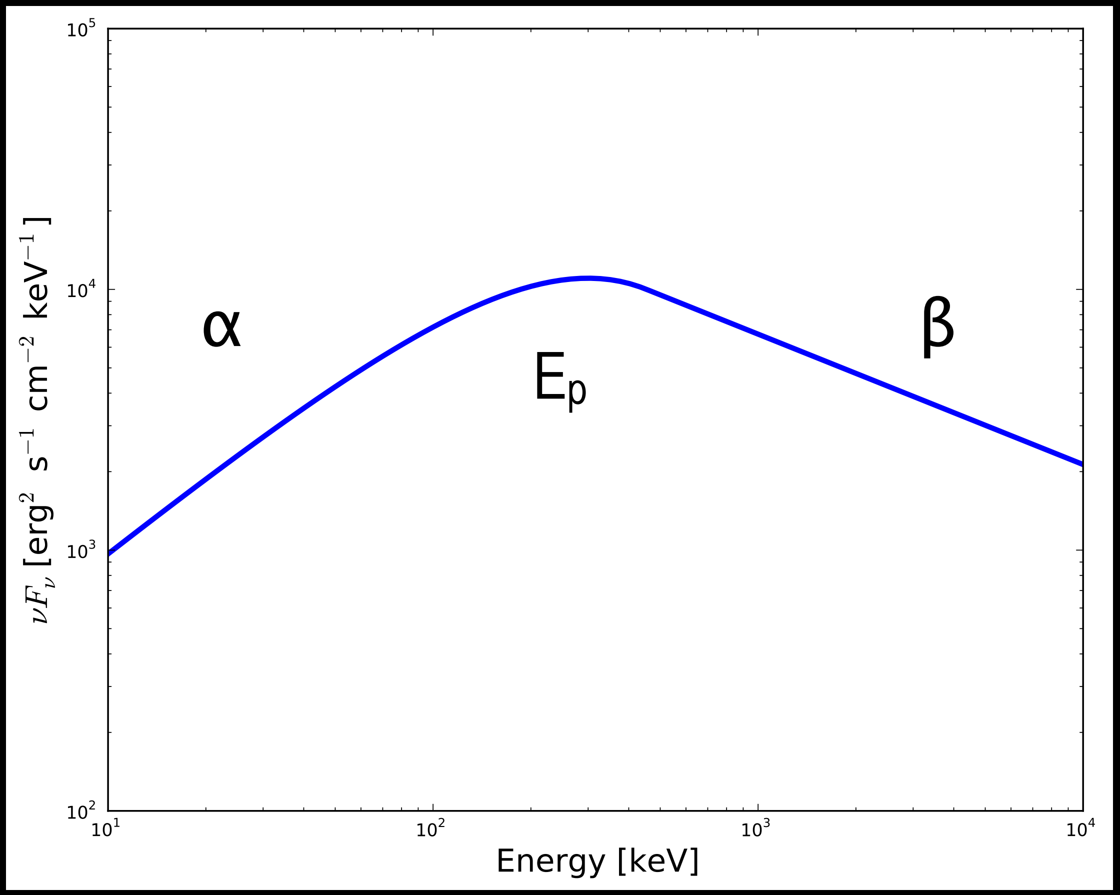
FLUENCE: $(2.4\pm0.1)\times10^{-3}$ ERG CM^{-2}
DURATION: ~35 S
MOST FLUENT GRB EVER DETECTED

FIRST PULSE: ~2.5 S
BRIGHTER THAN MOST GRBS!

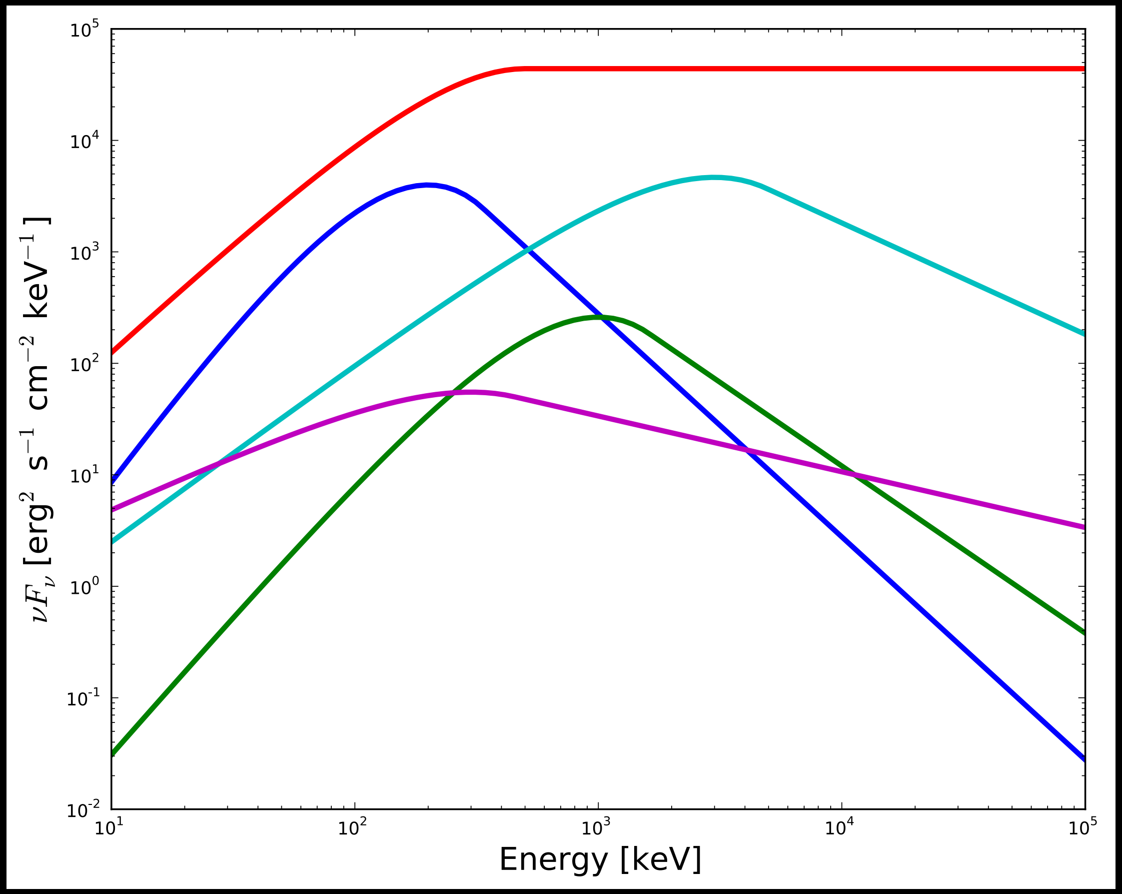


THE BAND FUNCTION

The Band function is the canonical function used to fit both time-resolved and time integrated GRB photon spectra



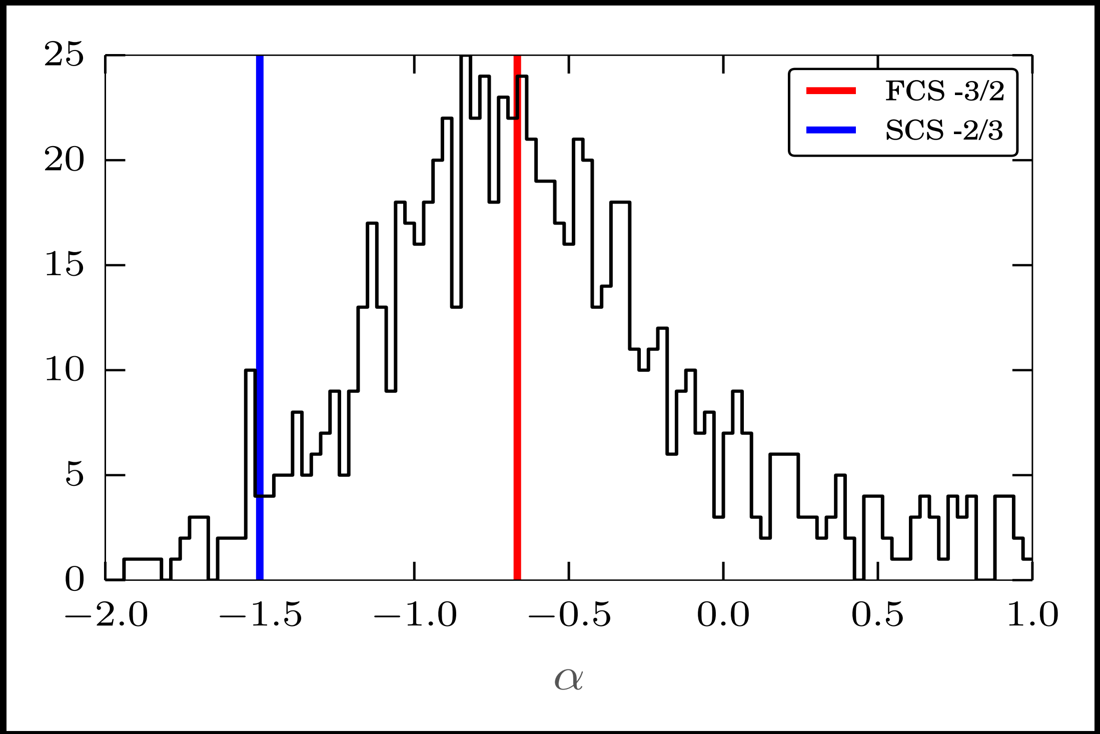
$$F_\nu(\mathcal{E}) \;=\; F_0 \begin{cases} \left(\frac{\mathcal{E}}{100\ \mathrm{keV}}\right)^{\alpha} \exp\left(-\frac{(2+\alpha)\mathcal{E}}{E_\mathrm{p}}\right), & \mathcal{E} \le (\alpha-\beta)\frac{E_\mathrm{p}}{(\alpha+2)} \\ \left(\frac{\mathcal{E}}{100\ \mathrm{keV}}\right)^{\beta} \exp(\beta-\alpha)\left[\frac{(\alpha-\beta)E_\mathrm{p}}{100\ \mathrm{keV}(2+\alpha)}\right]^{\alpha-\beta}, & \mathcal{E} > (\alpha-\beta)\frac{E_\mathrm{p}}{(\alpha+2)}\ , \end{cases}$$

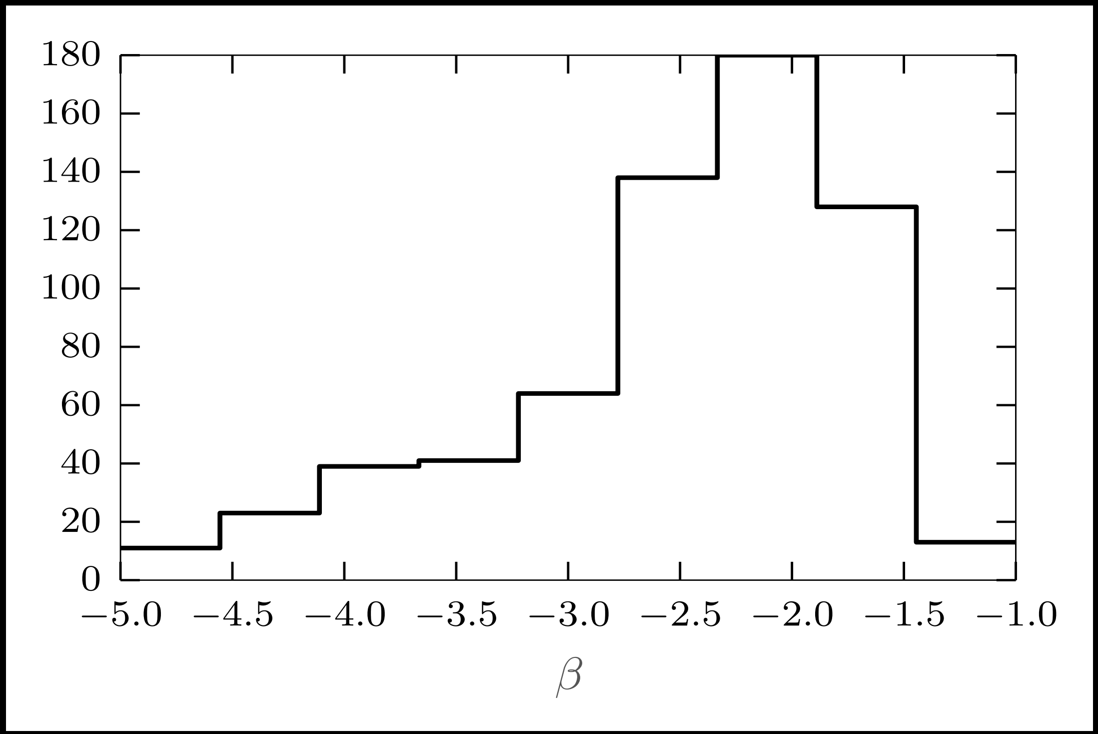


Highly flexible AND fits nearly all GRB spectra well.

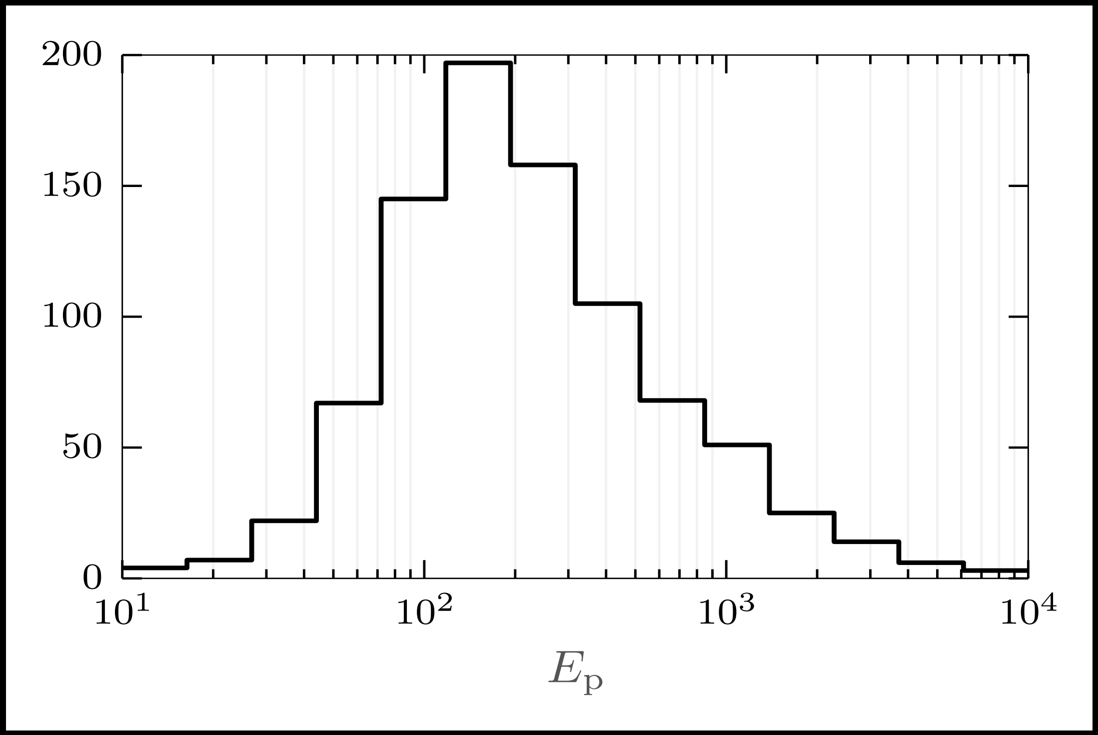
No physical basis. None, nada.

CONNECTING THE PHYSICAL TO THE EMPIRICAL



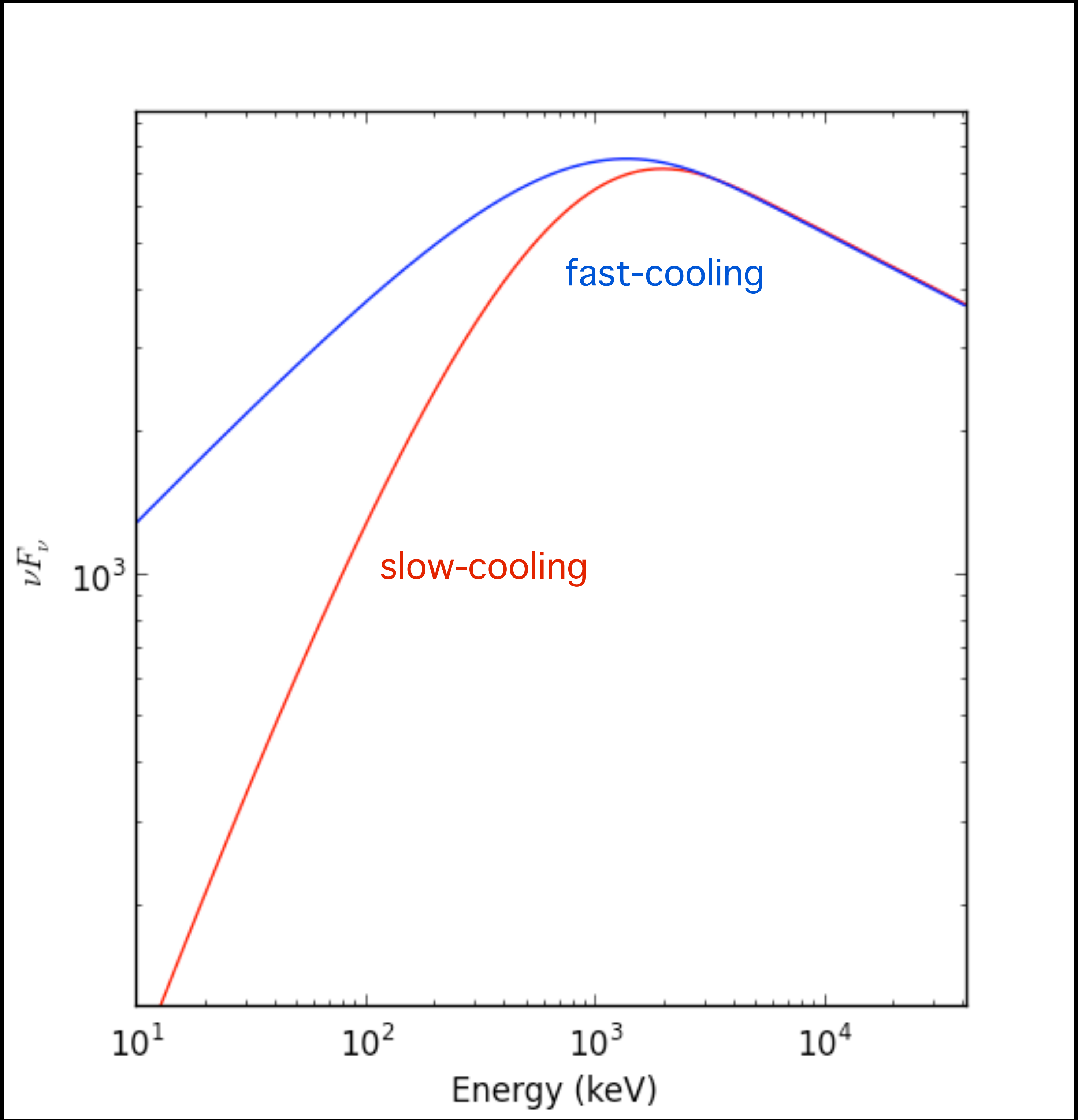


FERMI GBM SPECTRAL CATALOGS



Grouping the parameters from spectral fits to all GRBs. One can easily see characteristic features… but are they physical?

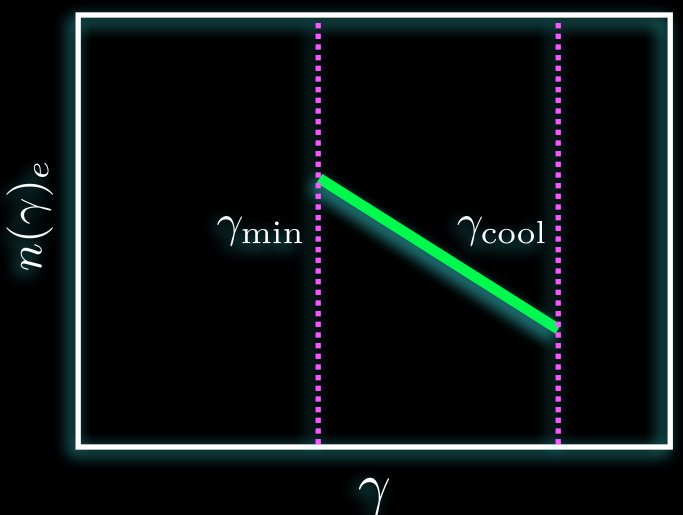
SYNCHROTRON



SYNCHROTRON

Slow cooling

$$\gamma_{\rm min} \ll \gamma_{\rm cool}$$

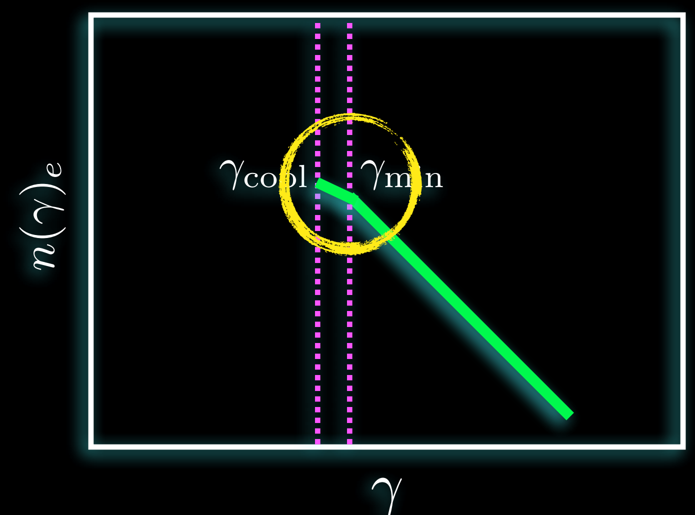


$$\alpha \simeq -2/3$$

Marginally fast cooling

$$\gamma_{\rm min} \simeq \gamma_{\rm cool}$$

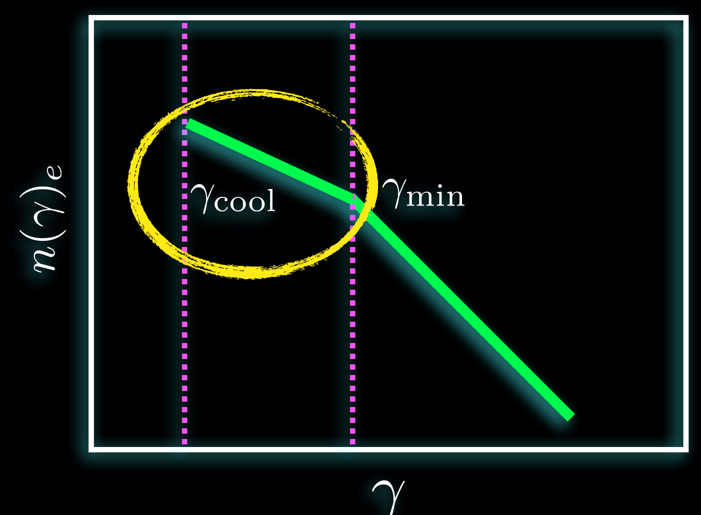
see Beniamini & Piran (2013)



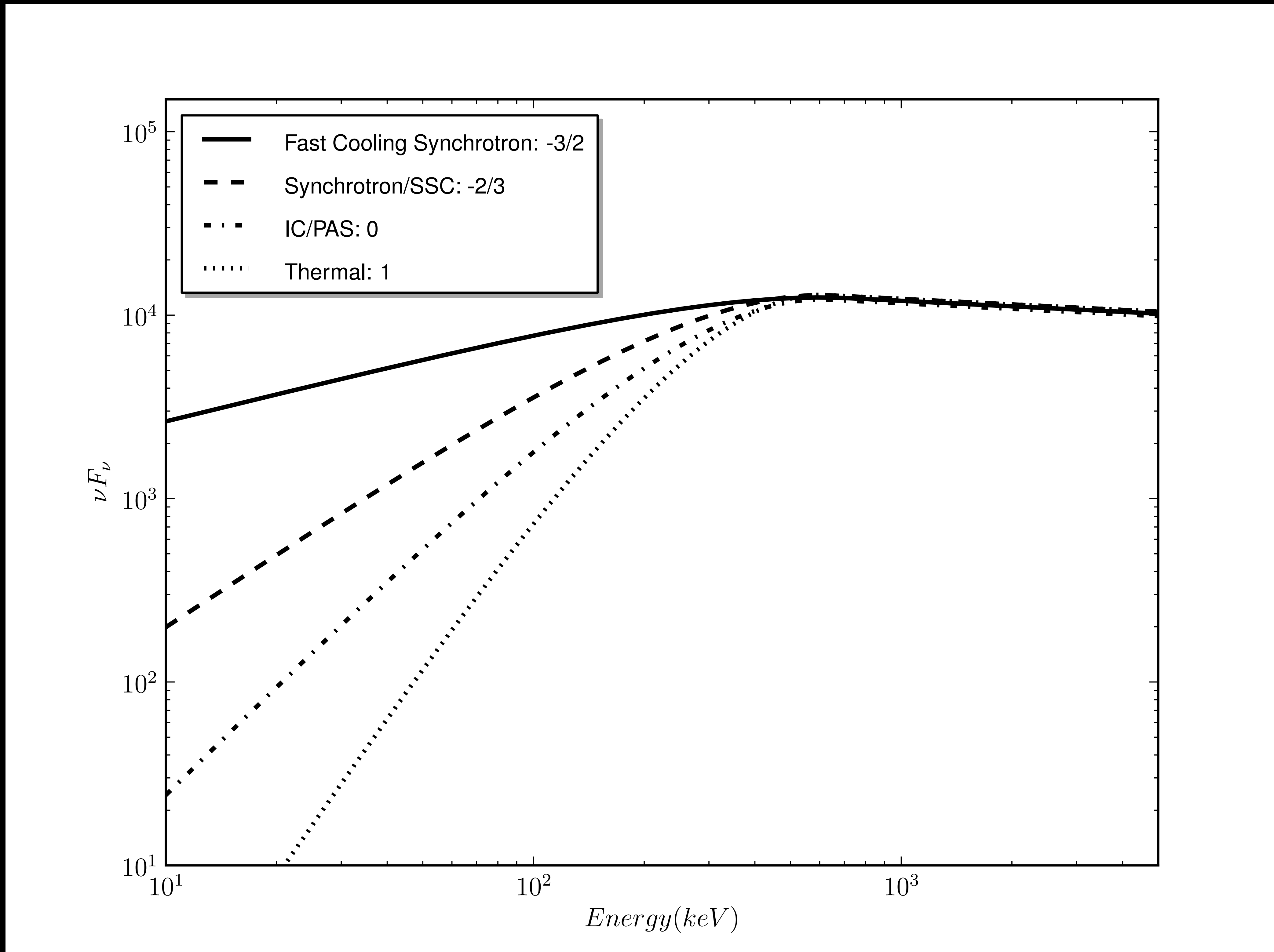
$$\alpha \simeq -2/3$$

Fast cooling

$$\gamma_{\rm cool} \ll \gamma_{\rm min}$$



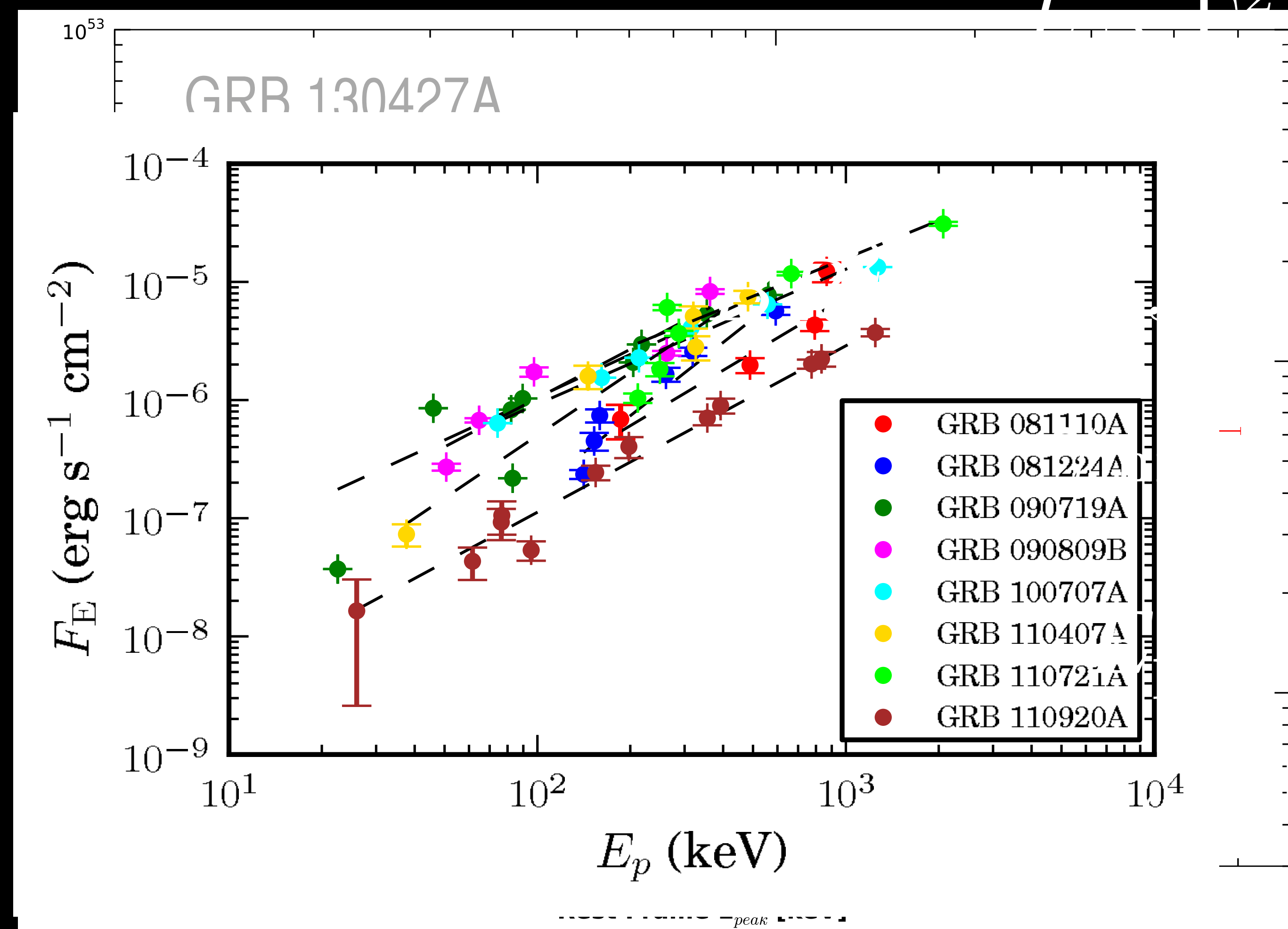
$$\alpha \simeq -3/2$$



Low-energy indices are not the best way to infer models!!

$$E_{\rm p} \propto \Gamma B \gamma_{\rm min}^2$$

$$L \propto \Gamma^2 B^2 \gamma_{\rm min}^2$$



$$\ldots nt \;\Rightarrow\; B \propto R^{-2}$$

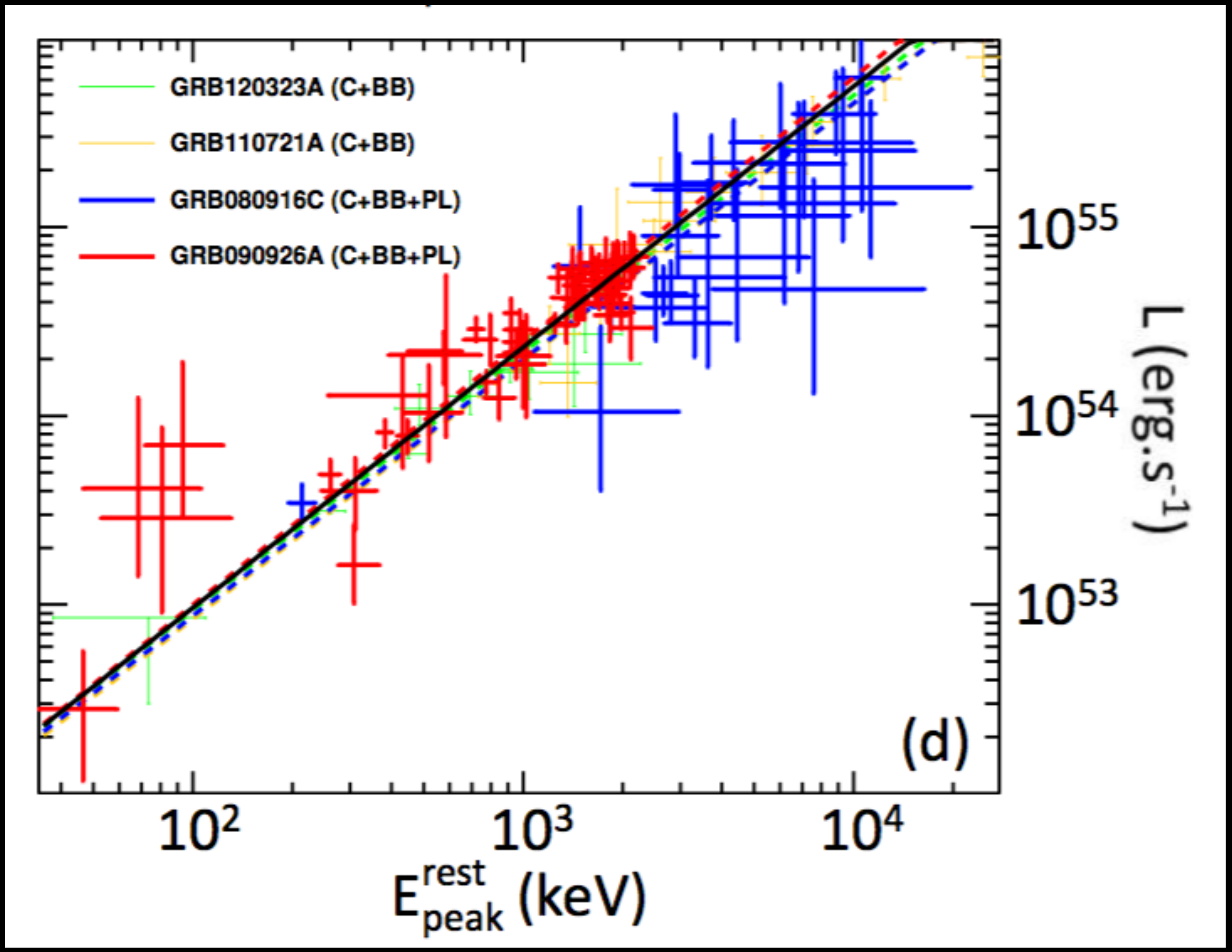
$$\ldots R^{-1}$$

$$\ldots \Gamma R^{-4}$$

$$\ldots \Gamma^2 R^{-6}$$

$$L_{\rm synch} \propto E_p^{3/2}$$

HIGH ENERGY CORRELATIONS

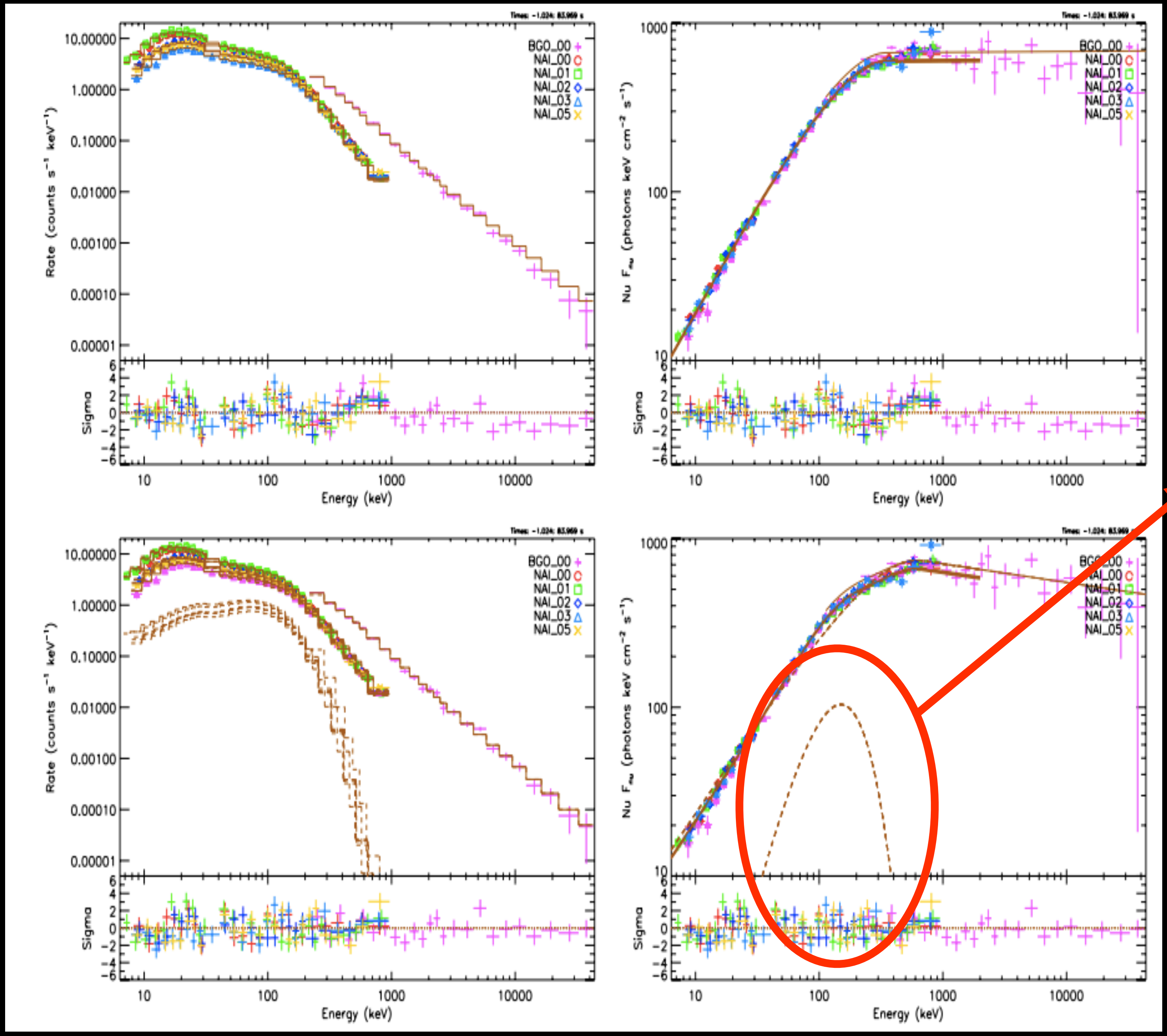


GUIRIEC ET AL 2015

Correlations can also be related to cosmology. It may be possible to use them to obtain redshifts.

HIGH ENERGY CORRELATIONS

MULTI-COMPONENT SPECTRA

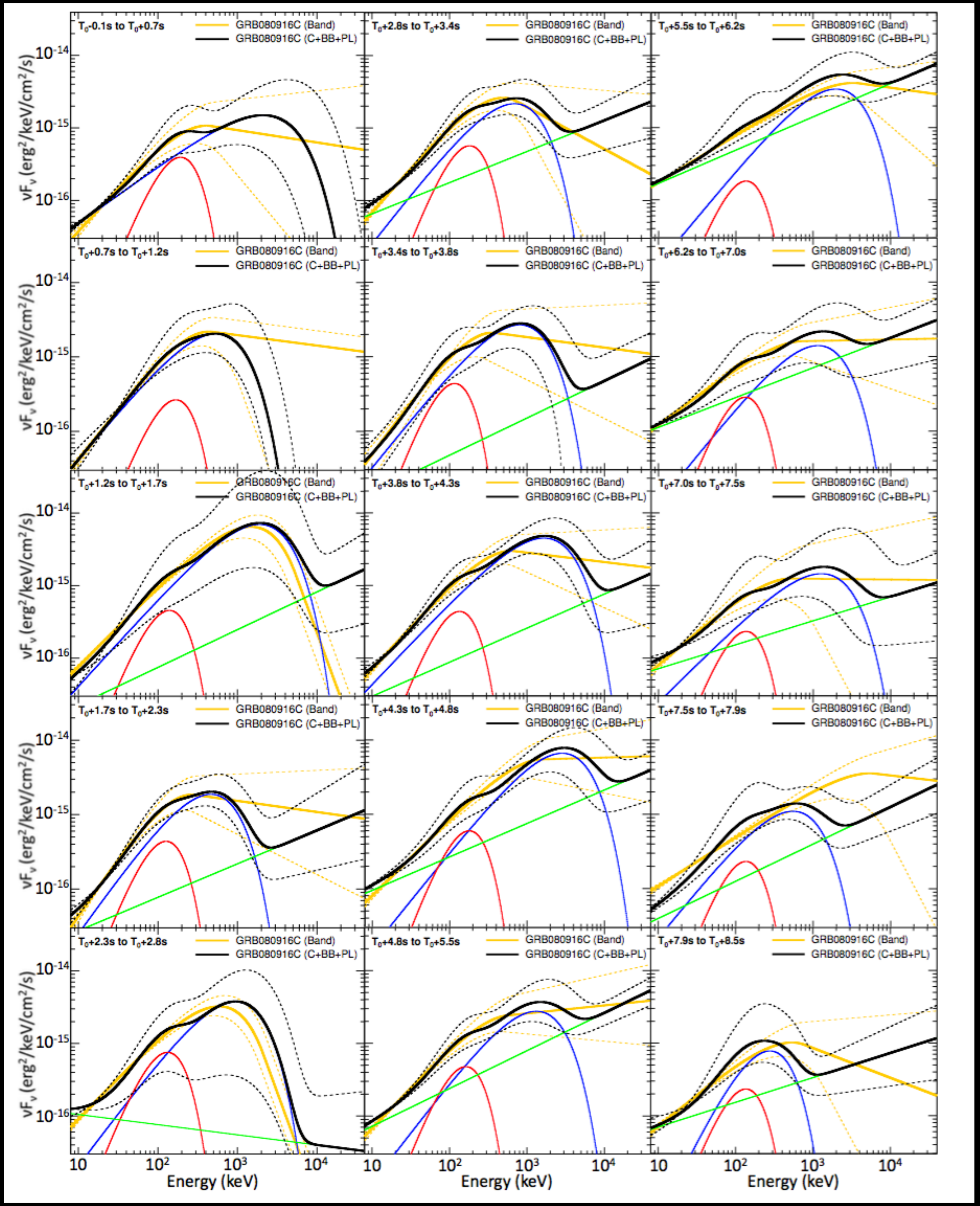


GUIRIEC ET AL 2011

In several GRBs, two emission components have been observed. One of them well modeled as a blackbody (photosphere) and the other is consistent with a Band function.

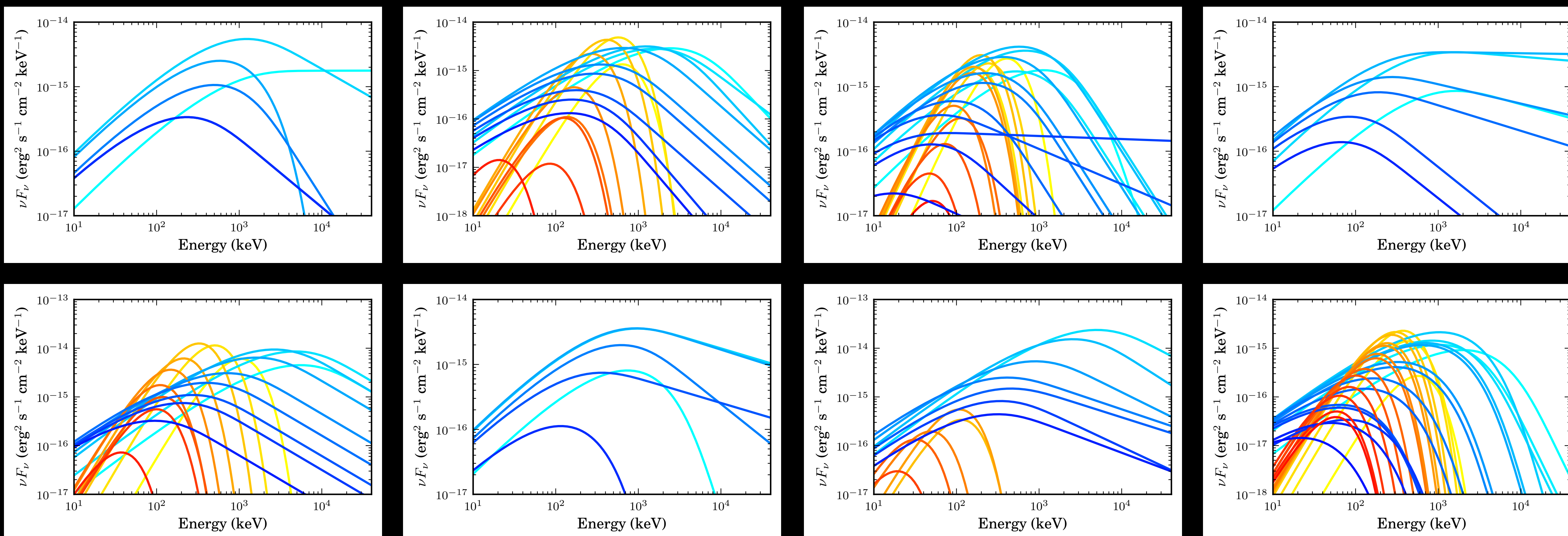
MULTI-COMPONENT SPECTRA

Even more components can be seen in some GRBs including and extra power law.



GUIRIEC ET AL 2015

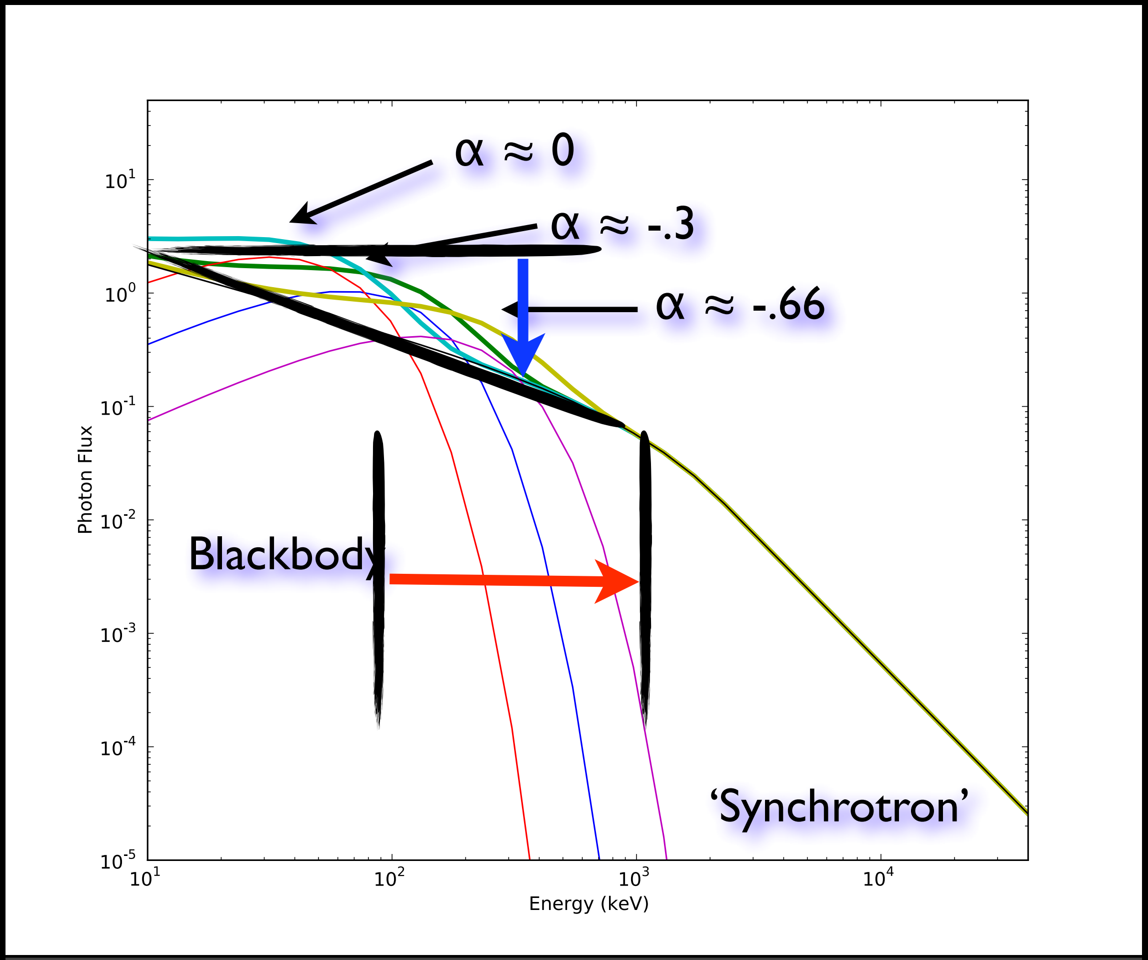
MULTI-COMPONENT SPECTRA



BURGESS ET AL 2014

MULTI-COMPONENT FITTING

Alpha typically steepens with the introduction of the blackbody making the synchrotron scenario much more plausible.



Ep is moved to higher energies instead of being forced to compensate for the vFv peak made up by the two unresolved components.

If the non-thermal emission is synchrotron and a blackbody is present, fitting with only a band function would recover an alpha as hard as ~0. Using the Band function with a blackbody can leave a lot of freedom below Ep resulting in swapping of flux between the components.

IS THE BLACKBODY REAL?

- A Poisson likelihood (Castor statistic) is used to compute the significance of the blackbody component
- The likelihood ratio test (maximum likelihood) is *not* valid for additive components that are null on the boundary.
- Must use simulations to test significance.
- We find that the blackbody is very significant (~5σ) in many cases!

The Astrophysical Journal, 571:545–559, 2002 May 20

STATISTICS, HANDLE WITH CARE: DETECTING MULTIPLE MODEL COMPONENTS WITH THE LIKELIHOOD RATIO TEST

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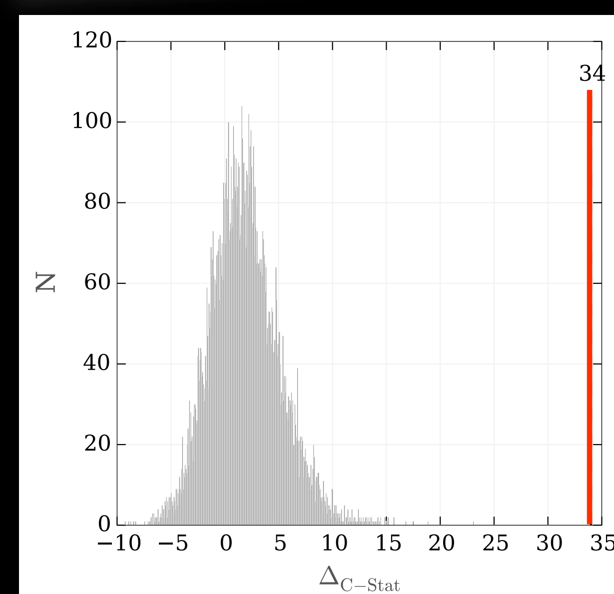
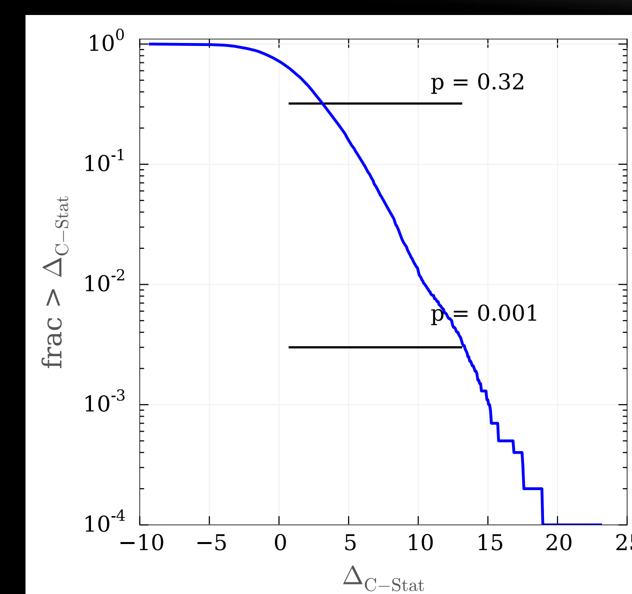
ABSTRACT

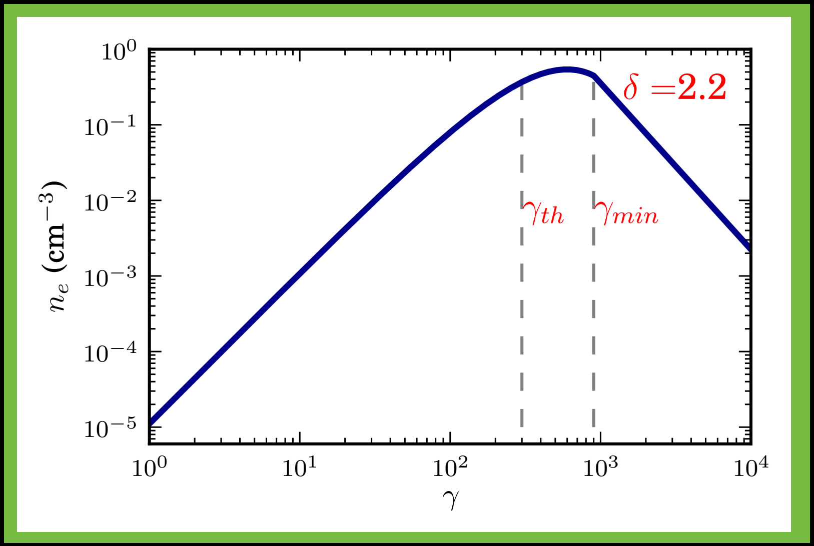
The likelihood ratio test (LRT) and the related *F*-test, popularized in astrophysics by Eadie and coworkers in 1971, Bevington in 1969, Lampton, Margon, & Bowyer, in 1976, Cash in 1979, and Avni in 1978, do not (even asymptotically) adhere to their nominal χ^2 and *F*-distributions in many statistical tests common in astrophysics, thereby casting many marginal line or source detections and nondetections into doubt. Although the above authors illustrate the many legitimate uses of these statistics, in some important cases it can be impossible to compute the correct false positive rate. For example, it has become common practice to use the LRT or the *F*-test to detect a line in a spectral model or a source above background despite the lack of certain required regularity conditions. (These applications were not originally suggested by Cash or by Bevington.) In these and other settings that involve testing a hypothesis that is on the boundary of the parameter space, *contrary to common practice, the nominal* χ^2 *distribution for the LRT or the F-distribution for the F-test should not be used.* In this paper, we characterize an important class of problems in which the LRT and the *F*-test fail and illustrate this nonstandard behavior. We briefly sketch several possible acceptable alternatives, focusing on Bayesian posterior predictive probability values. We present this method in some detail since it is a simple, robust, and intuitive approach. This alternative method is illustrated using the gamma-ray burst of 1997 May 8 (GRB 970508) to investigate the presence of an Fe K emission line during the initial phase of the observation. There are many legitimate uses of the LRT and the *F*-test in astrophysics, and even when these tests are inappropriate, there remain several statistical alternatives (e.g., judicious use of error bars and Bayes factors). Nevertheless, there are numerous cases of the inappropriate use of the LRT and similar tests in the literature, bringing substantive scientific results into question.

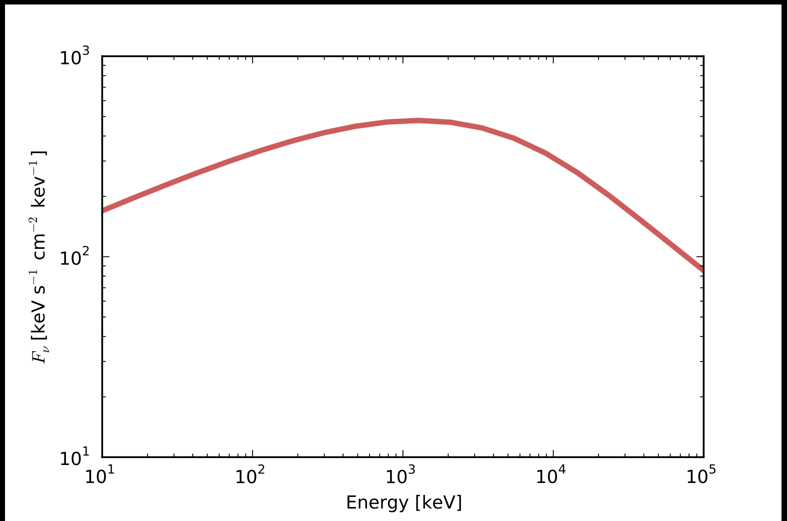
Subject heading: methods: statistical





BUILDING A PHYSICAL MODEL





$$F_\nu(\mathcal{E}) = \int_1^\infty \mathrm{d}\gamma\, n_e(\gamma) \mathcal{F}\left(\frac{\mathcal{E}}{\mathcal{E}_c(\gamma)}\right)$$

$$\mathcal{F}(w) = w \int_w^\infty K_{5/3}(x)\, dx$$

$$\mathcal{E}_c \equiv \gamma^2 \frac{3q\hbar B \sin\alpha}{2m_e c}$$

$$\dot{\gamma} = -\frac{2}{3}\frac{r_0 c}{r_g^2}\gamma^2 \sin^2\theta$$

Compute synchrotron emission via first principles. Kernel is convolved with a variable electron distribution in real time.

BUILDING A PHYSICAL MODEL

- SYNCHROTRON COOLING:
  - INJECTED POWER-LAW E-:

$$Q_e(\gamma) \;=\; q_e(\delta-1)\gamma_{min}^{(\delta-1)}\gamma^{-\delta}\;,\;\gamma_{min}\leq\gamma$$

- CONTINUITY EQUATION:

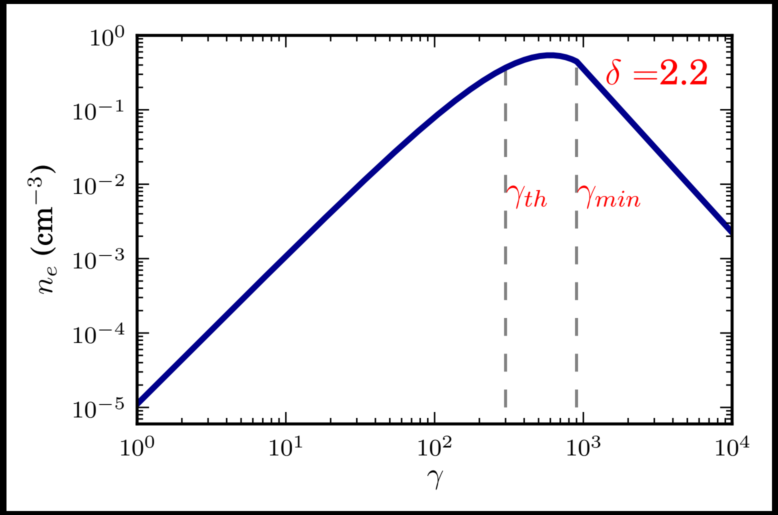
$$\frac{\partial n_e(\gamma,t)}{\partial t}+\frac{\partial}{\partial\gamma}[\dot{\gamma}n_e(\gamma,t)]+\frac{n_e(\gamma,t)}{t_{esc}} \;=\; Q_e(\gamma)$$

- SYNCHROTRON COOLING RATE:

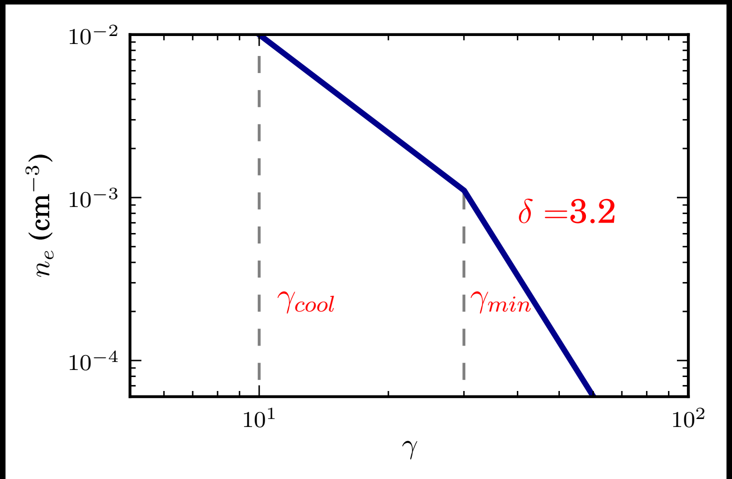
$$\dot{\gamma} \;=\; -\frac{2}{3}\frac{r_0 c}{r_g^2}\gamma^2\sin^2\theta$$

- RADIATIVE TIME SCALE << DYNAMIC TIME SCALE

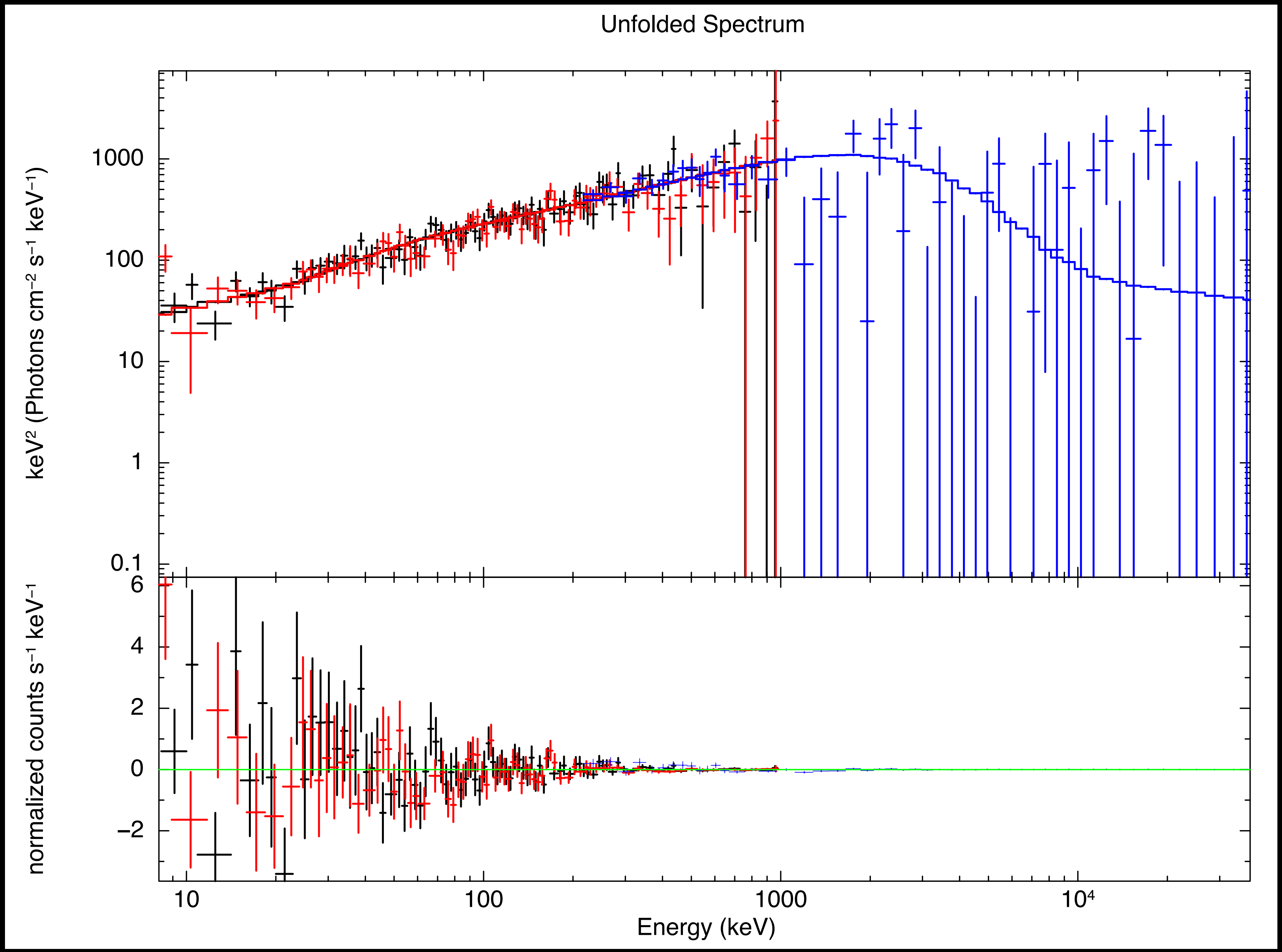
$$n_e(\gamma,t)\;\approx\;\frac{1}{\dot{\gamma}}\int_{\gamma}^{\infty}Q_e(\gamma')d\gamma'$$



$$n_e^{cool}\;\propto\;\frac{q_e\gamma_{min}}{\gamma^2}\;\min\left\{\left(\frac{\gamma}{\gamma_{min}}\right)^{-(\delta-1)},1\right\}\;,\;\gamma_{cool}\leq\gamma$$



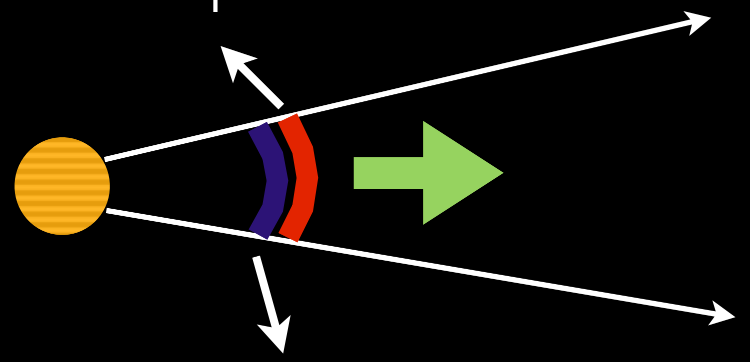
RETURN TO SUBPHOTOSPHERIC DISSIPATION



AHLGREN IN PREP.

Beginning to fit physical subphotospheric dissipation models to data.

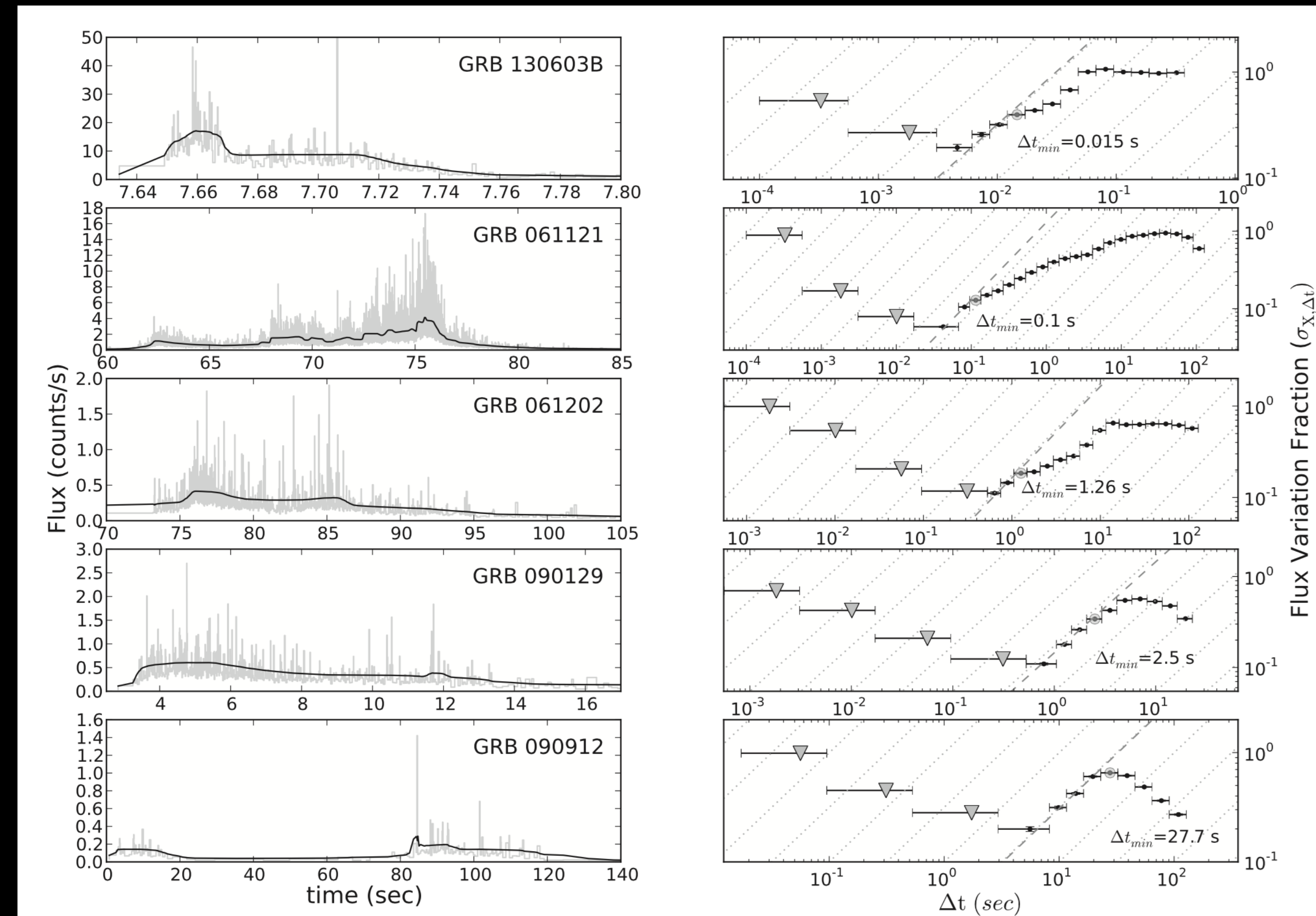
However, currently both models can fit the data

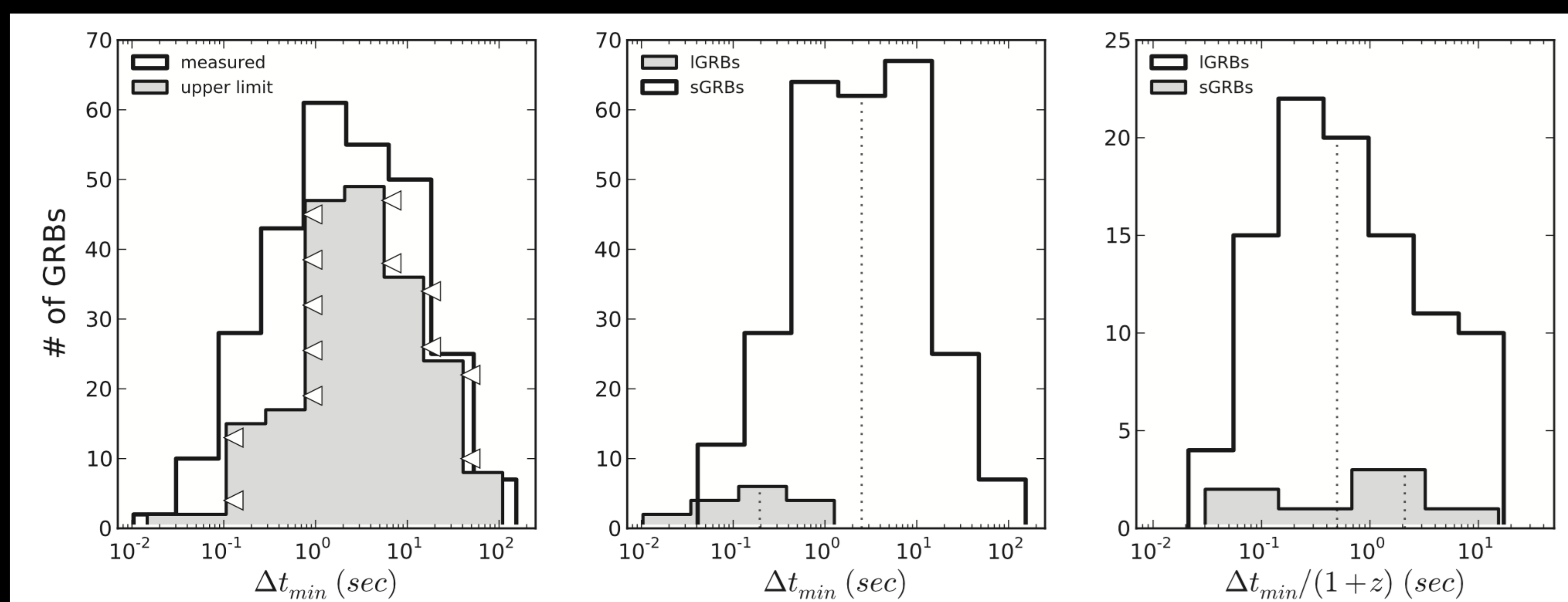


VARIABILITY

GOLKHOU & BUTLER 2015

Variability provides clues to central engine activity as well has source size. Provides constraints on several aspects of GRB physics.



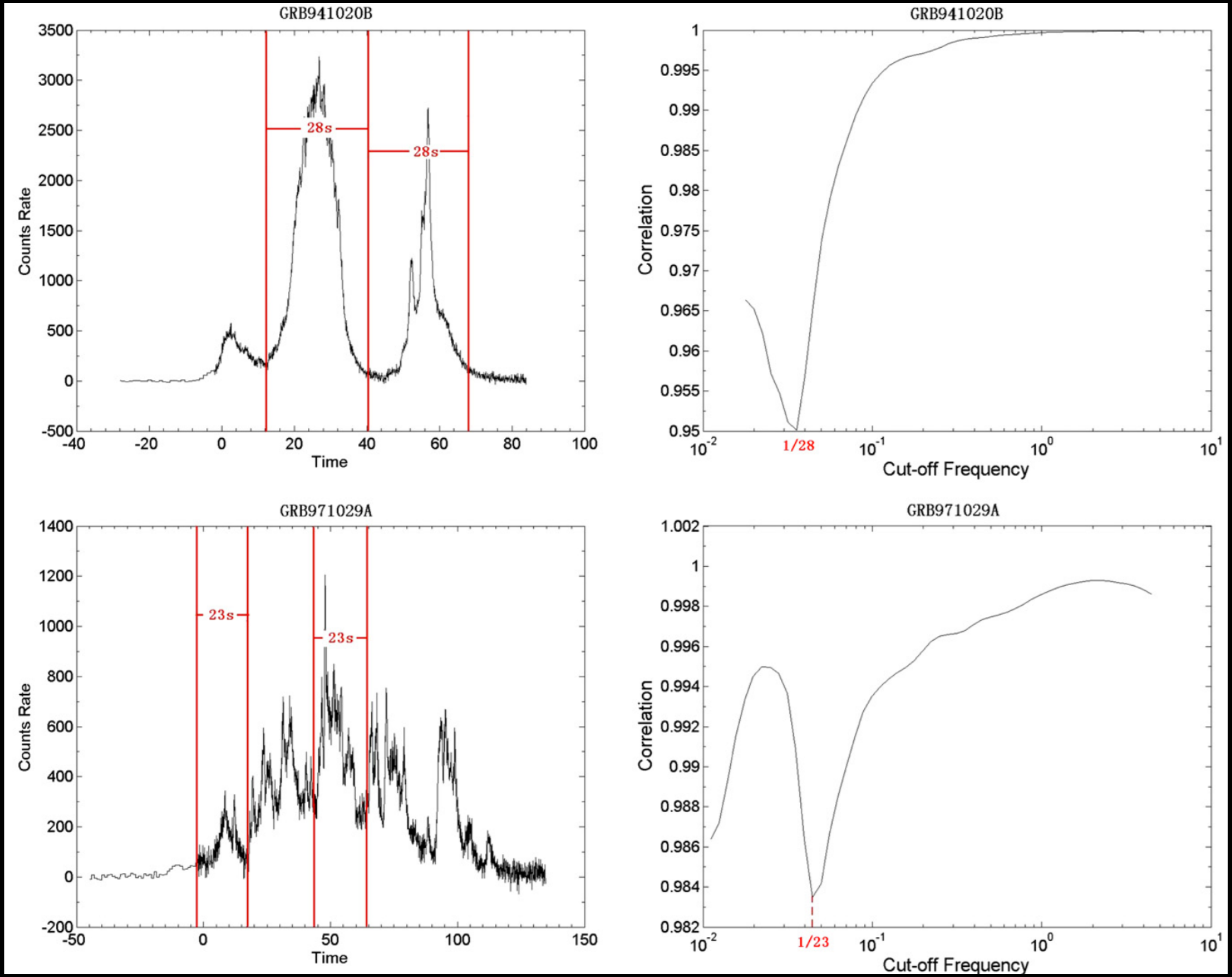


VARIABILITY

Several methods to measure variability.

Difficult to decide which method to use and what the values mean.

GAO ET AL 2012



SUMMARY

- Things to explore
  - Spectral shapes and physical models: What is the correct spectrum?
  - Spectral/Flux correlations: What do these tell us about the intrinsic GRB physics? Can they inform us about cosmology?
  - Variability: What is the best way to measure variability? What does it tell us about the source?