Spectral and Temporal Properties of Pre-Fermi GRBs

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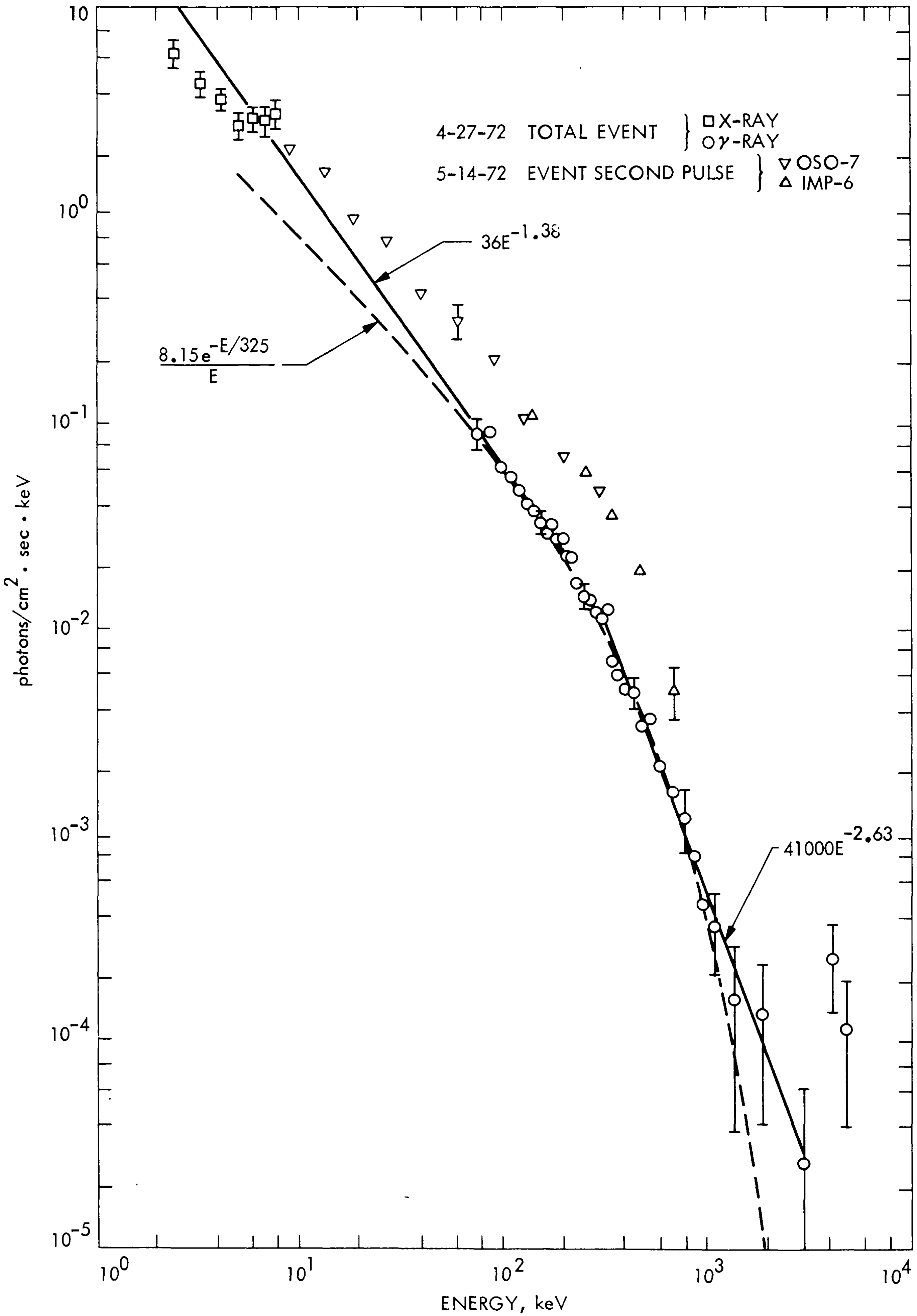
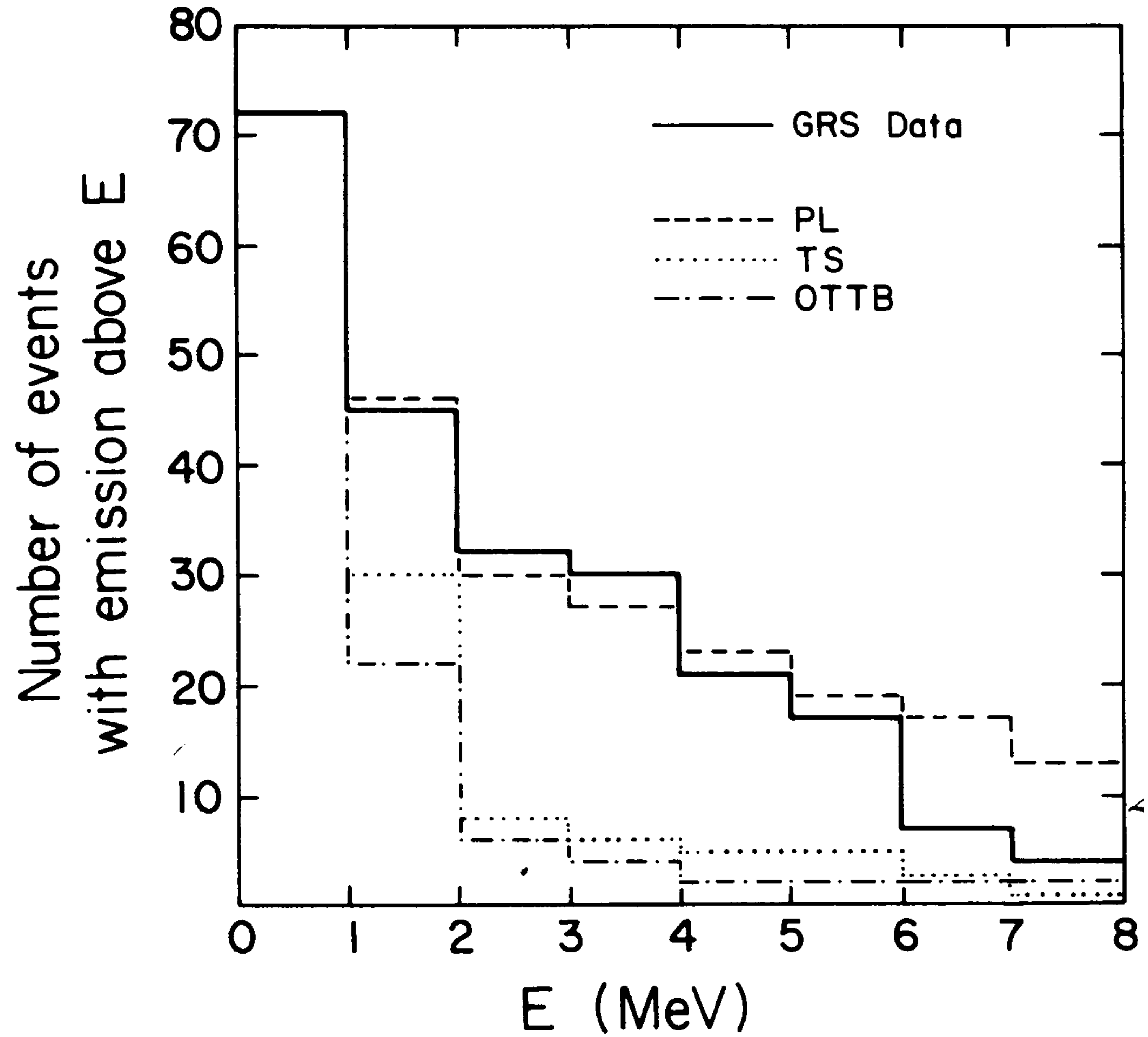
Early Days

- Observations by two instruments aboard Apollo 16 Service Module suggested a broken power law over 3 decades in energy (Metzger et al. 1974)
- Venera 11 & 12 observed GRBs to have OTTB spectra (with possible line features) (Mazets et al. 1981)
- Insufficient counts at the highest energies limit the ability to fully determine HE behavior



More Early Days

- High energy emission (> 1 MeV) was firmly established by HEAO-1 and the GRS aboard SSM (Matz et al. 1985)
  - Here, the number of GRBs, assuming OTTB or thermal synchrotron spectra, under-predicts the observation
  - A strict power law extrapolation also doesn't fit, at the highest energies, suggesting a break

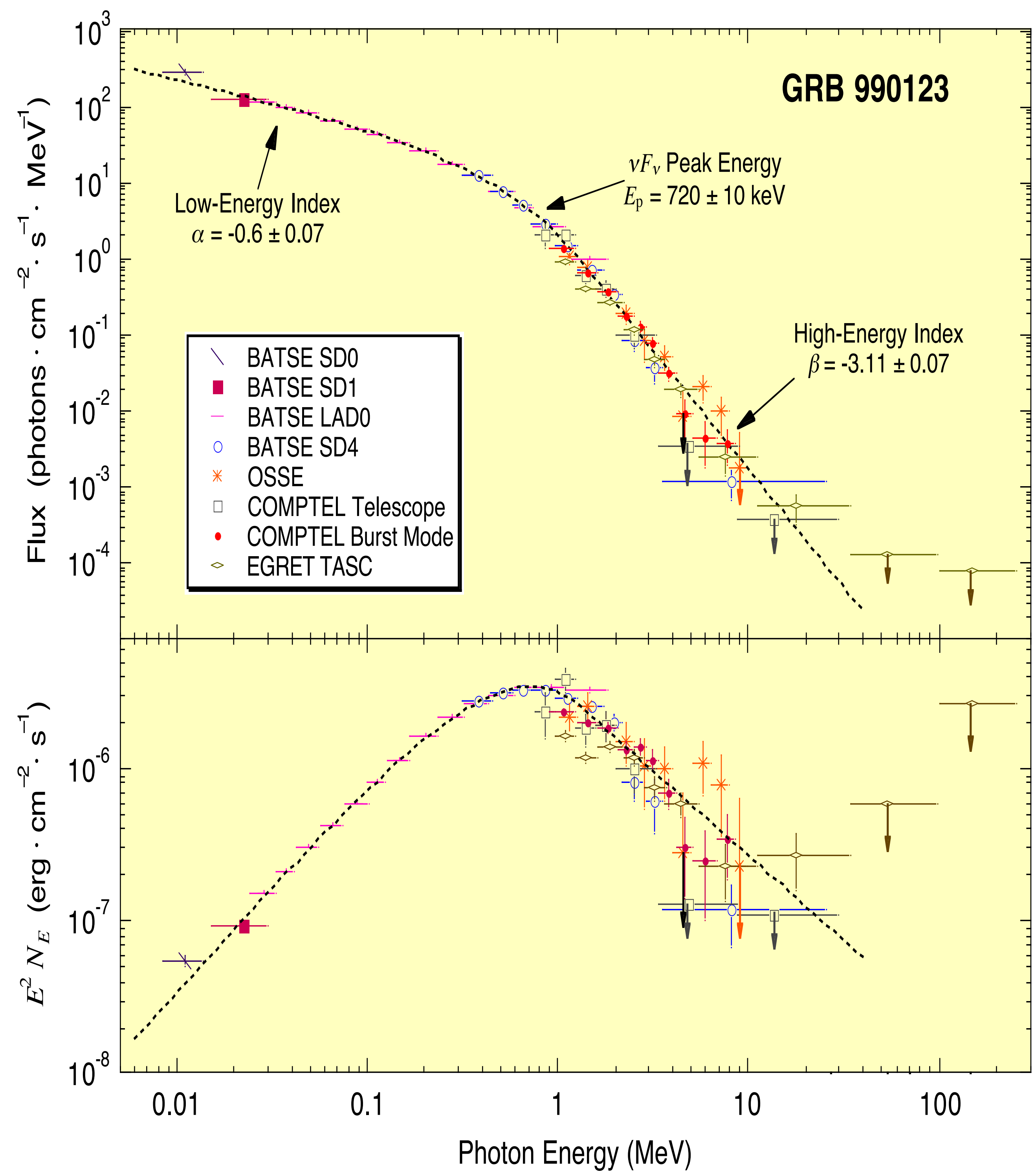


Band '93

- Unique function that joins two power laws with continuous 1st derivative
- Although it is completely empirical, it can mimic OTTB, OT synchrotron & BB, each in the appropriate limit
- Usually parametrized in terms of the energy at the peak of the PD distribution: E_{peak}
  - This definition requires that HE PL index $\beta < -2$

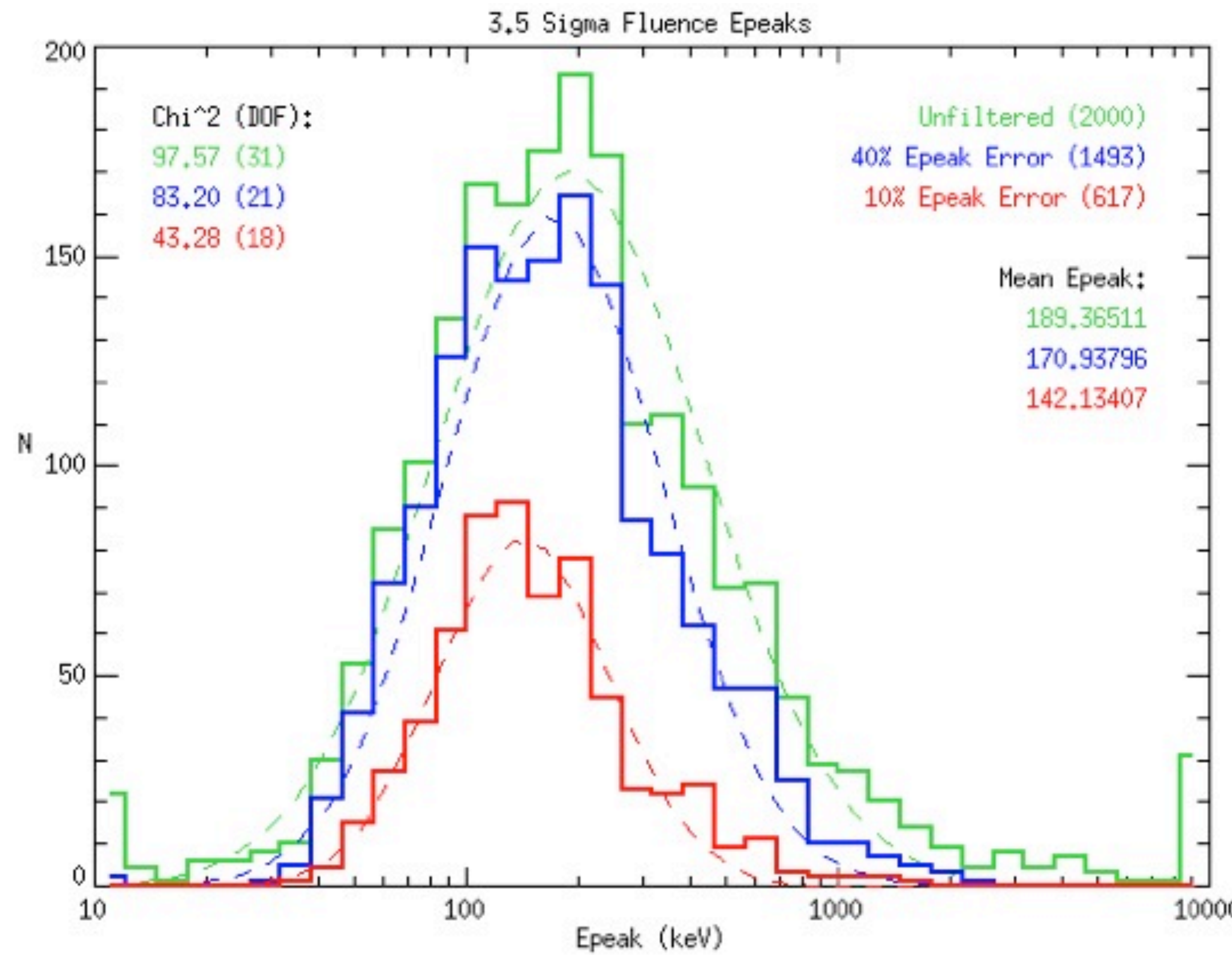
$$
f(E) = \begin{cases} A(E/100)^{\alpha} e^{-E(2+\alpha)/E_{\mathrm{peak}}} \\ \quad \text{if } E < \dfrac{(\alpha-\beta)E_{\mathrm{peak}}}{(2+\alpha)} \equiv E_{\mathrm{break}} \,, \\ A\left[\dfrac{(\alpha-\beta)E_{\mathrm{peak}}}{100(2+\alpha)}\right]^{(\alpha-\beta)} \exp(\beta-\alpha)(E/100)^{\beta} \\ \quad \text{if } E \geq \dfrac{(\alpha-\beta)E_{\mathrm{peak}}}{(2+\alpha)} \,. \end{cases}
$$

Briggs et al. 1999



BATSE: Full Sample

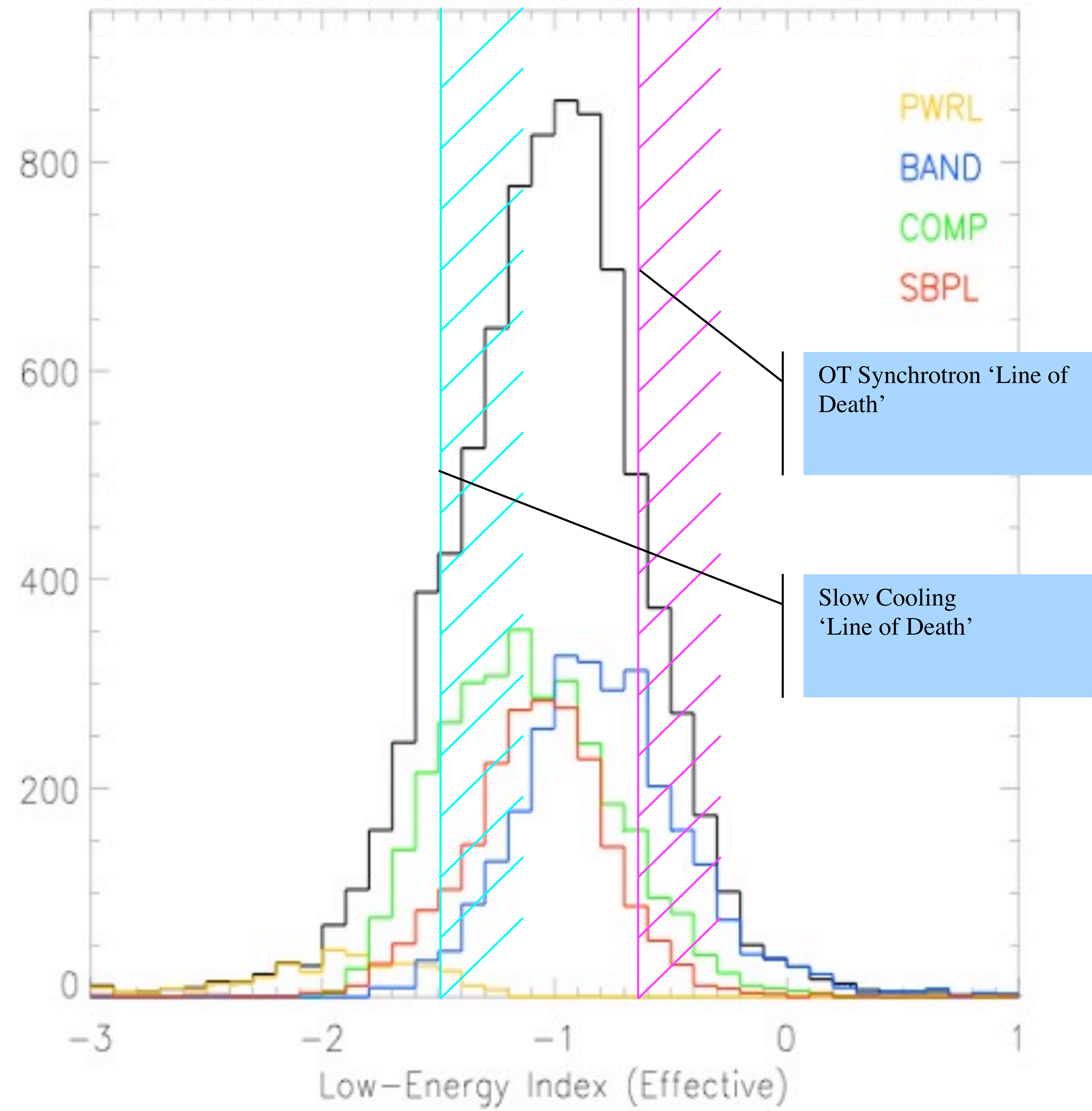
- E_{peak} distribution is narrow (FWHM ~ 1 decade in energy)
    - Although a few very hard and very soft bursts exist, the predominant fitted values cluster near 200 keV
    - Hard to soft evolution during a pulse may tend to pick out the median values
    - Inclusion of weaker bursts adds events on the high energy side



Goldstein et al. 2013 - sub.

BATSE Bright Bursts

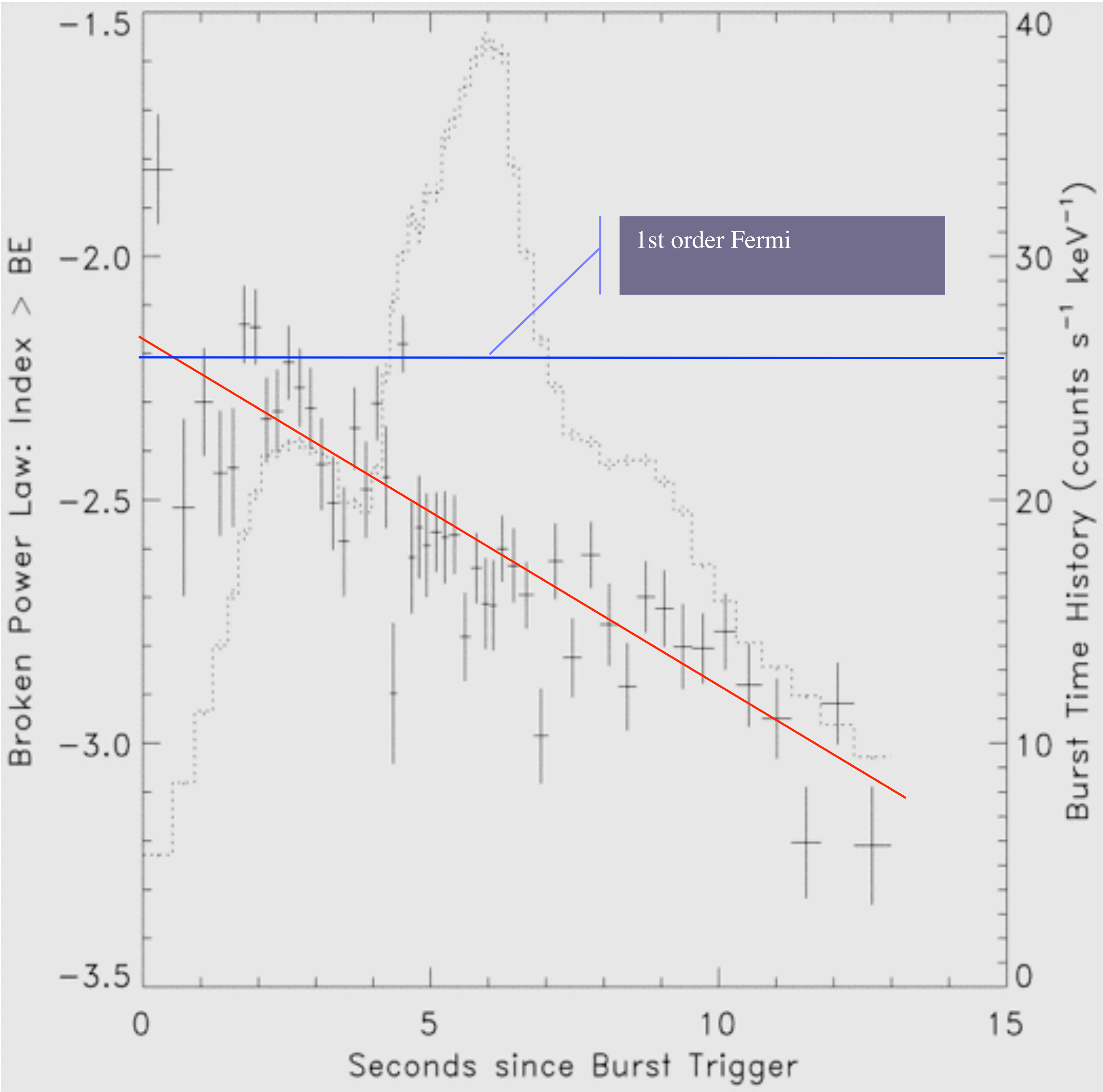
- If α is a proxy for the low energy PL behavior of synchrotron, the distribution contains many that violate both 'lines of death' (Preece et al. 1998; Cohen et al. 1997)



Kaneko et al. 2005

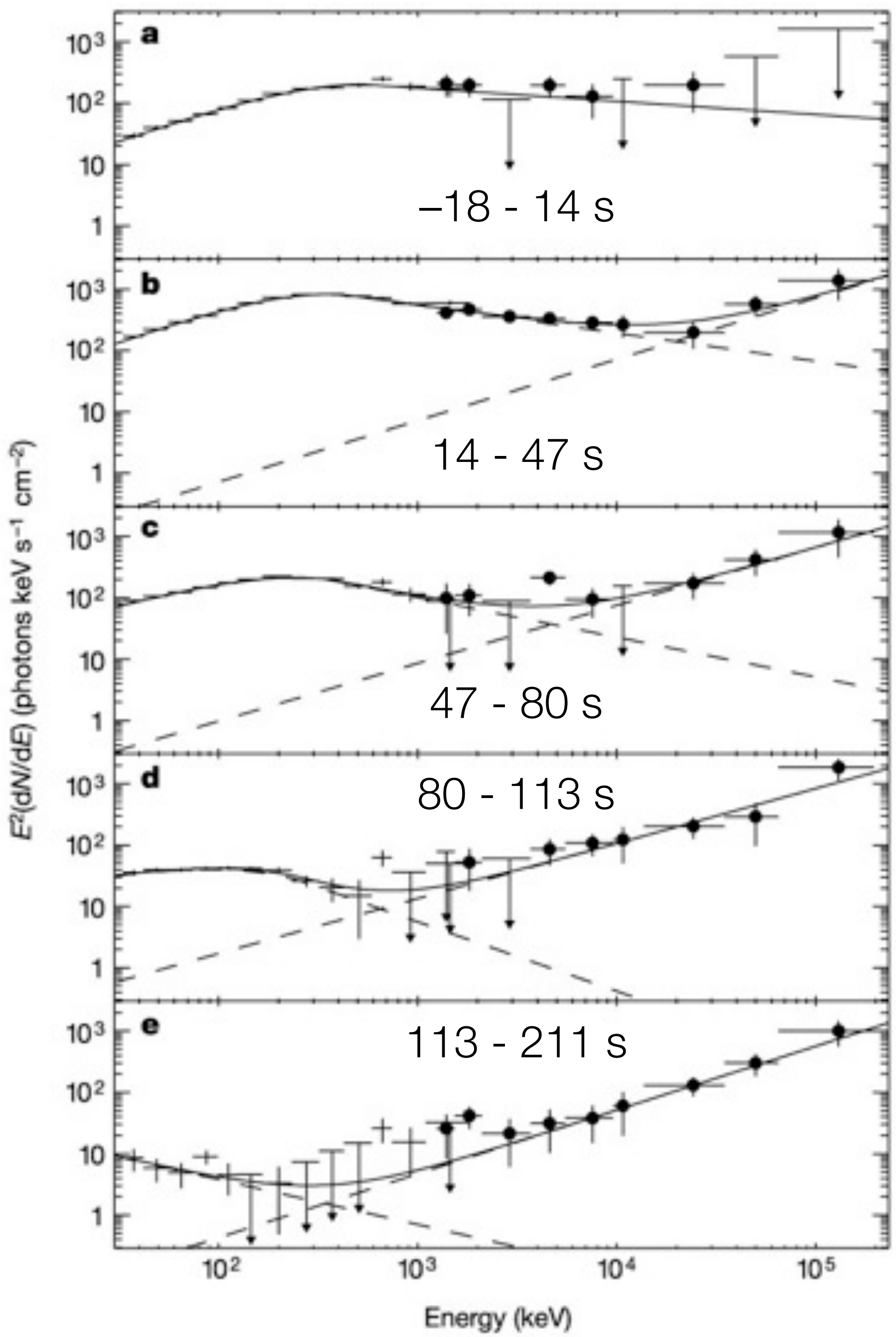
Fermi Acceleration?

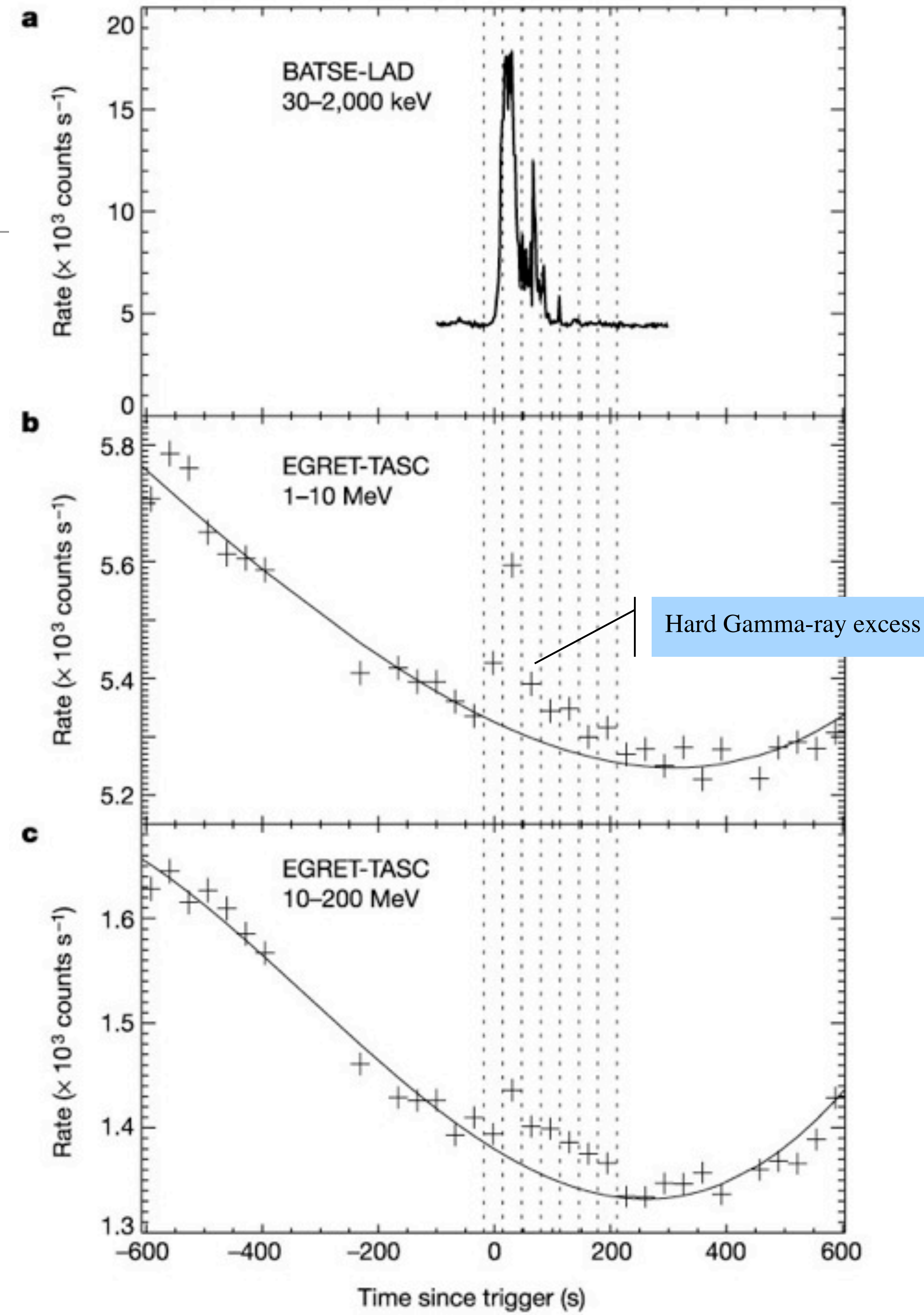
- Relativistic shock simulations tend to show universal PL acceleration for the electrons, ~ –2.4
    - Assuming that the photon spectrum reflects this, we expect HE PL index to be constant at –2.2
    - Typically, the HE PL index changes by –0.6 over the burst duration (Preece et al. 98b)



Hints of More Structure

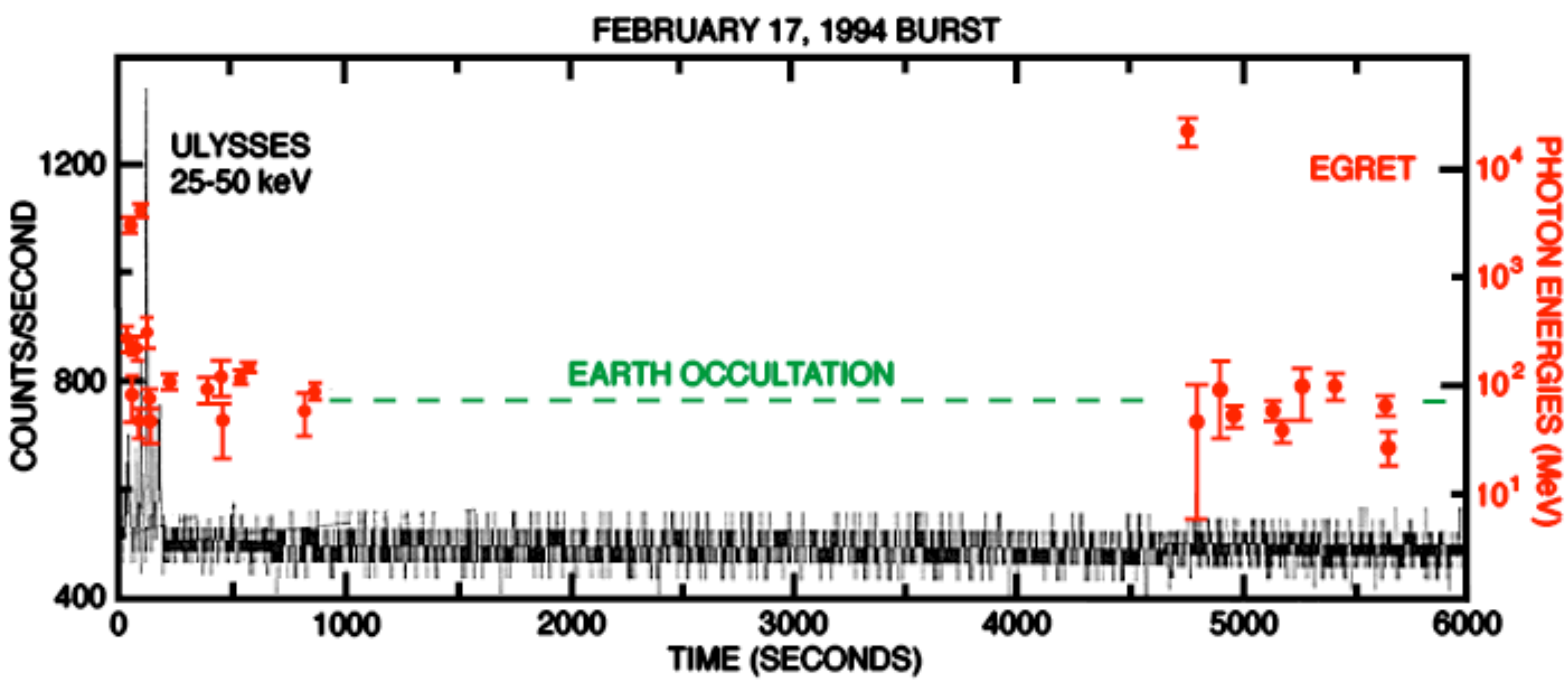
- GRB 941017: Gonzalez et al. (2003)





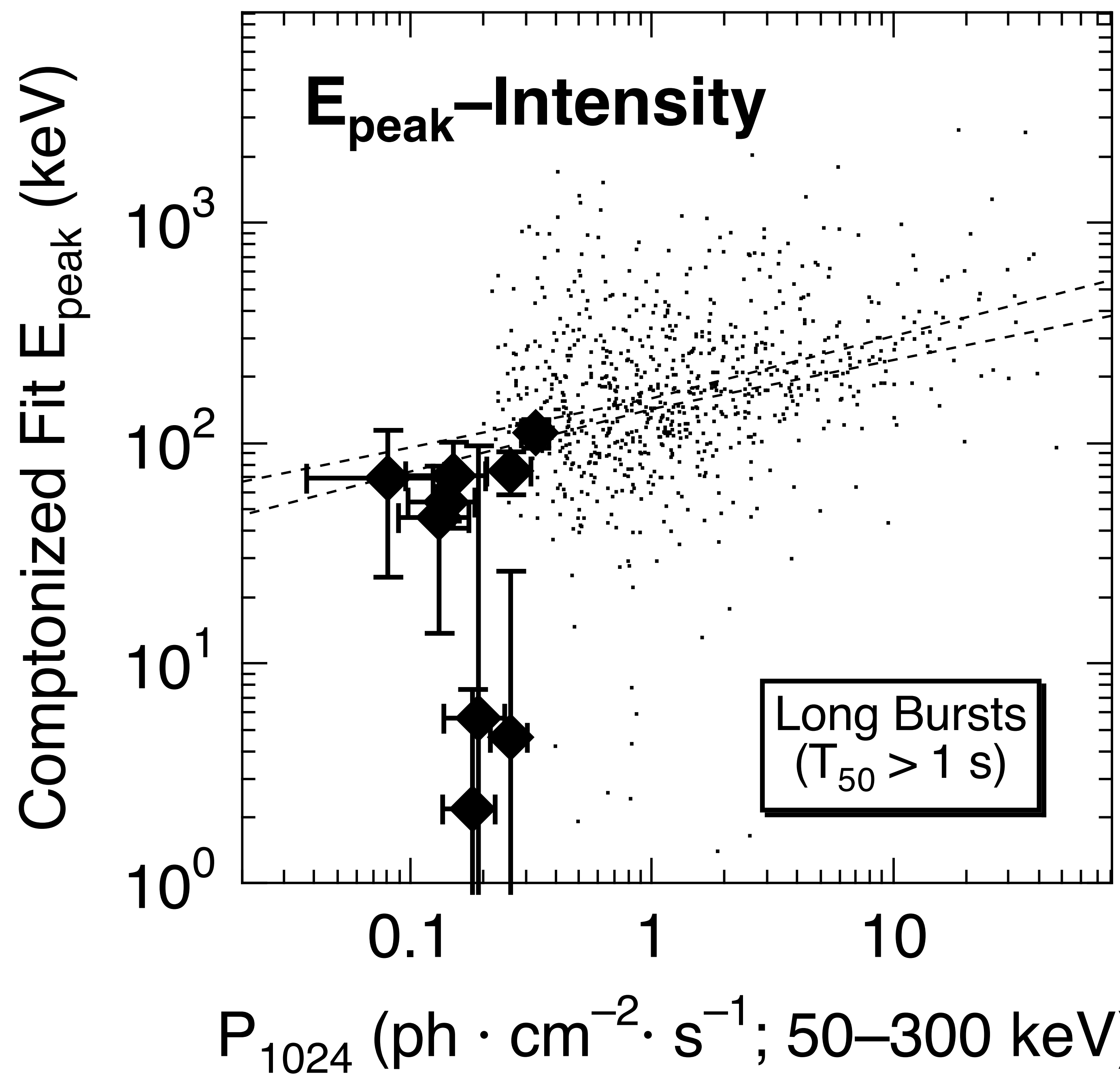
Gamma-Ray Extended Emission

- EGRET Observation of 940217 (Hurley et al. 1994, Nature)
  - Persistent hard emission lasted nearly 92 minutes after the BATSE emission ended
  - A single 18 GeV photon is observed at ~T+80 min: hardest confirmed event from any GRB at the time



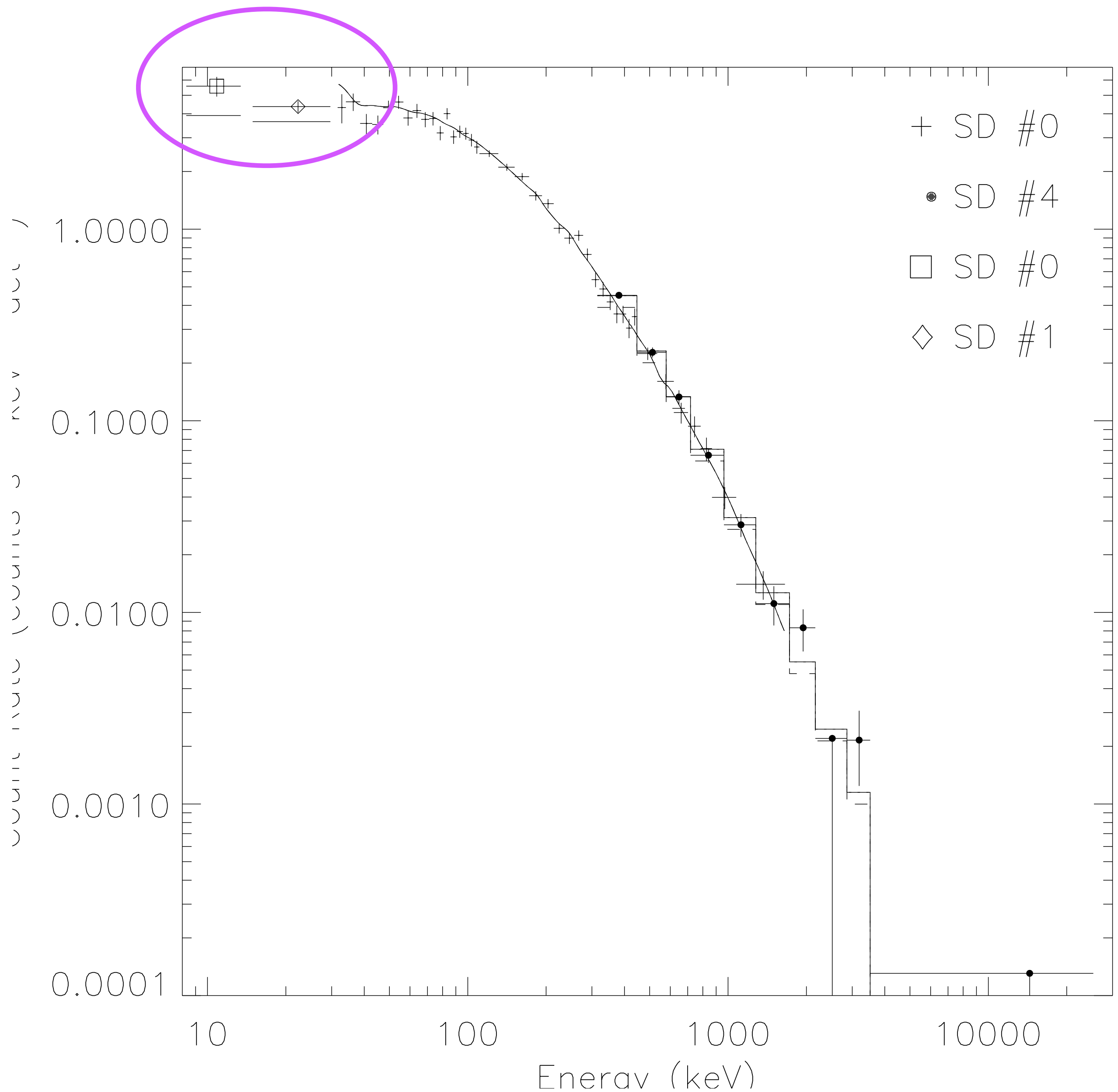
X-ray Rich Bursts

- Kippen et al., 2001: Compared 9 BeppoSAX WFC Fast X-Ray Transients with 1023 long BATSE GRBs
  - In terms of spectral properties, these events compare quite favorably with the main population
  - Here, we see the fitted E_{peak} vs. the 1 s peak flux
  - Dashed lines represent the spread in the mean of the correlation



X-Ray Excess

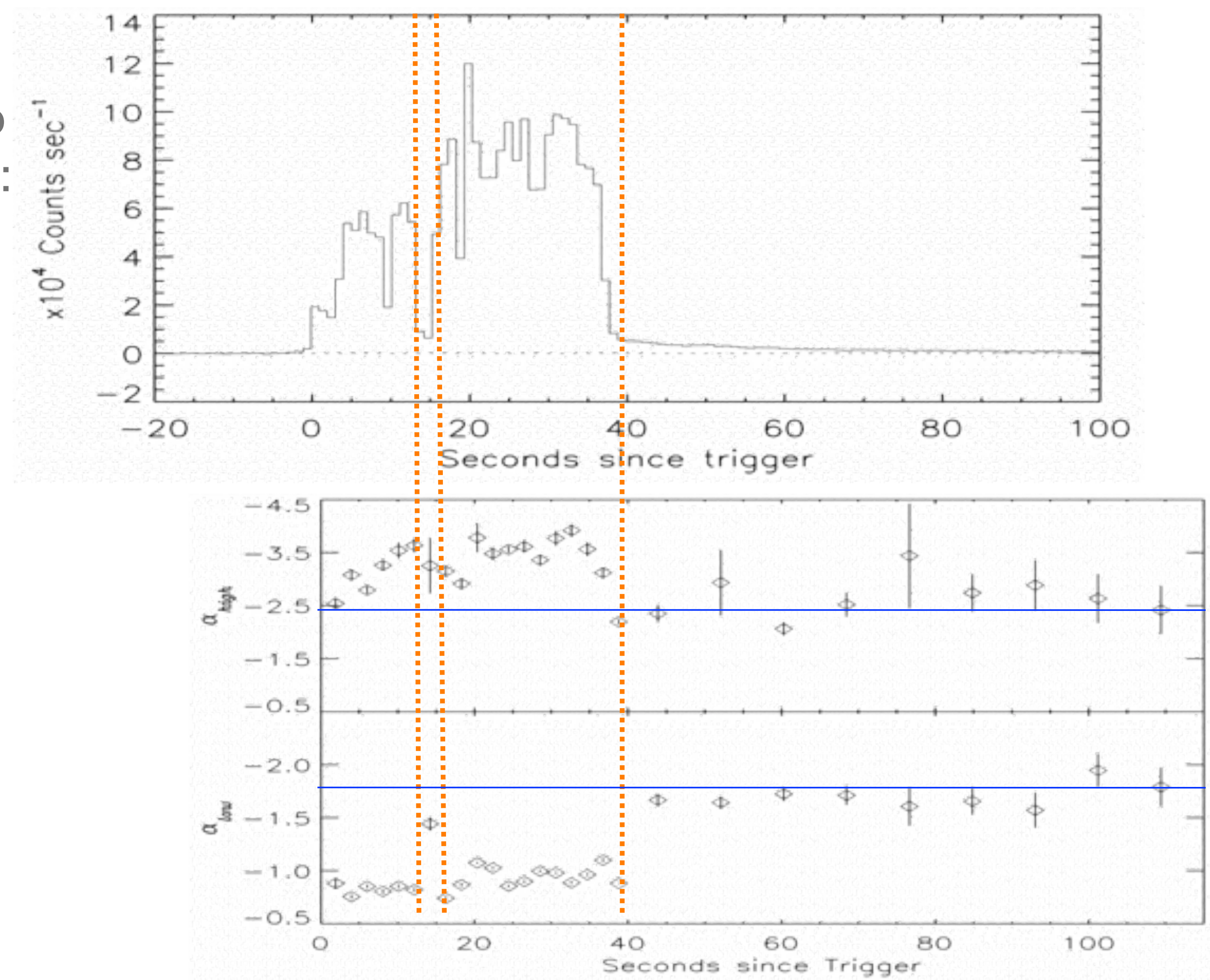
- Preece, et al. 1996 (c.f. Tierney et al. 2013)
  - Low-energy (7 - 25 keV) DISCSP data is compared with extrapolation of a Band fit. All data are included in the fit.
  - 15% out of 151 bright GRBs show an excess > 5 σ
  - 2 bursts show deficit > 5 σ
  - GRB990123: SD #0 shows a 14.5 σ excess; SD #1 is ~ 5 σ



Transition to Afterglows:

- Giblin (1999) and Connaughton (2002) reported smooth transitions to afterglow in gamma-ray energy band:
  - Two different types of spectral behavior:
    - Prompt: $\Delta s \neq 1/2$
    - Afterglow: $\Delta s \sim 1/2$
  - Gamma-ray Afterglow spectral index behaves like 1st order Fermi PIC value:
    - $\beta = -2.4$

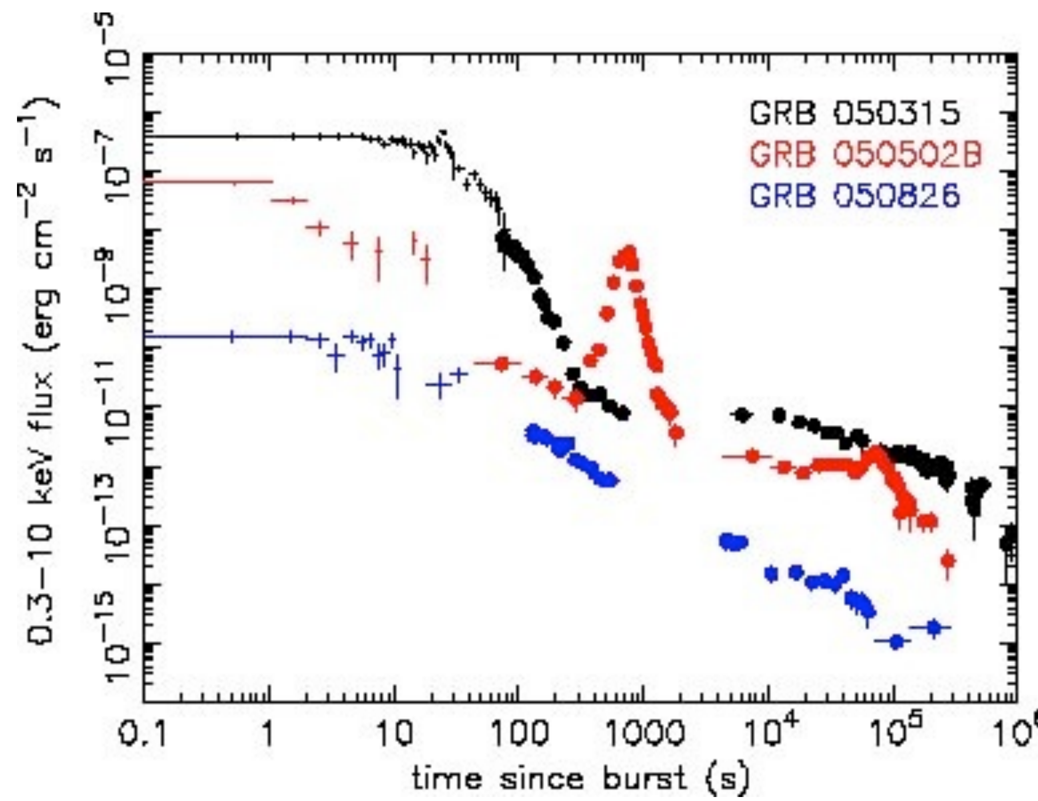
GRB 980923



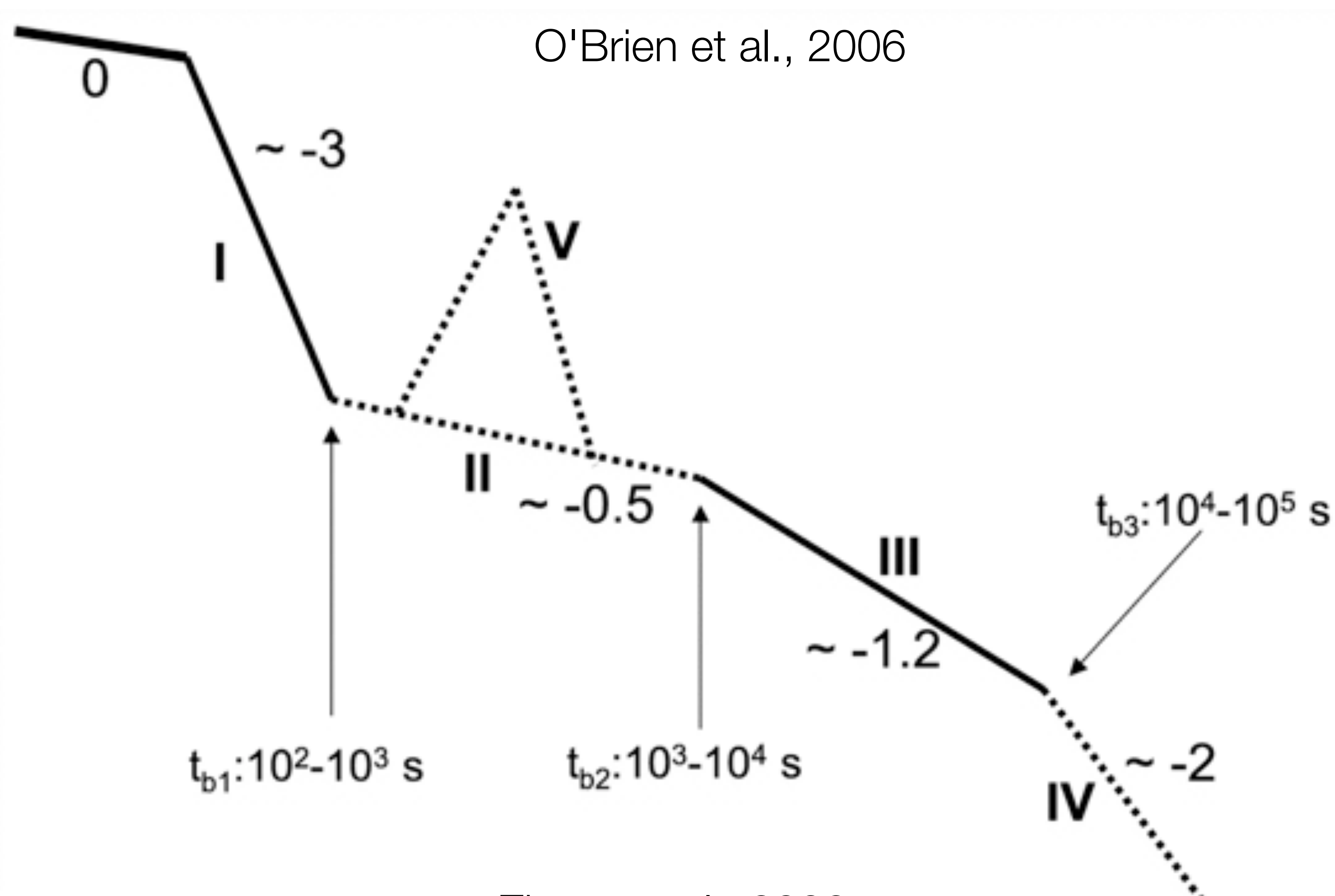
Giblin et al., ApJ 1999

Swift Afterglows:

- Here, I try and summarize 100+ months of Swift GRB results!
- Schematic is in log time; dotted elements are optional:
  - 0: Prompt emission (BAT)
  - I: Rapid decline (BAT - XRT)
  - II: Plateau (XRT: unknown, pre-Swift)
  - III: ‘Traditional’ AG
  - IV: After the ‘Jet Break’
  - V: X-Ray Flares
- Sometimes: SN lightcurve on top!



O'Brien et al., 2006



Zhang et al., 2006

Conclusions:

- Pre-Fermi, the Band GRB function does an adequate job of spectral fitting; however, there are hints of problems:
    - Synchrotron lines of death
    - X-Ray excesses
    - Extremely hard spectra
    - Extended gamma-ray tails
    - Empirical spectral function instead of physical
- One *can* reference 15 different instruments in 12 viewgraphs!