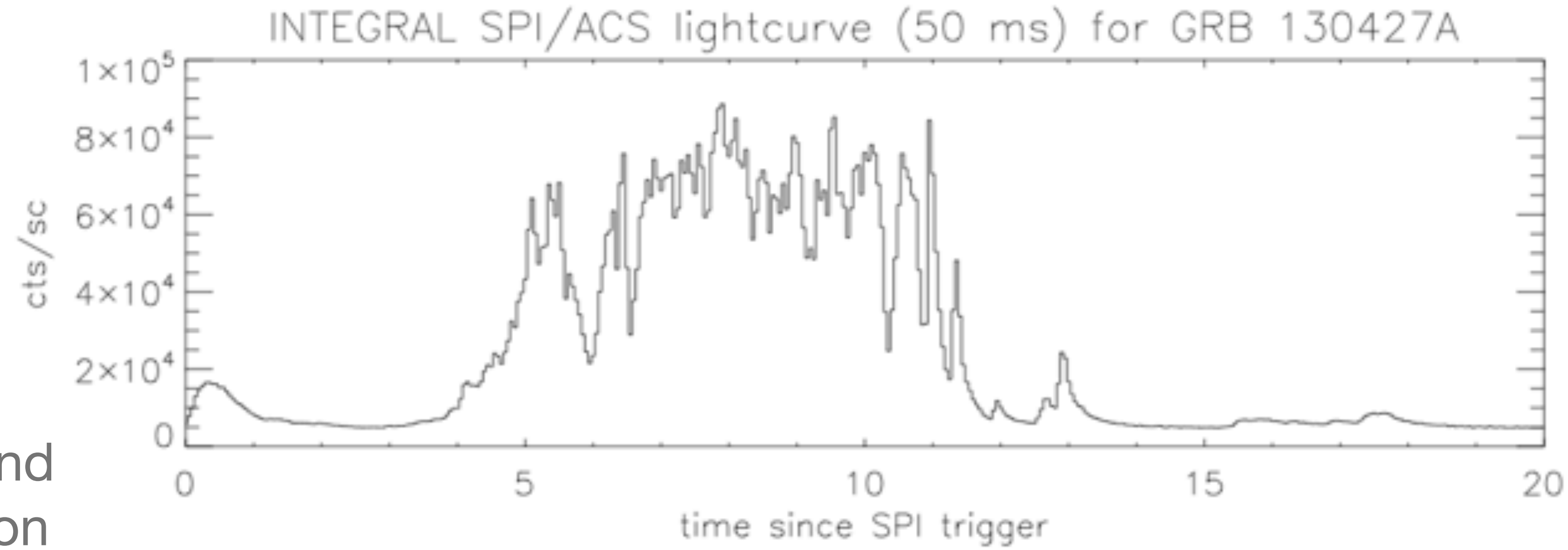
GRB 130427A: A Very Bright, Nearby, Laboratory for Synchrotron Shocks

Rob Preece
UAH Dept. of Space Science

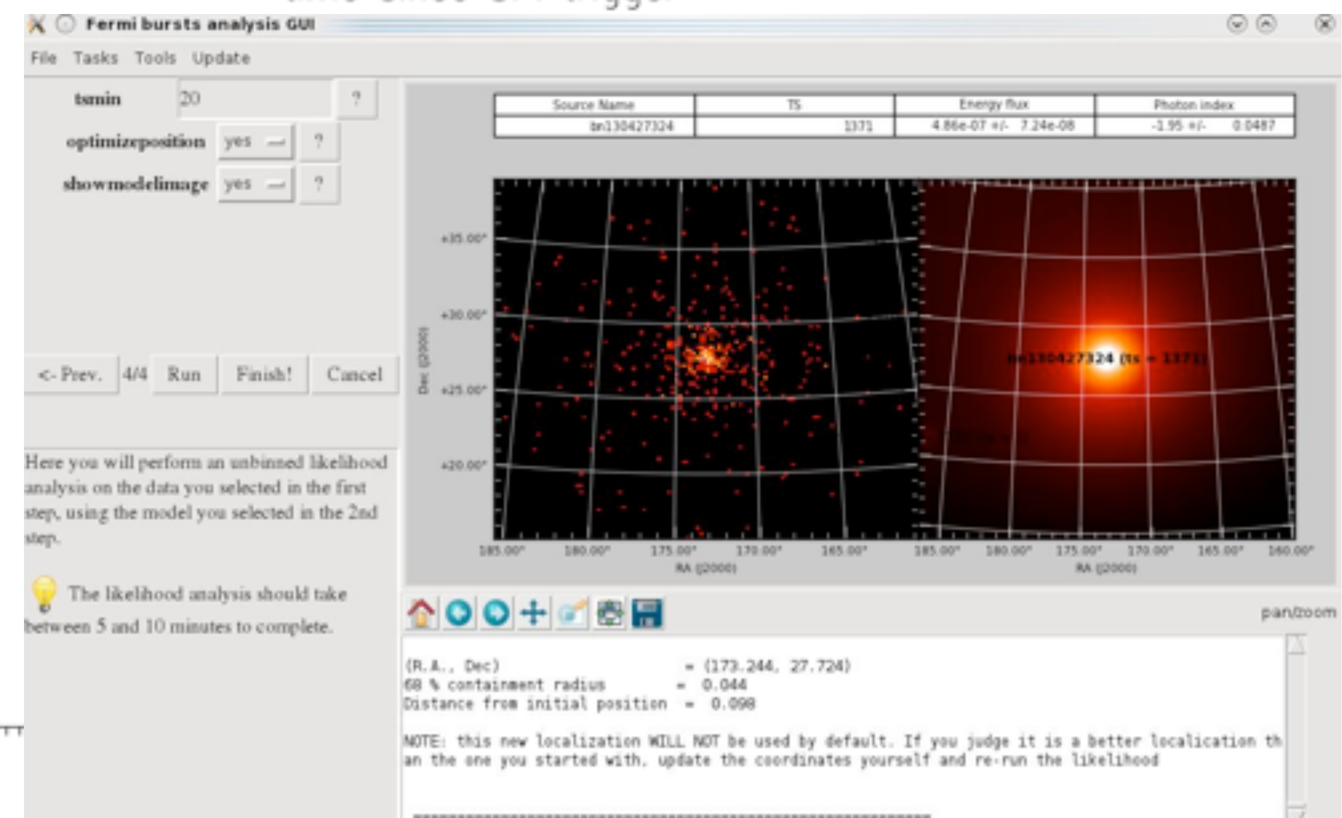
(with contributions by J. Michael Burgess, Nicola Omodei, Chuck Dermer, Andreas von Kienlin and a host of others on the Fermi GBM and LAT teams!)

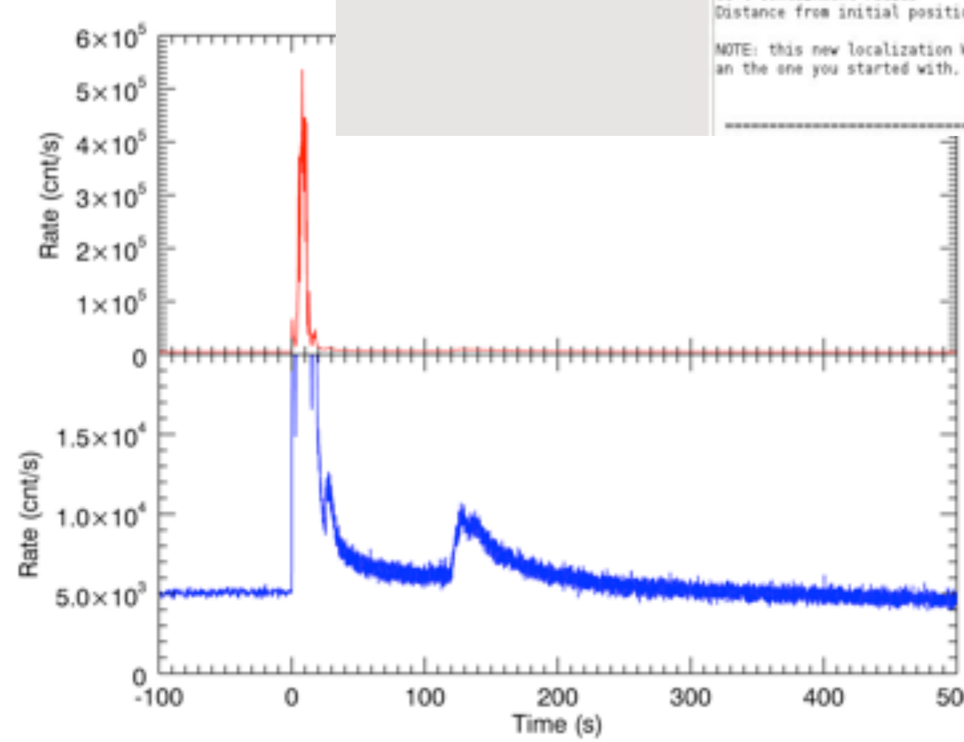
GRB 130427A

- Highest gamma-ray fluence and highest-energy (95 GeV) photon ever seen in a GRB
- Longest-lived gamma-ray emission (20 hours) from a GRB
- Observed simultaneously from radio to gamma-ray energies in exceptional detail
- Extremely bright afterglow (optical flash is second-brightest on record, reached mag. 7)
- Nearby – redshift 0.34, light travel time 3.6 billion years
- Supernova SN 2013cq detected



Fermi LAT Localization Plots:

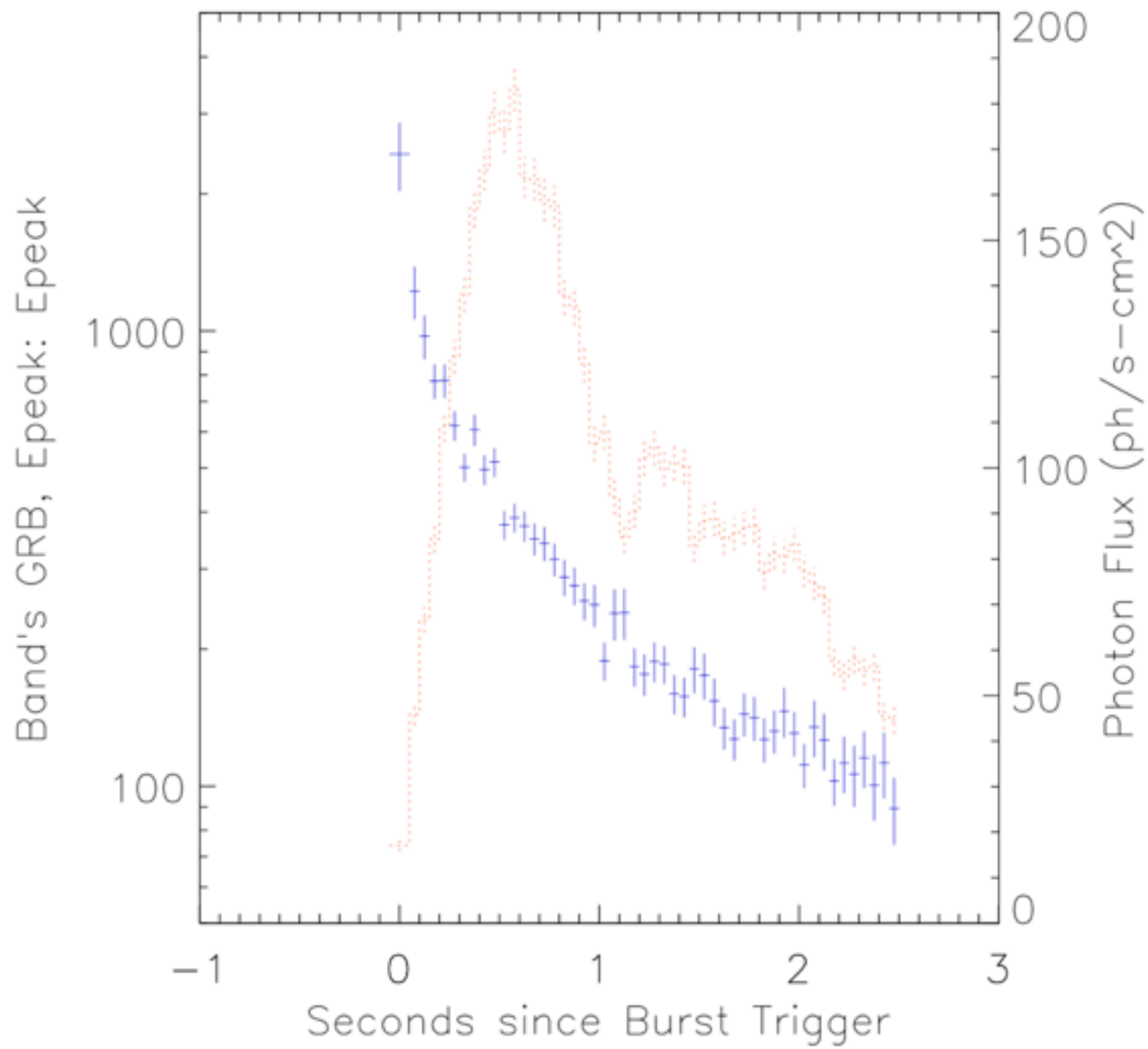




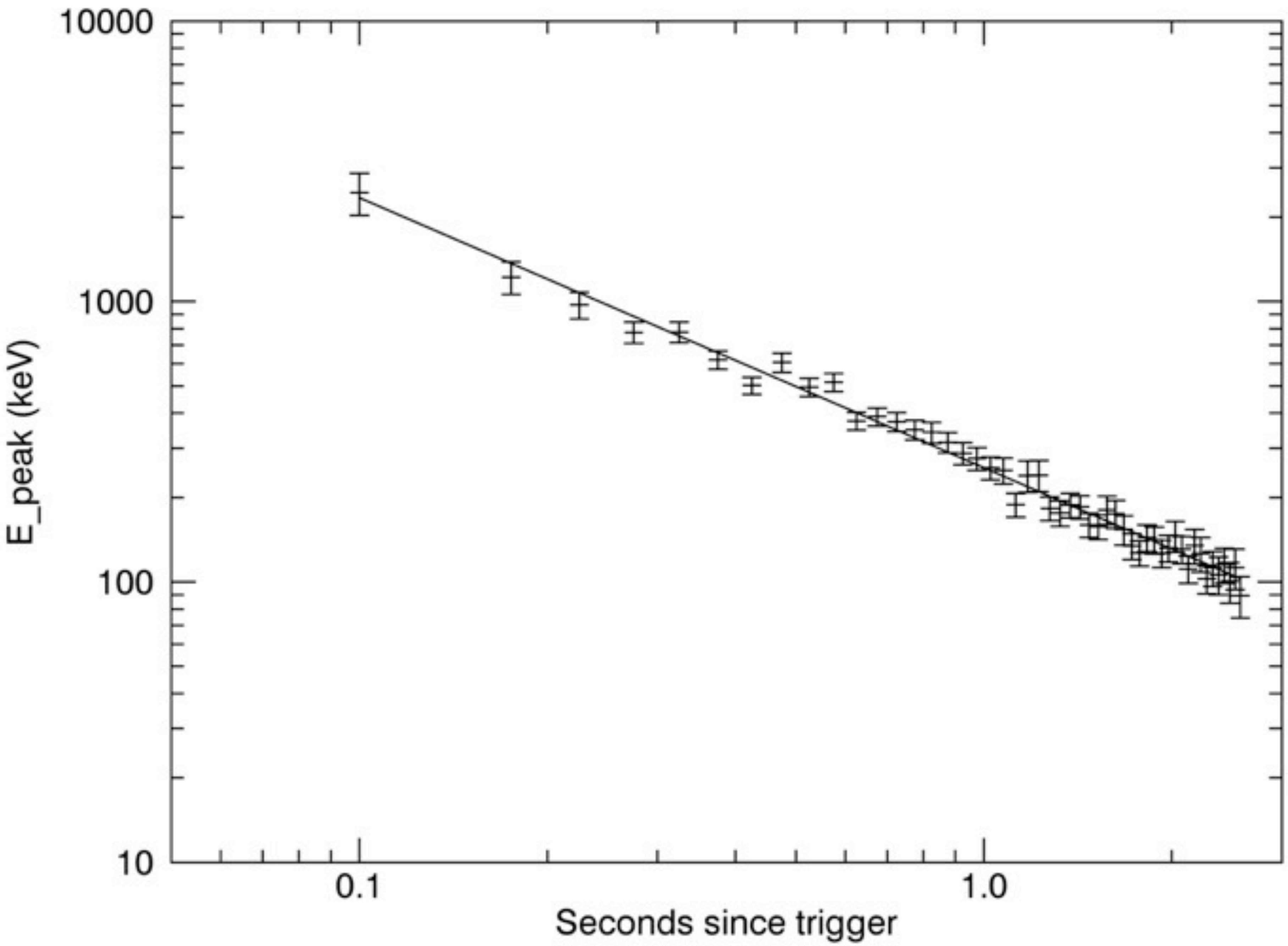
So bright that GBM NaI detectors saturated during the peak!

Spectral Analysis

- Because the GBM data are saturated throughout the main emission episode, we looked instead at the cleaner, first pulse.
- The Band GRB function is fitted to 0.1 s intervals, using three datasets: GBM NaI, GBM BGO & LAT LLE.
- Strikingly, the peak energy seems to show a very simple behavior.

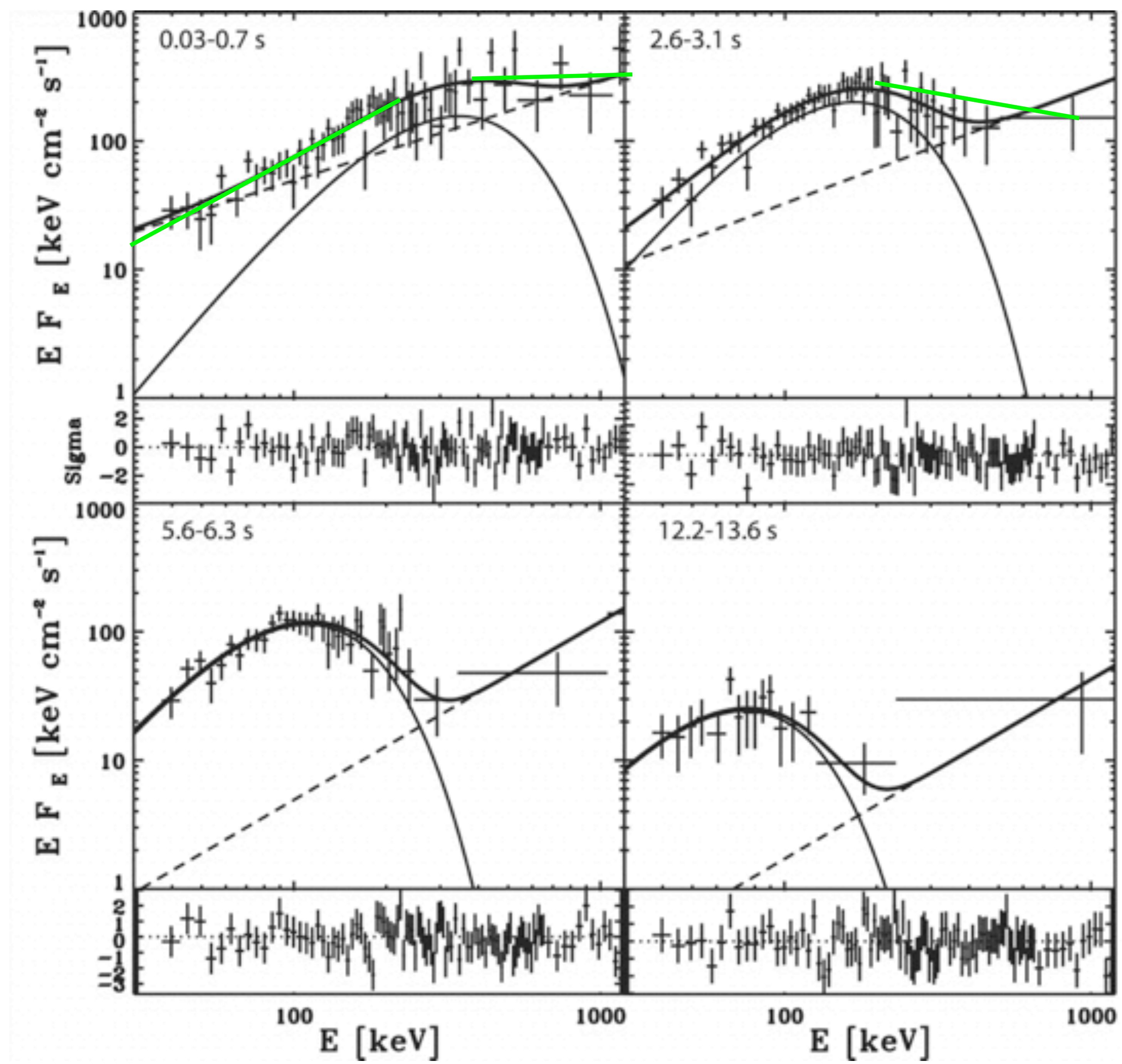


A –1 Power-law as a Function of Time!



The Case for a Photosphere

- Ryde et al., 2006: fitted photospheric function + PL to archival BATSE spectra
- Why does this work?
  - GRB spectra with sufficient statistics for spectral analysis (45 σ) typically allow only 4 free parameters for fitting, as with Band GRB function
  - BB + PL also has 4 free parameters
- Line of death problem replaced by physical values. Band α values are replaced by sum of BB +1 index and fitted PL index
- HE PL index change is also accounted for

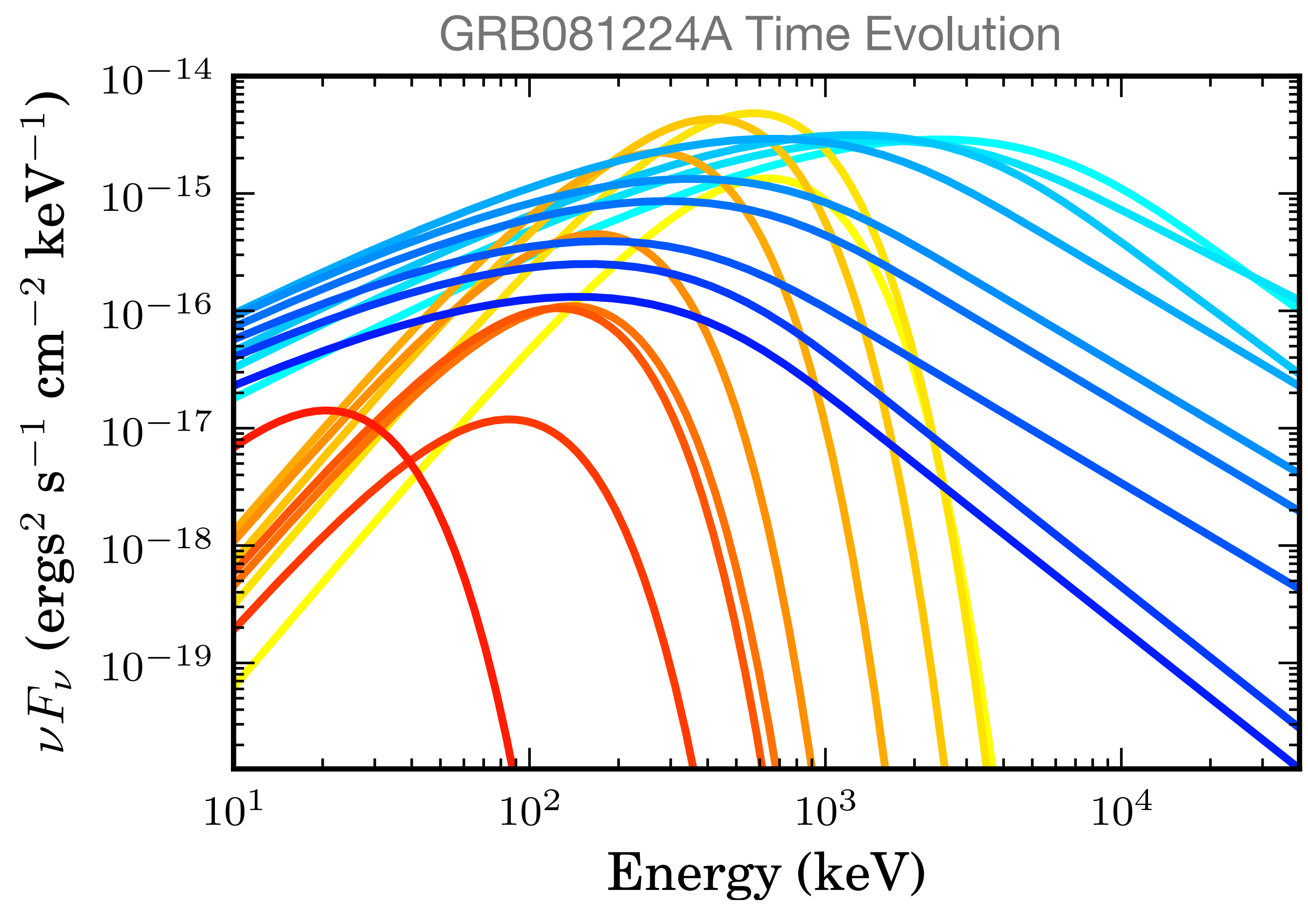


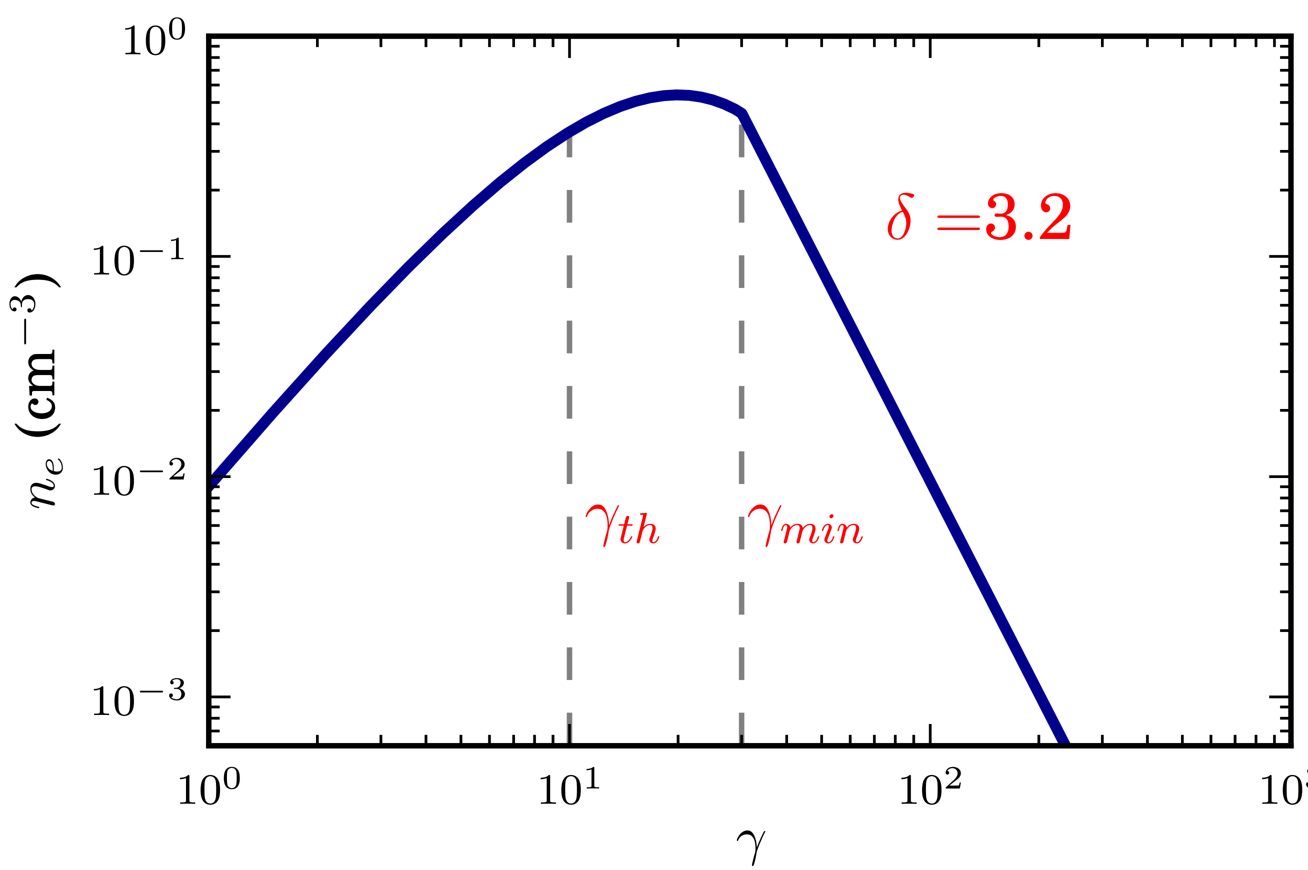
Next Steps

- Motivated by Baring & Braby (2004), Burgess et al. (2011) began fitting spectra with numerically integrated synchrotron emission from parametrized electron distributions

- Electron distributions are 'life-like': Fermi shock accelerated PL from a thermal (rel. Maxwellian) reservoir or fast cooling broken PL

- Fitting is done to the electron distribution, convolved with synchrotron emissivity kernel - too numerically intensive until recently

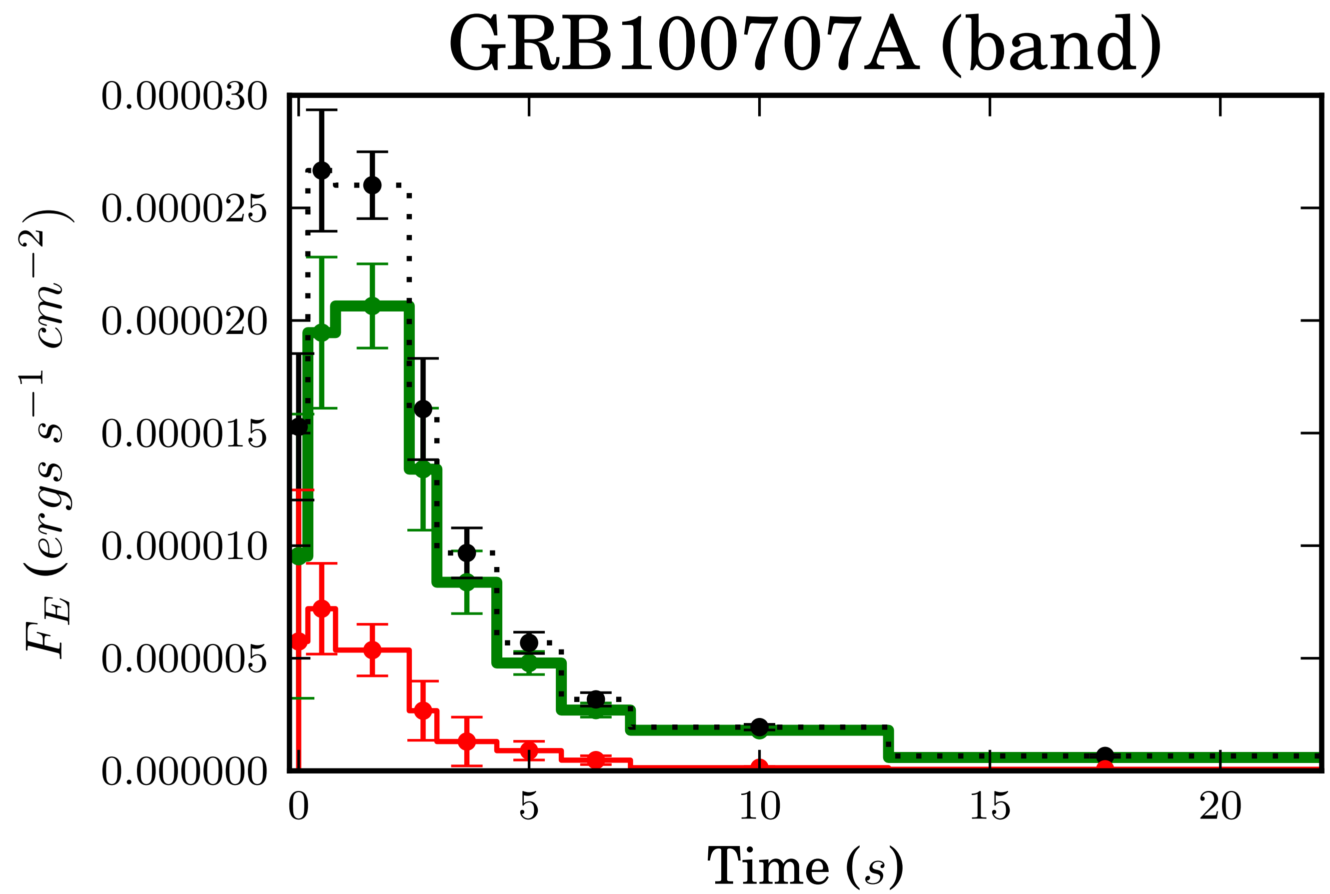


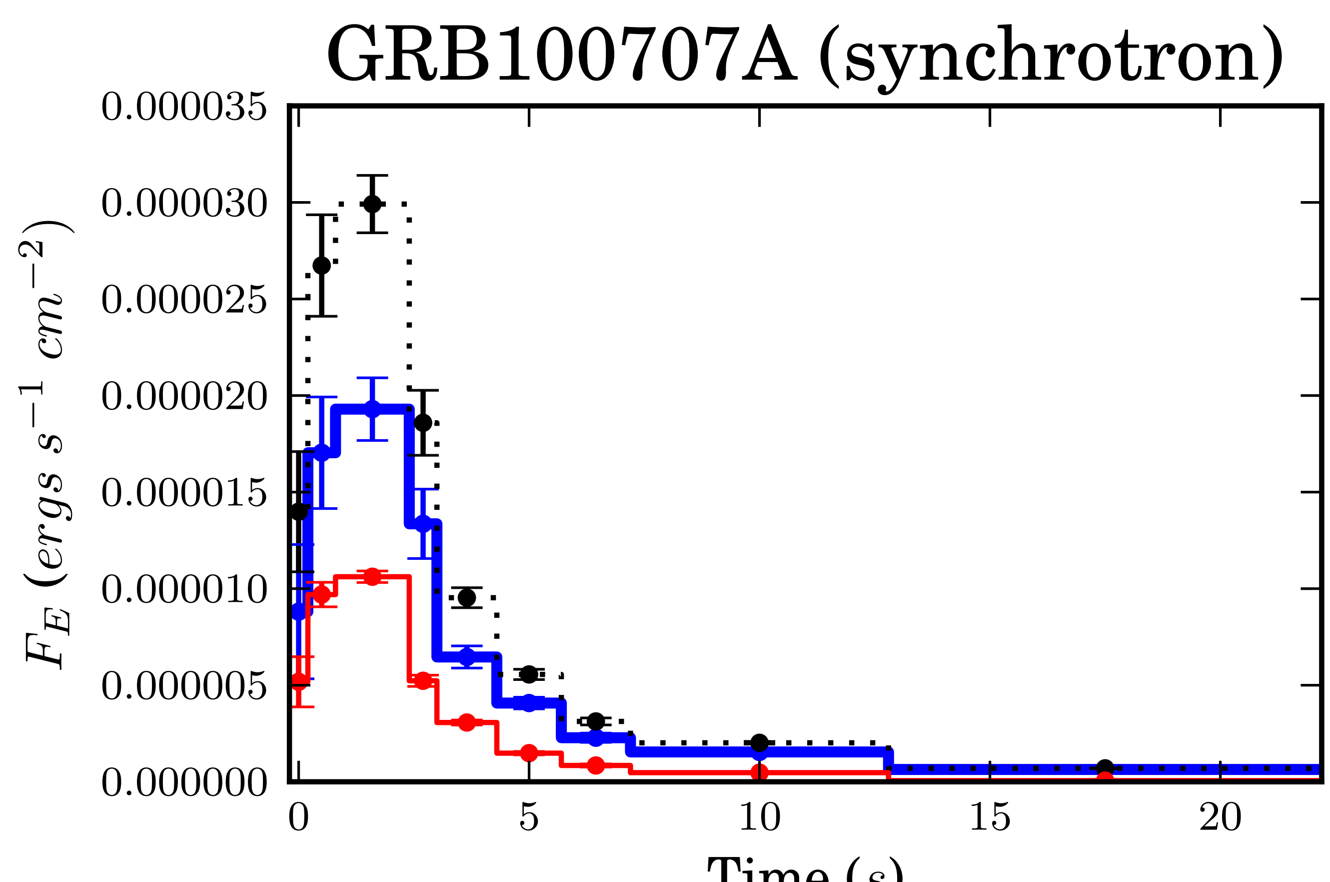


Burgess et al. 2013

Advantages

- Photospheric component evolution more tightly constrained
    - kT better determined
    - Probe independence (or correlation) of each component
    - Same number of parameters as Band GRB function
- Can use to model the interplay between physical emission mechanisms
- Need a *really bright* burst to test this



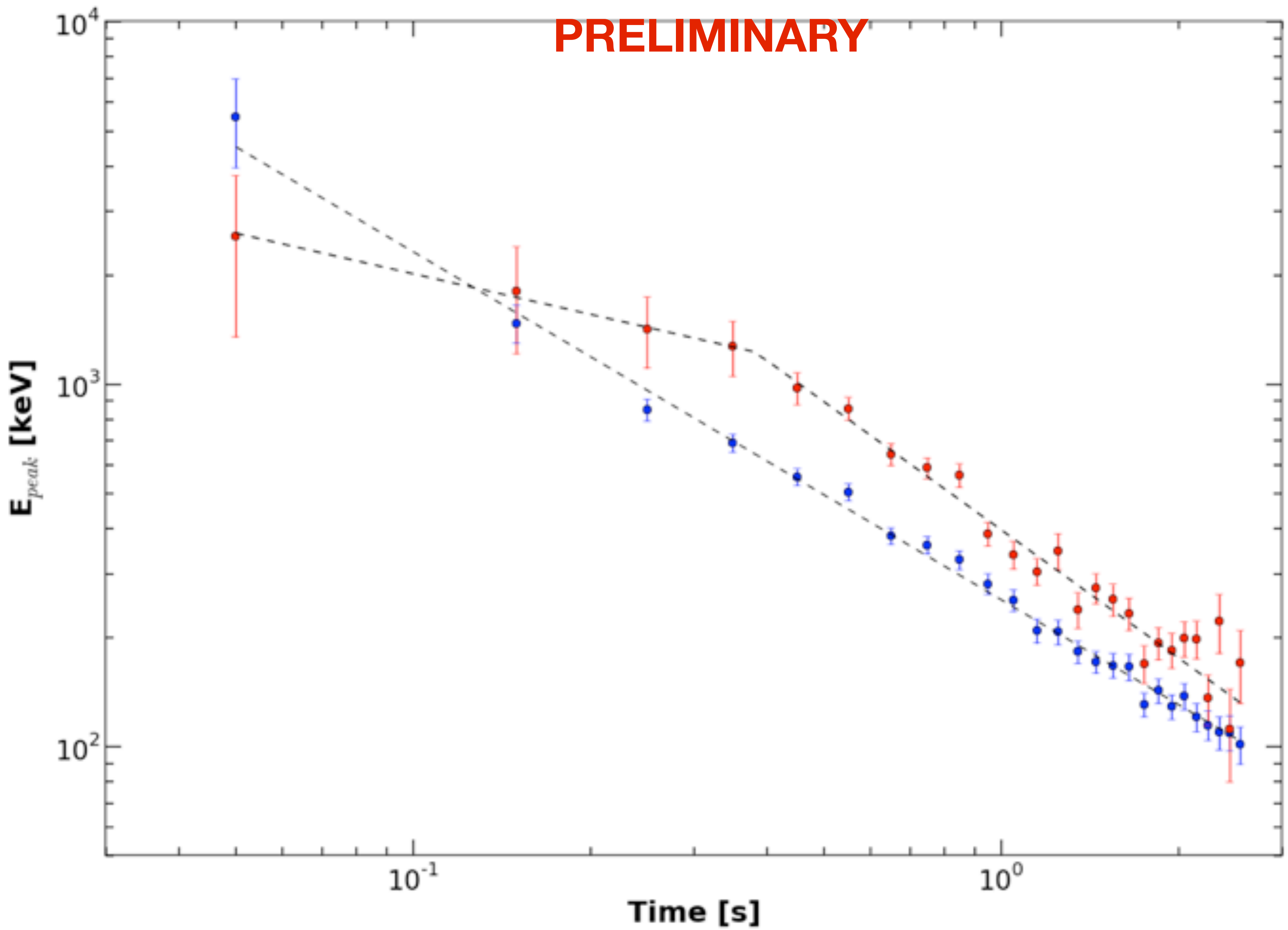


Burgess et al. 2013

Peak Energy Evolution

- Fitted Band function Epeak values (blue) for the first 2.5 s of 130427A in 0.1 s time bins. Fitted with a single power law (slope of –0. 96 +/– 0.02). Time has been offset by 0.1 s,

- The Burgess et al. Synchrotron + BB characteristic energy values are in red. A broken power-law fit is indicated by the dashed line (early time decay index is -0.37 +/- 0.23, with a break at 0.38 +/- 0.08 s., breaking to an index of -1.173 +/- 0.045).

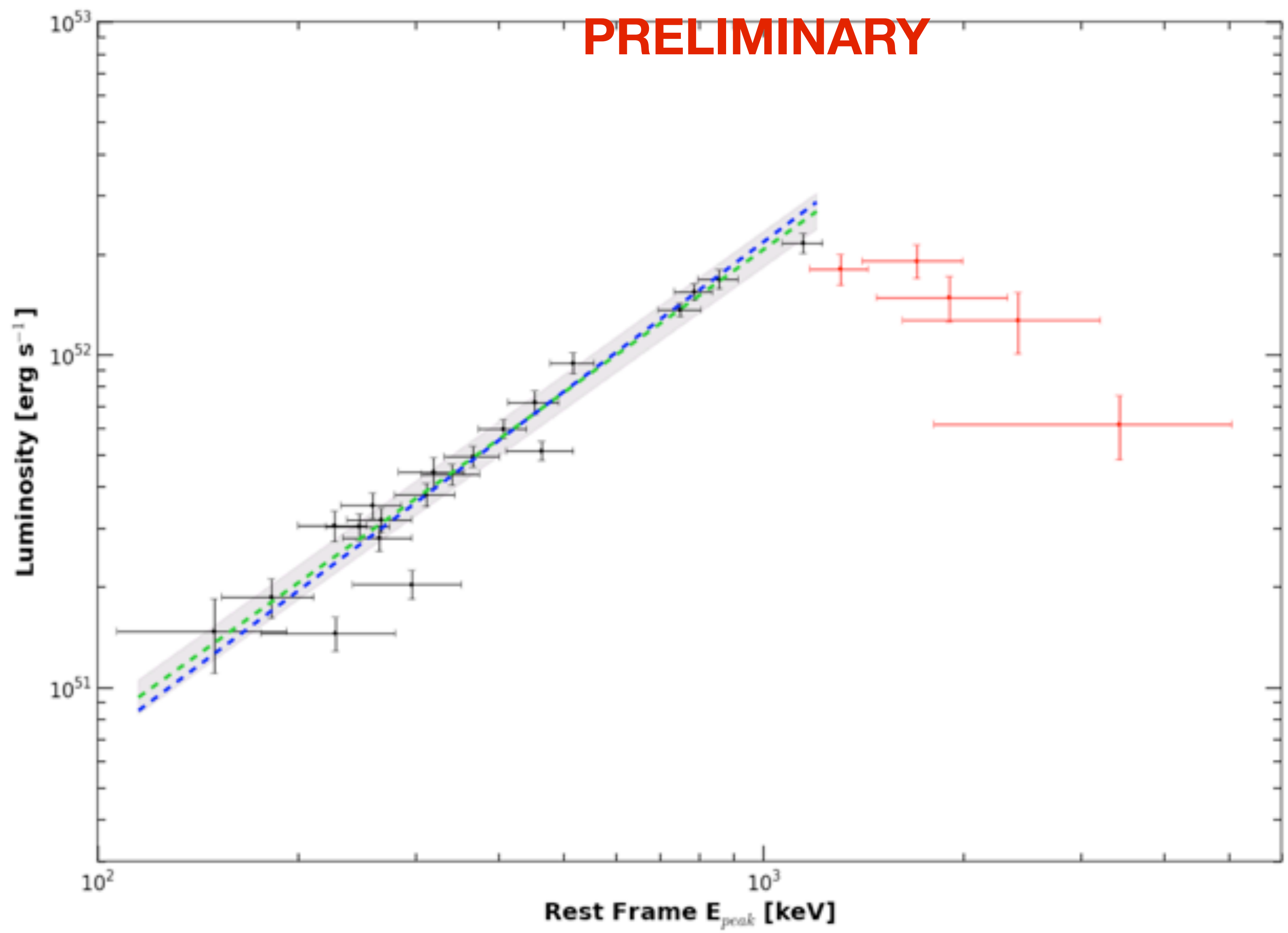


Preece et al., *Science* 2013

Luminosity-E_{peak} Correlation

- The decay phase L- E_{peak} correlation is fit with a power-law index of 1.43 +/- 0.04. Analysis of high-latitude curvature radiation from relativistic, spherical blast waves produced in shell collisions show that the apparent isotropic luminosity $L \propto E_{peak}^3$ during the decay phase of a pulse [Dermer 2004]

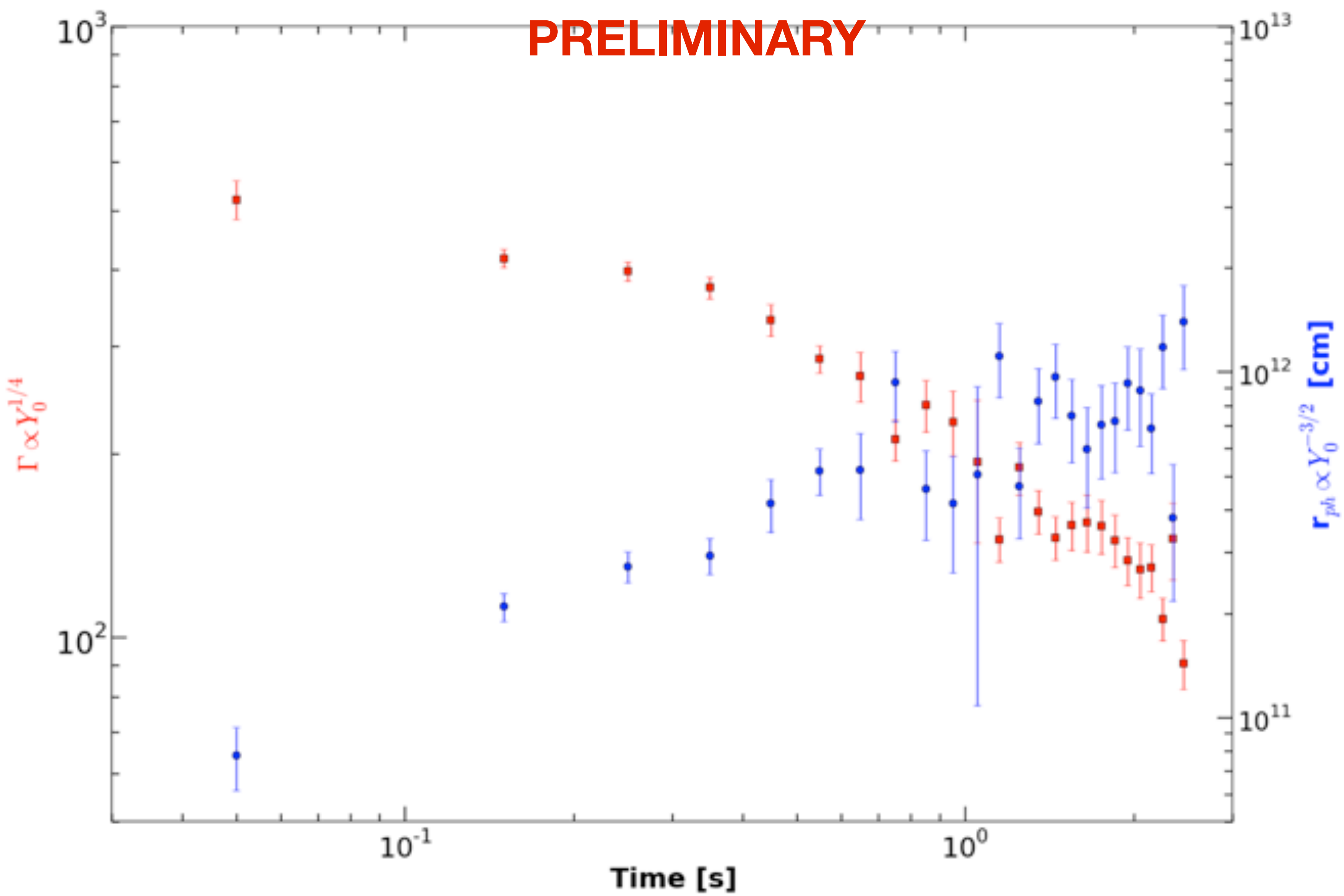
- We can obtain the 3/2 PL index by assuming magnetic flux freezing.



Preece et al., *Science* 2013

Derived Photosphere Parameters

- Plot showing trends in the derived bulk Lorentz factor (red – left axis) and photospheric radius (blue – right axis).
- We obtain both values from the instantaneous ratio of the observed blackbody component flux to the total flux, following Eq. 4 & 5 in Pe’er et al. 2007
- Really do not expect the bulk Lorentz factor to decrease in shock scenario. Suggests magnetic model.



Preece et al., *Science* 2013

Lag Analysis

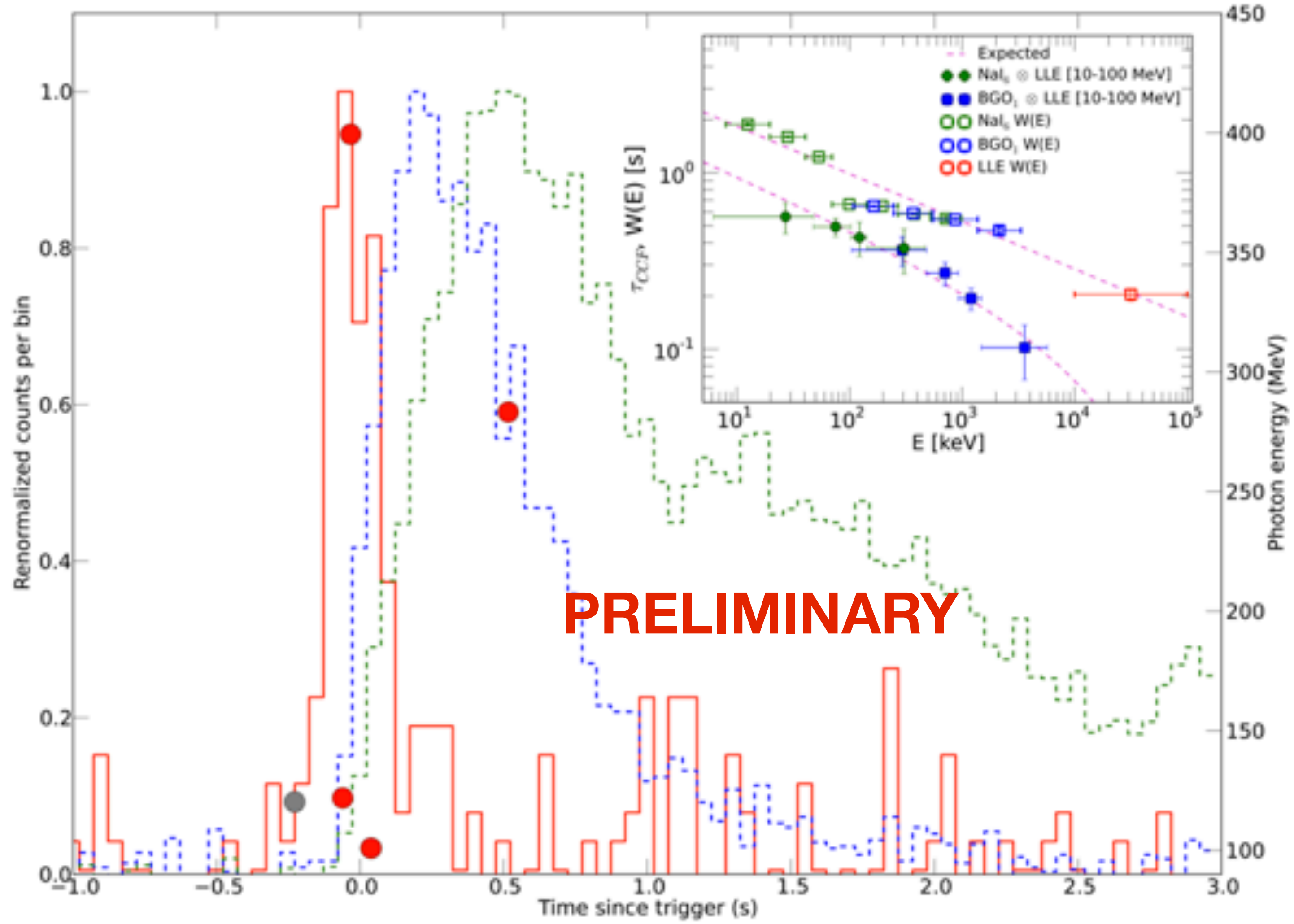
- Composite light curves for the three Fermi detector types (green: GBM NaI #6; blue: GBM BGO #1; red: LAT LLE during the first 3 s of GRB 130427A. Each curve has been normalized so that their peak intensities match. LAT photons > 100 MeV are indicated by circles

- (Inset Figure:) Time lag τ (filled symbols) as determined by the CCF analysis between the LLE lightcurve and selected energy bands of the NaI (green) and BGO (blue) lightcurves.

- Also displayed are fitted pulse widths as a function of energy W(E) ~ E^p (hollow symbols). The two dashed lines represent:

  1) the best fit power law model for W(E),

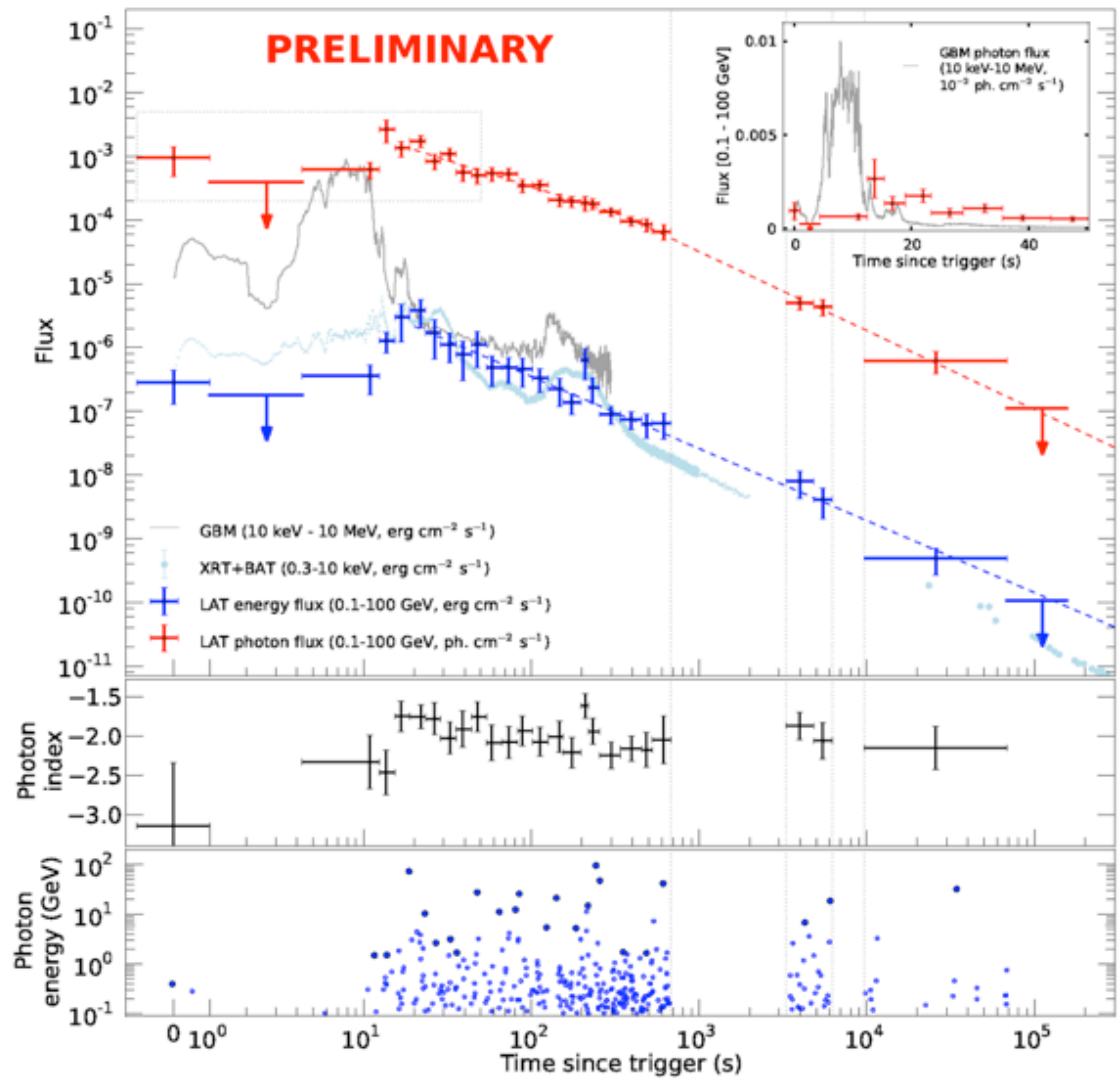
  2) the expected dependence of the time lag τ as a function of energy, assuming the same power law index as in 1).



Preece et al., *Science* 2013

LAT + GBM Afterglow

- LAT Lightcurve belongs to the afterglow:
  - Except for 3 photons right at the trigger, nearly all the LAT photons come after 10 s.
  - LAT Photon flux is a broken power law
- GBM late-time activity is also due to afterglow:
  - Swift XRT and GBM late pulse @ 100 s peaks are nearly coincident in time and temporal decays are consistent
  - GBM late-time data is at the limit of detectability - would not be seen if burst were less bright



Ackermann et al., *Science* 2013

Conclusions

- The isolated initial pulse of GRB 130427A is apparently unmodified by preceding engine activity or nascent external shock emission.
- Our analysis shows:
    - There is good agreement between the pulse width as a function of energy and the expected lag,
    - The characteristic energy has roughly a –1 power-law decay with time during the decaying phase,
    - The temperature of the blackbody component implies a photospheric radius that is incompatible with the internal shock radius,
    - The apparent isotropic luminosity is related to the characteristic energy to the 3/2 power.
- It is a challenge to explain all these behaviors simultaneously.