A Simple Energy-Dependent Model for GRB Pulses with Interesting Physical Implications

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Abstract

A simple mathematical model for GRB pulses is postulated in both time and energy. The model breaks GRB pulses up into four component functions, one predominantly in the time dimension and three exclusively in the energy dimension. The model is shown statistically fit to several of the most fluent GRB pulses known. Even without theoretical interpretation, the model may be immediately useful for fitting prompt emission from GRB pulses across energy channels with a minimal number of free parameters, sometimes far fewer than freshly fitting a GRB pulse in every energy band separately. Some theoretical implications of the model might be particularly interesting, however, as the temporal component (e.g. the shape of the light curve) can be characterized at any one energy by a confined blackbody distribution.

GRBs & Pulses

- Pulses compose GRBs
- Pulses usually overlap in time
- ~ 100 "bright" "separable" pulses known
- Pulse light curves parametrized only in time
  - Spectra fit at discrete times
- Pulses light curves fit independently in each energy band

Pulse Light Curve Functions
P(t) = photon number

Norris et al. 1996:

$$P(t) = Ae^{-(|t-t_{max}|/\tau_{r,d})^{\nu}}$$

Ryde et al. 2002:

$$P(t) = \frac{A}{(1+t/\tau)^n}$$

Norris et al. 2005:

$$P(t) = Ae^{-(\tau_r/t+t/\tau_d)}$$

Pulse Light Curve Function

Norris et al. 2005: $$P(t) = Ae^{-(\tau_r/t+t/\tau_d)}$$

- Independent fits for each energy band.
- Assume 4 BATSE energy bands:
- Fit A, t_o, τ_r, τ_d for each energy channel
  - Hakkila et al. 2008
- 16 free parameters
- Computationally expensive
- Harder to see correlations between energies

A different parametrization of Norris et al. 2005

$$P(t) = Ae^{-\beta(t/\tau+\tau/t))}$$

where

$$\tau = \sqrt{\tau_r \tau_d}$$

$$\beta = \sqrt{\tau_d/\tau_r}$$

so that

- A scales only the y-axis (flux)
- τ uniquely scales only the x-axis (time) and
- β uniquely determines the light curve shape

A different parametrization of Norris et al. 2005

$$P(t) = Ae^{-\beta(t/\tau+\tau/t))}$$

Rise and decay of pulse are dependent!

Energy dependent generalization

$$P(t, E) = A(E)e^{-\beta(E)(t/\tau(E)+\tau(E)/t)}$$

Now

- A(E) tells how the pulse amplitude changes over energy. This is like an "pulse-coherent spectrum".
- τ(E) tells how the pulse duration changes as function of energy. This is like an "pulse-coherent lag".
- β(E) tells how the pulse shape changes as a function of energy.

Energy dependent generalization

$$P(t,E) = A(E)e^{-\beta(E)(t/\tau(E)+\tau(E)/t)}$$

t should really be written (t-to(E)), where to(E) is the start time for the pulse.

- Pulse Start Conjecture: to(E) = to
  - Nemiroff (2000); Hakkila et al. (2009)
- Pulse Scale Conjecture: β(E) = β
  - Nemiroff (2000)

New: Planckian Pulse Parametrization

$$P(t) = \frac{A(\tau/t)^{\beta}}{e^{\tau/t} - 1}$$

- Exponential rise in t retains a unique pulse start time.
- Power law decay similar to Ryde et al form.
- Scales in x, y and shape as Norris et al. 2005 form.
- Appears to fit pulses as well as Norris et al. 2005.
- A Planck function where β is determined by the number of free spatial dimensions.

Planckian Pulse Parametrization

$$P(t) = \frac{A(\tau/t)^{\beta}}{e^{\tau/t} - 1}$$

- Planck form is in TIME not energy.
- What?
- The "FRED" shape of many GRB pulses is well fit to a blackbody in time, not energy.
- 3D blackbody: $\beta = 6$
- Typical GRB pulse: $\beta = 6$, but occasionally less
- Less? Expected for < 3D: "confined blackbodies"
- Theoretical speculations solicited
  - thermalized massive particles fly free initially?
  - blackbody radiation enters a dispersive medium?
  - B field dimensionally confining?

Energy dependent Planckian pulse form

$$P(t) = \frac{A(E)(\tau(E)/(t - t_o(E)))^{\beta(E)}}{e^{\tau(E)/(t - t_o(E))} - 1}$$

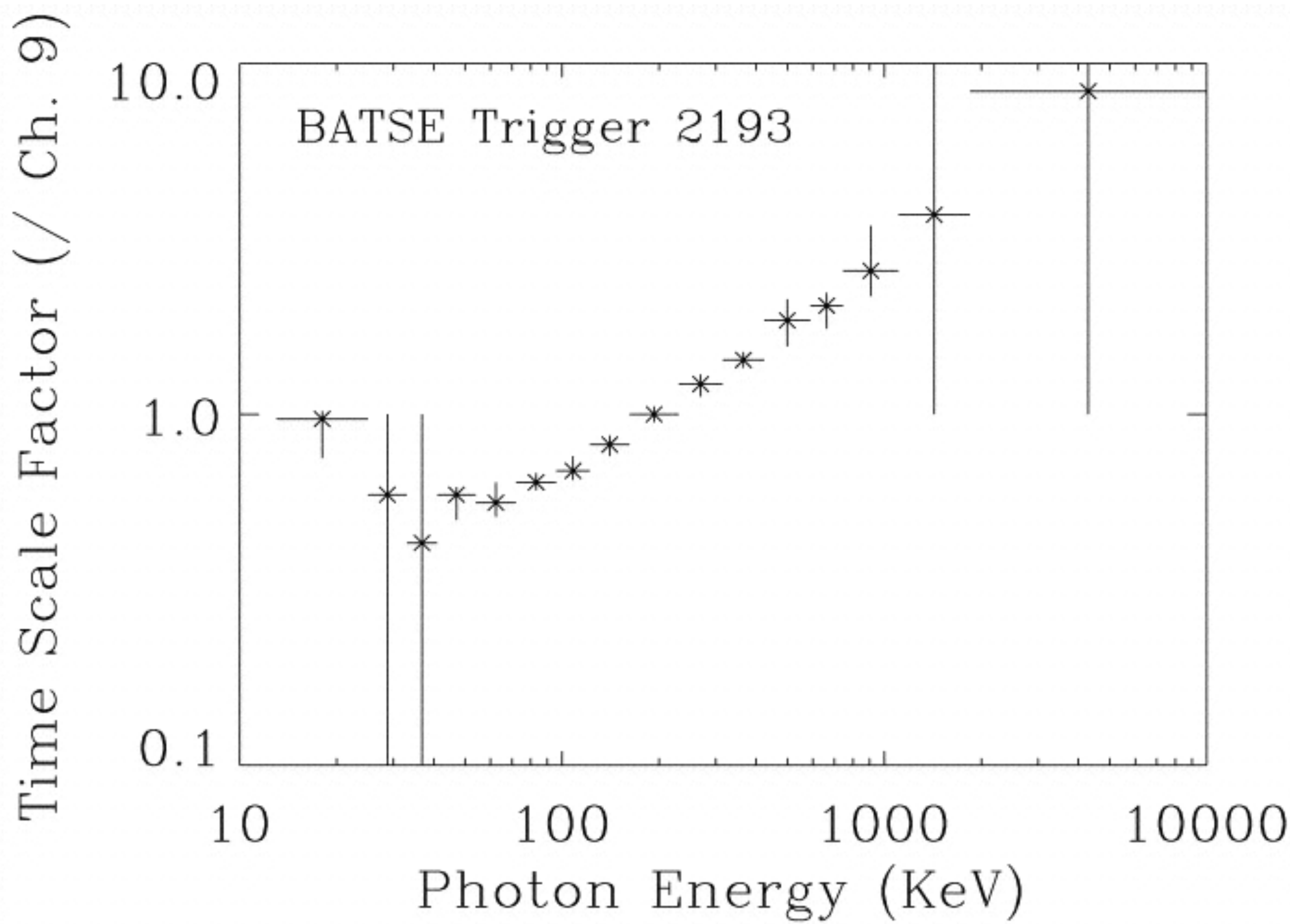
Regardless of theory, preliminary data fits indicate that, typically, start time to is independent of energy.

- Now fit one to for all energies, instead of to(E)
- Possible explanations: energy released, shells collide, dispersive boundary breached, etc.
- β "frequently" independent of E
  - Studying seemingly E dependent cases

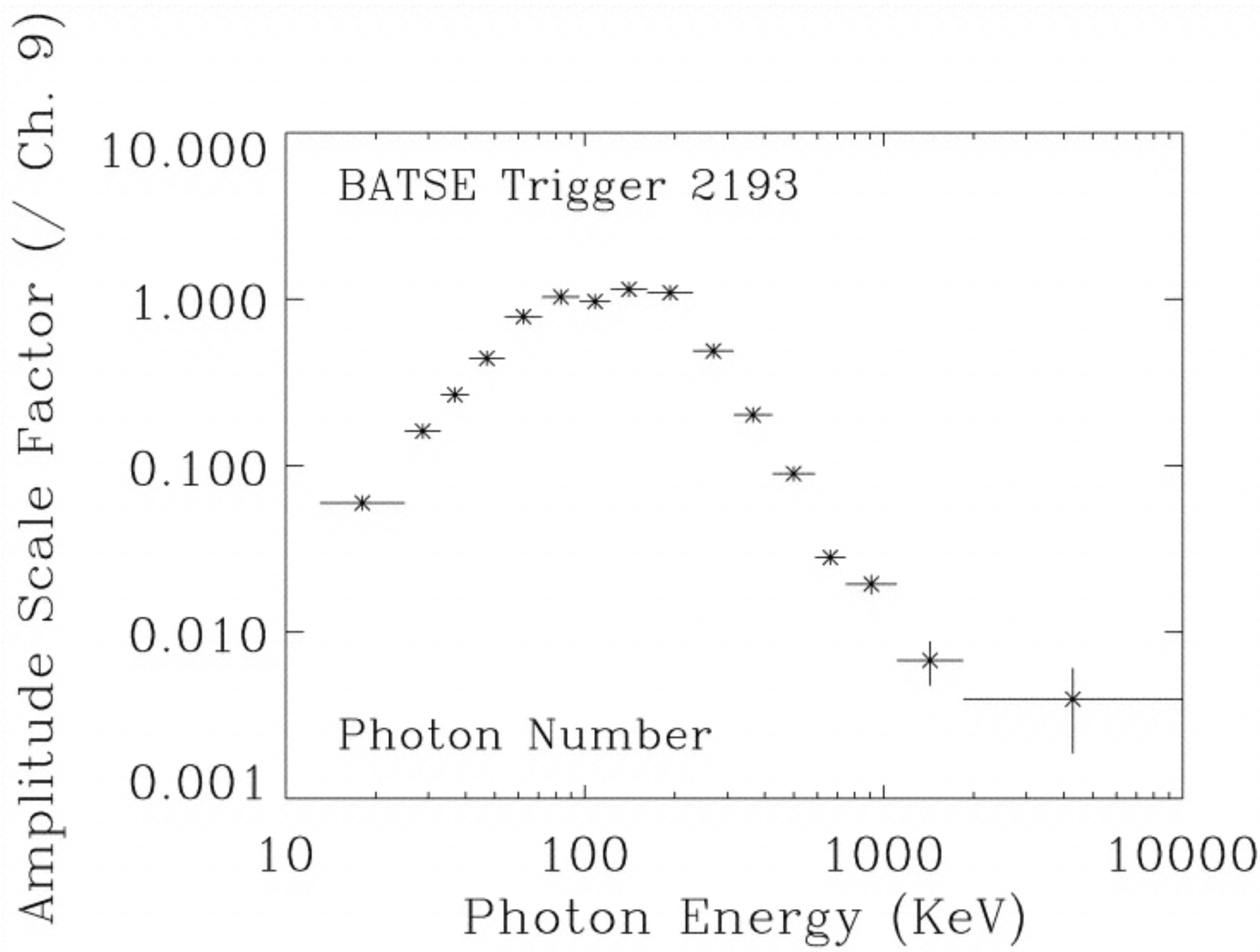
Secrets "They" Don't Want You to Know

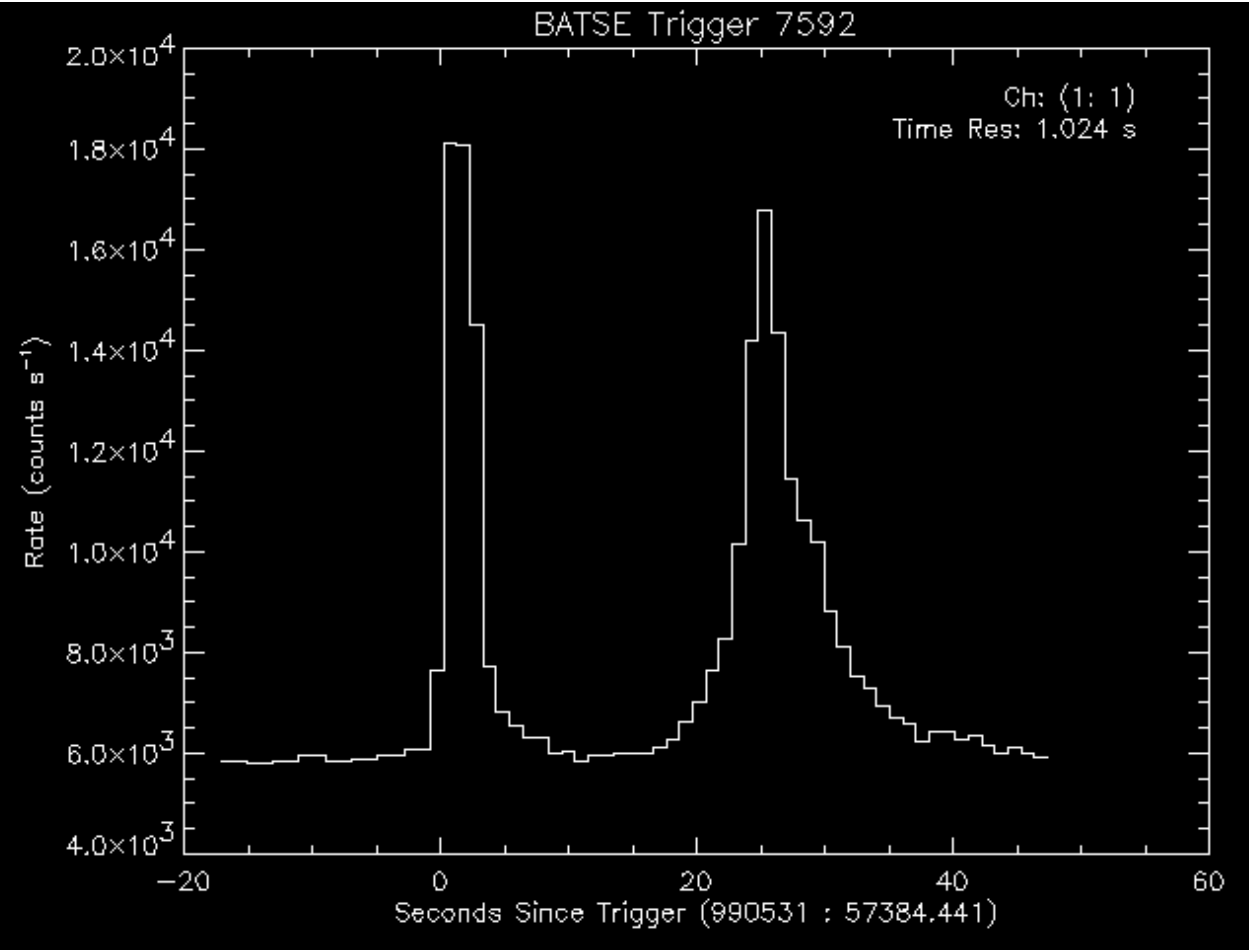
- Energy channels do not correspond to a single energy
  - energy integrations change the pulse shape
    - spectrum dependent
    - no one has yet accounted for this
- Some pulses are not fit by any known form
  - Multiple pulses?
- Pulses like the second pulse in BATSE 7592 are really strange
  - are they trying to tell us something?
  - does they fit a different spectral distribution?

Example of $\boldsymbol{\tau}$(E)



Example of A(E)




BATSE Trigger 7592
Ch: (1: 1)
Time Res: 1.024 s
Rate (counts s^{-1})
2.0×10^4
1.8×10^4
1.6×10^4
1.4×10^4
1.2×10^4
1.0×10^4
8.0×10^3
6.0×10^3
4.0×10^3
−20
0
20
40
60
Seconds Since Trigger (990531 : 57384.441)