UV/Optical and X-ray Flares in Gamma-ray Burst Light Curves

Galaxies meet GRBs at Cabo de Gata

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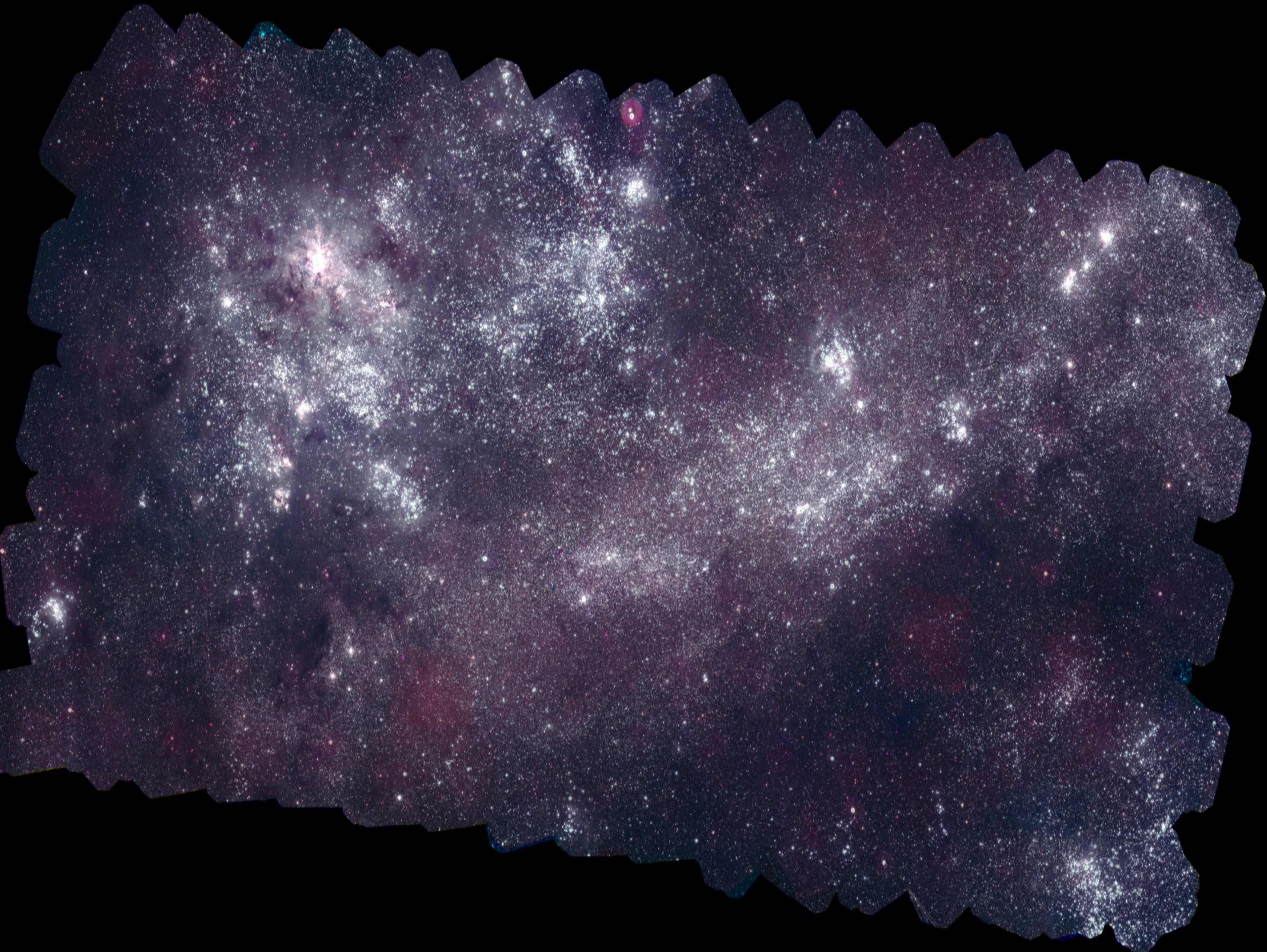
PENNSTATE

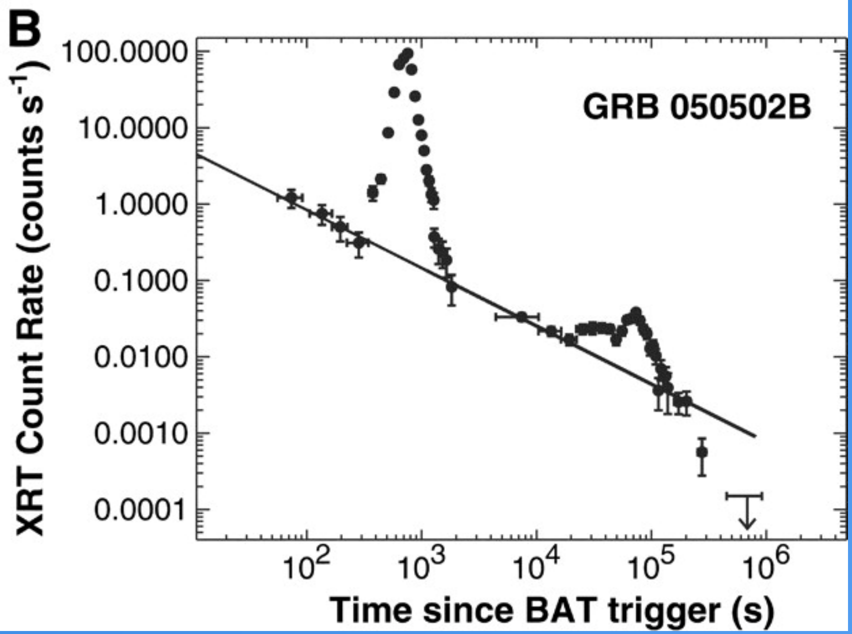
1855



Flares in the *Swift* era

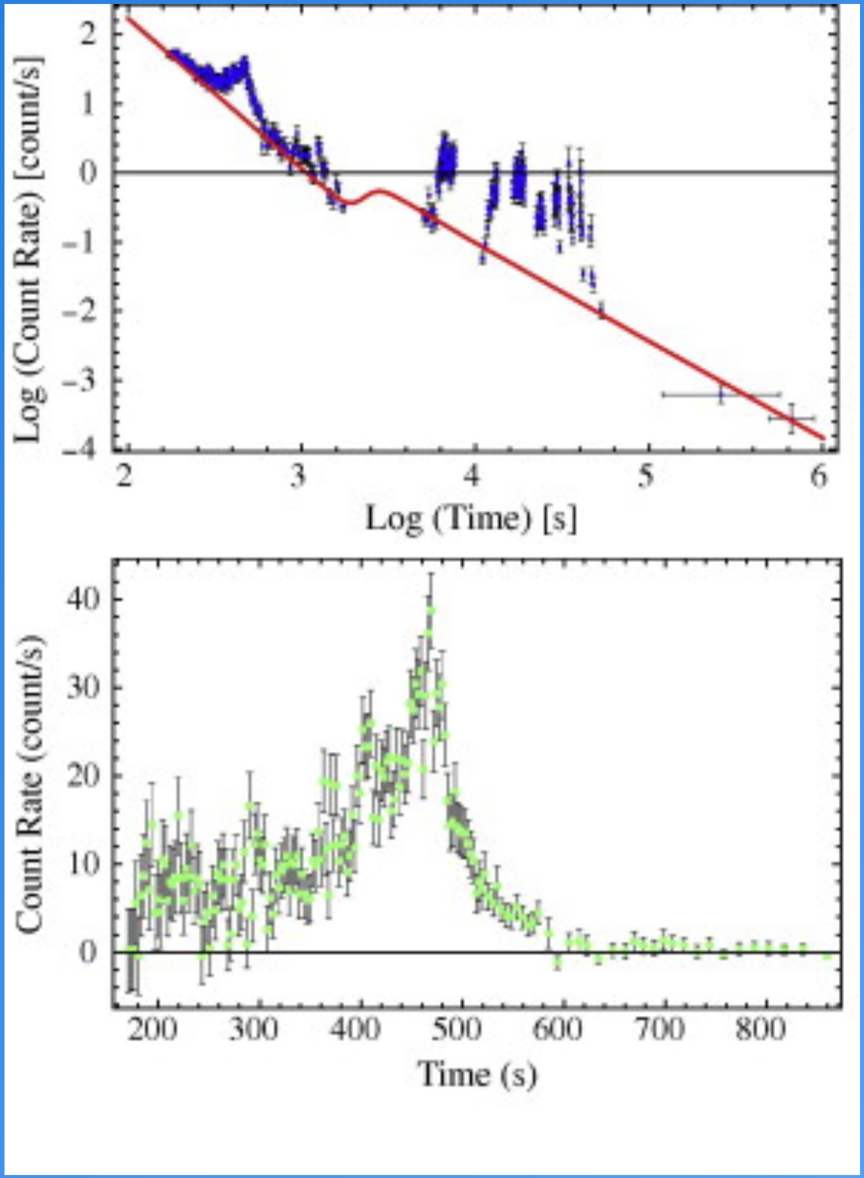
- X-ray flares in as many as 50% of GRBs
  (O'Brien+2006)
- Distinctly separate emission source than afterglow
- Long/Short GRBs
- Observed to $T_0 > 10^5$ s
- Internal source "likely"

(Romano+2006, Flacone+2006, Morris2007, Campana+2006, Cusumano+2007, Swenson+2010)



Burrows+2005

- Studies with limited samples
  - Falcone+2007, Chincarini+2007
    - 110 GRBs and 33 Flares
  - Chincarini+2009
    - Only GRBs with measured *z*
  - Chincarini+2010
    - Clearly distinguishable
    - $T_{peak} < 1000$ s
    - Fitted with analytic function
  - Margutti+2010
    - 9 bright flares



Chincarini+2010

What about the UVOT?

- Largely overlooked (Roming+2006)
  - More difficult to identify than X-ray flares
    - Lower significance
    - UVOT light curves split across multiple filters
      - Lower sampling frequency unless light curves are normalized

What about the UVOT?

- Second *Swift* UVOT GRB Catalog (Roming+inPrep)
  - Catalog of UVOT GRB observations through December 2010
    - Light curves produced using optimal co-addition (Morgan+2008)
      - Higher rate of detections than previously (over 50%)
      - Light curves are more densely sampled on a per-filter basis
    - Normalized light curves
      - Multi-filter observations are normalized to a single filter

The search for Flares

- Blind, systematic search for flare in both the UV/optical and X-ray
  - Determine the optimal fit to each light curve using the Bayesian Information Criterion (BIC) (Schwarz1978)

$$BIC = -(2 \times L) + k \times \ln(n)$$

k = # of free parameters to be estimated

n = # of data point being fitted

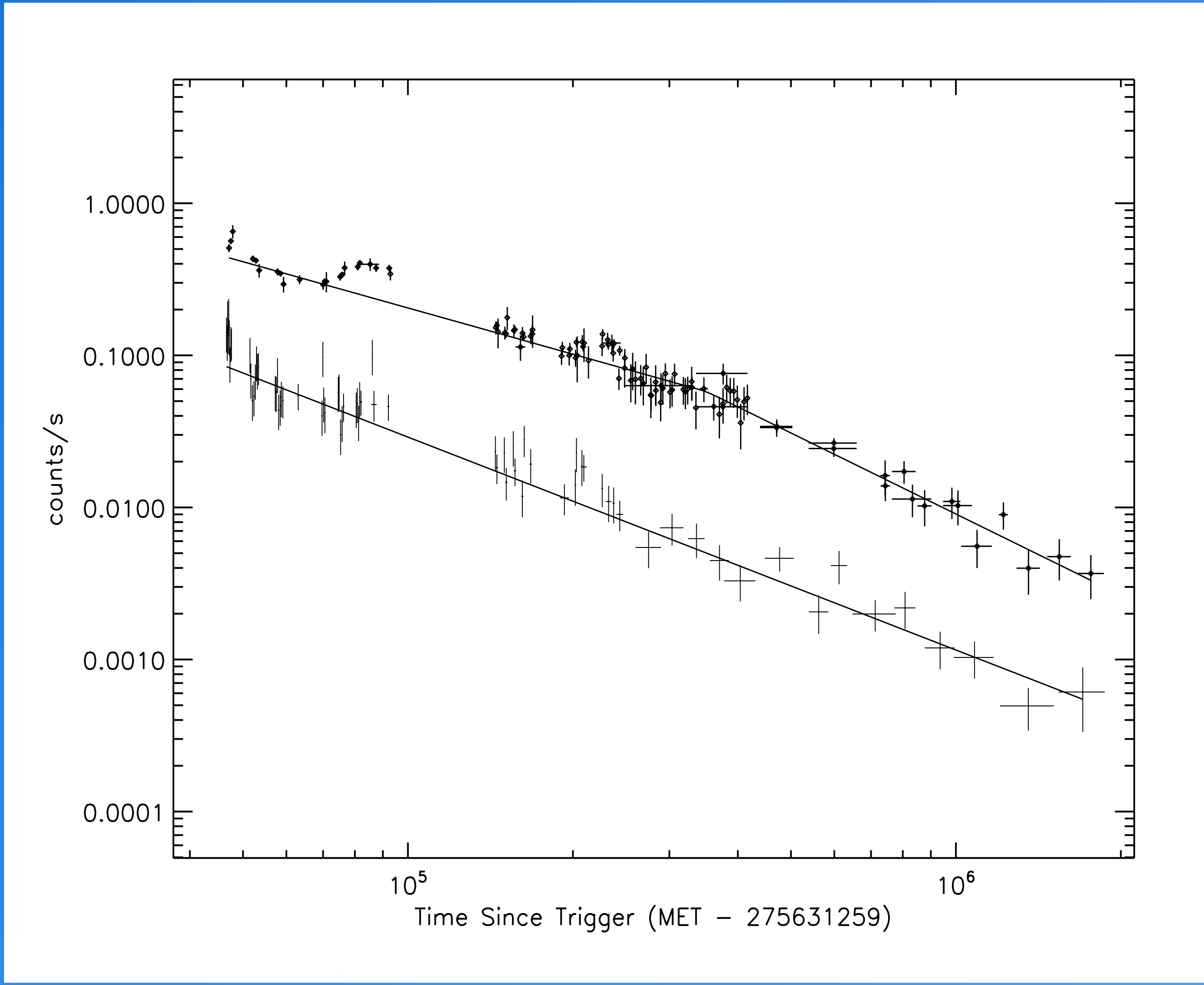
$L = (\log p(D | \theta_j, M_j)) - (\log p(D | \theta_{j+1}, M_{j+1}))$

- BIC is a comparative tool
  - Not a confidence interval or goodness of fit measure
  - A “summary of the evidence provided by the data in favor of one scientific theory, represented by a statistical model, as opposed to another” (Kass&Raftery1995)
  - $BIC_i - BIC_{MIN} < 6$

Flare identification

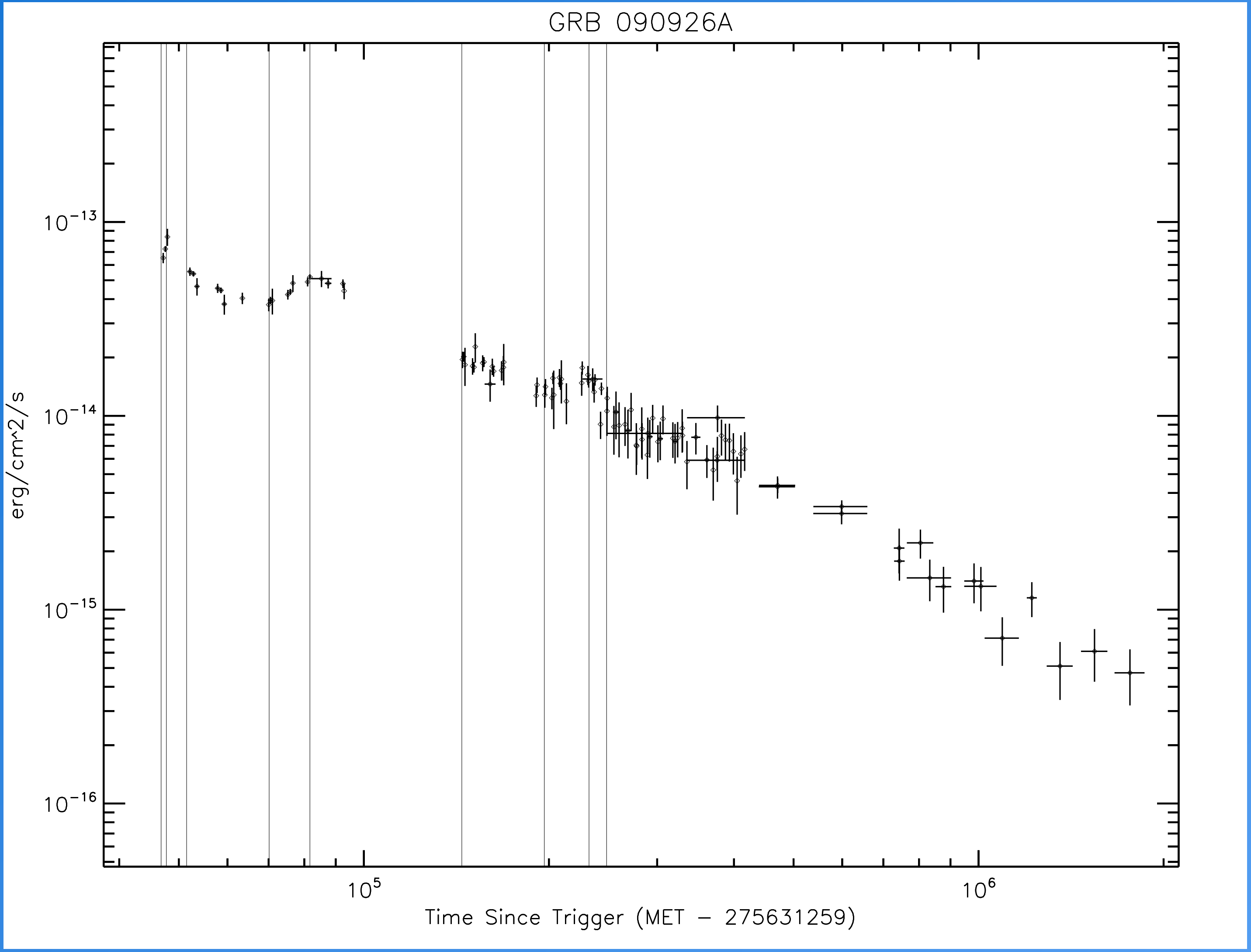
- strucchange package in R (Zeiles+2002)
  - Iteratively fits light curve
  - Identifies optimal number "breakpoints" needed to fit data
  - Calculates BIC value
    - Backstep to avoid over-fitting
- Perform 10,000 Monte Carlo iterations
  - Recoverability/"Confidence"

GRB 090926A



1.0000
0.1000
0.0100
0.0010
0.0001
counts/s
10^5
10^6
Time Since Trigger (MET − 275631259)

GRB 090926A


GRB 090926A
erg/cm^2/s
10^{-13}
10^{-14}
10^{-15}
10^{-16}
10^5
10^6
Time Since Trigger (MET − 275631259)

Flare Catalogs

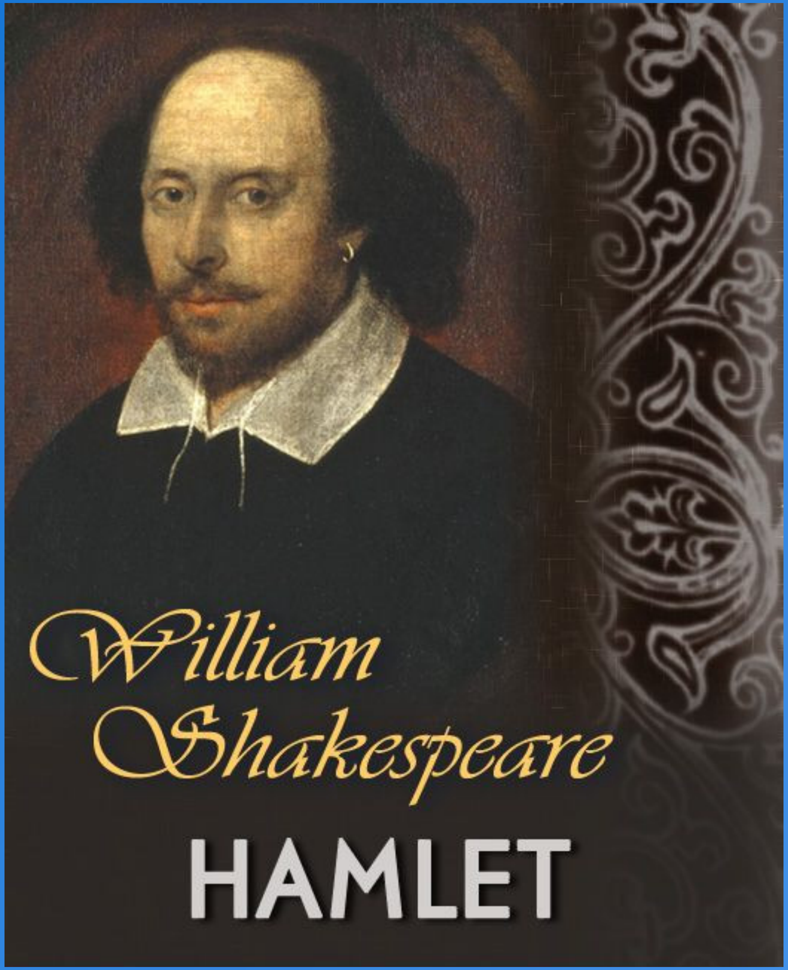
UV/Optical Flaring

- 201 *Swift* UVOT GRB light curves
  - Jan 2005 – Dec 2010
- 68 light curves with flaring (33%)
  - 119 flaring periods
- T_{start}, T_{stop}, T_{peak}, $\Delta t/t$, $\Delta F/F$
- Swenson+2013a (ApJ)

X-ray Flaring

- 680 *Swift* XRT GRB light curves
  - Jan 2005 – Dec 2012
- 324 light curves with flaring (48%)
  - 497 flaring periods
- T_{start}, T_{stop}, T_{peak}, $\Delta t/t$, $\Delta F/F$
- Swenson+2013b (inPrep)

To Flare, or Not to Flare



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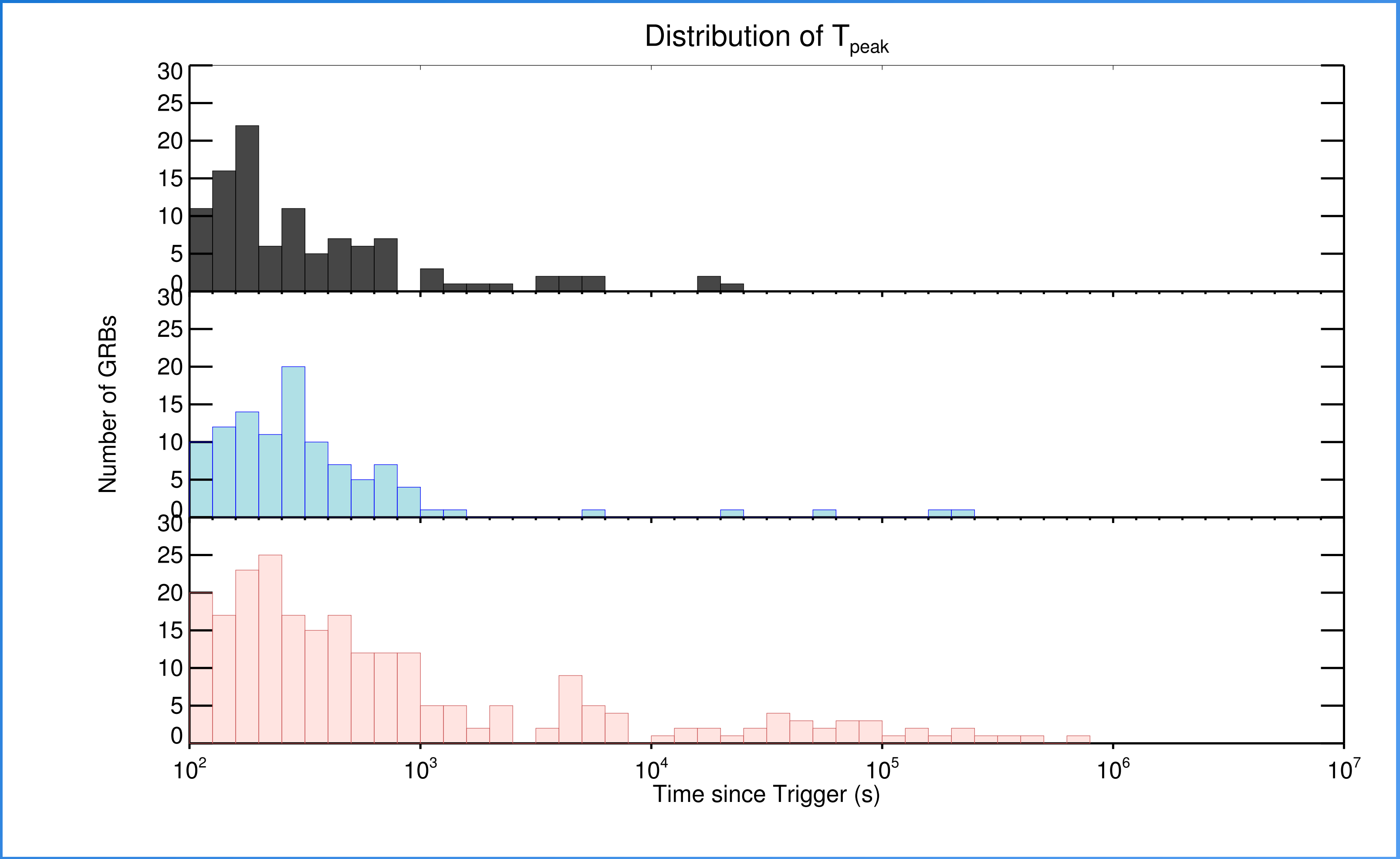
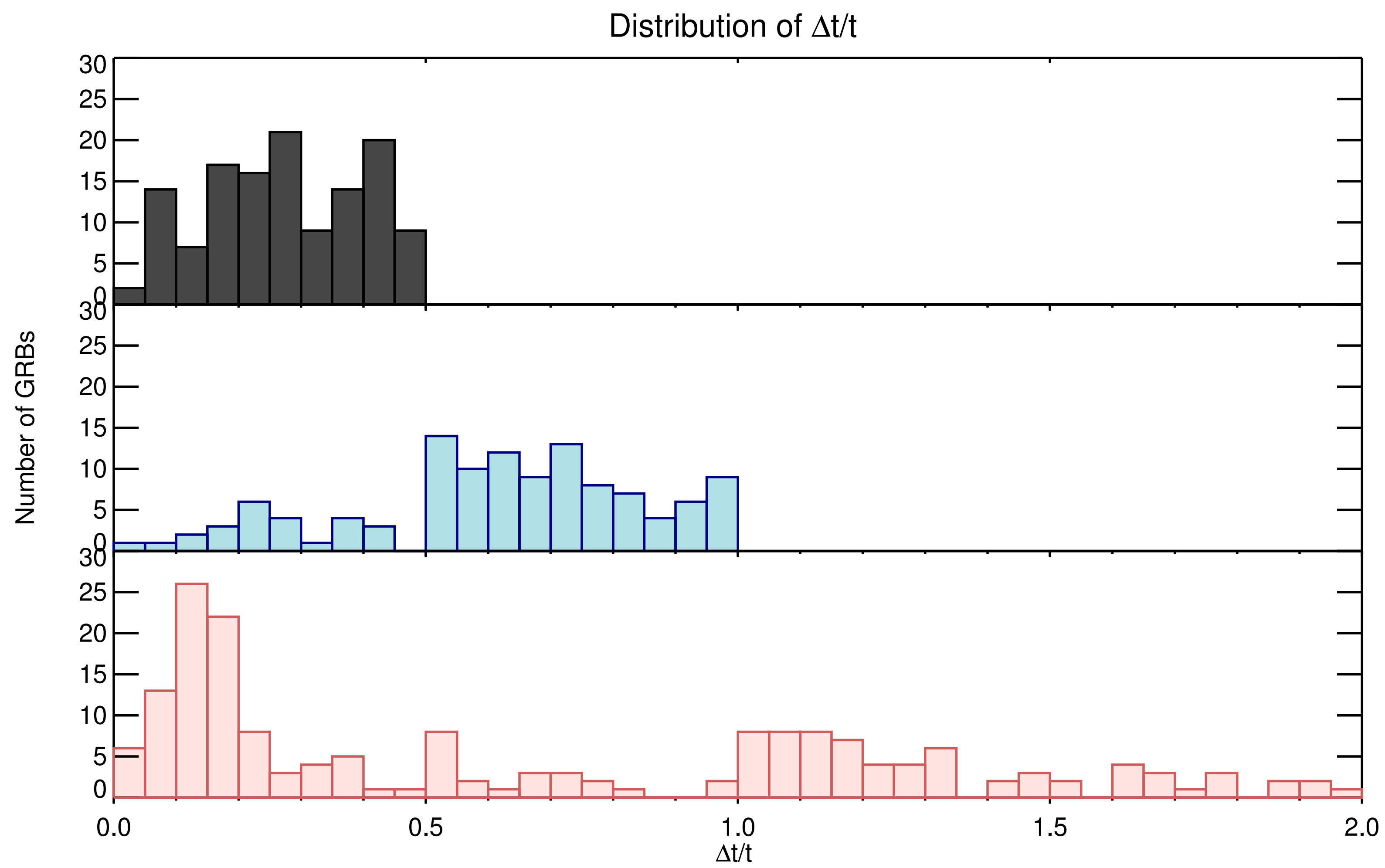
X-ray Flares



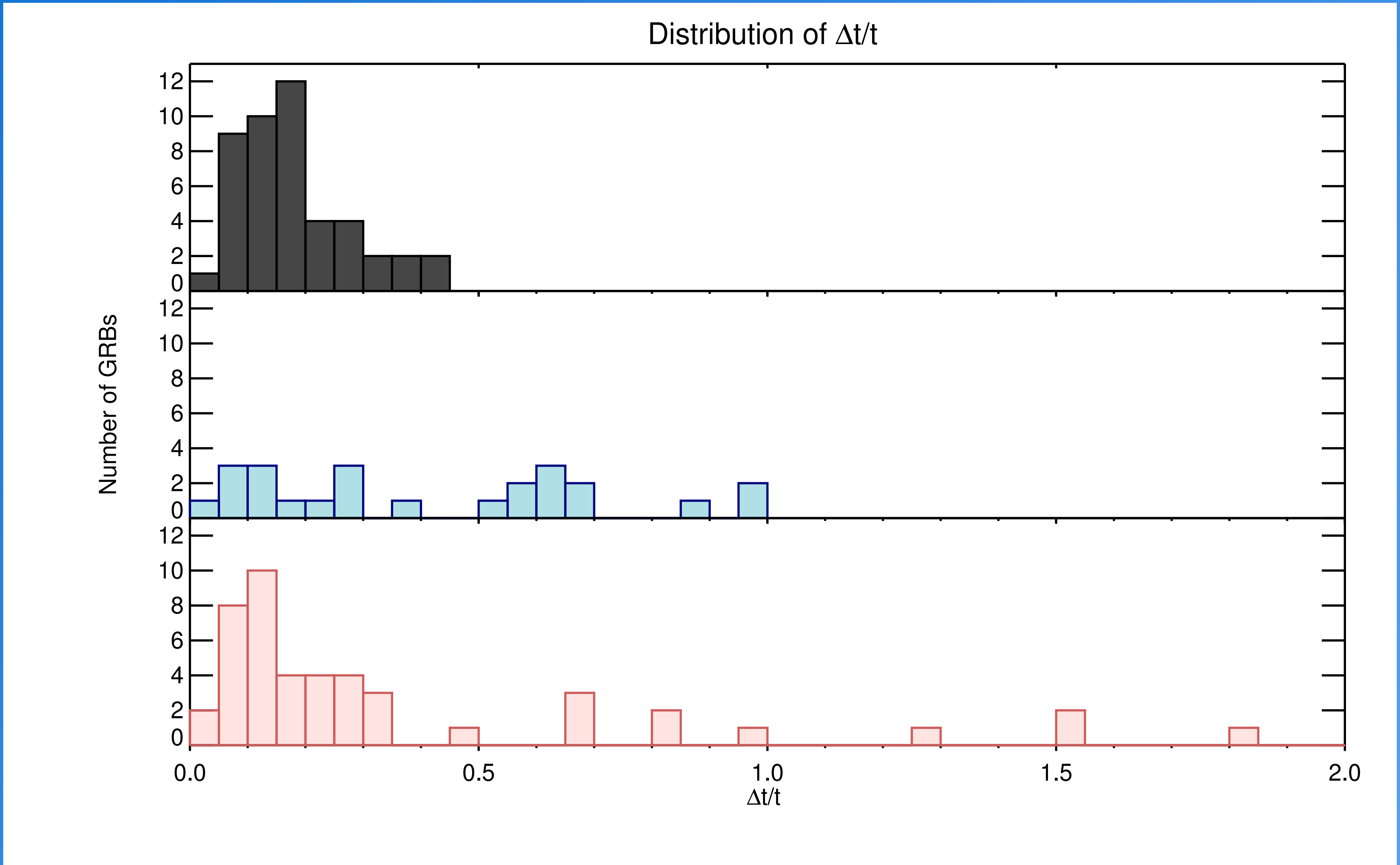
Distribution of T_{peak}
Number of GRBs
30
25
20
15
10
5
0
10^2
10^3
10^4
10^5
10^6
10^7
Time since Trigger (s)

X-ray Flares



Distribution of Δt/t
Number of GRBs
30
25
20
15
10
5
0
0.0
0.5
1.0
1.5
2.0
Δt/t

UV/Optical Flares



Results

- 75% of UV/optical flares with $\Delta F/F > 2$ occurred > 1000 s
  - Not observed in the X-ray
- 83% peak < 1000 s
- Significant number of X-ray flares with $\Delta t/t > 0.5$
  - Allows for external shocks?

Flare cross-correlation

- 263 GRBs with flares (Jan 2005 – Dec 2012)
  - 68 UV/optical
  - 235 X-ray
- 60% of UV/optical have potential X-ray counterparts
  - Similar emission mechanism?
- 40% of UV/optical with no X-ray counterparts
  - Different emission mechanism?
- 83% of X-ray with no UV/optical countparts

Future work

- Examine correlated flares
  - Lag time
- Correlation to GRB energetics
- Why 50/50 split in X-ray flaring
- Flares with $\Delta t/t > 0.5$