A Temporal Study of Multi-episodic Gamma-ray Bursts

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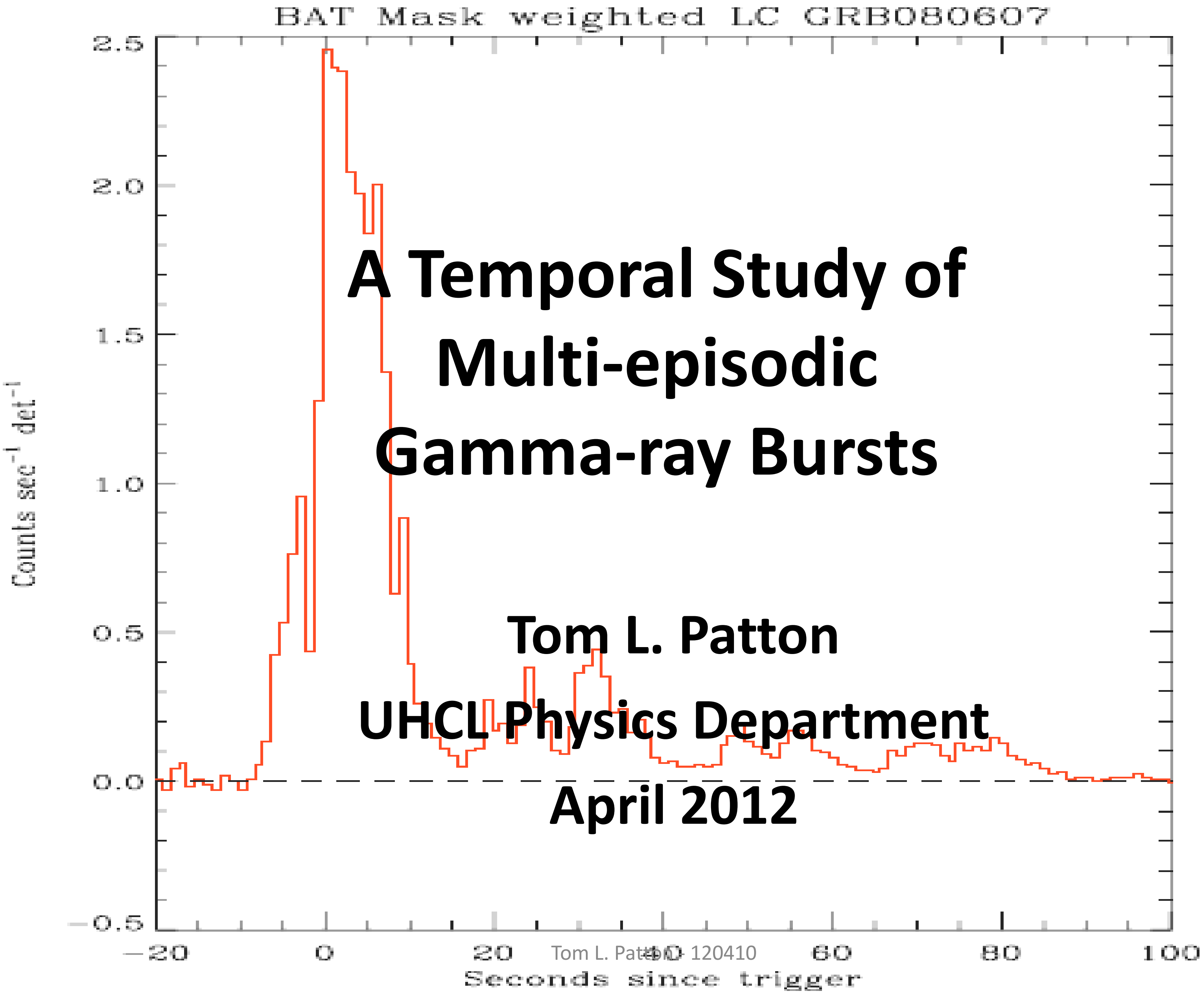
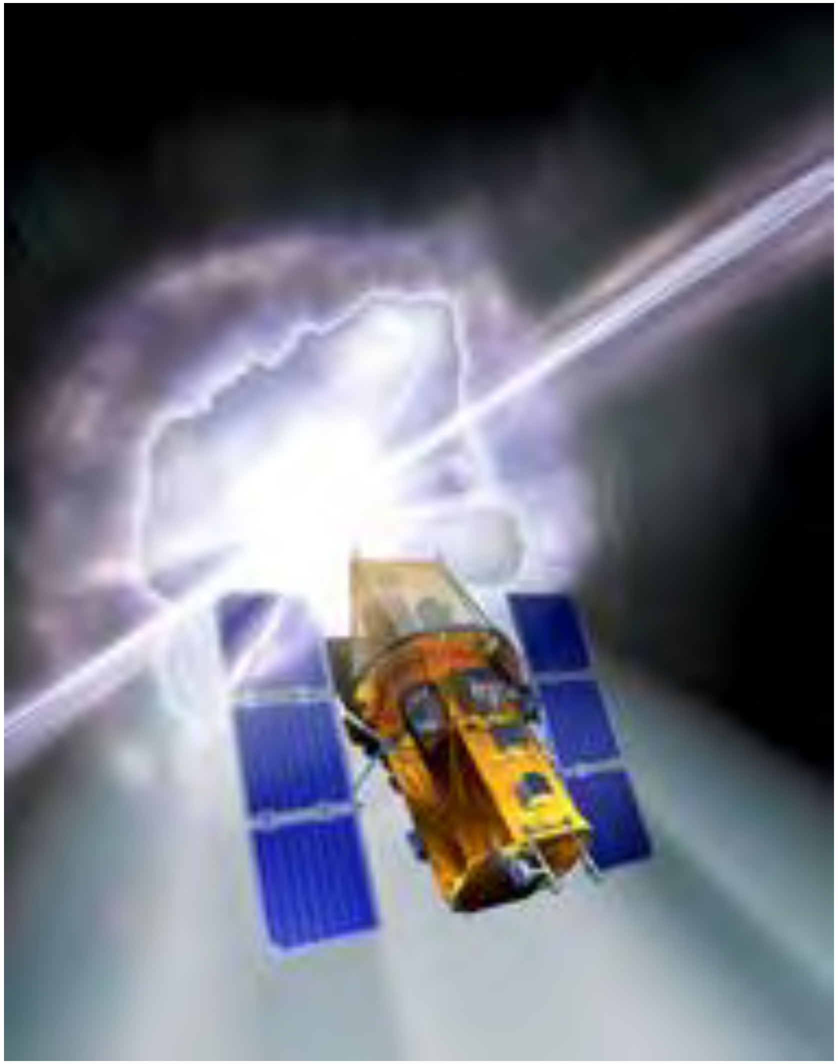


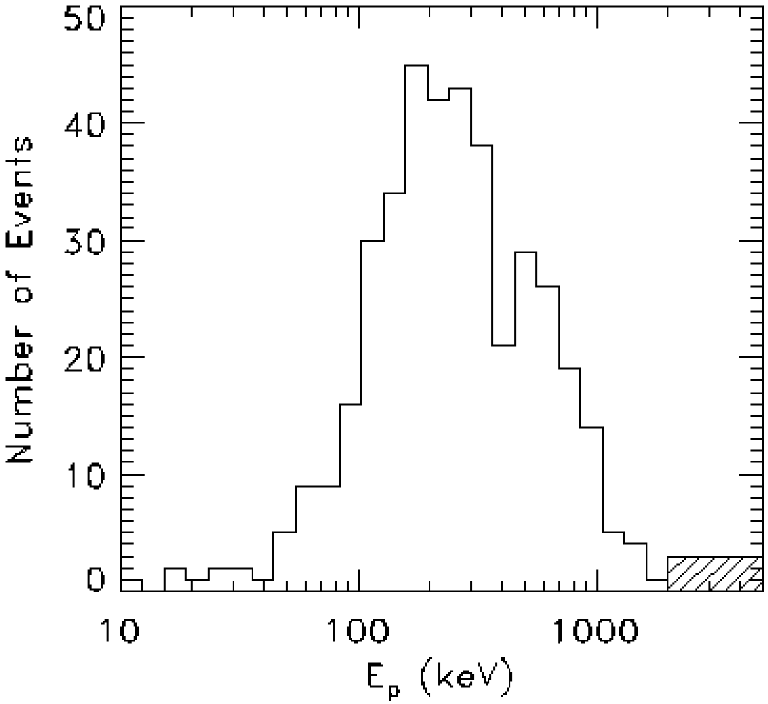
Presentation Agenda

- GRBs: a short history
- GRB phenomenology
- Burst physics
- A temporal study
- Conclusions
- References

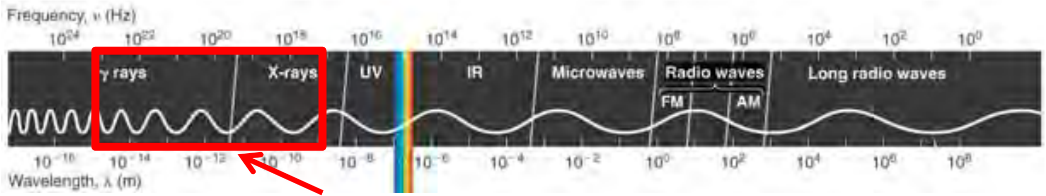


What are Gamma-Ray Bursts?

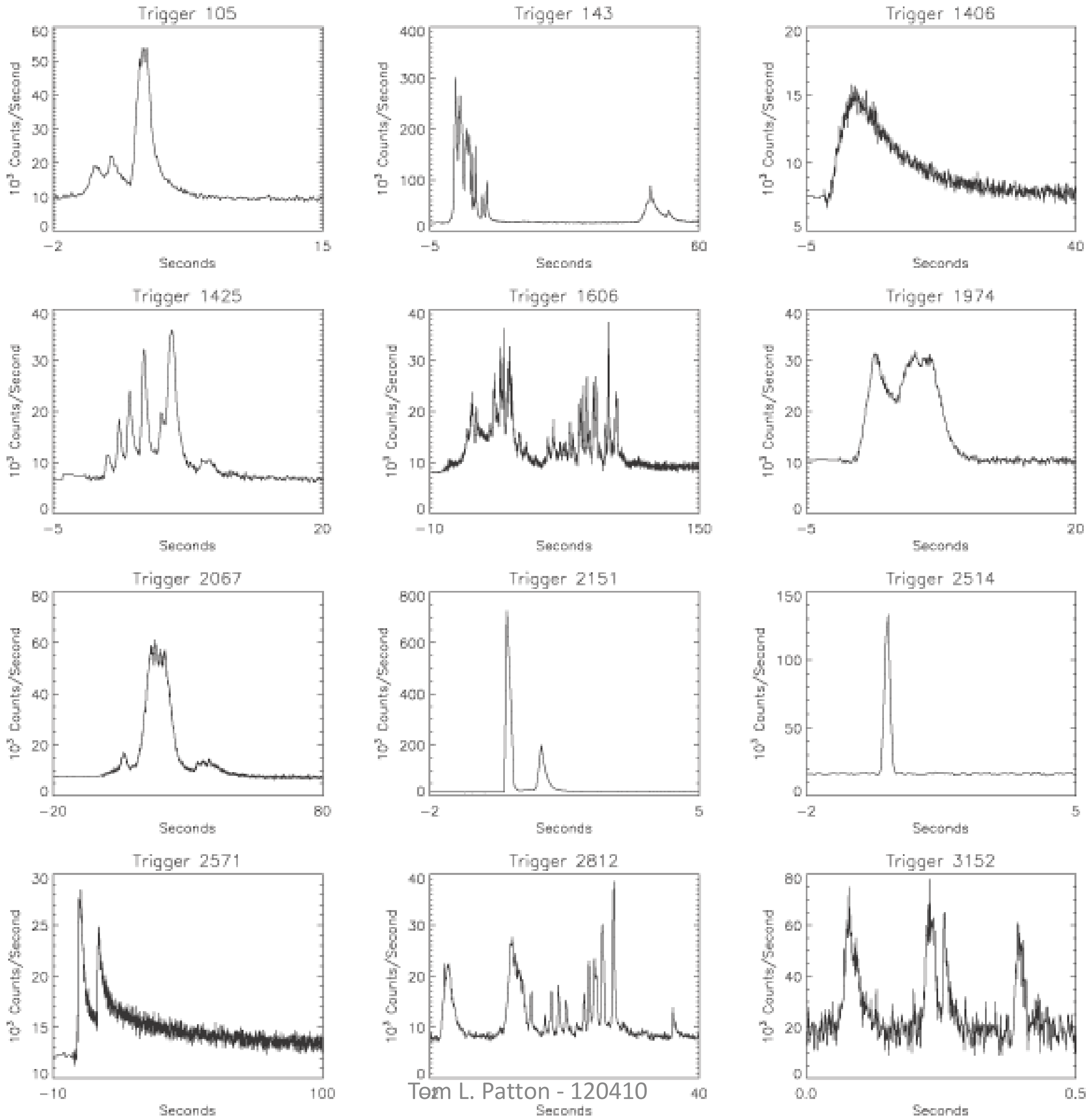
- GRBs are transient, emissions of high energy radiation which spectra are modeled as a broken power law
- Energy for these bursts peak range from several hundred eV to several hundred keV (hard x-rays to soft gamma-rays)
- Events are variable spatially, temporally, and morphologically



(Preece et al., *ApJS* 1999)
(Kaneko et al., *ApJS* 2006)

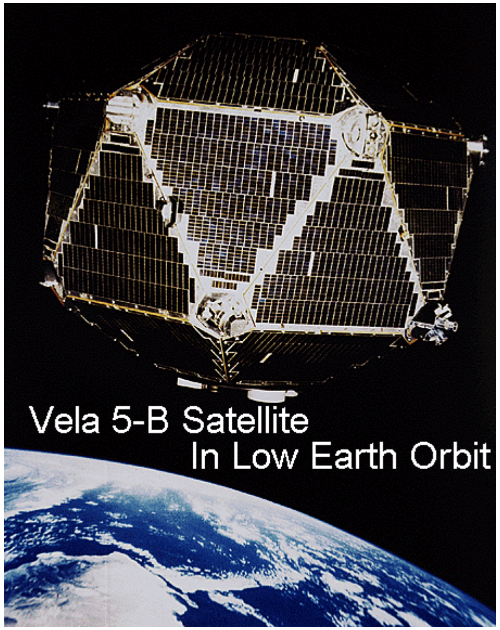


Approximate Energy range


Trigger 105
Trigger 143
Trigger 1406
Trigger 1425
Trigger 1606
Trigger 1974
Trigger 2067
Trigger 2151
Trigger 2514
Trigger 2571
Trigger 2812
Trigger 3152
10^3 Counts/Second
Seconds
-2
15
-5
60
40
-5
20
-10
150
-20
80
-2
5
-10
100
0.0
0.5

A short history…

- The discovery of GRBs
  - Detected by military satellites in 1967
  - Vela satellites used to watch for clandestine nuclear tests by the USSR
  - Classified information, not announced until 1973



A short history…

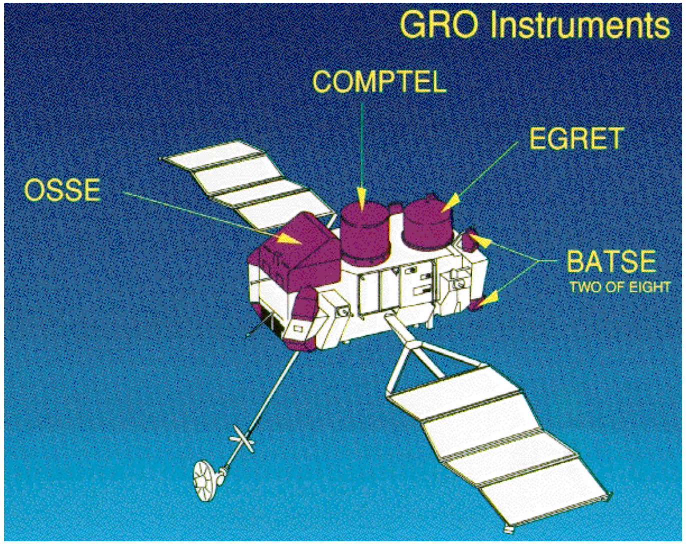
- The discovery of GRBs
  - Many questions related to GRB discovery
    - Where are these events occurring?
    - What are the event’s progenitors?
  - GRBs turned out to be unpredictable in both space and time
    - How will we investigate these events?

A short history…

- Detection evolution
  - After Vela, scientists started attaching gamma-ray spectrometers to interplanetary probes and satellites
  - Venera Satellites with KONUS instruments were launched in the late 1970s to get more accurate location information
  - Compton GRO with BATSE experiment for all-sky capability has detected the majority of GRBs in the catalog of bursts

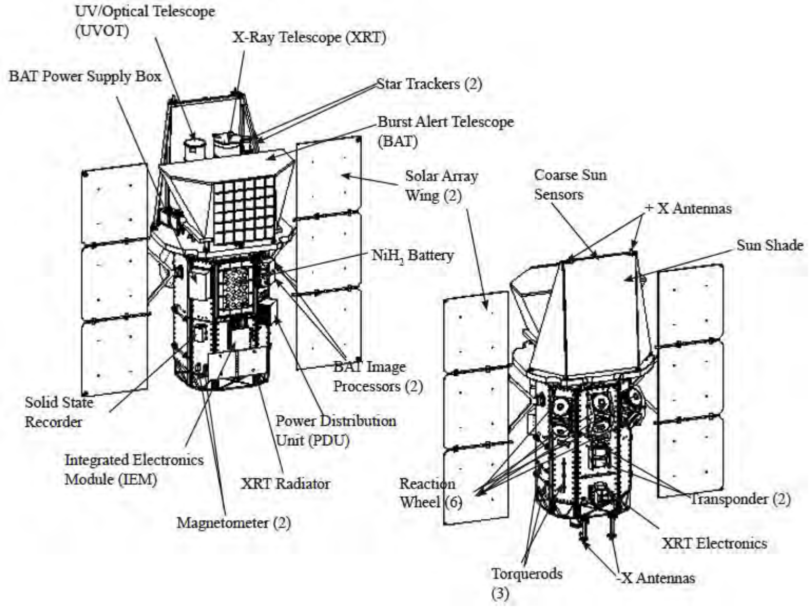
A short history…

- Detection evolution
  - Compton GRO with BATSE experiment for all-sky capability has detected the majority of GRBs in the catalog of bursts
    - 1991-2000
    - Higher sensitivity
    - More than 2500 bursts detected



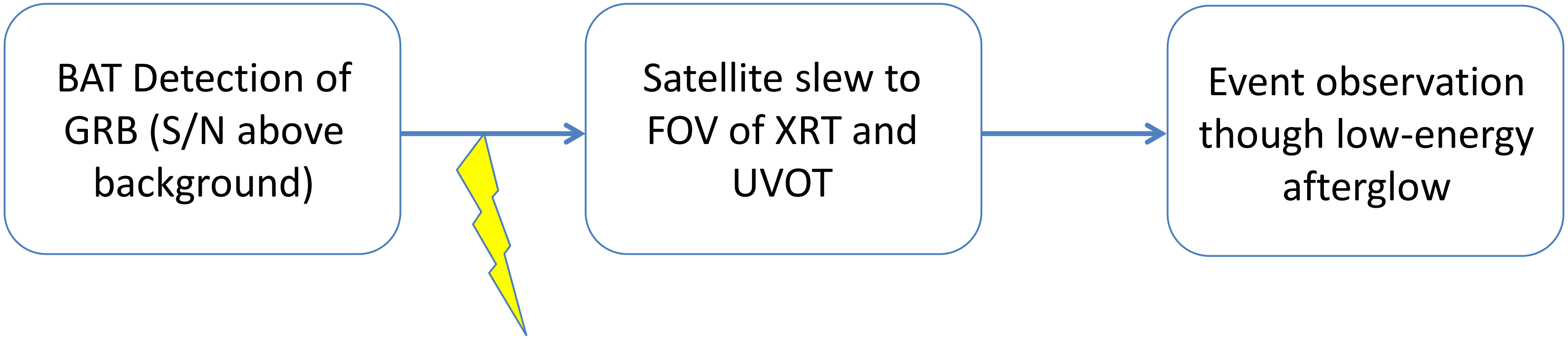
A short history…

- Current experiments
  - First x-ray detection by BeppoSAX in 1997
  - Followed by OT detection
  - Swift satellite
    - Designed specifically for detection and observation of GRBs
    - 3 instruments
    - Launched 2004
    - More than 650 GRBs detected



A short history…

- Current experiments
  - Swift satellite
    - Can maneuver to burst very quickly
    - 2 steradian field of view (~16% of the sky)



BAT Detection of GRB (S/N above background)

Satellite slew to FOV of XRT and UVOT

Event observation though low-energy afterglow

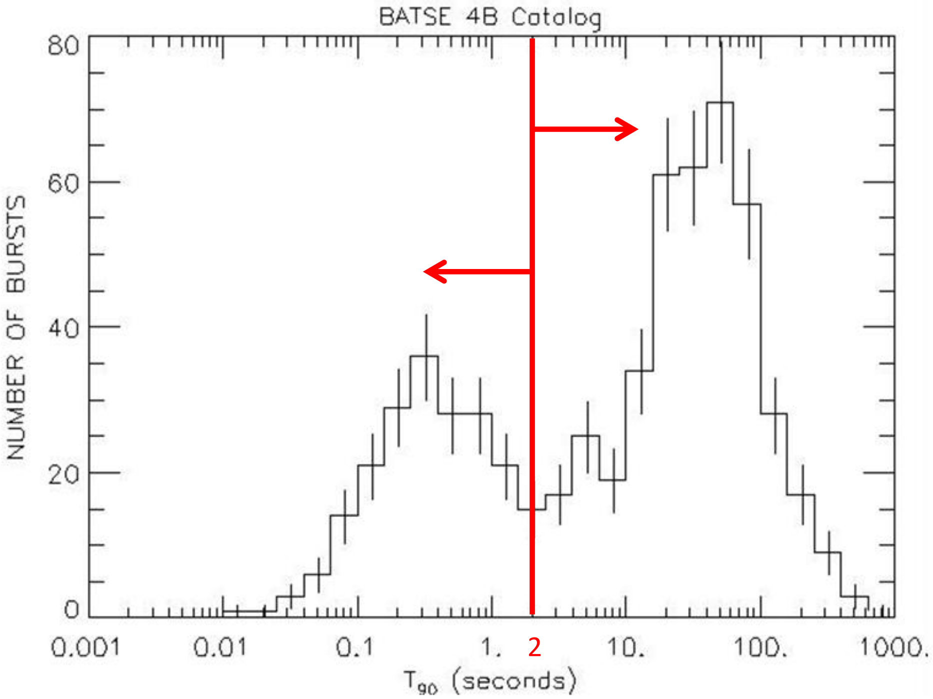
Transmission of GRB coordinates to GCN

Burst Phenomenology

- Observations
  - Most data we have comes from BATSE experiment
  - Some trends we are able to identify
    - Burst duration
    - Burst energies
    - Burst locations

Burst Phenomenology

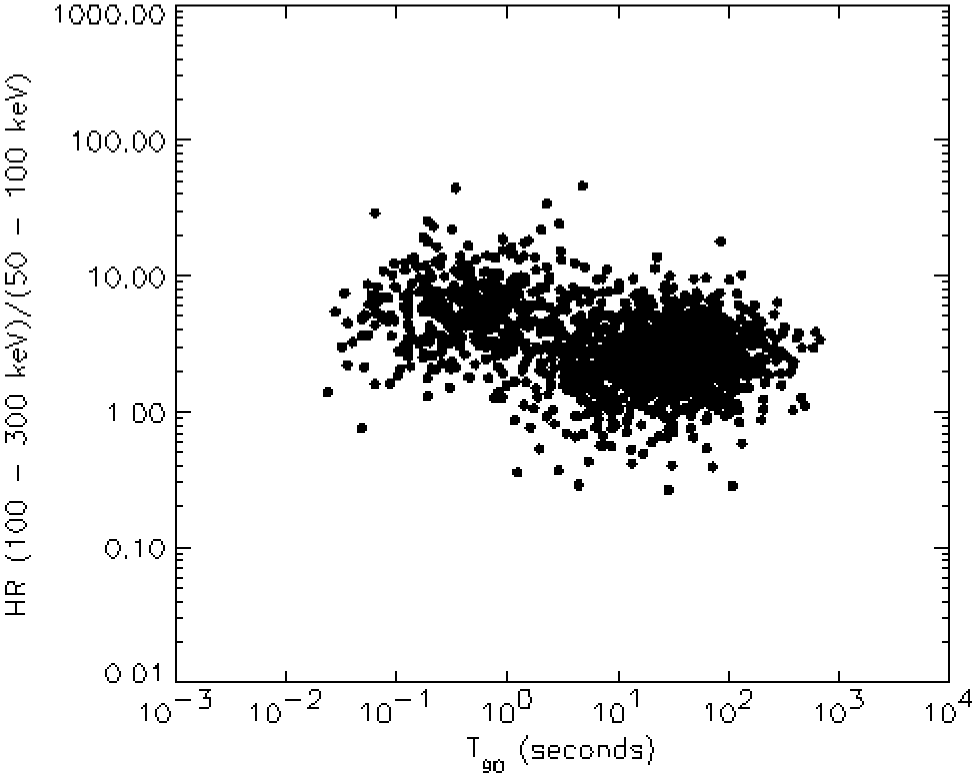
- Types of Bursts
  - Histogram shows bi-modal distribution of GRBs
  - This allows for a loose classification of short GRBs (<2s) and long GRBs (>2s)



(Kouveliotou et al., *ApJ* 1993)
(Paciesas et al., *ApJ* 1999)

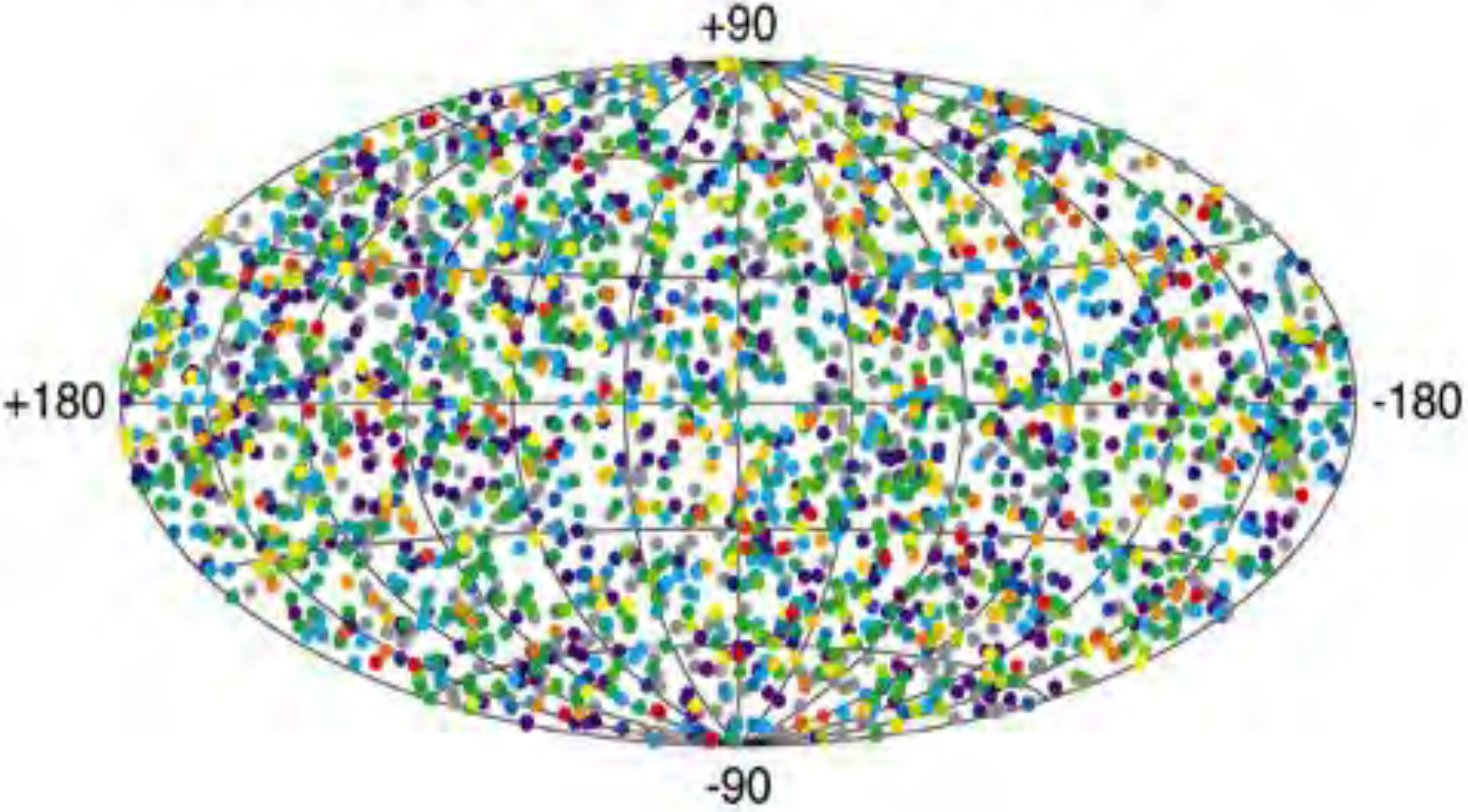
Burst Phenomenology

- Energies
  - In addition to the duration, the peak energy of the burst might be associated with duration
  - Short bursts tend to me more energetic
  - Long bursts, less energetic



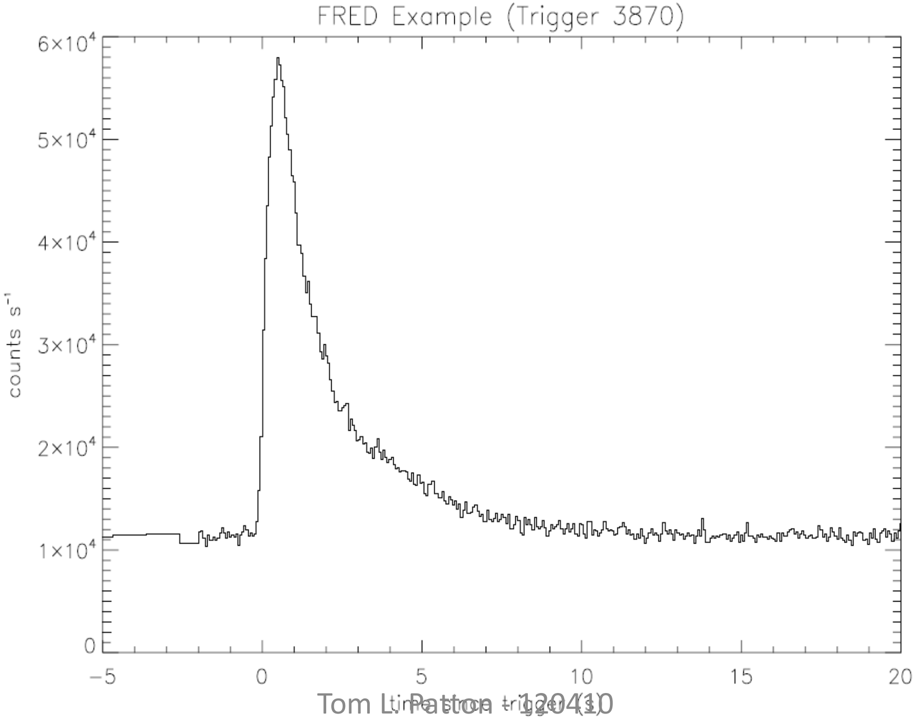
(Kouveliotou et al., 1996)
(Hakkila et al., *ApJ* 2000)

2704 BATSE Gamma-Ray Bursts



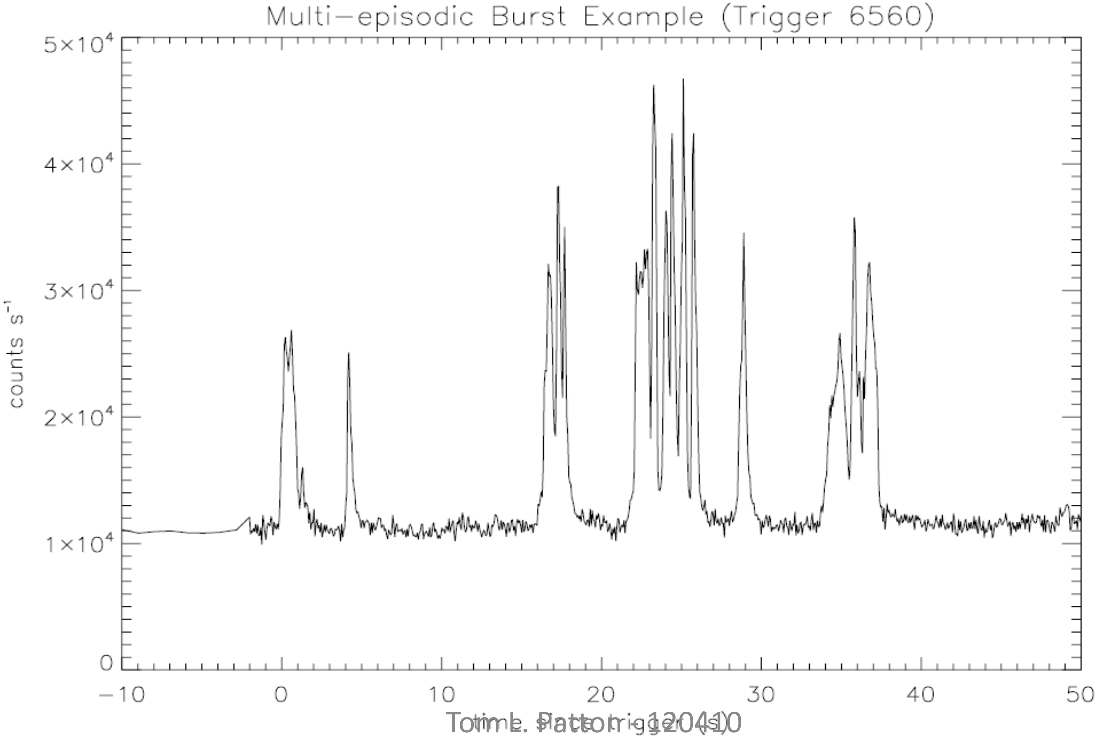
Burst Phenomenology

- Morphology
  - Not every type of GRB exhibits the same behavior
  - FRED (Fast-Rise Exponential Decay) Bursts



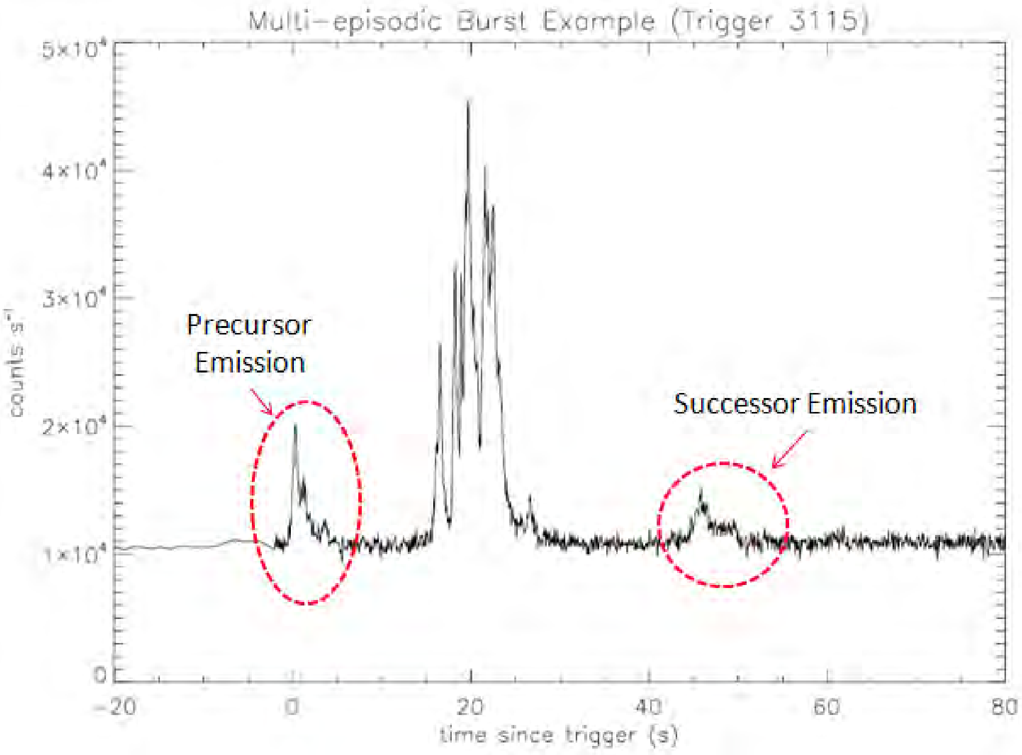
Burst Phenomenology

- Morphology
  - Other bursts are less well-behaved: Multi-episodic bursts



Burst Phenomenology

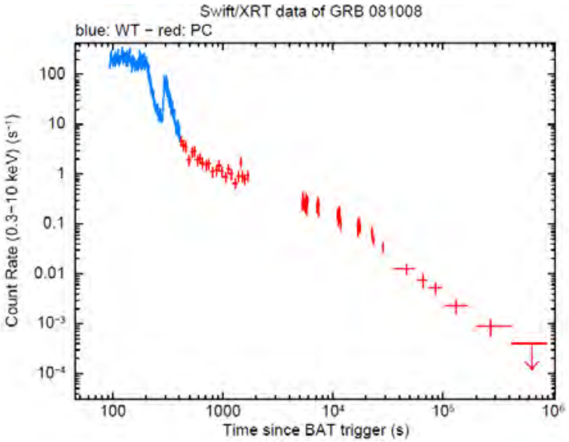
- Morphology
  - Multi-episodic emissions can be further classified
  - Precursor emission
  - Prompt emission
  - Successor emission



Burst Phenomenology

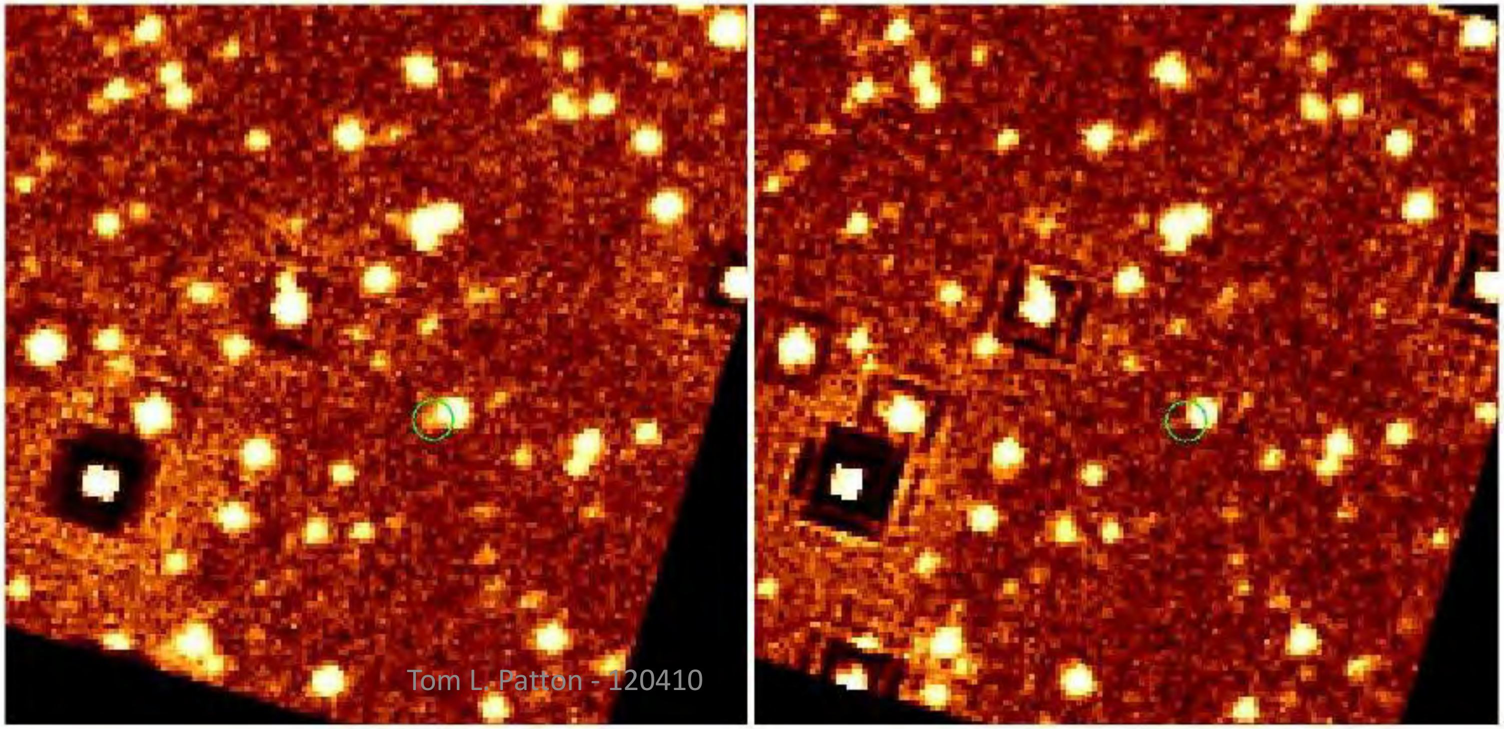
- GRB Afterglow
  - Bursts have extended activity following the emission in gamma rays
  - Followed by X-rays, Ultra-violet, optical, and radio emissions
  - Not all broadband spectra are recorded due to observation constraints

Burst Phenomenology



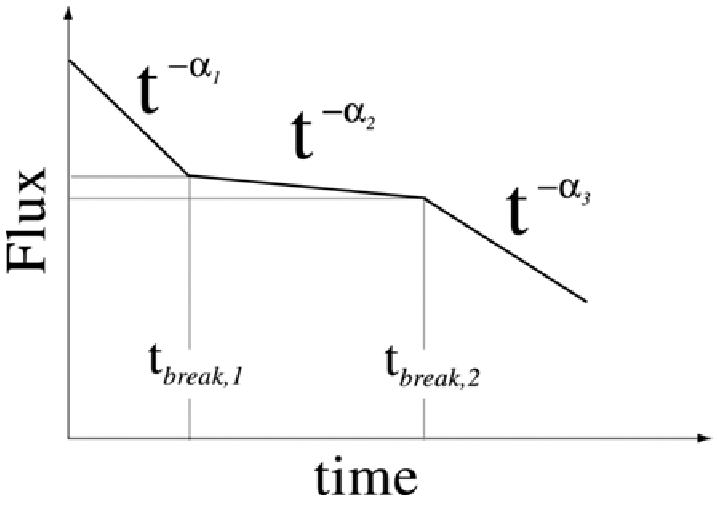
Swift XRT Detection
of
GRB 081008

Swift UVOT
Detection of
GRB 070107

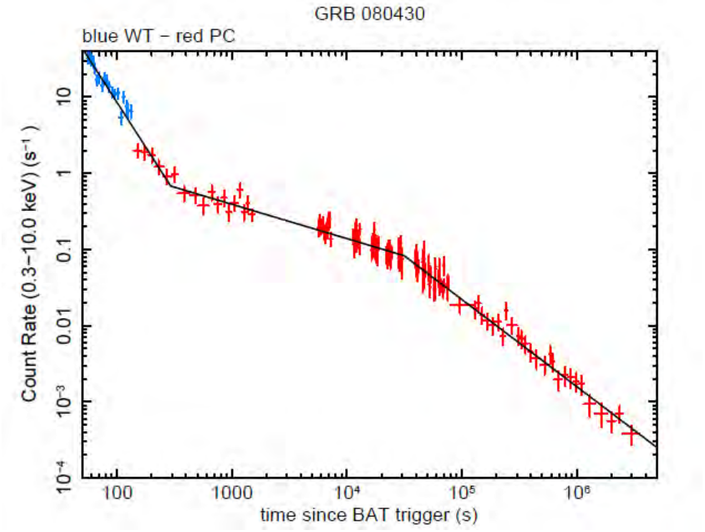


Burst Phenomenology

- GRB Afterglow
  - X-ray afterglow follows the GRB bulk prompt emission, includes X-ray flaring activity
  - Seems to follow a canonical behavior



(Nousek et al., *ApJ* 2006)



Burst Physics

- The Relativistic Fireball
  - GRBs are understood within the framework of a relativistically expanding fireball
  - The short timescale of the GRB emission in conjunction with the electromagnetic travel time across the surface, imply a compact source ~100-1000km….

$$R \geq c\Delta t$$

Burst Physics

- The Relativistic Fireball
  - Bursts release 10 $^{51\text{-}54}$ erg (just as a comparison, that's 1000 times more than a supernova)
  - By associating the energy released with the compact source, one can determine the optical depth of the object by using…

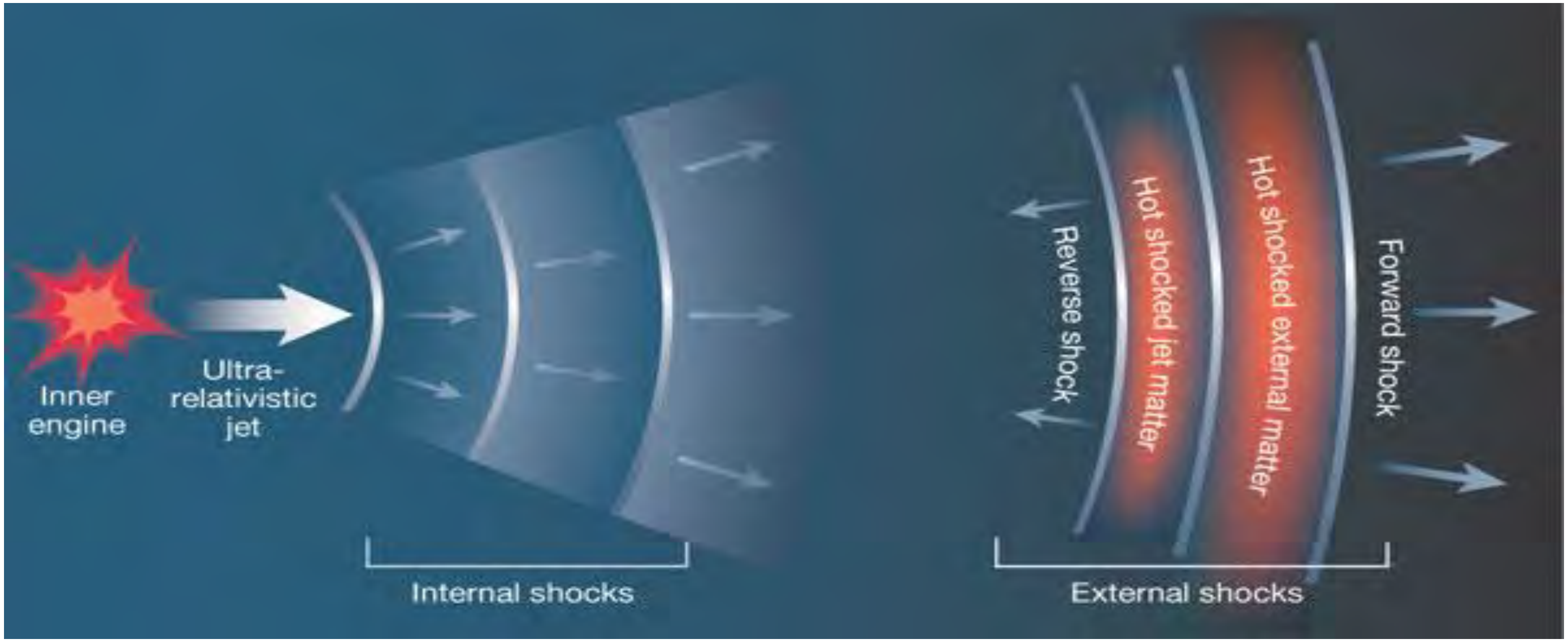
$$\tau_{\gamma\gamma} = \frac{\sigma_T F D^2}{R^2 m_e c^2}$$

Burst Physics

- The Relativistic Fireball
  - The optical depth with the initial conditions proves too high for photons to escape
  - Fireball must expand in order for the GRB to be detected
  - Since we know the distance to, and the radius of the source we can solve for Lorentz factor required for the photons to escape

$$R_f \geq 2\Gamma^2 c\Delta t,\ \Gamma = 10^{2\text{-}3}$$

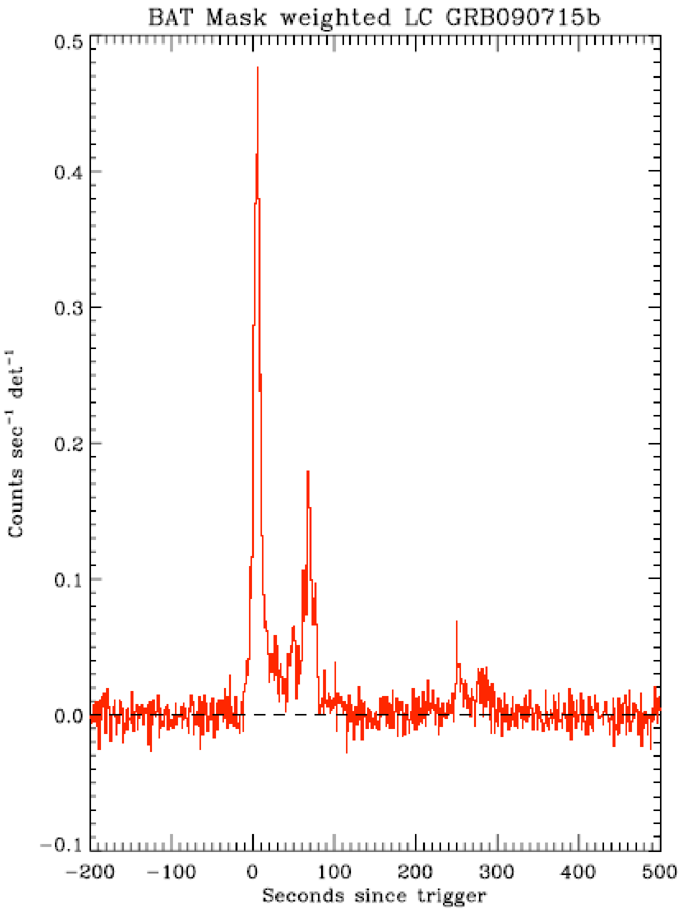
Burst Physics



- Relativistic Shocks
  - This relativistic flow is responsible for the prompt emission and after glow
  - The dissipation of the flow's kinetic energy through shocking (both internal and external)

Burst Physics

- Relativistic Shocks
  - The GRB light curves we see require both types of relativistic shocks: the Internal-External Shock Model
  - Internal shocks release enough kinetic energy to account for the prompt emission and allow for the burst variability…
  - …while the external shocks (lower energy) are responsible for the burst afterglow



Burst Physics

- Jetting
  - The relativistic fireball must expand as a sphere or a collimated jet
  - For a jet, less radiation is expected to been seen following the flow's impact with the medium surrounding the progenitor
  - We see this "break" in the light curve, which allows observers to conclude the expansion takes place as a conical jet

Burst Physics

- What is the progenitor?
  - – GRB progenitors are still largely unknown
  - – Collapsars
  - – Colliding compact objects (NS-BH, NS-NS, etc.)

A temporal study…

- Motivation
  - Multi-episodic bursts are not well understood in the framework of the internal-external shock model
  - Primarily to gleam understanding of the GRB progenitor
  - The multi-episodic nature of GRBs is an excellent laboratory to analyze the nature of the central engine responsible for the emissions detected

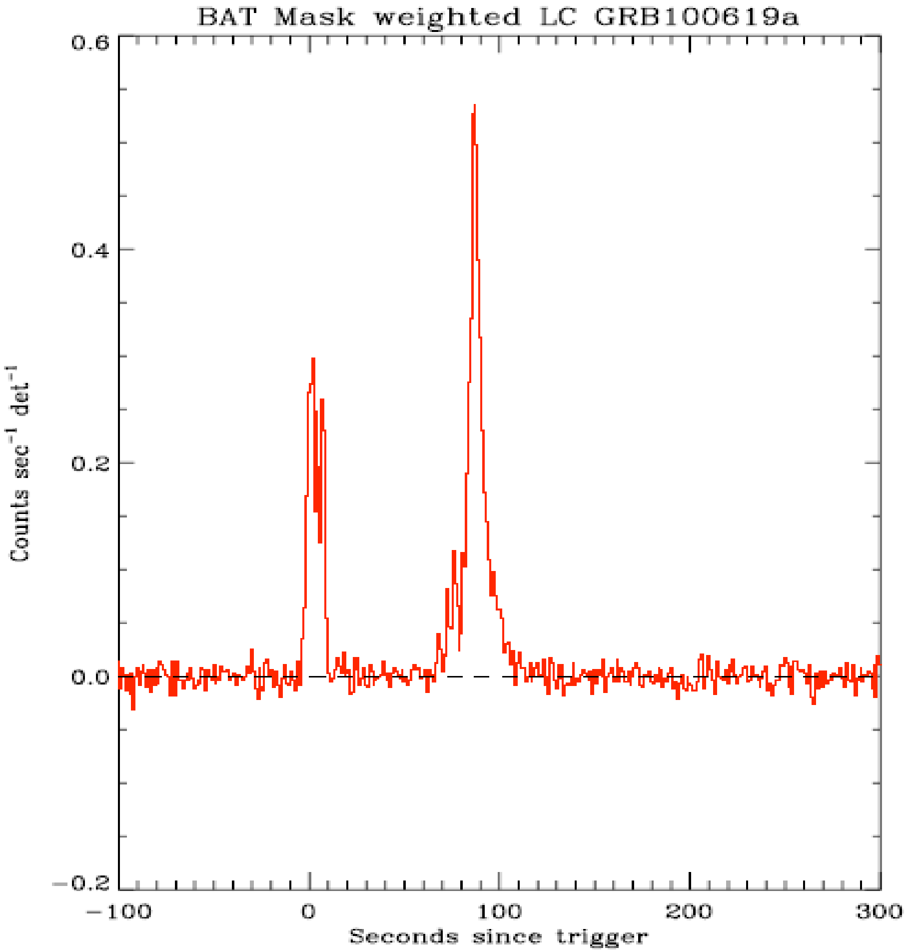
A temporal study…

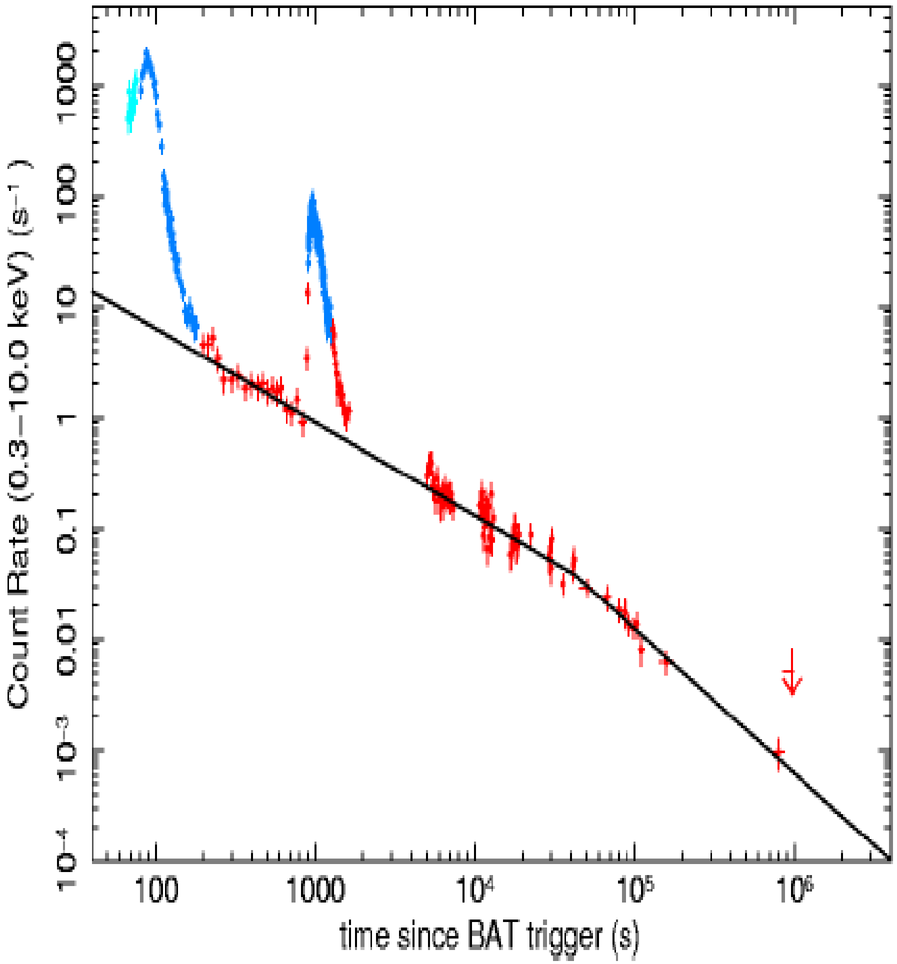
- Previous studies
  - Enrico Ramirez-Ruiz & Andrea Meloni (2000)
    - Work suggested a 1-to-1 correlation between the quiescent time and the after-quiet emission duration
    - Proposed a “hibernating” central engine
  - Timothy Giblin & Jon Hakkila (2004)
    - Late time emission activity resultant to external shocks from relativistic flow generated by progenitor
- Study
  - A survey of multi-episodic events, focusing on data from the Swift satellite’s BAT instrument
  - Gather durations from the burst emissions and quiet time between emissions
  - Examine the durations of emissions and quiet times looking for possible correlations

A temporal study…

- Data set selection
  1. Use of the GRB Coordinate network [GCN]
     - Review of several hundred GCN reports on Swift detected GRBs
     - Also several dozen pre-report GRB notices
  2. Highlight bursts that have multi-episodic morphologies and x-ray afterglow data
  3. Run code to search for statistically significant emission episodes

A temporal study…

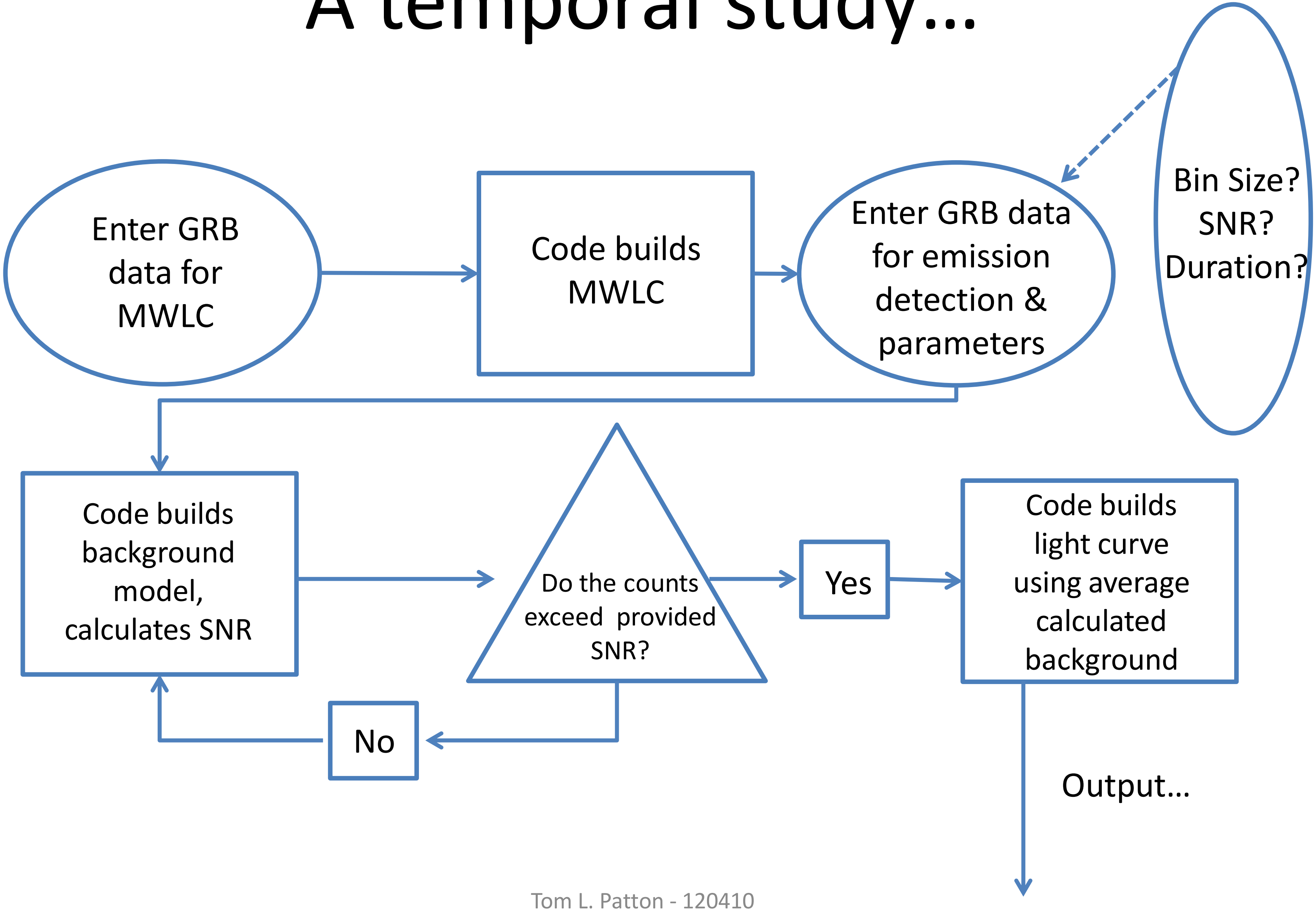




A temporal study…

- Emission Detection Code
  - Requires systematic method to detect statistically significant emission episodes
  - Code development using IDL (Interactive Data Language)
  - Use 64ms event data to develop mask-weighted, source photons for emission time history
  - Use 64ms raw burst count data for development of detection time history

A temporal study…



Enter GRB data for MWLC

Code builds MWLC

Enter GRB data for emission detection & parameters

Bin Size? SNR? Duration?

Code builds background model, calculates SNR

Do the counts exceed provided SNR?

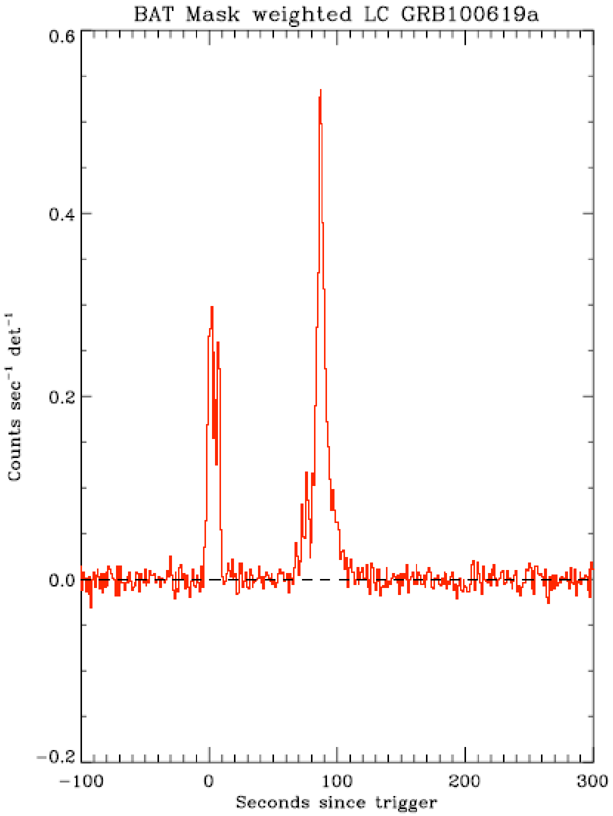
Yes

Code builds light curve using average calculated background

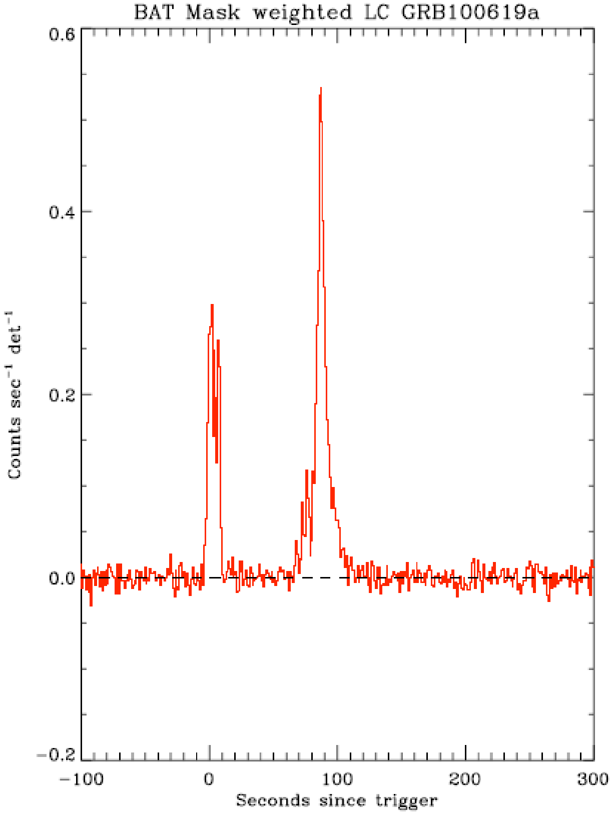
No

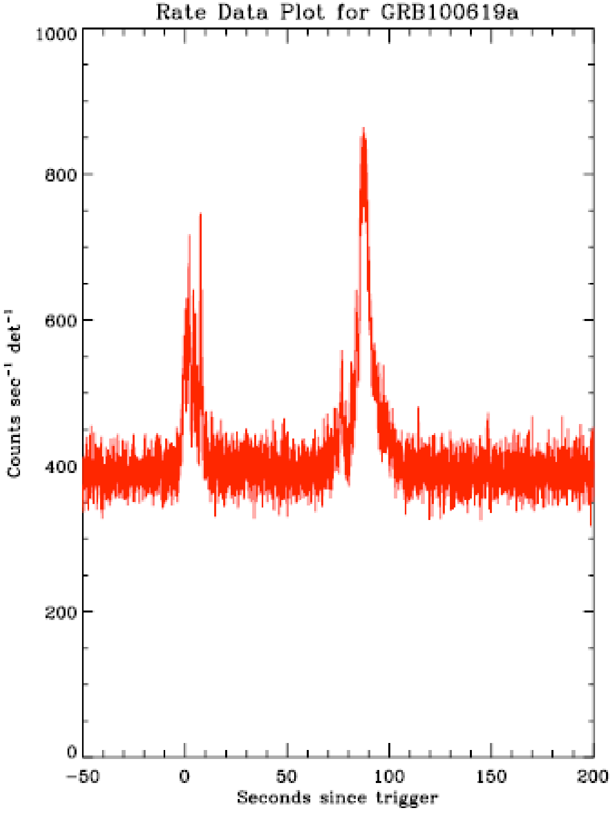
Output…

A temporal study…

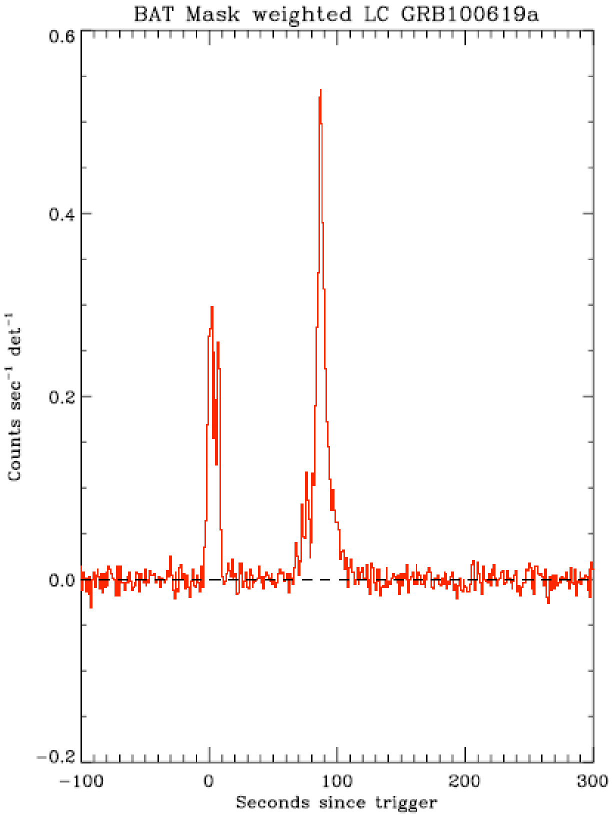


A temporal study…

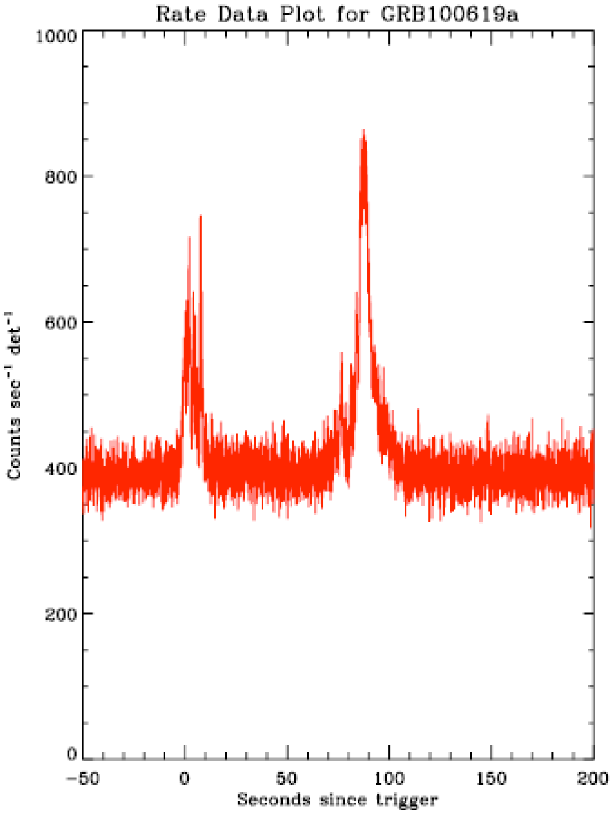




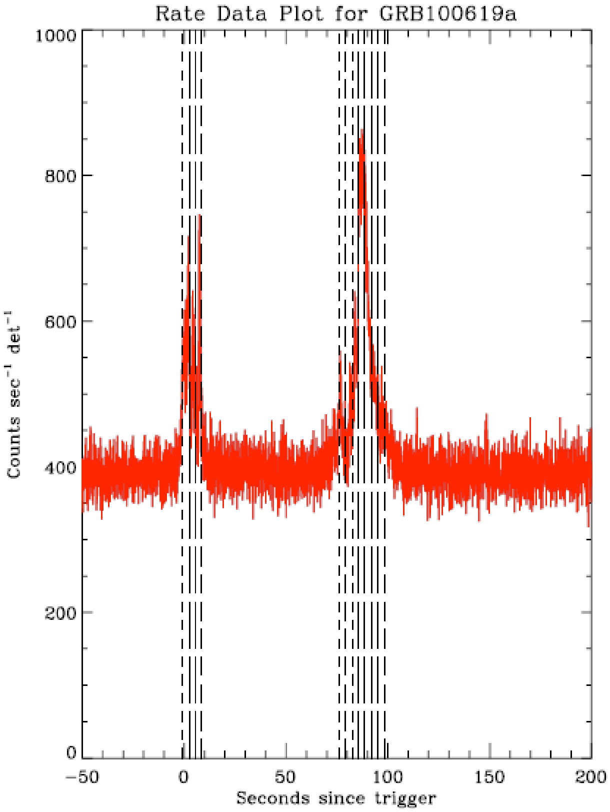
A temporal study…



BAT Mask weighted LC GRB100619a



Rate Data Plot for GRB100619a



Rate Data Plot for GRB100619a

A temporal study…

- Finding appropriate GRBs

143

51

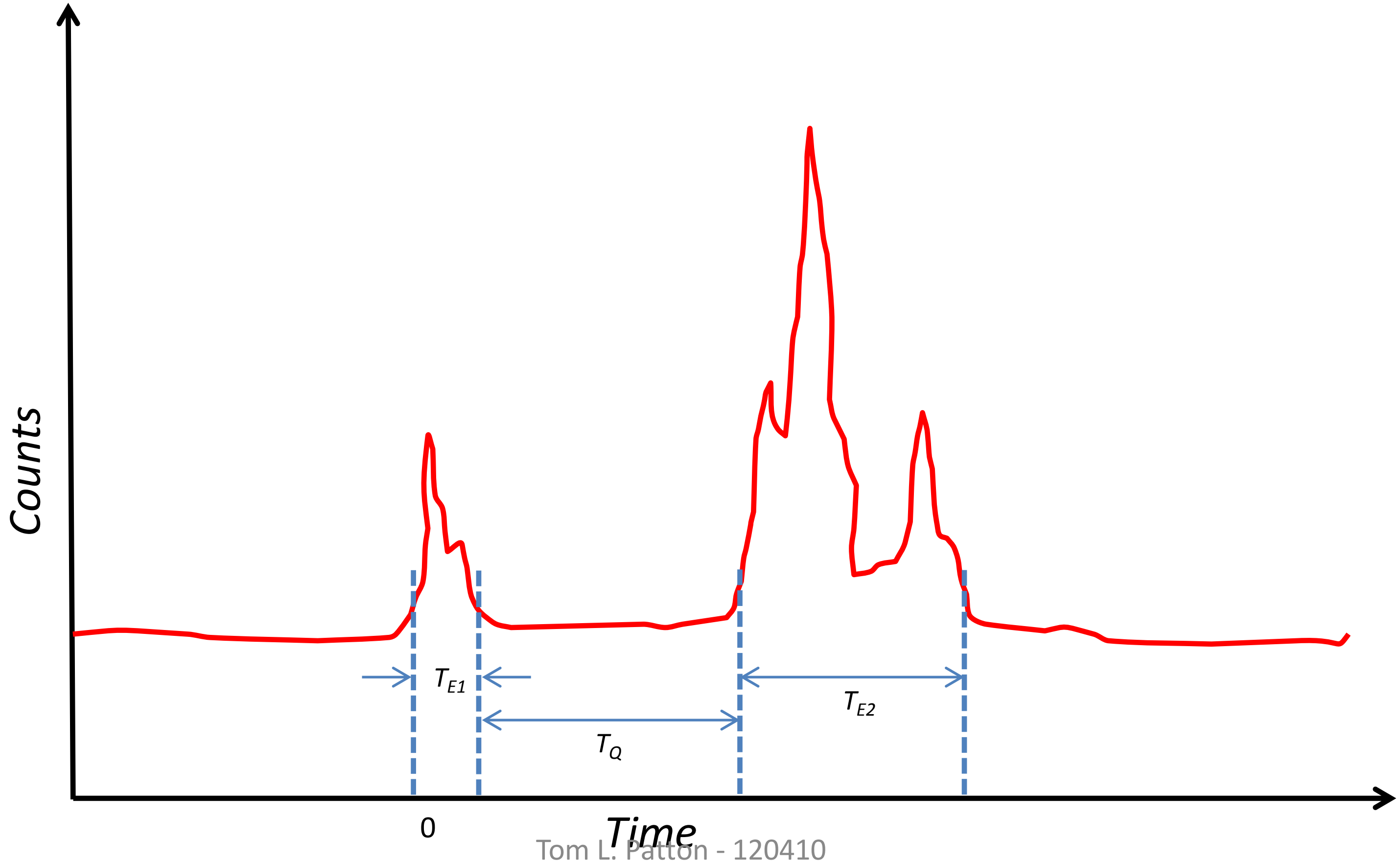
050820A
060115
060526
060814
060926
060929
070107
070318
070704
070721B
070911
071003
071031
071112C
071117
080205
080210
080319C
080320
080413A
080430
080603B
080607
080810
080805
080916A
081008
081102
081126
081210
081230
090530
090715B
090904A
090929B
091029
091221
100212A
100504A
100615A
100619A
100625A
100704A
100728A
100814A
110102A
110915A
111103B
111107A
120102A
120116A
111228A

22

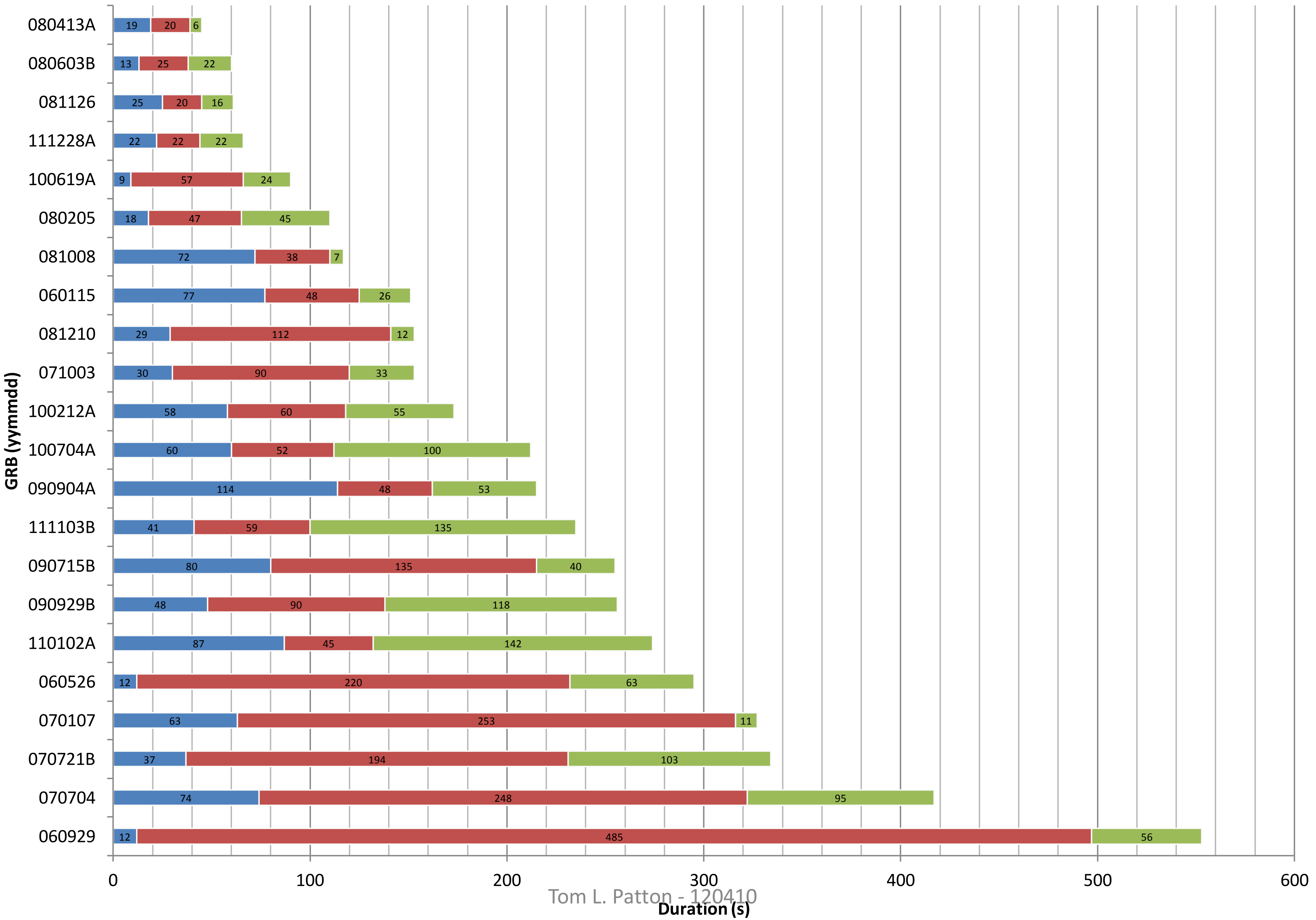
060115
060526
060929
070107
070704
070721B
071003
080205
080413A
080603B
081008
081126
081210
090715B
090904A
090929B
100212A
100619A
100704A
110102A
111103B
111228A

A temporal study…

- Analysis



Multi-Episodic GRB Emission Durations



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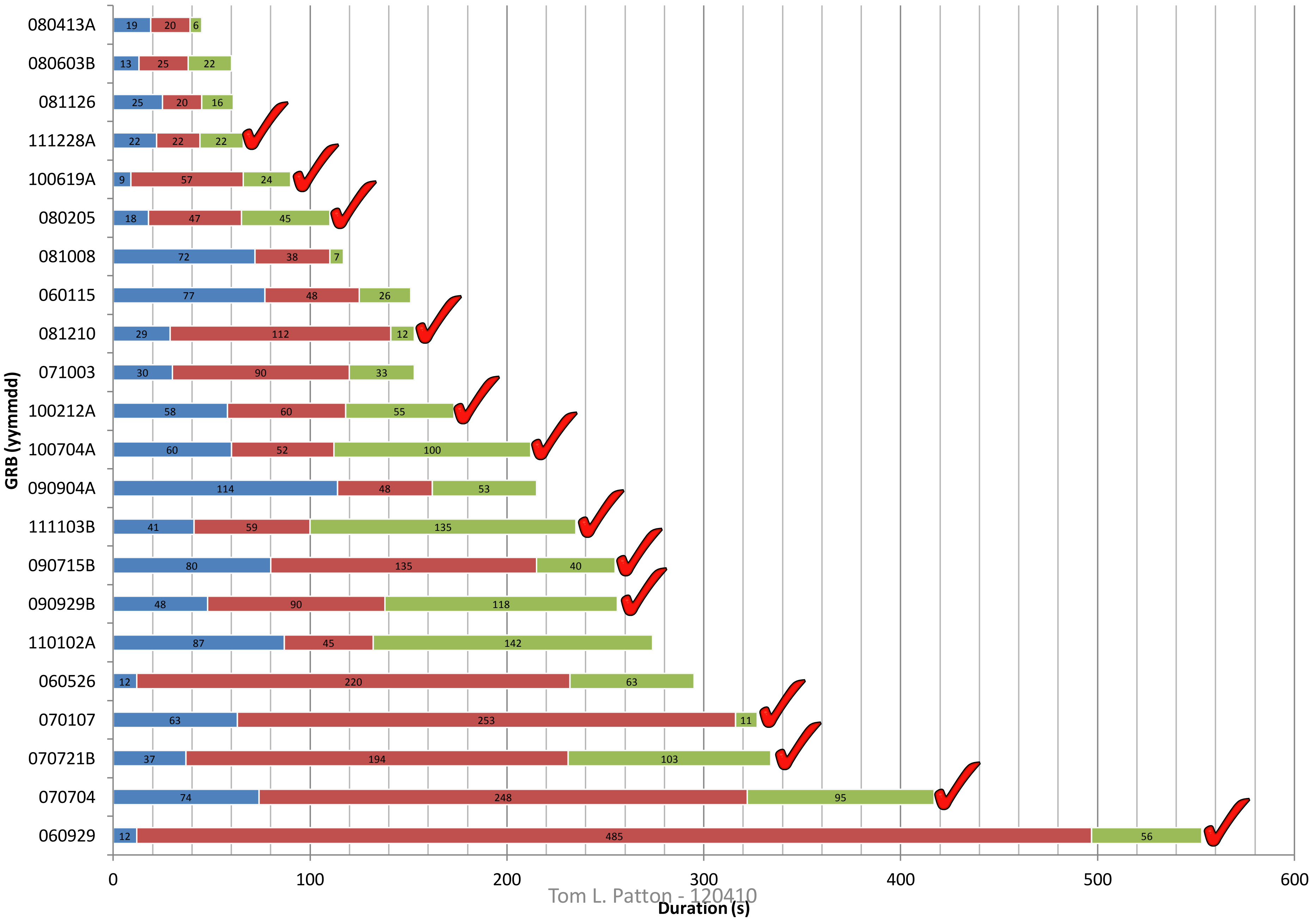
Multi-Episodic GRB Emission Durations



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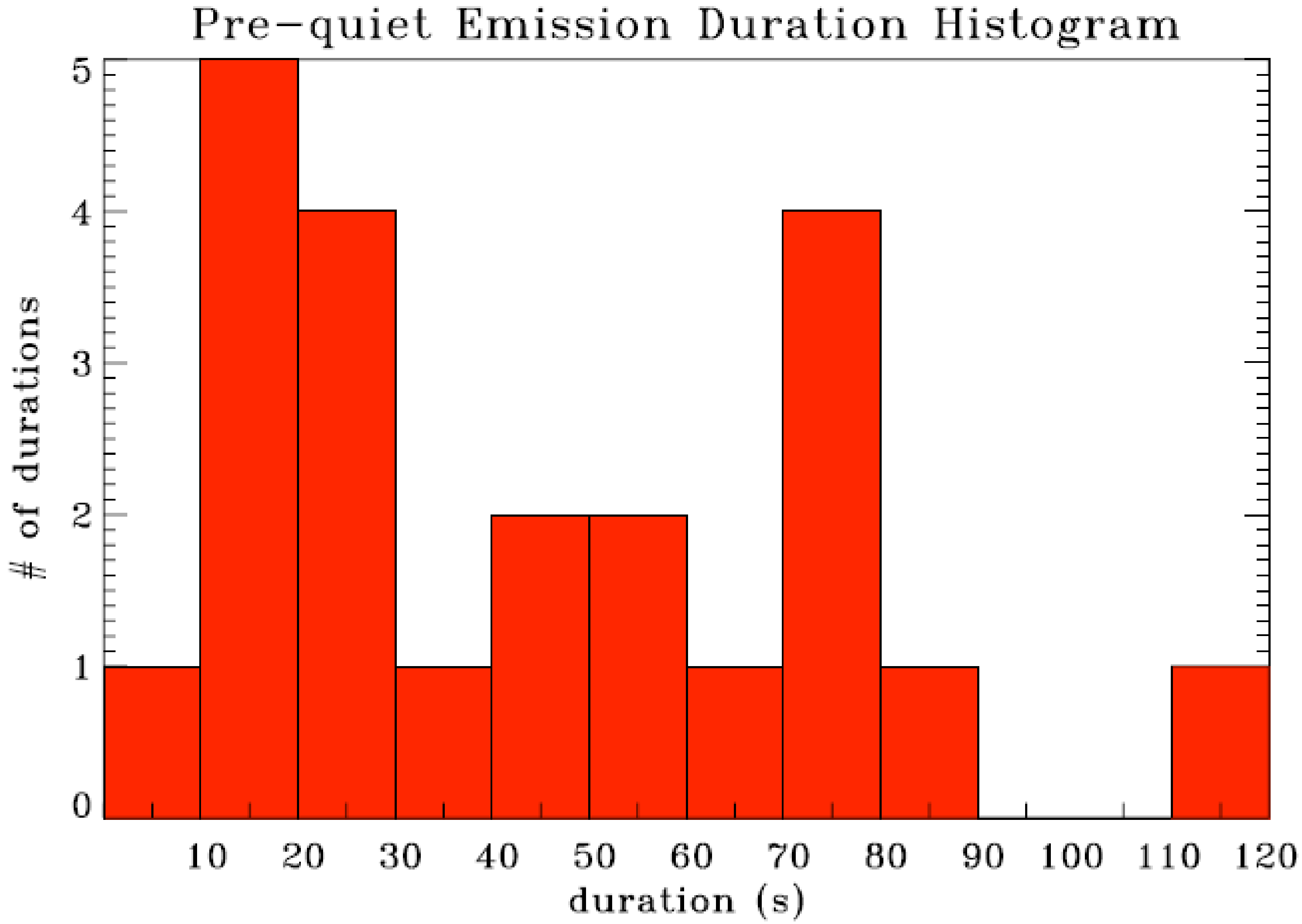
A temporal Study…

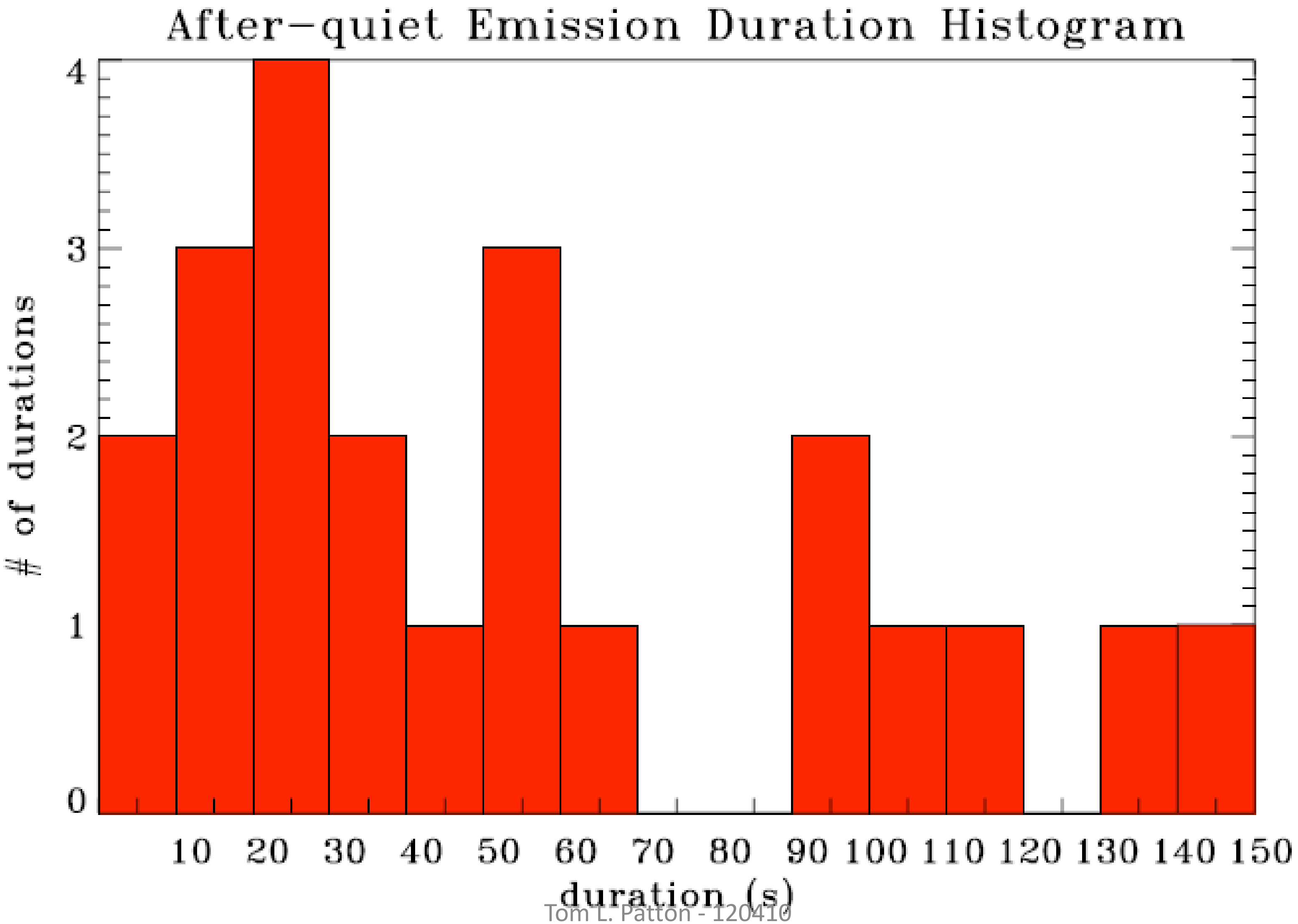
- Quiet time durations
  - Durations account for an average of 46.5% of the burst total duration
  - Standard deviation of percentages is 19.6%
  - Lowest 16.4% of duration
  - Highest 87.7% of duration

GRB	***Pre-quiet emission duraiton (s)***	***Quiet time***	***After-quiet emission duration (s)***	***Quiet time percentage of total duration***
060115	77	48	26	31.79
060526	12	220	63	74.58
060929	12	485	56	87.70
070107	63	253	11	77.37
070704	74	248	95	59.47
070721B	37	194	103	58.08
071003	30	90	33	58.82
080205	18	47	45	42.73
080413A	19	20	6	44.44
080603B	13	25	22	41.67
081008	72	38	7	32.48
081126	25	20	16	32.79
081210	29	112	12	73.20
090715B	80	135	40	52.94
090904A	114	48	53	22.33
090929B	48	90	118	35.16
100212A	58	60	55	34.68
100619A	9	57	24	63.33
100704A	60	52	100	24.53
110102A	87	45	142	16.42
111103B	41	59	135	25.11
111228A	22	22	22	33.33

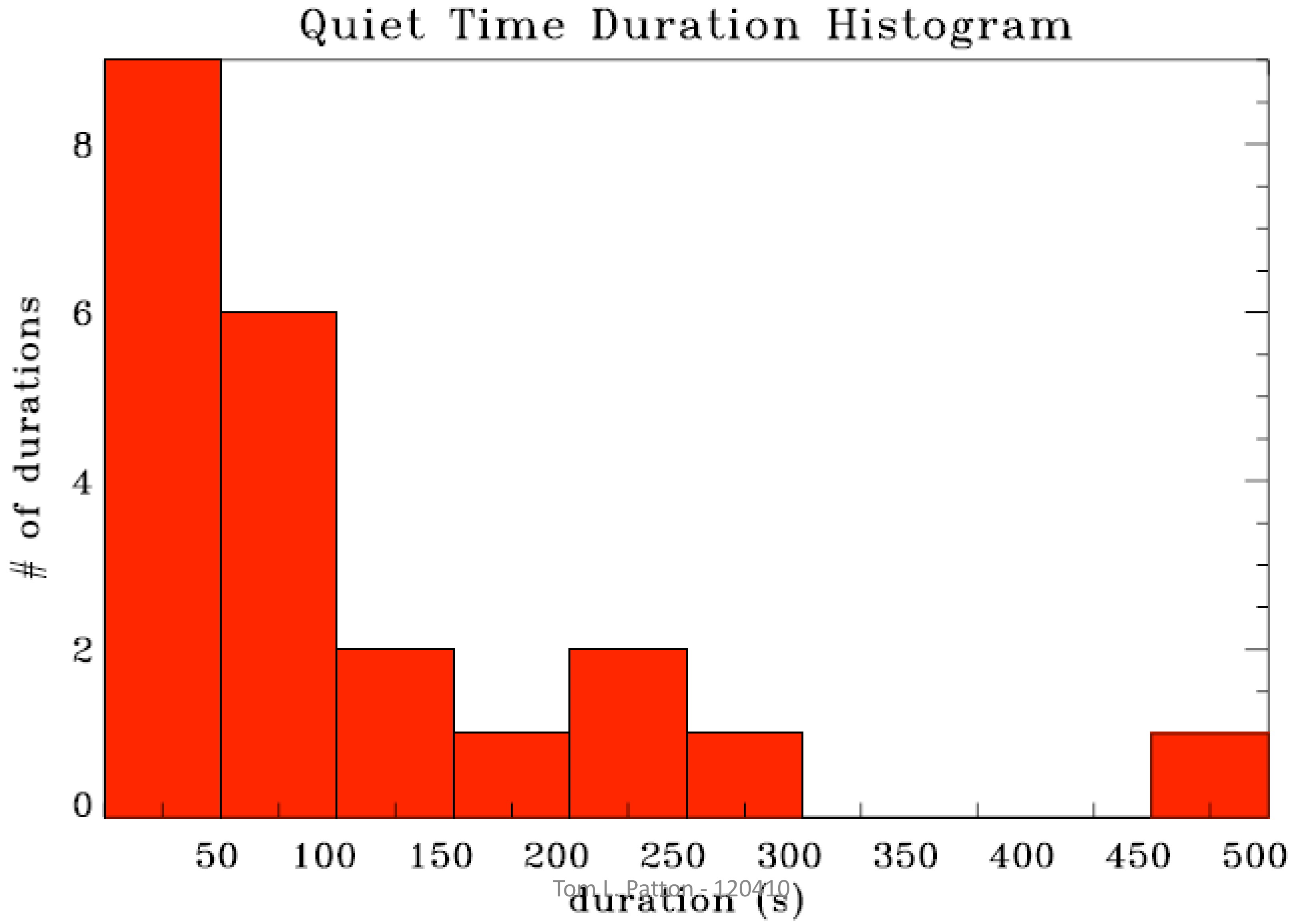
A temporal study…



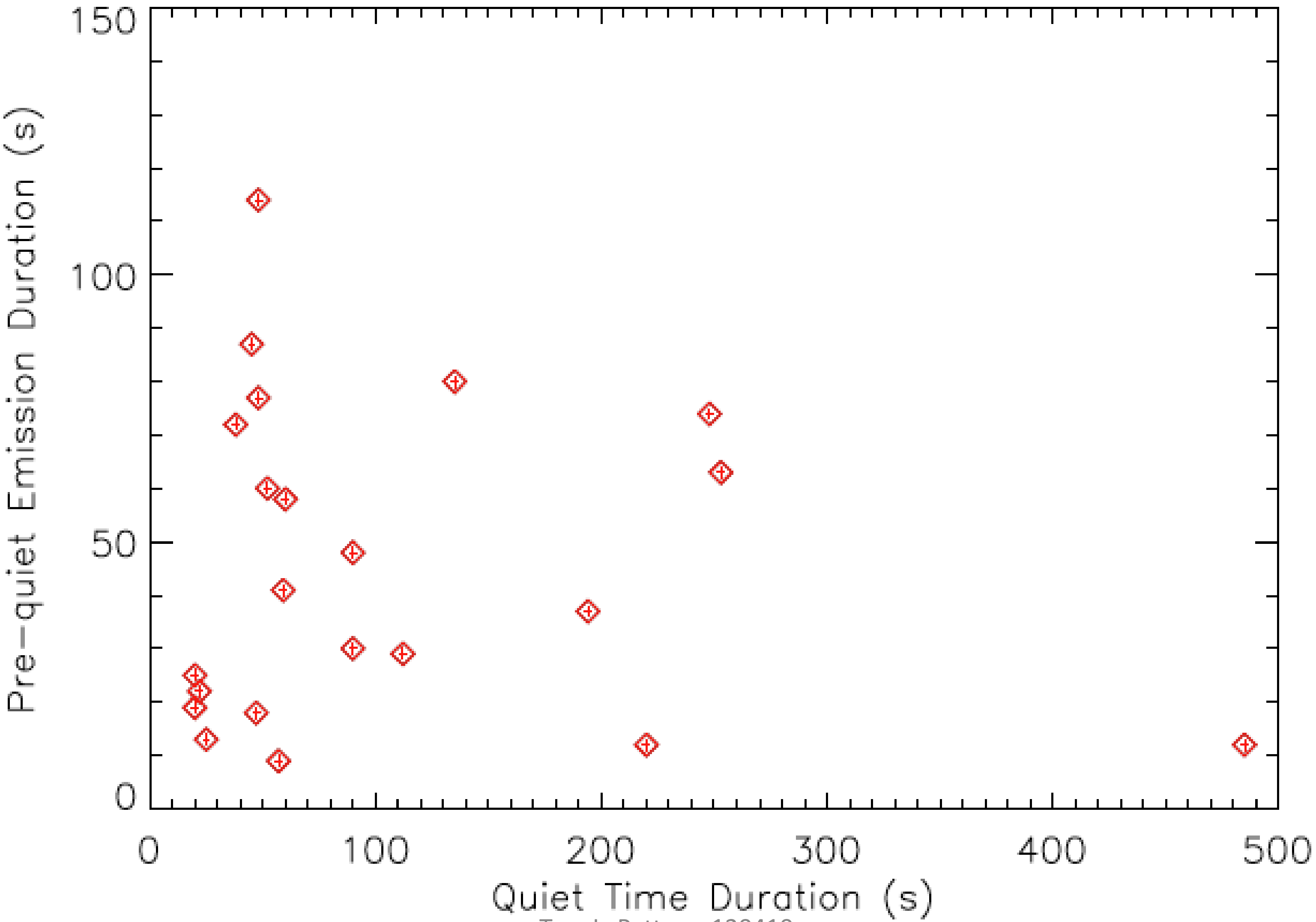
A temporal study…



A temporal study…

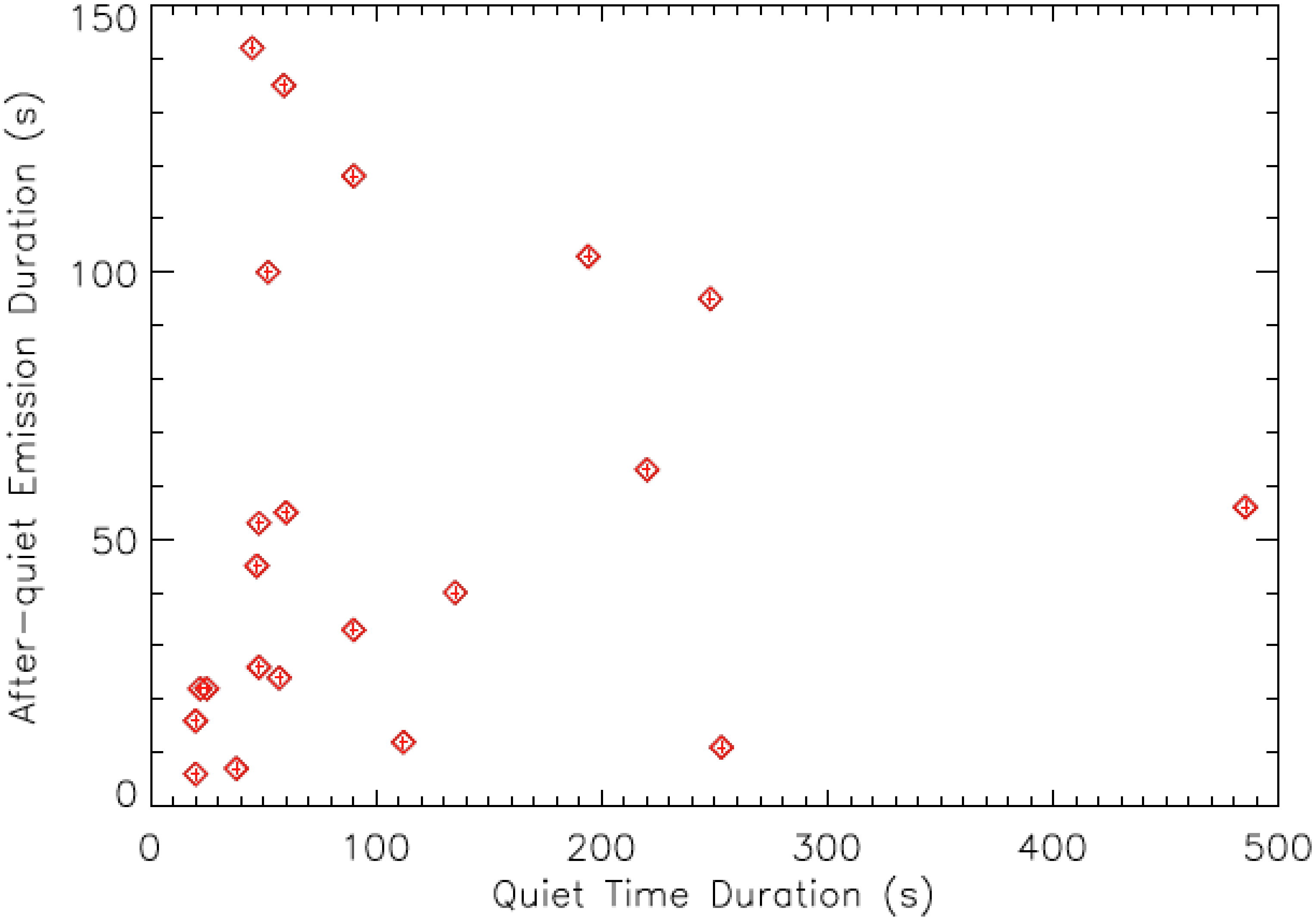


A temporal study…



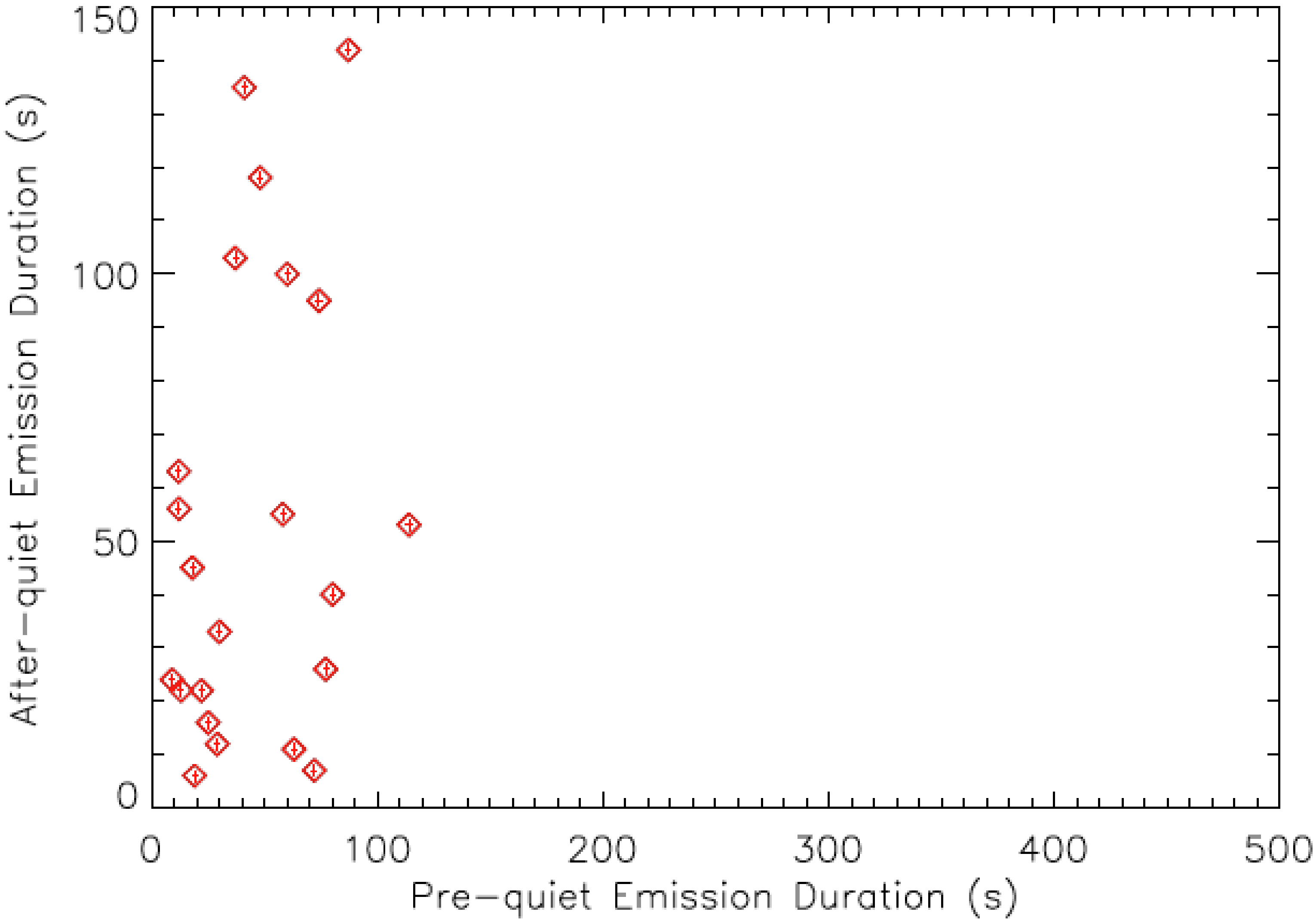
Spearman ρ = 0.05, prob.= 0.83 , Poor correlation

A temporal study…



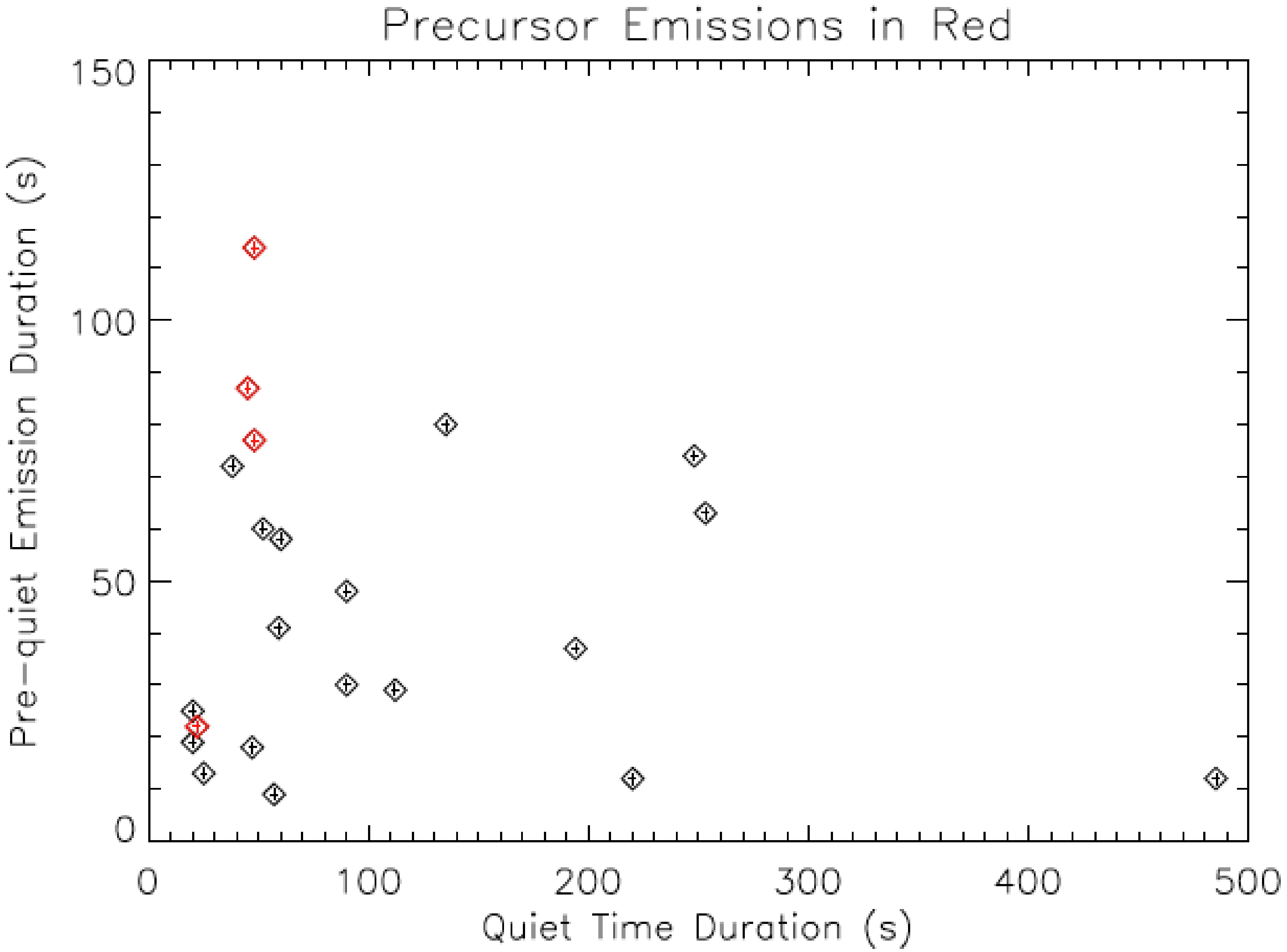
Spearman ρ = 0.37, prob. = 0.09, Weak correlation

A temporal study…



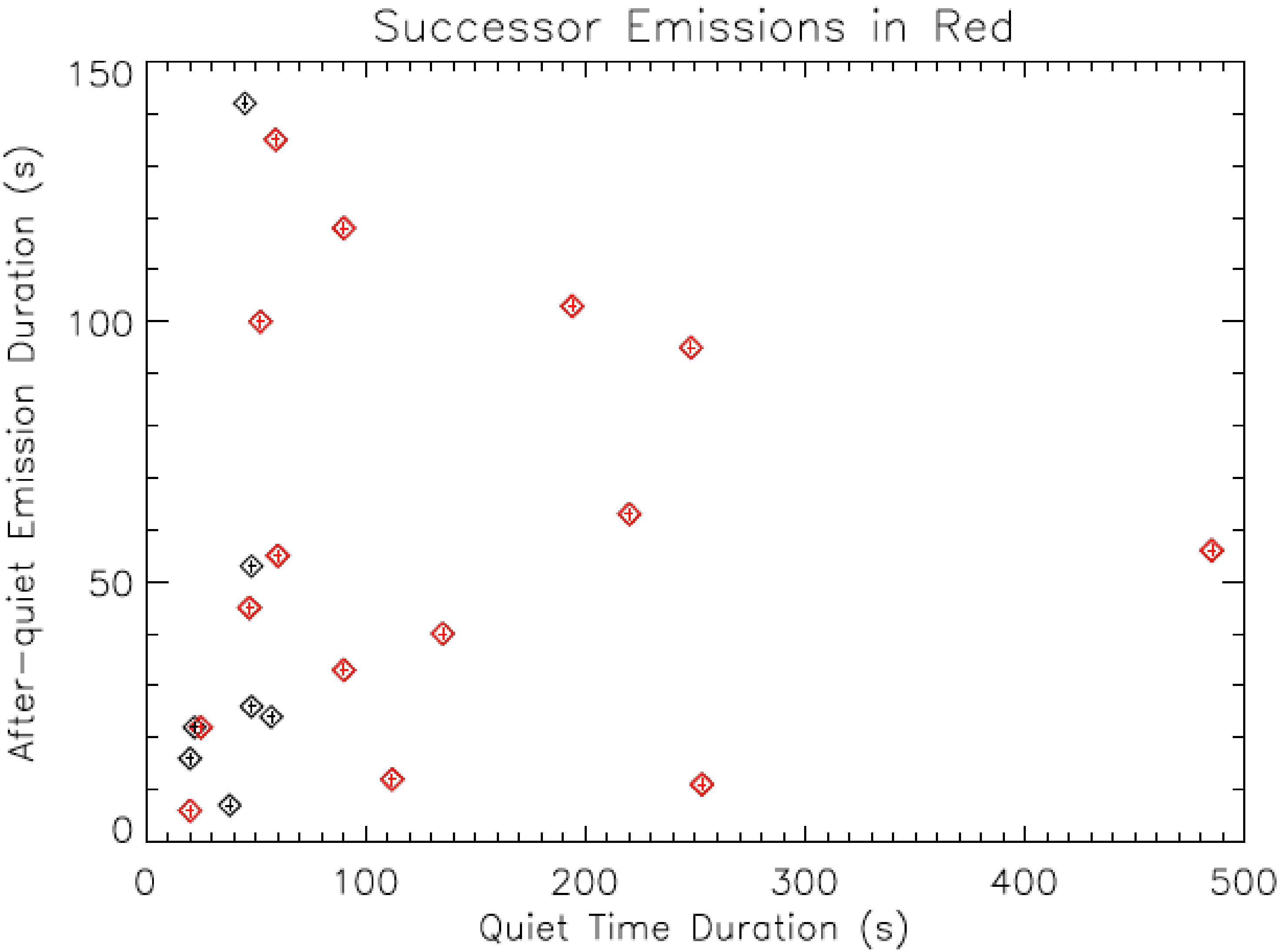
Spearman ρ = 0.23, prob. = 0.30, poor correlation

A temporal study…



Spearman ρ = 0.63, prob. = 0.37

A temporal study…



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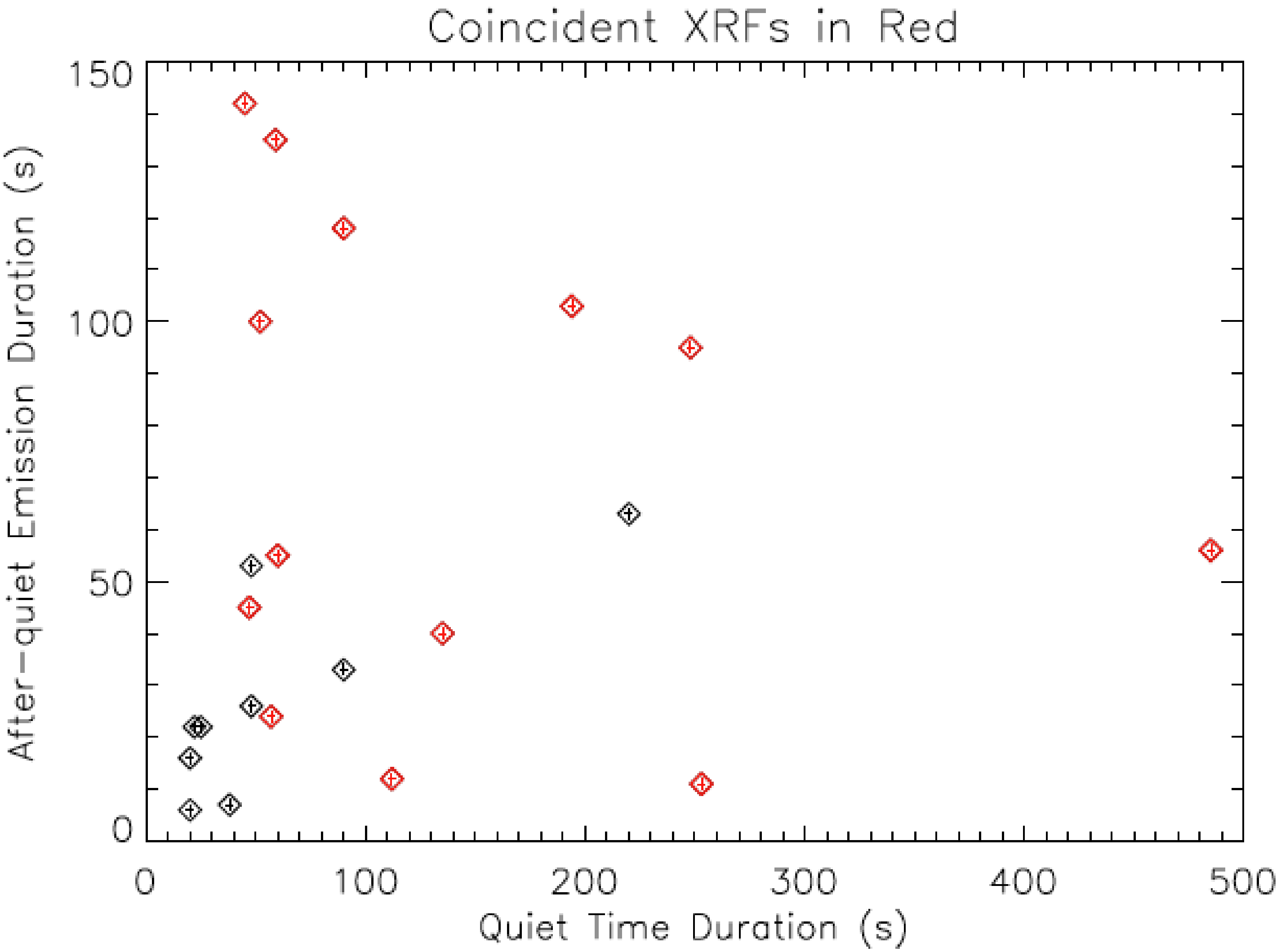
Spearman ρ = 0.14, prob. = 0.62

A temporal study…



Spearman ρ = -0.32, prob.= 0.28

~60% (13/22) of After-quiet Emissions detected by BAT are also detected by XRT

Conclusions

- Quiet Durations v. Emission Durations
  - No correlation between the pre-quiet emission and quiet time durations was found
    - Quiet time durations which are associated with precursors tend to be short, ~100s
  - A weak correlation between after-quiet emission and quiet time duration seems to exist
    - The longer the quiet time, the limit of the after-quiet emissions seem to decrease
  - Quiet times seem to be proportional to, and constitute the bulk of, the total burst duration
  - Gamma-ray emission durations seemed to be constrained to approximately 150s
- Detections
  - About 60% of after quiet emissions tend to be energetic enough to appear in both the BAT and XRT time histories

Conclusions

- Discussion
  - The lack of correlation between the burst emission parameters suggest several causes…
    - The progenitor is constantly and variably active. This behavior would explain the variable nature of the emissions versus their quiescent times.
    - After-quiet emissions could be indicative of refreshed shock activity. Late time emissions could be the result of subsequent progenitor ejecta interacting with the circumstellar medium; a late external shock.
  - These results do no support the 1-to-1 ratio of quiet time to after-quiet emission duration proposed

Conclusions

- Possible forward work…
  - A larger data set of multi-episodic bursts is needed
    - Could include BATSE (CGRO) bursts
      - BATSE bursts cover a different energy range
    - Could use x-ray flaring emissions and their quiescent times to expand upon the current swift data catalog
- Questions?

References (& special considerations)

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