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

Approximate Energy range

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

Transmission of GRB coordinates to GCN

BAT Detection of GRB (S/N above background) → Satellite slew to FOV of XRT and UVOT → Event observation though low-energy afterglow
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)
Burst Phenomenology

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

(Kouveliotou et al., 1996)
2704 BATSE Gamma-Ray Bursts
Burst Phenomenology

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

![FRED Example (Trigger 3870)](image)
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

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 $10^{51-54}$ 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

\[ R_f \geq 2\Gamma^2 c \Delta t, \quad \Gamma = 10^{2-3} \]
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
Jetting

- The relativistic fireball must expand as a sphere or a collimated jet.
- For a jet, less radiation is expected to be 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
    • Work suggested a 1-to-1 correlation between the quiescent time and the after-quiet emission duration
    • Proposed a “hibernating” central engine
    • 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...
A temporal study...

• Finding appropriate GRBs
A temporal study...

• Analysis
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

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A temporal study...
A temporal study...

After-quiet Emission Duration Histogram

# of durations

duration (s)
A temporal study...

Quiet Time Duration Histogram

# of durations

duration (s)
A temporal study...

Spearman $\rho = 0.05$, prob. $= 0.83$, Poor correlation
A temporal study...

Spearman $\rho = 0.37$, prob. = 0.09, Weak correlation
A temporal study...

Spearman $\rho = 0.23$, prob. = 0.30, poor correlation
A temporal study...

Precursor Emissions in Red

Spearman $\rho = 0.63$, prob. = 0.37

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A temporal study...

Spearman $\rho = 0.14$, prob. = 0.62

Successor Emissions in Red

After-quiet Emission Duration (s)

Quiet Time Duration (s)

Spearman $\rho = 0.14$, prob. = 0.62
A temporal study...

Spearman $\rho = -0.32$, 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)

This study was made possible by data collected and distributed by the NASA Astrophysics Science Division


