The Mysterious Burst
After the Short Burst

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- Brief History, Overview, Central Questions
- Spectral lag distributions (long & short GRBs)
- Pulse width distributions  (long & short GRBs)
- Canonical morphology of short GRBs
- Dynamic Range of  \( R_{\text{intensity}} = \frac{I_{EE}}{I_{IPC}} \)
- Prompt Extended Emission ≠ Onset of X-ray afterglow
- Summary
Brief History of Short GRBs

- **Ancient History** (1973-1983) KONUS*, ISSE-3
  There is a small hint of bimodality. SGRs discovered.

- **Dark/Middle Ages** (1984-1990) IPN, SMM
  SGRs consistent with Galactic Plane, LMC \((A/A_{\max})\).

- **BATSE Renaissance** (1991-2000) BATSE
  Bimodality is clear. Shorts separately isotropic.
  Shorts appear slightly spectrally harder, but dynamic ranges of Longs’ & Shorts’ spectra largely overlap.
  Shorts tend to have much narrower temporal structures.
  (Short bursts with Extended Emission secretly postulated.)

- **Statistical Interlude** (2000-2004) HETE-2

- **Modern Age** (2004 →) Swift, HETE-2
  Afterglows lead to Redshifts, and no SN.
  Extended Emission evident in ~ 33% of Swift Short GRBs.
  (*Konus lives)
Fig. 1. The bimodal duration distribution of GRBs. The observations (2041 bursts in the current BATSE catalog) are marked by the thick stairs. The decomposition of the distribution into two lognormal distributions, as determined by Horváth (2002), (thin solid lines) and the sum of these components (thick solid line) are superposed.
Swift/BAT: T90 vs. Spectral Hardness

![Graph showing T90 vs. Spectral Hardness](image-url)
**Statistical Interlude: Hard X-ray Afterglows of Short GRBs**

**Lazzati et al. 2001** (co-addition, 76 shorts)

Lazzati, Ramirez-Ruiz & Ghisellini: Afterglows of short GRBs

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**Fig. 2.** Overall lightcurves in the 4 BATSE channels (from left to right) of the sample of short bursts (see text). The rightmost panels show the average signal in the first and second channels. The time interval of the burst emission has been excluded. The upper panels show the lightcurves without background subtraction (a constant has been subtracted in all panels for viewing purposes in order to have zero counts at $t = 0$). The solid line is the best fit background plus afterglow model (in the channel 3 and 4 panels the $3\sigma$ upper limit afterglow is shown). The dashed line shows the background contribution in all channels. The lower panels show the same data and fit after background subtraction.
Fig. 7.—Light curve for 100 short (<1 s), summed, background-subtracted, BATSE bursts after peak alignment, with peak time suppressed.

Several central questions remain on short GRBs, especially concerning extended emission ...
Berger et al. 2006

Six Probable Short GRB Host Galaxy R magnitudes, 22.6 → 26.3

$z_{median\_shorts} \sim 0.75$
The Big Bang (13.7 Gyrs)

Trilobytes (500 Myrs)

Diamonds: Short GRBs
Red Histo: Long GRBs

Era of Long GRBs

Swift GRBs with Redshifts

$N_{\text{occurs}}$ vs. Lookback Time to GRB event (Giga yrs)

The Big Bang (13.7 Gyrs)
20 x before the age when the first Trilobites appeared, Gamma-Ray Bursts had their big heyday.
Questions on Short GRBs' Extended Emission

- (Usual) morphology of Short GRBs
- Dynamic range in $R_{int} = \frac{I_{EE}}{I_{IPC}}$
- Temporal structure of Extended Emission
- Spectra of Extended Emission (vs. $R_{int}$)

Fraction of *individual* short bursts (reported) with Extended Emission:

- BATSE $\sim 1.5\%$
- Swift/BAT $\sim 33\%$

Two instrumental effects increase BAT percentage:

1. BAT has $A_{eff}$ to $\sim 15$ keV, and
2. uses mask-tagged background estimation

{ NOT that: BAT less sensitive && $I_{EE} \propto I_{IPC}$ }
Spectral Lags: Short GRBs, w/ & w/o E.E.

**Swift/BAT**
- No E.E. (TTE)
- Yes E.E. (TTE)
- Yes E.E. (64 ms)

**BATSE**
- “No” E.E. (TTE)
- Yes E.E. (TTE)
- Yes E.E. (64 ms)
Spectral Lags: Short & Long GRBs

Generalities
(1) When good S/N, shorts have measured lags 0–few ms — fairly uniform picture.
(2) Median lag for bright long bursts is ~ 55 ms, with a few % extending to shorts’ domain
Lags for dimmer long bursts extend to several seconds.

Spectral Lag is a good discriminant — but by itself, not the “silver bullet”
**Pulse Widths: Brightest Short & Long GRBs**

**Generalities (when good S/N)**

1. Long bursts nearly always have pulse FWHM > 100 ms, even when lag is very short.
2. Short bursts usually have pulse FWHM ~ 5-30 ms.
Pulse Widths: GRB 060614 and 051221a

Swift/BAT Short Bursts

15–350 keV

FWHM ~ 30–100 ms

GRB 060614

× 8

FWHM ~ 5–30 ms

GRB 051221a
Short GRBs' Canonical Morphology: 3 phases

- Initial short pulses complex ~ 0.1-3 s
- ~ 5-10 s hiatus
- Extended Emission ~ 30 - 100 s
Short GRBs’ Canonical Morphology: Intensity Ratio

 BATSE trigger 2703

 BATSE trigger 5725

 BATSE trigger 1997

 BATSE trigger 7647
Short GRBs' Canonical Morphology

$R_{\text{int}}$ shrinks ...

$\times 13 \rightarrow$

$R_{\text{int}} \sim 1/600$

no hiatus
Short GRBs' Canonical Morphology

$R_{\text{int}}$ shrinks more

$R_{\text{int}} < 1/3000$

GRB 051221a — Momentarily, Brightest Swift/BAT burst !!!

So, what's the “normal” Intensity Ratio?
Short GRBs’ Canonical Morphology

- 231 bursts averaged, EE individually indiscernible
- 22 bursts, EE individually discernible

In most short bursts the E.E. component is present, but weak.
There is no obvious relation between IPC and EE intensities.

The average spectral hardness for bursts with weak EE is near the middle of the HR21 distribution.
231 Co-added BATSE bursts (where EE “indiscernible”):

\[ EE \approx 9.4 \text{ cts s}^{-1} \quad \text{IPC} \approx 5290 \text{ cts s}^{-1} : \quad R_{\text{int}} \approx 0.0018 \]
Short GRBs’ Canonical Morphology

Blue: Count Rate of BB at +55 s
Red: Avg Count Rate 6 à 76 s

2/3 of Signal contributed above ~ 35 counts s\(^{-1}\)
(1/10 of 231 short bursts)
Short GRBs' Canonical Morphology
~ (42+22) / (231+22) → 25% have $R_{\text{int}} \sim 0.001$
"The Mysterious Burst After the Short Burst"

Rint ~< 1/1

Initial short pulses complex ~ 0.1-3 s (6 s)

~ 5-10 s hiatus (5 s)

Extended Emission ~ 30 - 100 s (130 s)

(z = 0.125 and no SN)
Conclusions: Short GRB Morphology

- EE component is present in ~ 33% (25%) of BAT (BATSE) bursts at levels ranging over $R_{\text{int}} = \frac{I_{\text{EE}}}{I_{\text{IPC}}} \sim 0.001 - 0.6$, the large majority with $R_{\text{int}} \sim 0.001 - 0.01$.

- Over the range of $R_{\text{int}}$ the EE components of individual bursts are spectrally similar, and no correlation with $F_p\{\text{IPC}\}$.

- Some of the brightest short bursts have no EE component, to $R_{\text{int}} < 0.0003$.

- Vast dynamic range in $R_{\text{int}}$ is the clue to short bursts.
Prompt EE component spectrally different from X-ray afterglow
Prompt EE component temporally different from X-ray afterglow

Campana et al. — GRB 050724

Model fit: 4 Gaussians + triple power-law
Diverse X-ray Afterglows of Short GRBs, not correlated with presence/absence of EE component

Extended Prompt Emission:

No Extended Prompt Emission:

Late “flares”  Early “flares”  Three phases  Three phases
Summary

- No one attribute is a silver bullet indicating short vs. long. However, Long GRBs manifest a large range in temporal attributes {pulse width, duration} — Short GRBs less so.

- EE component is present in ~ 33% (25%) of BAT (BATSE) bursts, to levels $R_{\text{int}} > 0.001$. Much below this level, neither BAT nor BATSE have the sensitivity to comment.

- Infrequent bursts with $R_{\text{int}} \sim 0.1$ appear phenomenal, but just represent the tail of the distribution.

- A few of the very brightest short bursts have no EE component, to $R_{\text{int}} = I_{\text{EE}}/I_{\text{IPC}} < 0.0003$.

- Vast dynamic range in $R_{\text{int}}$ is the real mystery.