X-ray Flashes and Gamma-ray Bursts

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- Short transients detected in WFC (2–25 keV) with little/no signal in GRBM (40–700 keV) and no BATSE (>20 keV) trigger
- 17 events detected in 3.8 years of observations (cf. 36 GRBs)
- Use BATSE continuous data (>20 keV) to search for (untriggered) γ-ray emission
- Characterize γ-ray properties and wide-band spectra
- Compare to the observed properties of GRBs
Search for $\gamma$-ray Emission

- 10 unocculted events observed with BATSE
- 9 events detected (<300 keV) by combining detectors

~Isotropically distributed
Qualitatively similar to weak GRBs
Apply Std. BATSE burst analysis to flashes

Compare to BATSE GRB catalog (1973 bursts w/flux, flu, dur)

Flashes consistent with weak, long-duration GRBs

How do detailed spectra compare?

- **Peak Flux**
  - % of Bursts (>P)
  - $P_{1024}$ (ph cm$^{-2}$ s$^{-1}$)

- **Duration**
  - % of Bursts
  - $T_{50}$ Burst Duration (s)

- **Fluence**
  - % of Bursts (>S)
  - Fluence (erg cm$^{-2}$; 20–300 keV)
Time averaged flash spectra

Good agreement between WFC & BATSE around 20 keV

8 events have significant curvature (compared to single power law fit)

$E_{\text{peak}}$ and $\alpha$ are well constrained

Band/Comp models generally consistent

- 971019: $\Delta \chi^2 = 158$
  - $E_{\text{peak}} = 19 \pm 1$ keV

- 990520: $\Delta \chi^2 = 22$
  - $E_{\text{peak}} = 26 \pm 3$ keV

- 980128: $\Delta \chi^2 = 18$
  - $E_{\text{peak}} = 57 \pm 17$ keV
Flashes vs. Bright GRBs

- Compare to Preece et al. results for 156 bright GRB (BATSE-only)
- Also compare 18 WFC-selected GRBs (BATSE-only spectra)
- WFC-selected GRBs consistent with bright GRBs
- Flashes have consistent $\alpha$ & $\beta$
- $E_{\text{peak}}$ significantly different (lower)

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**Peak Energy**

$P_{\text{K-S}} \sim 10^{-8}$

**High-Energy Index**

$P_{\text{K-S}} \sim 0.1$

$P_{\text{K-S}} \sim 0.2$

Large Uncertainties!
Power $\nu F_{\nu}$ (keV $\cdot$ cm$^{-2} \cdot$ s$^{-1}$) vs. Photon Energy (keV)

- **X-ray Flashes**
- **Average Bright GRB Spectrum**
Flashes vs. *Dim* GRBs

  - $\alpha$ consistent with long GRBs
  - $E_{\text{peak}}$ *roughly* follows hardness intensity trend of long GRBs

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**$E_{\text{peak}}$ vs. Duration**

<table>
<thead>
<tr>
<th>Duration $T_{50}$ (s)</th>
<th>Comptonized $E_{\text{peak}}$ (keV)</th>
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<tbody>
<tr>
<td>0.1</td>
<td>10</td>
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<tr>
<td>1</td>
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<tr>
<td>10</td>
<td>1000</td>
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<td>100</td>
<td>1000</td>
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**$E_{\text{peak}}$ vs. Intensity**

<table>
<thead>
<tr>
<th>Peak Flux $P_{1024}$ (ph · cm$^{-2}$ · s$^{-1}$)</th>
<th>Comptonized $E_{\text{peak}}$ (keV)</th>
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**$E_{\text{peak}}$ vs. Index**

<table>
<thead>
<tr>
<th>Comptonized $\alpha$</th>
<th>$E_{\text{peak}}$ (keV)</th>
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<tbody>
<tr>
<td>-2</td>
<td>0.1</td>
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<tr>
<td>-1</td>
<td>1</td>
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<tr>
<td>0</td>
<td>10</td>
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<td>1</td>
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R. M. Kippen (LANL)
Flashes vs. *Dimmest* GRBs

- Compare to BATSE 5B catalog
  Briggs *et al.* [2002] (2704 triggers)

- Compare to Stern *et al.* [2000] catalog (3923 off-line triggers)

- Characterize spectra with broadband hardness ratios

- Flashes similar in hardness to bursts of same intensity

- ~400 bursts per year (full-sky) with similar hardness, duration, and intensity = 40% of all long bursts

- Consistent with WFC detection rate of FXTs = 32% of all SAX bursts
Conclusions

- X-ray flashes similar to GRBs except that they emit most power in X-rays

- Joint WFC+BATSE spectral fits reveal that flashes have significantly curved spectra — similar to GRBs

- Spectra of X-ray flashes are roughly consistent with the long GRB $E_{\text{peak}}$ vs. intensity trend

- Could represent a large extension of the full GRB population

Caveats:

- Small sample size
- Subject to selection and analysis biases

Future:

- Afterglow counterparts (so far elusive) will conclusively show how flashes are related to GRB
- BeppoSAX & HETE continue to routinely observe flashes, but lack sensitive $\gamma$-ray data
- Swift (5–150 keV) should provide a large sample for wide-band spectral comparisons
BATSE Search Results (20–300 keV)

- 10 unocculted events with BATSE continuous data
- 9 detections (> 5 sigma in select, summed detectors)
- No detections above 300 keV
Spectral Evolution

WFC_FLASH_971019

WFC_FLASH_000208

2-7 keV (WFC)

7-17 keV (WFC)

17-27 keV (WFC)

25-50 keV (BATSE)

50-100 keV (BATSE)

100-200 keV (BATSE)

>300 keV (BATSE)

2-7 keV (WFC)

7-17 keV (WFC)

17-27 keV (WFC)

25-50 keV (BATSE)

50-100 keV (BATSE)

100-200 keV (BATSE)

>300 keV (BATSE)
Spectral Evolution

WFC_FLASH_971024

WFC_FLASH_000206