Not Just Coincidence: Prospects for Detection of LIGO Burst Counterparts

Derek B. Fox
Astronomy & Astrophysics
Penn State University

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Short and Long-Duration GRBs
Long vs Short

“The spectral properties of short bursts are similar to the first second of long GRBs” – Ghirlanda, Ghisellini & Celotti (2004)
The First Four Afterglows:

050509B: Swift BAT+XRT

050709: HETE, Chandra, Ground, HST

050724: Swift BAT+XRT, Ground, VLA, Chandra

050813: Swift BAT+XRT

Nature - 6 Oct 2005
Key Papers

From the Nature issue:
• First SHB afterglow (GRB 050509B: Gehrels et al. 2005)
• Synthesis of the first four afterglows (Fox et al. 2005)

Other forums:
• First host redshift and broadband models (GRB 050509B: Bloom et al. 2006)
• First precision localization to elliptical galaxy (GRB 050724, Barthelmy et al. 2005, Berger et al. 2005)
• Broadband modeling (Panaitescu 2005)
Key Findings

Short bursts…

- Show afterglow emission
- Are cosmologically distant
- Can occur in & near host galaxies
- Can occur in galaxy clusters
- Draw from a different host galaxy population than long bursts
- Possess afterglow properties different from long bursts
- Lack associated supernovae
Evidence for mergers

Circumstantial:

- Old stellar populations
- No associated supernovae
- Energetics
  - 100x less than long burst / collapsar
  - 1000x greater than the magnetar giant flare (27 Dec 2004)
  - Comparable energy in afterglow
  - Okay for NS-NS, NS-BH

GRB 050509B (HST)
Prediction (Eichler, Livio, Piran & Schramm 1991):

- Well-known GW wave source
- Known GRB model, but:
  - Short bursts
  - Featureless spectra
- R-process elements
- Associated neutrino burst
Jet Breaks and Beaming in Short Bursts
GRB 050709: Optical Afterglow

1.5m Danish Telescope (La Silla)

t+1.4 d  t+2.4 d

Decays as $t^{-1.3}$

Hjorth et al 2005
GRB 050709: HST

4 epochs
6-35 days
F814W
Exp=6360 s

Blue dwarf
irregular galaxy
z=0.16
L=0.1 L_
SFR ~ 0.3 M_ yr^{-1}
Old + young stars
(Covino+05)

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Fox et al. 2005
Optical

Radio

X-ray

$F_v$ (mJy)

$10^{-6}$

$10^{-8}$

$10^{-10}$

$10^{-12}$

$10^{-14}$

$10^{-16}$

$10^{-18}$

$10^{-20}$

$t$ (days)

$10^{-2}$

$10^{-1}$

$10^{0}$

$10^{1}$

Solid: $E_{50}=6\times10^{49}$, ee=1/3, eb=0.2, theta=0.5, p=2.5, n=0.1
Dashed: $E_{50}=9\times10^{49}$, ee=1/3, eb=1/3, theta=0.35, p=2.5, n=0.01

Fox et al. 2005 & Hjorth et al. 2005b
Jet Break

$\theta_j = 15^\circ$

30:1 beaming

Fox et al. 2005 & Hjorth et al. 2005b
GRB 051221

$\theta_j = 7^\circ$

130:1 beaming

Soderberg et al. 2006
## Short Burst Beaming

<table>
<thead>
<tr>
<th>GRB</th>
<th>Redshift</th>
<th>Beaming</th>
<th>Break Mag</th>
</tr>
</thead>
<tbody>
<tr>
<td>050709</td>
<td>0.16</td>
<td>30:1</td>
<td>$i = 25.8$</td>
</tr>
<tr>
<td>051221</td>
<td>0.55</td>
<td>130:1</td>
<td>$r = 24.8$</td>
</tr>
</tbody>
</table>

050709 at 10 Mpc: $i > 16.4$ mag
051221 at 10 Mpc: $r > 12.3$ mag
LIGO and Short Bursts: Prospects for Coincidence
SHBs and LIGO

- Long progenitor lifetimes and a high local rate
- $R \approx 10 \text{ Gpc}^{-3} \text{ yr}^{-1}$ for NS-NS with no beaming and no extrapolation to lower fluxes
- $R > 300 \text{ Gpc}^{-3} \text{ yr}^{-1}$ with 30:1 beaming
- Exact number depends on lower flux threshold for population
- At limit of $10^{47} \text{ erg s}^{-1}$ (Tanvir et al. 2005): $R=10^5 \text{ Gpc}^{-3} \text{ yr}^{-1}$
- Max. 3 LIGO-I events yr$^{-1}$; 0.3 yr$^{-1}$ more likely

Nakar, Gal-Yam & Fox 2005
**SHB Orphans and LIGO**

- Estimated rates from SHBs:
  - Max. 3 LIGO-I events yr\(^{-1}\)
  - 0.3 yr\(^{-1}\) more likely
  - NS-BH or BH-BH models give higher rates
- Temporal coincidence filtering makes LIGO 1.5x more sensitive:
  - 3.3x increase in rate
  - 0.3 yr\(^{-1}\) -> 1.0 yr\(^{-1}\) for LIGO-I
- When & where are the nearest mergers occurring?
- SHBs are beamed explosions – GRB itself may not be seen

⇒ Optical searches for SHB “orphan” afterglows
Past Searches

NOAO Deep Lens Survey

- 28 deg² to \( R \sim 24 \) mag
- Multiple imaging epochs, with real-time image difference searches
- Three fast transients seen
  - Spectrum of one: M-dwarf
  - Late-time follow-up of two: same
- Less than 5.2 events per deg² per day in the range 19.5 < \( R < 23.4 \)

Past Searches

CFHT Legacy Survey “Very Wide” component

- 490 deg$^2$ to $r' \sim 22.5$ mag
- Three candidate orphan afterglows:
  - Two probable variable stars
  - One possible orphan afterglow
- Less than 220 orphans over the whole sky to this limit (at any time)

Palomar Transient Factory

- New 7-deg$^2$ camera for the Oschin Schmidt telescope at Palomar
- Three year dedicated project, 2008-2011
- Focus on fast transients and supernovae
- Single filter (or possibly two for dark vs. bright time)
- Depth of $R \sim 21$ mag, cadence of (1d, 3d, 9d)
- As many as 600 fields per night (4200 deg$^2$), depending on strategy
Pan-STARRS

- First light in 2008 (?)
- Four 1.8-m telescopes
- 7 deg² imaged on four 1.4 Gpix cameras simultaneously
- OTCCD technology for seeing-limited images (0.3")
- Multiple filters for weak lensing, supernovae, cosmology
- Per-field exposures reaching $m_{AB}=24$ mag
- 6000 deg² imaged every night
- N.B.: PS-1 now complete; one-telescope survey (beg. 2007) lacks transient aspect
Large Synoptic Survey Tel.

- First light in 2012 (?)
- 6.5m effective aperture
- 9.6 deg$^2$ imaged on 3.2 Gpix camera
- Entire night-visible sky imaged in 5 filters every 3 nights
- Individual 15s exposures reach $m_{AB} = 24.8$ mag
- N.B.: Penn State Astronomy is a member of the LSST board

LSST
Conclusions

• Strong evidence associating short bursts with NS merger events
• Opportunity to enhance LIGO (LIGO I.5) with photonic data:
  – Ordinary GRB triggers
  – Orphan optical afterglows
• Properties of observed short burst afterglows encouraging
• Past searches have been more deep than wide (CCD tech)
• Upcoming facilities will be far more capable
• Palomar Transient Factory has orphans as a key science driver
• Ultimately, LSST will provide the best possible limits, if not detections
The End