Short Gamma-Ray Bursts: The Shortest Route to Joint EM-GW Detections?!

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Outline: Environments are Key

- The discovery of short GRB afterglows & host galaxies
- Redshift distribution & galaxy-scale environments
- Offset distribution & sub-galactic environments
- Evidence for Kicks?
- Rates
- mini-, macro-, kilo-novae?

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Long GRBs: The Death of Massive Stars

Fruchter et al. 2006; Wainwright, Berger, & Penprase 2007

Long GRBs are not promising GW sources!

1. Exclusively in star-forming galaxies
2. Offsets trace star formation in an exponential disk

3. Coincident with the brightest UV regions of their hosts

Bloom et al. 2002

Fruchter et al. 2006
**Short GRB Progenitor Models**

- **NS-NS / NS-BH**
  - diverse environments
  - "kicks"

- **WD/NS AIC**
  - diverse environments; no kicks

- **Magnetar**
  - young environments

- **WD-WD merger**
Early “Smoking Guns”?

Unambiguous association with an elliptical galaxy & no accompanying supernova


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z = 0.257

Berger et al. 2005
Afterglows Galore...

Soderberg et al. 2006

Berger et al. 2007

D'Avanzo et al. 2009

Berger et al. 2009

Fong et al. 2011
... and Host Galaxies

Berger et al. 2007; Berger 2009
\( \frac{1}{2} \) of all short GRBs are located at \( z > 0.7 \) \( \Rightarrow \langle \text{age} \rangle \leq 7 \text{ Gyr} \)

Berger et al. 2007; Berger 2009; Fong et al. 2011

Host Galaxies: Redshifts
Short GRB hosts have lower specific star formation rates than long GRB hosts; they trace the general galaxy population.
Short GRB hosts have **higher metallicities** than long GRB hosts; they trace the general galaxy population.
Short GRB hosts have higher stellar masses than long GRB hosts.
Short GRB hosts (including star-forming) have older ages than long GRB hosts.

\[ \tau_{\text{short, SF}} \approx 0.3 \text{ Gyr} \]
\[ \tau_{\text{short, E}} \approx 3 \text{ Gyr} \]
\[ \tau_{\text{long}} \approx 60 \text{ Myr} \]
Early-type hosts track stellar mass, but star-forming hosts have lower masses than expected; star-forming dominate (1:1 expected)
Sub-galactic Environments

• Are short GRBs associated with young or old stellar populations within their hosts?

• Is the distribution of offsets indicative of “kicks”?

Fong, Berger, & Fox 2010
Short GRBs trace low luminosity regions of their hosts; track optical (mass) better than UV (SFR)
Sub-galactic Environments: Offsets

- Short GRB offsets are ~5x larger than for long GRBs
- Good agreement with model predictions for NS-NS binaries

Fong, Berger, & Fox 2010
Is there Evidence for Large Kicks?

Of 20 short GRBs with optical afterglows, 5 have no coincident hosts to \textgreater 26 mag.
Is there Evidence for Large Kicks?

- Underlying hosts >26 mag + fainter afterglows (high redshift)
- No hosts + fainter afterglows (kicks / low density)
Is there Evidence for Large Kicks?

**high-z:** same galaxies ⇒ bimodal redshift distribution

Offsets: low chance probability at ~10” ⇒ 50-100 kpc

Berger 2010
Kicks?

Extension to larger offsets provides better agreement with the NS-NS merger models. Not expected in other models.
Rates

Belczynski et al. 2007

\[ \mathcal{R} > 10 \text{ Gpc}^{-3} \text{ yr}^{-1} \]
Nakar et al. 2007

\[ R_{\text{ell}} \sim 6 \times 10^{-12} \text{ M}_\odot^{-1} \]
\[ R_{\text{sp}} \sim 2 \times 10^{-11} \text{ M}_\odot^{-1} \]
Leibler & Berger 2010

\[ \rho_* \sim 6 \times 10^{17} \text{ M}_\odot \text{ Gpc}^{-3} \]

Kalogera et al. 2004

\[ R_{\text{DNS}} \sim 17-290 \text{ Myr}^{-1} (95\%) \]

\[ \tau^{-1} > 0.4-1.2 \text{ Myr}^{-1} \]
Mini-SN / Macronova / Kilonova?

Models: Metzger et al. 2010
Data: Berger 2010

Short GRBs at $z \sim 0.1$ to $>26$ mag within $\sim1$ day; would afterglow dominate?

e.g. Perley et al. 2009
• The progenitors of short GRBs are *not* massive stars; they belong to an evolved population with a wide range of ages.

• The short GRB rate in star-forming galaxies is elevated relative to that in ellipticals ⇒ A channel that tracks SF?

• If related to the star formation activity, the typical delay time is \( \sim 0.3 \text{ Gyr} \); the typical delay time in ellipticals is \( \sim 3 \text{ Gyr} \).

• The short GRB volumetric rate, combined with the inferred rate per unit stellar mass, indicate a temporal rate of \( >1 \text{ Myr}^{-1} \) per galaxy (consistent with the MW DNS rate).
Summary II

• Distinct local environments for short and long GRBs:
  - larger offsets (in agreement with NS-NS models)
  - better correlated with optical light (mass), not correlated with UV light (star formation)

• Short GRBs with optical afterglows and no coincident hosts are likely due to kicks/GCs (bimodal redshift distribution?)

• Short GRB afterglows and mini-SNe too faint to be detected by small wide-field telescopes \(\Rightarrow\) \(\gamma\)-ray triggers are essential!

• It is crucial to have a \(\gamma/X\)-ray mission **capable of \(\sim\)arcmin positions** in conjunction with GW detectors.