A Short Talk On Short Duration Gamma Ray Bursts

Andrew Friedman, Astronomy 219, April 24th, 2003
Outline: Short GRBs

1. Differences Between Short & Long Bursts
2. Progenitor Models
3. Clues to their Origins
4. Constraints on Afterglow Observations
5. Future Observations: Swift
The Bimodal Distribution of GRBS

Short Duration GRBs: $T_{90} < 2s$ (58)
Long Duration GRBs: $T_{90} > 2s$ (164)

Separated by gap between ~1-10s w/ few bursts

(Kouveliotou et al 1993),
http://www.batse.msfc.nasa.gov/batse/grb/duration/
Hardness Ratio for Short vs. Long GRBs

• **Short Bursts**: (dashed line) Harder Spectra
• **Long Bursts**: (solid line) Softer Spectra
• $HR_{32} = \frac{\text{total counts in (100 - 300keV) band}}{\text{total counts in (50 - 100keV) band}}$

(Kouveliotou et al 1993)
Fluence-Duration Correlation

- Black points are fluences of 34 Long GRBs w/ detected afterglows.
- Red crosses are average fluence of:
  - 206 Short GRBs (lower left)
  - 486 Long GRBs (upper right)

From 3rd BATSE catalog (Panaitescu, Kumar, & Narayan 2001)

Short bursts have lower fluence than long bursts.
Isotropic Distribution of All GRBs

2704 BATSE Gamma-Ray Bursts

About 20-25% of bursts are short.
Galactic/Extragalactic Origin?

• Galactic/extragalactic debate raged until 1997.
• 1st localization (GRB970228): BeppoSAX
• Also 1st Optical, X-Ray Afterglow
• First redshift (GRB970508): $z > 0.835$

Debate Resolved: At least some long GRBs are of cosmological origin!

Summary in (Bloom et al. 2002)
Are Short Bursts Isotropic?

• Entire class of short bursts ($T_{90} < 2s$) appears highly isotropic

• However, very Short Bursts ($T_{90} < 100ms$) may not be isotropic

• May come from galactic sources (*Cline et al 2001*), or even extragalactic sources confined in super galactic plane out to low $z$ (i.e. out to Virgo cluster (*Heon-Young, Kim 2002*)

Short GRB Spatial Distribution

- **Thick Line**: (Long Bursts)
- **Thin Line**: (Short Bursts)
- **Dashed Line**: 
  \[ \langle \frac{V}{V_{\text{max}}} \rangle = 0.5 \]
  Euclidean distribution

\[ \langle \frac{V}{V_{\text{max}}} \rangle < 0.5 \rightarrow \]
Cosmological distribution

- It is likely that both groups have same spatial distribution
  (KS probability $\sim 42\%$)

- $\sim 10^{-4}$ prob. of being a Euclidean distribution

(Mao, Narayan, & Piran, 1994)
Favored GRB Progenitor Models

**Collapsar Model**: Collapse of a Massive star. Likely Progenitors: Wolf Rayet stars, also progenitors of hydrogen/helium deficient Type Ib/c SNe (*Woosley 1993*)

**Binary Merger Model**: NS-NS or NS-BH binaries merge within the Hubble time via emission of gravity waves. (*Narayan, Paczynski, & Piran 1992, Rees 1999, Narayan, Piran, & Kumar 2001*)
Comparison of the Models

- In both cases, a spinning BH is formed along with a temporary accretion disk, which then falls onto the BH and releases a fraction of its gravitational potential energy.
- Lifetime of the disk accounts for duration of the GRB.
- Light crossing time of BH sets variability timescale.

Bottom line:
- Accretion timescale of disk in binary merger model is short \( (t \sim 1 \text{s}) \). \( \Rightarrow \text{Short GRBs!} \)
- In collapsar model, if accretion disk is fed by fallback of SN material onto disk, timescale can be much longer \( (t \sim 10-100 \text{s}) \). \( \Rightarrow \text{Long GRBs!} \)

(Narayan, Piran, & Kumar 2001), (Rees 1999), (Bloom et al. 2002)
Other Possible Short GRB Progenitors

- **Other Binary Mergers:** WD-NS, WD-BH, He-BH, He-NS (He = Helium Core star) (*Belczynski et al. 2002*)

- **Primordial Black Holes:** Relics formed in Big Bang evaporate via Hawking Radiation. (*Cline et al. 2003*). No evidence of Hawking Radiation yet

- **Active Galactic Nuclei (AGN):** However, observed variability timescales still require a stellar mass object. (*Cheng & Wang 1999*)

- **Extragal. Magnetar Flares (Soft Gamma Repeaters):** Sources cluster in super-galactic plane, favored if short GRBs are not isotropic. \(<V/V_{\text{max}} > = 0.4459 \rightarrow\) cosmological but confined to low z. (*Heon-Young, Kim 2002*)
Location of GRBs as Clues to Their Origin

- Before 1\textsuperscript{st} afterglow, redshift, NS-NS merger model favored

- Existence of coalescing neutron stars in Hubble time assured from observations (i.e. the binary pulsar)

- Merger rate (\textit{Phinney 1991}) consistent with GRB rate (\textit{Narayan, Paczynski, \& Piran 1992})

- Since then, long GRBs w/ afterglows, redshifts, and optical identification of host galaxy, allow one to construct an offset distribution from host galaxy center

- Can try to determine the stellar population of progenitors
Offset Distribution of Long GRBs From Host Galaxy Center

- Does not fit predicted offset distribution of binary merger systems, for several models

- Fits offset distribution associated with star forming regions

- => favors massive star progenitors, collapsar model, for long GRBs.

(Bloom et al. 2002)
Discussion

- Long merger timescale ($10^6$ - $10^9$ yrs, Phinney 1991) =>
  expect to find NS-NS & NS-BH binary mergers preferentially in old stellar populations (i.e. ellipticals – like Type Ia SNe)

- Expect some in spirals, but binaries get formation kick from SNe and merge far their birth site. (Hansen & Phinney 1997)

- Also see (Perna & Belczynski 2002): New Population Synthesis Codes, offset distrib of NS-NS, NS-BH binaries following up on (Bloom et al. 2002)
Predictions for Short GRB Afterglows

- Short GRBs afterglows predicted 10-40 x fainter than for Long GRBs => Radio & Optical Afterglows hard to detect

- Early X-Ray observations (t<1day), best bet

- Afterglows even fainter if progenitors trigger in low density environments, expected for binary merger scenarios

Panaitescu, Kumar, & Narayan 2001
Observations/Limits of Short GRB Afterglows

• No optical, radio afterglows found for short GRBs localized by IPN (Hurley et al. 2002)

• No X-Ray afterglows found with short bursts localized by BeppoSAX (Gandolfi et al 2000), HETE 2 (Lamb 2002)

• Optical Transient found for short GRB 000313, localized by BATSE, but no afterglow, host galaxy (Castro et al. 02)

• Weak X-ray afterglows detected for some short bursts localized by BATSE (Lazzati et al 2002) (Averaged over best 76 BATSE bursts w/ highest SNR– a single afterglow is swamped by the background noise)
Dark Bursts

- Dark bursts, which show no detected optical afterglow, probably make up close of half of all GRBs.

- Dec 11, 2002: HETE Detects afterglow of “Dark Burst”, which faded after 2 hrs, and would have been labeled “dark” had it not been dark early.

- Burst was temporally transitional, lasting 2.5s, in gap between short and long GRBs.

- Could be a missing link…maybe GRBs have many possible progenitors….i.e. very short bursts are NS-BH mergers, and dark, transitional bursts are NS-NS mergers.

The Future for Short GRBs

Launching Dec 2003 (or, ask NASA) *Swift* will allow fast localization (hence its name) of both Long and Short GRBs.

- Fast X-Ray, Optical, Radio follow up may lead to detection of afterglows, redshifts, & host galaxies of short bursts.

- ?Resolution of the GRB progenitor mystery?

[http://swift.gsfc.nasa.gov/](http://swift.gsfc.nasa.gov/)
Final word...It’s probably these guys....
References

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