50 Years of Gamma-Ray Bursts*

* With a biased overemphasis on Neil & stuff I was involved in

Josh Bloom
UC Berkeley
@profjsb
Discovery & Demographics
High-energy Era

GRB 670702

OBSERVATIONS OF GAMMA-RAY BURSTS OF COSMIC ORIGIN
RAY W. KLEBESADEL, IAN B. STRONG, AND ROY A. OLSON

University of California, Los Alamos Scientific Laboratory, Los Alamos, New Mexico
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ABSTRACT
Sixteen short bursts of photons in the energy range 0.2–1.5 MeV have been observed between 1969 July and 1972 July using widely separated spacecraft. Burst durations ranged from less than 0.1 s to 30 s, and time-integrated flux densities from $\sim 10^{-9}$ ergs cm$^{-2}$ to $\sim 2 \times 10^{-7}$ ergs cm$^{-2}$ in the energy range given. Significant time structure within bursts was observed. Directional information eliminates the Earth and Sun as sources.

Subject headings: gamma rays — X-rays — variable stars

I. INTRODUCTION

On several occasions in the past we have searched the records of data from early Vela spacecraft for indications of gamma-ray fluxes near the times of appearance of supernovae. These searches proved uniformly fruitless. Specific predictions of gamma-ray emission during the initial stages of the development of supernovae have since been made by Colgate (1968). Also, more recent Vela spacecraft are equipped with much improved instrumentation. This encouraged a more general search, not restricted to specific time periods. The search covered data acquired with almost continuous coverage between 1969 July and 1972 July, yielding records of 16 gamma-ray bursts distributed throughout that period. Search criteria and some characteristics of the bursts are given below.

II. INSTRUMENTATION

The observations were made by detectors on the four Vela spacecraft, Vela 5A, 5B, 6A, and 6B, which are arranged almost equally spaced in a circular orbit with a geocentric radius of $\sim 1.2 \times 10^9$ km.

On each spacecraft six $10^3$ CsI scintillation counters are so distributed as to achieve a nearly isotropic sensitivity. Individual detectors respond to energy deposits of 0.2–1.0 MeV for Vela 5 spacecraft and 0.3–1.5 MeV for Vela 6 spacecraft, with a detection efficiency ranging between 17 and 50 percent. The scintillators are shielded against direct penetration by electrons below $\sim 0.75$ MeV and protons below $\sim 20$ MeV. A high-Z shield attenuates photons with energy below that of the counting threshold. No active anticoincidence shielding is provided.

Theory: Colgate 68
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- **Isotropic**
- **Non-Euclidean/Inhomogeneous**
- **Two Populations**

Kouveliotou+93, Mazets+81, Norris+84
“No Host Problem” (cf. Larson 97)

“Great Debate” here in DC (Apr 95):
*Galactic* or *Cosmological*?
"No Host Problem" (cf. Larson 97)

“Great Debate” here in DC (Apr 95): Galactic or Cosmological?

3rd Huntsville Conference (Oct 95)

THE CORRECTED LOG N-LOG FLUENCE DISTRIBUTION OF COSMOLOGICAL $\gamma$-RAY BURSTS

Joshua S. Bloom$^{1,2}$, Edward E. Fenimore$^2$, Jean in 't Zand$^{2,3}$

$^1$Harvard-Smithsonian Center for Astrophysics, Cambridge, MA 02138
$^2$Los Alamos National Laboratory, Los Alamos, NM 87544
$^3$Goddard Space Flight Center, Greenbelt, MD 20771

Recent analysis of relativistically expanding shells of cosmological $\gamma$-ray bursts has shown that if the bursts are cosmological, then most likely total energy ($E_0$) is standard and not peak luminosity ($L_0$). Assuming a flat Friedmann cosmology ($q_0 = 1/2$, $\Lambda = 0$) and constant rate density ($\rho_c$) of bursting sources, we fit a standard candle energy to a uniformly selected log $N$-log $S$ in the BATSE 3B catalog correcting for fluence efficiency and averaging over 48 observed spectral shapes. We find the data consistent with $E_0 = 7.3^{+0.7}_{-1.0} \times 10^{51}$ ergs and discuss implications of this energy for cosmological models of $\gamma$-ray bursts.

INTRODUCTION

On the basis of strong threshold effects of detectors, Klebesadel, Fenimore, and Laros (7) concluded that GRB fluence tests were largely inconclusive. As a result, nearly all subsequent number-brightness tests have used peak flux ($P$) rather than fluence ($S$). However, the standard candle peak luminosity assumption that is required by log $N$-log $P$ studies is unphysical. If, for instance, bursts originate at cosmological distances and are produced by colliding neutron stars then one might expect that total energy would be standard and not peak luminosity. Moreover, recent analysis of relativistically expanding shell models has cast doubt on the standard $L_0$ assumption (9).

In this paper, we seek to eliminate the large threshold effects present in
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Afterglow predictions:
Paczyński & Rhoads 93, Katz 94, Mészáros & Rees 97

BASIS: A GRB Mission Concept

N. Gehrels¹, B. Teegarden¹, L. Barbier¹, T. Cline¹, A. Parsons¹, J. Tueller¹, S. Barthelmy², D. Palmer², J. Krizmanic³, E. Fenimore⁴, G. Fishman⁵, C. Kouveliotou⁶, K. Hurley⁷, W. Paciesas⁸, J. van Paradijs⁹, S. Woosley¹⁰, M. Leventhal¹¹, D. McCammon¹², W. Sanders¹² and B. Schaefer¹³

¹NASA-GSFC, Greenbelt, MD 20771 ²USRA-GSFC ³NRC-GSFC ⁴LANL, Los Alamos, NM 87545 ⁵NASA-MSFC, Huntsville, AL 35812 ⁶USRA-MSFC ⁷UC Berkeley, Berkeley, CA 94720 ⁸UA Huntsville, Huntsville, AL 35899 ⁹U Amsterdam, Kruislaan 40, Netherlands ¹⁰UC Santa Cruz, Santa Cruz, CA 95064 ¹¹U Maryland, College Park, MD 20742 ¹²U Wisconsin, Madison, WI 53706 ¹³Yale, New Haven, CT 06520

We are studying a gamma-ray burst mission concept called the Burst ArcSecond Imaging and Spectroscopy (BASIS) as part of NASA’s New Mission Concepts for Astrophysics program. The scientific objectives are to accurately locate bursts, determine their distance scale, and measure the physical characteristics of the emission region. Arcsecond burst positions (angular resolution ~30 arcsec, source positions ~3 arcsec for >10⁻⁶ erg/cm² bursts) would be obtained for ~100 bursts per year using the 10-200 keV emission. This would allow the first deep, unconfused counterpart searches at other wavelengths. The key technological breakthrough that makes such measurements possible is the development of CdZnTe room-temperature semiconductor detectors with fine (~100 micron) spatial resolution. Fine spectroscopy would be obtained between 0.2 and 200 keV. The 0.2 keV threshold would allow the first measurements of absorption in our Galaxy and possible
Afterglows

GRB 970228
X-ray afterglow discovery
Optical afterglow discovery
Costa+97, van Paradijs+97

GRB 970508
Radio afterglow discovery
Absorption redshift
Host galaxy
Frail+97, Metzger+97, Taylor+97...

Burrows: this afternoon
Afterglows

Paradigmatic Model Emerges

Relativistic external shock model for Afterglows

Fig. 1.— Synchrotron spectrum of a relativistic shock with a power-law distribution of electrons. (a) The case of fast cooling, which is expected at early times ($t < t_0$) in a $\gamma$-ray burst afterglow. The spectrum consists of four segments, identified as A, B, C, D. Self-absorption is important below $\nu_a$. The frequencies, $\nu_m$, $\nu_c$, $\nu_a$, decrease with time as indicated; the scalings above the hear are adiabatic evolution, and the scalings below, in square brackets, to a fully radiative evolution. (b) The case of slow cooling, which is expected at late times ($t > t_0$). The evolution is always adiabatic. The four segments are identified as E, F, G, H.

Sari, Piran, Narayan 98
Afterglows

Paradigmatic Model Emerges

Collimation

Theory: Rhoads 97

Early Events:

• GRB 971214 Kulkarni+98
• GRB 990510 Harrison+99, Stanek+99

Summary: Frail+01
An infrared flash contemporaneous with the $\gamma$-rays of GRB 041219a


1 Harvard College Observatory, Cambridge, Massachusetts 02138, USA
2 Astronomy Department, University of California at Berkeley, Berkeley, California 94720, USA

- 3rd Swift localized event
- 1st long-wavelength afterglow detected for Swift
- “Forward shock” flashes (eg., GRB990123 Akerlof+00 )

http://w.astro.berkeley.edu/~jbloom/Autotel/Workshop_Talks/Bloom_grb.pdf
Hi Josh,

This looks excellent and exactly what is need for GRB progress. You can say that you have identified $50k to begin support without being specific. I may use some non-Swift hardware development funds for that support. I don't want to advertise such support too broadly because, then, everyone will be knocking at the door. On the other hand, it is not a secret and we should give straight answers when anyone asks directly.

Progenitors

- Long-soft GRBs (LSB) from massive stars (“collapsars”)
  Model: MacFayden & Woosley 99

- LSB locations correlated with the light of star forming galaxies
  Bloom, Kulkarni, Djorgovski 02, Fruchter+06
• Early Photometric evidence for a supernova connection
  GRB980326 Bloom+98
  GRB970228 Reichart+98

• Spectroscopic Confirmation:
  GRB030329 Stanek+03

cf., Woosley & Bloom 06; Hjorth & Bloom 12 for review
We have argued that the observations find natural explanation with a compact merger system progenitor. If so, then short-hard GRBs provide a bridge from electromagnetic to gravitational wave astronomy: indeed, had GRB 050509b occurred a factor of ~3 closer in luminosity distance, it might have produced a detectable chirp signal with the next-generation Laser Interferometer Gravitational-Wave Observatory (LIGO II).
A Short-Hard GRB Near a Massive Elliptical

130,000 light year

Region of Fading X-ray Afterglow

30,000 light year

Also, faint blue galaxies

Chance coincidence with elliptical galaxy small (<

Keck Imaging Data from Bloom et al.

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CLOSING IN ON A SHORT-HARD BURST PROGENITOR: CONSTRAINTS FROM EARLY-TIME OPTICAL IMAGING AND SPECTROSCOPY OF A POSSIBLE HOST GALAXY OF GRB 050509b


GRB 050509b
First Well-Localized Short-Hard GRB by Swift (BAT/XRT)

Received 2005 May 24; accepted 2005 September 3

We have argued that the observations find natural explanation with a compact merger system progenitor. If so, then short-hard GRBs provide a bridge from electromagnetic to gravitational wave astronomy: indeed, had GRB 050509b occurred a factor of $\sim 3$ closer in luminosity distance, it might have produced a detectable chirp signal with the next-generation Laser Interferometer Gravitational-Wave Observatory (LIGO II).
A tough act to follow

Bill Clinton on Life after the Presidency

Gamma Ray Bursters

Joshua Bloom, assistant professor of astronomy at the University of California, Berkeley
A short $\gamma$-ray burst apparently associated with an elliptical galaxy at redshift $z = 0.225$

N. Gehrels$^1$, C. L. Sarazin$^2$, P. T. O'Brien$^3$, B. Zhang$^4$, L. Barbier$^5$, S. D. Barthelmy$^1$, A. Blustin$^6$, D. N. Burrows$^6$, J. Cannizzo$^{1,7}$, J. R. Cummings$^{1,8}$, M. Goad$^9$, S. T. Holland$^{1,9}$, C. P. Hurkett$^1$, J. A. Kennea$^5$, A. Levan$^1$, C. B. Markwardt$^{1,10}$, K. O. Mason$^1$, P. Meszaros$^6$, M. Page$^1$, D. M. Palmer$^{11}$, E. Rol$^1$, T. Sakamoto$^{1,12}$, R. Willingale$^1$, L. Angellini$^{1,3}$, A. Beardmore$^1$, P. T. Boyd$^{2,7}$, A. Breeveld$^1$, S. Campana$^5$, M. M. Chester$^6$, G. Chincarini$^{1,13}$, L. R. Cominsky$^1$, G. Cusumano$^{12}$, M. de Pasquale$^7$, E. E. Fenimore$^1$, P. Giommi$^5$, G. Gronwall$^8$, D. Grupe$^2$, J. E. Hill$^8$, D. Hinshaw$^{1,14}$, L. Hjorth$^{1,15}$, D. Hullinger$^{1,16}$, K. C. Hurley$^9$, S. Klose$^{20}$, S. Kobayashi$^5$, C. Kouveliotou$^{11}$, H. A. Krimm$^5$, V. Mangano$^{12}$, F. E. Marshall$^1$, K. McGowan$^1$, A. Moretti$^{11}$, R. F. Mushotzky$^1$, K. Nakazawa$^{22}$, J. P. Norris$^1$, J. A. Nousek$^5$, J. P. Osborne$^1$, K. Page$^3$, A. M. Parsons$^5$, S. Patel$^{11}$, M. Perri$^{16}$, T. Poole$^3$, P. Romano$^{12}$, P. W. A. Roming$^1$, S. Rosen$^1$, G. Sato$^{11}$, P. Schady$^1$, A. P. Smale$^{14}$, J. Short$^{22}$, R. Starling$^{16}$, M. Still$^{18}$, M. Suzuki$^{27}$, G. Tagliaferri$^{12}$, T. Takahashi$^{12}$, M. Tashiro$^{27}$, J. Tueller$^1$, A. A. Wells$^{11}$, N. E. White$^1$ & R. A. M. J. Wijers$^{26}$

Gamma-ray bursts (GRBs) come in two classes: long ($>2 s$), soft-spectrum bursts and short, hard events. Most progress has been made on understanding the long GRBs, which are typically observed at high redshift ($z > 1$) and found in subluminous star-forming host galaxies. They are likely to be produced in core-collapse explosions of massive stars. In contrast, no short GRB had been accurately ($<1^\circ$) and rapidly ($\text{minutes}$) located. Here we report the detection of the X-ray afterglow from—and the localization of—the short burst GRB 050509B. Its position on the sky is near a luminous, non-star-forming elliptical galaxy at a redshift of 0.225, which is the location one would expect$^{14,15}$ if the origin of this GRB is through the merger of neutron-star or black-hole binaries. The X-ray afterglow was weak and faded below the detection limit within a few hours; no optical afterglow was detected to stringent limits, explaining the past difficulty in localizing short GRBs.

The new observations are from the Swift$^1$ satellite, which features a wide-field X-ray telescope and a corresponding optical/ultraviolet telescope (UVOT) for localization. Swift slewed promptly and XRT started acquiring data 62 s after the BAT trigger (the BAT trigger time). Ground-processed data revealed an uncatalogued X-ray source near the centre of the BAT error circle containing 11 photons (5.7e$^2$ significance due to near-zero background in image) in the first 1600 s of integration time. The XRT position is shown with respect to the Digitized Sky Survey (DSS) field in Fig. 1. A Chandra target-of-opportunity observation of the XRT error circle was performed on 11 May at 4:00 UT for 50 ks, with no sources detected in the XRT error circle. The light curve combining BAT XRT and Chandra data are shown in Fig. 3. The UVOT observed the field starting at 7:45 UT. No new optical/ultraviolet sources were found in the XRT error circle to within a radius of 20 arcsec of the XRT position.

GRB survey made with the Burst and Transient Source Experiment (BATSE). The 15–150 keV fluence is (9.5 ± 2.5) $\times$ 10$^{-6}$ erg cm$^{-2}$, which is the lowest imaged by BAT so far and is just below the short GRB fluence range detected by BATSE (adjusted for the different energy ranges of the two instruments). Swift slewed promptly and XRT started acquiring data 62 s after the burst ($T+62 s$, where $T$ is the BAT trigger time). Ground-processed data revealed an uncatalogued X-ray source near the centre of the BAT error circle containing 11 photons (5.7e$^2$ significance due to near-zero background in image) in the first 1600 s of integration time. The XRT position is shown with respect to the Digitized Sky Survey (DSS) field in Fig. 1. A Chandra target-of-opportunity observation of the XRT error circle was performed on 11 May at 4:00 UT for 50 ks, with no sources detected in the XRT error circle. The light curve combining BAT XRT and Chandra data are shown in Fig. 3. The UVOT observed the field starting at 7:45 UT. No new optical/ultraviolet sources were found in the XRT error circle to within a radius of 20 arcsec of the XRT position.
Progenitors

Short-Hard GRBs (SHBs):
- More diffusely positioned around galaxies
- More massive, earlier-type putative hosts
- Consistent with NS-NS/NS-BH merger simulations

Bloom & Prochaska 06, Troja+07; Fong+09; Gehrels, Ramirez-Ruiz & Fox 09; Berger 14

- Coincident GW would be the only smoking gun

P. O'Brien, P. Mészáros: this afternoon; W-f Fong tomorrow
Progenitors

Early indications that SHBs were from a different population

But the above statement can be reworked in the form of a generic set of predictions:

- In Long delay (>1 Gyr) progenitors scenarios with kicks the offsets should anti-correlate with host mass and correlate with average stellar age
- In Short delay (<1 Gyr) progenitors the offsets should correlate with host mass and anti-correlate with average stellar age.

If the progenitor lifetime of the SHBs is long and kicks are small, then the bursts should correspond spatially to the oldest stellar populations in a given galaxies. For early-type galaxies, the distribution would presumably follow the light of the galaxy. In contrast, the distribution in star-forming galaxies might be more concentrated in the spheroid (e.g., bulge of the Milky Way).
Progenitors

7.1. The Offset Distribution

Determining the locations of short GRBs relative to their host centers (offsets) and relative to the underlying light distribution in the rest-frame optical (stellar mass) and UV (star formation) bands requires the high angular resolution and superior depth of the HST. A comprehensive study based on HST observations of 32 short GRB host galaxies was carried out by Fong, Berger & Fox (2010) and Fong & Berger (2013; see also Church et al. 2011). The HST data, combined with ground-based optical afterglow observations (and, in two cases, Chandra observations), provide accurate offsets at the subpixel level and reveal the broad distribution shown in Figure 10. The projected offsets span 0.5–75 kpc with a median of about 5 kpc. These are about four times greater than the median offset for long GRBs (Bloom, Kulkarni & Djorgovski 2002) and about 1.5 times greater than the median offsets of core-collapse and Type Ia SNe (Prieto, Stanek & Beacom 2008).

In addition, though no long GRBs and only $\sim 10\%$ of SNe have offsets of $\gtrsim 10$ kpc, the fraction of short GRBs with such offsets is about 25%. For offsets of $\gtrsim 20$ kpc, the fraction of short GRBs is about 10%, but essentially no SNe exhibit such large offsets.

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  Bloom & Prochaska 06, Troja+07; Fong+09; Gehrels, Ramirez-Ruiz & Fox 09; Berger 14
- Coincident GW would be the only smoking gun

P. O'Brien, P. Mészáros: this afternoon; W-f Fong tomorrow
Oddballs, or Nature is good at Making Bursts of Gamma rays

- **X-ray Flashes (XRFs)**
  - Lower-energy events

- **Relativistically Beamed Tidal Disruption Events** - Sw 1644+57

- **Soft-gamma Ray Repeaters (SGRs)** - March 5 Events
  - ~15 known

- **Long GRBs without Supernovae**
GRBs as Probes

• ISM/IGM/Host via Absorption Spectroscopy
  Chen+05, Savaglio+07, Prochaska+07

• Reionization (Neutral Fraction vs Redshift)
  Miralda-Escudé 98, Bromm & Loeb 02, Kawai+05, Totani+06

• Signposts to Pop III stars in the early universe
  Bromm+00

Bloom+08
GRBs as Probes

- ISM/IGM/Host via Absorption Spectroscopy
  - Chen+05, Savaglio+07, Prochaska+07
- Reionization (Neutral Fraction vs Redshift)
  - Miralda-Escudé 98, Bromm & Loeb 02, Kawai+05, Totani+06
- Signposts to Pop III stars in the early universe
  - Bromm+00

For Swift:
- <7% of bursts from z>7
- <15% of bursts from z>5

median z \sim 2.1
GRBs as Probes

**Killer Apps**

- Testing compactness w/ Fermi
  e.g. 090510 ($\Gamma > 1200$) _Abdo+09_

- Testing curvature effect ("high latitude emission") in rapid fall
  e.g. 080503 _Genet+09_ _Willingale+09_

- Testing Lorentz Invariance Violation
  e.g. 090510 _Abdo+09_ (Fermi)

- Connection to Gravity Wave/Neutrino Domains
Multimessenger

Perley, Metzger+08; Also, GRB 130603B, Tanvir+03

short GRB 080503

Neil Gehrels to Fynbo, Berger, Tanvir, Kawai, Fox, Bloom, ...

short GRB (<0.25 sec)
bright fading XRT
no UVOT
7.6 hours from the sun

GRB 080503

short-lived afterglow

GRB 080503

Perley, Metzger+08; Also, GRB 130603B, Tanvir+03
GRB 080503

FIG. 11.—Two AB magnitude (Oke 1974) light-curve models for a Ni-powered “mini-SN” from GRB 080503, based on the model of Li & Paczyński (1998), Kulkarni (2005), and Metzger et al. (2008b). The solid line indicates a model at $z = 0.03$ with a $^{56}\text{Ni}$ mass $\approx 2 \times 10^{-3} \text{M}_\odot$, total ejecta mass $\approx 0.4 \text{M}_\odot$, and outflow velocity $\approx 0.1c$. The dotted line is for a pure Ni explosion at $z = 0.5$ with mass $\approx 0.3 \text{M}_\odot$ and velocity $\approx 0.2c$. Also shown are our $r$-band and F606W detections and upper limits from Gemini and HST.
Multimessenger

GRB/GW 170817 - NS-NS merger produced a GRB & kilonova

Kasliwal+17, Science

E. Troja, V. Kalogera: this afternoon; L. Singer, T. Piran: tomorrow
From a talk by me in Cefalu, 2008
50 Years of Gamma-Ray Bursts*

* With a biased overemphasis on Neil & stuff I was involved in

Josh Bloom
UC Berkeley
@profjsb