Figure 1. Number of gamma-ray burst publications as a function of year through 2004. Some milestones are indicated which reflect the sudden increases in the publication rate. Other fluctuations may be due to influxes of conference proceedings papers.
Discovery
Serendipitous Discovery in the Cold War

✴ “Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space, and Under Water”

✴ or “Limited Test Ban Treaty” began October 10, 1963, signed by US (Kennedy), Russia, Britain

✴ Project Vela (“Watchman”)

✴ search for non-compliance (launch 1963)

✴ pairs of satellites in 4 day orbits

✴ X-ray, γ-ray, EMP, neutron detectors

✴ Launched every few years with increasing sophistication.
670702: First GRB
not a characteristic nuclear test signal
(Vela 4)
Figure 1  Sample page from the First BATSE Catalog of Gamma-Ray Bursts (Fishman et al. 1994b), indicating the diversity in the time profiles, intensities, and durations of gamma-ray bursts.
Only One Prediction of Gamma-Ray Bursts

Colgate 1968, 1974:
Accelerated ions during supernova shock breakout ("cracking a whip")

EARLY GAMMA RAYS FROM SUPERNOVAE

This section of the text discusses the early gamma rays from supernovae and their implications for gamma-ray bursts. It references Colgate's work in 1968 and 1974 on accelerated ions during supernova shock breakout. The text also mentions the publication in the Canadian Journal of Physics in 1968.
OBSERVATIONS OF GAMMA-RAY BURSTS OF COSMIC ORIGIN

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Received 1973 March 16; revised 1973 April 2

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 \( \sim \)30 s, and time-integrated flux densities from \( \sim 10^{-5} \) ergs cm\(^{-2}\) s to \( \sim 2 \times 10^{-4} \) 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 an average altitude of 1000 km.
N.B.: SN 1968P ($z \approx 0.11$) was highest $z$ SN in 1973, lower than the redshifts of all classic GRBs
GRBs Confirmed by Apollo 16, Soviet Venera,..

* Spectra shown to be non-thermal,
* typically with a peak in $\nu f_\nu$ at $\sim 200$ keV

Klebesadel et al. 1975
Briggs et al. 1999 (1999ApJ...524...82B)
Origin Question intermingled with Distance Scale

- Brightness Distribution
- Energetics
- Sky Distribution
Classic Brightness Test: $\log N(>P) - \log P$

* Violation of $-3/2$ power law distribution

* Too few faint GRBs below $10^{-4}$ erg s$^{-1}$

* Seeing an “edge” to the distribution

---

*Fig. 1. Intensity distributions of $\gamma$-ray bursts. a) Kosmos 461; b) Meteor satellite; 1) Vela satellites. The open circles and curves 1 and 2 represent the same data after correction for observational selection.*

Fishman et al. 1975/78 balloon experiment
Sky Distribution: Isotropy

1st IPN network: 84 GRBs
(1978 - 1980)

Mazets et al. 1981; Atteia et al. 1987
\[ \cos(\theta) = \frac{c\Delta T}{D_{12}} \]

THE "TRIANGULATION" METHOD
Nature’s Three Curve Balls

*Spectral Lines

*Archival Transients

*March 5, 1979
Cyclotron Lines in Her X-1

\[ \omega = \frac{eB}{\Gamma mc} \]

\[ B = 1.4 \times 10^{10} \text{ Gauss } \frac{E}{\text{ keV}} \]

\[ B \approx 5.3 \times 10^{12} \text{ Gauss} \]


Fig. 2.—Deconvolved X-ray spectrum of the Her X-1 pulsar. Solid line, best-fitting exponential spectrum with a Gaussian line to the data points. The error bars are ±1; the upper limits are at 2σ. For comparison, a total X-ray spectrum of Her X-1 observed by OSO-8 during the 1975 August on-state is shown (Becker et al. 1977).
SEARCH FOR OPTICAL EMISSION FROM COSMIC GAMMA-RAY BURSTS

J. E. GRINDELAY, E. L. WRIGHT, AND R. E. McCROSKEY

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Received 1974 May 22; revised 1974 July 3

ABSTRACT

Long-exposure films are available for both times and regions of sky for several cosmic γ-ray bursts. An upper limit of $m_v > 6$ was set for optical emission from the well-observed 1972 May 14 event. The corresponding lower limit for the ratio of X-ray to optical energy flux in the burst is $F_x/F_{opt} > 100$. This may restrict solar-flare analogy models for the burst sources.

Subject headings: gamma-ray bursts — X-rays

Immediate searches for coincident transients

$m_v > 6$ mag

Archival Searches turned up optical transients

...but most believe them to be defects in the plates.

e.g. Zytkow: Are there optical counterparts to gamma-ray bursts?” 1990ApJ...359..138Z

Hudec et al. 1994 (1994A&A...284..839H)
"No Host Problem"  

Even in small error boxes, no low redshift galaxy hosts for the bright GRBs

Based on log \( N \)-log \( P \) and standard candle

\[ N \text{-log} P \text{ distribution, one must select the events uniformly and calculate the fluxes in a similar manner. The two instruments differ significantly in how the events are selected and the selection criteria we have used are described in the box.} \]

Figure 1 shows the resulting log \( N \)-\( P \) histograms for the 86 BATSE events and 146 PVO events selected. Without any arbitrary scaling, there is excellent agreement between the two curves. Six events seen by both PVO and BATSE had peak fluxes that agreed within the statistics. Unfortunately the events are so weak in PVO that these events cannot be used to independently determine the relative normalizations of the BATSE and PVO distributions.

We have fit the combined data to models\(^9\)\(^13\) that assume an \( \Omega_0 = 1 \) cosmology, a constant number of events per unit volume-time, and a constant intrinsic peak luminosity (that is, a standard candle). The dotted and dashed vertical lines show the intensity intervals \( (P_{p,i}, P_{p,i+1}) \) for which the differential number of observed events are compared to the model for BATSE and PVO, respectively. The number of expected events between the (photon cm\(^{-2}\) s\(^{-1}\)) values of \( P_{p,i} \) and \( P_{p,i+1} \) is

\[
\Delta N(P_{p,i}, P_{p,i+1}) = \int_{r_{i}}^{r_{i+1}} \left( \frac{2}{2 - rH_0/c} \right)^{-2} 4\pi \rho r^2 dr \tag{1}
\]

where \( \rho \) is the rate-density of events per comoving volume (bursts yr\(^{-1}\) Gpc\(^{-3}\)) and \( r_i \) is the distance to the bursts with

**BOX 1** BATSE and PVO event selection

The PVO triggers in the energy range of 100–2000 keV on timescales of 1/4, 1 and 4 s and most events have their peak intensities known at 0.1875-s intervals. BATSE triggers in the energy range 50–3000 keV on timescales of 64, 256 and 1,024 ms and most events have their peak intensity known for sliding time periods of 64, 256, 1,024 ms. In addition, a burst brighter than an event in BATSE’s memory can overwrite the memory, thus increasing the effective threshold for the brighter event above that expected from

---

Fenimore et al. 1993  
March 5, 1979 Event

super bright \((10^{-3} \text{ erg sec}^{-1} \text{ cm}^{-2})\) - 9 satellites
short burst localized to the in the LMC
coincident with a supernova remnant (N49)
“soft” spectrum after first 0.2 sec
\((\sim 30 \text{ keV}; \text{ OTTB})\)
\(10^6\) times Eddington limit for a NS
A NEW TYPE OF REPETITIVE BEHAVIOR IN A HIGH-ENERGY TRANSIENT

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CESR, Toulouse, France

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C. Kouveliotou, T. L. Cline, B. R. Dennis, U. D. Desai, and L. E. Orwig
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Institute for Space Research, Moscow

Received 1987 April 14; accepted 1987 June 15

ABSTRACT

The source of GB 790107, an event originally classified as a γ-ray burst, has been seen to repeat approximately 100 times during the time interval from 1978 August 13 to 1986 June 27. Most of the repetitions occurred in late 1983. Two Letters present the initial observations of this new type of repetitive behavior in a high-energy burster. The emphasis of this Letter, which uses primarily 5–100 keV data from the UCB/Los Alamos experiment on the International Cometary Explorer spacecraft, is on arguments for the reality and correct interpretation of the observed phenomenon, and on the properties of the source that are revealed by noting the intensities and occurrence times of the repetitions. We find that the outbursts occur in clusters having time scales ranging approximately from an hour to a month. There is little evidence for any other pattern to the repetitions. The separation between events can range from seconds to years, with little correlation between separation and event intensity. The observed range in intensity, limited by the instrumental threshold, is greater than a factor of 30. The spectra of events are similar to one another and can be described (nonuniquely) as \(~ 35\) keV thermal bremsstrahlung with evidence for a low-energy deficiency. The companion Letter emphasizes time histories, localizations, and additional spectral information on this enigmatic high-energy burster.

Subject heading: gamma rays: bursts
Soft-Gamma Ray Repeaters (SGRs)

* SGR 0526-66 (March 5th)
* 1900+14
* 1806-20
* 1801-23  (discovered in 1997)
* 1627-41  (discovered in 1998)

http://solomon.as.utexas.edu/~duncan/magnetar.html
Great Debate: Distance Scale

“Galactic” - high-velocity NS streaming from our Galaxy and repeat

“Cosmological” - Something that releases a lot of energy quickly and most are outside the supergalactic plane

2704 BATSE Gamma-Ray Bursts
“Galactic” - high-velocity NS streaming from our Galaxy and repeat

+ energetics of NS about correct (and appealing)
+ solves “No host problem” and lack of counterparts
+ edge of halo accounts for log $N$-log $P$
+ naturally explains cyclotron lines

- isotropy means halo must be huge
- contrived repeat rate and beaming towards Earth
$d_{\text{max}} \sim 100$-500 kpc

turn on delay $\sim 10^7$ yr

lifetime $\sim 10^9$ yr

Lamb 1995
“Cosmological” - Something that releases a lot of energy quickly and most are outside the supergalactic plane

+ accounts for isotropy AND log N-log P in a natural way

- cannot explain cyclotron lines
- energies enormous
- cannot explain apparent repetitions
Fig. 1—The distribution of 528 nearby stars is shown in galactic coordinates. The data were obtained from the CDS in Strasbourg (P87A) and it is based on W. J. Luyten (1976). These are stars with a proper motion in excess of one second of arc per year. The distribution is approximately isotropic and random. Some apparent clustering is due to nonuniform sky coverage of the search for high proper-motion stars.

Fig. 2—The distribution of the 1143 galactic planetary nebulae (PN) is shown in galactic coordinates. The data were obtained from the CDS in Strasbourg (V84) and it is based on Acker et al. (1992, Strasbourg-ESO Catalogue of Galactic Planetary Nebulae). Notice the strong concentration of objects toward the galactic plane, typical for the distribution of distant stars.

Fig. 3—The distribution of the 160 galactic globular clusters (GLOB.CL) is shown in galactic coordinates. The data were obtained from the CDS in Strasbourg (V17) and it is based on Monella (1985, Coelum III, 267). Notice the strong concentration toward the galactic center of these typical galactic halo objects.

Fig. 4—The distribution of 276 nearby galaxies is shown in galactic coordinates. The data were obtained from the CDS in Strasbourg (V161) and it is based on Schmidt et al. (1993, Astron. Nach., 313, 189–231). Nearby galaxies I—The catalogue. Notice the highly irregular distribution concentrated on the nearby Virgo cluster.

Fig. 5—The distribution of the 233 strongest 2.7 GHz extragalactic radio sources is shown in galactic coordinates. The data were obtained from Wall and Peacock (1985). These sources are associated with very distant galaxies, and they are apparently distributed isotropically and randomly in the sky. Sources in the “zone of avoidance” close to the galactic equator are not shown to avoid confusion with the large number of galactic sources.

Fig. 6—The distribution of the galactic X-ray bursts (XRB—filled circles) and the three known soft gamma repeaters (SGR—open circles) is shown in galactic coordinates. The data were obtained from van Paradijs (1995 private communication). Notice the strong concentration of sources toward the galactic plane and the galactic center.
## Table 1

Comparison of Evidence for (✓) and against (☐) the Cosmological and Galactic Hypotheses

<table>
<thead>
<tr>
<th>Evidence</th>
<th>Cosmological</th>
<th>Galactic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isotropy and brightness distribution</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Similarities of SGRs &amp; GRBs</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Famous 1979 March 5 event</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Cyclotron lines</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Repeating</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Time stretching</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>No bright optical counterparts</td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>

*Hindsight*
BeppoSAX and X-ray Afterglow Discovery

Launched April 30, 1996

GRB 970228: fading X-ray source
6 arcmin → 1 arcmin
Discovery of an X-ray afterglow associated with the γ-ray burst of 28 February 1997

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Establishing the nature of γ-ray bursts is one of the greatest challenges in high-energy astrophysics. The distribution of these bursts is isotropic across the sky, but inhomogeneous in space, with a deficit of faint bursts. It is currently unknown whether γ-ray bursts are produced in our Galaxy or at cosmological distances. The detection and identification of counterparts at other wavelengths are seen as crucial for resolving the origin of the events. Here we report the detection by the Beppo-SAX satellite of an X-ray ‘afterglow’, associated with the γ-ray burst of 28 February 1997 (GRB970228; ref. 3)—the first such detection for a γ-ray burst. The X-ray transient was found to contain a significant fraction of the total energy of the γ-ray burst and, following the initial detection eight hours after the main burst, faded within a few days with a power-law decay function. The rapid locating of this γ-ray burst instigated a multi-wavelength observational campaign that culminated in the identification of a faint optical transient in a position consistent with the X-ray afterglow, but at a distance of 30 Mpc. This breakthrough underscores the capability of detecting and fast positioning GRBs and starting follow-up observations.

We developed a procedure for fast localization and rapid follow-up observations of GRBs with the Beppo-SAX Narrow Field Instruments (NFIs), a cluster of telescopes pointing towards the same field of view and covering the large band of 0.1–300 keV (refs 10, 12–14), taking advantage of having them aboard the same satellite and under the same Operation Control Centre.

On 1997 February 28.123620 UT the GRBM was triggered by a GRB event (GRB970228). When the data from the whole orbit were transferred to the ground station and forwarded to the Scientific Operation Centre, ‘quick-look’ analysis of data from the WFCs at the trigger time showed that a counting excess was also present in one WFC. The X-ray excess was imaged, showing a point-like source. WFC images before and after the event showed that the source was transient and simultaneous with the burst. Light curves in the γ-ray and X-ray band are shown in Fig. 1.

Figure 1 Time profile of GRB970228 in the γ-ray (from the Gamma-Ray Burst Monitor) and X-ray (from the Wide Field Camera) bands. The origin is the trigger time. The first pulse is shorter in γ-rays than in X-rays. Three other pulses follow (at ~35, 50 and 70 s from the trigger) that are much enhanced in the X-ray band. The total burst duration is ~80 s.

The burst position was first determined from a ‘quick-look’ analysis of the WFC data with an error radius of ~10 arcmin, suitable for planning a Target of Opportunity pointing (TOO) of
Transient optical emission from the error box of the γ-ray burst of 28 February 1997


For almost a quarter of a century, the origin of γ-ray bursts—brief, energetic bursts of high-energy photons—has remained unknown. The detection of a counterpart at another wavelength has long been thought to be a key to understanding the nature of these bursts (see, for example, ref. 2), but intensive searches have not revealed such a counterpart. The distribution and properties of the bursts are explained naturally if they lie at cosmological distances (a few Gpc), but there is a counterviewing view that they are relatively local objects, perhaps distributed in a very large halo around our Galaxy. Here we report the detection of a transient and fading optical source in the error box associated with the burst GRB970228, less than 21 hours after the burst.

GRB970228 was detected with the Gamma-ray Burst Monitor on board the Italian–Dutch BeppoSAX satellite on 1997 February 28, UT 02 h 58 m 01 s. The event lasted ~80 s and reached peak fluxes of ~4 × 10⁻⁵, ~6 × 10⁻⁶, and ~10⁻⁷ erg cm⁻² s⁻¹ in the 40–600 keV, 40–1000 keV, and 1–5.7 keV bands, respectively (note that the peak flux of 0.23 Crab quoted in ref. 9 is in error). It occurred in the field of view of one of the BeppoSAX Wide Field Cameras (WFCs)¹. The spectrum of the event is characteristic of classical γ-ray bursts (GRBs)². Its position (about halfway between a Tauri and a Orionis) was determined with an accuracy of 3' (radius) at right ascension (RA) 05 h 01 m 57 s, declination (dec.) 11° 46′. The location of the long-baseline timing technique³ to the GRB data obtained with the Ulysses spacecraft, and with the BeppoSAX and the Wind satellites, respectively, constrained this location to be within each of two parallel annuli, with half-widths³⁶ of 31' (3σ) and 30' (3σ) respectively, which intersect the WFC error circle (Fig. 1).

Eight hours after the burst occurred, BeppoSAX was re-oriented so that the GRB position could be observed with the LECS and MECS detectors. A weak X-ray source was then found at RA 05 h 01 min 44 s, dec. +11° 46′ (error radius 50″), near the edge of the WFC error circle (Fig. 1). The 2–10 keV (MECS) flux of this source was 2.4 × 10⁻¹¹ erg cm⁻² s⁻¹. The LECS instrument measured a 0.1–10 keV spectrum flux of (2.6 ± 0.6) × 10⁻¹³ erg cm⁻² s⁻¹. The source spectrum was consistent with a power-law model with photon index 2.7, reduced at low energy by a column density N₉ of 5.6 × 10¹⁸ cm⁻². During an observation with the same instruments on March 3, UT 17 h 37 min this flux had decreased by a factor of 20 (ref. 19). With ASCA the X-ray source was detected on 7 March at a 2–10 keV flux of (0.8 ± 0.2) × 10⁻¹¹ erg cm⁻² s⁻¹.

On February 28, UT 23 h 48 min, 20.8 hours after the GRB occurred, we had a second, strong burst. We obtained a V-band and an I-band image (exposure time 300 s) of the WFC error box with the Prime Focus Camera of the 2.2-m William Herschel Telescope (WHT) on La Palma. The 1.024 × 1.024 pixel CDF frames (pixel size 24 μm, corresponding to 0.42″) cover a 7.2 × 7.2′ field, well matched to the size of the GRB error box. Photometric calibration was obtained from images of standard star number 336 and Landolt field 104. The images were reduced using standard bias subtraction and flat-fielding.

A comparison of the two image pairs immediately revealed one object with a large brightness variation: it is clearly detected in both the V- and I-band images taken on 28 February, but not in the second pair of images taken on 8 March (Fig. 2). From a comparison with positions of nearby stars that were obtained with the Digitized Sky Survey, we find that the WFC position (RA 05 h 01 m 46 s, dec. +11° 46′ 35″) (equinox 2000); this position has an estimated (internal) accuracy of 0.2″. The object is located in the error box defined by the WFC position, the Ulysses/BeppoSAX/Wind annuli, and the transient X-ray source position (Fig. 1).

Figure 1 The position of the optical transient, indicated with an asterisk, is shown with respect to the 3″ (radius) WFC location error circle. The 50″ (radius) error circle of the BeppoSAX X-ray transient, and the 60″ (radius) error circle of the γ-ray burst, are also shown. The area in common between these error regions is indicated by a dotted line. The coordinates are given in units of arcmin with respect to the position of the optical transient (RA 05 h 01 min 46 s; dec. +11° 46′ 35″) (equinox 2000).

The position of an unrelated radio source was in the error circle of the X-ray transient and is indicated with the square symbol.

A 3" × 3" (23 × 23 kpc² in projection) region of the HST/STIS image (1997 September 4.7 UT) of the host galaxy of GRB 970228. The image has been smoothed (see text) and is centered on the optical transient. North is up and east is left. Contours in units of 3, 4, 5, 6, 7, and 8 background (sigma = 2.41 DN) are overlaid. The transient is found on the outskirts of detectable emission from a faint, low surface brightness galaxy. The morphology is clearly not that of a classical Hubble type, though there appears to be a nucleus and an extended structure to the north of the transient.

. Macchetto and P. Caraveo, both reported on the HST observations of GRB970228: the latter detects and the former does not detect proper motion in the pointlike source. This is one of the biggest controversies currently that has to be resolved. The extended source properties of GRB970228 (decay or not decay) is another one. D. Lamb reports that his simulations show that the two HST images are consistent with each other but not consistent with the Keck results that show a fading of the extended source. Golden also reported that his analysis of the HST data supports the Caraveo results, insofar that he also detects a proper motion but of half the amplitude.
Radio Afterglow! GRB 970508

Scintillation quenching @ 20 days
gives source size $\sim 10^{17}$ cm
confirms relativistic motion.

The radio afterglow from the
$\gamma$-ray burst of 8 May 1997


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Important insight into the nature of $\gamma$-ray bursts (GRBs) has been gained in recent months mainly due to the immediate, precise localization of the bursts$^1$ and the discovery of relatively long-lived X-ray afterglows$^{19}$ by the satellite BeppoSAX. These advances have enabled deep searches which have led to the discovery of optical transients$^{27}$ coincident with fading X-ray sources. Optical spectroscopy of the latest burst (GRB970508; ref. 8) has clearly demonstrated that it lies at a cosmological distance, thus resolving a long-standing controversy about the distance scale to GRBs. Here we report a variable radio source within the error box of GRB970508 and coincident with the optical transient. We suggest that this is the much-sought-after radio counterpart of a GRB. If the observed fluctuations in the radio emission ("twinkling") are a result of a strong scattering by the irregularities in the ionized Galactic interstellar gas, then the source must have an angular size of about 3 microarcseconds in the first few weeks. The damping of the fluctuations with time indicates that the source expands to a significantly larger size later on.

Figure 1 Light curves of the radio counterpart of GRB970508. a. Light curve at 8.46 GHz. Data points consist of VLA (open triangles) and VLBI data (filled triangles)$^{25}$. The flux densities from the VLBI measurements$^{25}$ were determined by splitting each data set in half and measuring them independently. There is close agreement between those flux densities which were independently measured by the VLA and VLBI. The first detection of the source was made on May 13.96 UT, 5 days after the GRB event. The delay, if any, between the onset of the radio emission and the high-energy radiation is not well constrained, as the earliest VLA observations were made at 1.43 GHz. Unfortunately, as shown in b and c, the source was weak for the first month at this frequency. b. Light curve at 8.46 GHz (open squares) and 1.43 GHz (filled squares). The sampling at 4.86 GHz

Don Lamb of the University of Chicago, a vocal proponent of the local view, isn't convinced, saying that he has "increasing doubts that [Bond's star] has anything to do with the gamma-ray burst." Lamb points out that the variable object shows all the signs of being a so-called BL Lacertae object, a kind of turbulent, energetic galaxy. Because efforts to link earlier bursts to such galaxies had failed, Lamb thinks the burst and the high-redshift optical variable are unrelated. "Time will tell," he says; "that's the wonderful thing in science."

from 23 May 1997 Nature Research News
Fig. 1. Number of $\gamma$ bursts $N(S)$ with energy flux per pulse larger than $S$. Deviations from the law $N(S) \propto S^{-3/2}$ are shown by continuous line for the galactic models and by dashes and dash-dots for models where the $\gamma$ bursts are generated in supernova explosions and the collapse of the cores of active galaxies respectively. Observations of $\gamma$ bursts with $S > 10^{-9}$ $10^{-8}$ erg $cm^{-2}$ became difficult due to their small radiation flux compared to the background.
Twinkle, twinkle, gamma star,
I don’t wonder where you are.

For BeppoSAX pinned down the place,
for Jan’s and Howard’s optic chase.

Mark Metzger with his spectrograph,
then wrote your riddle’s epitaph,

\[ z > 0.835 \]

--Ralph Wijers