OPTICAL LIMITS ON PRECURSOR EMISSION FROM GAMMA-RAY BURSTS WITH KNOWN REDSHIFT

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Received 2003 April 9; accepted 2004 January 23

ABSTRACT

Making use of virtual observatory data, we present the first comprehensive sample of optical observations conducted before the explosion times of all gamma-ray bursts (GRBs) with known redshifts. In total, the fields of 11 such GRBs were observed by the Near-Earth Asteroid Tracking (NEAT) program from years to hours before the bursts. Although the typical limiting magnitudes from these observations are \( R \approx 20 \) mag, we find no evidence for a significant detection of a precursor. The deepest nondetection of precursor emission is from GRB 030329, reaching down to an absolute \( B \)-band magnitude of \( M_B \approx -18 \) mag from 6 to 1500 days (rest frame) before the burst. This is of comparable brightness to supernovae, which in some scenarios for GRB progenitors are predicted to predate a GRB on similar timescales. Since sources cannot be localized to better than \( \sim 500 \) mas (3 \( \sigma \)) with current large-area surveys, unrelated supernovae or active galactic nucleus activity in GRB hosts could be mistaken for genuine precursor emission. This possibility motivates the need for not only deep wide-field imaging, but imaging at high spatial resolution.

Subject headings: cosmology: observations — gamma rays: bursts

On-line material: Machine-readable table

1. INTRODUCTION

Constraints on the character and occurrence of precursor emission from gamma-ray bursts (GRBs) offer insight into the nature of the explosions. On timescales of hours to seconds before a burst, precursor emission could occur from the central engines themselves by, for example, blackbody emission from the early fireball (Li & Paczyński 1998; Lloyd & Petrosian 1999; Lyutikov & Usov 2000; Daigne & Mochkovitch 2002) or a pre-fireball created in the merger of neutron stars (Rosswog & Ramirez-Ruiz 2002). If GRBs were to occur from stellar disruption around a massive black hole (Carter 1992), then thermal precursors (\( T \sim 50 \) eV), which decay as power laws (e.g., Li, Narayan, & Menou 2002), might be expected if other stars are disrupted by the same black hole.

If GRBs arise from the death of massive stars, the progenitor star (or its companion, if the progenitor is in a binary system) could produce precursor emission in the form of novae or supernovae (SNe). A precursor SN is a generic prediction of the so-called supranova scenario (Vietri & Stella 1998, 1999). In the supranova scenario, a massive stellar progenitor explodes to produce a SN, leaving behind a supermassive spinning neutron star. The neutron star eventually collapses to form a black hole and a GRB. Vietri & Stella (1998) posited the supranova picture as a means to pre-evacuate the space around the GRB explosion and avoid baryonic contamination to the relativistic blast wave. Aside from this theoretical consideration, the supranova scenario is attractive for two observational reasons. First, the sequence of events in this scenario is a natural means to explain transient X-ray features attributed to dense subrelativistic matter streaming away at a distance of \( 10^{14} \text{–} 10^{17} \) cm from the explosion site (e.g., Piro et al. 2000; Amati et al. 2000; Reeves et al. 2002). Second, the gas behind the SN shock can be thermalized by the time the GRB fireball sweeps through, leading to an apparent constant-density medium in afterglow modeling (Königl & Granot 2002; Inoue, Guetta, & Pacini 2003). This would then explain why GRBs from massive stars would typically not show evidence for a wind-blown medium surrounding most bursts (e.g., Chevalier & Li 1999; Panaitescu & Kumar 2001). While the significance of some of the X-ray features has been questioned (e.g., Rutledge & Sako 2003) and winds are generally not ruled out statistically through afterglow modeling (Panaitescu & Kumar 2001), the possibility of a precursor SN on timescales of days (Davies et al. 2002) to years is a prime motivation to search for precursor emission from GRBs.

As summarized in Hudec, Pravec, & Borovicka (1994), archival photographic plate searches (e.g., Schaefer 1983) for optical precursors (in the context of recurrence of counterpart emission) revealed only a few genuine astrophysical sources, with no definitive establishment of a physically associated precursor to any GRB. Using pre-images of the fields of seven Burst and Transient Source Experiment (BATSE) GRBs from the Explosive Transient Camera, Krimm, Vanderspek, & Ricker (1996) found no precursors to \( V \approx 6 \) mag. Greiner et al. (1995) presented eight upper limits to precursor emission at \( V = 11\text{–}13 \) mag within 12 hr preceding BATSE bursts. Had a genuine transient been found before a GRB, the large GRB error boxes (typically much larger than tens of arcmin\(^2\)) would have required an association based on probabilistic arguments. Since the chance for unrelated transients to occur in GRB error boxes is nonnegligible, the large BATSE error boxes all but prevented an unambiguous association with the GRBs themselves.

Since 1997, over 40 GRBs have been localized to the sub-arcsecond level by way of transient afterglow emission. This, coupled with the growing number of large-area survey projects...
(\(\geq \pi\) sr), dramatically increases the likelihood of deep pre-imaging of GRB positions. Pre-imaging from near-Earth asteroid surveys allowed Gal-Yam et al. (2002) to show that the transient optical source SDSS J124602.54+011318.8 was not an orphan afterglow (Vanden Berk et al., 2002), but instead was a rare class of active galactic nucleus (AGN). Recently, Heyl (2003) suggested that with an increased frequency of GRB localizations from Swift (Gehrels 2000) and very deep large-field optical imaging surveys such as the Sloan Digital Sky Survey (SDSS; York et al., 2000) and PanSTARRS (Kaiser et al., 2002), constraints could routinely be placed on SN (or, more generally, SN-like) precursors to GRBs.

Other than progenitor scenarios in which a SN precedes a GRB, we stress that few models exist that make specific predictions (e.g., of light curves, spectra, and start times relative to the GRB) for precursor emission. To this end, we have undertaken an exploratory study of public pre-imaging to search for any optical precursor transients at GRB positions. Here we present pre-imaging observations of 11 GRBs. By focusing on those bursts with known redshift, we can translate the derived upper limits into absolute magnitudes in comoving time. In most bursts, the upper limit to optical precursor emission is \(\sim 3-5\) mag brighter than the brightest supernovae known, but comparable to afterglow brightnesses. These derived upper limits are consistent with the known (fainter) brightnesses of the respective GRB host galaxies, later found at the transient positions.

2. OBSERVATIONS AND ANALYSIS

Most of the pre-imaging data presented herein were obtained by the Near-Earth Asteroid Tracking (NEAT) program (Pravdo et al., 1999). From 1995 December to 1999 February, the NEAT camera was mounted on the 1 m Ground-based Electro-Optical Deep Space Surveillance (GEODSS) telescope in Haleakala, Maui, Hawaii. From 2000 February onward, the camera was then mounted on the Maui Space Surveillance Site (MSSS) 1.2 m telescope. Another NEAT camera began operation on the Oschin 48 inch Schmidt telescope at the Palomar Observatory. Briefly, the NEAT imager on Palomar consists of three 4080 \(\times\) 4080 170 pixel\(^{-1}\) CCD arrays covering approximately 1.13 \(\times\) 1.13 deg\(^2\). Typical exposure times are 20–60 s, and the images are unfiltered, giving a broad spectral response from 4000 to 9000 Å. A 60 s exposure reaches \(V \sim 19–21\) mag (3 \(\sigma\)) depending on sky brightness. We also examined the Digital Sky Survey II (DSS II) scans of the photographic Palomar Sky Survey (Lasker et al., 1998).

For the 30 GRBs with a known redshift, we queried the public NEAT data archive\(^1\), retrieving all data that predated the respective burst trigger date. Imaging data for 11 GRBs were found in the NEAT archive, all with at least one epoch of high enough quality to produce good photometry. The amount of available data for each GRB ranged from 3 to 80 individual 8' \(\times\) 8' images with exposure times between 20 and 150 s. The data for each GRB were first aligned with subpixel accuracy to the same astrometric grid using bilinear interpolation. A triangle matching algorithm was used to determine a transformation between each frame and a common reference image by taking into account translation, rotation, and magnification. A World Coordinate System astrometric solution was fitted to the aligned images using reference stars from the USNO A2.0 astrometric catalog starting from the approximate center of field and plate scale. The photometric zero point for each image was estimated in the \(R\) and \(B\) band by comparison with the magnitudes given in the USNO A2.0. While the photometric errors on individual catalog magnitudes is large (= 0.25 mag), a number of stars typically larger than 100 was utilized in order to accurately derive the photometric zero point for each frame. The individual images were photometered at the known position of the optical transient (OT) using apertures of radius 1.2 \(\times\) FWHM of the seeing (Howell 1989) and local sky subtraction based on an annulus of radii 15 and 30 pixels. Photometric limits were estimated for each image by analyzing the histogram of flux in 1500 apertures of radius 1.2 \(\times\) FWHM of the seeing placed randomly within the image. Iterative \(\sigma\) clipping was used to reject flux values contaminated by stars in order to determine the errors due to the sky background. The standard deviation of the Gaussian distribution of the sky background aperture flux values was used with the previously determined photometric zero point to estimate the photometric upper limits for each image. The aperture fluxes were measured at the OT position in both the individual epoch images and the

\(^1\) The SkyMorph GSFC Home Page is located at http://skyview.gsfc.nasa.gov/skymorph; Pravdo et al. (1998).

### Table 1

| GRB     | R-band Limit (mag) | R.A. (J2000.0) | Decl. (J2000.0) | \(z\) | \(E(B-V)\) (mag) |
|---------|--------------------|---------------|----------------|------|-----------------|
| 030329  | 21.10              | 10 44 50.0    | +21 31 17      | 0.169| 0.025           |
| 030323  | 21.31              | 11 06 09.4    | -21 46 13      | 3.372| 0.049           |
| 030226  | 21.49              | 13 82 04.9    | +25 53 56      | 1.986| 0.019           |
| 021211  | 22.01              | 08 08 59.9    | +06 43 38      | 0.800| 0.027           |
| 021004  | 21.69              | 00 26 54.7    | +18 55 41      | 2.328| 0.058           |
| 020813  | 21.59              | 19 46 41.9    | -19 36 05      | 1.254| 0.110           |
| 020405  | 20.26              | 13 58 03.1    | -31 22 22      | 0.695| 0.110           |
| 010222  | 19.85              | 14 52 12.6    | +43 01 06      | 1.477| 0.023           |
| 009911  | 20.55              | 02 18 34.4    | +07 44 29      | 1.059| 0.118           |
| 000418  | 20.62              | 12 25 19.3    | +20 06 11      | 1.118| 0.033           |
| 000301C | 19.67              | 16 20 18.6    | +29 26 36      | 2.037| 0.052           |

Notes.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds. Redshift references for bursts up to and including GRB 021004 are given in Bloom (2003). The following references apply to the newer measurements: Vreeswijk et al. (2002) (GRB 021211); Price et al. (2003a) (GRB 030226); Vreeswijk et al. (2003) (GRB 030323); and Greiner et al. (2003) (GRB 030329).

\(^1\) The 2 \(\sigma\) R-band upper limit at the position of the transient, derived from the sum of all NEAT pre-imaging data for the field.
stacked images. Tables 1 and 2 summarize the upper limits for all the NEAT imaging. Subsets of the NEAT data on four of these bursts have been presented previously (Wood-Vasey, Aldering, & Lee 2002; Wood-Vasey, Nugent, & Lee 2003; Wood-Vasey 2002, 2003a). Our photometric measurements of the same data agree with those reports to within 0.5 mag.

Figure 1 shows the stacked pre-images of the individual fields surrounding all 11 GRBs. Before making a stacked image of a given field, individual exposures are visually inspected for the presence of defects near the known position of the burst and excluded if defects or cosmic rays are found. We photometered the 11 stacked images at the position of the GRB and the same data agree with those reports to within 0.5 mag.

As seen in Table 1, there are no significant detections of precursor emission at the positions of the 11 GRBs for which a search was conducted. To place this in the context of physically meaningful quantities, we translate the upper limits to an approximate absolute magnitude in the rest-frame $B$ band using a cosmological $k$-correction. This $k$-correction is derived assuming an intrinsic source spectrum of $f_\nu(\nu) \propto \nu^{-3/4}$, which approximates the typical median $B-R$ colors of the photometric calibration objects in the GRB fields (in § 3.1.2, we vary this assumed precursor spectrum). We use the zero points, $z_{p_{B,R}}$, and effective wavelengths, $\lambda_{B,R}$, of the photometric bandpasses from Fukugita, Shimasaku, & Ichikawa (1995). We convert the extinction-corrected upper limit, $m_R$, in the $R$ band to absolute magnitude in the $B$ band as

$$M_B(z) \approx m_R - DM(z) - 2.5 \log \left[ \frac{z_{p_B}}{z_{p_R}} \frac{\lambda_B(1 + z)}{\lambda_R} \right] - 2.5 \log (1 + z),$$

where $DM(z)$ is the distance modulus to the burst at redshift $z$, computed assuming $H_0 = 65$ km s$^{-1}$ Mpc$^{-1}$, $\Omega_m = 0.3$, and $\Omega_{\Lambda} = 0.7$. The third term accounts for the assumed spectrum of the precursor, and the last term accounts for the intrinsically smaller bandpass in the rest frame. We also find $M_B(z)$ by

| $l_{obs}$ (UT Date)$^a$ | $l_{GRB} - l_{obs}$ (day) | Exposure Time ($N \times x$) | $R$ Band (mag)$^b$ | $B$ Band (mag)$^b$ | OT Flux (ADU) | $\sigma$ (ADU)$^c$ |
|--------------------------|--------------------------|-----------------------------|---------------------|---------------------|---------------|-----------------|
| 2002 Apr 26 09:10:48     | 337.10                   | $3 \times 20$              | 18.95               | 19.88               | 123.8         | 174.6          |
| 2002 Apr 12 09:41:59     | 351.08                   | $3 \times 20$              | 20.47               | 20.82               | -11.5         | 41.2           |
| 2002 Apr 4 08:09:35      | 359.14                   | $3 \times 20$              | 20.13               | 20.77               | 28.4          | 57.0           |
| 2002 Apr 1 07:00:00      | 362.19                   | $3 \times 60$              | 20.64               | 20.53               | 20.5          | 111.3          |
| 2002 Feb 13 13:18:36     | 408.93                   | $2 \times 60$              | 17.86               | 18.80               | 169.7         | 122.8          |
| 2002 Jan 14 10:52:48     | 439.03                   | $3 \times 20$              | 20.28               | 20.93               | -9.2          | 51.1           |
| 2002 Jan 8 11:23:24      | 445.01                   | $3 \times 20$              | 20.35               | 21.02               | -42.9         | 51.7           |
| 2000 Apr 13 14:15:00     | 1079.89                  | $2 \times 20$              | 18.65               | 19.64               | -171.3        | 141.1          |
| 2000 Apr 13 06:37:48     | 1080.21                  | $3 \times 20$              | 18.80               | 19.87               | -47.6         | 390.9          |
| 2000 Mar 14 15:00        | 1109.89                  | $2 \times 20$              | 19.25               | 20.33               | -225.6        | 201.7          |
| 2000 Mar 8 11:09:35      | 1116.02                  | $2 \times 20$              | 20.26               | 21.06               | -49.7         | 97.0           |
| 1999 Feb 19 12:30:00     | 1498.96                  | $3 \times 20$              | 19.43               | 19.87               | 225.1         | 102.6          |
| 1998 Mar 27 09:30:00     | 1828.09                  | $3 \times 20$              | 19.13               | 20.02               | 560.8         | 213.6          |
| 1998 Mar 26 09:23:24     | 1829.09                  | $3 \times 20$              | 19.07               | 19.91               | -386.3        | 209.5          |
| 1998 Feb 23 10:23:24     | 1860.05                  | $3 \times 20$              | 19.11               | 20.46               | 134.9         | 159.5          |
| 1998 Feb 22 10:23:59     | 1861.05                  | $3 \times 20$              | 19.43               | 20.11               | -199.1        | 163.5          |
| 1998 Jan 24 12:50:24     | 1889.95                  | $3 \times 20$              | 19.54               | 20.10               | 81.9          | 139.9          |
| 1995 Mar 25 06:00:00     | 17536.23                 | $1 \times 300$             | 18.16               | 18.93               | 203.1         | 2037.3         |

Note.—Table 2 is published in its entirety in the electronic edition of the Astrophysical Journal. A portion is shown here for guidance regarding its form and content.

$^a$ Mean time of observation epoch. All observation dates before 1995 are from photographic imaging during the Palomar Sky Survey, scanned into digital form in the Digitized Sky Survey II. Observation dates after 1995 are from the NEAT experiment on the same telescope.

$^b$ The 3 $\sigma$ upper limit to detection of precursor emission at the position of the GRB. These magnitudes have been calibrated using field stars and the USNO A2.0 Catalog (see text). These limits do not include a correction for Galactic extinction [given as $E(B-V)$ from Schlegel, Finkbeiner, & Davis 1998].

$^c$ The 1 $\sigma$ error on the measured flux at the OT position.
Fig. 1.—Stacked pre-images of the fields surrounding the 11 GRBs with known redshift, presented achronologically from the trigger date. Images are 150 × 150 arcsec$^2$ with north up and east to the left. The 5″ × 5″ box shows the position of the GRB afterglow location. The typical rms astrometric error on our derived plate solution is 0′′.5 in both axes. Stacked pre-images of the fields surrounding the 11 GRBs with known redshift are presented achronologically from the trigger date.
Fig. 1.—Continued
prevented detail (Stanek et al. 2003; Chornock et al. 2003; Hjorth et al. 2003; Henden et al. 2003; Kawabata et al. 2003).

Although this firm detection of a nearly contemporaneous SN suggests that a single event destroyed the progenitor—rendering unlikely the possibility of a similar precursor event—it is still of interest to know what limits can be placed on the occurrence of a similar precursor.

At this redshift, a bright supernova–like precursor $[M_B(\text{peak}) = -20 \text{ mag}]$ would have peaked at $V \sim 19.7 \text{ mag}$ and could have remained above our nominal single-epoch magnitude limit of $V \sim 21 \text{ mag}$ for $\sim 2–3 \text{ weeks}$. Since there are temporal gaps in the data, particularly between 30 and 300 days before the GRB, it is certainly possible that a bright precursor could have been missed by the pre-imaging. However, three upper limits less than 30 days before the burst exclude such a bright SN-like precursor preceding the GRB by $\sim 45–10 \text{ days}$.

3.1.2. SN-Like Precursors

To estimate how restrictive the entire data set is to SN-like precursors, we created a Monte Carlo test by assuming that every GRB in the sample had the same precursor at some random explosion date less than 1000 days before the burst. The working hypothesis is that a GRB with a SN-like precursor would be of type Ib/Ic, and so we use SN 1998bw as a template. Because of the extreme deficit of flux blueward of $\sim 3000 \AA$ of Ib/Ic SNe, we only use precursor photometry from bursts that originated from $z < 1.2$. Since SNe generally appear red in $B-V$, especially after the peak, we recalculated the apparent absolute magnitude limits in Table 2 using a source spectrum with $f_\nu \propto \nu^{-2.3}$. Synthetic SN light curves were created from the $B$-band data of SN 1998bw published in Galama et al. (1998) and McKenzie & Schaefer (1999). For a given peak brightness (allowed to vary from $-15$ to $-35 \text{ mag}$), we randomly selected 1000 explosion dates before the GRB and then constructed a set of synthetic light curves, noting the frequency of synthetic precursors brighter than at least one of the detection limits. For simplicity, we assumed no correlation in peak brightness with a light-curve shape.

For two different distributions of starting times, we computed the probability that the precursor would have been found in the NEAT data, taking the ratio of the number of “detected” sources in the Monte Carlo test to the total number in the simulation. The result is seen in Figure 4. For uniformly random explosion dates before the GRB, almost all SN-like precursors brighter than (peak) $M_B \approx -25 \text{ mag}$ would have been detected at some point during the 3 yr before the GRBs in the sample. For both preburst SN explosion date distributions, the limits on SNe with 1998bw-like peak magnitudes ($M_B = -18.88 \text{ mag}$; McKenzie & Schaefer 1999) is not very strong. Following Figure 4, there is only about a $10\%–30\%$ chance that such SNe would have been detected. Therefore, although there are specific time windows when SNe could not have occurred before the GRBs in the sample, we cannot rule out the possibility that a SN with brightness comparable to 1998bw (or 2003dh) occurred for all GRBs but was missed because of the sparse sampling of the data.

3.1.3. Power-Law Precursors

GRB precursors could, of course, be of a different physical nature than supernovae. We have also tested the detection sensitivity to decaying power-law precursors. We used a model for the flux of the precursor as $f_\nu \propto (t - t_0)^\alpha$ (for $t > t_0 + 1 \text{ day}$), with the magnitude of the source at 1 day...
since $t_0$ of $M_B$(1 day). As above, we simulated 1000 precursors with a characteristic start time $t_0$ less than 1000 days before the GRB set. The spectral index of the precursor was assumed to be 1, for consistency with the conversion of apparent magnitude to absolute $B$-band magnitude. For a range of decay indices, $\beta$, and $M_B$(1 day), we found the probability of detection using the results in Table 2.

Figure 5 shows the results for two different probability distributions of $t_0$. The lines of 0.95 and 0.99 show the equivalent windows for detection of most such transients. For example, if all precursors have $\beta = -1$ and $M_B$(1 day) $= -30$ mag, then there is a greater than 99% chance that the NEAT set would have detected at least one such precursor if it occurred less than 1000 days before the GRB. Precursors that fade more quickly easily evade detection in the sample. For example, only about 5% of precursors with $M_B$(1 day) $= -20$ mag and $\beta < -1.5$ would be detected in the current sample. Thus, there is little constraint on the existence of faint precursors generated from tidal disruption around a massive black hole ($\beta = -5/3$; Li et al. 2002).
It is of interest to compare the brightness sensitivity of power-law precursors to known afterglow brightnesses. Following from the GRB 030329 afterglow measurement of Fitzgerald & Orosz (2003) and the extinction measurement in Bloom et al. (2004), the rest-frame extinction-corrected $B$-band magnitude of the afterglow was $M_B(1\text{ day}) \approx -23.7$, fairly typical of other long-duration GRBs. Although there were deviations from a power law, the secular decay after 0.5 days was approximately $\beta = -2$ (Price et al. 2003b). Following from Figure 5, had a precursor—perhaps of a similar physical origin as GRB afterglows (a “foreglow”)—with the same parameters occurred for all bursts at some time less than 1000 days before the GRB, there is only a 50% chance that such precursors would be seen in the NEAT imaging.

4. DISCUSSION AND CONCLUSIONS

The nondetection of at least some power-law precursors—at magnitudes comparable to afterglow brightnesses—supports the notion that GRBs are due to explosive catastrophic events rather than recurrent activity (e.g., from an AGN; Gal-Yam et al. 2002). For consistency with all the limits presented herein, precursor theories must now posit optical precursor emission fainter than $M_B \approx -25\text{ mag} (t_{\text{obs}} - t_{\text{GRB}} < 1\text{ day})$. From the analysis in § 3, we can also rule out the possibility that SN-like precursors with $M_B(\text{peak}) \leq -25$ and explosion dates less than 1000 days after the bursts occurred for all GRBs in the sample. Likewise, we exclude the possibility that all GRBs in the sample had a precursor with $M_B(1\text{ day}) \leq -25$ and a slowly fading ($\beta \lesssim -1$) power-law light curve. It is possible that a subset of GRBs had precursors at least this bright. While providing the strongest comprehensive precursor limits thus far, despite the nearly 200 photometric pre-imaging measurements of 11 GRBs, the NEAT data are not very sensitive to realistic precursor brightnesses. Even if all GRBs had extremely bright $[M_B(\text{peak}) \approx -20]$ SN-like precursors, these would have been missed with an $\sim 80\%$ probability. Similarly, more than half of the precursors with similar power laws and brightnesses as GRB afterglows would have been missed. Figure 6 shows how various precursors could have been detected or could have evaded detection.

Since GRB hosts are known to be forming stars vigorously, novae and SNe should not be uncommon in such hosts. If the star formation rate in a GRB host is $40\ M_\odot\ yr^{-1}$, then the canonical SN rate is about 1 yr$^{-1}$ from somewhere within the host. At spatial resolutions of $1'' - 2''$ (such as from NEAT), the best astrometric localizations of a precursor should be $\sim 200\ mas$ (1 $\sigma$). This corresponds to a $3\sigma$ localization uncertainty of 4 kpc in projection at a redshift of $z = 0.5$, larger than the exponential scale lengths of all GRB hosts measured to date (Bloom, Kulkarni, & Djorgovski 2002). Therefore, any precursor emission could easily be confused with an unrelated SN somewhere in the host (this essentially extends the confusion problem encountered by plate archive studies from the arcminute to the subarcsecond level). This disturbing possibility motivates the additional need for high spatial resolution in pre-imaging surveys. To this end, future deep wide-field imaging surveys, such as PanSTARRS, should be sufficient: a precursor detected with a signal-to-noise ratio of 30 at the Nyquist sample resolution of PanSTARRS (0′′6) will result in a positional confusion about 100 times smaller than with NEAT. This means that if PanSTARRS detects an apparent
precursor to a GRB within the host galaxy (say 1 yr before the burst), a significant association with the GRB itself should be possible for even the most vigorously star-forming host galaxies.

The quality and quantity of "preobservations" of transient locations will dramatically improve with the increasing size of the National Virtual Observatory. Digital imaging surveys such as RAPTOR (Vestrand et al. 2002) and BOOTES (Castro-Tirado et al. 1999) have already presented limits acquired a few hours before bursts to the $R \sim 12$–15 mag level (e.g., Castro-Tirado et al. 2003; Wren & Vestrand 2003). Deeper surveys such as SDSS should be searched systematically for pre-imaging observations of GRB locations. Identification of precursors with SDSS will have the added benefit of color information, yielding important clues about the physical nature of precursors, should any be detected.

The higher localization rates of Swift will increase the likelihood of deeper pre-imaging with the next generation of large-area surveys (Heyl 2003). With the advent of large synoptic imaging programs (LSS and PanSTARRS), with the primary science goals to detect near-earth asteroids, the deepest and most frequent imaging will be at low ecliptic latitudes. This observing strategy will be well matched to satellite missions like the High Energy Transient Explorer (HETE-II) (Ricker et al. 2002), which preferentially localize GRBs antisolar. Thus, the rates of deep pre-imaging may be higher than those predicted by Heyl (2003). If some subpopulation of bursts originates from within the Galaxy or in the local group (such as potentially short bursts and supernovae GRBs), then, as has been demonstrated with a handful of SNe (see Van Dyk, Li, & Filippenko 2003), space-based pre-imaging might someday retroactively resolve the progenitors directly.

We are exceedingly grateful to the NEAT team (S. Pravdo, D. R. Rabinowitz, E. F. Helin, K. Lawrence, T. McGlynn, L. Angelini, and N. White) for making images public and so readily accessible. Without their dedication to this wonderful experiment and user-friendly archive, none of this work would be possible. We thank S. Kulkarni for bringing to our attention a concern from P. Kumar about the possibility of misidentifying the origin of an SN bump after a GRB because of confusion with unrelated supernovae in the host galaxies; our discussion of precursor confusion follows from that concern. We would also like to thank S. Kulkarni, B. Paczyński, and D. Fox for helpful comments on the manuscript. J. S. B. is supported by a Junior Fellowship to the Harvard Society of Fellows and by a generous research grant from the Harvard-Smithsonian Center for Astrophysics. C. B. would like to thank the Berkeley Deep Extragalactic Evolutionary Probe (DEEP) team for their hospitality during the completion of this work. We thank our physics teacher at Bethlehem Central High School, K. Neff. We would also like to thank an anonymous referee for excellent suggestions for improvements to our original manuscript.
