THE X-RAY AFTERGLOW OF DARK GRB 970815: A COMMON ORIGIN FOR GAMMA-RAY BURSTS AND X-RAY FLASHES?

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Received 2004 August 10; accepted 2004 October 25

ABSTRACT

GRB 970815 is a well-localized gamma-ray burst (GRB) detected by the All-Sky Monitor (ASM) on the Rossi X-Ray Timing Explorer (RXTE) for which no afterglow was identified despite follow-up ASCA and ROSAT pointings and optical imaging to limiting magnitude $R > 23$. Although an X-ray source, AX/RX J1606.8+8130, was detected just outside the ASM error box, it was never associated with the GRB because it was not clearly fading and because no optical afterglow was ever found. We recently obtained an upper limit for this source with $Chandra$ that is at least a factor of 10 fainter than the ASCA detection. We also made deep optical observations of the AX/RX J1606.8+8130 position, which is blank to limits $V > 25.2$ and $I > 24.0$. In view of these extreme limits, we conclude that AX/RX J1606.8+8130 is indeed the afterglow of GRB 970815, which corresponds to an optically "dark" GRB. AX/RX J1606.8+8130 can therefore be ruled out as the counterpart of the persistent EGRET source 3EG J1621+8203. The early light curves from BATSE and the RXTE ASM show spectral softening between multiple peaks of prompt emission. We propose that GRB 970815 might be a case in which the properties of an X-ray flash and a "normal" GRB coincide in a single event.

Subject headings: gamma rays: bursts — gamma rays: observations — X-rays: individual (GRB 970815)

1. INTRODUCTION

One of the intriguing results from 5 yr of gamma-ray burst (GRB) localizations by $BeppoSAX$ is that roughly 60% of well-localized GRBs lack an optical transient despite intensive searches (e.g., Reichart & Yost 2001; Djorgovski et al. 2001). Some of these "dark" GRBs could simply be due to a failure to image deeply or quickly enough (Fox et al. 2003; Li et al. 2003; Lamb et al. 2004). However, in certain cases the optical afterglow may have been missed either because it is obscured by dust in the host galaxy or because it is located at high redshift ($z > 5$).

In the first few months of the "afterglow era," which began with the localization of the X-ray afterglow of GRB 970228 (Costa et al. 1997), the Burst and Transient Source Experiment (BATSE) detected a GRB that falls in the category of "dark." The bright event detected on UT 1997 August 15.50491 and labeled GRB 970815 had a total gamma-fluence $\approx 5.8 \times 10^{-5}$ ergs cm$^{-2}$, placing it in the top 15% of the BATSE fluence distribution. Nearly simultaneous detection by the Rossi X-Ray Timing Explorer (RXTE) ASM refined the position of GRB 970815 to a small error box (Smith et al., 1997, 1999). The localization by RXTE ASM was followed several days later by ASCA (Murakami et al. 1997) and ROSAT (Greiner 1997) pointings. Although a bright X-ray source AX/RX J1606.8+8130 was detected just outside the ASM error box, it was never associated with the GRB because it was not clearly fading and because prompt optical observations failed to reveal an optical transient to limiting magnitude $R > 23$ (Harrison et al. 1997).

In a subsequent review of the evidence we nevertheless hypothesized that AX/RX J1606.8+8130 was the afterglow of GRB 970815, and proposed that this could be tested (Mirabal et al. 2003a). In this paper, we present new $Chandra$ and optical observations of this source that, together with an analysis of the ASCA and ROSAT data, indicate that GRB 970815 was one of the earliest and most luminous "dark" bursts in the afterglow era (see De Pasquale et al. [2003] for a complete list). In addition, we discuss the unusual softening over the burst's multiple peaks, which suggests that the intrinsic properties of GRB 970815 varied over the duration of the event. Finally, we mention the implications for the counterpart of the steady unidentified EGRET source 3EG J1621+8203 (Mukherjee et al. 2002), whose error ellipse includes the position of GRB 970815.

2. X-RAY OBSERVATIONS

2.1. Prompt Localization and Follow-Up

GRB 970815 was localized by the RXTE ASM on UT 1997 August 15.50623 (Smith et al. 1997). Simultaneous detection with two of the ASM scanning cameras refined the position of GRB 970815 to the small error box shown in Figure 1 (Smith et al. 1999). The superposed annulus based on the BATSE and $Ulysses$ triangulation confirmed the ASM position (Smith et al. 1999). The prompt (1.5–12 keV) X-ray light curve had a multiple-peak structure lasting $\approx 130$ s and reaching a maximum intensity of $\approx 2$ crab (Smith et al. 2002).

Following the prompt localization by RXTE, two X-ray observations were made that covered the entire RXTE error box, one by ASCA and one by the ROSAT High Resolution Imager (HRI). The ASCA observation took place on UT 1997 August 18.71–19.88, 3.2–4.4 days after the burst (Murakami et al. 1997), for a total usable exposure time of 54.8 ks in both the Gas Imaging Spectrometer (GIS) and Solid-State Imaging Spectrometer (SIS) detectors. Analysis of the data revealed no source brighter than $1 \times 10^{-13}$ ergs cm$^{-2}$ s$^{-1}$ within the RXTE error box. There was, however, a source AX J1606.8+8130 just outside the RXTE error box with an average flux $F_X (2–10 \text{ keV}) = 4.2 \times 10^{-13}$ ergs cm$^{-2}$ s$^{-1}$. Figure 1 shows the combined ASCA SIS image and the location of AX J1606.8+8130 with respect to the burst error box.
The second X-ray observation of the RXTE error box was obtained during UT 1997 August 20.99–22.73 with the ROSAT HRI, 5.5–7.2 days after the burst, with a total exposure time of 17.1 ks (Greiner 1997). This observation (Fig. 1) detected a source at 16h06m52s0 +81°30'28" (J2000:0), consistent with but more precise than the position of the ASCA source (hereafter referred to as AX/RX J1606.8+8130). The count rate ($3.4 \pm 0.5 \times 10^{-3}$ s$^{-1}$) extracted from a 15″ radius centered on RX J1606.8+8130 corresponds to an extrapolated flux in the 2–10 keV band of $2.1 \times 10^{-13}$ ergs cm$^{-2}$ s$^{-1}$, or almost exactly half the ASCA value. This extrapolation assumes the power-law spectral parameters derived in the next section from the ASCA source. In addition, Greiner (1997) noted a fainter ROSAT source, RX J1608.8+8131, with a flux of $5 \times 10^{-14}$ ergs cm$^{-2}$ s$^{-1}$ in the 0.1–2.4 keV band. This clouded the interpretation because, although RX J1608.8+8131 lies inside the RXTE error box, its existence is of marginal statistical significance. This possible source does not warrant further comment, since it was not detected in the earlier ASCA observation. We concentrate our attention on the brighter source AX/RX J1606.8+8130, which, although it lies just outside the RXTE error box, is within the BATSE/Ulysses annulus.

2.2. ASCA Spectral Parameters

The ASCA GIS and SIS spectra of AX/RX J1606.8+8130 are shown in Figure 2. We fitted the spectra individually as well as jointly with common model parameters by treating the normalization constant as a free parameter. A simple absorbed power-law model provides a good description of the spectrum with photon index $\Gamma = 1.64 \pm 0.35$ and $N_H < 1.3 \times 10^{21}$ cm$^{-2}$ (the error bars correspond to 90% confidence for two interesting parameters). The fitted spectral index is insensitive to the Galactic absorbing column density whether $N_H$ is treated as a free parameter or held fixed at the maximum Galactic value in this direction, $N_{H,\text{Gal}} = 4.6 \times 10^{20}$ cm$^{-2}$.

Since discrete X-ray emission features have been reported in a few GRB afterglow spectra (see Piro et al. 2000), we looked for discrete emission features, absorption edges, and narrow radiative recombination continua in the X-ray spectrum following the procedure described in Mirabal et al. (2003b). Unfortunately, the absence of a redshift determination weakens the search. Thus, we proceeded to determine upper limits on equivalent width by holding the power-law model parameters fixed and assuming a Gaussian line profile of fixed velocity width. The derived upper limit (90% confidence level) corresponds to $\text{EW} < 0.2$ keV at 1.5 keV for a line of FWHM comparable to GRB 991216 (Piro et al. 2000). This is less than the reported EW measurement in GRB 991216, so long as the redshift of GRB 970815 does not exceed $z = 1.3$.

![Fig. 1.—(a) ASCA SIS CCD image of the field of GRB 970815 at 3.2–4.4 days after the burst, with the RXTE ASM error box (solid line) and BATSE/Ulysses annulus (dashed lines) from Smith et al. (2002) superposed. (b) ROSAT HRI image at 5.5–7.2 days after the burst. Locations of ROSAT HRI point sources are indicated by plus signs. The marginal ROSAT source RX J1608.8+8131 (Greiner 1997) is probably not real (see text).](image1)

![Fig. 2.—ASCA GIS (bottom line) and SIS (top line) spectra of the source AX/RX J1606.8+8130. Top: Data (plus signs) and best-fit simultaneous absorbed power-law model (solid line), which has photon index $\Gamma = 1.64 \pm 0.35$. Bottom: Difference between data and model; units are the same as in the top panel.](image2)
2.3. Chandra Observation

The entire error box of GRB 970815 was observed on 2004 June 17 with the Advanced CCD Imaging Spectrometer (ACIS; Burke et al. 1997) onboard Chandra (Weisskopf et al. 1996, 2002). The source AX/RX J1606.8+8130 was positioned at the default location on the back-illuminated S3 CCD of the ACIS-S array. The standard TIMED readout with a frame time of 3.2 s was used, and the data were collected in VFAINT mode. A total of 10,130 s of on-time was accumulated, while the effective exposure live-time was 9998 s. We verified that the Chandra astrometry is accurate to 0.3 or better in each coordinate by identifying four serendipitous sources on our optical images. Within the 10″ radius error circle of AX/RX J1606.8+8130, there is no Chandra point source with more than one photon in the 0.2–10 keV band. Adopting a 96% confidence upper limit of five photons, we convert to a flux upper limit in the 2–10 keV band using the ASCA spectral index $\Gamma = 1.64$ and $N_{\text{H}} < 1.3 \times 10^{21} \text{ cm}^{-2}$. The Web-based simulator PIMMS\(^4\) allows us to make this conversion while accounting for the time-dependent degradation of the ACIS throughput in the AO5 observing period in which the observation was conducted. The result is $F_\text{X}(2–10 \text{ keV}) < 3.7 \times 10^{-15} \text{ ergs cm}^{-2} \text{s}^{-1}$, or less than 1% of the ASCA measured flux in the same band. Such a dramatic disappearance is strong evidence that AX/RX J1606.8+8130 is the afterglow of GRB 970815. In combination with the lack of an optical counterpart such as a variable star or galactic nucleus (see below), this identification is compelling.

We also note that nothing was detected by Chandra at the location of the marginal ROSAT source RX J1608.8+8131 (Greiner 1997) to a similar flux limit. In the absence of any other evidence for the existence of this source, we conclude that it was never real.

2.4. Combined X-Ray Light Curve

Figure 3 shows the combined X-ray light curve of GRB 970815. Comparison of the various energy channels of ASM and BATSE indicates that the third and final peak in the ASM (1.5–12 keV) prompt emission, the one that began $\approx 130$ s after the BATSE trigger, has the softest spectrum, with a peak energy in $\nu F_\nu$ of $E_{\text{peak}} \leq 25$ keV and a photon index $\Gamma = 1.8 \pm 0.1$ (Smith et al. 2002). Smith et al. (2002) suggested that this third peak is the beginning of the afterglow phase as a relativistic shock decelerates. The flux during the third peak, converted here from the reported ASM flux to the 2–10 keV energy band, reached a maximum $F_\text{X}(2–10 \text{ keV}) = 4.4 \times 10^{-8} \text{ ergs cm}^{-2} \text{s}^{-1}$ (â2 Crab) at $t = 152$ s after the BATSE trigger (Smith et al. 2002). It then dimmed drastically during the next 148 s to $F_\text{X}(2–10 \text{ keV}) \leq 6.6 \times 10^{-10} \text{ ergs cm}^{-2} \text{s}^{-1}$ (Smith et al. 2002). Fitting the ASM points to a power law requires a decay as steep as $F_\text{X} \propto t^{-6.2}$, with the origin of time set at the BATSE trigger. We show this early decay phase in Figure 3.

The ASCA light curve in Figure 3 consists of the sum of the counts from all four of its detectors. The ROSAT points correspond to an extrapolated flux in the 2–10 keV band, assuming the power-law spectral parameters derived from ASCA. The individual ASCA and ROSAT components of the light curve show no obvious evidence for variability. However, if the flux remained constant between the ASCA and ROSAT observations, then we should expect to find a total of $\approx 114$ source photons in the 0.1–2.0 keV ROSAT energy band, whereas only 63 net photons are detected in the HRI observation. The Poisson probability of obtaining 63 or fewer events when 114 are expected is $1 \times 10^{-7}$. Instead, we find that the flux of AX/RX J1606.8+8130 is more consistent with a $F_\text{X} \propto t^{-1.4}$ decay between the ASCA and ROSAT observations, easily within the range of well-studied GRB X-ray afterglows. If we extrapolate the 2–10 keV X-ray flux from 500 to $10^6$ s after the burst using $\alpha = 1.4$, we get a fluence of $4.4 \times 10^{-6} \text{ ergs cm}^{-2}$, or $\approx 8\%$ of the burst fluence, which is in agreement with the properties of other GRBs (Frontera et al. 2000).

3. OPTICAL AND RADIO OBSERVATIONS OF AX/RX J1606.8+8130

Following the rapid dissemination of the RXTE position for GRB 970815, a number of groups obtained optical images of its error box including the position of AX/RX J1606.8+8130. No significant variable source was found in or near the RXTE error box to limits $V > 21.5$ (Groot et al. 1997), $R > 21$ (Stanek et al. 1997), and $R > 23$ (Harrison et al. 1997) starting 14–17 h after the burst. Much later, while conducting a search for the gamma-ray source 3EG J1621+8203 (Mukherjee et al. 2002), we obtained deep optical images in several colors of the X-ray position of AX/RX J1606.8+8130 with the MDM Observatory 1.3 and 2.4 m telescopes over the period 2001 June–2004 July. Figure 4 shows a V-band image obtained on 2004 July 12. The adopted 10″ radius ROSAT error circle is conservative, since the ROSAT aspect is confirmed by the detection of the bright star BD+82 477 in the same image (Mukherjee et al. 2002). The error circle is blank to a 3σ confidence upper limit of $V > 25.2$, which corresponds to $F_\text{X}/F_\text{V} > 800$ for the ASCA source under the definition of Maccacaro et al. (1982). In other filters, AX/RX J1606.8+8130 shows no evidence of a host galaxy or any other optical counterpart to limits of $B > 21.5, R > 22.0$, and $J > 24.0$. Such extreme $F_\text{X}/F_\text{V}$ ratios are seen only among isolated neutron stars or

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\(^4\) Available at http://asc.harvard.edu/toolkit/pimms.jsp.
low-mass X-ray binaries. The former is ruled out here by the extreme X-ray variability and the latter by the absence of an optical counterpart. Thus, we are convinced that the X-ray afterglow of GRB 970815 was detected.

Several nondetections were obtained with the VLA between 1 and 103 days after the burst at frequencies of 4.89 and 8.44 GHz (Frail et al. 2003). The rms noise in these observations ranged from 98 to 16 μJy.

4. DISCUSSION

4.1. GRB 970815 as a Dark Burst

Although the ASCA/ROSAT light curve supports a possible decay for AX/RX J1606.8+8130 (Greiner 1997), the follow-up efforts for GRB 970815 were abandoned prematurely, we judge in hindsight, mainly because of the small positional inconsistency of AX/RX J1606.8+8130 with the RXTE error box and the absence of an optical afterglow. Little was known about “dark” GRBs at the time to motivate further observations. In fact, the “dark” GRB hypothesis is justified when one extrapolates the X-ray decay and spectral index backward to predict the optical magnitude at the time of the reported optical observations. It is important to note that there are now many examples of nonmonotonic decays in GRB afterglows; therefore, the observed behavior of GRB 970815 may not be representative of its long-term decay. However, the following analysis is reasonable as long as the deviations are not extreme. Starting with the observed X-ray flux density $f_X$, we can extrapolate a broadband spectrum of the form $f_R = f_X (\nu_R / \nu_X)^{\beta}$ where $f_R$ is the R-band optical flux density at a frequency $\nu_R$ and $\beta$ is the X-ray spectral index. From the ASCA spectra we have $f_X \approx 0.04 \mu$Jy ($\nu_X = 4.84 \times 10^{17}$ Hz) at a time $t = 3.74$ days after the burst, and $\beta \approx 0.64$. The optical flux density evolution would then correspond to $f_R(t_d) \approx 22t_d^{-1.4} \mu$Jy where $t_d$ is the time in days elapsed since the BATSE trigger. This translates into $R \approx 20.1$ on UT 1997 August 16.31. Therefore, the predicted magnitude is brighter than the $R > 21$ (Staneck et al. 1997) or $R > 23$ (Harrison et al. 1997) upper limits reported at that time. The difference would require an observer-frame extinction $A_R \geq 3$ mag.

In order to convert the observer-frame extinction to the rest frame of the host galaxy, we make the simple assumption that its redshift falls near the average GRB redshift, $(z) \approx 1.4$. This is a conservative assumption for the sake of our argument, since the required rest-frame extinction increases if $z < 1.4$. At $z \approx 1.4$, the effective R-band wavelength is $\approx 2740$ Å. Assuming an extinction curve with a fixed form (Cardelli et al. 1989), this translates into a visual extinction $A_V \geq 2$ mag. A rest-frame extinction $A_V \geq 2$ for $z \leq 1.4$ implies significant dust extinction at the host galaxy, possibly characteristic of molecular clouds at the birth site of the GRB progenitor (Djorgovski et al. 2001), and supports a “dark” GRB description.

On the basis of the plausible values of observed column density ($N_H < 1.3 \times 10^{21}$ cm$^{-2}$), we cannot formally rule out large extinction at the host galaxy from the X-ray spectra alone. In fact, this maximum allowed column density (90% confidence level) would translate to $N_H \approx 10^{22}$ cm$^{-2}$ at $z \approx 1.4$ (Morrison & McCammon 1983). The derived $N_H$ is well within the characteristic column density for giant molecular clouds found in our Galaxy (Solomon et al. 1987). The values obtained for $z \leq 1.4$ are also in rough agreement with the relation between $A_V$ and $N_H$ for the Milky Way (Predehl & Schmitt 1995). It is possible that effects such as dust sublimation (Waxman & Draine 2000) and grain charging (Fruχer et al. 2001) can play a significant role in GRB environments. These dust destruction mechanisms could be effective as far as $\sim 100$ pc from the burst site, which might lead to gray dust (e.g., Mirabal et al. 2002) and lower extinction (Galama & Wijers 2001). Alternatively, the absence of an optical afterglow could be attributed to a high redshift ($z \geq 5$) for which the Lyman break moves into the R passband. However, if interpreted as a jet at $z \geq 5$, GRB 970815 would require a very small opening angle, $\theta_j \leq 0.7$, once corrected for a standard energy reservoir (Bloom et al. 2003). Such a small angle might be difficult to achieve in an expanding jet breaking through the circumburst medium.

4.2. Modeling the Afterglow and Reflecting on the Prompt Emission

Of the synchrotron models involving a blast wave expanding relativistically in a stellar wind medium (Chevalier & Li 1999), the combination of electron power-law distribution index $p = 2.2$, spectral index $\beta = (1 - p)/2 = -0.6$, and decay slope $\alpha = (1 - 3p)/4 = -1.4$, corresponding to $\nu_m < \nu < \nu_c$, provides a remarkably good description for the afterglow as measured by ASCA and ROSAT. Such a model, however, cannot account for the significantly steeper decay index ($\alpha = -6.2$) in the ASM light curve (Fig. 3). One possibility is that the steepening in the decay follows the passage of the typical frequency $\nu_m$ through the X-ray band. However, this transition should steepen to $\alpha = (2 - 3\beta)/4$ (Granot & Sari 2002), which yields a physically unreasonable $p = 9$. Similar theoretical predictions for the decay of reverse shock emission impose an equally extreme $p \approx 8$ (Kobayashi 2000). This led Smith et al. (2002) to suggest that the final peak might be due to refreshed shocks or density inhomogeneities. It is, however, difficult to reconcile a steep decay with energy or density variations (Nakar et al. 2003). Thus, by a process of elimination, we find it unlikely that the ASM data represent the beginning of the afterglow.
Instead, we propose that the third peak represents a continuation of the prompt GRB emission and the onset of a soft X-ray flash (XRF). The latter are believed to arise from a softer GRB mechanism, which produces a peak energy on the order of 1 keV \( \leq E_{\text{peak}} \leq 40 \) keV (Heise et al. 2001; Kippen et al. 2003; Sakamoto et al. 2004). Remarkably, the observed peaks in GRB 970815 drift by a large factor during the duration of the burst, reaching a first maximum with \( E_{\text{peak}} \geq 110 \) keV at \( t \approx 1 \) s, another at \( t \approx 98 \) s in the 60 \( \leq E_{\text{peak}} \leq 110 \) keV range, and a pronounced third with \( E_{\text{peak}} \leq 25 \) keV at \( t \approx 152 \) s, in which an 8 s delay between the maximum in the C band (\( E \approx 7 \) keV) and the A band (\( E \approx 2.25 \) keV) is observed (Smith et al. 2002; Bradt et al. 2001). Interestingly, the third peak has a duration (\( \approx 80 \) s) and power-law spectrum (\( I = 1.8 \)), comparable to the parameters of XRFs measured by BeppoSAX, BATSE, and HETE-2 (Heise et al. 2001; Kippen et al. 2003; Barraud et al. 2003; Sakamoto et al. 2004). This might be an indication that the individual properties of an XRF and a “normal” GRB can coincide in a single event. A possibly related phenomenon is the hard-to-soft spectral evolution that has been seen in a number of BeppoSAX and HETE-2 GRBs (e.g., Sakamoto et al. 2004). In addition, the precursors and tails of some GRBs seen by Ginga had spectral properties similar to XRFs (see Murakami et al. [1992] and references therein). Since the prompt emission is a function of various physical parameters, it is unclear what provides the necessary softening over multiple peaks. However, a variable Lorentz factor in a long-lived, “tired” central engine or a decreasing magnetic field are attractive possibilities (Lloyd-Ronning 2003).

4.3. Implications for the Counterpart of 3EG J1621+8203

Our analysis of AX/RX J1606.8+8130 also has implications for the completeness of the survey for a counterpart of the unidentified EGRET source 3EG J1621+8203 (Mukherjee et al. 2002), whose error ellipse includes the position of GRB 970815. Based on existing X-ray and radio data, the FR I radio galaxy NGC 6251 ranks as the most likely counterpart for 3EG J1621+8203 (Mukherjee et al. 2002) now that AX/RX J1606.8+8130 has been eliminated from consideration. NGC 6251 is a notable object because of the possible link between BL Lac objects and FR I radio galaxies. FR I radio galaxies are hypothesized to be the likely parent populations of BL Lac objects, which are believed to be FR I radio galaxies with jets pointing near the line of sight (Urry & Padovani 1995). In the third EGRET catalog (Hartman et al. 1999), Cen A (NGC 5128) is the only FR I radio galaxy identified as a source at energies above 100 MeV (Sreekumar et al. 1999). NGC 6251 could then be the second FR I radio galaxy to be detected in high-energy gamma-rays.

5. CONCLUSIONS AND FUTURE WORK

In summary, our verification of the transient nature of AX/RX J1606.8+8130 and the lack of an optical counterpart for it compel the conclusion that GRB 970815 is an optically “dark” GRB, quite possibly the first one in the afterglow era. Its light curve can be fitted by a power-law decay of index \( \alpha = -1.4 \) between the ASCA and ROSAT observations, with a spectrum of photon index \( \Gamma = 1.64 \pm 0.35 \). Analysis of the RXTE ASM observation leads to the conclusion that at least some GRBs exhibit properties that are similar to XRFs after the cessation of “normal” gamma-ray activity. Such a detection suggests that variations in the intrinsic properties of the burst might partly account for the observed distribution of XRFs and GRBs.

This finding warrants a fresh examination of archival optical/IR data, as well as follow-up optical, IR, and submillimeter observations to search more deeply for a host galaxy and determine if it is obscured by dust or located at high redshift. Even if ambiguous within the ROSAT HRI error circle, identification of the host may be supported by spectroscopic detection of strong Ly\( \alpha \) emission, a common signature of large star formation rates in GRB host galaxies (Fynbo et al. 2003).

We thank the referee for a number of valuable comments. We acknowledge helpful correspondence with Marc Kippen regarding BATSE. This work was supported by SAO grant GO4-5057X and by the National Science Foundation under grant 0206051.

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Note added in proof.—While this paper was in press, the optical afterglow corresponding to AX/RX J1606.8+8130 was discovered by A. Soderberg, G. Djorgovski, J. P. Halpern, & N. Mirabal (2004, GCN Circ. 2837 [http://gcn.gsfc.nasa.gov/gcn/gcn3/2837.gcn3]).