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THE X-RAY AFTERGLOW OF DARK GRB 970815: A COMMON ORIGIN FOR GRBS AND XRFS?

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ABSTRACT

GRB 970815 was 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 $R > 23$. While 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 factor of 100 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 was 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 (XRF) 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 five years of 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 ($z \gtrsim 5$).

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 γ-ray fluence $\approx 5.8 \times 10^{-5}$ erg cm^{-2}, placing it in the top 15% of the BATSE fluence distribution. Nearly simultaneous detection by the *RXTE* ASM refined the position of GRB 970815 to a small error box (Smith et al. 1997, 1999). The localization by the *RXTE* ASM was followed several days later by *ASCA* (Murakami et al. 1997) and *ROSAT* (Greiner 1997) pointings. While 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 hypothesized nevertheless that AX/RX J1606.8+8130 was the afterglow of GRB 970815, and proposed that this could be tested (Mirabal et al. 2003). In this paper, we present new *Chandra* and optical observations of this source, which, 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 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 Aug. 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 Gas Imaging Spectrometer (GIS) and Solid-state Imaging Spectrometer (SIS) detectors. Analysis of the data revealed no source brighter

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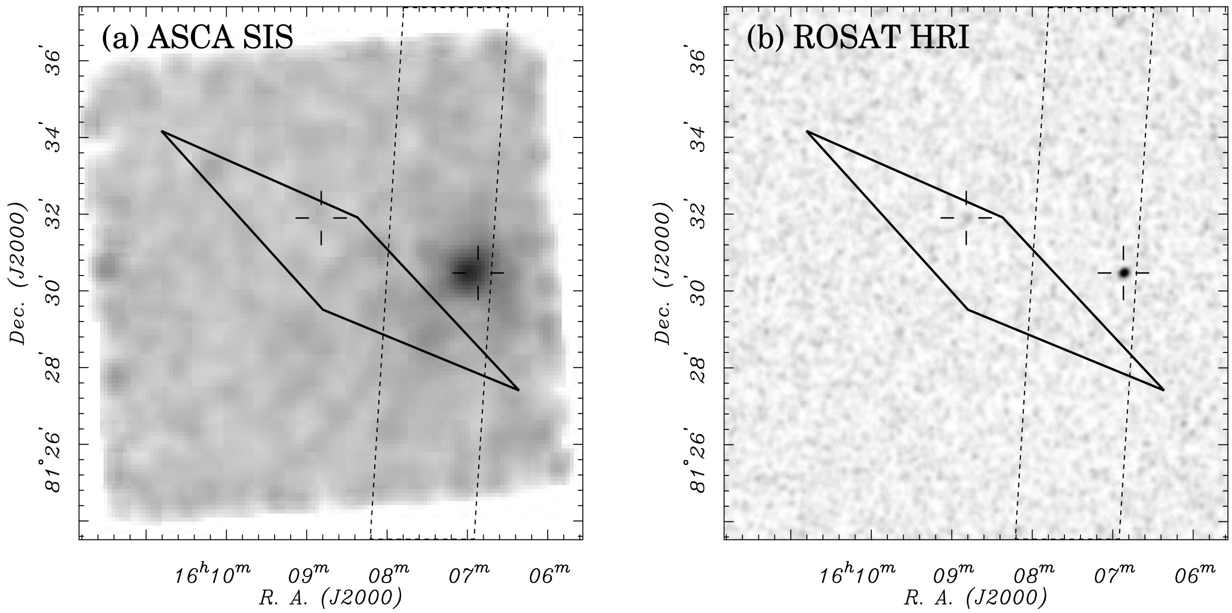

FIG. 1.— (*a*) *ASCA* SIS CCD image of the field of GRB 970815 at 3.2–4.4 days after the burst, with the *RXTE* ASM error box (*solid line*) and BATSE/*Ulysses* annulus (*dashed lines*) from Smith et al. (2002) superposed. (*b*) *ROSAT* HRI image at 5.5–7.2 days after the burst. Locations of *ROSAT*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

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 keV) = 4.2×10^{-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 (J2000.0) $16^{\rm h}06^{\rm m}52\overset{\rm s}{.}0$, $+81°30'28''$, consistent with but more precise than the position of the *ASCA* source (hereafter referred to as AX/RX J1606.8+8130). The count rate $(3.4\pm0.5)\times10^{-3}$ 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 2.1×10^{-13} ergs cm^{-2} s^{-1}, or $\approx 1/2$ 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 $\sim 5 \times 10^{-14}$ 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, as 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 $N_{\rm H} < 1.3 \times 10^{21}$ cm^{-2} (the error bars corresponds to 90% confidence for two interesting parameters). The fitted spectral index is insensitive to Galactic absorbing column density whether $N_{\rm H}$ is treated as a free parameter or held fixed at the maximum Galactic value in this direction, $N_{\rm H,Gal} = 4.6 \times 10^{20}$ 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, Paerels, & Halpern (2003). 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 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 than the reported EW measurement in GRB 991216, so long as the redshift of GRB 970815 does not exceed $z \approx 1.3$.

2.3. *Chandra Observation*

The entire error box of GRB 970815 was observered on 2004 June 17 with the Advanced CCD Imaging Spectrometer (ACIS; Burke et al. 1997) onboard the *Chandra* X-ray Observatory (Weisskopf, O'Dell, & van Speybroeck 1996; Weisskopf et al. 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 10130 s of on-time was accumulated, while the effective exposure live-time was 9998 s. We

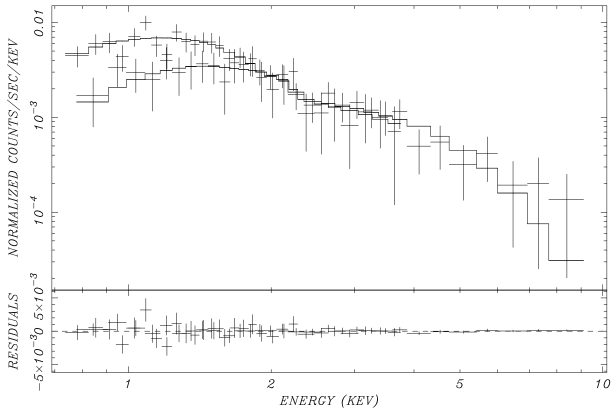

Fig. 2.— *ASCA* GIS (*lower line*) and SIS (*upper line*) spectra of the source AX/RX J1606.8+8130. *Top*: Data (*crosses*) and best-fit simultaneous absorbed power-law model (*solid line*), which has photon index $\Gamma = 1.64 \pm 0.35$. *Bottom*: Difference between data and model; units are the same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

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 $N_{\rm H} < 1.3 \times 10^{21}$ 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 $F_X(2-10\,{\rm keV}) < 3.7 \times 10^{-15}$ ergs cm^{-2} 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 was 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 the ASM and BATSE indicates that the third and final peak in the ASM (1.5–12 keV) prompt emission, the one that began ≈ 130 after the BATSE trigger, has the softest spectrum with a peak energy in νF_ν of $E_{\rm peak} \leq 25$ keV and a photon index $\Gamma = 1.8 \pm 0.1$ (Smith et al. 2002). The latter authors 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 $F_X(2-10\,{\rm keV}) = 4.4 \times 10^{-8}$ ergs cm^{-2} s^{-1} (≈ 2 Crab) at $t = 152$ s after the BATSE trigger (Smith et al. 2002). It then dimmed drastically during the next 148 s to $F_X(2-10\,{\rm keV}) \leq 6.6 \times 10^{-10}$ ergs cm^{-2} s^{-1} (Smith et al. 2002). Fitting the ASM points to a power law requires a decay as steep as $F_X \propto t^{-6.2}$ with the origin of time set at the BATSE trigger. We show this early decay phase in Figure 3.

[4] Available at http://asc.harvard.edu/toolkit/pimms.jsp.

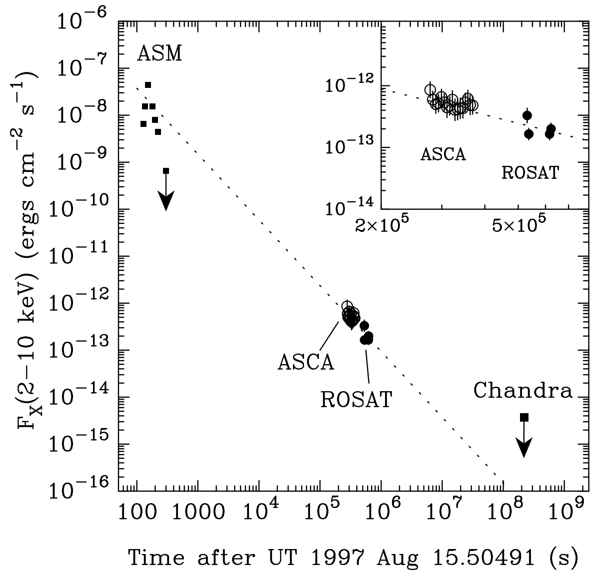

Fig. 3.— The X-ray light curve of the GRB 970815 afterglow. *RXTE* ASM fluxes were derived by converting the reported 1.5–12 keV power-law spectrum (Smith et al. 2002) to the 2–10 keV energy band. The arrows indicate ASM and *Chandra* upper limits. *ROSAT* HRI fluxes were derived by assuming that the source has the same power-law spectrum as its *ASCA* counterpart. The dotted line shows a power-law decay $F_X \propto t^{-1.4}$, although the variation in the *ASCA* points are also consistent with no overall decay. *Inset*: Expanded view of the *ASCA* and *ROSAT* light curves.

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* observation, then we should expect to find a total of ≈ 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 1.3×10^{-7}. Instead, we find that the flux of AX/RX J1606.8+8130 is more consistent with a $F_X \propto t^{-1.4}$ 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 s to 10^6 s after the burst using $\alpha = -1.4$, we get a fluence of 4.4×10^{-6} 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, Sasselov, & Garcia 1997), and $R > 23$

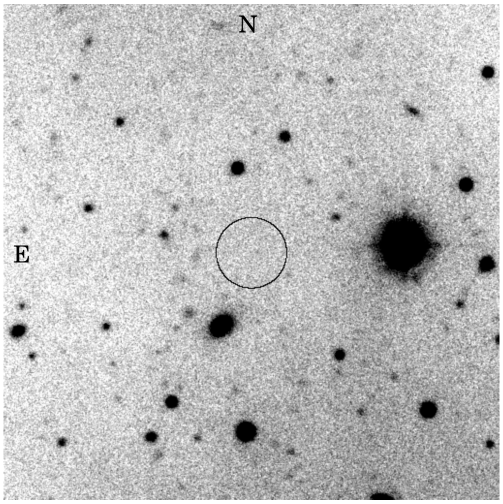

FIG. 4.— A V-band image taken on 2004 July 12 with the MDM Observatory 2.4 m telescope at the location of the unidentified X-ray source AX/RX J1606.8+8130, whose *ROSAT* HRI position is (J2000.0) $16^{\rm h}06^{\rm m}52.^{\rm s}0, +81^\circ 30' 28''$. The seeing was $1.''6$. The field is $2'.3$ across, and the adopted *ROSAT* HRI error circle is a conservative $10''$ in radius. The 3σ upper limit is $V > 25.2$.

(Harrison et al. 1997) starting 14–17 hours after the burst. Much later, while conducting a search for the γ-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 m 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 limit of $V > 25.2$, which corresponds to $F_X/F_V > 800$ 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 $I > 24.0$. Such extreme F_X/F_V ratios are seen only among isolated neutron stars or 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 non-detections 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 non-monotonic 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 broad-band 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 ν_R and β is the X-ray spectral index. From the *ASCA* spectra we have $f_X \approx 0.10\,\mu$Jy ($\nu_X = 4.84 \times 10^{17}$ Hz) at a time $t \approx 3.74$ days after the burst, and $\beta \approx 0.64$. The optical flux density evolution would then correspond to $f_R(t_d) \approx 55\,t_d^{-1.4}\,\mu$Jy where t_d is days elapsed since the BATSE trigger. This translates into $R \approx 19.0$ on UT 1997 August 16.31. Therefore, the predicted magnitude is brighter than the $R > 21$ (Stanek et al. 1997), or $R > 23$ (Harrison et al. 1997) upper limits reported at that time. The difference would require an observer-frame extinction $A_R \gtrsim 4$ mag.

In order to convert the observer-frame extinction to the rest frame of the host galaxy, we make a 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 ≈ 2740 Å. Assuming an extinction curve with a fixed form (Cardelli et al. 1989), this translates into a visual extinction $A_{V,\rm rest} \gtrsim 2$ mag. A rest-frame extinction $A_{V,\rm rest} \gtrsim 2$ for $z \lesssim 1.4$ 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.

Based on the plausible values of observed column density ($N_{\rm H} < 1.3 \times 10^{21}$ 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 $N_{\rm H,rest} \approx 10^{22}$ cm^{-2} at $z \approx 1.4$ (Morrison & McCammon 1983). The derived $N_{\rm H,rest}$ is well within the characteristic column density for giant molecular clouds found in our Galaxy (Solomon et al. 1987). The values obtained for $z \lesssim 1.4$ are also in rough agreement with the relation between A_V and $N_{\rm H}$ for the Milky Way (Predehl & Schmitt 1995). It is possible that effects such as dust sublimation (Waxman & Draine 2000) and grain charging (Fruchter, Krolik, & Rhoads 2001) can play a significant role in GRB environments. These dust destruction mechanisms could be effective as far as ~ 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 ($z \gtrsim 5$) for which the Lyman break moves into the R passband. However, if interpreted as a jet at $z \gtrsim 5$, GRB 970815 would require a very small opening angle $\theta_{\rm j} \leq 0.^\circ 7$, once corrected for a standard energy reservoir (Bloom, Frail, & Kulkarni 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 ν_m through the X-ray band. However, this transition should steepen to $\alpha = (2-3p)/4$ (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, Piran, & Granot 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 XRF. The latter are believed to arise from a softer GRB mechanism that produces a peak energy of order 1 keV $\leq E_{\rm peak} \leq$ 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 $E_{\rm peak} \geq$ 110 keV at $t \approx 1$ s, another at $t \approx$ 98 s in the $60 \leq E_{\rm peak} \leq 110$ keV range, and a pronounced third with $E_{\rm peak} \leq 25$ 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 (≈ 80 s) and power-law spectrum ($\Gamma = 1.8$) 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 γ-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 was 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 account partly 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 sub-mm 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 Lyα emission, a common signature of large star formation rates in GRB host galaxies (Fynbo et al. 2003).

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