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THE FIRST SEARCH FOR A GAMMA-RAY BURST QUIESCENT COUNTERPART IN THE EXTREME ULTRAVIOLET WITH *EUVE*

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ABSTRACT

The opening of the extreme ultraviolet window by the *EUVE* satellite has provided the unique opportunity to perform the first search for a quiescent gamma-ray burst counterpart at these wavelengths. Such emission might be expected if some bursts are related to nearby hot neutron stars or neutron stars with accretion disks, among other objects. We report here on a 40 ks observation on the 1992 March 25 gamma-ray burst error box, determined by triangulation with the Third Interplanetary Network. No quiescent 40–190 Å EUV source was identified using the Deep Survey instrument, and a 3 σ upper limit of 2.9×10^{-14} erg cm^{-2} s^{-1} was obtained. Similarly, upper limits to the 140–380 and 280–760 Å fluxes were obtained with the medium- and long-wavelength spectrometers; they are 1.1×10^{-12} and 5.0×10^{-13} erg cm^{-2} s^{-1}, respectively. We discuss the constraints which these limits impose on thermally radiating quiescent counterparts.

Subject headings: gamma rays: bursts — stars: neutron — ultraviolet: general

1. INTRODUCTION

Prior to the launch of the *Compton Gamma-Ray Observatory* (*CGRO*), it was generally believed that gamma-ray bursts (GRBs) were likely to come from galactic neutron stars (see, e.g., Hurley 1989 and Higdon & Lingenfelter 1990 for reviews). It was expected that the Burst and Transient Source Experiment (BATSE) aboard *CGRO* would confirm this picture and solve the 20 year old GRB mystery. However, the BATSE results have only deepened the mystery. They have shown that the GRB spatial distribution is clearly isotropic but inhomogeneous, with the number of weak events lower than that expected from an isotropic distribution (Meegan et al. 1992). This suggested that BATSE has sampled to the edge of the GRB distribution. Thus it is possible that the majority of the GRBs may not be galactic, although this has not been completely ruled out (Quashnock & Lamb 1993). Cosmological models (Paczyński 1991a; Mao & Paczyński 1992) are currently favored, although multi-component models (e.g., disk + halo: Smith & Lamb 1993; Higdon & Lingenfelter 1993) may be marginally consistent with the observations. The dark matter halo model has been shown to be inconsistent with the observations (Paczyński 1991b). The proposed source distances range from hundreds of parsecs to Gpc and this contentious issue is fundamental for the comprehension of the physics of GRBs.

The most direct method for obtaining the distance scale and understanding GRB sources is to identify counterparts, both quiescent and transient. However, the quiescent counterparts to GRB sources have thus far proven to be extremely elusive. Deep searches in the radio, infrared, optical, soft and hard X-ray, and gamma-ray regions have not yet revealed any objects that can be convincingly demonstrated to be associated with bursts (Schaefer 1994). Nevertheless, the recent identification of the soft gamma repeater SGR 1806 − 20 with a plerionic supernova remnant (Kouveliotou et al. 1994; Murakami et al. 1994; Kulkarni et al. 1994), as well as the X-ray confirmation of the older March 5/N49 association (Rothschild, Kulkarni, & Lingenfelter 1994), and the possible association between SGR 1900 + 14 and G42.8 + 0.6 (Hurley et al. 1994) indicate that these sources are associated with young ($< 10^4$ yr) neutron stars, and provide hope that detectable quiescent counterparts to the classical gamma-ray bursters may indeed exist.

The opening of any new wavelength region to deep observations presents a unique opportunity to search for burster counterparts which may have eluded detection at other wavelengths due to particular source characteristics. With the launch of the *Extreme Ultraviolet Explorer* (*EUVE*) in 1992, one of the last windows in space astrophysics was opened. We have taken advantage of this new opportunity and used the *EUVE* to carry out a deep search of the error box of a gamma-ray burst which occurred on 1992 March 25. The *EUVE* wavelength range is well suited to the detection of accretion disks and neutron stars cooler than those accessible to soft X-ray experiments. For example, Pounds et al. (1993) noted that about 15% of the 1000 sources detected by the *ROSAT* Wide Field Camera survey had no known counterpart, and Pounds (1992) speculated that they might be old, single neutron stars associated with gamma-ray bursters. The first *EUVE* source catalog (Bowyer et al. 1994) similarly contains 22 unidentified sources out of a total of 410 (~5%), and the preliminary second catalog (available electronically as Appendix F of NRA 94-OSS-13), 79 out of 465 (17%). It is also possible that a small fraction of the GRB sources could be associated with nearby flare stars (Liang & Li 1993; Li et al. 1995) which might be detectable in the EUV.

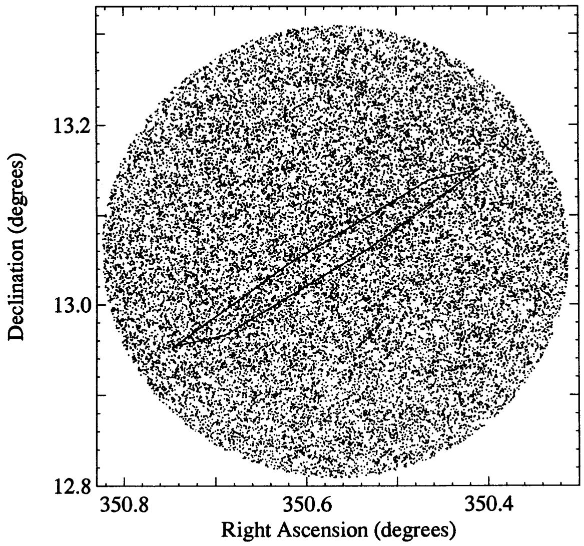

FIG. 1.—Central portion (0°.5 diameter) of the *EUVE* Deep Survey instrument image showing the error box of GRB 250392.

2. INSTRUMENTATION AND OBSERVATION

An overview of the *EUVE* mission can be found in Bowyer & Malina (1991); here we review the details of the instruments used for this search. The *EUVE* Deep Survey instrument (DSI: Bowyer et al. 1994) provides 40–190 Å images with a spatial resolution of up to about 20″ over a ~2° diameter field of view and an effective area 1068 cm^2 Å. It shares the focal plane with short-, medium-, and long-wavelength spectrometers covering the 70–190, 140–380, and 280–760 Å ranges, respectively. As the DSI is considerably more sensitive than the SW spectrometer, we present here only the DSI, MW, and LW results. On 1993 August 25–26, *EUVE* performed a 38,993 s observation of GRB 250392. The ~35 arcmin^2 error box of this burster is centered at $\alpha(2000) = 350^\circ.577$, $\delta(2000) = 13^\circ.053$ ($b^{\rm II} \approx -44^\circ$). The selection of this source was based on the fact that it was relatively bright and well localized, in a region of relatively low column density, and satisfied the *EUVE* pointing constraints. The central portion of the DSI image is shown in Figure 1 with the error box superposed. To obtain a typical value for the number of source plus background counts from the region containing the burster, we defined a 2′ radius circle centered at the burster position; a surrounding annulus with radii 4′ and 6′ was used to estimate the background. A total of 463 source + background counts was found, and 2410 background counts. We obtain a 3 σ upper limit to the source counts of 71, or a source flux of 1.1×10^{-6} photons cm^{-2} s^{-1} Å^{-1}. For a bandpass of 150 Å and an average wavelength of 115 Å, this is equivalent to $\sim 2.9 \times 10^{-14}$ erg cm^{-2} s^{-1}. MW and LW spectrometer upper limits are 1.1×10^{-12} and 5.0×10^{-13} erg cm^{-2} s^{-1}, respectively. These are shown in Figure 2, which also displays a number of typical upper limits to the quiescent fluxes from gamma-ray burst sources across the electromagnetic spectrum. Some overlap can be noted between the energy ranges of *EUVE* and *EXOSAT*. Although *EXOSAT* had some sensitivity up to 500 Å, the *EUVE* DSI and spectrometers have effective areas which exceed that of *EXOSAT* by approximately two orders of magnitude.

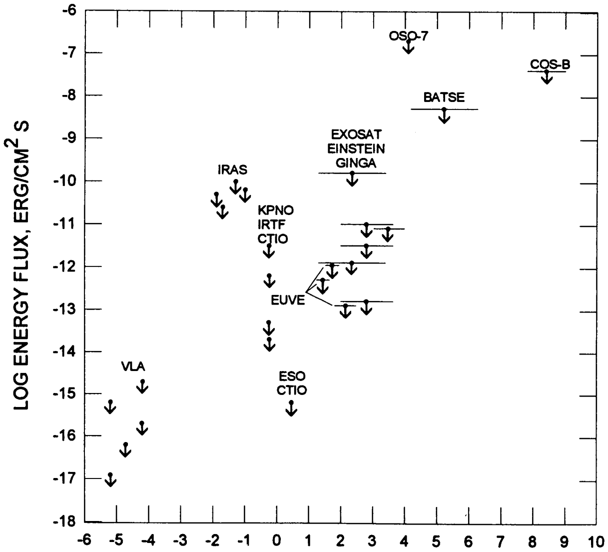

FIG. 2.—Upper limits to the quiescent emission from various gamma-ray burst sources across the electromagnetic spectrum. VLA: Schaefer et al. (1989). *IRAS*, KPNO, IRTF, and CTIO: Schaefer et al. (1987). ESO, CTIO: Schaefer et al. (1983); Motch et al. (1985). *EXOSAT*, *EINSTEIN*, *GINGA*: Pizzichini et al. (1986); Boer et al. (1988, 1991); Murakami et al. (1990). BATSE: Horack & Emslie (1994). The 40 ks *EUVE* DSI, MW, and LW observations of GRB 250392 are indicated.

3. CONSTRAINTS ON A NEUTRON STAR AS A POSSIBLE COUNTERPART

What kind of an object could have been detected in this observation? If we think of thermal sources such as neutron stars, Figure 3 provides a partial answer to this question. Here we have plotted the expected fluxes at Earth from a 10 km radius, 1 $M_\odot$ object. The photon flux is given by

$$F = \int_{E_1}^{E_2} \frac{(1+z)^2 A_0}{2c^2 d^2 h^3} \frac{E_\infty^2 \tau(n, E_\infty)}{\exp[(1+z)E_\infty/kT_0] - 1} dE_\infty ,$$

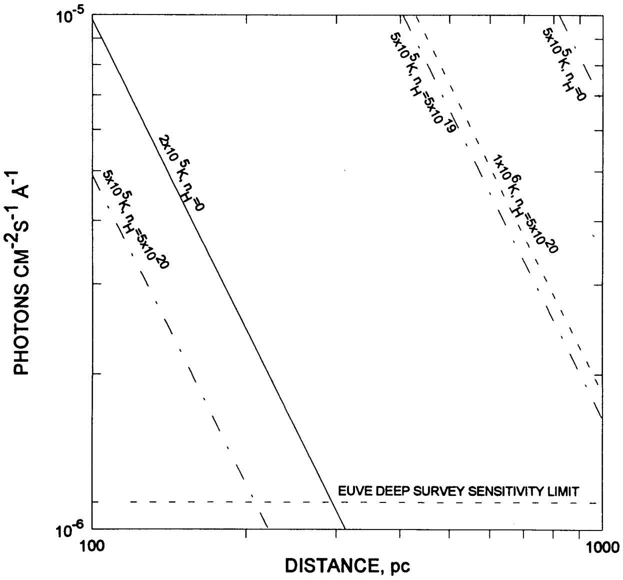

FIG. 3.—*EUVE* DSI sensitivity (*horizontal dashed line*) compared with the 40–190 Å fluxes of neutron stars at various temperatures and absorptions as a function of distance. *Solid line*: 2×10^5 K. *Dot-dashed line*: 5×10^5 K. *Dashed line*: 10^6 K.

where $(1 + z)$ is the gravitational redshift (1.13), A_0 is the true area of the emitting region (taken to be the entire surface of the neutron star), c is the speed of light, d is the distance to the source, h is Planck's constant, E_∞ is the photon energy in the observer's frame, $\tau(n, E_\infty)$ is the transmission of the interstellar medium as a function of the column density n and photon energy, and T_0 is the true temperature of the neutron star (see, e.g., Pizzichini et al. 1986). The integration limits E_1 and E_2 correspond to the 40–190, 140–380, or 280–760 Å ranges. A problem arises in the evaluation of τ. The distances to gamma-ray bursters are unknown; even in those cases where the column density has been measured along the line of sight to a GRB source, the absorption cannot be estimated. The approach we have taken is therefore the following. Using the cross section σ from Cruddace et al. (1974), we take $\tau = \exp(-\sigma n)$ and evaluate this equation for a grid of values for n ($n = 5 \times 10^{20}$ cm^{-2} in this *general* direction). Similarly, we evaluate it for a range of neutron star temperatures. Figure 3 shows some of the results, and compares them with the *EUVE* DSI sensitivity; the DSI gives the most constraining results for this model. If a neutron star is the counterpart to this gamma-ray burst source, its temperature may have been below the *EUVE* range (see, e.g., Tsuruta 1986 for a discussion of neutron star cooling), the emitting area may have been smaller (e.g., a polar cap), or it may have been two distant or too heavily absorbed to detect.

4. DISCUSSION AND CONCLUSION

A number of follow-up searches of this error box were carried out at various wavelengths. An optical observation at the Haute Province Observatory in 1992 September revealed no suspicious objects (M. Boer 1992, private communication), nor did UBVI photometry carried out at USNO (F. Vrba 1994, private communication); inspection of the *ROSAT* All Sky Survey data similarly revealed no soft X-ray source in the vicinity (J. Greiner 1993, private communication). No source was identified in the error box during the *EUVE* all-sky survey; flux limits of approximately 2.7×10^{-12}, 1.7×10^{-11}, 6×10^{-11}, and 9×10^{-11} erg cm^{-2} s^{-1} were obtained for the 58–174, 156–234, 345–605, and 500–740 Å bandpasses, respectively; this survey was carried out between 1992 July and 1993 January, or 4 to 10 months after the burst (Malina et al. 1994). A SIMBAD search turned up only two objects, an F8 star and a 5 GHz double radio source with a strength of $\sim$50 mJy (Lawrence et al. 1986). Lacking any EUV source detection, we can only speculate about the nature of an object which might be EUV bright, but remain optically unidentified. As the majority of the sources in the first *EUVE* Source Catalog were optically identified as interacting binaries, flare stars, stars within about 25 pc of the Sun, and emission line stars within about 50 pc of the Sun (Bowyer et al. 1994), we naturally come to objects with blackbody temperatures in the 10^5–10^6 K range. Depending upon the exact temperatures, distances, and absorptions, such objects—lone neutron stars or possibly fossil accretion disks around them—could have *B*-magnitudes fainter than 25, yet emit detectable fluxes in the EUV, as Figure 3 indicates. Although, as noted above, *EXOSAT* had some sensitivity in the EUV range (its lower threshold was 0.02 keV), Figure 2 indicates that *EUVE* achieved a sensitivity about one order of magnitude better to this type of source.

The lack of a source detection might be due to numerous factors; one is that counterparts might be EUV-bright only for a short time around the burst, and that the source of this burst had faded by the time of the observation, 17 months later. To investigate this possibility, we have done a preliminary comparison of the pointing positions and times of the *EUVE* sky survey observations with well-localized gamma-ray bursts. However, no coincidences were found (H. Marshall 1994, private communication).

This *EUVE* observation has added yet another upper limit to the curve of Figure 2, increasing the coverage of the electromagnetic spectrum. Although no quiescent counterpart to a GRB source has yet to be identified, most searches have been carried out months or even years after the bursts. It is possible that enhanced emission at other wavelengths only lasts for a short period after the GRB. Rapid follow-up searches with the *EUVE* and other ground- and space-based observatories within hours or days of a burst, will test this idea. Constraints inherent within the triangulation method using interplanetary spacecraft generally limit the response time to the order of half a day. Future missions such as HETE can provide accurate source positions in near real-time, as well as simultaneous UV, X-ray, and gamma-ray observations of GRB, and hold the promise of providing a breakthrough.

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