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ABSTRACT

The location of the soft gamma repeater SGR 1900+14 was recently reduced to two ∼5 arcmin^2 alternate error boxes by the network synthesis method. We have used the *ROSAT* High Resolution Imager to observe the error box that is closest to the supernova remnant G42.8+0.6. A quiescent, steady, point X-ray source was found at $\alpha(2000) = 19^{\rm h}07^{\rm m}14\overset{\rm s}{.}15$, $\delta(2000) = 9°19'19\overset{''}{.}06$, whose unabsorbed flux is 3×10^{-12} ergs cm^{-2} s^{-1}. Its position is also consistent with a peculiar double infrared source described in a companion paper. We have also examined this region using the VLA,[1] and have obtained upper limits to the extreme ultraviolet flux of this object using the *Extreme-Ultraviolet Explorer.*
Subject headings: gamma-rays: bursts — stars: neutron — supernova remnants

1. INTRODUCTION

The several thousand gamma-ray bursts observed to date have hard energy spectra sometimes extending to the GeV range, average durations of several tens of seconds, and an isotropic spatial distribution; they do not appear to repeat. In contrast, the three soft gamma repeaters (SGRs) discovered to date have soft energy spectra extending to ∼100 keV, average durations of several tenths of a second, and repeat. The first, SGR 0525−66, is the source of the well-known 1979 March 5 burst; its position is consistent with that of the N49 supernova remnant (SNR) in the Large Magellanic Cloud (Cline et al. 1982). Both a diffuse and a point soft X-ray source appear to be associated with N49 (Rothschild, Kulkarni, & Lingenfelter 1994), although Dickel et al. (1995) have questioned the latter association. The second, SGR 1806−20, is located toward the Galactic center, and is associated with SNR G10.0−0.3 and a soft X-ray source (Kouveliotou et al. 1994; Kulkarni et al. 1994; Murakami et al. 1994) and possibly with a luminous blue variable (van Kerkwijk et al. 1995). The third, SGR 1900+14, was observed to burst three times in 1979 (Mazets et al. 1979) and three times in 1992 (Kouveliotou et al. 1993). The precise location of SGR 1900+14 has been determined using network synthesis to two alternate error boxes (Hurley et al. 1994). One of them is in the vicinity of the Galactic SNR G42.8+0.6, and Vasisht et al. (1994) noted that a quiescent soft X-ray source, cataloged in the *ROSAT* all-sky survey, was present at this position.

It is not known what makes SGRs burst, but their durations, energy spectra, and possible associations with X-ray point sources within SNRs suggest that the sources may be compact objects. The quiescent X-ray sources associated with SGR 0525−66 and SGR 1806−20 might be neutron stars. We have conducted long *ROSAT* soft X-ray observations of the region around the error box of SGR 1900+14 near G42.8+0.6 to determine the position, morphology, and temporal characteristics of the Vasisht et al. (1994) source more accurately than is possible with the sky survey data; in addition, these data may be used to search for an extended source associated with G42.8+0.6, similar to the one associated with N49.

2. *ROSAT* OBSERVATIONS

2.1. *HRI Images*

Two observations were carried out with the *ROSAT* High Resolution Imager (HRI). The first observation was started on 1994 October 11, and targeted the center of G42.8+0.6, with a total observation time of 33 ks. The second was started on

[1] The Very Large Array is a facility of the National Science Foundation, operated under cooperative agreement by Associated Universities, Inc.

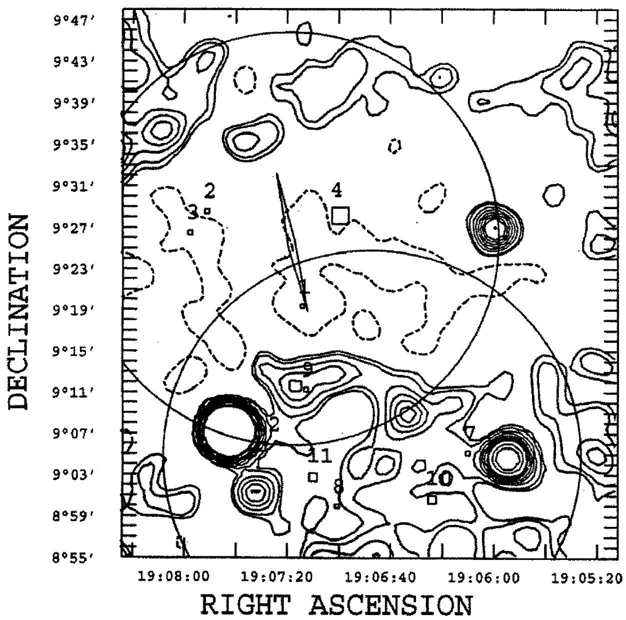

FIG. 1.—*ROSAT* observations and 327 MHz radio contours. X-ray sources are shown as squares whose sizes are equal to the detection cell size (see Table 1). Sources 5 and 6 encompass sources 2 and 3; in the interest of clarity, they are not shown. Sources 7, 9, and 12 may be associated with features in G42.8+0.6. The two circles represent the *ROSAT* HRI fields of view for the two pointings. The diamond-shaped network synthesis error box of SGR 1900+14 is also shown.

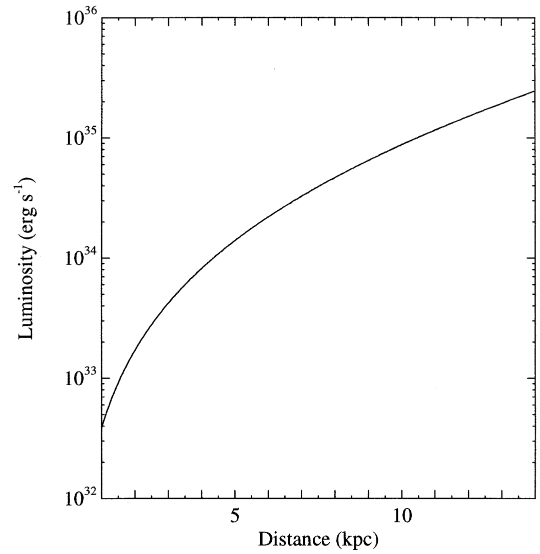

FIG. 2.—Source luminosity as a function of assumed distance. The total column density in this direction, 10^{22} cm^{-2} (determined using the HEASARC on-line service) along a line of sight of 14 kpc, has been scaled linearly to the distance.

1994 October 13, and targeted the center of the SGR 1900+14 network synthesis error box, with a total observation time of 37 ks. The two images partially overlap (Fig. 1). Following the standard *ROSAT* image analysis procedures, square detection cells of sizes 12″, 24″, 48″, 72″, and 120″ were used to identify sources. A total of 12 were found; the X-ray source in the all-sky survey (No. 1 in Table 1—the possible counterpart) is the strongest, and 263 net counts were collected from it. Using the same methods as those in Hurley et al. (1996), we can estimate the probability of a chance association between a source and the 5 arcmin^2 error box to be between 5×10^{-3} and 3×10^{-2}.

Since the HRI has no spectral capability, a spectral shape must be assumed to find the source intensity. Taking an H I column density along the line of sight of $\sim 10^{22}$ cm^{-2} (obtained from the HEASARC on-line service nh program), and assuming a 1 keV blackbody, the unabsorbed flux is 3×10^{-12} ergs cm^{-2} s^{-1}, corresponding to an absorbed flux of 8.6×10^{-13} ergs cm^{-2} s^{-1}. The source distance is unknown, so we have estimated the luminosity as a function of distance by scaling the column density linearly to the assumed distance (i.e., 10^{22} cm^{-2}/14 kpc) and calculating the luminosity using the assumed blackbody spectrum. The result is shown in Figure 2. If we further assume that this source is related to G42.8+0.6, and estimate the distance of the latter from the surface brightness–diameter relation, we obtain ~5 kpc and a luminosity of $\sim 10^{34}$ ergs s^{-1}. Both assumptions, however, are highly uncertain. Nevertheless, we note that if the distance is $\gtrsim 5$ kpc, the luminosity is high enough that it is unlikely to originate from coronal X-ray emission from a field star.

2.2. *Temporal and Spatial Features of the X-Ray Source*

We have examined the long-term variability of this source by comparing the *ROSAT* all-sky survey data, taken during 1990 September–October, with this observation. Only six photons were collected from the source in this survey, giving rise to a count rate of $(11 \pm 5) \times 10^{-3}$ counts s^{-1} (Vasisht et al. 1994; J. Greiner 1995, private communication). The difference be-

TABLE 1

ROSAT X-RAY SOURCES

No.	α(2000)	δ(2000)	Detection Cell Size	Intensity (10^{-3} counts s^{-1})	Comments
1	$19^h07^m14^s.15$	$9°19'19''.06$	12″	7.2 ± 0.5	All-sky survey source
2	19 07 51.29	9 28 32.14	12	0.7 ± 0.3	
3	19 07 57.70	9 26 28.46	12	1.0 ± 0.4	
4	19 06 59.43	9 28 07.86	48	1.0 ± 0.3	
5	19 07 43.94	9 27 01.73	120	0.3 ± 0.3	Encompasses source 2
6	19 07 50.79	9 25 34.01	120	0.3 ± 0.3	Encompasses source 3
7	19 06 9.94	9 05 03.22	12	1.0 ± 0.3	
8	19 07 0.90	8 59 56.18	12	0.6 ± 0.3	
9	19 07 12.53	9 11 13.86	12	1.4 ± 0.4	
10	19 06 23.85	9 00 34.65	24	0.9 ± 0.3	
11	19 07 9.96	9 02 44.10	24	0.9 ± 0.3	
12	19 07 30.06	9 05 41.98	24	0.8 ± 0.4	

tween the two count rates is $(3.8 \pm 2.3) \times 10^{-3}$. We conclude that the source intensity has not changed significantly over ~4 yr. We have also studied the temporal characteristics of the source over the 37 ks observation. A Kolmogorov-Smirnov (KS) test of the photon arrival times, after elimination of data gaps, indicates that a constant-intensity source model cannot be rejected with 99.9% confidence, and a fast Fourier transform (FFT) gives no statistically significant indication of periodicity.

We have also studied the spatial profile of the X-ray source. There is no apparent azimuthal asymmetry in the source count distribution, and the radial profile has a full width at half-maximum (FWHM) of 8″, consistent with the point-spread function of the HRI (7″ FWHM at this position). We conclude that the image is consistent with that of a point source. Finally, we find no extended source at the position of G42.8+0.6, although sources 7, 9, and 12 may be associated with features in the SNR (Fig. 1).

3. *EUVE* AND VLA OBSERVATIONS

No source is listed for this position in the most complete source catalog currently available for the extreme-UV wavelength range (Bowyer et al. 1995). Because this catalog is essentially complete, down to a limiting flux of 0.03 counts s^{-1} in its 100 Å band (or 4×10^{-5} photons cm^{-2} s^{-1} Å^{-1}), we are confident that around late 1992 when the survey was conducted this object was below that flux level in the EUV. We subsequently observed this location with the *Extreme-Ultraviolet Explorer* Deep Survey telescope using its 100 Å band filter. Observations were conducted on JD 2,449,900.5, for a total exposure of 20,000 s. Following the standard data reduction procedure, we first examined the data quality flags, the spacecraft pointing behavior, and the detector count rate in order to eliminate periods of elevated background due to geophysical on-orbit phenomena and South Atlantic Anomaly passages, leaving 9431 s of highest quality exposure. Next, we reduced the accumulated photoevent image to correct for known flat-field variations and a slight geometric distortion, and prepared a sky intensity map based on this image. The image shows no visible intensity peaks that might correspond to a point-source object. To determine how strong a source could be present in this image, we fitted a mathematical point-spread function to each pixel in this image and evaluated the statistical quality of the fit by its χ^2 statistic. In this way, we obtain a 3 σ upper limit to the intensity of any possible source within 42″ of the X-ray position of 0.0033 counts s^{-1}, corresponding to 4×10^{-6} photons cm^{-2} s^{-1} Å^{-1} for a flat continuum spectrum. We also searched a 180″ radius error circle and found no EUV emission, with an upper limit of 0.0056 counts s^{-1}. However, the column density in this direction is high enough to prevent all but the most nearby sources from being detected; a 1 keV blackbody would not have been observed at a distance $\gtrsim$100 pc and a column density $\gtrsim 10^{20}$ cm^{-2}.

Radio observations were carried out in 1995 December with the VLA, centered on source 1. Two short continuum observations were made at 4.56 and 8.44 GHz, and the data were reduced following standard procedures. A single radio source was detected in a 2′ radius around the nominal X-ray peak. It lies at $\alpha(2000) = 19^h07^m15^s.27$, $\delta(2000) = +9°19'51''.9$, with an uncertainty of approximately 0″.1. The peak flux density at both frequencies is 0.25 ± 0.1 mJy, and it remains unresolved at the highest angular resolution (0″.7). The flat radio spectrum

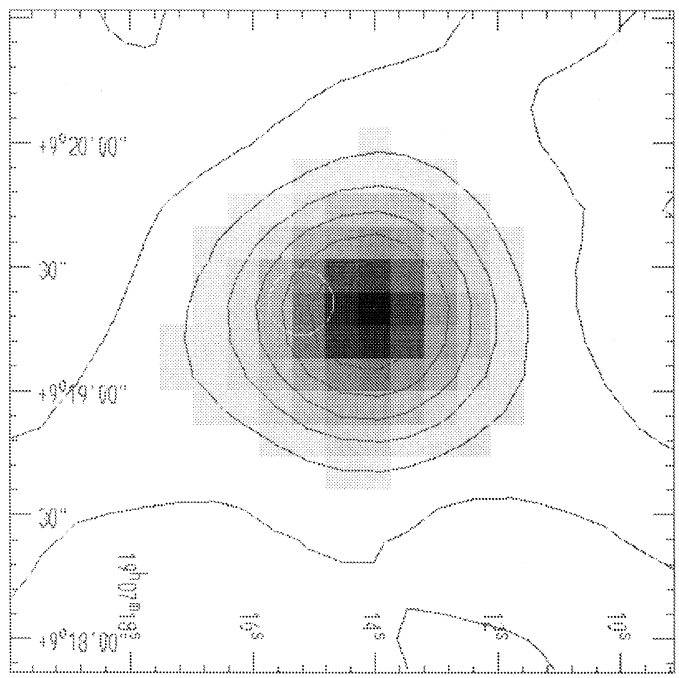

FIG. 3.—Enlargement of the area around source 1. The two infrared sources in Vrba et al. (1996) are located at the center of the circle.

and compact (core) morphology are common characteristics of active galactic nuclei (Kellermann & Owen 1988). Although background radio source counts predict only 0.01 sources $arcmin^{-2}$ above this flux density (Windhorst et al. 1993), the separation between the X-ray and radio peaks ($\Delta\theta \sim 37''$) is too large for there to be a real physical association between the two objects.

4. DISCUSSION

Since it is possible for neutron stars to overtake the shells of their SNRs, the X-ray source and G42.8 could be related. If so, a rough estimate of the neutron star transverse velocity is $v(\mathrm{km\ s^{-1}}) = 276D(\mathrm{kpc})\theta(\mathrm{arcmin})A^{-1}(\mathrm{kyr})$, where D is the distance to the SNR, θ is the angular separation between the SNR center and the X-ray source, and A is the age. For $D = 5$ kpc, $\theta = 12'$, and $A = 10$ kyr, we obtain a velocity greater than 1000 km s^{-1}. Although this is not unreasonable, it rests on highly uncertain estimates for D and A.

The observations discussed in Vrba et. al. (1996) suggest that the explanation may be more complex, however. Two M5 stars are present 18″ from the X-ray source (Fig. 3). The accuracy of the *ROSAT* source coordinates depends on the centroid of the X-ray image and the satellite pointing accuracy, determined by the satellite aspect solution and detector boresight. The X-ray source is only 6′.6 off center, and the deformation of the point-spread function is only ~3%, so most of the error comes from the pointing. The average pointing error is ~5″ (J. Silverman 1995, private communication), but errors as large as ~10″ or more are not unknown. We have attempted to refine the *ROSAT* coordinates by comparing the positions of the X-ray sources in Table 1 with digitized optical sky survey data. Because the image is located in the Galactic plane, however, there are numerous possible optical counterparts to each source, and it is difficult to relate them to the X-ray sources by simple pattern matching or flux ratio methods. We are also limited by the lack of spectral information for the sources. Although we cannot demonstrate conclusively that the X-ray and IR sources are related due to this offset, we note that far-IR observations of this region clearly indicate that at 60 μm the IR source is extended (van Paradijs et al. 1996) and the X-ray source lies within its contours. At the distance of the M star pair (12 kpc), the X-ray source luminosity would be $\sim 10^{35}$ ergs s^{-1}. An association between the IR and X-ray sources would probably rule out the high-velocity neutron star hypothesis but would leave the question of the nature of the X-ray source unanswered.

An *Infrared Space Observatory* observation of the infrared source is planned, as is another *ROSAT* HRI observation of the alternate network synthesis error box. However, the possible association of the X-ray source with SGR 1900 could be strengthened considerably by a determination of the X-ray spectrum and its absorption. An *ASCA* observation of this region will be proposed; if accepted, it will provide the missing spectral information.

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