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OBSERVATIONS OF A POSSIBLE NEW SOFT GAMMA REPEATER, SGR 1801−23

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ABSTRACT

We report on two 1997 June observations of a soft bursting source whose time histories and energy spectra are consistent with those of the soft gamma repeaters. The source can be localized only to an $\approx 3\overset{\circ}{.}8$ long error box in the direction of the Galactic center, whose area is ≈ 80 arcmin^2. The location of the source, while not consistent with that of any of the four known soft repeaters, is consistent with those of several known and possible supernova remnants.

Subject headings: gamma rays: bursts — stars: neutron — supernova remnants — X-rays: stars

1. INTRODUCTION

Soft gamma repeaters (SGRs) are neutron stars in or near radio or optical supernova remnants. There is good evidence that they are "magnetars," i.e., neutron stars in which the magnetic field energy dominates all other sources of energy, including rotation (Duncan & Thompson 1992). In the case of SGR 1806−20, evidence for this comes from observations of the period and period derivative of the quiescent soft X-ray emission (Kouveliotou et al. 1998). In the case of SGR 1900+14, evidence comes from observations of both the spin-down and a giant flare (Kouveliotou et al. 1999; Hurley et al. 1999a; however, see Marsden, Rothschild, & Lingenfelter 1999 for a different interpretation). The magnetar model (Thompson & Duncan 1995) predicts a Galactic birthrate of $\approx$1–10 per 10,000 yr, and a lifetime of $\approx$10,000 yr, so at any given time, up to 10 magnetars could be active. This is consistent with observational estimates of the magnetar birthrate and of the total number in the Galaxy (Kouveliotou et al. 1998). Only four have been identified to date, however, and various studies have placed upper limits on the number of active SGRs (e.g., Norris et al. 1991; Kouveliotou et al. 1992; Hurley et al. 1994). Taking the Galactic magnetar census is therefore an interesting exercise for understanding the formation and life cycles of these unusual objects.

In 1997 June, during a period when SGR 1806−20 was undergoing a phase of intense activity, two bursts were observed whose positions were close to, but clearly inconsistent with, that of this source. It was hoped that this new source would remain active, allowing a better determination of its position, but to date this has not happened. Therefore, we present the existing data at this time, even though the picture is still incomplete.

2. OBSERVATIONS

The two bursts were observed by four instruments: BATSE aboard *Compton Gamma Ray Observatory* (*CGRO*) (Meegan et al. 1996), Konus-A aboard the *Kosmos* spacecraft (Aptekar et al. 1997), Konus-W aboard the *Wind* spacecraft (Aptekar et al. 1995), and the gamma-ray burst (GRB) experiment aboard *Ulysses* (Hurley et al. 1992). Table 1 gives the details of the observations, including the time resolutions ΔT with which each instrument observed the bursts; the time histories are shown in Figures 1 and 2. Both are short and have soft energy spectra, consistent with an optically thin thermal bremsstrahlung (OTTB) function with a kT of $\approx$25 keV. The peak fluxes and fluences are reported in Tables 1 and 2. Note that the peak flux of the second burst implies that the source is super-Eddington for any distance $\gtrsim$250 pc; at the distance of the Galactic center (see below) it would be $\gtrsim 1200 L_{\rm E}$. All these characteristics are typical of SGRs in general. In addition, there is evidence in the Konus-W data for spectral evolution in the second burst (Frederiks et al. 1998): the initial phase has a spectrum consistent with an OTTB function with $kT \approx 20$ keV, softening to $kT \approx 9$ keV in the final phase.

3. LOCALIZATION

The second event was observed by three instruments in high time resolution modes (Table 1), leading to two statistically independent, narrow triangulation annuli. However, since two of the spacecraft (Konus-W and *CGRO*) were separated by only 1.4 lt-s, these annuli (i.e., Konus-W/*Ulysses* and *CGRO*/*Ulysses*) have practically identical centers and radii, and therefore intersect at grazing incidence to define two long, narrow error boxes, whose lengths are constrained by the third (Konus-W/BATSE) annulus. Only one is consistent with the BATSE error circle (radius $\approx 5°$), but the error box is fully contained within it, and is therefore not constrained by it.

The first event was observed with high time resolution by *Ulysses* but with time resolution a factor of 2 greater than the event duration by the two Konus instruments, leading to relatively wide triangulation annuli. These two annuli are consistent with the error box of the second event, but because this event occurred only $\approx$9000 s before the second one, the *Ulysses*-Earth vector moved only slightly between the two, resulting again in annuli that intersect the first error box at grazing incidence. This intersection is consistent with the coarse localization capabilities of Konus-A and Konus-W. Table 3 gives the details of the triangulation annuli, and Table 4 gives the coordinates of the error box.

Initially, it was thought, based on preliminary data, that a third burst originated from this source on 1997 September 12 (Hurley et al. 1997; Kouveliotou et al. 1997) and that the

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TABLE 1

IPN OBSERVATIONS OF SGR 1801−23

Date	UT (s)	ΔT (s) BATSE	Konus-A	Konus-W	*Ulysses*
1997 Jun 29......	14,424	O[a]	2.0	1.472	0.03125
1997 Jun 29......	23,492	TTS,[b] .064	O	0.002	0.03125

[a] Source was Earth-occulted.
[b] Time-to-spill mode: variable time resolution from ≈5 ms up.

Rossi X-Ray Timing Explorer had observed it in the collimated field of view of the All-Sky Monitor (ASM), providing an error box that intersected the annuli (Smith et al. 1997). However, on this day, the *Ulysses*-Earth vector was equidistant from this error box and the position of SGR 1806−20; thus the triangulation annulus for either one of these sources would automatically pass very close to the other. When the final data were obtained and a more precise annulus could be obtained, it proved to be consistent with the position of SGR 1806−20 to better than 10″, making this SGR the likely source of this event. Moreover, it turned out that the burst had entered the *RXTE* ASM proportional counters through their sides, and no location information could in fact be extracted from the data (D. Smith, private communication). Thus, the only information on the location of this new SGR comes from the triangulation annuli and the BATSE error circle.

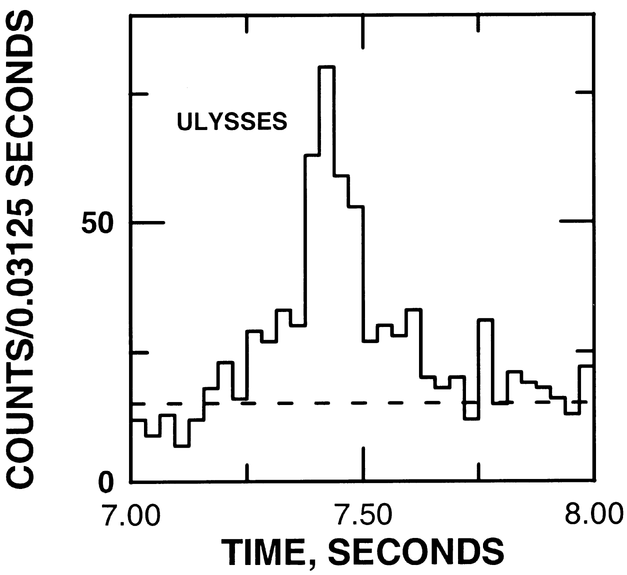

FIG. 1.—Time history of the first burst from SGR 1801−23, as observed by *Ulysses*. The energy range is ≈25–150 keV. The background rate is indicated by a dashed line.

The error box, which is in the direction of the Galactic center, is shown in Figure 3. The triangulation annuli of the two bursts may also be combined using the statistical method of Hurley et al. (1999b) to derive an error ellipse. The method gives an acceptable χ^2 but results in an ellipse that is somewhat longer than the error box and only slightly smaller in area. Given the density of possible counterpart sources in the region of Figure 3, the error box is probably the more useful description of the SGR location. It lies ≈0°.93 from the position of SGR 1806−20. A timing error of ≈39 s would have to be invoked for one spacecraft in each of the two observations to achieve consistency with this SGR, and there is no evidence in any of the data for such an error.

4. DISCUSSION

As the four known SGRs are associated with supernova remnants (SNRs), we have searched several catalogs for

TABLE 2

PEAK FLUXES AND FLUENCES

Date	UT (s)	Peak flux, 25–100 keV, over 32 ms (ergs cm^{-2} s^{-1})	Fluence, 25–100 keV (ergs cm^{-2})
1997 Jun 29......	14,424	5×10^{-6}	9×10^{-7}
1997 Jun 29......	23,492	2×10^{-5}	5×10^{-6}

TABLE 3

IPN LOCALIZATIONS OF SGR 1801−23

Date	UT (s)	Spacecraft	Annulus Center α(2000) (deg)	δ(2000) (deg)	Radius, θ (deg)	3 σ Half-Width (deg)
1997 Jun 29......	14,424	*Ulysses*—Konus-W	333.7154	−25.9376	57.2971	0.0206
1997 Jun 29......	14,424	*Ulysses*—Konus-A	333.6945	−25.9347	57.2813	0.0268
1997 Jun 29......	23,492	*Ulysses*—BATSE	333.7050	−25.9223	57.2819	0.0030
1997 Jun 29......	23,492	*Ulysses*—Konus-W	333.7251	−25.9253	57.2990	0.0030
1997 Jun 29......	23,492	Konus-W—BATSE	295.6453	−15.1844	25.1863	0.9472

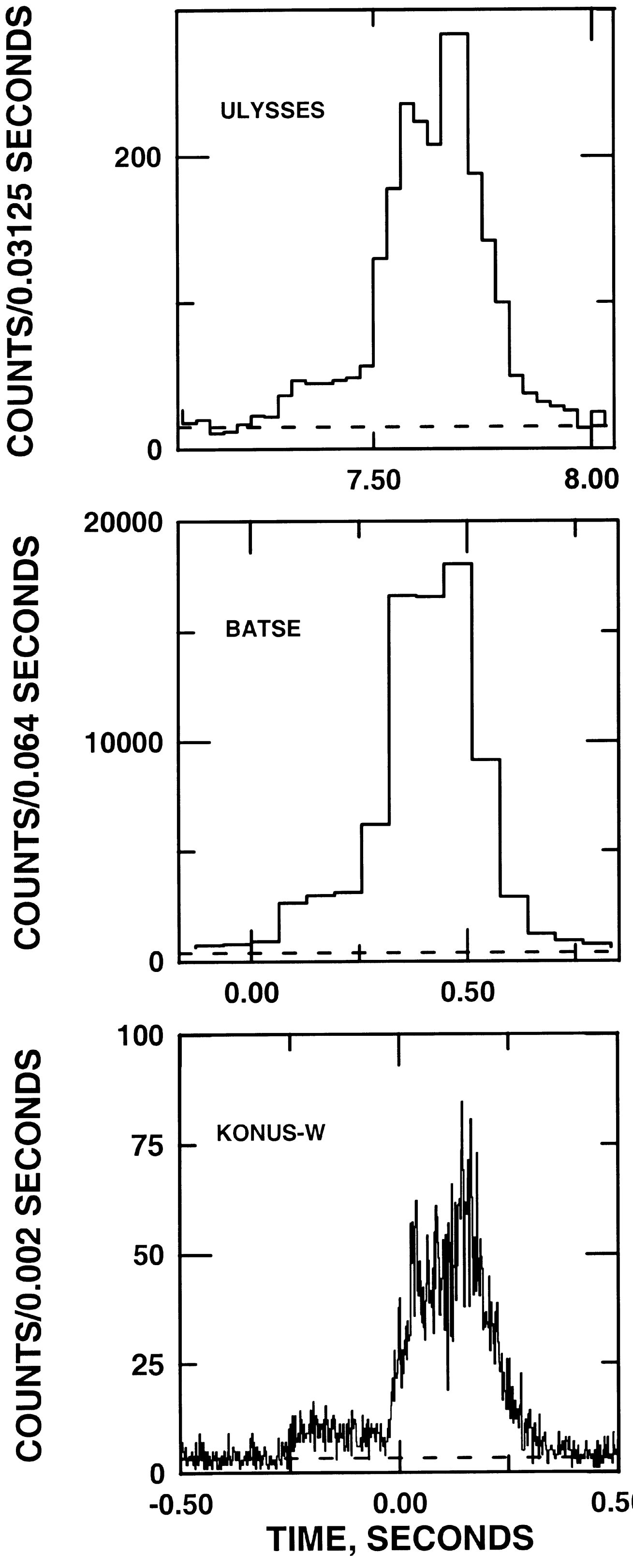

FIG. 2.—Time history of the second burst as observed by Konus-W (14–230 keV), BATSE (25–100 keV), and *Ulysses* (25–150 keV). The background rates are indicated by dashed lines.

possible associations. The results are shown in Figure 3. G5.4−1.2, G6.4−0.1, and G8.7−0.1 are from D. A. Green.[8] G6.0−1.2 is from Goss & Shaver (1970), and all other sources are from Reich, Reich, & Fürst (1990). Not all of these objects are confirmed SNRs. Of the confirmed SNRs, only G6.4−0.1 (=W28) is consistent with the error box. However, this SNR may be associated with the pulsar B1758−23 (Kaspi et al. 1993), which lies outside the error box. G5.4−0.29, G7.2+0.2, and G8.1+0.2 are other possible associations. Given that SGR 1900+14 lies outside its supernova remnant (Hurley et al. 1999c), SGR 1801−23 could also be associated with an object such as G5.9−0.4, which lies slightly outside the error box.

The four known SGRs are also quiescent soft X-ray sources (e.g., Hurley et al. 1999d and references therein) with fluxes $\approx 10^{-11}$–10^{-12} ergs cm^{-2} s^{-1}, i.e., bright enough to

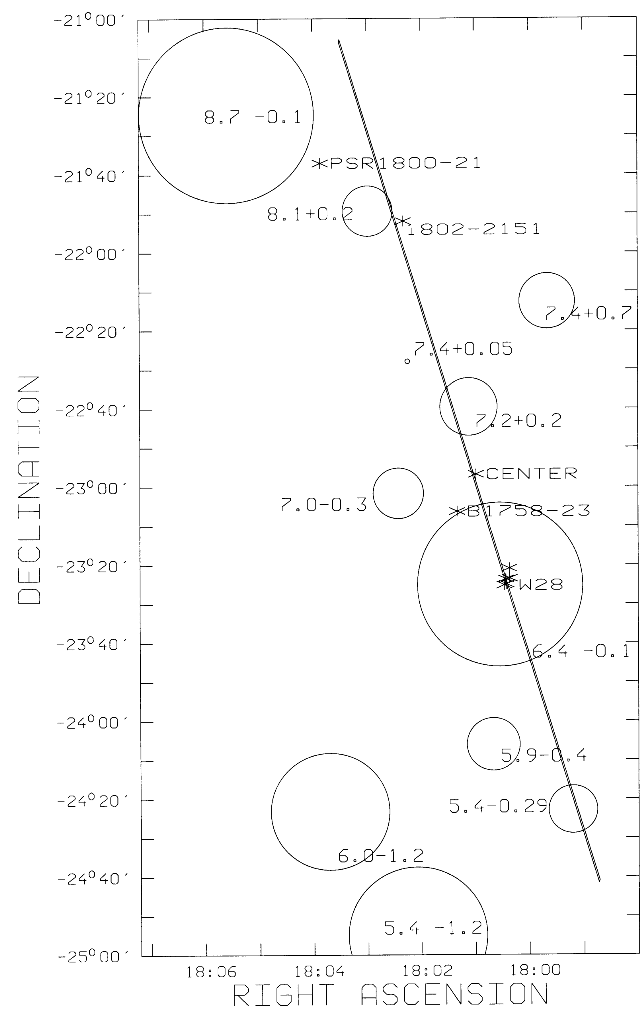

FIG. 3.—Interplanetary Network (IPN) error box for SGR 1801−23 (the lines are too closely spaced to distinguish). The center is indicated with an asterisk. Circles give the approximate locations of confirmed and suspected SNRs; the radii have been taken as half the size given in the catalogs. Asterisks give the positions of *ROSAT* X-ray sources and two pulsars, PSR 1800−21 and B1758−23, probably associated with SNRs 8.7−0.1 and 6.4−0.1. Coordinates are J2000.

[8] See "A Catalogue of Galactic Supernova Remnants" (1998 September version), Mullard Radio Astronomy Observatory, Cambridge, United Kingdom, available at http://www.mrao.cam.ac.uk/surveys/snrs.

TABLE 4

TRIANGULATION ERROR BOX OF SGR 1801−23

α(2000) (deg)	δ(2000) (deg)
Center	
270.2454	−22.9468
Corners	
269.6792	−24.6820
270.8738	−21.0889
269.6827	−24.6929
270.8762	−21.1016

be detected not only in pointed observations, but also in sky surveys. Accordingly, we have searched the *ROSAT* catalogs available through the HEASARC. Only two objects are close to the error box. One is the unidentified source 1WGA J1802.3−2151 in the WGA catalog,[9] which lies slightly outside it. The other is the diffuse emission associated with W28.

Finally, it has been suggested that magnetars evolve into anomalous X-ray pulsars (AXPs) (Kouveliotou et al. 1998). Sporadic bursts from an AXP could confirm this association. Accordingly, we have checked the positions of the six known (Gotthelf & Vasisht 1998 and references therein) and one proposed (Li & van den Heuvel 1999) AXPs, but none lies near this source.

Given the shape and location of the error box, it is not unlikely that it will cross several interesting objects by chance coincidence, and the nature of this source therefore remains unknown. Based on the properties of the two events observed to date, it most closely resembles an SGR. Indeed, SGR 1900+14 was discovered when it burst just 3 times in 3 days (Mazets, Golenetskii, & Guryan 1979); 13 years elapsed before it was detected again (Kouveliotou et al. 1993). Until SGR 1801−23 bursts again, allowing a more accurate position to be derived for it, associating it with an SNR or quiescent soft X-ray source will be difficult.

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[9] See "The WGA Catalog of *ROSAT* Point Sources," by N. White, P. Giommi., & L. Angelini (1995), which is available at http://lheawww.gsfc.nasa.gov/users/white/wgacat/wgacat.html.

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