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REACTIVATION AND PRECISE INTERPLANETARY NETWORK LOCALIZATION OF THE SOFT GAMMA REPEATER SGR 1900+14

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ABSTRACT

In 1998 May, the soft gamma repeater SGR 1900+14 emerged from several years of quiescence and emitted a series of intense bursts, one with a time history unlike any previously observed from this source. Triangulation using *Ulysses*, BATSE, and KONUS data gives a 1.6 arcmin^2 error box near the Galactic supernova remnant G42.8+0.6. This error box contains a quiescent soft X-ray source that is probably a neutron star associated with the soft repeater.

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

1. INTRODUCTION

The soft gamma repeaters (SGRs) differ from the classical gamma-ray bursts by their durations (typically 0.1–1 s), soft spectra ($kT \sim 35$ keV), and their repetition. Four SGRs are now known, and there is evidence that all of them are associated with supernova remnants (SNRs) and therefore are neutron stars. The source of the well-known 1979 March 5 burst, SGR 0525−66, is consistent with the position of the N49 supernova remnant in the Large Magellanic Cloud (Cline et al. 1982). SGR 1806−20 (Atteia et al. 1987) is associated with the SNR G10.0−0.3, which is located toward the Galactic center (Kulkarni & Frail 1993; Kouveliotou et al. 1994; Kulkarni et al. 1994; Murakami et al. 1994). SGR 1627−41 may be associated with G337.0−0.1 (Hurley et al. 1998b, 1998c; Woods et al. 1998).

SGR 1900+14 is located near the Galactic plane and, until 1998 May, was the least active of the SGRs (Hurley 1996), hindering attempts to locate the source accurately. Two possible small error boxes for SGR 1900+14 were obtained by Hurley et al. (1994) with the network synthesis method, using the Interplanetary Network (IPN) data from *Ulysses* and BATSE. The location of the first is very close to the SNR G42.8+0.6, which has been suggested by Kouveliotou et al. (1994) as one of two possible SNRs associated with this object. Both the *ROSAT* sky survey (Vasisht et al. 1994) and a pointed observation at this position (Hurley et al. 1996a) indicated that a pointlike quiescent X-ray source was associated with this error box. Optical and infrared observations of the X-ray position revealed a peculiar double M star system (Vrba et al. 1996). No *ROSAT* source was detected in the second error box, which lies 3°.75 from the first (Li et al. 1997). SGR 1900+14 underwent an extraordinary resumption of activity starting in 1998 May, and triangulation using IPN data (*Ulysses*, BATSE, and KONUS-*Wind* in this case) has now reduced the possible source location to a single, 1.6 arcmin^2 error box that is consistent with the *ROSAT* quiescent source.

2. SOURCE ACTIVITY

SGR 1900+14 was discovered when it burst three times in 1979 (Mazets, Golenetskii, & Guryan 1979). It was not heard from again until 1992, when it emitted four bursts (Kouveliotou et al. 1993). It then lay dormant again until 1998 May 26, when it began a series of more than 50 bursts over the next several months (Kouveliotou et al. 1998), culminating in the giant flare of 1998 August 27 (Hurley et al. 1998d). The source remains active as of this writing. In addition to these events, which were confirmed by either their BATSE and/or IPN localizations, over 30 bursts have occurred that are suspected to originate from this source, but for which no locations can be derived. It is also possible that numerous weak bursts could have occurred during periods of BATSE Earth occultation, which would have been below the thresholds of *Ulysses* and KONUS-*Wind*.

The time histories of most of these events consisted of a single peak with duration $\lesssim$100 ms (Fig. 1). However, on 1998 May 30, the source emitted a 320 s–long burst consisting of multiple peaks, many with structures and/or durations longer than 100 ms (Kouveliotou et al. 1998; Fig. 1). "Bunching" of bursts had been reported previously from SGR 1806−20 (Kouveliotou et al. 1996). However, whereas the bursts from SGR 1806−20 were observed by the *Rossi X-Ray Timing Explorer* Proportional Counter Array in the 2–60 keV range, and came at a rate of $\lesssim$1 minute^{-1}, the bunching observed from SGR 1900+14 was in the hard X-ray range, 25–300 keV, and came at a rate up to one every several seconds. At least three BATSE events during this period reached peak 25–300 keV luminosities of $\sim 1000 L_{\rm Edd}$, which is considerably greater than the *XTE* events. Thus, this type of event appears to be unique to SGRs.

3. SOURCE LOCATION

We have localized this source by triangulation. Specifically, each *Ulysses* event for which there was a BATSE and/or a KONUS-*Wind* response was used to produce an annulus of possible arrival directions. The method is explained in more detail in Hurley et al. (1998a), and Table 1 lists the events triangulated to date. However, there are two aspects that make the localization of SGRs, in general, and this SGR, in particular, unique. First, it is the first time since the launch of *Ulysses* in

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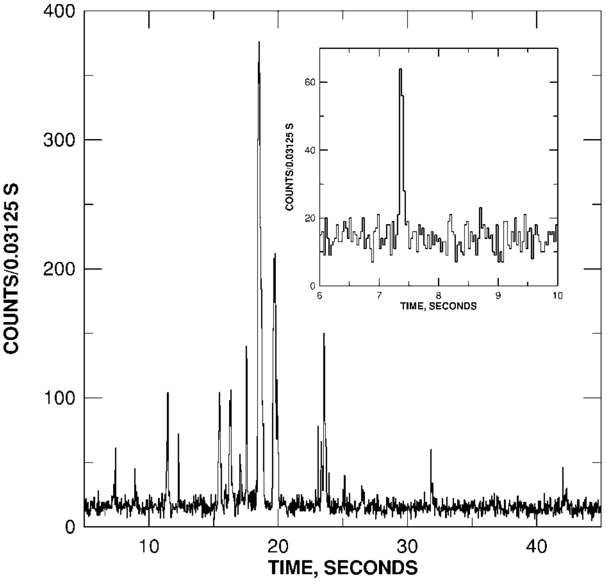

FIG. 1.—*Ulysses* 25–150 keV time history of a portion of the unusual event of 1998 May 30. This type of time history has never been observed from SGR 1900+14 before. *Inset*: *Ulysses* 25–150 keV time history of a single-spike burst from SGR 1900+14 on 1998 May 26. This time history is typical of this source and most SGR bursts.

1990 that the bursts from SGR 1900+14 have been intense enough to trigger the gamma-ray burst detector on this spacecraft, providing 32 ms time resolution data that can be used for precise triangulation, and second, this period of activity lasted long enough that the changing direction of the *Ulysses*-Earth vector, which is the center of the triangulation annulus, made it possible to derive annuli that crossed one another, generating a small error box. For simplicity, we have defined this error box with only two ~24″ wide annuli, one from 1998 May 26 and the other from 1998 July 19. Although all the events in Table 1 produced annuli that are consistent with it, they are, in some cases, redundant and, in others, wider than the two we have selected because of the low time resolution data.

Figure 2 shows the new localization and the VLA[6] radio contours of G42.8+0.6. The *ROSAT* quiescent X-ray source error circle is also shown. This error box is consistent with the previous ones, but the area has decreased from ≈3.5 deg^2 (Mazets et al. 1979 error box quoted in Kouveliotou et al. 1993) to ≈10 arcmin^2 (for the two widely separated network synthesis error boxes) to ≈1.6 arcmin^2 (for the single error box derived from the recent source activity). Table 2 gives the coordinates of the conservatively estimated 3 σ confidence error box corners. The error box center is at $\alpha(2000) = 286^\circ\!.8120$, $\delta(2000) = 9^\circ\!.3283$.

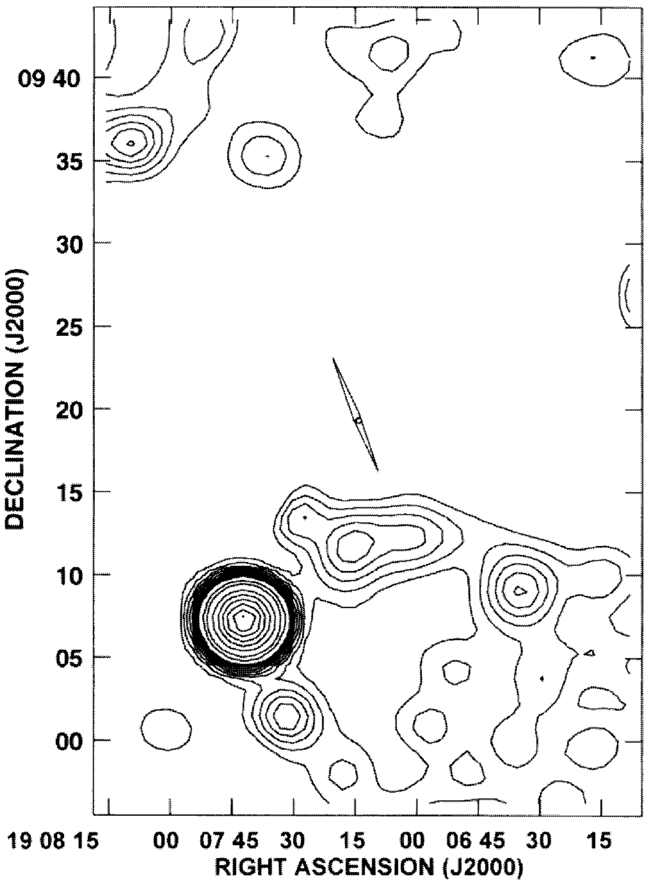

FIG. 2.—Error box for SGR 1900+14 superposed on a radio map of this region. The radio continuum image was taken at the VLA on 1994 February 7 at a frequency of 327 MHz (Vasisht et al. 1994). The synthesized beam size is approximately 3′. The contour levels progress in steps of 20–200 mJy beam^{-1}. The higher contour levels progress in steps of 20 mJy beam^{-1} to the peak of 1.6 Jy. The position of the *ROSAT* source within the error box is indicated.

It has been suggested that the superluminal Galactic source GRS 1915+105 is responsible for the bursts from SGR 1900+14 (Mirabel et al. 1994; Mirabel & Rodriguez 1994). The error box in Table 2, however, lies ~$2^\circ\!.5$ from this source, definitively excluding it as a candidate.

TABLE 1

SGR 1900+14 BURSTS TRIANGULATED BY THE IPN

Date	UT (s)	*Ulysses*	BATSE	KONUS-*Wind*
1998 May 26	77429	Yes	RI	...
	80646	Yes	RI	Yes
1998 May 27	15721	Yes	No	Yes
1998 May 30	32624	Yes	Yes	Yes
	34076	RI	RI	...
	41332	RI	RI	Yes
	84457	Yes	...	Yes
1998 Jun 7	30749	RI	Yes	Yes
1998 Jul 19	30383	Yes	Yes	Yes
	60010	Yes	Yes	Yes

NOTE.—Yes: the burst was observed in triggered, high time resolution mode. RI: the burst was observed as a rate increase, in low time resolution mode. No: data were available, but the event was not observed.

TABLE 2

ERROR BOX CORNERS FOR SGR 1900+14

α(2000) (deg)	δ(2000) (deg)
286.7895	9.2717
286.8135	9.3224
286.8108	9.3338
286.8349	9.3844

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[6] The Very Large Array is a facility of the NRAO, which is operated by Associated Universities, Inc., under contract with the NSF.

4. DISCUSSION

Since an SNR-SGR connection exists for three SGRs, it seems likely that SGR 1900+14 is also associated with an SNR. Similarly, since at least two SGRs have quiescent soft X-ray sources associated with them (SGR 0525−66 and SGR 1806−20), it is likely that the *ROSAT* source in the error box of SGR 1900+14 is associated with this SGR (further evidence for this association is presented in Hurley et al. 1999). The X-ray source is clearly not located within the radio contours of G42.8+0.6 (Fig. 2), and this poses an interesting question. If the two are associated, the neutron star would have to have a transverse velocity $v(\mathrm{km\ s^{-1}}) = 276D(\mathrm{kpc})\theta(\mathrm{arcmin})A^{-1}(\mathrm{kyr})$, where D is the distance to the supernova remnant, θ is the angular separation between the site of the supernova explosion and the neutron star, and A is the remnant's age (see, e.g., Hurley et al. 1996b). The actual velocity might be $\approx(3/2)^{1/2}$ times as much as this. The distance to G42.8+0.6 has been estimated as 5 kpc using the luminosity-diameter relation (see, e.g, Vasisht et al. 1994), which is probably uncertain by a factor of 2. However, it agrees with an independent estimate from the n_{H} as measured from the quiescent X-ray spectrum (Hurley et al. 1999). The angular separation is difficult to judge because G42.8+0.6 is highly asymmetrical. Reasonable estimates might range from 7′ to 20′. Finally, the age is probably less than 20,000 yr, or the SNR would not be detectable (Braun, Goss, & Lyne 1989), and might be as young as 5000 yr. This leads to a wide range of possible velocities, from 480 to 5500 km $\mathrm{s^{-1}}$, even the lowest of which are rather high. This may be compared with the estimated velocity of SGR 0525−66, which is 1200 km $\mathrm{s^{-1}}$ (Thompson & Duncan 1995), and that of SGR 1806−20, which is greater than 500 km $\mathrm{s^{-1}}$ (Kulkarni et al. 1994). How did the neutron star acquire this velocity?

Elsewhere, evidence has been presented that SGR 1900+14 may be a magnetar (Kouveliotou et al. 1999; Hurley et al. 1998d), i.e., a neutron star with a field strength in excess of 10^{14} G. If the magnetar model is basically correct, it may provide an explanation for the high velocity of this object (Thompson & Duncan 1995): the strong field may bring about an anisotropy in the neutrino radiation of the newly formed neutron star. Moreover, since magnetar lifetimes are expected to be on the order of 10,000 yr, they are detectable over shorter times than supernova remnants. Thus, the magnetar model constrains one to accept the hypothesis that SGR 1900+14 originated in the SNR G42.8+0.6. The only other possibility is that it originated in an SNR that is presently undetectable, contradicting the lifetime arguments.

As SGR 1900+14 remains active, it is possible that this error box can be refined further in the future. Such error boxes will provide interesting calibrations of the triangulation technique. However, in view of the present error box, as well as the 5.16 s periodicity observed in the quiescent X-ray source (Hurley et al. 1999) and the bursting SGR (Hurley et al. 1998d), the association between the quiescent source and the SGR may be considered secure.

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