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PRECISE INTERPLANETARY NETWORK LOCALIZATION OF A NEW SOFT GAMMA REPEATER, SGR 1627−41

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ABSTRACT

We present *Ulysses*, Konus-*Wind*, and BATSE observations of bursts from a new soft gamma repeater that was active in 1998 June and July. Triangulation of the bursts results in a ∼1°.8 by 16″ error box whose area is ∼7.6 arcmin^2 and which contains the Galactic supernova remnant G337.0−0.1. This error box intersects the position of a *BeppoSAX* X-ray source that is also consistent with the position of G337.0−0.1 and is thought to be the quiescent counterpart to the repeater. If so, the resulting error box is ∼2′ × 16″ and has an area of ∼0.6 arcmin^2. The error box location within the supernova remnant suggests that the neutron star has a transverse velocity of ∼200–2000 km s^{-1}.

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

1. INTRODUCTION

There is good evidence that the three known soft gamma repeaters (SGRs) are associated with supernova remnants (SNRs). SGR 0525−66 appears to be in N49 in the Large Magellanic Cloud (Cline et al. 1982), and SGR 1806−20 (Atteia et al. 1987) in G10.0−0.3 (Kulkarni & Frail 1993; Kouveliotou et al. 1994; Kulkarni et al. 1994; Murakami et al. 1994). SGR 1900+14 lies close to, although not within, G42.8+0.6 (Kouveliotou et al. 1994; Hurley et al. 1999a). The SGRs are believed to be magnetars, i.e., neutron stars with magnetic field strengths in excess of 10^{14} G. In these objects, magnetic energy dominates rotational energy.

In this Letter, we present gamma-ray observations of a new source, SGR 1627−41, first detected in 1998 June, whose repetition, time histories, energy spectra, and location are all consistent with the properties of the known SGRs. We present observations by the third Interplanetary Network (IPN)—consisting in this case of the Gamma-Ray Burst (GRB) experiment aboard the *Ulysses* spacecraft, the Konus experiment aboard the *Wind* spacecraft, and the Burst and Transient Source Experiment (BATSE) aboard the *Compton Gamma-Ray Observatory* (*CGRO*)—and use them to derive a precise source location for SGR 1627−41. The typical energy ranges for the experiments and the data considered here are 25–150, 50–200, and 25–100 keV, respectively. At the time of these observations, *Ulysses* was located ∼2900 lt-s from Earth, while *Wind* was ∼3 lt-s away; *CGRO* was in near-Earth orbit.

2. OBSERVATIONS

The first confirmed *Ulysses* observation of the new SGR was on 1998 June 17. The last was on 1998 July 12. In all, 36 events were observed by *Ulysses* and an instrument on at least one near-Earth spacecraft, either Konus-*Wind* or BATSE, and triangulation gave mutually consistent annuli. (Numerous other events were observed by BATSE alone, and numerous candidate events were also observed by a single instrument, either Konus or *Ulysses* GRB experiment, which could not be localized; we do not consider them here.) Each of the three instruments has various data-collecting modes that may be summarized as either "triggered" or "untriggered." The time resolutions in triggered modes are as fine as 2 ms, while in untriggered modes they may be as coarse as ∼1 s. Table 1 lists the bursts and the modes, and Figure 1 shows a typical time history. When observed in triggered mode by *Ulysses*, almost all of the events considered here had durations ≲200 ms; as observed by BATSE, several events had durations of up to ∼2 s.

In principle, short events such as these present an ideal case for localization by triangulation, since the width of a triangulation annulus is proportional to the uncertainty in cross-correlating the time histories observed by a pair of spacecraft. However, three other factors must be considered. First, to obtain a small cross-correlation uncertainty, the event must be observed in triggered modes by *Ulysses* and another spacecraft; only 11 of the events in Table 1 satisfy this criterion. (Intense activity from a repeating source tends to fill trigger memories, so that subsequent events can only be recorded in an untriggered mode.) Second, the proximity of the *Wind* and *CGRO* spacecraft means that the directions of the *Ulysses*-*Wind* and *Ulysses*-*CGRO* vectors are almost identical, and the centers of the corresponding triangulation annuli are almost coincident; this results in annuli that intersect at grazing incidence for any given burst, resulting in a long, narrow error box. Third, the angle between the *Ulysses*-*Wind* and *Wind*-*CGRO* vectors is only ≈24° for events in Table 1. Thus, the wide *Wind*-*CGRO* annulus intersects the *Wind*-*Ulysses* annulus to produce an error box that is many degrees long. To reduce the length of the error box for this SGR, we have combined annuli for bursts from the first and last triggered mode observations, on June 17 and July 12. The direction of the slowly moving *Ulysses*-Earth vector, which is approximately the center of the triangulation annulus, produces a shorter error box. The statistical uncertainties in cross-correlating the time histories are ≈20 ms. In principle the accuracy of the *CGRO* and *Wind* clocks are less than 1 ms and that of the *Ulysses* clock is ≈3 ms. However, since the *Ulysses* clock accuracy cannot be directly confirmed to better than ≈125 ms (Hurley & Sommer 1994), we have

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TABLE 1
OBSERVATIONS OF SGR 1627−41

Date (1998)	UT[a] (s)	*Ulysses*	BATSE	Konus
Jun 17	68005	T	6832[b]	U
	68294	U	U	U
	68892	U	U	NO
	71911	T	O	T
	72390	U	U	U
	73067	U	SAA	U
	75446	T	6833[b]	NO
	75880	U	U	T
	76004	U	O	T[c]
	76626	U	O	U
	77838	U	6834[b]	U
	79030	T	SAA	U
	79557	U	SAA	U
	82448	U	O	T
Jun 18	935	U	O	U
	6151	U	6837[b]	T
	11269	T	U	U
	12510	U	O	T[c]
	14031	U	6838[b]	NO
	14053	U	U	NO
	14379	U	U	U
	14395	U	U	NO
	14524	U	U	NO
	14661	U	6839[b]	U
	16227	U	U	U
	16229	T	U	T
	16460	U	U	U
	22593	T	U	T
	27246	T	6841[b]	T
	59884	T	SAA	T
	64276	T	O	U
Jun 22	48596	T	O	T
	51084	U	6861[b]	NO
	68197	T	6862[b]	T
Jun 25	39379	T	SAA	T
Jul 12	78639	T	6919[b]	T

NOTE.—T = recorded in triggered mode; U = recorded in untriggered mode; O = the source was occulted by the Earth; SAA = the spacecraft was passing through the South Atlantic Anomaly (SAA) and the high voltage was turned off; NO = not observed.
[a] Time at *GRO* or *Wind*.
[b] BATSE trigger number.
[c] Second burst recorded in a single *Wind* trigger.

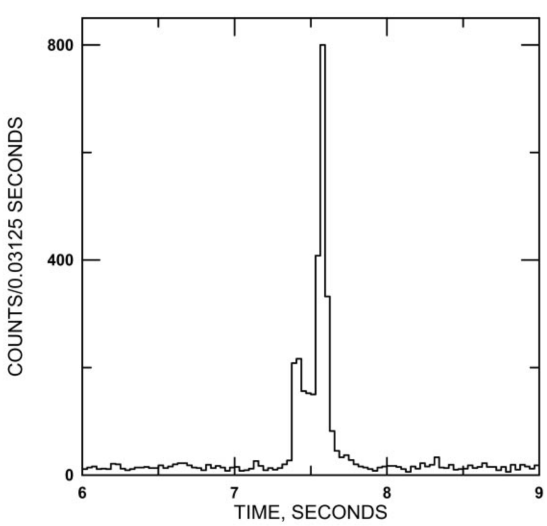

FIG. 1.—Time history of the burst on 1998 June 18, 16,229 s, from the *Ulysses* GRB experiment. The energy range is 25–150 keV.

TABLE 2
CORNERS OF THE IPN ERROR BOX FOR SGR 1627−41

α(2000) (deg)	δ(2000) (deg)
248.9621	−47.6015
248.9503	−48.4118
248.9891	−46.6026
248.9707	−47.5451

conservatively taken a total uncertainty of 125 ms for the triangulation.

3. RESULTS

Figure 2 shows a portion of the IPN error box, defined by the intersection of two ∼16″ wide annuli. The corners of this ∼7.6 arcmin^2 error box are given in Table 2. Strictly speaking, the curvature of the annuli does not allow the resulting error box to be defined by straight-line segments; for this reason, we also give the centers, radii, and widths of the annuli in Table 3. Figure 2 also includes the 843 MHz radio contours of the Galactic supernova remnant G337.0−0.1, taken from the catalog of Whiteoak & Green (1996). Finally, Figure 2 also shows the position of a *BeppoSAX* quiescent X-ray source believed to be the SGR counterpart (Woods et al. 1999). The intersection of the 3 σ IPN annuli with the 95% confidence error circle defines a ∼2′ × 16″ error box whose area is ∼0.6 arcmin^2; the coordinates of this error box are given in Table 4.

These two error boxes are consistent with, but considerably smaller than, the following locations previously determined for this SGR: (1) the BATSE error circle derived from four triggers (Kouveliotou et al. 1998b; based on this initial location, the source was named SGR 1627−41); (2) the initial IPN annulus (Hurley et al. 1998b); (3) the restriction of the initial IPN annulus to locations consistent with BATSE Earth-limb occultation considerations (Woods et al. 1998); (4) a refined, but still preliminary IPN annulus (Hurley et al. 1998a), and (5) the initial *Rossi X-Ray Timing Explorer* All-Sky Monitor (*RXTE*-ASM) error box (Smith & Levine 1998). They are also consistent with the intersection of the final *RXTE*-ASM error box with the IPN annuli (Smith et al. 1999).

4. DISCUSSION

If we adopt as a working hypothesis that SGR 1627−41 is a magnetar and that magnetars have lifetimes ∼10,000 yr (Thompson & Duncan 1995), then we would expect the IPN position to be coincident with that of a radio supernova remnant, whose observable lifetimes are $\lesssim$20,000 yr (Braun, Goss, & Lyne 1989). Also, three SGRs are known to be quiescent soft X-ray point sources: SGR 0525−66 (Rothschild, Kulkarni, & Lingenfelter 1994), SGR 1806−20 (Murakami et al. 1994), and SGR 1900+14 (Hurley et al. 1994, 1999b). With this in mind, we can then inquire how compelling the IPN/G337.0−0.1/*BeppoSAX* association is. We first calculate the probability that the $1\overset{\circ}{.}8$ by 16″ IPN annulus intersects an SNR in the 843 MHz survey of the Molonglo Observatory Synthesis

TABLE 3
PARAMETERS OF THE TWO IPN ANNULI DEFINING THE ERROR BOX

Date (1998)	$\alpha(2000)_{center}$ (deg)	$\delta(2000)_{center}$ (deg)	Radius (deg)	3 σ Half-Width (deg)
Jun 17	330.4126	−10.1705	76.7554	0.002599
Jul 12	332.6195	−8.3063	79.6049	0.002440

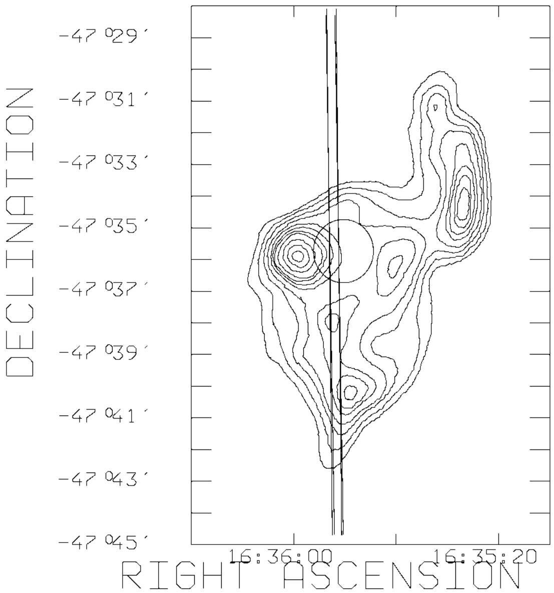

FIG. 2.—Two IPN annuli superposed on the 843 MHz radio contours of G337.0−0.1 from Whiteoak & Green (1996). They characterize the remnant as a peculiar nonthermal object, part of which may be extragalactic. The *BeppoSAX* error circle is also shown (Woods et al. 1999). Given the rough alignment of the two radio lobes and the IPN/*BeppoSAX* error box, we speculate that another explanation of the morphology might be an asymmetric supernova explosion.

Telescope (MOST) catalog (Whiteoak & Green 1996). A rigorously correct method to estimate this probability was presented by Kulkarni & Frail (1993), but a very simple argument can be used to derive an absolute lower limit. The MOST survey covered Galactic coordinates $245° < l < 355°$, $|b| < 1\overset{\circ}{.}5$. Seventy-three SNRs with measured sizes are cataloged, and they occupy ∼0.022 of the total area surveyed. Thus, in the limit in which the error box is a point, the probability of a chance association would be ∼0.022. However, two factors will increase this substantially. First, given the fact that SGR 1900+14 appears to be outside its supernova remnant (Hurley et al. 1999a), we would probably accept an SGR/SNR association in which the error box lay outside the remnant, increasing the effective occupied area of the survey. Second, the method of Kulkarni & Frail (1993), which is more appropriate for the long, narrow IPN error box, would result in a higher probability.

TABLE 4
CORNERS OF THE IPN/*BEPPOSAX* ERROR BOX FOR SGR 1627−41

α(2000) (deg)	δ(2000) (deg)
248.9618	−47.6121
248.9626	−47.5792
248.9691	−47.6106
248.9698	−47.5808

We next ask what the probability is that the IPN error box will coincide with a quiescent soft X-ray source. One unidentified source with a 1′ error radius was detected in the *BeppoSAX* observations (Woods et al. 1999), and the field of view was 28′ in radius. Applying the method of Kulkarni & Frail (1993) gives a chance probability of 0.17. Thus, the joint probability of the IPN/G337.0−0.1/*BeppoSAX* association is greater than 0.004.

Fortunately, more data that can substantiate the IPN/X-ray source/SNR association are forthcoming. An *ASCA* observation of the X-ray source has taken place in 1999 February. This will allow us to confirm the suggested 6.47 s period, observed with a low statistical significance in the *BeppoSAX* data (Woods et al. 1999), and possibly estimate the period derivative. A high spin-down rate, as found for SGR 1806−20 and SGR 1900+14 (Kouveliotou et al. 1998a, 1999), would be a compelling argument that the source is indeed a magnetar associated with the SNR.

If this indeed proves to be the case, the transverse velocity of the magnetar can be estimated. The distance to G337.0−0.1 has been estimated to be as small as 5.8 kpc by Case & Bhattacharya (1998) based on a new Σ-*D* relation for supernova remnants and as large as 11 kpc by Sarma et al. (1997) based on radio recombination lines. The displacement between the core of the remnant and the IPN/*BeppoSAX* error box is $\sim 1\overset{\prime}{.}3$. From this, we obtain velocities between ∼200 and 2000 km s^{-1} for the smaller distance, and for assumed ages of 10,000 and 1000 yr, consistent with the transverse velocities of the other three SGRs.

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