DISCOVERY OF A NEW SOFT GAMMA REPEATER, SGR 1627–41

Peter M. Woods1, Chryssa Kouveliotou2,3, Jan van Paradis1,4, Kevin Hurley5, R. Marc Kippen3,6, Mark H. Finger2,3, Michael S. Briggs1,3, Stefan Dieters1,3 and Gerald J. Fishman3

ABSTRACT

We report the discovery of a new soft gamma repeater (SGR), SGR 1627–41, and present BATSE observations of the burst emission and BeppoSAX NFI observations of the probable persistent X-ray counterpart to this SGR. All but one burst spectrum are well fit by an optically thin thermal bremsstrahlung (OTTB) model with $kT$ values between 25 and 35 keV. The spectrum of the X-ray counterpart, SAX J1635.8–4736, is similar to that of other persistent SGR X-ray counterparts. We find weak evidence for a periodic signal at 6.41 s in the light curve for this source. Like other SGRs, this source appears to be associated with a young supernova remnant G337.0–0.1. Based upon the peak luminosities of bursts observed from this SGR, we find a lower limit on the dipole magnetic field of the neutron star $B_{\text{dipole}} \gtrsim 5 \times 10^{14}$ Gauss.

1. INTRODUCTION

Soft gamma repeaters (SGRs) are a rare type of stellar object characterized by their transient emission of bursts of hard X-rays and soft $\gamma$-rays. Bursts have been detected from three such sources from 1979 (Mazets et al. 1981) until early 1998; two are in the galactic plane (SGR 1806–20, SGR 1900+14) and one is in the Large Magellanic Cloud (SGR 0526–66). One of the first SGR bursts detected, the famous 1979 March 5 burst from SGR 0526–66 (Mazets et al. 1979), provided a wealth of information about these sources (Thompson & Duncan 1995). This flare started with a short initial spike followed by a 3 minute train of coherent 8 s pulsations. A precise location of this burst was consistent with a young ($\sim 10^4$ year) supernova remnant (SNR) N49 (Cline et al. 1982). The train of pulsations and the positional coincidence with the SNR indicated that the burst source is a young, magnetized neutron star.

Pointed X-ray observations of SGR burst location regions have shown that each SGR has associated with it a persistent X-ray source (Murakami et al. 1994, Hurley et al. 1999a, Rothschild et al. 1994) within or near a young SNR (Kulkarni & Frail 1993, Hurley et al. 1999a, Cline et al. 1982). Furthermore, the persistent sources associated with the two galactic SGRs are X-ray pulsars (Kouveliotou et al. 1998a, Hurley et al. 1999a) which show secular spin down at a rate $\sim 10^{-10}$ s$^{-1}$ (Kouveliotou et al. 1998a, 1999). As argued by Kouveliotou et al. (1998a), this spin down is likely caused by magnetic dipole radiation which implies a neutron star dipole magnetic field of $\sim 10^{14}$–$15$ Gauss. These results have provided strong observational evidence in support of the idea that SGRs are strongly magnetized neutron stars or ‘magnetars’ (Duncan & Thompson 1995).

The majority of SGR bursts have durations less than 200 msec and are well characterized by optically thin thermal bremsstrahlung (OTTB) spectra with temperatures $kT \sim 30 – 40$ keV (Kouveliotou 1995). With the exception of the much more luminous March 5th event and a similar bright flare detected recently from SGR 1900+14 (Hurley et al. 1999c), SGR bursts reach peak luminosities up to $\sim 10^{42}$ ergs sec$^{-1}$, far exceeding the Eddington luminosity for a 1.4 $M_{\odot}$ neutron star. A statistical study of bursts from SGR 1806–20 has shown that no correlation exists between the energy released in a burst and the time until the next burst (Laros et al. 1987). Also, it was found that both burst peak fluxes and time intervals between bursts resemble truncated log-normal and log-normal distributions, respectively (Laros et al. 1987, Hurley et al. 1994). A differential energy distribution of events follows a Gutenberg-Richter power law ($–1.66$ exponent; Gutenberg & Richter 1956) with a maximum energy $E_{\text{max}} \approx 5 \times 10^{41}$ ergs (Cheng et al. 1995). Each of these statistical properties are consistent with characteristics of earthquakes, which suggests the SGR bursts may be triggered by neutron star crustquakes (Thompson & Duncan 1995).

Here, we report the discovery of SGR 1627–41, the first new SGR to be detected since 1979. We provide information on general burst characteristics and the persistent X-ray emission and draw comparisons to other SGRs. Like the other SGRs, this SGR is associated with a persistent X-ray source and the young SNR, G337.0–0.1.

2. BATSE OBSERVATIONS

During a period of intense burst activity from SGR 1900+14, the Burst and Transient Source Experi-
ment (BATSE; Fishman et al. 1989) trigger criteria were optimized to detect SGR burst events. On 1998 June 15, three consecutive BATSE triggered bursts short in duration and having soft spectra, originated from a region of the sky which was inconsistent with the three known SGR locations. Two days later, BATSE detected another 17 events from the same region, confirming the existence of a new SGR, SGR 1627–41 (Kouveliotou et al. 1998b; source name based upon initial BATSE location). Over the course of the next month and a half, a total of 99 bursts from this source were detected with BATSE, 39 of which triggered the instrument. Figure 1 shows the observed burst rate as seen with BATSE.

The bursts from SGR 1627–41 last between 25 msec and 1.8 sec with most burst durations clustering near 100 msec. In Figure 2, we show some representative burst profiles. This small sample shows the diverse temporal variability observed in bursts from this source. The longest event (Figure 2d) is similar to two bursts seen from SGR 1900+14 with respect to both spectrum and temporal structure. These bursts are much longer than typical SGR events and have very smooth temporal profiles with abrupt γ-ray emission start and end points.

Due to the rapid succession of bursts on June 17 and 18, only limited fine spectral data for a given trigger were read out from the spacecraft before the next trigger, making detailed spectral reconstruction impossible for most bursts. Of the 39 triggered bursts, fine spectral resolution data were available for only 8 events, including two very bright bursts (Figures 2c and 2d). In fact, these two bright bursts have the two highest peak count rates of any extra-Solar event ever observed with BATSE. We fit power law, blackbody and OTTB spectral models to those bursts, and find the OTTB model best represents the time-integrated burst spectra of the six dim events and one of the two bright bursts (Figure 2d). The measured $kT$ values of the six dim events range between 25 – 35 keV; having a weighted mean of 27 keV. The spectral form of these six events agrees well with previous modeling of burst spectra from the other three SGRs (see e.g. Fenimore et al. 1994).

Due to dead-time problems at the peak of the two bright bursts, we fit spectra taken at the tail of each event. For the longest event (Figure 2d), we find the tail spectrum is best fit by an OTTB model with a $kT = 27.0 ± 0.4$ keV. Two spectra taken from the tail of the brightest event (Figure 2c) are significantly harder than any other SGR 1627–41 burst spectrum measured with BATSE. Furthermore, they are not consistent with one another, which shows spectral evolution exists for this event. The OTTB and power law spectral models cannot fit the first spectrum separately, but a combination of the two yields an acceptable fit. For this fit, the power law (photon) index $\alpha = -2.07 ± 0.13$ and the OTTB $kT = 32 ± 1$ keV. The following spectrum taken is at a lower flux level and is much harder. We find this spectrum can be fit by a simple power law with an index $\alpha = -1.86 ± 0.07$. Evidence for similar hard burst emission from SGR 1806–20 was found by Strohmayer & Ibrahim (1997). A detailed discussion of this topic is beyond the scope of this Letter, but it will be presented elsewhere (Woods et al. 1999a).

In order to estimate the peak fluxes of a larger sample of bursts, we applied the OTTB model to bursts with coarse spectral resolution (4 channels) and fair temporal resolution (64 msec). We assumed a fixed $kT$ corresponding to the measured weighted mean value for the five dim events (27 keV) and allowed only the normalization (energy flux) to vary. One drawback to this method is that many bursts reach their peak flux for only a short time, less than 64 msec, so these peak flux measurements will underestimate the true peak flux for some events. Given the limited data availability, however, this time scale provided the largest sample of events. Figure 3 shows the cumulative peak flux distribution on the 64 msec time scale for 57 events. The observed peak fluxes range over 3 orders of magnitude between $9 × 10^{−8}$ and $1.1 × 10^{−4}$ ergs cm$−2$ sec$−1$. Dead-time effects for the two brightest events were excessive, so these peak flux measurements ($1.1$ and $0.51 × 10^{−4}$ ergs cm$−2$ sec$−1$) can be treated as lower limits. The dashed line represents a power law fit to this distribution which has an exponent $\gamma = -0.6 ± 0.1$. No turnover is seen for this distribution out to $1.1 × 10^{−4}$ ergs cm$−2$ sec$−1$. We also constructed a cumulative burst fluence distribution for these events, which has a slightly flatter slope of $\gamma = -0.5 ± 0.1$. The differential fluence (energy) distribution then has an exponent equal to $−1.5$, which agrees well with the the Gutenberg-Richter power law index $−1.66$.

Using the BATSE triggers, the burst source was coarsely located (Kouveliotou et al. 1998b) at $\alpha = 16^h 27^m$ and $\delta = −41^◦$ (J2000) with an error circle of radius 2$. Detection of SGR events by both BATSE and the Ulysses spacecraft provided a narrow location annulus 1.7′ wide (Hurley et al. 1998a). Using BATSE Earth occultation constraints, we limited the allowable range along the annulus to 1.5◦ (Woods et al. 1998; Figure 4). A more detailed account of the localization of this SGR is reported in Hurley et al. (1999d) and Smith et al. (1999). In view of the association of SGRs with young SNRs, we searched the Whiteoak & Green (1996) catalogue of SNRs near the refined error box. A single SNR, G337.0–0.1 (Sarma et al. 1997), was found (Woods et al. 1998) within the 1.5◦ × 1.7′ error box. With hopes of detecting an X-ray counterpart for this SGR, a ToO observation of this SNR was initiated using the BeppoSAX (Boella et al. 1997a) Narrow Field Instruments (NFIs).

3. BEPPOSAX OBSERVATIONS

Two observations of SNR G337.0–0.1 were performed on 1998 August 7 and again on September 16. These observations revealed a previously undetected X-ray source (SAX J1635.8–4736) at $\alpha = 16^h 35^m 49.8^s$ and $\delta = −47^◦ 35′ 44″$ (J2000) with an error circle of radius 1′ (95% confidence; Figure 4), consistent with the SNR location. A known source, 4U1630–472, is also seen near the edge of the field of view for each observation. A light curve of the new source for each observation does not show any burst activity which is consistent with BATSE observations for those time periods (see Figure 1). Using the Low Energy Concentrator Spectrometer (LECS; Parmar et al. 1997) and two Medium Energy Concentrator Spectrometers (MECS; Boella et al. 1997b), we fit the spectrum of SAX J1635.8–4736 from 0.1 – 10 keV. The spectrum is well represented by a power law with interstellar absorption. Under the assumption that the spectral form
(i.e. the power law index and Hydrogen column density) remains constant between observations, we fit the observations simultaneously allowing only the normalization to vary between the two. We get an acceptable fit with a reduced χ² value of 0.92 for 160 degrees of freedom and find a power law (photon) index $\alpha = -2.5 \pm 0.2$ and a column density $N_H = (7.7 \pm 0.8) \times 10^{22}$ cm$^{-2}$. The unabsorbed flux (2 – 10 keV) declines between the observations (40.3 days) from $(6.7 \pm 0.3) \times 10^{-12}$ ergs cm$^{-2}$ sec$^{-1}$ to $(5.2 \pm 0.4) \times 10^{-12}$ ergs cm$^{-2}$ sec$^{-1}$. Assuming this source is located within the SNR, the distance is 11 kpc (Sarna et al. 1997). The source luminosity is then $9.7 \times 10^{34}$ ergs sec$^{-1}$ and $7.6 \times 10^{34}$ ergs sec$^{-1}$ for the two observations.

Using standard SAX analysis techniques, source counts were extracted from the combined MECS units for SAX J1635.8–4736 and binned at 0.5 sec time resolution. We then performed a Fast Fourier transform (FFT) of the 1998 August light curve searching frequencies from 0 – 1 Hz and found the largest value in the power density spectrum was at 0.156 Hz. Although not very significant by itself, the corresponding period falls within the tight range of observed periods (5 – 8 sec) for the other SGRs. Using the barycenter corrected time tags, we ran an epoch fold search about the period corresponding to the highest power, which revealed a marginally significant peak $(6 \times 10^{-3}$ chance probability taking into account the number of trials; 1500 between 6.38 and 6.44 sec) at 6.41318(3) sec (JD = 2451032.5). The nearly sinusoidal pulse profile has an r.m.s. pulse fraction of 10.0 ± 2.6 %. We performed the same analysis on the 1998 September observation, but did not find any significant peak in the power density spectrum near 0.156 Hz or anywhere else between 0 – 1 Hz. However, given the weak signal found in August and the fact that 45% fewer source counts were recorded in the MECS units during the September observation, we would not expect to find this pulsed signal.

4. DISCUSSION

We propose that SAX J1635.8–4736 is the X-ray counterpart to SGR 1627–41. There are a number of observations discussed here which support this claim. First, the position of SAX J1635.8–4736 is mutually consistent with the narrow error box for SGR 1627–41 (Hurley et al. 1999d, Smith et al. 1999) and the SNR G337.0–0.1. Second, its spectrum is very similar to those found for the other SGR X-ray counterparts (Hurley et al. 1999a). Also, this X-ray source is variable near a burst active period for SGR 1627–41 which has also been found for the X-ray counterpart of SGR 1900+14 (Hurley et al. 1999a, Murakami et al. 1999, Woods et al. 1999b). Finally, the marginal detection of pulsations at 6.4 sec, if confirmed, would agree well with the known spin periods of the three other SGRs which fall within a tight range of 5 – 8 sec (Kouveliotou et al. 1998a, Hurley et al. 1999a, Mazets et al. 1979).

For the distance of 11 kpc, G337.0–0.1 has a small diameter of ~ 5 pc (Sarna et al. 1997). There are only a few SNRs this small (see Case & Bhattacharya 1998), and a large fraction of them are very young (e.g. Tycho, Kepler, Cas A). This suggests that G337.0–0.1 is also very young. The association of SGR 1627–41 with G337.0–0.1 strengthens the connection between SGRs and young SNRs.

Given the distance to the SNR G337.0–0.1 and assuming isotropic emission, the burst peak luminosities (> 25 keV) vary from $10^{39}$ to $10^{42}$ ergs sec$^{-1}$ (Figure 3). Paczynski (1992) suggested that SGR 0526–66 may have a critical luminosity ~ $2 \times 10^{42}$ ergs sec$^{-1}$. He calculated the relation between the dipole magnetic field ($B_{\text{dipole}}$) of a neutron star and the critical luminosity ($L_{\text{crit}}$) the magnetosphere will allow to escape in the limit where $L_{\text{crit}} > L_{\text{Edd}}$ ($L_{\text{Edd}}$ is the standard Eddington luminosity for a 1.4 $M_\odot$ neutron star). This relation is given by

$$L_{\text{crit}} \approx 2 \left( \frac{B_{\text{dipole}}}{10^{12} \text{Gauss}} \right)^{4/3} \left( \frac{g}{2 \times 10^{13} \text{cm sec}^{-1}} \right)^{-1/3}$$

where $g$ is the surface acceleration due to gravity. For SGR 0526–66, Paczynski found a dipole magnetic field of ~ $6 \times 10^{14}$ Gauss, which agrees with independent estimates made by Duncan & Thompson (1992). For SGR 1627–41, we do not detect a turnover in the cumulative peak luminosity distribution, but we can place a lower limit on this value of $1.6 \times 10^{42}$ ergs sec$^{-1}$ based upon the highest observed peak luminosity. This, in turn, places a lower limit on the magnetic field of the presumed magnetar associated with SGR 1627–41 of $B_{\text{dipole}} \gtrsim 5 \times 10^{14}$ Gauss. This estimate may be confirmed with the definitive measurement of a pulse period and its derivative for SGR 1627–41.

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Fig. 1.— Burst rate of SGR 1627–41 (triggered and untriggered) as observed with BATSE. In total, 99 bursts were detected within 60 days. Arrows indicate times of BeppoSAX NFI observations of G337.0–0.1.

Fig. 2.— A sample of six bursts of SGR 1627–41 observed with the BATSE Large Area Detectors (LADs). The upper and lower panels are Time-Tagged Event (TTE) data (> 25 keV) accumulated with 4 msec (a), 2 msec (b), 2 msec (e) and 1 msec (f) time resolution. The middle panels are DISCrinator SCience (DISCSC) data (> 25 keV) accumulated with 64 msec time resolution. Trigger times for these six events are 50981.87322 (a), 50982.03545 (b), 50982.07120 (c), 50982.16969 (d), 50993.30911 (e) and 51006.91017 (f) in MJD (UT). BATSE trigger numbers are given in the upper left corner of each panel.

Fig. 3.— Cumulative peak flux (0.064 sec) distribution for 57 events. Dashed line is a power law fit to these data having an exponent equal to –0.6. Bottom horizontal axis labels the peak flux and the top horizontal axis gives the peak luminosity assuming isotropic emission and an 11 kpc distance to the source.

Fig. 4.— Localization of SGR 1627–41 and SAX J1635.8–4736. Panel (a) shows the Interplanetary Network (IPN) arc (solid lines) and Earth occultation constraints (shaded region). Panel (b) is a magnification of region near G337.0–0.1 (radio contours; Whiteoak & Green 1996). Solid straight lines represent BATSE-Ulysses IPN arc. Dotted lines are the Konus-Ulysses IPN arc (Hurley et al. 1998b). Solid, bold circle represents error region for SAX J1635.8-4736.
10^3 counts/sec

Time (Seconds since trigger)
