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# *ASCA* DISCOVERY OF AN X-RAY PULSAR IN THE ERROR BOX OF SGR 1900+14

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## ABSTRACT

We present a 2–10 keV *ASCA* observation of the field around the soft gamma repeater SGR 1900+14. One quiescent X-ray source was detected in this observation, and it was in the SGR error box. In 2–10 keV X-rays, its spectrum may be fitted by a power law with index −2.2, and its unabsorbed flux is $9.6 \times 10^{-12}$ ergs cm$^{-2}$ s$^{-1}$. We also find a clear 5.16 s period. The properties of the three well-studied soft gamma repeaters are remarkably similar to one another, and they provide evidence that all of them are associated with young, strongly magnetized neutron stars in supernova remnants.

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

## 1. INTRODUCTION

Four soft gamma repeaters (SGRs) are now known to exist with certainty, and there is good evidence that all of them are associated with supernova remnants (SNRs). The position of SGR 0525−66 is consistent with that 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 that 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 (Woods et al. 1998; Hurley et al. 1998a, 1998b). SGR 1900+14 lies close to G42.8+0.6 (Kouveliotou et al. 1994; Hurley et al. 1999). Three of the four are 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, 1999). Finally, two of the SGRs, 0525−66 (Mazets et al. 1979; Barat et al. 1979) and 1900+14 (Hurley et al. 1998c), display periodicities in their bursting emission, and one, 1806−20 (Kouveliotou et al. 1998), displays a periodicity in its quiescent emission; this indicates that they are all neutron stars.

In this Letter, we present soft X-ray observations of the quiescent X-ray source associated with SGR 1900+14 by the *Advanced Satellite for Cosmology and Astrophysics* (*ASCA*) indicating that it also displays a periodicity in its quiescent emission. Furthermore, its X-ray spectrum is similar to that of SGR 1806−20. In another Letter (Hurley et al. 1999), we present evidence, based on the burst localization by the interplanetary network, that this X-ray source is indeed associated with the SGR. Thus, SGR 1900+14 is similar to the other SGRs in many respects, pointing toward a unified model for these sources.

Kouveliotou et al. (1994) suggested that SGR 1900+14 might be associated with one of two SNRs, G43.9+1.6 or G42.8+0.6. Both the *ROSAT* sky survey (Vasisht et al. 1994) and a pointed observation at the position of G42.8+0.6 (Hurley et al. 1996) indicated that a pointlike quiescent X-ray source was present near this SNR. This source was also associated with one of the two network synthesis error boxes for this SGR (Hurley et al. 1994). No *ROSAT* source was detected in the second network synthesis error box (Li et al. 1997), and the more recent localization for SGR 1900+14 (Hurley et al. 1999) indicates that the first error box is indeed the one that contains the SGR and the quiescent X-ray source. Optical and infrared observations of the X-ray position revealed a peculiar double M star system within the X-ray source error box (Vrba et al. 1996). A rough estimate of the probability of finding a random X-ray source of any intensity in the error box for this SGR may be obtained from the statistics of the WGA Catalog.[10] There are ∼10,000 sources located at Galactic latitudes $|b| < 20°$, or $1.12 \times 10^{-3}$ sources arcmin$^{-2}$, and the error box area is ∼1.6 arcmin$^2$ (Hurley et al. 1999). Thus, the probability is ∼0.0018. This estimate makes no correction for the sky exposure as a function of Galactic latitude and encompasses the widely varying sensitivities of the *ROSAT*-pointed observations in the public domain (the typical observation times are 5000–30,000 s). However, as we show here, due to the fact that the period of the quiescent source is identical to that found in the giant flare of 1998 August 27 (Hurley et al. 1998c), the association between the SGR and the X-ray source does not depend strongly on this probability.

## 2. *ASCA* OBSERVATIONS

The position of the quiescent X-ray point source associated with SGR 1900+14, $\alpha(2000) = 19^{\mathrm{h}}07^{\mathrm{m}}14^{\mathrm{s}}$, $\delta(2000) = 9°19'19''$, was known from previous *ROSAT* observations (Hurley et al. 1994). *ASCA* was pointed to within ∼0°.1 of this position on 1998 April 30. (An earlier attempt at an observation on 1997 October 22 was incorrectly pointed.) The observation began around 20:55 UT and lasted 2.3 days, resulting in 74 ks of on-source exposure with the solid-state imaging spectrom-

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[10] The WGA Catalog of *ROSAT* Point Sources is available at http://lheawww.gsfc.nasa.gov/users/white/wgacat/wgacat.html, which is maintained by N. White, P. Giommi, and L. Angelini at NASA/GSFC/HEASARC.

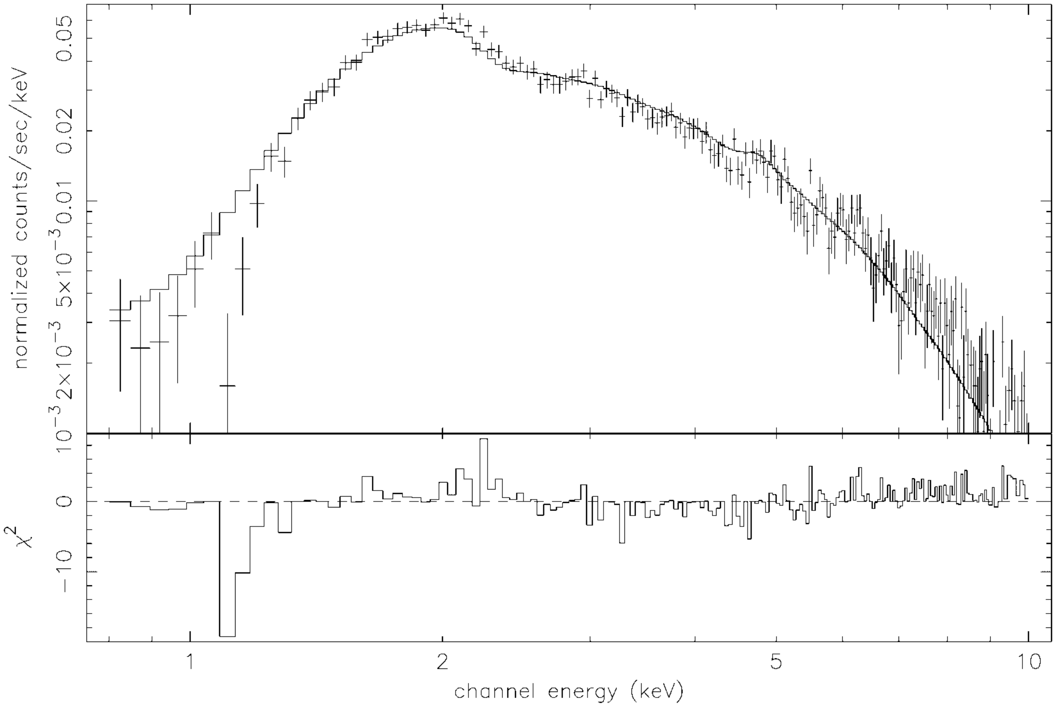

FIG. 1.—Best-fit power-law spectrum and residuals for the GIS2 and GIS3 data. The large residuals around 1 keV are believed to be caused by a small gain shift.

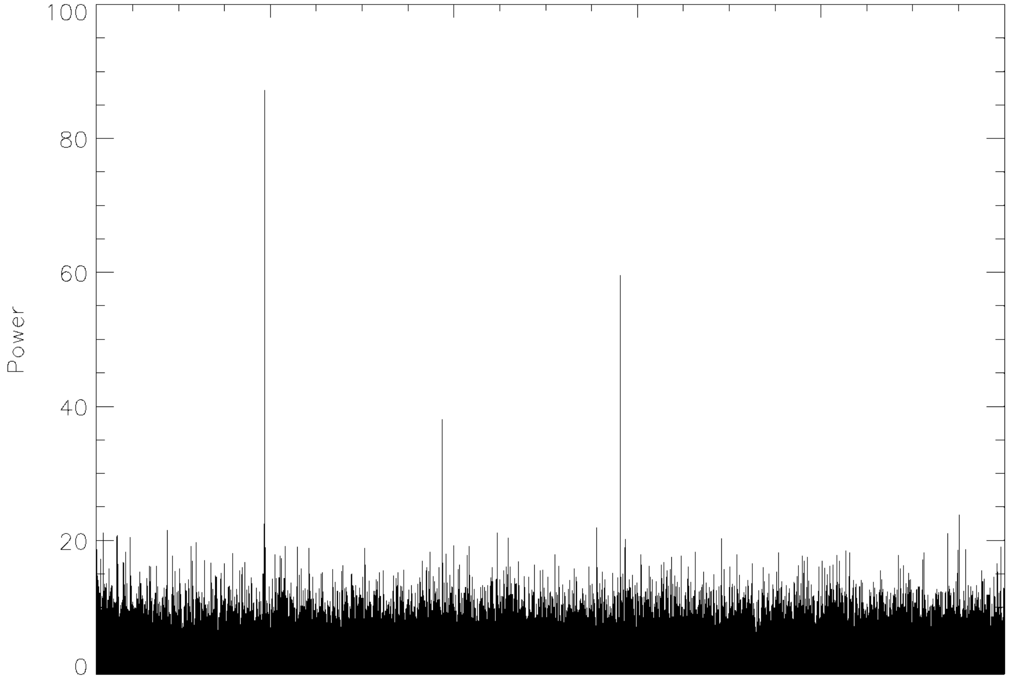

FIG. 2.—Power spectrum of the 2–10 keV soft X-ray source associated with SGR 1900+14. The 0.19384 Hz–pulsed signal and its first and second harmonics are well above the noise level.

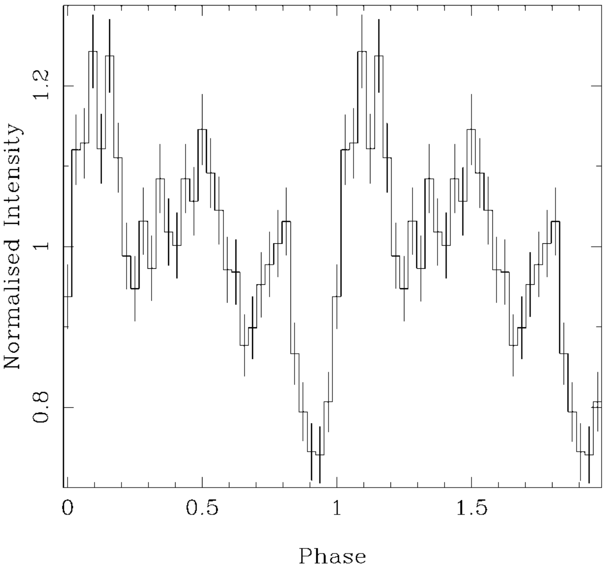

FIG. 3.—Epoch-folded pulse profile of SGR 1900+14 from the 2–10 keV *ASCA* data.

eter (SIS) and 84.6 ks with the gas imaging spectrometer (GIS). We used the standard screening criteria for such parameters as Earth elevation angle, South Atlantic Anomaly, and cutoff rigidity in order to extract photons. These are described in the *ASCA* Data Reduction Guide, Version 2.[11] No bursts from the source were observed by *Ulysses*, BATSE, KONUS, or *ASCA* during the observation. One quiescent source was detected at $\alpha(2000) = 19^{h}07^{m}16\overset{s}{.}4$, $\delta(2000) = +09^{\circ}19'44\overset{''}{.}1$ with an error radius 40″, which is consistent with the position of the *ROSAT* source. The source location was determined with the Ximage source detection tool, which uses a sliding window technique.

The region used for the spectral analysis consisted of a 6′ radius circle centered at the source position; the background was taken from the same observation, using a 6′ radius circle at a region where no source was present, as determined by the same sliding window technique. Spectral fitting was done using XSPEC and three trial functions: blackbody, thermal bremsstrahlung, and a power law, all with absorption. Using GIS2 and GIS3 data, a power law gave the best fit, with a reduced $\chi^2$ of 1.48 for 182 degrees of freedom (dof). The best reduced $\chi^2$ for the blackbody fit was 4.38, and that for the bremsstrahlung was 2.04. We therefore adopt the power-law fit; the best-fit photon, power-law index was $2.25 \pm 0.04$, and the absorption was $n_{\rm H} = (2.16 \pm 0.07) \times 10^{22}$ cm$^{-2}$. This corresponds to an unabsorbed 2–10 keV flux of $(9.6 \pm 0.7) \times 10^{-12}$ ergs cm$^{-2}$ s$^{-1}$. The fit is shown in Figure 1.

Previously, the distance to SGR 1900+14 had been estimated as 5 kpc using the $\Sigma$-$D$ relation (see, e.g., Vasisht et al. 1994). The measurement of $n_{\rm H}$ now permits an independent estimate. Using the W3nH tool available on-line from HEASARC,[12] we obtain ≈5.7 kpc. Both methods are subject to uncertainties; in what follows, we adopt a distance of 5 kpc.

To search for periodicity, light curves were constructed with 0.5 s binning from the sum of the GIS2 and GIS3 data by extracting ≈ 1–10 keV counts from a 4 ′ radius circular region around the source. The power spectrum is shown in Figure 2. A significant barycenter-corrected period was found at $5.1589715 \pm 0.0000008$ s. The distribution of powers closely follows a $\chi^2$ distribution with 2 dof. Taking into account the number of frequencies searched, the chance probability of finding a peak this strong or stronger in the power spectrum may be estimated at $4.7 \times 10^{-14}$, a conservative number that does not take the presence of the harmonics into account. A folded light curve is shown in Figure 3. This period agrees well with that found for the SGR in outburst on 1998 August 27 (Hurley et al. 1998c), making the identification of the quiescent source and the SGR quite secure.

## 3. DISCUSSION AND CONCLUSION

The *ASCA* observations of SGR 1900+14 may be used to estimate the magnetic field of the neutron star in two ways. First, we can use the association between the quiescent X-ray source and G42.8+0.6. The observable lifetime of SNRs is less than ~20,000 yr (Braun, Goss, & Lyne 1989). The characteristic age $\tau$ of a rotating, magnetized neutron star is related to the period $P$ and its derivative $\dot{P}$ by $\tau = P/2\dot{P}$, while $P$ and $\dot{P}$ are related to the field strength $B$ by $P\dot{P} = AB^2$, where $A = 9.8 \times 10^{-40}$ s G$^{-2}$ (see, e.g., Lyne, Manchester, & Taylor 1985). Thus, $B = (P^2/2A\tau)^{1/2}$. For SGR 1900+14, we obtain $B = 2 \times 10^{14}$ G for an age of $10^4$ yr, which is remarkably similar to estimates made from the energy contained in the soft tail of the giant flare of 1998 August 27 (Hurley et al. 1998c) and from a direct measurement of $\dot{P}$ (Kouveliotou et al. 1999). It is also comparable to the field strength of SGR 1806−20, which is estimated from direct measurements of $P$ and $\dot{P}$ for that source (Kouveliotou et al. 1998). This suggests that SGR behavior can be described by the magnetar model (Thompson & Duncan 1995). If this is the case, a second estimate of $B$

TABLE 1

PROPERTIES OF THREE SGRS

| SGR | Soft X-Ray Spectrum | Flux (ergs cm$^{-2}$ s$^{-1}$) | Period (s) | Distance (kpc) |
|---|---|---|---|---|
| 0525−66[a,b,c,d] ...... | ?[e] | $2 \times 10^{-12}$ | 8 | 55 |
| 1806−20[b,c,f] ....... | $E^{-2.2}$ | $1 \times 10^{-11}$ | 7.5 | ~15(?) |
| 1900+14 .......... | $E^{-2.2}$ | $9.6 \times 10^{-12}$ | 5.2 | ~5(?) |

[a] Rothschild et al. 1994.

[b] Murakami 1995.

[c] Murakami et al. 1996.

[d] Barat et al. 1979.

[e] The source was detected by the *ROSAT* HRI but not resolved by *ASCA*; no spectral measurement is available. The flux is for 0.1–2.4 keV.

[f] Kouveliotou et al. 1998.

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[11] See http://heasarc.gsfc.nasa.gov/docs/asca/abc/abc.html, maintained at LHEA at NASA/GSFC by M. Arida.

[12] See http://heasarc.gsfc.nasa.gov/docs/frames/mb_w3browse.html, maintained at LHEA at NASA/GSFC by S. Calvo.

comes from one of the predictions of that model, namely, that persistent soft X-ray emission is powered by crustal magnetic energy: $(B_{\rm crust}^2/8\pi)\, 4\pi R_*^2 \Delta R \gtrsim L_x \tau$, where $R_*$ is the radius of the neutron star (10 km), $\Delta R$ is the thickness of the crust (~1 km), and we take $L_x = 2.7 \times 10^{34}$ ergs s$^{-1}$ for a distance of 5 kpc and $\tau = 10{,}000$ yr. We obtain $B_{\rm crust} \gtrsim 4 \times 10^{14}$ G. The two estimates would agree ($B \sim 2.5 \times 10^{14}$ G) for an age $\tau \sim 7100$ yr, or about 70% of the lifetime of a typical magnetar, in the model.

Table 1 compares the properties of the three SGRs and their soft X-ray counterparts. The X-ray spectrum of SGR 0525 is unknown. However, the spectra of SGR 1806 and SGR 1900 have identical power-law indices; their 2–10 keV luminosities agree to within an order of magnitude when their estimated distances are taken into account. The periods of all three sources agree to within a factor of ~1.6. The four known SGRs therefore share many similarities—in their periods, the properties of their quiescent soft X-ray sources, their ages, their magnetic fields, and their associations with supernova remnants. This provides further evidence that, as a class, the SGRs are strongly magnetized, young neutron stars whose behavior can be described by the magnetar model of Thompson & Duncan (1995).

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