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ACCURATE POSITION OF SGR 1900+14 BY BURSTS AND CHANGES IN PULSE PERIOD AND FOLDED PULSE PROFILE WITH *ASCA*

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ABSTRACT

The *Advanced Satellite for Cosmology and Astrophysics* (*ASCA*) observed the soft gamma repeater SGR 1900+14 on 1998 April 30–May 1 and discovered a pulsar with a period of 5.1589715(8) s from the known X-ray source of RX J190714.2+0919.3. Four months later, on September 16–17, *ASCA* observed SGR 1900+14 again just after the giant burst on 1998 August 27. Comparing the observations in September with those in April, there are several changes in characteristics. The pulse period changed to 5.160295(3) s, and thus the long-term period derivative is 1.1×10^{-10} s s^{-1}. This strongly supports a magnetar model. The folded pulse profile in 2–10 keV largely changed from three peaks in April to one simple peak, while the steady intensity increased by a factor of 2. Finally, we successfully determined the accurate location of SGR 1900+14 by the bursts with an accuracy of 1′.5 in diameter.

Subject headings: gamma rays: bursts — stars: individual (SGR 1900+14) — stars: neutron

1. INTRODUCTION

Four soft gamma repeaters (SGRs) are known so far, and three of them have a point-steady X-ray source (Cline et al. 1982; Atteia et al. 1987; Kouveliotou et al. 1993; Hurley et al. 1994, 1996; Kulkarni et al. 1994). Two X-ray point sources for SGR 1806−20 and 0525−66 were localized to the well-known supernova remnants (SNRs), N49 in LMC and G10.0−0.2 (Rothschild, Kulkarni, & Lingenfelter 1994; Kulkarni & Frail 1993; Kulkarni et al. 1994; Kouveliotou et al. 1994). Then SGR 1806−20 was clearly identified with an X-ray source, AX 1805.7−2025, by a burst (Murakami et al. 1994). The close relationship between the X-ray sources and the young SNRs suggests that these X-ray sources might be X-ray pulsars. Recently, SGR 1806−20 and 1900+14 have turned out to be X-ray pulsars (Kouveliotou et al. 1998a, 1998b, 1999; Hurley et al. 1998a, 1999). The period derivative of both pulsars amounted to a large value on the order of 10^{-11}–10^{-10} s s^{-1}. If we simply assume magnetic dipole radiation like other radio pulsars, because of no binary evidence, both are required to have a magnetic field of more than 10^{14} G. This magnetic field value strongly supports a magnetar model for SGRs (Duncan & Thompson 1995; Thompson & Duncan 1995, 1996).

A group of X-ray pulsars with a period of 5–12 s are called anomalous X-ray pulsars (AXPs). There is no evidence of a binary nature. Strong magnetic fields such as those of SGRs are invoked to explain the fast slowdown of AXPs (Mereghetti & Stella 1995; van Paradijs, Taam, & van den Heuvel 1995). Although burst activities have not been observed from AXPs, AXPs seem to be SGRs in an inactive phase. We need to accumulate more data in order to establish the relation between SGRs and AXPs.

In this Letter, we report the results of the second observation of SGR 1900+14 with the *Advanced Satellite for Cosmology and Astrophysics* (*ASCA*). The motivation for this observation is to examine the timing and spectral properties soon after the giant burst on 1998 August 27 (Cline et al. 1998; Hurley et al. 1998b).

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2. OBSERVATIONS

The second *ASCA* observation of SGR 1900+14 was conducted from September 16.72 (UT) to September 17.75 (UT) with the gas imaging spectrometer (GIS) and solid-state imaging spectrometer (SIS) detectors. The net exposure of this observation was 39 ks. Soon after the announcement of a giant burst activity on August 27, we requested to observe this region, but because of the Sun-angle constraint, we could not observe this until September 11. Soon after the *ASCA* window opened and the rescheduling was made, we started the Time of Opportunity Observation in September 16.72 (UT). The details of the GIS and SIS instrumentation used for this observation were already reported separately in the instrumentation papers (Serlemitsos et al. 1995; Makishima et al. 1996). The only special arrangement considered for this observation was the pointing position. The *Rossi X-Ray Timing Explorer* (*RXTE*) reported an 89.17 s pulsar in the vicinity of SGR 1900+14, and there was a small possibility that the two periods of 5.16 and 89.17 s were from the same source (Marsden et al. 1998; Takeshima, Corbet, & Swank 1998). Thus, we intended to include both of the pulsars in the same GIS field of view (FOV). Figure 1 shows an overall log of the observation of the central source of RX J190714.2+0919.3 (Vrba et al. 1996).

2.1. *Burst Activity and Intensity Variation*

Thanks to a huge number of the CCD pixels on the SIS, we are able to detect burst events without the dead time. Then we compared the possible *ASCA* bursts carefully with the *RXTE* events, which were used for establishing the bursts. As a result of the comparison, we found at least 19 SGR bursts. We note that these events are not uniformly distributed over the observational window. The source had much more burst activity in the second half of the window than in the first half, as shown in Figure 1.

After removing all the bursts from the light curve of Figure

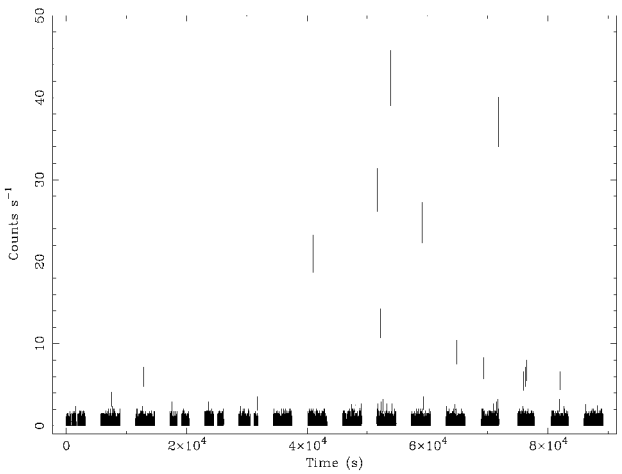

FIG. 1.—The overall light curve of SGR 1900+14 plotted with 4 s bins during the *ASCA* observation on September 16–17. The data start at $19^h04^m29^s$ (UT) on 1998 September 16. The spikes in the figure are the recorded SGR bursts.

1, we determined the steady level of the X-ray flux. The steady flux is rather constant on a timescale of 256 s–1 day. The mean flux of the source is 2.3×10^{-11} ergs s^{-1} cm^{-2} in 2–10 keV for the September observation, while in the April observation, it was 1.28×10^{-11} ergs s^{-1} cm^{-2} (Hurley et al. 1999). The mean steady flux in September is twice as bright as that in April. The burst activity changed largely between the first and second half of the observation period in September, whereas the steady flux remained almost constant. The burst activity may not be relevant to the level of the steady flux.

2.2. *Burst Position*

Using only the burst intervals in Figure 1, we produced a composite burst image in the right panel of Figure 2 by the burst photons alone and compared this image with the nonburst image in the left panel of Figure 2. Both are in J2000 coordinates. It is clear that two images are located in the same position within an accuracy of 1′.5 in radius. The accuracy of the burst position is limited by the number of photons. The position determined is consistent with that of RX J190714.2+0919.3 (Vrba et al. 1996; Vashist et al. 1994). Although the burst source was already associated with a pulsar by the 5.16 s pulsation on the shoulder of the giant burst on August 27 (Hurley et al. 1998b), the direct *ASCA* image by the burst photons clearly confirms this identification with the best accuracy presently available of 1′.5.

2.3. *The* 5.16 s *Pulse Period*

Conducting the pulse period search, we found the period of 5.160295(3) s. Combining this period with the period of 5.1589715(8) s on April 30 (Hurley et al. 1999), we found a long-term pulse period derivative between the two observations of 1.1×10^{-10} s s^{-1}. The last known pulse period from this source by *RXTE* is 5.160200(2) s, which was obtained on August 28 (Kouveliotou et al. 1999). Thus, the short-term pulse period derivative between August 28 and September 17 is 1.0×10^{-10} s s^{-1}. We find no significant change in the pulse period derivative even after the giant burst on August 27.

RXTE reported an 89.17 s period in the *RXTE*/Proportional Counter Array FOV, together with 5.16 s (Takeshima et al. 1998). However, we could not detect the 89.17 s period at the position of RX J190714.2+0919.3 nor could we detect it within the full GIS FOV of 25′ in diameter. Hence, the 89.17 s pulsar is outside the full GIS FOV and is therefore not associated with the SGR (Takeshima & Murakami 1998).

2.4. *Pulse Profile and Spectrum*

The most striking feature of our observation is the large change in the folded pulse profile. In the April observation, the pulse profile in 2–10 keV was composed of three major peaks (Hurley et al. 1998b). In the September data, the folded pulse profile has only one peak with a small shoulder in 2–10 keV. The same change is also reported by *RXTE* (Kouveliotou et al. 1999). In order to examine the change in more detail, we produced the folded pulse profile separately in two energy bands of 2–10 and 0.5–2 keV. As shown in Figure 3, the three-

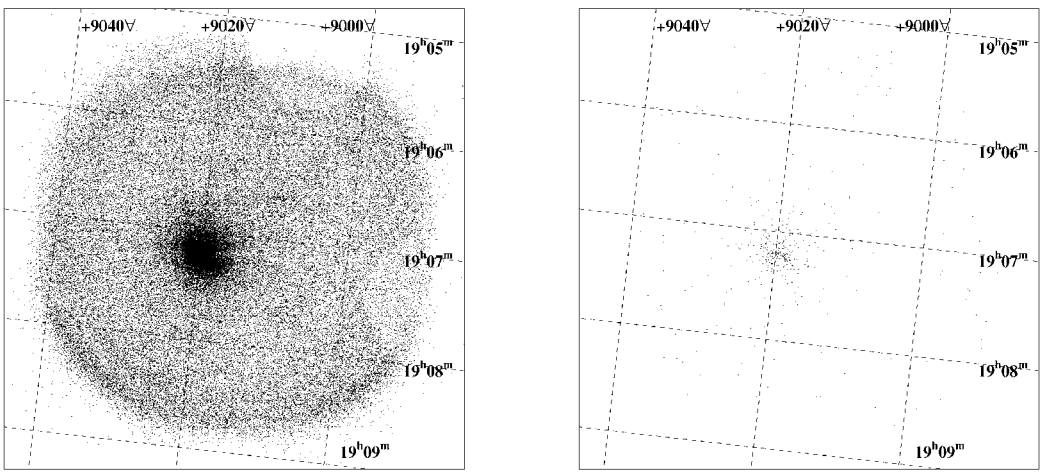

FIG. 2.—X-ray images produced from the burst photons alone (*right panel*) and the steady photons (*left panel*) in J2000 coordinates. The location of the steady component is consistent with RX J190714.2+0919.3, and the two images coincide with each other within the GIS accuracy of 1′.5 in radius.

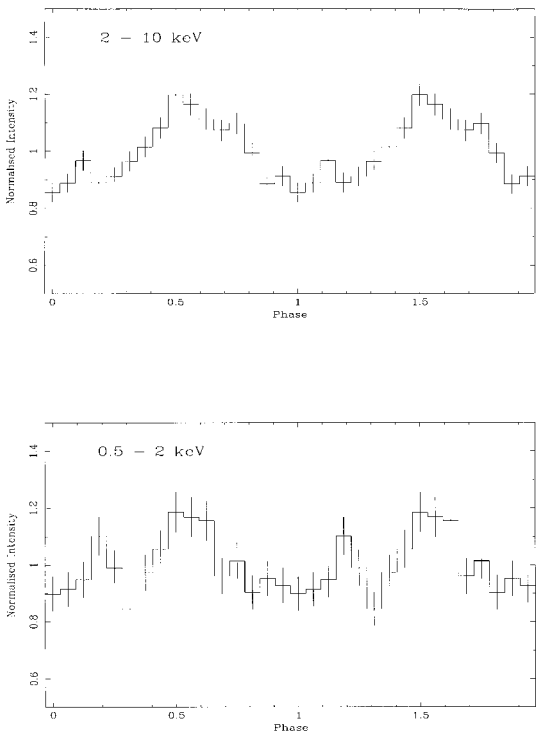

FIG. 3.—Pulse profiles in the 0.5–2 and 2–10 keV bands. The three-peak profile is only seen in the lower energy band.

peak pulse was observed only in the soft band of 0.5–2 keV, where absorption becomes important. We note that this type of profile change, which depends on intensity, is seen commonly among binary X-ray pulsars (Nagase 1989).

The spectra in both April and September are well fitted by a power-law (nonthermal) form with an absorption. The September observation of Figure 4 yields a power-law photon index of -2.40 ± 0.06 and a hydrogen column density of $(2.88 \pm 0.11) \times 10^{22}$ cm^{-2}. The best fit is summarized in Table 1. The value for column density is consistent with interstellar hydrogen and suggests a distant source. The spectral change between April and September is insignificant, whereas the pulse profile and flux changes are significant.

TABLE 1

BEST-FIT PARAMETERS OF THE SPECTRUM

Model Parameter	Unit	Value	Error[a]
Photon index	...	2.40	0.06
Hydrogen column density	$\times 10^{22}$ atoms cm^{-1}	2.88	0.11
χ^{2b}	...	149.0 (198)	...
Model flux (0.5–10 keV)	$\times 10^{-11}$ ergs cm^{-2} s^{-2}	2.47	...
Model flux (2–10 keV)	$\times 10^{-11}$ ergs cm^{-2} s^{-2}	2.30	...

[a] All errors are for a $\pm 90\%$ confidence level.

[b] The number of degrees of freedom is given in parentheses.

2.5. *A Burst Spectrum in* 1–10 keV

Figure 5 depicts a composite spectrum of many bursts. If we use a power-law model for this, the best fit is obtained with a power-law index of -1.1 ± 0.3. The burst spectrum is much harder than the steady spectrum of -2.4. We note also that the required column density of $(5.5 \pm 1.2) \times 10^{22}$ cm^{-2} is much larger than that of the steady component. So there should be an excess absorption, if the power-law model is correct. However, synchrotron self-absorption might be a more plausible mechanism than a photoionization process in such a high magnetic field. In any case, the origin of the burst might be much closer to the neutron star surface. The same type of behavior was also reported for SGR 1806−20 with *ASCA* (Murakami et al. 1995a, 1995b).

3. DISCUSSION

Assuming isotropic emission and a distance of 10 kpc for SGR 1900+14, we have 3×10^{35} ergs s^{-1} for the persistent X-ray luminosity in quiescence. Several possibilities for an energy source for the emission are raised. The rotational energy loss, which is estimated to be 3×10^{34} ergs s^{-1} from P and $\dot{P}$, is not sufficient to explain the observed luminosity. Mass accretion is another candidate. The pulse profile change, which depends on intensity, and the spin-down behavior, as presented here for SGR 1900+14, are also seen from many accreting X-ray pulsars in the massive X-ray binaries (Nagase 1989). The intensity variation and the pulse profile change favor the accretion pulsars. If the observed spin-down is caused by the accreting matter opposite to the rotation of the star, the accretion torque theory (Ghosh & Lamb 1979) requires a mass accretion

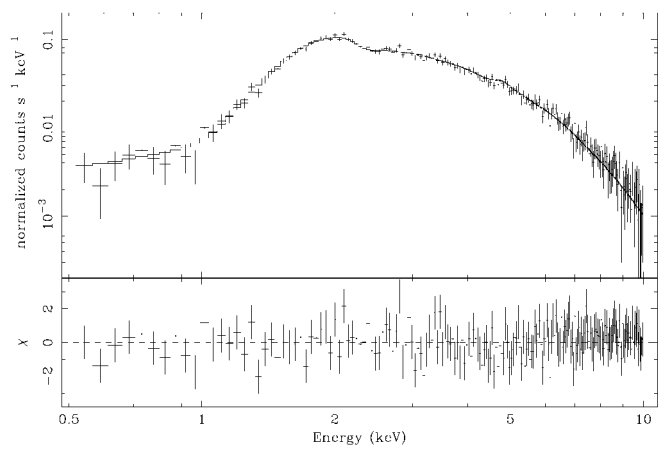

FIG. 4.—Mean spectrum of the September observation together with the best-fit power-law model. The overall spectrum is not so different from the spectrum before the giant burst.

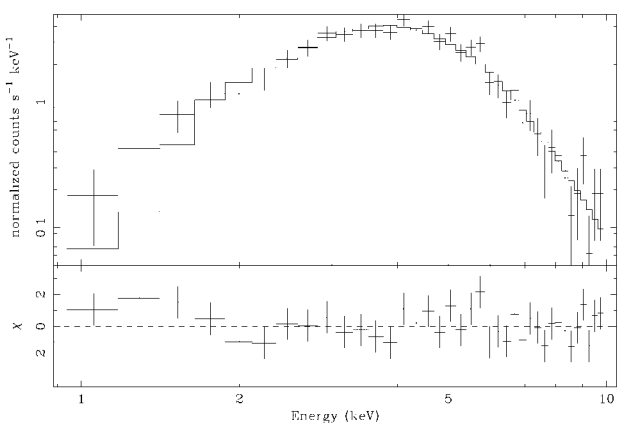

FIG. 5.—A composite burst spectrum together with the best-fit power-law model. Let us compare this with the steady spectrum in Fig. 4. The burst spectrum is much harder and heavily absorbed.

rate at least 2 orders of magnitude larger than that implied from the X-ray luminosity and magnetic fields less than 10^{12} G. Furthermore, we note that the spectrum without iron lines is quite different from those spectra of accreting low- and high-mass X-ray binaries (Nagase 1989, 1997). These arguments suggests that mass accretion may be less likely.

The most promising candidate for the source of free energy is a strong magnetic field in the neutron star interior (Thompson & Duncan 1995, 1996). Assuming magnetic dipole braking and using the observed P and $\dot{P}$, we obtain 8×10^{14} G for the field strength at the surface of the star. The ambipolar diffusion causes a decay of the magnetic field in the core, dissipating its energy into heat (Goldreich & Reisenegger 1992). Most of the released energy is emitted in the form of neutrinos, while a small fraction is transported to the surface and emitted there in the form of thermal X-rays. The observed X-rays may not be ascribed to these thermal X-rays since the observed spectra are of nonthermal type. The ambipolar diffusion in the core drives the seismic shear waves in the crust, which then couple directly to magnetospheric Alfvén modes. Thompson & Duncan (1996) estimate the Alfvén wave luminosity to be $2 \times 10^{36}(Bc/10^{15}\ \mathrm{G})^2(t/10^2\ \mathrm{yr})^{-1}(DRc/1\ \mathrm{km})\ \mathrm{ergs\ s^{-1}}$, where Bc is the crustal field strength, t is the star age, and DRc is the crust thickness. Alfvén wave luminosities are sufficient to provide the observed X-ray emission. A mechanism of energy conversion from Alfvén waves to X-rays and gamma rays should be studied. Initial work on this problem was done by Thompson & Blaes (1998).

In addition to the P and $\dot{P}$, the spectrum and luminosity of persistent X-rays observed from SGR 1806−20 are similar to those of SGR 1900+14 (Kouveliotou et al. 1998a). The persistent X-rays from SGR 1806−20 may also be ascribed to magnetospheric emission. Although the spectral shape of the persistent X-rays are not known yet, we expect that the same conclusion mentioned above may be applied to SGR 0525−66.

The AXPs (Mereghetti & Stella 1995; Mereghetti, Stella, & Israel 1997), the pulse periods of which are in a narrow range of 5–12 s, may also belong to the same category as SGRs, although the burst activities have not yet been observed from AXPs. The persistent X-ray spectra of AXPs are different from those of SGRs and consist of two components, a steep power law and a soft blackbody. One interpretation is that the power law and the soft blackbody components are associated with the magnetospheric and surface thermal radiation, respectively. The physical cause for the difference in burst activity and spectra between SGRs and AXPs needs to be investigated.

We find that the pulse period continues to increase through the giant burst on August 27, whereas the crust-cracking model predicts the sudden decrease in the pulse period at bursts. The total energy released at this giant burst may exceed 10^{43} ergs, whereas the maximum strain energy stored in the crust is estimated to be less than 10^{41} ergs (Baym & Pines 1971). The crust cracking may not be a trigger for the giant burst. Finally, we note that Thompson & Duncan (1995) already propose a promising model for giant bursts that invokes a large-scale reconnection of the strong magnetic field. To confirm this, we need further monitoring of the pulse period change.

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