File ID	uvapub:6659
Filename	75936y.pdf
Version	unknown

SOURCE (OR PART OF THE FOLLOWING SOURCE):

Type	article
Title	BeppoSAX observations of SGR 1900+14 in quiescence and during an active period
Author(s)	P.M. Woods, C. Kouveliotou, J.A. van Paradijs, M.H. Finger, C. Thompson
Faculty	FNWI: Astronomical Institute Anton Pannekoek (IAP)
Year	1999

FULL BIBLIOGRAPHIC DETAILS:
http://hdl.handle.net/11245/1.158675

THE ASTROPHYSICAL JOURNAL, 518:L103–L106, 1999 June 20

BEPPOSAX OBSERVATIONS OF SGR 1900+14 IN QUIESCENCE AND DURING AN ACTIVE PERIOD

PETER M. WOODS,[1] CHRYSSA KOUVELIOTOU,[2,3] JAN VAN PARADIJS,[1,4]
MARK H. FINGER,[2,3] AND CHRISTOPHER THOMPSON[5]

Received 1999 April 7; accepted 1999 April 21; published 1999 May 6

ABSTRACT

We present results from two *BeppoSAX* Narrow-Field Instrument observations of SGR 1900+14 made during a quiescent and an active period of the source. We detect pulsations in the 1997 May 12–13 observation (quiescence) at 5.157190(7) s and the 1998 September 15–16 observation (active period) at 5.160261(12) s. Using results recently reported by Hurley et al., we establish a long-term spin-down rate during quiescence of $5.82(2) \times 10^{-11}$ s s^{-1}, which implies a dipole magnetic field of $\sim 5.5 \times 10^{14}$ G. We confirm deviations from a constant spin-down rate during the active period. We also find spectral similarities between SGR 1900+14 in quiescence and anomalous X-ray pulsars.

Subject headings: pulsars: general — stars: individual (SGR 1900+14) — stars: neutron — X-rays: bursts

1. INTRODUCTION

First detected in the late 1970s (Mazets & Golenetskii 1981), soft gamma repeaters (SGRs) were not recognized as a distinct class of stellar objects until the mid-1980s (Atteia et al. 1987; Laros et al. 1986; Kouveliotou et al. 1987). To date, there are four known SGRs (SGR 0526−66, SGR 1627−41, SGR 1806−20, and SGR 1900+14) and one as yet unconfirmed candidate (Hurley et al. 1997; Kouveliotou et al. 1997; Smith et al. 1997). SGRs get their name from the burst characteristics that distinguish them from classical gamma-ray bursts. SGRs emit short, recurrent bursts, which have much softer spectra then classical gamma-ray bursts (see, e.g., Kouveliotou 1995). The majority of SGR bursts last tens of milliseconds, although a small fraction of the extremely bright events have extended tails that last hundreds of seconds (Mazets et al. 1979; Cline, Mazets, & Golenetskii 1998; Hurley et al. 1999a). The first of these long events was emitted from SGR 0526−66, the famous 1979 March 5 burst. This flare started with a sharp rise followed by a ∼3 minute train of 8 s pulsations. These pulsations, in conjunction with the positional coincidence of the burst source with the supernova remnant (SNR) N49 in the Large Magellanic Cloud (Cline et al. 1982), strongly suggested that the source of the bursts was a magnetized neutron star.

The presence of the train of 8 s pulsations following the 1979 March 5 event and the discovery of persistent X-ray emission from SGR 0526−66 (Rothschild, Kulkarni, & Lingenfelter 1994), SGR 1806−20 (Murakami et al. 1994), and SGR 1900+14 (Vasisht et al. 1994; Hurley et al. 1996) inspired searches for pulsations from the remaining SGRs. These searches were finally rewarded when 7.47 s periodic pulsations were detected in the persistent X-ray flux of SGR 1806−20, which showed a secular spin down at a rate of 8.3×10^{-11} s s^{-1} (Kouveliotou et al. 1998a). As argued by Kouveliotou et al. (1998a), the spin down is the result of magnetic-dipole radiation and surface particle emission induced by burst activity; the corresponding neutron star magnetic field equals $\sim 8 \times 10^{14}$ G. This result is consistent with the "magnetar" model proposed by Duncan & Thompson (1992) and Thompson & Duncan (1995, 1996), which accounts for SGR phenomena.

Recent observations have led to the discovery of a second magnetar associated with SGR 1900+14 (Kouveliotou et al. 1999). First detected in 1979, this SGR was the least active of the three SGRs known of during the 1980s and early 1990s (Kouveliotou et al. 1993). Over an 18 yr period, only seven bursts were recorded from this source until 1998 May 26, when this SGR became extremely active (Kouveliotou et al. 1998b; Hurley et al. 1998). From 1998 May through October, more than 100 bursts were recorded by numerous instruments. Shortly before the onset of the 1998 burst activity from SGR 1900+14, an observation with *ASCA* of the most promising quiescent X-ray counterpart (RX J190714.2+0919.3) for this SGR (Hurley et al. 1996; Vasisht et al. 1994) revealed coherent 5.16 s pulsations (Hurley et al. 1999b). During the period of enhanced burst activity, these pulsations were again detected in the persistent X-ray emission, and a spin-down rate of 1.1×10^{-10} s s^{-1} was determined for this source (Kouveliotou et al. 1999), indicating a magnetic field of $\sim(2–8) \times 10^{14}$ G (depending upon surface particle emission). The persistent X-ray flux was found to increase with burst activity (Remillard, Smith, & Levine 1998; Kouveliotou et al. 1999; Murakami et al. 1999). On 1998 August 27, an exceptional burst from SGR 1900+14 resembling the March 5 event from SGR 0526−66 was recorded with multiple spacecraft. This burst also started with an initial bright pulse followed by a ∼300 s train of 5.16 s pulsations (Cline, Mazets, & Golenetskii 1998; Hurley et al. 1999a).

Here, we discuss two separate observations of SGR 1900+14 taken with the Narrow-Field Instruments aboard *BeppoSAX* (Boella et al. 1997a). These observations were performed in 1997 when the source was in quiescence and again in 1998 during an active period. We compare the spectral and temporal characteristics of the persistent emission during the observations and, incorporating previously reported results with our own, provide a long-term spin-down rate of the pulsar during quiescence.

2. OBSERVATIONS

The first observation was performed during 1997 May 12.06–13.05 (UT), when the source was in quiescence. The

---

[1] Department of Physics, University of Alabama in Huntsville, Huntsville, AL 35899; peter.woods@msfc.nasa.gov.

[2] Universities Space Research Association.

[3] NASA Marshall Space Flight Center, ES-84, Huntsville, AL 35812.

[4] Astronomical Institute "Anton Pannekoek," University of Amsterdam, 403 Kruislaan, 1098 SJ Amsterdam, Netherlands.

[5] Department of Physics and Astronomy, University of North Carolina, Philips Hall, Chapel Hill, NC 27599-3255.

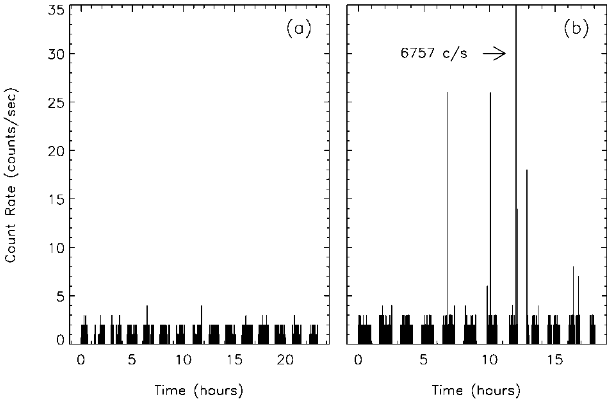

FIG. 1.—MECS2 + MECS3 light curves (1.8–10 keV) binned at 1 s time resolution for the (*a*) 1997 May and (*b*) 1998 September observations.

second observation took place while the source was active during 1998 September 15.24–16.01 (UT). The detector on-source times for the two Medium-Energy Concentrator Spectrometer (MECS; Boella et al. 1997b) units during the two observations were 45.7 and 33.2 ks, respectively. For the Low-Energy Concentrator Spectrometer (LECS; Parmar et al. 1997), the on-source times were much lower, at 19.9 and 13.8 ks. Using two MECS units, we detect a single point source in each observation at $\alpha = 19^{h}7^{m}14^{s}$ and $\delta = +9°19'46''$ (J2000), with an error circle of radius 1′ (95% confidence). This location is consistent with the refined Interplanetary Network error box (Hurley et al. 1999c) as well as the radio counterpart for SGR 1900+14 (Frail, Kulkarni, & Bloom 1999).

For each of the two observations, light curves were generated for the combined MECS2 and MECS3 units. For both MECS units, events within a ~4′ radius of the source location were binned at 1 s time resolution. Comparison of these two light curves (Fig. 1) shows the difference in source activity. During the 1997 May observation we detected no bursts, whereas during the 1998 September observation nine events are seen and the persistent count rate increased by a factor of ~3.

3. PULSED SIGNAL

We applied a barycentric correction to the event times for the summed MECS units, correcting for both Earth and spacecraft motion. For the 1998 September observation, the bursts were removed prior to correction. For each observation, we epoch-folded the data over a narrow range of periods between 5.15 and 5.17 s. Figure 2 shows the χ^2 statistic plotted versus period for these searches. The chance probabilities of detecting signals this strong are 7×10^{-8} and 1×10^{-15} for the respective observations. Using a pulse phase analysis, we determined the period for each observation at 5.157190(7) (JD = 2,450,581.0) and 5.160261(12) (JD = 2,451,072.0). Thus, there is a significant spin down between the two observations. Using the period measurement reported by Hurley et al. (1999b) for 1998 May 1 and our 1997 May measurement, we find a long-term spin-down rate of $5.82(2) \times 10^{-11}$ s s^{-1} before burst activity was detected in 1998. Extrapolation of this "quiescent" spin-down rate grossly underestimates the period found within our 1998 September observation. This supports the finding of Kouveliotou et al. (1999) that the spin-down rate evolves in time.

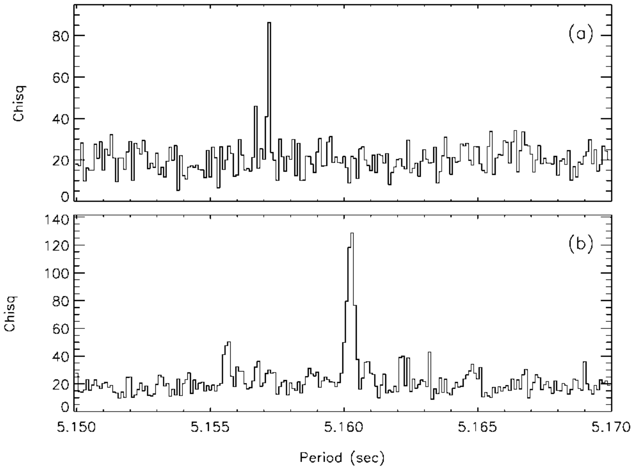

FIG. 2.—Epoch-fold period searches (χ^2 vs. period) for the (*a*) 1997 May and (*b*) 1998 September observations.

In agreement with other results (Kouveliotou et al. 1999; Hurley et al. 1999b; Murakami et al. 1999), we find that the phase-folded profile changes dramatically as the source burst activity increases (Fig. 3). During quiescence, the profile is complex, showing a ~0.6 cycle long plateau, followed by a dip and then a sharp peak. For 1998 September, the profile is nearly sinusoidal. Furthermore, we find that although the source intensity increases and the pulse profile changes shape considerably, the rms pulsed fraction remains constant at 11.6% ± 1.7% and 11.3% ± 1.2% for May and September, respectively.

4. SPECTRAL PROPERTIES

For each of the two observations, we used XSPEC v10.00 to simultaneously fit the spectra obtained with the two MECS units and the LECS unit, for which we used extraction radii of 4′ and 8′, respectively. By inspection of the 1998 September light curve, time selections were made to remove the bursts. The persistent emission spectra were rebinned and then deconvolved using response and effective area files from 1997 September.[6] Due to the low galactic latitude, contemporaneous background were taken from each observation. Background

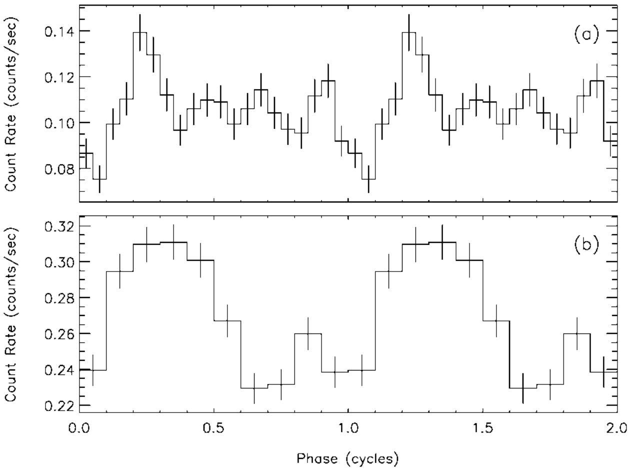

FIG. 3.—Epoch-folded light curves (1.8–10 keV) for the (*a*) 1997 May and (*b*) 1998 September observations (MECS2 + MECS3).

---

[6] These files can be found at ftp://www.sdc.asi.it/pub/sax/cal/responses/97_9.

TABLE 1

SUMMARY OF SPECTRAL FITS

Observation	Model	χ^2/dof[a]	N_H (10^{22} cm^{-2})	kT (keV)	R_{bb}[b] (km)	α[c]	Flux[d] (ergs cm^2 s^{-1})
1997 May ……	Power law	1.41	1.5 ± 0.2	…	…	1.89 ± 0.06	$(9.0 \pm 0.6) \times 10^{-12}$
	Blackbody + power law	1.06	1.8 ± 0.4	0.51 ± 0.05	1.4 ± 0.2	1.1 ± 0.2	$(9.9 \pm 0.4) \times 10^{-12}$
1998 Sep …….	Power law	1.04	2.6 ± 0.2	…	…	2.20 ± 0.05	$(2.6 \pm 0.2) \times 10^{-11}$
	Blackbody + power law	1.00	2.2 ± 0.3	0.62 ± 0.07	1.0 ± 0.2	1.8 ± 0.2	$(2.5 \pm 0.2) \times 10^{-11}$

[a] 143 degrees of freedom (dof) for power-law fit, 139 dof for blackbody plus power law.

[b] Blackbody radius (assumes $d = 5$ kpc).

[c] Power-law index.

[d] Unabsorbed flux (2–10 keV).

spectra were extracted from regions defined by a concentric ring outside our source region (~6′–8′ and ~9′–11′, respectively).

For the persistent emission (0.1–10 keV), we tried fitting a blackbody, a power law, and a blackbody plus power law to the spectra, all with interstellar absorption. We rejected the blackbody based upon the large χ^2 values for both observations (3.3 and 3.1, respectively). We obtained reasonable χ^2 values for the other two spectral models (see Table 1), but find that the blackbody plus a power law best represents the data for both observations. This same model has been used to fit spectra from anomalous X-ray pulsars (AXPs; Thompson & Duncan 1996, and references therein). These sources have periods and spin-down rates similar to the two SGRs for which this information is known (Vasisht & Gotthelf 1997; Kouveliotou et al. 1998a; Kouveliotou et al. 1999), and like SGRs, AXPs are also believed to be isolated neutron stars with strong magnetic fields and large X-ray luminosities (Mereghetti & Stella 1995; van Paradijs, Taam, & van den Heuvel 1995).

We find that during the burst active period, the blackbody component showed little or no change. The blackbody radius remained constant at ~1 km (for an assumed distance of 5 kpc; Vasisht et al. 1994; Hurley et al. 1999a), suggesting anisotropic emission from the surface of the neutron star. The power-law component, however, softened and dominated the X-ray spectrum during the second observation. In terms of unabsorbed flux (2–10 keV), the ratio of power-law to blackbody flux doubled between the two observations. This is qualitatively consistent with what was found with *ASCA* by Hurley et al. (1999b) and Murakami et al. (1999) in that the persistent emission is better fit by a power-law model during the active period. Furthermore, the 1997 May flux measurement confirms that the source was in quiescence during the 1998 May observation (Hurley et al. 1999b). For an assumed distance of 5 kpc, the persistent source luminosity increased from 3.0×10^{34} to 7.5×10^{34} ergs s^{-1}.

More than 75% of the burst counts recorded during the 1998 September observation occurred during a single burst. The count rate during this burst was so large ($\gtrsim$25 crab) that detector dead time was excessive. As a result, deconvolution of this spectrum was not performed. We were left with 109 burst counts from the remaining eight bursts, which was inadequate to construct a reasonable spectrum. We instead calculated a hardness ratio (h) for the remaining bursts defined by the counts in the MECS units from 4 to 10 keV divided by the 1.8–4 keV counts. The burst hardness ratio ($h_B = 2.1 \pm 0.6$) is higher than the persistent emission hardness ratio ($h_P = 0.74 \pm 0.02$) at the 2.3 σ level, which suggests that the burst emission is harder than the persistent emission. This is consistent with what has been found elsewhere (see, e.g., Murakami et al. 1999).

5. DISCUSSION

We confirm significant deviations from a constant spin-down rate of the pulsar in SGR 1900+14 (Kouveliotou et al. 1999) during a period of enhanced burst activity. The results presented here establish the spin down of the source in quiescence and confirm deviations from a secular trend during an active phase for the source. The spin evolution of SGR 1900+14 is discussed in detail by Woods et al. (1999).

In the context of the magnetar theory (Thompson & Duncan 1995), seismic activity that leads to burst production is expected to continue, but at a lower level in quiescence. The resulting particle emission would impart an excess torque on the star. The vacuum dipole formalism may, therefore, overestimate the dipole magnetic field of magnetars (Thompson & Blaes 1998). At the time of the 1997 May *BeppoSAX* observation and the 1998 May *ASCA* observation, the source was at the same flux level, in quiescence. We also know that no burst activity was detected (1) during almost 5 yr prior to the 1997 May observation (Kouveliotou et al. 1993), (2) following the 1998 May observation for 3 weeks (Hurley et al. 1998; Kouveliotou et al. 1998b), or (3) any time in between the two observations. Since these observations are separated by a year-long interval with no burst activity, they provide the best estimate so far of the quiescent spin-down rate and, consequently, the magnetic field of the magnetar. Using the magnetic dipole equation (Michel 1991), we find the magnetic field to be $B_\star \sim 5.5 \times 10^{14}$ G if the vacuum magnetic torque were the only torque acting on the star. The characteristic age ($P/2\dot{P}$) is ~1400 yr.

It has been argued that AXPs are a dormant phase of SGRs that are not burst active (Thompson & Duncan 1996). Up until now, similarities have been drawn between the two classes based largely upon temporal characteristics, namely the period distributions and spin-down rates (Kouveliotou et al. 1998a; Hurley et al. 1999b; Kouveliotou et al. 1999), as well as spatial coincidence with SNRs. Here, we have found evidence for spectral similarities in the persistent emission between the two classes. Like AXPs, the persistent emission spectrum of SGR 1900+14 during a period of quiescence is significantly better represented by a blackbody plus a power law rather than a simple power law. Applying the former model to a period of burst activity shows that the blackbody component remains nearly constant, but the power-law component changes dramatically. It thus appears that the change in the nonthermal (power-law) component is directly related to the burst activity of the source. A likely mechanism for SGR bursts involves magnetically forced fractures of the rigid crust (Thompson & Duncan 1995, 1996). The compressive mode of ambipolar diffusion requires persistent small-scale fracturing, which in turn drives relativistic particle emission from the neutron star surface. Enhanced particle emission associated with the increase in burst activity may be the cause of the large changes observed in the persistent emission spectrum. It remains to be seen whether the nonthermal component will recede once burst activity ceases.

This research has made use of SAXDAS linearized and cleaned event files produced at the *BeppoSAX* Science Data Center. We would also like to thank Lorella Angelini, Tim Oosterbroek, and Fabrizio Fiore for their assistance in analyzing the *BeppoSAX* data. We would like to thank Colleen Wilson-Hodge for her help with barycenter-correcting the time tags. J. v. P. acknowledges support from NASA via grant NAG5-7060, C. K. acknowledges support under grant NAG5-4799, and P. M. W. acknowledges support under the Cooperative Agreement NCC 8-65.

REFERENCES

Atteia, J. L., et al. 1987, ApJ, 320, L105
Boella, G., Butler, R. C., Perola, G. C., Piro, L., Scarsi, L., & Bleeker, J. A. M. 1997a, A&AS, 122, 299
Boella, G., et al. 1997b, A&AS, 122, 327
Cline, T. L., et al. 1982, ApJ, 255, L45
Cline, T. L., Mazets, E. P., & Golenetskii, S. V. 1998, IAU Circ. 7002
Duncan, R., & Thompson, C. 1992, ApJ, 392, L9
Frail, D., Kulkarni, S., & Bloom, J. 1999, Nature, 398, 127
Hurley, K., et al. 1999a, Nature, 397, 41
———. 1997, IAU Circ. 6743
Hurley, K., Kouveliotou, C., Mazets, E., & Cline, T. 1998, IAU Circ. 6929
Hurley, K., et al. 1999b, ApJ, 510, L111
Hurley, K., Kouveliotou, C., Woods, P., Cline, T., Butterworth, P., Mazets, E., Golenetski, S., & Frederics, D. 1999c, ApJ, 510, L107
Hurley, K., et al. 1996, ApJ, 463, L13
Kouveliotou, C. 1995, Ap&SS, 231, 49
Kouveliotou, C., et al. 1998a, Nature, 393, 235
———. 1993, Nature, 362, 728
Kouveliotou, C., Fishman, G., Meegan, C., & Woods, P. 1997, IAU Circ. 6743
Kouveliotou, C., et al. 1987, ApJ, 322, L21
———. 1999, ApJ, 510, L115
Kouveliotou, C., Woods, P., Kippen, M., Briggs, M., & Hurley, K. 1998b, IAU Circ. 6929
Laros, J., Fenimore, E. E., Fikani, M. M., Klebesadel, R. W., & Barat, C. 1986, Nature, 322, 152
Mazets, E. P., & Golenetskii, S. V. 1981, Ap&SS, 75, 47
Mazets, E. P., Golenetskii, S. V., Il'inskii, V. N., Aptekar, R. L., & Guryan, Yu. A. 1979, Nature, 282, 587
Mereghetti, S., & Stella, L. 1995, ApJ, 442, L17
Michel, F. C. 1991, Theory of Neutron Star Magnetospheres (Chicago: Univ. Chicago Press)
Murakami, T., Kubo, S., Shibazaki, N., Takeshima, T., Yoshida, A., & Kawai, N. 1999, ApJ, 510, L119
Murakami, T., Tanaka, Y., Kulkarni, S. R., Ogasaka, Y., Sonobe, T., Ogawara, Y., Aoki, T., & Yoshida, A. 1994, Nature, 368, 127
Parmar, A. N., et al. 1997, A&AS, 122, 309
Remillard, R., Smith, D., & Levine, A. 1998, IAU Circ. 7002
Rothschild, R., Kulkarni, S., & Lingenfelter, R. 1994, Nature, 368, 432
Smith, D., Levine, A., Morgan, E., Remillard, R., & Rutledge, R. 1997, IAU Circ. 6743
Thompson, C., & Blaes, O. 1998, Phys. Rev. D, 57, 3219
Thompson, C., & Duncan, R. 1995, MNRAS, 275, 255
———. 1996, ApJ, 473, 322
Woods, P., et al. 1999, in preparation
van Paradijs, J., Taam, R. E., & van den Heuvel, E. P. J. 1995, A&A, 299, L41
Vasisht, G., & Gotthelf, E. V. 1997, ApJ, 486, L129
Vasisht, G., Kulkarni, S., Frail, D., & Greiner, J. 1994, ApJ, 431, L35