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DISCOVERY OF A PECULIAR X-RAY PULSAR GS 1843+00

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ABSTRACT

A transient X-ray pulsar with a period of about 29.5 s was discovered with the *Ginga* satellite at a position of α (1950) = $18^h43^m \pm 1^m$, δ (1950) = $0°52' \pm 7'$ (GS 1843+00). The X-ray intensity was in the range of 30–60 mCrab. The peak-to-peak pulse amplitude was unusually small, about only 4% of the average flux in the 2–37 keV band. This amplitude is smaller at lower energies. The pulse profile is a simple sinusoid at low energies, whereas it exhibits two peaks at higher energies. GS 1843+00 also exhibits a large-amplitude aperiodic intensity variation on a wide range of time scales, which is superposed on this small amplitude of the coherent pulsation. The amplitude of the aperiodic variation is larger at low energies than at high energies, in contrast to the coherent pulsation.

Subject headings: pulsars — X-rays: sources — X-rays: spectra

I. INTRODUCTION

More than 24 binary X-ray pulsars have been discovered before the launch of the *Ginga* satellite (e.g., Nagase 1989). About half of them have been reported as transient pulsars. Since the duty cycle of flare states of a transient pulsar was considered to be rather small (e.g., Rappaport and van den Heuvel 1982), one may expect that there remained many new transient X-ray pulsars in our Galaxy. Koyama *et al.* (1989) pointed out the high probability of discovering new transient pulsars with high-sensitivity Galactic plane surveys. We have systematically carried out a transient pulsar search in the Galactic plane using the *Ginga* satellite. This program was found to be very fruitful, as is reported by several authors (Koyama *et al.* 1989; Koyama *et al.* 1990; Tawara *et al.* 1989; Nagase 1989; Takeuchi *et al.* 1989). During the plane scan observation in 1988 April, we discovered a transient X-ray pulsar GS 1843+00 (Makino *et al.* 1988*a*, *b*). The X-ray intensity was highly variable on a wide range of time scales. The pulse amplitude, on the other hand, is unusually small as compared with the typical X-ray pulsars. In this *Letter*, we report timing and spectral analyses of this peculiar X-ray pulsar GS 1843+00.

II. OBSERVATIONS AND RESULTS

a) Position of the X-Ray Source

A transient X-ray source was discovered near the Scutum region during the plane scan observation on 1988 April 3, with an intensity of about 50 mCrab. The scan observation was made using the Large Area Counter (LAC) (Turner *et al.* 1989) onboard *Ginga* (Makino *et al.* 1987), having an energy range and effective area of 2–37 keV and 4000 cm^2, respectively. Although the LAC field of view is as large as $1° \times 2°$ (FWHM), we can determine the position along the scan path more accurately by the intensity peak during the scan observation. In order to determine the two-dimensional position, we scanned again from a different direction on 1988 April 19. These two scan paths and the position of intensity peak are given by solid boxes in Figure 1. The overlapped region of these two boxes shows a 90% confidence region of the position of the new X-ray transient source. The most probable position is $\alpha = 18^h43^m \pm 1^m$, $\delta = 0°52' \pm 7'$ (1950 equinox). Thus we designated this source as GS 1843+00 (the GS 1840+00 in the IAUC 4583 should be read as GS 1843+00).

b) X-Ray Light Curve and Pulse Timing Analysis

After the determination of the two-dimensional position of the transient source GS 1843+00, we carried out a pointed observation of GS 1843+00 on 1988 April 19–20. The data accumulation was done with the 48 channel energy mode (MPC-2 mode) with time resolution of 62.5 ms, 0.125, and 0.5 s. The X-ray light curve after background subtraction and aspect correction is given in Figure 2. The accumulation time for each data point was taken to be 5 minutes. As is seen in Figure 2, the X-ray flux was highly variable, ranging from 30 to 60 mCrab. Such a variability was found on a wide range of time scales. In order to examine the intensity variability, the standard Fourier analysis was carried out and the results, after subtraction of Poisson noise, are given in Figure 3 for several energy bands. In any energy band, the power density spectrum (PDS) is given as a power-law function of the frequency. This means that the variability has self-similar shape in a wide frequency range (or wide time scale). The power-law slope (power index) in the energy bands of 2–10 keV, 10–15 keV, and 15–37 keV are about 1.3, 1.2, and 1.1, respectively. We integrated the power density spectrum (PDS) over 3×10^{-3} Hz to 3×10^{-2} Hz and divided the root square of the integrated PDS by an average intensity. This relative amplitude of aperiodic variation is found to be energy-dependent, which are about 20%, 12%, and 10% in the 2–10, 10–15, and 15–37 keV bands, respectively. Thus the aperiodic variation is larger in the low-energy band than that in the high-energy band.

In addition to this aperiodic variation, a coherent oscillation with a fundamental frequency of about 0.03 Hz was found. This is shown in Figure 3. We searched for a pulse period around 30 s with the folding technique and found a helio-

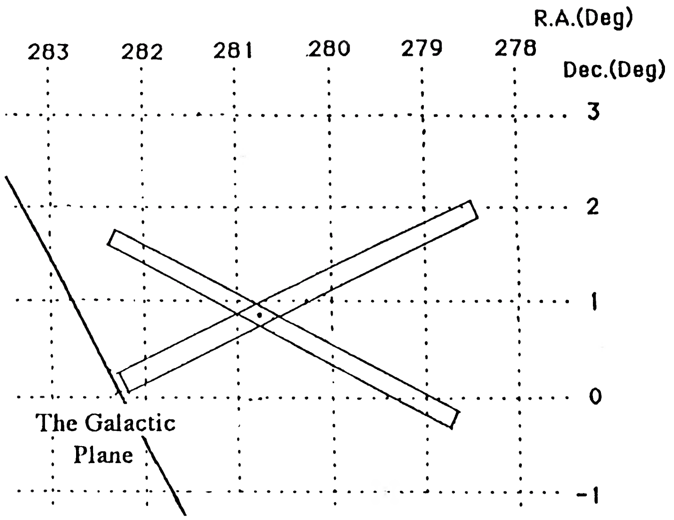

FIG. 1.—The position of GS 1843+00. The solid boxes are the error region of the peak intensity along the scans, and the overlapped region of the two boxes is the probable position (with 90% confidence). The most probable position is $\alpha = 18^h43^m \pm 1^m$, $\delta = 0°52' \pm 7'$ (1950 equinox).

centric pulse period of 29.5056 ± 0.0002 s on 1988 April 19–20. The folded pulse profiles are given in Figure 4 in several energy bands. The pulse profile in the low-energy band is roughly a simple sinusoid, whereas that of the high-energy band is more complex. The pulse profile of the medium-energy band shows the averaged profile of the low-energy and the high-energy bands.

The pulse fraction (peak-to-peak pulse amplitude divided by an average intensity) in the 2–10, 10–15, and 15–37 keV bands are 2.4%, 6.2%, and 12%, respectively. In contrast to the aperiodic variation, the fractional periodic variation is smaller in a low-energy band than that of a high-energy band.

Since the pulse amplitude was very small, it is difficult to determine the pulse period in a short time span. We therefore divided the data into two halves and examined the pulse period change. The pulse period from the first half of the data (1988 April 19) was 29.5076 ± 0.0003 s and that of the second half (1988 April 20) was 29.5041 ± 0.0006 s. Thus, we detected a significant spin-up trend between one day's interval. The mean pulse period change ($\dot{p}/p$) was found to be about -3×10^{-2} yr^{-1}. This spin-up rate is larger than the intrinsic spin-up rate from any X-ray binary pulsar reported thus far (e.g., Nagase 1989). Therefore, we regard that the pulse period change of GS 1843+00 may, at least partly, be due to an orbital Doppler motion, indicating that GS 1843+00 is likely a member of the class of X-ray binary pulsars.

c) Energy Spectrum

The spectrum analysis was made with different intensity levels. No remarkable spectral change with the intensity was found. A typical X-ray spectrum is given in Figure 5 together with the best-fit curve using the conventional power-law plus exponential cutoff model including an iron emission line at 6.4

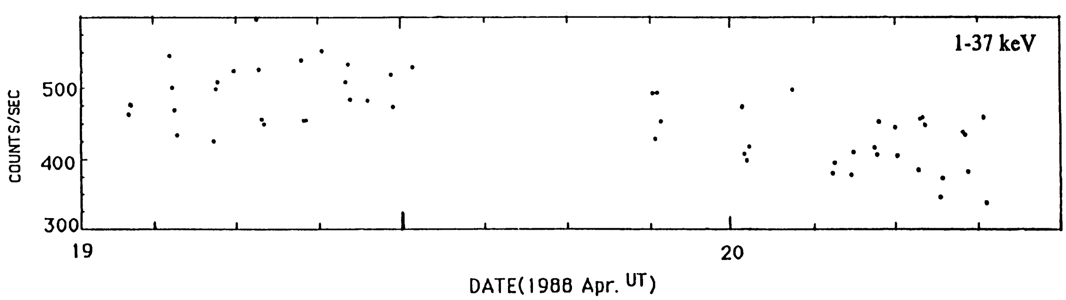

FIG. 2.—The X-ray intensity after the background subtraction and aspect correction is given by the dots. The accumulation time of each data point is 5 minutes.

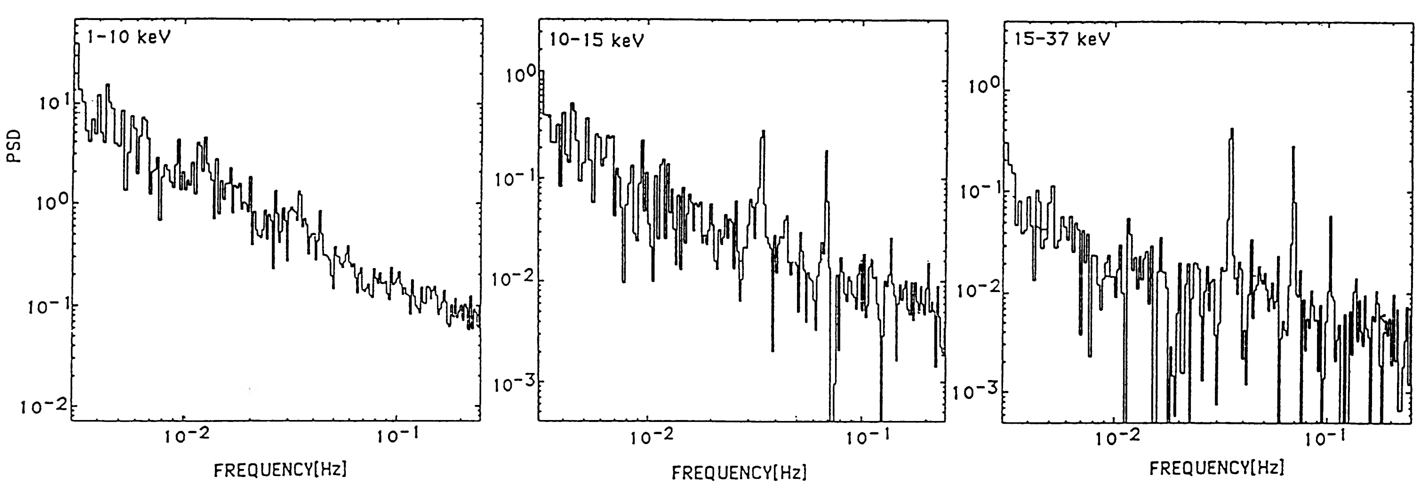

FIG. 3.—The power spectra after the subtraction of Poisson noise are given in three energy bands of 1–10 keV, 10–15 keV and 15–37 keV. The coherent pulse period and its harmonics are observed in the power spectrum of the 10–15 and 15–37 keV bands.

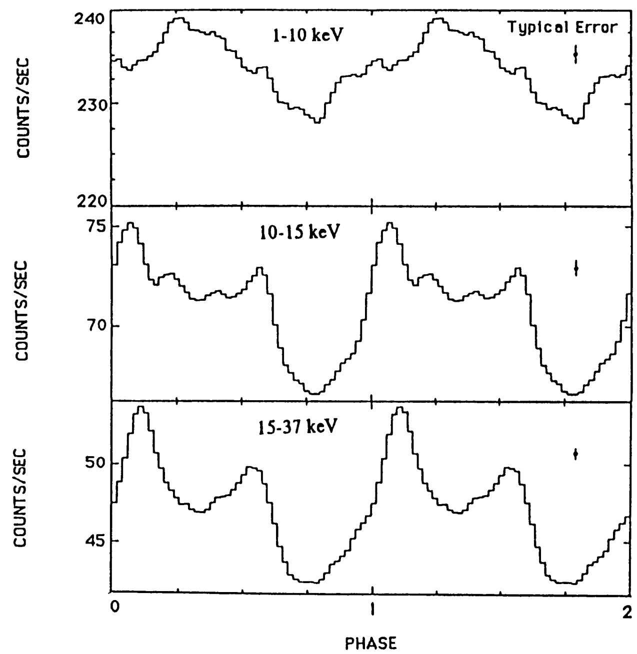

FIG. 4.—The pulse profile in three energy bands of 1–10 keV, 10–15 keV and 15–37 keV.

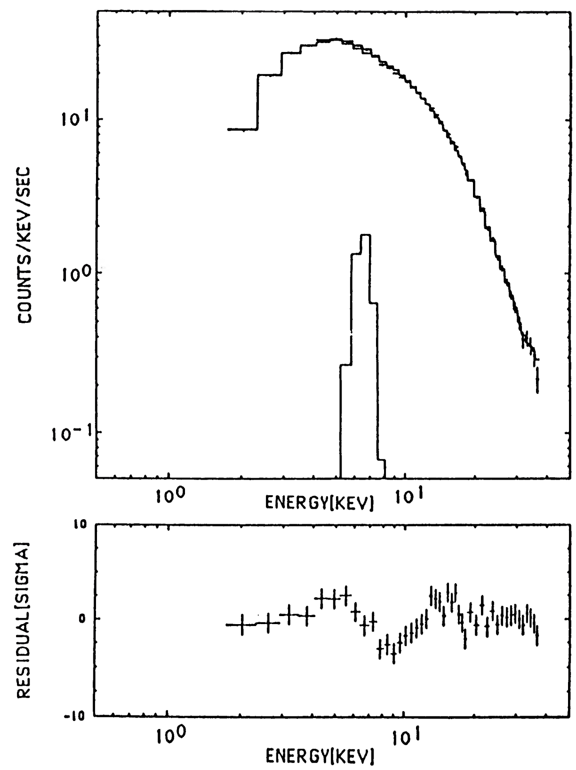

FIG. 5.—The X-ray spectrum together with the best-fit power-law model (*upper panel*) and residuals from the model curve (*lower panel*).

keV. The cross section of photoelectric absorption is taken from Morrison and McCammon (1983). The best-fit parameters are similar to those of typical X-ray pulsars as given in Table 1. In detail, this simple model shows significant deviation at an energy around 7 keV. A similar feature of the discrepancy has been reported near the cut-off energy for several X-ray pulsars (Makishima *et al.* 1989). The cut-off energy in the spectrum of GS 1843+00 is about 18 keV. Therefore, in the case of GS 1843+00, the discrepancy is not due to an artificial break at the cut-off energy. The deviation at 7 keV corresponds to the energy of the iron K-edge, suggesting a larger absorption edge of iron than that expected from the cosmic abundance.

III. DISCUSSION

Since GS 1843+00 exhibited coherent pulsation during the 2 days of observation and the observed spin-up trend is due possibly to orbital motion, GS 1843+00 is very likely to be a member of the class of binary X-ray pulsars. In fact the X-ray spectrum is approximated with the conventional model for a binary X-ray pulsars. The cut-off energy (about 18 keV) may reflect the strength of the magnetic field as is suggested by many authors (see, e.g., Makishima *et al.* 1989). Then GS 1843+00 has a magnetic field similar to those of typical X-ray pulsars. Although the X-ray spectrum of GS 1843+00 is like that of other binary X-ray pulsars, it shows peculiar features in its time variability. GS 1843+00 exhibits an unusually small pulse amplitude, contrary to the large amplitude of aperiodic variation on time scales of hours to seconds. This phenomenon has not been observed from the other binary X-ray pulsars other than X0331+53 (Stella *et al.* 1985; Makishima *et al.* 1989). The relative amplitude of periodic and aperiodic variations for X0331+56 is found to be about 10%–15% and 25%, respectively.

Recently, *Ginga* observed a similar behavior of aperiodic variations from several X-ray pulsars, such as GX 301−2 and GX 1+4. The PDS of GX 301−2 and GX 1+4 are given as power-law functions of the frequency (Makishima 1988). The amplitude of aperiodic variation for GX 301−2 was about 10%, which is not very much smaller than those of X0331+53 and GS 1843+00. From this similarity, Makishima *et al.* (1989) pointed out that the aperiodic variation is more or less common among X-ray pulsars but is manifest when the pulse amplitude is very small, such as with X0331+53. GS 1843+00 is the second case having very small pulse amplitude following X0331+53.

The amplitude of the aperiodic variation from GS 1843+00 is larger in the lower energy band, whereas the pulse amplitude is larger in the higher energy band. This may be the first case of a clear correlation between X-ray energy and amplitude of periodic and aperiodic variations seen in X-ray pulsars.

One may suggest that the small pulse amplitude can be

TABLE 1

BEST-FIT SPECTRAL PARAMETERS WITH THE CONVENTIONAL MODEL

Photon Index	Cutoff Energy (keV)	*e*-folding Energy (keV)	Column Density (log N_H)	Equivalent Width of Iron (keV)
0.71 ± 0.02..........	18.3 ± 0.9	25 ± 3	22.3 ± 0.1	0.11 ± 0.03

NOTE.—Error is 90% level for a single parameter.

explained by a weakly magnetized neutron star, which leads to a small beaming effect. However this may not be the case of GS 1843+00, because the X-ray spectrum, in particular the cut-off energy, is typical of the known X-ray pulsars, indicating that the strength of magnetic field of GS 1843+00 is not small but typical. Alternatively, we suggest that the pulsar beam is almost out of our line of sight or the magnetic field is almost co-aligned to the rotation axis. From the present data alone, however, it is hard to establish a true picture of the peculiar X-ray pulsar GS 1843+00. Further systematic search and observations of small pulse amplitude pulsars such as GS 1843+00 and X0331+53 are crucial to understand the nature of the aperiodic variability.

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