Discovery of the Slowest X-Ray Pulsar in the SMC, AX J0049.5–7323, with ASCA

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Abstract

The discovery of coherent pulsations with ASCA from an X-ray source, AX J0049.5–7323, is reported. The barycentric period was determined to be 755.5 ± 0.6 s, which is the longest among X-ray pulsars in the SMC. The X-ray spectrum has been found to be unchanged through ASCA observations, with a photon index of ≈0.8 and a luminosity of ≈5 × 10^{35} erg s^{-1} (0.7–10 keV). Archival data of the Einstein and the ROSAT satellites indicate that the flux has been <10^{-12} erg s^{-1} cm^{-2} (≈5 × 10^{35} erg s^{-1}) for over 20 years and exhibits a variability with a factor of ≈10. We argue that AX J0049.5–7323 is an X-ray pulsar with a Be star companion.

Key words: pulsars: individual (AX J0049.5–7323) — stars: emission-line, Be — stars: neutron — X-rays: stars

1. Introduction

X-ray binary pulsars (XBPs) are mostly classified into OB supergiant binaries and Be X-ray binaries (hereafter Be-XBPs) according to their companion stars. Traditionally, Be-XBPs have been known to exhibit very active outbursts with an X-ray luminosity of ≈10^{35}–10^{36} erg s^{-1}, which are brighter than the quiescent state by a factor of >100–1000 (Stella et al. 1986). However, recently, Mereghetti et al. (2000) proposed the existence of a subgroup of Be-XBPs which show a relatively persistent X-ray luminosity with no active outburst. Members of this subgroup (hereafter, quiescent Be-XBPs), such as X Per and RX J0146.9+6121, are characterized by a low-luminosity (≈10^{36} erg s^{-1}), a rather modest flux variability within a factor of ≈10, and a long spin period (≈300 s). This is probably because a magnetized neutron star with a slow rotation permits a low accretion rate, i.e., a low luminosity, due to a weak centrifugal barrier at the magnetosphere (Stella et al. 1986).

There have been successive discoveries of new XBPs in the Small Magellanic Cloud (SMC). Most of them have a luminosity ≈10^{36} erg s^{-1} (Yokogawa et al. 2000a), which probably indicates that it has been difficult to detect coherent pulsations from a low-luminosity source (≈10^{36} erg s^{-1} or ≈2 × 10^{-12} erg s^{-1} cm^{-2} at the distance of the SMC, 60 kpc; van den Bergh 2000) because of limited photon statistics. Recently, we made an observation on the SMC with an exceptionally long exposure time (≈177 ks), and discovered coherent pulsations from a low-luminosity source (≈6 × 10^{35} erg s^{-1}), AX J0051.6–7311 (Torii et al. 2000; Yokogawa et al. 2000b). This discovery well demonstrates that in the SMC there may be many hidden low-luminosity pulsars, including quiescent Be-XBPs, and that they will be discovered by observations with a very long exposure time.

In this letter, we report on a new X-ray pulsar in the SMC having a long period of 755.5 s and a low luminosity of ≈5 × 10^{35} erg s^{-1} (Ueno et al. 2000), discovered during the very long observation. The history of the flux variability was also investigated with archival data of Einstein Observatory and ROSAT.

2. Observations and Data Reduction

The position of AX J0049.5–7323 has been covered with three ASCA observations. The observations spanned during 50765.179–50766.285 (hereafter obs. A1), 51309.604–51310.682 (obs. A2), and 51645.986–51651.490 (obs. A3), in units of Modified Julian Day (MJD).

ASCA carries four XRTs (X-ray Telescopes, Serlemitsos et al. 1995) with two GISs (Gas Imaging Spectrometers, Ohashi et al. 1996) and two SISs (Solid-state Imaging Spectrometers, Burke et al. 1994) on the focal planes. Since AX J0049.5–7323 was outside of the field of view (FOV) of the SIS in all observations, we do not refer to the SIS any more. In each observation, the GIS was op-
erated in the normal PH mode with a time resolution of 0.0625/0.5 s for a high/medium bit rate. We rejected the GIS data obtained in the South Atlantic Anomaly, or in low cut-off rigidity regions (＜4 GV), or when the target’s elevation angle was low (＜5°). Particle events were removed by a rise-time discrimination method. After the screening, the total available exposure times in obs. A1, A2, and A3 were ∼43 ks, ∼41 ks, and ∼177 ks, respectively.

3. Results

3.1. Source Identification

In obs. A3, a faint source was detected at ∼15′ from the center of FOV. Its position was determined with the method described by Ueda et al. (1999) to be (00^h49^m33^s, -73°23′23″) for equinox 2000.0; we thus designate this source as AX J0049.5−7323. Note that this source was originally named AX J0049.4−7323 in Ueno et al. (2000). The radius of the error circle would be ∼1.5′, because of the large off-axis angle. This source was also detected in obs. A1 and A2 at ∼16′ and ∼22′ from the center of FOV, respectively. Here and in the following analyses, we used GIS 2 + GIS 3 data for obs. A1 and A3, while only GIS 2 was used for obs. A2, because AX J0049.5−7323 was located near to the calibration source of GIS 3.

We investigated catalogs of X-ray sources detected with the Einstein and the ROSAT satellites (Wang, Wu 1992; Haberl et al. 2000). Only one ROSAT source, No. 468 in Haberl et al. (2000), was found in the ASCA error circle.

3.2. Timing Analyses

In each observation, source photons were collected from a circle with a radius of ∼3′ centered on AX J0049.5−7323. We made a barycentric correction on the photon arrival times and performed an FFT (Fast Fourier Transformation) on the event lists in each observation. A significant peak was detected at a frequency of ∼0.0013 Hz only in the power spectrum of obs. A3 (figure 1). A maximum power of 49.12 was obtained from events in the energy band of 1.2–5.5 keV. The probability to detect such a large power in any frequency from random events is estimated to be very low, ∼1 × 10⁻⁵; we thus consider that pulse detection is significant. We then performed an epoch folding search and determined the barycentric period to be \( P = 755.5 \pm 0.6 \) s, which is the longest among the X-ray pulsators known in the SMC. We did not find any evidence for pulsations from obs. A1 and A2, either by an FFT analysis or by an epoch folding search.

Figure 2 shows the pulse profiles during obs. A3 in the energy bands of 1.2–2.0 keV, 2.0–5.5 keV, and 5.5–10.0 keV. The pulse shape is rather spiky in 1.2–2.0 keV, while it is nearly sinusoidal in 2.0–5.5 keV. It should also be noticed that higher energy photons (＞5.5 keV) do not exhibit definite pulsations. The pulsed fraction, defined as \((\text{pulsed flux})/(\text{total flux})\) without background, is ∼45% in 2.0–5.5 keV.

We also searched for an aperiodic intensity variation during each observation, but neither bursts nor large a flux variation was detected.

3.3. Spectral Analyses

The source spectrum in each observation was extracted from the same region used in the timing analyses, while...
the background spectrum was from an off-source area near to the source.

At first, we separately fitted each spectrum to a simple power-law model with the interstellar absorption. The derived parameters (photon index $\Gamma$ and column density $N_H$) were found to be consistent throughout all observations within the statistical errors. Therefore, to strictly constrain the parameters, we assumed that $\Gamma$ and $N_H$ were identical in all observations, and simultaneously fitted all of the spectra to the same model. The best-fit parameters may indicate 1-$\sigma$ statistical errors. The data points for which only error bars are given indicate no detection.

For obs. A3, we extracted phase-resolved spectra from phase 0–0.2, which represents the “spike” seen in 1.2–2.0 keV, and phase 0.2–1 (see figure 2), and fitted them with the power-law model. The best-fit parameters may indicate a slight change in the spectrum: $\Gamma = 1.4$ (95% confidence limits) and $N_H = 9 \times 10^{21}$ cm$^{-2}$ in 1.2–2.0 keV, while $\Gamma = 0.8$ (0.6–0.9) and $N_H = 0 (< 3) \times 10^{21}$ cm$^{-2}$ in phase 0.2–1.

4. Discussion

AX J0049.5−7323 has been covered by 3 and 16 observations with Einstein and ROSAT, respectively. We used these archival data to investigate any long-term flux variation of this source. We first derived the count rate from AX J0049.5−7323 after background subtraction and a vignetting correction in each observation. We then converted the count rate to the X-ray flux with the PIMMS software, assuming that $\Gamma$ and $N_H$ are the same as those derived from ASCA observations ($\Gamma = 0.78$ and $N_H = 0$ cm$^{-2}$). The results are shown in figure 4; we found that AX J0049.5−7323 has been detected with a flux of $\lesssim 10^{-12}$ erg s$^{-1}$ cm$^{-2}$, and occasionally it went down below a detection upper limit of $\sim 10^{-13}$ erg s$^{-1}$ cm$^{-2}$. We can point out a flux variability with a factor of $\gtrsim 20$ from figure 4. However, we should note that the assumption of $N_H$ has some impact on the Einstein/ROSAT fluxes in this procedure, because the energy ranges covered by Einstein and ROSAT extend well below that of ASCA. To estimate the effect of $N_H$, we assumed $N_H = 3 \times 10^{21}$ cm$^{-2}$ (upper limit derived in the spectral analysis) and derived the Einstein/ROSAT fluxes with PIMMS again. We found that the fluxes increase by a factor of $\sim 1.5–2.5$. Taking these facts into account, we conclude that AX J0049.5−7323 has been faint ($\lesssim 10^{-12}$ erg s$^{-1}$ cm$^{-2}$) for $\sim 20$ yr and has experienced a flux variation of a factor of at least $\sim 10$.

We detected coherent pulsations only from obs. A3. It would be attributed to the much better statistics in obs. A3, which has a very long exposure time ($\sim 177$ ks), or it may imply a smaller pulsed fraction in obs. A1 and A2. To examine the former possibility, we divided obs. A3 into four segments, each having an exposure time of $\sim 44$ ks, and performed the FFT and the epoch folding search on each segment. We detected no significant pulsations from any segment. Therefore, we conclude that a very long observation was essential for pulse detection from this source. The same condition applies to another new pulsar, AX J0051.6–7311 (Yokogawa et al. 2000b).

We discuss the nature of AX J0049.5−7323. The pulse period of 755.5 s is common with both XBPs and white dwarf (WD) binaries. However, the X-ray spectra showing no emission line and its luminosity of $\sim 5 \times 10^{35}$ erg s$^{-1}$ ($\sim 1 \times 10^{-12}$ erg s$^{-1}$ cm$^{-2}$ in flux) are rather
typical for XBPs (e.g., Stella et al. 1986), and against the possibility of a WD binary, which has a spectrum dominated by strong emission lines from ionized atoms and a luminosity of $\lesssim 10^{33} \text{erg s}^{-1}$ (see Ezuka, Ishida 1999). In addition, the ROSAT counterpart, No. 468 in Haberl et al. (2000), is proposed to be a Be/X-ray binary (Haberl, Sasaki 2000), because an emission line object is found in the error circle (14′′ radius) determined with ROSAT. Therefore, we would conclude that AX J0049.5−7323 is a Be-XBP with the longest spin period in the SMC.

We point out that AX J0049.5−7323 shares some characteristics with quiescent Be-XBPs in our Galaxy: the long pulse period, no large outburst, and small and relatively persistent luminosity (although the lower limit could not be determined). However, the strong energy dependence of the pulse shape (figure 2) in AX J0049.5−7323 is rather peculiar, when compared with five quiescent Be-XBPs (X Per, RX J0146.9+6121, RX J0440.9+4431, RX J1037.5−564, and 1SAX J0103.2−7209 — White et al. 1983; Mereghetti et al. 2000; Reig, Roche 1999; Israel et al. 2000). Whether AX J0049.5−7323 is unusual or not will be examined by studying the energy-resolved pulse shapes of other quiescent Be-XBPs.

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