1. Introduction

Since the discovery of X-ray pulsation from Cen X-3 (Giacconi et al. 1971), about 80 X-ray binary pulsars have been discovered at present (e.g., Nagase 1999). Most of them are located in either the Galactic plane or the satellite galaxies, the Large Magellanic Cloud and the Small Magellanic Cloud (SMC).

The SMC, with its reasonable size (≈ 3' x 3'), proximity (62 kpc; Laney, Stobie 1994), and small galactic absorption (≈ 10^20 cm^-2), is suitable for population studies of X-ray binaries. At an SMC distance of 62 kpc, an X-ray binary pulsar with a typical luminosity of ≈ 10^{35} erg s^-1 should be observed with a flux of ≈ 10^{-13} erg cm^-2 s^-1, which is well above the detection limit of the current X-ray satellites (ROSAT, ASCA, RXTE, and BeppoSAX). During the last 3 years, more than a dozen binary pulsars have been discovered in the SMC (e.g., Yokogawa et al. 2000).

Most of the new X-ray binary pulsars either show a transient behavior or are associated with a Be star, or both. Hence, X-ray pulsars newly discovered in the SMC are naturally classified as Be/X-ray binary pulsars (e.g., Yokogawa et al. 2000). Recent discoveries of transient pulsars have revealed that the fraction of Be star binaries in the SMC is much larger than that of our Galaxy. This suggests an active star-formation history within the past ≈ 10^7 years (Haberl, Sasaki 2000; Yokogawa et al. 2000). Encouraged by these fruitful outcomes, we have further continued the pulsar search project of the SMC. This letter reports on a serendipitous discovery of a new pulsar, AX J0049−732, in the SMC with ASCA.

2. Observation and Data Reduction

ASCA observed an SMC region centered at R.A. = 00^h47^m16^s, Decl. = −73°08′30″ (J2000) in 1997 November 13–14 in order to study N 19, a radio supernova remnant in the SMC.

ASCA (Tanaka et al. 1994) has four identical X-ray telescopes with nested thin foil mirrors (XRT; Serlemitsos et al. 1995). The focal-plane instruments consist of the two Solid-state Imaging Spectrometers (SISs: Burke et al. 1994) and the two Gas Imaging Spectrometers (GISs: Ohishi et al. 1996; Makishima et al. 1996). In this observation, GISs were operated in the normal PH mode, providing time resolutions of 62.5 ms and 0.5 s in high and medium bit-rates, respectively. The SISs were operated in the 2-CCD Faint/Bright mode with the a level discrimination of 0.7 keV.

We screened both the GIS and SIS data using the standard procedure by rejecting data obtained in the South Atlantic Anomaly, in low cut-off rigidity regions (< 6 GV for GIS and < 4 GV for SIS), and at an elevation angle lower than 5°. A rise-time discrimination was applied to the GIS data to reject particle events. Hot and/or flickering pixels were rejected from the SIS data. The resultant effective exposures after these screenings were ~ 40 ks for GIS and ~ 33 ks for SIS. Since the dark current and its pixel-to-pixel fluctuation in the SIS have significantly increased after the 5 years of operation in orbit, we applied the Residual Dark Distribution correction (T. Dotani et al. 1997, ASCA News 5, 14) for the faint mode data.

3. Analysis
3.1. Images

The GIS image in the energy band of 0.7–7.0 keV is shown in figure 1. The bright source at the field center is the radio supernova remnant, N 19. Two pulsars, AX J0049–729 and AX J0051–733, were serendipitously found, as already reported by Yokogawa et al. (1999) and Imanishi et al. (1999). Another pulsar, RX J0052.1–7319 (Lamb et al. 1999; Israel et al. 1999) discovered with ROSAT, is also in the field of view and marginally detected in this observation. A point source at the south of N 19 coincides with the position of source No. 1 in Inoue et al. (1983) (hereafter IKT 1) or source No. 434 in the ROSAT PSPC catalogue of Haberl et al. (2000). IKT 1 is the only bright point source which is in the field of SIS. To remove systematic errors in the coordinates, we shifted the sky coordinates of ASCA so that the position of IKT 1 in the ASCA observation comes to the position of the ROSAT PSPC catalogue.

Since a faint source in the east of N 19 shows a complex spatial structure, we made two energy band images of this particular region. Figure 2 shows magnified views of the region in both the 0.7–2.0 keV (soft) and 2.0–7.0 keV (hard) bands, and both with GIS and SIS. We can see two sources: one in the soft band and the other in the hard band, each separated by 2′. The soft source coincides with the position of SNR 0047–735 (Haberl et al. 2000). Using the SIS hard band (2.0–7.0 keV) image, we determined the position of the hard source to be R.A. = 00h49m13s, Decl. = −73°11′42″ (J2000) with an error of 40″ radius, hence designated as AX J0049–732 (Imanishi et al. 1998).

3.2. Energy Spectrum

The X-ray spectra of AX J0049–732 were made by accumulating photons in the region of a circle of 2′ radius for GIS and 1′ radius for SIS, as shown in figure 2. In order to remove any possible contamination from SNR 0047–735 located 2′ away, the background spectra were made using data in the regions at the same distance (2′) from SNR 0047–735. These background regions are also shown in figure 2.
The background-subtracted spectra of GIS and SIS are given in figure 3. Since no conspicuous line structure was found, we fitted the GIS and SIS spectra to a power-law with soft X-ray absorption by the interstellar medium. We obtained statistically acceptable fits for both the GIS and SIS spectra. Since the best-fit parameters were consistent with each other, we carried out a simultaneous fit to the combined GIS and SIS spectra. The fit was acceptable with a $\chi^2$ value of 7.76 for 11 degrees of freedom. The resultant best-fit parameters are the photon index $\Gamma = 0.6^{+1.0}_{-0.7}$, the normalization $= 3.0^{+12.5}_{-2.2}$ photons s$^{-1}$ keV$^{-1}$ cm$^{-2}$ at 1 keV, and the absorption column density $N_H = 1.3^{+2.9}_{-1.3} \times 10^{22}$ cm$^{-2}$. The model spectrum convolved with the best-fit parameters is shown by the solid and dashed lines in figure 3, respectively, for the SIS and GIS.

The absorbed and unabsorbed X-ray fluxes in the 0.7–10.0 keV band were calculated to be $\sim 6.9 \times 10^{-13}$ erg cm$^{-2}$ s$^{-1}$ and $\sim 7.8 \times 10^{-13}$ erg cm$^{-2}$ s$^{-1}$, respectively.

### 3.3. Time Variability

For a timing analysis of AX J0049–732, X-ray photons in the 1.0–5.1 keV band were extracted from a circular region of 3' radius in the GIS 2 and GIS 3 images. After converting to the barycentric arrival time, we searched for periodicity using a Fast Fourier Transformation (FFT) algorithm. Figure 4 shows the resultant power density spectrum in the $1.0 \times 10^{-5}$–1.0 Hz frequency band. A significant peak can be clearly seen at 0.1095 Hz with 99.99% confidence. Since SNR 0047–735 is located near AX J0049–732, one may argue that the pulsations might originate from a putative neutron star in SNR 0047–735. To solve this ambiguity we also searched for pulsations in the SNR data extracted from a region of the same size circle centered on SNR 0047–735. However, no significant pulsation was found in the power spectrum of the SNR 0047–735 data. Therefore, it is concluded that the 0.1095 Hz pulsations are not attributed to SNR 0047–735, but to AX J0049–732.

To determine the pulse period more precisely, we performed an epoch folding near the trial period found with the FFT; barycentric pulse period of 9.1320 ± 0.0004 s was obtained. The pulse profile folded with this period is shown in figure 5. The profile is nearly sinusoidal with a pulse fraction, defined as (pulsed flux)/(total flux), of $\sim 56%$.

We examined the aperiodic intensity variation in the 0.7–7.0 keV light curve of the whole observation period. Neither a significant flux variation, nor any burst-like activity was found on the time scale from seconds to hours.
4. Discussion

At the distance of the SMC, the intrinsic luminosity of AX J0049–732 is estimated to be $4 \times 10^{35}$ erg s$^{-1}$, which is below the range of bright X-ray pulsars. Thus, AX J0049–732 would not be a member of luminous X-ray pulsars powered by Roche-lobe over-flow from a companion star. Although the observed luminosity suggests that the pulsar might be a wind-fed supergiant system, the short spin period of 9 s does not favor this class, which typically shows a spin period of 100–1000 s.

A more likely scenario for AX J0049–732 is either a Be star X-ray binary system, or an anomalous X-ray pulsar (e.g., Bildsten et al. 1997; Mereghetti, Stella 1995). Direct information to distinguish these two possibilities can be obtained by measuring the pulse period derivative and its orbital modulation. Limited photon statistics and observation coverage, however, do not allow us to derive any constraints on the pulse period derivative and the orbital motion. Nevertheless, the hard X-ray spectrum with a photon index of $\sim 0.6$ favors a Be star X-ray binary system for the pulsar. The existence of a Be star counterpart, if confirmed, would be strong evidence for this scenario.

Two sources, No. 427 and No. 430, in the ROSAT PSPC catalogue of Haberl et al. (2000) are possible counterparts of AX J0049–732 located at distances of 1.43 and 0.15, respectively. Filipović et al. (2000) searched for optical counterparts of these ROSAT sources, and found an emission line object, possibly a Be star, at the position of source No. 427, but found no counterpart for source No. 430. Hence, they suggest that source No. 427 is more likely to be a counterpart of AX J0049–732. This possibility, however, may be rejected, because the angular separation of these sources of 1.43 is significantly larger than the ASCA error radius. We rather propose that No. 430 is a more likely counterpart. The flux of source No. 430 was roughly the same as that of AX J0049–732, although systematic errors in the flux determination make it ambiguous to compare the fluxes by different instruments. We searched for an optical object in the error circle of AX J0049–732 using the SIMBAD database, but found no optical counterpart. Although a Be/X-ray binary pulsar is likely, we thus need further X-ray observations and a search of an optical counterpart to establish the true nature of this new pulsar.

AX J0049–732 is the fourth X-ray pulsar discovered in the small area of the SMC South (within 30' radius from N 19). The three pulsars previously reported are all identified to Be star X-ray binary systems (Haberl, Sasaki 2000; Israel et al. 1999), and the fourth pulsar, AX J0049–732, can probably be classified into the same class. The high density of Be/X-ray binaries of this region in the SMC suggests an active star-formation history of this area within the past $\sim 10^7$ yrs which is the typ-ical age of Be star X-ray binary pulsars. We note that the four pulsars are all located along the edge of the H$\alpha$ supergiant shell (Stanimirović et al. 1999), whose age is estimated to be about $10^7$ years. The supergiant shell may be other evidence for the star-formation history.

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