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Letter to the Editor

Discovery of a faint 437 s X-ray pulsar 1SAX J1452.8-5949

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Abstract. A new pulsar, 1SAX J1452.8−5949, was discovered during a BeppoSAX galactic plane survey on 1999 July 20 at R.A.=$14^{\rm h}$ $52^{\rm m}$ $49\overset{\rm s}{.}3$, Dec=-59° $49'$ $18''$ (J2000) with a 90% confidence uncertainty radius of $50''$. Coherent pulsations were detected with a barycentric period of a 437.4 ± 1.4 s. The X-ray spectrum can be modeled by a power-law with a photon index of 1.4 ± 0.6 and absorption consistent with the galactic value in the direction of the source (1.9×10^{22} atom cm^{-2}). An Fe K line with a equivalent width of $\gtrsim$1.3 keV may be present in the spectrum. The unabsorbed 2–10 keV flux is 9×10^{-13} erg cm^{-2} s^{-1}. The X-ray properties and lack of an obvious optical counterpart are consistent with a Be star companion at a distance of between approximately 6 and 12 kpc which implies a luminosity of (4–15)$\times 10^{33}$ erg s^{-1}.

Key words: X-rays: stars – stars: individual: 1SAX J1452.8-5949 – stars: neutron – stars: binaries: close – accretion, accretion disks

1. Introduction

As well as studying studying the unresolved diffuse galactic emission (the galactic ridge X-ray emission), one of the main scientific objectives of the BeppoSAX galactic plane survey is to search for faint X-ray pulsars. Currently, there are ∼80 known accreting X-ray pulsars (see Bildsten et al. 1997 for a recent review). Until recently only relatively bright nearby pulsars were visible due to the limited sensitivity of the available detectors. This is changing with the discovery by ASCA, BeppoSAX, and RXTE of a population of faint ($\sim 10^{-11}$–10^{-12} erg cm^{-2} s^{-1}) pulsars (e.g., Angelini et al. 1998; Kinugasa et al. 1998; Santangelo et al. 1998; Sugizaki et al. 1997; Torii et al. 1998, 1999). These new pulsars tend to have long periods and it is likely that the centrifugal barrier, which inhibits accretion in rapidly rotating neutron stars at low luminosities (e.g., Stella et al. 1986), is almost always open, allowing them to reach very low flux levels. It is thus likely that a population of low-luminosity X-ray binaries is being observed, the emission from which may contribute significantly to the unresolved galactic component.

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2. Observations

Results from the Low-Energy Concentrator Spectrometer (LECS; 0.1–10 keV; Parmar et al. 1997), and the Medium-Energy Concentrator Spectrometer (MECS; 1.8–10 keV; Boella et al. 1997) on-board BeppoSAX are presented. The MECS consists of two grazing incidence telescopes with imaging gas scintillation proportional counters in their focal planes. The LECS uses an identical concentrator system as the MECS, but utilizes an ultra-thin entrance window and a driftless configuration to extend the low-energy response to 0.1 keV. The fields of view (FOV) of the LECS and MECS are 37′ and 56′, respectively.

During a systematic survey of part of the galactic plane, BeppoSAX observed the region of sky around $\rm l, b = 318^\circ, -0.5^\circ$ between 1999 July 20 11:59 and July 21 02:05 UTC. Good data were selected from intervals when the elevation angle above the Earth's limb was $>4^\circ$ and when the instrument configurations were nominal, using the SAXDAS 2.0.0 data analysis package. The exposures in the LECS and MECS are 9.6 ks and 27 ks, respectively. The MECS image (Fig. 1) reveals the presence of at least 3 relatively bright sources. Of interest here is a new source located $7\overset{\prime}{.}1$ off-axis, with a count rate of $(1.86 \pm 0.07) \times 10^{-2}$ s^{-1} for both MECS units. This position is $2\overset{\prime}{.}2$ from the inner edge of the MECS window support structure. The J2000 coordinates, derived from the MECS data, are R.A.=$14^{\rm h}$ $52^{\rm m}$ $49\overset{\rm s}{.}3$, Dec=-59° $49'$ $18''$ $(\rm l, b = 317.645^\circ, -0.463^\circ)$ with a 90% confidence uncertainty radius of $50''$. Although the presence of the window support structure will bias the centroid of the X-ray counts in the MECS somewhat, the position determina-

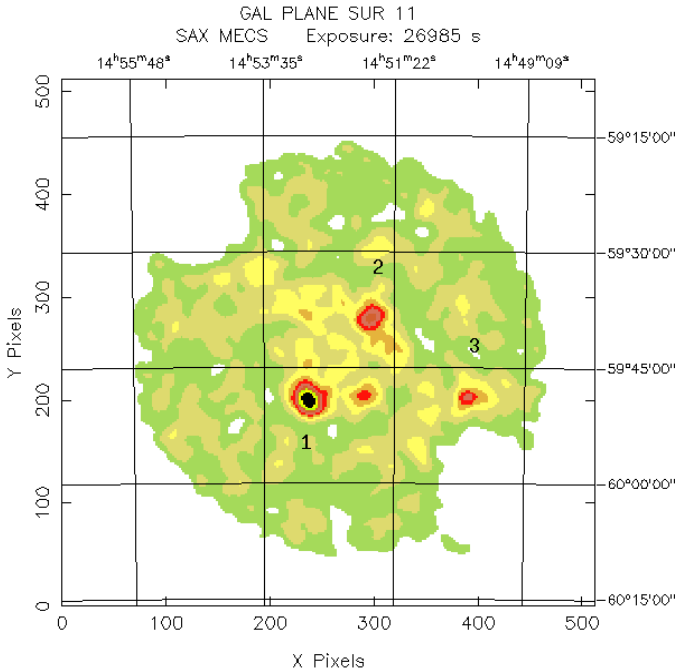

Fig. 1. The MECS image (equinox J2000) smoothed with a Gaussian filter with a σ of 24″. 1SAX J1452.8−5949 is the brightest source in the image, located just below center (labeled “1”). The two “cut-outs” are due to the removal of internal calibration source events

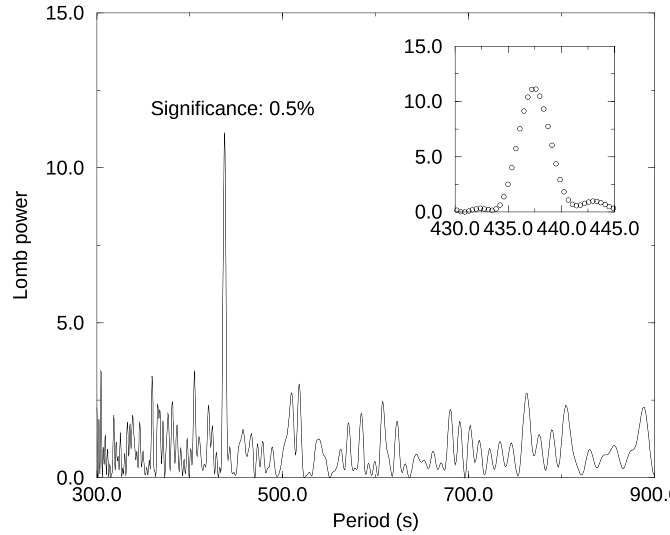

Fig. 2. The MECS 1.8–10 keV 1SAX J1452.8−5949 Lomb-Scargle periodogram. The inset shows the region around the probable periodicity in more detail

tion is limited by the uncertainty in the BeppoSAX position reconstruction. We designate the source 1SAX J1452.8−5949.

2.1. Timing analysis

A total of 479 MECS events within a radius of 4.′7 of 1SAX J1452.8−5949 were extracted. The arrival times were corrected to the solar system barycenter. Initially, a period search (using the XRONOS routine `efsearch`) in the range 100–1000 s was performed. The strongest peaks were found at a period of 437 s and at twice this period (874 s), with χ^2 values of 42 and 34, respectively, for 8 degrees of freedom (dof). In order to better asses the significance of these peaks a Lomb-Scargle periodogram was generated (Fig. 2). A strong peak is detected at 437.1 s. The chance probability of detecting a peak of this strength or higher in any of the bins in the Lomb-Scargle periodogram is 0.5%. No other strong peaks are evident. The period was refined by cross-correlating pulse profiles each obtained by folding data from 5 consecutive intervals. This yields a pulse period of 437.4 ± 1.4 s (at 90% confidence). The 1.8–10 keV background subtracted pulse profile (Fig. 3) shows a peaked modulation with a semi-amplitude (half of the peak-to-peak modulation divided by the mean) of 74 ± 24%, with an additional uncertainty due to the uncertainty in the background subtraction of 10% (see Fig. 3). The pulse profile does not show any obvious energy dependence. The 1.8–10 keV lightcurve does not show evidence for variability. The χ^2 obtained when fitting a constant value to the lightcurve with 4096 s bins is 11.9 for 12 dof. The 3σ upper limit to any variability on this timescale is <22% rms.

2.2. Spectral analysis

LECS and MECS data were extracted centered on the position of 1SAX J1452.8−5949 using a radius of 4′ for both instruments. Both spectra were rebinned to a minimum of 30 counts per bin, and oversampling the full-width at half maximum of the energy resolution by at most a factor 3 to allow use of the χ^2 statistic. Response matrices appropriate to the off-axis source location in the FOV were used and spectral fits performed in the 1.0–6 keV (LECS) and 1.8–10 keV (MECS) energy ranges. Uncertainties are given at 68% confidence for one interesting parameter. Due to the presence of counts from the galactic ridge within the source extraction region, background spectra were extracted from 3 different source free regions at the same offset in the FOV as the source and with the same extraction radius. Each MECS background spectrum contains ∼250 counts. Fits using these backgrounds give consistent results, so a mean background was used in the subsequent analysis.

The spectrum can be well fit with a power-law model giving a χ^2 of 6.8 for 9 dof, with a photon index, α, of 1.4 ± 0.6, when the low-energy absorption, N_H, was fixed at the galactic value in the direction of the source of 1.9×10^{22} atom cm^{-2} (Dickey & Lockman 1990) This fit is shown in Fig. 4. Trials with N_H as a free parameter show that this parameter can only be constrained to be $<6.1 \times 10^{22}$ atom cm^{-2}. The unabsorbed 2–10 keV flux is 7×10^{-13} erg cm^{-2} s^{-1} (the 2–10 keV flux absorbed by the galactic value is only 12% lower). When a narrow line with an energy of $6.45^{+0.3}_{-0.2}$ keV and an equivalent width with a 1-σ lower limit of 1.3 keV is added to the model, the χ^2 reduces to 3.5 for 7 dof and α is 1.9 ± 0.7. Although the line feature appears quite evident in Fig. 4, an F-test reveals that

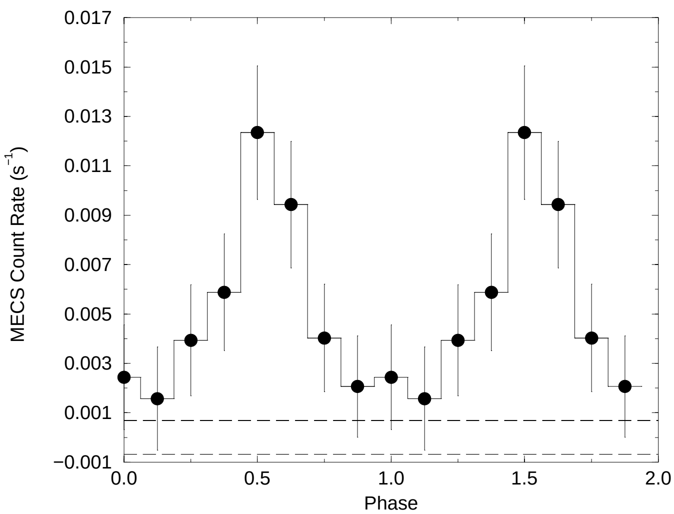

Fig. 3. The MECS 1.8–10 keV background subtracted (see text) pulse profile. The pulse profile is repeated for clarity. The 1σ uncertainty in the zero-level due to uncertainties in the background level is indicated by the dashed lines

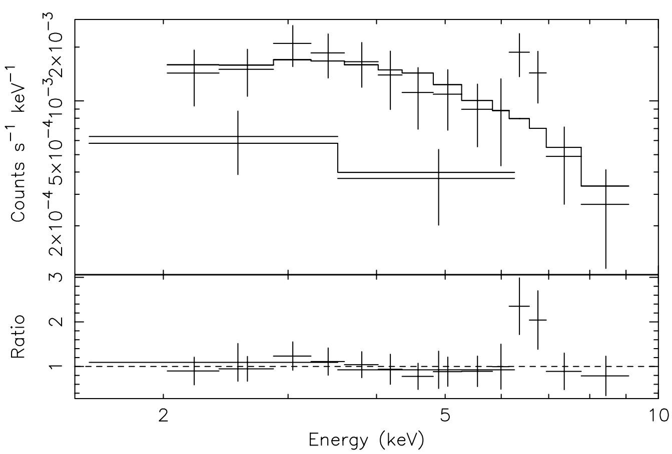

Fig. 4. The LECS and MECS source spectra fit with the best-fit power-law model. Note the clear deviations from the model at ~6.5 keV implying the presence of an Fe emission feature

the addition of this feature is only significant at a confidence level of 90%. A similar line feature is also evident in the mean MECS background spectrum, but with an intensity ~0.25 of that above. Thus, unless the background line intensity varies by a factor ~5 on a spatial scale of 15′, the probable line feature is associated with the pulsar.

Since the source is partly obscured by the MECS entrance window support structure, a MECS spectrum was extracted with a 2′ radius in order to investigate this effect. The appropriate off-axis response matrix was used. The fit parameters so derived are consistent with those obtained from the spectra extracted with a 4′ radius. The only significant difference is in the unabsorbed 2–10 keV flux estimate which increases to 9×10^{-13} erg cm^{-2} s^{-1}. This is thus the best estimate of the source intensity.

Although 1SAX J1452.8−5949 is in the FOV of the non-imaging High Pressure Gas Scintillation Proportional Counter (5–120 keV) and Phoswich Detector System (15–300 keV) instruments, no useful spectral or timing information could be extracted from these data.

3. Previous observations

We have searched the X-ray catalogs at the HEASARC for any previous observations of the region of sky containing 1SAX J1452.8−5949. No previous detections of a source with a position consistent with 1SAX J1452.8−5949 are reported. The two most sensitive observations of the 1SAX J1452.8−5949 region were by RXTE and ROSAT.

This region of sky was observed twice by RXTE during scans of the galactic plane (Valinia & Marshall 1998). From their Fig. 1 the upper limit to the strength of any possible point source near 1SAX J1452.8−5949 is ~20 PCA count s^{-1}. This corresponds to a 2–10 keV flux (using the BeppoSAX power-law spectral parameters) of 4×10^{-11} erg cm $^{-2}$ s^{-1}, which is a factor ~40 greater than the intensity observed by BeppoSAX.

During the ROSAT All-Sky Survey the region of sky containing 1SAX J1452.8−5949 was observed. No source at a position consistent with the new pulsar is present in the Bright Source Catalogue with an upper limit of 0.05 count s^{-1} (Voges et al. 1999), corresponding to an unabsorbed flux of $\sim2\times10^{-11}$ erg cm $^{-2}$ s^{-1}, again significantly above the intensity observed here. However, the ROSAT count rate to flux conversion depends strongly on the amount of interstellar absorption, which is not well constrained by our observation.

4. Distance estimate

The line of sight towards 1SAX J1452.8−5949 intersects the spiral arms of our Galaxy at ~1.5, 4, and 12 kpc. We have searched the USNO-A on-line database for possible optical counterparts. Fig. 5 shows the color-magnitude diagram for stars located in and around the 1SAX J1452.8−5949 error region. Assuming that the optical counterpart is of spectral type O or B (either a main-sequence or a (super-)giant star, see Sect. 5), the absence of a bright blue star in the BeppoSAX error region indicates that the distance is $\gtrsim$6kpc, and probably less than about 12 kpc (since this is the "edge" of the galaxy). This implies a 2–10 keV luminosity of (4–15)$\times10^{33}$ erg s^{-1}.

5. Discussion

Recently, the population of accretion-powered X-ray pulsars has increased markedly, due to observations with the sensitive detectors on ROSAT, ASCA, RXTE and BeppoSAX. Bildsten et al. (1997) list 44 X-ray pulsars and at least 8 others have been recently discovered (Israel et al. 1998; Kinugasa et al. 1998; Corbet et al. 1998; Marshall et al. 1998, 1999; Wijnands & van der Klis 1998; Hulleman et al. 1998; Torii et al. 1999). Most X-ray pulsars are in high-mass X-ray binaries systems (HMXRB) with a few exceptions which are in low-mass systems (LMXRB). 1SAX J1452.8−5949 is unlikely to be such a system since LMXRBs tend to be more luminous and show different types of variability such as flares, bursting, and transient

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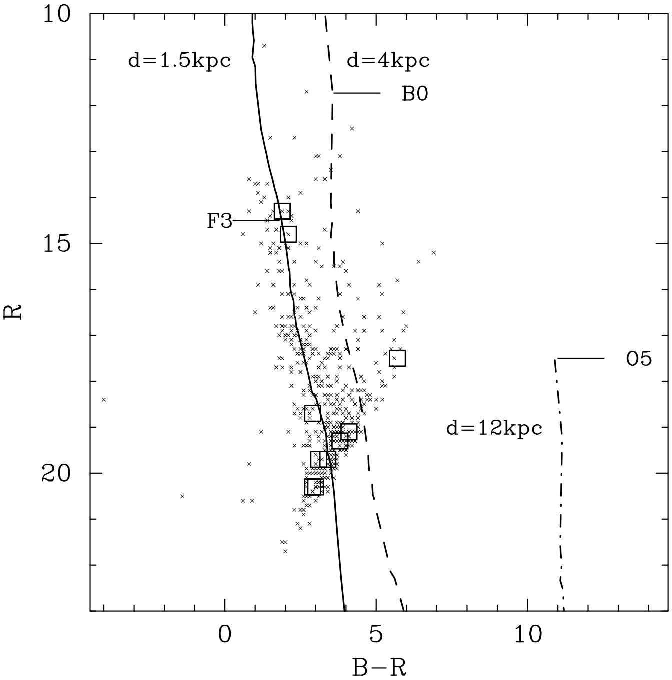

Fig. 5. The color-magnitude diagram of stars in the USNO-A catalog. Open squares denote stars within the BeppoSAX error region and small crosses denote stars within 5′. The main sequences for 1.5, 4, and 12 kpc are indicated by the continuous, dashed, and dot-dashed lines, respectively. The locations of 3 spectral types are indicated. Reddening is included assuming linear absorption (which should be a reasonable approximation for d<6 kpc), with values from Fitzpatrick (1999)

behavior. The large pulse amplitude of 1SAX J1452.8−5949 (74±34%) is unusual. While being consistent with the pulse amplitude found in many HMXRB systems (40–60%), it may also be substantially higher. On the basis of the properties reported here, we cannot exclude the possibility that the compact object is a magnetized white dwarf.

HMXRB with supergiant companions are luminous ($\sim 10^{35}$–10^{38} erg s^{-1}) systems which show marked X-ray intensity variability. Unless the BeppoSAX observation took place during an unusually low state of 1SAX J1452.8−5949, a supergiant companion seems unlikely because of the low luminosity. More than half of the HMXRB are associated with Be star companions and typically show transient behavior. The luminosity of Be-star systems during outbursts can change dramatically from 10^{33} to 10^{38} erg s^{-1}, whereas persistent Be system such as X Per, or Be systems in quiescence, and e.g. the recently discovered long period pulsars such as 1WGA J1958.2+3232 (Israel et al. 1998) have more modest luminosities of $\sim 10^{33}$–10^{35} erg s^{-1}, consistent with the crude estimate of the 1SAX J1452.8−5949 luminosity in Sect. 4. Be/X-ray systems display a correlation between their spin and orbital periods (Corbet 1986; Bildsten et al. 1997) which in this case implies an orbital period of $\gtrsim$200 days for 1SAX J1452.8−5949.

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