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Swift observations of the X-ray pulsar SAX J1324–6200 *(Research Note)*

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ABSTRACT

We present recent observations of the X-ray pulsar SAX J1324–6200 obtained in December 2007 with the Swift satellite, significantly improving the source localization over previous data and providing a new measurement of the spin period P = 172.84 s. A single object that is consistent in colors with a highly reddened early type star is visible in the X-ray error box. The period is significantly longer than what was obtained in 1997, indicating that SAX J1324–6200 has been spinning down at an average rate of $\sim 6\times 10^{-9}$ s s^{-1}. We discuss the possible nature of the source, showing that it most likely belongs to the class of low-luminosity, persistent Be/neutron star binaries.

Key words. X-rays: binaries

1. Introduction

Little is known about the X-ray pulsar SAX J1324–6200, serendipitously discovered in 1997 during an observation of the bright X-ray burster 4U 1323–619 (Angelini et al. 1998). Its X-ray spectrum, a highly absorbed power law with photon index ~1, and its pulsations period of 171 s are typical of accreting pulsars in binary systems. However, due to the lack of an accurate position, optical identification has not been obtained to date, leading to different possible interpretations of the nature of this source.

The great majority of accreting X-ray pulsars are high-mass X-ray binary systems (HMXRB), either with OB-supergiant or Be type companion stars. Angelini et al. (1998) have suggested that SAX J1324–6200 belong to the latter group, which is the most numerous, but its being a white dwarf system of the intermediate polar class could not be completely excluded.

A long observation of SAX J1324–6200, carried out with the ASCA satellite in February 2000, led to the discovery of a secular spin down at $\sim 5\times 10^{-9}$ s s^{-1} (Lin et al. 2002). This is quite unusual for an HMXRB, since these systems are generally spinning up while accreting. The source flux measured with ASCA was similar to what was seen in all the previous observations of this source, arguing against a transient nature. Lin et al. (2002) also report marginal evidence of a periodic flux modulation at 27 ± 1 h, which could be interpreted as the orbital period of the system. Based on these findings, they propose that SAX J1324–6200 is a low-mass X-ray binary (LMXRB), similar to other pulsars, such as GX 1+4 and 4U 1626–67, which exhibited long spin-down episodes. If confirmed, this would be particularly interesting, since only a few LMXRB pulsars of this kind are currently known.

2. Observations and data analysis

We performed two observations of SAX J1324–6200 with the Swift satellite on 2007 December 21 and 30 (see Table 1 for details), for a total on-source time of 7.4 ks. The X-ray Telescope (XRT) data were processed with standard procedures (`xrtpipeline` v0.11.6), filtering, and screening criteria by using FTOOLS in the `Heasoft` package (v.6.4).

Table 1. Observation log.

Sequence	Date and Start time (UT) (yyyy-mm-dd hh:mm:ss)	End time (hh:mm:ss)	Exposure (s)
37 039 001	2007-12-21 07:20:40	13:32:56	1664
37 039 002	2007-12-30 00:02:31	08:21:57	5762

SAX J1324-6200 was detected in both observations with a net count rate of $(2.9\pm0.5)\times10^{-2}$ and $(3.8\pm0.3)\times10^{-2}$ counts s^{-1} in the 0.2–10 keV energy range. The source position, obtained by summing all the data, is RA(J2000) = $13^{h}24^{m}26\overset{s}{.}81$, Dec(J2000) = $-62°01'19\overset{''}{.}1$, with an error of $3\overset{''}{.}8$ (90% confidence). The XRT coordinates lie inside the error circles derived with BeppoSAX (1.5 arcmin radius, Angelini et al. 1998) and ASCA (~1 arcmin radius, Lin et al. 2002).

The UVOT data were reduced with the standard software and procedures, using the tasks *uvotimsum* to produce the coadded images and *uvotsource* to estimate the optical/UV magnitudes (U and $W1$ filters). There is no detection within the XRT error circle whether in individual images (6 frames in U filter and 5 in $W1$ filter) or in coadded images (6113 s in U and 1989 s in $W1$), down to a magnitude of $U > 21.2$ mag and $W1 > 20.5$ mag (both consistent with the background limit).

Given the low rate of the source, we only considered photon-counting (PC) data and then selected XRT grades 0–12 (Burrows et al. 2005). No pile-up correction was necessary. Therefore, for our spectral analysis, we extracted the source events from a circular region with a radius of 18 pixels (1 pixel ~$2\overset{''}{.}37$). To estimate the background spectrum, we extracted the events within a source-free annular region centered on SAX J1324–6200 and with radii of 60 and 100 pixels. Ancillary response files, generated with `xrtmkarf`, account for different extraction regions,

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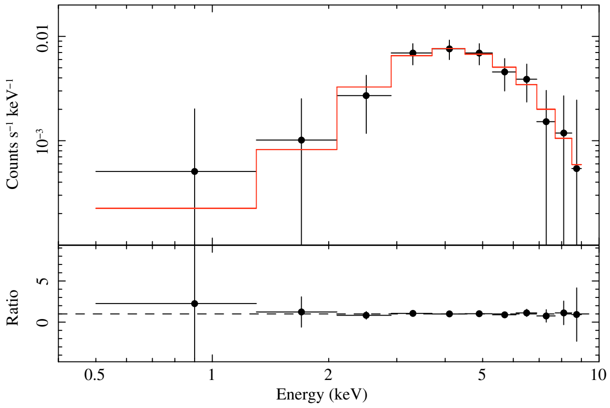

Fig. 1. XRT/PC data fitted with an absorbed power-law model (*top*) and data/model ratio (*bottom*).

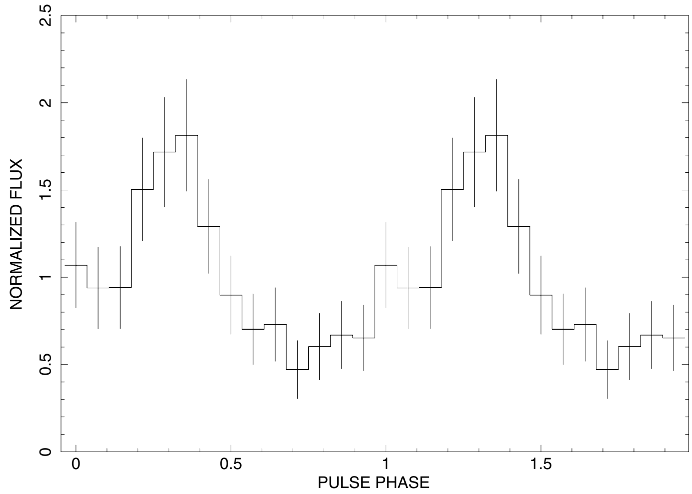

Fig. 2. Folded light curve in the 0.5–9 keV energy range at the period $P = 172.84$ s.

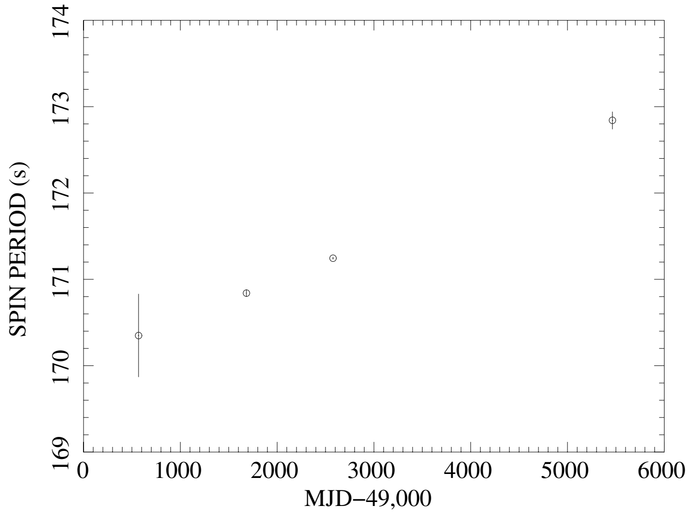

Fig. 3. Long-term evolution of the spin period of SAX J1324–6200.

vignetting, and PSF corrections. We used the latest spectral redistribution matrices (v010) in the Calibration Database maintained by HEASARC.

We fitted the spectrum of SAX J1324–6200 (216 counts) in the 0.5–9 keV energy range using Cash statistics and unbinned data. Adopting an absorbed power-law model, we obtained a photon index of 1.25 ± 0.7, a column density $N_{\rm H} = (7.5 \pm 3) \times 10^{22}$ cm^{-2}, and a Cash statistics of 579.7 using 850 PHA bins (Fig. 1). We calculated the goodness of the fit via 10^4 Monte Carlo simulations, and found that 76.1% of realizations have a fit statistic <579.7. The observed flux is 5.0×10^{-12} erg cm^{-2} s^{-1} in the 1–10 keV range (8.6×10^{-12} erg cm^{-2} s^{-1}, corrected for the absorption). This corresponds to an unabsorbed 1–10 keV luminosity of $10^{35} d_{10}^2$ erg s^{-1} (where we indicate the distance in units of 10 kpc with d_{10}).

For the timing analysis, we used a source extraction radius of 25 pixels to increase the statistics. This resulted in 239 counts, 6% of which we estimate as due to the background. Considering the small number of counts, we used the Z^2 test (Buccheri et al. 1983) to search for the 171 s period, because it does not require data binning. The times of arrival were corrected to the solar system barycenter.

Swift observations consist of several snapshots (continuous pointings at the target) whose durations do not exceed ~1.3 ks in our case. The periodicity is very visible in three of the longest snapshots of the second observations. By analyzing all the data of the second observation, we could derive the best period as 172.84 ± 0.1 s. The periodicity is only marginally visible in the first observation, which was shorter and yielded only ~46 source counts.

The folded light curve obtained by using all the data is shown in Fig. 2. The profile has a single broad peak, as observed in the previous ASCA and BeppoSAX observations. The pulsed fraction is about 50%. A hardness ratio analysis does not show any spectral variations as a function of the pulse phase, but this is not particularly constraining in view of the limited number of counts.

3. Discussion

All the spin period measurements of SAX J1324–6200 are plotted in Fig. 3. While, as mentioned by Lin et al. (2002), the period increase between the ASCA 2000 and the BeppoSAX values could have been a short term fluctuation around a long term spin-up trend, as often observed in accreting pulsars (see, e.g., Bildsten et al. 1997), the new XRT measure makes this possibility less likely. The current period $P = 172.84$ s (at MJD = 54 464.2) is consistent with the extrapolation of the previous period and period derivative, $\dot{P}$, values. This suggests that SAX J1324–6200 has been spinning-down at a nearly constant rate of $\sim 6 \times 10^{-9}$ s s^{-1} for the past ten years, and possibly longer.

The precise localization of SAX J1324–6200 obtained with the Swift/XRT instrument has reduced the error region area by a factor ~500, thus allowing us to exclude many of the previous possible counterparts present in this crowded region of the Galactic plane.

An infrared image of the field, obtained from the 2MASS All-Sky Survey (Skrutskie et al. 2006) in the $K_{\rm s}$ (2.16 μm) band, is shown in Fig. 4, with the XRT error circle superimposed. Only one object is visible inside the X-ray error circle, at RA(J2000) = $13^{\rm h}24^{\rm m}26\overset{\rm s}{.}65$, Dec(J2000) = −62° 01′19″.1. Its $K_{\rm s}$ mag is 14.39 ± 0.08 mag and it is not detected in either J or H, implying $J - K \gtrsim 2.5$ and $H - K \gtrsim 1$.

The next closest objects are located at RA(J2000) = $13^{\rm h}24^{\rm m}27\overset{\rm s}{.}53$, Dec(J2000) = −62° 01′17″.5 (J = 14.15 ± 0.03, H = 13.80 ± 0.04, $K_{\rm s}$ = 13.59 ± 0.05 mag), and RA(J2000) = $13^{\rm h}24^{\rm m}26\overset{\rm s}{.}91$, Dec(J2000) = −62°01′13″.1 (J = 16.66 ± 0.12 mag, undetected in K and H).

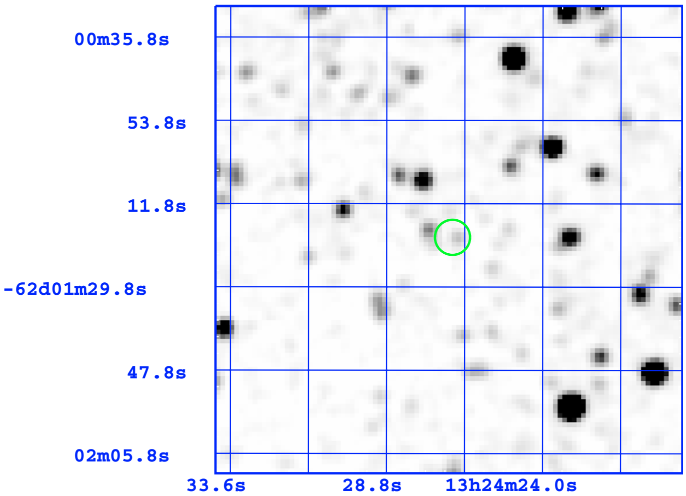

Fig. 4. Image of the region of SAX J1324–6200 in the K_s band. The circle is the XRT 90% c.l. error region, with a radius of 3.″8. North is to the top, east to the left.

SAX J1324–6200 lies in a very reddened region. The total optical extinction in this direction is $A_V \sim 29$, as provided by the NASA/IPAC Infrared Science Archive[1]. The high column density derived from the X-ray spectral fits also points to a rather distant and absorbed system. The NIR colors and magnitudes of the only object detected in the error region are consistent with highly reddened, early type stars. For example, the counterpart could be an OB supergiant with $A_V \gtrsim 15$. In this case the distance should be ~30 kpc to be compatible with the observed magnitudes. This would place SAX J1324–6200 far away at the other edge of the Galaxy, with an X-ray luminosity of $\sim 10^{36}$ erg s^{-1}.

The observed spin-down in SAX J1324–6200 is not a problem in this scenario. For example, a decade long spin-down phase at nearly constant X-ray flux has been observed in the supergiant system 4U 1907+09 (Baykal et al. 2001).

In the alternative hypothesis of a main sequence Be counterpart, a shorter distance in the range ~5–15 kpc and $A_V \sim 15$ would agree with the colors and magnitudes of the candidate counterpart. In this case SAX J1324–6200 could be located either in the Crux galactic arm, which is tangential to this direction (Galactic coordinates $l = 306.8$, $b = +0.61$), or in the more distant Carina arm, which is crossed at ~10 kpc. For the closest distances, it would have an X-ray luminosity of a few 10^{34} erg s^{-1}, similar to other non-transient Be/neutron star binaries (Reig & Roche 1999; La Palombara & Mereghetti 2006), which are characterized by a relatively small luminosity compared to transient systems in outburst. Also among these persistent, low-luminosity Be systems there are sources that have shown long periods of spin-down, similar to SAX J1324–6200. For example, X Per has been spinning down since 1978 at an average rate of 3.5×10^{-9} s s^{-1} (La Palombara & Mereghetti 2007). The absence of a strong Fe emission line[2] in SAX J1324–6200 fits with the properties observed in this class of persistent, low-luminosity Be systems (Reig & Roche 1999).

Of course, both HMXRB scenarios discussed above argue against the tentative[3] orbital period of 27 h reported by Lin et al. (2002). Their suggestion of a spinning down LMXRB, similar to 4U1626–67 and GX1+4, is not supported by the low flux of SAX J1324–6200. These LMXRB are rather luminous systems (10^{36}–10^{37} erg s^{-1}) and SAX J1324–6200 needs to be at more than 30 kpc to have a similar luminosity. Moreover, our refined error region excludes a bright red-giant companion star similar to the counterpart of GX1+4. In view of the HMXBs showing long-term spin-down phases mentioned above, we believe that there is no convincing evidence that SAX J1324–6200 is a LMXRB.

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[1] http://irsa.ipac.caltech.edu/applications/DUST/

[2] An upper limit of 80 eV was derived on the equivalent width of a 6.4 keV line with ASCA (Lin et al. 2002). Our data are consistent with this limit, but due to the limited statistics cannot improve it.

[3] Indeed Lin et al. (2002) mentioned the possibility that this periodicity be spurious, due to the unusual shape of the light curve and the fact that the observation in which it was detected spanned only two cycles of the putative period.