On the nature of the X-ray pulsar SAX J1324–6200

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Received 15 January 2008 / Accepted 21 February 2008

Abstract. We present recent observations of the X-ray pulsar SAX J1324–6200 obtained in December 2007 with the Swift satellite yielding a significant improvement in the source localization with respect to previous data and a new measurement of the spin period P=172.84 s. A single object consistent in colors with a highly reddened early type star is visible in the X-ray error box. The period is significantly longer than that obtained in 1997, indicating that SAX J1324–6200 has been spinning down at an average rate of $\sim 6 \times 10^{-9}$ 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. stars: individual: SAX J1324–6200 - X-rays: binaries

1. Introduction

Little is known on 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 $\sim 1$, and its pulsations period of 171 s are typical of accreting pulsars in binary systems. However, due to the lack of an accurate position, an optical identification has not been obtained to date, thus leading to different possible interpretations for 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) suggested that SAX J1324–6200 belong to the latter group, which is the most numerous, but a white dwarf system of the intermediate polar class could not be completely excluded.

In February 2000 a long observation of SAX J1324–6200, carried out with the ASCA satellite, led to the discovery of a secular spin down at $\sim 5 \times 10^{-9}$ s$^{-1}$ (Lin et al. 2002). This is quite unusual for a HMXRB, since these systems are generally spinning up while accreting. The source flux measured with ASCA was similar to that seen in all the previous observations of this source, arguing against a transient nature. Lin et al. (2002) also reported marginal evidence for a periodic flux modulation at 27±1 hours, that could be interpreted as the orbital period of the system. Based on these finding, they proposed that SAX J1324–6200 is a Low Mass X-ray Binary (LMXRB), similar to other pulsars, like 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).

SAX J1324-6200 was detected in both observations with a net count rate of $(2.9 \pm 0.5) \times 10^{-2}$ and $(3.8 \pm 0.3) \times 10^{-2}$ 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$26.81, Dec(J2000) = $-62^\circ$01′19″1, with an error of 3″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).

UVOT data were reduced with the standard software and procedures, using tasks uvsimsum to produce the coadded images and uvsources to estimate the optical/UV magnitudes (U and W1 filters). There is no detection within the XRT error circle either 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 further 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 ~ 20″). To estimate the background spectrum, we extracted the events within a source-free annular region centered on SAX J1324–6200 and with radii 60 and 100 pixels. Ancillary response files, generated with xrtmkarf, account for different extraction regions, 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 $1.25 \pm 0.7$, a column density $N_H = (7.5 \pm 3) \times 10^{22} \text{ cm}^{-2}$, and a Cash statistics of 579.7 using 850 PHA bins (Fig. 1). We calculated the goodness of the fit via $10^4$ Montecarlo simulations, and obtained that 76.1% of realizations have a fit statistic < 579.7. The observed flux is $5.0 \times 10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}$ in the 1-10 keV range ($8.6 \times 10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}$, corrected for the absorption). This corresponds to an unabsorbed 1-10 keV luminosity of $10^{35} d_{10}^{-2} \text{ erg s}^{-1}$ (where we indicate with $d_{10}$ the distance in units of 10 kpc).

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

Swift observations consist of several snapshots (continuous pointings at the target) whose durations, in our case, do not exceed ~1.3 ks. The periodicity is well visible in three of the longest snapshots of the second observations. By analyzing together 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 is 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 of 239 counts, 6% of which we estimate are due to the background, corrected for the absorption). This corresponds to an unabsorbed 1-10 keV luminosity of $10^{35} d_{10}^{-2} \text{ erg s}^{-1}$ (where we indicate with $d_{10}$ the distance in units of 10 kpc).

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=54464.2) is consistent with the extrapolation of the previous period and period derivative, $P′$, values. This suggests that SAX J1324–6200 has been spinning-down at a nearly constant rate of $5 \times 10^{-9}$ s s$^{-1}$ for the last 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 $K_s$ (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) = $13^h 24^m 26^s 65$, Dec(J2000) = $-62° \ 01′ 19″$. Its $K_s$ magnitude is 14.39 ± 0.08 mag and it is not detected in either $J$ or $H$, implying $J - K \gtrsim 2.5$ and $H - K \gtrsim 1$. 

![Fig. 1. XRT/PC data fitted with an absorbed power law model (top) and data/model ratio (bottom).](image1)

![Fig. 2. Folded light curve in the 0.5-9 keV energy range at the period $P=172.84$ s.](image2)

| Observation log. |
|------------------|
| Sequence | Date and Start time (UT) | End time (hh:mm:ss) | Exposure (s) |
|----------|--------------------------|---------------------|-------------|
| 37039001 | 2007-12-21 07:20:40 | 13:32:56 | 1664 |
| 37039002 | 2007-12-30 00:02:31 | 08:21:57 | 5762 |

| Table 1. Observation log. |
The circle is the XRT 90% c.l. error region, with a radius of 13′′.

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

The next closest objects are located at RA(J2000) = 13h24m27.53, Dec(J2000) = −62° 01′ 17″/5 (J = 14.15 ± 0.03, H = 13.80 ± 0.04, Ks = 13.59 ± 0.05 mag), and RA(J2000) = 13h24m26.91, Dec(J2000) = −62° 01′ 13″/1 (J = 16.66 ± 0.12 mag, undetected in K and H).

SAX J1324–6200 lies in a very reddened region. The total optical extinction in this direction, as provided by the NASA/IPAC Infrared Science Archive\footnote{http://irsa.ipac.caltech.edu/applications/DUST/}, is A_V ~ 29. 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 ~ 15. In this case the distance should be of ~30 kpc in order to be compatible with the observed magnitudes. This would place SAX J1324–6200 far at the other edge of the Galaxy, with an X-ray luminosity of ~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 near 0.2 keV flux has been observed in the pulsar system 4U 1907+09 (Baykal et al. 2001).

In the alternative hypothesis of a main sequence Be counterpart, a larger distance in the range ~5–15 kpc and A_V ~ 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 2000), 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 which showed 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\footnote{Indeed Lin et al. (2002) mentioned the possibility that this periodicity is 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} 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, would argue against the tentative\footnote{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.} orbital period of 27 hours 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^{36–37} erg s^{-1}) and SAX J1324–6200 should 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 conclusion, also in view of the HMXBs showing long-term spin-down phases mentioned above, we believe that there is no convincing evidence for SAX J1324–6200 being a LMXRB.

This work has been partially supported by the ASI/INAF contract I/023/05/0. We thank N. Gehrels and the Swift team for making these observations possible, in particular the duty scientists and science planners. PR thanks INAF-IASFMi, where part of the work was carried out, for their kind hospitality.

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