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LETTER

Letter to the Editor

The discovery of 321 s pulsations in the ROSAT HRI light curves of 1BMW J080622.8+152732 = RX J0806.3+1527

Gian Luca Israel[1,⋆], **Maria Rosa Panzera**[2], **Sergio Campana**[2,⋆], **Davide Lazzati**[2,3], **Stefano Covino**[2], **Gianpiero Tagliaferri**[2], **and Luigi Stella**[1,⋆]

[1] Osservatorio Astronomico di Roma, Via Frascati 33, I-00040 Monteporzio Catone (Roma), Italy
[2] Osservatorio Astronomico di Brera, Via E. Bianchi 46, I-23807 Merate (Lc), Italy
[3] Dipartimento di Fisica, Università degli Studi, via Celoria 13, I-20133 Milano, Italy

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Abstract. During a systematic search for periodic signals in a sample of ~ 3000 ROSAT HRI (0.1–2.4 keV) light curves, we discovered ~ 321 s pulsations in the X–ray flux of RX J0806.3+1527. Two different HRI observations of RX J0806.3+1527 were obtained with the source at flux level of 3 and 5×10^{-12} erg cm^{-2} s^{-1}, respectively. Only a faint $B=20.5$ object is possibly present within the error circle, while no optical counterpart is present in the R plate down to a limiting magnitude of ~ 20. This indicates that the object is intrinsically blue. The X–ray and optical findings imply that RX J0806.3+1527 is a relatively distant (~ 500 pc) intermediate polar (IP) or, more unlikely, a nearby (~ 10 pc) isolated neutron star accreting from the interstellar medium.

Key words: stars: individual: RX J0806.3+1527 – stars: novae, cataclysmic variables – stars: pulsars: general – stars: rotation – X-rays: stars

1. Introduction

ROSAT observations have substantially increased the number of known X–ray pulsars and cataclysmic variables. These results are mainly based on PSPC data due to its higher efficiency. A systematic exploitation of the public ROSAT HRI observations (0.1–2.4 keV energy range) has started only recently.

We developed a wavelet–based detection technique, the Brera Multiscale Wavelet (BMW) algorithm, to analyse high energy astronomical images (Lazzati et al. 1999). A first application of this algorithm to high resolution X–ray images obtained with the ROSAT HRI has been presented in Campana et al. (1999). From the analysis of the ROSAT HRI dataset a catalog of ~ 26000 sources with significance $\geq 4.5\,\sigma$ has been obtained (the BMW–HRI catalog; Panzera et al. 1999). The BMW–HRI catalog contains about 3000 light curves with more than 160 photons, which we set as the minimum number required to carry out a meaningful search for periodic signals (see Israel et al. 1998). These light curves were analysed in a systematic way by using the algorithm of Israel & Stella (1996) for the detection of coherent or quasi–coherent signals in the power spectra even in presence of additional non–Poissonian noise components. The technique was modified to correct for the spurious effects which characterise the ROSAT light curves: these are the signals at the ROSAT orbital period (96 min) and the pointing direction wobble (402 s), and the statistical correlations between adjacent power spectrum estimates caused by large data gaps which are often present (Israel et al. 1998). By adopting a peak detection threshold of $4.3\,\sigma$, we expect some $\sim 3\times 10^{-2}$ false alarm periodicities in the whole sample of BMW–HRI light curves.

In this Letter we present the discovery of 321 s X–ray pulsations in the ROSAT HRI flux of 1BMW J080622.8 +152732 = RX J0806.3+1527 and discuss the possible nature of the pulsating compact object.

2. ROSAT observations and data analysis

The field of RX J0806.3+1527 was observed twice by the ROSAT HRI: between 1994 October 23 and November 1 (ROR 300421n00) for a total exposure time of ~ 4740 s, and on 1995 April 15–19 (ROR 300421a01) for a total exposure of ~ 8640 s.

The source was detected at a level of 0.082 ± 0.004 and 0.052 ± 0.003 cts s^{-1} in the 1994 and 1995 observations, respectively (90% uncertainties are used throughout this letter; see also Table 1). During both observations RX J0806.3+1527 was on–axis (i.e., the target of the pointing). The position of the source in the two HRI images was obtained using the BMW detection algorithm. In the longest observation (1995) the source was detected at R.A.=08$^{\rm h}$06$^{\rm m}$22$\overset{\rm s}{.}$84 and Dec.=+15$^{\rm o}$27′31$\overset{\prime\prime}{.}$5 (equinox 2000), with a statistical error of only 0$\overset{\prime\prime}{.}$17 ($1\,\sigma$). The 1994 observation was analysed in the same way and provided a slightly different position, R.A.=08$^{\rm h}$ 06$^{\rm m}$23$\overset{\rm s}{.}$06 and Dec.=

Send offprint requests to: Gianluca.Israel@oar.mporzio.astro.it
⋆ Affiliated to I.C.R.A.

Table 1. BMW–HRI catalog parameters for 1BMW J080622.8+152732=RX J0806.3+1527.

Start Time	Stop Time	Exposure (s)	Off–axis (′)	R.A.[a] (h m s)	Dec.[a] (° ′ ″)	Count Rate (cts s^{-1})	Flux (erg s^{-1} cm^{-2})
94 Oct 23 11:19	94 Nov 01 17:08	4741	0.29	08 06 23.06	+15 27 29.6	0.082 ± 0.004	4.8×10^{-12}
95 Apr 15 11:42	95 Apr 19 13:10	8643	0.25	08 06 22.84	+15 27 31.5	0.052 ± 0.003	3.0×10^{-12}

Note: Fluxes refer to the 0.5–2 keV energy band and are unabsorbed. See text for details.
[a] 10″uncertainty radius.

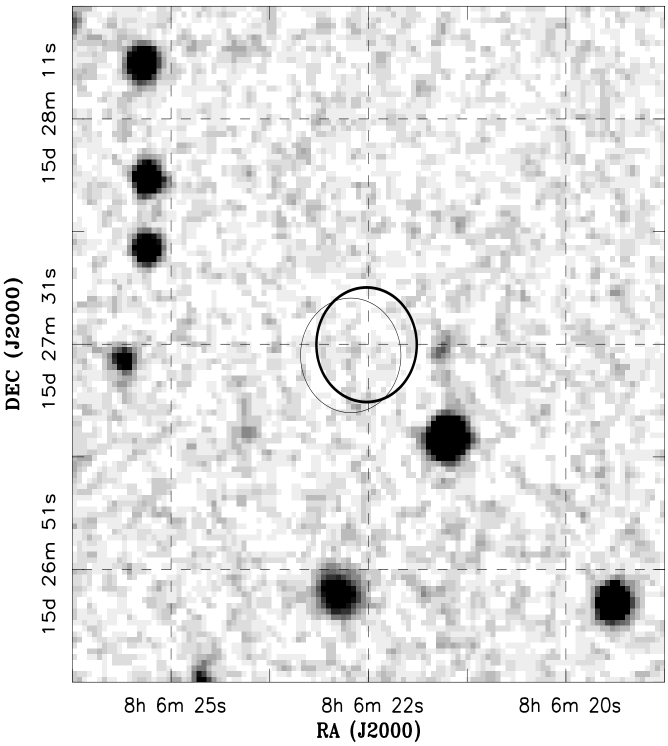

Fig. 1. Digital Palomar chart (R filter) of the region around 1BMW J080622.8+152732. The circles indicates the ROSAT HRI error regions. The heavier circle refers to the longest (1995) observation.

+15°27′29.″6. We assume the position obtained in the longest (1995) observation as the reference position.

The one and four additional X–ray sources (beside RX J0806.3+1527) detected in the 1994 and 1995 observations, respectively, do not allow a secure correction of the RX J0806.3+1527 position for the boresight uncertainty. Therefore, we adopt a standard error radius of $\sim 10''$ for the source position during both observations (see Fig. 1). RX J0806.3+1527 lies away from the Galactic plane at a Galactic latitude of b_{II}=23.°96 (and l_{II}=207.°37). We assume a Galactic disk height of $\sim$300 pc, consistent with the z–dispersion of cataclysmic variables (see below). Correspondingly we expect that the source is unlikely to be more distant than $\sim$750 pc. We adopt 500 pc as the likely distance of RX J0806.3+1527.

The ROSAT HRI has very poor intrinsic spectral resolution. Therefore in order to obtain the flux of RX J0806.3 +1527 from the observed count rates we assumed a Crab–like spectrum, i.e. a power–law with photon index $\Gamma = 2$, and adopted the whole Galactic hydrogen column in the direction of RX J0806.3+1527. This amounts to N_H=2.7× 10^{20} cm^{-2} (Dickey & Lockman 1990). In this way we determined an unabsorbed flux of 4.8 and 3.0×10^{-12} erg cm^{-2} s^{-1} in the 0.5–2 keV energy range for the 1994 and 1995 observation, respectively (cf. David et al. 1998; see Table 1). At a distance of 500 pc, the source unabsorbed 0.5–2 keV luminosity is $L_X \sim 1.4$ and 0.9×10^{32} erg s^{-1} in 1994 and 1995 observations, respectively.

The ROSAT event lists of RX J0806.3+1527 were extracted from a circle of $\sim 6''$ radius (i.e. twice the source width) around the X–ray position. The photon arrival times were corrected to the barycentre of the solar system and background subtracted light curves accumulated in 1 s bins. An average power spectrum (5 intervals of 2 hr duration each) was calculated for the two observations in order to achieve a better statistics and reduce the effects of data gaps. A highly significant peak ($\sim 9\,\sigma$ based on the fundamental only) was found at a frequency of 0.0031127 Hz, corresponding to a period of 321.25 s. A similar result was obtained by analysing the two observations separately. A unique phase fitting solution could not be obtained across the $\sim$6 month interval spanned by the observations. Therefore we derived an accurate period measurement by determining with a Rayleigh periodogram the best period in each of the four time intervals containing most of the photons (cf. Leahy et al. 1983). The average of these period estimates is 321.25 ± 0.25 s. An upper limit to the period derivative of $|\dot{\rm P}| < 2\times 10^{-8}$ s s^{-1} ($3\,\sigma$ confidence level) was also derived.

We also carried out several independent checks to make sure that the detected $\sim$321 s signal is significantly different from the 402 s wobble in the pointing direction of ROSAT that causes the source detector coordinates to oscillate periodically. A visual inspection of the RX J0806.3 +1527 power spectrum does not reveal any significant peak at the wobble frequency or its higher harmonics (see Fig. 2a). Moreover we confirmed that the wobble frequency during the observations of RX J0806.3+1527 was at its usual value of $\nu_{\rm wobble} = 2.49 \times 10^{-3}$ Hz through the power spectrum analysis of the housekeeping data of the R.A., Dec. and roll angles of the pointings (see Fig. 2b). We folded the RX J0806.3+1527 light curve at both the 321.25 s and wobble period. In the former case the modulation is strong and fairly sinusoidal, with a pulse fraction (semiamplitude of modulation divided the mean source count rate) of $\sim$90% (see Fig. 2c and Fig. 3). The light curve folded at the wobble period shows no obvious modulation (pulse fraction upper limit of $\sim$20%, see Fig. 2d). Moreover the wobble–induced modulation is pronounced for only those HRI sources which lie close to the edge

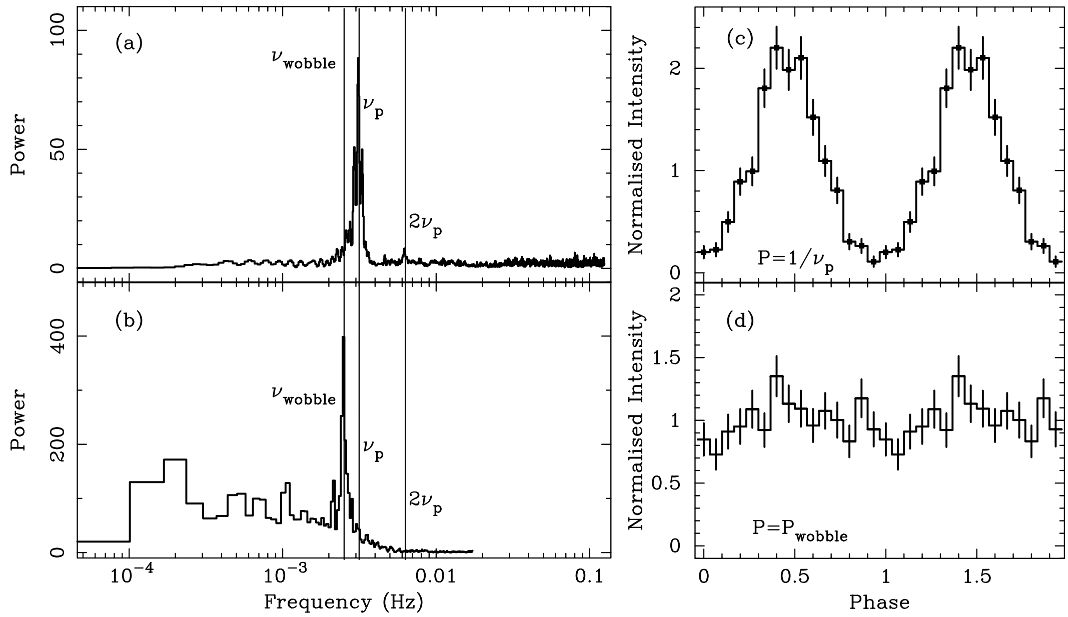

Fig. 2a–d. The average power spectra obtained for **a** the RX J0806.3+1527 light curves by using both 1994 and 1995 data, and **b** the pointing R.A. housekeeping data. The frequency of the wobble ($\nu_{\rm wobble}$), the 321 s signal ($\nu_{\rm p}$) and its second harmonic ($2\,\nu_{\rm p}$) are marked with vertical solid lines. The RX J0806.3+1527 light curves folded at the best period (321.25 s) and the wobble period (402 s) are also shown (panel **c** and **d**, respectively). The minimum of the best fitting sinusoid (phase ~ 0.93 in panel **c** of the 321.25 s period corresponds to JD 2,449,648.50116$\pm$0.00002

of the field of view. So far we have not detected significant signals at the wobble period (or its harmonics) in any of the power spectra of on–axis HRI sources. Examples of the ROSAT HRI light curves of RX J0806.3+1527 are show in Fig. 3. Large pulse to pulse amplitude fluctuations are clearly visible.

We did not find any other observation of RX J0806.3 +1527 in the public available databases of past and present high energy missions. Moreover, the source is not present in the Bright Source Catalog from the ROSAT All–Sky Survey (RASS; count rates > 0.05 cts s^{-1}; Voges et al. 1998), despite the PSPC is a factor of ~ 4 more efficient than the HRI for the source spectrum assumed above.

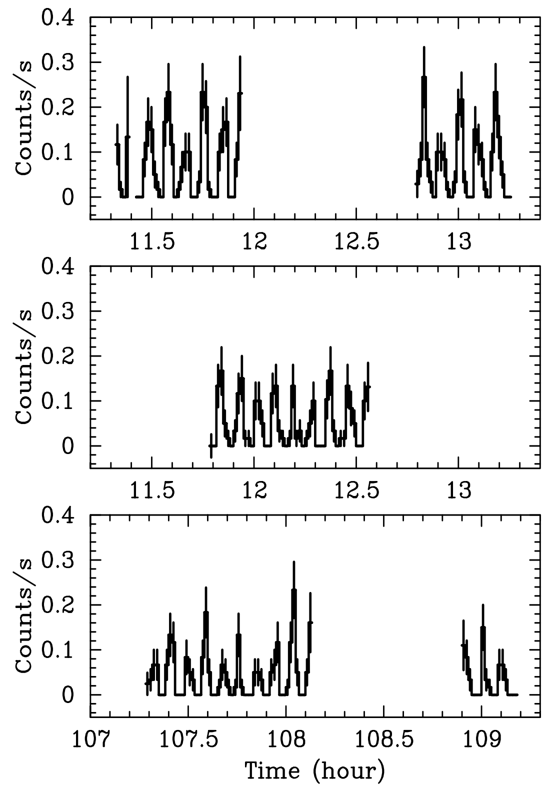

Fig. 3. Three examples of the RX J0806.3+1527 light curves during 1994 (upper panel) and 1995 (central and lower panels) observations.

3. Discussion

Based on the available X–ray data, it is not possible to unambiguously assess the nature of the object responsible for the X–ray pulsations observed in RX J0806.3+1527.

No obvious counterpart was found in the Palomar R chart (mean limiting magnitude of about 20.0 ± 0.5). However, by using the Automatic Plate Measuring (APM) machine catalog (Irwin, Maddox & McMahon 1994) we found a blue object at a position of R.A.=08$^{\rm h}$06$^{\rm m}$22$^{\rm s}$.94 and Dec.=+15$^{\rm o}$27$'$31$''$.1 (equinox 2000), which lies at 1$''$.5 from the X–ray source position. The object has $B = 20.5$ (mean image limiting magnitude of about 21.5 ± 0.5). If this is the optical counterpart of RX J0806.3+1527, we infer an X–ray to B flux ratio of $F_X/F_B \geq 10$.

The Galactic column density in the direction of RX J0806.3+1527 ($N_{\rm H} \sim 2.7 \times 10^{20}$ cm^{-2}) translates to $E_{B-V} \sim N_{\rm H}/5.8 \times 10^{21} \sim 0.05$ (Bohlin et al. 1978). If we also assume the standard reddening law (Fitzpatrick 1999) the Galactic absorption in the B and R bands along line of sight can be $A_B \sim 0.2$ and $A_R \sim 0.1$ at the most. The reddened B and R distance moduli for an object at 500 pc are therefore $m–M_B \sim 8.7$ and $m–M_R \sim 8.6$. Only an M1–2V spectral type star (or later spectral types) is consistent with the measured B magnitude ($\sim$20) of the object within the error circle. However, such an object should be brighter than $R \sim 18.5$ and therefore easily detectable in the R frame. Any earlier object should be much more distant (i.e. a generic K0 dwarf star will be at ~ 5 kpc) and therefore likely outside the Galaxy. This rules out the possibility that RX J0806.3+1527 is a Be star X–ray pulsar binary. The only isolated stellar object consistent with the B and R magnitudes of the APM object would be a white dwarf (Sion & Liebert 1977) at a distance of ~ 500 pc even if, in consideration of the large X–ray pulse amplitude and variability, we regard this possibility as very unlikely.

The non detection of RX J0806.3+1527 in the RASS and the flux variability (on timescales of months) in the ROSAT HRI observations indicate a variable source on timescale of years. We warn the reader that the large X–ray to optical flux ratio derived above might be influenced by source variability, if the optical plates were obtained at a time when the source was quiescent.

These findings suggest that RX J0806.3+1527 is a cataclysmic variable. A large pulse to pulse X–ray variability is often observed in magnetic cataclysmic variables (Hellier, Cropper and Mason 1991). However, the polar sub–class objects have pulsation period phase–locked to the orbital one and are in the 10^2–10^3 min range, thus rather longer than that detected in RX J0806.3+1527 (5.4 min). Moreover the magnetic field inferred from these systems ($\sim 10^7$ G) usually prevents the formation of an accretion disk and the optical spectrum is dominated by the companion (usually a K or M stars): it is hard to reconcile this scenario with the faint blue object detected in the APM.

A likely interpretation is that RX J0806.3+1527 belongs to the IP sub–class (see Hellier 1999 for a recent review). In this scenario the blue optical emission should be dominated by the disk emission. The X-ray energy spectra of IPs are, in most cases, well described by a thermal bremsstrahlung with a temperature of a few tens of keV. The white dwarf rotation periods are usually in the 5–30 min range, whereas the orbital periods are of a few hours. A small group of short period (5–15 min) intermediate polars are characterised by an additional very soft spectral component, likely originating from the reprocessing at the white dwarf surface of the primary hard X–ray radiation emitted at the end of the accretion column (Duck et al. 1994; Haberl & Motch 1995). These soft IPs are more easily detected by low energy X–ray telescopes and often possess a very large soft X–ray modulation, similar to that revealed here. The inferred X–ray luminosity of RX J0806.3+1527 ($L_X \sim 10^{32}$ erg s^{-1} for a distance of 500 pc) is in the range measured from IPs. We note that if this scenario is correct, RX J0806.3+1527 would be the IP with the faintest known optical counterpart.

A further, even if more unlikely, possibility is that RX J0806.3+1527 is a nearby old neutron star accreting from the interstellar medium (ISM). Scaling the results of Walter & Matthews (1997) on RX J0806.3+1527, a blue magnitude of ~ 20.5 can be achieved at a distance of ~ 10 pc. The corresponing 0.5–2 keV luminosity amounts to $\sim 5 \times 10^{28}$ erg s^{-1}. Given the very low density of the ISM in the solar proximity (~ 0.05 cm^{-3}) a relatively low velocity of ~ 30 km s^{-1} is required. This is sufficient to provide a sizeble proper motion of $\sim 0.5''$ yr^{-1}, which could be easily detected with an optical exposure.

4. Conclusion

We discovered highly significant 321 s pulsations in the ROSAT HRI light curves of RX J0806.3+1527. The most likely interpretation is that it is a cataclysmic variable of the IP sub–class. At this stage we can not exclude that it is an isolated neutron star even if more unlikely. Further observations at X–ray and optical wavelengths are needed to firmly assess the nature of this new X–ray pulsator.

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