

Unveiling the nature of the 321s Orbital Period X-ray source RX J0806.3+1527

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Abstract. A nearly simultaneous X-ray/optical (*Chandra* and VLT) observational campaign of RX J0806.3+1527 has been carried out during 2001. These observations allowed us to phase the X-ray and optical light curves for the first time. We measured a phase-shift of ~ 0.5 , in good agreement with the presence of two distinct emission regions and with the X-ray irradiation process predictions. The *Chandra* data allowed us also to study in details the X-ray spectrum of RX J0806.3+1527, which is consistent with a soft ($kT < 70$ eV) and small ($R_{BB} < 20$ km) black-body component. We discuss the present findings in the light of the models proposed so far to account for the X-ray emission detected from RX J0806.3+1527, and its twin source RX J1914.4+2456.

1. Introduction

RX J0806.3+1527 was discovered in 1990 by the *ROSAT* satellite during the All Sky Survey (RASS; Beuermann et al. 1999). However, it was only in 1999 that

a periodic signal at 321 s was detected with *ROSAT* HRI in its soft X-ray flux (Israel et al. 1999, hereafter I99; the discovery of X-ray pulsations were also reported independently by Burwitz & Reinsch 2001). Based on the large pulsed fraction ($\sim 100\%$), relatively low 0.5–2.0 keV flux ($3.0\text{--}5.0 \times 10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}$), modest distance (edge of the Galaxy is at ≤ 1 kpc in the direction of the source) and presence of a faint ($B=20.7$) blue object in the Digitized Sky Survey 1.5" away from the nominal X-ray position, the source was tentatively classified as a cataclysmic variable of the intermediate polar class (I99).

Subsequent deeper optical studies carried out during 1999–2001 both at the Very Large Telescope (VLT; Cerro Paranal) and at the Telescopio Nazionale Galileo (TNG; La Palma) allowed us to unambiguously identify the optical counterpart of RX J0806.3+1527, a blue $V=21.1$ ($B=20.7$) star consistent with that proposed by I99 and Burwitz & Reinsch (2001), and with no significant proper motion (Israel et al. 2002a, Israel et al. 2002b, hereafter I02). B, V and R time-resolved photometry revealed the presence of $\sim 15\%$ pulsations at the ~ 321 s X-ray period (Israel et al. 2002a; I02). Independently, the discovery of the optical counterpart was reported by Ramsay et al. (2002) ten days later based on photometric observations carried out at the Nordic Telescope (NOT; La Palma).

However, one of the most important piece of information was obtained based on medium-resolution spectroscopy (VLT) of this faint object and reported in I02. The spectral study revealed a blue continuum with no intrinsic absorption lines. Broad ($\text{FWHM} \sim 1500 \text{ km s}^{-1}$), low equivalent width ($\text{EW} \sim -2 \div -6 \text{ \AA}$) emission lines from the HeII Pickering series (plus additional emission lines likely associated with HeI, CIII, NIII, etc.) were instead detected. These findings, together with the period stability and absence of any additional modulation in the 1 min–5 hr period range, are interpreted in terms of a double degenerate He-rich binary (similar to the AM CVn class) with an orbital period of 321 s, the shortest ever recorded (I02; see also Ramsay et al. 2002).

2. Models

The nature of the X-ray emission detected from RX J0806.3+1527 and its twin source RX J1914.4+2456 is still under debate. A number of models have been proposed in the last years (for details see Cropper et al. in these proceedings). Among these is the double degenerate binary system with mass transfer model which has been proposed in two flavors: with a weakly magnetic primary (Polar-like; Cropper et al. 1998) and with a non-magnetic accretor (Algol-like, also known as direct impact accretion model; Marsh & Steeghs 2002). An additional model involves a secondary star which does not fill its Roche lobe and crossing the magnetic field of the primary produces an induced electric field (Wu et al 2002). Finally, the possibility that RX J0806.3+1527 and RX J1914.4+2456 are stream-fed intermediate polars (IP) seen face-on has been recently proposed under the hypothesis that the even terms of the HeII Pickering series might be partially due to the presence of H. In the IP scenario the 321 s pulsation would represent the spin period of the accreting white dwarf (Norton et al. 2002).

The lack of good quality (and statistics) X-ray spectra has been the most important limiting factor in the study and understanding of the nature of this source. Moreover, the study of the possible presence of delays of the minima

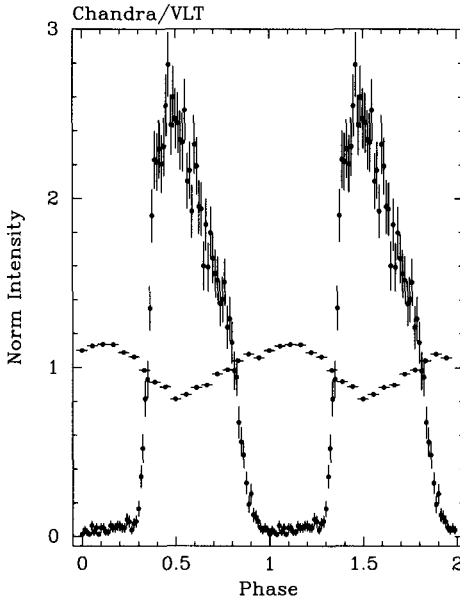


Figure 1. *Chandra* ACIS-S folded light curve of RX J0806.3+1527 (dots with vertical error bars; nearly 100% pulsed fraction; eclipse is evident at phases 0.0-0.3), with the VLT optical light curve superposed (R band; dots with horizontal error bars). Optical and X-ray peaks are phase-shifted of about 0.5. The light curves are plotted twice for clarity.

and/or maxima in the pulse shapes between the X-ray and the optical band is important for understanding the emission geometry from RX J0806.3+1527. Therefore, the optical observations of RX J0806.3+1527 we requested and carried out in parallel with the X-ray *Chandra* pointing offered us a nice opportunity to shed light on the puzzling nature of this object.

3. Optical/X-ray observational campaign

On 11 November 2001 a 20 ks *Chandra* ACIS-S observation was carried out as part of the AO3. At the same time we requested a 3 hr long Discretionary Director Time (DDT) optical observations at the 8.2 m VLT-U4 Yepun (the name of Venus in the old Mapuche language), partially overlapping in time the *Chandra* data. The data were reduced with standard tools both for X-ray (CIAO package) and optical observations (MIDAS and IRAF). We used the *Chandra* observation (longer and with higher statistics than the VLT one) to rely upon an accurate value of the 321 s modulation. This is 321.51 ± 0.03 s (90% confidence level). Then, the optical and X-ray light curves were folded at this period and the result is shown in Figure 1. A ~ 0.5 phase-shift between the optical and X-ray peak emission is evident, in good agreement with the predictions of the X-ray irradiation. Specifically, we note that the minimum of the optical and the maximum of the X-ray are at the same phase. The pulsed fraction of the

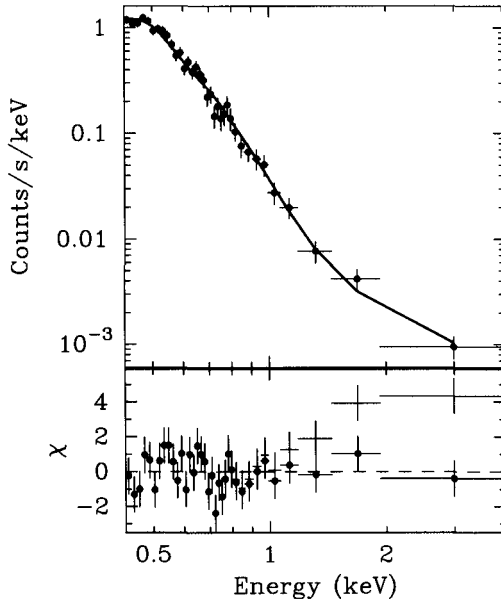


Figure 2. The *Chandra* ACIS-S 20 ks phase-averaged spectrum of RX J0806.3+1527 fitted with a simple blackbody model. Residuals (lower panel) are obtained for the 'raw' blackbody model (crosses) and taking into account the pile-up (circled crosses).

321 s modulation is 100% and 14% in the X-ray and optical bands, respectively (consistent with results reported by I99, 102 and Ramsay et al. 2002).

The X-ray data were also used to perform a detailed spectral analysis and below we report some preliminary results. In particular, we checked the double degenerate model predictions, where a hot spot (a soft blackbody as a first approximation) is thought to be formed at the polar caps or at the equator of the primary star: this would be responsible for the irradiation of part of the companion star and of the accretion stream (if any). A first attempt in fitting the data with a simple blackbody model resulted in the possible presence of a high energy tail (above ~ 2 keV; crosses in the lower panel of Figure 2). However, an inspection of the *Chandra* light curve count rate is consistent with the source being piled-up in the phase interval 0.35–0.85 of Figure 1. Pile-up is inherently a nonlinear process occurring in single photon counting CCD cameras. Hence, corrections are not easy to be taken fully into account, and a parametrization of the effects must be considered (Davis 2001).

With this in mind, we performed a pulse phase spectroscopic (PPS) analysis adding to the blackbody component an ad hoc model (developed at the Chandra Science Data Center) for the pile-up. The results of this study are reported in Figure 3 and can be summarised as follows: the migration grade parameter α is extremely variable and confirmed that the pile-up plays an increasingly important role as the X-ray emission approaches the peak of the modulation, where 90% of the photons are affected. It is also worth noting that the size of the corresponding blackbody is in the 10–20 km range (assuming a distance of 500 pc),

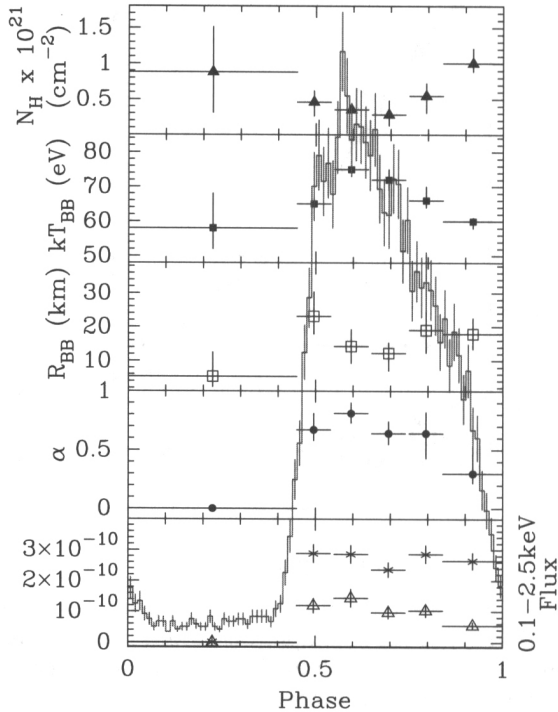


Figure 3. The results of the PPS analysis are reported for a number of spectral parameters (from top to bottom): absorption, blackbody temperature, blackbody radius, photon migration grade fraction, and absorbed (triangles) and unabsorbed (asterisks) flux. Superposed is the folded light curve.

corresponding to an extremely small surface fraction of a white dwarf. Moreover, the unabsorbed 0.1–2.5 keV flux during the pulse-on of RX J0806.3+1527 is $\sim 3 \times 10^{-10} \text{ erg cm}^{-2} \text{ s}^{-1}$ corresponding to a maximum luminosity of less than $10^{35} \text{ erg s}^{-1}$ (assuming a maximum distance of 1 kpc). There is a factor of more than 10^4 between the on- and off-pulse fluxes.

Based on the above results we fitted the phase-averaged spectrum with weighted PPS parameters. We obtained a satisfactory χ^2_ν of 1.02 for 32 degree of freedom (see Figure 2 and the circled crosses in the lower panel) for a blackbody with $kT \sim 65 \text{ eV}$, and absorption of $\sim 4 \times 10^{20} \text{ cm}^{-2}$. Similar results, although with larger uncertainties, were obtained for an annular region around the position of the source, where the pile-up is negligible.

We also performed a radial profile study of RX J0806.3+1527 thanks to the spatial resolution offered by *Chandra*: this was found to be in good agreement with the expected point spread function.

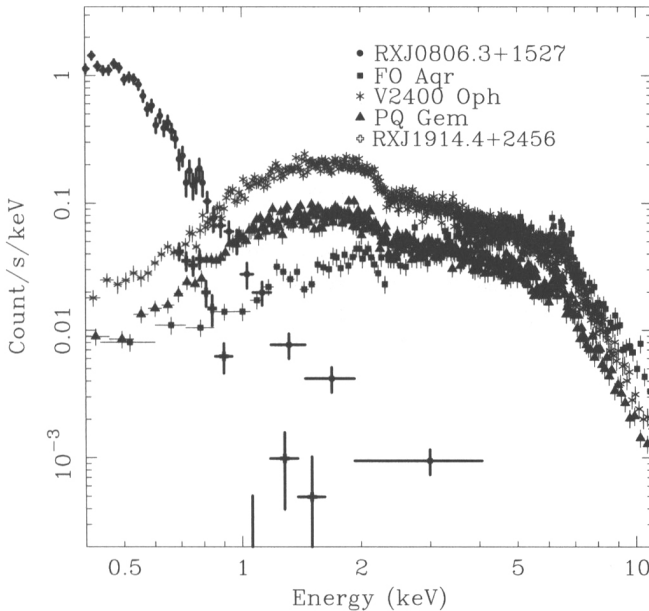


Figure 4. *ASCA* and *Chandra* spectral comparison between RX J0806.3+1527 and RX J1914.4+2456, and a number of IPs. See the text for more details.

4. Discussion and forthcoming observations

The nearly-simultaneous optical and X-ray observations of RX J0806.3+1527 carried out during 2001 allowed us have a closer look at this source. The following preliminary implications can be reported.

(i) The nearly half pulse phase-shift between the two datasets is a clear signature of the fact that the optical and X-ray photons come from two different regions. This behavior is often observed in binary systems where X-ray irradiation occurs. It is also worth noting that the same level of phase-shift was measured for the twin source RX J1914.4+2456 (Ramsay et al. 2000; this is also true for the shape of the X-ray and optical modulations). In the Algol-like model this is easily explained in terms of an elongated equatorial X-ray emitting region self-eclipsed by the accreting white dwarf. In the Polar-like and unipolar inductor models the X-ray emitting region is at the polar cap(s) of the accretor. In both cases a 40-50% of phase-shift is expected.

(ii) The inferred size of the blackbody component is ~ 20 km, a factor of about 10 lower than expected in the case of the electric star model (Wu et al. 2002), and measured in IPs. However, we note that the predicted radius in the unipolar inductor model depends on a number of parameters; a more accurate prediction will be likely available soon.

(iii) In order to check the IP scenario we compared the spectral X-ray emissions of RX J0806.3+1527 and RX J1914.4+2456 with a number of IP which are thought to be stream-fed or at least related to (FO Aqr, V2400 Oph and PQ Gem). Figure 4 shows the result of the analysis: all the data are taken

from the *ASCA* database but RX J0806.3+1527 (for which we used the *Chandra* data; note that due to the different energy responses of *ASCA* and *Chandra*, only the 0.7–5 keV energy interval can be compared). It is evident how the RX J0806.3+1527 and RX J1914.4+2456 spectra stand out. It is difficult to reconcile such a difference only to a different viewing angle.

(iv) Regardless the nature of RX J0806.3+1527 the number of similarities shared with RX J1914.4+2456 is so large that we are necessarily forced in considering them as members of the same class (currently made up of two objects).

Finally, within one year we will rely upon new observations which will allow us to likely distinguish among the proposed scenarios. Specifically, we will be able to detect any period derivative larger than about $10^{-5} \text{ s yr}^{-1}$. On longer time-scales the LISA mission will search for gravitational waves from RX J0806.3+1527, the strain amplitude of which are among the highest expected from known binary sources (see Phinney et al. these proceedings).

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