Mem. S.A.It. Suppl. Vol. 5, 148
© SAIt 2004

Memorie della
Supplementi

Taking the pulse of the shortest orbital period binary system RX J0806.3+1527⋆

G.L. Israel[1], S. Covino[2], S. Dall'Osso[1], D. Fugazza[2], C.W. Mouche[3], L. Stella[1], S. Campana[2], V. Mangano[1,4], G. Marconi[5], S. Bagnulo[5] and U. Munari[6]

[1] INAF - Osservatorio Astronomico di Roma, Via Frascati 33, Monteporzio Catone, Italy
[2] INAF - Osservatorio Astronomico di Brera, Via Bianchi 46, Merate, Italy
[3] Lawrence Livermore National Laboratory, 7000 East Avenue, Livermore, USA
[4] IASF - CNR Sezione di Palermo, Via Ugo La Malfa 153, 90146 Palermo, Italy
[5] European Southern Observatory, Casilla 19001, Santiago, Chile
[6] INAF - Osservatorio Astronomico di Padova, I-36012 Asiago, Italy

Abstract. RX J0806.3+1527 is thought to be a 321s orbital period (the shortest known) double white dwarf binary system. According to the double degenerate binary (DDB) scenario this source is expected to be one of the strongest Gravitational Wave (GW) emitter candidates. In the last years RX J0806.3+1527 has been studied in great details, through multiwavelength observational campaigns and from the point of view of data analysis result interpretations. We present here the timing results obtained thanks to a 3.5-year long optical monitoring campaign carried out by the Very Large Telescope (VLT) and the Telescopio Nazionale Galileo (TNG) which allowed us to detect and study the orbital period derivative (spin–up at a rate of $\sim 10^{-3}$s yr^{-1}) of the 321s modulation, to detect the linear polarisation (at a level of about 2%), and to study the broad band energy spectrum. The VLT/TNG observational strategy we used allowed us to rely upon a P-$\dot{\text{P}}$ coherent solution which we finally extended backward to the 1994 ROSAT observation of RX J0806.3+1527.

Key words. cataclysmic variables – white dwarfs – ultracompact binaries – X-rays binaries

1. Introduction

RX J0806.3+1527 was discovered in 1990 with 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 in its soft X-ray flux with the *ROSAT* HRI (Israel et al. 1999,hereafter I99) . The detection of X-ray pulsations was also reported independently by Burwitz & Reinsch (2001). Subsequent deeper optical studies allowed to unambiguously identify the optical counterpart of RX J0806.3+1527, a blue $V = 21.1$ ($B = 20.7$) star (Israel et al. 2002a,b,hereafter I02B) . *B*, *V* and *R* time-resolved photometry revealed the presence of a $\sim$ 15% modulation at the $\sim$ 321 s X-ray period (Israel et al. 2002b; Ramsey et al. 2002a). The

Send offprint requests to: GianLuca Israel
⋆ Based on observations collected at the European Southern Observatory, Chile (268.D-5737, 070.D-652 and 072.D-0717)
Correspondence to: gianluca@mporzio.astro.it

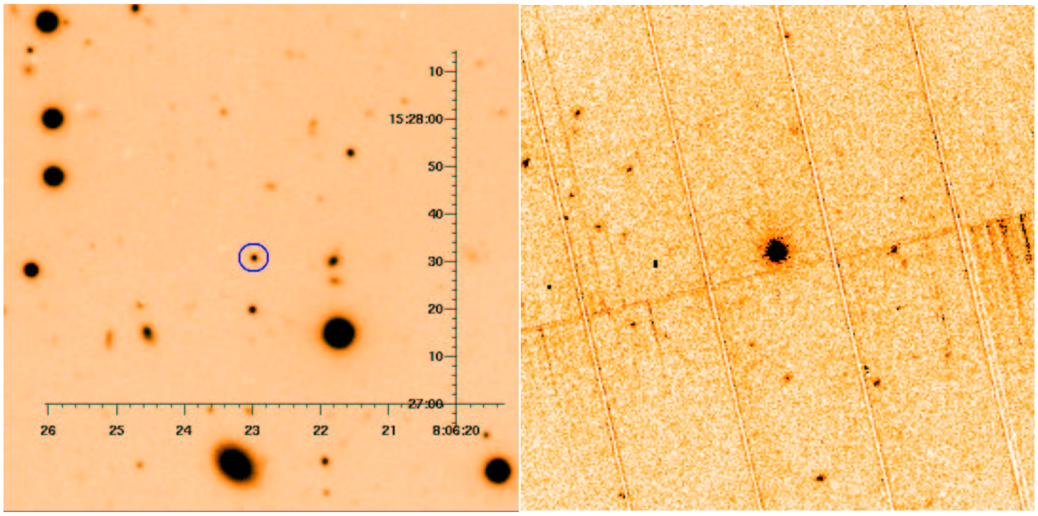

Fig. 1. Left panel: March 2003 VLT FORS1 R-band image of the sky region including the position of the optical counterpart to RX J0806.3+1527 (marked with the circle; effective exposure time of 40 minutes). Right panel: 0.2-10.0 keV EPIC-pn *XMM–Newton* image of RX J0806.3+1527 (brightest object; exposure time of ∼26000 s).

VLT spectral study revealed a blue continuum with no intrinsic absorption lines (I02B). Broad (FWHM ∼ 1500 km s^{-1}), low equivalent width (EW ∼ −2 ÷ −6 Å) emission lines from the He II Pickering series (plus additional emission lines likely associated with He I, C III, N III, 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 (a subset of the AM CVn class; see Warner 1995,for a review) with an orbital period of 321 s, the shortest ever recorded. Moreover, RX J0806.3+1527 was noticed to have optical/X-ray properties similar to those of RX J1914.4+2456, a 569 s modulated soft X-ray source proposed as a double degenerate system (Ramsey et al. 2000, 2002b).

More recently, Hakala et al. (2003, 2004) reported on the detection of spin–up, at a rate of $\sim 6.2\times10^{-11}$ s s^{-1}, for the 321 s orbital modulation, based on optical data taken form the Nordic Optical Telescope (NOT) and the VLT archive, and by using incoherent timing techniques. Similar results were reported also by Strohmayer (2003) for the X-ray data (ROSAT and Chandra) of RX J0806.3+1527 spanning over 10 years and based on the Hakala et al. (2003) results. Finally, Israel et al. (2003b) carried out a nearly-simultaneous Chandra/VLT observational campaign reporting the presence of nearly anti correlation between the optical and X–ray modulation. The X-ray spectral study also allowed to characterise the emission mechanism; a black body with a temperature of ∼60 eV (Israel et al. 2003b).

The study of RX J0806.3+1527 and RX J1914.4+2456 has posed, in the last years, serious questions about their possible origin (see Cropper 2003,for a review of the proposed theoretical models). Moreover, there is a number of additional nice reasons for studying RX J0806.3+1527 and the related objects. Among other are the study of the gravitational wave, and the possibility that RX J0806.3+1527 is a progenitor of the He-accreting DDBs also named AM CVns. For this reason we requested and performed in the last 3.5 years several observations ranging from IR to X-ray band in order to unveil the nature of RX J0806.3+1527 and, correspondingly, of RX J1914.4+2456. Here

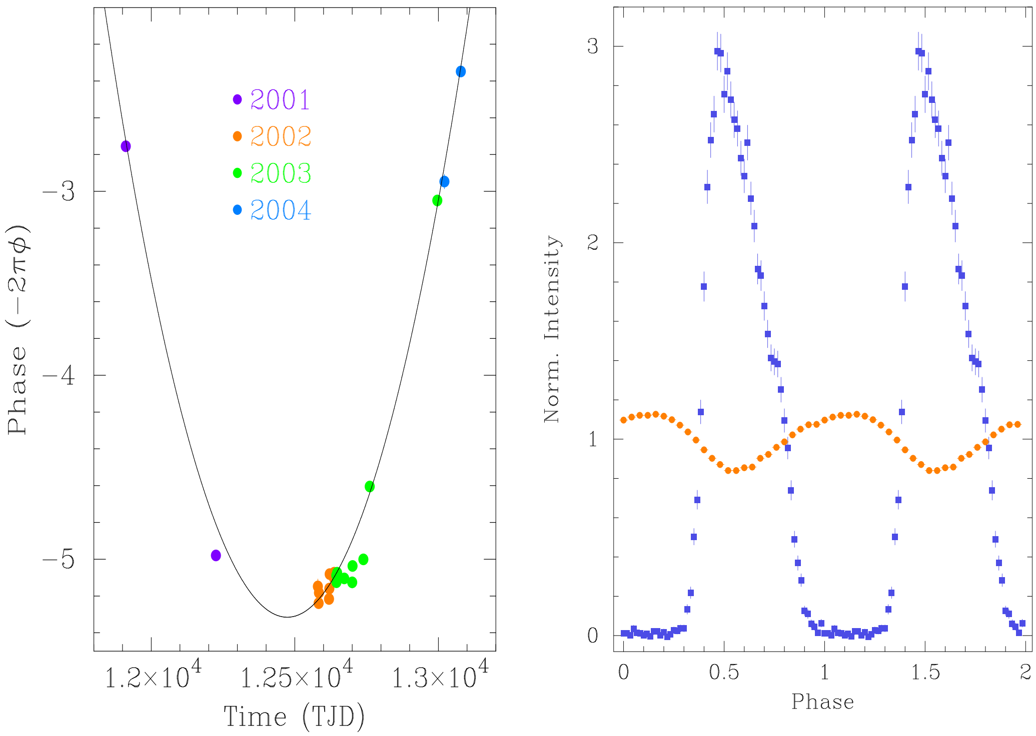

Fig. 2. Left panel: Results of the phase fitting technique used to infer the P-$\dot{P}$ coherent solution for RX J0806.3+1527: the linear term (P component) has been corrected, while the quadratic term (the $\dot{P}$ component) has been kept for clarity. The best $\dot{P}$ solution inferred for the optical band is marked by the solid fit line. Right panel: 1994–2002 phase coherently connected X–ray folded light curves (largest pulsed fraction) of RX J0806.3+1527, together with the 2001-2004 phase connected folded optical light curves. Two orbital cycles are reported for clarity.

we report on the results obtained from (a) the VLT/TNG time-resolved photometric monitoring aimed at accurately measure the P and $\dot{P}$ of RX J0806.3+1527 based on coherent timing techniques, (b) VLT-FORS1 polarimetry observations, and (c) an *XMM–Newton* pointing.

2. Optical Observations

After the successful first optical time-resolved observations of RX J0806.3+1527 during 2001 (January 1st at TNG, and November 11th), we started a relatively long-term project aimed at monitoring the source 321 s modulation. We obtained 21 pointings between November 2002 and May 2004 (11 at VLT and 10 at TNG) scheduled in a way such that it was possible to keep the phase coherence among observations (the first observations were obtained at 1st-2nd nights, 9-10th nights, 19-20th nights, 49-50th nights, etc.). Four different optical bands (B, V, R and I) have been used in order to study and monitor the pulse shape and pulsed fraction as a function of wavelength and time (left panel of figure 1 shows the R-band image of the region around RX J0806.3+1527).

Such a strategy resulted quite efficient in reaching the purposes of the timing analysis, and allowed us also to extend the coherent solution backward to the 2001 optical observations. The best optical solution we found for P-$\dot{P}$ is for P=321.53040(4) s, $\dot{P}$=-3.6(1)$\times 10^{-11}$ s s^{-1} (90% uncertainties are re-

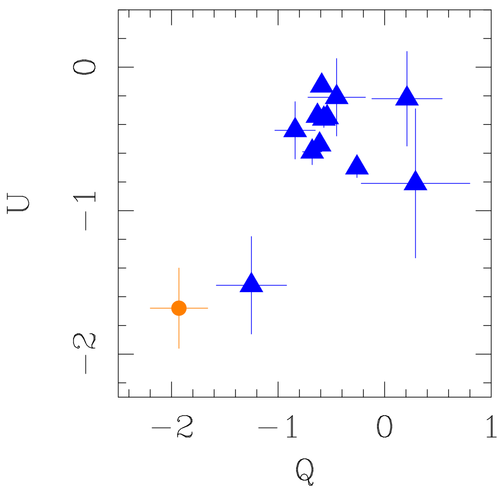

Fig. 3. Q and U Stokes parameters for all the objects detected within 3′ from the RX J0806.3+1527 position (on-axis). Values inferred for RX J0806.3+1527 are clearly marked (filled circle).

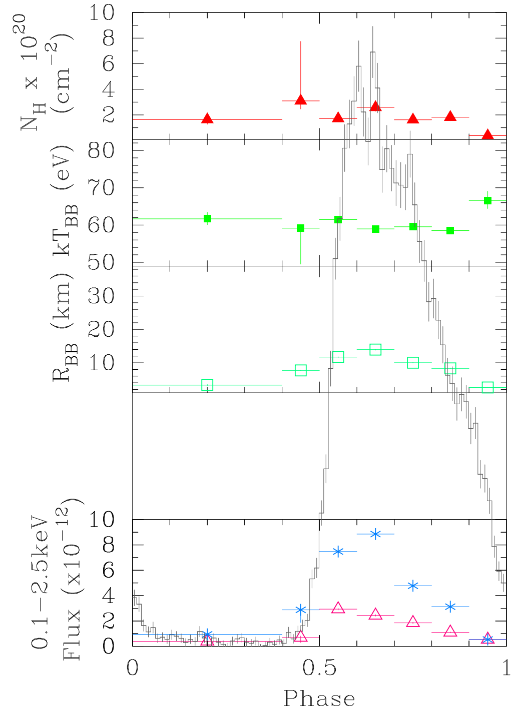

Fig. 4. The results of the *XMM–Newton* phase-resolved spectroscopy (PRS) analysis for the absorbed blackbody spectral parameters: absorption, blackbody temperature, blackbody radius (assuming a distance of 500 pc), and absorbed (triangles) and unabsorbed (asterisks) flux. Superposed is the folded X-ray light curve.

ported; for more details see Israel et al. 2004,see also figure 2, left panel). Moreover, we found a slightly energy–dependent pulse shape with the pulsed fraction increasing toward longer wavelengths, from ∼12% in the B-band to nearly 14% in the I-band (Israel et al. 2004).

The relatively high accuracy obtained for the optical phase coherent P-$\dot{P}$ solution (in the January 2001 - May 2004 interval) allowed us to extrapolate it backward to the ROSAT observations without loosing the phase coherency, i.e. only one possible period cycle consistent with our P-$\dot{P}$ solution. Given the wider time interval spanned by the X–ray observations (9.5 years) an even more accurate solution was possible. After taking into account the ROSAT photon arrival time spacecraft clock time - UTC correction (in order to compare the ROSAT data with the Chandra and *XMM–Newton* observations), our best (optically selected) X-ray solution is P=321.53033(2) s, $\dot{P}$=-3.67(1)$\times10^{-11}$ s s^{-1} (for more details see Israel et al. 2004). Figure 2 (right panel) shows the optical (2001-2004) and X–ray (1994-2002) light curves folded by using the above reported P-$\dot{P}$ coherent solution, confirming the amazing stability of the X–ray/optical anti correlation first noted by Israel et al. (2003b).

In February 2003 we also collected VLT FORS1 polarimetry data for the optical counterpart to RX J0806.3+1527 in the B-band. Due to unforeseen large FORS1 overheads only phase-resolved linear polarisation observations were obtained. In figure 3 we reported the U and Q Stokes parameters for all the detected objects within 3′ from the RX J0806.3+1527 optical counterpart position (objects at larger off–axis angles are indeed affected by the presence of spurious polarisation: more details on this problem can be found at www.eso.org/instruments/fors/pola.html).

RX J0806.3+1527 was found to be linearly polarised at a level of ∼2.0±0.3% (after correcting the the field average polarisation, ∼0.7%). It is worth noting that the marginal detection of circular polarisation, at level of about 0.5%, has been recently reported by Reinsch et al. (2004), and ascribed to a $\sim 10^6$ Gauss magnetic field.

3. The *XMM–Newton* observation

During 2001 a Chandra observation of RX J0806.3+1527 was obtained; in that case the source was found to be more intense than expected resulting in a high (and phase dependent) number of piled–up photons (the results of the Chandra observation are reported in Israel et al. 2003b). On 2002 November 1st we had the chance to observe RX J0806.3+1527 with the *XMM–Newton* instrumentations for about 26000 s (see figure 1, right panel). This ensured us a dataset of unpiled–up photons allowing us to increase the spectral analysis accuracy. Figure 4 shows the results of the phase-resolved spectroscopic study we carried out (similar to the analysis reported in Figure 4 of Israel et al. 2003b). With respect to the latter analysis, the *XMM–Newton* data show a lower value of the absorption column, a relatively constant black body temperature, a smaller black body size, and, correspondingly, a slightly lower flux. All these differences may be ascribed to the pile–up effect in the Chandra data, even though we can not completely rule out the presence of real spectral variations as a function of time. In any case we note that this result is in agreement with the idea of a self-eclipsing (due only to a geometrical effect) small, hot and X–ray emitting region on the primary star. Timing analysis did not show any additional significant signal at periods longer or shorter than 321.5 s, (in the 5hr-200ms interval). Results from the *XMM–Newton* observation are more diffusely reported by Israel et al. (2004).

4. Discussion

In this contribution we briefly listed the main results obtained thanks to a four years optical and X-ray monitoring of RX J0806.3+1527, a DDB with an orbital period of only 5.4min. Even though the optical monitoring is still active (in fact is quite important to continue the $\dot{P}$ study to look for variations or, more interestingly, a $d\dot{P}/dt$ component) a number of important implications can be considered.

It is now assessed that the orbital period is decaying at a rate that is nearly consistent with that predicted by the ultracompact binary model in which the loss or orbital angular momentum is dominated by gravitational radiation and in which there is no mass exchange between the two stars (see also Strohmayer 2003). In this respect the unipolar inductor model proposed by Wu et al. (2002) is a possible scenario to account for the observed X–ray flux from RX J0806.3+1527.

The X–ray and optical emissions are anti correlated at a level of stability (no variations on a baseline of at least 4 years) which is only observed in phase-locked binary systems. The anti correlation is by far and so far the strongest (indirect) suggestion of the binary nature of the 321 s, where the X–rays illuminate the companion surface originating the phase–shifted optical modulation.

The detection of linear and circular polarisation might imply the presence of a relatively faint magnetic field, however we note that the low polarisation level is also consistent with other possibilities, such as the Thomson scattering (sometimes observed in eclipsing binaries).

Acknowledgements. GianLuca Israel (GLI) is deeply grateful to Paul Plucinsky, Guenther Hasinger, Piero Rosati, Roberto Gilmozzi and Martino Romaniello for their help in planning and executing of the 2001 *Chandra*/VLT observational campaign. GLI also thanks Rosario Gonzalez–Riestra for his help in setting the successful 2002 *XMM–Newton*/VLT observational campaign. GLI is also deeply indebted with Leonardo Vanzi and Stephen Potter for their nice advices concerning the polarimetry observations. GLI is also grateful to the VLT and TNG Team, in particular to Marco Pedani (TNG), for their effort in optimising and executing the FORS1 and DoLoRes observations of RX J0806.3+1527 during the last 4 years !

This work is Based on observations made with the Italian Telescopio Nazionale Galileo (TNG) operated on the island of La Palma by the Centro Galileo Galilei of the INAF (Istituto Nazionale di Astrofisica) at the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofisica de Canarias

This work was supported by COFIN grants from the Ministero dell'Università e Ricerca Scientifica e Tecnologica (MURST), and by the Italian Space Agency (ASI).

References

Beuermann, K., Thomas, H.-C., Reinsch, K., Schwope, A. D., Trümper, J, Voges, W., 1999, A&A, 347, 47

Burwitz. V., Reinsch, K. 2001, *X-ray astronomy : stellar endpoints, AGN, and the diffuse X-ray background*, Bologna, Italy, eds White, N. E., Malaguti, G., Palumbo, G., AIP conference proceedings, 599, 522 Mereghetti, S., Stella, L., & Tavani, M. 1998, A&A Rev., 8, 279

Cropper, M., Harrop-Allin, M. K., Mason, K. O., Mittaz, J. P. D., Potter, S. B., Ramsay, G., 1998, MNRAS, 293, L57

Cropper, M., Ramsay, G., Wu, K. 2003, ASP Conf. Ser., Proceedings of Cape Town Workshop on magnetic CVs, December 2002, (see also astro-ph/0302240) of the American Astronomical Society, 29, 823

Hakala, P., Ramsay, G., Wu, K., Hjalmarsdotter, L., Järvinen, S., Järvinen, A., Cropper, M. 2003, MNRAS, 343, L10

Hakala, P., Ramsay, G., Byckling, K. 2004, MNRAS, in press, (astro–ph/0405548)

Israel, G.L., Panzera, M.R., Campana, S., Lazzati, D., Covino, S., Tagliaferri, G. 1999, A&A, 349, L1 (I99)

Israel, G.L., Stella, L., Hummel, W., Covino, S., & Campana, S. 2002a, IAU Circ., 7835

Israel, G.L. et al. 2002b, A&A, 386, L13 (I02)

Israel, G.L., Stella, L., Covino, S., Campana, S., Marconi, G., Mauche C.H., Mereghetti, S., Negueruela, I. 2003a, ASP Conf. Ser., Proceedings of Cape Town Workshop on magnetic CVs, December 2002, (see also astro-ph/0303124)

Israel, G.L. et al. 2003b, ApJ, 598, 492

Israel, G.L. et al. 2004, A&A, submitted 375, 890

Reinsch, K., Burwitz, V., and Schwarz R. 2004, *IAU Colloquium 194: Compact binaries in the Galaxy and Beyond*, RevMexAA, in press (astro–ph/0402458)

Ramsay, G., Cropper, M., Wu, K., Mason, K. O., Hakala, P. 2000, MNRAS, 311, 75

Ramsay, G., Hakala, P., Cropper, M. 2002a, MNRAS, 332, L7

Ramsay, G., Wu, K., Cropper, M., Schmidt, G., Sekiguchi, K., Iwamuro, F., Maihara, T., 2002b, MNRAS, 333, 575

Strohmayer, T., 2003, ApJ, 593, L39

Warner, B., 1995, Ap&SS, 225, 249

Wu, K., Cropper, M., Ramsay, G., Sekiguchi, K. 2002, MNRAS, 331, 221