Spectral and Timing properties of the recently discovered Be/X-ray pulsar eRASSUJ 052914.9-662446

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ABSTRACT
We have presented NuSTAR and Swift observations of the newly discovered Be/X-ray pulsar eRASSU J052914.9-662446. This is the first detailed study of the temporal and spectral properties of the pulsar using 2020 observations. A coherent pulsation of 1411.5±0.5 s was detected from the source. The pulse profile was found to resemble a simple single peaked feature which may be due to emission from the surface of the neutron star only. Pulse profiles are highly energy dependent. The variation of the pulse fraction of the pulse profiles are found to be non-monotonic with energy. The 0.5-20 keV Swift and NuSTAR simultaneous can be fitted well with power-law modified by high energy cutoff of ~ 5.7 keV. The NuSTAR luminosity in the 0.5-79 keV energy range was ~ 7.9×10^{35} erg/s. The spectral flux in 3-79 keV shows modulation with the pulse phase.

Key words: stars: neutron – pulsars: individual: eRASSU J052914.9-662446 – X-rays: stars

1 INTRODUCTION
Neutron star X-ray binaries (NS XRBs) are categorized into two classes - High mass X-ray binaries (HMXBs) and Low mass X-ray binaries (LMXBs). Be/X-ray binaries (BeXRBs) belong to a subclass of the HMXBs which are binary systems of a neutron star (NS) and a Be-star. A detailed information about the systems can be found in Reig (2011). However, the majority of the X-ray pulsars discovered so far belong to the above class of binary systems. The strength of the magnetic field of the neutron star in this system is about 10^{12} G or even higher (Iksanov & Mereghetti 2015). BeXRBs are mostly observed during an X-ray outburst when the X-ray flux coming out from them is sufficient enough so that the flux is detected by the X-ray detectors. There are two types of outbursts namely, - Type I & Type II. The type I outbursts occur frequently with luminosity ($L_x \sim 10^{36}$ erg/s) and generally originate during periastron passage when the NS passes through the circumstellar disc of the Be-star. It is also found to depend on the binary orbital phase. Type II outbursts are characterized by a significantly large luminosity ($L_x \geq 10^{36}$ erg/s) and it lasts for the time duration of a few orbital periods. It is known that type II outbursts may be due to warped Be-disk (Okazaki et al. 2013) and are very rarerly observed. Only a few type II outbursts are observed in a year. Persistent BeXRBs are also observed (Reig 2011) but they are associated with a low luminosity ($L_x \leq 10^{35}$ erg/s), less X-ray variability and slow rotational period ($P_\text{rot} > 200$ s). Corbet (1984) observed correlation between spin period ($P_s$) and the orbital period ($P_{\text{orb}}$) of the NS of BeXRBs. However, with the increase in the number of BeXRBs discovery, the correlation is found to diminish significantly (Haberl & Sturm 2016), providing an insight for the better understanding of the sources. A bimodal distribution of the spin period of Be/X-ray pulsars are also reported (Kniege et al. 2011). A systematic study of 16 Be/X-ray pulsars during their quiescent states by (Tsygankov et al. 2017a) reported that the source can be divided into two separate categories - (a) bright sources having hard power law spectra with luminosity about $\sim 10^{36}$ erg s^{-1}, and (b) faint sources having thermal spectra. The X-ray sources belonging to group (a) show pulsation. (Reig & Nespoli 2013) and are found to follow two different branches in the hardness-intensity diagram during giant outbursts in Be/X-ray pulsars. It reveals a horizontal branch during the low-intensity state and a diagonal branch during the bright intensity state with luminosity exceeding the critical luminosity. The recently discovered Be/X-ray source, eRASSU J052914.9-662446 is the second Be/X-ray pulsar (Maitra et al. 2020a) discovered in the LMC after eRASSU J050810.4-660653 (Haberl et al. 2021; Ghising et al. 2022). It was discovered during the first all sky survey (eRASS1) by (ing et al. 2022). It was discovered during the first all sky survey (eRASS1) by (ing et al. 2022).
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| Observatory | Date of observation | OBs ID          | Exposure (in ksec) |
|-------------|---------------------|-----------------|-------------------|
| NuSTAR      | 2020-04-08          | 90601312002     | 62.74             |
| Swift       | 2020-03-30          | 00013298001     | 1.17              |
|             | 2020-04-08          | 00013298003     | 0.97              |
|             | 2020-04-09          | 00013298004     | 1.68              |

Table 1. Observation details of the source eRASSUJ 052914.9-662446.

3 RESULTS

3.1 X-ray pulsation

The source eRASSUJ 052914.9-662446 was observed by \textit{NuSTAR} during a faint state. The X-ray variability of the source has been investigated using the light curve of 1 s binning in the energy range 3-79 keV. The average count rate of the source in the above energy range is \( \sim 0.122 \pm 0.003 \) count s\(^{-1}\). The effective exposure time of \textit{NuSTAR} on the source was \( \sim 62.738 \) ks. We examined the signal pulsation in the light curve of the pulsar eRASSUJ 052914.9-662446 using the methodology of the fast Fourier transformation (FFT). The FFT analysis was carried out using the \textit{ftool} power spec. The FFT of the source light curve is shown in the left of Figure 1. A Leahy normalized (Leahy et al. 1983) power spectrum consisting of 32768 bins in the frequency range \( \sim 0.159 \times 10^{-4} - 0.125 \) Hz was generated. In a Leahy normalized power spectrum, the Poissonian noise present in the spectrum follows the \( \chi^2 \) probability distribution with two degrees of freedom (dof). The peak corresponding to the coherent pulsation was found at a frequency \( \sim 7.08 \times 10^{-4} \) Hz in the power spectrum. We do not find the existence of any harmonic peak in the spectrum. Using the probability distribution of the Poisson noise and the number of trials, we found that the detection of the peak is significant by more than 5\( \sigma \) level (Reig & Zezas 2018; Fornasini et al. 2017). The corresponding time period estimated here is 1412.4 s.

The FFT method is invalid if the signal’s profile is nonsinusoidal or the noise is nongaussian (Gregory & Loredo 1996). Also the FFT is best for the continuous data. We further refined the estimated pulse period of the pulsar using the epoch-folding technique (Leahy et al. 1983). For a given trial period, \( (P_{\text{trial}}) \) we determined the value of \( \chi^2 \). If there is a presence of pulsation in the light curve then a peak is found to appear in the \( \chi^2 \) vs \( P_{\text{trial}} \) plot (Figure 1). The \textit{f tool} e spec is used to obtain the pulse period through this method. The best value of the pulse period for the source was estimated to be \( \sim 1411.5 \) s (Leahy 1987). The advantage of the epoch folding method over the FFT is that it is independent of the shape of the light curves or signal. The error associated with the pulse period determination can be estimated by the following method given by Lutovinov et al. (2012). Applying this method, we have simulated 500 light curves using the errors of the original data points. The best period of each simulated light curve is then estimated using the epoch folding method. The standard deviation of the best periods distribution is then determined, which finally gives us an estimation of the uncertainty in the pulse period. The estimated uncertainty in the pulse period is 0.5 s. Using the estimated pulse period, we folded the light curve to obtain the pulse profile of the pulsar. The pulse profile in the 3-79 keV resembles a simple single-peak behaviour. The dependence of pulse profiles on energy is explored by generating the pulse profiles in the three different energy ranges, i.e. 3-10 keV, 10-20 keV, and 20-40 keV. The pulse profiles presented in Figure 2 reveals its energy dependence. The pulse profile in the 3-10 keV energy range is found to resemble a similar morphological pattern to that in the full energy range of 3-79 keV. However, change in its morphology is evident above 10 keV energy and one can also
Figure 1. Left - FFT of the NuSTAR light curve of the source. The x-axis has been plotted in log scale. A shape peak in the figure corresponding to the pulse period. The dash line indicates 5σ significance level. Right - Variation of χ² with pulse period. The maximum value of χ² corresponds to 1411.5 s.

Figure 2. Pulse profiles of the pulsar in three different energy bands - 3-10 keV, 10-20 keV, 20-40 keV and 3-79 keV from top to bottom, normalized at average count rates.

Figure 3. Variation of pulse fraction with energy. PF_{max/min} and PF_{rms} are the pulse fraction given by Eq. 1 and 2 respectively.

notice that there is a shift in the pulse phase of the corresponding maximum value of the intensity. The change in the morphology of the pulse profile with the increase in energy is common in X-ray pulsar but in this particular case it can be due to low count rate in hard energy range.

We also study the variation of the pulse fraction with the energy. The standard definition of the pulse fraction (PF) is given by

\[ PF = \frac{p_{\text{max}} - p_{\text{min}}}{p_{\text{max}} + p_{\text{min}}} \]  

where \( p_{\text{max}} \) and \( p_{\text{min}} \) are the maximum and minimum intensities of the pulse profile. The variation of the pulse profile given by Eq. (1) is represented by the purple color figure in Figure 3. We consider another definition of the pulse fraction defined as,

\[ PF_{\text{rms}} = \left( \frac{1}{N} \sum_{i=1}^{N} (p_i - \langle p \rangle)^2 \right)^{1/2} \]  \(< \langle p \rangle >\)  

where \( p_i \) is the intensity of \( i^{th} \) bin of the pulse profile, \( \langle p \rangle \) is the average intensity and \( N \) denotes the number of the phase bins. The r.m.s. pulse fraction is found to be lower than the pulse fraction obtained using the definition of Eq. (1). However, the variation of the pulse fraction with the energy obtained using the two different definitions given above are similar (see Fig. (4)). The pulse fraction (PF) given by Eq. (1) is found to be 49.533 % at 4 keV. Thereafter, it decreases slowly and attains a minimum value of 45.236 % at 10 keV. Above 10 keV, an increase in the PF is observed. The variation of the r.m.s. pulse fraction (PF_{rms}) obtained here is also the same as that admitted by PF but the magnitude of the former diminishes from 8.162 % at 4 keV to 5.297 % at 8 keV followed by an increase in its value.
Flux -0.5
-0.2
0
0.2
0.4
0.6
0.8

Photon-index
1
1.5
2
2.5
3
0.2
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8

Phase

Flux

Figure 4. Top panel - The unfolded spectra of the pulsar, the green, black and red points represent Swift-XRT, FPMA and FPMB spectra respectively. The green, black and red lines represent best fitted lines for the Swift-XRT, FPMA & B spectra respectively. Bottom panel - Residuals left after fitting.

Figure 5. Variation of photon-index (top) and flux (bottom). The flux is on the scale of $10^{-12}$ erg/s/cm$^2$ and is measured in 3-79 keV energy range.

| Model | Parameters | Values |
|-------|------------|--------|
| constant*tbabs*cutoffpl | constant | CFPM | 1 (fixed) |
| | CFMB | 1.06 ± 0.05 |
| | Ccut | 0.8±0.3 |
| | nh (10$^{22}$ cm$^{-2}$) | 0.1$^{+1.1}_{-0.1}$ |
| | photon-index ($\alpha$) | 0.4±0.3 |
| | highcutoff (keV) | 5.7$^{+2.3}_{-1.1}$ |
| | flux ($10^{-12}$ erg cm$^{-2}$ s$^{-1}$) | 2.6 ± 0.7 |
| | C/ dof | 550.95/667 |

Table 2. Best fitted values of the spectral parameters of NuSTAR spectra (FPMA & B). The errors quoted in the table are within 90% confidence interval. The flux is estimated in 0.5-79 keV energy range.

3.2 Spectral analysis

Swift-XRT and NuSTAR simultaneous spectral fitting

Since the NuSTAR and one of the Swift observation having Obs ID 00013298003 are simultaneous, we fitted Swift-XRT and NuSTAR spectra simultaneously. The Swift-XRT and NuSTAR - FPMA & B spectra were simultaneously fitted in the energy range 0.5-20 keV, as the NuSTAR spectra were dominated by the background above 20 keV. The spectral fitting is done in X-ray Spectral Fitting Software (XSPEC) (Arnaud 1996). We have grouped the Swift and NuSTAR spectra such that each bin contains minimum of 1 count and followed C-statistic (Cash 1979). The spectra were best fitted by a power-law with high energy cutoff (cutoffpl) model. For the estimation of the photoelectric absorption along the direction of the source, we have used tbabs model. The model tbabs was implemented using the cross-section vern (Verner et al. 1996) and abundance wilm (Wilms et al. 2000). The best fitted spectral parameters are shown in Table 2. The estimated column density along the direction of the was found to be $\sim 0.14\times10^{22}$ cm$^{-2}$ which is higher than the expected value of the column density $\sim 6.76\times10^{20}$ cm$^{-2}$. The estimated flux in the 0.5-79 keV energy range is about $\sim 2.6\times10^{-12}$ erg/cm$^2$s$^{-1}$. Considering a distance to the source to be 50 kpc (Haberl et al. 2022), the luminosity in the 0.5-79 keV energy range was computed to be $\sim 7.9\times10^{35}$ erg/s. The fitted spectrum of the source is shown in Figure 4.

Swift-XRT spectral fitting

The three Swift-XRT spectra in the 0.5-10 keV energy range were fitted using tbabs and power-law models. The spectra were grouped in such a way that each bin contains a minimum of 1 count. We adopted C-statistics while fitting the spectra 2. We were unable to constrain the value of column density (nh) for the ObsID 00013298001 and 00013298004, so we fixed it to the expected value of 6.76$\times10^{20}$ cm$^2$. The main motivation behind fitting the Swift-XRT spectra is to estimate the flux (see Table 3) of the source.

Phase-resolved analysis

Phase-resolved spectroscopy provides us with the diagnostic tool to study the geometry of the emission region close to the surface of the neutron star by looking at the variation of spectral parameters with the pulse phase. So for this purpose, we have extracted the source spectra for 10 different phase intervals each of size 0.1. The spectra were fitted with the cutoffpl model. We have used tbabs model for the estimation of photoelectric absorption along the direction of the source. We were unable to constraint the value of nh and the cutoff energy of the cutoffpl. Therefore we fixed the nh value to its expected value of $\sim 6.76\times10^{20}$ cm$^{-2}$ and the cutoffpl energy to the value obtained from the phase-averaged spectral fitting. The spectra were grouped in such a way that each bin contains a minimum of 1 count. We have adopted C-statistics to obtain the fit statistics in these cases. The variation of the spectral parameters with the pulse phase is shown in Figure 5. Due to large uncertainties associated with the photon index it is hard to say that photon-index shows a modulation with pulse phases (Figure 5) but the flux shows some modulation with the pulse phase.

1 https://heasarc.gsfc.nasa.gov/cgi-bin/Tools/w3nh/w3nh.pl?
2 https://www.swift.ac.uk/analysis/xrt/spectra.php
In the present paper we consider a study of recently discovered Be/X-ray pulsar namely, eRASSUJ 052914.9-662446 which is a slowly rotating X-ray pulsar \( (P_s > 200 \text{ s}) \) and has a pulse period of \( \sim 1411.5 \pm 0.5 \text{ s} \). This pulse period is not orbital corrected as the orbital parameters of the source is not known. The other Be/X-ray pulsars with pulse period greater than 1000 s are SXP1062 (Hénault-Brunet et al. 2012), SXP1323 (Sasaki et al. 2000) and SXP4693 (Laycock et al. 2010). SXP1062 and SXP1323 are the X-ray pulsars that show largest observed spin-up rate (Carpano et al. 2017; Tsygankov et al. 2010). SXP1062 is a slowly rotating X-ray pulsar namely, eRASSUJ 052914.9-662446 which is a slowly rotating X-ray pulsar. Due to scarcity of the data it is not possible to constrain the magnetic field of the pulsar directly. So we can use indirect method to estimated the magnetic field of the pulsar. One such method is based on the quasi-spherical accretion model in X-ray pulsar given by Shakura et al. (2012). The low luminosity (of order \( 10^{35} \text{ erg/s} \)) and long pulse period \( (>200 \text{ s}) \) of the pulsar supports quasi-spherical accretion from stellar wind in the source (González-Galán et al. 2017; Postnov et al. 2015; Maitra et al. 2022; Jaisawal et al. 2020). In this accretion process, a hot quasi-spherical shell is formed around a magnetospheric boundary of the pulsar from where the mass is accreted onto the surface of the neutron star. Depending on the mass accretion rate, a pulsar will either spin-up or spin-down. Assuming spin equilibrium of the spin period in this accretion regime, the magnetic field strength can be estimated using the following equation (Postnov et al. 2015),

\[
P_{\text{eq}} \approx 940 \, \text{erg} \, \text{s}^{-1} \left( \frac{P_{50}}{10^{-5}} \right) \left( \frac{M_{16}}{10^{16} \text{ g}} \right) \left( \frac{c}{v_{\text{th}}^4} \right) \, \text{G},
\]

where \( \mu_{30} = \mu / 10^{30} \text{ g cm}^{-2} \) is the neutron star (NS) dipole magnetic moment, \( M_{16} = M / 10^{16} \text{ g} \) is the rate of mass accreting onto the surface of the NS, \( P_{50} \) is the orbital period of the binary system and \( v_{\text{th}} = v / 10^{8} \text{ cm s}^{-1} \) is the velocity of the stellar wind. The luminosity in 3-7 keV energy range for the NuSTAR is \( \sim 7.9 \times 10^{35} \text{ erg s}^{-1} \). The luminosity is related to the mass accretion rate as \( L \sim 0.1 M c^2 \), where \( c \) is the velocity of the light in vacuum. The mass accretion rate \( (M_{\text{eq}}) \) for the given luminosity is \( \sim 0.9 \). Considering \( P_{50} \) as 151 days (Maitra et al. 2022), \( P_{\text{eq}} \) as 1412 s and \( v_{\text{th}} \) about 0.2, which is the typical value of wind velocities observed in Be stars (Waters et al. 1988), we get \( \mu_{30} = 59.8 \). This corresponds to a magnetic field of \( \sim 6 \times 10^{13} \text{ G} \). It has been found that for pulsars with spin period \( P_s \sim 1000 \text{ s} \), the estimated magnetic field is very high \( (>10^{13} \text{ G}) \) like in SXP 1062 (Fu & Li 2012), SXP 1323 (Mereminskiy et al. 2022), SS 0114+650 (Li et al. & van den Heuvel 1999) and 4U 2206+54 (Reig et al. 2012), Li & van den Heuvel (1999). Considering the spin period \( (\sim 2.7 \text{ hr}) \) in 25 S1:44+650 argued that its magnetic field should be \( \sim 10^{14} \text{ G} \). Similarly Reig et al. (2012) proposed that a high magnetar-like field can be produced if the \( P_s > 1000 \text{ s} \). Doroshenko et al. (2012) also showed that for slow rotating pulsar the magnetic field should be \( \sim 10^{14} \text{ G} \). So it is possible that the magnetic field of the eRASSUJ 052914.9-662446 be \( > 10^{13} \text{ G} \). A pulsar with magnetic field \( > 10^{13} \text{ G} \) and \( P_s > 1000 \text{ s} \) can never reach a propeller phase if it accretes through a disc, then it is possible for the pulsar to pass through a cold accretion state (Tsygankov et al. 2017b).

The NuSTAR pulse profile in 3-7 keV energy range of the source is single peaked and no additional feature like dips is observed. The luminosity in 0.5-7.9 keV energy range is \( \sim 7.9 \times 10^{35} \text{ erg/s} \), at this luminosity we cannot expect an extended accretion column to form (Mustukov et al. 2015a; Mustukov et al. 2015b). So most of the X-ray photons should originate from the region very close to the surface of the neutron star. In such a case the emission pattern should be of pencil beam shaped (Basko & Sunyaev

| ObsID          | 00013298001 | 00013298003 | 00013298004 |
|---------------|-------------|-------------|-------------|
| time (MJD)    | 58938.57    | 58947.067   | 58948.063   |
| nh (10^{25} \text{ cm}^{-2}) | 6.76 (fixed)  | 6.76 (fixed)  | 6.76 (fixed)  |
| photon-index  | \(-0.479 \pm 0.5\) | 1.0 \pm 1.3 | 0.4 \pm 1.1 |
| flux (10^{-12} \text{ erg cm}^{-2} \text{s}^{-1}) | \(3.4_{-3.3}^{+5.1}\) | \(1.1_{-0.7}^{+1.4}\) | \(1.7_{-1.2}^{+2.7}\) |
| C/dof     | 15.2/14     | 10.5/21     | 15.7/21     |

Table 3. The fitted parameters Swift-XRT spectra. The models used were tbabs*powerlaw. C denotes the fitting statistics. The errors quoted above are within 90\% confidence range. The flux is estimated in 0.5-10 keV energy range.
A certain luminosity called critical luminosity \( L_{\text{crit}} \) linked with two different accretion regimes are well separated by a plexpulse profile. Actually the two different beam emission patterns range is supported by argument (Vasilopoulos et al. 2017). At a luminosity above the critical luminosity no radiation dominated shock is formed and the emission of radiation occurs from the surface of the neutron star forming a pencil beam, perpendicular to the surface of the neutron star. The shape of the pulse profiles were found to vary with the energy. The pulse fraction (PF and \( \text{PF}_{\text{rms}} \)) of the pulse profile is also found to depend on energy which does not change monotonically but rather it decreases with the energy initially (\( \leq 10 \text{ keV} \)) and thereafter it is found to increase. The pulse fraction of X-ray pulsars show local feature like maxima or minima near the cyclotron line energy (Lutovinov \\& Tsygankov 2009; Tsygankov et al. 2010; Molkov et al. 2021). For hard X-ray (\( > 10 \text{ keV} \)) range the pulse fraction of X-ray pulsars are found to increase with increase in energy (except presence of other local features). With the increase in energy the pulse profile becomes less structured due to which the pulse fraction is found to increase (Bildsten et al. 1997; Staubert et al. 2019).

**DATA AVAILABILITY**

The data used in this research are downloaded from NASA HEASARC data archive.

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**REFERENCES**

Arnaud K. A., 1996, in Jacoby G. H., Barnes J., eds, Astronomical Society of the Pacific Conference Series Vol. 101, Astronomical Data Analysis Software and Systems V, p. 17

Basko M. M., Sunyaev R. A., 1976, MNRAS, 175, 395

Becker P. A., et al., 2012, A&A, 544, A123

Bildsten L., et al., 1997, ApJS, 113, 367

Burnows D. N., et al., 2005, Space Sci. Rev., 120, 165

Carpiano S., Haberl F., Sturm R., 2017, A&A, 602, A81

Cash W., 1979, ApJ, 228, 939

Corbet R. H. D., 1984, A&A, 141, 91

Doroshenko V., Sanyal A., Kreykenbohm I., Doroshenko R., 2012, A&A, 540, L1

Fornasini F. M., Tomsick J. A., Bachetti M., Krivonos R. A., Fürst F., Natalucci L., Pottschmidt K., Wilms J., 2017, Astrophys. J., 841, 35

Fu L., Li X.-D., 2012, ApJ, 757, 171

Gehrels N., et al., 2004, ApJ, 611, 1005

Ghisins M., Toubj R., Tamang R., Rai B., Paul B. C., 2022, Monthly Notices of the Royal Astronomical Society

González-Galán A., Osokin L. M., Popov S. B., Haberl F., Kühlmehl M., Gallagher J. J., Schurch M. P. E., Guererro R., 2017, Monthly Notices of the Royal Astronomical Society, 457, 2809

Gregory P. C., Loredo T. J., 1996, ApJ, 473, 1059

Gvaramadze V. V., Kuzavey A. Y., Osokin L. M., 2019, MNRAS, 485, L6

Haberl F., Sturm R., 2016, A&A, 586, A81

Haberl F., et al., 2021, The Astronomer’s Telegram, 15133, 1

Haberl F., Maitra C., Vasilopoulos G., Maggi P., Udalski A., Monageng I. M., Buckley D. A. H., 2022, arXiv e-prints, p. arXiv:2203.00625

Harrison F. A., et al., 2013, The Astrophysical Journal, 770, 103

Hénault-Brunet V., et al., 2012, MNRAS, 420, L13

Ikhsanov N. R., Mereghetti S., 2015, MNRAS, 454, 3760

Jaisawal G. K., Saik N., Ho W. C. G., Kumari N., Epili P., Vasilopoulos G., 2020, MNRAS, 498, 4830

Knigge C., Cee M. J., Polesiowski P., 2011, Nature, 479, 372

Laycock S., Zezas A., Hong J., Drake J. D., Antoniu V., 2010, ApJ, 716, 1217

Leahy D. A., 1987, A&A, 180, 275

Leahy D. A., Darbo W., Elsner R. F., Weisskopf M. C., Sutherland P. G., Kahn S., Grindlay J. E., 1983, ApJ, 266, 160

Li X. D., van den Heuvel E. P. J., 1999, ApJ, 513, L45

Lutovinov A., Tsygankov S. S., 2009, Astronomy Letters, 35, 433

Lutovinov A., Tsygankov S. S., Chernyakova M., 2012, Monthly Notices of the Royal Astronomical Society, 423, 1978

Maitra C., et al., 2020a, The Astronomer’s Telegram, 13610, 1

Maitra C., Haberl F., Koenig O., Doroshenko V., Carpano S., Ducci L., 2020b, The Astronomer’s Telegram, 13650, 1

Maitra C., et al., 2022, arXiv e-prints, p. arXiv:2209.01664

Mereminskiy I. A., Mushlukov A. A., Lutovinov A. A., Tsygankov S. S., Semena A. N., Molkov S. V., Shtykovsky A. E., 2022, A&A, 661, A33

Molkov S., Doroshenko V., Lutovinov A., Tsygankov S., Santangelo A., Mereminskiy I., Semena A., 2021, ApJ, 915, L27

Mushlukov A. A., Saleimanov V. F., Tsygankov S. S., Poutanen J., 2015a, MNRAS, 447, 1847

Mushlukov A. A., Saleimanov V. F., Tsygankov S. S., Poutanen J., 2015b, MNRAS, 454, 2539

Okazaki T. H., Hayasaki K., Moritani Y., 2013, Publications of the Astronomical Society of Japan, 65, 41

Postnov K. A., Mirnov A. I., Lutovinov A. A., Chakraverty A. Y., Tsygankov S. S., 2015, MNRAS, 446, 1013

Reig P., 2011, Ap&SS, 332, 1

Reig P., Nespoli E., 2013, A&A, 551, A1

Reig P., Zezas A., 2018, A&A, 613, A52

Reig P., Torrejón J. M., Blay J., 2012, Monthly Notices of the Royal Astronomical Society, 425, 595

Sasaki M., Haberl F., Pietsch W., 2000, A&AS, 147, 75

Shakura N., Postnov K., Kochetkova A., Hjalmarsdotter L., 2012, MNRAS, 423, 1978

Staubert R., et al., 2019, A&A, 622, A61

Tsygankov S. S., Lutovinov A. A., Serber A. V., 2010, MNRAS, 401, 1628

Tsygankov S. S., Wijnands R., Lutovinov A. A., Degenaar N., Poutanen J., 2017a, Monthly Notices of the Royal Astronomical Society, 470, 126

Tsygankov S. S., Mushlukov A. A., Saleimanov V. F., Doroshenko V., Ambrosio P. K., Lutovinov A. A., Poutanen J., 2017b, A&A, 608, A17

Tsygankov S. S., et al., 2020, A&A, 637, A33

Vasilopoulos G., Zezas A., Antoniu V., Haberl F., 2017, MNRAS, 470, 4534
Verner D. A., Ferland G. J., Korista K. T., Yakovlev D. G., 1996, ApJ, 465, 487
Waters L. B. F. M., van den Heuvel E. P. J., Taylor A. R., Habets G. M. H. J., Persi P., 1988, A&A, 198, 200
Wilms J., Allen A., McCray R., 2000, ApJ, 542, 914

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