Astronomical and Astrophysical Transactions (*AApTr*), 2018, Vol. 30, Issue 4, pp. 409–416,
ISSN 1055-6796, Photocopying permitted by license only, ©Cambridge Scientific Publishers

Spectropolarimetric observations of the Be/X-ray binary star LSI+61°303

Y.M. Nikolov[1,*], V. Golev[2], G. Borisov[1,3], R.K. Zamanov[1], A. Tasheva[4], S. Boeva[1]

[1]*Institute of Astronomy and National Astronomical Observatory, Bulgarian Academy of Sciences, Tsarigradsko Shose 72, BG-1784, Sofia, Bulgaria*
[2]*Department of Astronomy, Faculty of Physics, St. Kliment Ohridski University of Sofia, 5 James Bourchier Blvd, 1164 Sofia, Bulgaria*
[3]*Armagh Observatory, College Hill, Armagh, BT61 9DG, UK*
[4]*Faculty of Computer System and Control, Technical University of Sofia, Bulgaria*

Received 16 March, 2017

We report our first optical spectropolarimetric observations of the Be/X-ray binary LSI+61°303. The observations are performed with the 2.0m telescope of Bulgarian National Astronomical Observatory Rozhen on March 18, 2015. We obtain degree of linear polarization $P_{int} = 2.36 \pm 0.19\%$ and position angle $\theta_{int} = 17°.90 \pm 9°.98$ in the wavelength range 6550–6576 Å.

Keywords: Stars: emission line, Be-polarization – binaries: spectroscopic – stars: individual: LSI+61°303

1 Introduction

LSI+61°303 is a gamma-ray and radio emitting Be/X-ray binary star, located at a distance of 2.3 kpc (Steele et al. 1998; Jaron et al. 2016). It consists of a B0Ve star with a mass of 12.5 $M_{\odot}$, radius 6.7 $R_{\odot}$ (Grundstrom et al. 2007) and a compact object – black hole or neutron star (Aragona et al. 2009). Nonradial pulsations and rapid rotation form a circumstellar disc around the primary. When unpolarized light undergoes scattering (Thomson scattering) in the circumstellar disc the scattered light is linearly polarized and the electric vector vibrates in the scattering plane. The degree of polarization depends on the orientation of the disc relative to the line of sight. When the inclination angle of the disc to the line of sight is $i = 0$ the linear polarization is 0. The maximum degree of polarization is when the disc is visible edge-on (e.g. Halonen 2013).

Here we report our first optical spectropolarimetric observations of the Be/X-ray binary star LSI+61°303.

*Email: ynikolov@astro.bas.bg

2 Observations

The spectropolarimetric observations of LSI+61°303 and HD 43384 were secured with the 2-Channel-Focal-Reducer Rozhen (FoReRo2) similar to that described by Jockers et al. (2000), attached at the Cassegrian focus of the 2.0m RCC telescope of the Bulgarian National Astronomical Observatory (NAO) Rozhen. The observations were made on March 18, 2015 in a window of a few hours of clear weather (from UT 18:45 to UT 21:20). We obtained polarized spectra of LSI+61°303 and the standard star with a high degree of linear polarization HD 43384 (Hsu & Breger 1982) (see Fig. 1). HD 43384 was observed with the same instrumental setup as LSI+61°303. The journal of observations is given in Table 1.

Table 1 Journal of observations.

Object	V	Spec.	Date	Retarder angles	Exp-time [s]
HD 43384	6.25	B3 Ib	2015-03-18	0°	180
				22.5°	180
				45°	180
				67.5°	180
LSI+61°303	10.8	B0 Ve	2015-03-18	0°	300
				22.5°	300
				45°	300
				67.5°	300

The profile of the H_α emission line of the LSI+61°303 shown in the upper panel of Fig. 2 is obtained with Coudé spectrograph of the 2.0m telescope of NAO Rozhen on July 07, 2015 (see Zamanov et al. 2013).

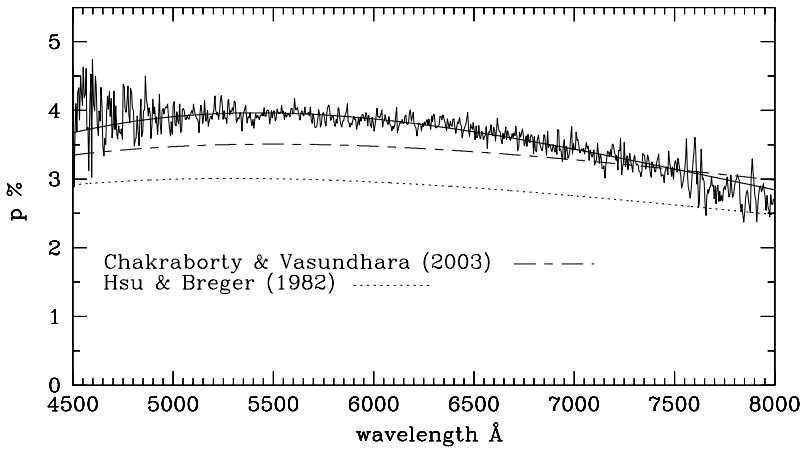


Figure 1 Degree of linear polarization p% of HD 43384. Our results are compared with those obtained by Chakraborty & Vasundhara (2003) and Hsu & Breger (1982). The solid line represents Eq. (8).

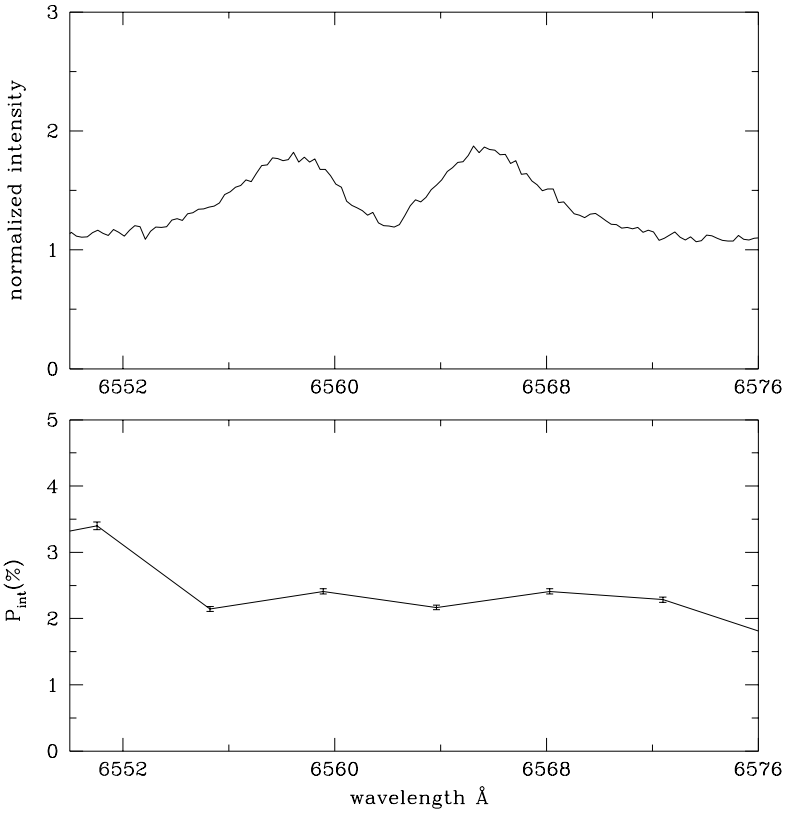


Figure 2 The upper panel represents H_α emission line (intensity normalized to the local continuum) obtained with Coudé spectrograph. The lower panel represents the degree of polarization P_{int}% of LSI+61°303 (corrected for the insterstellar polarization) as a function of the wavelength, obtained with 2-Channel-Focal-Reducer Rozhen.

3 Data analysis

3.1 Beam swapping technique

Polarized spectra are obtained at 4 retarder angles 22.5 degrees apart. Beam swapping technique is used for polarimetric data processing. The values of f$(\lambda)^{\perp}$ and $f(\lambda)^{\parallel}$ are obtained at different retarder angles. The following formulas (Bagnulo et al. 2009) are used to calculate the Stokes parameters:

$$\frac{Q(\lambda)}{I(\lambda)} = \frac{1}{2}\left[\left(\frac{f(\lambda)^{\parallel} - f(\lambda)^{\perp}}{f(\lambda)^{\parallel} + f(\lambda)^{\perp}}\right)_{0^\circ} - \left(\frac{f(\lambda)^{\parallel} - f(\lambda)^{\perp}}{f(\lambda)^{\parallel} + f(\lambda)^{\perp}}\right)_{45^\circ}\right] \quad (1)$$

$$\frac{U(\lambda)}{I(\lambda)} = \frac{1}{2}\left[\left(\frac{f(\lambda)^{\parallel} - f(\lambda)^{\perp}}{f(\lambda)^{\parallel} + f(\lambda)^{\perp}}\right)_{22.5^\circ} - \left(\frac{f(\lambda)^{\parallel} - f(\lambda)^{\perp}}{f(\lambda)^{\parallel} + f(\lambda)^{\perp}}\right)_{67.5^\circ}\right] \quad (2)$$

The degree of polarization is

$$P(\lambda)_L = \sqrt{P(\lambda)_Q^2 + P(\lambda)_U^2}, \tag{3}$$

where $P(\lambda)_Q = \dfrac{Q(\lambda)}{I(\lambda)}$ and $P(\lambda)_U = \dfrac{U(\lambda)}{I(\lambda)}$. The position angle is

$$\theta(\lambda) = \frac{1}{2}\ \arctan\frac{P(\lambda)_U}{P(\lambda)_Q} + \Theta_0, \tag{4}$$

where Θ_0 is

$$\Theta_0 = \begin{cases} 0^\circ & \text{if } P_Q > 0 \text{ and } P_U \geq 0 \\ 180^\circ & \text{if } P_Q > 0 \text{ and } P_U < 0 \\ 90^\circ & \text{if } P_Q < 0 \end{cases} \tag{5}$$

or

$$\Theta = \begin{cases} 45^\circ & \text{if } P_Q = 0 \text{ and } P_U > 0 \\ 135^\circ & \text{if } P_Q = 0 \text{ and } P_U < 0. \end{cases} \tag{6}$$

3.2 Interstellar polarization

The interstellar polarization is produced by dichroic absorption by magnetically aligned aspherical dust grains existing between the object and the Earth. In the optical region the degree of interstellar polarization is a function of wavelength (Serkowski et al. 1975):

$$P_{ISP}(\lambda) = P_{max}\ \exp(-K \ln^2 \frac{\lambda_{max}}{\lambda}), \tag{7}$$

where P_{max} is the peak of the interstellar polarization at wavelength λ_{max}.

4 Results

4.1 Spectropolarimetric observation of standard star HD 43384

Hsu & Breger (1982) give for the standard star HD 43384 a degree of polarization $p\% = 2.94 \pm 0.04\%$ and polarization angle $\theta = 169.8 \pm 0.7$. They determine the following values in Serkowski's law: $\lambda_{max} = 5310$Å, $P_{max} = 3.10\%$ and K=1.15. Chakraborty & Vasundhara (2003) indicate that the degree of polarization is 0.49% higher than the old values of Hsu & Breger (1982). Chakraborty & Vasundhara (2003) give the following values in Serkowski's law: $\lambda_{max} = 5498$ Å, $P_{max} = 3.50\%$ and $K = 1.15$. Our observation of HD 43384 in the wavelength range between 6500 Å and 7500 Å are closer to the values obtained by Chakraborty & Vasundhara (2003). Our values are $\lambda_{max} = 5420$ Å, $P_{max} = 3.96\%$ and $K = 2.19$,

$$P_{ISP}(\lambda) = 3.96\ \exp\left(-2.19 \ln^2 \frac{5420}{\lambda}\right). \tag{8}$$

In Fig. 1 we plot the degree of linear polarization p% of HD 43384 compared with the results obtained by Chakraborty & Vasundhara (2003) and Hsu & Breger (1982). We used the observation of HD 43384 to determine the zero point of the position angle (P.A.). We obtained $\theta = 152°.98 \pm 1°.12$ for the position angle toward HD 43384. The difference between our value and the catalog gives the offset with which we correct the position angle of LSI+61°303.

4.2 Spectropolarimetric observations of LSI+61° 303

The first spectropolarimetric observations of LSI+61°303 were made by Nagae et al. (2006, 2009). To get the intrinsic polarization of the object we determine the polarization of the interstellar medium using the Serkowski's law (Serkowski et al. 1975). Components of interstellar polarization toward LSI+61°303 are obtained by Nagae et al. (2009). The coefficients in Eq. (7) are $P_{peak} = 2.20 \pm 0.18\%$, $K = 0.92 \pm 0.1$, $\theta = 126.5 \pm 3.7$ (Nagae et al. 2009). We calculated Stokes parameters Q and U of the interstellar polarization.

To calculate the Stokes parameter of the intrinsic polarization (q_{int} and u_{int}) of LSI+61°303, we derive the values from our observations and correct them for the interstellar polarization using

$$q_{obs}(\lambda) = q_{int}(\lambda) + P_{ISP} \cos 2\theta_{ISP}, \tag{9}$$

$$u_{obs}(\lambda) = u_{int}(\lambda) + P_{ISP} \sin 2\theta_{ISP}, \tag{10}$$

where q_{obs} and u_{obs} are Stokes parameters of the observed polarization. P_{ISP} and θ_{ISP} are the degree of the interstellar polarization and its position angle, respectively. After it we calculated the degree of polarization $P_{int}\%$ (Fig. 2, lower panel) and position angle θ_{int} (Fig. 3) of LSI+61°303 applying Eqs (3) and (4).

For LSI+61°303 we estimate $q_{obs} = 0.0167 \pm 0.0053$ and $u_{obs} = -0.0191 \pm 0.0052$, which are the average values in the wavelength range 6550–6576 Å. The derived intrinsic values are presented in Table 2. In this table the orbital phase is calculated

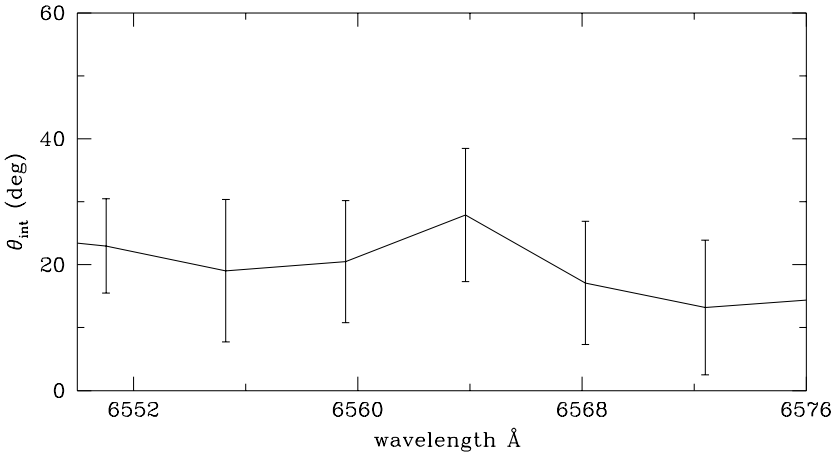


Figure 3 Position angle θ_{int} of LSI+61°303, corrected for the insterstellar polarization.

Table 2 Polarimetric observations of LSI+61°303 around orbital phase 0.33. The table gives the Julian Day of observation, orbital phase, equivalent width (EW) of H_α emission line, degree of intrinsic polarization and position angle. P_{int} and θ_{int} are the average values and standard deviation in interval between $\lambda_1 = 6550$ Å and $\lambda_2 = 6576$ Å.

JD	phase	EW_{H_α}[Å]	P_{int}	θ_{int}
2457099.4	0.33	10.8 ± 0.4	$2.36\% \pm 0.19\%$	$17°.9 \pm 9°.9$

using $P_{orb} = 26.4960 \pm 0.0028$ days, based on Bayesian analysis of the radio observations (Gregory 2002). The zero of phase is by convention $JD_0 = 2443366.775$, the date of the first radio detection of the star (Gregory & Taylor 1978).

5 Discussion

The polarized light coming from astronomical objects brings important information about their geometry. The degree of intrinsic optical linear polarization of X-ray binaries can be up to a few percents. For Cyg X-1 and LS 5039, Nagae et al. (2009) measure optical linear polarization of Cyg X-1 and LS 5039, 4.82% and 5.53% respectively. For 4U 2238+60 (SAX J2239.3+6116), Reig et al. (2016) give optical linear polarization ≈4%. For LSI+61°303 Nagae et al. (2006, 2009) give $p\% \sim 1.3\%$ in continuum; position angle of the intrinsic polarization ∼25°. Nagae et al. (2006) obtained degree of polarization across H_α $P_{H_\alpha} = 2.16 \pm 0.20\%$. It appears that the optical linear polarization of LSI+61°303 is relatively lower in comparison with other similar objects.

It is worth noting that LSI+61°303 probably shows variations of the intrinsic polarization which correlate with the equivalent width of $H\alpha$ emission line (Nagae et al. 2009). The degree of polarization depends on factors such as the density of circumstellar disc around mass donor star and its inclination to the line of sight. On the other hand the dynamics of the processes occurring due to the interaction between the different components of this object are such that we expect changes in the measured Stokes parameters Q and U.

Conclusions

For the Be/X-ray binary star LSI+61°303, we obtain degree of polarization $P_{int} = 2.36\% \pm 0.19\%$ and position angle $\theta_{int} = 17°.9 \pm 9°.9$ in the wavelength range between $\lambda_1 = 6550$ Å and $\lambda_2 = 6576$ Å. For the standard star HD 43384 we obtain degree of polarization $P_{max} = 3.96\%$ at $\lambda_{max} = 5420$ Å.

Acknowledgements This work has been partially supported through the Joint Research Project "Investigation of visual double and multiple stars" between Bulgarian Academy of Sciences and Serbian Academy of Sciences and Arts and by the Bulgarian National Science Fund of the Ministry of Education and Science under grant DN 08-1/2016. We also thank the anonymous referee for useful suggestions that improved the paper.

References

Aragona, C., McSwain, M.V., Grundstrom, E.D., Marsh, A.N., Roettenbacher, R.M., Hessler, K.M., Boyajian, T.S., & Ray, P.S.V. (2009), *Astrophys. J.* **698**, 514

Bagnulo, S., Landolfi, M., Landstreet, J.D., Landi Degl'Innocenti, E., Fossati, L., & Sterzik, M.V. (2009), *Publications of the Astronomical Society of the Pacific* **121**, 993

Chakraborty, P., & Vasundhara, R. (2003), *Experimental Astronomy*, **16**, 69

Gregory, P.C. (2002), *Astrophys. J.* **575**, 427

Gregory, P.C. and Taylor, A.R. (1978), *Nature* **272**, 704

Grundstrom, E.D., Caballero-Nieves, S.M., Gies, D.R., Huang, W., McSwain, M.V., Rafter, S.E., Riddle, R.L., Williams, S.J., and Wingert, D.W. V. (2007), *Astrophys. J.* **656**, 437

Jaron, F., Torricelli-Ciamponi, G., & Massi, M. (2016), *A&A*, **595**, A92

Jockers, K., Credner, T., Bonev, T., Kisele, V.N., Korsun, P., Kulyk, I., Rosenbush, V., Andrienko, A., Karpov, N., Sergeev, A., & Tarady, V. (2000), *Kinematika i Fizika Nebesnykh Tel Supplement* **3**, 13

Halonen, R.J. (2013), PhD thesis, The University of Western Ontario

Hsu, J.-C. and Breger, M.V. (1982), *Astrophys. J.* **262**, 732

Nagae, O., Kawabata, K.S., Fukazawa, Y., Okazaki, A., Isogai, M., and Yamashita, T.V. (2009), *The Astronomical Journal* **137**, 3509

Nagae, O., Kawabata, K.S., Fukazawa, Y., Yamashita, T., Ohsugi, T., Uemura, M., Chiyonobu, S., Isogai, M., Cho, T., Suzuki, M., Okazaki, A., Okita, K., & Yanagisawa, K.V. (2006), *Publications of the Astronomical Society of Japan* **58**, 1015

Reig, P., Blay, P., Blinov, D.V. (2016), *Astron. Astroph.*, in press

Serkowski, K., Mathewson, D.S., and Ford, V.L.V. (1975), *Astrophys. J.* **196**, 261

Zamanov, R., Stoyanov, K., Martí, J., Tomov, N.A., Belcheva, G., Luque-Escamilla, P.L., & Latev, G.V. (2013), *Astron. Astroph.* **559**, A87