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Spectropolarimetric Observations of the Recurrent Nova RS Oph[1]

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ABSTRACT

We report spectropolarimetric observations of the recurrent nova RS Oph obtained during four nights between July 2017 and July 2018. In the wavelength range from 5000 Å to 8000 Å, we find the maximum degree of linear polarization $P_L(\mathrm{obs}) = (2.9 \pm 0.09)\%$ at $\lambda \approx 5600$ Å and the position angle $\theta = 47\overset{\circ}{.}2 \pm 0\overset{\circ}{.}9$. We do not detect any variability of the degree of polarization and the position angle. At the time of our observations, there is no intrinsic polarization in RS Oph and the observed values represent the interstellar polarization.

Key words: *binaries: symbiotic – novae, cataclysmic variables – Techniques: polarimetric – Stars: individual: RS Oph*

1. Introduction

RS Ophiuchi (HD 162214) is a symbiotic binary system. The primary is a near Chandrasekhar-mass white dwarf (Mikołajewska and Shara 2017) accreting material from an M2 III companion (*e.g.*, Hachisu and Kato 2001, Shenavrin, Taranova and Nadzhip 2011). The orbital period of the binary is 453.6 d and the orbit inclination is $49^\circ \div 52^\circ$ (Brandi *et al.* 2009). RS Oph undergoes novae eruptions with amplitude of more than 6 mag (*V*-band) approximately every 20 yr (Schaefer 2010). The novae eruptions occur when hydrogen-rich material provided by the companion star ignites on the surface of the white dwarf.

In this paper we report spectropolarimetric observations of RS Oph at quiescence.

2. Observations

Spectropolarimetric observations of RS Oph were secured with the 2-Channel-Focal-Reducer Rozhen (FoReRo2) similar to that described by Jockers *et al.* (2000),

[1]Based on data obtained with the Rozhen telescope, Bulgaria

attached to the Cassegrian focus of the 2.0-m RCC telescope of the Bulgarian Rozhen National Astronomical Observatory. A wave-plate retarder is added to FoReRo2. We utilized a Super-Achromatic (in the range 3800–7900 Å) True Zero-Order Wave-plate 5[2] retarder (APSAW-5) and used a beam swapping technique (Bagnulo *et al.* 2009) to minimize instrumental polarization (Section 3).

The observations were made on July 21, 2017, February 7, 2018, March 2018 and July 7, 2018, hence covering 0.77 of the orbital period. We obtained polarized spectra of RS Oph and standard stars with high (HD 204827 and HD 161056, Schmidt *et al.* 1992) and zero degree of polarization (HD 212311 and HD 154892, Turnshek *et al.* 1990). Polarization standards were observed with the same instrumental setup as RS Oph on the same nights. The spectra were reduced using IRAF (Tody 1993) in the standard way including bias removal and wavelength calibration. Polarized spectra are obtained at eight retarder angles: 0°, $22.^\circ5$, 45°, $67.^\circ5$, 90°, $112.^\circ5$, 135° and $157.^\circ5$. The journal of observations is given in Table 1. The table contains the date (in format YYYYMMDD), UT of the middle of the observation, retarder angles, the number of exposures for all retarder angles, the exposure time for each exposure and the last column lists observed high and zero polarization standards.

For the spectrum obtained on July 21, 2017 we used slit with width of 110 μm. In this case we have resolving power $R = 750$ at $\lambda = 6562$ Å. The other spectra were obtained using slit-less spectropolarimetry. In this case we have lower resolving power, that depends on the seeing. During our observations equivalent widths (W_α) of a H_α emission line were: $-101.6 < W_\alpha < -135.3$ Å. Typical errors of equivalent width (W_α) of a H_α emission line were 10%. The data were not corrected for the telluric lines, because it is not necessary for spectropolarimetric data reduction.

T a b l e 1

Journal of observations of RS Oph

Date	UT	Retarder angles	Exp-time [s]	Standards
2017-07-21	20:32:26	0°, $22.^\circ5$, 45°, $67.^\circ5$ 90°, $112.^\circ5$, 135°, $157.^\circ5$	8×10	HD 204827[a] HD 212311[b]
2018-02-17	03:38:29	0°, $22.^\circ5$, 45°, $67.^\circ5$ 90°, $112.^\circ5$, 135°, $157.^\circ5$	16×90	HD 161056[a] HD 154892[b]
2018-03-11	03:13:19	0°, $22.^\circ5$, 45°, $67.^\circ5$ 90°, $112.^\circ5$, 135°, $157.^\circ5$	8×60	HD 161056[a] HD 154892[b]
2018-07-07	20:54:00	0°, $22.^\circ5$, 45°, $67.^\circ5$ 90°, $112.^\circ5$, 135°, $157.^\circ5$	16×60	HD 161056[a] HD 154892[b]

Note: [a] – high polarization standards; [b] – zero polarization standards

[2] *http://astropribor.com/waveplates/*

3. Data Analysis

A beam swapping technique is used for polarimetric data processing. The values of $f(\lambda)^{\parallel}$ and $f(\lambda)^{\perp}$, where $f(\lambda)^{\parallel}$ and $f(\lambda)^{\perp}$ are the fluxes of the parallel and perpendicular beam of the Wollaston prism respectively, are obtained for the different retarder angles. The following formulae are used to calculate the Stokes parameters (Bagnulo *et al.* 2009):

$$\begin{aligned} P_Q(\lambda) = \frac{Q(\lambda)}{I(\lambda)} = \frac{1}{4}\left[\left(\frac{f(\lambda)^{\parallel}-f(\lambda)^{\perp}}{f(\lambda)^{\parallel}+f(\lambda)^{\perp}}\right)_{0^\circ} - \left(\frac{f(\lambda)^{\parallel}-f(\lambda)^{\perp}}{f(\lambda)^{\parallel}+f(\lambda)^{\perp}}\right)_{45^\circ}\right] \\ +\frac{1}{4}\left[\left(\frac{f(\lambda)^{\parallel}-f(\lambda)^{\perp}}{f(\lambda)^{\parallel}+f(\lambda)^{\perp}}\right)_{90^\circ} - \left(\frac{f(\lambda)^{\parallel}-f(\lambda)^{\perp}}{f(\lambda)^{\parallel}+f(\lambda)^{\perp}}\right)_{135^\circ}\right] \end{aligned} \tag{1}$$

$$\begin{aligned} P_U(\lambda) = \frac{U(\lambda)}{I(\lambda)} = \frac{1}{4}\left[\left(\frac{f(\lambda)^{\parallel}-f(\lambda)^{\perp}}{f(\lambda)^{\parallel}+f(\lambda)^{\perp}}\right)_{22.5^\circ} - \left(\frac{f(\lambda)^{\parallel}-f(\lambda)^{\perp}}{f(\lambda)^{\parallel}+f(\lambda)^{\perp}}\right)_{67.5^\circ}\right] \\ +\frac{1}{4}\left[\left(\frac{f(\lambda)^{\parallel}-f(\lambda)^{\perp}}{f(\lambda)^{\parallel}+f(\lambda)^{\perp}}\right)_{112.5^\circ} - \left(\frac{f(\lambda)^{\parallel}-f(\lambda)^{\perp}}{f(\lambda)^{\parallel}+f(\lambda)^{\perp}}\right)_{157.5^\circ}\right] \end{aligned} \tag{2}$$

We correct the Stokes parameter $P_Q(\lambda)$ and $P_U(\lambda)$ of RS Oph for the instrumental polarization using the $P_Q(\lambda)$ and $P_U(\lambda)$ of standard star with zero degree of polarization. The degree of polarization is:

$$P_L(\lambda) = \sqrt{P_Q^2(\lambda) + P_U^2(\lambda)} \tag{3}$$

and the position angle is:

$$\theta(\lambda) = \frac{1}{2}\ \arctan\frac{P_U(\lambda)}{P_Q(\lambda)} + \Theta_0 \tag{4}$$

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

$$\Theta_0 = \begin{cases} 45^\circ & \text{if } P_Q = 0 \text{ and } P_U > 0 \\ 135^\circ & \text{if } P_Q = 0 \text{ and } P_U < 0. \end{cases} \tag{6}$$

4. Results

We observed RS Oph approximately ten years after its last recurrent nova outburst which occurred on February 12, 2006 (Narumi *et al.* 2006). Optical spectra (Stokes I) of RS Oph are shown in Fig. 1.

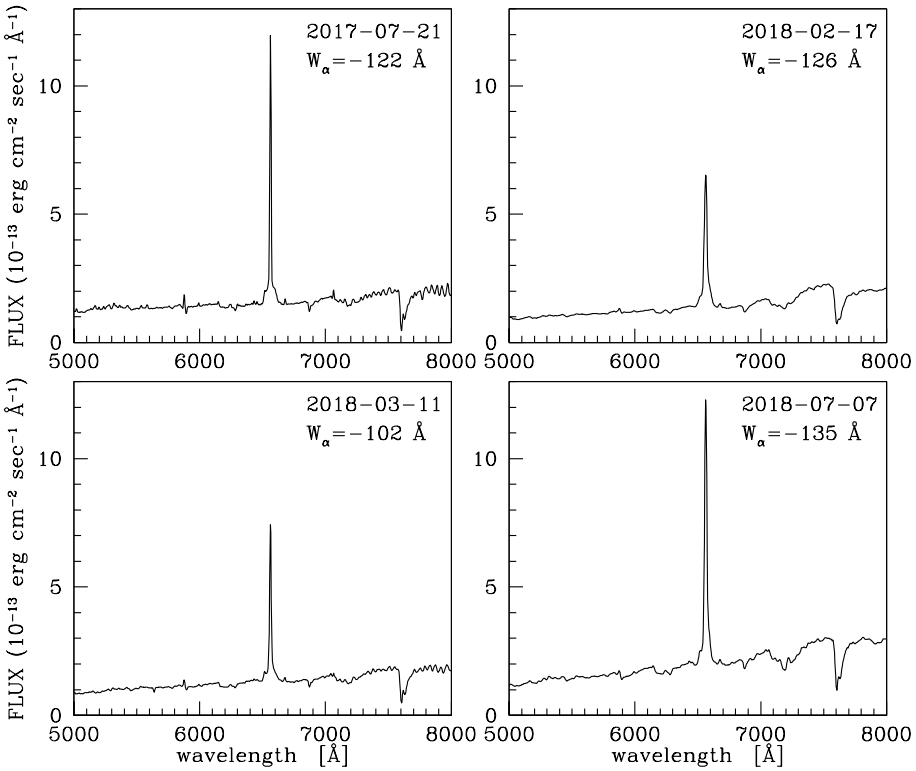

Fig. 1. Optical spectra of RS Oph. The absorption features around 7600 Å onwards are due to the atmosphere.

The observed degree of polarization and position angle in the wavelength range from 5000 Å to 8000 Å are plotted in Fig. 2 and Fig. 3, respectively. The maximum of a degree of polarization is $P_L(\mathrm{obs}) = (2.9 \pm 0.09)\%$ at $\lambda \approx 5600$ Å. The values of the degree of polarization in the wavelength range from 5000 Å to 8000 Å have a characteristic corresponding to the polarization due to the interstellar medium. The angle of polarization has a flat behavior with no visible wavelength dependence and it has value of $\theta = 47^0.2 \pm 0^0.9$.

The average value of the observational Stokes parameters $\overline{P_Q}(\mathrm{obs})$ and $\overline{P_U}(\mathrm{obs})$ in the wavelength range from 5500 Å to 7500 Å are presented in Table 2, where the orbital phase is calculated using $P_{\mathrm{orb}} = 453.6$ d and $T_{\mathrm{conj}} = 2445043.54 \pm 5$ (the time of the inferior conjunction of the M giant, Brandi *et al.* 2009).

In Table 3 are presented the parameters of the Serkowski's law fit (Serkowski *et al.* 1975).

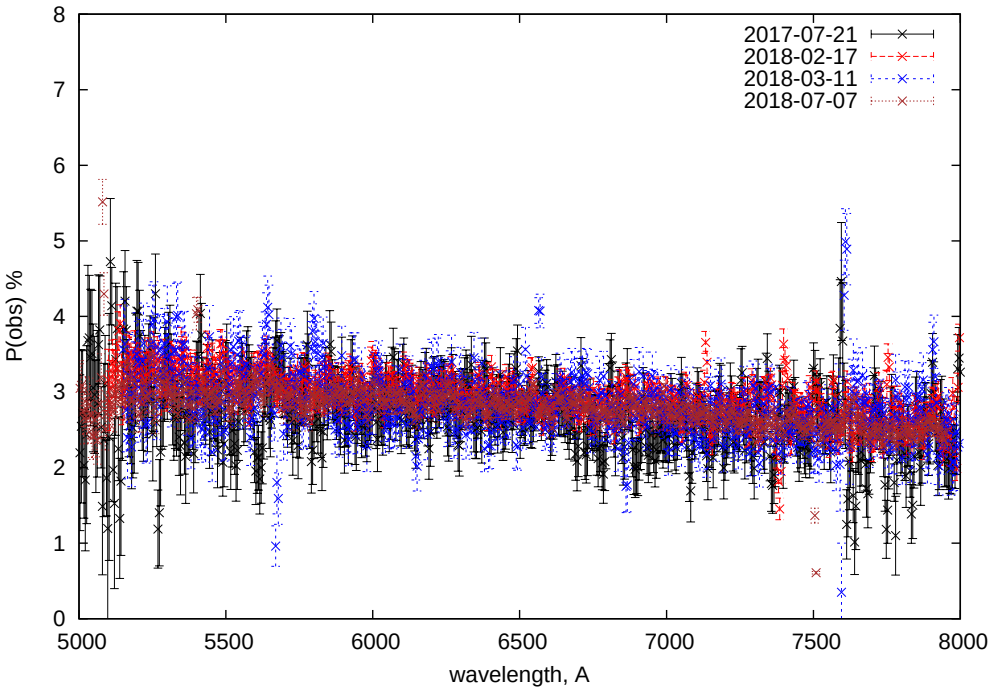

Fig. 2. Observed degree of polarization of RS Oph.

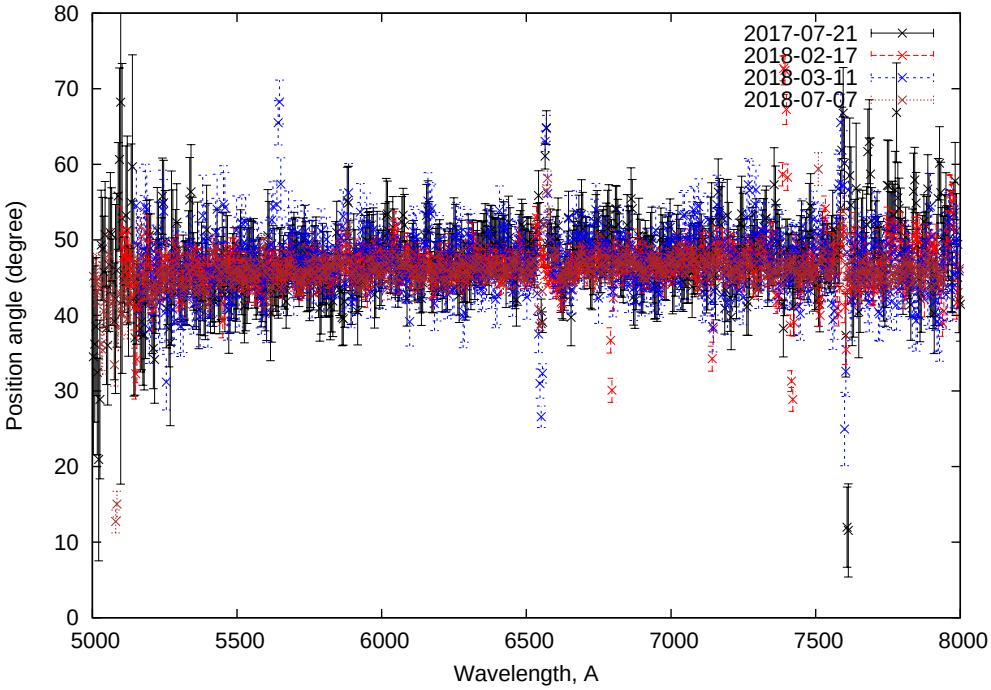

Fig. 3. Observed position angle of RS Oph.

T a b l e 2

Observational average value of Stokes parameters P_Q and P_U

Object	JD	Orbital phase	$\overline{P_Q}$(obs)	$\overline{P_U}$(obs)
RS Oph	2457956.3558	0.47	-0.002 ± 0.003	0.027 ± 0.004
	2458166.6517	0.93	-0.002 ± 0.002	0.029 ± 0.003
	2458188.6342	0.98	-0.003 ± 0.003	0.028 ± 0.003
	2458307.3708	0.24	-0.001 ± 0.002	0.028 ± 0.002

T a b l e 3

The parameters of the Serkowski's law fit

Object	$P(\lambda)_{\max}(\%)$	K	$\lambda_{\max}$ [Å]
RS Oph	2.9 ± 0.09	1.75 ± 0.28	5627 ± 184

5. Discussion

The interstellar polarization is produced by dichronic 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 the wavelength (Serkowski *et al.* 1975):

$$P_{\rm ISP}(\lambda) = P_{\max} \exp\left(-K \ln^2 \frac{\lambda_{\max}}{\lambda}\right) \quad (7)$$

where $P_{\max}$ is the peak of the interstellar polarization at wavelength $\lambda_{\max}$. Table 3 presents the parameters of the Serkowski's law fit.

The relationship between polarization and extinction has been quantified by Fosalba *et al.* (2002) as:

$$P_{\max,\rm ISM(\%)} = 3.5 E_{B-V}^{0.8}. \quad (8)$$

For RS Oph we use $E_{B-V} = 0.69 \pm 0.07$ (Zamanov *et al.* 2018) so that $P_{\max,\rm ISM} = (2.6 \pm 0.2)\%$. Snijders (1987) determined $E_{B-V} = 0.73 \pm 0.10$ on the basis of UV spectra, and using this value we calculate $P_{\max,\rm ISM} = (2.7 \pm 0.3)\%$. This estimation of the interstellar polarization from the extinction is consistent with that directly measured in our spectropolarimetry.

Cropper (1990) observed variable linear polarization during 1985 outburst indicating the presence of intrinsic polarization. He separated the interstellar polarization from the intrinsic polarization and found that the position angle is aligned with the radio structure. Cropper (1990) determined the mean position angle of the nine field stars and its value is $46\overset{\circ}{.}6 \pm 4\overset{\circ}{.}5$, which is close to that obtained on day 488 after the 1985 outburst for RS Oph ($44\overset{\circ}{.}2 \pm 1\overset{\circ}{.}4$) and the degree of interstellar polarization $P_{\max} = 2.6\%$ at $\lambda_{\max} = 5900$ Å.

Somero, Hakala and Wynn (2017) obtained $P(\lambda_{max}) = (2.75 \pm 0.02)\%$ at $\lambda_{max} = 5867.94 \pm 37.41$ Å and average value of position angle $\theta = 78\overset{\circ}{.}7 \pm 5\overset{\circ}{.}1$.

Our average value of position angle in the region from 5000 Å to 8000 Å is $47\overset{\circ}{.}2 \pm 0\overset{\circ}{.}9$. This is very close to the value of position angle for interstellar polarization determined by Cropper (1990), and the degree of polarization is also consistent with that measurement.

It is worth noting that the optical and radio observations after the outburst confirmed an asymmetric double-ring structure of the nova remnant (O'Brien *et al.* 2006, Bode *et al.* 2007, Rupen *et al.* 2008). It is likely that the intrinsic polarization can be observed only during the outburst when the ejected material scatters the light.

6. Conclusions

We obtained spectropolarimetric observations of the recurrent nova RS Oph on July 21, 2017, February 7, 2018, March 2018 and July 7, 2018. In the wavelength range from 5000 Å to 8000 Å, we find a maximum degree of linear polarization $P_L(\text{obs}) = (2.9 \pm 0.09)\%$ at $\lambda \approx 5600$ Å. The polarization generally decreases from a peak at 5600 Å and can be fitted by a Serkowski's law. The position angle is $47\overset{\circ}{.}2 \pm 0\overset{\circ}{.}9$. There is no wavelength dependence of position angle. We do not detect any variability of the degree of polarization and the position angle. Our results indicate that at the time of our observations, there is no intrinsic polarization in RS Oph and the derived values represent the interstellar polarization. The data reported here can be useful to investigate possible variability of polarization during the next outburst.

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