Monthly Notices of the Royal Astronomical Society

Mon. Not. R. Astron. Soc. **404,** 381–386 (2010) doi:10.1111/j.1365-2966.2010.16289.x

UBVRI observations of the flickering of RS Ophiuchi at quiescence★

R. K. Zamanov,[1]† S. Boeva,[1]† R. Bachev,[1]† M. F. Bode,[2] D. Dimitrov,[1] K. A. Stoyanov,[1] A. Gomboc,[3] S. V. Tsvetkova,[1] L. Slavcheva-Mihova,[1] B. Spasov,[1] K. Koleva[1] and B. Mihov[1]

[1]*Institute of Astronomy, Bulgarian Academy of Sciences, 72 Tsarighradsko Shousse Blvd., 1784 Sofia, Bulgaria*
[2]*Astrophysics Research Institute, Liverpool John Moores University, Twelve Quays House, Birkenhead CH41 1LD*
[3]*Faculty of Mathematics and Physics, University of Ljubljana, Jadranska 19, 1000 Ljubljana, Slovenia*

Accepted 2010 January 4. Received 2010 January 4; in original form 2009 October 1

ABSTRACT

We report observations of the flickering variability of the recurrent nova RS Oph at quiescence on the basis of simultaneous observations in five bands ($UBVRI$). RS Oph has a flickering source with $(U-B)_0 = -0.62 \pm 0.07$, $(B-V)_0 = 0.15 \pm 0.10$ and $(V-R)_0 = 0.25 \pm 0.05$.

We find for the flickering source a temperature $T_{\rm fl} \approx 9500 \pm 500$ K, and luminosity $L_{\rm fl} \sim 50$–$150\,{\rm L}_{\odot}$ (using a distance of $d = 1.6$ kpc).

We also find that on a $(U-B)$ versus $(B-V)$ diagram, the flickering of the symbiotic stars differs from that of the cataclysmic variables. The possible source of the flickering is discussed.

The data are available upon request from the authors.

Key words: binaries: symbiotic – stars: individual: RS Oph – novae, cataclysmic variables.

1 INTRODUCTION

In the symbiotic recurrent nova RS Ophiuchi (HD 162214), a near-Chandrasekhar-mass white dwarf (WD) accretes material from a red giant companion (e.g. Hachisu & Kato 2001; Sokoloski et al. 2006). It experiences nova eruptions approximately every 20 yr (Evans et al. 2008), with the most recent eruption having occurred on 2006 February 12 (Narumi et al. 2006). Fekel et al. (2000) found that RS Oph has an orbital period of 455 d and give red giant and WD masses of 2.3 ${\rm M}_{\odot}$ and close to 1.4 ${\rm M}_{\odot}$, respectively, with a separation of $a = 2.68 \times 10^{13}$ cm between the components. For the range of spectral types suggested (Worters et al. 2007) for the red giant in the RS Oph system, its radius is smaller than its Roche lobe, and accretion on to the WD may occur only from the red giant wind.

The flickering (stochastic light variations on time-scales of a few minutes with an amplitude of a few × 0.1 mag) is a variability observed in the three main types of binaries that contain WDs accreting material from a companion mass-donor star: cataclysmic variables (CVs), supersoft X-ray binaries and symbiotic stars (Sokoloski 2003). The flickering of RS Oph has been detected by Walker (1977). The systematic searches for flickering variability in symbiotic stars and related objects (Dobrzycka, Kenyon & Milone 1996a; Sokoloski, Bildsten & Ho 2001; Gromadzki et al. 2006) have shown that among ∼200 symbiotic stars known, only nine present flickering – RS Oph, T CrB, MWC 560, Z And, V2116 Oph, CH Cyg, RT Cru, o Cet and V407 Cyg.

Here, we investigate the flickering variability of RS Oph in the *UBVRI* bands and discuss its possible origin.

2 OBSERVATIONS

On the night of 2008 July 6, we observed RS Oph simultaneously with four telescopes equipped with CCD cameras. The 2-m RCC telescope of the National Astronomical Observatory (NAO) Rozhen equipped with a dual channel focal reducer was observed in U and V bands. In the U band, a Photometrics CCD (1024 × 1024 pixels, field of view of 4.9 × 4.9 arcmin^2) has been used, and in the V band a VersArray 1330B CCD (1340 × 1300 pixels, field of view of 6.3 × 6.3 arcmin^2). The 60 cm Rozhen telescope was observed in the R band (equipped with an FLI PL09000 CCD with 3056 × 3056 pixels and field of view of 5.7 × 5.7 arcmin^2), the 50/70 cm Schmidt telescope of NAO Rozhen in the B band (SBIG STL11000M CCD, 4008 × 2672 pixels and field of view of 16 × 24 arcmin^2) and the 60 cm telescope of the Belogradchick Astronomical Observatory in the I band (SBIG ST8 CCD, 1530 × 1020 pixels and field of view of 6.4 × 4.2 arcmin^2).

On the night of 2009 July 21, we observed RS Oph simultaneously with three telescopes. The 50/70 cm Schmidt telescope was observed in the U band, the 60 cm Rozhen telescope in repeating B

★Based on data from Bulgarian observatories Rozhen and Belogradchik.

†E-mail: rkz@astro.bas.bg (RKZ); sboeva@astro.bas.bg (SB); bachevr@astro.bas.bg (RB)

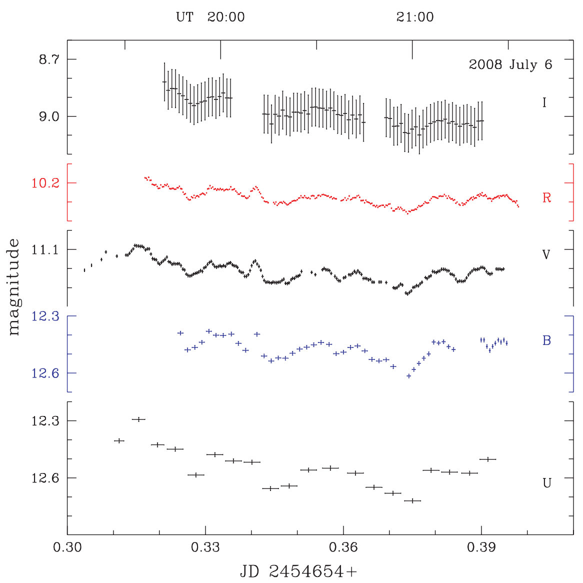

Figure 1. Variability of RS Oph in the *UBVRI* bands on 2008 July 6.

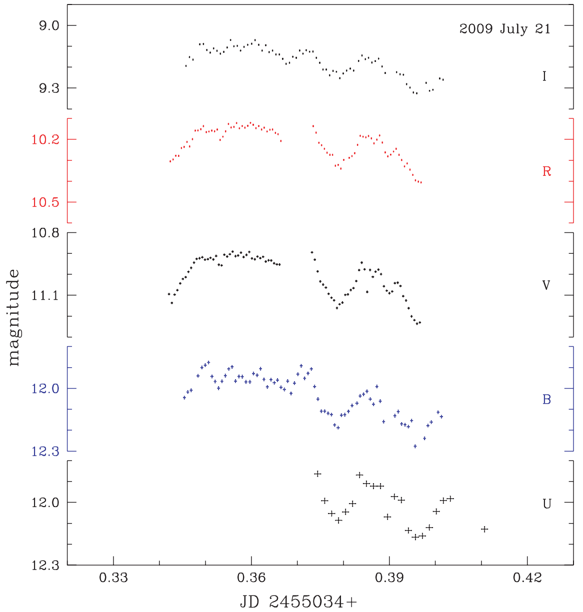

Figure 2. Variability of RS Oph in the *UBVRI* bands on 2009 July 21.

and *I* bands and the 60 cm Belogradchick telescope in repeating *V* and *R* bands.

On the night of 2009 July 23, we observed RS Oph simultaneously with three telescopes. The 2 m RCC telescope was observed simultaneously in *U* and *V* bands, the 50/70 cm Schmidt telescope in the *B* band and the 60 cm Rozhen and Belogradchick telescopes in the *I* band.

All the CCD images have been bias subtracted and flat fielded, and standard aperture photometry has been performed. The data reduction and aperture photometry are done with IRAF and have been checked with alternative software packages. The comparison stars of Henden & Munari (2006) have been used.

The results of our observations are summarized in Table 1 and plotted in Figs 1–3. For each run we measure the minimum, maximum and average brightness in the corresponding band, plus the standard deviation of the run.

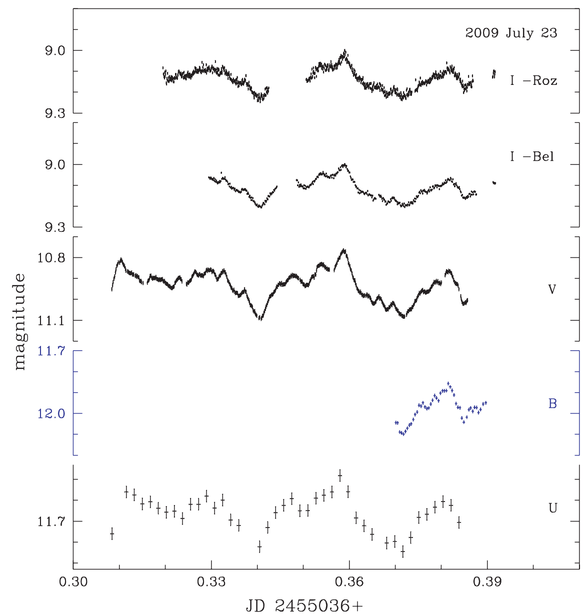

Figure 3. Variability of RS Oph in the *UBVI* bands on 2009 July 23.

3 COLOUR VARIATIONS

As can be seen in Figs 1–3 and Table 1, during our observations, RS Oph exhibited variability on a time-scale of 1–30 min with an amplitude of 0.3 mag in *V*. The amplitude increases to shorter wavelengths and decreases to longer.

3.1 Magnitude–colour relation

In Fig. 4, we plot the colours of RS Oph versus the *R*-band magnitude for 2008 July 6. The *R* band is chosen because we have the shortest exposure time. In order to relate magnitudes in different bands, taken at non-matching start times and different exposure times, we linearly interpolated the light curves. The colours have been calculated over three grids with time resolutions of 70, 120 and 360 s, to match the poorest filter sampling in the corresponding colour relation: 70 s for $(V - R)$ versus R, 120 s for $(B - R)$ versus R and 360 s for $(U - R)$ versus R. Linear fits (of type $y = a + bx$) to the data points in Fig. 4 give

$$(U - R) = -9.73(\pm 1.15) + 1.17(\pm 0.11)R \quad (1)$$

$$(B - R) = -5.91(\pm 0.71) + 0.79(\pm 0.07)R \quad (2)$$

$$(V - R) = -0.86(\pm 0.29) + 0.17(\pm 0.03)R. \quad (3)$$

The errors of the coefficients are given in brackets. These relations are obtained on the basis of the observations from 2008 July 6. They are valid over the range $10.20 \le R \le 10.35$ mag. Spearman's (rho) rank correlation gives $\rho = 0.85$ (significance of 8×10^{-6}) for equation (1), $\rho = 0.66$ (1×10^{-7}) for equation (2) and $\rho = 0.57$ (2×10^{-10}) for equation (3). The significance in equations (1)–(3) is always $\ll$0.001, indicating that all these correlations are highly significant and changes in the colours of RS Oph are correlated with brightness variations.

Table 1. CCD observations of RS Oph. The following are given in the table: the telescope, band, UT start and UT end of the run, exposure time, number of CCD images obtained, average magnitude in the corresponding band, minimum–maximum magnitudes in each band, standard deviation of the mean and typical observational error.

Telescope	Band	UT start–end	Exp time (s)	$N_{\rm pts}$	Average (mag)	Min.–Max. (mag) (mag)	St. dev. (mag)	Error (mag)
2008 July 6		JD 245 4654						
2.0 m Rozhen	*U*	19:27–21:26	300	20	12.546	12.293–12.721	0.103	0.011
50/70 cm Schmidt	*B*	19:46–21:29	100,60,20	50	12.471	12.380–12.615	0.051	0.005
2.0 m Rozhen	*V*	18:54–21:29	30	196	11.215	11.079–11.333	0.052	0.007
60 cm Rozhen	*R*	19:36–21:33	15,20	301	10.277	10.172–10.362	0.036	0.002
60 cm Belogr	*I*	19:42–21:22	60	74	8.990	8.855–9.098	0.057	0.100
2009 July 21		JD 245 5034						
50/70 cm Schmidt	*U*	20:58–21:52	120	21	12.020	11.863–12.166	0.092	0.013
60 cm Rozhen	*B*	20:17–21:38	40	70	12.030	11.876–12.277	0.098	0.007
60 cm Belogr	*V*	20:12–21:31	30	81	11.009	10.891–11.236	0.092	0.004
60 cm Belogr	*R*	20:12–21:31	10	80	10.219	10.121–10.406	0.074	0.003
60 cm Rozhen	*I*	20:17–21:38	10	70	9.172	9.070–9.325	0.066	0.003
2009 July 23		JD 245 5036						
2.0 m Rozhen	*U*	19:23–21:14	120	41	11.659	11.482–11.845	0.081	0.028
50/70 cm Schmidt	*B*	20:53–21:21	30	46	11.978	11.857–12.099	0.062	0.007
2.0 m Rozhen	*V*	19:24–21:15	10	467	10.932	10.766–11.093	0.070	0.008
60 cm Rozhen	*I*	19:40–21:17	5	766	9.096	8.970–9.216	0.050	0.005
60 cm Belogr	*I*	19:55–21:24	10	404	9.118	8.998–9.206	0.048	0.003

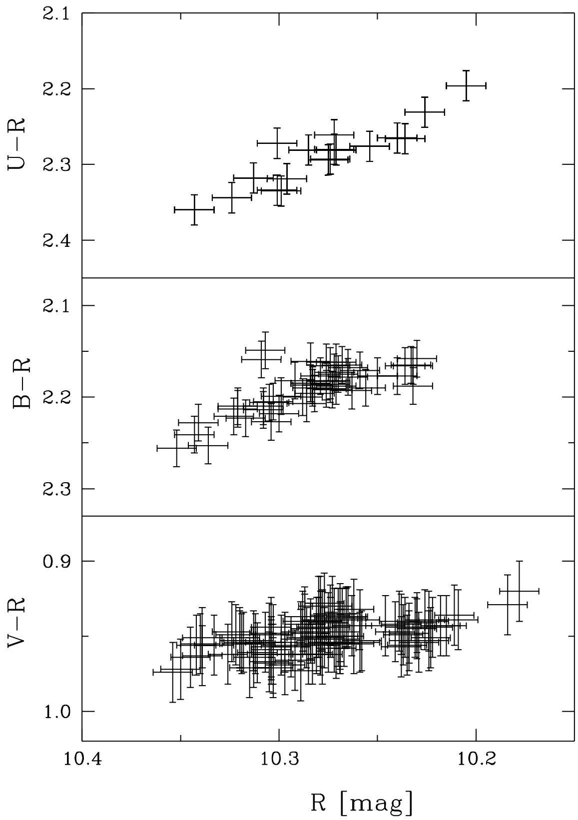

Figure 4. $(U - R)$, $(B - R)$ and $(V - R)$ colours of RS Oph versus R-band magnitude for 2008 July 6.

3.2 Colours of the flickering source

Bruch (1992) proposed that the light curve of CVs can be separated into two parts – constant light and variable (flickering) source. We assume that all the variability is due to flickering. In these suppositions, the flickering light source is considered 100 per cent modulated. Following these suggestions, we calculate the flux of the flickering light source as $F_{\rm fl} = F_{\rm av} - F_{\rm min}$, where $F_{\rm av}$ is the average flux during the run and $F_{\rm min}$ is the minimum flux during the run (corrected for the typical error of the observations). $F_{\rm fl}$ has been calculated for each band, using the values given in Table 1 and Bessell (1979) calibration for the fluxes of a zero-magnitude star.

Adopting these results, we find that the flickering light source contributes about 6 per cent of the light in the R band, 7 per cent in V, 10 per cent in B and 13 per cent in U.

Following Snijders (1987), we assume interstellar extinction $E_{B-V} = 0.73$ and an extinction law as given in Cardelli, Clayton & Mathis (1989). Using the colour relations (equations 1–3, derived in Section 3.1) in the interval $R = 10.28$–10.34 mag (in other words average $R = 10.28$ and we calculate average values for other bands, minimal brightness in $R = 10.34$, and derive minimal fluxes in other bands), we obtain colours of the flickering light source in RS Oph as $(U - B)_0 = -0.67 \pm 0.06$, $(B - V)_0 = 0.08 \pm 0.06$ and $(V - R)_0 = 0.28 \pm 0.08$. On 2009 July 21, we obtained $(B - V)_0 = 0.22$ and $(V - R)_0 = 0.22$. Using the entire runs in the U band from 2009 July 23 and B and V from 2009 July 21 (as plotted in Fig. 5), we calculate $(B - V)_0 = 0.22$ and $(U - B)_0 = -0.57$. The values are similar to the colours of the flickering source in 1983 July–August $(U - B)_0 = -0.71$ and $(B - V)_0 = 0.07$–0.11 (Bruch 1992).

4 FLICKERING

4.1 Temperature and size of the flickering source

The derived $(U - B)_0$ colour corresponds to a B4V star ($T_{\rm eff} \approx 17\,000$ K) and a blackbody with $T \approx 9000$ K. The $(B - V)_0$ colour corresponds to an A5V ($T_{\rm eff} \approx 9000$ K) star and a blackbody with $T \approx 10\,000$ K. $(V - R)_0$ corresponds to an F8V star ($T_{\rm eff} = 7000$ K).

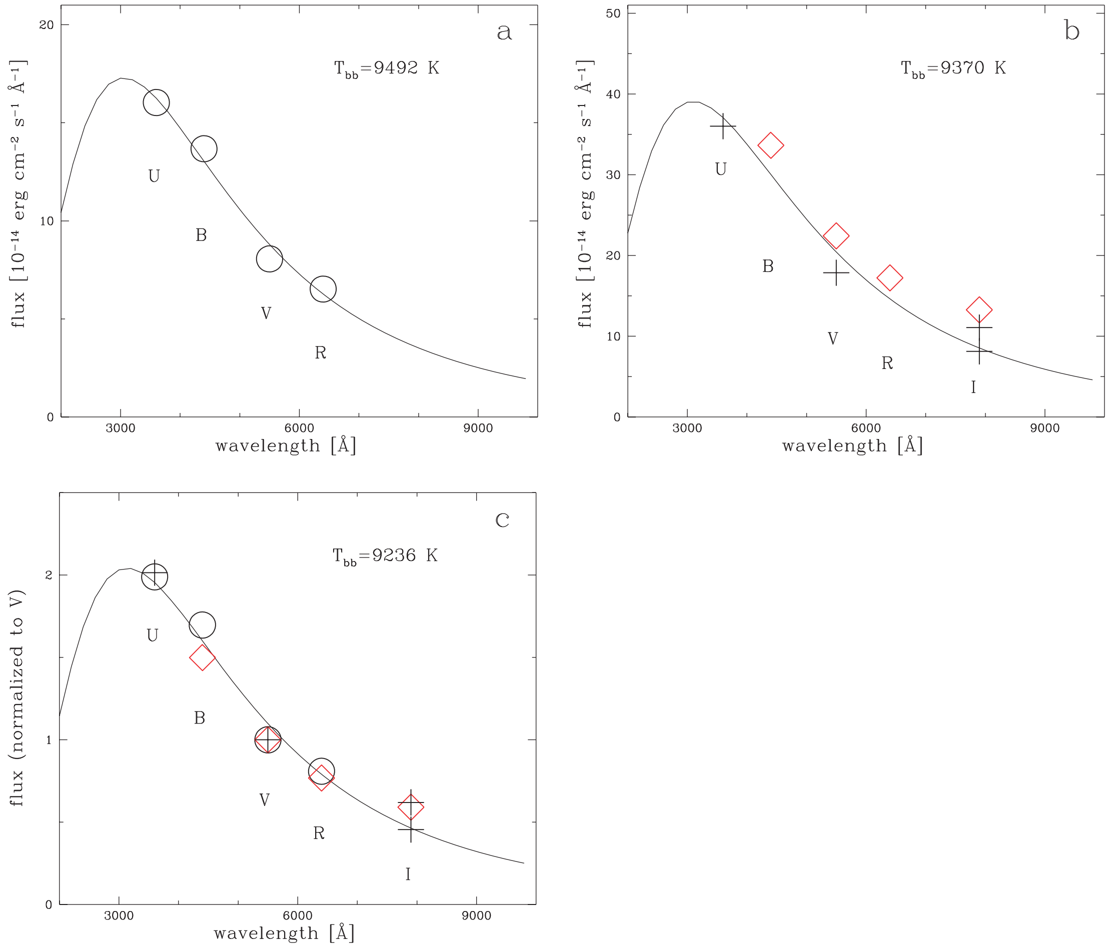

Figure 5. Dereddened fluxes of the flickering light source of RS Oph. The solid line represents a blackbody fit. (a) 2008 July 6 (circles), $T_{\rm bb} = 9492$ K, radius $R = 2.6\,{\rm R}_\odot$, located at distance $d = 1.6$ kpc. (b) 2009 July 21 (diamonds) and 2009 July 23 (pluses) plotted together. The fit is $T_{\rm bb} = 9370$ K and radius $R = 4.7\,{\rm R}_\odot$. (c) All data normalized to the V band and plotted together. The fit is $T_{\rm bb} = 9236$ K. Symbols are identical to those in (a) and (b).

These estimates give an approximate temperature of the flickering light source $T_{\rm fl} = 9000$–$12\,000$ K.

For the flickering light source, we obtain the following magnitudes (corrected for interstellar extinction):

2008 July 6: $U = 11.40$, $B = 12.06$, $V = 11.92$, $R = 11.55$ mag;
2009 July 21: $B = 10.73$, $V = 10.52$, $R = 10.29$, $I = 9.94$ mag;
2009 July 23: $U = 10.00$, $V = 10.76$, $I = 10.11$–10.45 mag.

The errors are in $U \pm 0.04$, $B \pm 0.05$, $V \pm 0.08$, $R \pm 0.10$ and $I \pm 0.12$.

We adopt $d = 1.6 \pm 0.3$ kpc as given in Bode (1987). In Fig. 5, we plot these magnitudes transformed to fluxes. Using a blackbody fit (*nfit1d* routine of IRAF), we calculate for the flickering light source: $T_{\rm fl} = 9492 \pm 300$ K, $R_{\rm fl} = 2.6 \pm 0.3\,{\rm R}_\odot$, $L_{\rm fl} \sim 50\,{\rm L}_\odot$ (2008 July 6) and $T_{\rm fl} = 9370 \pm 300$ K, $R_{\rm fl} = 4.7 \pm 0.3\,{\rm R}_\odot$, $L_{\rm fl} \sim 150\,{\rm L}_\odot$ (2009 July 21 and 23). In Fig. 5(c), we plot all points normalized to the corresponding V-band flux. The fit gives $T_{\rm fl} = 9236 \pm 200$ K.

Our I-band data from 2008 July 6 have considerably larger observational errors due to a technical problem which gave as a consequence a variable dark current pattern of the CCD. U from 2009 July 21 and B from 2009 July 23 are short. They are therefore not used in the blackbody fits nor plotted in Fig. 5.

There are several different estimates of the mass accretion rate in RS Oph. An estimate of $\dot{M}_{\rm acc} \approx 2 \times 10^{-7}\,{\rm M}_\odot\,{\rm yr}^{-1}$ arises from the required mass accreted on to the WD to give rise to the outburst plus the latest inter-outburst time-scale of 21 yr (Osborne et al., in preparation). Assuming $R_{\rm wd} = 0.003\,{\rm R}_\odot$ (Starrfield et al. 1991), this results in a total accretion luminosity $L_{\rm acc} \approx G M_{\rm wd} \dot{M} / R_{\rm wd} \approx 2900\,{\rm L}_\odot$. Alternatively, Walder, Folini & Shore (2008) explore the hydrodynamics of wind accretion in the system and find $\dot{M}_{\rm acc} \approx 10^{-8}\,{\rm M}_\odot\,{\rm yr}^{-1}$, i.e. $L_{\rm acc} \approx 146\,{\rm L}_\odot$ [which compares to $L_{\rm acc} \approx 190$–$740\,{\rm L}_\odot$ from *International Ultraviolet Explorer* (*IUE*) observations at quiescence – Snijders 1987]. The spectral energy distribution of the accretion disc around the WD is similar to the mid-B spectral type (Dobrzycka et al. 1996b) with a luminosity of 100–600 ${\rm L}_\odot$. Therefore, in practice, the different estimates give $L_{\rm acc} \sim 140$–$2800\,{\rm L}_\odot$, which means that 5–35 per cent of the total accretion luminosity is emitted by the flickering source (in other words, $L_{\rm fl}/L_{\rm acc} \sim 0.05$–$0.35$).

4.2 Time delay

We searched for time lags between the light curves in different bands, using the interpolation cross-correlation method (Gaskell & Sparke 1986), but found no delays longer than 10 s, which is shorter than our time resolution (the exposure times).

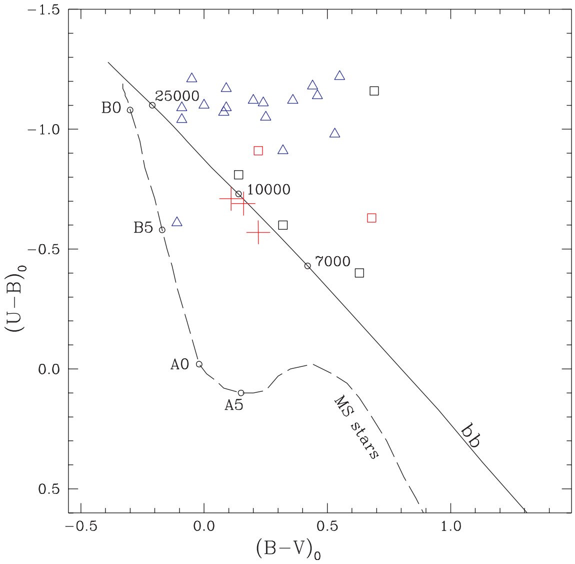

Figure 6. Position of the flickering light source on a $(U - B)$ versus $(B - V)$ diagram. The dashed line is the main sequence. The solid line is a blackbody, (blue) triangles – CVs (from Bruch 1992), (black) squares – symbiotic stars (MWC 560, V407 Cyg), (red) crosses – RS Oph, (red) squares – T CrB.

4.3 Difference between symbiotics and CVs?

Fig. 6 represents a two-colour diagram, $(U - B)_0$ versus $(B - V)_0$ for the flickering light source in a number of CVs and symbiotics. The data for the CVs and T CrB are from Bruch (1992). We also plot two points for MWC 560 and two for V407 Cyg, which are calculated from the data of Gromadzki et al. (2006)

The crosses represent RS Oph. The three crosses refer to the three epochs of observations – 1983, 2008 and 2009. They lie well outside the area of the CVs. To address the possible errors of our measurement, we separated our light curves of RS Oph (plotted in Fig. 1) into two parts (UT 19:46–20:26 and UT 20:27–21:22). We obtained for the flickering source $(U - B)_0 = -0.61$ $(B - V)_0 = 0.11$ for the first time interval and $(U - B)_0 = -0.74$ $(B - V)_0 = 0.15$ for the second. This indicates that for RS Oph, the errors are approximately equal to the size of the symbols.

To search for differences between the flickering of symbiotic stars and CVs, we performed a two-dimensional Kolmogorov–Smirnov test (Peacock 1983; Fasano & Franceschini 1987), using the data plotted in Fig. 6. We compare colours of the flickering of the recurrent novae RS Oph and T CrB with those of the CVs. The test gives a probability of 2×10^{-3} that both distributions are extracted from the same parent population.

We also performed the same test but comparing CVs with all symbiotic stars. The test gives a probability of 4×10^{-4} that both distributions are extracted from the same parent population. The number of points is not high, but sufficient, as shown in Fasano & Franceschini (1987), and the difference is significant. This result indicates that in this diagram, there are clues to the cause of the differences between the flickering of these two classes of accreting WDs.

In the symbiotics of course, the mass donor is a red giant and the orbital periods are >100 d. In the CVs, the mass donors are late-type dwarfs and the orbital periods are $\sim$1000 times shorter. To the best of our knowledge, this is the first evidence that flickering differs in these types of accreting WDs and the physical cause of this difference warrants further investigation (see below).

5 DISCUSSION

In quiescence, RS Oph varies irregularly between $V = 10.0$–12.2 (Collazzi et al. 2009; AAVSO light curves). This variability is observed before as well as after the 2006 outburst. Darnley, Hounsell & Bode (2008) detected an increase in the brightness in B from 13.5 to 11.9 mag and in V from 12.0 to 10.5 for a year after the 2006 outburst. Worters et al. (2007) detected an increase in V from 11.3 to 11.9 for two weeks. The brightness of RS Oph at the time of our flickering observations is well inside these limits (unfortunately, there does not seem to be any published U light curve). The derived parameters of the flickering can be considered as typical for quiescence.

After the 2006 outburst, the flickering of RS Oph disappeared (Zamanov et al. 2006) probably as a result of (1) destruction of the accretion disc from the nova explosion or (2) a change in the inner disc associated with jet production (Sokoloski, Rupen & Mioduszewski 2008). The flickering resumed by day 241 of the outburst (Worters et al. 2007). For the symbiotic star CH Cyg, Sokoloski & Kenyon (2003) observed changes in the flickering in association with the mass ejection event. Observations of CH Cyg and RS Oph therefore indicate that a connection does exist between the flickering behaviour and the ejection of matter from the WD.

Different sites for the origin of the flickering have been discussed. They are all related to the accretion process:

(i) the bright spot (the region of impact of the stream of transferred matter from the mass-donor star on the accretion disc);
(ii) the boundary layer (between the innermost accretion disc and the WD surface);
(iii) inside the accretion disc itself.

The findings of Bruch (2000) for HT Cas, V2051 Oph, IP Peg and UX UMa demonstrated that the flickering in these CVs can originate in both regions (i) and (ii).

(i) The temperature and the size of the bright-spot are derived for a number of CVs. A few examples of temperatures are as follows: for OY Car, Wood et al. (1989) calculated blackbody $T = 13\,800 \pm 1300$ K and colour temperature $T = 9000$ K; for IP Peg, Marsh (1988) calculated $T = 11\,200$ K; for U Gem, Zhang & Robinson (1987) calculated $T = 11\,600 \pm 500$ K; and Robinson, Nather & Patterson (1978) gave $T = 16\,000$ K for the bright spot in WZ Sge. The temperature of the optical flickering source of RS Oph $T_{\rm fl} \approx 10\,000$ K (see Section 4.1) is similar to the temperature of the bright spot for the CVs. The mass transfer in RS Oph may not be from the Roche lobe overflow (as in CVs), but via stellar wind accretion. As a result of the supersonic motion of the WD through the red giant wind, there should be a shock cone and an accretion wake. Around the WD, it is likely that an accretion disc and/or a cocoon is formed. In the place where the matter flowing through the accretion wake encounters the accretion disc/cocoon, a bright spot could be formed (analogous to the bright spot formed in the case of CVs, where the mass flow from the inner Lagrangian point encounters the accretion disc).

(ii) Another possible site for the origin of the flickering in RS Oph is the boundary layer between the WD and accretion disc. Bruch & Duschl (1993) estimated the size of the boundary layer (ϵ) in RS Oph as $\epsilon = 2.20$. In their model, $L_{\rm d}/L_{\rm bl}$ is connected with the size of the boundary layer ($L_{\rm d}$ is the luminosity of the accretion disc and $L_{\rm bl}$ is the luminosity of the boundary layer; see fig. 1 in Bruch & Duschl 1993). If we assume $L_{\rm d} + L_{\rm bl} \approx L_{\rm acc} \approx 110$–$2000\,{\rm L}_\odot$ and $L_{\rm bl} \approx L_{\rm fl} \approx 5$–$150\,{\rm L}_\odot$, then we calculate $L_{\rm d}/L_{\rm bl} = 1.2$–$12$, and the lower value agrees with the size of the boundary layer as estimated by Bruch & Duschl (1993). However, $T_{\rm fl}$ of RS Oph as derived in Section 4.1 is too low for a boundary layer.

(iii) For UU Aqr, Baptista & Bortoletto (2008) found no evidence of flickering generated in regions (i) and (ii). They suggested that the flickering in UU Aqr is generated in the accretion disc itself, and a possible reason can be turbulence generated after the collision of disc gas with the density-enhanced spiral wave in the accretion disc.

The radial temperature profile of a steady-state accretion disc is

$$T_{\rm eff}^4 = \frac{3G\dot{M}_{\rm acc}M_{\rm wd}}{8\pi\sigma R^3}\left[1 - \left(\frac{R_{\rm wd}}{R}\right)^{1/2}\right], \quad (4)$$

where σ is the Stefan–Boltzmann constant and R is the radial distance from the WD. Using the parameters for RS Oph, a temperature $T_{\rm fl} \sim 9500$ K (the temperature of the flickering light source as derived in Section 4.1) should be achieved at a distance $R \approx 0.5$–$1\,{\rm R}_\odot$ from the WD. If (iii) is the place for the origin of the flickering of RS Oph, then it comes from $R \lesssim 1\,{\rm R}_\odot$ from the WD.

To understand more fully the nature of the flickering variability of RS Oph, we need to acquire a set of spectra simultaneously with photometry and with a time resolution of ~30 s (see also Sokoloski 2003). Such spectra potentially can directly give the spectrum of the flickering light source.

6 CONCLUSIONS

We report our CCD observations of the flickering variability of the recurrent nova RS Oph, simultaneously with four telescopes in the *UBVRI* bands. RS Oph has a flickering source with $(U - B)_0 = -0.62 \pm 0.07$, $(B - V)_0 = 0.15 \pm 0.10$ and $(V - R)_0 = 0.25 \pm 0.05$.

For the flickering light source in RS Oph, (1) we estimate $T_{\rm eff} \approx 9500 \pm 500$ K, which is similar to the temperature of the bright spot in CVs, and (2) using a distance of $d = 1.6$ kpc, we find size $R_{\rm fl} \approx 3.5 \pm 0.5\,{\rm R}_\odot$ and luminosity $L_{\rm fl} \sim 50$–$150\,{\rm L}_\odot$.

We find that on the $(U - B)$ versus $(B - V)$ diagram, the flickering of the symbiotic stars differs from the flickering of the CVs.

The possible sites for the origin of the flickering are briefly discussed, and it is suggested that time-resolved spectroscopy should be carried out to explore this in more detail.

ACKNOWLEDGMENTS

RKZ, AG and KAS acknowledge the partial support by Bulgarian NSF (HTC01-152) and Slovenian Research Agency (BI-BG/09-10-006). We are grateful to the referee, Dr P. Woudt, for very helpful comments on the initial version of this paper.

REFERENCES

Baptista R., Bortoletto A., 2008, ApJ, 676, 1240
Bessell M. S., 1979, PASP, 91, 589
Bode M. F., 1987, in Bode M. F., ed., RS Ophiuchi (1985) and the Recurrent Nova Phenomenon. VNU Science Press, Utrecht, p. 241
Bruch A., 1992, A&A, 266, 237
Bruch A., 2000, A&A, 359, 998
Bruch A., Duschl W. J., 1993, A&A, 275, 219
Cardelli J. A., Clayton G. C., Mathis J. S., 1989, ApJ, 345, 245
Collazzi A. C., Schaefer B. E., Xiao L., Pagnotta A., Kroll P., Löchel K., Henden A. A., 2009, AJ, 138, 1846
Darnley M. J., Hounsell R. A., Bode M. F., 2008, in Evans A., Bode M. F., O'Brien T. J., Darnley M. J., eds, ASP Conf. Ser. Vol. 401. RS Ophiuchi (2006) and the Recurrent Nova Phenomenon. Astron. Soc. Pac., San Francisco, p. 203
Dobrzycka D., Kenyon S. J., Milone A. A. E., 1996a, AJ, 111, 414
Dobrzycka D., Kenyon S. J., Proga D., Mikolajewska J., Wade R. A., 1996b, AJ, 111, 2090
Evans A., Bode M. F., O'Brien T. J., Darnley M. J., eds, 2008, ASP Conf. Ser. Vol. 401, RS Ophiuchi (2006) and the Recurrent Nova Phenomenon. Astron. Soc. Pac., San Francisco
Fasano G., Franceschini A., 1987, MNRAS, 225, 155
Fekel F. C., Joyce R. R., Hinkle K. H., Skrutskie M. F., 2000, AJ, 119, 1375
Gaskell C. M., Sparke L. S., 1986, ApJ, 305, 175
Gromadzki M., Mikolajewski M., Tomov T., Bellas-Velidis I., Dapergolas A., Galan C., 2006, Acta Astron., 56, 97
Hachisu I., Kato M., 2001, ApJ, 558, 323
Henden A., Munari U., 2006, A&A, 458, 339
Marsh T. R., 1988, MNRAS, 231, 1117
Narumi H., Hirosawa K., Kanai K., Renz W., Pereira A., Nakano S., Nakamura Y., Pojmanski G., 2006, IAU Circular, 8671, 2
Peacock J. A., 1983, MNRAS, 202, 615
Robinson E. L., Nather R. E., Patterson J., 1978, ApJ, 219, 168
Snijders M. A. J., 1987, in Bode M. F., ed., RS Ophiuchi (1985) and the Recurrent Nova Phenomenon. VNU Science Press, Utrecht, p. 51
Sokoloski J. L., 2003, in Corradi R. L. M., Mikolajewska R., Mahoney T. J., eds, ASP Conf. Ser. Vol. 303, Symbiotic Stars Probing Stellar Evolution. Astron. Soc. Pac., San Francisco, p. 202
Sokoloski J. L., Kenyon S. J., 2003, ApJ, 584, 1021
Sokoloski J. L., Bildsten L., Ho W. C. G., 2001, MNRAS, 326, 553
Sokoloski J. L., Luna G. J. M., Mukai K., Kenyon S. J., 2006, Nat., 442, 276
Sokoloski J. L., Rupen M. P., Mioduszewski A. J., 2008, ApJ, 685, L137
Starrfield S., Truran J. W., Sparks W. M., Krautter J., 1991, in Malina R. F., Bowyer S., eds, Extreme Ultraviolet Astronomy. Pergamon Press, New York, p. 168
Walder R., Folini D., Shore S. N., 2008, A&A, 484, L9
Walker A. R., 1977, MNRAS, 179, 587
Wood J. H., Horne K., Berriman G., Wade R. A., 1989, ApJ, 341, 974
Worters H. L., Eyres S. P. S., Bromage G. E., Osborne J. P., 2007, MNRAS, 379, 1557
Zamanov R., Boer M., Le Coroller H., Panov K., 2006, Inf. Bull. Var. Stars, 5733
Zhang E.-H., Robinson E. L., 1987, ApJ, 321, 813

This paper has been typeset from a TEX/LATEX file prepared by the author.