The recurrent nova RS Oph: Flickering and Hα emission variability

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Abstract. This paper summarizes our recent results on the short term photometic and Hα variability of the recurrent nova RS Oph. We have performed spectroscopic and photometric observations using a few telescopes. We found that the flickering disappeared after the 2006 outburst. The reappearance of the flickering permit us to estimate the Shakura-Sunyaev parameter $\alpha = 0.26 \pm 0.12$ for the accretion disk in RS Oph. We estimated the temperature, radius and luminosity of the flickering light source on base of simultaneous observations in UBVRI bands. The variability in the wings of the $H\alpha$ emission line is most probably due to ejections of blobs with typical mass $\sim 10^{-10}$ $M_{\odot}$.We also found that the red giant in RS Oph rotates 2-3 times faster than the orbital period.

The observational data are now available on our server http://195.96.237.247/.

Key words: stars: rotation – binaries: spectroscopic – binaries: symbiotic – stars: emission-line, Be – stars: late type

Повторната нова RS Oph: Фликеринг и променливост в емисионната линия $H\alpha$

Радослав К. Заманов

Тази статия представя накратко резултатите от нашите изследвания на повторната нова звезда RS Oph, на нейната кратковременна променливост и променливостта й в емисионната линия $H\alpha$. Проведени са спектрални и фотометрични наблюдения с няколко телескопа. Установихме, че фликерингът е изчезнал след избухването през 2006 г. Появяването на фликеринга ни дава възможност да оценим α параметъра на Шакура-Сюняев за акреционния диск в RS Oph: $\alpha = 0.26 \pm 0.12$. На базата на едновременни наблюдения в UBVRI, оценихме температурата, размера и светимостта на източника на фликеринг. Променливостта в крилата на емисионната линия $H\alpha$, най-вероятно се дължи на изхвърляния на топки (сгъстявания) с типична маса $\sim 10^{-10}$ $M_{\odot}$. Ние получихме, че червеният гигант в RS Oph се върти 2-3 пъти по-бързо от орбиталния период. Наблюдателните данни са достъпни онлайн на нашия сървър http://195.96.237.247/.

1 Introduction

RS Oph comprises a high mass white dwarf (WD) in a 455 day orbit with a red giant. RS Oph has had recorded outbursts in 1898, 1933, 1958, 1967, 1985 and 2006, plus probable eruptions in 1907 and 1945. The optical behaviour from one outburst to the next is very similar. RS Oph is a peculiar symbiotic star exhibiting different types of activity (see Bode 1987, Evans et al. 2008, and papers therein):

– recurrent nova eruptions (light curves are discussed in Adamakis et al. 2011);

– collimated ejecta (Sokoloski et al. 2008; Eyres et al. 2009);

– flickering (Walker 1977, Kundra et al. 2010);
– high velocity outflows (Zajczyk et al. 2008);

It is also suggested that RS Oph is a strong candidate for a future supernova explosion (Patat et al. 2011; Osborne et al. 2011).

The aim here is to present our findings on the Hα variability, flickering, parameters of the flickering source, the value of Shakura-Sunyaev α parameter in the accretion disk, and fast rotation of the mass donor.

2 Observations

Photometric and spectroscopic observations are performed with the following telescopes: the 2m RCC and the 60 cm telescope of the Bulgarian National Astronomical Observatory "Rozhen", 1.2m telescope of Observatoire de Haute-Provence (France), 60 cm telescope of the Belogradchik observatory, the 2.2 m telescope of the European Southern Observatory (ESO) and from the archive of Isaac Newton Group of telescopes (ING). The data are now available online (http://mars.astro.bas.bg/) or upon request from the author.

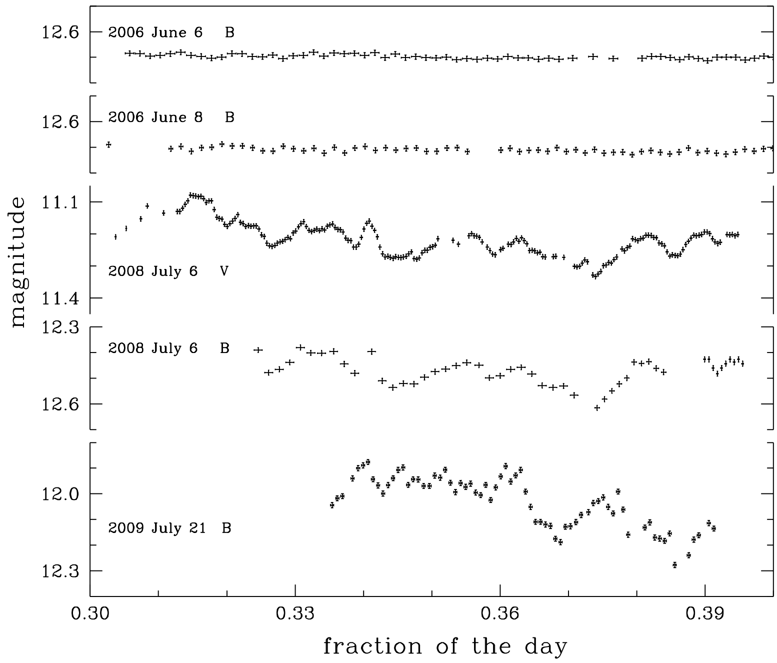

Fig. 1. Examples of our CCD photometric observations. In June 2006 no variability has been detected. In 2008 and 2009 flickering with amplitude in B band > 0.2 mag is visible. The 2006 observations are obtained with the 1.2 m telescope of OHP (France), 2008 V - 2m RCC, B - Schmidt, 2009 - 60 cm Rozhen.

Table 1. Observations of RS Oph in B band on minute-to-hour time scale. In the table are given the date of observations, the amplitude of the B band variability (on time scale minutes-hours), σ_B, and the reference.

Date-obs yyyy/mm/dd	ΔB [mag]	σ_B [mag]	Reference
1983/07/14	0.32	0.07	Bruch 1992
1983/07/18	0.38	0.06	Bruch 1992
1983/08/14	0.34	0.07	Bruch 1992
1993/06/06	0.19	0.07	Dobrzycka et al. 1996
1993/06/07	0.28	0.06	Dobrzycka et al. 1996
1993/06/09	0.24	0.05	Dobrzycka et al. 1996
1997/09/02	0.36		Sokoloski et al. 2001
2002/16/06	0.330	0.057	Gromadzki et al. 2006
2002/08/27	0.275	0.047	Gromadzki et al. 2006
2006/06/06	< 0.058	0.014	Zamanov et al. 2006
2006/06/08	< 0.050	0.011	Zamanov et al. 2006
2006/06/09	< 0.045	0.012	Zamanov et al. 2006
2006/06/10	< 0.035	0.008	Zamanov et al. 2006
2006/07/09	< 0.07		Hric et al. 2008
2006/08/18	0.11		Hric et al. 2008
2007/04/13	0.33		Hric et al. 2008
2007/05/03	0.60		Hric et al. 2009
2007/08/02	0.55		Hric et al. 2009
2008/07/06	0.23	0.051	Zamanov et al. 2010
2008/05/28	0.40		Hric et al. 2009
2008/07/12	0.38		Hric et al. 2009
2009/07/21	0.40	0.098	Zamanov et al. 2010
2009/07/23	0.24	0.062	Zamanov et al. 2010

3 Accretion onto white dwarf

At a process of accretion onto white dwarf the accreted material falls on the white dwarf surface and forms envelope around the white dwarf. The mass of the envelope (ΔM) increases with the time as

$$\Delta M = \dot{M} \Delta t. \tag{1}$$

The pressure at the base of the envelope increases as

$$P_{base} = \frac{G M_{\rm WD} \Delta M}{R^2} \frac{1}{4\pi R^2} = \frac{G M \Delta M}{4\pi R^4}, \tag{2}$$

where G is the gravitational constant, $M_{\rm WD}$ is the white dwarf mass,

When the pressure achieves a critical value $P_{\rm base} \geq 2 \times 10^{19}$ dynes cm^{-2}, a thermonuclear runaway begins on the white dwarf surface (see Gehrz et al. 1998). This thermonuclear runaway we observe as nova outburst. The amount of time between eruptions of a novae is determined by the mass of the white dwarf itself and the amount of accreted material required to trigger the outburst. The recurrent novae are much like classical novae but are different as they are observed to have more then one outburst.

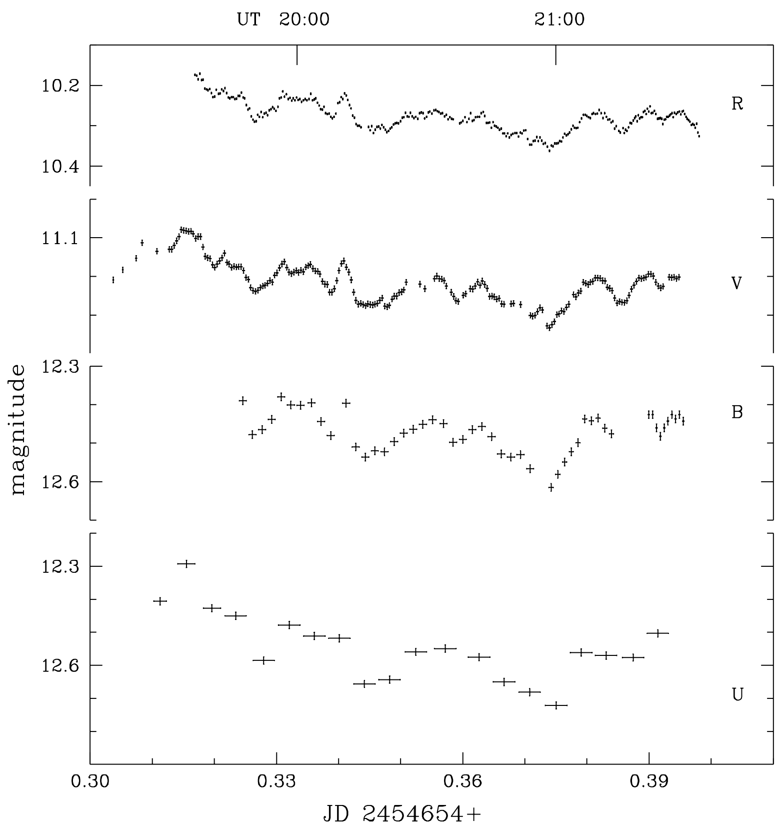

Fig. 2. 95 minutes simultaneous UBVR observations of RS Oph obtained on July 6, 2008.

4 Photometry and accretion disc viscosity

Rapid light variations with amplitude ~0.3 mag in RS Oph were discovered by Walker (1957). They were also observed by Bruch (1980, 1992). Dobrzycka et al. (1996) even detected semiregular oscillations with period 82 min in June 1993.

The latest outburst of the recurrent nova RS Oph occurred in 2006 February. In June 2006 (~ 120 days after the outburst) we performed CCD photometry. Our result was that the flickering was missing at that time. The total intranight amplitude was $\Delta B < 0.06$ and standard deviation of the mean was $\sigma < 0.015$. The disappearance of the flickering is also confirmed by the observations of Hric et al. (2008). In Table 1 are summarized the measurements of amplitude and σ in Johnson B band. A comparison with other data indicates that the short term photometric variability is missing in June 2006. The disappearance of the flickering of RS Oph indicates that the accretion disk around the white dwarf has been destroyed by the 2006 outburst.

Worters et al. (2007) observed resumption of the mass accretion and reappearance of the optical flickering by the day 241 after the outburst.

Combining their and our results, we can obtain an estimate of the Shakura-Sunyaev α parameter for the accretion disk in RS Oph. The time needed the matter to cross the accretion disk (viscous time scale) is

$$\Delta t = \frac{2(R/H)^2 R_{out}^{3/2}}{3\alpha\sqrt{GM_{\rm WD}}}, \qquad (3)$$

where R_{out} is the outer radius of the accretion disk. For a typical Shakura-Sunyaev accretion disk, we can use for the ratio $(R/H) \approx 10$. The parameters appropriate for RS Oph are $R_{out} \approx 10$–$20\ R_{\odot}$, $M_{\rm WD} \approx 1.4\ M_{\odot}$.

For the viscosity parameter in RS Oph, we calculate $\alpha = 0.26 \pm 0.12$, where the error includes the uncertainties of R_{out}, $\mathrm{M}_{\rm WD}$, etc. The Shakura-Sunyaev α parameter is already estimated for a few dozens of object (see King et al. 2007 and references therein):
dwarf novae – $\alpha = 0.1 - 0.3$ (Smak 1999);
PG quasars – $\alpha = 0.01 - 0.03$ (Starling et al. 2004);
blazars – $\alpha = 0.10 - 0.33$ (Xie et al. 2009).

Not surprisingly, the value ($\alpha \approx 0.26$ for RS Oph) is similar to that of the accreting WDs in dwarf novae (dwarf novae are binary star systems in which a red dwarf transfers hydrogen-rich matter to its WD companion).

5 Simultaneous multicolour observations of the flickering

We performed a study of optical flickering in RS Oph, using optical photometry obtained in July 2008 and July 2009 (Zamanov et al. 2010). Based on the degree of flickering in each of our program filters (U, B, V, R or I), we calculate the flux of the flickering component at multiple wavelengths (following the method of Bruch 1992). We then deredden these values assuming $E(B-V) = 0.73$. We calculate the colours of the flickering $(U-B)_0 = -0.62 \pm 0.07$, $(B-V)_0 = 0.15 \pm 0.10$, $(V-R)_0 = 0.25 \pm 0.05$. We determine the best blackbody fit to the derived flickering spectrum at the two observation epochs. We find that the source of the optical flickering has a temperature of around $T_{fl} \approx 9500 \pm 500$ K in both observations, but that the flickering source is significantly brighter in 2009 than in 2008, with a bolometric luminosity of 150 $L_{\odot}$ (vs. 50 $L_{\odot}$ in 2008).

Recently, Nelson et al. (2011) obtained a flickering source flux density from UV photometry ($\lambda = 2310$ Å) which is consistent with our July 2009 fit.

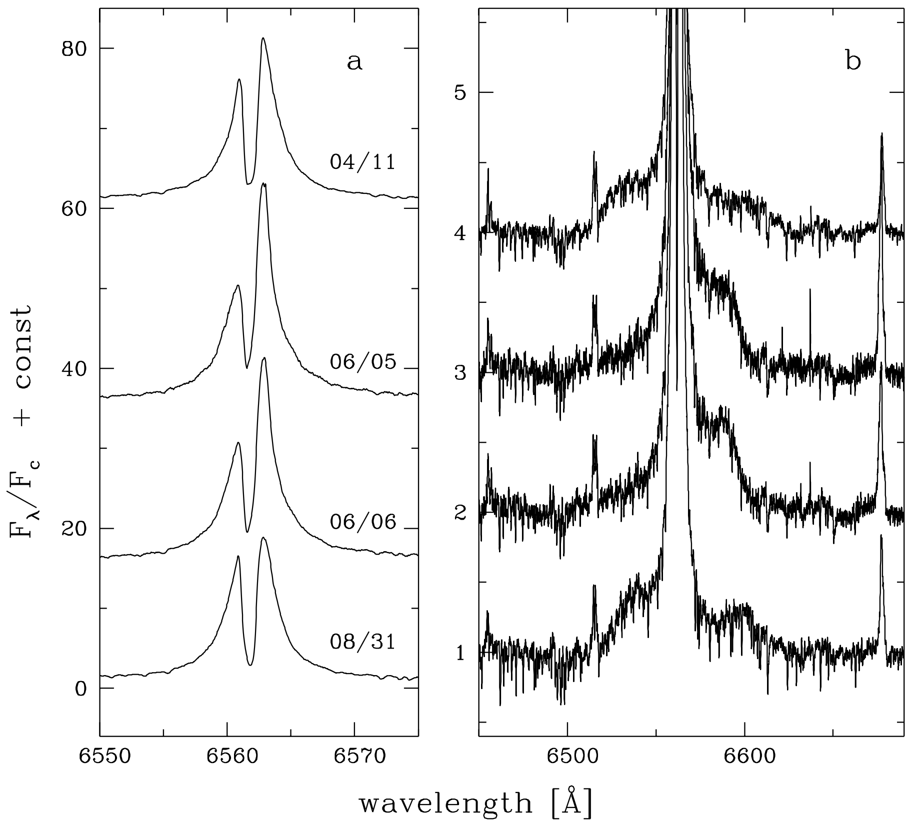

Fig. 3. Plot of Hα emission line of RS Oph.
a) The Hα central double peaked component with FWHM $\sim$5Å (220 km s^{-1}).
b) The same spectra as in a) but on different scales, so the Hα broad component is visible. From up to down are plotted spectra from 2004/04/11, 2004/06/05, 2004/06/06, and 2004/08/31.

6 Hα variability

We report that the Hα emission line of RS Oph was strongly variable during our 2004 observations on a time scale of 1 month (Fig.3). Our data suggest that the Hα profile of RS Oph is purely in emission and consists of both a double peaked central narrow component (FWHM $\sim$ 220 km s^{-1}) and a strongly variable broad one (FWHM $>$ 2000 km s^{-1}). The base of the Hα line was very broad with FWZI$\approx$4600 km s^{-1} on all spectra from 1986 to 2004. The variability of the broad component extends from -2000 to $+2000$ km s^{-1}.

The Balmer emission lines, appearing in the extended envelopes of symbiotic stars usually have an ordinary nebular profile with typical FWHM$\sim$100-

150 $\mathrm{km\,s^{-1}}$. FWHM increases to 200 $\mathrm{km\,s^{-1}}$ only during the active phases. The basic mechanism determining their width is turbulence in the gas. The central narrow emission of RS Oph is very similar to the double peaked Hα line of T CrB (other well known symbiotic recurrent nova) and the two stars have practically the same FWHM of about 200-250 $\mathrm{km\,s^{-1}}$. The Hα line of T CrB is supposed to be formed in the outer part of an accretion disk around the hot compact object. However the peak of this component exceeds the level of the continuum by a factor of 20-25 like purely nebular lines of the symbiotic stars. This peak height differs from that one of T CrB, which exceeds the level of the continuum by a factor of 2-6 only.

While the appearance and the variability of the narrow component is relatively common in symbiotic stars, appearance and variability of broad component is detected in about 10 objects up to now. Fast ($\sim$1000 $\mathrm{km\,s^{-1}}$) bipolar winds/jets were detected in Hen 3-1341 and StHα 190 (Tomov 2003). The jets in both systems appeared as satellite emission components on both sides of the strong HI Balmer and HeI emission lines, and they looked similar to the additional emission bumps in RS Oph (Fig. 3b). Similar profiles have been observed in the symbiotic star AR Pav (Quiroga et al. 2002).

Here, we consider three possible origins for the broad component in RS Oph:

(1) The first possible origin is related to ejection of blobs of matter. These blobs could be expelled by a rotating white dwarf magnetosphere (Tomov 2003 and references therein) or by a jet mechanism. The de-projected velocity of the ejection is $\sim$1500-4000 $\mathrm{km\,s^{-1}}$, assuming it is realized normal to the orbital plane, and also the orbital inclination is $30^0 - 40^0$. This velocity is practically the same as ejection velocities of up to 3800 $\mathrm{km\,s^{-1}}$ seen during the 1985 and 2006 nova outbursts.

(2) Variable disk winds with similar (to RS Oph and CH Cyg) velocities were detected in a few cataclysmic variables and the whole wind can even turn on and off. The terminal velocity of the wind in the BZ Cam system is v_t $\sim$3000 km $\mathrm{s^{-1}}$ and the time scale of the variability is 30-40 min (Ringwald & Naylor 1998). Indeed, their profiles bear a noticeable similarity to those in RS Oph at some epochs. For Q Cyg the terminal velocity is v_t $\sim$1500 km $\mathrm{s^{-1}}$ and the events last about 1.5 hours (Kafka et al. 2003). These time scales are similar to those of the Balmer line variability of CH Cyg but not to RS Oph. It is possible that the disk wind of RS Oph varies on longer time scales.

(3) If the variable broad component of RS Oph originates in an asymmetric disk, then a Keplerian velocity of 1000 km $\mathrm{s^{-1}}$ requires a distance from a 1.4 $M_\odot$ WD of about 2×10^{10} cm. At that distance the Keplerian period is 20 min, which is considerably different from the observed time scale of Hα variability of RS Oph.

All of the mechanisms considered are related to the accretion and the loss of mass by the system. Whenever such mass-loss occurs, a question about its quantitative estimate arises.

The velocity distribution of this line proposes movement of discrete regions (blobs of matter) in the emitting environment (Fig. 3). We obtained a rough estimate of the mass of one "average" blob. On the basis of its Hα emission, we obtain mass of the blob $M_{blob} \sim 2 \times 10^{-8} - 2 \times 10^{-10}$ $M_\odot$.

One other estimate of the mass of the blobs can be obtained from the calculated mass accretion rate $\dot{M}_{acc} \approx 2 \times 10^{-7} - 10^{-8}\ M_{\odot}$. Assuming 1 blob per month and 10% of the mass accretion rate ejected in blobs, we calculate $M_{blob} \sim 2 \times 10^{-9} - 8 \times 10^{-11} M_{\odot}$ in agreement with the above estimate based on Hα emission (more details can be found in Zamanov et al. 2005).

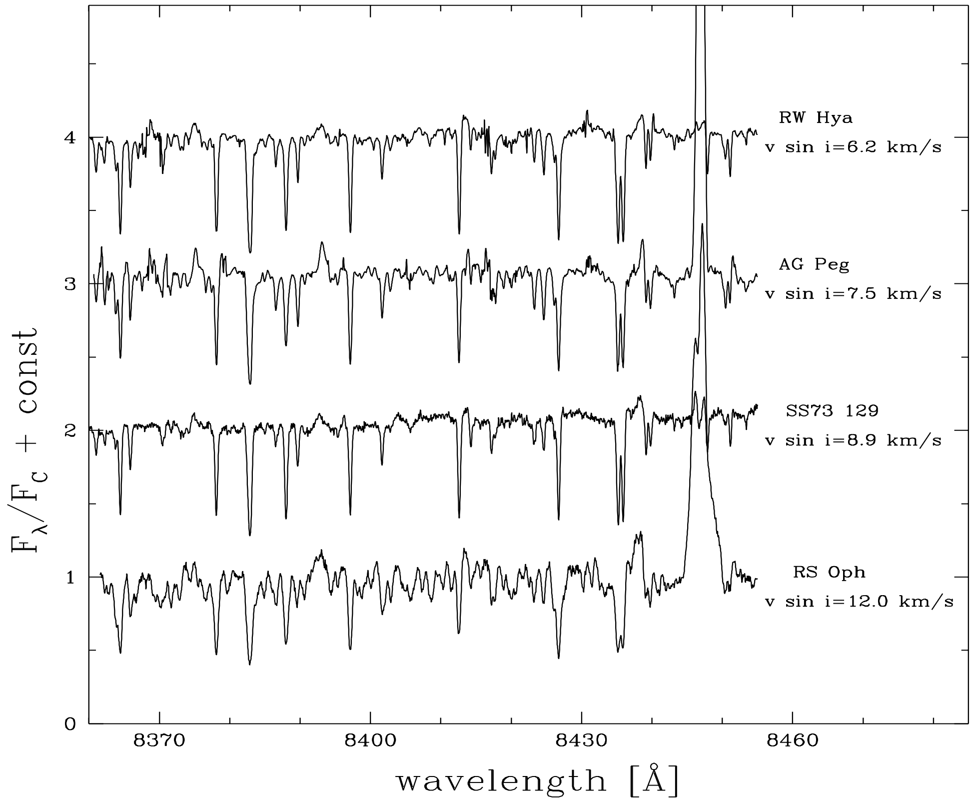

Fig. 4. Spectra of a few symbiotic in the near IR: wavelength range 8360-8450 AA. From up to down: RW Hya (M2III, $v\ \sin i = 6.2 \pm 1.0$ km s^{-1}), AG Peg (M4III, $v\ \sin i = 7.5 \pm 1.0$ km s^{-1}), SS73 129 (M0III, $v\ \sin i = 8.9 \pm 1.0$ km s^{-1}), RS Oph (M0III, $v\ \sin i = 12.0 \pm 1.2$ km s^{-1}). The absorption lines in the RS Oph spectrum are broader due to the faster rotation.

7 Fast rotation of the mass donor

RS Oph has orbital period $P_{orb} = 455.72 \pm 0.83$ days (Fekel et al. 2000). The inclination is about 30–40° (Ribeiro et al. 2009). A normal M0III giant should have a radius $R_g = 59.1 \pm 3\ R_{\odot}$ (van Belle et al. 1999).

We obtained high resolution spectra of a number of southern symbiotic stars with the FEROS spectrograph mounted on 2.2m ESO telescope. Spectra of a few symbiotics in the near IR are plotted in Fig. 4. One can see that the absorption lines in RS Oph are broader than the those of other symbiotics, probably due to a faster rotation. Details of our data and measurement technique can be found in Zamanov et al. (2008). For the projected rotational velocity of the red giant in RS Oph we measure $v\ \sin i = 12 \pm 1.5$ km s^{-1}. This will give for the rotational period of the red giant a $108 < P_{rot} < 197$ days, i.e. P_{rot} is 2–3 times less than the orbital period.

The red giant in RS Oph seems to rotate faster than the orbital period, which means that it has to be in a process of deceleration. The expected synchronization time is $\tau_{syn} \leq 5.10^4$ yr.

While there are no doubts about P_{orb}, any of the other parameters ($v \sin i$, inclination, red giant radius) have to be checked with independent measurements. It is noteworthy that our experiments to measure $v\ \sin i$ with CCF and spectra from different epochs showed that $v\ \sin i$ could even be higher (up to 14.5 ± 1.5 km s^{-1}).

A possible reason for the fast rotation of the giant is that it was spun up during the evolution of the system, when the present day red giant was a main sequence star accreting material via Roche lobe overflow from the former red giant which is the white dwarf now.

Open questions, which should be addressed in the future:
- what is the reason and mechanism generating the Hα variability (blobs or disk wind)?
- what is the reason for the fast rotation of the red giant in RS Oph?
- what is the value of the viscosity α parameter in other symbiotic stars?

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References

Adamakis, S., Eyres, S. P. S., Sarkar, A., & Walsh, R. W. 2011, MNRAS, 504
Bode M.F. (editor), 1987, RS Ophiuchi (1985) and the recurrent nova phenomenon. VNU Science Press
Bruch, A. 1980, Information Bulletin on Variable Stars, 1805, 1
Bruch, A. 1992, A&A, 266, 237
Dobrzycka, D., Kenyon, S. J., & Milone, A. A. E. 1996a, AJ, 111, 414
Evans, A., Bode, M., O'Brien, T.J., Darnley, M.J. (editors), 2008, RS Ophiuchi (2006) and the Recurrent Nova Phenomenon, ASP Conf Ser., vol. 401
Eyres, S. P. S., O'Brien, T. J., Beswick, R., et al. 2009, MNRAS, 395, 1533
Fekel, F. C., Joyce, R. R., Hinkle, K. H., & Skrutskie, M. F. 2000, AJ, 119, 1375
Gehrz, R. D., Truran, J. W., Williams, R. E., & Starrfield, S. 1998, PASP, 110, 3
Hric, L., Kundra, E., & Gális, R. 2009, Young Scientists 16th Proceedings, 11
Hric, L., Kundra, E., Niarchos, P., Manimanis, V. N., Liakos, A., & Gális, R. 2008, *in* RS Ophiuchi (2006) and the Recurrent Nova Phenomenon, Evans, A., Bode, M., O'Brien, T.J., Darnley, M.J. (eds.), ASP Conf Ser., vol. 401, p. 215
Kafka, S., Tappert, C., Honeycutt, R. K., & Bianchini, A. 2003, AJ, 126, 1472
King, A. R., Pringle, J. E., & Livio, M. 2007, MNRAS, 376, 1740
Kundra, E., Hric, L., & Gális, R. 2010, ASP Conf. Series, 435, 341
Nelson, T., Mukai, K., Orio, M., Luna, J., & Sokoloski, J. 2011, ApJ, (in press), arXiv:1105.2569

Ringwald, F. A., & Naylor, T. 1998, AJ, 115, 286
Osborne, J. P., et al. 2011, ApJ, 727, 124
Patat, F., Chugai, N. N., Podsiadlowski, P., Mason, E., Melo, C., & Pasquini, L. 2011, A&A, 530, A63
Quiroga, C., Mikołajewska, J., Brandi, E., Ferrer, O., & García, L. 2002, A&A, 387, 139
Ribeiro, V. A. R. M., et al. 2009, ApJ, 703, 1955
Smak, J. 1999, AcA, 49, 391
Sokoloski, J. L., Rupen, M. P., & Mioduszewski, A. J. 2008, ApJ, 685, L137
Starling, R. L. C., Siemiginowska, A., Uttley, P., & Soria, R. 2004, MNRAS, 347, 67
Tomov, T. 2003, Astronomical Society of the Pacific Conference Series, 303, 376
van Belle, G. T., Lane, B.F., Thompson, R.R., Doden, A.F., Colavita, M.M., et al. 1999, AJ, 117, 521
Walker, M. F. 1957, *in* Non-stable stars, IAU Symposium no. 3, Edited by George H. Herbig., Cambridge University Press, p.46
Walker, A. R. 1977, MNRAS, 179, 587
Worters, H. L., Eyres, S. P. S., Bromage, G. E., & Osborne, J. P. 2007, MNRAS, 379, 1557
Xie, Z. H., Ma, L., Zhang, X., Du, L. M., Hao, J. M., Yi, T. F., & Qiao, E. L. 2009, ApJ, 707, 866
Zajczyk, A., Tomov, T., Mikolajewski, M., Bull, C., Kolev, D., Cikala, M., Georgiev, L., & Galazufdinov, G. 2008, RS Ophiuchi (2006) and the Recurrent Nova Phenomenon, 401, 106
Zamanov, R. K., Bode, M. F., Tomov, N. A., & Porter, J. M. 2005, MNRAS, 363, L26
Zamanov, R. K., Bode, M. F., Melo, C. H. F., Bachev, R., Gomboc, A., Stateva, I. K., Porter, J. M., & Pritchard, J. 2007, MNRAS, 380, 1053
Zamanov, R. K., Boeva, S., Bachev, R., et al. 2010, MNRAS, 404, 381