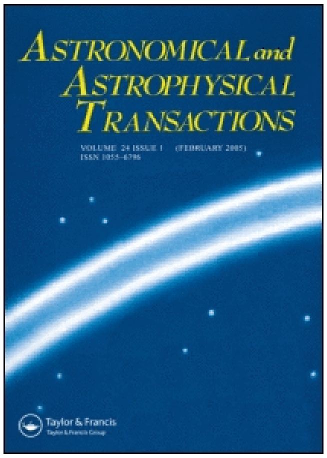

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M. Kumsiashvili [a]; R. Natsvlishvili [a]; N. Kochiashvili [a]
[a] Georgian National Astrophysical Observatory, Tbilisi, Georgia

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A new unique phenomenon for the RY Scuti binary star

M. KUMSIASHVILI*, R. NATSVLISHVILI and N. KOCHIASHVILI

Georgian National Astrophysical Observatory, 2a Kazbegi Avenue, Tbilisi 0160, Georgia

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We present the results of reanalysis of old electrophotometric data on RY Scuti obtained at the Abastumani Astrophysical Observatory, Georgia, during 1972–1990 and at the Maidanak Observatory, Uzbekistan, during 1979–1991. Unstable processes in RY Sct from period to period, from month to month and from year to year are revealed. The magnitude of this variation is from hundredths to tenths. Furthermore, periodic changes in the system's light are displayed near the first maximum on timescales of a few years. This is of great interest with regard to some similar variations seen in luminous blue variable stars and, in particular, in S Dor-type stars. This also could be closely related to the question of why RY Sct ejected its nebula.

Keywords: Close binaries; Eclipse; Periodic variations in light; RY Scuti

1. Introduction

RY Scuti is a unique massive binary star system in a rare transitional evolutionary phase. The short history of investigation of this binary system is as follows: Merrill [1] found the He II ($\lambda = 4686$ Å) line in the spectrum of RY Sct, which is specific only to nebulae and their nuclei. There are also the strongly forbidden lines [Fe III] and [Si III] in the spectrum, as well as the emission lines of hydrogen, helium and other elements. RY Sct was observed to be a radio source [2]. The presence of the intense emission lines and radio emission (as in β Lyr) favoured the assumption that there may be a small H II region around RY Sct [3]. The star is strongly reddened by the surrounding gas and dust shell [4]. Based on spectroscopic observations, Cowley and Hutchings [5] found that the binary system consists of two early-type supergiants with a mass ratio $q = M_2/M_1 = 1.25$. King and Jameson [3] suggested the following model for RY Sct: the B0V primary (brighter) fills its Roche lobe and rapidly transfers its mass to the more massive but less luminous secondary. Guirichin and Mardirossian [6] suggested that the secondary must be surrounded by a geometrically thick accretion disc, which can explain its anomalously low luminosity, and that RY Sct is similar to the peculiar β Lyr system and is currently on its way to becoming a Wolf–Rayet (WR) system. Milano *et al.* [7] and Guirichin

*Corresponding author. Email: mzcherkez@yahoo.com

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and Mardirossian [6] analysed the photometric light curves obtained by Ciatti *et al.* [8], assuming a component mass ratio $q = M_2/M_1 = 1.25$. Later a number of researchers working within the framework of an international coordinated programme (the Georgian National Astrophysical Observatory was the coordinator of this programme) used the spectroscopic data obtained by R. West to infer a new component mass ratio $q = M_2/M_1 = 3.3$ [9]. Spectral observations of RY Sct have been carried out by R.West in the region $\lambda = 3450$–5160 Å with a dispersion of 12 Å mm^{-1}.

Antokhina and Cherepashchuk [10] adopted this new mass ratio and applied the synthetic light curve method to interpret photometric observations made by Kumsiashvili [11], Ciatti *et al.* [8] and Zakirov [12] of RY Sct in the V band. It was concluded that the parameters of RY Sct make it look very much like a WR + OB binary if we assume that the less massive star is at the end of the stage of preliminary mass transfer and is now exposing its helium core on its way to becoming a WR system.

During this time, RY Sct was reinvestigated on the basis of spectroscopic material obtained at the European Southern Observatory (ESO) at La Silla, at the Cerro Tololo Inter-American Observatory (CTIO), covering the spectral regions 3400–5150 Å and 5700–6700 Å, and with International Ultraviolet Explorer (IUE) [13].

A 'new era' of investigation of RY Sct began with articles by Smith and co-workers [14–24] based on the analysis of Hubble Space Telescope (HST) observations and high-resolution ground-based data in multiple spectral regions. The results mainly concern the physical characteristics of the compact nebula around RY Sct. They obtained and analysed rich high-quality observational material in various spectral intervals: visual, infrared and radio. They have spectral material obtained at ESO, HST, Kitt Peak National Observatory (KPNO) and CTIO. In addition, they have HST, Palomar (5 m) and Keck (10 m) telescope images, and Very Large Array radio continuum maps. On the basis of this material, they published detailed analyses of the peculiar nebula around RY Sct [18–24]. These American investigators determined the masses of the companion stars ($49M_\odot$ and $39M_\odot$) and a total bolometric luminosity of $3.4 \times 10^6 L_\odot$ [25]. This value is near the Eddington limit for this system. The spectral classes of the companion stars were O9.5 and O6.5, and the distance between them was 0.43 AU. From HST and Keck images, it was first shown directly that around the close binary there exists a double-lobed $1' \times 2'$ nebula, corresponding to radii of a few thousand astronomical units at a distance of 1.8 kpc [18–21, 23, 24]. The velocity of the system was estimated to be 20 ± 3 km s^{-1}; the electron density $n_e = 2 \times 10^5$ cm^{-3} and the temperature in the nebula of RY Sct was $9000\,\mathrm{K} < T < 10\,000\,\mathrm{K}$ [18–21]. The expansion rate of the nebula at the southwest side is twice that at the northeast side. For estimations, Smith and co-workers used different methods and obtained similar values, which indicates the correctness of their approach. For the mass of the nebula they obtained $M \approx 0.003M_\odot$.

They found that RY Scuti's nebula is helium and nitrogen rich while oxygen and carbon are probably underabundant compared with the solar values, indicating that CNO-processed material is exposed at the surface of the star that has ejected the nebula. This is critical for understanding the system's current evolutionary state [18–21].

The observation that the nebula appears to have been ejected recently (about 120 years ago) during an outburst of the star [22], combined with strong asymmetry in the nebula, may suggest that this short-lived evolutionary phase is characterized by sporadic mass loss. Available evidence [22] implies that RY Scuti may have suffered some event analogous to the S Doradus outbursts of luminous blue variables (LBVs), although this type of outburst might appear phenomenologically different in a contact binary system.

The cooler component in RY Sct resembled an Ofpe/WNS star which is related to passive S Dor-type stars, and both components of RY Sct are located in the instability strip in the Hertzsprung–Russell diagram for quiet S Dor-type stars, although it should be noted that some stars near or within the instability strip are not S Dor-type variables. Preliminary investigation of long-period variations in the RY Sct spectrum is a very important test for this hypothesis.

After these articles were published, we decided to reconsider observational material from an old project on RY Sct, in which the Abastumani Astrophysical Observatory was a coordinator, in an effort to collaborate with the American investigators. Cooperation occurred in the form of a common project.

So, to reveal RY Sct phenomenon, it is essential to investigate the kinds of non-stationary process that occur year after year.

2. Old photoelectric observations: new results

2.1 *Observations*

During 1972–1985, *UBV* electrophotometric observations were made at Abastumani for 97 nights [11]. The average values of phases and brightnesses for each night were calculated. The phase-dependent light curve was plotted (figure 1).

Analysis showed that, during the same phase in different years, the variation in the magnitude of the light is from hundredths to tenths. For instance, if we begin from the light minimum it is noticeable that from 12–13 June to 23–24 June 1982 the eclipse intensity grew by a magnitude of 0.05. This means that the variability occurred during a period. From our data it is evident that the magnitude of the eclipse depth varies by 0.12 year after year. Accordingly, a conclusion can be drawn that the eclipse depth varies during several days, months and years as well.

The picture is similar at the phase maximum. In particular, on 2–3 August 1984 we observed that the magnitude of the light decreased by about 0.08 at a phase of 0.277 compared with other years. The same event is noticed for 1985; at about the same phase (the same maximum phase)

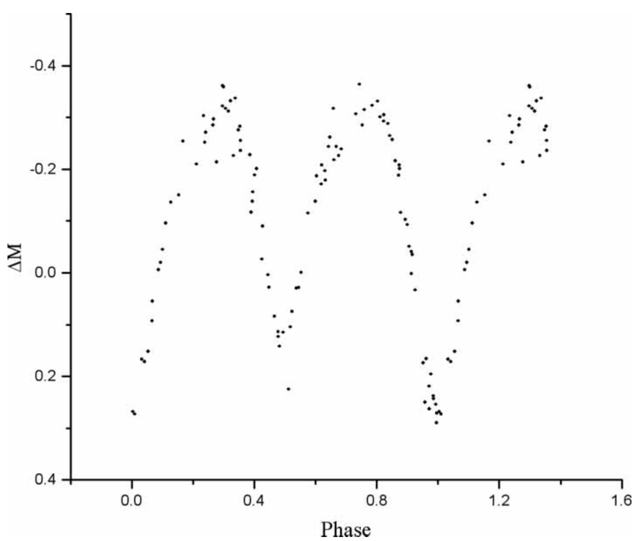

Figure 1. The mean *V* light curve of RY Sct (1972–1985).

from 10–11 to 21–22 June 1985 the magnitude of the stellar light changed by approximately 0.08. This variability also occurred during a period.

The light variation near a phase of 0.4 is essential on the curve. In particular, the star is brighter at a phase of 0.402 than at a phase of 0.390 by a magnitude of about 0.07; this means that, instead of the decrease with the phase increase towards the secondary minimum, an increase in the light is observed. The same feature occurs at phases of 0.425 and 0.427. The star is brighter near the last phase by a magnitude of about 0.065. The phase of 0.512 requires special consideration. For the 17–18 July 1980 observation, the depth of the secondary minimum rose by a magnitude of 0.1 compared with other years. Comparison of observations performed in different years shows that the depth similarly varies at a phase of 0.5 by a magnitude of about 0.05. Fluctuations in the light are observed at the secondary maximum as well, at a phase of about 0.75 phase by a magnitude of 0.08.

As a consequence, relatively smaller intensity microvariations are observed in this system.

Also six-colour photoelectric observations of RY Sct were performed at Abastumani with the cooperation programme [26, 27]. The star was observed in the Stromgren medium-band system (*ubvy*) and Hβ line in 1983–1990 during 49 nights with the 1.25 m telescope. 230 individual measurements were made for each filter. To reveal unstable processes from period to period, from month to month or from year to year, a mean value for each night was estimated in six colours. The *v* colour curve is plotted in figure 2. Small-scale microvariations in the curve are clearly seen. In more detail, it can be said that the light variation by an amplitude magnitude of 0.05 can possibly occur at the same phase from year to year. The observations at phases of 0.252, 0.255, 0.256 and 0.265 carried out in 1983, 1986, 1984 and 1990, respectively are noteworthy. The derived magnitude values of 0.985, 0.972, 0.982 and 0.972 are coincident within an accuracy of 0.01.

A situation similar to three-colour observations is observed in six-colour observations, when the following phase of the descending branch shows more brightening.

In our opinion, these results favour the assumption made by the American researchers that one of the components is probably an S Dor-type variable. They think that the star experienced an outburst 120 years ago with an equivalent magnitude of 2, specific to this type of variable. As a consequence of this, a relatively smaller intensity microvariation is observed in this system. Any periodicity of this variability has not been revealed yet.

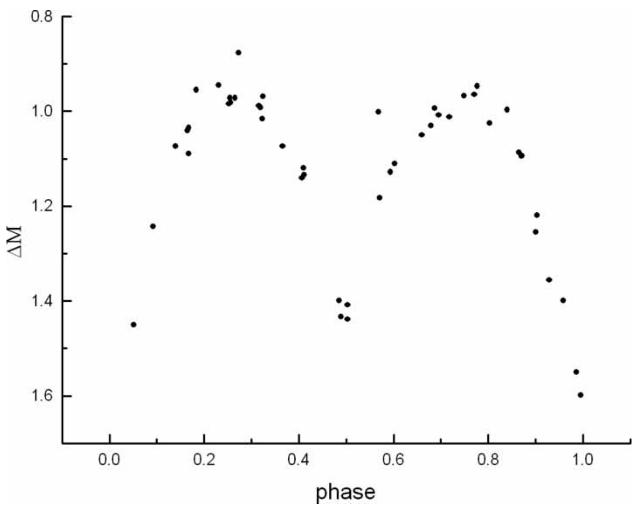

Figure 2. The *v* light curve of Stromgren bands.

2.2 *New results: periodic variations*

After analysis of our three-colour, our six-colour and Zakirov's five-colour observations it is obvious that sometimes the variable returns to its initial state. This was especially seen in the first maximum of the curve. Therefore, on the basis of our three-colour and Zakirov's five-colour observations, we decided that, beginning with the V colour, we should plot the mean night values according to Julian dates (JDs) for the first and second maxima to be observed. Then we tried to fit our data and Zakirov's observations to each other. For this the existence of common observational nights and also observations at the same phase were necessary, namely on 24–25 June 1979 we had both carried out observations at a phase of 0.545, and on 31 May 1976 at phases of 0.0869 (our data) and 0.0860 (Zakirov's data). Accordingly, as a consequence of elementary calculations we estimated the magnitude of the comparison star: $m = 9.387$.

From this value, our observations were converted into magnitudes at phases of $\varphi = 0.170$–0.355 and $\varphi = 0.640$–0.850 for the moments of the first and second maxima. The derived mean night values together with Zakirov's observations were plotted (figures 3 and 4) according to the years 1972–1991 for both maxima separately. It was found that, on the curve appropriate to the first maximum, a certain periodicity of variability is observed, whereas the same cannot be said about the second maximum. In our opinion, the periodic variability observed from the analysis of our observations is probably related to the physics of the primary component, *i.e.* to that star which eclipsed at its primary minimum, filling its limiting Roche lobe. This variability takes place in the following way: approximately every 4 years the curve first falls to a minimum, then in the same period increases to a maximum and finally decreases to a minimum, *i.e.* from minimum to minimum this period is about 8 years.

As can be seen, there has never been much reported photometry on RY Sct. For every observation, in future, a new phenomenon in the light variability of the system could be revealed.

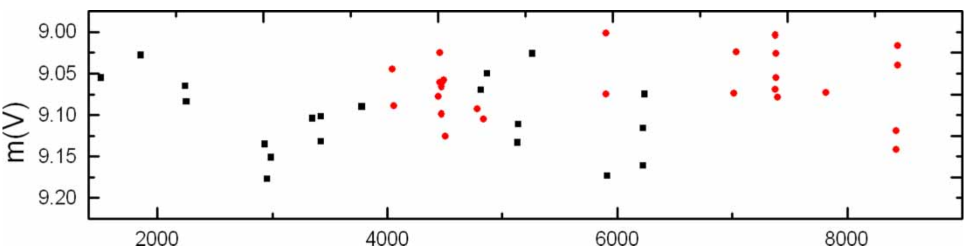

Figure 3. The first maximum for JD 2 440 000+: ■, our observations; •, Zakirov's observations.

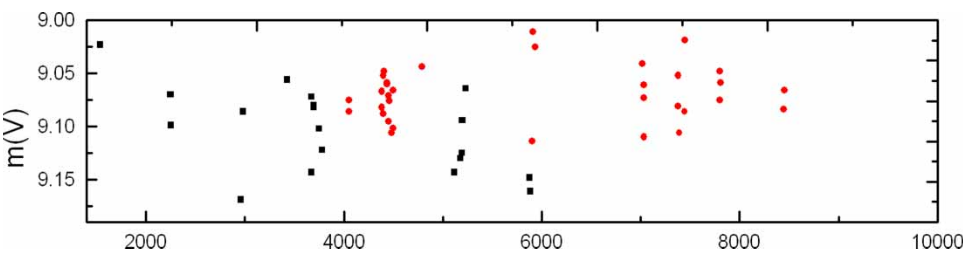

Figure 4. The second maximum for JD 2 440 000+: ■, our observations; •, Zakirov's observations.

3. About variations in the period

An assumption on the sporadic mass ejected from stars exists. Also, there are many photometric and spectral data on the unstable processes that take place in stars. Recent extra-atmospheric, infrared and radio observations also indicate this. Therefore the following ideas naturally arose: the problem of variations in the period should be examined on the basis of the photometric data at our disposal. This suggestion was found to be even more attractive after the earlier photographic data had been reviewed. For instance, in the framework of the collaboration programme, following our request, Belserene [28] revised the Harvard Observatory (USA) plate library containing RY Sct observations since 1888. Having analysed the data from the standpoint of the variations in the period, she concluded that there are small parabolic variations.

The plate library of the Moscow Sternberg Astronomical Institute (observations of 1899–1978) was revised likewise under the supervision of Cherepashchuk [29]. He inferred that there is no reason for a significant variation in the period of RY Sct.

As the variation in the period based on the Abastumani photoelectric material has not been studied yet, we decided to carry out calculations in this direction. The differences between the observed and estimated minima, *i.e.* the $O-C$ values, and our E values were drawn on the curve obtained by Cherepashchuk [29] (figure 5).

In figure 5, crosses denote our data which clearly indicate that the initial epoch and period are refined. As for the variation in the period, this phenomenon is not pronounced. We think that, to solve the problem finally, it is necessary to carry out a long series of precise photoelectric observations exactly at the primary minimum.

4. New spectral and polarimetric observations

Spectral observations of RY Sct were made using the 2.6 m telescope of the Byurakan Astrophysical Observatory (Armenian National Academy of Sciences) in August 2005. The telescope is equipped with a charge-coupled device (CCD) 'SCORPIO'. The size of CCD is 2058 pixels × 2063 pixels. Cooling was achieved using liquid nitrogen. The dispersion is 1.7 Å pixel^{-1} and the spectral region is 4000–7150 Å. Observations were made during three nights: 5, 9 and 12 August 2005. 24 spectrograms were obtained.

In our new data, changes that do not depend on the phase for the continuum spectrum can also be seen. Because of this, spectral monitoring of RY Sct is advisable at any time for as long a spectral region as possible.

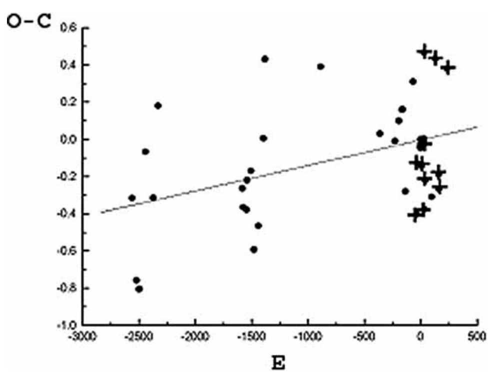

Figure 5. Plot of $O-C$ versus E.

Table 1. Polarization parameters.

Date	Universal time (h min)		Phase	P (%)	Θ (deg)	σ_Θ (deg)
8 June 2005	22	44	0.80	2.78	32.4	±2.0
10 June 2005	22	26	0.97	2.58	34.6	2.0
3 July 2005	21	41	0.04	2.56	31.2	2.1
27 July 2005	20	57	0.19	2.81	29.8	1.9
29 July 2005	19	54	0.37	2.84	30.5	1.7
31 July 2005	21	16	0.55	2.68	28.9	2.2
6 August 2005	20	42	0.09	2.72	32.4	1.8
8 August 2005	20	26	0.27	2.80	29.5	1.7
6 September 2005	19	07	0.87	2.54	28.5	1.9

Polarimetric observations of RY Sct were made at the Abastumani Astrophysical Observatory using the 1.25 m telescope during nine nights: 8–9 June 2005, 10–11 June 2005, 3–4 July 2005, 27–28 July 2005, 29–30 July 2005, 31 July–1 August 2005, 6–7 August 2005, 8–9 August 2005 and 6–7 September 2005. Observations were made using integral light. The collecting time was 18 s. An automatic scanning electropolarimeter (ASEP-78) was made at the Abastumani Astrophysical Observatory. It is equipped with different light filters but we could not observe the system with the filters. It is principally for significant polarimetric observations in different irradiative diapasons as the degree of polarization often depends on the wavelength of the radiation. This dependence is significant for the determination of the physical parameters of the polarizing environment. For example, for Thomson scattering of radiation, the degree of polarization does not depend on the wavelength but, in the case of Rayleigh scattering, it depends on the wavelength.

Very fast changes in the degree of polarization of integral light are observed, but the data obtained are insufficient to consider that they are reliable. After fixing rapid spectral changes, we think that it is possible that rapid changes in the degree of the proper polarization of light also occur. The polarization position angle changed in a certain range (table 1). The polarization parameters are averaged for each date. The times and phases are given for the mean moment of an observation.

In fact, the RY Sct system is located in the Galactic plane ($b \approx 0°$) and at a distance of 1.8 kps; so there may be a fairly large amount of interstellar matter in its direction. However, because of the observed structure around this object, we can assume that there is a large quantity of gas and dust near this system.

So, on the basis of the existing and new observational data, we think that the observational properties of RY Sct are directly connected to the state of the system's components and its surrounding environment, *i.e.* to its structure and dynamics. However, the geometry of the system is a result of those inner physical processes, which are characteristic of components in a recent evolutionary stage. So, observations show a great number of rapid changes in the RY Sct system, which are the results of inner processes that take place in components in a certain evolution phase.

5. Conclusions

(1) According to the Abastumani three-colour *UBV* photoelectric data covering an interval of 14 years and Zakirov's *UBVRI* data the average values of phases and brightnesses for each night were calculated. The phase-dependent *V* light curve was plotted. Analysis showed that during the same phase in different years the light varies by a magnitude from

hundredths to tenths. It is evident that the magnitude of the eclipse depth varies by 0.12 from year to year. Accordingly, a conclusion can be drawn that the light curve varies from period to period, from month to month and from year to year.

(2) In a similar way to the above, certain periodic light changes in the first maximum are revealed but the same cannot be said about the second maximum. This result favours the assumption of the American researchers that one of the components is probably a S Dor-type variable. Now we can be definite that it must be the primary component, *i.e.* the star that eclipsed in the primary minimum, filling its limiting Roche lobe. So, we regard the primary component of RY Sct as responsible for ejecting its young circumstellar nebula seen in the HST image.

(3) Changes in the period are not revealed according to the available photometric material. However, to solve the problem finally, it is essential that special precise photometric observations are made in the primary minimum over as long a time as possible.

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