Advances in Astronomy and Space Physics, **3**, 75-78 (2013)

V407 Cyg and RS Oph – comparison of two exotic variables

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V407 Cygni and RS Ophiuchi are two similar but unique objects. It can be said that they each belong to an individual type of stars. During their quiet state they seem to be symbiotic stars. However, both stars have previously displayed nova-like outbursts. We would like to take a closer look at these two unique objects, and to compare them. We presented spectroscopic and photometric observations of V407 Cyg and RS Oph obtained throughout the period from 2006 until 2013. Our data show the different activity stages connected with the two components of these binary systems. Multicolour photometry and spectra obtained in a wide frequency range are utilized to understand the behaviour of such extremely binaries.

Key words: stars, binaries, observations

INTRODUCTION

V407 Cygni was discovered by Hoffmeister [8] in 1936 as a possible classical nova. However, extensive observations of the object showed that it exhibited symbiotic star attributes, rather than those of classical nova: a dense nebula and the presence of a red giant. Some features are characteristic of a D-type (dust) system, similar to that of the CH Cyg star [20]. With such peculiar objects it is rather challenging to understand their true nature.

The same problem occurs with RS Oph, which was firstly recognized as "probably a new star" by Cannon [4] on Draper Memorial photographs. Now, following outbursts in 1933 [11], 1958 [27], 1967 [26], 1985 [1] and 2006 [22], it is considered to be a recurrent nova [11].

Identification of the type of variability strongly depends on the activity stage during which our observations are carried out. In the case of the V407 Cyg system, we find the red giant which pulsates like a Mira variable, with a period of about 745^d and amplitude of $\Delta m_{pg} > 3^m$ [16]. The second component is the white dwarf, which is the source of long-lasting active phases observed during recent decades by several authors [13, 14, 17]. Active stages of V407 Cygni are connected by occasionally increasing of the mass transfer rate from the red giant to hot component via stellar wind [23]. Simultaneously, in 2010 V407 Cygni revealed the classical nova outburst and unexpectedly become a good candidate for the recurrent symbiotic nova.

RS Oph system contains a red giant and a white dwarf inside a massive envelope, which formed following several outbursts [2]. This configuration, a long orbital period ($P_{orb} = 455.72 \pm 0.83$ days [5]), and the presence of both TiO bands and emission lines, make this binary appear similar to many symbiotic stars.

SYMBIOTIC STARS SURVEY

For the past three decades many symbiotic stars and related objects were observed at Piwnice Observatory near Toruń in Poland. We monitored practically all symbiotic stars brighter than 15^m, located in the Northern hemisphere. Simultaneously, the Targets of Opportunity project enabled us to collect many useful data on classical novae. Our observations are collected using a Schmidt Cassegrain 60/90 cm telescope to obtain spectra in low and high resolution, and a Cassegrain 60 cm telescope to obtain UBVRI photometry. Our experience with erupting events aids us in observations and analysis of symbiotic novae. For example, we observed the outburst of RS Oph and AG Dra in 2006 and CI Cyg in 2008. One of the recent nova-like outbursts in a symbiotic star was observed in Piwnice in 2010 and affected the V407 Cygni system.

PHOTOMETRIC OBSERVATIONS

Outburst of V407 Cygni in 2010 was first reported in [18]. Several features suggest that it was classical nova outburst, unlike the symbiotic outburst most often observed in symbiotic stars: (i) strong wind was observed shortly after maximum outburst, what in our colour light curves is seen as fast changes in V-R and R-I indices (Fig. 1); (ii) in the short period of time prior to the appearance of the strong wind, ejecta from the white dwarf surface formed a thick envelope, observed in the B-V index as "red

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dip", at a time very close to the outburst maximum (JD 2455266). The mean measurement errors are 0.07^m in the U band, 0.04^m in B, 0.03^m in V, 0.03^m in R, and 0.02^m in the I band.

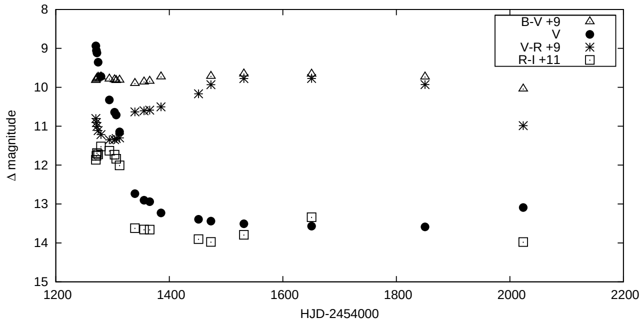

Fig. 1: The light and colour evolution after V407 Cyg outburst maximum.

It is interesting how a classical nova outburst and strong wind from the white dwarf have influenced the Mira structure and pulsations. Swift satellite detected strong X-ray radiation following the outburst maximum [21]. This was a sign that strong shocks were formed in a very hot environment between components, caused by the interactions of the winds emanating from Mira and that of the white dwarf. On the other hand, we plotted ephemeris for giant pulsations from [12, 19] together with our Infrared data, and presented the results in Fig. 2 – prior to the outburst maximum (JD 2455266) the pulsations were in good agreement with predictions for this Mira, however following the outburst maximum the character of variability changed. In frequency it is evident, but hard to determine due to a long pulsation period. However, the change in amplitude is not clear, because a deep minimum in the light curve is not necessarily caused by changes in cool giant; it can also be caused by the opaque envelope.

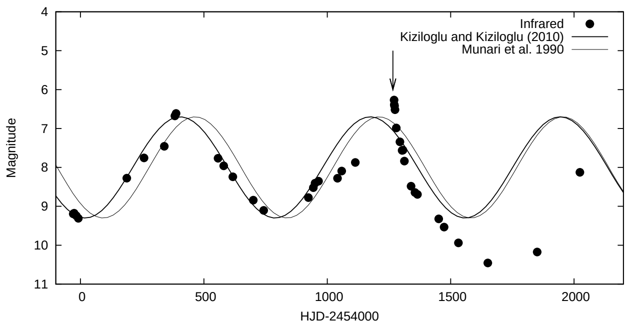

Fig. 2: Brightness changes connected with pulsations of Mira component in V407 Cyg binary observed after and before outburst maximum. Plotted ephemeris contains periods from [12, 19] (thick and thin line, respectively), amplitude and offset are adjusted to the selected filter (I band). The moment of the outburst maximum is indicated by an arrow.

A similar minimum can be seen in the RS Oph light curve (Fig. 3). However, what is of interest in Fig. 3, is that there are several changes long after the outburst (indicated by arrows). There was no evidence prior to 2006 of pulsations in the system, however we could not be sure that the brightenings were not connected with some kind of pulses. Nevertheless, there might be other explanations (arrows in Fig. 3 are also pointing to the conjunctions): it is possible that changes are caused by dust destroyed by high-energetic radiation at this moment [25].

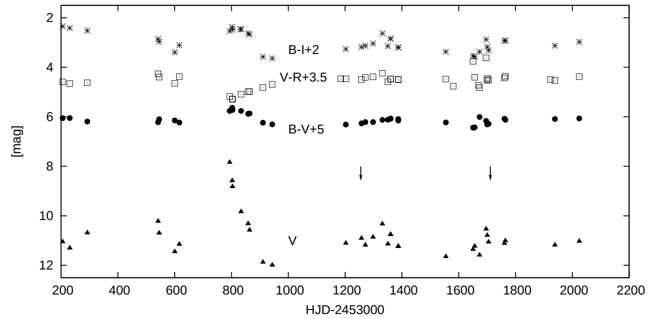

Fig. 3: The light and colour evolution after RS Oph outburst maximum. Conjunctions in the system are pointed with arrows.

In both stars the plateau was observed in light curves shortly after the rapid early decline phase (Fig. 4). These attributes are common to U Sco subclass of the recurrent novae, and indicate that following the outburst maximum, an extended supersoft source illuminated the accretion disc. Moments of nearby constant magnitudes occurred approximately 40 days and 65 days following the outburst maximum for V407 Cygni and RS Oph, respectively. This indicates the presence of a more massive white dwarf in V407 Cygni than in RS Oph [7]. However, it is unusual for the disc to form so shortly after such an energetic outburst, and even more unusual for the disc to survive such a destructive event. Nevertheless, the presence of a disc may explain the plateau stages.

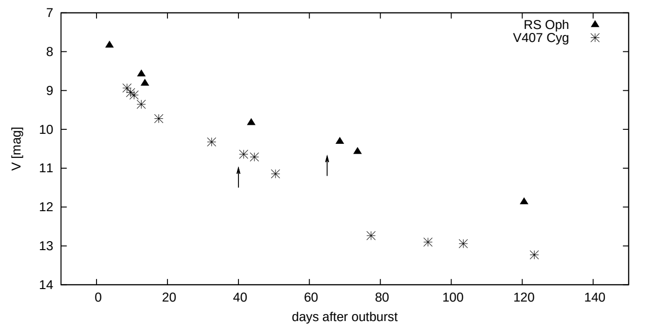

Fig. 4: Optical light curves of RS Oph and V407 Cygni, plateau mid-phases pointed with arrows.

The presence of discs prior to outbursts in both systems may explain the well-observed flickering [3, 6]. But for RS Oph, flickering can be seen for several months, not days, following the outburst [28], while for V407 Cyg, the flickering is not clearly visible. Therefore, if the rapid changes in the light curves are caused by changes in disc, then the peculiar events discussed above can not be explained by the presence of the disc.

SPECTROSCOPIC OBSERVATIONS

Most of the spectroscopic data of the V407 Cyg were taken by Schmidt-Cassagrain Telescope with an objective prism, during the outburst of 2010. Fig. 6 shows some of the most representative data. Even in such low-resolution spectra (12 Å in H_α), one can see changes in several emission lines. The changes are especially pronounced in the end of April H_γ, and decline towards early June. What is noteworthy, 85 days following the outburst, the flux in H_β profile is lower than the flux in forbidden [O III] $\lambda5007$ profile ([O III]/H_β = 1.83). This is potentially an indication of the beginning of the nebular stage [10] and shows that the envelope started to be optically thin. Spectra also show the dual nature of system. At the same time, features of a nova star and symbiotic star can be seen. For example, the number of lines of Fe is characteristic for Fe-nova (e. g. [24]), but in the red part TiO bands can be found, which indicates a late spectral type object; this is a characteristic of symbiotic system.

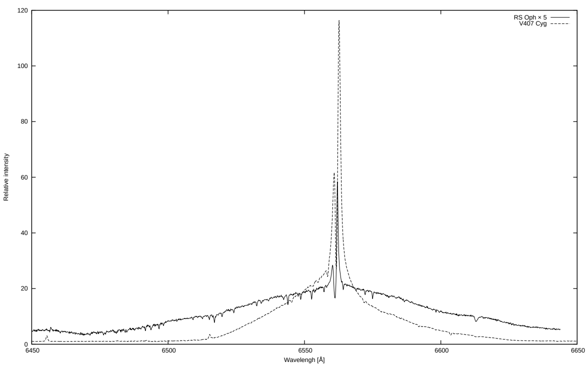

Fig. 5: Comparison of H_α profile in V407 Cyg and RS Oph, four and two days following the outburst, respectively. Spectrum of RS Oph was multiplied by a factor of five.

Spectra for the investigation of RS Oph were collected by a 28 cm diameter telescope with a grating spectrograph. Fig. 5 shows the shape of H_α profiles shortly after outbursts in both discussed stars. For this comparison we used echelle spectrum for V407 Cyg and 2400 g/mm grating for RS Oph, so the resolution is comparable. As we can see, profiles are different in the wings, but the core of this complicated line looks exactly the same: an asymmetric emission with central absorption.

More than five years after the outburst in RS Oph system, one can still see that the nebular stage is not over: many emission lines can be seen, including Fe lines (Fig. 7). However, this feature can not be mistaken with Fe-nova properties, for example, in V407 Cyg, those lines disappeared shortly after the envelope became transparent. There are no leads to presume, that 5 years after the outburst in RS Oph we still have to deal with an optically-thick environment, so emission in Fe lines must be generated by another source.

CONCLUSIONS

V407 Cygni and RS Oph exhibit several features that make them one of the most interesting stars observed at Piwnice Observatory. Their unique behaviour may show us a new class of binaries; it may be passage stage between nova systems and symbiotic stars, as they exhibit characteristics of both types of stars. New observations could bring more insight, however, both objects are faint in their quiet states, so there are difficulties with regular data collecting, especially with V407 Cyg, which tends to blend with another object in the blue part of spectrum. Simultaneously, observations during quiescence can shed some light on the nature of secondary components, because the pulsations that might be sources of brightness changes in late type stars, are attenuated during outburst.

ACKNOWLEDGEMENT

We are greatful to former students of Nicolaus Copernicus University, Cezary Galan and Piotr Wychudzki, for conducting part of the photometric observations, and Agnieszka Fidos, Jedrzej Osiwala, Grzegorz Rycyk, and Malgorzata Wozniak, for conducting part of the spectroscopic observations.

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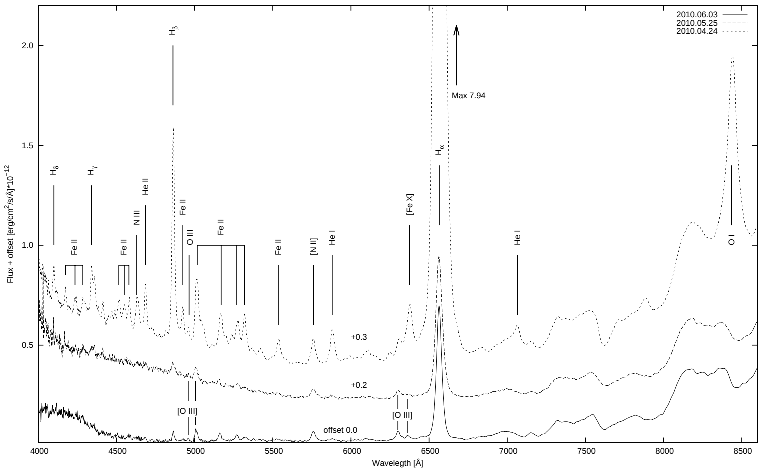

Fig. 6: Evolution of optical spectrum of the V407 Cyg during the 2010 outburst. Only some emission lines are identified [18].

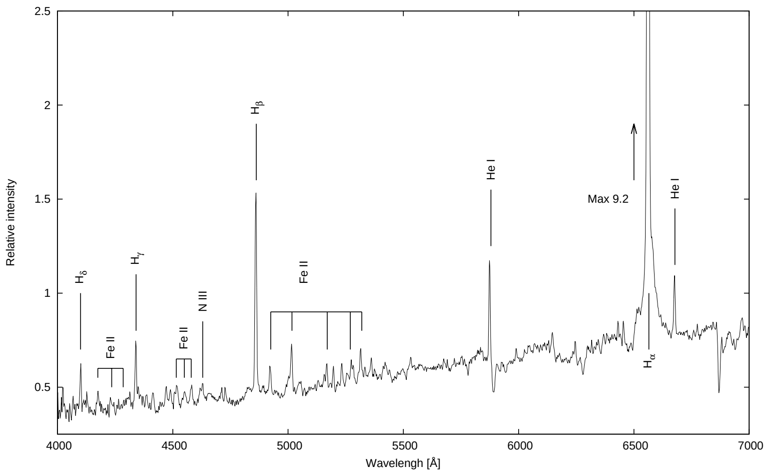

Fig. 7: Optical spectrum of the RS Oph during the 2006 outburst. Only some emission lines are identified [18].

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