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Properties of a cool component in the symbiotic nova V1016 Cyg

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Abstract. Analysis of all available infrared JHK photometry was performed to determine interstellar extinction, distance and basic parameters of the cool component in the symbiotic nova V1016 Cyg. The cool component is a Mira variable of the spectral type M 7 and pulsation period 474 ± 2 days. Its mass is 0.81 ± 0.20 $M_\odot$, mean radius 485 ± 40 $R_\odot$, mean effective temperature 2450 ± 150 K and luminosity 7600 ± 100 $L_\odot$. The distance to symbiotic system was determined to be 2.93 ± 0.75 kpc.

Key words: stars – binaries – symbiotic – photometry – V1016 Cyg

1. Introduction

V1016 Cyg (MHα 328-116) is a member of a small group of symbiotic stars called symbiotic novae. Symbiotic novae are interacting binaries, where matter from a late-type giant is transferred onto the surface of a more compact companion. A nova-like optical outburst ($\Delta m \sim 5 - 7$ mag), lasting decades, is caused by a thermonuclear runaway on the surface of a wind accreting white dwarf after a critical amount of material has been accumulated (Mikolajewska & Kenyon, 1992).

The nova-like outburst of V1016 Cyg occurred in 1964 (McCuskey, 1965). Analysis of historical photographic and photoelectric UBV light curves was performed by Parimucha et al. (2000). These authors discovered a ∼15 years periodicity of activity in the system. Parimucha et al. (2002) showed that the same periodicity is present in the long-term variations of the $J-K$ infrared color index and in variations of both the ultraviolet continuum and in collisionally excited UV emission lines. This periodicity could be interpreted as the orbital period in a binary or triple system.

V1016 Cyg is classified as a D-type symbiotic. The cool component of the system is a Mira variable (Harvey, 1974), which is embedded in a dust envelope. Its pulsation period turned out to be ∼478 days (Munari, 1988). The onset of a dust formation episode in 1983 is reported by Taranova & Yudin (1986).

The aim of this paper is to analyze all available infrared JHK observations in a homogenous way, to determine a more precise period of pulsation of the cool component in the system and to determine interstellar extinction, distance and basic parameters of the cool component.

2. *JHK* observations and the period of pulsation of the cool component

Infrared photometry of V1016 Cyg was published by Harvey (1974), Kenyon & Gallagher (1983), Lorenzetti et al. (1985), Taranova & Yudin (1986), Kenyon (1988), Munari (1988), Ananth & Leahy (1993), Kamath & Ashok (1999) and Taranova & Schenavrin (2000). A few unpublished JHK observations obtained in 1993 were kindly provided by Strafella (private communication). A historical JHK light curve composed from the whole dataset is shown in Fig. 1 (top) together with corresponding $J-K$ and $J-H$ color indices (bottom).

Infrared JHK light curves of V1016 Cyg are affected by Mira pulsations and a long-term increase of brightness. Parimucha et al. (2002) analysed long-term variations of the $J-K$ color index. They found a 15-year variability of the color index phased with UBV brightness variations. These findings ware interpreted as orbitally-related dust obscuration episodes in the system.

All observations were used to newly estimate the period of pulsation of the Mira variable in the system. After removing a parabolical trend from the data due to long-term increase of the brightness (see Taranova & Schenavrin, 2000), a phase dispersion minimization (PDM) method (Stellingwerf, 1978) was used to analyze the corresponding JHK residuals. Significance of the periods in all colors is shown in Fig. 2 (top). The strongest period featured is 474±2 days, which is little shorter than the period estimated by Munari (1988). Fitting the data in all the filters separately with a trigonometrical polynomial led to the following ephemeris:

$$\begin{array}{rlll} \mathrm{JD}_{min} = & 2444357 & +\ 474 & \times E. \\ & \pm 10 & \ \ \pm 2 & \end{array} \quad (1)$$

The data phased with ephemeris (1) are shown in Fig. 2 (bottom). The amplitudes of the variations (m_{max} - m_{min}) in all the colors are ∼1 mag. No periods around 474 days were found in the $J-H$ and $J-K$ color indices. The color indices are therefore not affected by Mira pulsations, but they are strongly influenced by the presence of dust around the system, as was suggested by e.g. Whitelock (1987).

3. Interstellar reddening and distance to V1016 Cyg

Nussbaumer & Schmid (1981) determined interstellar extinction $E(B-V) = 0.28$ from ultraviolet emission lines ratios and from the shape of the ultraviolet

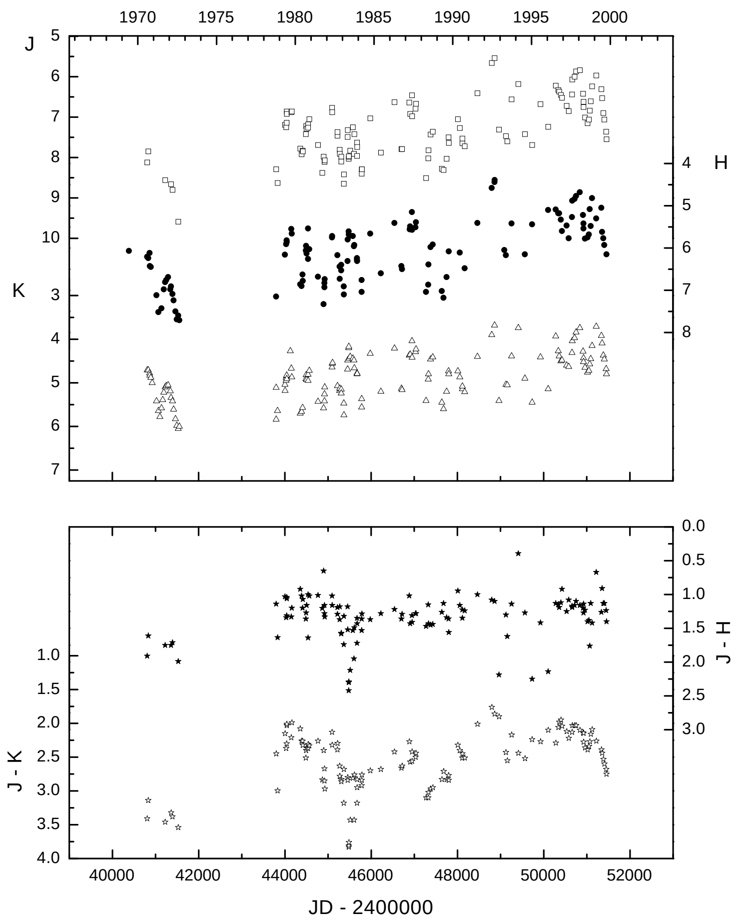

Figure 1. The historical infrared JHK light curves of V1016 Cyg (top) and the corresponding $J-H$ and $J-K$ color indices.

continuum around 2200Å. The ultraviolet emission lines and continuum are formed in the vicinity of the hot component and are not seriously affected by the dust around cool component. We can ascribe this it to real interstellar extinction toward the system. On the other hand, the extinction in the direction towards the cool component is the sum of the real extinction and the extinction from the dust in the envelope around the cool component of the system (Parimucha, 2002). This has to be taken into account, if we want to determine the distance to the system.

Determination of the interstellar reddening toward the cool component and

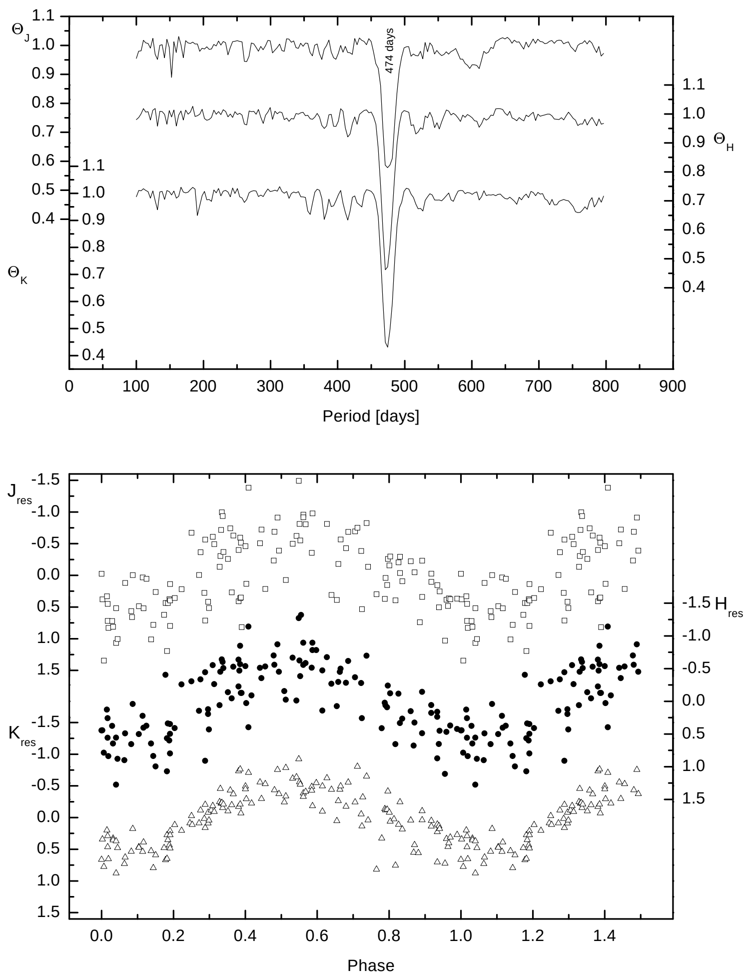

Figure 2. Significances of the periods in JHK filters (top) and the phase diagram corresponding to ephemeris (1) (bottom).

distance d of the system could be based on pulsations of the Mira variable. Van Leeuven et al. (1997) determined a period - luminosity relation between the mean absolute magnitude M_K of the star in a K filter and the period of pulsation P in days

$$M_K = 0.88 - 3.47 \log P, \tag{2}$$

which is based on the period-luminosity relation of Mira variables from the Large Magellanic Cloud (Feast et al., 1989). Using a well known formula for the distance modulus

$$< m_K > -M_K = 5 \log d - 5 + A_K \tag{3}$$

we can determine the distance d of an object, assuming that $< m_K >$ is the mean apparent brightness of a Mira in a K filter. The greatest uncertainty in the application of the previous formula arises from the uncertainty in the estimation of the interstellar absorbtion A_K. Mikolajewska et al. (1999) mentioned that the period-color relation for Mira variables in the solar neighborhood is

$$(J - K)_0 = -0.78 + 0.87 \log P, \tag{4}$$

where $(J - K)_0$ is a color index not affected by interstellar reddening. For interstellar extinction in a $J - K$ color index one can obtain (Fitzpatrick, 1999)

$$E(J - K) = (J - K) - (J - K)_0 \sim 0.5E(B - V) \tag{5}$$

and interstellar absorbtion in K filter in magnitudes could be written as (see e.g. Fitzpatrick, 1999).

$$A_K = 0.36 \; E(B - V). \tag{6}$$

From equation (2) one can obtain the mean absolute magnitude of the Mira variable in the K filter M_K = -8.41 ± 0.16 and equation (4) led to the intrinsic color index $(J - K)_0$ = 1.55 ± 0.09 for the period determined (ephemeris (1)). Due to long-term variations of the K brightness and $(J - K)$ color index (see Fig. 1), the average values of apparent magnitude in a K filter $< m_K >$ = 4.6 ± 1.7 and $(J - K)$ = 2.5 ± 0.6 were estimated from observations obtained in the period from 1985 to 1999.

Equation (5) leads to the interstellar plus dust extinction E(B - V) = 1.9 ± 0.6 and directly from formula (6) we can obtain the interstellar plus dust absorbtion A_K = 0.68 ± 0.22. Applying formula (3) using the previous values, we find out, that the distance of V1016 Cyg is $d = 2.93 \pm 0.75$ kpc.

4. Determination of the basic parameters of the cool component

If we know the pulsation period P of a Mira variable in days we are able to determine its other basic parameters. The equation of pulsations, which describes pulsations of a star, could be written in the form (e.g. Feast, 1996)

$$\log P = 1.5 \log \frac{R_c}{R_\odot} - 0.5 \log \frac{M_c}{M_\odot} + \log Q, \tag{7}$$

where R_c is the radius of the cool component, M_c is the mass of the star and Q is a pulsation constant. The most of Mira variables pulsate in the first overtone (Feast & Whitelock, 1999 and references therein) and so $Q = 0.04$ (Feast, 1996).

Table 1. The parameters of the cool component in V1016 Cyg

Mass [$M_\odot$]	0.81±0.20
Radius [$R_\odot$]	485±40
Effective temperature [K]	2450±150
Luminosity [$L_\odot$]	7600±100
Spectral type	M7
Pulsation period [days]	474±2

The absolute bolometric brightness of Mira variable could be determined from an empirical period - luminosity relation (see e.g. Cox, 2000)

$$M_{bol} = 1.3 - 2.34 \log P, \tag{8}$$

and the bolometric luminosity L_c of the Mira gives a well-known relation (Cox, 2000)

$$M_{bol} = -2.5 \log \frac{L_c}{L_\odot} + 4.74. \tag{9}$$

A combination of relations (8) and (9) gives us the equation

$$\log \frac{L_c}{L_\odot} = 1.376 + 0.936 \log P. \tag{10}$$

Glass & Feast (1982) analyzed 121 Miras in our Galaxy and determined an empirical period - temperature relation

$$\log T_{eff} = 3.862 - 0.177 \log P. \tag{11}$$

The effective temperature and luminosity are connected by the relation

$$\frac{L_c}{L_\odot} = \left(\frac{R_c}{R_\odot}\right)^2 \left(\frac{T_{eff}}{T_\odot}\right)^4 \tag{12}$$

where $T_\odot = 5777$K is the effective temperature of the Sun (Cox, 2000).

If we know the period of pulsation of the cool component we can determine its luminosity using (10) and effective temperature using (11). From equation (12) we find the mean radius of the Mira variable and from pulsation equation (7) we can estimate its mass. The basic parameters of the cool component in V1016 Cyg obtained by the previous formulae are summarized in Table 1.

5. Discussion

It is no doubt that the cool component in the symbiotic nova V1016 Cyg is Mira type variable. Its pulsation period 474 days is longer than pulsation periods of the majority of Miras in symbiotic stars (for references see e.g. Munari 1997). In the context of stellar evolution, the Mira stage appears to occur at the very end of the asymptotic giant branch (AGB) just prior to a planetary nebula formation. Whitelock et al. (1991) showed, that the lifetime of Mira type variables is few times 10^4 years. Feast & Whitelock (1987) showed that by relating the empirical period - luminosity relation with stellar evolution theory, one can estimate the mass of a typical Mira variable to be $\sim$0.9M$_{\odot}$. The estimated mass of the cool component in V1016 Cyg (see Table 1) is less than the typical value. This could mean, that the cool component in the system loses a significant fraction of its mass by strong stellar wind and is at the end of a Mira state. This strong stellar wind has formed a dust envelope around the Mira component. Taranova & Schenavrin (2000) showed that the dust envelope around the cool component in V1016 Cyg is spherically symmetric with the radius of about 1400 $R_{\odot}$ and mass $\sim 3 \times 10^{-5} M_{\odot}$. Its temperature is about 600K. The envelope is composed of silicate dust grains with a typical dimension of $\sim 0.1\mu$m and is optically thick.

Parimucha (2002) gave a review of determined distances of the symbiotic nova V1016 Cyg. These were shown to range from 1 to 7 kpc using different methods. The most employed method was based on pulsations of the cool component. However this technique is very sensitive to a correct estimate of the interstellar reddening toward the Mira variable as well as to the period - luminosity and period - color relations. The generality of the period - luminosity relation for Mira variables was discussed by Feast & Whitelock (1999). The period - luminosity relation (2) determined by van Leeuven et al. (1997) is not properly calibrated for the pulsation periods $>$ 400 days. It could cause some systematic error in luminosity estimates and, consecutively, in determination of the distance. This error is very difficult to assess. Van Leeuven et al. (1997) showed that some long-period Miras may be fainter than one would expect to get from the period - luminosity relation. But this is probably not the case for the cool component in V1016 Cyg, because the determined distance to the system in this paper 2.93 $\pm$ 0.75 kpc, using equations (2) and (4), agrees well with the previously estimated distances 3.4 kpc (Whitelock, 1987) and 2.8 kpc (Taranova & Yudin, 1986).

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