SYMBIOTIC NOVA V1016 CYG AS INTERACTING BINARY

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ABSTRACT. Long-term *UBV* photoelectric and photographic photometry of the symbiotic nova V1016 Cyg is discussed. The pre-outburst brightening in 1949, main nova-like outburst in 1964 and two small brightenings in 1980 and 1994 suggest 15.1±0.2 years period of activity. It is shown that a variation in the $(J-K)$ colour index as well as that in the UV continuum and emission line fluxes in the IUE, HUT and HST spectra exhibit the same periodicity, which is interpreted as the orbital period of the binary on an eccentric orbit. The basic parameters of the system are given.

Key words: Stars: symbiotic, stars: individual - V1016 Cyg, stars: photometry, stars: UV spectroscopy

1. Introduction

V1016 Cyg is a member of a small subgroup of symbiotic novae, also including V1329 Cyg and HM Sge, in which the outburst leads to a nebular spectrum (Mürset & Nussbaumer, 1994). Symbiotic novae are wide interacting binaries, where matter from a late-type giant is transferred onto the surface of the more compact companion. The 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 the critical amount of material has been accumulated (e.g., Mikolajewska & Kenyon, 1992). V1016 Cyg underwent such nova-like outburst in 1964 (McCuskey, 1965). The object is classified as a D-type symbiotic. The cool component is the Mira variable embedded in the dust envelope. Its pulsation period of ~478 days was determined by Munari (1988). Episodic formation of the dust in the system in 1983 was reported by Taranova & Yudin (1986).

Previous estimates of the orbital period of the symbiotic binary V1016 Cyg were not succesful. Taranova & Yudin (1983) used an increase of Balmer emision lines in combination with the appearance and disappearance of FeII lines to estimate the orbital period of ≈20 years. Nussbaumer & Schmid (1988) proposed the orbital period of 9.5 years on the basis of periodicity in the UV fluxes of OI and MgII lines observed by IUE satellite. However they have not observed any two subsequent maxima or minima indicating that a phenomenon repeats with time. Munari (1988) analyzed IR observations and proposed 6-year orbital period based on modeling of the dust obscuration episodes related to the passage of the Mira at the inferior conjunction in the system. Wallerstein (1988) suggested that the sharp FeII emission lines are formed in the chromosphere of the cool star and reflect the orbital motion. Their radial velocities between 1978-1985 limit any orbit of high inclination to a period greater than 25 years or to a large eccentricity. Schild & Schmid (1996) concluded from analysis of spectropolarimetric data taken from 1991-94, that the orbital period is about 80 ± 25 years. However, new observations in 1997 put this result into question (Schmid, 1988).

Long-term photographic, photoelectric and visual photometry of the object gathered and analysed by Parimucha et al. (2000), led to the discovery of 15-year periodicity of activity, interpreted as the orbital period. The aim of the present paper is to confirm this period using available IR photometry and the IUE, HUT and HST spectroscopic observations and to determine the basic parameters of the system.

2. *UBV* photoelectric and photograhic photometry

The historical light curve of V1016 Cyg based on the photographic and *UBV* data gathered by Parimucha et al. (2000) is presented in Fig. 1. The light curve suggests four stages of activity marked by arrows in the figure: the pre-outburst flare *a* in 1949, the main nova-like outburst *b* in 1964 and two post-outburst flares *c* and *d* in 1980 and 1994, respectively. The ephemeris for maxima of activity calculated in Parimucha et al. (2000) is as follows:

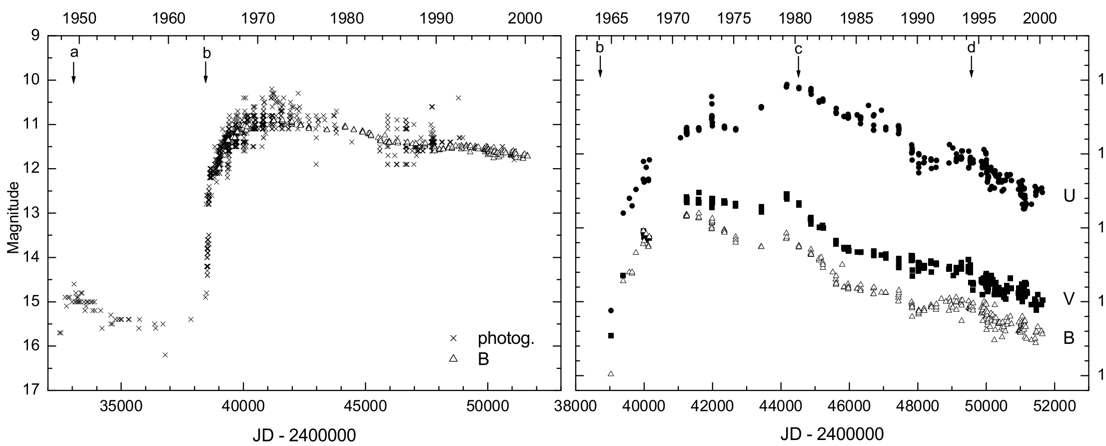

Figure 1: Long-term photographic and photoelectric UBV observations

$$\mathrm{JD}^{phot}_{max} = \underset{\pm 250}{2427590} + \underset{\pm 90}{5510} \times E. \qquad (1)$$

The brightness maxima in 1980 and 1994 followed the well detected brightness decreases as possible signatures of an enhanced mass transfer from the cool to the hot component. Similar effect was detected in the light curve of very slow classical nova V723 Cas (Chochol & Pribulla, 1998).

3. Infrared photometry

We have used all available infrared photometry (for complete list of the observations see Parimucha (2001)) to improve the period of pulsation of the Mira variable present in the system. The Fourier period analysis applied to the JHK data, after the trend removal, led to the mean period $P = 474 \pm 6$ days (Fig. 2). Corresponding phase diagrams are presented in Fig. 3.

According to Whitelock (1987), the $(J-K)$ color index in symbiotic Miras is little affected by the Mira pulsation but it is very sensitive to the circumstellar dust around cool component. The transient dust obscuration episodes are orbitally related, so they could be used to find the orbital period. It is well known, that the dust can be formed also in the ejecta of novae (e.g., Bode, 1993).

The long-term behaviour of the $(J-K)$ color index of V1016 Cyg using all available infrared data is presented in Fig. 4. The most interesting feature is a short-term but strong dust formation episode in 1983 detected by Taranova & Yudin (1986), which occurred three years after the brightness maximum of the nova in U passband. We interpret this by a dust formation in the ejecta of the symbiotic nova. Detailed inspection of the behaviour of the $(J-K)$ index shows wave-like variation with the maxima in 1988 and possibly in 1973 (marked by o and o?) and minima in 1992 and possibly in 1977 (marked by b and b?). It suggests the ≈15-years periodicity in agreement with that found from UBV photometry. The $(J-K)$ index is influenced also by a dust formation due to the activity of the hot component and possible mass transfer bursts in the periastron of eccentric orbit. Combination of all these effects leads to ≈ 6-year periodicity interpreted by Munari (1988) as the orbital period of the binary.

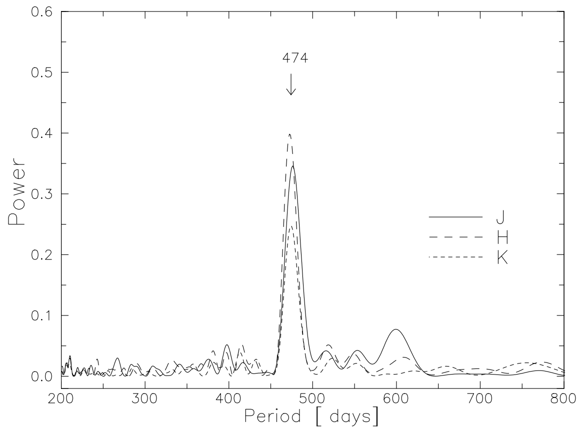

Figure 2: The Fourier power spectra of the pulsation period of Mira in the JHK data

4. Ultraviolet spectroscopy

We have analyzed low and high dispersion IUE (International Ultraviolet Explorer) spectra, HUT (Hopkins Ultraviolet Telescope) spectrum taken on March 6, 1995 and two HST (Hubble Space Telescope) spectra taken on March 24, 2000 (for complete list see

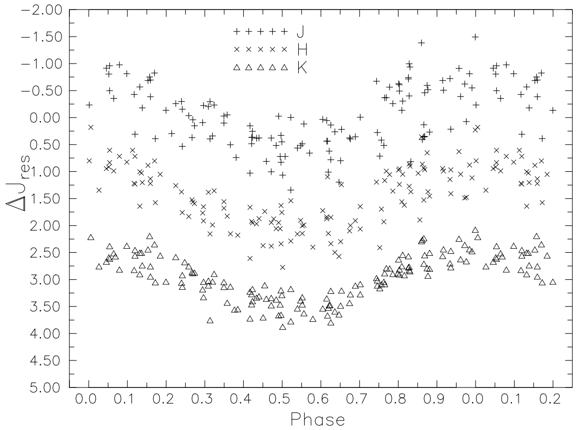

Figure 3: The JHK residual light curves phased with the ephemeris $\mathrm{JD}_{max} = 2447442 + 474 \times E$. The ΔH_{res} and ΔK_{res} are shifted by 1.5 and 3.0 mag, respectively

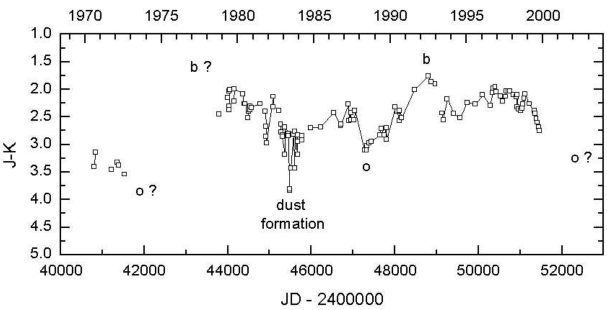

Figure 4: $(J-K)$ color index of V1016 Cyg

Parimucha (2001)). We have excluded saturated spectra or saturated lines and bad pixels. The low dispersion IUE spectra and the HST spectra were used to determine the continuum flux. To establish the continuum behaviour, we measured average fluxes in 20Å bins free from emission lines. The high dispersion IUE spectra, the HUT and HST spectra were used to determine the fluxes of the emission lines. The spectra were dereddened with $E(B-V) = 0.28$ (Nussbaumer & Schild, 1981). Fluxes of non-saturated lines were determined by fitting Gaussian profiles.

The temporal behaviour of the continuum and line fluxes are shown in Figs. 5 and 6, respectively. We have found the ephemerides for the maxima of the continuum and line fluxes as follows:

$$\mathrm{JD}^{cont}_{max} = \begin{array}{lll} 2444150 & +5400 & \times E. \\ \pm 120 & \pm 200 & \end{array} \qquad (2)$$

$$\mathrm{JD}^{lines}_{max} = \begin{array}{lll} 2444650 & +5630 & \times E. \\ \pm 240 & \pm 300 & \end{array} \qquad (3)$$

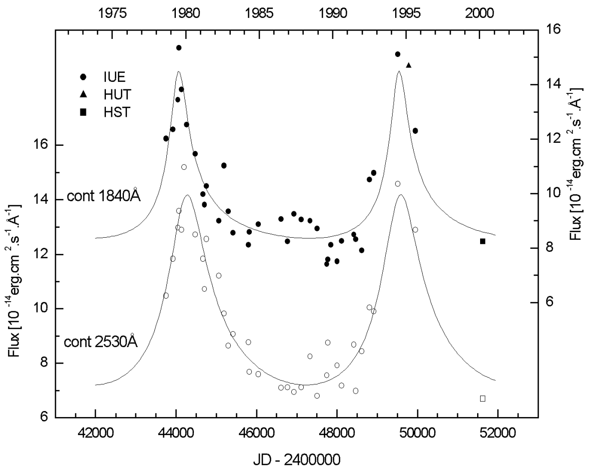

Figure 5: Fluxes of the UV continuum

The maximum of the continuum flux agrees within the uncertainty with that detected photometrically (see ephemeris (1)). On the other hand, the maximum of emission lines occurred 1.4 years after the maximum of the continuum. Nevertheless, the ≈15-year period is clearly present in all sets of data.

4. Basic parameters of the binary system

The period of Mira star pulsation in V1016 Cyg allows to determine basic parameters of the cool component using the standard pulsation equation, period-luminosity relation, period-T_{eff} relation and Stephan-Boltzmann law (Cox, 2000; Glass & Feast, 1982): $L_c = 7600 \pm 100\ \mathrm{L}_\odot$, $T_{eff} = 2450 \pm 50$ K, $R_c = 485 \pm 20\ \mathrm{R}_\odot$, $M_c = 0.81 \pm 0.11\ \mathrm{M}_\odot$. If we accept the orbital period of the binary 5510 days and the mass of the hot component 1.1 $\mathrm{M}_\odot$ estimated by Mürset & Nussbaumer (1994) and Mikolajewska & Kenyon (1992), the semi-major axis of the system is 1630 $\mathrm{R}_\odot$. Then, the Roche lobe radius of the cool component is $R_{Roche} = 576\ \mathrm{R}_\odot$. The possible small eccentricity of the orbit can cause the pulsating Mira variable to fill-up the Roche lobe near periastron, so the matter is easy transferred to the hot component. The distance to V1016 Cyg derived from IR photometry by Parimucha (2001) is 2.9±0.7 kpc.

5. Discussion

Symbiotic nova V1016 Cyg is a wide-orbit binary consisting of a pulsating Mira and a white dwarf that after prolonged accretion underwent a thermonuclear outburst in 1964 leading straight to a nebular spectrum. According to the ionization model of symbiotic binaries, the hot luminous component ionizes the neu-

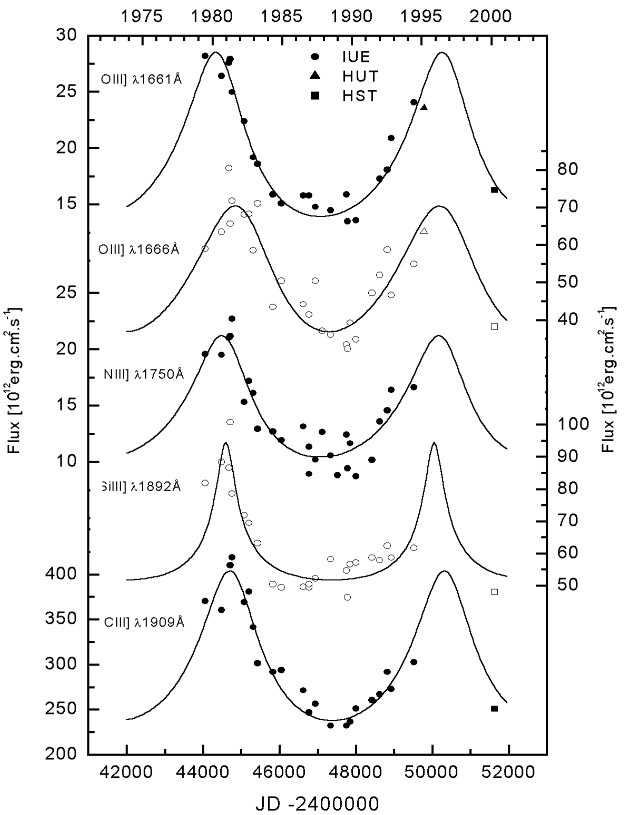

Figure 6: Fluxes of the emission lines

tral wind of the giant giving rise to the nebula in the system. The times of brightness maxima in the U passband observed in 1980 and 1994 agree with that in the ultraviolet continuum. This suggests that the nebula is responsible for both continua. The periodic variations of the optical and UV continuum can be caused by the different contribution of the nebula to the brightness of the system along the orbital cycle (Skopal, 2001) and individual flares originated in the accretion disk of the white dwarf. These flares are triggered by enhanced mass transfer bursts from the Mira during the periastron passage of the hot object on the 15-year eccentric orbit. The pre-outburst flare in 1949 could be of the same nature. The 1.4 years delay of the maxima of the OIII], CIII], NIII] and SiIII] UV emission line fluxes in comparison with the maximum in the UV continuum shows that the lines are excited in the surrounding nebula collisionally when the fast wind from the hot object interacts with the slow wind from the Mira variable.

Present analysis of the photometry and UV spectroscopy shows that V1016 Cyg is a binary system with the orbital period 15.1±0.2 years (Parimucha et al., 2001). V1016 Cyg is the first D-type symbiotic system in which the orbital period was determined.

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