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LONG-TERM PHOTOMETRY OF VERY SLOW NOVAE

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Abstract. Long-term photographic, photoelectric and recent CCD photometry of the classical nova V723 Cas and symbiotic novae V1329 Cyg, PU Vul, V1016 Cyg and HM Sge were used to find their orbital periods. The arguments in favor of the presence of the third components in these systems are given. Physical processes, responsible for the brightness variations, are discussed.

Key words: stars: novae, symbiotic, individual: V723 Cas, V1329 Cyg, PU Vul, V1016 Cyg, HM Sge

1. INTRODUCTION

Outbursts of novae are caused by a thermonuclear runaways of the hydrogen-rich material on the surface of the white dwarf that accretes matter from the companion. The mass loser in classical novae is a Roche lobe filling red dwarf, in symbiotic novae – a cool red giant (S-type systems) or a Mira variable surrounded by dust (D-type systems) located well inside their Roche lobe and loosing matter via a stellar wind. The orbital periods in classical novae are shorter than two days, in symbiotic novae they are larger than two years. The orbital periods of D-type systems are expected in a range of 20–200 years (Whitelock, 1987).

The increase of brightness due to the outburst in classical and symbiotic novae can reach 6–19 mag and 4–7 mag, respectively. Very slow classical novae are characterized by the lowest amplitudes of outburst and gradual rise to the maximum. They remain there for several months or years before declining. The outburst of symbiotic novae lasts decades. The hot star with $T \approx 100\,000$ K ionizes a portion of the giant's wind, giving rise to a nebular emission. The nebula is the main source of the optical continuum.

The basic information about the nature of very slow novae provides the study of brightness variations of these objects in optical, IR and UV regions caused by: thermonuclear outbursts and flares, accretion powered flares, changes of the structure of the circumstellar matter including accretion and excretion disks, interaction zone of colliding winds, dust formation, the eclipses of the components, the reflection effect, the orbital variations of the emission measure in the nebular continuum, pulsations of the hot and cool components. The slow novae binaries can be influenced by the presence of third components, with orbital periods much longer than the period of the binary, which can induce mass transfer in the binary in periastrons of their orbits. In symbiotic Miras, the third body can revolve the hot component on an inner orbit.

2. PHOTOMETRIC OBSERVATIONS

In 1990 we started the program of photoelectric observations of very slow novae at the Skalnaté Pleso and Stará Lesná observatories. The telescopes and instruments are described in Pribulla & Chochol (2003). Our observations are supplemented by photoelectric and CCD photometry obtained at observatories in Moscow, Crimea and Wise, archive photographic observations from Sonneberg, Moscow and Odessa, and visual observations from the international databases: AAVSO, AFOEV, VSOLJ and VSNET.

Due to the presence of strong emission lines in the spectra of novae, the transformation of the instrumental UBV magnitudes to the international ones is unreliable (see, e.g., Chochol et al. 1993). Therefore, we transformed the data to the photometric system of one instrument, by which most of the data were obtained.

3. CLASSICAL NOVA V723 CAS

Nova Cas 1995 (V723 Cas) brightened in August 1995 and reached a peak magnitude of V_{max} = 7.09 on Dec. 16, 1995 in a sharp flare (Figure 1). The gradual decline of brightness was accompanied by large flares, which repeated with a period of 182 days (Chochol & Pribulla 1998). The nebular stage was reached 660 days after the outburst. Chochol & Pribulla (1997) classified the object as a slow nova of HR Del type and determined its basic parameters. Chochol et al. (2000) determined a 0.69325 day orbital period of the binary. Goranskij et al. (2002) improved the period to 0.693265 days and interpreted the observed quasi-periodic photometric oscillations by the pulsation of the expanded envelope of the white dwarf. Our CCD

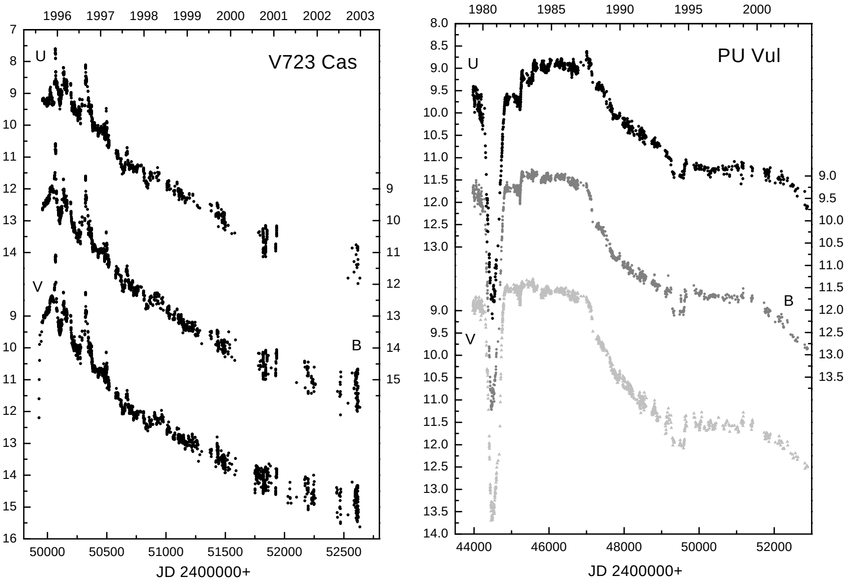

Fig. 1. *UBV* light curves of V723 Cas (left) and PU Vul (right).

B, V phase light curves of the nova taken in 2003, presented in Figure 2, show that the nova is highly inclined eclipsing system.

Chochol & Pribulla (1998) investigated the evolution of V723 Cas during maximum brightness in the $U-B$, $B-V$ diagram in the context of an expansion of the supergiant due to a TNR on the white dwarf. The derived velocity of expansion, 210 km/s, is in agreement with the velocity of expansion of the main envelope of the nova found from the spectra in the nebular stage (Chochol et al. 2000). During the August 1997 flare the spectra exhibited very broad C III and C IV WR feature and the broadening of He II emission, suggesting that the flare was caused by a non-degenerate flash on the hot white dwarf. The flare was probably induced by a mass transfer burst from the red to the white dwarf due to the periastron passage of the third body on its 182 day orbit.

4. S-TYPE SYMBIOTIC NOVAE PU VUL AND V1329 CYG

In 1898–1956 the brightness of PU Vul fluctuated between 15–16 mag (Liller & Liller 1979). Period analysis of these data by Chochol et al. (1997) revealed the periods of 4897 days and 231.5 days interpreted as eclipses in the system and pulsations of the cool AGB star in the system. The outburst started in 1977. In 1979 the bright-

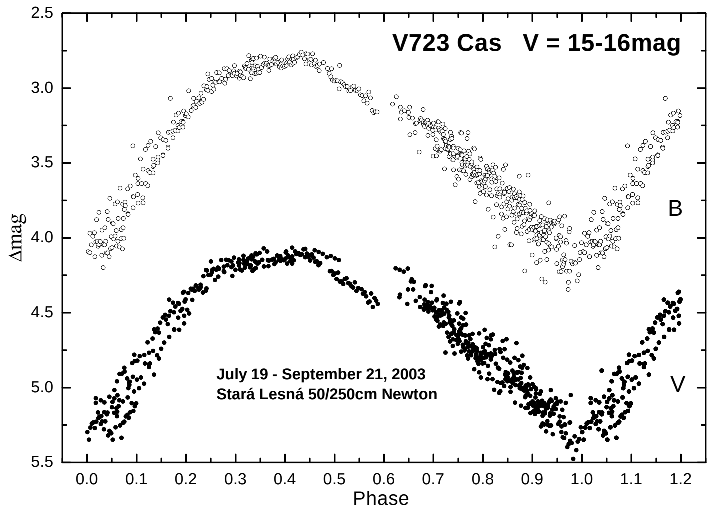

Fig. 2. The new CCD BV phase light curve of V723 Cas.

ness reached $B \sim 9.3$ mag. The light curve exhibited an almost flat maximum (1979–1987) followed by a decline interrupted by two minima in 1980–1982 and 1993–1994 explained by Nussbaumer & Vogel (1996) as eclipses in a binary system with the orbital period 4900 days (Figure 1). Chochol et al. (1998) found from V and R photometry the pulsation period of the AGB component in PU Vul to be 217 days and determined $R_c = 282\,R_\odot$ in close agreement with the value derived from the analysis of the 1993–1994 eclipse (Chochol et al. 1997). They also studied the radial velocities of the outbursting white dwarf in PU Vul, mimicking an F-supergiant (from 1979 to 1987) and found a possible 761 day spectroscopic orbit, suggesting triplicity of the system.

In 1891–1964 the brightness of V1329 Cyg fluctuated around $m_{pg} \sim 15$ mag with occasional 2.5 mag deep decreases, which repeated with a period of 959 days. Stienon et al. (1974) interpreted them as eclipses of the hot component by the red giant. The nova-like outburst started in 1964. The brightness maximum of 11.5 mag was reached in 1966. The brightness decline was accompanied by wave-like variations with an orbital period 956.5 days (Chochol et al. 1999), reflecting the orbital variation of the nebular emission in the continuum (Skopal 2003). These variations were modulated by a possible cycle of ≈ 5300 days and a secondary period of 553 days, which can be explained by the precession and nutation of the accretion disk around the hot white dwarf. The existence of the accretion disk in V1329 Cyg was proposed by Chochol & Vittone (1986). A sudden flare observed in 2003 (see Pribulla & Chochol 2003) and the previous maxima of the 5300 day cycle, can also be explained by the increase of mass transfer during the periastron passage of the third body in the system.

5. D-TYPE SYMBIOTIC NOVAE V1016 CYG AND HM SGE

Infrared observations demonstrated that D-type systems contain long-period Mira variables. The pulsation period of V1016 Cyg is 470±5 days and that of HM Sge is 535±5 days (Taranova & Shenavrin 2000).

Prior to 1948, V1016 Cyg was fainter than 16 mag. It reached 15 mag during pre-outburst brightening in 1948–1952. The outburst started in 1964. In 1971 the brightness reached $\mathrm{m}_{pg} \sim 10.5$ mag. During the decline, two other brightenings were detected in 1980 and 1994, suggesting variability of activity with a period ≈ 15 years, found also in UV continuum and emission-line fluxes (Parimucha et al. 2002). If a Mira variable and a white dwarf form the wide-orbit system with a period of 544 years, as proposed by Brocksopp et al. (2002), we could interpret the detected 15-year period of activity as the orbital period of the third component. Observed flares would be triggered by an enhanced mass transfer from the cool giant to the white dwarf during its periastron passage.

Prior to 1975, the brightness of HM Sge fluctuated between 16.9 and 18.1 mag and partly reflected the pulsation of the Mira variable (Arkhipova et al. 1994). The outburst started in December 1974. The nova reached its maximum $m_{pg} = 11.13$ mag in August 1975. As it was shown by Chochol et al. (2004), in 1975 a 750 day eclipse of the hot component started, followed by 2100 day eclipse of the hot, shocked interaction zone of the colliding winds (detected in the U band) from the Mira companion. Then an almost linear decrease of brightness was observed. The main outburst, followed by flares, which repeated with the 535 day period, was triggered by a mass transfer burst from the Mira companion to the hot component at periastron of the long-period orbit (>50 years). Arkhipova et al. (2004) found the 6.3 year period of the infrared continuum intensity and interpreted it as a result of variable dust obscuration of the cool component due to the orbital motion. If confirmed, HM Sge is a triple system.

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