MAGNETIC ASYNCHRONOUS NOVA V1500 CYG IN AN "EARLY" AND A "MEADLE" POST-NOVA STATE

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ABSTRACT. A detailed analysis of photometric observations of magnetic nova V1500 Cyg in the "early" (1978-1988) and "middle" post-nova state (2000-2002) is presented. The brightness of Nova varies mostly with orbital 0.139613-day and spin-orbit 8-day beat phases. The periodogram constructed for 1980-1984 data shows a strong peak at the orbital frequency ($7.163d^{-1}$) and reveals the presence of three side-band frequencies $2w_{orb} - w_{spin}$, $2w_{spin} - w_{orb}$ and $3w_{spin} - 2w_{orb}$, indicating the spin-orbit asynchronism (The spin period is taken from measurements of Schmidt, Liebert and Stockman (1995)).The later (2000-2002) data show the presense of spin modulation in R band while these of the early quiescent state - not. The typical beat light curve profile is one-humped, and seldom it could be two-humped one. The all available timings of minima and maxima obtained since 1978 agree both with long-term orbital period increasing and with constant but slightly reduced its value (0.1396129 day). The timings of orbital maxima and minima sometimes show dependence on the beat phase during almost half beat period. The nature of beat modulation is still unclear, although the periodical brightening of accretion disk and/or accretion stream could occur depending on the orientation of magnetic white dwarf axis in binary.

Key words: Stars: binary: cataclysmic; stars: individual: V1500 Cyg.

1. Introduction

V1500 Cyg = Nova Cygni 1975 is the famous fast nova from a peculiar subgroup of the so-called asynchronous polars or BY Cam stars (Patterson et al., 1995) which includes only 4 binaries: V1500 Cyg itself (Stockman et al. 1988; Schmidt et al. 1995, hereafter SLS), BY Cam (Silber et al. 1992), $V1432Aql = RXJ19402 - 1025$ (Patterson et al., 1995) and RX J2115.7-5840 (Schwope et al. 1997). SLS showed that contrary to other asynchronous polars, V1500 Cyg seems to have the "abbreviated disk", or ring, or "orbiting debris in a disklike geometry" around a white dwarf. The Hubble Space Telescope observations (SLS) revealed the presence of a hot white dwarf (70,000-120,000 K) in this system that heats a faced side of a main-sequence companion up to 8000 K, with a "backside" temperature of $\sim 3000K$. SLS confirmed the original suggestion by Patterson (1979) that the irradiated facing surface of the secondary heated by the hot white dwarf mostly causes the light variations with orbital phase in the optical band, while accretion columns give only a small contribution. According to SLS model, the transferred material is first stored in a ring for a short time and then is channeled onto the white dwarf magnetic poles producing the observed circular polarization. Due to the respectively broad accretion region on the white dwarf surface, thay can't produce the light modulation in optical band with phase of spin period. A comprehensive investigation of V1500 Cyg with the Hubble Space Telescope lead SLS to conclude that postnova white dwarf is the dominant source of ultraviolet flux and of unusually large bolometric luminosity of the system, compared with typical AM Her - type binaries. The orbital inclination is $50^{o} < i < 75^{o}$.In addition to the white dwarf photosphere authors considered three more possible origins: (1) cyclotron emission, (2)relatively broad, optically thick accretion columns with lumps of dense gas and/or (3) orbiting debris in a disklike geometry. the transferred material is first storred in this ring for a short time and then is channeled onto the white dwarf magnetic poles producing the observed circular polarization.

V1500 Cyg is known to exhibit three different periodicities: the stable since 1977 photometric periodicity that is the orbital period $P_{orb} = 0.139613$ day (Semeniuk et al, 1995), the polarimetric spin period $P_{spin} = 0.137$ day decreasing at a rate of $\dot{P}_{spin} = 3.86 \pm 0.18 \times 10^{-8}$ (SLS 1995), and the third photometric spin-orbit beat period $P_{beat} = 7.7$ day discovered by Pavlenko and Pelt for 1980-1984 data set (Pavlenko and Pelt, 1988; Pavlenko and Pelt, 1991).

The beat period increases with time due to white dwarf spin down (some evidence of the beat period change where found earlier by Pavlenko and Pelt, 1988, Pavlenko and Malanushenko, 1996). All these periodicities are related as

$$P_{beat}^{-1}(T) = P_{spin}^{-1}(T) - P_{orb}^{-1}, \qquad (1)$$

where T is time.

Since then more precise ephemeris for P_{spin} and $\dot{P}_{spin}$ have become available. This allows to study in detail the photometric behavior of V1500 Cyg with the beat phase on a longer time-scale. Here we perform the analysis using the standard V-band photometry of V1500 Cyg carried out at the Crimean astrophysical observatory on the TV-complex of 0.5-m meniscus telescope in 1978-1987 (Pavlenko 1982, Abramenko and Pavlenko 1983, Pavlenko 1983a, 1983b,1988, Pavlenko and Pelt 1988) and CCD R-band photometry obtained in 2000 - 2002 at the 0.6-m Zeiss telescope and 1.25-m ZTE SAI telescope (Pavlenko and Shugarov, 2004). During the early state of the outburst decline the comparison stars published in (Pavlenko, 1988) have been used. Later the star C3 (Kaluzhny and Seneniuk, 1987) was used as comparison one. In total all the data include about ~ 170 nights of observations.

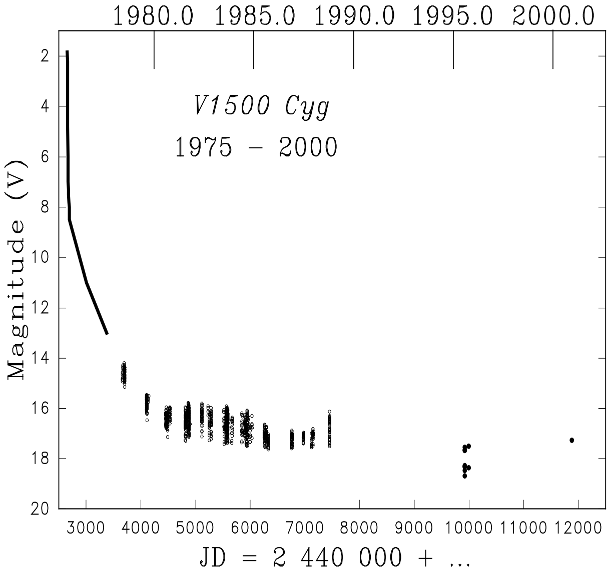

Figure 1: The overall 1975-2000 light curve of the V1500 Cyg. The upper scale is in years. Our data correspond to years 1978 - 1988 and to 2000, data for 1995 are taken from the Somers and Naylor (1999). The solid line is drawn using the data taken from Patterson, 1979.

1. Cooling of the white dwarf after explosion

The light curve of the outburst decay has an exponencial shape. It is shown in Fig.1. Nova Cyg faded most rapidly during the first 5 years after the outburst. The average rate of brightness decline was 0.1 mag (V) per year since 1980. Taking into account substantional slowing down of the outburst decay after 1980, we defined interval of 1980-1984 as reffered to ”‘early post-nova state”’ and those for 2000-2002, i.e. in ~ 25 since outburst as ”‘middle post-nova state”’. Actually Nova is still far from its pre-outburst brightness (21^m). Prialnik has shown that a hot white dwarf should cool after the nova expolsion as $t^{-1.14}$ (Prialnik, 1986). Somers and Naylor (1999) first confirmed Prialnik's prediction. They measured the amplitudes of orbital period using all avaible data in B-band and found the decreasing of amplitudes with time (and, so, cooling of the white dwarf and, hence, weakening of reflection effect) with predictioned rate. This decrease of orbital amplitudes with time is shown in Fig.2. The Somers's and Naylor's data are shown by strate line. We also plotted here our data in the V-band and R-band (Pavlenko et al., 2002). Note the same rate of amplitude decrease in B and V. It is clear visible that in ~ 25 years the orbital amplitude decreases ten times! The white dwarf cooling time was found by Somers and Naylor to be about 280 ± 140 years after the nova outburst which coincides with theoretical predictions of Prialnik (1986).

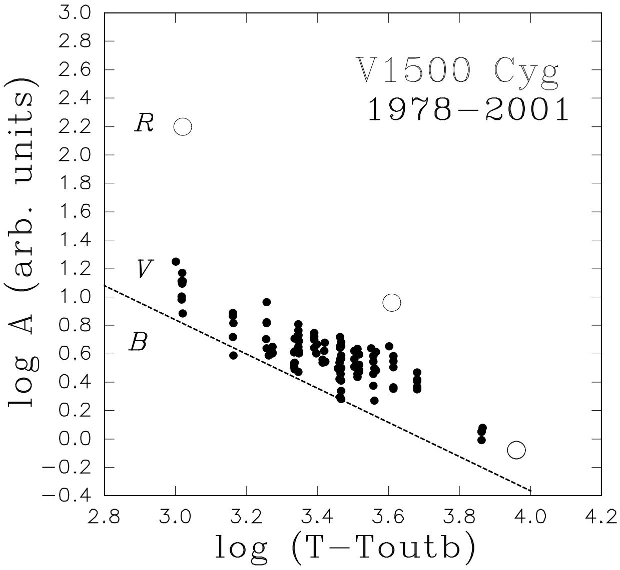

Figure 2: Orbital amplitude in B, V and R bands decrease with time passed after Nova explosion. Data taken from Somers and Naylor, 1999 are drawn by line. Our V data are marked by filled circless and R data - by open circles. All data are expressed in arbitrary flux units.

2. The orbital periodicity

Here we present the mean orbital profiles obtained at the early post-nova state of quiescent, in V-band,

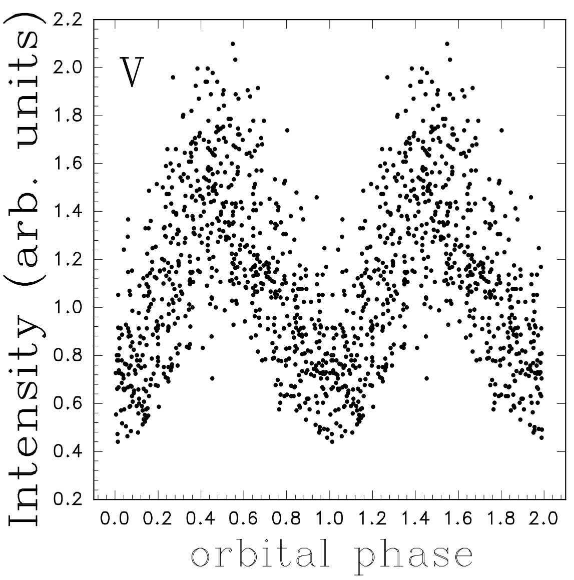

Figure 3: The V 1980-1984 data folded on the orbital period For clarity data are plotted twice.

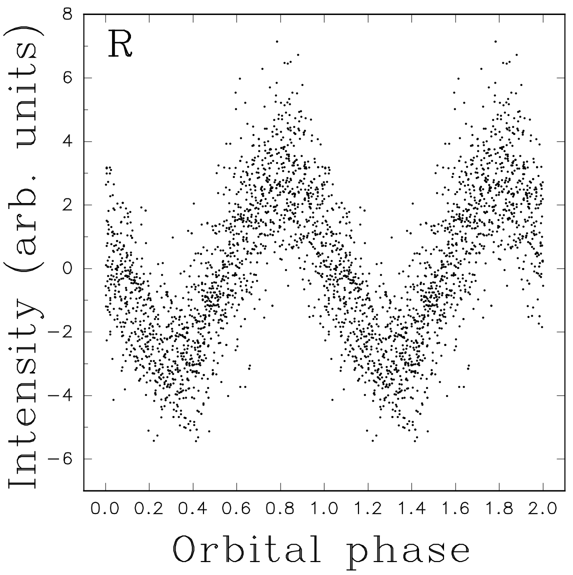

Figure 4: The R 1980-1984 data folded on the orbital period .

and at middle post-nova state in R-band (see Fig.3).

The orbital phases were calculated using the ephemeris given by Semeniuk et al., 1995 (hereafter SON):

$$HJD_{Min} = 2446694.6730 + 0.139613E \qquad (2)$$

$$HJD_{Max} = 2446694.7408 + 0.139613E \qquad (3)$$

The profile of orbital light curves are shown in Fig. 3 and 4. The data in V and R were converted from magnitudes into intensities (after subtracting of beat modulation) and artificially scaled to the equal amplitudes. The mean light curves have a strong sine-like form during all course of the outburst decline.The scattering of points is caused by some night-to-night and cycle-to-cycle brightness variations that occure during all course of the outburst decline. The example of such profile change is presented in Fig. 5. It is seen that amplitudes in neighbour nights are differ drastically on $0^m.6$. Howerver if converting into intensities, the amplitudes become equal, the only mean brightness is different.

We have constructed the orbital profiles without periodogram analyses because of the well-known value of the orbital period. However the periodogram itself is interesting from the point of view of another possible periodisities.

The periodograms constructed for these two separated in time data sets are slightly different and this difference is substantial. In this section the analyses for the early quiescence data is done, while analyses for the later data will be done in the next section. The periodogram for 1980 - 1984 data (V-band) was constructed using the Irregularly Spaced Data Analysis (ISDA) package (Pelt, 1980, 1992) near the orbital frequency (5 − 10 day^{-1}). The 1978-1979 data were excluded because of the much lower (in stellar magnitudes) orbital modulations. The periodogram is computed by the Stellingwerf method with the Abbe statistics, also known as the Lafler-Kinman statistics (Lafler and Kinman, 1965). It is shown in Fig.6. The strongest peaks in the periodogram are due to the orbital period 0.139613 day and its 1-day aliases at frequencies 8.17 day^{-1} and 9.17 day^{-1}. There are three closest peaks to the orbital one at frequencies marked as $w_1 = 7.06$ day^{-1}, $w_2 = 7.46$ day^{-1} and $w_3 = 7.545$ day^{-1}. These peaks can be interpreted as the side-band frequencies $w_1 = 2w_{orb} - w_{spin}$, $w_2 = 2w_{spin} - w_{orb}$ and $w_3 = 3w_{spin} - 2w_{orb}$. The presence of the side-band $2w_{spin} - w_{orb}$ frequency was actually predicted

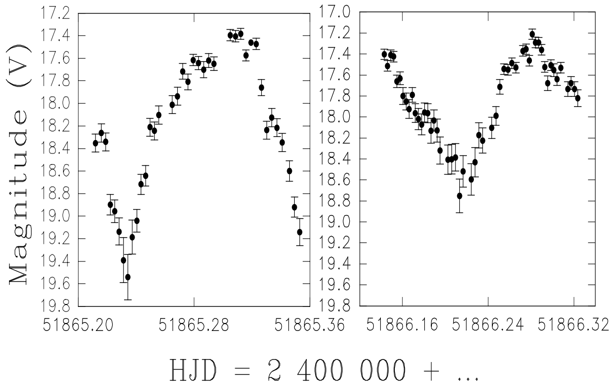

Figure 5: The example of two R-band lightcurves.

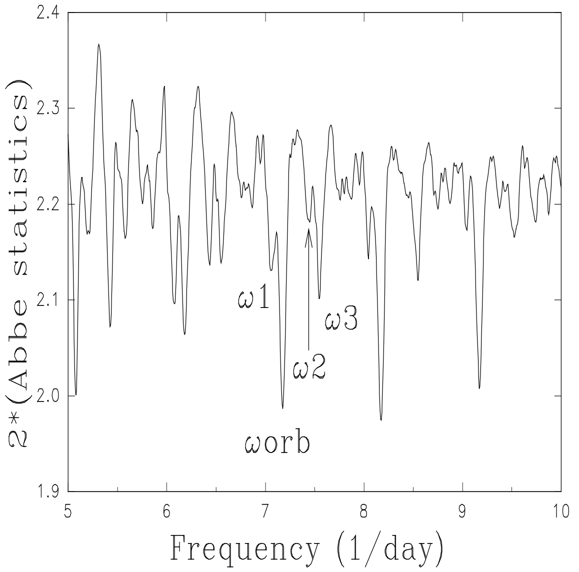

Figure 6: The periodogram constructed by Stellingwerf method in the frequency domain 5-10 day^{-1} for all 1980-1984 data. The highest peak points at the orbital frequency, another marked peaks correspond to the side-band frequencies: $w_1 = 7.06$ day^{-1}, $w_2 = 7.46$ day^{-1}, $w_3 = 7.545$ day^{-1}.

by Wynn and King (1992) for diskless asynchronously rotating magnetic cataclysmic variables and later discovered in the power spectra of another asynchronous polar BY Cam (Mason et al. 1998).

No peaks at the P_{spin} frequency itself is visible, so it proves that the mean light modulation at the early quiescent time is caused by the reflection effect and spin-orbital beat effect.

3. The spin period

The periodogram for the middle post-nova state data (in R-band) in the vicinity of the orbital period is presented in Fig.7. As for the previous case, data were detrended by the beat-modulation subtracted. The upper panel displays the periodogram where the strongest peak indicates the orbital period. In residual periodogram after the orbital modulation subtraction one can find a broad peak including the predicted spin period 0.13734 day. In Fig. 8 the data convolved on this period are shown separately for 2000, 2001 and 2002. The spin profile is different for each year, however one common fiture is obvious: the minimum at phase 0.5. The more detailed and correct analyses of spin modulation contribution to the total light will follow elsewhere.

Here it is possible to declare than in 25 years after Nova explosion the spin period became detectable. This small-amplitude modulation with spin period of white dwarf is caused by varying aspect of accretion column/columns close to the white dwarf magnetic poles.

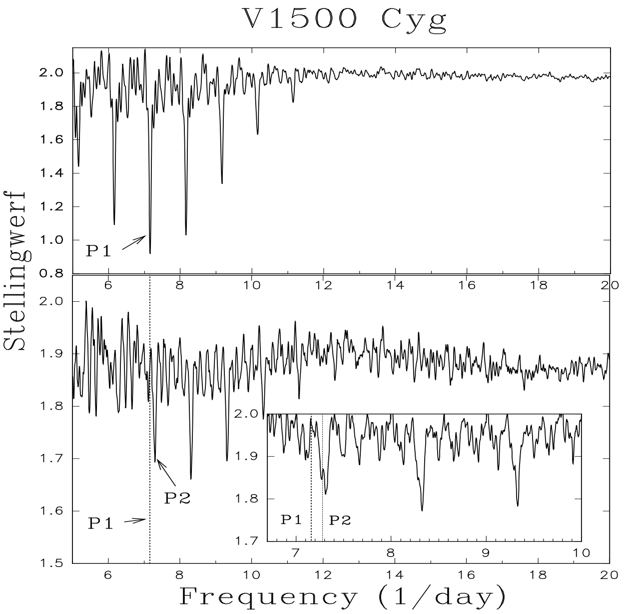

Figure 7: The periodogram in the vicinity of orbital and spin periods. Upper panel: The strongest peak correspons to the orbital period P_1 is shown. Lower panel: The residual periodogram after subtraction of orbital modulation. The peak including the current spin period P_2 is shown. The incut frame shows this peak in detail.

4. Spin-orbital beat period

Here we consider the evolution of the profile of the spin-orbit beat period from erly to the middle post-nova state.

Fig. 9 shows an example of modulations with the beat period for the most dense observations obtained in 1981 and 1983. The example of a dense coverage in 2001 was sown in (Pavlenko et al., 2002).

To analyse the behavior of V1500 Cyg beat profile separately for each year, the corresponding current value of this period is needed. Unfortunately, it is hard to derive its precise value directly from our observations only, because the relatively long value of the beat period require a much better data coverage than we have. Nevertheless, the value of the beat period can be evaluated using the rotational ephemeris obtained by SLS:

$$P_{rot,i} = P_{rot,0} + 3.86 \times 10^{-8} \times (T_i - 2447593) \quad (4)$$

with $P_{rot,0} = 0.1371709$ day and $T_{rot,0} = 2447593$. For example, the beat period at the starting point $T_0 =$

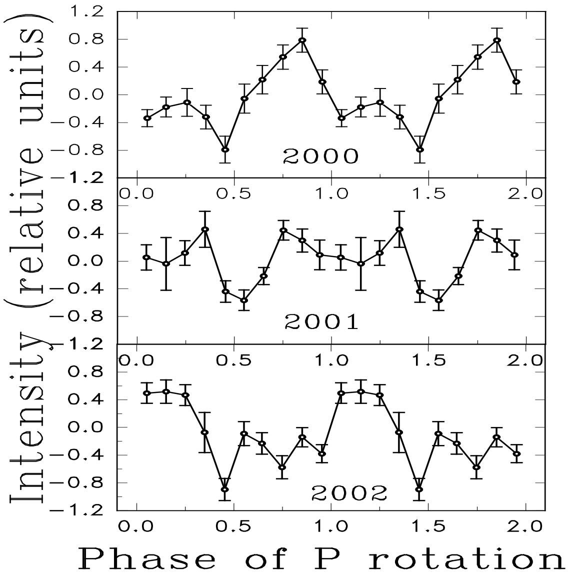

Figure 8: The R-band data for 2000, 2001 and 2003 folded on the orbital period.

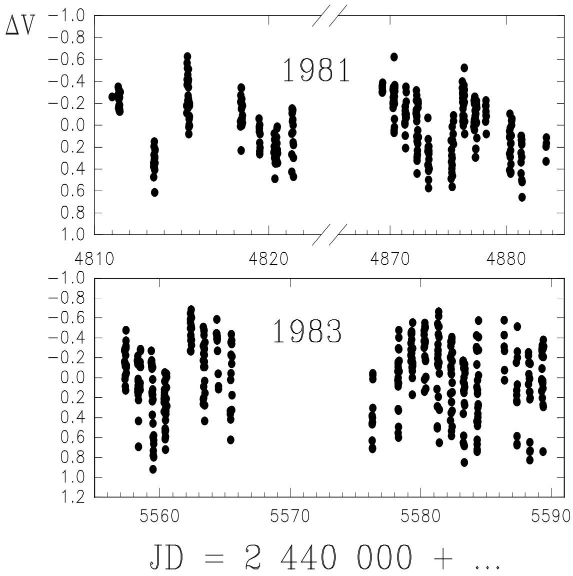

Figure 9: The The original lightcurves of V1500 in V-band. The modulation with beat period is clearly seen.

2443659 of our 1978-88 data base is $P_{beat,0} = 7.37457$ day.

The beat period ephemeris reads

$$T_{0,i} = T_0 + P_{beat,0} \times E + \dot{P}_{beat} \times E(1+E)/2 \qquad (5)$$

where $\dot{P}_{beat}$ is the beat period increase per one beat cycle, E is the number of the beat cycles. We have taken $\dot{P}_{beat} = 0^d.000825$ per beat cycle and assumed it to be constant over the entire 10-years time interval.

To study the photometric behavior of V1500 Cyg with the beat phase over several years, we first transformed the stellar magnitudes into fluxes and subtracted the polynomial fit corresponding to the secular light decrease. To depress the orbital periodicity, we calculated separately the best-fit orbital variations for each year and subtracted them from the original data. The residuals were folded with the current beat period calculated from Eqs. (1-3). Since the real orbital profiles varied slightly from cycle to cycle and the orbital O-C also shown some wondering (will be considered in next section), the orbital periodicity could not be completely removed, so these "orbital residuals" do contaminate the flux variations with the beat period. The evolution of the beat profiles in 1978 - 1987 is presented in Fig. 10. Only the beat phases with the most dense data coverage are shown. The correspondent mean profiles as the least-square best-fit lines are also given. Using the Fisher test, we calculated a confidence level of a statistical assurance of variations against beat phase for the selected years. It was 99, 95, 93, 72 and 92 per cents for the 1981, 1982, 1983, 1985 and 1987 accordingly. For 1978 the beat profile is best fitted by a two-humped shape with a confidence level 92 per cent, while fitting by a one-humped shape is unsignificant, because gives 60 per cent only. The first minimum lies at the beat phase 0.21 ± 0.13, and the second one at the beat phase 0.66 ± 0.13. We calculated the phases of extremuma by method of asymptotic parabola (Marsakova and Andronov, 1996).

The behaviour of beat period in the middle post-nova state is shown in Fig.11, upper panel. The corresponded mean beat period was ~ 8.5 day (Pavlenko et al., 2002). It is seen that the amplitude of beat profile decreased slightly from 2000 to 2001, while the shape changed from one-humped to two-humped one.

5. Orbital O-C residuals

Turning to the orbital profiles, let's point attention on the scattering of the light curves. They are caused mainly by some wondering of the timings of minima and maxima. It is shown (Pavlenko and Shugarov, 2004), that there are two sources of this shifting: some beat-phase dependence (read the previous section) and more long-term dependence. The former is shown in Fig.11, lower panel. The method of asymptotic parabola (Marsakova and Andronov, 1996) was used for the extremuma determinations and the ephemeris of SON were used in the O-C calculations. In 2000 during almost half of beat cycle (phases 0.8-1.2) the beat phase of the orbital O-C minima has been decreasing. That corresponded to the minimum of a beat period. Than O-C became behave random. Next year O-C behaved in another manner. Fig.12 shows the long-term (since 1998 up to 2002) O-C deviations, including also

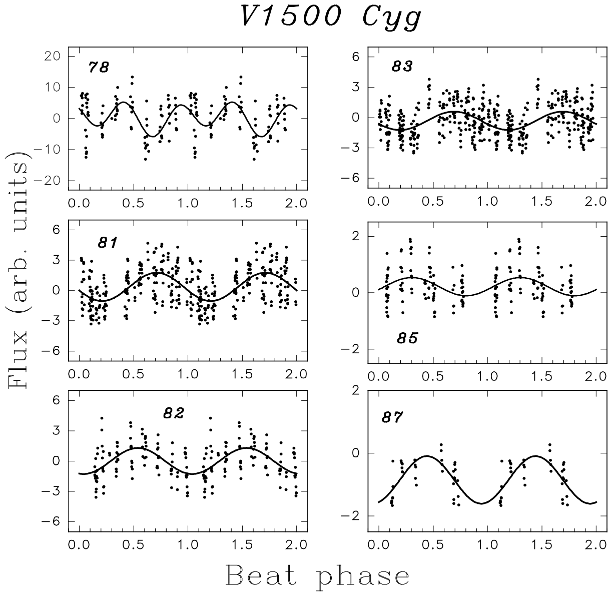

Figure 10: The evolution of the beat profiles folded with the current beat period in 1978-1987. The best-fit profile is obtained using least square minimization. The scattering at each beat phase is due to short-term flickering, orbital O-C variations, some variations of the profile of the orbital lightcurve.

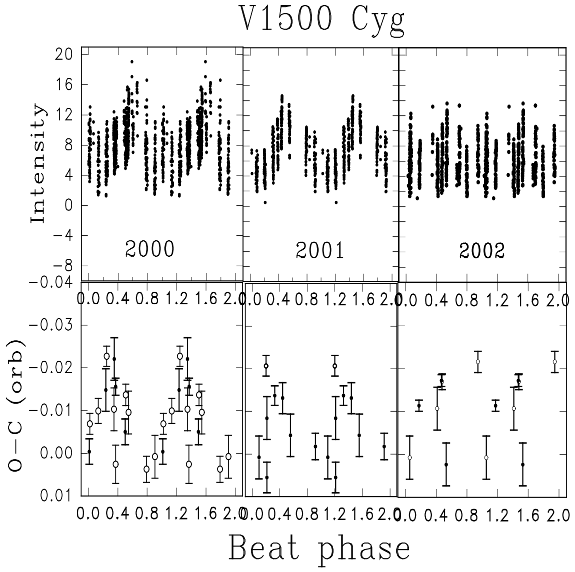

Figure 11: The 2000-2002 R-band data (is given in arbitrary units) folded on the current 8.5-day beat period (upper panel). Lower panel: The dependence of orbital O-C on the phase of beat period. Minima are marked by open circles and maxima - by filled.

mentioned above. It is seen that in a whole they are spread whithin a curve streap. If we adopt parabolic fitting, it means that the orbital period over all the time is decreasing accordingly to the ephemeris

$$O-C = -0.0066+5.4\times10^{-7}\times E-9.6\times10^{-13}\times E^2 \quad (6)$$

$$\pm0.0015 \quad \pm 15\times10^{-13} \quad \pm 22\times10^{-13} \quad (7)$$

in the case of the linear fitting the improved value of orbital period should be slightly shorter (0.1396129 day). The parabolic model mathematically is preferable because it gives less residuals.

6. The nature of the beat period

Generally, the spin-orbit beat phenomena in asynchronous polars may appear for different reasons (the presence or absence of disk-like structures around the white dwarf, accretion curtain near the white dwarf surface, etc.) The first issue to solve is what does the beat period seen in V1500 Cyg reflect: is it a regular brightening or fading every beat cycle? To answer this question, we can compare the photometric behavior of V1500 Cyg during the beat period with another asynchronous polar BY Cam. We recall that the main difference between asynchronous polars V1500 Cyg and BY Cam is that in V1500 Cyg it is the irradiated secondary that mostly contributes to the light curve, while in BY Cam the accretion columns do. Also, the existence of a disk-like structure in V1500 Cyg and its absence in BY Cam can produce different photometric effects during the beat period.

In V1500 Cyg optical light curve, the spin-orbit beat phenomenon shows up as a prominent evidence of (1) the orbital side-band $2w_{orb} - w_{spin}$, $2w_{spin} - w_{orb}$, and $3w_{spin} - 2w_{orb}$ frequencies, (2) the brightness modulation with the beat phase, and, sometimes the orbital O-C shifting with beat phase. The orbital amplitude seems to be constant over all beat cycle.

Like V1500 Cyg, BY Cam has two side-band frequencies $2w_{spin} - w_{orb}$ (which is even stronger than the spin frequency) and $3w_{spin} - 2w_{orb}$ (Ramsay et al. 1996). Contrary to V1500 Cyg, the most significant feature in BY Cam behavior is the strong orbital O-C and amplitude dependence on the beat phase, with the spin O-C residuals jumping from the positive to negative values simultaneously with the amplitude drop (Silber et al. 1997). The latter is interpreted as the stream impact on different magnetic poles during the beat period (Silber et al. 1997; Mason et al. 1998).

So what is the reason for light modulation with the beat phase in V1500 Cyg? Clearly, it can not be due to magnetic pole switching because the observed light curve is shaped mainly by the heated side of the secondary component. In general, there could be three processes responsible for the beat modulation:

1) periodical shadowing of the facing side of the secondary by accretion structures.

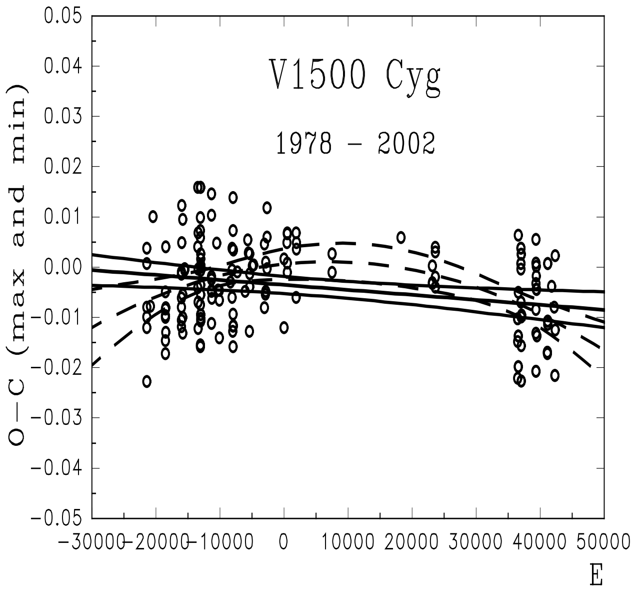

Figure 12: The orbital O-C residuals for both minima and maxima versus the cycle number E. The 99% confidence interval is drawn.

2) periodical change of the accretion rate and/or brightness of the accretion ring,

3) additional periodical heating of the secondary caused by the changing orientation of the white dwarf magnetic axes with respect to the companion.

Probably in V1500 binary act all these processes: the systematical shifting of the orbital O-C could indicate on the periodical shadowing of the secondary by inhomogenious structures. However the practical constancy of the orbital amplitudes strongly supports the idea of periodical brightening uneclipsed source of light, which could be accretion ring and accretion stream. Perhaps the periodical brightening is the winner in this competition.

7. Conclusion

Nova V1500 Cyg is remarcable binary. It displays in our presence very fast in astronomical respect processes: synchronization of components and cooling of the white dwarf after the nova explosion. However the accretion processes in such asynchronous binary with strong reflection effect are still unclear.

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