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CCD photometry of Nova V1974 Cygni in 1995

by

A. Olech[1], I. Semeniuk[1], T. Kwast[1], W. Pych[1],
J.A. DeYoung[2], R.E. Schmidt[2] and M. Nałeżyty[1]

[1] Warsaw University Observatory, Al. Ujazdowskie 4, 00-478 Warszawa, Poland
e-mail:(olech,is,tk,pych,nalezyty)@sirius.astrouw.edu.pl

[2] US Naval Observatory Time Service Department,
3450 Massachusetts Avenue, NW, Washington, DC 20392-5420
e-mail:(dey,res)@herschel.usno.navy.mil

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ABSTRACT

We report on analysis of I CCD photometry of Nova V1974 Cygni from the observational season 1995. The analysis shows that both short-term modulations with periods 0.0813 and 0.085 days (whose values are close to 2-day aliases of one another) are still present in the light curve of Nova V1974 Cygni. Contrary to the 1994 situation the amplitude of the 0.085-day modulation in 1995, was, on the average, smaller than the amplitude of the 0.0813-day modulation. The observations give evidence that the 0.0813-day period, interpreted as the orbital period of the system, decreased during the time interval 1993–1995. The 0.085-day period, observed as decreasing in 1994, stopped decreasing and seems to increase since the middle of 1995. The light curve of V1974 Cygni observed during some nights at the end of the 1995 season resembles the light curve of a polar with two sets of minima.

Key words: *Stars: individual: V1974 Cyg – binaries: close – novae, cataclysmic variables*

1. Introduction

V1974 Cygni (Nova Cygni 1992), discovered by Collins (1992) was the brightest nova of the last twenty years. Although the star faded now to about 15 mag, it is still an object perfectly suitable for photometry with small telescopes equipped with a CCD camera. The star is still a very interesting object for cataclysmic variables observers due to its intriguing short-term periodicities. Earlier observations of these periodicities were extensively described in a previous paper (Semeniuk *et al.* 1995). Here we only remind that V1974 Cygni reveals two short-term photometric modulations with periods 0.0813 days (117 min) and 0.085 days (122 min), whose values are close to 2-day aliases of one another. The modulation with the shorter period, discovered by DeYoung and Schmidt (1993, 1994), was the only photometric modulation observed in the light curve of V1974 Cygni in 1993. Its amplitude was then equal to 0.16 mag. The modulation with the longer period, discovered by Semeniuk *et al.* (1994), appeared in the light curve of the star only in 1994, *i.e.*, in about two years after outburst. In 1994 both above mentioned short-term modulations were clearly observed in photometry of the star with a comparable amplitude of several hundredths of magnitude. The presence of two periods being 2-day aliases of one another resulted in difference between appearance of the light curves from two consecutive nights; the 0.08-day modulation was distinctly visible only every second night, when the two periodicities met in approximately the same phase.

The shorter 0.0813-day period was observed to be stable during the 1993 and 1994 observational seasons and was interpreted (DeYoung and Schmidt 1994, Semeniuk *et al.* 1995) as the orbital period of the system. The longer 0.085-day period observed in 1994 appeared to be decreasing, and Semeniuk *et al.* (1994, 1995) suggested, that it might be the spin period of the white dwarf component of the binary system. Instead, Retter, Ofek and Leibowitz (1995), and Leibowitz *et al.* (1995) suggested that it might be a superhump period, as the two periods obey exactly the relation of Stolz and Schoembs (1981) for the SU UMa type stars, with the 0.085-day period being about 5% longer than the orbital period.

In the present paper we report on results of CCD photometry of V1974 Cygni performed during the observational season 1995.

2. Observational Material

The present observations of V1974 Cygni were obtained on 40 nights during the period from February 22, to December 9, 1995, at the Ostrowik station of the Warsaw University Observatory and at the US Naval Observatory in Washington, DC. Cassegrain telescopes of the same diameter, 0.6 m, were used at both observatories. The employed CCD cameras, the procedures of data reduction and the way of obtaining relative magnitudes were described in our first papers on V1974 Cygni (DeYoung and Schmidt 1994, Semeniuk *et al.* 1994). We have monitored the star in the Cousins I filter. The exposure times were generally 180 seconds for the Ostrowik observations and 120 seconds for the USNO observations. A mean visual magnitude of V1974 Cygni was approximately 14.7 at the beginning of the present observational period and fell to about 15.0 at its end. A journal of observations is given in Table 1.

Figs. 1 and 2 display some observational runs from July and September 1995. We can see that the 0.08-day modulation is still present with an amplitude of about 0.1 mag. However, the difference in light curves for odd and even nights, resulting from the beat phenomenon of the two periods, so characteristic for the

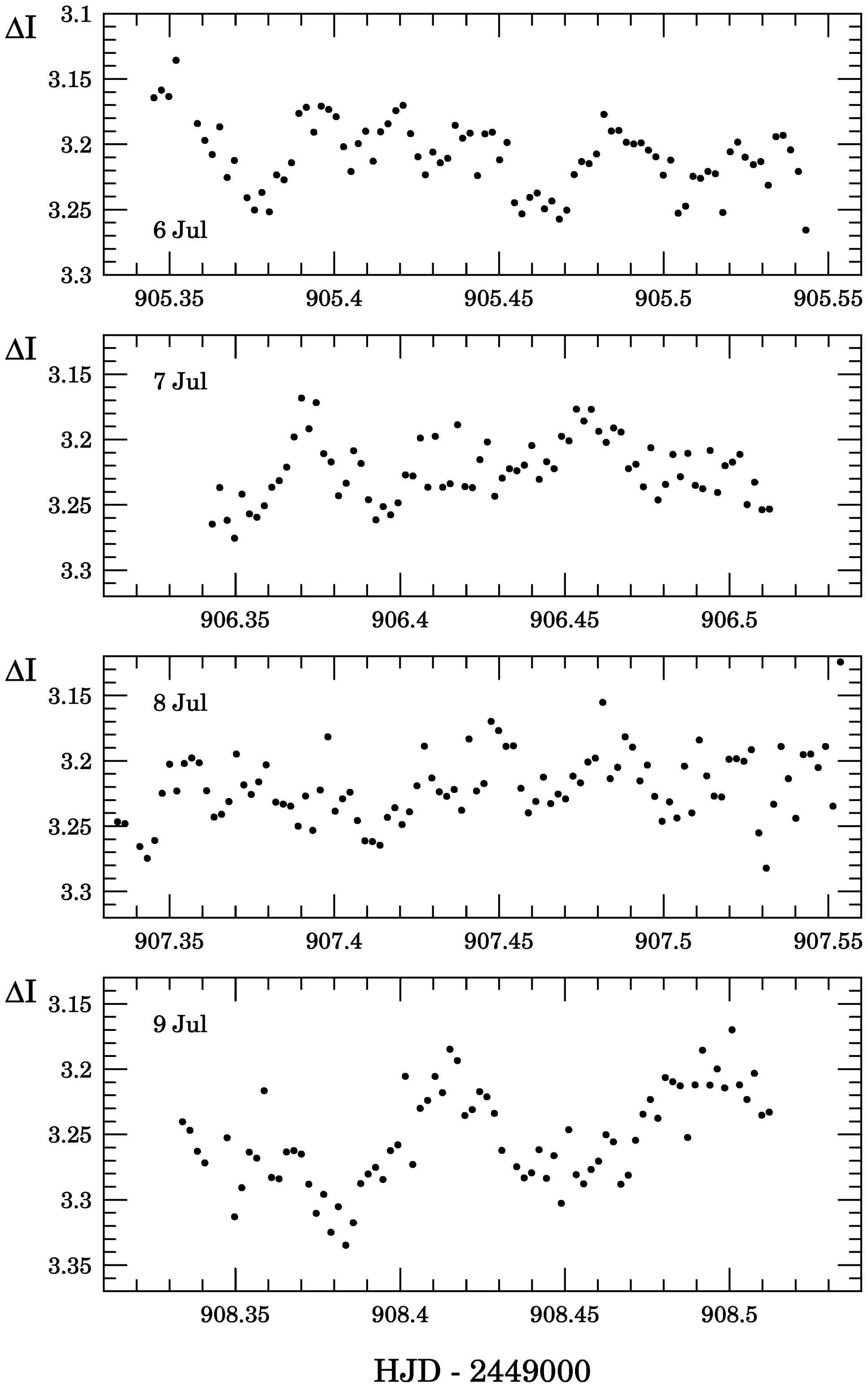

Fig. 1. The light curves of V1974 Cygni observed during four consecutive nights in July 1995.

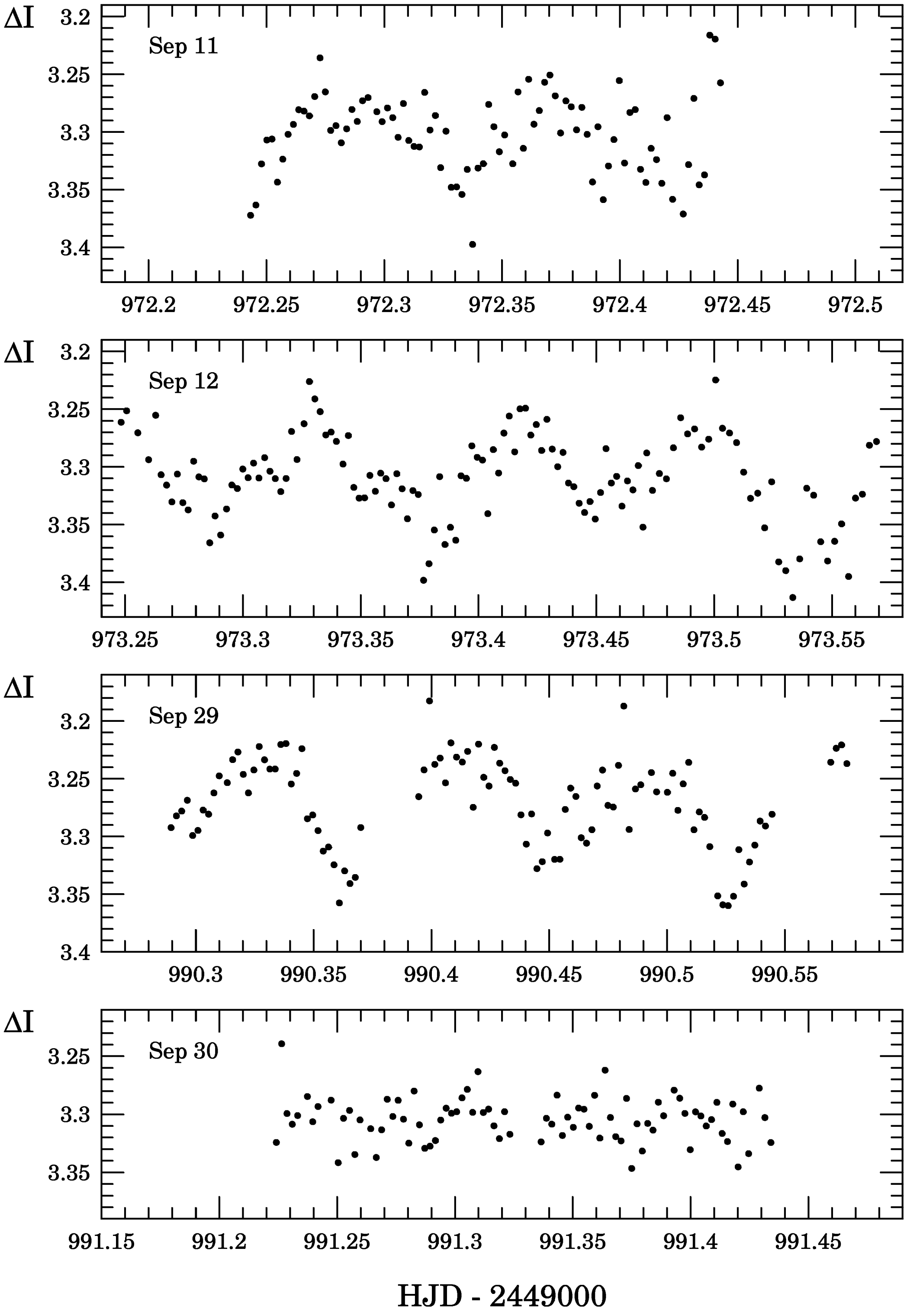

Fig. 2. The light curves of V1974 Cygni observed in September 1995.

Table 1

Journal of the CCD observations of V1974 Cygni

Date 1995	Time of start JD 2449000. +	Length of run (hr)	Date 1995	Time of start JD 2449000. +	Length of run (hr)
Ostrowik			Ostrowik		
Feb 22	771.560	3.3	Sep 11	972.243	4.8
Mar 31	808.475	3.6	Sep 12	973.248	7.7
Jun 28	897.352	4.4	Sep 13	974.242	2.6
Jun 29	898.372	3.3	Sep 29	990.290	6.9
Jun 30	899.342	3.6	Sep 30	991.224	5.0
Jul 4	903.342	2.6	Oct 9	1000.382	2.2
Jul 5	904.340	3.6	Oct 10*	1001.216	2.2
Jul 6	905.345	4.7	Oct 21	1012.188	6.9
Jul 7	906.343	4.1	Oct 26	1017.229	6.3
Jul 8	907.334	5.3	Oct 27	1018.183	7.3
Jul 9	908.334	4.3	Nov 30	1052.178	1.4
Jul 13	912.432	2.8	Dec 7	1059.145	4.4
Jul 25	924.362	4.6	Dec 8	1060.140	5.5
Jul 26	925.338	5.2	Dec 9	1061.142	5.8
Jul 30	929.328	5.9	USNO		
Jul 31	930.326	6.0			
Aug 1	931.466	2.5	Oct 9	1000.480	2.4
Aug 2	932.325	2.9	Oct 22	1013.462	4.1
Aug 16	946.348	4.5	Oct 23	1014.463	3.7
Sep 7	968.321	5.8	Oct 24	1015.474	2.3
Sep 10	971.312	4.0	Oct 28	1019.467	1.9

* observations without filter

1994 observations, seems to be not so regularly pronounced in 1995. We expect that it may be related to changing ratio of the amplitudes of the two modulations. To check the relative contribution of both periodicities to the 1995 light curve of V1974 Cygni we have performed Fourier analysis of our data.

3. Power Spectrum Analysis

To obtain power spectra of the 1995 photometric observations of V1974 Cygni, we have used, the Lomb-Scargle (Lomb 1976, Scargle 1982) method of Fourier analysis for unevenly spaced data.

For our analysis we have separated from our data five subsets corresponding to five consecutive time intervals. The subsets contained data taken on ten to three nights, and were spaced by several days. Before calculating power spectra we have removed the nightly mean and a longer-scale trend from each individual run. Fig. 3

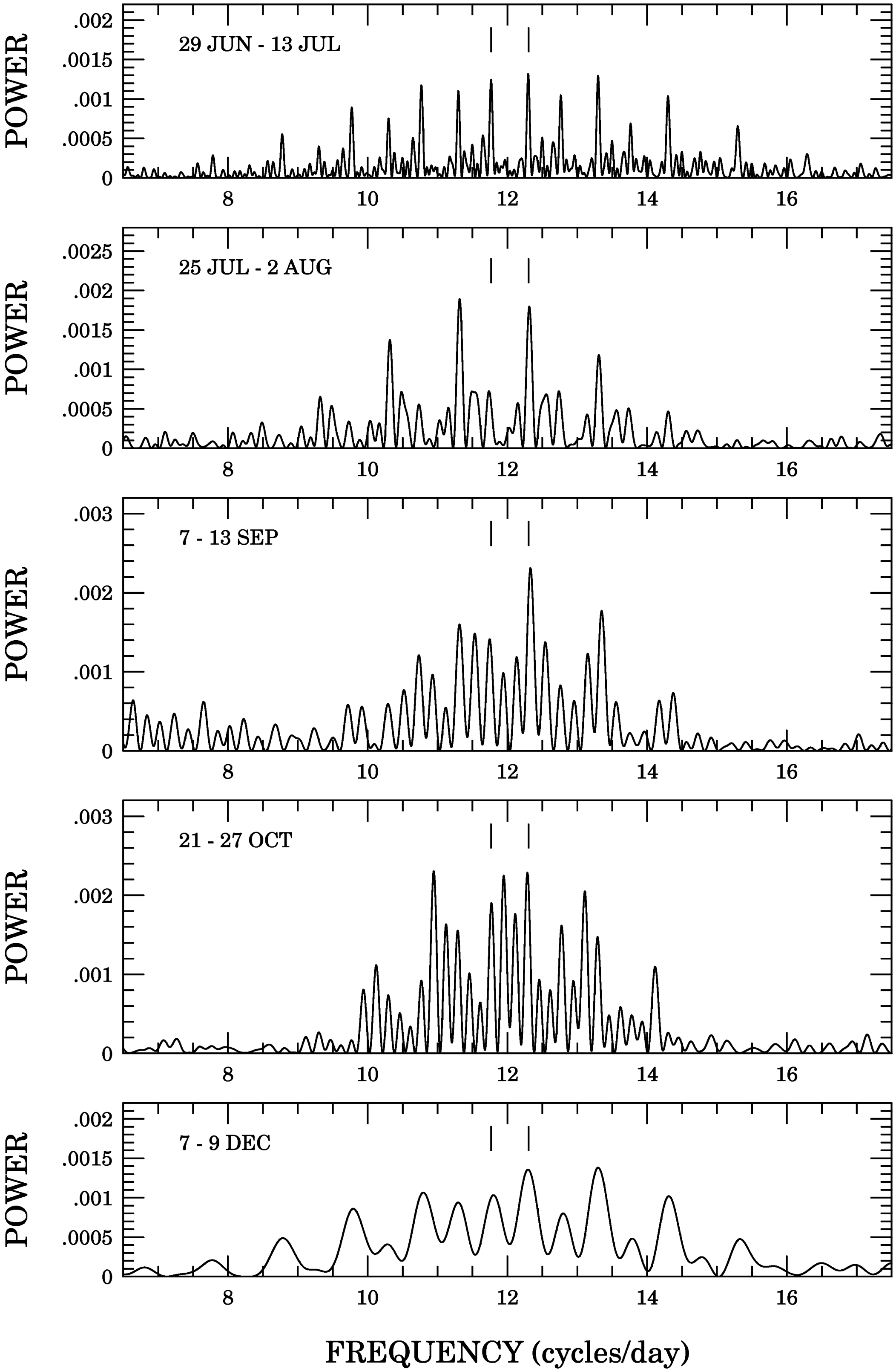

Fig. 3. Power spectra for five consecutive subsets of the 1995 observations. The solid vertical ticks indicate peaks at frequencies 11.77 and 12.30 corresponding to the periods 0.085 and 0.0813 days.

presents results of the analysis for the five subsets of the 1995 observations. The solid vertical ticks in the figure indicate the frequencies 11.77 and 12.30 cycles/day corresponding to the periods of 0.085 and 0.0813 days, respectively. We can see that peaks corresponding to both periods are present in all five frames of Fig. 3. The 0.0813-day peak appears with the highest or the second highest power in all spectra, while the power of the 0.085-day peak is changing. It is comparable to the power of the 0.0813-day period for the June-July spectrum (the uppermost frame) and for the October spectrum, but it is significantly lower than the 0.0813-day period power in the other spectra. The situation in this respect seems to be reverse to that in 1994, when generally the 0.085-day modulation was visible in the spectra with a power little higher than the 0.0813-day one.

The main conclusions derived from the Fourier analysis is that both short-term modulations with periods 0.0813 and 0.085 days, observed by us in 1994, are still present in the 1995 observations of V1974 Cygni, although, contrary to the situation in 1994, the amplitude of the 0.0813-day modulation is now, on the average, a little greater than the amplitude of the 0.085-day modulation. The present mean values of both amplitudes estimated from the power spectra are 0.035 and 0.042 mag.

4. The Temporal Evolution of the Periods of the Short-Term Modulations

In our previous paper (Semeniuk *et al.* 1995) based on the observations from the years 1993 and 1994 we have concluded that the 0.0813-day period is stable and can be interpreted as the orbital period of Nova V1974 Cygni; the 0.085-day period is decreasing. This conclusion was derived from the $O-C$ analysis of times of maxima of the short-term modulations. In the previous paper we have demonstrated that the 0.08-day period extrema observed on the light curve of V1974 Cygni in 1994 come generally from a superposition of maxima of the two modulations. As the extrema of both periodicities do not meet exactly at the same phase, so their times, as obtained directly from the light curve, are determined rather unprecisely. This results in a rather great scatter in the $O-C$ diagrams for both periods. For the 1995 observations the scatter appeared to be even greater than for the 1994 observations, particularly in the 0.085-day period diagram, as the 1995 amplitude of 0.085-day modulation is generally smaller than that of the 0.0813-day modulation. To lessen the scatter we have used another method of determining the times of extrema from the 1995 season. We divided the observations into consecutive subsets of a few (at least two) nights and fitted, to each subset separately, a combination of four sinusoids. In particular we fitted the phases and amplitudes of the sinusoids, while the frequencies were fixed as corresponding to the 0.0813-day and 0.085-day periods and to their first overtones. Then for each of the two modulations we have taken a single time of maximum obtained from the fit as a value representative for a given subset. The times of maxima obtained in this way and collected in Tables 2 and 3 have been used for analysis of the evolution of the two periods. The mean amplitudes of the two modulations determined from the fit agree well with those obtained from the power spectra.

4.1. The 0.0813-day Period

Table 2

The 1995 Times of Maxima of the 0.0813 d Periodicity

HJD 2449000. +	E	$O-C$ cycles	HJD 2449000. +	E	$O-C$ cycles
771.658	2907	0.004	972.286	5376	0.028
897.438	4455	–0.087	973.419	5390	–0.029
903.369	4528	–0.097	990.408	5599	0.046
908.418	4590	0.038	1012.344	5869	0.001
925.396	4799	–0.023	1018.359	5943	0.024
930.431	4861	–0.060	1060.289	6459	0.035

Table 2 contains 12 times of maxima of the 0.0813-day modulation determined from the 1995 observations in the way described above. A global analysis of all times of the 0.0813-day maxima, those from the 1993 and 1994 (Semeniuk *et al.* 1995) and from Table 2 has led to the conclusion, that contrary to our expectation the 0.0813-day period was not stable during the years 1993-1995. The 0.0813-day period behavior in this time interval is illustrated in Fig. 4. The $O-C$ residuals displayed in the figure were calculated with the linear ephemeris:

$$\begin{aligned} \mathrm{HJD}_{\mathrm{Max}} &= 2449535.4405 + 0.0812580\,E \\ &\quad\pm 0.0012 \pm 0.0000004 \end{aligned} \tag{1}$$

This ephemeris results from the least-squares method employed for the maxima of the 1994 and 1995 years only. The $O-C$ values given in Table 2 relate to this ephemeris.

Fig. 4 demonstrates that the 0.0813-day period, interpreted by us as the orbital period of the system, has shortened by about 0.4 s during the three years of our observations. The continuous lines in the figure, corresponding to an initial and the actual period values, would suggest an abrupt change of the orbital period. However, we are prone to believe that the change did not follow abruptly but rather in a continuous way in an early epoch after the nova outburst. A possible mechanism of such a shortening of the orbital period may be outflow of mass from the system through an outer Lagrangian point (see *e.g.*, Kruszewski 1966) that occurred just after the outburst. One cannot also exclude another explanation of Fig. 4. It assumes that the orbital period was constant in the whole interval 1993-1995 but the shape of the 1993 light curve was significantly different from

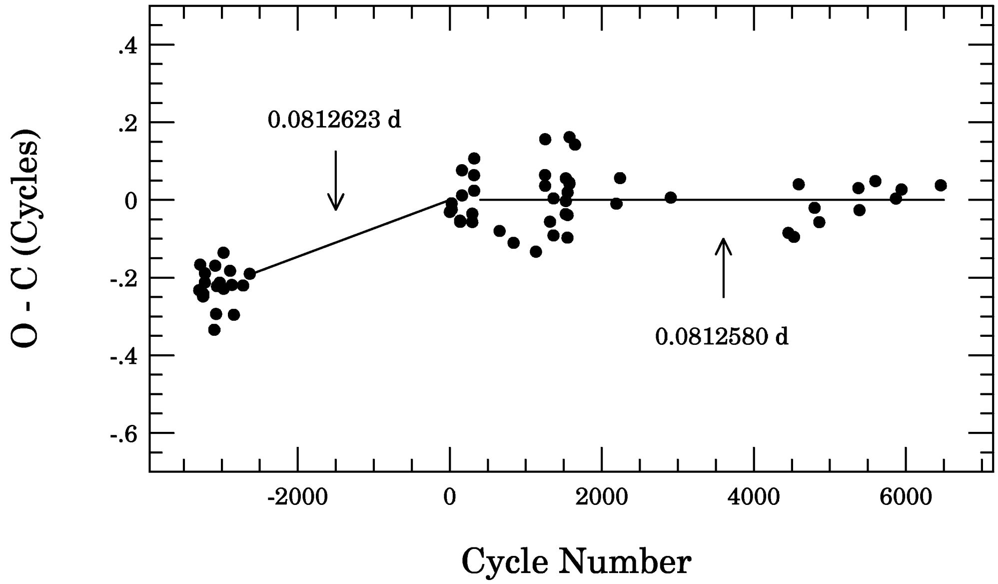

Fig. 4. $O-C$ diagram for times of maxima of the 0.0813-day (orbital) modulation observed in the years 1993–1995. The $O-C$ residuals were calculated from the ephemeris (1). The decrease of the orbital period is marked with the continuous lines.

that observed in later epochs in such a way that the observed 1993 maxima were displaced by about 0.2 of phase in comparison with their phase observed in later epochs.

4.2. The 0.085-day Period

The 1995 maxima of the 0.085-day periodicity are contained in Table 3.

Table 3

The 1995 Times of Maxima of the 0.085 d Periodicity

HJD 2449000. +	E	HJD 2449000. +	E
771.607	2779	972.301	5141
897.449	4260	973.409	5154
903.385	4330	990.407	5354
908.409	4389	1012.334	5612
925.391	4589	1018.375	5683
930.408	4648	1060.274	6176

To investigate the 0.085-day period behavior we have combined the times of maxima of Table 3 with the 1994 times of maxima published in our previous paper (Semeniuk *et al.* 1995) to construct the $O-C$ diagram. It is displayed in Fig. 5.

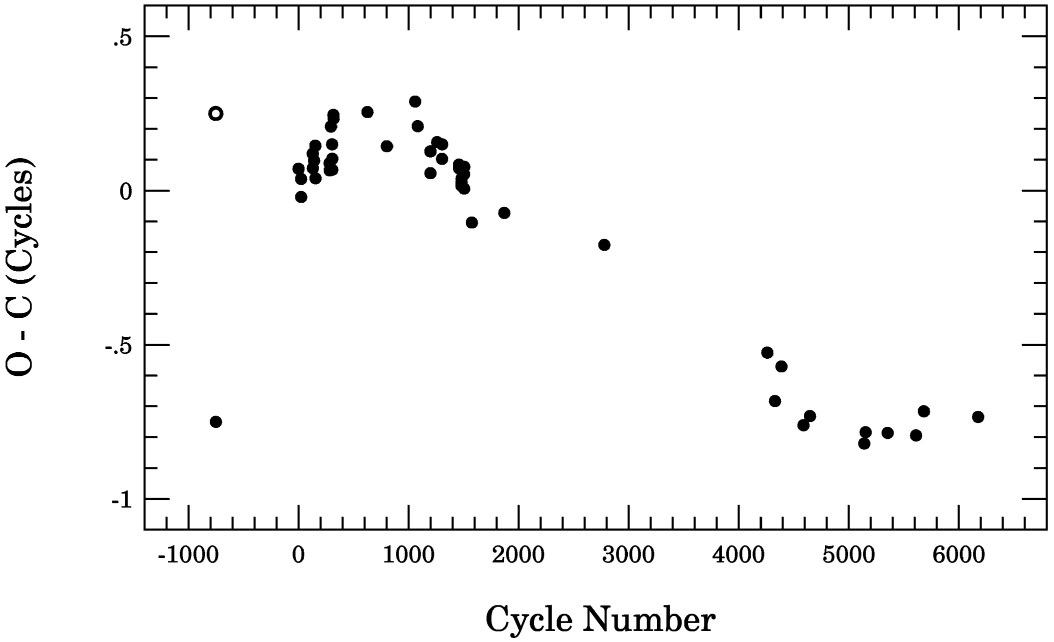

Fig. 5. $O-C$ values for times of maxima of the 0.085-day modulation observed in the years 1994–1995. The $O-C$ residuals were calculated with the linear ephemeris (2).

The $O-C$ deviations plotted in the figure, as well as the cycle numbers E in Table 3, were calculated with the following linear ephemeris:

$$\mathrm{HJD}_{\mathrm{Max}} = 2449535.4320 + 0.084991\,E \tag{2}$$

The two $O-C$ values plotted in Fig. 5 as the open and filled circles for the first time of maximum were obtained with their cycle numbers different by one.

Fig. 5 presents the temporal evolution of the 0.085-day period of V1974 Cygni during the seasons 1994 and 1995. In our previous paper (Semeniuk *et al.* 1995) we have demonstrated that the 0.085-day period was quickly decreasing during the 1994 season. We expected that this decrease will be continued in 1995. Fig. 5 shows, however, that in 1995 the period stopped to decrease and since the middle of July 1995 seems to be increasing. Changes of the time derivative are known to be observed for the spin periods of intermediate polars. FO Aqr is a known example of such objects (Osborne and Mukai 1989, Kruszewski and Semeniuk 1993). What concerns V1974 Cygni there were proposed up to now two possible explanations of the nature of the 0.085-day period (Retter, Ofek and Leibowitz 1995, Semeniuk *et al.* 1995); one that it is the superhump period of a SU Ma type star, and the second one that it is spin period of the magnetized white dwarf in the system. The resemblance of the $O-C$ diagram of Fig. 5 to that observed for the spin period of the intermediate polar FO Aqr might serve as an argument for the spin nature of the 0.085-day period of V1974 Cygni.

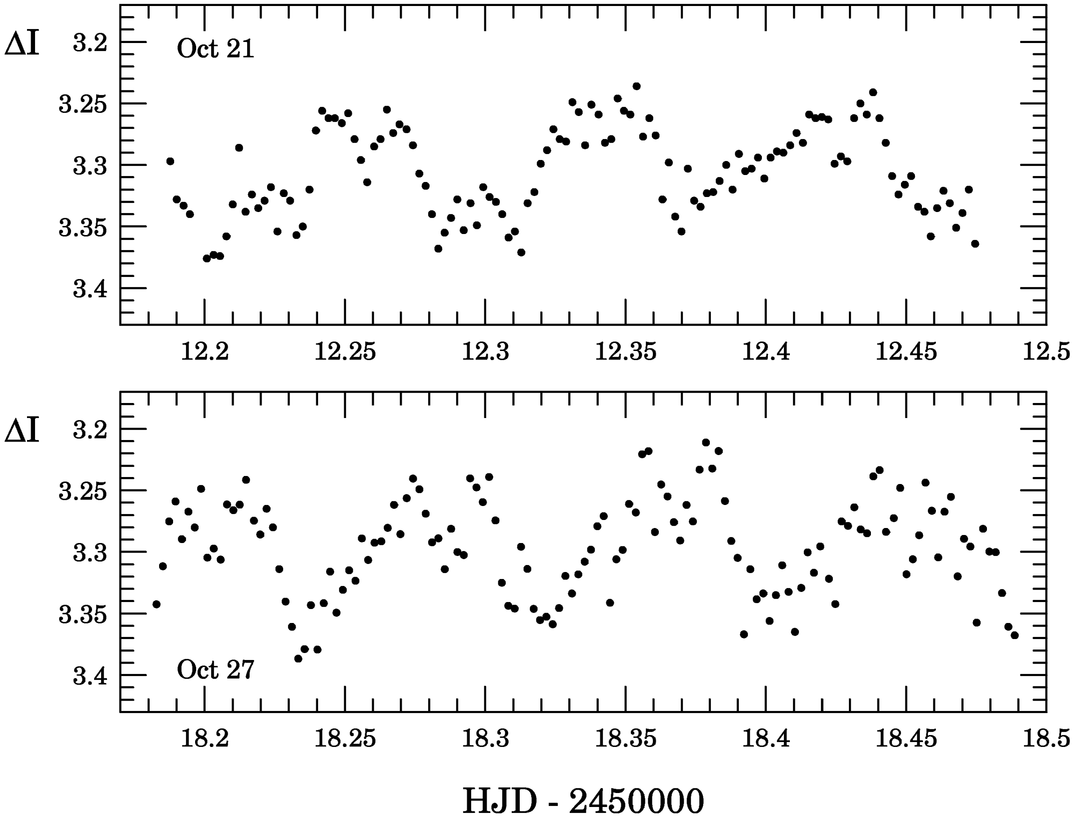

Fig. 6. The light curves of V1974 Cygni observed on two nights of October 1995 showing a double structure of maxima.

5. October Light Curves of V1974 Cygni

As an additional argument for the spin nature of the 0.085-day period one may consider a characteristic appearance of light curves observed during some nights at the end of 1995 season. Two such runs obtained in October are displayed in Fig. 6. A characteristic feature of these light curves is a double structure of maxima. A secondary minimum is observed in the middle of maxima. Such light curves are observed for polars possibly due to existence of two magnetic poles. A classic example is the polar AM Her (Olson 1977, Gilmozzi, Messi, and Natali 1978). One can argue that the double structure of maxima on the light curve of V1974 Cygni may not be necessarily related to the 0.085-day period but perhaps to the orbital, 0.0813-day period. Fig. 7 seems to be an evidence that rather the 0.085-day period is responsible for the double structure. It presents two composite light curves obtained from the observations of the two nights of Fig. 6 after removing the nightly mean and a longer-scale trend from each individual run. The upper and lower curves correspond respectively to the 0.085-day and 0.0813-day periods used for phasing the observations. One can see that the double structure is much better retained in the upper curve.

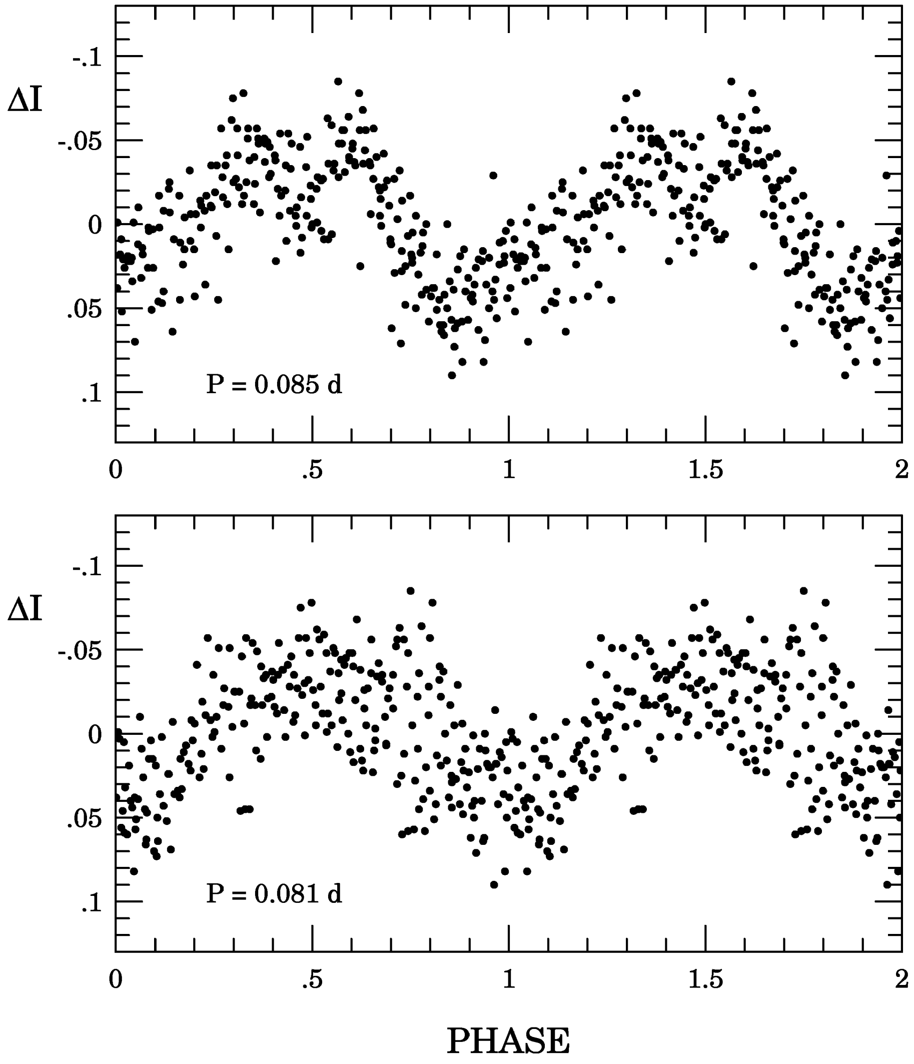

Fig. 7. The composite light curves obtained from the runs displayed in Fig. 6 with the periods 0.085 (upper frame) and 0.0813 (lower frame) days. The double structure of maxima is better reproduced in the upper frame.

6. Conclusions

Our analysis of the the CCD *I* observations obtained on 40 nights between February 20 and December 9, 1995 led to the following conclusions.

Both short-term periodicities with periods 0.0813 and 0.085 days observed on the light curve of V1974 Cygni in 1994 were also present during the 1995 season. Contrary to the 1994 season the amplitude of the 0.085-day modulation in 1995 was, on the average, smaller than the amplitude of the 0.0813-day modulation. The mean values of these amplitudes for the 1995 season were about 0.035 and 0.042 mag, respectively.

Analysis of all observations from the time interval 1993–1995 has given an evidence that the 0.0813-day period, interpreted by us as the orbital period of the system, decreased. We suggest that the decrease may be due to mass loss from the system through an outer Lagrangian point that occurred in an earlier epoch, after the outburst of the nova. One may also try to explain the observed $O-C$ diagram (Fig. 4) with a constant orbital period assuming that some changes of the light curve shape are responsible for the observed displacement of the 1993 maxima.

The nature of the 0.085-day period still remains unexplained. There are two possibilities considered up to now; 1) it might be the superhump period of a SU Ma type star (Retter, Ofek and Leibowitz 1995, Leibowitz *et al.* 1995), as the two short periods obey exactly the relation of Stolz and Schoembs (1981), and the value of the orbital period is just below the period gap, and 2) it might be the rotation period of the magnetized white dwarf in the system. The analysis of the 1995 observations supply us with two results that might be interpreted as arguments for the second explanation. The temporal evolution of the 0.085-day period resembles that of some intermediate polars, and the light curve of the nova, observed on some nights at the end of 1995, is characteristic for photometric behavior of some polars.

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