COMMISSIONS 27 AND 42 OF THE IAU
INFORMATION BULLETIN ON VARIABLE STARS

Number 5218

Konkoly Observatory
Budapest
04 January 2002

HU ISSN 0374 – 0676

NN Ser AND V664 Cas: TWO PRE-CATACLYSMIC BINARIES WITH LARGE REFLECTION EFFECT

PIGULSKI, A.; MICHALSKA, G.

Wrocław University Observatory, Kopernika 11, 51-622 Wrocław, Poland, e-mails: pigulski@astro.uni.wroc.pl, michalska@astro.uni.wroc.pl

Pre-cataclysmic binaries (Ritter & Kolb 1998; Marsh 2000; Hillwig et al. 2000) constitute a small group of detached short-period systems formed from wide binaries during the common-envelope stage of evolution (Paczyński 1976). They usually consist of a hot white dwarf and a low-mass cool main-sequence secondary. The systems become further the cataclysmic ones loosing angular momentum via gravitational waves and/or magnetic braking (Ritter 1986). The light curves of many pre-cataclysmic variables exhibit large variations caused by the reflection effect. This is a consequence of large temperature differences at the secondary's surface which are caused by the heating of its hemisphere by a hot companion. The full amplitude of the reflection effect exceeds 1 mag in some systems. The study of the reflection effect, especially when observed in several bands, can help to constrain system's parameters. This is very important in systems which are non-eclipsing.

We observed two relatively poorly studied pre-cataclysmic stars, NN Ser and V664 Cas. All observations were carried out at the Białków station of the Wrocław University Observatory with a 60-cm Cassegrain telescope equipped with a 576 × 384 pixels CCD camera, an autoguider, and a set of $UBV(RI)_{\rm C}$ filters of the Johnson-Cousins system. For both stars differential magnitudes with respect to nearby relatively bright stars of similar colour have been formed. The differential photometry was left in the instrumental system.

Using the positions of stars from the Hubble Guide Star Catalog, we derived the positions of NN Ser and V664 Cas with an accuracy $\sim$0.″1. They are the following: NN Ser, $\alpha_{2000.0} = 15^{\rm h}52^{\rm m}56\overset{\rm s}{.}12$, $\delta_{2000.0} = +12^\circ54'44\overset{''}{.}3$, V664 Cas (GSC 4056.01762), $\alpha_{2000.0} = 3^{\rm h}03^{\rm m}47\overset{\rm s}{.}01$, $\delta_{2000.0} = +64^\circ54'36\overset{''}{.}2$. The photometric data for NN Ser and V664 Cas presented here are available from the authors upon request.

The photometric variations of NN Ser (PG 1550+131), a $V \approx 17$ mag pre-cataclysmic variable, were revealed by Wilson et al. (1986) and Häfner (1989). The star shows nearly sinusoidal variations due to the reflection effect and a very deep 10.5 min-long primary eclipse. Because the star is very faint, the true shape and depth of the eclipse was not known until the recent observations with the VLT ANTU by Häfner (2000) on 10/11 June 1999. The 18.5-min trail exposure showed clearly that the eclipse is total and has a record depth equal to 6.04 mag in the V filter.

We observed NN Ser on one night, 2/3 May 2000, in two bands, V and $I_{\rm C}$. The star was too faint for our telescope to be seen within the eclipse, but the out-of-eclipse variations could easily be recorded. They are shown in Fig. 1 together with synthetic light changes. The latter were obtained by means of the Wilson-Devinney code (Wilson & Devinney 1971) with parameters taken from Häfner (2000). Our photometry is not good enough to improve system parameters given by this author, but the I_C observations we provide are the first presented for NN Ser in filter other than V. As expected, the reflection effect in the I_C light curve has a range of about 1 mag in comparison with about 0.6 mag in V. From our out-of-eclipse observations in the V filter we derived the time of minimum light: HJD 2 451 667.4771 ± .0004. The time of mid-eclipse was derived by means of the least-squares shifting the synthetic light curve (shown in Fig. 1) in time. Only the V observations were used for that. Four other times of minimum are available from the literature (Table 1). All times of minimum resulted in the following ephemeris for the primary eclipse in NN Ser:

$$T_{\rm min}\,{\rm I} = {\rm HJD}\ 2\,447\,344.52413(11) + 0\overset{\rm d}{.}13008010(2)E, \qquad (1)$$

where the numbers in parentheses denote the r.m.s. errors of the last digit(s) and E is the number of cycles elapsed from the starting epoch.

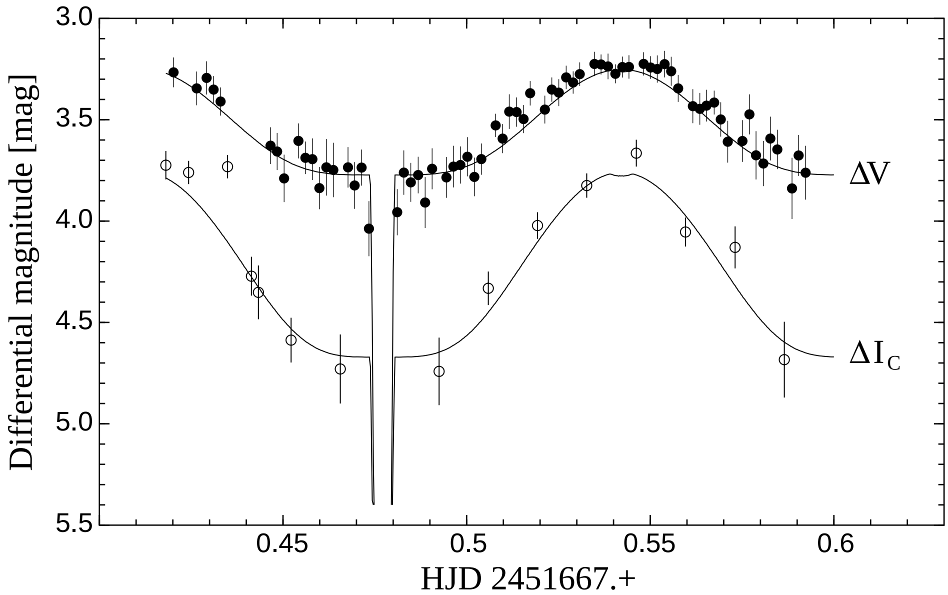

Figure 1. Differential V (dots) and I_C-filter (open circles) light curve of NN Ser obtained on 2/3 May 2000. In order to indicate the location of the eclipse, synthetic changes are also shown with continuous line.

Table 1. Times of primary minimum for NN Ser

Time of minimum HJD 2 400 000.+	E	O−C [d]	Reference
47344.5240(5)	0	−.00013	Häfner (1989)
47712.78093(5)	2831	+.00004	Wood & Marsh (1991)
47713.82158(5)	2839	+.00005	Wood & Marsh (1991)
48301.91353(5)	7360	−.00013	Wood & Marsh (1991)
51667.4771(4)	33233	+.00101	this paper

The variability of V664 Cas, the central object of the faint planetary nebula HFG 1 (Heckathorn et al. 1982) was found by Grauer et al. (1987). They derived a period of $0\overset{d}{.}5817$ and the range of about 1.1 mag in B filter. The light curve they show is nearly sinusoidal. Despite the large variations, the variability is entirely due to the reflection effect. The system is non-eclipsing (Grauer el al. 1987). As far as we are aware, no other photometry is available for this star.

V664 Cas was observed by us on two consecutive nights, 18/19 and 19/20 October 1999 through the V, $R_{\rm C}$, and $I_{\rm C}$ filters. These observations phased with the period derived by Grauer et al. (1987) are shown in Fig. 2. Although the phases near minimum were not covered, it is clear that the light curve is, likewise in the B filter, nearly sinusoidal. It can be also seen that the range of the reflection effect is nearly the same in all three filters. Fitting a sinusoid we derived the range of $1.132 \pm .012$, $1.140 \pm .008$, and $1.118 \pm .006$ mag in V, $R_{\rm C}$, and $I_{\rm C}$, respectively. The average time of maximum light derived from our data in all three filters is the following: HJD 2 451 470.5241 ± .0004. Unfortunately, we cannot improve the period derived by Grauer et al. (1987), because the time of maximum light is not available for their observations.

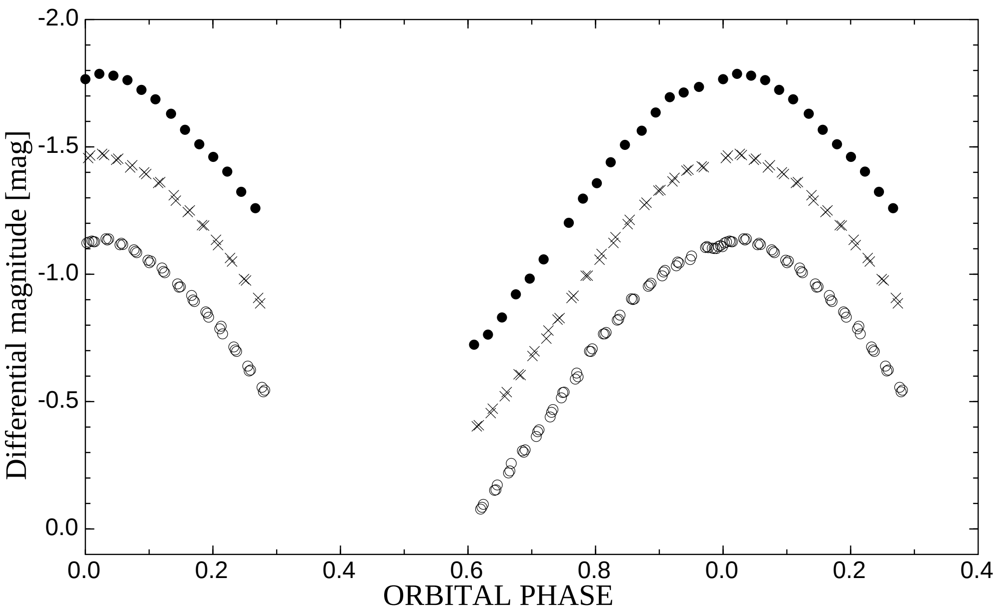

Figure 2. Differential light curve of V664 Cas in V (dots), $R_{\rm C}$ (crosses), and $I_{\rm C}$ (open circles) band phased with a period of 0.5817 d derived by Grauer et al. (1987). Phase 0.0 was chosen arbitrarily.

As was shown by Acker & Stenholm (1990), the optical spectrum of V664 Cas is dominated by strong emission lines coming from the secondary's heated hemisphere. The effective temperature of the primary estimated from its ultraviolet spectrum was found to be in the range 50 000–60 000 K (Heckathorn & Fesen 1985). It is therefore likely a hot white dwarf. The diameter of the primary cannot be constrained from the analysis of the light curve because the system is non-eclipsing. Nevertheless, we have tried to fit the $V(RI)_{\rm C}$ light curves using again the Wilson-Devinney code. We found that the only parameter which can be reliably estimated is the inclination of the orbit which amounts to about 30°.

There are several pre-cataclysmic binaries which, like V664 Cas, show large reflection effect. These are: BE UMa, TW Crv, FF Aqr, VW Pyx, V 474 Lyr, UU Sge, and NN Ser.

However, except maybe VW Pyx (Kohoutek & Schnur 1982; Bond 1988), the amplitude of the reflection effect increases towards longer wavelengths. In this respect, V664 Cas seems to be exceptional. Its large reflection effect with amplitudes practically independent of the wavelength in the optical range can be qualitatively explained if we recall two facts: (i) the main contribution to the total light comes from the heated secondary's hemisphere not the primary component, (ii) there is a strong gradient of the surface brightness in the heated hemisphere. In general, for a given system, the larger the inclination, the larger the amplitude of the reflection effect is. So, how we can get a 1.1-mag reflection effect in such a low-inclination system like V664 Cas? Simple comparison of the areas of the heated hemisphere seen by the observer at the epochs of maximum and minimum light is not sufficient to explain this. However, we have to remember the fact (ii) which means that in the phases around the maximum light we see very hot areas nearby the substellar point. This is not the case in the minimum, when we see only much colder areas of the heated hemisphere. Moreover, if we consider only the contribution of the secondary, we should observe the *increase* of amplitude with decreasing wavelength. However, there is a primary in the system. Because it is hot, its contribution is larger in short wavelengths. This leads to the reduction of the amplitude calculated from the contribution of the secondary. In V664 Cas the two effects balance perfectly, leading to the independence of the observed amplitude of the reflection effect of the wavelength in the optical range.

References:

Acker, A., Stenholm, B., 1990, *A&A*, **233**, L21.

Bond, H.E., 1988, *BAAS*, **20**, 735.

Grauer, A.D., Bond, H.E., Ciardullo, R., Fleming, T.A., 1987, *BAAS*, **19**, 643.

Häfner, R., 1989, *A&A*, **213**, L15.

Häfner, R., 2000, *The Messenger*, **100**, 42.

Hillwig, T.C., Honeycutt, R.K., Robertson, J.W., 2000, *AJ*, **120**, 1113.

Heckathorn, J.N., Fesen, R.A., Gull, T.R., 1982, *A&A*, **114**, 414.

Heckathorn, J.N., Fesen, R.A., 1985, *A&A*, **143**, 475.

Kohoutek, L., Schnur, G.F.O., 1982, *MNRAS*, **201**, 21.

Marsh, T.R., 2000, *New Astronomy Rev.*, **44**, 119.

Paczyński, B., 1976, Proc. IAU Symp. 73, *Structure and Evolution of Close Binary Systems*, eds. P.P. Eggleton, R.O. Redman, M. Mathioudakis, p. 75.

Ritter, H., 1986, *A&A*, **169**, 139.

Ritter, H., Kolb, U., 1998, *A&AS*, **129**, 83.

Wilson, J., Devinney, E.J., 1971, *ApJ*, **166**, 605.

Wilson, J., Miller, H.R., Africano, J.L., Goodrich, B.D., Mahaffey, C.T., Quigley, R.J., 1986, *A&AS*, **66**, 323.

Wood, J.H., Marsh, T.R., 1991, *ApJ*, **381**, 551.