ACTA ASTRONOMICA
Vol. **47** (1997) pp. 201–209

CCD Photometry of SW Ursae Majoris during the 1996 Superoutburst

by

I. Semeniuk, A. Olech, T. Kwast and M. Należyty

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

Received March 22, 1997

ABSTRACT

We present CCD R photometry of SW Ursae Majoris – an SU UMa type cataclysmic variable – obtained during its April 1996 superoutburst. The mean value of the superhump period $P_{\rm sh}$ derived from our observations is 0.05818($\pm$2) days (83.8 min). The analysis of times of superhump maxima gives clear evidence for the increase of the superhump period with $\dot{P}_{\rm sh} = 8.9 \times 10^{-5}$.

Key words: *binaries: close – novae, cataclysmic variables – individual: SW UMa*

1. Introduction

The SU UMa type star, SW Ursae Majoris, was discovered by Mrs L. Ceraski in 1909 (Ceraski 1910), when as a result of an outburst it appeared over the threshold magnitude on an inspected plate. Due to its rare outbursts and their relatively great amplitudes Wellmann (1952) suggested that the star may be considered as an intermediate link between the U Gem type stars and Nova-like or Nova stars. Discovery of the superhump phenomenon during the 1986 superoutburst of the star (Robinson *et al.* 1987) made it clear that the object belongs to the SU UMa type stars.

The SU UMa stars are a subclass of dwarf novae stars, whose distinctive feature is that they exhibit two essentially different types of outbursts. Beside the so called short or normal outbursts (normal maxima), typical for all dwarf novae and lasting a few days, the SU UMa stars show the so called superoutbursts or supermaxima. The superoutbursts last 5–10 times longer than the normal outbursts, and their amplitudes exceed that of the normal outbursts by about 1 mag. A characteristic feature of the superoutbursts light curves is their sloping plateau which begins just after the supermaximum brightness and ends with a rapid decline to the minimum state. All SU UMa type stars – and this is their most distinctive defining mark

– show during superoutbursts some short period light variability, the so called superhumps, repeating with a period of the order of 100 min and amplitude of about 0.2–0.3 mag. The superhump periods of the SU UMa stars are by a few percent longer than their orbital periods derived from spectroscopy or photometry obtained during quiescence. Some SU UMa stars, like other dwarf novae, reveal the so called orbital humps during quiescence *i.e.*, light modulation repeating with the orbital period that results from a favorable inclination of the binary orbit with respect to the observer. It should be stressed that superhumps appear on superoutburst light curves of all SU UMa stars independently of whether they show orbital humps during quiescence or not, *i.e.*, independently of inclination of their orbits.

Recently Howell, Szkody and Cannizzo (1995) distinguished a subgroup of the SU UMa type stars which they called "tremendous outburst amplitude dwarf novae" or "TOADs". Their superoutburst amplitudes are in the range 6–10 mag. At the same time the TOADs are the SU UMa systems with the shortest orbital periods, the longest intervals between superoutbursts and they hardly ever undergo normal outbursts. For the SU UMa stars of longer orbital periods and smaller superoutburst amplitudes normal outbursts are generally observed much more frequently than superoutbursts. SW UMa with its superoutburst amplitude of about 7 mag was included into the TOADs.

SW Ursae Majoris is a star of $V = 16.5 - 17$ at quiescence. Its orbital period determined from spectroscopy (Shafter, Szkody and Thorstensten 1986) and improved with the aid of photometric observations of orbital humps visible on the quiescence light curve of the star (Szkody, Osborne and Hassall 1988) is equal to 0.056815 days (81.8 min). It is the second shortest orbital period among the SU UMa type stars (Warner 1995) with their orbital periods determined observationally.

The mean recurrent time of SW UMa superoutbursts, given by Howell, Szkody and Cannizzo (1995) is 400 days. According to Howell *et al.* (1995) in the time interval between November 1977 and August 1993 the AAVSO observers recorded 10 outbursts of SW UMa. Only one of these outbursts was a normal one.

The superhump period of SW UMa was determined as equal to 0.05833 days (84.0 min) by Robinson *et al.* (1987) during the 1986 superoutburst. To our knowledge the only other published observations of superhumps are those from the March 1992 superoutburst reported by Kato, Hirata and Mineshige (1992). The obtained then superhump period value was in good agreement with the Robinson *et al.* one. The superhump period of SW UMa is by about 3% longer than the orbital period.

In April 1996 we were notified by the electronic *VSNET*, run by Drs T. Kato and D. Nogami of the Kyoto University in Japan, that a superoutburst of SW UMa had just begun. In the present paper we report on results of CCD photometry of SW UMa performed during this superoutburst.

2. Observations

The present superoutburst observations of SW UMa were carried out at the Ostrowik station of the Warsaw University Observatory with a TK512 CCD at the Cassegrain focus of the 0.6 m telescope. The camera is described by Udalski and Pych (1992). We have monitored the star in the Cousins R filter on 9 nights from April 17 to 27, 1996. The exposure times varied between 20 and 45 seconds, depending on atmospheric conditions, dead time between the frames was 15 seconds. Journal of observations is given in Table 1.

Table 1

Journal of the Ostrowik CCD observations of SW UMa

Date 1996	Time of start JD 2450000. +	Length of run (h)	Date 1997	Time of start JD 2450000. +	Length of run (h)
Apr 17	191.311	3.7	Apr 22	196.268	7.0
Apr 18	192.291	4.2	Apr 23	197.314	2.8
Apr 19	193.380	4.2	Apr 24	198.299	1.2
Apr 20	194.300	3.6	Apr 27	201.348	4.9
Apr 21	195.276	6.9			

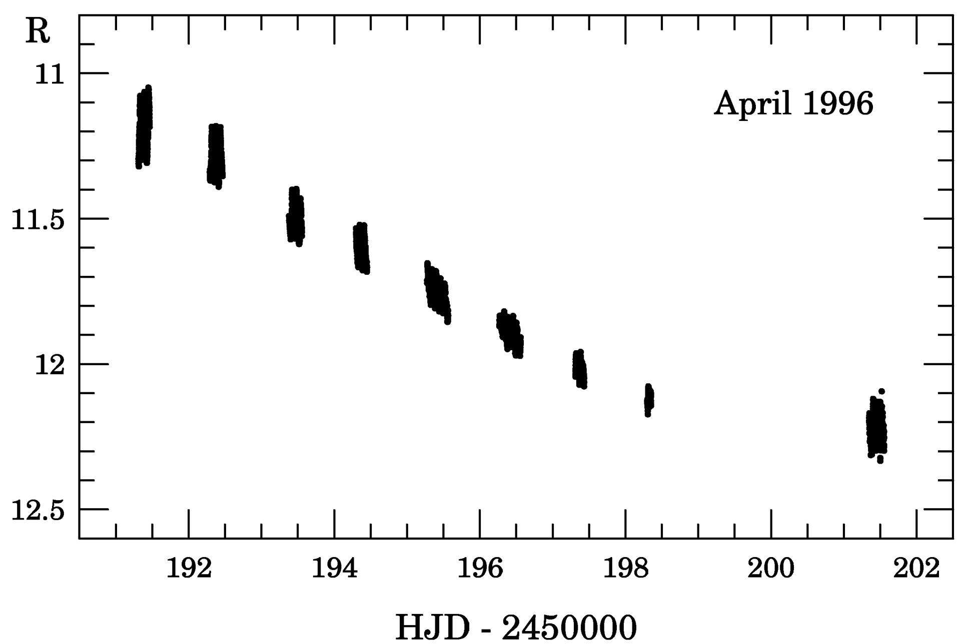

Fig. 1. The general decrease of brightness of SW Ursae Majoris observed during the plateau phase of the 1996 superoutburst.

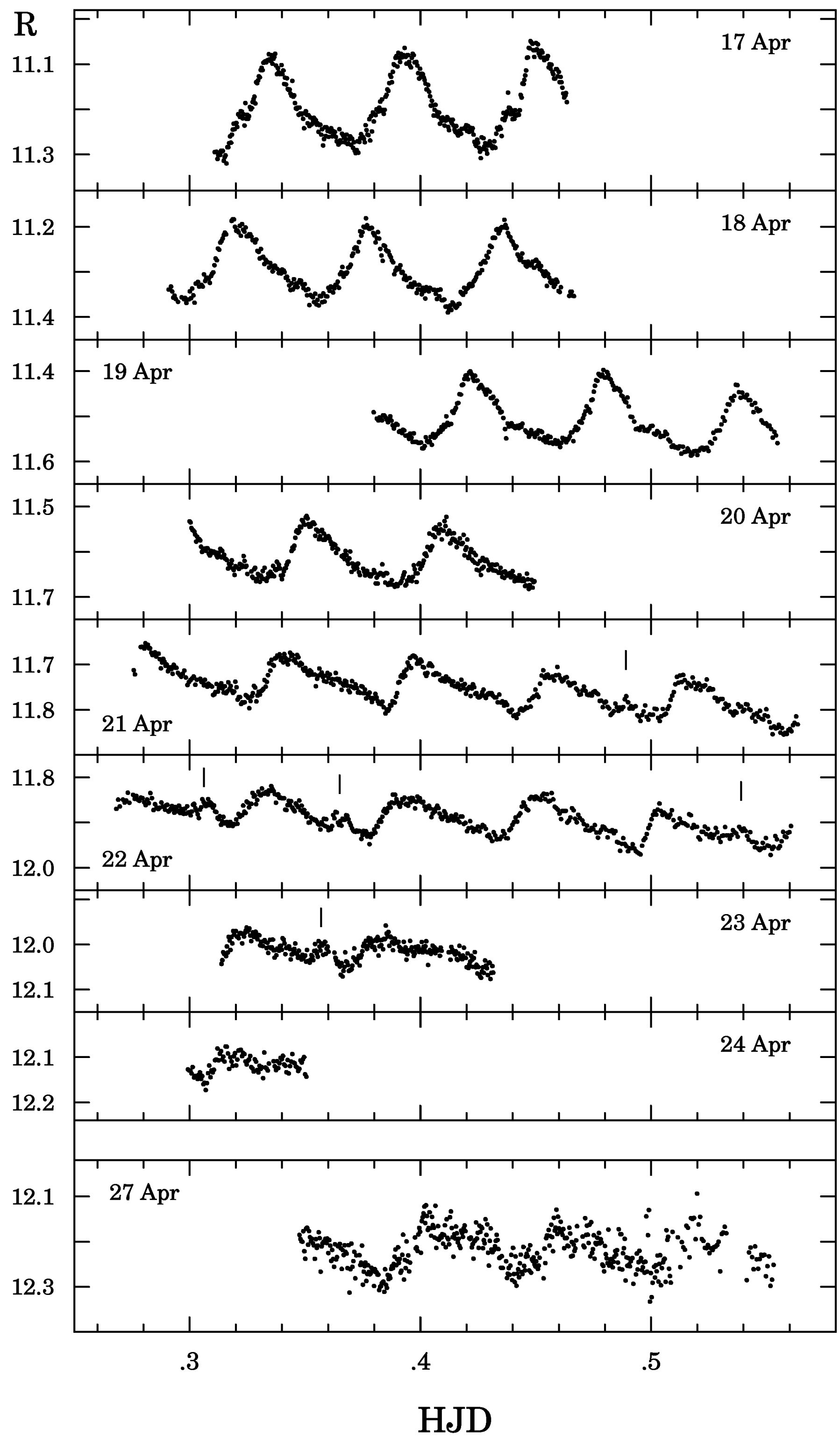

Fig. 2. The light curves of SW Ursae Majoris observed during nine nights of April 1996. Ticks in the panels for the nights of April 21, 22 and 23 indicate positions of interpulses.

The data reduction was performed using IRAF. The profile photometry was done with the DAOphotII package. The stars GSC 3798-0481 and GSC 3798-0491 served as the comparisons in obtaining relative ΔR magnitudes of SW UMa. The first of these stars is a secondary photometric standard in the field of SW UMa (Misselt 1996) with R magnitude equal to 12.68, so we have eventually decided to reduce all the observations of SW UMa to the observed instrumental R magnitudes.

According to the observations of the *VSNET* observers SW UMa started its rapid superoutburst at the end of April 11 and attained the supermaximum brightness at the beginning of April 13. We started to monitor the star on April 17, *i.e.*, about four days after the moment of maximum superoutburst brightness, when its brightness fell already by about 0.5 mag. Fig. 1 shows a general decrease of brightness of SW UMa in the time interval of our observations, characteristic for the sloping plateau of superoutbursts of SU UMa type stars. During 11 days the brightness fell by about 1 mag.

Fig. 2 presents nightly light curves of SW UMa for the nine April nights. First eight nights are consecutive, while the last one is separated from them by two nights. Superhumps, a typical phenomenon of the SU UMa type stars superoutbursts, are observed on each night with their characteristic profile of steeper increase to the maximum and slower decrease. Their amplitude decreases during the eight consecutive nights from 0.2 mag on April 17 to about 0.07 mag on April 23 and 24. On the last night of our observations (April 27) the superhump amplitude increased slightly to about 0.12 mag and we observed a greater scatter of the observations resulting probably from a rapid flickering.

3. The Superhump Period

We have determined 26 times of superhumps maxima from our observations. They are listed in Table 2.

In this Table only the first 23 times observed during the eight consecutive nights are the times of normal superhumps. The last three maxima are shifted by about half superhump period compared with the earlier ones and we assume that they relate rather to the phenomenon of so called late superhumps, observed frequently at the end of superoutburst of SU UMa type stars (Vogt 1983, Udalski 1990, Warner 1995). Therefore, to determine the superhump period we have analyzed only the first 23 maxima of Table 2. The best linear fit to these maxima obtained with the least squares method gives the following ephemeris:

$$\begin{aligned} \mathrm{HJD}_{\mathrm{Max}} = & \, 2450191.3294 + 0.05818\, E \\ & \pm 0.0014 \pm 0.00002 \end{aligned} \qquad (1)$$

The obtained superhump period is slightly shorter than the value 0.05833 days determined by Robinson *et al.* (1987) from the 1986 superoutburst. Our value is a mean superhump period of the eight consecutive nights. The true superhump

Table 2

Times of Superhump Maxima of SW UMa

HJD 2450000. +	E	$O-C$ cycles	HJD 2450000. +	E	$O-C$ cycles
191.3345	0	0.0870	195.5154	72	–0.0559
191.3926	1	0.0856	196.2770	85	0.0337
191.4488	2	0.0515	196.3342	86	0.0168
192.3190	17	0.0076	196.3943	87	0.0497
192.3766	18	–0.0024	196.4520	88	0.0414
192.4360	19	0.0185	196.5033	89	–0.0769
193.4217	36	–0.0403	197.3243	103	0.0336
193.4793	37	–0.0503	197.3844	104	0.0666
193.5373	38	–0.0535	198.3176	120	0.1055
194.3508	52	–0.0719			
194.4089	53	–0.0733	Late Superhumps		
195.3418	69	–0.0396	201.4057	172.5	0.6806
195.3972	70	–0.0874	201.4628	173.5	0.6619
195.4578	71	–0.0459	201.5214	174.5	0.6691

period is changing. This can be seen from the third and sixth columns of Table 2, where we have given the $O-C$ values calculated with the ephemeris (1). These residuals evidently indicate an increase of the period. The quadratic ephemeris obtained as the best least squares fit to the same 23 maxima as used previously is the following:

$$\begin{aligned} \mathrm{HJD_{Max}} = & \, 2450191.3339 + 0.05790\,E + 2.6\times10^{-6}E^2 \\ & \pm 0.0009 \pm 0.00004 \quad \pm 0.3 \end{aligned} \qquad (2)$$

The increase of the superhump period is shown in Fig. 3, where we have plotted the $O-C$ residuals taken from Table 2. The solid line in Fig. 3 presents the fit corresponding to the quadratic ephemeris (2). The open circles correspond to the three last times of Table 2, which we interpret as the times of the late superhumps. The $O-C$ values for these times were calculated with the same ephemeris (1) as the other residuals, only their cycle numbers E were augmented by 0.5.

4. Interpulses and Late Superhumps

Beginning with the fifth night of our run (April 21) we can trace secondary humps located on the light curves approximately midway between the main (normal) superhumps. In Fig. 2 they are marked with ticks. Such interpulses with

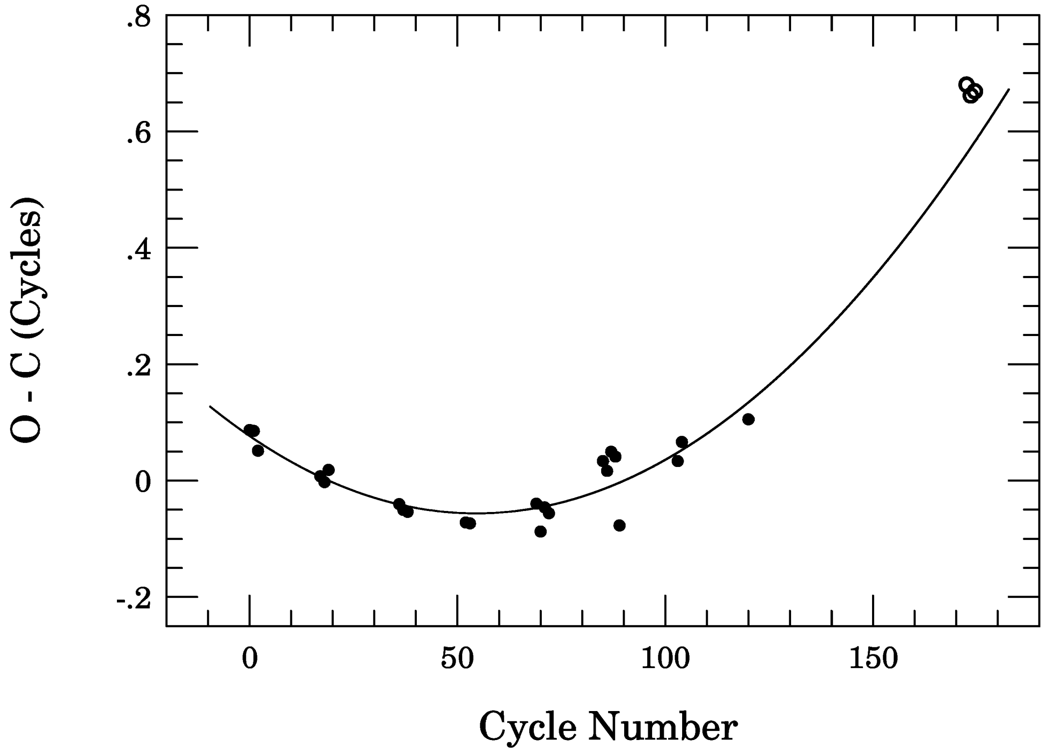

Fig. 3. The $O-C$ values for times of superhump maxima calculated with the linear ephemeris (1). The open circles correspond to the three last values of Table 2, which we interpret as late superhump times. Their cycle numbers were augmented by 0.5. The solid line presents the fit corresponding to the quadratic ephemeris (2).

Table 3

Times of Interpulse Maxima of SW UMa

HJD 2450000. +	E	$O-C$ cycles	HJD 2450000. +	E	$O-C$ cycles
195.489	71.5	–0.010	196.539	89.5	0.037
196.306	85.5	0.032	197.357	103.5	0.096
196.365	86.5	0.046			

progressively increasing amplitude were also observed during the 1986 superoutburst of SW UMa (Robinson *et al.* 1987) and during its 1992 superoutburst (Kato, Hirata and Mineshige 1992). They were also observed in certain stages of superoutbursts of other SU UMa type stars. Udalski (1990) observed them for SU UMa itself. It was suggested (Schoembs and Vogt 1980, Warner 1995, p. 199) that the late superhumps in VW Hyi may develop out of such interpulses. The times of interpulses determined from our light curves are collected in Table 3. Their average phase relative to the superhump maximum is 0.55. Assuming that in

SW UMa the interpulses also represent the late superhumps that have just begun to emerge, we attempted to fit a quadratic ephemeris to the times of Table 3 supplemented with three last times from Table 2. The resulting quadratic term is equal to $(2.7 \pm .4) \times 10^{-6}$, what, within the error limits, is the same as the quadratic term for the normal superhumps (ephemeris (2)). This result may be considered as an evidence that the temporal evolution of the late superhump period follows the evolution of the normal superhump period. The $O-C$ residuals in Table 3 were calculated with the ephemeris (1).

5. Conclusions

From our CCD R photometry performed during the 1996 superoutburst of SW UMa we have determined a mean value of its superhump period $P_{\rm sh}$ as being equal to 0.05818(2) days. We have demonstrated that the instantaneous value of the superhump period increases during the superoutburst. The period derivative $\dot{P}_{\rm sh}$, obtained from a parabolic fit to the $O-C$ diagram, is equal to 8.9×10^{-5}. Such a rate of the superhump period change is typical of SU UMa stars. Generally, however, the SU UMa stars show decreasing superhump periods during the declining plateau phase of superoutbursts. All SU UMa stars with measured superhump period changes listed by Warner(1985) and Patterson *et al.* (1993) have negative $\dot{P}_{\rm sh}$. Hence, SW UMa would be, to our knowledge, the first SU UMa type star with well proved superhump period increase. Recently, Howell *et al.* (1996) and Patterson *et al.* (1996) published $O-C$ diagrams for the superhump period of AL Comae Berenices observed during the 1995 superoutburst of the object. The diagrams seem to suggest that at least in certain time interval during the superoutburst of AL Com the superhump period derivative was positive. Like SW UMa, AL Com is also a member of the TOADs (Howell, Szkody and Cannizzo 1995). It might suggest that the SU UMa stars with the shortest orbital periods and the longest superoutburst recurrence times would have preferably increasing superhump periods contrary to the other SU UMa stars whose $\dot{P}_{\rm sh}$ have negative values.

Under the assumption that interpulses (secondary humps), visible on the light curves of SW UMa beginning from a middle phase of the superoutburst, developed into the late superhumps observed on the night of April 27, we have shown that times of their maxima evolve in the same manner as those of the normal superhumps. The quadratic terms in parabolic fits describing the temporal behavior both of the normal superhump times as well as interpulses supplemented with late superhumps are, within the error limits, the same. It may be an evidence that interpulses and late superhumps are related to the same physical mechanism which underly normal superhumps and makes both phenomena to appear in antiphase.

Kato, Hirata and Mineshige (1992) reported the discovery of quasi-periodic oscillations with a recurrence time of about 6.1 min visible during the early phase of the 1992 superoutburst. We have undertaken an attempt to search for some other periodicities in our observational material. We have fitted, for each night independently, the superhump profiles with a combination of three sinusoids with frequencies corresponding to the superhump period and to its first and second overtones. We have removed this fit from observations and performed periodogram analysis for the obtained residuals. In resulting periodograms for the eight consecutive nights only the fourth and fifth harmonics of the superhump period appeared with some significant power. A rather week peak around the frequency corresponding to about 6 min could be seen only in the periodogram for the night of April 27.

Acknowledgements. We wish to express our gratitude to Professor Andrzej Kruszewski for having given us his observational time, for making for us the observations from April 20, for many helpful discussions and comments on the manuscript.
This work was partly supported by the KBN grant BW to the Warsaw University Observatory.

REFERENCES

Ceraski, W. 1910, *Astron. Nachr.*, **109**, 109.
Howell, S.B., DeYoung, J.A., Mattei, J.A., Foster, G., Szkody, P. Cannizzo, J.K., Walker, G., and Fierce, E. 1996, *Astron. J.*, **111**, 2367.
Howell, S.B., Szkody, P., and Cannizzo, J.K. 1995, *Astrophys. J.*, **439**, 337.
Howell, S.B., Szkody, P., Sonneborn, G., Fried, R., Mattei, J. Oliversen, R.J., Ingram, D. and Hurst, G.M. 1995, *Astrophys. J.*, **453**, 454.
Kato, T., Hirata, R., and Mineshige, S 1992, *PASJ*, **44**, L215.
Misselt, K.A. 1996, *P.A.S.P.*, **108**, 146.
Patterson, J., Augusteijn, T., Harvey, D.A., Skillman, D.R., Abbott, T.M.C., and Thorstensen, J. 1996, *P.A.S.P.*, **108**, 748.
Patterson, J., Bond, H.E., Grauer, A.D., Shafter, A.W., and Mattei, J.A. 1993, *P.A.S.P.*, **105**, 69.
Robinson, E.L., Shafter, A.W., Hill, J.A., Matt, A.W., and Mattei, J.A. 1987, *Astrophys. J.*, **313**, 772.
Schoembs, R., and Vogt, N. 1980, *Astron. Astrophys.*, **91**, 25.
Shafter, A.W., Szkody, P., and Thorstensten, J.R. 1986, *Astrophys. J.*, **308**, 765.
Szkody, P., Osborne, J. and Hassall, B.J.M. 1988, *Astrophys. J.*, **328**, 243.
Udalski, A. 1990, *Astron. J.*, **100**, 226.
Udalski, A. and Pych, W. 1992, *Acta Astron.*, **42**, 285.
Vogt, N. 1983, *Astron. Astrophys.*, **118**, 95.
Wellmann, P. 1952, *Zs. Ap.*, **31**, 123.
Warner, B. 1985, "Interacting Binaries", ed. P.P. Eggleton and J.E. Pringle (Dodrecht, Reidel) 367.
Warner, B. 1995, "Cataclysmic Variable Stars", (Cambridge), Cambridge University Series 28.