On the evidence for brown-dwarf secondary stars in cataclysmic variables

S. P. Littlefair1⋆, V. S. Dhillon2, E. L. Martín3

1School of Physics, University of Exeter, Stocker Road, Exeter EX4 4QL, UK
2Department of Physics and Astronomy, University of Sheffield, Sheffield S3 7RH, UK
3Institute for Astronomy, University of Hawai‘i, 2680 Woodlawn Drive, Honolulu, HI 96822, USA

Accepted 2002 July 10. Received 2002 July 10; in original form 2002 July 10

ABSTRACT

We present the K-band spectrum of the cataclysmic variable LL And, obtained using nirspec on Keck-II. The spectrum shows no evidence for the absorption features observed by Howell & Ciardi (2001), which these authors used to claim a detection of a brown-dwarf secondary star in LL And. In light of our new data, we review the evidence for brown-dwarf secondary stars in this and other cataclysmic variables.

Key words: binaries: spectroscopic – stars: individual: LL And – novae, cataclysmic variables – infrared: stars – stars: low-mass, brown dwarfs

1 INTRODUCTION

Cataclysmic variables (CVs) are semi-detached binary stars consisting of a white dwarf primary and a Roche-lobe filling secondary star. Evolutionary models predict that as the secondary transfers mass to the white dwarf, the period of the binary star decreases. Eventually, the mass of the secondary drops below the hydrogen-burning limit and the secondary star becomes degenerate. This change in the structure of the secondary star means that further mass loss is accompanied by an increase in the orbital period (see Kolb 1993, for example). This is often used to explain the orbital period minimum which is observed in CVs at around 80 minutes.

Although for the purposes of this paper we will refer to the secondary stars in post period-minimum CVs as brown dwarfs, it must be stressed that they are actually a completely new class of stellar object – the degenerate remains of hydrogen-burning stars which have been stripped of their outer envelopes. Howell et al. (1997) predict that ∼70 per cent of CVs should have passed the orbital period minimum and contain brown dwarf secondary stars and yet there is direct spectroscopic evidence for the existence of only one such object – LL And (Howell & Ciardi 2001).

LL And is an extremely faint (V ∼ 20, K ∼ 18) dwarf nova. Its orbital period of 79.2 minutes places it very close to the orbital period minimum. In this paper we present a higher-quality spectrum of LL And which shows no sign of a brown-dwarf secondary star. In light of this, we review the evidence for the existence of brown-dwarf secondary stars in CVs.

⋆ E-mail: sl@astro.ex.ac.uk

2 OBSERVATIONS AND DATA REDUCTION

On the night of 2001 November 2 we obtained 2.0560–2.4730 µm (∼270 km s⁻¹ resolution) spectra of the CV LL And with nirspec (McLean et al. 1998) on the 10-m Keck-II telescope on Mauna Kea, Hawaii. A total exposure time of one hour was obtained between airmasses 1.007–1.056 in photometric conditions. The seeing was approximately 0.7 arcseconds and the slit width was set to 0.76 arcseconds. Observations of the A0V star HD 6457 were also taken to correct for the effects of telluric absorption and to provide flux calibration.

nirspec introduces curvature and distortion in both the spatial and dispersion directions. Prior to extraction of spectra, these effects were removed using the WMKONSPEC package in IRAF. Following the removal of the distortion, the nodded frames were subtracted, the residual sky removed by subtracting a polynomial fit, and the spectra extracted. There were two stages to the calibration of the extracted spectra. The first was the calibration of the wavelength scale using argon arc-lamp exposures; the fourth-order polynomial fits to the arc lines yielded an error of less than 0.4 angstroms (rms). The second step was the removal of telluric features and flux calibration. This was performed by dividing the spectra to be calibrated by the spectrum of the A0V star HD 6457, which has prominent stellar features interpolated across. We then multiplied the result by the known flux of the standard at each wavelength, determined using a black body function set to the same effective temperature and flux as the standard. As well as providing flux calibrated spectra, this procedure also removed telluric absorption features from the object spectra. A final, average spectrum was...
The spectrum of LL And is dominated by a strong, broad, single-peaked emission line of Brackett-γ (Brγ), most probably originating in the accretion disc. The full-width, half-maximum (FWHM) of the line is 1200 ± 200 km s\(^{-1}\), compared to the average Brγ FWHM in dwarf novae below the period gap of 1500 km s\(^{-1}\) (Dhillon et al. 2000). The equivalent width (EW) of Brγ in LL And is 68 ± 8\(\AA\), compared to the average Brγ EW in dwarf novae below the period gap of 84\(\AA\) (Dhillon et al. 2000). The spectrum of LL And is therefore typical of dwarf novae below the period gap.

We see no sign of the secondary star in our spectrum. The spectra is characterised by a flat continuum and a high level of noise. There is no marked change in the continuum slope around 2.3 \(\mu\)m, which would have been indicative of the presence of water absorption from a late-type secondary (see Dhillon et al. 2000, for example). Furthermore, there is no evidence for the methane and CO absorption bands which Howell & Ciardi (2001) claim to have observed in their spectrum of LL And (obtained with the CGS4 spectrograph on the 3.8-m UKIRT telescope on Mauna Kea).

By convolving the spectrum of LL And in Fig. 1 with a K-band filter, we obtain a K-band magnitude of 17.9, very similar to the value of K=17.5–18 reported in Howell & Ciardi (2001). Note that both of these values only represent lower limits, because they take no account of slit losses.

### 4 DISCUSSION

#### 4.1 Is the secondary star in LL And a brown dwarf?

On the basis of their proposed detection of methane, water and CO bands in LL And, Howell & Ciardi (2001) claim that this system harbours a brown-dwarf secondary star. The spectrum of LL And we present in Fig. 1 appears to contradict these claims, as it shows no sign of these features. There are two possible explanations for this discrepancy:

(i) The accretion state of LL And may have changed between the two observations (which were taken approximately one year apart). Specifically, our data showing the prominent emission-line from the accretion disc may have been obtained during a period of high mass-transfer. If this were the case, the secondary star absorption features might be swamped by the shot noise from the additional light. This is unlikely to be true, however, as our K-band magnitude is almost identical to that of Howell & Ciardi (2001), indicating that the object was in a similar state during the two observations.

(ii) The signal-to-noise of the Howell & Ciardi (2001) spectrum may be significantly worse than in our spectrum. Unfortunately, it is not possible to estimate the signal-to-noise per pixel in the spectrum of LL And presented by Howell & Ciardi (2001) because it appears to have been smoothed. It is possible, however, to predict the relative quality of the Keck+NIRSPEC and UKIRT+CGS4 spectra using on-line data for the performance of the two instruments. We find that the spectrum of Howell & Ciardi (2001) should have approximately half the signal-to-noise of our data, which is to be expected given the relative collecting areas of the telescopes. In order to simulate the effect of this degradation in signal-to-noise, we added noise to our spectrum so that the signal-to-noise ratio was halved. We found that this was sufficient to mask the prominent Brγ feature in our Keck spectrum of LL And and it therefore seems likely that the absorption features observed by Howell & Ciardi (2001) are due to noise.

In summary, Howell & Ciardi (2001) would not have been able to obtain the signal-to-noise to detect the features claimed. In addition, for Howell & Ciardi (2001) to have detected a brown-dwarf secondary in LL And, the distance to the CV must be only 30 pc (Howell & Ciardi 2001). This is in serious conflict with the lower limit of 364 pc found by Szkody et al. (2000) and the distance of 760 pc determined from ultraviolet spectroscopy of the white dwarf by Howell et al. (2002). Hence we believe that there is as yet no direct spectroscopic evidence for a brown-dwarf secondary star in LL And.

#### 4.2 Evidence for brown-dwarf secondary stars in the literature

So what evidence is there for brown-dwarf secondary stars in CVs? In table 1 we list all of the known candidates from the literature. There are fifteen such systems and the evidence for their candidacy varies in nature and quality, as described below.
Table 1. Brown-dwarf candidates in CVs from the literature. The central column indicates the methods used to detect the brown dwarf: RV1 and RV2 refer to the use of the radial velocity of the white dwarf and secondary star, respectively; SUP refers to the use of the superhump period-mass ratio relation of Patterson (2001); SED refers to the use of spectral-energy distribution fitting.

| Object          | Evidence                  | Reference |
|-----------------|---------------------------|-----------|
| 1RXS J105010.3-140431 | RV1                       | 1         |
| LL And          | lines?                    | 2.3       |
| VY Aqr          | SED+lines+SUP             | 4.5,6     |
| OY Car          | SUP                       | 4         |
| V436 Cen        | SUP                       | 4         |
| WX Cet          | SED+SUP                   | 4.7       |
| EG Cnc          | SUP                       | 4         |
| AL Com          | RV1+SUP                   | 4.8       |
| EF Eri          | SED+lines                 | 2.9       |
| V592 Her        | SED                       | 10        |
| MM Hya          | SUP                       | 4         |
| DI UMa          | SUP                       | 4         |
| SW UMa          | SED                       | 7         |
| WZ Sge          | RV2+SED+SUP               | 4.11,12   |
| HV Vir          | SED+SUP                   | 6.7       |

1. Mennickent et al. (2001); 2. Howell & Ciardi (2001); 3. this paper; 4. Patterson (2001); 5. Littlefair et al. (2004); 6. Mennickent & Diaz (2002); 7. Mason (2001); 8. Howell et al. (1998); 9. Beuermann et al. (2001); 10. van Teeseling et al. (1999); 11. Steeghs et al. (2001); 12. Ciardi et al. (1998).

4.2.1 Superhump period excess-mass ratio relation

The evidence for brown-dwarf secondary stars in many CVs comes from the relationship between mass ratio and superhump period excess (Patterson 2001). Together with an assumed (or measured) value for the primary mass, this relationship allows one to calculate the mass of the secondary star for any system with known superhump and orbital periods. For systems in which the white dwarf mass was unknown, Patterson (2001) assumed the mean white dwarf mass for CVs below the period gap of 0.7 M⊙. The calibration of the relationship between superhump period excess and mass ratio is uncertain, relying heavily on the assumed mass ratio for WZ Sge. Patterson (2001) finds 10 candidates using this method, which are listed in table 1. Despite the uncertainties in the method, DI UMa, AL Com, WZ Sge, and EG Cnc should be considered good candidates, having implied secondary masses below 0.045 M⊙. The evidence is less compelling in VY Aqr, HV Vir, WX Cet, OY Car, V436 Cen and MM Hya, in which the implied secondary star masses range from 0.06 to 0.08 M⊙. For 1RXS J105010.3-140431, Mennickent et al. (2003) find a white dwarf radial velocity of 4 ± 1 km s⁻¹. They claim that such a low radial velocity for the white dwarf suggests a very low-mass secondary star (around 10–20 Jovian masses). However, the inclination and white dwarf mass are unknown for this system; a combination of a heavy white dwarf (1.4 M⊙) and low inclination (5°) would allow a secondary star mass of up to 0.11 M⊙.

For the third system, WZ Sge, Steeghs et al. (2001) have measured the radial velocity of the secondary star directly, using irradiation-induced emission features observed during superoutburst. Without a reliable estimate of the white dwarf radial velocity, the authors conservatively derive M₂ < 0.1 M⊙. Observations to determine the white dwarf radial velocity in WZ Sge are hence sorely needed.

4.2.3 SED modelling and absorption lines

The data used to model spectral-energy distributions in CVs varies widely from simultaneous, low-resolution spectrophotometry (Mennickent & Diaz 2002) and non-simultaneous spectra uncorrected for slit losses (Ciardi et al 1998). Even when using the best data, uncertainties in deconvolving the contributions from secondary star, white dwarf and accretion disc make the process highly uncertain. Therefore, we do not consider any of the CVs in which the SED provides the only evidence for a brown-dwarf secondary as good candidates.

In two candidates (VY Aqr & EF Eri), the absorption lines from the secondary have also been observed. Mennickent & Diaz (2002) find a spectral type for the secondary star in VY Aqr of M9.5V, whilst Howell & Ciardi (2001) find a spectral type for the secondary star in EF Eri of either M6V or L4–5. It is not possible to say whether these objects are brown dwarfs solely on the basis of their spectral type as temperatures may depend on irradiation and the secondary star’s thermal history. It would be possible, however, to obtain a dynamical mass estimate for these systems by measuring the radial velocities of the absorption lines. Such a mass estimate would allow us to determine if the secondary star has been eroded beyond the hydrogen burning limit.

In summary, there is evidence for a brown dwarf secondary in fifteen systems. However, there is as yet no direct evidence (i.e. a reliable measurement of the secondary star mass) for such an object. The best candidates are those systems in which an indirect estimate of the secondary star mass exists (DI UMa, AL Com & WZ Sge).

4.3 Infrared photometry of CVs

Hoard et al. (2002) recently published infrared photometry for all CVs contained within the 2MASS 2nd Incremental data release. That data is plotted in figure 4. The infrared colours of most CVs (marked by circles) are easily understood. The secondary star in these systems is very similar to a late-type, main sequence star. There is also a blue component of highly variable strength from the accretion flow and white dwarf. This results in most CVs occupying a region offset bluewards (i.e down and left) from near the end of the main sequence.
Figure 2. Infrared colour-colour diagram for CVs and late-type dwarfs. The open circles show the CVs from the 2nd incremental data release of the 2MASS survey (Hoard et al. 2002). The asterisks show the CVs which we believe are possible brown-dwarf candidates (see text for details). Brown-dwarf candidates which we believe might allow a direct detection of the secondary star are marked with crosses (see text for details). The positions of late-type dwarfs (from Leggett et al. 2002) in the colour-colour diagram are represented by a text string indicating their spectral type. The solid curve shows the position of the main sequence from spectral-types O9 to M5; the dashed curve shows the position of the giant sequence from spectral-types G8 to M5 (Cox 2000). The colours of the main sequence and late-type stars were put on the 2MASS photometric system using the transformations of Carpenter (2001).

The 2MASS data release contains photometry for four of the brown-dwarf candidates in Table 1; these systems are labelled in figure 2. Three of these four (VY Aqr, WZ Sge & SW UMa) are significantly redder in $H-K$ than the majority of CVs. The locations of VY Aqr, WZ Sge & SW UMa in the colour-colour diagram are consistent with very late-type secondary stars ($\sim$M6-L4) and a blue accretion disc component. The colours of EF Eri are remarkable. Whilst the spectrum of Howell & Ciardi (2001) shows that the secondary star dominates the infrared light, EF Eri is significantly redder in $J-H$ than most CVs. Also, a non-detection of the secondary star in the optical was used to constrain its spectral type to be later than M9V (Beuermann et al. 2000). Given this evidence, it seems likely that EF Eri contains a highly unusual secondary star. Other possible explanations for the unusual infrared colours are that EF Eri is strongly reddened, or that it may be a triple system.

It can be seen in figure 2 that there is a population of CVs which occupies the same region as the brown-dwarf candidates from table 1. This population is distinct from the population of CVs as a whole. On the basis of their infrared colours, and bearing in mind the difficulty of deconvolving contributions from the white dwarf, accretion disc and secondary star to the SED, we identify these systems as new (weak) brown-dwarf candidates. Our new candidates were selected according to the colour selection, $J - H \leq 3(H-K) - 0.8$. They are plotted with asterisks in figure 2. In light of the position of EF Eri in the colour-colour diagram, we also identify systems with $J - H > 1.5$ as new brown-dwarf candidates.

Of the CVs with 2MASS photometry, we identify approximately 10 per cent as brown-dwarf candidates on the basis of their infrared colours. This is in contrast to the 70 per cent of systems which are expected to have passed the period minimum, and contain brown-dwarf secondary stars. The small percentage of brown dwarf candidates in the 2MASS data could be due to selection effects (these systems may be fainter as a group than most CVs), alternatively, the
Table 2. Brown-dwarf candidates in CVs from our 2MASS selection, and those from table 1 ranked according to distance from the Earth and apparent V-band magnitude (see text for details).

| Object    | Distance (pc) | Quiescent mag (V-band) | J − H | H − K |
|-----------|---------------|------------------------|-------|-------|
| VY Aqr    | 34            | 17.1                   | 0.354 | 0.455 |
| WZ Sge    | 48<sup>3</sup> | 14.5                   | 0.342 | 0.525 |
| WX Cet    | 70            | 17.5                   | n/a   | n/a   |
| SW Uma    | 110           | 16.5                   | 0.290 | 0.575 |
| EF Eri    | <128<sup>2</sup> | 18.0                   | 1.538 | 0.306 |
| HV Vir    | 149<sup>3</sup> | 19.0                   | n/a   | n/a   |
| AL Com    | 250<sup>3</sup> | 22.0                   | n/a   | n/a   |
| OY Car    | 260           | 15.3                   | n/a   | n/a   |
| V436 Cen  | 260           | 15.3                   | n/a   | n/a   |
| EG Cnc    | 343<sup>3</sup> | 19.0                   | n/a   | n/a   |
| MM Hya    | 580           | 18.7                   | n/a   | n/a   |
| V630 Cyg  | 590           | 17.2                   | 0.143 | n/a   |
| LL And    | 760<sup>3</sup> | 19.9                   | n/a   | n/a   |
| V4140 Sgr | 1100          | 17.5                   | n/a   | n/a   |
| DI UMa    | 1320          | 18.0                   | n/a   | n/a   |

1. Spruit & Rutten (1998); 2. Benomar et al. (2000); 3. Szkoła et al. (2000); 4. Sproats et al. (1996); 5. Howell et al. (2002).

The prospect of direct detection of the secondary star in most of the candidates shown in figure 2 is remote: $M_K$ for a spectral type of L3 is $\sim 11$ (Leggett et al. 2002), whereas the limiting magnitude ($3\sigma$, 30 minute exposure) of Keck-NIRSPEC is 18.6. This suggests that a secondary star of spectral type L3 would only be observable out to distances of 330 pc, even if there were no contaminating light from the accretion disc or white dwarf. In CVs, this contamination makes the task of detecting the secondary much more difficult. As an example, one of the best candidates in table 2 is WZ Sge. Extensive infrared spectroscopy has failed to reveal the secondary in this system (Littlefair et al. 2000; Dhillon et al. 2003; Mennecke & Diaz 2002). It seems likely that in the majority of systems containing brown-dwarf secondaries, the secondary stars are too faint, the discs too bright, or the system too far away for a direct spectroscopic detection in the near-infrared.

There are, however, a few systems in figure 2 which offer brighter prospects. A number of systems are co-incident with the colours of late-M and L-type dwarfs, suggesting that a very late-type secondary dominates the near-infrared light in these systems. These systems are: Psc3, V529 Ori, 1RXS J114247.5+215717, RX J0502.8+1624 & Her<sup>4</sup>. These systems are shown in figure 2 with a cross. Of the systems, Psc3, 1RXS J114247.5+215717 and Her have uncertain designations as CVs (Ritter & Kolb 1998). Also, EF Eri and another system, V732 Sqr show highly unusual infrared colours. Follow-up near-infrared spectroscopy of all these systems is highly desirable.

4.4 Future detection of brown-dwarf secondary stars: the prospects

Combining systems with existing evidence in the literature (table 1) and systems selected on the basis of their infrared colours, we now have a list of thirty-nine CVs which may possess brown-dwarf secondary stars. What are the chances of detecting the secondary stars in these candidates? Ideally, for a CV to have a detectable brown-dwarf secondary it should be nearby, and have little or no ongoing accretion (i.e. it should be optically faint). With this in mind, table 2 shows distances and V magnitudes for the thirty-nine brown dwarf candidates. Where no distance was available in the literature, distances have been estimated using the relationship which exists for dwarf novae between the absolute magnitude at outbursts maximum and orbital period. Errors in distances to SU UMa stars derived from this relationship arise from two sources: scatter within the relationship and the variations in the maximum magnitude at outburst for a single system. This can introduce scatter of up to 1 mag, leading to an uncertainty in the distance of a factor of $\sim 1.5$ at worst. If no distance could be obtained, the system is not listed. $J − H$ and $H − K$ colours are shown, where available to aid in the location of the objects in figure 2.

The prospect of direct detection of the secondary star in most of the candidates shown in figure 2 is remote: $M_K$ for a spectral type of L3 is $\sim 11$ (Leggett et al. 2002), whereas the limiting magnitude ($3\sigma$, 30 minute exposure) of Keck-NIRSPEC is 18.6. This suggests that a secondary star of spectral type L3 would only be observable out to distances of 330 pc, even if there were no contaminating light from the accretion disc or white dwarf. In CVs, this contamination makes the task of detecting the secondary much more difficult. As an example, one of the best candidates in table 2 is WZ Sge. Extensive infrared spectroscopy has failed to reveal the secondary in this system (Littlefair et al. 2000; Dhillon et al. 2003; Mennecke & Diaz 2002). It seems likely that in the majority of systems containing brown-dwarf secondaries, the secondary stars are too faint, the discs too bright, or the system too far away for a direct spectroscopic detection in the near-infrared.

There are, however, a few systems in figure 2 which offer brighter prospects. A number of systems are co-incident with the colours of late-M and L-type dwarfs, suggesting that a very late-type secondary dominates the near-infrared light in these systems. These systems are: Psc3, V529 Ori, 1RXS J114247.5+215717, RX J0502.8+1624 & Her<sup>4</sup>. These systems are shown in figure 2 with a cross. Of the systems, Psc3, 1RXS J114247.5+215717 and Her have uncertain designations as CVs (Ritter & Kolb 1998). Also, EF Eri and another system, V732 Sqr show highly unusual infrared colours. Follow-up near-infrared spectroscopy of all these systems is highly desirable.

5 CONCLUSIONS

(i) We have presented the Keck K-band spectrum of LL And, and find no evidence for a brown-dwarf secondary star.

(ii) We find no direct evidence for brown-dwarf secondary stars in CVs in the literature.

(iii) Significant indirect evidence exists for brown-dwarf secondary stars in DI UMa, AL Com, EG Cnc (from the superhump period excess), WZ Sge (from the superhump period excess and radial velocity of the secondary star), and in EF Eri and VY Aqr (from the spectral features of the secondary star).

(iv) The distances to these CVs imply that the short-term prospects of detecting the secondary star is poor. Even in the nearby candidate WZ Sge, infrared spectroscopy has failed to detect the secondary star, because of the contribution from the accretion flow and white dwarf.

(v) There are a small number of CVs whose infrared colours suggest that they may contain detectable, brown-dwarf secondary stars. However, the prospects of studying large numbers of brown-dwarf secondary stars in CVs are bleak.

ACKNOWLEDGMENTS

We would like to thank Tom Marsh for pointing out the usefulness of the absolute outburst magnitude-orbital period relationship for estimating distances to CVs. We would also like to thank Paul Hirst and Tim Naylor for invaluable discussions regarding UKIRT pointing. Data presented herein were obtained at the W. M. Keck Observatory, which

---

1 The system Her has no unique identifier. It is found at $\alpha = 17^h 48^m 0.5^s, \delta = +34^\circ 04^\prime 01^\prime\prime$.
is operated as a scientific partnership among the California Institute of Technology, the University of California and the National Aeronautics and Space Administration. The Observatory was made possible by the generous financial support of the W. M. Keck Foundation. It is a pleasure to acknowledge the hard work and dedication of the NIRSPEC instrument team at UCLA: Maryanne Anglionto, Odvar Bendiksen, George Brims, Leah Buchholz, John Canfield, Kim Chinn, Jonah Hare, Fred Lacayanga, Samuel B. Larson, Tim Liu, Nick Magnone, Gunnar Skulason, Michael Spencer, Jason Weiss, and Woon Wong. In addition, we thank the observing assistants at Keck observatory: Joel Aycock, Gary Puniwai, Charles Sorenson, Ron Quick, and Wayne Wack.

REFERENCES

Beuermann K., Wheatley P., et al. 2000, A&A, 354, L49
Carpenter J. M., 2001, AJ, 121, 2851
Ciardi D. R., Howell S. B., Hauschildt P. H., Allard F., 1998, ApJ, 504, 450
Cox A. N., 2000, Allen’s astrophysical quantities. AIP Press, New York
Dhillon V. S., Littlefair S. P., et al. 2000, MNRAS, 314, 826
Downes R. A., Webbink R. F., et al. 2001, PASP, 113, 764
Hoard D. W., Wachtler S., Clark L. L., Bowers T. P., 2002, ApJ, 565, 511
Howell S. B., Ciardi D. R., 2001, ApJ, 550, L57
Howell S. B., Gansicke B., Szkody P., Sion E., 2002, ApJ, in press
Howell S. B., Hauschildt P., Dhillon V. S., 1998, ApJ, 494, L223
Howell S. B., Rappaport S., Politano M., 1997, MNRAS, 287, 929
Kolb U., 1993, A&A, 271, 149
Leggett S. K., Golimowski D. A., et al. 2002, ApJ, 564, 452
Littlefair S. P., Dhillon V. S., Howell S. B., Ciardi D. R., 2000, MNRAS, 313, 117
McLean I. S., Becklin E. E., et al. 1998, in Fowler A. M., ed., Proc. SPIE Vol. 3354, p. 566
Mason E., 2001, Ph.D. Thesis
Mennickent R. E., Diaz M., Skidmore W., Sterken C., 2001, A&A, 376, 448
Mennickent R. E., Diaz M. P., 2002, A&A, in press
Patterson J., 2001, PASP, 113, 736
Pinsonneault M. H., Andronov N., Sills A., 2002, in ASP Conf. Ser. 261: The Physics of Cataclysmic Variables and Related Objects p. 208
Ritter H., Kolb U., 1998, A&AS, 129, 83
Sprouts L. N., Howell S. B., Mason K. O., 1996, MNRAS, 282, 1211
Spruit H. C., Rutten R. G. M., 1998, MNRAS, 299, 768
Steeghs D., Marsh T., Knigge C., Maxted P. F. L., Kuulkers E., Skidmore W., 2001, ApJ, 562, L145
Szkody P., Desai V., et al. 2000, ApJ, 540, 983
van Teeseling A., Hessman F. V., Romani R. W., 1999, A&A, 342, L45