A search for brown dwarf like secondaries in cataclysmic variables

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ABSTRACT

We present VLT/ISAAC infrared spectroscopy of a sample of short-orbital-period cataclysmic variables that are candidates for harbouring substellar companions. We have detected the K I and Na I absorption lines of the companion star in VY Aqr. The overall spectral distribution in this system is best fitted with an M9.5 type dwarf spectrum, implying a distance of 100 ± 10 pc. VY Aqr seems to fall far from the theoretical distribution of secondary star temperatures around the orbital period minimum. Fitting of the IR spectral energy distribution (SED) was performed by comparing the observed spectrum with late-type templates. The application of such a spectral fitting procedure suggests that the continuum shape in the 1.1–2.5 µm spectral region in short-orbital-period cataclysmic variables may be a useful indicator of the companion’s spectral type. SED fitting for RZ Leo and CU Vel suggests M5-type dwarf companions, and distances of 340 ± 110 and 150 ± 50 pc, respectively. These systems may be placed in the upper evolution branch for short-period cataclysmic variables.

Key words: binaries: close – binaries: general – novae, cataclysmic variables – stars: dwarf novae – stars: evolution – stars: fundamental parameters.

1 INTRODUCTION

Cataclysmic variable stars (CVs) are semi-detached binaries consisting of an accreting white dwarf and a red dwarf donor transferring matter to the compact object via the inner Lagrangian point. The orbiting gas interacts with itself dissipating energy by viscous forces, forming a luminous accretion disc around the white dwarf. The spectral energy distribution of CVs in X-rays and the ultraviolet is dominated by white dwarf and inner-disc emission, whereas the accretion disc contribution is dominant in the optical and eventually in the near infrared. In some cases the emission from the accretion disc in the IR is approximated by a power law (Ciardi et al. 1998). However, in general we expect a much more complex emission from low-luminosity discs that may contain extended optically-thin regions. On the other hand, the secondary star might contribute significantly in the infrared. The determination of the secondary mass in CVs is key to understanding the secular evolution of these objects. Current theories state that the process of mass transfer becomes linked with the loss of orbital momentum, so the binary period becomes shorter while the hydrogen secondary becomes less and less massive, eventually being eroded by the process, resulting in a kind of brown dwarf star when the orbital period approaches 80 min (see, e.g., Howell, Nelson & Rappaport 2001). An alternative scenario considers that most CVs may not yet have had time to evolve to their theoretical minimum orbital periods. In this case, for initial configurations with intermediate secondary masses, thermal-time-scale mass transfer may occur. ‘If some nuclear evolution has already occurred, this phase can shrink the binary drastically and strip the hydrogen-rich envelope from the donor, ultimately producing an ultrashort-period system with a low-mass, hydrogen-poor and probably degenerate secondary’ (from King & Schenker 2002).

From the above it is evident that relevant observations for probing current theories of CV evolution should focus on the determination of the physical parameters of the secondary star for systems below the orbital period gap. At present, four methods have been used to search for undermassive secondary stars in cataclysmic variable stars: (i) analysis of the spectral energy distribution using multi-waveband observations through the ultraviolet, optical and infrared spectral regions (Ciardi et al. 1998; Mason 2001); (ii) looking for signatures of the secondary star (Dhillon & Marsh 1995; Littlefair et al. 2000; Steeghs et al. 2001); (iii) ‘weighting’ the secondary star in systems where the superhump and orbital periods are known (the primary mass is usually assumed, see for instance Patterson 2001); and (iv) by spectroscopic diagnostic of the stellar masses in systems where the white dwarf is revealed by their optical absorption wings (Mennickent et al. 2001). Concerning the first two methods, one should mention that the determination of the basic properties of secondaries in CVs by comparison of their spectra with field star calibrations is intrinsically uncertain. These results are prone to illumination and heating of the companion photosphere. In addition, the absorption spectrum may be affected by the filling of some lines with emission components.

While the IR spectra of CVs have been measured and modelled in past years, there are only a few spectrophotometric observations of low-luminosity systems in the J, H and K bands. In this paper...
we describe the spectra of seven CVs with orbital period below the period gap. These candidates for systems at late evolutionary stages were selected for observation following the criteria: (i) their short orbital period and/or (ii) a low mass-transfer rate, inferred from their high-amplitude dwarf nova outbursts with long recurrence time. In the next section we describe the IR spectroscopic observations, while in Section 3 a description of each spectrum is given. A brief discussion of the observational results is made in Section 4. A few conclusions and perspectives are outlined in Section 5.

2 OBSERVATIONS AND DATA REDUCTION

The infrared spectroscopic observations reported in this paper were obtained at the European Southern Observatory (ESO) with VLT-Antu using the ISAAC spectrophotograph in service-mode. Data were taken under photometric atmospheric conditions. An observing log is given in Table 1. Spectra in the J, H and K bands were obtained. Sufficient overlapping was assured for composing a single spectrum ranging from 1.09 to 2.57 µm with a full width at half maximum (FWHM) resolution of 12 (J) to 27 (K) Å. The data were reduced using IRAF1 by first applying the combined dark and flat-field images as supplied by the ESO-service-mode operation group. Median sky frames were then combined for each object and spectral window. This process made use of jittered images where the object is located at different positions along the slit. Wavelength calibration was achieved by measuring the location of atmospheric OH emission lines (Rousselot et al. 2000) in the sky background. The flux calibration was performed using observations of the A0 standard HD 216009, made with the same instrumental setup (but with a wider slit) by the ESO operation team as part of the service-mode program. Finally, the telluric absorption features were corrected with the aid of the absorption template constructed by dividing the spectrum of HD 216009 by a low-order polynomial fit, excluding a few stellar absorption lines. The IRAF task ‘telluric’ was used to find the best scale and shift factors which, when applied to the normalized telluric template, provided a reasonable correction of the telluric absorptions in HD 216009 and science exposures. This procedure worked well, except for the regions between 1.35 and 1.44 µm and 1.80 and 1.94 µm, characterized by heavy telluric absorption. These regions, corresponding to the ends of the J, H and K spectra, were excluded from the analysis and are not shown in this paper. Synthetic J, H and K photometry of our calibrated standard star observations were compared with broadband photometry by Carter & Meadows (1995) showing differences below 0.08 mag. Slit losses for our objects were estimated by assuming a Gaussian seeing profile centred in the slit aperture. For that we used the seeing value included in the report of the observing block and neglected any factor due to telescope guiding. These corrections were included in the J, H and K magnitudes and in the final spectrum as well. We are confident that this method worked well, since our spectrophotometric magnitudes compare well with previously-published photometry. In addition, we obtain a good match in the overlapping region between J, H and K spectra.

2.1 Infrared spectral fitting

An attempt to quantify the properties of the IR spectra was made by employing a numerical fitting procedure. The spectral energy distribution (SED) in the IR was tentatively parametrized by adding the contribution from a late-type template spectrum and power-law component. Although the emission of the disc should differ substantially from a power-law in the IR, we introduced this component as a first approximation to the accretion disc continuum. While the power law is smooth in our wavelength domain and basically affects the slope of the IR continuum, the detailed shape of the synthetic continuum in the J, H and K is strongly dependent on the stellar template contribution. A non-linear least squares fitting procedure was calculated using the following equation:

\[ S(\lambda) = aT(\lambda) + b\lambda^c, \]

where \( S \) is the observed spectrum, \( T \) the red dwarf template spectrum, \( \lambda \) the wavelength in microns and \( a, b, c \) parameters to be found. The parameters \( a, b \) and \( c \) were adjusted to minimize the reduced \( \chi^2 \) between the observed spectrum and a model fit. Of course, \( a \) and \( b \) are constrained to the positive domain. The data fitted in this way were selected carefully avoiding emission lines and deep telluric bands. A sequence of template spectral types between M1 and L7 at two subtype steps was taken from Leggett et al. (2001). The resolution of the template spectra (typically between 20 and 35 Å) was matched by convolving our data with a Gaussian with the appropriate FWHM. Owing to the low velocity of the templates, it was not necessary to account for rotational broadening when fitting the spectrum.

3 RESULTS

The infrared spectra for all program stars are shown in Fig. 1. The synthetic magnitudes are given in Table 2 and the emission line parameters in Table 3. Table 4 summarizes the results of the spectral-energy-distribution fitting, giving the parameters for the best-fitting function as defined in equation (1).

3.1 VY Aqr

VY Aqr is a cataclysmic variable showing one of the largest outburst amplitudes among dwarf novae (Downes et al. 2001). According to current models of dwarf nova outbursts (Osaki 1996), this is consistent with a very-low-mass-transfer rate system. Spectroscopic studies in the optical region have revealed the orbital period [0.063 09(4) d – see Thorstensen & Talyor 1997], but not the stellar masses, probably due to the biasing nature of the emission line radial velocities (see, e.g., Augusteijn 1994). J-band spectroscopy by Littlefair et al. (2000) revealed spectral features of the secondary star, but they were too weak to make an estimate of the spectral type. According to the current CV evolution scenario (see, e.g., Howell et al. 2001),

<table>
<thead>
<tr>
<th>Object</th>
<th>UT-date</th>
<th>J</th>
<th>H</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>VY Aqr</td>
<td>23/05/00</td>
<td>300</td>
<td>600</td>
<td>1200</td>
</tr>
<tr>
<td>V485 Cen</td>
<td>21/05/00</td>
<td>600</td>
<td></td>
<td>600</td>
</tr>
<tr>
<td>RZ Leo</td>
<td>21/05/00</td>
<td>840</td>
<td>840</td>
<td>840</td>
</tr>
<tr>
<td>WZ Sge</td>
<td>20/05/00</td>
<td>240</td>
<td>480</td>
<td>720</td>
</tr>
<tr>
<td>CU Vel</td>
<td>22/05/00</td>
<td>120</td>
<td>240</td>
<td>480</td>
</tr>
<tr>
<td>HV Vir</td>
<td>19/05/00</td>
<td>1800</td>
<td>1800</td>
<td></td>
</tr>
<tr>
<td>1RXS J105010.3</td>
<td>21/05/00</td>
<td>240</td>
<td>480</td>
<td>720</td>
</tr>
</tbody>
</table>

Table 1. Journal of observations. The total integration time, in seconds, is given for every spectral band.

1 IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.
the orbital period and the low-mass-transfer rate of VY Aqr should suggest a system beyond the orbital period minimum, probably containing an undermassive secondary star. This is also supported by the difference between the observed superhump period and the orbital period (Patterson 2001). In this section we present direct evidence suggesting a system beyond the orbital period minimum, probably containing an undermassive secondary star.

We measured synthetic magnitudes $J = 15.17$, $H = 14.66$ and $K = 14.14$ with estimated errors of 0.10 mag, indicating that VY Aqr was observed in quiescence. Our $J$ and $K$ magnitudes compare well with the $15.24 \pm 0.15$ and $14.42 \pm 0.13$ values given by Sproats, Howell & Mason (1996). The infrared spectrum of VY Aqr shows Bracket and Paschen emission lines. Fig. 2 clearly shows the K I doublet at 1.169–1.177 and 1.244–1.253 \mu m and the Na I line at 1.141 \mu m, which are signatures of a cool secondary star, confirming previous indications found by Littlefair et al. (2000).

![Figure 1. Combined $J$, $H$, $K$ spectrum for selected short-orbital-period CVs. Fluxes are normalized by the factors shown in Table 2.](image)

**Table 2.** Synthetic magnitudes and normalization factors used in Fig. 1, in units of $10^{-17}$ erg cm$^{-2}$ s$^{-1}$ \AA$^{-1}$.

<table>
<thead>
<tr>
<th>Object</th>
<th>$J$</th>
<th>$H$</th>
<th>$K$</th>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>VY Aqr</td>
<td>15.17</td>
<td>14.66</td>
<td>14.14</td>
<td>29.7</td>
</tr>
<tr>
<td>V485 Cen</td>
<td>16.47</td>
<td>15.85</td>
<td>15.30</td>
<td>9.16</td>
</tr>
<tr>
<td>RZ Leo</td>
<td>16.57</td>
<td>15.88</td>
<td>15.45</td>
<td>8.89</td>
</tr>
<tr>
<td>WZ Sge</td>
<td>14.25</td>
<td>14.07</td>
<td>13.78</td>
<td>74.0</td>
</tr>
<tr>
<td>CU Vel</td>
<td>14.74</td>
<td>13.94</td>
<td>13.51</td>
<td>46.6</td>
</tr>
<tr>
<td>HV Vir</td>
<td>18.86</td>
<td>16.98</td>
<td>16.07</td>
<td>1.06</td>
</tr>
<tr>
<td>1RXS J105010.3</td>
<td>17.07</td>
<td>16.77</td>
<td>16.07</td>
<td>5.20</td>
</tr>
</tbody>
</table>

From visual inspection of the spectral features detected in VY Aqr, we conclude that the secondary in VY Aqr is of spectral type later than M6 because of the following features. (1) The depth of K I doublets increases for later types. Even disregarding veiling, their depth suggests a type cooler than M5. (2) The depth of the water band at 1.32 \mu m is too shallow in dwarf spectra earlier than M6. (3) Strong Al I lines at 1.313 and 1.32 \mu m, usually visible in dwarfs hotter than M6, are not seen in the object spectrum. On the other hand, a secondary spectrum earlier than L5 is suggested by: (1) the strength of Na I 1.141 \mu m relative to the K I doublet at 1.169, 1.177 \mu m and (2) the depth of the water band.

When fitting the spectral energy distribution (Fig. 3), we observed that spectral types earlier than M7 fail to reproduce the depth of K I lines in the $J$ band and the continuum in the $K$ band. On the other hand, spectral types later than L3 do not fit the $H$- and $K$-band continuum shape well. These cool types present a well-defined CO bandhead at 2.29 \mu m, which is not seen in our data. Our fit with an M9.5-type secondary is slightly better than that for M7- and L3-type templates, giving a $\chi^2$ parameter about 15 per cent lower. If such a spectral contribution is in fact due to the emission of the secondary star in the system, one may estimate its temperature. Using the effective temperatures for L-type dwarfs derived by Leggett et al. (2001) when structural models, we find $T_2 = 2300 \pm 100$ K for the secondary star in VY Aqr. We note that our result is in apparent disagreement with the result of 1400 $\pm$ 50 K obtained by Mason (2001) by modelling the (non-simultaneous) UV–optical–infrared spectra. However, our result is still below the 2600 K upper limit she found by fitting her photometric data set. Also, our result is consistent with the upper limit suggested by Littlefair et al. (2000).

The best fit with a M9.5 companion is shown for illustration in Fig. 3. Representative fits using types between M7 and L3 indicate that the secondary star may contribute 55 to 45 per cent of the flux at 2.17 \mu m, depending on the spectral type. Later types yield better fits for smaller flux fractions. Using the distance values for our templates from M7 to L2 (LHS 3003 and LHS 429 by van Altena et al. 1994 and Kelu-1 from Dahn et al. 2000) and the flux fractions derived

**Table 3.** Equivalent width [W($\lambda$) in \AA] and peak flux [F($\lambda$) in units of $10^{-16}$ erg s$^{-1}$ cm$^{-2}$ \AA$^{-1}$] of the main emission lines.

<table>
<thead>
<tr>
<th>Object</th>
<th>W(Pa$\beta$)</th>
<th>F(Pa$\beta$)</th>
<th>W(Br$\gamma$)</th>
<th>F(Br$\gamma$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VY Aqr</td>
<td>$-52$</td>
<td>$4.79$</td>
<td>$-59$</td>
<td>$1.45$</td>
</tr>
<tr>
<td>V485 Cen</td>
<td>$-18$</td>
<td>$1.01$</td>
<td>$-37$</td>
<td>$0.37$</td>
</tr>
<tr>
<td>RZ Leo</td>
<td>$-34$</td>
<td>$1.01$</td>
<td>$-37$</td>
<td>$0.37$</td>
</tr>
<tr>
<td>WZ Sge</td>
<td>$-144$</td>
<td>$17.3$</td>
<td>$-142$</td>
<td>$2.76$</td>
</tr>
<tr>
<td>CU Vel</td>
<td>$-41$</td>
<td>$6.44$</td>
<td>$-26$</td>
<td>$2.30$</td>
</tr>
<tr>
<td>1RXS J105010.3</td>
<td>$-107$</td>
<td>$1.00$</td>
<td>$-142$</td>
<td>$0.32$</td>
</tr>
</tbody>
</table>

**Table 4.** Summary of the best SED models. We give the best template spectral type (Sp2), their relative contribution at $\lambda 2.17$ \mu m (in per cent) and the parameter $c$. N/A means not applicable.

<table>
<thead>
<tr>
<th>Object</th>
<th>Sp2</th>
<th>Rel. cont.</th>
<th>c</th>
</tr>
</thead>
<tbody>
<tr>
<td>VY Aqr</td>
<td>M9.5</td>
<td>44</td>
<td>$-2.2$</td>
</tr>
<tr>
<td>V485 Cen</td>
<td>N/A</td>
<td>0</td>
<td>$-1.7$</td>
</tr>
<tr>
<td>RZ Leo</td>
<td>M5</td>
<td>100</td>
<td>N/A</td>
</tr>
<tr>
<td>WZ Sge</td>
<td>N/A</td>
<td>0</td>
<td>$-2.7$</td>
</tr>
<tr>
<td>CU Vel</td>
<td>M5</td>
<td>100</td>
<td>N/A</td>
</tr>
<tr>
<td>HV Vir</td>
<td>L5</td>
<td>39</td>
<td>$-0.9$</td>
</tr>
<tr>
<td>1RXS J105010.3</td>
<td>N/A</td>
<td>0</td>
<td>$-2.1$</td>
</tr>
</tbody>
</table>
from the spectral fitting we were able to derive a distance estimate for the system between 80 and 120 pc, with a most likely value of 100 ± 10 pc. The spectroscopic parallax given above is in agreement with the distance of 110 pc found by Augusteijn (1994) using the average absolute magnitude value for dwarf novae in outbursts.

3.2 V485 Cen

This is a dwarf nova with an ultra-short orbital period of 59 min (Augusteijn et al. 1996). These authors found strong evidence for a significant contribution from the secondary to the spectrum at wavelengths longer than λ 5900, which was confirmed by Munari & Zwitter (1998), based on the observed colour progression. According to Augusteijn et al. (1996), the most likely explanation for the extremely short orbital period is that it is a non-fully degenerate secondary star with a low, but finite, hydrogen content. Considering our M–L spectral type templates, the best fit was reached with a simple power continuum with index 1.7.

3.3 RZ Leo

The long cycle length and large amplitude outburst relate this star to WZ Sge; however, the orbital period (0.07651 d, Mennickent & Tappert 2001) is longer and the spectral distribution redder (see, e.g., Mennickent et al. 1999). This fact, along with the rather normal mass ratio estimated from the superhump period (Ishioka et al. 2001) point to a normal secondary for this object. Our data seems to confirm this view. Fig. 4 shows that the best SED model for RZ Leo is reached with an M5-type spectrum and almost zero contribution from the power law. M3- and M7-subtype templates failed to match the shape of the spectrum, giving, in both cases, a χ² three times larger than the M5 template. We do not see the absorption lines of the secondary in the J-band spectrum, probably due to our poor S/N in this range. Using the M_j for M dwarfs from Leggett et al. (2000), we estimate a distance of 340 ± 110 pc. Our J and K magnitudes, viz. 16.57 and 15.45, are similar to those given by Sproats et al. (1996), namely 16.56 ± 0.19 and 15.55 ± 0.17.
3.4 WZ Sge

The spectral type of the secondary in this system has been constrained to be later than M7.5 (Littlefair et al. 2000), whereas an upper limit for the secondary star temperature of 1700 K has been obtained by Ciardi et al. (1998). These spectral signatures along with the extremely small difference between superhump and orbital period (Patterson 2001), strongly suggests that the star is placed beyond the orbital period minimum. The discovery of emission lines of the secondary during the 2001 superoutburst placed an upper limit on the secondary mass of 0.11 M⊙, but did not rule out the hypothesis of a non-degenerate-mass donor (Steeghs et al. 2001).

Our infrared spectroscopy, obtained outside eclipse, shows a rich emission line spectrum, as previously found by Dhillon et al. (2000), Littlefair et al. (2000) and by Mason et al. (2000). We identify Paschen β double emission with a half-peak separation of 610 km s⁻¹ and FWZI of 3900 km s⁻¹. The Bracket series is also present as double emission, with the violet peak larger than the red one, except in the Brγ line where the asymmetry reverses. Our J magnitude, 14.25, compares well with the J magnitude 14.2 ± 0.2 given by Ciardi et al. (1998). Our H magnitude, 14.07, is within the uncertainties of the 13.8 ± 0.2 value given by the above authors. Our K magnitude, 13.78, is lower than the 13.3 ± 0.2 value reported by Ciardi et al. (1998). This is the only case where a significant difference exists between one of our spectrophotometric magnitudes and previously published values.

A simple power law provides the best fit for this object (Table 4). By looking at the scaled-template linestrength in the K band we estimate that the late-type component contributes less than 25 per cent to the flux in the K band for the range M9.5–L7. By assigning such an upper limit to the companion star emission and using the astrometric parallax of 45 pc (J. Thorstensen, private communication), we estimate M_K > 12 for the secondary. This figure corresponds to a secondary with a mass lower than or equal to the hydrogen burning minimum mass (0.07 M⊙), for ages between 0.1 and 10 Gyr, according to the models of very-low-mass stars and brown dwarfs with dusty atmospheres of Chabrier et al. (2000).

3.5 CU Vel

This object is a rather typical dwarf nova with orbital period of 0.0785 d and moderate outburst credentials (see, e.g., Mennekent & Diaz 1996). The Lyman alpha absorption has been modelled as photospheric emission from a white dwarf with an effective temperature of 18 500 K (Gänsicke & Koester 1999). Fig. 5 shows that the best SED model for CU Vel is reached with an M5-type spectrum and almost zero contribution from a power-law continuum. As in the case of RZ Leo, M3- and M7-subtype templates failed to match the shape of the spectrum, giving, in both cases, χ² about three times larger than for the M5 template. We do not see the absorption lines of the secondary in the J-band spectrum, probably due to our poor S/N in this range. The M5 spectral type is consistent with the 0.15 M⊙ secondary derived from the dynamical analysis of the Hα emission line by Mennekent & Diaz (1996). Following the same procedure as for RZ Leo, we find a distance of 150 ± 50 pc.

3.6 HV Vir

This is the faintest target in our sample, with magnitudes 18.7 and 17.0 in J and K, respectively. Our 30 min integration time resulted in a very noisy spectrum. However, the spectrum seems to indicate line emission in Paβ, and a rather flat continuum. The object has been identified as a member of the sparsely-populated group of WZ Sge stars (Kato et al. 2001). Our SED algorithm reveals that an L5 late-type template contributing about 39 per cent to the total light at 2.17 μm gives a slightly better fit than a simple power law. With the addition of an L5 template we get a χ² parameter slightly lower than for the L3 and L7 templates. The χ² is larger for power laws combined with other spectral types. The differences found in χ² are so small that we should quote the possible detection of an L5-type spectral contribution in HV Vir with extreme caution. Using the effective temperatures of L-type dwarfs by Leggett et al. (2001), one finds T_eff = 1550 ± 200 K for the secondary of HV Vir, and a distance of 175 ± 15 pc.

3.7 1RXS J105010.3

This ROSAT source was recently identified as a cataclysmic variable star, with an optical spectrum closely resembling WZ Sge, and probably containing a sub-stellar secondary (Mennenkent et al. 2001). The infrared spectrum is very similar to that of WZ Sge too, both in the shape of the continuum as well as in the rich emission line spectrum and linestrengths. No traces of the secondary spectral features were found.

As in the case of WZ Sge, our SED models reveal than a simple power law provides the best fit. This fact may suggest that, in spite of the low mass-transfer rate, the accretion disc is more luminous than the secondary even in this spectral region.

4 DISCUSSION

In Fig. 6 we show the J–H : H–K colour diagram for short-period dwarf novae, along with data for M–L-type dwarfs. Colours for a pure power-law energy distribution are also included for comparison. We observe that the CV colours are distributed in a rather ordered way, following a well-defined track. Longer-period systems (RZ...
Leo, CU Vel) show redder colours, above the region of the stellar photospheres, whereas systems around the orbital period minimum are bluer, and best represented by a simple power-law continuum with indexes between $-2.8$ and $-1.8$.

The most prominent emission lines are Paschen and Brackett lines. Helium lines were not observed in our (small) sample. Among the observed spectra, WZ Sge, 1RXSJ105010.3, and VY Aqr show the strongest emission lines. These three systems are supposed to sustain very-low mass-transfer rates during quiescence, as may be inferred from their long recurrence times and large amplitude outbursts.

In this paragraph we compare our results on the secondary star of short-orbital-period CVs with the evolutionary predictions of the population synthesis code by Howell et al. (2001). At this point we emphasize the caveat already made concerning the reliability of secondary temperature estimates from the observed emission of a particular spectral type. Fig. 7 shows a comparison of the $T_{\text{eff}}-P_{\text{orb}}$ CV evolution tracks near the orbital period minimum with our data and some additional data taken from the literature. From this figure we conclude the following: (1) HV Vir, WZ Sge, EF Eri, WX Cet, LL And and SW UMa seem to be post-orbital period minimum systems; (2) it is difficult to reconcile the positions VY Aqr in the diagram with the code’s predictions; (3) in the same context, RZ Leo and CU Vel should be evolving toward the orbital period minimum.

The results from the application of the spectral fitting procedure suggests that the infrared continuum shape in short-period cataclysmic variables may be a useful indicator of the companion’s spectral type. This point is specially important if we consider that, owing to the limitation imposed by the spectrum S/N in such faint systems, it is not always possible to detect the secondary star’s individual lines, but only the continuum shape. Also, the method has the advantage of avoiding the uncertainties associated with non-simultaneous multi-wavelength observations, although their predictive power might not be so good as the ideal case of modelling simultaneous multi-waveband observations (see, e.g., Mason 2001).

In the future, we plan to observe a larger sample of CVs that are candidates for harbouring brown dwarf-like secondaries. In this regard, the application of the method to below-the-gap polars at deep quiescence turns out to be especially attractive (Howell & Ciardi 2001). In these cases, the accretion of matter by the white dwarf virtually stops, resulting in the easier detection of the secondary star at infrared wavelengths. In addition, a more realistic description of the disc emission in the IR will be incorporated into the analysis.

5 CONCLUSIONS

(i) We have found some evidence for an M5-type spectral distribution in RZ Leo and CU Vel. This may suggest that these systems are in the upper branch of the CV evolution track, i.e. prior to the orbital period minimum.

(ii) We find marginal evidence for an L5-type secondary star in HV Vir. A secondary star with spectral type M9.5 may be identified in VY Aqr. These systems have probably passed beyond the orbital period minimum. However, the position of VY Aqr in the $T_{\text{eff}}-P_{\text{orb}}$ diagram conflicts with the results of the population synthesis code of Howell et al. (2001).

(iii) For some objects, namely V485 Cen, WZ Sge and 1RXSJ105010.3, we found no significant improvement of the spectral fitting by adding a stellar atmosphere template. This may indicate that, even for such low-luminosity systems, the accretion disc spectrum dominates the flux in the IR.

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A search for brown dwarf secondaries in CVs

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