Search for brown-dwarf like secondaries in cataclysmic variables II

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ABSTRACT

We have examined VTL/ISAAC 1-2.5 \( \mu \)m spectroscopy of a sample of short orbital period cataclysmic variables which are candidates for harboring substellar companions. We provide descriptions of the infrared spectrum of EI Psc, V834 Cen, WX Cet, VW Hyi, TY PsA and BW Scl. Fitting of the IR spectral energy distribution (SED) was performed by comparing the observed spectrum with late-type templates. Absorption features of the secondary star were detected in EI Psc and V834 Cen, consistent with dwarf secondaries of spectral type K 5 \( \pm \) 1 and M 8 \( \pm \) 0.5, respectively. In addition, we report the first detection of the secondary star in VW Hyi. The SED in this case is well matched by an L 0 \( \pm \) 2 type secondary contributing 23 per cent to the overall flux at \( \lambda = 1.15 \) \( \mu \)m. This is a surprising result for a system with a relatively high mass transfer rate. We discuss the implication of our findings on the current scenarios for cataclysmic variable star evolution.

Key words: Stars: individual: EI Psc, V834 Cen, WX Cet, VW Hyi, TY PsA, BW Scl, Stars: binaries: close, Stars: Cataclysmic Variables, Dwarf novae, fundamental parameters, evolution, Stars: binaries: general, Stars: low-mass

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 and forming a luminous accretion disk around the white dwarf. The spectral energy distribution of CVs in X-rays and ultraviolet is dominated by white dwarf and inner disk emission, whereas the accretion disk contribution is dominant in the optical and possibly in the near infrared. In some cases the emission from the accretion disk in the IR is approximated by a power-law (Giard et al. 1993). However, in general we expect a much more complex emission, especially from low-luminosity disks which 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 understand the secular evolution of these objects. Current theories state that the process of mass transfer becomes linked with the loss of orbital momentum, so that the binary period becomes shorter while the hydrogen rich 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 minutes (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-timescale mass transfer may occur, eventually producing ultrashort-period systems with a low-mass, hydrogen poor and probably degenerate secondary (King & Schenker 2002). One must keep in mind that these secondaries are formed very differently from field brown dwarfs. 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.

Observational methods to search for undermassive secondary stars in cataclysmic variable stars have been summarized in Paper I. The empirical evidence available for this class of objects has been critically examined by Littlefair, Dhillon & Martin (2003). They conclude that no direct evidence for brown-dwarf secondaries in CVs exists in the literature. Specifically they show a Keck-II spec-

\footnote{Indirect methods include radial velocity studies, modeling of the spectral energy distribution and the use of a superhump period-mass ratio relation.}
trum of LL And with no evidence for the absorption features previously claimed by [Howell & Ciardella (2001)]. However, recently [Harrison et al. (2003)] reported the detection of a carbon-deficient brown dwarf-like secondary in EC Er. In this paper we continue the search for brown dwarfs in CVs initiated by Mennickent & Diaz (2002, Paper I) by analysing the infrared spectral energy distribution of a sample of 6 CV candidates for systems at late evolutionary stages. The objects were selected for their orbital periods being below the period gap. The sample includes SU UMa type dwarf novae as well as magnetic CVs in their photometric low states.

One should mention that the determination of basic properties of secondaries in CVs by comparison of their spectra with field stars templates 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. On the other hand, a direct comparison with line strengths or spectral indices specially designed for classifying late-M and L dwarfs is unreliable due to the unknown nature of the continuum emission sources.

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. Conclusions and future prospects are outlined in Section 5.

2 OBSERVATIONS AND DATA ANALYSIS

The infrared spectroscopic observations reported in this paper were obtained at ESO with VLT-Antu using the ISAAC spectrograph in service mode. The data were taken under clear atmospheric conditions. An observing log is given in Table 1. Spectra in the J, H and K bands were obtained with full width at half maximum (FWHM) resolutions ranging from 24 (J) to 46 (K) angstroms. Pipeline reduced spectra were used, but re-calibrated in wavelength by measuring the location of atmospheric OH emission lines [Rousselot et al. 2003] in the sky background.

The telluric absorption features were removed with the aid of an absorption template available in the ISAAC web page, properly degraded in resolution to the instrumental resolution of our objects. 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 standards and science exposures. This procedure worked well, except for the regions between 1.35-1.44 microns and 1.80-1.94 microns, characterized by heavy telluric absorption. These regions, corresponding to the wavelength limits of the J, H and K spectra, were excluded from the analysis and are not shown in this paper.

A rough flux calibration was performed using observations of the B2IV type telluric standard Hip087287, made with the same instrumental setup by the ESO operation team as part of the service mode program. Since the slit losses might be significant for our science objects, this calibration is intended to provide a rough correction for the instrumental response only, leaving the photometric zero point uncertain. The flux of the standard at each wavelength was determined using a black body function set to the same effective temperature of the standard and matching the reported infrared magnitudes.

Prior to measuring line parameters, the spectra were normalized by fitting a low-order polynomial function to the continuum. Then we measured the equivalent width, the FWHM, the full width at zero intensity (FWZI) and in cases of fully resolved double peaked emission lines, the full peak separation $\Delta \lambda$. In these cases we also measured the (continuum normalized) intensity of the violet (V) and red (R) emission components as defined by a double gaussian fit to the emission line. It should be noted that the equivalent widths of absorption lines in late type stars are very hard to determine, since most lines are superposed at some level on molecular bands and in many cases also blended with other atomic lines. We used the same procedure for each line in different objects trusting that these widths should be at least internally consistent.

2.1 Infrared spectral fitting

An attempt to quantify the properties of the IR spectra of the targets where a secondary was detected (see next section) was made by employing a numerical fitting procedure. The spectral energy distribution (SED) in the IR was tentatively parameterized by adding the contribution from a late-type template spectrum and power-law component. Although the emission of the disk 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 bands is strongly dependent on the stellar template contribution. A nonlinear least squares fitting procedure was calculated using the following equation:

$$S(\lambda) = a \times T(\lambda) + b \times \lambda^c$$

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-square between the observed spectrum and a model fit. Of course, $a$ and $b$ are constrained to the positive domain. The above procedure has proven to be useful to estimate the temperatures of secondaries of short orbital period cataclysmic variables (Paper I). The data fit ranges were selected carefully to avoid emission lines and deep telluric bands. A sequence of template spectral types between M3 and L7 with a stepsize of typically 2 subclasses was taken from [Leggett et al. 2001] and [Reid et al. 2001]. For the case of El Psc (see next section), we used a grid of (continuum normalized) H-band spectra, provided by [Meyer et al. 1998], that covers the spectral types between K2 and M3. The resolution of the templates was matched with those of the science spectra by convolving the data with a Gaussian with the appropriate FWHM. Due to the low rotational velocity of the templates, it was not necessary to account for rotational broadening when fitting the spectrum. In practice, the fitting of J and H spectral bands provided most of the information in this method, while the use of the K band was limited to spectral line analysis due to...
Table 1. Journal of observations. The total integration time, in seconds, is given for each spectral band.

| Star       | UT-date | J  | H  | K  |
|------------|---------|----|----|----|
| EI Psc     | 2002-08-10 | 3600 | 3600 | 3600 |
| V834 Cen   | 2002(06-23(J,K),08-09(H)) | 2400 | 2400 | 2400 |
| WX Cet     | 2002-08-10 | 4320 | 4320 |  -  |
| VW Hyi     | 2002-08-13 | 480  | 480  | 480  |
| TY PsA     | 2002-08-10 | 1600 | 1200 | 800  |
| BW Scl     | 2002-07-22 | 2400 | 2400 |  -  |

Table 2. Equivalent widths of absorption lines.

| Ion       | λ (µm)    | VW Hyi | V834 Cen | EI Psc |
|-----------|-----------|--------|----------|--------|
| Na i      | 1.1404,1.1381 | 4.1    | 3.3      | -      |
| K i       | 1.1690     | 1.7    | 1.3      | -      |
| K i       | 1.1777,1.1773 | 1.6    | 2.0      | -      |
| K i       | 1.2432     | 2.8    | 1.2      | -      |
| K i       | 1.2522     | 1.9    | 1.6      | -      |
| K i       | 1.5167,1.5172 | 0.7    | -        | -      |
| Mg i      | 1.5770,1.5753,1.5745 | -    | -        | 3.6    |
| CO(8,5)   | 1.6620     | -      | -        | 5.5    |
| OH        | 1.6890     | -      | -        | 4.2    |
| Na i      | 2.2062,2.2090 | 7.0    | 8.0      | 6.0    |
| Ca i      | 2.2614,2.2631,2.2657 | -    | -        | 3.0    |
| CO(2,0)   | 2.2935     | -      | 2.4      | -      |
| Na i      | 2.3355,2.3386 | -    | -        | 11.0   |

the lack of adequate templates at the required instrumental resolution.

3 RESULTS

The infrared spectra for all program stars are shown in Figs. 1–3. Spectroscopic parameters are given in Tables 2 and 3.

3.1 EI Psc

This recently discovered SU UMa subtype dwarf nova (Uemura et al. 2001), also named RXS J232953.9+062814, has a unique short orbital period of 64 minutes, shorter than any other hydrogen-rich cataclysmic variable. At quiescence, the spectrum shows the absorption features of a type K4 ± 2 secondary star (Thorstensen et al. 2002). Both the radial velocity study and the observed period excess indicate a secondary mass around 0.12 M⊙ (Thorstensen et al. 2002; Skillman et al. 2002). The secondary star is much hotter than main sequence stars of similar mass, but it is well matched by helium-enriched models, indicating that it evolved from a more massive progenitor (Thorstensen et al. 2002; Skillman et al. 2002; Uemura et al. 2002). According to Thorstensen et al. (2002), the secondary star contributes 50 ± 20 per cent to the light near 5500 Å.

Our observations reveal weak Paschen β and Brackett γ emission, the former being clearly double with the violet component stronger than the red one. The H-band and K-band spectra show absorption features probably arising from the secondary star. This view is supported by the comparison with a K5 V type template (Meyer et al. 1998) rectified to the resolution of our H-band spectra (Fig. 4). We identify several absorption features like Mg i 1.5760, 1.7113 µm, Si i 1.5964, 1.6685 µm, 12CO i 1.619, 1.662 µm, Al i 1.6742 µm and OH 1.689 µm.

We performed the fitting of the function described by Eq. (1) in the range 1.52–1.78 µm, using the K2–M3 type templates and the continuum normalized spectrum observed at the H-band, forcing c = 0. This was needed since only continuum-normalized templates were available for these spectral types. We obtained the best fit with a K5 ± 1 type secondary contributing 50 ± 10 per cent to the total flux in the H-band. This number was particularly sensitive to the spectral range considered in the fit. Including only the absorption lines and excluding the continuum at the end of the spectrum, and also the "bump" between 1.60–1.61 µm, the estimated secondary star contribution increases to 67 ± 6 per cent. The fit is severely degraded for earlier or later type templates. In the above estimate we have assumed that the relative disc contribution is nearly constant through the spectral range considered. Our result of a K5 type secondary is in agreement with the spectral type reported by Thorstensen et al. (2002).

Ramirez et al. (1997) found that the veiling-independent indicator:

\[ r = \log \left[ \frac{EW(12 CO(2,0))}{EW(Na i)+EW(Ca i)} \right] \]  

is a strong luminosity indicator among K-M stars, independent of effective temperature. The almost null visibility of
$^{12}$CO(2,0) features in our spectra along with the detectable presence of the sodium doublet and the calcium triplet, point to a very low $r$ value and therefore a dwarf secondary, as expected in a short orbital period CV.

We have tried to establish the temperature of the secondary star using the veiling-independent temperature/luminosity discriminator:

$$\frac{EW(OH \lambda 6994 \text{Å} \times EW(CO \lambda 1014 \text{Å} \times CO \lambda 1017 \text{Å})}{EW(Mg \lambda 5775 \text{Å})}$$  

(3)

as proposed by Ramirez et al. (1997). We find for this discriminator (1.2 ± 0.2, 1.5 ± 0.2). Using Eq. (5) from Meyer et al. (1998) yields an effective temperature, $T_{\text{eff}} = 1585 ± 745$ K, which is incompatible with a K-type star. A close inspection of Fig. 4 reveals that the discrepancy arises from the anomalously large OH line, which in K-type stars is normally weaker. A departure of normal conditions of the irradiated secondary could provide an explanation for the discrepancy.

### 3.2 V834 Cen

In this paper we present the first observations of the IR spectrum of this short-period AM Her system. V834 Cen is the only magnetic CV in our sample. The object has been relatively well studied in X-ray, UV and optical wavelengths. The orbital period is 101.5 min (Mason et al. 1983) and the object spectrum in Fig. 5. From the arguments above we suspect that previous identifications of the spectral type is later than those estimated by Beuermann, Thomas & Schwope (1989), viz. dM 5, based on the detection of TiO bands in the optical spectrum at low state, and it is at the cooler limit of the M5−M8 range derived by Maraschi et al. (1984) from the study of multi-wavelength photometry. It is also later than the dM.6.5 classification provided by Puchnarewicz et al. (1990) from spectroscopic modeling. However, these authors did not use templates with spectral types later than dM.6.5. Our best fit is shown along with the object spectrum in Fig. 5. From the arguments above we suspect that previous identifications of the spectral type of the secondary star in V834 Cen may suffer from large uncertainties and that the value of M8 derived in this paper possibly represents a more robust determination. The continuum slope given above implies a very strong dependence on $\lambda$. Just for comparison, a black body with temperature in the range of 15000–50000 K should contribute with a continuum with a spectral index $c$ between −3.5 and −4 in the spectral range considered. We conclude that there is a bright hot source contributing to the IR flux that may be related to the weak mass accretion during low states.

### Table 3. Spectroscopic data for the main emission lines. $V, R$ are the continuum normalized intensities of the violet and red emission components of the double emission lines and $\Delta \lambda$ is the peak separation.

| Star  | Line | $EW$ | $\Delta \lambda$ | $FWHM$ | $FWZI$ | $V, R$ |
|-------|------|------|------------------|--------|--------|--------|
| El Psc | Pa $\beta$ | -20  | 1085  | 1800 | 3205 | 1.28,1.22 |
| El Psc | Br $\gamma$ | -26  | -    | -    | 2860 | -      |
| WX Cet | Pa $\beta$ | -93  | -    | 1920 | 3745 | -      |
| VW Hya | Pa $\beta$ | -22  | 940   | 1440 | 3460 | 1.36,1.25 |
| VW Hya | Br $\gamma$ | -16  | 1010  | -    | 3765 | 1.18,1.10 |
| TY PsA | Pa $\beta$ | -40  | -    | 2130 | 3440 | -      |
| TY PsA | Br $\gamma$ | -34  | -    | 1925 | 2730 | -      |
| BW Scl | Pa $\beta$ | -100 | 1285  | 2290 | 3090 | 2.24,2.12 |

2 VSNET: Variable Star Network (http://vsnet.kusastro.kyoto-u.ac.jp/vsnet/index.html)
3.3 WX Cet

This dwarf nova was originally proposed as a WZ Sge-like system, due to scarce and large amplitude outbursts (Bailey 1974). However, observations during superoutbursts revealed a rather mild photometric period excess, supporting the hypothesis that WX Cet is a fairly normal large-amplitude SU UMa-type dwarf nova, rather than a WZ Sge-type dwarf nova (Patterson 1998; Kato et al. 2001a). Recent time-resolved spectroscopy suggests that WX Cet possesses a more massive secondary and represents an earlier stage of mass transfer in a cataclysmic binary than WZ Sge (Rogozińcki & Schwarzenberg-Czerny 2003). However, the secondary star mass derived by these authors, viz. $M_2 = 0.047 \pm 0.013 \, M_\odot$, is still below the accepted value for the hydrogen-burning minimum mass $\sim 0.07 \, M_\odot$ (Chabrier et al. 2000). This is consistent with the recent result of the multi-component fitting to the SED by Mason (2001), who obtained a secondary star temperature of 850 ± 150 K, which is, surprisingly, compatible with a 5 Gyr old brown-dwarf of 0.05 $M_\odot$ (Chabrier et al. 2000). Evidently, the possibility of a period bouncer is still open and the star deserves further study, especially in the infrared.

Our $J$-$H$ band spectra show no sign of the secondary star, but do show broad Paschen $\beta$ emission and very weak emission in high order Brackett lines. Our Paschen $\beta$ emission profile does not reproduce the strong asymmetry observed in the same line by Mason (2001), suggesting a variability reminiscent of that observed in the Balmer emission lines. The fact that no secondary star features were detected in our IR spectra may suggest that the secondary is particularly cool and is being outshined by the disk emission. Further IR spectroscopy with improved $S/N$ is encouraged in order to better clarify this point.

3.4 VW Hyi

Comparatively few spectroscopic studies exist of this rather bright southern SU UMa star. A reddening-based distance of 40 pc is given by (Beuermann 1985). The orbital period was established as 107 min (Schoembs & Vogt 1981). The extensive photometric record existing in the VSNET archives supports the dwarf nova classification and evidences the rather short recurrence time of $\sim 27$ days and outburst amplitude of about 5 magnitude. According to these records, our observations were taken at quiescence, 17 days before maximum. VW Hyi is one of the few CVs where Doppler tomography clearly shows the contributions of the different line emitting sources in the system: accretion disc, gas stream, hot spot and possibly secondary star (Mennickent, Tappert & Diaz 2002; Tappert et al. 2003). In particular, the above study indicates that the secondary star could significantly contribute to the overall Hα emission during quiescence.

Our $J$-$H$-$K$ band spectra clearly reveal the presence of the absorption features of the secondary star. We observe the K i doublets at 1.169-1.177 $\mu$m and 1.244-1.253 $\mu$m and the Na i lines at 1.011, and 2.206-2.209 $\mu$m. Paschen $\beta$ and Brackett $\gamma$ appears like asymmetric double emissions with the violet peak stronger than the red one. Strong H $\upalpha$ double emissions also appear in the IR spectra shown by Mason (2001), but they are symmetric, and no evidence of the secondary star is visible in her (lower $S/N$) spectra.

The best spectral fitting for the $J$ band spectrum was obtained with an L0 type secondary contributing 23 per cent to the overall flux at $\lambda = 1.15 \, \mu$m, and a continuum characterized by an exponential index $e = -0.38 \pm 0.02$. The fit is also good for spectral types M8 up to L2, but degrades significantly outside this range (Fig. 6). If we assume $J = 12.56$ from the 2MASS photometry (Hoard et al. 2002), we get for the secondary star $m_J = 11.14$, which is compatible with a secondary star below the hydrogen-burning minimum mass limit but with an age less than 0.5 Gyr (Chabrier et al. 2001). A late type secondary for VW Hyi is a surprising result, in apparent conflict with the 0.11 $M_\odot$ secondary found by (Schoembs & Vogt 1981). However, these authors used a dynamical model based on the radial velocity amplitude of the emission lines, which has proven to be, at least for some systems, an highly unreliable indicator. In fact, Schoembs & Vogt (1981) determined a semi-amplitude of the radial velocities $K_1 = 78 \pm 14 \, km \, s^{-1}$, while Tappert et al. (2003) obtained a much lower value of 38 ± 9 km s$^{-1}$. We will discuss the implications of this finding in the next section.

3.5 TY PsA

The quiescent optical spectrum of the SU UMa-type dwarf nova TY PsA is characterized by broad, double-peaked emission lines (O’Donoghue & Soltynski 1992). A periodic modulation observed in the radial velocities during quiescence suggests an orbital period of 0.08414 d (O’Donoghue & Soltynski 1992). The absence of radial velocities of the broad shallow absorption lines during superoutburst could be explained if TY PsA has an extreme mass ratio and an unusually low-mass secondary star (O’Donoghue & Soltynski 1992). However, this view apparently conflicts with the rather large observed difference between orbital and superhump period (Patterson 1998). To our knowledge, our spectra are the first to reveal the infrared emission of this CV; showing no absorption features of the secondary star, but strong emission in Paschen $\beta$ and Brackett $\gamma$ and weaker emission in higher order Brackett lines. The central reversal in the emission line, if present, is quite shallow, indicating a moderate systemic inclination.

3.6 BW Scl

This variable star, also named HE 2350-3908 and RX J2353.0-3852, was discovered independently in the Hamburg/ESO and the ROSAT surveys (Augusteijn & Wisotzki 1997, Abbott, Fleming & Pasquini 1997). It has one of the shortest orbital periods (78 min) among CVs with normal hydrogen-rich secondaries. The optical spectrum and the orbital light curve of BW Scl is very similar to WZ Sge, suggesting that the source is a dwarf nova type cataclysmic variable with a very low mass-transfer rate, and a long recurrence time (Augusteijn & Wisotzki 1997). This view has not yet been tested, partly due to the lack of an adequate long-term photometric record. However, our $J$-$H$ band spectra – the first obtained in this spectral region – seem to corroborate the dwarf nova classification; they show a broad double-peaked Paschen $\beta$ emission line and weaker broad emission in the Brackett series, typical credentials
of dwarf novae. No sign of the secondary star is visible in our spectra. The central absorption observed in Paschen $\beta$ suggests a moderate inclination for the system. The star shows the strongest Paschen $\beta$ emission in our sample, with an equivalent width comparable to those shown by the WZ Sge type star candidate 1RXS J105010.3-140431 (Mennickent et al. 2001). The rather large Pa$\beta$ emission is compatible with an origin in a low mass accretion rate disc.

4 DISCUSSION

In the above section we have reported evidence for M8 and L0 type secondaries in V834 Cen and VW Hyi, respectively, and for a K5 type secondary in El Psc. While El Psc has already been discussed in the context of CV evolution, being interpreted as the result of mass transfer on a thermal timescale in a system with a secondary initially more massive that the white dwarf (Thorstensen et al. 2001), the other cases are, at first glance, new candidates for period bouncers. As an illustration, a CV with orbital period around 105 minutes should possess a secondary star of spectral type around M3 in the upper branch of the CV evolutionary track (Howell, Nelson & Rappaport 2001). However, VW Hyi appears like a bizarre object, since this star does not show the typical credentials of a star which has bounced-off from the orbital period minimum, viz. a low mass transfer rate evidenced in a long recurrence time and large amplitude outbursts. For this reason, the star has never been included in the list of WZ Sge type candidates or related systems (Kato et al. 2001).

To our knowledge, VW Hyi is the first CV showing simultaneously evidence for a late type secondary and relatively high mass transfer rate. Based on the evidence, it is hard to conclude that the star is the result of the evolution of a shorter period system. A period bouncer with an orbital period around 105 minutes should possess a secondary star of spectral type around M 3 in the upper branch of the CV evolutionary track (Howell, Nelson & Rappaport 2001). However, VW Hyi appears like a bizarre object, since this star does not show the typical credentials of a star which has bounced-off from the orbital period minimum, viz. a low mass transfer rate evidenced in a long recurrence time and large amplitude outbursts. For this reason, the star has never been included in the list of WZ Sge type candidates or related systems (Kato et al. 2001).

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5 CONCLUSIONS

- We have found evidence for K5, M8 and L0 type secondaries in El Psc, V834 Cen and VW Hyi, respectively. This may suggest that V834 Cen and VW Hyi have probably passed beyond the orbital period minimum. However, the case of VW Hyi is peculiar, in the sense that the system also shows a relatively high $M$. We prefer to interpret this result for VW Hyi in terms of a recently formed CV with a brown-dwarf like secondary.
- For some objects, namely WX Cet, TY PsA and BW Scl, 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 disk spectrum dominates the flux in the IR.
- In this paper and Paper I we find that the fitting of the infrared spectral distribution using stellar templates is an useful diagnostic tool for the secondaries in ultra-short orbital period CVs. However, there exists evidence that due to irradiation, only upper limits for the secondary star temperature can be derived with the current instrumentation, and that exact measurements of $T_2$ should wait for even larger telescopes with the ability of time-resolved infrared spectroscopy of faint CVs.

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better visualization. The spectrum of a B-type standard is also shown indicating the position of the telluric absorption bands. Vertical lines show the rest wavelength of H lines and some spectral features commonly observed in late M stars.

Fig. 2 Same as Fig. 1 for H-band spectra. The spectra are normalized to the mean flux at 1.54–1.56 µm, and shifted by multiples of 1.

Fig. 3 Same as Fig. 1 for K-band spectra. The spectra are normalized to the mean flux at 2.09–2.11 µm, and shifted by multiples of 0.5. The feature observed around 2.186 µm in the spectrum of EI Psc is probably an artifact.

Fig. 4 The continuum normalized H-band spectrum of EI Psc (thin line) along with the spectrum of the K5 V-type star HR 8085 (thick line). Features of the secondary star are clearly visible in the spectrum of EI Psc.

Fig. 5 The J-band spectrum of V 834 Cen and the best composite SED fit (thick line). The individual M8 type template spectrum and power law continuum are also shown.

Fig. 6 The J-band spectrum of VW Hyi, normalized to the flux at λ = 1.15 µm, and the best composite SED fit (thick line), for different secondary star templates. The best fit is obtained with a template spectrum of spectral type L0.

This paper has been typeset from a \TeX/LaTeX file prepared by the author.
Normalized flux + constant for the stars V834 Cen, WX Cet, VW Hyi, TY PsA, and BW Scl as a function of wavelength (Å). The lines represent the normalized flux of each star, with markers for specific wavelengths and symbols for different emission lines.
Normalized intensity vs. wavelength (Å) with peaks at MgI, HI, SiI, 12CO, 12CO, AlI, OH, and MgI.
