K-band spectroscopy of pre-cataclysmic variables

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ABSTRACT

Aims. There exists now substantial evidence for abundance anomalies in a number of cataclysmic variables (CVs), indicating that the photosphere of the secondary star incorporates thermonuclear processed material. However, the spectral energy distribution in CVs is usually dominated by the radiation produced by the accretion process, severely hindering an investigation of the stellar components. On the other hand, depending on how the secondary star has acquired such material, the above mentioned abundance anomalies could also be present in pre-CVs, i.e. detached white/red dwarf binaries that will eventually evolve into CVs, but have not yet started mass transfer, and therefore allow for an unobstructed view on the secondary star at infrared wavelengths.

Methods. We have taken K-band spectroscopy of a sample of 13 pre-CVs in order to examine them for anomalous chemical abundances. In particular, we study the strength of the $^{12}$CO and $^{13}$CO absorption bands that have been found diminished and enhanced, respectively, in similar studies of CVs.

Results. All our systems show CO abundances that are within the range observed for single stars. The weakest $^{12}$CO bands with respect to the spectral type are found in the pre-CV BPM 71214, although on a much smaller scale than observed in CVs. Furthermore there is no evidence for enhanced $^{13}$CO. Taking into account that our sample is subject to the present observational bias that favours the discovery of young pre-CVs with secondary stars of late spectral types, we can conclude the following: 1) our study provides observational proof that the CO anomalies discovered in certain CVs are not due to any material acquired during the common envelope phase, and 2) if the CO anomalies in certain CVs are not due to accretion of processed material during nova outburst, then the progenitors of these CVs are of a significantly different type than the currently known sample of pre-CVs.

Key words. binaries: close – Stars: late-type – cataclysmic variables – Infrared: stars

1. Introduction

A cataclysmic variable (CV) is a close interacting binary consisting of a white dwarf (WD) and a red (K–M) main-sequence star (RD). The latter, secondary star, transfers mass via Roche-lobe overflow to the more massive white dwarf, the primary component. Typical orbital periods range from ~80 min to ~10 h. For comprehensive overviews on CVs see Warner (1995) and Hellier (2001).

The progenitors of CVs are thought to be initially wide, detached binaries. As the more massive component expands in the course of its nuclear evolution, it fills its Roche lobe and transfers matter at high rates onto the red dwarf. At mass-loss rates $M_1 \sim 0.1\, M_\odot\, \text{yr}^{-1}$, the corresponding dynamical time scale is much shorter than the Kelvin-Helmholtz time scale for thermal adjustment of the secondary star. A common-envelope (CE) configuration results, providing an enhanced braking mechanism that rapidly shrinks the orbital separation, until, at $P_{\text{orb}} \lesssim 1\, \text{d}$, the kinetic energy stored in the CE exceeds the binding energy, and the CE is expelled as a planetary nebula, leaving a close, but still detached, WD/RD binary. The remaining mechanisms for angular-momentum loss, magnetic braking and/or gravitational radiation, further shrink the orbital separation, now on a much longer time scale, until the Roche lobe of the secondary star comes into contact with the stellar surface, initiating mass-transfer and the proper CV phase. Systems that have gone through such a CE configuration and eventually will evolve into a CV, are known as post-CE binaries. Using the criterion by Schreiber & Gänsicke (2005), such objects are called pre-CVs if they evolve into CVs in less than Hubble time (~13 Gyr) and can thus be regarded as representative progenitors of the current CV population.

While it had been originally assumed that the secondaries enter the CV phase as main-sequence stars, during the past decade substantial evidence has been mounted that a large fraction of the secondary stars in long-period ($P_{\text{orb}} > 3\, \text{h}$) CVs shows signs of nuclear evolution (Beuermann et al. 1998; Harrison et al. 2004, 2005b). This would mean that the binary spends a much longer time in its pre-CV state than hitherto assumed, and could provide the solution to certain discrepancies between modelled and observed CV population (e.g. Patterson 1998; Gänsicke 2005).

In particular, the work by Harrison et al. revealed diminished $^{12}$CO and – in comparison – enhanced $^{13}$CO absorption bands in the $K$ spectra of dwarf novae with orbital periods > 3
h, which they interpret as being due to CNO processed material finding its way into the stellar photosphere of the secondary star. Currently discussed scenarios that could lead to this phenomenon can be divided in two principal categories: 1) nuclear evolution of the secondary star, and 2) accretion of nuclear processed material.

The former implies that sufficient time for nuclear evolution has to pass from the CE to the CV phase, and is only feasible for secondary stars of comparatively early spectral type (≤K0V) since dwarfs of later spectral type will not evolve within Hubble time (e.g. Pols et al. 1998). As a consequence, the secondary star temporarily might become the more massive component after the CE phase, and so through a phase of thermal-timescale mass transfer (Schenker & King 2002, Schenker et al. 2002; Gänsidee et al. 2003, Harrison et al. 2005a, the latter discuss this in the context of anomalous abundances).

For the accretion scenario there are two principle sources of processed material: either the secondary star swept up processed material during the CE phase, or it accreted ejected material during nova eruptions. These possibilities have been discussed by Marks & Sarna (1998), who find that the significance of such effect strongly depends on the (unknown) efficiency of the secondary to accrete such material. Furthermore, in the case of accretion from the CE, such material will be stripped away from the secondary already in the early stages of the semi-detached CV phase (see also the respective discussion in Harrison et al. 2004).

Both the evolution scenario and accretion from the CE would also lead to anomalous chemical abundances in the progenitors of CVs, i.e. in pre-CVs. We here present K band spectroscopy of a sample of pre-CVs to investigate the strength of the CO features in these systems.

2. The sample

We have used the TPP catalogue (Kube et al. 2002) to search for confirmed and candidate pre-CVs that are observable from the southern hemisphere. We have restricted our sample to confirmed pre-CVs with known orbital period, and excluded systems in nebulae and with primary components other than white dwarfs. There are a number of exceptions to the first criterion, in that we include three systems with uncertain orbital periods, and one, as yet unconfirmed pre-CV candidate P831-57 (also known as Ret1; Downes et al. 2005). These objects have been part of a project that aimed at confirming the pre-CV nature of a number of candidates, and finding the orbital period by photometric means (Tappert et al. 2004, 2006). The light curves of EC 12477-1738, EC 13349-3237, and EC 14329-1625, showed the periodic modulations that are typical for the sinusoidal or ellipsoidal variations in pre-CVs, although due to insufficient data no conclusive period could be determined. Initial observations of P831-57 showed variations that could be interpreted as part of a pre-CV light curve: a decline of ~0.005 mag over ~5 h in one night, and a rise of similar dimensions in the subsequent night, and thus the object was included in our target list for the K band spectroscopy. However, later observations could not confirm this variation, so the pre-CV status of P831-57 remains doubtful at the moment and needs to be clarified by future observations.

Previous studies have already provided an estimate of the spectral type of the secondary star for about two thirds of the systems in our sample. All of them are M dwarfs that have time scales for nuclear evolution > $t_{\text{Hubble}}$ ~ 13 Gyr (e.g., Pols et al. 1998). Furthermore, most of these systems are relatively young objects, with white dwarf cooling times of less than a few $10^8$ yr (except RR Cae and LTT560, which are ~1 Gyr old). Given that the typical time to evolve into a semidetached CV configuration is several Gyr (assuming the standard prescription for orbital angular momentum loss, Schreiber & Gänsidee 2003), most of the systems have lived only through a relatively small fraction of their pre-CV live. In fact, only EC 13471-1258 and potentially BPM 71214 (depending on the model for angular momentum loss) have already passed more than half of their time as a post-CE binary. In this, our sample reflects the present observational bias towards systems with hot white dwarf primaries and/or comparatively late-type secondary stars (Schreiber & Gänsidee 2003). Our targets therefore do not represent the progenitors of CVs with anomalous abundances if scenario 1 (evolution) applies. A positive detection of anomalous CO strengths in our targets would be a strong indication that such material has been acquired by the secondary star during the CE phase (Marks & Sarna 1998).

For comparison we observed three late-type M dwarfs with spectral types similar to those of our program objects. Table 1 presents selected known properties of our targets.

3. Observations and data reduction

The data were obtained with ISAAC mounted at Antu (UT1), VLT, Paranal, Chile. The instrument was operated in SWS (short-wavelength spectroscopy) mode, and the grating was used in its low-resolution (resolving power ~1500), K-band, position. The nominal wavelength coverage was ~1.85–2.57 µ, though only data in the wavelength range ~2.00–2.45 µ were useful. Observations were conducted in service mode and included flat fields and wavelength calibration (Xe-Ar) data at the start of night, and telluric standard stars taken within 1 h and an air-mass difference $\Delta M(z) = 0.2$ of the target spectra. The data were taken in AB–BA cycles, i.e. with small telescope offsets after the first and then after every second spectrum, so that spectra 1, 4, 5, 8, ..., occupy positions in the lower half of the CCD (position A), and spectra 2, 3, 6, 7, ..., are located in the upper half of the CCD (position B). Some stars were observed twice, since the first observations did not match ESO’s quality criteria (regarding, e.g., seeing, difference in airmass between target and telluric standard, etc.). In one case (CC Cet), both spectra were found to be of sufficient quality, and could be combined in order to improve the S/N. For another system (BPM 6502) the spectra of the telluric standards presented significant disturbances on both occasions, fortunately once a
Table 1. Previously known properties of the sample stars. Coordinates (J2000.0) were taken from SIMBAD. JHKs magnitudes are from the 2MASS database. Typical photometric errors are ~0.03 mag for Ks, and ~0.036 for the colours. Uncertain orbital periods are marked with a colon.

| name          | R.A.     | DEC      | Ks  | J−H    | H−Ks    | P_orb [h] | spType     | References              |
|---------------|----------|----------|-----|--------|---------|-----------|------------|-------------------------|
| BPM 6502      | 10 44 11 | −69 18 20| 10.56| 0.527  | 0.335   | 8.08      | M2.5V      | Kawka et al. (2000)      |
| BPM 71214     | 03 32 43 | −08 55 40| 9.30 | 0.655  | 0.233   | 4.33      | M4.5−M5V   | Kawka et al. (2002)      |
| CC Cet        | 03 10 55 | +09 49 27| 12.93| 0.540  | 0.249   | 6.82      | M3.5−M4V   | Saffer et al. (1993)     |
| EC 12477-1738 | 12 50 22 | −17.54 46| 12.60| 0.639  | 0.262   | 13.7      | Tappert et al. (2004)  |
| EC 13349-3237 | 13 37 51 | −32 52 22| 13.25| 0.669  | 0.129   | 11.4      | Tappert et al. (2004)  |
| EC 13471-1258 | 13 49 52 | −13 13 38| 9.98 | 0.558  | 0.288   | 3.62      | M3.5−M4V   | Kilkenny et al. (1997).  |
| EC 14329-1625 | 14 35 46 | −16 38 17| 10.87| 0.580  | 0.288   | 8.4      | Tappert et al. (2006b) |
| LTT 560       | 00 59 29 | −26 31 01| 11.86| 0.521  | 0.270   | 3.54      | M5.5V      | Tappert et al. (2006a), Hoard & Wachter (1998) |
| NN Ser        | 15 52 56 | +12 54 44| 16.17| 0.653  | 0.086   | 3.12      | M4.75V     | Haefner (1989), Haefner et al. (2004) |
| P83l-57       | 03 34 34 | −64 00 56| 11.54| 0.594  | 0.204   |           | M4V        |                        |
| RE 1016-053   | 10 16 29 | −05 20 27| 9.77 | 0.617  | 0.220   | 18.9      | M1.5V      | Thorstensen et al. (1996) |
| RR Cae        | 04 21 06 | −48 39 08| 9.85 | 0.572  | 0.296   | 7.29      | ≥M6V       | Bruch & Diaz (1998), Bruch (1999) |
| UZ Sex        | 10 28 35 | +00 00 29| 10.94| 0.532  | 0.276   | 14.3      | M4V        | Saffer et al. (1993)     |

Table 2. Log of observations, containing the date of the observations (start of night), the number of individual spectra, the exposure time for a single exposure, and the total exposure time. The last three columns give the corresponding atmospheric standard star, its spectral type, and its adopted effective temperature.

| object          | date      | n_data | t_exp [s] | t_tot [s] | std     | spType     | T_eff [K] |
|-----------------|-----------|--------|-----------|-----------|---------|------------|-----------|
| BPM 6502        | 2005-12-21| 2      | 10        | 20        | Hip030743| B4V        | 17000     |
|                 | 2006-01-12| 2      | 10        | 20        | Hip031068| B3V        | 19000     |
| BPM 71214       | 2005-11-17| 2      | 5         | 10        | Hip026939| B5V        | 15200     |
| CC Cet          | 2005-10-13| 10     | 60        | 600       | Hip024809| B9V        | 10300     |
|                 | 2005-11-12| 10     | 60        | 600       | Hip034669| B4V        | 17000     |
| EC 12477-1738   | 2005-03-28| 10     | 60        | 600       | Hip0665475| B2IVn     | 21000     |
| EC 13349-3237   | 2005-04-18| 10     | 60        | 600       | Hip055051| B1V        | 25500     |
| EC 12471-1258   | 2005-04-18| 2      | 5         | 10        | Hip055051| B1V        | 25500     |
| EC 14329-1625   | 2005-04-18| 2      | 10        | 20        | Hip055051| B1V        | 25500     |
| LTT 560         | 2005-06-01| 2      | 30        | 60        | Hip0104320| B3V       | 19000     |
| NN Ser          | 2005-03-28| 24     | 300       | 7200      | Hip081362| B0.5III    | 27750     |
| P83l-57         | 2005-11-17| 2      | 30        | 60        | Hip026939| B5V        | 15200     |
|                 | 2005-11-22| 2      | 30        | 60        | Hip015188| B3V        | 19000     |
| RE 1016-053     | 2005-12-24| 2      | 5         | 10        | Hip057080| B3V        | 19000     |
|                 | 2006-01-12| 2      | 5         | 10        | Hip033575| B2V        | 21000     |
| RR Cae          | 2005-11-17| 2      | 5         | 10        | Hip026939| B5V        | 15200     |
| UZ Sex          | 2006-01-12| 2      | 10        | 20        | Hip033575| B2/V3      | 21000     |

| IE 2310.4-4949  | 2005-05-26| 2      | 5         | 10        | Hip088426| G0V        | 5940      |
| J223315.83-603224.0 | 2005-05-25| 2   | 10        | 20        | Hip095103| G3V        | 5700      |
| LP 759-25       | 2005-05-25| 2      | 10        | 20        | Hip105633| B2/B3V     | 20200     |

to the extracted data using the night sky lines (Roussel et al. 2000).

With Brγ at 2.17 μ, the telluric standards of spectral type B have basically only one intrinsic absorption line in the K band. The very early type B stars also show a very weak HeI line at 2.11 μ. In both cases, those lines were fitted with a Voigt profile and subsequently subtracted from the spectrum. For the standards of spectral type G, a solar spectrum (NSO/Kitt Peak FTS data) was rebinned and smoothed down to the resolution of the ISAAC spectra, shifted in wavelength to correct for different zero points, and finally subtracted from the telluric spectra. The resulting pure atmospheric absorption spectra then were shifted and scaled to match position and depth of the atmospheric features in the corresponding target spectrum. Reference points for the shifting were the narrow absorption lines in the red part of the spectrum, while the broad feature between 2.0 and 2.1 μ was used to adjust for the depth of the atmospheric absorption. Finally, the target spectra were divided by the telluric spectra, and, in order to recover the intrinsic SED of the targets, multiplied with a blackbody spectrum corresponding to the effective temperature of the telluric standard (see Table 2).

4. Results

4.1. Spectral types

Based on optical spectra, earlier studies have provided estimates of the spectral type for the majority of the targets in our sample. To obtain independent estimates for the spectral types of

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Fig. 2. Continuum-normalised target spectra. The data have been smoothed to match the resolution of Ivanov et al. (2004). Spectra are roughly sorted according to their estimated spectral type. For comparison, the plot also includes the following objects from Ivanov et al.: HR8832 (K3V), GJ388 (M3V), GJ866 (M5V), and GJ905 (M5.5V).

Fig. 1. Unsmoothed K-band spectrum of NN Ser. The only detected spectral feature is the Brγ emission line.

the secondary stars in our program pre-CVs, we have compared our K spectra to the spectral catalogues of Leggett et al. (2000), Kleinmann & Hall (1986), and Ivanov et al. (2004)\(^1\) (hereafter L00, KH86, and I04, respectively). Each catalogue has strengths and weaknesses for this application. The L00 data represent the

\(^1\) See [http://ftp.jach.hawaii.edu/ukirt/skl/dM.spectra] for Leggett's data, the other two are available via CDS.

Fig. 3. Equivalent width of NaI as a function of effective temperature. Stars from Ivanov et al. (2004) with \(-0.1 \leq [\text{Fe/H}] \leq 0.1\) are marked by +, those with metallicities outside this range, or, in the one case of the star with the lowest \(T_{\text{eff}}\), unknown, with x. Open circles indicate the pre-CVs from our sample, filled ones represent the three comparison late-type dwarfs.
The table is sorted with respect to the strength of the latter.

| object      | spType               | $\log T_{\text{eff}}$ | NaI |
|-------------|----------------------|------------------------|-----|
| RR Cae      | M3–M4.5 (>M6V)       | 3.510(10)              | 3.4 |
| UZ Sex      | M2.5–M5 (M4V)        | 3.515(25)              | 3.5 |
| EC 13349-3237 | K2–M1             | 3.590(60)              | 3.9 |
| RE 1016-053  | K1–K5 (M1.5V)       | 3.670(30)              | 4.1 |
| BPM 71214    | K2–M1 (M2.5V)       | 3.590(60)              | 4.9 |
| LTT 560      | M5.5–M6 (M5.5V)     | 3.430(20)              | 4.9 |
| EC 13471-1258 | M3.5–M5 (M3.5-M4V) | 3.485(25)              | 5.2 |
| BPM 6502     | M2.5–M5             | 3.500(40)              | 5.6 |
| EC 12477-1738 | M3.5–M5           | 3.475(15)              | 6.0 |
| PS3l-57      | M2.5–M3.5           | 3.510(30)              | 6.4 |
| CC Cet       | M3.5–M5.5 (M4.5–M5V) | 3.480(30)              | 7.8 |
| EC 14329-1625 | M3.5–M4.5      | 3.495(15)              | 8.1 |
| LP 759-25    | M5.5–M6 (M5.5V)     | 3.430(20)              | 4.3 |
| J223315.83-603224.0 | M1–M2.5 (M2V) | 3.530(10)              | 4.6 |
| I1E 2310.4-4949 | M3–M4.5 (M3Ve) | 3.485(25)              | 5.2 |

The latter are labelled in sequence of increasing $H–K_s$, as follows: (1) EC 13349-3237, (2) PS3l-57, (3) RE 1016-053, (4) BPM 71214, (5) CC Cet, (6) EC 12477-1738, (7) LTT 560, (8) UZ Sex, (9) EC 13471-1258 (10) EC 14329-1625, (11) RR Cae, (12) BPM 6502. Only systems with photometric errors <0.05 in either of the colours are shown. The cross in the upper left corner indicates the average error ~0.036 mag for the objects included in this plot.

The spectral types from the literature (listed in Table 1) are repeated here (in brackets). The error in the temperature column corresponds to the estimated range. The last column gives the equivalent width (in Å) of the NaI $\lambda$2.21 $\mu$ absorption line. The table is sorted with respect to the strength of the latter.

with the blackbody spectrum of an A0V star (Förster Schreiber 2000). We therefore estimated the spectral type (and $T_{\text{eff}}$) of our targets by comparing their spectral energy distribution to the L00 and KH86 dwarfs, and tested this estimate using the equivalent width of the NaI $\lambda$2.21 $\mu$ absorption line in the I04 spectra.

For the comparison of the SED, we first shifted our data to the rest wavelength of the NaI $\lambda$2.21 $\mu$ line, then smoothed our and KH86’s data to match the resolution of the L00 data, and finally normalised all three data sets by dividing through the average flux value of the 2.10–2.14 $\mu$ wavelength interval. The results of the visual comparison are summarised in Table 3. This, and the subsequent analysis, does not include the object NN Ser, since the S/N proved too low for the detection of absorption features. For completeness, we present its unsmeared spectrum in Fig. 4.

Such visual comparison over a limited spectral range can certainly yield only a very rough estimate of the spectral type. Since several members of our sample have been found to show significant irradiation by the white dwarf, one should furthermore expect that those stars appear somewhat bluer, and that the corresponding temperatures will be overestimated.

We can test these estimates by measuring the strength of suitable absorption features in our spectra. In the $K$ band, the NaI $\lambda$2.21 $\mu$ line appears as the best choice, since it shows a distinctive dependence of temperature, but is independent of luminosity class, and thus nuclear evolution (Ivanov et al. 2004, their Fig.9). The stars in the I04 library were taken with the same instrumentation as our targets, although at a slightly lower spectral resolution. We then normalised the spectra for their SED by fitting splines to the continuum and dividing by the fit. These spectra are shown in Fig. 4. Equivalent widths were measured using the index definition from Ali et al. (1995) as listed in I04. The results are summarised in Table 4 and plotted in Fig. 5 together with the stars from the I04 catalogue.

Although this index presents a large scatter even within the library stars, the plot does show that the pre-CVs on the average appear to have slightly higher equivalent widths at a given temperature. With CC Cet and EC 14329-1625 there are two systems with exceptionally strong NaI absorption, be it due to enhanced NaI, or due to a much later spectral type than estimated (note,
however, that our estimate for CC Cet fits well the result from Saffer et al. (1993). On the other hand, the two confirmed M5.5-M6 dwarfs LTT 560 and LP 759-25 (the latter being one of the comparison stars) have a comparatively shallow Na I absorption line. Still, on the whole, our estimates appear consistent with the behaviour of the Na I spectral index.

The referee suggested to use the 2MASS JHK database in order to further explore the possibility that irradiation by the primary alters the intrinsic SED in the K band, thus causing an over-estimation of the temperature in our targets. In Fig. 4 we present the corresponding colour-colour diagram to compare our targets with the late-type dwarfs from the spectroscopic catalogues of Ali et al. (1995), Kleinmann & Hall (1986), Ivanov et al. (2004), and Leggett et al. (2000). Following Hoard et al. (2002), we have also included the main-sequence from Cox (2000, p. 151), converted to the 2MASS photometric system using the transformations from Carpenter (2001). Irradiation would make the secondary stars in pre-CVs appear bluer, and thus result into a displacement towards the lower left of the main sequence. We do find four of our targets in this direction, but still well within the general scatter that is observed also for single late-type stars. We do find four of our targets in this direction, but still well within the general scatter that is observed also for single late-type stars.

Three targets lie somewhat above the main-sequence, i.e. they cause a stronger deviation of the SED in the blue part of the spectral range, while a broad ‘emission’ feature affected the red part (2.27–2.35 μ). We attempted to remove the latter by fitting a broad Gaussian, and this spectrum is shown in Fig. 5 (middle plot). There remained, however, notable differences in comparison with the – apparently unaffected – red part of the first spectrum, so the latter was used to measure equivalent widths (and is presented in Fig. 2).

There is no previous estimate on the spectral type of the secondary in this system, but Kawka et al. (2000) find a mass to M2 = 0.16(09)M⊙, indicative of an ~M5-M6 dwarf. The K-band SED points to a somewhat earlier type. However, as explained above, that SED is not entirely trustworthy. Indeed, the Na I and Ca I line strengths suggest a spectral type close to M5V, since they are similar to the M5.5V standard from KH86 (Na I is a bit weaker, and Ca I slightly stronger). All CO absorption bands show normal strengths.

In Table 4 we compare the spectral types of our targets determined with the three different methods. If irradiation had any effect on the K-band SED, we would expect that the spectral-type estimates from 2MASS and from SED agree well with each other, but not with the estimates from the line strengths. The fact that we find all three methods providing very similar results (+1 subclass) for most of the systems shows that this is not the case.

4.2. The 12CO absorption

The principal result of the K-band spectroscopy of cataclysmic variables by Harrison et al. (2004, 2005) was the unusual weakness of the 12CO absorption together with enhanced 13CO. While a more quantitative method would in principle be desirable, we here follow the approach by Harrison et al. and visually compare our target spectra to single stars of similar spectral type. The reason for this is that the only available library that includes a large number of late-type dwarfs at sufficient spectral resolution by Ivanov et al. (2004) contains continuum normalised data. For the comparison of the NaI absorption, this did not pose a great difficulty, since the blue part can be fitted relatively easily. Furthermore, the slope of the NaI relation with temperature is steep, making the NaI strength a comparatively robust parameter. In contrast, in the red part of the spectrum, the continuum is not well defined due to the extended and overlapping CO absorption bands. Systematic differences between the library stars and our data are thus easily introduced right in the spectral range that is of most interest.

We therefore turn to the aforementioned visual approach and in Fig. 5 present a comparison of our unsmoothed spectra with the KH86 data. For this purpose, the latter have been smoothed to match our spectral resolution. In the following we summarise the results for each object in detail.

**BPM 6502:** This object was observed twice, unfortunately both times with unsatisfactory results. The first spectrum showed a strong deviation of the SED in the blue part of the spectral range, while a broad ‘emission’ feature affected the red part (2.27–2.35 μ). We attempted to remove the latter by fitting a broad Gaussian, and this spectrum is shown in Fig. 5 (middle plot). There remained, however, notable differences in comparison with the – apparently unaffected – red part of the first spectrum, so the latter was used to measure equivalent widths (and is presented in Fig. 2).

**BPM 71214:** Kawka et al. (2002) give M2.5V as spectral type. Again, our SED analysis yields an earlier type, but the line strengths (Na I, Ca I) are very similar to the M3Ve star 1E2310.4-4949, favouring the Kawka et al. result. This is supported by the weakness of the Mg I λ2.11/2.28 μ lines, which are barely, if at all, detected. On the other hand, the CO features are very weak for such spectral type and fit much better the K5V star from KH86.

**CC Cet:** This object was also observed twice. Both spectra were of sufficient quality, so that they could be combined in order to increase the S/N. The spectral type suggested by the SED agrees well with the previous estimate of M4.5–M5 by Saffer et al. (1993). Also the line strengths place the object between the M3Ve star 1E2310.4-4949 and KH86’s M5.5 dwarf. In comparison, the CO absorption appears slightly too weak.

**EC 12477-1738:** The spectroscopic characteristics are similar to CC Cet. The stronger Ca I indicates a slightly earlier type, probably closer to M3V than M5.5V, CO appears at about the same strength as in CC Cet.

**EC 13349-3237:** The faintest member of our sample (apart from NN Ser), and this is unfortunately reflected in the low S/N. The spectral type suggested by the SED agrees well with the previous estimate of M4.5–M5 by Saffer et al. (1993). Also the line strengths place the object between the M3Ve star 1E2310.4-4949 and KH86’s M5.5 dwarf. In comparison, the CO absorption appears slightly too weak.

**EC 13349-3237:** The faintest member of our sample (apart from NN Ser), and this is unfortunately reflected in the low S/N. The SED and line strengths both place it somewhere between the KH86’s K5V and M2V, with the clearly detected Mg I λ2.28 μ line pointing to the earlier limit of this range. Worth noting is furthermore the non-detection of the AⅡ λ2.11/2.12 μ lines. These have lesser strength than Mg I only for spectral types earlier than K5V. In contrast, CO bands are clearly visible, although the low S/N impedes a more precise comparison of their strength.

**EC 13471-1258:** O’Donoghue et al. (2003) found that this system is already close to start its CV phase, and estimated its spectral type to M3.5–M4V. The absorption features in our spectrum, comparatively weak Na I, Ca I, and CO, place it close to the M2V star J223315.83-603224.0, although both the 2MASS colours and the K-band SED agree better with the
Fig. 5. Unsmoothed, normalised spectra. Each plot includes four pre-CVs, the three comparison stars, and the four late-type dwarfs from the [Kleinmann & Hall (1986)] catalogue. The individual spectra are vertically displaced by 0.2 units. The sequence roughly corresponds to the estimated spectral type, with the plot at the top containing the earliest, and the one at the bottom the latest. Note that the M2V standard, Gl 411, has a rather low metallicity of $-0.33$ dex ([Bonfils et al. 2005]), resulting in generally weaker absorption features.
former estimate.

**EC 14329-1625:** The spectrum shows great similarities with the M3Ve star 1E2310.4-4949, with the notable exception of the enhanced NaI line.

**LTT 560:** This object is almost a spectroscopic twin to the M5.5 dwarf LP 759-25, with only slightly weaker absorption lines and bands. LTT 560 is a remarkable system in many aspects: it contains the coolest white dwarf in a pre-CV besides RR Cae, and there is evidence for stellar activity and low-level mass transfer, although the secondary star does not fill its Roche lobe (Tappert et al. 2007). Its K-band spectrum, however, does not show any anomalies.

**P83l-57:** NaI and Cal line strengths are similar to the M3Ve star 1E2310.4-4949, while the CO bands resemble more those in the M2 dwarf J223315.83-603224.0. Initial suspicions about photometric variability in the form of a sinusoidal or ellipsoidal light curve (Tappert et al. 2004) could not be confirmed. Since there are a several narrow emission lines detected in the optical spectrum (e.g., Ca H and K, and the Balmer series; Rodgers & Roberts 1994), this object is either a wide, detached, binary with a very active red dwarf, or – somewhat more likely – seen at low orbital inclination. Note also that the 2MASS data indicates a slightly earlier type (M1V) which could be due to irradiation, implying that this system indeed has a hot companion.

**RE 1016-053:** Both SED and the NaI and Cal are very similar to BPM 71214, although the presence of the MgI lines indicates an earlier type. Comparison with the KH86 stars on the basis of the MgI strength with respect to all places the star somewhat later than K5V and somewhat earlier than M2V, in good agreement with Thorstensen et al. (1996), who found M1.5V. The CO bands appear at normal strength, and stronger than in BPM 71214, emphasising their weakness in the latter star.

**RR Cae:** The SED of this star fits best with the M3.5V standards from the L01 library. Bruch & Diaz (1998) find ≥M6V, but this appears unlikely, since the blue part of the spectrum does not show any evidence of the H$_2$O depression that is typical for late M dwarfs. RR Cae contains a very cool white dwarf primary (T$_{WD}$ ≥ 7000 K; Bragaia et al. 1995), so that there are no irradiation effects present that could alter the intrinsic slope of the secondary’s continuum. Both SED and line strengths are similar to UZ Sex, which has been classified as M4V (Safer et al. 1993). Furthermore, a recent study on optical spectra of RR Cae by Maxted et al. (2007) also finds an M4V secondary star, in good agreement with our infrared data. For such spectral type, the CO bands show normal abundances.

**UZ Sex:** As mentioned above, this is probably an M4V star with perfectly normal abundances.

In any case, this potential depletion of CO is not nearly as dramatic as found in certain CVs (Harrison et al. 2004, 2005b). Taking into account the spread of CO line strengths in single late-type dwarfs (Ivanov et al. 2004, their Fig. 9), and also the fact that none of our systems shows any enhancement of $^{13}$CO with respect to $^{12}$CO, we conclude that, at least regarding the CO abundance, all pre-CVs in our sample are consistent with main-sequence stars.

A comparatively large fraction of our targets appears to have abnormally strong NaI absorption (Fig. 3, Table 3). While in three systems (RE 1016-053, BPM 71214, P83l-57) such potential enhancement is unclear due to the uncertainty regarding their spectral type, both CC Cet and especially EC 14329–1625 inhabit a stronger NaI line than any other star in the Ali et al. (1995), Ivanov et al. (2004), and Kleinmann & Hall (1980) catalogues. All these catalogues only include M dwarfs up to ~M5.5, but Cushing et al. (2005) have shown that NaI has maximum strength at ~M6V and diminishes towards later spectral types, disappearing completely around ~L1. The enhanced line in CC Cet and EC 14329–1625 is therefore not due to an erroneous assignment of the spectral type. However, since the uncertainties in the spectral type for the three above mentioned systems are comparatively large, and since the effect in CC Cet is not overly dramatic (Cushing et al. 2005), give $W_{\lambda, NaI} = 7.6 \pm 0.2 \AA$ for the M6V star Gl 406, while CC Cet has $W_{\lambda, NaI} = 7.8 \AA$, it is well possible that this apparent anomaly of a group of pre-CVs melts down to just one peculiar object, EC 14329–1625.

In agreement with previous results, most pre-CV secondary stars in our sample turned out to have spectral types ≥M2V, and therefore will not evolve within Hubble time (e.g. Pols et al. 1998). As discussed in Section 2, we therefore did not expect to be able to confirm scenario 1 (nuclear evolution of the secondary star). The possibility that processed material is accreted by the secondary star during the CE phase has been investigated in detail by Marks & Sarna (1998), who find that such potential accretion can not account for the abundance anomalies observed in CVs, since the accreted material will be stripped from the secondary star during the initial stages of mass-transfer. Our K-band spectra of pre-CVs now show that only a very small amount of CE material, if any, is accreted by the secondary, since it leaves no trace already in comparatively young pre-CVs.

There remain therefore two possibilities for the presence of anomalous CO strengths in certain CVs. Either these systems originate from a very different type of pre-CV (e.g., supersoft binaries; Schenker et al. 2002), or the material was accreted during nova eruptions.

**5. Discussion and conclusion**

With BPM 71214 we find one system in our sample that at first glance appears as a promising candidate for diminished $^{13}$CO. There seem to be certain problems with the reduction for telluric features, as indicated by two unexplained absorption lines at 2.318 $\mu$m and 2.372 $\mu$m (Fig. 5). However, if additional telluric absorption should also affect the CO band, this would result in enhanced absorption, and not in the observed diminished one.

We close this section with the remark that, while we detect $^{13}$CO in all stars in our sample, none of the systems shows it at anomalous strength.
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