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Spectroscopically confirmed brown dwarf members of Coma Berenices and the Hyades

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ABSTRACT

We have obtained low- and medium-resolution spectra of nine brown dwarf candidate members of Coma Berenices and the Hyades using SpEX on the NASA InfraRed Telescope Facility and Long Slit Intermediate Resolution Infrared Spectrograph on the William Herschel Telescope. We conclude that seven of these objects are indeed late M or early L dwarfs, and that two are likely members of Coma Berenices and four of the Hyades. Two objects, cbd40 and Hy3, are suggested to be field L dwarfs, although there is also a possibility that Hy3 is an unresolved binary belonging to the cluster. These objects have masses between 71 and 53$M_{\rm Jup}$, close to the hydrogen-burning boundary for these clusters; however, only an optical detection of lithium can confirm if they are truly substellar.

Key words: brown dwarfs – stars: low-mass – open clusters and associations: individual: Hyades.

1 INTRODUCTION

The Hyades (Melotte 25; RA = 04 26.9, Dec. = +15 52) and Coma Berenices (Melotte 111; RA = 12 23 00, Dec. = +26 00 00, J2000.0) are the closest open star clusters to the Sun at distances of 46.45 ± 0.5 and 86.7 ± 0.9 pc, respectively (van Leeuwen 2009). Both these clusters are relatively mature at 625 ± 50 (Perryman et al. 1998) and ∼500 Myr, and have low reddening values of $E(B-V) < 1.0$ and 3.2 mmag, respectively (Taylor 2006), but this is where the similarities end. The Hyades has been well studied (e.g. Reid 1992; Gizis, Reid & Monet 1999; Dobbie et al. 2002) and contains many members (∼400), whereas Coma Ber has been the subject of relatively few detailed studies and membership is less certain.

One of the reasons Coma Ber is often neglected is that it covers a relatively large region on the sky (∼100 deg^2), while being sparsely populated. A low proper motion (−11.5, −9.5 mas yr^{-1}) also makes kinematic surveys with a baseline of less than 10 yr difficult. We performed a wide-area search for new stellar members in Casewell, Jameson & Dobbie (2006), identifying 60 candidates. A more recent kinematic and photometric survey by Kraus & Hillenbrand (2007) discovered 149 candidate members, of which 98 have a membership probability of >80 per cent, and determined that this survey was complete to 90 per cent between the spectral types of F5 and M6. A search for substellar members was also performed by Casewell, Jameson & Dobbie (2005) who identified 13 new brown dwarf candidates using optical and near-IR photometry. A similar optical photometric survey was performed by Melnikov & Eislöffel (2012) who surveyed 22.5 deg ^{2} and combined *RI* photometry with Two Micron All Sky Survey (2MASS) and UKIRT Infrared Deep Sky Survey (ULIDSS). They discovered 12 new low-mass members down to a spectral type of M6-8. Terrien et al. (2014) also performed a photometric and proper motion survey of the cluster, discovering eight new stellar members, and confirming the membership of six M dwarfs discovered by Kraus & Hillenbrand (2007) by measuring their radial velocity. Mermilliod, Grenon & Mayor (2008) also performed a radial velocity study of 69 solar type stars, 46 of which were candidate cluster members, to search for close, low-mass companions. Of these 46, only 8 stars appear to be cluster members, and 6 additional members were determined to be spectroscopic binaries, suggesting a spectroscopic binary fraction of 22 per cent.

Coma Ber is only estimated to have 145 ± 15 stars earlier than M6 (Kraus & Hillenbrand 2007) and a total mass of 112 ± 16 $M_\odot$ compared to a total mass of 300–460 $M_\odot$ for the Hyades (Reid 1992).

These mature clusters are expected to have undergone some form of mass segregation as part of their dynamical evolution, with some sources suggesting that as many as 50 per cent of the low-mass members being lost with time (de La Fuente Marcos & de La Fuente Marcos 2000). In their large-area study of Coma Ber, Kraus & Hillenbrand (2007) suggest that some mass-loss has occurred, but over a lower mass range than their survey covered. Despite there being clear evidence of mass segregation in Praesepe, a similarly aged cluster, recent surveys have identified many new candidate brown dwarfs (Baker et al. 2010; Boudreault et al. 2012), one of which has recently been spectroscopically confirmed (Boudreault & Lodieu 2013). There are also two known T dwarf members of the Hyades (Bouvier et al. 2008), and Goldman et al. (2013) reports the discovery of 43 new cluster members, many of which are low mass, but are not in the substellar regime. They also suggest that one

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previously known L0 dwarf, 2MASSI J02330155+270406 (Cruz et al. 2007) is also a cluster member.

These open clusters provide excellent laboratories for studying brown dwarfs, mainly due to their coeval nature and known distances, ages and metallicities. Using brown dwarfs found in open clusters as benchmark objects is not new, as evidenced by the many field objects that are discovered, and latter associated with moving groups (e.g. Casewell, Jameson & Burleigh 2008; Jameson et al. 2008). Recent work on the field population has separated brown dwarfs into gravity categories, using the suffixes α, β, γ and δ (Cruz, Kirkpatrick & Burgasser 2009), where α is used to denote a field or 'normal' gravity object, β is used for an intermediate-gravity object (100 Myr), γ a low-gravity object (10–30 Myr) and δ a very low gravity object (1 Myr). At the age of the Hyades and Coma Ber, however, the gravity is high enough to be very similar to, but slightly lower than that of field dwarfs (Chabrier et al. 2000). This does, however, mean that any object with a lower than average gravity can be discounted as a potential cluster member.

We recently performed proper motion and photometric searches of both the Hyades and Coma Ber clusters to discover new substellar candidate members (Casewell et al. 2005; Hogan et al. 2008). These surveys identified 12 new Hyades L dwarf candidates (using the moving group method and near-IR photometry) and 13 new brown dwarf candidates (using optical and near-IR photometry only) in Coma Ber. These objects, if bona fide cluster members, can be used as benchmarks as their age and metallicity are known, and they provide a sample of brown dwarfs with a near, but lower than field gravity. In this paper, we present near-infrared spectra of nine of these candidates.

2 OBSERVATIONS AND DATA REDUCTION

We observed two Coma Ber brown dwarf candidates using SpeX (Rayner et al. 2003) on the 3-m InfraRed Telescope Facility (IRTF) and another two using Long Slit Intermediate Resolution Infrared Spectrograph (LIRIS) on the William Herschel Telescope (WHT) on La Palma. All of the Hyades brown dwarf candidates were observed using LIRIS and the WHT. These were, in general, the brightest of the identified candidate members.

2.1 IRTF

We observed cbd34 and cbd67 (Casewell et al. 2005; Table 1) on the 14-04-2010 in thin cirrus and seeing of 0.5 arcsec with SpeX using the low-resolution prism mode ($R \sim 200$) and the 0.8 arcsec slit. We used an ABBA nod pattern, and used 120 s exposures and 5 nods for cbd34 (600 s) and 180 s exposures and 8 nods for cbd67 (1440 s). The spectra typically have S/N = 40. The data were reduced and telluric corrected using SPEXTOOL (Vacca, Cushing & Rayner 2003; Cushing, Vacca & Rayner 2004).

2.2 WHT

We observed cbd36 and cbd40 (Casewell et al. 2005; Table 1) on 18-03-2006 with LIRIS on the WHT. We used the ZJ grating and the 1 arcsec slit with 300 s second exposures and an ABBA nod pattern. cbd36 was observed for 8 exposures (2400 s) and cbd40 for 6 exposures (1800 s). The seeing was 0.8–1 arcsec and the signal-to-noise (S/N) was 15 for both objects.

The Hyades brown dwarf candidate members Hy1, Hy2, Hy3, Hy4 and Hy6 (Hogan et al. 2008; Table 1) were observed again using LIRIS with the 1 arcsec slit and the ZJ grating ($R \sim 700$) on the 10-12-2009. The exposure times were 300 s and an ABBA nod pattern was used. Hy1 was observed for 8 nods (2400 s), Hy2 for 13 (3900 s), Hy3 for 19 (5700 s), Hy4 for 12 (3600 s) and Hy6 for 8 (2400 s). The seeing was ~1–2 arcsec and the S/N was 15, 12, 23, 14, and 12, respectively.

The LIRIS data were all reduced using the STARLINK packages FIGARO and KAPPA.

3 RESULTS

We compared our reduced SpeX spectra to near-infrared standards from M8 to L4 (VB10: Burgasser et al. 2004; LHS2924: Burgasser & McElwain 2006; DENIS-P J220002.05-202832.98: Burgasser & McElwain 2006; 2MASSW J2130446−084520: Kirkpatrick et al. 2010; Kelu-1: Burgasser et al. 2007; 2MASSW J1506544+132106: Burgasser 2007; 2MASS J21580457−1550098: Kirkpatrick et al. 2010) from the SpeX prism library hosted by Adam Burgasser (http://pono.ucsd.edu/~adam/browndwarfs/spexprism/links.html). DENIS-PJ220002.5-202832.98 is not defined as a standard, but was included to provide a template for the L0 spectral class.

The LIRIS spectra were compared to medium-resolution spectra of M and L dwarfs hosted in the IRTF spectral library maintained by John Rayner (http://irtfweb.ifa.hawaii.edu/~spex/IRTF_Spectral_Library/). From M8 to L3, these objects were: VB10, LHS2924, 2MASS J07464256+2000321AB, 2MASS J14392836+1929149, Kelu-1, 2MASS J15065441+1321060, 2MASS J22244381−0158521 (Cushing, Rayner & Vacca 2005; Rayner, Cushing & Vacca 2009). 2MASS J07464256+2000321AB

Table 1. Names, co-ordinates, near-IR magnitudes and proper motion for the observed objects. The top four objects (cbd) are Coma Ber candidates (magnitudes in MKO)and the remaining objects (Hy) are Hyades candidates (magnitudes from 2MASS).

Name	RA	Dec.	J	H	K	μ_α	μ_δ
	J2000.0					(mas yr^{-1})	
cbd34	12:23:57.37	+24:53:29.0	15.94 ± 0.2	–	14.93 ± 0.2	–	–
cbd36	12:17:10.45	+24:36:07.6	16.28 ± 0.2	–	15.11 ± 0.2	–	–
cbd40	12:16:59.89	+27:20:05.5	16.30 ± 0.2	–	15.14 ± 0.2	–	–
cbd67	12:18:32.71	+27:37:31.3	17.68 ± 0.2	–	16.10 ± 0.2	–	–
Hy1	04:20:24.5	+23:56:13	14.6 ± 0.03	13.85 ± 0.04	13.42 ± 0.04	148 ± 7	−46.41 ± 7
Hy2	03:52:46.3	+21:12:33	15.94 ± 0.09	14.81 ± 0.07	14.26 ± 0.07	114.31 ± 7	−36.95 ± 7
Hy3	04:10:24.0	+14:59:10	15.75 ± 0.07	14.78 ± 0.07	14.17 ± 0.06	102.46 ± 7	−7.86 ± 7
Hy4	04:42:18.6	+17:54:38	15.60 ± 0.06	14.97 ± 0.09	14.23 ± 0.07	82.71 ± 7	−21.25 ± 7
Hy6	04:22:05.2	+13:58:47	15.50 ± 0.06	14.81 ± 0.06	14.25 ± 0.08	99.37 ± 7	−23.48 ± 7

Table 2. Measured rms fits for the Hyades and Coma Ber brown dwarf candidates to the spectral templates. As all the spectra have been normalized to 1, the rms of the fit is also given.

Name	M8	M9	L0.5	L1	L2	L3
cbd34	0.081	0.052	0.068	0.070	0.142	0.142
cbd40	0.248	0.160	0.138	0.136	0.126	0.136
cbd67	0.136	0.093	0.080	0.071	0.092	0.106
Hy1	0.208	0.124	0.113	0.117	0.140	0.160
Hy3	0.240	0.195	0.189	0.187	0.189	0.202
Hy4	0.229	0.163	0.152	0.149	0.159	0.174
Hy6	0.310	0.335	0.355	0.361	0.368	0.387

has a spectral type of L0.5 not L0, as there were no L0 spectra available.

To determine the goodness of fit for the SpeX data, we normalized the spectra to have a value of 1 in the 1.2–1.3 μm region as in Burgasser et al. (2010), cross-correlated the data and model to take into account any velocity shift or error in wavelength calibration and rebinned the spectra on to the model template wavelength range. As the templates were also SpeX prism data, no broadening was required.

We then computed the root mean square (rms) of the residuals to the fit, normalized to the number of points in the spectrum. The same process was used for the LIRIS data, but the normalization region was moved to 1.25–1.3 μm to avoid the K I lines. In this case, the templates were rebinned to data wavelength scale. The SpeX medium-resolution template spectra have $R \sim 2000$, compared to the LIRIS data which has $R \sim 700$. The results are shown in Table 2 and Fig. 1 for the SpeX data and Figs 3 and 4 for the LIRIS data.

In both sets of data, no radial velocity shift has been taken into account; however, the radial velocity of Coma Ber is -1.2 km s^{-1} (van Leeuwen 2009) and the Hyades is 40 km s^{-1} (Perryman et al. 1998). Such velocities are too small to be determined using the resolution of both SpeX and LIRIS.

It was clear from the data on Hy2 that it is not a brown dwarf. It is missing the FeH feature in the *Z* band and the K I doublets in the *J* band. It is shown in Fig. 3 for completeness, but without the template spectra comparison. Similarly, cbd36 is of low S/N but also appears to be missing the alkali lines and FeH feature.

From Fig. 2 and Table 2, it can be seen that cbd67 has a best fit to the L1 template, where cbd34 is best fitted by an M9. cbd40 is best fitted by an L2 template, which is anomalous as it is brighter than cbd67, and so should be of a later spectral type if they are both cluster members (Casewell et al. 2005).

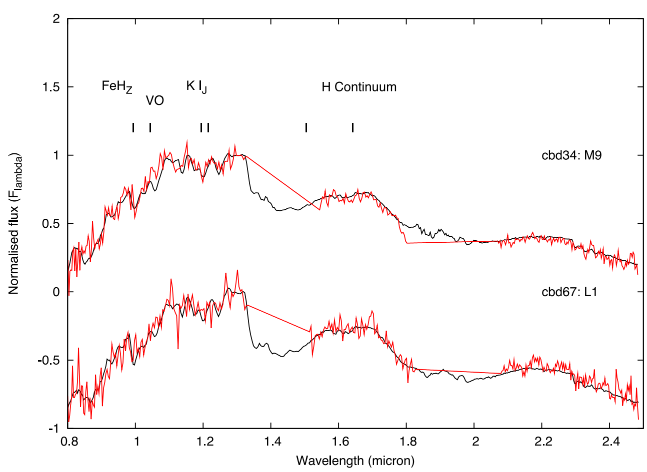

Figure 1. The IRTF spectra (grey line) for cbd67 and cbd34 and their best-fitting templates (red line).

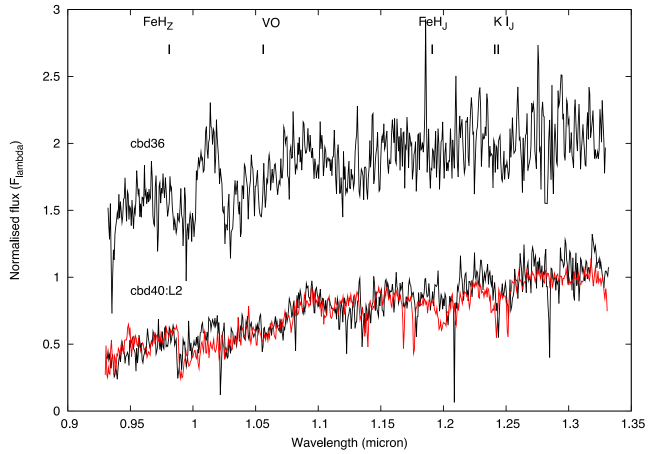

Figure 2. The LIRIS spectra (grey line) for cbd36 and cbd40 and their best-fitting templates (red line). cbd36 is not a brown dwarf and therefore has no template matched to it.

For Hy1, the L0.5 template has the lowest rms, and represents the FeH feature at 0.99 μm well, but the K I and Na I lines are not as deep in Hy1 as in the template, suggesting a spectral type of L0.

For Hy3, the L1 template has the best fit and replicates the shape and the line profiles of the spectra well.

Hy4 is best fitted by the L1 template. Hy6 has the lowest rms and σ^2 for the M8 template, but the spectrum has a low S/N and very little FeH edge in the *Z* band, though the alkali lines are present in the spectrum.

3.1 Spectral indices

We have determined the spectral indices defined in Allers & Liu (2013) for FeH$_Z$ (0.99 μm), VO$_Z$ (1.06 μm), FeH$_J$ (1.20 μm) and KI$_J$ (1.244 and 1.253 μm). For the SpeX data, we also determined the *H*-cont index. We were unable to do this for the LIRIS data as they were taken in the *ZJ* filter and did not extend into the *H* band. Similarly, the FeH$_J$ was only determined for the higher resolution LIRIS data. The indices are shown in Table 3.

FeH$_Z$

cbd34 and Hy1 have an FeH$_Z$ index consistent with the field population as seen in Allers & Liu (2013). cbd40, cbd67 and Hy3 appear to have a much lower gravity score, as do Hy4 and Hy6, although it

Table 3. Measured indices for the Hyades and Coma Ber brown dwarf candidates.

Name	FeH$_Z$	VO$_Z$	FeH$_J$	KI$_J$	*H*-cont
cbd34	1.27 ± 0.06	–	0.88 ± 0.02	1.16 ± 0.06	0.96 ± 0.02
cbd40	1.09 ± 0.06	1.11 ± 0.04	0.92 ± 0.17	1.14 ± 0.03	–
cbd67	1.02 ± 0.16	0.96 ± 0.03	–	1.09 ± 0.01	0.86 ± 0.03
Hy1	1.20 ± 0.04	1.14 ± 0.03	1.18 ± 0.030	1.12 ± 0.03	–
Hy3	1.00 ± 0.06	1.14 ± 0.05	1.37 ± 0.30	1.10 ± 0.05	–
Hy4	1.17 ± 0.05	1.13 ± 0.05	1.31 ± 0.13	1.16 ± 0.03	–
Hy6	1.14 ± 0.12	1.18 ± 0.07	1.75 ± 0.59	1.07 ± 0.08	–

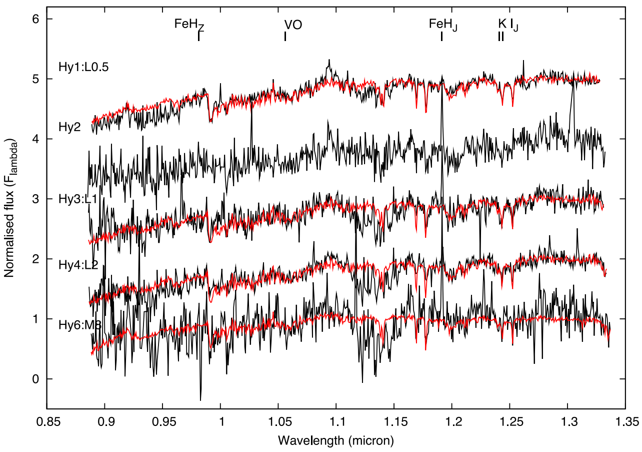

Figure 3. The LIRIS spectra of the Hyades brown dwarf candidates (grey line) and their best-fitting templates (red line). Hy2 is not a brown dwarf.

should be noted that Hy6 has a barely discernible FeH_Z feature in Fig. 3.

VO_Z

The VO_Z index is only applicable to objects with spectral types later than L0 (Allers & Liu 2013), so we have not included cbd34 in this analysis. All other objects except cbd67 have indices which are consistent with their being field objects within the errors on this index. cbd67 has a low value, but not within the low-gravity range. If it were of 0.5 spectral type later, it would be within the normal-gravity range.

KI_J

The KI_J index was measured for all objects and all appear within the field dwarf region. Hy6 appears to have a lower value, which is not surprising as these lines are very weak. However, the large error bar on this measurement still puts it within the field dwarf region.

H-cont

Only cbd34 and cbd67 have an *H*-cont measurement as the LIRIS grating does not cover the *H* band. cbd34 has a slightly low gravity for its spectral type of M9; however, the error bars on the measurement could move it into the field dwarf sequence. cbd67 has a low value, for its spectral type, whereas most young objects have a higher value. A slightly lower gravity than the field measurement is consistent with it being a member of Coma Ber.

3.2 Equivalent width measurements

For the Hyades objects and the higher resolution data from LIRIS, we were also able to measure the equivalent widths (EWs) of the Na I lines at 1.1396 μm and the K I lines at 1.1692, 1.1778, 1.2437 and 1.12529 μm. For this, we fitted the continuum in a window around the line, and Gaussians to the lines themselves (see Table 4). Hy4 and Hy6 (Fig. 3) are of very low S/N and so their measurements have large errors. The 1.1396 μm feature is particularly unreliable for these objects as it is a blended feature in the majority of these spectra.

We were unable to measure the EWs of the Coma Ber objects as the data are of too low S/N.

These EWs were compared to the EWs presented in Cushing et al. (2005), and we used the EW versus spectral type in table 8 and fig. 17 to estimate a spectral type for these objects. The EWs give a spectral type of between M9 and L1 for Hy1, M8 for Hy3, L3 for Hy4 and L3 for Hy6. The EW of the 1.1692 μm line for Hy3 suggests a spectral type of M6, the 1.1252 μm line M8 and the 1.1778 μm line L2. However, the earlier spectral types are inconsistent with the best spectral fit (L1).

When compared to the EWs presented in Allers & Liu (2013) and using the gravity scores from the same work (<0.5 = field dwarf gravity, 1 = intermediate gravity, >1.5 = very low gravity), the K I line measurements at 1.1252 μm show scores of 0 for Hy2 and Hy4, and 1 for Hy3 and Hy6. Hy1 has an anomalously high value. For the K I 1.169 μm line, Hy3 has a low-gravity score of 1, but the error bars overlap the field dwarf region. All the other objects have a gravity score of 0 in line with field dwarfs. For the K I 1.177 μm line, all objects are consistent with having field gravity apart from Hy6, which scores 1. It should be noted, however, that the large error bars on the measurement overlap with the field dwarf region. The Na I 1.138 μm doublet gives scores of 1 for all objects; however, the resolution is not good in this region of the spectrum and the region is being affected by the telluric correction.

4 DISCUSSION

Comparing the EW measurements to the spectral types determined from the spectral fitting, we conclude that Hy1 has a spectral type of L0.5, Hy3 a spectral type between M8 and L0.5 and Hy4 has a spectral type between L2 and L3 (Table 5). Hy6 has a very inconclusive result, having a best-fitting spectral template of M8, yet EW measurements suggesting L2. This is likely due to the low S/N of the data. cbd67 is assigned a spectral type of L1 and cbd34, M9. cbd40 has been assigned a spectral type of L2, although if this is correct, it is unlikely to be a member of Coma Ber, as cbd67 is much fainter (by a magnitude in *J* and *K*). Indeed, comparing the $J - K$ colour for these two objects to the spectral type versus colour relations presented in Knapp et al. (2004), we see that cbd67 with a $J - K$ colour of 1.58 should have a later spectral type (L2-L3) than cbd40 which has a $J - K$ colour of only 1.16 (L0.5) if they are both members of Coma Ber.

The fit of the L0.5 standard to cbd40 is not a good fit. cbd40 has much weaker alkali lines and FeH absorption than the template. As it is clear that cbd40 is a brown dwarf of likely spectral type

Table 4. Measured EWs in nm for the Hyades brown dwarf candidates. The 1.2436 μm line is blended with an FeH feature and so we do not use the EW of this line to determine spectral type.

Name	1.1396 μm	1.1692 μm	1.1778 μm	1.2437 μm	1.1252 μm
Hy1	1.286 ± 0.079	0.552 ± 0.057	1.055 ± 0.067	0.997 ± 0.076	0.917 ± 0.079
Hy3	2.345 ± 0.130	0.385 ± 0.082	0.906 ± 0.094	0.639 ± 0.093	0.449 ± 0.099
Hy4	1.528 ± 0.174	0.971 ± 0.134	1.043 ± 0.134	0.470 ± 0.116	0.639 ± 0.120
Hy6	1.613 ± 0.417	1.153 ± 0.224	0.760 ± 0.201	0.744 ± 0.321	0.812 ± 0.326

Table 5. Spectral types for the Hyades and Coma Ber brown dwarf candidates.

Name	Spectral Type	Comment
cbd34	M9	–
cbd36	–	Not a brown dwarf
cbd40	L2	Field dwarf
cbd67	L1	–
Hy1	L0.5	–
Hy2	–	Not a brown dwarf
Hy3	M8-L0.5	Possible field dwarf/cluster binary
Hy4	L2-L3	–
Hy6	M8-L2	–

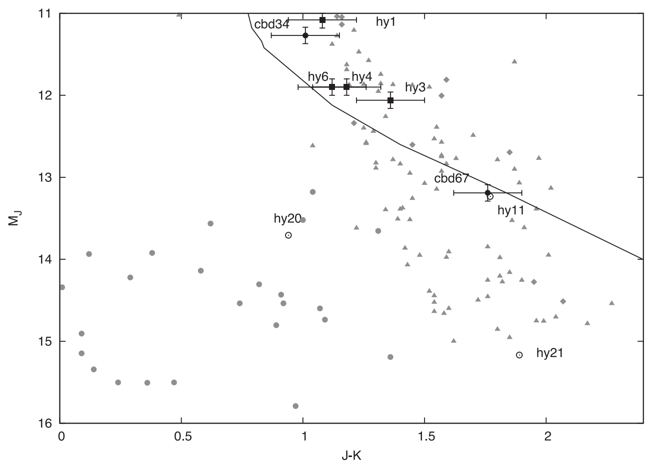

Figure 4. M_J, $J-K$ colour–magnitude diagram for the Hyades candidates (filled squares) and Melotte candidates (filled circles). We have used the cluster distance (85 pc) for the Coma Ber objects, and the kinematic distance given by Hogan et al. (2008) for the Hyads. The Dusty (Chabrier et al. 2000) isochrone for 500 Myr is shown as the solid line. Field L dwarfs (grey filled triangles) and T dwarfs (grey filled circles) from Faherty et al. (2012) are also plotted as well as low-gravity field L and M dwarfs (grey diamonds). The Hyades T dwarfs and Hy11 are plotted as open circles for comparison.

L2, and has gravity appropriate to field objects, we conclude that it is likely to be a foreground field dwarf. As can be seen in Fig. 4, the remaining two objects have similar colours to field dwarfs, and are consistent with the field L dwarf track and the 500 Myr Dusty model. Using the space density for M dwarfs and early L dwarfs from Cruz et al. (2007), we estimate that our original survey (Casewell et al. 2005) should contain one field L dwarf and two field M dwarf contaminants. Our results so far are consistent with this level of contamination. The Coma Ber objects were not selected using proper motion, as there is not a sufficient epoch difference between our Z band data and the UKIDSS Galactic Cluster Survey (Lawrence et al. 2007) data due to the low proper motion of Coma Ber. This is also compounded by the sparsity of objects at this high Galactic latitude ($b = 38°$), making suitable reference stars difficult to find.

Examining the spectral types and magnitudes of the Hyades objects, and using the distance estimates from Hogan et al. (2008), we see that Hy3 is the faintest and reddest source which is not consistent with its spectral type when compared to Hy4 (Fig. 4). Although the photometric errors are large, and will increase if the errors on the distance estimate are taken into account, it seems unlikely that Hy3 could have an earlier spectral type than all the other candidates and belong to the cluster. The fact that it is very red could indicate that it is an unresolved binary as it is close to the equal-mass binary sequence of Bannister & Jameson (2007) in fig. 4 of Hogan et al. (2008); however, no evidence is seen for this in the spectrum. Hy6 is the second brightest object and has an uncertain spectral type – ranging between M8 and L2, probably due to the low S/N of the data.

Table 6. Masses and temperatures for the Hyades and Coma Ber brown dwarf candidates. $T_{\rm eff}$ emp refers to the temperature derived from the empirical relationship in Golimowski et al. (2004) and $T_{\rm eff}$ model refers to the temperature obtained from the Dusty models (Chabrier et al. 2000). Consequently, if an object has a range of spectral types from our analysis, there will be a range of temperatures derived from the empirical model.

Name	Mass ($M_{\rm Jup}$)	$T_{\rm eff}$ emp (K)	$T_{\rm eff}$ model (K)
cbd34	64	2350	2145
cbd67	53	2200	1838
Hy1	71	2250	2310
Hy4	69	2000–2100	2289
Hy6	67	2500–2100	2230

In the Hyades, there are also two known T dwarfs, CFHT-Hy-20 (T2) and CFHT-Hy-21 (T0), which have $J-K$ colours of 0.94 and 1.89 and $J = 17.02$ and 18.48, respectively (Bouvier et al. 2008). One of the 12 L dwarf candidates identified by Hogan et al. (2008), Hy11, had previously been identified as an L3 dwarf (2MASSW J0355419+225702) by Kirkpatrick et al. (1999). The colours of the Hyades candidates presented here are consistent with the spectral types of these objects, and the spectral types of the field objects from L1 to L3 span the gap between Hy4 and Hy6 and the L3 dwarf 2MASSW J0355419+225702 (Hy11).

Hogan et al. (2008) determined that of the 12 L dwarf candidates identified, two were likely to be field dwarf contaminants. Of the five candidates we observed, one (Hy2) is not an L dwarf, and one object, Hy3, may be an equal-mass binary, or may be a field contaminant. This is broadly consistent with the estimated contamination rate.

If these M and L dwarfs are field objects they should have a log$g$ of 5.40 for their masses; however, if they are members of their respective clusters (age ∼ 500 Myr), their gravity should be lower, at 5.24 (Chabrier et al. 2000). The intermediate-gravity ranking with a score of 1 is consistent with these objects having a gravity of near to, but lower than the average field object.

Using the Dusty models of Chabrier et al. (2000), their K magnitudes, cluster distance and $J-K$ colours, we have estimated the masses of these brown dwarf candidates which can be seen in Table 6. Owing to the shape of the brown dwarf sequence, for objects with $M_K > 11$, the temperature has been calculated by interpolating between the $J-K$ values, whereas for the brighter objects that all have similar $J-K$ colours, we used the K magnitude. All objects have masses between 71 and 53$M_{\rm Jup}$, with Hy1 the most massive at 71$M_{\rm Jup}$. cbd67 is the least massive, at 53$M_{\rm Jup}$. It is to be expected that the slightly younger Melotte 111 brown dwarfs are of lower mass for similar spectral types. The Dusty model grid is quite coarse between 70 and 50$M_{\rm Jup}$ and so even adding on an error of 0.1 mag in both J and K does not produce a significant error in mass.

We compared the temperature given by the effective temperature ($T_{\rm eff}$) versus spectral type relationships in Golimowski et al. (2004) to those given by the Dusty models for the respective masses at 500 Myr. The Dusty models (Chabrier et al. 2000) give $T_{\rm eff}$ of

2295 K for a $70M_{\rm Jup}$ object, 2048 K for a $60M_{\rm Jup}$ object and 1751 K for a $50M_{\rm Jup}$ object. These temperatures interpolated to the masses of the objects studied here can be seen in Table 6.

The temperature values derived from the empirical relations in Golimowski et al. (2004) are slightly lower than those provided by the Dusty models, but are broadly consistent. It should be noted here that these mass estimates are consistent with there being a sequence of brown dwarfs in the Hyades, with the two known T dwarfs CFHT-Hy-20 (T2) and CFHT-Hy-21 (T0) having estimated masses of $50M_{\rm Jup}$ (Bouvier et al. 2008).

These masses and effective temperatures indicate that these objects are all very close to the H-burning limit. Therefore, without an optical spectrum and a lithium detection, we are unable to be sure whether these objects are truly brown dwarfs or stars. However, the lack of low-gravity scores for all of these objects indicate that these objects are not young field objects, increasing the likelihood of their being cluster members. These M and L dwarfs are also the remnants of the low-mass star and brown dwarf population in these clusters, and while there are too few of them to make any firm conclusions about the mass functions of these clusters, they can be used as evidence of mass segregation and a history of dynamical evolution that has ejected the low-mass cluster members.

5 CONCLUSIONS

Using near-IR spectra from SpeX on IRTF and LIRIS on the WHT, we have obtained spectra of nine brown dwarf candidate members of the Hyades and Coma Ber. We have rejected cbd36 and Hy2 as brown dwarfs from their spectra. We also reject cbd40 as a member of Coma Ber, and suggest that Hy3 may be a field object or an unresolved binary that is a cluster member. The remaining objects have spectral types ranging from M9 to L2 and masses between 71 and $53M_{\rm Jup}$. Using EWs and the indices defined by Allers & Liu (2013), we have determined that none of these objects have low gravity, which would indicate that they are younger than the clusters they have been identified with, thus supporting their cluster membership. These are the first spectroscopically confirmed L dwarfs in the Hyades cluster and Coma Ber; however, optical spectra containing a lithium detection is required to determine if these objects have a truly substellar nature.

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