Mon. Not. R. Astron. Soc. **000**, 1–8 (2005) Printed 12 December 2008 (MN LaTeX style file v2.2)

Identifying nearby field T dwarfs in the UKIDSS Galactic Clusters Survey ⋆

N. Lodieu[1]†, B. Burningham[2], N. C. Hambly[3], D. J. Pinfield[2]
[1] *Instituto de Astrofísica de Canarias, Vía Láctea s/n, E-38205 La Laguna, Tenerife, Spain*
[2] *Centre for Astrophysics Research, Science and Technology Research Institute, University of Hertfordshire, Hatfield AL10 9AB*
[3] *Scottish Universities' Physics Alliance (SUPA), Institute for Astronomy, School of Physics and Astronomy, University of Edinburgh, Royal Observatory, Blackford Hill, Edinburgh EH9 3HJ, U.K.*

Accepted 12 December 2008. Received 12 December 2008; in original form 12 December 2008

ABSTRACT

We present the discovery of two new late-T dwarfs identified in the UKIRT Infrared Deep Sky Survey (UKIDSS) Galactic Clusters Survey (GCS) Data Release 2 (DR2). These T dwarfs are nearby old T dwarfs along the line of sight to star–forming regions and open clusters targeted by the UKIDSS GCS. They are found towards the α Per cluster and Orion complex,respectively, from a search in 54 square degrees surveyed in five filters. Photometric candidates were picked up in two–colour diagrams, in a very similar manner to candidates extracted from the UKIDSS Large Area Survey (LAS) but taking advantage of the Z filter employed by the GCS. Both candidates exhibit near–infrared J-band spectra with strong methane and water absorption bands characteristic of late–T dwarfs. We derive spectral types of T6.5±0.5 and T7±1 and estimate photometric distances less than 50 pc for UGCS J030013.86+490142.5 and UGCS J053022.52−052447.4, respectively. The space density of T dwarfs found in the GCS seems consistent with discoveries in the larger areal coverage of the UKIDSS Large Area Survey, indicating one T dwarf in 6–11 square degrees. The final area surveyed by the GCS, 1000 square degrees in five passbands, will allow expansion of the LAS search area by 25%, increase the probability of finding ultracool brown dwarfs, and provide optimal estimates of contamination by old field brown dwarfs in deep surveys to identify such objects in open clusters and star–forming regions.

Key words: Stars: brown dwarfs — techniques: photometric — techniques: spectroscopic — Infrared: Stars — surveys

1 INTRODUCTION

The advent of large–scale sky surveys has revolutionised our knowledge of ultracool dwarfs (refered to as dwarfs with spectral types of M7 and later). The first spectroscopic brown dwarfs were confirmed in 1995: Gl229B, a T dwarf orbiting an M dwarf (Nakajima et al. 1995) and Teide 1 in the Pleiades open cluster (Rebolo et al. 1995). More than twenty years later, about 530 L dwarfs with effective temperatures ($T_{\rm eff}$) between ∼2200 and ∼1400 K (Basri et al. 2000; Leggett et al. 2000) have now been identified (as of May 2008), along with around 140 T dwarfs with lower temperatures ($T_{\rm eff} \simeq$ 1400–700 K; Golimowski et al. 2004; Vrba et al. 2004). The full catalogue of L and T dwarfs is available on the DwarfArchives.org webpage[1]. There are currently 63 T5 or later dwarfs at the time of writing, refered to here as late-T dwarfs. The spectral classification of T dwarfs follows the unified scheme by Burgasser et al. (2006a) and is based on the strength of methane and water absorption bands present in the near-infrared. This sample of ultracool dwarfs is now large enough to characterise the binary properties of brown dwarfs (Close et al. 2002; Burgasser et al. 2003; Bouy et al. 2003; Burgasser et al. 2006b; Liu et al. 2006; Burgasser 2007) and investigate the influence of gravity and metallicity on their spectral energy distributions (Kirkpatrick 2005; Jameson et al. 2008b).

The UKIRT Infrared Deep Sky Survey (UKIDSS) is defined in Lawrence et al. (2007). UKIDSS uses the Wide

---

⋆ Based on observations made with the United Kingdom Infrared Telescope, operated by the Joint Astronomy Centre on behalf of the U.K. Science Technology and Facility Council.

† E-mail: nlodieu@iac.es

[1] http://dwarfarchives.org, a webpage dedicated to M, L, and T dwarfs maintained by C. Gelino, D. Kirkpatrick, and A. Burgasser.

Field Camera (WFCAM; Casali et al. 2007) installed on the UK InfraRed Telescope (UKIRT) and a photometric system described in Hewett et al. (2006). The pipeline processing is made at the Cambridge Astronomical Unit (CASU; Irwin et al., in prep)[2] and the data are available from the WFCAM Science Archive (Hambly et al. 2008). The survey is now well underway with several ESO-wide releases: the Early Data Release (EDR) in February 2006 (Dye et al. 2006) and the Data Release 1 (DR1; Warren et al. 2007a) in 2006, the Data Releases 2 & 3 in March and December 2007 (Warren et al. 2007b)[3], and DR4 in July 2008, the latest to date.

The Galactic Cluster Survey (GCS), one of the five components of UKIDSS, will cover 1000 deg^2 in $ZYJHK$ in ten clusters and star–forming regions down to a 5σ sensitivity limit of $K \simeq 18.7$ mag after two epochs at K. The main science goal of the GCS is to derive the very low–mass stellar/substellar mass function in several open clusters and star–forming regions over large areas to investigate the (possible) role of environment and time on the mass function. We have already described the selection procedure of low–mass stars, brown dwarfs, and planetary-mass members of the Upper Sco association (Lodieu et al. 2006, 2007a) and confirmed many photometric candidates as young L dwarf members (Lodieu et al. 2008). Additionally, we have derived the mass function in the Pleiades down to 30 Jupiter masses over 12 square degrees and estimated the photometric brown dwarf binary fraction (Lodieu et al. 2007c).

Although the GCS is not sensitive to young T dwarfs at the distance of the targeted clusters, it is possible to look for nearer, old field T–type dwarfs in a similar manner to the LAS (Kendall et al. 2007; Warren et al. 2007c; Lodieu et al. 2007b; Pinfield et al. 2008; Burningham et al. 2008) which is beneficial both in the context of field and cluster brown dwarf studies. It is a headline science goal of UKIDSS to find the so-called Y dwarfs: current searches have focused on the LAS but ignored the GCS as a ground to uncover field T dwarfs. Ultimately, the GCS will provide an additional 25% coverage in five filters to the 4000 deg^2 planned by the LAS.

In this paper we describe the first search using the GCS DR2 in this context and report the discovery of a T6.5±0.5 and a T7±1 towards α Per and Orion, respectively. In Section 2 we describe the photometric selection of late–T dwarfs from two–colour diagrams. In Section 3 we present the near–infrared spectra for both targets, assign spectral types based on the unified classification scheme by Burgasser et al. (2006a), and derive their main properties. In Section 4 we examine the issue of field dwarf contamination towards young clusters and star–forming regions targeted by the GCS. In Section 5 we discuss future prospects offered by the GCS to extend this preliminary search for field T dwarfs and further constrain levels of field dwarf contamination.

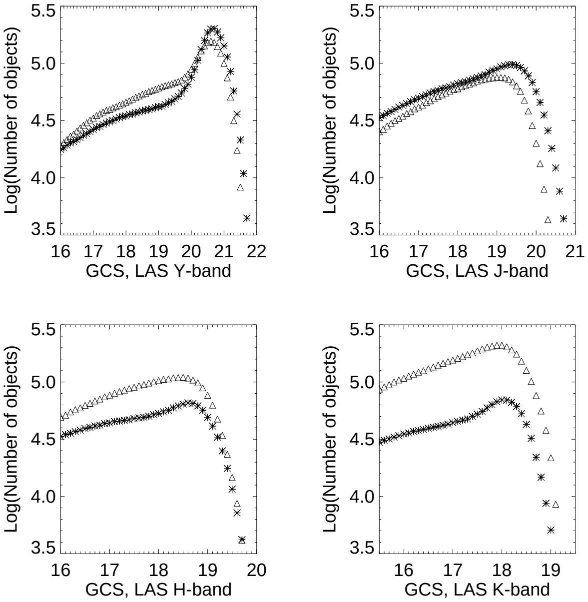

Figure 1. Histograms for the number of objects in the LAS (black) and the GCS (red) per magnitude bin as a function of magnitudes for the Y (top left), J (top right), H (bottom left), and K (bottom right) filters. The 100% completeness limits are quoted in Table 1.

2 SAMPLE SELECTION

2.1 The GCS coverage

The GCS is designed to cover fully 10 open clusters and star–forming regions. The Second Data Release provides coverage in many regions at least in one filter, usually K. However, only 54 square degrees have been surveyed in the Pleiades (8.8 deg^2), α Per (7.6 deg^2), Upper Sco (7.5 deg^2), IC 4665 (4.05 deg^2), Taurus-Auriga (13.3 deg^2), and Orion (13 deg^2) and have been released in DR2. A cross–match between the L and T dwarfs listed in the dwarfarchives.org webpage[1] with the GCS DR2 returned only one source with a spectral type later than T5 (Fig. 2): 2MASS J04070885+1514565 (J = 16.05 mag; T5; Burgasser et al. 2004c) towards the Hyades cluster. This object was only observed in the K-band and thus was not recovered by our search. The number density of T dwarfs (and more generally ultracool dwarfs) varies across the sky (when measured in an aperture of a few degrees radius i.e. the size of a typical cluster). Hence, it is highly desirable to determine the number of such objects towards clusters if one is to accurately account for such contamination in cluster studies. The GCS offers a new opportunity to extend the search for field brown dwarfs towards clusters and star–forming regions to a significantly greater depth than 2MASS.

2.2 LAS/GCS comparison

In addition to the traditional JHK filters and the Y filter centered at 1.03 (0.98–1.08) microns used by the LAS, the GCS also employs a Z filter centered at 0.88 (0.83–0.925) microns. We will take advantage of this filter to select old T dwarfs and effectively replace the z-band filter from the

---

[2] http://casu.ast.cam.ac.uk/surveys-projects/wfcam/technical

[3] DR2 is now a public worldwide release since September 2008

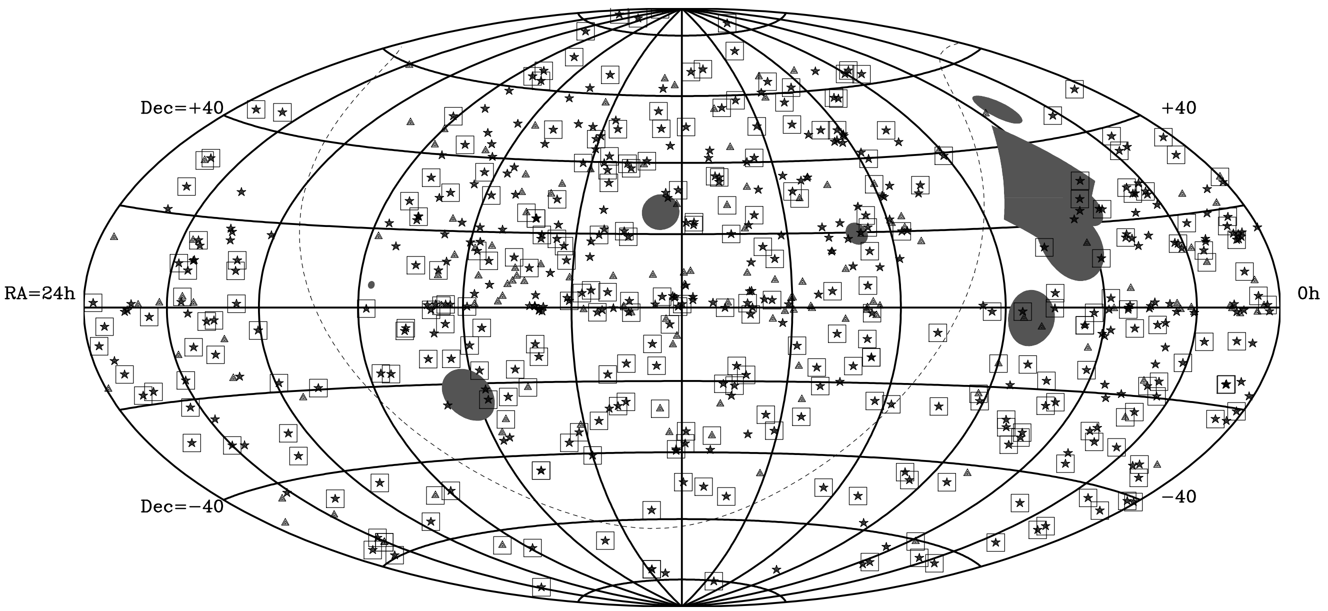

Figure 2. Location of the known L (star symbols) and T (filled triangles) dwarfs listed in the DwarfArchives.org webpage in the sky. Open squares represent the brightest L and T dwarfs with $J \leqslant 15.5$ mag. These objects were essentially identified in 2MASS and SDSS. We have excluded young L dwarfs members of the Pleiades (Martín et al. 1999), σ Orionis (Zapatero Osorio et al. 2000), and Upper Sco (Lodieu et al. 2008) that were identified in deeper surveys. Overplotted are the 10 open clusters and star–forming regions (grey areas) that the GCS will fully cover in five filters after completion of the survey.

Sloan Digital Sky Survey (SDSS) that is used to search for late–T dwarfs in the LAS (e.g. Lodieu et al. 2007b). Note that the GCS exposure times and quality control procedures are the same as those for the LAS for the filters in common. This has been done to enable homogeneous sample selections across both surveys.

We have compared the depth of the Second Data Release of the LAS and GCS (Warren et al. 2007b) for the four common filters ($YJHK$). Figure 1 displays the histograms of the number of objects as a function of magnitude for the LAS and GCS surveys. Completeness limits for the four filters are very similar for both surveys as expected from the similar exposure times although the GCS tends to be slightly shallower (Table 1).

We have also compared the effects of optical-to-infrared colour selection: we used the $(Z-J)_{\rm UKIDSS}$ for the GCS as opposed to the $z_{\rm SDSS} - J_{\rm GCS}$ for the LAS. T dwarfs have typically $z_{\rm SDSS} - J_{\rm GCS}$ redder than 2.6 mag (Hawley et al. 2002) criterion used for searches in the LAS. Hewett et al. (2006) report synthetic colours for T dwarfs of $(Z-J)_{\rm GCS}$ redder than 2.8 mag. Therefore, our colour criteria defined in Sect. 2.3 should pick up all T dwarfs that the LAS criteria would identify. However, the rejection rate of contaminating sources might be lower at the faint end because the $Z_{\rm GCS}$ detection limit is shallower than the $z_{\rm SDSS}$ limit (20.4 mag vs 20.8 mag). sources.

Table 1. Comparison of the depth between the LAS and GCS: the numbers quoted correspond to the point where the number of objects as a function of magnitude deviates from a straight line. Values are given for the 2$^{\rm nd}$ Data Release of the LAS and GCS.

Survey	Y	J	H	K
LAS	20.7	19.4	18.6	18.0
GCS	20.6	18.9	18.3	17.9

2.3 Selection procedure

Figure 1 of Lodieu et al. (2007b) displays a ($Y-J$,$J-H$) two-colour diagram showing the location of spectroscopically confirmed field L and T dwarfs from UKIDSS DR1 (Warren et al. 2007a), along with model predictions (Allard et al. 2001; Marley et al. 2002; Baraffe et al. 2003; Tsuji et al. 2004). T dwarfs exhibit neutral to blue near-infrared colours ($J-H$ or $J-K$) with decreasing effective temperature (Burgasser et al. 2002) and a $Y-J$ colour between 0.7 and 1.3 mag with a possible trend towards a bluer $Y-J$ colour with cooler temperatures (Pinfield et al. 2008). On the other hand, SDSS discoveries (Geballe et al. 2002; Hawley et al. 2002) show that T dwarfs have red optical-to-infrared colours (typically $z-J \geqslant 2.5$). Furthermore, atmosphere models predict blue near-infrared colours ($J-H < 0.0$) for late-T dwarfs and cooler objects (Kirkpatrick et al. 1999). However, their predictions differ on the expected $Y-J$ as a function of temperature with a colour range between 0.5 and 1.5 mag.

We have applied the following selection constraints to look for old field late-T dwarfs in the 54 square degrees surveyed in $ZYJHK$ by the GCS DR2 (Warren et al. 2007b):

- $Y-J \geqslant 0.7$ mag
- $J-H \leqslant -0.2$ mag
- Z non detection or $Z-Y \geqslant 1.7$ mag
- $J = 15.0$–19.6 mag and $H \leqslant 19.2$ mag
- Point sources i.e. `mergedClass`[2] $= -1$

Table 2. Coordinates (J2000), infrared magnitudes ($YJHK$) on the WFCAM MKO system with their associated errors taken from the Second Data Release of the GCS (Warren et al. 2007b), spectral types with uncertainties, and estimated photometric distances for both T dwarfs identified in the UKIDSS GCS and confirmed spectroscopically with Gemini/NIRI.

Name	RA	dec	Y	J	H	K	SpType	dist
UGCS J030013.86+490142.5	03 00 13.86	+49 01 42.5	18.99±0.07	17.99±0.04	18.37±0.16	>18.2	T6.5±0.5	20–46 pc
UGCS J053022.52−052447.4	05 30 22.52	−05 24 47.4	19.45±0.12	18.35±0.07	19.13±0.29	>18.2	T7.0±1.0	19–42 pc

- Good quality detections i.e. `ppErrBits`[4] $\leqslant 256$

The query returned three potential late–T dwarfs and we present here J–band spectroscopy for two of them (Table 2; Figs. 3 & 4), UGCS J030013.86+490142.5 (hereafter UGCS0300) and UGCS J053022.52−052447.4 (UGCS0530). We note that no bright sources detected in Z and satisfying $Z-Y \geqslant 1.7$ mag were identified.

3 PROPERTIES OF THE NEW T DWARFS

3.1 Gemini/NIRI spectroscopy

Spectroscopy in the J-band was obtained using the Near InfraRed Imager and Spectrometer (NIRI; Hodapp et al. 2003) on the Gemini North Telescope on Mauna Kea under program GN-2007B-Q-26. UGCS0300 was observed on the night of 2007 December 23, and UGCS0530 was observed on the night of 2008 January 04. All observations were made up of a set of sub-exposures in an ABBA jitter pattern to facilitate effective background subtraction, with a slit width of 1 arcsec. The length of the A-B jitter was 10 arcsecs. The total integration time for UGCS0300 was 16 minutes, whilst for UGCS0530 it was 32 minutes. The observations were reduced using standard IRAF Gemini packages (Lodieu et al. 2007b; Pinfield et al. 2008).

A comparison argon arc frame was used to obtain a dispersion solution, which was then applied to the pixel coordinates in the dispersion direction on the images. The resulting wavelength-calibrated subtracted pairs had a low-level of residual sky emission removed by fitting and subtracting this emission with a set of polynomial functions fit to each pixel row perpendicular to the dispersion direction, and considering pixel data on either side of the target spectrum only. The spectra were then extracted using a linear aperture, and cosmic rays and bad pixels removed using a sigma–clipping algorithm.

Telluric correction was achieved by dividing each extracted target spectrum by that of an F type star observed just before or after the target and at a similar airmass. Prior to division, hydrogen lines were removed from the standard star spectrum by interpolating the stellar continuum. Relative flux calibration was then achieved by multiplying through by a blackbody spectrum of the appropriate $T_{\rm eff}$. The spectra were then rebinned by a factor of three to increase the signal-to-noise, whilst avoiding under-sampling for the spectral resolution. final spectra are shown in Fig. 4.

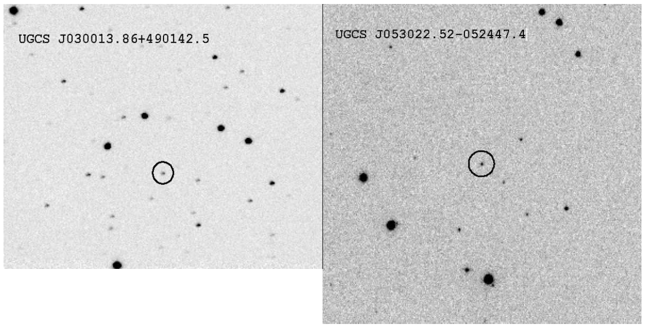

Figure 3. Finding charts for the two new nearby old T dwarfs extracted from the UKIDSS GCS DR2: UGCS0300 (left) and UGCS0530 (right). Finding charts are J-band images of 2 arcmin on a side with North up and East left.

3.2 Spectral classification

Figure 4 compares the spectra for UGCS0300 and UGCS0530 with three spectral standards: SDSSp J162414.37+002915.6 (T6; Strauss et al. 1999), 2MASSI J0727182+171001 (T7) and 2MASSI J0415195−093506 (T8; Burgasser et al. 2002, 2006a). Although the Y-band peak appears to be enhanced in UGCS0300 with respect to the spectral type standards, this comparison suggests a spectral type of T6.5 (Fig. 4). The calculated spectral indices on the system of Burgasser et al. (2006a) and Burningham et al. (2008) are given in Table 3. These tend to support the spectral type implied by template comparison, and we adopt a spectral type of T6.5±0.5 for UGCS0300.

The template comparison across most of the spectral coverage suggests a T7 classification for UGCS0530. The red side of the J-band peak, however, is at odds with this, appearing brighter and reminiscient of an earlier type. The calculated spectral indices in Table 3 (CH_4–J index) reflect this morphology. Considering the low signal of the spectrum in this region, we choose to disregard it in this classification, pending higher signal-to-noise observations with broader coverage at a later date. We adopt a type of T7±1 for UGCS0530.

3.3 Distances of the new T dwarfs

We have identified two T dwarfs with spectral types later than T5 in 54 square degrees surveyed in all five filters by the GCS DR2. Those numbers are consistent with the eight late-T dwarfs found in the LAS DR2 over 282 square degrees surveyed in $YJHK$ and satisfying the criteria described in Sect. 2. Since these are field T dwarfs and not cluster T dwarfs, we can simply estimate their photometric distances

---

[4] Definitions of these parameters can be found in the web pages of the WFCAM Science Archive

Table 3. Spectral types for UGCS0300 and UGCS0530 derived from direct comparison with template T dwarfs, and several spectral indices defined in the literature.

Indicator	UGCS0300	UGCS0530
Template	T6.5±0.5	T7±1
H_2O–J	0.145±0.015 (T6)	0.108±0.018 (T7)
CH_4–J	0.212±0.014 (T7)	0.537±0.017 (T3)
W_J	0.39±0.01 (T7/T6)	0.40±0.01 (T6/T7)
Adopted type	T6.5±0.5	T7±1

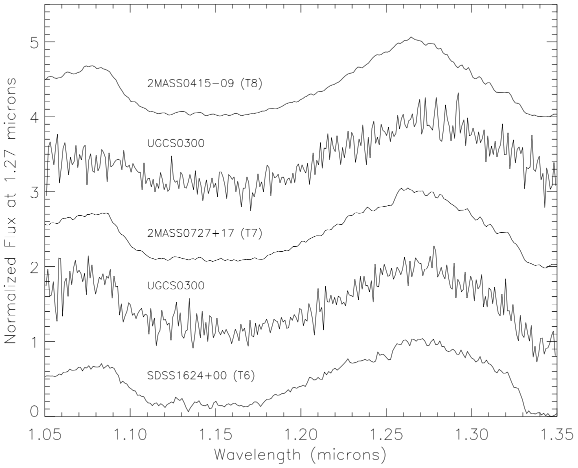

Figure 4. Gemini/NIRI J-band (1.05–1.35 microns) spectra (binned by a factor three) of two new T dwarfs identified in the UKIDSS GCS (UGCS0300 and UGS0530). Overplotted are spectral templates for direct comparison, including SDSSp J162414.37+002915.6 (T6; Strauss et al. 1999), 2MASSI J0727182+171001 (T7), and 2MASSI J0415195−093506 (T8; Burgasser et al. 2002, 2006a).

by comparison with known T dwarfs with measured parallaxes (Fig. 5; Vrba et al. 2004; Tinney et al. 2003).

There are three known T6.5 dwarfs (infrared spectral types based on the classification of Burgasser et al. (2006a)) listed in the brown dwarf archive with measured parallaxes and not part of a binary system: 2MASSI J104753.8+212423 (J = 15.819 mag and d = 10.6 pc), 2MASSI J123739.2+652614 (J = 16.053 mag and d = 10.4 pc; Burgasser et al. 1999; Vrba et al. 2004), and SDSSp J134646.4−003150 (J = 16.0 mag and d = 14.6 pc; Tsvetanov et al. 2000; Tinney et al. 2003). Assuming a spectral type of T6.5 for UGCS0300 and assuming that the object is single, we derive an average distance of 30 pc with a possible range of 25–37 pc (1σ limits). We estimate an error on the distance of ∼10 pc assuming a dispersion of ±0.5 mag on the spectral type-absolute magnitude relation, yielding an expected distance interval of 20 to 46 pc.

Similarly, only one T dwarf with measured parallax has a spectral type of T7 (Burgasser et al. 2006a), 2MASSI J072718.2+171001 (J = 15.6 mag and d = 9.08 pc; Burgasser et al. 2002; Vrba et al. 2004). Assuming a spectral type of T7 for UGCS0530 and assuming that the object is single, we derive a distance of 32 pc. We estimate an error on the distance of ∼13 pc, mainly due to the uncertainty on the spectral type (±1 subclass).

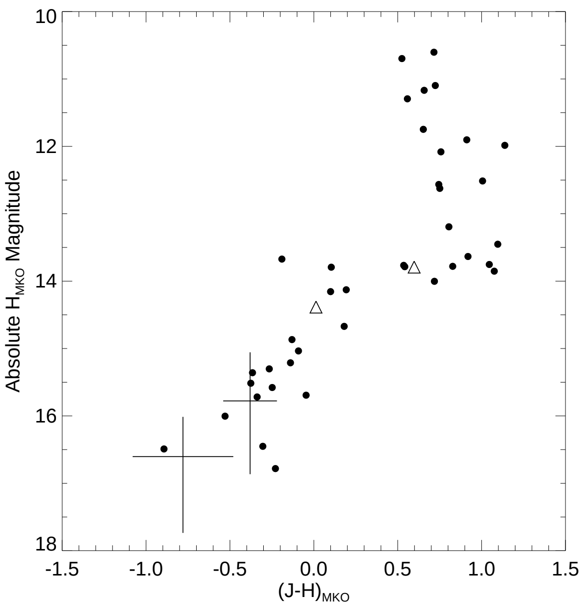

Figure 5. $J-H$ colour as a function of absolute H magnitude in the MKO system. The two new T dwarfs identified in the GCS are marked with crosses representing the errors in the colours and distance estimates. For comparison, we have also plotted two Pleiades T dwarfs candidates (not confirmed spectroscopically yet) as open triangles (Casewell et al. 2007).

3.4 Cluster membership

Since the primary aim of the GCS is to test the universality of the substellar Initial Mass Function (IMF; Salpeter 1955), its emphasis is on achieving full spatial coverage of several young clusters and star–forming regions, rather than achieving the required depth to identify very faint T dwarfs within them. We have recently demonstrated that the coolest brown dwarf candidates identified in Upper Sco are early-L dwarfs (Lodieu et al. 2008). Much deeper, but smaller area, surveys of the Pleiades (Casewell et al. 2007) and σOri (Zapatero Osorio et al. 2000, 2002; Martín & Osorio 2003; Burgasser et al. 2004b; Zapatero Osorio et al. 2008) have been able to extract candidate T dwarf members.

Figure 5 compares the colours of UGCS0300 and UGCS0530 with those of known single T dwarfs extracted from the L and T dwarfs archive[1] in the Mauna Kea Observatory system (MKO; Tokunaga et al. 2002). Both objects lie in the sequence of late-T dwarfs and do not show obvious sign of peculiar colours that could indicate a young age (Casewell et al. 2007; Zapatero Osorio et al. 2008). The errors, represented by large crosses in Fig. 5 come from the uncertainty on the colour (GCS photomery) and from the uncertainty on the distance estimates (see Section 3.3).

Additionally, we have looked into the expected number of late-T dwarfs from the simulations published by Caballero et al. (2008). These authors used a “standard” model for the Galaxy and compiled available data on late-

Table 4. Expected numbers of T dwarf (T0–T8.5) contaminants (second lines) as a function of areal coverage in square degrees (first lines) in each individual young cluster and star–forming region targeted by the UKIDSS Galactic Cluster Survey. We have also included the expected numbers of late-T dwarfs in 2MASS (2M), assuming a search complete to J = 15.65 mag.

	Total	Pleiades	α Per	IC 4665	USco	Coma Ber	Praesepe	Taurus	Hyades	Orion	Per OB
2M	1000	79	50	4	154	79	28	218	291	154	13
	0.9–1.5	0.07–0.12	0.04–0.08	<0.01	0.14–0.24	0.07–0.12	0.02–0.04	0.20–0.33	0.26–0.45	0.14–0.24	0.01–0.02
DR2	54	8.81	7.60	4.05	7.46	0	0	13.3	0	13.0	0
	5–9	0.8–1.4	0.7–1.2	0.4–0.	0.7–1.2	0	0	1.2–2.1	0	1.2–2.0	0
Full	1000	79	50	4	154	79	28	218	291	154	13
	93–157	7.3–12.4	4.6–7.9	0.4–0.6	14.3–24.2	7.3–12.4	2.6–4.4	20.2–34.2	27.0–45.7	14.3–24.2	1.2–2.1

type dwarfs to estimate their absolute magnitudes, colours, space densities, and scale heights. For late-T dwarfs, they used a space density of 1–5$\times10^{-3}$ pc^{-3} based on a mass function defined by dN/dM$\propto$M$^{-0.5}$ and a normalisation factor of 0.0037 pc^{-3} over the 0.09–0.10 M$_\odot$ mass range (Reid et al. 1997; Deacon et al. 2008). We have assumed that late-T dwarfs have typical $I - J$ colours around 5 mag and that our search is complete down to J = 19 mag (Sect. 2.3). Following Table 4 of Caballero et al. (2008), we have found that the number of T5–T8 dwarfs in 54 square degrees range from 4.6 to 23 with a most probable value of nine. Our GCS search contains a few additional potential T dwarfs not yet confirmed spectroscopically, suggesting that our results are most likely consistent with the lowest numbers predicted by Caballero et al. (2008). The difference between our numbers and the ones in Caballero et al. (2008) might originate from one of the assumptions on the properties (binary fraction, mass ratio distribution, number density) of late-T dwarfs made by Caballero et al. (2008) or on the selected mass function. However, one would need to test the level of influence that each (assumed) parameters has on the final numbers quoted by Caballero et al. (2008) to provide a statistical interpretation on the observed difference. Note that testing the birth rate would require a significantly larger number of T dwarfs, not yet available from UKIDSS (Deacon et al. 2008).

Larger areas will become available in upcoming GCS releases and should allow us to constrain further the level of contamination by late-T dwarfs towards clusters.

4 CONTAMINATION TOWARDS CLUSTERS

We have confirmed spectroscopically two late-T dwarfs with $Y - J \geqslant 0.7$ mag, $J - H \leqslant -0.2$ mag, and $H \leqslant 19.2$ mag (Sect. 2.3). These numbers are consistent with the number of late-T dwarfs identified in the LAS (Pinfield et al. 2008) based on a larger sample and greater areal coverage. In total, Pinfield et al. (2008) estimated to 26–44 T0–T8.5 dwarfs in 280 square degrees taking into account biases due to incompleteness and binarity, implying one T0–T8 dwarf per 6–11 deg^2 or 1.5 late-T dwarf ($\geqslant$ T4) in 54 deg^2. We can apply these values to the GCS because the LAS and the GCS share the same design (Lawrence et al. 2007) and have comparable completeness limits (Sect. 2.2; Table 1; Warren et al. 2007b).

These new T dwarfs lie towards α Per, located at a distance of 180 pc (Pinsonneault et al. 1998; Robichon et al. 1999) and along the line of sight of Orion ($\sim$480 pc; Genzel et al. 1981). They were identified in 7.6 and 13 deg^2 coverage in α Per and Orion, respectively. Those numbers match well the one T dwarf expected in 6–11 deg^2 of the LAS. Considering the area covered in Taurus, the Pleiades, and Upper Sco, which are on the same order as the ones surveyed in α Per and Orion, we should have found one T dwarf along their line of sight. However, this lack of detection likely originates from our stringent constraints (Sect. 2.3) because neither late-T dwarfs with redder $J - H$ colours nor early-T dwarfs are considered by our search.

Table 4 shows the expected numbers of T dwarfs (T0–T8.5) in the area surveyed in each regions and released in the GCS DR2 as well as those expected after completion of the GCS. The latter values are approximate due to unpredictable factors that could affect the survey (e.g., quality control). Those numbers are also compared to the expected numbers of T dwarfs in each regions, assuming a coverage equivalent to the one after completion of the GCS. Additionally, we have assumed a 5σ completeness limit of J = 16.55 and H = 15.85 for 2MASS (Cutri et al. 2003), corresponding to J 15.65 mag to match our search criteria (Sect. 2.3). Repeating this exercise for L dwarfs based on known absolute magnitudes and densities (Vrba et al. 2004; Caballero et al. 2008), we should expect around 380 L0–L8 dwarfs in the full 2MASS database. The GCS should provide 100 times more L and T dwarfs, hence decreasing the uncertainty on estimates of the level of contamination.

More specifically, the Pleiades survey described in Lodieu et al. (2007c), covering 12 square degrees would contain one T dwarf contaminant down to its completeness limit of J = 18.9 mag. Similarly, Casewell et al. (2007) reported four T dwarf candidates in a 2.5 deg^2 area down to a completeness limit of J = 19.7 mag. Scaling the numbers derived above, we argue that $\sim$1 of their candidates could be a field T dwarf rather than a cluster T dwarf of 10 Jupiter masses.

Finally, we can compare our results to the simulations presented by Caballero et al. (2008). Their work is based on a galactic model and uses the most recent data available for field L and T dwarfs. Assuming a mean $I - J$ colour of 5 for T0–T8 dwarfs (their Table 3) and comparing the ΔI magnitude range given in their Table 4, the GCs is able to find T dwarfs down to I = 24 mag. Adding up all the numbers, Caballero et al. (2008) calculated 0.218–0.823 T0–T8 dwarfs down to I = 24 mag (or $J \sim 19$ mag) in one square degree, indicating a total of 1–8 T0–T8 dwarfs in 6–11 deg^2. Their lower limit is consistent with our observational results whereas their upper limits seem to overestimate significantly the expected number of T dwarf contaminants.

5 FUTURE PROSPECTS

Our results, combined with our previous published studies in the LAS, show that the GCS is not only powerful in identifying young low–mass stars and brown dwarfs in clusters but also in finding nearby old late–T dwarfs in the field. Also, thanks to its large coverage, the GCS constitutes a tool to constrain observationally the level of contamination at the faint end of the cluster mass functions. Besides the natural extension of this work to upcoming UKIDSS releases and ultimately the full GCS, this work opens several advantages:

- Extend the search area of the LAS by 25%, expand the sample of late–T dwarfs, and increase the chance to find Y dwarfs, one of the UKIDSS main science objectives. The LAS will cover 4000 square degrees in $YJHK$ while the GCS will survey 1000 square degrees in the same set of filters with an additional Z passband acting as a proxy for the SDSS z filter. Moreover, the contamination by young T dwarfs members of open clusters should be negligible since the GCS is not sensitive to detect such cool, dim brown dwarfs at the distance of the various clusters/star–formation regions targeted by the GCS (Sect. 3.4).
- Pin down the level of contamination towards open clusters and star–forming regions where L and T dwarfs are now found with a wide range of ages: Upper Sco (Lodieu et al. 2008), σ Orionis (Zapatero Osorio et al. 2000; Caballero et al. 2007), Alpha Per (Jameson et al. 2008b), the Pleiades (Bihain et al. 2006; Lodieu et al. 2007c; Casewell et al. 2007), Ursa Major and Hyades (Jameson et al. 2008a). Those numbers will likely grow quickly in the coming years with the advent of deeper and larger-scale sky surveys, including VISTA (Visible and Infrared Survey Telescope for Astronomy), PanStarrs, and the LSST (Large Synoptic Survey Telescope).
- Expand the current search to field L dwarfs to provide an estimate of the level of contamination in deep surveys targeting open clusters and star–forming regions (references therein). This search will be affected by the presence of young L dwarfs belonging to the clusters targeted by the GCS because the $Y-J$ and $J-K$ colours get redder with younger ages (Jameson et al. 2008b).

6 CONCLUSIONS

We have presented the spectroscopic confirmation of two new nearby old late–T dwarfs identified in 54 square degrees surveyed as part of the Second Data Release of the UKIDSS Galactic Cluster Survey. Those sources lie in front the Alpha Per cluster and Orion complex at distances less than 50 pc. These sources have been identified in regions previously ignored by earlier searches for cool brown dwarfs.

This work opens new prospects to (i) extend the search area of the UKIDSS LAS and increase the number of late–T dwarfs by 25%, and (ii) estimate the contamination in deep optical and near–infrared surveys of young open clusters and star–forming regions by nearby old L and T dwarfs and thereof correct the faint end of the photometric mass functions.

ACKNOWLEDGMENTS

This research has made use of the Simbad database of NASA's Astrophysics Data System Bibliographic Services (ADS), and has benefitted from the M, L, and T dwarf compendium housed at DwarfArchives.org and maintained by Chris Gelino, Davy Kirkpatrick, and Adam Burgasser.

The United Kingdom Infrared Telescope is operated by the Joint Astronomy Centre on behalf of the U.K. Science and Technology Facilities Council.

Based on observations obtained at the Gemini Observatory (program GN–2007B–Q–26), which is operated by the Association of Universities for Research in Astronomy, Inc., under a cooperative agreement with the NSF on behalf of the Gemini partnership: the National Science Foundation (United States), the Science Technology and Facility Council (United Kingdom), the National Research Council (Canada), CONICYT (Chile), the Australian Research Council (Australia), CNPq (Brazil) and SECYT (Argentina).

REFERENCES

Allard F., Hauschildt P. H., Alexander D. R., Tamanai A., Schweitzer A., 2001, ApJ, 556, 357

Baraffe I., Chabrier G., Barman T. S., Allard F., Hauschildt P. H., 2003, A&A, 402, 701

Basri G., Mohanty S., Allard F., Hauschildt P. H., Delfosse X., Martín E. L., Forveille T., Goldman B., 2000, ApJ, 538, 363

Bihain G., Rebolo R., Béjar V. J. S., Caballero J. A., Bailer-Jones C. A. L., Mundt R., Acosta-Pulido J. A., Manchado Torres A., 2006, A&A, 458, 805

Bouy H., Brandner W., Martín E. L., Delfosse X., Allard F., Basri G., 2003, AJ, 126, 1526

Burgasser A. J., 2007, ApJ, 658, 617

Burgasser A. J., Geballe T. R., Leggett S. K., Kirkpatrick J. D., Golimowski D. A., 2006a, ApJ, 637, 1067

Burgasser A. J., et al. 2002, ApJ, 564, 421

Burgasser A. J., et al. 1999, ApJL, 522, L65

Burgasser A. J., Kirkpatrick J. D., Cruz K. L., Reid I. N., Leggett S. K., Liebert J., Burrows A., Brown M. E., 2006b, ApJS, 166, 585

Burgasser A. J., Kirkpatrick J. D., McGovern M. R., McLean I. S., Prato L., Reid I. N., 2004, ApJ, 604, 827

Burgasser A. J., Kirkpatrick J. D., Reid I. N., Brown M. E., Miskey C. L., Gizis J. E., 2003, ApJ, 586, 512

Burgasser A. J., McElwain M. W., Kirkpatrick J. D., Cruz K. L., Tinney C. G., Reid I. N., 2004, AJ, 127, 2856

Burningham B., et al. 2008, arXiv0806.0067

Caballero J. A., et al. 2007, A&A, 470, 903

Caballero J. A., Burgasser A. J., Klement R., 2008, A&A, 488, 181

Casali M., et al. 2007, A&A, 467, 777

Casewell S. L., Dobbie P. D., Hodgkin S. T., Moraux E., Jameson R. F., Hambly N. C., Irwin J., Lodieu N., 2007, MNRAS, 378, 1131

Close L. M., Siegler N., Potter D., Brandner W., Liebert J., 2002, ApJL, 567, L53

Cutri R. M., et al. 2003, 2MASS All Sky Catalog of point sources, 2246

Deacon N. R., Nelemans G., Hambly N. C., 2008, A&A, 486, 283

Dye S., et al. 2006, MNRAS, 372, 1227

Geballe T. R., et al. 2002, ApJ, 564, 466

Genzel R., Reid M. J., Moran J. M., Downes D., 1981, ApJ, 244, 884

Golimowski D. A., et al. 2004, AJ, 127, 3516

Hambly N. C., et al. 2008, MNRAS, 384, 637

Hawley S. L., et al. 2002, AJ, 123, 3409

Hewett P. C., Warren S. J., Leggett S. K., Hodgkin S. T., 2006, MNRAS, 367, 454

Hodapp K. W., et al. 2003, PASP, 115, 1388

Jameson R. F., Casewell S. L., Bannister N. P., Lodieu N., Keresztes K., Dobbie P. D., Hodgkin S. T., 2008a, MNRAS, 384, 1399

Jameson R. F., Lodieu N., Casewell S. L., Bannister N. P., Dobbie P. D., 2008b, MNRAS, 385, 1771

Kendall T. R., et al. 2007, A&A, 466, 1059

Kirkpatrick J. D., 2005, ARA&A, 43, 195

Kirkpatrick J. D., et al. 1999, ApJ, 519, 802

Lawrence A., et al. 2007, MNRAS, 379, 1599

Leggett S. K., et al. 2000, ApJL, 536, L35

Liu M. C., Leggett S. K., Golimowski D. A., Chiu K., Fan X., Geballe T. R., Schneider D. P., Brinkmann J., 2006, ApJ, 647, 1393

Lodieu N., Dobbie P. D., Deacon N. R., Hodgkin S. T., Hambly N. C., Jameson R. F., 2007c, MNRAS, 380, 712

Lodieu N., Hambly N. C., Jameson R. F., 2006, MNRAS, 373, 95

Lodieu N., Hambly N. C., Jameson R. F., Hodgkin S. T., 2008, MNRAS, 383, 1385

Lodieu N., Hambly N. C., Jameson R. F., Hodgkin S. T., Carraro G., Kendall T. R., 2007a, MNRAS, 374, 372

Lodieu N., et al. 2007b, MNRAS, 379, 1423

Marley M. S., Seager S., Saumon D., Lodders K., Ackerman A. S., Freedman R. S., Fan X., 2002, ApJ, 568, 335

Martín E. L., Basri G., Zapatero Osorio M. R., 1999, AJ, 118, 1005

Martín E. L., Osorio M. R. Z., 2003, ApJL, 593, L113

Nakajima T., Oppenheimer B. R., Kulkarni S. R., Golimowski D. A., Matthews K., Durrance S. T., 1995, Nat, 378, 463

Pinfield D. J., et al. 2008, MNRAS, 390, 304

Pinsonneault M. H., Stauffer J., Soderblom D. R., King J. R., Hanson R. B., 1998, ApJ, 504, 170

Preibisch T., Guenther E., Zinnecker H., 2001, AJ, 121, 1040

Preibisch T., Zinnecker H., 1999, AJ, 117, 2381

Rebolo R., Zapatero-Osorio M. R., Martín E. L., 1995, Nat, 377, 129

Reid I. N., et al. 1997, PASP, 109, 559

Robichon N., Arenou F., Mermilliod J.-C., Turon C., 1999, A&A, 345, 471

Salpeter E. E., 1955, ApJ, 121, 161

Strauss M. A., et al. 1999, ApJL, 522, L61

Tinney C. G., Burgasser A. J., Kirkpatrick J. D., 2003, AJ, 126, 975

Tokunaga A. T., Simons D. A., Vacca W. D., 2002, PASP, 114, 180

Tsuji T., Nakajima T., Yanagisawa K., 2004, ApJ, 607, 511

Tsvetanov Z. I.,et al. 2000, ApJL, 531, L61

Vrba F. J., et al. 2004, AJ, 127, 2948

Warren S. J., et al. 2007b, astro-ph/0703037

Warren S. J., et al. 2007a, MNRAS, 375, 213

Warren S. J., Mortlock D. J., Leggett S. K., Pinfield D. J., Homeier D., 19 co-authors 2007, MNRAS, 375, 213

Zapatero Osorio M. R., Béjar V. J. S., Martín E. L., Rebolo R., Barrado y Navascués D., Bailer-Jones C. A. L., Mundt R., 2000, Science, 290, 103

Zapatero Osorio M. R., Béjar V. J. S., Martín E. L., Rebolo R., Barrado y Navascués D., Mundt R., Eislöffel J., Caballero J. A., 2002, ApJ, 578, 536

Zapatero Osorio M. R., et al. 2008, A&A, 477, 895