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Letter to the Editor

Two very nearby ($d \sim 5$ pc) ultracool brown dwarfs detected by their large proper motions from WISE, 2MASS, and SDSS data*

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ABSTRACT

Aims. WISE provides an infrared all-sky survey that aims at completing our knowledge on the possibly dramatically increasing number of brown dwarfs with lower temperatures. We search for the nearest representatives of the coolest brown dwarfs, which will be very interesting for detailed follow-up observations, once they have been discovered.

Methods. We used the preliminary data release from WISE, then selected bright candidates with colours typical of late-T dwarfs, and tried to match them with faint 2MASS and SDSS objects, to determine their proper motions, and to follow them up spectroscopically.

Results. We have identified two new ultracool brown dwarfs with large proper motions, WISE J0254+0223 (2.5 arcsec/yr) and WISE J1741+2553 (1.5 arcsec/yr). With their $w1-w2 \sim 3.0$ and $J-w2 \sim 4.0$ colour indices, we expect both to have spectral types of ~T8-T10 and absolute magnitude of $M_{w2} \sim 14$. We confirm WISE J1741+2553 as a T9-T10 dwarf from near-infrared spectroscopy with LBT/LUCIFER1. From their bright WISE $w2$ magnitudes of 12.7 and 12.3, we estimate distances of $5.5^{+2.3}_{-1.6}$ pc and $4.6^{+1.2}_{-1.0}$ pc and tangential velocities of ~65 km s^{-1} and ~34 km s^{-1} that indicate Galactic thick and thin disk membership, respectively.

Key words. astrometry – proper motions – stars: distances – stars: kinematics and dynamics – brown dwarfs – solar neighborhood

1. Introduction

The Wide-field Infrared Survey Explorer (WISE; Wright et al. 2010) observed the sky in four infrared bands ($w1$ at 3.4 μm, $w2$ at 4.6 μm, $w3$ at 12 μm, and $w4$ at 22 μm). It allows the detection of nearby cool brown dwarfs (spectral types >T5) with much higher efficiency than the existing Two Micron All Sky Survey (2MASS; Skrutskie et al. 2006) and the ongoing Sloan Digital Sky Survey with its two recent data releases (SDSS DR7, Abazajian et al. 2009; and SDSS DR8, Aihara et al. 2011).

As for the nearest stars in the catalogue of Gliese & Jahreiß (1991), we expect the nearest cool brown dwarfs to be high proper motion (HPM) objects. Figure 1 shows the correlation between proper motion and parallax. HPM stars with $\mu >$ 1 arcsec/yr typically lie within 10 pc. Compared to 912 nearby stars shown with their mean values, only a few (34) late-T dwarfs are available with parallax measurements. However, seven out of ten HPM late-T dwarfs with $\mu > 1$ arcsec/yr fall in the 10 pc sample, whereas the other three are very close to the 10 pc horizon.

This motivated our HPM search for cool brown dwarfs in the immediate solar neighbourhood using the preliminary WISE data release combined with the previous near-infrared (2MASS) and deep optical (SDSS) surveys. The first results are presented.

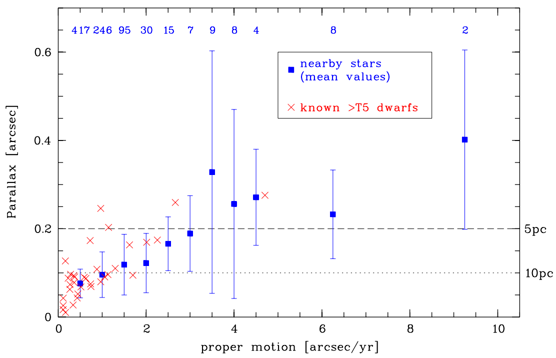

Fig. 1. Mean distances of nearby stars (from Gliese & Jahreiß 1991) with 10% accurate parallaxes vs. their proper motions. The number of stars in each proper motion bin is given at the top. The last two bins are wider to have enough stars per bin. Error bars show the width of the distribution in each bin. Known >T5 dwarfs with parallaxes (from the compilation of Gelino et al. 2011, supplemented by data from Marocco et al. 2010; Liu et al. 2011; Luhman et al. 2011, and Subasavage et al. 2009) are overplotted as red crosses.

2. Selection of candidates and cross-identification

To identify possible HPM and thus nearby cool brown dwarfs in the WISE data we used the following selection criteria:

- The colour constraints $w1-w2 > 2$ and $w2-w3 < 2.5$ are also applied by Burgasser et al. (2011) in search of late-T dwarfs, where the second condition aims at excluding extragalactic sources (Wright et al. 2010).
- We considered only bright WISE sources $w2 < 13$, since those have a higher probability of showing up in 2MASS or SDSS if we consider the limiting magnitudes of these surveys (see Table 9 in Metchev et al. 2008) and the typical colours of known late-T dwarfs ($J - w2 \gtrsim 2$; Mainzer et al. 2011 and $z - J \sim 3.5$; Metchev et al. 2008).
- We included only WISE point sources outside the Galactic plane ($|b| > 10°$ to avoid problems due to reddening.

* based on observations with the Large Binocular Telescope (LBT).

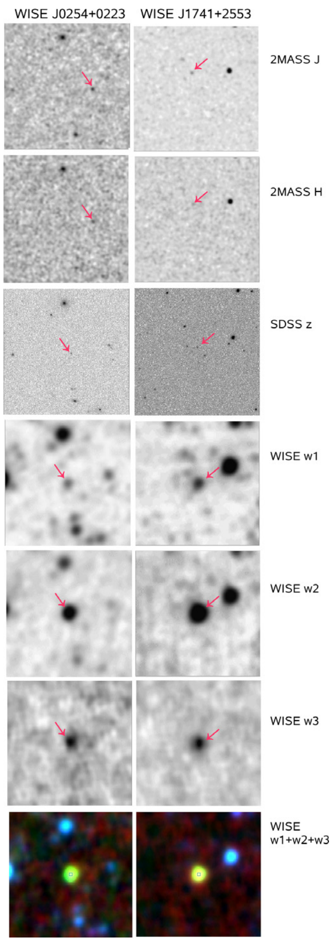

Fig. 2. Finding charts of WISE J0254+0223 (left column) and WISE J1741+2553 (right column) showing 2×2 arcmin fields centred on the WISE positions with north up and east to the left. The charts are sorted by the epochs of the images, 2MASS, SDSS, WISE (from top to bottom). The lower row shows WISE false colour composites.

– We looked only for WISE sources without a 2MASS counterpart within 3 arcsec, which implies a minimum proper motion of $\mu \gtrsim 0.3$ arcsec/yr with the typical ten year epoch difference between 2MASS and WISE.

Only 98 candidates remained after this selection, and all of them were subsequently inspected by eye on 2 × 2 arcmin finding charts (as shown in Fig. 2) from WISE, 2MASS, and SDSS (if available) in search of shifted counterparts with corresponding proper motions up to about 6 arcsec/yr. The majority of candidates were rejected as reddened stars, background galaxies, and artefacts (in diffraction spikes of bright stars), and no lucid explanation could be given for a few candidates. However, we found four known T7-T8 dwarfs discovered by Burgasser et al. (2002), Looper et al. (2007), and Burgasser et al. (2000) (see also Gelino et al. 2011 and references therein; with proper motions from 1.3 to 2 arcsec/yr), 2MASSI J0415195−093506 (T8 at 5.7 pc), 2MASSI J0727182+171001 (T7 at 9.1 pc), 2MASS J07290002−3954043 (T8p), Gliese 570D (T7.5 at 5.9 pc), and two new objects. There are 32 more known ≳T7 dwarfs in Gelino et al. (2011), of which however, only UGPS J072227.51−054031.2 (hereafter UGPS J0722−0540; T10 at 4.1 pc) in the Galactic plane and three fainter ($13.9 < w2 < 15.2$) and likely more distant T7-T7.5 dwarfs are measured as resolved sources by WISE.

3. Discovery of two new HPM brown dwarfs

The four known late-T dwarfs, which we identified on the WISE and 2MASS finding charts with positional separations of about 15 to 25 arcsec, showed up as bright and unusual

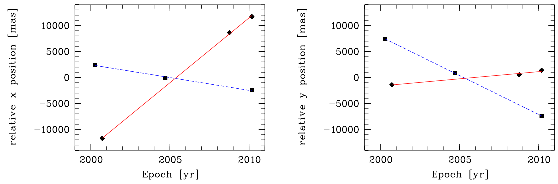

Fig. 3. Relative positions from 2MASS, SDSS, and WISE (from left to right) and proper motion fits for WISE J0254+0223 (filled lozenges, solid lines) and WISE J1741+2553 (filled squares, dashed lines)

"green" sources in the WISE false colour composites and as relatively faint ($15.3 < J < 15.9$) and "blue" ($-0.2 < J - H < +0.2$ and $0.0 < J - K_s < +0.3$) 2MASS sources. Except for the T8p dwarf, they were still detected in the 2MASS K_s-band. For two new "green" and "yellow" WISE sources (see Fig. 2), WISEPC J025409.45+022359.1 (hereafter WISE J0254+0223) and WISEPC J174124.25+255319.5 (hereafter WISE J1741+2553), we found even fainter ($16.4 < J < 16.6$) 2MASS counterparts at similar large separations. The last two objects are not detected in the 2MASS K_s-band, and only the second one is blue ($J - H \approx +0.1$ and $J - K_s \lesssim -0.3$), whereas the first one appears to be relatively red ($J - H \approx +0.7$ and $J - K_s \lesssim +0.6$). However, the 2MASS magnitudes of the two new objects are close to the survey limits, and the corresponding colours from 2MASS are rather uncertain, compared to those of the four brighter known late-T dwarfs.

The additional identification of WISE J0254+0223 in SDSS DR8 (Aihara et al. 2011) and of WISE J1741+2553 in SDSS DR7 (Abazajian et al. 2009) has led to clear proper motion fits (Fig. 3). The very large proper motions are a first hint that these objects should be very close to the Sun. Both objects are only detected in the SDSS z-band, which is typical of nearby late-T dwarfs. Metchev et al. (2008) mention that there were no T8 and later type brown dwarfs known in the SDSS. The 11 late-T dwarf candidates identified by Scholz (2010) in SDSS and UKIDSS (six of which have been confirmed spectroscopically as T5-T8 dwarfs by Burningham et al. 2010; Burgasser et al. 2010; and Murray et al. 2011) have $19.9 < z < 20.7$. None of them were detected in 2MASS. In comparison, our two new objects are with $z = 19.9$ and $z = 19.7$ relatively bright and have at least 2–3 times larger proper motions than the above mentioned 11 objects.

The photometry and different epoch positions of WISE J0254+0223 and WISE J1741+2553 from SDSS, 2MASS, and WISE, as well as their proper motions, are shown in Table 1. The proper motions are derived from simple linear fitting and may be affected by parallactic motions. We also detected both objects at the positions 02 54 07.301 +02 23 56.91 (1996.805) and 17 41 24.649 +25 53 40.25 (1996.449), respectively, on I-band photographic Schmidt plates (not shown in Fig. 2) scanned in the SuperCOSMOS Sky Surveys (Hambly et al. 2001). The proper motions involving these positions (+2438.7 ± 40.6, +176.1 ± 64.1 and −407.8 ± 59.7, −1507.2 ± 7.0, respectively) confirm our HPM measurements but are slightly less accurate than our preferred solutions given in Table 1 and shown in Fig. 3.

4. Photometric classification and distances

With their large $w1 - w2$ colour indices of +3.04 and +2.92, WISE J0254+0223 and WISE J1741+2553 are expected to have spectral types of ∼T7-T10 according to Mainzer at al. (2011),

Table 1. Astrometry and photometry of two new HPM brown dwarfs.

Parameter	WISE J0254+0223	WISE J1741+2553
WISE RA (J2000)	02 54 09.4501	17 41 24.2578
WISE Dec (J2000)	+02 23 59.136	+25 53 19.507
WISE epoch	2010.182	2010.182
SDSS RA (J2000)	02 54 09.2449	17 41 24.4306
SDSS Dec (J2000)	+02 23 58.268	+25 53 27.805
SDSS epoch	2008.764	2004.7095
SDSS run/data release	7717/DR8	4832/DR7
2MASS RA (J2000)	02 54 07.8864	17 41 24.6206
2MASS Dec (J2000)	+02 23 56.346	+25 53 34.361
2MASS epoch	2000.723	2000.277
$\mu_\alpha \cos\delta$ [mas/yr]	+2496 ± 46	−492 ± 43
μ_δ [mas/yr]	+276 ± 47	−1500 ± 11
SDSS z [mag]	19.861 ± 0.074	19.745 ± 0.105
2MASS J [mag]	16.557 ± 0.156	16.451 ± 0.099
2MASS H [mag]	15.884 ± 0.199	16.356 ± 0.216
2MASS K_s [mag]	>16.006	>16.785
WISE $w1$ [mag]	15.743 ± 0.070	15.228 ± 0.040
WISE $w2$ [mag]	12.707 ± 0.031	12.312 ± 0.025
WISE $w3$ [mag]	11.042 ± 0.131	10.675 ± 0.075

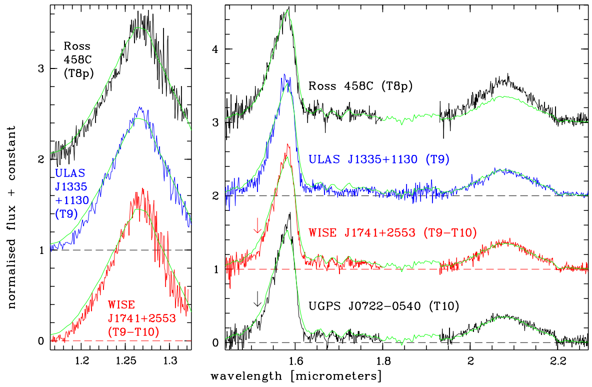

Fig. 4. LBT/LUCIFER1 J- (*left*) and $H + K$-band (*right*) spectra of WISE J1741+2553 and two other objects (see Table 2). Also shown is a T9 template spectrum from Burningham et al. (2008). A lower resolution spectrum of the T8 template 2MASSI J0415195−093506 (from Burgasser et al. 2004) is overplotted. Arrows mark the candidate NH_3 absorption feature, mentioned by Lucas et al. (2010).

although we find somewhat lower values of $+2.30 < w1 - w2 < +2.85$ for the four known T7-T8 dwarfs (two of which are listed in Mainzer at al. 2011 with different WISE photometry) detected in our HPM search (Sect. 1). Therefore, we believe our two new objects are more likely ultracool (≳T8) brown dwarfs. In support of this classification we mention their large $J - w2$ indices of +3.85 and +4.14 (compared to values from +2.67 to +3.46 for the four known T7-T8 dwarfs) corresponding to an absolute magnitude of $M_{w2} \sim 14$ if we use the linear relation between M_{w2} and $J - w2$ given in Wright et al. (2011). For comparison, UGPS J0722−0540 (Lucas et al. 2010) is detected in WISE with $w2 = 12.17$ and has an absolute magnitude of $M_{w2} = 14.11$, whereas all T dwarfs with known distances from Patten et al. (2006) plotted by Wright et al. (2011) have brighter absolute magnitudes ($M_{w2} < 13.5$) with colour indices $J - w2 < +3.3$. The $J - w2$ colours of WISE J0254+0223 and WISE J1741+2553 do not reach the very high values (≳5) of the two coolest known (probably >T10) but more distant brown dwarfs WD 0806−661B at ∼19 pc (Luhman et al. 2011; Rodriguez et al. 2011; Subasavage et al. 2009) and CFBDSIR J145829+101343B at ∼23 pc (Liu et al. 2011). They are comparable to the A component (T9.5) of the latter as shown in Wright et al. (2011).

For a first approximation of the distances of WISE J0254+0223 and WISE J1741+2553, we used the preliminary classification of both objects as ∼T8-T10 dwarfs with an absolute magnitude of $M_{w2} \sim 14$. Conservatively, we assumed an uncertainty of 0.75 mag in this absolute magnitude, by considering the ∼0.5 mag spread in absolute magnitudes shown in Wright et al. (2011) and the $J - w2$ colour spread observed for the known T8-T10 dwarfs. There is also significant scatter in the near-infrared (MKO) to mid-infrared (Spitzer) colours of late-T dwarfs (Leggett et al. 2010). We then arrived at photometric distances from the Sun for WISE J0254+0223 of $5.5^{+2.3}_{-1.6}$ pc and WISE J1741+2553 of $4.6^{+1.9}_{-1.4}$ pc.

With these distance estimates, we computed absolute magnitudes $M_z \sim 21.2$ and $M_z \sim 21.4$, respectively for WISE J0254+0223 and WISE J1741+2553. These values are 1.3–1.5 mag fainter than the $M_z \sim 19.9$ of Ross 458C (=Hip 63510C), the only ≳$T8$ dwarf with distance and SDSS detection now available (Goldman et al. 2010; Scholz 2010; Burgasser et al. 2010). The latter is in good agreement with the assumed $M_z \sim 20.0$ for T8 dwarfs in Metchev et al. (2008). On the other hand, the z-band photometry obtained by Lucas et al. (2010) for the T10 dwarf UGPS J0722−0540 leads to M_z values between 22.4 and 22.6, about 1 mag fainter than our values.

5. Spectroscopic observations with LBT/LUCIFER

We used the Large Binocular Telescope (LBT) near-infrared spectrograph LUCIFER1 (Mandel et al. 2008; Seifert et al. 2010; Ageorges et al. 2010) in long-slit spectroscopic mode with the $H + K$ (200 lines/mm + order separation filter) and $zJHK$ gratings (210 lines/mm + J filter) to observe UGPS J0722−0540 on 2011 March 06 (only in $H + K$, total integration 30 min) and WISE J1741+2553 (40 min $H + K$, 27 min J), together with Ross 458C (30 min $H + K$, 20 min J) on 2011 May 12. The central wavelengths were chosen at 1.835 μm ($H + K$) and 1.25 μm (J) yielding a coverage of 1.38–2.26 and 1.17–1.32 μm, respectively. The slit width was 2 arcsec for UGPS J0722−0540 and 1 arcsec (4 pixels) for the other objects. For the 1 arcsec slit, the spectral resolving power is $R = \lambda/\Delta\lambda \approx 4230$, 940, and 1290 at $\lambda \approx 1.24$, 1.65, and 2.2 μm, respectively. Observations consisted of individual 75 s exposures in $H + K$ and 200 s exposures in J with shifting the target along the slit following an ABBA pattern (to allow sky subtraction) until the total integration time was reached. A0V standards were observed just before or after the targets with similar airmasses.

The raw spectroscopic data were reduced using standard routines within the `IRAF`[1] environment. The spectra were sky-subtracted, aligned, combined, optimally extracted, and wavelength-calibrated using vacuum wavelengths of Ar arc lamps and the deep telluric absorption features. No flat division was applied to avoid including additional noise features from the halogen lamp. The instrumental response and telluric bands were removed by dividing by the A0 star spectra and multiplying by a black-body spectrum with the same effective temperature. The intrinsic lines in the hot-star spectra were removed before dividing the science spectra. Residuals from intense sky emission lines in the target spectra were removed by interpolation across

[1] IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

Table 2. Spectral indices obtained from LBT/LUCIFER1 spectra.

Object	SpT	Reference for SpT	W_J	NH_3 - H	H_2O -H	CH_4 - H	CH_4 - K
Ross 458C	T8p	Burgasser et al. 2010	0.264 (<T9)	0.664 (<T9)	0.206 (<T9)	0.107 (<T9)	0.054 (>T9)
UGPS J0722−0540	T10	Lucas et al. 2010		0.530 (>T9)	0.141 (<T9)	0.055 (>T9)	0.079 (>T9)
WISE J1741+2553	T9-T10	this paper	0.234 (>T9)	0.551 (<T9)	0.119 (>T9)	0.066 (>T9)	0.056 (>T9)

Notes. SpT from comparison with T9 average from Lucas et al. (2010) in brackets.

the lines. The J and $H+K$ spectra were normalised by the average flux in the range 1.20–1.30 and 1.52–1.61 μm, respectively.

The $H + K$ spectra of WISE J1741+2553 and the T10 dwarf UGPS J0722−0540 are very similar, including a possible common NH_3 feature expected for Y-type objects, whereas both spectra ($H + K$ and J) of WISE J1741+2553 indicate a type later than T8 (Fig. 4). We have computed spectral indices used for the classification of ultracool brown dwarfs (see Burningham et al. 2008 and references therein) and compare them with average values of T9 dwarfs given by Lucas et al. (2010) in Table 2. Unfortunately, no other indices than W_J could be determined in the J-band, since the LUCIFER J grating provides a very narrow wavelength interval. Our indices are in good agreement with the measurements of Lucas et al. (2010) for UGPS J0722−0540 and of Burgasser et al. 2010 for Ross 458C, except for NH_3 - H, where our indices are larger by about 0.04 and 0.06, respectively. As in the case of the known T10 dwarf, all but one index of WISE J1741+2553 classify it as >T9, although the usefulness of some indices has been questioned. In the T dwarf classification system originally defined by Burgasser et al. (2006) the CH_4 - K index was shown to be degenerate for types >T6. Extending the system to T9 Burningham et al. (2008) showed that the CH_4 - H index is also degenerate with >T7, whereas the T8, T9 average, and T10 values of the latter show a clear trend in Lucas et al. (2010). We consider Ross 458C as T8p since it is a relatively young (0.15–0.80 Gyr) object (Burgasser et al. 2010), whereas the field brown dwarfs are assumed to be older (0.2–10 Gyr; see e.g. Lucas et al. 2010). We conservatively assign a spectral type of T9-T10 to WISE J1741+2553, reduce the assumed absolute magnitude uncertainty to 0.5 mag, and get a more accurate spectroscopic/photometric distance of $4.6^{+1.2}_{-1.0}$ pc.

6. Conclusions

While WISE J0254+0223 and WISE J1741+2553 are very likely similar to the few other T8-T10 brown dwarfs known, they are the first ultracool brown dwarfs detected in both 2MASS and SDSS. With their relatively bright magnitudes, they are excellent targets for detailed spectroscopic investigations and for high-resolution imaging in search of possible binarity. They may become important laboratory sources at the boundary between the T-type and the suggested Y-type (Kirkpatrick et al. 1999) classes of brown dwarfs.

Our initial photometric classification of both objects as ∼T8-T10 dwarfs was confirmed for WISE J1741+2553, for which we obtained spectroscopy with LBT/LUCIFER1 and classified it more accurately as a T9-T10 dwarf. Our photometric(/spectroscopic) distances place both objects at about 5 pc from the Sun, probably nearly as close as the T10 dwarf UGPS J0722−0540 in the Galactic plane ($b = +4°$), and make them highly interesting targets for near-infrared parallax programs. With the upper limits of our distance estimates they fall still clearly in the 10 pc sample.

The larger proper motion and slightly larger distance of the higher Galactic latitude object WISE J0254+0223 ($b = -48°$) lead to a relatively high tangential velocity of ∼65 km s^{-1} (possibly indicating a Galactic thick disk membership), compared to ∼34 km s^{-1} for WISE J1741+2553 ($b = +26°$), which is typical of the thin disk population.

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