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LETTER TO THE EDITOR

ULAS J141623.94+134836.3 – a faint common proper motion companion of a nearby L dwarf

Serendipitous discovery of a cool brown dwarf in UKIDSS DR6

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ABSTRACT

Aims. New near-infrared large-area sky surveys (e.g. UKIDSS, CFBDS, WISE) go deeper than 2MASS and aim at detecting brown dwarfs lurking in the solar neighbourhood that are even fainter than the latest known T-type objects, so-called Y dwarfs.
Methods. Using UKIDSS data, we found a faint brown dwarf candidate with very red optical-to-near-infrared, but extremely blue near-infrared colours next to the recently discovered nearby L dwarf SDSS J141624.08+134826.7. We checked if the two objects are co-moving by studying their parallactic and proper motion and compared the new object with known T dwarfs.
Results. The astrometric measurements are consistent with a physical pair (sep $\approx$ 75 AU) at a distance $d \approx 8$ pc. The extreme colour ($J - K \approx -1.7$) and absolute magnitude ($M_J = 17.78 \pm 0.46$ and $M_K = 19.45 \pm 0.52$) make the new object appear as one of the coolest ($T_{\rm eff} \approx 600$ K) and nearest brown dwarfs, probably of late-T spectral type and possibly with a high surface gravity ($\log g \approx 5.0$).

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

1. Introduction

One of the open questions of low-mass star formation is the ratio of successful/failed star formation processes. In other words, is the solar neighbourhood populated by as many cool brown dwarfs as red dwarf stars? Several new near-infrared surveys like UKIDSS[1], CFBDS (Delorme et al. 2008b) and WISE (Wright 2008; Mainzer et al. 2009) try to answer this question by going deeper than the Two Micron All Sky Survey (2MASS; Skrutskie et al. 2006) to detect a new class of ultracool brown dwarfs, so-called Y dwarfs.

The appearance of ammonia absorption in the near-infrared spectra is being discussed as a criterion for the new Y spectral type (Burningham et al. 2008; Delorme et al. 2008b). Whereas the latest-type (coolest) objects discovered in the 2MASS are of spectral type T8 (Burgasser et al. 2002; Tinney et al. 2005; Looper et al. 2007), a handful of even cooler ($T_{\rm eff} \approx 500$–600 K) brown dwarfs (T8.5-T9) have already been discovered in UKIDSS (Warren et al. 2007; Burningham et al. 2008, 2009) and CFBDS (Delorme et al. 2008a) that do not look conspicuously different in their near-infrared spectra from late-type T dwarfs. A unique Y dwarf has not yet been found and classified.

We describe a new cool brown dwarf, which is probably a late-T dwarf with unusual properties, detected as a wide companion of a nearby blue L dwarf.

2. Identification of a faint object with unusual colors near the blue L dwarf SDSS J141624.08+134826.7

While inspecting the UKIDSS finding charts around the recently discovered (Schmidt et al. 2010, hereafter S10; Bowler et al. 2010, hereafter B10) nearby blue L6 dwarf SDSS J141624.08+134826.7 (hereafter called object A), we found a fainter nearest neigbouring object with extreme colours, separated by about 9.4 arcsec. This object, ULAS J141623.94+134836.3 (hereafter called object B) was not detected in the SDSS DR7 (Abazajian et al. 2009), but is well measured in the UKIDSS, where it has $Y - J \approx +0.9$, but a very blue near-infrared colour of $J - H \approx -0.3$ and $J - K \approx -1.7$ (Fig. 1; Table 1). Abazajian et al. (2009) describe the completeness limit of SDSS DR7 with a 95% detection repeatability for point sources at $u = 22.0$, $g = 22.2$, $r = 22.2$, $i = 21.3$, and $z = 20.5$. The non-detection of object B in SDSS DR7 hints at a very red optical-to-near-infrared colour ($z - Y > +2.3$ and $z - J > +3.1$). Using two available overlapping z-band FITS images (SDSS runs 3971 and 3996) downloaded from the SDSS DR7, we were able to detect object B (for the astrometry see Table 2) and measure its magnitude as $z_{3971} = 21.24 \pm 0.50$ and $z_{3996} = 21.02 \pm 0.39$. The resulting mean colour indices are $z - Y = +2.97 \pm 0.32$ and $z - J = +3.87 \pm 0.32$.

Comparing the near-infrared colour indices of object B with those of the known T dwarfs (Fig. 2), one can see that similar moderately negative $J - H$ have been measured for the latest-type (T9), but also for other mid- and late-type T dwarfs, whereas the extremely large negative $J - K$ of object B clearly stands out against the rest of the T dwarfs. Both colours are in the range typical of model T and Y dwarfs, but rule out a high-redshift quasar (Hewett et al. 2006). However, before further

Table 1. SDSS DR7 *z* (on the AB system) and UKIDSS DR6 *YJHK* (on the Vega system using the MKO photometric system) photometry.

object	mean *z* (3971+3996)	*Y* (2325240)	*J* (2325252)	*H* (1906043)	*K* (1905923)
SDSS J141624.08+134826.7 (object A)	15.897 ± 0.005	14.255 ± 0.003	12.995 ± 0.001	12.469 ± 0.001	12.053 ± 0.001
ULAS J141623.94+134836.3 (object B)	$21.13 \pm 0.32^*$	18.162 ± 0.027	17.259 ± 0.017	17.581 ± 0.030	18.933 ± 0.244

Notes. * Not detected in SDSS DR7 (see text). *z* magnitudes are mean values from two SDSS runs (given in brackets). *YJHK* magnitudes are *aperMag3* derived from the multiframes (given in brackets) for point sources (Dye et al. 2006). A second set of *YJHK* measurements was not used due to the location of objects A and B close to the edge of the frames.
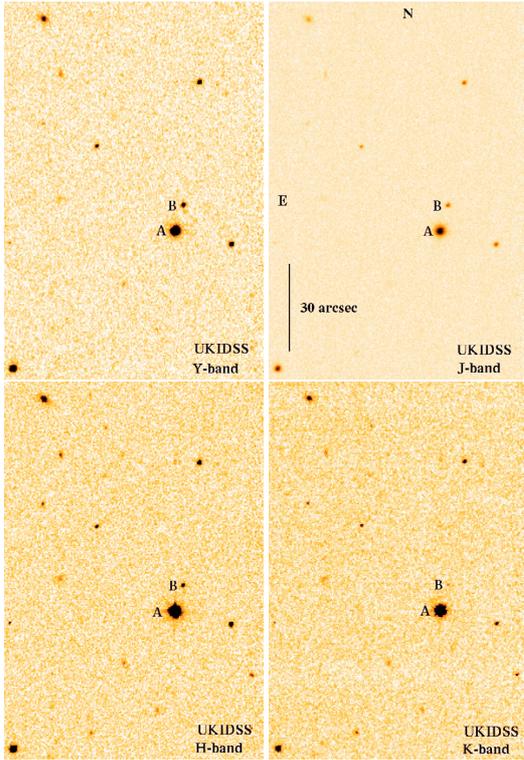

Fig. 1. UKIDSS *YJHK* images of objects A and B. Image scale and orientation (North is up, East to the left) are shown in the *J*-band image.
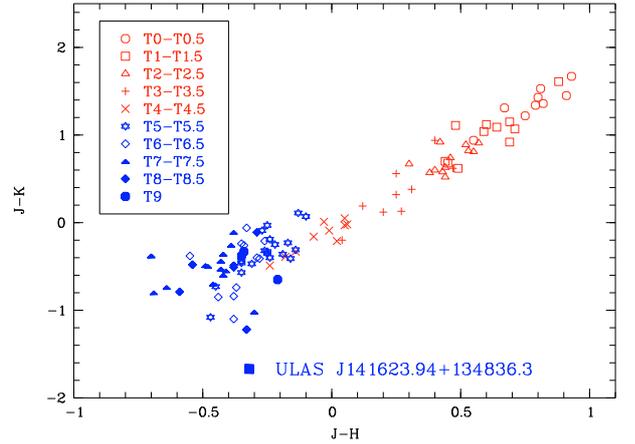

Fig. 2. Near-infrared two-colour diagram $J - K$ vs. $J - H$ (in MKO system) for all T dwarfs in Leggett et al. (2010) and the new cool brown dwarf candidate ULAS J141623.94+134836.3 (object B).

Table 2. Multi-epoch positions α, δ (J2000.0): $14^h 16^m ...^s$, $+13°48'...''$

A		B		Epoch	Source
s	''	s	''	yr	
23.804	19.88			1954.338	SSS *E*
24.050	25.48			1994.338	SSS *R*
24.068	25.85			1997.521	SSS *I*
24.0847	26.345			2000.164	2MASS
24.0886	26.741	23.886*	35.88*	2003.409	SDSS 3971
24.0859	26.683	23.916*	35.49*	2003.472	SDSS 3996
24.1305	27.339	23.9480	36.268	2008.189	UKIDSS *H*
24.1325	27.355	23.9466	36.273	2008.189	UKIDSS *K*
24.1260	27.410	23.9421	36.319	2008.362	UKIDSS *Y*
24.1254	27.416	23.9435	36.334	2008.362	UKIDSS *J*

Notes. $^{(*)}$ Not detected in SDSS DR7 (see text).

analysis we need to check the physical association of object B with object A and to confirm its distance.

3. Confirmation of common proper motion

For a first check of a possible common motion of objects A and B, one can use the accurate UKIDSS data alone. There are two different epochs for the *HK* and *YJ* observations respectively (Table 2). The corresponding multiframe numbers are listed in Table 1. Short-term proper motions were determined from simple linear fitting over the four epoch positions of objects A and B as well as of six field stars in their vicinity, well measured on the same multiframes (Fig. 3). Significant results, which agree within their errors, were obtained for A and B (solution 1-A and 1-B in Table 3). The common short-term proper motion of A and B is a first strong hint on a physical pair, but it is more spread out and in a different direction than the long-term proper motions of object A obtained by S10 and B10. We will show that this discrepancy can be explained by the expected common parallactic motion.

With two *z*-band SDSS images that contain object A, we were able to detect object B with the help of the ESO skycat

tool and the "pick object" option that is based on Gaussian fitting (Table 2). We think the reason why object B does not appear in the SDSS DR7 is that it is >0.5 mag fainter than the already mentioned 95% detection limit in *z* and cannot be detected in *ugri*, where it should be much fainter than the corresponding limits. Using now our two SDSS positions of object B together with its four UKIDSS positions, we again got similar proper motions (solutions 2-A and 2-B in Table 3), now also approaching the known long-term proper motion of object A. We further improved this (Fig. 4, solution 3-A in Table 3) by including all available epochs, also 2MASS and SuperCOSMOS Sky Surveys (SSS; Hambly et al. 2001) data (Table 2). Note that S10 did not use UKIDSS, whereas B10 missed the important old SSS *E* epoch for their proper motion solutions of object A.

The spectrophotometric distance of object A is still very uncertain (8.0 ± 1.6 pc according to S10 and 8.4 ± 1.9 pc according
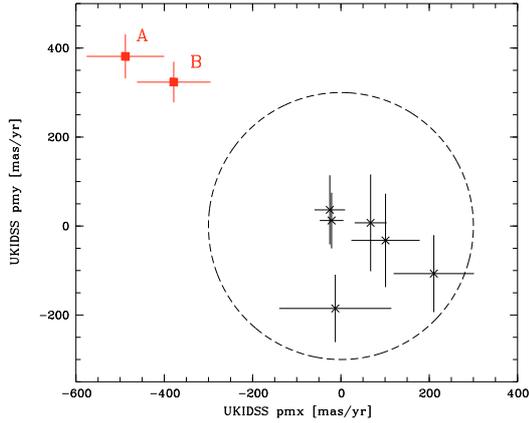
Fig. 3. Short-term proper motions (from 2×2 UKIDSS epochs separated by 0.17 years) of objects A and B (filled squares, solutions 1-A and 1-B in Table 3) in comparison to those of field stars (crosses). Typical proper motion errors of $\sigma \approx 75$ mas/yr were achieved in both directions. The dashed circle represents a 4σ significance level.
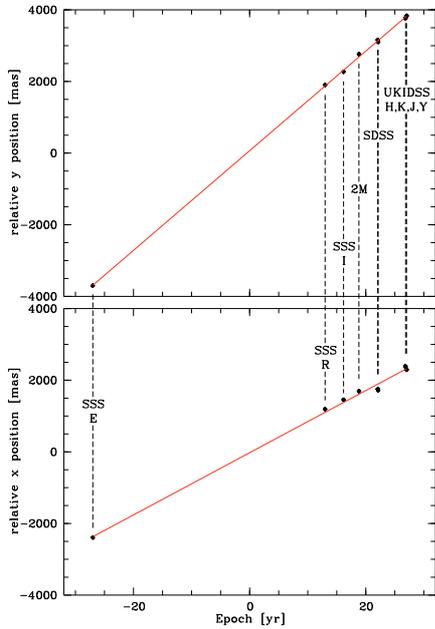

Fig. 4. Linear proper motion fit for object A (solution 3-A).

to B10), because the spectral type-absolute magnitude relations are not yet well determined for the class of blue L dwarfs. B10 mentioned a notable parallactic motion of object A, but their trigonometric parallax ($\pi_{rel} = 107 \pm 34$ mas) leads to a less accurate distance (9.3 ± 3.0 pc) than the aforementioned spectrophotometric distance estimates.

We applied the software of Gudehus (2001) for combined proper motion and parallax solutions. In the full solution for object A (solution 4-A), we made use of all ten available epochs, assigning the following uncertainties to the α, δ given in Table 2: 70 mas for UKIDSS and SDSS, 100 mas for 2MASS, 150 mas for SSS I-band, 200 mas for SSS R-band, and 250 mas for the SSS measurement of the old E plate (expected colour-dependent systematic errors in the different α, δ are much smaller and have been neglected). As an alternative, we used only the most accurate data (UKIDSS and SDSS) and the proper motion obtained in solution 3-A as a fixed input parameter in fitting only the parallactic motion of object A (solution 5-A in Table 3) and object B

Table 3. Proper motion and parallax solutions for objects A and B.

Solution	$\mu_\alpha \cos \delta$ mas/yr	μ_δ mas/yr	π_{rel} mas
1-A	-488.1 ± 87.8	$+381.3 \pm 49.4$	
1-B	-378.6 ± 83.3	$+323.5 \pm 45.7$	
2-A	$+123.9 \pm 10.1$	$+132.7 \pm 28.3$	
2-B	$+138.3 \pm 05.8$	$+126.7 \pm 25.4$	
3-A	$+86.8 \pm 02.1$	$+139.1 \pm 00.9$	
4-A	**$+86.2 \pm 02.6$**	**$+138.8 \pm 02.6$**	**127.0 ± 27.0**
5-A			153.7 ± 20.5
5-B			104.4 ± 45.5

Notes. Linear fit using UKIDSS (1), UKIDSS+SDSS (2), all data for A (3). Combined proper motion and parallax solution for A (4). Parallax solution using UKIDSS+SDSS and the previously determined linear proper motion of object A as input (5).
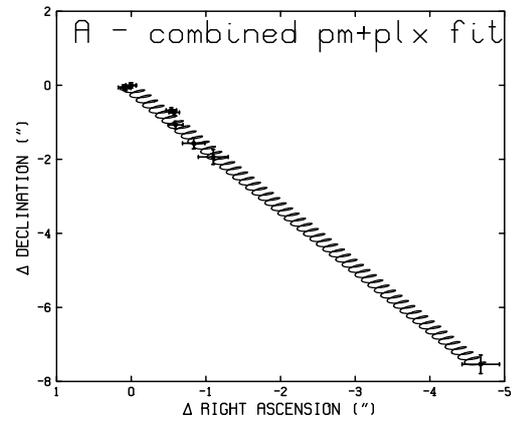

Fig. 5. Combined proper motion and parallax solution with all available epochs for object A (solution 4-A). Zero point is the UKIDSS J epoch.

(solution 5-B). In the latter case we assigned uncertainties of 200 mas to our SDSS α, δ measurements.

Our preferred solution for object A (4-A) gives a proper motion nearly identical to the linear fit (3-A) and provides a parallax leading to a distance of 7.9 ± 1.7 pc in perfect/good agreement with the spectrophotometric distances of S10/B10, respectively. Its accuracy is also comparable with that of the spectrophotometric estimates. However, the full range of the parallaxes±errors in solutions 4-A, 5-A, and 5-B implies a larger uncertainty for the system. Figure 6 shows that the short-term (UKIDSS only) proper motion of both objects (solutions 1-A and 1-B) is well explained by their common parallactic motion (the parallax results of solutions 5-A and 5-B agree within their errors).

4. Conclusions and discussion

We discovered a faint common proper motion companion (object B) of a blue nearby L6 dwarf (object A). Based on the astrometric measurements, which are consistent with a wide binary (projected physical separation 75 AU) at a distance of about 8 pc, and on the accurate near-infrared colours placing object B at the end of the T dwarf sequence (Figs. 2, 7), we conclude that this object is one of the coolest known brown dwarfs, probably with a late-T spectral type.

The latest-type brown dwarfs with trigonometric parallaxes available are the T8.5 dwarfs Wolf 940B at a distance of 12.5 ± 0.7 pc (=ULAS J214638.83-001038.7; Burningham et al. 2009; with a parallax measurement for the primary Wolf 940A by Harrington & Dahn 1980) and
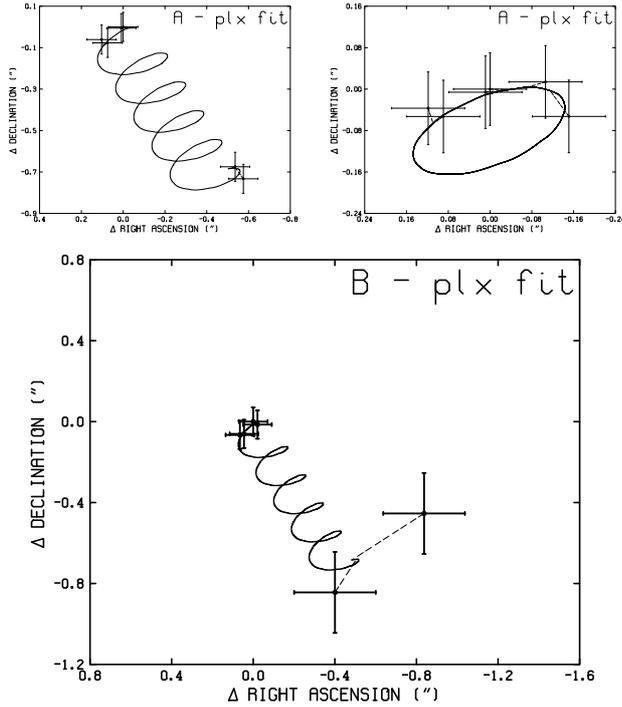
Fig. 7. Absolute magnitudes M_K (*bottom*) and M_J (*top*) vs. $J - K$ colour (in MKO system) for all T dwarfs with measured trigonometric parallaxes as listed in Leggett et al. (2010) and for ULAS J141623.94+134836.3 (object B) with error bars obtained from using the parallax of object A (solution 4-A) and the magnitude errors of object B (Table 1).

binary brown dwarf or a much older analogue of the young low-mass star plus massive planet system 2MASS 1207−3932AB (Gizis 2002; Chauvin et al. 2004).

Fig. 6. Parallax solution for objects A (top, solution 5-A; top, right shows the parallax fit with the proper motion removed) and B (bottom, solution 5-B) using UKIDSS+SDSS and the known long-term proper motion (from solution 3-A) as fixed input parameter.

ULAS J003402.77−005206.7 (Warren et al. 2007; Smart et al. 2009) at a distance of 12.6 ± 0.6 pc. Gelino et al. (2009) list only one more T8.5 (ULAS J123828.51+095351.3; Burningham et al. 2008) and two T9 dwarfs (ULAS J133553.45+113005.2; Burningham et al. 2008 and CFBDS J005910.90−011401.3; Delorme et al. 2008a), which are still lacking trigonometric parallaxes. However, their spectrophotometric estimates hint at distances of (slightly) more than 8 pc. Object B is by 0.5–1.7 mag brighter in the *J*- and *H*-band than the above mentioned five objects. In particular, the possibly nearest of the objects, the T9 dwarf ULAS J133553.45+113005.2 at 8–12 pc according to Burningham et al. (2008) is 0.5–0.6 mag fainter than object B in the *YJH*-bands, whereas it is about 0.5 mag brighter than object B in the *K*-band. Adopting the mean distance of 10 pc for ULAS J133553.45+113005.2 and 8 pc for object B, their absolute *YJH* magnitudes are comparable, whereas object B is fainter in M_K (Fig. 7). Therefore we think that object B is probably the nearest among the latest-type brown dwarfs and offers excellent opportunities for follow-up observations.

With an $H - K \approx -1.35$ and $M_H \approx 18.1$, object B falls outside Fig. 9 (top panel) in Leggett et al. (2010), where these authors compare T dwarf observations with models. However, extrapolating the model line with solar metallicity but high gravity (log g = 5.0) gives the best fit, possibly with a $T_{\rm eff} \approx 600$ K. Alternatively, a slightly lower metallicity would also fit, but B10 excluded an L subdwarf classification of object A, and the kinematics of the system is clearly not typical of the Galactic halo or thick disc. The blue colour of object A could also be caused by high surface gravity as discussed by Burgasser et al. (2008) for the class of blue L dwarfs. If the high gravity is correct, then the evolution models of Saumon & Marley (2008, their Fig. 4) show that the system is likely ≈5 Gyr old, and object B could have a mass of ≈30 Jupiters. Further investigation will show whether objects A and B represent a wide
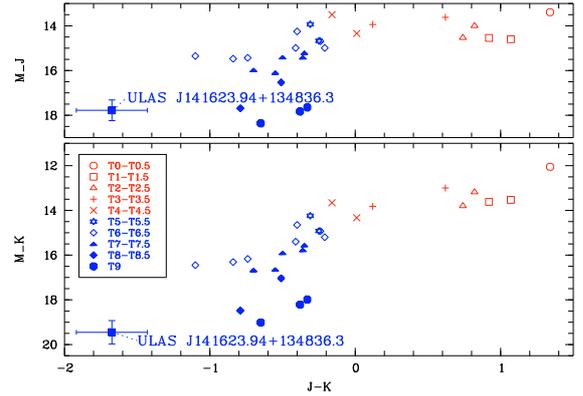
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