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LHS 2803B: A VERY WIDE MID-T DWARF COMPANION TO AN OLD M DWARF IDENTIFIED FROM PAN-STARRS1

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ABSTRACT

We report the discovery of a wide (∼1400 AU projected separation), common proper motion companion to the nearby M dwarf LHS 2803 (PSO J207.0300–13.7422). This object was discovered during our census of the local T dwarf population using Pan-STARRS1 and Two Micron All Sky Survey data. Using the Infrared Telescope Facility/SpeX near-infrared spectroscopy, we classify the secondary to be spectral type T5.5. University of Hawaii 2.2 m/SuperNova Integral Field Spectrograph optical spectroscopy indicates that the primary has a spectral type of M4.5, with approximately solar metallicity and no measurable Hα emission. We use this lack of activity to set a lower age limit for the system of 3.5 Gyr. Using a comparison with chance alignments of brown dwarfs and nearby stars, we conclude that the two objects are unlikely to be a chance association. The primary's photometric distance of 21 pc and its proper motion implies thin disk kinematics. Based on these kinematics and its metallicity, we set an upper age limit for the system of 10 Gyr. Evolutionary model calculations suggest that the secondary has a mass of 72^{+4}_{-7} $M_{\rm Jup}$, temperature of 1120 ± 80 K, and log g = 5.4 ± 0.1 dex. Model atmosphere fitting to the near-IR spectrum gives similar physical parameters of 1100 K and log g = 5.0.

Key words: brown dwarfs – stars: low-mass

Online-only material: color figures

1. INTRODUCTION

The past two decades have seen an explosion of interest in the study of ultracool dwarfs (spectral types of M6 or later), which can be stars or brown dwarfs. However, determining the physical properties of brown dwarfs, such as their mass, age, and radius, is complicated due to their substellar nature. Unlike main-sequence stars, the lack of hydrogen burning means that brown dwarfs have no stable luminosity and hence there is a degeneracy between effective temperature, mass, and age. This degeneracy can be broken for two classes of objects. The first type ("mass benchmarks"; Liu et al. 2008) are binary brown dwarfs whose dynamical mass can be measured from their orbits. There are over a dozen such systems known (Dupuy & Liu 2011).

The second type, "age benchmarks," have their ages inferred from associated stars. This can be done by studying low-mass members of stellar clusters. However, the confirmed, young substellar populations of such associations are currently limited to mid-M to early-L dwarfs (e.g., Lodieu et al. 2012) and is hence not directly applicable to cooler field objects. Another source of benchmarks is substellar companions to higher mass stars. These objects have their ages determined from their stellar primaries and span a wide range in spectral types (Faherty et al. 2010). Three close T dwarf companions have been discovered by high contrast imaging—Gl 229B (Nakajima et al. 1995), GJ 758B (Thalmann et al. 2009), and SCR 1845–6357B (Biller et al. 2006)—along with eleven wide companions to main-sequence stars discovered using wide-field surveys or conventional imaging—GL 570D (Burgasser et al. 2000), HD 3651B (Mugrauer et al. 2006; Luhman et al. 2007), HN Peg B (Luhman et al. 2007), Wolf 940B (Burningham et al. 2009), Ross 458C (Goldman et al. 2010), HIP 63510C (Scholz 2010), HIP 73786B (Scholz 2010; Murray et al. 2011), ϵ Indi Bab (Scholz et al. 2003; McCaughrean et al. 2004), Gl 337CD (Wilson et al. 2001; Burgasser et al. 2005), HIP 38939B (Deacon et al. 2012), and BD +01° 2920B (Pinfield et al. 2012). Additionally, Albert et al. (2011) identify a potential companion to HD 15220 (CFBDS J022644–062522) while Dupuy & Liu (2012) establish ULAS 1315 + 0826 (Pinfield et al. 2008) as a potential companion to TYC 884-383-1. Finally, two ultracool companions have been discovered to white dwarfs, LSPM 1459+0857B (Day-Jones et al. 2011) and WD 0806–661b (Luhman et al. 2011), the latter of which has no spectroscopic data but is likely to be of the newly discovered Y spectral class (Cushing et al. 2011). These benchmarks can be used to test atmospheric and evolutionary models for mutual consistency by comparing their expected effective temperatures from their age and luminosity to the effective temperatures from atmospheric model fits to their spectra. The analysis of benchmark T dwarfs presented in Deacon et al. (2012) indicates that the most recent atmospheric models (Allard et al. 2011; Saumon & Marley 2008) match the effective temperatures inferred from evolutionary models to within ∼100 K.

The vast majority of wide brown dwarf companions have been discovered by mining large astronomical surveys. One of the leading survey telescopes currently in operation is

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Pan-STARRS1 (PS1; Kaiser et al. 2002). This 1.8 m wide-field telescope sits atop Haleakalā on Maui in the Hawaiian Islands. The facility is operated by a consortium of US, German, UK, and Taiwanese institutions and has been conducting full survey operations since 2010 May. The telescope carries out a variety of astronomical surveys covering a wide range of science areas, from the solar system (Hsieh et al. 2012), to the solar neighborhood (Deacon et al. 2011; Liu et al. 2011), to high-redshift supernovae (e.g., Chomiuk et al. 2011). The most valuable of these surveys for ultracool dwarf science is the 3π Survey. This is covering the three-quarters of the sky ($\delta > -30°$) visible from Maui in five filters in the PS1 system ($g_{P1}, r_{P1}, i_{P1}, z_{P1}, y_{P1}$; Tonry et al. 2012). Two pairs of images will be taken per year in each passband for each area of sky during each of the three years of planned survey operation. Due to the fact that PS1 is only now finishing its second year of survey operation, our search for ultracool T dwarfs using PS1 has so far used data from the Two Micron All Sky Survey (2MASS; Skrutskie et al. 2006) as an additional epoch for proper motion determination and as a source of near-infrared photometry. This has resulted in the discovery of four relatively bright ($J \sim 16.5$ mag) T dwarfs in PS1 commissioning data (Deacon et al. 2011) and, in combination with data from the *Wide-field Infrared Survey Explorer* (*WISE*; Wright et al. 2010), the identification of PSO J043.5395+02.3995, a nearby T8 brown dwarf with an extremely high proper motion (Liu et al. 2011; see also Scholz et al. 2011; Kirkpatrick et al. 2012). Using the proper motion catalog produced for the PS1–2MASS T dwarf search, a dedicated search for cool companions to main-sequence stars is also underway. This has already resulted in the discovery of HIP 38939B, a T4.5 companion to a mid-K star in the solar neighborhood (Deacon et al. 2012).

Here, we present the discovery of a mid-T-type companion to the M dwarf LHS 2803[7] (PSO J207.0300–13.7422). The primary is of a much lower mass than most other stars with a wide (>1000 AU) T dwarf companion. We use spectroscopic observations to characterize both the primary and secondary stars. These data are then used to fit substellar evolutionary and atmospheric models to the secondary, allowing a comparison of the best-fit models.

2. IDENTIFICATION IN PAN-STARRS1 DATA

For the past two years, we have undertaken a survey for ultracool, methane-bearing T dwarfs in the solar neighborhood (Deacon et al. 2011; M. C. Liu et al. in preparation) combining PS1, 2MASS (Skrutskie et al. 2006), and UKIRT/UKIDSS (Lawrence et al. 2007) data. The selection process used is similar to that outlined in Deacon et al. (2011). Objects with apparent proper motion between PS1 and 2MASS, red $y_{P1} - J_{2MASS}$ and $z_{P1} - y_{P1}$ colors, and a blue $J_{2MASS} - H_{2MASS}$ color are selected as the initial sample. These candidates had proper motions calculated from their 2MASS and PS1 astrometry assuming a systematic error floor between the two surveys of 80 mas. After anti-matching with optical plate data (Monet et al. 2003; Hambly et al. 2001), the candidates are then visually inspected to remove spurious associations. Objects without UKIDSS data are then targeted for near-infrared photometry. We then obtain spectroscopy for objects selected from this process.

In order to identify wide common proper motion companions to objects for which we have spectra, we performed a Simbad[8] search within 20 arcmin of our target coordinates. LHS 2803 (Luyten 1979) emerged as an excellent candidate companion to one of our spectroscopically confirmed T dwarfs. Details of the primary and secondary components of this system are listed in Table 1, and the images of the cool secondary are shown in Figure 1. The separation of the two components is 67$''$.6 based on their 2MASS positions, the primary is saturated in PS1 and hence we did not attempt to use this source of astrometry or photometry.

2.1. Companionship

In order to test the likelihood of these two objects being physically associated, we applied the criterion described in Dupuy & Liu (2012) that the total difference in the proper motion between the two components must be less than one-fifth of the total proper motion of the system. While this is not absolute proof of companionship, all known wide ultracool common proper motion companions in the literature meet this criterion. The fractional difference in proper motion for the two components of the LHS 2803 system is 0.05 ± 0.02, giving us confidence that the two are likely to be physically associated. In order to further check if these two objects are physically associated, we adopted the approach of Lépine & Bongiorno (2007) who also attempt to quantify chance alignments of common proper motion pairs. Their method works by applying an offset to the positions of each star in their catalog and then seeing how many apparent (but false) common proper motion pairs are identified. Their Figure 1 shows the results of this analysis, which extends to proper motions up to 0$''$.45 yr^{-1}. As expected, this analysis shows that chance alignments become more common with larger proper motion differences, decreasing total proper motion and wider separations. Using the catalog of objects from our ongoing search for T dwarfs in PS1, we conducted a similar analysis. First, to distinguish proper motions from spurious associations between PS1 and 2MASS, we selected only objects with United Kingdom Infrared Telescope (UKIRT) follow-up photometry that agreed within 0.6 mag in the J band with their 2MASS J-band measurement. This was used by Deacon et al. (2011) as a dividing line between likely true high proper motion objects and spurious associations. We then applied an offset of two degrees in right ascension to each object and paired them with objects in the Revised NLTT catalog of Salim & Gould (2003), yielding a catalog of purely chance associations. The result of this comparison is shown in Figure 2 along with LHS 2803 B. It is clear that LHS 2803 B lies in the region of the diagram devoid of chance associations. LHS 2803 B also has a significantly higher proper motion than the bulk of the chance associations. Given that the probability of chance alignment falls with increasing proper motion, it would seem highly unlikely that this is a coincidence of two unassociated objects.

3. FOLLOW-UP OBSERVATIONS

3.1. UKIRT/WFCAM

As part of our follow-up program for candidate T dwarfs identified in PS1, we imaged LHS 2803B on 2011 May 27 (UT) using the WFCAM instrument (Casali et al. 2007) on the UKIRT located on Mauna Kea, Hawaii. Observations were taken in Y_{MKO}, J_{MKO}, H_{MKO}, and K_{MKO} using a five-point dither pattern and 5 s integration times per dither in Y_{MKO}, J_{MKO}, and H_{MKO} and 10 s integrations per dither in K_{MKO}. The observations were reduced at the Cambridge Astronomical Survey Unit using the

[7] This object was independently discovered by Muzic et al. (2012).
[8] http://simbad.u-strasbg.fr

Table 1
The Two Components of the LHS 2803 System

	LHS 2803A	LHS 2803B
Position (J2000)	13 48 07.218–13 44 32.13[a]	13 48 02.90–13 44 07.1[a]
Epoch (UT)	2001-01-25[a]	2001-01-25[a]
$\mu_\alpha \cos(\delta)$ (arcsec yr^{-1})	-0.675 ± 0.005[b]	-0.660 ± 0.008[c]
μ_δ (arcsec yr^{-1})	-0.503 ± 0.005[b]	-0.543 ± 0.008[c]
V (mag)	15.098 ± 0.008[d]	...
$V - R$ (mag)	1.303 ± 0.004[d]	...
$R - I$ (mag)	3.044 ± 0.011[d]	...
z_{P1} (AB mag)	...	21.0 ± 0.2[e]
y_{P1} (AB mag)	...	19.17 ± 0.12[e]
J_{2MASS} (mag)	10.41 ± 0.03[a]	16.48 ± 0.12[a]
H_{2MASS} (mag)	9.94 ± 0.02[a]	16.09 ± 0.17[a]
$K_{S,2MASS}$ (mag)	9.66 ± 0.02[a]	<16.45[a]
Y_{MKO} (mag)	...	17.49 ± 0.05[c]
J_{MKO} (mag)	...	16.39 ± 0.02[c]
H_{MKO} (mag)	...	16.57 ± 0.04[c]
K_{MKO} (mag)	...	16.90 ± 0.08[c]
$W1$ (mag)	9.46 ± 0.02[f]	16.15 ± 0.07[f]
$W2$ (mag)	9.24 ± 0.02[f]	14.18 ± 0.05[f]
$W3$ (mag)	9.11 ± 0.03[f]	<12.1[f]
$W4$ (mag)	8.7 ± 0.3[f]	<9.1[f]
Photometric distance (pc)	21 ± 3[d]	24^{+5}_{-4} pc[c]
$T_{\rm eff}$ (K)	2940 ± 60[g]	1100[h]
		1120 ± 80[i]
Spectral type	$M4.5 \pm 0.5$[c]	$T5.5 \pm 0.5$[c]

Notes.
[a] Skrutskie et al. (2006).
[b] Salim & Gould (2003).
[c] This work.
[d] Reid et al. (2003).
[e] Zero points are calibrated to the PS1 AB magnitude system using the ubercal analysis of Schlafly et al. (2012), in which photometric data are identified and tied together via overlaps, with nightly zero points allowed to vary. Additional non-photometric exposures are tied to the ubercal system via relative photometry overlaps (E. A. Magnier et al. in preparation). The overall system zero points are set to place the photometry on the AB system using photometry of spectrophotometric standards (Tonry et al. 2012).
[f] Wright et al. (2010) and Cutri et al. (2012).
[g] Casagrande et al. (2008).
[h] This work, atmospheric model comparison.
[i] This work, evolutionary model comparison.

WFCAM reduction pipeline (Irwin et al. 2004; Hodgkin et al. 2009). The resulting photometry is shown in Table 1.

3.2. NASA IRTF/SpeX

We obtained spectroscopic observations of LHS 2803 B using the low-resolution prism mode of the SpeX instrument (Rayner et al. 2003) on the NASA Infrared Telescope Facility (IRTF) on 2011 May 14 UT. This was done prior to our UKIRT observing run. LHS 2803B was selected for spectroscopic follow-up without near-IR photometry due to its red $z - y$ color, a reliable indicator of an object being a T dwarf (Deacon et al. 2011). Conditions were good during our observations with 0$''$.8 seeing, hence the 0.8×15 arcsec slit was used. LHS 2803 B was observed at an airmass of 1.44 with a total integration time of 900 s. Individual observations of 90 s were taken with the telescope nodded in an ABBA pattern to allow for sky subtraction. The slit was oriented to the parallactic angle to minimize atmospheric dispersion. The data were extracted, telluric corrected, and flux calibrated using a contemporaneously observed A0V star and the SpeXTool software package (Cushing et al. 2004; Vacca et al. 2003).

Table 2
Near-infrared Spectral Measurements for LHS2803B

H2O-J	CH4-J	H2O-H	CH4-H	CH4-K	Avg/rms	Visual	Final
0.180	0.387	0.279	0.407	0.263	$T5.3 \pm 0.5$	T5.5	T5.5

The resulting spectrum is shown in Figure 3 and has a spectral resolution of 82.

3.3. Spectral Classification

LHS 2803B was classified using the flux indices of Burgasser et al. (2006; see Figure 3) and the polynomial relations of Burgasser (2007). The individual ratios are given in Table 2. This resulted in a spectral type of $T5.3 \pm 0.5$. Additionally, the spectrum was visually compared with IRTF/SpeX prism data for the spectral standards from Burgasser et al. (2006), resembling an intermediate type between T5 and T6. Hence, we assign a final spectral type of T5.5 to LHS 2803B.

3.4. UH 2.2 m/SNIFS

Compared to most primary stars of benchmark brown dwarfs, LHS 2803 A is a relatively poorly studied object. The only

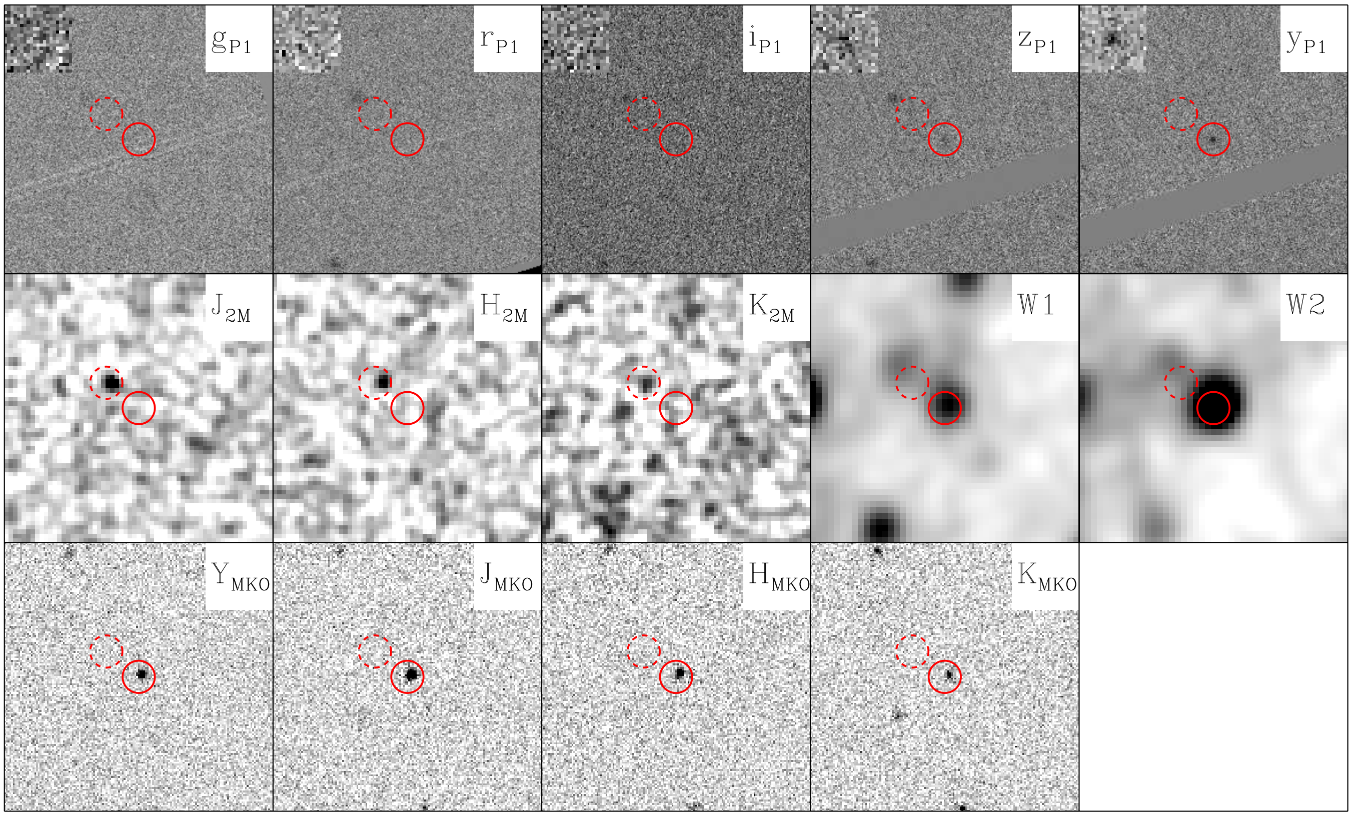

Figure 1. Images of LHS 2803B in different filters from Pan-STARRS1 (g_{P1}, r_{P1}, i_{P1}, z_{P1}, y_{P1}), 2MASS (J, H, K_s), *WISE* ($W1$, $W2$), and UKIRT ($Y_{\rm MKO}$, $J_{\rm MKO}$, $H_{\rm MKO}$, $K_{\rm MKO}$). The red circles are centered on the Pan-STARRS1 position (center, solid circles, epoch 2011.06) and the 2MASS position (dashed circle, epoch 2001.07). Images are 1 arcmin across, with north up and east left. LHS 2803B was not detected in the g_{P1}, r_{P1}, and i_{P1} bands.

(A color version of this figure is available in the online journal.)

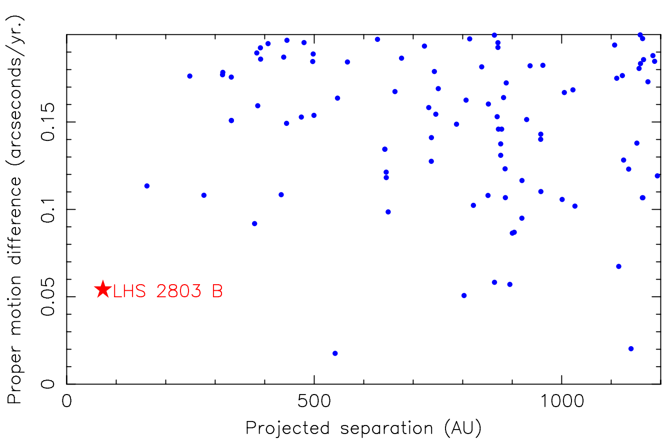

Figure 2. Comparison of the separation and proper motion difference of the LHS 2803 system (red star) with blue dots showing the chance alignments of objects in our Pan-STARRS1 T dwarf search with stars in the Revised NLTT catalog (Salim & Gould 2003). The change alignments are produced using the method of Lépine & Bongiorno (2007). The LHS 2803 system clearly lies in a region of the diagram not occupied by chance alignments.

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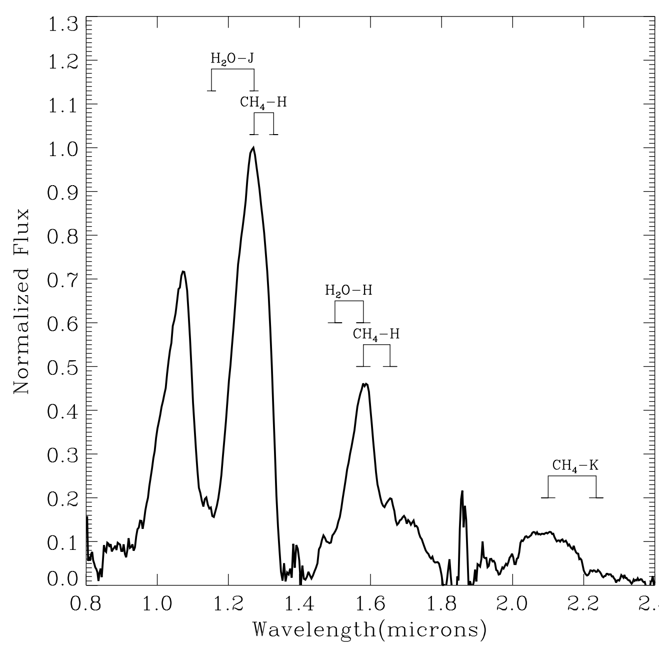

Figure 3. Near-infrared prism spectrum of LHS 2803B. The marked molecular bands (Burgasser et al. 2006) were used along with visual comparison in the spectral typing of the object. LHS 2803B was assigned a spectral type of T5.5.

detailed study of the object comes from Casagrande et al. (2008) who use broadband photometry from Reid et al. (2003) to estimate an effective temperature of 2942 ± 58 K.

In order to better classify LHS 2803 A, we obtained an optical spectrum on 2012 April 19 UT in photometric conditions using the SuperNova Integral Field Spectrograph (SNIFS; Lantz 2004) on the University of Hawaii 2.2 m telescope atop Mauna Kea. SNIFS is an optical integral field spectrograph with $R = 1000$–1300 that separates the incoming light with a dichroic mirror into blue (3000–5200 Å) and red (5200–9500 Å) channels. A single 370 s exposure of the science target at airmass

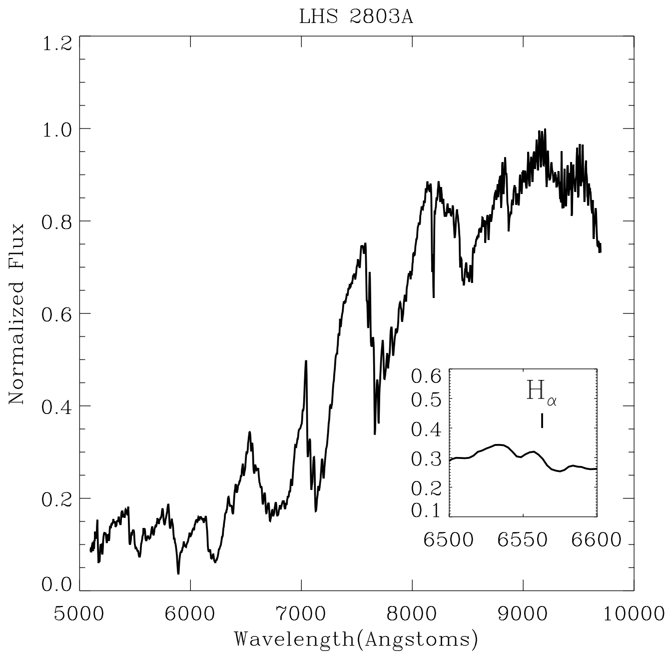

Figure 4. Optical spectrum of LHS 2803A. The inset shows the Hα region of the spectrum, where there is no strong emission line. The measured equivalent width of the Hα is 0.06 ± 0.33 Å. Clearly, this object cannot be considered to be active. Using the spectral typing scheme of Lépine et al. (2003), we classify this star to be an M4.5 dwarf with an error of 0.5 subclasses.

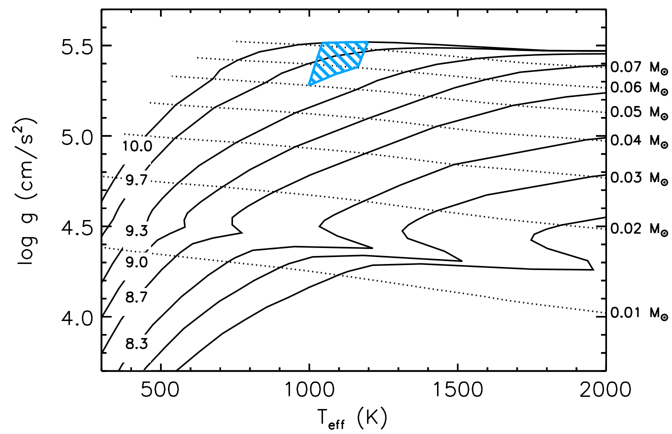

Figure 5. Our derived age and bolometric luminosity for LHS 2803B plotted against the evolutionary models of Burrows et al. (1997). The blue-colored hatched area indicates the constraints on the parameters given the uncertainties on $M_{\rm bol}$ and the age of the primary. Solid lines mark isochrones with the annotated values of log(age). The two unmarked isochrones at the bottom are log(age) = 8.0 and 7.7. The dotted lines represent lines of equal mass with the corresponding values noted at their intersection with the right-hand y-axis.

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1.24 was sufficient to achieve a high signal-to-noise ratio (∼150) in the red channel. SNIFS data processing was performed with the SNIFS data reduction pipeline, which is described in detail in Bacon et al. (2001) and Aldering et al. (2006). SNIFS processing included dark, bias, and flat-field corrections, assembling the data into red and blue three-dimensional data cubes, and cleaning them for cosmic rays and bad pixels. Wavelengths were calibrated with arc lamp exposures taken at the same telescope pointing as the science data. The calibrated spectrum was then sky-subtracted, and a one-dimensional (1D) spectrum was extracted using a point-spread function model. Corrections were applied to the 1D spectrum for instrument response and telluric lines based on observations of the spectrophotometric standards HZ 21 and Feige 34 (Oke 1990), both taken within one hour of the science exposure.

The spectrum was shifted to zero radial velocity by cross-correlating it with templates from Bochanski et al. (2007). The spectral type was determined to be M4.5 ± 0.5 following the technique of Lépine et al. (2003), which is based on empirical relations between spectral type and the spectral indices: TiO5, CaH2, CaH3 (Reid et al. 1995), VO1 (Hawley et al. 2002), and TiO6 (Lépine et al. 2003). This makes LHS 2803A marginally later-type than Wolf 940A (M4; Reid et al. 1995), the latest previously known star with a wide (>100 AU) T dwarf companion (Burningham et al. 2009).

4. DISCUSSION

Using our spectral classification of T5.5, together with our UKIRT $Y_{\rm MKO}$, $J_{\rm MKO}$, $H_{\rm MKO}$, and $K_{\rm MKO}$ photometry, we calculated the photometric parallaxes of LHS 2803B using the relations of Dupuy & Liu (2012). These yielded distances of $d_Y = 24^{5}_{4}$ pc, $d_J = 23^{5}_{4}$ pc, $d_H = 23^{5}_{4}$ pc, and $d_K = 26^{4}_{3}$ pc. We adopt the Y-band distance (one of the median distances) of 24^{5}_{4} pc as our final distance to LHS 2803B.

4.1. Characterizing LHS 2803 A

One of the key indicators of youth in M dwarfs is Hα emission. We measure the equivalent width of the Hα line to be 0.06 ± 0.33 Å, indicating that this star is not chromospherically active (see the inset in Figure 4). We compared this result and our derived spectral type of M4.5 ± 0.5 with the activity lifetimes listed by West et al. (2008). Hence, we take the lower age bound for an M4 star of 3.5 Gyr as being the lower age bound of LHS 2803 A. This lower age bound comes with two caveats. First, the activity lifetimes were calculated using the bulk properties of populations of stars at different Galactic scale heights. It is possible that individual objects may be older/younger than the quoted activity lifetime and still be active/inactive. Second, the activity-lifetime–spectral-type relation changes rapidly around M5. If LHS 2803 A is on the later end of the uncertainty for our spectral type, then it would have a substantially older lower age bound (6.5 Gyr for an M5).

We also measured the metallicity index ζ (originally derived by Lepine et al. 2007, here we use the definition of Dhital et al. 2012) to be 1.02. This, combined with a TiO5 equivalent width of 0.36, indicated that the object is an M dwarf and not significantly metal poor (see Figure 7 of Dhital et al. 2012).

Unfortunately, LHS 2803 has no trigonometric parallax measurement in the literature. However, Reid et al. (2003) calculate a photometric distance of 20.9 pc. They do not quote an error on individual distances; however, they estimate their errors to be in the 0.25–0.35 mag range. Taking the middle of this range, we adopt a photometric distance of 21 ± 3 pc as the distance to LHS 2803. This distance implies that the system has a separation of 1400 ± 200 AU and compares well with our calculated photometric distance for LHS 2803B of 24^{5}_{4} pc.

Using Reid et al. (2003)'s photometric distance estimate along with the proper motion from Salim & Gould (2003) gives a tangential velocity of 83 ± 12 km s^{-1}. Comparing this value with the conditions set out in Dupuy & Liu (2012) for kinematic population membership, we determine that LHS 2803A is most likely a member of the thin disk. Thus, its age is likely less than 10 Gyr.

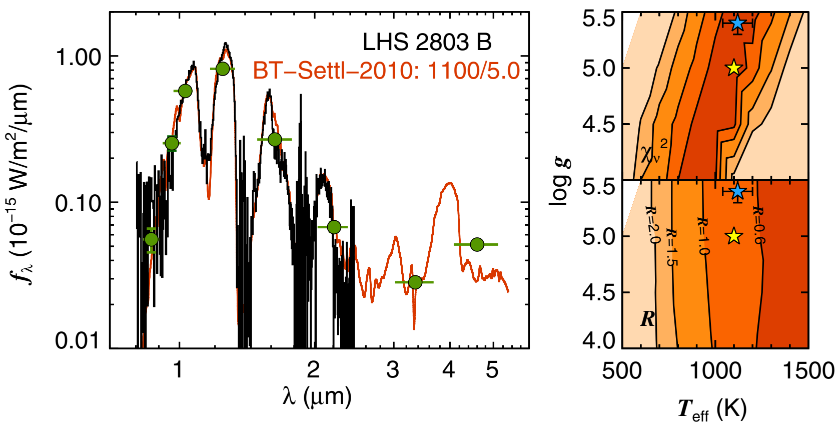

Figure 6. Comparison of the best-fit BT-Settl-2010 model spectrum (red) to our SpeX/prism spectrum of LHS 2803B (black), and 0.8–5 μm photometry (green). The *z*- and *y*-band photometry are from PS1, the *YJHK* photometry are from our UKIRT observations, and the 3.3 and 4.6 μm photometry are from *WISE* (Wright et al. 2010). Zero-point flux densities for PS1, UKIRT, and *WISE* are from Tonry et al. (2012), Hewett et al. (2006), and Wright et al. (2010), respectively. The photometric uncertainties are smaller than the size of the symbols. Right: reduced χ^2 surface of the model atmosphere fitting (top) and the inferred radius (in R_{Jup}) from the fits (bottom; see Bowler et al. 2009 for details). Yellow stars show the best-fitting model atmosphere parameters and blue stars show the results from evolutionary models. The best-fit parameters are within one grid step of the evolutionary model predictions.

(A color version of this figure is available in the online journal.)

4.2. Comparison of LHS 2803B with Evolutionary Models

Using the Reid et al. (2003) photometric distance, we derived an absolute *H*-band magnitude in the MKO system for LHS 2803B of 15.0 ± 0.3 mag. Applying the bolometric correction relation from Liu et al. (2010) gives a bolometric magnitude of 17.4 ± 0.3 mag. We then compared this value along with our range of ages for the primary (3.5–10.0 Gyr) to the evolutionary models of Burrows et al. (1997). The resulting constraints on the effective temperature and gravity of LHS 2803B are shown in Figure 5. We also ran Monte Carlo models using our estimated bolometric luminosity and a uniform distribution of ages across our estimated age range. This predicted an effective temperature in the range 1120 ± 80 K and showed that LHS 2803B appears to be a relatively high mass brown dwarf with $m = 72^{+4}_{-7}\ M_{Jup}$ and $\log g = 5.4 \pm 0.1$ dex.

4.3. Comparison of LHS 2803B with Atmospheric Models

We fit the solar metallicity BT-Settl-2010 models (Allard et al. 2011) to our SpeX/prism spectrum of LHS 2803B following the χ^2 minimization technique described in Cushing et al. (2008) and Bowler et al. (2009). The spectrum was first flux calibrated to the UKIDSS *J*-band photometry, which is the most precise of the UKIDSS photometric measurements for LHS 2803B. We use the 0.8–2.4 μm region in the fits, but exclude the 1.60–1.65 μm window because of incomplete methane line lists in the models (Saumon et al. 2007) and also the 1.80–1.95 μm region, which suffers from strong telluric absorption. The grid of 42 models spans effective temperatures from 500 to 1500 K with 100 K intervals and $\log g$ from 4.0 to 5.5 dex in steps of 0.5 dex. The prism spectrum contains 387 data points, which dominates the selection of the best-fitting model, over the small number of photometric measurements (like PS1 or *WISE*). Hence, we did not use the photometric data points in our model spectrum selection process.

The best-fit model atmosphere has $T_{eff} = 1100$ K and $\log g = 5.0$. Given the relatively coarse grid spacing of the models, this result agrees quite well with the predictions from evolutionary models ($T_{eff} = 1120$ K ± 80 K, $\log g = 5.4 \pm 0.1$). Fits to the T4.5 companion HD 38939B in Deacon et al. (2012) using the same fitting technique and model atmospheres also resulted in best-fit parameters that were within one grid step of the evolutionary model predictions. Figure 6 shows the best-fit model compared to the prism spectrum and the 0.8–5 μm photometry. The model is an excellent match to the near-infrared data, but disagrees with the *WISE* *W*2-band photometry.

5. CONCLUSIONS

We have identified a common proper motion companion to the M dwarf LHS 2803. Spectroscopic observations classify the primary as M4.5 ± 0.5 and the secondary as T5.5 ± 0.5. Based on the literature photometric distance of 21 ± 3 pc, we calculate a projected separation of 1400 ± 200 AU. This system is among the widest known substellar companions to an M dwarf. We use the primary's lack of Hα emission to set a lower limit of 3.5 Gyr on the system age and its disk kinematics and approximately solar metallicity to set an upper age bound of 10 Gyr. Based on this age range, evolutionary model calculations indicate that the secondary has $T_{eff} = 1120 \pm 80$ K and $\log g = 5.4 \pm 0.1$ with a mass of $72^{+4}_{-7}\ M_{Jup}$, suggesting a relatively old, higher gravity object close to the maximum possible mass for a T dwarf. Comparing atmospheric models to our near-IR spectrum gives a best fit of 1100 K and $\log g = 5.0$, within one grid point of our evolutionary model calculations. The effective temperatures from the evolutionary and atmospheric models are in good agreement, in common with the similar benchmark mid-T dwarfs HN Peg B and HIP 38939 B (Deacon et al. 2012). PS1 is ideally suited for identifying substellar companions to nearby stars, and a dedicated effort is underway to identify such objects.

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REFERENCES

Albert, L., Artigau, E., Delorme, P., et al. 2011, AJ, 141, 203
Aldering, G., Antilogus, P., Bailey, S., et al. 2006, ApJ, 650, 510
Allard, F., Homeier, D., & Freytag, B. 2011, in ASP Conference Series, Vol. 448, Model Atmospheres From Very Low Mass Stars to Brown Dwarfs, ed. C. M. Johns-Krull, M. K. Browning, & A. A. West (San Francisco, CA: ASP), 91
Bacon, R., Copin, Y., Monnet, G., et al. 2001, MNRAS, 326, 23
Biller, B. A., Kasper, M., Close, L. M., Brandner, W., & Kellner, S. 2006, ApJ, 641, L141
Bochanski, J. J., West, A. A., Hawley, S. L., & Covey, K. R. 2007, AJ, 133, 531
Bowler, B. P., Liu, M. C., & Cushing, M. C. 2009, ApJ, 706, 1114
Burgasser, A. J. 2007, ApJ, 659, 655
Burgasser, A. J., Geballe, T. R., Leggett, S. K., Kirkpatrick, J. D., & Golimowski, D. A. 2006, ApJ, 637, 1067
Burgasser, A. J., Kirkpatrick, J. D., Cutri, R. M., et al. 2000, ApJ, 531, L57
Burgasser, A. J., Kirkpatrick, J. D., & Lowrance, P. J. 2005, AJ, 129, 2849
Burningham, B., Pinfield, D. J., Leggett, S. K., et al. 2009, MNRAS, 395, 1237
Burrows, A., Marley, M., Hubbard, W. B., et al. 1997, ApJ, 491, 856
Casagrande, L., Flynn, C., & Bessell, M. 2008, MNRAS, 389, 585
Casali, M., Adamson, A., Alves de Oliveira, C., et al. 2007, A&A, 467, 777
Chomiuk, L., Chornock, R., Soderberg, A. M., et al. 2011, ApJ, 743, 114
Cushing, M. C., Kirkpatrick, J. D., Gelino, C. R., et al. 2011, ApJ, 743, 50
Cushing, M. C., Marley, M. S., Saumon, D., et al. 2008, ApJ, 678, 1372
Cushing, M. C., Vacca, W. D., & Rayner, J. T. 2004, PASP, 116, 362
Cutri, R. M., Wright, E. L., Conrow, T., et al. 2012, WISE All-Sky Data Release (Cutri + 2012)
Day-Jones, A. C., Pinfield, D. J., Ruiz, M. T., et al. 2011, MNRAS, 410, 705
Deacon, N. R., Liu, M. C., Magnier, E. A., et al. 2011, AJ, 142, 77
Deacon, N. R., Liu, M. C., Magnier, E. A., et al. 2012, ApJ, 755, 94
Dhital, S., West, A. a., Stassun, K. G., et al. 2012, AJ, 143, 67
Dupuy, T. J., & Liu, M. C. 2011, ApJ, 733, 122
Dupuy, T. J., & Liu, M. C. 2012, ApJ, 201, 19
Faherty, J. K., Burgasser, A. J., West, A. A., et al. 2010, AJ, 139, 176
Goldman, B., Marsat, S., Henning, T., Clemens, C., & Greiner, J. 2010, MNRAS, 405, 1140
Hambly, N., MacGillivray, H. T., Read, M. A., et al. 2001, MNRAS, 326, 1279
Hawley, S. L., Covey, K. R., Knapp, G. R., et al. 2002, AJ, 123, 3409
Hewett, P. C., Warren, S. J., Leggett, S. K., & Hodgkin, S. T. 2006, MNRAS, 367, 454
Hodgkin, S. T., Irwin, M. J., Hewett, P. C., & Warren, S. J. 2009, MNRAS, 394, 675
Hsieh, H. H., Yang, B., Haghighipour, N., et al. 2012, ApJ, 748, L15
Irwin, M. J., Lewis, J., Hodgkin, S., et al. 2004, Proc. SPIE, 5493, 411
Kaiser, N., Aussel, H., Burke, B. E., et al. 2002, Proc. SPIE, 4836, 154
Kirkpatrick, J. D., Gelino, C. R., Cushing, M. C., et al. 2012, ApJ, 753, 156
Lantz, B. 2004, Proc. SPIE, 5249, 146
Lawrence, A., Warren, S. J., Almaini, O., et al. 2007, MNRAS, 379, 1599
Lépine, S., & Bongiorno, B. 2007, AJ, 133, 889
Lépine, S., Rich, R. M., & Shara, M. M. 2003, AJ, 125, 1598
Lepine, S., Rich, R. M., & Shara, M. M. 2007, ApJ, 669, 1235
Liu, M. C., Deacon, N. R., Magnier, E. A., et al. 2011, ApJ, 740, L32
Liu, M. C., Dupuy, T. J., & Ireland, M. J. 2008, ApJ, 689, 436
Liu, M. C., Dupuy, T. J., & Leggett, S. K. 2010, ApJ, 722, 311
Lodieu, N., Deacon, N. R., & Hambly, N. C. 2012, MNRAS, 422, 1495
Luhman, K. L., Burgasser, A. J., & Bochanski, J. J. 2011, ApJ, 730, L9
Luhman, K. L., Patten, B. M., Marengo, M., et al. 2007, ApJ, 654, 570
Luyten, W. J. 1979, LHS Catalogue. A Catalogue of Stars with Proper Motions Exceeding 0"5 Annually (Minneapolis, MN: Univ. Minnesota)
McCaughrean, M. J., Close, L. M., Scholz, R.-D., et al. 2004, A&A, 413, 1029
Monet, D. G., Levine, S. E., Canzian, B., et al. 2003, AJ, 125, 984
Mugrauer, M., Seifahrt, A., Neuhäuser, R., & Mazeh, T. 2006, MNRAS, 373, L31
Murray, D. N., Burningham, B., Jones, H. R. A., et al. 2011, MNRAS, 414, 575
Muzic, K., Radigan, J., Jayawardhana, R., et al. 2012, ApJ, submitted (arXiv:1205.0818)
Nakajima, T., Oppenheimer, B. R., Kulkarni, S. R., et al. 1995, Nature, 378, 463
Oke, J. B. 1990, AJ, 99, 1621
Pinfield, D. J., Burningham, B., Lodieu, N., et al. 2012, MNRAS, 422, 1922
Pinfield, D. J., Burningham, B., Tamura, M., et al. 2008, MNRAS, 390, 304
Rayner, J. T., Toomey, D. W., Onaka, P. M., et al. 2003, PASP, 115, 362
Reid, I. N., Cruz, K. L., Allen, P., et al. 2003, AJ, 126, 3007
Reid, I. N., Hawley, S. L., & Gizis, J. E. 1995, AJ, 110, 1838
Salim, S., & Gould, A. 2003, ApJ, 582, 1011
Saumon, D., & Marley, M. S. 2008, ApJ, 689, 1327
Saumon, D., Marley, M. S., Leggett, S. K., et al. 2007, ApJ, 656, 1136
Schlafly, E., Finkbeiner, D., & Juric, M. 2012, ApJ, accepted (arXiv:1201.2208)
Scholz, R.-D. 2010, A&A, 510, L8
Scholz, R.-D., Bihain, G., Schnurr, O., & Storm, J. 2011, A&A, 532, L5
Scholz, R.-D., McCaughrean, M. J., Lodieu, N., & Kuhlbrodt, B. 2003, A&A, 398, L29
Skrutskie, M. F., Cutri, R. M., Stiening, R., et al. 2006, AJ, 131, 1163
Thalmann, C., Carson, J., Janson, M., et al. 2009, ApJ, 707, L123
Tonry, J. L., Stubbs, C. W., Lykke, K. R., et al. 2012, ApJ, 750, 99
Vacca, W. D., Cushing, M. C., & Rayner, J. T. 2003, PASP, 115, 389
West, A. a., Hawley, S. L., Bochanski, J. J., et al. 2008, AJ, 135, 785
Wilson, J. C., Kirkpatrick, J. D., Gizis, J. E., et al. 2001, AJ, 122, 1989
Wright, E. L., Eisenhardt, P. R. M., Mainzer, A. K., et al. 2010, AJ, 140, 1868