ULAS J141623.94+134836.3: A BLUE T DWARF COMPANION TO A BLUE L DWARF

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ABSTRACT

We confirm the substellar nature of ULAS J141623.94+134836.3 (aka SDSS J1416+1348B), a common proper motion companion to the blue L dwarf SDSS J141624.08+134826.7 identified by Burningham et al. and Scholz. Low-resolution 0.8–2.4 μm spectroscopy obtained with the Infrared Telescope Facility/SpeX shows strong H2O and CH4 absorption bands, consistent with a T7.5 spectral type, and we see possible indications of NH3 absorption in the 1.0–1.3 μm region. More importantly, the spectrum of SDSS J1416+1348B shows a broadened Y-band peak and highly suppressed K-band flux, both indicative of high surface gravity and/or subsolar metallicity. These traits are verified through spectral model fits, from which we derive atmospheric parameters $T_{\text{eff}} = 650 \pm 60$ K, $\log g = 5.2 \pm 0.4$ cgs, $[\text{M}/\text{H}] \leq -0.3$, and $K_{\text{c}} = 10^4$ cm$^2$ s$^{-1}$, the temperature being significantly warmer than that estimated by Burningham et al. These fits also indicate a model-dependent spectroscopic distance of $10.6^{+3.0}_{-2.8}$ pc for SDSS J1416+1348B, formally consistent with the $7.9 \pm 1.7$ pc astrometric distance for SDSS J1416+1348A from Scholz. The common peculiarities of these two co-spatial, co-moving sources suggest that their unusual blue colors—and those of other blue L and T dwarfs in general—arise from age/gravity or metallicity effects, rather than cloud properties alone.

Key words: binaries: visual – brown dwarfs – stars: fundamental parameters – stars: individual (SDSS J141624.08+134826.7, ULAS J141623.94+134836.3) – stars: low-mass

Online-only material: color figures

1. INTRODUCTION

Over the past 15 years, well over 500 brown dwarf members of the late-M, L, and T dwarf spectral classes have been identified in various Galactic environments, encompassing a broad diversity in color, spectral properties, and physical characteristics (Kirkpatrick 2005, and references therein). Sustained effort has been made to identify the coldest of these sources, which encompass the low-mass extremity of star formation and primordial relics of the Galactic halo population. The most recent discoveries made with the Two Micron All Sky Survey (2MASS; Cutri et al. 2003; Skrutskie et al. 2006), the UKIRT Infrared Deep Sky Survey (UKIDSS; Lawrence et al. 2007), and the Canada–France Brown Dwarf Survey (CFBDS; Delorme et al. 2008b) have extended the known population down to and below effective temperatures $T_{\text{eff}} \approx 600$ K (e.g., Warren et al. 2007; Burningham et al. 2008, 2009; Burgasser et al. 2008b; Delorme et al. 2008a; Leggett et al. 2009). This has raised the question as to where the currently coldest class of brown dwarfs (the T dwarfs) ends and the next cooler class (the Y dwarfs) might begin. Such exceedingly dim and cold sources are predicted to encompass several major chemical transitions in brown dwarf atmospheres, including the disappearance of Na and K into salt condensates, the emergence of strong NH3 absorption across the infrared band, and the formation of photospheric water ice clouds (e.g., Marley et al. 1999; Lodders 1999; Lodders & Fegley 2002; Burrows et al. 2003). Accordingly, there is considerable interest and controversy as to how to delineate this putative class; see discussions by Leggett et al. (2007), Burningham et al. (2008), and Delorme et al. (2008a).

A promising low-temperature brown dwarf candidate was recently identified by Burningham et al. (2010) and Scholz (2010) as a co-moving companion to the nearby blue L6 dwarf SDSS J141624.08+134826.7 (hereafter SDSS J1416+1348A; Bowler et al. 2010; Schmidt et al. 2010; Kirkpatrick et al. 2010). The object, ULAS J141623.94+134836.3 (hereafter SDSS J1416+1348B), was identified in UKDSS as a faint ($J = 17.35 \pm 0.02$) and unusually blue ($J - K = -1.58 \pm 0.17$) near-infrared source separated by 9′ from the L dwarf. Using astrometry from 2MASS, UKIDSS, the Sloan Digital Sky Survey Data Release 7 (SDSS DR7; York et al. 2000; Abazajian et al. 2009), and follow-up imaging, both Burningham et al. (2010) and Scholz (2010) were able to confirm common proper motion of this pair. Scholz (2010) also determined an astrometric distance to the primary of $7.9 \pm 1.7$ pc, consistent with spectrophotometric estimates from Bowler et al. (2010, 6.5–10.7 pc) and Schmidt et al. (2010, 6.4–9.6 pc). At this distance, the (poorly constrained) absolute magnitudes of SDSS J1416+1348B, $M_J = 17.8 \pm 0.5$ and $M_K = 19.4 \pm 0.5$, are equivalent to or fainter than those of the latest-type brown dwarfs with measured distances, Wolf 940B ($M_J = 17.68 \pm 0.28$ and $M_K = 18.37 \pm 0.28$; Burningham et al. 2009) and ULAS J003402.77−005206.7 ($M_J = 17.65 \pm 0.11$ and $M_K = 17.98 \pm 0.12$; Warren et al. 2007; Smart et al. 2010). Burningham et al. (2010) report a 1.0–2.5 μm spectrum of SDSS J1416+1348B, identifying it as a T7.5 brown dwarf with highly suppressed K-band flux. Indeed, SDSS J1416+1348B is the bluest T dwarf in $J - K$ color identified to date, matching the unusually blue nature of its L dwarf companion. Spitzer photometry reported in Burningham et al. (2010) further suggests an exceptionally...
low-temperature ($T_{\text{eff}} \approx 500$ K), metal-poor ([M/H] $\approx -0.3$), and high surface gravity atmosphere ($\log g \approx 5.0-5.3$ cgs).

In this paper, we report our measurements of the near-infrared spectrum of SDSS J1416+1348B obtained with the NASA Infrared Telescope Facility (IRTF) SpeX spectrograph (Rayner et al. 2003). This spectrum encompasses the 0.8–2.4 $\mu$m region, including the metallicity-sensitive $Y$-band peak. The unusual shape of this and the $K$-band flux peak, along with fits to spectral models, affirm the interpretation of this source as a metal-poor, high surface gravity T7.5 brown dwarf, albeit with a $T_{\text{eff}}$ that is significantly warmer than that reported by Burningham et al. (2010). In Section 2 we describe our observations and discuss the spectral properties of SDSS J1416+1348B, including its classification, spectral anomalies, and possible indications of NH$_3$ absorption in the 1.0–1.3 $\mu$m region. In Section 3 we present our spectral model fits to the data and corresponding atmospheric parameters, as well as a model-dependent spectroscopic distance that is in accord with the astrometric distance of the primary. We discuss the relevance of this system with regard to the nature of blue L and T dwarfs in Section 4. Results are summarized in Section 5.

2. NEAR-INFRARED SPECTROSCOPY

2.1. Observations and Data Reduction

Low-resolution near-infrared spectral data for SDSS J1416+1348B were obtained with SpeX on 2010 January 23 (UT) in mostly clear skies with some light cirrus and 0.8" seeing. We used the SpeX prism mode with the 0.5" slit aligned to the parallactic angle for all observations, providing 0.7–2.5 $\mu$m coverage in a single order with resolution $R \approx \lambda/\Delta\lambda \approx 120$ and dispersion of 20–30 A pixel$^{-1}$. SDSS J1416+1348B was acquired with the slit viewing camera using the $J$-band filter and guiding was performed on the nearby primary. A total of 34 exposures of 180 s each were obtained in ABBA dither pairs, nodding along the slit. The first 16 exposures of the source were obtained over an airmass range of 1.28–1.41. We then observed the A0 V star HD 121880 ($V = 7.59$) at an airmass of 1.12 for flux calibration and telluric absorption correction, as well as internal and instrumental response corrections were determined from the A0 V spectrum following the method of Vacca et al. (2003), with line-shape kernels derived from the arc lines and adjustments made to the H1 line strengths and wavelength scale, as outlined in Cushing et al. (2004).

2.2. The Spectrum of SDSS J1416+1348B

The reduced spectrum of SDSS J1416+1348B is shown in Figure 1, compared to equivalent data for the T8 dwarfs 2MASS J0415–0935 (red line; Burgasser et al. 2004) and 2MASS J0939–2448 (blue line; Burgasser et al. 2006b). All three spectra are normalized at 1.27 $\mu$m, and the corresponding noise spectrum for SDSS J1416+1348B is indicated by the light gray line. Prominent H$_2$O and CH$_4$ absorption features are labeled, as well as the region influenced by the pressure-broadened K$_{\text{I}}$ doublet wing ($\lambda \lesssim 1$ $\mu$m) and collision-induced H$_2$ opacity ($\lambda \gtrsim 1.75$ $\mu$m).

Figure 1. SpeX prism spectrum of SDSS J1416+1348B (black line) compared to equivalent data for the T8 dwarfs 2MASS J0415–0935 (red line; Burgasser et al. 2004) and 2MASS J0939–2448 (blue line; Burgasser et al. 2006b). All three spectra are normalized at 1.27 $\mu$m, and the corresponding noise spectrum for SDSS J1416+1348B is indicated by the light gray line. Prominent H$_2$O and CH$_4$ absorption features are labeled, as well as the region influenced by the pressure-broadened K$_{\text{I}}$ doublet wing ($\lambda \lesssim 1$ $\mu$m) and collision-induced H$_2$ opacity ($\lambda \gtrsim 1.75$ $\mu$m).

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

What is most remarkable about the spectrum of SDSS J1416+1348B is the breadth of its 1.07 $\mu$m $Y$-band peak in the spectrum of SDSS J1416+1348B is slightly weaker than those of the T8 comparison sources, although the breadth of the $J$- and $H$-band peaks (both shaped by the wings of H$_2$O and CH$_4$ bands) are equivalent to the spectrum of 2MASS J0415–0935. T dwarf classification indices (Burgasser et al. 2006b) indicate a spectral type of T7.5 ± 0.5 for this source, which is also consistent with its NH$_3$-H and $W_J$ indices (Table 1; Warren et al. 2007; Burningham et al. 2008; Delorme et al. 2008a). This classification and most of the spectral indices are in agreement with those determined by Burningham et al. (2010). However, we find a significant disagreement in our measurement of the CH$_4$-$J$ index. Burningham et al. (2010) specifically note this index as anomalous, whereas our value is consistent with the overall spectral classification of SDSS J1416+1348B. As both spectra were obtained at roughly the same resolution ($\lambda/\Delta\lambda \approx 100$), and signal-to-noise ratio of the SpeX data in the $Y$-, $J$-, and $H$-band peaks is good (∼40–70), the origin of this anomaly is unclear.

This value was determined by calculating the colors of 100 realizations of the spectral data, with fluxes varied following a normal distribution of the noise spectrum. We report here the mean and standard deviation of these measures.
2.3. NH₃ Absorption in the 1.0–1.3 μm Region?

In addition to these broad spectral anomalies, we identified several intriguing absorption features around the Y-, J-, and H-band flux peaks in the spectrum of SDSS J1416+1348B. As shown in Figure 2, these features are at 0.997, 1.039, 1.072, 1.232, 1.249, 1.292, 1.302, and 1.570 μm, none of which are present in the late-type T dwarfs with comparable SpeX data. Among these features, the 1.072, 1.232, and 1.570 μm features are also seen in the absorption spectrum of Jupiter (Rayner et al. 2009). Given tentative suggestions of the onset of NH₃ absorption in the near-infrared spectra of the latest-type T dwarfs (Saumon et al. 2000; Leggett et al. 2007; Delorme et al. 2008a), we examined whether any of these features might be coincident with NH₃ opacity. Figure 2 overlays the laboratory transmission function of NH₃ from Irwin et al. (1999), measured at temperatures of 200–300 K and pressures of 0.01–1 bar. Structure in the NH₃ spectrum appears to be coincident with some of the features, most notably the 0.997, 1.039, and prominent 1.072 μm dips in the Y band, and the weaker 1.292 and 1.302 μm dips in the J band. However, strong NH₃ opacity features, such as the 1.01–1.05 μm, 1.19–1.23 μm, and 1.50–1.55 μm bands, are not seen in the data.

There are important caveats to such comparisons of opacity measurements to low-resolution brown dwarf spectra. First, opacity from several species, most notably H₂O and CH₄ gas, blankets the entire near-infrared region, and the resolution of the SpeX data makes it impossible to separate narrow features from these species from coincident absorption arising from NH₃. Second, the laboratory measurements of Irwin et al. (1999) were obtained in very different gas conditions than those that characterize the warmer photospheres of T dwarfs, and are not likely to include the higher angular momentum states expected to be present in brown dwarf spectra. Indeed, Leggett et al. (2007) have shown that current brown dwarf models incorporating the Irwin et al. (1999) opacities predict NH₃ bands that are much stronger than observed, even when nonequilibrium abundances due to vertical mixing are considered (Saumon et al. 2006; Hubeny & Burrows 2007).

In summary, while these features are notable, they cannot be conclusively associated with NH₃ absorption. Higher-resolution spectra coupled with better opacity data are needed to verify their origin.

3. THE PHYSICAL PROPERTIES OF SDSS J1416+1348B

3.1. Qualitative Indicators of High Surface Gravity and Subsolar Metallicity

The broadened Y-band and suppressed K-band peaks in the spectrum of SDSS J1416+1348B are similar in nature to those seen in previously identified, unusually blue T dwarfs, and are indicative of pressure effects related to surface gravity and metallicity (Burgasser et al. 2002, 2006a; Knapp et al. 2004; Chiu et al. 2006; Leggett et al. 2007; Stephens et al. 2009). K-band flux is regulated in part by collision-induced H₂ absorption (Linsky 1969; Saumon et al. 1994; Borysow 2002), which is sensitive to both photospheric gas temperature and pressure. The short wavelength slope of the Y-band peak is shaped by the red wing of the pressure-broadened 0.77 μm K I doublet, which is also modulated by temperature (affecting the K abundance).
and pressure (affecting the pressure-broadened wings; Allard et al. 2003; Burrows & Volobuyev 2003). The \( Y \)-band peak has been specifically noted as being metalliclicity sensitive in comparison of synthetic atmosphere models, becoming both broadened and blueshifted for lower metallicities (Burgasser et al. 2006a; Leggett et al. 2007).

The archetype blue T dwarf, 2MASS J09373487+2931409 (hereafter 2MASS J0937+2931; Burgasser et al. 2002), exhibits the same \( Y \)-band and \( K \)-band anomalies as SDSS J1416+1348B and, importantly, is consistently well matched to models with subsolar metallicities ([M/H] = −0.1 to −0.4) and high surface gravities (log \( g \) = 5.2–5.5; Burgasser et al. 2006a; Geballe et al. 2009). 2MASS J0939−2448 also exhibits these peculiarities (Figure 1), and its near- and mid-infrared spectrum is well matched to subsolar metallicity models as well, although it is additionally suspected of being an unresolved binary (Burgasser et al. 2008b; Leggett et al. 2009). Importantly, the \( Y \)-band and \( K \)-band anomalies are more pronounced in the spectrum of SDSS J1416+1348B than in those of 2MASS J0937+2931 and 2MASS J0939−2448. Our measure of the \( K/J \) index—the relative flux between the \( J \)- and \( K \)-band peaks—is the smallest reported to date: 0.037 ± 0.004 compared to 0.059 for 2MASS J0939−2448 (see Table 6 in Burgasser et al. 2006b and Table 6 in Burningham et al. 2009). These measures suggest that SDSS J1416+1348B is a true outlier in terms of its physical properties.

### 3.2. Comparison to Spectral Models

To quantify these properties, we compared the spectrum of SDSS J1416+1348B to the atmosphere models of Saumon & Marley (2008). We followed the prescriptions detailed in Cushing et al. (2008) and Burgasser et al. (2008b), comparing our SpeX spectrum, flux calibrated to the \( J \)-band photometry reported in Burningham et al. (2010), to models spanning temperatures \( T_{\text{eff}} \) = 500–1000 K (50 K steps); surface gravities \( \log g = 4.0–5.5 \) cgs (0.5 dex steps); metallicities [M/H] = −0.3, 0, and +0.3 dex relative to solar; and vertical diffusion coefficients \( K_{zz} = 0 \) and \( 10^4 \) cm\(^2\) s\(^{-1}\) (see Saumon et al. 2006). The models were smoothed to the resolution of the SpeX data using a Gaussian kernel, and interpolated onto a common wavelength scale. Fits were made exclusively to the 0.9–2.4 \( \mu \)m region. The goodness-of-fit statistic \( G_k \) (Cushing et al. 2008) was used to gauge the agreement between models and data, and we followed the same weighting scheme employed by those authors in which each pixel is weighted by its breadth in wavelength space. Model surface fluxes were scaled by the factor \( e^{-0.5G_k} \). The means and uncertainties of \( T_{\text{eff}} \) and \( \log g \) were determined by Gaussian fits to their respective distributions (see Burgasser et al. 2008b). The [M/H] distribution peaked at the lower limit of the sampled parameter space, while the models slightly favor \( K_{zz} = 10^4 \) cm\(^2\) s\(^{-1}\) over 0 cm\(^2\) s\(^{-1}\).

#### Table 2

| Rank | \( T_{\text{eff}} \) (K) | \( \log g \) (cgs) | [M/H] (dex) | \( K_{zz} \) (cm\(^2\) s\(^{-1}\)) | \( G_k \) | \( d/R \) (pc/R\(_{\text{Jup}}\)) |
|------|----------------|----------------|-----------|----------------|--------|----------------|
| 1\(^a\) | 650 | 5.0 | −0.3 | \( 10^4 \) | 5.70 | 12.8 |
| 2 | 700 | 5.0 | −0.3 | \( 10^4 \) | 5.97 | 15.5 |
| 3 | 700 | 5.0 | −0.3 | \( 10^4 \) | 6.10 | 10.2 |
| 4 | 700 | 5.0 | −0.3 | 0 | 6.53 | 15.4 |
| 5 | 650 | 5.0 | −0.3 | 0 | 6.58 | 12.7 |
| 6 | 600 | 5.5 | 0.0 | \( 10^4 \) | 6.85 | 10.5 |
| 7 | 650 | 5.5 | 0.0 | \( 10^4 \) | 6.88 | 13.0 |
| 8 | 700 | 5.5 | 0.0 | \( 10^4 \) | 7.31 | 15.7 |
| 9 | 600 | 5.0 | −0.3 | 0 | 7.37 | 10.2 |
| 10 | 650 | 5.5 | 0.0 | 0 | 8.01 | 13.3 |

Avg.\(^b\) 650 ± 60 5.2 ± 0.4 \( \leq −0.3 \) \( \sim 10^0 \) \( \cdots \) 12.8 ± 3.0

**Notes.**

\(^a\) Best-fitting model for 1000 synthesized spectra in Monte Carlo simulation; i.e., \( f_{\text{MC}} = 1.000 \) (see Cushing et al. 2008).

\(^b\) Based on the weighted parameter distributions shown in Figure 3. Each model contributes its parameters to the distributions scaled by the factor \( e^{-0.5G_k} \). The means and uncertainties of \( T_{\text{eff}} \) and \( \log g \) were determined by Gaussian fits to their respective distributions (see Burgasser et al. 2008b). The [M/H] distribution peaked at the lower limit of the sampled parameter space, while the models slightly favor \( K_{zz} = 10^4 \) cm\(^2\) s\(^{-1}\) over 0 cm\(^2\) s\(^{-1}\).
metallicity. In fact, the one-sided distribution in our limited model set means that we cannot rule out metallicities less than $-0.3$. The model fits also indicate that some vertical mixing is present, favoring $K_{zz} = 10^4$ cm$^2$ s$^{-1}$ over 0 cm$^2$ s$^{-1}$, although a strict constraint cannot be made.

With respect to surface gravity and metallicity, our fits to the spectrum of SDSS J1416+1348B are in agreement with the estimates of Burgasser et al. (2010), indicating that this unusually blue T dwarf is likely to be old, massive, and metal-poor. The derived $T_{\text{eff}}$ and log $g$ parameters and their uncertainties correspond to an age of 2–10 Gyr and a mass of 0.021–0.045 $M_\odot$ according to the evolutionary models of Baraffe et al. (2003). This age is consistent with membership in the Galactic disk population, as previously suggested by system’s kinematics (Bowler et al. 2010; Schmidt et al. 2010). The subsolar metallicity favored by the model fits is in quantitative agreement with spectral analyses of other blue T dwarfs, as well as characterization of the L dwarf companion, SDSS J1416+1348A, which does not appear to be a full-fledged L subdwarf (Bowler et al. 2010; however, see Kirkpatrick et al. 2010). As such, these fits support our qualitative analysis of the spectrum: the spectral peculiarities and blue color of SDSS J1416+1348B appear to be the result of a higher pressure atmosphere arising from higher surface gravity and subsolar metallicity.

3.3. The $T_{\text{eff}}$ of SDSS J1416+1348B

Our inferred $T_{\text{eff}}$ for SDSS J1416+1348B is somewhat low for T7–T8 dwarfs, which typically have $T_{\text{eff}} \approx 700–900$ K (Golimowski et al. 2004; Vrba et al. 2004; Stephens et al. 2009). This is likely to be a surface gravity and/or metallicity effect. Burgasser et al. (2006a) have previously found that late-type T dwarfs with higher surface gravities tend to have lower $T_{\text{eff}}$s for a given spectral type. Burgasser et al. (2006a) have previously found that late-type T dwarfs with higher surface gravities tend to have lower $T_{\text{eff}}$s for a given spectral type. Burgasser et al. (2006a) have previously found that late-type T dwarfs with higher surface gravities tend to have lower $T_{\text{eff}}$s for a given spectral type. Burgasser et al. (2006a) have previously found that late-type T dwarfs with higher surface gravities tend to have lower $T_{\text{eff}}$s for a given spectral type. Burgasser et al. 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Warren et al. (2007), and has been shown to provide increased sensitivity for the latest-type T dwarfs (Stephens et al. 2009; Leggett et al. 2010). However, Leggett et al. (2009) have noted that metallicity effects are relevant and can shift $H - [4.5]$ to the red by roughly 0.1 mag for every 0.1 dex decrement in metallicity (see also Figure 6 in Burningham et al. 2010).

If SDSS J1416+1348B has a metallicity significantly below $[M/H] = -0.3$ — not ruled out by the present model fits — then this characteristic may have as much to do with its extreme color as its low temperature. It is relevant to note that the $[3.6] - [4.5]$ color of SDSS J1416+1348B, another $T_{\text{eff}}$ indicator (Patten et al. 2006), is not an extremum; this source is in fact bluer than 2MASS J0939–2448.

This may be an indication that the 3.3 μm CH$_4$ band, like the 1.6 μm band, is relatively weak compared to other T8–T9 dwarfs, consistent with a warmer $T_{\text{eff}}$. However, metallicity and/or surface gravity effects may again complicate this interpretation.

The Saumon & Marley (2008) spectral model based on the atmosphere parameters favored by Burningham et al. (2010) — $T_{\text{eff}} = 500$ K, log $g = 5.0$ cgs, $[M/H] = -0.3$ dex, and $K_{\text{zz}} = 10^4$ cm$^2$ s$^{-1}$ — is also shown in Figure 3. The cooler model actually provides a better match to the relative flux between the $J$- and $H$-band peaks and the width of the $J$-band peak; but predicts stronger 1.6 μm CH$_4$ absorption, a far more distorted $Y$-band peak and a more suppressed $K$-band flux peak than observed. These deviations make this model a 2σ outlier compared to the best-fit model for our data. We emphasize that the differences between these fits do not explicitly rule out either set of parameters. It is well known that incomplete opacity tables, inaccurate treatment of K$_{\text{1}}$ pressure broadening, and the influence of distributed condensate opacity (“cloud tops”) can result in poor fits to T dwarf near-infrared spectra (Burgasser et al. 2006a; Saumon et al. 2007; Cushing et al. 2008; Stephens et al. 2009; Burningham et al. 2009). However, within the limits of the current spectral models, our analysis favors a warmer temperature for SDSS J1416+1348B than indicated by its $H - [4.5]$ color.

3.4. Spectroscopic Distance

Following Bowler et al. (2009), we calculated a spectroscopic parallax for SDSS J1416+1348B using the model-to-data flux scaling factor $C_k$ derived from the spectral modeling. The mean value and uncertainty of this factor (based on the same $G_k$ weighting scheme used for the parameter distributions) yield a distance-to-radius ratio $d/R = 12.8 \pm 3.0$ pc/$R_{\text{Jup}}$. From the inferred $T_{\text{eff}}$ and log $g$ ranges, the evolutionary models of Saumon & Marley (2008) predict a radius $R = 0.83^{+0.14}_{-0.10} R_{\text{Jup}}$, corresponding to a distance of $10.6^{+2.0}_{-2.8}$ pc. This is larger than but within 1σ of the astrometric distance of the primary from Scholz (2010), 7.9 ± 1.7 pc. In contrast, the 500 K model shown in Figure 3 requires $d/R = 5.8$ pc/$R_{\text{Jup}}$, and the corresponding $R = 0.73 R_{\text{Jup}}$ implies a distance of only 4.2 pc, significantly smaller than both spectrophotometric and astrometric estimates for SDSS J1416+1348A. Hence, to the limits of the accuracy of the spectral and evolutionary models of Saumon & Marley (2008), our atmospheric parameter determinations for SDSS J1416+1348B are commensurate with this source being co-spatial with its co-moving L dwarf companion.

4. THE NATURE OF BLUE L AND T DWARFS

The SDSS J1416+1348AB system provides a unique opportunity to explore the underlying physical properties that distinguish blue L and T dwarfs. While surface gravity and metallicity effects have long been acknowledged as contributors to the peculiarities of blue T dwarfs, condensate cloud properties have been seen as playing a more important role in shaping the spectra of blue L dwarfs. Several studies have argued that thin and/or patchy condensate clouds in the photospheres of blue L dwarfs adequately explain their unique photometric and spectroscopic characteristics (Knapp et al. 2004; Cruz et al. 2007; Burgasser et al. 2008a; Stephens et al. 2009). However, thin clouds cannot be responsible for the colors and spectra of late-type blue T dwarfs — such as SDSS J1416+1348B — since clouds are buried deep below the visible photosphere in these low-temperature objects (Ackerman & Marley 2001).

The distinct empirical characteristics shared by SDSS J1416+1348A and B must have an origin that is common to both sources; this argues for age and/or metallicity. Older ages for blue L and T dwarfs are supported by their collective kinematics; Faherty et al. (2009) and Kirkpatrick et al. (2010) have shown that this subgroup exhibits a much broader range of tangential velocities ($\sigma_t \approx 50$ km s$^{-1}$) than L and T dwarfs with “normal” colors ($\sigma_t \approx 22$ km s$^{-1}$). The high surface gravities inferred from spectral model fits to blue L and T dwarfs further support older ages for these sources (e.g., Burgasser et al. 2008b; Cushing et al. 2008; Geballe et al. 2009). Subsolar metallicities are also supported by spectral model fits to blue T dwarfs, and the fact that blue L dwarfs exhibit spectral characteristics that are intermediate between normal field L dwarfs and halo L subdwarfs (Burgasser 2004; Kirkpatrick et al. 2010). However, the discovery of a blue L5 dwarf companion to the solar-metallicity field M4.5 star G 203-50 (Radigan et al. 2008) suggests that metallicity does not play a consistent role in shaping these spectra.

We argue that the common photometric and spectroscopic properties of SDSS J1416+1348A and B favor old age, and possibly subsolar metallicity, as the physical trait that characterizes the blue L and T dwarf populations. Thin condensate clouds may still be common for blue L dwarf atmospheres, with higher surface gravities and subsolar metallicities contributing to increased sedimentation rates and a reduced supply of condensate species, respectively. However, our conjecture predicts that these cloud properties are simply a consequence of the higher pressure photospheres characterizing old, high surface gravity and—at least for SDSS J1416+1348A—metal-poor brown dwarfs.

5. SUMMARY

We have measured the 0.8–2.4 μm spectrum of SDSS J1416+1348B, the common proper motion companion to the blue L dwarf SDSS J1416+1348A. These data confirm the T7.5 spectral type determined by Burningham et al. (2010), show possible NH$_3$ features in the 1.0–1.3 μm region, and reveal broadened $Y$-band and highly suppressed $K$-band peaks consistent with a high surface gravity and/or subsolar metallicity. Spectral model fits based on calculations by Saumon & Marley (2008) indicate atmospheric parameters $T_{\text{eff}} = 650 \pm 60$ K, log $g = 5.2 \pm 0.4$ cgs, $[M/H] \leq -0.3$, and $K_{\text{zz}} = 10^4$ cm$^2$ s$^{-1}$. The metallicity and surface gravity are consistent with the analysis by Burningham et al. (2010), but our $T_{\text{eff}}$ is $\sim 150$ K (2.5σ) warmer. If correct, our results suggest that the extreme $H - [4.5]$ color of this source may be due to metallicity and/or surface gravity effects, rather than an exceedingly low $T_{\text{eff}}$. Our fit parameters for SDSS J1416+1348B imply a model-dependent spectroscopic distance that is formally consistent with the astrometric distance of SDSS J1416+1348A measured by Scholz (2010), and further strengthens the case that this pair is a coeval system of
unusually blue brown dwarfs. We argue that the common peculiarities of the SDSS J1416+1348AB system implies that most unusually blue L and T dwarfs derive their unique properties from old age/high surface gravity and/or subsolar metallicity, with the thin clouds of blue L dwarfs being a secondary effect.

Despite the substantial amount of follow-up already done for the SDSS J1416+1348AB system, its benchmark role in understanding temperature, surface gravity, metallicity, and cloud effects in L and T dwarf spectra motivates further observational study of both components. These include higher precision parallax measurements to verify absolute fluxes; higher-resolution near-infrared spectroscopy and mid-infrared spectroscopy of the secondary to validate potential NH3 features and discern the origin of its unusual mid-infrared colors; broadband spectral energy distribution measurements of both components to measure luminosities and constrain $T_{\text{eff}}$; high-resolution imaging to search for additional components; and improved model fits to better constrain atmospheric parameters. In addition, the $\sim 100$ AU projected separation of this system—wider than any L dwarf/T dwarf pair identified to date—raises questions as to the formation of it and other widely separated, very low mass stellar/brown dwarf multiples (e.g., Luhman 2004; Billères et al. 2005; Close et al. 2007). Coupled with its proximity to the Sun, the SDSS J1416+1348AB system is a target of opportunity for studies of cold brown dwarf atmospheres and origins.

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