RESOLVED SPECTROSCOPY OF THE T8.5 AND Y0–0.5 BINARY WISEPC J121756.91+162640.2AB

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ABSTRACT

We present 0.9–2.5 μm resolved spectra for the ultracool binary WISEPC J121756.91+162640.2AB. The system consists of a pair of brown dwarfs that straddles the currently defined T/Y spectral type boundary. We use synthetic spectra generated by model atmospheres that include chloride and sulfide clouds (Morley et al.), the distance to the system (Dupuy & Kraus), and the radius of each component based on evolutionary models (Saumon & Marley) to determine a probable range of physical properties for the binary. The effective temperature of the T8.5 primary is 550–600 K and that of the Y0–Y0.5 secondary is ∼450 K. The atmospheres of both components are either free of clouds or have extremely thin cloud layers. We find that the masses of the primary and secondary are 30 and 22 M_Jup, respectively, and that the age of the system is 4–8 Gyr. This age is consistent with astrometric measurements (Dupuy & Kraus) that show that the system has kinematics intermediate between those of the thin and thick disks of the Galaxy. An older age is also consistent with an indication by the H − K colors that the system is slightly metal poor.

Key words: brown dwarfs — stars: atmospheres

Online-only material: color figures

1. INTRODUCTION

The Wide-field Infrared Survey Explorer (WISE; Wright et al. 2010) has significantly advanced the study of brown dwarfs, stellar-like objects that have insufficient mass for stable hydrogen burning (Kumar 1963; Hayashi & Nakano 1963). About the size of Jupiter, the cool brown dwarfs are intrinsically very faint. Prior to WISE, brown dwarfs as cool as \( T_{\text{eff}} = 500 \) K had been found in near-infrared (NIR) surveys undertaken by 4 m class ground-based telescopes (e.g., Lucas et al. 2010). Two brown dwarfs were also known with \( T_{\text{eff}} \approx 400 \) K: CFBDsIR J145829+101343B, a companion to a warmer brown dwarf, discovered using laser guide star adaptive optics imaging (Liu et al. 2011), and GJ 3483B, a companion to a white dwarf, found using the Infrared Array Camera on the Spitzer Telescope in a proper motion search for faint companions (Luhman et al. 2011). These 400 K brown dwarfs were expected to have a later spectral type than all previously known T dwarfs. Observations beyond the NIR, such as those obtained with the Spitzer Space Telescope, are advantageous for studying cool brown dwarfs because objects with \( T_{\text{eff}} < 700 \) K emit >50% of their energy at \( \lambda > 3 \) μm (Leggett et al. 2010a). In 2011, the mid-infrared 0.4 m WISE telescope identified the first large sample of brown dwarfs with \( T_{\text{eff}} < 500 \) K (Cushing et al. 2011; Kirkpatrick et al. 2011, 2012). Kirkpatrick et al. (2011) presented the first hundred WISE brown dwarfs and this paper studies one of those objects, WISEPC J121756.91+162640.2 (hereafter, WISE 1217+16), which was classified as a T9 spectral type by Kirkpatrick et al.

WISE 1217+16 was found to be a binary system by Liu et al. (2012, hereafter Liu12) using Keck laser guide star adaptive optics. The pair is separated by 0′′.76 at a position angle of 14°.3. It is an unusual binary, having a relatively wide separation and a large difference in NIR brightness between the two components (see Table 1). Liu12 obtained resolved H-band spectra of the two components and classified WISE 1217+16A as a T9 and WISE 1217+16B as a Y0, using the spectral classification scheme for the latest T-type and early Y-type brown dwarfs proposed by Cushing et al. (2011). Here, we present resolved spectra for the system covering a wider wavelength range of 0.9–2.5 μm and expand on the analysis presented by Liu12.

2. OBSERVATIONS

We used the Gemini Near-Infrared Spectrograph (GNIRS; Elias et al. 2006) to obtain 0.9–2.5 μm cross-dispersed spectra of WISE 1217+16AB via queue program GN-2012B-Q-28. In order to resolve the pair, observations were carried out only when the natural seeing FWHM was 0′′.45 or better and only at airmasses less than 1.2. Both photometric and cloudy conditions were utilized. The 0′′.3 slit was used with the 0′′.15 pixel−1 camera, resulting in a resolving power \( \lambda/\delta\lambda \approx 1700 \). The slit was placed at 14°:3 so that both sources were in the slit. Individual exposure times of 300 s were used, with the target nodded along the slit. The A0 star HD 101060 and the F4 star HD 114072 were used as calibrators to remove telluric features.

Observations were obtained on 2013 February 21, April 9, April 26, and May 8 UT. Time on source on these nights was 35, 40, 60, and 60 minutes, respectively. The data from 2013 February 21 were obtained in thicker cloud cover and as the signal was around half that of the three other nights, those data were omitted. Calibration lamps on the telescope provided data for wavelength calibration and flat fielding, as well as pinhole images for tracing the cross-dispersed data along the detector. Figure 1 shows the flat fielded, sky-subtracted, and rectified J-band spectrum from 2013 May 8 as a two-dimensional (2D) image. The FWHM is around 2 pixels (0′′.3) and the separation between components is 5 pixels (0′′.76).

The spectra of both the A and B components were extracted using apertures centered at the respective peaks, with a lower limit of −2.5 pixels and an upper limit of 2.5 pixels. Where B is extremely faint, we used the known offset from A to place the aperture. The contribution of the brighter component to the
fainter component’s spectrum was determined by extracting the signal of the A component at the location of the B component’s aperture on the opposite side of the profile. Typically, the contribution was 5% of the signal of the A component and 20% of that of the B component. To avoid adding noise, we subtracted an appropriately scaled version of the A spectrum from the B spectrum and not the spectrum extracted from the wing. The spectral orders for each component were combined, averaging the regions of overlap at 0.98–0.95, 0.98–1.06, 1.13–1.25, 1.45–1.52, and 1.88–1.90 μm. The combined flux was 5% of the signal of the A component at the location of the B component’s aperture on the opposite side of the profile. Typically, this fraction was constant, although in the case of the WISE 1217+16B comparison the contribution was 5% of the signal of the A component at the location of the B component.

The agreement with the Keck data is excellent and that with the WISE 1217+16A implies that it either has a high gravity or low metallicity that enhances the H2 absorption at 2 μm (e.g., Leggett et al. 2009). It is likely that metallicity and gravity, as well as temperature, impact the shape of the J-band peak and that we are seeing variations in these parameters for the three Y dwarfs. The fact that the K band is suppressed for WISE 1217+16A implies that it either has a high gravity or low metallicity that enhances the H2 absorption at 2 μm (e.g., Leggett et al. 2009); we are also possibly seeing enhanced H2 absorption in the blue wing of the J-band peak. We define WISE 1217+16B as Y0–0.5.

Note that the NIR spectra of these components, which straddle the current T/Y classification boundary, are overall very similar. Increased molecular absorption narrows the flux peaks at lower $T_{\text{eff}}$, but there is otherwise no strong spectral marker for the transition from T to Y in the NIR. One difference that is apparent is the height and width of the Y-band peak around 1 μm – relative to the J-band peak, the later spectral type and cooler object has a taller and broader Y-band peak. This is also seen in the $Y - J$ colors, which become bluer. Figure 4 is the $Y - J, M_Y$ color–magnitude diagram, showing the trend to bluer $Y - J$. Also, this figure shows about half the drop in absolute magnitude between T9 and Y0 than is seen for $M_J$ and $M_H$ (Dupuy & Kraus 2013; Figure 5 and Section 4.3). For T9 types with $T_{\text{eff}} \approx 500$ K, the alkali elements are condensing into chlorides and sulfides, weakening the strong 0.77μm K1 resonance doublet, the red wing of which suppresses the Y-band flux. This likely explains the brightening at Y (Liu et al. 2012). There is a lot of scatter in the $Y - J$ colors of early Y dwarfs (Figure 4), again suggesting that there are variations in metallicity and gravity, as well as temperature, within this small sample. This disparity can also be seen spectroscopically in Figure 3: WISE 1217+16B has a broader Y-band peak than the comparison Y dwarfs and is bluer in $Y - J$.

The gap in $M_Y$ and $M_H$ at the T-to-Y transition is striking in Figures 4 and 5. This gap is not seen at mid-infrared wavelengths (Leggett et al. 2013, hereafter Leg13; Dupuy & Kraus 2013).
The Astrophysical Journal, 780:62 (8pp), 2014 January 1

Leggett et al.

Figure 1. Flat fielded, sky-subtracted, and rectified $J$-band spectral order of WISE 1217+16AB from 2013 May 8. The faint trace of the cooler component that is more peaked in wavelength can be seen to the left of the primary in this image. The wavelength range is approximately 1.18–1.34 $\mu$m, from bottom to top.

The gap may disappear as more very late-type T and Y dwarfs are found and more distances are determined but it is tempting to associate the distinct drop in flux at 1–2 $\mu$m at $T_{\text{eff}} \approx 400$ K with a physical phenomenon. Possibilities include the appearance of water clouds or the impact of a newly significant opacity such as H$_2$. Improved models are required to explore this further.

Finally, we note that the object initially identified as the prototype Y dwarf, WISEP J182831.08+265037.8 (Cushing et al. 2011), appears to be different from the other Y dwarfs

Figure 2. Complete 1D GNIRS spectrum of each component of the WISE 1217+16 binary is shown in black. Also shown is the summed spectrum (cyan or dashed line) and an observed unresolved spectrum from Kirkpatrick et al. (2011, magenta or gray in print). The inset plot compares our $H$-band spectral order with the resolved spectra obtained previously at Keck by Liu12 (red and blue lines or gray in print).

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

Figure 3. Spectrum of each component of the WISE 1217+16 binary (black line) is compared with template T and Y types (red and blue lines or light and dark gray lines in print). The comparison spectra have been scaled to the $J$-band flux peaks. The inset plots zoom in on the $J$-band flux peak, the width of which is diagnostic of type. Note that the two spectra are plotted on different flux scales and on different wavelength scales.

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MnS, Na2S, ZnS, and KCl to the cloud-free models. These have added absorption and scattering by condensates of Cr, are described in detail in Morley et al. (2012). Morley et al. H2, as described in Saumon et al. (2012). The cloudy models atmospheres by Lodders (1999) and Visscher et al. (2006). In terms of colors and luminosity (Section 4.3; Beichman et al. 2013; Dupuy & Kraus 2013; Leg13; Kirkpatrick et al. 2013). Once a larger sample of Y dwarfs is known, it is likely that the spectral classification scheme will have to be revisited. Also, as the models are improved with more complete treatment of opacities, clouds, and turbulence, we hope to disentangle the effects of temperature, metallicity, and gravity on the NIR spectrum of these cold objects.

4. COMPARISON WITH THE MODELS

4.1. The Models

Leg13 compare NIR photometry to cloud-free models and to a new generation of models that include clouds consisting of sulfide and chloride condensates; we use the same models here. The cloud-free model atmospheres are as described in Saumon & Marley (2008) and Marley et al. (2002), with updates to the line list of NH3 and the collision-induced absorption of H2, as described in Saumon et al. (2012). The cloudy models are described in detail in Morley et al. (2012). Morley et al. have added absorption and scattering by condensates of Cr, MnS, Na2S, ZnS, and KCl to the cloud-free models. These condensates have been predicted to be present in low-Teff atmospheres by Lodders (1999) and Visscher et al. (2006). Morley et al. use the Ackerman & Marley (2001) cloud model to account for these previously neglected clouds. The vertical cloud extent is determined by balancing upward turbulent mixing and downward sedimentation. A parameter fsed describes the efficiency of sedimentation and is the ratio of the sedimentation velocity to the convective velocity; lower values of fsed imply thicker (i.e., more vertically extended) clouds. We have found that models that include iron and silicate grains and that have fsed of typically 2–3 fit L-dwarf spectra well, those with fsed 2–4 fit T0 to T3 spectral types well, and cloud-free models fit T4–T8 types well (e.g., Saumon & Marley 2008; Stephens et al. 2009). However, for the latest T types, significant discrepancies exist between the models and the observations in the NIR (e.g., Leggett et al. 2009, 2012). The new models with chloride and sulfide clouds help to resolve these discrepancies, because these clouds are significant for dwarfs with Teff = 400–900 K (approximately T7 to Y1 spectral types), with a peak impact at around 600 K. Below Teff ~ 400 K, water clouds are expected to form (Burrows et al. 2003), which have not yet been incorporated into the models (although water condensation is accounted for in the gas opacity).

The models used in the present analysis have solar metallicity and neglect departures from chemical equilibrium caused by vertical mixing. The mixing enhances the abundance of CO and CO2 and reduces the 5 μm flux (Saumon et al. 2006). Vertical mixing also decreases the abundance of NH3, which would otherwise produce stronger absorption features at 1.03 and 1.52 μm than are seen in the known Y dwarfs (Leg13). The mixing can be parameterized with the eddy diffusion coefficient Kzz cm2 s−1, where values of log Kzz = 2–6 corresponding to mixing timescales of ~10 yr to ~1 hr, respectively, reproduce the observations of T dwarfs (e.g., Saumon et al. 2007). Leggett et al. (2012) find that the Teff = 500 K dwarf UGPS J0722−0540 is undergoing vigorous mixing, with log Kzz ~ 5.5–6.0, and that this impacts the WISE 4.6 μm W2 band by ≥0.3 mag. Leg13 find that increasing the calculated W2 flux by 0.3 mag results in the model sequences reproducing the observed color trends in T and Y dwarfs quite well.

4.2. Previously Determined Properties of WISE 1217+16AB

Liu12 derived a photometric distance of 10.5 ±1.7 pc for WISE 1217+16A based on a spectral type assignment of T9 and a J-band bolometric correction for very late-type T dwarfs. The luminosity was combined with evolutionary models to derive physical properties for ages of 1 Gyr and 5 Gyr. For the younger age, the inferred Teff and mass are 550 K and 13 MJup for the primary and 400 K and 7 MJup for the secondary, respectively. For the older age, these values are 650 K and 33 MJup for the primary and 400 K and 17 MJup for the secondary, respectively. Dupuy & Kraus (2013) have recently published a trigonometric distance to the binary of 10.1±1.9 pc. Using this distance and model-based bolometric corrections to the summed observed flux given by the measured magnitudes, they determine, for an age of 5 Gyr, Teff and mass of 600 K and 31 MJup for the primary and 450 K and 19 MJup for the secondary.

Leg13 compare the observed resolved NIR colors of the WISE 1217+16 components with the Morley et al. (2012) cloudy models. The W2 magnitudes for each component are estimated based on spectral type, constrained by the unresolved W2 value. Leg13 find that the model sequences are consistent with a single-age solution for the binary. Higher gravity solutions, corresponding to an age ~5 Gyr, provided better fits than the lower gravity solutions, corresponding to 1 Gyr because of the relatively blue H − K color. The colors also suggested that the atmospheres of both components had thin cloud layers with fsed ~ 5.
Figure 5. Location of WISE 1217+16A and WISE 1217+16B in NIR color–magnitude diagrams. Sources labeled 2, 3, and 5 are discussed in the text. The typical spectral types and derived $T_{\text{eff}}$ at particular $M_H$ are shown on the right axis. All data are on the MKO photometric system. Sources are (1) CFBDSIR J145829+101343A (Delorme et al. 2010; Liu et al. 2011), (2) BD +01°2920B (Pinfield et al. 2012), (3) SDSS J141624.08+134826.7B (Burgasser et al. 2010; Burningham et al. 2010; Scholz 2010), (4) ULAS J173855.52+273258.9 (Cushing et al. 2011), (5) Wolf 940B (Burningham et al. 2009), (6) CFBDS J005910.90-011401.3 (Delorme et al. 2008), (7) ξ UMaC (Wright et al. 2013), (8) UGPS J072227.51054031.2 (Lucas et al. 2010), (9) CFBDSIR J145829+101343B (Delorme et al. 2010; Liu et al. 2011), (10) WISEP J154151.65225025.2 (Cushing et al. 2011), (11) WISEPC J140518.40+553421.5 (Cushing et al. 2011), (12) WISEP J182831.08+265037.8 (Cushing et al. 2011), (13) WISEP J154151.65225025.2 (Cushing et al. 2011), (14) WISEPC J140518.40+553421.5 (Cushing et al. 2011), (15) WISEP J182831.08+265037.8 (Cushing et al. 2011), (16) WISE J035934.06540154.6 (Kirkpatrick et al. 2012), and (17) WISE J064723.23623235.5 (Kirkpatrick et al. 2013).

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

The proper motion for the binary is measured to be $1.45 \pm 0.04$ yr$^{-1}$ (Dupuy & Kraus 2013), implying a tangential velocity of $70 \pm 10$ km s$^{-1}$. This velocity implies kinematics intermediate between the thin and thick disk populations (e.g., Brook et al. 2012; Dupuy & Liu 2012) and therefore an age around 7 Gyr. This result is consistent with the findings of Leg13 that the higher gravity and therefore older age of 5 Gyr is favored over the younger 1 Gyr age.

4.3. Color–Magnitude and Spectral Energy Distribution

Figure 5 illustrates the location of WISE 1217+16A and WISE 1217+16B in a NIR color–magnitude diagram. Here, $M_H$ is used as the luminosity indicator as $H$ is less sensitive to the clouds than $Y$ or $J$ and less sensitive to metallicity and gravity than $K$. The intrinsically faintest sources are identified. Photometry and parallaxes are taken from Leg13 and references therein, updated by measurements from Beichman et al. (2013), Dupuy & Kraus (2013), Kirkpatrick et al. (2013), Mace et al. (2013), Marsh et al. (2013), and Wright et al. (2013). Note that the latest type Y dwarf currently identified, WISEP J182831.08+265037.8 (15), appears to be unusually bright in $H$ (Beichman et al. 2013; Dupuy & Kraus 2013; see also Section 3).

The typical spectral types and approximate $T_{\text{eff}}$ at particular $M_H$ are shown along the right axis of Figure 5 (e.g., Burningham et al. 2010; Dupuy & Kraus 2013; Leggett et al. 2009, 2010a, 2010b, 2012, 2013; Liu12; Pinfield et al. 2010; Smart et al. 2010; Wright et al. 2013). The $T_{\text{eff}}$ have been derived primarily from luminosity arguments and evolutionary models. There are three brown dwarfs with $T_{\text{eff}} \approx 600$ K and log $g \approx 5.0$ that are of particular interest: BD +01°2920B (2), SDSS J141624.08+134826.7B (3), and Wolf 940B (5). These are companions to a G, L, and M dwarf, respectively. Although $T_{\text{eff}}$ and log $g$ are similar, Wolf 940B has a metallicity close to solar, while SDSS J141624.08+134826.7B and BD +01°2920B have $[\text{Fe}/H] \lesssim -0.3$ dex (Burgasser et al. 2010; Burningham et al. 2010; Leggett et al. 2010b; Pinfield et al. 2012; see also Burningham et al. 2013). The impact of the lower metallicity is clearly seen in the $H - K$ color in Figure 5, which also suggests that
the WISE 1217+16 system may be slightly metal poor. If, instead, the blue $H - K$ is due to gravity only, the size of the shift ($\approx 0.3$ mag) implies a gravity $\sim 1.0$ dex higher than typical for the type (e.g., Burningham et al. 2013; their Figure 10). A gravity this large is unlikely, given that at $T_{\text{eff}} \approx 600$ K an increase in age from 1 to 10 Gyr corresponds to an increase in gravity of 0.6 dex (Saumon & Marley 2008; their Figure 4). Hence, we suggest that the system has a relatively high gravity combined with a metallicity of about $-0.1$ dex.

It can be seen that the absolute $H$ magnitudes for the WISE 1217+16 components are consistent with the assigned spectral types of T8.5 and Y0–0.5. Using the previous studies of late T and early Y dwarfs, the figure suggests that the components have $T_{\text{eff}} = 550–600$ K and 400–450 K, respectively, which is also consistent with previous determinations (Section 4.2). Table 2 gives physical parameters for each component for these values of $T_{\text{eff}}$, for a range in age of 4 Gyr to 10 Gyr, calculated using the evolutionary models of Saumon & Marley (2008).

Figure 6 shows the spectrum of each component and synthetic spectra generated by the Morley et al. (2012) models. The spectra have been scaled by the known distance to the binary (Table 1) and the radius of each component as given by the evolutionary models for an age of 6 Gyr (Table 2). The inset shows a comparison using fluxes scaled by the radii corresponding to an age of 10 Gyr.

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

![Figure 6. Spectrum of each component of WISE 1217+16 (black curve) is compared with synthetic spectra generated by the Morley et al. (2012) models. The legends list each model’s $T_{\text{eff}}$, log $g$, and cloudiness parameter. The synthetic spectra have been scaled by the known distance to the binary (Table 1) and the radius of each component, as given by the evolutionary models for an age of 6 Gyr (Table 2). The inset shows a comparison using fluxes scaled by the radii corresponding to an age of 10 Gyr.](image)

Table 2

| Property       | Primary | Secondary |
|----------------|---------|-----------|
|                | 550 K   | 600 K     | 400 K | 450 K     |
| Mass ($M_{\odot}$) | 25      | 26        | 16    | 19        |
| Radius ($R_{\odot}$) | 0.0953  | 0.0936    | 0.1016 | 0.0993 |
| log $g$ (cm s$^{-2}$) | 4.859   | 4.929     | 4.600  | 4.699     |
| Mass ($M_{\odot}$) | 29      | 34        | 19    | 22        |
| Radius ($R_{\odot}$) | 0.0917  | 0.0895    | 0.0982 | 0.0964 |
| log $g$ (cm s$^{-2}$) | 4.966   | 5.053     | 4.708  | 4.757     |
| Mass ($M_{\odot}$) | 33      | 37        | 21    | 25        |
| Radius ($R_{\odot}$) | 0.0891  | 0.0871    | 0.0961 | 0.0934 |
| log $g$ (cm s$^{-2}$) | 5.044   | 5.119     | 4.773  | 4.877     |
| Mass ($M_{\odot}$) | 35      | 42        | 23    | 28        |
| Radius ($R_{\odot}$) | 0.0870  | 0.0851    | 0.0942 | 0.0915 |
| log $g$ (cm s$^{-2}$) | 5.108   | 5.180     | 4.832  | 4.977     |

For the A component, the best match to the models occurs if $T_{\text{eff}} = 500$ K and age is 6 Gyr, then radius and gravity are $R = 0.0938 R_\odot$ and log $g$(cgs) = 4.888. If $T_{\text{eff}} = 500$ K and age is 10 Gyr, then radius and gravity are 0.0896 $R_\odot$ and log $g = 5.026$ (Saumon & Marley 2008). The spectral change due to a change in gravity of 0.14 dex is small (e.g., Leggett et al. 2009), while the change in the flux scaling factor ($R^2$) of 10% is significant.

Another factor to bear in mind when examining Figure 6 is that the models do not include the vertical mixing that likely occurs in such atmospheres (e.g., Leg13; Section 4.1). The mixing is expected to increase the abundance of $N_2$ at the expense of that of NH$_3$. In the NIR, this affects the $H$ band in particular; the NH$_3$ absorption is much reduced, making the blue wing and peak of the $H$ band brighter. The effect is $\sim 20\%$ at the peak of the $H$ band at these temperatures (based on preliminary Saumon & Marley models).

The model comparison in Figure 6 and the relative strengths of the $Y$, $J$, and $H$ peaks ($K$ is very faint) suggests that each component of the WISE 1217+16 binary has very thin to no sulfide/chloride clouds: $f_{\text{sed}} \gtrsim 6$. The brightness of the flux peaks, especially considering that the $H$ peak is likely to be brighter when mixing is included, suggests that the age is unlikely to be less than 4 Gyr, as the model spectra will then be too bright. The system may be as old as 10 Gyr, as shown in the inset in Figure 6, although there is a discrepancy at $J$ for the B component in that case. Enhanced H$_2$ absorption, if the system is metal poor, could reduce the flux at $K$ and possibly at the blue wing of $J$ for the cooler dwarf, improving the fit. The relative height of the flux peaks are likely to also be sensitive to the detailed structure of any cloud decks, as is seen at the L/T dwarf transition (e.g., Marley et al. 2012; Apai et al. 2013). In summary, plausible fits are obtained for an age range of 4 to 8 Gyr.

For the A component, the best match to the models occurs if $T_{\text{eff}} \lesssim 450$ K and there are no clouds. For the B component, the best match to the models occurs if $T_{\text{eff}} \approx 450$ K and there are no clouds or an extremely thin sulfide/chloride cloud layer with $f_{\text{sed}} > 5$. Other spectral comparisons (not...
shown) where the synthetic spectra are scaled by the known distance and the evolutionary-determined radius showed that we can exclude $T_{\text{eff}}$ values of 500 K for either the A or B component, due to large discrepancies in brightness levels. Similarly temperatures as high as 650 K can be excluded for WISE 1217+16B. Although we do not have 350 K model spectra, luminosity arguments (see Figure 5 and Dupuy & Kraus 2013, their Table SS) show that WISE 1217+16B cannot be as cool as 350 K.

Table 3 summarizes the likely values for the physical properties for the system.

5. CONCLUSIONS

We have used nights of excellent seeing on Mauna Kea to obtain resolved 0.9–2.3 $\mu$m spectra for the T dwarf and Y dwarf binary WISEPC J121756.91+162640.2AB. The spectral extraction is confirmed to be accurate by comparing with the unresolved spectrum and resolved $H$-band spectra obtained previously. Comparison with the NIR spectra of the (small number of) very late-type T dwarfs and early-type Y dwarfs implies spectral types of T8.5 and Y0–0.5 for the primary and secondary, respectively. Thus, the system straddles the currently defined T/Y spectral type boundary.

Using synthetic spectra generated by model atmospheres that include chloride and sulfide clouds (Morley et al. 2012) and constrained by the distance to the system (Dupuy & Kraus 2013) and the radius of each component based on evolutionary models (Saumon & Marley 2008), we can determine a probable range of physical properties for the binary. The effective temperature of the primary is 550–600 K and that of the secondary is 450 K. Temperatures warmer or cooler by 50 K can be excluded as they result in significant discrepancies in brightness between the observed and calculated spectra. The shapes of the spectral distributions show that the atmospheres of both components have either very thin or no chloride/sulfide cloud layers, with a sedimentation parameter $f_{\text{sed}} \gtrsim 6$. We find that the masses of the primary and secondary are around 30 and 22 $M_{\oplus}$, respectively, and that the age of the system is 4–8 Gyr. This age is consistent with astrometric measurements by Dupuy & Kraus (2013), which show that the system has kinematics intermediate between the thin and thick disk populations of the Galaxy. The system may be metal poor based on the $H - K$ colors of both components, which would also generally be consistent with an older age.

Coeval binary systems such as WISEPC J121756.91+162640.2AB offer a powerful probe of the atmospheric changes that occur at very low temperatures. At $T_{\text{eff}} \approx 500$ K, the alkali elements are condensing and cloud decks of sulfides and chlorides form. This system offers an insight into the interplay between temperature, gravity, metallicity, and cloud formation in cold atmospheres and will provide a benchmark for the models as they are improved with more complete treatment of opacities, clouds, and turbulence. In the near term, model atmospheres with a range of metallicity and mixing efficiency would enable a significant improvement in our understanding of the recently discovered Y dwarf population.

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