SDSS J111010.01+011613.1: A NEW PLANETARY-MASS T DWARF MEMBER OF THE AB DORADUS MOVING GROUP

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ABSTRACT

We present a new radial velocity measurement that, together with a trigonometric parallax, proper motion and signs of low gravity from the literature, confirms that SDSS J111010.01+011613.1 is a new T5.5 bona fide member of AB Doradus. Fitting \( \lambda/\Delta \lambda \approx 6000 \) Folded-port InfraRed Echellelet spectroscopy in the 1.20–1.33 \( \mu \)m region to BT-Settl atmosphere models yielded a radial velocity of \( \pm 7.5 \) \( \pm 0.8 \) km \( s^{-1} \). At such a young age (110–130 Myr), current evolution models predict a mass of \( \sim 10\,M_{\text{Jup}} \), thus placing SDSS J1110+0116 well into the planetary-mass regime. We compare the fundamental properties of SDSS J1110+0116 with a sequence of seven recently identified M8–T5 brown dwarf bona fide or high-confidence candidate members of AB Doradus. We also note that its near-infrared \( J-K \) color is redder than field T5–T6 brown dwarfs, however its absolute \( J \)-band magnitude is similar to them. SDSS J1110+0116 is one of the few age-calibrated T dwarfs known to date, as well as one of the coolest bona fide members of a young moving group.

Key words: brown dwarfs – stars: kinematics and dynamics – techniques: radial velocities

1. INTRODUCTION

Young, low-mass brown dwarfs of the solar neighborhood provide a unique opportunity to understand the properties of directly imaged gaseous giant exoplanets and study the low-mass end of the initial mass function. Young moving groups in the solar neighborhood are ideal laboratories to search for such young brown dwarfs, due to their relative proximity to the Sun (\( \lesssim 100 \) pc) and their young age (\( \lesssim 120 \) Myr). These moving groups consist of stars that have formed together at the same time and in a common environment, and that share similar space velocities (e.g., see Zuckerman & Song 2004).

The first few brown dwarf members and candidate members of these young moving groups were identified both in pointed searches and as serendipitous discoveries (e.g., Rebolo et al. 1998; Gizis 2002; Rice et al. 2010; Faherty et al. 2013; Liu et al. 2013b; Naud et al. 2014; Schneider et al. 2014; Gizis et al. 2015). The main difficulties that hindered locating such low-mass members of moving groups were intrinsic faintness and sparse location on the sky. Trigonometric distances and radial velocities are not available for all known brown dwarfs that could correspond to low-mass members of young moving groups. Furthermore, the census of brown dwarfs in the solar neighborhood is still incomplete (e.g., Luhman 2013; Scholz 2014).

T dwarf members younger than \( \sim 120 \) Myr have masses in the planetary regime and are located in the immediate solar neighborhood (\( \lesssim 20 \) pc), which makes them accessible now for follow-up observing and prime targets for detailed study using the next generation of facilities such as the James Webb Space Telescope (Gardner et al. 2006), the Thirty Meter Telescope (Nelson & Sanders 2008), the European Extremely Large Telescope (Gilmozzi & Spyromilio 2008), and the Giant Magellan Telescope (Johns et al. 2014). To date, only one isolated T dwarf planetary-mass candidate member of a young moving group has been uncovered, CFBDSIR J214947.2–040308.9, a T7 candidate member of the \( \sim 120 \) Myr AB Doradus moving group (Zuckerman et al. 2004) with an estimated mass of \( 4–7 \, M_{\text{Jup}} \) (Delorme et al. 2012). However, a parallax measurement has recently rejected a possible membership of CFBDSIR J214947.2–040308.9 to AB Doradus or any other known moving group (P. Delorme et al. 2015, in preparation). In this Letter we report the identification of a T dwarf bona fide member of AB Doradus, SDSS J111010.01+011613.1 (hereafter SDSS J1110+0116).

2. THE IDENTIFICATION OF SDSS J111010.01+011613.1

We have identified SDSS J1110+0116 as a candidate member of AB Doradus while preparing the BASS-Ultracool survey, which is an extension of the BASS survey (Gagné et al. 2015; hereafter Paper V) that will aim at the identification of ultracool \( \geq 5 \) brown dwarf members of young moving groups. The survey is based on an updated version of the BANYAN II tool (Gagné et al. 2014; hereafter Paper II). More detail on the BASS-Ultracool survey will be presented in a future paper (J. Gagné et al. 2015, in preparation). The BANYAN II tool uses the sky position, proper motion, the

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2MASS and AllWISE photometry, radial velocity and trigonometric distance to derive a membership probability that an object belongs to several young moving groups and the field based on spatial and kinematic models. A detailed description of this tool can be found in Paper II.

SDSS J1110+0116 was identified by Knapp et al. (2004) as a peculiar T5.5 dwarf that displays unusually strong K I absorption doublets at 1.17 and 1.25 μm; these are a sign of low surface gravity as predicted by atmosphere models for T dwarfs (see the discussion in Knapp et al. 2004). They also noted that its H − K color is unusually red for its spectral type, which further strengthens the low-gravity hypothesis. Using atmosphere models of Marley et al. (2002), they inferred a surface gravity of log g = 4.0−4.5 and an estimated age of 100−300 Myr for this object. More recently, Dupuy & Liu (2012) measured a trigonometric distance of 19.19 ± 0.44 pc and a proper motion of −217.1 ± 0.7 mas yr⁻¹ (μ_h cos δ) and −280.9 ± 0.6 mas yr⁻¹ (μ_o). From our cross-match of the 2MASS and AllWISE catalogs we calculate μ_h cos δ = −245.0 ± 19.1 mas yr⁻¹ and μ_o = −279.1 ± 18.8 mas yr⁻¹, which is marginally consistent with (1.6σ) but less precise than the measurement of Dupuy & Liu (2012). We thus adopt the former measurement for the remainder of this work. Without information on the radial velocity of this object, the observables mentioned above along with the BANYAN II tool allowed us to obtain a membership probability of 94.4% to AB Doradus and a negligible membership probability to any other moving groups considered.

The predicted radial velocity if this object as a member of AB Doradus is 4.3 ± 1.8 km s⁻¹. We did not include photometric measurements in this calculation since a trigonometric distance is available and the young photometric sequences are still uncertain for such a late spectral type. However, even if we use the extended color−magnitude sequences described in Paper II, we obtain similar results. The Monte Carlo analysis described in Paper II yields a small probability (0.6%) that a relatively young (<1 Gyr) object from the field obtains such a high bayesian membership probability to AB Doradus at this galactic latitude (b = 54±53) and for this magnitude of proper motion (355 mas yr⁻¹).

The age of AB Doradus (110−130 Myr; Barenfeld et al. 2013) is consistent with the estimated age of Knapp et al. (2004) for this object, further indicating that SDSS J1110+0116 is a compelling candidate member of AB Doradus.

3. OBSERVATIONS

We obtained a near-infrared (NIR) spectrum of SDSS J1110+0116 with the Folded-port InfraRed Echellette (FIRE; Simcoe et al. 2013) at the Magellan Telescopes on 2011 March 25 (UT), in conditions of light cirrus and 0''7 seeing at J-band. We used the cross-dispersed echellette mode and 0''6 slit to obtain 0.8–2.45 μm spectroscopy at a resolving power λ/Δλ ≈ 6000. Two exposures of 1204.7 s were obtained at an airmass of 1.21–1.26. This was followed by observations of the A0 V star HD 93346 (V = 7.42) at an airmass of 1.24 for telluric correction and flux calibration, and ThAr emission lamps for wavelength calibration. We obtained high- and low-illumination flat fields at the beginning of the night for pixel response calibration. All data were reduced using the Interactive Data Language pipeline FIREHOSE, which is based on the MASE (Bochanski et al. 2009) and SpeXTool (Vacca et al. 2003; Cushing et al. 2004) packages, as described in Bochanski et al. (2011). The reduced spectrum, a portion of which is shown in Figure 1(a), has a peak signal-to-noise of 30 per resolution element in the 1.2−1.3 μm region.

4. RESULTS AND DISCUSSION

4.1. Radial Velocity Measurement

The radial velocity of SDSS J1110+0116 was measured by cross-correlating its spectrum with zero-velocity BT-Settl models (Allard et al. 2012) smoothed to the resolution of the FIRE data using a Gaussian profile. We first determined the best model parameters by comparing FIRE data to models with T_eff = {800, 900, 1000, 1100, 1200, 1300} K and log g = {4.0, 4.5, 5.0} (in units of cm s⁻²) in the 1.20−1.33 μm region. The best-fitting model, T_eff = 1000 K and log g = 4.5 is shown in

(a) Observed spectrum and best-fitting BT-Settl model

(b) Distribution of radial velocity measurements

Figure 1. Panel (a): J-band FIRE spectrum (black) of SDSS J1110+0116 compared with the best-fitting BT-Settl model (red; T_eff = 1000 K; log g = 4.5). The uncertainty spectrum is displayed in gray and the zero baseline as a dotted line. The K I absorption doublet and features due to the CH4 and H2O elements in the 1.20–1.33 μm region are identified. Panel (b): histogram distribution of individual radial velocity measurements, compared with the adopted central value (dashed line) and the measurement uncertainties (dotted lines).
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Figure 1(a). Note that these parameters are consistent with an age <250 Myr (e.g., Baraffe et al. 2003).

We cross-correlated the model and observed spectrum over discrete spectral segments within the highly structured 1.26–1.31 μm H2O and CH4 absorption region (Figure 1(a)). As discussed in A. J. Burgasser et al. (2015, in preparation), this region is particularly well-matched to spectral models and its structure allows fine sampling of wavelength shifts. We fit a total of 15 0.02 μm regions in the 1.26–1.31 μm range in 0.002 μm (10 resolution elements) steps. This was done to account for small systematic effects that may be present in the wavelength calibration at the sub-pixel scale. Rejecting one outlier measurement, we find a mean and standard deviation in cross-correlation shifts of 7.5 ± 2.3 km s\(^{-1}\) (Figure 1(b)). Similar analysis of T dwarfs with radial velocity measurements (e.g., Zapatero Osorio et al. 2007; A. J. Burgasser et al. 2015, in preparation) suggests a 3 km s\(^{-1}\) systematic uncertainty on this method, so we adopt a final radial velocity of 7.5 ± 3.8 km s\(^{-1}\). Given the low signal-to-noise spectrum, we did not attempt to measure \(v \sin i\) for this source.

4.2. AB Doradus Membership

Adding in the radial velocity measurement, we obtain a bayesian probability of 96.8% that SDSS J1110+0116 is a member of the AB Doradus moving group. This is associated with a false positive field contamination probability of 0.4%. We find a galactic position \(XYZ = \{-2.79 \pm 0.06, -10.78 \pm 0.25, -15.62 \pm 0.36\}\) pc and a space velocity \(UVW = \{-5.9 \pm 0.7, -30.1 \pm 2.2, -12.6 \pm 3.1\}\) km s\(^{-1}\) for SDSS J1110+0116, placing it 34 ± 17 pc and 3.3 ± 2.5 km s\(^{-1}\) away from the core of our AB Doradus spatial and kinematic models, which is within the spread of members of this moving group. Based on this high membership probability, signs of low-gravity in its structure allows member of AB Doradus. The age estimate of 100 Myr based on comparison to atmospheric models, we conclude that SDSS J1110+0116 is a bona fide member of AB Doradus. The probabilities derived in this section conservatively assume an age younger than 1 Gyr since the NIR spectrum of SDSS J1110+0116 displays signs of a low surface gravity.

4.3. The Properties of SDSS J1110+0116

We used the method described in Paper II and Paper V to estimate the mass of SDSS J1110+0116; the method consists of comparing the absolute 2MASS J, H and K\(_{S}\) and Wide-field Infrared Survey Explorer (WISE) W1 and W2 magnitudes with the BT-Settl isochrones (Baraffe et al. 2003; Allard et al. 2012) at the age of AB Doradus (110–130 Myr; Barenfeld et al. 2013) in a maximum likelihood analysis. We obtain a mass estimate of 10–11 \(M_{\text{Jup}}\).

It is important to note that current evolution and atmosphere models likely suffer from important systematics, which are not well characterized and thus not included in our mass measurement error. For example, these models do not account for magnetic fields and assume a “hot start” formation, which could lead to an underestimation of the mass (Malo et al. 2014; Marleau & Cumming 2014). Additionally, it has been demonstrated that current atmosphere models do not correctly reproduce the effects of dust, particularly in the case of young objects (e.g., Barman et al. 2011; Faherty et al. 2012; Liu et al. 2013b).

| Property | Value | Property | Value |
|----------|-------|----------|-------|
| RA       | 11:10:10.011 | J (UKIDSS) | 16.16 ± 0.01 |
| Decl.    | +01:16:13.09 | H (UKIDSS) | 16.20 ± 0.02 |
| \(\mu_\alpha\cos \delta\) (mas yr\(^{-1}\)) | −217.1 ± 0.7 | K (UKIDSS) | 16.05 ± 0.03 |
| \(\mu_\delta\) (mas yr\(^{-1}\)) | −280.9 ± 0.6 | W1 (AlWISE) | 15.44 ± 0.04 |
| RV (km s\(^{-1}\)) | 7.5 ± 3.8 | W2 (AlWISE) | 13.92 ± 0.04 |
| Distance (pc)* | 19.19 ± 0.44 | W3 (AlWISE) | 12.00 ± 0.29 |
| X (pc) | −2.79 ± 0.06 | Spectral type | T5.5 pec |
| Y (pc) | −10.78 ± 0.25 | Mass (\(M_{\text{Jup}}\)) | 10–12 |
| Z (pc) | 15.62 ± 0.36 | Radius (\(R_{\text{Jup}}\)) | 1.18 ± 0.02 |
| \(U\) (km s\(^{-1}\)) | −5.9 ± 0.7 | \(T_\text{eff}\) (K) | 940 ± 20 |
| \(V\) (km s\(^{-1}\)) | −30.1 ± 2.2 | log \(g\) | 4.28 ± 0.04 |
| \(W\) (km s\(^{-1}\)) | −12.6 ± 3.1 | \(L_{\text{bol}}/L_{\odot}\) | −4.99 ± 0.02 |

Note. * Measurement from Dupuy & Liu 2012.

It has been proposed that the effects of enhanced dust clouds in young brown dwarfs also slow down the NIR cooling rates which would lead to an over-estimation of the mass (Saumon & Marley 2008). This has been demonstrated by the recent dynamical mass measurements of dusty brown dwarfs (e.g., Konopacky et al. 2010; Dupuy et al. 2015).

We have furthermore used the method of Filippazzo et al. (2015) to obtain several of the fundamental parameters of SDSS J1110+0116. We calculated the bolometric luminosity of SDSS J1110+0116 using its parallax, NIR spectrum combined with NIR and mid-infrared photometry (see Table 1) and obtained log \(L_{\text{bol}}/L_{\odot} = −4.99 ± 0.02\). We have then used solar metallicity, hybrid cloud (SMHCO8) evolutionary model isochrones (Saumon & Marley 2008) to obtain a semi-empirical radius of \(R = 1.18 ± 0.02\) \(R_{\text{Jup}}\) using the above bolometric luminosity at the age of AB Doradus (110–130 Myr). This in turn allowed us to derive an effective temperature of \(T_\text{eff} = 940 ± 20\) K from the Stefan–Boltzmann Law. Evolutionary tracks also provide estimates for the surface gravity (log \(g\) = 4.28 ± 0.04) and mass (10–12 \(M_{\text{Jup}}\)) of SDSS J1110+0116, the latter of which is consistent with our previous mass estimate based on the BT-Settl models.

We used the same method to calculate the properties of all brown dwarf bona fide or high-confidence candidate members of AB Doradus from the literature (Schlitter et al. 2012; Liu et al. 2013a; Gizis et al. 2015; Gagné et al. 2015; J. K. Faherty et al. 2015, in preparation; see Table 2). In this work, the term high-confidence candidate member refers to those that have at least an RV or a parallax measurement and that have unambiguous, high (>90%) bayesian membership probabilities to AB Doradus, as calculated by BANYAN II.

We note that SDSS J1110+0116 has an effective temperature which is marginally lower than those of typical T5–T6 dwarfs in the field (1000–1100 K; Stephens et al. 2009), as is the case for GU Psc b (see also Naud et al. 2014) and for the young (~125–400 Myr) T2.5 dwarf HR Peg B (Luhman et al. 2007). A similar but more pronounced effect has already been noted for young L-type brown dwarfs (Metchev & Hillenbrand 2006; Faherty et al. 2012; Bowler et al. 2013; Liu et al. 2013a; Naud et al. 2014; Gauza et al. 2015). Table 2 provides a sequence of the fundamental properties of young brown dwarfs at the age of
Table 2
Properties of Brown Dwarf High-confidence Candidates Or Bona Fide Members of AB Doradus

| Name                  | Bona Fide? | Spectral Type | $L_{bol}$ | Radius | $T_{eff}$ | log g | Mass |
|-----------------------|------------|---------------|-----------|---------|-----------|-------|------|
| 2MASS J00192626+4614078 | N (1)      | M8 β          | –2.75 ± 0.08 | 1.65 ± 0.11 | 2890 ± 170 | 4.93 ± 0.04 | 80–111 |
| CD-35 2722B            | Y (3)      | L3 β          | –3.45 ± 0.08 | 1.27 ± 0.02 | 2200 ± 100 | 4.84 ± 0.06 | 39–51 |
| 2MASS J14252798–3650229 | Y (2)      | L4 γ          | –4.04 ± 0.01 | 1.23 ± 0.01 | 1590 ± 10  | 4.64 ± 0.04 | 25–29 |
| 2MASS J03552337+1133437 | Y (5)      | L3–L6 γ       | –4.06 ± 0.03 | 1.20 ± 0.04 | 1590 ± 40  | 4.67 ± 0.05 | 21–30 |
| 2MASS J00470038+6803543 | Y (6)      | L6–L8 γ       | –4.38 ± 0.03 | 1.28 ± 0.07 | 1280 ± 40  | 4.39 ± 0.15 | 13–22 |
| GU Psc b               | N (7)      | T3.5          | –4.88 ± 0.06 | 1.19 ± 0.03 | 1000 ± 40  | 4.31 ± 0.06 | 10–13 |
| SDSS J111010.01+011613.1 | Y (8)    | T5.5          | –4.99 ± 0.02 | 1.18 ± 0.02 | 940 ± 20   | 4.28 ± 0.04 | 10–12 |

Notes.

* NIR spectral types.

* Estimates of fundamental parameters are based on the method described in J. Filippazzo et al. (submitted to ApJ).

* Mass estimates were derived from a comparison of absolute NIR magnitudes with both the BT-Settl and the SMHC08 model isochrones at the age of AB Doradus (110–130 Myr), as described in the text.

References. (1) Schlieder et al. (2012), (2) Gagné et al. (2015), (3) Wahhaj et al. (2011), (4) Allers & Liu (2013), (5) Liu et al. (2013a), (6) Gizis et al. (2015), (7) Naud et al. (2014), (8) This work, (9) Knapp et al. (2004).

Figure 2. Color–magnitude diagram of field (black diamonds) and young (purple open circles) low-mass stars and brown dwarfs compared with the bona fide or high confidence brown dwarf members of AB Doradus (red stars). We used statistical distances from BANYAN II for young dwarfs with no parallax measurements. Field dwarfs with spectral types in the T5–T6 range are circled in green for comparison with SDSS J1110+0116. Young directly imaged planets, substellar companions and isolated brown dwarfs are displayed as blue right-pointing triangles for comparison. The NIR colors of SDSS J1110+0116 are unusually red compared with field dwarfs of similar spectral types, despite its normal absolute J-band magnitude. J and K magnitudes are displayed in the Mauna Kea Observatory (MKO) system.

AB Doradus (110–130 Myr) and how those relate to their NIR spectral types.

We note the interesting fact that 2MASS J14252798–3650229 and 2MASS J03552337+1133437 have remarkably similar fundamental physical properties albeit different NIR spectral shapes (e.g., J0355 has a much redder continuum, weaker FeH absorption at ∼1.0 μm and a shallower CO band at ∼2.3 μm). This is an additional indication for the diversity of the spectral properties of young brown dwarfs with similar fundamental physical properties (see Allers & Liu 2013), an effect that could be explained by different cloud properties. Alternatively, this could also be a consequence of either object having an unresolved companion.

In Figure 2, we compare the position of SDSS J1110+0116 with that of field and young brown dwarfs and planetary-mass companions in a $M_J$ versus $J–K$ color–magnitude diagram. We display bona fide and high-confidence candidate members of AB Doradus that are listed in Table 2 using red star symbols to outline a preliminary sequence of brown dwarfs in AB Doradus. These objects fall on the right of the field sequence, an effect that is also observed for earlier-type young brown dwarfs and planetary-mass companions (e.g., Metchev & Hillenbrand 2006; Kirkpatrick et al. 2008; Burgasser et al. 2010; Barman et al. 2011; Liu et al. 2013a; Faherty et al. 2013). We note that SDSS J1110+0116 has absolute magnitudes similar to field T5–T6 dwarfs in the 2MASS $J, H,$
$K_S$ and WISE W1 and W2 bands (Dupuy & Liu 2012). This may reflect a balance between a large radius and enhanced dust opacity in its high atmosphere. A compilation of the properties of SDSS J1110+0116 are listed in Table 1.

4.4. The Search for a Co-moving Companion

We performed a search for a co-moving companion to SDSS J1110+0116 using all 335 2MASS entries within a conservatively large radius of 15\degree, which corresponds to $\sim$17,000 AU at the distance of SDSS J1110+0116. We cross-matched every 2MASS source with the AllWISE catalog using the method described in Paper V. The proper motions that we derived for this set of objects have a median precision of $\sim$20 mas yr$^{-1}$ for both $\mu_\alpha \cos \delta$ and $\mu_\delta$. We find no object matching the proper motion of SDSS J1110+0116 within 15$\arcmin$ and $<$240 mas yr$^{-1}$. We can thus reject the possibility of a common proper motion companion that would be bright enough to be detected in the 2MASS and AllWISE catalogs. The faintest of these 335 objects has $J = 17.3$ and $W_1 = 17.1$, and the completeness limits of 2MASS and AllWISE are $J = 15.8$ (Skrutskie et al. 2006) and $W_1 = 17.1$, respectively.\(^{11}\)

5. CONCLUSION

Using existing previously reported astrometry and a new radial velocity measurement coupled with low-gravity features in its atmosphere, we have determined that SDSS J1110+0116 is a T5.5 bona fide member of AB Doradus, with an estimated mass of $\sim$10–12 $M_{\text{Jup}}$. This is one of the coldest member of any young moving group identified so far and its relatively high brightness will make it useful to better understand how age and surface gravity shape the atmospheres of low-mass brown dwarfs and planets, influence evolution, and guide future searches for planetary-mass members of young moving groups. This new object falls into a region of the mass/age parameter space that we have only recently begun to explore. It is similar to GU Psc b (Naud et al. 2014) albeit for the fact that it has a slightly lower mass/temperature and is isolated in space. It is also comparable to PSO J318.5338–22.8603 (Liu et al. 2013b), at an older age and with a slightly larger mass, or to the young T dwarfs ROSS 458 C (Burgasser et al. 2010; Goldman et al. 2010) at a younger age and warmer temperature. All data presented in this work can be found at www.astro.umontreal.ca/~gagne and in the Montreal Spectral Library, located at www.astro.umontreal.ca/~gagne/MSL.php.

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Facility: Magellan:Baade (FIRE)

Note added in proof. An updated relative-to-absolute parallax correction for SDSS J1110+0116 has brought the proper motion measurement of Dupuy et al. (2012) in better agreement with our measurement based on 2MASS and AllWISE. The two measurements thus agree within 1\sigma (T. Dupuy, private communication). This does not affect the Bayesian membership probability to AB Doradus in a significant way.

REFERENCES

Allard, F., Homeier, D., & Freytag, B. 2012, RSPTA, 370, 2765
Allers, K. N., & Liu, M. C. 2013, ApJ, 772, 79
Baraffe, I., Chabrier, G., Barman, T. S., Allard, F., & Hauschildt, P. H. 2003, A&A, 402, 701
Barenfeld, S. A., Bubar, E. J., Mamajek, E. E., & Young, P. A. 2013, ApJ, 766, 6
Barman, T. S., Macintosh, B., Konopacky, Q. M., & Marois, C. 2011, ApJL, 735, L39
Bochanski, J. J., Burgasser, A. J., Simcoe, R. A., & West, A. A. 2011, AJ, 142, 169
Bochanski, J. J., Hennawi, J. F., Simcoe, R. A., et al. 2009, PASP, 121, 1409
Bowler, B. P., Liu, M. C., Shkolnik, E. L., & Dupuy, T. J. 2013, ApJ, 774, 55
Burgasser, A. J., Simcoe, R. A., Bochanski, J. J., et al. 2010, ApJ, 723, 1405
Cushing, M. C., Vacca, W. D., & Rayner, J. T. 2004, PASP, 116, 362
Delorme, P., Gagné, J., Malo, L., et al. 2012, A&A, 548, A26
Dupuy, T. J., & Liu, M. C. 2012, ApJS, 201, 19
Dupuy, T. J., Liu, M. C., Leggett, S. K., et al. 2015, ApJ, 805, 56
Faherty, J. K., Burgasser, A. J., Walter, F. M., et al. 2012, ApJ, 752, 56
Faherty, J. K., Rice, E. L., Cruz, K. L., Mamajek, E. E., & Núñez, A. 2013, AJ, 145, 2
Filippazzo, J. C., Rice, E. L., Faherty, J. K., et al. 2015, ApJ, submitted
Gagné, J., Faherty, J. K., Cruz, K. L., et al. 2015, ApJS, in press
Gagné, J., Lafrenière, D., Doyon, R., Malo, L., & Artigau, É. 2014, ApJ, 783, 121
Gagné, J., Lafrenière, D., Doyon, R., Malo, L., & Artigau, É. 2015, ApJ, 798, 73
Gardner, J. P., Mather, J. C., Clampin, M., et al. 2006, SSRv, 123, 485
Gauza, B., Béjar, V. S. J., Pérez-Garrido, A., et al. 2015, ApJ, 804, 96
Gilmozzi, R., & Spypromilo, J. 2008, Proc. SPIE, 7012, 701219
Gizis, J. E. 2002, ApJ, 575, 484
Gizis, J. E., Allers, K. N., Liu, M. C., et al. 2015, ApJ, 799, 203
Goldman, B., Marsat, S., Henning, T., et al. 2010, MNRAS, 405, 1140

\(^{11}\) See http://wise2.ipac.caltech.edu/docs/release/allwise/expsup/sec2_4a.html.
Johns, M., Hull, C., Muller, G., et al. 2014, Proc. SPIE, 9145, 91451F
Kirkpatrick, J. D., Cruz, K. L., Barman, T. S., et al. 2008, ApJ, 689, 1295
Knapp, G. R., Leggett, S. K., Fan, X., et al. 2004, AJ, 127, 3553
Konopacky, Q. M., Ghez, A. M., Barman, T. S., et al. 2010, ApJ, 711, 1087
Liu, M. C., Dupuy, T. J., & Allers, K. N. 2013a, AN, 334, 85
Liu, M. C., Magnier, E. A., Deacon, N. R., et al. 2013b, ApJL, 777, L20
Luhman, K. L. 2013, ApJL, 767, L1
Luhman, K. L., Patten, B. M., Marengo, M., et al. 2007, ApJ, 654, 570
Malo, L., Doyon, R., Feiden, G. A., et al. 2014, ApJ, 792, 37
Marleau, G. D., & Cumming, A. 2014, MNRAS, 437, 1378
Marley, M. S., Seager, S., Saumon, D., et al. 2002, ApJ, 568, 335
Metchev, S. A., & Hillenbrand, L. A. 2006, ApJ, 651, 1166
Naud, M.-È, Artigau, É, Malo, L., et al. 2014, ApJ, 787, 5
Nelson, J., & Sanders, G. H. 2008, Proc. SPIE, 7012, 70121A
Rebolo, R., Zapatero Osorio, M. R., Madruga, S., et al. 1998, Sci, 282, 1309
Rice, E. L., Faherty, J. K., & Cruz, K. L. 2010, ApJL, 715, L165
Saumon, D., & Marley, M. S. 2008, ApJ, 689, 1327
Schlieder, J. E., Lépine, S., & Simon, M. 2012, AJ, 143, 80
Schneider, A. C., Cushing, M. C., Kirkpatrick, J. D., et al. 2014, AJ, 147, 34
Scholz, R. D. 2014, A&A, 561, A113
Simcoe, R. A., Burgasser, A. J., Schechter, P. L., et al. 2013, PASP, 125, 270
Skrutskie, M. F., Cutri, R. M., Stiening, R., et al. 2006, AJ, 131, 1163
Stephens, D. C., Leggett, S. K., Cushing, M. C., et al. 2009, ApJ, 702, 154
Vacca, W. D., Cushing, M. C., & Rayner, J. T. 2003, PASP, 115, 389
Wahhaj, Z., Liu, M. C., Biller, B. A., et al. 2011, ApJ, 729, 139
Zapatero Osorio, M. R., Martín, E. L., Béjar, V. J. S., et al. 2007, ApJ, 666, 1205
Zuckerman, B., & Song, I. 2004, ARA&A, 42, 685
Zuckerman, B., Song, I., & Bessell, M. S. 2004, ApJL, 613, L65