DISCOVERY OF AN L4/β CANDIDATE MEMBER OF ARGUS IN THE PLANETARY MASS REGIME: WISE J231921.92+764544.4

PHILIP J. CASTRO AND JOHN E. GIZIS
Department of Physics and Astronomy, University of Delaware, Newark, DE 19716, USA; philip.j.castro@gmail.com, gizis@udel.edu
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ABSTRACT

We present the discovery of a young L dwarf, WISE J231921.92+764544.4, identified by comparing the Wide-field Infrared Survey Explorer (WISE) All-Sky Catalog to the Two Micron All Sky Survey (2MASS). A medium-resolution optical spectrum provides a spectral type of L4/β, with a photometric distance estimate of 26.1 ± 4.4 pc. The red WISE W1 – W2 color provides additional evidence of youth, while the 2MASS J – Ks color does not. WISE J231921.92+764544.4 is a candidate member of the young moving group Argus, with the space motion and position of WISE J231921.92+764544.4 giving a probability of 79% for membership in Argus and a probability of 21% as a field object, based on BANYAN II. WISE J231921.92+764544.4 has a mass of 12.1 ± 0.4 MJup based on membership in Argus, within the planetary mass regime.

Key words: brown dwarfs – infrared: stars – proper motions – stars: distances – stars: individual (WISE J231921.92+764544.4) – stars: late-type

1. INTRODUCTION

Brown dwarfs are objects that lie between the mass range of stars and planets (13 M_{Jup} \lesssim M \lesssim 75 M_{Jup}); they have insufficient mass to sustain hydrogen fusion but enough mass to burn at least deuterium. Brown dwarfs are brightest when they are born and continuously dim and cool thereafter (Basri 2000), and as a consequence, evolve through the MLT spectral sequence. An early L dwarf could be an old very low mass star, a young brown dwarf, or an even younger planetary mass object (Kirkpatrick 2005; Cruz et al. 2009). Brown dwarfs contract as they age, with the radius of young brown dwarfs being as much as three times greater than their eventual equilibrium state (Burrows et al. 2001; McGovern et al. 2004). With g \sim M/R^2, brown dwarfs evolve from low to high surface gravity as they age (McGovern et al. 2004; Kirkpatrick 2005).

G196-3B was discovered by Rebolo et al. (1998) as a companion to a young M2.5 dwarf (G196-3A, \sim 100 Myr) by direct imaging. The low-resolution optical spectrum indicated a candidate L dwarf and showed weak Na I, Rb I, and Cs I, interpreted as an indication of low surface gravity. Follow-up optical observations by Kirkpatrick et al. (2001) showed it to be an L2 dwarf. Observations of G196-3B by McGovern et al. (2004) in the near-infrared (J band) are supportive of low surface gravity, showing the presence of TiO and VO, weak K I lines, and weak FeH absorption. McGovern et al. (2004) showed that TiO, VO, K I, Na I, Cs I, Rb I, CaH, and FeH are gravity sensitive features in brown dwarfs by comparing these features in late-type giants and in old field dwarfs using low-resolution J band and optical spectra. 2MASS J01415823-4633574 was discovered by Kirkpatrick et al. (2006), classified as L0 pec, and is another benchmark object that set the framework for understanding young L dwarfs in the field. Its optical spectrum showed very strong bands of VO and weak absorptions by TiO, K I, and Na I, with low-gravity being an explanation for these unique spectral signatures. The near-infrared spectrum showed a triangular-shaped H band, where this feature was reported in the spectra of young brown dwarf candidates in the Orion Nebula Cluster (Lucas et al. 2001), providing further evidence of youth. The near-infrared spectrum was also much redder than spectra of normal late-M/early-L dwarfs, its 2MASS J – Ks color being significantly redder than the average color for normal field L0 dwarfs. The near-infrared spectrum showed strong VO and weak Na I, K I, and FeH, analogous to the peculiarities seen in the optical spectrum. Numerous other young L dwarfs have been identified in the field (Cruz et al. 2007; Kirkpatrick et al. 2008; Reid et al. 2008), culminating with a preliminary spectral sequence for low-gravity L dwarfs by Cruz et al. (2009). This sequence includes very low-gravity (γ) and intermediate-gravity (β) L dwarfs spanning L0–L5, with the greek suffix appending the spectral type to indicate gravity type as suggested by Kirkpatrick (2005). The low-gravity (γ) are estimated to be closer to \sim10 Myr, and the intermediate gravity (β) are more likely \sim100 Myr (Cruz et al. 2009). Young brown dwarfs play an important role in that they are analogs to giant exoplanets. Young brown dwarfs and giant exoplanets share overlapping temperature regimes, condensate clouds in their atmospheres, and have similar photometric and spectroscopic characteristics. Current technology only allows a handful of planetary systems to be directly studied. With young brown dwarfs being numerous, bright, and isolated in the field, they serve as excellent candidates for extensive studies that are not feasible with exoplanets. Additionally, young brown dwarfs associated with young moving groups provide a more precise age estimate than other young brown dwarfs in the field and will therefore play a role in helping to constrain substellar evolutionary models (Faherty et al. 2013a).

The Wide-field Infrared Survey Explorer (WISE) all-sky data release (occurred on 2012 March 14) covers the entire sky in four bands centered at wavelengths 3.4 μm (W1), 4.6 μm (W2), 12 μm (W3), and 22 μm (W4), and achieves 5σ detections for point sources (Wright et al. 2010). The Two Micron All Sky Survey (2MASS) is a near-infrared survey performed from 1997 to 2001 covering virtually the entire sky at wavelengths 1.25 μm (J), 1.65 μm (H), and 2.16 μm (Ks), providing a 10σ point-source detection level of better than 15.8, 15.1, and 14.3 mag, respectively (Skrutskie et al. 2006). These two all-sky surveys, with a difference in epochs of \sim10 years, and photometry in the near and mid-infrared, provide an ideal setup
to search for low-mass stars and brown dwarfs via their apparent motion. Multi-epoch searches using 2MASS and WISE have yielded numerous discoveries (e.g., Castro & Gizis 2012; Gizis et al. 2012; Luhman et al. 2012; Castro et al. 2013; Luhman 2013).

This manuscript presents the discovery of a young brown dwarf, with a mass estimate in the planetary mass regime based on membership in Argus. In Section 2 we discuss the discovery and observations of WISE J231921.92+764544.4. Section 3 features the analysis, which includes the optical spectrum, photometric colors, and the distance and physical properties, and lastly Section 4 features the conclusions and considerations for future work.

2. DISCOVERY AND OBSERVATIONS

We have performed a search for objects that have moderate apparent motion between 2MASS and the WISE all-sky data release1, complementary to previous searches (Gizis et al. 2011a, 2011b; Castro & Gizis 2012; Gizis et al. 2012; Castro et al. 2013). Since WISE is already matched to 2MASS within 3′, and we are searching for objects with moderate proper motion, we can use the 2MASS information within the WISE catalog in addition to the WISE parameters to help constrain the search. One of our searches required a detection in W1, W2, and W3, an extended source flag of zero, “PH_QUAL”2 of “AAA” for W1, W2, and W3, color constraints for WISE and 2MASS of 0.4 ≤ W1 – W2 ≤ 0.8, 0.8 ≤ W2 – W3 ≤ 1.2, W1 ≤ 13.0, 1.55 ≤ J – Ks ≤ 1.95, and the distance between a WISE source and a 2MASS source of ≥1″. WISE sources meeting our criteria were examined visually using 2MASS and WISE finder charts3 in order to look for apparent motion of a source between the two surveys. This search criteria yielded six results; five were spurious, while one of them was real, WISE J231921.91+764544.3. Although the original search that discovered WISE J231921.91+764544.3 was done using the WISE all-sky data release, we present our results using the most recent reprocessed AllWISE data release4 for WISE J231921.91+764544.3, using the AllWISE designation of WISE J231921.92+764544.4 (W2319+7645, hereafter).

W2319+7645 is found a distance of 2″0 to the northeast of the 2MASS source 2MASS J23192137+7645437. The WISE source shows colors that are red, W1 – W2 = 0.48 ± 0.12, consistent with that of a late L dwarf (Kirkpatrick et al. 2011); the 2MASS source has red colors, J – Ks = 1.71 ± 0.08, that are consistent with an L dwarf (Kirkpatrick et al. 2000). Figure 1 shows the WISE Ks and WISE W1, W2, W3, and W4 images centered on W2319+7645; in all of the images the red circle shows the location of W2319+7645 based on the WISE epoch and in the Ks image the green circle shows the location of W2319+7645 based on the 2MASS epoch.

W2319+7645 was observed using the Gemini-north telescope. The Gemini-north observations (Gemini program GN-2012B-Q-105) were on UT Date 2012 September 11 with the GMOS spectrograph (Hook et al. 2004) using grating R831, and consisted of four 600 s exposures. The wavelength coverage was 6340–8460 Å with a resolution of ~2 Å. Conditions were non-photometric. All spectra were processed using standard IRAF tasks.

3. ANALYSIS

3.1. Optical Spectrum

Figure 2 shows the Gemini GMOS-N spectrum of W2319+7645 (black) compared to the L0 through L5 optical standards (red). The standards are as follows: 2MASS J0345432+254023 (L0; Kirkpatrick et al. 1999), 2MASSW J1439284+192915 (L1; Kirkpatrick et al. 1999), Kelu-1 (L2; Kirkpatrick et al. 1999), DENIS-P J1058.7–1548 (L3; Delfosse et al. 1997), 2MASSW J1155009+230706 (L4; Kirkpatrick et al. 1999), and DENIS-P J1228.2–1547 (L5; Delfosse et al. 1997). The TiO head at 7053 Å has a maximum at about spectral type M8, and disappears at about L2 (Kirkpatrick et al. 1999). The lack of TiO absorption at 7053 Å and red L dwarf J – Ks colors indicates that W2319+7645 is an L dwarf later than L1. We performed a by-eye comparison of the overall continuum of W2319+7645 to the L0–L5 standards (Kirkpatrick et al. 1999). W2319+7645 best fits the L2 standard and is a poor fit to the other L dwarf standards. VO has a broad trough at about 7334–7534 Å and about 7851–7973 Å, has a maximum at about spectral type M9, and has disappeared at ~L4 (Kirkpatrick et al. 1999). The L2 standard shows VO present at 7334–7534 Å and 7851–7973 Å, however, W2319+7645 does not have any evidence of VO in these wavelength regions. The lack of VO in W2319+7645 indicates it is an ~L4 or later, therefore, W2319+7645 is not consistent with a spectral type of L2. With W2319+7645 not being consistent with any of the normal L dwarf standards we investigate the potential of it being a low-gravity L dwarf.

As suggested by Cruz et al. (2009), we use a by-eye analysis to compare W2319+7645 to L dwarf standards and low-gravity L dwarfs (from Cruz et al. 2009), along with spectral

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1 http://wise2.ipac.caltech.edu/docs/release/allsky/expsup/
2 The “PH_QUAL” flag is a measure of the photometric quality in each band, with flags A, B, C, U, X, and Z. A to C represent detections with a decreasing signal to noise. For more details refer to the Explanatory Supplement to the WISE All-Sky Data Release Products, http://wise2.ipac.caltech.edu/docs/release/allsky/expsup/sec2_2a.html#ph_qual
3 Finder charts at IRSA can be found at http://irsa.ipac.caltech.edu/
4 http://wise2.ipac.caltech.edu/docs/release/allwise/expsup/
indices, in order to investigate low-gravity and consequently determine spectral type. We compare the overall continuum in the relatively gravity-insensitive region (8000–8400 Å) (Cruz et al. 2009) of W2319+7645 to the L0–L5 standards. A comparison using the gravity-insensitive region will aid in constraining the low-gravity spectral subtype of W2319+7645. W2319+7645 best fits the gravity-insensitive region of the L4 standard. W2319+7645 has too much flux for the K1 doublet and the surrounding region compared to the L4 standard. We compare the overall continuum of W2319+7645 to the low-gravity L dwarf subtypes of Cruz et al. (2009); with the exception of the L3β subtype whose spectrum was not available for comparison. Of the low-gravity L dwarfs compared to, W2319+7645 is a fit to the L4β, L4γ, L5β, and L5γ. With a best fit to the gravity-insensitive region of the L0–L5 standards being the L4 standard, and W2319+7645 being a fit to the low-gravity L dwarfs, we place the focus on a spectral type of L4β and L4γ. Figure 3 shows the Gemini GMOS-N spectrum of W2319+7645 (black) compared to the L4 standard 2MASSW J1155009+230706 (red) (Kirkpatrick et al. 1999), the intermediate-gravity L4β 2MASS J00332386–1521309 (blue), and the very low-gravity L4γ 2MASS J05012406–0010452 (green) (Cruz et al. 2009). Weaker absorption due to the K1 doublet is the most prominent feature of the low-gravity L dwarfs, with the later-type (L3–L5) low-gravity L dwarfs showing more flux than normal L dwarfs near the K1 doublet (7300–8000 Å) (Cruz et al. 2009). W2319+7645 shows weaker absorption of the K1 doublet and the surrounding region compared to the L4 standard. Of the low-gravity L dwarfs, W2319+7645 best fits the overall continuum of the L4γ. However, the K1 doublet of the L4γ is much sharper than that of W2319+7645. W2319+7645 has a slight lack of flux in the region surrounding the K1 doublet compared to the L4β, in the region most affected by gravity (7300–8000 Å) (Cruz et al. 2009), as well as for wavelengths shortward of 7300 Å. The NaI doublet at 8183 and 8195 Å is either not present or very weak in low-gravity L dwarfs (Cruz et al. 2009). The NaI doublet of the L4 standard and the L4β are similar, with W2319+7645 matching them quite well, while the L4γ is very weak in comparison; see the zoomed in view of the NaI doublet to the right of each spectrum. The NaI doublet is a distinctive feature distinguishing the normal-gravity L4 standard and the intermediate-gravity L4β from the very low-gravity L4γ. With the NaI doublet of W2319+7645 being a poor match to the L4γ, we conclude a by-eye spectral type of L4β.

Figure 4 shows the spectral indices for W2319+7645 (gray star), the L4 standard 2MASSW J1155009+230706 (red circle), the L4β 2MASS J00332386–1521309 (blue square), and the L4γ 2MASS J05012406–0010452 (green diamond), based on spectral indices defined by Kirkpatrick et al. (1999) and Cruz et al. (2009). These spectral indices were shown by Cruz et al. (2009) to be gravity sensitive. Error bars for the spectral indices were determined following Cruz et al. (2009). The K-a, K-b, and Rb-b indices strongly indicate that W2319+7645 is low-gravity, while Rb-b supports low-gravity. The indices overall are consistent with a spectral type of L4β or L4γ. Based on our by-eye analysis of the spectrum of W2319+7645 and its spectral indices, we find a spectral type for W2319+7645 of L4β.

The unresolved absorption doublet at 6708 Å, Li i, is clearly present in the spectrum of W2319+7645. W2319+7645 passes the lithium test (Rebolo et al. 1992). We measure an equivalent width (EW) of Li i for W2319+7645 of 6.3±0.3 Å in the same manner as Cruz et al. (2009). At about 1800 K (L4 spectral subtype), 50% lithium depletion occurs at about 1 Gyr and a mass of about 0.06 Mα (Kirkpatrick 2005). The lithium absorption of W2319+7645 indicates substellarity and youth (<1 Gyr). The lack of Li i absorption in the L4β and the presence of Li i absorption in the L4γ cannot be used as an indicator of youth. Li i absorption is expected to be weaker for lower gravity early to mid L dwarfs (Kirkpatrick et al. 2008), in contradiction to the situation shown for the L4β and L4γ. Li i absorption is still not fully understood in young brown dwarfs (Kirkpatrick et al. 2008; Cruz et al. 2009).

### 3.2. Photometric Colors

Low-gravity L dwarfs have been shown to have red near-infrared colors (J − Ks), and it has been shown that they tend to fall at the red end of the distribution within their spectral class (Cruz et al. 2009). Faherty et al. (2013b) demonstrated that Lγ dwarfs tend to lie at the red end of the distribution within their spectral class for near-infrared colors (J − Ks) and
analogously for mid-infrared colors (W1 − W2). Figure 5 shows 2MASS J − K_s (top) and WISE W1 − W2 (bottom) colors as a function of spectral type for W2319+7645 (gray star), normal L dwarfs (red circles), L\(_{\beta}\) dwarfs (blue squares), and L\(_{\gamma}\) dwarfs (green diamonds) for spectral types L0−L5. The normal L dwarfs average values of J − K_s and W1 − W2, and their standard deviations are from Faherty et al. (2013b); we note that the W1 − W2 is All-sky WISE data. The L\(_{\beta}\) and L\(_{\gamma}\) dwarfs, and their J − K_s colors are from Cruz et al. (2009), while the W1 − W2 colors were retrieved from AllWISE. Just as the L\(_{\beta}\) dwarfs tend to be at the red end of the distribution of their spectral types in J − K_s, this appears to be the case as well for W1 − W2 colors. We note there are two L\(_{\beta}\) dwarfs, one L1\(_{\beta}\) and one L4\(_{\beta}\), that lie at the average color of the normal L
dwarfs within their spectral class and are not red in W1 – W2 colors. The $J - K_s$ color of W2319+7645 is consistent with normal L4 dwarfs and does not provide additional evidence of youth. This is similar to one of the L1/β dwarfs that has a $J - K_s$ color consistent with normal L1 dwarfs. The W1 – W2 color of W2319+7645 is at the red end of the distribution for normal L4 dwarfs; albeit with large error bars. While an L dwarf having red colors alone does not imply youth, unusually thick clouds can also result in red colors (Cruz et al. 2009), the red W1 – W2 color of W2319+7645 combined with the optical spectral type of L4/β provides additional evidence of youth.

### 3.3. Distance and Physical Properties

We provide a crude distance estimate by using the spectral-type-absolute-magnitude relationships of Looper et al. (2008) for 2MASS photometry and the spectral-type-absolute-magnitude relationships of Dupuy & Liu (2012) for 2MASS and WISE photometry. We find a distance of 26.8 ± 3.7 pc from 2MASS $J$ photometry, 27.7 ± 3.8 pc from 2MASS $H$ photometry, and 26.9 ± 4.1 pc from 2MASS $K_s$ photometry using the relations from Looper et al. (2008), and 27.6 ± 5.0 pc from 2MASS $J$ photometry, 28.2 ± 5.2 pc from 2MASS $H$ photometry, 25.4 ± 5.0 pc from 2MASS $K_s$ photometry, 24.1 ± 4.7 pc from WISE $W1$ photometry, and 22.5 ± 3.8 pc from WISE $W2$ photometry using the relations from Dupuy & Liu (2012). The uncertainty in the distance estimates comes from the uncertainty in the photometry and the rms from the spectral-type-absolute-magnitude relationships. The mean of these estimates provides a distance of 26.1 ± 4.4 pc, assuming no binarity. Trigonometric parallax measurements are needed for a reliable distance estimate.

Based on a direct comparison of the 2MASS and WISE positions, W2319+7645 has a proper motion of $\mu_\alpha \cos(\delta) = 0''19 \pm 0''01$ yr$^{-1}$ and $\mu_\delta = 0''07 \pm 0''01$ yr$^{-1}$, with total apparent motion $0''20 \pm 0''01$ yr$^{-1}$. Based on the estimated distance and apparent motion, W2319+7645 has a tangential velocity of $25 \pm 5$ km s$^{-1}$. A radial velocity of $10 \pm 5$ km s$^{-1}$ was measured for W2319+7645 using the narrow atomic lines in the Gemini spectrum, giving a total space velocity of $27 \pm 7$ km s$^{-1}$. Faherty et al. (2009) gives a median tangential velocity for L4 dwarfs of $25$ km s$^{-1}$ with a dispersion of $20$ km s$^{-1}$, while the median tangential velocity for low surface gravity dwarfs is $15$ km s$^{-1}$. W2319+7645 is consistent with both of these populations. Using the position, motion, and distance of W2319+7645, from Gagné et al. (2014) we determine a heliocentric galactic position of $(X, Y, Z) = (-12 \pm 2, 22 \pm 4, 7 \pm 1)$ pc and a galactic motion of $(U, V, W) = (-27 \pm 5, -3 \pm 5, 2 \pm 2)$ km s$^{-1}$, using a right-handed coordinate system with $X$ and $U$ positive toward the galactic center.

In Figure 6, we compare the galactic position (XYZ) and galactic velocity (UVW) of W2319+7645 (red star) with 1σ error bars to the mean galactic position and mean galactic velocity of young moving groups with their 1σ dispersions. The 2σ (dashed line) and 3σ (dotted line) dispersion values are shown for Argus. The XYZ and UVW values for young moving groups are from Malo et al. (2013). W2319+7645 is consistent with the $\sim$2σ dispersion values of the galactic position and galactic velocity of Argus if we allow 3σ error bars for W2319+7645. We use the BANYAN II web tool (Malo et al. 2013; Gagné et al. 2014) to determine the probability of W2319+7645 belonging to one of the young moving groups. We used input parameters of R.A., decl., proper motion in R.A., proper motion in decl., radial velocity, distance, error in proper motion in R.A., error in proper motion in decl., error in

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\[ \delta = 19 \pm 0.01 \text{ yr}^{-1} \]

\[ \mu_\delta = 0.07 \pm 0.01 \text{ yr}^{-1} \]

\[ \text{total apparent motion: } 0.20 \pm 0.01 \text{ yr}^{-1} \]

\[ \text{tangential velocity: } 25 \pm 5 \text{ km s}^{-1} \]

\[ \text{radial velocity: } 10 \pm 5 \text{ km s}^{-1} \]

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\[ \text{Reference: Gagné, Jonathan; Astrolib (2014): IDL routines to compute XYZ and UVW coordinates. Retrieved 21:06, 2014 August 24, (GMT).} \]
Figure 6. The galactic position (XYZ) and galactic velocity (U/V/W) of W2319+7645 (red star) compared to the mean galactic position and mean galactic velocity for young moving groups from Malo et al. (2013). The 1σ error bars are shown for W2319+7645 and the 1σ dispersion values are shown for the young moving groups. The 2σ (dashed line) and 3σ (dotted line) dispersion values are shown for Argus. W2319+7645 is consistent with the ∼2σ dispersion values of the galactic position and galactic velocity of Argus if we allow 3σ error bars for W2319+7645. The probability of W2319+7645 being a member of Argus is 79% based on BANYAN II.
Table 1
Parameters of WISE J231921.92+764544.4

| Parameters          | WISE J231921.92+764544.4 |
|---------------------|--------------------------|
| WISE R.A. (J2000)   | 23:19:21.93              |
| WISE Decl. (J2000)  | +76:45:44.5              |
| WISE Epoch          | 2010.41                  |
| 2MASS R.A. (J2000)  | 23:19:21.37              |
| 2MASS Decl. (J2000) | +76:45:43.8              |
| 2MASS Epoch         | 2000.46                  |
| 2MASS J (mag)       | 15.35 ± 0.06             |
| 2MASS H (mag)       | 14.39 ± 0.05             |
| 2MASS Ks (mag)      | 13.65 ± 0.05             |
| WISE W1 (mag)       | 12.95 ± 0.12             |
| WISE W2 (mag)       | 12.45 ± 0.02             |
| WISE W3 (mag)       | 11.52 ± 0.15             |
| WISE W4 (mag)       | >8.65                    |
| J – H (mag)         | 0.97 ± 0.08              |
| J – Ks (mag)        | 1.71 ± 0.08              |
| H – Ks (mag)        | 0.74 ± 0.07              |
| W1 – W2 (mag)       | 0.48 ± 0.12              |
| W1 – W3 (mag)       | 1.19 ± 0.19              |
| W2 – W3 (mag)       | 0.93 ± 0.15              |
| Spectral Type (Opt) | L4.5                     |
| Li i EW (Å)         | 6.3 ± 0.3                |
| Distance (pc)       | 26.1 ± 4.4               |
| \(\mu_L,\cos(b)\) (mas yr\(^{-1}\)) | 190 ± 10                |
| \(\mu_L\) (mas yr\(^{-1}\)) | 70 ± 10                  |
| Total Apparent Motion (" yr\(^{-1}\)) | 0.20 ± 0.01              |
| \(v_{\text{tan}}\) (km s\(^{-1}\)) | 25 ± 5                   |
| \(v_{\text{rad}}\) (km s\(^{-1}\)) | 10 ± 5                   |
| \(v_{\text{rot}}\) (km s\(^{-1}\)) | 27 ± 7                   |
| \(X\) (pc)         | –12 ± 2                  |
| \(Y\) (pc)         | 22 ± 4                   |
| \(Z\) (pc)         | 7 ± 1                    |
| \(U\) (km s\(^{-1}\)) | –27 ± 5                 |
| \(V\) (km s\(^{-1}\)) | –3 ± 5                   |
| \(W\) (km s\(^{-1}\)) | 2 ± 2                    |
| \(T_{\text{eff}}\) (K) | 1800 ± 200               |
| Age (Myr)           | 30–50                    |
| Mass (\(M_{\text{Jup}}\)) | 12.1 ± 0.4               |

Note. **WISE** data is from the AllWISE data release.

radial velocity, error in distance, and include that W2319+7645 is younger than 1 Gyr. The probability of membership for W2319+7645 to the young moving groups shown in Figure 6 is 79.44% for membership in Argus and 20.56% as a field star. W2319+7645 is a candidate for membership in Argus.

The spectral-type-effective-temperature relationship (Looper et al. 2008) gives a \(T_{\text{eff}} = 1840 ± 170\) K, where the uncertainty in \(T_{\text{eff}}\) is twice the rms in the spectral-type-effective-temperature relation; we use double the rms for the uncertainty in \(T_{\text{eff}}\) because W2319+7645 is not a normal L dwarf. We use an IDL routine\(^6\) (Baraffe et al. 2003; Allard et al. 2013; Rajpurohit et al. 2013; Gagné et al. 2014) to estimate the mass of W2319+7645. This routine uses distance, an estimated age range, and 2MASS \((J, H, K_s)\) and **WISE** (W1, W2) photometry to determine the most probable mass range in a likelihood analysis. Using our estimated distance, an age range of 30–50 Myr (Gagné et al. 2014) based on membership in Argus, and the 2MASS and **WISE** photometry, we find a mass of \(12.1 ± 0.4 M_{\text{Jup}}\) for W2319+7645, within the planetary mass regime. Using an age estimate of \(~100–120\) Myr for an intermediate-gravity L dwarf in the field, we find a mass of \(21.9 ± 2.0 M_{\text{Jup}}\) for W2319+7645; this firmly places W2319+7645 in the substellar regime. Table 1 gives the properties of W2319+7645.

4. CONCLUSIONS

W2319+7645 is a young L dwarf of spectral type L4.5, with a crude photometric distance estimate of \(26.1 ± 4.4\) pc. An analysis of the 2MASS and **WISE** photometry of W2319+7645 reveals that the red **WISE** W1 – W2 color provides additional evidence of youth while the 2MASS J – Ks color does not. W2319+7645 is a candidate member of the young moving group Argus. Based on BANYAN II, the space motion and position of W2319+7645 give a probability of 79% membership in Argus and a probability of 21% as a field object. Based on membership in Argus, W2319+7645 has a mass estimate of \(12.1 ± 0.4 M_{\text{Jup}}\), within the planetary mass regime.

Future work should include a parallax measurement, a more accurate radial velocity measurement, and near-infrared spectroscopy. A parallax measurement will provide a reliable distance estimate, since the photometric distance estimate is only a crude indicator for young L dwarfs. A more accurate radial velocity measurement combined with a parallax measurement will help to provide a more accurate membership probability to the young moving group Argus. Near-infrared spectroscopy will help to further characterize the youth of this object, following the near-infrared classification and low-gravity scheme of Allers & Liu (2013).

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