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DISCOVERY OF A LATE L DWARF: WISEP J060738.65+242953.4

Philip J. Castro and John E. Gizis
Department of Physics and Astronomy, University of Delaware, Newark, DE 19716, USA; pcastro@udel.edu, gizis@udel.edu
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ABSTRACT

We discover a late-type L dwarf, WISEP J060738.65+242953.4 (W0607+2429), by comparing the *Wide-field Infrared Survey Explorer* (*WISE*) preliminary data release to the Two Micron All Sky Survey (2MASS) in search of high proper motion objects ($\gtrsim 0\farcs3$ yr^{-1}). W0607+2429 was found to have a proper motion of $0.57 \pm 0\farcs02$ yr^{-1}. Based on colors and color–color diagrams using 2MASS and Sloan Digital Sky Survey photometry, we estimate the spectral type (optical) to be L8 within a spectral sub-type. Based on the spectral type estimated we find W0607+2429 to have a distance of $7.8^{+1.4}_{-1.2}$ pc, making it one of only four very late L dwarfs within 10 pc, and the third closest L dwarf overall. This close L/T transition dwarf will play a pivotal role in resolving outstanding issues of condensate clouds of low-temperature atmospheres.

Key words: brown dwarfs – infrared: stars – proper motions – stars: distances – stars: individual (WISEP J060738.65+242953.4) – stars: late-type

Online-only material: color figures

1. INTRODUCTION

The *Wide-field Infrared Survey Explorer* (*WISE*) mission is an all-sky survey, whose bands are centered on wavelengths 3.4 μ ($W1$), 4.6 μ ($W2$), 12 μ ($W3$), and 22 μ ($W4$), achieving 5σ point source sensitivities. One of the main scientific goals of the *WISE* mission is to detect cool brown dwarfs (BDs), ranging from T dwarfs to the evasive Y dwarfs (Wright et al. 2010; Mainzer et al. 2011). It accomplishes this by observing at wavelengths where the spectral energy distribution of late T dwarfs and Y dwarfs peak (Wright et al. 2010). The *WISE* preliminary release has yielded multiple late T dwarf discoveries (Burgasser et al. 2011b; Mainzer et al. 2011; Wright et al. 2011). As an all-sky survey, *WISE* provides an ideal platform, in conjunction with other all-sky surveys such as the Two Micron All Sky Survey (2MASS), to study the proper motion of BDs by creating an all-sky multi-epoch survey. By comparing *WISE* to 2MASS, with similar photometric bands, and a sizable difference in epochs, ~10 yr, these two all-sky surveys provide an ideal setup to find BDs with large proper motion (nearby BDs). Multi-epoch searches using *WISE* have already produced numerous BD discoveries (Aberasturi et al. 2011; Liu et al. 2011; Loutrel et al. 2011; Gizis et al. 2011a, 2011b; Scholz et al. 2011).

Late L dwarfs are characterized by very red near-infrared colors ($J - K_s \sim 2$), H_2O absorption, and CO absorption in the K band. Early T dwarfs have a reversal of near-infrared colors to blue ($J - K_s \sim 0$), brightening of the J band (Dahn et al. 2002), weakening of CO absorption, and the strengthening of CH_4 (the onset of CO to CH_4 conversion) and H_2O absorption, where the unambiguous detection of CH_4 at the H and K bands is the defining characteristic of T dwarfs (Kirkpatrick 2005). This L/T transition occurs over a small temperature range of ~200–300 K (Kirkpatrick 2005) and is believed to be caused by the depletion of condensate clouds, where the driving mechanism for the depletion is inadequately explained by current cloud models (Burgasser et al. 2011a). The bluer $J - K$ and the brightening of the J band at the L/T transition can be explained by decreasing cloudiness. A mechanism suggested for the L/T dwarf spectral-type transition is the appearance of relatively cloud-free regions across the disk of transition L/T dwarfs as they cool (Marley et al. 2010). The complex dynamic behavior of condensate clouds of low-temperature atmospheres at the L/T transition is one of the leading problems in BD astrophysics today (Burgasser et al. 2011a).

There are dozens of known very late L dwarfs at the L/T transition. There are 26 L7-L8 dwarfs with optical (opt) classification and 24 L7-L9.5 dwarfs with solely near-infrared (NIR) classification listed in the Dwarf Archives[1] as of 2011 February 14 (Gelino et al. 2009), and four additional L7-L8 dwarfs from Schmidt et al. (2010). However, there are only three very late L dwarfs within 10 pc. The L8 (opt) dwarf DENIS-P J0255-4700 (Martín et al. 1999) at 4.97 ± 0.10 pc (Costa et al. 2006), the recently discovered L7.5 (NIR) dwarf WISEP J180026.60+013453.1 at 8.8 ± 1.0 pc (Gizis et al. 2011a), and the L8 (opt) dwarf 2MASS J02572581-3105523 (Kirkpatrick et al. 2008) at 9.7 ± 1.3 pc (Looper et al. 2008b). Clearly very late L dwarfs within 10 pc are rare. These close L/T transition BDs are fundamental in providing observational constraints to understanding the low-temperature atmospheres of these objects.

We present the discovery of a late L dwarf, WISEP J060738.65+242953.4 (W0607+2429), as part of a continued effort to discover BDs by their high proper motion between 2MASS and *WISE* (Gizis et al. 2011a, 2011b). In Section 2 we present our analysis; the discovery of W0607+2429, determine the proper motion, and estimate the spectral type based on colors and color–color diagrams, distance, and other physical properties. In Section 3 we will summarize our findings and discuss future work.

2. ANALYSIS

2.1. Discovery

We used the same criteria to search for high proper motion objects as Gizis et al. (2011b), but extended the search to red colors. We searched for *WISE* sources that had detections at $W1$ (3.4 μ), $W2$ (4.6 μ), and $W3$ (12 μ), no 2MASS counterpart within 3″,

[1] Available at http://dwarfarchives.org.

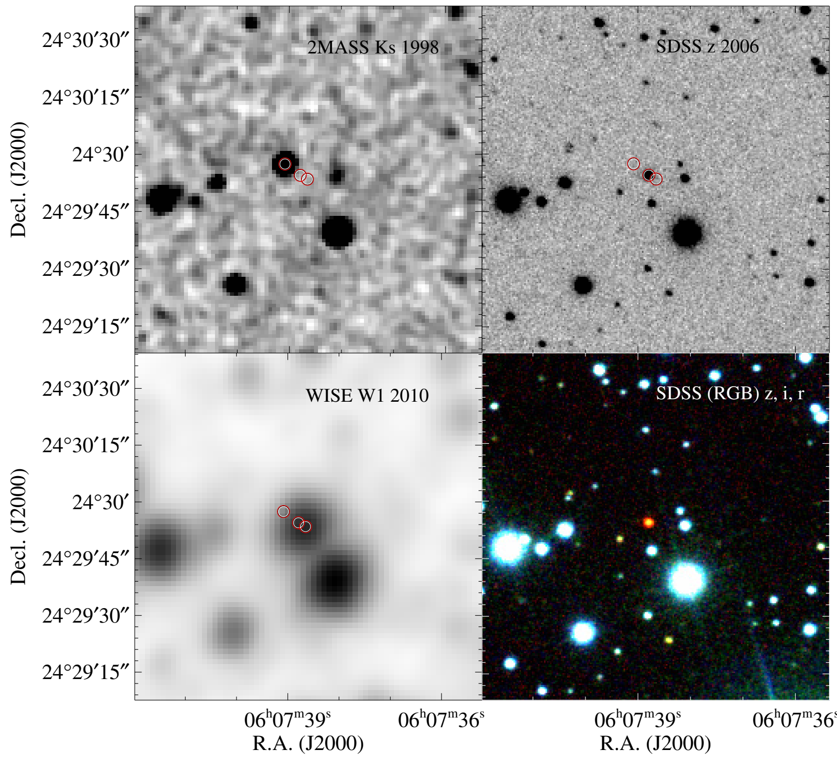

Figure 1. Finder chart showing the proper motion of W0607+2429 from the 2MASS K_s band image (top left) to the SDSS z-band image (top right, DR8, run 6585, rerun 301) to the *WISE* $W1$ image (bottom left). The three circles in each image show, from top left to bottom right, the position of W0607+2429 at the 2MASS, SDSS, and *WISE* positions, respectively. The bottom right image is an RGB image of SDSS, where the z band is red, the i band is green, and the r band is blue. The prominent red source in the SDSS RGB image, W0607+2429, is unmistakably a late-type star. North is up and east is to the left.

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

and red colors $W1 - W2 > 0.3$. *WISE* and 2MASS images were used to create finder charts to visually search for high proper motion candidates. WISEP J060738.65+242953.4 (W0607+2429) was found to have a separation of $\approx 7''$ from a 2MASS source to the northeast, 2MASSW J06073908+2429574. The *WISE* source shows colors that are red, $W1 - W2 = 0.60 \pm 0.05$, consistent with that of a late L dwarf/early T dwarf (Mainzer et al. 2011), where the 2MASS source has red colors that are consistent with an L dwarf (Kirkpatrick et al. 2000), $J - H = 1.18 \pm 0.05$ and $H - K_s = 0.57 \pm 0.05$. SDSS J060738.79+242954.4 (DR7) was found between the 2MASS and *WISE* positions at an intermediate epoch, and was recognized as having very red colors, $i - z = 3.08 \pm 0.04$, indicative of a late L dwarf (Schmidt et al. 2010), see Figure 1 bottom right image. We positively identify the 2MASS and the Sloan Digital Sky Survey (SDSS) source as W0607+2429 at their respective epochs. With a high proper motion indicating a nearby object and red colors in 2MASS, SDSS, and *WISE* indicating a late spectral type, we confidently claim the detection of a nearby ultracool dwarf. A finder chart for W0607+2429 showing a clear linear sequence of positions at the epoch of 2MASS, SDSS, and *WISE* is shown in Figure 1.

2.2. Proper Motion

We calculate the difference in position of W0607+2429 between the 2MASS, SDSS, and *WISE* epochs based on reference stars within $5'$, with the uncertainty in position based on the uncertainties in the 2MASS, SDSS, and *WISE* catalogs. We determine the proper motion of W0607+2429 by using a linear least-squares fit to the relative position at the 2MASS, SDSS, and *WISE* epochs, as shown in Figure 2. We find a proper motion of $\mu_\alpha \cos(\delta) = -0.47 \pm 0''.01$ yr^{-1} and $\mu_\delta = -0.33 \pm 0''.02$ yr^{-1}, with total motion $0.57 \pm 0''.02$ yr^{-1}. We corrected for the parallactic motion of the 2MASS, SDSS, and *WISE* positions using NOVAS V3.0 software (Kaplan et al. 2009) based on the estimated distance (see Section 2.4) of W0607+2429. In the *WISE* preliminary release source catalog a pipeline processing error resulted in a declination bias of $0''.5$, to account for the declination bias the actual declination errors of all *WISE* sources were inflated by adding a $0''.5$ error term in quadrature. However, it was discovered that this pipeline processing error affected *WISE* sources fainter than $W1 > 13.0$. We restricted *WISE* sources to $W1 < 13.0$ and W0607+2429 ($W1 < 13.0$) is not affected, we removed this $0''.5$ error term from the reported declination error to determine the actual error in calculating the proper motion. For more details see the Explanatory Supplement to the *WISE* Preliminary Data Release Products.[2] We use the astrometry and photometry from SDSS DR7 (Abazajian et al. 2009) rather than DR8 (Aihara et al. 2011) due to astrometric errors associated with DR8; we use the DR8 image in Figure 1. We note that the astrometry is different by 50 mas for W0607+2429, and the photometry in the i and z band are almost identical for W0607+2429, between DR7 and DR8. For additional information regarding the astrometric errors in DR8 refer to SDSS III.[3]

2.3. Spectral-type Estimate

We produce the color versus spectral-type plots for $i - z$ and $i - J$ from Schmidt et al. (2010), and overplot W0607+2429; see

[2] http://wise2.ipac.caltech.edu/docs/release/prelim/expsup/sec6_5.html
[3] http://www.sdss3.org/dr8/algorithms/astrometry.php#caveats

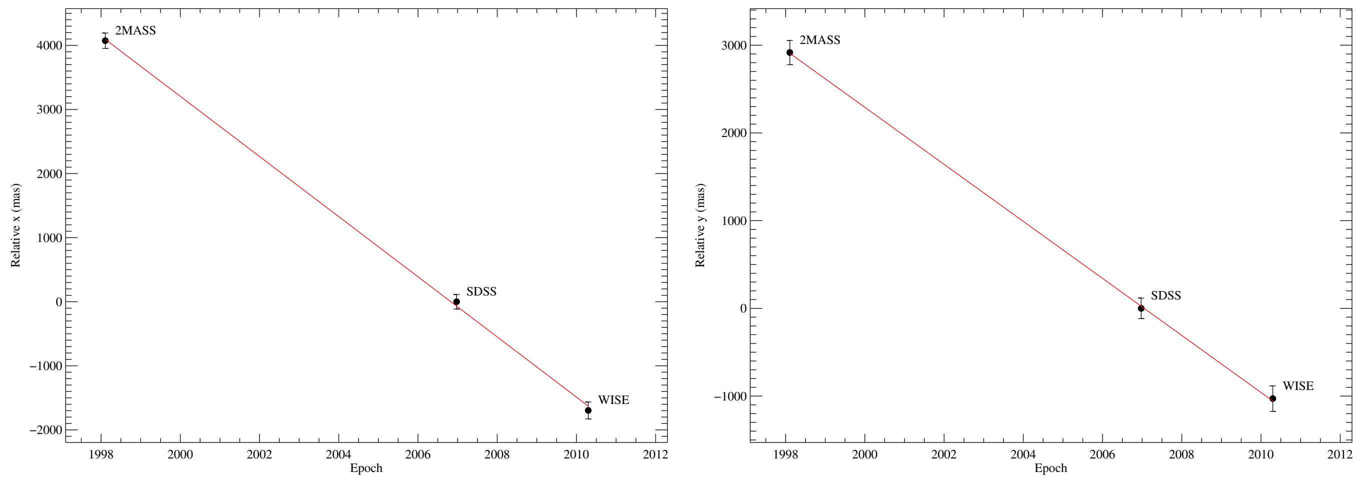

Figure 2. Best-fit line determining proper motion based on the relative 2MASS, SDSS (DR7), and *WISE* positions of W0607+2429 for right ascension (left) and declination (right).

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

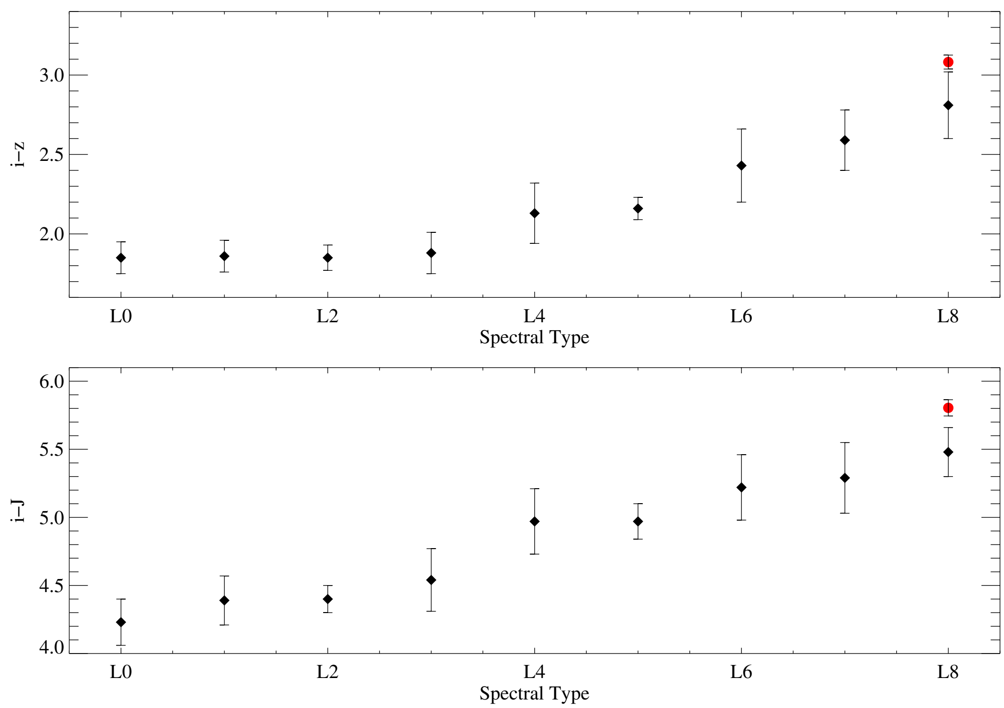

Figure 3. Color vs. spectral type for L dwarfs using data from Schmidt et al. (2010) with W0607+2429 overplotted. The diamonds show the mean values of color for each spectral type with the error bars showing the standard deviation (the standard deviation reflects the intrinsic scatter in each spectral type). The red circle is W0607+2429, whose position in color space is consistent with that of a late L dwarf.

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

Figure 3. The $i - z$ and $i - J$ colors are relatively good predictors of spectral type (Schmidt et al. 2010). It is clear from Figure 3 that W0607+2429 is a late L dwarf.

We produce color–color diagrams from Schmidt et al. (2010) using their Table 1 data and one additional L8 dwarf from their Table 5, and overplot W0607+2429. Figure 4 shows four color–color diagrams, where all four show W0607+2429 consistently lies in the color–color space that is the locus of L8 dwarfs. Based on the colors of W0607+2429, with confidence we estimate the spectral type as L8 within a spectral sub-type. We note that W0607+2429 has very similar colors to the L8 dwarf 2MASSW J1632291+190441 (Kirkpatrick et al. 1999) at ≈15 pc (Dahn et al. 2002), with $i - z = 3.11 \pm 0.20$, $i - J = 5.82 \pm 0.23$, $z - J = 2.71 \pm 0.11$, and $J - K_s = 1.86 \pm 0.12$. W0607+2429 has colors that are too red to be considered a T0 dwarf, with $J - W_2 = 3.27 \pm 0.05$ and $H - W_2 = 2.09 \pm 0.05$ (Mainzer et al. 2011), $J - K_s \not\sim 0$ (Kirkpatrick 2005), and 2MASS colors that place W0607+2429 far from the T dwarf locus in a $J - H$, $H - K_s$ color–color diagram (Kirkpatrick et al. 2000).

2.4. Distance

We estimate the distance by using the spectral-type–absolute-magnitude relationships from Looper et al. (2008a) for 2MASS photometry and Schmidt et al. (2010) for SDSS photometry. We find distance estimates of $7.9^{+1.2}_{-1.1}$ pc from 2MASS J photometry, $7.9^{+1.2}_{-1.1}$ pc from 2MASS H photometry, $8.4^{+1.3}_{-1.1}$ pc

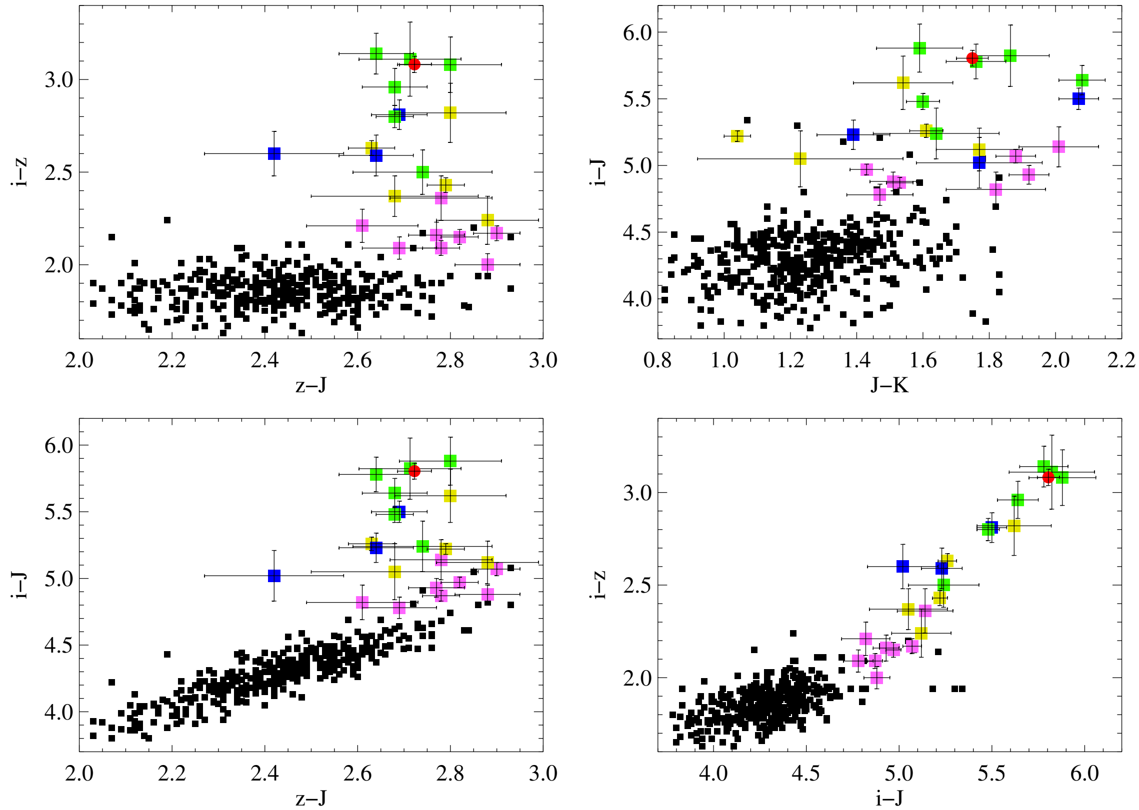

Figure 4. Color–color diagrams produced with data from Schmidt et al. (2010) with W0607+2429 overplotted. The black boxes are early L dwarfs, L0-L4, and the larger colored boxes are L5-L8 dwarfs. L5 dwarfs are magenta, L6 dwarfs are yellow, L7 dwarfs are blue, and L8 dwarfs are green. The red circle is W0607+2429, which lies at the locus of L8 dwarfs in color–color space.

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

from 2MASS K_s photometry, and $7.2^{+1.6}_{-1.3}$ pc from SDSS i and z photometry, where 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 $7.8^{+1.4}_{-1.2}$ pc, assuming no binarity. This distance estimate places it as the third closest L dwarf, after the L8 dwarf DENIS-P J0255-4700 (Martín et al. 1999) at 4.97 ± 0.10 pc (Costa et al. 2006) and the L5 dwarf 2MASSW J1507476-162738 (Reid et al. 2000) at 7.33 ± 0.03 (Dahn et al. 2002). The uncertainty in distance gives W0607+2429 a range of the second closest to the seventh closest L dwarf, refer to Gizis et al. (2011a) for a discussion of L dwarfs within 10 pc. This proximity of W0607+2429 brings the number of very late L dwarfs within 10 pc from three to four. Trigonometric parallax measurements are needed for a more reliable distance estimate.

2.5. Other Physical Properties

W0607+2429 has a tangential velocity of 21^{+4}_{-3} km s^{-1}, within range of transverse motions for other L8 dwarfs from Faherty et al. (2009), who quote a median value of 25 km s^{-1} and a dispersion of 19 km s^{-1}. This $v_{\rm tan}$ is consistent with that expected for a member of the Galactic thin disk (Faherty et al. 2009). Spectral-type–effective-temperature (Looper et al. 2008a) and spectral-type–absolute-bolometric-magnitude (Burgasser 2007) relationships give a $T_{\rm eff} = 1460 \pm 90$ K and a $\log L/L_\odot = -4.56 \pm 0.09$, where the uncertainty in $T_{\rm eff}$ comes from the rms in the spectral-type–effective-temperature relation and the uncertainty in $\log L/L_\odot$ is from the rms in the spectral-type–absolute-bolometric-magnitude relation. Based on these physical properties, theoretical isochrones from Baraffe et al. (2003) give a range of 0.5 Gyr and 0.03 $M_\odot$ to 10 Gyr and 0.072 $M_\odot$, W0607+2429 is in the substellar regime, as are all of the latest L dwarfs (Kirkpatrick 2005).

Field binaries are primarily equal brightness/mass systems in tightly bound orbits (<20 AU), where the separation of binary systems peaks at <10 AU (Allen 2007; Burgasser et al. 2007). A secondary to W0607+2429 of equal or earlier spectral type ($\lesssim$L8) would have been detected at $\gtrsim$8 AU based on the FWHM ($\approx$1″) of SDSS in the i and z band. If W0607+2429 was an unresolved binary system, for example, consisting of two L8 dwarfs, it would push the distance estimate out to 11.1 pc. The highest resolution imaging/spectroscopy is warranted to search for a companion to W0607+2429. The sensitivity of current imaging surveys begins to fall off at separations of $\lesssim$3–4 AU, where there is a model predicted frequency peak of binarity (Allen 2007). Rare nearby L dwarfs (Gizis et al. 2011a) such as W0607+2429, if found to have companions, will help to fill this void. A summary of characteristics for W0607+2429 is found in Table 1.

3. CONCLUSIONS

We have discovered a high proper motion late L dwarf, WISEP J060738.65+242953.4 (W0607+2429), with a proper motion of $0.57 \pm 0\overset{''}{.}02$ yr^{-1} and an estimated spectral type (optical) of L8 based on its colors. We estimate a distance of $7.8^{+1.4}_{-1.2}$ pc based on this spectral type, placing W0607+2429 as the third closest L dwarf, and one of only four very late L dwarfs within 10 pc.

Table 1
Parameters of WISEP J060738.65+242953.4

Parameters	WISEP J060738.65+242953.4
WISE R.A. (J2000)	06:07:38.65
WISE Decl. (J2000)	+24:29:53.5
WISE epoch[a]	2010.30
SDSS R.A. (J2000)	06:07:38.79
SDSS Decl. (J2000)	+24:29:54.5
SDSS epoch	2006.98
SDSS Data Release/Run/Rerun	DR7/6586/648
2MASS R.A. (J2000)	06:07:39.08
2MASS Decl. (J2000)	+24:29:57.5
2MASS epoch	1998.11
$i - z$ (mag)	3.08 ± 0.04
$i - J$ (mag)	5.80 ± 0.06
$z - J$ (mag)	2.72 ± 0.04
$J - K_s$ (mag)	1.75 ± 0.05
WISE $W1$ (mag)	11.55 ± 0.03
WISE $W2$ (mag)	10.95 ± 0.02
WISE $W3$ (mag)	9.93 ± 0.05
WISE $W4$ (mag)	>8.54
SDSS i (mag)	20.02 ± 0.03
SDSS z (mag)	16.94 ± 0.01
2MASS J (mag)	14.22 ± 0.03
2MASS H (mag)	13.04 ± 0.03
2MASS K_s (mag)	12.47 ± 0.02
Spectral type (optical est.)	L8
$\mu_\alpha \cos(\delta)$ (mas yr^{-1})	-470 ± 10
μ_δ (mas yr^{-1})	-330 ± 20
Distance (pc)	$7.8^{+1.4}_{-1.2}$
$v_{\rm tan}$ (km s^{-1})	21^{+4}_{-3}
$T_{\rm eff}$ (K)	1460 ± 90
log $L/L_\odot$	-4.56 ± 0.09

Note. [a] The *WISE* epoch is the average of the first and last run.

Follow-up spectroscopy is necessary to confirm the spectral type of W0607+2429, parallax measurements are needed to determine the distance with more confidence, and highest resolution imaging/spectroscopy is warranted to determine binarity. Observations to determine the photometric variability and polarization of W0607+2429 will address theories regarding the inhomogeneity of cloud cover and the color change across the L/T transition (Marley et al. 2010). Improving these inadequate models of L/T transition dwarf atmospheres has implications beyond BDs, such as hot exoplanets (HR 8799b) that are analogs to L and T dwarfs (Fortney 2005; Currie et al. 2011). W0607+2429 will serve as a fundamental testbed to further resolve outstanding issues regarding the L/T transition.

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