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Distances to WISE Y dwarfs

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Abstract. The WISE satellite has detected some of the coldest, lowest mass objects in the solar neighborhood. These late T and early Y dwarfs have effective temperatures in the range 250-800 K and inferred masses in the range 5-25 M_{Jup}. A critical piece of information for determining the physical properties of a brown dwarf is its distance, which greatly improves the comparison with evolutionary models. We discuss the importance of Y dwarfs in the context of star and planet formation. We also update our recent paper on Y dwarf parallaxes with improved values for four objects based on recent observations.

Key words. Stars: brown dwarfs

1. Introduction

Beichman et al. (2014) reported parallax and proper motion results for a sample of 15 WISE late T and Y dwarfs based on astrometric measurements from WISE, Spitzer, Keck, and the Hubble Space Telescope. Distances to objects in the sample ranged from 5 to 15 pc with most of the sample having fractional parallax errors less than ∼15%. Using the distances it is possible to turn the proper motions of the T and Y dwarfs into physical tangential velocities for comparison with other stellar types. Following Faherty et al. (2009), Beichman et al. (2014) concluded that the late T and Y dwarfs share the kinematic properties of late type Population I objects (M, L and earlier T dwarfs) with inferred ages of 2-5 Gyr.

Table 1 reports new observations using the Keck telescope, and Table 2 describes the improved parallax measurements (see Beichman et al. 2014 for details and additional observations), which have yielded significantly better astrometric solutions for four of our late T dwarfs – WISE0836−1859, WISE1311+0122, WISE1542+2230, and WISE1804+3117 – relative to the values reported in Beichman et al. (2014). For WISE1311+0122 and WISE1804+3117 the fractional parallax uncertainty is less than the 15% threshold necessary for avoiding serious errors in estimating absolute magnitudes (Lutz & Kelker 1973). For the other two objects the uncertainties remain large, ∼ 25%, and the parallaxes should be treated with caution.

By combining photometric data from 1.25 to 4.5 μm with our distance values it was possible to significantly reduce the degeneracy between the mass and age that affects the characterization of brown dwarfs based solely on the basis of photometric colors. We were able to derive model-based ages, masses, and effective temperatures with values in the range of

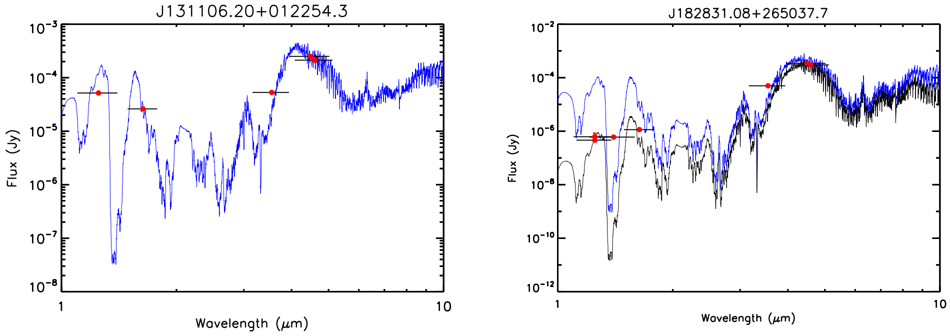

Fig. 1. BT-Settl models (Allard et al. 2011) for WISE1311+0122 (left) and WISE1828+2650 (right) are compared with photometric and absolute magnitudes to characterize the effective temperature, mass, and age of the objects. The fit for the T9 dwarf WISE1311+0122 is quite good where the fit for the *geq*Y2 dwarf WISE1828+2650 is quite poor. In the latter case the black curve shows a better fitting model in which a dust layer with A_V = 19 mag has been added to improve the fit at short wavelengths (Beichman et al. 2014)

Table 1. Keck Observation Log

Object	Sp. Type	Date
J083641.10−185947.0 (WISE0836−1859)	T8p	2014-Feb-09
		2014-Apr-15
J131106.20+012254.3 (WISE1311+0122)	T9	2014-Feb-09
		2014-Apr-15
		2014-May-18
J154214.00+223005.2 (WISE1542+2230)	T9.5	2014-Feb-09
		2014-May-18
J180435.37+311706.4 (WISE1804+3117)	T9.5:	2014-May-18

Table 2. Parallax and Proper Motion Solutions

WISE Designation	RA (J2000.0)	DEC (J2000.0)	$\mu_\alpha('' yr^{-1})^a$	$\mu_\delta('' yr^{-1})$	$\pi('')$	Dist (pc)	V_{tan}	$\chi^{2\ b}$	$\chi^{2\ c}$
J083641.10−185947.0	$8^h36^m41.2140^s$±0.0076s	$-18^o59'44.9920''\pm0.''120$	−0.051±0.009	−0.151±0.009	0.038±0.011	26.3±7.4	20±6	9.6(17)	16.4(18)
J131106.20+012254.3	$13^h11^m6.0574^s$±0.0072s	$1^o23'2.6549''\pm0.''107$	0.276±0.008	−0.823±0.008	0.063±0.009	16.0±2.2	66±9	14.7(23)	48.1(24)
J154214.00+223005.2	$15^h42^m14.7200^s$±0.0088s	$22^o30'9.1587''\pm0.''127$	−0.977±0.010	−0.379±0.010	0.084±0.019	11.9±2.8	59±14	10.2(17)	21.3(18)
J180435.37+311706.4	$18^h4^m35.5650^s$±0.0076s	$31^o17'6.2005''\pm0.''131$	−0.264±0.009	0.027±0.010	0.080±0.010	12.5±1.6	16±2	27.0(29)	73.8(30)

[a]Proper motion in right ascension is given in units of arcsec yr^{-1} and includes the correction for $cos(\delta)$. [b] χ^2 value with degrees of freedom in parentheses. Fit includes parallax.[c] χ^2 value with degrees of freedom in parentheses. Fit does not include parallax.

2-5 Gyr (consistent with kinematic estimates), 5-25 M_{Jup} and 400-800 K for objects ranging from T8 to *geq*Y2 spectral types (Table 3). The model fits for the warmer late T dwarfs, e.g. WISE1311+0122, are of higher fidelity than for the colder objects, e.g. WISE1828+2650 (Figure 1). For WISE1828+2650, it was impossible to find a model that would fit the 1.25-

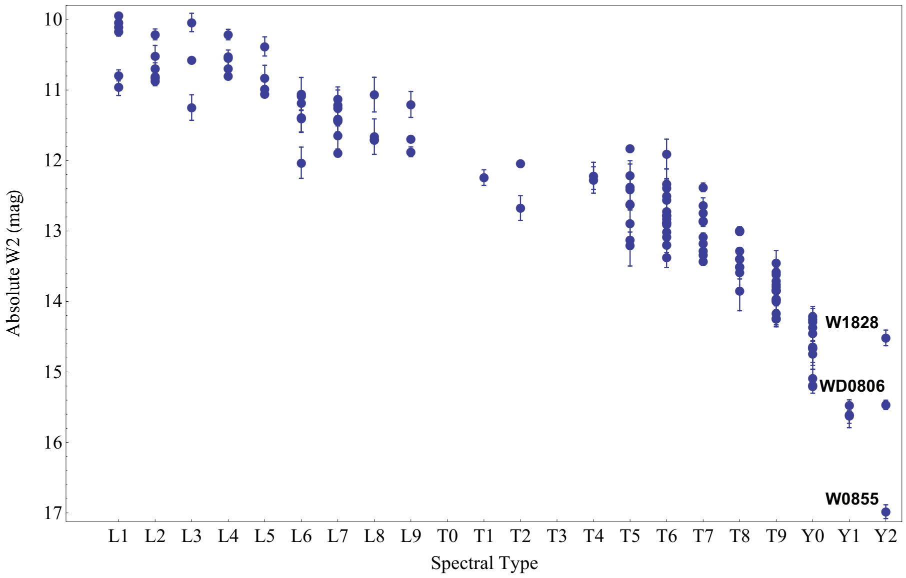

Fig. 2. A color-magnitude diagram showing WISE W2 (4.5 μm; right) magnitudes vs. spectral type shows a smooth shape from the L and T dwarfs through to the early Y dwarfs. The three Y2 dwarfs are labelled individually. WISE1828+2650 and WD0806−661b deviate strongly from the trend defined by the earlier spectral types while the object, WISE0855−0714, sits closer to an extrapolation to the trend. Data sources for this plot are described in Kirkpatrick et al. (2012) with parallaxes updated according to Table 2.

1.65 μm data and the 3.4-4.6 μm data simultaneously without invoking a thick dust layer to absorb the shorter wavelengths.

A color-magnitude diagram (Figure 2; updated from Kirkpatrick 2012) shows the T and early Y dwarfs following a reasonably smooth trend of fainter absolute magnitudes for cooler spectral types. The exceptions are WISE1828+2650 and the putative Y dwarf companion to the white dwarf WD 0806−661 (Luhman et al. 2012) which are 1-2 magnitudes brighter at 4.5 μm than a simple extrapolation would suggest. On the other hand, the nearby, cold Y dwarf WISE0855−0714 (Luhman 2014) appears to fit the extrapolation to later spectral types better than the other ≥Y2 objects,

The number density of T and Y dwarfs appears to be relatively flat although the nearby census is still modestly incomplete with $<$ V/V_{max} $>\sim$ 0.3 (Kirkpatrick et al. 2012). However, the relative lack of late T and Y dwarfs compared with higher mass objects suggests that we are seeing the lowest mass end of the star formation process, consistent with theoretical estimates that there is an opacity limited cutoff in the mass of a cloud fragment which can produce a “stellar core” with a Jeans Mass around 5 M_{Jup} (Low & Lynden-Bell 1976).

The analysis of short duration, low amplitude microlensing events suggests the existence of a large number of free-floating, few M_{Jup} objects (Sumi et al. 2011), at least as numerous as local M star population. There is no evidence in the WISE data for a dramatic upturn in the low mass population. The ratio of local (<10 pc) M dwarfs ($75 < M < 600$) M_{Jup} to low mass brown dwarfs ($5 < M < 15$) M_{Jup} in logarithmic mass units, $N(M_1 \rightarrow$

Table 3. Average Properties From Model Fits[1]

Model	Age (Gyr)	T_{eff} (K)	Mass (M_{Jup})
All	6.5±1.8	472±112	19±6
T dwarf	6.9±0.8	577±36	25±1
Y dwarf	7.2±0.8	395±12	15±1

[1]Values derived using BT-Settl models (Allard et al. 2011).

$M_2)/log(M_1/M_2)$, is large $\sim 10:1$ with an obviously large uncertainty due to the uncertain mass estimates. Kirkpatrick et al. (2012) cite a similar number, 6:1, from their volume limited brown dwarf sample. The Jupiter-mass objects suggested by the microlensing results could either represent "planets" built up by core-accretion in protoplanetary systems and ejected from their host stars or they could be planets on very wide orbits which are still bound to their host stars (Veras & Raymond 2012). It is unlikely that even the lowest mass WISE Y dwarfs (M> $5M_{Jup}$) are escaped planets due to simulations showing that it is the lower mass object which is expelled from a system leaving the higher mass object still in orbit around the star (Ford et al. 2001). In the context of planetary systems the number of high mass ejectors, M>> $5M_{Jup}$, capable of ejecting the M$\sim$ $5M_{Jup}$ objects observed by WISE are very rare.

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