The Astrophysical Journal, 604:L61–L64, 2004 March 20

2MASS J05185995−2828372: DISCOVERY OF AN UNRESOLVED L/T BINARY

Kelle L. Cruz,[1,2] Adam J. Burgasser,[2,3,4] I. Neill Reid,[1,2,5] and James Liebert[6]

Received 2003 December 5; accepted 2004 February 5; published 2004 February 23

ABSTRACT

We present the peculiar near-infrared spectrum of the newly discovered brown dwarf 2MASS J05185995−2828372, identified in the Two Micron All Sky Survey. Features characteristic of both L and T dwarfs are present, namely, strong carbon monoxide absorption in the *K* band, strong methane absorption in the *J* and *H* bands, and red near-infrared colors. We consider several scenarios that could produce these features and conclude that the object is most likely to be an unresolved L/T binary system. We discuss how the estimated photometric properties of this object are consistent with the observed *J*-band brightening of brown dwarfs between late-L and early-T dwarfs, making detailed study of this system an important probe of the L/T transition.

Subject headings: binaries: general — stars: individual (2MASS J05185995−2828372) — stars: low-mass, brown dwarfs

On-line material: color figures

1. INTRODUCTION

The existence of brown dwarfs, low-mass ($M \lesssim 0.075\ M_{\odot}$) objects that form like stars but are incapable of maintaining core hydrogen fusion, was first postulated by Kumar (1962). After several decades of unsuccessful searches, well over 100 brown dwarfs are currently known, primarily as a consequence of the availability of deep far-red and infrared sky surveys (the Deep Near-Infrared Survey [Epchtein et al. 1999], the Two Micron All Sky Survey [2MASS; Skrutskie et al. 1997], and the Sloan Digital Sky Survey [SDSS; York et al. 2000]). Without a long-lived energy source, brown dwarfs cool rapidly, exhibiting spectra dominated by a sequence of complex molecular bands. Metal hydride absorption (e.g., FeH, CrH, and CaH) replaces titanium oxide at optical wavelengths as the effective temperature falls below 2100 K, and the spectral type evolves from type M to type L (Kirkpatrick et al. 1999; Chabrier et al. 2000). As the temperature drops below 1300 K, methane forms in the outer atmosphere (Tsuji 1964), and the strong absorption from 1 to 3 μm leads to significantly bluer near-infrared colors. These are T dwarfs (Burgasser et al. 2002a; Geballe et al. 2002).

We are currently using near-infrared photometry from 2MASS to search for all late-type M and L dwarfs lying within 20 pc of the Sun (Cruz et al. 2003). In the course of follow-up observations, we have identified a cool dwarf that appears to break the current spectral classification paradigm. 2MASS J05185995−2828372 (hereafter 2M 0518) was selected for observation based on its red ($J-K_s$) color of 1.82 mag and its relatively bright apparent magnitude, $J = 15.98$. The peculiar near-infrared spectrum of this object, however, exhibits both L and T dwarf spectral features. In the following section we describe our observations, and in § 3 we discuss possible explanations for the observed properties of this intriguing object.

2. OBSERVATIONS

2M 0518's location on the color-color diagram is shown in Figure 1, and a finder chart is given in Figure 2. Near-infrared spectroscopy was obtained on 2003 September 19 with SpeX (Rayner et al. 2003) on the NASA Infrared Telescope Facility (IRTF) on Mauna Kea. Observations were taken in low-resolution ($R = 250$) prism mode yielding a single order from 0.8 to 2.5 μm, encompassing the *J*, *H*, and *K* bands (centered at 1.2, 1.6, and 2.2 μm, respectively). For the flux calibration, an A0 star (HD 36965) was observed immediately after the target observation and at a similar air mass. This was followed by acquisition of flat-field and arc-line calibration frames. Conditions were good, although the data were obtained during morning twilight and at an air mass of 1.6. The data were flat-fielded, extracted, wavelength-calibrated, and telluric-corrected with Spextool (Cushing, Vacca, & Rayner 2003; Vacca, Cushing, & Rayner 2003). The spectrum of 2M 0518 is shown in Figure 3 with reference spectra of L6, T0, and T4 dwarfs obtained with the same instrumental setup. The near-infrared observational properties for all of these objects are listed in Table 1.

3. DISCUSSION

While 2M 0518 lies at the red end of the L dwarf sequence, as shown in Figure 1, its spectrum clearly shows methane absorption, the hallmark characteristic of T dwarfs. Additionally, the relative strengths of the absorption bands (specifically H_2O, CH_4, and CO) are anomalous and are not consistent with either a classical L or T dwarf. The strong methane absorption in the *J* and *H* bands and the water absorption in the *J* band are consistent with a mid-T dwarf (cf. 2M 2254 in Fig. 3), whereas the weak methane feature in the *K* band more resembles an early-T dwarf (cf. SDSS 0423 in Fig. 3). In addition, carbon monoxide absorption in the *K* band is typical of late-L dwarfs (cf. 2M 0103 in Fig. 3). In the following section we consider four possible explanations for the unusual properties of 2M 0518.

[1] Department of Physics and Astronomy, University of Pennsylvania, 209 South 33rd Street, Philadelphia, PA 19104-6396; kelle@sas.upenn.edu.

[2] Visiting Astronomer at the Infrared Telescope Facility, which is operated by the University of Hawaii under Cooperative Agreement NCC 5-538 with the National Aeronautics and Space Administration, Office of Space Science, Planetary Astronomy Program.

[3] Division of Astronomy and Astrophysics, University of California at Los Angeles, Los Angeles, CA, 90095-1562; adam@astro.ucla.edu.

[4] Hubble Fellow.

[5] Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218; inr@stsci.edu.

[6] Department of Astronomy and Steward Observatory, University of Arizona, 933 North Cherry Avenue, Tucson, AZ 85721; liebert@as.arizona.edu.

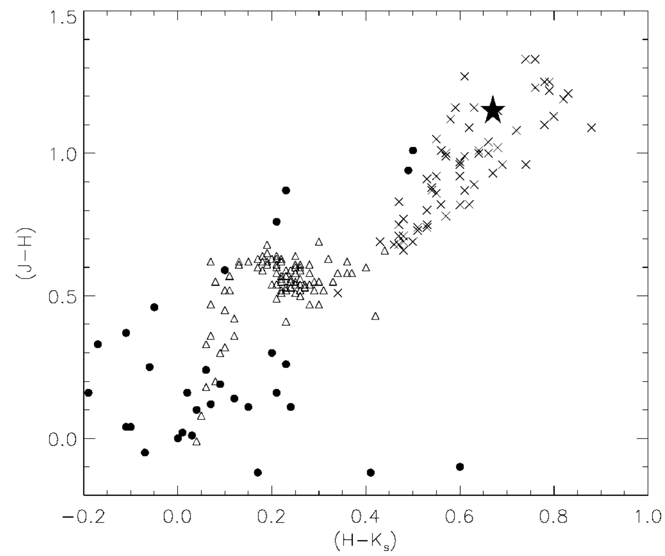

FIG. 1.—Color-color diagram for 2M 0518 (*five-pointed star*), late-type stars (*triangles*), L dwarfs (*crosses*), and T dwarfs (*circles*).

3.1. *Possible Scenarios*

Youth.—Two characteristics of young objects are reddening by dust and spectral features indicative of low gravity. The above-average red color of young objects is attributed to circumstellar dust or line-of-sight reddening. Dust preferentially absorbs shorter wavelength radiation, changing the slope of the spectrum and reddening the colors, but cannot account for the anomalous absorption-band strengths observed in 2M 0518. Low gravity, the other characteristic of youth, does affect *K*-band spectral features. In particular, a key signature of low gravity is a decrease in the flux suppression in the *K* band due to the weakening of H_2 collision-induced absorption (CIA; Burrows et al. 2002; Saumon et al. 1994). However, the downward slope of the *K*-band peak in the spectrum of 2M 0518 does not indicate weak CIA H_2 absorption. The unusual spectral features of 2M 0518 cannot be explained by either reddening or low gravity, and thus the object is not likely to be a young T dwarf.

Single L/T transition o bject.—An example of a transition object is SDSS 04234858−0414035, which is typed as L7.5 in the optical and T0 in the near-infrared and also has red colors (J. D. Kirkpatrick et al. 2004, in preparation; Geballe et al. 2002; Table 1). This object is discussed in detail by J. D. Kirkpatrick et al. (2004, in preparation), and its spectrum is shown in Figure 3. In general, L/T transition objects have weak methane absorption in the *K* band and almost nonexistent methane features in the *J* and *H* bands (Geballe et al. 2002). In 2M 0518, we see the opposite—strong methane absorption in the *H* band while weak in the *K* band. The spectrum of 2M 0518 does not fit the description of a single L/T transition object.

Low metallicity.—The weakness of the *K*-band methane and carbon monoxide features in the spectrum of 2M 0518 may be attributed to low metallicity. In metal-poor dwarfs, increased CIA H_2 absorption significantly masks these features and results in blue near-infrared colors (Burgasser et al. 2003). There is no evidence of enhanced CIA H_2 absorption in the spectrum of 2M 0518, and its near-infrared colors are red, not blue. It is highly unlikely that 2M 0518 is metal-poor.

Unresolved L/T binary.—Late-L and mid-T dwarfs have similar *J*-band absolute magnitudes but very different near-infrared colors. Since there is no methane absorption in L dwarfs, they are much brighter than T dwarfs in the *K* band, and thus their near-infrared colors are also redder. For this reason, in a late-L/mid-T binary system, the L dwarf would be expected to dominate the joint flux distribution longward of ∼1.6 μm, partially filling in the methane absorption in the *H* and *K* bands and producing red ($J-K$) composite colors.

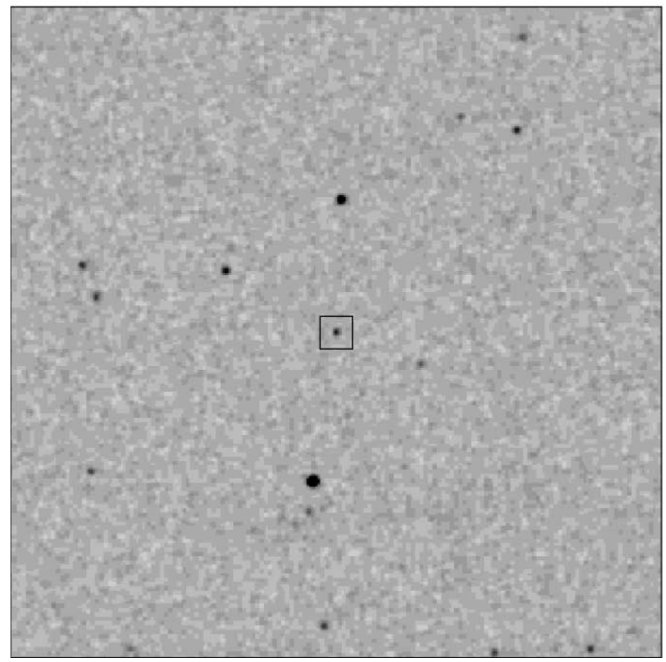

FIG. 2.—K_s-band finder chart for 2M 0518 as taken from the 2MASS Quick-look Image Service. The epoch of the image is 1999 January 6. Images are 5′ on each side, with north up and east to the left.

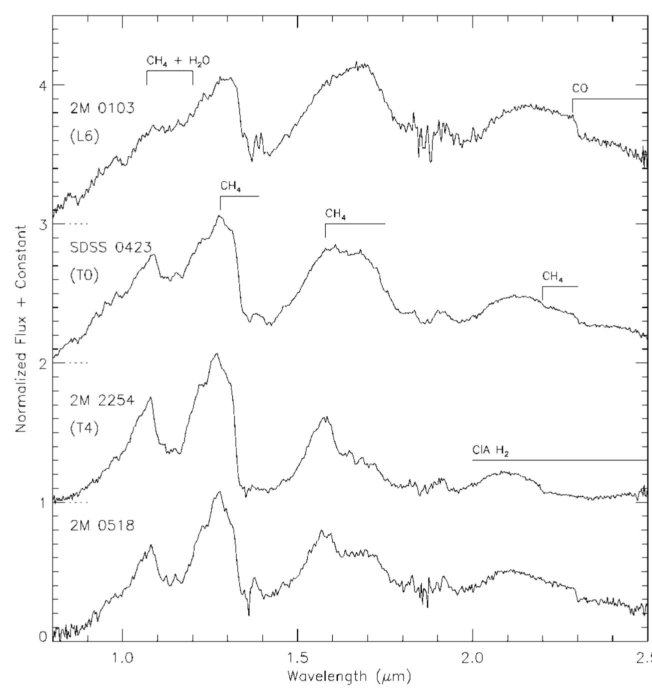

FIG. 3.—Spectrum of 2M 0518 (*bottom*) and reference spectra for L6, T0, and T4. The dotted lines mark the zero points for each spectrum. [*See the electronic edition of the Journal for a color version of this figure.*]

TABLE 1
NEAR-INFRARED OBSERVATIONAL PROPERTIES FOR OBJECTS PLOTTED IN FIGURE 3

α_{J2000}	δ	Spectral Type	2MASS J	2MASS H	2MASS K_s	$(J-H)$	$(H-K_s)$	$(J-K_s)$	Refs.
01 03 32.03	+19 35 36.1	L6	16.29 ± 0.08	14.90 ± 0.06	14.15 ± 0.06	1.39 ± 0.10	0.75 ± 0.08	2.14 ± 0.10	1
04 23 48.58	−04 14 03.5	T0	14.47 ± 0.03	13.46 ± 0.04	12.93 ± 0.03	1.00 ± 0.04	0.53 ± 0.05	1.54 ± 0.04	2, 3, 4
22 54 18.92	+31 23 49.8	T4	15.26 ± 0.05	15.02 ± 0.08	14.90 ± 0.15	0.24 ± 0.09	0.12 ± 0.17	0.36 ± 0.15	5, 6
05 18 59.95	−28 28 37.2	?	15.98 ± 0.10	14.83 ± 0.07	14.16 ± 0.07	1.15 ± 0.12	0.67 ± 0.10	1.82 ± 0.12	

NOTE.—Units of right ascension are hours, minutes, seconds, and units of declination are degrees, arcminutes, and arcseconds.

REFERENCES.—(1) Kirkpatrick et al. (2000); (2) Geballe et al. (2002); (3) Schneider et al. (2002); (4) J. D. Kirkpatrick et al. (2004, in preparation); (5) Burgasser et al. (2002a); (6) Burgasser et al. (2004).

This is in qualitative agreement with the available 2MASS photometry and our spectrum of 2M 0518.

Of these four options, the last offers the most plausible means of explaining the observed properties of 2M 0518, and, in the following section, we discuss the binary scenario in detail.

3.2. *2M 0518 as an Unresolved L/T Binary*

We have made a qualitative attempt at reproducing the spectrum of 2M 0518 by separately combining spectra of four mid/late-L dwarfs with three early/mid-T dwarfs using various scale factors. The best qualitative match is clearly obtained by summing the red L6, 2MASS J01033203+1935361, with the T4, 2MASS J22541892+3123498, weighted by a factor of 1.2, after both spectra have been normalized to 1.3 μm. The individual spectra of 2M 0103 and 2M 2254 are shown in Figure 3, and their scaled sum is superposed on the spectrum of 2M 0518 in Figure 4. The measured colors of the composite spectrum are $(J-H) = 0.9$, $(H-K_s) = 0.6$, and $(J-K_s) = 1.5$ and are comparable to the colors of 2M 0518 (listed in Table 1). Based on the overall agreement between the spectral features and the resultant colors of the combined spectrum with those of 2M 0518, we find this scenario to be the most compelling and conclude that 2M 0518 is likely to be an unresolved binary system composed of a late-L dwarf and a mid-T dwarf.

The two other candidate L/T binary systems, 2MASS J08503593+1057156 and 2MASS J17281150+3948593, were discovered with *Hubble Space Telescope* (*HST*) WFPC2 imaging (Reid et al. 2001; Gizis et al. 2003). Neither these data nor ground-based spectroscopy, however, are able to robustly obtain spectral type estimates for the secondaries. J. E. Gizis et al. (2004, in preparation) have obtained *HST* NICMOS imaging that measures the near-infrared properties of the individual components and thus will definitively determine if these systems are comprised of an L and T dwarf or two L dwarfs.

We adopt $M_J = 13.9$ for the L6 component using the spectral type/absolute magnitude relation found by Tinney, Burgasser, & Kirkpatrick (2003). While scaling the T4 component by 1.2 causes the J-band peak height of the T4 to be higher than that of the L dwarf, the T4 still has a fainter J magnitude due to strong water and methane absorption. We measure $\Delta J = 0.1$, yielding $M_J = 14.0$ for the T4 component. This estimate is very similar to the $M_J = 13.9$ measured for the T3, SDSS J10210969−0304201, and to the $M_J = 13.8$ measured for the T5, 2MASS J05591914−1404488, the two objects with parallax measurements that have spectral types closest to T4.

While tentative, this observation further supports the argument that there is a *physical* brightening of T dwarfs at the J band compared with L dwarfs as observed by Dahn et al. (2002) and Tinney et al. (2003) and is more likely due to the clearing of clouds and an increased optical depth as proposed by Burgasser et al. (2002b) rather than the age selection effects as suggested by Tsuji & Nakajima (2003).

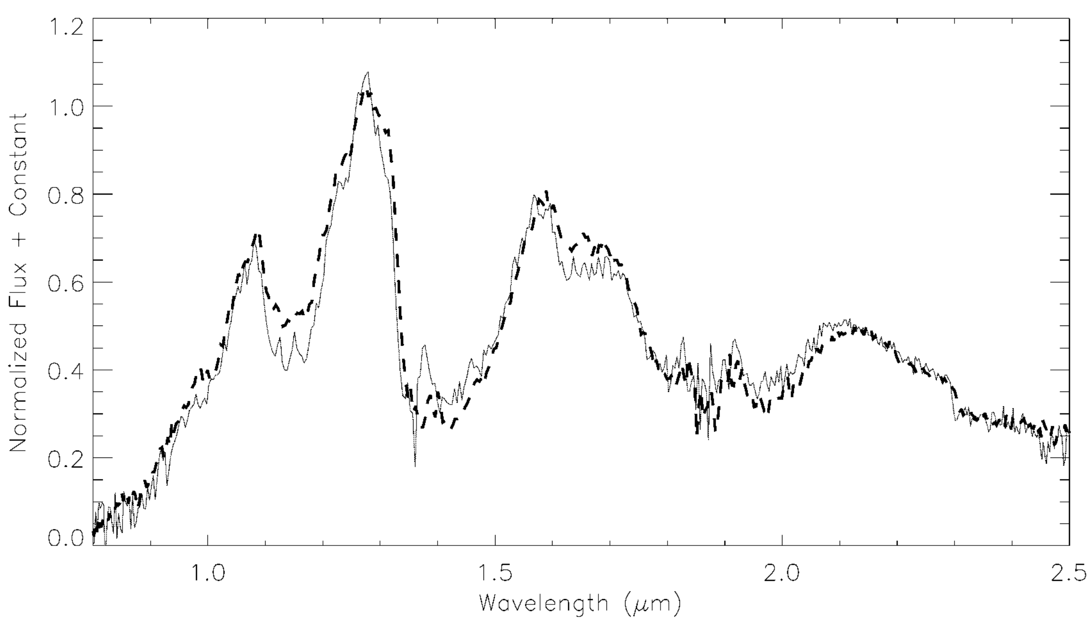

FIG. 4.—Spectrum of 2M 0518 (*solid*) with the scaled sum of 2M 0103 (L6) and 2M 2254 (T4) (*dashed*) superposed. [*See the electronic edition of the Journal for a color version of this figure.*]

Combining the individual absolute magnitude estimates for the two components yields a photometric distance of 36 pc for 2M 0518. If the 2M 0518 system can be resolved and if the components can be studied separately, this object will provide strong constraints on substellar evolutionary models and will be an important probe of the poorly understood L/T transition.

We would like to thank our IRTF telescope operators, Bill Golish, Dave Griep, and Eric Volguardsen. We would also like to thank the referee for excellent suggestions that improved the manuscript. This research was partially supported by a grant from the NASA/NSF NStars initiative, administered by JPL, Pasadena, CA. K. L. C. acknowledges support from a NSF Graduate Research Fellowship. A. J. B. acknowledges support provided by NASA through Hubble Fellowship grant HST-HF-01137.01 awarded by the Space Telescope Science Institute, which is operated by AURA, Inc., under NASA contract NAS5-26555. This publication makes use of data products from the Two Micron All Sky Survey, which is a joint project of the University of Massachusetts and IPAC/CalTech, funded by NASA and the NSF, and from the NASA/IPAC Infrared Science Archive, which is operated by JPL/CalTech, under contract with NASA.

REFERENCES

Burgasser, A. J., et al. 2002a, ApJ, 564, 421
———. 2003, ApJ, 592, 1186
Burgasser, A. J., Marley, M. S., Ackerman, A. S., Saumon, D., Lodders, K., Dahn, C. C., Harris, H. C., & Kirkpatrick, J. D. 2002b, ApJ, 571, L151
Burgasser, A. J., McElwain, M. W., Kirkpatrick, J. D., Cruz, K. L., Tinney, C. G., & Reid, I. N. 2004, AJ, submitted
Burrows, A., Burgasser, A. J., Kirkpatrick, J. D., Liebert, J., Milsom, J. A., Sudarsky, D., & Hubeny, I. 2002, ApJ, 573, 394
Chabrier, G., Baraffe, I., Allard, F., & Hauschildt, P. 2000, ApJ, 542, 464
Cruz, K. L., Reid, I. N., Liebert, J., Kirkpatrick, J. D., & Lowrance, P. J. 2003, AJ, 126, 2421
Cushing, M. C., Vacca, W. D., & Rayner, J. T. 2003, PASP, submitted
Dahn, C. C., et al. 2002, AJ, 124, 1170
Epchtein, N., et al. 1999, A&A, 349, 236
Geballe, T. R., et al. 2002, ApJ, 564, 466
Gizis, J. E., Reid, I. N., Knapp, G. R., Liebert, J., Kirkpatrick, J. D., Koerner, D. W., & Burgasser, A. J. 2003, AJ, 125, 3302
Kirkpatrick, J. D., et al. 2000, AJ, 120, 447
———. 1999, ApJ, 519, 802
Kumar, S. S. 1962, AJ, 67, 579
Rayner, J. T., Toomey, D. W., Onaka, P. M., Denault, A. J., Stahlberger, W. E., Vacca, W. D., Cushing, M. C., & Wang, S. 2003, PASP, 115, 362
Reid, I. N., Gizis, J. E., Kirkpatrick, J. D., & Koerner, D. W. 2001, AJ, 121, 489
Saumon, D., Bergeron, P., Lunine, J. I., Hubbard, W. B., & Burrows, A. 1994, ApJ, 424, 333
Schneider, D. P., et al. 2002, AJ, 123, 458
Skrutskie, M. F., et al. 1997, in The Impact of Large Scale Near-IR Sky Surveys, ed. F. Garzon et al. (Dordrecht: Kluwer), 25
Tinney, C. G., Burgasser, A. J., & Kirkpatrick, J. D. 2003, AJ, 126, 975
Tsuji, T. 1964, Ann. Tokyo Astron. Obs., 9, 110
Tsuji, T., & Nakajima, T. 2003, ApJ, 585, L151
Vacca, W. D., Cushing, M. C., & Rayner, J. T. 2003, PASP, 115, 389
York, D. G., et al. 2000, AJ, 120, 1579