THE TRIGONOMETRIC PARALLAX OF THE BROWN DWARF PLANETARY SYSTEM 2MASSW J1207334−393254

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Received 2007 August 3; accepted 2007 September 7; published 2007 October 12

ABSTRACT

We have measured a trigonometric parallax to the young brown dwarf 2MASSW J1207334−393254. The distance (54.0±1.2 pc) and space motion confirm membership in the TW Hydrae Association. The primary is a ∼25 M_Jup brown dwarf. We discuss the “planetary mass” secondary, which is certainly below the deuterium-burning limit but whose colors and absolute magnitudes pose challenges to our current understanding of planetary-mass objects.

Subject headings: open clusters and associations: individual (W Hydrae Association) — planetary systems — stars: individual (2MASSW J1207334−393254) — stars: low-mass, brown dwarfs

Online material: color figure

1. INTRODUCTION

The M8 brown dwarf 2MASSW J1207334−393254 (hereafter 2M1207A) is proving to be an important system for studying the formation of substellar objects. It was discovered by Gizis (2002) in a search for brown dwarf members of the ∼10 Myr old TW Hydrae Association (Webb et al. 1999). 2M1207A is a very low mass substellar analog to a classical T Tauri star: It has broad, variable Hα emission due to accretion (Mohanty et al. 2003; Scholz & Jayawardhana 2006), mid-infrared excess due to a disk (Sterzik et al. 2004; Riaz et al. 2006), ultraviolet emission due to hot accreted gas and warm circumstellar molecular hydrogen gas (Gizis et al. 2005), and forbidden oxygen emission due to an outflow (Whelan et al. 2007). Despite its youth, it is not detected in X-rays (Gizis & Bharat 2004) or radio (Osten & Jayawardhana 2006), so it is apparently relatively magnetically inactive.

Chauvin et al. (2004) discovered a red companion (2M1207B), 5 mag fainter in the K band. Common proper motion confirms that this is a bound pair (Chauvin et al. 2005; Song et al. 2006) with a separation of 773 ± 14 mas. The secondary has a late-L spectral type (Mohanty et al. 2007). The inferred luminosity implies a mass ∼5 M_Jup (Chauvin et al. 2004; Song et al. 2006), although Mohanty et al. (2007) suggest that the secondary is 8 ± 2 M_Jup and viewed through an edge-on disk.

Because the TWA is a relatively nearby, loose association, there has been some confusion on the distance to the system. Chauvin et al. (2004) adopted a distance of 70 pc, on the basis of theoretical models of brown dwarf evolution. The Hipparcos distance of TW Hya itself is 56±8 pc (Perryman et al. 1997). Mamajek (2005) used the moving cluster distance method to estimate the distance to 2M1207A to be 53 ± 7 pc, while Song et al. (2006) used the same method, but an updated proper motion and a different group membership list to estimate 59 ± 7 pc. With uncertainties in the distance to the TW Hya group of ∼15%, firm conclusions about the natures of 2M1207A and B, as well as other members of the group, have been elusive. Here we present the first trigonometric parallax for 2M1207A. We confirm that it is a member of the TW Hya Association and put constraints on the planet candidate 2M1207B.

2. PARALLAX RESULTS AND DISCUSSION

Observations of 2M1207A in the I Kc band were obtained at the CTIO 0.9 m telescope by the RECONS group via the SMARTS Consortium. There are 54 parallax frames obtained over 2.14 yr. The observing techniques and data reduction are fully described by Jao et al. (2005). The resulting relative parallax is πrel = 17.93 ± 1.03 mas. VRI photometry was obtained in 2007 July on five nights using the same telescope and reduced as described in Jao et al. (2005). We estimate the correction to absolute parallax to be 0.58 ± 0.05 mas on the basis of photometry of the seven reference stars (Table 1.) The absolute parallax is therefore 18.51 ± 1.03 mas, for a distance of 54.0±1.2 pc. The observed proper motion is 66.7 ± 1.5 mas yr⁻¹ at position angle θ = 250.0° ± 2.4°.

The distance and proper motion of 2M1207A is consistent with TWA membership. The position angle expected for motion toward the Mamajek (2005) TWA convergent point is 251.4°, consistent with the measured proper motion. Using the Mohanty et al. (2003) radial velocity of +11.2 ± 2.0 km s⁻¹ for 2M1207A, the (U, V, W) space velocities are (−8, −18, −4) km s⁻¹, consistent with Mamajek’s centroid group value of (−10.2, −17.1, −5.1) km s⁻¹. In particular, the measured distance rules out any association with the background Lower Centaurus Crux discussed by Mamajek (2005). Using the Song et al. (2006) measurements and our distance, the projected separation is 41.7 ± 2.3 AU.

The Primary and its disk.—Mohanty et al. (2007) found 2M1207A to be a 24 ± 6 M_Jup brown dwarf. Because they used Mamajek’s value of 53 pc as the distance, this mass is not changed significantly by a distance increase of 2%. 2M1207A is best understood as a ∼25 M_Jup brown dwarf. The disk parameters derived by Riaz & Gizis (2007) also remain unchanged because they used the same distance. The observed V − Ks = 8.00 ± 0.19 is consistent with the M8 spectral type and suggests that the accretion rate at the time was ∼10⁻¹¹ M_Jup yr⁻¹ (see Riaz & Gizis 2007, 2007).
TABLE 1

| Item          | 2M1207A       | 2M1207B       |
|--------------|---------------|---------------|
| V            | 19.95 ± 0.19  | ...           |
| R            | 17.99 ± 0.07  | ...           |
| I            | 15.92 ± 0.05  | ...           |
| J            | 13.00 ± 0.03  | 20.0 ± 0.2    |
| H            | 12.39 ± 0.03  | 18.09 ± 0.21  |
| k            | 11.95 ± 0.03  | 16.93 ± 0.11  |
| π(m) (mas)   | 17.93 ± 1.03  | ...           |
| π(m) (mas)   | 0.58 ± 0.05   | ...           |
| π(m) (mas)   | 18.51 ± 1.03  | ...           |
| Mₖ           | 16.29 ± 0.22  | ...           |
| Mₜ           | 9.34 ± 0.12   | 16.3 ± 0.3    |
| Mₘ           | 8.73 ± 0.12   | 14.4 ± 0.3    |
| Mₑ           | 8.29 ± 0.12   | 13.27 ± 0.16  |
| Mass (M_{Jup}) | ~25           | ~3–8          |

Note.—VR/I and astrometry from this paper: JHK for 2M1207A from 2MASS Skrutskie et al. (2006); J for 2M1207B from Mohanty et al. (2007); H and K from Chauvin et al. (2004).

In Figure 1 we plot the H-R diagram of the local field population and 2M1207A. Like the young M dwarf AU Mic (Gl 803), 2M1207A lies ~1.5 mag above the main sequence in the Mₜ versus V – K diagram, confirming youth.

The secondary.—The usual procedure for analyzing 2M1207B is to assume a bolometric correction appropriate to late-L dwarfs and then fit the luminosity to evolutionary models. Chauvin et al. (2004) estimated 5 ± 2 M_{Jup}, for 70 pc, Song et al. (2006) estimated 5 ± 3 M_{Jup}, for 59 pc, and Mamajek (2005) estimated 3–4 M_{Jup} for 53 pc. The trigonometric parallax would therefore support the last two estimates. Mohanty et al. (2007), however, noted an inconsistency with this procedure. They argued that their H- and K-band near-infrared spectra of 2M1207B were best fit by an effective temperature of 1600 ± 100 K. However, for the 3–5 M_{Jup} fits, the expected effective temperature is more like 1000–1200 K. They suggest the best resolution is that 2M1207B is viewed through an edge-on gray disk and that therefore it is more luminous than otherwise estimated. 2M1207B is then a 8 ± 2 M_{Jup} planetary mass brown dwarf. The wide separation and mass ratio (q ≈ 0.2–0.3) suggests that this planetary-mass object did not form through core accretion (Chauvin et al. 2005).

Without rejecting the possibility of an edge-on disk, we argue that available evidence does not rule out a low temperature for 2M1207B. In Figure 2, we plot colors and absolute magnitudes for late-M, L, and T dwarfs with parallaxes (Perryman et al. 1997; Dahn et al. 2002; Tinney et al. 2003; Vrba et al. 2004; Henry et al. 2006). All the previous attempts to fit 2M1207B noted that it is red compared to field brown dwarfs, which can be attributed to having more dust in the photosphere. The faintness at J band measured by Mohanty et al. (2007; ΔJ = 7.0 ± 0.2) is supported by the NICMOS F110M measurement of Song et al. (2006; Δm_{110M} = 7.17 ± 0.15). Chauvin et al. (2004) measured ΔK = 4.98 and K = 16.93 ± 0.11 for 2M1207B. On the other hand, it is clear from the Mohanty et al. (2007; SN ≈ 3–10) spectrum that there is deep water absorption but little methane absorption. We conclude that 2M1207B has a spectral energy distribution that is L-type, but very red. Reversing the usual procedure, in Figure 3 we plot the required K-band bolometric correction required to fit the Chabrier et al. (2000) models at an age of 10 Myr. Observed bolometric corrections for field L and T dwarfs from Golimowski et al. (2004) as a function of temperature for an assumed age of 3 Gyr are also shown. The L to T transition is believed to occur at ~1300 K and can be marked in Figure 3 by the change in bolometric corrections. The transition is related to the change in dust properties in photosphere (see Kirkpatrick 2005 for a review), and some of the first fits to late-L dwarf spectra gave incorrect values of ≥1600 K due to the failure of cooler models to resemble the real spectra. This simply reflects the extreme difficulty of modeling the temperature range 1200–1400 K, and indeed in light of this, no models succeed in fully explaining both the blue hook and brightening in J band of field T dwarfs. Analysis of the luminosity (see Kirkpatrick 2005) has been the most reliable way to derive temperatures. This history suggests to us that the existing fit must be viewed with caution—while apparently very good, it
is inconsistent with the absolute magnitudes unless an edge-on disk is invoked. Although Mohanty et al. show that the DUSTY models do fit the observed color of 2M1207B, it must be noted that the same models predict very red colors for field L dwarfs, which are not observed. Indeed, Chabrier et al. (2000) note that “the DUSTY and COND models represent extreme situations which bracket the more likely intermediate case resulting from complex, and presently not understood, thermo-chemical and dynamical processes.” We think it plausible that existing DUSTY models fail to properly model the dust in low surface gravity dwarfs, and that 2M1207B might therefore be ∼1200 K, as expected for the ∼5 $M_{\text{Jup}}$ model. As an example of how this might occur, we note that Tsuji (2005) invokes a parameter, $T_{\text{eff}}$, that characterizes the thickness of the clouds and argues that the wide range of colors for field objects near 1400 K is due to changes in this parameter in otherwise similar brown dwarfs. In one case, Tsuji (2005) is able to fit an L6.5 dwarf with $T_{\text{eff}} = 1700$ K or $T_{\text{eff}} = 1300$ K (without methane absorption) by varying $T_{\text{eff}}$ by only 100 K. Evidently, an extremely red color like 2M1207B could be obtained for a low $T_{\text{eff}} < 1700$ K—that is, a very thick cloud compared to field L dwarfs. This would be the opposite situation from field T dwarfs, where the cloud becomes thinner ($T_{\text{eff}}$ increases.) Similarly, in the Marley et al. (2002) models, a parameter, $f_{\text{out}}$, represents sedimentation, and redder colors are produced by smaller values of $f_{\text{out}}$ (i.e., less precipitation and thicker clouds.) Regardless of how the proper degree of dust is produced, if our speculation that $T_{\text{eff}} \approx 1200$ K is correct, the implied $BC_{K} \approx 2.5$ would require that more of 2M1207B’s energy is escaping at wavelengths longward of 3 μm than in field L dwarfs. In any case, the observed colors and spectrum do not match any field brown dwarf, so there is not much doubt that atmosphere is dustier, but a low temperature remains speculative.

Unfortunately, there is a third problem with estimating the mass of 2M1207B. Marley et al. (2007) have investigated the dependence of the structure models to the initial conditions and found that the luminosity is very sensitive to the initial conditions for up to 100 Myr. In specifically discussing the case of 2M1207B, they note that for a “warm start” rather than usually assumed “hot start,” the best-fit mass is 8 $M_{\text{Jup}}$ rather than 5 $M_{\text{Jup}}$. The situation therefore is that given the now known distance, 2M1207B may be $\sim 5 \pm 2$ $M_{\text{Jup}}$ if current structural models are correct, the red color implies a cool temperature, and there is no disk, but both Mohanty et al. (2007) and Marley et al. (2007) present plausible scenarios in which the mass is higher.

3. CONCLUSIONS

We have measured the trigonometric parallax of 2M1207 and found that the distance and space motion are consistent, as expected, with membership in the TW Hydrae Association. Indeed, 2M1207 now has a more precise distance determination than TW Hya itself. There are no difficulties in modeling the primary: it is a $\sim 25$ $M_{\text{Jup}}$ brown dwarf that is accreting from a circumstellar disk. The faint secondary remains problematic. Because we do not know the appropriate initial conditions, do not have a model atmosphere that reproduces the colors, and do not know whether it is observed through a disk, a case can be made that 2M1207B’s mass is as low as 3 $M_{\text{Jup}}$ or as high as 8 $M_{\text{Jup}}$. Our best estimate is $\sim 5$ $M_{\text{Jup}}$ if 2M1207B is not viewed through a disk. Further study of this planetary mass object is needed; we particularly need to know if it has an effective temperature of 1600 K, 1200 K, or even less.

We thank Eric Mamajek and Davy Kirkpatrick for useful discussions. We thank Charlie Finch for his initial reduction of the parallax data. We thank the anonymous referee for a discussion of the Tsuji paper. We also thank the members of the SMARTS Consortium, without whom the parallax observations could not have been made. Support for this work was provided by NASA Research Grant NNG06GJ03G. The RECONS parallax program has been supported by the NASA/NSF NStars Project, NASA’s Space Interferometry Mission (SIM), the National Science Foundation (grant AST 05-07711), and Georgia State University. Research has benefitted from the M, L, and T dwarf compendium housed at http://www.DwarfArchives.org and maintained by Chris Geline, Davy Kirkpatrick, and Adam Burgasser.

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