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Letter to the Editor

# An accurate distance to 2M1207Ab*

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**ABSTRACT**

*Context.* In April 2004, the first image was obtained of a planetary mass companion (now known as 2M1207 b) in orbit around a self-luminous object different from our own Sun (the young brown dwarf 2MASSW J1207334-393254, hereafter 2M1207 A). That 2M1207 b probably formed via fragmentation and gravitational collapse offered proof that such a mechanism can form bodies in the planetary mass regime. However, the predicted mass, luminosity, and radius of 2M1207 b depend on its age, distance, and other observables, such as effective temperature.
*Aims.* To refine our knowledge of the physical properties of 2M1207 b and its nature, we accurately determined the distance to the 2M1207 A and b system by measuring of its trigonometric parallax at the milliarcsec level.
*Methods.* With the ESO NTT/SUSI2 telescope, we began a campaign of photometric and astrometric observations in 2006 to measure the trigonometric parallax of 2M1207 A.
*Results.* An accurate distance (52.4 ± 1.1 pc) to 2M1207A was measured. From distance and proper motions we derived spatial velocities that are fully compatible with TWA membership.
*Conclusions.* With this new distance estimate, we discuss three scenarios regarding the nature of 2M1207 b: (1) a cool (1150 ± 150 K) companion of mass 4 ± 1 $M_{\rm Jup}$, (2) a warmer (1600 ± 100 K) and heavier (8 ± 2 $M_{\rm Jup}$) companion occulted by an edge-on circumsecondary disk, or (3) a hot protoplanet collision afterglow.

**Key words.** stars: distances – stars: low-mass, brown dwarfs – planetary systems

## 1. Introduction

Ever since the discovery of the enigmatic classical T Tauri star TW Hya isolated from any dark cloud (Rucinski & Krautter 1983), significant progress has been made with diagnostic selection and the identification of young stars near the Sun. In addition to the members of the TW Hydrae association (Kastner et al. 1997, hereafter TWA), we nowadays can count more than 200 young (<100 Myr), nearby (≤100 pc) stars, gathered in different clusters and co-moving groups, such as $\eta$ Chamaleontis (Mamajek et al. 1999), $\beta$ Pictoris (Zuckerman et al. 2001), Tucana-Horologium (Torres et al. 2000; Zuckerman & Webb 2000), AB Doradus (Zuckerman et al. 2004), and the most recent identified candidates of the SACY survey (Torres et al. 2006). Their youth and proximity make these stars ideal sites for studying the mechanisms of planet, brown dwarf and star formation. They also represent favorable niches for calibrating evolutionary tracks through dynamical mass measurements. With the development of direct-imaging and interferometric techniques, the circumstellar environment of these young stars is now probed down to a few AU. The number of resolved disks ($\beta$ Pic, Smith & Terrille 1984; HR 4796, Schneider et al. 1999; TW Hya, Krist et al. 2000; AU Mic, Liu 2004), substellar companions (TWA5, Lowrance et al. 1999; HR7329, Lowrance et al. 2000; GSC 8048-00232, Chauvin et al. 2003; and AB Pic, Chauvin et al. 2005), and pre-main-sequence binaries with dynamically determined masses (HD 98800, Boden et al. 2005; TWA5, Konopacky et al. 2007) continues to increase.

In the rush to discover companions with masses below what is required for burning deuterium, Chauvin et al. (2004) has obtained an image of an extrasolar companion of a planetary mass. This object was discovered near 2MASS J1207334-393254 (hereafter 2M1207A), a brown dwarf (BD) member of the 8 Myr old TWA (Gizis 2002). It is proposed 2M1207A has a near edge-on accreting disk (Gizis 2002; Mohanty et al. 2003; Sterzik et al. 2004) and drives a bipolar resolved jet (Whelan et al. 2007). This binary system, the lightest known to drive an outflow, offers new insights into the study in the mechanisms of formation and evolution of BDs, including their disk and jet properties and physical and atmospheric characteristics of objects as light as a few Jupiter masses.

Although numerous techniques have been devoted to studying this binary system (imaging, spectroscopy, astrometry) at different wavelengths (X-ray, UV, visible, near-IR, mid-IR, radio), its distance has remained uncertain and not well-constrained. The initial distance estimate of ~70 pc by

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Chauvin et al. (2004) was improved by Mamajek (2005) who obtained an estimate of 53 ± 6 pc based on the moving cluster method. This method relies on the space motion determination for the TWA and the proper motion of 2M1207A. The space motion determination for the TWA was based on the four members with known Hipparcos distance: TWA1, TWA4, TWA9, and TWA11. Song et al. (2006) suggests that significant uncertainties in the Hipparcos distance to TWA9 might affect the cluster distance estimation. They proposed a new distance estimate of 59 ± 7 pc based on an improved proper motion determination for 2M1207A scaled with the proper motion and the Hipparcos distance to HR 4796 A (TWA11).

To determine a firm estimate for the distance to 2M1207 via measurement of its trignometric parallax, since January 2006 we conducted astrometric and photometric observations at the ESO NTT telescope. At the same time other observational programs have been developed yielding results similar to ours (Biller & Close 2007; Gizis at al. 2007; Mamajek & Meyer 2007) as discussed below. Our observations are presented in Sect. 2. The data reduction and analysis and the result of this trigonometric parallax program are given in Sect. 3. Finally, the physical properties and different hypotheses for the nature of 2M1207 b are discussed in Sect. 4.

## 2. Observations

Astrometric and photometric ($V$, $R$, $I$) observations were performed with the ESO NTT telescope equipped with the SUSI2 camera, which offers a nice compromise between the field of view ($5.5' \times 5.5'$) and the pixel scale 80.5 mas/pixel and assures a reasonable number of field stars (113) for performing accurate astrometric reductions. Seven sets of data were acquired between January 2006 and May 2007 with a total of fourteen nights of observation. All astrometric observations were realized in the ESO I#814 filter. A calibration star with known trigonometric parallax, DEN 1048-3956, was also observed in order to validate our results.

Atmospheric refraction will affect our target brown dwarf and the background reference stars (typically main-sequence G or K stars) differently when observed through a given filter bandpass because of their difference in effective wavelength. This is called differential color refraction (DCR) (Ducourant et al. 2007), and it is a major source of systematic errors in parallax programs. To minimize the DCR, all measurements were performed near the transit of the target (projected tangent of the zenith distance in RA ≤ 20°). Following Monet et al. (1992), we observed at small and large hour angles during an observing night to empirically calibrate the difference in refraction between the target and the reference stars. We present this calibration in Fig. 1. All measurements of the target were corrected for DCR. The difference in slope between 2M1207A and background stars is $\Delta F = -0.004 \pm 0.001$ pix/deg. One can evaluate the accuracy of the DCR correction as $\sigma_{\rm dcr} = \sigma_{\Delta F} \langle Z_{\rm a} \rangle = 0.38$ mas (with $\langle Z_{\rm a} \rangle = 11.8°$, the mean projected tangent of the zenith distance in right ascension of observations).

## 3. Data reduction and analysis

### 3.1. Astrometry

Images were measured using the `DAOPHOT-II` package (Stetson 1987) by fitting a PSF to the images. The astrometric reduction of the whole dataset (261 images) was performed iteratively through a global central overlap procedure (see Ducourant et al. 2007), in order to determine simultaneously the position, the proper motion, and the parallax of each object in the field. Each valid observation of each well-measured object in the field participates in the final solution (error on instrumental magnitude ≤0.07, (as given by DAOPHOT), $I_{\rm mag} \leq 21.5$). We present in Fig. 2 the observations of 2M1207 A, together with the fitted path (relative parallax and proper motions).

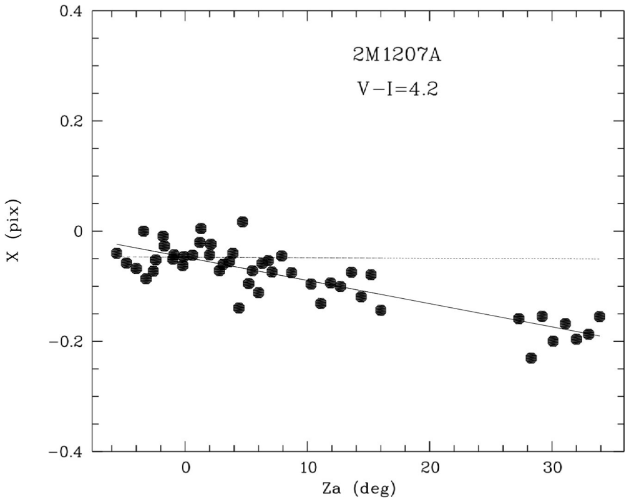


**Fig. 1.** Atmospheric refraction shift (X) in RA in the $I$ filter as a function of the projected tangent of the zenith distance in RA for 2M1207. The horizontal line represents the mean atmospheric shift for reference background stars.

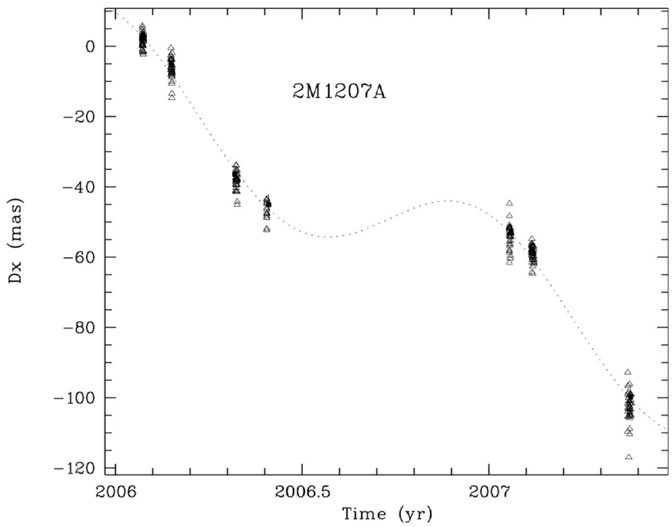


**Fig. 2.** 2M1207 A observations in right ascention, together with the fitted path along time: $\pi_{\rm rel} = 18.5 \pm 0.4$ mas, $\mu_\alpha^* = -57.5 \pm 0.4$ mas/yr, $\mu_\delta = -22.5 \pm 0.4$ mas/yr.

### 3.2. Conversion from relative to absolute parallax

As a consequence of the least-square treatment, the parallax and proper motion of the target is relative to reference stars (that are supposed to reside at infinite distances). The correction from this relative parallax to the absolute value is performed using a statistical evaluation of the distance of the 113 reference stars ($13.5 \leq I \leq 21.5$), which uses the Besançon Galaxy model (Robin et al. 2003, 2004). This correction is $\Delta\pi = +0.58 \pm 0.01$ mas. The same method is used to convert the relative proper motion of 2M1207A into absolute proper

**Table 1.** Astrometric and Bessel photometric parameters for 2M1207 A measured with ESO NTT/Susi2.

| $\alpha$ (2000) | $\delta$ (2000) | $\mu_{\alpha\mathrm{abs}}$ (mas/yr) | $\mu_{\delta\mathrm{abs}}$ (mas/yr) | $\pi_{\mathrm{abs}}$ (mas) | $d$ (pc) | $V$ (mag) | $R$ (mag) | $I$ (mag) |
|---|---|---|---|---|---|---|---|---|
| $12^{\mathrm{h}}07^{\mathrm{m}}33.460^{\mathrm{s}}$ | $-39°32'53.97''$ | $-64.2 \pm 0.4$ | $-22.6 \pm 0.4$ | $19.1 \pm 0.4$ | $52.4 \pm 1.1$ | $20.15 \pm 0.19$ | $18.08 \pm 0.17$ | $15.95 \pm 0.13$ |

**Table 2.** Distance determinations for 2M1207A.

| Authors | year | Distance (pc) | Method |
|---|---|---|---|
| Chauvin et al. | 2004 | $70 \pm 20$ | photometry |
| Mamajek | 2005 | $53.3 \pm 6.0$ | moving cluster |
| Song et al. | 2006 | $59 \pm 7$ | scale proper motion |
| Biller & Close | 2007 | $58.8 \pm 5.5$ | trig. parallax |
| Gizis et al. | 2007 | $54^{+3.2}_{-2.8}$ | trig. parallax |
| Mamajek & Meyer | 2007 | $66 \pm 5$ | moving cluster |
| This work | 2007 | $52.4 \pm 1.1$ | trig. parallax |

motion. We derive the corrections: $\Delta\mu_{\alpha*} = -6.66 \pm 0.04$ mas/yr and $\Delta\mu_{\delta} = -0.02 \pm 0.02$ mas/yr.

### 3.3. Space motion

With our measured absolute parallax, together with a radial velocity of $+11.2 \pm 2.0$ km s$^{-1}$ from Mohanty et al. (2003) and absolute proper motion, we calculated the Galactic space velocity ($U$, $V$, $W$) of 2M1207A as ($-7.9 \pm 0.8$, $-18.3 \pm 1.7$, $-3.5 \pm 0.8$) km s$^{-1}$. The comparison of our results with the data from Reid (2003) ($-10.0 \pm 2.6$, $-17.8 \pm 2.1$, $-4.6 \pm 1.1$) confirms the compatibility of 2M1207A motion with TWA membership.

### 3.4. Control star

Our parallax solution for DEN 1048-3956 is $\pi_{\mathrm{abs}} = 251.5 \pm 0.7$ mas and $(\mu_{\alpha}^{*}, \mu_{\delta}) = (-1170.0, -996.0) \pm (0.6, 0.6)$ mas/yr, which is in good agreement with Costa et al. (2005), $\pi_{\mathrm{abs}} = 249.8 \pm 1.8$ mas, $(\mu_{\alpha}^{*}, \mu_{\delta}) = (-1175.3, -993.2) \pm (2.2, 2.2)$ mas/yr.

We present the astrometric and photometric parameters for 2M1207A in Table 1.

## 4. Discussion

Since the discovery of the planetary mass companion 2M1207 b in 2004, several groups have worked on its distance determination (see Table 2). Chauvin et al. (2004) first estimated a distance to and mass for 2M1207 b of 70 pc and $5 \pm 2$ $M_{\mathrm{Jup}}$, and an associated effective temperature of $1250 \pm 200$ K. A low signal-to-noise spectrum in $H$-band enabled them to suggest a mid to late-L dwarf spectral type for 2M1207 b, supported by its very red near infrared colors. With a revised distance of $53.3 \pm 6$ pc, based on the moving cluster method, Mamajek (2005) re-estimated the mass of 2M1207 b. By converting the $K_{\mathrm{s}}$ absolute magnitude into luminosity using a bolometric correction appropriate for mid and late-L dwarfs (Golimowski et al. 2004), based on his nearer distance estimate, he derived a mass of 3–4 $M_{\mathrm{Jup}}$ from both DUSTY and COND evolutionary models (Baraffe et al. 2003). With HST/NICMOS multi-band (0.9 to 1.6 $\mu$m) photometry and a distance estimate of $59 \pm 7$ pc, Song et al. (2006) derived a mass of $5 \pm 3$ $M_{\mathrm{Jup}}$ for 2M1207 b, due to its brighter flux than expected from model predictions at shorter wavelengths (for a given mass and age) and to the scatter in the emergent flux predicted by the DUSTY and COND03 evolutionary models at wavelengths less than 2.2 $\mu$m (and shown in Fig. 3).

**Table 3.** DUSTY (Chabrier et al. 2000) and COND03 (Baraffe et al. 2003) predictions for the physical properties of 2M1207 b for (1) the hypothesis of a $1150 \pm 150$ K planetary mass companion (Chauvin et al. 2004), (2) a warmer $1600 \pm 100$ K and heavier $8 \pm 2$ $M_{\mathrm{Jup}}$ occulted planetary mass companion (Mohanty et al. 2007), and (3) an alternative hypothesis proposed by Mamajek & Meyer (2007) of a hot protoplanet collision afterglow.

| Hyp. | $M_{K_{\mathrm{s}}}$ (mag) | $T_{\mathrm{eff}}$ (K) | Mass ($M_{\mathrm{Jup}}$) | $\log(L/L_{\odot})$ (dex) | $\log(g)$ (dex) |
|---|---|---|---|---|---|
| (1) | $13.33 \pm 0.13$ | *1150 ± 150* | *4 ± 1* | $-4.5 \pm 0.2$ | *3.6 ± 0.2* |
| (2) | *11.2 ± 0.3* | $1600 \pm 100$ | *8 ± 2* | $-3.8 \pm 0.1$ | *3.9 ± 0.1* |
| (3) | $13.33 \pm 0.13$ | $1600 \pm 100$ | *~0.25* | $-3.8 \pm 0.1$ | *~3.0* |

Note: In *italics* the predicted fluxes, masses, effective temperatures, luminosities, and surface gravities to be compared with the observed flux in $K_{\mathrm{s}}$ and effective temperature of Chauvin et al. (2004) and Mohanty et al. (2007) respectively.

In addition to $J$-band photometry, Mohanty et al. (2007) obtained an HK spectrum of 2M1207 b at low resolution ($R_{\lambda}$ = 100). Comparison with synthetic spectra DUSTY, COND and SETTLE yielded an effective spectroscopic temperature of $1600 \pm 100$ K, leading Mohanty et al. (2007) to suggest a mass of $8 \pm 2$ $M_{\mathrm{Jup}}$ for 2M1207 b. However, this mass and temperature are inconsistent with what is expected from model predictions based on absolute magnitudes spanning $I$ to $L'$-band photometry. This discrepancy is explained by Mohanty et al. (2007) by a gray extinction of ~2.5 mag between 0.9 and 3.8 $\mu$m caused by the occultation of a circumsecondary edge-on disk. This hypothesis is illustrated in Fig. 3.

Gizis et al. (2007) note that the hypothesis of a lighter and cooler 2M1207 b cannot be ruled out by the current photometric, spectroscopic, and parallax observations. Synthetic atmosphere models clearly encounter difficulties in faithfully describing the late-L to mid-T dwarf transition (~1400 K for field L/T dwarfs). This transition corresponds to the process of cloud-clearing, that is, an intermediate state between two extreme cases of cool atmospheres: saturated in dust (DUSTY) and where dust grains have sunk below the photosphere (COND03). It is therefore probable that synthetic spectra fail for the moment to properly model the spectroscopic and physical characteristics of young L and T dwarfs. Comparison of absolute fluxes of 2M1207 b with DUSTY and CON03 model predictions for the age of the TWA illustrates this possible intermediate state. In such a scenario, absolute magnitude and luminosity based on the $K_{\mathrm{s}}$-band photometry indicate a mass of $4 \pm 1$ $M_{\mathrm{Jup}}$ and an effective temperature of $1150 \pm 150$ K. Such a low temperature for a young mid to late-L dwarf would corroborate the observations of HD 203030 B (Metchev & Hillenbrand 2006) and HN Peg (Luhman et al. 2007), indicating that the L/T transition is possibly gravity-dependent and appearing for temperatures as low as ~1200 K. Our current accurate parallax measurement ($52.4 \pm 1.1$ pc) changes the absolute magnitudes and errors slightly from the ones given by Mamajek (2005), Song et al. (2006), Mohanty et al. (2007), and Gizis et al. (2007), but does not modify their conclusions. The predicted physical properties (mass, luminosities, effective temperature, and

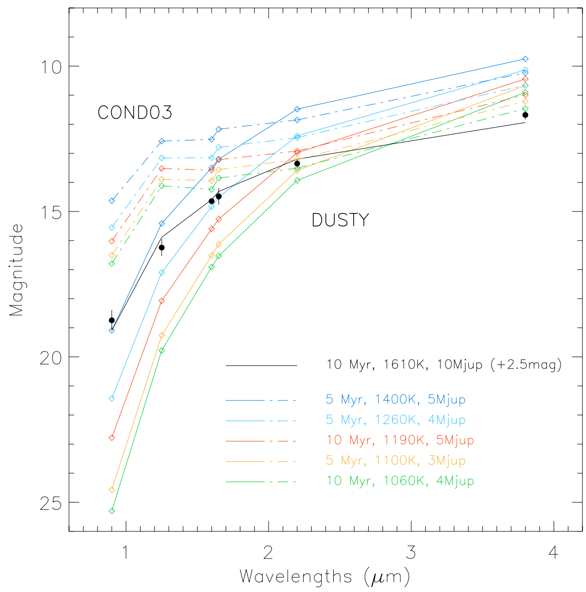


**Fig. 3.** HST/NICMOS and VLT/NACO absolute magnitudes compared to predictions of the DUSTY (*solid line*) and COND03 (*dash-dotted line*) evolutionary models at the age of the TWA and for a distance of 52.4 ± 1.1 pc. The VLT/NACO magnitudes have been converted into the CIT and Johnson-Glass system for direct comparisons with model predictions. Current observations are compatible with (1) a 4 ± 1 $M_{\rm Jup}$ planetary-mass companion if DUSTY and COND03 atmospheric models currently fail to describe the atmosphere of 2M1207 b faithfully or (2) a warmer 1600 ± 100 K and heavier 8 ± 2 $M_{\rm Jup}$ planetary mass companion occulted by a circumsecondary edge-on disk (*black solid line*, with a +2.5 mag of grey extinction).

gravity) are summarized in Table 3 for the two models described above. An alternative hypothesis has been proposed by Mamajek & Meyer (2007) to explain the subluminosity of 2M1207 b. Their explanation is that the apparent flux is produced by a hot protoplanet-collision afterglow. Mamajek & Meyer (2007) suggest several ways to test this hypothesis, for example, by a lower surface gravity ($\log(g) \sim 3$) and a rich metallicity for the protoplanetary collision remnant. In addition, potential observables such as polarized emission, infrared excess, resolved scattered light, or a proposed 10 $\mu$m silicate absorption feature (predicted if 2M1207b is occulted by a circumsecondary edge-on disk), should help to clarify the nature of 2M1207 b.

## 5. Conclusion

Motivated by the need to accurately determine the distance of the 2M1207 A and b system to better refine the properties of 2M1207b, we measured the trigonometric parallax of the unresolved system with a precision better than 2%. This parallax puts 2M1207 A and b at 52.4 ± 1.1 pc from our Sun and, along with our accurately measured proper motion, lends substantial support to the notion that this binary is a member of the young TW Hydrae Association and, thus, that the mass of 2M1207b clearly lies in the planetary mass range.

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