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A MOVING CLUSTER DISTANCE TO THE EXOPLANET 2M1207b IN THE TW HYDRAE ASSOCIATION

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ABSTRACT

A candidate extrasolar planet companion to the young brown dwarf 2MASSW J1207334−393254 (hereafter 2M1207) was recently discovered by Chauvin et al. They find that the temperature and luminosity of 2M1207b are consistent with a young, $\sim 5 M_J$ planet. The 2M1207 system is purported to be a member of the TW Hya association (TWA) and situated $\sim$70 pc away. Using a revised space motion vector for TWA and improved proper motion for 2M1207, I use the moving cluster method to estimate the distance to the 2M1207 system and other TWA members. The derived distance for 2M1207 (53 ± 6 pc) forces the brown dwarf and planet to be half as luminous as previously thought. The inferred masses for 2M1207A and 2M1207b decrease to $\sim$21 and ~ 3–$4 M_J$, respectively, with the mass of 2M1207b well below the observed tip of the planetary mass function and the theoretical deuterium-burning limit. After removing probable Lower Centaurus Crux (LCC) members from the TWA sample, as well as the probable nonmember TWA 22, the remaining TWA membership is found to have distances of 49 ± 3 (s.e.m.) ± 12 ($1\ \sigma$) pc and an internal one-dimensional velocity dispersion of $0.8^{+0.3}_{-0.2}$ km s^{-1}. There is weak evidence that the TWA is expanding, and the data are consistent with a lower limit on the expansion age of 10 Myr (95% confidence).

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

1. INTRODUCTION

Indirect detection methods for finding extrasolar planets have yielded in excess of 150 candidate planets over the past decade (Marcy et al. 2005). None have been directly imaged; however, two have had their light detected through transit studies with the *Spitzer Space Telescope* (HD 209458b and TrES-1; Charbonneau et al. 2005; Deming et al. 2005). Recently, an object has been imaged and resolved whose properties appear somewhat consistent with being a young extrasolar planet: the companion to 2MASSW J1207334−393254 (2M1207; Chauvin et al. 2004). These objects appear to represent the opening chapter in humanity's quest to study the atmospheres of planets beyond our solar system.

As one of the nearest and youngest brown dwarfs yet identified, 2M1207 has received considerable attention since its discovery. Gizis (2002) discovered 2M1207 in a spectroscopic survey of red Two Micron All Sky Survey (2MASS) sources and claimed that the object was a $\sim$10 Myr old, $\sim 25 M_J$ member of the nearby ($\sim$55 pc) TW Hya association (TWA; Webb et al. 1999). Further observations of its radial velocity (Mohanty et al. 2003) and proper motion (Scholz et al. 2005) are roughly consistent with TWA membership. With low-resolution spectroscopy, Gizis (2002) found 2M1207 to show signs of low surface gravity and strong Hα emission (EW = 300 Å). In their echelle spectroscopy survey, Mohanty et al. (2003) found the Hα emission line to be broad and asymmetric and accompanied by several other Balmer and He I emission lines. Mohanty et al. (2003) hypothesize that the brown dwarf is probably still accreting from a circumstellar disk.

While it is astrophysically interesting in its own right as a representative of the new class of young, accreting brown dwarfs (e.g., Muzerolle et al. 2005; Mohanty et al. 2005), it appears that 2M1207 may become most famous for being the host "Sun" for the first imaged extrasolar planet, if indeed 2M1207b can be called a "planet." Chauvin et al. (2004) discovered a faint companion to 2M1207 that has near-IR photometry and a low–signal-to-noise ratio spectrum consistent with having a late L spectral type. Recently, Chauvin et al. (2005) and G. Schneider et al. (2005, in preparation) confirmed that the companion 2M1207b is indeed comoving with 2M1207A. Debate on the origin and classification of this object is in its infancy. To help better constrain the physical nature of this object, I present an improved distance estimate to the 2M1207 system through the moving cluster method. The new distance provides more accurate luminosities (and inferred masses) for the components of this interesting substellar binary.

2. ANALYSIS

Although a trigonometric parallax is not yet available for 2M1207, one can exploit the star's putative membership in the TW Hya association to derive a distance using the cluster parallax (or "moving cluster") method (e.g., Atanasijevic 1971; de Bruijne 1999a). With an observed proper motion and radial velocity (as well as other supporting evidence), I test whether the star is consistent with being a TWA group member. To exploit this technique, one needs to take the following steps: (1) estimate the space motion vector for the TWA, (2) test whether the observations for 2M1207 (e.g., proper motion, radial velocity) are consistent with the TWA motion vector, and (3) use the moving cluster method to estimate the parallax from the proper motion and TWA space motion data. I address these steps in order. Although the rest of the TWA membership is not the focus of this study, I briefly mention relevant results for these systems throughout this analysis. I also examine whether the expansion of the TWA is detectable and whether it can help constrain the age of 2M1207 and the rest of the association.

2.1. *Sample*

The initial pool of candidate TWA members considered in this study is listed in Table 1. I add to TWA 1–25 (Zuckerman & Song 2004) the three new, low-mass candidate members 2M1207 and

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TABLE 1

Properties of Proposed TW Hya Association Members

TWA No. (1)	Other Name (2)	μ_{α^*} (mas yr^{-1}) (3)	μ_δ (mas yr^{-1}) (4)	Ref. (5)	Prob. (%) (6)	d (pc) (7)	v_{rad}(pred.) (km s^{-1}) (8)	v_{rad}(obs.) (km s^{-1}) (9)	Ref. (10)	Final Member? (11)
1	TW Hya	−66.8 ± 1.6	−15.2 ± 1.3	1	97	51 ± 4	13.2	12.7 ± 0.2	7	Y
2	CD −29 8887	−91.6 ± 1.8	−20.1 ± 1.3	2	57	39 ± 3	12.4	11.0 ± 0.1	7	Y
3	Hen 3-600	−109.3 ± 8.7	0.8 ± 8.9	3	18	34 ± 4	12.9	12.5 ± 1:	8, 9	Y
4	HD 98800	−91.7 ± 1.5	−30.0 ± 1.5	1	73	40 ± 3	11.0	9.3 ± 1:	10, 11	Y
5AB	CD −33 7795	−85.4 ± 3.6	−23.3 ± 3.7	1	88	44 ± 4	11.4	var.	7	Y
6	Tyc 7183 1477 1	−57.0 ± 2.1	−20.9 ± 2.1	1	53	51 ± 5	15.4	16.9 ± 5	9	Y
7	Tyc 7190 2111 1	−122.2 ± 2.3	−29.3 ± 2.3	4	100	27 ± 2	14.2	11.7 ± 2	9	Y
8A	GSC 06659-01080	−99.3 ± 9.0	−31.3 ± 8.9	3	83	38 ± 4	10.5	7.8 ± 2	9	Y
8B	2MASS J11324116−2652090	−95.3 ± 10.0	−29.5 ± 10.3	3	84	39 ± 5	10.5	7.8 ± 2	9	Y
9A	CD −36 7429A	−52.8 ± 1.3	−20.2 ± 1.8	1	81	69 ± 6	10.6	9.5 ± 0.4	7	Y
9B	CD −36 7429B	−70.7 ± 13.3	−6.6 ± 15.8	3	67	56 ± 12	10.6	11.3 ± 2	9	Y
10	GSC 07766-00743	−72.6 ± 12.2	−32.1 ± 12.3	3	100	53 ± 9	8.3	6.6 ± 2	9	Y
11A	HR 4976A	−53.3 ± 1.3	−21.2 ± 1.1	4	99	73 ± 6	8.0	6.9 ± 1.0	9, 12, 13	Y
12	RX J1121.1−3845	−36.3 ± 8.6	−1.6 ± 8.9	3	69	103 ± 26:	12.4	10.9 ± 1.0	7, 14	N
13	RX J1121.3−3447	−67.4 ± 11.8	−17.0 ± 11.8	3	99	53 ± 10	12.0	12.1 ± 1:	7, 14	Y
14	UCAC2 12427553	−43.4 ± 2.6	−7.0 ± 2.4	1	96	80 ± 8	13.1	16.0 ± 2	9	Y?
15	GSC 08236-01074	−100.0 ± 33.0	−16.0 ± 6.0	5	88	41 ± 6	9.1	11.2 ± 2	9	Y
16	UCAC2 12217020	−53.3 ± 5.2	−19.0 ± 5.2	1	100	72 ± 9	8.8	9.0 ± 2	9	Y
17	GSC 08248-00700	−28.0 ± 8.5	−11.1 ± 8.5	3	84	163 ± 46:	6.3	4.6 ± 6	9	N
18	UCAC2 12908626	−29.0 ± 5.2	−21.2 ± 5.2	1	64	121 ± 20:	6.0	6.9 ± 3	9	N
19A	HD 102458A	−33.6 ± 0.9	−8.5 ± 0.9	1	73	109 ± 9:	11.6	13.5 ± 2.4	7, 9	N
19B	HD 102458B	−35.6 ± 4.8	−7.5 ± 4.6	1	97	103 ± 16:	11.6	15.2 ± 2	9	N
20	GSC 08231-02642	−52.0 ± 5.0	−16.0 ± 6.0	5	97	75 ± 9	9.0	8.1 ± 4	15	Y
21	HD 298936	−65.3 ± 2.4	13.7 ± 1.0	1	99	45 ± 4	15.8	17.5 ± 0.8	16	Y
22	SSSPM J1017−5354	−176.0 ± 7.0	−22.0 ± 8.0	6	2	18 ± 2:	15.5	...		N?
23	SSSPM J1207−3247	−68.0 ± 4.0	−23.0 ± 4.0	6	86	57 ± 5	8.9	...		Y
24	MML 5	−34.4 ± 2.8	−13.1 ± 1.7	1	10	107 ± 12:	11.1	11.9 ± 0.9	16	N
25	Tyc 7760 283 1	−75.0 ± 2.0	−26.9 ± 1.4	1	100	51 ± 4	9.2	9.2 ± 2.1	16	Y
26	2MASSW J1139511−315921	−93.0 ± 5.0	−31.0 ± 10.0	6	99	40 ± 4	10.6	11.6 ± 2	17	Y
27	2MASSW J1207334−393254	−71.6 ± 6.7	−22.1 ± 8.5	3	98	53 ± 6	9.7	11.2 ± 2	17	Y
28	SSSPM J1102−3431	−82.0 ± 12.0	−12.0 ± 6.0	6	70	43 ± 7	13.2	...		Y

Notes.—Columns: (1) TWA number, (2) other name, (3) proper motion in right ascension ($\mu_{\alpha*} \equiv \mu_\alpha \cos\delta$; ICRS frame; 1 σ errors), (4) proper motion in declination (μ_δ; ICRS frame; 1 σ errors), (5) proper-motion reference, (6) membership probability (§ 2.4), (7) predicted distance from the moving group method (§ 2.5) and 1 σ uncertainty, (8) predicted radial velocity from the moving group method (with uniform 1.6 km s^{-1} 1 σ uncertainty), (9) observed mean radial velocity, (10) radial velocity reference, and (11) final TWA membership assessment. For some binaries, I have estimated the systemic velocity by assuming a mass ratio. These are probably good to ~1 km s^{-1}, and their errors have been marked with colons. For the systemic radial velocity of HD 98800, I adopted the component masses from Prato et al. (2001) and assumed M(Ab) = 0.5 $M_\odot$. The radial velocity listed for TWA 15A and B is that measured for TWA 15A, but the proper motion is for the photocenter of TWA 15A and B (TWA 15A = 2MASS J12342064−4815135, and TWA 15B = 2MASS J12342047−4815195). Kinematic distances to nonmembers (TWA 12, 17, 18, 19A and B, and 24 are probably LCC members; TWA 22 may not be a member) should not be taken seriously. However, due to the similarity in space motions between TWA and LCC, the distances to TWA 12, 17, 18, 19A and B, and 24 that are listed are probably within 5% of the real distance if they are indeed LCC members.

References.—(1) Zacharias et al. (2004; UCAC2); (2) Platais et al. (1998); (3) calculated by the author using positions from the following catalogs: the Guide Star Catalog (GSC-ACT; VizieR Online Data Catalog, 255; B. M. Lasker, J. N. Russell, & H. Jenkner, 1990), USNO-A2.0 (VizieR Online Data Catalog, 1252; Monet et al., 1998), the GSC 2.2 (VizieR Online Data Catalog, 1271; STScI and Osservatorio Astronomico di Torino collaboration, 2001), 2MASS (VizieR Online Data Catalog, 2246; Cutri et al., 2003), DENIS (VizieR Online Data Catalog, B/denis; The DENIS Consortium, 2003), UCAC1 (VizieR Online Data Catalog, 1268; Zacharias et al., 2001), and the Southern Hemisphere Catalogue of Bordeaux (VizieR Online Data Catalog, 1230; J. M. Rousseau, J. P. Perie, & M. T. Gachard, 1996); (4) Tycho-2 (Høg et al. 2000); (5) USNO-B1.0 (Monet et al. 2003); (6) Scholz et al. (2005); (7) Torres et al. (2003); (8) de la Reza et al. (1989); (9) Reid (2003); (10) Torres et al. (1995); (11) Prato et al. (2001); (12) Barbier-Brossat & Figon (2000); (13) Grenier et al. (1999); (14) Sterzik et al. (1999); (15) Webb (1999) (as reported in Reid 2003); (16) Song et al. (2003); (17) Mohanty et al. (2003).

2MASSW J1139511−315921 from Gizis (2002) and SSSPM J1102−3431 from Scholz et al. (2005). The TWA members from Webb et al. (1999), TWA 1–11, and Sterzik et al. (1999), TWA 12 and 13, comprise what I tentatively call the "classic" membership of the TW Hya association. These are young stars that were mostly selected due to infrared or X-ray excesses within the immediate vicinity of TW Hya. There has been debate regarding the membership for TWA 14–19 (Mamajek & Feigelson 2001; Lawson & Crause 2005), since their positions, proper motions, and rotational properties are at variance with those of TWA 1–13. Mamajek & Feigelson (2001) and Lawson & Crause (2005) have suggested that TWA 14–19 are probably members of the more distant (~120 pc; de Zeeuw et al. 1999) and older (~16 Myr; Mamajek et al. 2002) Lower Centaurus Crux OB association (LCC). TWA 20 was claimed to be a TWA member by Reid (2003, hereafter R03) but was rejected by Zuckerman & Song (2004) due to its weak Li. As the Li data are not published and the similarity in proper motion between TWA 20 and the other TWA members is quite striking, I retain TWA 20 in the candidate pool. TWA 21–25 were selected by Song et al. (2003, hereafter SZB03) because of their strong Li and Hα emission. From Figure 6 of SZB03, it appears that TWA 23 and 25 have positions and proper motions very close to those of TWA 1–13, but TWA 21 and 22 are spatially isolated and TWA 24 has a small proper motion, similar to LCC members. Hence, it is not obvious that many of the TWA 14–25 stars were born in the same star formation event as were TWA 1–13. I conservatively include only the classic members (TWA 1–13) in the initial calculations for estimating the convergent point and space motion vector for the TW Hya association.

2.2. *Astrometric Data*

The adopted proper-motion and radial velocity data for proposed TWA members, along with their associated references, are presented in Table 1. I searched the literature and online catalogs[2] to find the best values for the proper motions and radial velocities of TWA members. To mitigate the effects of short-term astrometric perturbations by short-period companions, I preferentially adopted the long-baseline proper motion with the smallest error bars (usually Tycho-2 or USNO CCD Astrograph Catalog 2 [UCAC2]; Høg et al. 2000; Zacharias et al. 2004) over *Hipparcos* values (Perryman et al. 1997) when available. In a few instances, I calculated new proper motions using published positions. I calculated weighted mean radial velocities when multiple values were available or adopted systemic velocities for spectroscopic binaries, when available.

2M1207 has two published proper-motion estimates in the literature (Gizis 2002; Scholz et al. 2005). The Gizis (2002) proper motion ($\mu_{\alpha*} = -100$ mas yr^{-1} and $\mu_\delta = -30$ mas yr^{-1}) does not have error bars and is based on only a few plate images in the US Naval Observatory (USNO) image archive. Scholz et al. (2005) estimated a proper motion for 2M1207 of $\mu_{\alpha*} = -78 \pm 11$ mas yr^{-1} and $\mu_\delta = -24 \pm 9$ mas yr^{-1}. This proper-motion estimate included a *Chandra* pointing rather than an actual measured position and so is invalid. Omitting the *Chandra* pointing, R.-D. Scholz has calculated a revised proper motion of $\mu_{\alpha*} = -67 \pm 7$ mas yr^{-1} and $\mu_\delta = -28 \pm 11$ mas yr^{-1} using a least-squares fit with equal weighting (R.-D. Scholz 2005, private communication).

As there are large differences in the accuracy between the SuperCOSMOS, 2MASS, and Deep Near Infrared Survey (DENIS) positions ($\sim$60 mas vs. $\sim$500 mas), I recalculated the proper motion using weighting by the inverse of the square of the positional errors, following the method of Corbin (1977).[3] The SuperCOSMOS and 2MASS positions are tied to the International Celestial Reference System (ICRS) via the Tycho-2 catalog, and so for our purposes they are on the same system. In order to estimate a positional error for the SuperCOSMOS positions, I performed a least-squares fit to the four SuperCOSMOS points and found their scatter to be consistent with positional errors of $\sigma_{\alpha*} = 143$ mas and $\sigma_\delta = 196$ mas. These errors are very consistent with the SuperCOSMOS positional errors quoted by Hambly et al. (2001). I corrected the DENIS position for the 2MASS-DENIS offset found by Cabrera-Lavers & Garzón (2003), since the 2MASS positional errors are much smaller than those of DENIS (2MASS is tied to the ICRS via the Tycho-2 catalog to an accuracy of $\sim$80 mas).[4] For the DENIS positional errors, I adopted the square root of the 2MASS-DENIS rms differences added in quadrature with the 2MASS-ICRS rms residuals ($\sim$80 mas), giving $\sigma_{\alpha*} = 430$ mas and $\sigma_\delta = 320$ mas. I estimate the proper motion of 2M1207 to be $\mu_{\alpha*} = -72 \pm 7$ mas yr^{-1} and $\mu_\delta = -22 \pm 9$ mas yr^{-1}, which is within 1 σ of both of Scholz's estimates. The change in the position of 2M1207 over time is plotted in Figure 1.

[2] See, for example, ADS (http://adsabs.harvard.edu/), VizieR (http://vizier.u-strasbg.fr/viz-bin/VizieR), and SIMBAD (http://simbad.harvard.edu/sim-fid.pl).

[3] The formulae are given in the online documentation for the AC2000.2 catalog (Urban et al. 1998) at http://ad.usno.navy.mil/ac/.

[4] VizieR Online Data Catalog, 246 (Cutri et al., 2003).

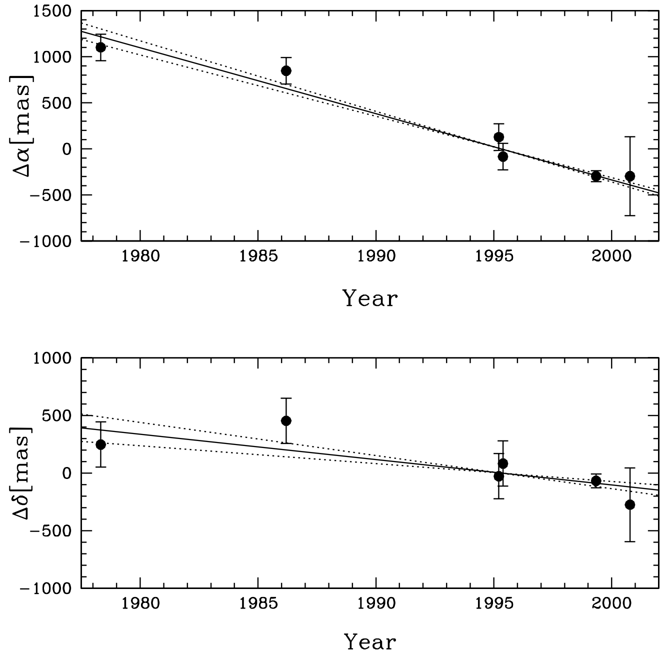

FIG. 1.—Relative change in position of 2M1207 since the late 1970s in α (*top*) and δ (*bottom*). The position offsets are relative to the positions on the ICRS at mean epoch. The mean epoch positions and mean epochs are $\alpha_0 = 181\overset{\circ}{.}889563$ [$t_0(\alpha_0) = 1995.08$] and $\delta_0 = -39\overset{\circ}{.}548315$ [$t_0(\delta_0) = 1996.57$]. The effects of parallax were not included, since the predicted amplitude ($\sim$20 mas) is smaller than the individual position errors. The positional errors at mean epoch are $\sigma_{\alpha_0} \simeq \sigma_{\delta_0} \simeq 50$ mas. The data are consistent with $\mu_{\alpha*} = -71.6 \pm 6.7$ mas yr^{-1} and $\mu_\delta = -22.1 \pm 8.5$ mas yr^{-1} for 2M1207.

2.3. *The Space Motion of the TWA*

In order to calculate a cluster parallax for 2M1207, we require an accurate convergent point solution for the TW Hya association, of which 2M1207 is proposed to be a member. Mean space motion vectors and/or convergent point solutions for the TWA were previously estimated by Frink (2001, hereafter F01), Makarov & Fabricius (2001, hereafter MF01), R03, and SZB03. Considering the increase in proposed association membership (SZB03) and the wealth of new proper-motion data (UCAC2; Zacharias et al. 2004) and radial velocity data (Torres et al. 2003) made available since R03, I briefly discuss and reanalyze the kinematics of TWA. To estimate the space motion for TWA, I combine information from two different methods: using what little data there are regarding the three-dimensional space motion vectors for individual members, as well as applying the convergent point method to the classical membership.

Only four classic TWA members have sufficient data to reliably calculate the three-dimensional space motion vector (TWA 1, 4, 9, and 11), and these individual determinations have modest errors in any given velocity component ($\sigma \sim 1$–2 km s^{-1}; Mamajek et al. 2000). Three of the systems are binaries, but their systemic velocities are probably accurate to $\sim$1 km s^{-1} or better. The mean barycentric Galactic space motion vector for these four systems ($U, V, W = -10.2, -17.1, -5.1$ km s^{-1}) provides the best estimate of the *centroid* velocity vector for the TW Hya association.

To help refine the vertex estimate for the TWA, I use the convergent point method on the classical membership. The convergent point, as calculated only from the proper-motion data, will also become important when the question of the expansion of the association is addressed (§ 2.6). I approximately follow the convergent point grid technique of Jones (1971). In this implementation, I alter Jones's definition of t^2, following de Bruijne (1999a), and include an intrinsic velocity dispersion term ($\sigma_v = 1$ km s^{-1}) and an assumed distance (50 pc) in the definition for t^2 (the method is rather insensitive to both input values). Over the entire hemisphere $0° < \alpha < 180°$, I calculate the t^2 statistic at every 0$.\!\!^\circ$1 grid step and find the celestial position that gives the minimum t^2-value. For every grid point, the method assumes that this position is the convergent point for the group and rotates the stellar proper-motion components (in $\mu_{\alpha*}$ and μ_δ) to the proper motion directed toward the convergent point (μ_v) and perpendicular to the great circle joining the star and the test convergent point (μ_τ). The method iteratively searches for the test convergent point that minimizes the τ-components of proper motion for the input sample. Jones's and de Bruijne's t^2-value can be treated statistically as the classic χ^2 (Bevington & Robinson 1992). In its iterative search for the group convergent point, the method rejects stars contributing the most to the t^2 statistic until the position with the lowest t^2-value corresponds to a sufficiently high χ^2 probability that the best convergent point cannot be statistically rejected. For a statistical rejection threshold, I adopt a 5% level of significance (i.e., a 5% probability of falsely rejecting the null hypothesis), following Trumpler & Weaver (1953).

The TWA stars are sufficiently convergent, and the proper-motion errors for the faint members are large enough, that a convergent point can be determined for all the classic TWA members (1–13) with a low value of χ^2_ν ($\chi^2/\nu = 15.9/13$; χ^2 probability = 25%). For internal velocity dispersions of $\sigma_v > 0.6$ km s^{-1}, the method is able to find a convergent point with a χ^2 probability of >5% without rejecting any of the classic members. If a value of $\sigma_v = 0.6$ km s^{-1} is adopted, TWA 6 (which contributes the most to the t^2 statistic) is rejected, and a sound solution is found with the other nuclear members (χ^2 probability = 21%). The internal velocity dispersion is probably near $\sigma_v \simeq 1$ km s^{-1}, and with this adopted velocity dispersion, 33% of the classical members contribute $\Delta t^2 > 1$ (similar to how MF01 estimate the velocity dispersion). Hence, there is no good reason to remove TWA 6 in the hunt for a statistically satisfactory convergent point for TWA 1–13. I will determine a more refined estimate of the velocity dispersion for TWA in § 2.5. The ability of the technique to give a statistically sound convergent point solution ($\chi^2_\nu \simeq 1$) with $\sigma_v = 1$ km s^{-1} already suggests that the velocity dispersion of TWA is similar to that of nearby OB associations (Madsen et al. 2002).

In Figure 2, I plot the convergent points for subsamples of the TW Hya association, as well as previous determinations from the literature. I also plot the convergent points for subsamples of the TWA 14–25 membership in Figure 2. The confidence regions of these subsamples are roughly twice as large as that for TWA 1–13 but not wholly inconsistent, given the large error bars. Much of the positional deviance of these subsample convergent points is owed to TWA 22, which may not be a kinematic TWA member (§ 2.5). From Figure 2, one can conclude that the convergent point for TWA 1–13 (within the dashed confidence regions) agrees well with that predicted by the TWA space motion vectors found by R03 and SZB03. The TWA vertex found by MF01 is just outside of the 95% confidence region and seems to be deviant when compared to the values from R03, SZB03, F01, and the results of this convergent point analysis. This fact, combined with the finding that most of the stars in the MF01 convergent point analysis are not pre–main-sequence (pre-MS; Song et al. 2002), suggests that their convergent point and dynamical age for the TWA (8.3 Myr) are not valid. I will discuss the expansion age further in § 2.6.

After considering the agreement between the TWA 1–13 convergent point and that inferred from the mean TWA space motions from R03 and SZB03, I adopted the following fiducial TWA parameters. For the group vertex, I took the weighted mean of the vertices from my convergent point analysis of TWA 1–13 ($\alpha = 100° \pm 10°$, $\delta = -28° \pm 4°$) and the individual vertices inferred from the space motion vectors for TWA 1, 4, 9, and 11 (using eq. [10] of de Bruijne 1999a). This analysis assumes zero association expansion and assumes that there is no significant offset between spectroscopic and physical radial velocities, both of which are acceptable assumptions at this level of accuracy. The best estimate of the convergent point for the TWA is calculated to be ($\alpha = 103.\!\!^\circ2 \pm 1.\!\!^\circ5$, $\delta = -30.\!\!^\circ7 \pm 1.\!\!^\circ5$). For the mean speed of the classic TWA membership, I adopt the weighted mean barycentric speed ($v = 21.3 \pm 1.3$ [s.e.m.] km s^{-1}) of TWA 1, 4, 9, and 11, using their astrometry and radial velocities in Table 1 and weighted mean *Hipparcos* and Tycho parallaxes.

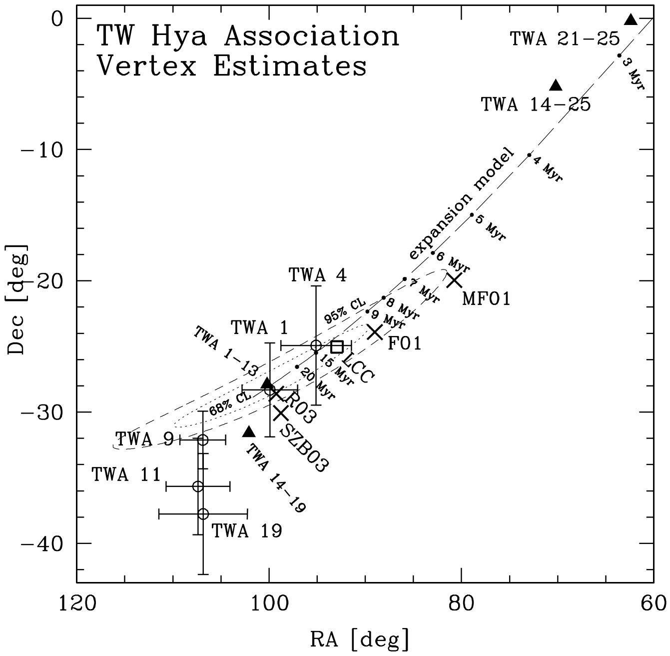

FIG. 2.—New and previously determined convergent point (vertex) estimates for the TW Hya association. The open circles show the inferred convergent points for TWA 1, 4, 9, 11, and 19, based on their *UVW* space motions (and 1 σ error bars). Large crosses represent previously published TWA vertices from F01, MF01, R03, and SZB03. Filled triangles show the vertices for several subsamples of TWA objects (TWA 1–13, 14–19, 21–25, and 14–25) found through the convergent point method (based solely on the proper-motion data). The dotted line and dashed line indicate the 68.3% (1 σ) and 95.5% (2 σ) confidence levels in α and δ around the vertex found for the "classic" TWA sample (TWA 1–13). The error regions around the other filled triangles (TWA 14–25, 21–25, and 14–19) are 50%–100% larger than that for TWA 1–13 and are similarly shaped (but not shown, for clarity). Predicted vertices for the TWA with a wide range of expansion ages are distributed along the long-dashed line.

2.4. *Is 2M1207 a TWA Member?*

Given the adopted convergent point solution for the classic TWA members and a proper motion for 2M1207, one can estimate a membership probability and predict the star's radial velocity. Using the updated proper motion for 2M1207 (§ 2.2), I find that most of the motion is indeed pointed toward the convergent point ($\mu_v = 75 \pm 7$ mas yr^{-1}), and very little of it is in the perpendicular direction ($\mu_\tau = 2 \pm 8$ mas yr^{-1}). Using the membership probability equation from de Bruijne (1999a), his equation (23), and adopting a mean cluster distance of 50 pc and velocity dispersion of 1 km s^{-1}, I estimate a membership probability of 98%. This membership probability should be interpreted as the following: given the proper-motion errors, 98% of the bona fide

TWA members are expected to have μ_τ-values more deviant than that of 2M1207. That is, the proper motion of 2M1207 is consistent with the null hypothesis ($\mu_\tau = 0$) for an "ideal" member. One can also use the predicted and observed radial velocity as a check of the moving cluster method. Assuming parallel motion among group members, the method predicts the radial velocity as $v_{\rm rad} = v \cos\lambda$, where v is the speed of the group and λ is the angular separation ($62\overset{\circ}{.}9 \pm 1\overset{\circ}{.}5$) between 2M1207 and the convergent point. The predicted radial velocity for 2M1207 (9.7 ± 1.6 km s^{-1}) is within 0.6 σ of the observed radial velocity measured by Mohanty et al. (2003), 11.2 ± 2 km s^{-1}. Both the proper-motion and radial velocity data for 2M1207 are quantitatively consistent with TWA membership, and its evidence of membership is as strong as that for most of the classical members.

2.5. *Distances*

2.5.1. *The Distance to 2M1207*

If a star belongs to a moving group, its proper motion can be used to estimate its distance. The star's moving cluster parallax (ϖ) is calculated as $\varpi = A\mu_\upsilon/v \sin\lambda$, where μ_υ, v, and λ are as described before, and A (=4.74047) is the astronomical unit expressed in the convenient units of km yr s^{-1} (de Bruijne 1999a). Using the values (and uncertainties) for μ_υ, v, and λ as given in §§ 2.2 and 2.3, I calculate a cluster parallax for 2M1207 of $\varpi = 18.8 \pm 2.3$ mas, or a corresponding distance of $d = 53 \pm 6$ pc. The only published distance estimates to 2M1207 are $\sim$70 pc (Chauvin et al. 2004) and 70 ± 20 pc (Chauvin et al. 2005). Both are photometric distance estimates that force 2M1207A to be an unreddened M8 star on a 10 Myr old isochrone. Considering the variations between published evolutionary tracks, especially for stars that are young and have low mass (Hillenbrand & White 2004), the cluster parallax distance should be considered an improved estimate.

2.5.2. *Distances to TWA Objects: Implications and Final Membership*

The agreement between the trigonometric parallaxes for TWA 1, 4, 9, and 11 and their cluster parallaxes are excellent, as shown in Table 2. All the parallaxes are within 2 σ of each other, with an insignificant weighted-mean zero-point offset of -0.8 ± 1.2 mas, in the sense of "cluster minus trigonometric." Cluster parallax distances for all TWA member candidates are given in column (9) of Table 1.

There is a small caveat regarding the cluster parallax distances in Table 1 and Figure 3 that is worth elaborating upon. There have been suggestions that some TWA stars may actually be background members of the $\sim$16 Myr old LCC OB subgroup at $d \simeq 110$ pc (e.g., Mamajek & Feigelson 2001; Mamajek et al. 2002). The space motion vectors for TWA and LCC are very similar and are within roughly $\sim$5 km s^{-1} (Mamajek et al. 2000). If one calculates cluster parallax distances to "TWA" objects using the space motion vector of LCC (Madsen et al. 2002), the mean distances in column (7) of Table 1 change by less than $\pm$5% (rms). This is smaller than the quoted distance errors (typically $\sim$11%). Hence, any conclusions based on the distribution of cluster parallax distances (i.e., Fig. 3) are very insensitive to whether individual "TWA" objects are comoving with either TWA or LCC.

I plot the cluster parallax distances versus right ascension in Figure 3. Figure 3 illustrates that there appears to be a gap in the distances between LCC members and the classic TWA members near $d = 85$ pc, effectively splitting the groups spatially. Hence, TWA 12, 17, 18, 19, and 24 have distances that are more consistent with LCC than the other TWA members. Previous investigators (MF01; R03) have suggested that the TWA members are clustered at distances of $\sim$70 pc; however, Figure 3 suggests that what is really being seen is two detached populations of young stars: one at $\sim$50 pc (TWA) and one at $\sim$110 pc (LCC). The agreement between the observed and predicted radial velocities for TWA 12, 17, 18, 19, and 24 are probably due to the similarity in space motion between LCC and TWA (see Fig. 2). As it is often not clear how "TWA" candidate members have been retained (or rejected) in past studies, there may be an observational bias present for the radial velocities of these more distant objects to agree well with that of the foreground members.

TABLE 2

Trigonometric versus Cluster Parallaxes

Name (1)	$\varpi_{\rm trig}$ (mas) (2)	$\varpi_{\rm clus}$ (mas) (3)
TW Hya	17.8 ± 2.2	19.5 ± 1.6
HD 98800	20.5 ± 2.8	25.0 ± 2.0
TWA 9	19.9 ± 2.4	14.8 ± 1.1[a]
HR 4796	15.1 ± 0.7	13.8 ± 1.1

Note.—Columns: (1) common star name, (2) weighted mean of *Hipparcos* and Tycho-1 trigonometric parallax (Perryman et al. 1997), and (3) parallax from the cluster parallax method (this work).

[a] Weighted mean of individual estimates for TWA 9A and 9B.

As Figure 3 suggests that some of the "TWA" stars may be more distant members of LCC, it is worth reexamining the vertex of the remaining TWA members, including the new brown dwarf members TWA 26–28. If the convergent point method (§ 2.3) is run on the remaining members (again assuming a mean distance of 50 pc and $\sigma_v = 1$ km s^{-1}), a somewhat poor vertex solution is found ($\chi^2/\nu = 39.8/23$; χ^2 probability = 1.6%). The biggest contributor to the χ^2 (contributing a third of the quantity) is the closest TWA candidate, TWA 22. If TWA 22 is dropped, the convergent point method shifts by a few σ in position, and a much more statistically sound vertex is found: $\alpha = 100\overset{\circ}{.}5 \pm 5\overset{\circ}{.}0$, $\delta = -27\overset{\circ}{.}9 \pm 2\overset{\circ}{.}3$, with $\chi^2/\nu = 17.5/22$; χ^2 probability = 74%. Rejecting further members has negligible effect on the vertex and only pushes the χ^2 probability to absurdly higher levels. This remarkable reduction in χ^2, upon removal of TWA 22 from the sample, suggests that TWA 22 should probably be excluded as a TWA member. Clearly, it is a nearby, young star; however, it does not appear to be a kinematic TWA member. In the initial calculation of membership probabilities (col. [8] of Table 1; § 2.4), TWA 22 had $P = 2\%$, by far the lowest value. This new a posteriori convergent point estimate is currently the best that can be done purely geometrically, i.e., with proper motions alone. It is in excellent agreement with the original TWA 1–13 vertex determination and with the individual vertices for TWA 1, 4, 9, and 11.

With the sample of "final" TWA members (denoted "Y" or "Y?" in col. [11] of Table 1), one can independently estimate the velocity dispersion σ_v of TWA on the basis of how well the proper motions determine the convergent point. Considering the range of χ^2-values for an acceptable fit (see discussion in Gould 2003), the final estimate of the velocity dispersion of TWA, from the proper-motion data alone, is $\sigma_v = 0.8^{+0.3}_{-0.2}$ km s^{-1}. By adopting $\sigma_v = 0.8$ km s^{-1}, the uncertainties on the proper motion–determined convergent point decrease to $\sigma_\alpha = 4\overset{\circ}{.}2$ and $\sigma_\delta = 1\overset{\circ}{.}9$. Using the revised, proper motion–based convergent point estimate and the new estimate of the velocity dispersion of the group has a negligible effect on the distance determinations. For these reasons (and for clarity of presentation), I have chosen not to list the reevaluated quantities.

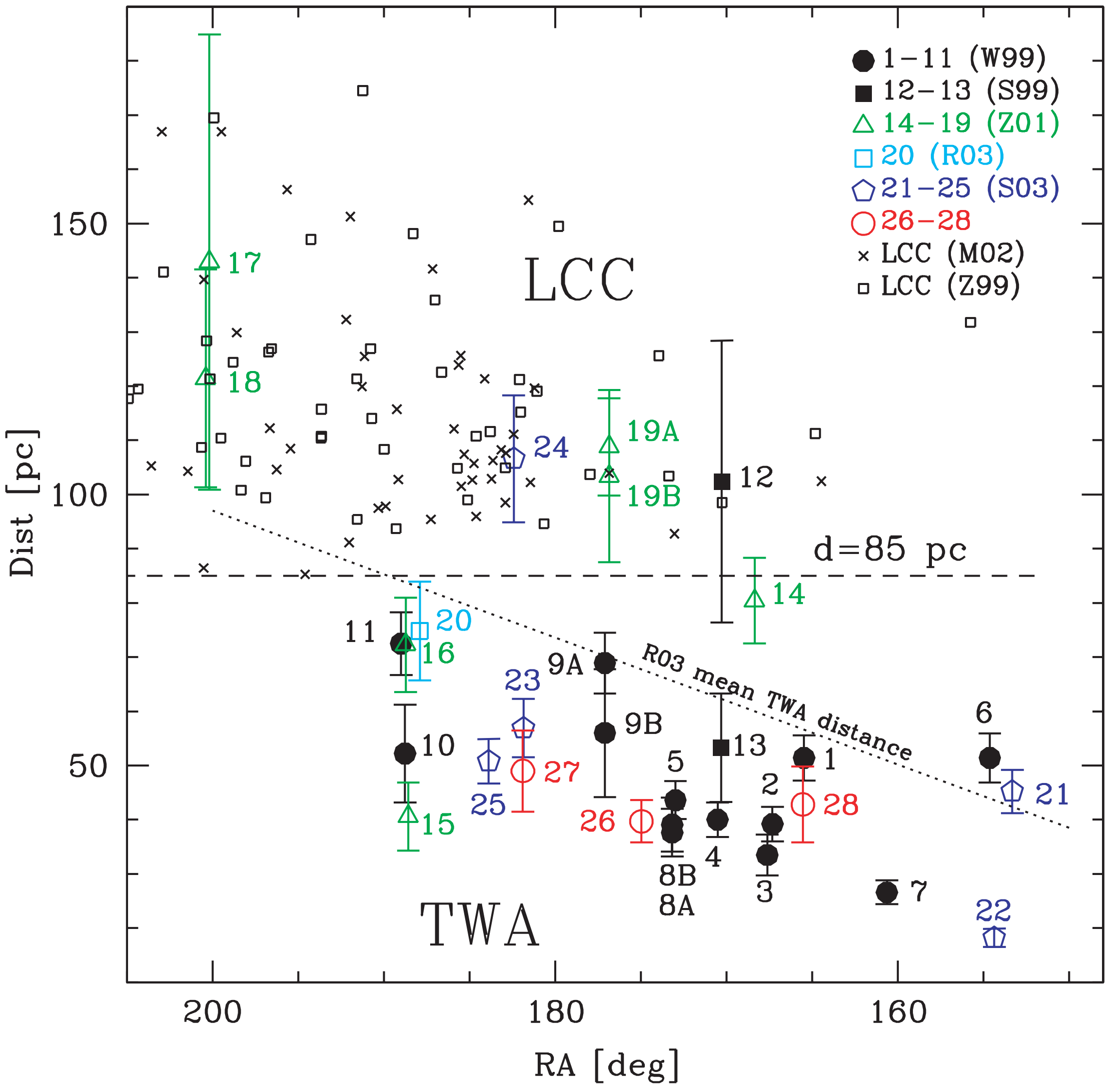

FIG. 3.—Right ascension vs. distance for candidate members of TWA and LCC. Filled black circles represent TWA 1–11 from Webb et al. (1999), filled black squares show TWA 12–13 from Sterzik et al. (1999), open green triangles show TWA 14–19 from Zuckerman et al. (2001), the open cyan square represents TWA 20 from R03, open blue pentagons indicate TWA 21–25 from SZB03, open red circles show TWA 26–28 (2M1139, 2M1207, and SSSPM J1102), small crosses show pre-MS LCC members from Mamajek et al. (2002), and small open squares show B-type LCC members from de Zeeuw et al. (1999). The dotted line represents the mean TWA distance relation from R03. The dashed line at $d = 85$ pc illustrates the detached nature of the TWA and LCC groups; i.e., although they have similar space motions, they appear to occupy separate regions. If the likely LCC members (TWA 12, 17, 18, 19, and 24) are excluded, as well as the probable nonmember TWA 22, the rest of the TWA membership is consistent with having distances of $d = 49 \pm 12$ ($1\ \sigma$) pc.

After excluding TWA 12, 17, 18, 19, 22, and 24 as TWA members, I characterize the final TWA membership with probability plots (so as to be immune to the effects of outliers; Lutz & Upgren 1980): $d_{\rm TWA} = 49 \pm 3$ (s.e.m.) ± 12 ($1\ \sigma$) pc, $\alpha_{\rm TWA} = 174\overset{\circ}{.}8 \pm 12\overset{\circ}{.}3$ ($1\ \sigma$), and $\delta_{\rm TWA} = -37\overset{\circ}{.}1 \pm 7\overset{\circ}{.}5$ ($1\ \sigma$). The projected radii in α and δ correspond to $\sim$7 pc at $d = 49$ pc. Taking into account the typical distance errors ($\sim$5 pc) and the observed distance dispersion ($\sim$12 pc), the data are consistent with the radius along the line of sight being $\sim$10 pc ($\sim$40% larger than the projected width of $\sim$7 pc). All three of the new brown dwarf members (TWA 26–28; Fig. 3, *open red circles*) lie between $d = 40$ and 53 pc, close to the classic TWA membership.

With the membership and characteristics of the TWA better defined, one can ask the question, Are there other stars in the vicinity whose astrometric data also suggest that they are TWA members? Dozens of other young, low-mass field stars have been proposed as TWA members, enough that assessing their membership is probably worth a separate study. A question that can be answered here is, *Are there any high-mass TWA members besides HR 4796?* The quoted magnitude limits of the *Hipparcos* catalog suggest that it should be complete for unreddened A- and B-type stars on, or above, the main sequence within $\sim$85 pc (Perryman et al. 1997). I queried the *Hipparcos* database for stars within a 15° radius centered on the TWA central position given earlier. I retained the 31 stars with parallaxes of >10 mas and $B - V$ colors of <0.30 (consistent with unreddened stars earlier than F0). I calculated membership probabilities and predicted cluster parallaxes for these stars in the same manner that was done for 2M1207 in § 2.4. Of these 31 stars, only 8 had membership probabilities of >5%. For these eight stars, I compared the moving cluster parallax values to the *Hipparcos* trigonometric parallaxes. Only three of these eight stars had agreement between cluster and trigonometric parallaxes at better than 2 σ: HR 4796 (known member), HIP 54477 (A1 V, $d = 58$ pc), and HIP 53484 (F0 V, $d = 97$ pc). HIP 53484 is $\sim$4 σ more distant than the mean TWA distance and nearly $\sim$15° from the TWA centroid position, so I reject its TWA membership and discuss it no further. HIP 54477 is not so easy to dismiss as a TWA member. This A1 dwarf has a high TWA membership probability (90%), and its trigonometric parallax (17.2 ± 0.7 mas) agrees fairly well with its predicted TWA cluster parallax (20.8 ± 1.6 mas). Its projected position is in the core region near TWA 2, 4, and 8. At $d \simeq 56$ pc (*Hipparcos*) or $d \simeq 48$ pc (predicted cluster parallax distance), it would be slightly further than TWA 2, 4, and 8 (all of which have $d \simeq 40$ pc). The radial velocity of HIP 54477 is not well constrained ($v_{\rm rad} = 16.2 \pm 10$ km s^{-1}; Barbier-Brossat & Figon 2000) but is consistent with that for a TWA member at its position (12.2 ± 1.6 km s^{-1}). The star appears to be close to the zero-age main sequence and so could be as young as the other TWA members. Further observations should be undertaken to see if the object has any low-mass companions that may further constrain its age. The membership of HIP 54477 to TWA cannot be rejected on kinematic grounds, but one would certainly like to see further data before claiming that it is a true TWA member. In summary, *the TWA appears to contain at least one (HR 4796), but possibly two (HIP 54477), stars hotter than F0 in its membership.*

2.6. *Expansion Age of TWA*

One may be able to put an interesting astrophysical constraint on the age of the 2M1207 system through calculating an "expansion age" for the TW Hya association. MF01 claimed that the kinematics of the TWA are consistent with an expansion age of 8.3 Myr. The analysis of MF01 included tens of X-ray–selected stars in their analysis that have been since shown to not be pre-MS stars (SZB03; Torres et al. 2003). As the majority of the stars in the MF01 analysis are not genetically related to TW Hya or its cohort, *this expansion age is not a useful constraint on the age of the TWA or 2M1207.* With the best proper-motion and radial velocity data currently available, I investigate whether an expansion is still evident in the TWA using a Blaauw expansion model. For discussions on trying to detect the linear expansions of unbound associations, see Blaauw (1956, 1964), Bertiau (1958), Jones (1971), Brown et al. (1997), Dravins et al. (1999), and Madsen et al. (2002).

2.6.1. *The Blaauw Linear Expansion Model*

Linear expansion of an association cannot be demonstrated with proper motions alone (Blaauw 1964; Brown et al. 1997). A group of stars with generally parallel motion vectors but with a small linear expansion simply appears to converge to a point further away (with higher λ) than that demonstrated by a group with strictly parallel motion vectors. The classical convergent point method equations that assume parallel motion are slightly modified to allow for expansion. In the Blaauw (1964) linear expansion model, the individual cluster parallax (ϖ) for an association member is calculated as

$$\varpi = \frac{\mu_v A}{v' \sin \lambda'}, \tag{1}$$

and the radial velocity is predicted to follow the relation

$$v_{\rm rad} = v' \cos \lambda' + \kappa d + K, \tag{2}$$

where A is the AU as previously defined, μ_v is the proper motion directed toward the convergent point, κ is the expansion term in units of km s^{-1} pc^{-1}, d is the distance to the star in pc (where $d_{\rm pc} \simeq 1000\varpi_{\rm mas}^{-1}$), and K is a zero-point term that may reflect gravitational redshift or convective blueshift terms (see Madsen et al. 2003 for a detailed discussion). The "expansion age" τ of the association in Myr is

$$\tau = \gamma^{-1}\kappa^{-1}, \tag{3}$$

where γ is the conversion factor of 1.0227 pc Myr^{-1} km^{-1} s. The cluster speed v' and star-vertex angular separation λ' are defined differently than in the standard case of parallel motions. In the Blaauw model, v' is the barycentric speed of a hypothetical association member participating in the expansion, situated at the barycenter of our solar system (see Fig. 3 of Blaauw 1964), and λ' is the angular separation between a star and the association convergent point as defined solely by the stars' proper motions. If an association is expanding, the convergent point determined from the mean three-dimensional space motion of its members (the "centroid" space motion) defines a different "convergent point" than the vertex determined through a convergent point analysis of the stars' proper motions.

To test whether the association is expanding or not and possibly assign an "expansion age," I analyze the data for TWA members two ways. First, I compare model convergent points for varying expansion ages to the observed convergent point. Second, I use the available radial velocities and cluster parallax distances to directly measure the expansion rate.

2.6.2. *Expanding versus Nonexpanding Association Convergent Point*

In Figure 2, I plot the variation in the convergent point (*long-dashed line*) if one takes the TWA "centroid" space motion vector (using the mean velocity vector for TWA 1, 4, 9, and 11) and adds linear expansion with characteristic expansion timescales. In § 2.5, I determined that the best convergent point for the final TWA membership using the proper-motion data alone was ($\alpha = 100\overset{\circ}{.}5 \pm 4\overset{\circ}{.}2$, $\delta = -27\overset{\circ}{.}9 \pm 1\overset{\circ}{.}9$). Predicted expansion model convergent points for ages 0–100 Myr were statistically compared to the observed convergent point error ellipse. From this analysis alone, *one can reject expansion ages of <7 Myr at 5% significance and <6 Myr at 1% significance*.

The close agreement between the TWA vertex found by the convergent point method and the vertices for the four individual TWA members with known *UVW* vectors (see Fig. 2) suggests that any kinematic expansion must be very subtle and perhaps not even demonstrable with existing data. It is worth exploring whether the radial velocity data can help either determine a significant expansion age, or at least place a more interesting lower limit.

2.6.3. *A "Hubble Diagram" for TWA?*

Blaauw (1956, 1964) suggested that linear expansion or contraction may be detectable if deviations are present between the observed spectroscopic radial velocities and those predicted from the moving group method for parallel motion. If a significant linear expansion term κ is present, then the Blaauw expansion model equations (eqs. [1] and [2]) predict that one should see a correlation between distance d and the difference ($v_{\rm rad} - v \cos \lambda$) between the observed and predicted spectroscopic radial velocities. As the radius of the TWA is $\sim$10 pc and the isochronal age is $\sim 10^7$ yr, one expects that κ should be of order $\sim$0.1 km s^{-1} pc^{-1}, if the stars are linearly expanding from a point.

The effects of expansion on cluster parallax distances are usually negligible (e.g., as shown by comparing trigonometric parallaxes to cluster parallaxes; de Bruijne 1999b; Mamajek et al. 2002; Madsen et al. 2002). For the case of TWA, the change in cluster parallax distances, between assuming parallel motion and linear expansion, is <6% rms for expansion ages of >5 Myr and

<3% rms for >10 Myr. Note that expansion ages of <6 Myr were effectively ruled out in § 2.6.2, and the typical distance errors from other sources (e.g., proper motions) are $\sim$11%. One can then conclude that the effects of association expansion (if any) on the distances and distance errors quoted in this study are negligible.

In order to detect any possible expansion by fitting the Blaauw model to the observations, I adopt the convergent point defined solely using the proper-motion data. I estimate v' for the four TWA members (TWA 1, 4, 9, and 11) with trigonometric parallaxes through the equation

$$v' = \frac{\mu_v A}{\varpi \sin \lambda'}. \tag{4}$$

The mean value for the four TWA members is $v' = 20.4 \pm 2.2$ km s^{-1}. Already, one notices that v (21.3 ± 1.3 km s^{-1}) is indistinguishable from v', which is consistent with no expansion.

In order to see whether a nonzero κ coefficient is detectable, I plot in Figure 4 the data in the format d versus ($v_{\rm rad} - v' \cos \lambda'$) so that one can solve for the slope κ and intercept K:

$$v_{\rm rad} - v' \cos \lambda' = \kappa d + K. \tag{5}$$

Plotted in this form, any expansion will manifest itself as a significantly positive slope. The individual distance estimates for the expansion model are calculated as

$$d_{\rm pc} = \frac{1000 v' \sin \lambda'}{A \mu_v}. \tag{6}$$

As seen in Figure 4, it is a success of the kinematic model that the ($v_{\rm rad} - v' \cos \lambda'$) values are crowded near zero at all. Recall that the *predicted* radial velocity component ($v' \cos \lambda'$) is totally independent of *any* measured radial velocity data; i.e., it is solely dependent on the convergent point position (via λ') and the trigonometric parallax distances and proper motions for TWA 1, 4, 9, and 11 (via v'). This agreement further strengthens the interpretation that the TWA constitutes a bona fide kinematic group.

The errors in distance and velocity difference have some peculiarities worth mentioning. The distance errors tend to scale with distance; i.e., $\sigma_d \propto d$. Secondly, the distances will all be affected systematically if the convergent point is in error. Finally, the linear fit of the data to equation (5) using weighting in both variables (using `fitexy`; Press et al. 1992) gives an uncomfortably good fit ($\chi^2/\nu = 7.8/19$), presumably due to overestimated errors in either the observed radial velocities, group speed, or convergent point. This weighted fit finds $\kappa = 0.036 \pm 0.039$ km s^{-1} pc^{-1} and $K = 1.07 \pm 0.51$ km s^{-1}, but again, due to the very low χ^2, it is unclear how much to believe the errors.

To avoid overinterpreting a derived slope κ whose error bars may not be believable, I fit an unweighted, ordinary least-squares line to the data, with the distance d as the independent variable and the velocity difference ($v_{\rm rad} - v' \cos \lambda'$) as the dependent variable. I do this for the 19 TWA "final" members whose radial velocity errors are <2.5 km s^{-1}. Since the sample is small, I use bootstrap and jackknife resampling to help determine the error in the derived slope (Feigelson & Babu 1992), although the agreement with the errors derived from the asymptotic formulae is excellent. The least-squares fit finds $\kappa = 0.049 \pm 0.027$ km s^{-1} pc^{-1} and $K = 1.20 \pm 0.36$ km s^{-1} (evaluated at the mean distance). Although the sign of the slope is consistent with expansion, the correlation is very weak (Pearson $r = 0.42 \pm 0.19$). The basic result is unchanged whether all of the TWA members are retained,

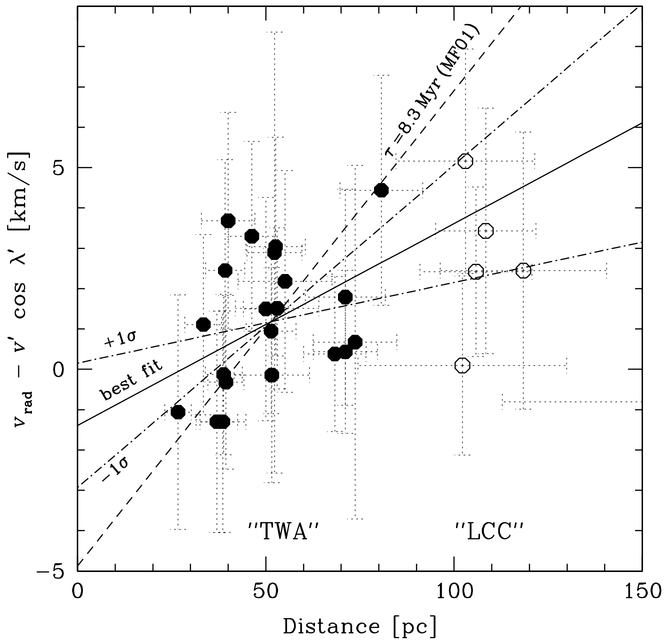

FIG. 4.—Distance vs. the difference between the observed radial velocity ($v_{\rm rad}$) and the distance-dependent radial velocity component of the Blaauw expansion model ($v' \cos \lambda'$). "Final" TWA members are shown by filled circles, and probable LCC members are shown by open circles. For parallel motion and no expansion, a slope of zero is expected. In the case of expansion, one expects the closest members to be more blueshifted and the more distant members to be more redshifted. The solid line indicates the best-fit slope κ ($= 0.049 \pm 0.027$ km s^{-1}) to the data, with 1 σ error bars shown as dot-dashed lines. The prediction for a system with expansion age of 8.3 Myr (MF01) is shown by the dashed line and is ruled out by the data.

independent of radial velocity error, or if only the eight TWA stars with radial velocity errors of <2 km s^{-1} are retained.[5]

Although the slope κ is small, one can state that it is positive at 95% confidence; i.e., that the data are consistent with some expansion. Unfortunately, the derived expansion age has very large errors and is of limited utility: $\tau = \gamma^{-1}\kappa^{-1} \simeq 20^{+25}_{-7}$ Myr. The probability distribution function of κ *excludes* expansion ages of <8.7 Myr at 99% confidence and <10.4 Myr at 95% confidence. The confidence intervals on the expansion age are very wide: 13–43 Myr (68% CL) and 9.5–262 Myr (90% CL), with $\sim$4% of the probability distribution corresponding to contraction. The expansion age advocated by MF01 (8.3 Myr) can, however, be statistically rejected. *It does not seem appropriate at this time to quote an unambiguous "expansion age" for the TW Hya association, but to quote the lower limit* ($\gtrsim$10.4 Myr).

3. DISCUSSION

With an improved distance estimate, one can revise the absolute magnitude, luminosity, and inferred mass estimates for 2M1207A and 2M1207b. The properties of 2M1207A and 2M1207b, both from the literature and derived here, are listed in Table 3. Using the photometry from Chauvin et al. (2004) and

[5] A nonzero velocity offset K should not cause too much alarm. Part of the offset may be due to gravitational redshift, which for the typical $\sim$10 Myr old TWA member with mass $\sim$0.5 $M_\odot$ should be on the order of $\sim$0.4 km s^{-1} (Greenstein & Trimble 1967, using radii from the D'Antona & Mazzitelli 1997 tracks), compared to $\sim$0.6 km s^{-1} for the Sun. An unexplained radial velocity offset of 0.4 km s^{-1} appears to be present among low-mass Hyades members (Gunn et al. 1988) even after accounting for gravitational redshift. The offsets between measured "spectroscopic" radial velocities and "astrometric" radial velocities are difficult to quantify but should be more easily measurable for larger samples of stars with future astrometric missions (Dravins et al. 1999; Madsen et al. 2003).

TABLE 3
PROPERTIES OF 2M1207A AND 2M1207b

Property (1)	2M1207A (2)	2M1207b (3)	Notes (4)
Spectral type	M8.5 ± 1	L7.25 ± 2.25	1
K (mag)	11.96 ± 0.03	16.93 ± 0.11	2
M_K (mag)	8.32 ± 0.27	13.30 ± 0.29	3
BC_K (mag)	3.12 ± 0.14	3.25 ± 0.14	4
$\log(L/L_\odot)$ (dex)	−2.68 ± 0.12	−4.72 ± 0.14	5
Mass (Baraffe et al. 2003) (M_J)	21 (19–30)	3.3 (2.3–4.8)	6
Mass (Chabrier et al. 2000) (M_J)	21 (19–31)	3.2 (2.3–4.8)	7
Mass (Burrows et al. 1997) (M_J)	20 (17–24)	4.2 (2.6–6.5)	8

NOTES.—(1) Spectral types from Chauvin et al. (2004). (2) K-band photometry from Chauvin et al. (2004). (3) Absolute K magnitudes, assuming distance from § 2.5 and no reddening. (4) Bolometric corrections are from the polynomial of Golimowski et al. (2004). Error includes uncertainty in spectral type and rms of their BC_K(SpT) fit. (5) Luminosity, using M_{K_s} and BC_K and assuming a solar absolute bolometric magnitude of 4.75. (6) Mass (and mass range) from the COND evolutionary tracks of Baraffe et al. (2003). (For all evolutionary tracks, the best interpolated mass estimate at age 8 Myr is given, followed by the extrema of the mass range considering the uncertainties in luminosity and age, where I assume an age of 8^{+4}_{-3} Myr, following Chauvin et al. 2004.) (7) Mass (and mass range) from the DUSTY evolutionary tracks of Chabrier et al. (2000). (8) Mass from the evolutionary tracks of Burrows et al. (1997).

the revised distance estimate from the moving cluster method, the absolute magnitudes of 2M1207A and 2M1207b are $M_K(\mathrm{A}) = 8.32 \pm 0.27$ and $M_K(\mathrm{b}) = 13.30 \pm 0.29$ mag, respectively. These are 0.6 mag fainter than one would derive using $d = 70$ pc (i.e., a factor of 2 intrinsically dimmer). I calculate luminosities using these absolute magnitudes and the bolometric correction estimates of Golimowski et al. (2004). Using the constraints on luminosity and age (Chauvin et al. 2005), I interpolate masses from the nongray evolutionary tracks of Burrows et al. (1997), the DUSTY tracks of Chabrier et al. (2000), and the COND tracks of Baraffe et al. (2003). For all three sets of evolutionary tracks, the masses of 2M1207A and 2M1207b cluster near $\sim$21 and $\sim$3–4M_J, respectively. Table 3 also lists the mass extrema from the 1 σ extrema in both luminosity and age (i.e., the low-mass end is for the $-1\ \sigma$ luminosity *and* age, and the high-mass end is the $+1\ \sigma$ luminosity *and* age). With the previous distance estimates ($\sim$70 pc), Chauvin et al. (2004) estimates mass of 25 and 5M_J for 2M1207A and 2M1207b, respectively. For all three models, the inferred upper mass limit of 2M1207b ($\sim$5–7M_J) is less than half of the deuterium-burning mass limit ($\sim$13M_J; Burrows et al. 1997) and less than half of the maximum mass of Doppler velocity planets ($\sim$15M_J; Marcy et al. 2005). Hence, 2M1207b could be considered a "planet" on the merits of its inferred mass.

The angular separation of 2M1207A and 2M1207b (778 mas) measured by Chauvin et al. (2004) translates into a projected physical separation of 41 ± 5 AU at the revised distance (similar to the semimajor axis of Pluto). If the observed separation is assumed to be equal to the semimajor axis and one adopts masses of 21 and 3.5M_J for 2M1207A and 2M1207b, then one naively predicts an orbital period of $\sim$1700 yr. The pair has a high mass ratio ($q \sim 0.2$), and 2M1207b is massive enough to force the primary to be $\sim$6 AU from the system barycenter. A solid detection of orbital evolution (or any hint of the dynamical masses of the components) will probably not be reported anytime soon.

One cannot rule out whether the TWA is expanding on a timescale longer than its isochronal age (>10 Myr). The slow, or negligible, expansion may also be a clue that the proto-TWA molecular cloud complex was perhaps not a small parsec-sized core with tens of stars, similar to those seen in Taurus (e.g., LDN 1551). The TWA members may have formed in a series of small-N systems ($N \sim$ few stars) distributed along filaments, separated by a few pc, and with similar bulk motions. The TWA appears to be moving away from the LCC subgroup (Mamajek et al. 2000), so it is conceivable that the proto-TWA cloudlets were simply fragments of the proto-LCC cloud, which owed their velocities to molecular cloud turbulence (Feigelson 1996). An alternative scenario is that the proto-TWA cloudlets were bright-rim clouds or cometary globules on the periphery of LCC $\sim$10–15 Myr ago, when presumably the LCC subgroup still had a few late O stars (de Geus 1992). Such cloudlets could have been accelerated away from the LCC O star population through the rocket effect (Oort & Spitzer 1955) and compressed to form stars due to radiation-driven implosion (Bertoldi & McKee 1990). The energy input from deceased LCC members (via UV light, winds, and supernovae) has probably dominated the energy input of the local interstellar medium over the past 10 Myr and within 100 pc in the general direction of LCC and TWA (Maíz-Apellániz 2001). Small-scale star formation in cometary globules on the edge of OB associations has strong observational support (Reipurth 1983; Ogura & Sugitani 1998), and there is strong evidence for triggering by the massive stellar population (e.g., Kim et al. 2005; Lee et al. 2005). A cometary globule formation scenario for TWA might explain a few observational quirks of the group, namely, its location ($\sim$70 pc away from the nearby LCC OB subgroup), age ($\sim$7 Myr younger than LCC), space motion vector (directed $\sim$5 km s^{-1} away from the LCC; Mamajek et al. 2000), and low stellar density. The small, young stellar groups associated with η Cha, ϵ Cha, and β Pic show many of these same symptoms (Mamajek et al. 1999, 2000; Ortega et al. 2002; Jilinski et al. 2005), although the η and ϵ Cha clusters appear to be more strongly bound than the TWA and β Pic groups. Cloudlets analogous to those on the periphery of Vel OB2 (Kim et al. 2005) and Ori OB1 (Lee et al. 2005) may be the evolutionary predecessors of small, unbound, $\sim$10 Myr old associations such as TWA. That 2M1207 and the TWA formed in a region of rather low stellar density could explain how such a wide, low-mass binary system as 2M1207 could survive its birth environment intact.

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