IDENTIFICATION OF A NEARBY STELLAR ASSOCIATION IN THE HIPPARCOS CATALOG:
IMPLICATIONS FOR RECENT, LOCAL STAR FORMATION.

B. ZUCKERMAN¹ & R. A. WEBB¹
Dept. of Astronomy and Physics - Univ. of California, Los Angeles
8371 Math Science Bldg. - Box 951562
Los Angeles, CA 90095-1562
ben@astro.ucla.edu; webbr@astro.ucla.edu
Accepted for publication in The Astrophysical Journal

ABSTRACT

The TW Hydrae Association (∼55 pc from Earth) is the nearest known region of recent star formation. Based primarily on the Hipparcos catalog, we have now identified a group of 9 or 10 co-moving star systems at a common distance (∼45 pc) from Earth that appear to comprise another, somewhat older, association (“the Tucanae Association”). Together with ages and motions recently determined for some nearby field stars, the existence of the Tucanae and TW Hydrae Associations suggests that the Sun is now close to a region that was the site of substantial star formation only 10-40 million years ago. The TW Hydrae Association represents a final chapter in the local star formation history.

Subject headings: open clusters and associations: individual (Tucanae, TW Hydrae) — stars: pre-main sequence — stars: kinematics

1. INTRODUCTION

For many years, the only known star clusters within 70 pc of Earth were the rich Hyades (at ∼ 45 pc) and the sparse U Ma nucleus (at ∼25 pc). Then a group of stars ∼55 pc from Earth was established as a bona fide association of T Tauri stars of age ∼10 million years (Webb et al 1999; Sterzik et al 1999; Webb, Reid, & Zuckerman 2000). This TW Hydrae Association (hereafter TWA) was unrecognized for many decades in spite of its being the nearest region of recent star formation (Kastner et al 1997). A ubiquitous signpost of newly formed stars has been a nearby molecular cloud. But no interstellar cloud has been found near TW Hya despite multiple searches. Therefore, we ask: do additional unrealized young associations far from molecular clouds exist near Earth?

Different teams have used the Hipparcos catalog to search for previously unrecognized stellar associations. For example, Platais et al (1998) undertook “A search for star clusters from the Hipparcos Data” and list basic data for 5 “very likely” new clusters and associations as well as 15 “possible” ones. Yet, in their own words, “At distances <100 pc the survey is incomplete as a result of the chosen search strategy.” Of the 20 potential new groupings in their Table 1, the closest, which contains 11 members from Hipparcos, is 132 pc away.

By contrast, the “Tucanae Association” we propose in the present paper is only ∼45 pc from Earth and much younger than the U Ma and Hyades clusters. Just as the sparse U Ma cluster nucleus is accompanied by more numerous U Ma stream stars, we suggest that the Sun is embedded in a stream of stars with similar space motions (the “Tucanae Stream”), with the Tucanae Association playing a role analogous to the U Ma nucleus. Figures 1a and 1b depict the Tucanae Association and some stream stars, respectively. These stars likely represent some of the younger, nearer, members of the more extensive Pleiades group or Local Association proposed by Eggen (e.g., see Jeffries 1995 and references therein).

2. OBSERVATIONS

Excepting TW Hya itself, the first T Tauri stars in the TWA were identified in a study of IRAS sources at high galactic latitude (de la Reza et al 1989; Gregorio-Hetem et al 1992). It has been shown that, on the main sequence, young stars are more likely 60 µm IRAS sources than are old stars (e.g., Jura et al 1993 & 1998; Silverstone et al 2000) and young stars are also more apt to be members of associations than are older stars. Therefore, we interrogated the Hipparcos catalog within a six degree radius of two dozen stars detected by IRAS at 60 µm and scattered around the sky. The stars were those with, in our opinion, reliable excesses at 60 µm listed by Mannings & Barlow (1998), Backman & Paresce (1993), and/or Silverstone et al. (2000). We searched for Hipparcos stars with similar proper motions and distances to the IRAS stars; results for our most interesting regions are presented in Figure 1, Tables 1 & 2 and are discussed below. Results at additional IRAS stars will be discussed in a later paper.

To verify or deny common space motions of Table 1 stars with similar distances and proper motions in the Hipparcos catalog, we measured radial velocities with the Bench Mounted Echelle (BME) spectrograph on the 1.5-m telescope at the Cerro Tololo Interamerican Observatory (CTIO). The spectra cover from ∼ 5000 - 8200Å at a typical measured resolution of 0.15Å. The data, obtained 21-26 (UT) August 1999, were reduced and calibrated in IRAF.

Six radial velocity standard stars were observed during the run with spectral types ranging from F6 to M1.5. Radial velocity was determined by cross-correlating the spectrum of the target and a standard star of similar spectral type observed close in time to the target. Approximately 15 echelle orders, chosen to produce strong correlations and have few atmospheric features, were used to compute the correlation. The accuracy of these measurements is strongly dependent on the S/N of the spectra and the spectral type and rotational velocity of the target star. The uncertainty ranges from ∼ 1-10 km/s, the majority being <2 km/s. Hα line profiles and equivalent widths of lithium

¹Visiting astronomer, Cerro Tololo Inter-American Observatory (CTIO) which is operated by AURA Inc. under contract to the National Science Foundation
(6708Å) were also measured and are listed in Table 2.

Projected rotation velocities ($v \sin i$) were measured and are listed in Table 2. We used a procedure similar to that of Strassmeier et al. (1990), specifically we followed the prescription described in their Section IIId. We measured the FWHM of lines in the 6420Å region and corrected them for the instrumental broadening (0.134 km/s, FWHM) determined from five ThAr lamp lines at similar wavelengths. Following Strassmeier et al, we assumed a macroturbulent velocity, $\zeta$, equal to $3 \text{ km/s}$. For a few of the faint late K-type and M-type stars, $v \sin i$ is quite uncertain due to low S/N.

With the 0.9-m telescope at CTIO we obtained BVRI photometry of stars in Table 1. The purpose was to determine whether any of the stars were sufficiently young to still be above the main sequence. These data will be reported in a later paper.

Properties of the 37 star systems we observed at CTIO are listed in Tables 1 and 2. The calculated UVW and the age indicators usually agree in the sense that the stars with space motions similar to those of stars in the youthful TWA (Soderblom, King & Henry 1998; Webb et al. 2000), Beta Pic moving group (Barrado y Navascues et al. 1999), and Local Association (Jeffries 1995), usually also have additional indications of youth. Youth is deduced from one or more of the following characteristics: ROSAT All-Sky Survey Bright Source Catalog (RASS-BSC, Voges et al. 1998) X-ray source, strong lithium 6708Å absorption, H$\alpha$ emission or weak (filled-in) absorption, rapid rotation, IRAS far-infrared excess emission, and, for the A- and late-B type stars, location near the bottom envelope of brightness of stars of comparable spectral type i.e. on or near the zero-age main sequence, (Jura et al 1998; Lowrance et al 2000).

We interprete Tables 1a and 2a in the following way. Nine or ten star systems near zero hours right ascension are likely to be part of a small stellar association similar to the TWA or the U Ma nucleus (see Figure 1c). These 10 stars are indicated in column 4 of Table 1a and we dub them "the Tucanae Association": their distribution is shown in Figure 1a. Other stars in the Tables and Figures, may be placed into one of the following categories: (1) a member of the stream of nearby, young Local Association stars, or (2) a star with no obvious indications of youth that happens to have distance from Earth and proper motions similar to those of the Tucanae Association. Some of these stars may indeed be Tucanae Association members without signatures of youth (e.g. see discussion of HD 207129 below). An excess of stars with similar proper motions and distance from Earth seems to exist in the Tucanae region, indicating some stars listed in Table 1b may be Tucanae members. But individually, each of these stars is unlikely to be a member.

3. RESULTS & DISCUSSION

Ages have been deduced for a few stars in Table 1a. For example, HIP 92680 (PZ Tel) is above the main sequence and estimated to be 15-20 million years old (Favata et al. 1998; Soderblom et al. 1998). With the NICMOS camera on HST, Lowrance et al. (2000) discovered a late M-type object within 4″ of the A-type star HR 7329; if a companion, which appears very likely, then the object is a brown dwarf of age ~20 Myr. Other stars with similar space motions and ages around 20 million years have been identified close to the Sun, for example, Beta Pictoris (Jura et al. 1993; Barrado y Navascues et al. 1999) and Gliese 799 and 803 (Barrado y Navascues et al. 1999).

The Tucanae Association itself is probably somewhat older than 20 million years. We tentatively assign an age of 40 Myrs based on the strength of H$\alpha$ emission lines seen in HIP 1910, 1993, and 2729 which are brighter than in stars of similar spectral type in the $\alpha$ Per cluster (see Figure 16 in Prosser 1992) whose age has recently been estimated to be 90 +/- 10 Myr (Stauffer et al. 1999). Other indicators of age, the presence of rapid rotators, stars with high Li abundance and or large X-ray flux, all agree with this estimate but are somewhat less diagnostic. For example, the X-ray counts per second of the K- and M-type stars in Table 1a imply $L_x/L_{bol}$ comparable to that of late-type stars in very young clusters (see Fig. 1 in Kastner et al. 1997). And $L_x/L_{bol}$ of the late F- and G-type stars in Table 1a are typically three orders of magnitude larger than $L_x/L_{bol}$ of the Sun (Fleming 1999) which suggests an age younger than the Pleiades (see Fig. 2 in Gaidos 1998).

Over 40 Myr, dispersion as small as 1 km/s in the critical V component of space velocity would lead to a 40 pc separation between stars. Since no such separation is present among the nuclear members (Fig. 1a), either the range in V given in Table 2a is due to measurement error or the stars are younger.
than 40 Myr or both. Measurement errors are characterized by, for example, differences between Hipparcos and PPM proper motions and the large uncertainty in radial velocity for A- and B-type members. Also, close companions in unrecognized binary systems will generate orbital motion that could shift the measured value of V away from the true V velocity of the binary system.

We chose the stars in Table 1 for further study at CTIO because of similar distances from Earth and proper motions. However, once radial velocities were measured it became clear that many of these stars share similar space motions (UVW) with other very young nearby stars found in very different directions. The mean UVW for the nine likely member systems of the Tucana nucleus (PPM 366328 not included) is \((-10.5, -20.8, +0.3)\) (Jeffries 1995). In addition, we calculate UVW \(= -11.7, -22.3, +0.6\), is actually a member of

Note.—Position, apparent V magnitudes (mV), color (B-V) and parallax (π in milliarcsec) are from the Hipparcos catalog unless otherwise noted. Spectral types (SpT) are taken from various sources in the literature, luminosity classes are main sequence (V) unless otherwise noted. A check in the “nuclear member” column indicates the star is likely a member of the Tucanae Association (or nucleus), a blank indicates possible membership in the “stream”. The ROSAT fluxes in counts per second (cps) are from the ROSAT Bright Source Catalog (Voget et al. 1998) and the X-ray positions match the stellar positions to within 20′′. Proper Mot (mas yr \(^{-1}\)) is the brightness of the recently identified, young, com- pact \(\eta\) Chamaeleontis cluster (Mamajek, Lawson & Feigelson 1999). Similar space motions are also evident for some stars with far-IR excess emission as measured by IRAS or having strong lithium 6708Å lines (Jeffries 1995). As noted by Jef- riees, many of these lithium stars have space motions similar to that of Eggen’s Local Association (U,V,W = -11, -21, -11). Four such stars, HD 172555, HD 195627, HD 207129 and HD 10647, are plotted as asterisks on Figures 1a and 1b. These four stars were not targeted by us for CTIO observations because they are significantly closer to Earth than stars in Table 1 and we did not initially recognize them as potential members of a common stream.

The G-type star HD 207129 is of special interest because it is surrounded by a cold dust ring detected by IRAS and is only 15.6 pc from Earth. Jourdain de Muizon et al (1999) argue that this star is 4.7 Gyrs old and construct a corresponding model for evolution of the dust ring. In contrast, we believe that HD 207129, UVW = -13.7, -22.3, +0.6, is actually a member of
TABLE 2
MEASURED AND DERIVED QUANTITIES

| HIP | Hα profile | Li 6708Å | \(v \sin i\) | RV | Space Mot. (km s\(^{-1}\)) |
|-----|------------|----------|---------------|----|-----------------------------|
|     |            | EW mÅ    | km s\(^{-1}\) |     | U                          |
|     |            |          |               |     | V                          |
|     |            |          |               |     | W                          |
|     |            |          |               |     |                             |
|     |            |          |               |     |                             |

2a. Probable and possible members of the nucleus or stream

2b. Improbable members

Nearby moving groups

TWA

Local Assoc.

UMa

Hyades

NOTE.—In the Hα column, “Normal” indicates an absorption line similar to inactive stars of comparable spectral type (e.g. see figures in Soderblom et al. 1998). “Filled” indicates a shallow absorption or completely absent Hα feature. Negative equivalent widths (EW) indicate an emission line. Stars without entries in the Hα, Li and FWHM columns are A- and B-type stars with broad Hα lines and few other photospheric features. The Li equivalent widths (EW) are not corrected for possible contamination from FeI 6707.44Å line whose contribution is typically \(< 10 \text{ mÅ}\) for F- and G-type stars and \(< 25 \text{ mÅ}\) for K- and M-type stars. First listed radial velocity (RV) is used to calculate UVW. This value is generally our CTIO measurement. If additional values appear, the first value in parentheses is our CTIO measurement followed by alternative measurements which appear in the literature. CTIO measured velocities have an error of less than 2 km/s unless otherwise noted. Heliocentric UVW space motions have been computed according to the equations of Johnson and Soderblom (1987), positive U in the direction of the galactic center, V the direction of galactic rotation and W toward the North Galactic Pole. The space motions for moving groups are from Jeffries 1995 (Local Assoc). taken from Eggen 1992), Soderblom & Mayor 1993 (UMa & Hyades) and Webb, Reid & Zuckerlman 2000 (TW Hydrae = TWA) and are included for comparison.

a: double peaked Hα profile

b: Error of the RV measurement is significantly larger than typical because the star is a rapid rotator and/or an early spectral type with few spectral features. Uncertainty of these measurements is typically \(10 \text{ km/s}\).

c: The BSC lists HIP 2487 as a 0.75+A7 binary system, several ionized metal lines are double peaked and the red peak is not well fit by a gaussian profile. Nonetheless we measure velocities of the components at -10.5 km/s and +18 km/s (with a large uncertainty). For calculation of UVW, we adopt an average of our weighted mean system velocity and previously measured velocities. \(v \sin i = 6.1\) applies to the blue shifted star. The red shifted component, based on deblending of only four lines, appears to be somewhat more rapidly rotating but the non-gaussian profile suggests the situation is more complicated. All measurements as of HJD 2451414.934.

d: Double-lined spectroscopic binary. Strength of photospheric features is approximately equal and components are at RV = -82 and +90 km/s on HJD = 2451415.472. If stars are equal masses, average system velocity = +4 km/s, also previously measured to be +2 km/s.

e: blue shifted component

f: red shifted component

g: Very broad Hα profile

h: Extreme rapid rotator? Spectrum is essentially featureless. Broad shallow depressions appear at the positions of a couple of strong spectral lines which are likely rotationally broadened features.

i: We adopt RV = 0.6 km s\(^{-1}\) from Grenier et al (1999) in preference to our measurement of -3 km s\(^{-1}\) which has a larger uncertainty.
the Tucanae stream and probably only about as old as the Tucanae Association. Stars with space motions within the range encompassing the young groups listed above, \((-15, -23, -13) < (U, V, W) < (-9, -16, +3)\), comprise less than 2% of the stars in Gleise’s Catalog of Nearby Stars. Thus the chance that HD 207129 is as old as 4.7 Gyr and yet have a space motion so similar to many very young stars is small. Also, location of HD 207129 in the same direction as the Tucanae stream stars seen in Figure 1 supports the idea that they are kinematically associated. This strikes us as more compelling evidence for youth than the weak Ca II K-line emission, relied on by Jourdain de Muizon, as an indicator of a much older star. Not all young stars have activity in the Ca II lines. For example, the very young, F-type star HD 135344 which has a huge far-IR excess and associated CO rotational emission (Zuckerman, Forveille, & Kastner 1995), has no Ca activity (Duncan, Barlow & Ryan 1997). Finally, we note that the intrinsic X-ray luminosity of HD 207129 as measured by ROSAT is about 10 times that of the Sun.

Many papers published recently describe field stars with high lithium abundance, large X-ray fluxes, and other indicators suggestive of youth, but no consistent or compelling picture has been established for the solar vicinity. We believe it is now possible to paint a plausible picture of the recent star formation history of the present solar neighborhood.

Between 10 and 40 million years ago in a co-moving frame centered near the present position of the Sun, an ensemble of molecular clouds were forming stars at a modest rate. The spectral types of these stars ranged primarily from A to M, but included a few B-type stars also. About 10 Myrs ago, the most massive of the B-type stars exploded as a supernova at about the time that stars in the TWA were forming. This event terminated the star formation episodes and helped to generate a very low density region with radius of order 70 pc in most directions from the present position of the Sun (Welsh, Crifo & Lallement 1998 and references therein). Thus we now have a “150 pc conspiracy” whereby molecular clouds (Taurus, Lupus, Cha, Sco, Oph) are seen in various directions, typically less than 2% of the stars

REFERENCES

Backman, D. E. & Paresce, F. 1993, in “Protostars & Planets III” eds. E. H.
Levy & J. I. Lunine, Tucson: Univ. of Arizona Press p. 1253
Barrado y Navascues, Stauffer, J. R., Song, I & Cauillault J-P. 1999, ApJ, 520, L123
de la Reza, R., Torres, C. A. O., Quast, G. Castilho, B. V. & Vieira, G. L., 1989, 
ApJ, 343, L61
Duncan, S. K., Barlow, M. J., & Ryan, S. G. 1997, MNRAS, 290, 165
Eggen, O. J. 1992, AJ, 103, 1302
Elmegreen, B.G. 1992, in “Star Formation in Stellar Systems” eds. G. Tenorio-
Tagle et al, Cambridge: Cambridge Univ. Press p. 381
Elmegreen, B.G. 1993, in “Protostars & Planets III” eds. E. H. Levy & J. I.
Lunine, Tucson: Univ. of Arizona Press p. 97
Favata, F., Micela, G., Sciorinto, S. & D’Antona, F. 1998, A&A, 335, 218
Fleming, T. A. 1999, private communication
Gaidos, E. 1998, PASP, 110, 1259
Gregorio-Hetem, J., Lepine, J. R. D., Quast, G. R., Torres, C. A. O. & de la 
Reza, R. 1992, AJ, 103, 549
Grenier, S., Burnage, R., Faragigliana, R., Gerbaldi, M., Delmas, F., Gómez, A.
E., Sabas, V. & Sharif, L. 1999, A&AS, 135, 503
Jefrões, R. D. 1985, MNRAS, 223, 599
Johnson, D. R. H. & Soderblom, D. R. 1987, AJ, 93, 864
Jourdain de Muizon, M. et al 1999, A&A, 350, 875
Jura, M., Malkan, M., White, R., Telesco, C., Pina, R. & Fisher, R. S. 1998, 
ApJ, 505, 897
Jura, M., Zuckerman, B., Becklin, E. E. & Smith, R. C. 1993, ApJ, 418, L37
Kastner, J. H., Zuckerman, B., Weintraub, D. A. & Forveille, T. 1997, Science,
277, 69
Lowrance, P. J. et al 2000, ApJ, submitted.
Mamajek, E. E., Lawson, W. A. & Feigelson, E. D. 1999, ApJ, 516, L77
Mannings, V. & Barlow, M. J. 1998, ApJ, 497, 330
Platais, I., Kozhurina-Platais, V. & Van Leeuwen, F. 1998, AJ, 116, 2423
Prosser, C. F. 1992, AJ, 103, 488
Silverstone, M. D. et al 2000, in preparation
Soderblom, D. R., King, J. R. & Henry T. J. 1998, AJ, 116, 2423
Soderblom, D. R. & Mayor, M. 1993, AJ, 105, 226
Stauffer, J. R., Cauillault, J-P., Gagne, M., Prosser, C. F. & Hartmann, L. W.
1994, ApJS, 91, 625
Stauffer, J. R. et al 1999, ApJ, 527, 219
Sterzik, M. F. et al 1999, A&A, 346, L41
Strassmeier, K. G., Fekel F. C., Bopp, B. W., Dempsey, R. C., & Henry, G. W.
1990, ApJS, 72, 191
Voges, W. et al. 1999, A&A, 349, 389
Webb, R. A., Zuckerman, B., Platais, I., Patience, J., White, R. J., Schwartz, M.
Unia, K. G., Fekel F. C., Bopp, B. W., Dempsey, R. C., & Henry, G. W.
1990, ApJS, 72, 191
Welsh, B. Y., Crifo, F. & Lallement R. 1998, A&A, 333, 101
Zuckerman, B., Forveille, T. & Kastner, J. H. 1995, Nature, 373, 494

4. CONCLUSIONS

We have found a previously unrecognized southern association - “the Tucanae Association” - which is only \(\sim 45\) pc from Earth, but not quite as young as the recently established TW Hydrae Association. Thus, in the past year, the number of known stellar associations within 60 pc of Earth has increased from two (the Hyades and U Ma) to four. The existence of the Tucanae and TW Hydrae Associations resolves the mystery of how the Beta Pictoris moving group can be so young, 20 \(\pm 10\) Myrs (Barrado y Navascues et al 1999) and yet so near to Earth (within 20 pc). That is, 10-40 million years ago, the region through which the Sun is now passing experienced a significant era of star formation which produced the Beta Pictoris group, the two southern associations, and related stream stars.

We thank the crew at CTIO including N. Sunzteff, T. Ingersson, M. Fernandez, A. Gomez, E. Cosgrove & R. Venegas for critical help acquiring these data. A special thanks to M. Smith for his flexibility with telescope maintenance schedules. We are grateful to M. Jura for calling the Mannings and Barlow paper to our attention and for pointing out the likelihood of proper motion companions to some of the stars in Table 1. We thank Dr. Jura and E. E. Becklin and P. Lowrance for comments on drafts of the paper. This research was supported by NSF Grant 9417156 to UCLA and by the UCLA Center for Astrobiology.