Radial-Velocity Monitoring of Members and Candidate Members of the TW Hydrae Association

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Abstract. We present our spectroscopic measurements of the radial velocity, effective temperature, and projected rotational velocity of several of the known members of the TW Hya association, as well as measurements for candidate members selected on the basis of their X-ray or kinematic properties. A number of our targets turn out to be binaries, but most are non-members. The radial velocities for some of the other candidates support the conclusion that they are kinematically associated with the group, although further observations are required to show that they are indeed pre-main sequence objects.

1. Introduction

The TW Hya association, a loose grouping of very young stars that does not appear to be related to any nearby molecular cloud material, has been the subject of considerable attention in recent years. The prototype of the association, TW Hya itself, was the first recognized example of an isolated T Tauri star. The first few members of the association were discovered more or less by accident, and were only later recognized to be related. Aside from these, the systematic search for additional stars belonging to the group has relied on their X-ray properties (such as their detection as a ROSAT source), or their similar kinematics (proper motions).

Follow-up studies have been made in many cases to establish the youth of the candidate members, for example by the presence of strong Lithium λ6708 absorption, Hα emission, infrared excess, etc. To date there are 19 objects recognized as true members in the published literature (see, e.g., Kastner et al. 1997; Webb et al. 1999; Sterzik et al. 1999; Zuckerman et al. 2001), along with many other potential members that need to be studied further. One of the goals of the present work is to investigate the kinematics of the candidate
members, but in the direction orthogonal to previous studies that have focused only on proper motions. We present measurements along the line of sight (radial velocities), which are complementary to the proper motions and help define the space motion of these objects. Another goal of this project is to detect any spectroscopic binaries that might be present through repeated measurements of the radial velocities of our targets, and to determine their orbits.

2. Sample and observations

Our observations were obtained using nearly identical echelle spectrographs on the MMT prior to conversion (Mt. Hopkins, AZ), the 1.5m Tillinghast reflector at the F. L. Whipple Observatory (also on Mt. Hopkins, AZ), and on the 1.5m Wyeth reflector at the Oak Ridge Observatory (Harvard, MA). A single echelle order was recorded with a photon-counting Reticon diode array, at a resolving power of $\lambda/\Delta\lambda = 35,000$ and a central wavelength of 5187Å. The spectral coverage is 45Å. We report here on the results based on some 300 spectra, and an additional 150 archival spectra from the CfA echelle database.

Table 1 presents the sample of stars studied in this program, including for completeness HD 98800 (TWA-4), which was observed several years ago with the same instrumental setup and was discovered to be a quadruple system (Torres et al. 1995). The second column in the table gives the “official” designation within the association, and the last column collects the available measurements of the Li $\lambda$6708 equivalent width for these stars.

All recognized members are seen to have strong Li in absorption, while some of the other objects (proposed by a number of authors as candidate members) have much weaker Li. Not all of the potential members have estimates of this crucial youth indicator, so their status is unclear.

| TWA # | Other name | R.A. (J2000) | Dec. (J2000) | V (mag) | SpT | Li $\lambda$6708 eq. width (Å) |
|-------|------------|-------------|-------------|---------|-----|-------------------------------|
| 1     | HIP 48273  | 09:50:30.1  | +04:20:37   | 6.24    | F6  | ...                           |
| 2     | TYC 6804-0118-1 | 09:59:08.4   | −22:39:35   | 10.09   | K2  | 0.143                         |
| 3     | HIP 50796  | 10:22:18.0  | −10:32:15   | 10.80   | ... | ...                           |
| 4     | HIP 53486  | 10:56:31.0  | +07:23:19   | 7.37    | K0  | ...                           |
| 5     | RXJ1100.0−3813 | 11:00:02.4  | −38:13:20   | 12.29   | ... | ...                           |
| 6     | HD 95490   | 11:00:51.2  | −34:42:16   | 10.92   | K8e | 0.43                          |
| 7     | TWA-1      | TW Hya      | 11:01:52.0  | −34:42:16 | 10.92 | K8e 0.43                     |
| 8     | TWA-2A     | CD−29°8887A | 11:09:13.9  | −30:01:39 | 11.07 | M2e 0.52                     |
| 9     | RXJ1109.7−3907 | 11:09:40.1  | −39:06:48   | 10.58   | G3  | 0.190                         |
| 10    | TWA-3A     | Hen 3-600A  | 11:10:28.0  | −37:31:53 | 12.04 | M4e 0.57                     |
| 11    | HD 97131   | 11:10:34.2  | −30:27:19   | 9.01    | F2  | 0.03                          |
| 12    | CD−37°7097 | 11:12:42.7  | −38:31:04   | 10.24   | F5  | ...                           |
| 13    | RXJ1151.5−3233 | 11:15:06.9  | −32:32:46   | 12.36   | ... | ...                           |
| 14    | TWA-12     | RXJ1121.1−3845 | 11:21:05.5  | −38:45:17 | 12.85 | M2 0.53                      |
| 15    | TWA-13A    | RXJ1121.3−3447N | 11:21:17.3  | −34:46:47 | 11.46 | M2e 0.65                     |
| 16    | TWA-13B    | RXJ1121.3−3447S | 11:21:17.5  | −34:46:51 | 12.00 | M1e 0.51                     |
| 17    | TWA-4A     | HD 98800A   | 11:22:05.3  | −24:46:40 | 9.41  | K5 0.425                     |
| 18    | TWA-4B     | HD 98800B   | 11:22:05.3  | −24:46:39 | 9.94  | ... 0.335+0.450              |
| 19    | TWA-5A     | CD−33°7795A | 11:31:55.4  | −34:36:27 | 11.37 | M3 0.55                      |
| 20    | TWA-9A     | CD−36°7429A | 11:48:24.3  | −37:28:49 | 11.26 | K5 0.46                      |
3. Results

Radial velocities were obtained using standard cross-correlation techniques (the XCSAO task running under IRAF), as described, e.g., by Latham (1992). The templates were taken from an extensive library of synthetic spectra based on the latest model atmospheres by Kurucz (Morse & Kurucz, in preparation). In addition, we derived effective temperatures \( T_{\text{eff}} \) and projected rotational velocities \( v \sin i \) for all our stars by comparison with the synthetic spectra. A number of objects have turned out to be double-lined. For these we used the two-dimensional cross-correlation algorithm known as TODCOR (Zucker & Mazeh 1994), and in most cases we were able to derive the \( T_{\text{eff}} \) and \( v \sin i \) for both components.

Table 2 lists our results for the temperatures (K) and rotational velocities (km s\(^{-1}\)). A comparison with \( T_{\text{eff}} \) values derived from the spectral types (adopting the calibration by de Jager & Nieuwenhuijzen 1987) and other sources shows generally good agreement. The agreement for the cooler stars is poorer due to limitations in the model atmospheres used to compute the synthetic spectra, which do not include several key molecular opacity sources. Our measures of \( v \sin i \) are also fairly consistent with other determinations.

| TWA # | Other names | SpT | \( T_{\text{eff}} \) (CfA) | \( T_{\text{eff}} \) (SpT) | \( T_{\text{eff}} \) (Other) | \( v \sin i \) (CfA) | \( v \sin i \) (Other) |
|-------|------------|-----|----------------|----------------|----------------|----------------|----------------|
| 1     | HIP 48273  | F6  | 6300/6150      | 6530           | 22/22          |                |                |
| 2     | TYC 6604-0118-1 | K2 | 5050/4850    | 4840           | 19/15          | 19             |                |
| 3     | HIP 50796  | ... | 4750           | ...            | 8              |                |                |
| 4     | HIP 53486  | K0  | 5050           | 5150           | 1              |                |                |
| 5     | RXJ1100.0−3813 | ... | 5750           | ...            | 35             |                |                |
| 6     | HD 95490   | F7  | 6500           | 6430           | 13             |                |                |
| 7     | TWA-1      | TW Hya | K8e          | 4150           | 4150          | 40              | 10, 15, 14     |
| 8     | TWA-2A     | CD−29°8887A | M2e | 4050:       | 3690           | 13              | 15             |
| 9     | RXJ1109.7−3907 | G3 | 5900           | 5710           | 5800           | 27              | 23             |
| 10    | TWA-3A     | Hen 3-600A | M4e | 4750:       | 3350           | 20              | 15             |
| 11    | HD 97131   | F2  | 6750/6750      | 7180           | 12/16          |                |                |
| 12    | CD−37°7097 | F5  | 6250           | 6650           | 14             |                |                |
| 13    | RXJ1115.1−3233 | ... | 5750/5250:  | 25/0           |                |                |                |
| 14    | TWA-12     | RXJ1121.1−3845 | M2 | 4000:       | 3520           | 3600           | 15              | 21             |
| 15    | TWA-13A    | RXJ1121.3−3447N | M2e | 4150:       | 3520           | 3600           | 12              | 16, 10         |
| 16    | TWA-13B    | RXJ1121.3−3447S | M1e | 4100:       | 3660           | 3800           | 12              | 16, 12         |
| 17    | TWA-4A     | HD 98800A  | K5  | 4410        | 4350           | 5              |                |                |
| 18    | TWA-4B     | HD 98800B  | ... | 4250/3700   | 3/2            |                |                |
| 19    | TWA-5A     | CD−33°7795A | M3  | 4050:       | 3490           | 36              | 58             |
| 20    | TWA-9A     | CD−36°7429A | K5  | 4350        | 4410           | 11             |                |

In addition to the well known quadruple system HD 98800, multiple measurements of the radial velocity of our other targets have revealed several binaries (some double-lined) with short orbital periods (RXJ1115.1−3233, TYC 6604-0118-1, HIP 48273, RXJ1100.0−3813) and one double-lined triple system (HD 97131). None of these appear to be true members of the TW Hya association, based on their Li abundance or kinematics (radial velocity of the center of mass). Details on these orbital solutions will be reported in a forthcoming paper.
In Table 3 we list the mean heliocentric radial velocities of all our targets. For the multiple systems we give the center-of-mass velocity. Our measurements are consistent with other determinations from the literature, but much more precise. Except for the case of Hen 3-600A (TWA-3A) and CD$-33^\circ7795A$ (TWA-5A), which are double-lined or possibly triple-lined but have not yet had their orbits determined (see also Webb et al. 1999), the other recognized members of the association have similar radial velocities. In the case of HD 98800, we have assumed that the average velocity of components A and B corresponds to the center of mass of the quadruple system. Similarly for RXJ1121.3$-3447$ (TWA-13), which is a visual binary. The mean velocity of TWA-1, TWA-2, TWA-9, TWA-12, and TWA-13 is $+11.30 \pm 0.56$ km s$^{-1}$.

Table 3. Radial velocity results (km s$^{-1}$).

| TWA # | Other names | N$_{\text{obs}}$ | Mean RV (CfA) | Mean RV (Other) | Remarks |
|-------|-------------|----------------|---------------|----------------|---------|
| 1     | HIP 48273   | 112            | +16.249 $\pm$ 0.071 |                  | Binary (orbit) |
| 2     | TYC 6604-0118-1 | 34          | +26.96 $\pm$ 0.24 |                  | Binary (orbit) |
| 3     | HIP 50796   | 2              | +13.1 $\pm$ 1.0  |                  |         |
| 4     | HIP 53486   | 6              | +5.54 $\pm$ 0.29  |                  |         |
| 5     | RXJ1100.0$-$3813 | 18          | +2.03 $\pm$ 0.92  |                  | Binary (orbit) |
| 6     | HD 95490    | 4              | $-7.51 \pm 0.17$ |                  |         |
| 7     | TWA-1       | 5              | +12.92 $\pm$ 0.23 | +13.5 $\pm$ 1.5  |         |
| 8     | TWA-2A      | CD$-29^\circ8887A$ | 6          | +11.20 $\pm$ 0.32 | +12 |         |
| 9     | RXJ1109.7$-$3907 | 7          | $-1.2 \pm 1.1$ | $-2.0 \pm 1.1$ | VAR? |
| 10    | TWA-3A      | Hen 3-600A    | 14            | +6.9 $\pm$ 1.7 | +14 Double-lined? |
| 11    | HD 97131    | 37             | $-27.10 \pm 0.26$ |                  | Triple (orbit) |
| 12    | CD$-37^\circ7097$ | 3            | $-8.19 \pm 0.26$ |                  |         |
| 13    | RXJ1115.1$-$3233 | 11          | $-10.0 \pm 1.1$ |                  |         |
| 14    | TWA-12      | RXJ1121.1$-$3845 | 2          | +12.23 $\pm$ 0.60 | +10.9 $\pm$ 1.1 |         |
| 15    | TWA-13A     | RXJ1121.3$-$3447N | 4          | +11.72 $\pm$ 0.61 | +10.5 $\pm$ 1.2 |         |
| 16    | TWA-13B     | RXJ1121.3$-$3447S | 4          | +12.41 $\pm$ 0.48 | +12.0 $\pm$ 1.2 |         |
| 17    | TWA-4A      | HD 98800A     | 152          | +12.75 $\pm$ 0.10 |                  | Binary (orbit) |
| 18    | TWA-4B      | HD 98800B     | 152          | +5.73 $\pm$ 0.14 |                  |         |
| 19    | TWA-5A      | CD$-33^\circ7795A$ | 26          | +6.9 $\pm 2.0$ | +14 Double-lined? |
| 20    | TWA-9A      | CD$-36^\circ7429A$ | 10          | +10.17 $\pm$ 0.36 |                  |         |

Though it is tempting to assign this mean radial velocity to the group as a whole, and to then use it as a criterion to accept or reject other candidate members, reality is more complex and various kinematical studies have shown that there is probably a gradient in the radial velocity across the large sky area covered by this association (several tens of degrees). One of such studies, by Makarov & Fabricius (2001), has modeled the kinematics of the association as a moving group using a variant of the convergent-point method. The authors used proper motions from the Tycho-2 catalogue along with Hipparcos parallaxes for the few members which have them, and searched an area of more than 3000 deg$^2$ for additional members with the same motion that are also X-ray sources from the ROSAT Bright Source Catalog. For each star they computed a “kinematical” distance as well as the predicted radial velocity. Comparing the latter with the few measurements available to the authors from the literature for the classical members, they found it necessary to include an expansion term in their model, which not only is not unexpected for this group, but also gives a dynamical age of 8.3 Myr, in good agreement with other estimates from pre-main sequence evolutionary tracks ($\sim 10$ Myr). The internal velocity dispersion they derived is 0.8 km s$^{-1}$, and the depth of the group is significant (tens of parsecs).
Makarov & Fabricius (2001) produced a list of 23 additional candidates, of which we have observed several (see Table 4). Our radial velocity measurements allow us to test these objects for membership. The known members of the association (designation in column 2) have radial velocities ($RV_{\text{obs}}$) very close to the predicted values ($RV_{\text{pred}}$) in most cases, but two of the other stars (HIP 48273 and TYC 6604-0118-1), which happen to be double-lined binaries, do not. On the other hand, the velocity for HIP 50796 agrees perfectly with the prediction. HIP 53486 is an especially interesting case because it is the nearest candidate member (17 pc), and its predicted distance ($D_{\text{kin}}$) agrees with the value measured by Hipparcos ($D_{\text{trig}}$). It has the lowest expected radial velocity ($+3.7$ km s$^{-1}$), and we do indeed measure a low value ($+5.5$ km s$^{-1}$). Further evidence that some of these new candidates may be true members is given by the fact that, unbeknownst to Makarov & Fabricius, one of their stars (HIP 57524, too faint for us and not shown in Table 4) is actually TW A-19, which is Li-rich. Follow-up observations of all these candidate are necessary to establish their youth, and our colleagues at this Workshop are encouraged to do so.

Table 4. Candidate members from the kinematical study by Makarov & Fabricius (2001) with measured RVs from our work.

| Name       | TWA # (2000) | R.A. Dec. (2000) | $\mu$ (mas/yr) | $D_{\text{trig}}$ (pc) | $D_{\text{kin}}$ (pc) | $RV_{\text{pred}}$ (km s$^{-1}$) | $RV_{\text{obs}}$ (km s$^{-1}$) |
|------------|--------------|-----------------|---------------|-------------------|-------------------|------------------------|------------------------|
| HIP 53911  | 1            | 11:01:51.9 -34:42:17 | 75.4          | 56.4              | 57.1              | +12.7                  | +12.9                  |
| TYC 7201-0027-1 | 2        | 11:09:13.8 -30:01:40 | 92.6          | 47.1              | +10.6             | +11.2                  |
| HIP 55505  | 4            | 11:22:05.3 -24:46:40 | 96.8          | 45.7              | +9.1              | +9.2                   |
| TYC 7223-0275-1 | 5        | 11:31:55.3 -34:36:28 | 86.7          | 50.9              | +10.0             | +6.9                   |
| HIP 57589  | 9            | 11:48:24.2 -37:28:49 | 158.1         | 50.3              | 76.3              | +12.6                  | +10.2                  |
| HIP 48273  | 09:50:30.1   | +04:20:37         | 157.9         | 45.9              | 26.6              | +10.7                  | +16.2                  |
| TYC 6604-0118-1 | 09:59:08.4 | -22:39:35         | 168.7         | 62.8              | +16.5             | +27.0                  |
| HIP 50796  | 10:22:18.0   | -10:32:16         | 179.1         | 34.0              | 53.8              | +13.1                  | +13.1                  |
| HIP 53486  | 10:56:30.8   | +07:23:18         | 268.1         | 17.6              | 16.7              | +3.7                   | +5.5                   |

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