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A DISK CENSUS FOR THE NEAREST GROUP OF YOUNG STARS: MID-INFRARED OBSERVATIONS OF THE TW HYDRAE ASSOCIATION

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ABSTRACT

A group of young, active stars in the vicinity of TW Hydrae has recently been identified as a possible physical association with a common origin. Given its proximity (∼50 pc), age (∼10 Myr), and abundance of binary systems, the TW Hya association is ideally suited to studies of the diversity and evolution of circumstellar disks. Here we present mid-infrared observations of 15 candidate members of the group, 11 of which have no previous flux measurements at wavelengths longer than 2 μm. We report the discovery of a possible 10 μm excess in CD −33°7795, which may be due to a circumstellar disk or a faint and as yet undetected binary companion. Of the other stars, only TW Hya, HD 98800, Hen 3-600A, and HR 4796A—all of which were detected by *IRAS*—show excess thermal emission. Our 10 μm flux measurements for the remaining members of the association are consistent with photospheric emission, allowing us to rule out dusty inner disks. In light of these findings, we discuss the origin and age of the TW Hya association as well as the implications for disk evolution timescales.

Subject headings: accretion, accretion disks — binaries: general — circumstellar matter — open clusters and associations: individual (TW Hydrae) — stars: pre–main-sequence

1. INTRODUCTION

Circumstellar disks appear to be a natural consequence of the star formation process. Observations of young pre–main-sequence stars show that many of them are surrounded by optically thick disks of solar system dimension with masses comparable to or greater than the "minimum-mass solar nebula" of 0.01 $M_\odot$ (see Beckwith 1999 for a review). Infrared emission in excess of stellar photospheric fluxes provides the most readily measurable signature of such disks. Excesses at $\lambda \leq 10$ μm are found in ∼50% of the low-mass stars in star-forming regions (Strom, Edwards, & Skrutskie 1993).

It has been suggested that circumstellar disks evolve from optically thick to optically thin structures in about 10 Myr (Strom et al. 1993). That transition may mark the assembly of grains into planetesimals or the clearing of the disk by planets. Indeed, low-mass debris disks have now been imaged around several main-sequence stars with ages ranging from 10 Myr to 1 Gyr (Jayawardhana et al. 1998; Holland et al. 1998; Greaves et al. 1998; Koerner et al. 1998; Trilling & Brown 1998). However, age estimates for early-type isolated main-sequence stars are highly uncertain. Therefore, the timescale for disk evolution and planet formation is still poorly constrained and may depend critically on the presence or absence of a close binary companion.

The recent discovery of a group of young stars associated with TW Hydrae offers a unique laboratory to study disk evolution and planet formation. TW Hya itself was first identified as an "isolated" T Tauri star by Rucinski & Krautter (1983). Subsequent searches by de la Reza et al. (1989) and Gregorio-Hetem et al. (1992) found four other young stars in the vicinity of TW Hya, and they have suggested that the stars may be associated kinematically. On the basis of strong X-ray emission from all five systems, Kastner et al. (1997) concluded that the group forms a physical association at a distance of ∼50 pc with an age of 20 ± 10 Myr (see Jensen, Cohen, & Neuhäuser 1998 for a different point of view). Webb et al. (1999) have identified five more T Tauri star systems in the same region of the sky as candidate members of the "TW Hya association" (TWA), based on the same signatures of youth—namely, high X-ray flux, large Li abundance, and strong chromospheric activity—and the same proper motion as the original five members. Furthermore, they suggest that the wide binary HR 4796, which contains an A0 V star, is also part of the association, even though its *Hipparcos* parallactic distance of 67 pc places it farther away than most other members of the group. The three other TWA stars with *Hipparcos* distances—TW Hya, HD 98800, and TWA 9—are at 56, 47, and 50 pc, respectively.

Being the nearest group of young stars, the TW Hya association is ideally suited for sensitive disk searches in the mid-infrared. Furthermore, its estimated age of ∼10 Myr provides a strong constraint on disk evolution timescales and fills a significant gap in the age sequence between the ∼1 Myr old T Tauri stars in molecular clouds, like Taurus-Auriga and Chamaeleon, and the ∼50 Myr old open clusters, such as IC 2602 and IC 2391.

Over the past 2 years, we have conducted mid-infrared observations of the candidate TWA stars. Our discovery of a spatially resolved disk around HR 4796A and our high-resolution observations of the close binary Hen 3-600 have already been reported (Jayawardhana et al. 1998, 1999). Here we present observations of the other members of the group, including the discovery of a possible 10 μm excess in CD −33°7795, and discuss implications for the origin and age of the TW Hya association as well as for disk evolution timescales.

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TABLE 1
LOG OF OBSERVATIONS

UT Date	Telescope	Target	Filter	On-Source Integration (s)	Flux Standards
1998 Mar 18	CTIO 4 m	CD −29°8887	*N*	600	λ Vel, γ Cru
	CTIO 4 m	CD −33°7795	*N*	600	λ Vel, γ Cru
	CTIO 4 m	HR 4796A, B	*N*	1800	λ Vel, γ Cru
	CTIO 4 m	HR 4796A, B	IHW18	1800	λ Vel, γ Cru
1999 Feb 23	CTIO 4 m	TW Hya	*N*	600	λ Vel, γ Cru
	CTIO 4 m	TW Hya	IHW18	1200	λ Vel, γ Cru
	CTIO 4 m	Hen 3-600A, B	*N*	600	λ Vel, γ Cru
	CTIO 4 m	Hen 3-600A, B	IHW18	600	λ Vel, γ Cru
1999 Feb 26	CTIO 4 m	TWA 7	*N*	400	γ Cru, α CMa
1999 May 2	Keck II	TWA 8A	*N*	85	μ UMa, α Boo
	Keck II	TWA 8B	*N*	300	μ UMa, α Boo
	Keck II	TWA 10	*N*	300	μ UMa, α Boo
1999 May 3	Keck II	CD −29°8887	*N*	150	μ UMa, α Boo
	Keck II	TWA 6	*N*	300	μ UMa, α Boo
	Keck II	TWA 9A, B	*N*	600	μ UMa, α Boo
	Keck II	HR 4796B	*N*	150	μ UMa, α Boo

2. OBSERVATIONS

During three observing runs in 1998 and 1999, we have obtained mid-infrared images of candidate members of the TW Hya association using the OSCIR instrument on the 4 m Blanco telescope at the Cerro Tololo Inter-American Observatory (CTIO) and the 10 m Keck II telescope. The log of our observations is given in Table 1. OSCIR is a mid-infrared imager/spectrometer built at the University of Florida, using a 128 × 128 Si : As blocked impurity band detector developed by Boeing.[5]

On the CTIO 4 m telescope, OSCIR has a plate scale of 0″.183 pixel^{-1}, which gives a field of view of 23″ × 23″. Our observations were made using the standard chop/nod technique, with a chop frequency of 5 Hz and a throw of 23″ in declination. On Keck II, its plate scale is 0″.062 pixel^{-1}, providing a 7″.9 × 7″.9 field of view. Here we used a chop frequency of 4 Hz and a throw of 8″. Images were obtained in the *N* (10.8 μm) band for the entire sample and in the IHW18 (18.2 μm) band for a few bright targets.

[5] Additional information on OSCIR is available on the Internet at www.astro.ufl.edu/iag/, which is maintained at the University of Florida Infrared Astrophysics Laboratory and NASA/MSFC by R. S. Fisher and K. Hanna.

3. RESULTS

In Table 2, we present the measured 10 μm fluxes for the entire sample and compare them with the expected photospheric fluxes, assuming $K-N = 0$ for all late-type stars. For HR 4796A, we used $K-N = -0.03$, as given by Kenyon & Hartmann (1995) for an A0 V star.

Among the candidate TWA stars, only TW Hya, HD 98800, Hen 3-600A, and HR 4796A—all of which were first detected by *IRAS*—show significant excess at mid-infrared wavelengths. We have detected a modest 10 μm excess in CD −33°7795 for the first time (see below). None of the other late-type stars have excess, suggesting that they do not harbor dusty inner disks.

Comments on individual objects are as follows:

TW Hydrae.—The spectral energy distribution (SED) of TW Hya from near- to far-infrared wavelengths, including our flux measurements at 10.8 and 18.2 μm, is shown in Figure 1*a*. The excess at λ ≥ 20 μm is unusually strong compared with the

TABLE 2
N-BAND FLUX MEASUREMENTS

TWA Number	Common Name	Spectral Type	Photospheric *N* (mJy)	Measured *N* (mJy)	Source
1	TW Hya	K7	43	580 ± 58	CTIO
2A	CD −29°8887	M0.5	50	49 ± 2	Keck/CTIO[a]
2B	...	M2	24	31 ± 4	Keck/CTIO[a]
3A	Hen 3-600A	M3	46	900 ± 90	CTIO
3B	Hen 3-600B	M3.5	29	<50	CTIO
4	HD 98800	K5	208	1400 ± 70	Gehrz et al. 1999
5A	CD −33°7795	M1.5	70	96 ± 9	CTIO
6	...	K7	24	22 ± 2	Keck
7	...	M1	66	62 ± 6	CTIO
8A	...	M2	40	41 ± 2	Keck
8B	...	M5	9	10 ± 2	Keck
9A	CD −36°7429	K5	31	26 ± 2	Keck
9B	...	M1	8	5 ± 2	Keck
10	...	M2.5	20	24 ± 2	Keck
11A	HR 4796A	A0	176	244 ± 25	CTIO
11B	HR 4796B	M2.5	17	16 ± 2	Keck/CTIO[b]

[a] This 0″.6 binary was not resolved at CTIO. However, the total flux that we measured at CTIO (82 ± 8 mJy) agrees extremely well with the sum of fluxes measured at Keck (80 mJy).
[b] Our Keck flux measurement of 16 ± 2 mJy is consistent with the CTIO upper limit of 23 mJy.

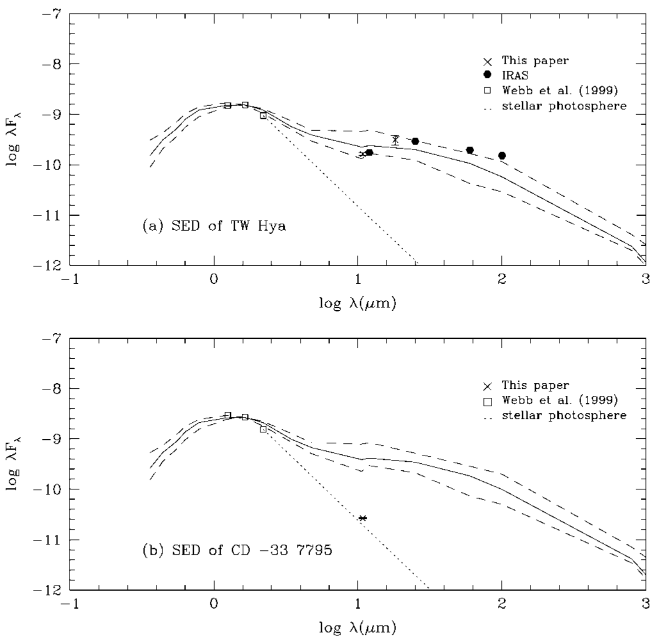

FIG. 1.—Composite SED of (*a*) TW Hydrae and (*b*) CD −33°7795. The solid line in each plot is the median SED for a Taurus CTTS, normalized at *H* (from D'Alessio et al. 1999), and the dashed lines show the quartile fluxes, to provide some idea of the range of observed CTTS fluxes.

median of classical T Tauri stars (CTTSs) in Taurus (*solid line*, Fig. 1*a*). It is worth noting that TW Hya also has a large Hα equivalent width of −220 Å, consistent with an actively accreting disk.

CD −33°7795.—We measure a 10 μm flux of 96 ± 9 mJy for CD −33°7795, which is somewhat above its estimated photospheric emission of 70 ± 5 mJy. This modest excess, at a level of 2.6 σ, is well below what is expected for an optically thick inner disk (Fig. 1*b*). One possibility is that our assumption $K-N = 0$ is not correct; if $K-N \sim 0.3$, there would be no 10 μm excess. However, we note that using $K-N = 0$ is in good agreement with measured fluxes for other stars of similar spectral type in the sample.

If the excess is real, it could be due to an optically thin disk or a faint and as yet undetected stellar companion. We note that CD −33°7795 may be a spectroscopic binary according to Webb et al. (1999). Furthermore, Lowrance et al. (1999) have reported the discovery of a possible brown dwarf companion 2″, or ∼100 AU, from CD −33°7795. Our 10 μm flux measurement is within an aperture of 1″ radius (seeing is ≈0″.7) and thus should not include a contribution from this brown dwarf. In any case, to account for the observed 10 μm excess, the brown dwarf ($K = 11.5$) would have to have $K-N = 3.6$!

HR 4796B.—We placed an upper limit of 23 mJy on the 10 μm emission from HR 4796B from CTIO data and have now detected its photosphere at 16 ± 2 mJy at Keck. This result is of particular interest because the age of HR 4796B is fairly well established. Using the *Hipparcos* distance of 67 pc to HR 4796A and the evolutionary tracks of D'Antona & Mazzitelli (1994), it is possible to estimate an age of 8 ± 3 Myr for HR 4796B, which is an M2.5 star (Jayawardhana et al. 1998). This age is consistent with the upper bound provided by the measurement of the strong Li absorption line at 6708 Å (Stauffer, Hartmann, & Barrado y Navascues 1995). The lack of 10 μm excess in this object suggests that HR 4796B does not have a dusty inner disk. Unfortunately, we cannot determine at present whether it originally had an optically thick disk, which has since depleted, or whether it formed without a disk (like some 50% of T Tauri stars appear to do). If future far-infrared and submillimeter observations find evidence for an outer disk around HR 4796B, that would argue for rapid evolution of the inner disk, either through coagulation of dust or through accretion onto the central star.

4. DISCUSSION

4.1. *Origin and Age of the TW Hya Association*

Whether the TWA stars are physically related in origin is a matter of controversy. Kastner et al. (1997) and Webb et al. (1999) argue that this is an unusual grouping of relatively young (10 Myr old) stars that is unlikely to be a chance coincidence, while Jensen et al. (1998) argue that the proper motions of three primary members—TW Hya, HD 98800, and CD −36°7429—are inconsistent with them having formed together 10 Myr ago. Confusing the issue further, TW Hya has all the characteristics of an actively accreting T Tauri star (Rucinski & Krautter 1983; de la Reza et al. 1989; Gregorio-Hetem et al. 1992), typical of much younger systems (ages of <3 Myr), while most of the other members show weak or no Hα emission (Kastner et al. 1997; Webb et al. 1999) and, as we have shown here, little or no infrared excess emission from dusty disks.

Our data do not bear directly on the question of the physical connection between the stars in this association, but a few comments can be made about membership determinations. The first question to be addressed is whether the TWA members really constitute a special and unlikely concentration of objects. Webb et al. (1999) argue for this conclusion, based on three points: first, essentially that there are few or no CTTSs known outside of clouds; second, that X-ray surveys do not show similar numbers of 10 Myr old stars; and third, that there is no evidence for 10–100 Myr old populations in the solar neighborhood. The first argument is not very strong because there is only one bona fide CTTS in the TW Hya group, and so statistics are poor. The third argument appears to be inconsistent with the results of Briceño et al. (1997), who show that many of the X-ray–bright low-mass stars in the *ROSAT* All-Sky Survey (RASS) have ages of 50–100 Myr. The second argument also has problems; as Martín & Magazzù (1999) show from a study of Li equivalent widths in RASS-selected stars in the direction of Taurus, while most of the systems are likely to be 50–100 Myr old, a modest fraction (∼20%) of these objects may indeed be ∼10 Myr old.

Another way to address the question of the overdensity is to use estimates of the expected average birthrate in the solar neighborhood. Using the results of Miller & Scalo (1979) for a constant birthrate and the age parameter $T_0 = 12 \times 10^9$ yr, and their form for the initial mass function, we predict that the number of stars formed per year between 0.8 and 0.3 $M_\odot$ in the solar neighborhood is $\sim 2.1 \times 10^{-9}$ stars yr^{-1} pc^{-2}. Thus, within a radius of 75 pc from the Sun, there should be approximately 370 stars with ages ≤10 Myr. If these stars were distributed uniformly across the sky within a band of ±45° from the Galactic equator (i.e., an effective scale height of approximately 70 pc), the surface density of such objects would then be $\sim 1.3 \times 10^{-2}$ stars deg^{-2}. The main body of the TW Hya association identified by Webb et al. (1999) spans a range of 13° in declination by about 19° in right ascension. Thus, in these 245 deg^2, one should expect on average 3.1 stars in the 1–10 Myr age range, whereas Webb et al. identify 11 such objects. If one includes HR 4796 and TWA 10, as suggested by Webb et al., the total number of observed objects increases to 14, but the number of predicted, randomly distributed objects in the larger 17° × 28° region also goes up to 6.

Thus, while the above calculations suggest that the TW Hya association is *probably* a significant enhancement in the local density of young stars, the possibility that this is a chance alignment cannot be completely ruled out. The predicted average density depends on parameter choices that are not certain, such as the precise volume that is being sampled and the actual ages of the stars (changes of a factor of 2 in these properties strongly affect the apparent significance of the grouping). While it is probably not appropriate to use an averaged birthrate for such young stars, note that for typical space velocities of ∼5 km s^{-1} (Hoff, Henning, & Pfau 1998), groups of ages 10–20 Myr can overlap if they originated 50–100 pc apart.

Regardless of the physical association of these objects (which really only is used to support the application of the *Hipparcos* distances of the main objects to all suggested members), the lack of Li depletion indicates that these stars cannot be much older than ∼10 Myr. Whatever molecular cloud(s) these stars formed in, the absence of relatively nearby molecular gas is most easily explained if the natal clouds disperse in ≲10 Myr (Hoff et al. 1998), consistent with the general absence of 3–10 Myr old stars in molecular clouds such as Taurus-Auriga (e.g., Briceño et al. 1997), rather than by requiring very high space velocities to move stars from present-day clouds (Soderblom et al. 1998).

4.2. *Implications for Disk Evolution Timescales*

Our mid-infrared observations show that many of the stars in the TW Hya association have little or no disk emission at 10 μm. Even among the five stellar systems with 10 μm excesses, most show some evidence of inner-disk evolution. The disk around the A0 star HR 4796A has an $r \approx 60$ AU central hole in mid-infrared images (Jayawardhana et al. 1998; Koerner et al. 1998). The SEDs of HD 98800 and Hen 3-600A also suggest possible inner-disk holes (Jayawardhana et al. 1999). The excess that we report here for CD −33°7795 is modest and could well be due to a faint companion. Only TW Hya appears to harbor an optically thick, actively accreting disk of the kind observed in ∼1 Myr old CTTSs; it is the only one with a large Hα equivalent width (−220 Å). It would be of great interest to constrain further TW Hya's SED with flux measurements at wavelengths between 2 and 10 μm.

If most TWA stars are ≲10 Myr old, the above results suggest that their inner disks have already depleted either through coagulation of dust or through accretion onto the central star. The fact that only one (TW Hya) out of 16 entries in Table 2 shows classical T Tauri characteristics—compared with ∼50% of the ∼1 Myr old stars in star-forming regions—argues for rapid evolution of inner disks in pre–main-sequence stars. Observations at far-infrared and submillimeter wavelengths may reveal whether most TWA stars still retain their outer disks. These stars are also ideal targets for sensitive brown dwarf and planet searches with the *Space Interferometry Mission* and the proposed Terrestrial Planet Finder.

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