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Finding Brown Dwarf Companions with HST/NICMOS

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Abstract. We present the results of a HST/NICMOS coronagraphic survey for the direct detection of substellar companions within the young TW Hydrae and Tucana Associations. At the distance of these associations, the lower mass limit of detection, based on models, is well into the high mass planet region for separations > 30 AU. Results presented here include spectra and proper motion verification of two brown dwarf companions located 100 AU and 180 AU from their primaries. We also present a possible exo-solar giant planet candidate located 125 AU from TWA 6. These few examples demonstrate that the young associations remain fertile ground for discovery and environmental study of planetary systems.

1. Introduction

In the last few decades, a primary goal of observational astronomy has been to gain more insight into stellar and planetary formation. Brown dwarfs occupy the niche in the mass range between stars and planets. They form like stars, but do not have enough mass to sustain hydrogen fusion. The observational distinctions between a planet and brown dwarf have yet to be constructed. Unfortunately, until just a few years ago, no unambiguous brown dwarfs were known.

Substellar objects cool indefinitely because they do not sustain hydrogen fusion and thus become fainter and more difficult to detect at older ages (c.f. Burrows et al. 1997). Therefore, the young 10–40 Myr associations such as TW Hydrae and Tucana represent excellent targets for a search for brown dwarfs and massive planetary companions.

As part of a larger coronagraphic survey program (Lowrance et al. 2001), we surveyed 5 of the members of the TW Hydrae Association, including TWA 1, 5, 6, 7, 8B, and 10 as well as 2 members of the Tucana Association for possible brown dwarf companions, low-mass stellar companions, and dust debris disks

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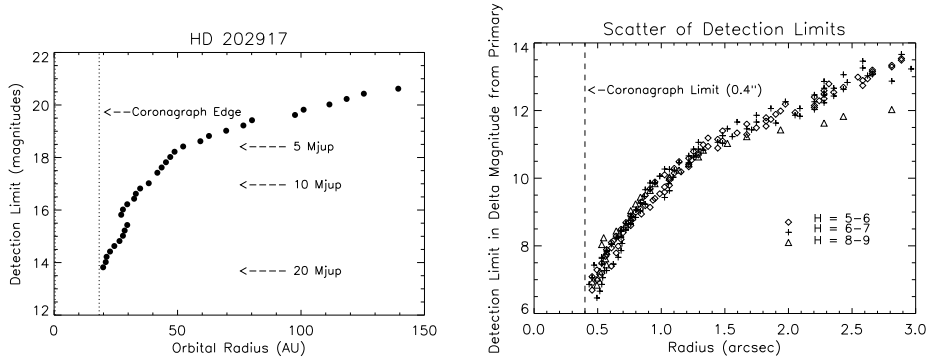


Figure 1. Detection limits for point sources around one primary, HD 202917, (*left*) and overall (*right*) in the survey. Masses associated with absolute magnitudes are derived from models (Burrows, A. pers comm).

(see Schneider et al. (2001); this volume). TWA 8A was included in another NICMOS imaging survey (Weintraub et al. 2000). All other TWA members from Webb et al. (1999) were close multiple systems and we did not observe these since other close companions can presumably be ruled out on dynamical grounds.

2. Using the coronagraph aboard NICMOS

The main problem with trying to image brown dwarfs or giant planets around main-sequence stars is the overwhelming brightness of the primary. A substellar companion will be much fainter than the star it orbits (i.e. a G1 229B-like object, $L=2\times 10^{-5}L_{\odot}$, orbiting a solar-like star of $1L_{\odot}$). The cool brown dwarf makes up a little of this in the infrared, where it radiates most of its power, and is brighter with youth, but the primary is still much brighter.

To facilitate the removal of background light from the primary near the coronagraphic hole, we designed pairs of observations with different spacecraft orientations ($\delta\theta = 29.9$) which could then be subtracted from one another to cancel scattered light. Each observation was about 800s long split into 3 Multi-Accum (non-destructive read) sets (see Lowrance et al. 1999).

In Figure 1, we plot the detection limits for the example of HD 202917 (*left*) and the limits overall (*right*) in the observations found from planting and recovering PSF stars in the images. At $1''$, we can detect a delta magnitude of 9.5 mag for all stars. For stars in the Tucana and TW Hya associations, the average primary is $H = 7$ mag, and our average limit corresponds to $M_H = 13.6$ mag at 50 AU (median distance is 50 pc). As these stars are very young (10–40 Myr), the detection limit is $\sim 5M_{Jupiter}$, based on the models of Burrows (pers comm). Even at $0.5''$, we can detect a delta magnitude of 6–8 mag, a full 2–4 mag better than most speckle imaging programs.

In Table 1 we present the results of the coronagraphic survey. ‘Stellar-like’ candidates are those that have a FWHM between 0.14 and $0.18''$, the brighter of which show an Airy diffraction pattern. The high resolution of the observations

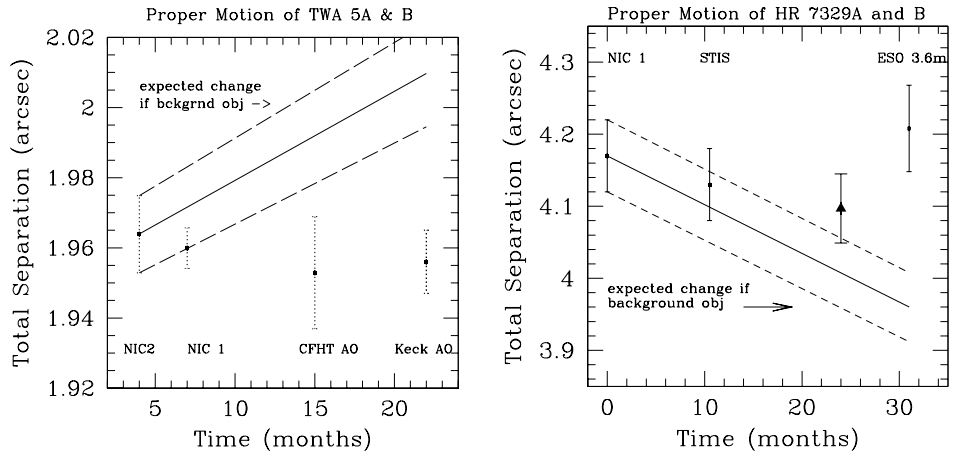


Figure 2. Measured separations of TWA 5A & B (*left*) and HR 7329A & B (*right*) over the last two and a half years. The dashed lines represent the change in separation expected if the candidate brown dwarf, B, is a stationary object in the background based on the measured proper motion (and error) of the primary.

makes it easy to distinguish between stars and diffuse background galaxies. All of the candidate companions have been re-observed with adaptive optics to confirm companionship and their possible substellar nature.

Table 1. Point Sources observed around TWA and Tucana stars

Star	Primary	<—	Secondary	—>	Results
	Sp Type	Sep (")	ΔH mag	Follow-up	
TWA 1	K7	none	—	—	—
TWA 5	M3	1.96	4.9	AO, STIS	brown dwarf
TWA 6	K7	2.54	13.1	NICMOS, AO	inconclusive
TWA 7	M4	2.47	9.6	NICMOS, AO	background
TWA 8B	M3	none	—	—	—
TWA 10	M3	none	—	—	—
HR 7329	A0	4.17	6.9	AO, STIS	brown dwarf
HD 202917	G5	none	—	—	—

3. Brown Dwarf Companions

3.1. Astrometry

The TWA 5 system was observed several times in the last two years – with NIC 1 (Weintraub et al. 2000) and with the AO systems on the Canada-France-Hawaii telescope (CFHT) and the 10-m W.M. Keck II telescope (Figure 3(a)). The HR 7329 system was observed with the Space Telescope Imaging Spectrograph (STIS) instrument and using the AO system on the 3.6m ESO telescope. We

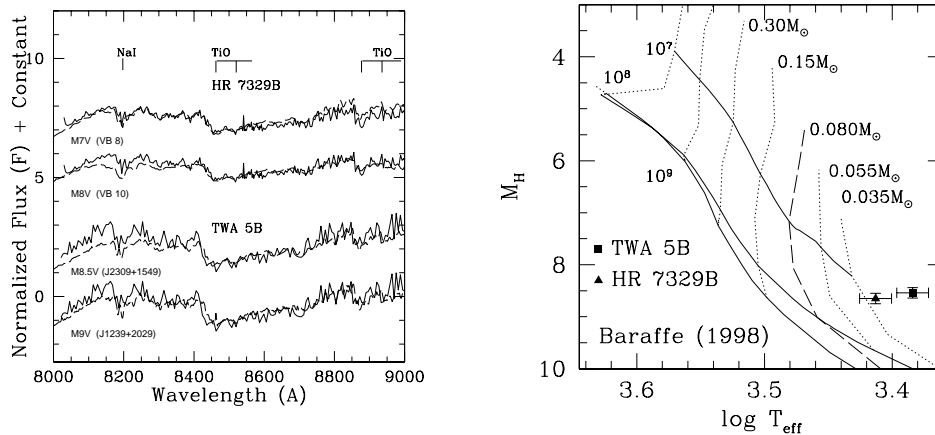


Figure 3. STIS spectra (*left*) of TWA 5B and HR 7329B compared with template late M-dwarf spectra. (*right*) The location of these two objects on theoretical evolutionary diagrams.

also include the measurement of HR 7329 from Guenther et al. (2000) as the triangle in Figure 3(b). From these observations, we plot the change in measured separation of the A and B components at each epoch and compare them with the expected change in separation for a background object. We conclude both TWA 5B and HR 7329B are true proper motion companions to their primaries.

3.2. STIS spectra

The companions to TWA 5A and HR 7329B were placed in the slit of the STIS by centering the primary and offsetting to the companion by the NICMOS-measured astrometry (Lowrance et al. 1999, Lowrance et al. 2000). Spectral imaging sequences were completed in one orbit with the G750M grating. The STIS spectra of TWA 5B and HR 7329B were fit to template M dwarf spectra (Figure 2), and classified as $M9 \pm 0.5$ for TWA 5B and $M7.5 \pm 0.5$ for HR 7329B. For TWA 5B, this is consistent with the photometric spectral type of M8-M8.5V derived by Lowrance et al. (1999) and more recent results by Neuhauser et al. (2000).

Using the temperatures derived from the spectral types and absolute H magnitudes which assume the same distance as the primary, we place these two objects on evolutionary diagrams of Baraffe et al. (1998) (Figure 2(b)). TWA 5B is consistent with a $20 M_{Jupiter}$ object at an age of 10 Myr old, which is the approximate age of the TW Hydra Association. HR 7329B is consistent with a $40 M_{Jupiter}$ object at an age of 30-40 Myr, the approximate age of the Tucana Association.

4. TWA 6B - giant planet candidate

A point-source was discovered at a separation of $2.549'' \pm 0.011$, and a position angle of $-278.7^\circ \pm 0.2$ from TWA 6 (TWA 6A). The H magnitude of TWA 6B

is 19.93 ± 0.08 mag. The field of TWA 6 was reobserved with the NICMOS 1 camera with a medium-band F090M filter (central wavelength: $0.9003 \mu\text{m}$, $\Delta\lambda = 0.1885 \mu\text{m}$) and TWA 6B was not detected. We derive an upper limit (3σ) to the flux of [F090M]=22.6 mag in the predicted position from the NICMOS images. Using low-temperature models to transform between F090M and I-band, we calculate an upper limit of $I-H > 3.3$ for the candidate companion. The color is equivalent to a spectral type later than M7V (Kirkpatrick & McCarthy 1994), so we conclude that the object is very red, even if it is not associated with TWA 6A. A background K giant would have an $I-H < 2$ mag, which would have been easily detected in the NIC 1 images. If associated with TWA 6A at 50 pc, this object would have an absolute magnitude, $M_H = 15.8$, which corresponds to a $\sim 2M_{Jupiter}$ object at 125AU (Burrows, A. pers comm).

Re-observations of TWA 6 are underway with the Keck AO system (Macintosh et al, this volume). Such astrometric measures are difficult with the current two year baseline, but high resolution observations are needed to establish if TWA 6B is a young Jovian planet.

5. Conclusions

With the NICMOS camera and the coronagraph, we have studied the environments of close to half of the young stars of the TW Hydrae Association and two of the Tucana Association. Around four of these stars we found point-like objects which were possible companions. After careful analysis and more observations, we find that TWA 5B is a $\sim 20 M_{Jupiter}$ brown dwarf, HR 7329B is a $\sim 40M_{Jupiter}$ brown dwarf and TWA 7B is a background object. We find no candidate companions around HD 202917, TWA 1, TWA 8B, or TWA 10 greater than a few $M_{Jupiter}$, based on models of giant planets, at $1''$, or 50 AU at the distance of the stars. A faint, point-like object $2.5''$ from TWA 6 remains a mystery, though. It has the potential to be the most significant discovery of this program as the first giant planet imaged around another star.

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