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Keck adaptive optics observations of TW Hydrae Association members

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Abstract. Adaptive optics (AO) on 8-10 m telescopes is an enormously powerful tool for studying young nearby stars. It is especially useful for searching for companions. Using AO on the 10-m W.M. Keck II telescope we have measured the position of the brown dwarf companion to TWA5 and resolved the primary into an $0.055''$ double. Over the next several years follow-up astrometry should permit an accurate determination of the masses of these young stars. We have also re-observed the candidate extrasolar planet TWA6B, but measurements of its motion relative to TWA6A are inconclusive. We are carrying out a search for new planetary or brown dwarf companions to TWA stars and, if current giant planet models are correct, are currently capable of detecting a 1 Jupiter-mass companion at $\sim 1.0''$ and a 5 Jupiter-mass companion at $\sim 0.5''$ around a typical TWA member.

1. Adaptive optics capabilities and limitations

Adaptive optics is a very powerful tool, allowing large ground-based telescopes to reach their diffraction-limited resolutions in the near IR – resolutions of $0.03''$ or better. For some applications, this allows ground-based telescopes to perform as well as or better than the 2.5 m HST. Detection of faint companions is one such application, since by concentrating the light of a companion into a diffraction-limited point, an AO system can enhance the contrast of such a companion by a factor of 100 or more relative to non-AO observations.

Young nearby stars such as those in the TW Hydrae association are an ideal target set for an AO companion search. They are still young enough that planetary-mass companions are detectable (Burrows et al. 1997) and close enough, in comparison to regions such as Taurus, that these companions can be seen at separations of 20-50 AU. TWA members are also generally bright enough at visible wavelengths to give good AO performance even for high-order AO systems such as Keck.

2. Keck adaptive optics

The Keck AO system is described in Wizinowich et al. (2000a and 2000b). The observations discussed here were made with KCam, an interim near-infrared camera provided by UCLA. KCam has a 256×256 pixel NICMOS3 HgCdTe array. Warm magnifying optics provide a plate scale of 0.01747 $''$/pixel. A cold filter wheel selects the standard J, H, and K' bands; an external warm filter wheel holds additional narrowband and neutral density (ND) filters. The latter are required to avoid saturation on any star brighter than $m_H \approx 8$.

3. Observations

We observed several TWA members in February 2000, both to confirm candidate companions from previous NICMOS observations and to search for new substellar companions. Results will be presented in detail in future papers. Here we discuss our observations of TWA5, TWA6, and our sensitivity estimates for new companion detection.

3.1. TWA5

TWA5 was observed to measure the current separation of the brown dwarf TWA5B (Lowrance et al. 1999, Webb et al. 1999). Seven images were taken, each of 10 coadds of 0.62 seconds integration. Two (in which TWA5A saturated) were with a standard H-band filter, five with the H filter plus an ND1 (90% attenuation) filter. A typical image is shown in Figure 1a.

TWA5A The most noteworthy discovery made was that TWA5A is a $\sim 0.06''$ binary (Figure 1b), easily visible in the unsaturated ND-filter images. TWA5A was thought to be a spectroscopic binary (Webb et al. 1999), although no period solution has yet been found (Torres et al. 2001.) Since our detection implies a period of several years, it is likely that the system is further multiple (making, including the brown dwarf, at least a quadruple) and one of the two components we detect is itself a short-period binary.

The pair is close enough to require careful deconvolution to obtain astrometry and photometry. Fortunately the brown dwarf TWA5B is present in all the images (even those taken through the ND filter) and this provides an estimate of the PSF. The data were reduced with the multi-frame blind deconvolution

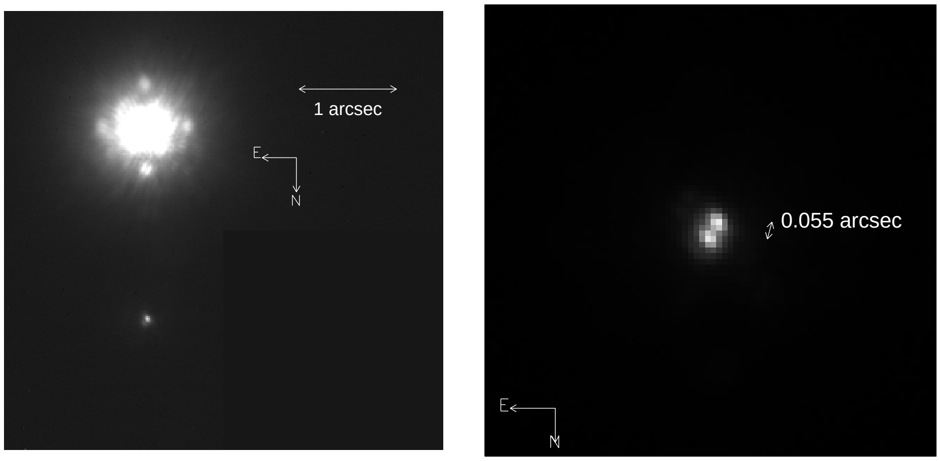

Figure 1. **Left:**Keck AO images of TWA5A (top, highly saturated) and B **Right:** Close-up of TWA5Aa and Ab. Both are 6.25 second H-band images. Right-hand image taken through a ND1 filter.

algorithm, IDAC[1] (Jefferies & Christou, 1993) using the 5 unsaturated images simultaneously and PSF estimates as discussed above. The procedure followed that described in Barnaby et al. (2000) using deconvolution of upsampled data and and gaussian fitting of the results to obtain the photometry and astrometry of the binary. We derive $\Delta H = 0.09 \pm 0.02$ with the brighter component (TWA5Aa) being the southernmost, a separation of 0.0548 ± 0.0005 arcseconds, and a position angle from Aa to Ab of 25.9 ± 0.5 degrees.

TWA5A was unresolved in NICMOS acquisition images obtained on April 25 1998. Although the resolution of NICMOS is less than the Feb. 2000 separation of the pair, this separation would still have been detectable as an elongation of the PSF or in template subtractions. Analysis of the NICMOS images indicates at the 3-sigma confidence level that the separation at this epoch must have been less than $0.025''$, further evidence of a short orbital period. Given the presence of TWA5B to serve as an absolute astrometric reference, and the possibility of obtaining resolved spectra with adaptive optics systems, an unambiguous mass solution should be obtainable for TWA5A over the next several years. This in turn can be compared to PMS evolution models to validate evoluationary tracks. Such comparison will also better constrain the age of the system, and in turn the new age can be used for a mass determination of TWA5B.

TWA5B The brown dwarf TWA5B was easily detected, even in images taken with the neutral density filter. We measured a separation between it and the photocenter of the TWA5A pair of 1.956 ± 0.012 arcseconds, with the uncertainties being dominated by the distortions mentioned below. This indicates very little change since the measured NICMOS value of 1.9639 ± 0.011 arcseconds in

[1]http://babcock.ucsd.edu/cfao_ucsd/idac/idac_package/idac_index.html

Lowrance et al. 1999. TWA5B is further discussed in Lowrance et al. (2001) in this volume.

3.2. TWA6

The most interesting candidate companion discovered during the NICMOS Environments of Nearby Stars (EONS) survey was the object which we will tentatively designate TWA6B. This is a $m_H = 20$ companion $2.5''$ from the TWA member TWA6, discussed in Lowrance et al. 2001 in this volume.

On Feb 21 2000 we took a series of images of TWA6 with Keck AO. Short-exposure images were taken with the ND filter to acquire and align TWA6 itself and then without the ND filter to search for the companion. TWA6B was detected in each of four 120 second H-band exposures.

We used these to measure the change in separation between TWA6B and TWA6A. The NICMOS measurement on 20 May 1998 was 2.549 ± 0.011 arcseconds. TWA6 has a proper motion from Tycho 2 of 57.0 ± 3.0 mas/year west and 20.6 ± 2.8 mas/year south, almost directly towards TWA6B, so the primary effect of its motion if TWA6B is a background object should be to decrease the separation to 2.459 ± 0.012 arcseconds . Since the orientation of our Keck images is influenced by uncertainty in the position of the image derotator used, we will only discuss measurements of the separation here.

Unfortunately, TWA6A is of course saturated in the long exposure non-ND images while TWA6B is undetectable in the unsaturated images. The neutral density filters, however, induce a position shift in the image of a star; this position shift was measured once later in the night using an intermediate-brightness star, but it is unknown if this shift varies due to small changes in the position of the filter as it is moved in and out. Including the estimated shift, we measure a separation between TWA6 and TWA6B of 144.1 ± 0.5 pixels.

The plate scale of the camera was determined through measurements of the Hipparcos binaries HIP51802, HIP50223, HIP52913 and HIP48618. The derived plate scale is 0.01747 ± 0.00006 arcseconds per pixel. Astrometric calibration will be discussed in detail in a seperate paper. Unfortunately, the data available are insufficient to measure any distortions inherent in the camera's optics or due to the ND filter. The TWA5B measurement discussed above is in good agreement with previous measurements, and the scatter between different HIP stars is consistent with the uncertainties in their positions, indicating that distortions are small, but the ND filter effects are unknown.

This leads to a separation in February 2000 of 2.517 ± 0.012 arcseconds. This is two sigma away from the measured NICMOS position and approximately 3 sigma away from the position of a background star - still inconclusive. (Figure 2.) Two additional measurements made in April 2000, with somewhat greater uncertainties, are closer to the background star position but also inconclusive. The February and April measurements disagree enough to indicate that an unmodeled source of error - almost certainly uncertainties in the displacement due to the ND filter - is present. Measurements made in February 2001, with a better camera and a longer time baseline, should determine the true nature of TWA6.

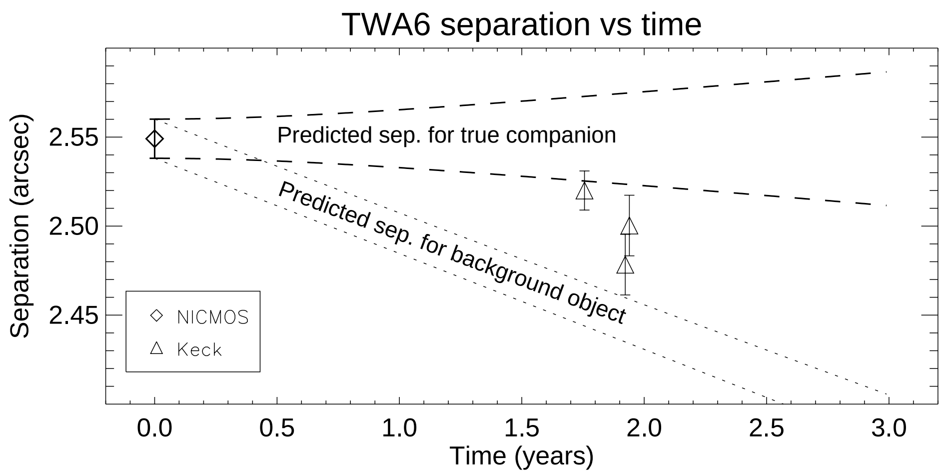

Figure 2. Separation vs time for TWA6AB, showing the original 1998 NICMOS measurement and the 2/2000 and 4/2000 Keck measurements. Diagonal lines show the likely range for a background object, and the slightly curved horizontal lines show the 1-sigma error on the initial position measurement plus the allowable orbital motion for a bound companion.

4. Search for new companions

Even if TWA6 proves to be a background star, it does demonstrate that we have the necessary sensitivity to see planet-like companions to nearby young stars at interesting ($\sim 100AU$) separations. We have begun a program to survey the ever-increasing number of known members of TWA and other young groups, as well as other young field stars accessible to the Keck observatory. Analysis of these data are ongoing. Figure 3 shows an estimate of our typical sensitivity, compared to that of earlier NICMOS measurements. The sensitivity in both cases has been computed based on the variance of PSF-subtracted data in successive annuli. This should not be considered definitive - a true detection would require multiple images of a given target at the 5-sigma level - but the variances were calculated in the same way for both instruments, and illustrate that the companion-detection sensitivity of Keck AO is currently comparable to NICMOS. Keck AO sensitivity at large radii was limited by high readnoise in the KCam camera and has improved as new instruments are used.

Improved image processing techniques are expected to enhance sensitivity by a factor of 3-10 at small radii. Even now, we are capable of detecting a $1M_J$ companion at a separation of $1''$ and a $5M_J$ companion at a separation of $0.5''$, assuming a TWA age of 10 MYr and using the models of Burrows et al. (1997). As more AO systems become operational on 8-10m telescopes, particularly in the southern hemisphere, direct detection of an extrasolar planet orbiting a young star seems almost inevitable, if such massive planets do exist with orbital separations greater than 20 AU.

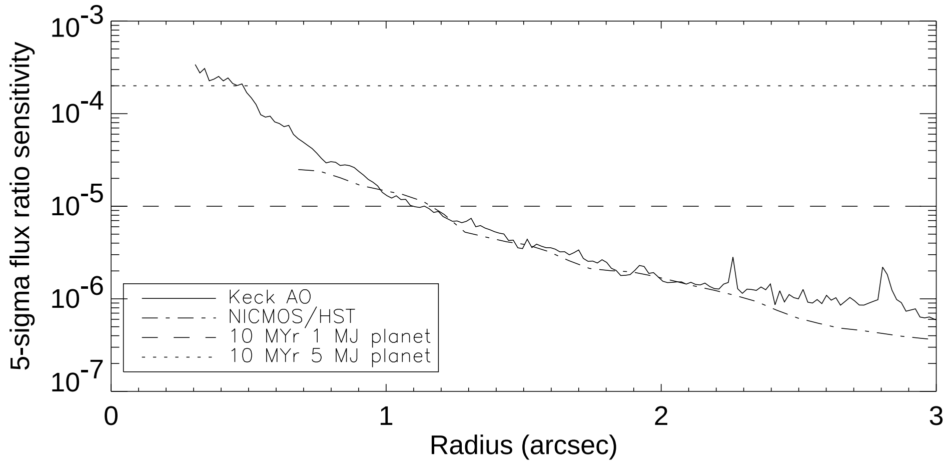

Figure 3. Estimated sensitivity to faint companions in Keck AO imaging. For comparison, a similarly-calculated sensitivity for NICMOS is shown. Overlaid are the flux-ratios for 1 and 5 Jupiter-mass companions to TWA stars, from Burrows et al. 1997

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