Brown Dwarfs
IAU Symposium, Vol. 211, 2003
E. L. Martín, ed.

CHAOS: The Cornell High-Order Adaptive Optics Survey for Brown Dwarfs

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Abstract. The Cornell High-order Adaptive Optics Survey for brown dwarfs (CHAOS), currently about 90% complete, uses the Palomar Hale Telescope's adaptive optics system to survey 80 bright stars out to 13 parsecs. Using the telescope's AO Science camera, brown dwarf companions 4-200 AU can be identified using coronagraphic imaging and spectroscopic modes. We will be using monte carlo simulations to create population models consistent with the CHAOS data set.

Currently, we have observed 70 systems out of a target sample of 80. Five candidate companions await follow-up observations. As of now, no systems in the target sample have shown strong evidence of having brown dwarf companions. These early results support previous speculations of a "brown dwarf desert" at orbital separations out to 200 AU.

While the target sources revealed no evidence of brown dwarf companions, accompanying observations of calibration stars provided evidence of an early methane dwarf candidate around the binary system HD150451AB. Forty seven parsecs from earth, the candidate indicated a projected orbital separation of 280 AU.

1. Observations and Results

The CHAOS target sample consists of 80 stars including 3 A stars, 8 F stars, 13 G stars, 29 K stars, 25 M stars and 2 stars with ambiguous spectral types. We used the Palomar Adaptive Optics system (PALAO) along with the Cornell-built PHARO camera's coronagraphic and spectroscopic modes to conduct high contrast observations of potential brown dwarf systems. Typical observations involved taking short exposures of the coronagraphically-masked parent star followed closely in time ($\lesssim$7 min from the start of a target exposure) by corresponding exposures of a nearby calibration star of similar brightness. Observations of the calibration star allowed us to remove the majority of the parent star's residual that had leaked from behind the coronagraph.

While our target star images have yet to provide conclusive evidence of a brown dwarf companion, calibration star images did reveal strong evidence of a methane dwarf companion to the binary system HD150451AB. The candidate was first imaged with adaptive optics in May of 2000 (see figure 1). At a separation of 6″, we observed a K-short magnitude of 16.0 ± 0.1. This value corresponded to an absolute magnitude of 12.6 ± 0.2. Differential photometry revealed J - K = 0.55 ± 0.10. All of these values are consistent with an early-type methane dwarf. By looking at the sky density of USNO catalog stars in this region, we estimated ~7 percent chance of a background star being within 6″of the parent binary. Taken alone, the color photometry and K-short magnitude allow the possibility of it being a background G or K dwarf or a foreground intermediate temperature (4700 K) white dwarf.

We followed these AO observations with differential methane-band imaging using WIRC, the Wide-field InfraRed Camera on the Palomar 200″. Methane-band imaging identifies atmospheric methane-band absorption by taking narrow band photometry on and just off the methane absorption window. The use of a wide field (5′× 5′) camera allows us to compare the brown dwarf candidate flux with background stars to avoid any contamination due to non-photometric sky conditions.

To perform accurate photometry on the brown dwarf candidate, it was important to ensure that the measured differential flux was not contaminated by residual flux from the parent star. To do this, we took data from three sets extending over two nights and, in each data set, used two independent star flux subtraction methods. In the first instance, the background flux was measured by creating an annulus centered around the candidate brown dwarf. We truncated the annulus in regions where the annulus overlapped with the diffraction spikes from the parent star. For the second method, the background flux was estimated by creating an arc extend along a constant radius from the parent star. This allowed us to estimate the residual flux at the brown dwarf's separation from the parent star. The resulting background-subtracted brown dwarf flux was compared to the measured flux of various background stars. Figure 2 shows the resulting flux ratios from these procedures. With the exception of one outlying star, all of the background stars show flux ratios that are within 3 $^{1}/_{2}$percent of unity. (For background stars, sky subtraction was conducted using a circular, star-centered annulus.) The background star data points give us an idea of our statistical uncertainty. Comparing this uncertainty to the spread in the candidate brown dwarf flux data points, we can see that systematic errors dominate over the statistical uncertainty. While the spread from systematic errors extends over a considerable range, it is clear that both nights' data indicate a drop in flux form short to long, the signature of a methane-abundant atmosphere. One can also see that the drop in flux between short and long is considerably larger the second night. This change in the flux ratio is compatible with other observations presented at this conference (see Enoch or Artigau) that show a high incidence of infrared variability in early-type methane dwarfs.

As a sanity check, we also measured the differential flux of the brown dwarf without conducting any parent star flux subtraction. All three data sets exhibited methane depression levels exceeding 7 percent.

As a final verification of the candidate's methane abundant properties, we mapped out the object's J - K value versus its methane depression. We then took published T-dwarf spectra and J - K magnitudes and convolved the spectra with our measured filter response curves. The comparison showed that all of our measured values were consistent with those of a methane dwarf.

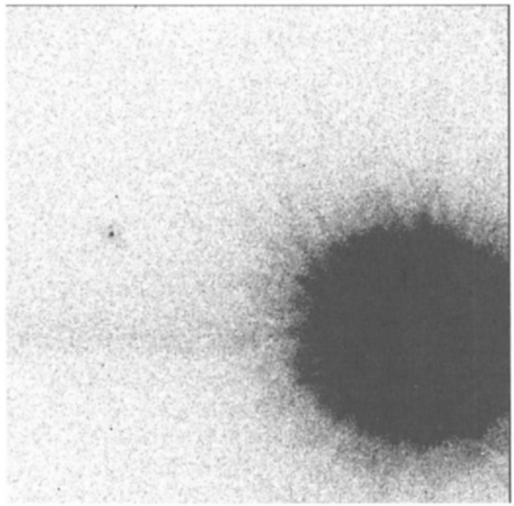

Figure 1. A likely methane-dwarf companion to the binary system HD150451AB imaged with Palomar AO in May of 2000 by Carson and Eikenberry. At a separation of 6″, the candidate companion exhibited a K-short magnitude of 16.0 ± 0.2 with J - K = 0.55 ± 0.10.

2. Conclusions

The Cornell High-order Adaptive Optics Survey for brown dwarfs is presently about 90% complete with no current positive identifications of brown dwarf companions out to 200 AU. A corresponding brown dwarf population analysis is currently underway to arrive at rigorous statistics. While we have yet to find any brown dwarfs out to 200 AU, we did find a strong brown dwarf candidate to HD150451AB at a projected orbital separation of 280 AU. Photometric observations in J, K, methane-short, and methane-long filters all displayed signatures of an early T-dwarf.

https://doi.org/10.1017/S0074180900210723 Published online by Cambridge University Press

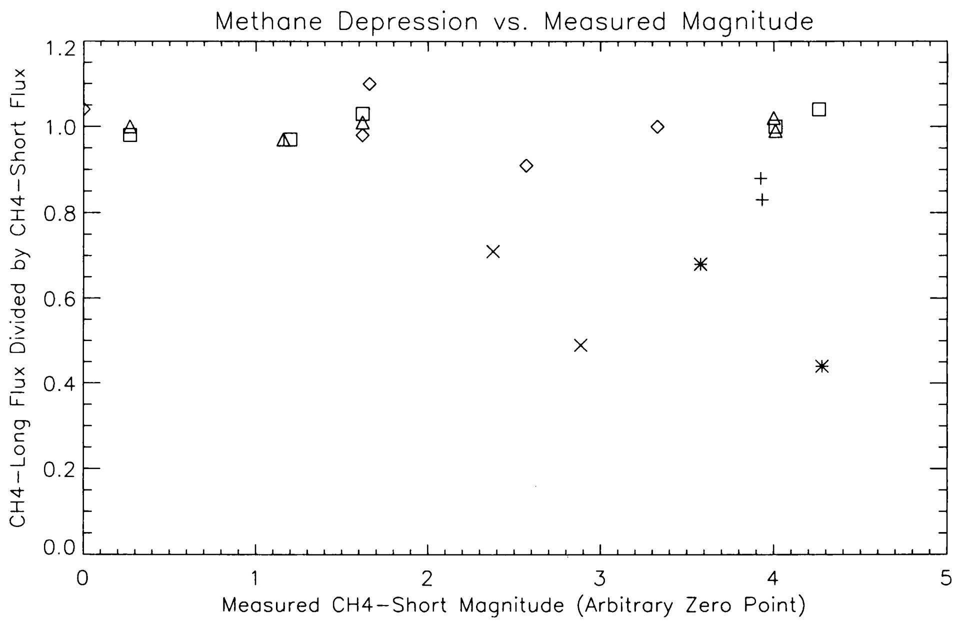

Figure 2. Methane depression plotted versus the measured methane-short magnitude for HD150451C and field stars. The data points correspond to the following symbols: (+) = HD150451C data set 1, 22nd March 2002; (*) = HD150451C data set 2, 26th March 2002; (×) = HD150451C data set 3, 26th March 2002; (◇) = data set 1 field stars, 22nd March 2002; (△) = data set 2 field stars, 26th March 2002; (□) = data set 3 field stars, 26th March 2002. All HD150451C data points exhibit methane depression, the signature of a methane-abundant atmosphere.

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