A Search for Close-in Stellar and Brown Dwarf Companions to Nearby Stars

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Project Overview

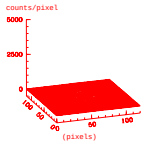
We present results from an on-going search for close-in (> 0.1 arcsec) stellar and sub-stellar companions conducted with the Palomar 200-inch adaptive optics system (PALAO) using the PHARO camera in coronagraphic mode. Our estimated dynamic range sensitivity is 12.5 mag (flux ratio = 10^5) at 1 arcsec and 15 mag (flux ratio = 10^6) at 2 arcsec in the *K* band (centered at 2.2 microns), corresponding approximately to 3 (10) and 1 (5) Jupiter masses at 10 pc for the 0.1 (1.0) Gyr old objects in our sample. We have imaged 12 sources with the coronagraph in place and present detection limits on close-in companions. From direct (non-coronagraphic) AO imaging, we find that 8 of 20 imaged stars are binaries, 7 of which are new discoveries. The observed stars are taken from the SIRTF Legacy Science Team sample (Meyer et al. 2001).

Observations

1) Instruments:

- Palomar AO system

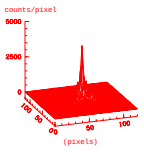
The Palomar Adaptive Optics system (PALAO; Troy et al. 2000) is a facility adaptive optics (AO) system built at JPL for use at the Cassegrain focus of the Palomar 200-inch (5-meter) Hale telescope. The system employs a deformable mirror with 349 actuators, each delivering a mechanical stroke of up to 4 microns. The use of adaptive optics improves the spatial resolution of a telescope by correcting for the variable scattering of starlight ("seeing") by the atmosphere of the Earth. In the case of the PALAO system, the correction is nearly perfect: the output point-spread function (PSF) is diffraction-limited (full-width half-maximum of 0.1 arcsec) at 2.2 microns (the infrared *K* band), and at nearly 50% the amplitude of the true (unperturbed by atmospheric seeing) diffraction-limited PSF.



No AO correction
FWHM = 36 pix = 0.80″

- PHARO camera

The Cornell near-infrared camera PHARO (Palomar High Angular Resolution Observer) was built for use with PALAO (Hayward et al. 2001). PHARO uses a 1024 x 1024 pixel HgCdTe detector for observations between 1 and 2.5 μm. For our observations we used the **coronagraphic** imaging capability of the camera with a 25-arcsec field of view. A coronagraph is a cold spot in the focal plane of the telescope, placed over the position of the star to block out its light, and to improve the sensitivity to nearby faint objects. We used a 0.97-arcsec diameter (9 λ/D at 2.2 microns for the 5-meter Hale telescope) coronagraph. The estimated improvement in flux sensitivity is a roughly factor of 100.



AO corrected PSF
FWHM = 10 pix = 0.10″

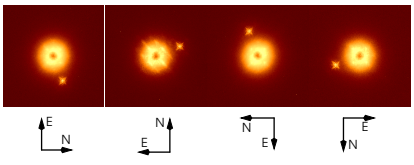
2) Methods:

- five-point dither

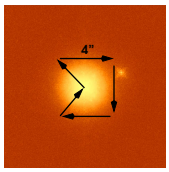
Five short (2 to 10 sec) unsaturated exposures were taken of each object in non-coronagraphic mode for the purpose of performing absolute *JHK* (1.2 to 2.2 micron) photometry, and to check for close (< 1 arcsec) binaries. A standard dithering technique was applied. The frames were aligned and summed to form the final image. Sky frames were created by median-combining the unaligned images.

- Cassegrain ring rotation

Six long (60 sec) exposures with the coronagraph (0.97 arcsec) in place were taken at each of four rotation angles of the Cassegrain ring, offset by 90 degrees from each other. This was done as an alternative to taking PSF exposures of a standard star, to maximize on-source time, and to average out non-radially symmetric artifacts (e.g., ghosts from the AO) of the PSF.



HIP 52498



27 sec combined exposure
no coronagraph

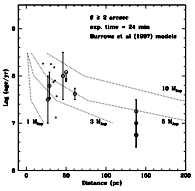
1440 sec (24 min) combined exposure; with coronagraph

Detection Limits

3) Sensitivity to low-mass objects:

Because planets and brown dwarfs are not massive enough to burn hydrogen via thermonuclear fusion, they cool radiatively as they age. Distance and age are thus two of the main factors (other than telescope sensitivity) limiting our ability to detect extrasolar giant planets.

The observed sample of stars is plotted on an age vs. distance diagram on the right. Stellar ages are as determined by members of the Meyer et al. Legacy Team (Soderblom, Mamajek, Hillenbrand). Superimposed (dotted lines) are detection limits for 1, 3, 5 and 10 Jupiter-mass planets, based on brown dwarf cooling curves by Burrows et al. (1997). The curves denote the minimum detectable mass of a planetary companion at a given age and distance.



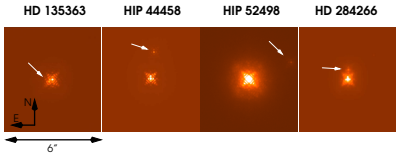
PHARO detection limits in *K*

Results

4) Detected objects:

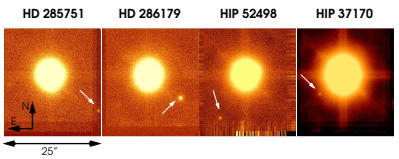
- probable binaries

Eight of the 20 imaged stars have apparent companions at separations < 3″ visible in the short exposures. Seven of these are new detections. Given the small angular separations, all of these systems are candidate physical companions. Color and spectroscopic information will be used to further constrain this likelihood. The least massive among the companions is that to HIP 52498, with inferred mass ~0.2 M_{sun}.



- fainter field objects

Four much fainter objects ($\Delta K_s > 6.5$) are present in the long coronagraphic exposures, only one of which is also distinguishable in the short (non-coronagraphic) exposures. For the remaining 3, colors are unavailable. Given the large angular separations (> 7″~ 300 AU for the mean distance of our sample), these are unlikely to be physically associated with the observed targets.



The case of HIP 37170 is interesting however, because at 37 pc and 38 Myr (Soderblom et al 2002, in prep), it is one of the nearest and youngest stars in our survey. If the faint object in the PHARO field is physically associated with the star (at projected separation of 290 AU), current evolutionary models (Burrows et al. 1997, Baraffe et al. 2002) place it just below the deuterium-burning limit (~13 Jupiter masses), making it a planetary (as opposed to a brown dwarf) companion

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