A Search for Close-in Companions and Circum-stellar Dust around 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 at 1″ and 15 mag at 2″ in the *K* band, 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.

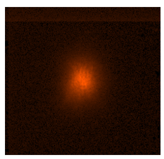
The observed stars are taken from the SIRTF Legacy Science Team sample (Meyer et al. 2001). Concurrent JHK_s and 10 μm photometry is used to determine upper limits on the presence of debris disks.

Observations

1) Instruments:

- Palomar AO system

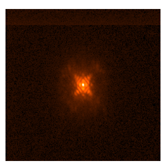
The Palomar Adaptive Optics system (PALAO; Troy et al. 2000) is a facility adaptive optics (AO) system built at JPL for use at the f/15.7 Cassegrain focus of the Palomar 200″ telescope. The system achieves diffraction-limited (0.1″) images in *K* with Strehl ratios as high as 50% on guide stars brighter than 8^{th} magnitude in the presence of 1″ seeing with estimated wind velocities on the order of 5 to 10 m/s.



No AO correction; FWHM = 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 HgCdTe HAWAII detector for observations between 1 and 2.5 μm. An all-reflecting optical system provides diffraction-limited images at two scales, 25 and 40 mas pixel^{-1} (25″ and 40″ field of view, respectively). For our observations we used the coronagraphic imaging capability of the camera with 25″ field of view. A cold Lyot stop was used to occult the telescope spiders.



AO corrected; FWHM=0.10″

- SpectroCam-10

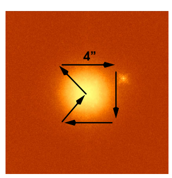
The Cornell-built 8 to 13 μm spectrograph and camera (Miles et al. 1993) for the 200″ Hale telescope, is being used to obtain 10 μm photometry of our targets.

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_s photometry, and to check for close (< 1″) 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.

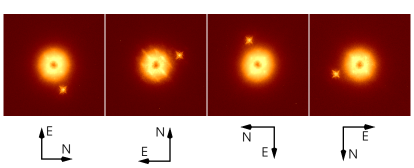
HIP 52498

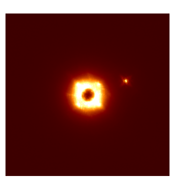


27 sec combined exposure no coronagraph

- Cassegrain ring rotation

Six long (60 sec) exposures with the coronagraph (0.97″) 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 point-spread function (PSF) exposures of a standard star, to maximize on-source time, and to average out non-radially symmetric artifacts (e.g., ghosts) of the PSF.





1440 sec (24 min) combined exposure; with coronagraph

REFERENCES:

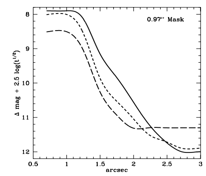
Baraffe et al. 2002, A&A, **382**, 563.
Burrows, A. et al. 1997, ApJ, **491**, 856.
Hayward et al. 2001, PASP, **113**, 105.
Hillenbrand et al. 2002, in preparation.
Meyer, M.R., Formation and Evolution of Planetary Systems SIRTF Legacy Science Team 2001 http://xxx.lanl.gov/abs/astro-ph/0109038.
Miles, J.W., Hayward, T.L. and Houck, J.R. 1993, ASP Conf. Series, **41**, 407.
Oppenheimer et al. 2000, SPIE, **4007**, 899.
Soderblom et al. 2002, in preparation.
Troy, M. et al. 2000, SPIE, **4007**, 31.

Detection Limits

3) Factors limiting sensitivity:

- dynamic range

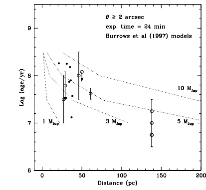
Detection limits for PHARO in coronagraphic mode, using Cassegrain ring rotation and as a function of Lyot stop size, are established by Oppenheimer et al. (2000). The curves are for 5σ detection of point sources near bright stars in the *K* band, for each of three different Lyot stops: standard (solid line), medium (short dashed line) and big (long dashed line). The graph presents the magnitude difference from a bright star (in this case, *V*=6.67, *K*=4.71), for an integration time of 1 sec. The ordinate indicates the dynamic range as a function of integration time, *t*, in seconds. For our images, *t*=1440 sec (24 min); the dynamic range with the big Lyot stop (inner diameter expanded by 1/5 and outer diameter reduced by 1/5) at angular separations θ > 2″ from the bright star is 15.2 mag in *K*.



PHARO dynamic range in *K*

- age and distance

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 the dynamic range results above (Oppenheimer et al. 2000), and on brown dwarf cooling curves by Burrows et al. (1997).



PHARO detection limits in *K*

Results

4) Detected objects:

- probable binaries

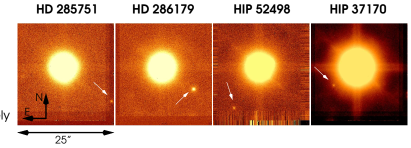
Eight of the 20 imaged stars have apparent companions at separations < 3″ visible in the short exposures. Seven of these are new detections. Given the small angular separations, all of these systems are candidate physical companions. Color and spectroscopic information will be used to further constrain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

HD 135363 HIP 44458 HIP 52498 HD 284266

- fainter field objects

Four much fainter objects (ΔK_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.

HD 285751 HD 286179 HIP 52498 HIP 37170



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.

5) Photometry

The table below lists the photometry (JHK_s differences and apparent K_s magnitude for the fainter object; errors are 0.1 mag) and angular separations for the stars observed during our first PALAO run. The last column combines 2MASS photometry with our 10 μm photometry for a subset of the observed targets. Of the latter, only HIP 50180 shows a (K_s-*N*) excess unusual for its spectral type (G5), while the remainder do not show presence of obviously strong dust disks.

Object	Δ *J*	Δ *H*	Δ K_s	K_s secondary	angular separation	distance	(K_s-*N*) primary
	mag	mag	mag	mag	arcsec	pc	mag (err)
candidate binaries:							
HD 284266A,B	1.5	1.8	1.7	10.3	0.60	...	...
HD 44458A,B	2.6	2.1	2.0	7.5	1.6	30	0.07 (0.07)
HD 284135A,B	...	...	0.13	8.5	0.36	138	...
HD 135363A,B	0.6	0.6	0.7	7.1	0.25	29	...
HD 285281A,B	1.3	1.2	1.2	8.9	0.75	138	...
HIP 52498A,B	4.5	4.5	4.3	14.8	2.9	35	...
HIP 63008A,B	2.1	2.1	2.2	7.7	1.51	34	...
faint object in the field of:							
HD 285751	...	...	8.8	17.6	15.1	138	...
HD 286179	...	....	6.8	15.2	10.1	138	...
HIP 37170	...	...	8.5	14.7	7.6	37	-0.14 (0.08)
HIP 52498	9.0	...	8.9	14.8	12.1	35	...
HD 105601*	7.6	7.3	7.0	13.7	9.5	120	...
apparent single stars:							
HD 70573	n.a.	n.a.	n.a.	n.a.	n.a.	46	0.0 (0.2)
HD 41184	n.a.	n.a.	n.a.	n.a.	n.a.	36	0.10 (0.08)
HIP 50180	n.a.	n.a.	n.a.	n.a.	n.a.	37	0.46 (0.08)
HIP 60074	n.a.	n.a.	n.a.	n.a.	n.a.	28	0.14 (0.08)

* Elias photometric standard.