A NEW HIGH-CONTRAST IMAGING PROGRAM AT PALOMAR OBSERVATORY

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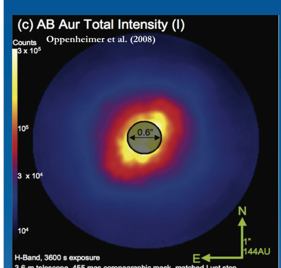
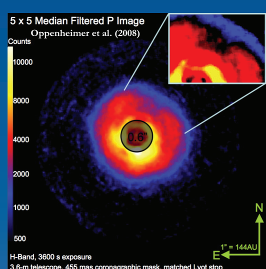
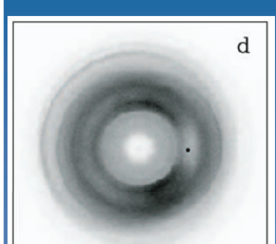
Previous Lyot Project Disk Imaging With Coronagraphy & Polarimetry: AB Aurigae







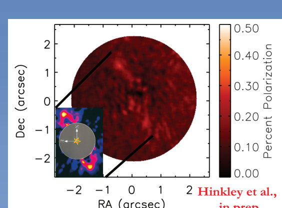
Moro-Martin et al. (2002) simulations

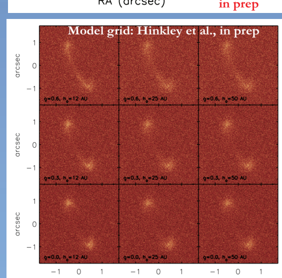
We have used a classical Lyot coronagraph combined with dual imaging polarimetry with the goal of detecting the polarized signatures of circumstellar disks. Above, we show an image of the disk structure surrounding the ~1-3 Myr old A0V star AB Aurigae as discussed in Oppenheimer et al (2008). Using dual-imaging polarimetry, we have imaged the dust between 43 and 302 AU from the star. The above left image shows the total intensity image; the upper right shows the Stokes P image. In the polarization image, we see evidence for an azimuthal gap at a radius of 102 AU, along with a clearing at closer radii inside this annulus. This suggests the formation of at least one small body at this orbital distance. Indeed, we report a low significance detection of a point source at this location (see above right) Such a structure seems consistent with models of mean motion resonances or accumulation of material at two of the Lagrange points relative to the putative object and the star (See left: Moro-Martin et al. 2002). This source may be an overdensity in the disk due to dust accreting onto an unseen companion, rather than the companion itself. Using the cooling models of Baraffe (2005), we estimate the object, if real, would have a mass between 5 and 37 Jupiter masses assuming the object and the star are coeval.

Polarimetry of the HR4796A Disk

At right, we show a faint, yet significant (5-7σ) detection of the ~80 AU diameter circumstellar disk around the star HR4796A. For comparison, the HST NICMOS image (Schneider et al. 1999) is shown. This ground-based H-band image was acquired in only 720 s using a dual-channel imaging polarimeter working in tandem with a classical Lyot coronagraph at the 3.63m AEOS telescope. This image was obtained during the commissioning of the Lyot Project's polarimeter, with only 3 out of 4 modes operating. Our data clearly show the outer ansae of the disk, evident in a longer 1024 s Hubble Space Telescope image acquired with the NICMOS coronagraph. Comparing our peak linearly polarized flux with the NICMOS intensity in the lobes, we derive a lower limit to the fractional linear polarization of ~44% caused by dust grains in the disk. This image also demonstrates the versatility of the speckle suppression achievable through the double differencing technique unique to this kind of dual-channel imaging polarimeter. For polarized sources at 1", we show that we are able to achieve levels of speckle suppression several times greater than simply using a coronagraph coupled to a high-order AO system.

We have fit our data to simple morphological models (see right) of optically thin disks assuming a Henyey-Greenstein phase function allowing us to constrain the disk dust scale height ~2.5 AU and Henyey-Greenstein phase function g~ 0.25. These values are similar to recent results by Schneider et al (2008). A sample grid of these models with scale heights of 12 AU, 25 AU, and 50 AU as well as Henyey-Greenstein parameters g=0.0,0.3, 0.6 are shown at right. Our models assume a Gausian vertical density distribution based onthe COBE model of zodiacal background light (Kelsall et al. 1998), and we have used the inner/outer radii, inclination, and position angle from Schneider et al (1999). Each thumbnail image uses the platescale of the Lyot Project's infrared camera (Perrin et al. 2002) and has been convolved with a PSF for th AEOS telescope at 1.6µm.





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The Lyot Project is also grateful to the Cordelia Corporation, Hilary and Ethel Lipsitz, the Vincent Astor Fund, Judy Vale and an anonymous donor, who initiated the project, as well as the Trustees and Provost, Dr. Michael Novacek, of the American Museum of Natural History who generously supported the establishment of the Astrophysics Laboratory in the Rose Center for Earth and Space.

Abstract:

In July 2008, a new integral field spectrograph and a diffraction limited, apodized-pupil Lyot coronagraph was installed behind the adaptive optics system at the Hale 200-inch telescope at Palomar. This instrument serves as the basis of a long-term observational program in high-contrast imaging. The technical goal is to utilize the spectral nature of speckle noise to overcome it. The coronagraph alone has achieved an initial dynamic range of 10^-4 to 10^-5 at 1", without speckle noise suppression. Initial work indicates that spectral speckle suppression will provide a factor of 10 to 100 improvement over this. Such sensitivity provides detection and low resolution spectra of young planets of several Jupiter masses around nearby stars. Priority targets will include those stars visible from the Northern Hemisphere and V<8 with known circumstellar disks and planets, and those younger than 1 Gyr. In addition, several hundred survey stars within 25pc will form the body of the target list. The spectrograph has a spectral resolution of 30-100 across the J and H bands (1.05 - 1.75 µm). The image plane is subdivided by a 200 x 200 element micro-lenslet array with a plate scale of 21 mas per lenslet, diffraction-limited at J-band. This system is the first of a new generation of apodized pupil coronagraphs combined with high-order adaptive optics and integral field spectrographs (e.g. GPI and SPHERE).

Property	Project 1640 IFU + Coronagraph
Wavelength coverage	1.05- 1.75 µm, $\Delta\lambda$ = 0.7 µm
Central wavelength	1.403 µm
IFU FOV	4200 mas
Platescale	21 mas/lenslet
Total spectra	200 x 200 = 40,000
Pixels per spectrum	3.2768 x 32
$\Delta\lambda$ per 2 pixels	.044 (.7µm/32 pix)
R = $\lambda/\Delta\lambda$	32
Lenslet Pitch	75 um (chosen for manufacturing issues)
Input f/ratio from coronagraph for λ/2D Spaxels at 1.0 µm	f = 143.21
Focal Plane Mask size	5.6 λ/d
Optimal coronagraph wavelength	1.65 µm
Apodizer throughput	51%

Phase 1: Pre-cursor Science

The initial phase of the project will utilize the low-order AO system and allow us to survey stars down to 13th magnitue (V band). This portion of the project will allow us to complete the survey of companions to nearby stars, as well as focus on Brown dwarfs and warm massive planets. This initial phase will also complement the later portions of the project, which is limited to brighter stars.

Phase 2: Upgrade & Key Project

Palomar -3000 AO system upgrade:

The Palomar AO system (PALAO) currently uses a 241-actuator AO system built by JPL (Dekany et al. 1997). PALAO is currently being upgraded to a 3000-actuator system with a 64x64 Shack-Hartmann wave front sensor, and a new infrared tip/tilt sensor (Dekany et al. 2007).

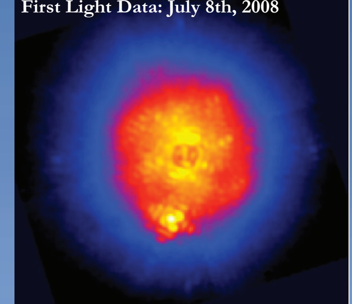
Wave front Calibration system:

JPL is currently constructing a wave front calibration system based on a Mach-Zender interferometer and will correct for the non-common path errors induced by optics downstream of the AO deformable mirror or in our coronagraph. These aberrations, since they are due to optical surfaces are extremely static with lifetimes of minutes or hours (Hinkley et al. 2007), and lead to the speckle pattern that is single biggest obstacle to high-contrast imaging.

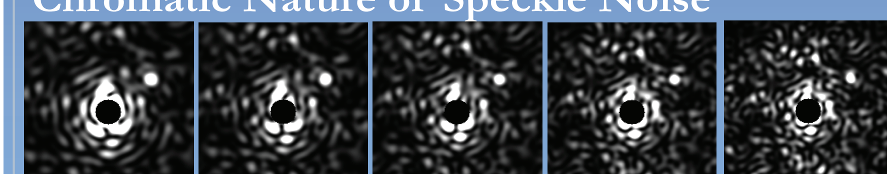
Key Project:

After the upgrade mentioned above, our system should be significantly more sensitive, going deep into the Jovian mass range for nearby young stars (< 1 Gyr). We will survey all stars visible brighter than 7th magnitude, obtain spectra for any detected companions. With low resolution spectra, we will have the capability to detect broad molecular spectral features.

First Light Data: July 8th, 2008



Chromatic Nature of Speckle Noise



Spectroscopic study of extrasolar companions will reveal fundamental aspects of their thermochemistry and atmospheric physics. We have built an integral field spectrograph to reach this goal. As discussed in the section above, the major limiting factor in the detection of substellar companions is the speckle noise due to the non-common path errors in the adaptive optics+coronagraph system. Each of these speckles has a size similar to the companion itself (~λ/D), and makes finding the companion harder. Our integral field spectrograph utilizes the wavelength-dependent nature of the speckle pattern and disentangle a substellar companion from the residual speckle noise. The spectral resolution of our spectrograph will be relatively low (R = $\lambda/\Delta\lambda$ ~ 30 - 100) in favor of data that is well sampled spatially. Rather than the traditional fiber-fed spectrograph, we use a grid of 200 x 200 lenslets, each 75 µm in size. The goal is to construct a data cube (x, y, λ) in which each two-dimensional image slice corresponds to a different wavelength. The figure above shows a simulation of several two-dimensional images, each one a different wavelength, in the data cube. The simulated companion at the two o'clock position maintains the same position through the data cube, but the position of the speckles is wavelength dependent. These two characteristics will allow us to disentangle a companion from the speckle pattern.

American Museum of Natural History