SCIENTIFIC JUSTIFICATION

Introduction and Motivation

As the circumstellar disk around a young star evolves, the formation of planets will influence the distribution of dust by forming gaps and resonances in the dust distribution (e.g. Wyatt 2003). These effects should be most pronouced for stars with a fully-formed planetary system, such as the older Vega-like stars or the so-called ‘transition’ objects: T Tauri and Herbig Ae/Be stars that have arrived or almost-arrived on the main-sequence but still show some signs of accretion. By studying the spatial distribution of dust around these stars, we can infer the presence of planets.

So far, the study of the spatial distribution of dust in older circumstellar disks has been dominated by studies of their spectral energy distribution, sub-mm or space-based observations. Sub-mm observations of the disk around Vega has clear inhomogeneities thought to be indicative of planetary resonances (e.g. Marsh et al. 2006). Coronography using HST has resolved scattered light from disks at radii greater than 1.5$''$: a thin ring of dust around HR 4796 and a gap (formed by a planet?) between inner and outer dusty region of HD 141569 (see the review of Zuckerman 2001).

From the ground, imaging in scattered light is difficult because of speckle noise, but has been achieved using PALAO for HD 141569 (Bocalletti et al. 2006). Imaging polarimetry can eliminate the effects of seeing and speckle noise, because only the light from the disk is polarized, suppressing the central star in the polarized-light image. Furthermore, by resolving out the disk structure, effects of interstellar polarization do not affect the measurement of disk polarization relative to the central star. Imaging polarimetry with adaptive optics is relatively new, but has already been used to image the closest T Tauri disk, TW Hya (Apai et al 2004), detecting polarized scattering down to their inner working radius of 0.1$''$.

Precision Calibration through Rapid Polarization Modulation

Achieving high contrast in imaging polarimetry requires either excellent and stable image quality or rapid polarization modulation that has no effect on image structure. The state-of-the art in detecting weak polarized flux integrated over a (large) single pixel is an accuracy of 10^{-6} (Hough et al., 2006), by using a photo-elastic modulator that operates at frequencies much higher than that of scintillation.

The use of a fast camera enables the possibility of polarization modulation at its fastest frame rate. LuckyCam with Adaptive Optics and Masking at Palomar (LAMP) is a new very-low-noise, fast-frame-rate, visible-light camera to be placed behind the Palomar 200” adaptive optics system. Images with FWHM=0.03 arcsec and Strehl ratios of 0.05-0.1 are expected to be produced by the AO system at 600nm. N. Law, a Co-I of this proposal, is the project lead for the instrument, which has been developed specfically for the P200 (see Nick Law’s proposal and www.astro.caltech.edu/∼nlaw/lamp/).

We propose adding 2 optical elements to the LAMP camera: a Liquid-Crystal Variable Retarder (LCVR) and a Wollaston prism made from α-BBO (which has low dispersion between 0.6

and 1.0 μm). When combined, these elements will split the star image into two images in orthogonal polarization states that will alternate in each sucsessive frame (20 ms per frame). A schematic of this is given in Figure 1. If LAMP is to become a more permanent fixture on the P200, then the PI is happy for other P200 observers to make use of this capability in future semesters.

By operating at speeds at least 100 times faster than previous imaging polarimetry experiments and by using no moving parts (such as rotating wave-plates), we should be able to obtain at least a factor of 10 better precision in Stokes images in the speckle-noise limited regime than previous experiments. Furthermore, as LAMP can take ∼100 times more exposures in a given time than conventional (non-speckle) cameras, we will be able to obtain a much higher dynamic range when operating in a low-gain mode, and will therefore not require a coronograph.

We have completed a preliminary study of the effect of speckle and photon noise on the imaging data. Using realistic values for Strehl and system throughput, Figure 2 shows a simulated image of a face-on $0.3''$ radius ring of small dust grains around an $m_I = 8$ star, that would have an integrated polarization of 0.5% if seen edge-on. This kind of image would not be able to be created with any existing technique.

The Proposed Study: Resolving Circumstellar-Disk Structure through Imaging Polarimetry

We propose to observe a sample of circumstellar disks using a rapid polarization modulation mode of LAMP. Our targets are selected from dusty Vega like stars and 'transition' young stellar objects (where the disk is transitioning to a Vega-like disk).

Rather than conducting a large survey of targets that may have only very marginal signals, we will focus on a few of the most promising targets for imaging disk sub-structure. These objects are given in Table 1. They were first selected from Vega-like systems in Bhatt and Manoj (2000) that have polarizations exceeding 0.3% and IR excesses with $L_{\rm IR}/L_*$ exceeding 10^{-3}, and then from objects already studied in the seeing-limited imaging polarimetry study of Hales et al. (2006). The last four sources in the table are a Vega-like system with a relatively large excess (HD 107067), the closest and most well-resoved T Tauri star (TW Hya), a nearby K dwarf with unusually small and hot grains and 3 Neptune-mass planets (HD 69830) and Vega itself.

In conclusion, rapid polarimetry modulation with LAMP will provide both the highest resolution and best speckle-noise supression to date in imaging polarimetry. We will use these capabilities to image dusty circum-stellar disks in polarized light. By focusing on dusty Vega-like systems, young stars with likely evolved disks and objects with existing complimentary data, we will maximise the chance of detecting clear evidence of the influence of planets on the disks.

REFERENCES

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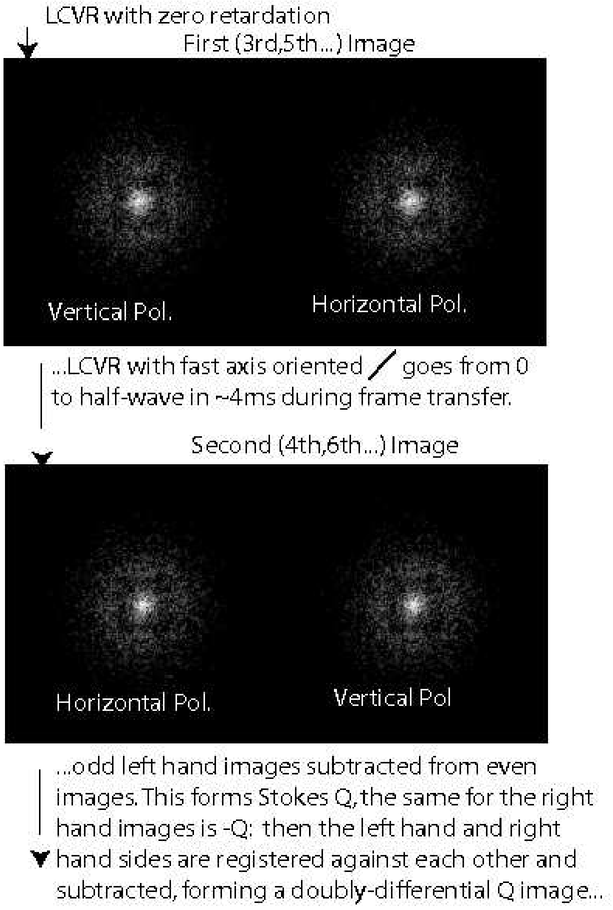

Figure 1. A Schematic of the double-differential analysis of data from LAMP with the polarimetry optics in place. The overall calibration strategy will also include rotating the Cassegrain cage and observations of standard stars.

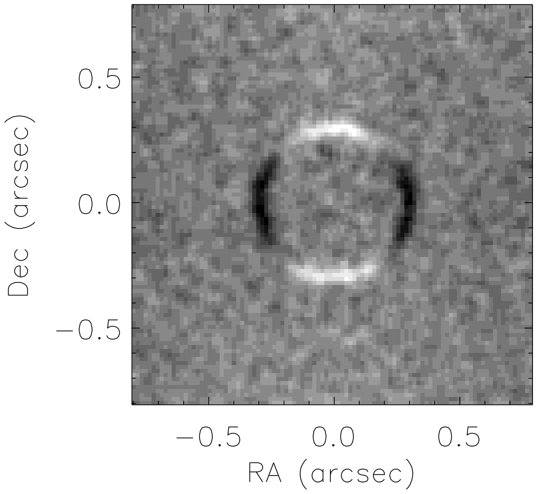

Figure 2. A simulated reconstructed I-band Stokes Q image of an $m_I = 9$ star, for a 5 min total exposure. The target has a $0.3''$ radius ring of small particles that would cause a total polarization of 0.5% if viewed edge-on. Assumed Strehl is 10%, total system QE is assumed to be 20%, and after the 15000 20 ms frames, it is assumed that speckle noise has beaten down to 1/400th of the mean speckle flux (less than $1/\sqrt{15000}$ as successive frames are highly correlated).

Table 1: Primary dusty disk sample. The polarization measurements are in V band and come from Bhatt and Manoj (2000).

Star	RA	Dec	B mag	V mag	Sp type	P (%)	m-M	$\log(L_{IR}/L_*)$
HD 98800	11 22 05.29	-24 46 39.8	10.27	9.11	K5Ve	0.54	3.34	-0.8
HD 109085	12 32 04.23	-16 11 45.6	4.69	4.31	F2V	0.38	1.30	-2.9
HD 143006	15 58 36.9	-22 57 15	10.94	10.21	G6/G8	0.69	5.6	-0.3
HD 149914	16 38 28.65	-18 13 13.7	6.96	6.74	B9.5IV	2.54	6.09	-2.3
HD 141569	15 49 57.75	-03 55 16.4	6.9	7.0	B9.5e	-	5.0	-2.1
HD 142666	15 56 40.02	-22 01 40.0	9.33	8.81	A8Ve	-	5.3	-0.5
HD 150193	16 40 17.92	-23 53 45.2	9.37	8.88	A1Ve	-	5.9	-0.4
HD 169142	18 24 29.78	-29 46 49.4	8.41	8.15	B9Ve	-	5.8	-1.1
HD 107067	12 18 36.2	+23 07 12.3	9.2	8.7	F8V	-	4.2	-2.85
TW Hya	11 01 51.91	-34 42 17.0	11.8	11.1	K8Ve	-	3.7	-0.6
HD 69830	08 18 23.9	-12 37 55.8	6.7	6.0	K0V	-	0.5	$\sim$-3.4
HD 172167	18 36 56.3	+38 47 01.3	0.03	0.03	A0V	-	-0.6	-4.8