Optical Interferometric Polarimetry

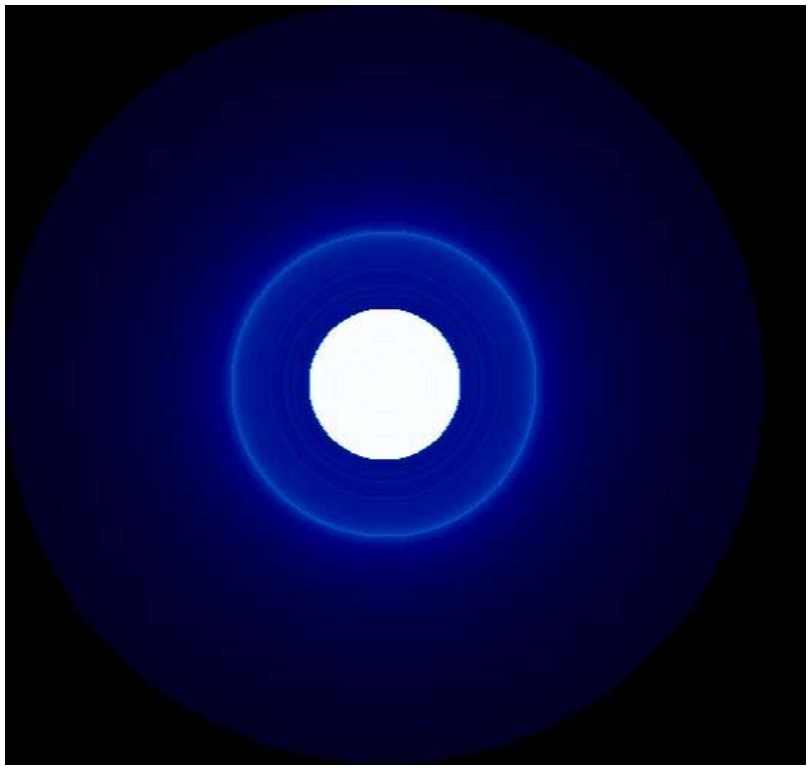
Michael Ireland

Outline

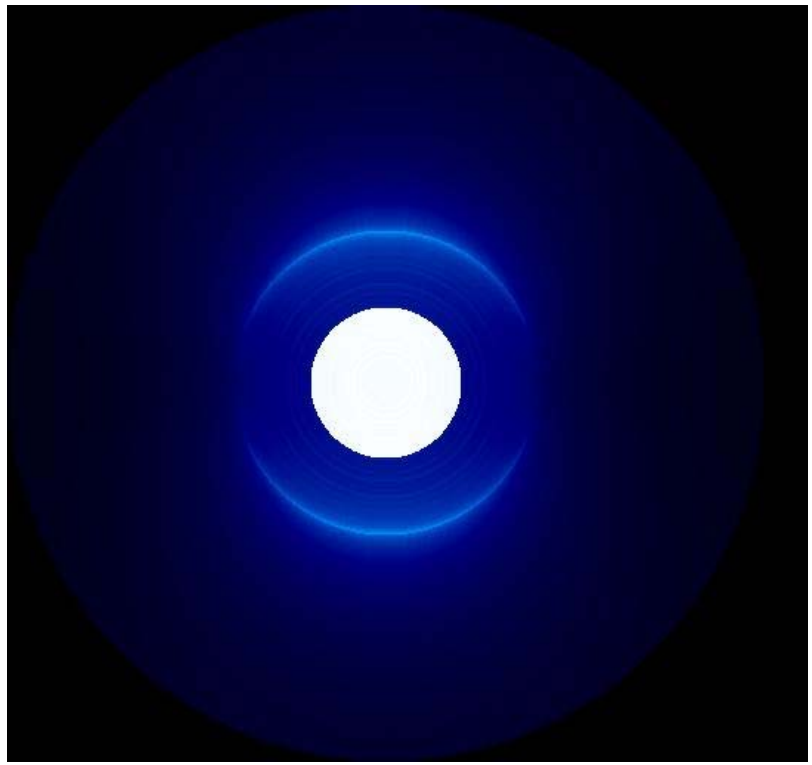
- What kind of observables result from combining polarimetry with long-baseline interferometry?
- How will I turn a `normal' interferometer into an OIP instrument?
- What precision should be achievable?
- What science areas will I focus on, and will it be possible to detect extra-solar planets using OIP?

Circumstellar Scattering

Unpolarized light



Polarized light

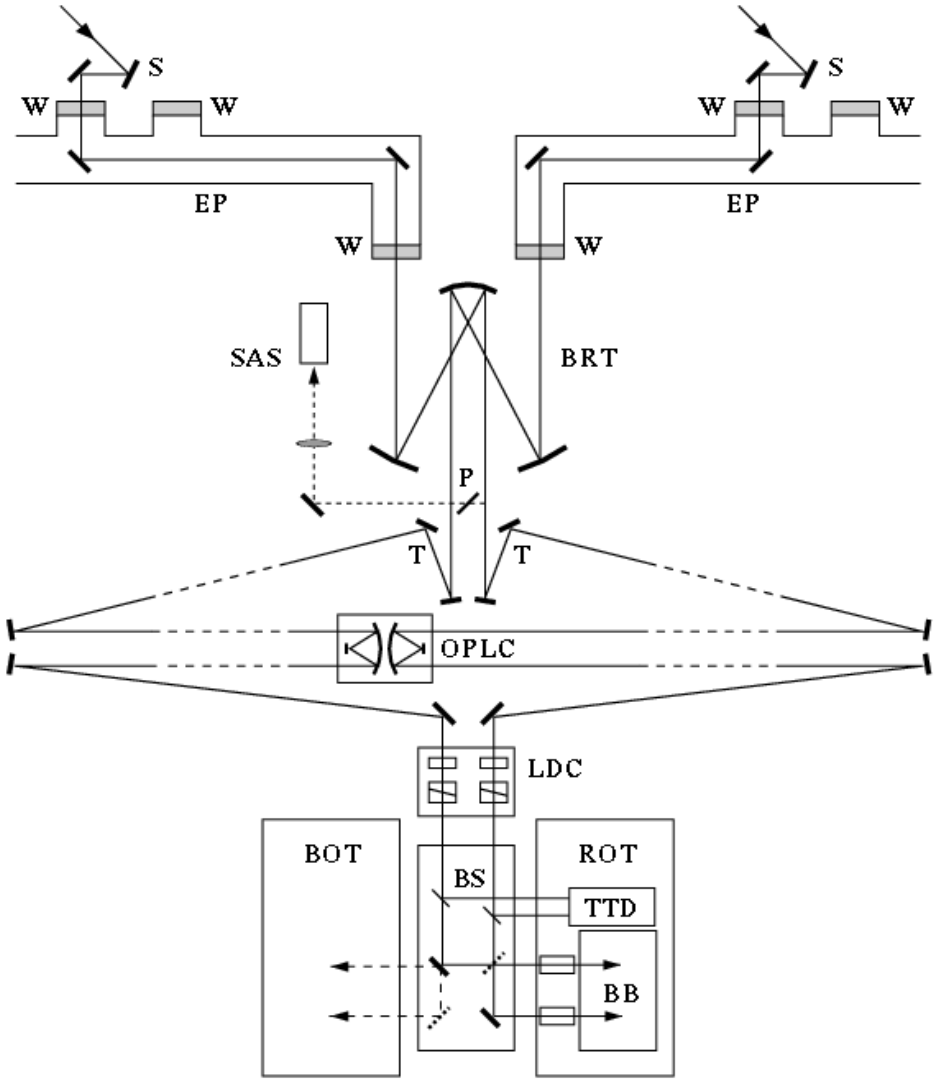


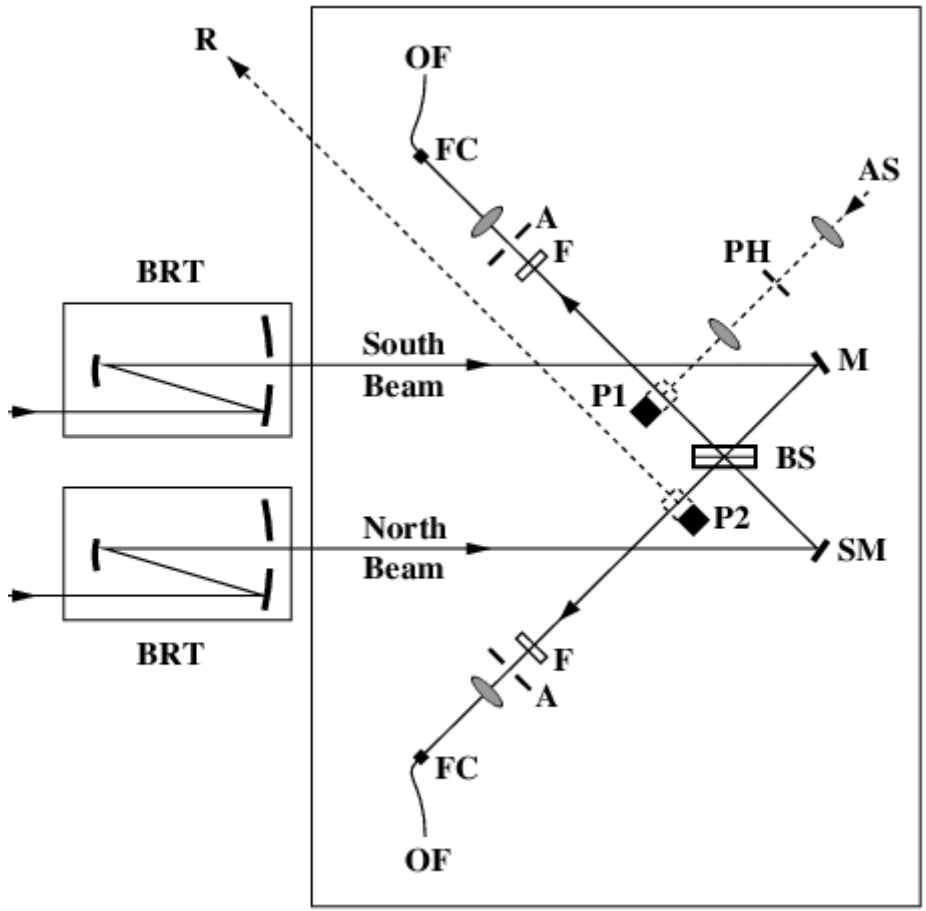
Visibilities and Images in Stokes Parameters

- The goal of OIP is to form images, or at least measure complex visibilities in Stokes parameters (I,Q,U,V).
- Stokes visibilities are measured in a lab frame: conversion to an on-sky frame needs Mueller matrices. These can be easily modelled and/or measured (e.g. Elias 2004).
- Ratios of complex visibilities in different polarization states are the primary indication of polarized source structure. e.g. The ratio of visibilities in Vertical (I – Q) and Horizontal (I + Q) polarizations will be unity unless V_Q is not equal to 0.

An Example from SUSI

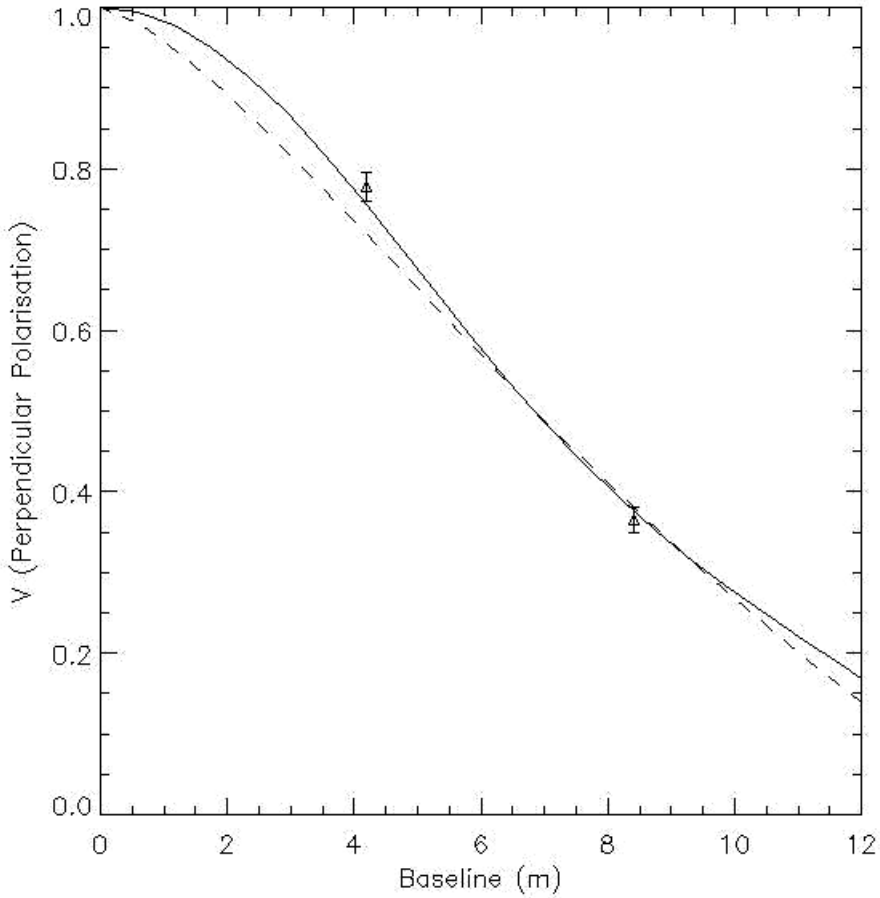
SUSI – Current Overview

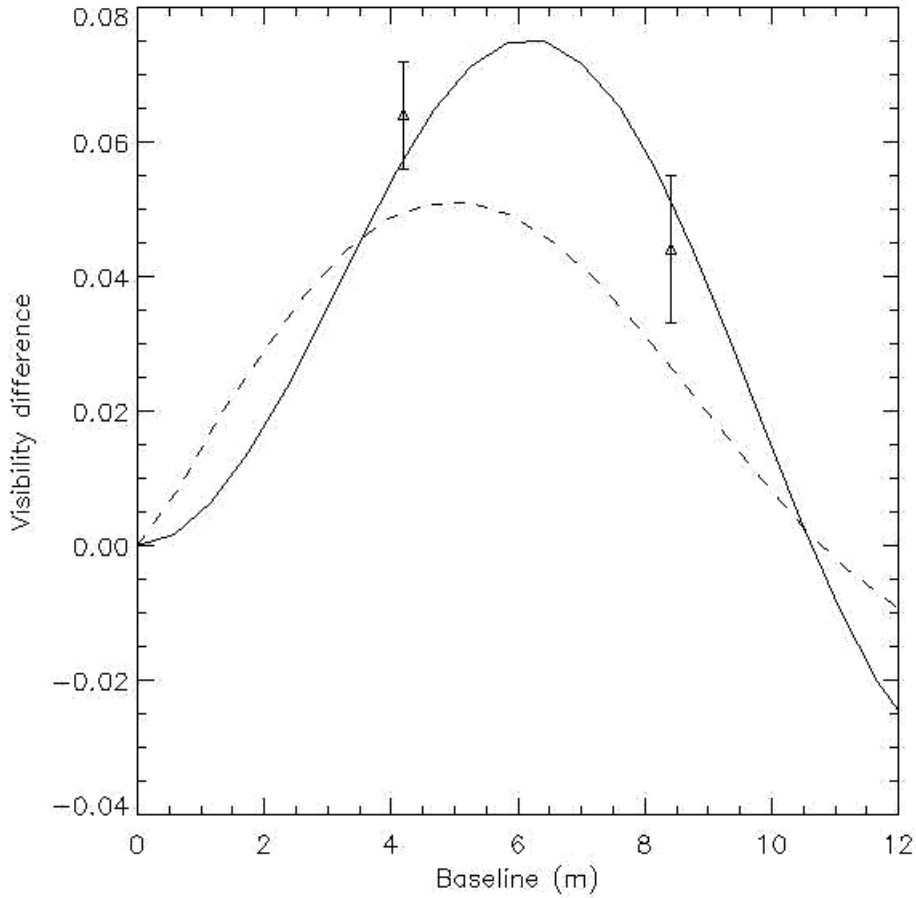




SUSI Results (R Car)

Solid lines: Thin shell model, Dashed lines: Outflow model





Ireland et al (2005)

Thin Shell Model Parameters

Phase	Model Prediction	UD Star Diameter (mas)	Shell Diameter (mas)	Optical depth at 900 nm
0.08	14.9	15.8 ± 0.5	32.3 ± 1.9	0.19 ± 0.03
0.15	16.0	16.6 ± 0.6	31.3 ± 3.6	0.14 ± 0.04

NB: Model prediction comes from the 1.2 solar mass Scholz 'M' Series, placed at a distance that fits the observed K band maximum.

Calibration: Easier for OIP than for Polarimetry or Interferometry!

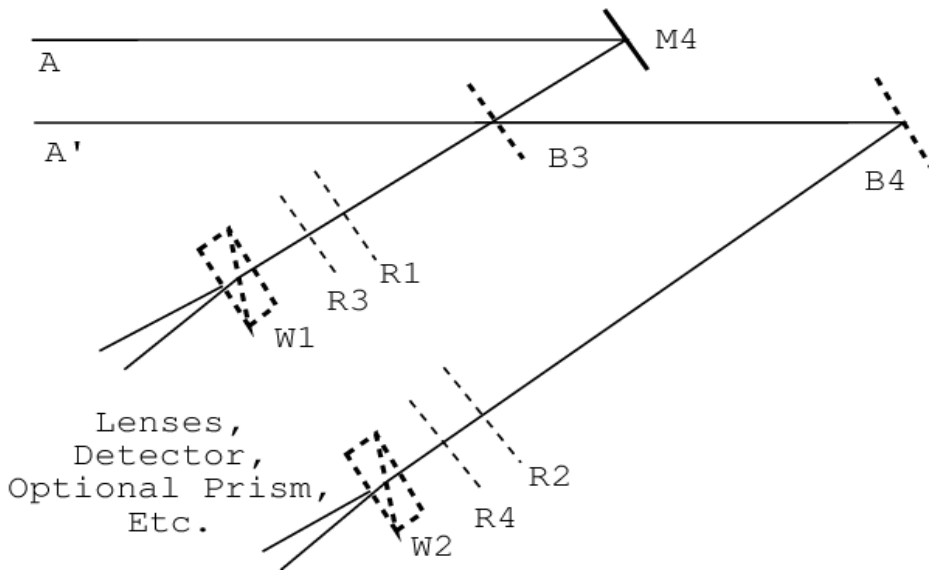
- Differential signals (e.g. V_V / V_H) are independent of seeing.
- Errors in selecting a polarization state (e.g. errors in half-wave plate orientation) translate to errors in V_Q proportional to $|1 - V_V / V_H|$, not the instrumental polarization.
- Errors due to spatially filtering different parts of the PSFs of the beams measuring V_V / V_H can be removed through modulation with a LCVR.
- e.g. polarization state known to within 10^{-2}, $|1 - V_V / V_H|$ less than 10^{-2} gives 10^{-4} precision.

Photon-Limited Signal-to-Noise

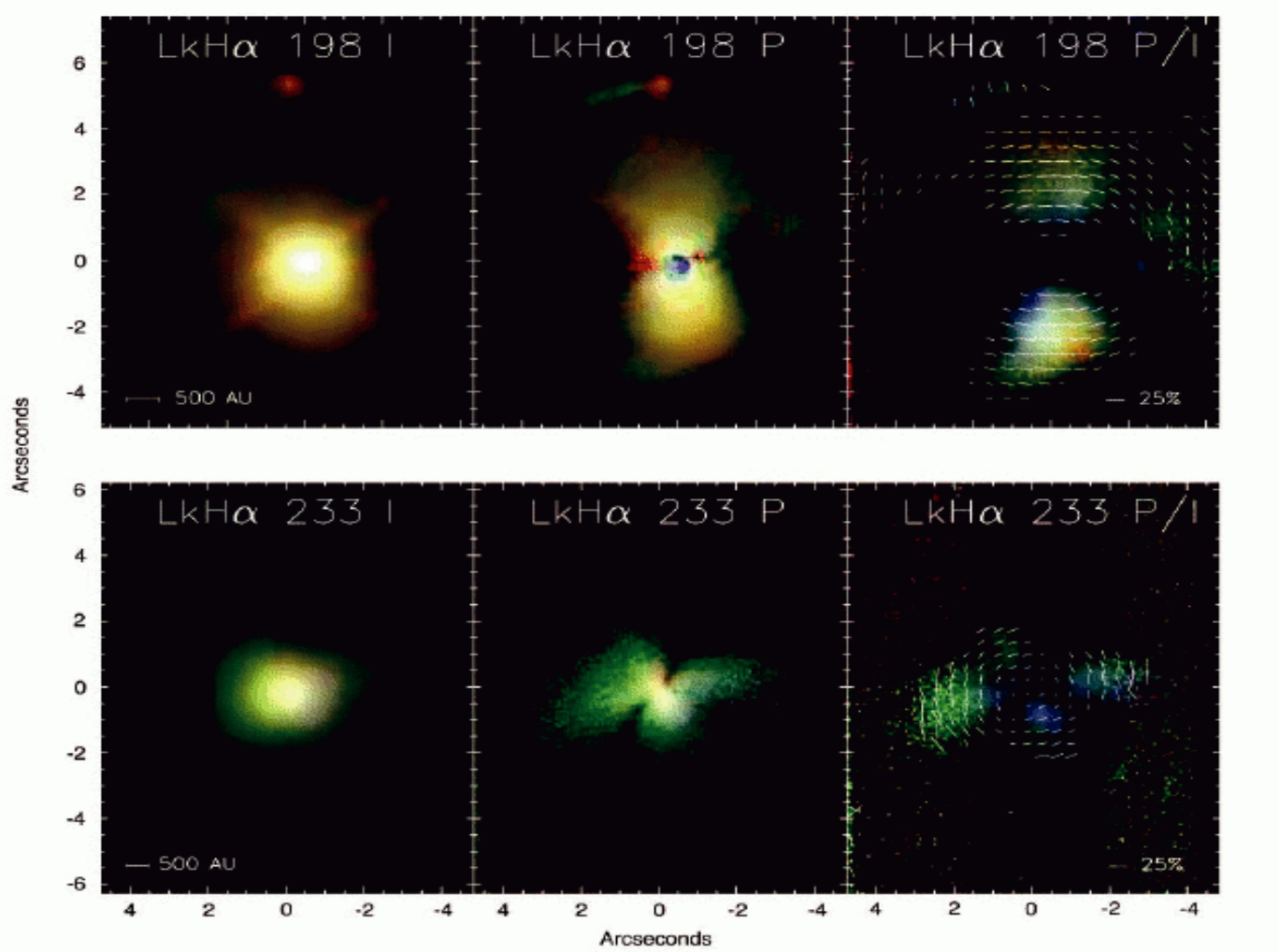
- Noise in $V_V + V_H$ is identical to $V_V - V_H$
- $\sigma(V_Q/V_I) \approx 1/ V_I\sqrt{N}$, where N is the total number of photons collected per aperture.
- e.g. (PTI?) 0.1 m^2 aperture, V_I=0.3 in H band, 10% throughput, Vega gives photon-limited S/N of 10^5 in 100 s.

Implementation at PTI

- Coherent integration of H-band fringes, while tracking at K.
- R1, R2 : half-wave plates. R3, R4 : LCVRs. W1, W2 : YVO_4 Wollastons.
- Initially operate with one beamsplitter output only and a prism.



Obvious OIP Targets...?



Herbig Ae/Be Stars from Perrin et al (2004)

Better OIP Targets

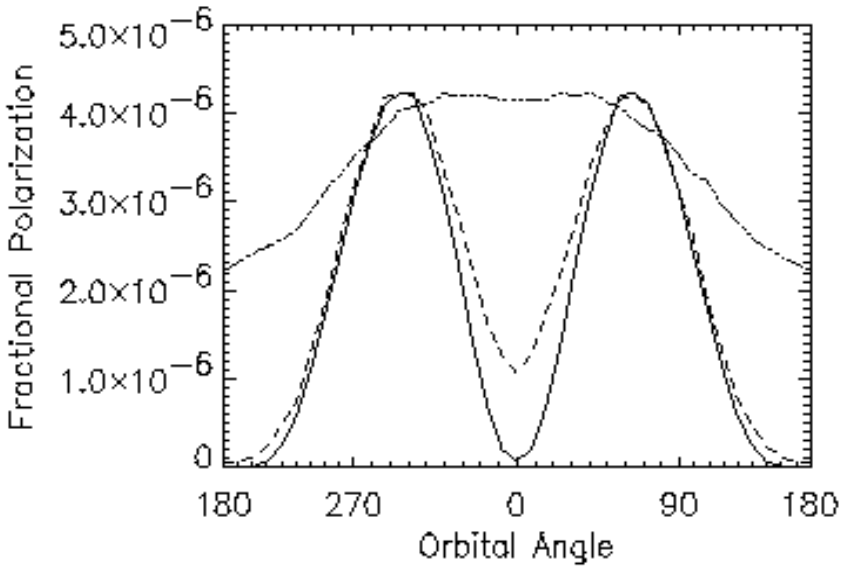
- Measuring v_Q/v_I is most useful if v_I can be modeled.
- A better target is an optically-thin disk/shell around an un- or barely-resolved star.
- Fractional disk luminosities should be less than 10^{-1}, and polarization should be in excess of 10%. Signals from 10^{-4} to 10^{-2} will have to be detected.

Expected Signal From Extrasolar Planets

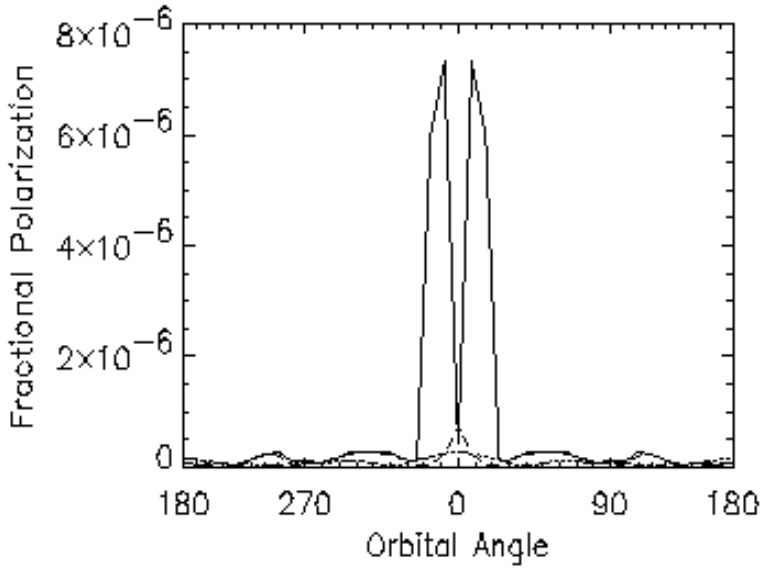
- Close-in Extrasolar Giant Planets (CEGPs) only have high albedos if they are very close, and have dusty upper atmospheres (Sudarsky et al. 2000).
- For albedos between about 0.2 and 1.0, polarimetric signal is nearly independent of albedo.
- Detection in a few week observing session requires at least about 10^{-5} precision per hour of observation, and time-variable systematics at the 10^{-6} level. Probably not achievable with current generation of interferometers (except maybe τ Boo).

Possible Signals as a Function of Phase

- A detection of polarized light from a CEGP will give a clear determination of grain size in the dust clouds.



λ = 5 times grain radius



λ = 0.05 times grain radius

Seager et al. (2000)

Conclusions

- OIP was used at SUSI with a 10^{-2} precision with very little sophistication.
- I will soon introduce an OIP mode in H band at PTI, with an expected 10^{-4} precision.
- This will enable detection of scattered light from debris disks (e.g. Vega-like stars), but won't detect extra-solar planets in the initial implementation.

Questions?