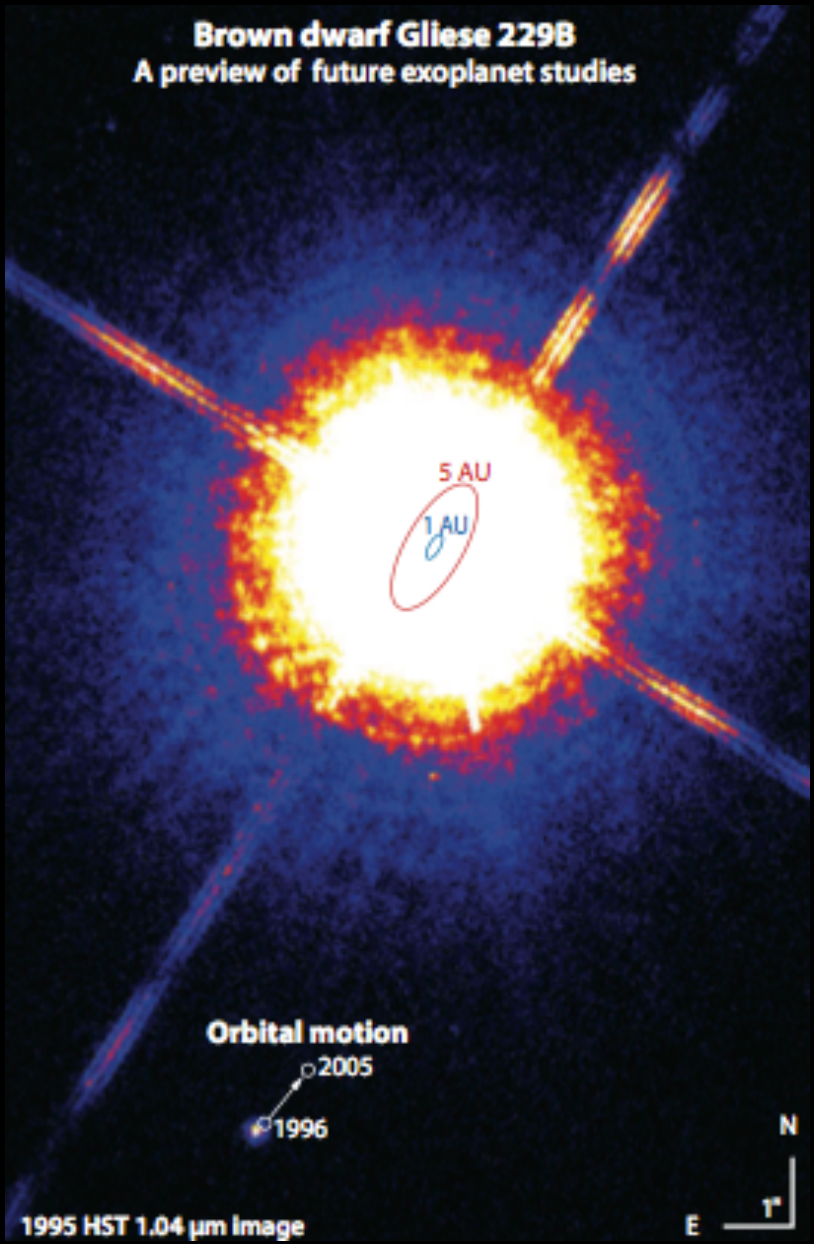
Controlling Scattered Starlight in Imaging

G. Vasisht (JPL, Caltech)



Oppenheimer & Hinkley 2009

Palomar P1640 Collaboration

American Museum of Natural History

Ben R Oppenheimer
Doug Brenner
Remi Soummer (STScI)
Laurent Pueyo (STScI)
A. Sivaramakrishnan
Neil Zimmerman

JPL

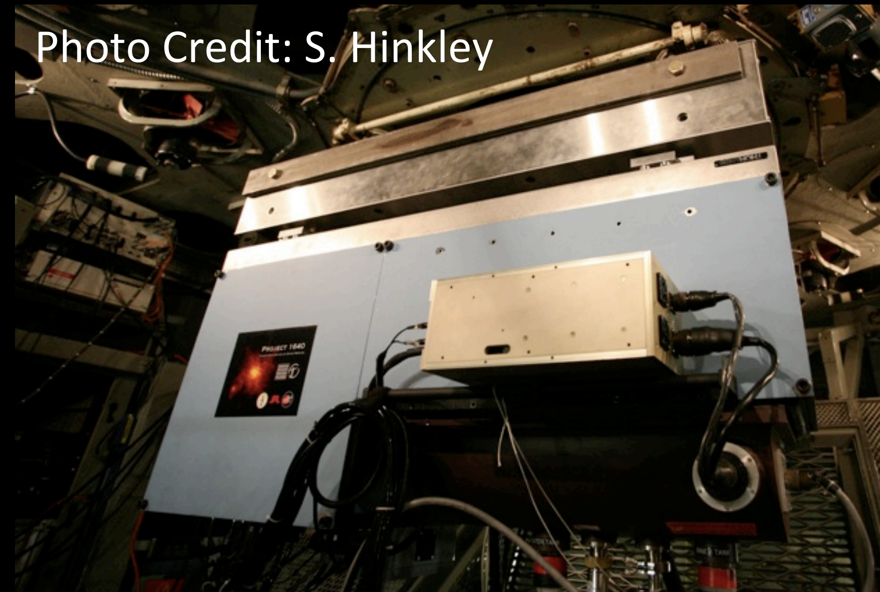
Gautam Vasisht
Chas Beichman
Rick Burruss
Jenny Roberts
Gene Serabyn
Mike Shao
James K. Wallace
C. X. Zhai

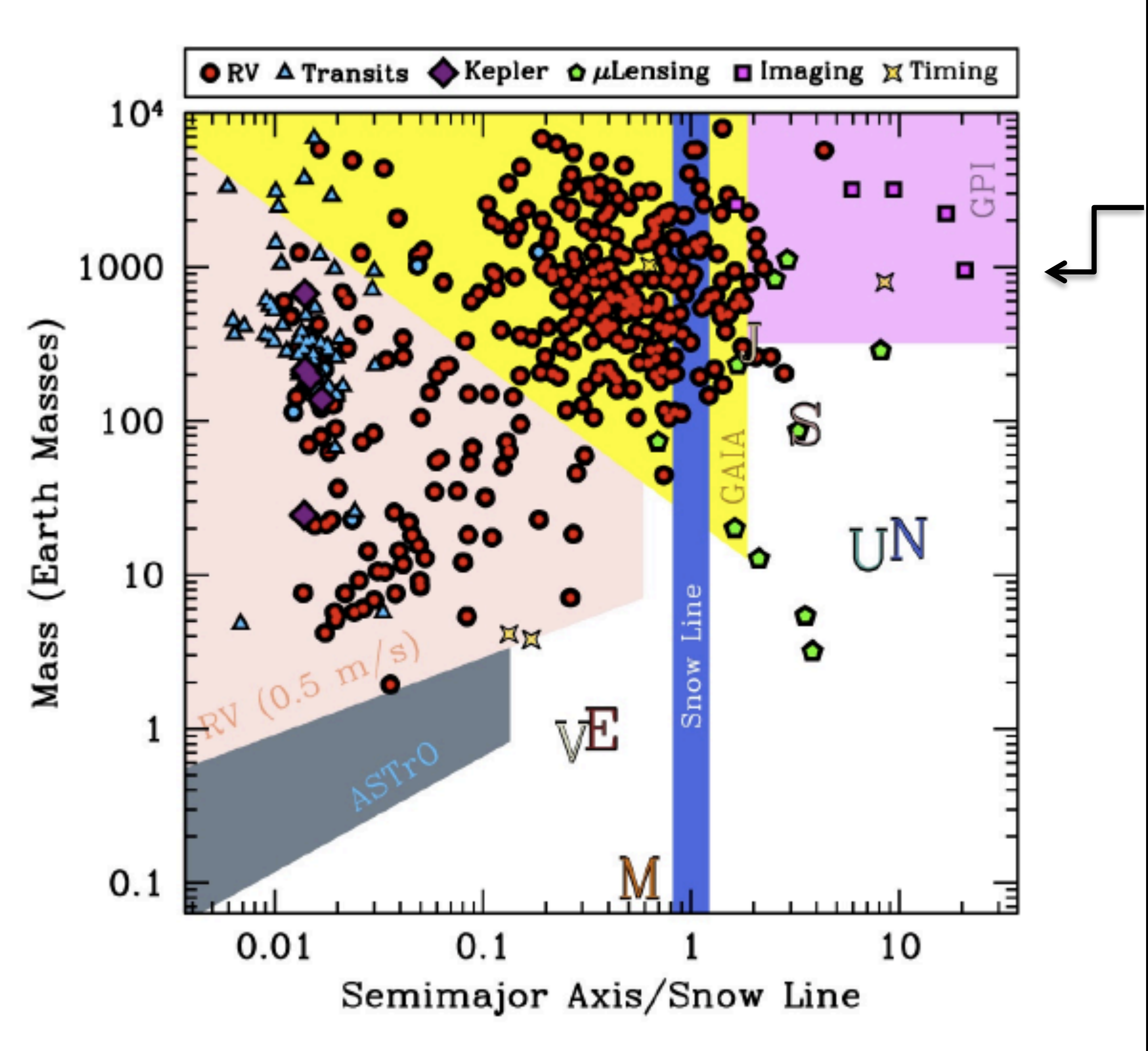
California Institute of Technology 1891

Rich Dekany
Justin Crepp
Sasha Hinkley
Lynne Hillenbrand

IoA University of Cambridge

Ian Parry

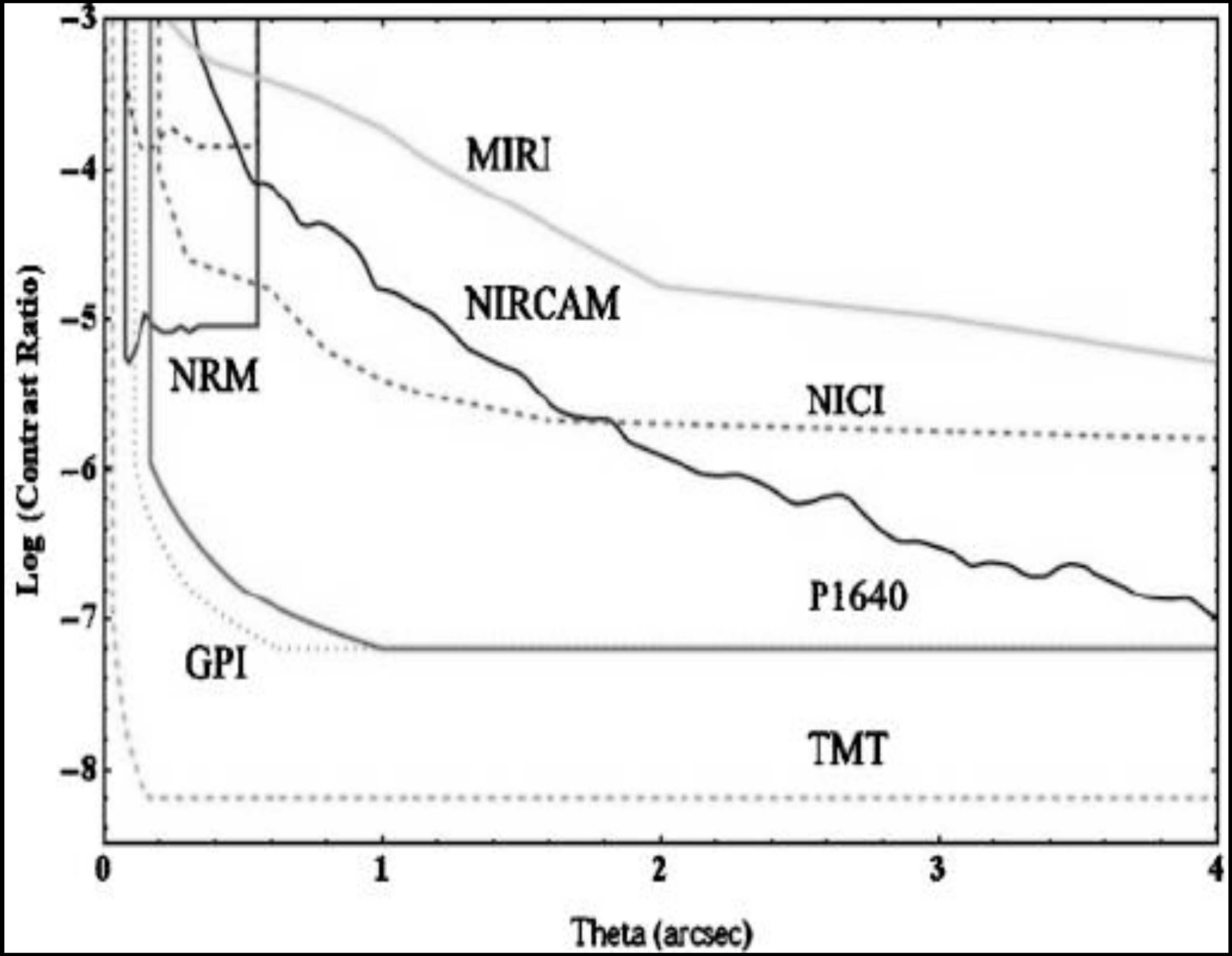




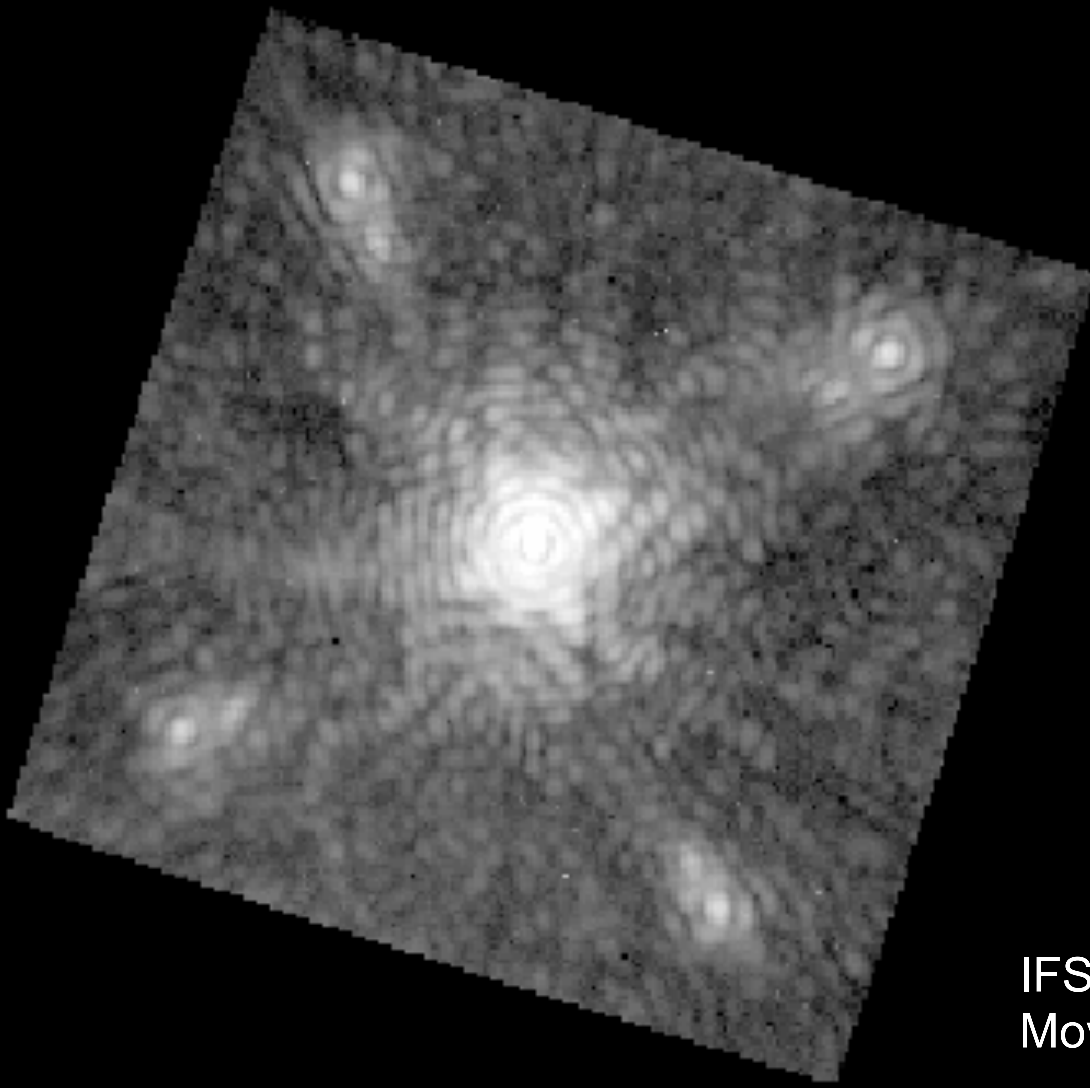
Next generation Direct Imaging

From S. Gaudi

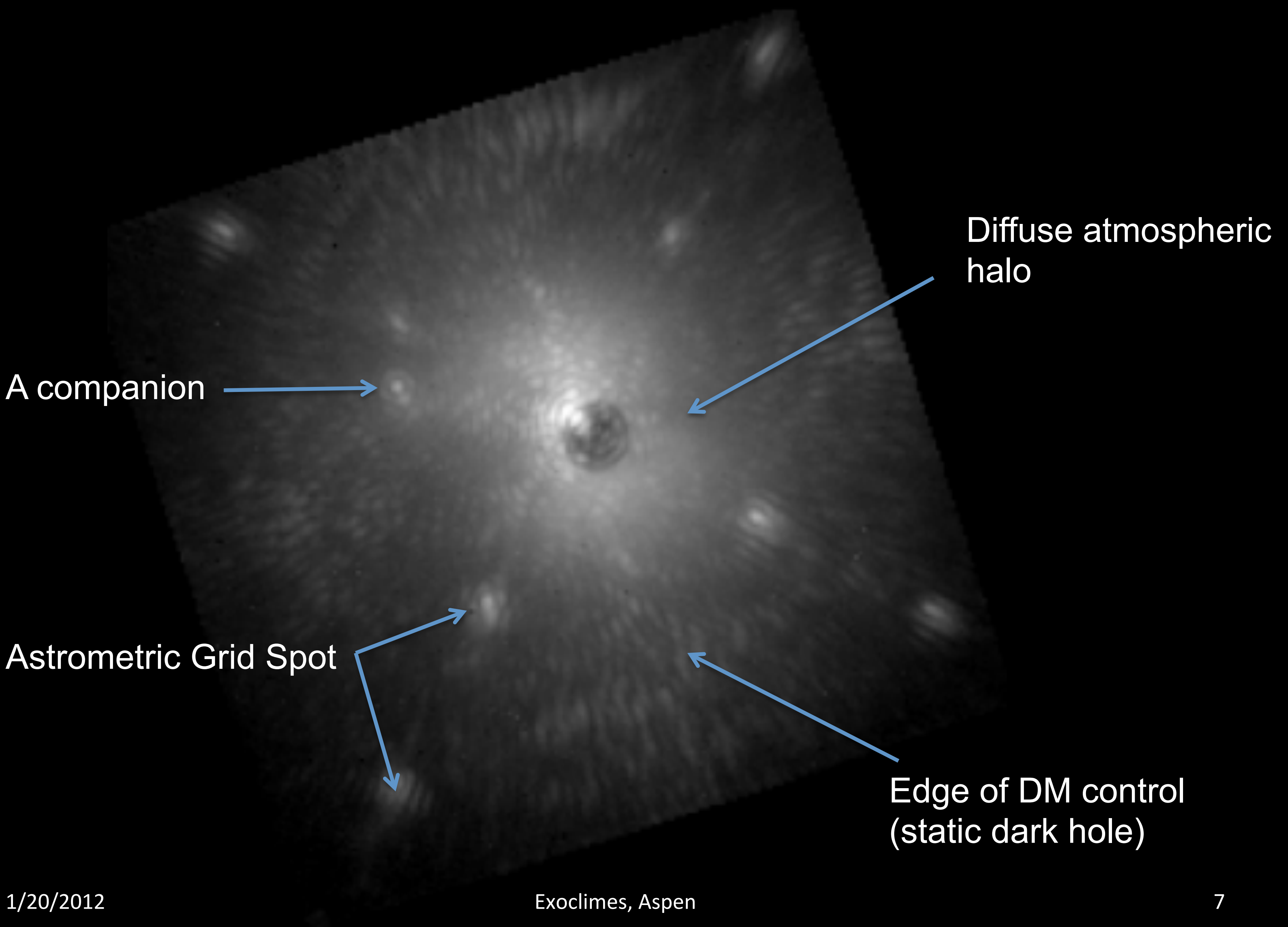
Contrast versus separation

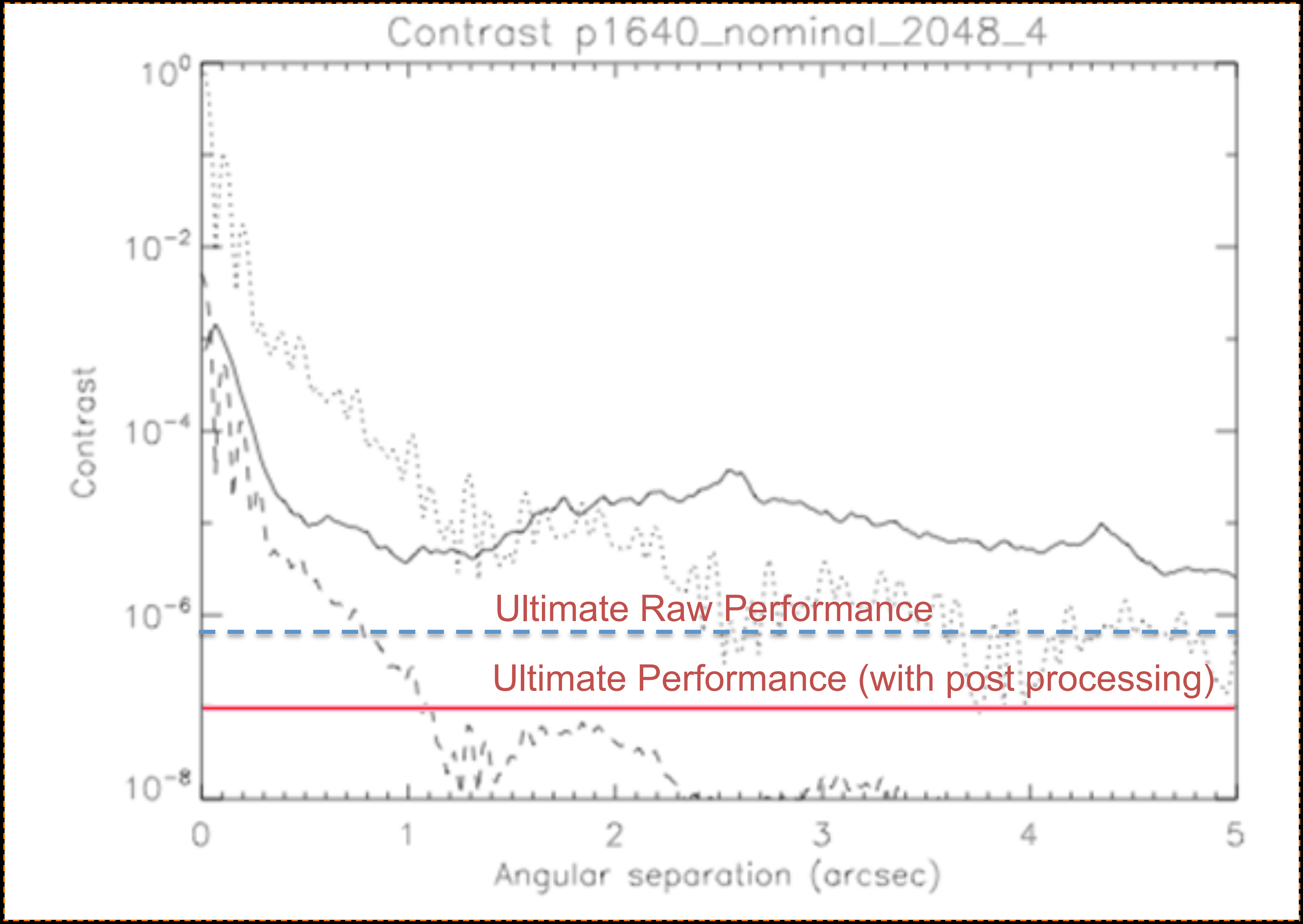


Beichman et al. 2010



IFS Dark Hole Movie

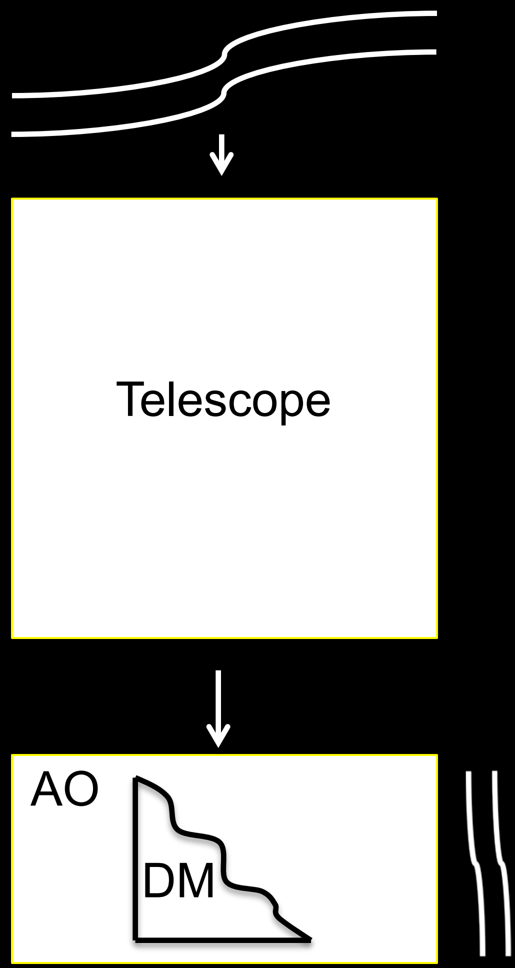

Diffuse atmospheric halo
A companion
Astrometric Grid Spot
Edge of DM control (static dark hole)

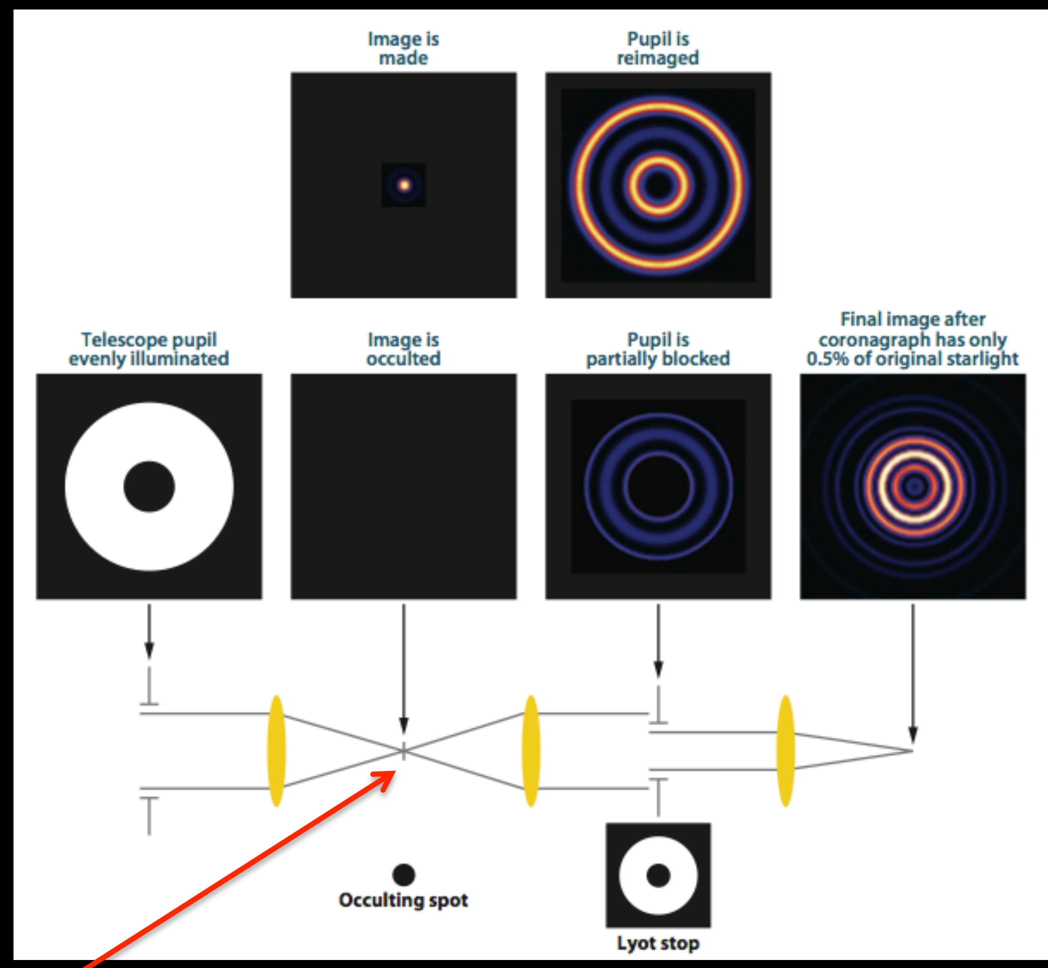

Contrast p1640_nominal_2048_4
Contrast
Angular separation (arcsec)
Ultimate Raw Performance
Ultimate Performance (with post processing)
10^{0}
10^{-2}
10^{-4}
10^{-6}
10^{-8}
0
1
2
3
4
5

Levels of Control

- Control of the dynamic atmosphere
  - ~100 nm residuals (rms)
  - Should set the ultimate contrast floor
- Control of slowly evolving wavefront corrugations in the optical system
  - Few nm (rms)
- Suppression of static diffraction by the coronagraph

Toy Next Gen AOC

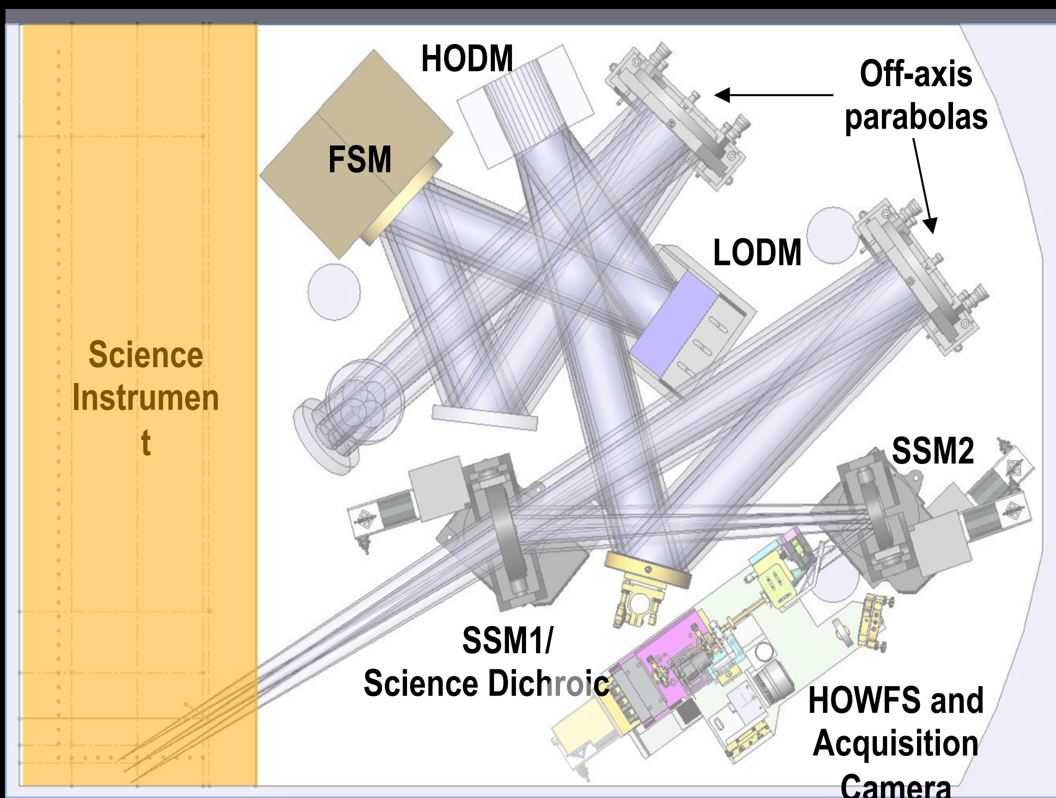


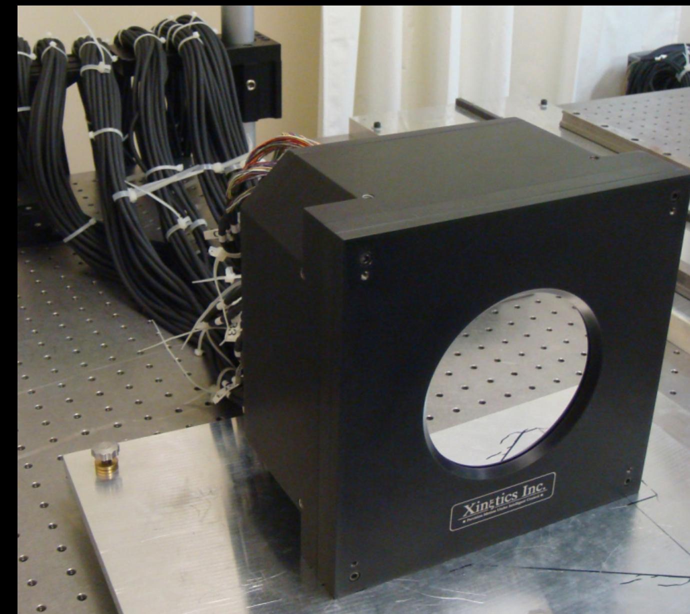


Observe the full E-field here (CAL)

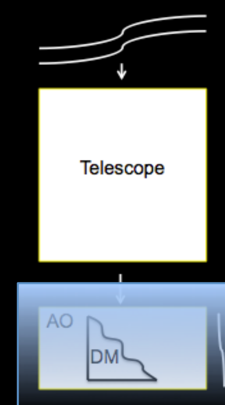
Upgrade Facility AO to Palm 3000 Complete

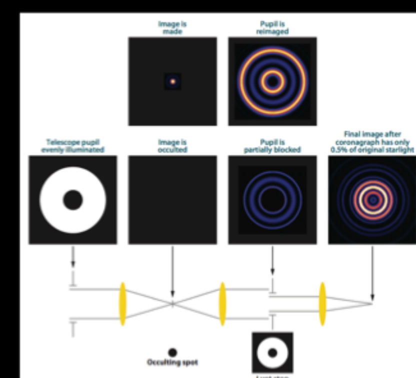
- 3,388 Actuator Xinetics Tweeter DM
- High-order Wave Front Sensor (2 KHz)
  (63 x 63 Shack-Hartmann, 2x2 subapertures).
- Configurable pupil subapertures



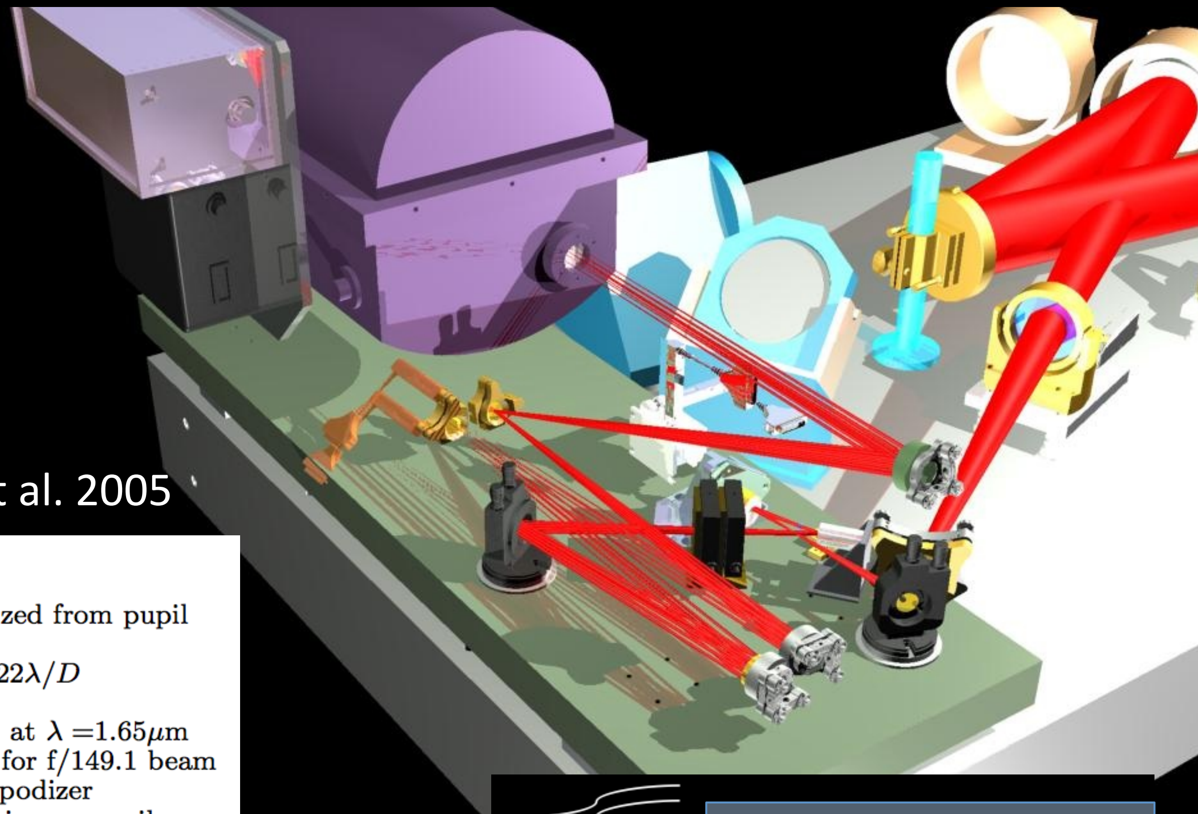


Dekany et al. 2006 etc.





P1640 Coronagraph + IFS

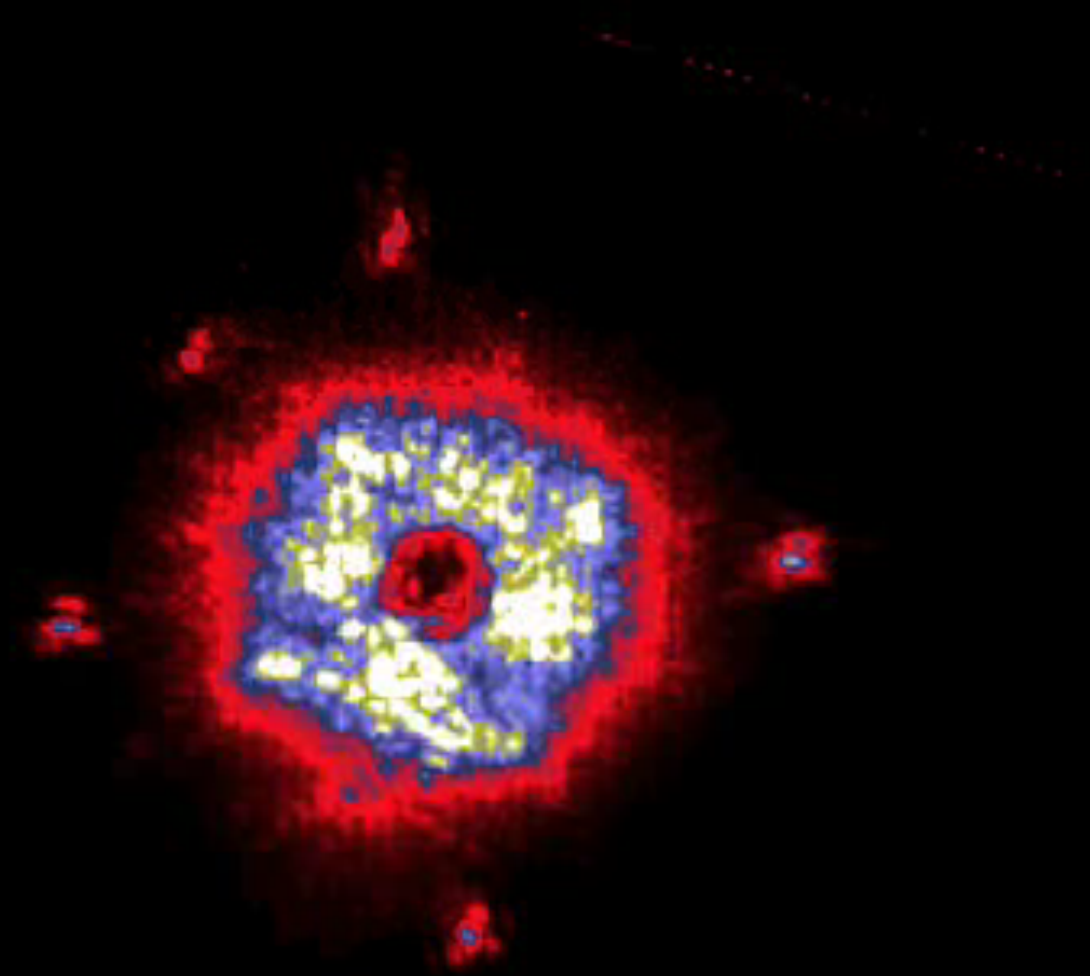


Hinkley et al. 2010; Soummer et al. 2005

Coronagraph:	
Apodizer diameter (mm)	3.80 2% undersized from pupil
Astrometric Grid	Δm = 7.4 4 spots at $22\lambda/D$
Focal Plane Mask Size	370 mas $=5.37\ \lambda/D$ at $\lambda=1.65\mu$m $=1322\ \mu$m for f/149.1 beam
Undersized Lyot Stop Factor	2% from Apodizer 4% from primary pupil
Final f/ratio	f/164.6 at IFS microlenses
Final diffraction limit (mas)	22.08 at 1.05μm
IFS:	
Wavelength Coverage (μm)	1.05 - 1.75
IFS Field of View (mas)	3840
IFS pixel scale (mas/microlens)	19.2
Microlens Pitch (μm)	75
Number of Spectra	$200 \times 200 = 4 \times 10^4$
Spectral Resolution ($\lambda/\Delta\lambda$)	33 to 58

1640 IFS
Extracted Cube

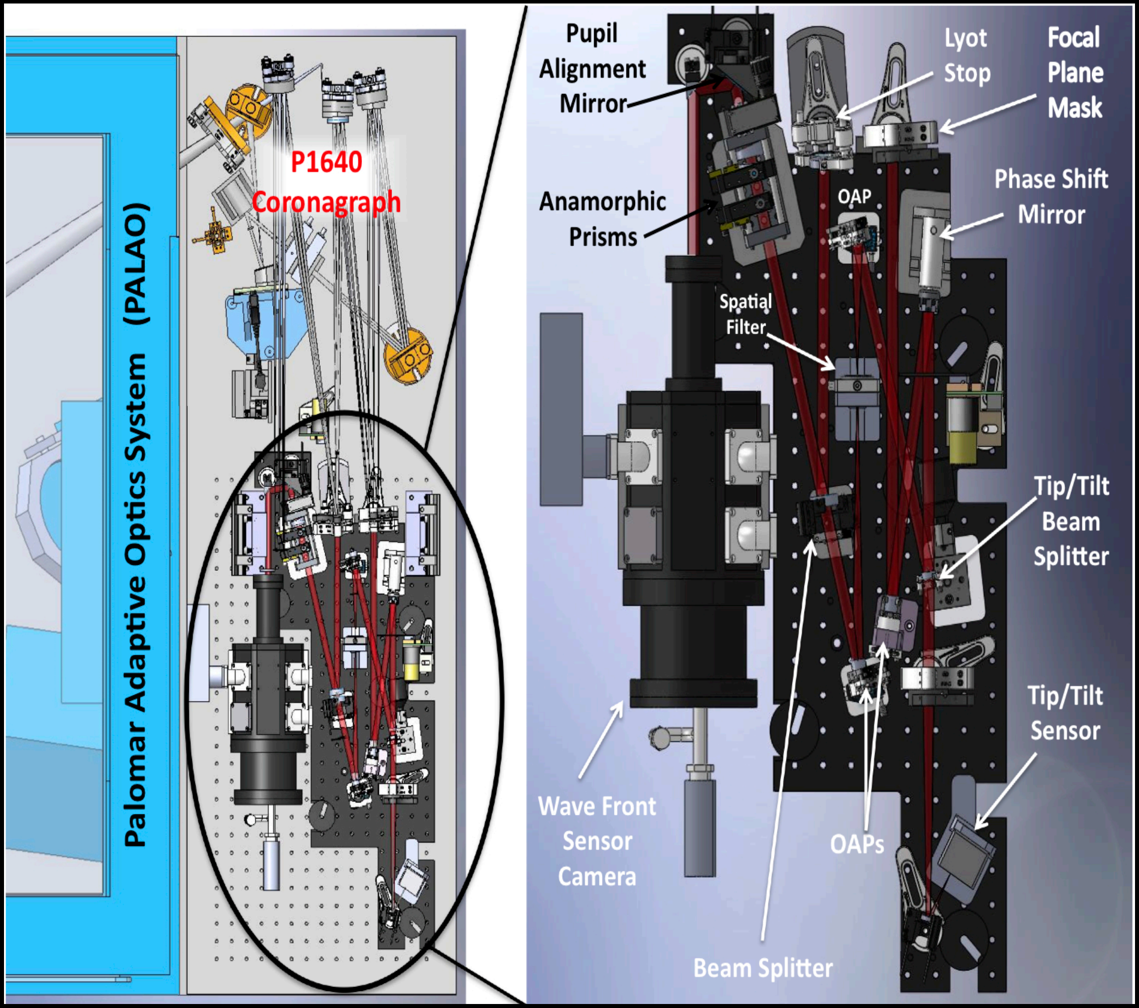
marching in λ



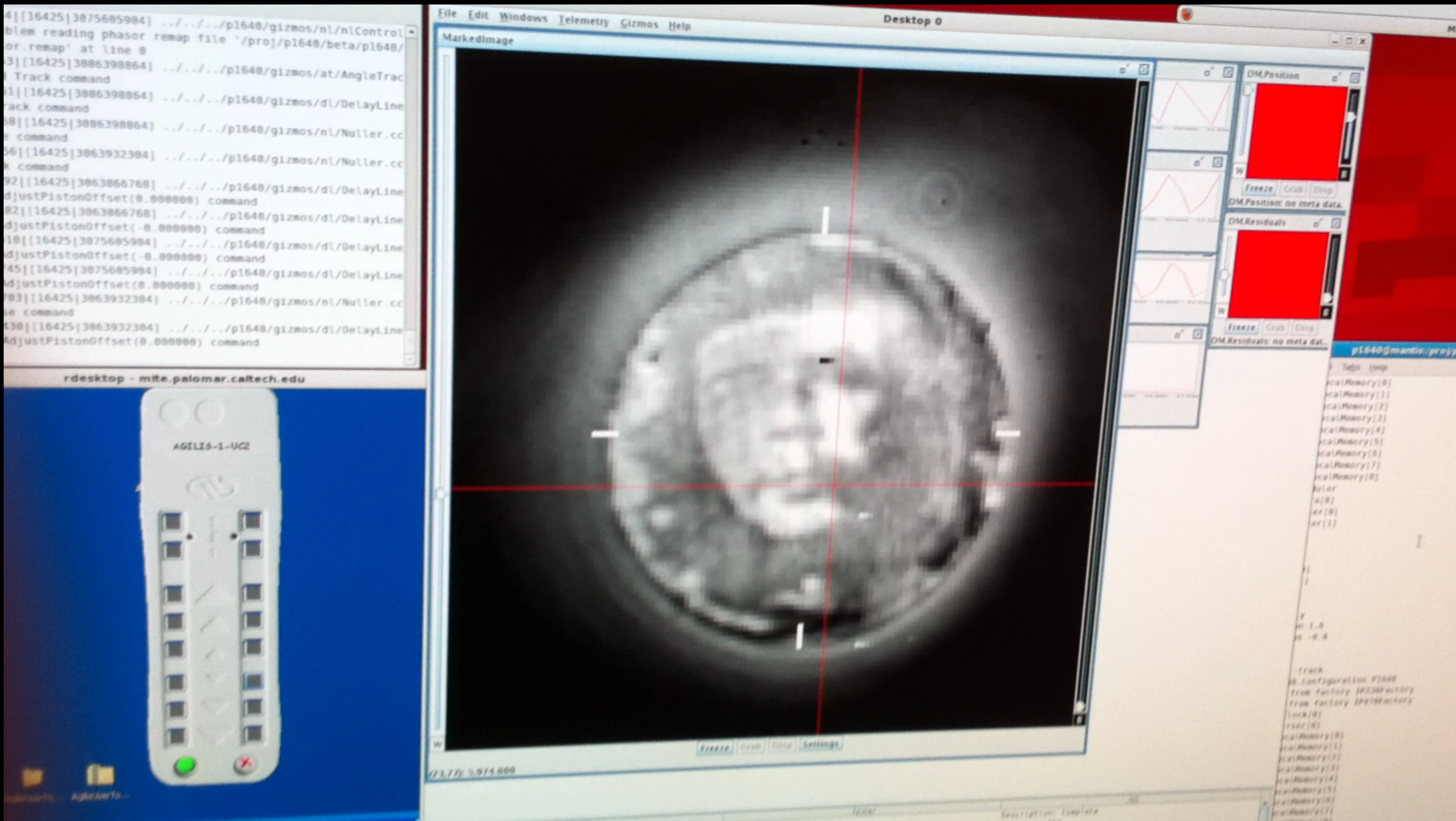
CAL – E field sensor

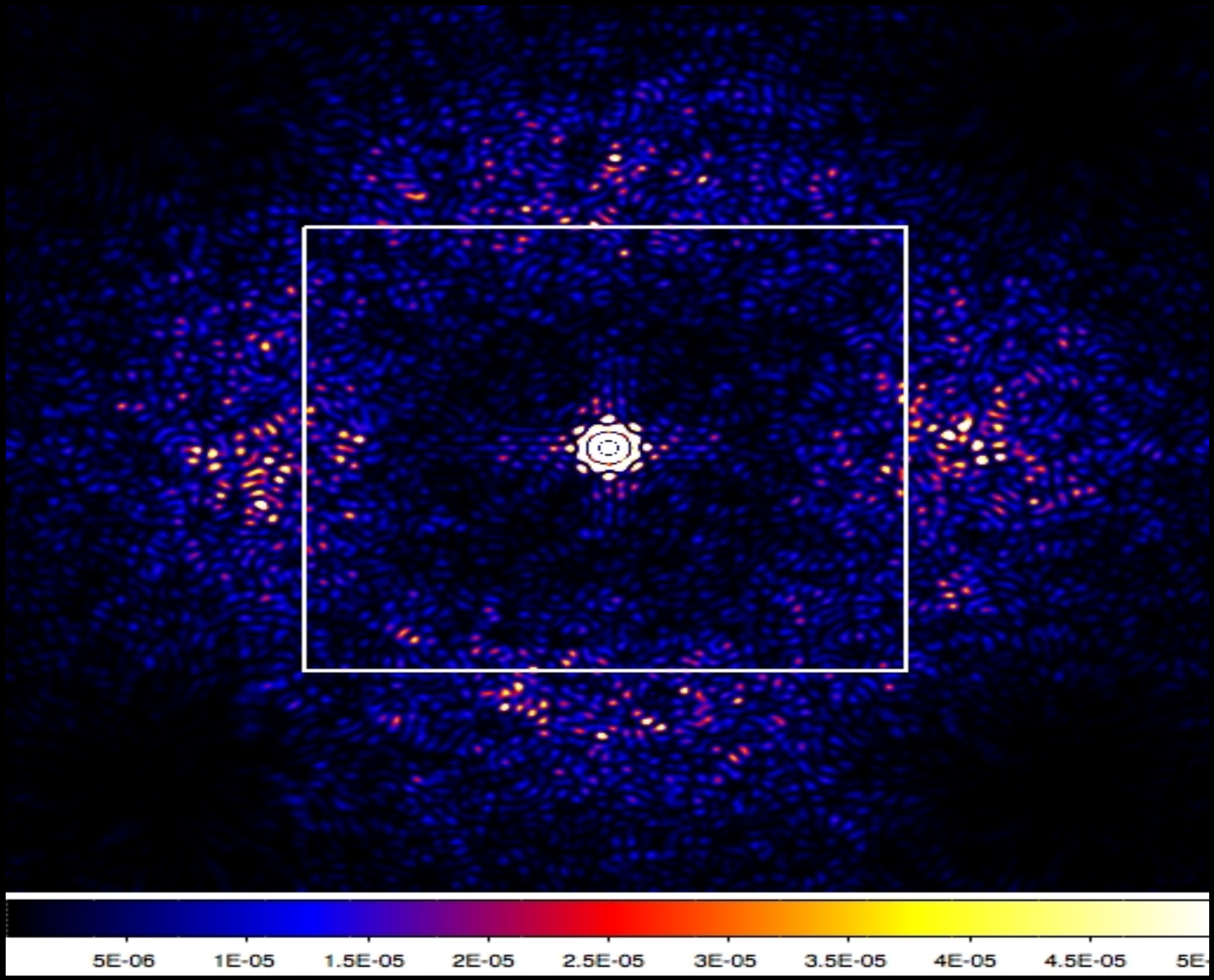
e.g. Wallace et al. 2004
Vasisht et al. 2006

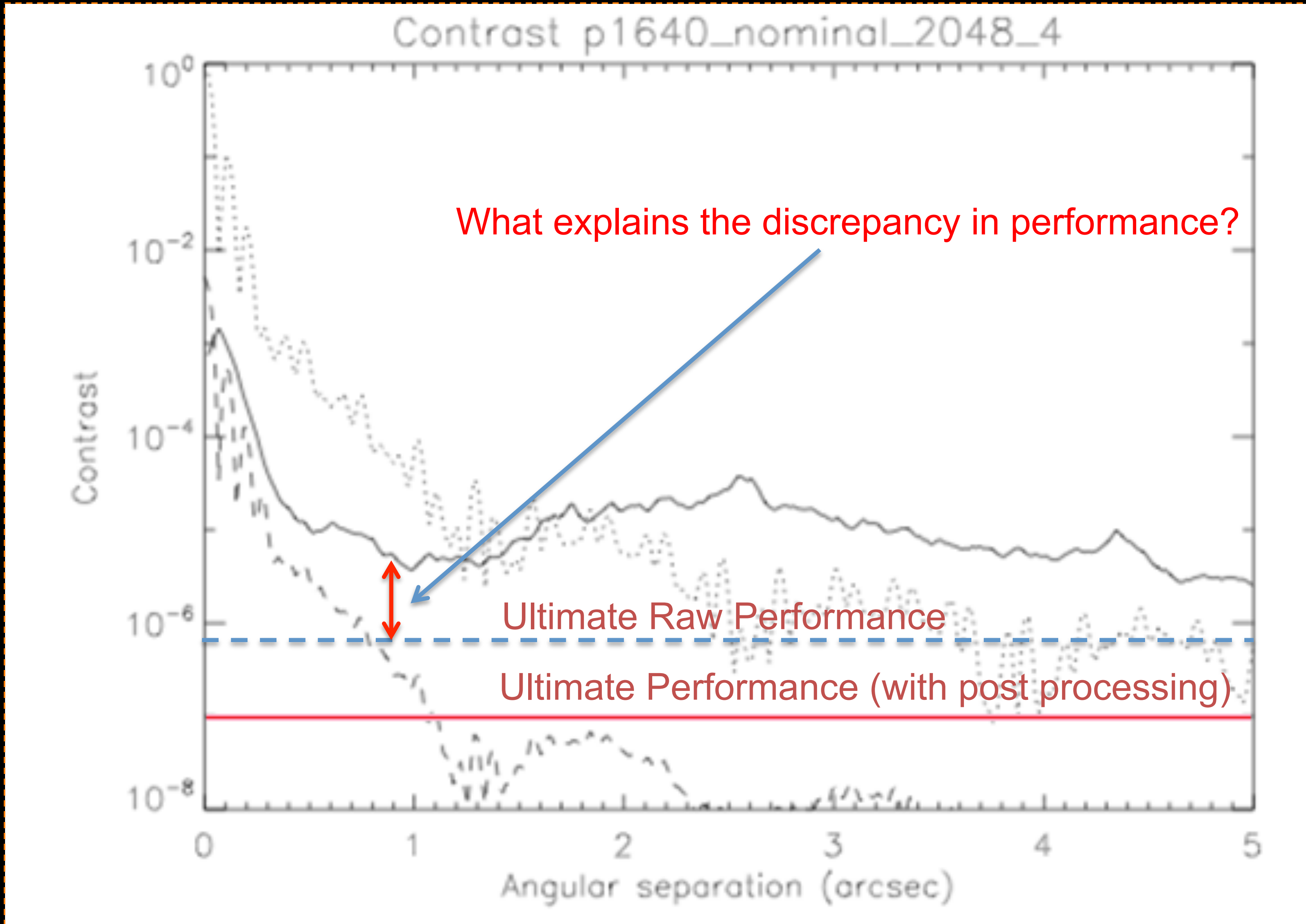
- "CAL" - Mach-Zehnder interferometer based WFS
- Functionally and optically similar to WFS for GPI, and developed in parallel
- Senses quasistatic wavefronts, with 0.1 Hz updates to AO
  - Requires ExAO to work well on sky
  - CAL severely underperforms in the limit of moderate Strehl



Working Principle

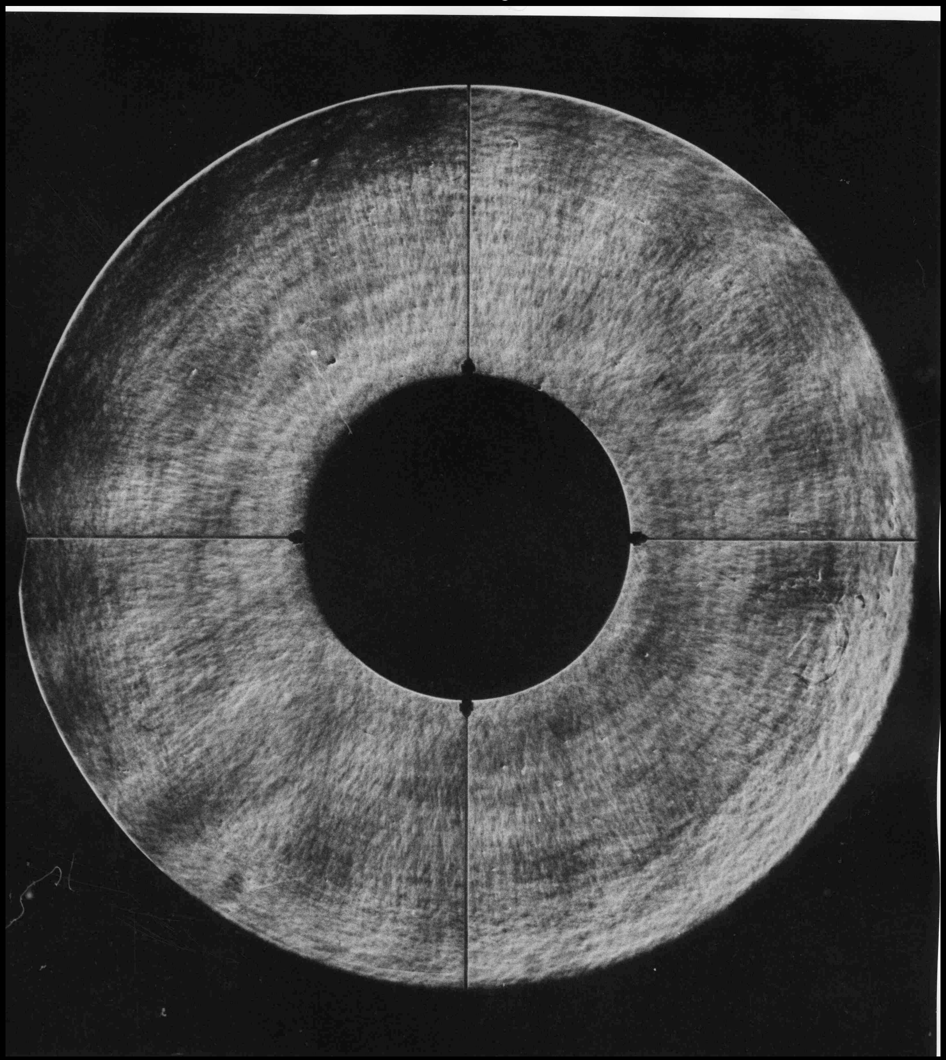



5E-06
1E-05
1.5E-05
2E-05
2.5E-05
3E-05
3.5E-05
4E-05
4.5E-05


Contrast p1640_nominal_2048_4
What explains the discrepancy in performance?
Ultimate Raw Performance
Ultimate Performance (with post processing)
Contrast
10^0
10^{-2}
10^{-4}
10^{-6}
10^{-8}
0
1
2
3
4
5
Angular separation (arcsec)

- … larger than expected Amplitude Corrugations (3x)
- Causes: not known
- Many candidates
- Large mirrors (M1, M2) ?

Courtesy: McKenna, Wallace



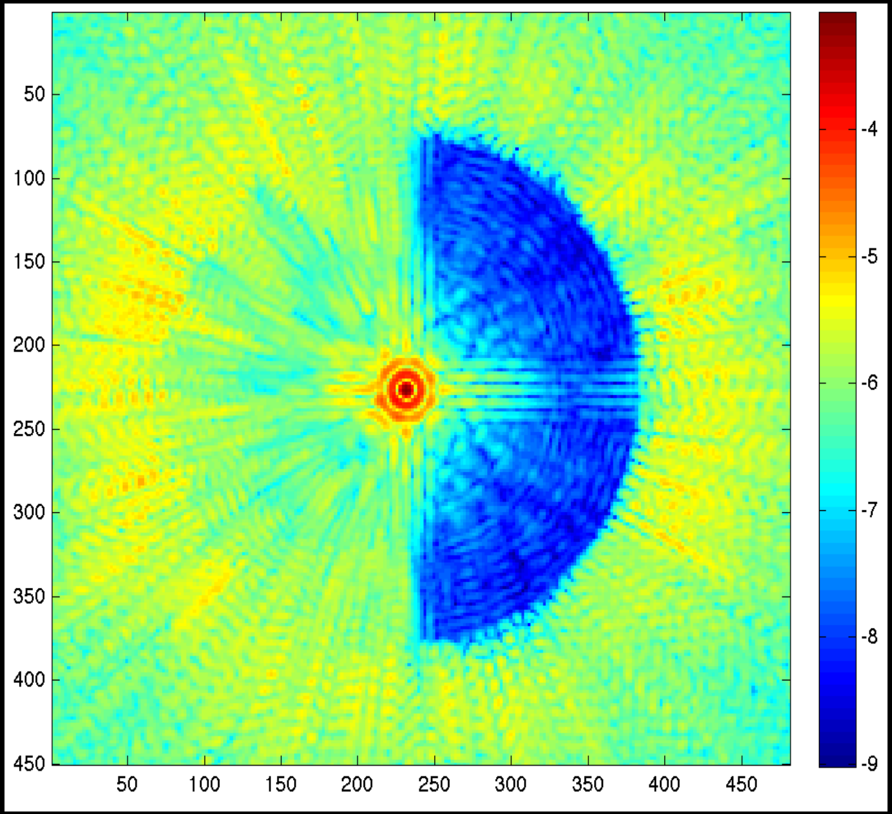
How to fix this: Active E-field Control

Model, then replace offending optics

Plus …

Full electric field control

Use the CAL E-field measurements to construct and maintain on-sky HALF PLANE DARK HOLES



Courtesy: E. Cady

Summary

- We are on sky with ExAO (P3K), active control of quasistatic errors (CAL), and an apodized Lyot coronagraph mated to an integral field spectrograph (P1640).
- CAL can control wavefront phase to the desired levels of ~5 nm rms
- There are larger than expected amplitude errors (~ 5% rms)
  - Reason presently unknown
  - Correction may require full E-field control
  - An interesting challenge

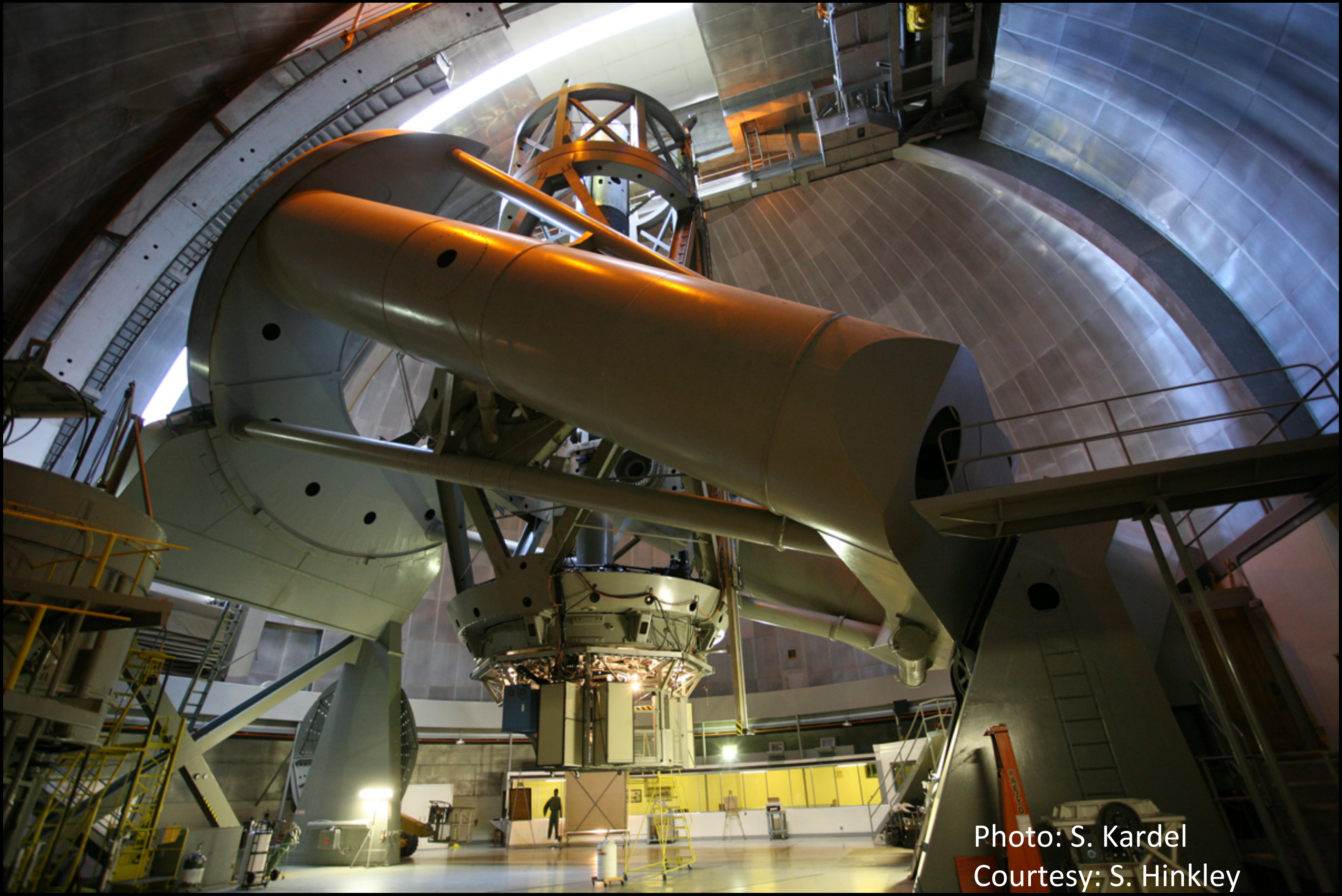


Photo: S. Kardel
Courtesy: S. Hinkley

Principle of Operation

Image of Reference Electric Field

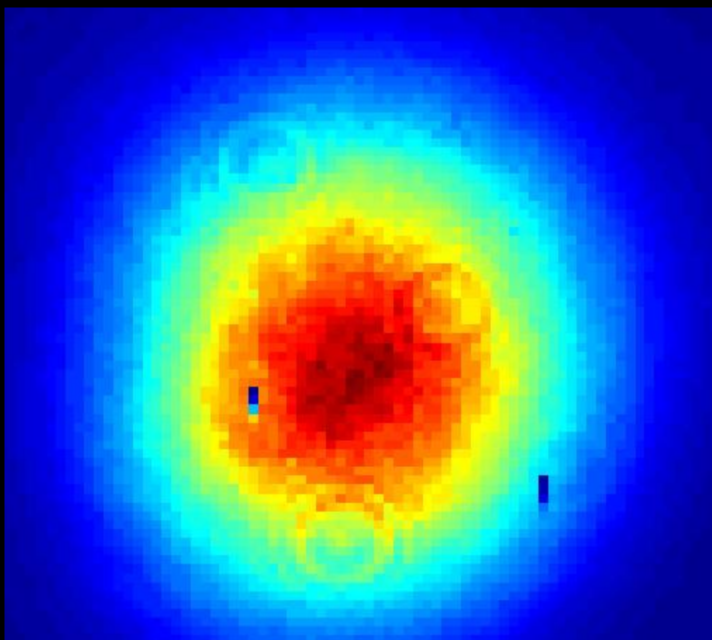
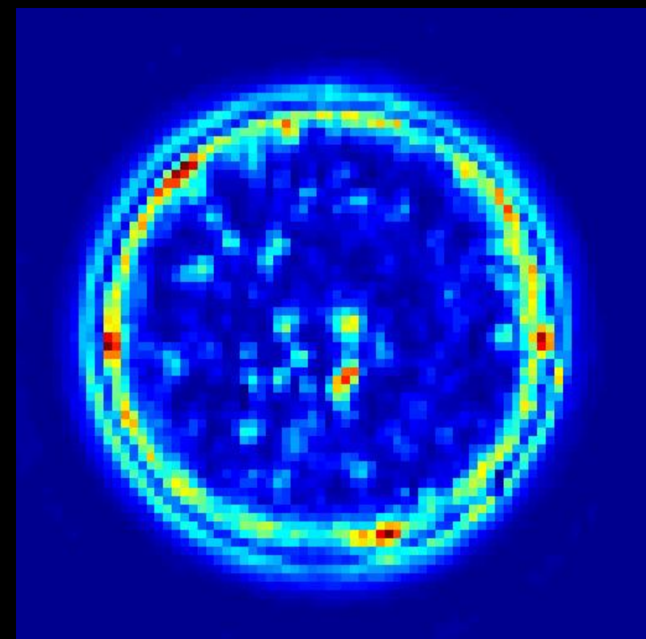


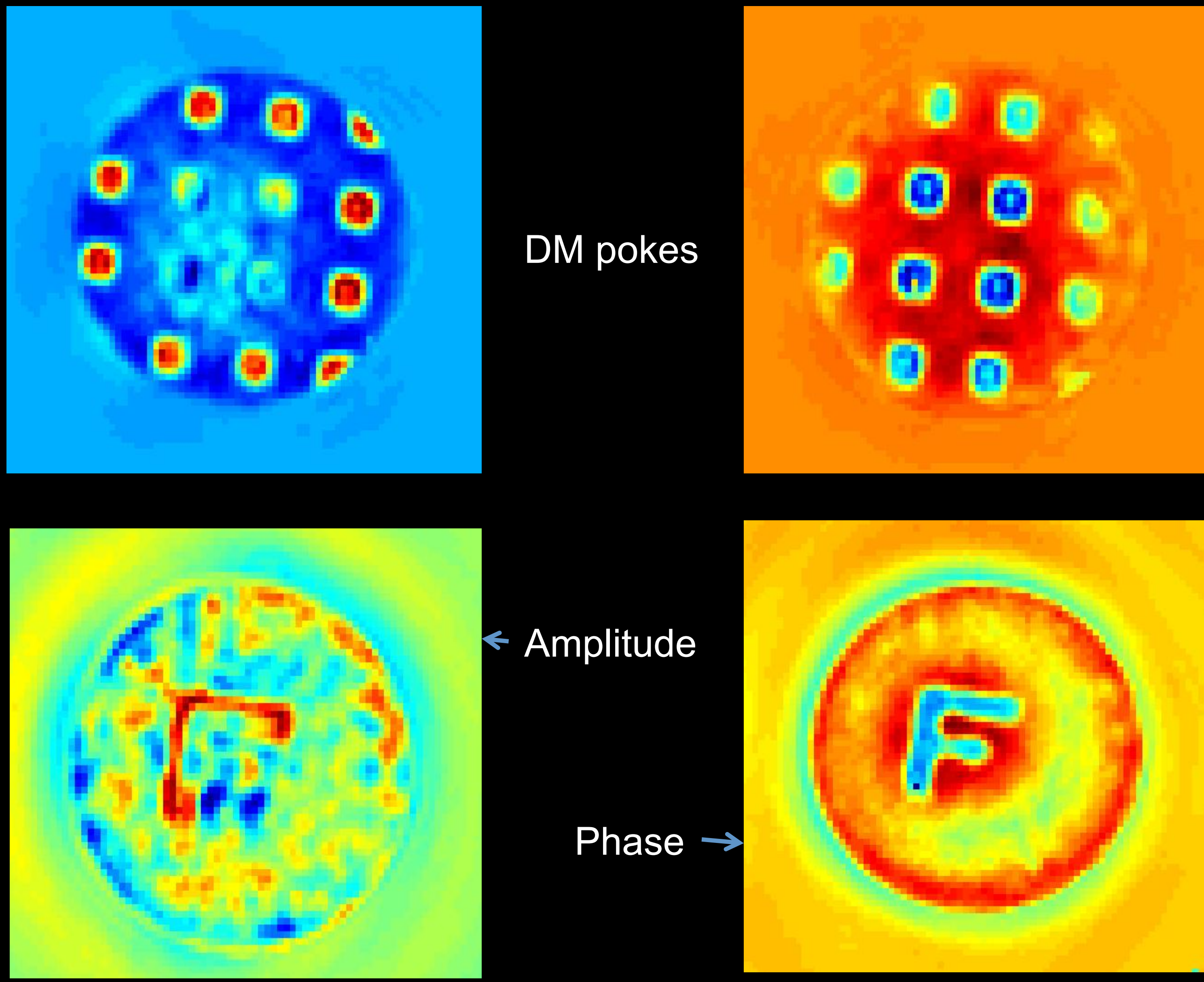
Image of Coronagraphic Pupil

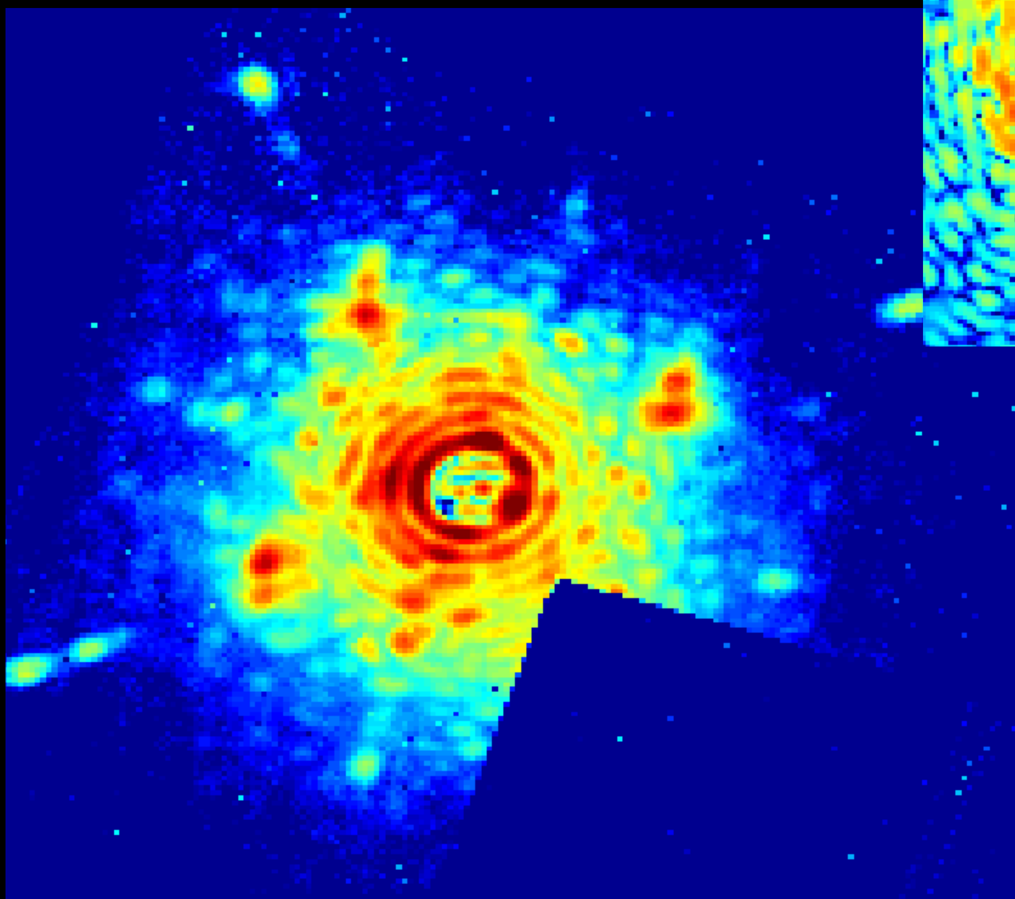


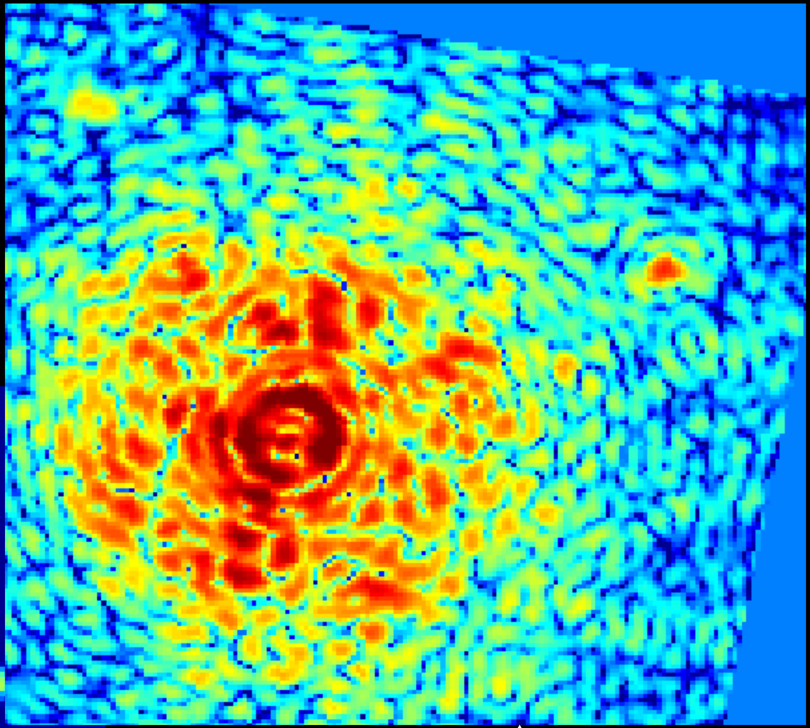
$$E_{wfs} = E_{ref} e^{j\chi} + E_{cor}$$

$$I_{wfs} = \left\langle E_{wfs} E_{wfs}^{*} \right\rangle$$

Calibrations







Synthetic Image