This work was performed under the auspices of the U.S. Department of Energy by University of California, Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

gpi Gemini Planet Imager

Bruce Macintosh

for the GPI team

Presented at the "Spirit of Lyot" conference June 7, 2007

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Berkeley
University of California

Université de Montréal

Laboratory for Adaptive Optics
UCO/Lick Observatory
University of California, Santa Cruz

American Museum of Natural History

CfAO

National Research Council Canada
Conseil national de recherches Canada

UCLA

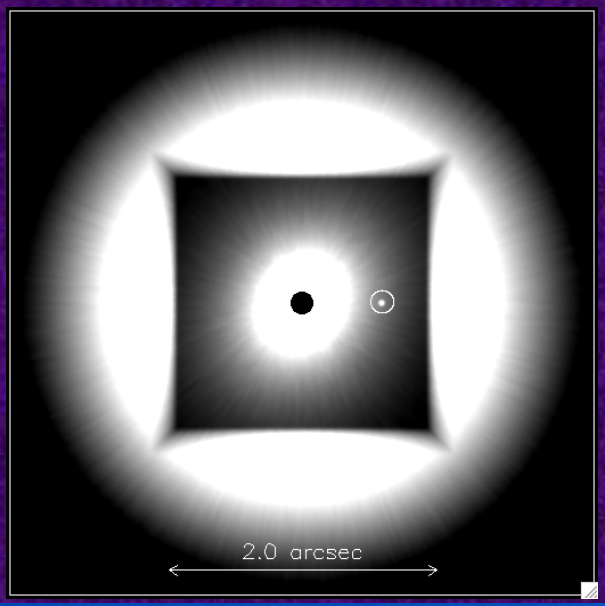
ExAOC / GPI history

2004: Gemini "Extreme AO Coronagraph" Conceptual design begins (CfAO-led)

2005: Gemini selects team and project

2006: (June): Project start

2007: (May): PDR pass



Team

LLNL: Project lead + AO

HIA: Optomechanical + software

UCB: Science modeling

UCLA: IR spectrograph

JPL: Interferometer WFS

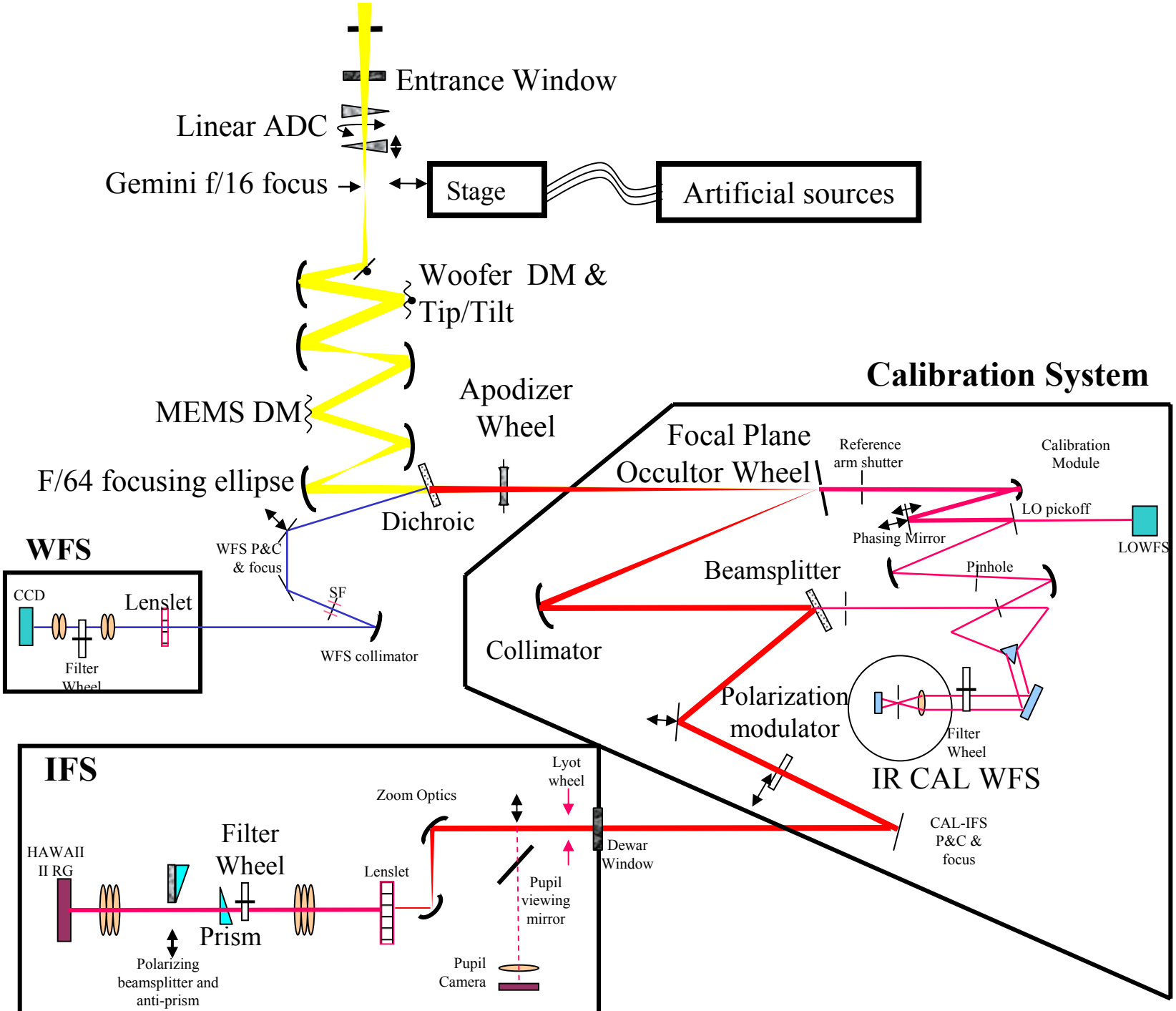
AMNH: Coronagraph masks&design

UdM: Data pipeline

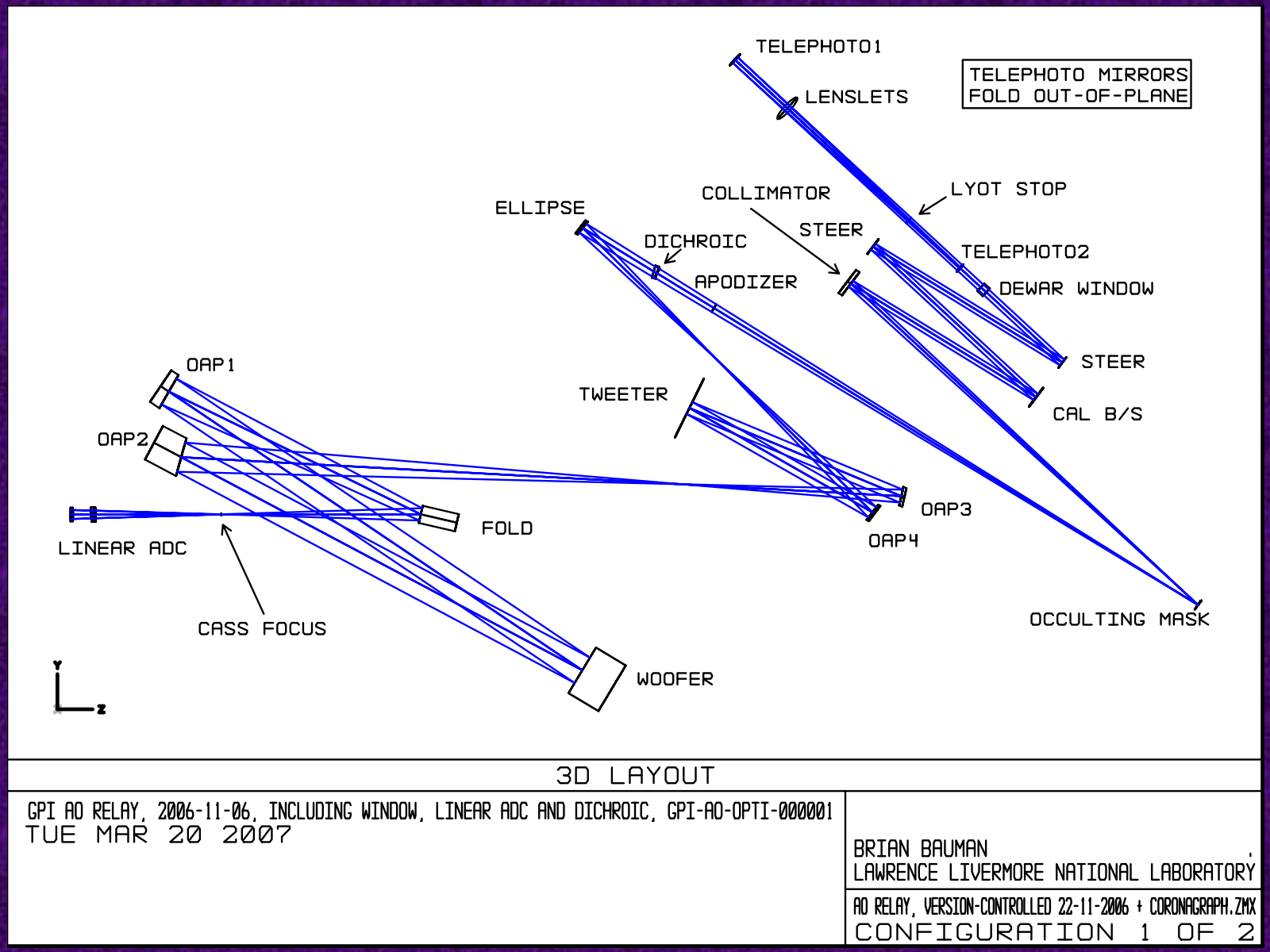
UCSC: Final integration&test

Key design requirements

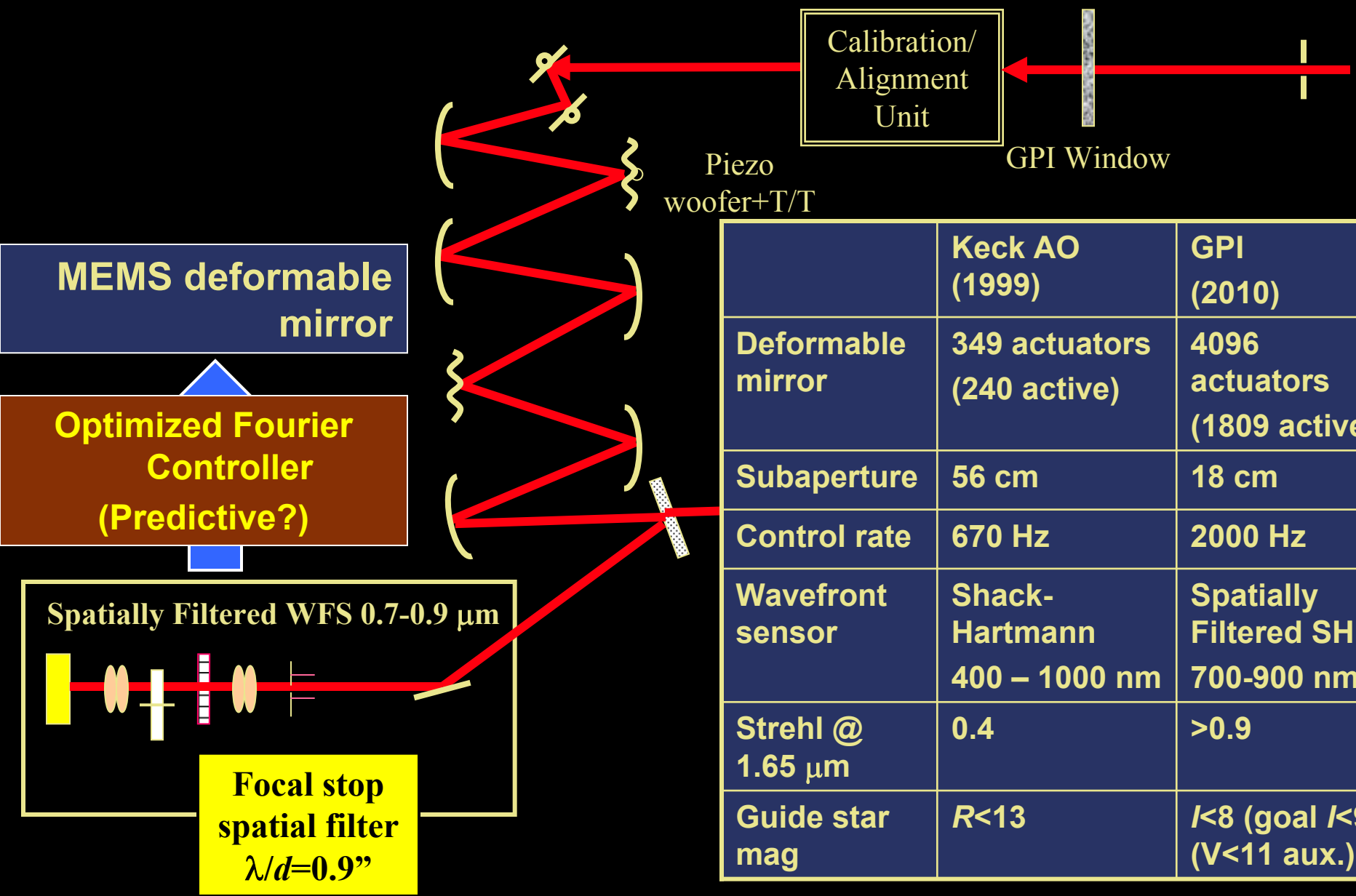
- **Detectable point-source contrast ~10^{-7} in 1 hour**
  - Fast (2000 Hz+) AO system to minimize atmosphere timelag errors
- **Science reach for a large sample of targets**
  - *I*<8 mag (I<9 goal)
- **Minimal systematic errors**
  - Goal: not be limited by systematic errors in 1-hr exposure
  - High-quality optics (1 nm mid-frequency WFE)
  - Precision infrared interferometer
  - Require 5+1 nm static WFE
  - Differential imaging helps but requires minimal chromatic errors
- **Differential imaging capability**
  - Distinguish planets from artifact speckles
  - Polarimetry for study of circumstellar dust
  - Lenslet integral field spectrograph + polarimeter
- **Spectral capability for followup**
  - R~40-50 sufficient given models + available photons


Entrance Window
Linear ADC
Gemini f/16 focus
Stage
Artificial sources
Woofer DM &
Tip/Tilt
MEMS DM
Apodizer
Wheel
F/64 focusing ellipse
Dichroic
Calibration System
Focal Plane
Occultor Wheel
Reference
arm shutter
Calibration
Module
LO pickoff
Phasing Mirror
LOWFS
Pinhole
Beamsplitter
Collimator
Polarization
modulator
Filter
Wheel
IR CAL WFS
CAL-IFS
P&C &
focus
WFS
CCD
Lenslet
Filter
Wheel
WFS P&C
& focus
SF
WFS collimator
IFS
HAWAII
II RG
Filter
Wheel
Prism
Polarizing
beamsplitter and
anti-prism
Lenslet
Zoom Optics
Lyot
wheel
Dewar
Window
Pupil
viewing
mirror
Pupil
Camera

GPI optical layout

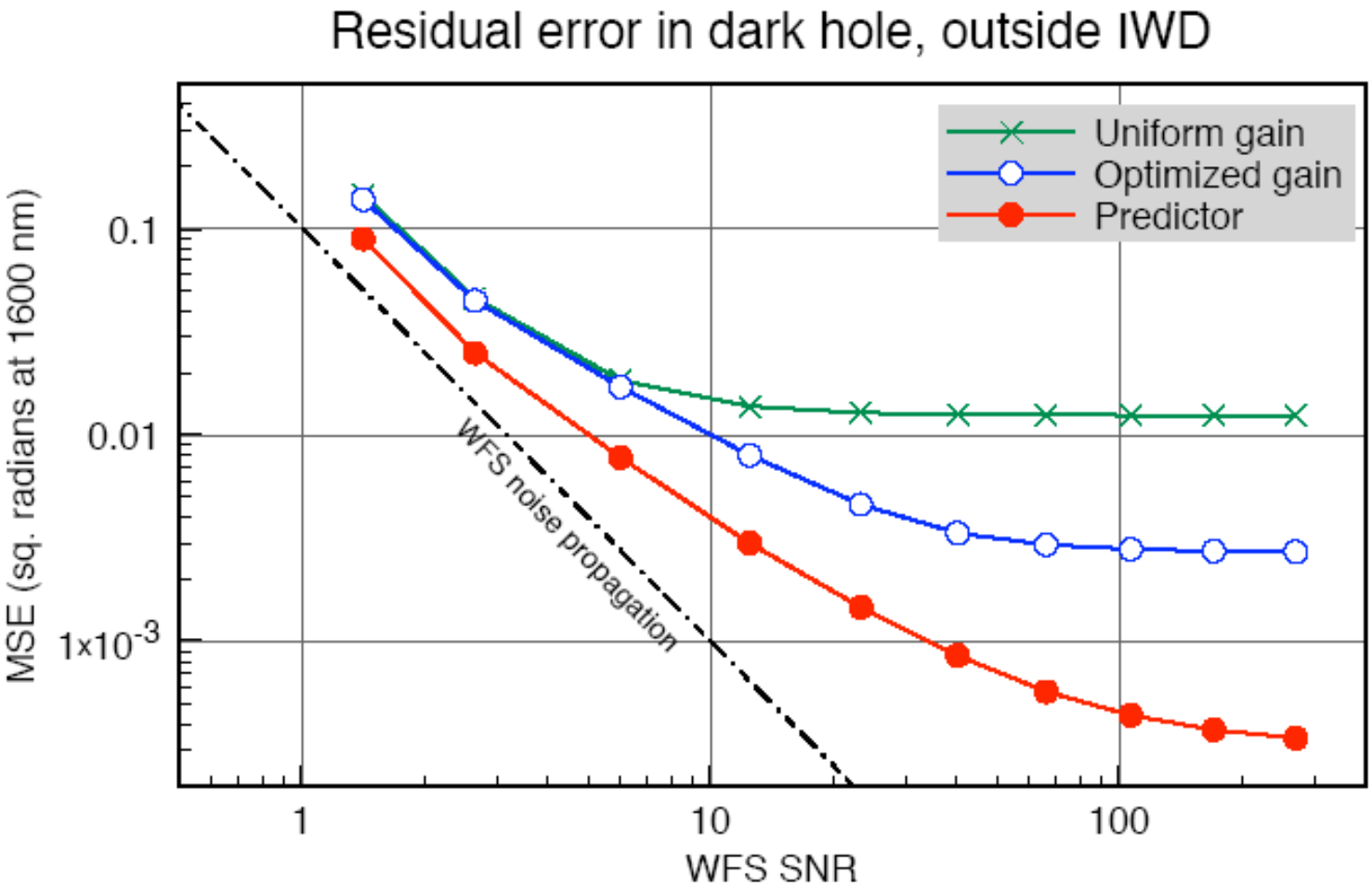


High order high-speed AO (LLNL)

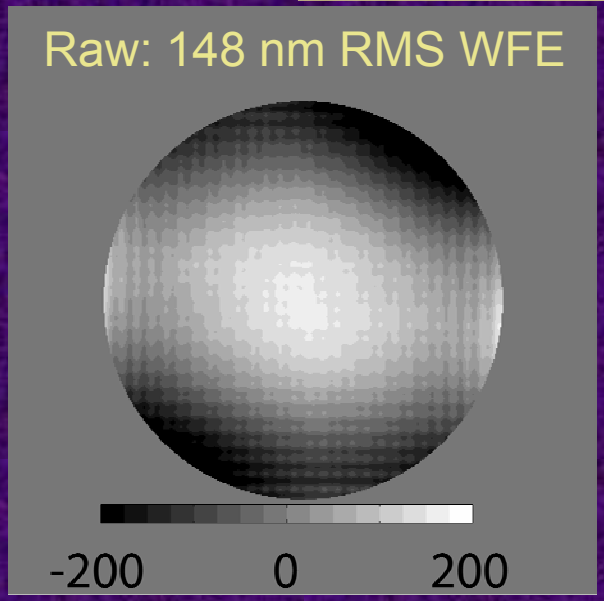


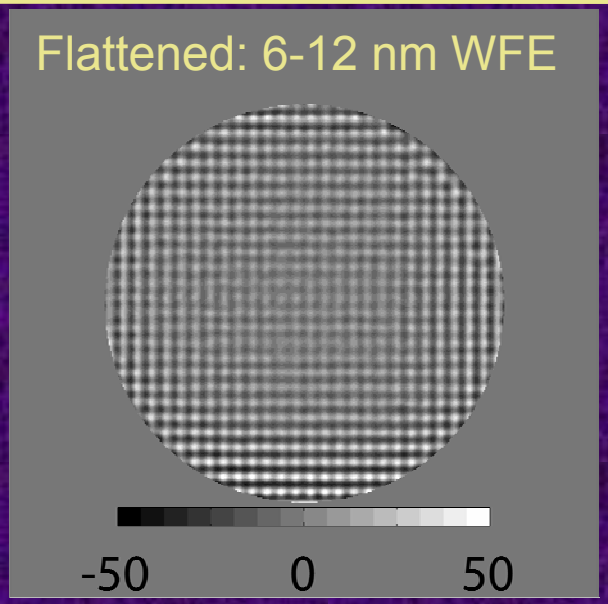
	Keck AO (1999)	GPI (2010)
Deformable mirror	349 actuators (240 active)	4096 actuators (1809 active)
Subaperture	56 cm	18 cm
Control rate	670 Hz	2000 Hz
Wavefront sensor	Shack-Hartmann 400 – 1000 nm	Spatially Filtered SH 700-900 nm
Strehl @ 1.65 μm	0.4	>0.9
Guide star mag	*R*<13	*I*<8 (goal *I*<9) (V<11 aux.)

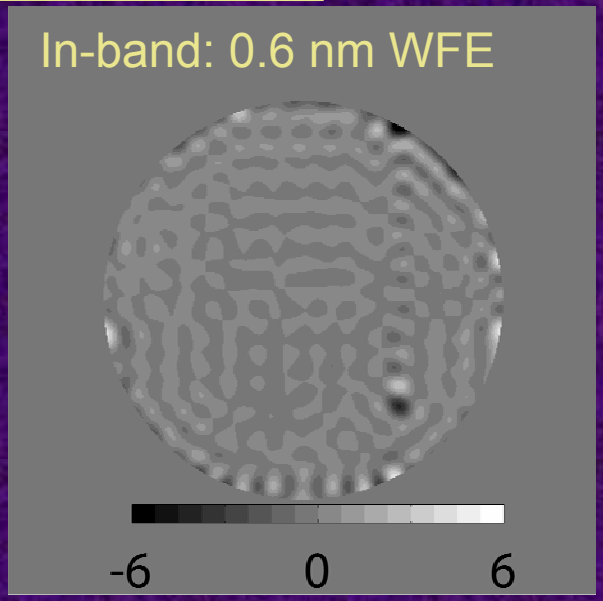
Optimized or predictive control



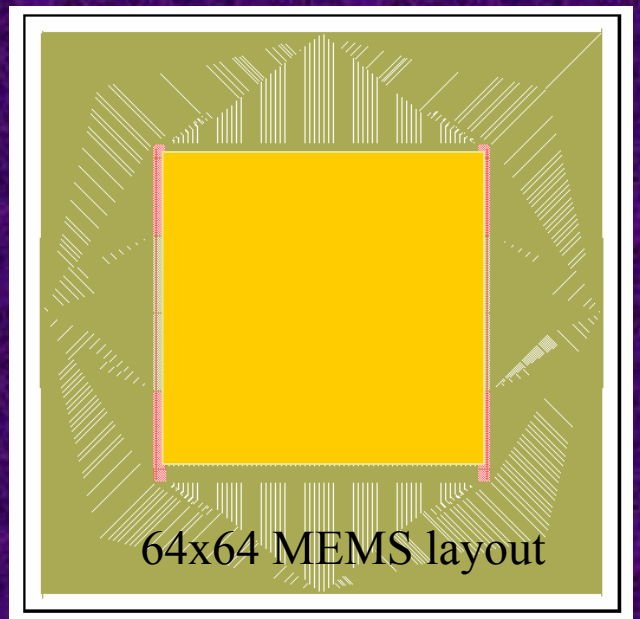
Boston Micromachines MEMS deformable mirror



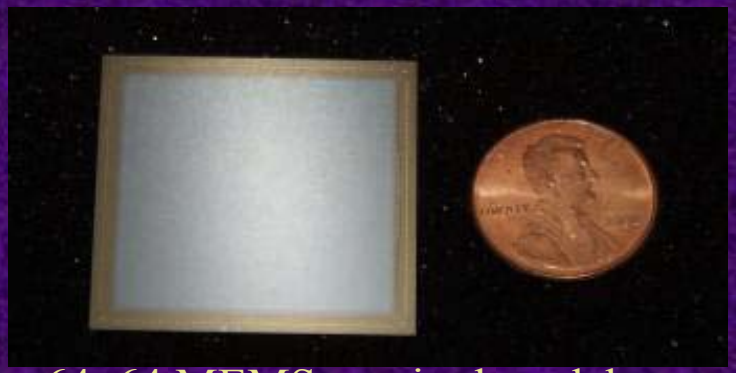




32x32 MEMS Evans et al 2006 Optics Exp. 14 5558

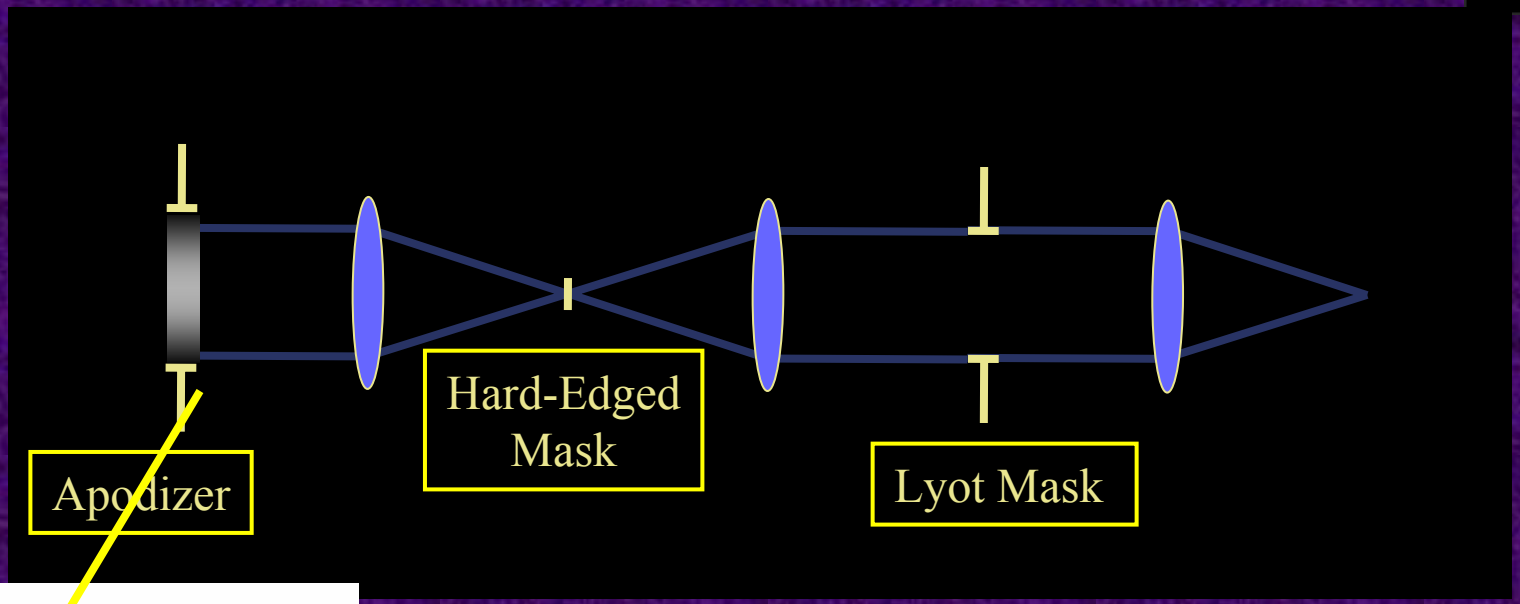


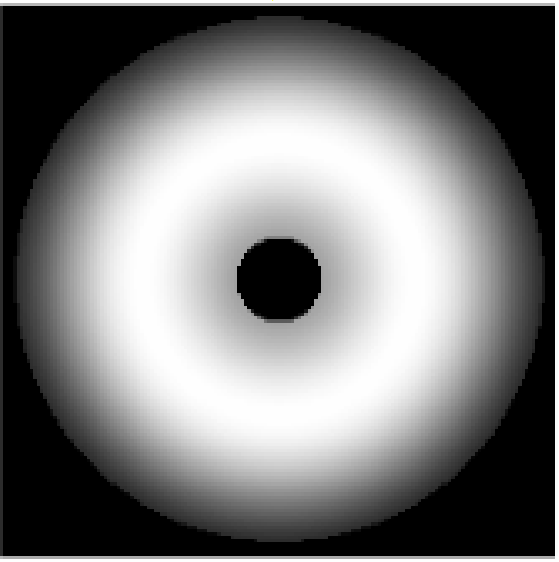
64x64 MEMS layout

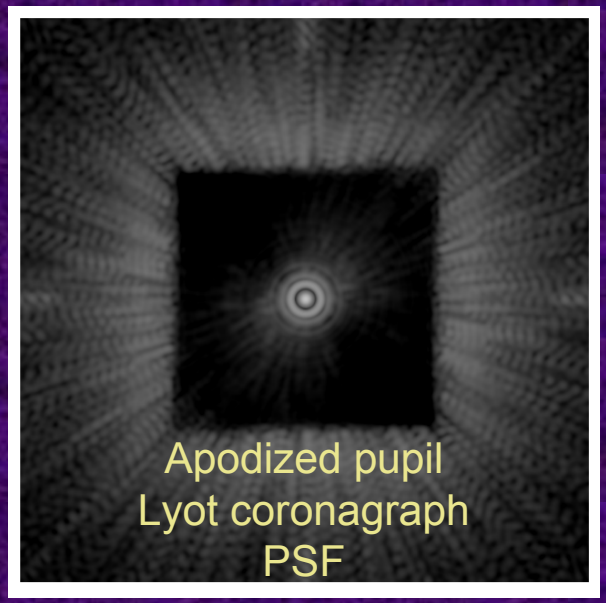


64x64 MEMS unwired model

Apodized-pupil Lyot coronagraph (Soummer 2005)





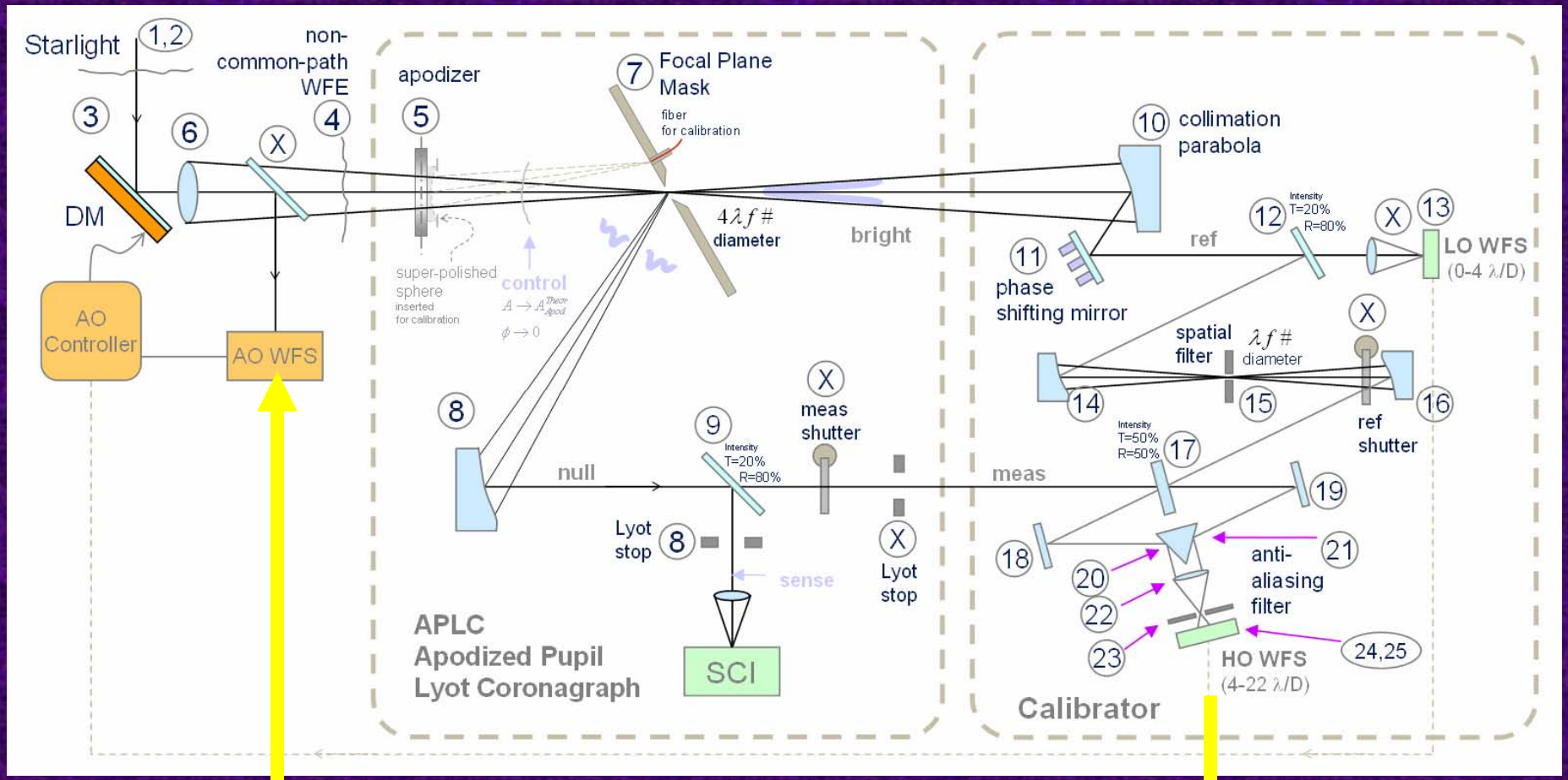


Soummer 2005

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Calibration interferometer



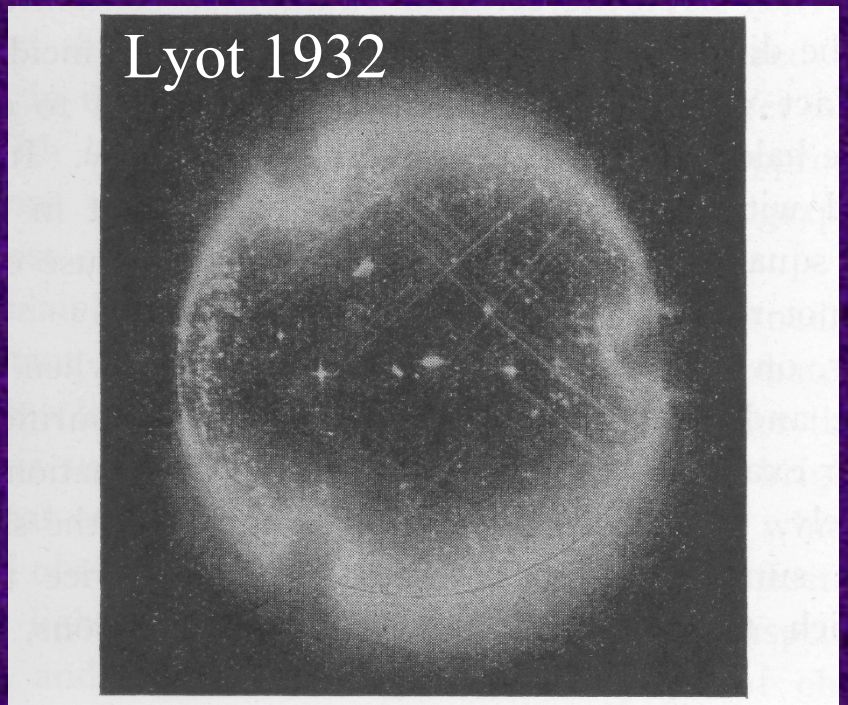
Invert coronagraph

National Aeronautics and Space Administration

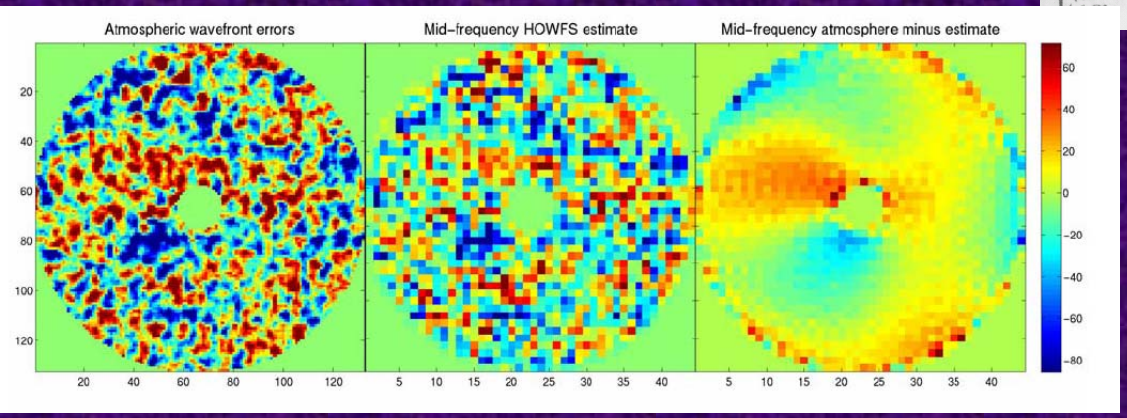
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Lyot invented the GPI CAL system!

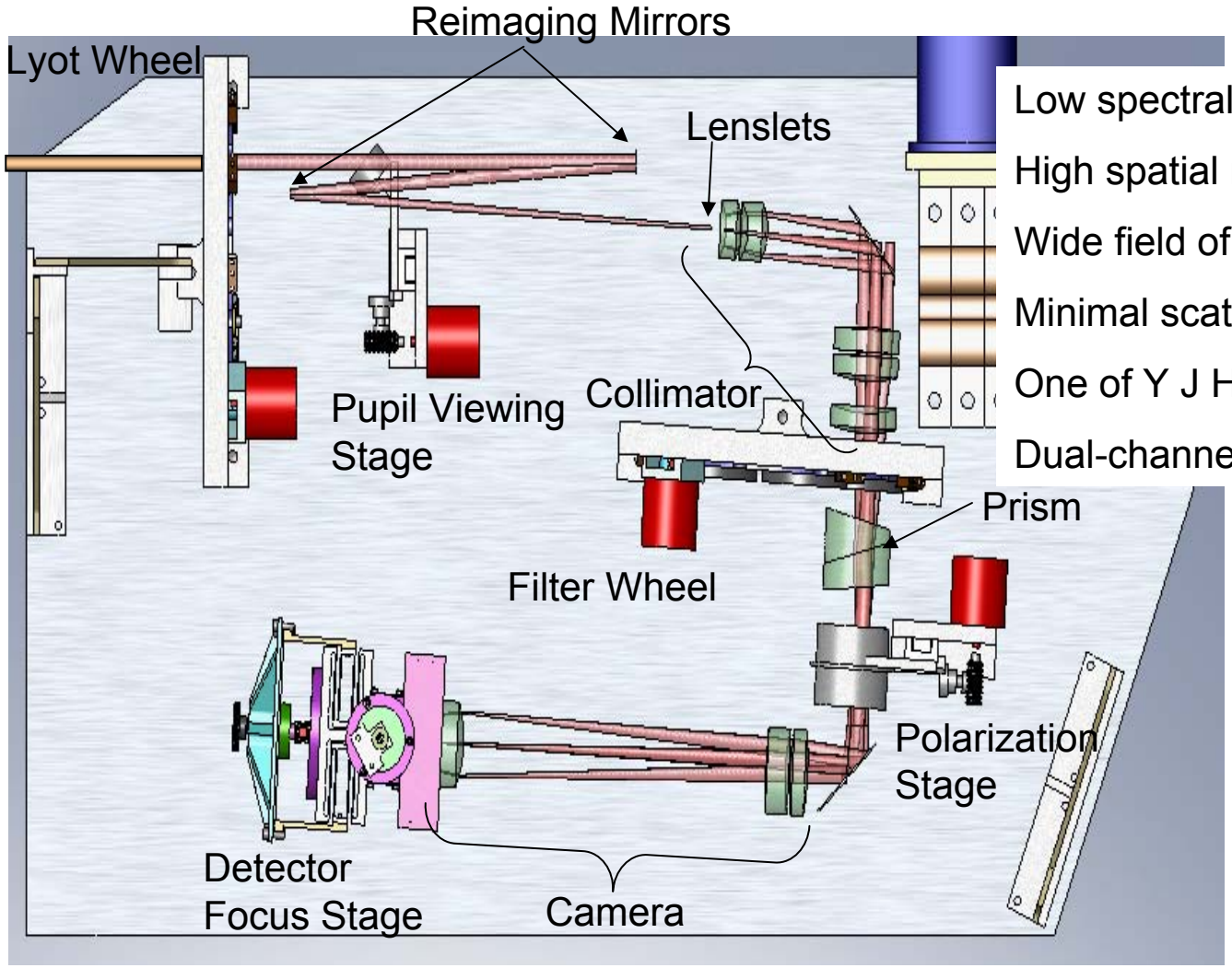
- Coronagraph acts to convert phase signal to intensity
- CAL interferometer primarily measures intensity
- Coarse phase informaiton needed to remove sign ambiguity and exclude pre-coronagraph amplitude errors



3. Parasitic light diffused by a simple lens.



Integral field spectrograph (UCLA+Montreal)



Low spectral resolution (R~45)

High spatial resolution (0.014 arcsec)

Wide field of view (3x3 arcsec)

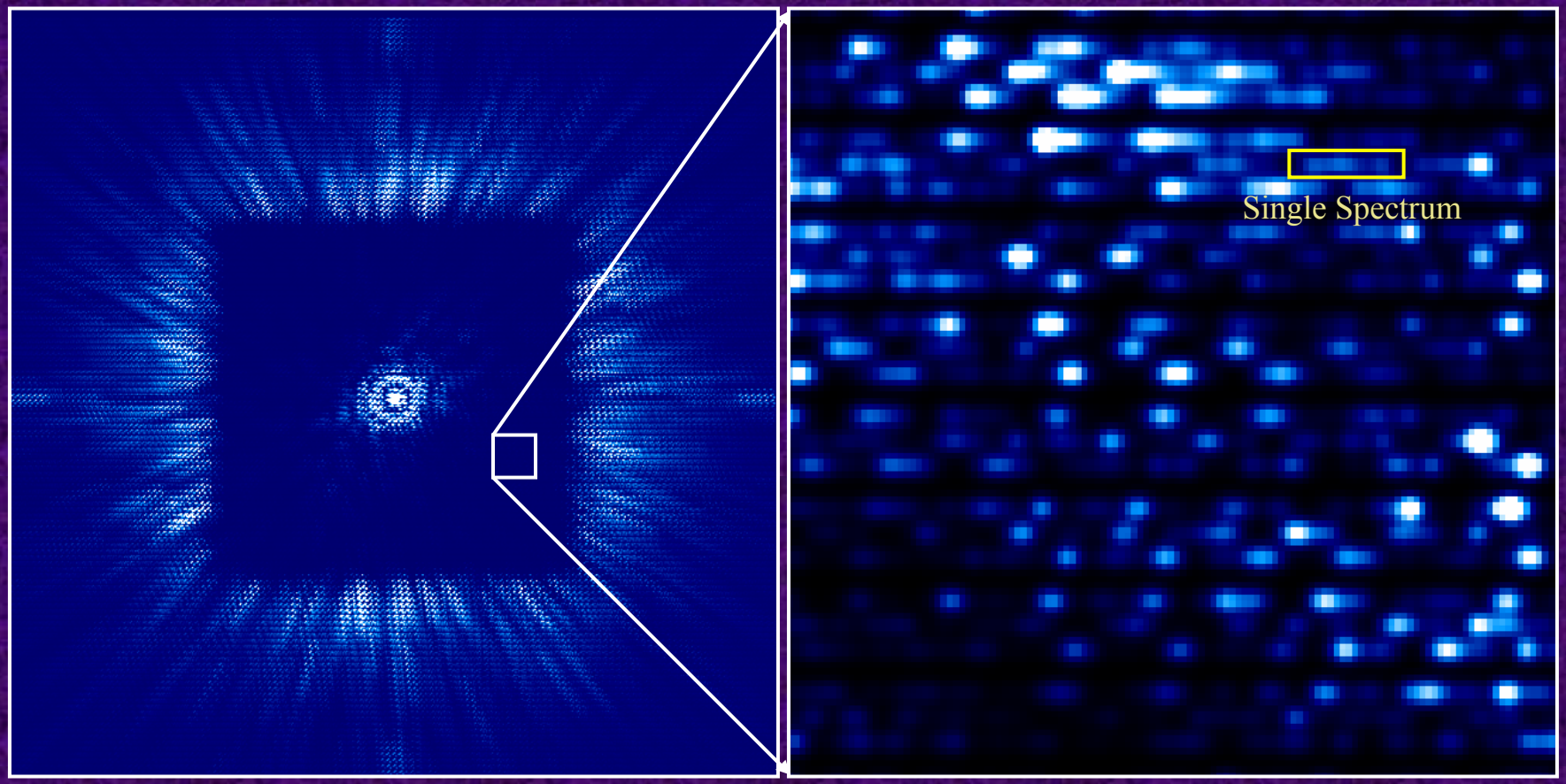
Minimal scattered light

One of Y J H K bands

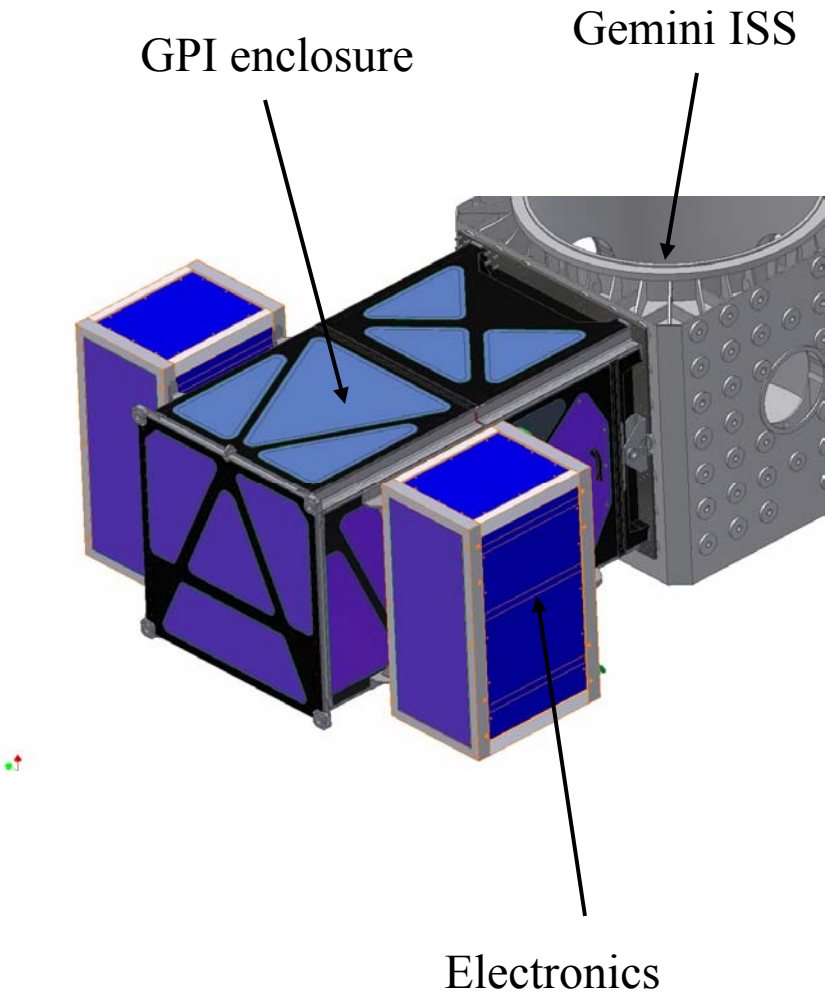
Dual-channel polarimetry

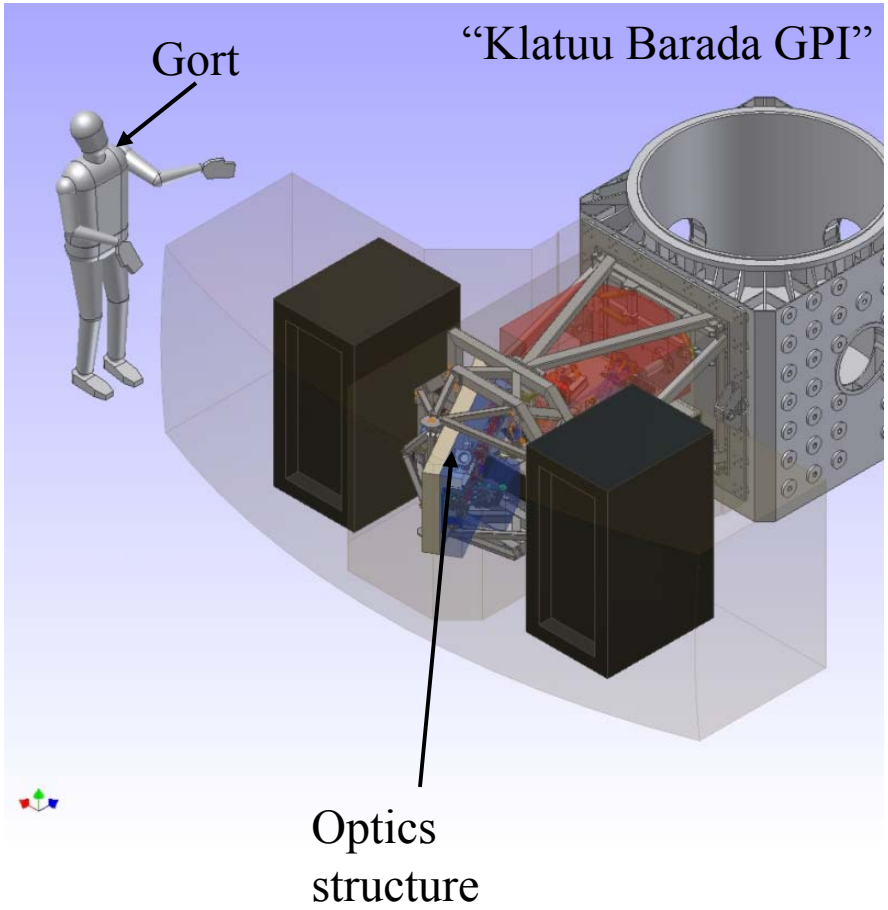
IFS Data

- Each spectrum is 16-17 pixels long (R~45).
- 68,000 spectra on a 2048x2048 detector.
- Spectra are separated by 4.5 pixels from their nearest neighbors.

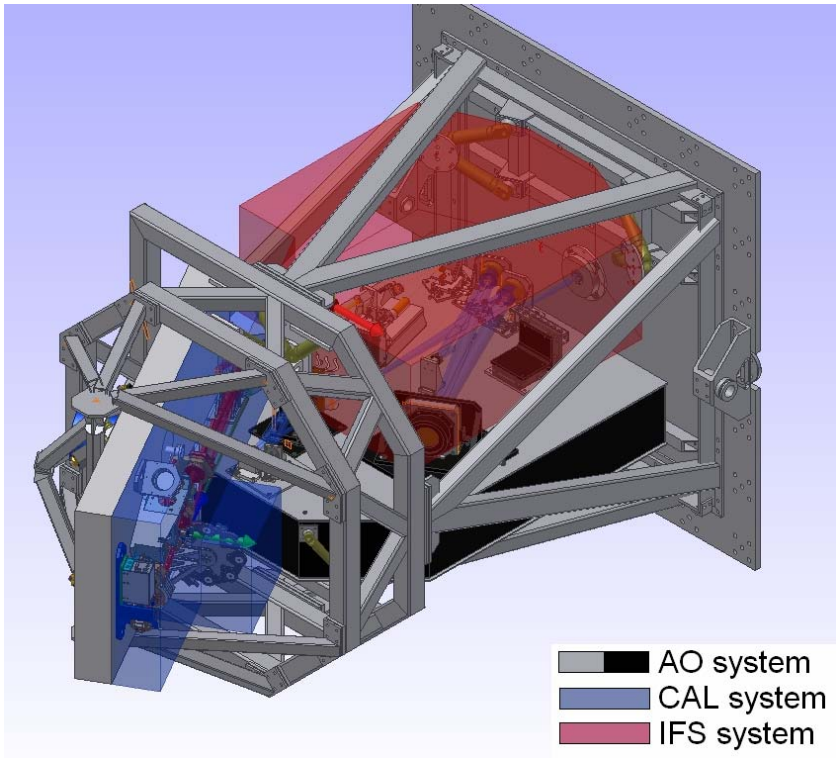


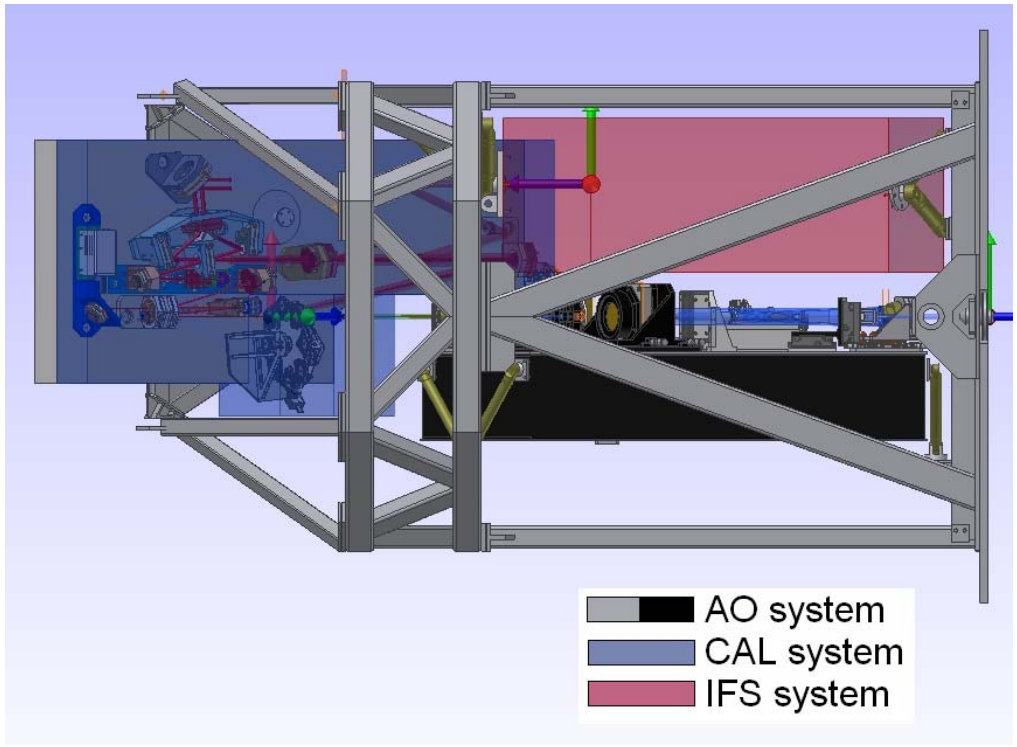
GPI mechanical design



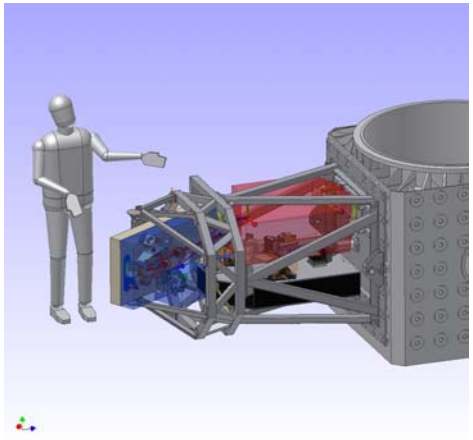


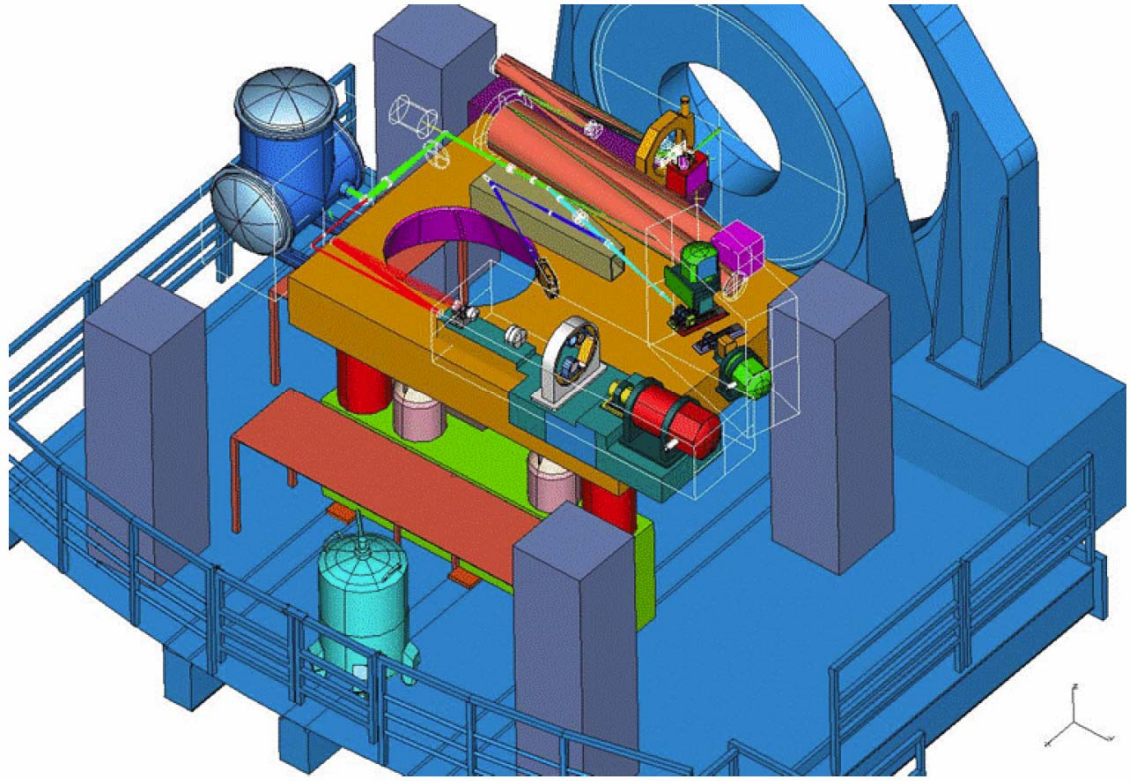
GPI optical structure



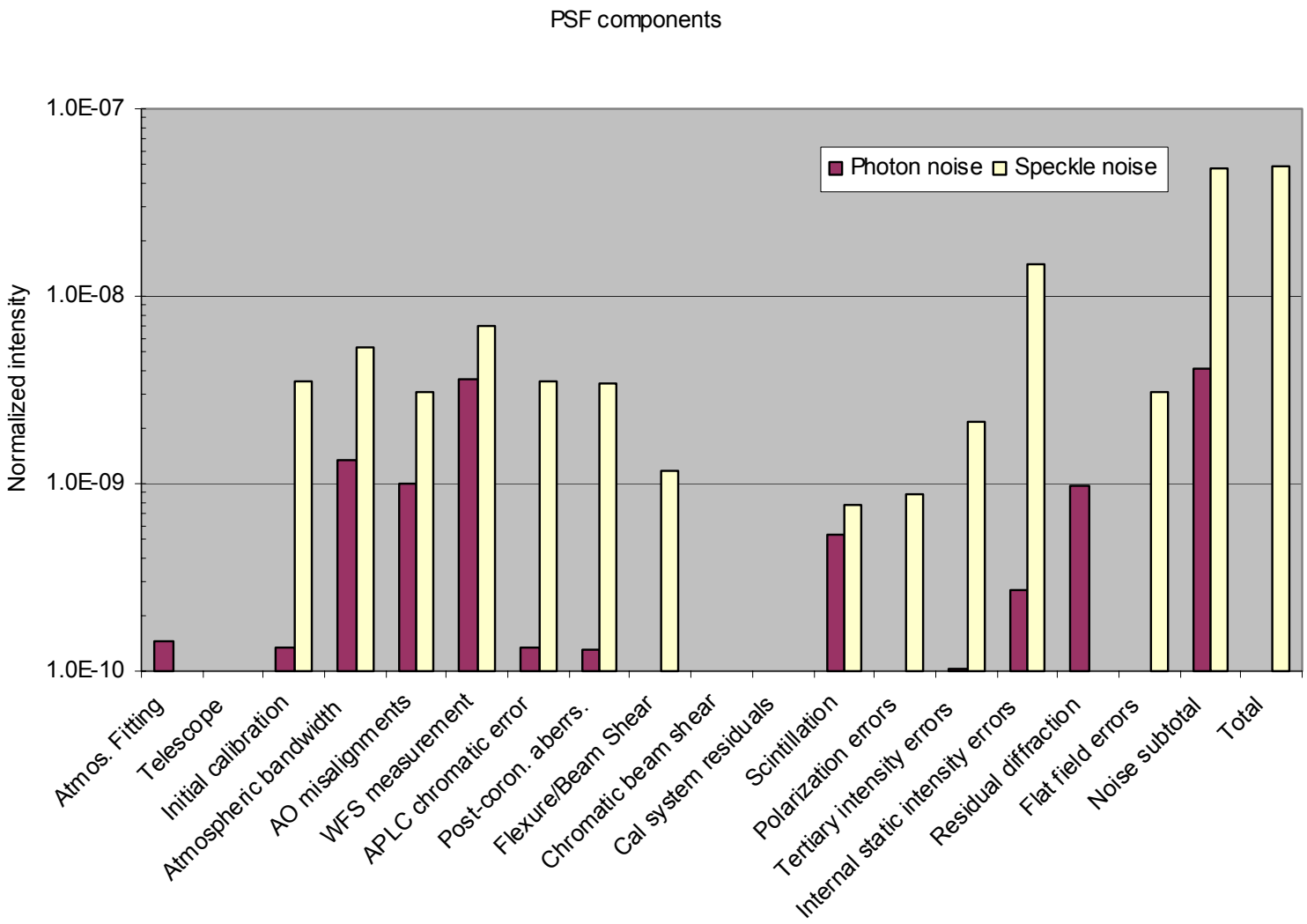


GPI and SPHERE

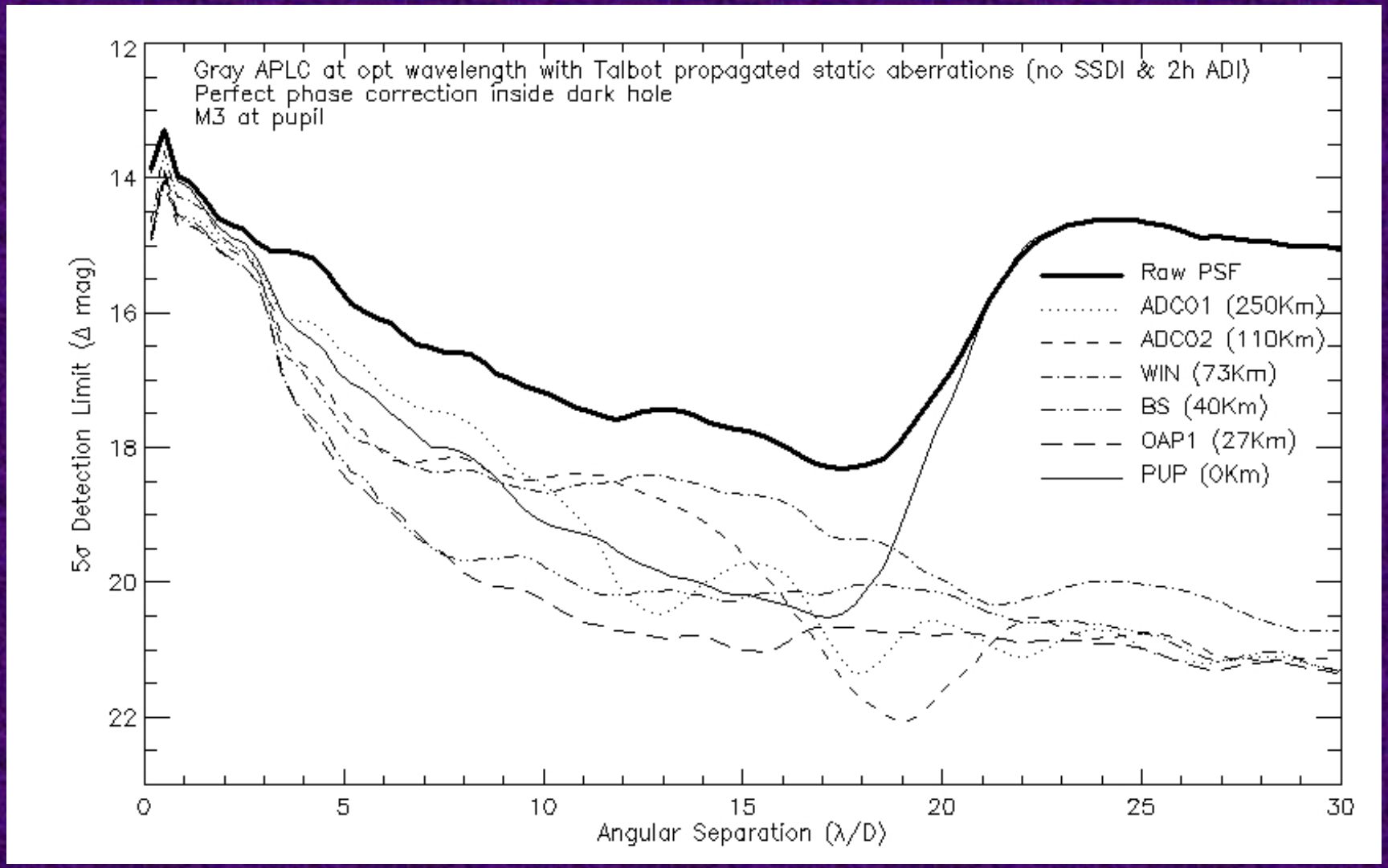




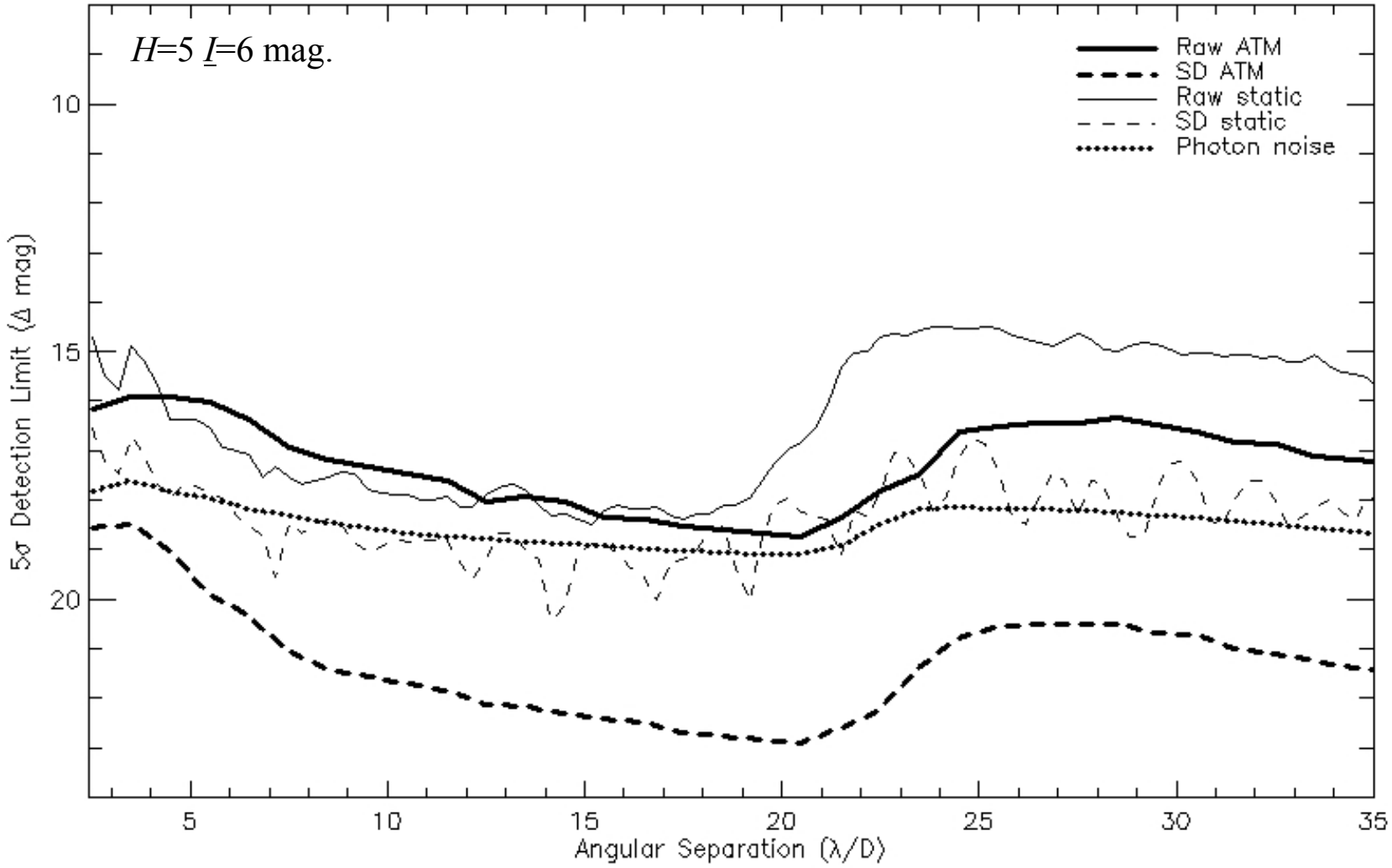
CoDR analytic error budget



GPI raw static contrast from each plane

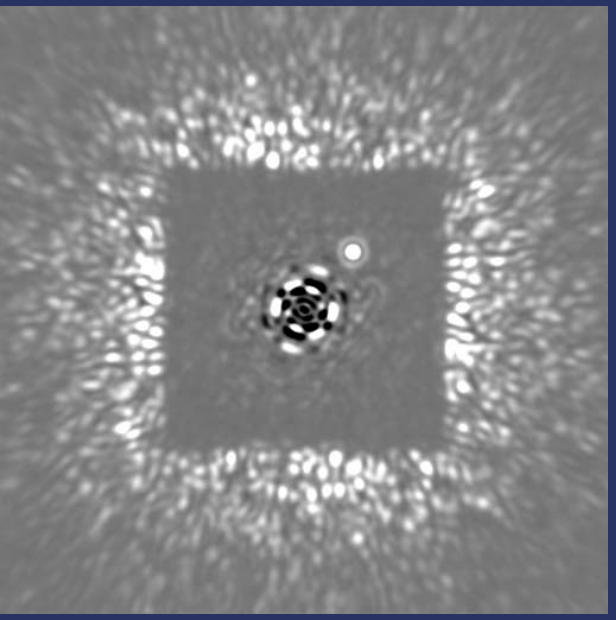


Detection limits from static and atmospheric speckles with and without spectral differencing

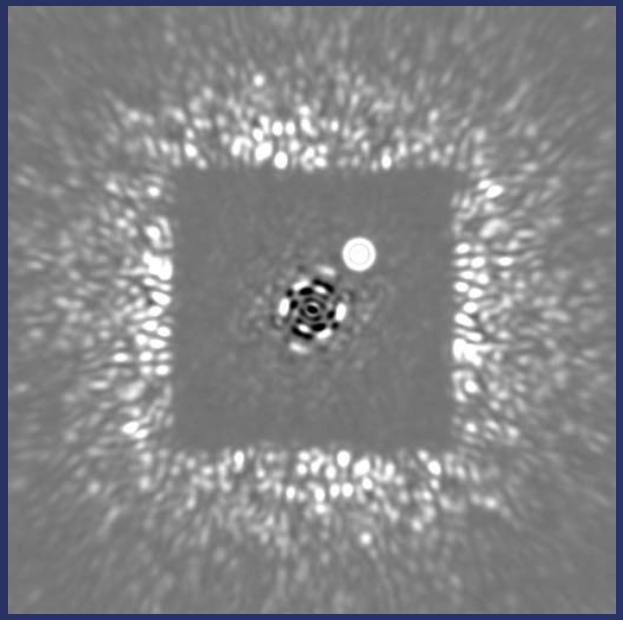


Long exposures images

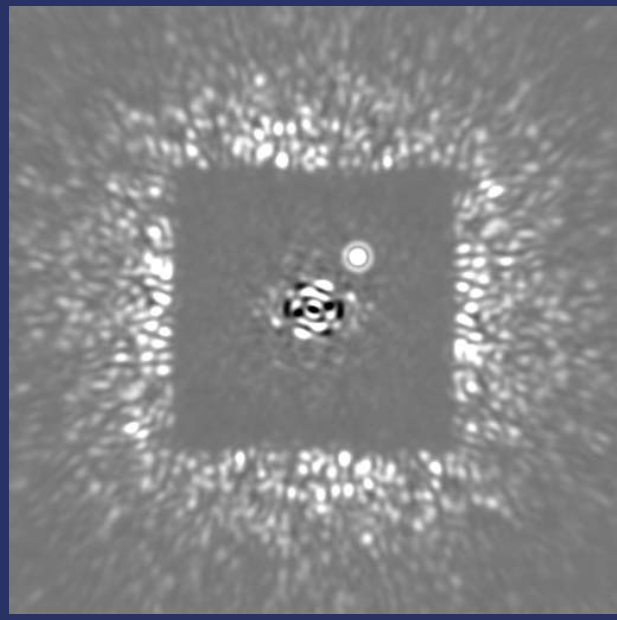
1.515 microns



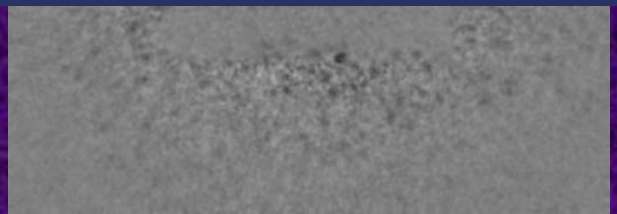
1.57 microns

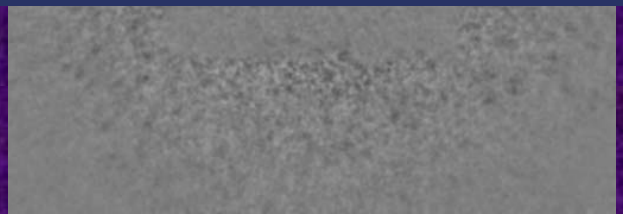


1.625 microns



Coro opt. wavelength

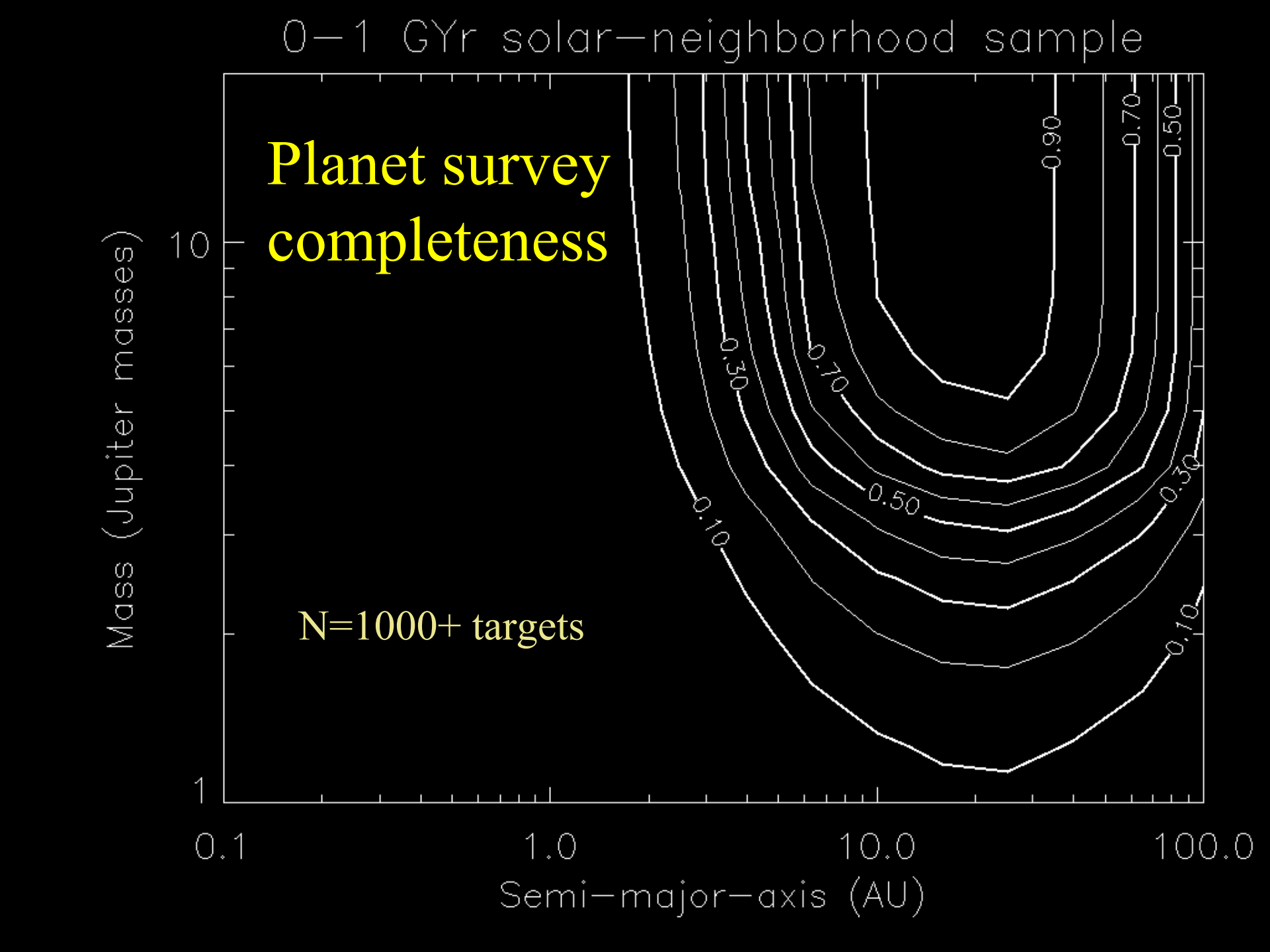




630K & 310K

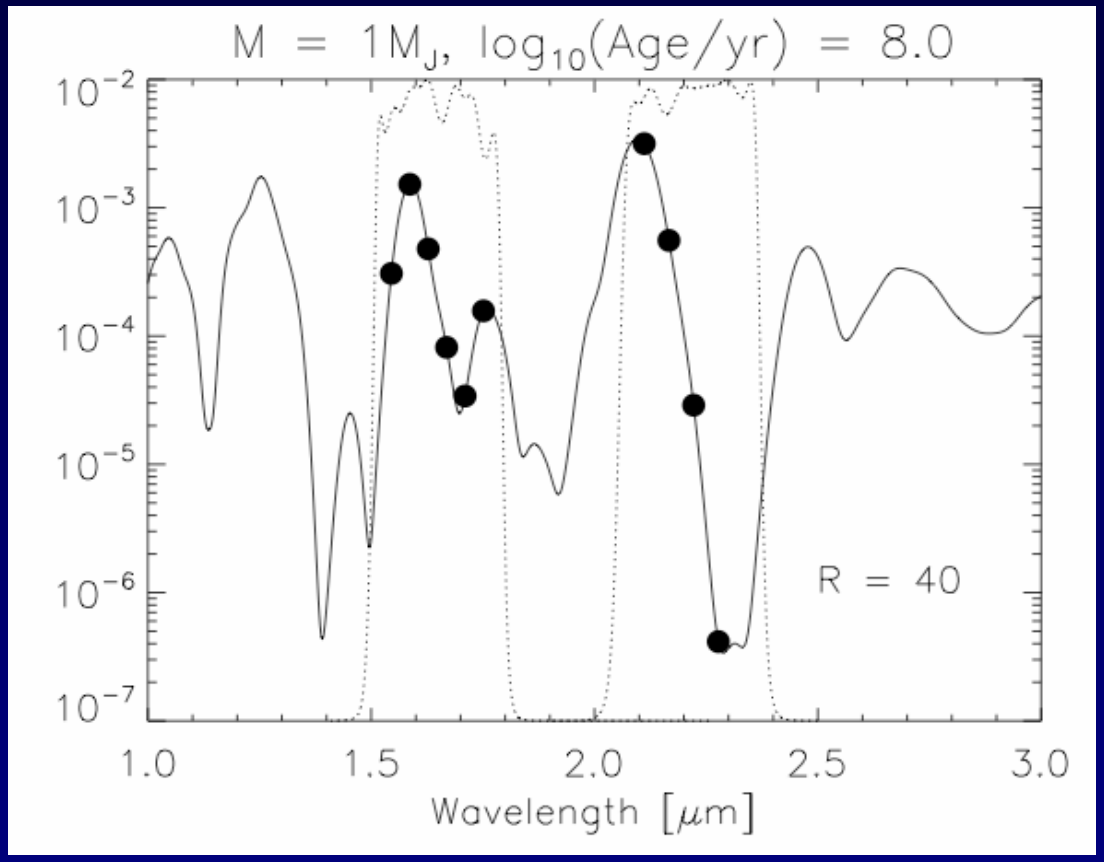
$\Delta H = 12$ & 17.4

(T8 spectrum)


0–1 GYr solar–neighborhood sample
Planet survey completeness
N=1000+ targets
0.90
0.70
0.50
0.30
0.10
Mass (Jupiter masses)
10
1
0.1
1.0
10.0
100.0
Semi–major–axis (AU)

Spectroscopy

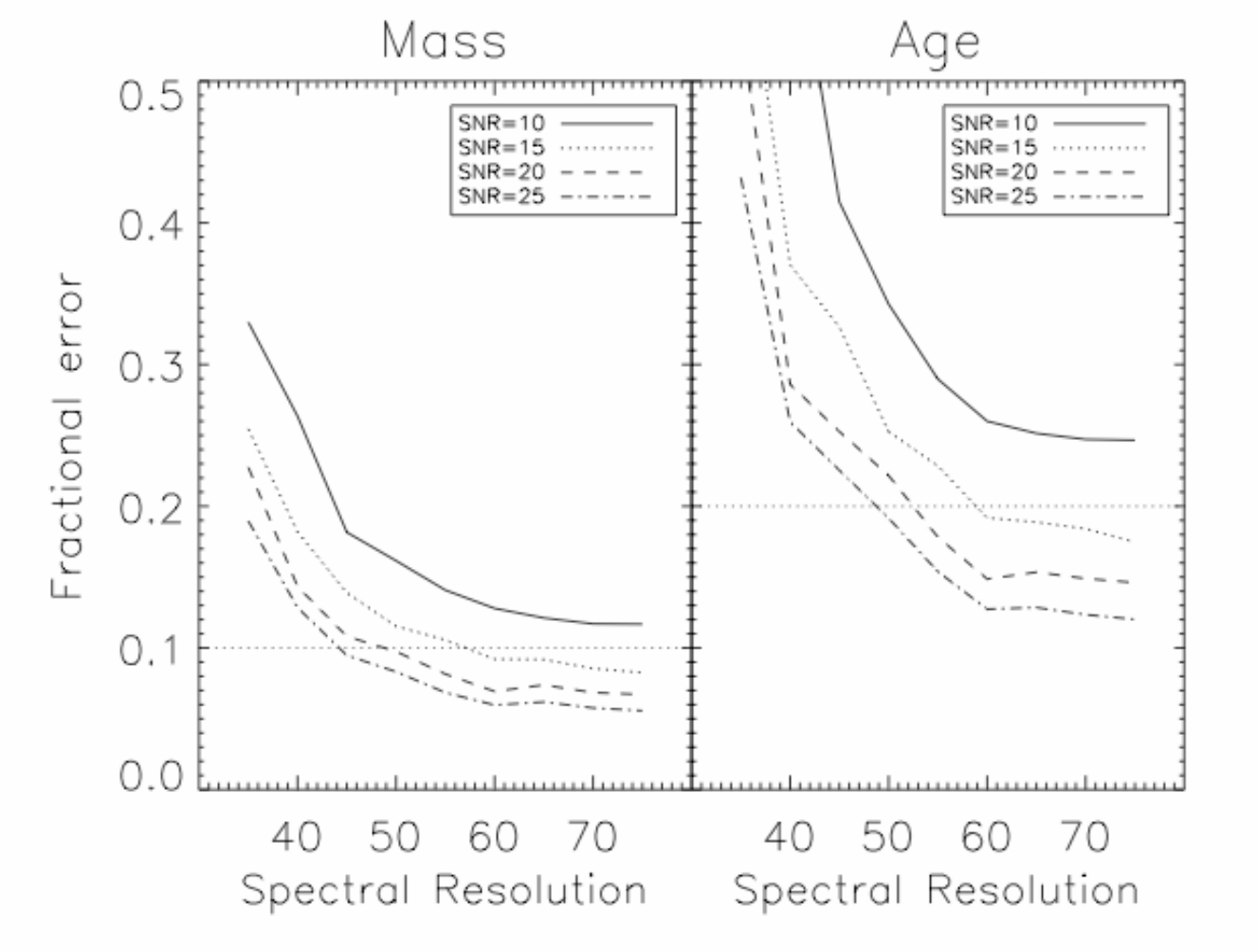
- **Exoplanet spectra indicate that *R* ~ 40-100 is suitable for measuring atmospheric parameters**
  - [1.5] – [1.6] is a good effective temperature indicator
  - [1.5] – [2.2] is a good gravity indicator
  - Higher spectral resolution could address composition of hot Jupiters



100 Myr/1 M_J planet convolved to *R* = 40 (Burrows et al. 2003). Dots represent sampling of the smoothed spectra in non-overlapping spectral channels.Ten independent flux measurements are combined to form to five colors in *H* and three colors in *K*. Dotted lines show the transmission of the GPI H& K filters.

Spectral Resolution

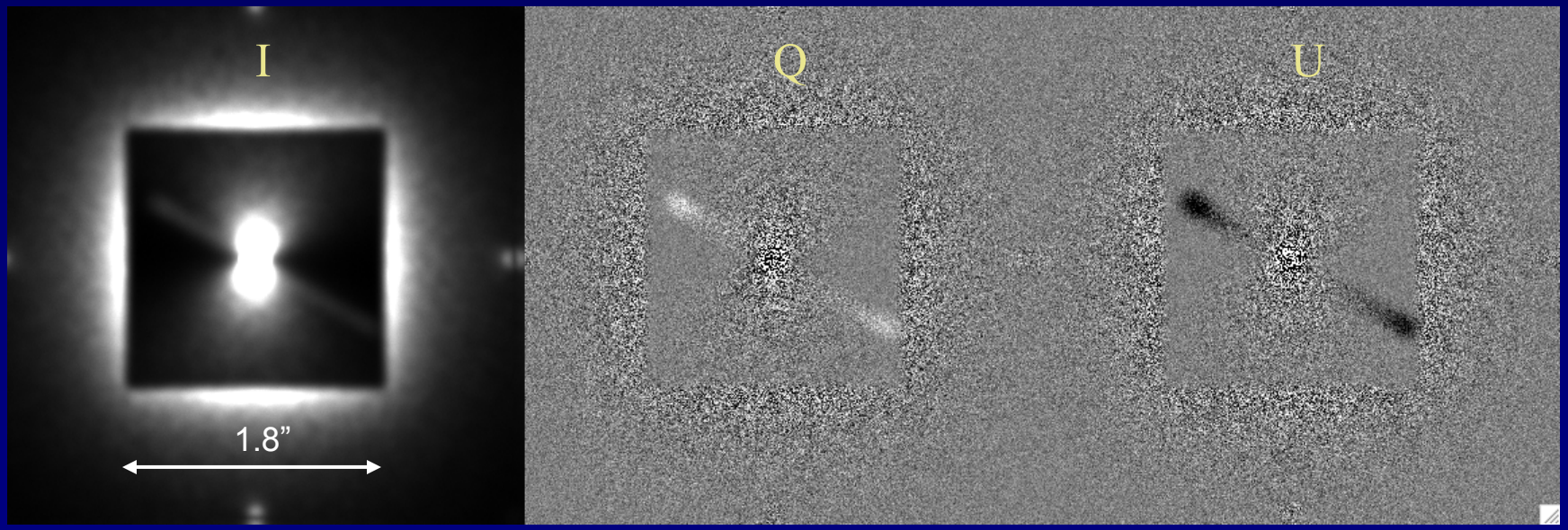
- **What spectral resolution is required for follow up**
  - Can we measure first-order parameters?
  - T_{eff} and log(g)?
- **Trade SNR & spectral resolution**



Variation of fractional rms error in mass (left) and age (right) vs. R. Four curves are shown in each panel for SNR ∈{10, 15, 20, 25}.

Dual Channel Polarimetry Simulations

- **Fomalhaut analog**
  - $\tau = 3 \times 10^{-4}$
  - $\theta = 0°$ 30°, 60° & 90°
- **Edge-on disk is easily detected in Stokes *I* in 90 s**
  - Progressively less visible in Stokes *I* in non edge-on configurations
- **Dual channel polarimetry reveals face-on disks to $\tau = 10^{-5}$**



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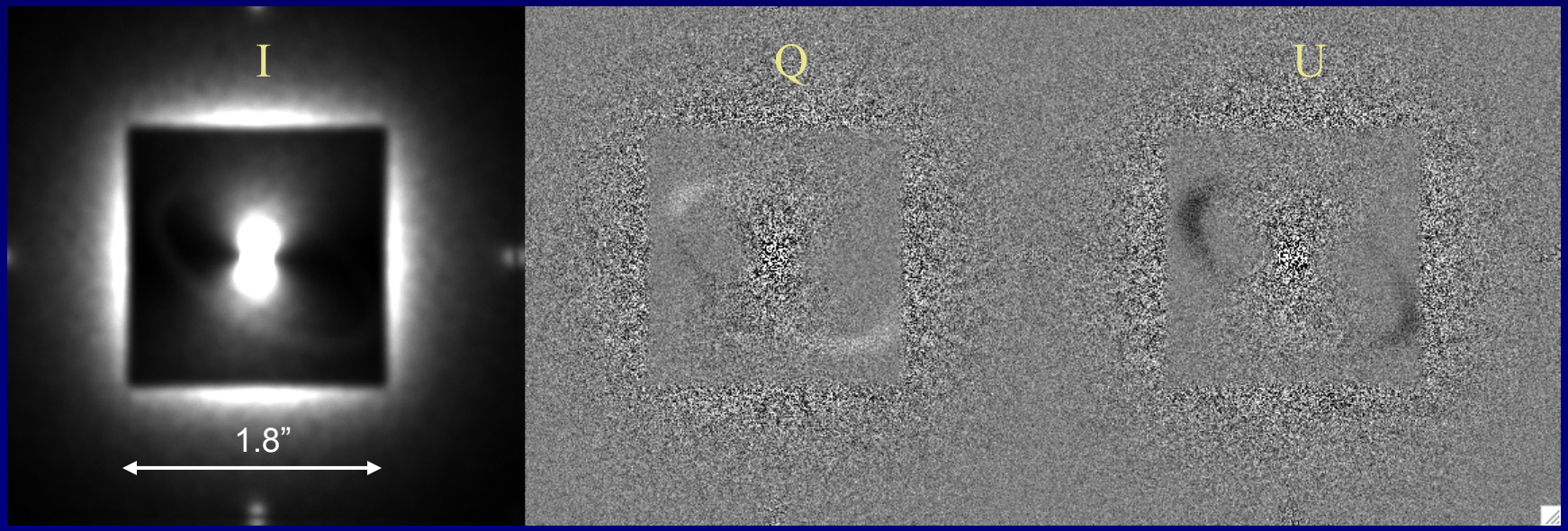

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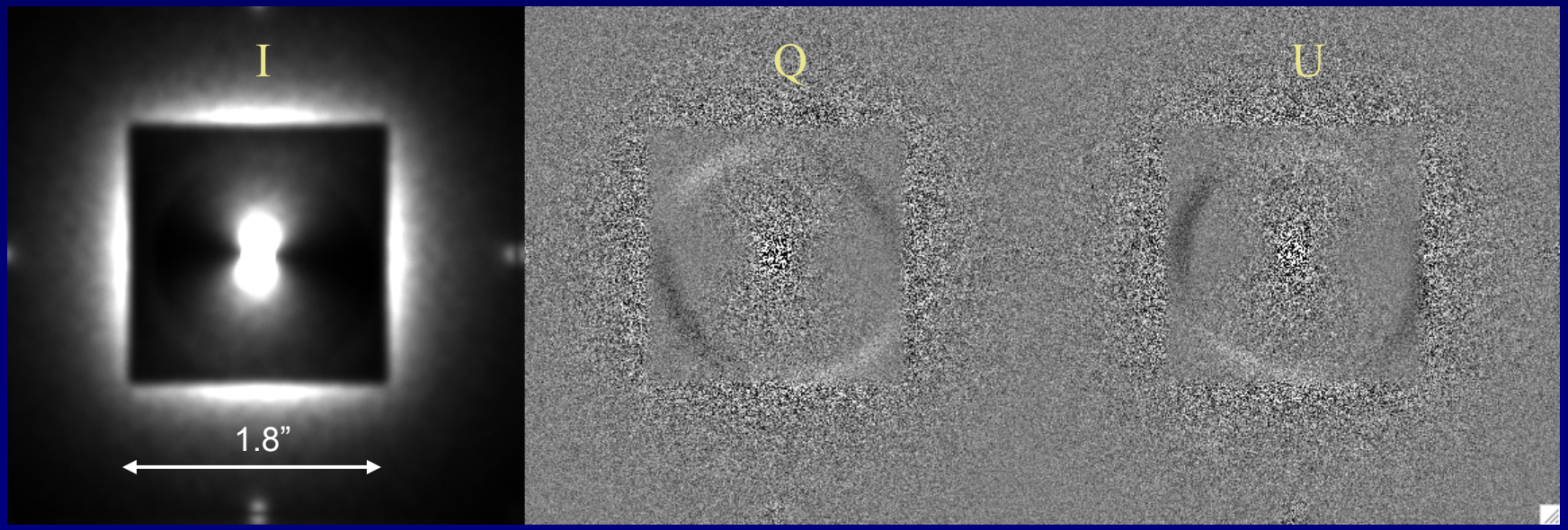

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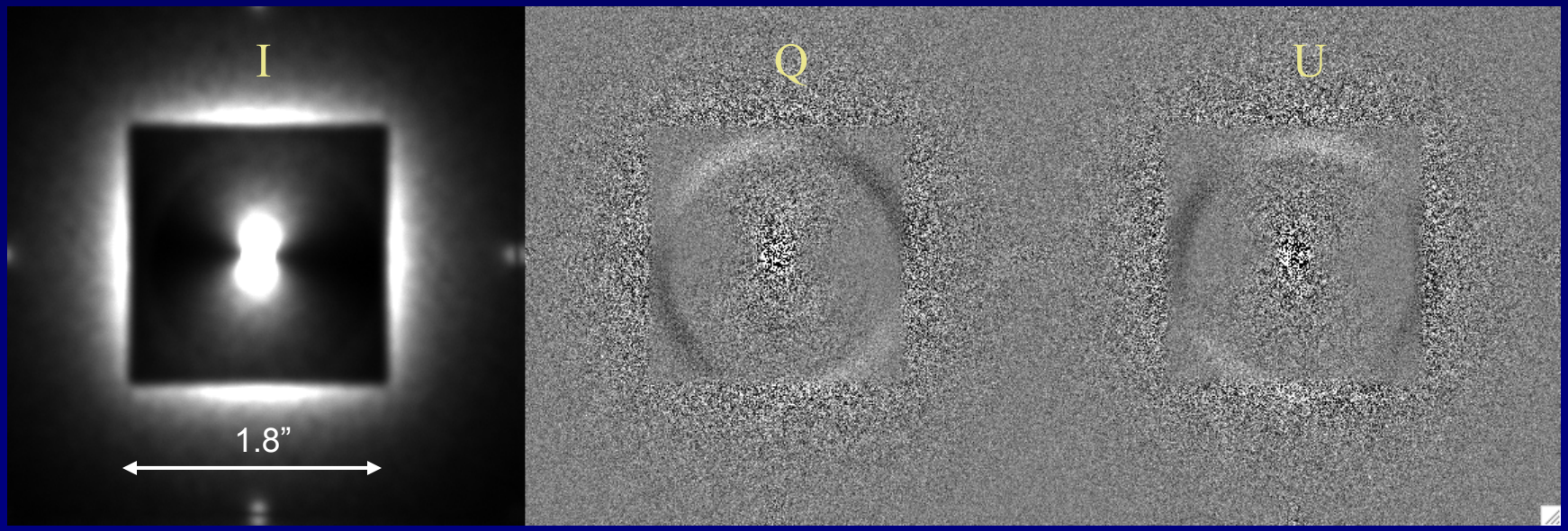
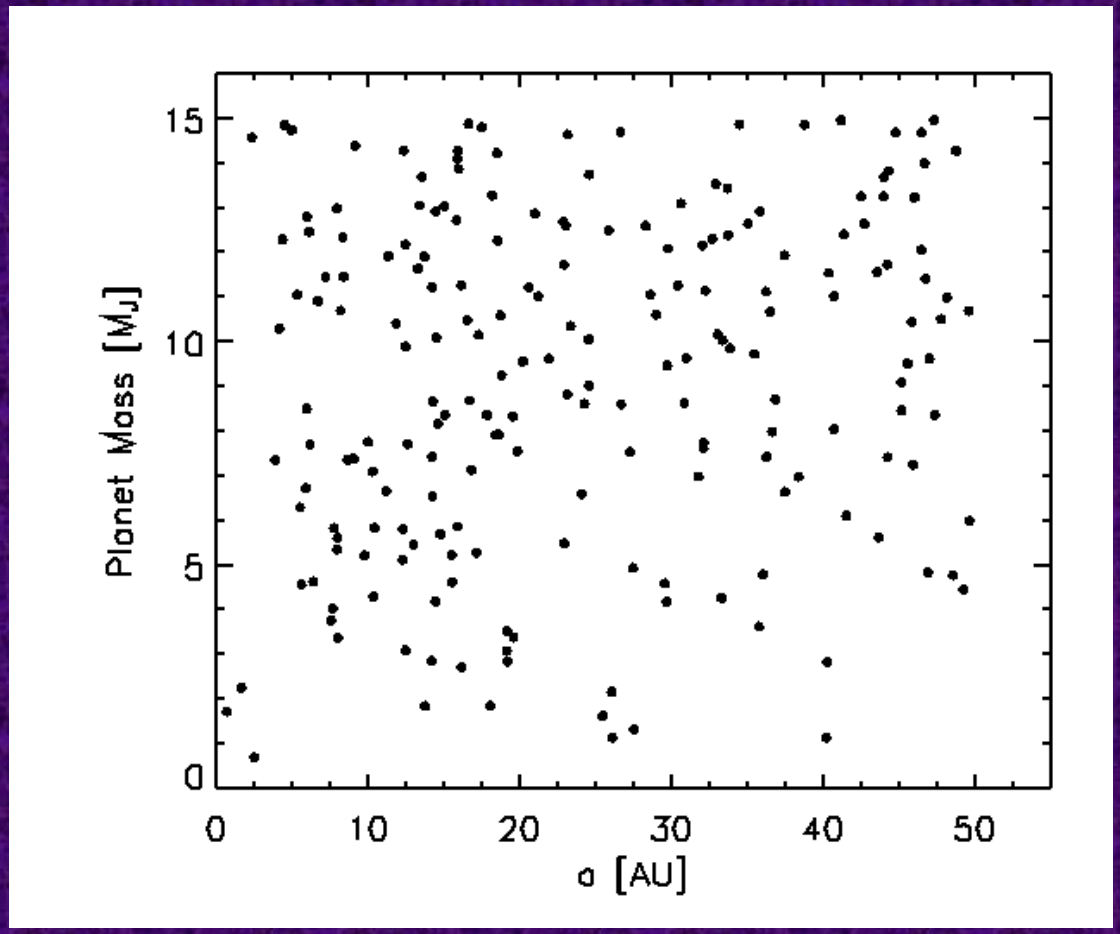
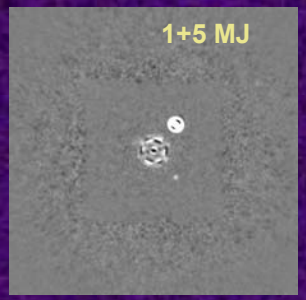
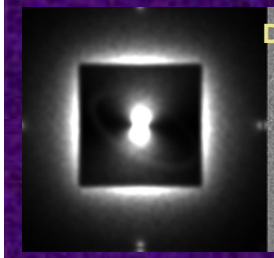


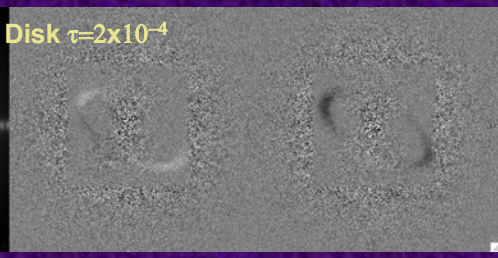
Gemini Planet Imager Science: Planets, moons, debris disks, evolved stars, binaries, etc.

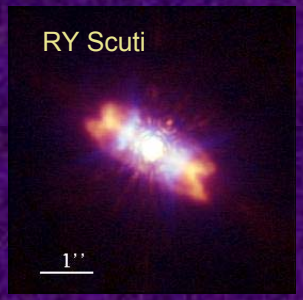


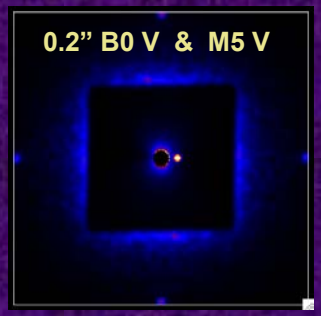
Detected exoplanets for *I<8* mag field survey



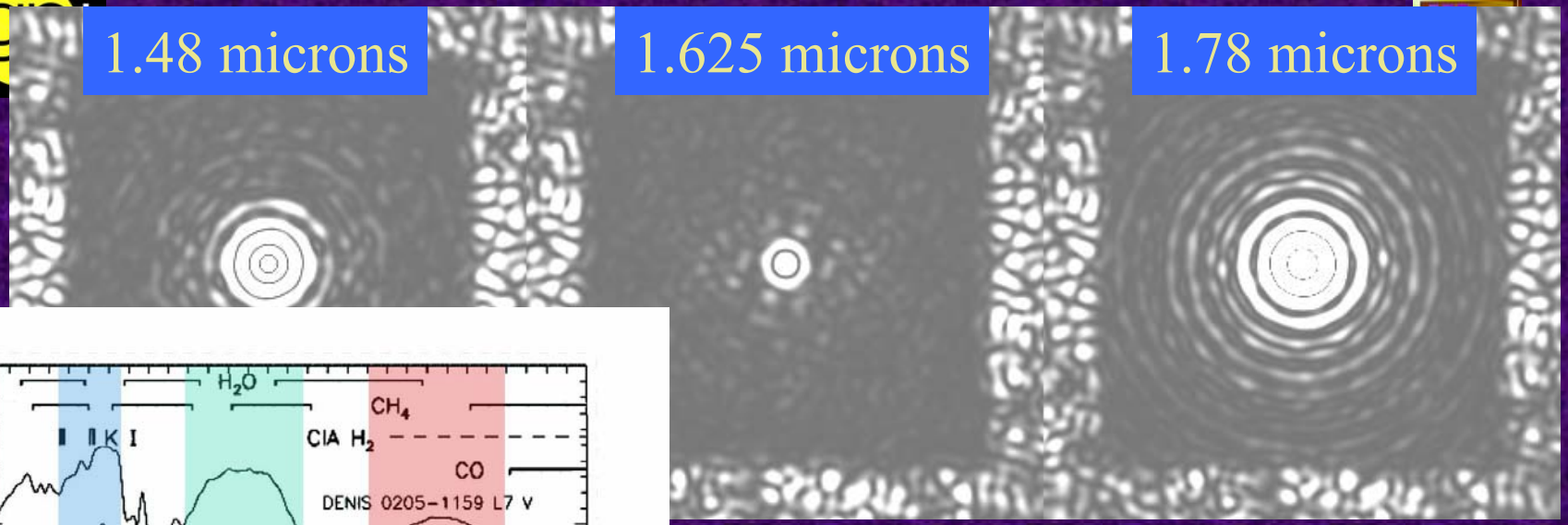


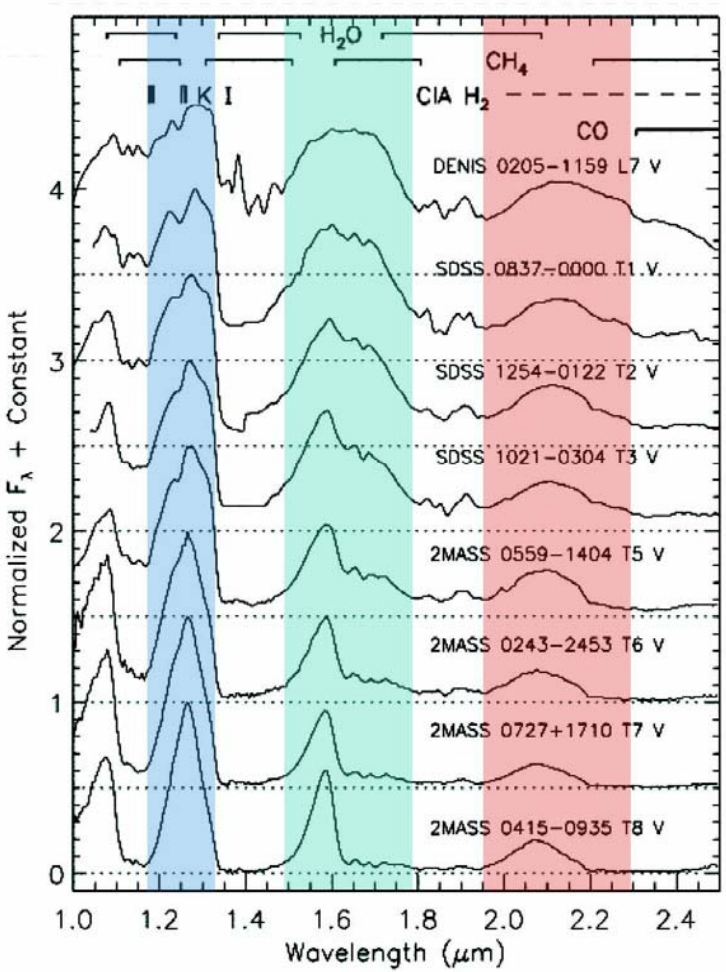


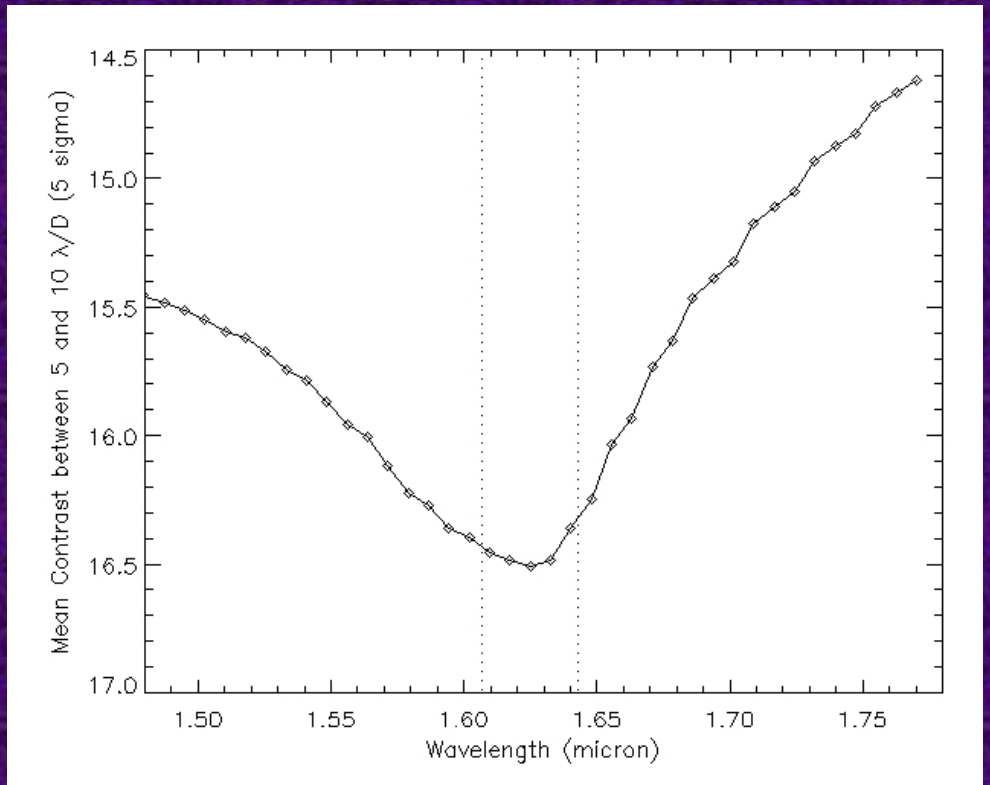




First light: late 2010 or early 2011


1.48 microns
1.625 microns
1.78 microns


H2O
CH4
CIA H2
CO
K I
DENIS 0205−1159 L7 V
SDSS 0837−0000 T1 V
SDSS 1254−0122 T2 V
SDSS 1021−0304 T3 V
2MASS 0559−1404 T5 V
2MASS 0243−2453 T6 V
2MASS 0727+1710 T7 V
2MASS 0415−0935 T8 V
Normalized Fλ + Constant
Wavelength (μm)


Mean Contrast between 5 and 10 λ/D (5 sigma)
Wavelength (micron)

GPI

AO Subaperture size	18 cm (1528 subapertures)
Primary deformable mirror	N=45 actuators on 64x64 DM
AO system update rate	2000 Hz
Limiting magnitude	*I*=8 mag (*I*=9 goal)
Coronagraph	Apodized-pupil Lyot
IWD	0.1 arcseconds (edge) 0.14 arcseconds
Science instrument	Integral field spectrograph
Wavelength coverage	0.9-2.35 μm (Y, J, H or K)
Pixel size	0.014 arc seconds
Field of view	2.8x2.8 arc seconds
Spectral resolution	R=45
Polarimetry	Dual-channel full FOV