A New High-Contrast Imaging Program for Exoplanetary Science at Palomar

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Sagan Fellowship Symposium, Nov. 12th 2009

American Museum of Natural History

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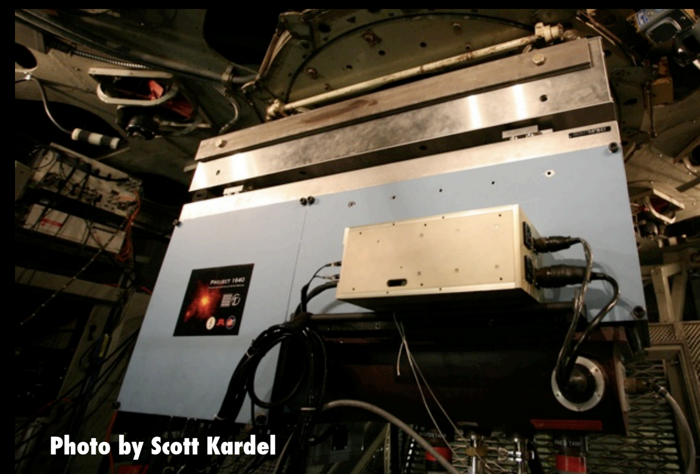
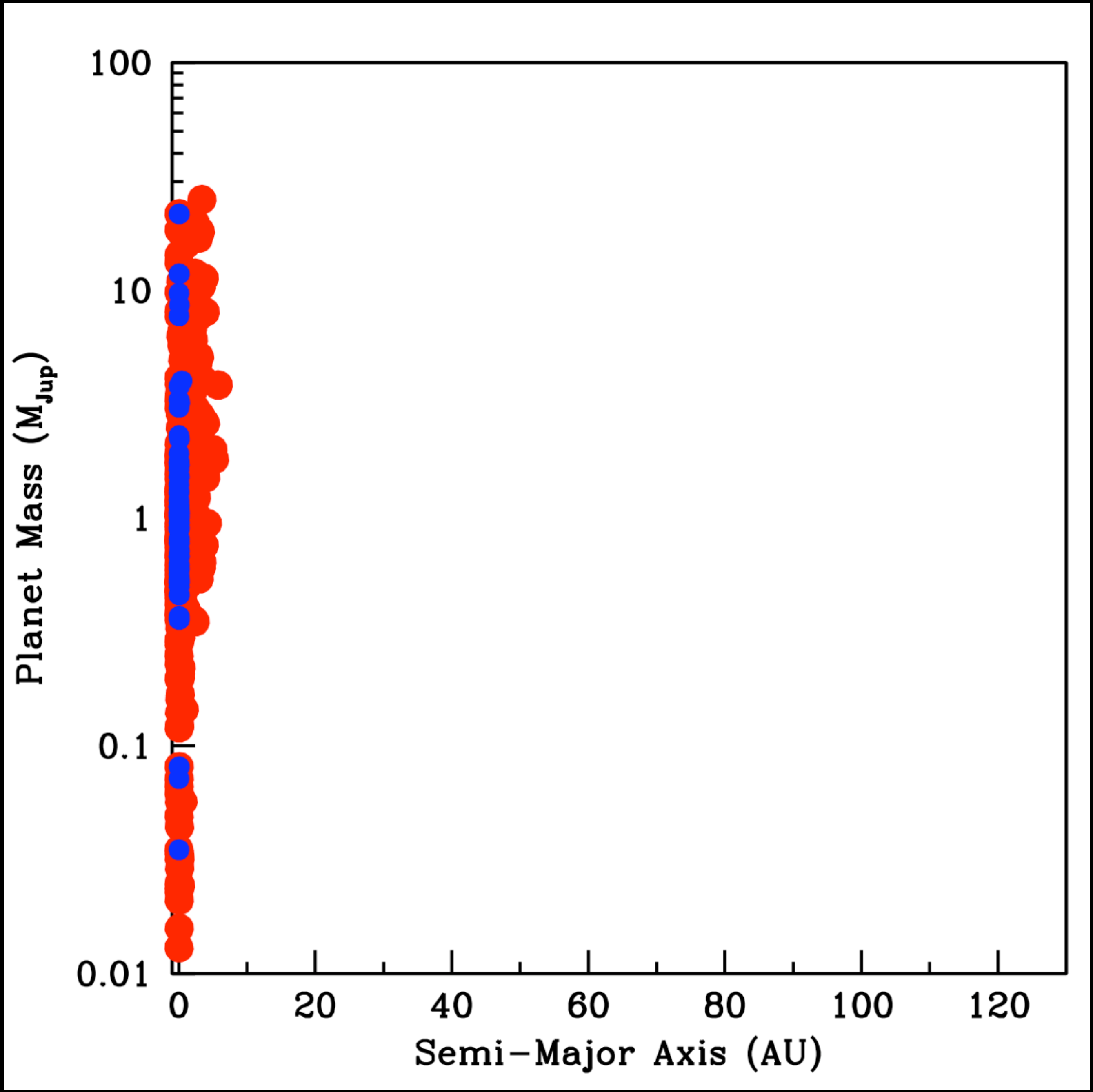
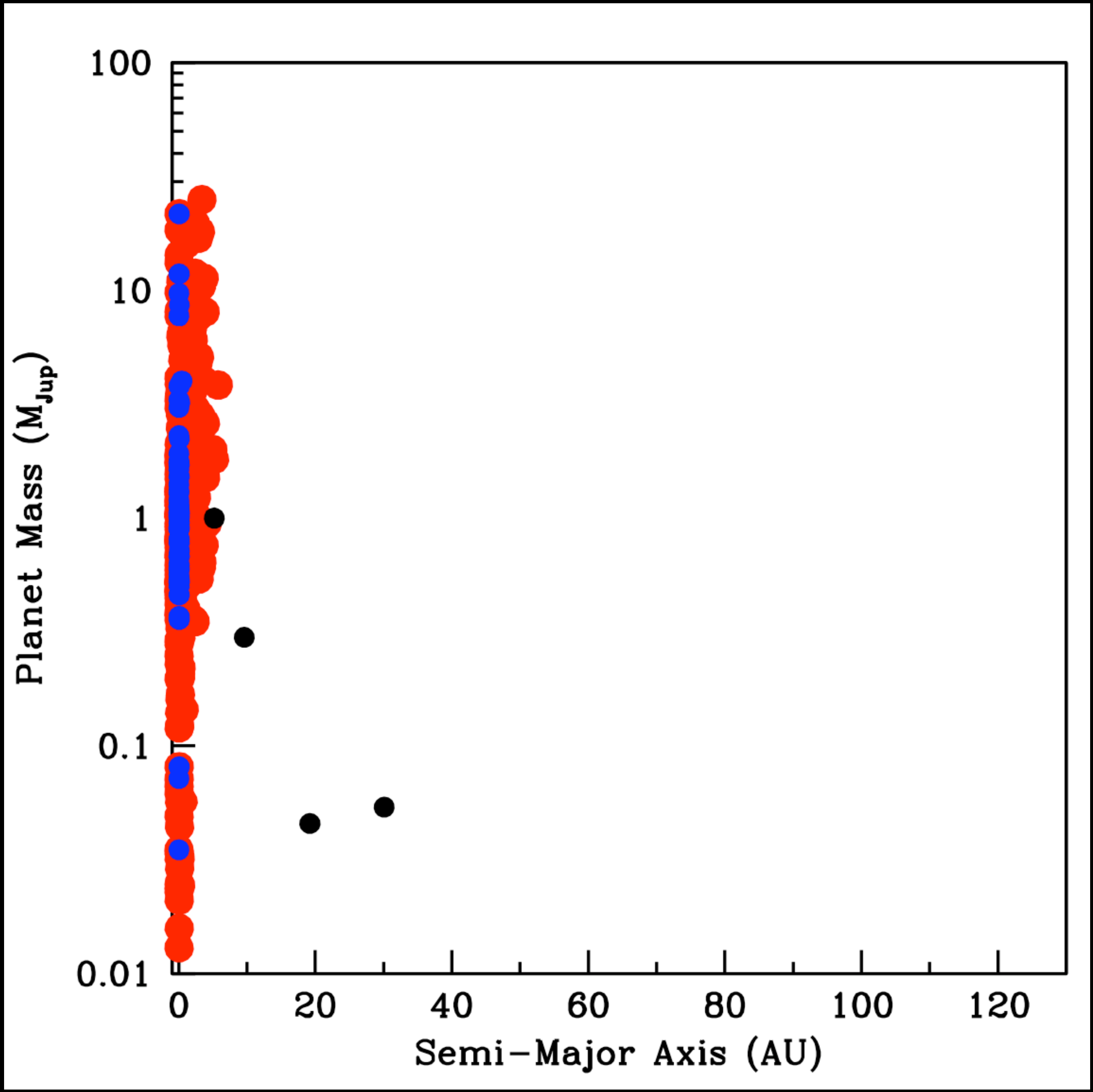


Photo by Scott Kardel



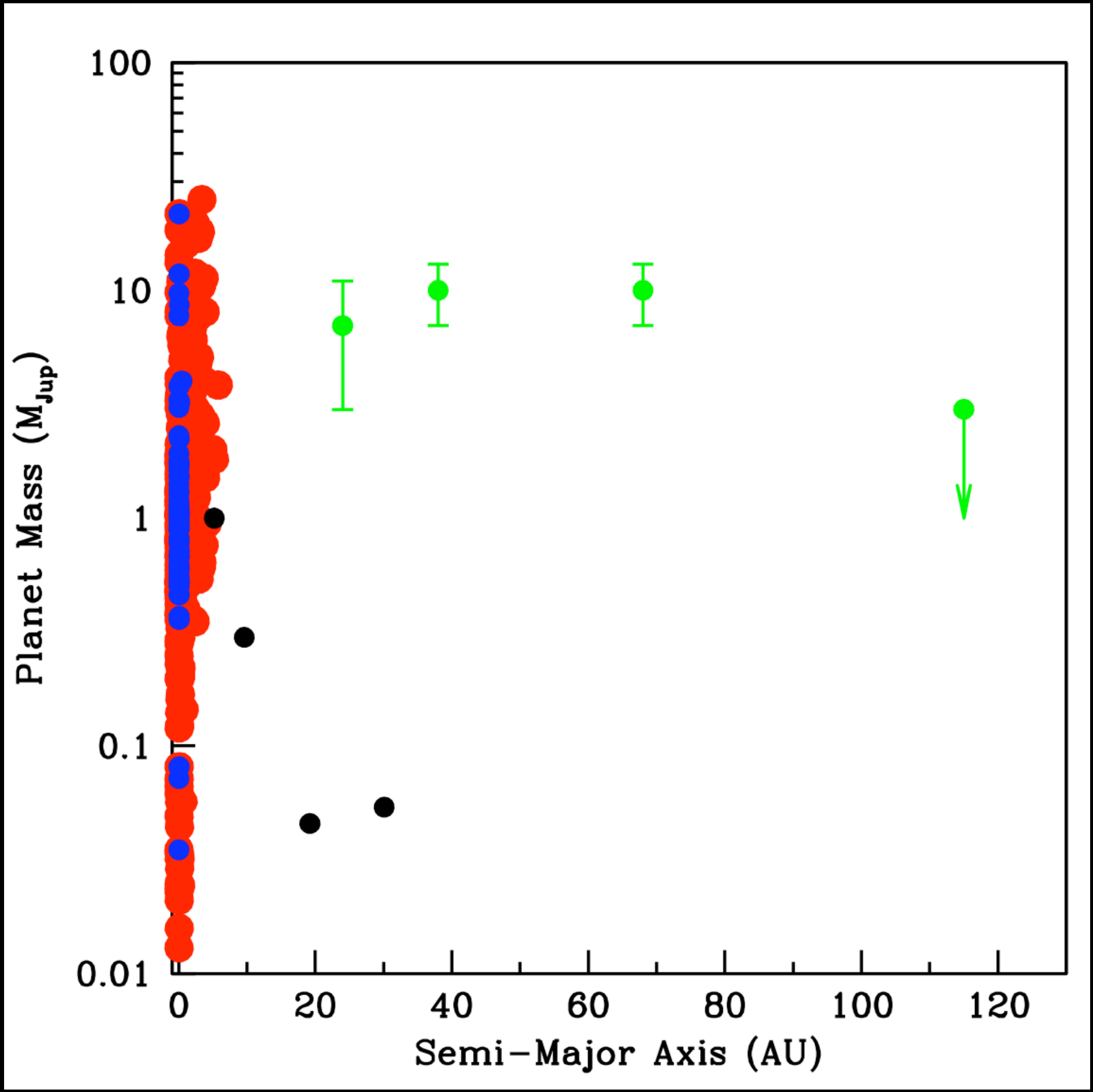
Transits

Radial Velocity



Transits

Radial Velocity

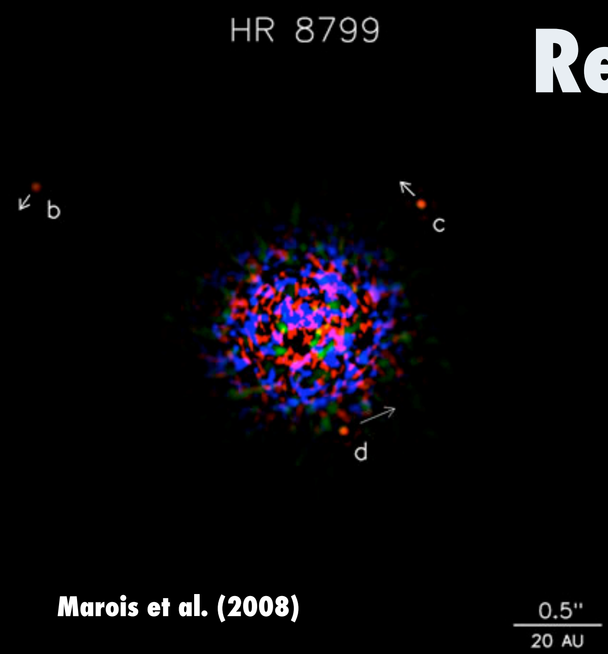


Transits

Radial Velocity

Direct Imaging

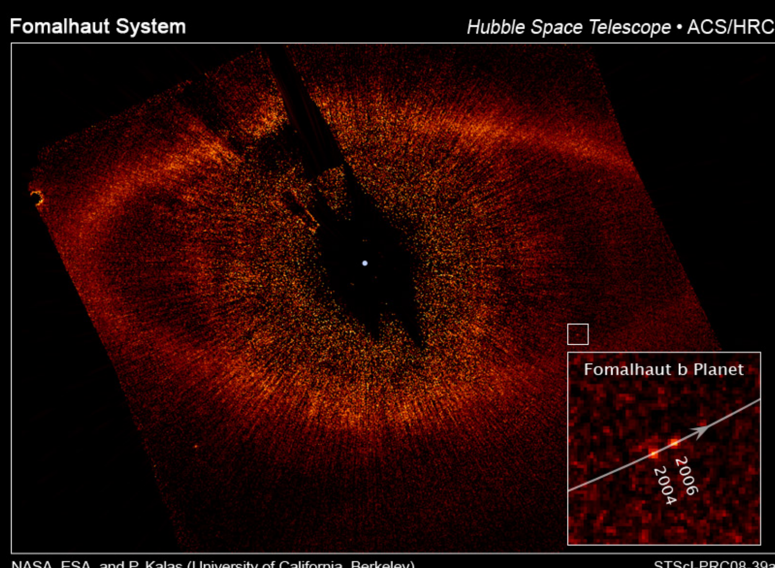
Recent Direct Imaging



Marois et al. (2008)

HR 8799 b, c, d:

- 68, 38, 24 AU
- 7, 10, 10 M_{Jup}
- 60 Myr system

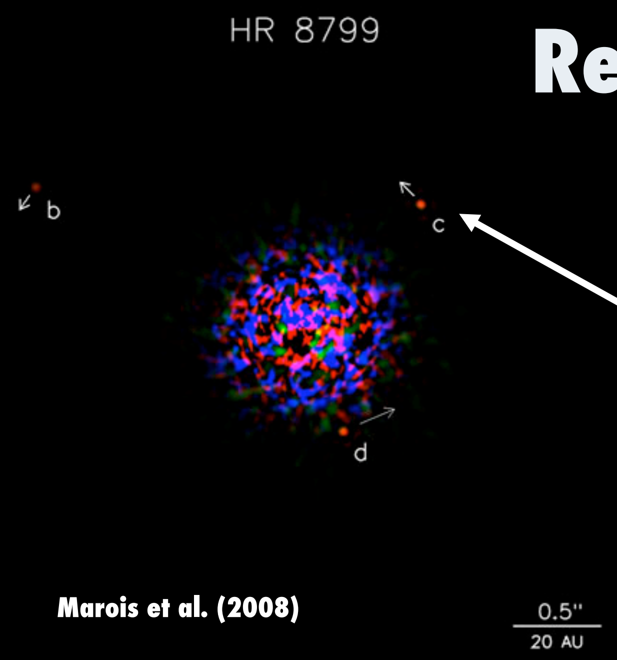


Kalas et al. (2008)

Fomalhaut b:

- 119 AU
- Few M_{Jup}

Recent Direct Imaging



Marois et al. (2008)

HR 8799 b, c, d:

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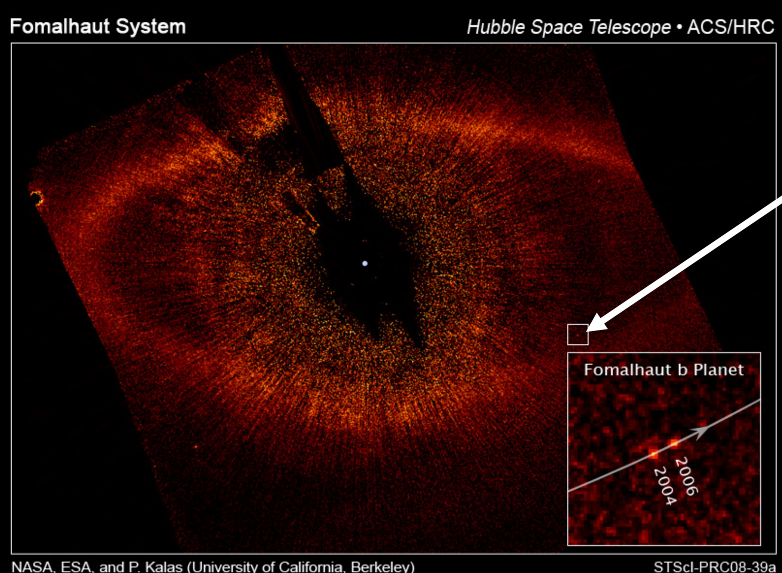
Get Spectra



Kalas et al. (2008)

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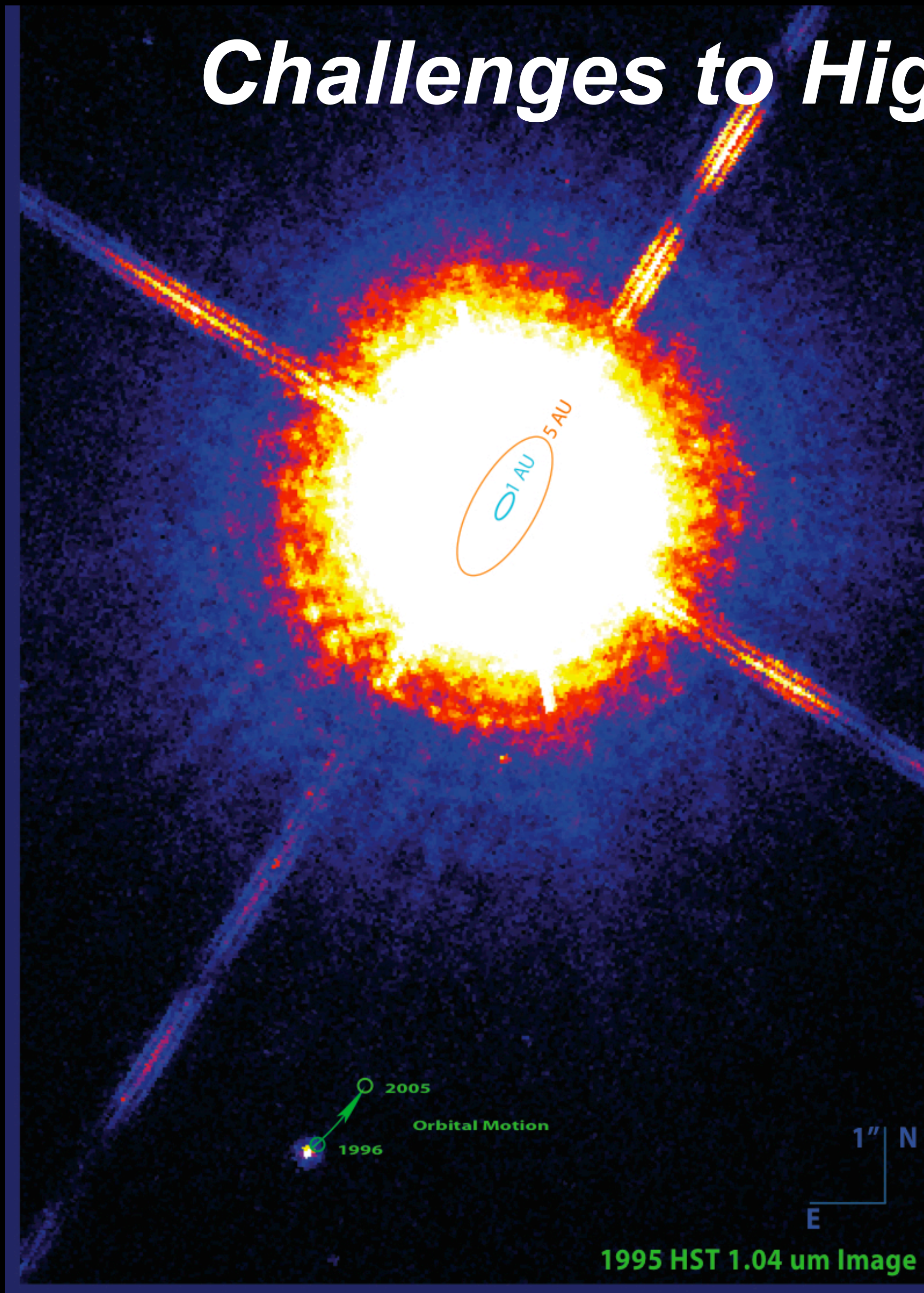
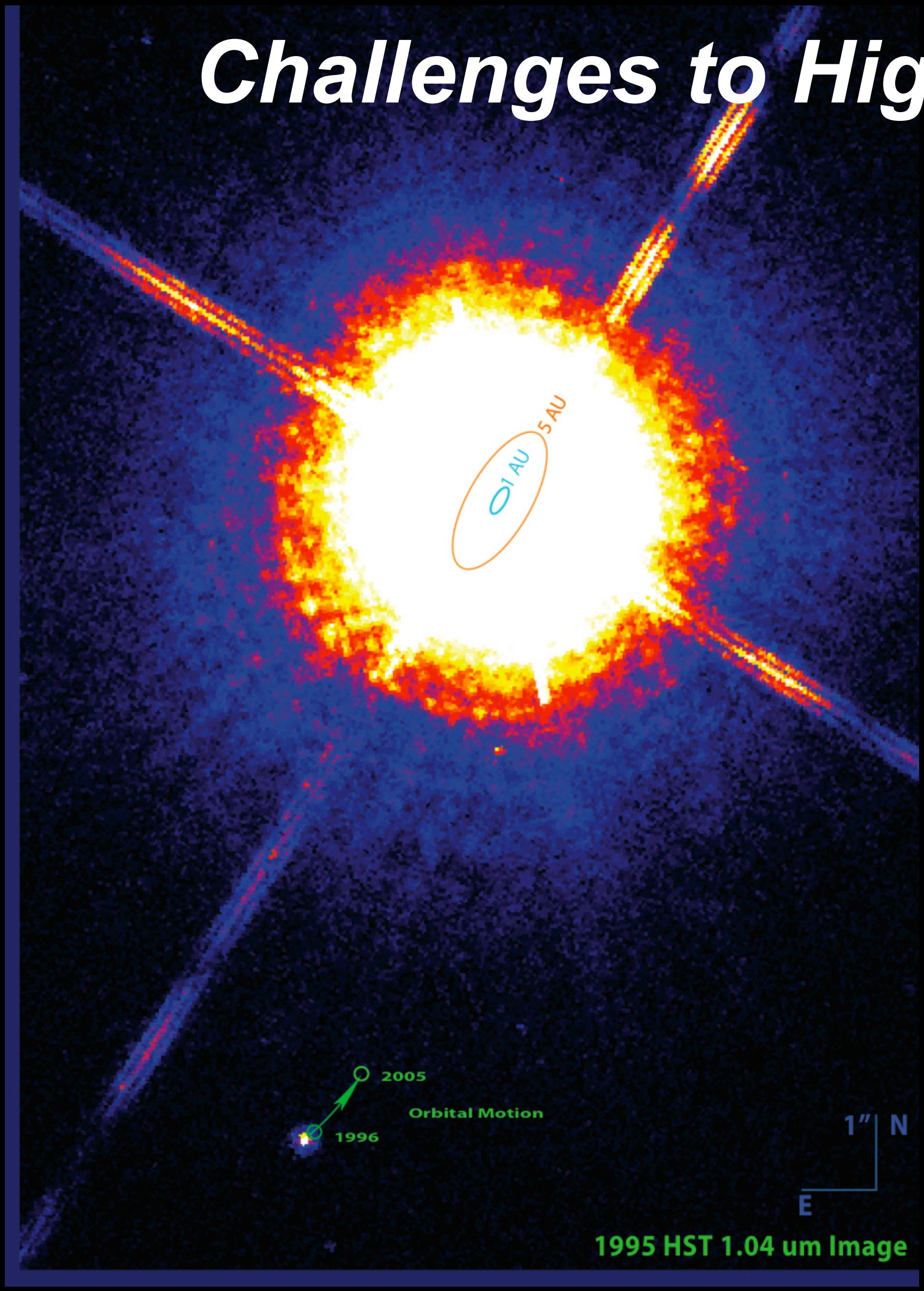
Challenges to High Contrast Imaging

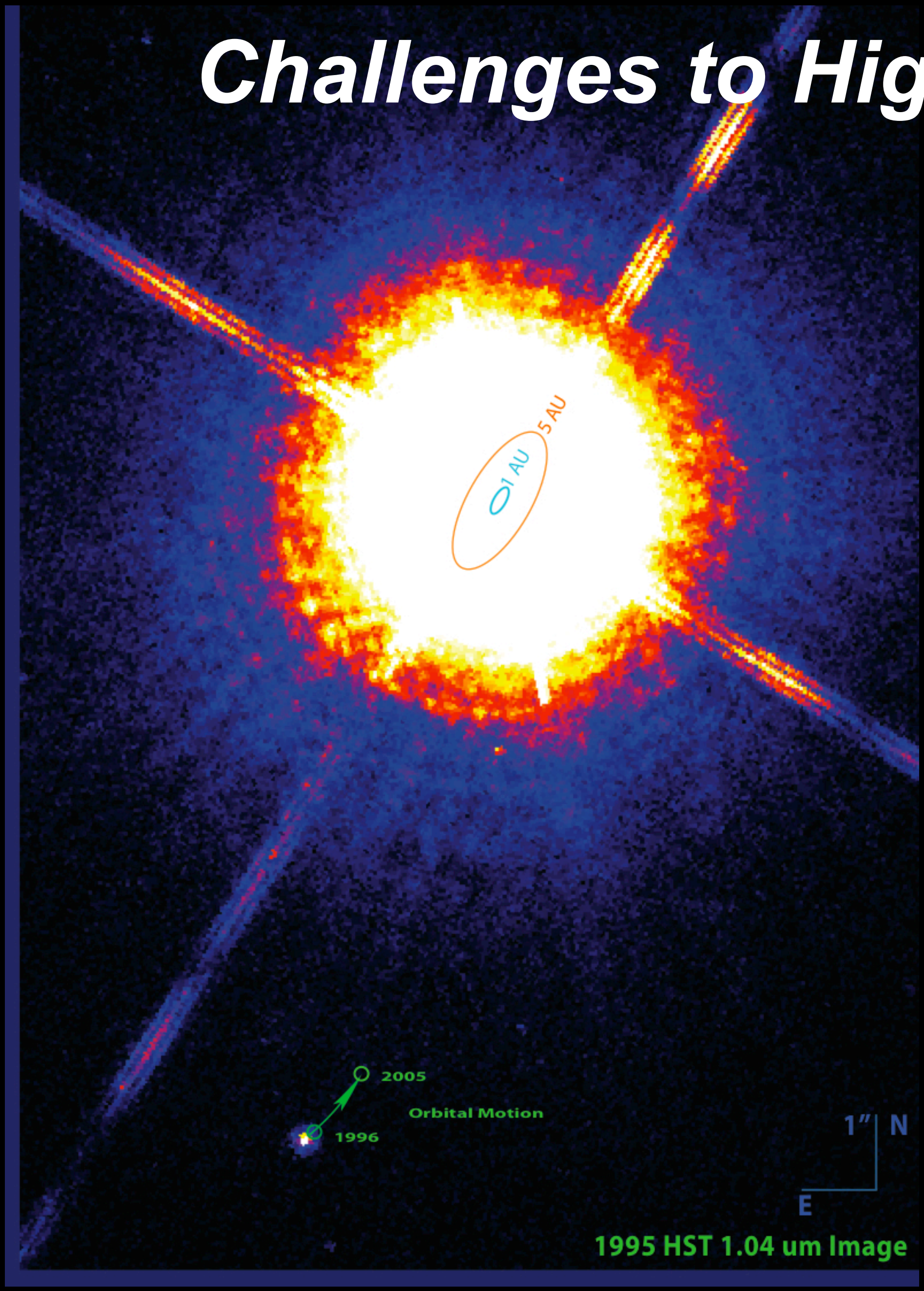


Challenges to High Contrast Imaging



1. Use Adaptive Optics to **stabilize** the starlight.

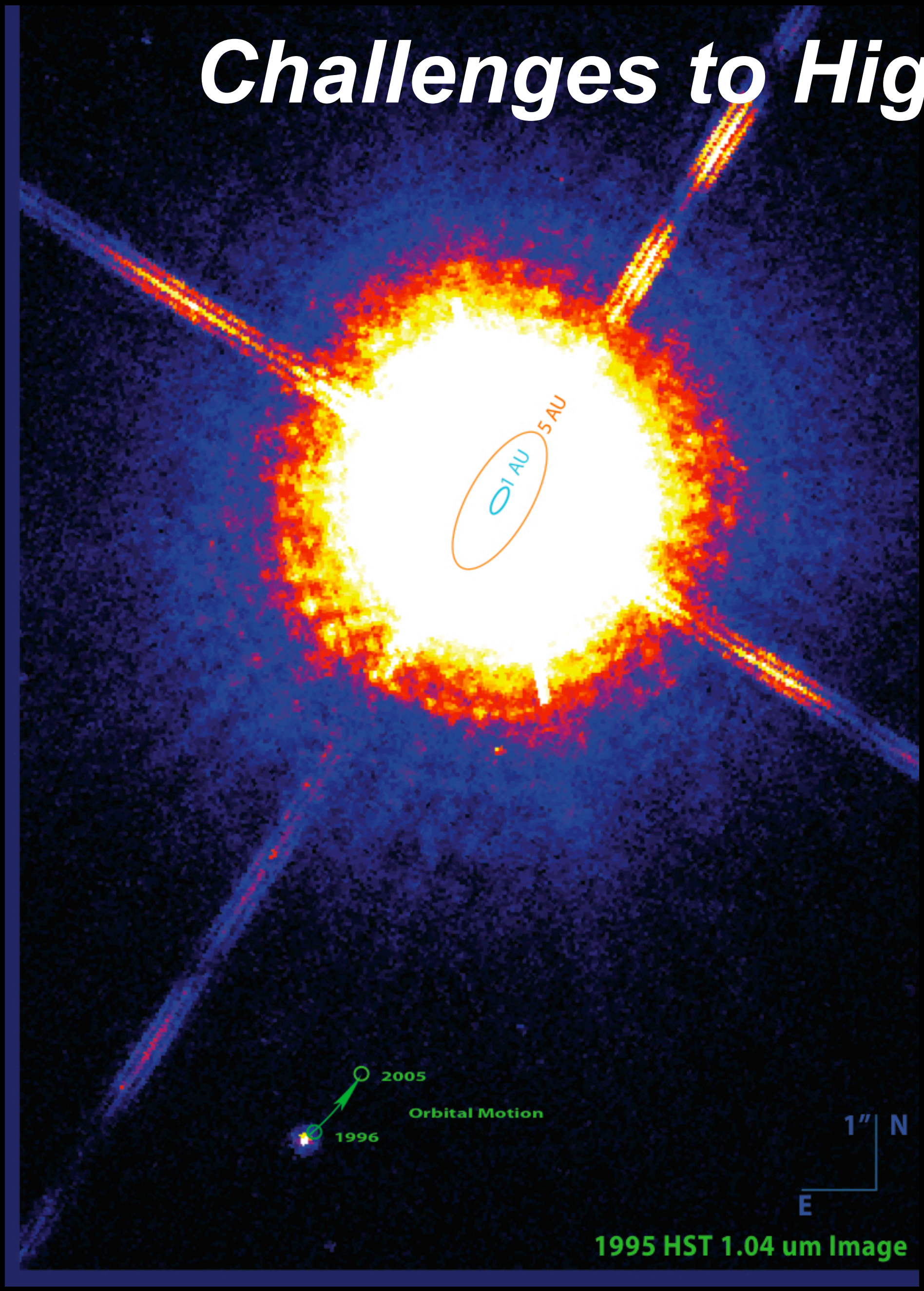
Challenges to High Contrast Imaging



1. Use Adaptive Optics to **stabilize** the starlight.

2. Block out this stable image with a **coronagraph.**

Challenges to High Contrast Imaging

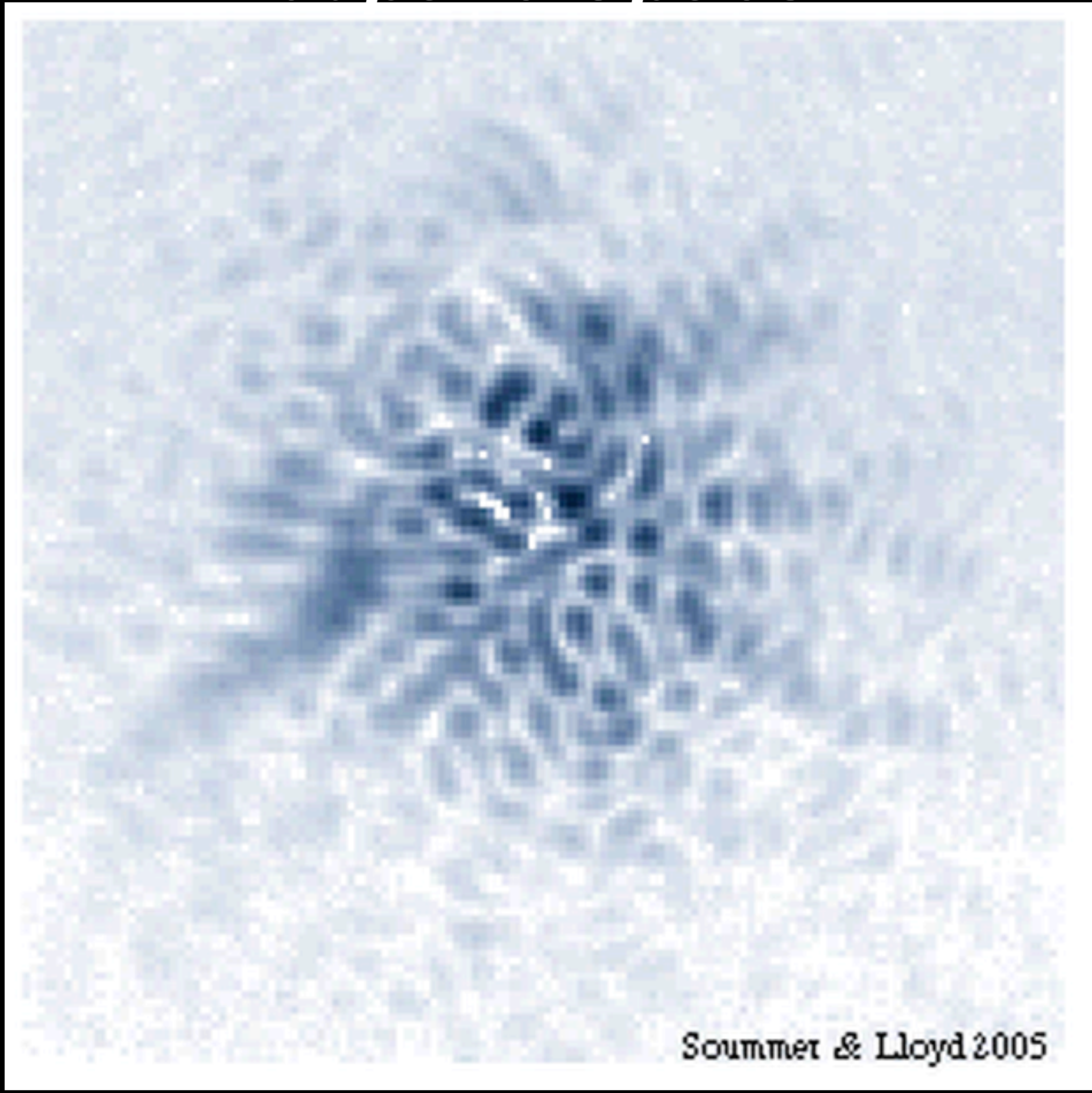


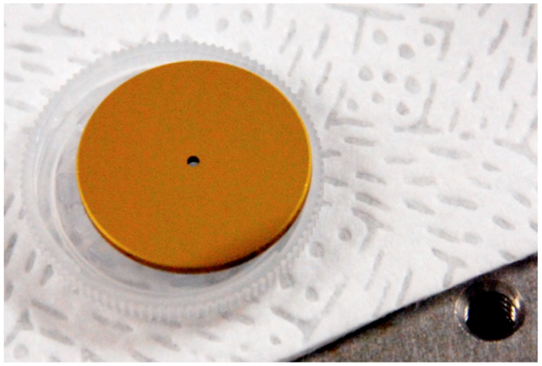
1. Use Adaptive Optics to stabilize the starlight.

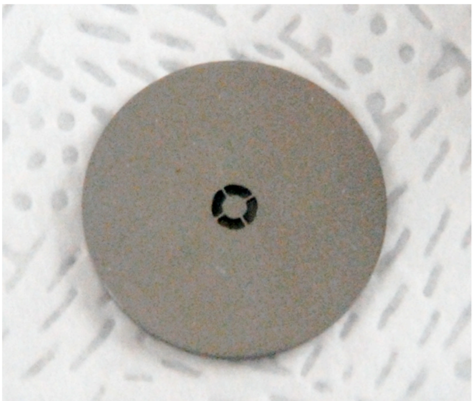
2. Block out this stable image with a coronagraph.

3. Correct Any residual uncorrected starlight.

Step 1: Starlight Stabilization with Adaptive Optics







Step 2: Coronagraphy

Focal Plane Mask:

5.37λ/D at 1.65 μm,
.37 arcsec on sky:
hole diameter 1332 microns

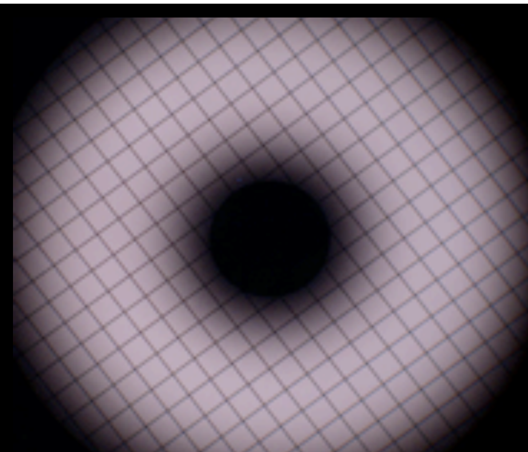
Lyot stop:

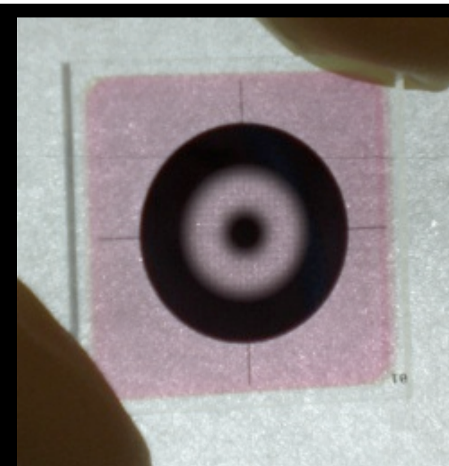
2% downsized from primary
Beam size at stop 3.8mm

Apodizing mask:

Chromium microdots
(1μm) on glass

Soummer et al. (2005)

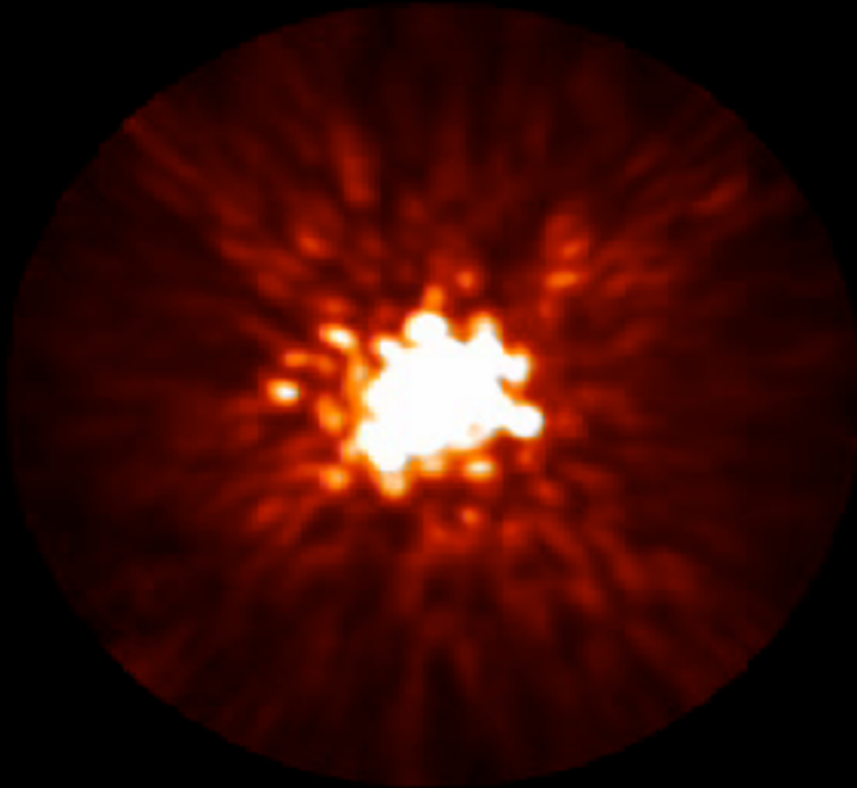




Correlated Speckle Noise Limits Sensitivity

40-minute H-band image sequence:

- **AO on**
- **Coronagraphically-occulted**

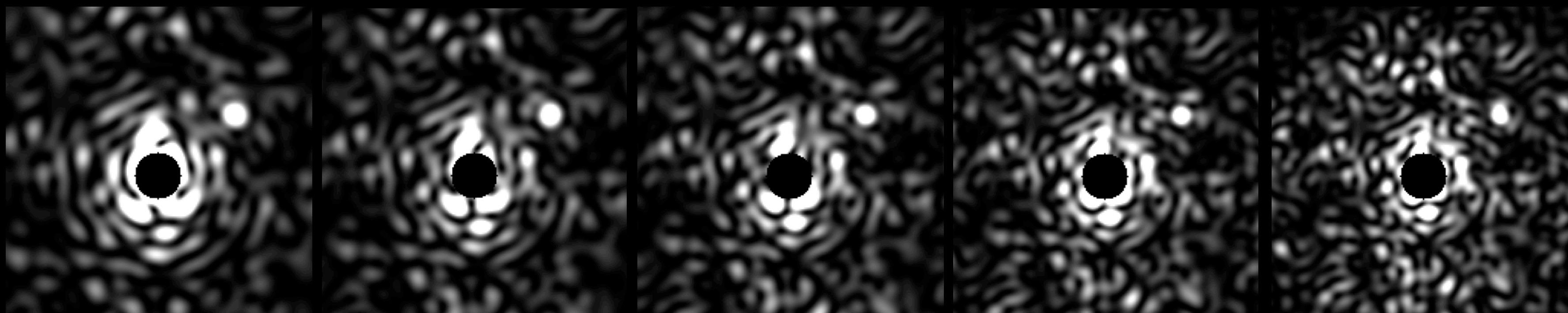


Correlated speckle noise: the greatest obstacle to ground-based exoplanet detection.

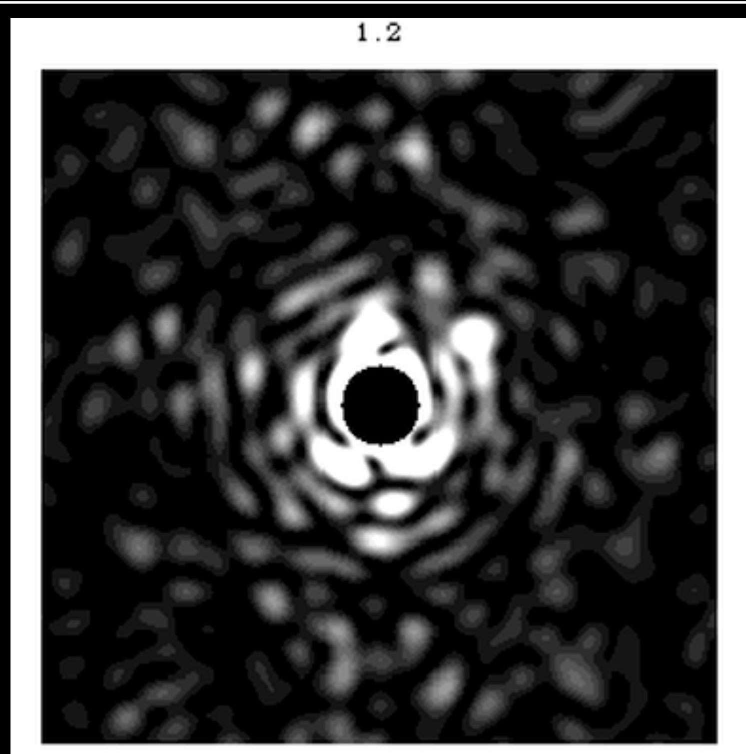
Hinkley et al. (2007)

Averaging does not work

Step 3: Speckle Suppression Through Chromaticity



RED (1.8 μm) BLUE (1.0 μm)



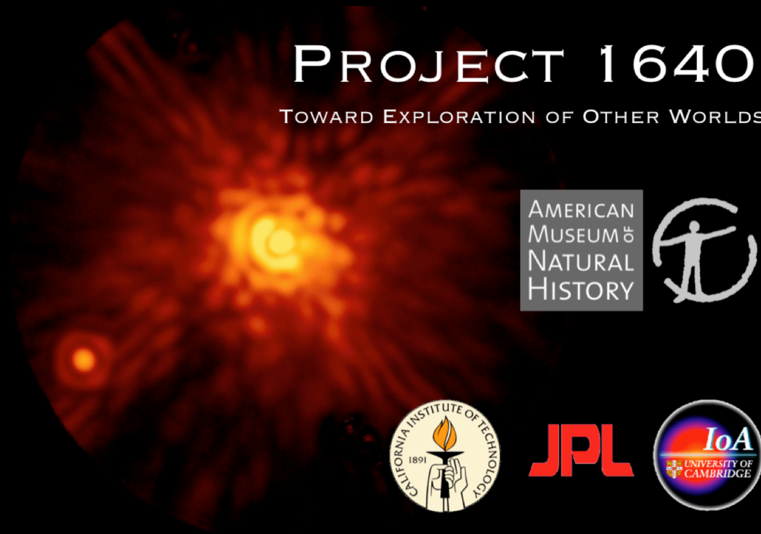
Plan: Utilize the chromatic nature of speckles with a IFS.

Enables differentiation between speckles and companions

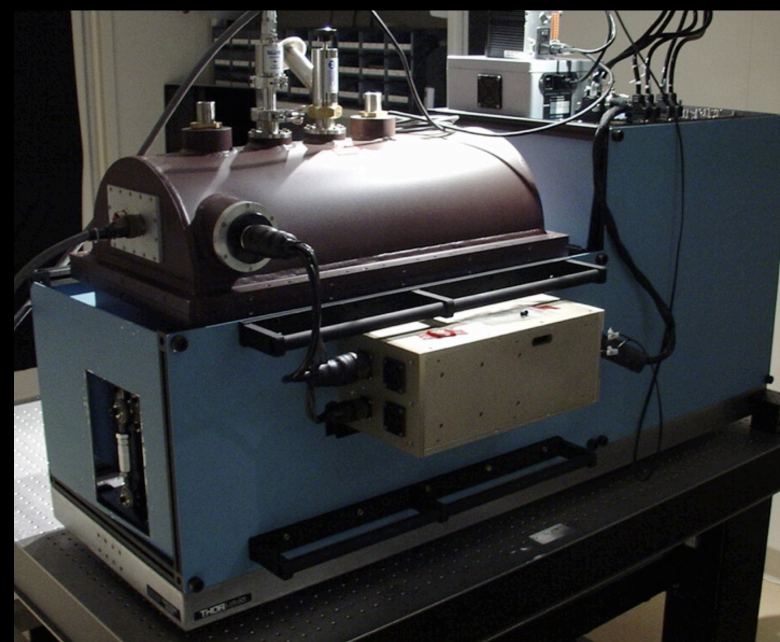
Automatically provides spectra of any companions.

Simulation courtesy of Remi Soummer & James Lloyd

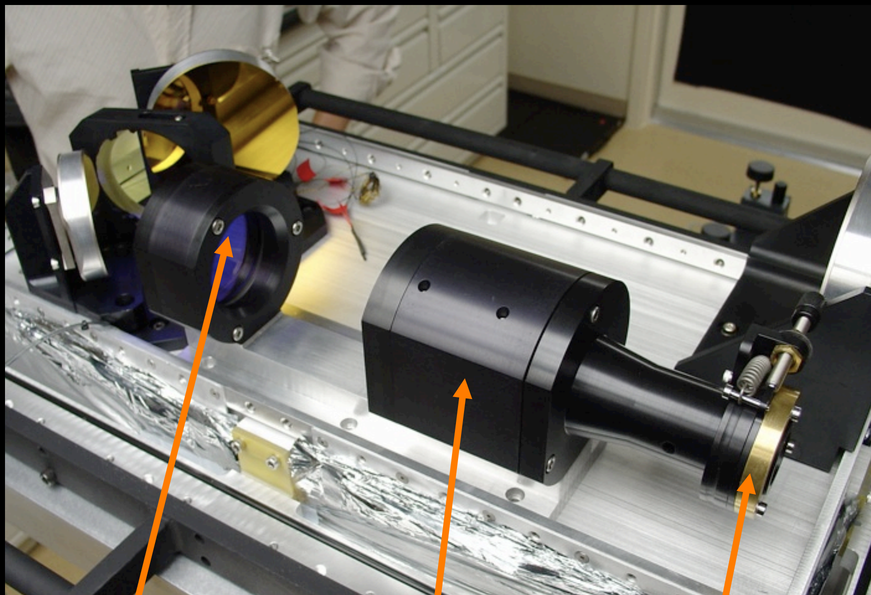
Project 1640: IFU+Coronagraph at Palomar



- Science Camera: IFU covering λ = 1.05 - 1.75μm (J to H bands)
- Diffraction-limited Apodized Pupil Lyot Coronagraph (APLC)
- Separate (2nd Stage) IR fine guidance system
- Designed to interface with the Palomar AO system (PALAO)
- Only project like it in the Northern Hemisphere.

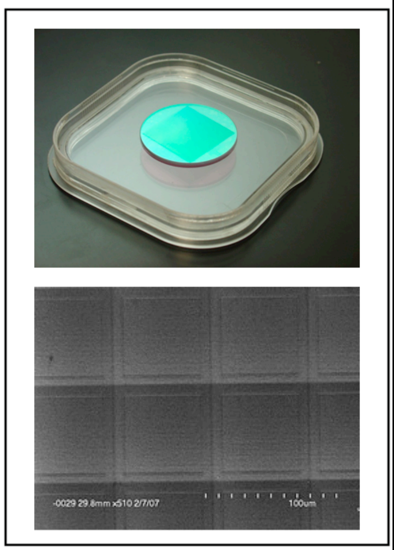


Integral Field Spectrograph

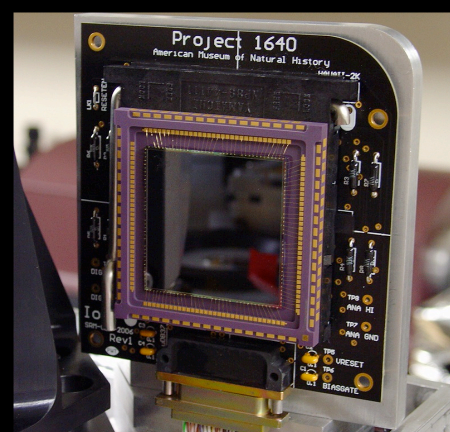


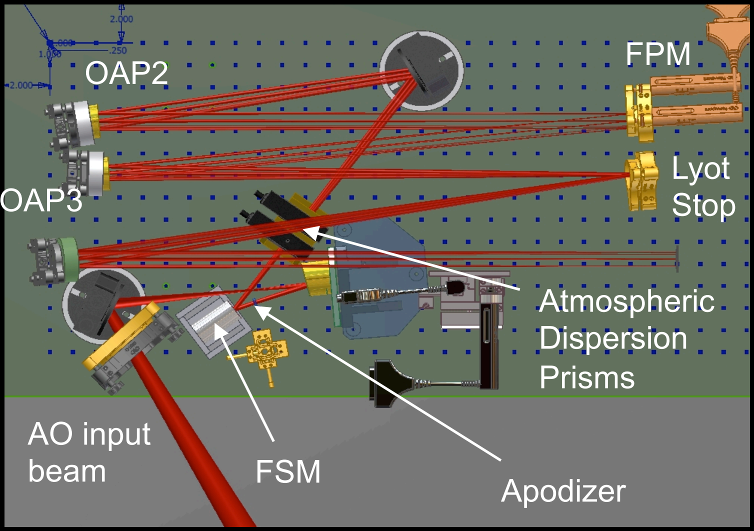
JH prism　Collimating optics　Lenslet array

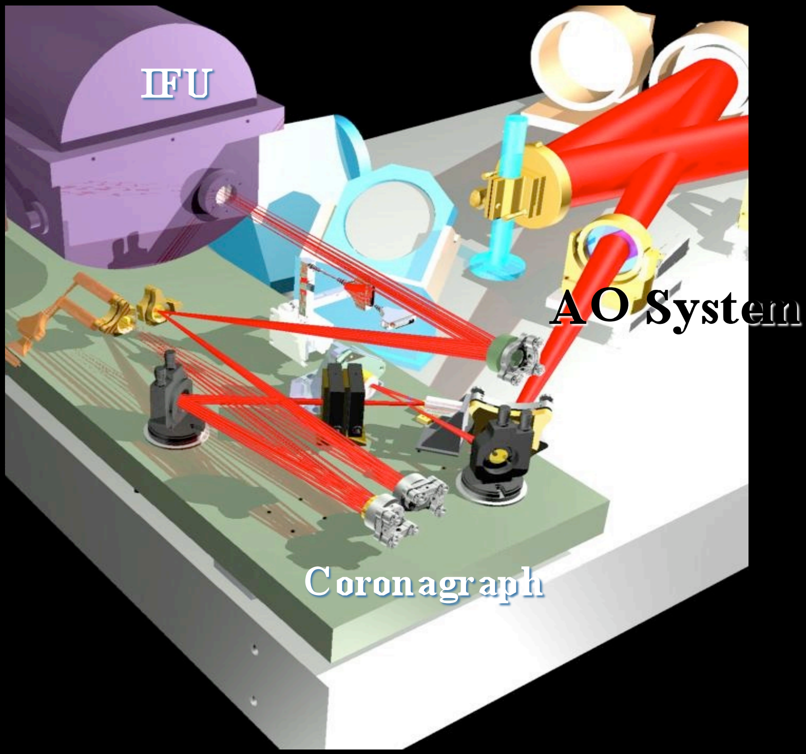
Property	Project 1640 IFU + Coronagraph
Wavelength coverage	1.05- 1.75 μm, $\Delta\lambda = 0.7$ μm
Central wavelength	1.403 μm
IFU FOV	4200 mas
Platescale	21 mas/lenslet
Total spectra	200 x 200 = 40,000
Pixels per spectrum	3.2768 x 32
$\Delta\lambda$ per 2 pixels	.044 (.7μm/32 pix)
$R = \lambda/\Delta\lambda$	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%



- Array of 270 x 270 microlenses 75μm pitch. Two powered faces.
- Rockwell Hawaii-II 2048x2048 pixel HgCdTe array

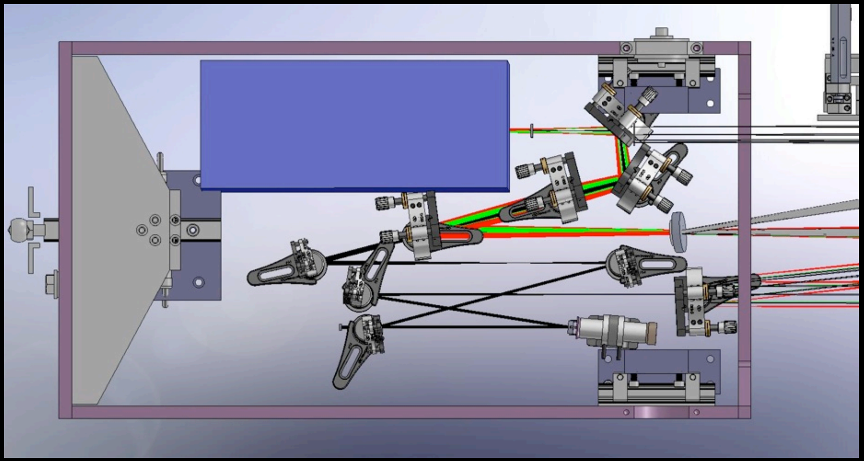






P1640 Coronagraph & Wave Front Calibration System

Wave Front Calibration system (2010):

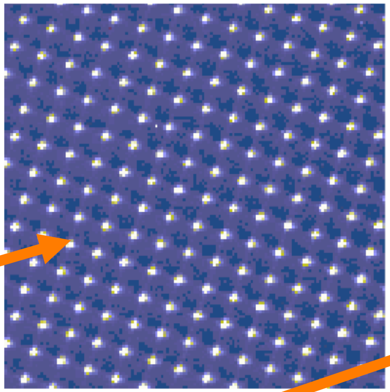


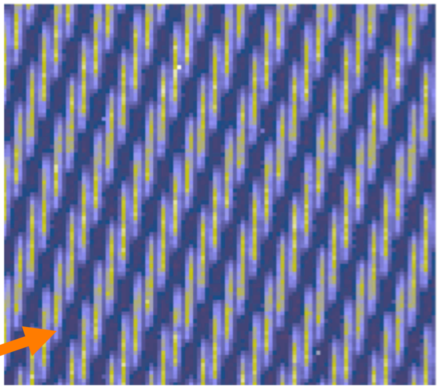
- Interferometer nearly identical to GPI
- Designed to achieve 1nm RMS wave front error measurement at 1Hz
- Dynamic Control of wave front errors.

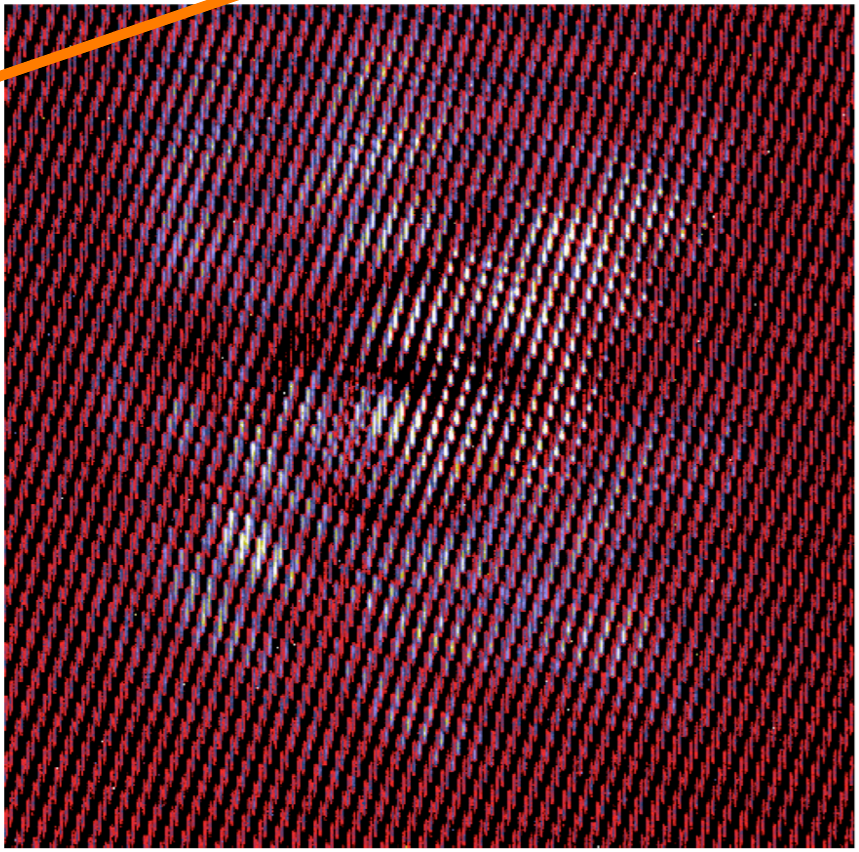
Laboratory Data

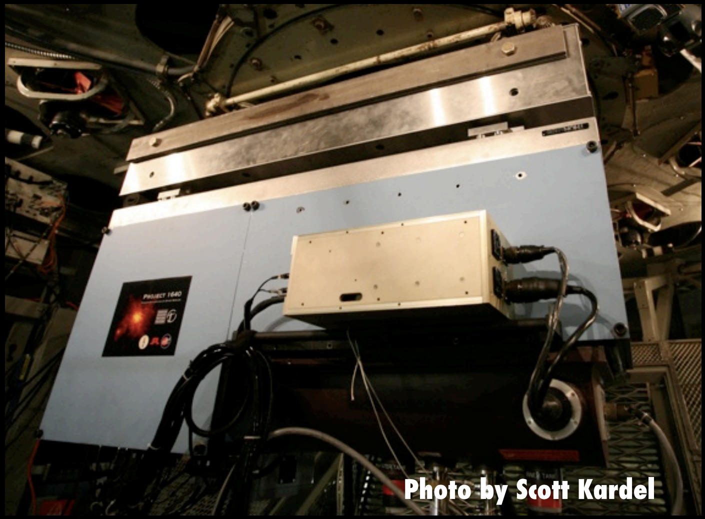
Monochromatic 1330 nm light source

Broadband white light source





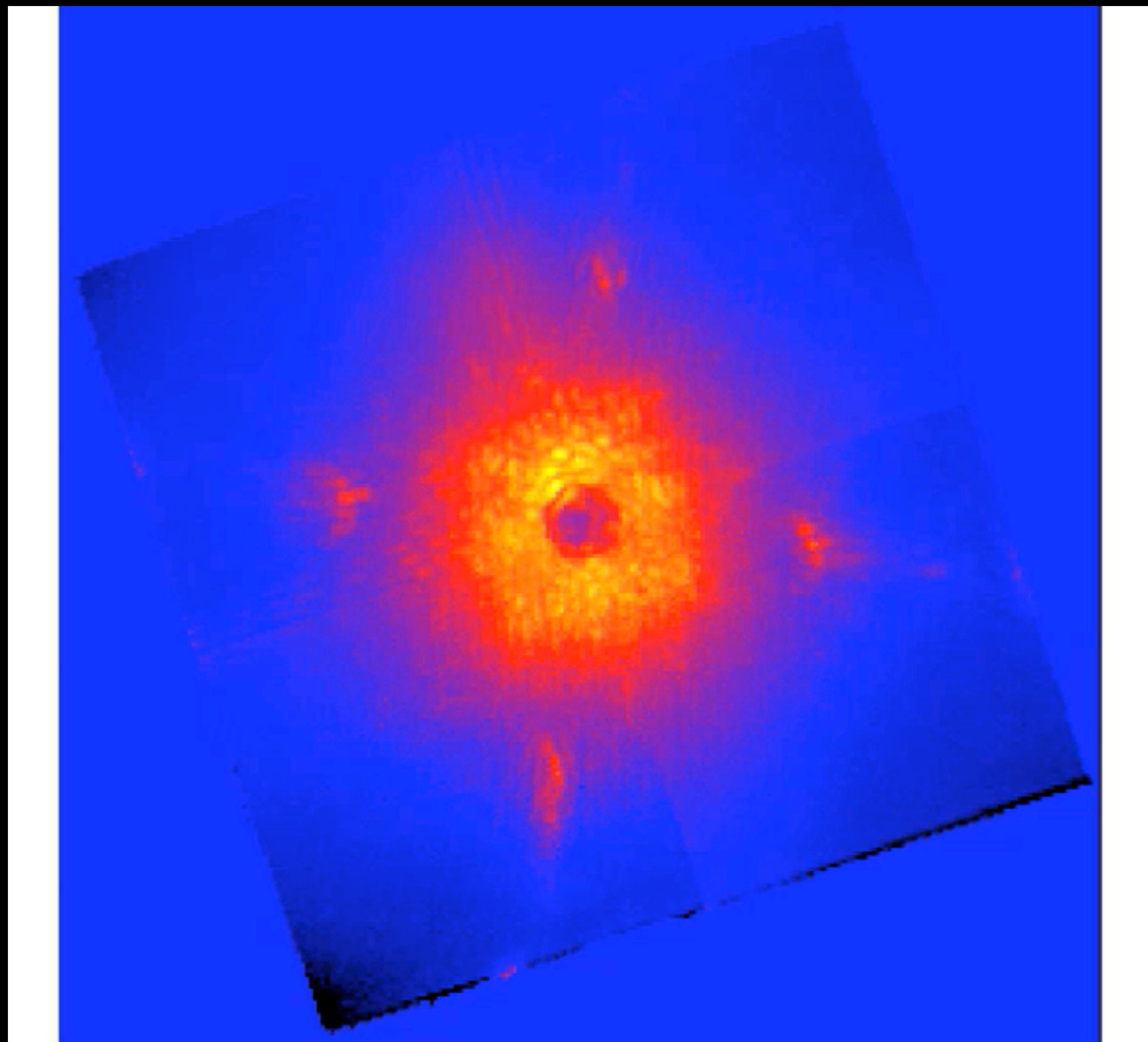




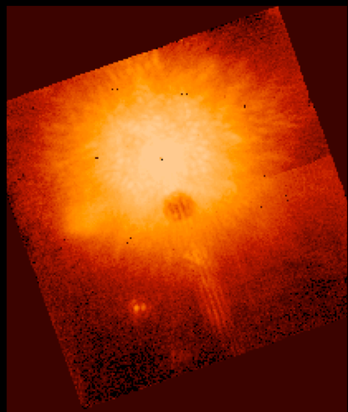
Data

Data cube spans 1.05 - 1.75 μm.

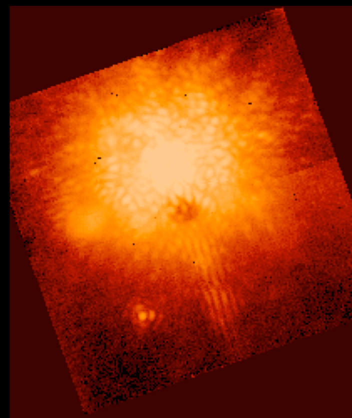
4”



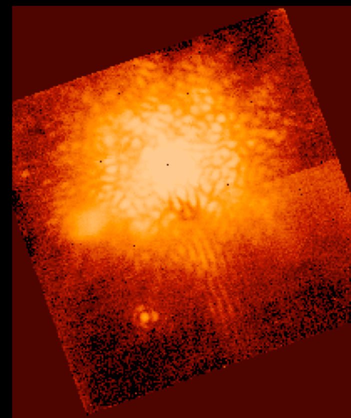
Stellar Companion to a Nearby A-star



1.25μm



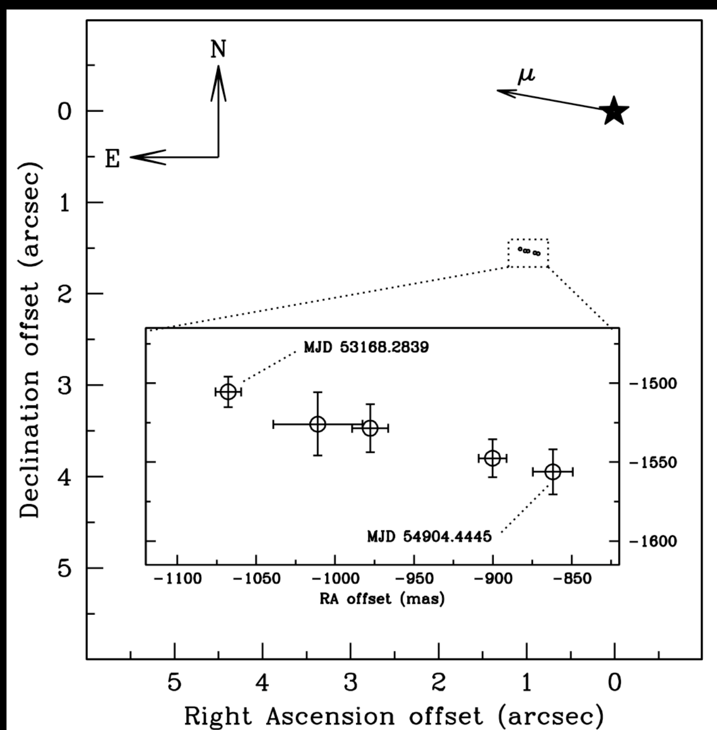
1.58μm

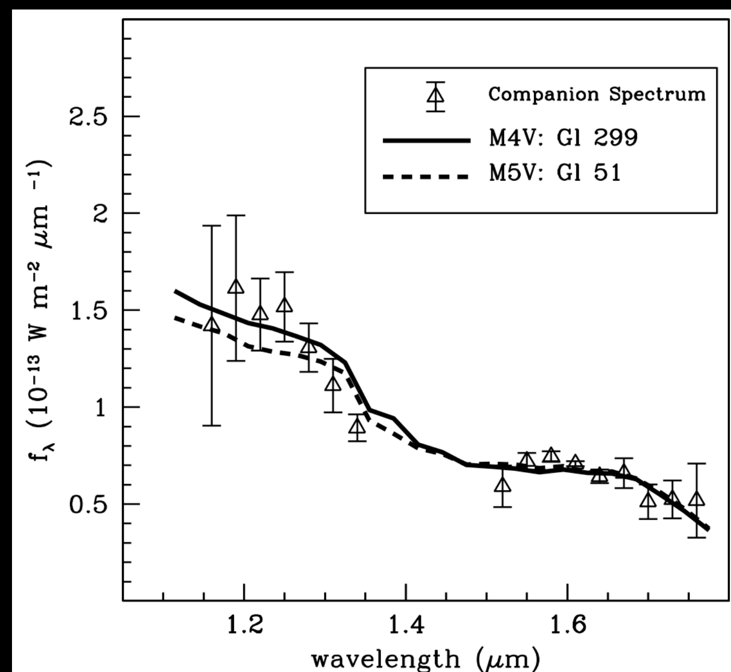


1.73μm

4”

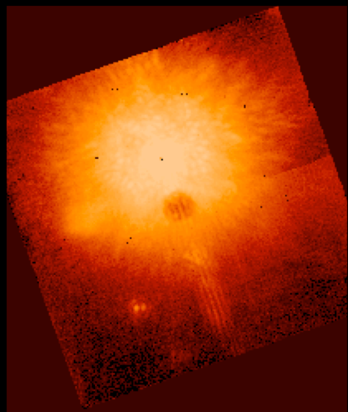
- Photometry
- Astrometry
- CPM
- Orbital motion
- Spectrum





Hinkley et al. (2009) submitted

Stellar Companion to a Nearby A-star



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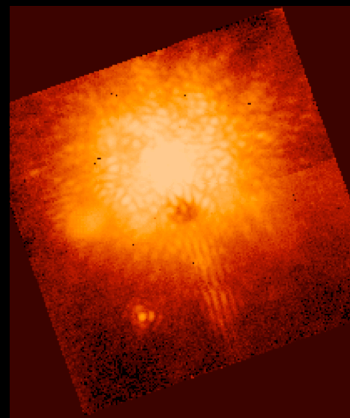

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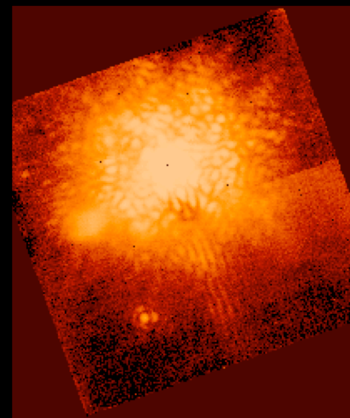
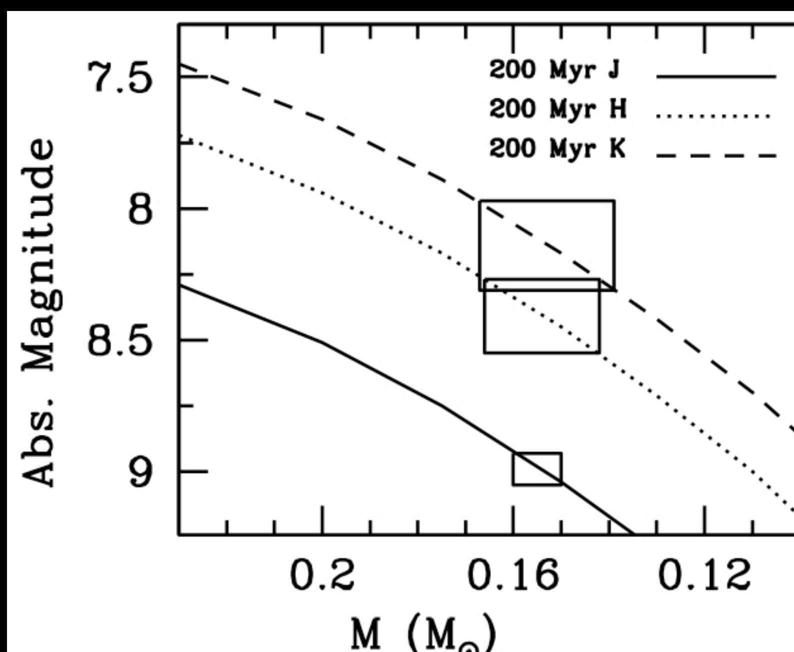
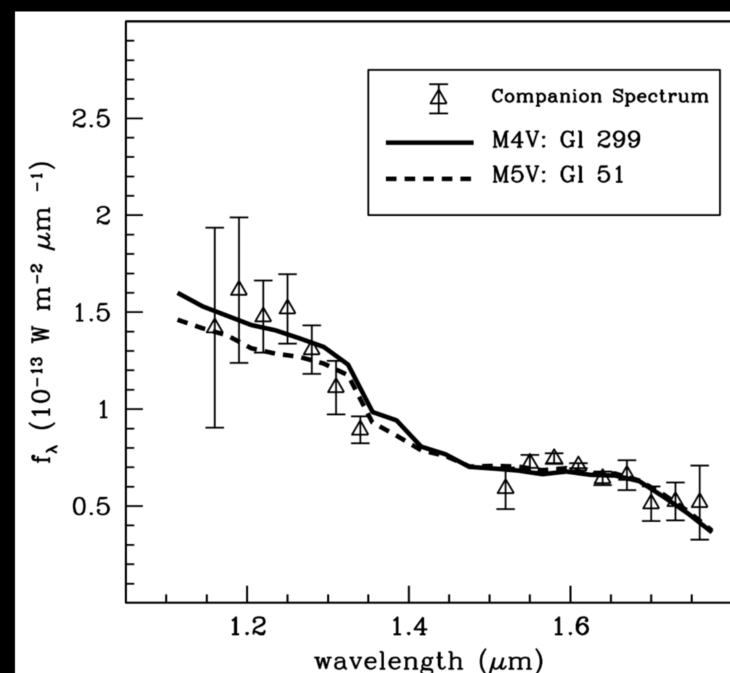


1.73μm

4”

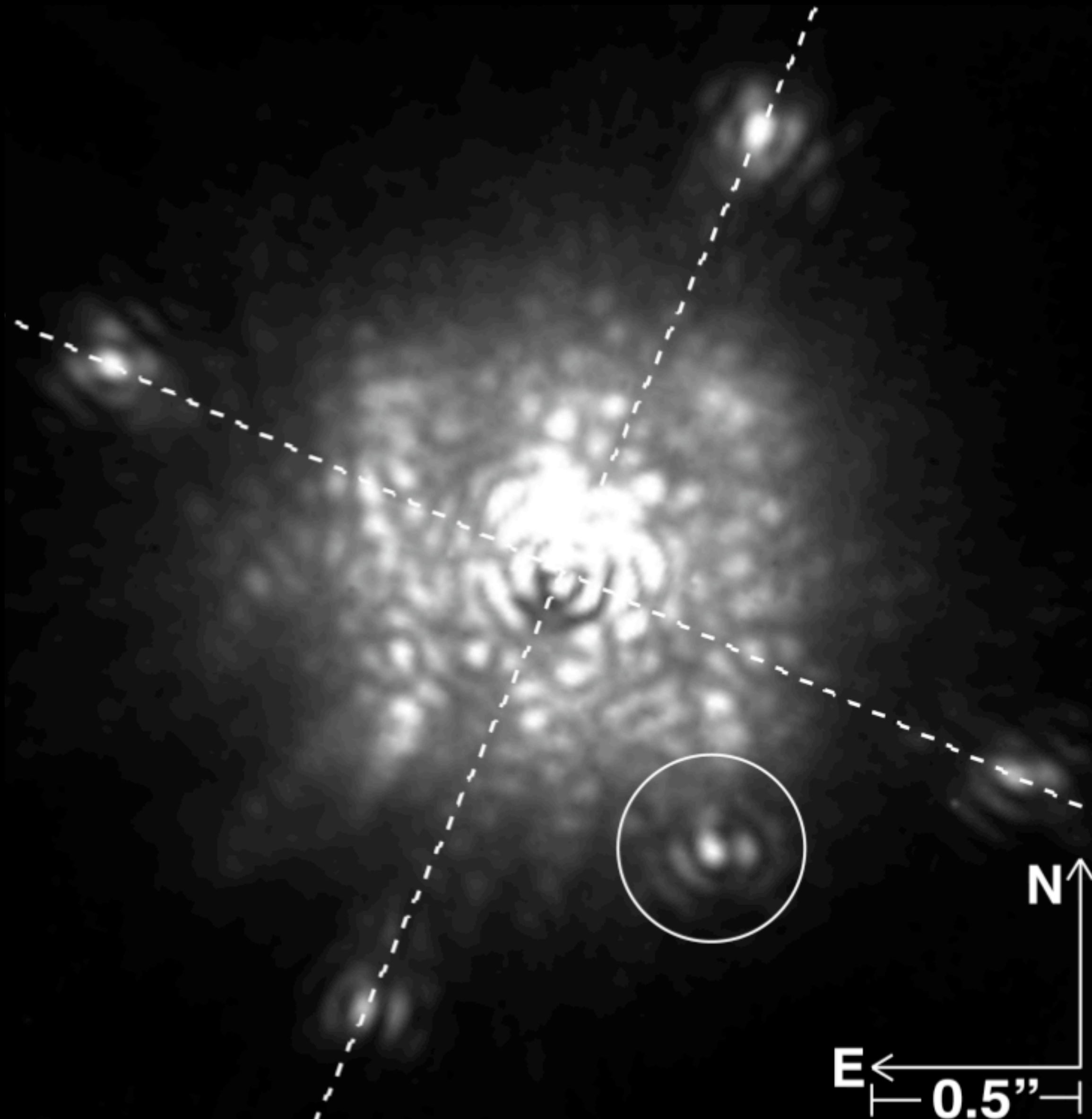
- Photometry suggests ~0.16 solar masses.
- Mass ratio q ~ 0.07





Hinkley et al. (2009) submitted

Stellar Companion to a different Nearby A-star

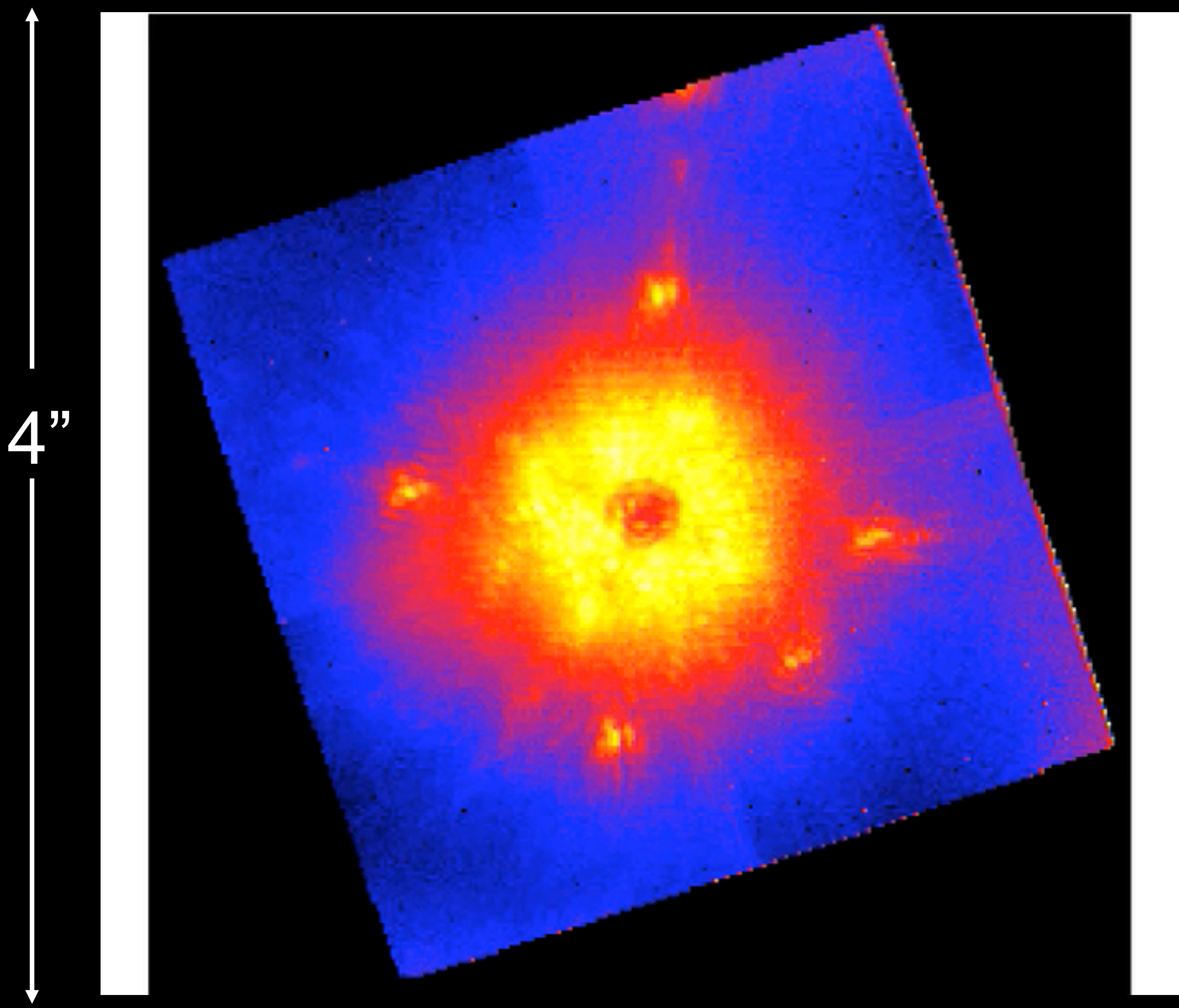


- **Are unseen low mass companions the source of anomolously high X-ray counts from A-stars?**

- **Common parallax obtained**
- **Anomolously high ROSAT brightness**
- **M3-M4 companion**

Zimmerman et al. (2009) in prep

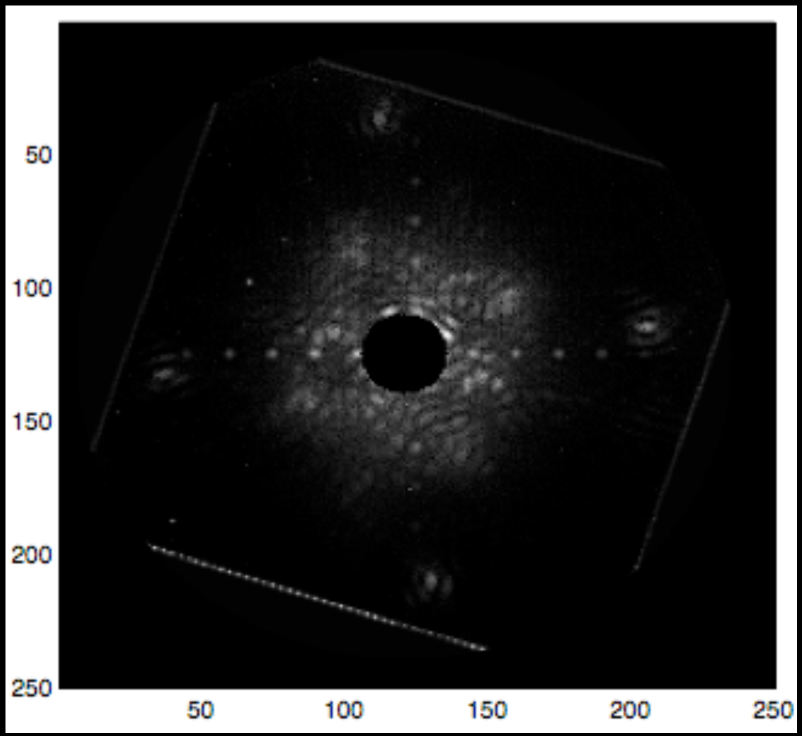
Stellar Companion to a different Nearby A-star

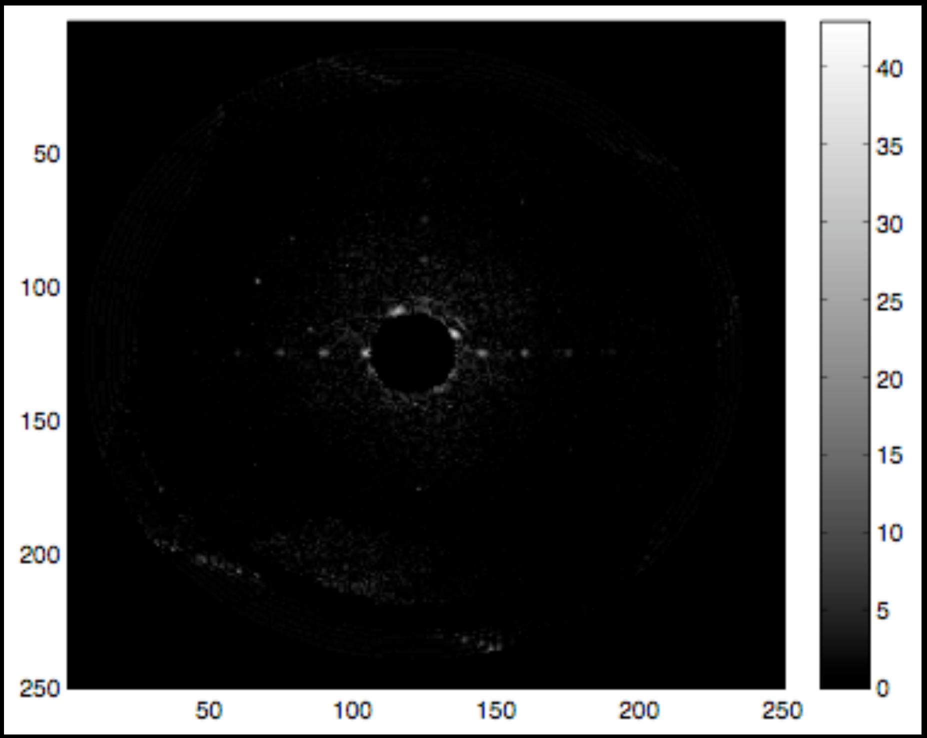


Data cube spans 1.05 - 1.75 μm.

Speckle Suppression with LOCI
(Locally Optimized Combination of Images)

See LaFrenière et al. (2007)





Images courtesy of Laurent Pueyo

Performance

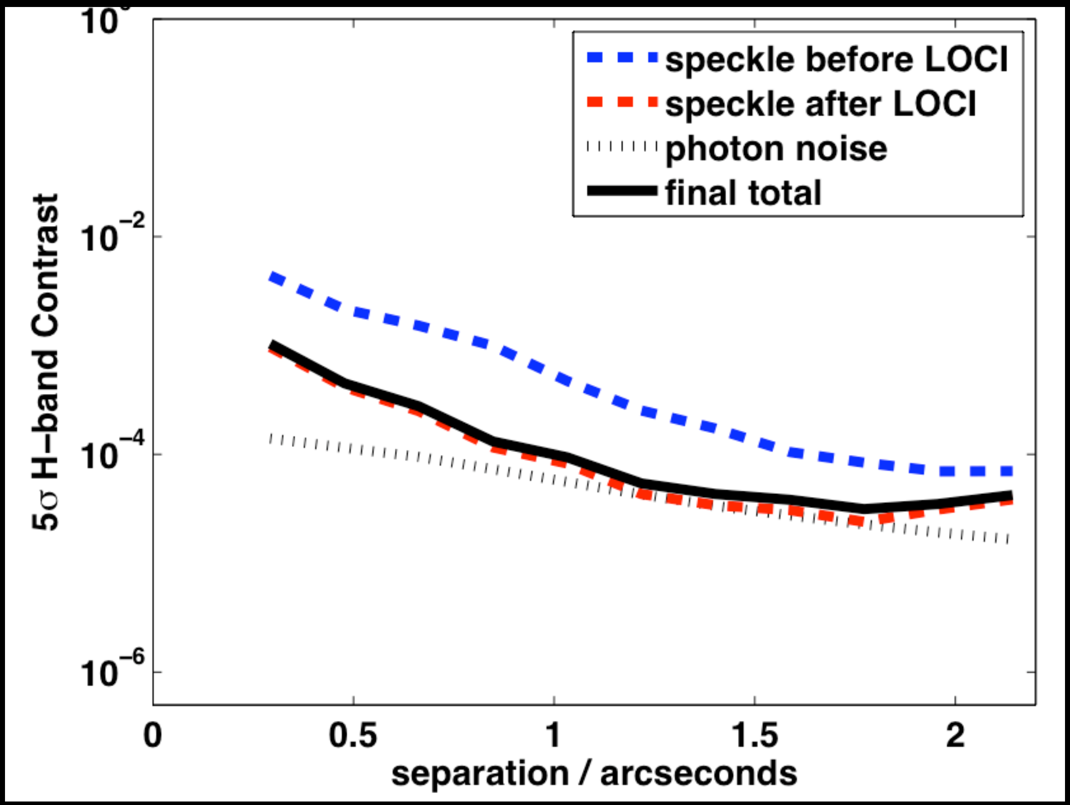


Image courtesy of Justin Crepp

Speckle suppression Through LOCI seems to gain 2-3 magnitudes.

Still some sensitivity issues.

Gemini Planet Imager

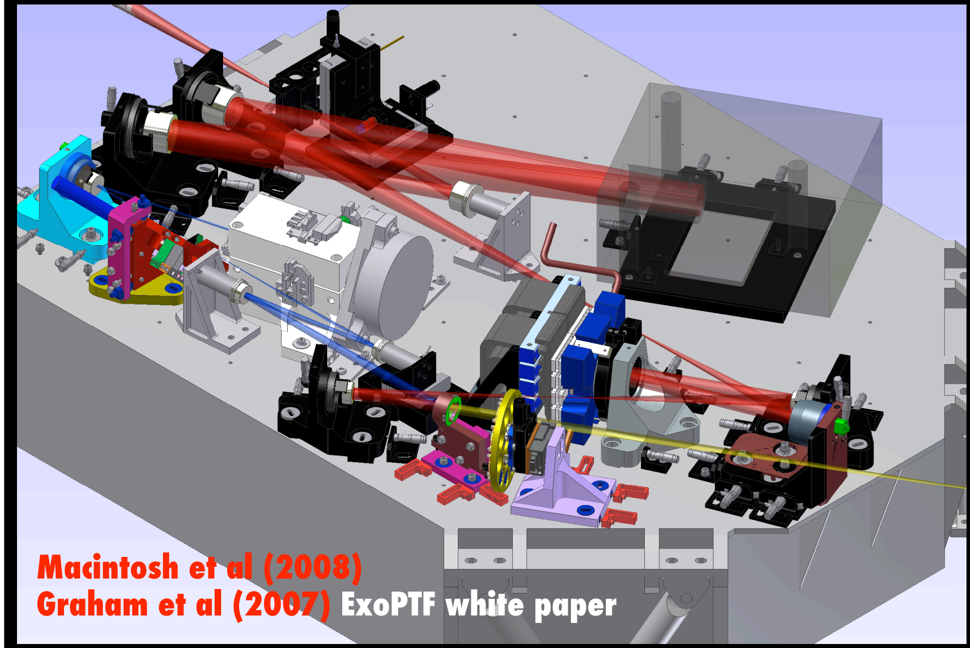
MEMS Extreme-AO +
apodized pupil coronagraph

IFS (1-2.4 μm), R=45,
2.8"x2.8" FOV

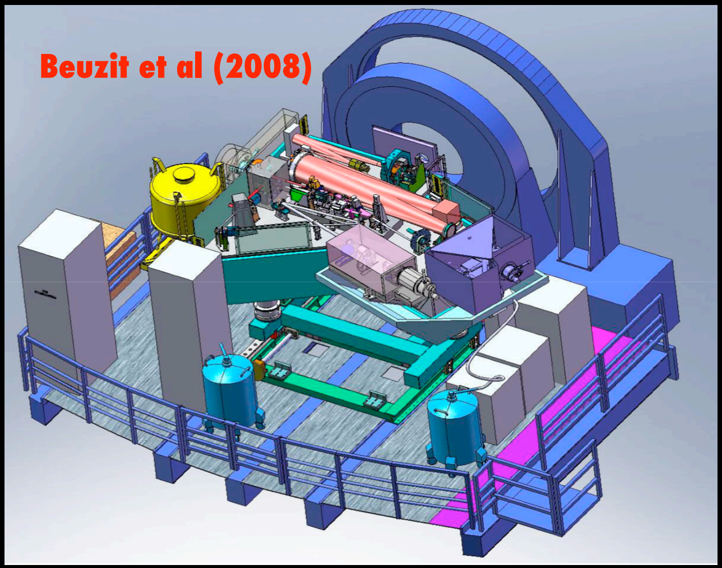
Dual channel polarimetry

Wave front calibration system

(southern hemisphere) First light: 2011



SPHERE (VLT)



Extreme-AO (41x41 actuator)
+ coronagraph

Differential imaging (Y, J, H, Ks)

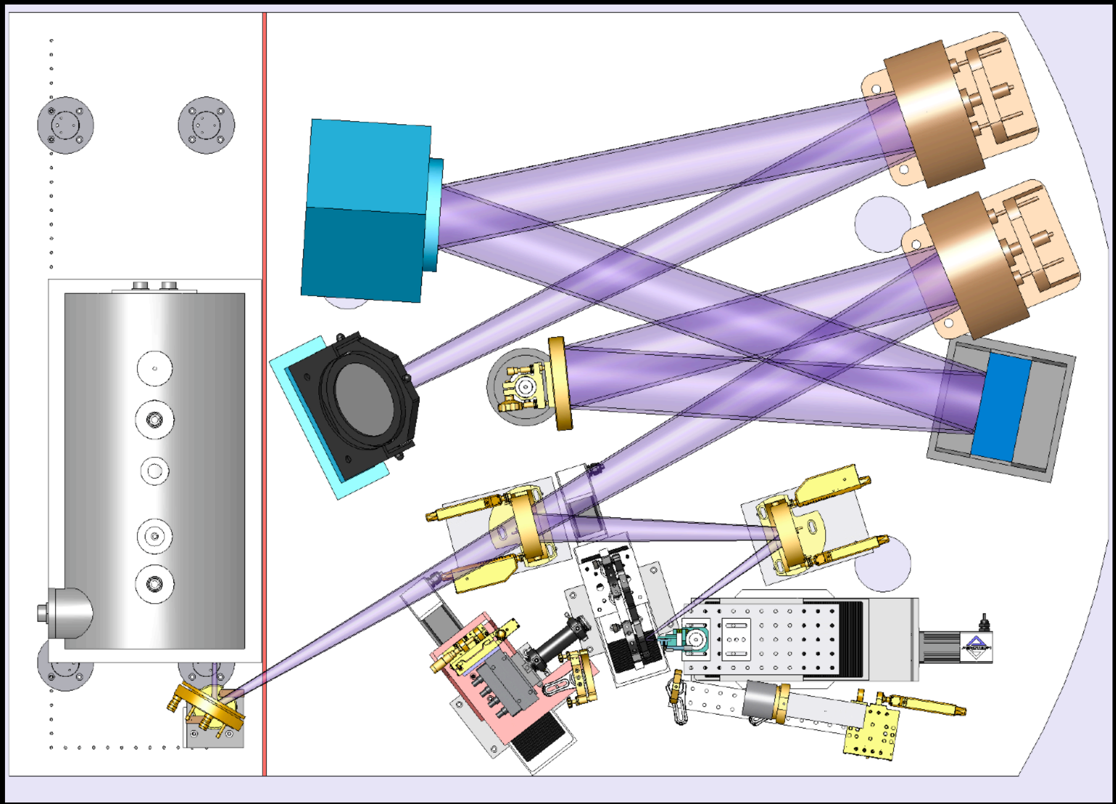
IFS (0.95-1.65 μm)
R=30, 1.8" x 1,8"FOV

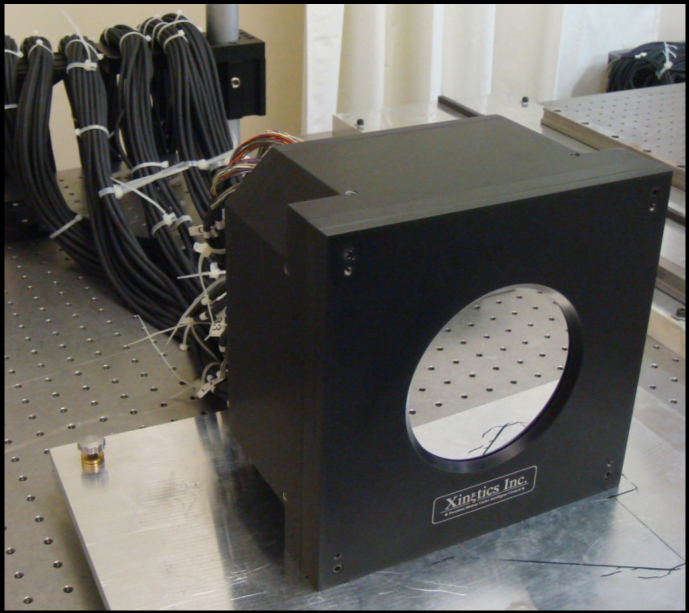
Visible Imaging Polarimeter

First light: 2011

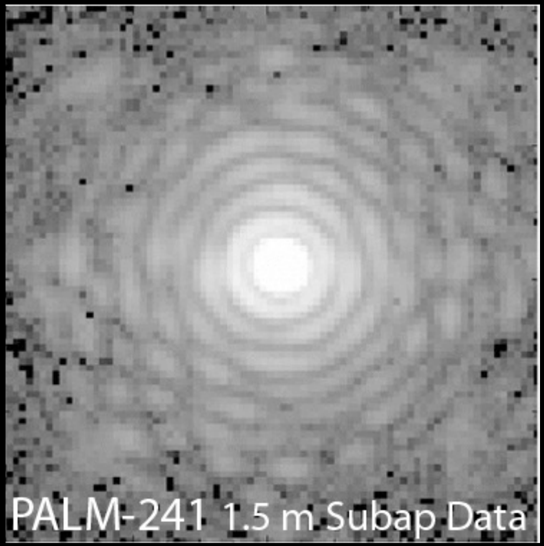
Palomar AO Upgrade: "PALM-3000" (2010)

- 3,388 Actuator Deformable Mirror.
- High-order Wave Front Sensor (62 x 62 Shack-Hartmann).





High Strehl Preview:



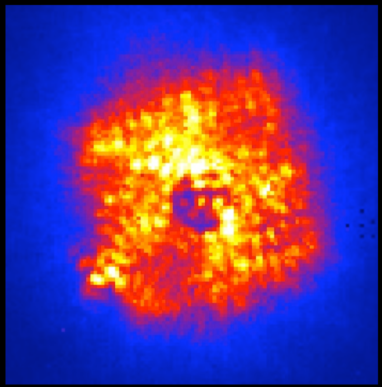
Serabyn et al. (2007)

Ongoing P1640 Observations

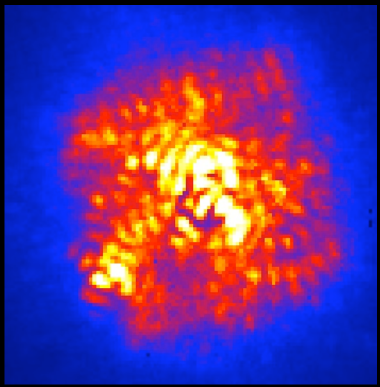
- Opportunities: planet searches, binary star studies, and planetary science.
- Data cubes obtained for at least 100 stars.
- Data cube extraction pipeline is mature.
- At least 500 GB of data.

Observing Plan:

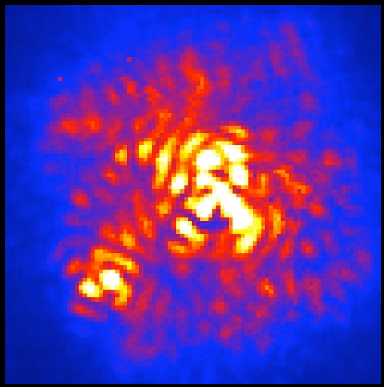
1. Initial survey with current PalAO system. Magnitude limit: 13th
2. Key Project Survey with PALM3000 and Calibration system (2010-12). Magnitude limit: 8th



1.34μm



1.55μm



1.67μm