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

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Photo by Scott Kardel
Transits

Radial Velocity
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Direct Imaging
Recent Direct Imaging

HR 8799 b, c, d:
- 68, 38, 24 AU
- 7, 10, 10 M$_{\text{Jup}}$
- 60 Myr system

Fomalhaut b:
- 119 AU
- Few M$_{\text{Jup}}$

Marois et al. (2008)

Kalas et al. (2008)
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Marois et al. (2008)
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High Contrast is Needed for Direct Imaging

Large planets are $10^7$ (that's 10,000,000!) times fainter than their host star.
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Challenges to High Contrast Imaging

1. Use Adaptive Optics to stabilize the starlight.
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Challenges to High Contrast Imaging

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

2. **Block out this stable image with a coronagraph.**
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Challenges to High Contrast Imaging

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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 (1 µm) 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.

Averaging does not work

Hinkley et al. (2007)
Step 3: Speckle Suppression Through Chromaticity

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 \( \lambda = 1.05 - 1.75 \mu m \) (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

- Collimating optics
- JH prism
- Lenslet array

Array of 270 x 270 microlenses 75 µm pitch. Two powered faces.

Rockwell Hawaii-II 2048x2048 pixel HgCdTe array

Property | Project 1640 IFU + Coronagraph
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Wavelength coverage | 1.05 - 1.75 µm, ∆λ = 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
∆λ per 2 pixels | .044 (.7µm/32 pix)
R = λ/∆λ | 32
Lenslet Pitch | 75 µm (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%
**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.
Stellar Companion to a Nearby A-star

- Photometry
- Astrometry
- CPM
- Orbital motion
- Spectrum

$1.25\mu m$

$1.58\mu m$

$1.73\mu m$

Hinkley et al. (2009) submitted
Stellar Companion to a Nearby A-star

- Photometry suggests ≈0.16 solar masses.
- Mass ratio $q \sim 0.07$

Hinkley et al. (2009) submitted
Stellar Companion to a different Nearby A-star

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

- Common parallax obtained
- Anomalously 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

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

Still some sensitivity issues.

Image courtesy of Justin Crepp
**Gemini Planet Imager**

MEMS Extreme-AO + apodized pupil coronagraph

IFS (1-2.4 $\mu$m), $R=45$, 2.8"x2.8" FOV

Dual channel polarimetry

Wave front calibration system (southern hemisphere)  
*First light: 2011*

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**SPHERE (VLT)**


Extreme-AO (41x41 actuator) + coronagraph

Differential imaging (Y, J, H, Ks)

IFS (0.95-1.65 $\mu$m)  
$R=30$, 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:

PALM-241 1.5 m Subap Data

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

1.34 μm  1.55 μm  1.67 μm