

**GEMINI**  
**OBSERVATORY**



*Exploring the Universe, Sharing its Wonders*

# Adaptive Optics Instrumentation and Capabilities

Presented by

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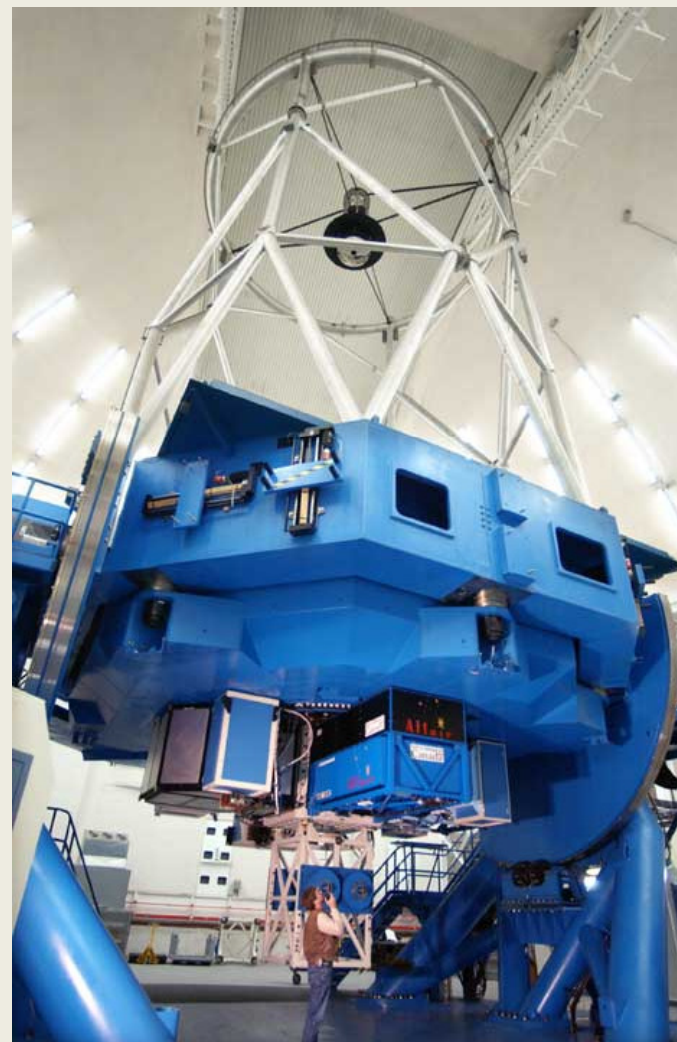
GNAO Workshop, Victoria BC, June 19-21, 2012

# Gemini Telescopes



Gemini International Community

- Optimized for:
  - Thermal IR
  - High angular resolution
- Optimization choices:
  - silver coating
  - low emissivity (2.5% M1+M2)
  - F/16 narrow field
  - Thin spiders
    - low diffraction
  - LLT behind M2
- Cass: 3 instr.+ Cal unit + AO system
- ~ 90% Queue



## **Gemini North:**

2000: Hokupa'a 36

**2002: Altair NGS (Facility Instrument\*)**

**2006: Altair LGS**

**2012: Altair LGS + P1**

## **Gemini South:**

2005: Hokupa'a 85

**2009: NICI (Coronagraph, BDs/Hot Jupiters)**

**Niche Instrument**

**2011: GeMS (Multi-Conjugate Adaptive Optics)**

**Facility Instrument\***

2013: GPI (Gemini Planet Imager)

Niche Instrument

**\*Facility Instrument is capable of feeding all science instruments**

## Currently Available Gemini AO Systems for Science

Telescope	Gemini North	Gemini South
Instrument	Altair (NGS/LGS)	NICI (NGS)
WFS/DM	SH 12 x 12 + 177 actuator DM	Curvature + 85 element bimorph
Design	Modular feeding other instruments (NIRI/NIFS/GNIRS)	Stand-alone with Coronagraph and Dual Channel imager
Loop Speed	1 kHz	1.2 kHz
Imaging	JHK	JHK
Pixel Scale	22 mas	18 mas
FoV	22.5" x 22.5"	18.4" x 18.4"
K-Band Strehl	30% - 45%	35% - 55%

# Gemini AO Instrumentation

AO System	Instrument	FoV (")	SR/FWHM (H-Band)	R <sub>lim</sub> (full/limit)	Sky Coverage (%)
UH36	QUIRC	20	15	15	1
Altair NGS	NIRI / NIFS / GNIRS	20	35	12/15	< 1
Altair LGS	NIRI / NIFS / GNIRS	20/50	20	15/18	~ 30
Altair LGS + P1	NIRI / NIFS / GNIRS	20/50	0.2"	14 15	~ 95 100
NICI	Coronagraph Imager	14	45	12/15	< 1
GeMS (MCAO)	GSAOI (GMOS?)	83	40	15/18	~ 30
GPI	Coronagraph IFU	4	90	8/11	< 0.1
Next Generation	?	?	?	?	?

Past

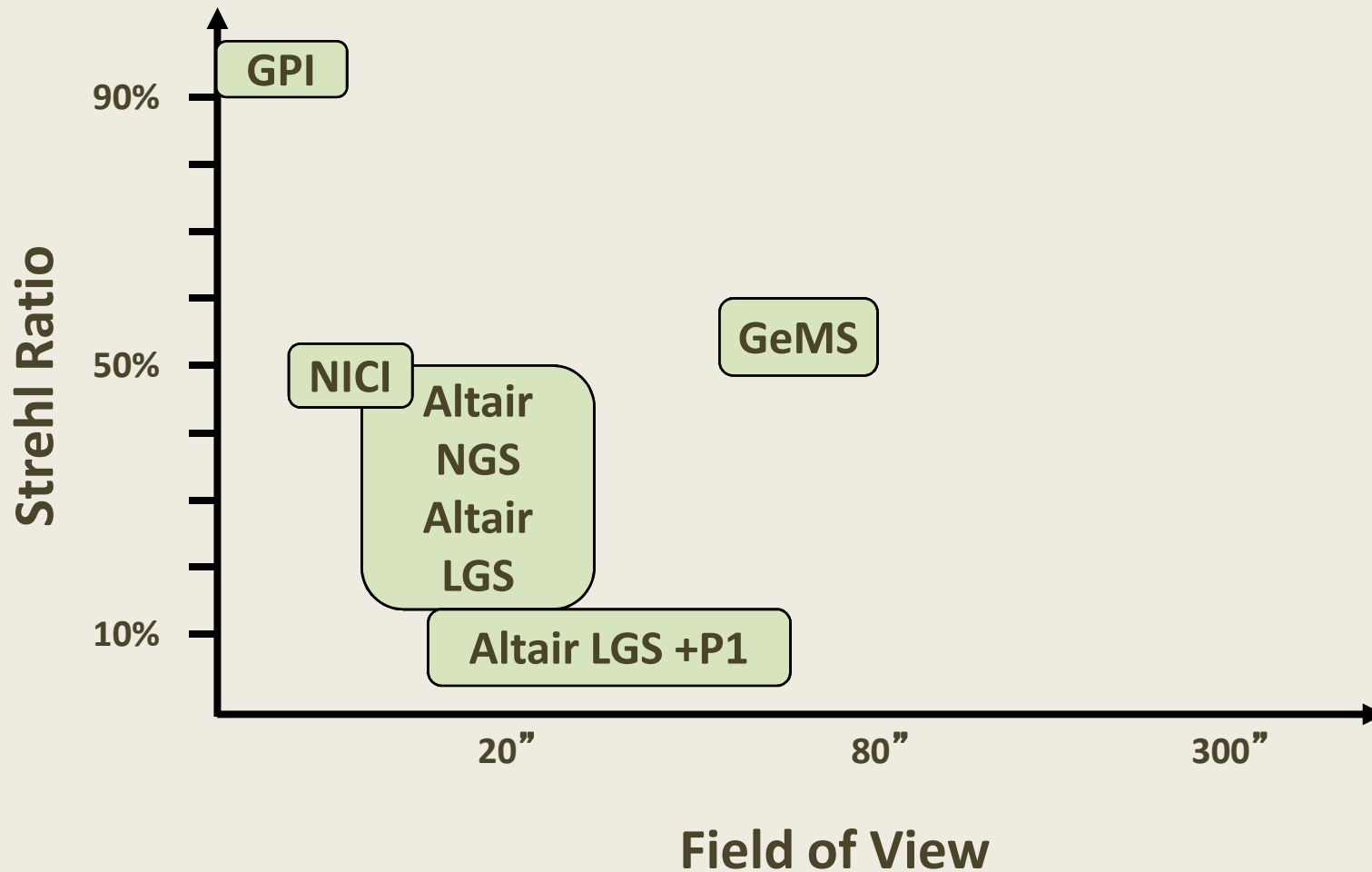
Present

In Development

Possible Future Instrument

# Gemini AO Performance

**Performance Metrics – Strehl Ratio, FWHM, Encircled Energy, Contrast**  
Depends upon guide star brightness and science wavelength



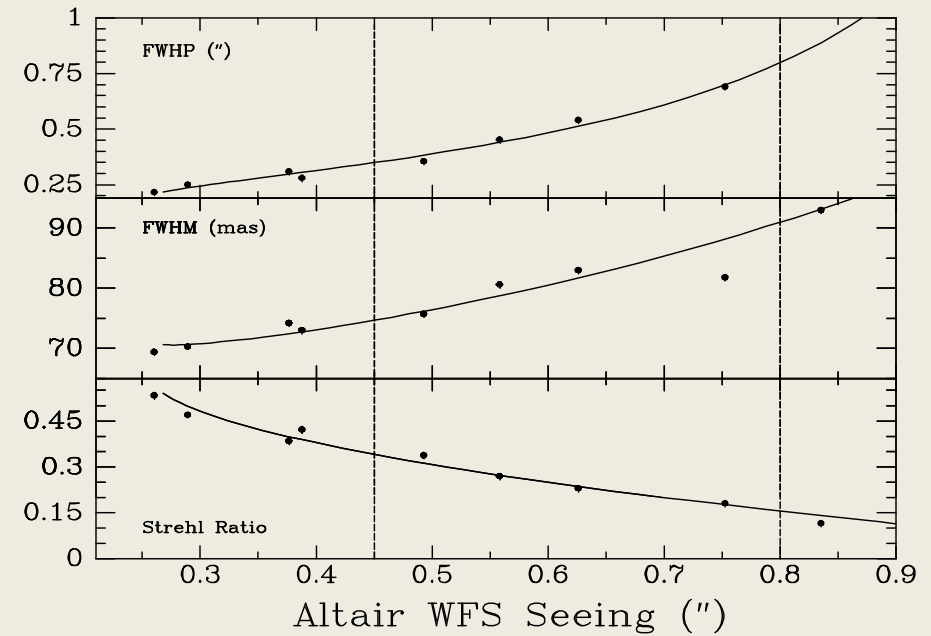
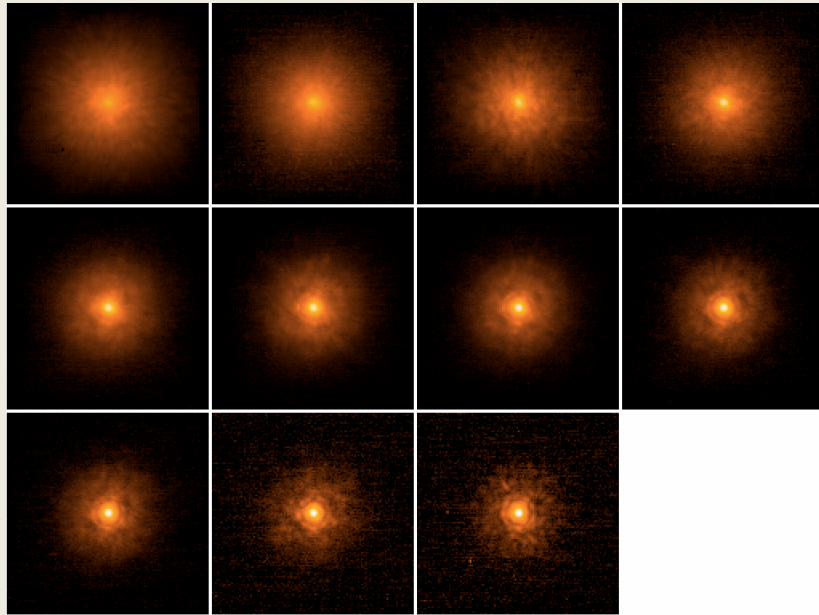


# Altair Overview

- Shack-Hartmann WFS –  $12 \times 12$  lenslet array – visible light.
- 177 actuator deformable mirror (DM) and a separate tip-tilt mirror (TTM)
- Closed loop operation at  $\leq 1$  KHz
- Initially single conjugate at 6.5 km redesigned to 0 km
- 87-92% *J - K* optical throughput
- NGS operation since 2004
  - Strehl ratio – typically 0.2 to 0.4 (best at *H, K*)
  - FWHM = 0.07"
- LGS commissioned in 2007
  - LGS Strehl ratio  $\sim 0.3$  at  $2.2 \mu\text{m}$  (FWHM = 0.083")
  - LGS sky coverage  $\sim 40\%$  (4% for NGS)
  - NGS tip-tilt star  $\leq 25''$
- LGS + P1 (2012)
  - 95% Sky Coverage
  - FWHM = 0.15" – 0.25"



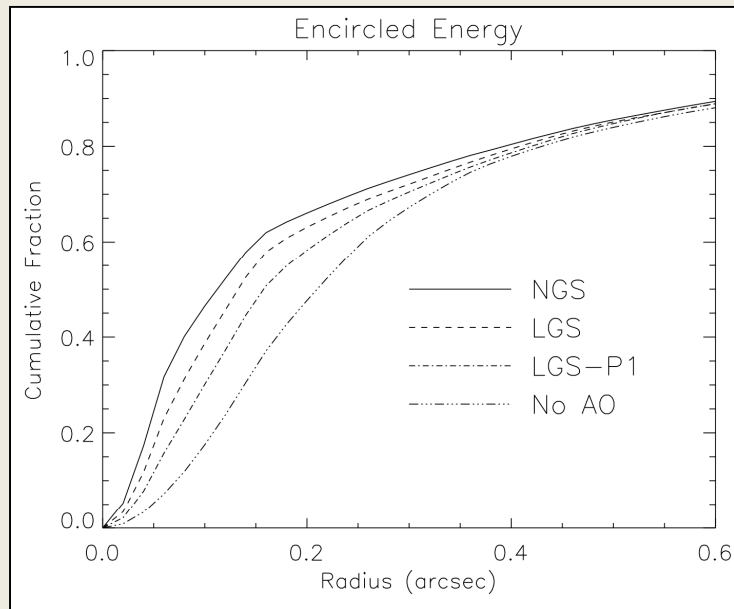
# K band NGS Performance



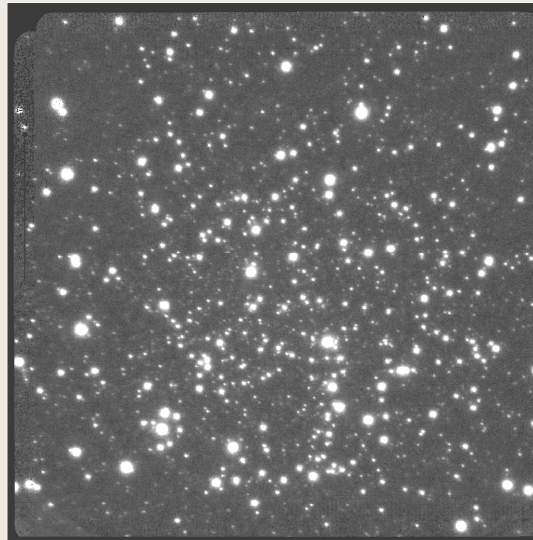
LGS performance is reduced by comparison



# LGS + P1 Mode Performance



NIFS PSF encircled energy for various guide configurations, NGS, LGS, LGS+P1 and No AO (using P2 guiding).

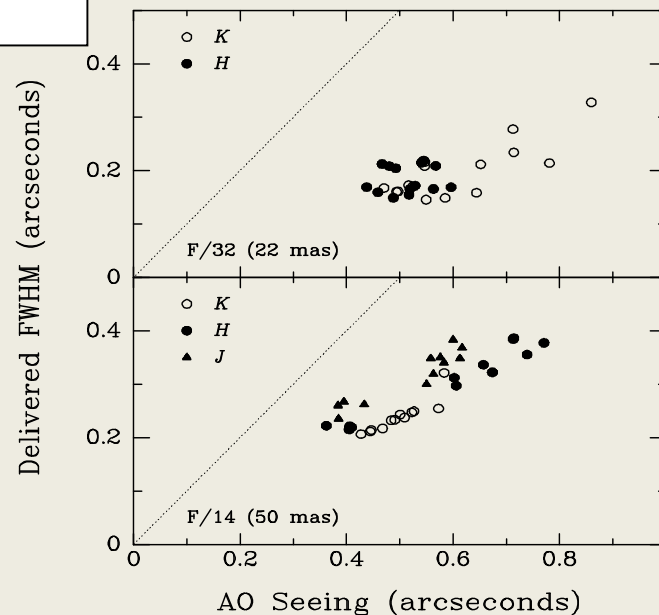


H-band NIRC2  $f/14$  image of a globular cluster.

FoV = 50"

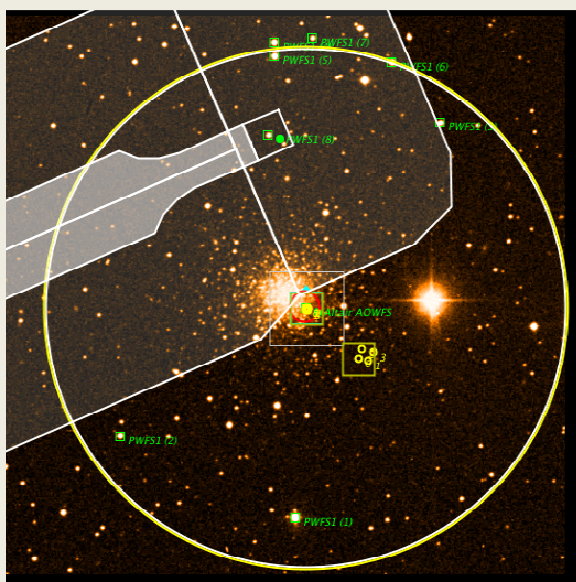
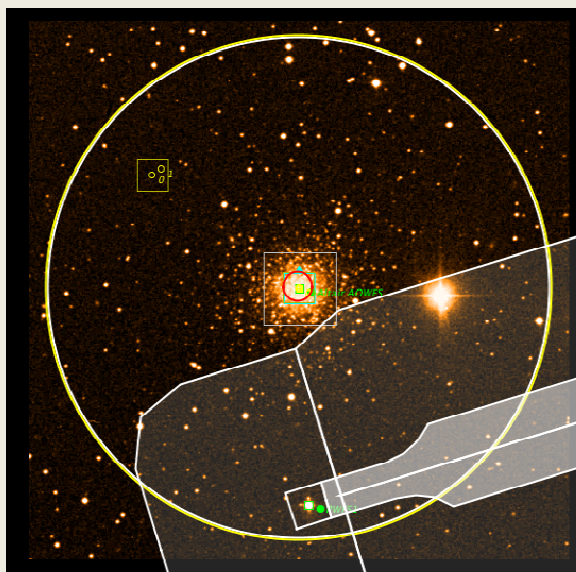
$\langle \text{FWHM} \rangle = 0.23''$

$\sigma_{\text{FWHM}} \sim 5\%$

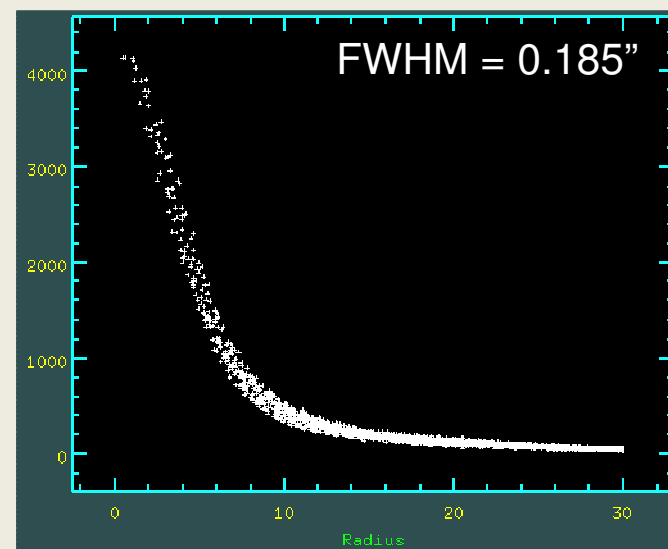
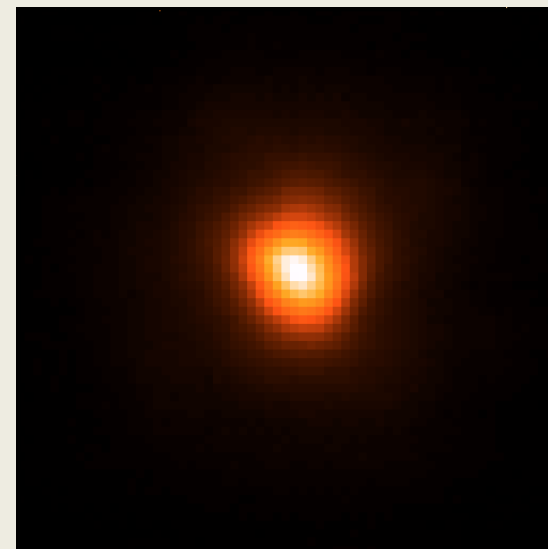


FWHM of NIRC2  $f/32$  H & K compared with  $f/14$  measurements.

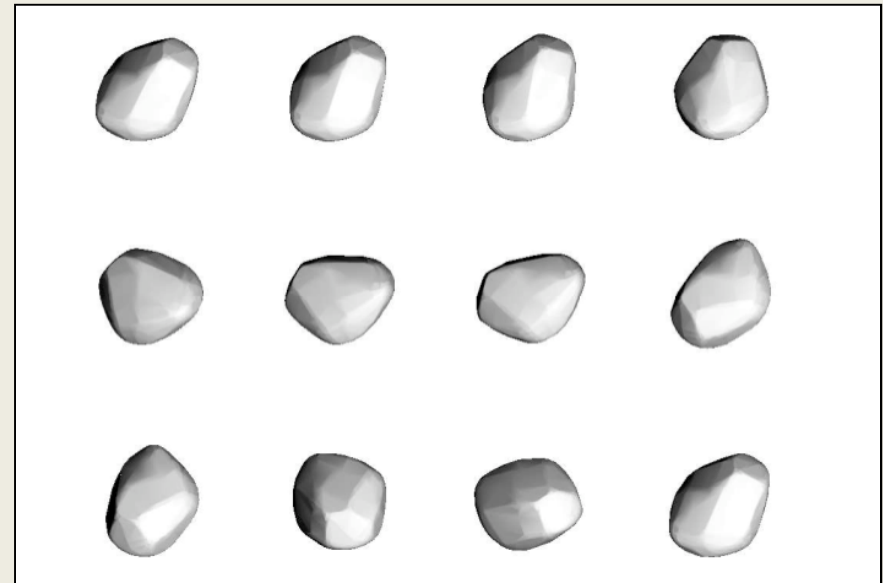
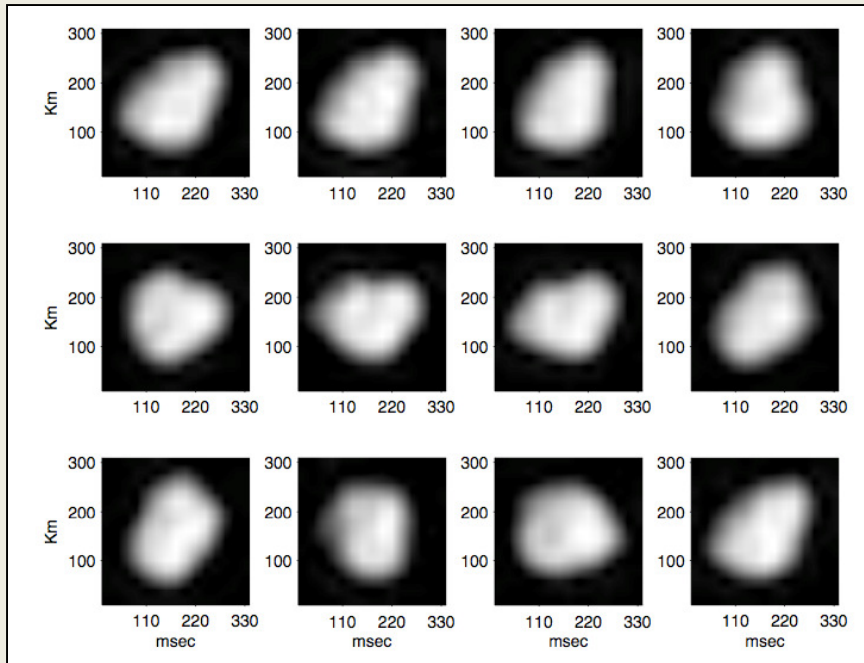
# Guiding for Altair



LGS + P1:  
15 co-added 10 sec  
exposures in K-band at  
22 mas/pixel. and the  
corresponding



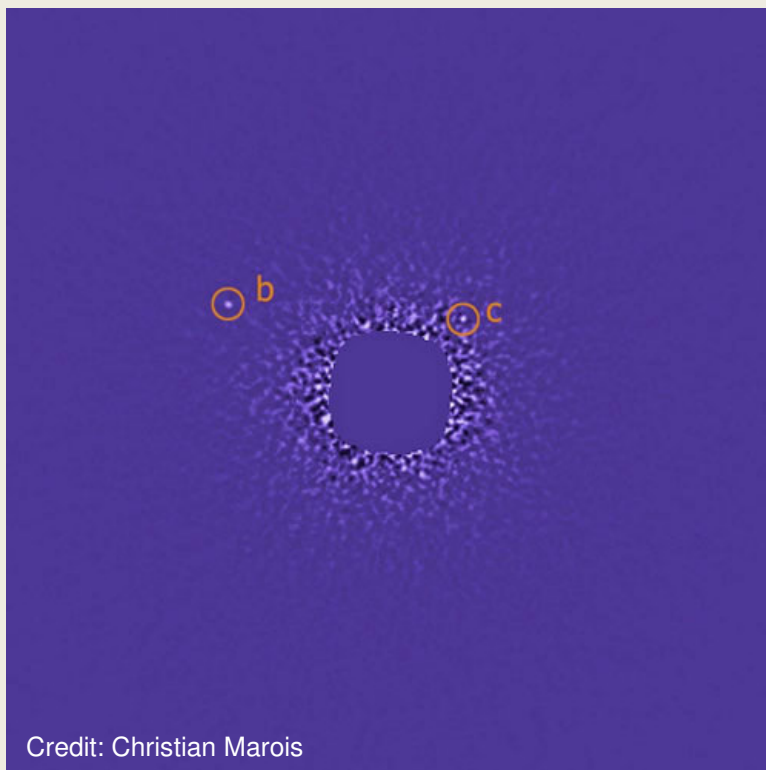
# Altair NGS Results – Asteroid Imaging



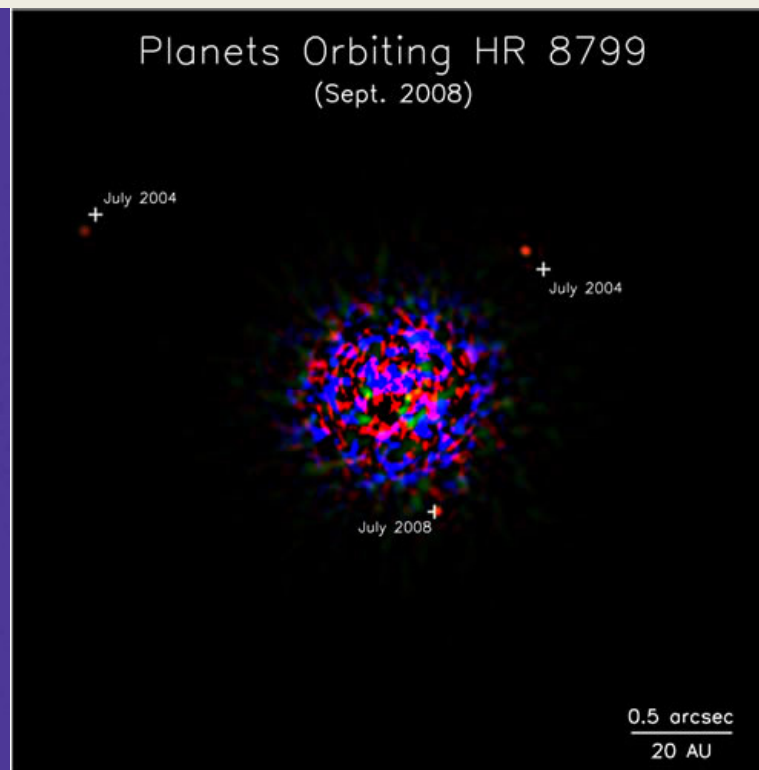
Altair/NGS images of the asteroid 9 Metis from December 2008 Gemini data (left) compared with one of the lightcurve inversion models projected forward from November 2, 1949 (right). (Each image is the average of 12 individual observations at that rotational phase.)

J. Drummond et al.

# Altair Results – HR8799



Gemini Observatory discovery image using the Altair/NGS + NIRI. Image shows "b", a ~7 Jupiter-mass planet orbiting at about 70 AU and "c", a ~10 Jupiter-mass planet orbiting the star at about 40 AU.

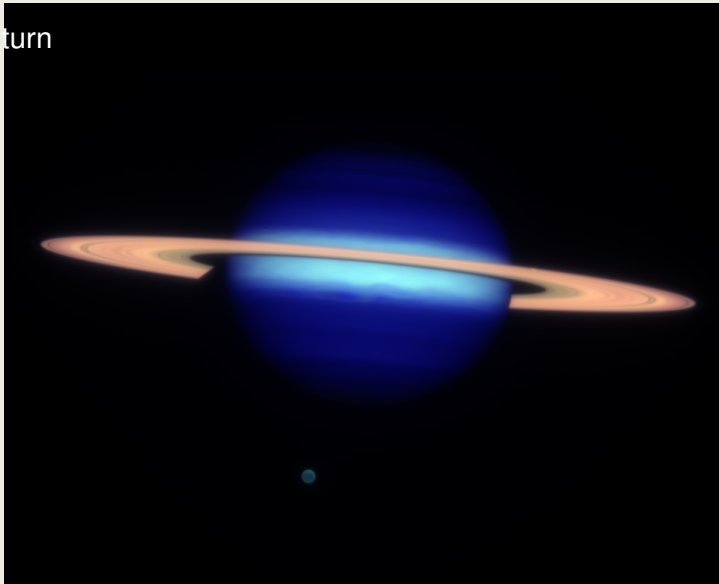


Keck II follow-up image of planetary system HR 8799 showing all three planets.

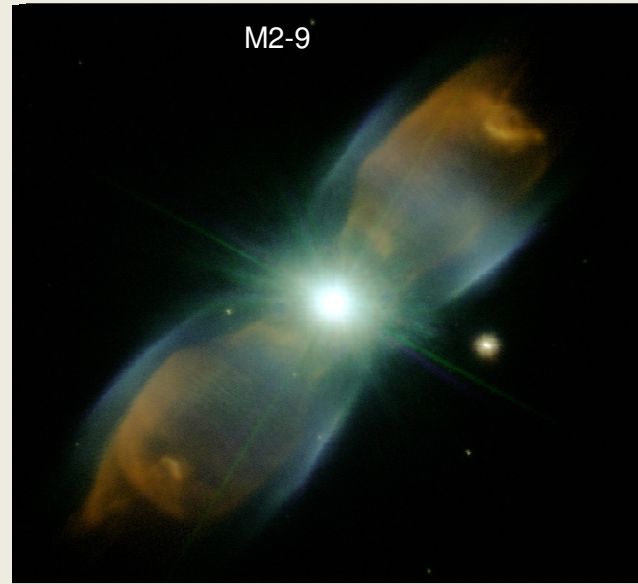
Extra Solar Planets

# Altair Image Gallery

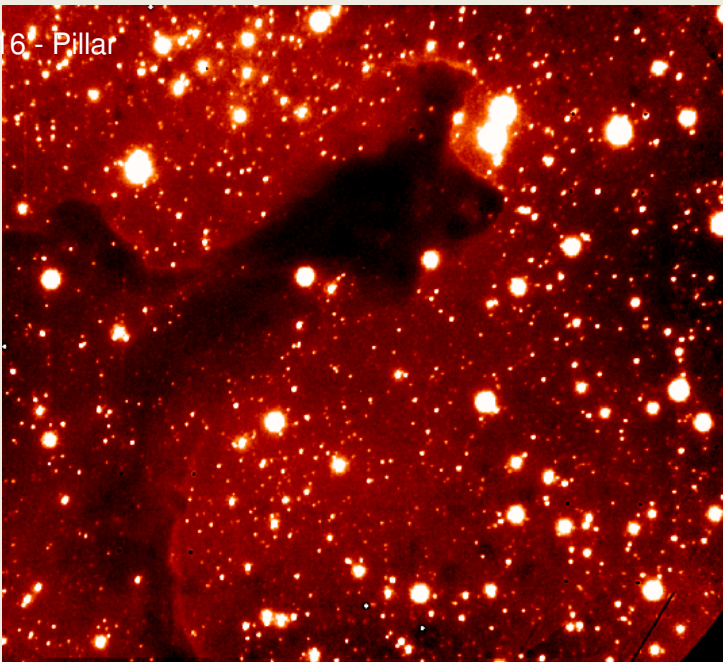
Saturn



M2-9



M16 - Pillar

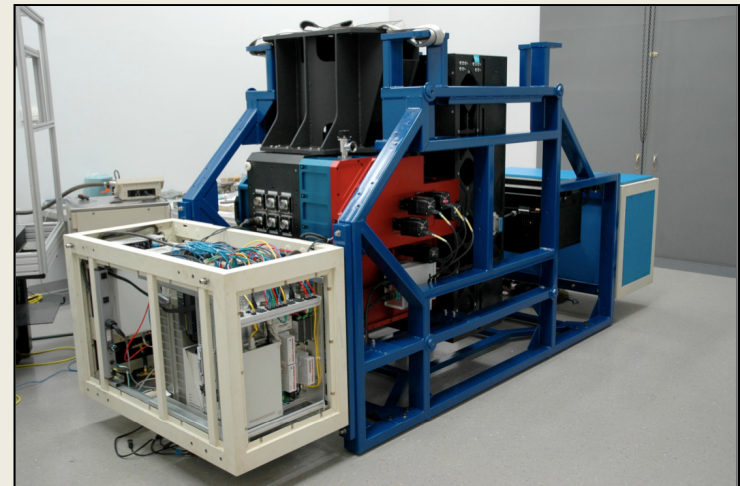


SN 2008cs



## Near Infrared Coronagraphic Imager - NICI

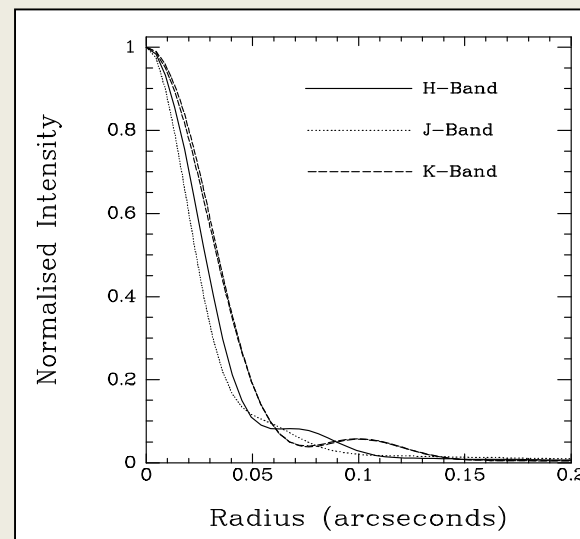
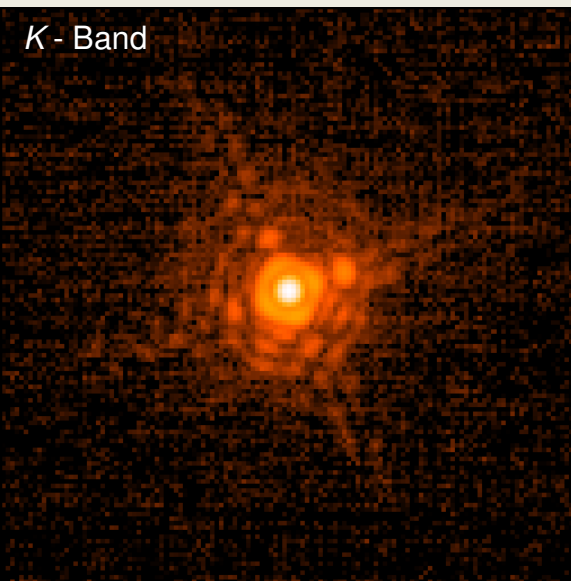
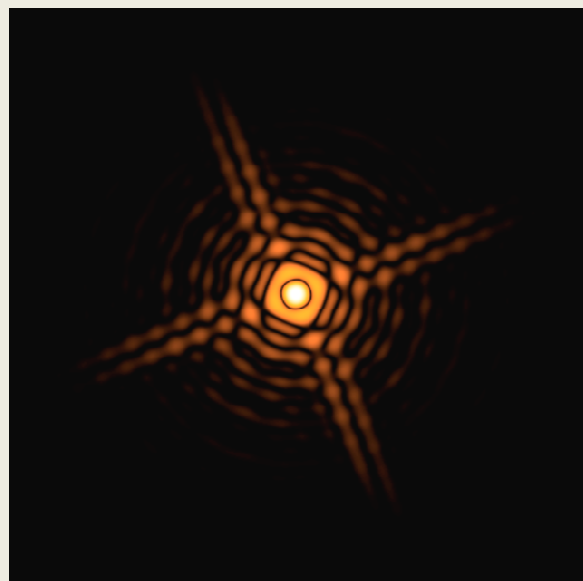
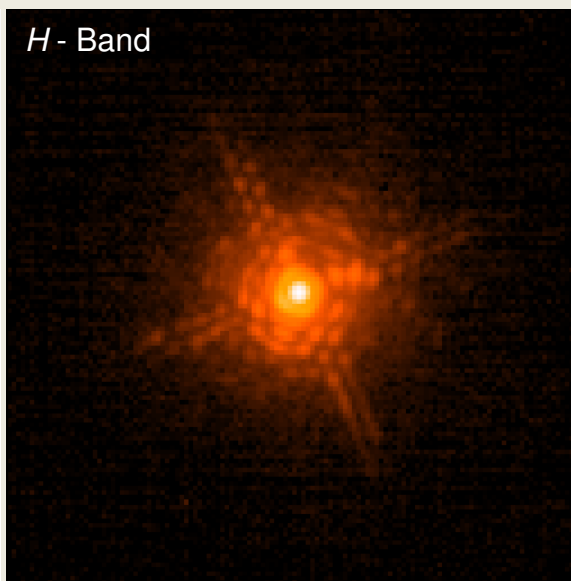
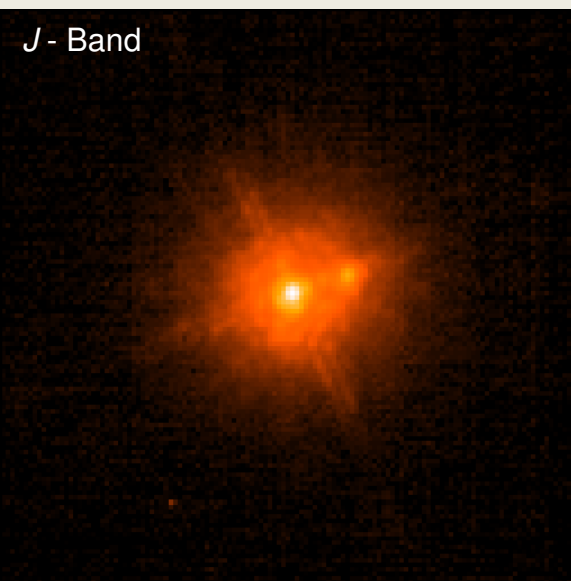
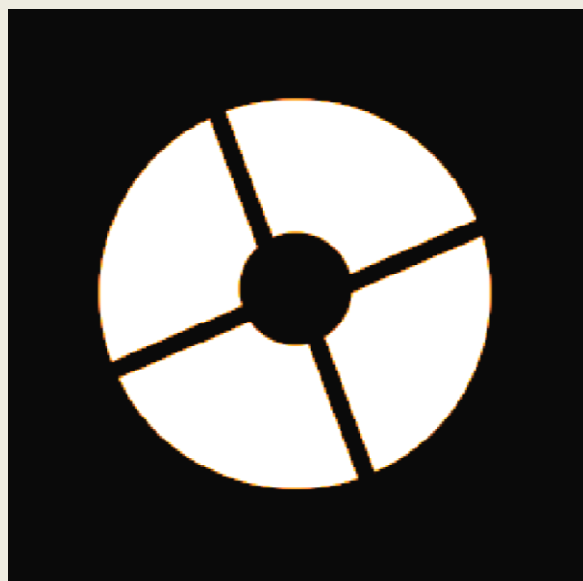
- AO System + Lyot Coronagraph + Dual Channel Near-IR Camera
  - Optimized for High-Contrast Imaging
    - Lensless
    - Minimum static aberrations
    - Differential Imaging
- 85-element curvature system
  - Natural Guide Star (on-axis)
  - H-Band Strehl ratio:
    - 20% for  $V = 13$
    - 40% for bright stars
- Dual channel InSb Imager
  - $1 \mu\text{m} \leq \lambda \leq 2.5 \mu\text{m}$  ( $J - K$  bands)
  - 1024 x 1024 ALADDIN InSb array (1 -5  $\mu\text{m}$ )
  - Focal plane and Pupil plane masks
  - Beamsplitting elements (Continuum & CH4)
  - Filters in each channel



## Observing Modes

- With Masks
  - Angular Differential Imaging (ADI)
    - Ideal PSF subtraction
    - Cassegrain Rotator Fixed
    - Stable pupil – stable speckle pattern
  - Spectral Differential Imaging (SDI)
    - Simultaneous Dual wavelength imaging
    - Contrast gain for targets with CH<sub>4</sub> absorption ( $T_{\text{eff}} < 1300$  K)
  - Angular-Spectral Differential Imaging (ASDI)
    - Combination of both techniques
  - Differential Image Motion between channels – 2mas – 4mas
- Without Masks
  - Dual Channel direct AO imaging of bright sources

# The NICI Point Spread Function





# Gemini Planet Imager (GPI)

- Extreme adaptive-optics imaging polarimeter/integral-field spectrometer.

- Diffraction-limited between 0.9 and 2.4 microns

- NGS
- contrast ratios of  $10^7$  for  $d = 0.2'' - 1''$
- $t_{\text{exp}} = 1 - 2$  hour observation
- $I < 9$  mag.

- AO system

- Two deformable mirrors
  - 4096 actuator, science-grade BMC “Tweeter”
  - 97 actuator CILAS “Woofers”
- AOWFS
  - Lincoln Lab 160 x 160 pixel CCID-66 detector

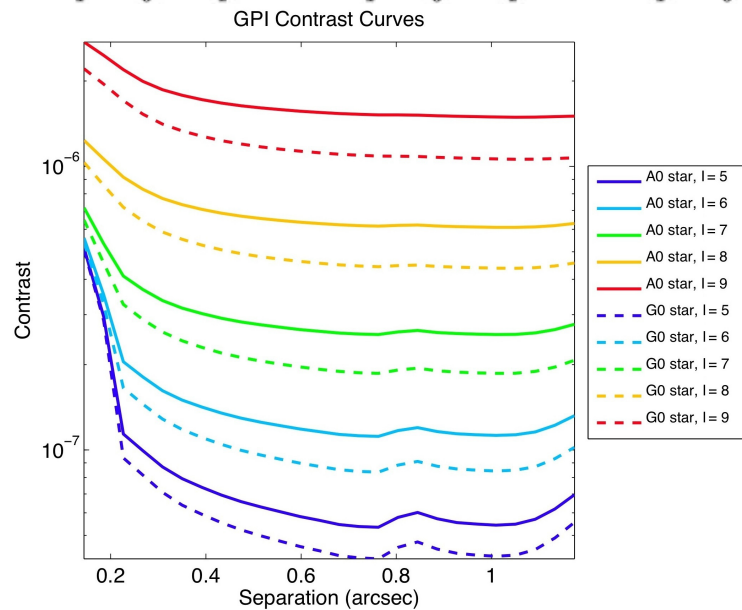
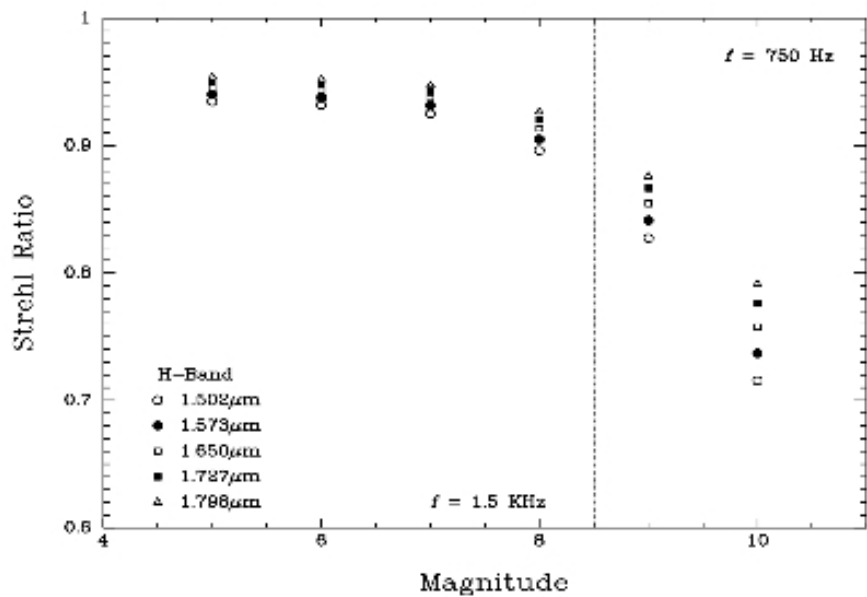
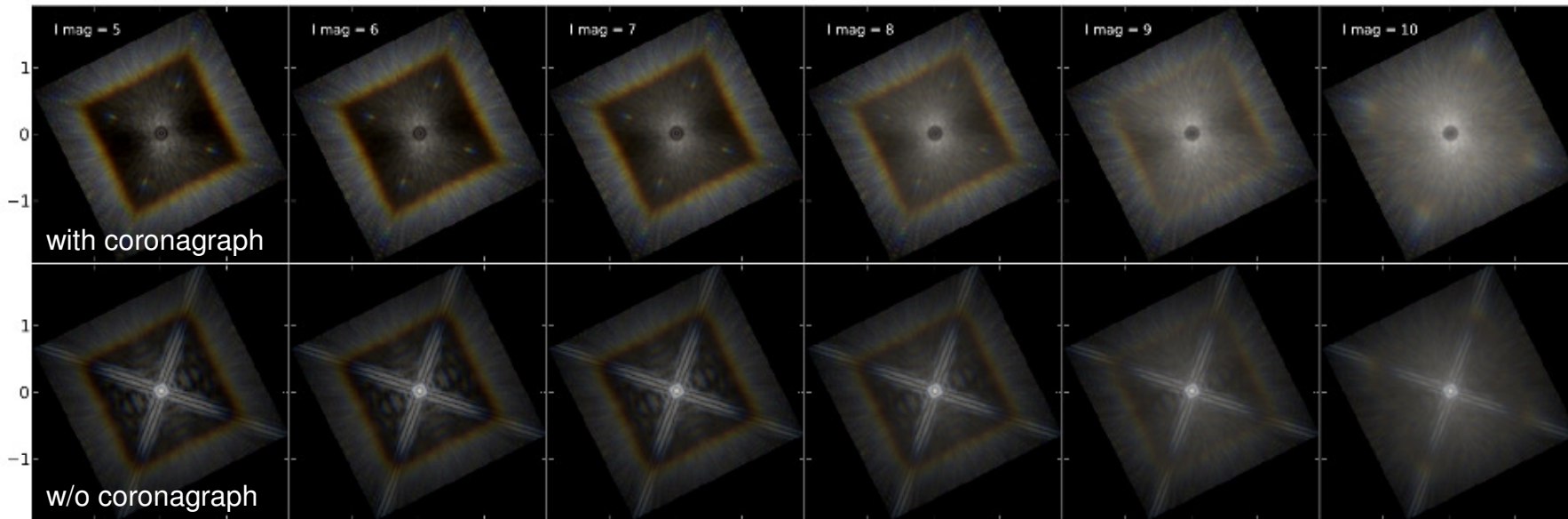
- IFS

- FoV =  $2.8''$  @ 14 mas/pixel
- Data cube  $\sim 200 \times 200$  spatial locations
  - 18 spectral channels
- Coronagraph (control diffraction and pinned speckles)
  - apodized masks
  - focal-plane stops



# GPI Performance

H band



# Canopus/GeMS

- 5 LGS WFS 16 x 16 Shack-Hartmann
- 3 Deformable Mirrors
  - ~800 actuators
  - Conjugated to 0, 4.5 and 9 km range
- 50W laser
  - 5 x 10W beams
  - 4 on the corners and 1 at the center of a 1' FoV
- 2 Dedicated Instruments
  - GSAOI (4k2 NIR imager), 80" FoV (20 mas pixels)
  - Flamingo II (NIR MOS), 2' FoV
- Many subsystems
  - Safety systems, infrastructure, laser(s), BTO, LLT, etc...
  - Highly Complex System

