GEMINI OBSERVATORY

Exploring the Universe, Sharing its Wonders

Adaptive Optics Instrumentation and Capabilities

Presented by

Julian Christou

Adaptive Optics Scientist

Science with Adaptive Optics, AAS June 7-11, 2009

Gemini AO Personnel

AO Scientists

- François Rigaut
- Julian Christou
- Markus Hartung
- Benoit Neiche
- Aurea Garcia

Laser Engineers

- Celine D'Orgeville
- Richard Oram
- Vincent Fesque
- Jeff Jarboe

Mechanical Engineer

- Mike Sheehan

Instrument Scientists

- Chad Trujillo (Altair)
- Tom Hayward (NICI)
- Andy Stephens (NIRI)
- Richard McDermid (NIFS)

System Support Associates

- Jesse Ball
- Anthony Matulonis

Science Fellow

- Silas Laycock (Altair)
- Étienne Artigau (NICI)

Software Engineer

- Angelic Ebbers

Electronic Engineer

- John White

+ LGS spotters and others

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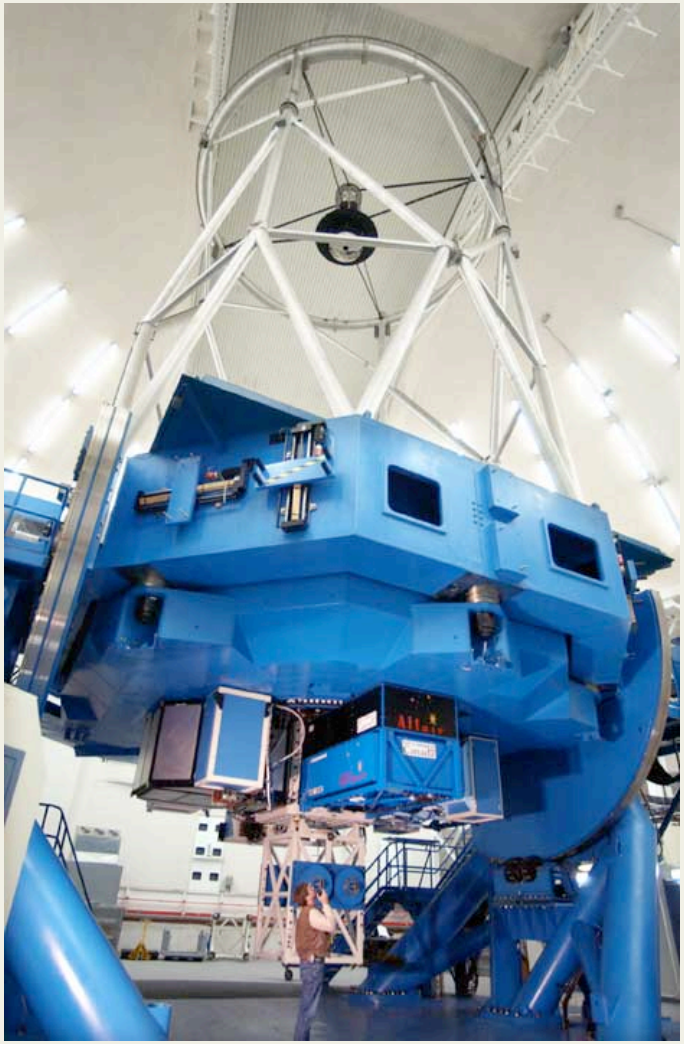
Talk Outline

- Gemini Adaptive Optics History
  - Past, Present & Future
- Existing Gemini AO Instruments
  - GN – Altair NGS/LGS
  - GS – NICI
- Future Projects
  - GeMs (GS)

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



An Integrated AO Program

Gemini North:

1999: Hokupa'a 36

2002: Altair NGS

2005: Altair LGS

201x: GLAO?

Gemini South:

2005: Hokupa'a 85

2007: NICI (Coronograph, BDs/Hot Jupiters)

2009: GeMS (Multi-Conjugate Adaptive Optics)

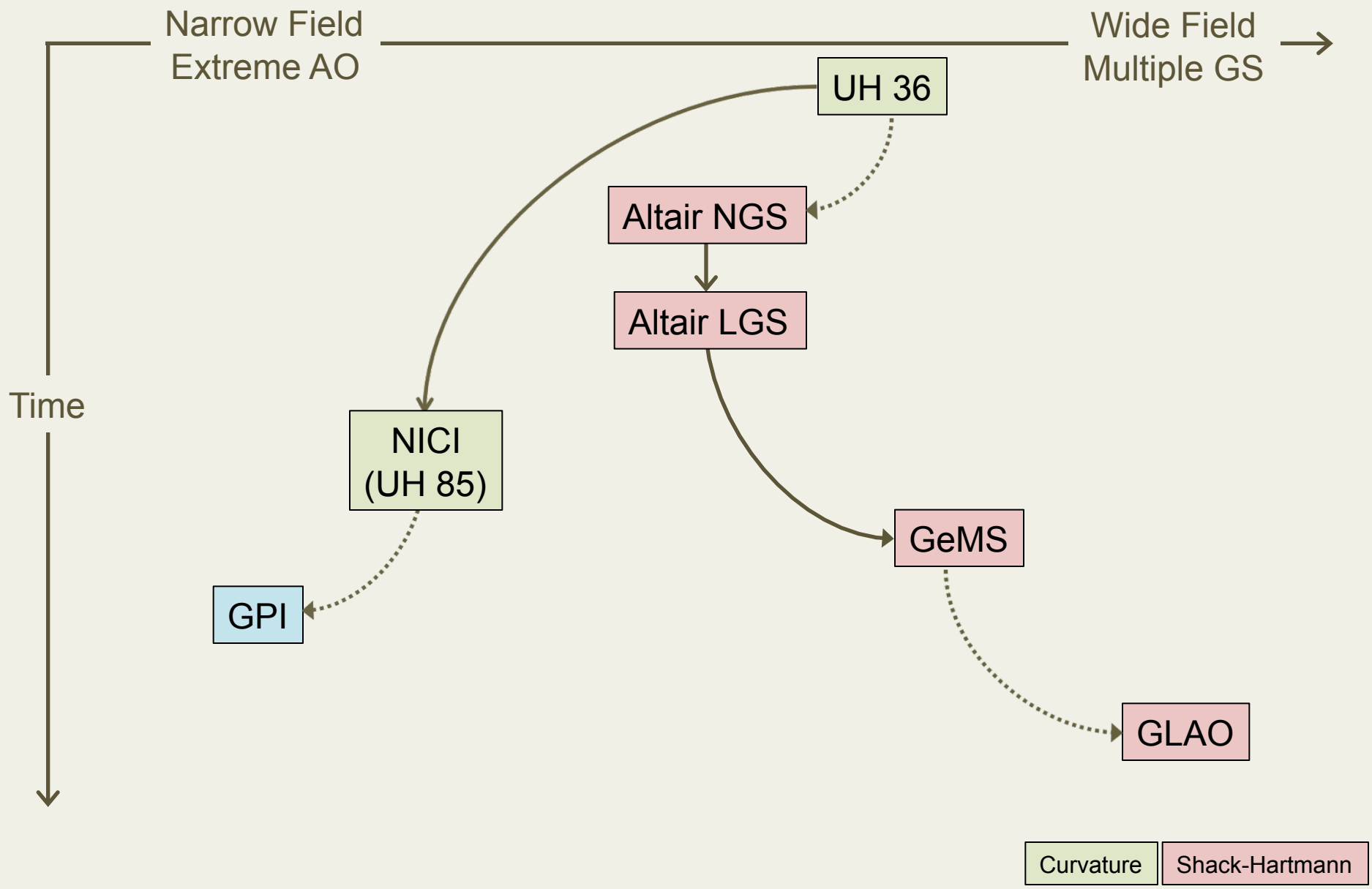
2010: GPI (Gemini Planet Imager)

Gemini AO Instrumentation

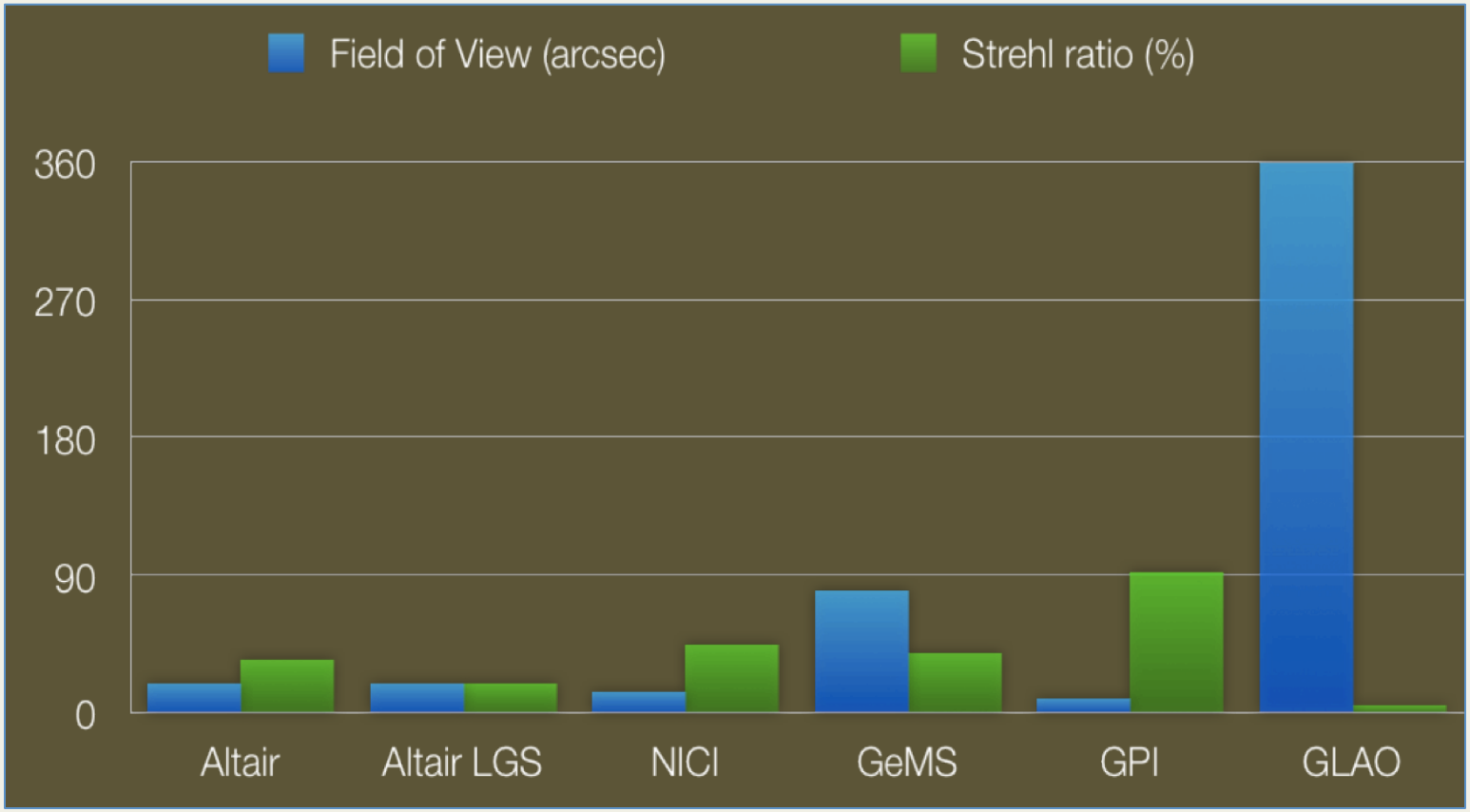
AO System	Instrument	FoV (“)	Strehl Ratio (H-Band)	R_{lim} (full/limit)	Sky Coverage (%)
UH36	QUIRC	20	15	15	1
Altair NGS	NIRI / NIFS	20	35	12/15	< 1
Altair LGS	NIRI / NIFS	20/50	20	15/18	~ 30
NICI	Coronograph Imager	14	45	12/15	< 1
GeMS (MCAO)	GSAOI Flamingos-2	83	40	15/18	~ 30
GPI	Coronograph IFU	? / 4	90	8/11	< 0.1
GLAO	all instruments	up to 360	5*	>15	100

Past | Present | In Development | Possible Future Instrument

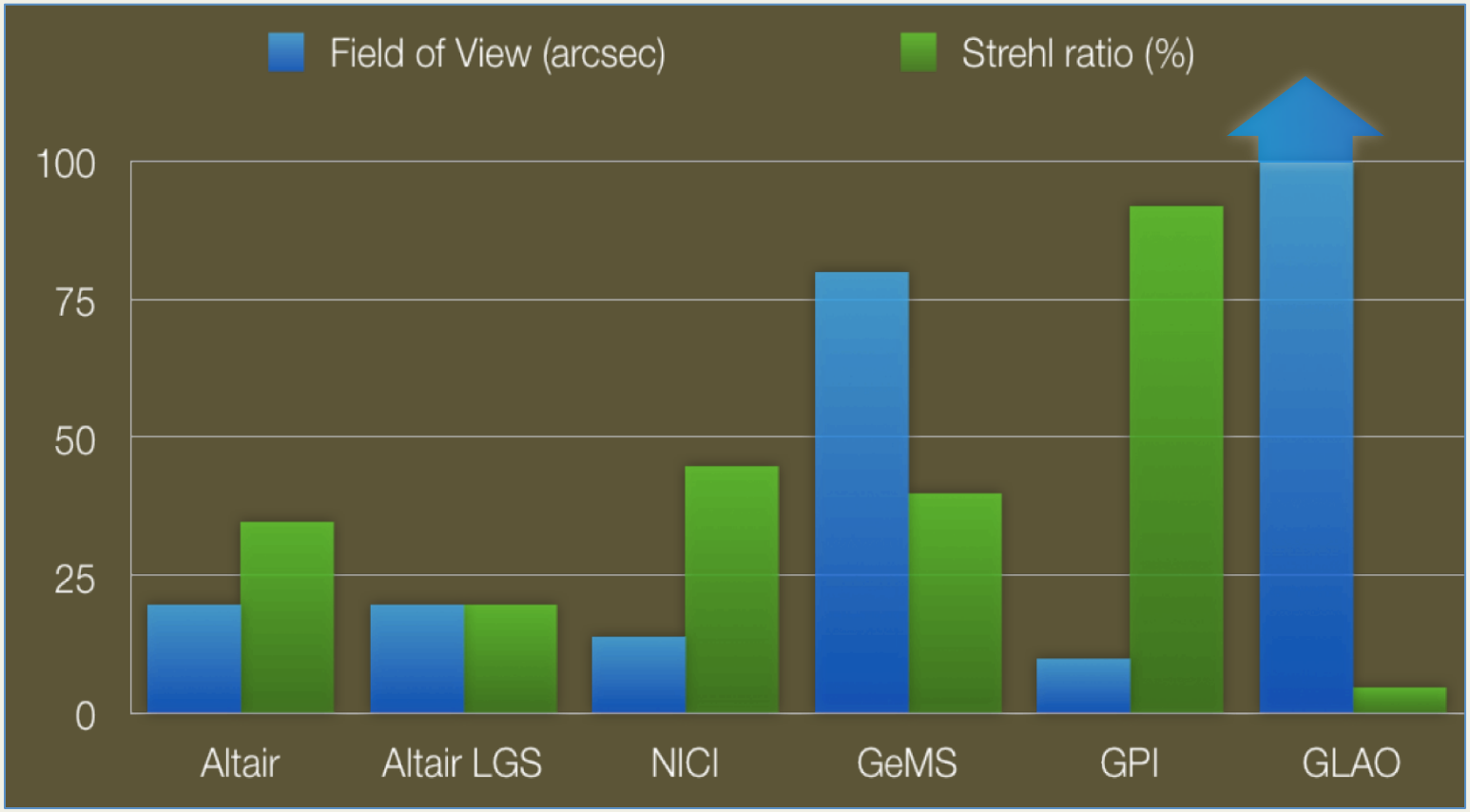
Gemini AO Program



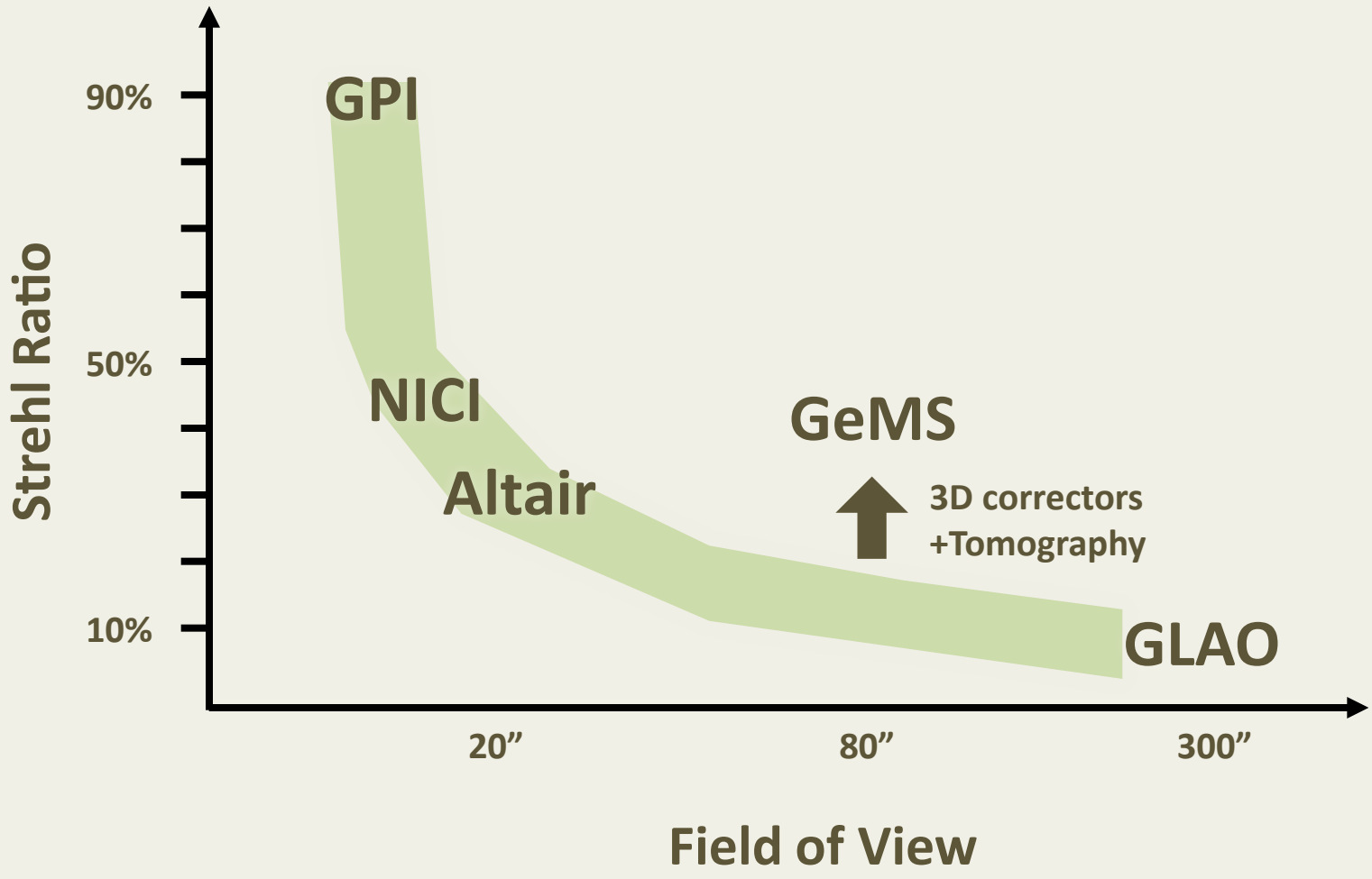
Gemini AO Performance



Gemini AO Performance



Gemini AO Performance



Gemini AO Systems

- Broad but not redundant
- Stick to newest techniques and technology to retain competitiveness for our user community

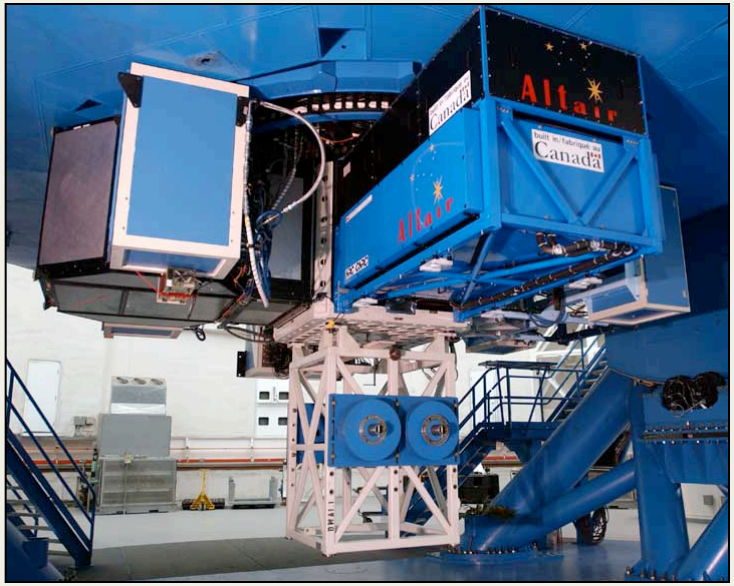
- Ability to retain expertise?
- Too ambitious?

Available Gemini AO Systems

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 Coronograph 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%

Altair Overview

- **Altair** - **ALT**itude conjugate **A**daptive optics for the **I**nfra**R**ed)
- Facility natural/laser guide star adaptive optics system of the Gemini North telescope.



- Built at HIA, Victoria, Canada

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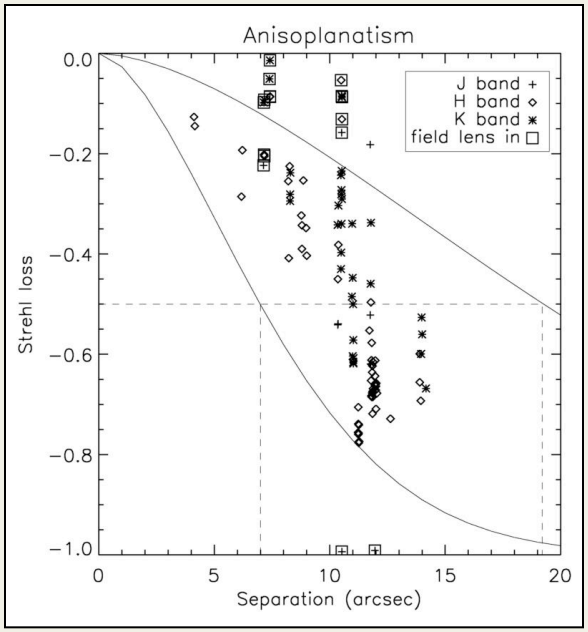
Altair Overview

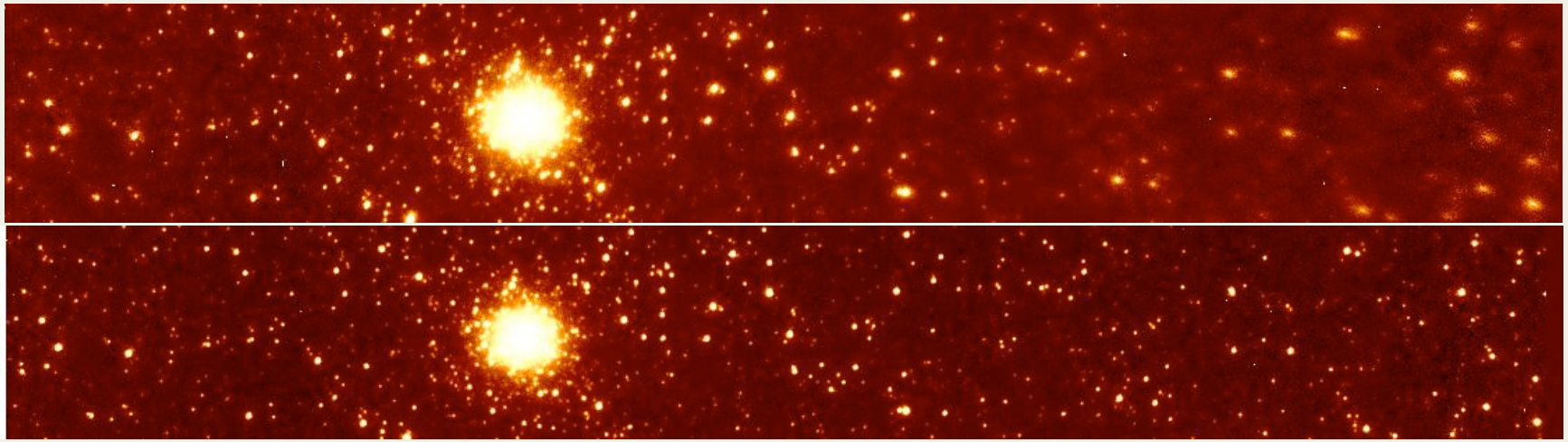
- Shack-Hartmann WFS – 12 × 12 lenslet array – visible light.
- 177 actuator deformable mirror (DM) and a separate tip-tilt mirror (TTM)
- Closed loop operation at ≤ 1 KHz
- Initially single conjugate at 6.5km
- 87-92% *J* - *K* optical throughput
- NGS operation since 2004
  - Strehl ratio – typically 0.2 to 0.4 (best at *H*, *K*)
  - FWHM = 0.07"
- LGS commissioned in 2007
  - LGS Strehl ratio ~0.3 at 2.2 μm (FWHM = 0.083")
  - LGS sky coverage ~ 40% (4% for NGS)
  - NGS tip-tilt star ≤ 25"
  - LGS science operations ~1 to 2 weeks/month

Altair Field Lens

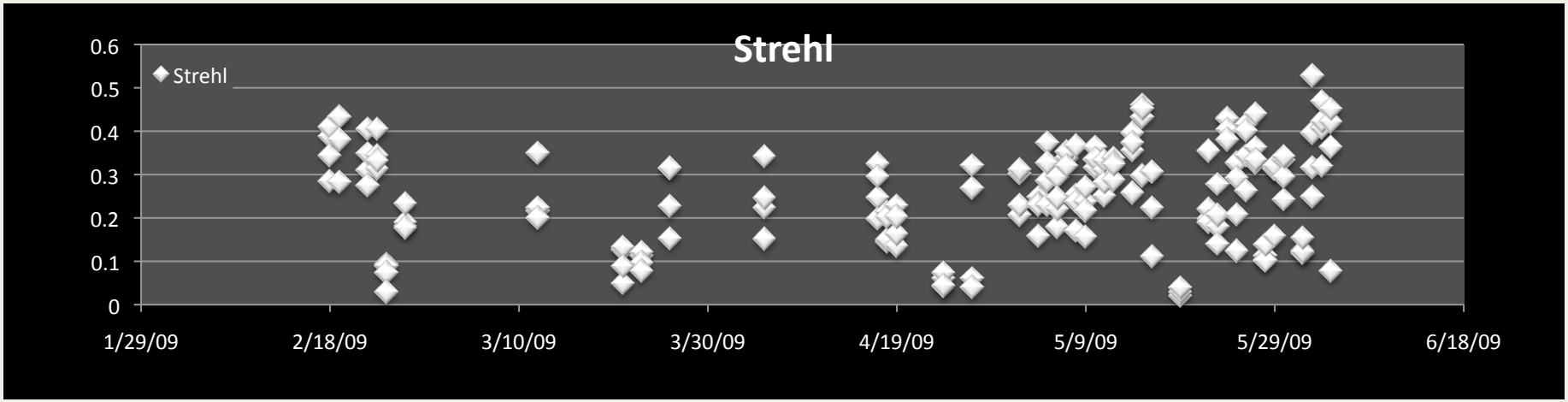
- **Altair** - **ALT**itude conjugate **A**daptive optics for the **I**nfra**R**ed)
  - Originally conjugated for 6 km to optimize corrected FoV
  - Reconjugated to 0km by means of a Field Lens installed in 2006
  - Increases the isoplanatic patch and FoV.
  - Larger guide star offset from 5" to 20"

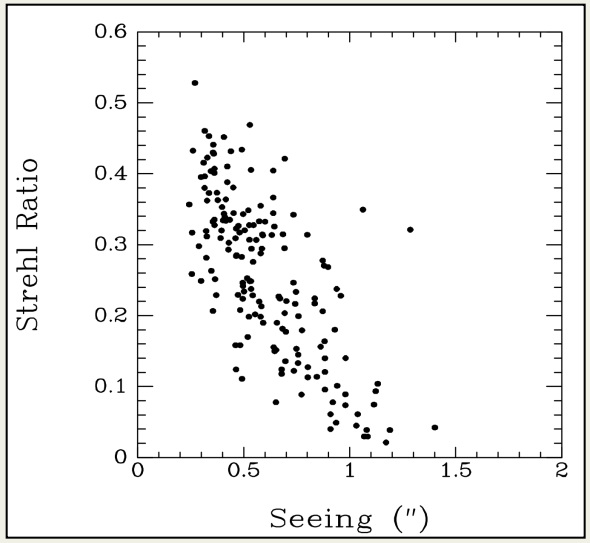


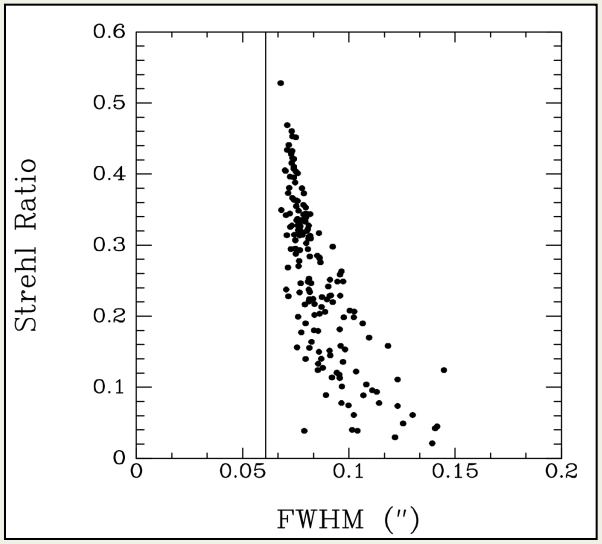
- Benefit is improved Strehl ratio and sharper image quality at large distances from the guide star.

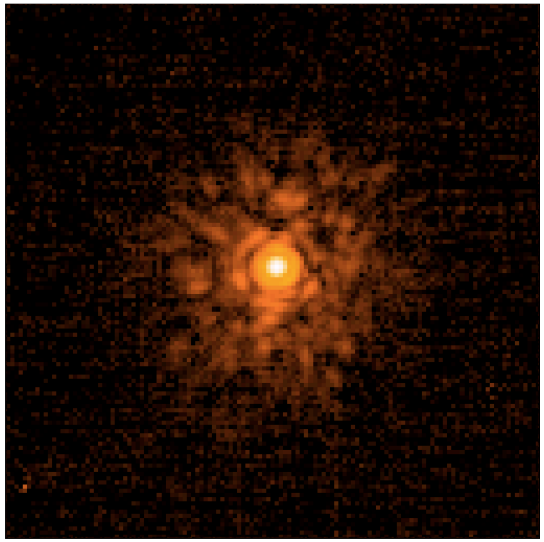


Altair NGS Performance 2009









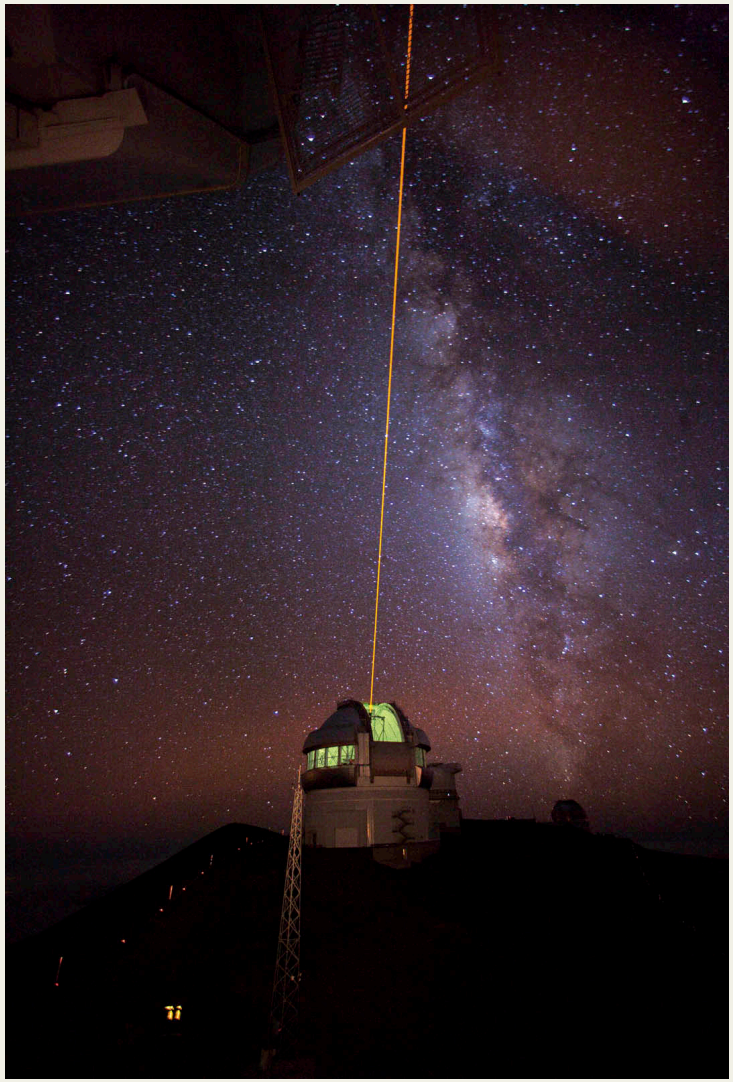
Altair NGS Operations

Spectral Type		A0	G6	K7	M4		
V-R color	-0.2	0.0	0.4	0.8	1.2	1.6	2.0
Limiting mag for full correction	11.0	11.1	11.4	11.7	12.0	12.3	12.6
Partial correction	14.9	15.1	15.3	15.6	15.9	16.2	16.5

- NGS Limitations
  - < 25" off-axis
  - Limiting *V* magnitude
  - Performance degrades with
    - Fainter guide stars
    - Increased angular separation from guide star to observed object
    - Extended guide "stars" (> 0.6")
  - Observing Conditions
    - Seeing
      - FWHM in V of less than 0.8 arcsec at zenith
    - Cloud Cover
      - CC ≤ 50% okay
      - CC = 70% - 0.3 mag extinction
      - CC = 90% - 3 mag extinction

Altair Laser Guide Star

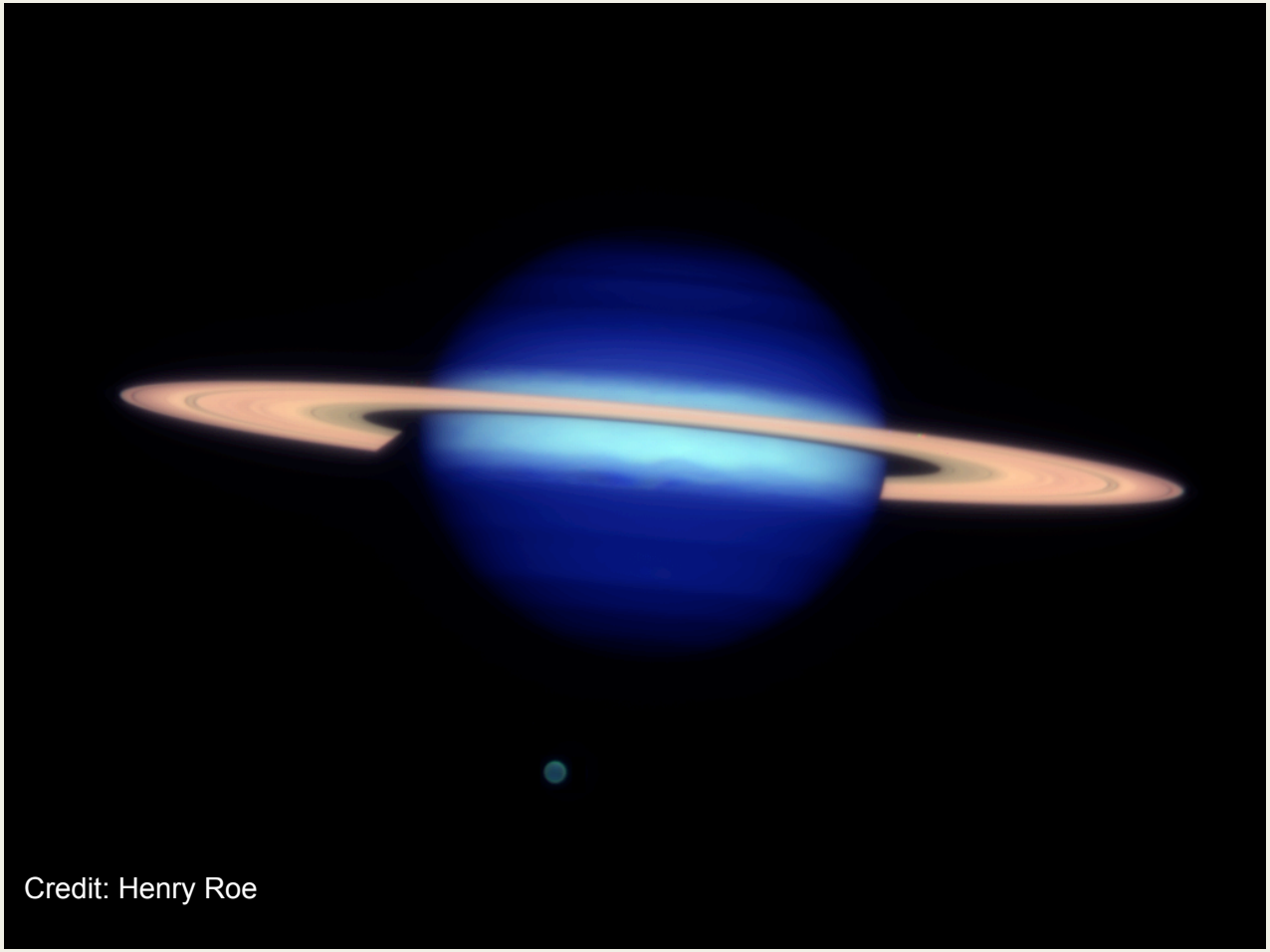
- First Science with LGS 11/2006
- 12-14 W LMCT Na solid state laser
- 8-10 W on sky
- Behind-M2 propagation
- 0.9" spot on sky
- Typical Strehl(*K*) = 25%
- STRAP Tip-Tilt WFS, limiting magnitude 18.5
- Operation block scheduled, well integrated
- Need 3 people (SSA/Obs/Laser tech) + 5 spotters
- Space command, aircraft, safety, etc



Altair LGS Operations

- Extends Altair for targets when an NGS is unavailable
- Lower Strehl Performance
  - extended source
  - cone-effect
- LGS Limitations
  - TT star < 25" off-axis (limited by field lens)
  - Observing Conditions
    - Seeing
      - FWHM in V of less than 0.8 arcsec at zenith
    - Cloud Cover
      - CC ≤ 50% okay

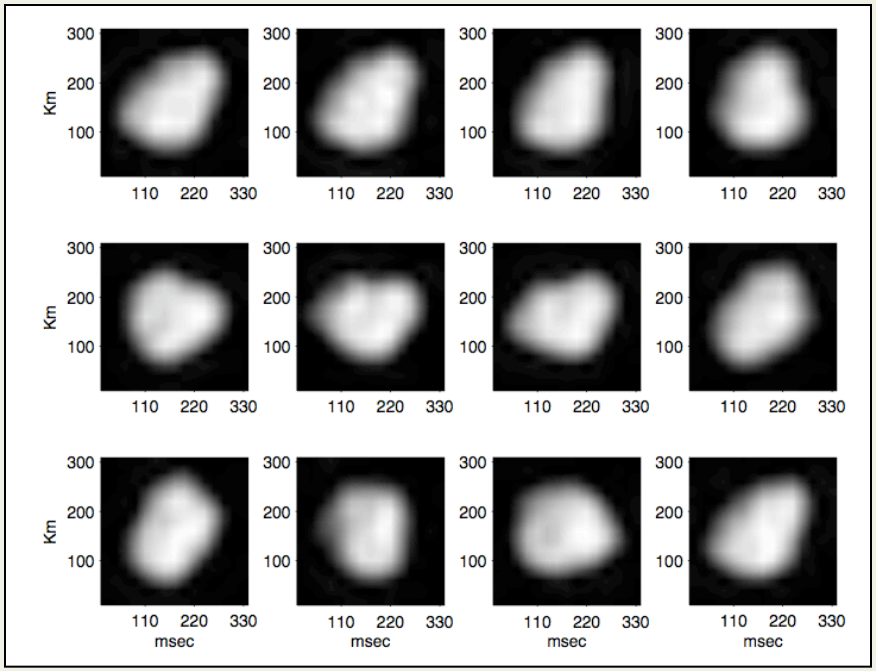
Altair NGS Results – Titan and Saturn

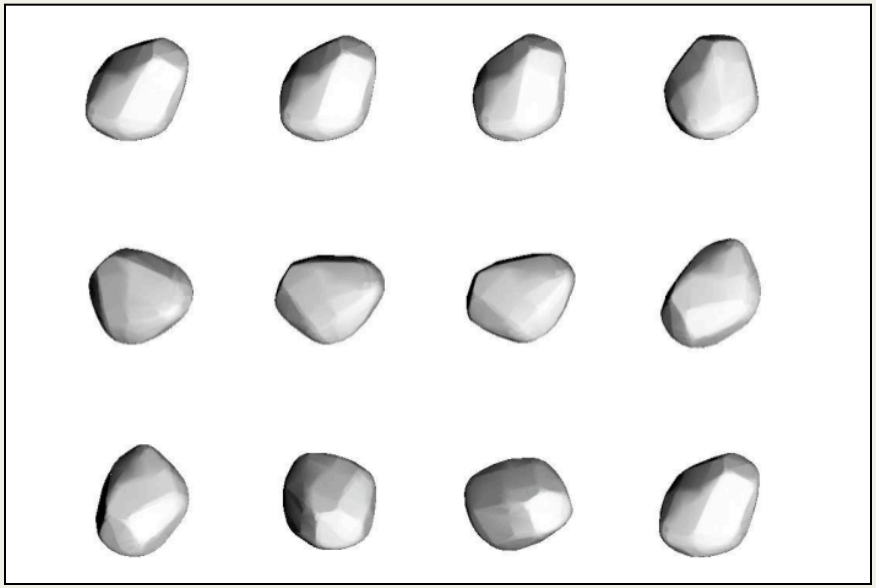


Altair/NIRI NGS image of Titan and Saturn using Saturn as the Guide star (< 1 arcsecond) (H. Roe)

Solar System

Altair NGS Results – Asteroid Imaging



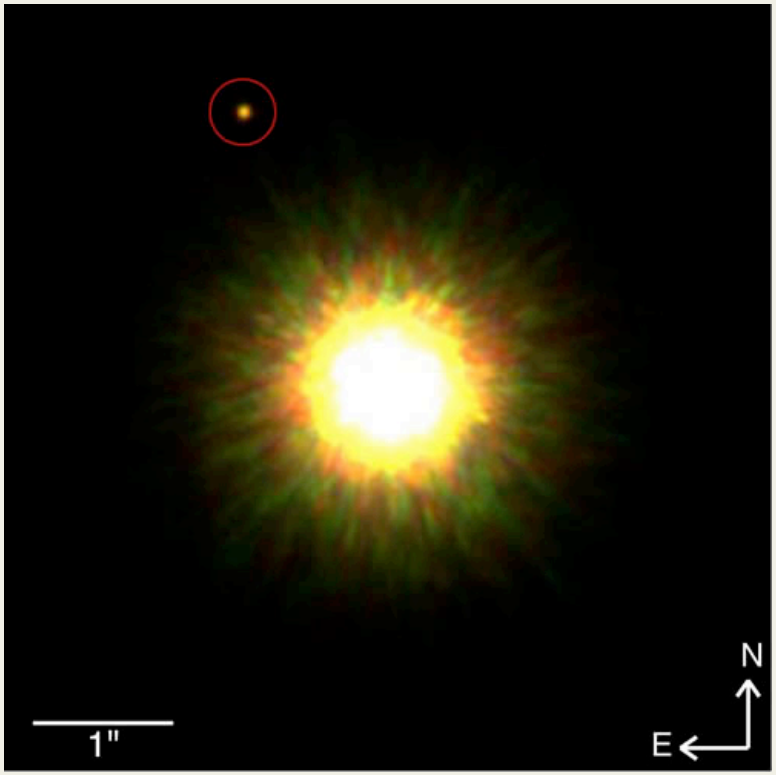


Altair/NGS images of the asteroid 9 Metis from December 2008 Gemini data (left) compared with one of the lightcurve inversion models projected forward from November 2, 1949 (right). (Each image is the average of 12 individual observations at that rotational phase.)

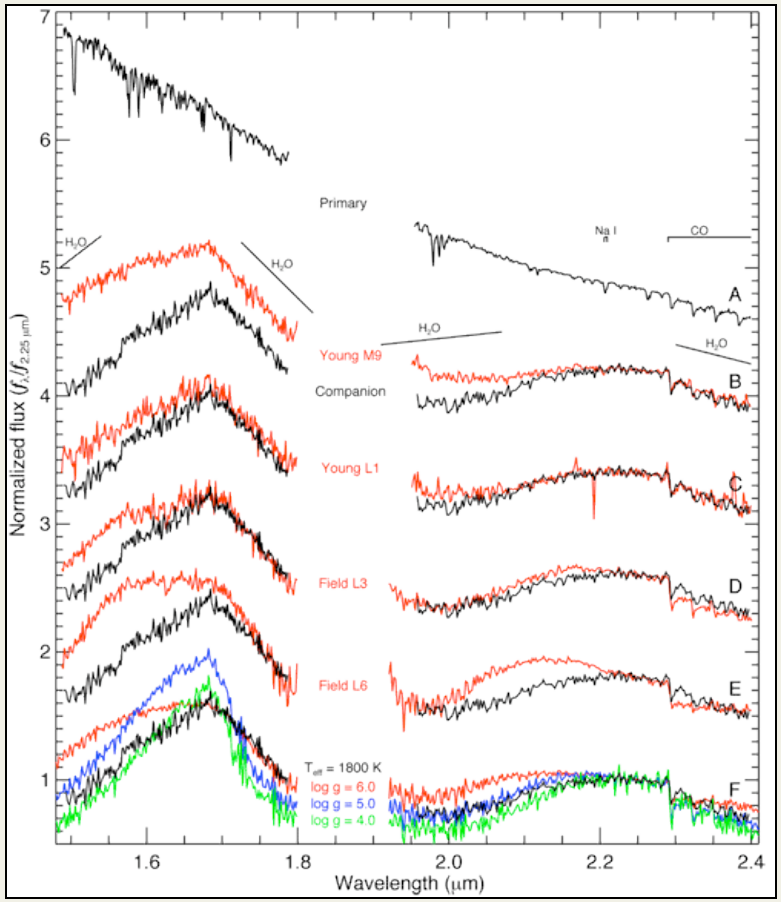
Credit: Henry Roe

J. Drummond et al.

Altair Results – 1RSXJ160929.1-210524

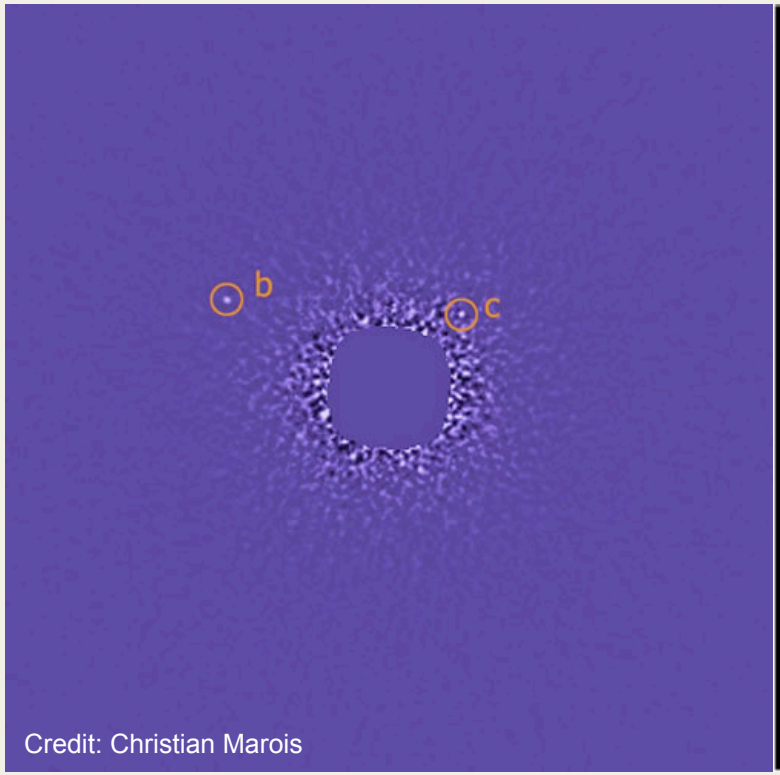


Altair/NIRI Image of the potential low-mass companion ($8m_J$) to a K7 star. The spectra suggest that the object to be closer to a young L1 brown dwarf.

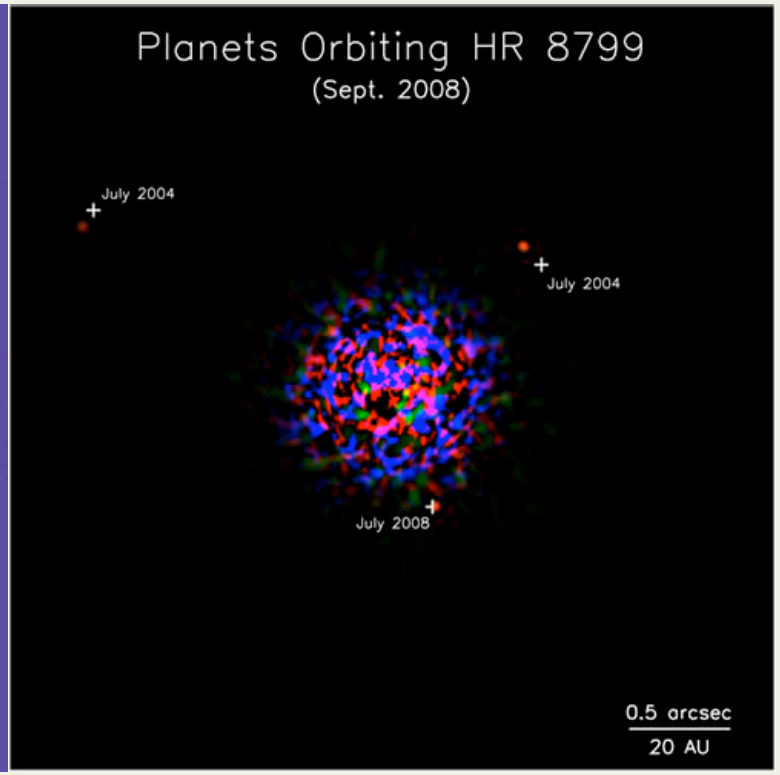


Credit: David Lafrenière

Altair Results – HR8799



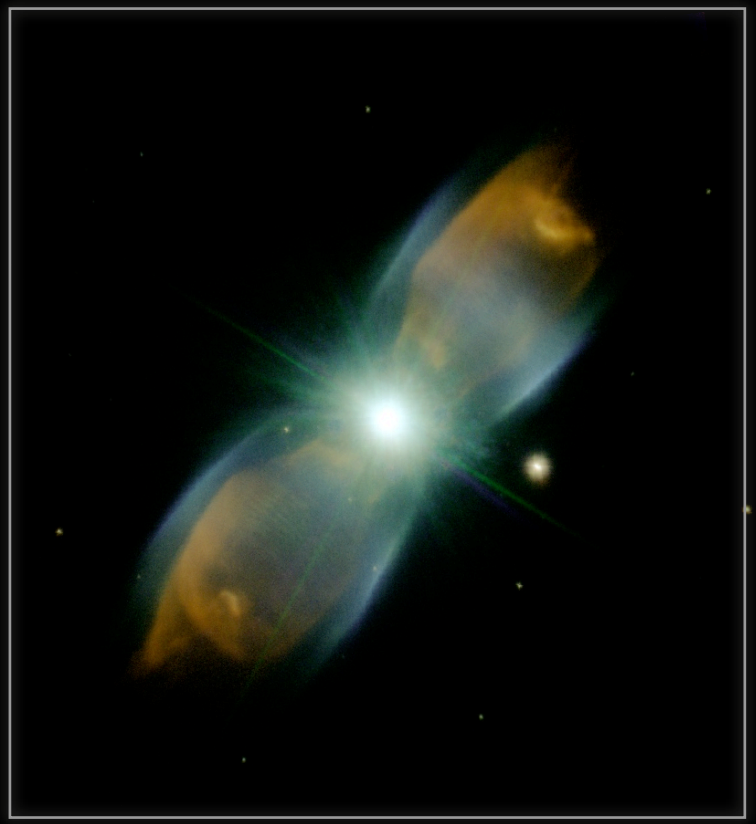
Gemini Observatory discovery image using the Altair/NGS + NIRI. Image shows "b", a ~7 Jupiter-mass planet orbiting at about 70 AU and"c", a ~10 Jupiter-mass planet orbiting the star at about 40 AU.



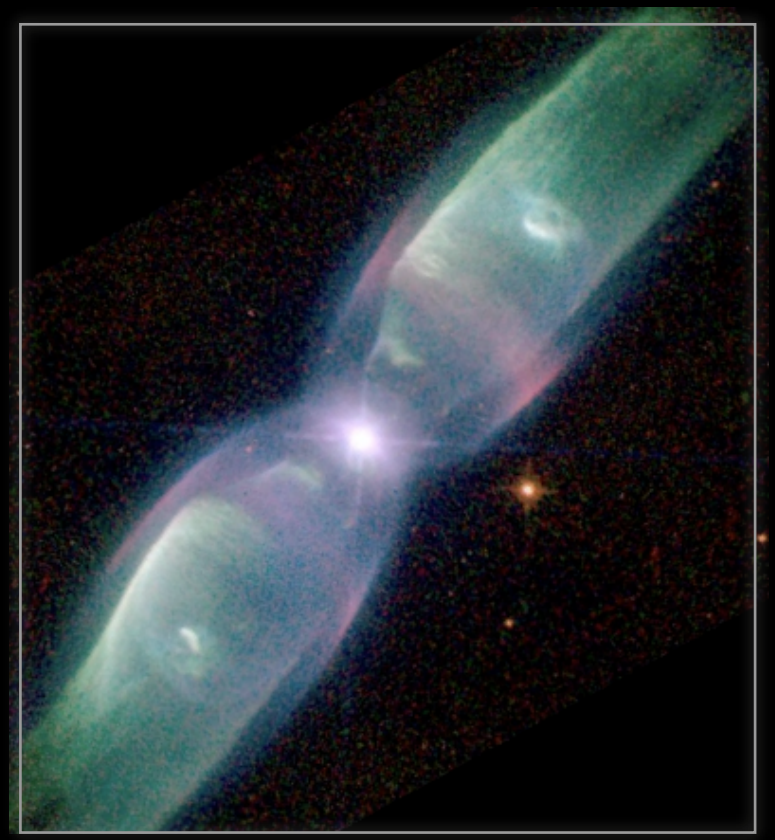
Keck II follow-up image of planetary system HR 8799 showing all three planets.

Extra Solar Planets

Altair Results – M2-9



M2-9, Gemini, NIR, 2005



M2-9, HST, Optical, 1997

Altair Results – SN 2008cs

Credit: Stuart Ryder

Detection of “hidden” supernovae (large extinction) by using Altair/LGS with NIRI. No bright enough NGS is available in this field. Off-axis TT guide star used.

M16 - Pillar details

- HST:
  - V Band
  - WFPC2

- Gemini Altair LGS:
  - 4x120s
  - K' band
  - FoV 43”x40”
  - FWHM <100mas
  - Meets or exceeds HST V resolution

Similar resolution
Different wavelengths
Complementary

HST V band

ALTAIR-LGS K’

Altair Fed Instruments

- **NIRI** - **N**ear **I**nfra**R**ed **I**mager and Spectrometer
  - 1024x1024 ALADDIN InSb array.
  - f/32, f/14, and f/6 (AO feed at f/14 or f/32)
  - Plate scales of 0.022", 0.050", and 0.117" / pixels
  - Fields of View (FoV) of 22" x 22", 51" x 51", and 120" x 120”
  - AO in *J*, *H* & *K*-Bands (*L*' is modest)
  - Three f/32 grisms covering 1.05 - 2.41 μm at f/32
    - Spectral resolution ~ 500-1000

- **NIFS** - **N**ear-**I**nfrared Integral **F**ield **S**pectrometer
  - 3D imaging spectroscopy
  - R ~ 5000
  - FoV - 3.0" x 3.0"
  - *Z* through *K*-band (0.95 to 2.40 μm)
  - AO - spatially resolved spectroscopy on scales as small as 0.1”
  - Spectral Resolution ~ 6000

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Altair Web Page

GEMINI OBSERVATORY

Images | Science | Public/Media | Jobs | About/Contact | Search

Change page style: Wide

Sciops

- Gemini Home
- Telescopes and Sites
- Instruments (Show All)
  - ALTAIR
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    - Use with NGS
    - Use with LGS
    - Field Lens Option
    - ITC, Sensitivity and Overheads
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- Observing With Gemini
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- Schedules
- Future Instrumentation
- Statistics
- Publications

ALTAIR

Home » Sciops » Instruments

ALTAIR (**ALT**itude congugate **A**daptive optics for the **I**nfra**R**ed) is the facility natural/laser guide star adaptive optics system of the Gemini North telescope. It can feed a corrected beam to Gemini instruments NIRI and NIFS. Deploying ALTAIR is "transparent" for the science instrument, as it reproduces the telescope focal ratio (f/16), pupil size and pupil position.

ALTAIR uses a 177 actuator deformable mirror (DM) and a separate tip-tilt mirror (TTM) to correct for image blurring and distortion caused by atmospheric turbulence. It is equipped with a Shack-Hartmann wave-front sensor (WFS) that uses the visible light to measure the turbulent incident wavefront. The correction is done at a rate of up to 1 kHz (one DM/TTM update every milli-second), and is optimized automatically. ALTAIR was built by the Herzberg Institute of Astrophysics (HIA), Canada.

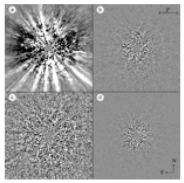
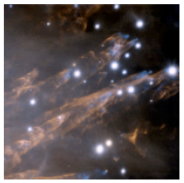
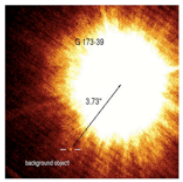
ALTAIR Natural Guide Star (NGS) function has been offered since 2004A. In 2007A, the ALTAIR Laser Guide Star (LGS) commissioning was completed.

The Instrument Scientist for ALTAIR is Chad Trujillo, assisted by Silas Laycock.

Announcements

No current announcements. See the Status and Availability pages for archived news items.

Altair science highlights

How to use these pages

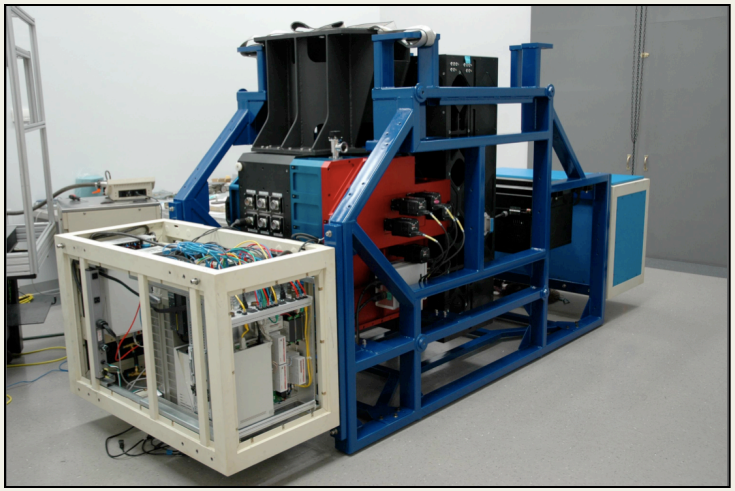
The ALTAIR pages are organized as follows:

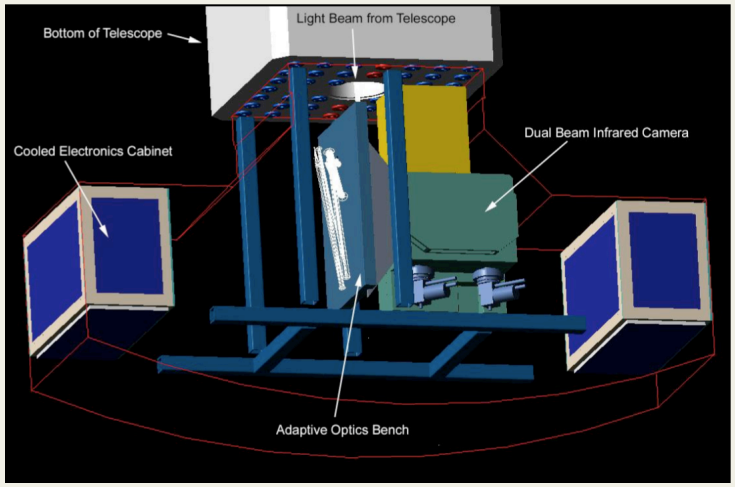
- Status and Availability: Modes available in the current and upcoming semesters; links to news items
- Use with NGS: Description of ALTAIR's natural guide star mode and guidance on how best to use the instrument in this mode
- Use with LGS: Information about ALTAIR's laser guide star mode and guidance on how best to use the instrument in this mode
- Field Lens Option: Pros and Cons of using ALTAIR's field lens
- Sensitivity and Overheads: Sensitivity tables, integration time calculator, and details of observing overheads
- Observation Preparation: How to configure NIRI in the Observing Tool
- Documents: ALTAIR design documents and references

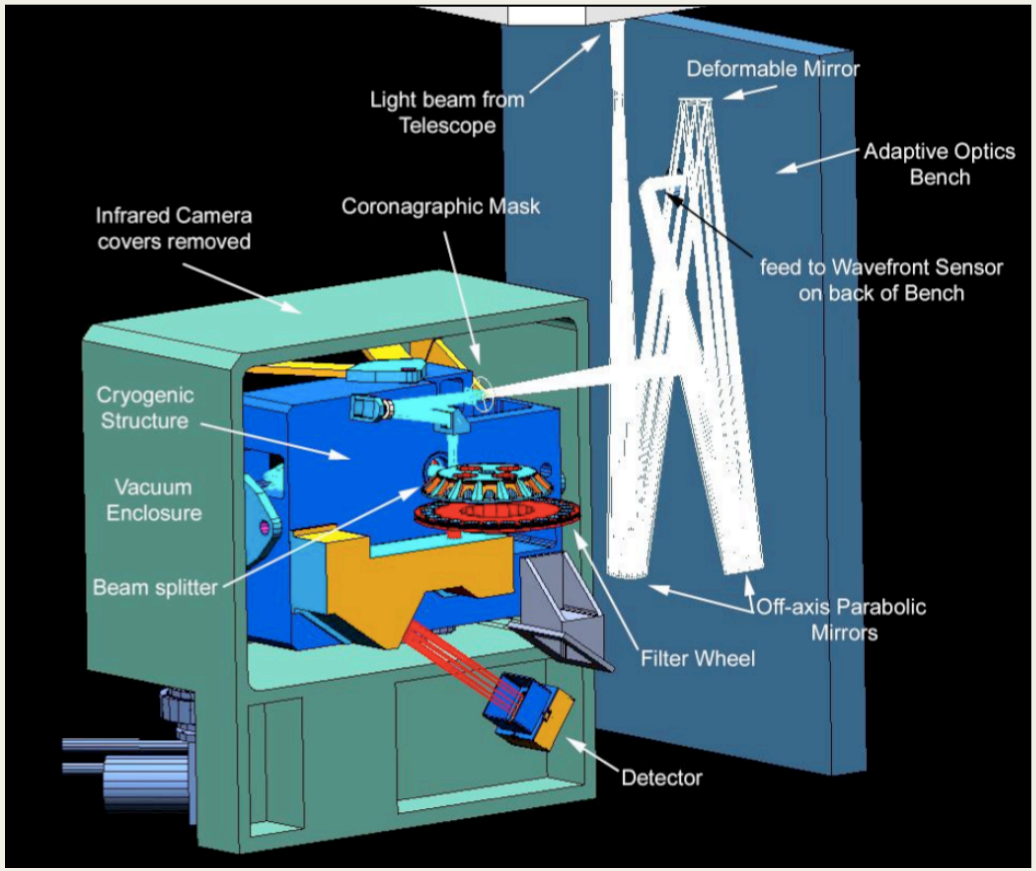
Near Infrared Corongraphic Imager - NICI

- AO System + Lyot Coronograph + 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
  - $1\ \mu m \leq \lambda \leq 2.5\ \mu m$ ($J - K$ bands)
  - Focal plane and Pupil plane masks
  - Beamsplitting elements
  - Filters in each channel

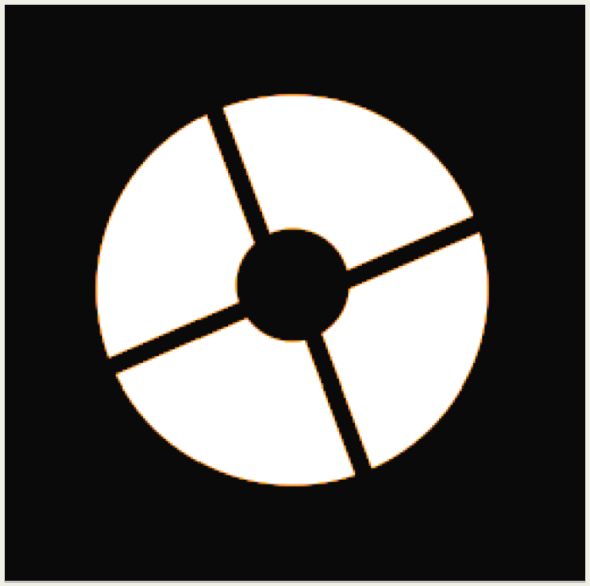
Near Infrared Coronographic Imager - NICI

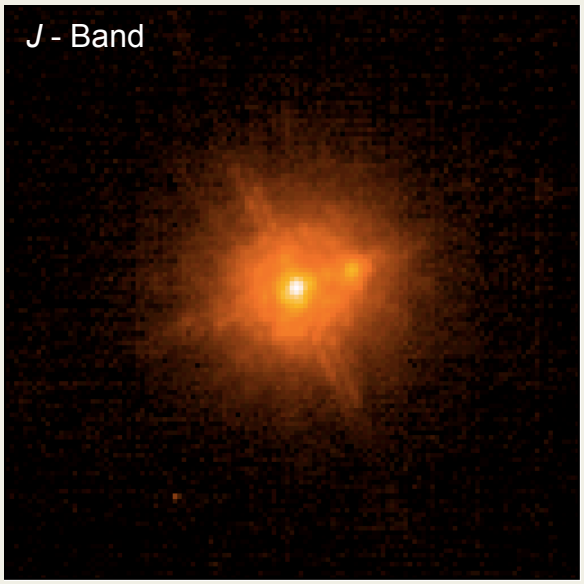


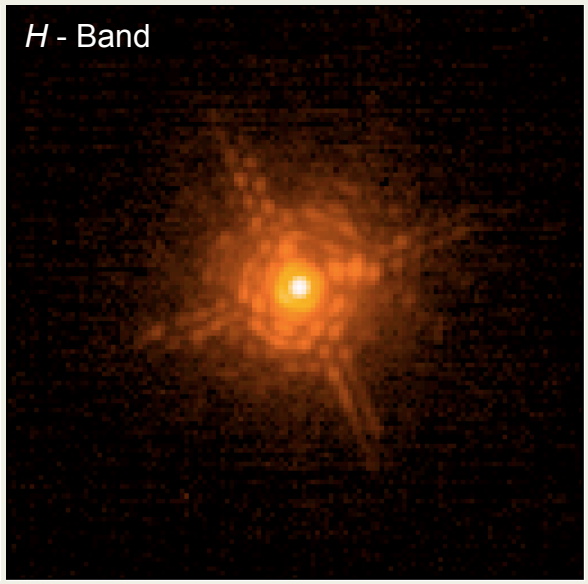


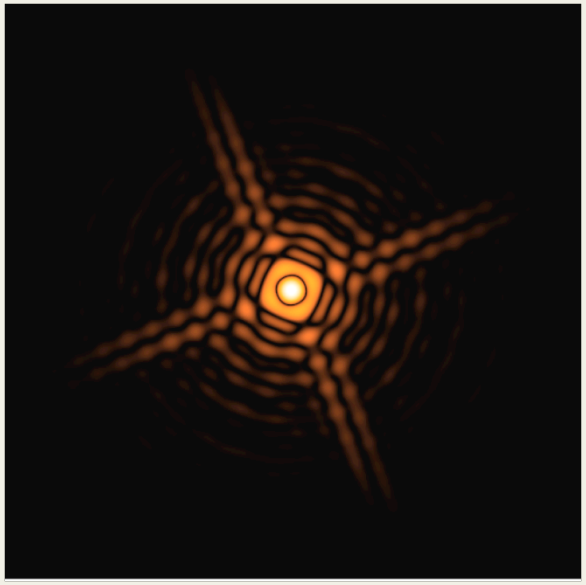


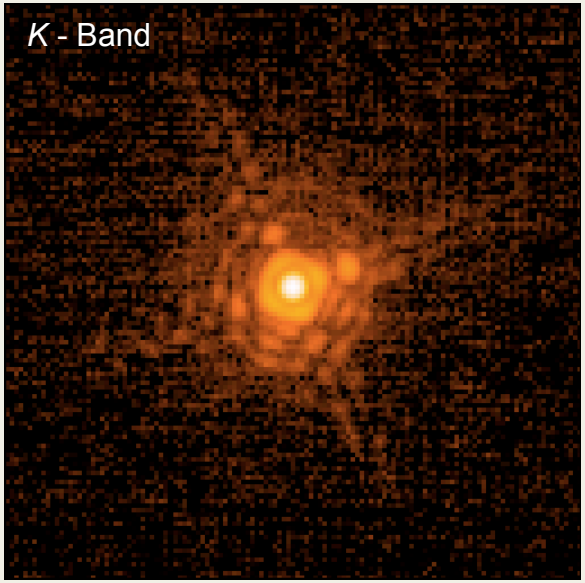
The NICI Point Spread Function

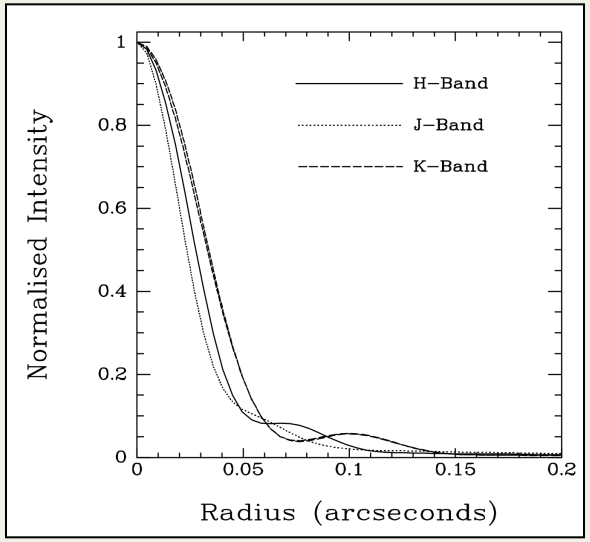












NICI Overview

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_4 absorption ($T_{eff} < 1300$ 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

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NICI Filters

NICI Filters				
Filter Name	Central Wavelength	Wavelength range or Width	Channel 1 (Red) Gemini ID	Channel 2 (Blue) Gemini ID
Block	--	--	--	--
CH4 H 1% S	1.587	0.0150 (0.94%)	G0724	G0722
CH4 H 1% Sp	1.603	0.0162 (1.01%)	G0728	G0726
CH4 H 1% L	1.628	0.0174 (1.07%)	G0720	G0732
CH4 H 1% L_2	1.628	0.0174 (1.07%)	G0735	
CH4 H 4% S	1.578	0.062 (4.00%)	G0742	G0743
CH4 H 4% L	1.652	0.066 (3.95%)	G0740	G0737
J	1.25	1.15-1.33		G0702
H	1.65	1.49-1.78		G0703
K	2.20	2.03-2.36	G0704	
Ks	2.15	1.99-2.30	G0705	
Kprime	2.12	1.95-2.30	G0706	
Lprime	3.78	3.43-4.13	G0707	
Mprime	4.68	4.55-4.79	G0708	
[Fe II]	1.644	1.5%		G0712
H2 1-0 S(1)	2.1239	1.23%		G0709
Br-gamma	2.1686	1.36%		G0711
Kcont	2.2718	1.55%	G0710	
CH4 H 6.5% S	1.596	0.1175 (7.3%)		G0713
CH4 H 6.5% L	1.701	0.0972 (5.7%)	G0714	

NICI Data Reduction

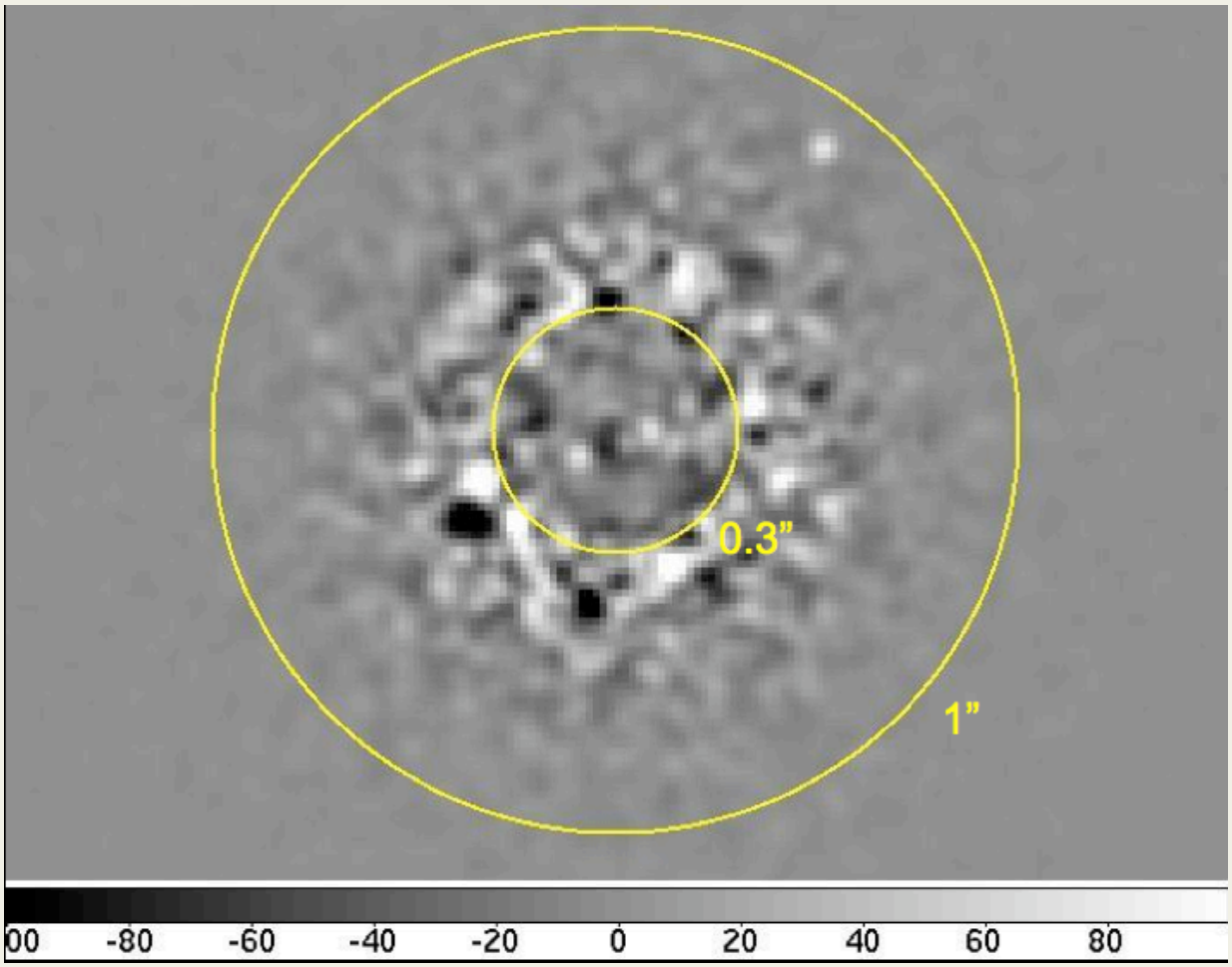
ADI Reduction (using field rotation)

- For Red and Blue Arms separately:
  - Standard Calibration – Flats, Darks, Bad Pixels etc.
  - Register (sub-pixel shift) to central star.
  - Highpass filter – look for point sources
  - Match speckles – simplex minimization – scale intensity
  - Median ADI cube for PSF
  - Subtract PSF from data cube matching speckles of individual frames.

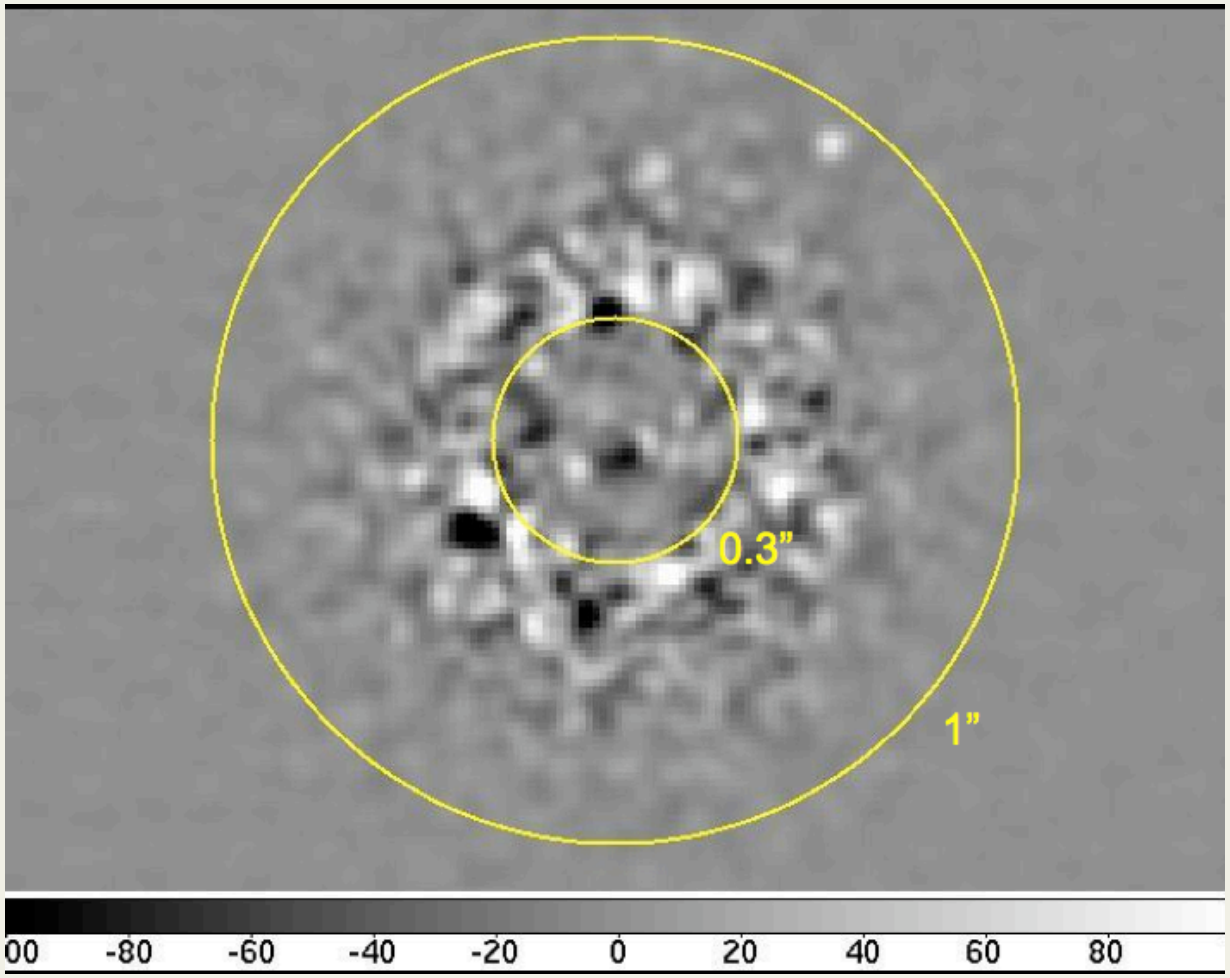
SDI Reduction

- Cancels primary retaining methane band object
  - Shift images, adjust image scale for wavelength
  - Subtract final results

NICI Data Reduction



NICI Data Reduction



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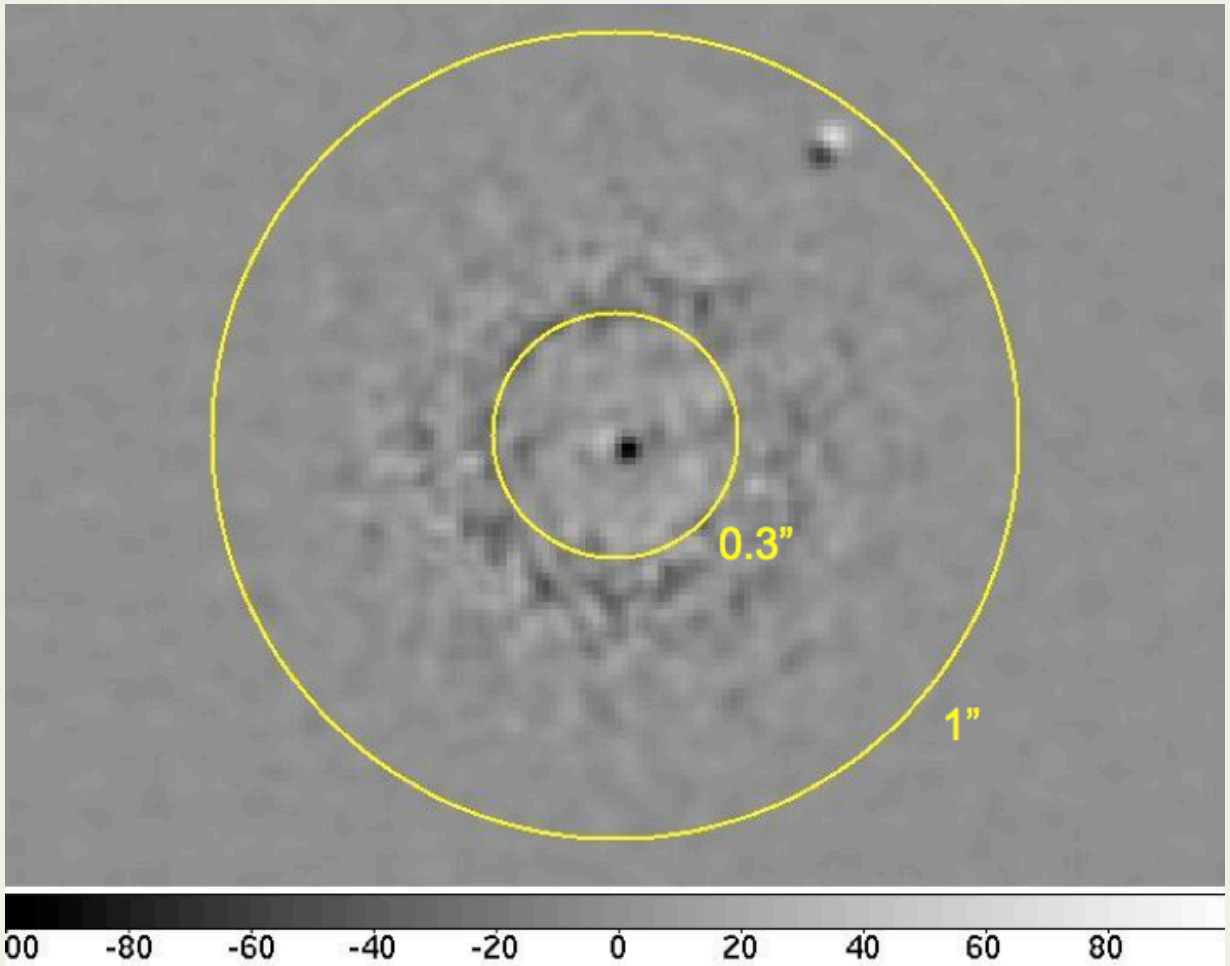
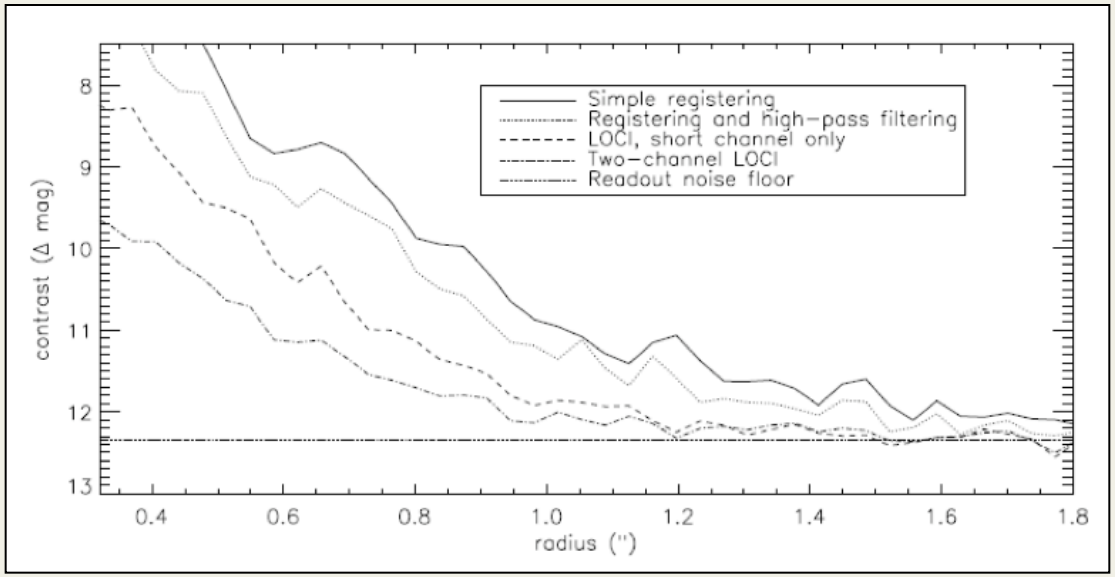
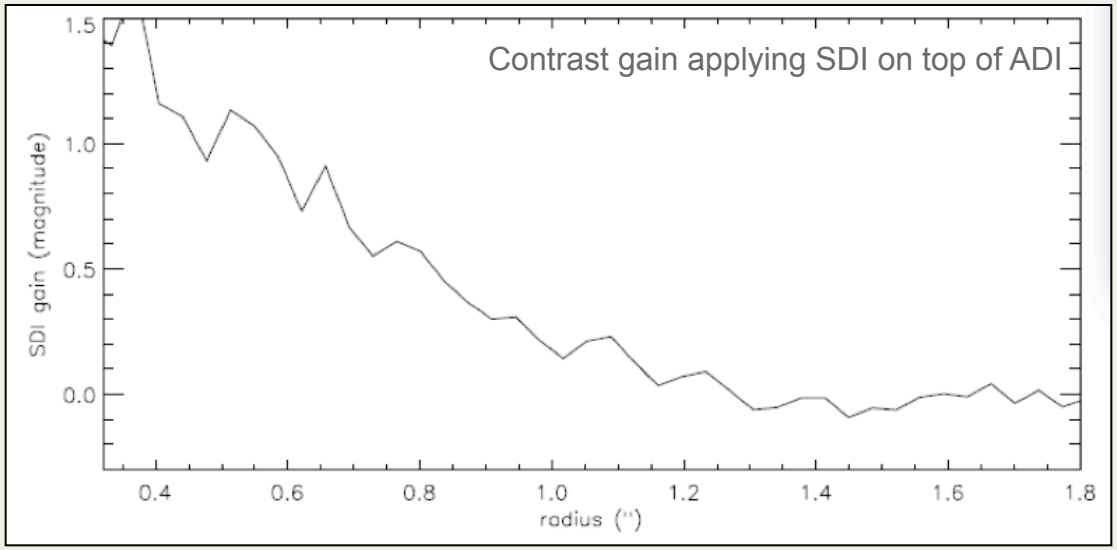


NICI Data Reduction





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NICI Web Page

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Sciops

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- Telescopes and Sites
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    - Calibration
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NICI

Home » Sciops » Instruments

Overview of NICI's capabilities

NICI, the Near-Infrared Coronagraphic Imager, is a dual-channel imager for use on Gemini South. Built by Mauna Kea Infrared (MKIR), NICI arrived on Cerro Pachon in November 2006 and obtained "first light" on 20 February 2007. It completed its main commissioning phase in 2008B and will be offered for queue observing in 2009B.

NICI combines an 85-element curvature adaptive optics system, a dedicated Lyot coronagraph, and a specialized dual-channel camera into a single instrument optimized to detect large Jovian-type planets around nearby stars. Sensitivity is enhanced by spectrally differencing two images taken simultaneously inside and outside the strong near-infrared methane absorption features found in substellar objects cooler than 1400 K. Integrating the three major subsystems into a single instrument keeps non-common path aberrations small, limited only by the residual atmospheric wavefront and scattering. Optical scattering and ghosts are minimized by using off-axis paraboloids instead of lenses. Both channels are equipped with a 1024x1024 ALADDIN InSb array (1 -5 μm), with an imaging scale of 18 mas/pix and field of view of 18x18 arcsec. A variety of broad- and narrow-band filters are available, including AO-quality filters to sample the methane absorption band at 1.6 μm.

The Instrument Scientist for NICI is Tom Hayward.

Announcements

NICI will be offered for queue observing in 2009B. See the Status and Availability pages.

How to use these pages

The NICI pages are organized as follows:

- Status and Availability: Modes available in the current and upcoming semesters; links to news items
- Imaging: Components used in NICI's imaging modes and guidance on how best to use the instrument in this mode
- Sensitivity and Overheads: Sensitivity tables, integration time calculator, and details of observing overheads
- Calibration: How to calibrate NICI observations
- Observation Preparation: How to configure NICI in the Observing Tool
- Data Format and Reduction: Examples of NICI data and links to data reduction resources
- Documents: NICI design documents and references

Also see the Near-IR Resources section, which contains generic information about observing at 1-5um as well as details about calibrations, standard stars, etc. that apply to NICI, NIRI, NIFS, GNIRS, Phoenix and FLAMINGOS-2.

Last update: 27 February 2009, M. Hartung & T. Hayward

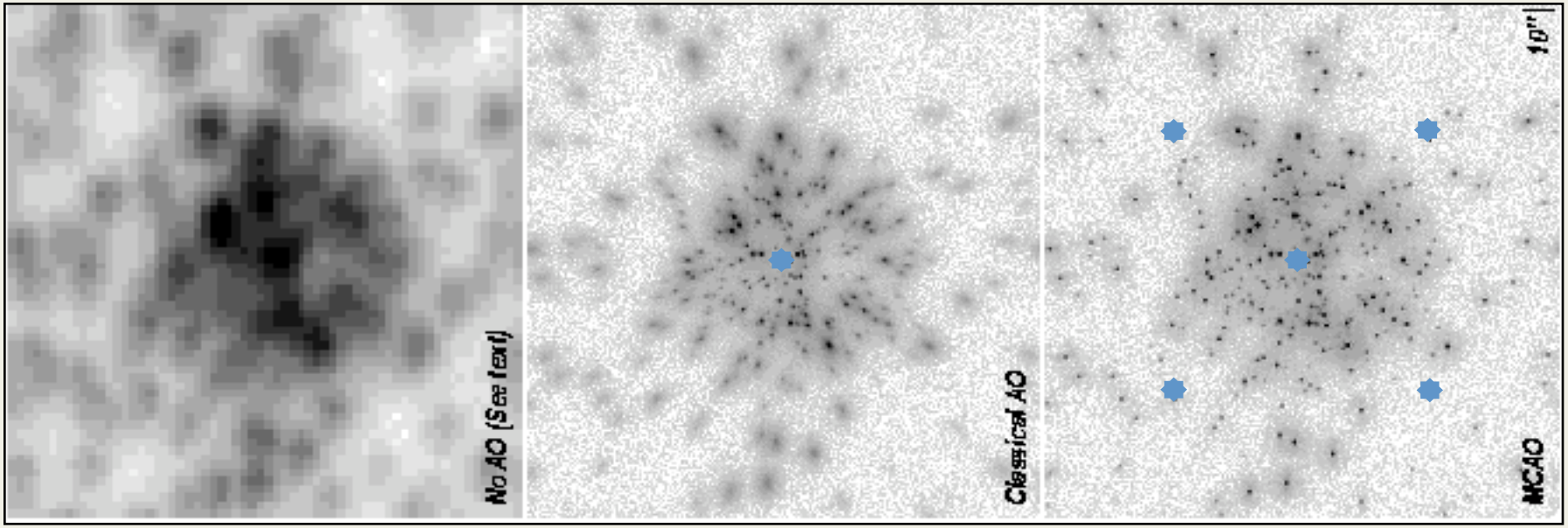
Created: 4 Jan 2006; Phil Puxley

The Future - GeMS

- 5 LGS WFS 16 x 16 Shack-Hartmann
- 3 Deformable Mirrors
  - ~800 actuators
  - Conjugated to 0, 4.5 and 9km range
- 1 NGS slow focus WFS
- 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
  - ASCAM
  - Safety systems, infrastructure, laser(s), BTO, LLT, etc...

MCAO Performance Summary

No AO | **Classical AO** (1 DM / 1 NGS) | **MCAO** (2 DMs / 5 NGS)



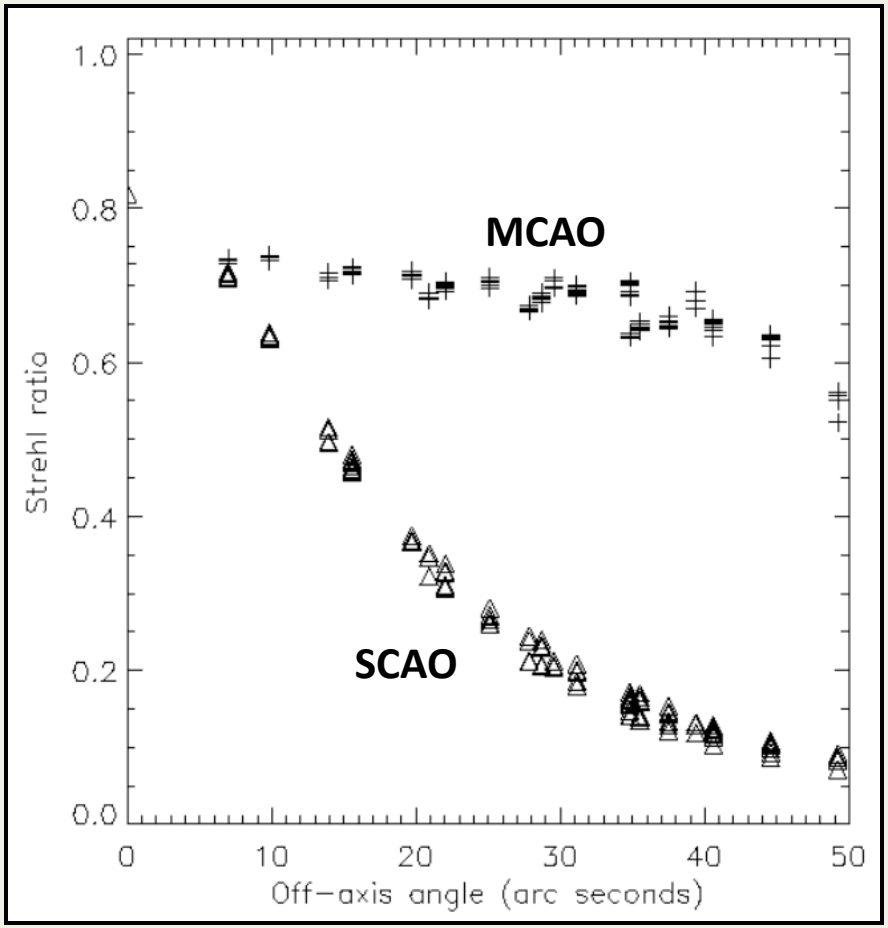
165''

320 stars / K band / 0.7'' seeing

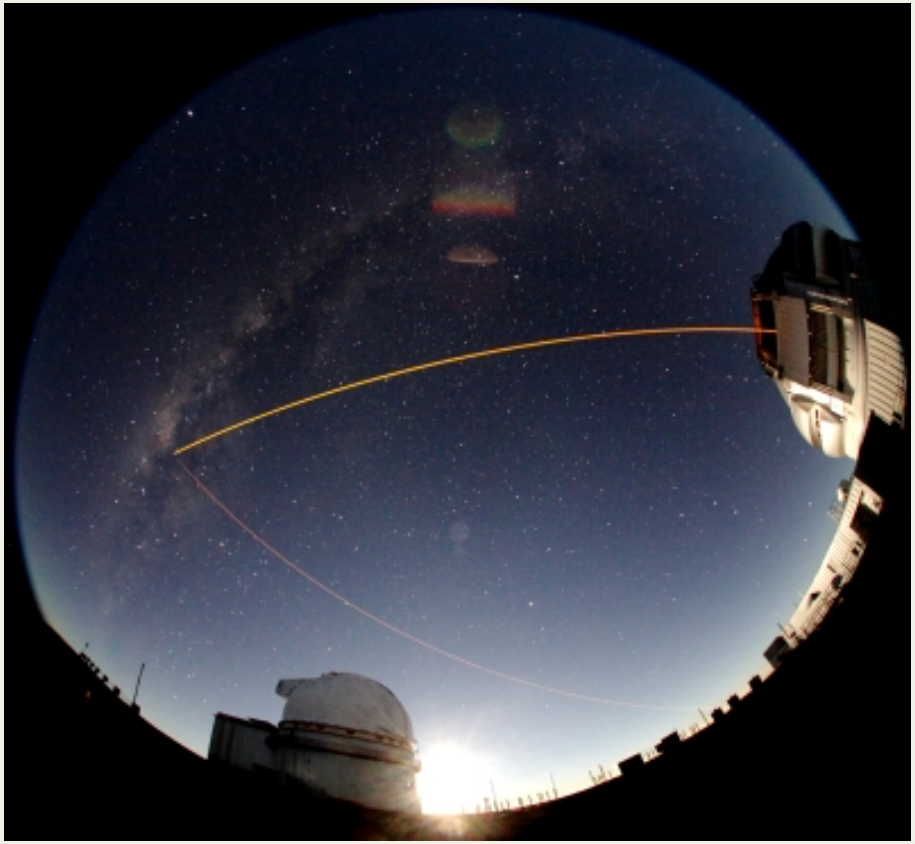
Stars magnified for clarity

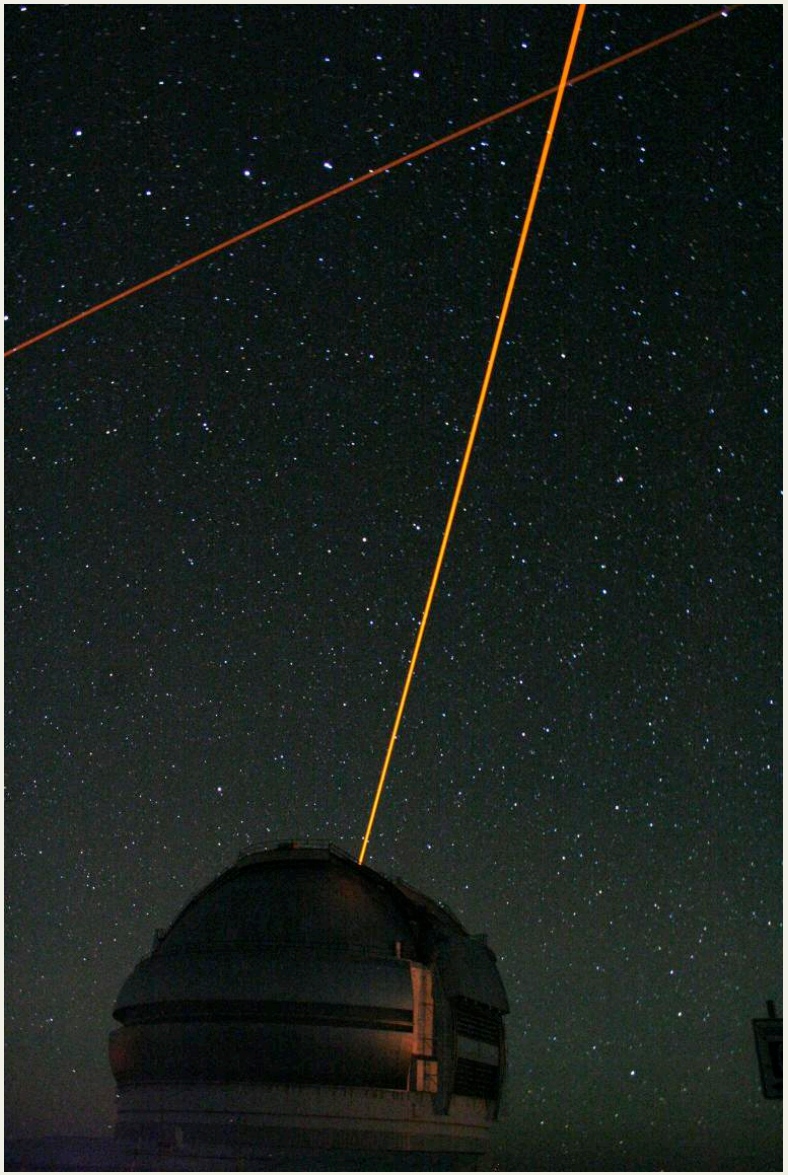
GeMS Performance

- Strehl under median seeing conditions (0.7”)
  - J ➜ 20% ; H ➜ 40% ; K ➜ 60%
  - Strehl uniformity:
    J ➜ 5% ; K ➜ 2%
- Sky coverage:
  - Need 3 TT guide stars
    (R_{lim} = 18.5)
  - Galactic pole ➜ 10%
  - Average over whole
    sky ➜ 30%
  - Compatible with degraded
    modes of operation (1 or 2 TTGS)



Mauna Kea LGS AO





Gemini and Keck LGS

… Subaru

Laser Traffic Control