AO capabilities at the MMT for the user

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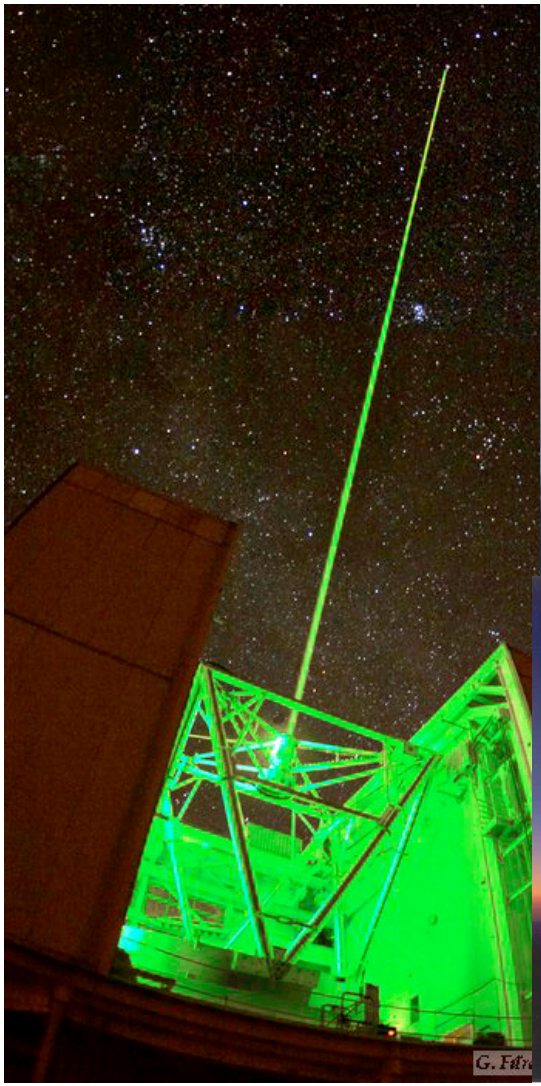
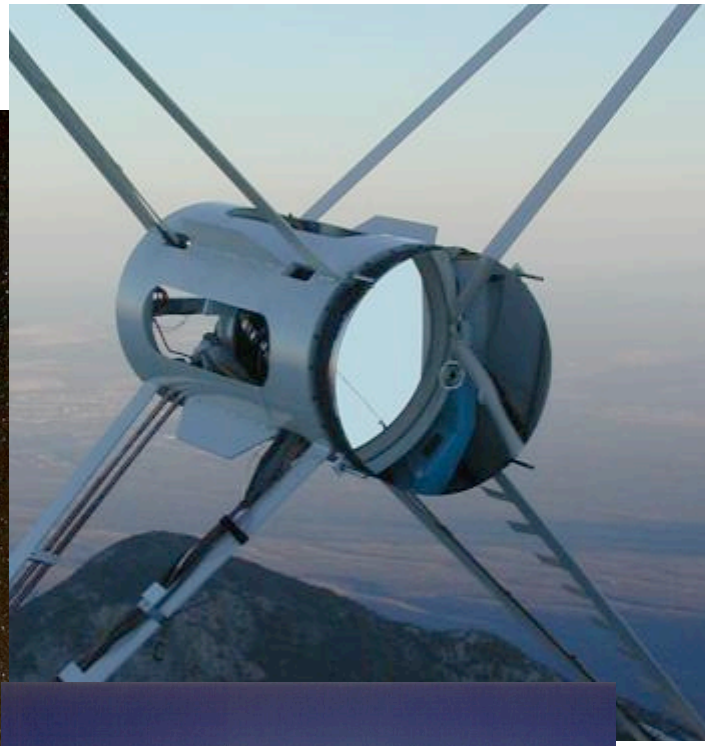
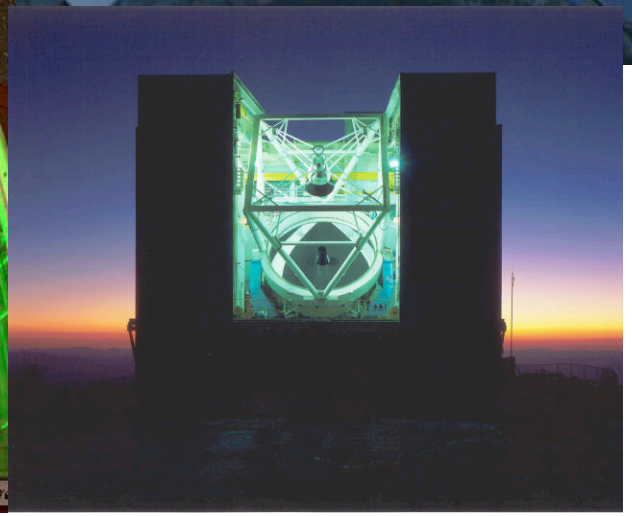
The MMT AO system







- NGS system description
- Available instruments and capabilities
- Illustrative results
- Current state of the multi-LGS system

Unique features of MMT AO

There are two features that are unique so far to the MMT (though given other observatories' plans they will not remain so):

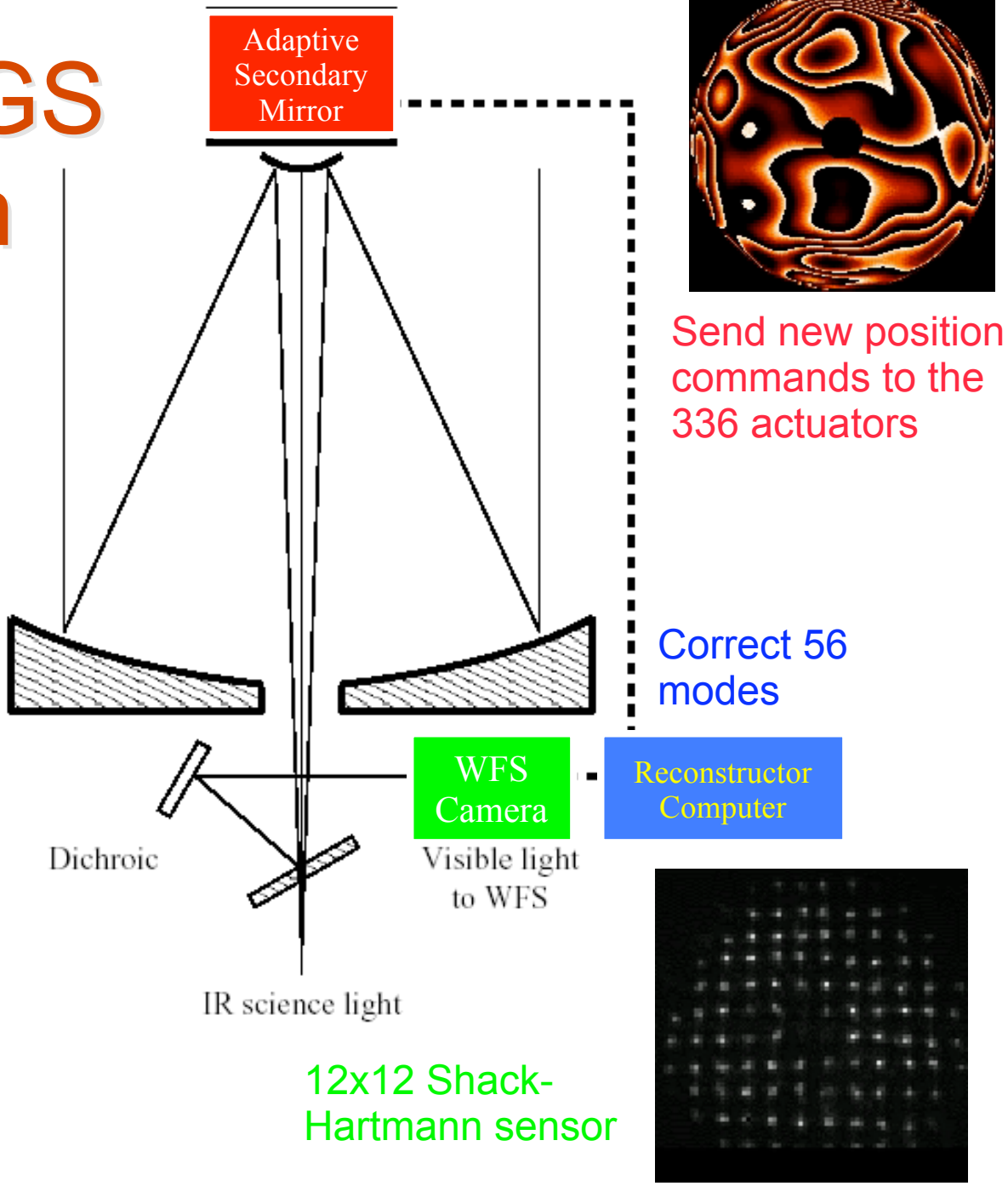
- The adaptive element is the secondary mirror of the telescope
- The laser AO system deploys multiple artificial beacons

These have allowed easier access to a number of science niches and served as pathfinders for systems on other telescopes.

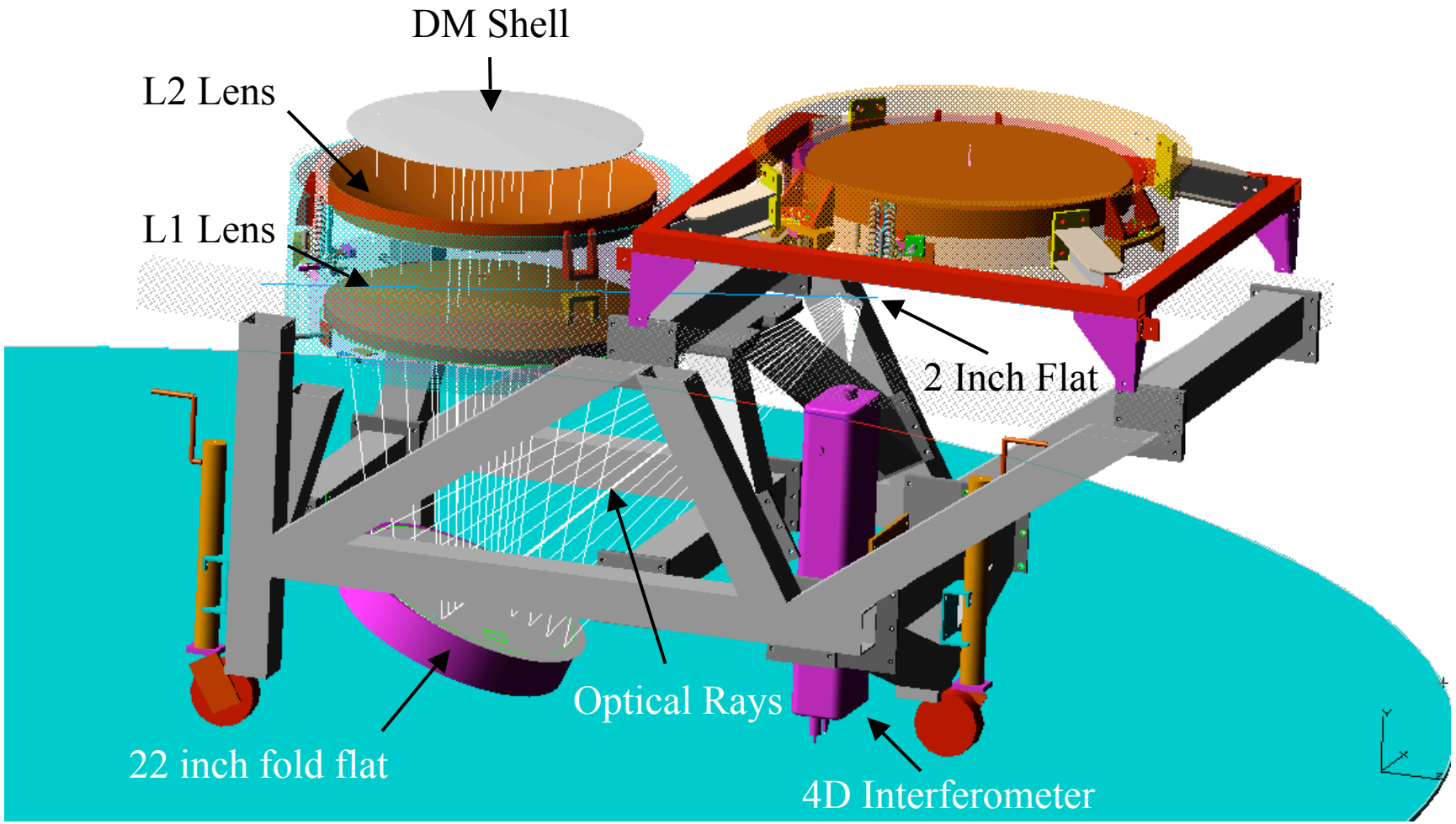
MMT AO usage over the past 12 months:

- Total 75 nights out of 322 scheduled observing nights (23%)
- 63 nights for NGS science with 3 instruments
- 10 nights for LGS engineering
- 2 nights for LGS science

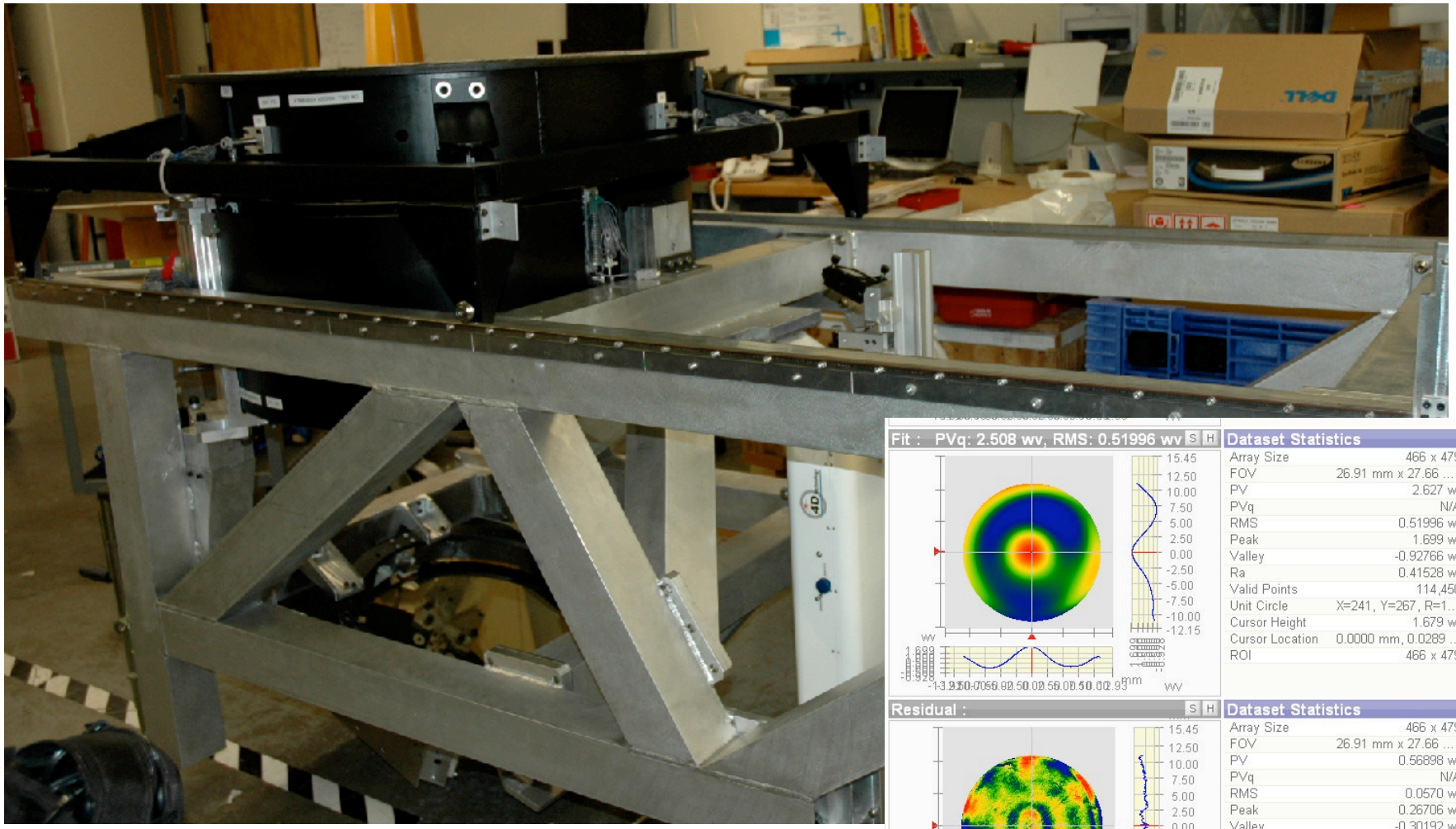
The MMT NGS AO system



DM calibration stand: mechanical design

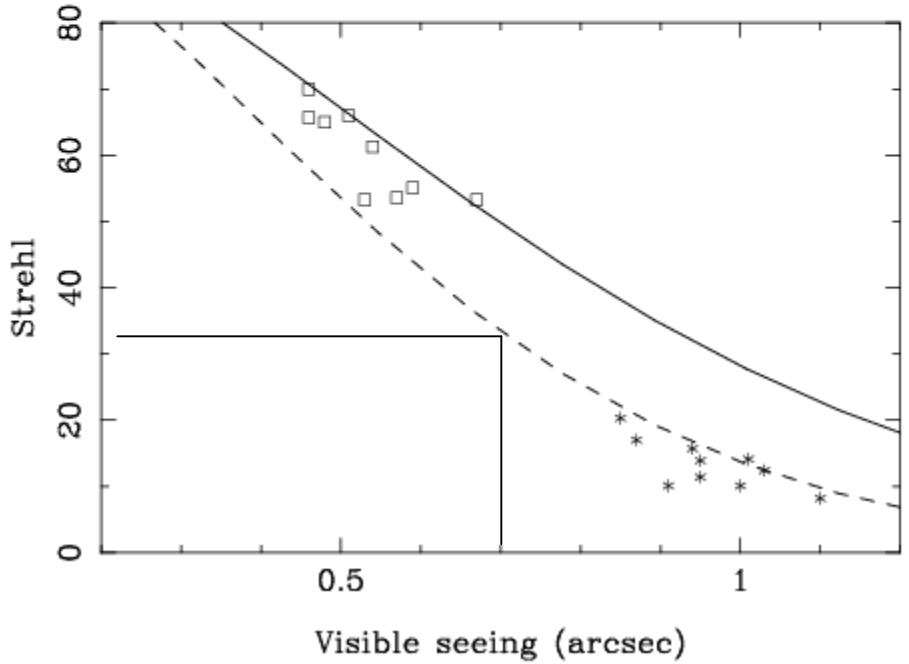


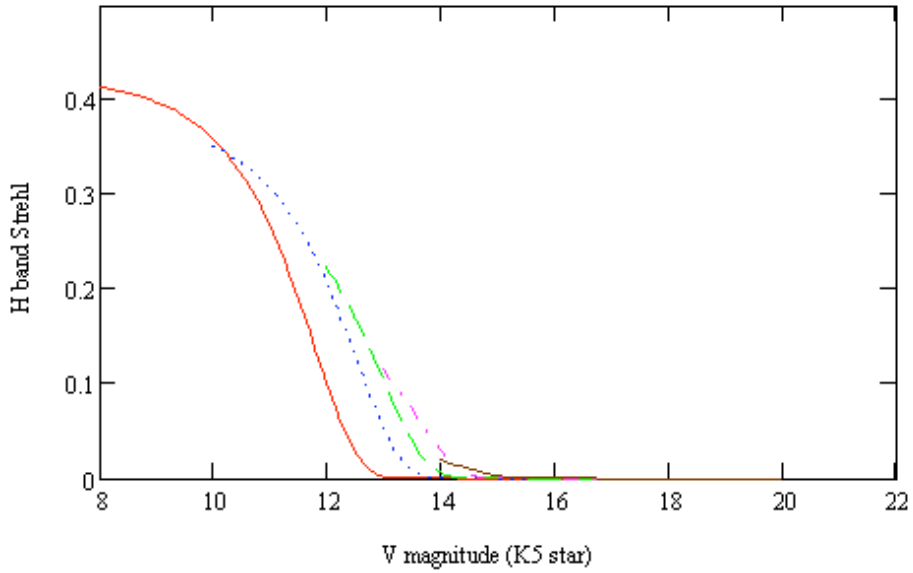
Calibration stand in the lab



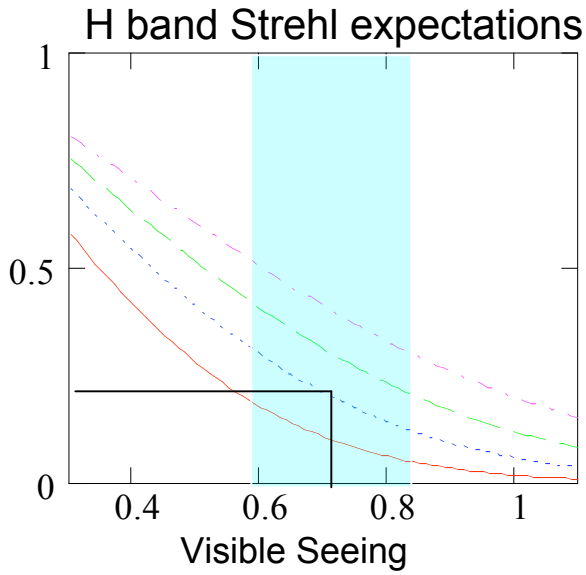
Current performance

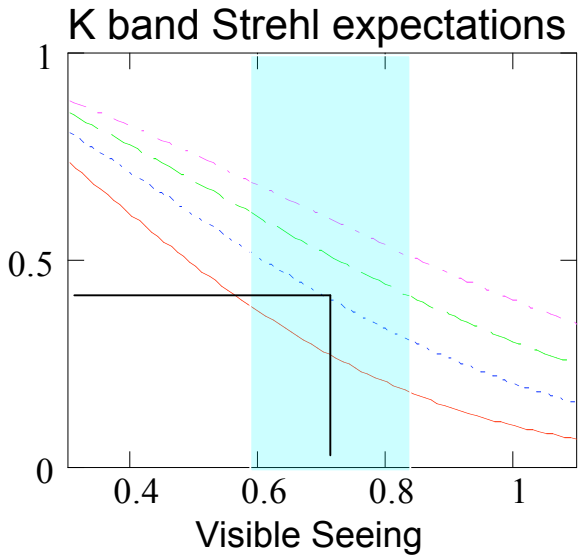
- Typical Strehl ratio is 40% in H band on bright stars, measured with an engineering camera installed next to the WFS.
- Limiting magnitude is V~14.5

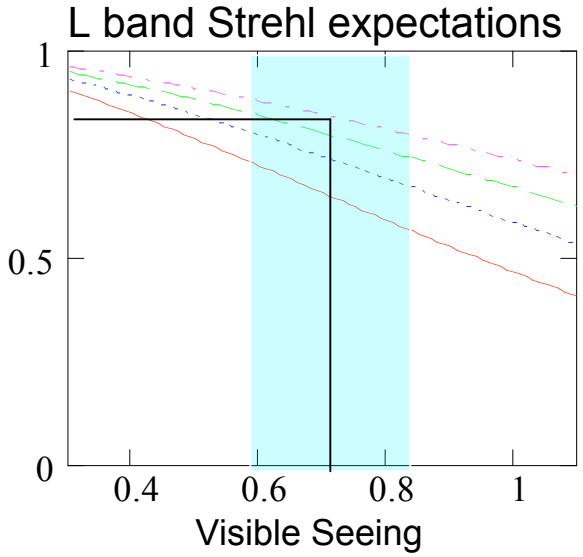


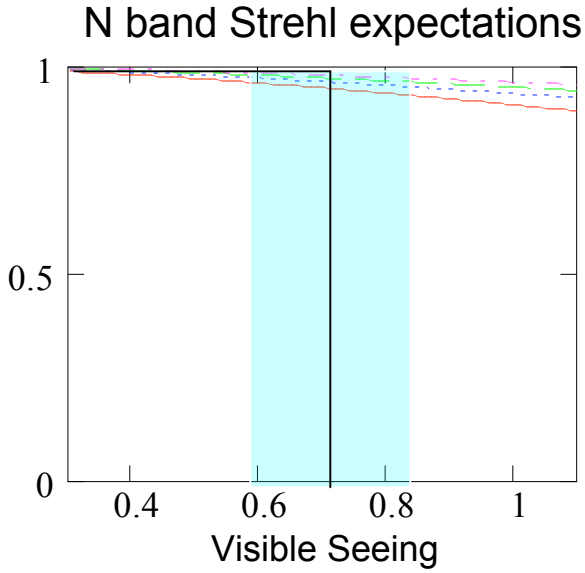


Performance versus seeing



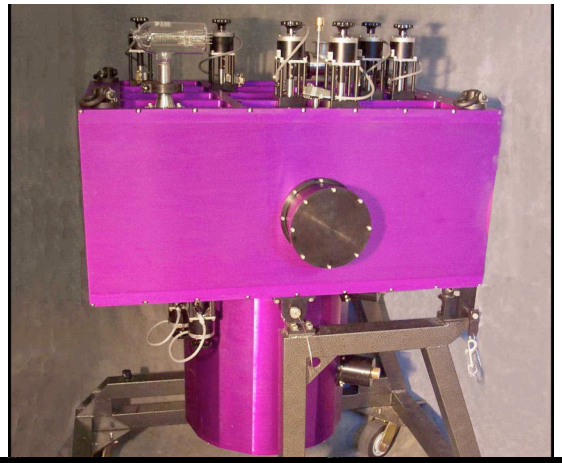






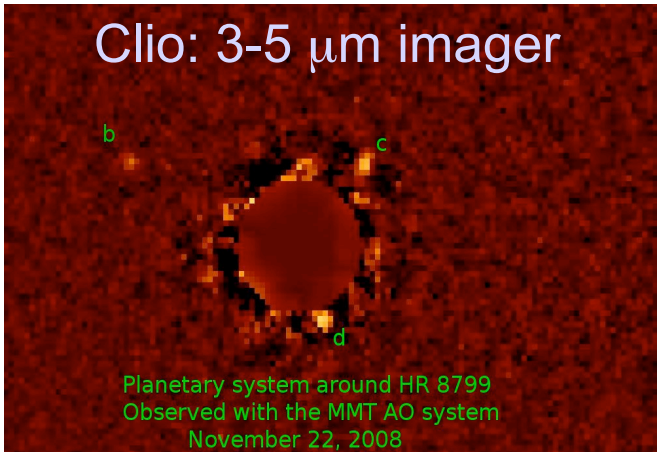
MMT AO science cameras

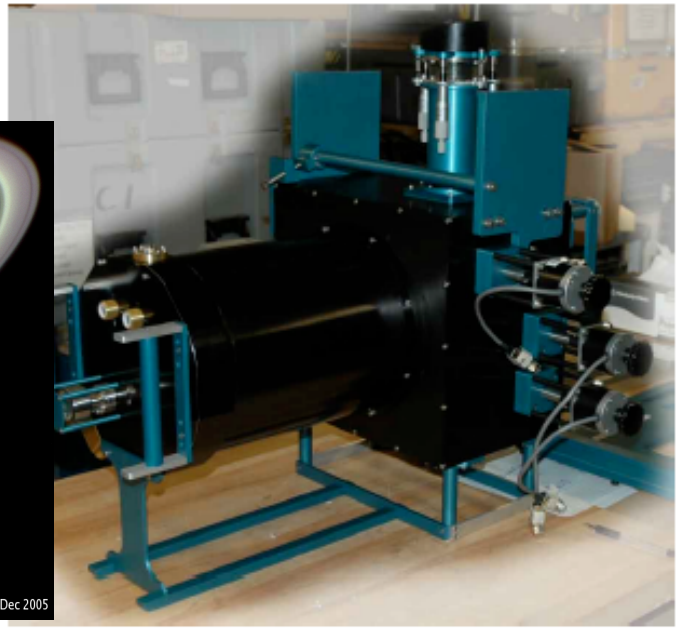
ARIES: 1-5 μm imager and spectrometer



Don McCarthy
Craig Kulesa

Clio: 3-5 μm imager

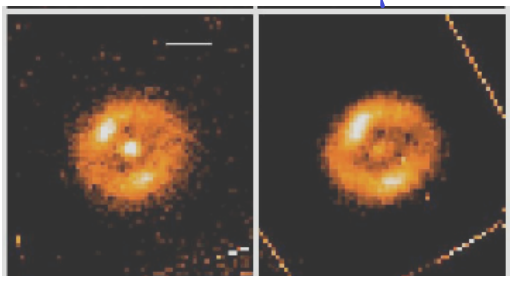




Suresh Sivinandam
Ari Heinze
Phil Hinz

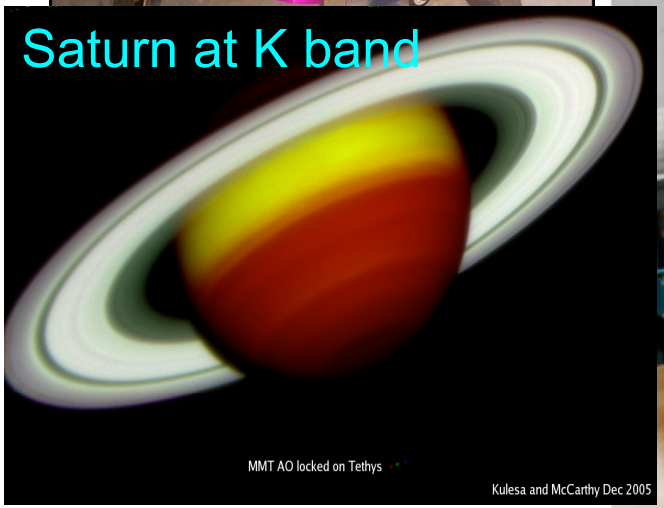
MIRAC-BLINC: 8-25 μm imager and nuller

Protoplanetary nebula at 9.8 and 11.7μm



Bill Hoffmann
Phil Hinz

Saturn at K band

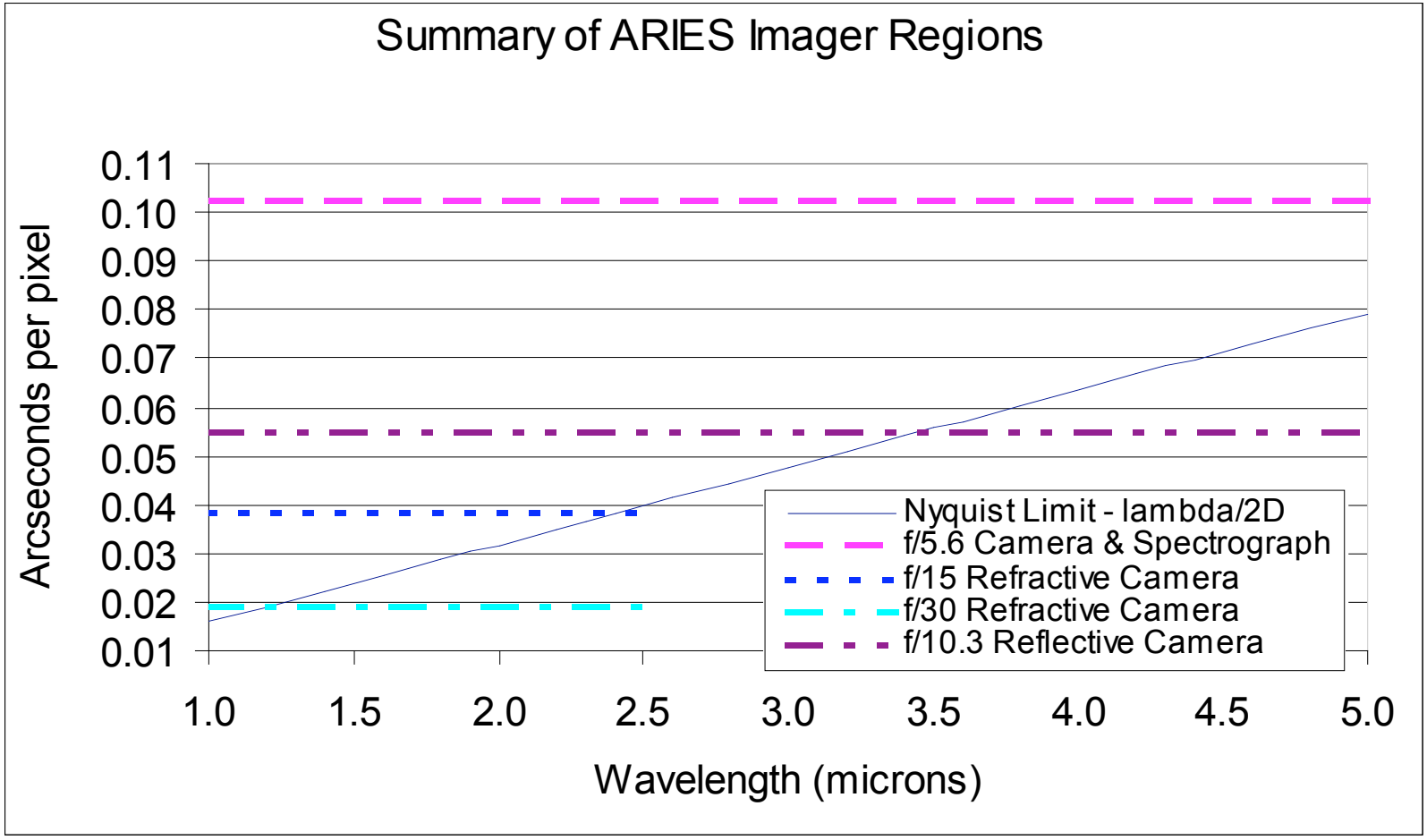


General features of ARIES

ARIES: Arizona Infrared Imager and Echelle Spectrometer

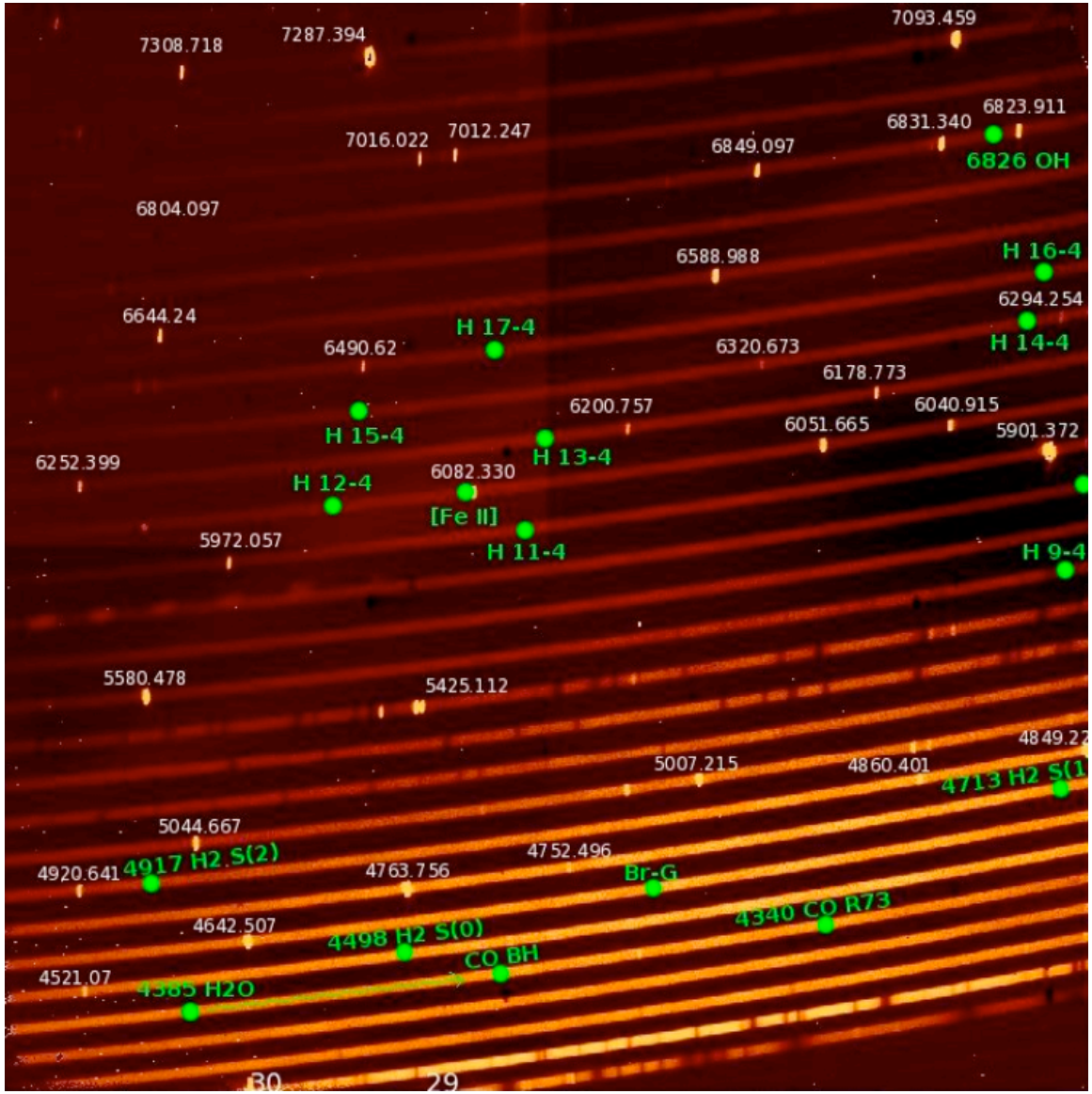
- Design principles:
  - Capitalize on MMT's adaptive secondary
    - Optically optimized
      - Nyquist sampling of diffraction limit from 1-5 μm
      - 0.1-0.2" wide slits
      - IR tip/tilt guide star probe which can be used either in NGS or LGS modes
    - Thermally optimized
      - Only emissive surface is warm dewar window
      - Cooled ADC for spectroscopy
  - AO allows compact, versatile instrument
    - High spectral resolution (R~50,000) in a compact device
  - Two science cameras are used simultaneously in different combinations of imaging and spectroscopy
    - "purple side": 1-2.5 μm with HAWAII-1 array (1024^2)
    - "green side": 1-5 μm with NIRCam HAWAII-2RG array (2048^2)

ARIES specifics



- Spectroscopy
  - JHK (R~3000)
  - LM (R~3000)
  - Echelle (R = 30,000 to 50,000)

High-resolution spectroscopy



- Resolution of 30,000 in the K band
- Orders well separated with ~1 arcsec spacing

Clio

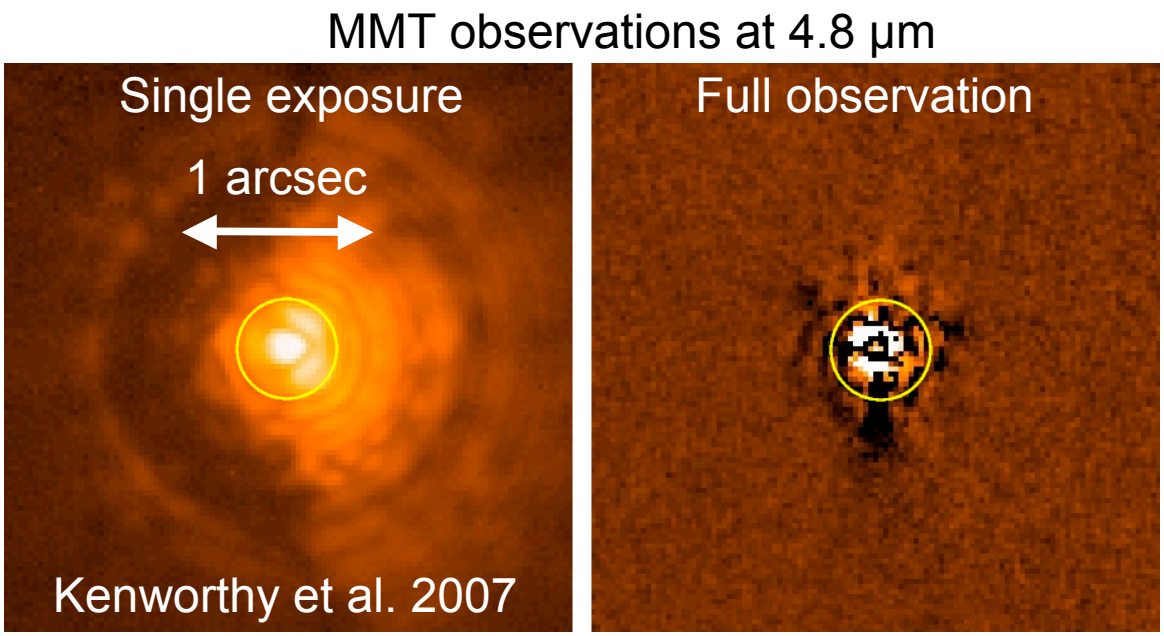
Clio is a mid-IR imaging camera.

Following the same design principle as ARIES, the entrance window to the dewar is the dichroic beam splitter that separates wavefront sensing light from science light.

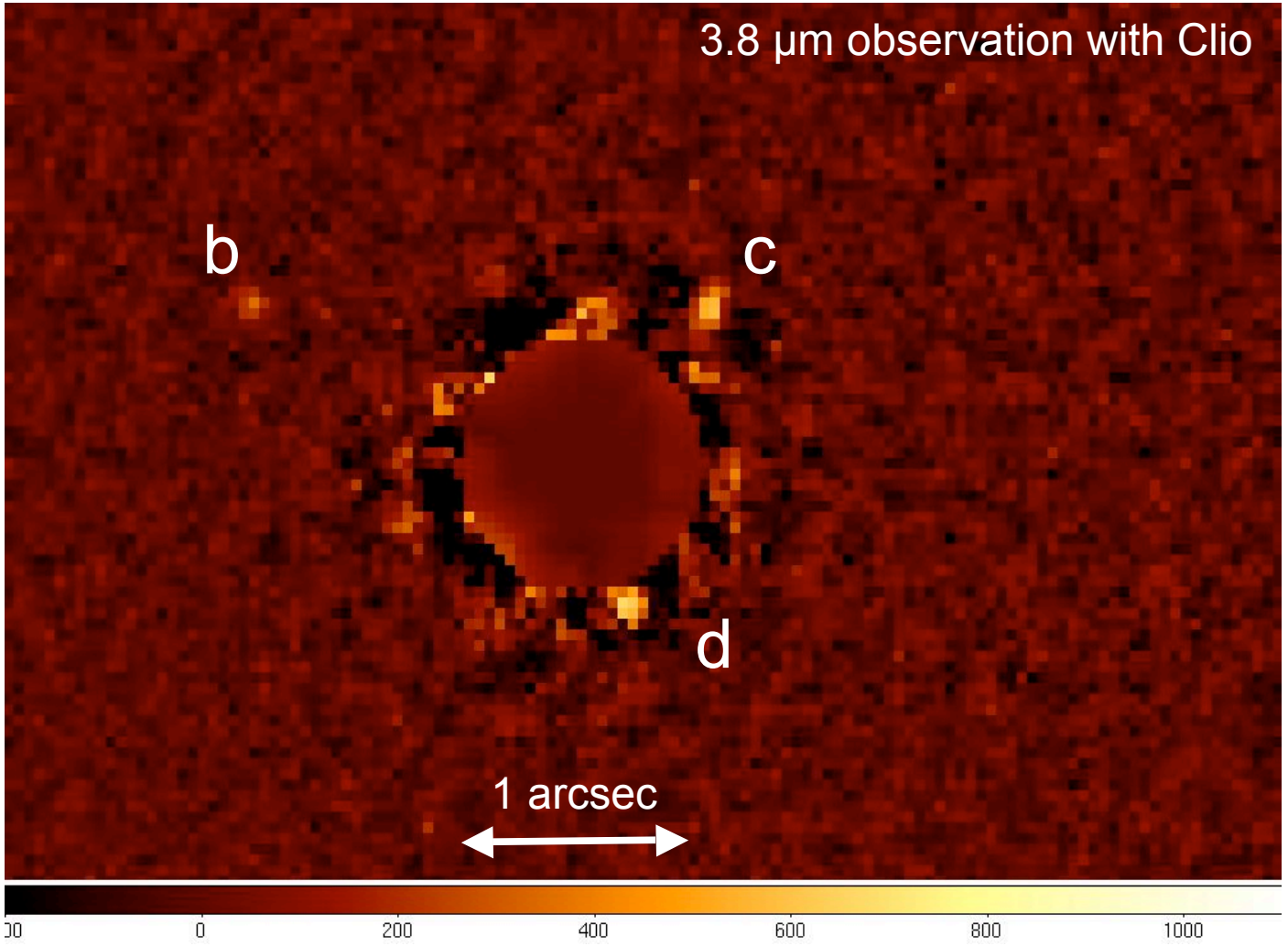
- 320x256 InSb array optimized for 3-5 μm, but can also see J-K.
- 15”x12” field of view which critically samples the L band diffraction limit.
- 9”x7” field of view critically samples H and K.

High contrast phase apodization

- Phase apodization coronagraphy uses a fixed phase plate to remove residual speckle halo from half the PSF
- PAC has been demonstrated to achieve 10^{-5} at 3 λ/D

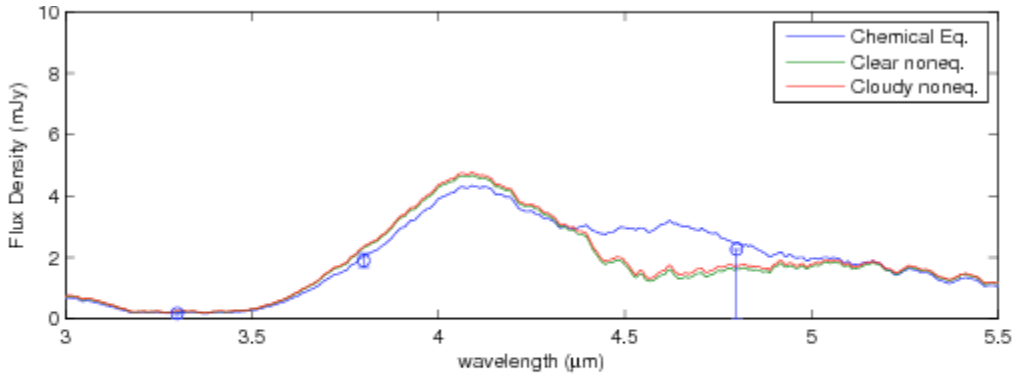


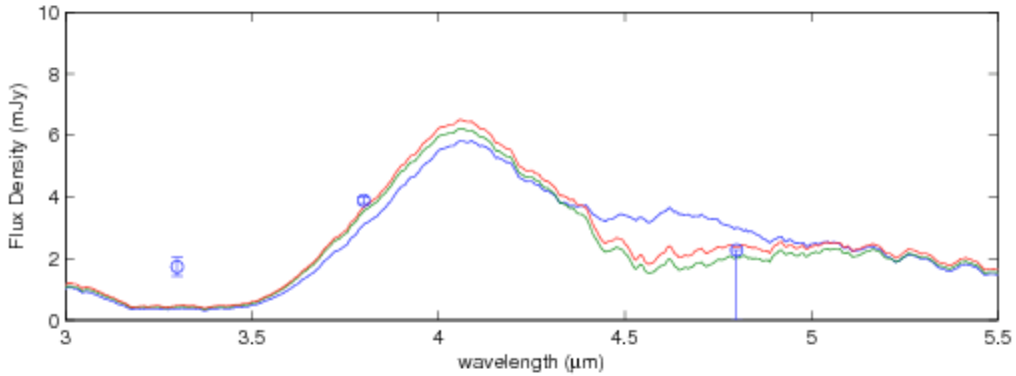
HR 8799 observations at 3-5 μm

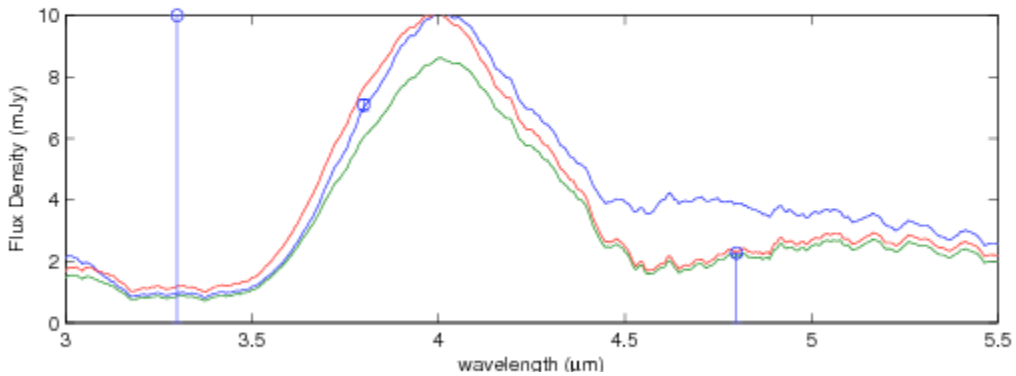


Exposure time is 1.5 hr, set by need for enough field rotation to separate planets from super-speckles.

Spectra of HR8799 b-d







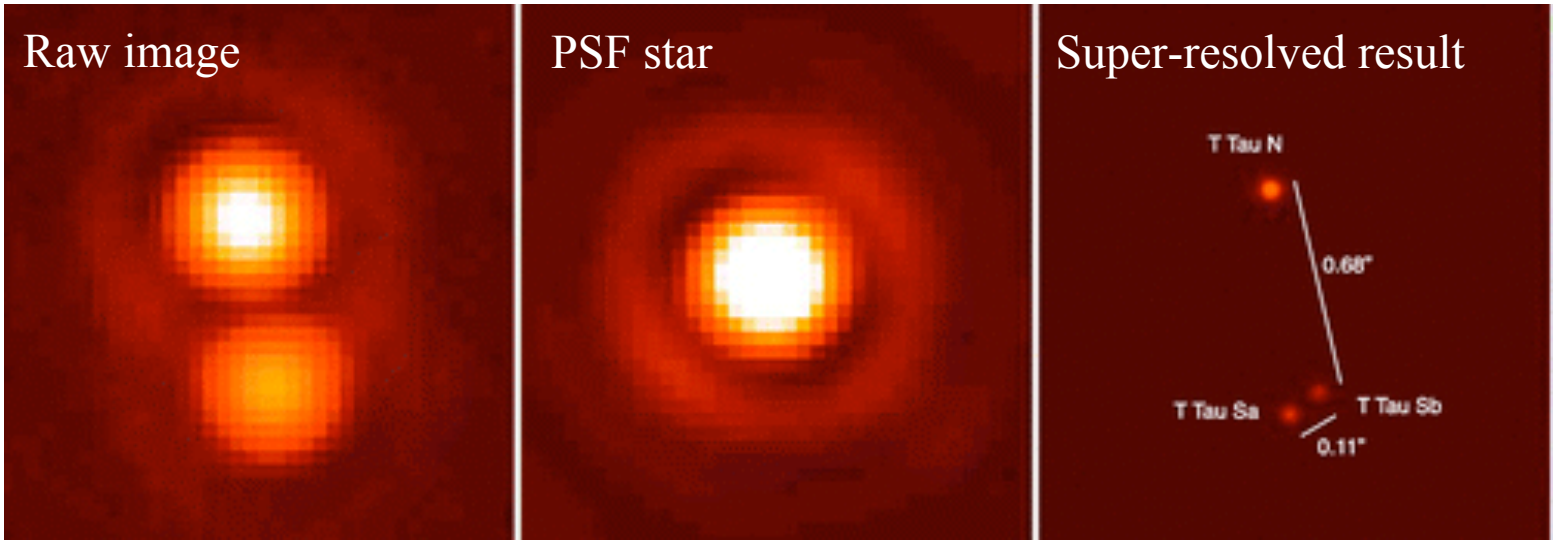
Objects appear bluer than model predictions, consistent with non-equilibrium chemistry.

BLINC/MIRAC

- MIRAC4 is a Si:As imaging camera sensitive from 8-25 μm.
- 256x256 focal plane array.
- 14”x14” field sampled at 0.055”/pixel
- 28”x28” field sampled at 0.11”/pixel (Nyquist at 6.8 μm)

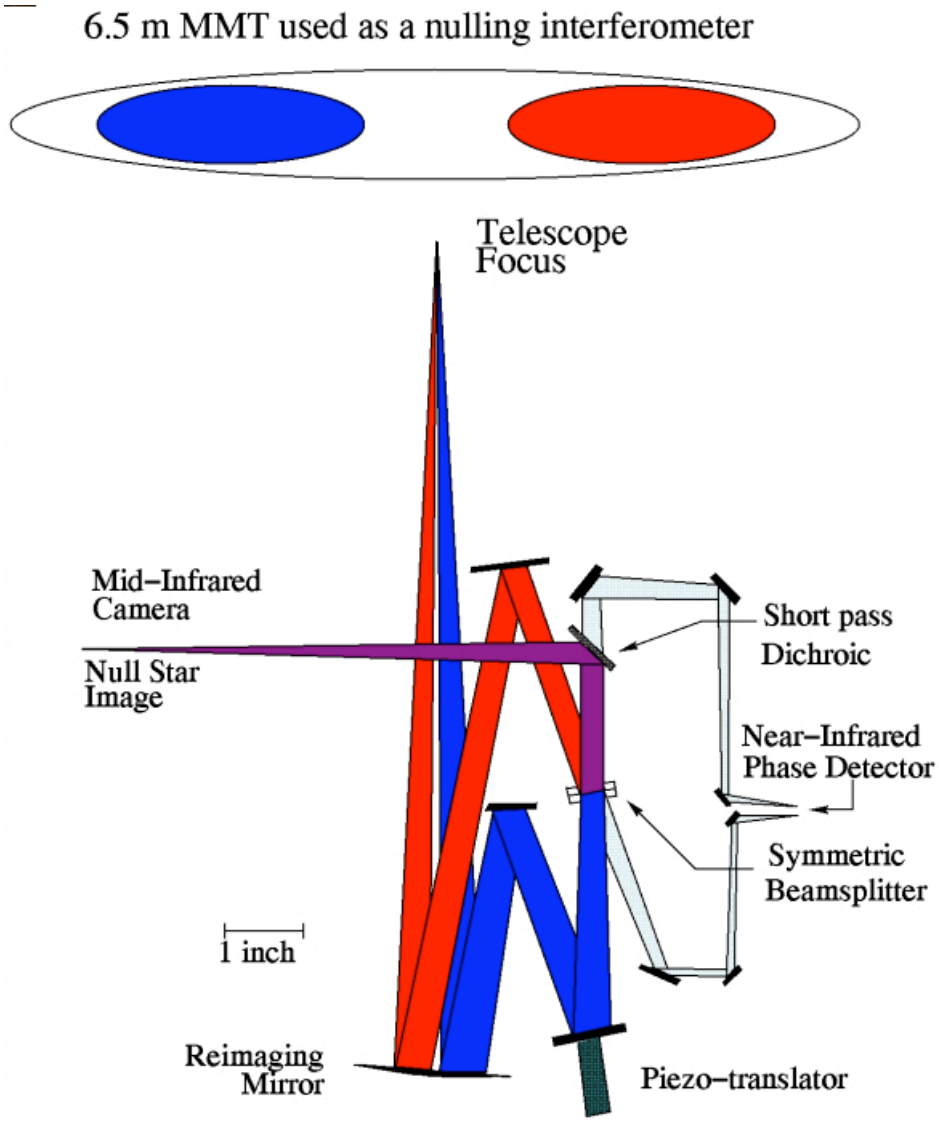
- BLINC is a Bracewell nulling interferometer that goes in front of MIRAC4.

MIRAC imaging



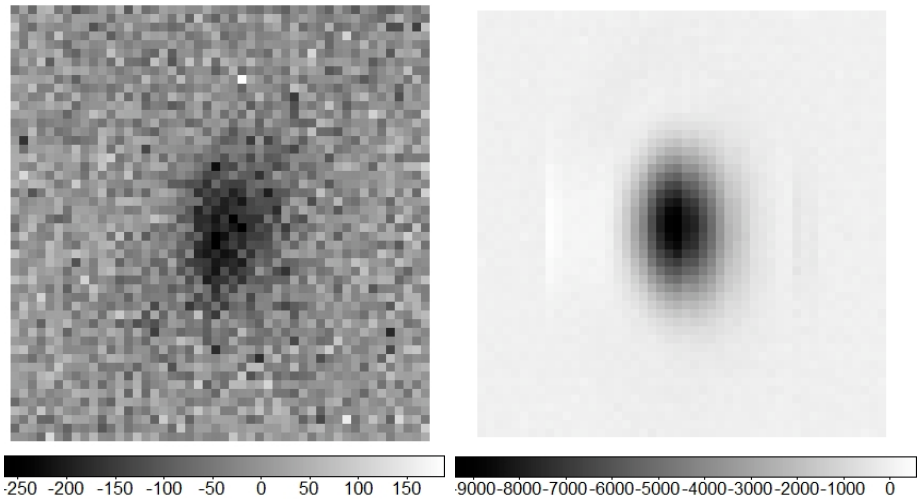
- 10.5 μm image of the T Tau triple star system
- High Strehl ratio allows robust super-resolution
- T Tau Sa, the most massive star in the system, has a nearly edge-on disk which is why it's faint.
- T Tau Sb also has a disk - but it's *not* edge on! (Why have they not been aligned by tidal forces??)

Nulling interferometry

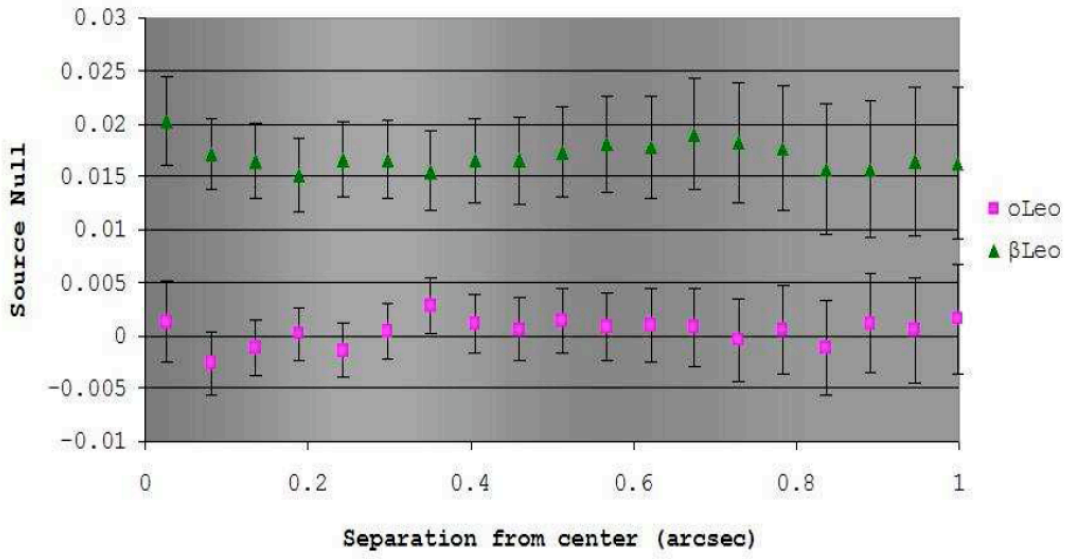


Optical layout of the BracewelL Infrared Nulling Cryostat (BLINC)

- 2.5x5 m apertures
- First fringe at 0.25”
- Used with the adaptive secondary for low background observations



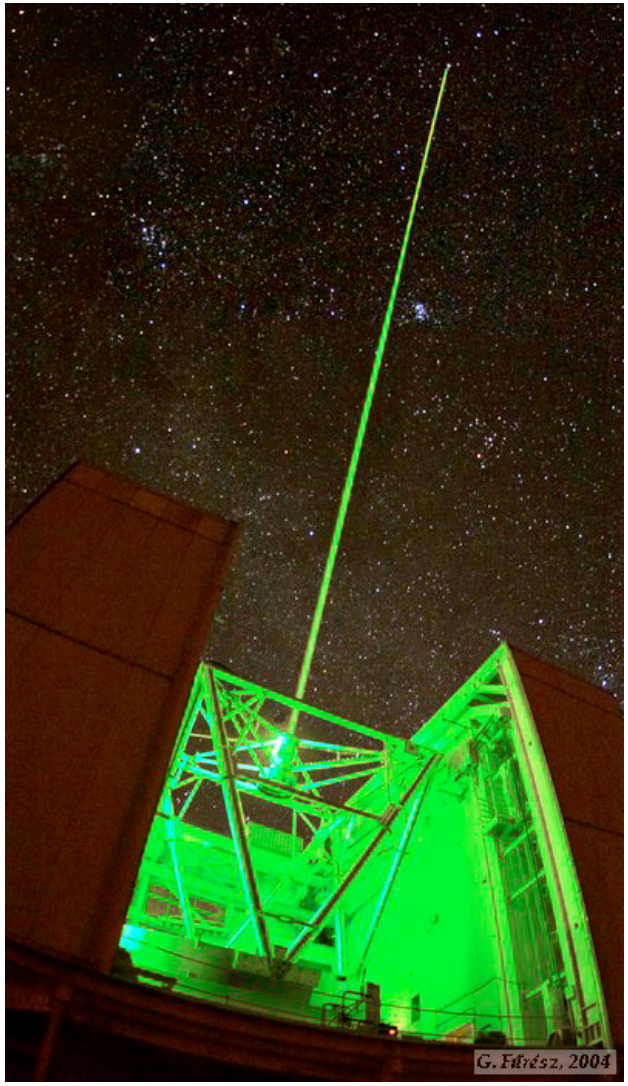
Dust disk detection

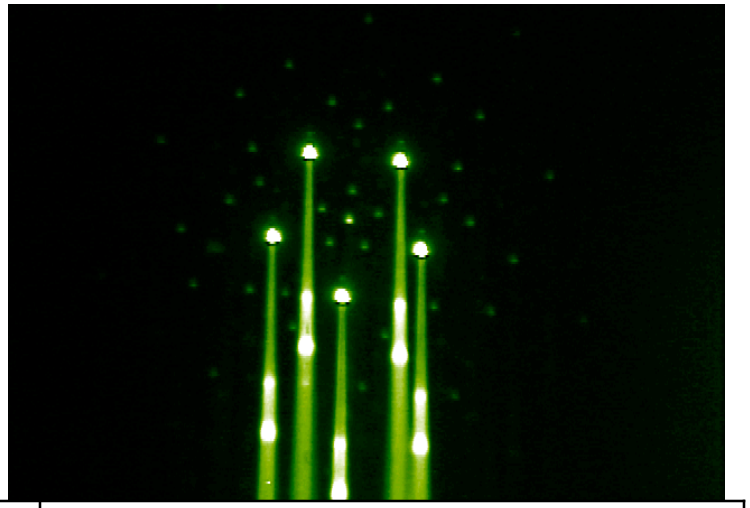


Detection of a 390±70 zody dust disk around β Leo and a non-detection around o Leo with an uncertainty of 50 zodies.

- There is a 1.6% excess at 10 microns when observing β Leo.
- Consistent with a dust disk at ~2-4 AU.
- Observations indicate nulling can achieve an uncertainty of ~50 zodies.

Laser-guided AO at the MMT



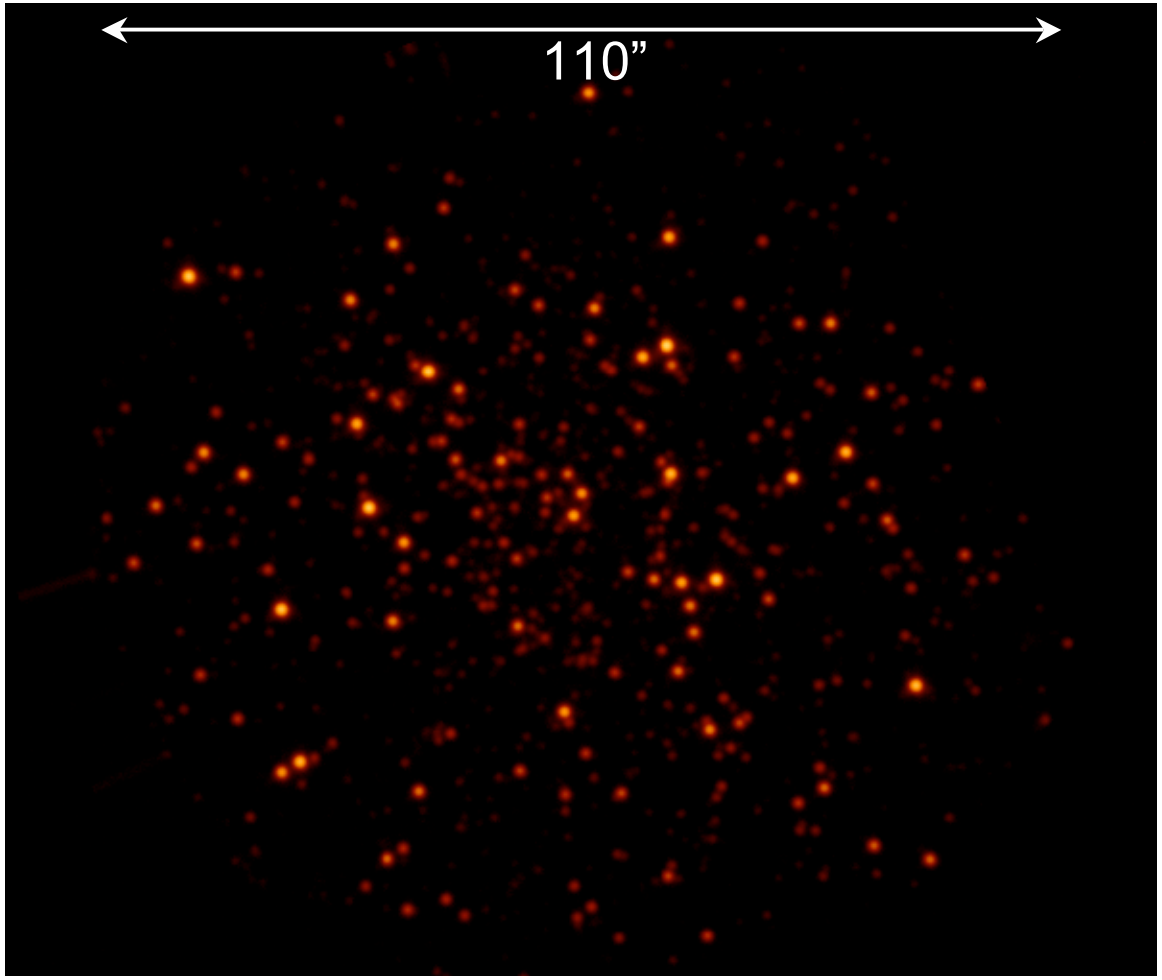


Laser type	2 x doubled YAG (15 W each)
Wavelength	532 nm
Pulse rep rate	5.2 kHz
Average power	30 W
Launch telescope location	Behind secondary mirror
Number of beacons	5, arranged as a regular pentagon
Enclosed field of view	2 arcminutes
Beacon type	Rayleigh scattering
Range gate	20-29 km with dynamic refocusing

Ground-layer AO operation

- The system is presently operating in GLAO mode, where the average of the 5 beacon signals is used to drive the DM.
- The only instrument available now is PISCES:
  - 1024^2 HAWAII-1 array
  - J-K imager with 0.1”/pixel plate scale, 110” field of view
- We are now building a mount to support ARIES which will be available in the fall.
- Clio has been designed to take advantage of the laser constellation too and will be added to the instrument suite later in 2009, allowing thermal imaging of heavily obscured regions.

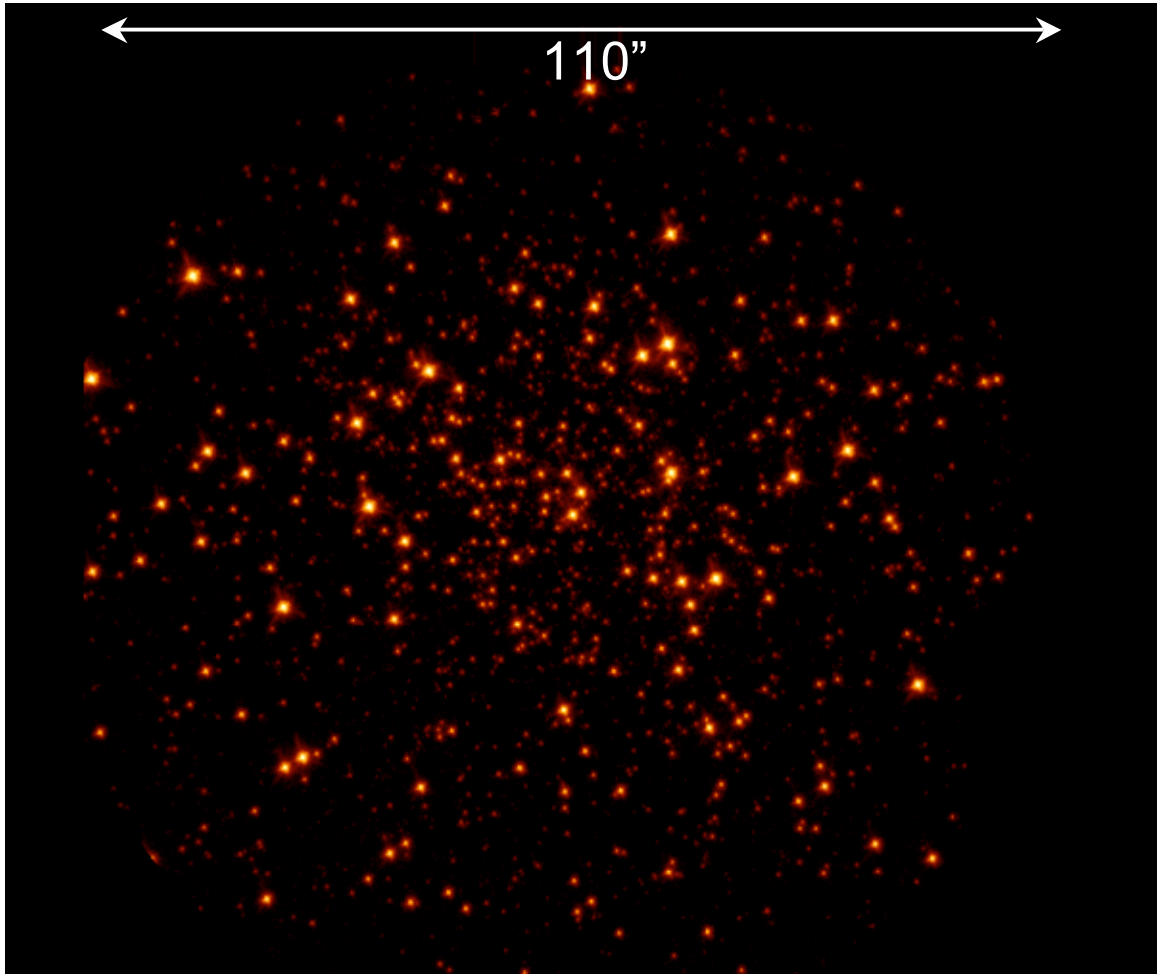
Globular cluster results: M3



Open loop, K_s filter, seeing 0.70”

Logarithmic scale, 60 s exposure

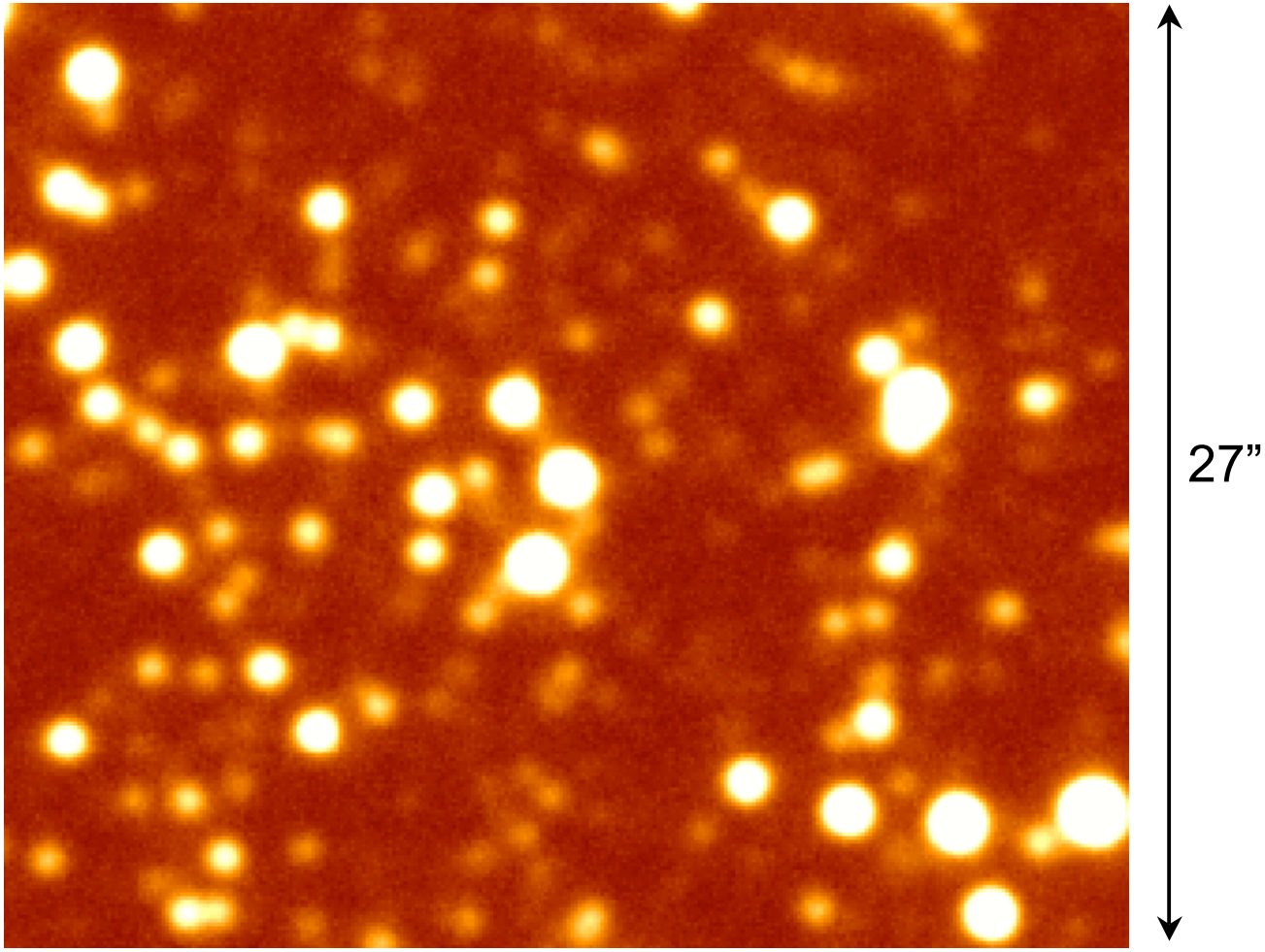
Globular cluster results: M3



Closed loop GLAO, K_s filter, seeing 0.30”

Logarithmic scale, 60 s exposure

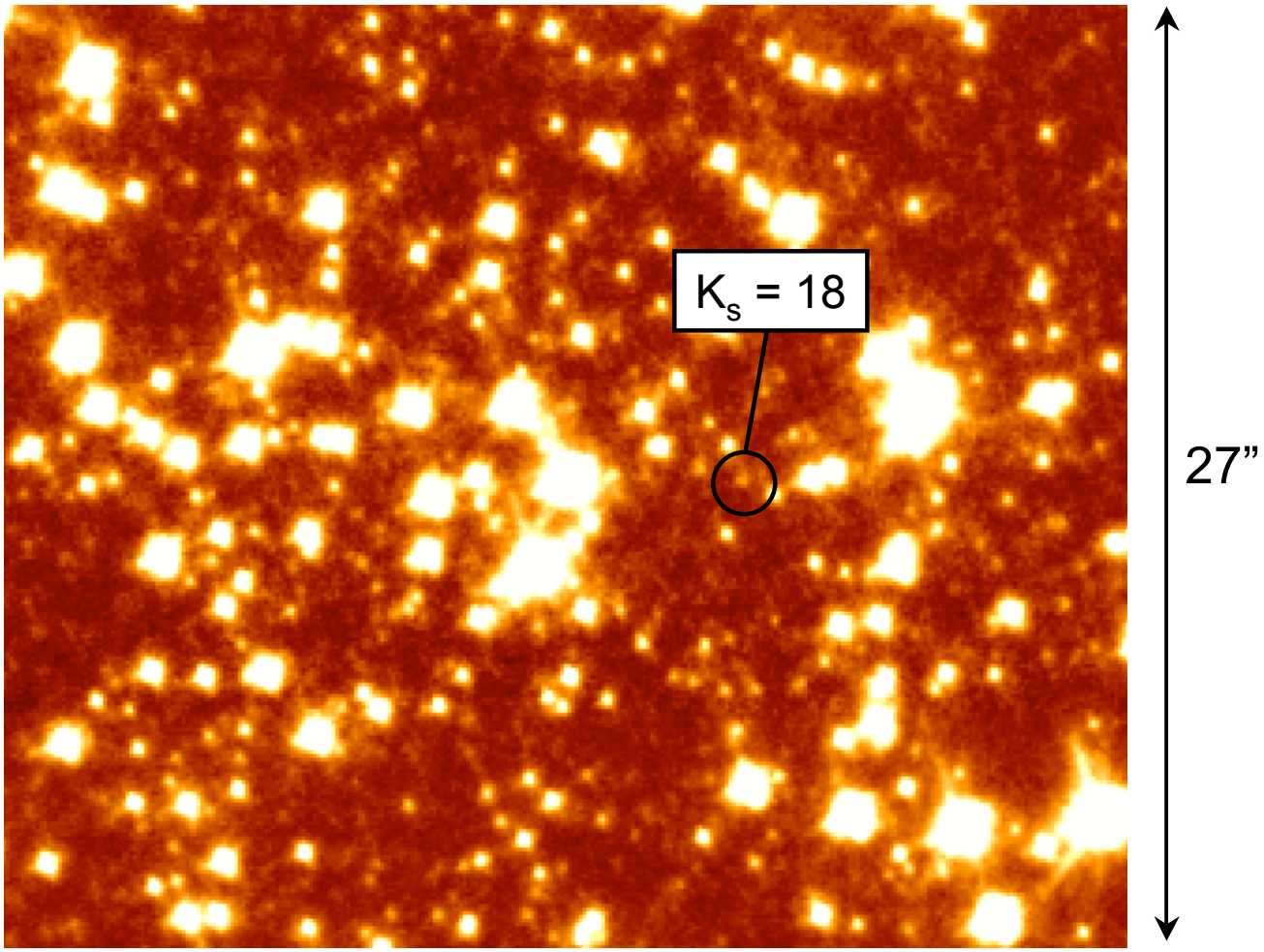
M3 zoomed in



Open loop, K_s filter, seeing 0.70”

Linear scale, 60 s exposure

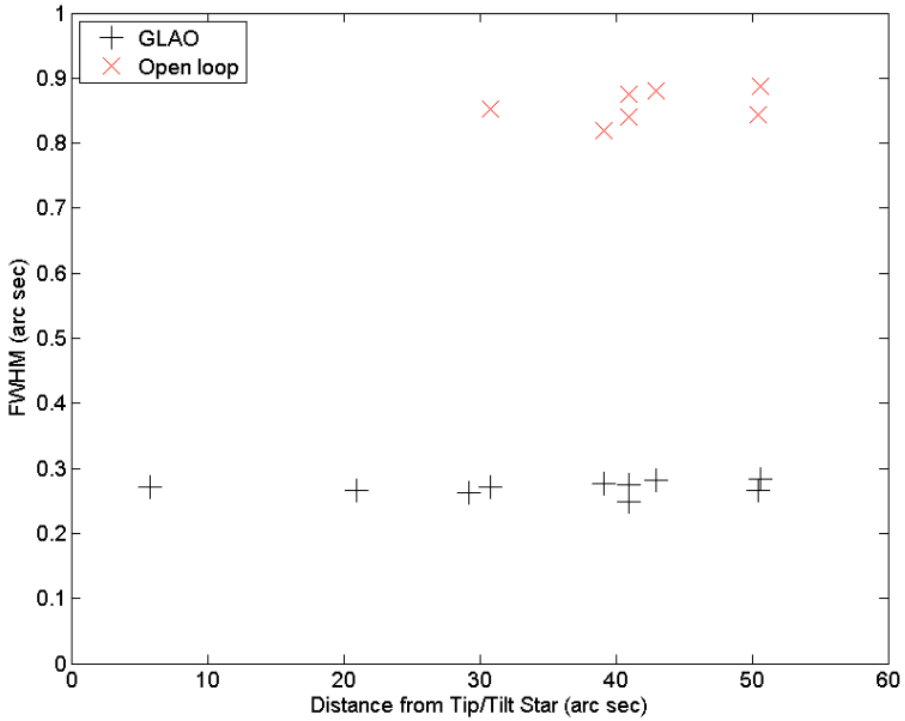
M3 zoomed in

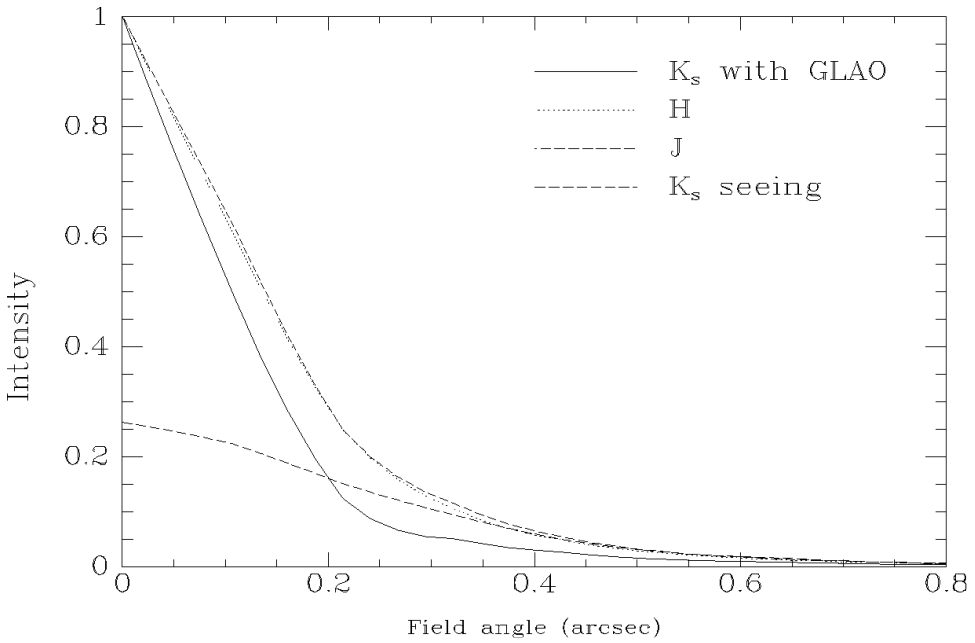


Closed loop GLAO, K_s filter, seeing 0.30”

Linear scale, 60 s exposure

GLAO performance



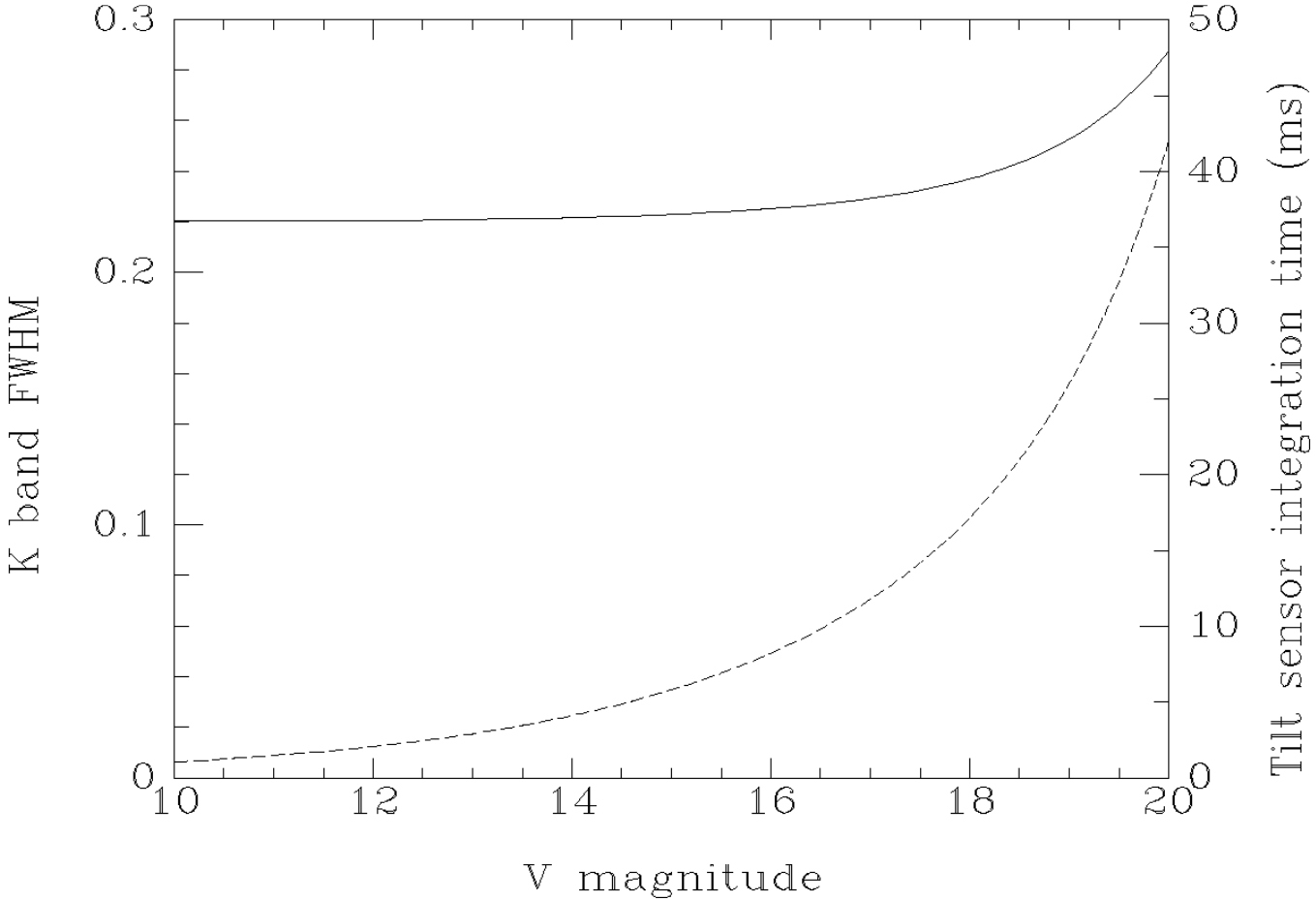


K band mean FWHM:

- Seeing limited = 0.86”
- GLAO = 0.27”

GLAO works at the level of performance predicted by simulations

Performance vs. tip-tilt star magnitude



- K band image width and tilt sensor integration time extrapolated from measurements made on a star of V = 10.6 and varying amounts of ND
- Measurements made in K band seeing of 0.65 arcsec (median is 0.6)

Summary

- MMT AO offers good performance in the near IR and exceptional performance in the thermal IR. Approximately 1/4 of the telescope time is devoted to AO.

- Three instruments are available for near-IR imaging and mid- to high-resolution spectroscopy, thermal imaging, and nulling interferometry.
  - ARIES, Clio, BLINC/MIRAC

- LGS ground-layer AO is now offered as a shared-risk mode, with support for normal observing expected to begin in spring 2010.