Ground-Layer Adaptive Optics

Christoph Baranec (IfA, U. Hawai`i)

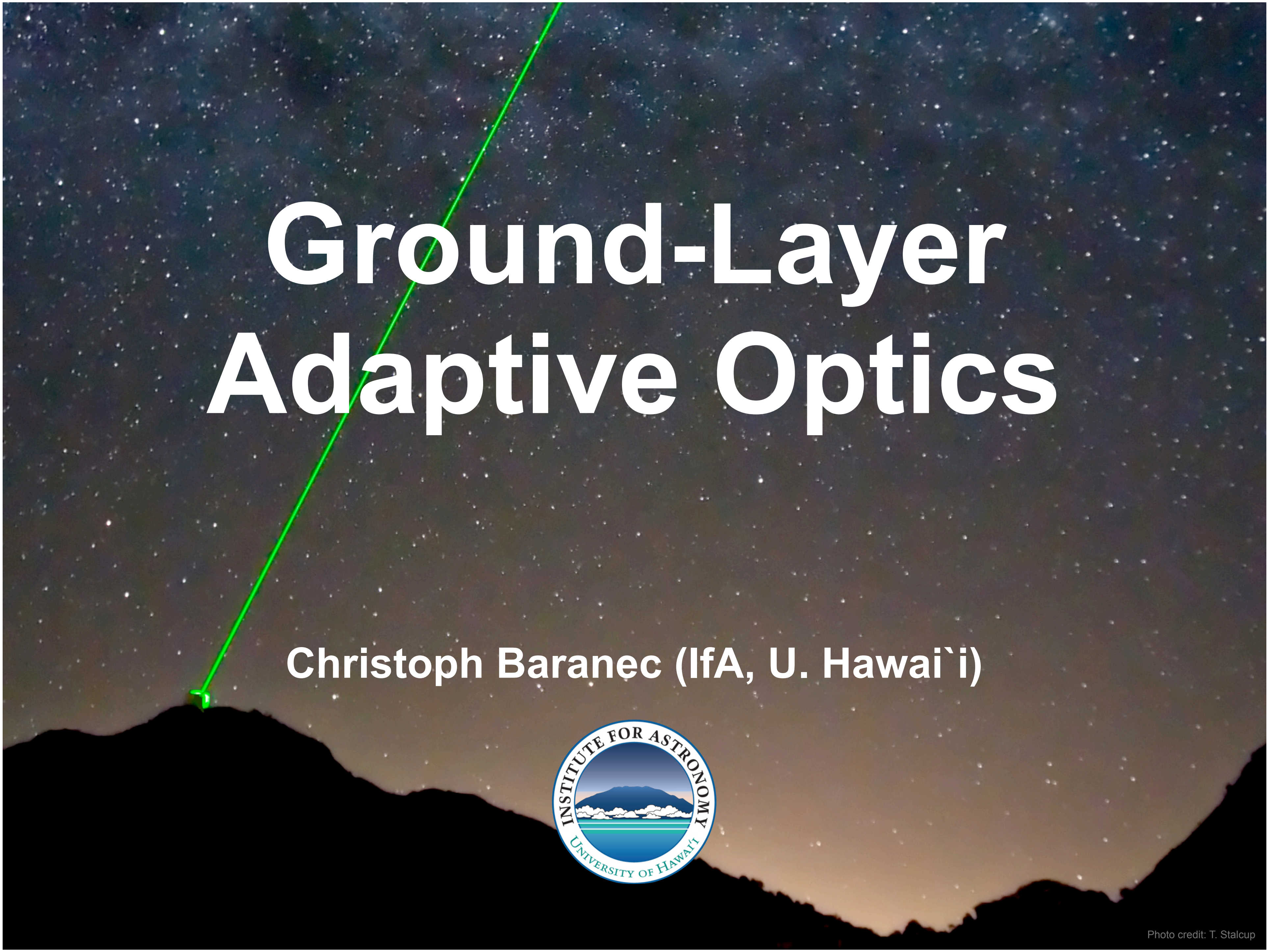


Photo credit: T. Stalcup

What is Ground-layer Adaptive Optics (GLAO)?

Benefits of GLAO to astronomy.

MMT multiple-laser AO system.

Ground-layer adaptive optics (GLAO)

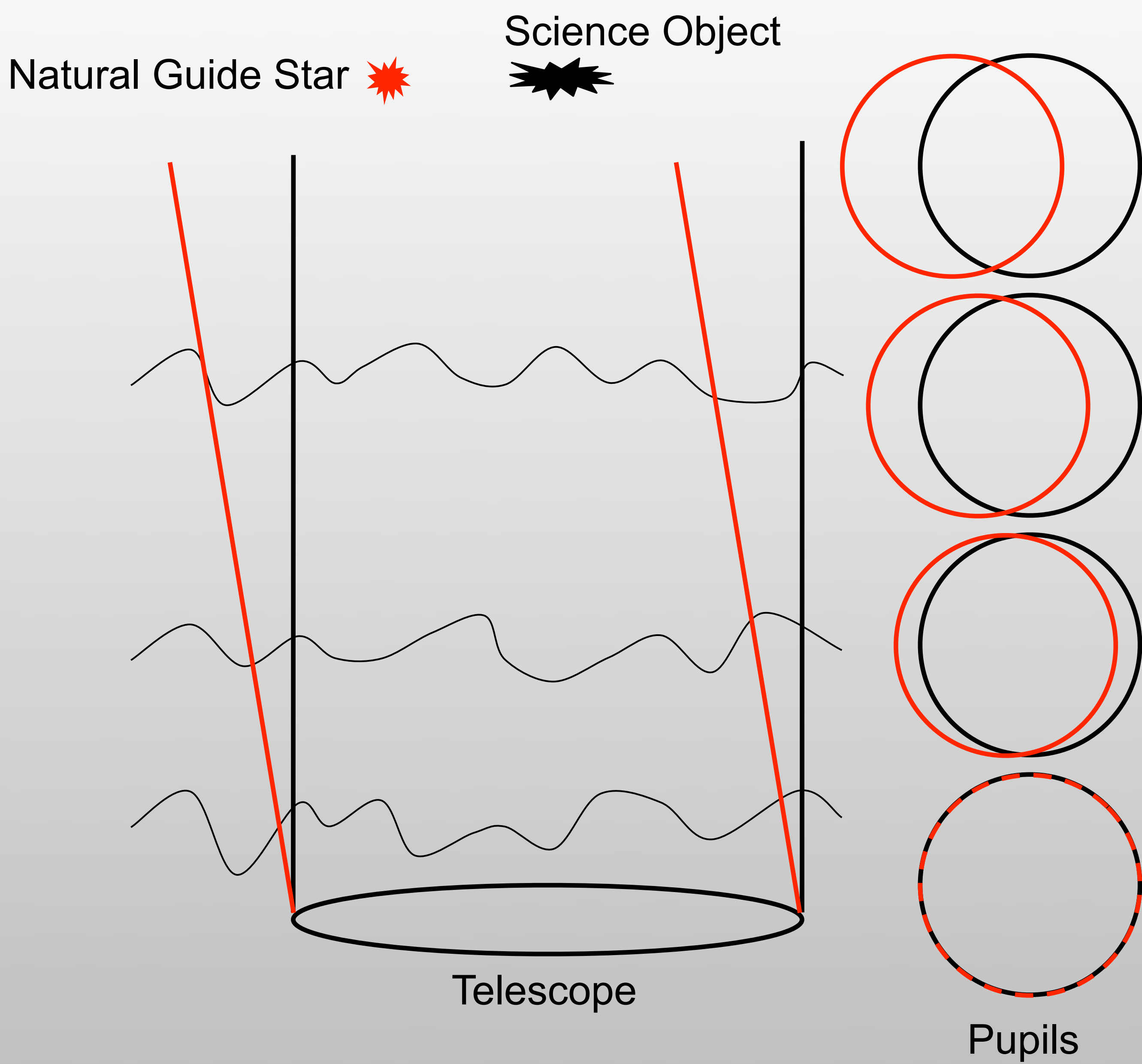
First detailed by F. Rigaut (Proc. ESO; 2002) as a way to improve wide-field imaging on large telescopes.

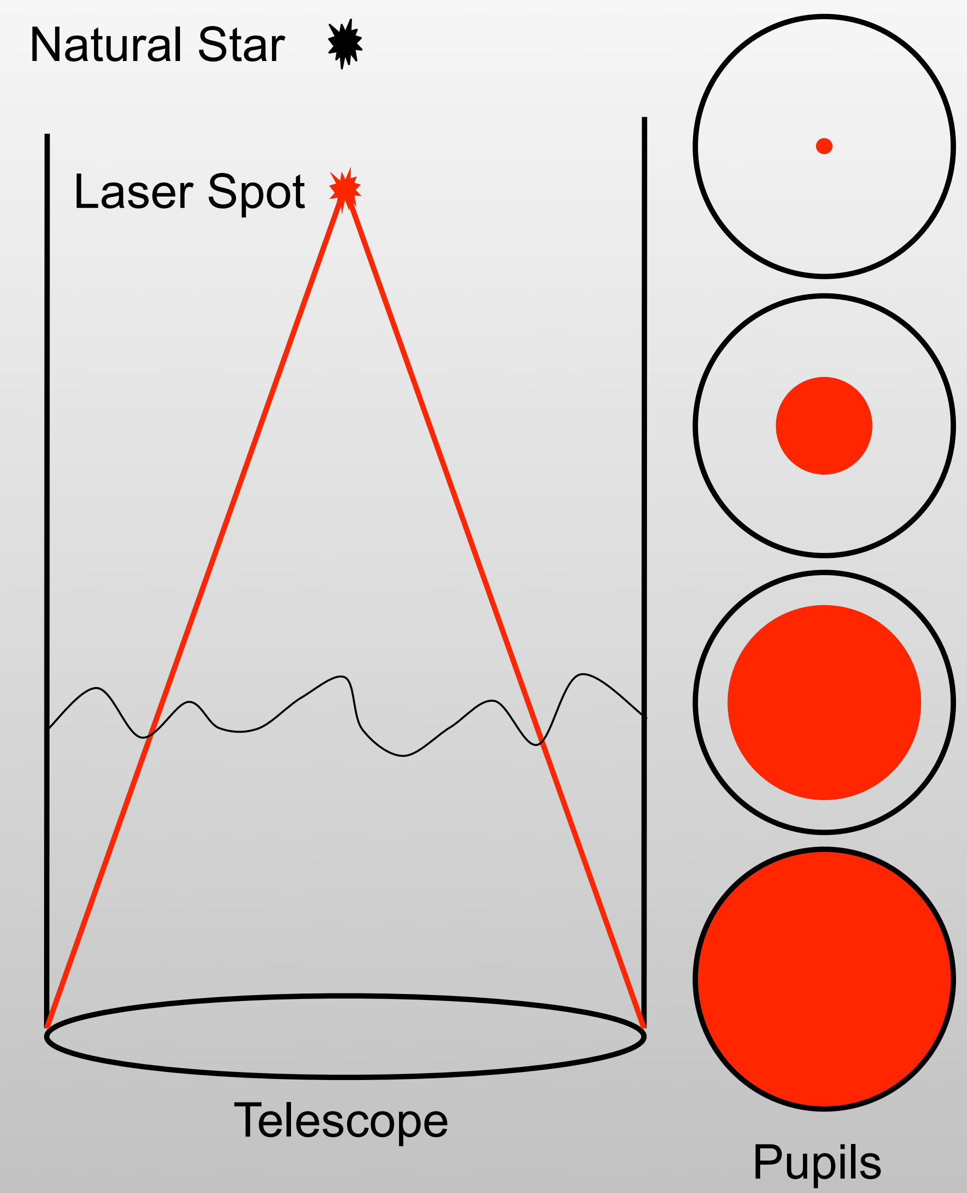
“Average” multiple wavefronts to estimate the turbulence close to the telescope aperture.

Correction applied to pupil/ground-layer conjugate deformable mirror(s).

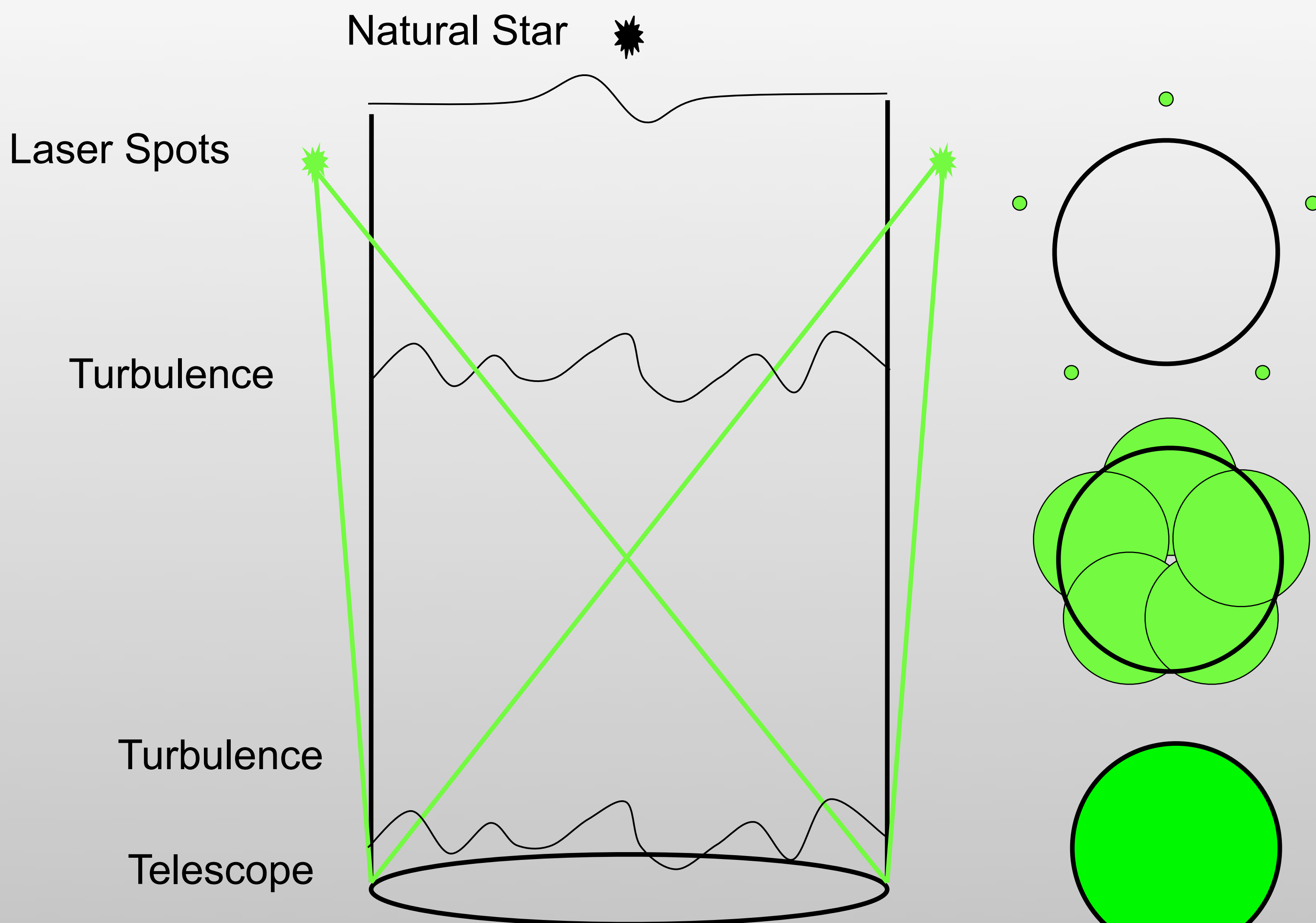
Partial adaptive optics correction over wide fields (>2’).

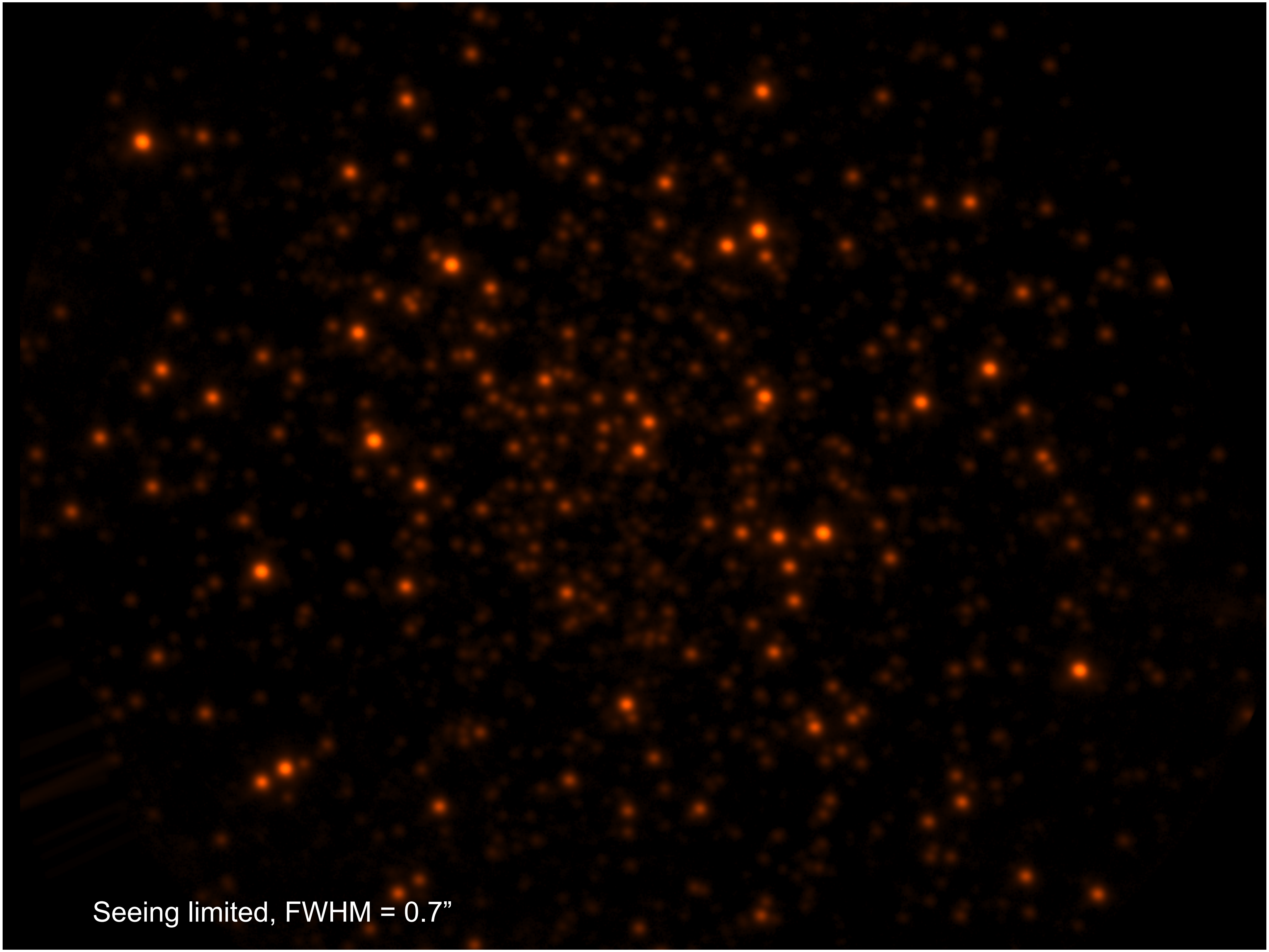
Single guide star adaptive optics

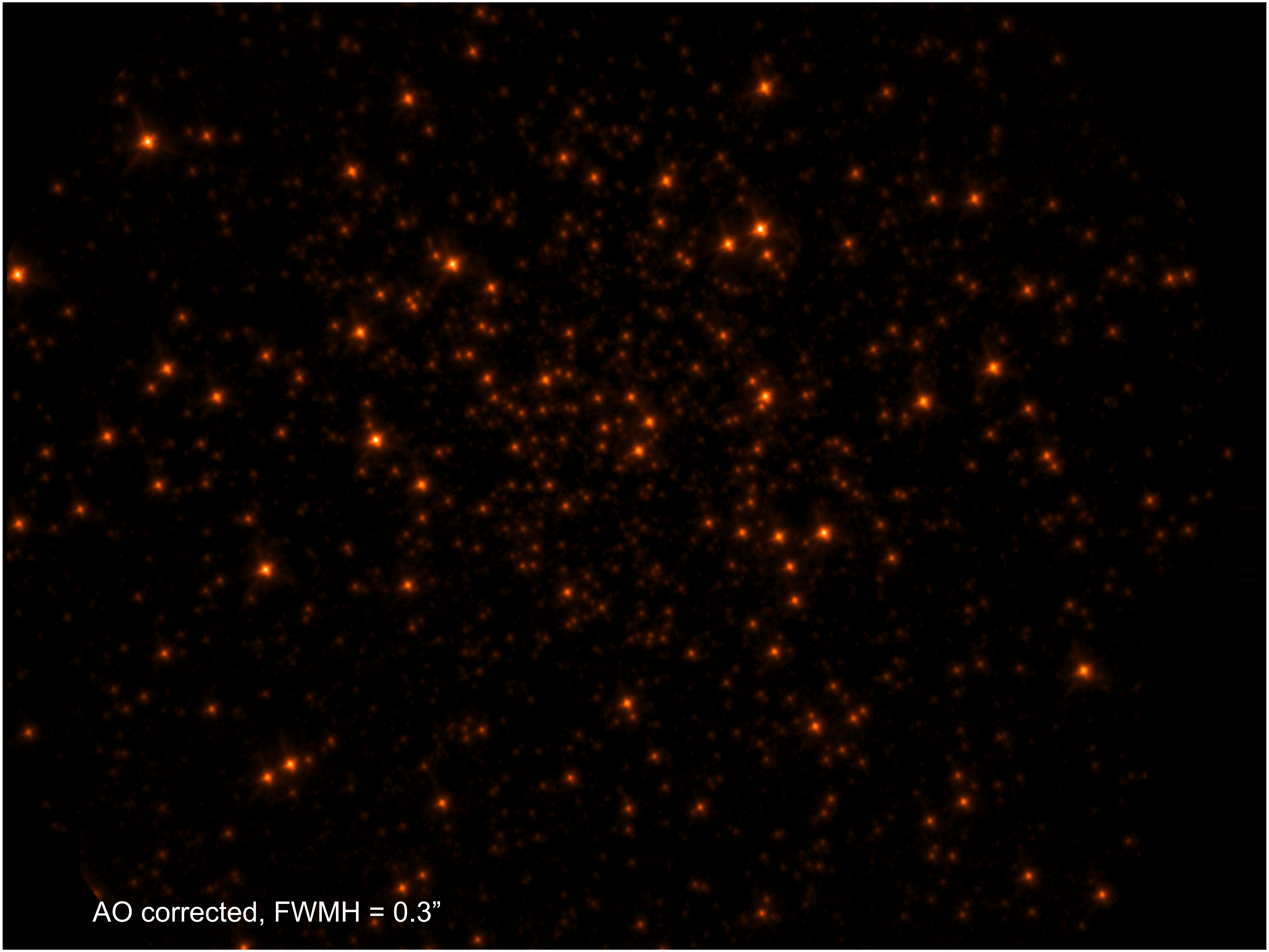



Natural Star
Laser Spot
Telescope
Pupils

Multiple guide star adaptive optics




Seeing limited, FWHM = 0.7”


AO corrected, FWMH = 0.3”

Benefits of GLAO

Decreased image FWHM

- Higher angular resolution
  - » 0.1”-0.2” in NIR
  - » Diffraction limit in MIR
- Increased signal-to-noise
- Higher precision astrometry

Increased energy concentration

- θ_{50}: 0.25”(SL) to 0.13”(GLAO) in K-band (Lloyd-Hart et al. SPIE 2006)
- Reduces size necessary for spectrograph instrumentation

Studies of GLAO

- Studies of the C_n^2 profile at a number of different observing sites indicate that typically 0.5 to 0.67 of the total atmospheric turbulence is in the ground-layer.

  (Andersen et al. PASP 2006; Avila et al. PASP 2004; Egner et al. SPIE 2006; Tokovinin & Travouillon MNRAS 2006; Tokovinin et al. PASP 2005; Baranec et al. ApJ 2007; Velur et al. SPIE 2006; Verin et al. Gemini Rpt. 2000)

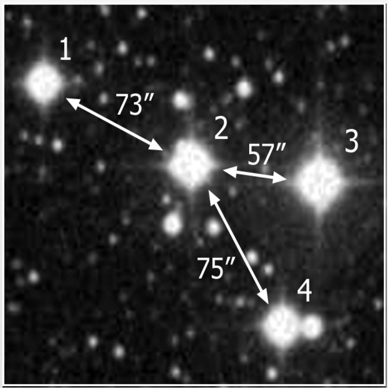
- Performance prediction of GLAO by many simulations.

  (Rigaut Proc. ESO 2002; Andersen et al. PASP 2006; Le Louran & Hubin MNRAS 2006; Tokovinin PASP 2004)

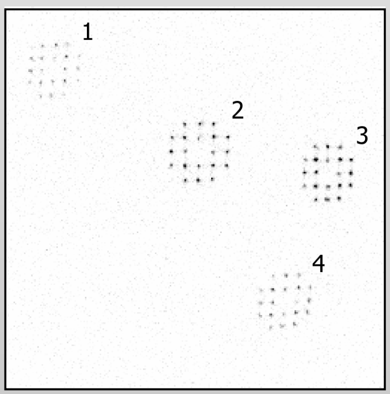
- Open-loop predictions of GLAO (comparing multiple reconstructed wavefronts)

  (Athey SPIE 2006;Lloyd-Hart et al. ApJ 2005, Op. Exp. 2006; Baranec et al. ApJ 2007)

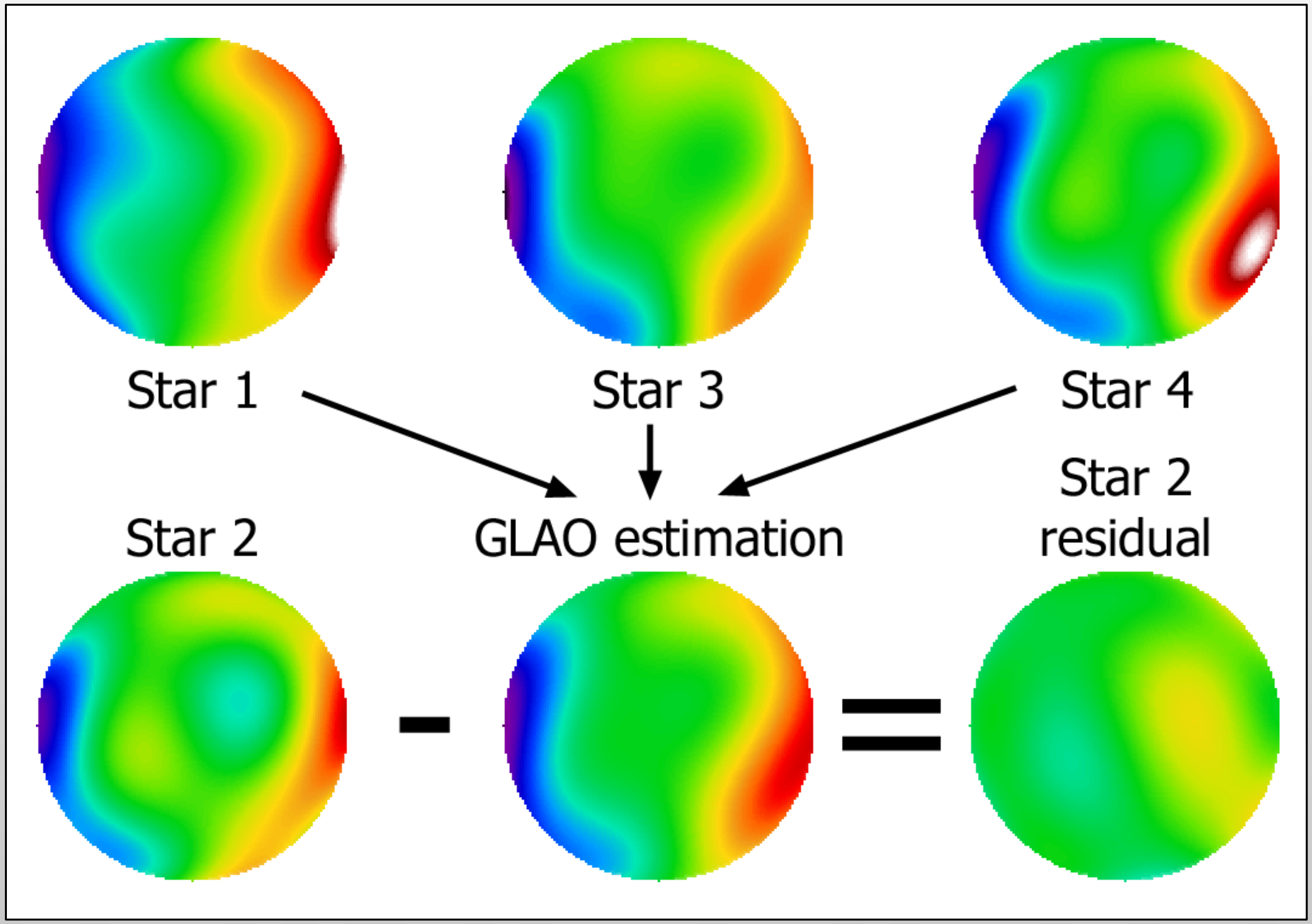
Open-loop estimation of GLAO (2003)



DSS archive image

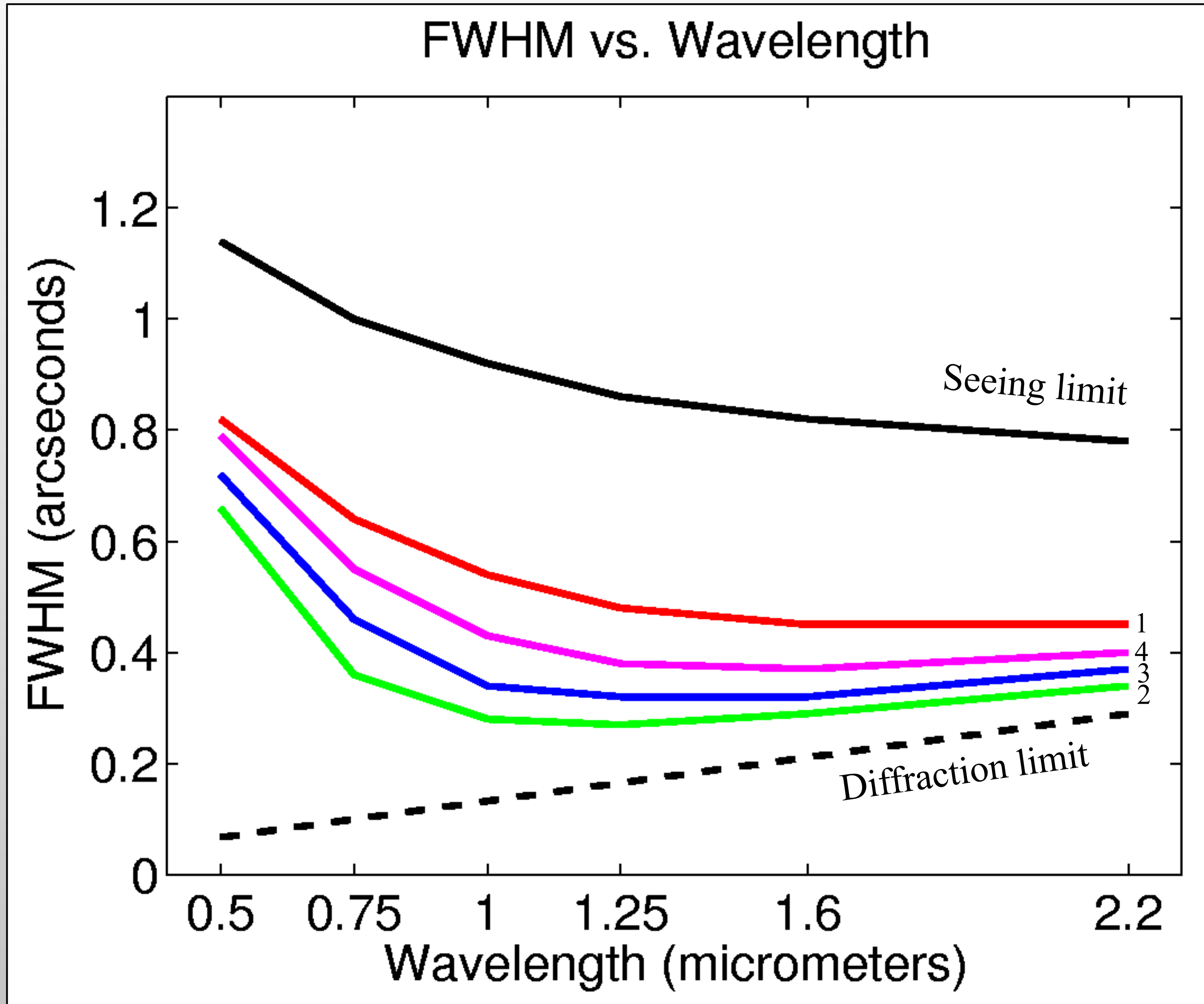


WFS image



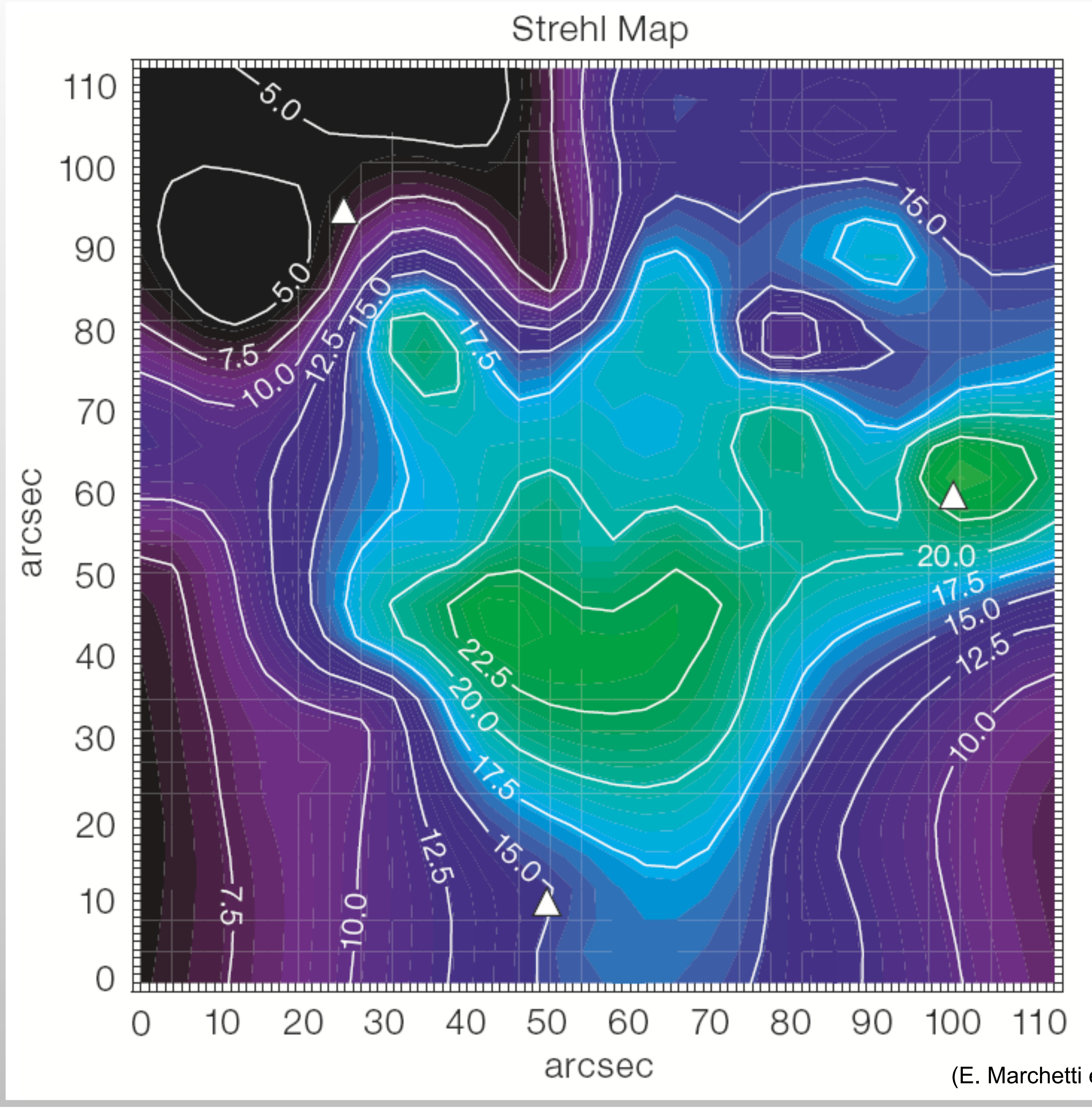
1.6 m aperture telescope, d = 30 cm, d/r_0 = 1.3 (at λ = 1.25 μm)

Predicted GLAO PSFs from open-loop data



Baranec, Lloyd-Hart & Milton, ApJ, 2007

First demonstration of GLAO: VLT-MAD, 2007



~60 mas
resolution
at 2.2um

(E. Marchetti et al. The Messenger 2007)

Why do GLAO with LGS instead of NGS?

Sky coverage.

• Negates need for many bright stars near science object.

• Still requires a $m_V \leq 18$ guide star to be nearby for low-order sensing.

More uniform correction.

• Can optimize geometry of guide sources.

• Less affected by correlations in upper-altitude turbulence. A time when focal anisoplanatism is beneficial!

Less complication.

• No need for dynamic wavefront sensor geometry or AO loop rates.

GLAO with LGS

Rayleigh LGS

More economical (by ~factor of ten)

More reliable

Less correlated high-altitude wavefront errors

Predictable and stable photoreturn

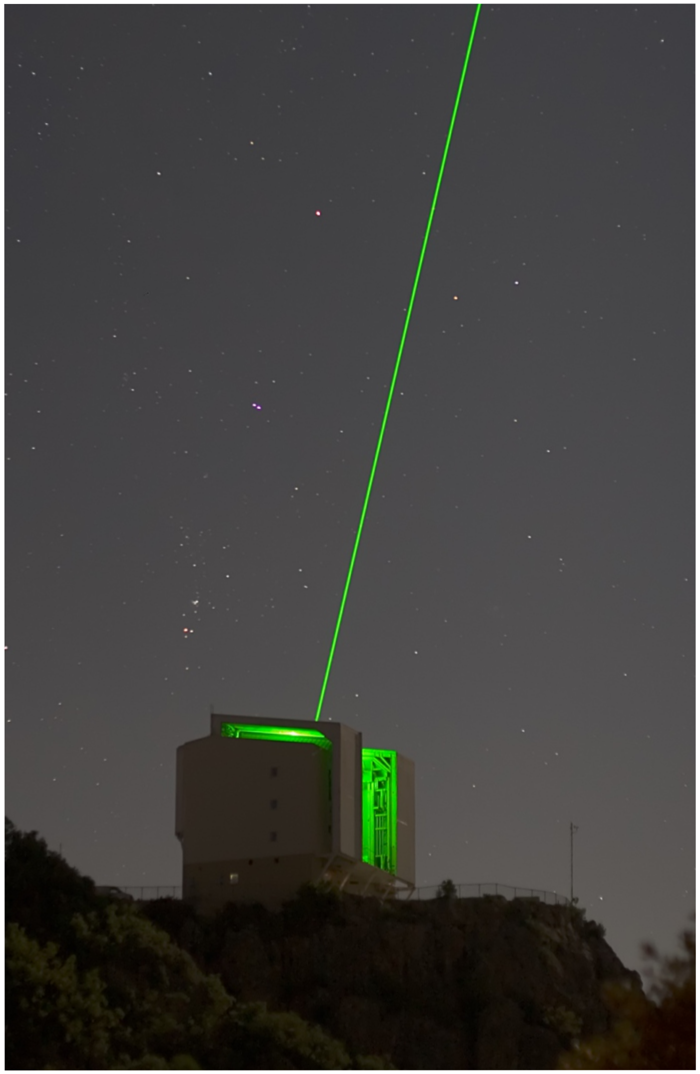
Stable line-of-sight distance (only stellar tip-tilt needed)

UV Rayleigh LGS are inherently safer (ANSI)

Na Resonance LGS

Closer to infinite conjugate: less focus shift - optical engineering easier on large telescopes

6.5-m MMT laser AO system



Pathfinder for LBT/GMT AO

- Exploring GLAO **and** LTAO
- Compromise 2' dia. of 5 RLGS
  - A little wide for LTAO
  - A little narrow for GLAO
- Additional dynamic refocus
  - Required for LTAO
  - Too complicated for GLAO

Baranec, Hart, Milton, et al., ApJ (2009); Hart, Milton, Baranec, et al., Nature (2010).

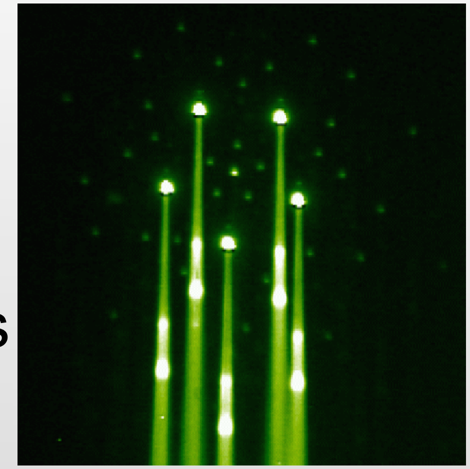
MMT LGS AO system components

•Adaptive Secondary Mirror

Brusa-Zappellini et al. SPIE 1998, Wildi et al. SPIE 2003.

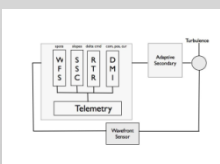
•Multiple Rayleigh laser beacons

Stalcup Ph. D Thesis 2006.



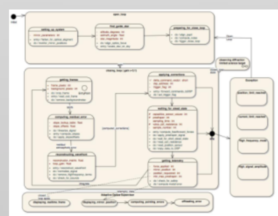
•Cassegrain mounted wavefront sensor instrument

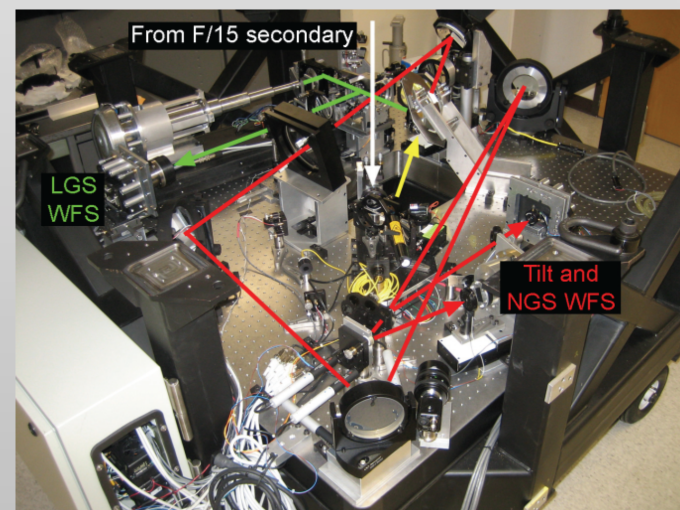
Stalcup Ph. D Thesis 2006, Baranec Ph. D Thesis 2007.



•PC-based real-time reconstructor

Vaitheeswaran et al. SPIE 2008





•MMT F/15 AO instrument suite

RLGS Beam Projector at the MMT

- Two commercially available 15 W doubled Nd:YAG lasers at 532 nm pulsed at 5 kHz.
- Mounted on side of telescope.
- The laser beams are combined with a polarizing beam splitter.
- A computer generated hologram creates the five beacons, 2 arc min diameter on-sky.
- Fast steering mirror controls beam jitter.
- Projection optics mounted on the telescope axis behind the secondary mirror.
- Photometry Return:
  - April '06: 1.4×10^5 photoelectrons/m^2/J
  - Equivalent to five $m_V \leq 9.6$ stars

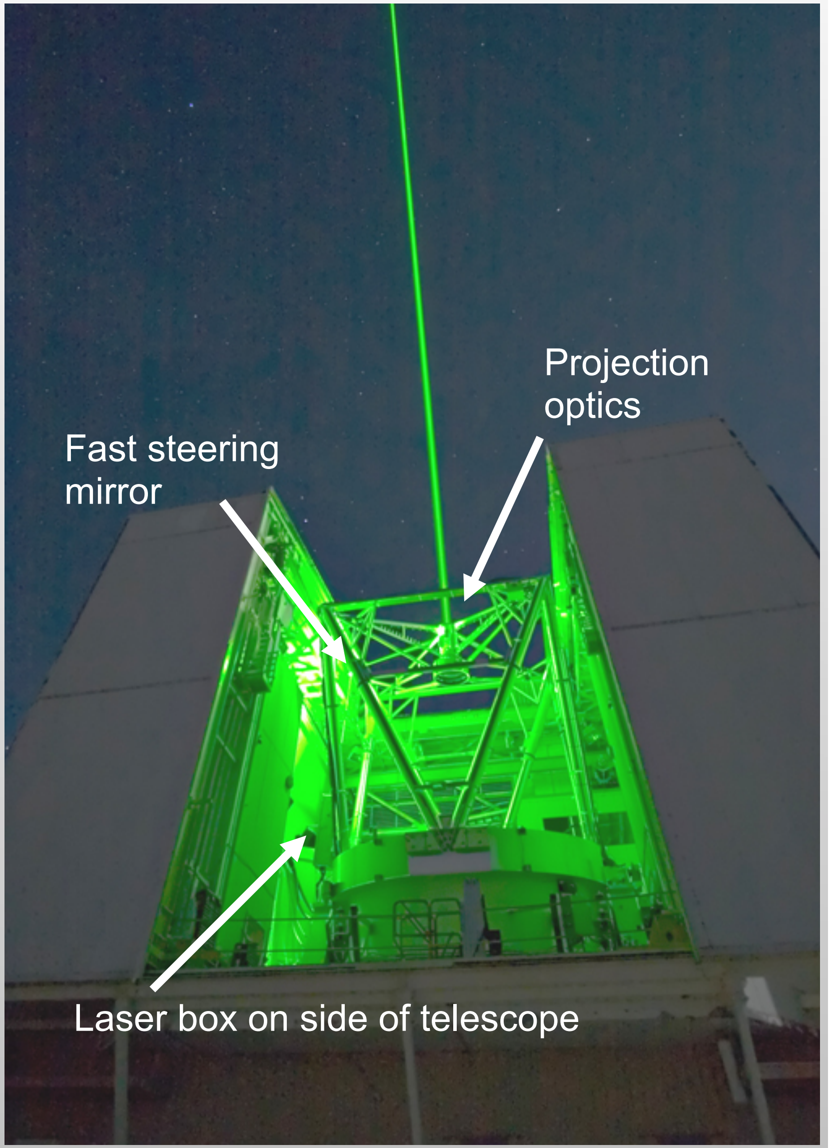
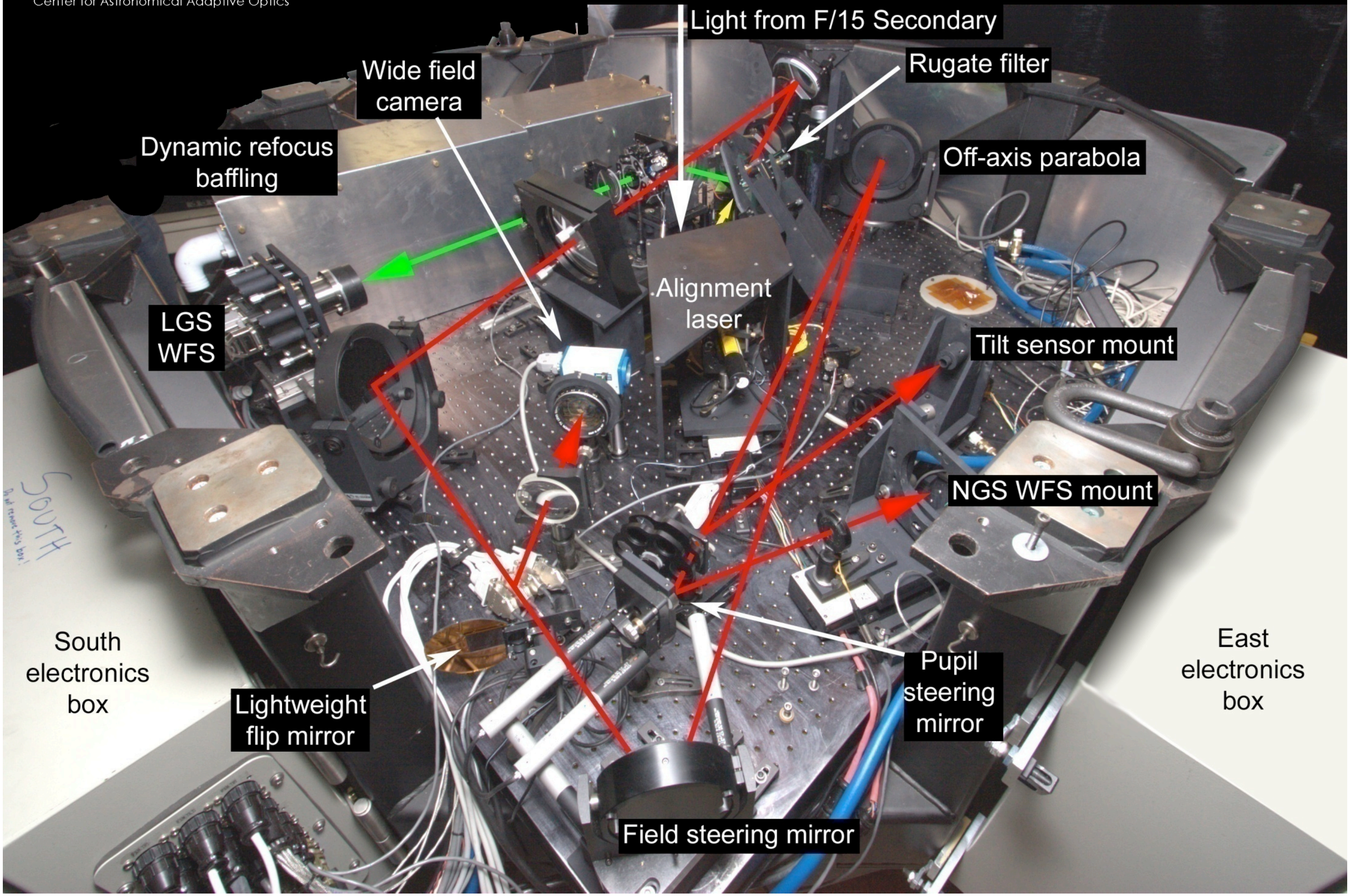


Photo credit: T. Stalcup

Center for Astronomical Adaptive Optics

Facility WFS Instrument

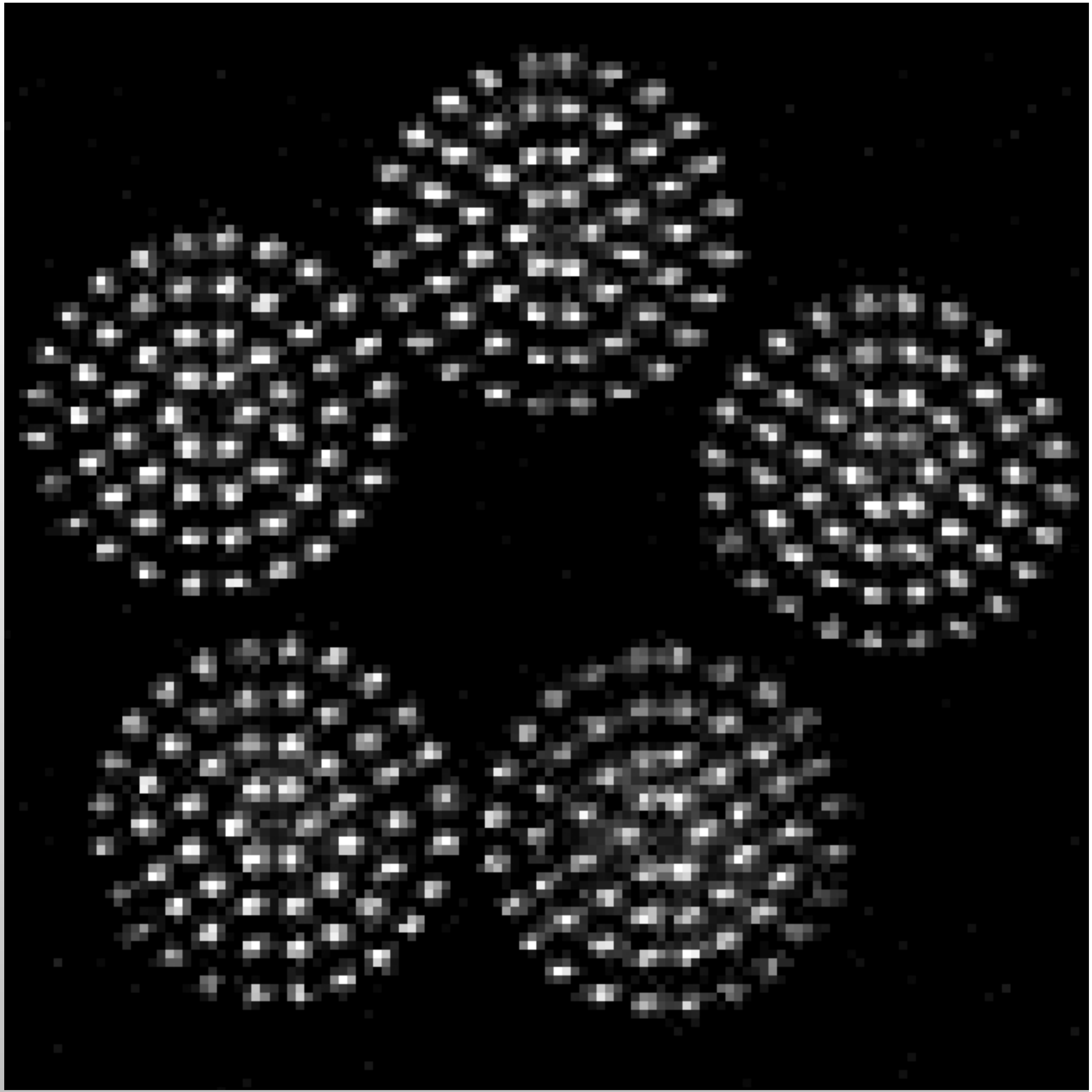


LGS WFS

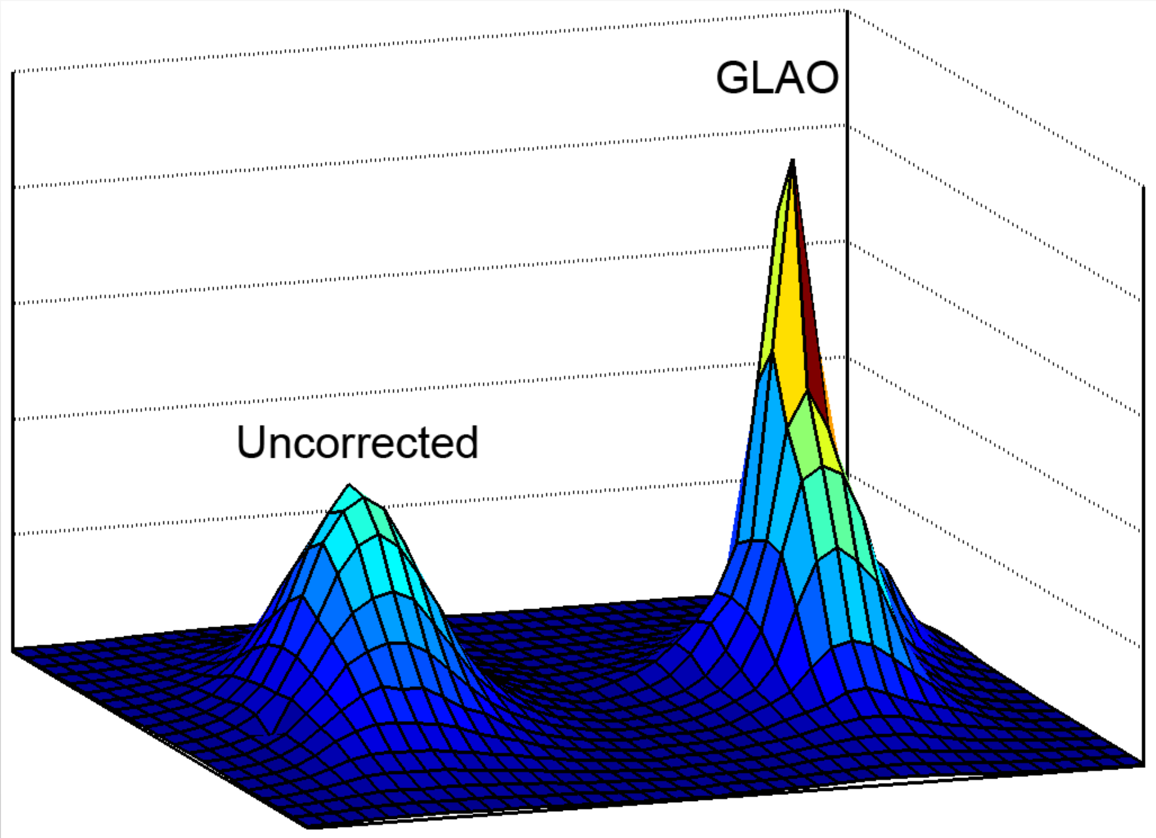
460 fps single frame from LGS WFS

Range gate: 20-29 km

Integration of 11 laser pulses

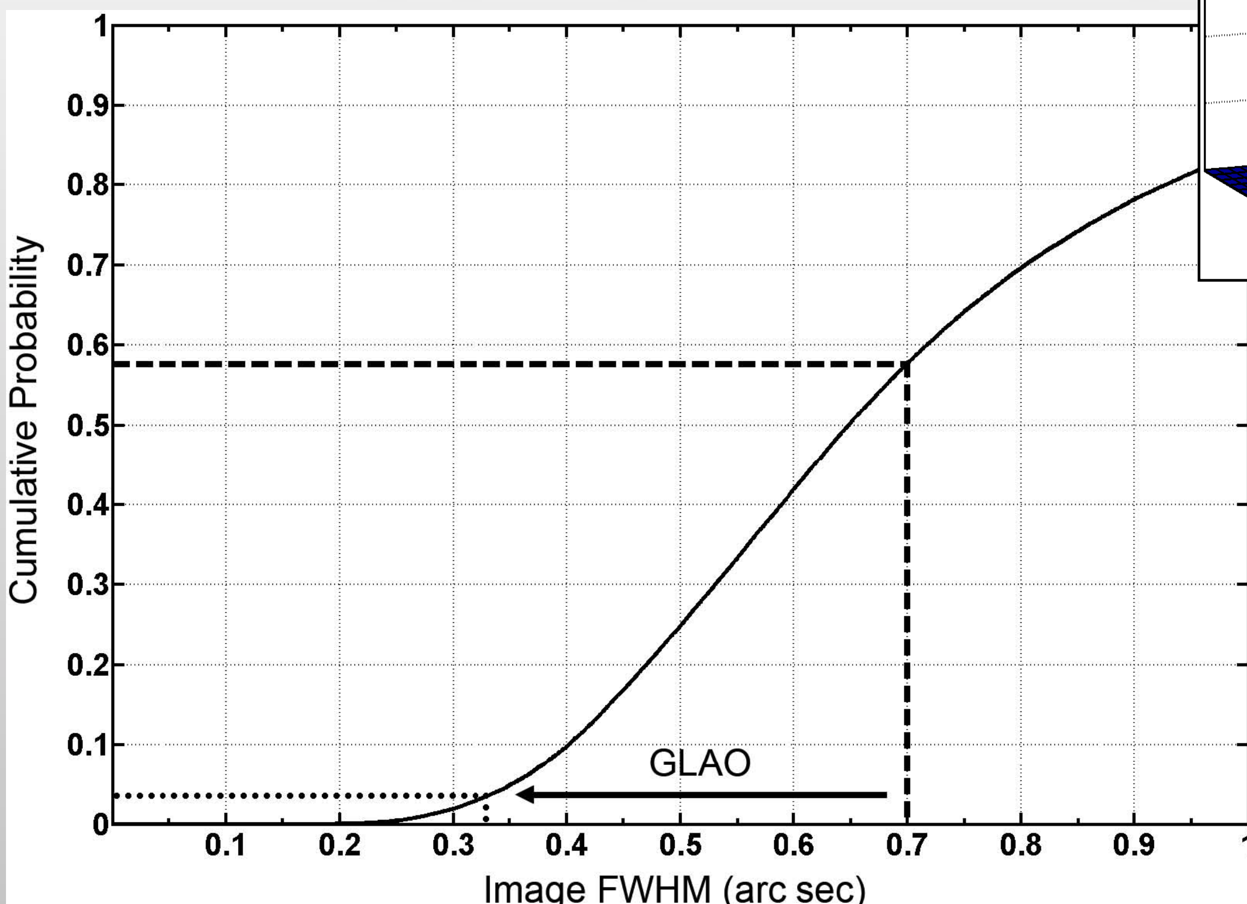


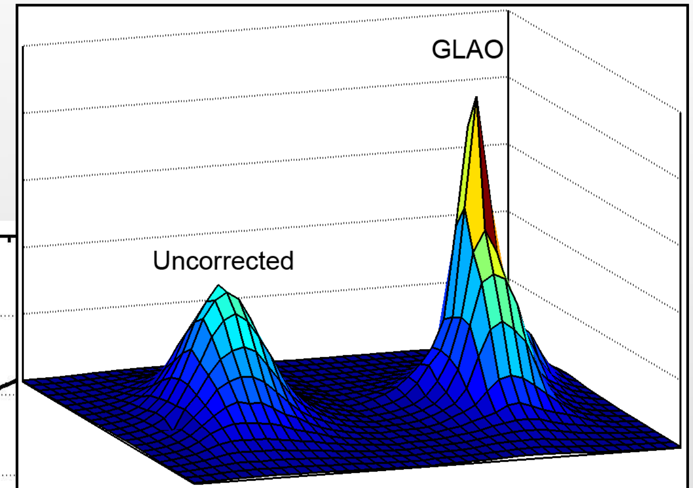
First results – Feb 2008



- m_V ~ 9, used as own tip-tilt reference
- Seeing limit at λ = 2.14 μm: **0.70”**
- With GLAO correction: FWHM **0.33”** and 2.3× greater peak intensity
- Stable PSF morphology, limited by non-common path errors

Cumulative seeing at the MMT





Relative to the cumulative seeing statistics at the MMT for λ = 2.14 μm, GLAO takes a 58th percentile night and corrects it to the level of a 4th percentile night.

October 2008 – M34

110” FOV GLAO Image of M34

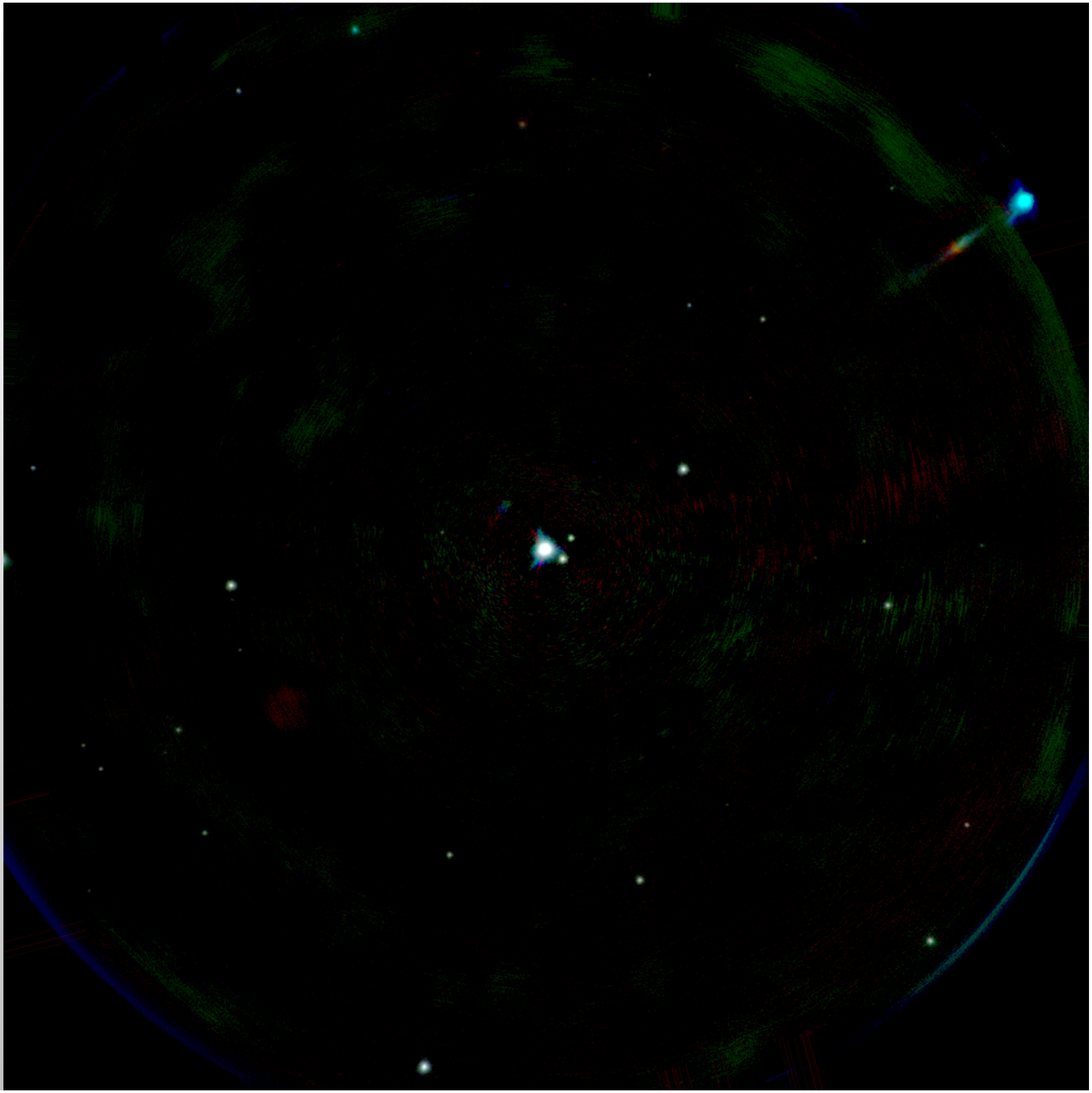
J, H, Ks

False color

Log stretch

Seeing Ks: 0.57”

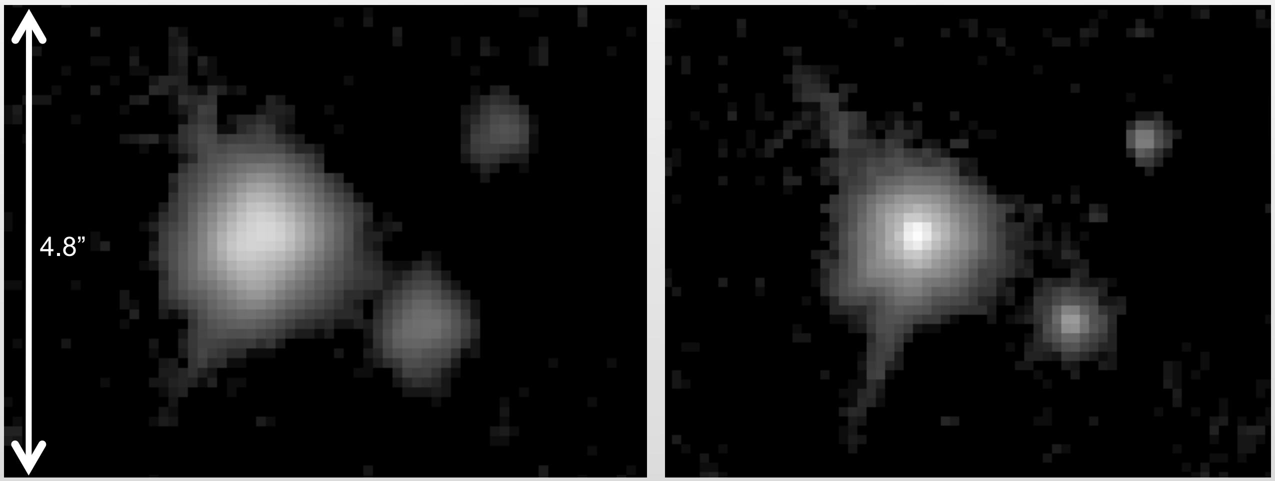
GLAO Ks: 0.19”



Oct 2008 – M34 magnified

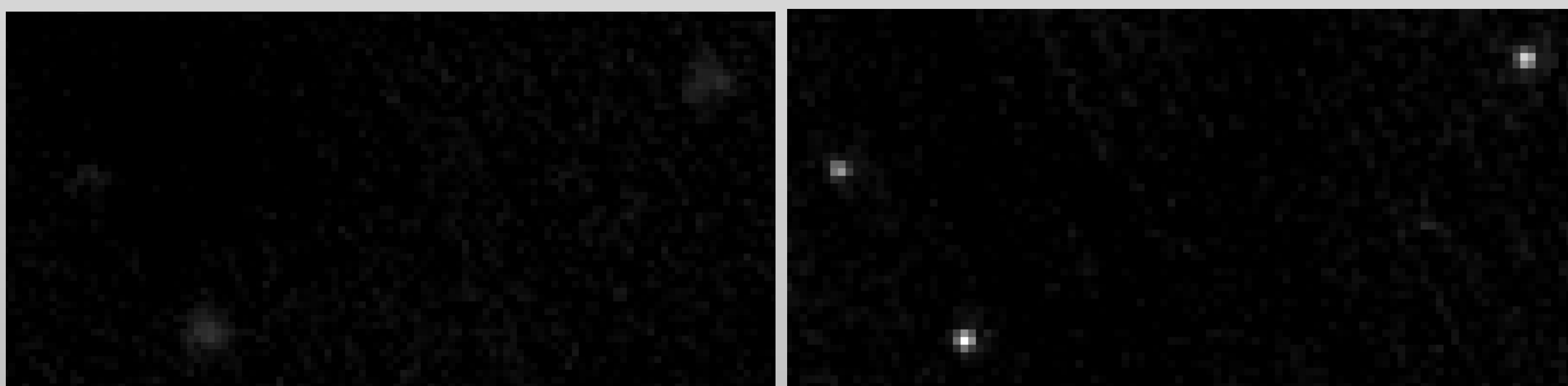
Central tip-tilt star - Ks – log stretch

Seeing:
0.57”

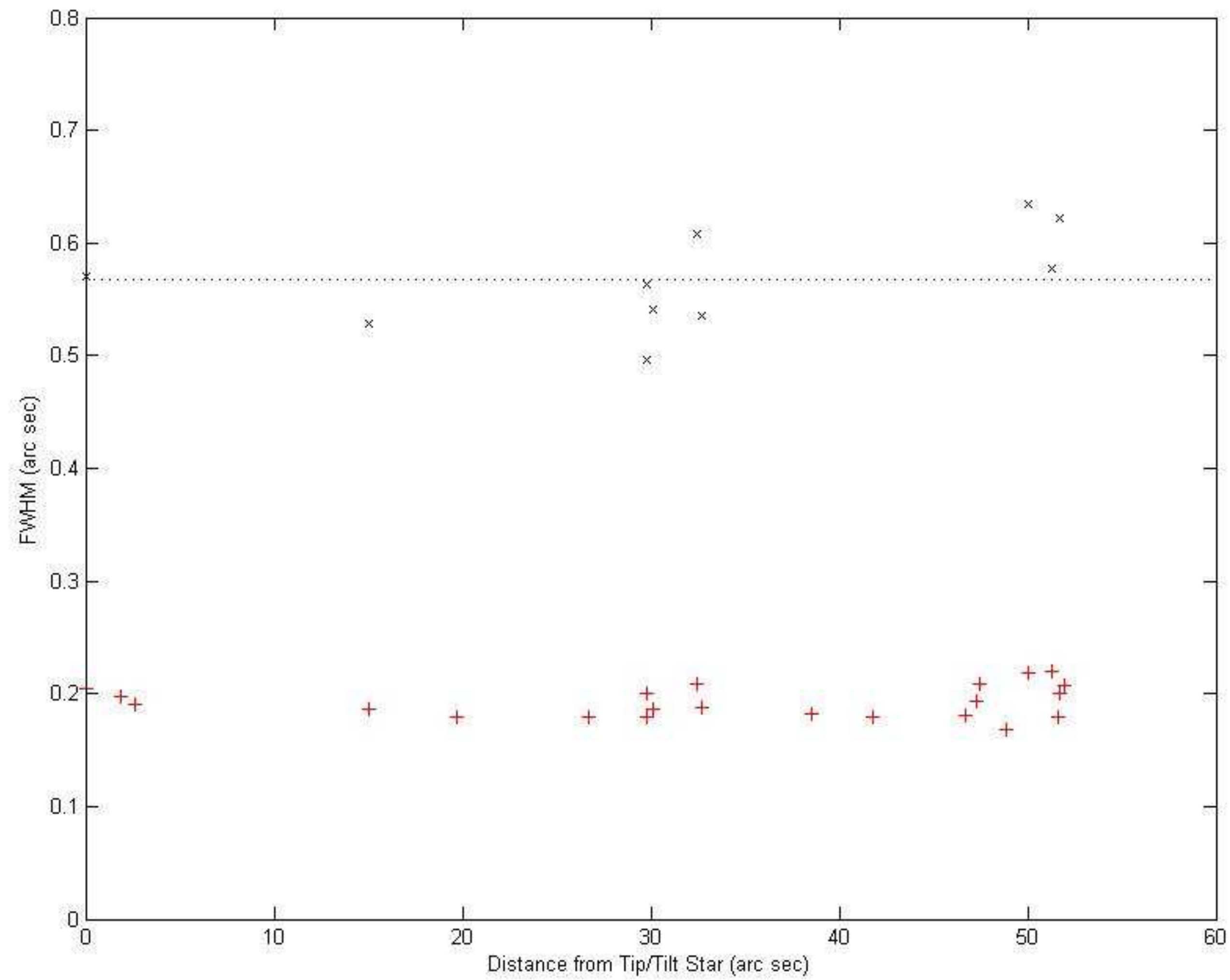


GLAO:
0.20”

Edge field stars - Ks – linear stretch



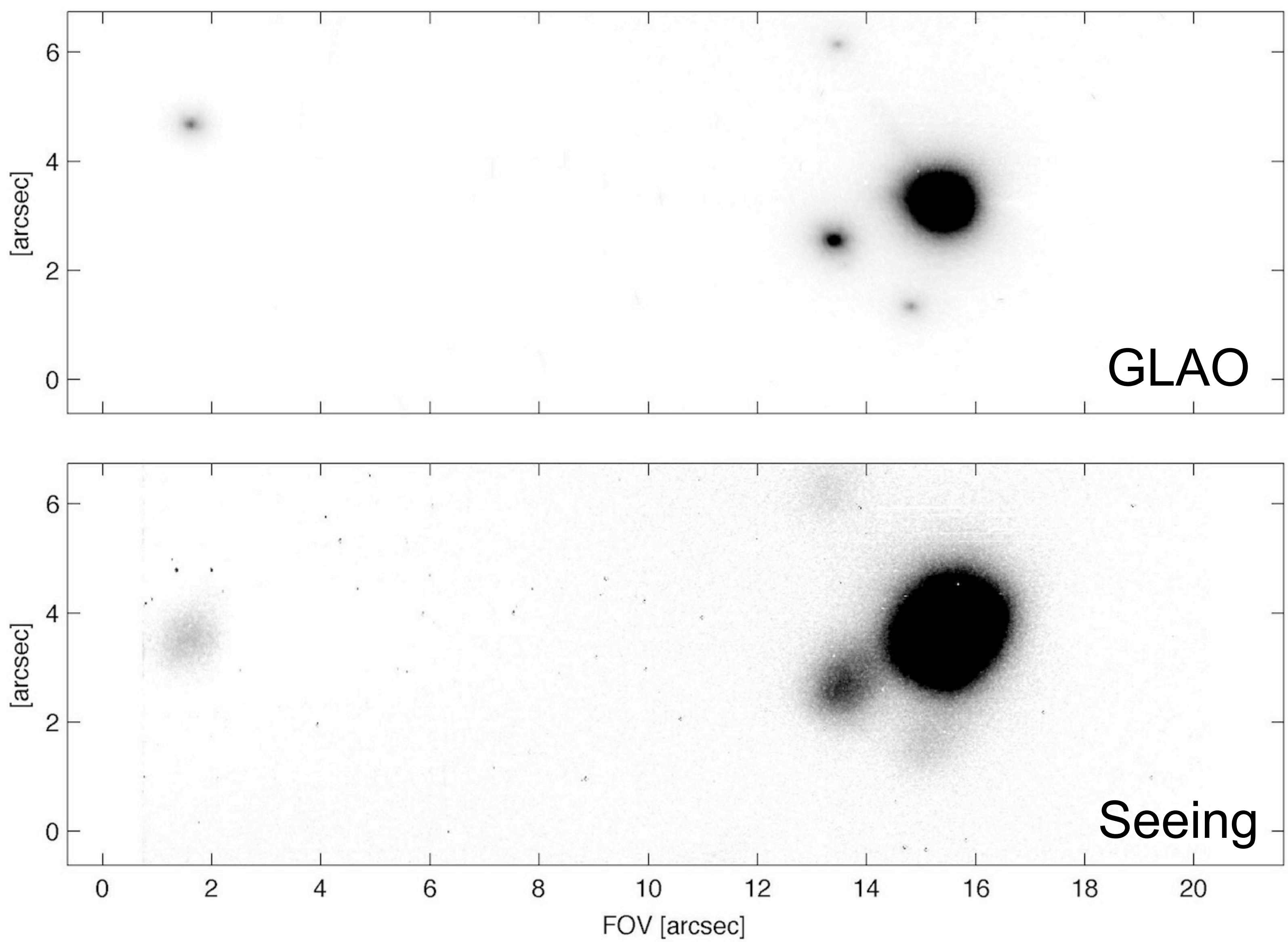
M34 with GLAO – Ks FWHM with field



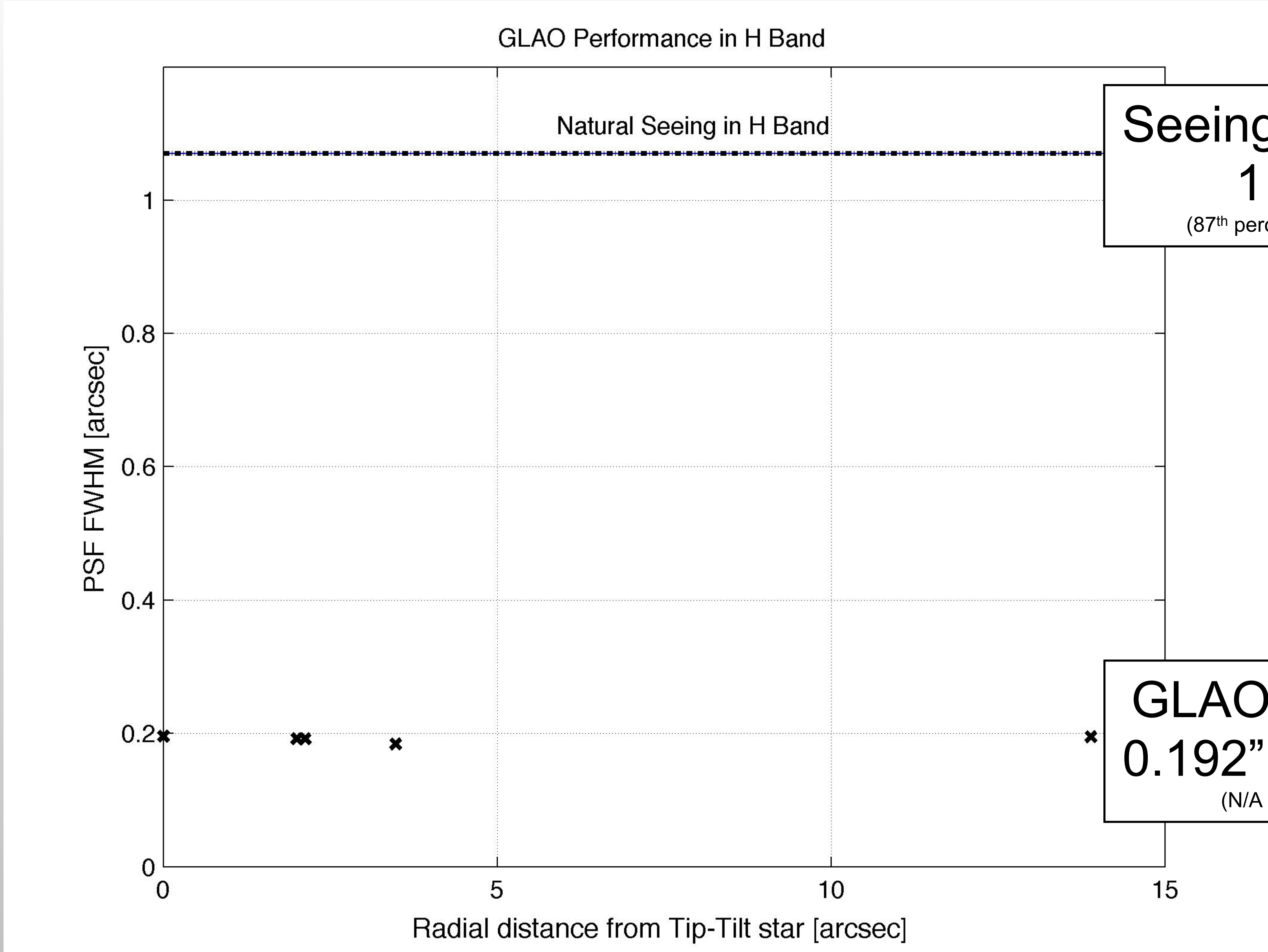
Seeing FWHM:
0.57” ± 0.04”
(37th percentile seeing)

GLAO FWHM:
0.19” ± 0.01”
(N/A percentile)

TYC3171-151-1 (May 2011)



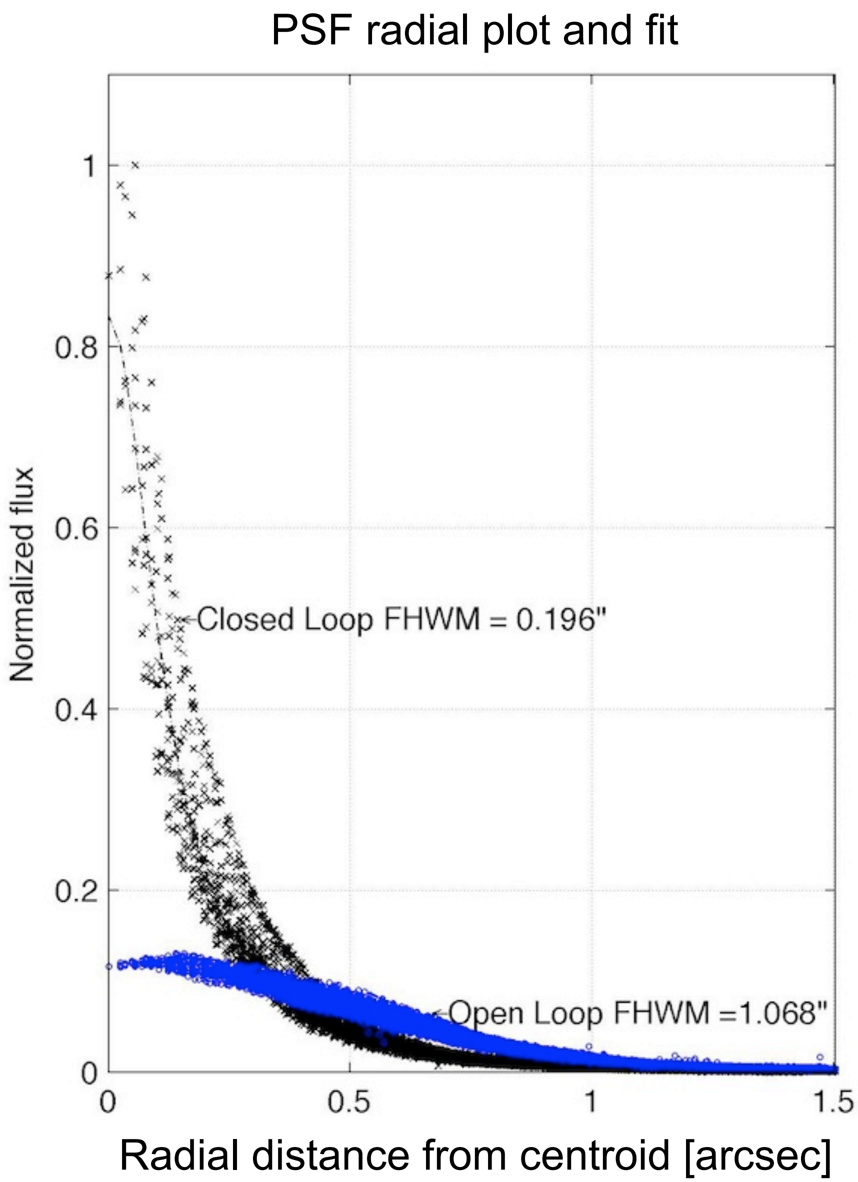
TYC3171-151-1 (May 2011)

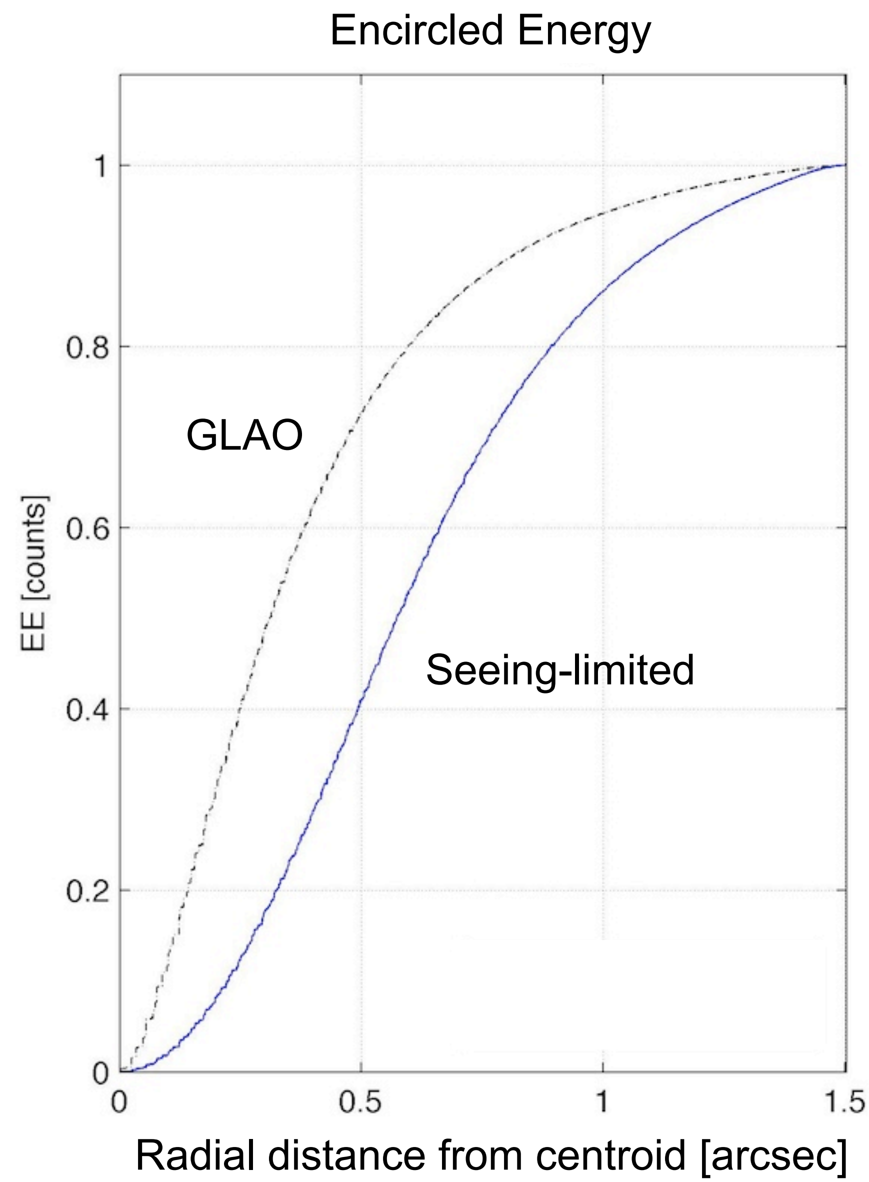


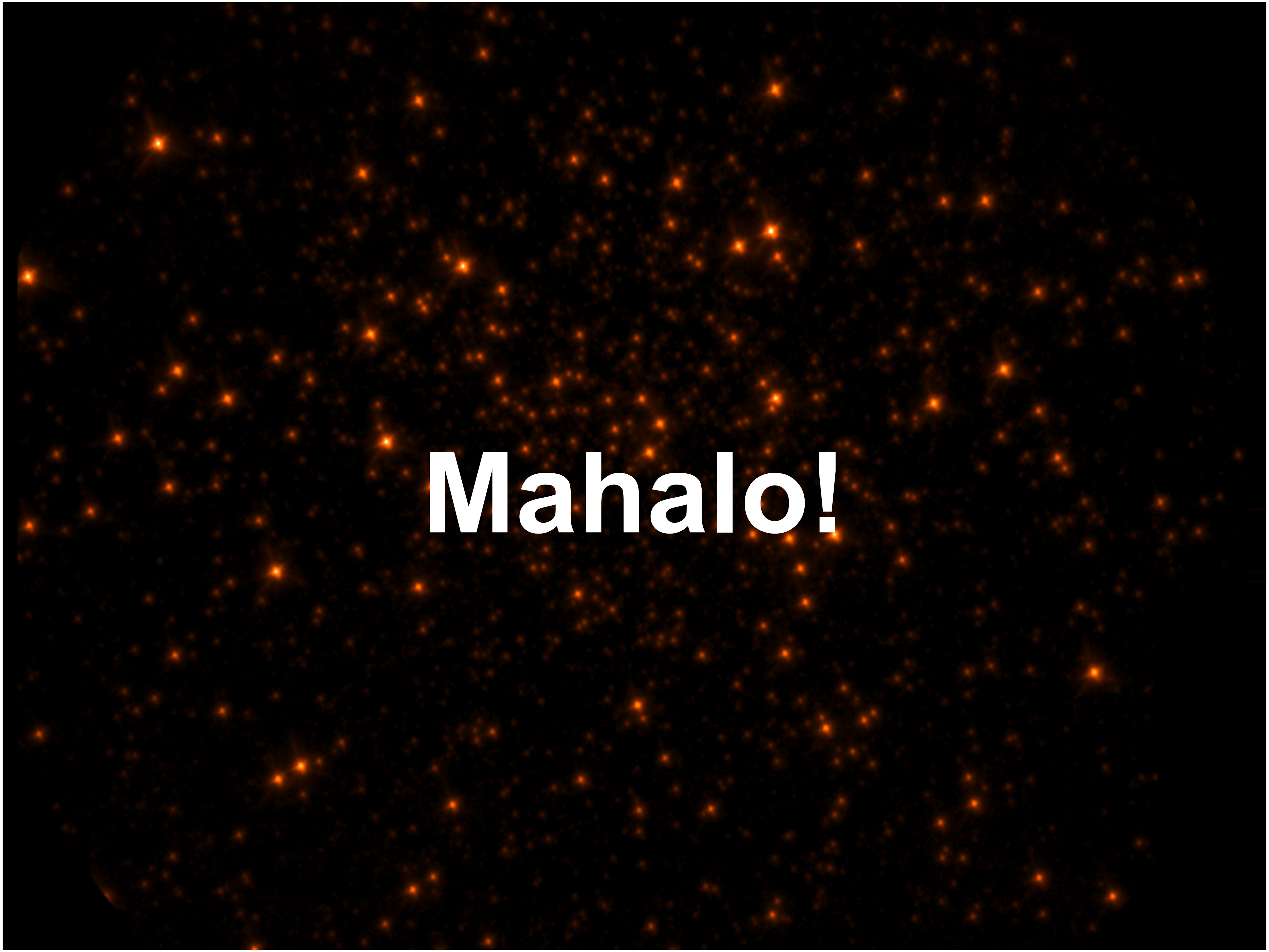
Seeing FWHM: 1.07”
(87th percentile seeing)

GLAO FWHM: 0.192” ± 0.005”
(N/A percentile)

Detailed GLAO PSF






Mahalo!