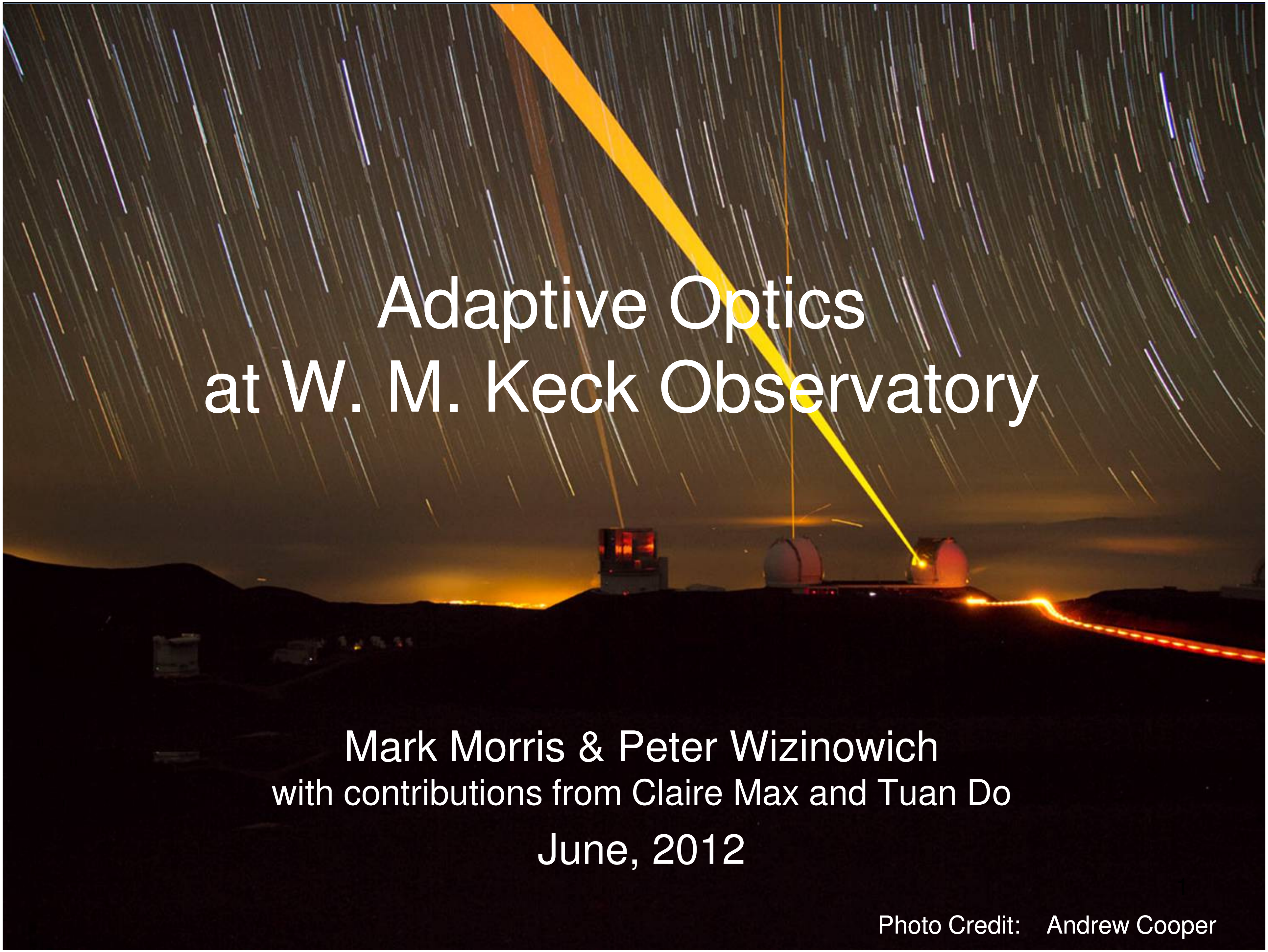


Adaptive Optics at W. M. Keck Observatory

Mark Morris & Peter Wizinowich
with contributions from Claire Max and Tuan Do

June, 2012

Photo Credit: Andrew Cooper

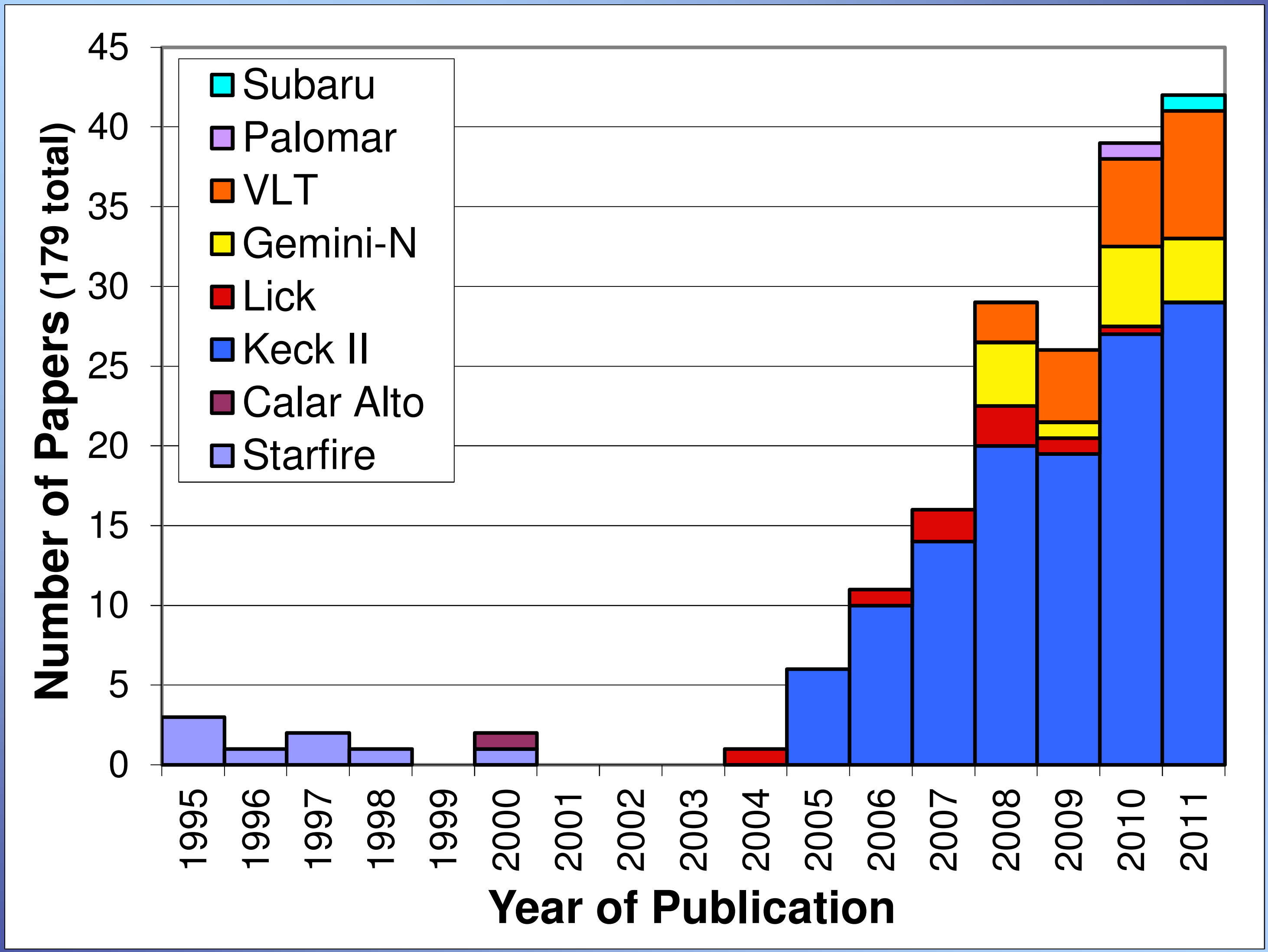
Science Impact

Performance

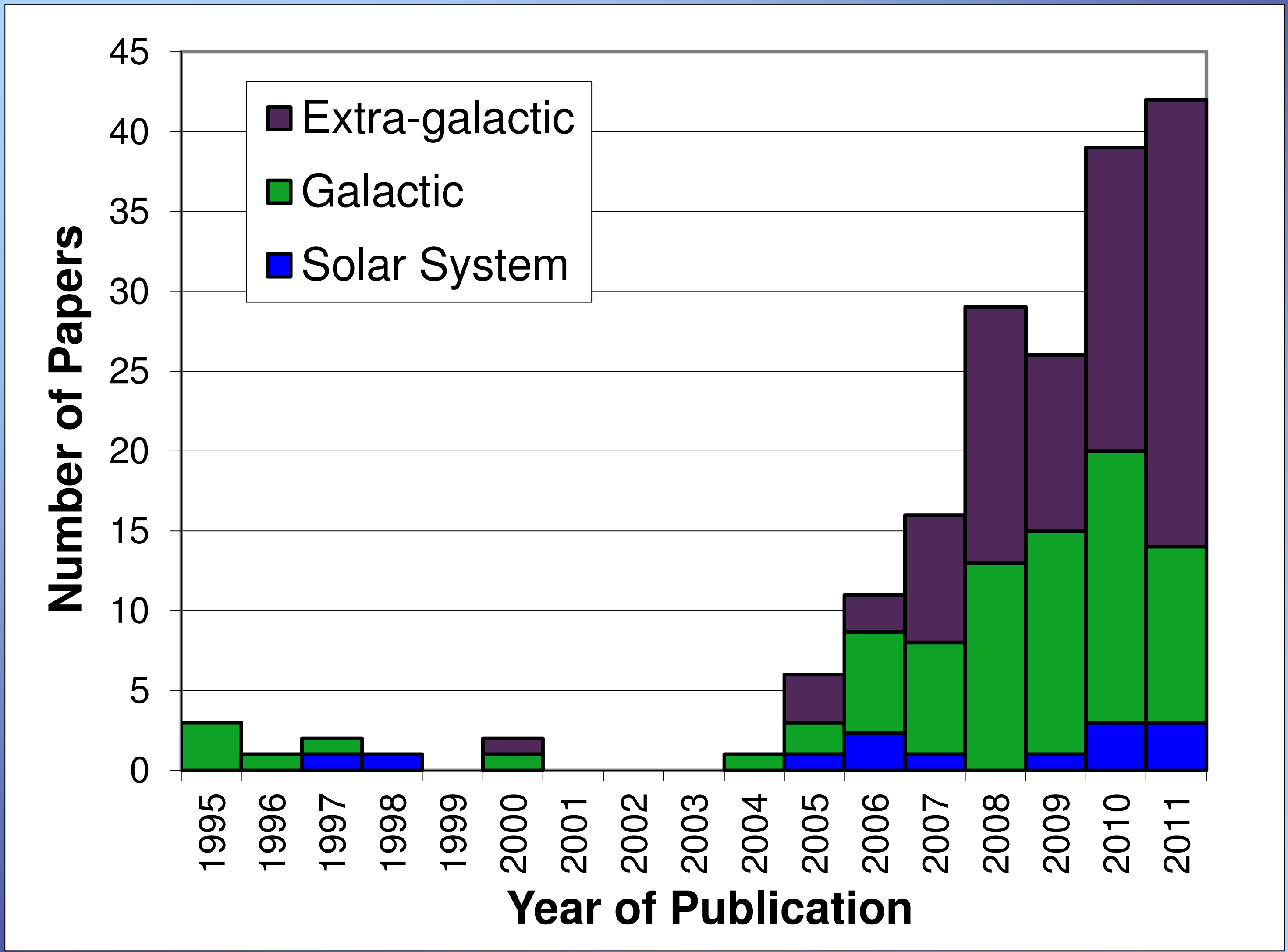
Performance Limitations

Recent Developments in Keck AO

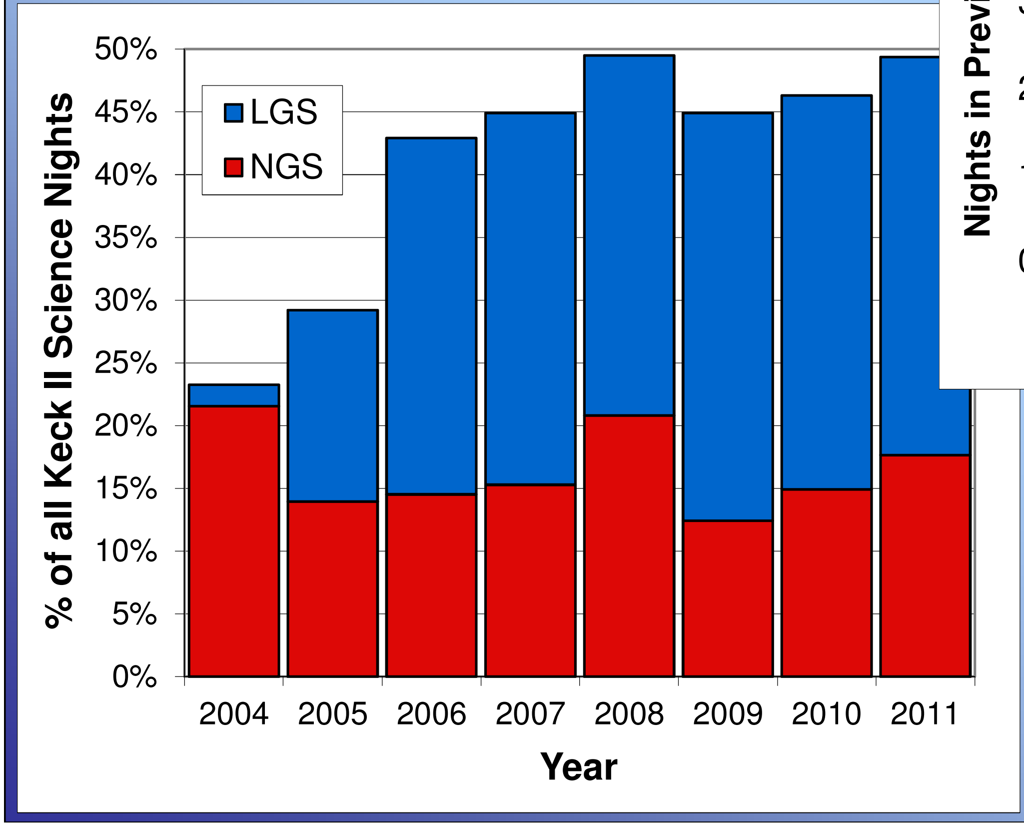
Science Productivity

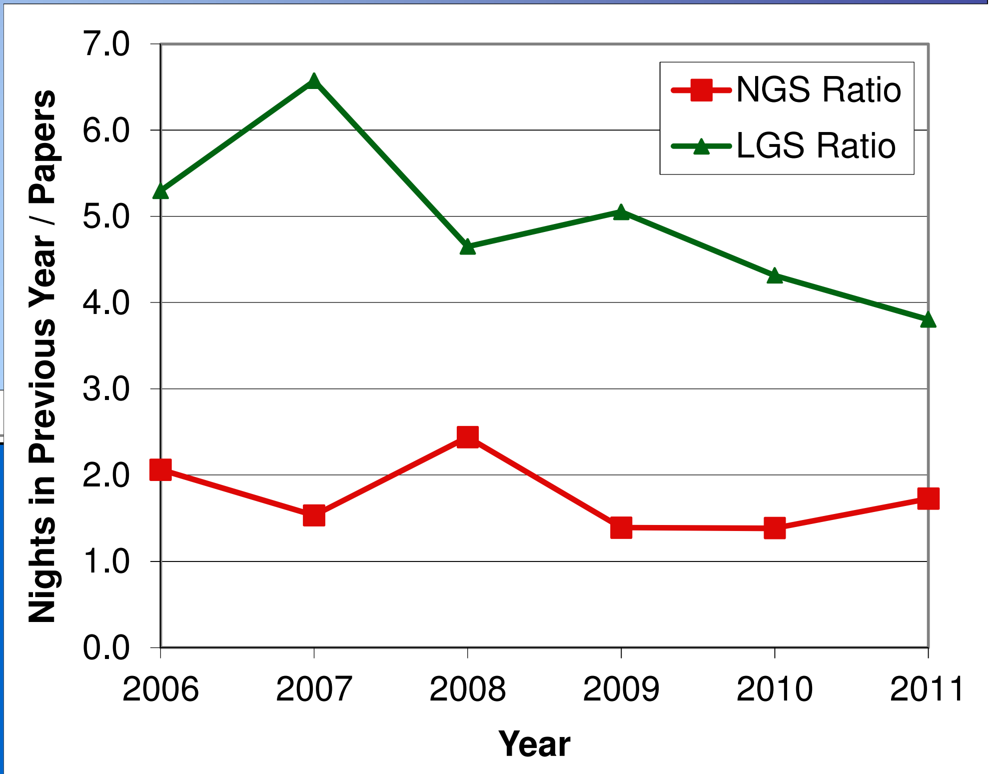


Science Productivity

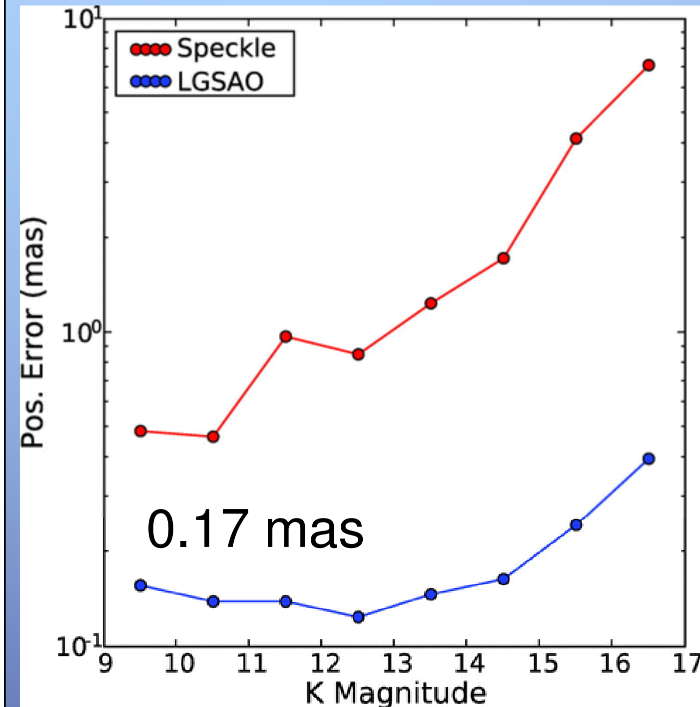


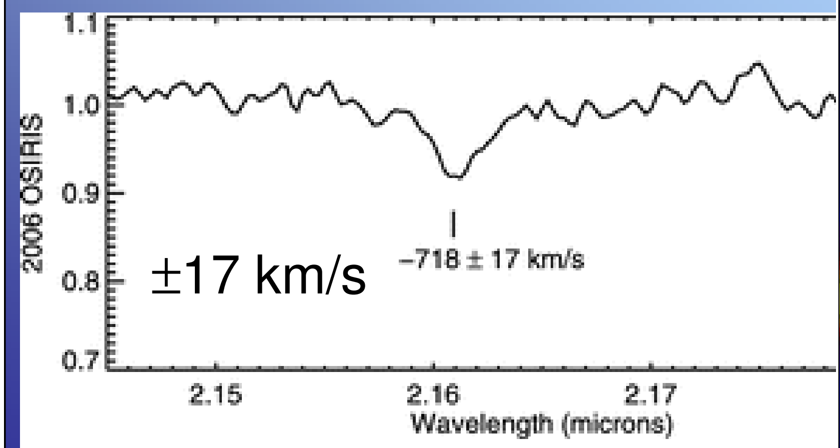
Keck LGS Science Demand & Efficiency



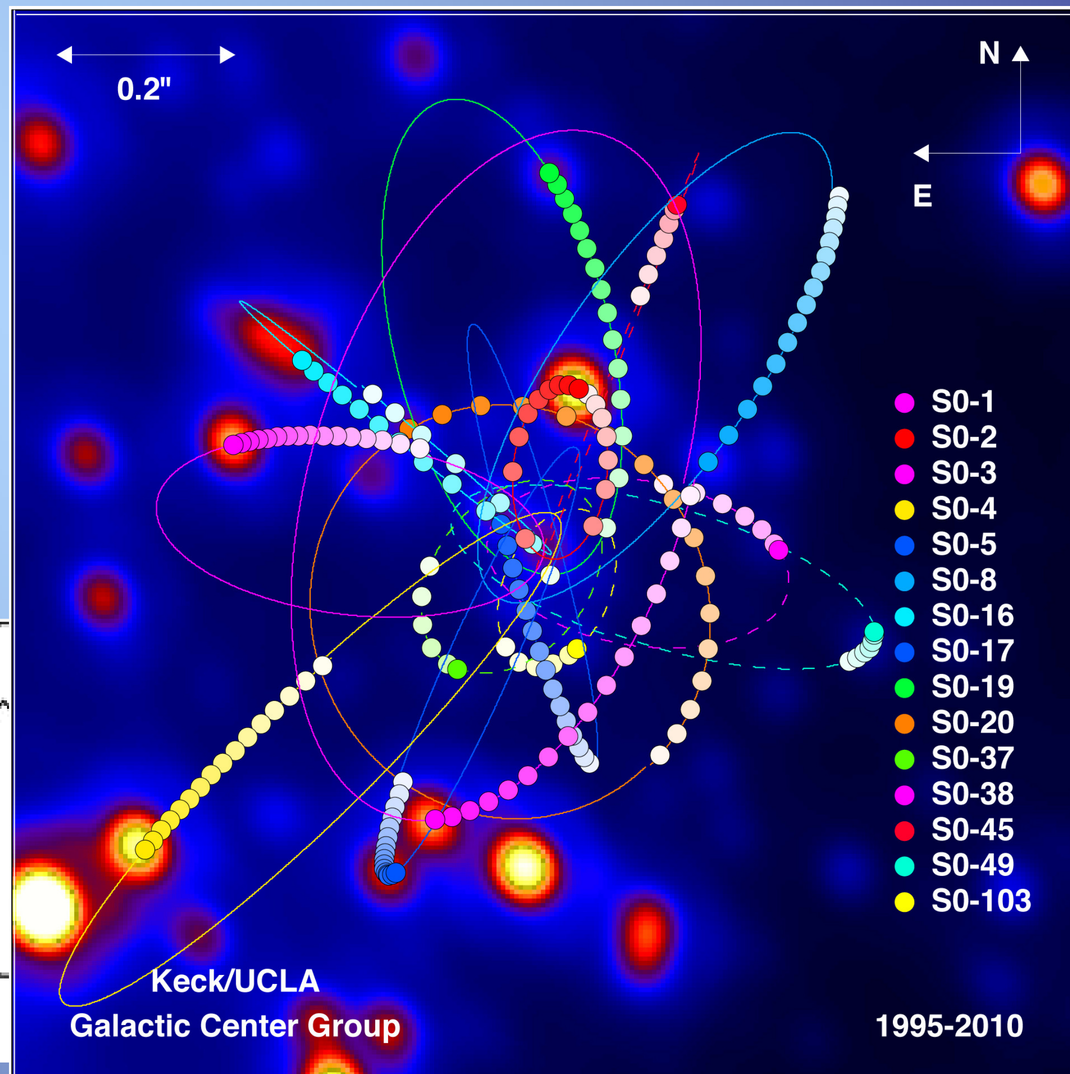


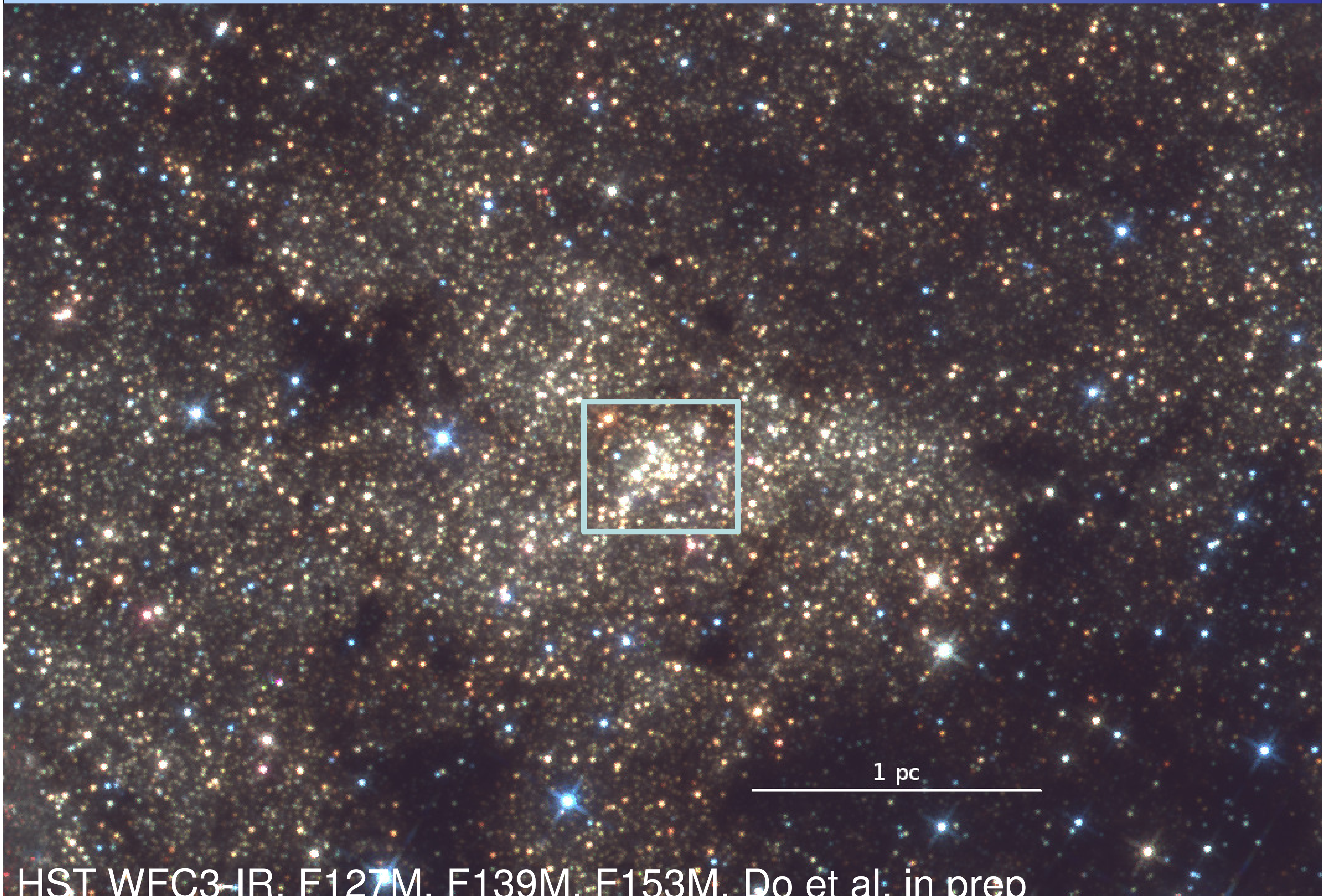
Galactic Center with Keck LGS AO



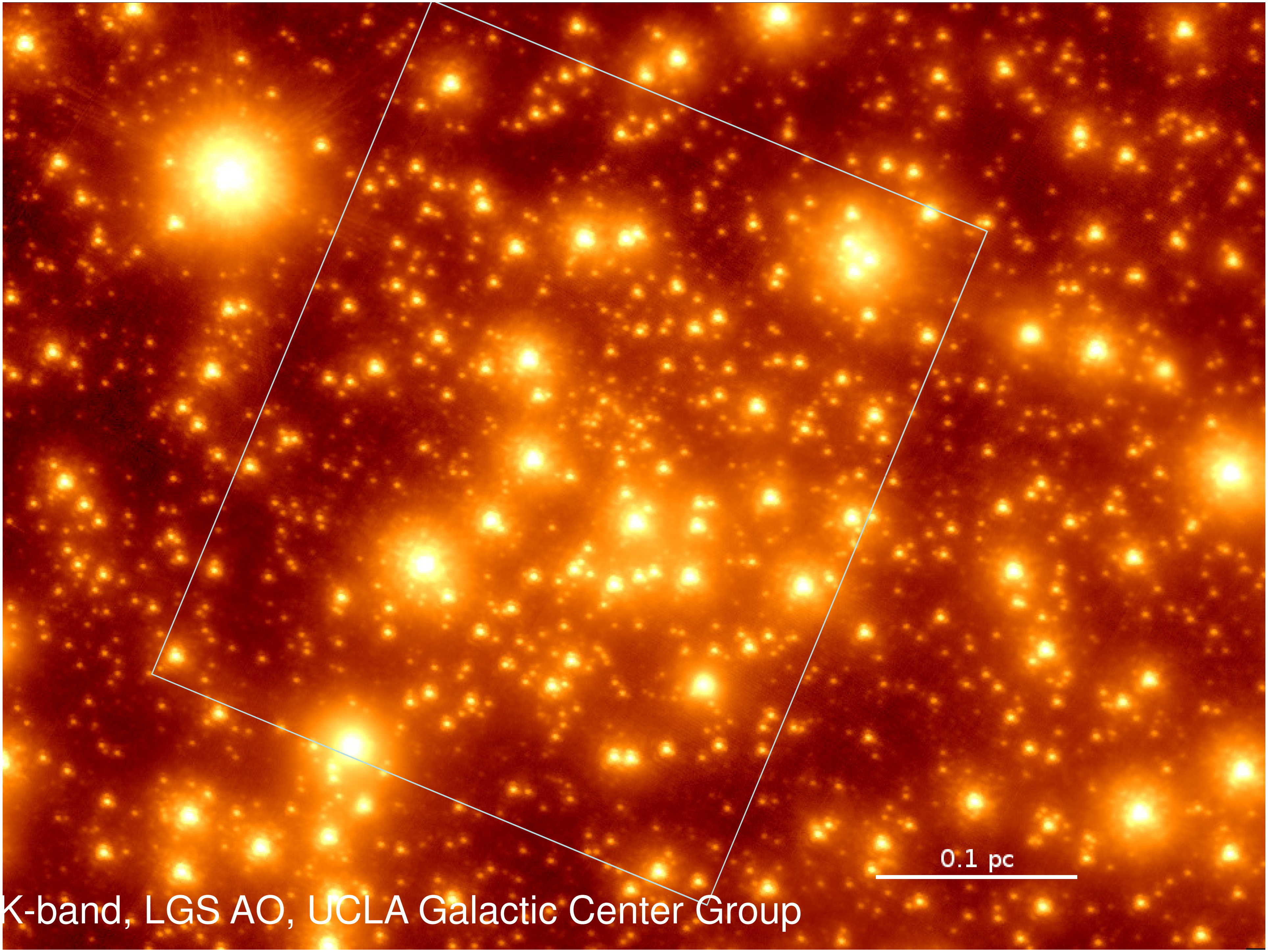


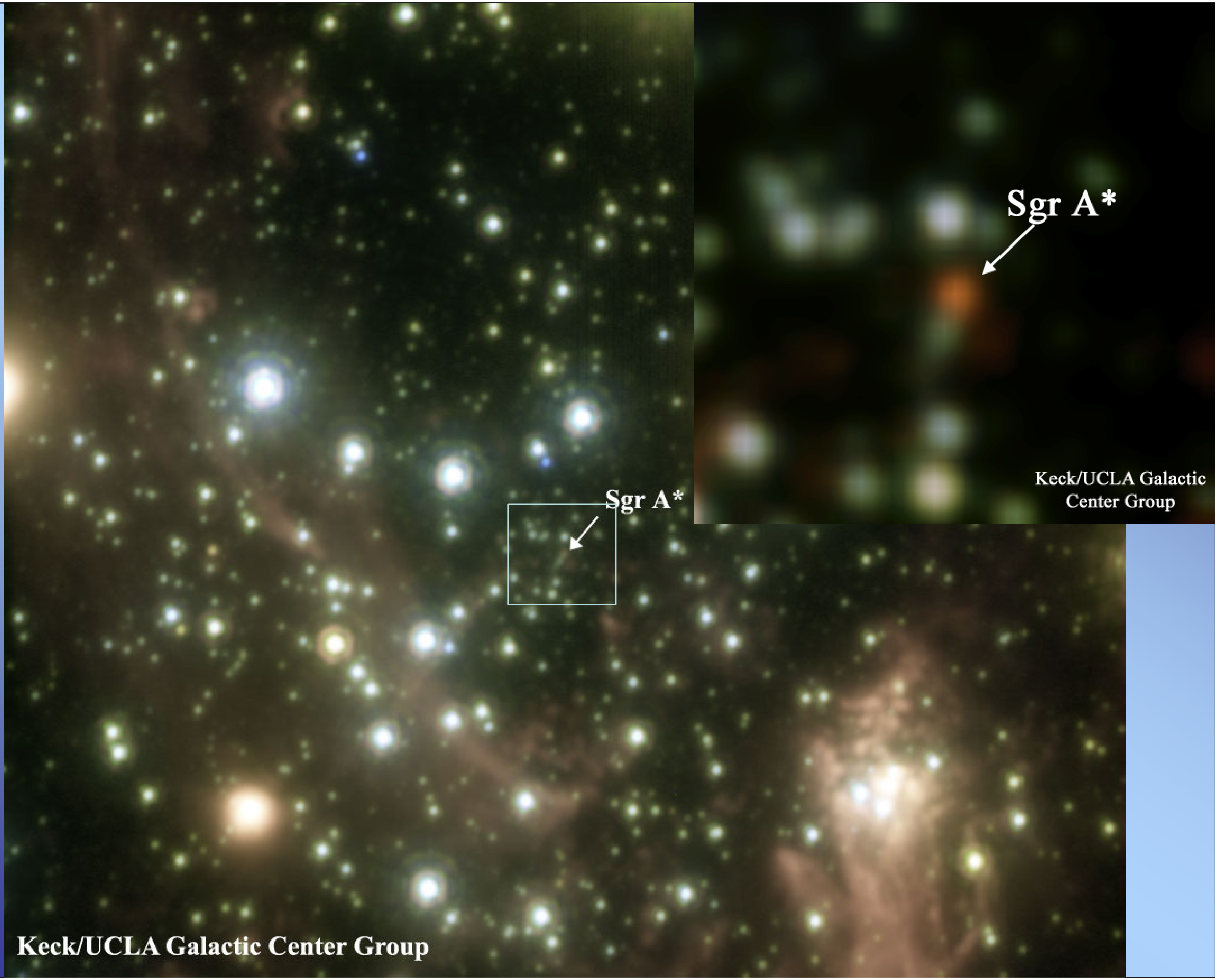
Limitation = Source Confusion → PSF





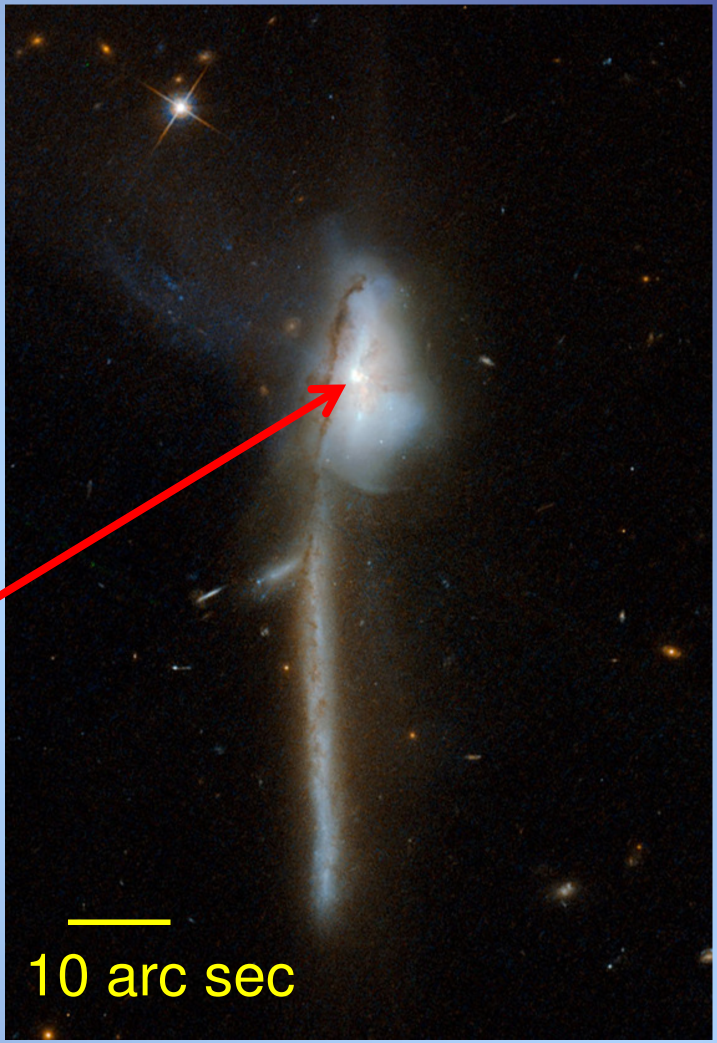
HST WFC3-IR, F127M, F139M, F153M, Do et al. in prep

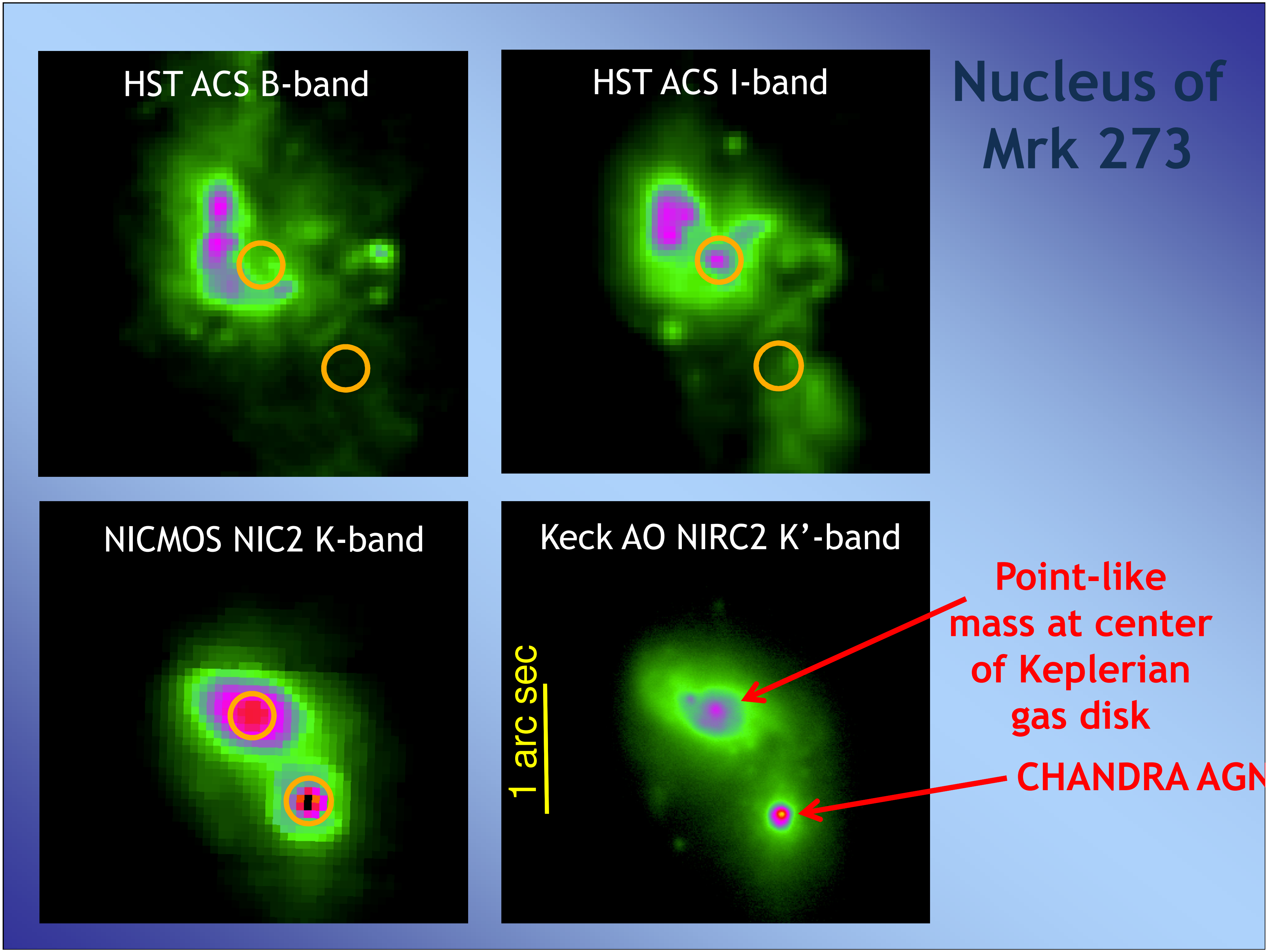

0.1 pc
K-band, LGS AO, UCLA Galactic Center Group


Sgr A*
Keck/UCLA Galactic Center Group
Sgr A*
Keck/UCLA Galactic
Center Group

Where are the two black holes after a gas-rich galaxy merger?

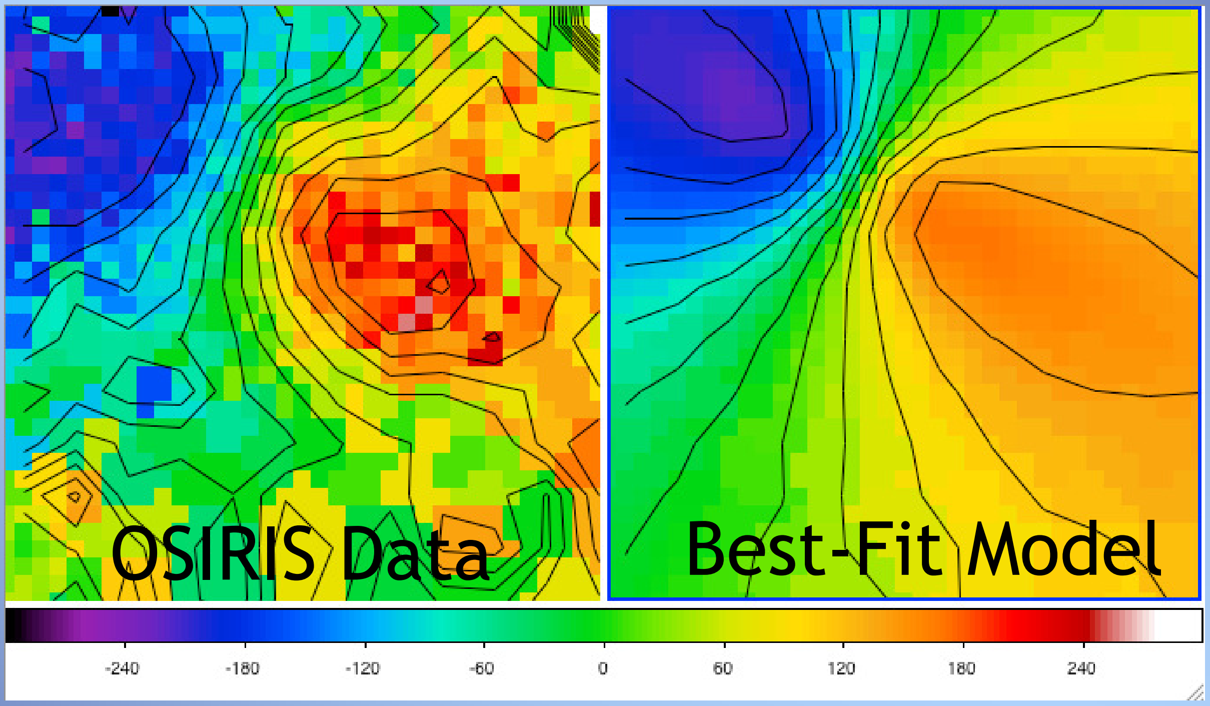
- Observe ULIRGs in late-stage mergers
  – Medling and Max, UCSC
- Look for kinematic or spectral signatures of supermassive black holes with OSIRIS IFU and Keck LGS AO
- Example: Mrk 273





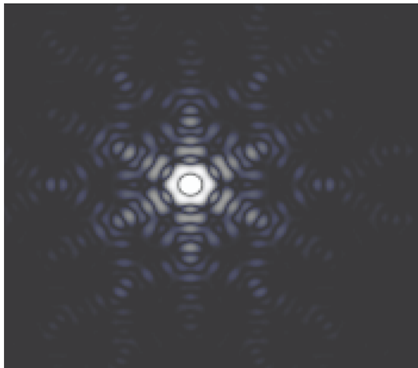
Nucleus of
Mrk 273
HST ACS B-band
HST ACS I-band
NICMOS NIC2 K-band
Keck AO NIRC2 K'-band
1 arc sec
Point-like
mass at center
of Keplerian
gas disk
CHANDRA AGN

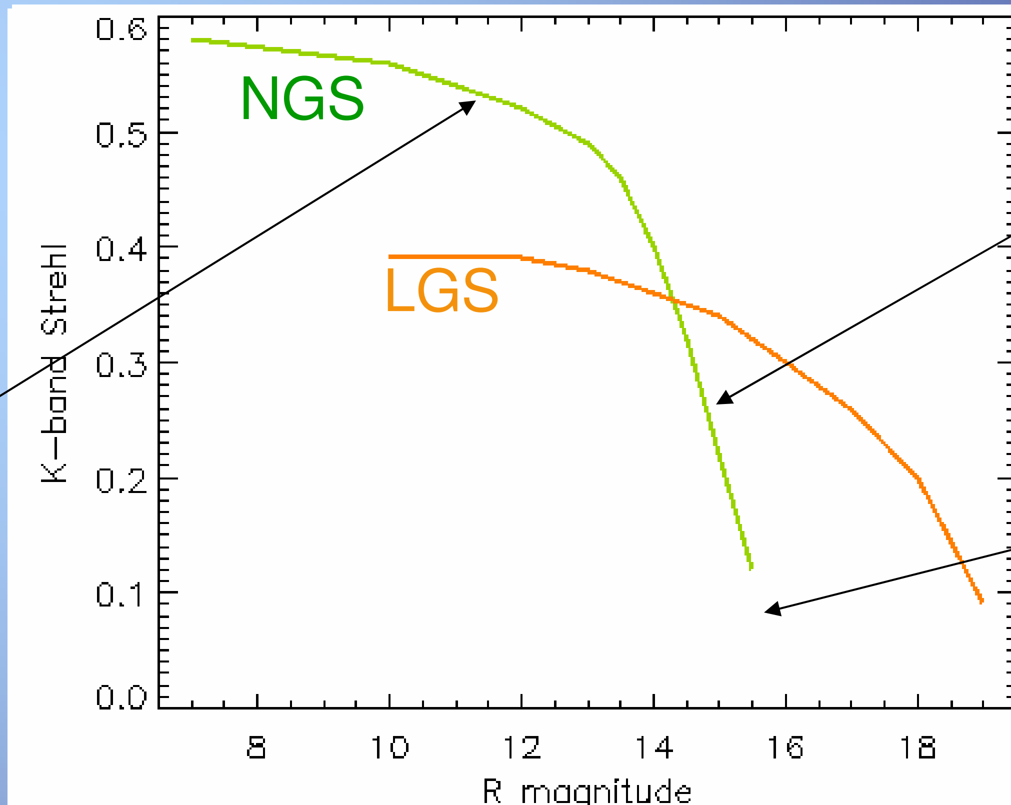
Does the North sub-nucleus host a black hole at the center of its disk?

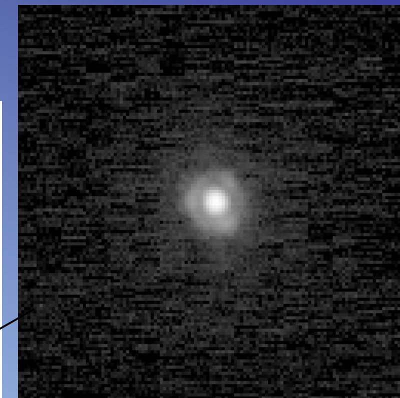


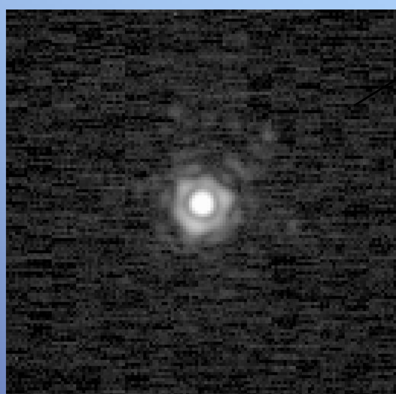
- Estimate enclosed mass (potential BH) in north disk from [Fe II] velocity field within BH sphere of influence
- Best fit: $M_{BH} = (2 \pm 1) \times 10^9 \, M_{sun}$

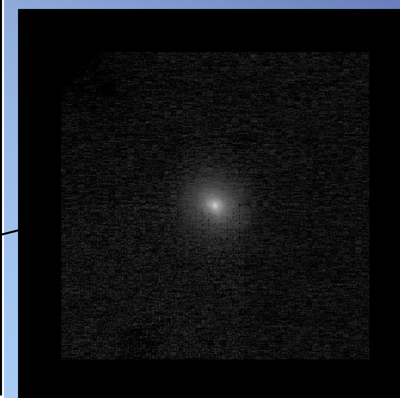
AO Performance

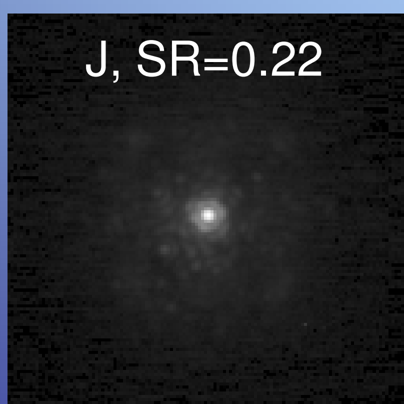


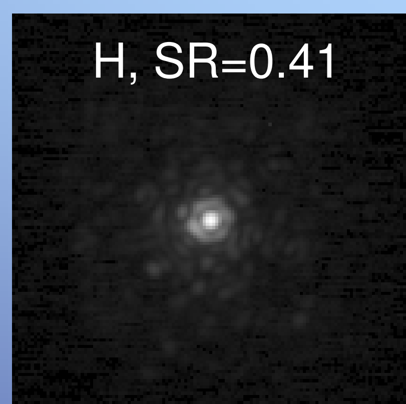


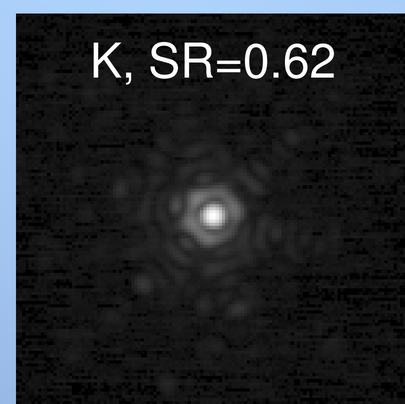








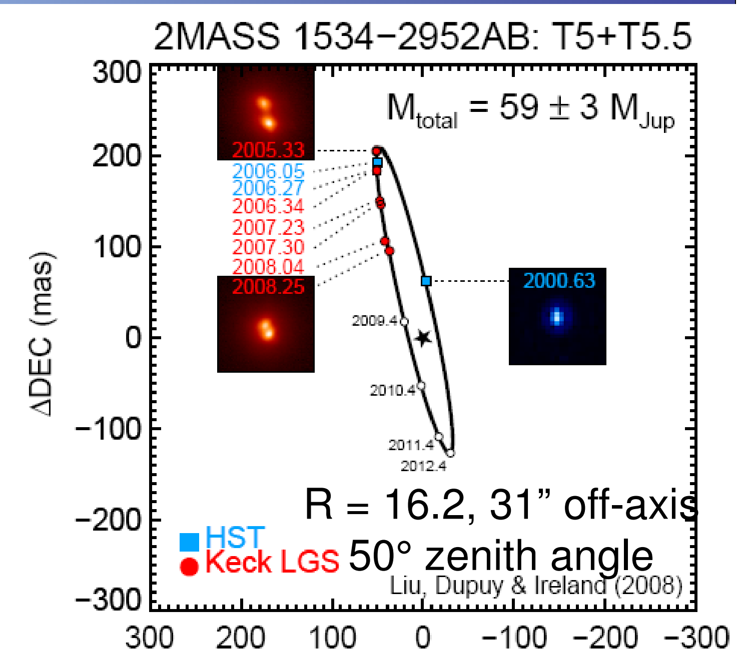


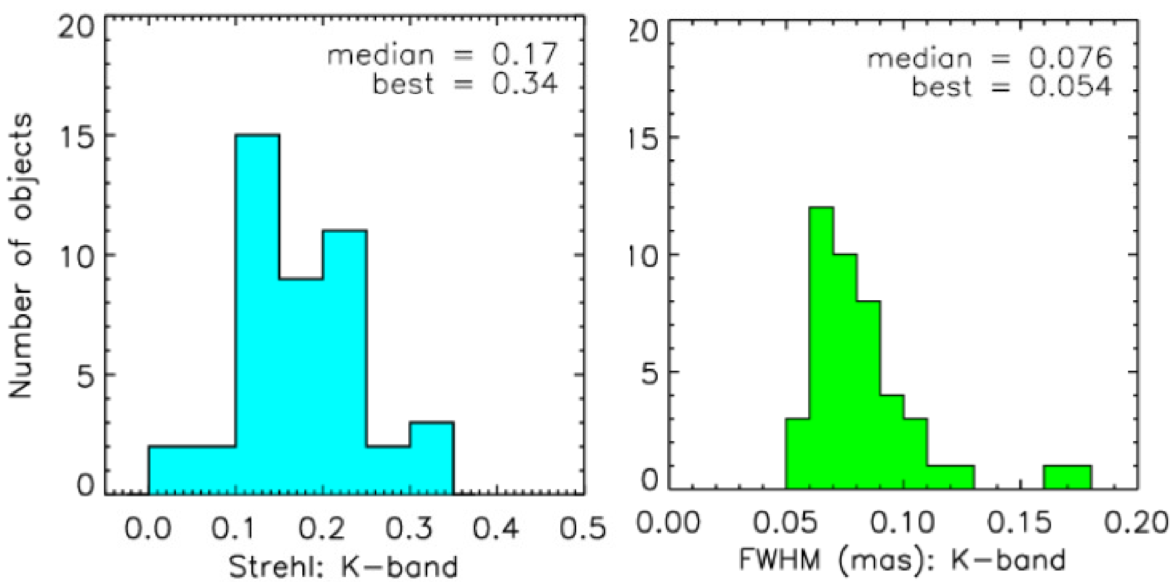


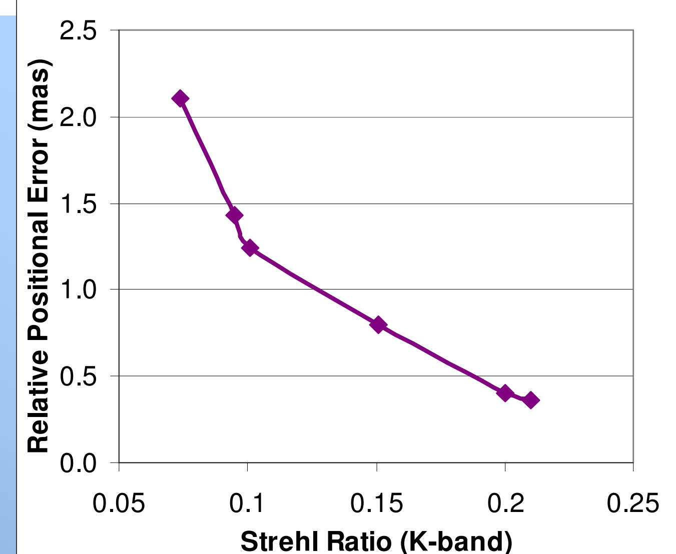
LGS AO Performance Variability

2005-07 Survey of field brown dwarfs (Liu et al.)

- No data censored. Mix of seeing conditions, off-axis tip-tilt properties & technical performance
- ~2/3 sky coverage with 60” off-axis radius & Strehl >~ 0.2







What's Limiting Science Performance?

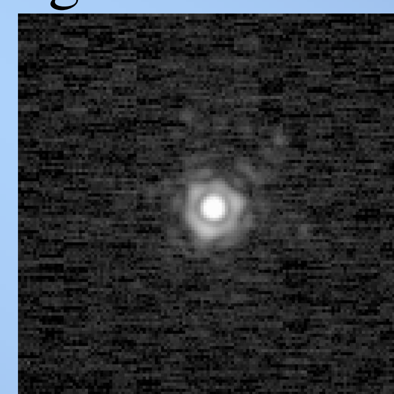
Error Term	KII Dye Laser off-axis	
Atmospheric Fitting	122	
Telescope Fitting	66	
Science Camera	110	
DM Bandwidth	182	
DM Measurement	216	
Tip-tilt Bandwidth	247	
Tip-tilt Measurement	214	
Tip-tilt Anisoplanatism	115	
LGS Focus Error	70	
Focus Anisoplanatism	181	
LGS High Order Error	80	
Calibration Errors	30	
Miscellaneous	73	
Total Wavefront Error	531 nm	
K-band Strehl	0.10	
Science Case Parameters	2MASS 1534-2952AB	Galactic Center
NGS R-magnitude	16.2	14
NGS off-axis distance (")	31	19.3
Zenith angle (deg)	50	50

LGS beacon

Tip-tilt sensor

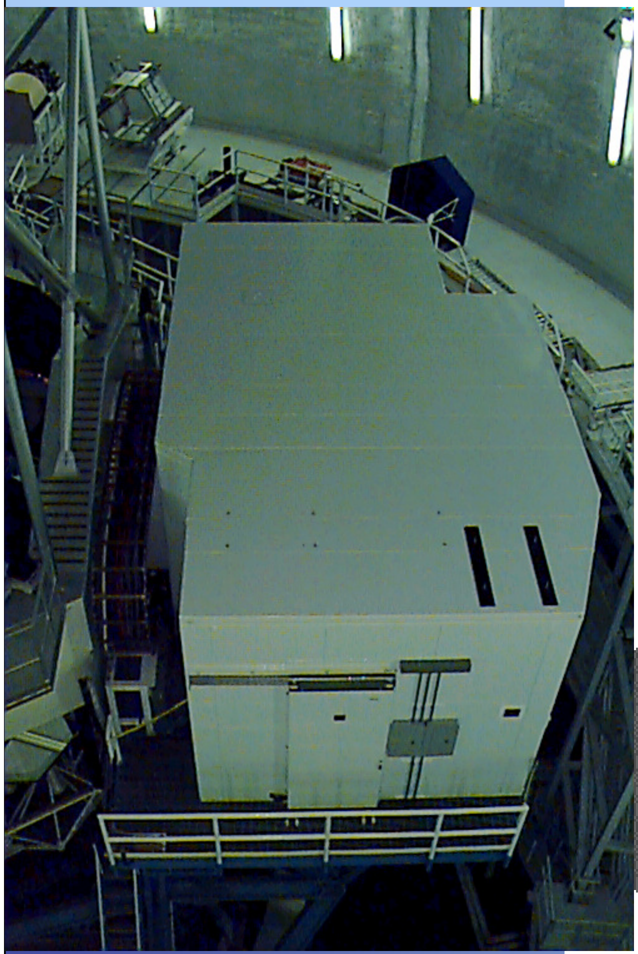
LGS asterism

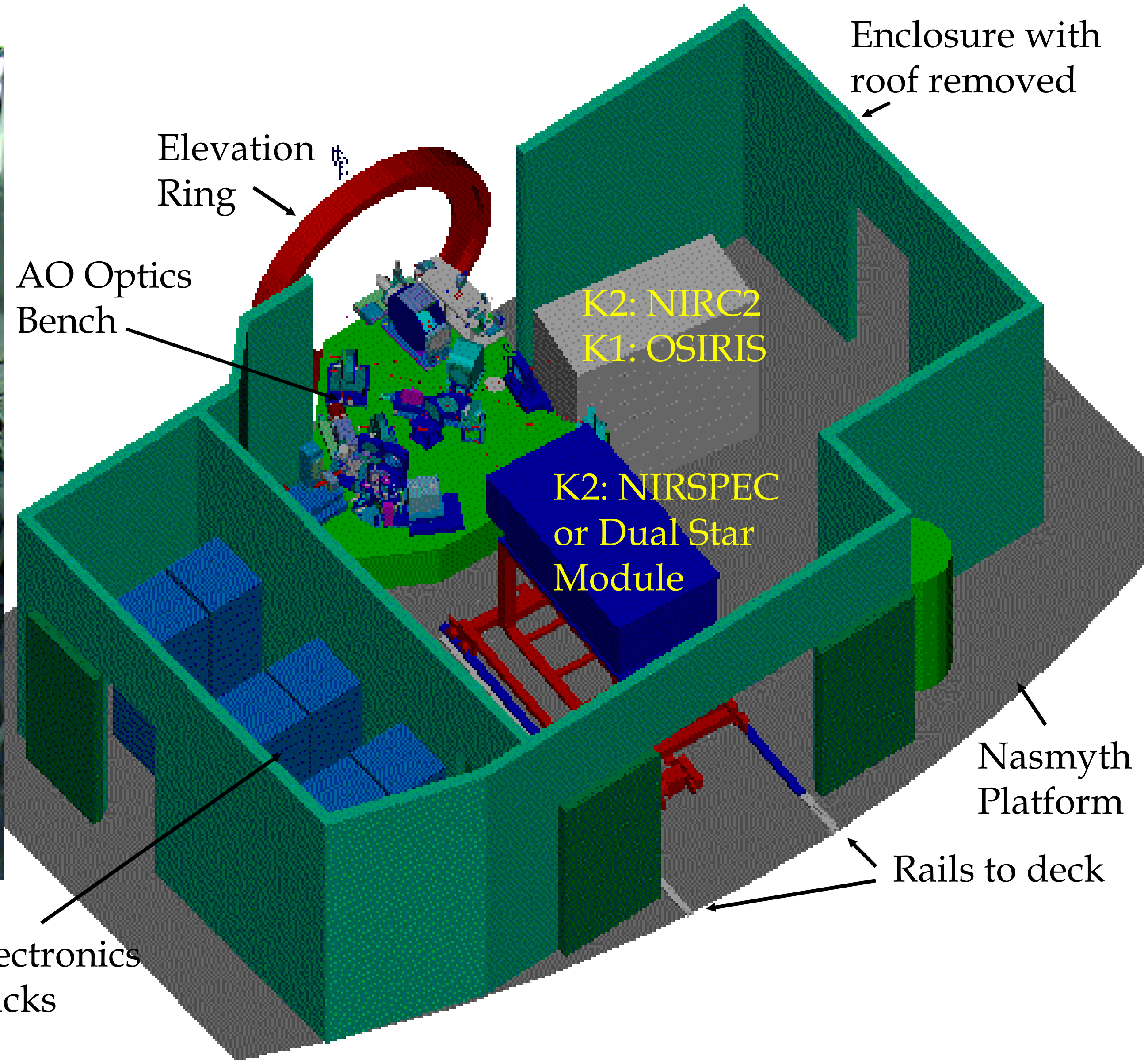
Plus lack of PSF knowledge



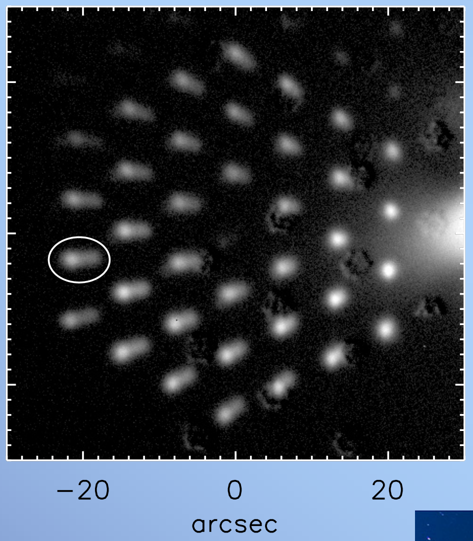
AO System Developments at Keck

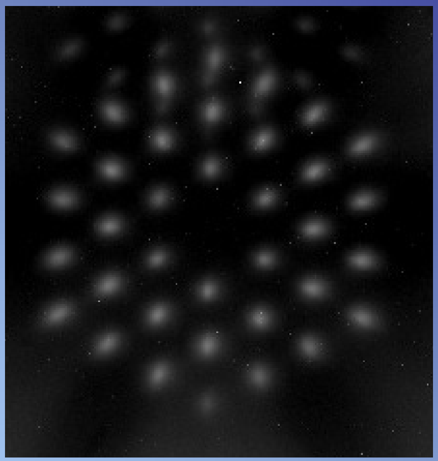
Left Nasmyth Platform

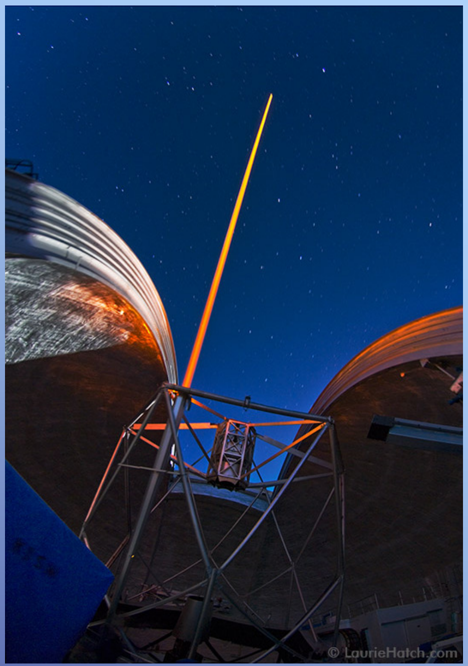




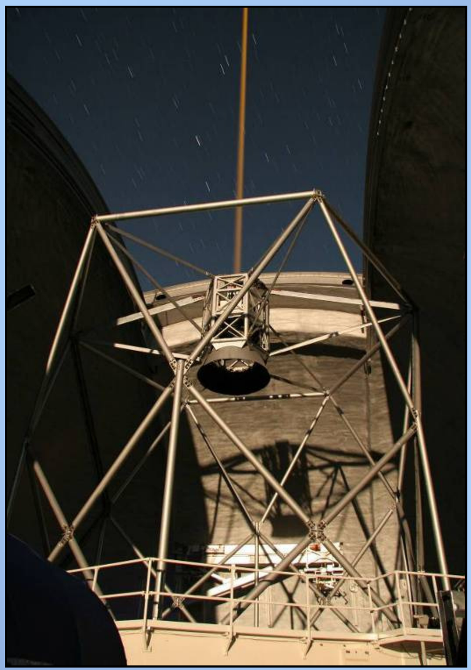
Keck Side & Center Launch







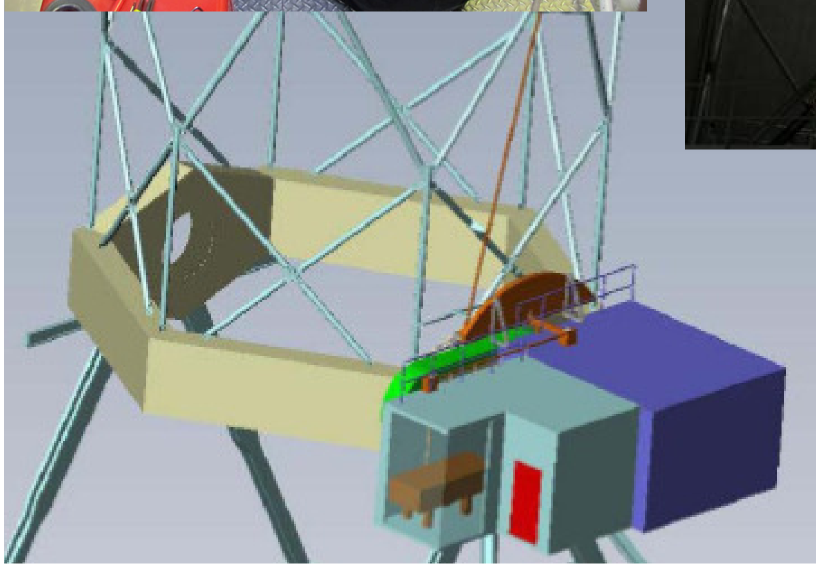
Side launch Keck II

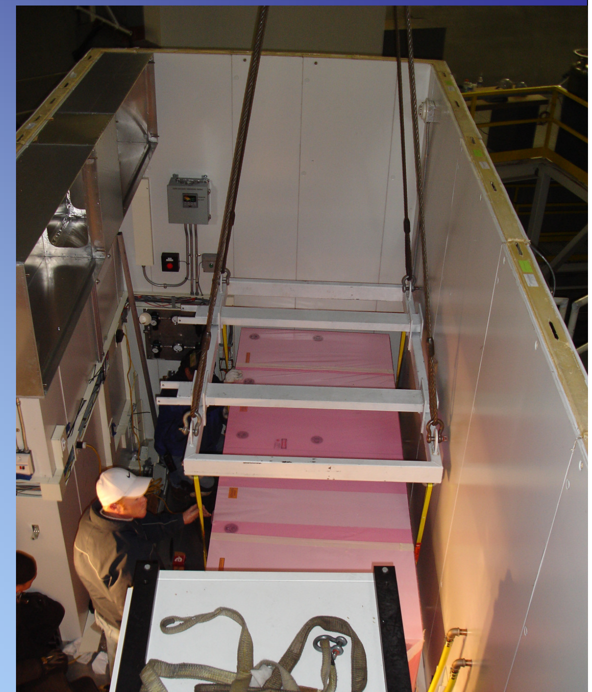


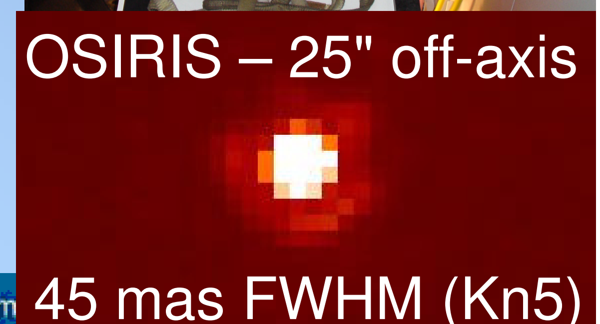
Center launch Keck I

Keck I LGS AO

10 shared-risk science nights in May/June

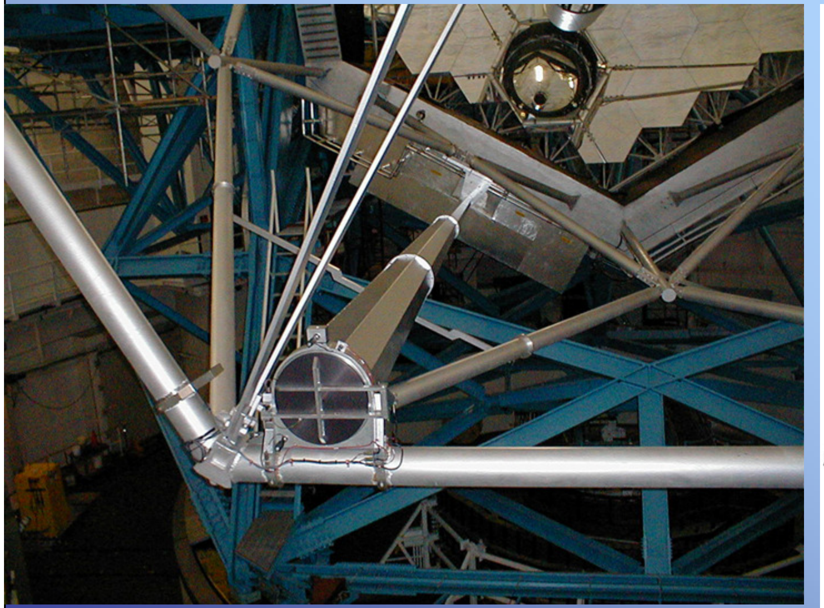


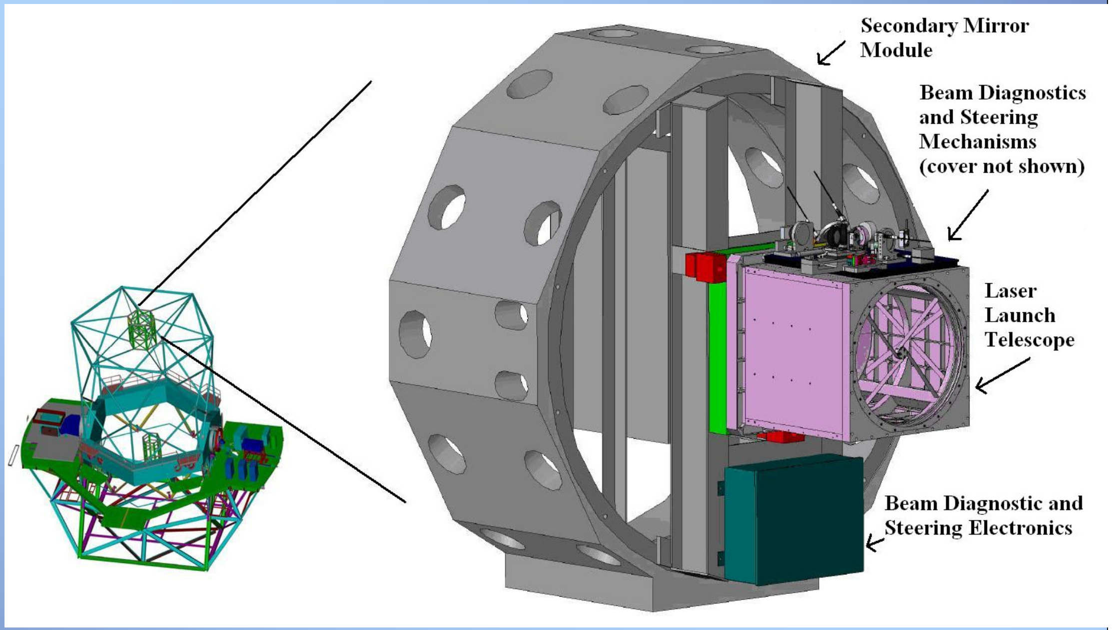




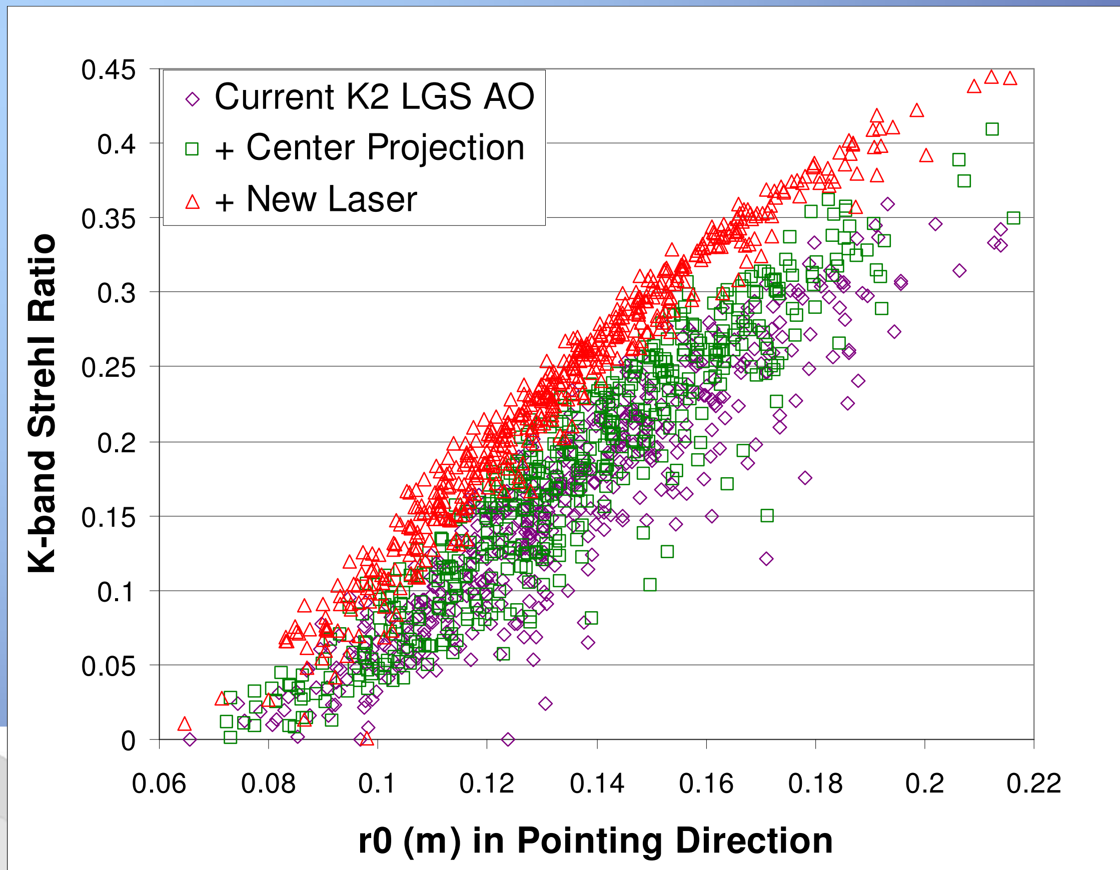
Keck II Center Launch
1st science 2014

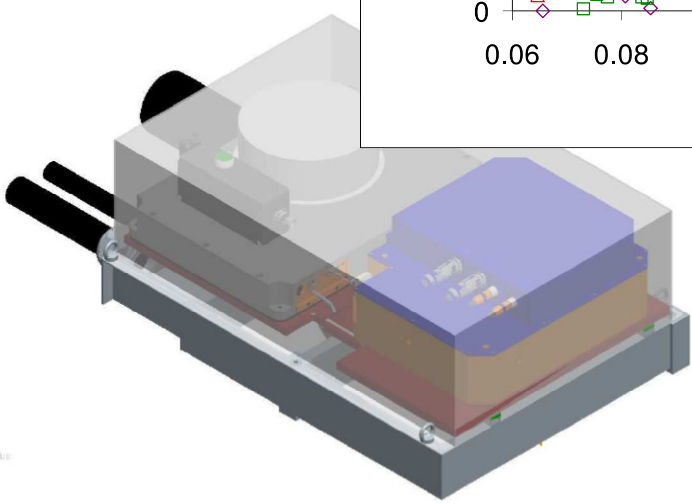
- PDR completed in October 2010
- Launch telescope DDR in April 2011
- Launch telescope currently being assembled

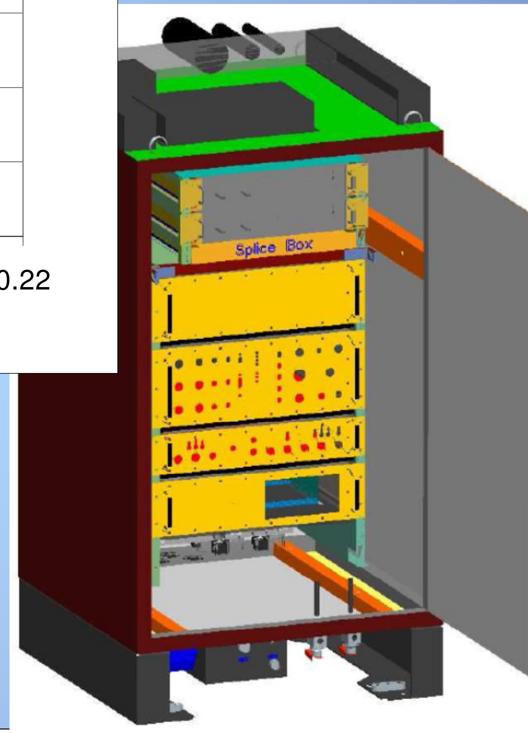




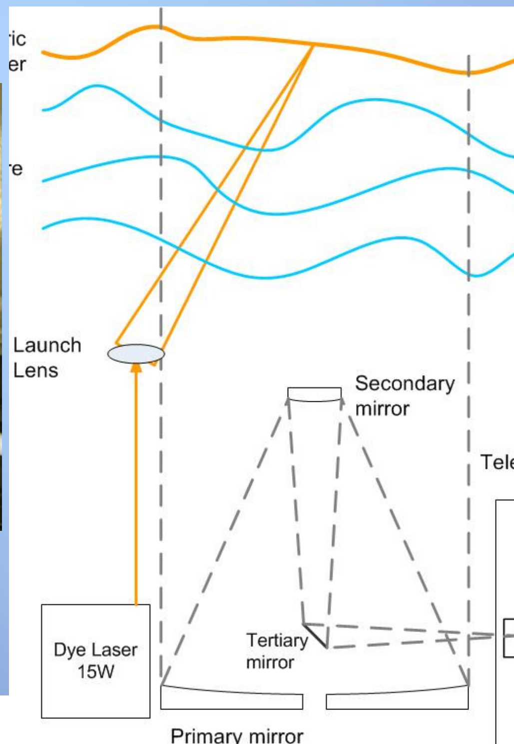
TOPTICA Laser

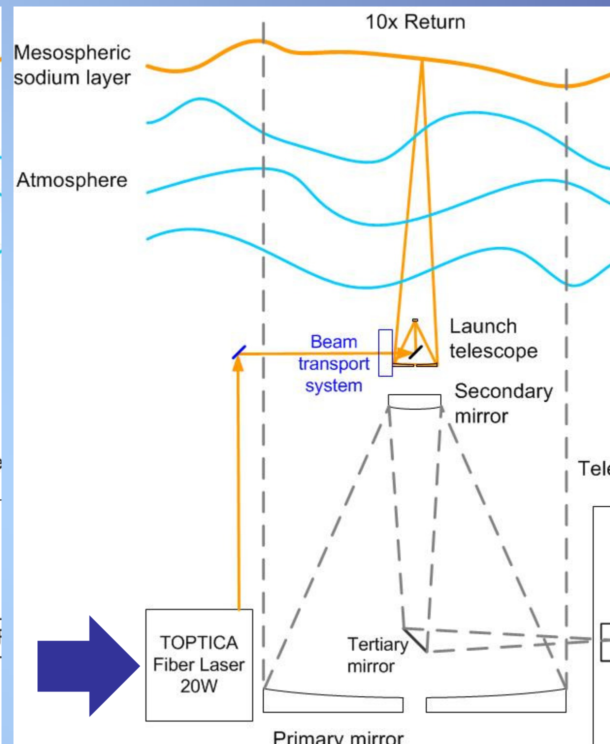


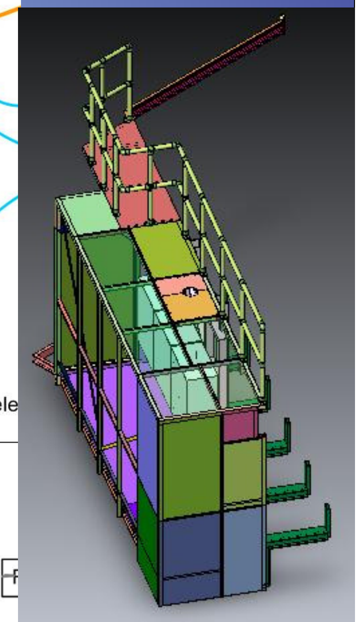


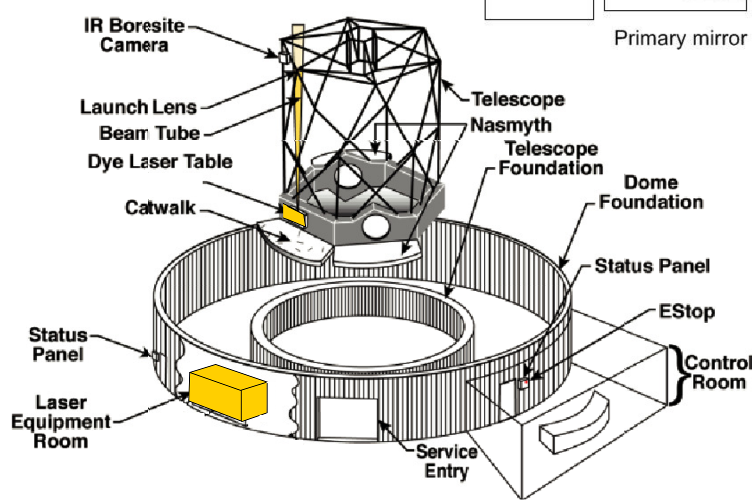


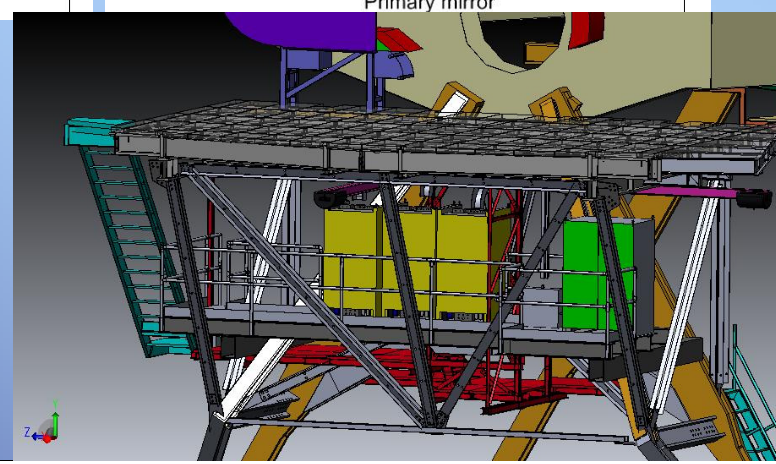
Laser Implementation





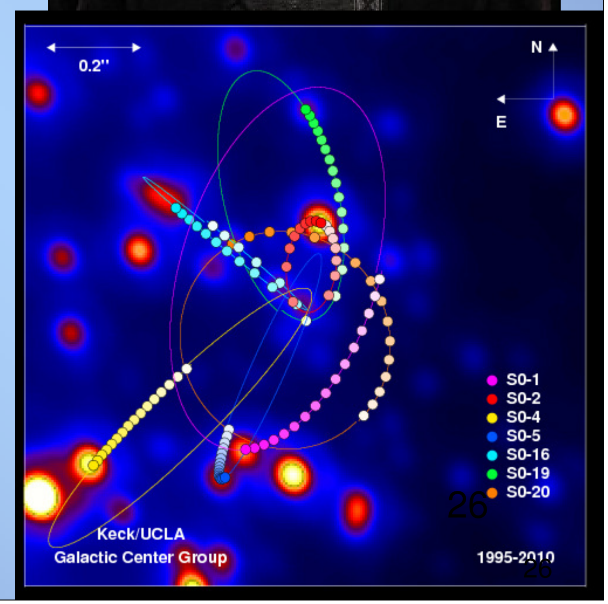




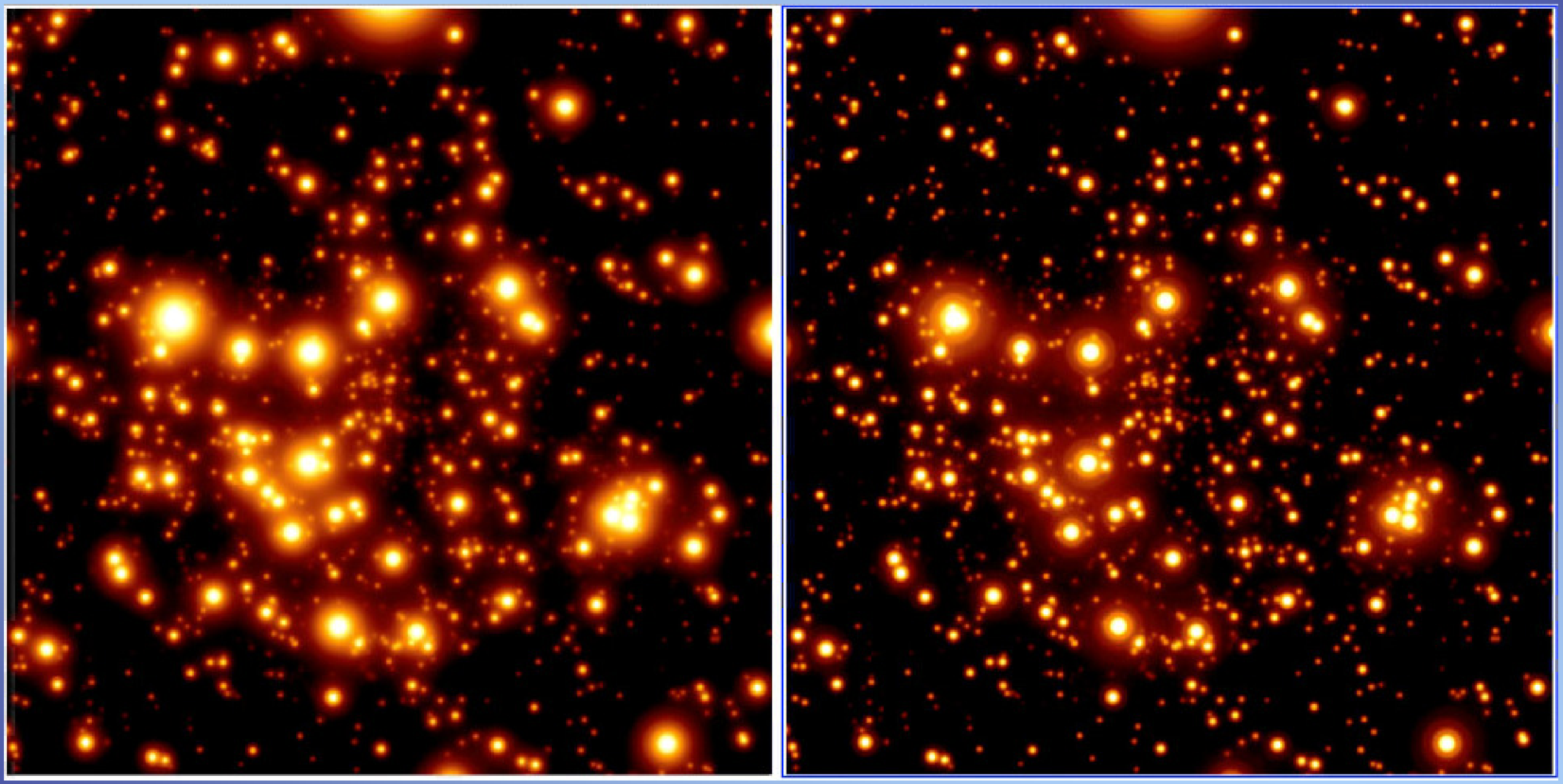


Crafoord Prize to Ghez and Genzel

- 2012 Crafoord Prize in Astronomy has been awarded to Andrea Ghez and Reinhard Genzel
- Two competing teams discovered supermassive black hole at Galactic Center
- All of Ghez's observations of Galactic Center are from Keck adaptive optics and speckle
- Endorsement that adaptive optics is a key astronomical technique



Benefit of Center Launch + new Laser



Current Laser *Galactic Center Simulations* Center + New Laser

Relative Strehl ratio improvement of a factor 1.5 - 2.5!

Keck I Near-IR Tip-Tilt Sensor

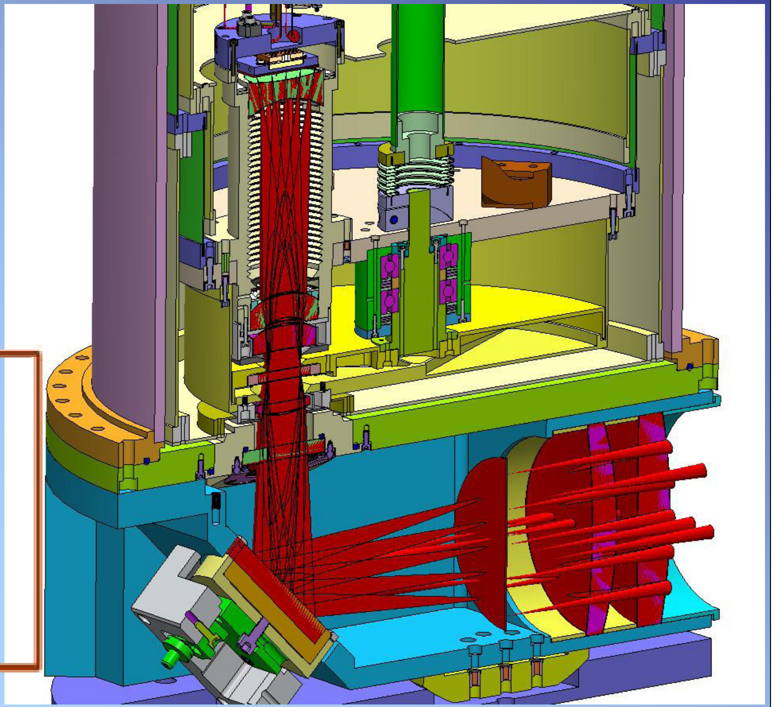
Operations Software System
- Pre-Observing Tools
- Observation Setup
- Calibration
- User Interface
- Observing Tools

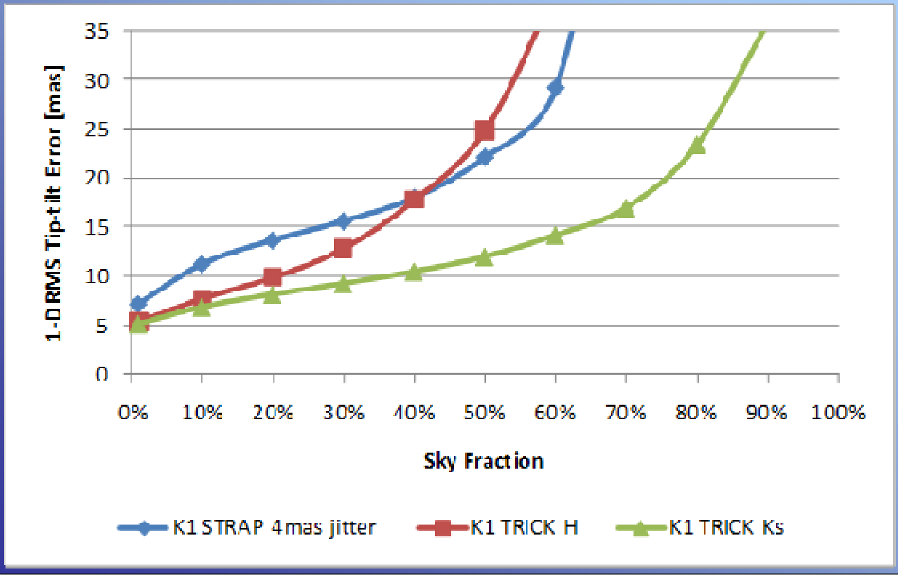
Controls System
- Pickoff & Focus Motion Control
- Camera Device Control
- Supervisory Controller Modifications

Camera System
- NIR Camera
- Camera Optics
- Camera Controller
- Filter Changer
- Cryo-cooler
- Host Computer

Real-Time Control System
- Camera Data Processing
- TT Determination
- Telemetry Input Mods

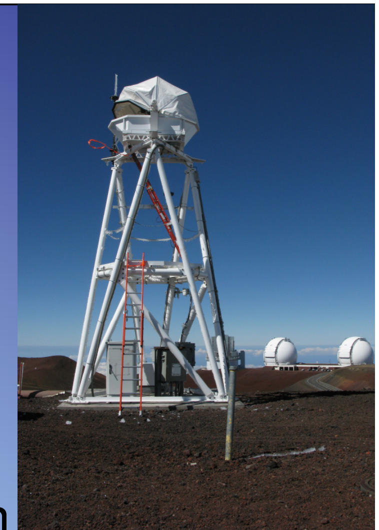
Opto-Mechanical System
- Pickoff Exchange Mechanism
- Focus Mechanism
- Mods to AO bench



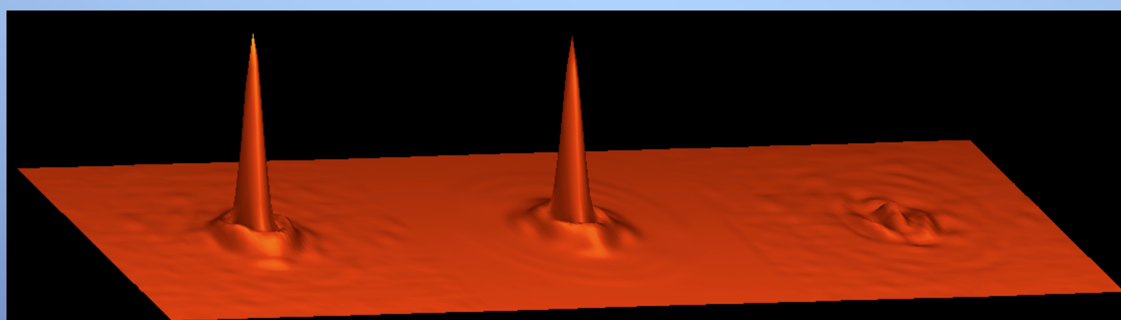


- 1st science in late 2013
- DDR in Feb. 2012

PSF Determination



- Ground work
  - MASS-DIMM + AO telemetry
- Bright on-axis NGS case
  - AquilAOptics, Gemini, Groningen & Keck collaboration
  - + working to understand Keck AO low order aberrations



- Off-axis NGS & LGS case
  - UCLA, tOSC, Keck collaboration funded by WMKF
- On-axis LGS case (+ faint NGS)
  - ATI-funded project to start in Aug/2012.

NGAO - Next Generation AO

Key Science Goals

Understanding the Formation and Evolution of Today's Galaxies since z=3

Measuring Dark Matter in our Galaxy and Beyond

Testing the Theory of General Relativity in the Galactic Center

Understanding the Formation of Planetary Systems around Nearby Stars

Exploring the Origins of Our Solar System

Key New Science Capabilities

Near Diffraction-Limited in Near-IR (K-Strehl ~80%)

AO correction at Red Wavelengths (0.7-1.0 μm)

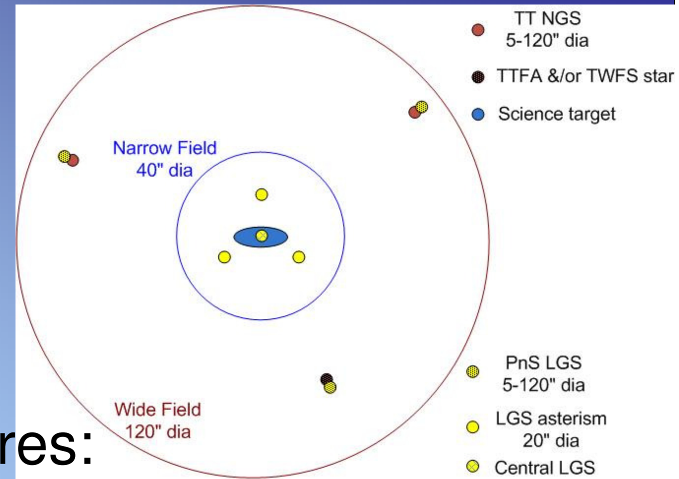
Increased Sky Coverage

Improved Angular Resolution, Sensitivity and Contrast

Improved Photometric and Astrometric Accuracy

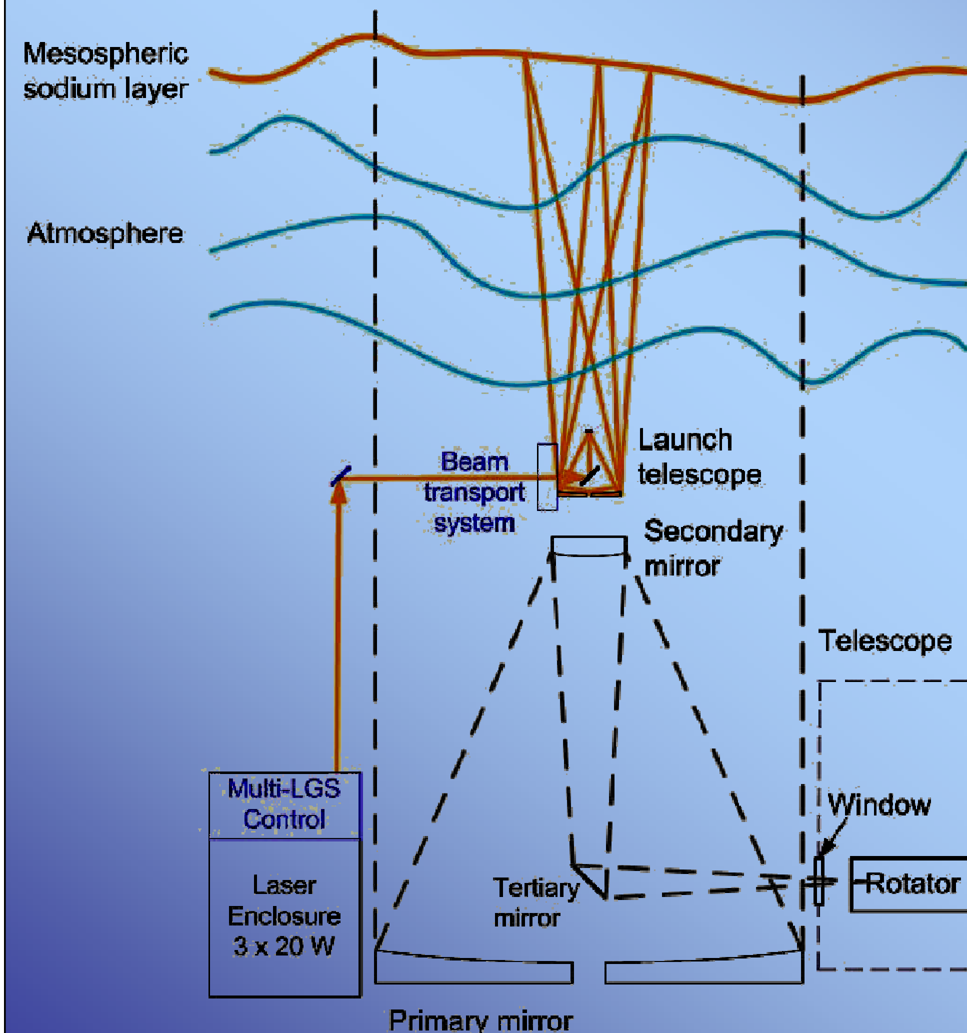
Imaging and Integral Field Spectroscopy

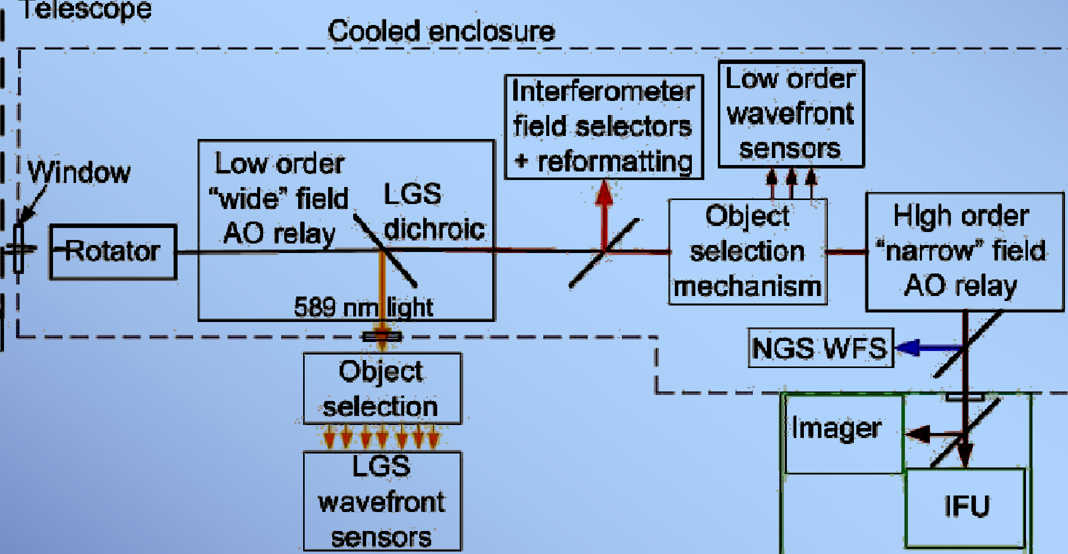
NGAO System Architecture



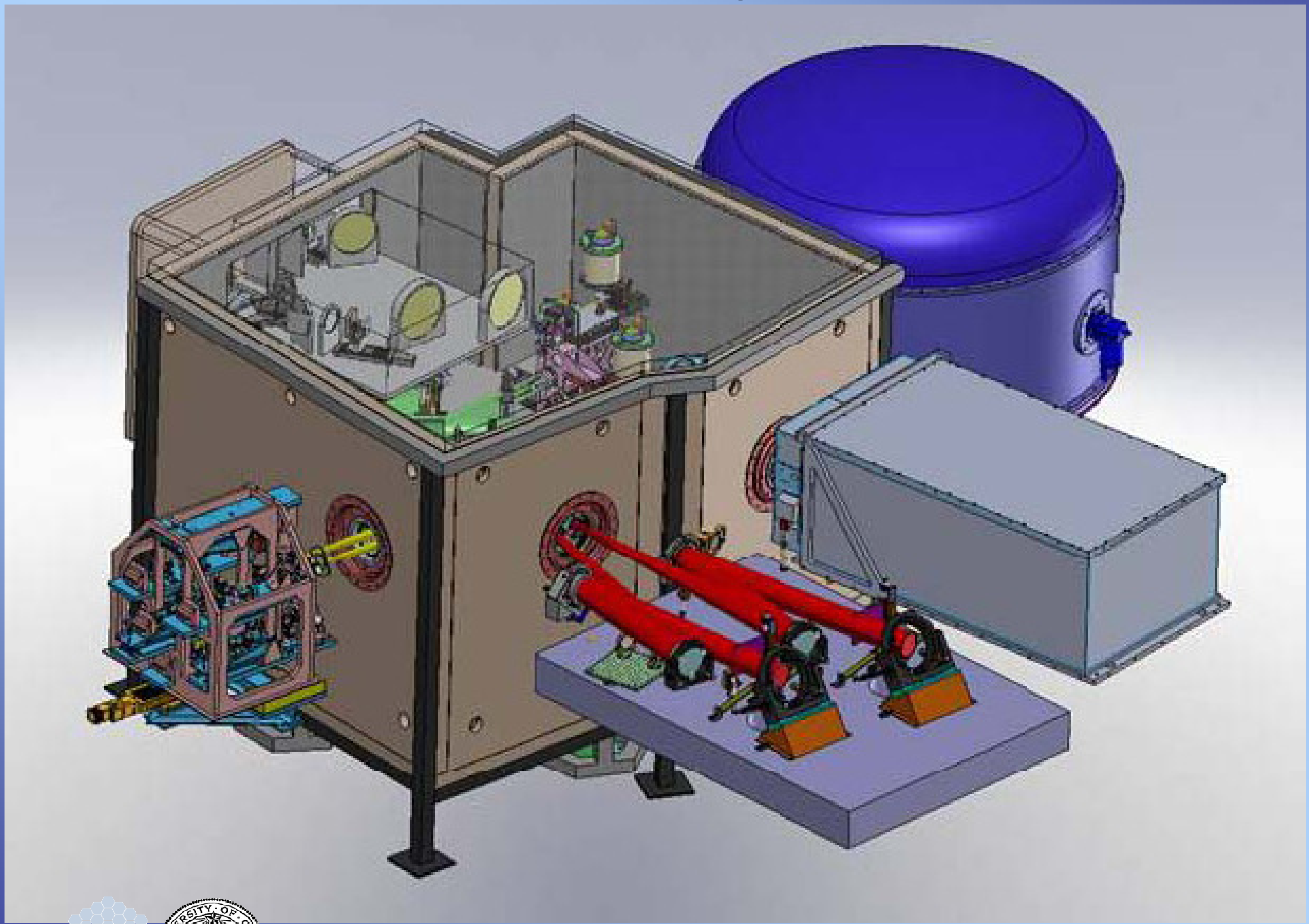
Key Features:

1. Fixed narrow field laser tomography
2. AO corrected NIR TT sensors
3. Cooled AO enclosure
4. Cascaded relay
5. Combined imager/IFU instrument



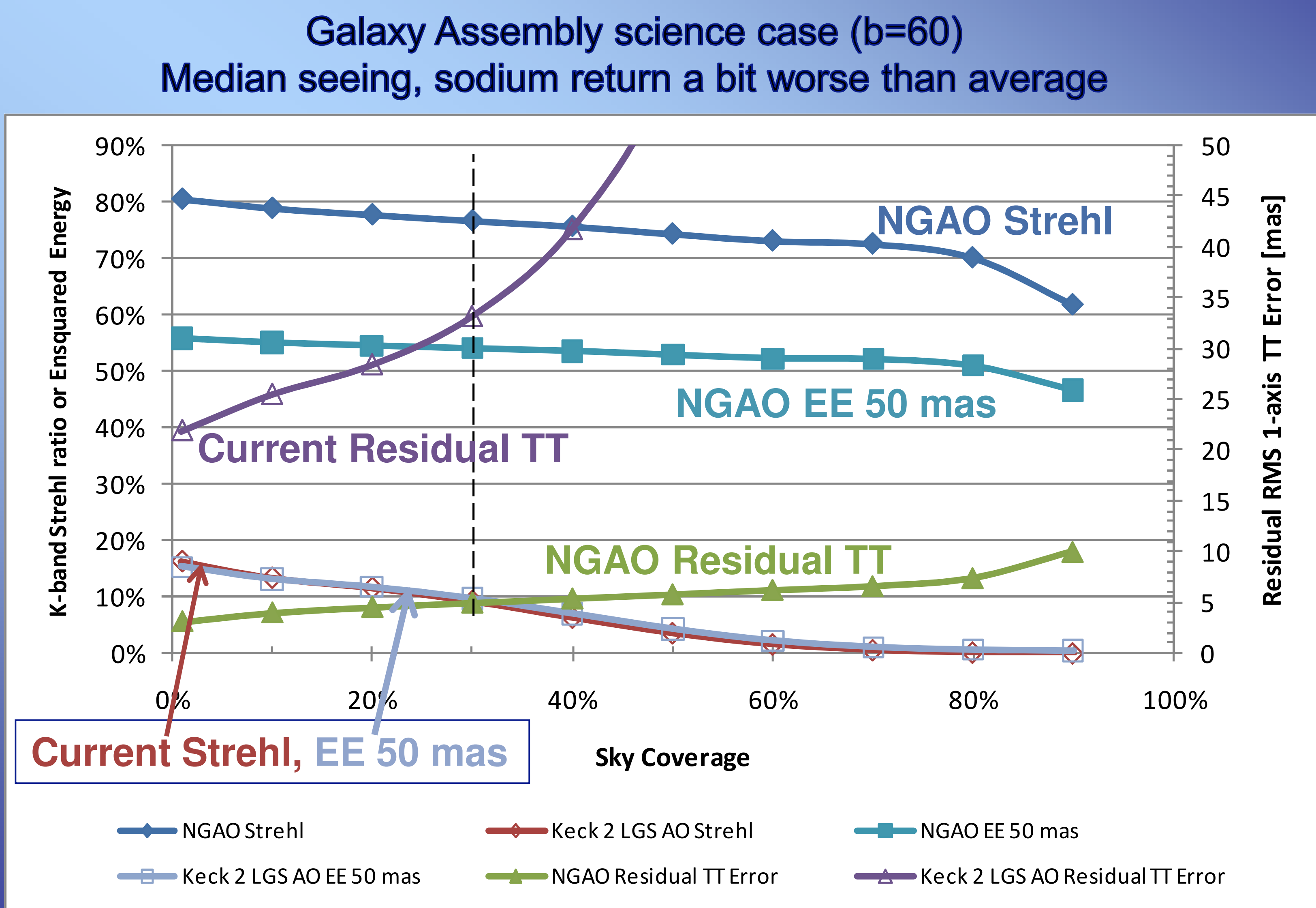


NGAO on Nasmyth Platform



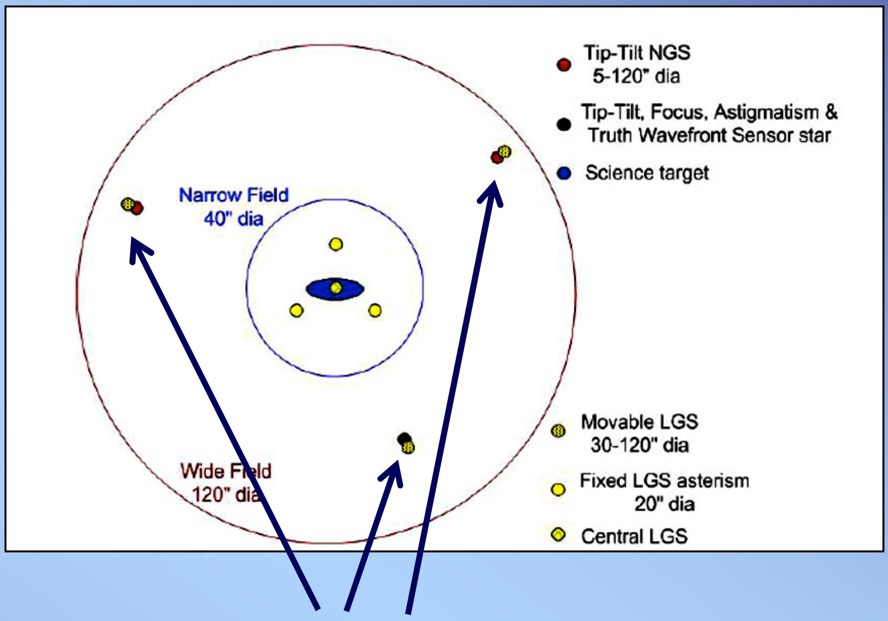
PDR in June 2010; NSF TSIP funded

Sky coverage of NGAO is dramatically better than Keck 2 LGS AO !



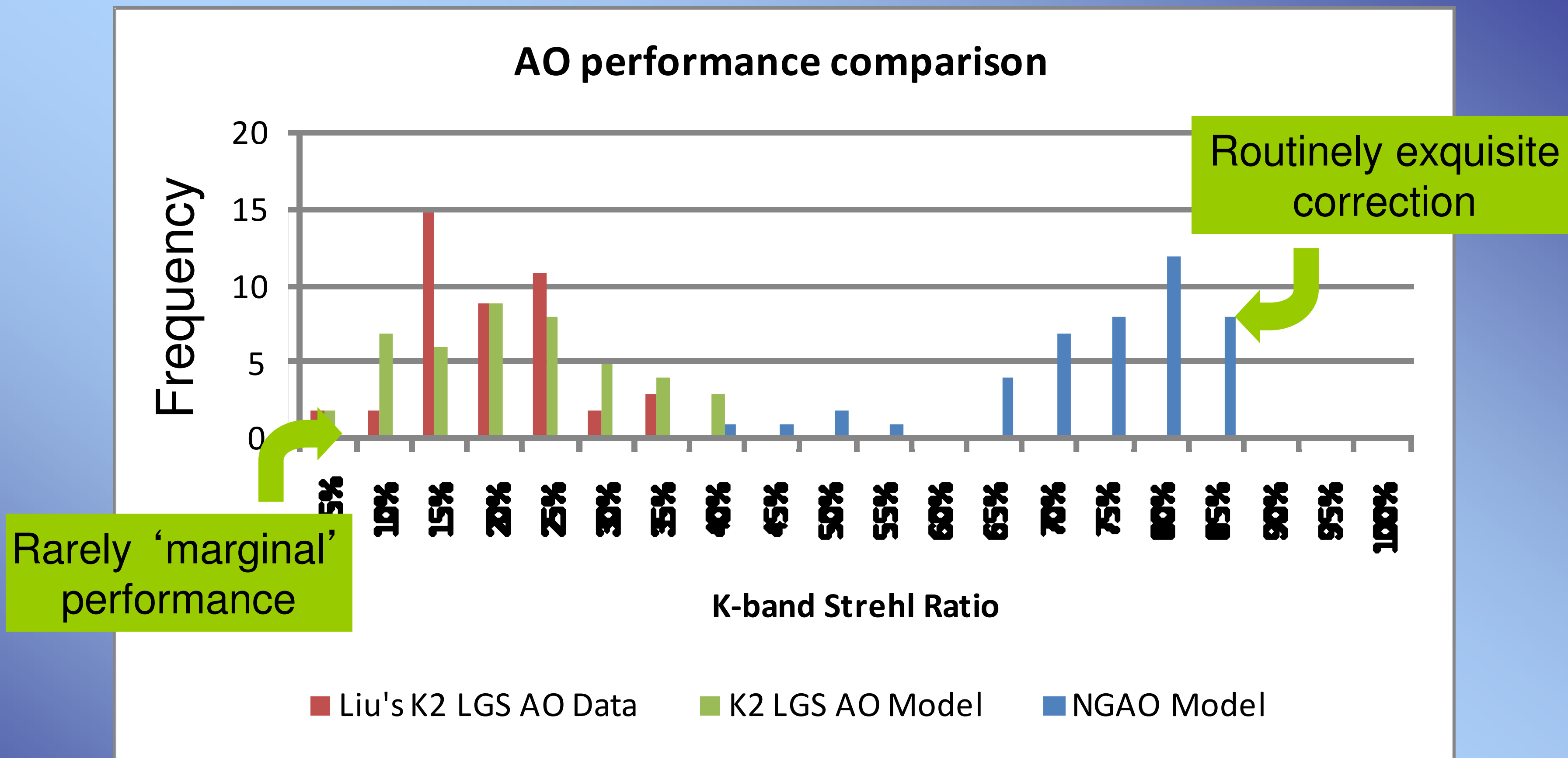
Sky Coverage is a Trade-off with Spatial Resolution

- NGAO: require three natural guide stars within a field 2 arc min in diameter.
- If these guide stars are farther away or fainter, the tip-tilt, focus, and astigmatism corrections degrade.
- But you are still left with very good high-order Strehl.
- Consequence: broader core of the PSF, but core contains same fraction of energy.



The key to NGAO's large sky coverage is AO correction of tip-tilt stars in the infrared

NGAO will change Keck AO observing experience



Monte Carlo performance estimate simulating 44 nights observing (Galaxy Assembly science case), drawing random values for r_0, wind speed, sodium abundance, and zenith angle (KAON 716, Figure 12)

Includes comparison with M. Liu's measured K2 LGS data (<SR> = 17%), the model prediction for K2 LGS (<SR> = 20%), and NGAO model prediction (<SR> = 70%)


Credit: Andrew Cooper