Pathfinders to ELT AO at W. M. Keck Observatory

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AO for ELT 2
Victoria, Canada
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What ELT AO Pathfinder Roles should AO on 10m Telescopes play?

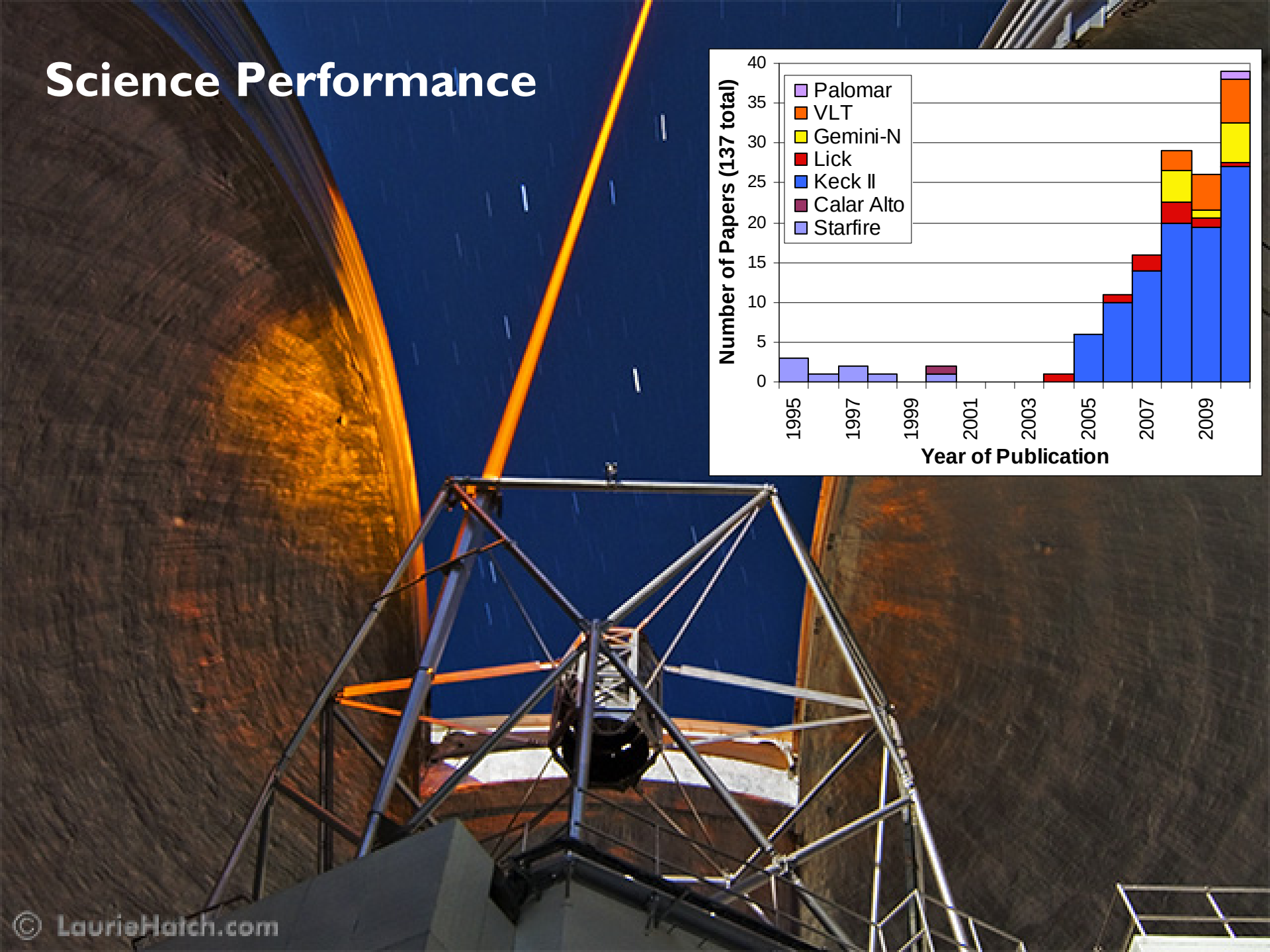
★ Quantitative understanding of on-sky AO performance & what's limiting performance

★ Implementation & on-sky demonstrations of technologies & techniques

★ Development of people and the AO user community

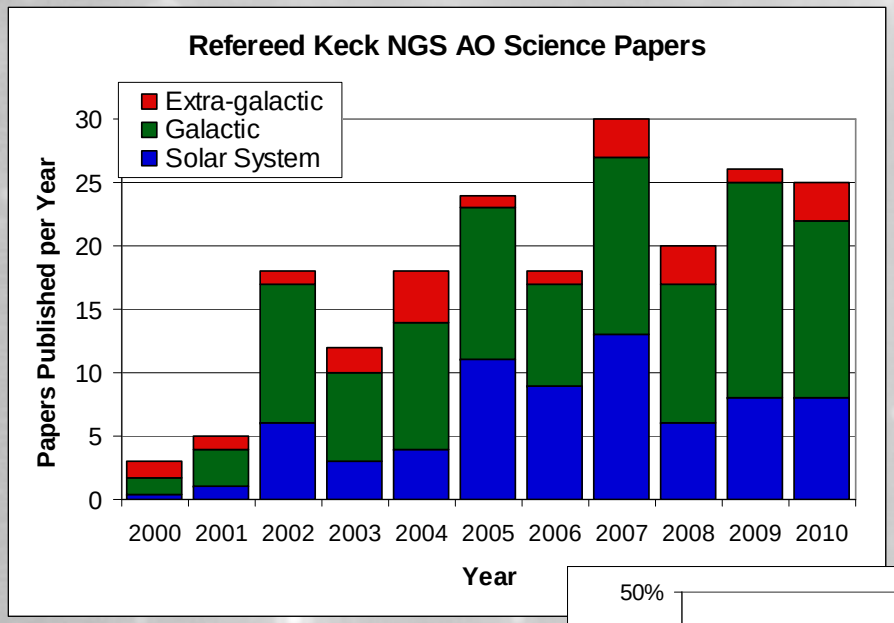
Within the above context what are we doing at WMKO?

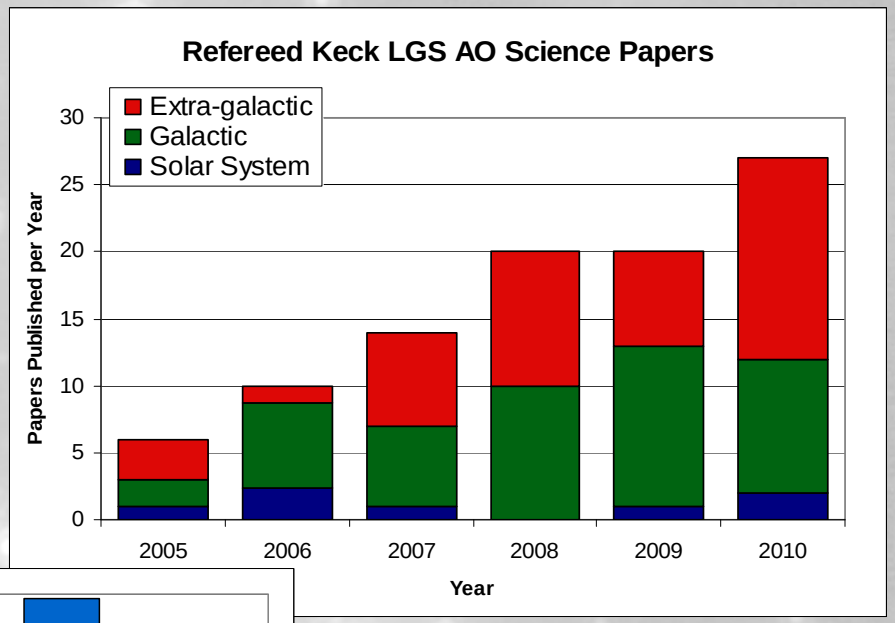
Science Performance

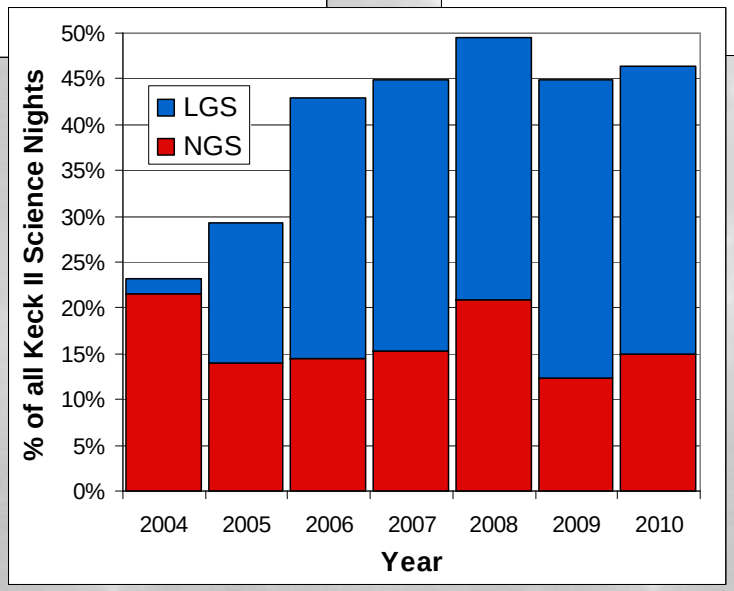


Science Productivity & Demand

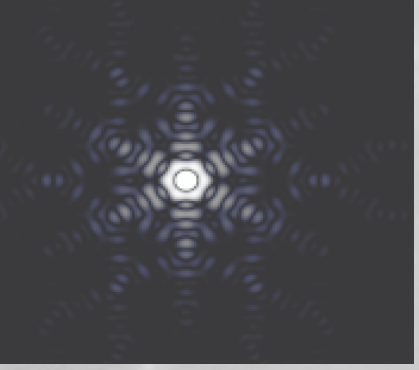
215 NGS & 118 LGS refereed science papers to date

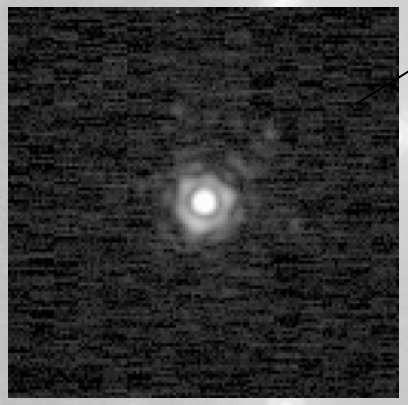


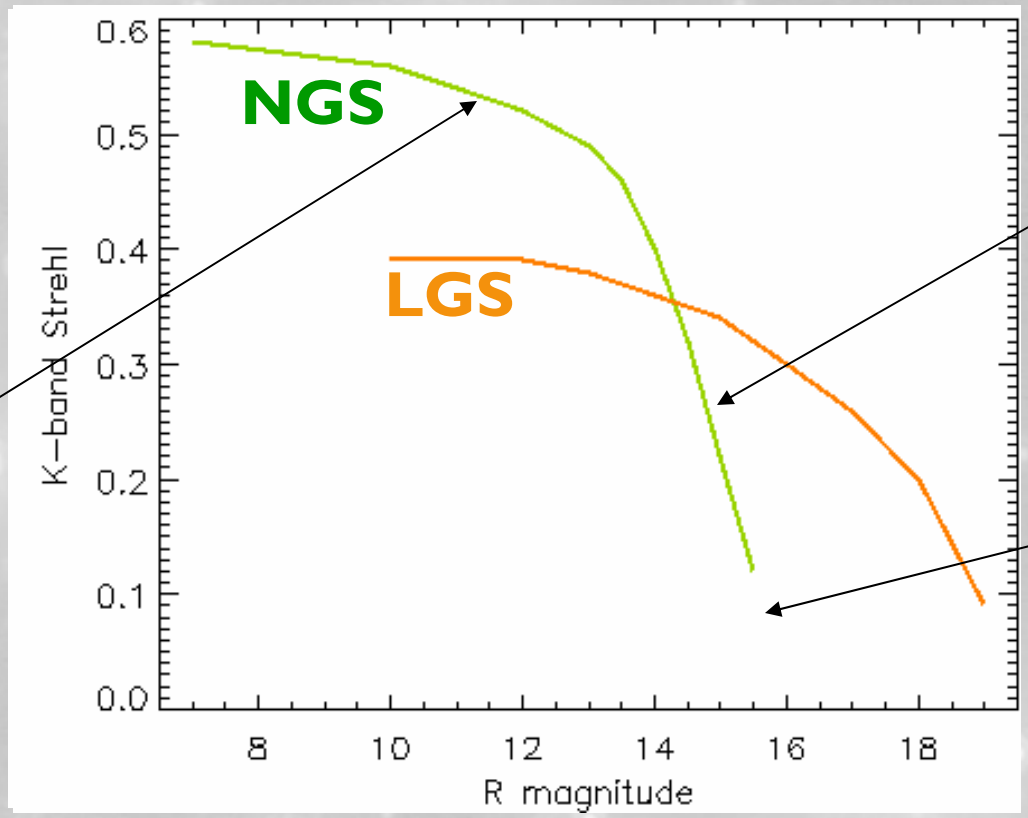


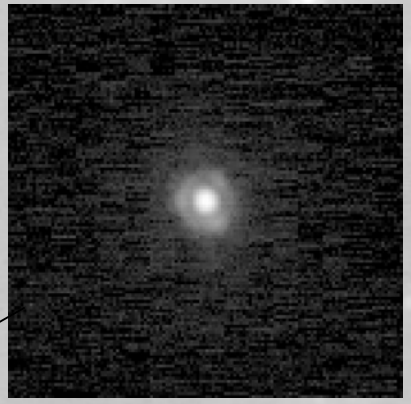


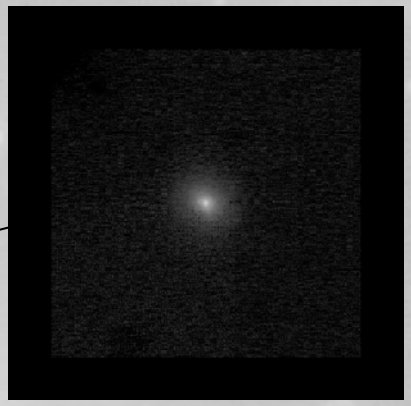
AO Performance

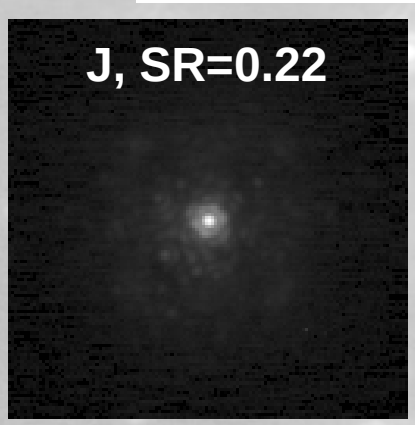


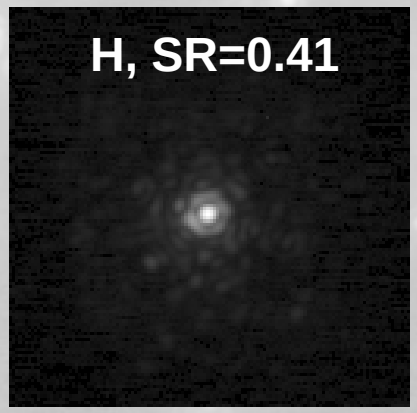


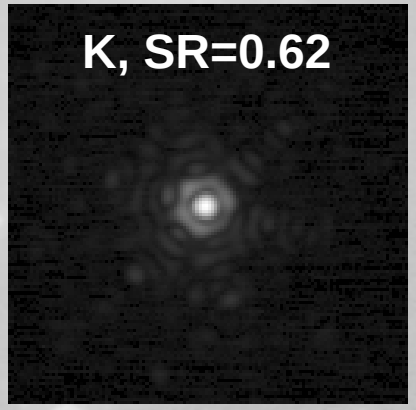








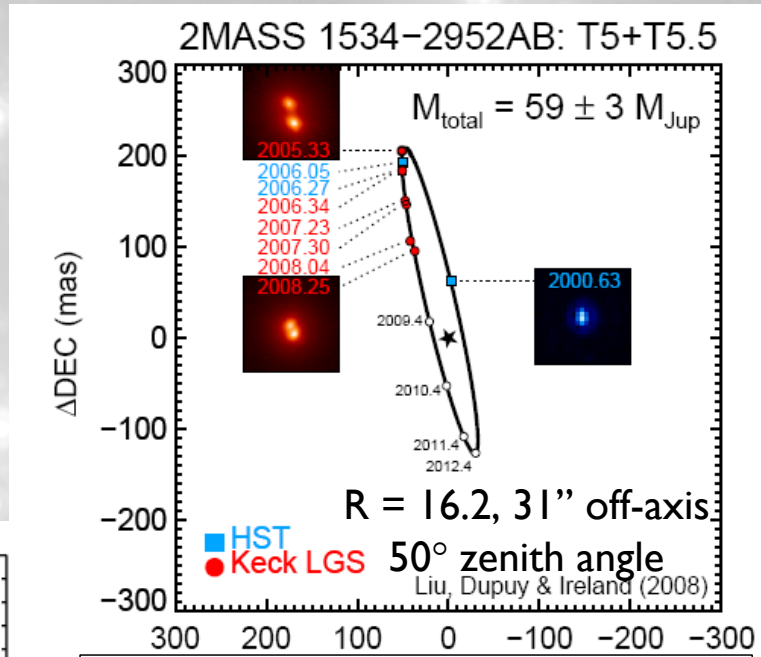


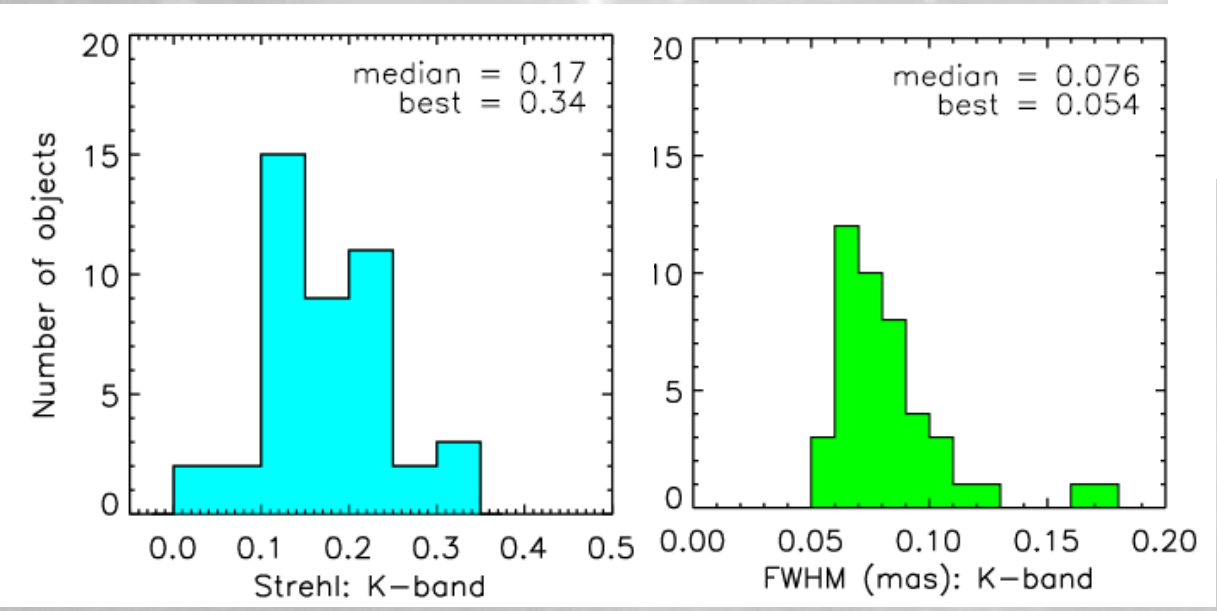


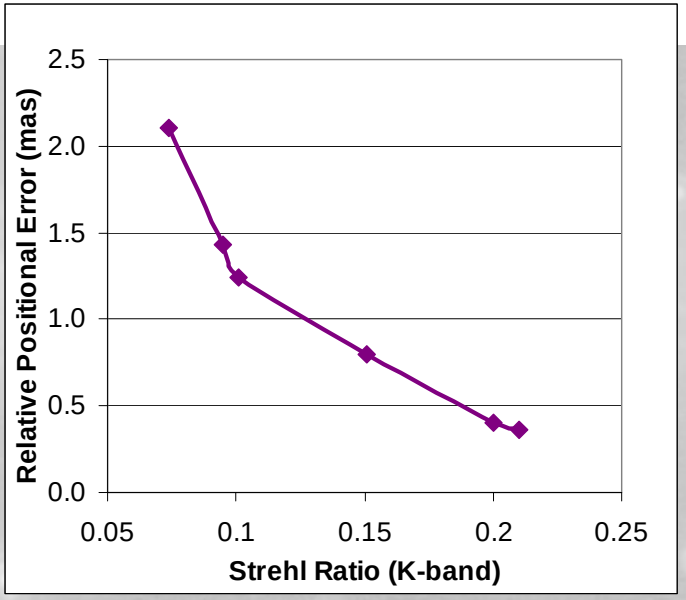
LGS AO Performance Variability

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







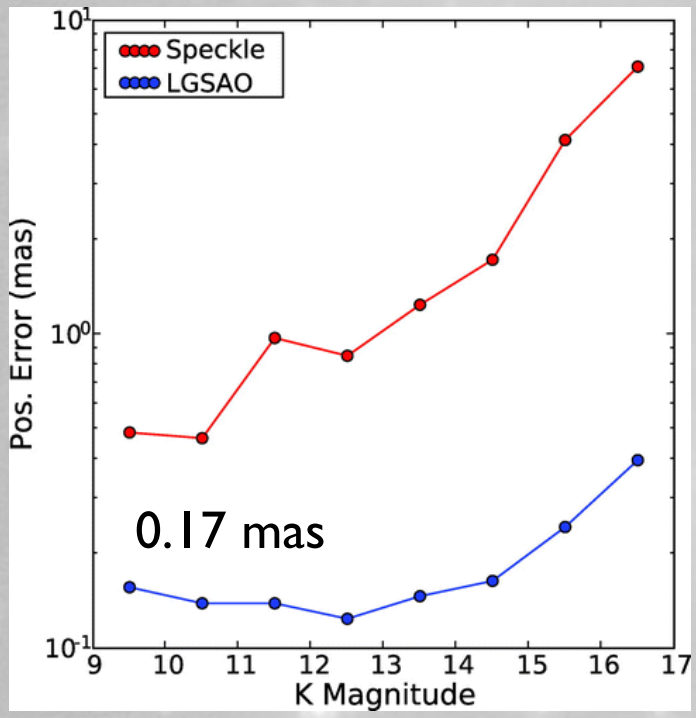
What's Limiting Performance?

Error Term (nm)	Bright NGS	T Dwarf Binary
Atmospheric Fitting	118	127
Telescope Fitting	66	66
Science Camera	110	110
DM Bandwidth	129	206
DM Measurement	156	242
Tip-tilt Bandwidth	102	260
Tip-tilt Measurement	19	186
LGS Focus Error	46	70
Focus Anisoplanatism	164	189
LGS High Order Error	80	80
Calibration Errors	30	30
Miscellaneous	70	74
Total Wavefront Error	351	538
K-band Strehl	0.37	0.09
K Strehl without tip/tilt	0.40	0.22
NGS R-magnitude	10	16.2
NGS off-axis distance	0	31
Zenith angle	10	50

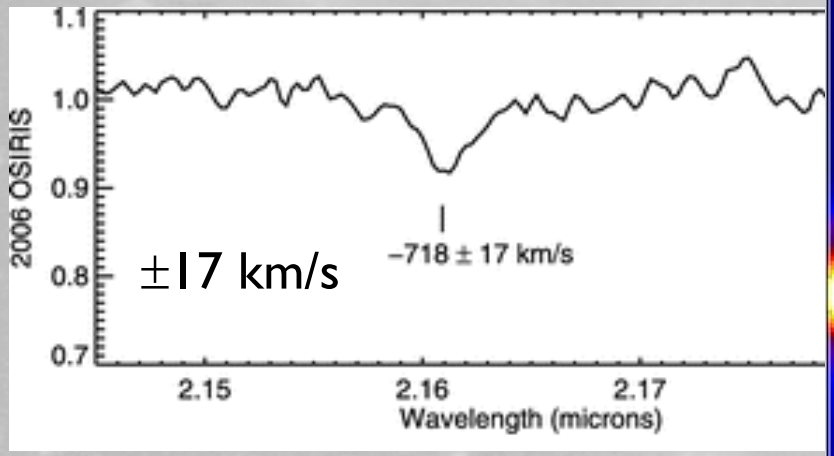
LGS beacon

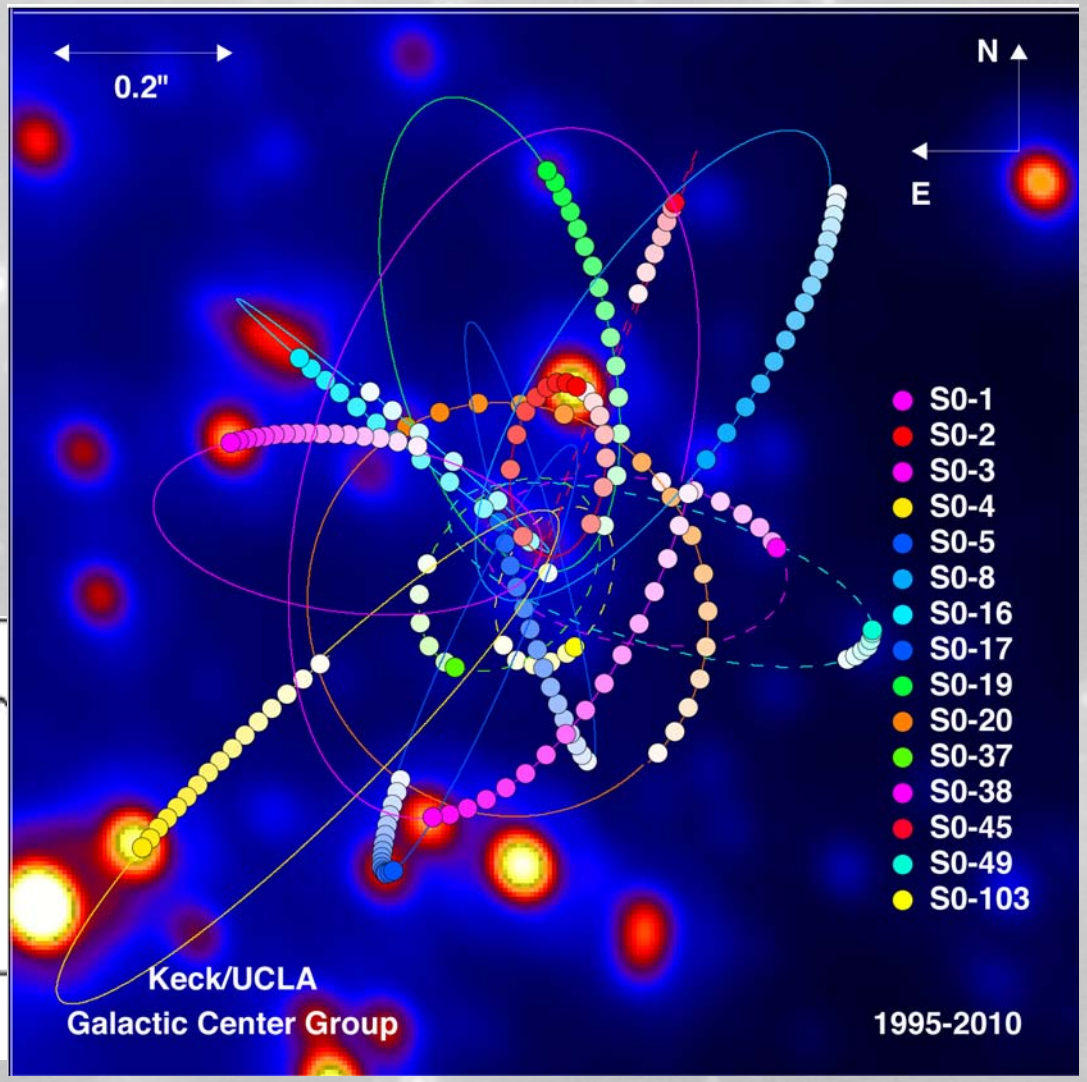
Tip-tilt sensor

Galactic Center with Keck LGS AO



Limitation = Source Confusion → PSF





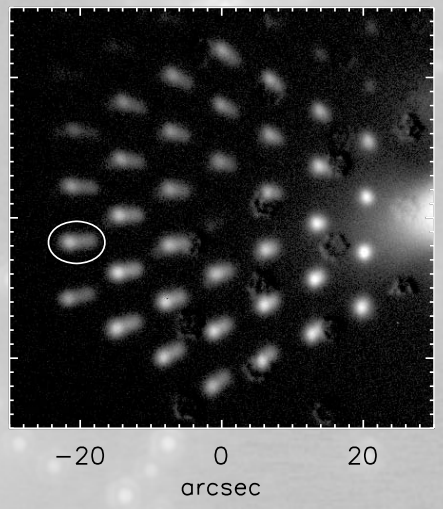
US AO Roadmap 2008: High Priority Investment Needs

Discipline	Element	Goal
Wavefront Sensing	LGS Beacons	Availability of robust, cost-effective LGS AO system lasers
	Tomographic Reconstruction	Validation of the tomographic wavefront sensing approaches to predicted small residual wavefront errors …
	Wavefront Sensor Design	Validation of robust, versatile wavefront sensors ... to maximize sky coverage and reduce laser costs
Wavefront Correction	High-Stroke DMs	Development of scalable, cost-effective deformable mirror technologies …
Calibration	PSF Estimation	Understanding of the delivered PSF in order to obtain very accurate relative photometry and astrometry
Human Resources	Education and Training	Creation of a new generation of experts …

Current Keck AO Development Projects

Keck II Center Launch

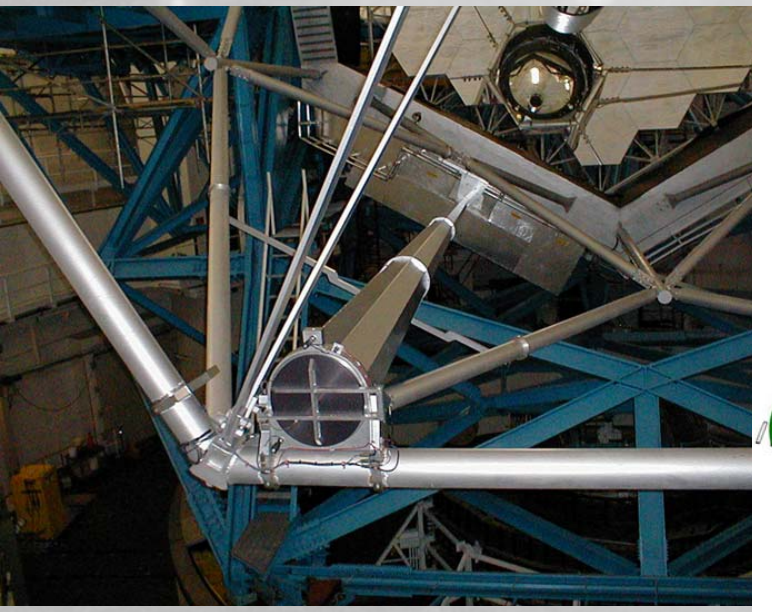
1st science in late 2012

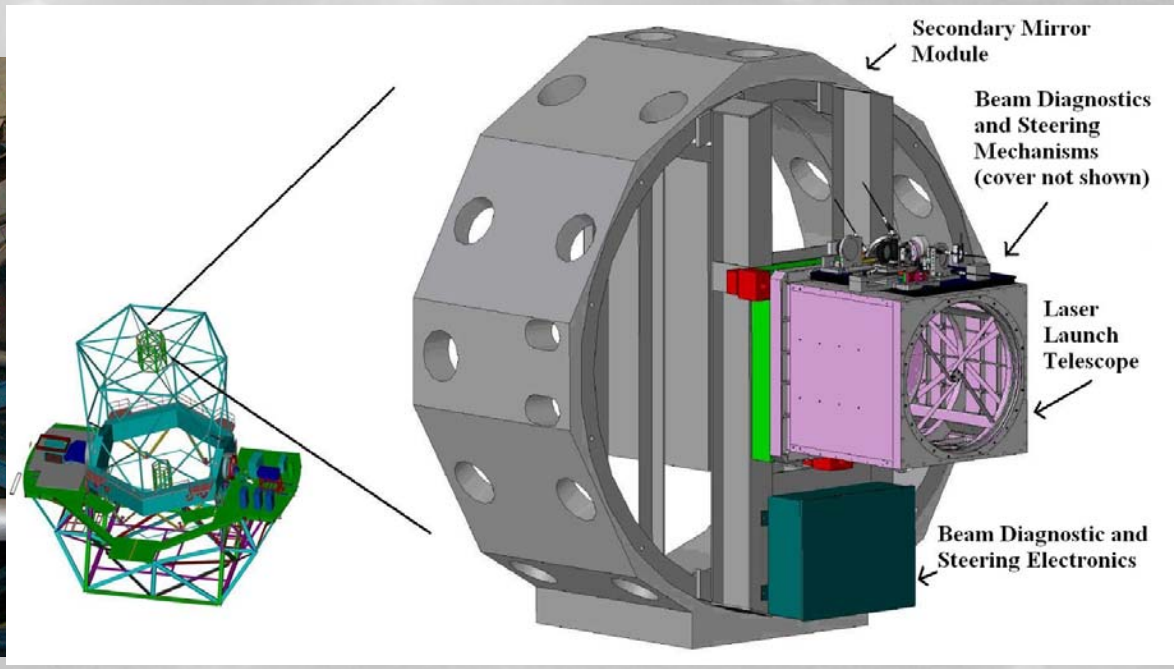


PDR completed in October 2010

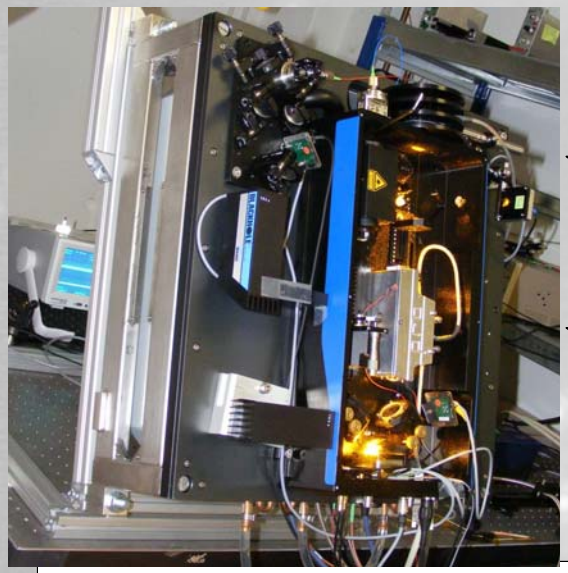
Launch telescope DDR in April 2011

NSF MRI funded



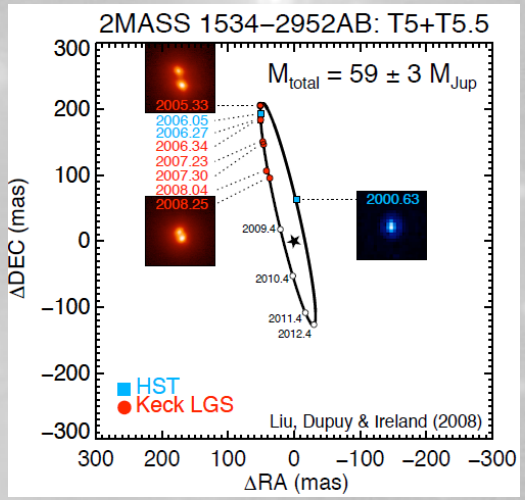


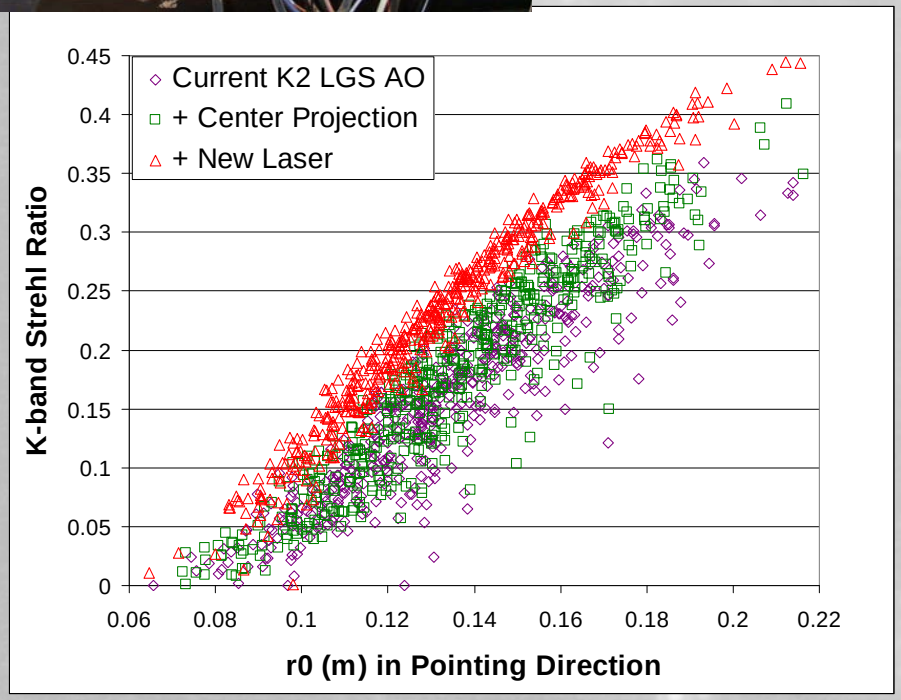
New Keck II Laser

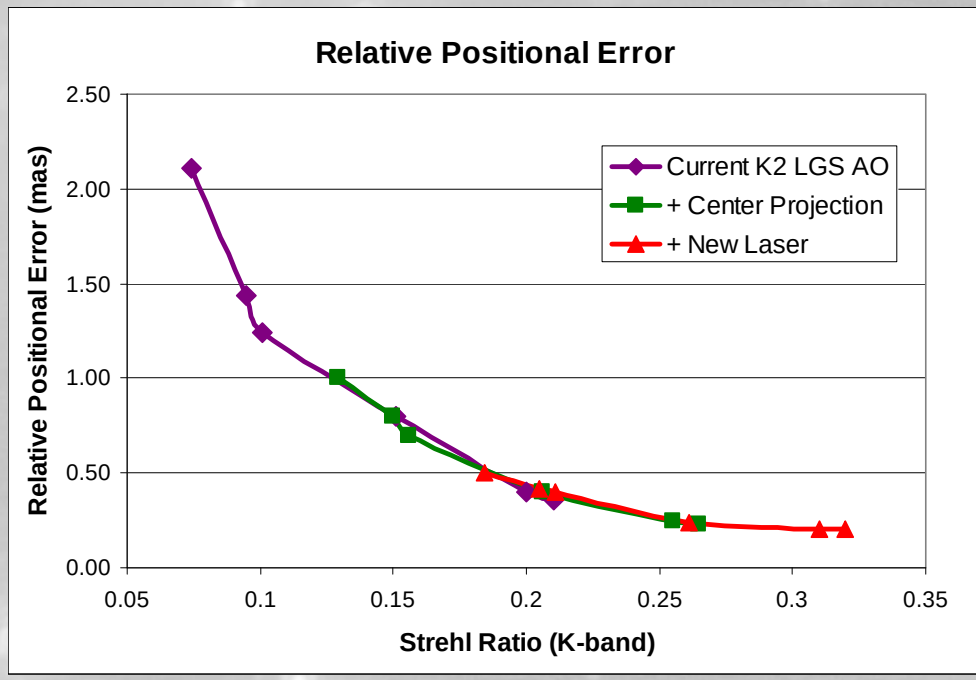


1st science in 2014

- ★ TOPTICA/MPBC laser (V. Karpov talk)
- ★ Collaboration with ESO & TMT

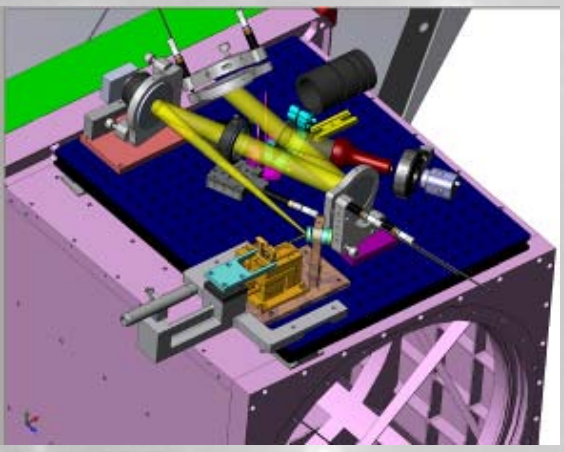


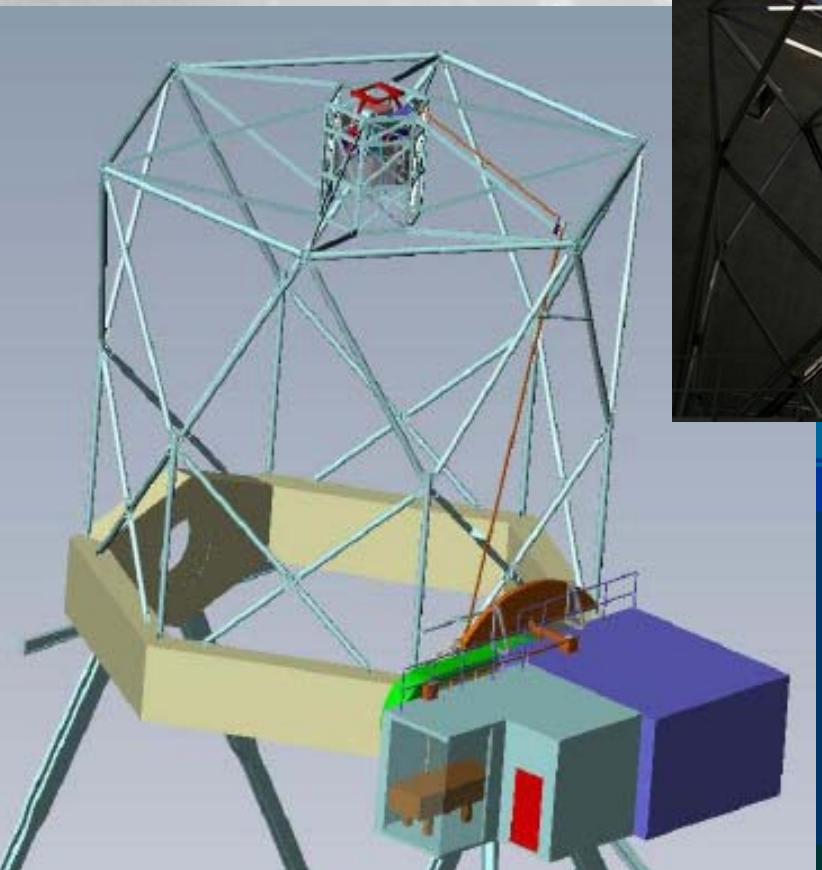


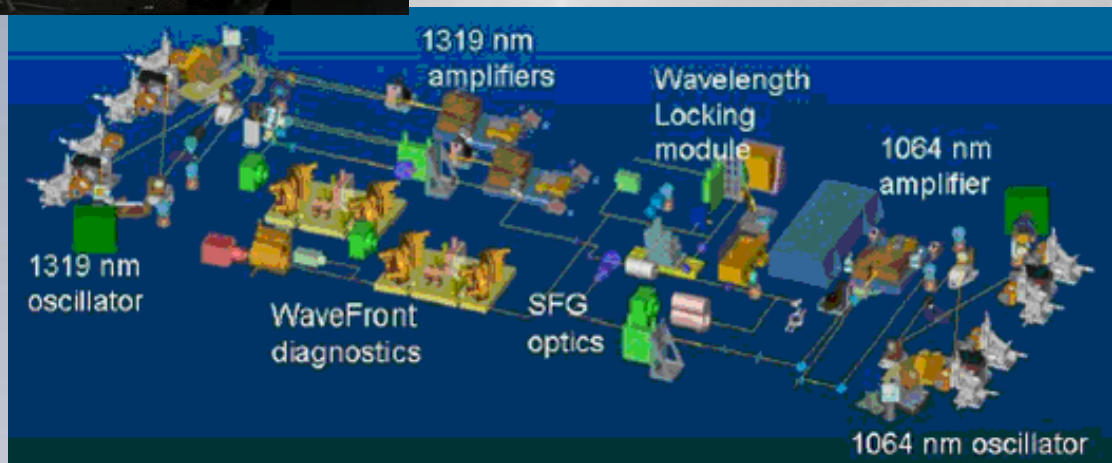


Keck I LGS AO

1st science in 2012





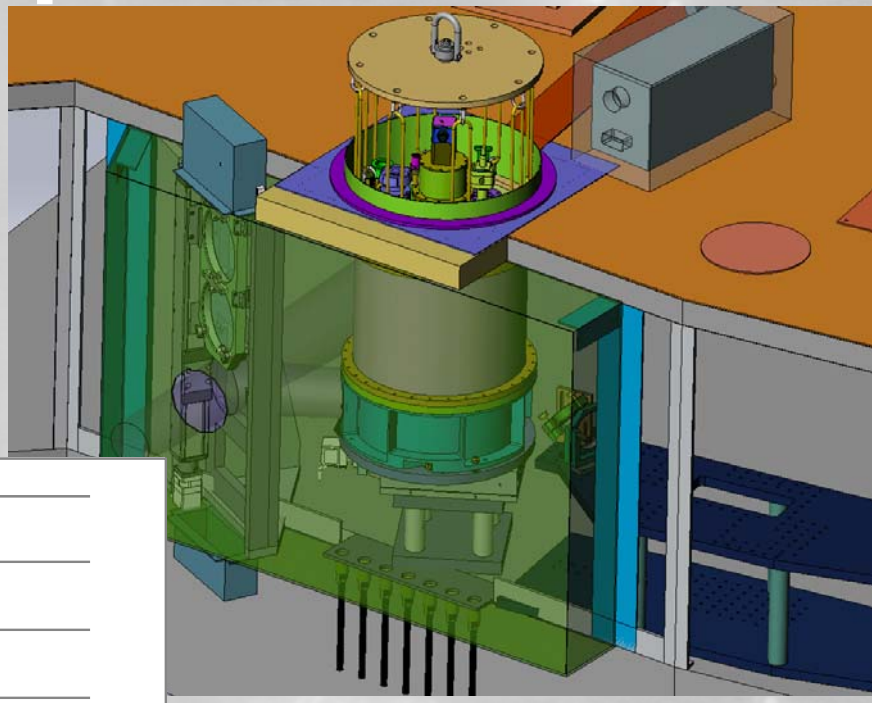


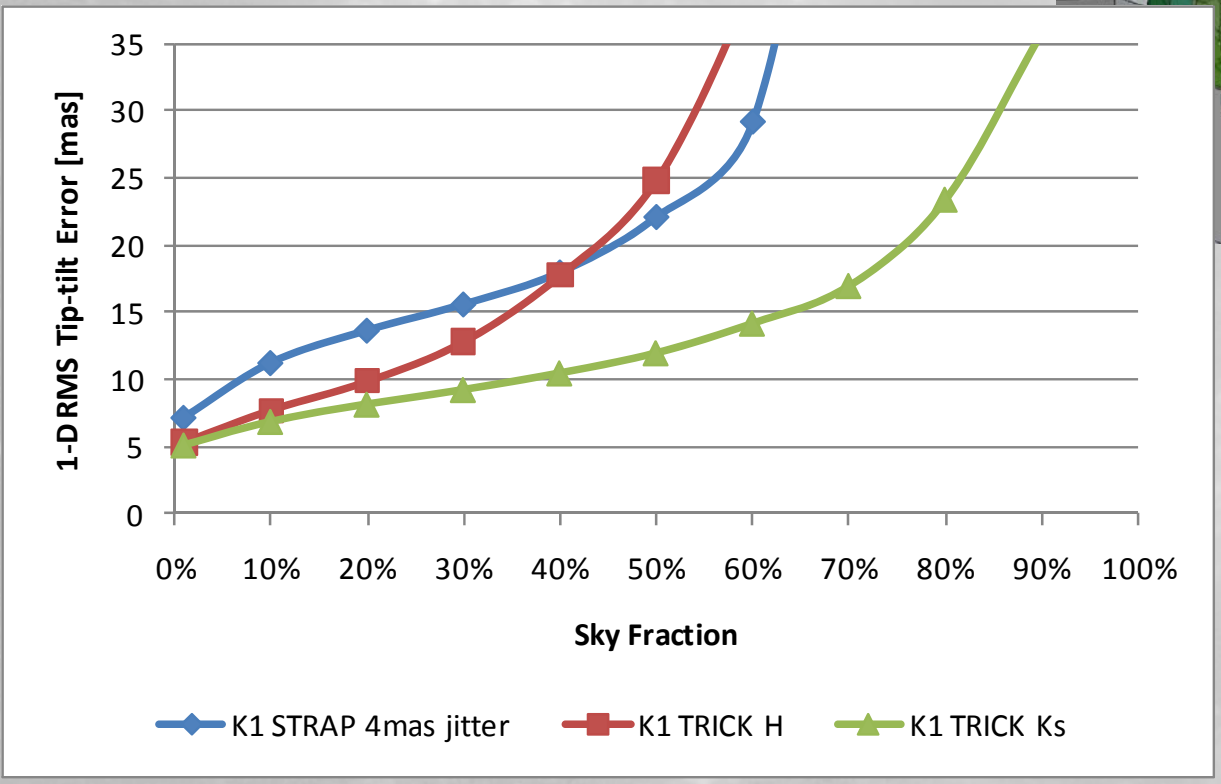
Keck I Near-IR Tip-Tilt Sensor

1st science in late 2013

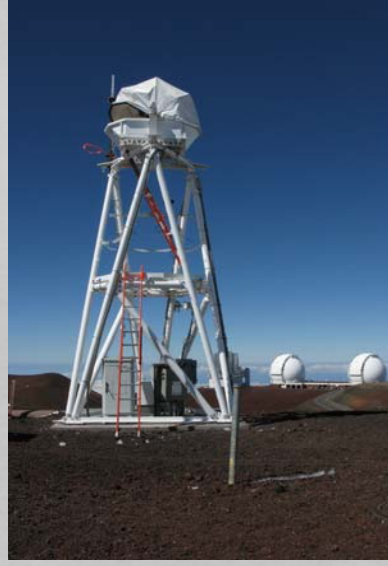
PDR in April 2011

NSF ATI funded





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)
  - Will submit an ATI proposal in Nov.

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)

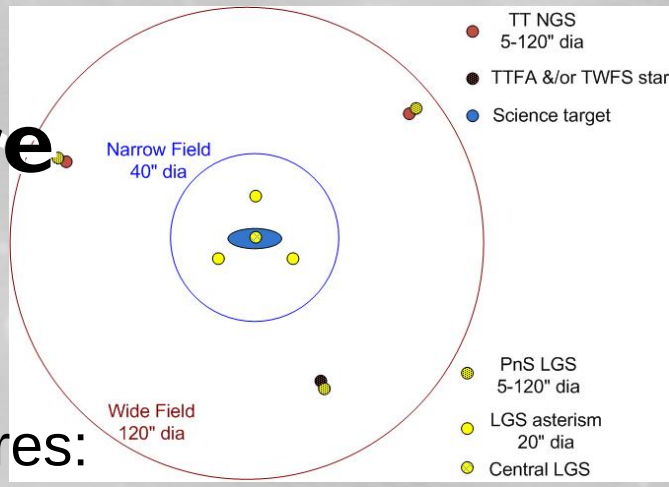
Increased Sky Coverage

Improved Angular Resolution, Sensitivity and Contrast

Improved Photometric and Astrometric Accuracy

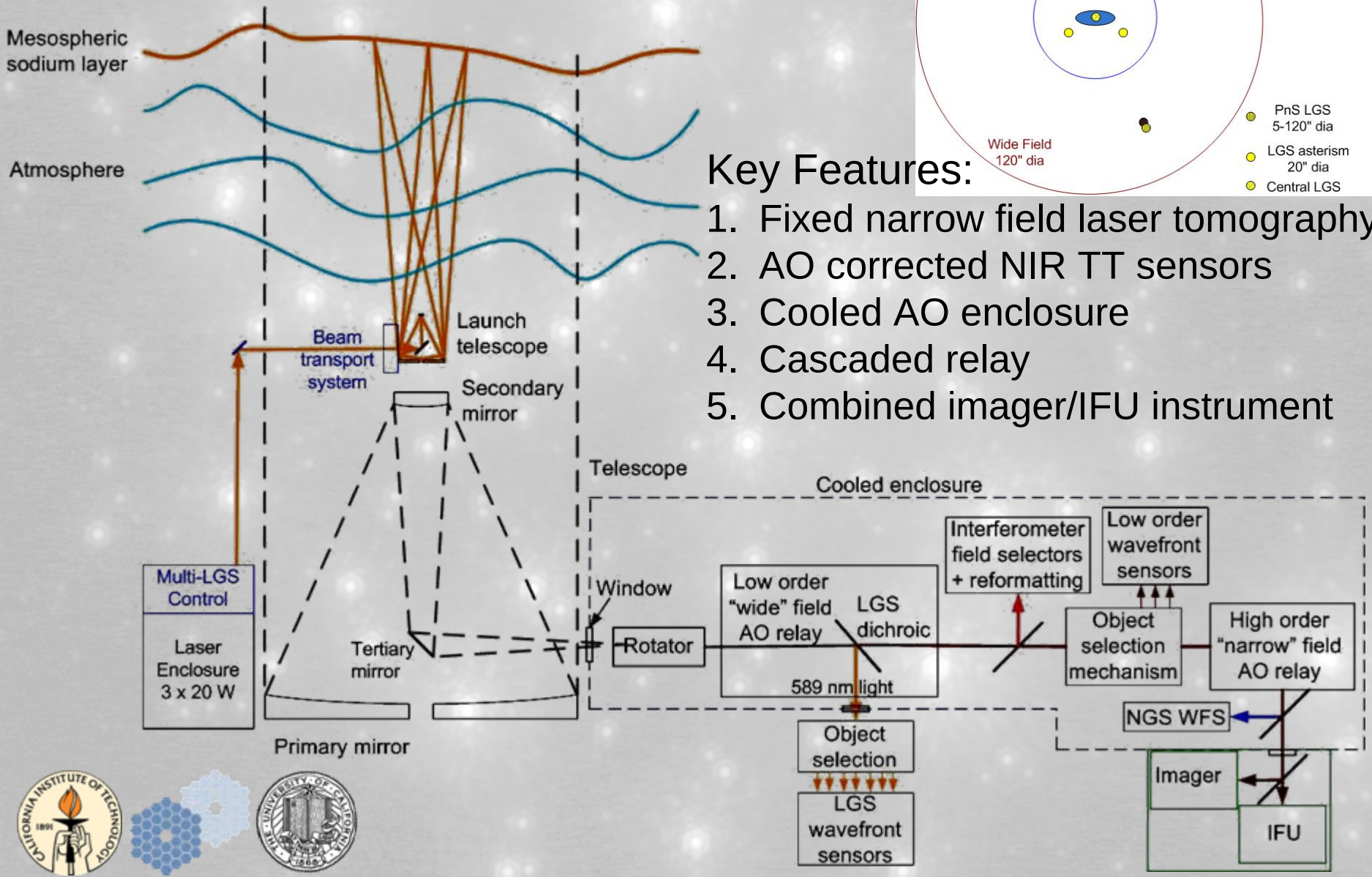
Imaging and Integral Field Spectroscopy

NGAO System Architecture

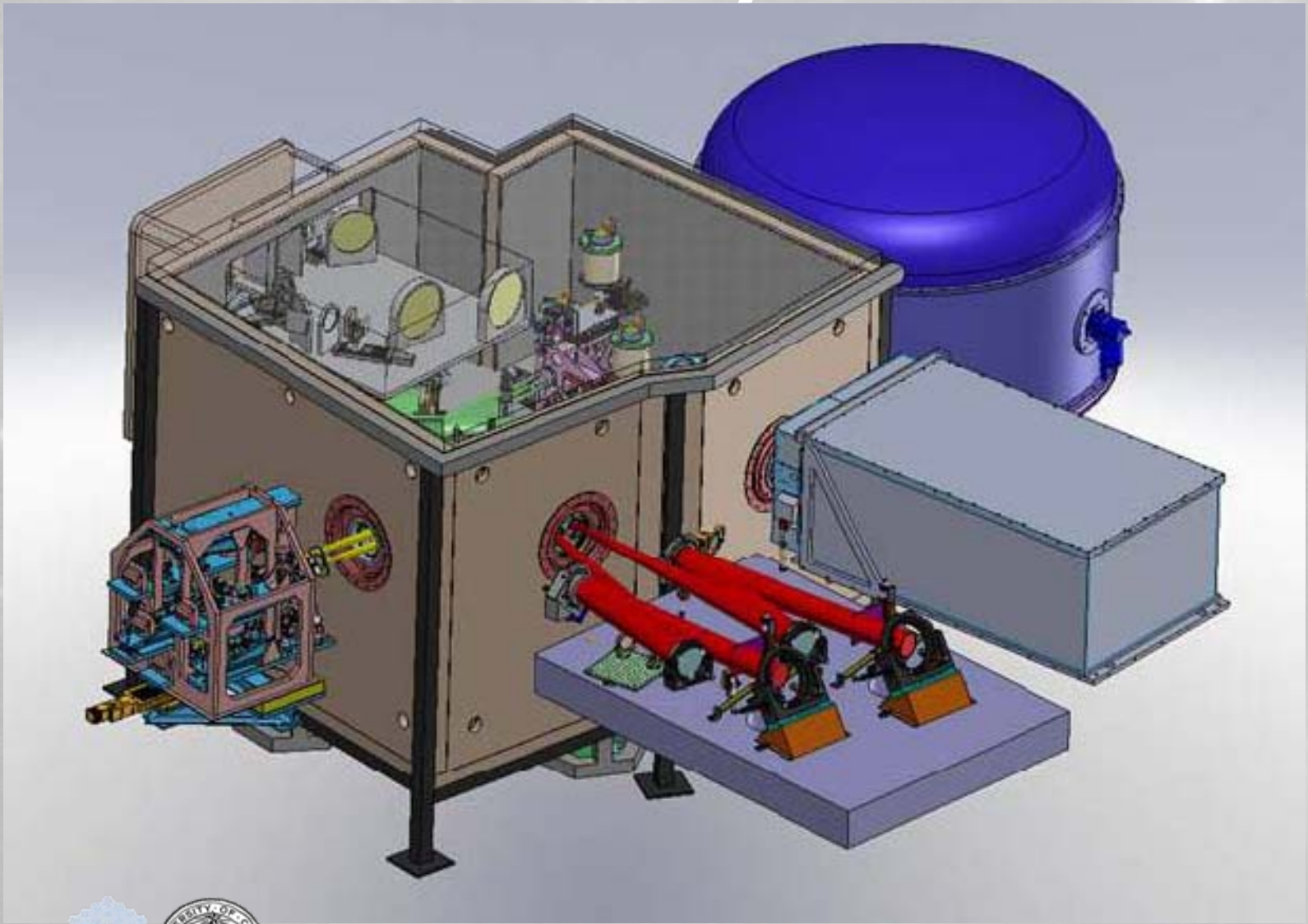


Key Features:

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

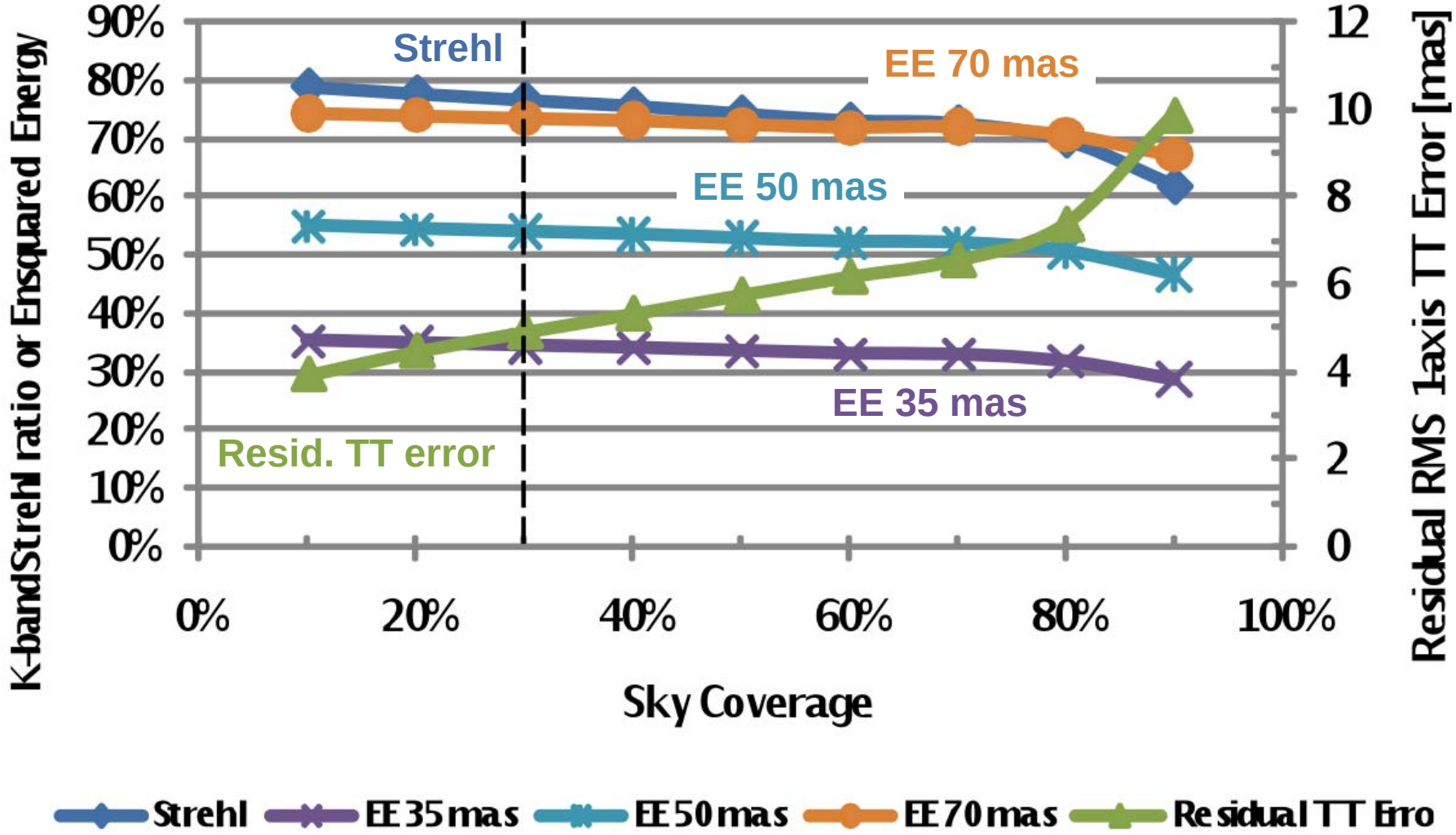


NGAO on Nasmyth Platform

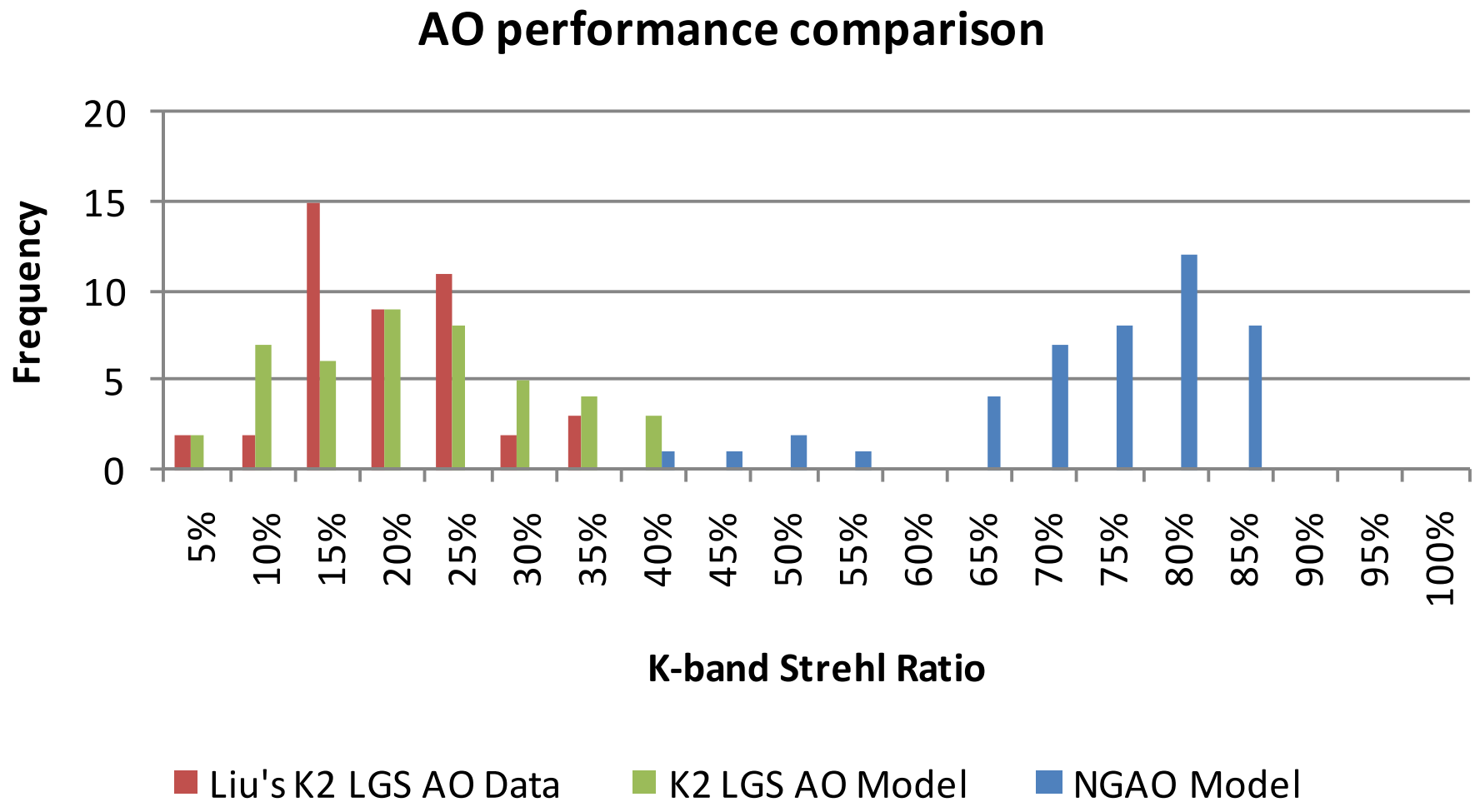


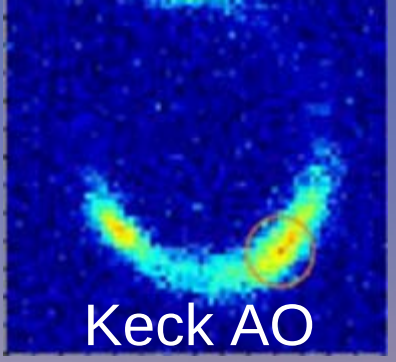
PDR in June 2010; NSF TSIP funded

NGAO Performance vs. Sky Coverage
(Galaxy Assembly Science Case)

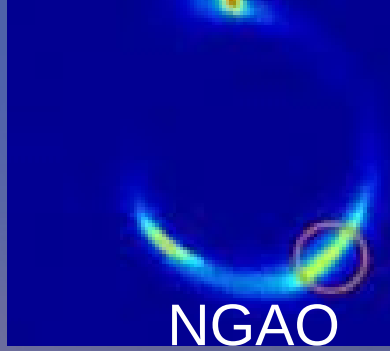


NGAO changes the AO Observing Experience





In Closing



★ Keck AO has been delivering great science

★ Keck AO & NGAO are pathfinders for ELT AO & for preparing the science community

★ We look forward to additional collaborations with ELT-AO projects