Science Impact
Performance
Performance Limitations
Recent Developments in Keck AO
Science Productivity

![Graph showing the number of papers published from 1995 to 2011 for different telescopes: Subaru, Palomar, VLT, Gemini-N, Lick, Keck II, Calar Alto, and Starfire. The y-axis represents the number of papers, and the x-axis represents the year of publication.]
Science Productivity

![Graph showing number of papers published by year in different categories: Extra-galactic, Galactic, and Solar System. The x-axis represents the year of publication from 1995 to 2011, and the y-axis represents the number of papers. The graph indicates a significant increase in the number of papers published in the later years, particularly in 2010 and 2011.](image)
Keck LGS Science Demand & Efficiency

% of all Keck II Science Nights

Year

Nights in Previous Year / Papers

2006 2007 2008 2009 2010 2011

NGS Ratio

LGS Ratio

0 1.0 2.0 3.0 4.0 5.0 6.0 7.0

2004 2005 2006 2007 2008 2009 2010 2011

0% 5% 10% 15% 20% 25% 30% 35% 40% 45% 50%

LGS

NGS
Galactic Center with Keck LGS AO

Limitation = Source Confusion → PSF

0.17 mas

±17 km/s

Keck/UCLA
Galactic Center Group
1995-2010
HST WFC3-IR, F127M, F139M, F153M, Do et al. in prep
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

10 arc sec
Nucleus of Mrk 273

- HST ACS B-band
- HST ACS I-band
- NICMOS NIC2 K-band
- Keck AO NIRC2 K’-band

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: \( M_{BH} = (2 \pm 1) \times 10^9 \, M_{\text{sun}} \)
AO Performance

NGS Performance

AO Performance

LGS

K, SR=0.62

H, SR=0.41

J, SR=0.22
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?

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<th>Error Term</th>
<th>KII Dye Laser off-axis</th>
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<td>Science Camera</td>
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<tr>
<td>Focus Anisoplanatism</td>
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<td>Calibration Errors</td>
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<td>Miscellaneous</td>
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<tr>
<td>Total Wavefront Error</td>
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<tr>
<td>K-band Strehl</td>
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**Science Case Parameters**

<table>
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<tr>
<th></th>
<th>2MASS 1534-2952AB</th>
<th>Galactic Center</th>
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<tr>
<td>NGS R-magnitude</td>
<td>16.2</td>
<td>14</td>
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<tr>
<td>NGS off-axis distance (&quot;)</td>
<td>31</td>
<td>19.3</td>
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<tr>
<td>Zenith angle (deg)</td>
<td>50</td>
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</tbody>
</table>

- LGS beacon
- Tip-tilt sensor
- LGS asterism
- Plus lack of PSF knowledge
AO System Developments at Keck
Left Nasmyth Platform

Enclosure with roof removed

Elevation Ring

AO Optics Bench

K2: NIRC2
K1: OSIRIS

K2: NIRSPEC or Dual Star Module

Electronics Racks

Nasmyth Platform

Rails to deck
Keck Side & Center Launch

Side launch Keck II  Center launch Keck I
Keck I LGS AO
10 shared-risk science nights in May/June

OSIRIS – 25'' off-axis
45 mas FWHM (Kn5)
Keck II Center Launch
1\textsuperscript{st} science 2014

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

K-band Strehl Ratio vs. r0 (m) in Pointing Direction

- Current K2 LGS AO
- + Center Projection
- + New 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 $\approx$ 80%)
- AO correction at Red Wavelengths (0.7-1.0 $\mu$m)
- 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!

Galaxy Assembly science case (b=60)
Median seeing, sodium return a bit worse than average

Current Strehl, EE 50 mas

Current Residual TT

NGAO Strehl

NGAO EE 50 mas

NGAO Residual TT

K-band Strehl ratio or Ensquared Energy vs. Sky Coverage
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 ($<SR> = 70\%$)