The Next-Generation Adaptive Optics System at Keck Observatory

Introduction & Overview

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on behalf of the NGAO concept study group

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Keck NGAO: Background

- This concept proposed to the Keck science steering committee this past June
- SSC allocated study money for 18 month system design phase
- Joint effort of Keck, Caltech, and University of California

Keck Next-Generation Adaptive Optics (NGAO) is designed to provide powerful new capabilities

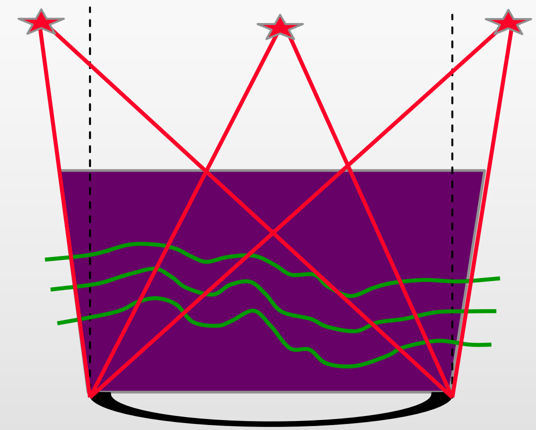
1. **Near diffraction-limited in the near-IR (Strehl >80%)**
   - A PSF with unprecedented precision, stability and contrast.

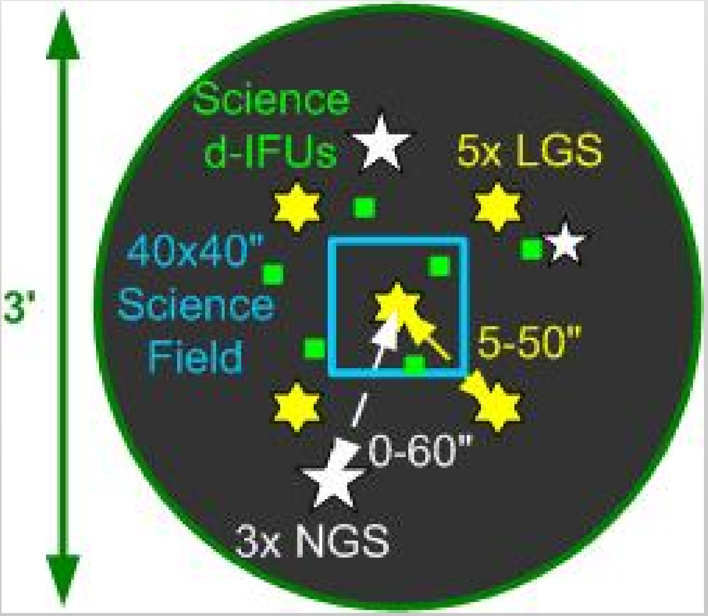
2. **Vastly increased sky coverage and multiplexing**
   - Enables a much broader range of science programs.

3. **AO correction at red optical wavelengths (0.6-1.0um)**
   - Highest angular resolution of any filled-aperture telscope.

Point Design Concept for NGAO

- **Multi-laser guidestar tomography, e.g. 5 LGS**
  - **cone effect mitigation**
  - **variable radius (high on-axis Strehl vs wider field correction)**
- **3 corrected tip-tilt stars for good sky coverage**
- **Wavefront sensors**
  - **LGS: Shack-Hartman**
  - **NGS: MOAO correction with MEMS, near-IR, pyramid WFS for tip/tilt/focus/astig**
  - **NGS: Slow S-H WFS for LGS calibration**

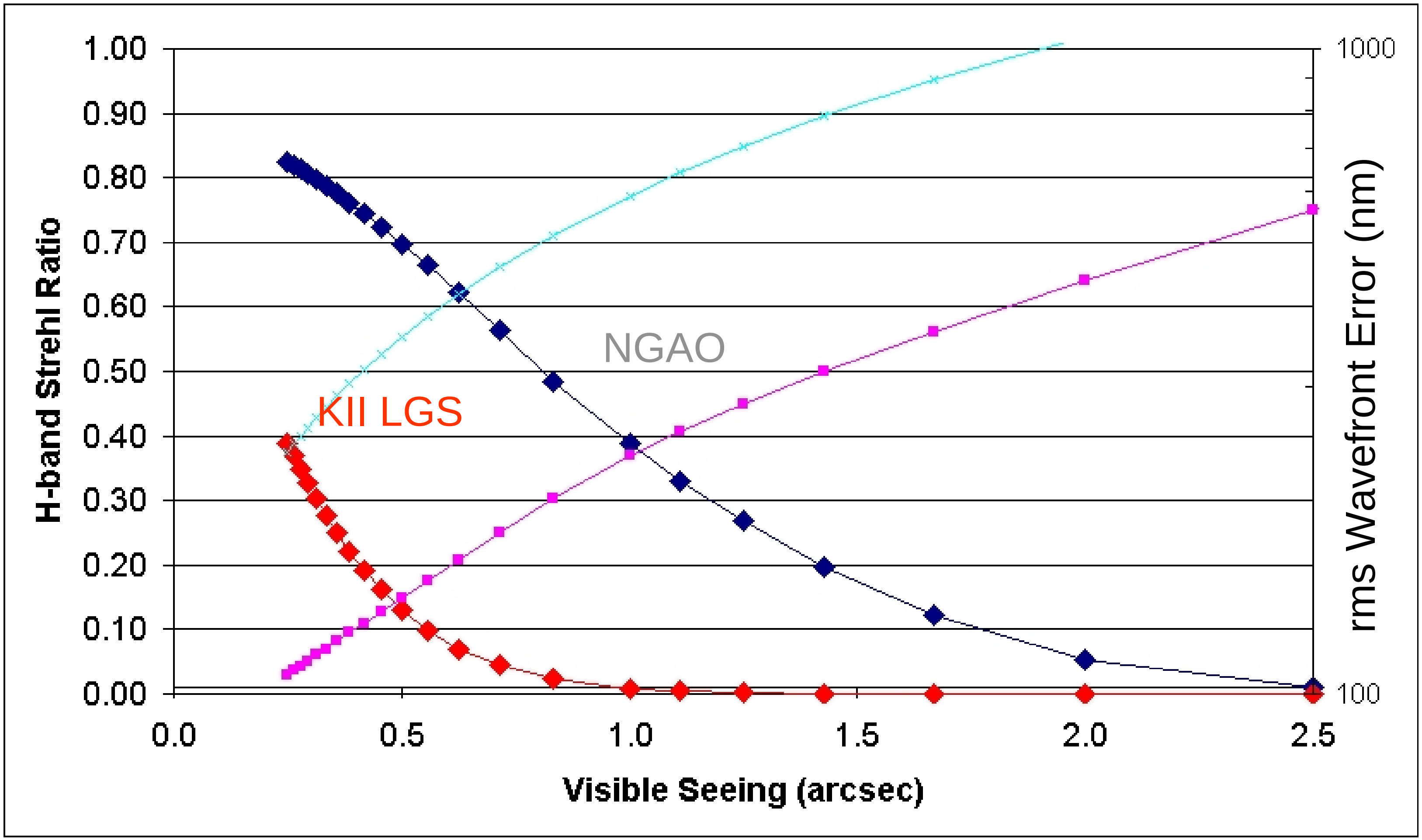




For comparison: 2nd-generation AO on other 8-10 meter telescopes

- Other observatories are focusing on high-contrast imaging or ground-layer AO
  1. High-contrast (Extreme AO)
     - Gemini (GPI, NICI), VLT (SPHERE), Subaru (HiCIAO)
  2. Ground-layer AO ("Seeing Improvement")
     - VLT (to feed MUSE and HAWK-I)
     - Gemini study
- VLT HAWK-I will have narrow field high Strehl mode
- Only Gemini-S is implementing well-corrected wider-field AO: multi-Conjugate AO (~2' FOV, K-Strehl~0.4)

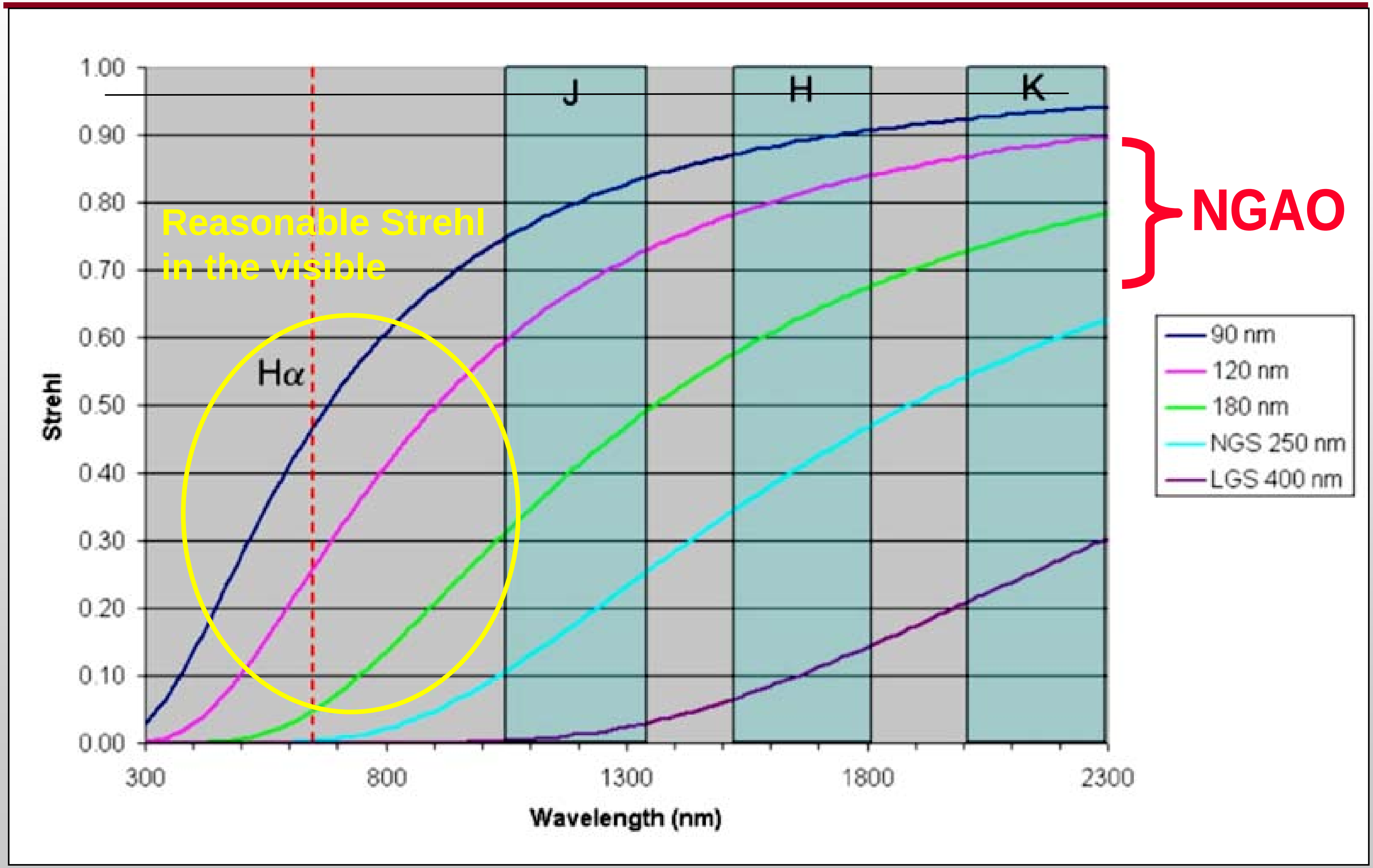
NGAO Improves Performance over Wide Range of Seeing Conditions



NGAO H-band Strehl improved by 5x in median conditions

Strehl > 40% for seeing < 1”

...and observing wavelengths

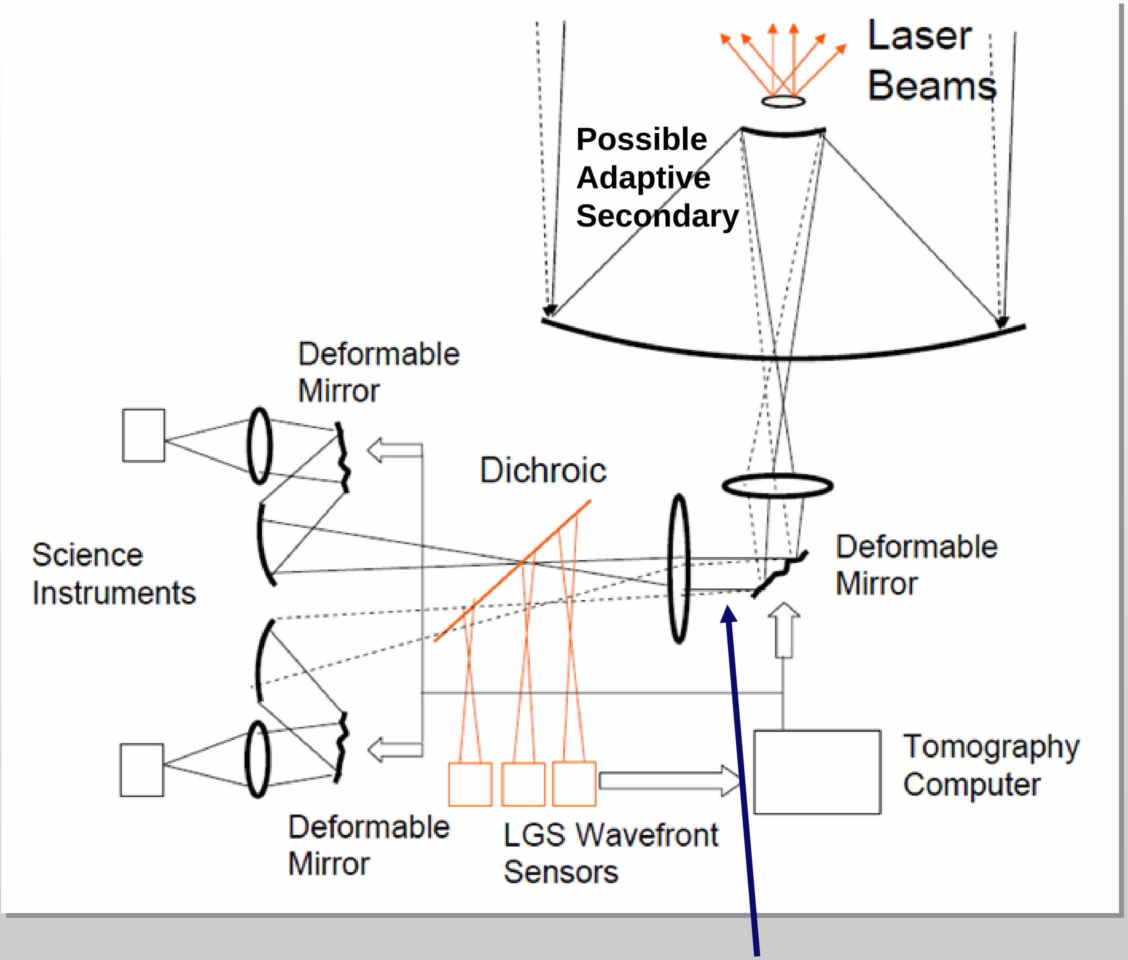


NGAO will allow us to tackle many high impact science areas

1. **Near diffraction-limited in the near-IR (Strehl >80%)**
   - Direct detection of planets around low-mass and young stars.
   - Astrometric tests of general relativity in the Galactic Center
   - Detailed structure/kinematics of high redshift galaxies
2. **Vastly increased sky coverage and multiplexing**
   - Multi-object IFU surveys of GOODS-N, COSMOS, etc.
   - Resolving the earliest stages of star + planet formation.
3. **AO correction at red optical wavelengths (0.6-1.0 μm)**
   - Scattered-light studies of debris disks and their planets
   - Kinematic mass determinations for super massive black holes

NGAO Architecture (point design)

- Tomography to measure wavefronts everywhere above telescope
- IR tip-tilt stars, partially AO-corrected, for broad sky coverage
- Closed-loop AO for narrow fields
- Open-loop AO for deployable IFUs



MCAO would add second DM here

Keck NGAO
Science Instrument Priorities

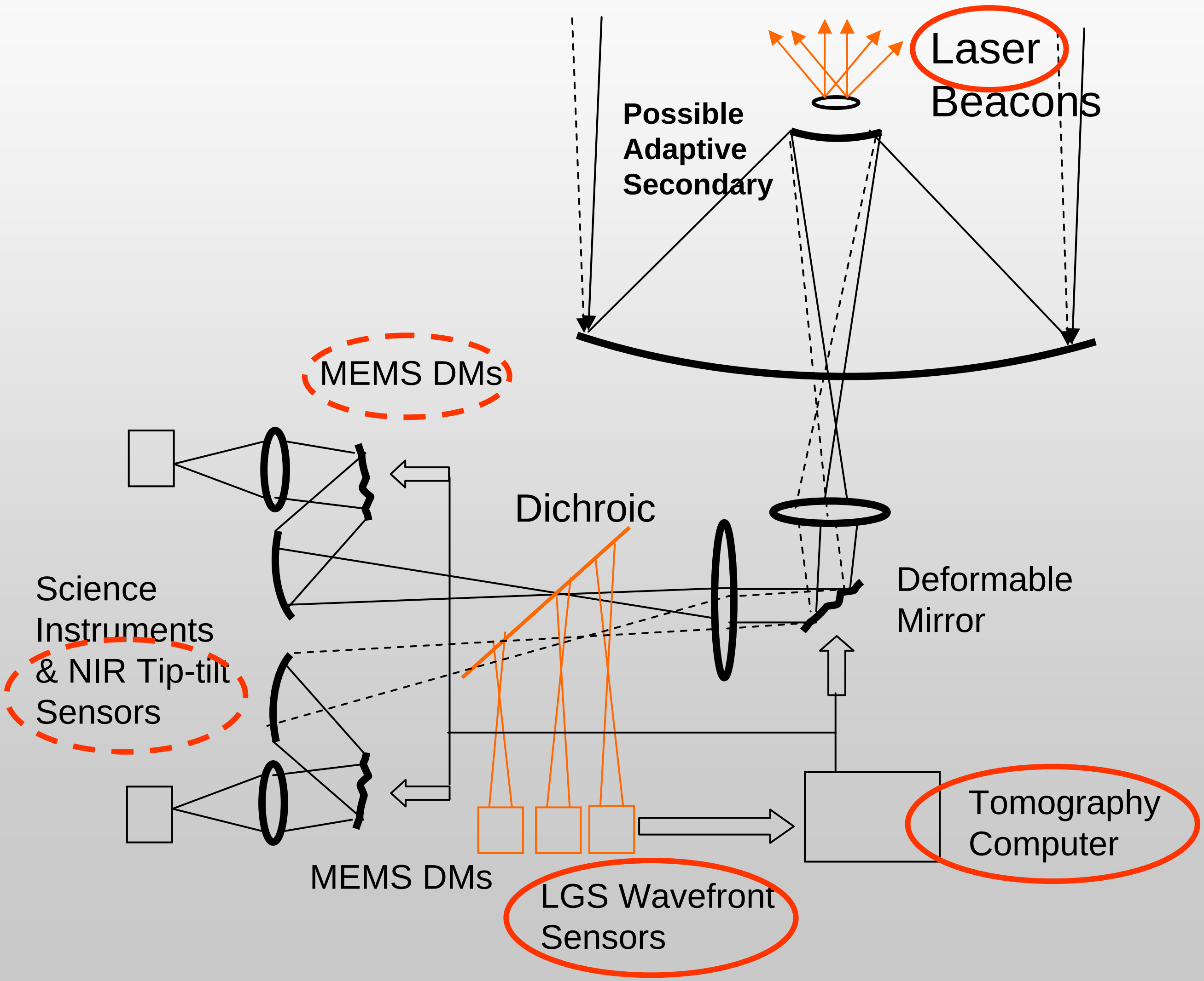
Single-object

1. Near-IR high-contrast imager
2. Visible imager
3. Near-IR IFU (OSIRIS?)
4. Visible single-field IFU
5. Thermal near-IR imager

Multi-object

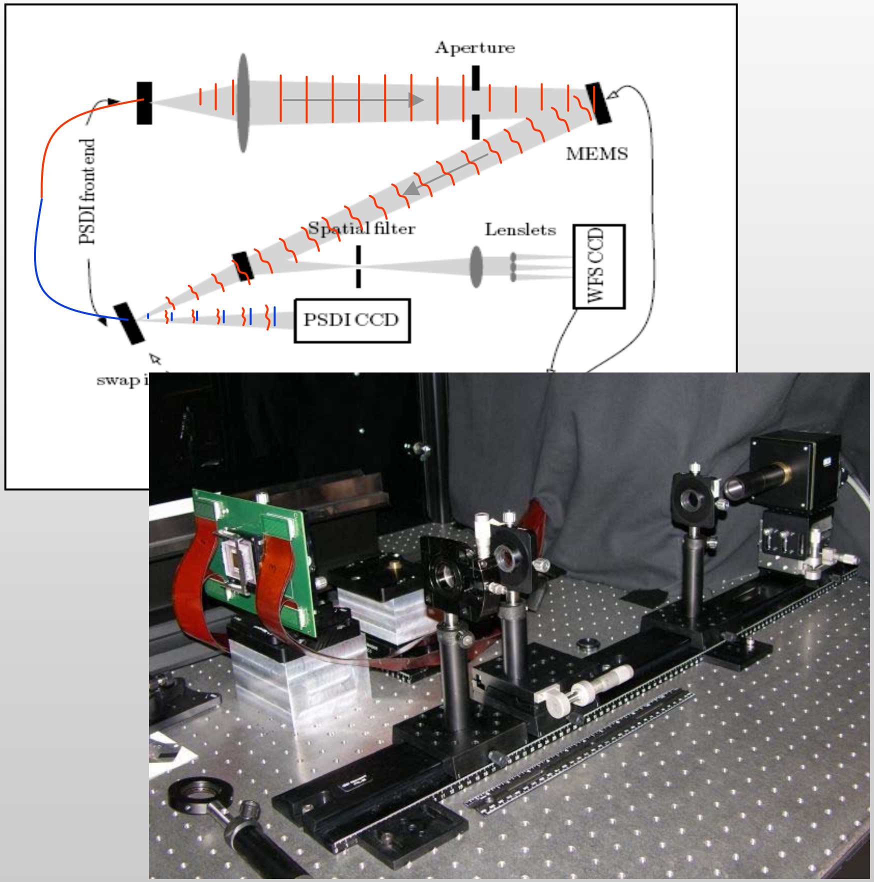
1. Deployable near-IR multi-object IFU (N~6-12)

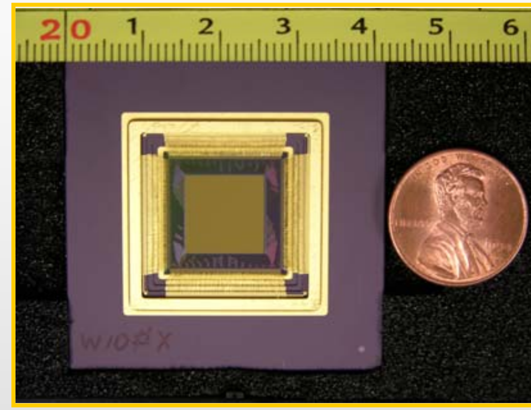
Key Technologies enable a unique architecture (mix of MCAO & MOAO)



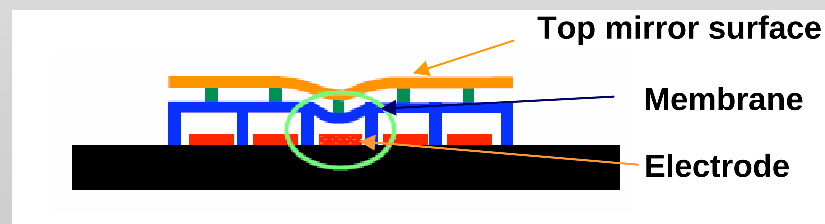
MEMS Deformable Mirror Technology

Development at the UCO/Lick Laboratory for Adaptive Optics and Boston Micromachines Corporation





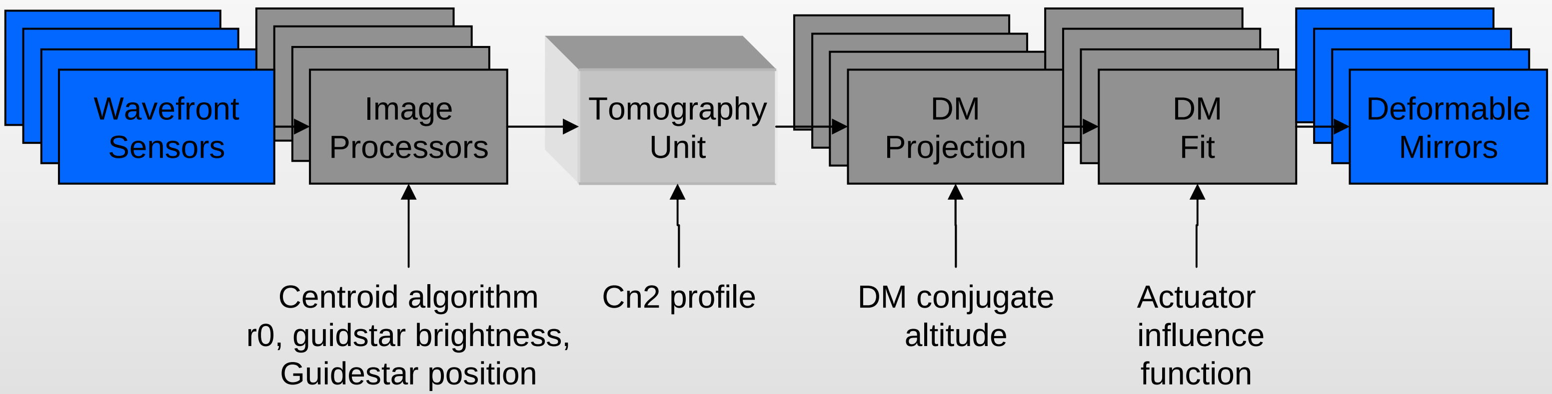
32x32 actuator MEMS DM
(Boston Micromachines Corp)



MEMS electrostatic actuator

Massively parallel real-time control architecture

addresses the $D^4 x N_{LGS} x N_{DM}$ computational scaling



- **Power & space requirements are reasonable**
  - **10-20 boards with 50-100 FPGA chips, <2 kW total power estimated**

There is synergy between Keck NGAO and TMT AO

- IRMOS: multi-object AO system with deployable IFUs
- We envision the Keck NGAO deployable-IFU system to be analogous to TMT IRMOS, but much less complex
  - Half a dozen IFUs instead of 20-30
  - More forgiving optical design
  - AO with fewer degrees of freedom
  - Larger IFU “pixels”
- We are benefiting from two excellent TMT feasibility studies for IRMOS
- In the opposite direction, Keck NGAO experience will help TMT
  - Continuing R&D, validation tests
  - Earlier implementation on telescope

Conclusion

There is a unique operating space for Keck NGAO

- **High Strehl in near-IR**
- **“Precision AO” - both high Strehl and more stable PSF**
- **Same Strehl at visible (red) wavelengths that we now have in the near IR**
- **Deployable AO-corrected IFU instrument**

- **Enables a <u>wide</u> variety of science**
- **Takes advantage of AO expertise in the CfAO**