Center for Adaptive Optics
An NSF Science & Technology Center

CfAO Theme 2: Adaptive Optics for the Extremely Large Telescopes

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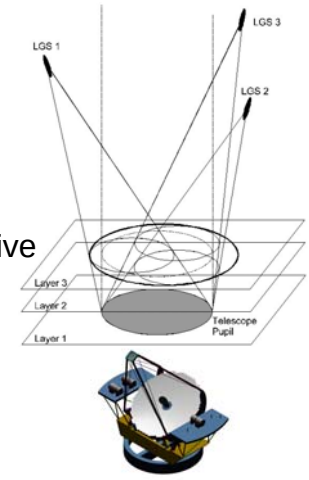
Outline

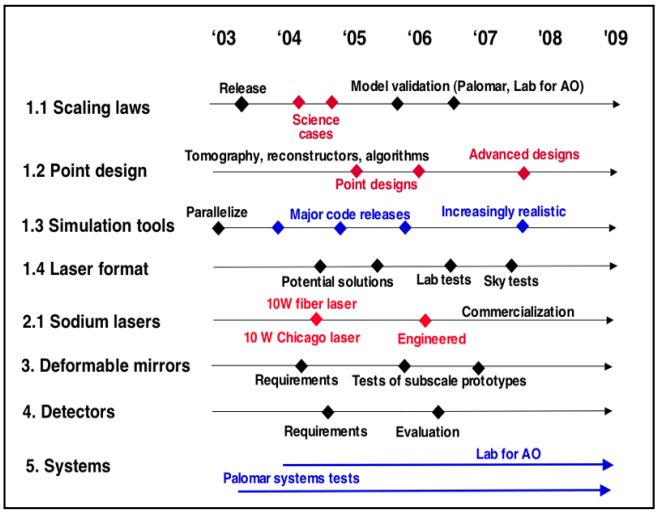
- Theme 2 development areas and roadmap for research
- Projects and progress
- Activities and spin-offs
  - TMT involvement
  - Laboratory for Adaptive Optics
- The future

Theme 2 development Areas

- Create workable “point designs” for wide field adaptive optics systems for future giant (30 meter class) telescopes
- Develop long-range partnerships for developing key AO technologies:
  - Deformable mirrors
  - Wavefront sensor detectors
  - Lasers to produce artifical guide stars
- Develop techniques for doing quantitative astronomy given adaptive optically corrected data
- Pursue astronomical science projects using existing laser guide star adaptive optics systems



Roadmap for Research

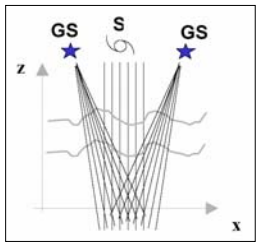


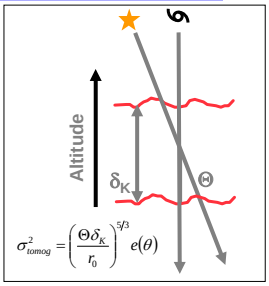
Theme 2 shift in emphasis in Year 7

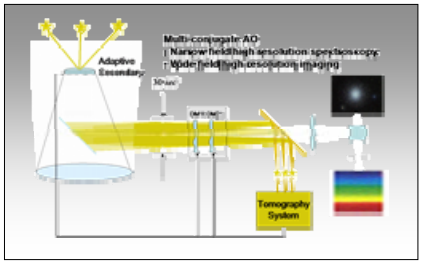
- Reflects our early success in the modeling/analysis work plus the current pressing need for component development
- Provides an exit strategy for CfAO/astronomy
  - Continuing involvement with the large telescope projects
  - Create lasting legacies for the CfAO
- Three main research areas:
  - Sodium guidestar laser development
  - MEMS deformable mirror development
  - Astronomical science using AO

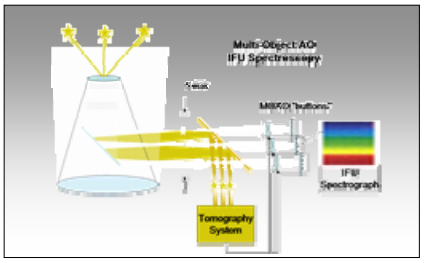
Progress on Major Projects
Analysis, Modeling, and Simulation

- Explore design parameter space (determine basic scaling laws)
- Invent fast, real-time tomography solutions
- Introduce novel concepts for system architectures



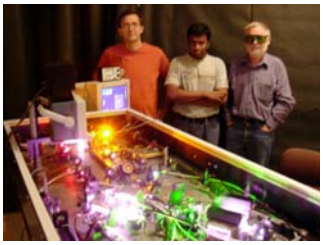


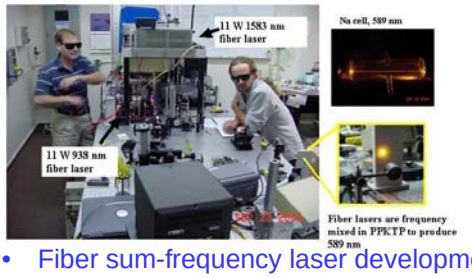




Progress on Major Projects
Guide Star Lasers

- Guide star lasers
  - Produce artifical beacons in the Sodium mesospheric layer to use as a reference for wavefront sensing
  - 3 μs quasi CW pulse is ideal format for ELTs



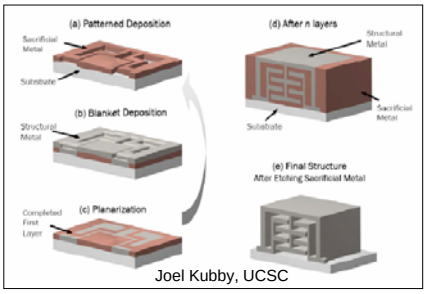


- Fiber sum-frequency laser development (D. Pennington, LLNL)
  - Near-term goal is 5 W CW laser
  - Achieved 2.7 Watts in lab
  - Next project: 3ms pulse
- Crystal sum-frequency laser (E. Kibblewhite, U. Chicago)
  - Older technology pulsed laser
  - Deployed at Palomar Observatory
  - First on-sky tests, 4 Watts on sky

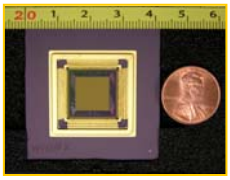
MEMS Deformable Mirrors

- Consortium to build 4K and 10K actuator devices

- Research on higher stroke actuator designs



Joel Kubby, UCSC



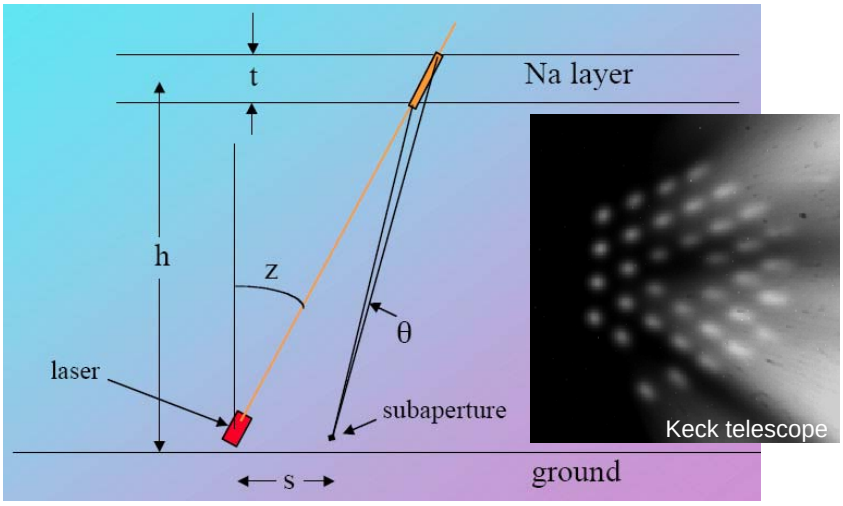
32x32 actuator MEMS DM
(Boston Micromachines Corp)

MEMS electrostatic actuator concept
(Tom Bifano, BMC)

Wavefront sensing

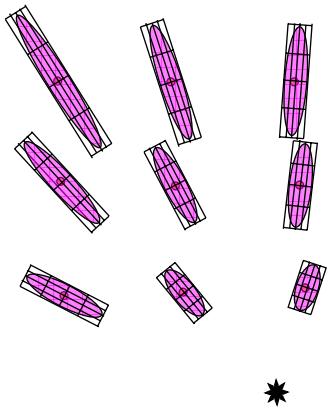
- Problem: laser guide star light is elongated (spread out spatially) due to finite thickness of mesospheric sodium layer
- Solutions:
  - Range-gating pulsed laser, and pulse compression techniques
  - Optimal image processing methods
  - Specialized detector design: radial architecture CCD
- Ongoing projects
  - Lincoln Labs/Rockwell/UCSC (J. Nelson) radial CCD design (AODP funded)
  - Optimal centroiders (B. Ellerbroek, TMT)
  - Pulse compression (B. Bauman, LAO)

LGS Spot Elongation



Custom CCD's for laser guide stars

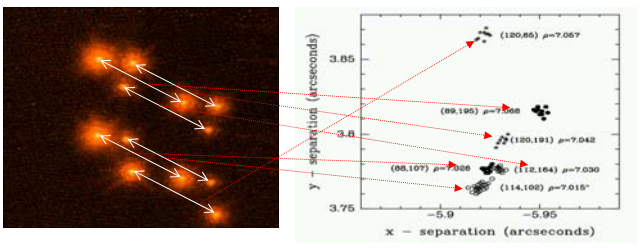
- It appears practical to make custom CCD's
  - Spot to spot separation is independent of the Na layer source on the CCD (set by lenslets on pupil)
  - Each lenslet image is sampled by "local" CCD. Example of a 4x4 pixel array covering each lenslet on the pupil is shown
  - Each array is custom to the direction and distance to the launch telescope
  - AODP funded program to develop these CCD's (Beletic & Nelson)



Quantitative Astronomy with AO

- Adaptive Optics changes the nature of the imaging data
  - Astrometry (positions of stars)
  - Photometry (brightness of stars)

  Depend on precise knowledge of the point spread function (PSF)
- Projects:
  - PSF Characterization (J. Christou, UCSC, J.P. Veran HIA)
  - Quantitative astronomy (J. Christou, UCSC)

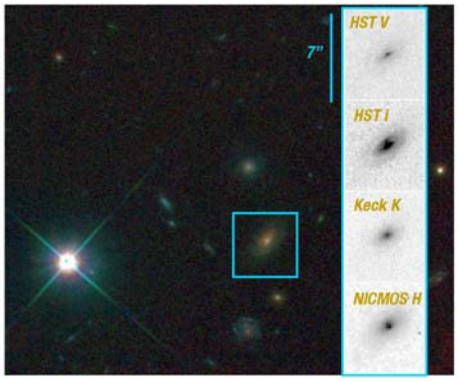


Astronomical Research with AO

CATS: CfAO Treasure Survey (C. Max, UCSC)

observe a large, deep sample of galaxies in the early universe

1. assembly of galaxies from smaller subunits to larger ones like our own Milky Way,
2. measure the rates of star formation and the evolution in stellar populations
3. discover the highest redshift supernovae
4. characterizing central active galactic nuclei (AGNs) throughout the past 10-12 Billion years

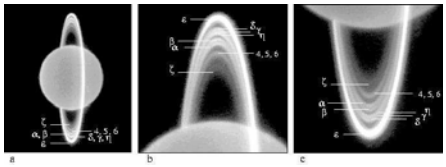


NIRC2 image is an hour exposure taken in Mar 2005 with the Keck laesr guide star AO system. The field is located in the Extended Groth Strip where HST ACS and NICMOS-3 images exist.

Such AO resolutions allow unique studies of small subcomponents within distant galaxies, such as bulges (see example below the marked galaxy), bars, AGNs, and supernovae.

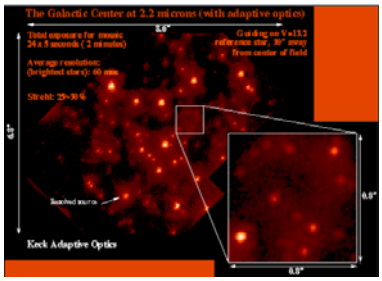
Astronomical Research with AO

- Solar system studies (I. De Pater, UCB)



Keck AO image of Uranus at near infrared wavelengths showing details of the ring structure.

- Black hole at the center of our Galaxy (A. Ghez, UCLA)



Activities and Spin-offs

- Thirty Meter Telescope
  - Started its preliminary design and costing
  - CfAO members involved at many levels
    - Jerry Nelson – Chief scientist
    - Brent Ellerbroek – AO systems manager
    - Donald Gavel – AO working group chair
  - CfAO and LAO involved in instrument development
    - Multi-conjugate AO system
    - Multi-object AO spectrograph
    - Extreme adaptive optics planet formation imager
- Laboratory for Adaptive Optics
  - Research arm for adaptive optics technology for Lick Observatory and the future giant telescopes
  - Themes: ELTs, ExAO, Component development, Teaching/Learning laboratory

Laboratory for Adaptive Optics

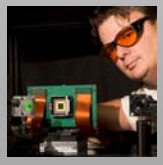
Laboratory for Adaptive Optics

Claire Max, Principal Investigator
Joseph Miller, co-Investigator
Jerry Nelson, co-Investigator
Donald Gavel, Laboratory Director

- **A permanent facility within the UCO/Lick Observatory located at the UC Santa Cruz campus**
- **Presently funded by a grant from the Gordon and Betty Moore Foundation**

LAO Goals

1. **Develop Adaptive optics technology and methods for the next generation of extremely large ground-based telescopes**
2. **Develop and build a planet finder instrument using "extreme" adaptive optics technology**
3. **Develop, test, and evaluate new components and key technologies for adaptive optics**
4. **Provide a laboratory where students and postdocs will be trained in adaptive optics design, modeling, and implementation**



Summary

- Significant progres in realizing our initial goal: feasible point designs for 30 m near-IR AO on a wide field
- Measurable progress on sodium guide star lasers
- Emphasis shifted to known workable MEMS technologies
- Strong coordination with related efforts
  - AODP program
  - TMT
- Ground breaking science results from AO are beginning to happen (Galactic center, planets, CATS)
  - and helping to drive the requirements for future AO systems