Adaptive Optics System and Infrared Instrumentation for the Shane 3-meter Telescope

UCO/Lick Observatory
University of California

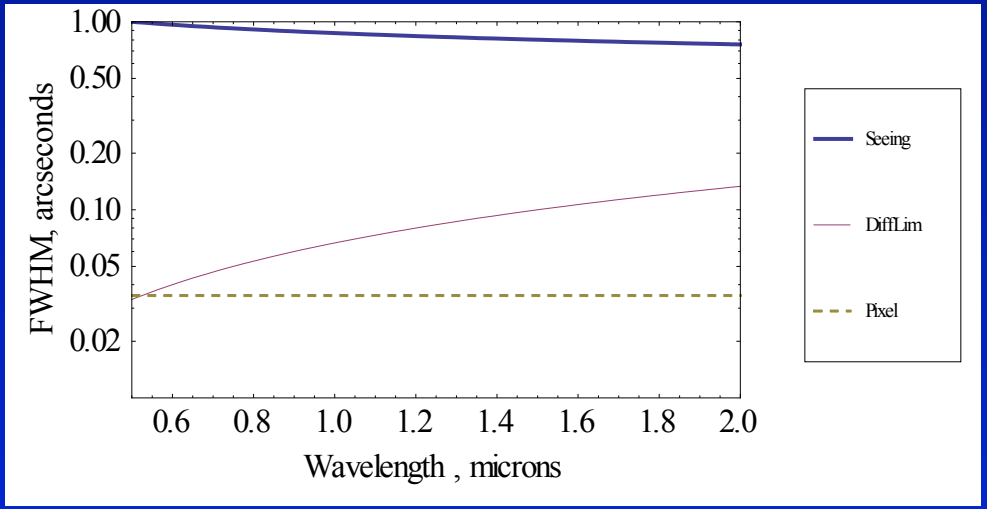
Presented to the UCOAC Meeting May 6, 2012

Context of ShaneAO
Adaptive Optics at Lick Observatory

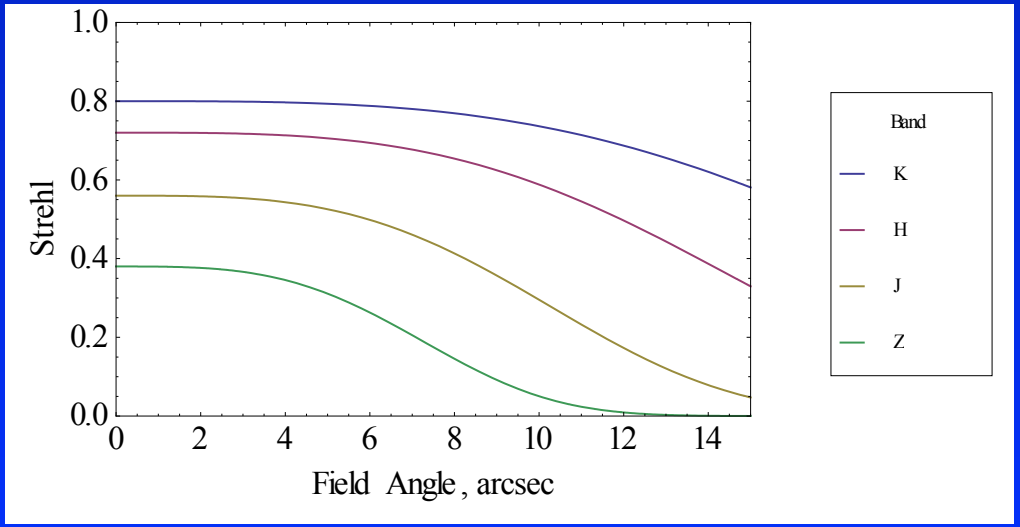
- Keck Next Generation Adaptive Optics (KNGAO)
  - Design effort 2006-2010
  - Reached PDR; on hold pending funding; spin-off efforts: new laser, on-axis LGS projection telescope, IR Tip/Tilt
- Visible Light Laser Guidestar Experiment (Villages)
  - Research effort 2010; Nickel telescope
  - First on-sky demonstration of MEMS and “open-loop” control – tip/tilt start sharpening in NGAO, vector to MOAO/ IRMOS

ShaneAO: Adaptive Optics System at the Shane 3-meter Telescope (LGS mode, new fiber laser)

- ShaneAO is a diffraction-limited imager, spectrograph, and polarimeter for the visible and near-infrared science bands.



- Adaptive optics corrects for the nominally ~1 arcsecond seeing blur to the diffraction limit over a field of view known as the isoplanatic patch



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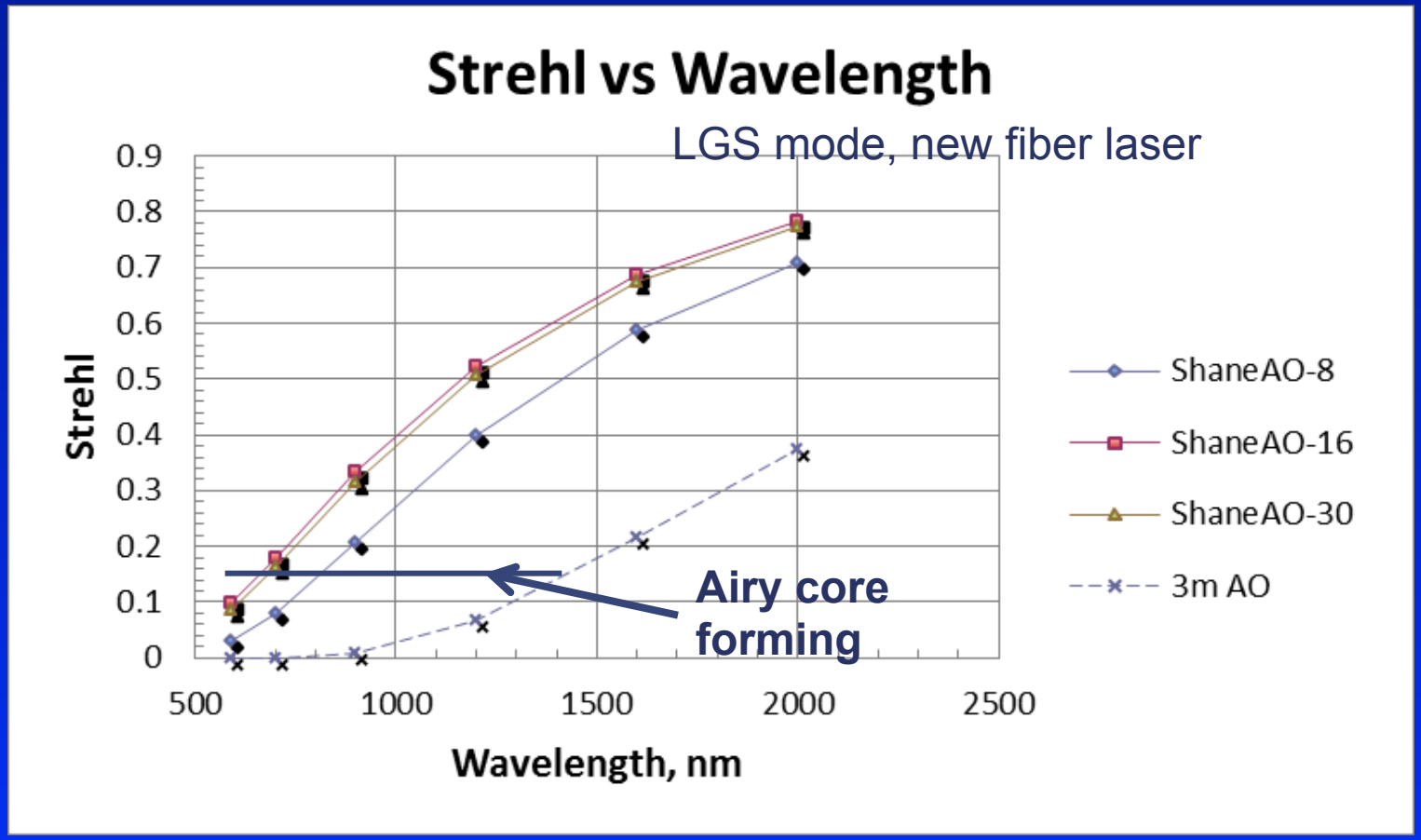
Strehl


Strehl vs Wavelength
LGS mode, new fiber laser
Strehl
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
500
1000
1500
2000
2500
Wavelength, nm
Airy core forming
ShaneAO-8
ShaneAO-16
ShaneAO-30
3m AO

ShaneAO instrument characteristics

Detector sampling	0.035	arcsec/pixel
Field of view	20	arcsec square
Science detector: Hawaii2RG	Hawaii2RG	
Science wavelength coverage: 0.7 to 2.2 microns	0.7 to 2.2	microns
Spectral resolution	R = 500	
Slit width: 0.1 arcseconds	0.1	arcsec
Slit decker: 10 arcseconds (?)	10	arcsec
Slit angle on sky	adjustable 0-360°	
Long-exposure stability	hold to the diffraction-limit for one hour hold to ½ slit width for 4 hours	
Polarimitry mode:	polarization analyzer and variable angle waveplate	
Delta magnitude within seeing disk	Dm_K=10	
Minimum brightness tip/tilt star:	m_V=18	
Tip/tilt star selection field	120	arcsec
Sky coverage	~90%	LGS mode
Minimum brightness natural guide star	m_V=13	
Camera readout modes	Correlated double-sampling (CDS) up the ramp (UTR) sub-frame region of interest (ROI) quick take	
Exposure support:	Multiple frame co-added automated nod and expose coordinated with telescope (snap-i-diff, box-4, box-5) automated darks sequence based of history of science exposures	
Observations support	automatic data logging automatic data archiving	

Comparison: current AO + IRCAL vs. ShaneAO + ShARCS

Punchline: Speed gain of a factor of 13.2 in Ks, K

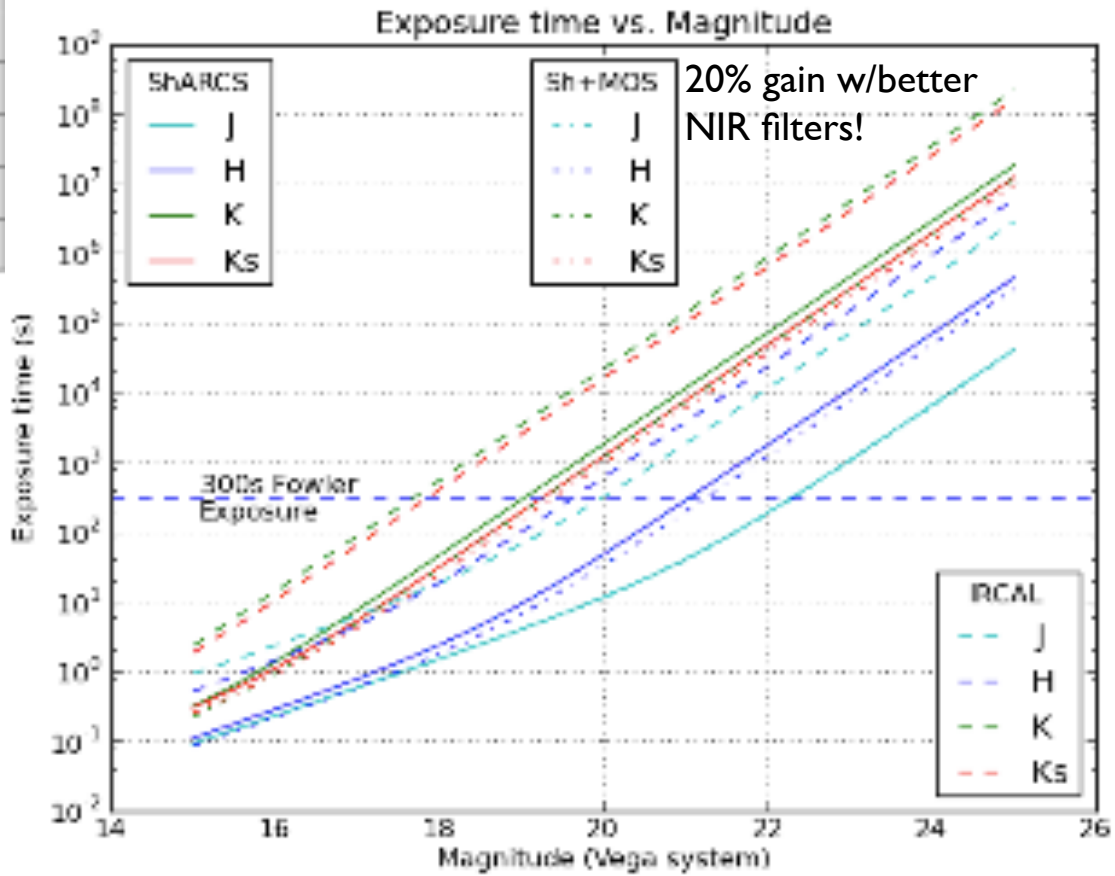
(time to fiducial S/N at fixed mag.)

5-sigma limiting magnitude for point sources
300s exposures, Fowler-32 reads, flux in Airy core:

	0.65 (NGS)	0.42 (LGS)	0.8 (LGS)
Filter	IRCAL measured	IRCAL predicted	ShARCS predicted
J	21.8	19.97	22.28
H	20.5	19.62	21.03
K	17.8	17.67	19.02
Ks	18.3	17.84	19.24

Much of the difference between this model and ideal design predictions is the model's reduced reflective coating transmission & increase in dust contamination to match IRCAL backgrounds and sensitivity. ShaneAO may yet do better.

Ks Strehl: (IRCAL NGS + LGS values from Olivier et al. 1999)



Long exposures should be possible for spectroscopy
Mechanical engineering effort to reduce flexure
Detector improvements

Better mechanical design to make alignment more robust, require less human intervention.
Keep ShaneAO clean! need 3x more dust contamination for our IRCAL model than required by NGAO to match observed data

ShaneAO Technology development connection to Keck NGAO

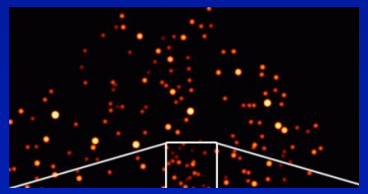
- MEMS deformable mirror
- Fiber laser tuned to atomic sodium transitions (optical pumping, re-pump line)
- Control system: woofer-tweeter, wind-predictive
- Other opto-mechanical stability design improvements

In the next few years, ShaneAO is the *only LGS-AO system* being planned (in the world) that will have the kind of low wavefront errors being contemplated by TMT NFIRAOS.

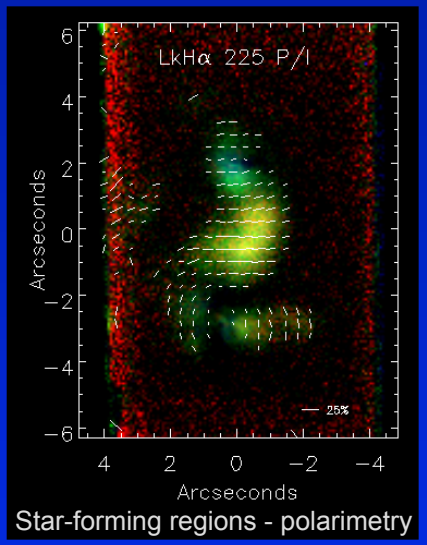
Thus ShaneAO is a TMT pathfinder in the system performance aspect, in addition to in the individual components.

ShaneAO Science Application

Crowded field imaging:
- Star counts, metallicity and ages in clusters within our Galaxy
- Star counts in Andromeda galaxy
- Astrometry – tracking the orbits of stellar companions



Detailed imaging of nebula and galaxies
- Gas and dust disks around young stars
- Multiple star systems in star forming regions
- Velocity dispersion of galaxies hosting active galactic nuclei
- Morphological detail of quasar host galaxies
- Details of morphology of merging galaxies



Star-forming regions - polarimetry

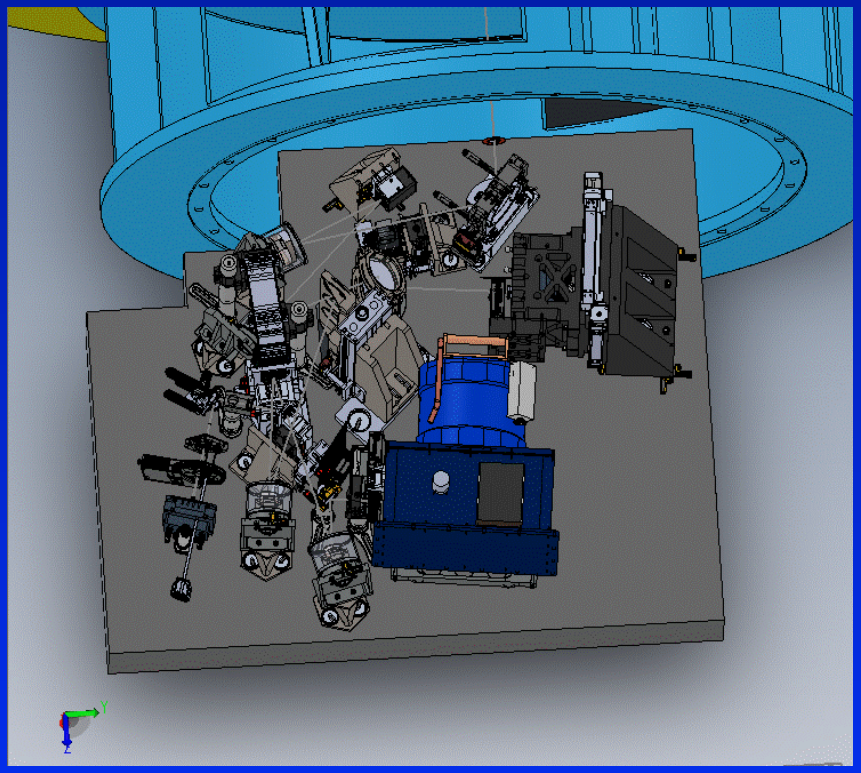
Exoplanets and planet formation statistics
- Follow up to radial velocity planetary systems (stellar companions)
- Follow up to Kepler survey stars (companions)
- Precursory work for Gemini Planet Imager target stars

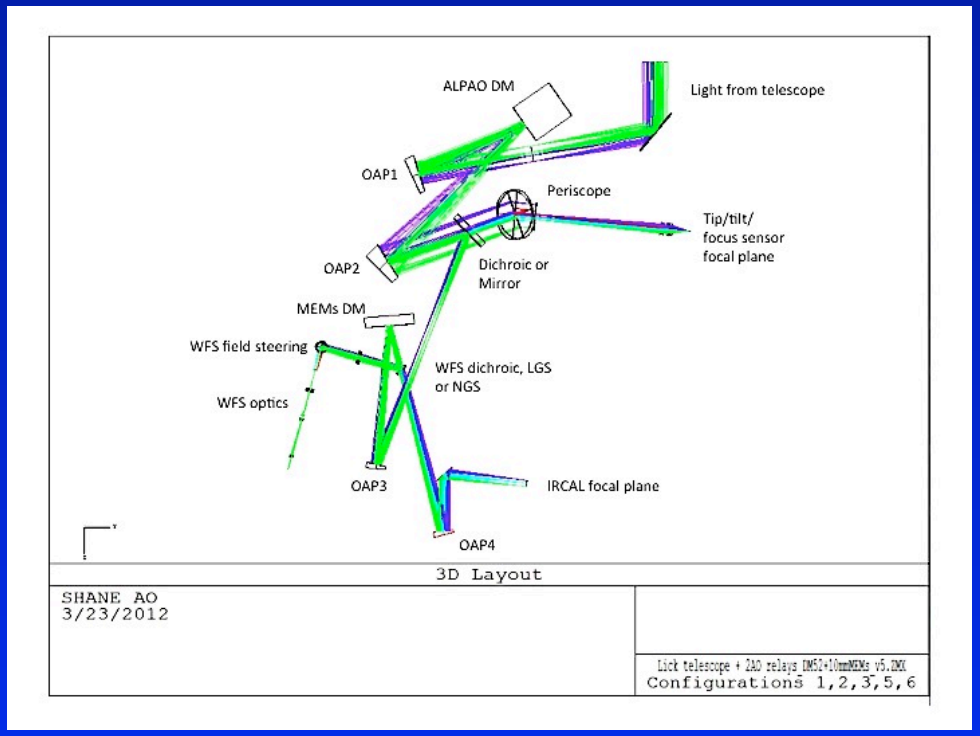
Solar system
- Composition and orbital parameters of Kuiper belt objects
- Composition and orbital parameters of asteroids and asteroid moons
- Details of gas-giant ring structure and positions of ring-shepherding moons
- Details and evolution of gas-giant weather

Updated ShaneAO Implementation Schedule

- AO system first light tests – Fall 2013
- IRCAL -> Sharcs mechancial conversion – Winter 2013
- Sharcs first light – Spring 2014
- Fiber laser first light – Summer 2014
- 30x mode upgrade – Early 2015
- Graduate student project: laser uplink correction

Optomechanical Architecture





Cassegrain mount

"Woofer-tweeter" architecture
- Closed-loop AO
- Partially corrected TT star

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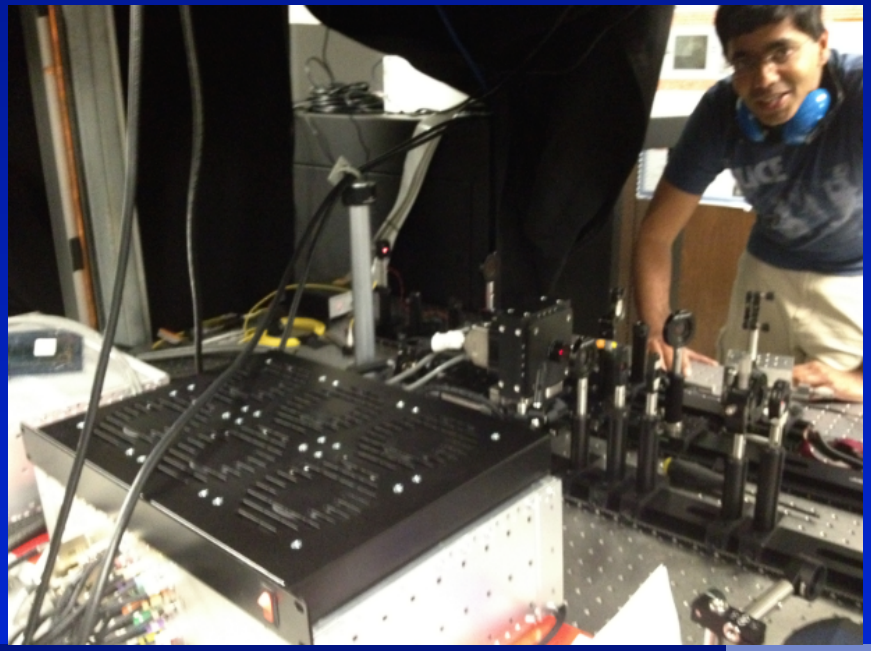
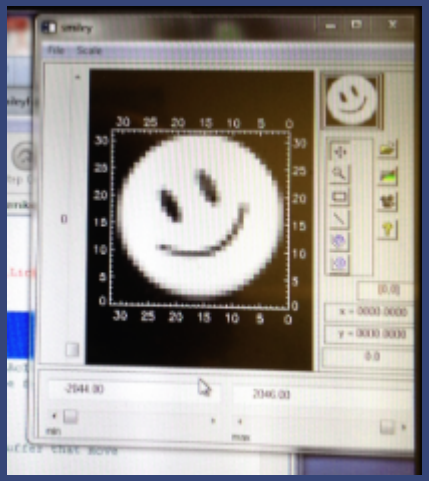
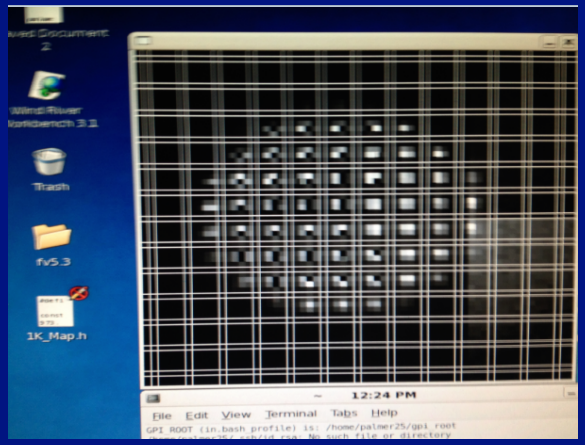
ShaneAO components in the lab



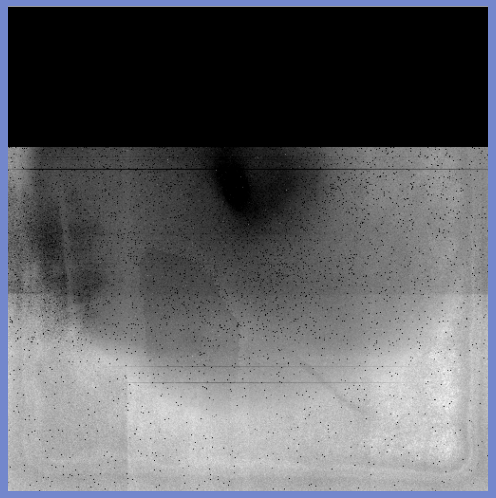


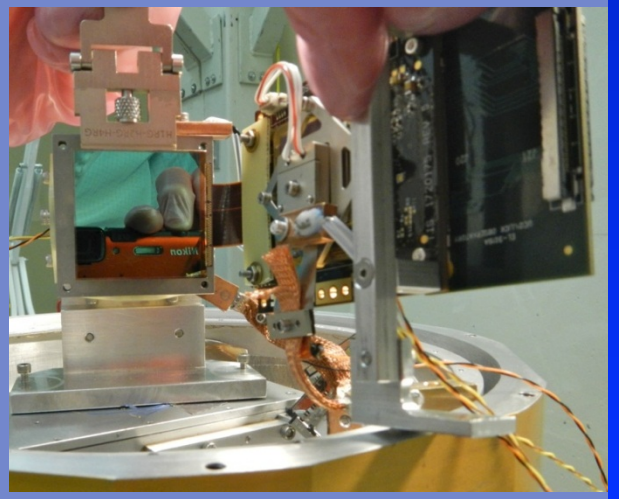
Deformable Mirror

Wavefront Sensor

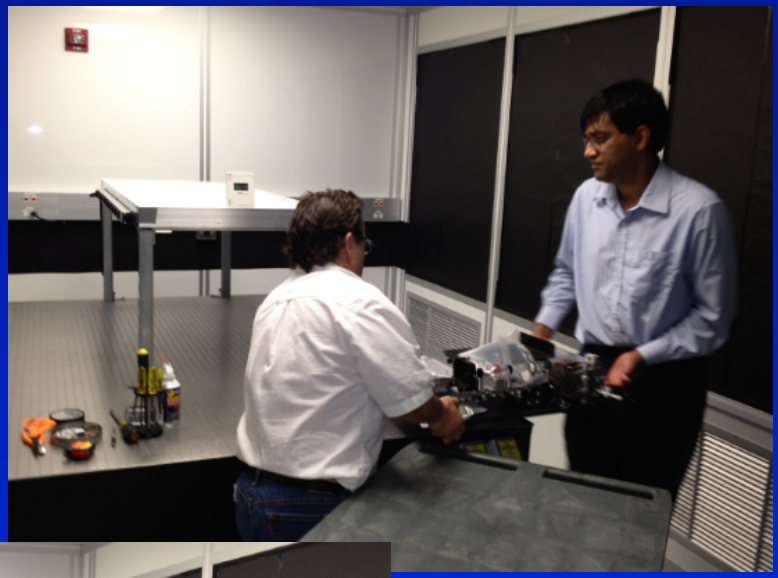


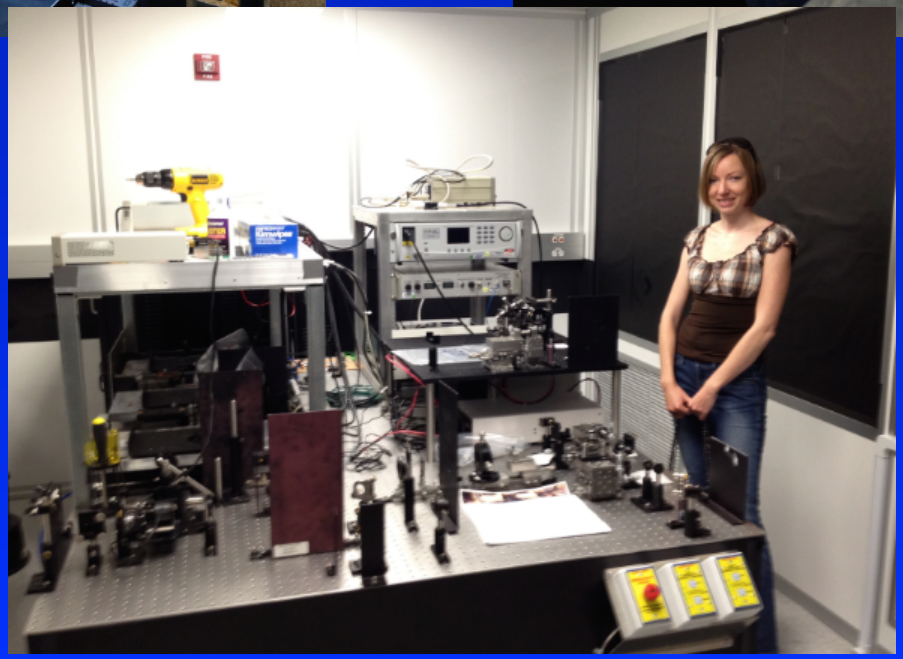
Science Detector





Laser Arrival at UCSC





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More information

- http://lao.ucolick.org/ShaneAO

- Yearly Project Reports to the NSF: 2010 2011 2012
- Design Review Presentation (April, 2012)
- ShaneAO Document

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