Robo-AO: Robotic Laser Guide Star Adaptive Optics on the Palomar 60” in 2011

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Why Robo-AO?

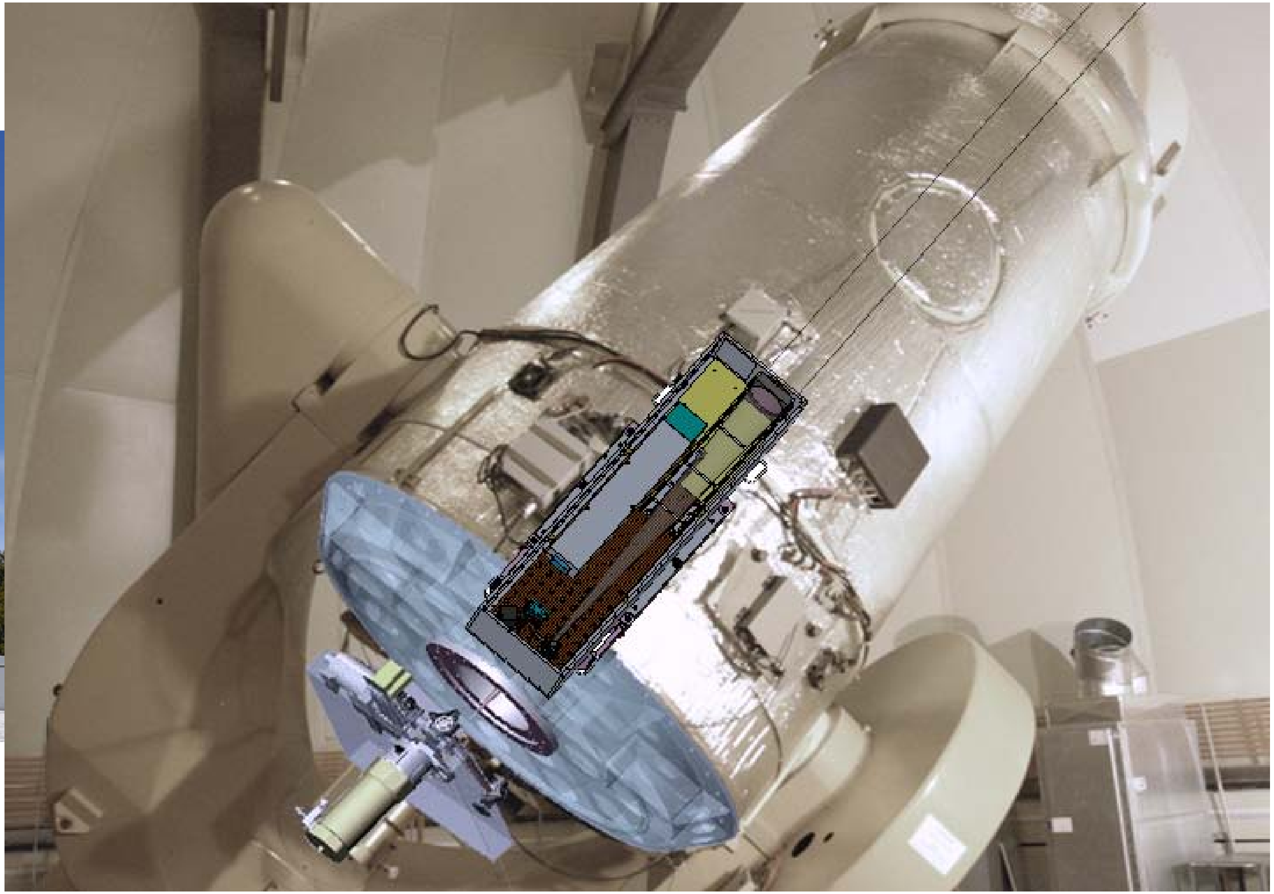
Robotic – high efficiency observing

Adaptive Optics – spatial resolution set by D

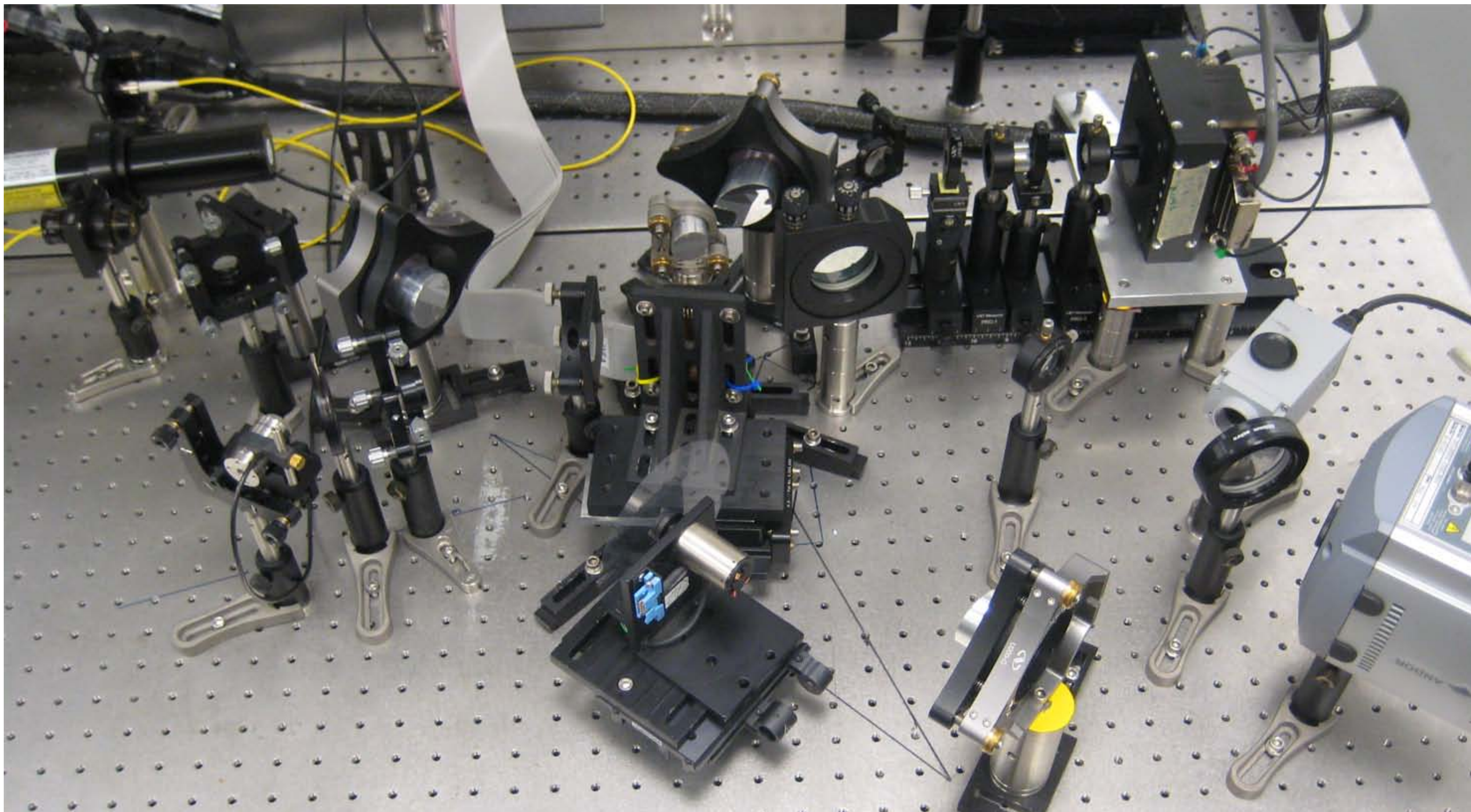
Laser Guide Star – high sky coverage

Small Telescopes – lots of available time

Robo-AO at the P60



Robo-AO in the lab



Vision

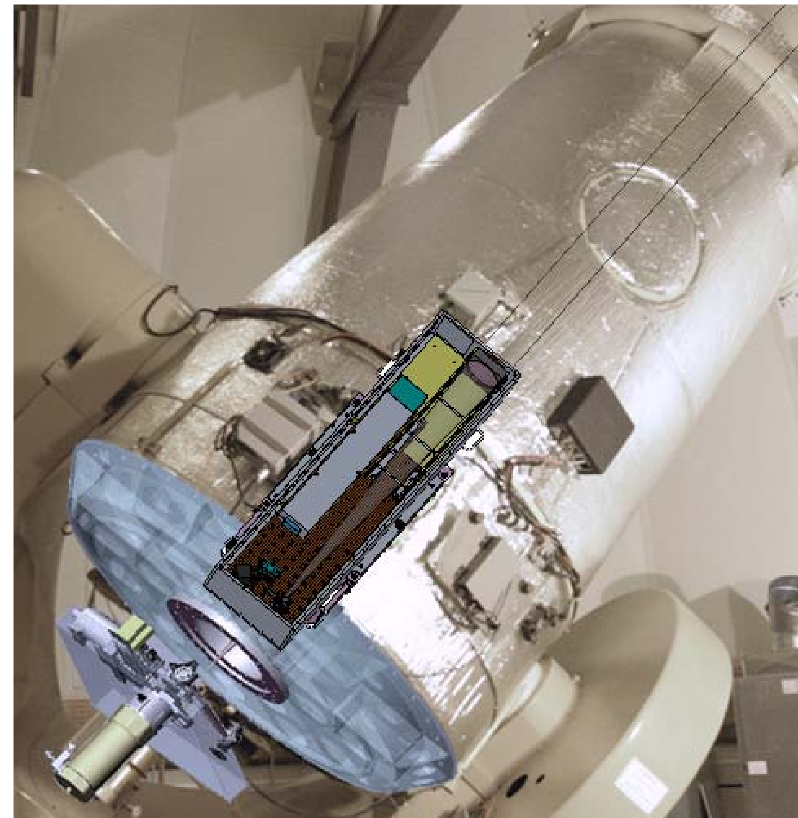
- Designing the system to be affordable and portable to 1-3 m class telescopes
- Demonstrate Robo-AO at P60
- Inter-University Centre for Astronomy and Astrophysics' 2 m Girawali Observatory
- Clone and deploy Robo-AO around the world

Robo-AO

General AO facility

+

unique capabilities



AO capabilities

- Diffraction-limited resolution
- 0.5+ Strehl in the NIR
- ~1’ field of view
- General imaging
  - range of filters, exposure times, observation setups

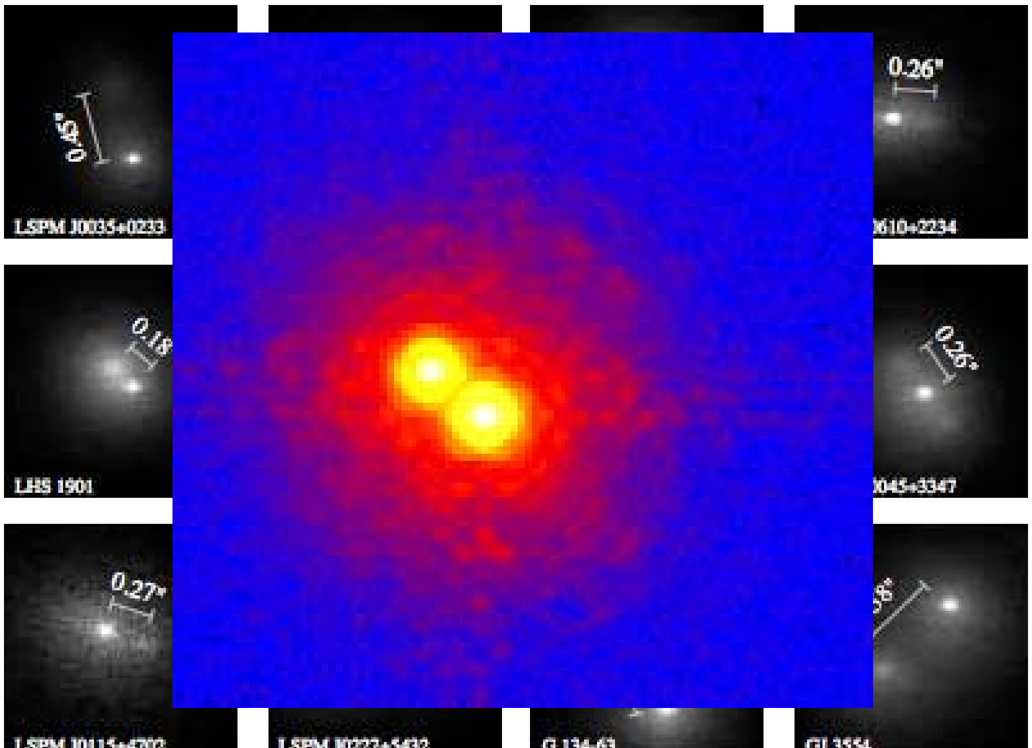
What's unique?

- Large surveys
- High efficiency
- Continual availability
- Great sky coverage
- Visible-light & high speed imaging

Large Surveys

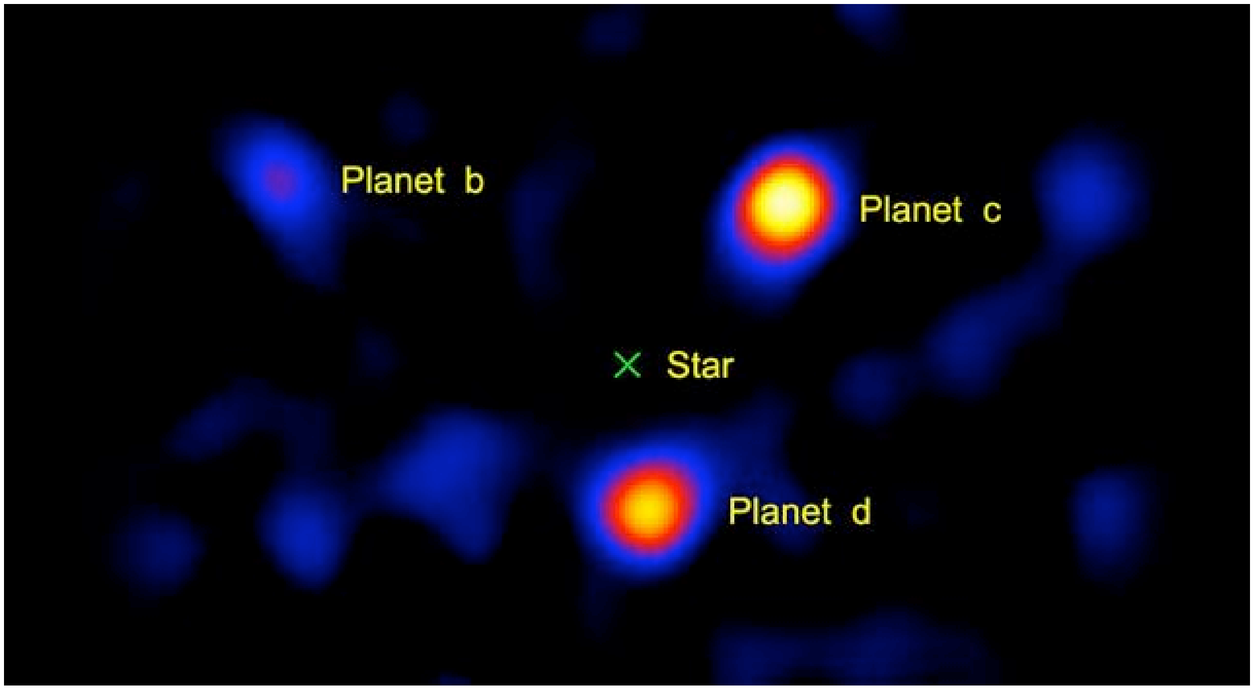
- Overhead ~70 seconds per target
- So, with 2 mins integration time, ~150 targets per night
- 4200 targets in 4 weeks -- actually possible on a 2m-class telescope!

Survey Programs - Binarity



- all spectral types, companions down to brown dwarfs for most
- cover range of stellar parameter space with one instrument and one coherent survey

Very high contrast?



3 planets around HR 8799

Image taken with 1.5m portion of P200 w. PALMAO

Vortex coronagraph for high-contrast imaging

Serabyn et al. 2010

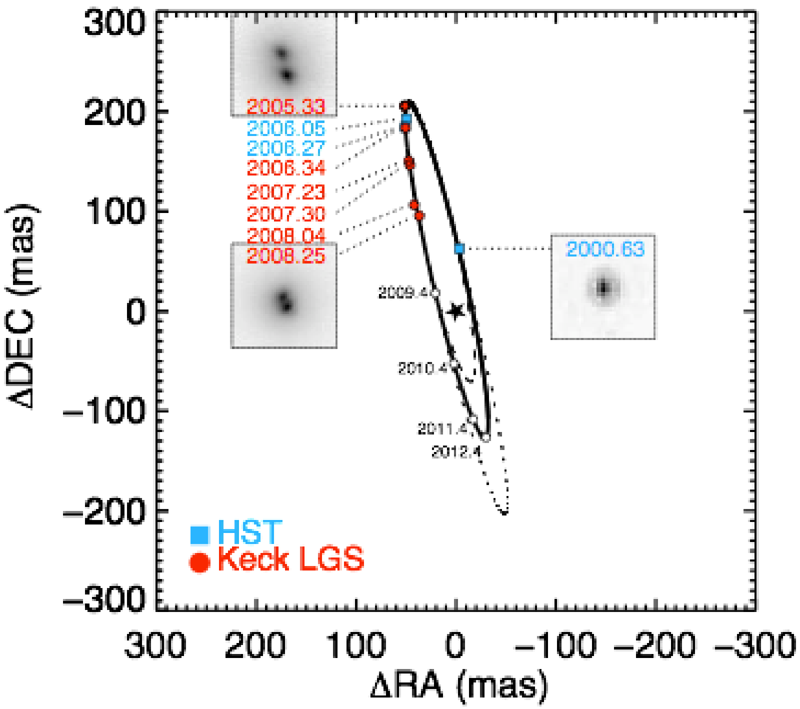
Survey Programs - Lensed Quasars

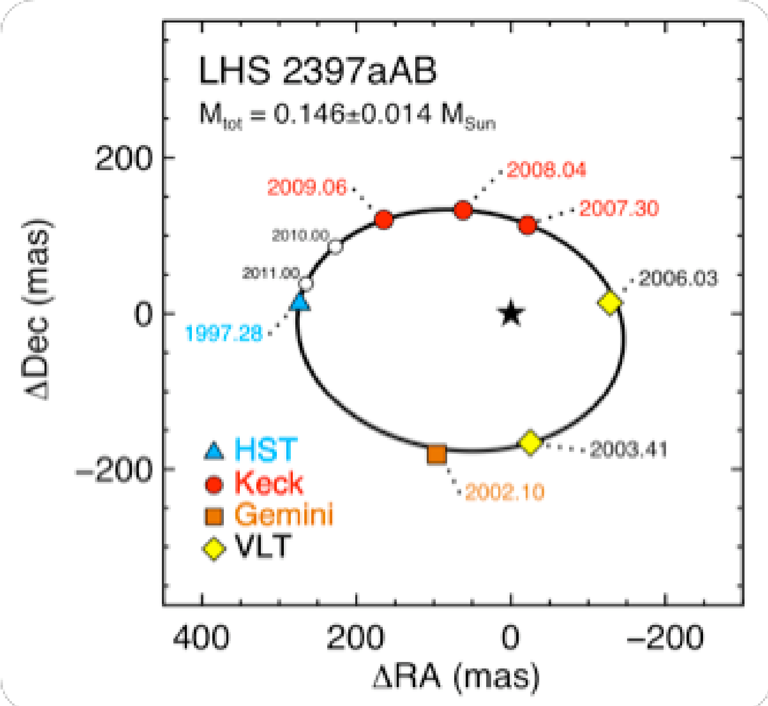
- Cover all quasars above a mag. limit
- Search for multiple images
- Model lenses for galaxy mass distribution (in a very large sample)
- Follow up for time delays

Sky coverage

- All targets brighter than V=17
- 30% sky coverage at diffraction-limited resolution
- 100% sky coverage in no-tip/tilt mode

Monitoring





Trent Dupuy 2008, 2009

SNR Improvements

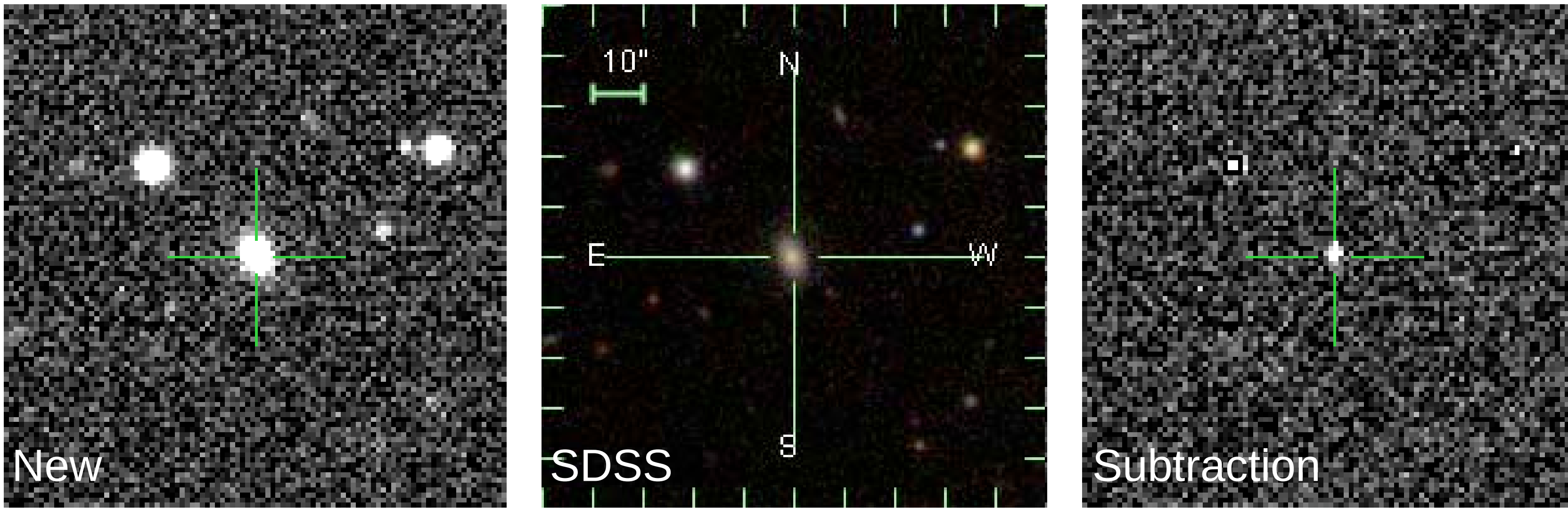
$$\sigma_x \propto \frac{\mathrm{FWHM}}{\mathrm{SNR}}$$

Band	SNR Compared to 1.5 m	SNR Compared to 4 m	FWHM (1" is typical)	Strehl
J	2.9X	0.4X	0.2"	50%
H	7.1X	0.98X	0.26"	70%

- Astrometric precision gains in both SNR and FWHM
- Prediction: 100uas precision in around 15 mins

(based on Cameron et al. Keck & Palomar performance)

High availability programs

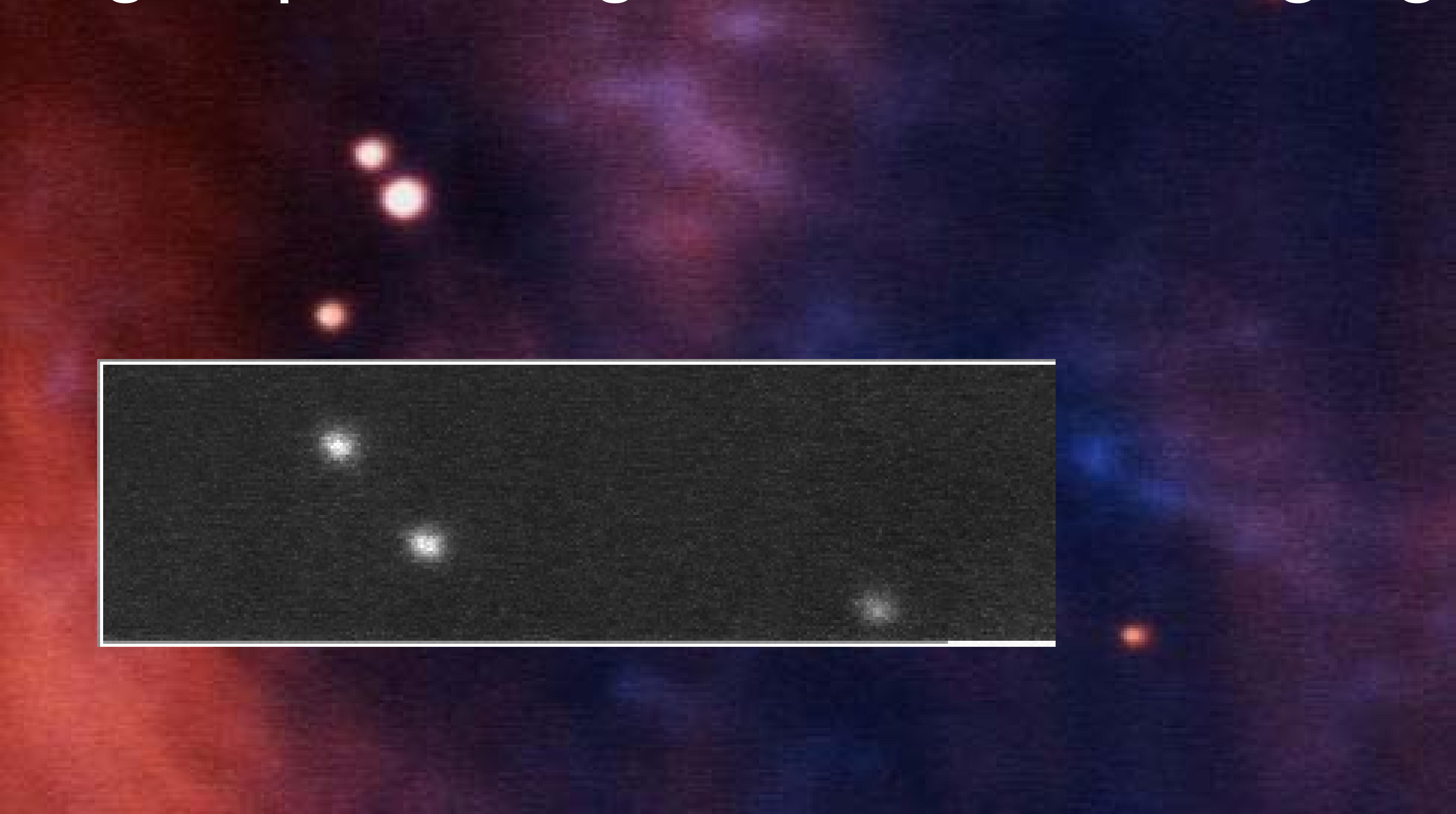


- The Palomar Transient Factory finds 1 transient candidate every ~10 minutes
- Many found near galactic nuclei - how do we separate them?

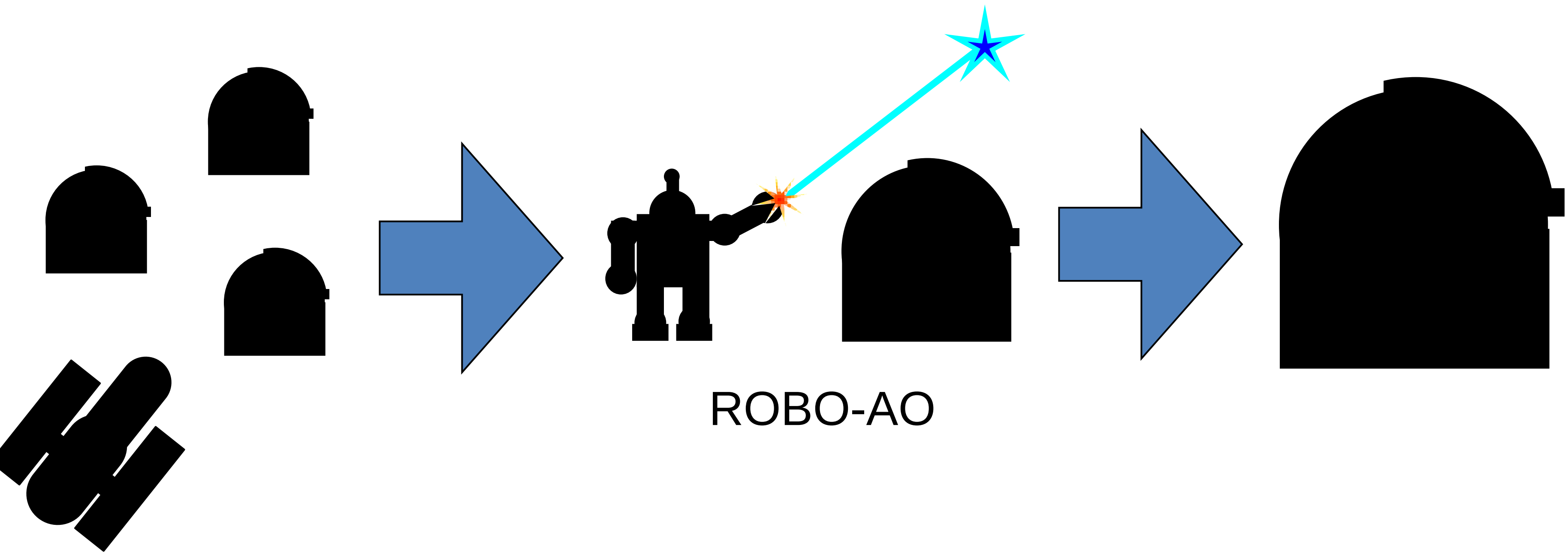

INFRARED WIDE FIELD
LICK
SN 2006GY
NGC 1260 NUCLEUS
CHANDRA

High-speed, high-resolution imaging

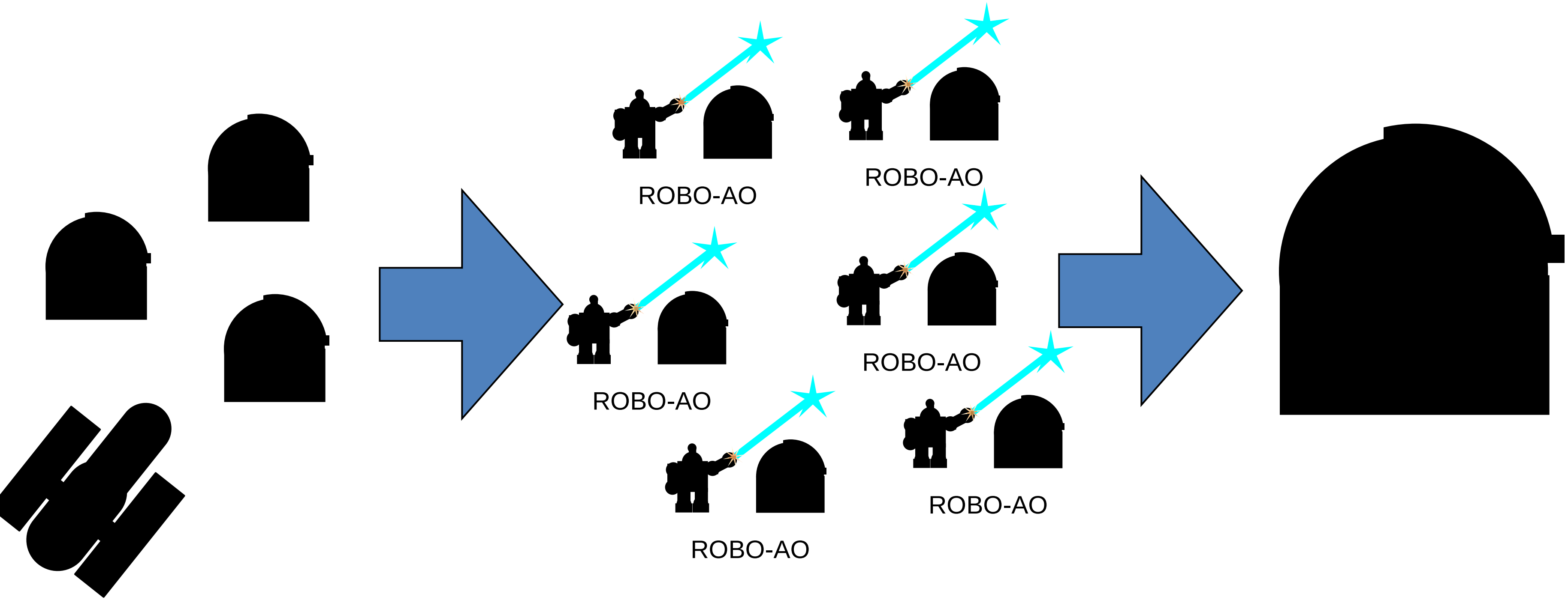
High-speed, high-resolution imaging



Robo-AO as part of the community



Robo-AO as part of the community



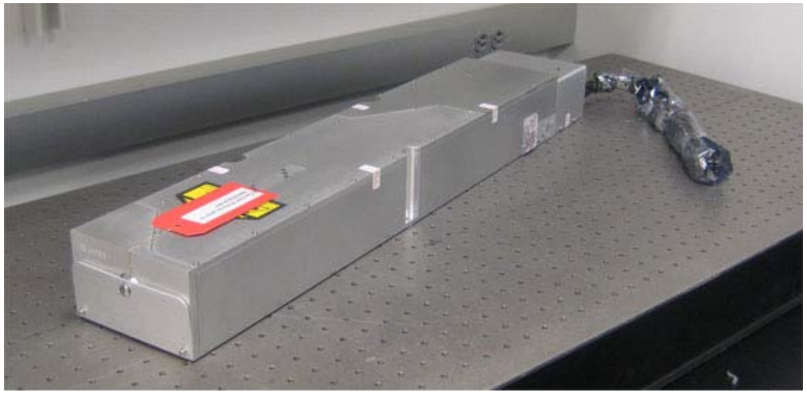
Robo-AO Science Workshop

- Please come to the Robo-AO science workshop on Thursday afternoon!
- Details online and at end of talk

Building Robo-AO

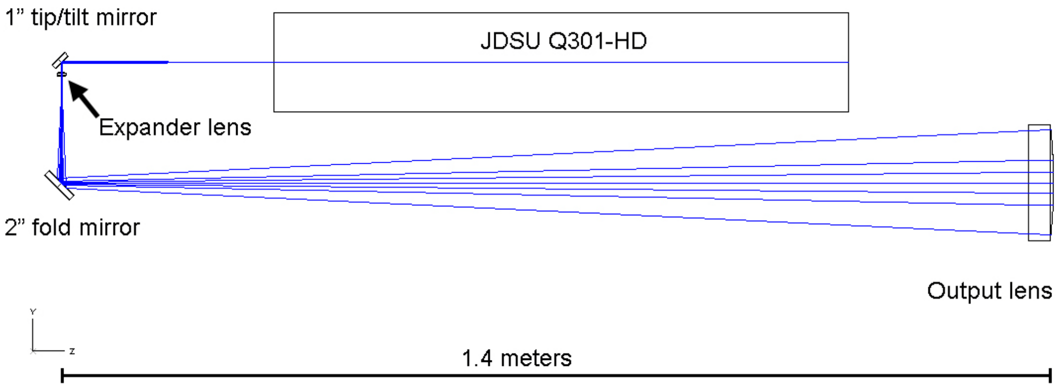
- Laser guide star
- Adaptive optics system
- Science instruments
- Robotic control software
- Robotic telescope

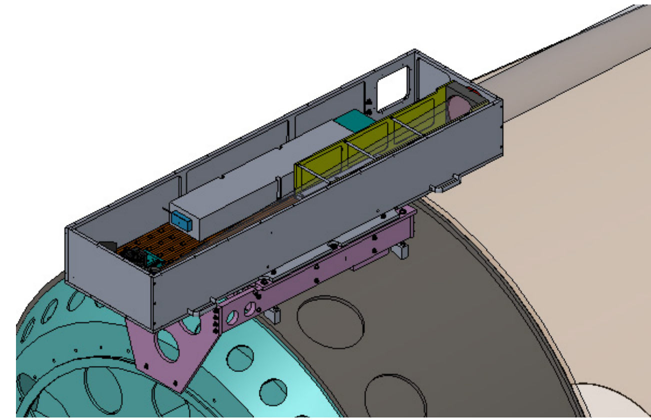
Laser guide star



- Rayleigh LGS (e.g. Starfire, Mt. Wilson, MMT, WHT, SOAR, LBT?)
  – Range gated – 650 m at 10 km – m_V~9
  – Less FA on small telescopes
- x10 more economical per W than Sodium

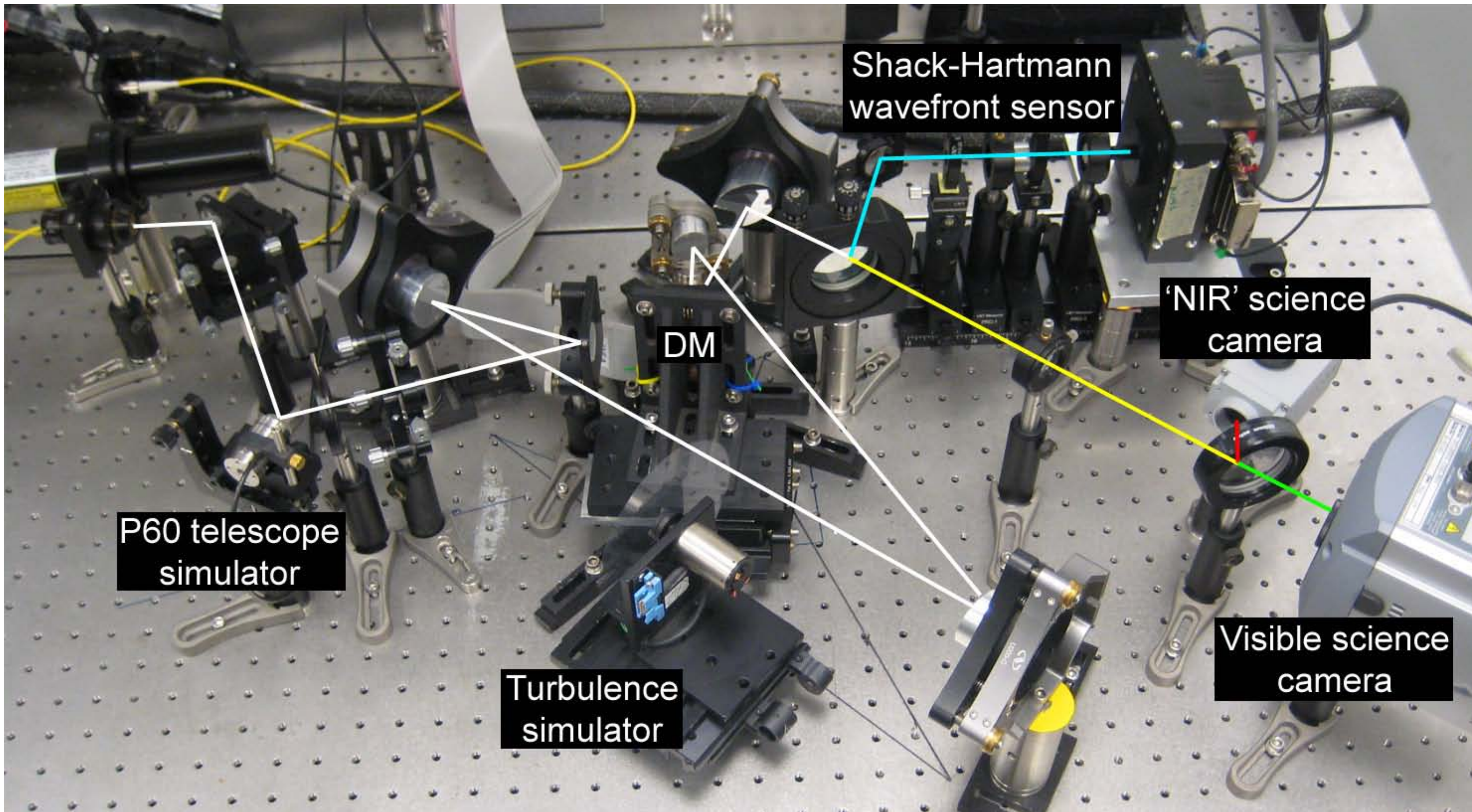
Laser beam projector





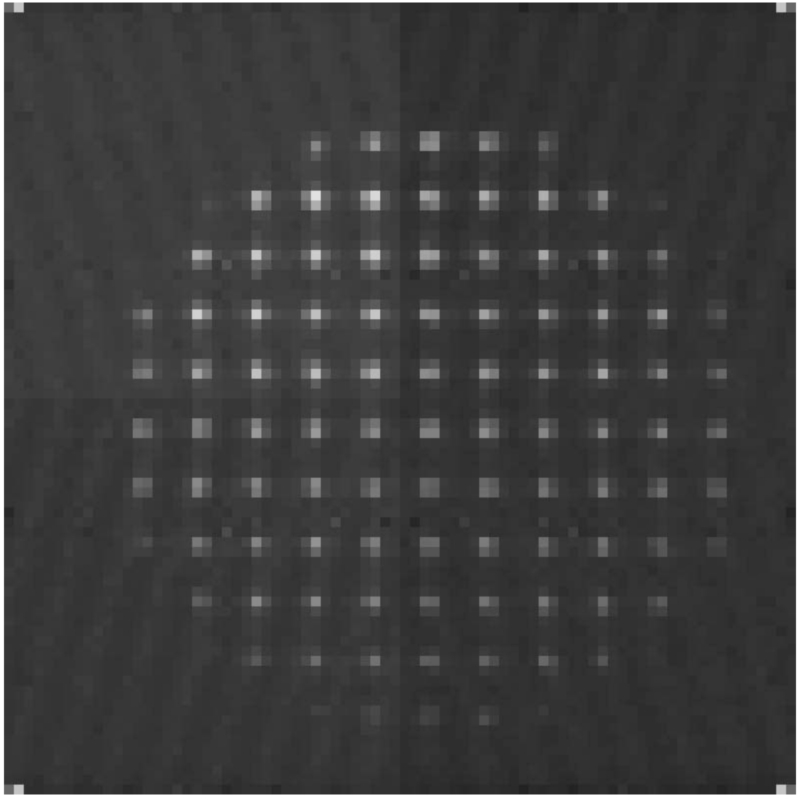
- Compact modular projector
- Optional periscope assembly
- UV Class 1 w.r.t. aircraft; no human spotters

Robo-AO adaptive optics



AO – Wavefront sensors

- Shack-Hartmann
  - 11 x 11 subapertures
  - E2V CCD39
  - 2kHz at 4.5 e-
- Image motion (tip/tilt)
  - From science instruments

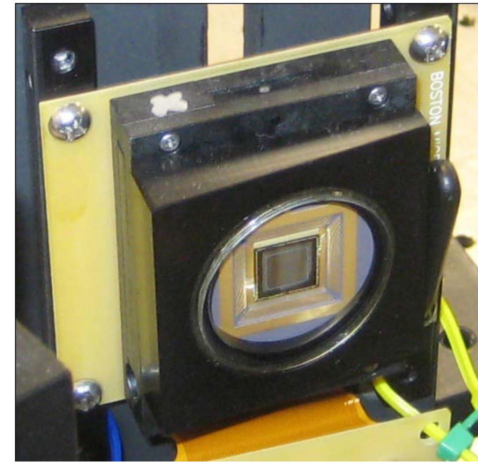


AO – Wavefront reconstructor

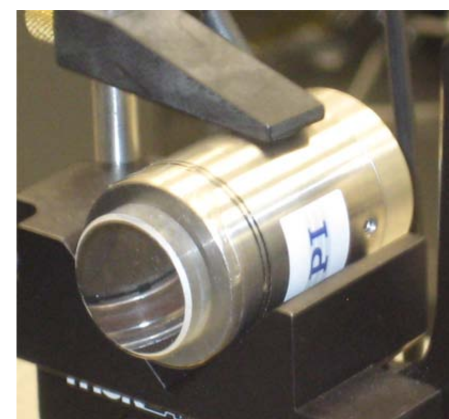
- Lightweight, fast Linux/C++ software
  - Capable of >3kHz
  - Running at 1.2 kHz
- Fully reconfigurable via user editable files
  - Custom reconstructor matrices
  - Adjustable loop parameters (gains, offsets, flat positions, etc.)

AO – Wavefront correctors

- Micro-Electro-Mechanical Systems deformable mirror
  - 12 x 12 actuators
  - 3.5 μm stroke



- Piezo fast steering mirror

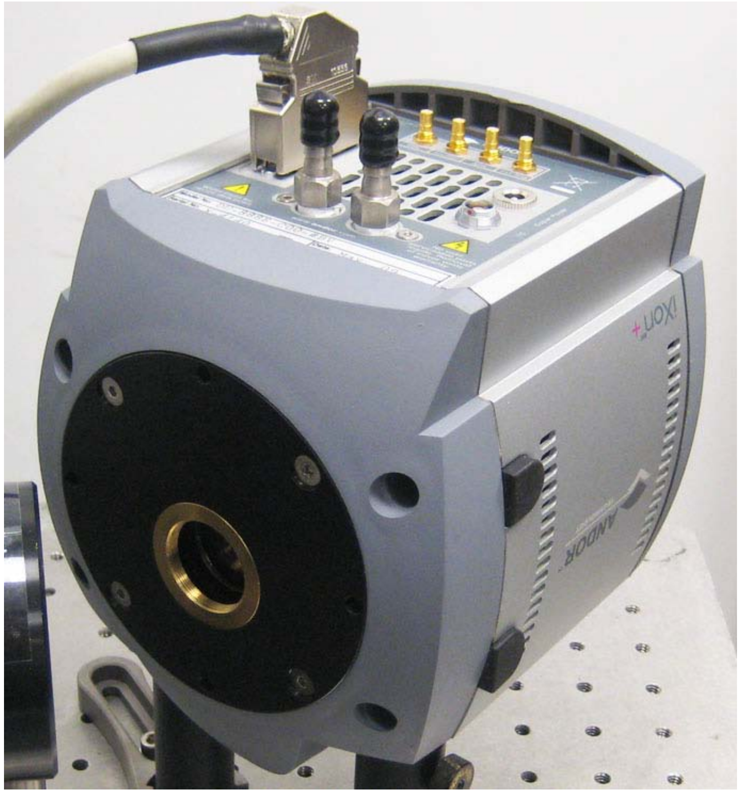


- USB electronics – 8 kHz
  - (IUCAA developed drivers)

Robo-AO in action

Visible science instrument

- Andor iXon^{EM}+ DU-888
- Electron Multiplying CCD
- 44” x 44” square FoV
- 0.043” pixels (Nyquist at λ = 620 nm)
- Full frame rate: 9 Hz
- Sub frame rate: ~200 Hz

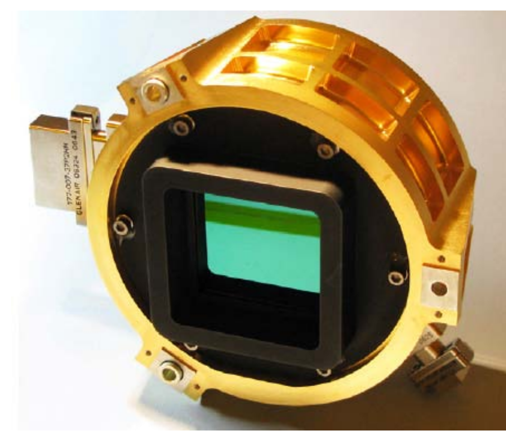


NIR science instrument

- InGaAs – (Xenics: Xeva)
  - + Affordable, readily available
  - - Noisy, small format

Xeva-1.7-320

- HgCdTe – (Teledyne: H2RG)
  - + 2’ FoV, 0.062” pixels (Nyquist at λ = 900 nm)
  - + Excellent noise, flexible readout
  - - Cost, development time



JWST Fine Guidance Sensor H2RG

Robotic control software

- Fully robotic control system
  - Subsystems work as daemons
  - Supervisor controls scheduling, operations
  - Watchdog processes
- Programming intelligence is a challenge
  - Error control and exception handling
  - Safety system for equipment
- Laser safety a priority

Palomar Observatory's P60

- Upgraded to robotic operation in 2004
- Part of Palomar Transient Factory providing primary rapid follow up observation with standard CCD camera
- Perfect platform for Robo-AO

Progress to date

- Lab AO system at 1.2 kHz
- Laser system designed, fabrication in progress, under full computer control
- Optimized WFS camera
- Visible camera – integrating tip/tilt control
- Currently reviewing optical design of Cassegrain instrument

Schedule

- On-sky laser test at P60 in August
- Full system test in January 2011
- Likely science demo period in Spring 2011

Upcoming Science Workshop

- Many new discoveries await with Robo-AO
- Encourage participation – bring your ideas!
- Guided lab tour
- Thursday 12:30pm-5pm
- http://www.astro.caltech.edu/Robo-AO/

Acknowledgements

The Robo-AO Team

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Co-I	A. N. Ramaprakash
Software Lead	Reed Riddle

Science team

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Timothy Morton	Eran Ofek
A. N. Ramaprakash	Reed Riddle
Shriharsh Tendulkar	Marten van Kerkwijk

Technical team

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Hillol Das	Richard Dekany
Jason Fucik	Nicholas Law
Sujit Punnadi	A. N. Ramaprakash
Reed Riddle	Shriharsh Tendulkar
Viswa Velur	Jeff Zolkower

Original CAMERA concept and testbed team

Matthew Britton	Nicholas Law
Viswa Velur	Dan Beeler (Pomona '09)
Lothar Ratschbacher (U. of Vienna)	

http://www.astro.caltech.edu/Robo-AO/