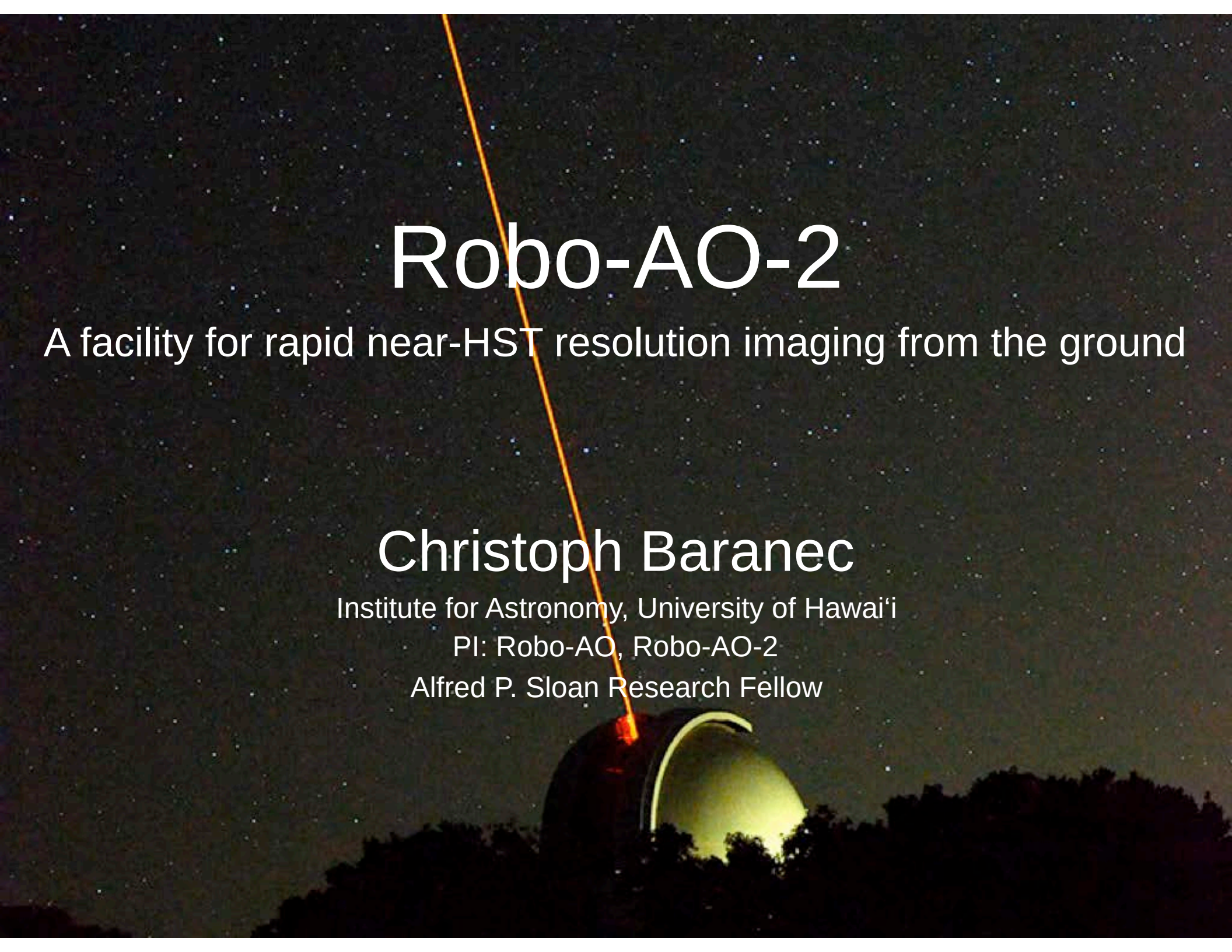


Robo-AO-2

A facility for rapid near-HST resolution imaging from the ground

Christoph Baranec

Institute for Astronomy, University of Hawai‘i

PI: Robo-AO, Robo-AO-2

Alfred P. Sloan Research Fellow

There is a growing need for very efficient adaptive optics (AO).

- Large surveys, large data sets
  - E.g., Kepler, TESS, Gaia, WFIRST, …
  - Binary stars, blends: exo-hosts, *microlensing*, …
- Rapid-response (transients)
  - E.g., ATLAS, ZTF, LSST, your favorite TDA project
  - Crowded fields, location in host galaxy, SNR boost
- Monitoring
  - E.g., planetary weather, lensed quasar dynamics

Efficient AO Design Philosophy

- Most large telescopes have (laser) AO.
- Primarily focused on very detailed studies of few interesting objects.
- Traditional Metrics: Strehl, contrast, EE, sky coverage

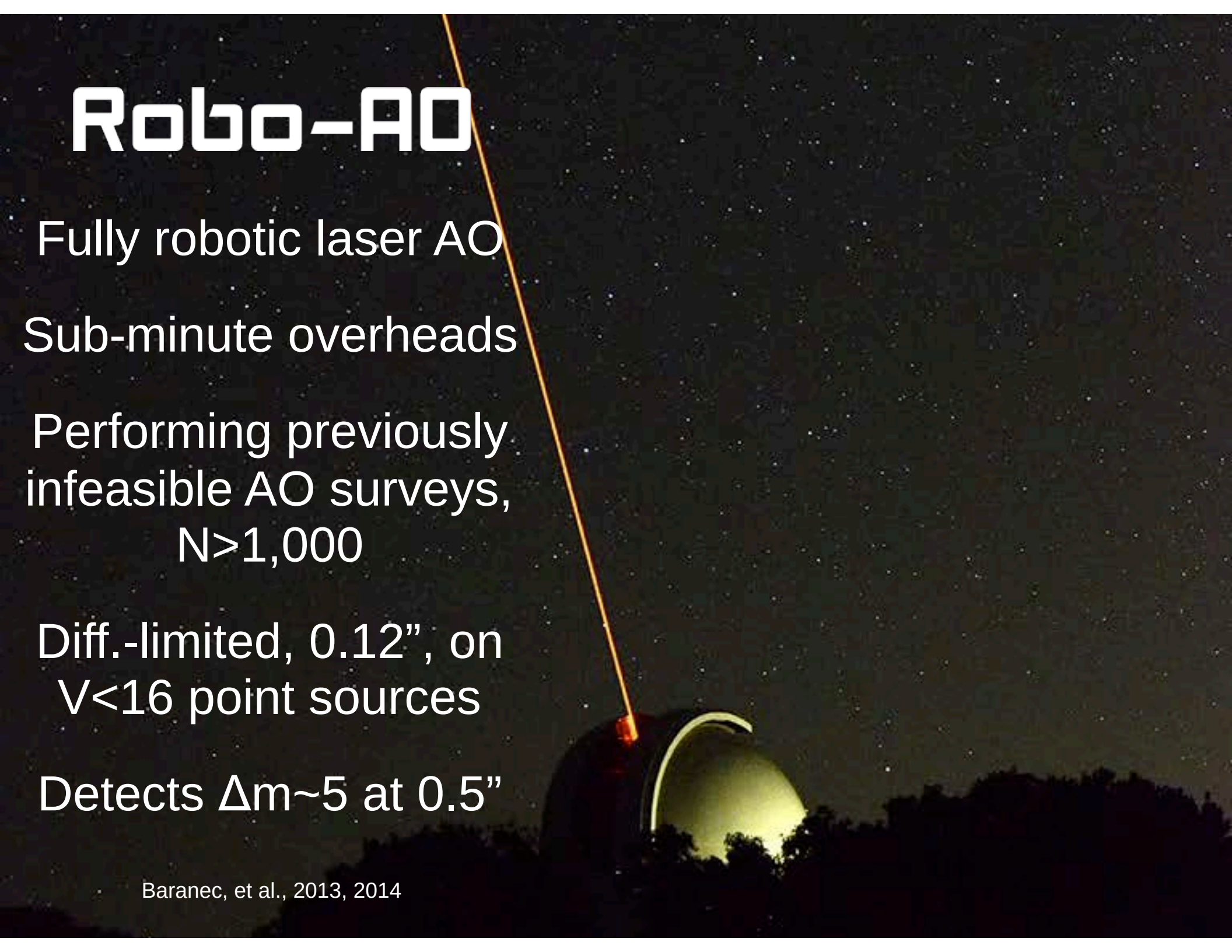
Efficient AO prioritizes:

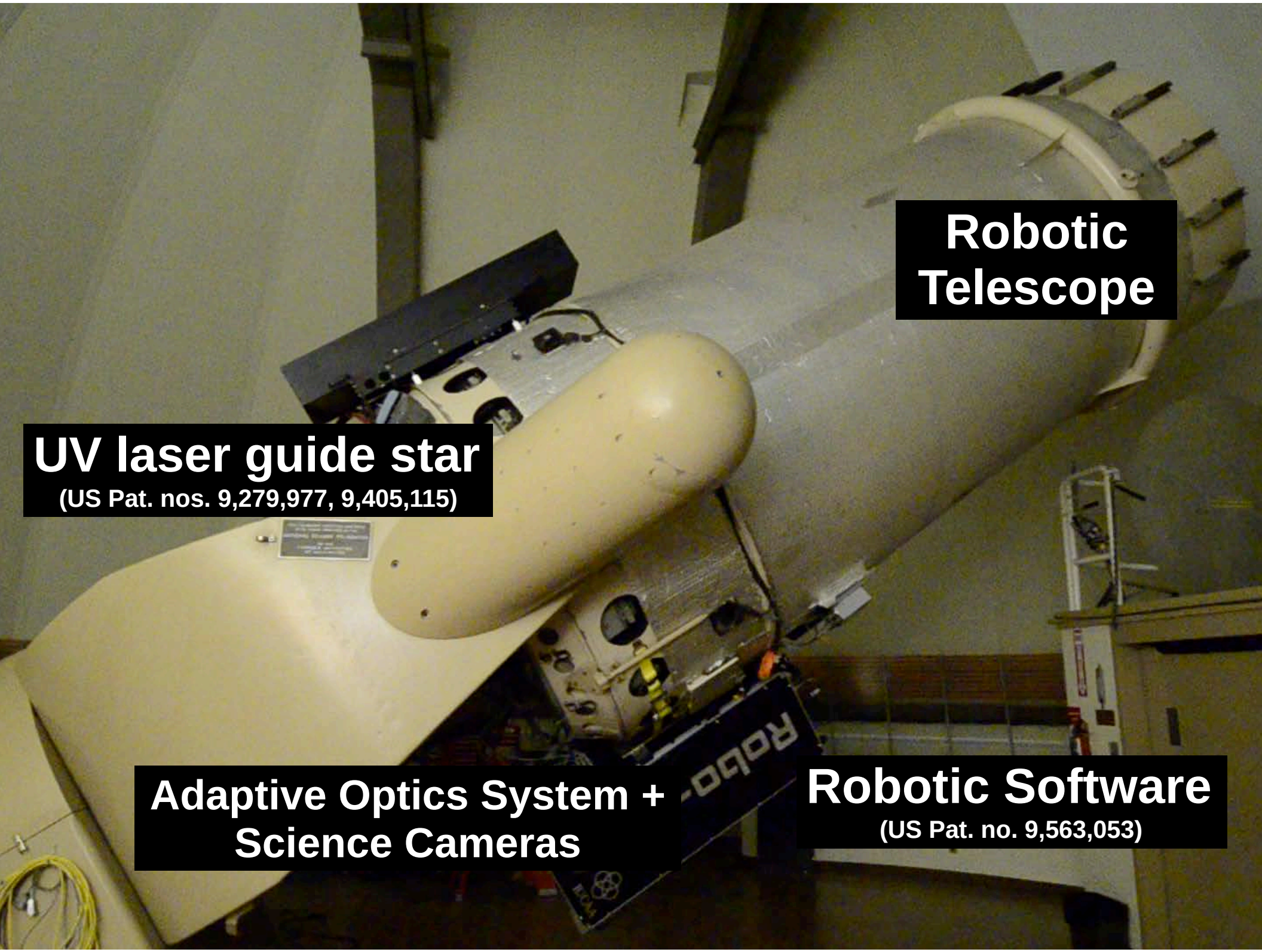
1. Reliability

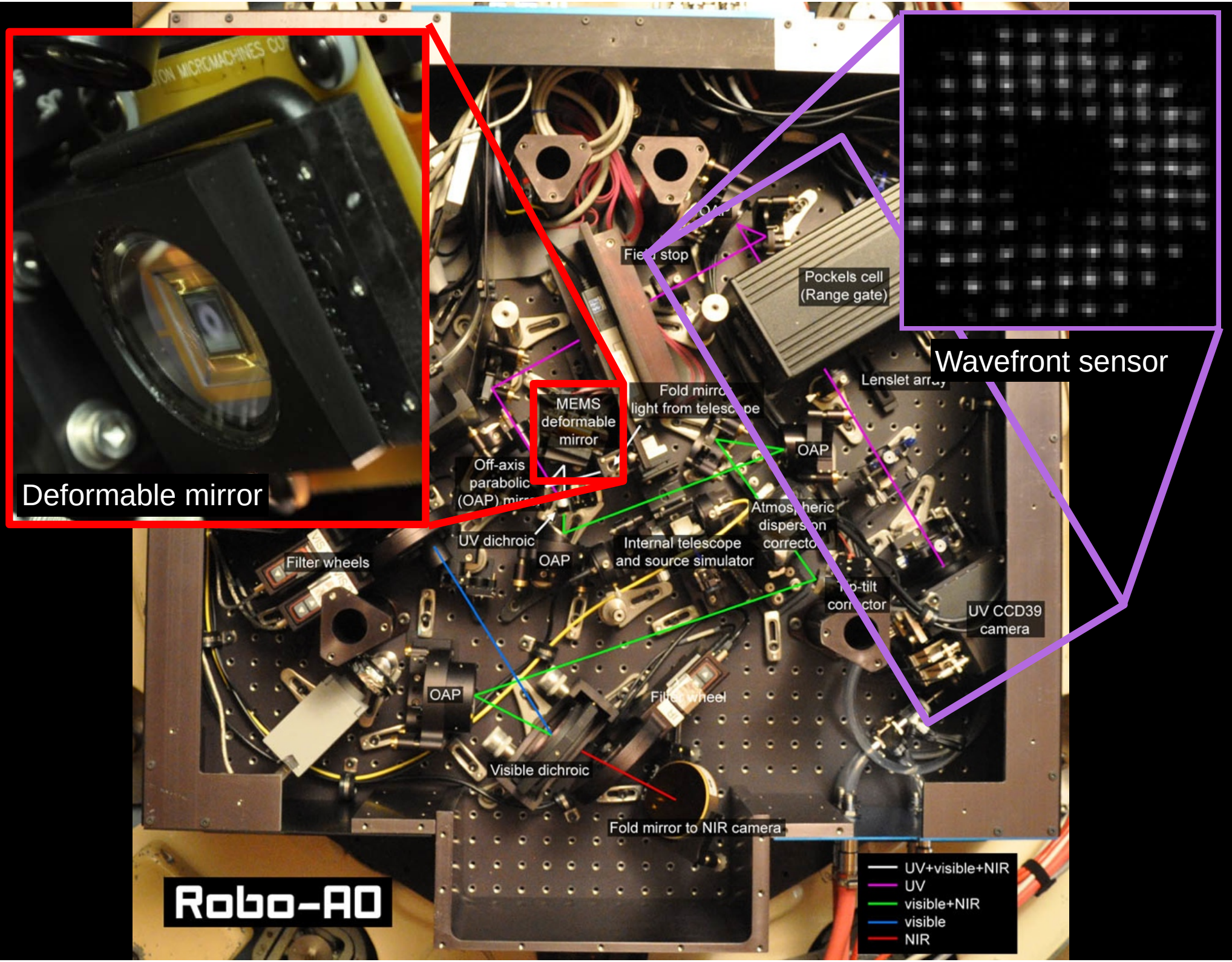
2. Predictability

3. Ease-of-use

Baranec, Riddle & Law, arXiv:1709.07103


Robo-AO
Fully robotic laser AO
Sub-minute overheads
Performing previously infeasible AO surveys, N>1,000
Diff.-limited, 0.12”, on V<16 point sources
Detects Δm~5 at 0.5”
Baranec, et al., 2013, 2014


Robotic
Telescope
UV laser guide star
(US Pat. nos. 9,279,977, 9,405,115)
Adaptive Optics System +
Science Cameras
Robotic Software
(US Pat. no. 9,563,053)


Deformable mirror
Wavefront sensor
Field stop
Pockels cell
(Range gate)
MEMS
deformable
mirror
Fold mirror
light from telescope
Lenslet array
OAP
Off-axis
parabolic
(OAP) mirror
Atmospheric
dispersion
corrector
UV dichroic
OAP
Internal telescope
and source simulator
Filter wheels
Tip-tilt
corrector
UV CCD39
camera
OAP
Filter wheel
Visible dichroic
Fold mirror to NIR camera
Robo-AO
UV+visible+NIR
UV
visible+NIR
visible
NIR

Robo-AO is fully automated.

Reed Riddle, Robotic software Guru

- A master sequencer runs the show.
- Subsystems run as daemons.
- Auto-recovery from unexpected errors
- Observations loaded into database via .xml.
- Intelligent obs. queue, mixes science programs
  - Automatic satellite/laser deconfliction
- Automatic data reduction and analysis pipeline (Reduced images are ready the next day!!!)

Dmitry Duev
CIT P.Doc

Robo-AO data archive | Data | Search | Logged in as **admin**

Nightly data

Toggle view

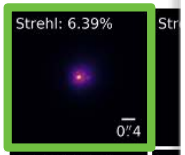
February 22, 2017 - February 23, 2017

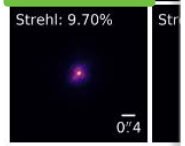
2017/02/22

Data preview | Auxiliary data | Download

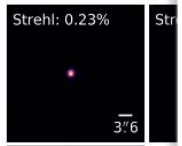
Toggle summary

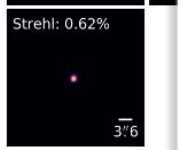
Program 0



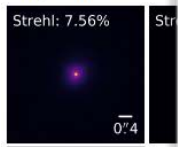


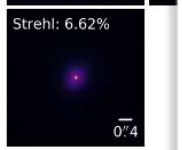
Program 24



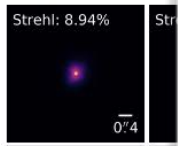


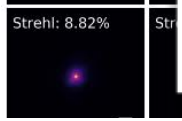
Program 283





Program 3

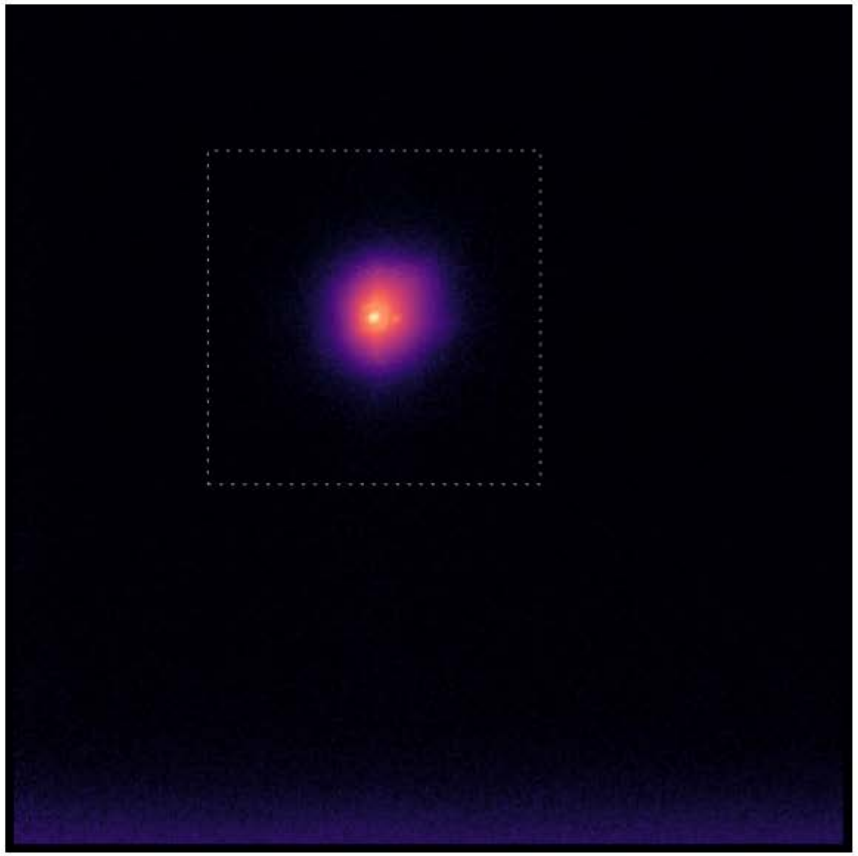




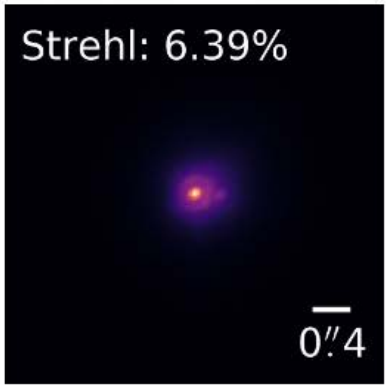
0_[redacted]_VIC_Si_o_20170222_092131.042223

Lucky pipeline | Faint pipeline | Header | External images of the field

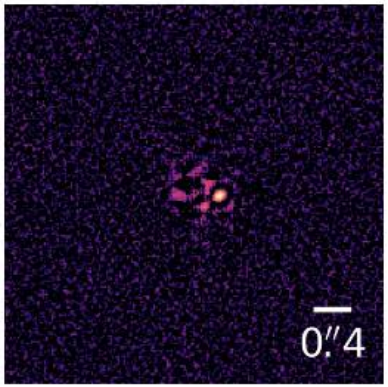
Full-size



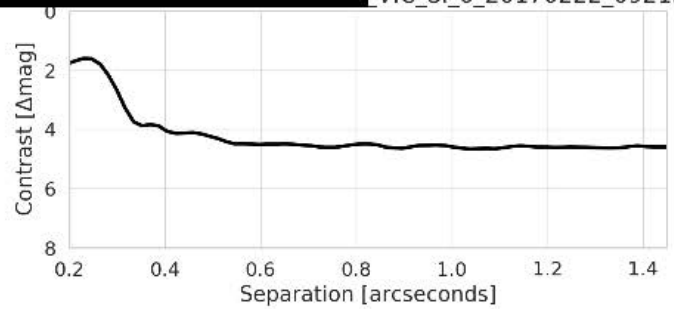
Cropped



PSF-subtracted



0_[redacted]_VIC_Si_o_20170222_092131.042223

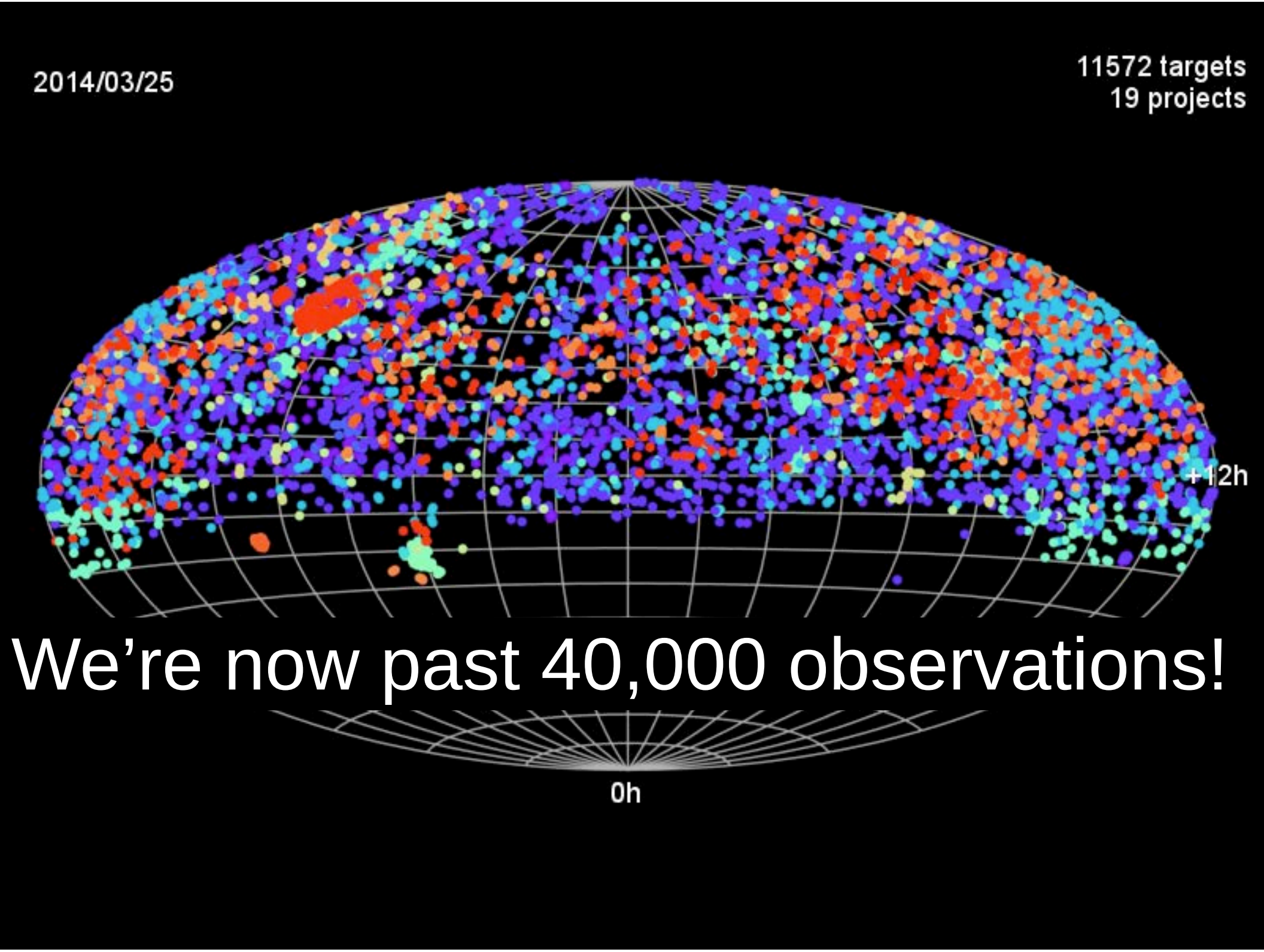


Download all source data

Close

40 second overhead / target

25 targets / hour



We’re now past 40,000 observations!

Robo-AO General Observing

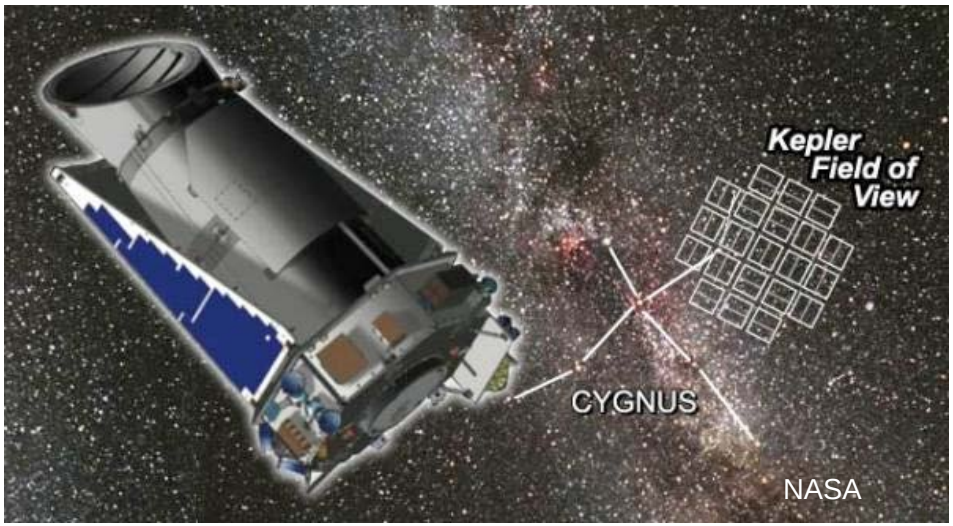
- **Nearby exoplanets & planetary formation:**
  - Stellar companions around K2 exoplanet hosts (Open c.o. Templeton Fnd.)
  - Verifying debris-disk stars (S. Hinkley)
  - Transit candidates from PTF/M-dwarfs survey (N.Law)
- **Field stellar multiplicity:**
  - High-order solar-type multiplicity (R. Riddle, A. Tokovinin)
  - All Northern stars within 25 pc (Robo-AO Team)

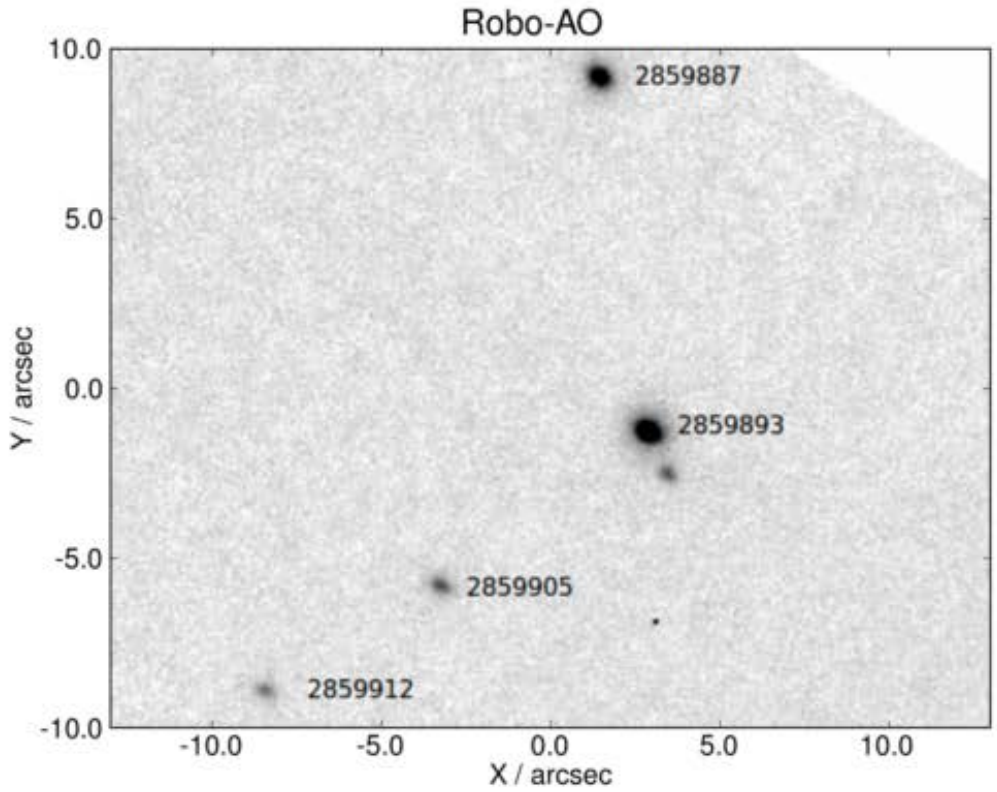
Robo-AO: 34 refereed scientific papers

- **Young stellar multiplicity:**
  - Pre-main-sequence multiplicity (L. Hillenbrand)
  - Multiplicity as a function of age (J. Curtis, R. Riddle, L. Hillenbrand)
- **Solar system science:**
  - Monitoring of outgassing from Comet ISON (M. Drahus)
  - Solar system imaging (R. Hueso, et al.)
  - Search for binary asteroids (D. Duev)
- **Extragalactic & high-energy:**
  - AGN nuclei binarity (S. Tendulkar)
  - High-precision astrometry for globular cluster black holes (S. Hildebrand)
  - Lensed Quasar discovery and monitoring (E. Ofek, R. Griffiths)

Robo-AO Kepler survey

NASA XRP grant NNX15AC91G (Law, Baranec & Morton)



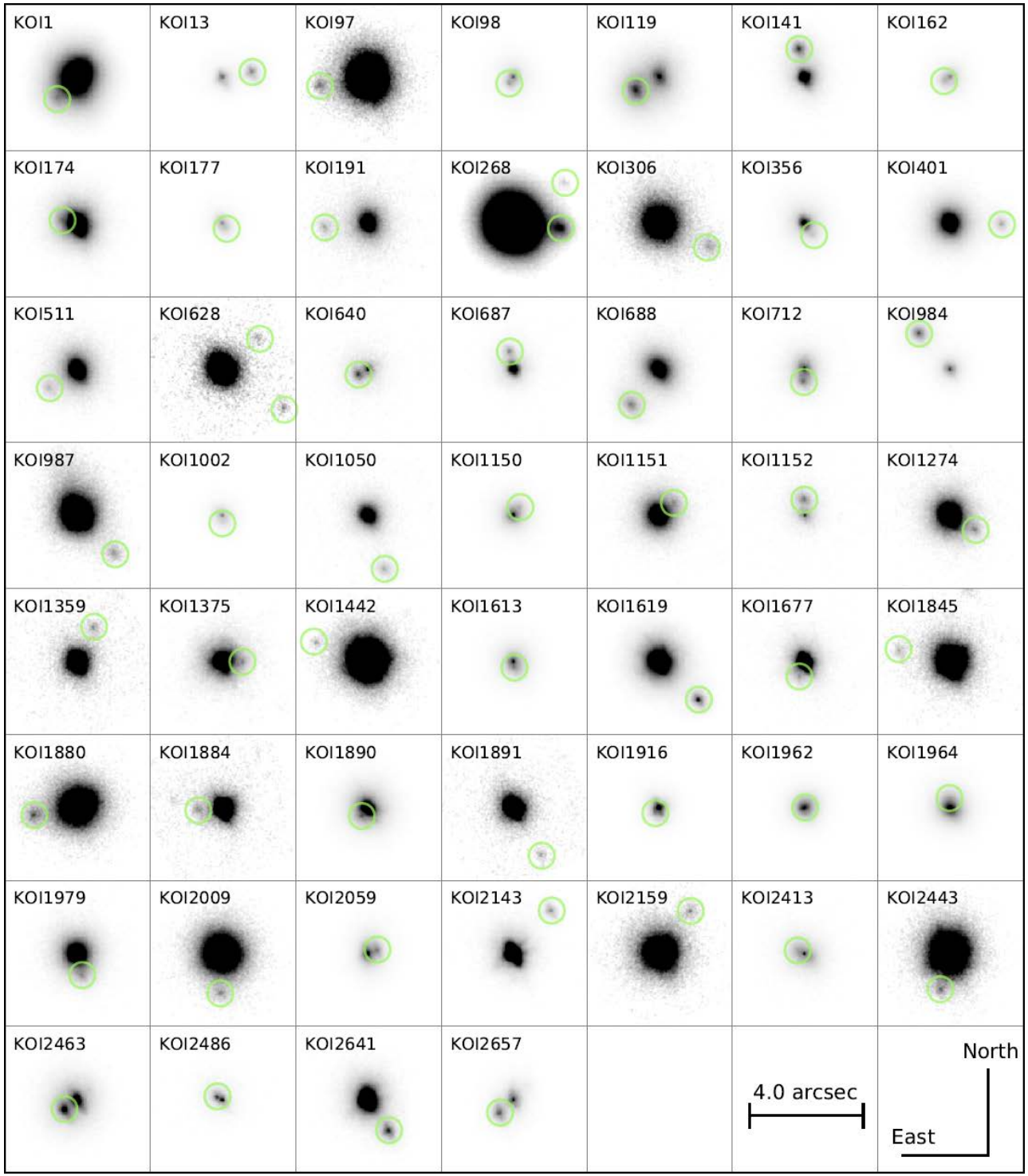


Kepler pixels are ~4”.

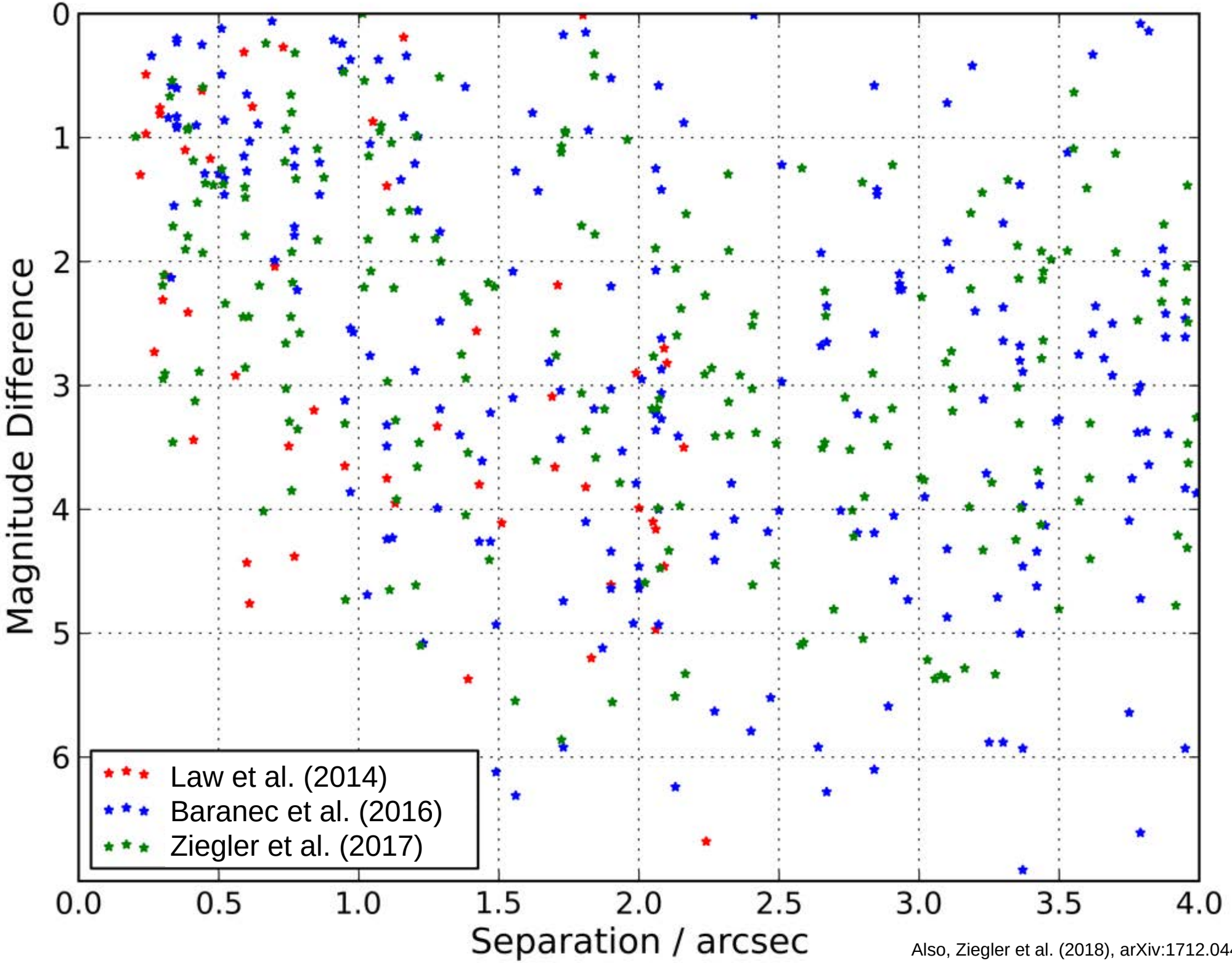
Photometric apertures can be 3 by 3 pixels.

Unresolved sources contaminate transits.

We used Robo-AO to image all of the KOIs.

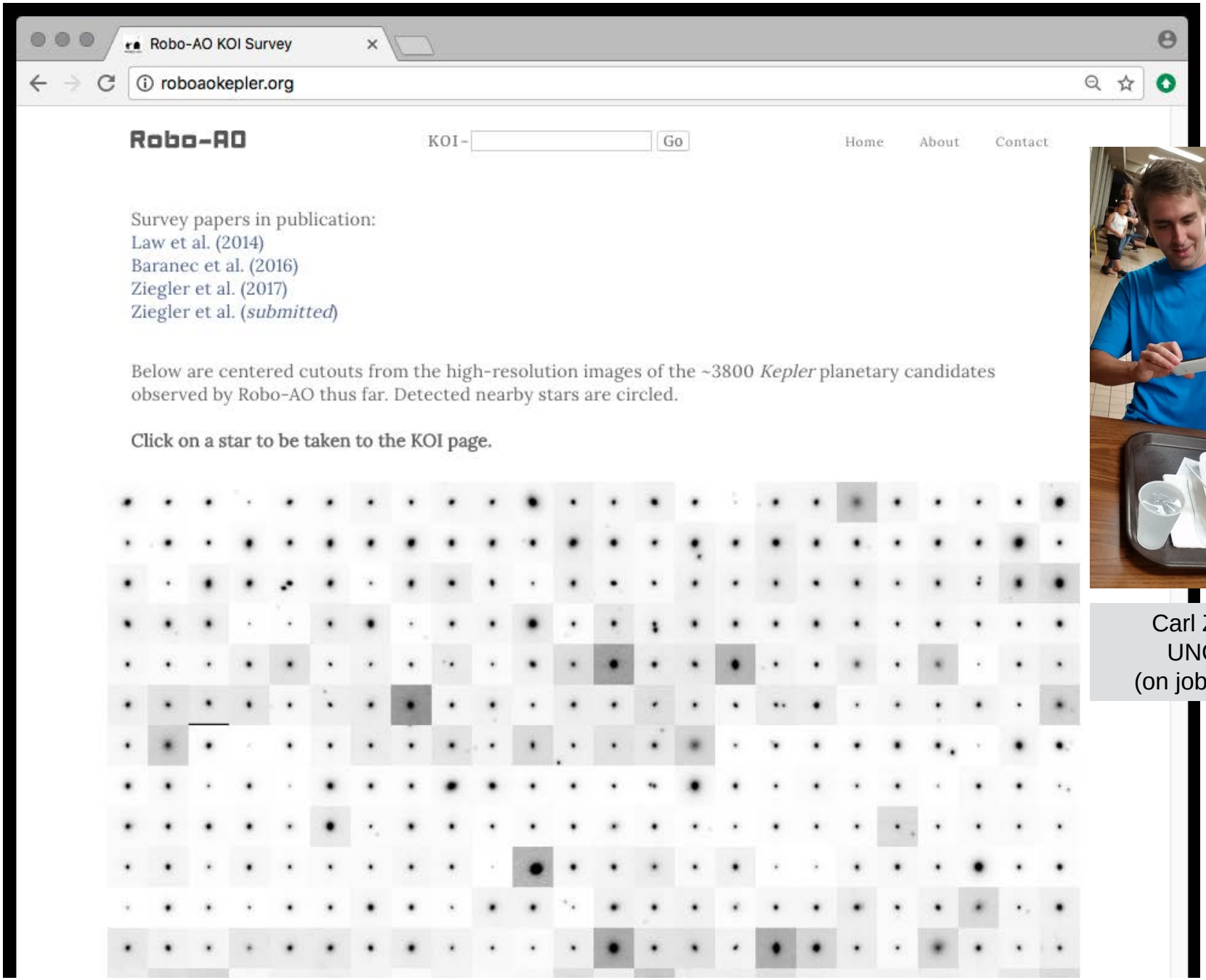


Law et al. 2014



Also, Ziegler et al. (2018), arXiv:1712.04454

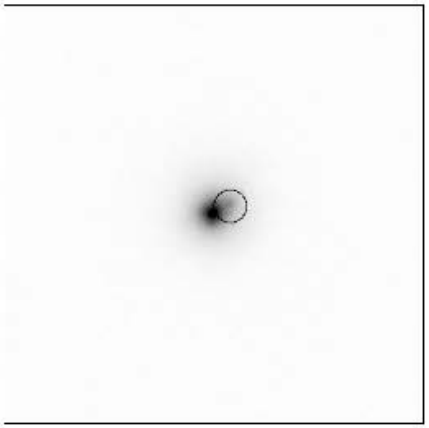
Public access to reduced data at roboaokepler.org



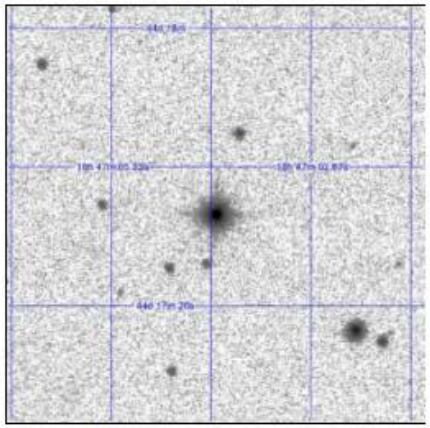
Carl Ziegler
UNC GS
(on job market)

KOI-1150

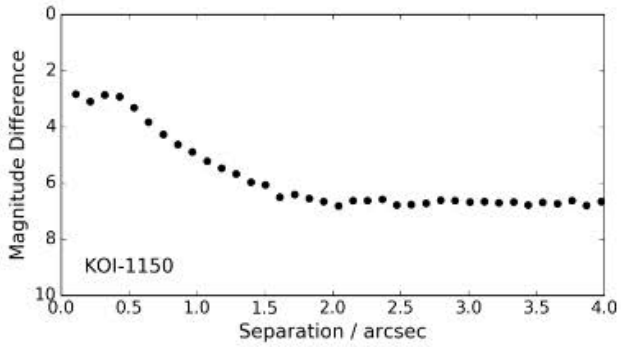
Confirmed planet
Kepler-780 b



Robo-AO 8-arcsec centered cutout image of KOI-1150 with any detected nearby stars circled (Law et al. 2014)



UKIRT 1-arcmin field centered on KOI-1150



Robo-AO 5-sigma detection sensitivity for KOI-1150

Nearby star properties

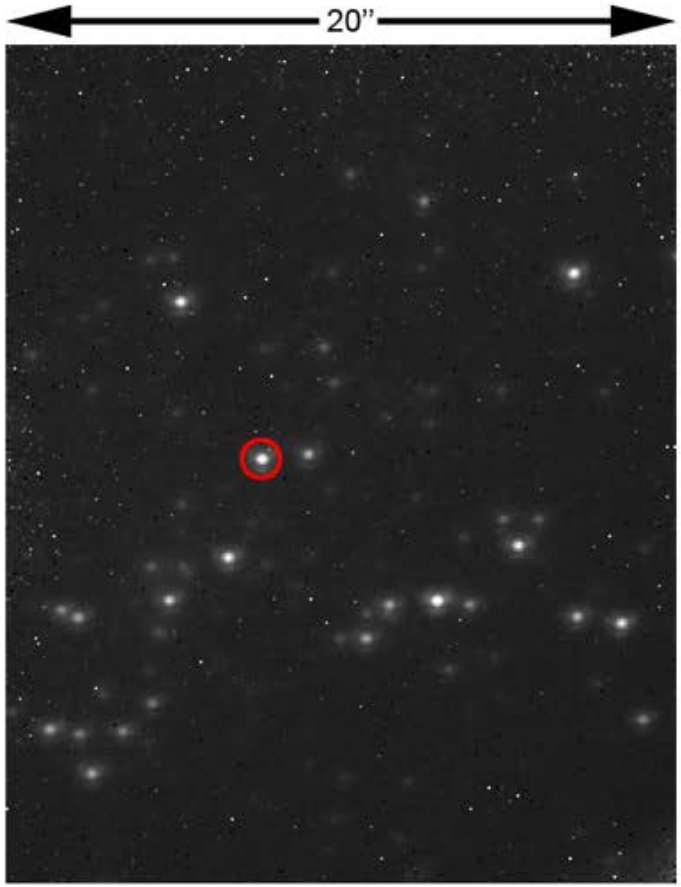
Separation (")	Position Angle (deg)	LP600 Contrast (mags)	Reference
0.39	322	2.41	Law et al. (2014)

Planet properties (Kepler DR25)

Planet	Disposition	Period (days)	Radius (R_Earth)	Epoch (BJD)	Transit duration (hrs)	Transit depth (ppm)	Eq. Temp. (K)

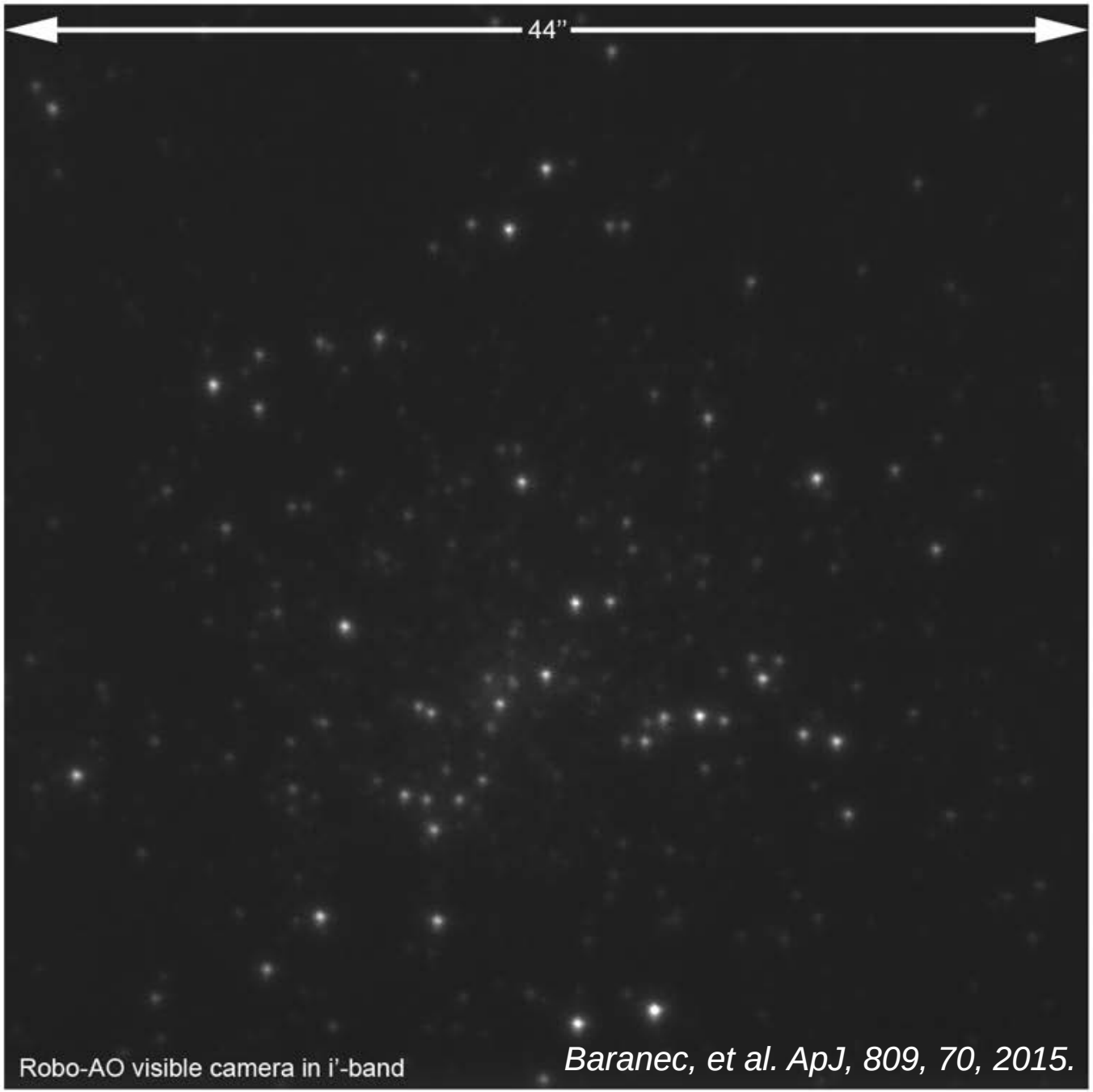
First demonstration of IR APDA in an AO system

The core of M15 imaged by Robo-AO
September 3rd, 2014.



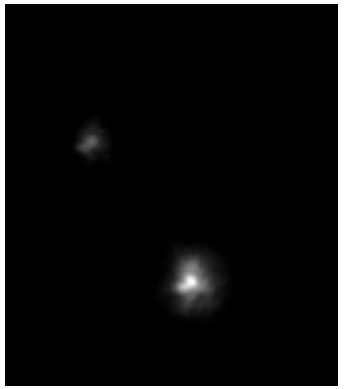
HiloCam (SAPHIRA) in H-band

IR tip-tilt guide star indicated by red circle.

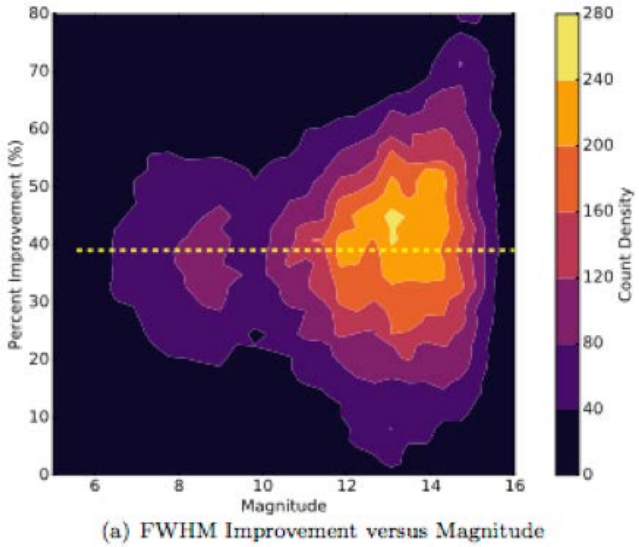


Baranec, et al. ApJ, 809, 70, 2015.

GenSTAC faint target pipeline



- Robo-AO → Fast frame rate data
- Post-facto registration requires sufficient flux
- New pipeline optimizes temporal binning -or-
- Stacks data for a improvement in FWHM of ~40% (All-sky)



(a) FWHM Improvement versus Magnitude

32 new KOI companions in existing data!

Howard, et al. 2018

Ward Howard, UNC GS

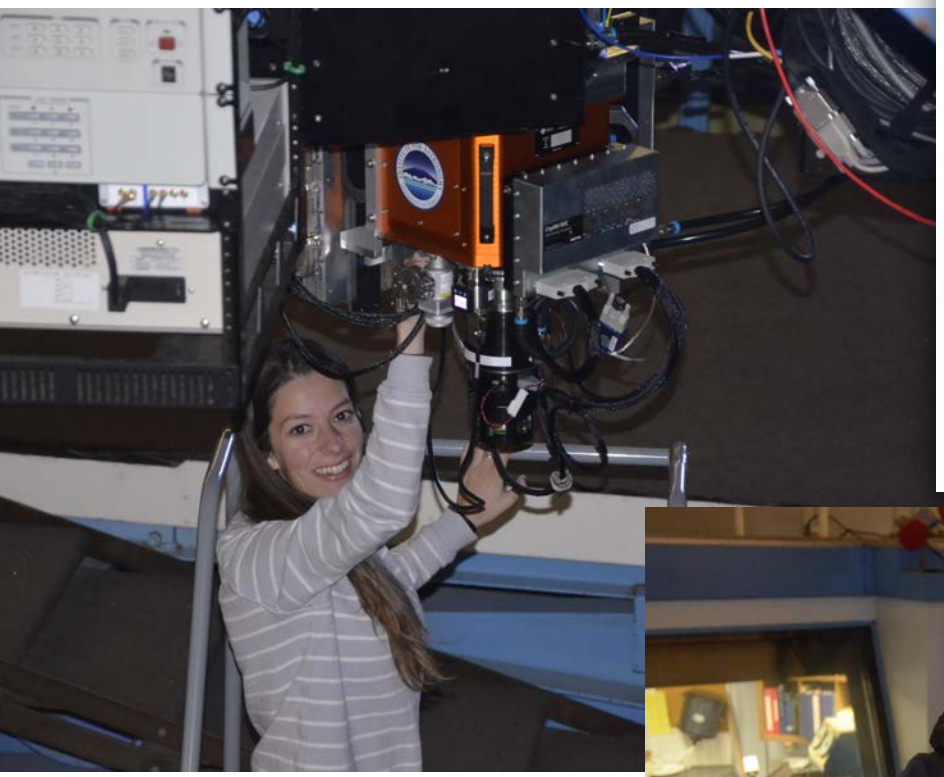
Robo-AO was moved to the 2.1 m telescope at Kitt Peak, AZ in Nov. 2015.

R. Jensen-Clem, et al., 2018
arXiv:1703.08867

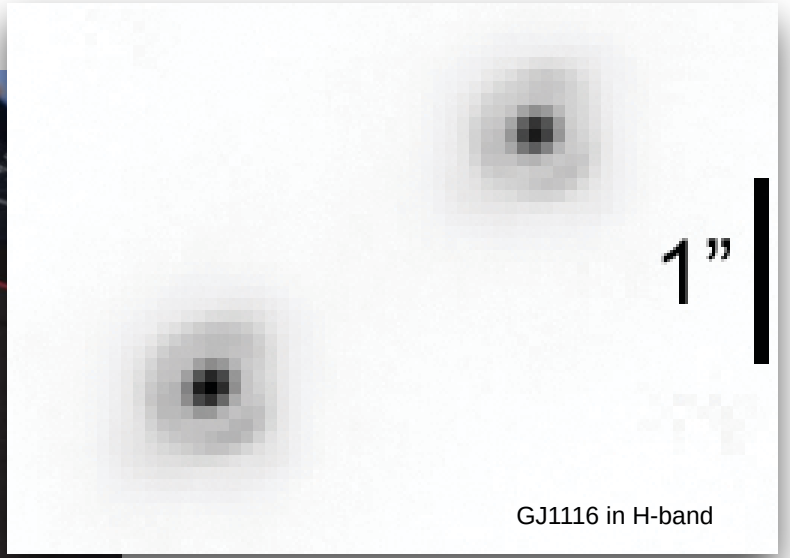
Science grade SAPHIRA ➔ Robo-AO Kitt Peak

Starting a N~4,000 survey for wide low-mass companions

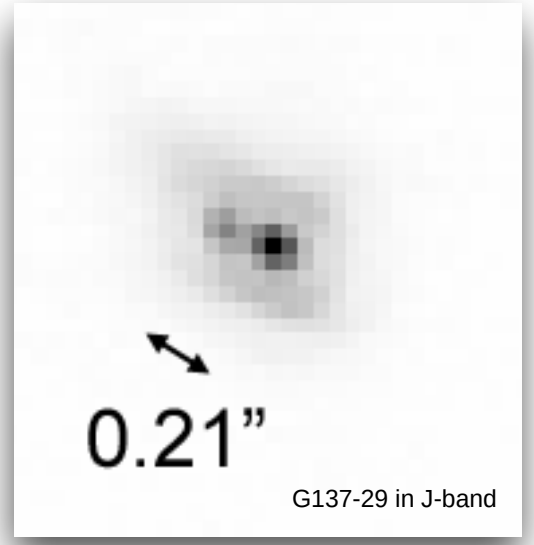
In collaboration with Mike Liu



Maïssa Salama
IfA GS



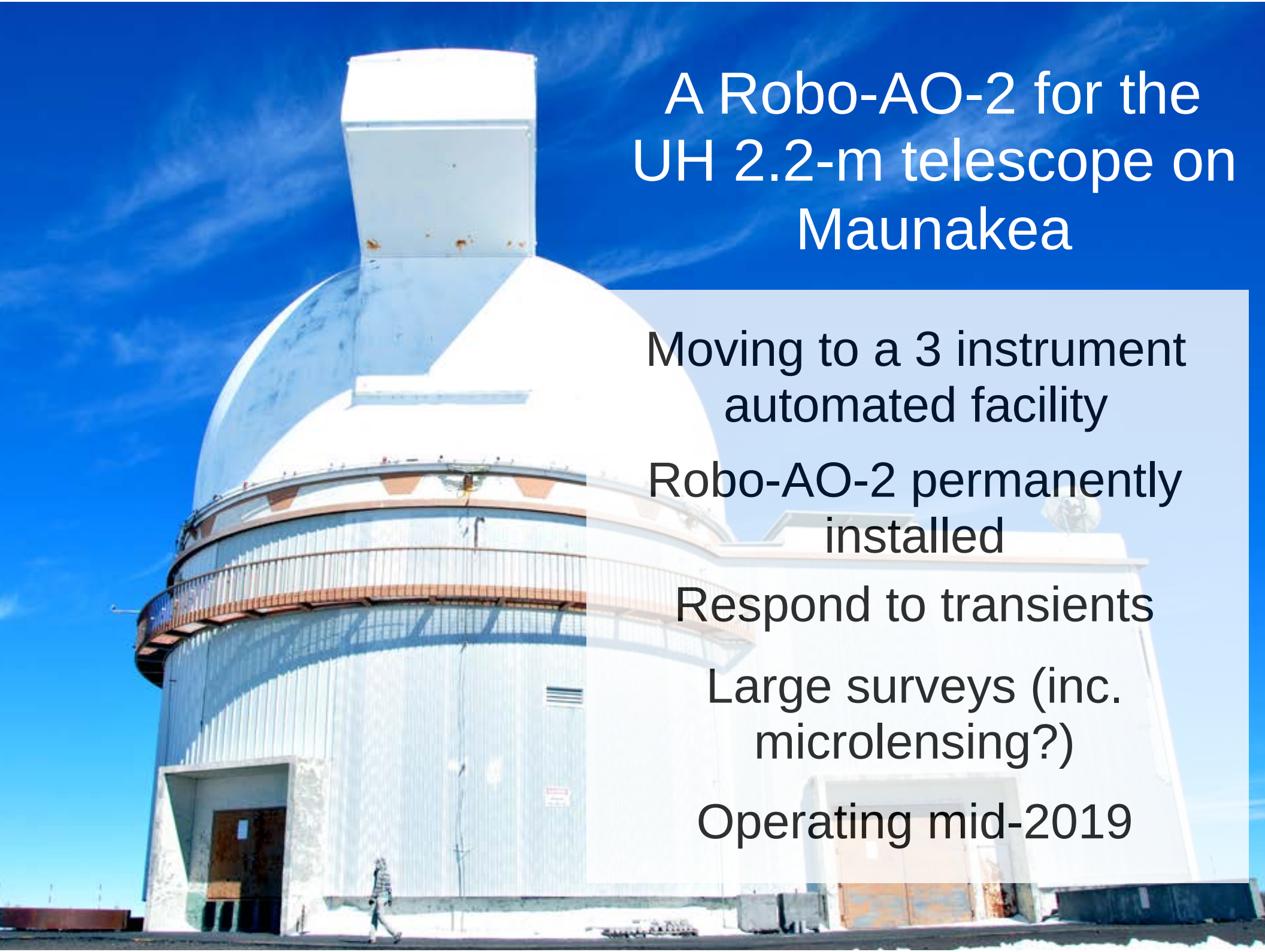
Replacing a leaky filter →



That’s great and all. What’s next?

- Kitt Peak - We’ll be observing for as long as we can keep funding going (~Sept. 2018).
- (Next???) IRTF → Planetary/NASA science
- **Robo-AO-2:**
  - **Imaging across the visible and near-infrared**
  - Demonstration of hybrid AO technologies
- Robotizing Sodium laser beacon systems:
  - Transfer tech to Keck for large survey and TDA support (Gemini S for LSST)
- Additional IFS instrumentation

Robo-AO-2 will be coming to Maunakea.



A Robo-AO-2 for the UH 2.2-m telescope on Maunakea

Moving to a 3 instrument automated facility

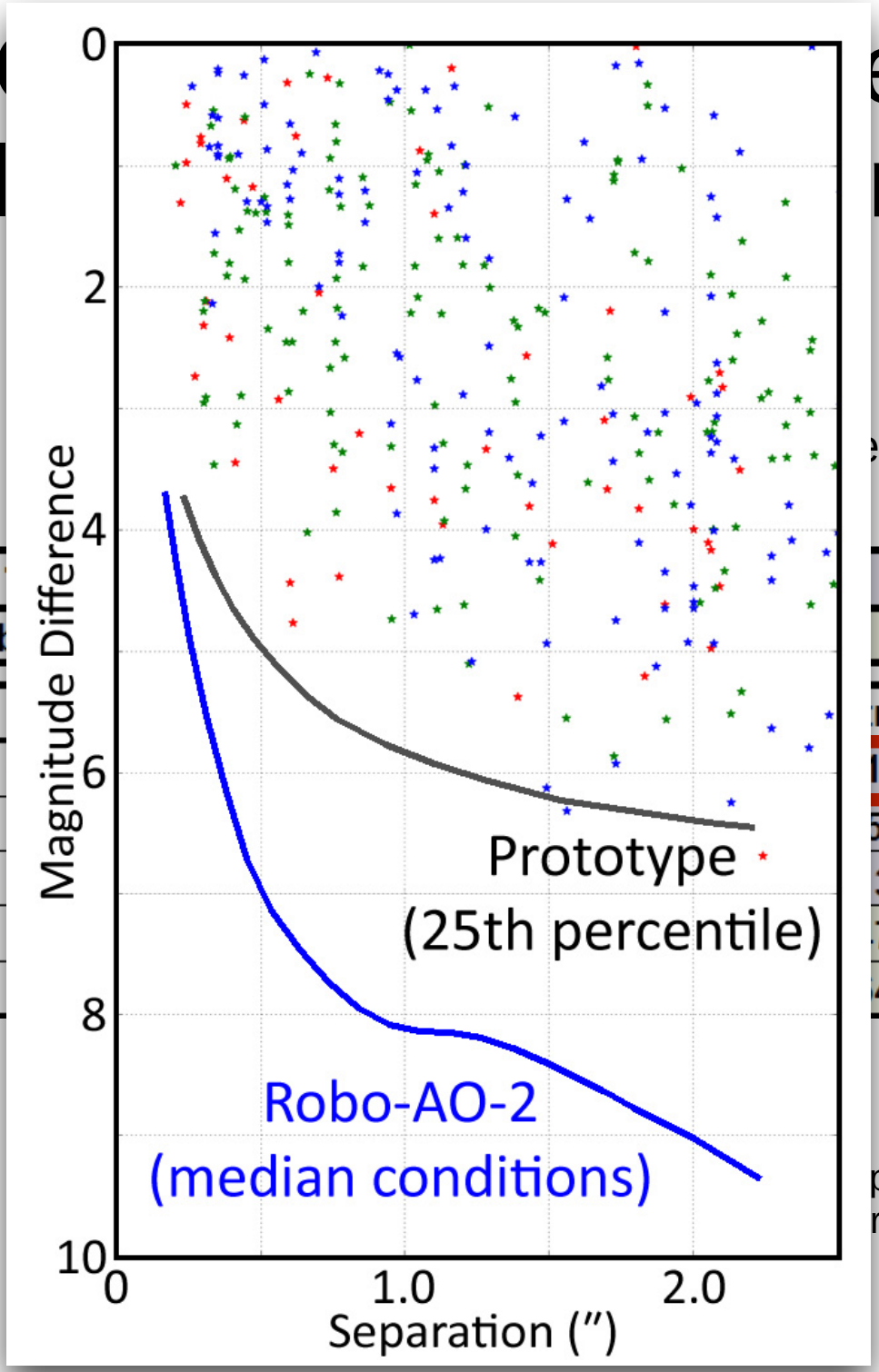
Robo-AO-2 permanently installed

Respond to transients

Large surveys (inc. microlensing?)

Operating mid-2019

Robo-A[illegible] quality and resol[illegible] mproved.



eeing =45°

Poor seeing

Total Wavefront Error (NIR			163 nm		206 nm	
Total Wavefront Error (Visi			163 nm		207 nm	
Spectral Band	λ		rehl	FWHM	Strehl	FWHM
g'	0.47 μ		1%	0.13"	0%	0.49"
r'	0.62 μ		5%	0.08"	1%	0.14"
i'	0.75 μ		3%	0.08"	4%	0.10"
J	1.25 μ		7%	0.12"	31%	0.13"
H	1.64 μ		4%	0.16"	50%	0.16"

pened m_V=17 (MV) tip-tilt star
ranec, et al., arXiv:1407.0094


http://robo-ao.org
Mahalo!