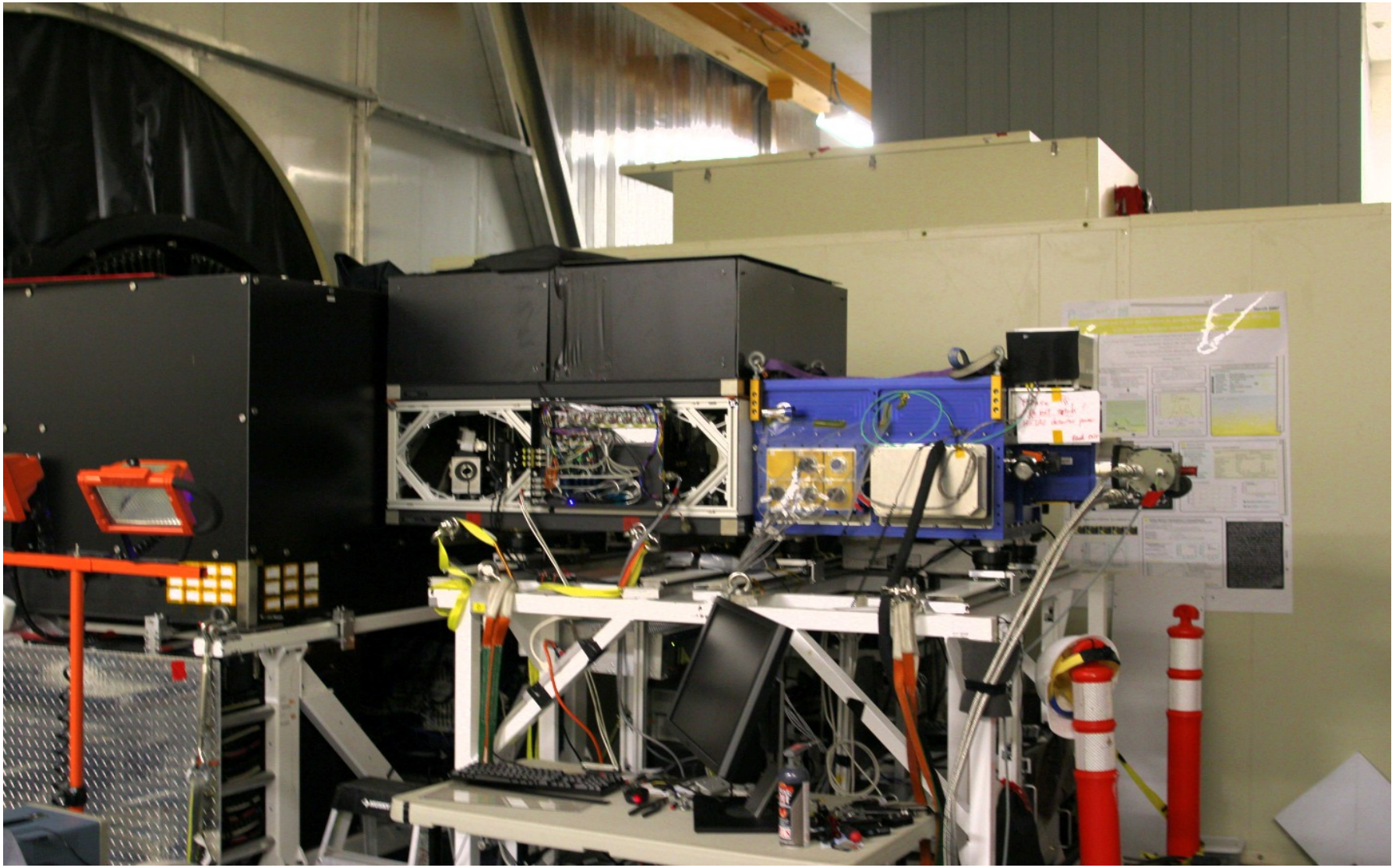
The Subaru Coronagraphic Extreme-Adaptive Optics (SCExAO) system



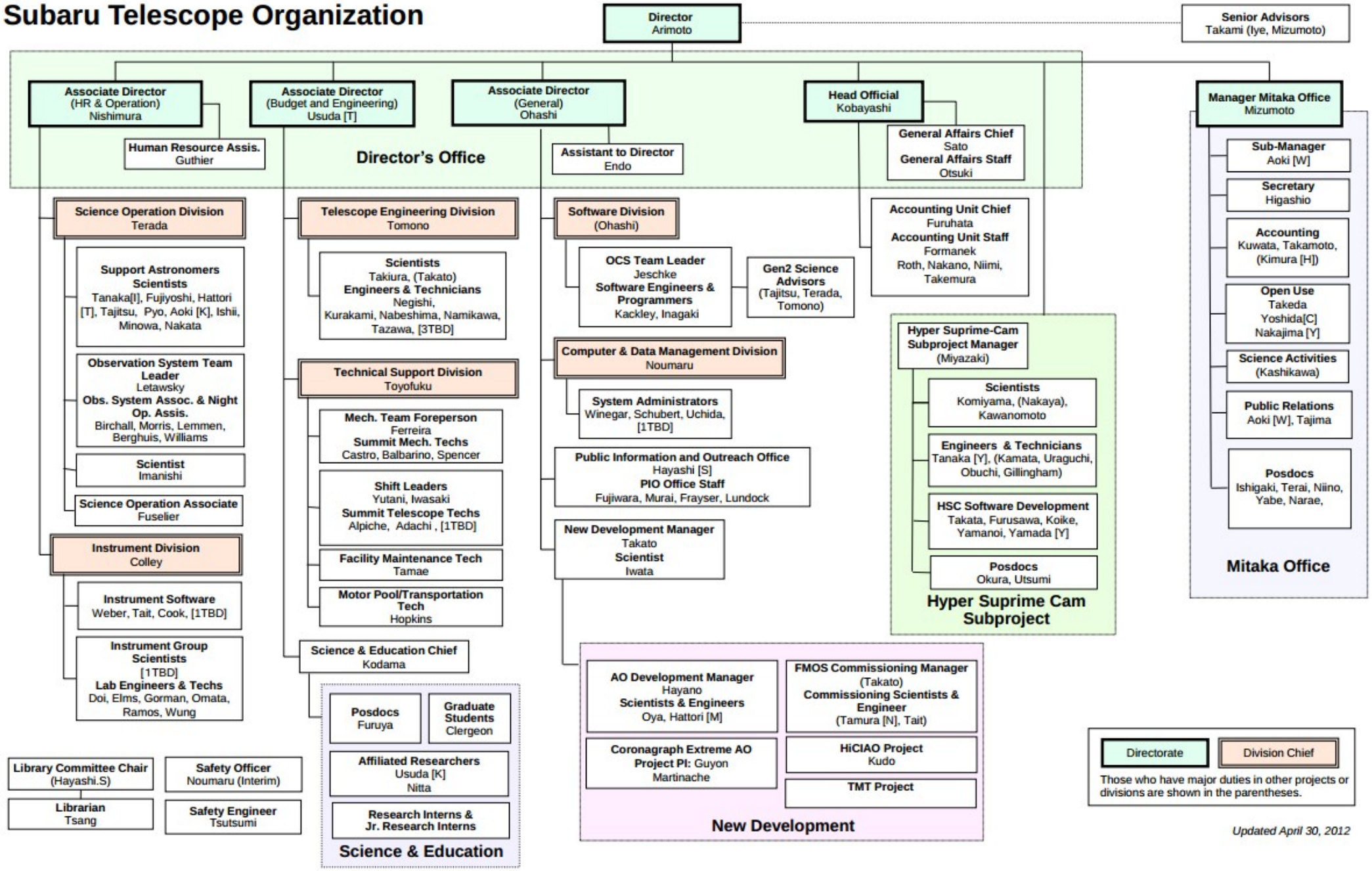
Subaru Coronagraphic Extreme-Adaptive Optics (SCExAO)

Coronagraph:
Optical system designed to remove light from a central object in order to see fainter objects around it.

Extreme-AO:
Adaptive optics system optimized for extremely good wavefront correction on bright natural guide star, over a very small field of view.

Coronagraphy *and* ***Extreme-AO*** *are the two key ingredients for imaging faint sources (planets, disks) very close to bright stars.*

Subaru Telescope Organization



Extreme AO Myths

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ExAO is extremely difficult

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ExAO is extremely costly

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ExAO doesn't work

Extreme AO Myths

ExAO is extremely difficult

ExAO is extremely costly

ExAO doesn't work

ExAO self proclaimed “scientists” don't know what they are doing – they change their mind every year about what is the best way to do it (coronagraphs, wavefront sensor, calibration scheme...)

The Subaru Coronagraphic Extreme-AO (SCExAO) group

Olivier Guyon [50% SCExAO, 50% space coronagraphy]
Frantz Martinache
Nemanja Jovanovic

SCExAO PhD students (+ ~20 unlisted interns):
Vincent Garrel [graduating Oct 2012] *Visible light imaging*
Celia Blain [graduating Oct 2012] *MEMS DM modeling*
University of Victoria, BC, Canada
Christophe Clergeon [graduating ~end 2013] *Visible light WFS*
Garima Singh [starting PhD in Oct 2012] Wavefront sensing

Associated teams / researchers:

- AO188 group, HiCIAO group, Kyoto 3-D
- Princeton University (CHARIS instrument)
- NASA Ames coronagraphy group & EXCEDE space mission
- University of Sydney (VAMPIRES instrument)
- Naoshi Murakami at Hokkaido University
- Eugene Serabyn at NASA JPL - Caltech
- Pierre Baudoz at Observatoire de Paris Meudon

SCExAO goals

- **Direct imaging of exoplanets and disks** in and near the habitable zone (HZ). Understand how planets form and evolve in the HZ, Constrain occurrence of habitable planets around nearby stars

- Provide a **platform for high contrast imaging techniques** development by our group and other groups. SCExAO is not a static instrument, its performance grows by addition of techniques/modules and scientific collaborations.

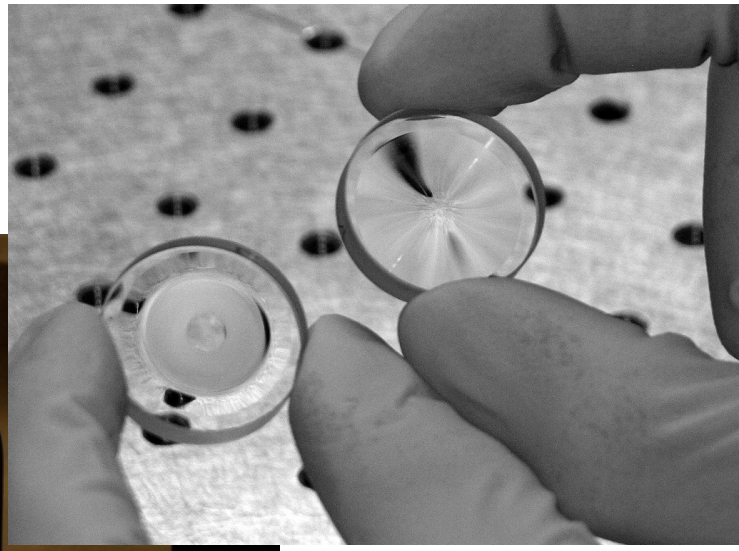
- Be an **active research group in exoplanet observation techniques** (new coronagraphs, wavefront control techniques, Kernel phases, transit observations) with applications for ground-based and space astronomy.

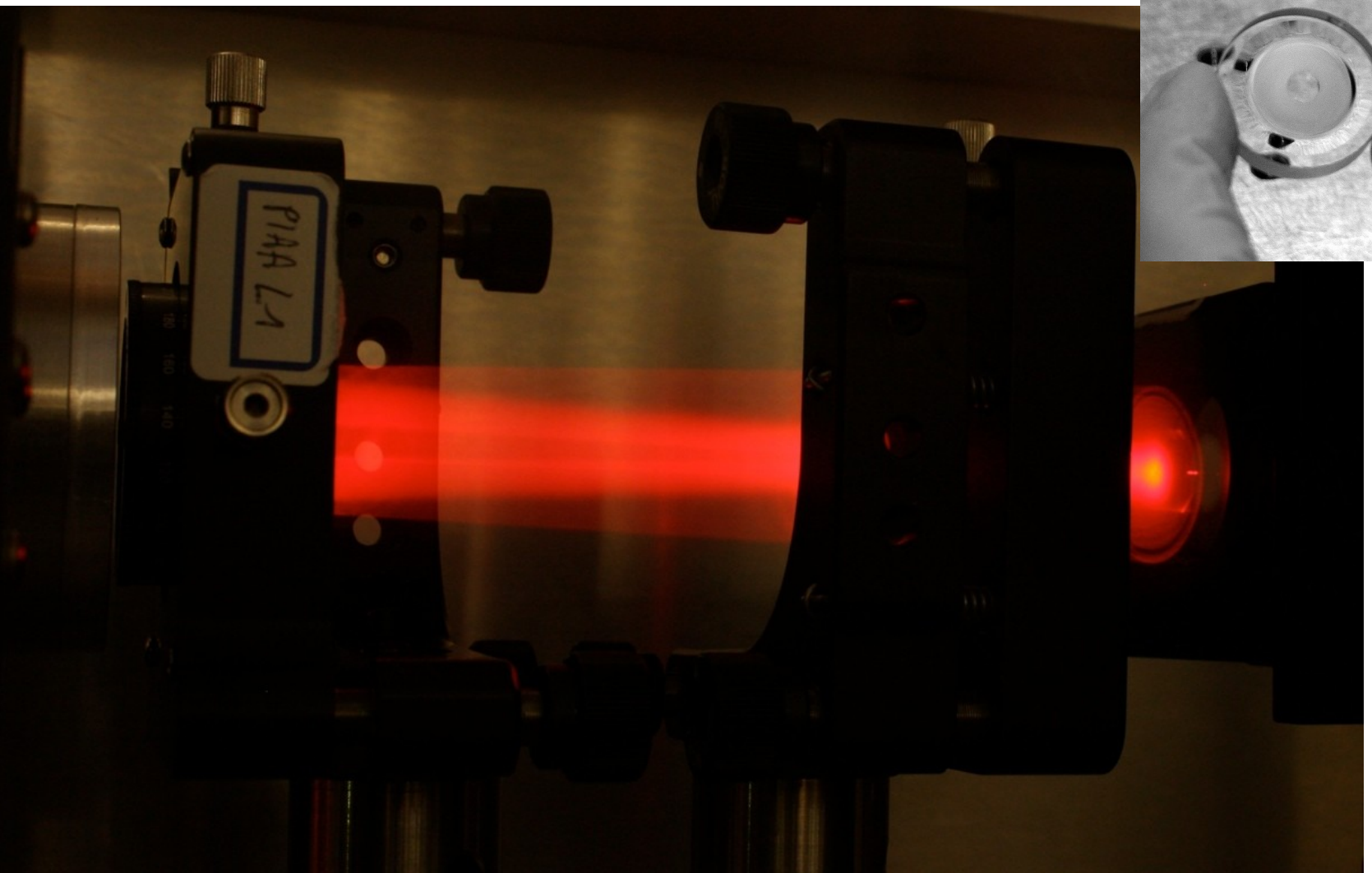
- **Train students** in high contrast imaging techniques. SCExAO offers a unique opportinity for students to develop and test new high contrast imaging techniques.

- Serve as a **prototype for future high contrast imaging instrument for ELTs** (TMT, GMT, E-ELT) → Direct imaging of habitable planets with ELTs

High performance PIAA coronagraphy

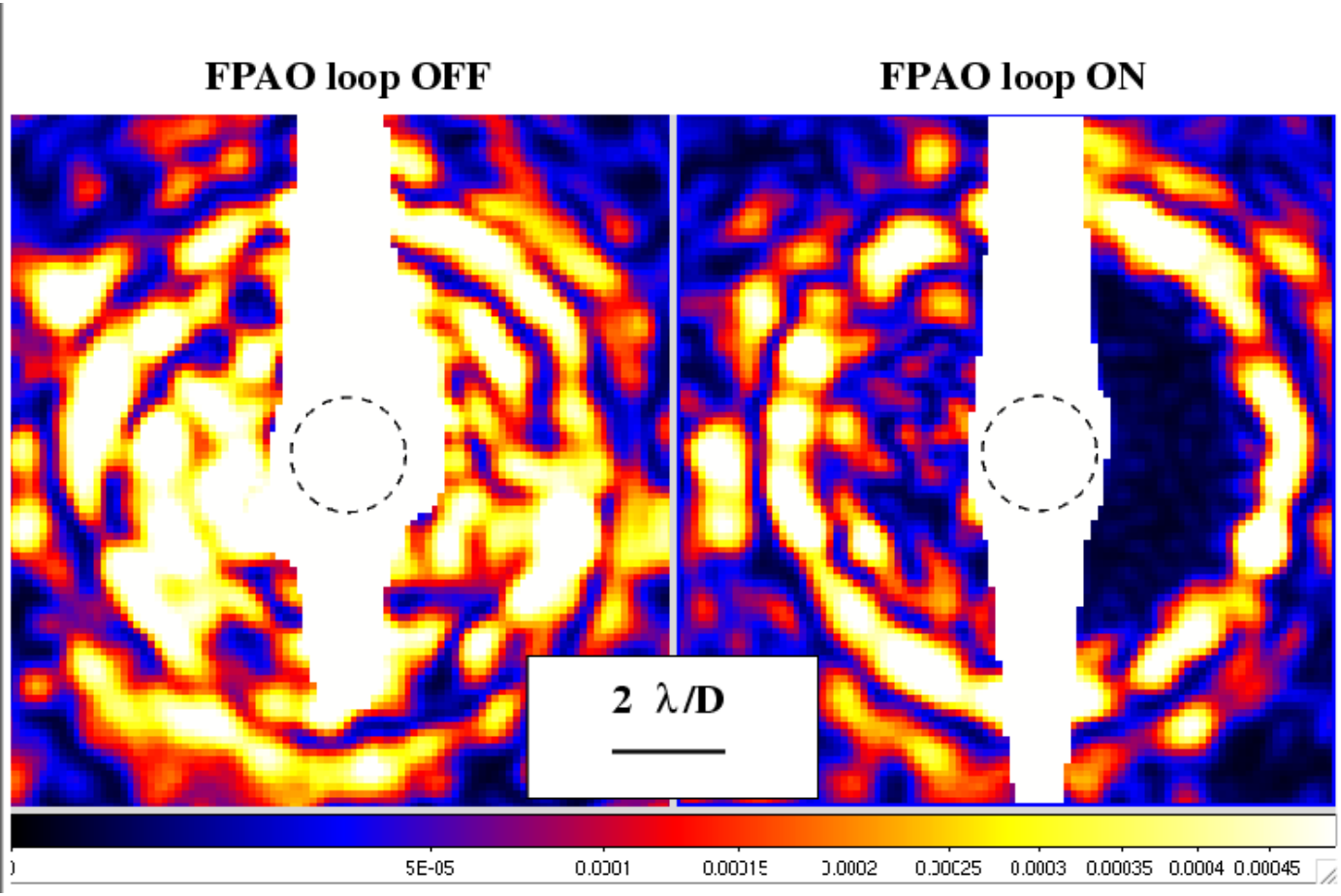
PIAA type coronagraph, based on lossless beam apodization
Can work down to 1 l/D (40mas) at high contrast with full efficiency
Has reached <1e-8 contrast at 2 l/D in lab (NASA JPL, NASA Ames)

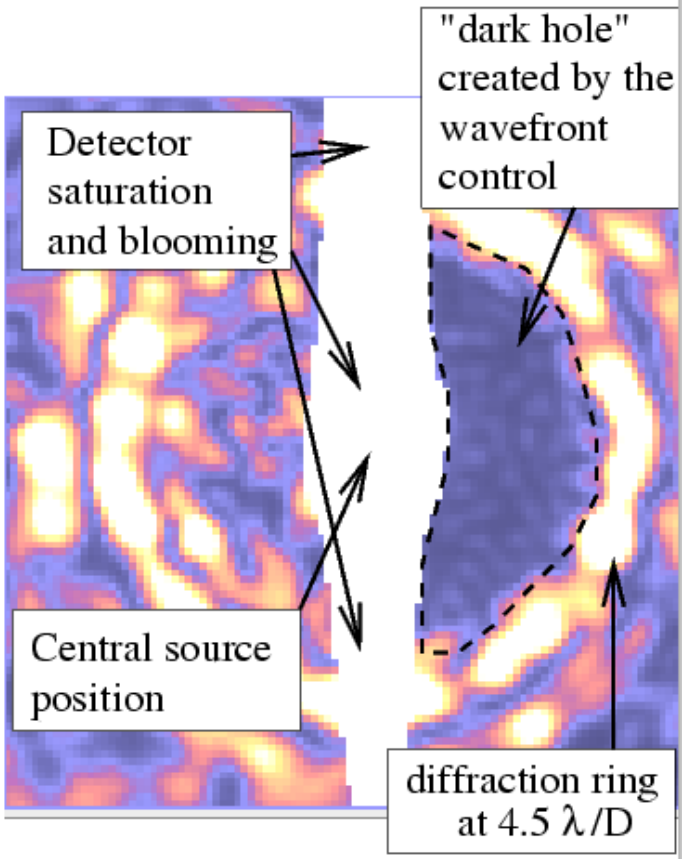




Speckle control and nulling

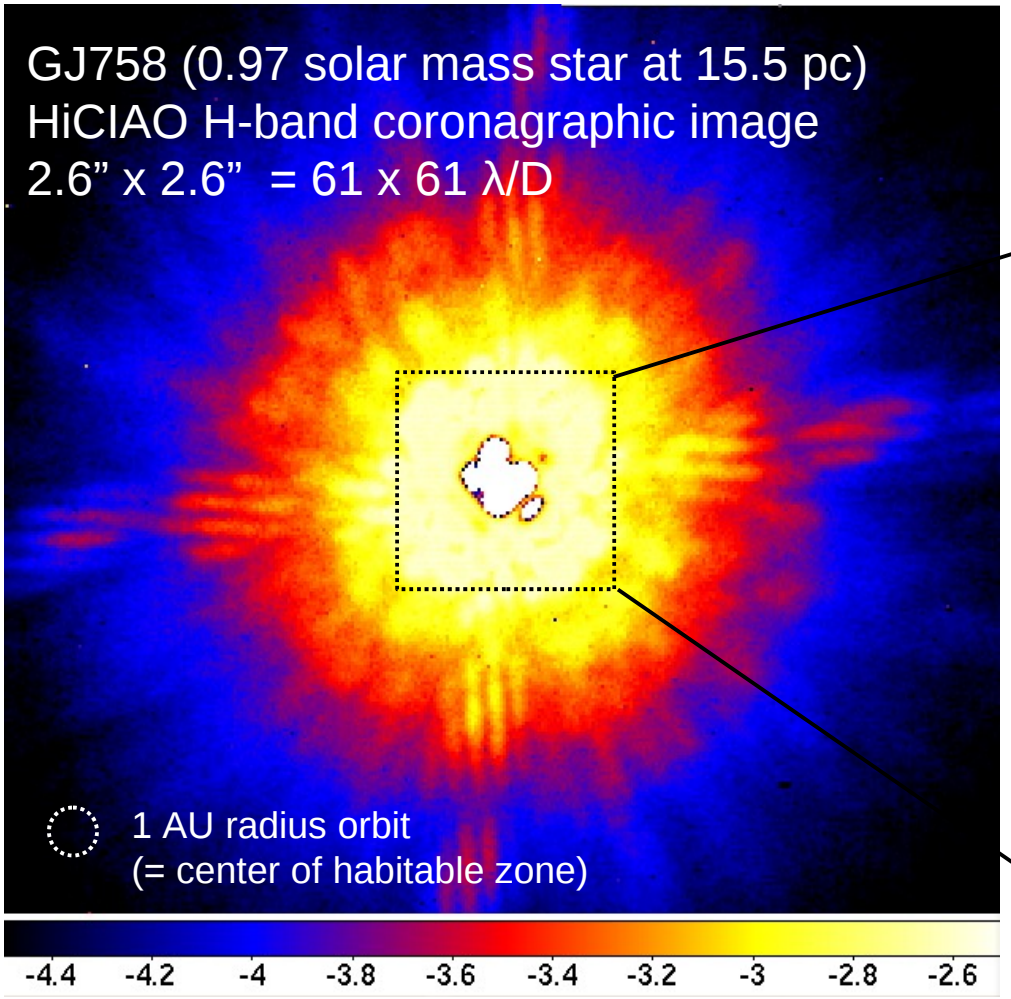
Speckle nulling
Subaru lab results with PIAA coronagraph + 32x32 MEMs DM



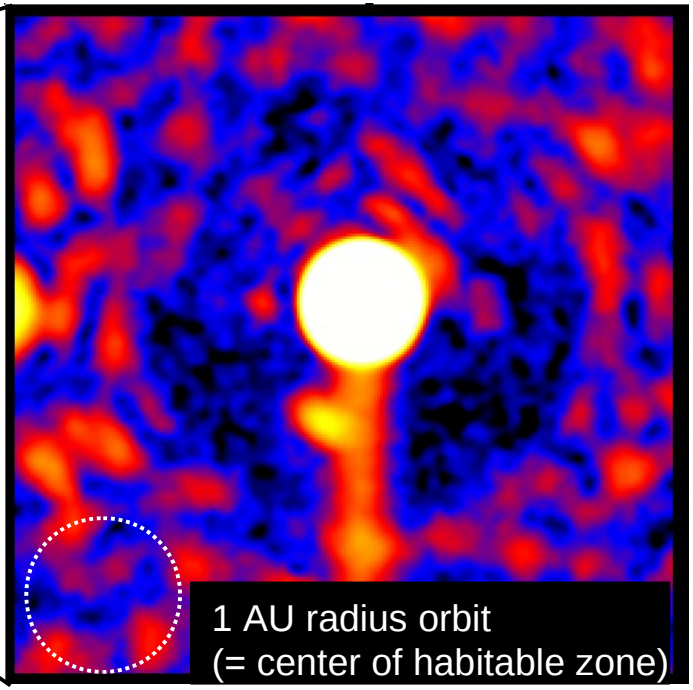


From lab to sky

High contrast imaging in lab reaches much higher performance than what is currently achieved on-sky: newer technologies, more stable environment, better calibrations
SCExAO's goal is to deploy on the telescope new techniques which have been demonstrated in the lab to offer high performance, and to create the conditions necessary to achieve this high performance

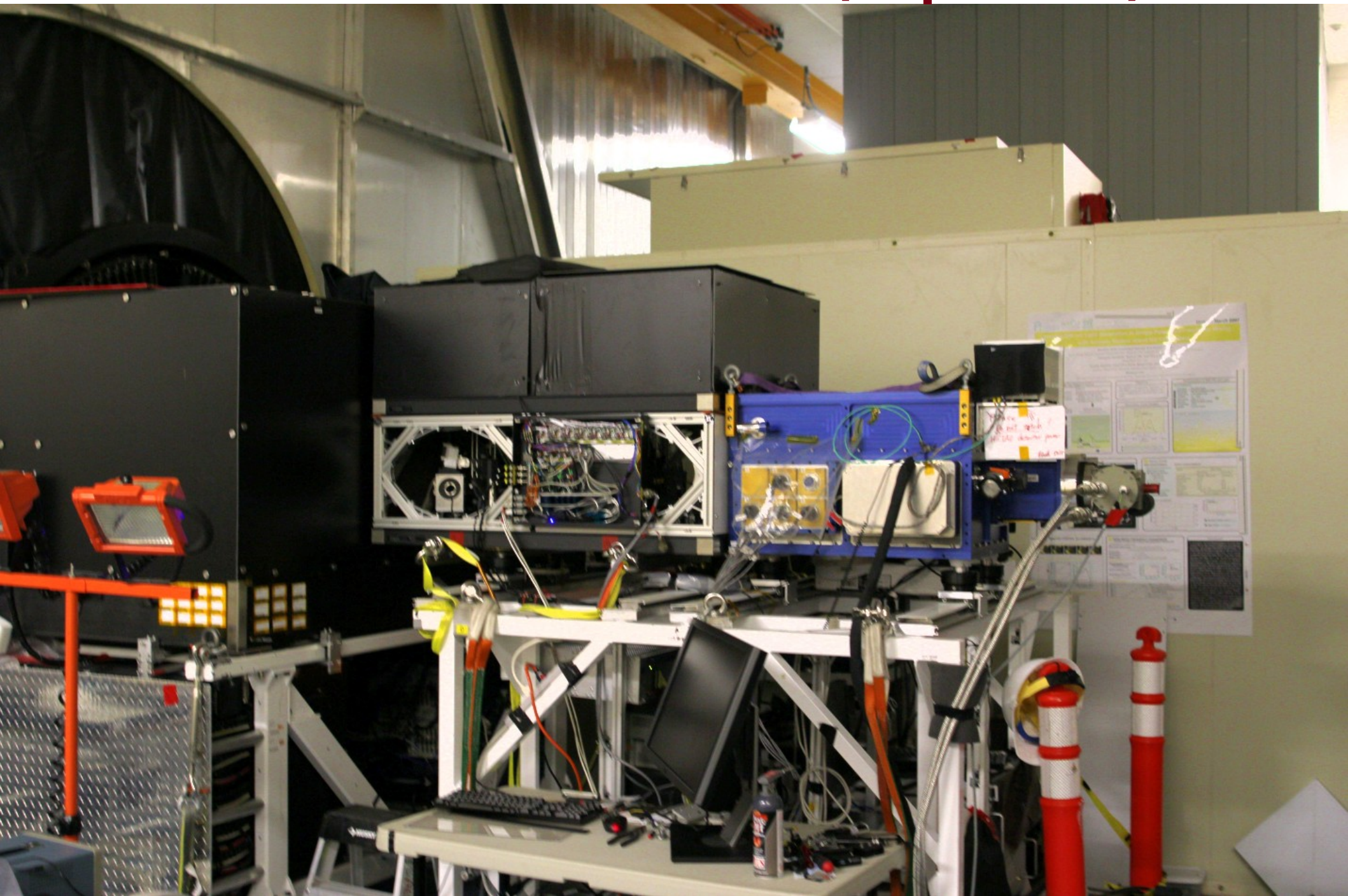


Subaru PIAA image (laboratory)
13.6 x 13.6 λ/D = 0.58” x 0.58”
(Same contrast color scale)

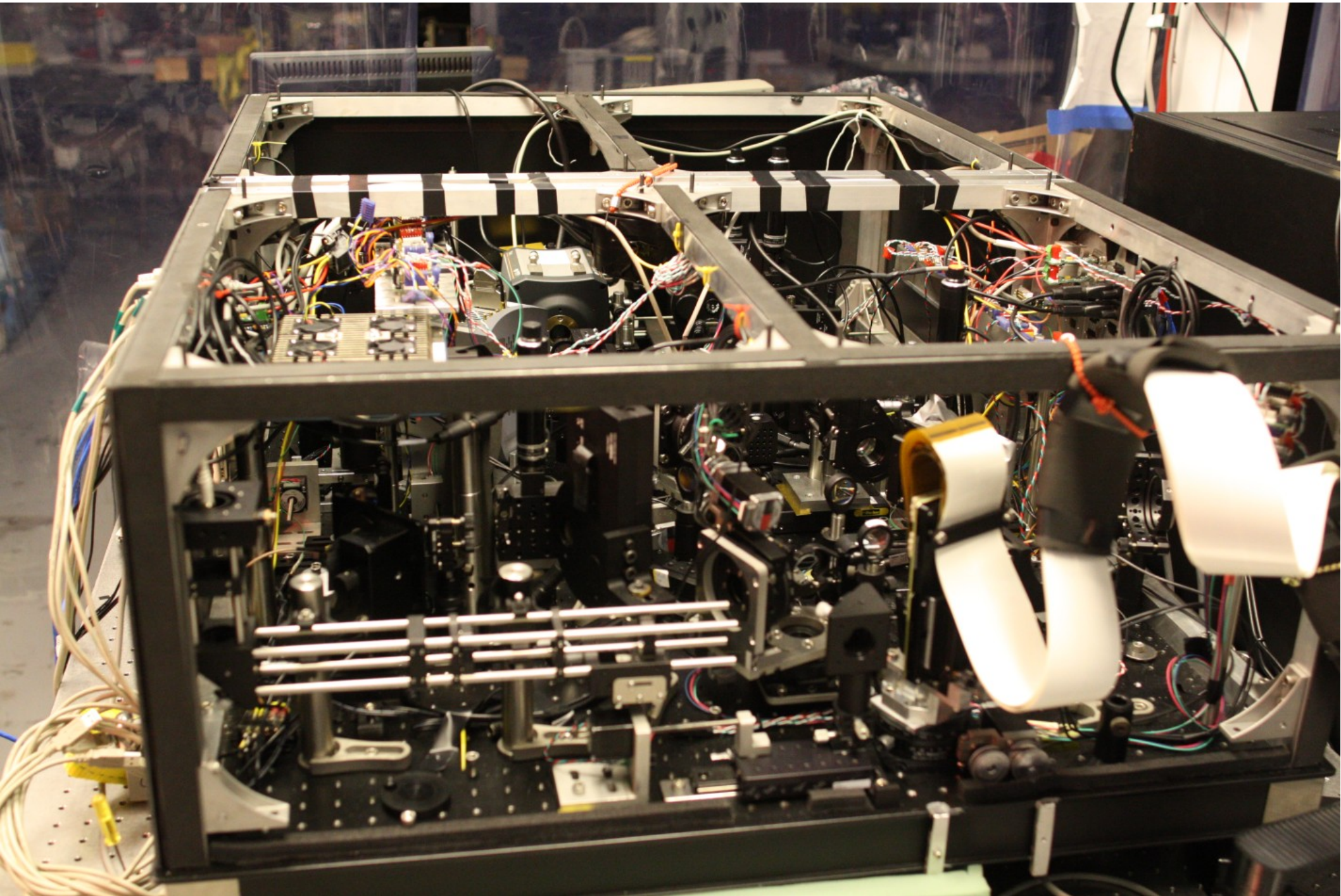


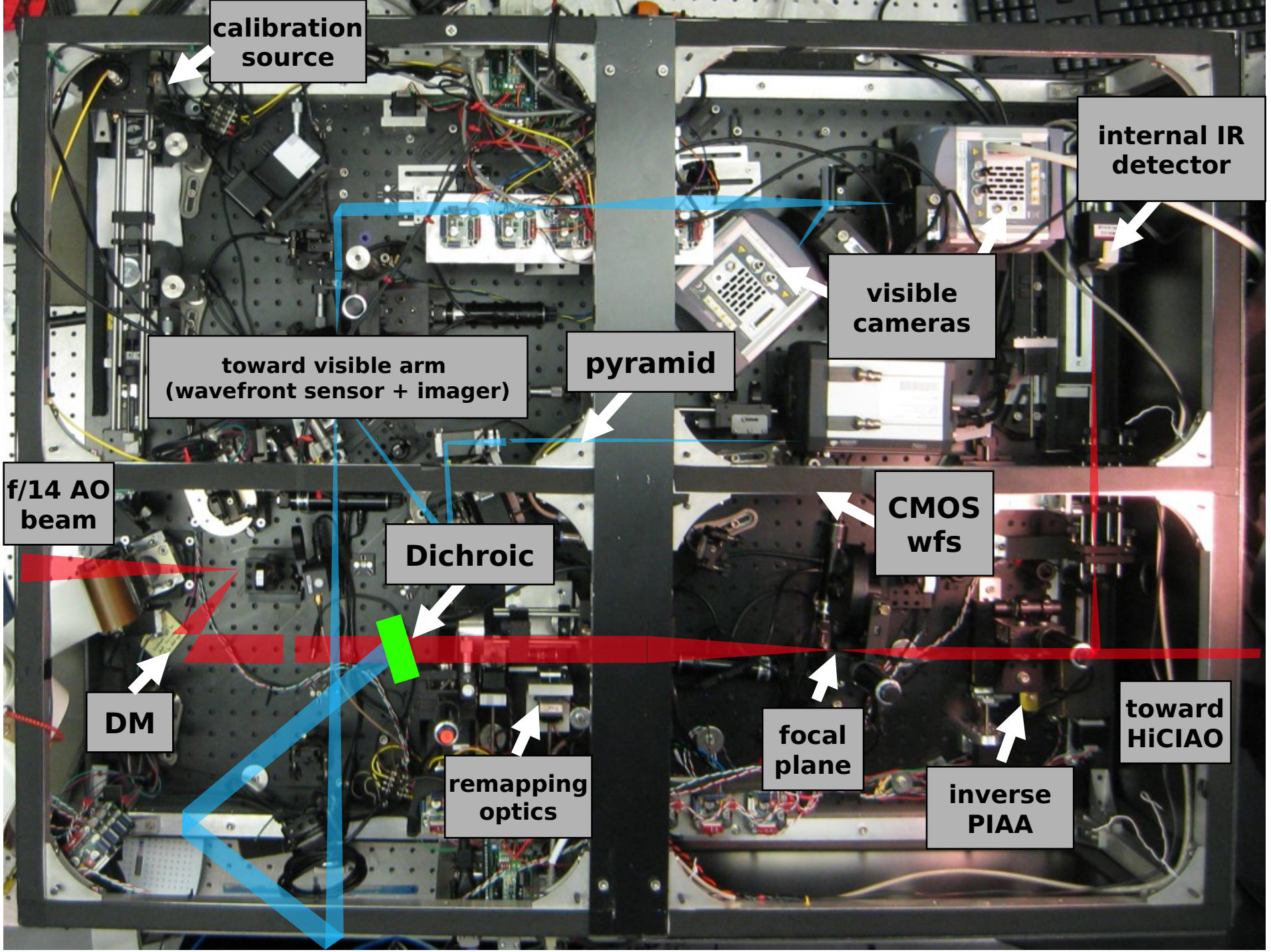

EXIT

Current AO188 → SCExAO → HiCIAO architecture
SCExAO at the summit (Sept 2012)



The Subaru Coronagraphic Extreme-AO (SCExAO) system




calibration source
internal IR detector
visible cameras
toward visible arm (wavefront sensor + imager)
pyramid
f/14 AO beam
CMOS wfs
Dichroic
DM
remapping optics
focal plane
inverse PIAA
toward HiCIAO

SCExAO status

SCExAO is currently in engineering, for phase 1

4 nights of engineering, then science observations begin

1st nighttime engineering Feb 2011 (2 nights): demonstrated coupling with AO188 system + basic functions (no science IR camera – using internal SCExAO video IR camera)

2nd nighttime engineering Sep 2011 (1 night): PIAA coronagraph, on-sky wavefront control: LOWFS, coupling with HiCIAO

May-June 2012: daytime engineering (2 weeks) to test and validate focal plane wavefront control + LOWFS

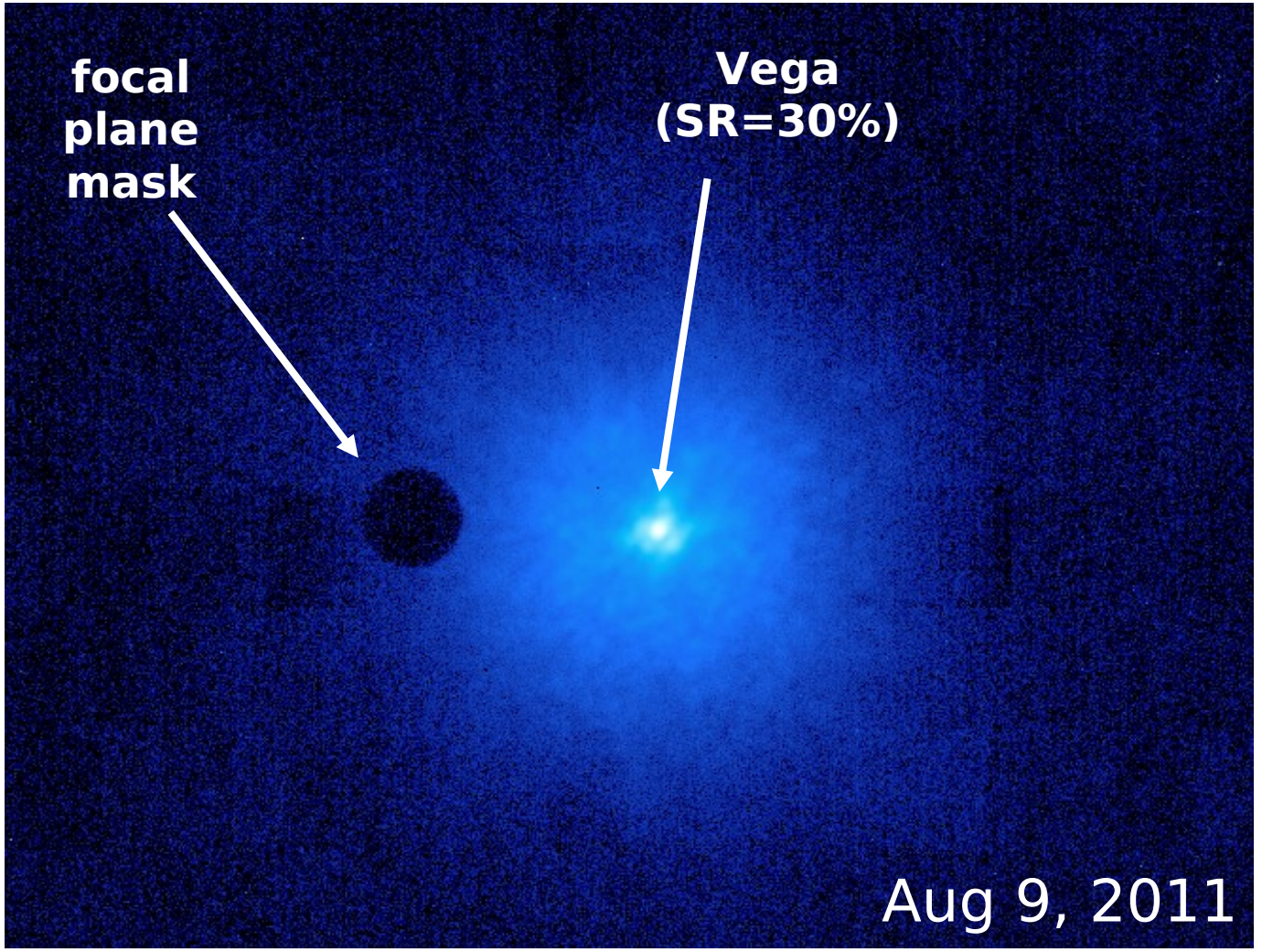
3rd nighttime engineering sept 2012 (1 night): on-sky wavefront control (focal plane WFC + LOWFS)+ HiCIAO

→ not successful due to telescope problem

Phase 2: integrate ExAO visible WFS

SCExAO/HiCIAO first light

After quite some time fiddling with fine collimation adjustments,
and hesitations due to bad seeing:



The rest of the observing night however ruined by weather...

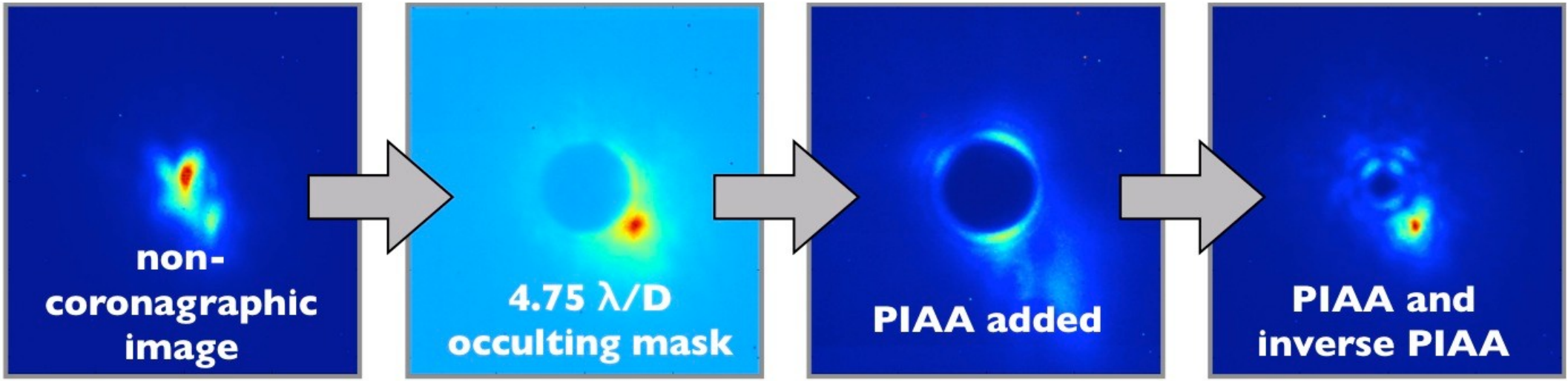
SCExAO coronagraph Results

LOWFS validated on sky

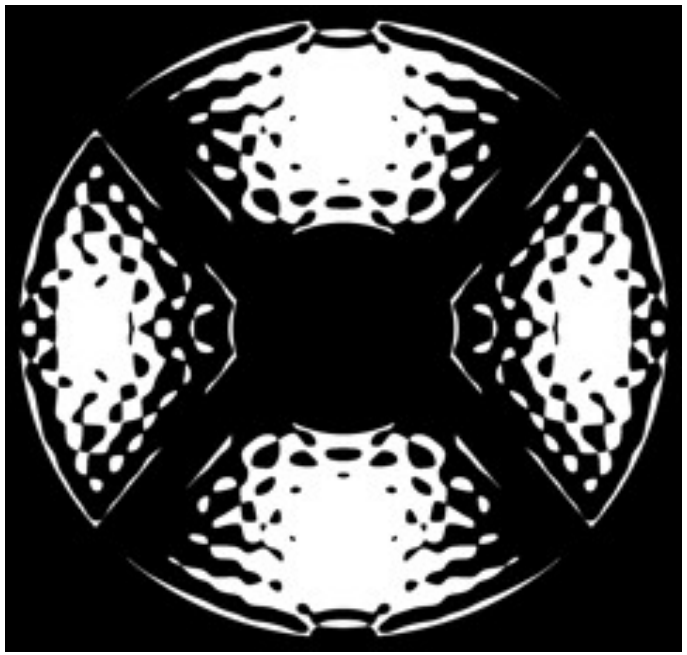
- robust performance at low gain (~0.1) in difficult conditions
- calibration can be time consuming

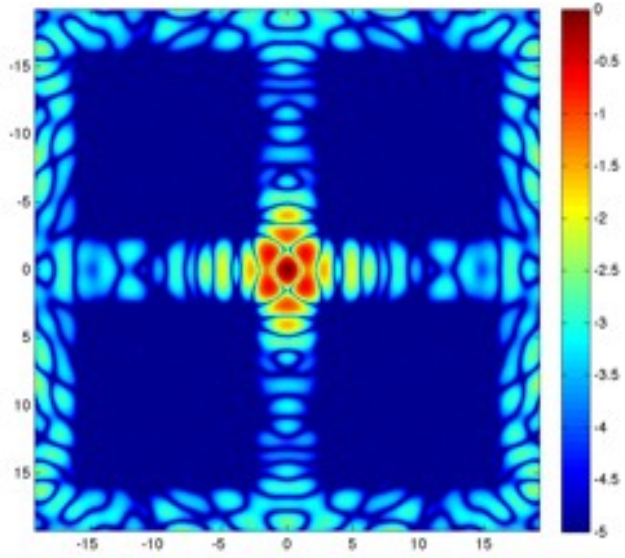
PIAA coronagraphy at 1.2 lambda/D validated

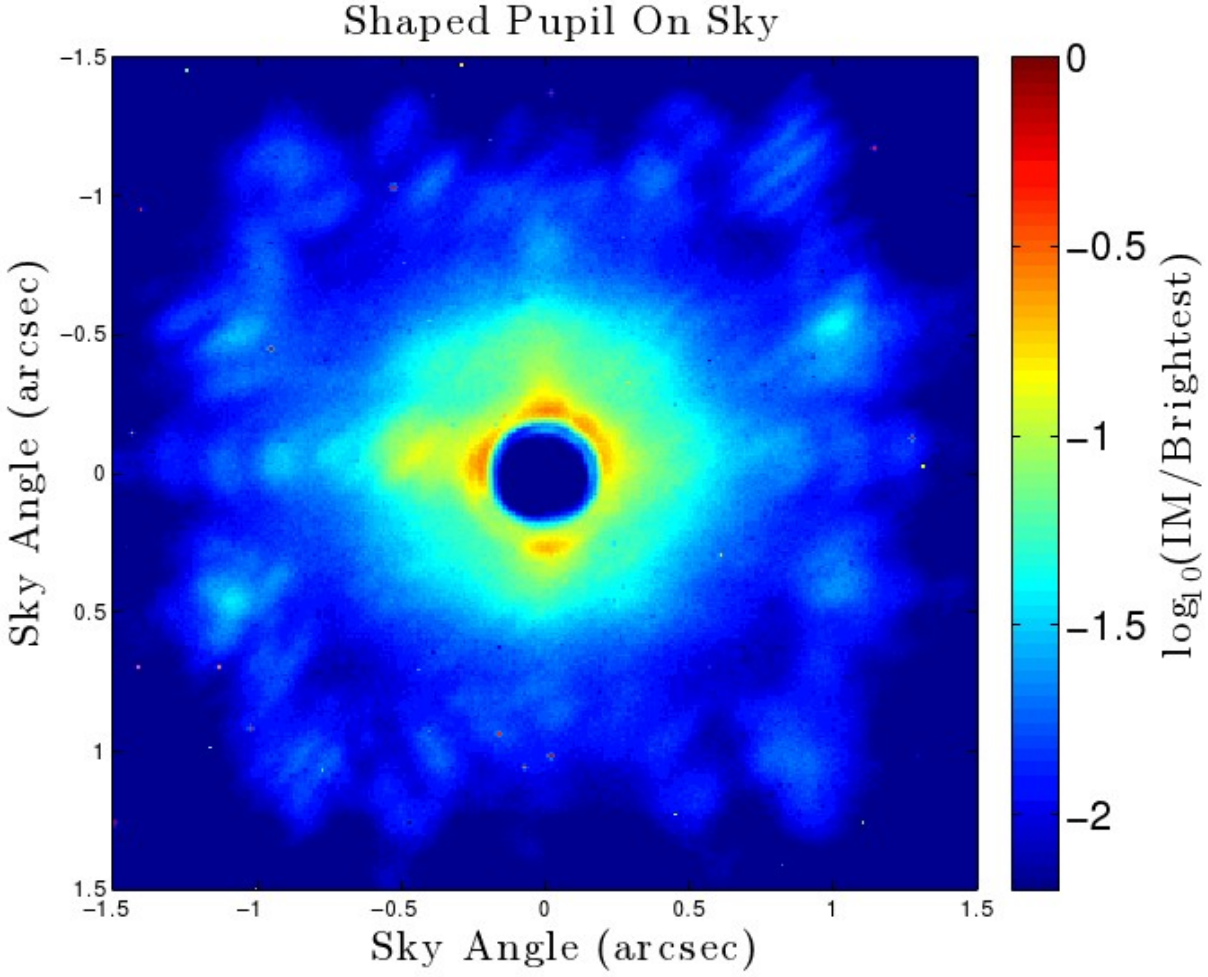
- Inverse PIAA image sharpening validated



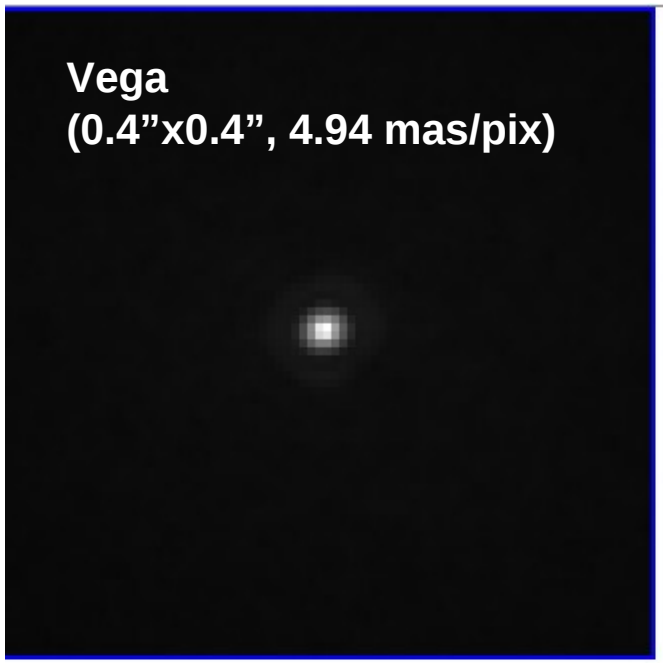
SCExAO shaped pupil Results (Sept 2012)

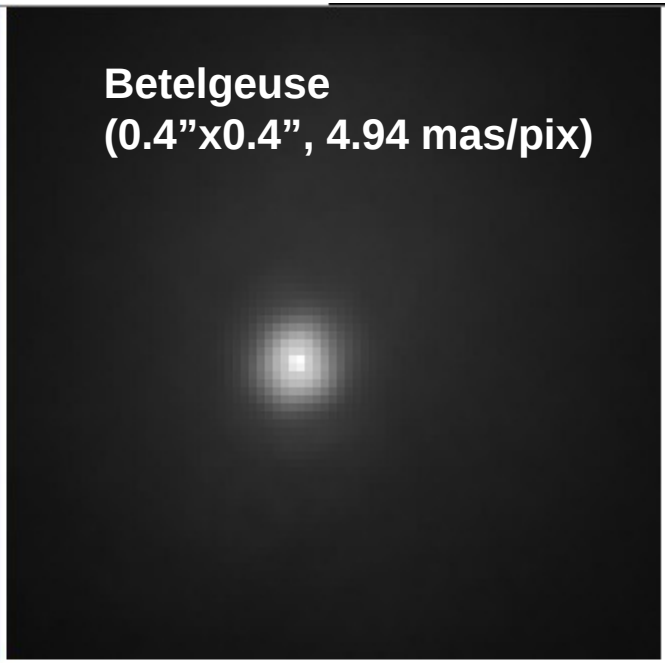


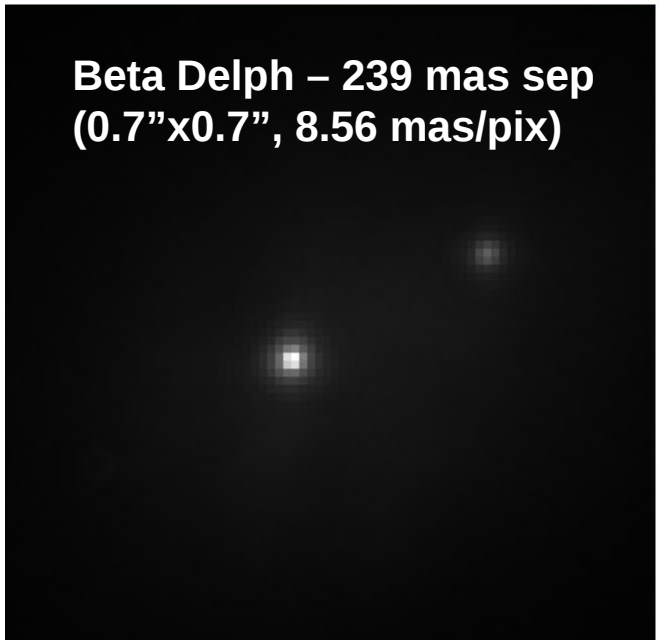




SCExAO first visible images (V. Garrel PhD)







- SCExAO acquired first visible light diffraction limited on Subaru in Feb and Sept 2011
- Despite moderate AO performance (seeing 1” to 2” + clouds in Feb, poor AO perf in Sept) selection + new Fourier-based reconstruction allowed diffraction-limited imaging.

Major upgrades in next 3 yrs

SCExAO phase 2: Integration with **visible light wavefront sensor**

Will provide ~90% Strehl ratio in H band

VAMPIRES (Univ. of Sydney instrument)

Visible light polarimetric imaging at the diffraction limit of Subaru Telescope

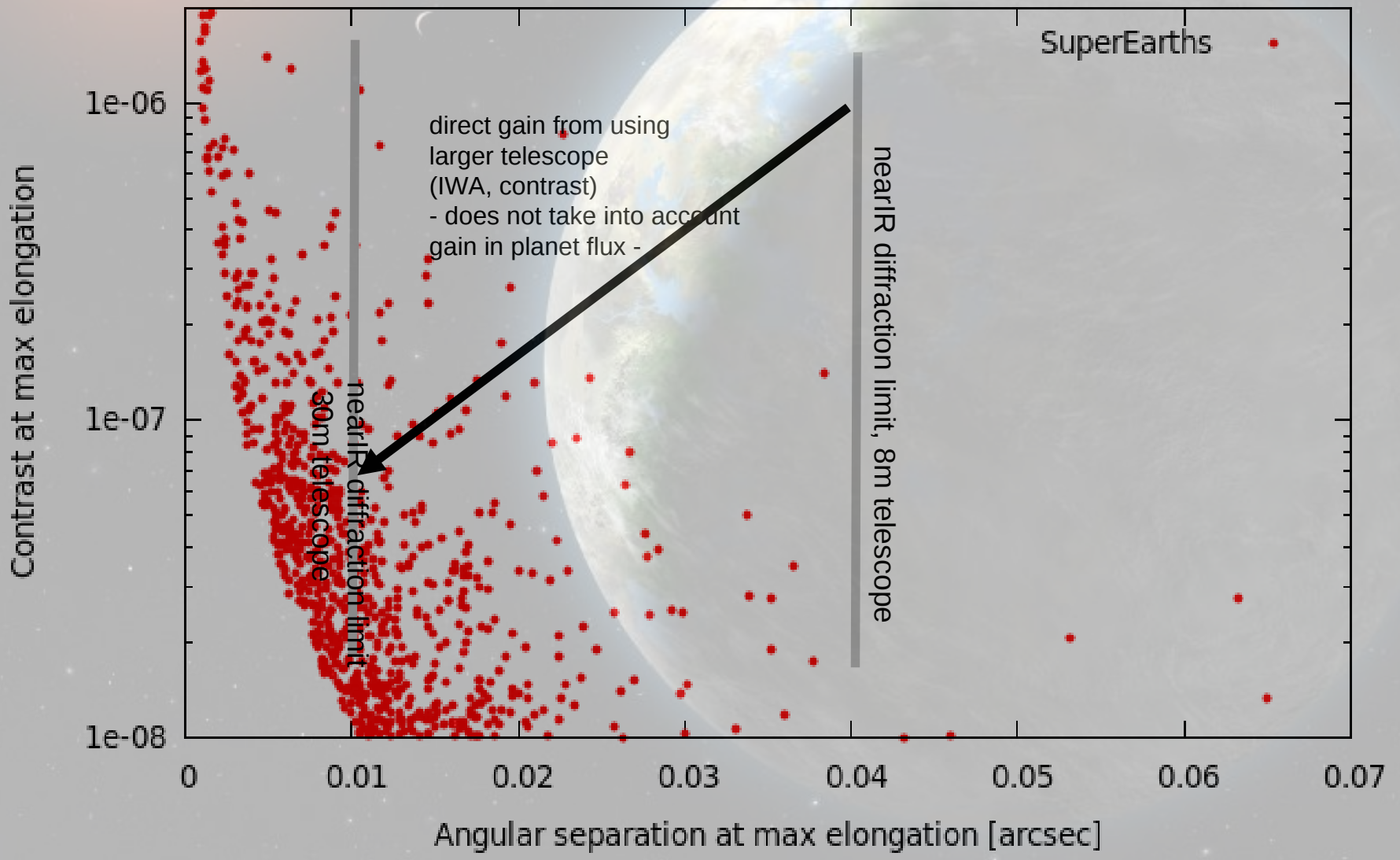
CHARIS (designed and build by Princeton Univ.)

Near-IR integral field spectroscopy for exoplanet detection and characterization

SCExAO as a prototype for direct imaging of habitable planets with ELTs

Assuming that each star has a SuperEarth (2x Earth diameter) at the 1AU equivalent HZ distance

(assumes Earth albedo, contrast and separation for max elongation)

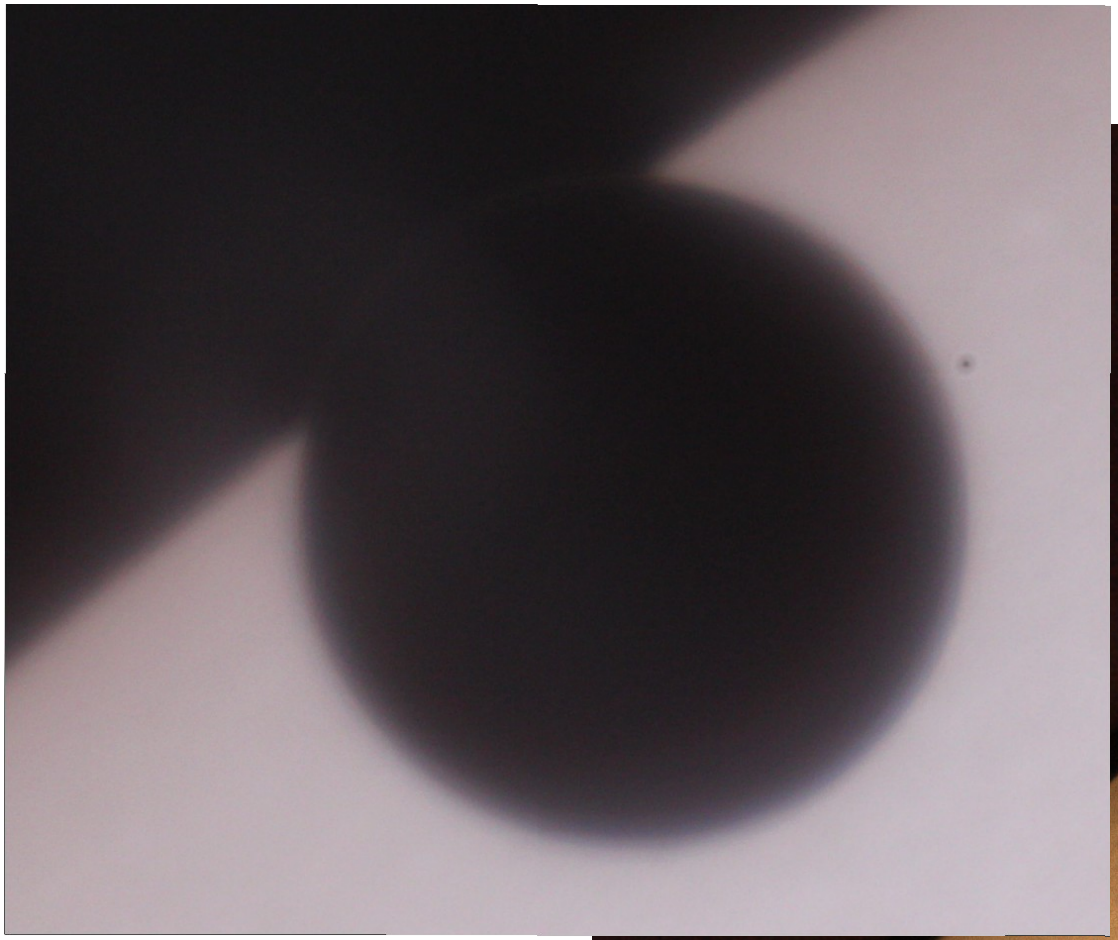


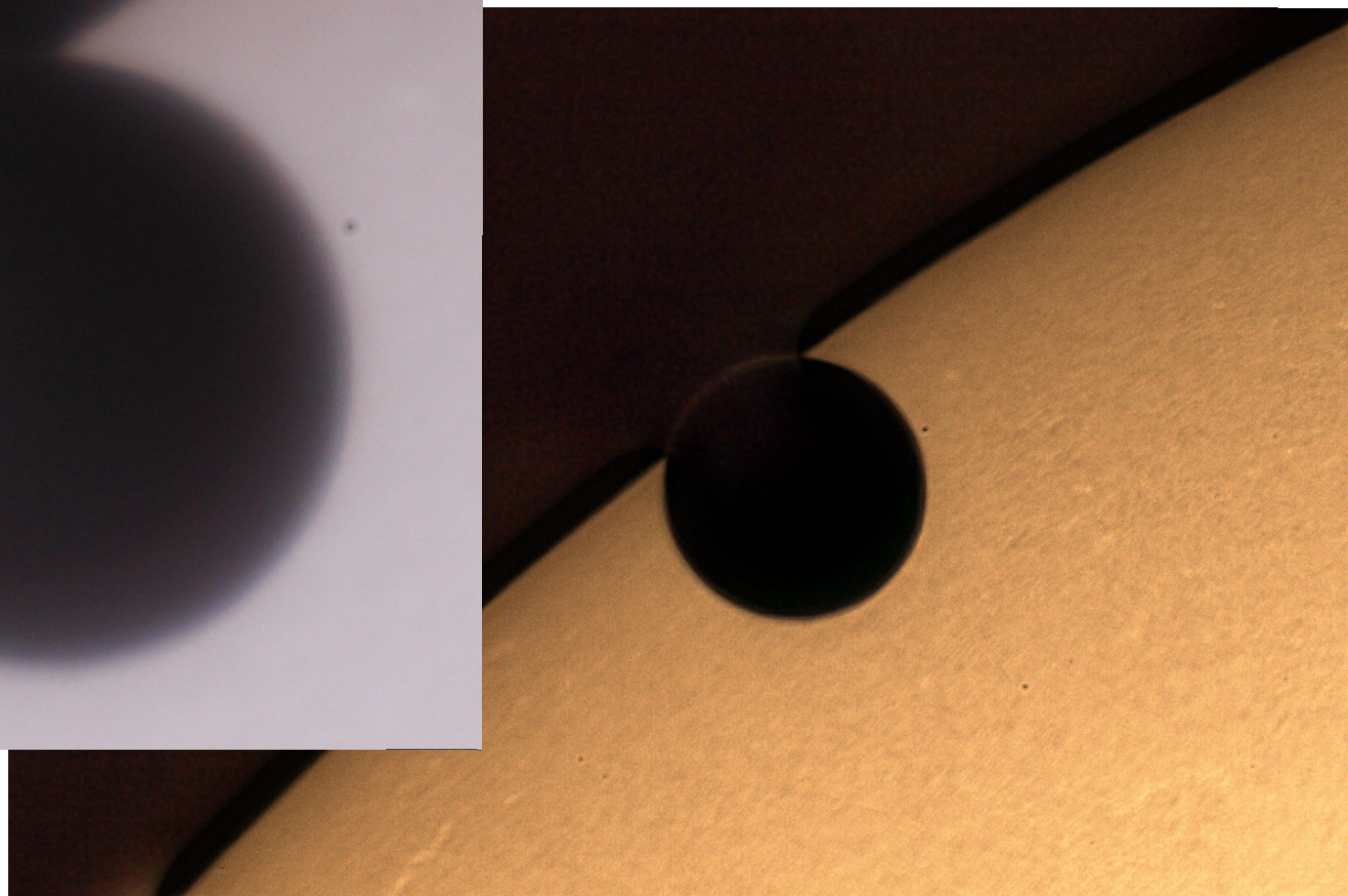
Other SCExAO group activities related to exoplanets

Exoplanet transit research: Venus transit, 2012

Other SCExAO group activities related to exoplanets

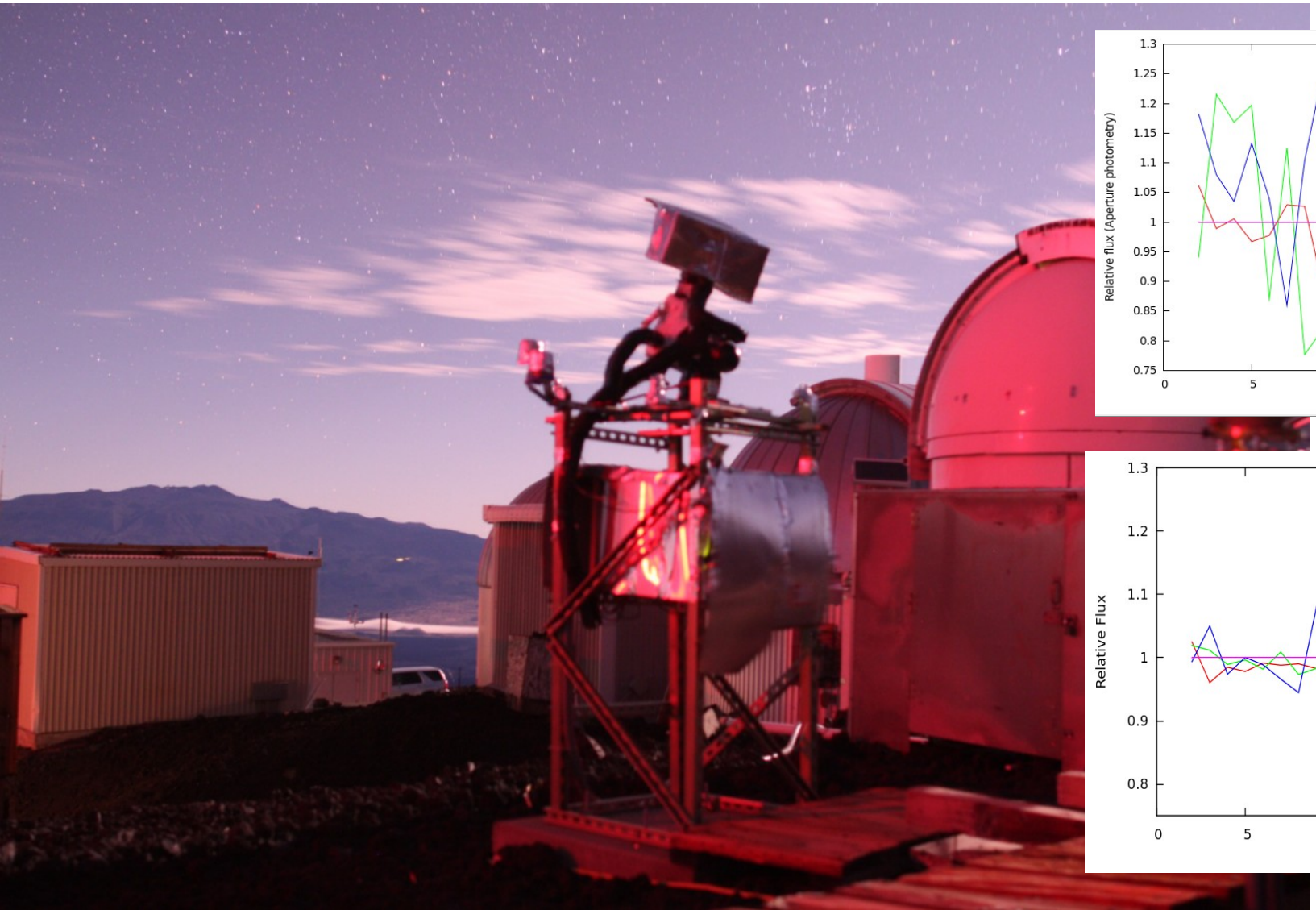
Exoplanet transit research: Venus transit, 2012

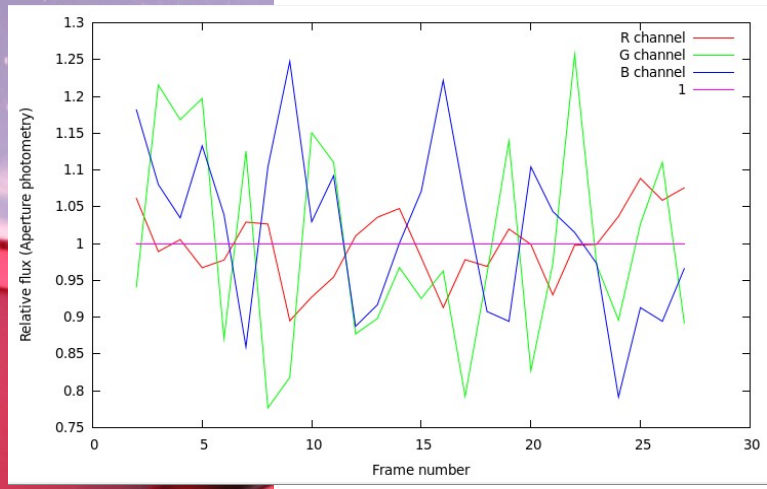


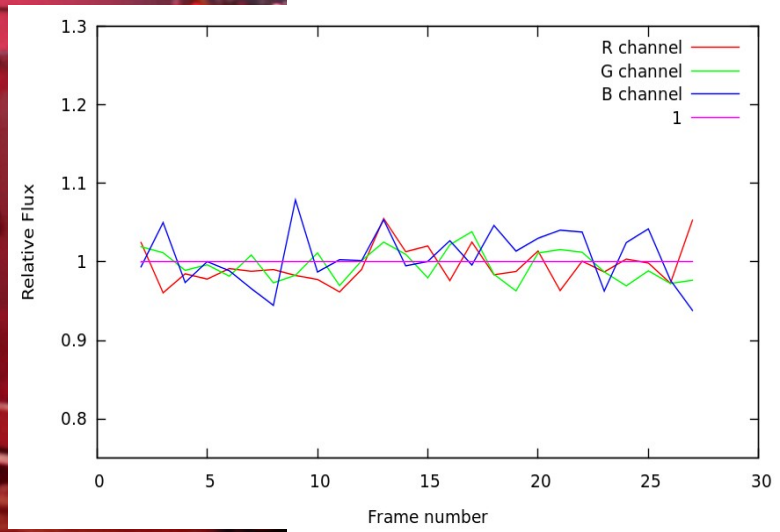


Other SCExAO group activities related to exoplanets

Exoplanet transit research: MLO system







Transit Field #1 (in Cygnus), camera 2 (Sept 11, 2012 UT)

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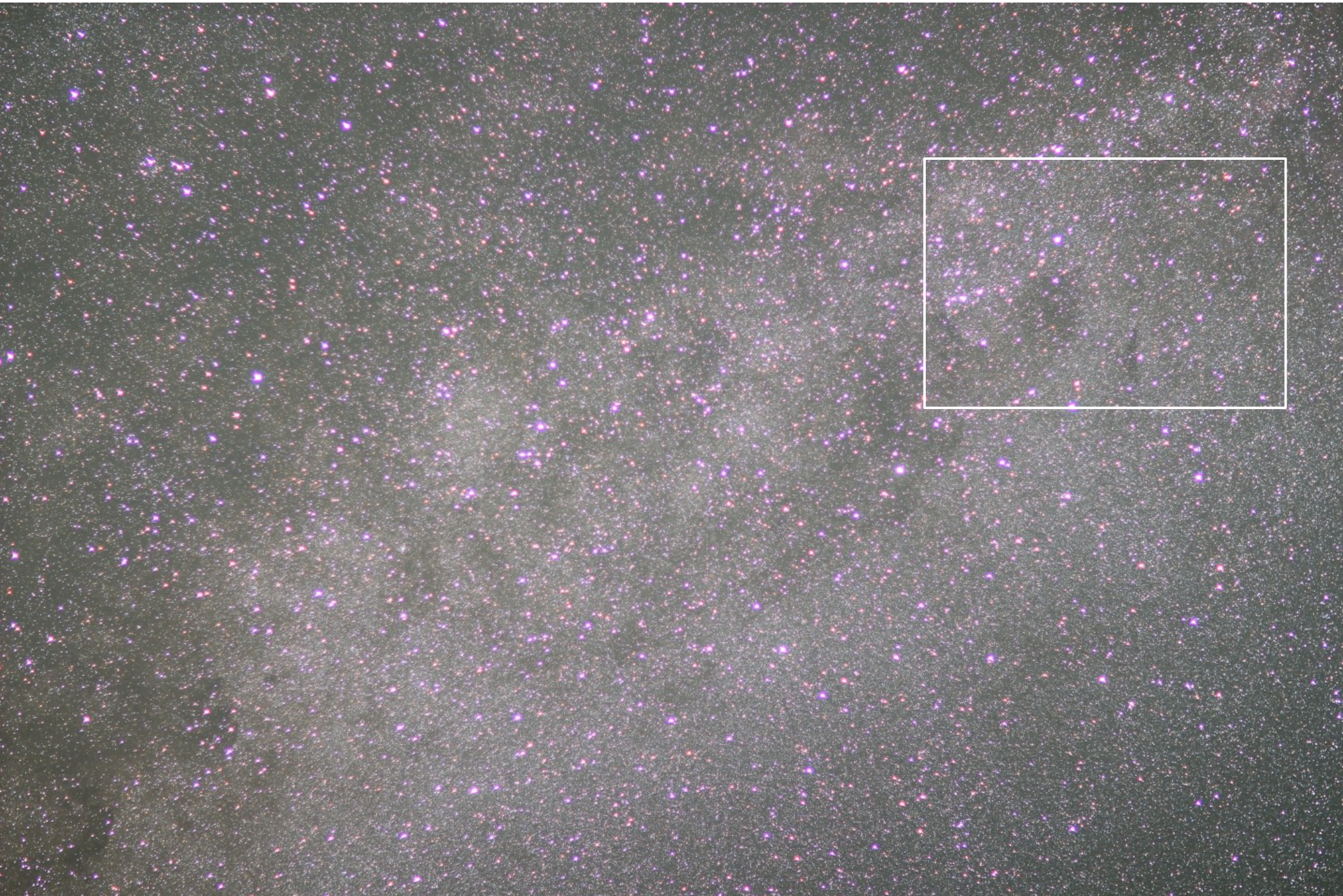

Transit Field #1 (in Cygnus), camera 2 (Sept 11, 2012 UT)