Entering a new Era of Adaptive Optics with more powerful Deformable Mirrors

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June 14, 2024

NASA ExoExplorers Science Series

Acknowledgements

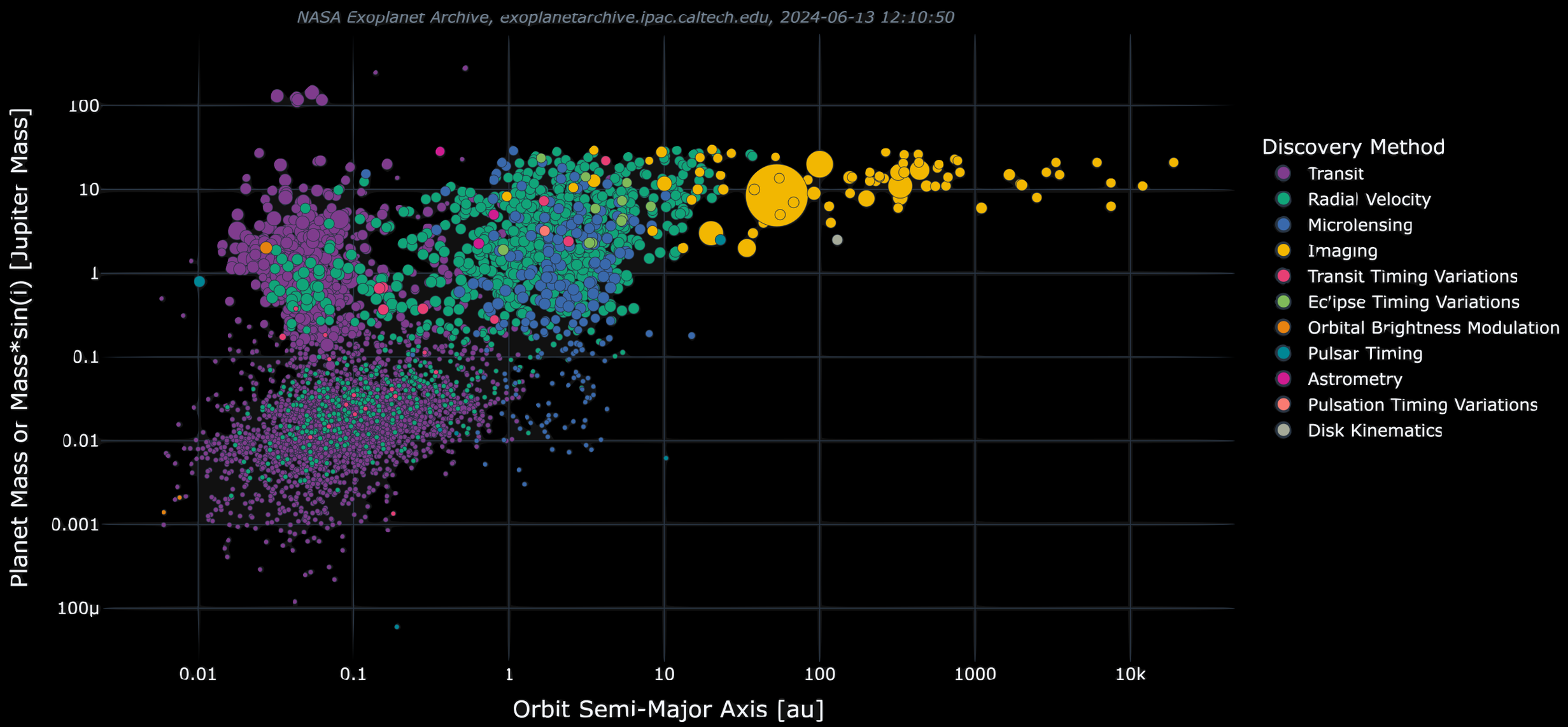
This presentation is about technologies on two telescopes on Maunakea. I recognize and acknowledge the very significant cultural role and reverence that the summit of Maunakea has always had within the indigenous Hawai'ian community, and consider myself fortunate to have the opportunity to conduct observations from and work on this mountain.

Acknowledgements

I would like to thank the respective instrument teams at Subaru Telescope and WM Keck Observatory for giving me this opportunity to work with them on these projects that take us to the next generation of Adaptive Optics and prepare us for the upcoming era of ELTs. I am grateful to my thesis advisors, Michael Bottom and Jonathan Williams for their support and paving the bridge that connected me to these institutions and the projects I am a part of today.

The Basics

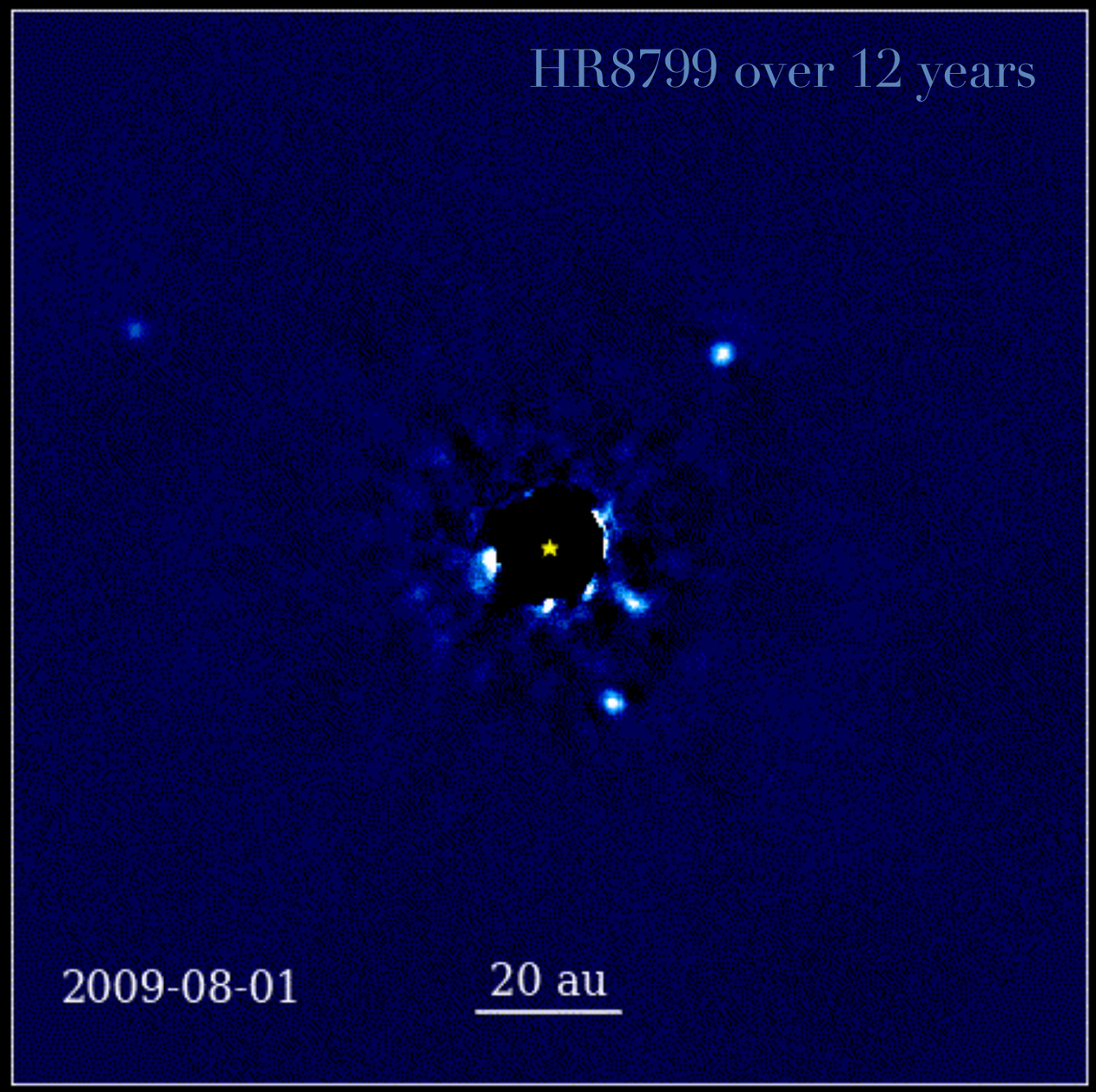
Discovering Planets



High Contrast (Direct) Imaging

Goal

Enable direct detections of faint sources in the vicinity of a much more luminous source



Jason Wang (Northwestern)/William Thompson (UVic)/
Christian Marois (NRC Herzberg)/Quinn Konopacky (UCSD)

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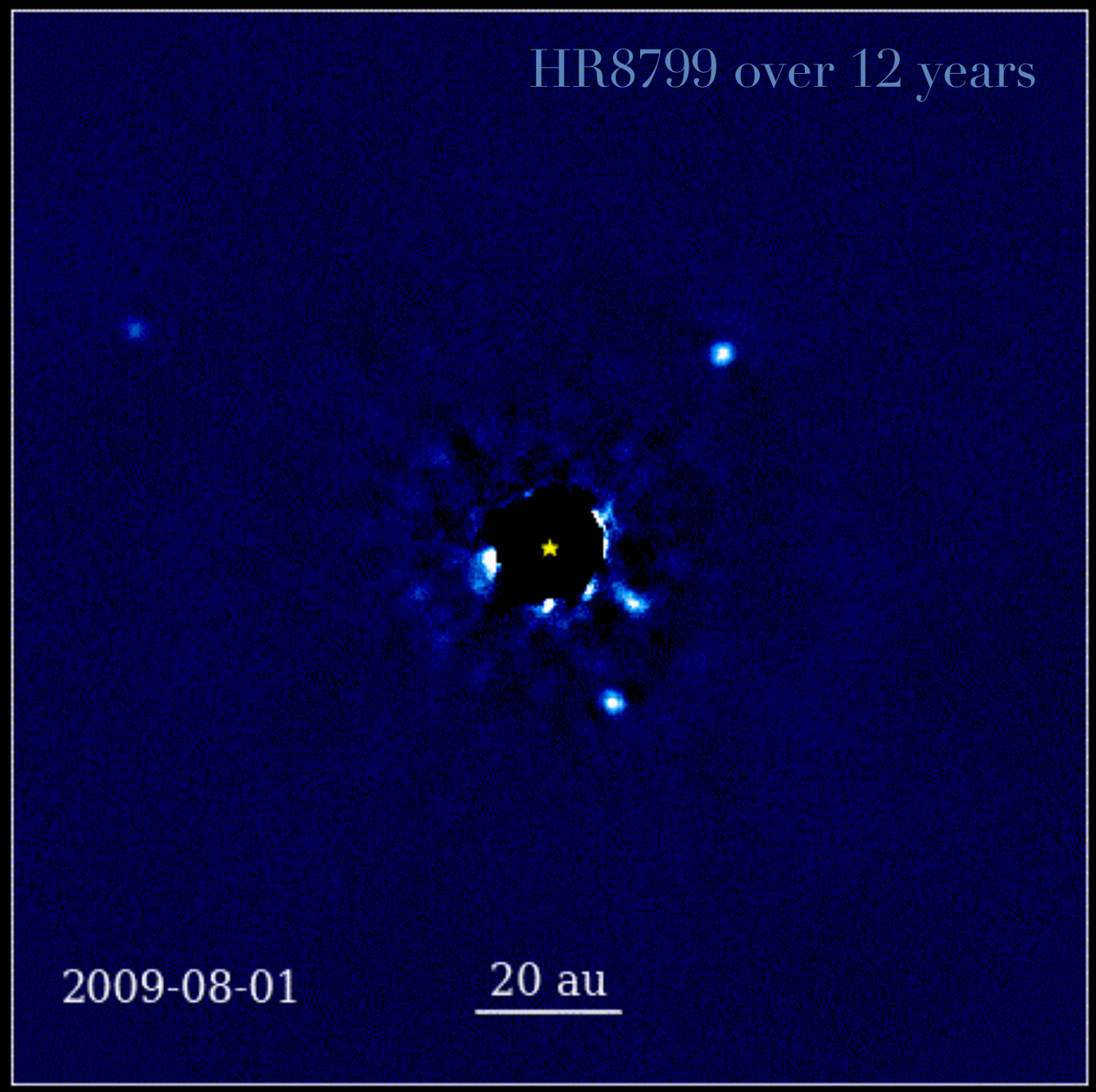

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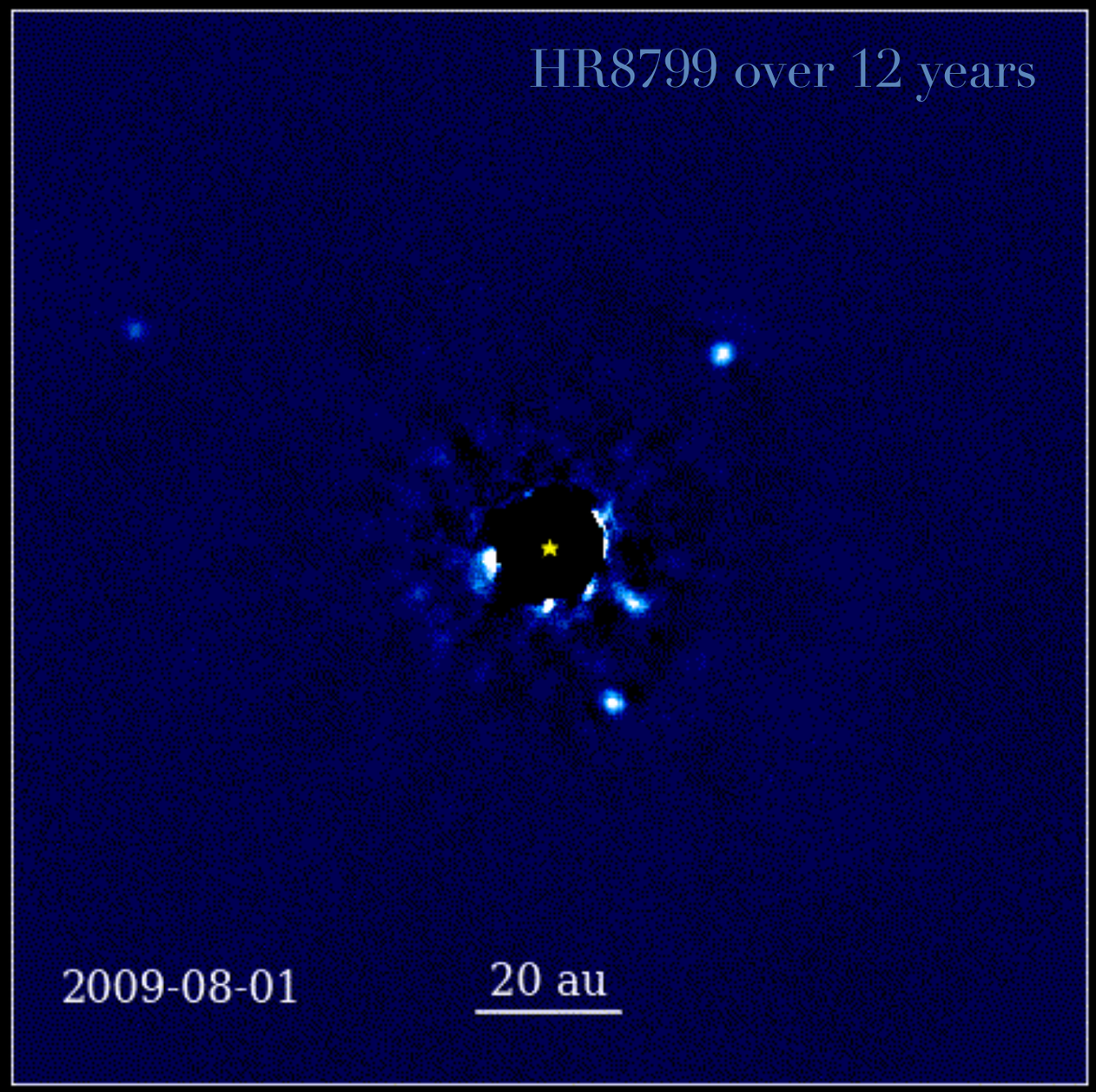
- Adaptive Optics
- Coronagraphy
- Differential Imaging



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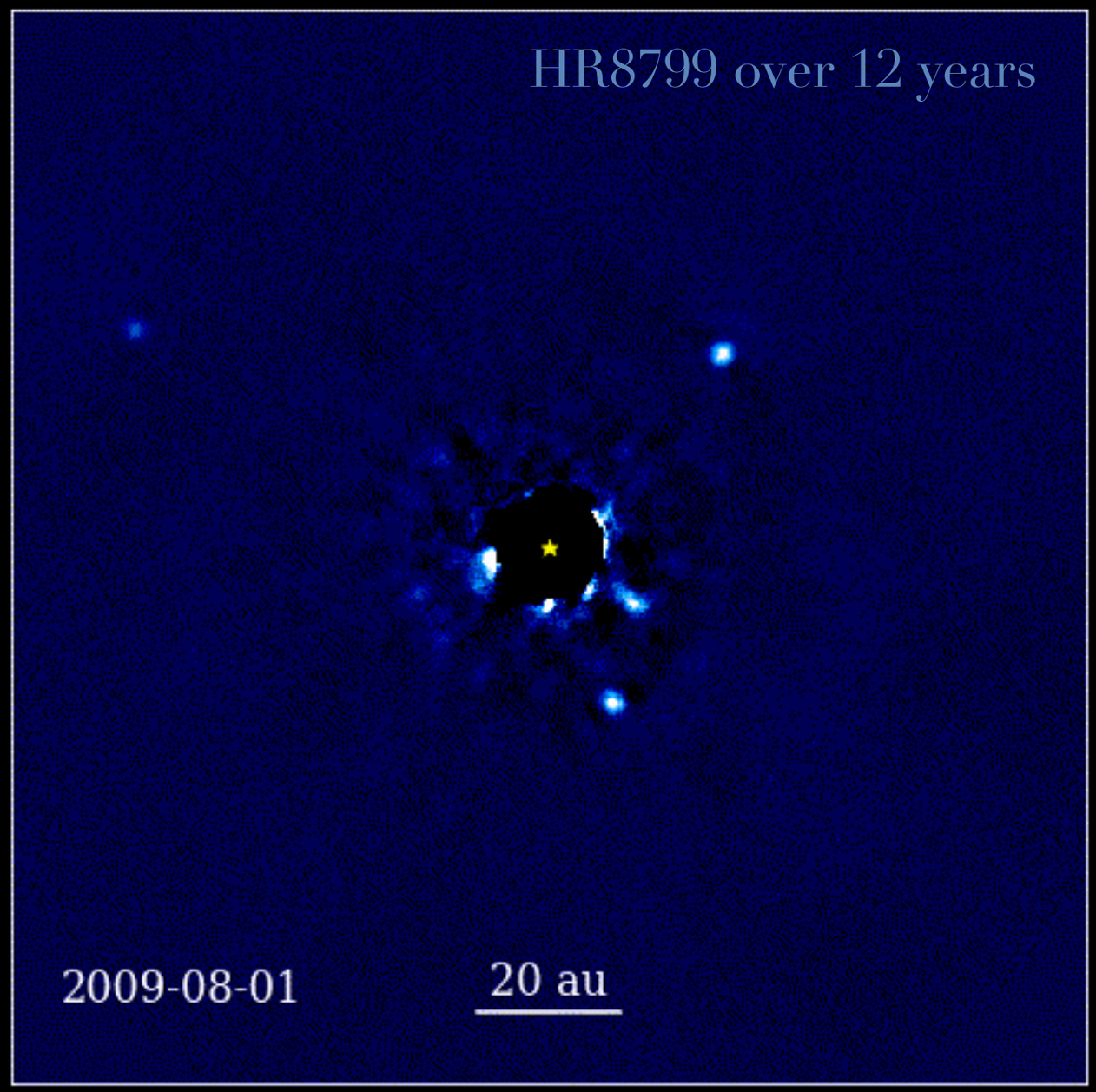

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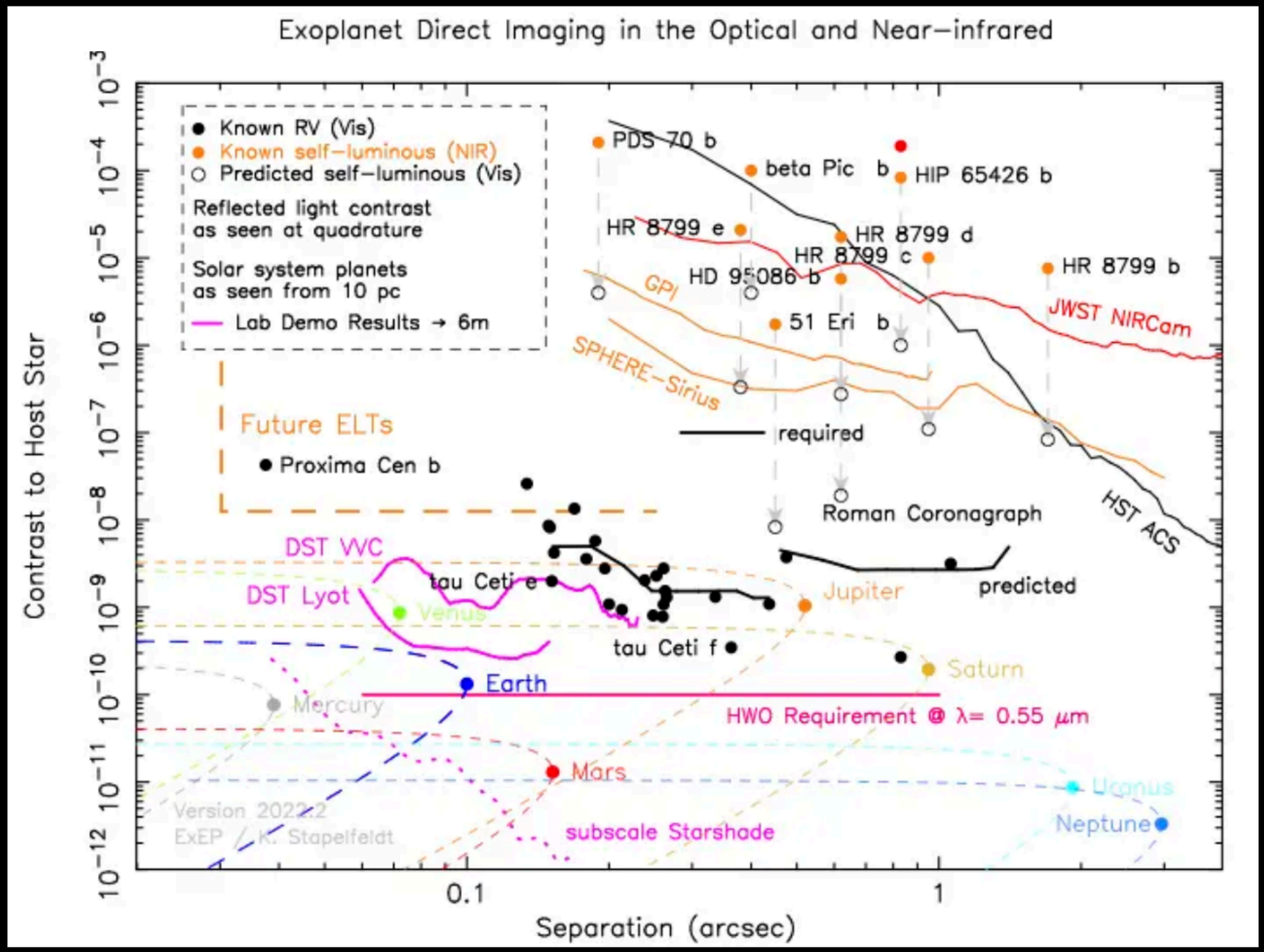
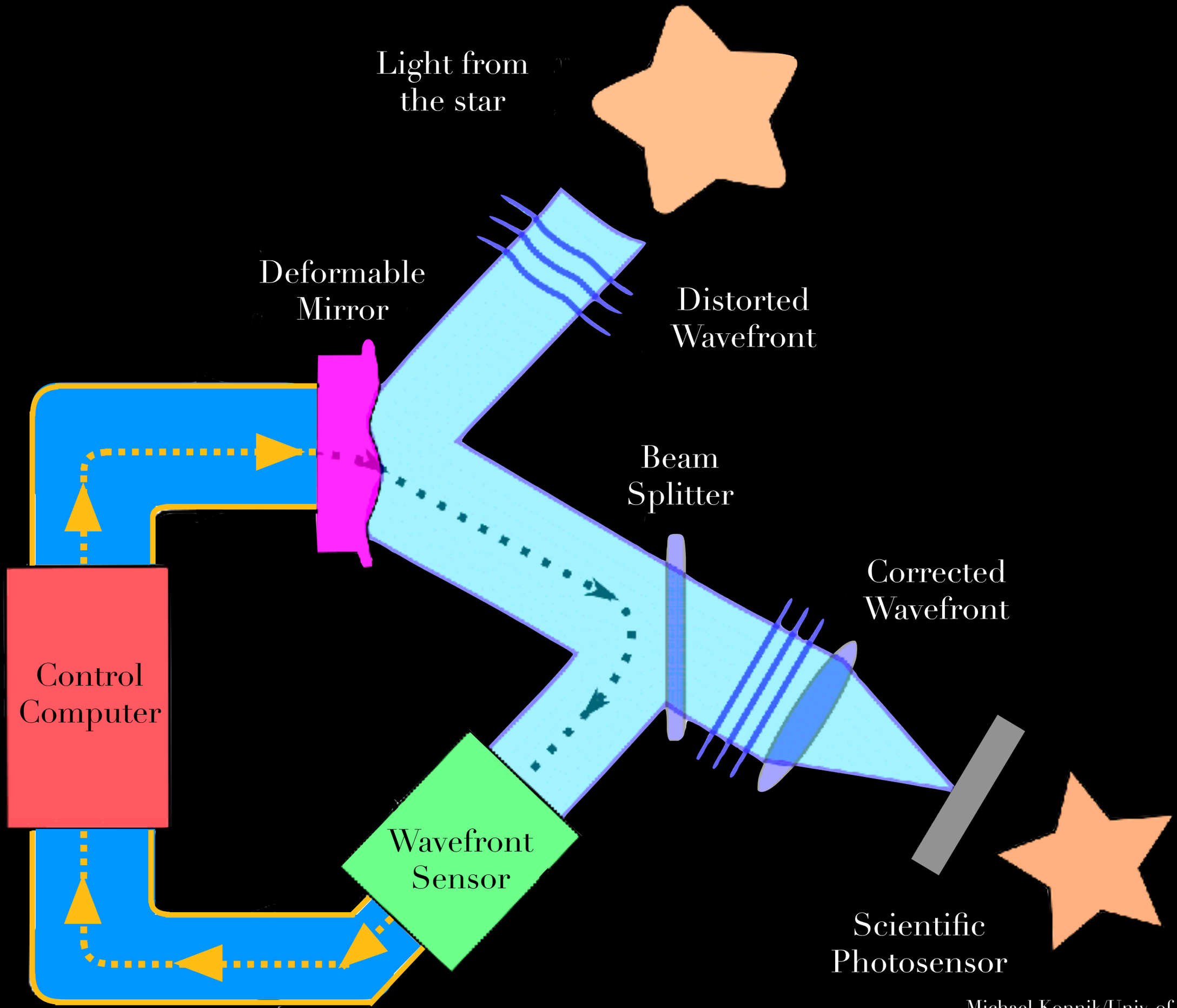
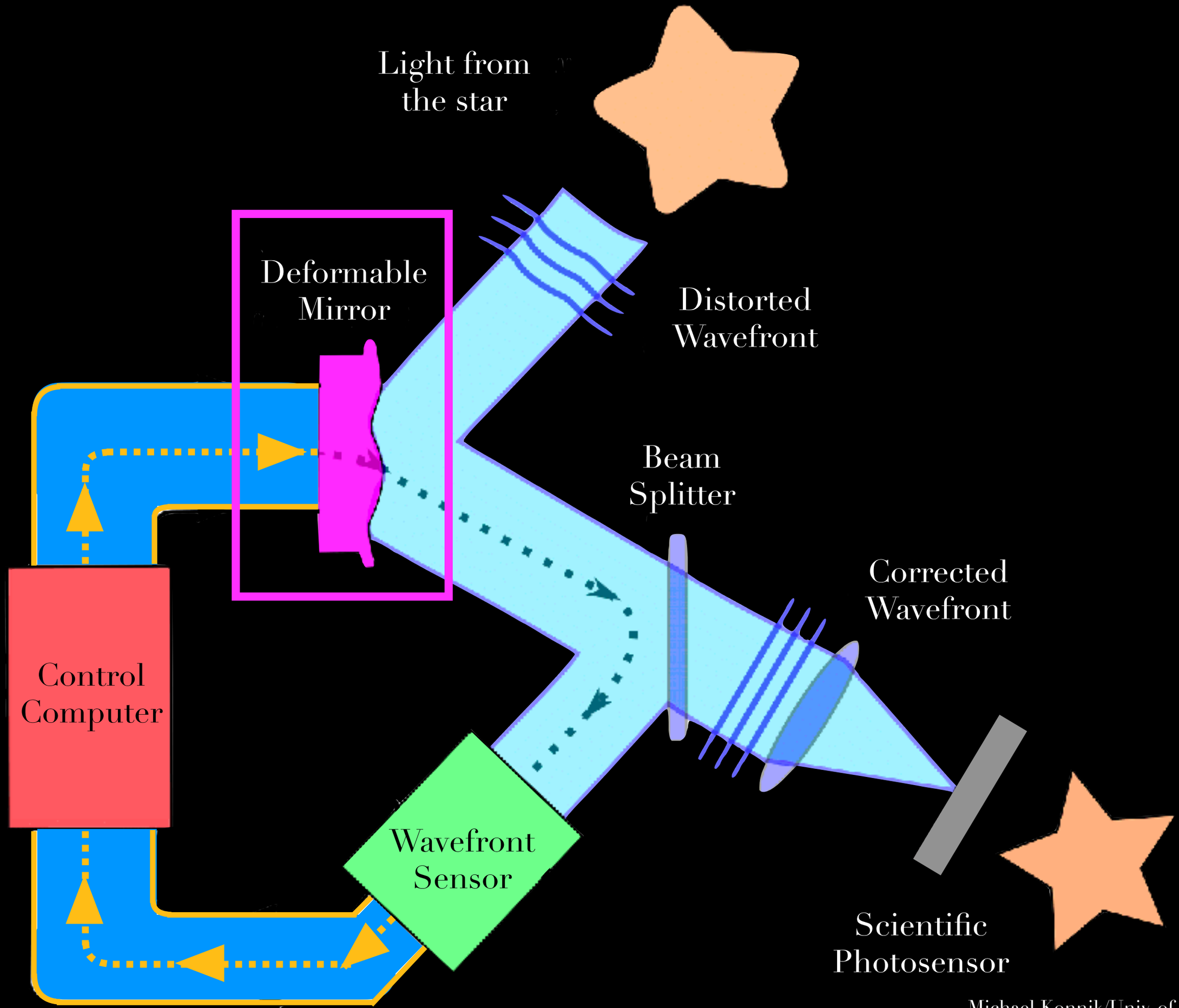


NASA/JPL/Caltech



Michael Konnik/Univ. of Newcastle



Michael Konnik/Univ. of Newcastle

Motivation

Upgrades— HAKA and AO3K

High Order Keck Adaptive Optics (HAKA) Upgrade: Improve corrections of atmospheric fitting error to optimize Keck AO system's performance for high contrast science by upgrading the **Keck II DM**, Shack-Hartmann wavefront sensor, and real-time controller to create a new high-order DM system.

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<u>Adaptive Optics 3K (AO3K) at Subaru:</u> Reach deeper contrasts for high-contrast imagers, fainter targets for imaging and spectroscopy, and redder targets through a phased upgrade of the AO system— installing a new NIR pyramid wavefront sensor, **upgrade to a higher order DM**, non-linear curvature visible wavefront sensor, and upgrade of the real-time control system.

HAKA Science Objectives: Exoplanets

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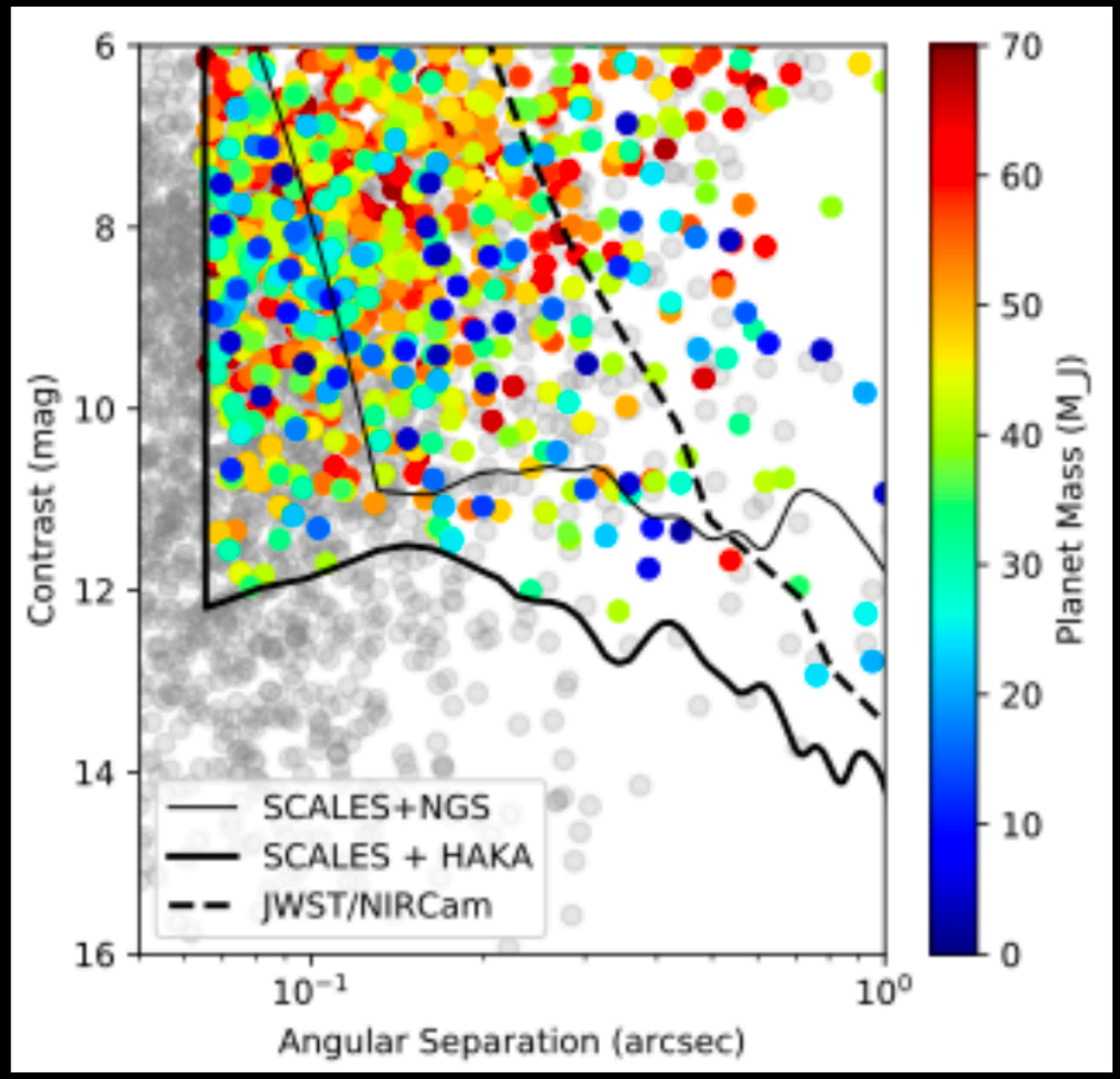
- Direct imaging and spectroscopic characterization of old, cold exoplanets



WMKO/HAKA Team

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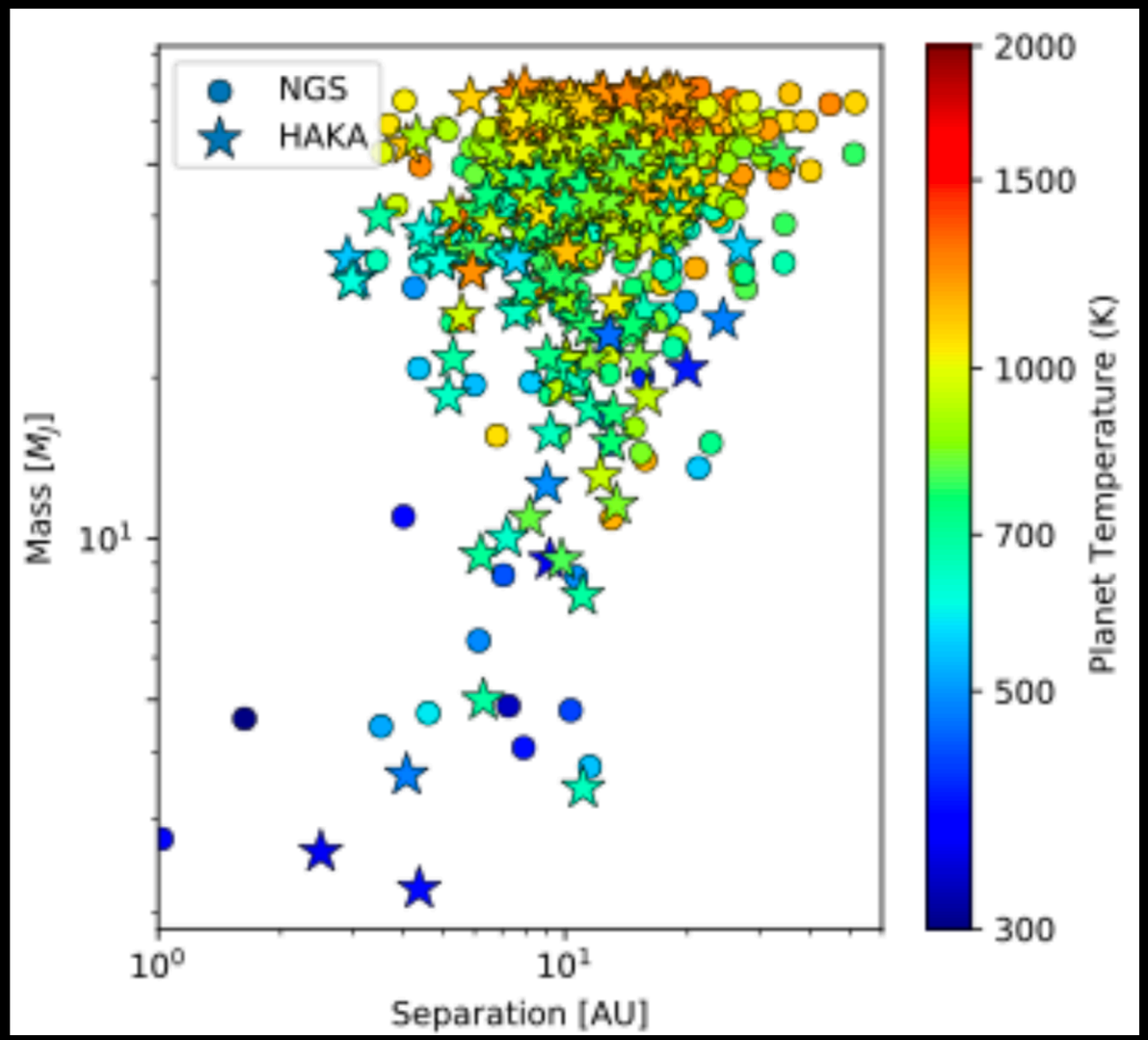
- Direct imaging and spectroscopic characterization of old, cold exoplanets
- Twice the number of planets with the AO upgrade in the extended *Gaia* era.



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HAKA Science Objectives: Exoplanets

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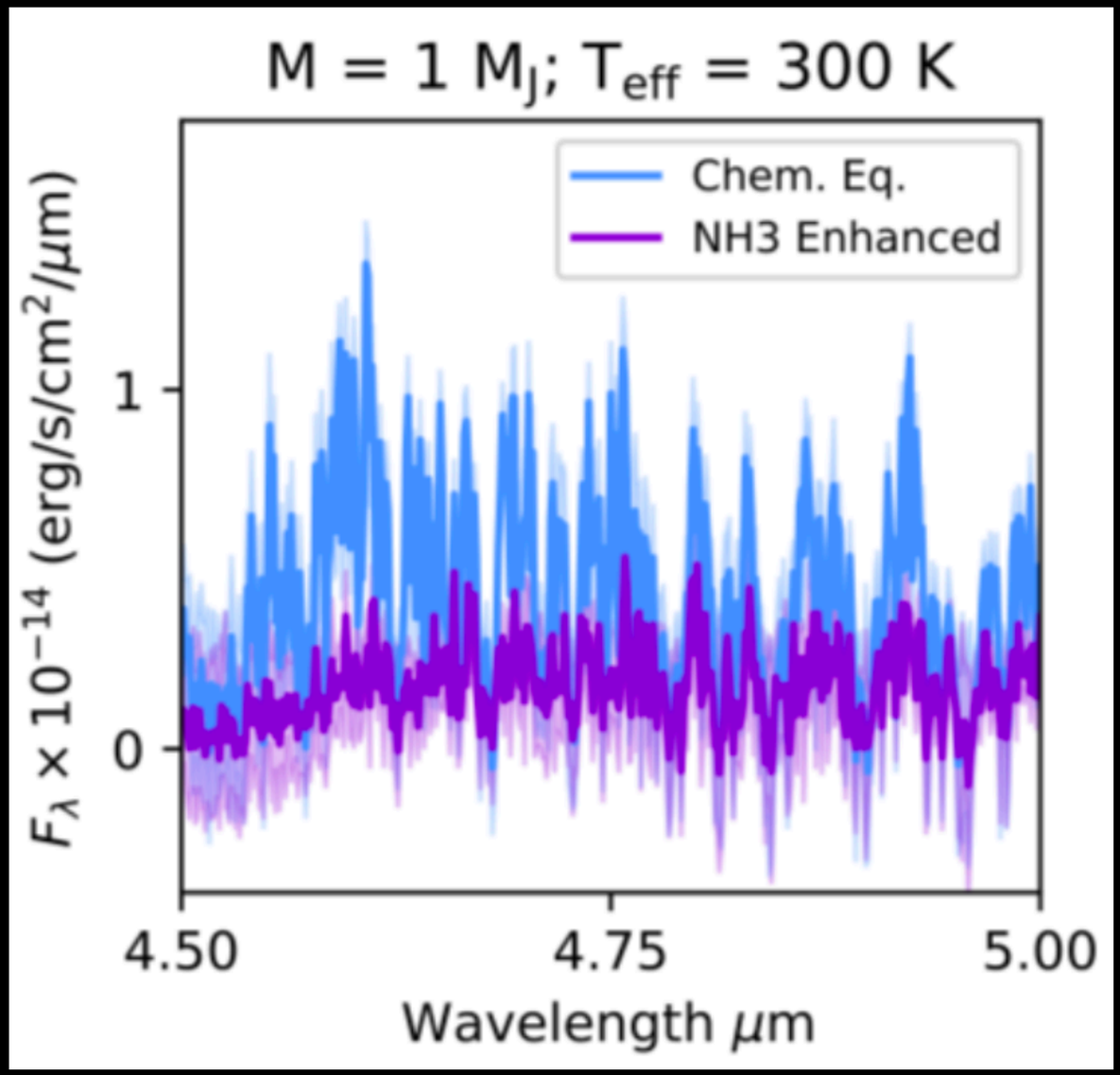
- Twice the number of planets with the AO upgrade in the extended *Gaia* era.
- High contrast R~3000 mid-IR spectroscopy allowing line-by-line identification of molecules, including abundances of major absorbers (CH_4, CO, H_2O, NH_3, PH_3) and also more tenuous species (CH_3D, GeH_4, C_2H_2, C_2H_4).



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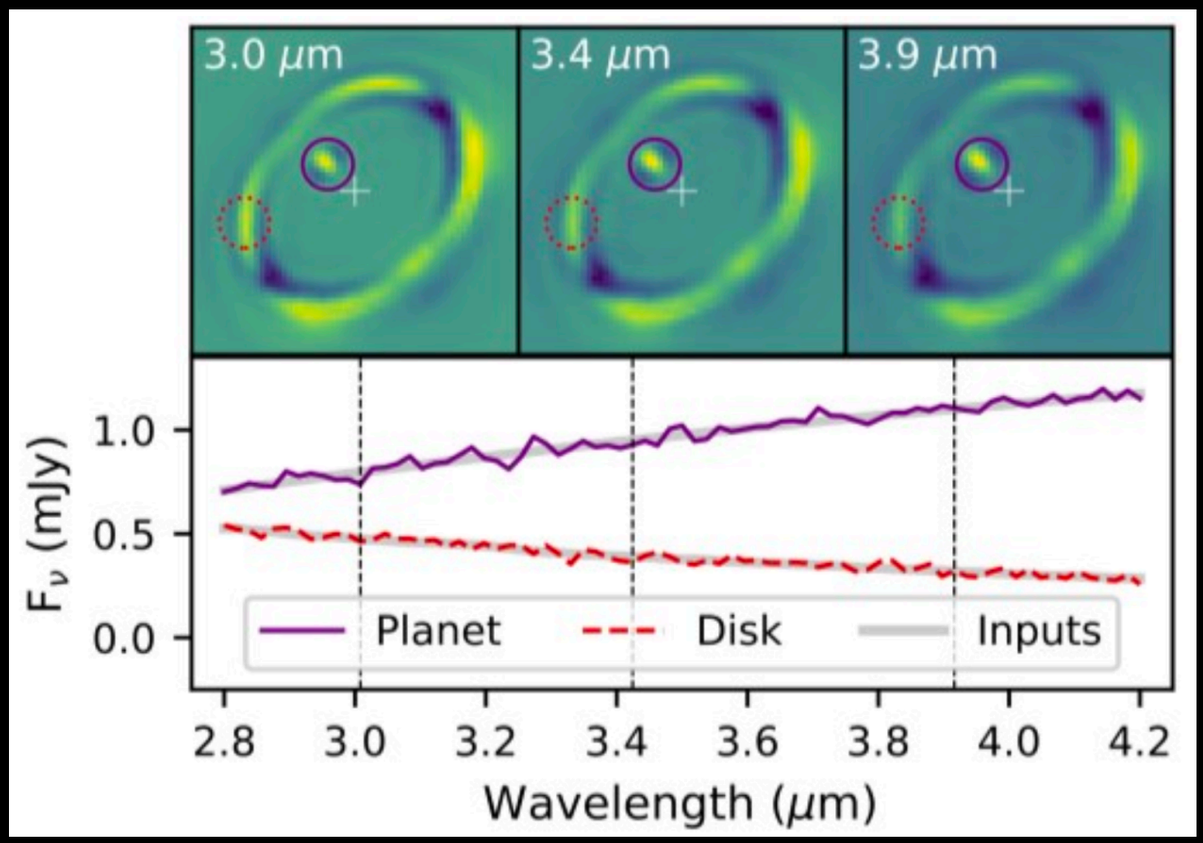
HAKA Science Objectives: Planet Formation

- Enhance imaging of protoplanets in their nascent disk and observe mass accretion



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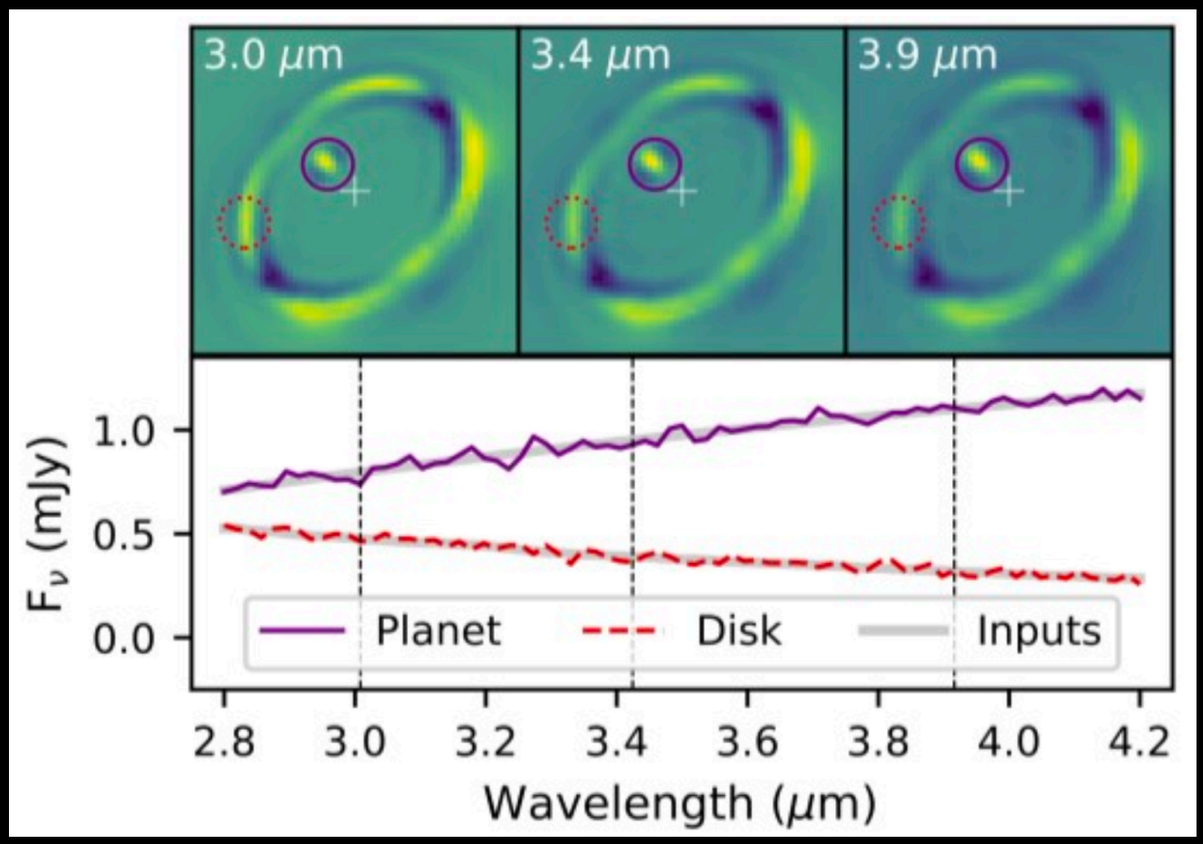
HAKA Science Objectives: Planet Formation

- Enhance imaging of protoplanets in their nascent disk and observe mass accretion
- Protoplanetary Disks: High spatial resolution mapping of dust, H2O ice, and organic features in disks.



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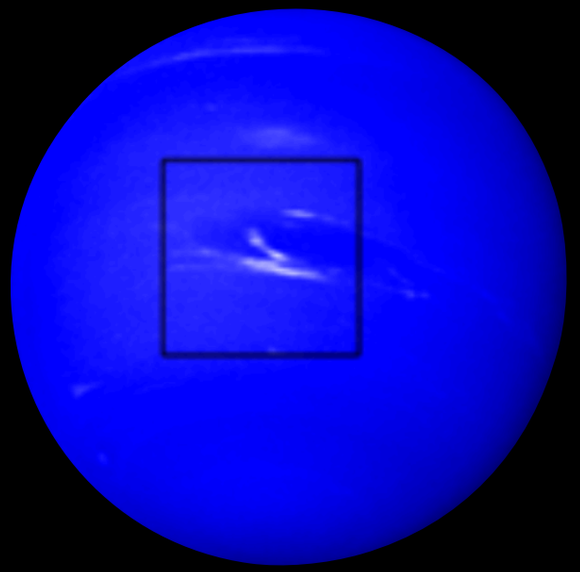
- Probe the atmospheres of our Solar System's ice giants



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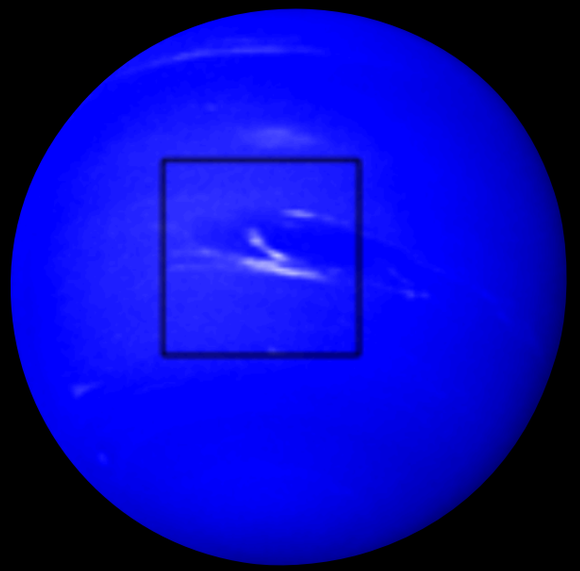

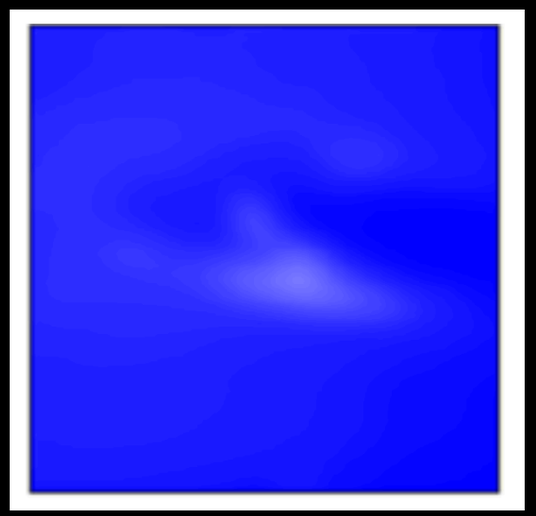

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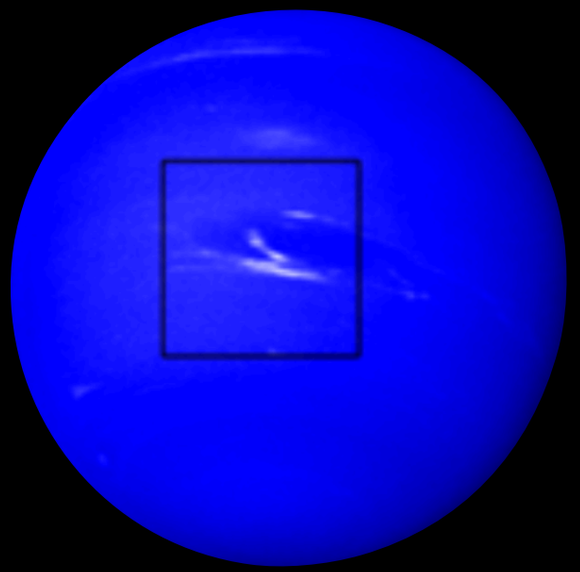

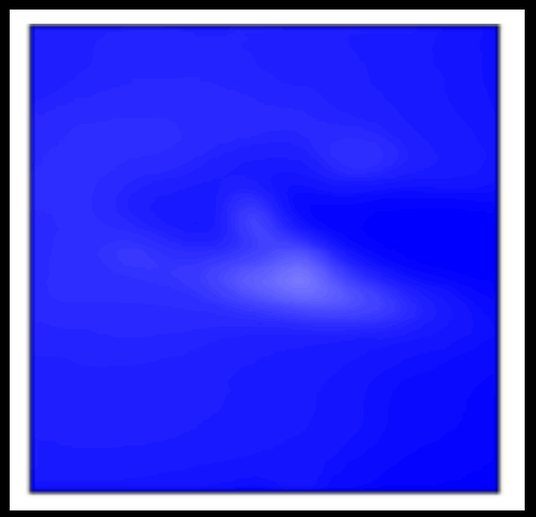

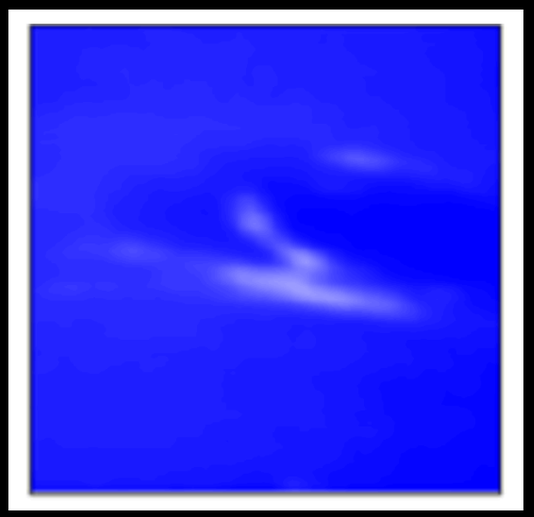

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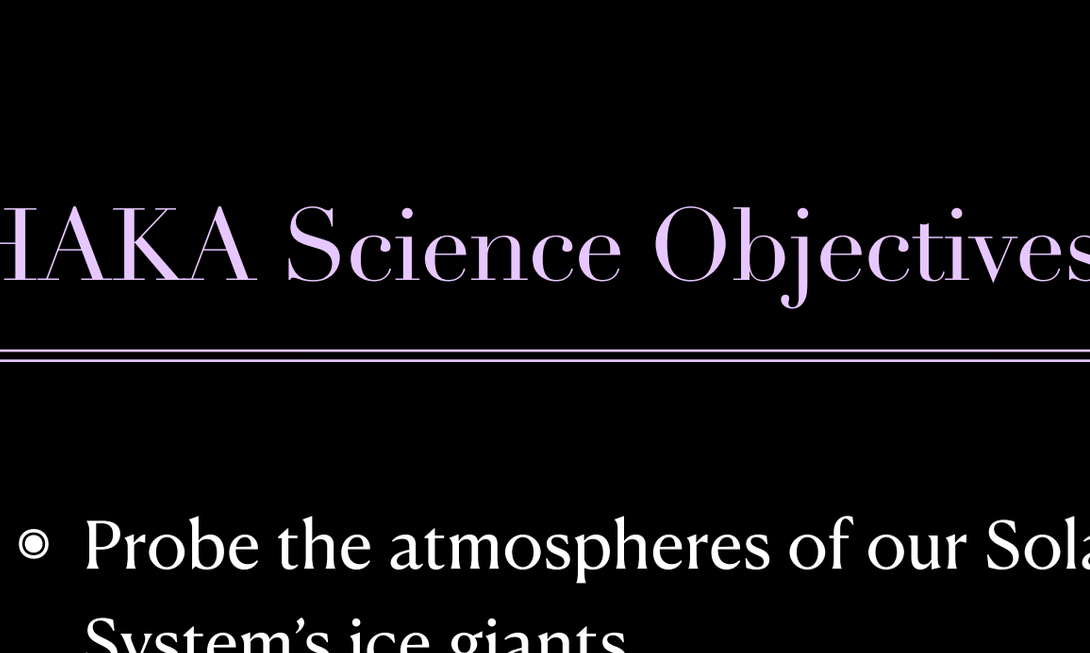
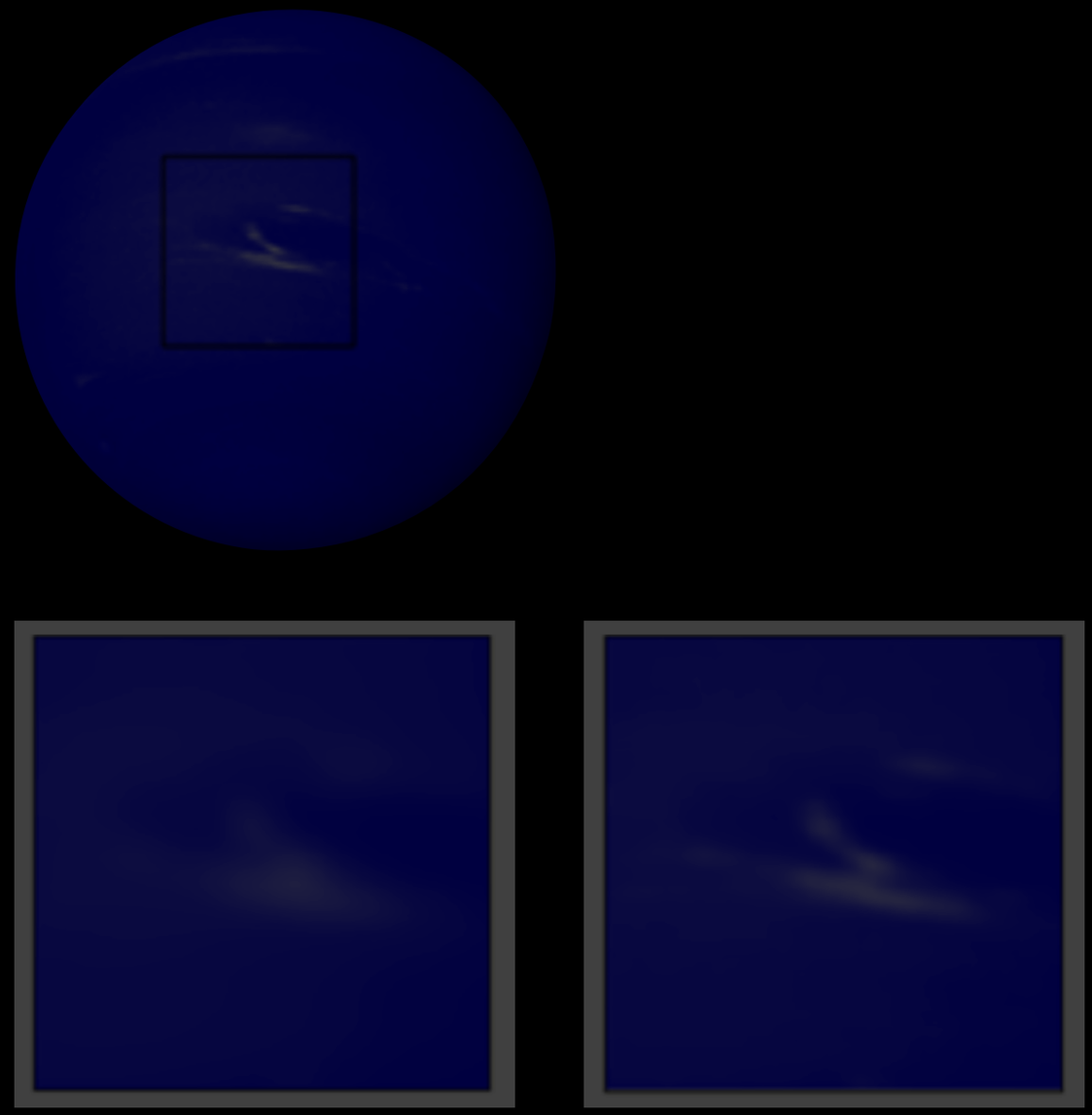
HAKA Science Objectives: Solar System

- Probe the atmospheres of our Solar System's ice giants
- Map the surfaces of the Galilean moons with lesser wavefront errors





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AO3K Science Objectives

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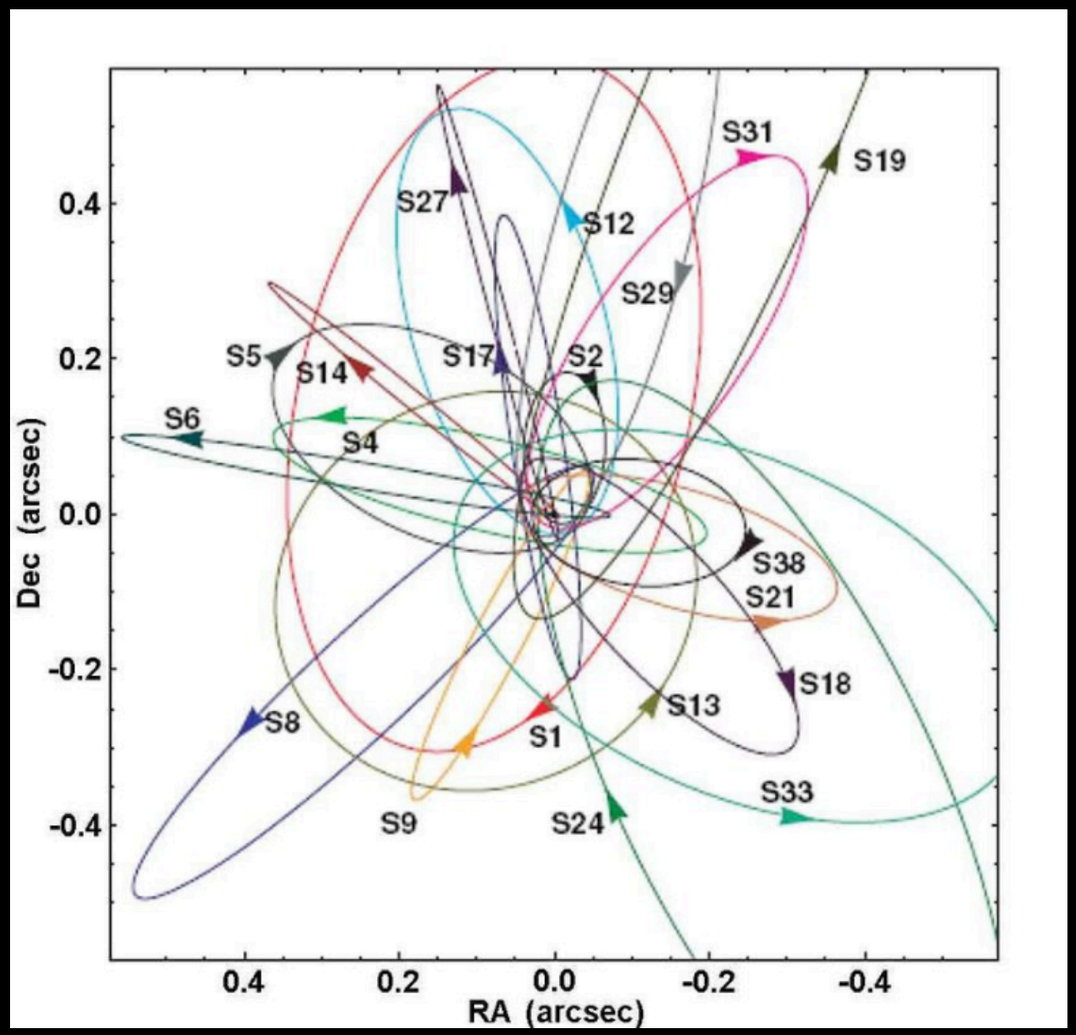
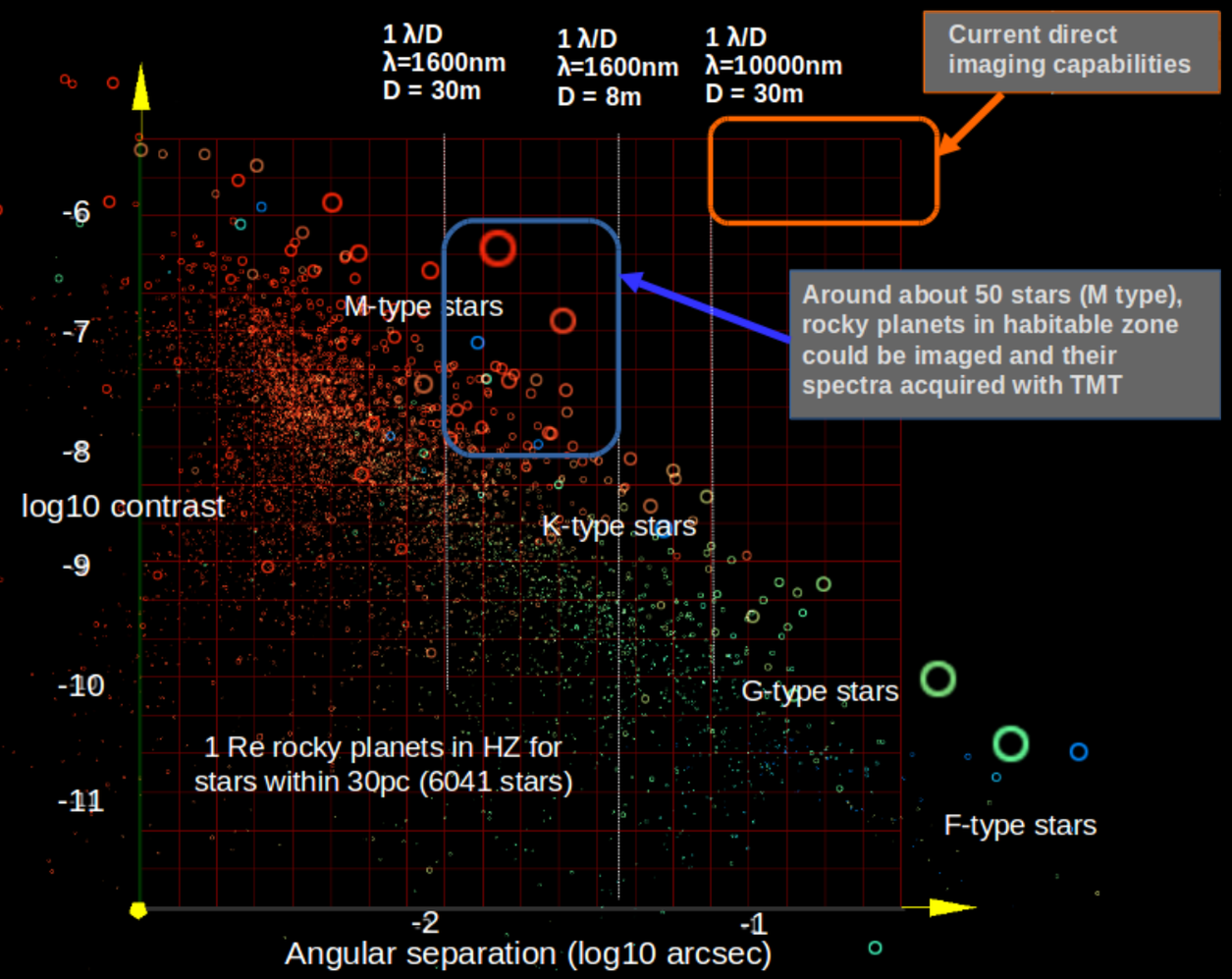


Subaru/AO3K Team

AO3K Science Objectives

- Enhanced imaging and spectroscopy of the stars orbiting the black hole at the Galactic Center
- Combination of NIR PyWFS and higher order DM will get us to K- to M-type stars, and stars with dust extinction, the prime targets for imaging habitable planets with ELTs



Subaru/AO3K Team

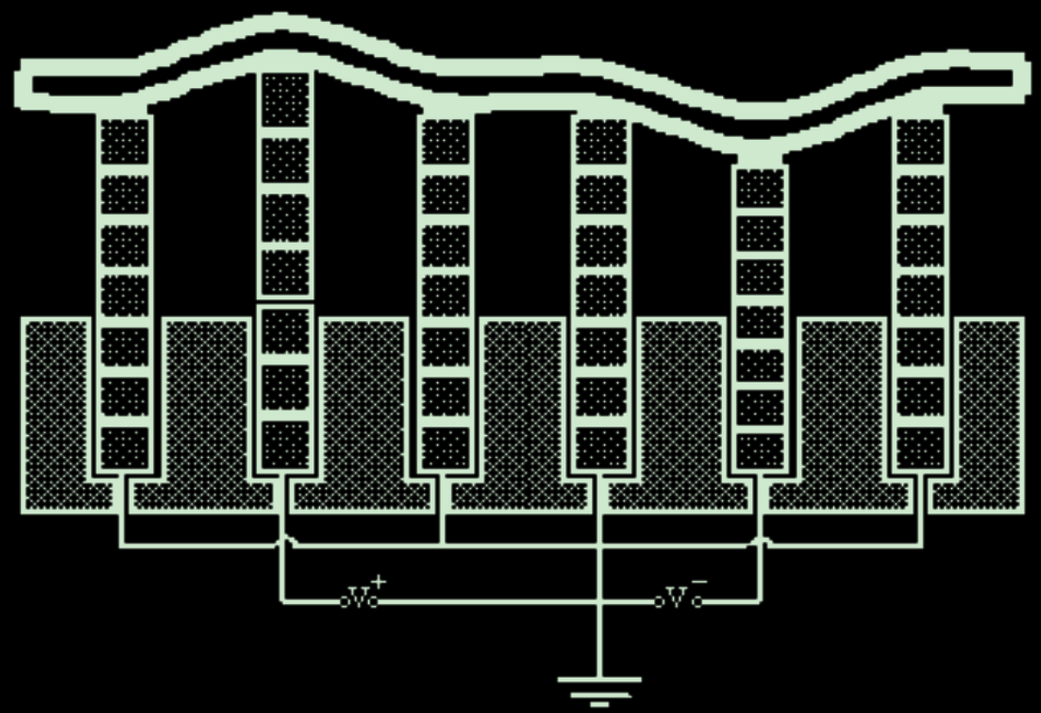
Deformable Mirror

Goal

- Apply an equal and opposite shape of the estimated wavefront to the pupil plane

Design

- A thin mirror supported by an array of actuators
- Actuators move quickly and precisely to shape the mirrored surface to match the estimated wavefront
- Total motion of a single actuator < 20 μm



Classic DM with PZT actuators

Why a new Deformable Mirror (DM)?

HAKA Upgrade

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HAKA Upgrade

Current DM

- Over 25 years old (first light— 2/5/99)
- 349 **piezoelectric** actuators
- Strehl Ratio: ~0.6 @ 2 μm
- Fitting Error: 121 nm

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New DM

- 2900 **magnetic coil** actuators
- Strehl Ratio: ~0.7 @ 2 μm
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$$\text{Strehl Ratio} = \exp[-(2\pi\sigma)^2]$$

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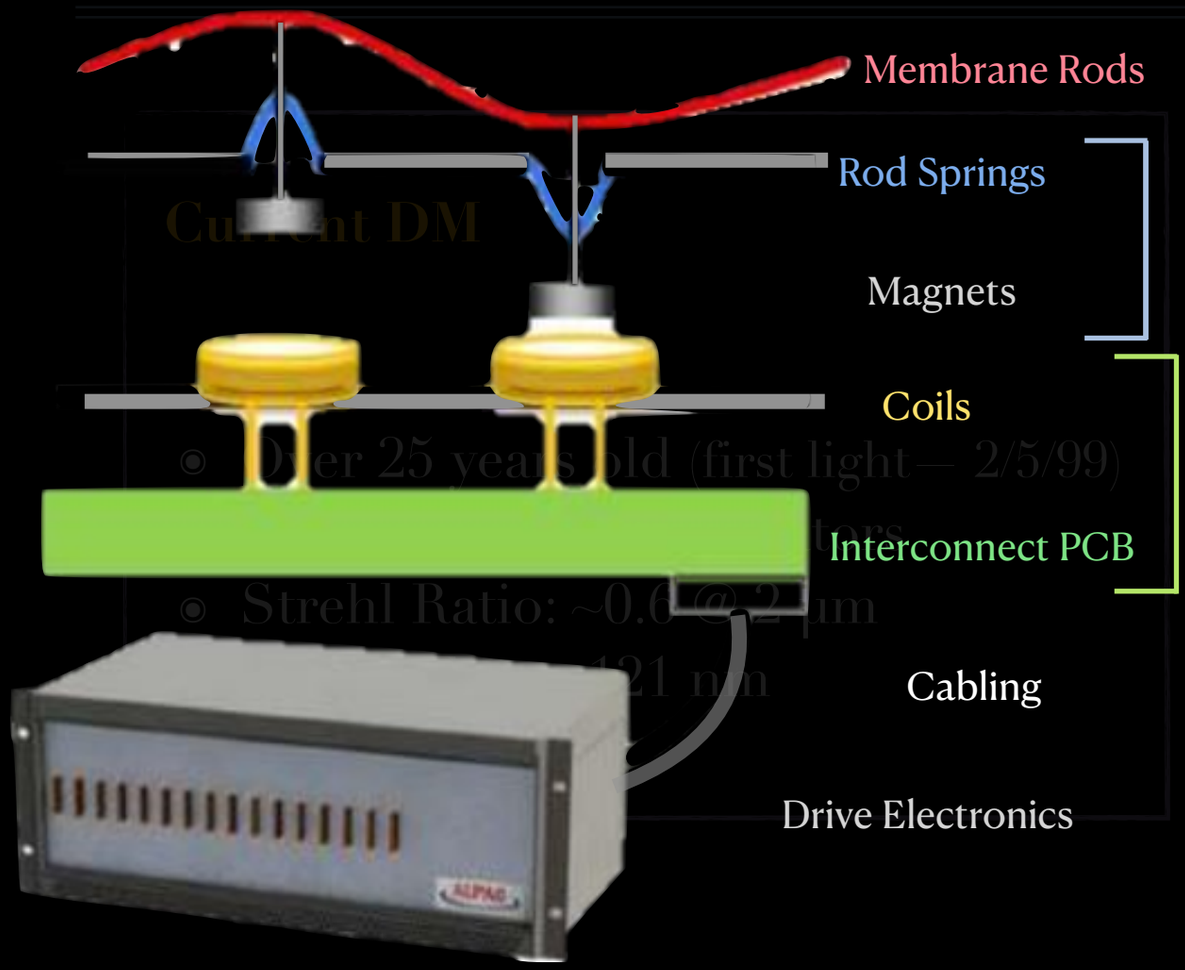

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- 188 bimorph DM actuator
- Strehl ~20-40% in H band (up to 65% seen with NIR wavefront sensor)

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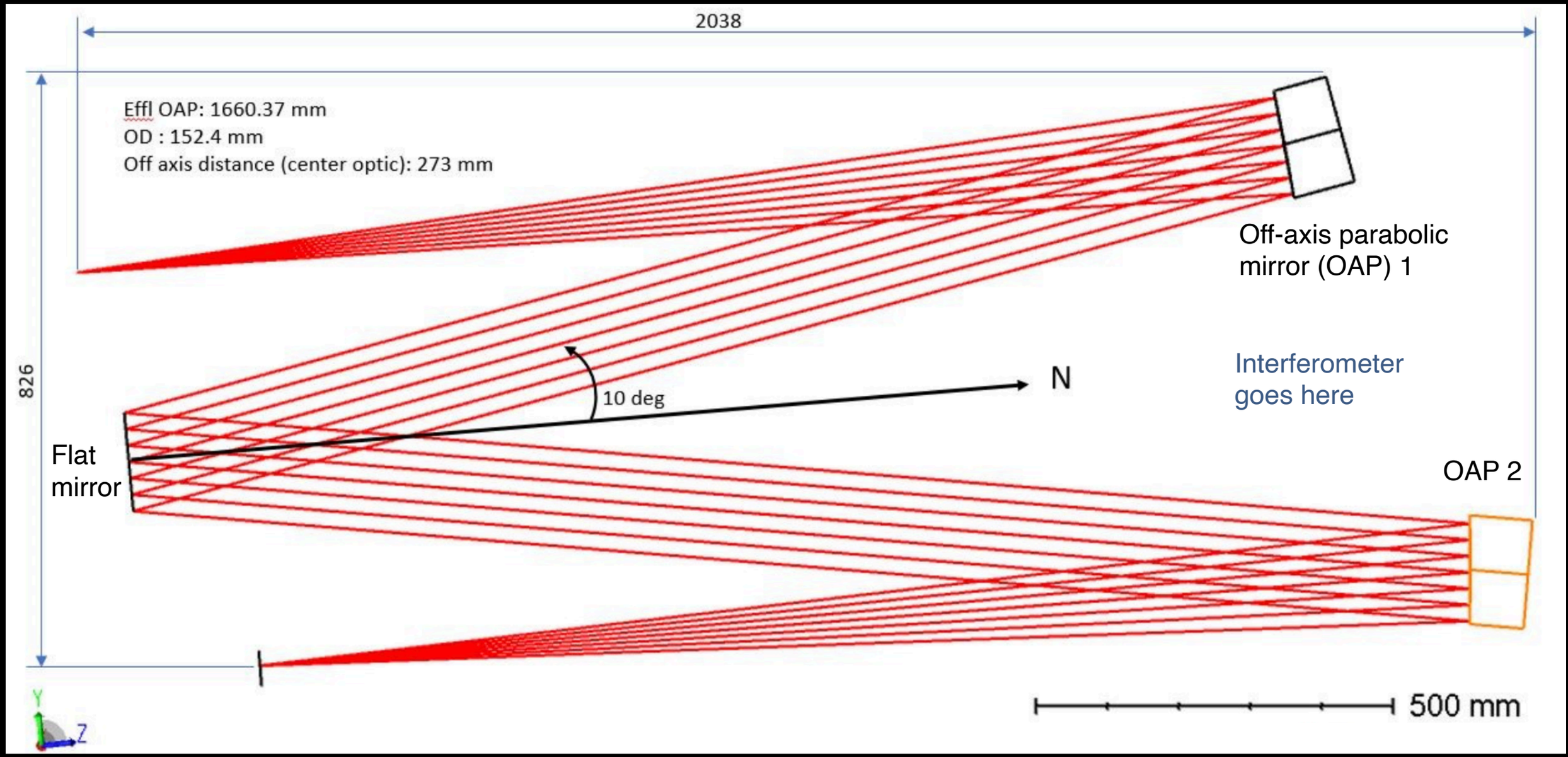
New DM

- 3228 magnetic voice coil actuators
- Up to 85% of Strehl seen in H-band with NIR wavefront sensor)

Testing the Deformable Mirror

Step 1: The Test Bench



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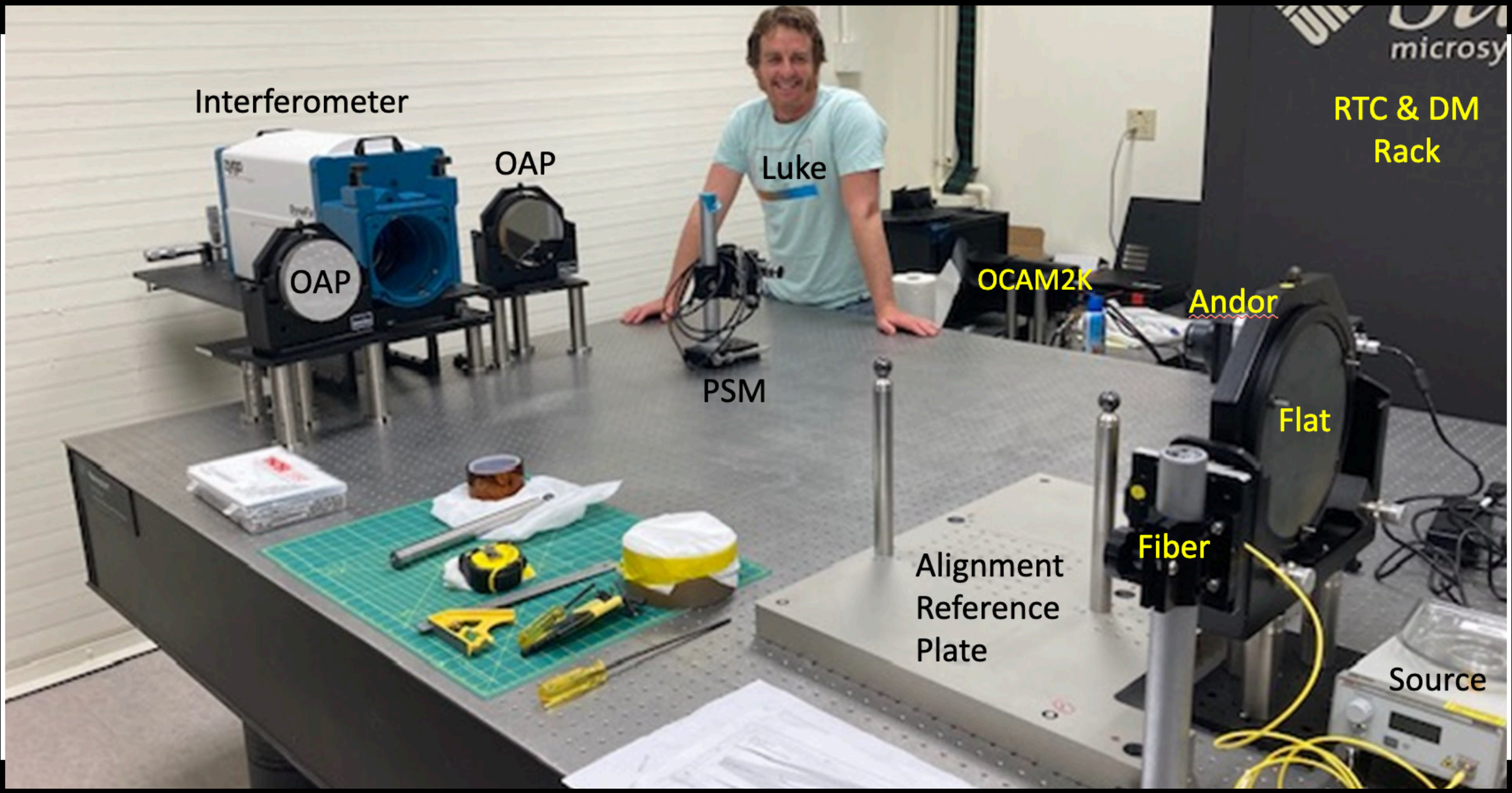

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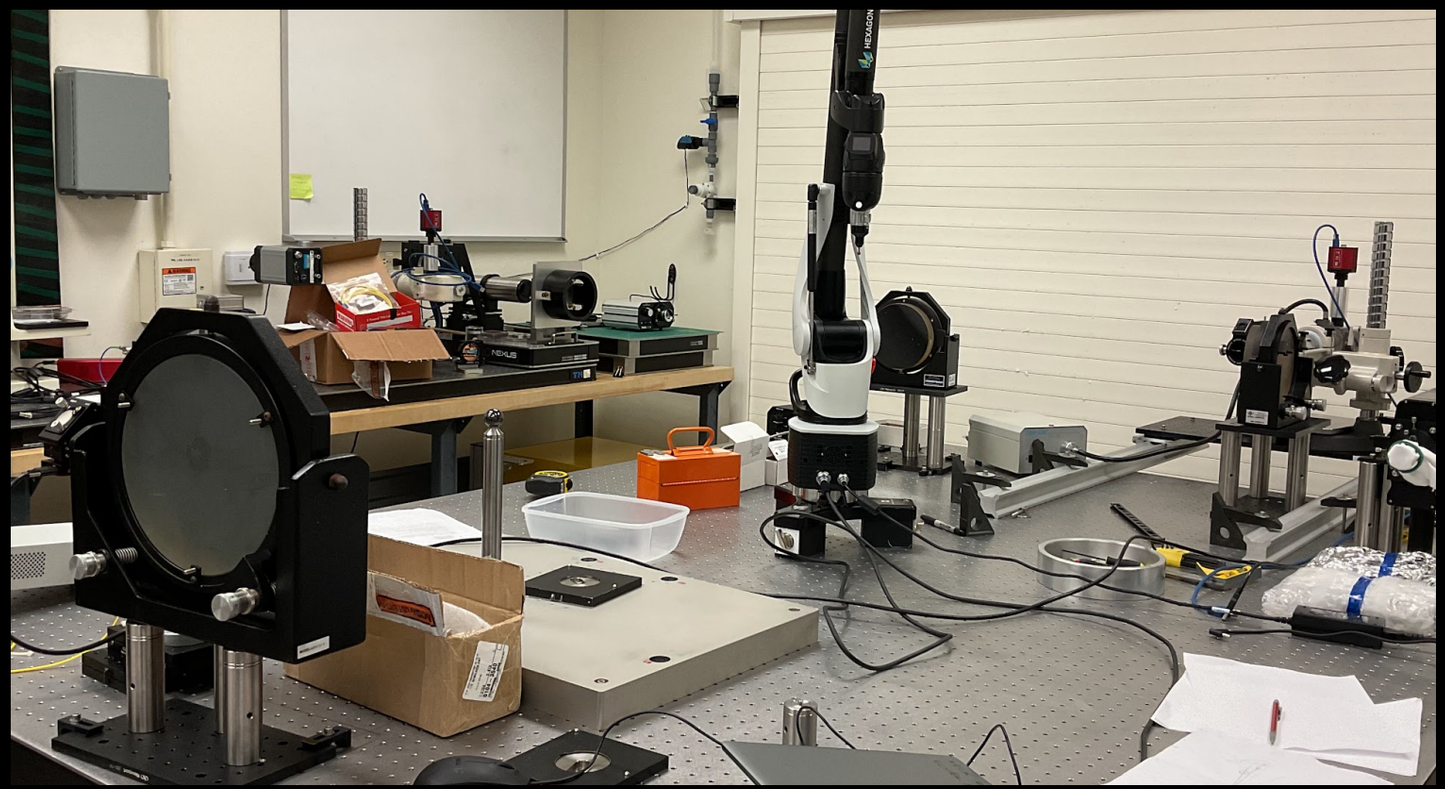
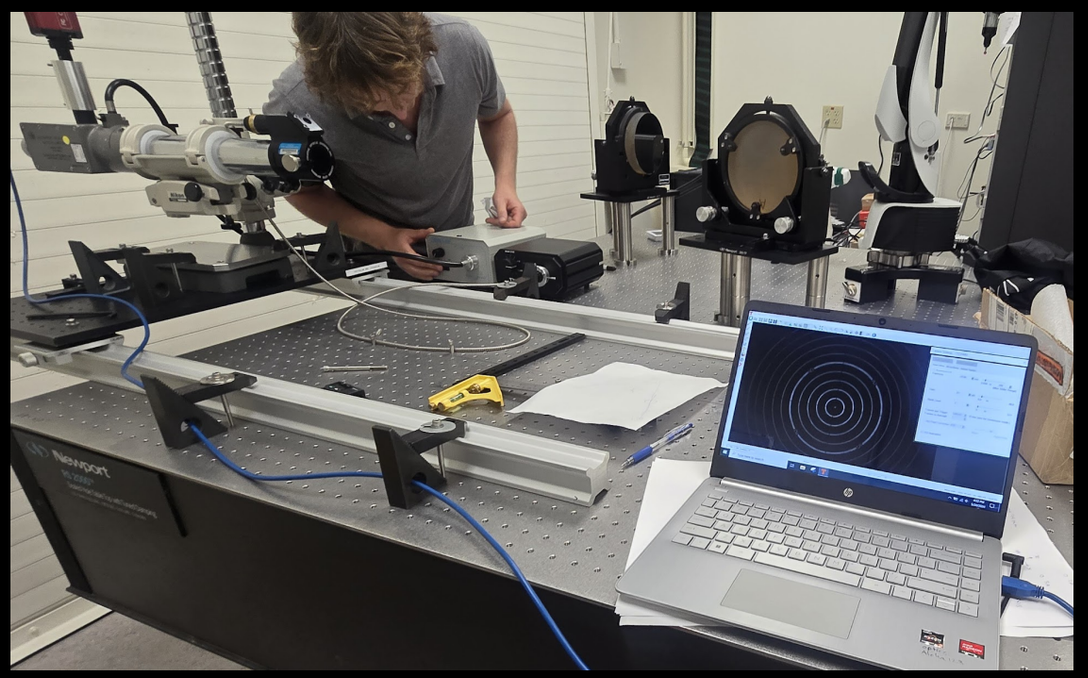
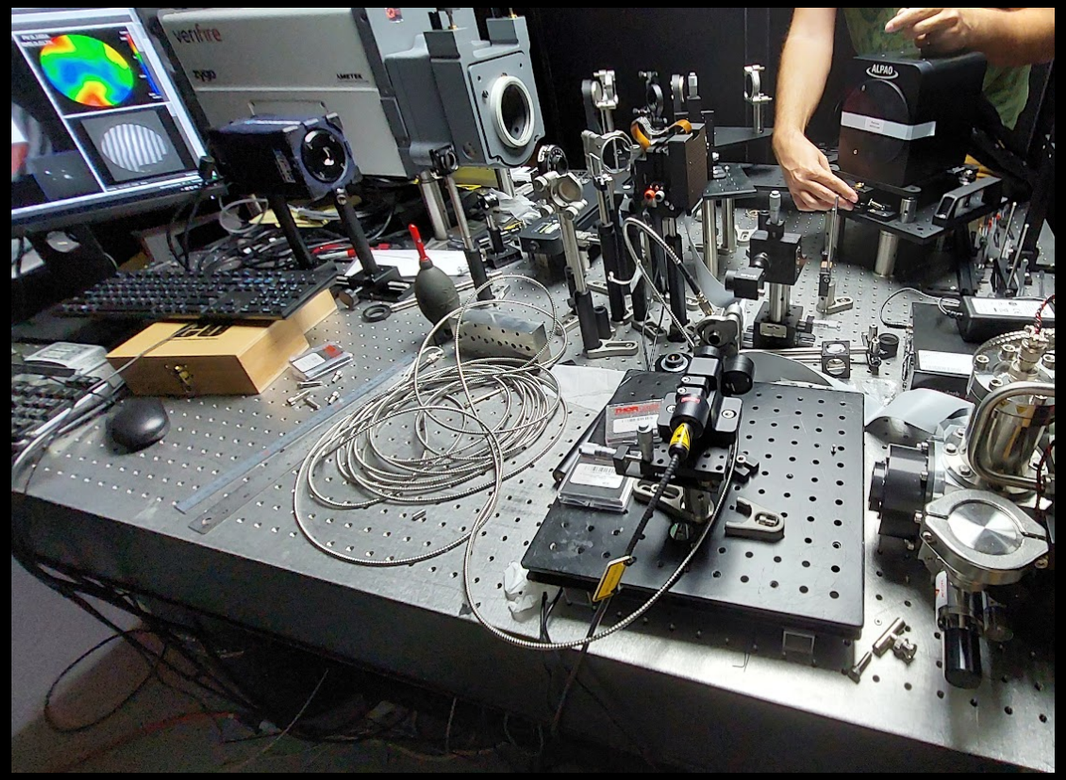

HEXAGON
NEXUS


Newport

Step 2: DM Characterization

- Functional Testing: Ensure that the DM is working properly and all setup steps work.
- Performance Testing: Test the performance of the DM and compare it to the performance reported by manufacturer.
  - Data Acquisition: Measure different aspects of the DM—temperature, actuator stroke, gain, and power dissipation and consumption.
  - Data Analysis: From the Data Acquisition tests, create an actuator model in the software pipeline for the DM.


ALPAO


ALPAO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DRIVE ELECTRONICS
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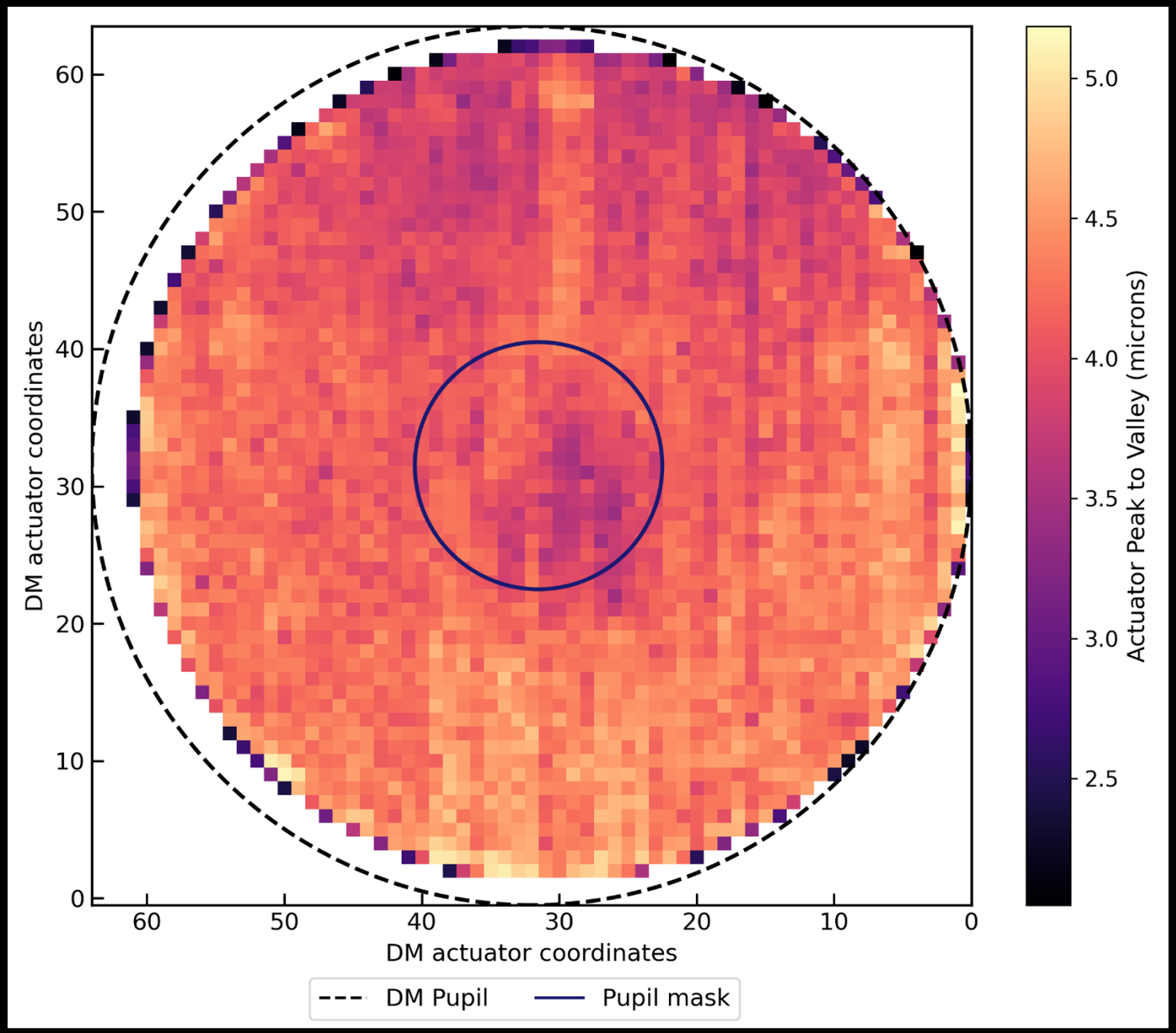
EXIT

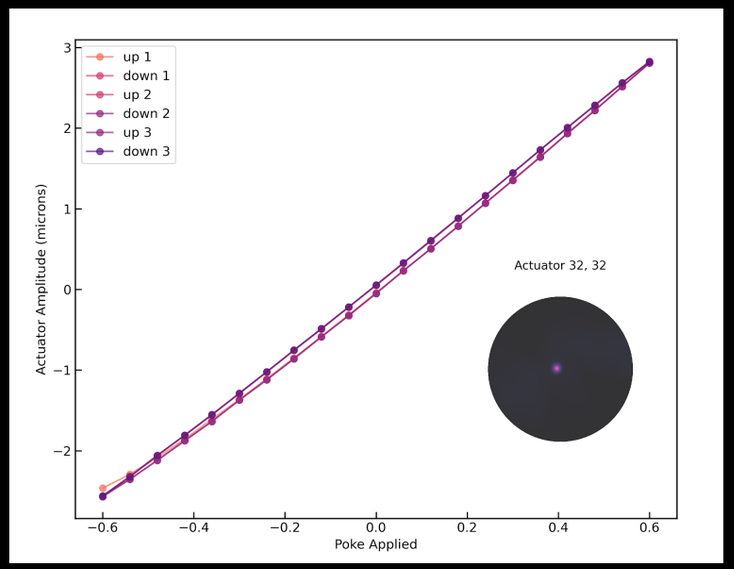
Gain Map

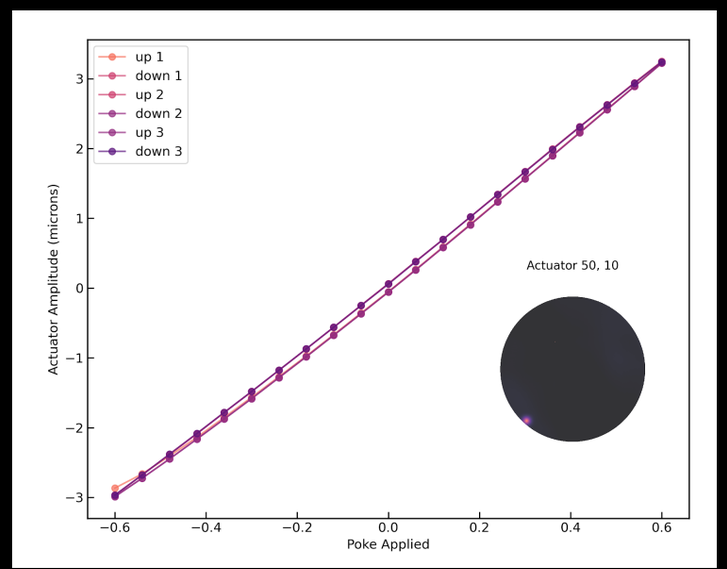


- Mapping the amplitudes of each of the actuators
- Gain map demonstrates the stroke of individual actuators
- “Lazy zone” in the center mostly goes behind a central obscuration

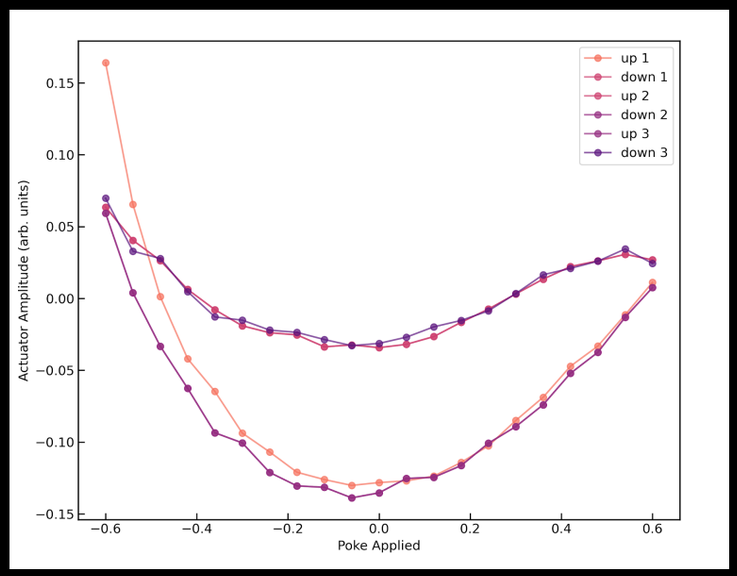
Linearity and Hysteresis

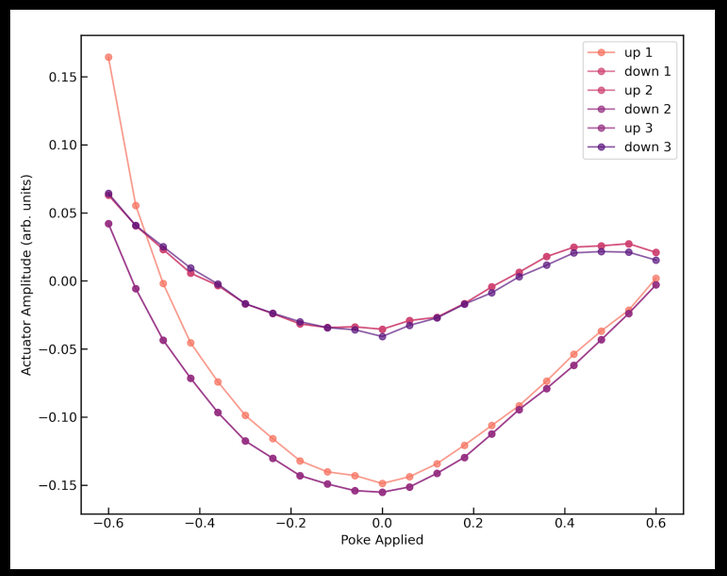
Measurement





- A test to check residual positional error from previous actuator position commands, and the repeatability of the stroke

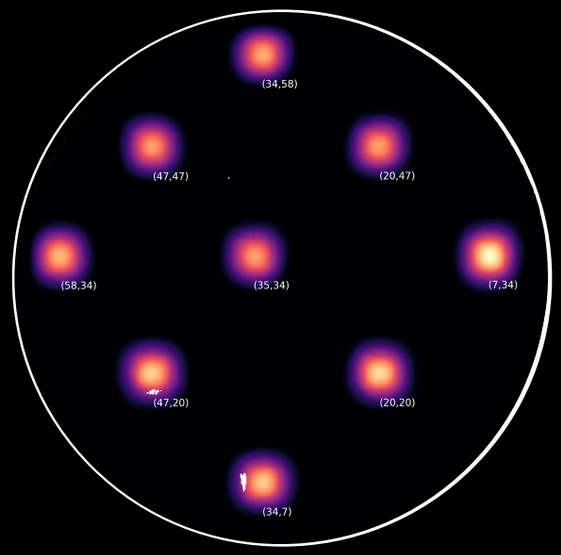


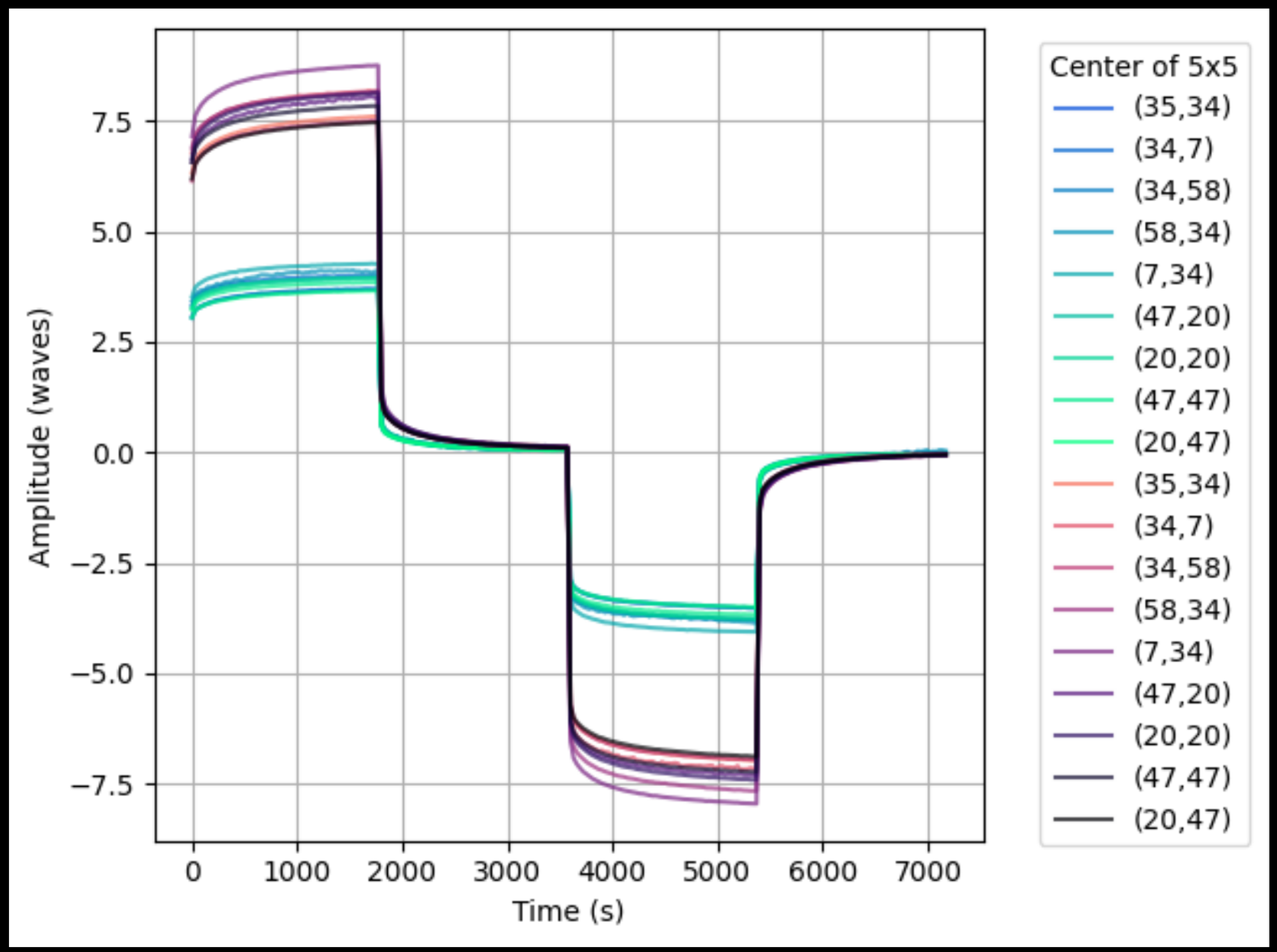


- Here we pushed select actuators from a negative to a positive stroke and back multiple times and checked if we began and ended at similar amplitudes.

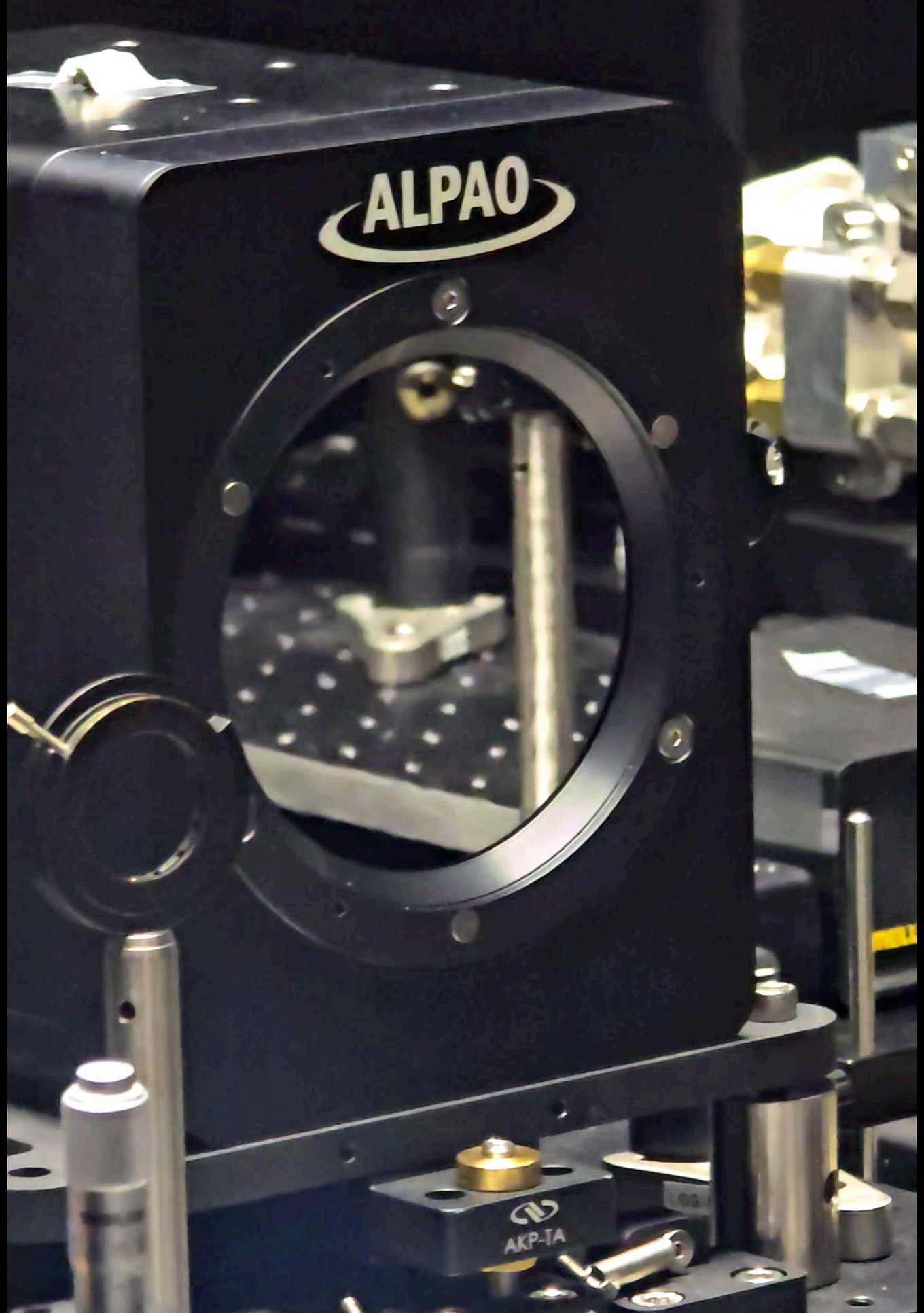
Detrended Measurement

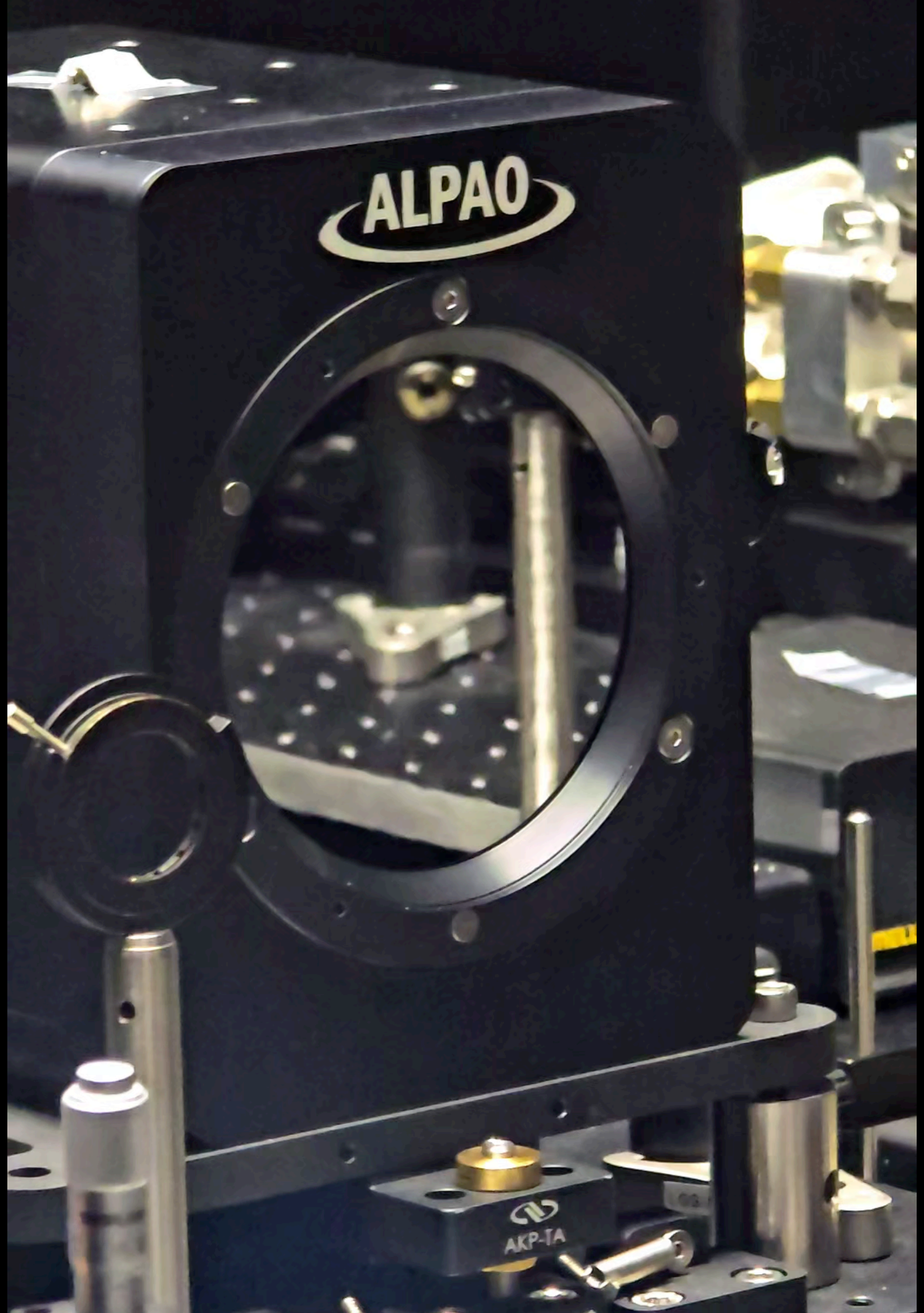
Creep



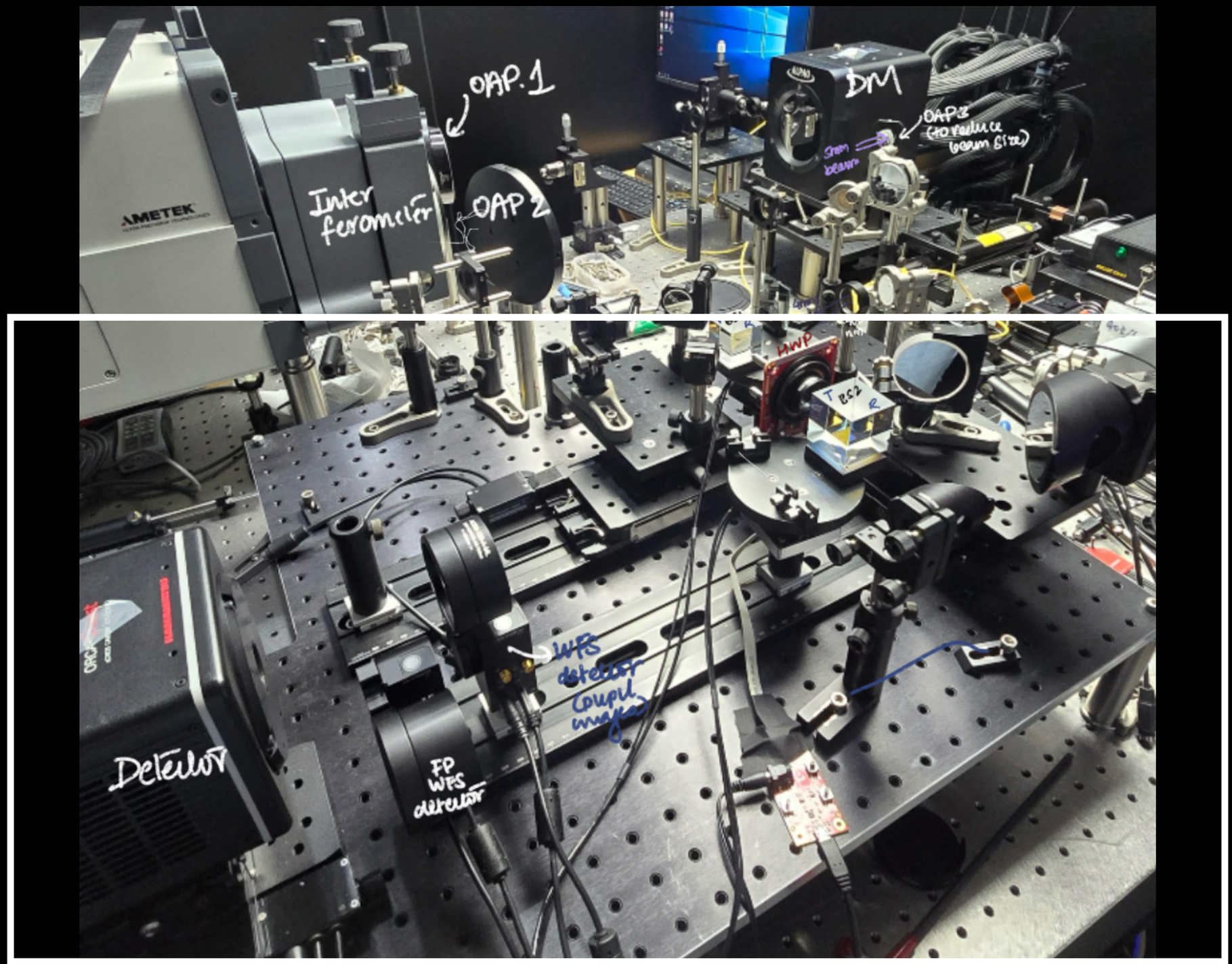


- When the actuator continues to expand or contract even after the voltage change is complete.
- Here we test how stable a set of actuators are under prolonged stress


ALPAO
AKP-TA

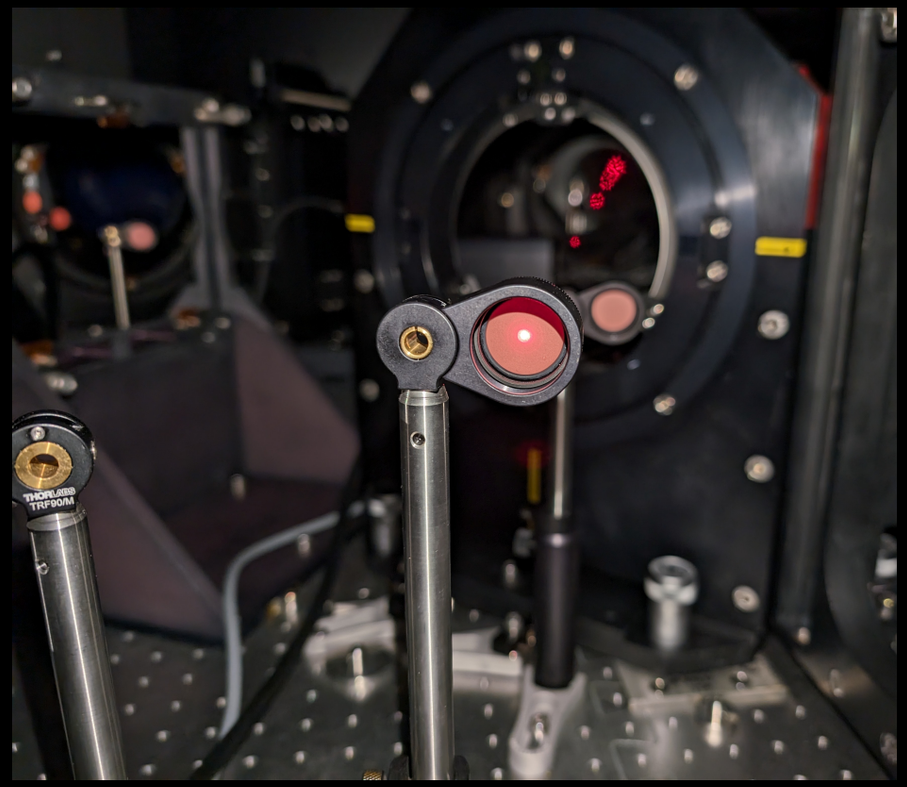

ALPAO
AKP-TA

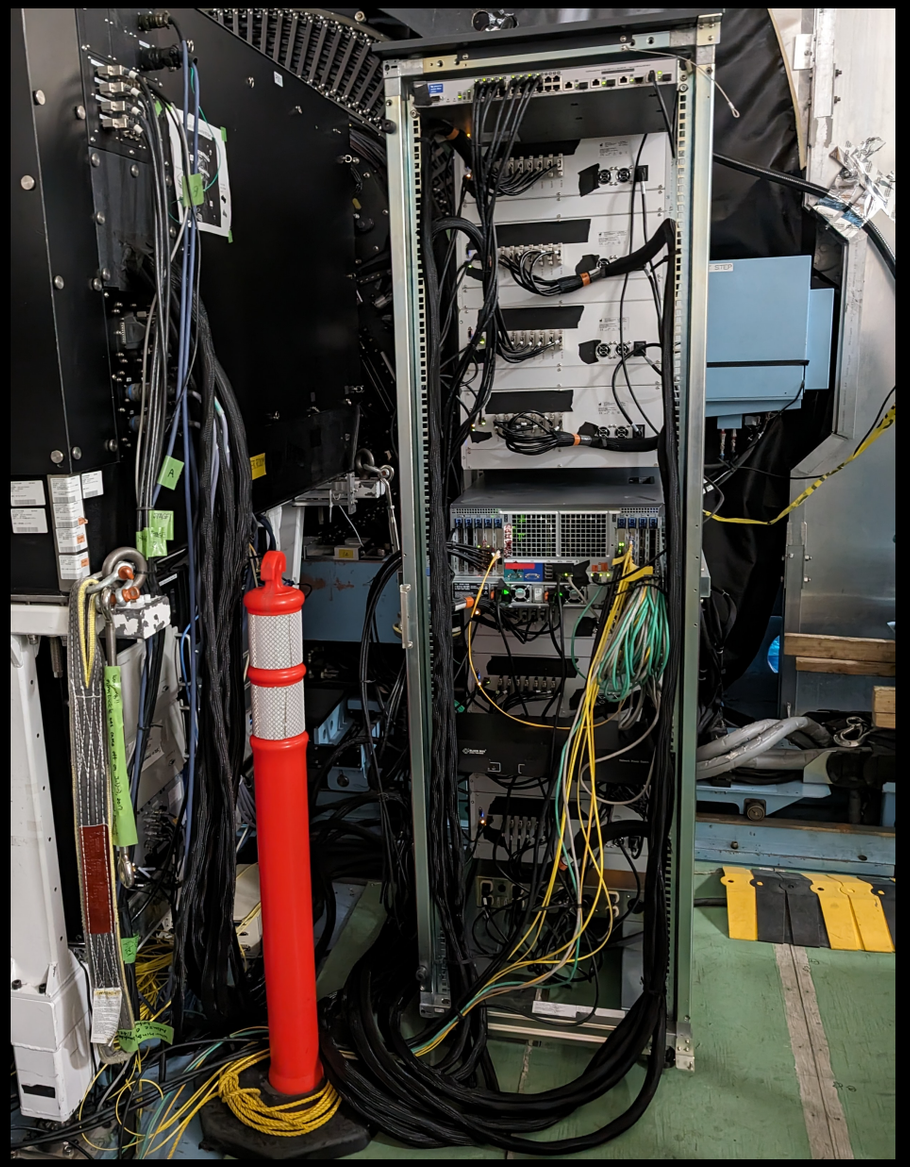
Step 3: Closing the AO Loop I

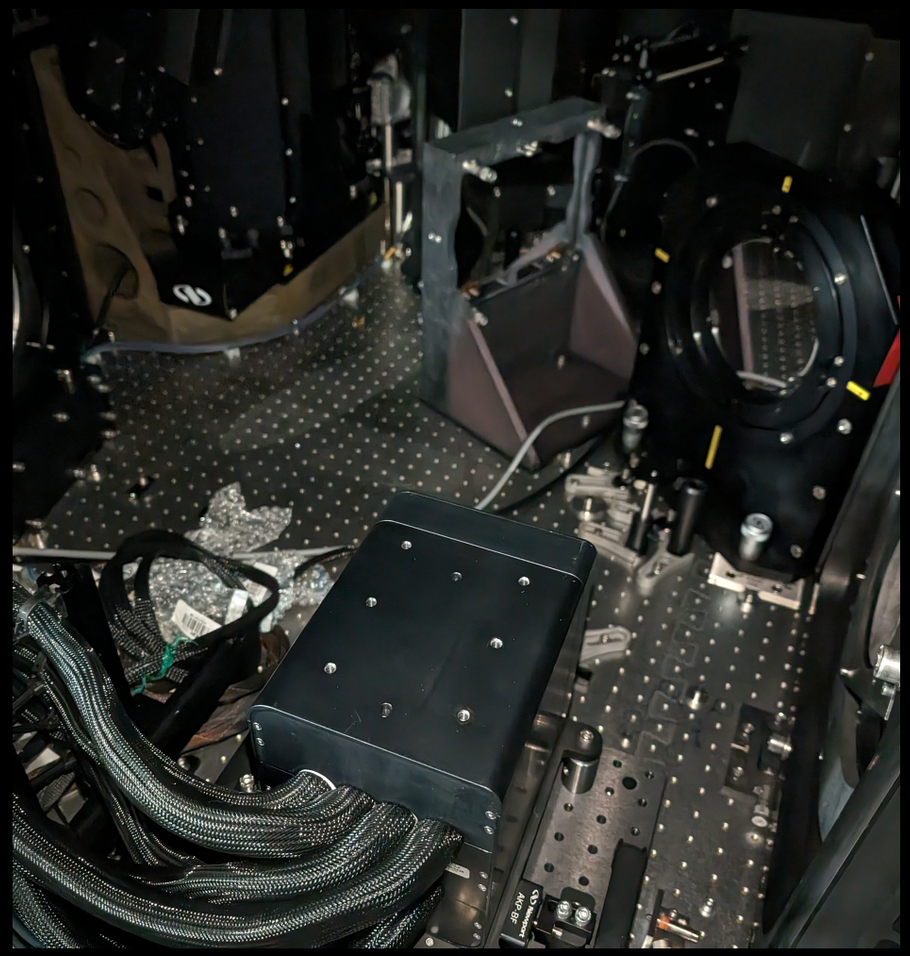


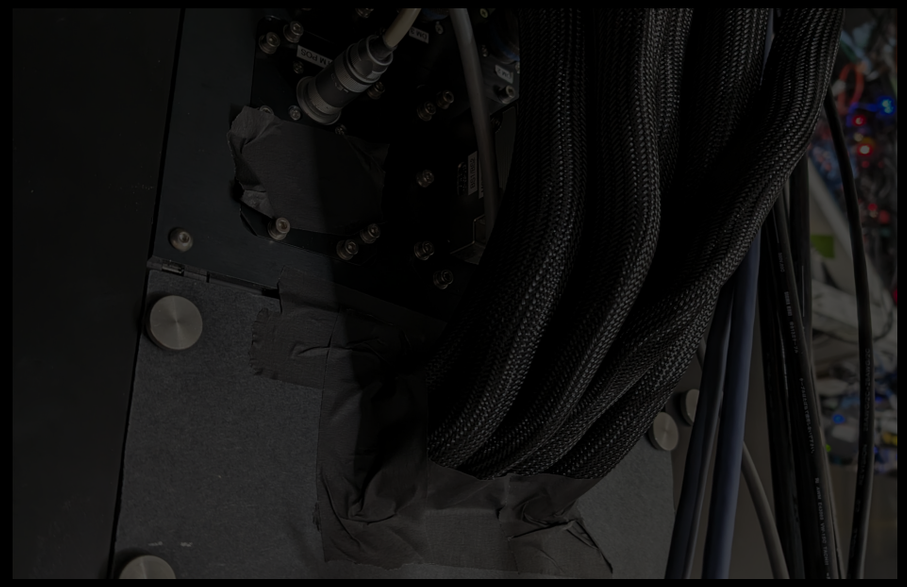
Summit Installation

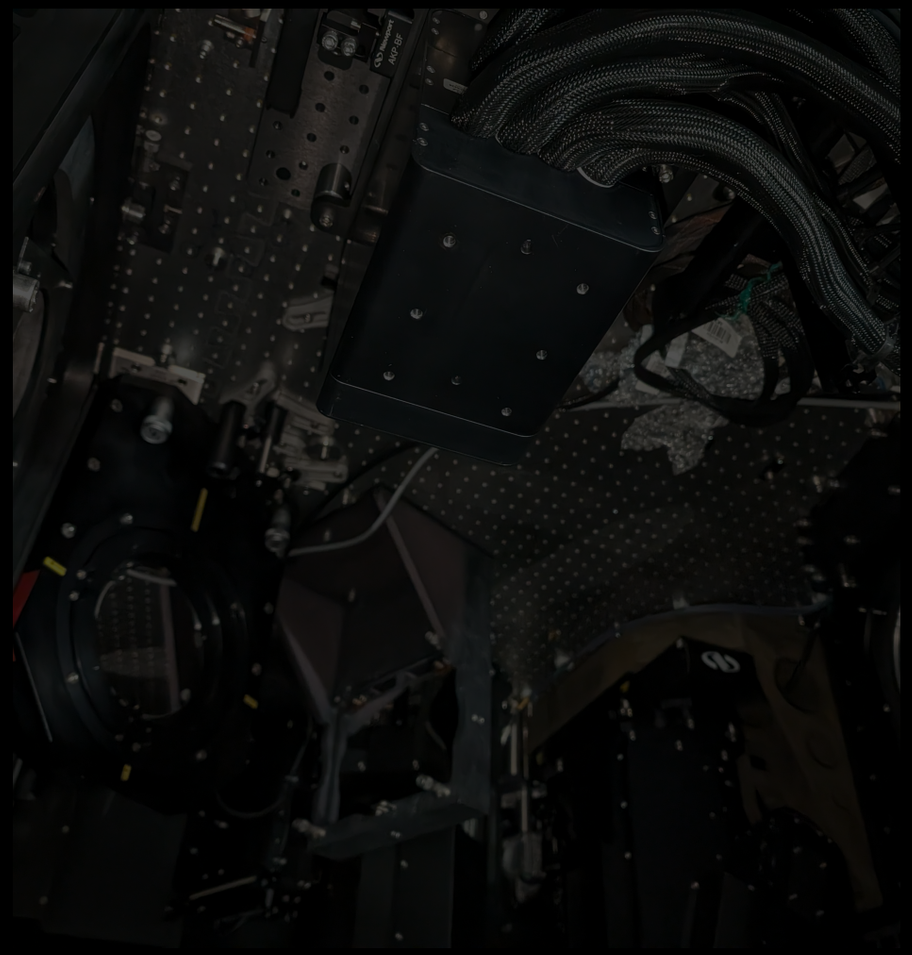
Ft. The Subaru DM

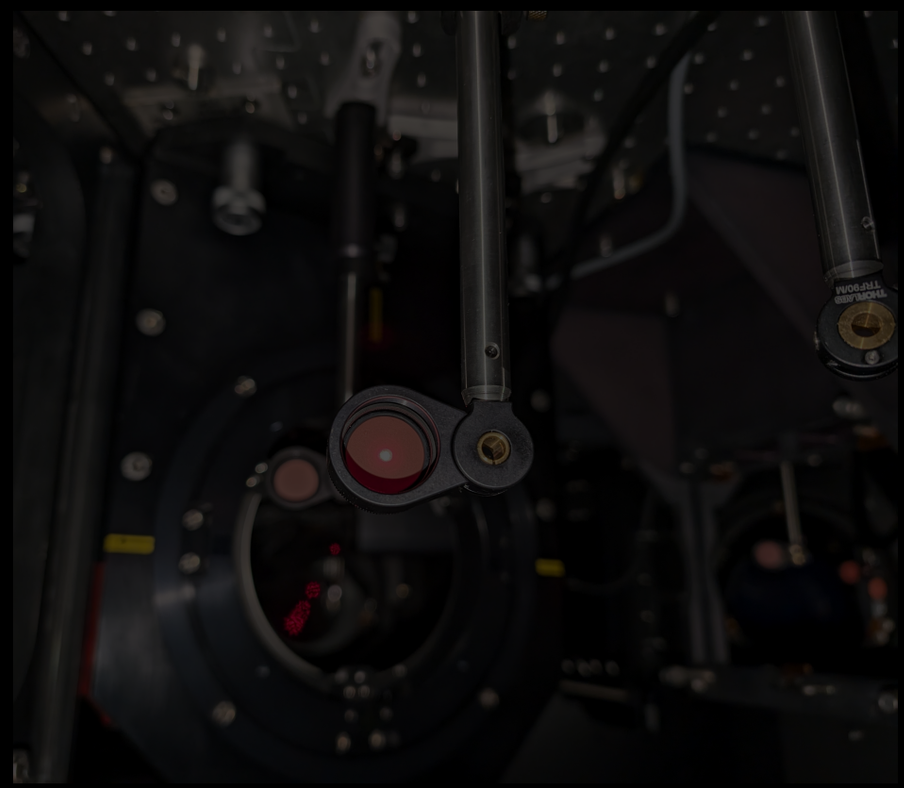

THORLABS
TRF90/M

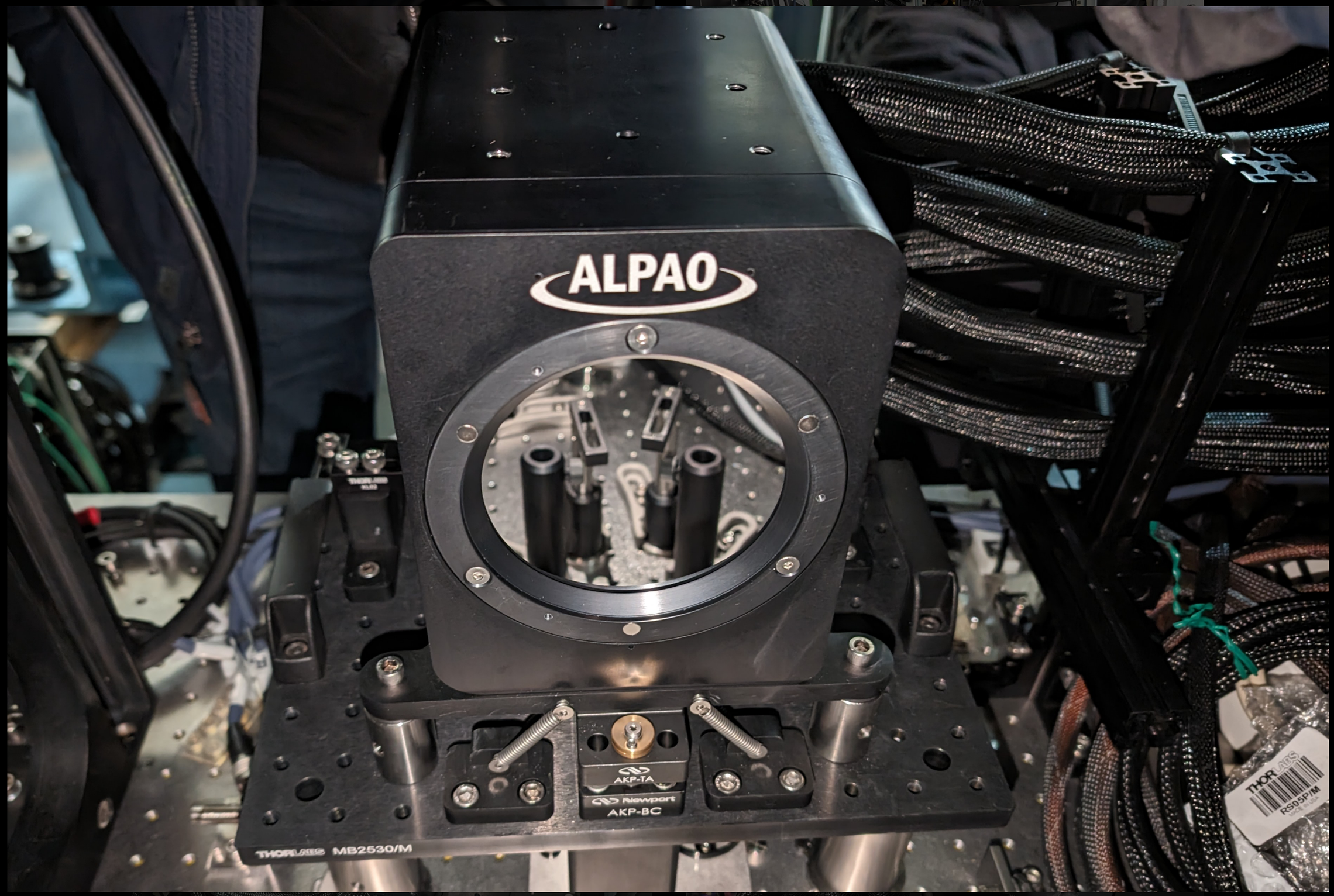




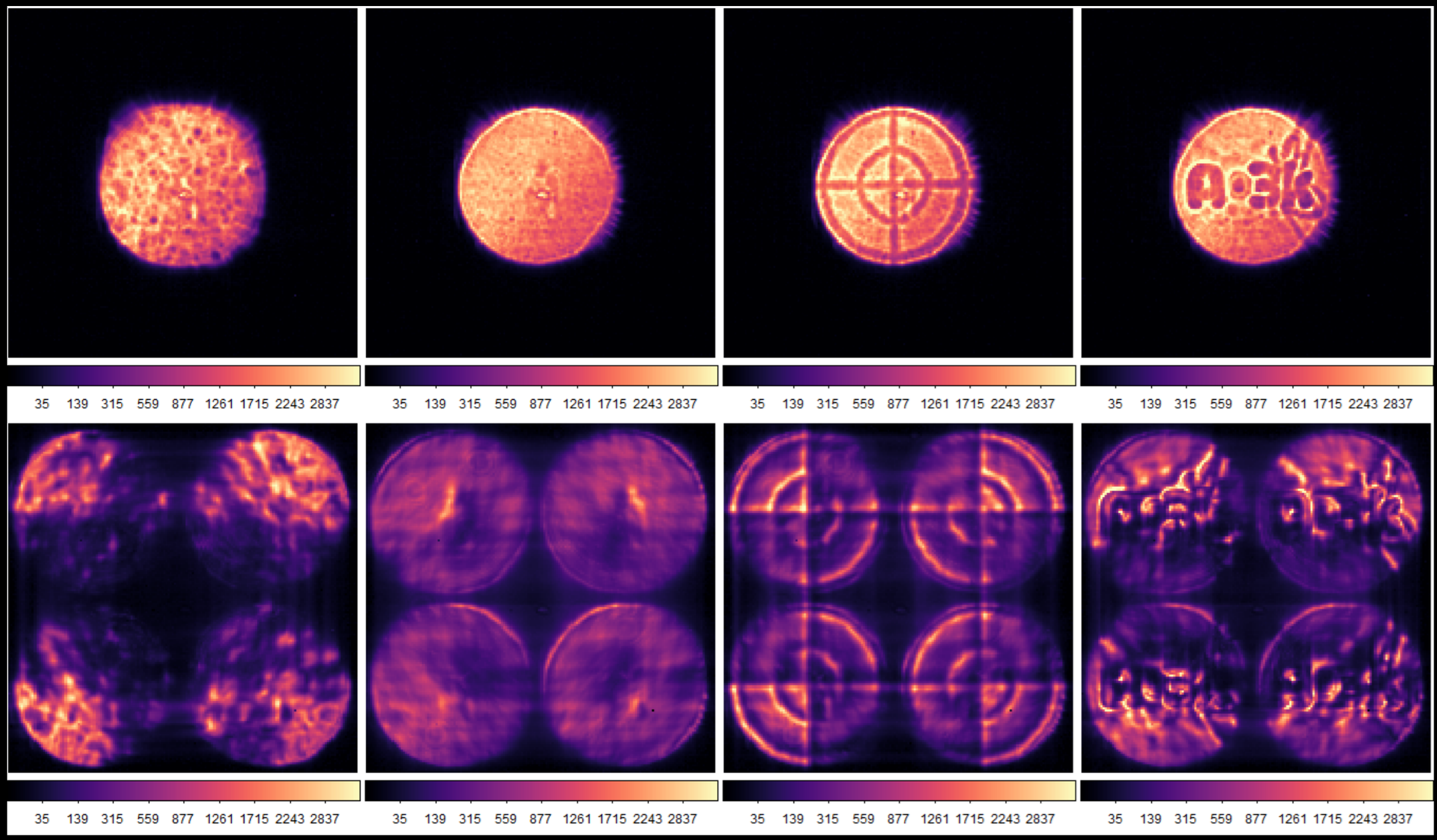





THORLABS
TRP90/M


ALPAO
THORLABS MB2530/M
AKP-TA
Newport
AKP-BC
THORLABS
RS05P/M

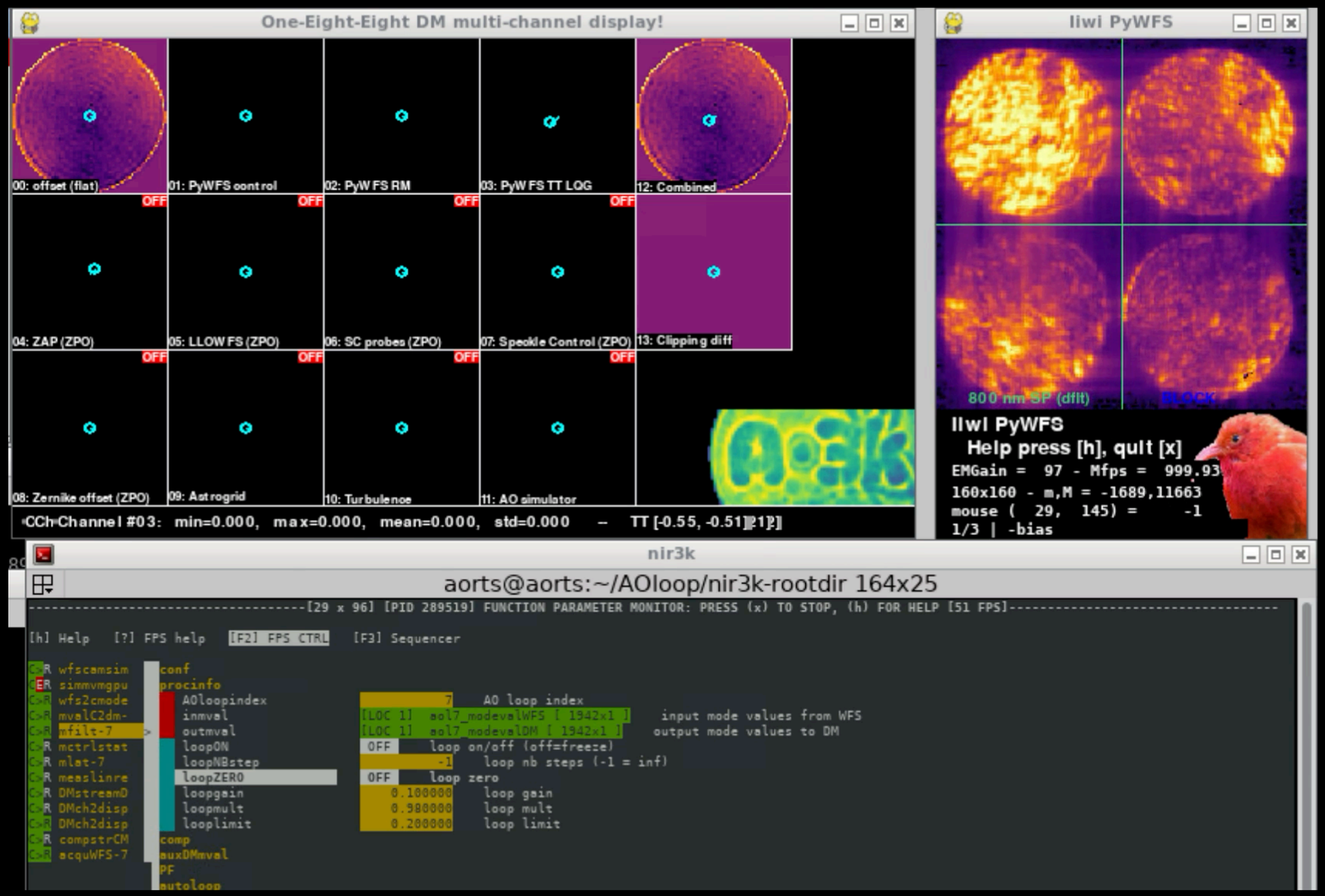
Step 4: Summit Installation



From Left to Right: Quasi-pupil plane (Top) and NIR WFS (Bottom) images of: Rest shape, Best flat from lab, Flat+Bullseye, Flat+logo.

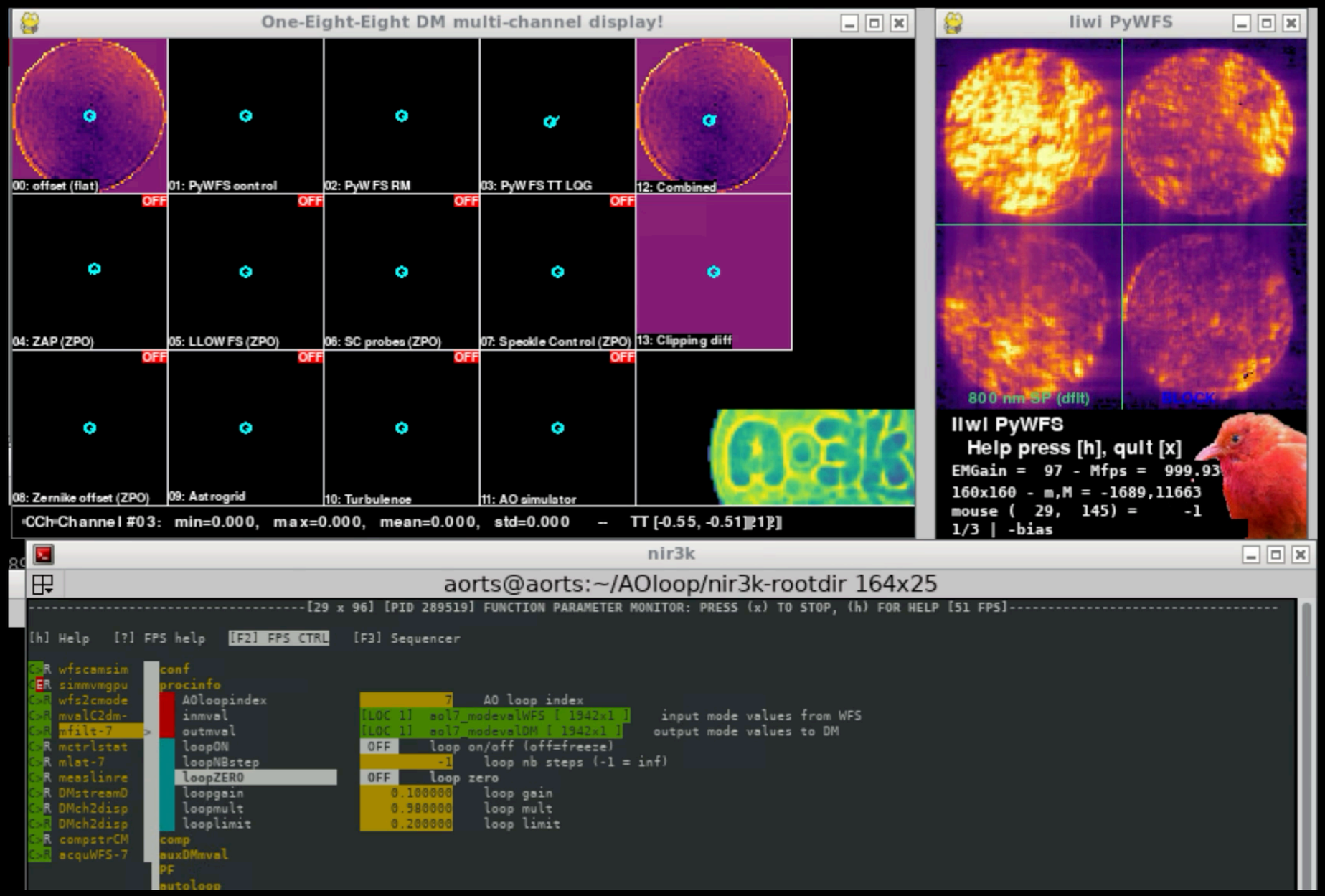
Subaru/AO3K

Step 5: Closing the AO loop II



Subaru/AO3K

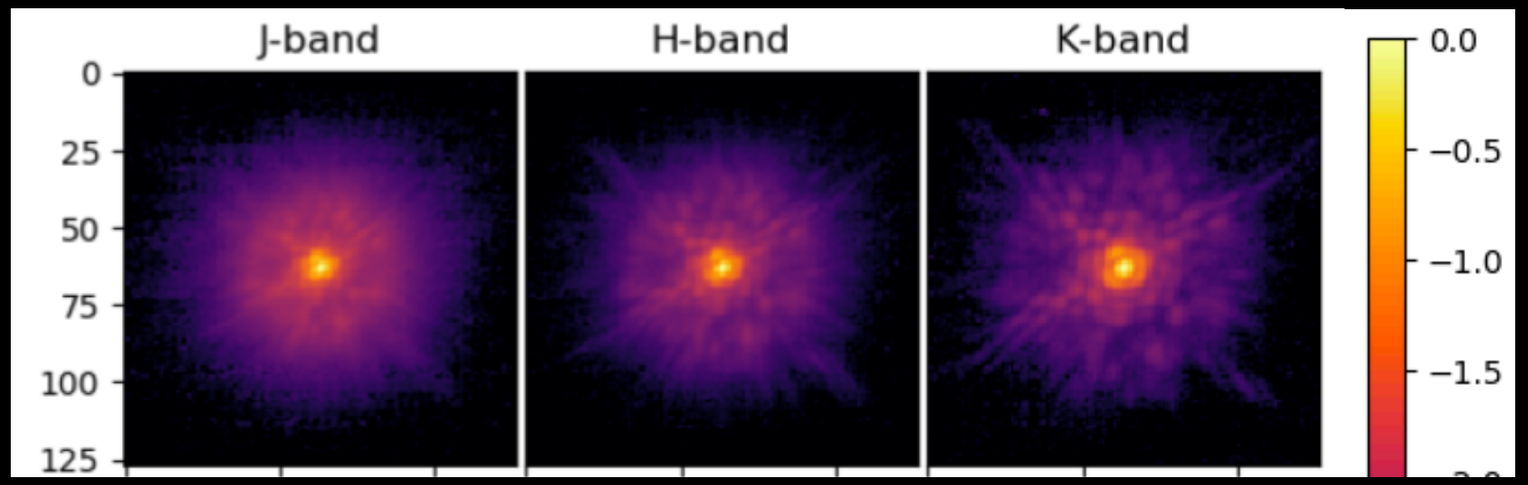
Step 5: Closing the AO loop II



Subaru/AO3K

Step 5: Closing the AO loop II

X Boo
H-mag: 8.30

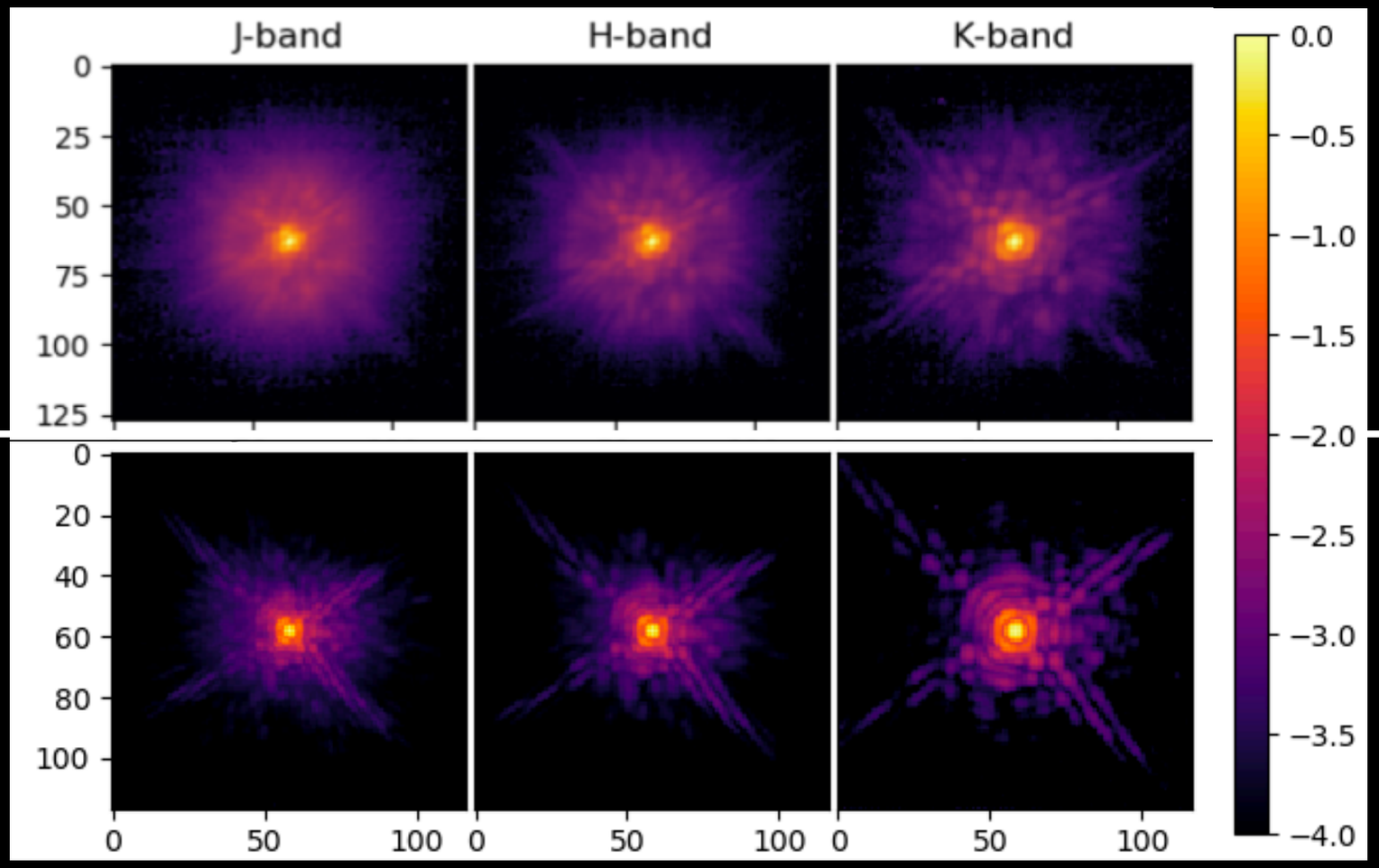


J: ~45%
H: ~65%
K: ~75%

Strehl

Step 5: Closing the AO loop II

X Boo
H-mag: 8.30



Strehl

J: ~45%
H: ~65%
K: ~75%

HD 172449
H-mag: 8.18

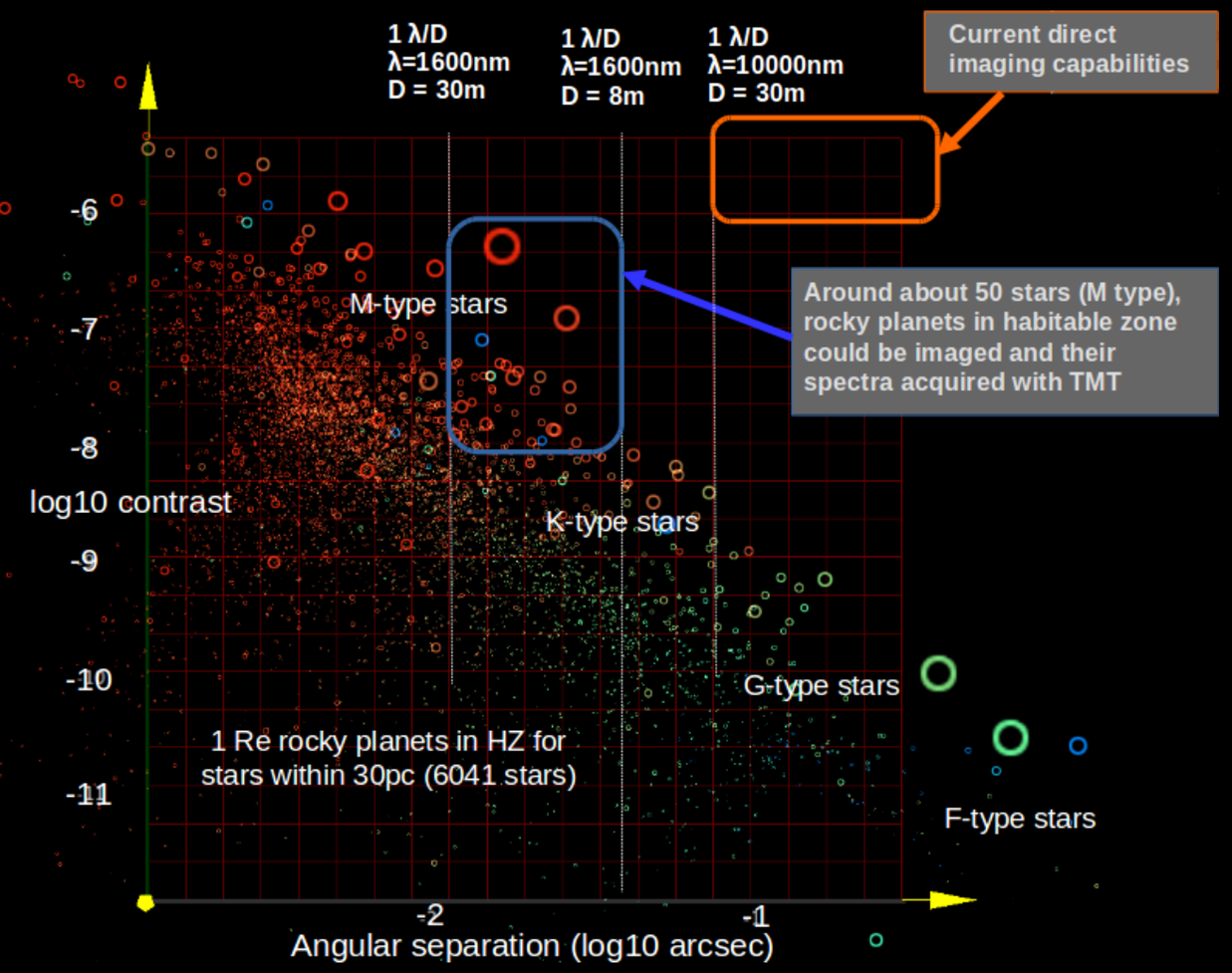
J: ~75%
H: ~85%
K: ~90%

Julien Lozi/Subaru

Concluding Notes

(Major) Goal of the Upgrades — Better Exoplanet Science

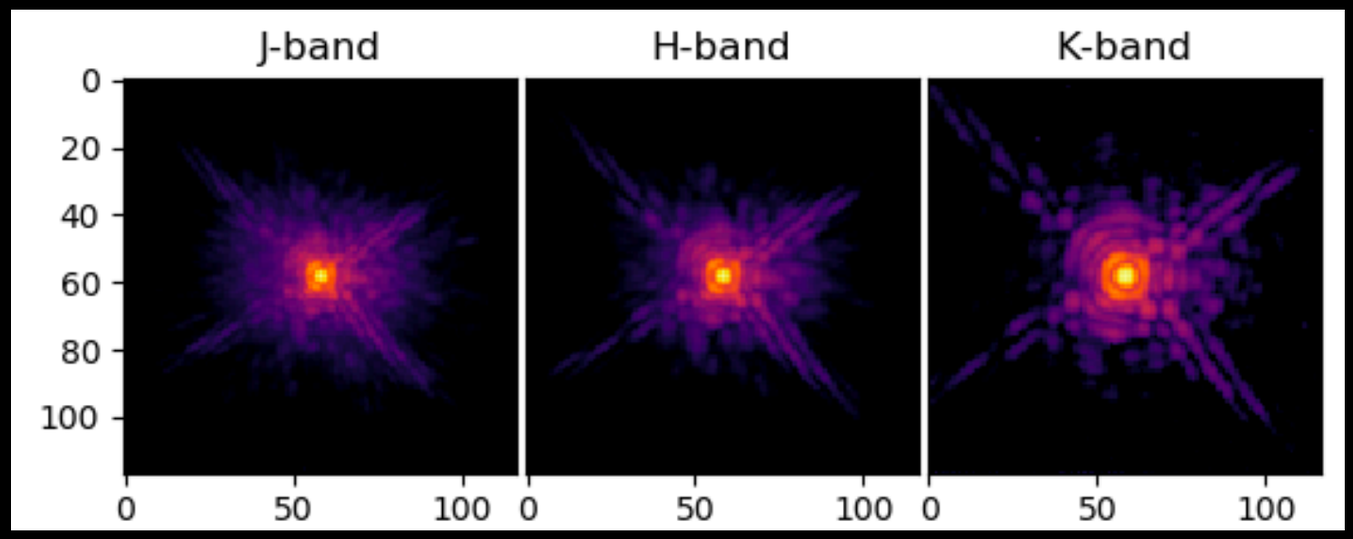
We will be able to access a less explored regime of planets in direct imaging— exoplanets that have lower contrasts than those detectable by JWST, and improve atmosphere characterization of exoplanets with more resolved spectral lines and identifying more tenuous molecular species

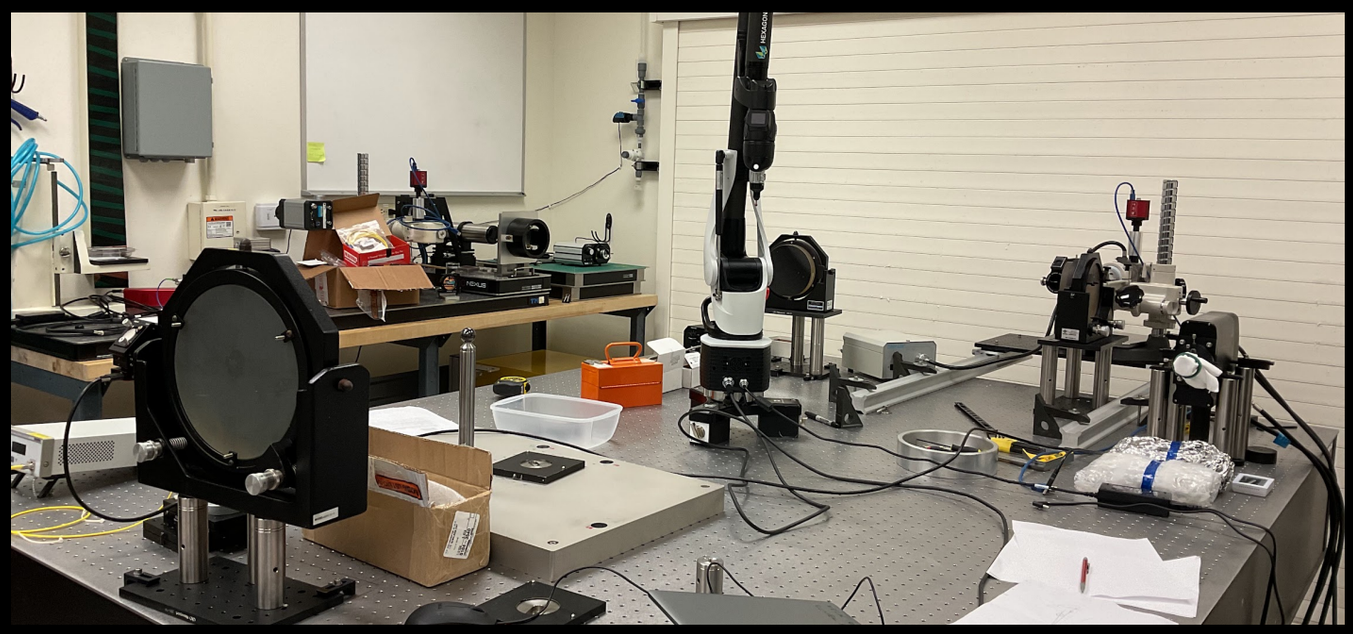


Where are we with the upgrades now?

Subaru— the new DM is on sky, and the engineering nights have reported much high Strehl

Keck— lab set up in progress





The Future…

These upgrades provide a technology demonstration for improvements in wavefront control and short wavelength AO for future extremely large telescopes.

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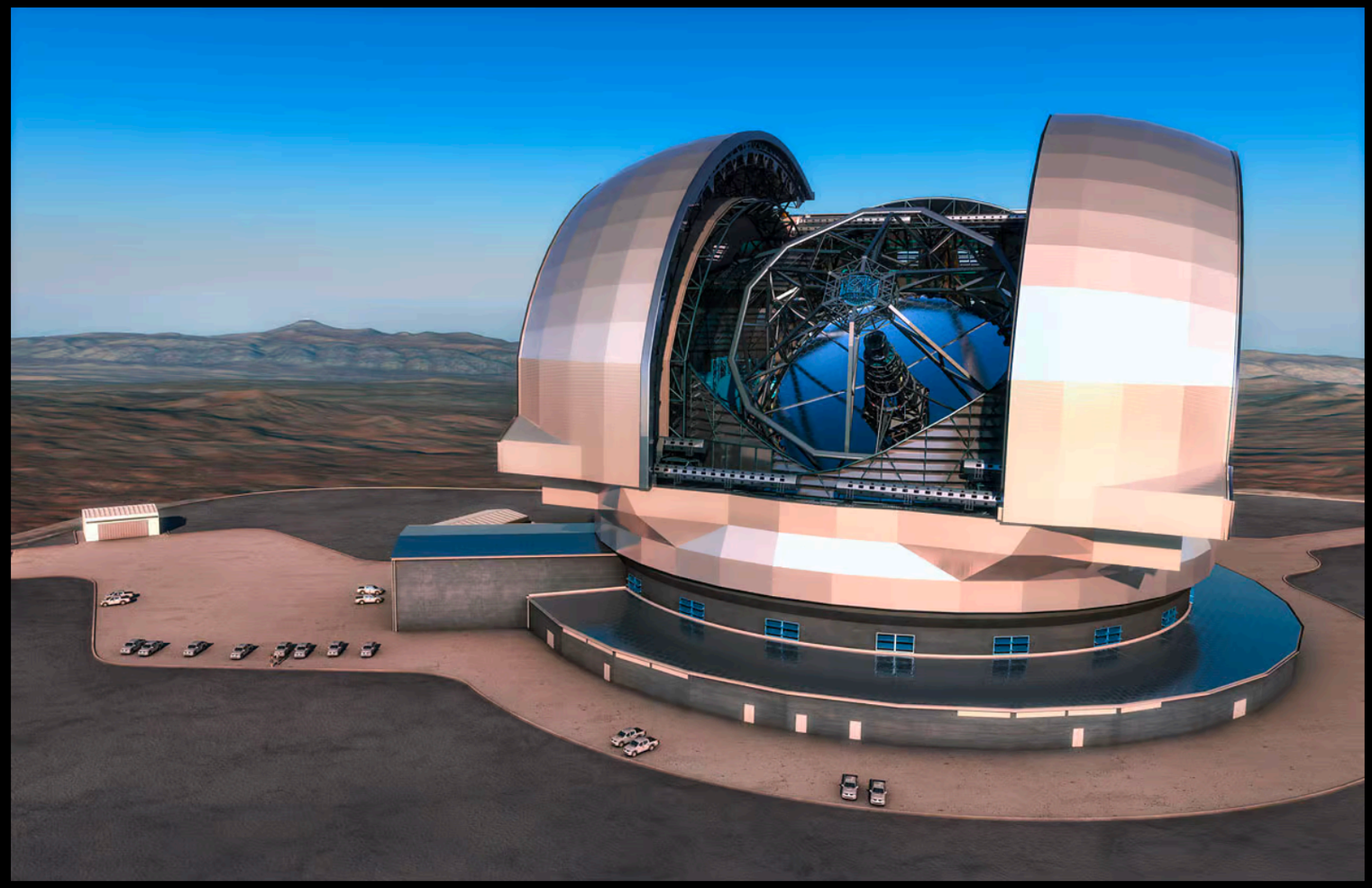

ESO