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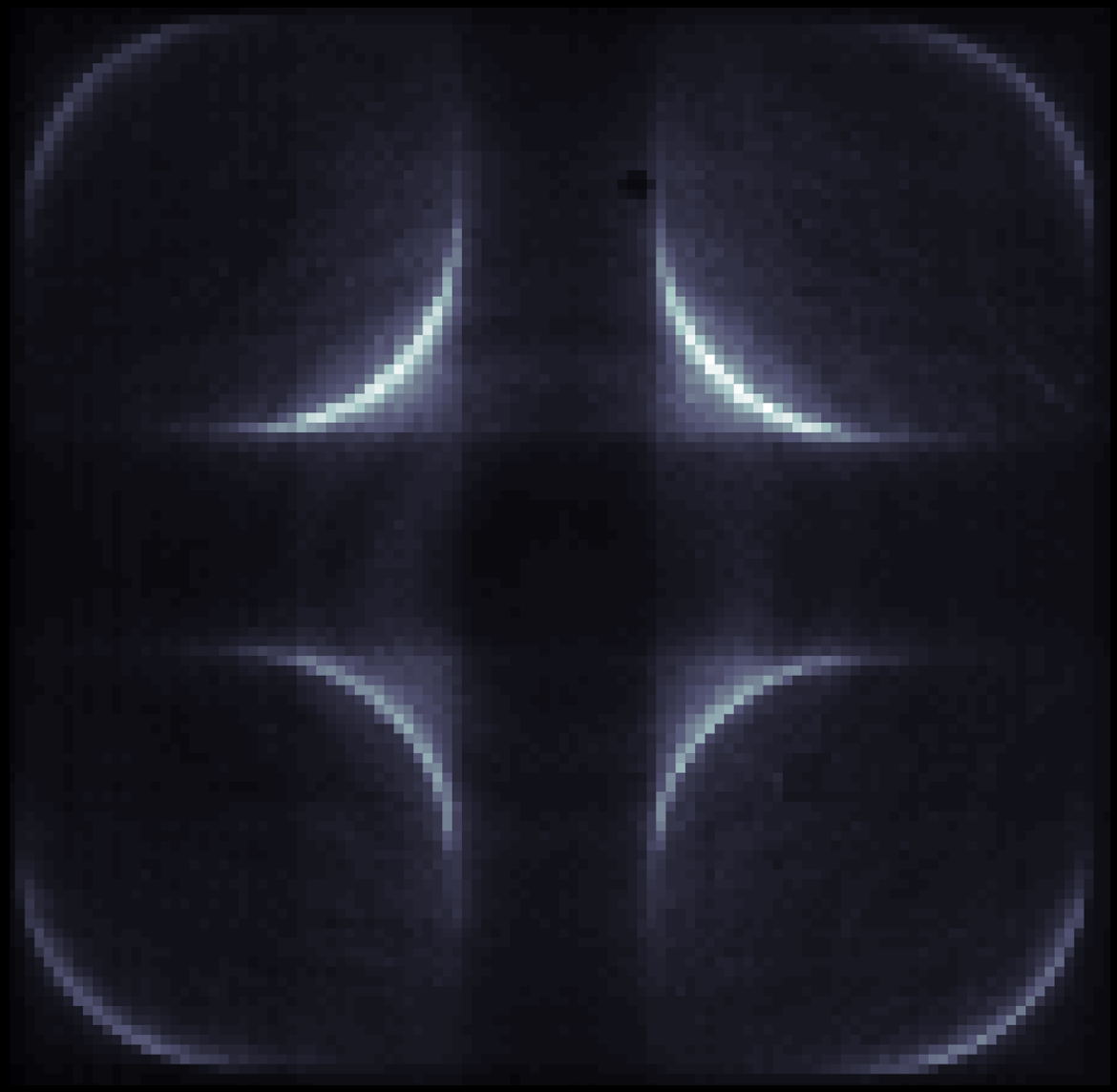
ADAPTIVE OPTICS WITH AN INFRARED PYRAMID WFS

10TH JANUARY 2019
LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE

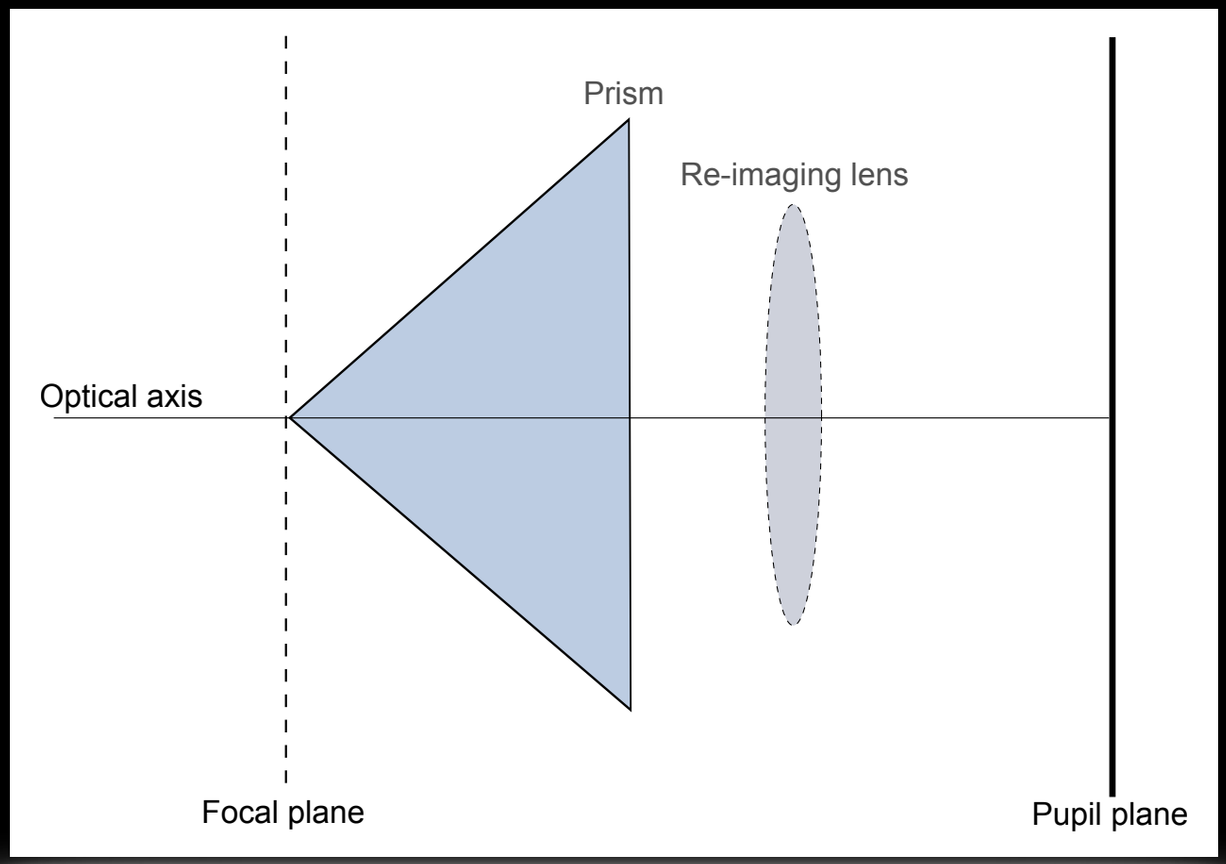
OVERVIEW

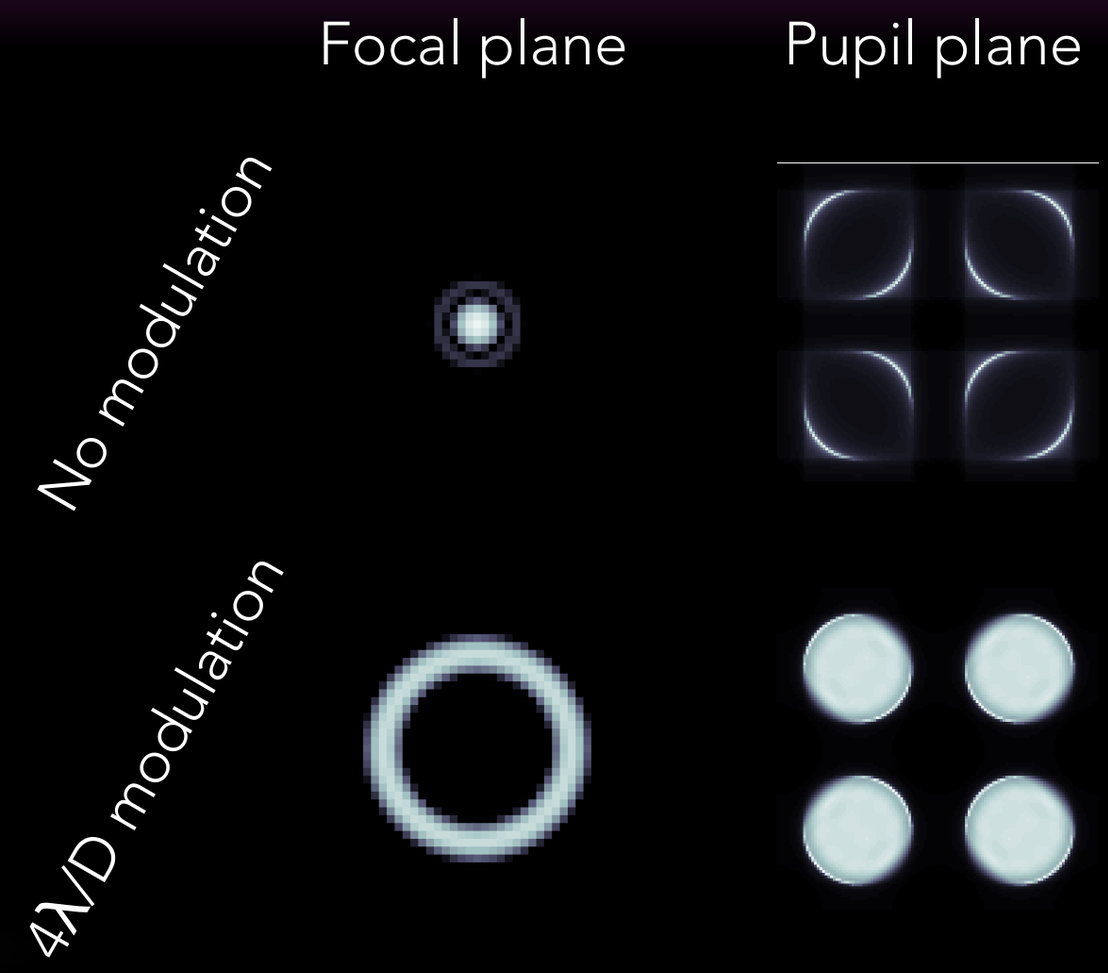
- Pyramid wavefront sensing
- KPIC: Keck Planet Imager and Characterizer
- Design, testing and installation on Keck II AO
- First on-sky results
- Next steps

PYRAMID WAVEFRONT SENSING



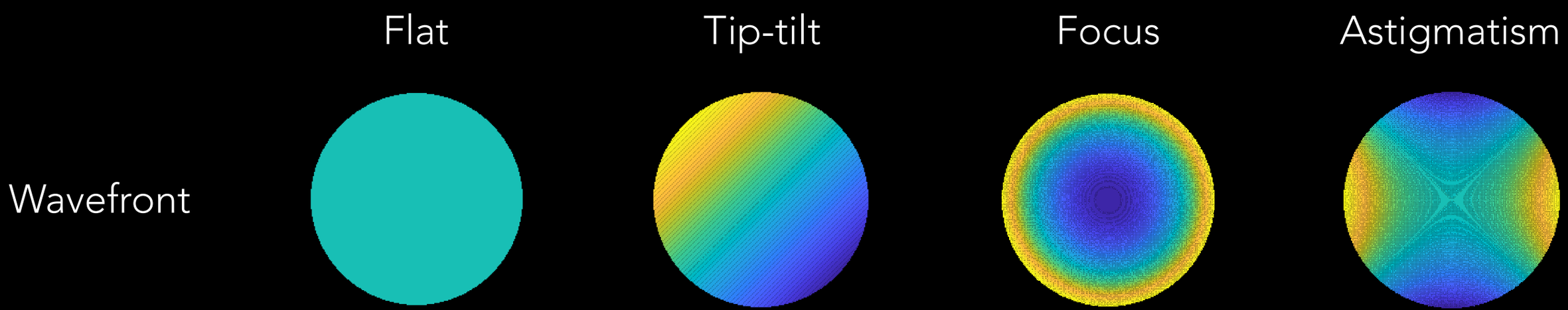
THE PYRAMID WFS





- Light from the telescope is focused onto the tip of a four-sided prism.
- **Four images of the pupil** are re-imaged onto a detector.

PYRAMID SIGNALS

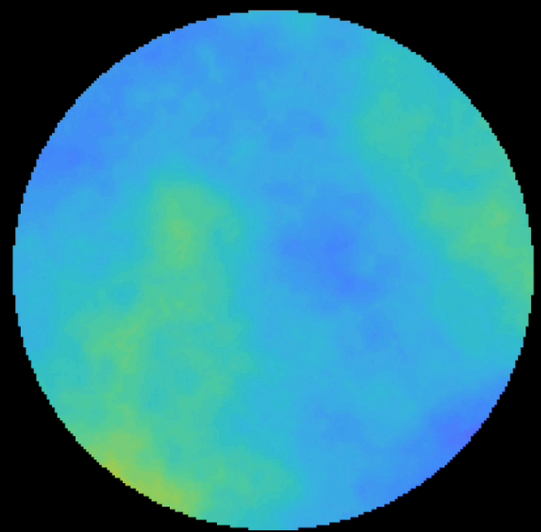


PYRAMID WFS IN CLOSED LOOP

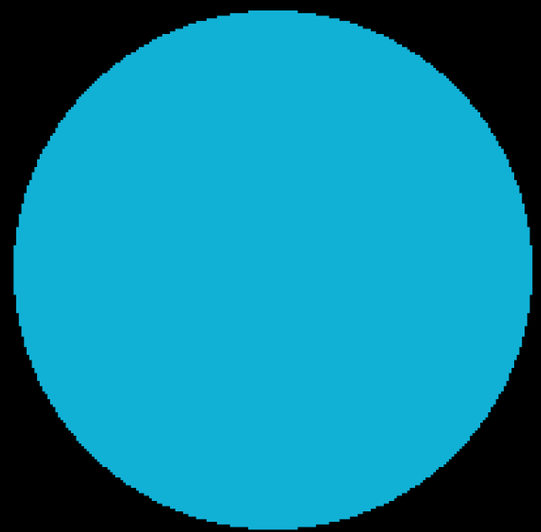
Closed loop simulation:

- AO correction: 32x32 DM
- Wavefront sensing: 40x40 Pyramid WFS
- Loop speed: 500Hz
- Mean wind speed: 17.1 m/s
- Seeing: 0.6 arcseconds

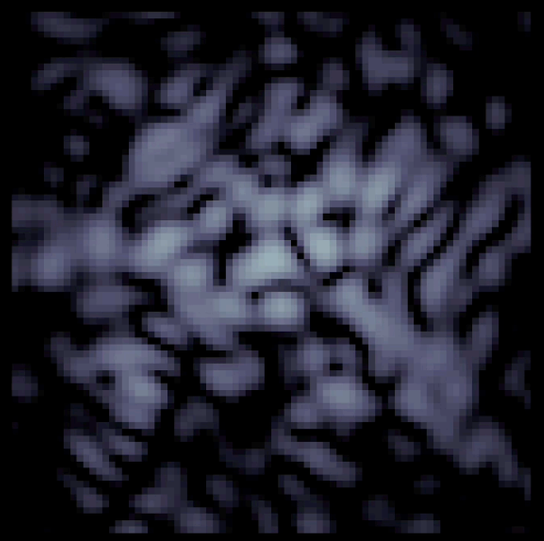
Residual wavefront



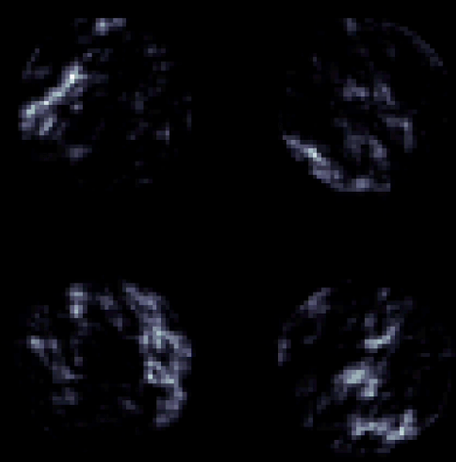
AO correction



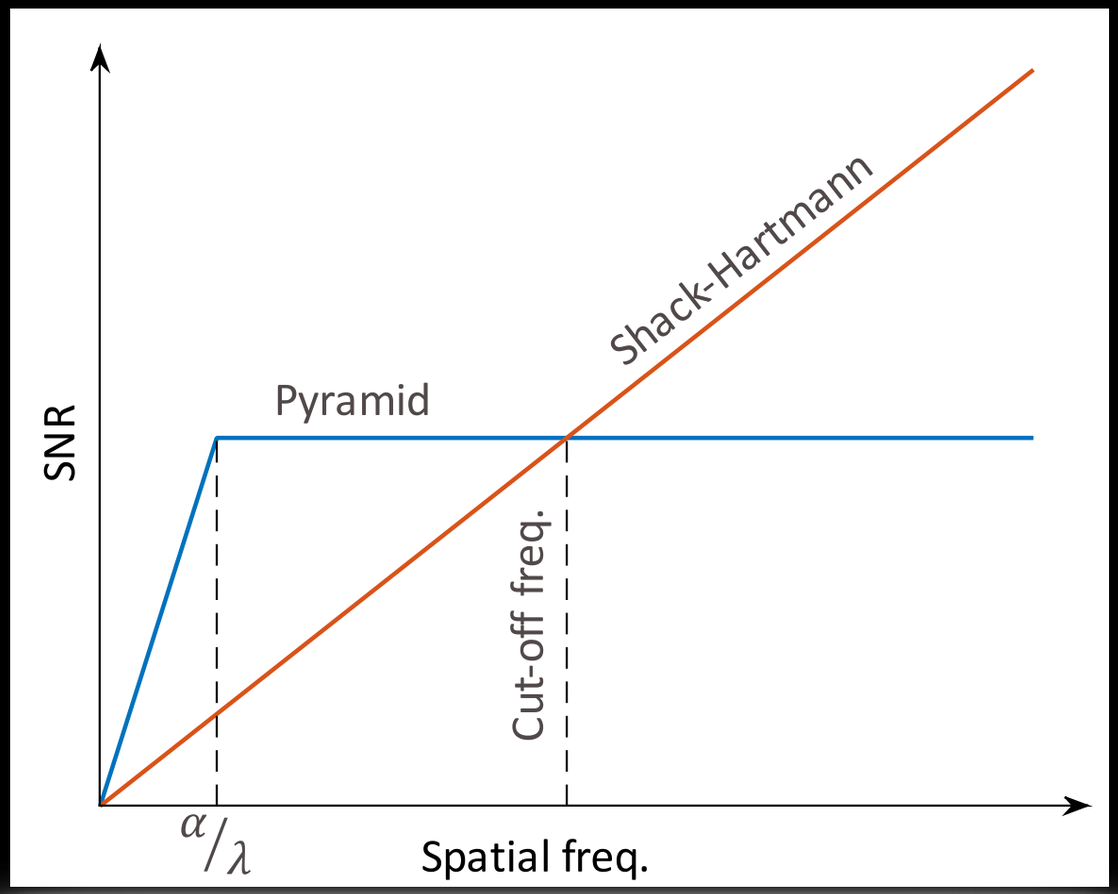
H-band PSF



Pyramid signals (H-band)

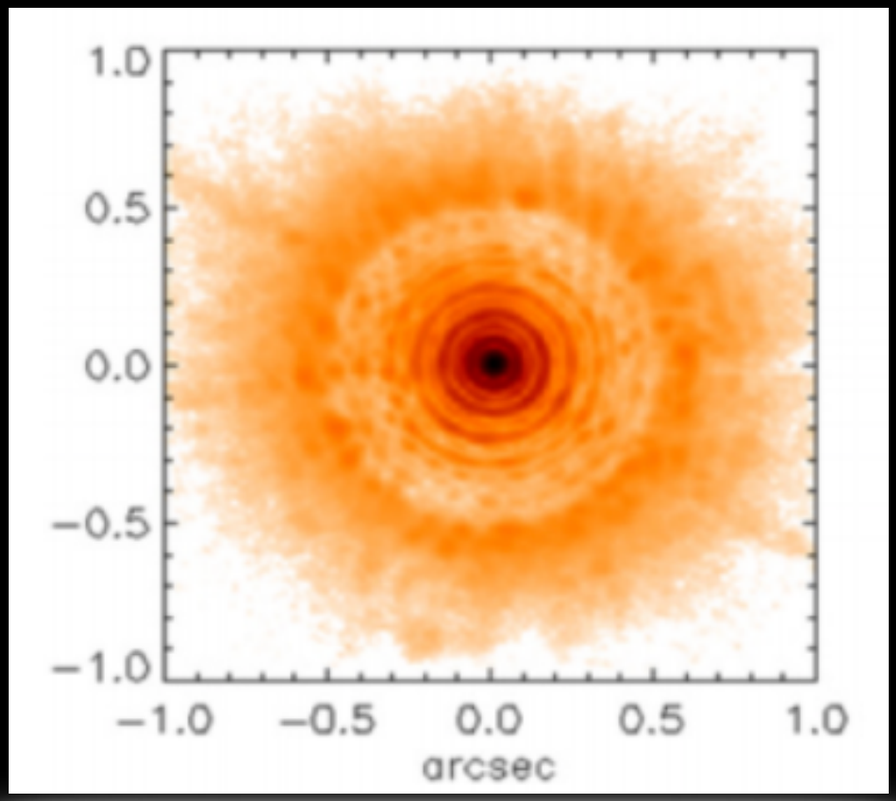


WHY PYRAMIDS?



C. Vérinaud, "On the nature of the measurements provided by a Pyramid wave-front sensor", Optics Comms., 2004.

- Increased sensitivity within the correction band.
- Reduced susceptibility to aliasing.

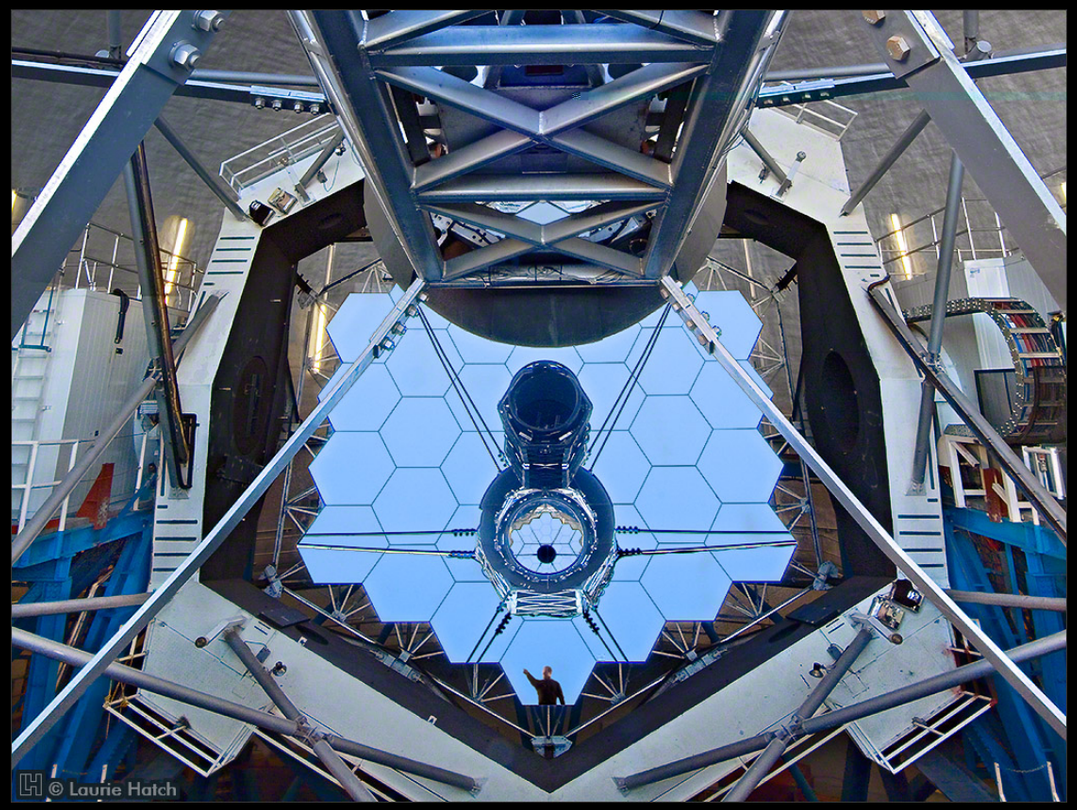


S. Eposito et al., "The LBT AO system on-sky results", AO4ELTII 2011.

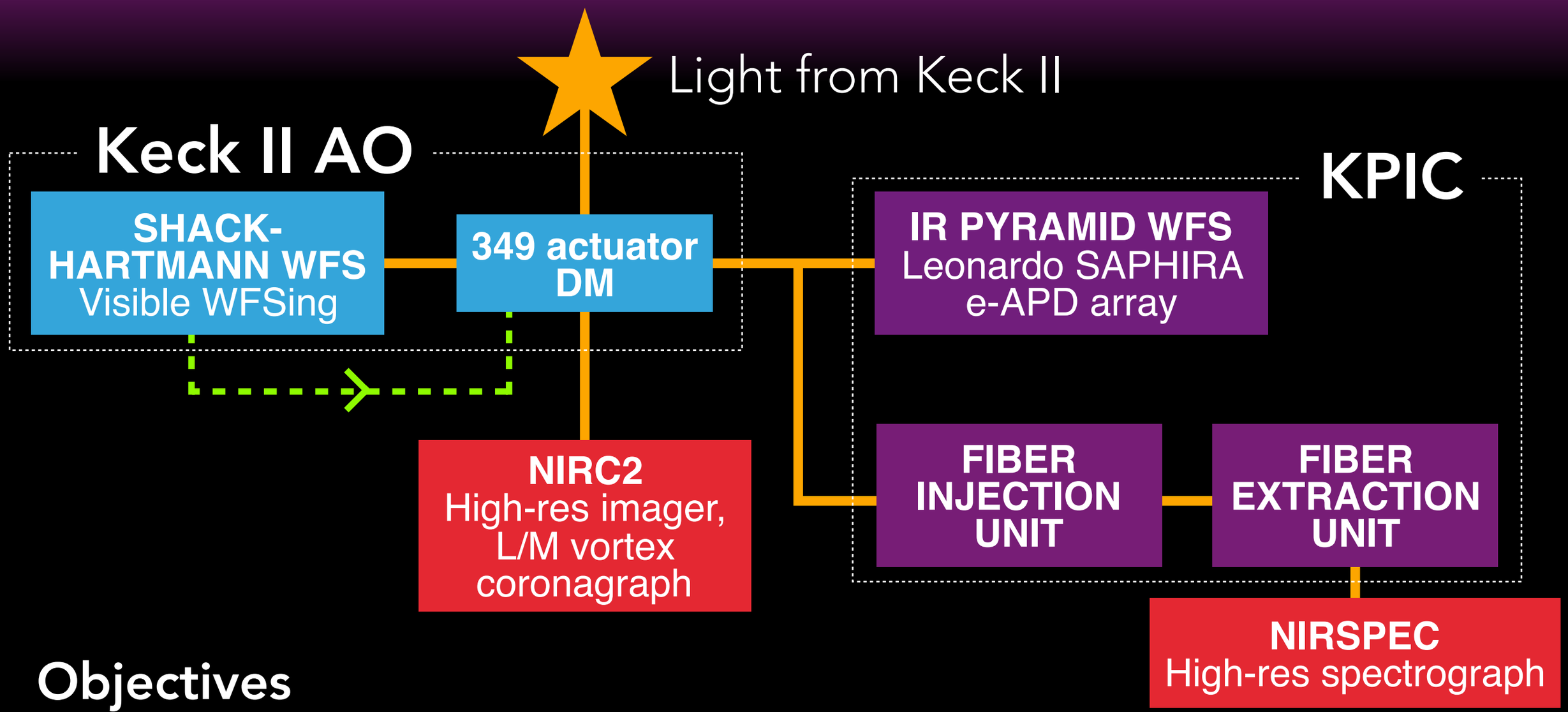
- Interest for future systems:

  First light ELT instruments, SPHERE upgrades, MAGAOX etc.

AN IR PYRAMID WFS FOR KECK



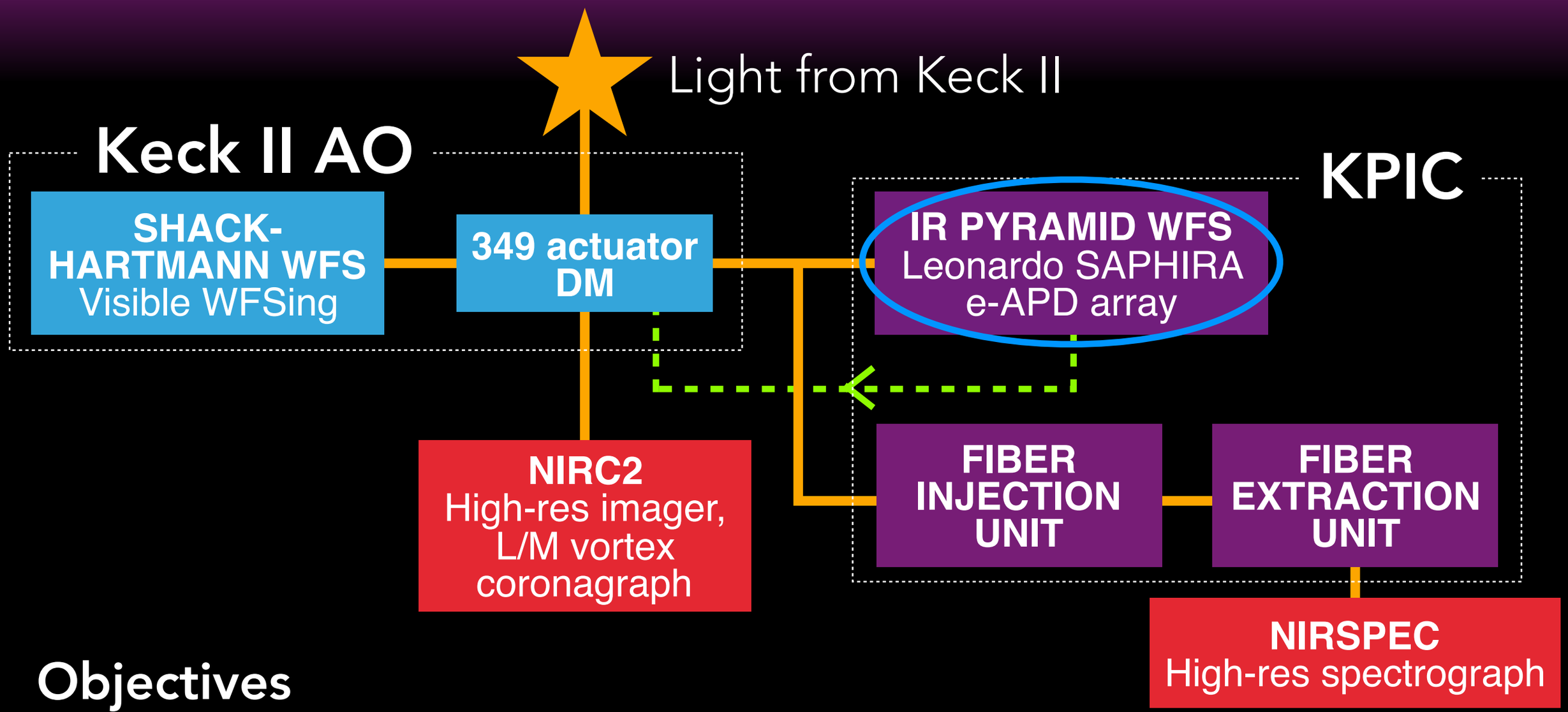
KECK PLANET IMAGER AND CHARACTERIZER



Objectives

- High resolution AO correction for the study of M-dwarf systems and young planets around proto-planetary discs.
- High contrast imaging and high resolution spectroscopy.

KECK PLANET IMAGER AND CHARACTERIZER



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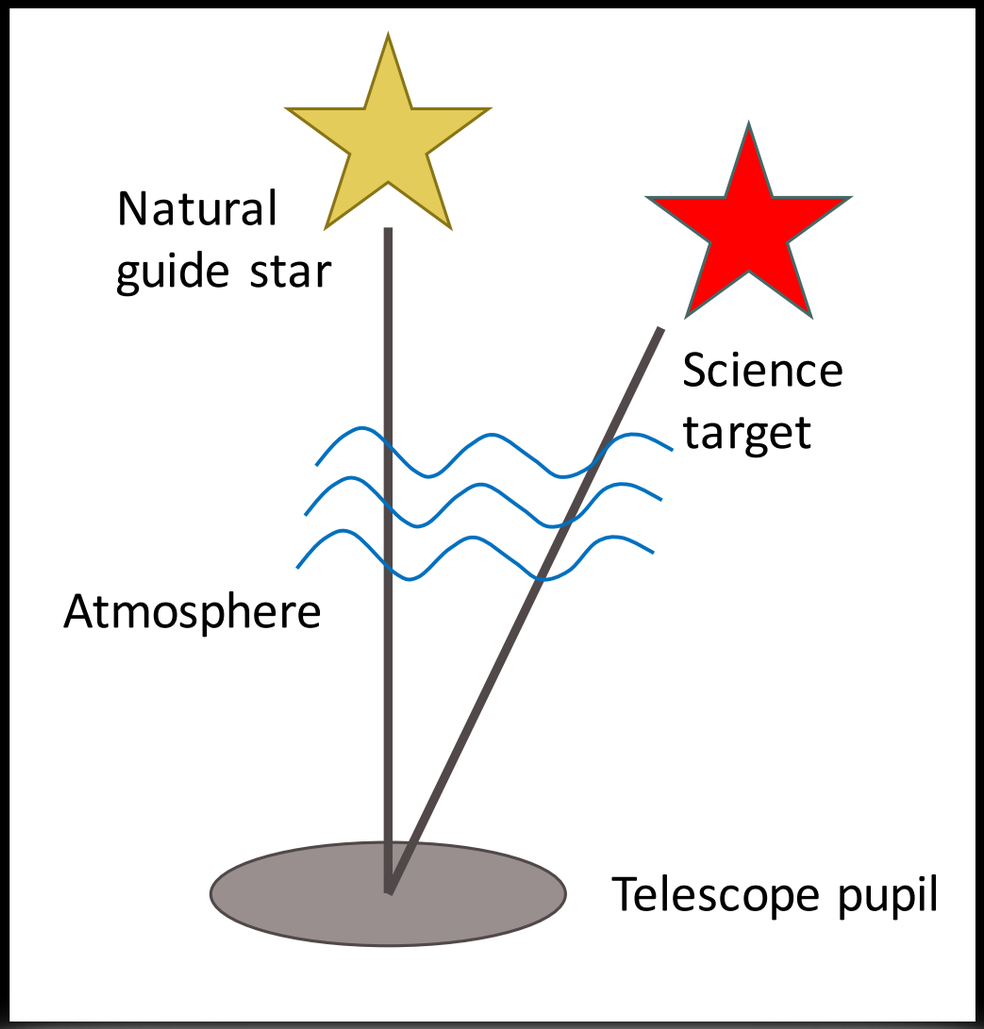
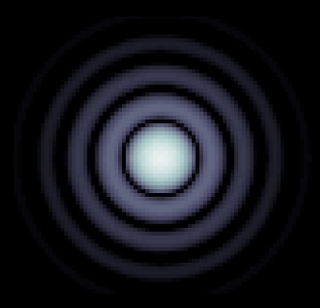
INFRARED WAVEFRONT SENSING

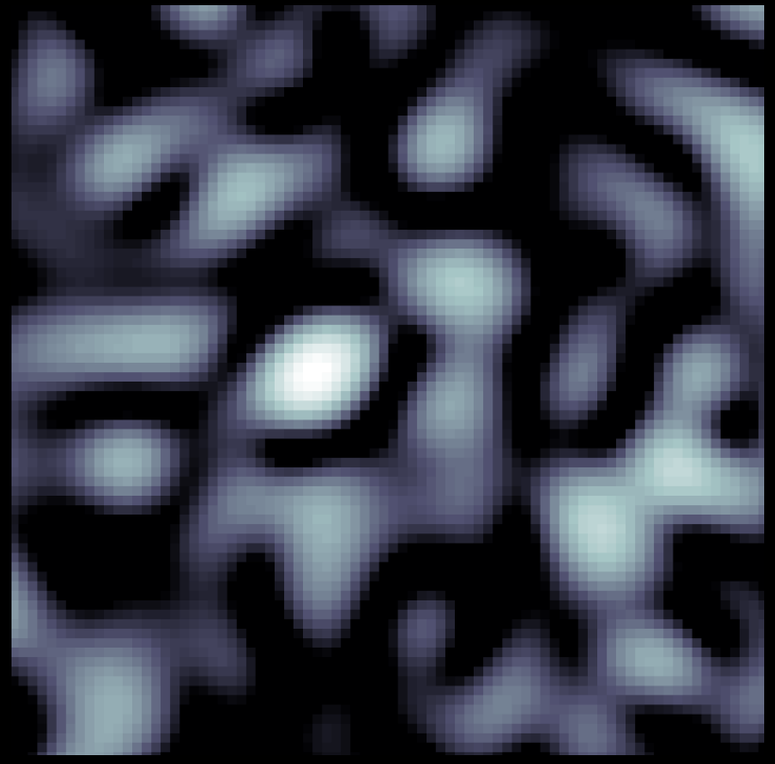


- High resolution correction for red objects of interest (i.e. M-dwarf systems).

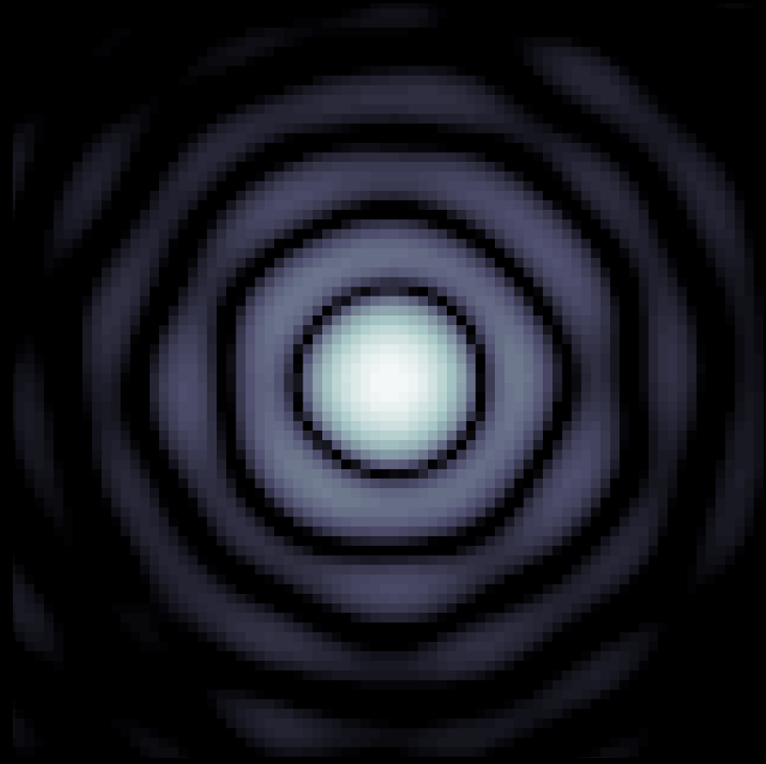
INFRARED PYRAMIDS



- Theoretical sensitivity corresponds to diffraction limited PSF.
- Any distortion of the PSF reduces the sensitivity.

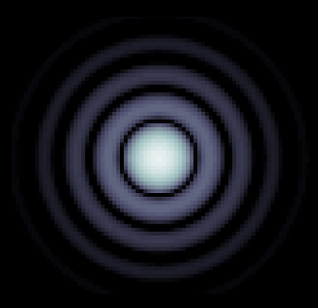


PSF on Pyramid with V-band WFSing



PSF on Pyramid with H-band WFSing

INFRARED PYRAMIDS



- Theoretical sensitivity corresponds to diffraction limited PSF.
- Any distortion of the PSF reduces the sensitivity.

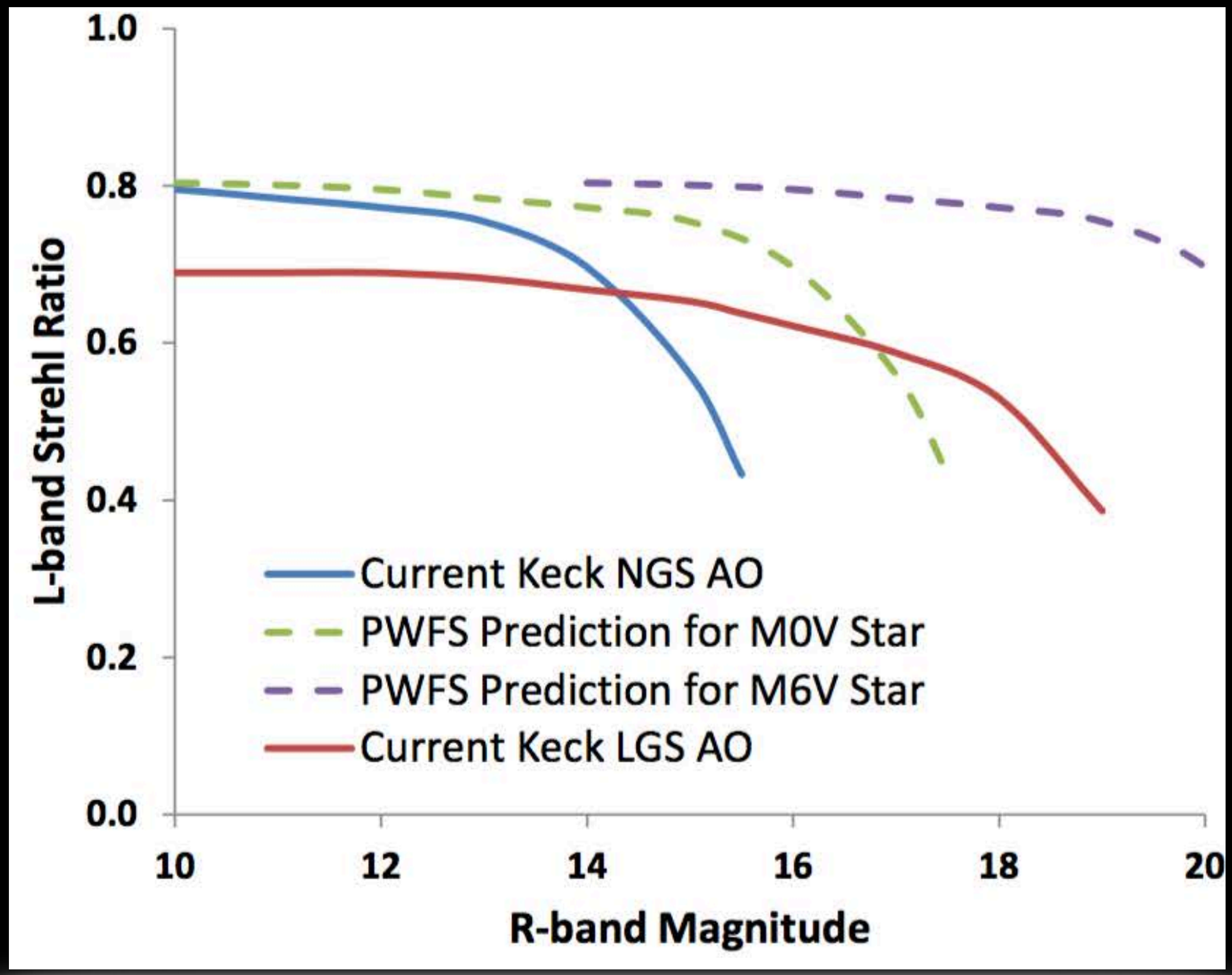
PSF on Pyramid with V-band WFSing

PSF on Pyramid with H-band WFSing

TRADE OFF BETWEEN SENSITIVITY AND RANGE

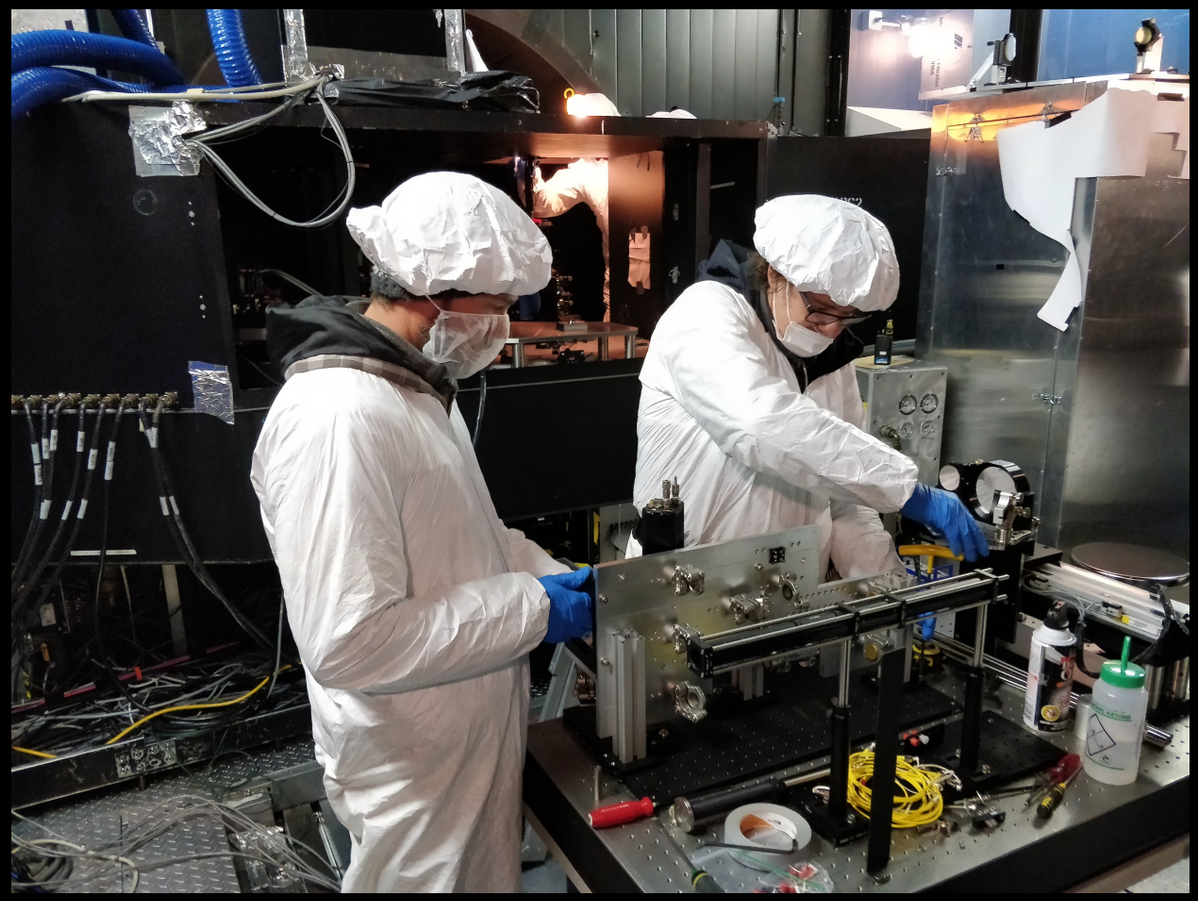
EXPECTED PERFORMANCE

- The Pyramid WFS increases the limiting magnitude.
- Potential to probe previously inaccessible stars (colder, redder).

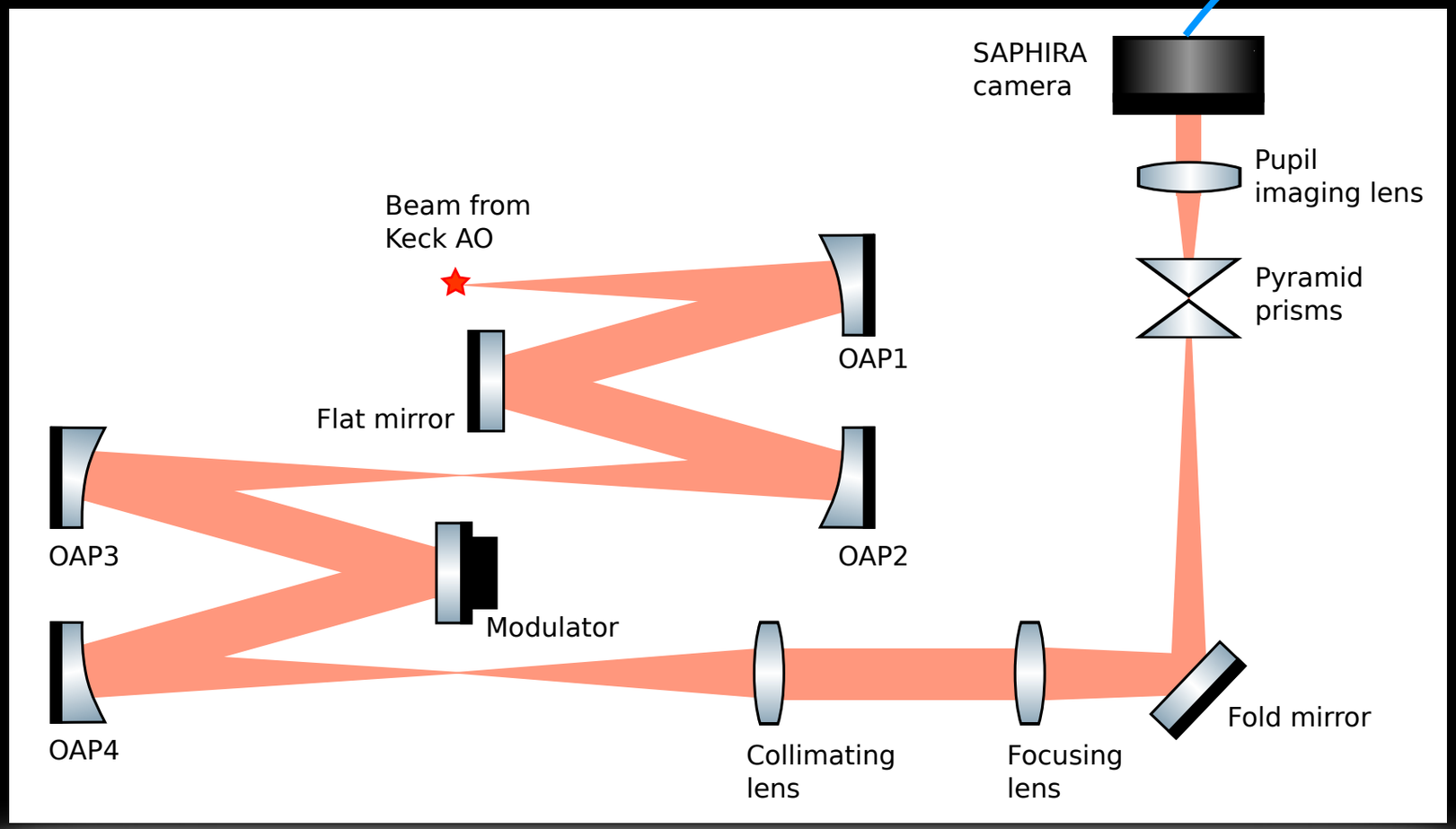


P. Wizinowich et al., "Near-Infrared Wavefront Sensing", SPIE 2016.

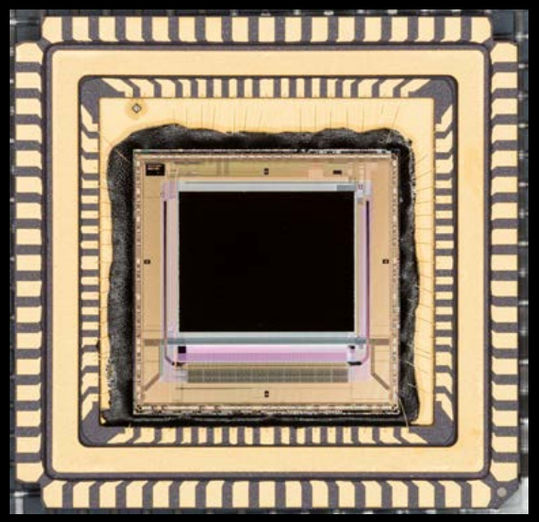
KPIC: DESIGN, INSTALLATION AND TESTING



OPTICAL DESIGN



S. Lilley et al., "A near-infrared pyramid wavefront sensor for Keck adaptive optics: onto-mechanical design", SPIE 2018, 10703-127.

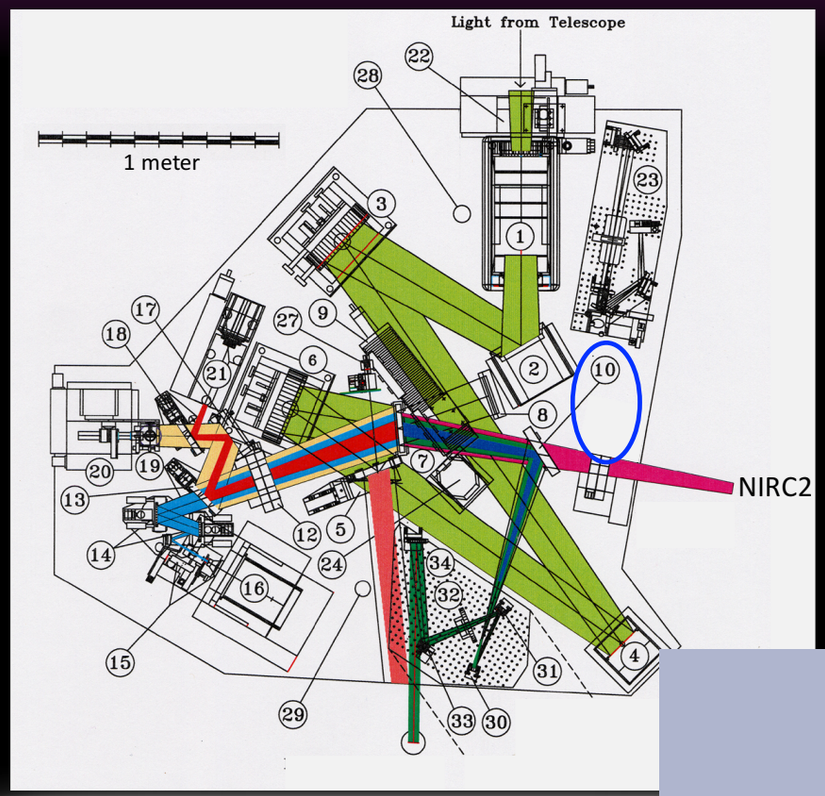


SAPHIRA APD array

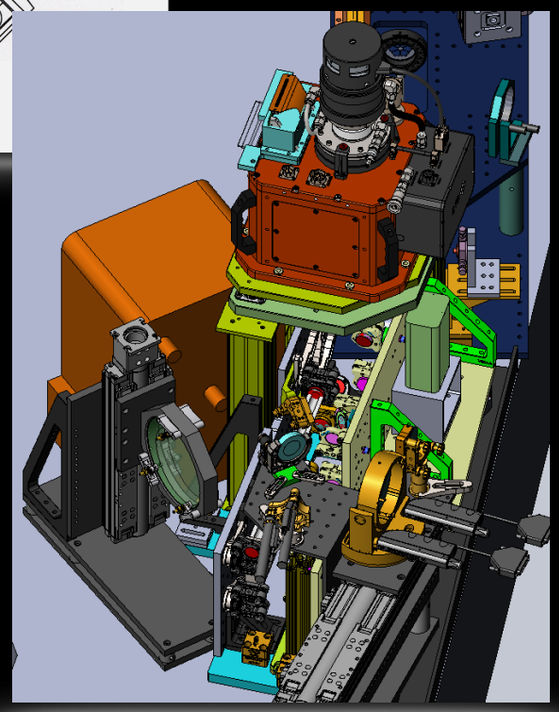
Key technology

- SAPHIRA: infrared avalanche photodiode array.
- Low noise: < $1e^-$
- High speed: 1.5kHz

MECHANICAL DESIGN



Keck AO bench

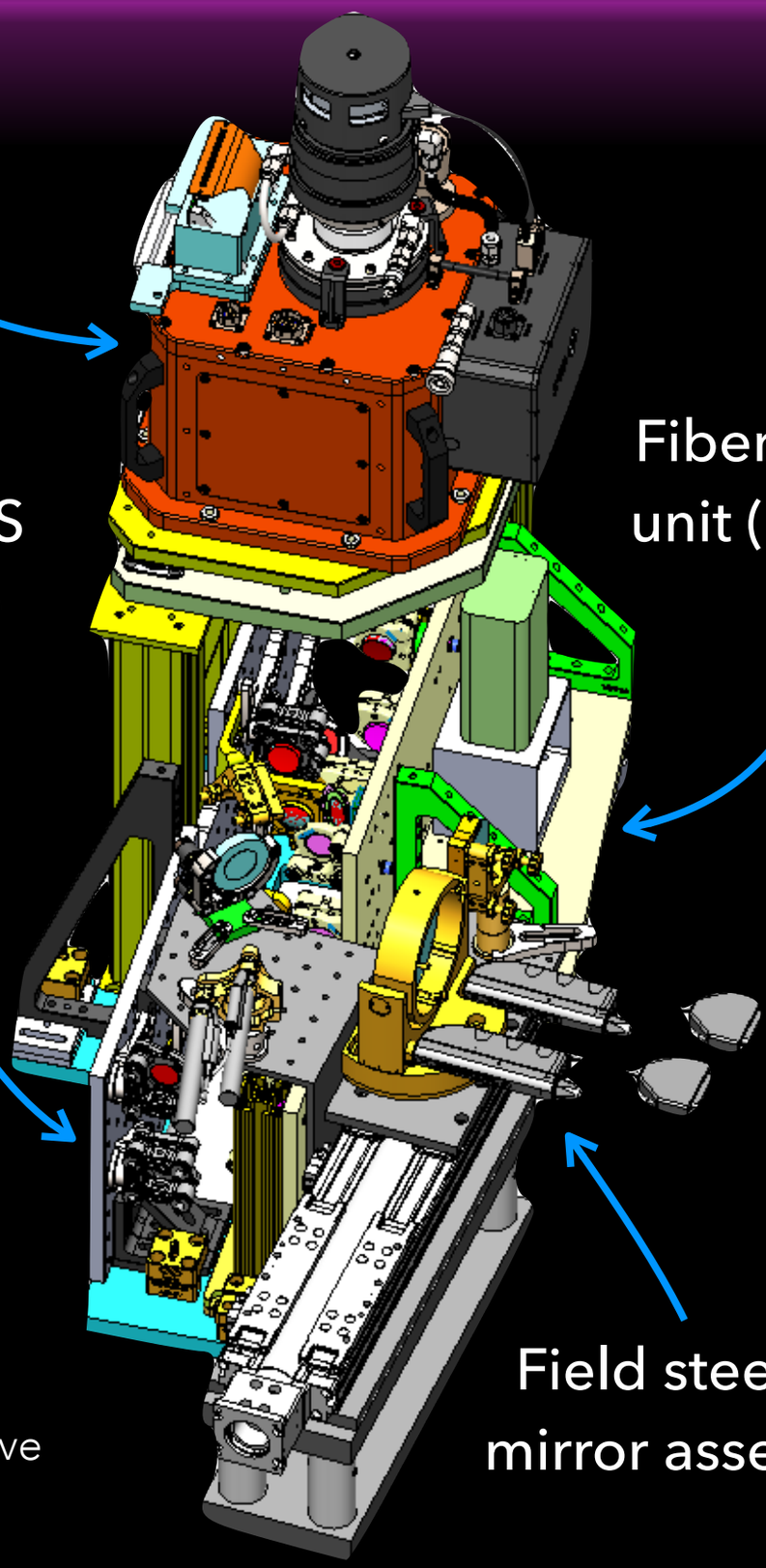


SAPHIRA camera

Pyramid WFS (PWS) plate

Fiber injection unit (FIU) plate

Field steering mirror assembly



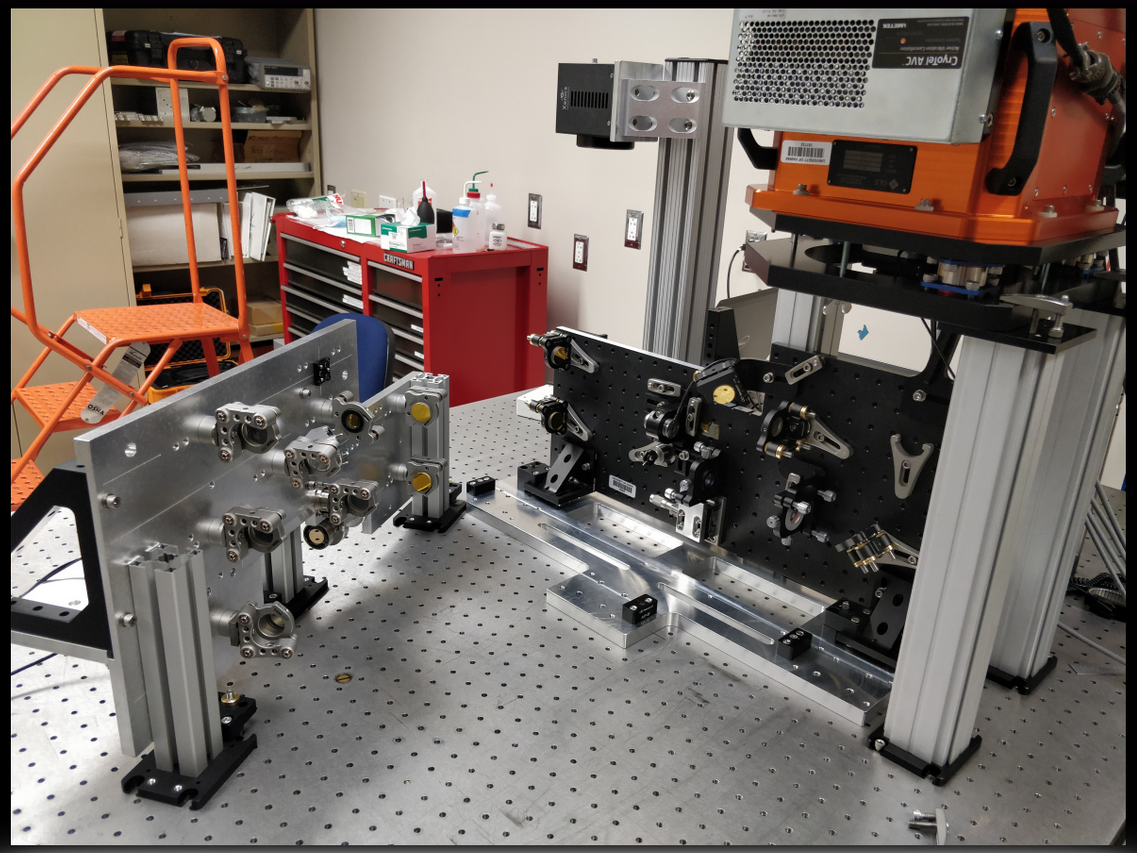
S. Lilley et al., "A near-infrared pyramid wavefront sensor for Keck adaptive optics: onto-mechanical design", SPIE 2018, 10703-127.

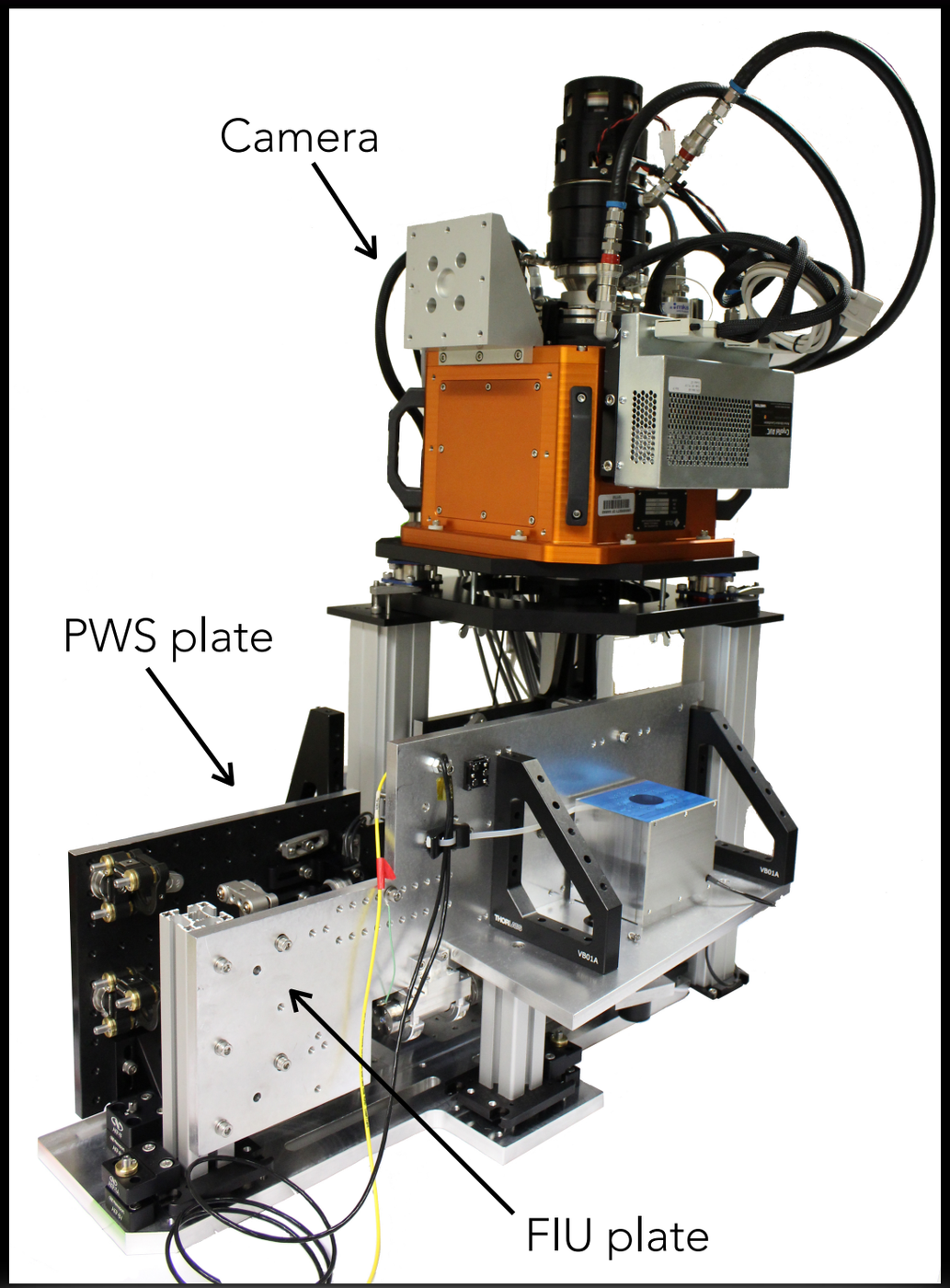
KPIC SUB-SYSTEMS

Fiber injection unit

Pyramid wavefront sensor

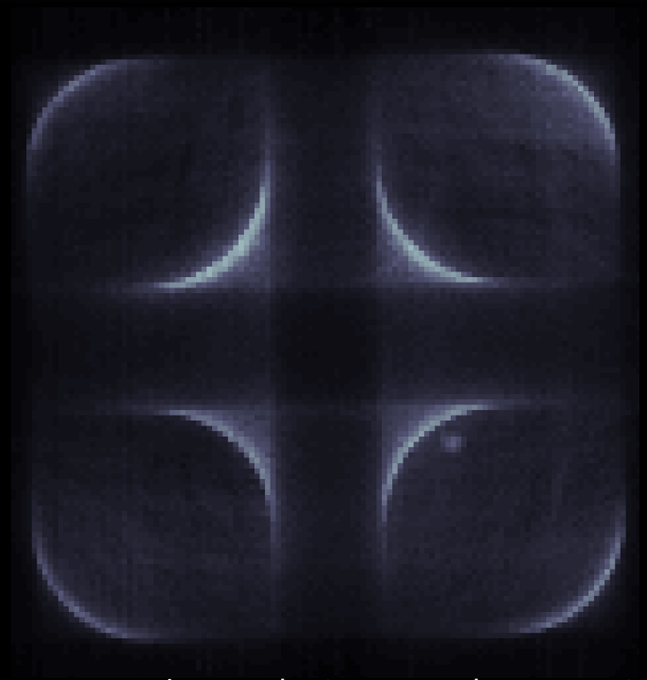
LAB ASSEMBLY





- PWS plate assembled at IfA Hilo.
- FIU plate assembled at Caltech.
- April 2018: two plates co-aligned in Hilo.

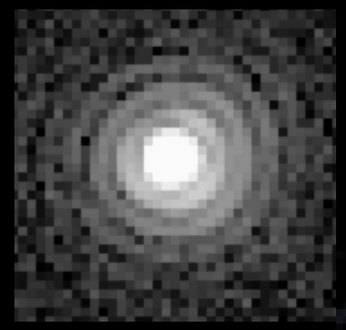
SYSTEM TESTS



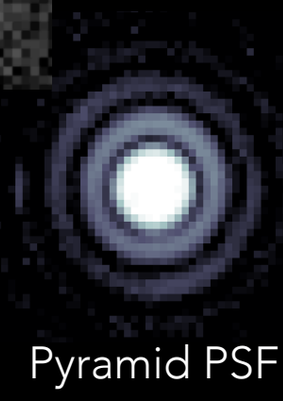
Pyramid pupils (internal source)

Good internal alignment:

- < 20nm rms wavefront error.
- Co-aligned with FIU.



FIU PSF



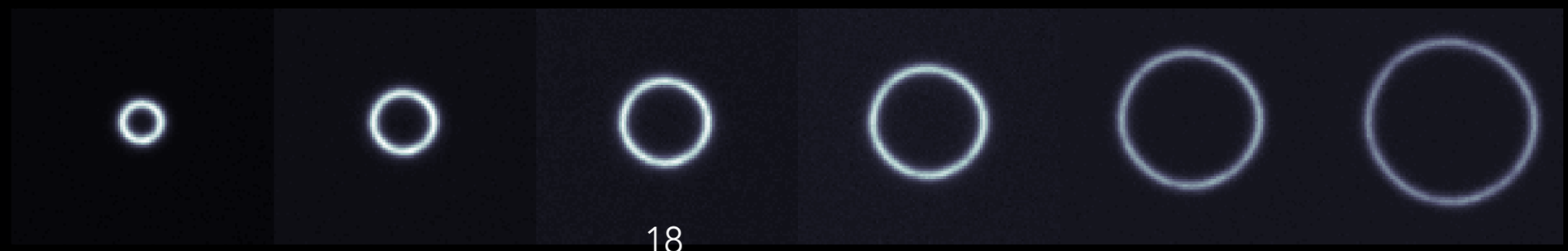
Pyramid PSF

Modulator:

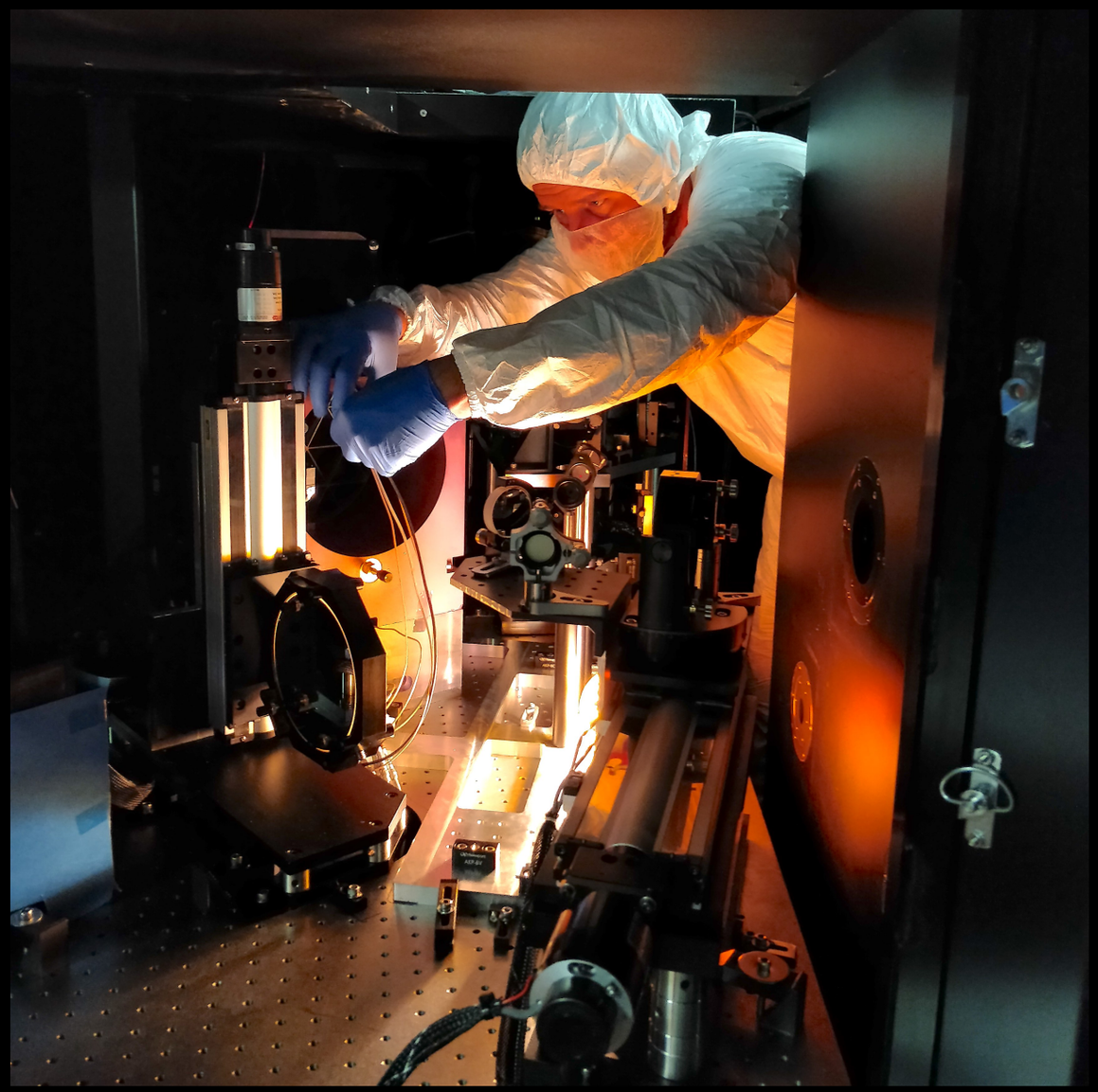
- Adjustment of internal alignment.
- Modulation up to 6λ/D, up to 1.5kHz.

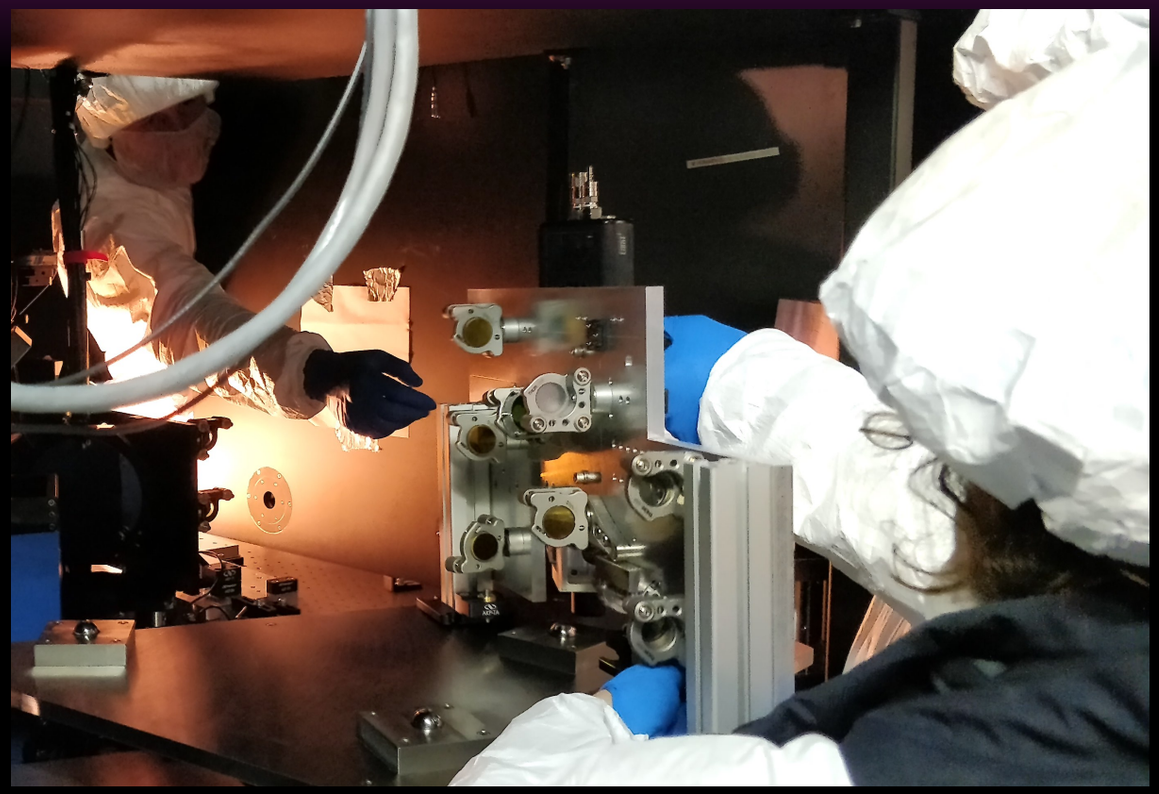
Detector characterization:

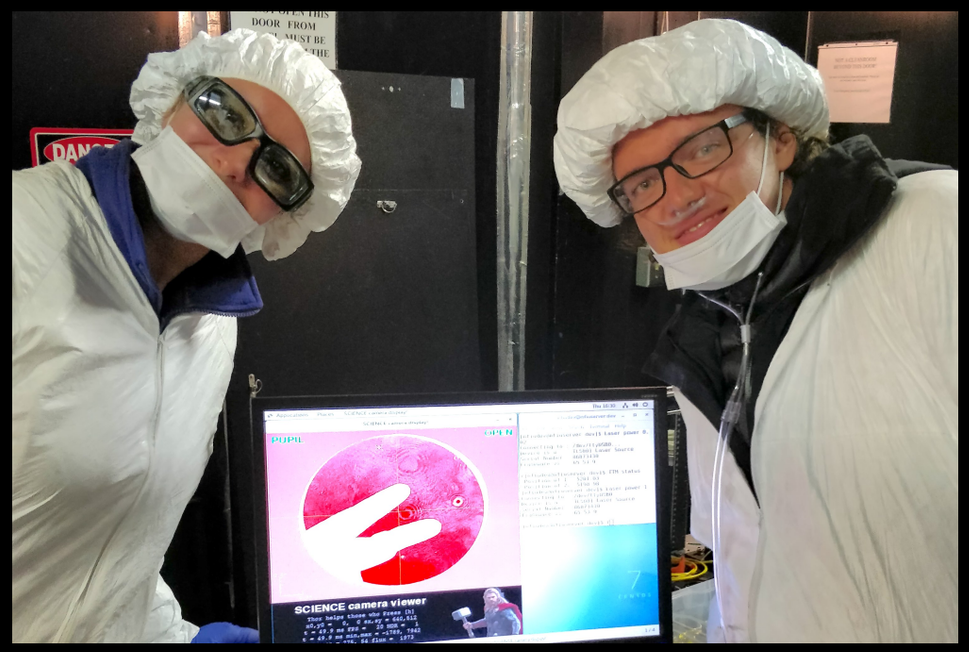
- Calibration.
- Noise measurements.



SEPTEMBER 2018: INSTALLATION ON KECK

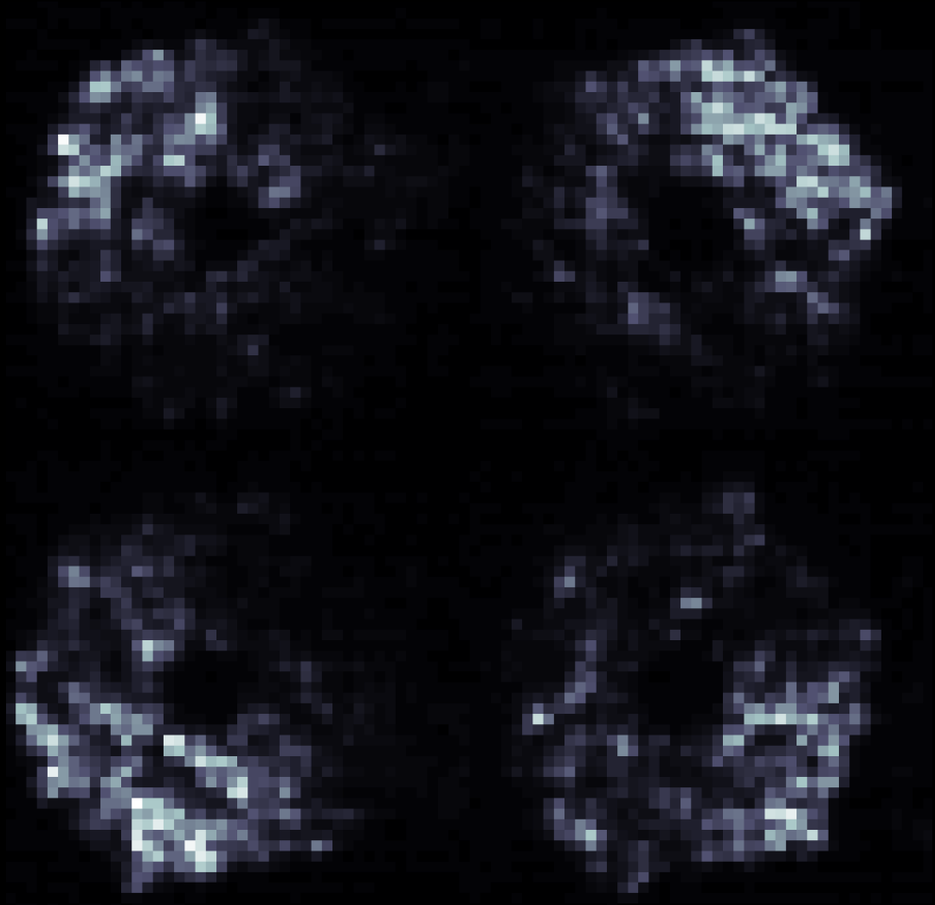






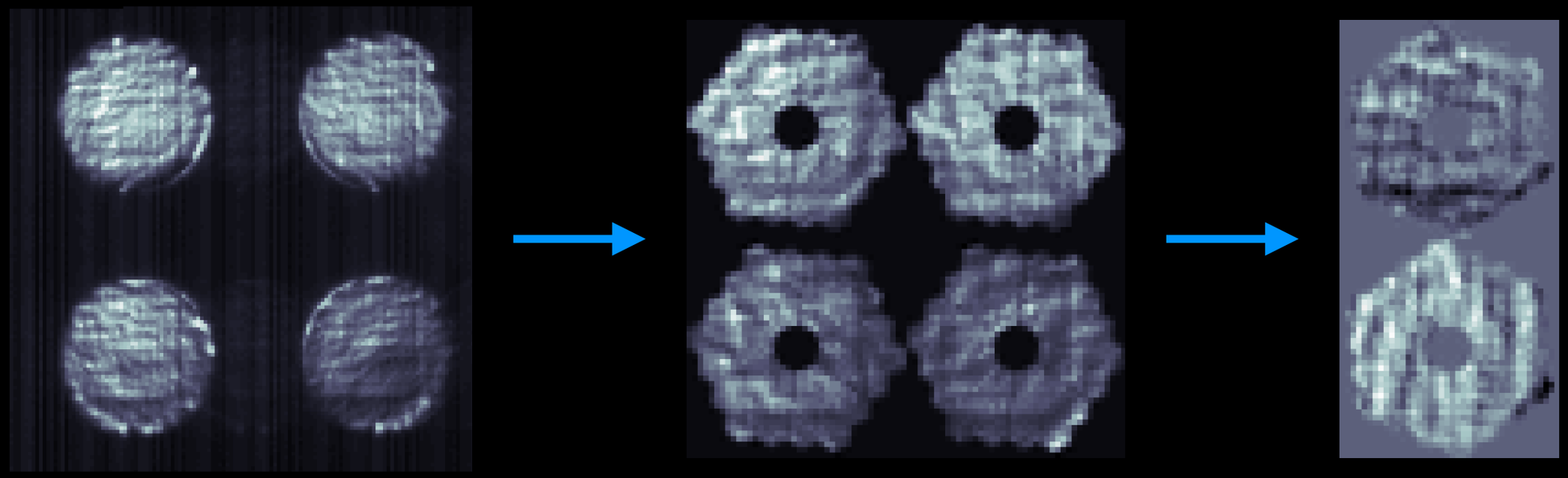
Installation and alignment with Keck AO.

AUTUMN 2018: FIRST ON-SKY TESTS



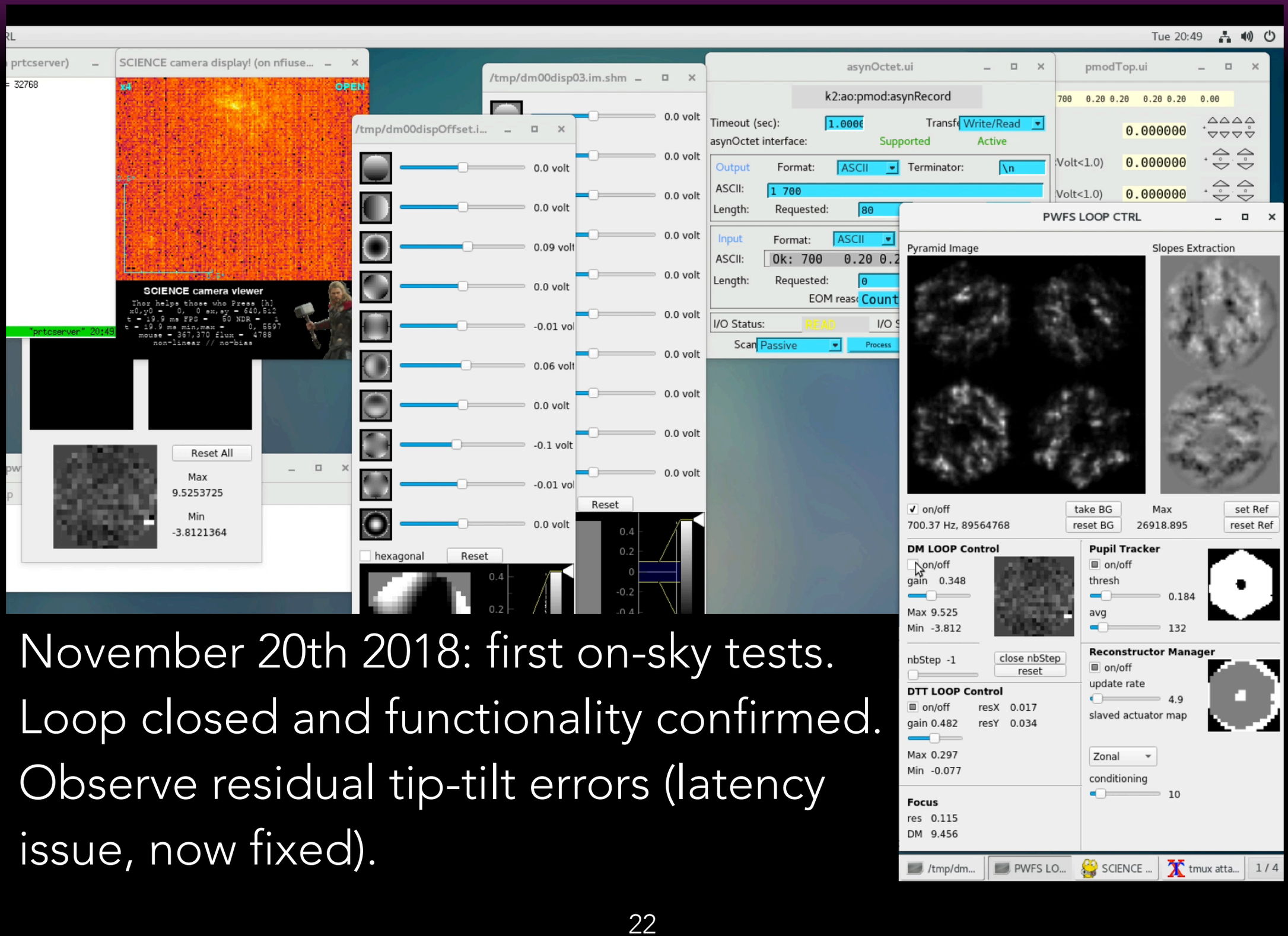
INTEGRATION WITH KECK II AO

- Dedicated PWS real time controller:
  - Can command DM and tip-tilt mirror.
- PWS processes integrated within Keck AO system.
- Calibration and closed loop with internal source.



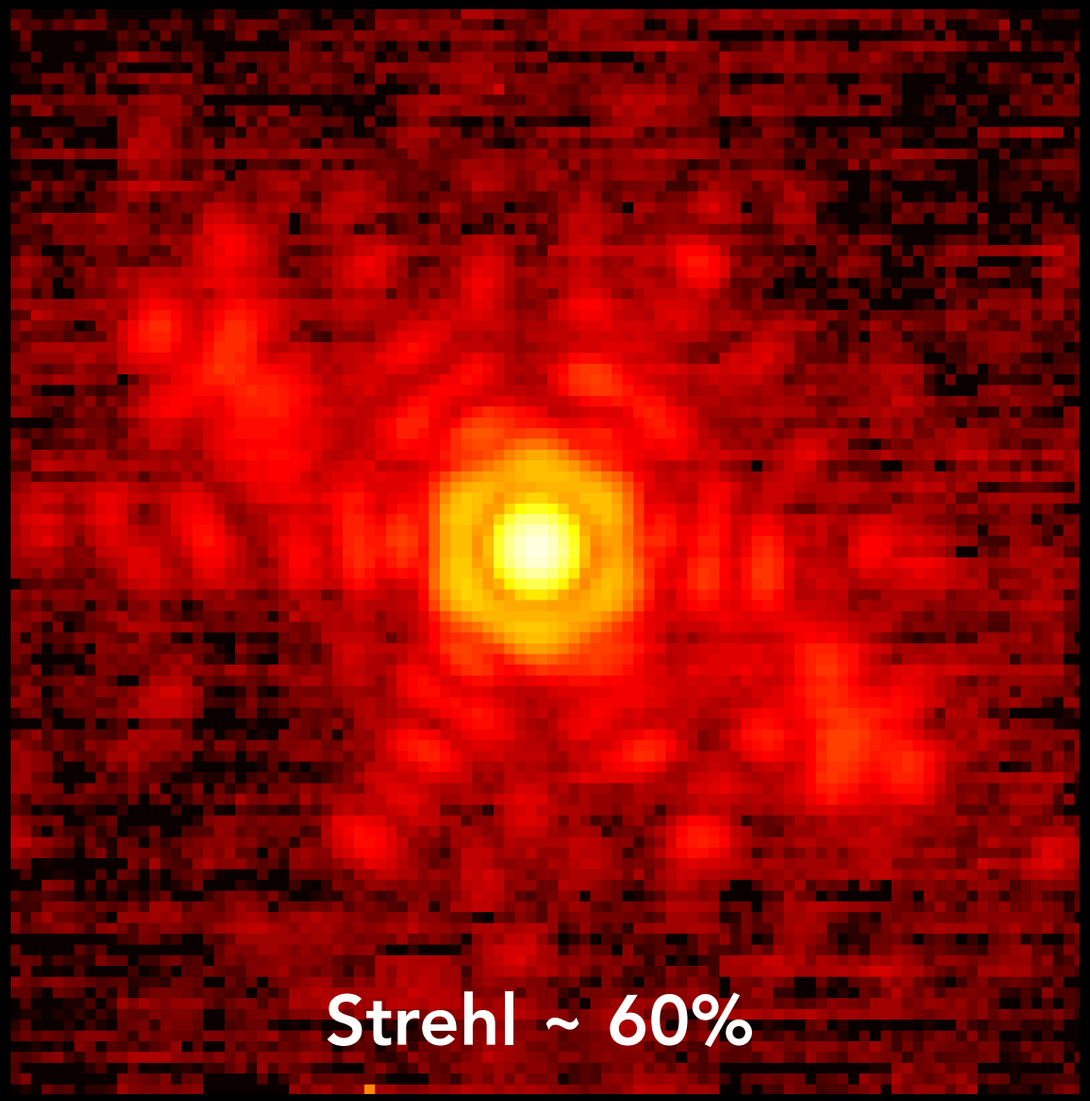
Full sub-array (128x128) Valid pupils Slopes

FIRST LIGHT AND CLOSED LOOP



- November 20th 2018: first on-sky tests.
- Loop closed and functionality confirmed.
- Observe residual tip-tilt errors (latency issue, now fixed).

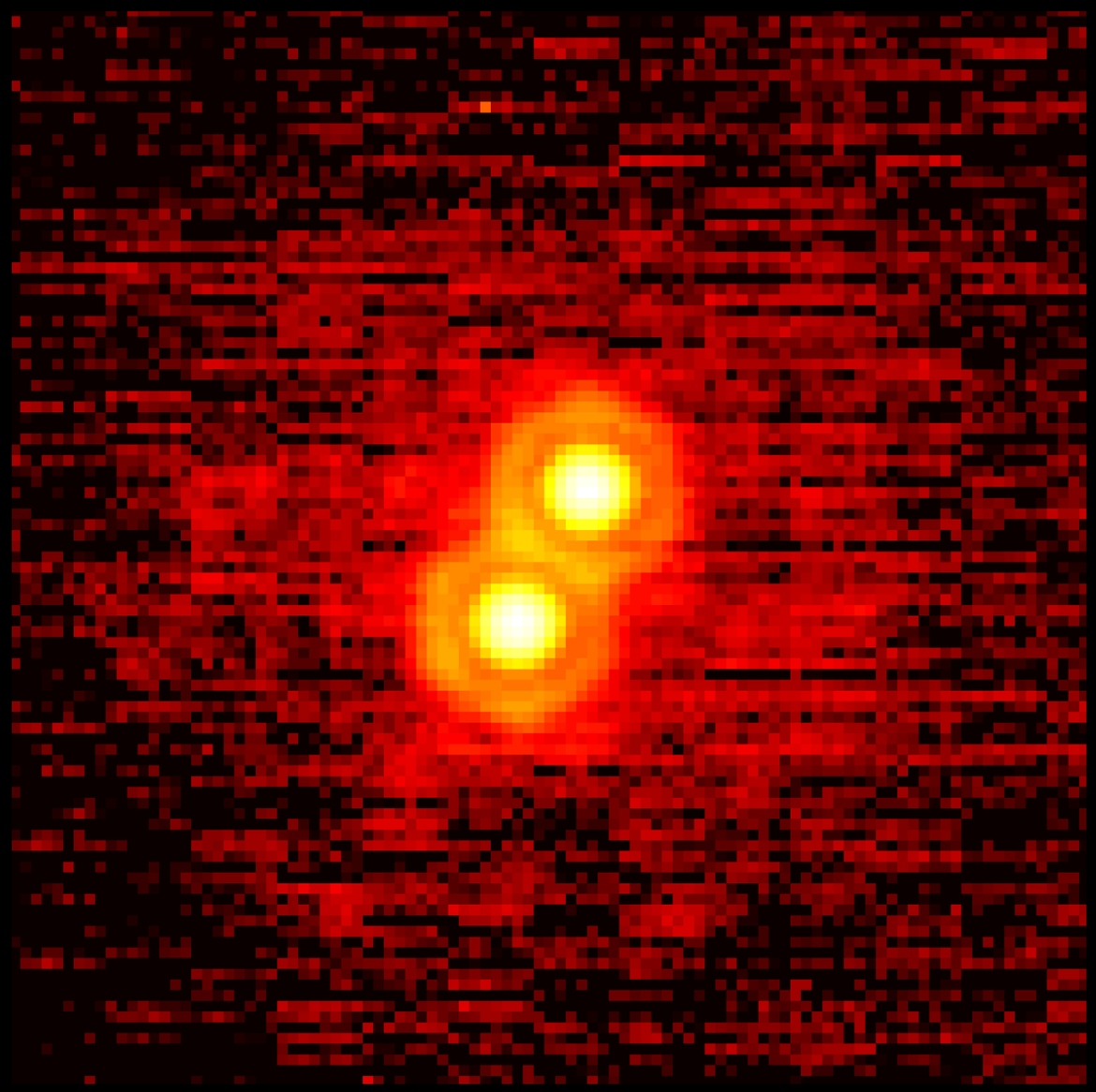
DECEMBER 2018: ON-SKY TESTS



NIRC2 image - K-band

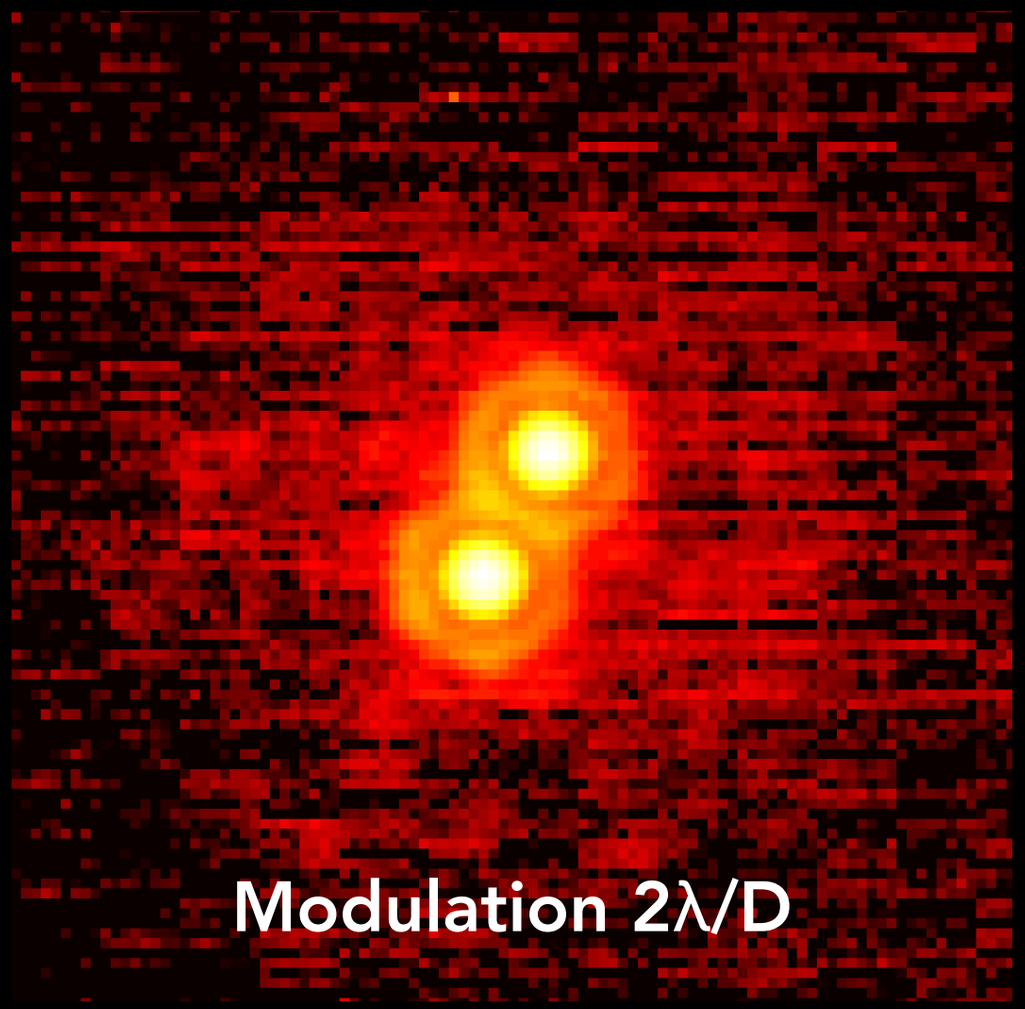
- Stable, consistent performance.
- Long exposure images.
- Seeing ~0.5”.
- Best results with modulation ~2 λ/D (consistent with simulations).

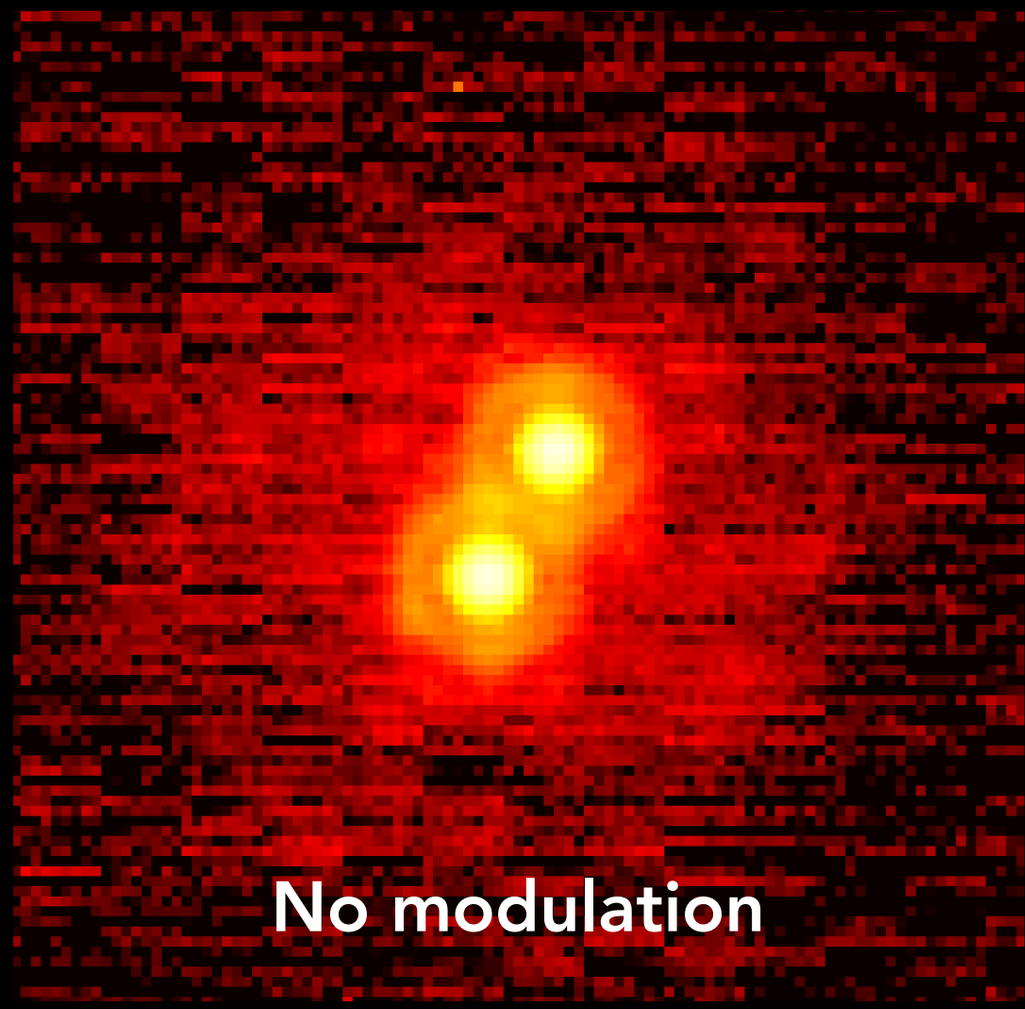
BINARY CLOSED LOOP



- Binary with similar magnitudes.
- Relatively small seperation (~100 mas).
- Red target: H-band mag. ~10, V-band mag. ~15.

BINARY CLOSED LOOP





- Can close the loop even without modulation.

NEXT STEPS

1. Further optimization:
   - On-sky calibration and gain tracking.
   - Predictive control.
   - Comparison with Shack-Hartmann.

2. Spring/ summer 2019: science demonstrations
   - Direct imaging with NIRC2 + vortex cornograph.
   - FIU/NIRSPEC observations - spectra of host stars and planets.

SUMMARY

- Combination of Pyramid and IR WFSing can optimize observations for red objects.

- Keck IR Pyramid installed on Keck II AO.

- On-sky closed loop demonstrated and performance optimization on-going.

- 2019: science demonstrations, PWS facilitization, predictive control.

ACKNOWLEDGEMENTS

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JPL
K. Wallace, R. Bartos.

W. M. Keck Observatory
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LAM: T. Fusco.
Arcetri: S. Esposito, C. Plantet, G. Agaptio, C. Giordano.
HIA: M. Taheri, J.-P. Véran.

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