Pyramid Wavefront Sensing for Extreme Adaptive Optics

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MagAO-X

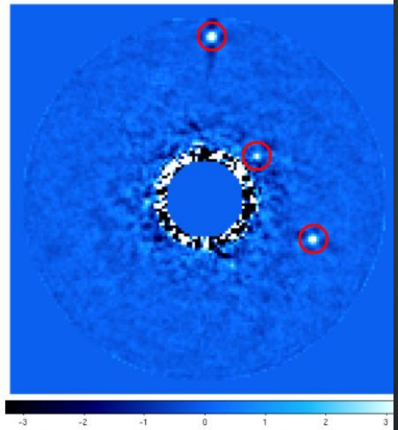
THE UNIVERSITY OF ARIZONA.
CAAO Center for Astronomical Adaptive Optics

Outline

- The MagAO-X system overview
- Pyramid Wavefront Sensing Ongoing Research

Why Direct Imaging?

- With direct imaging we can:
  - Use spectrometer and polarimeters on planets
  - Look for evidence of life on other planets



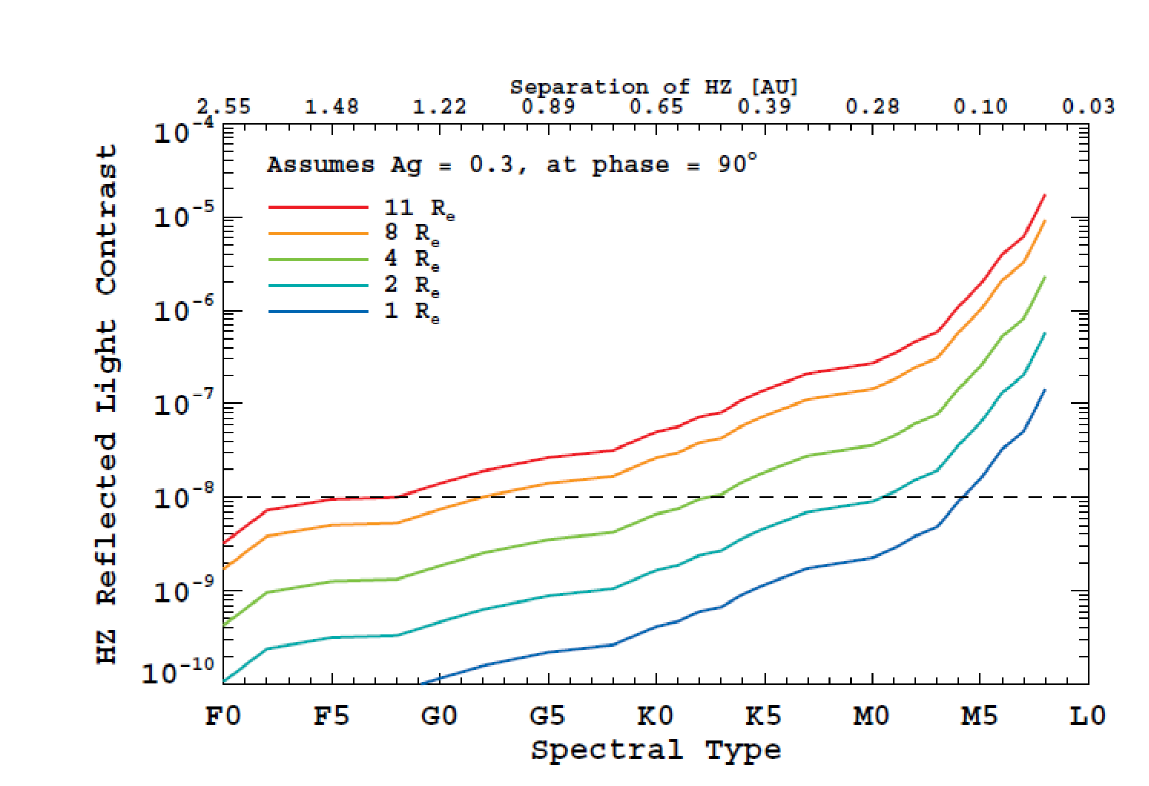
Data from CHARIS instrument during its commissioning observation run clearly shows multiple planets around the star known as HR 8799. Image credit: CHARIS/Princeton Team and NAOJ.

SCExAO+CHARIS

(extreme AO+ Integral Field Spectrograph)

Why is this so hard to do?

- Atmospheric turbulence
- Contrast

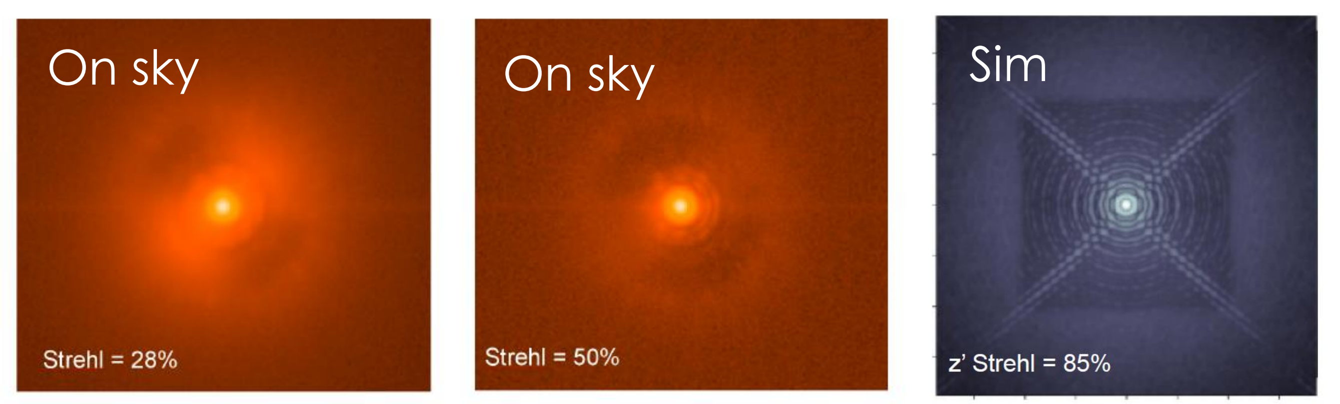


Males 2014

History and Context:

2k

1kHz 2kHz 3.63kHz



<u>MagAO</u>

- 585 adaptive secondary mirror
- Clone of LBTAO
- PWFS
- On 6.5m Magellan Clay
- 1kHz speed
- Clio IR camera (1-5 microns)
- VisAO (.6-1 microns)

<u>MagAO-2K</u>

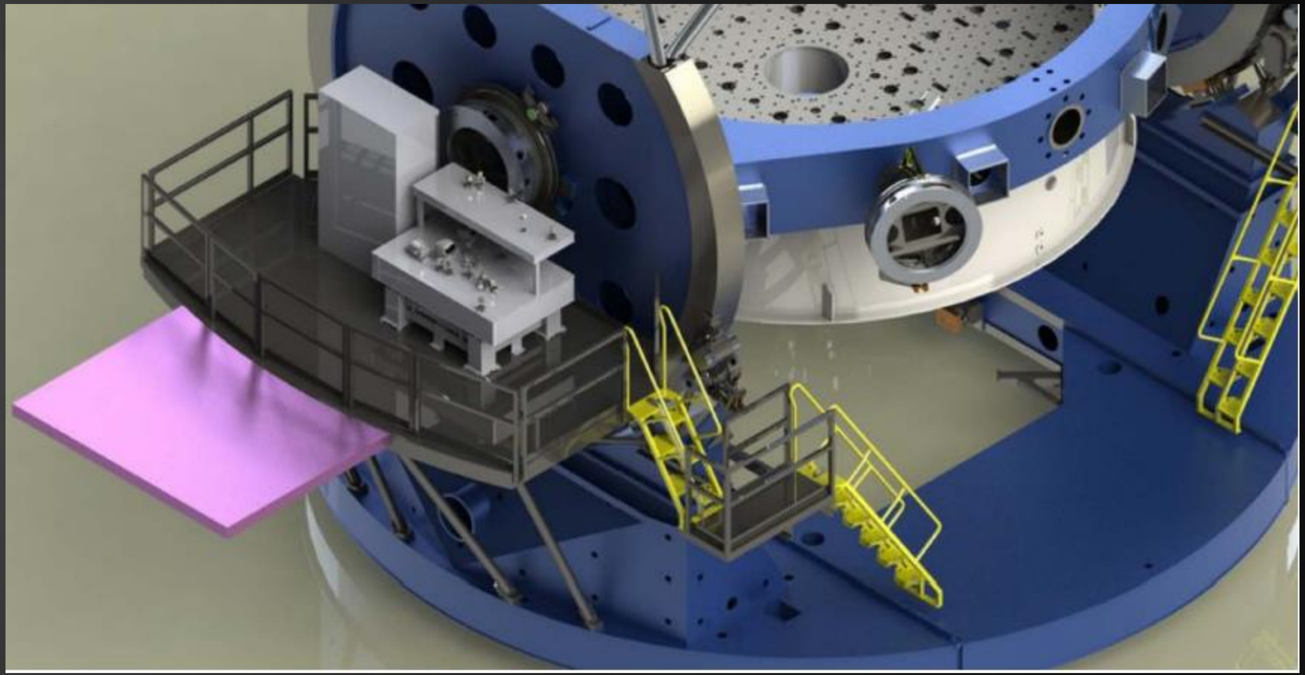
- 2kHz upgrade
- 300 to 400 controlled modes (degrees of freedom) on DM

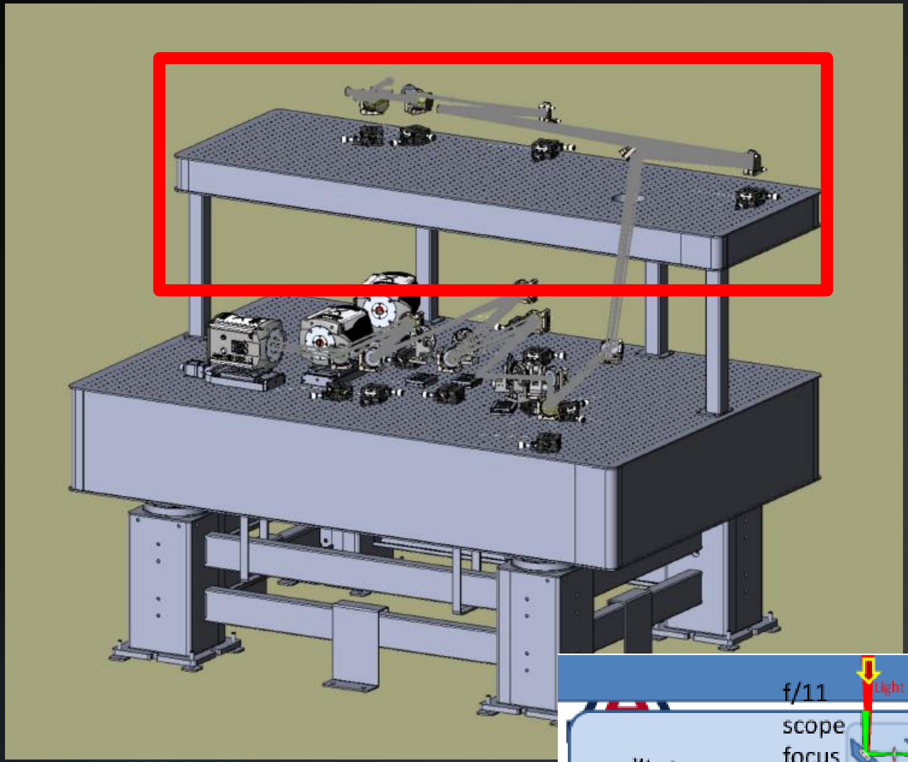
<u>MagAO-X</u>

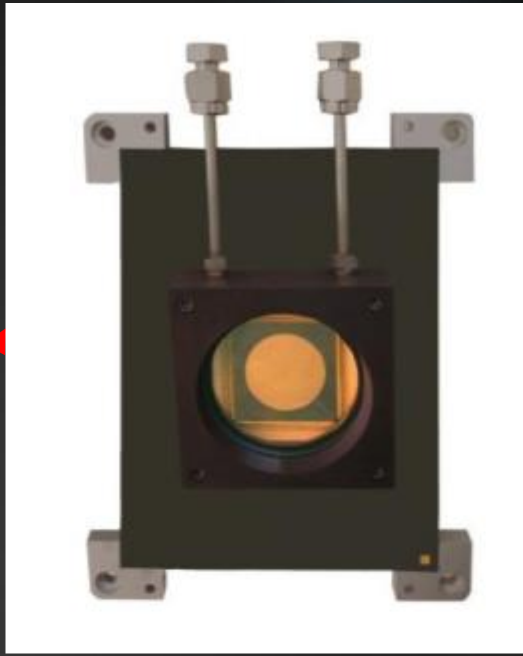
- Builds off of MagAO and SCExAO
- Three phase development

MagAO-X Overview

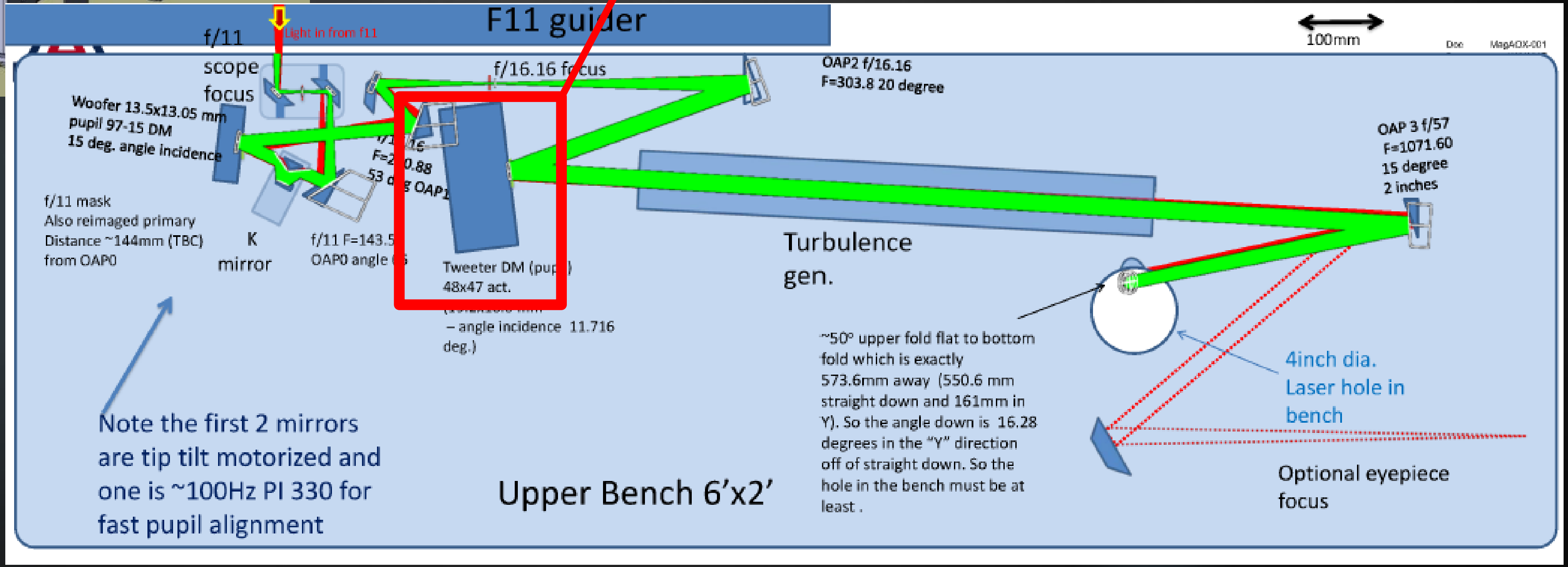
- Visible-to-near-IR “extreme” exAO system
- 2048 actuator BMC DM
- >70 % Strehl at H-alpha
- 3.7kHz speed
- Coronagraphs delivering contrasts <10^-4 from 1-10 λ/D
- PWFS
- LOWFS
- Imagers and spectrographs



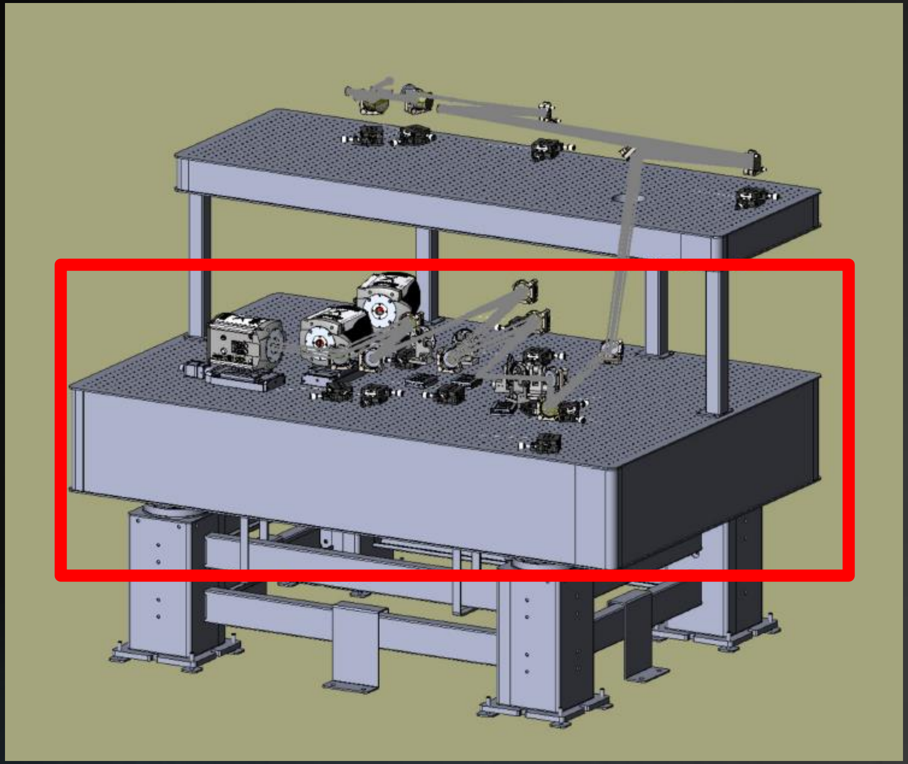


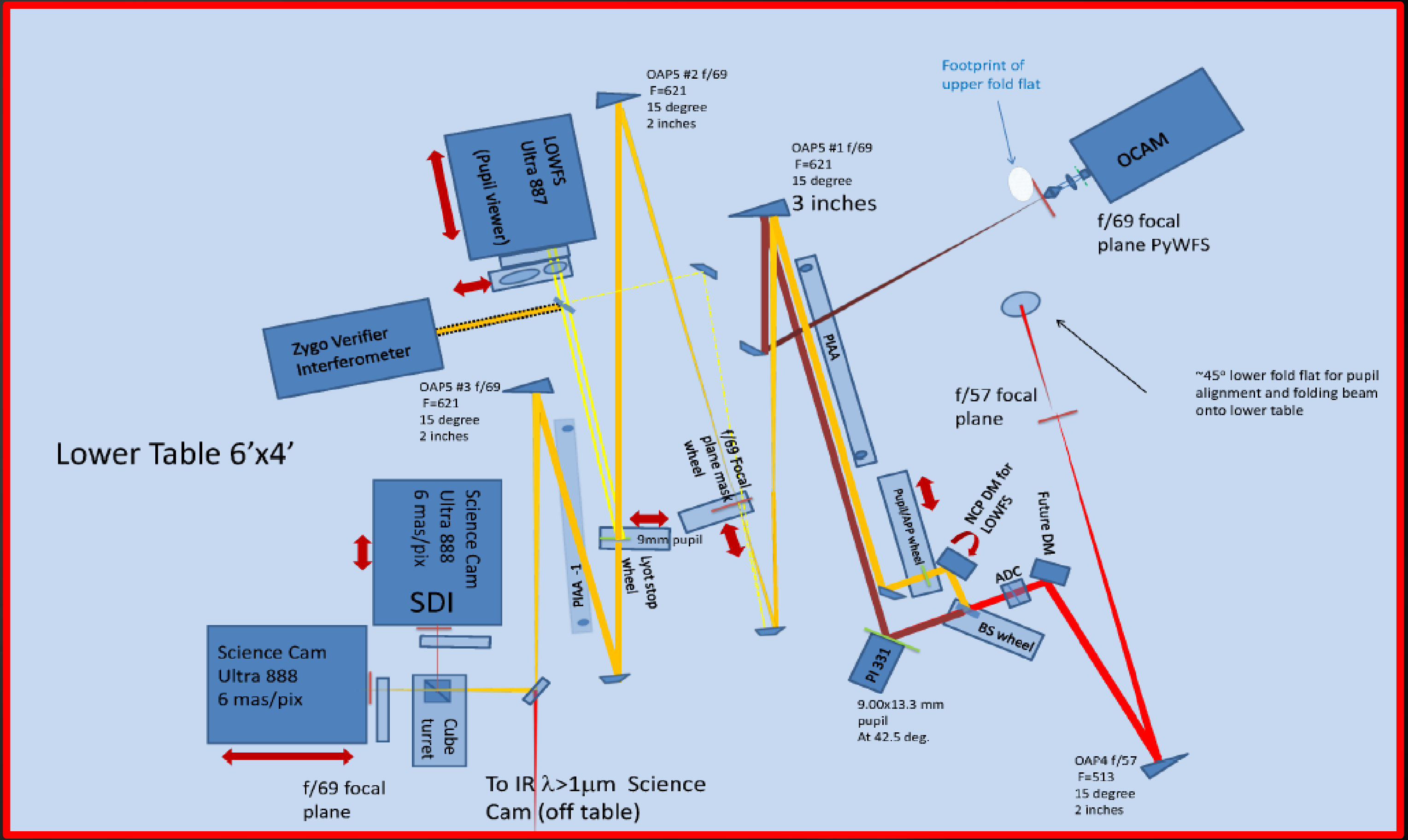


BMC 2K Tweeter DM



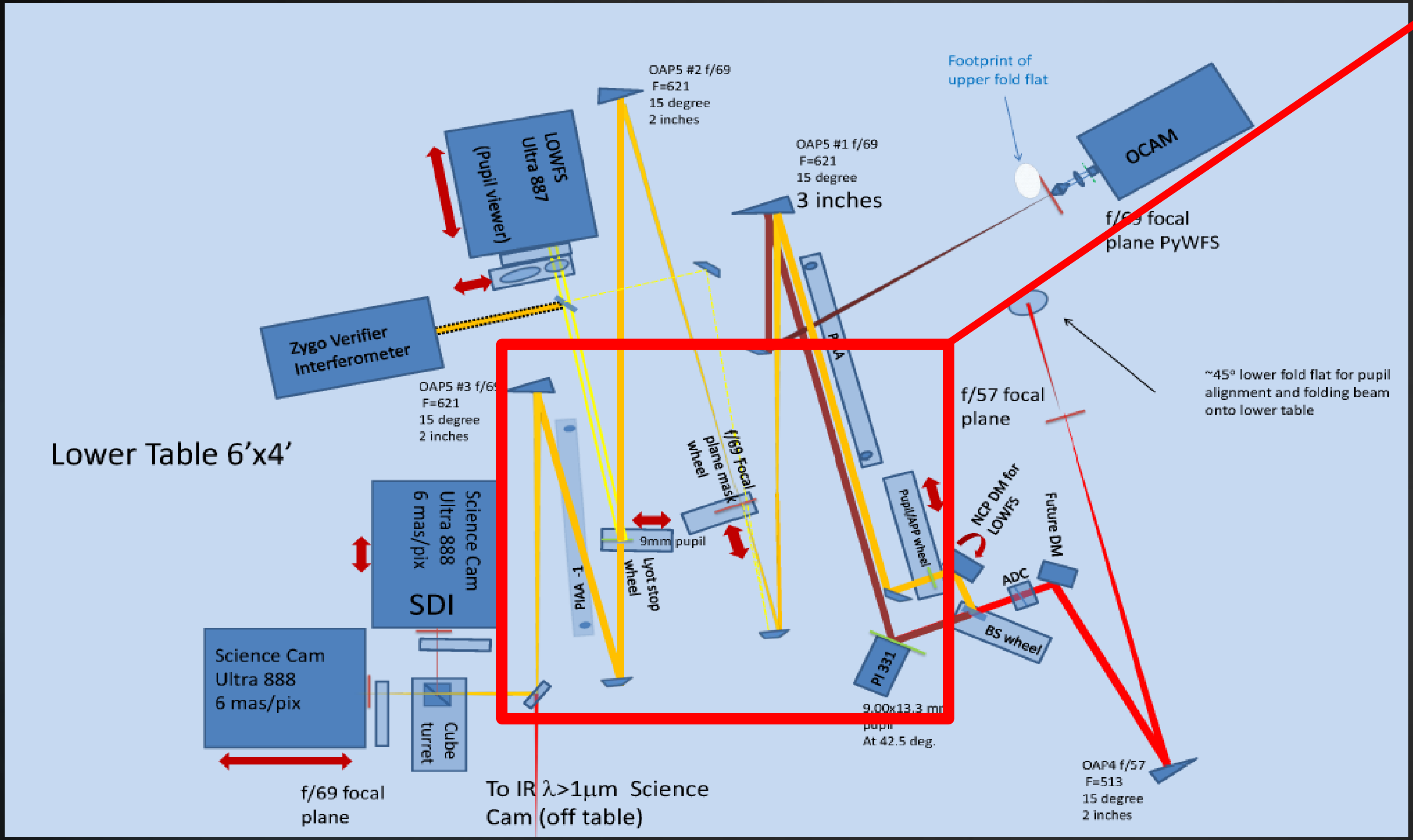
Lower bench



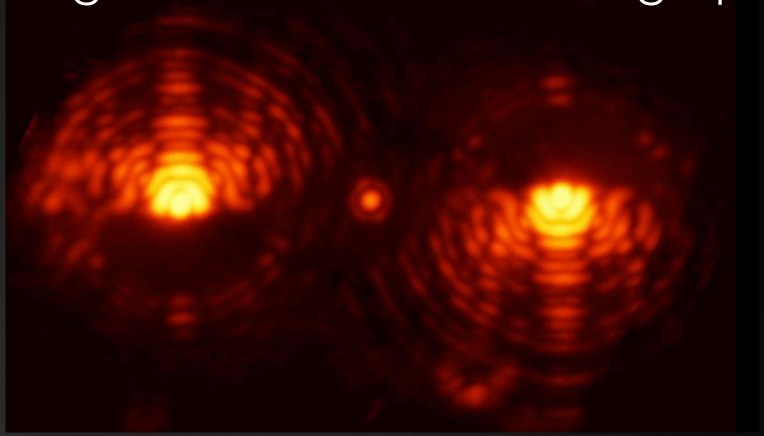


- WFS
- Coronagraphs
- Science Cameras

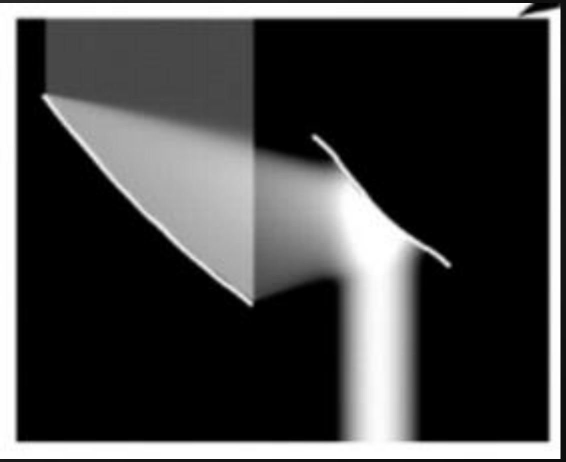
Coronagraph



MagAO: Clio+vAPP Coronagraph



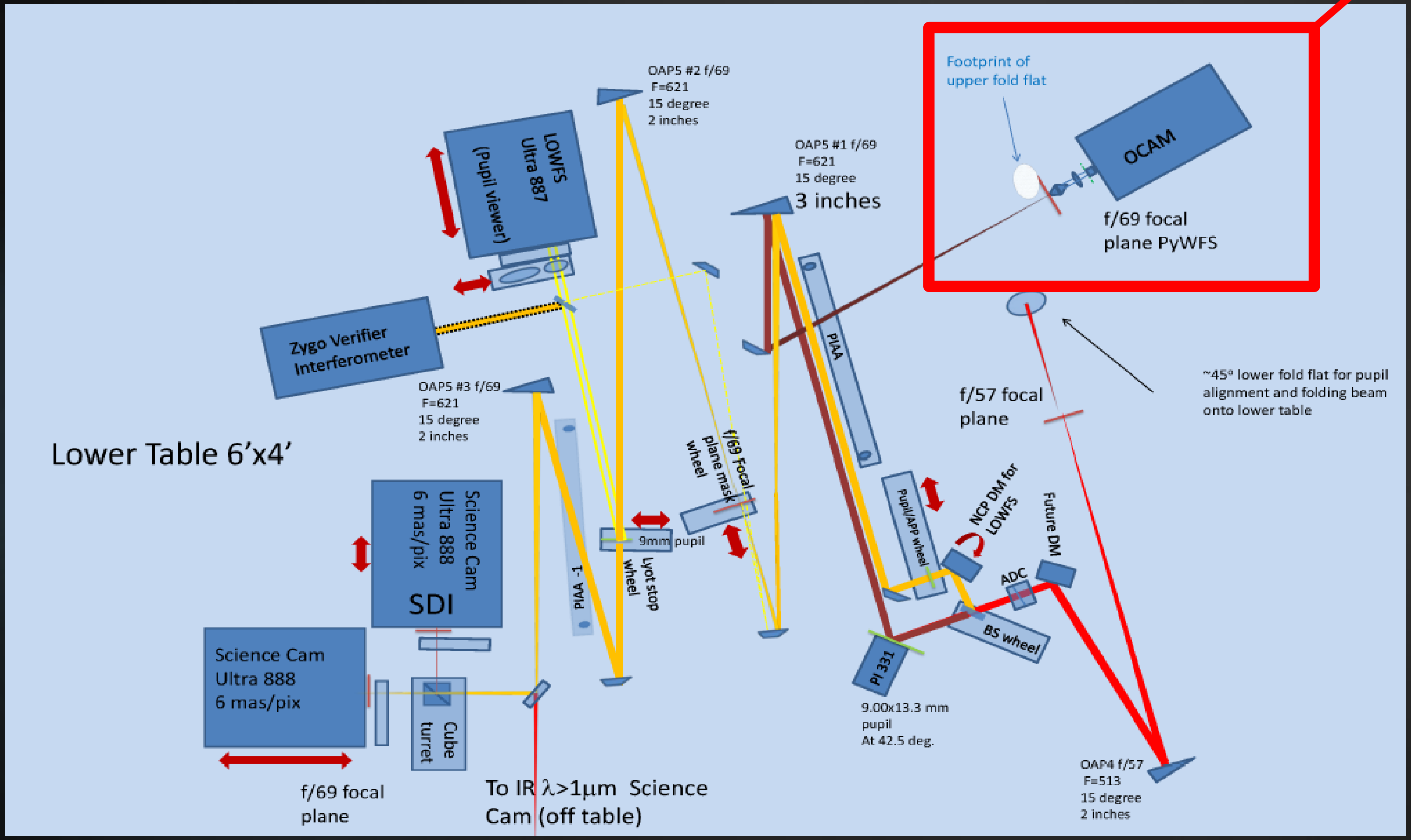
Vector Apodizing Phase Plate (vAPP) Coronagraph



University of Leiden:
Frans Snik, David Doelman,
Christoph Keller, Matthew Kenworthy

Phase-Induced Amplitude Apodization PIAACMC

Wavefront sensor



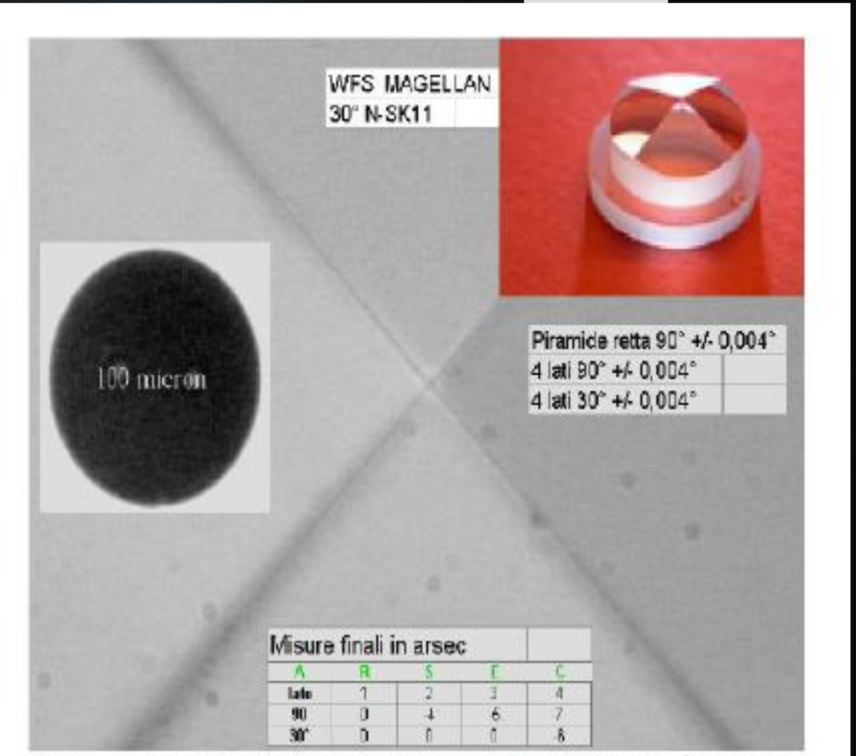
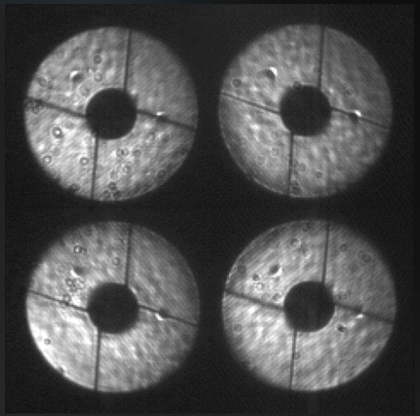


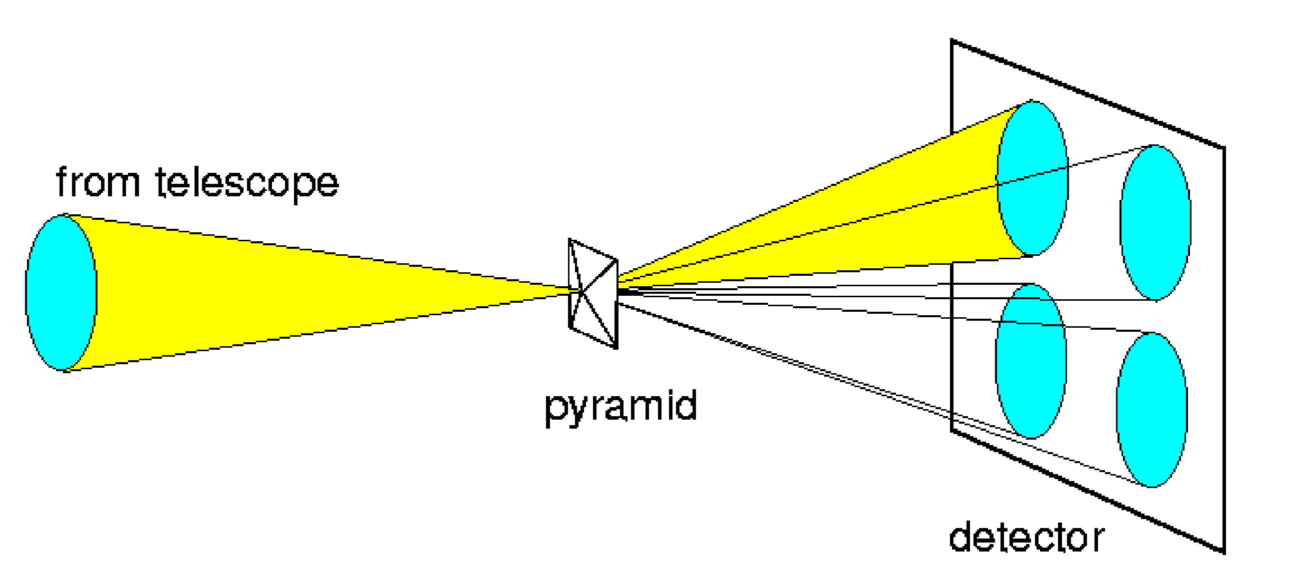
Figure 2: Fabricated pyramid made in Arcetri.

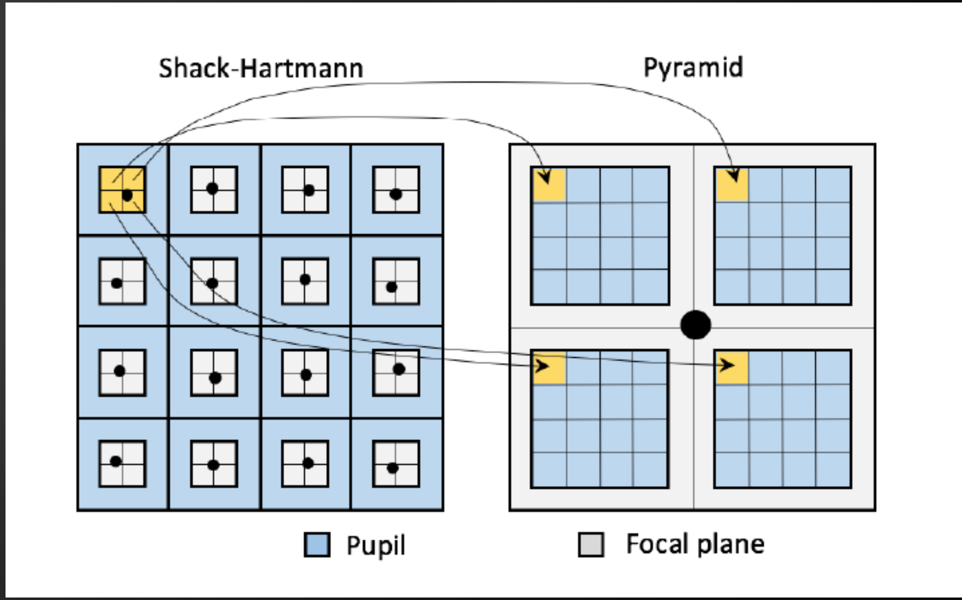
Pyramid Wavefront Sensor

Pyramid Wavefront Sensor

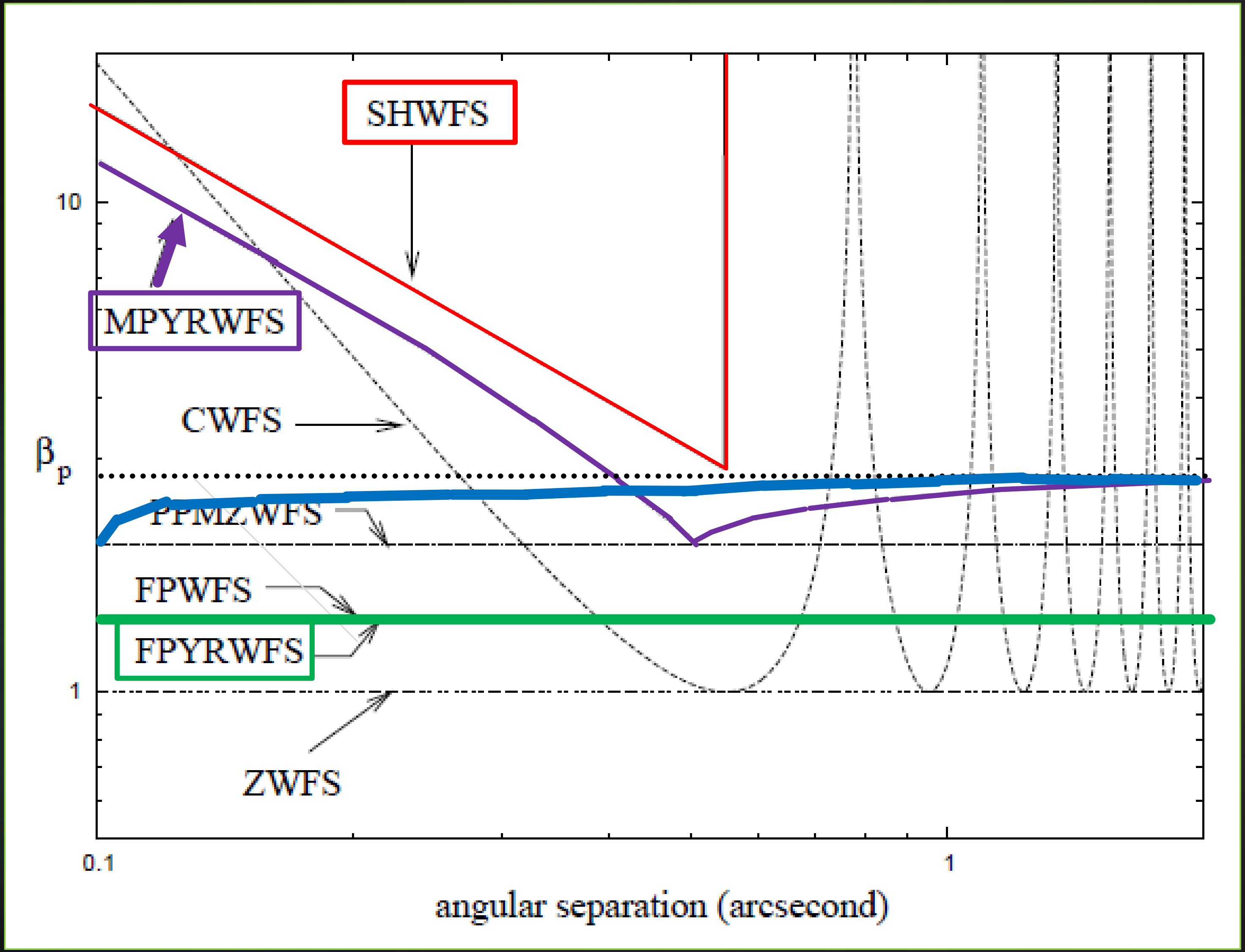


- Focal plane is split by pyramid
- Wavefront Sensing done in pupil plane
- Benefits from the full resolution of the telescope
- # Pixel in pupil = # of degrees of freedom controlled (actuators)





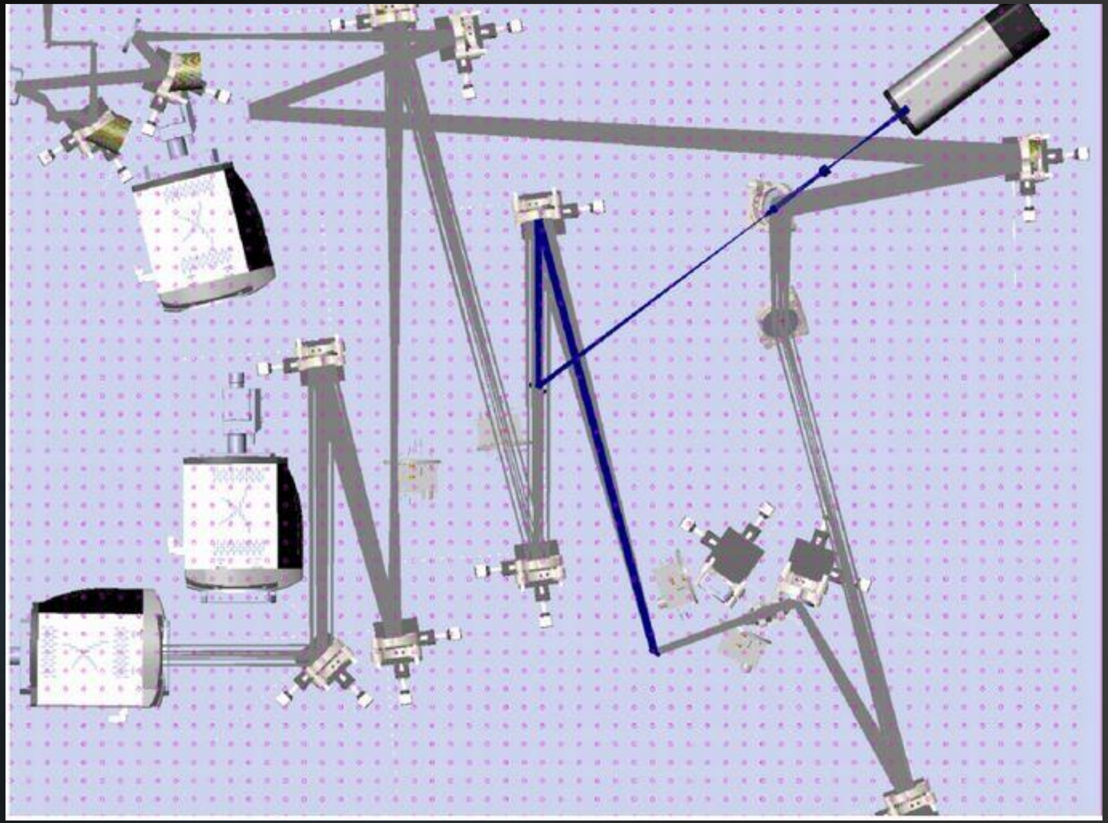
Sensitivity

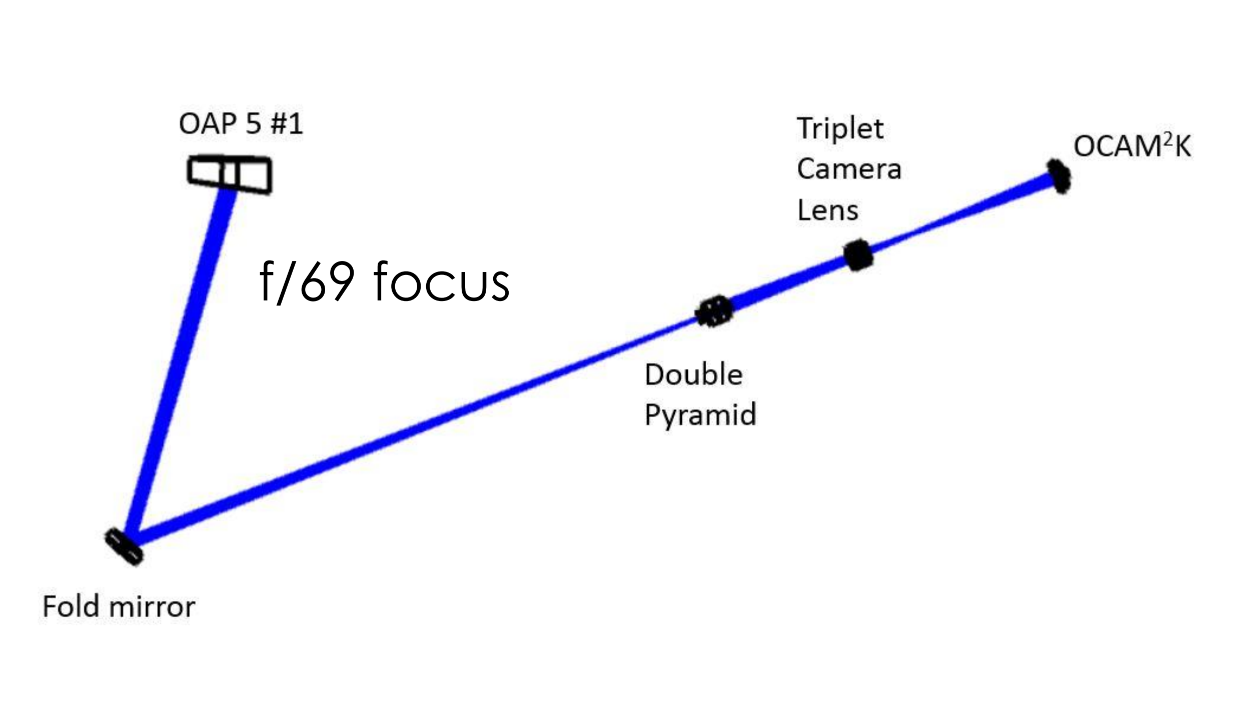


MPYRWFS modeled >> modulation than on sky MPYRWFS

Guyon 2005

PWFS Design for MagAO-X





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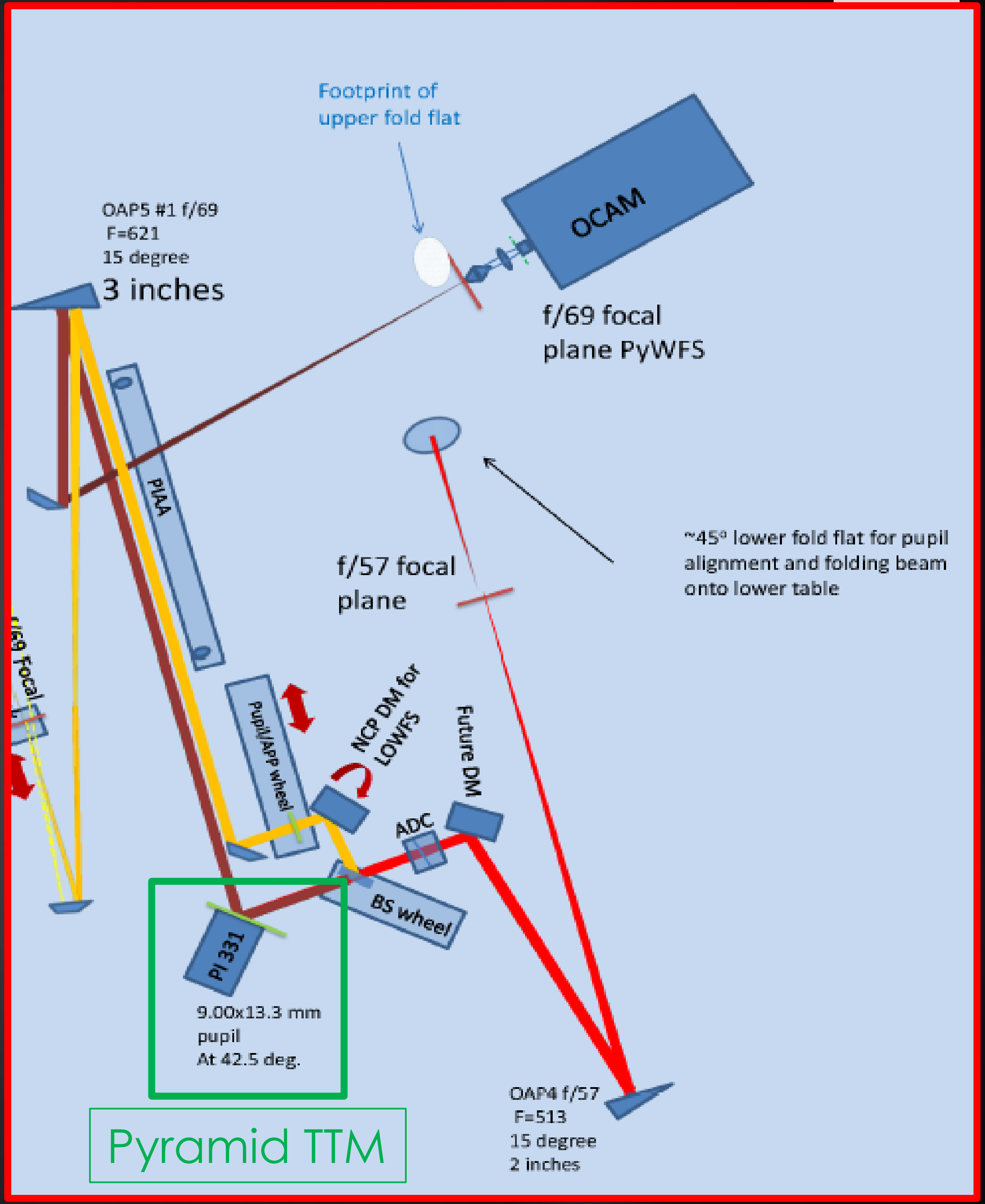
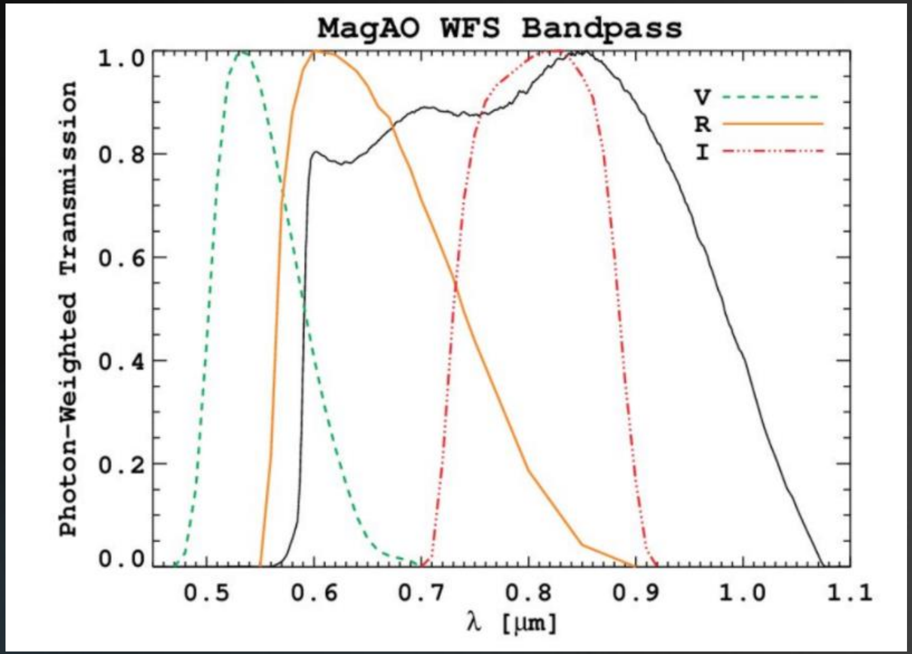
Differences from Arcetri Design

- OAP that forms pyramid focus **after** TTM
- TTM in collimated space
- No dynamic focus on pyramid
  - Designed to be fixed with respect to the coronagraph
  - Focus comes from M2 compensation



Expected Performance



Parameter	Requirement
Wavelength Range	600- 1000 nm
Pupil Size	56 pixels; 2.688 mm
Pupil Separation	60 pixels; 2.880 mm
Pupil Tolerances	$\Delta < 1/10\text{th pixel}; 2.4\ \mu m$
Lens Diameter	$10\ mm < D < 20\ mm$

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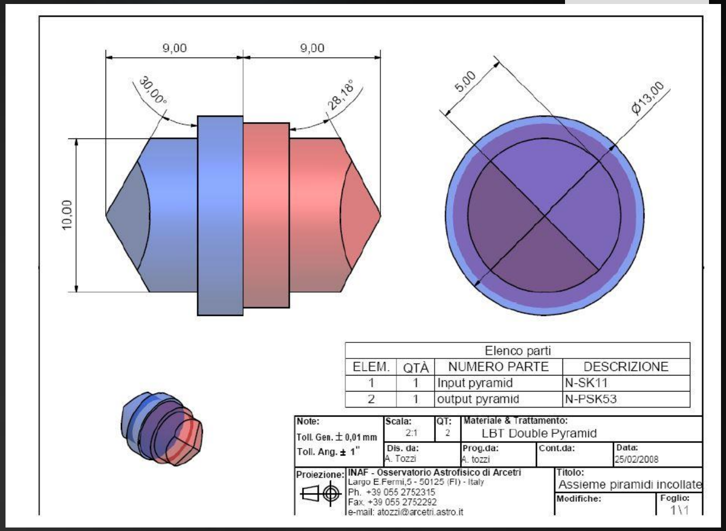
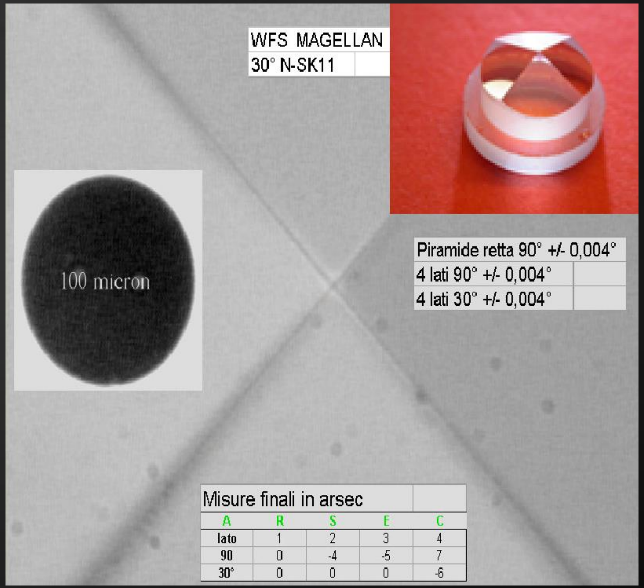
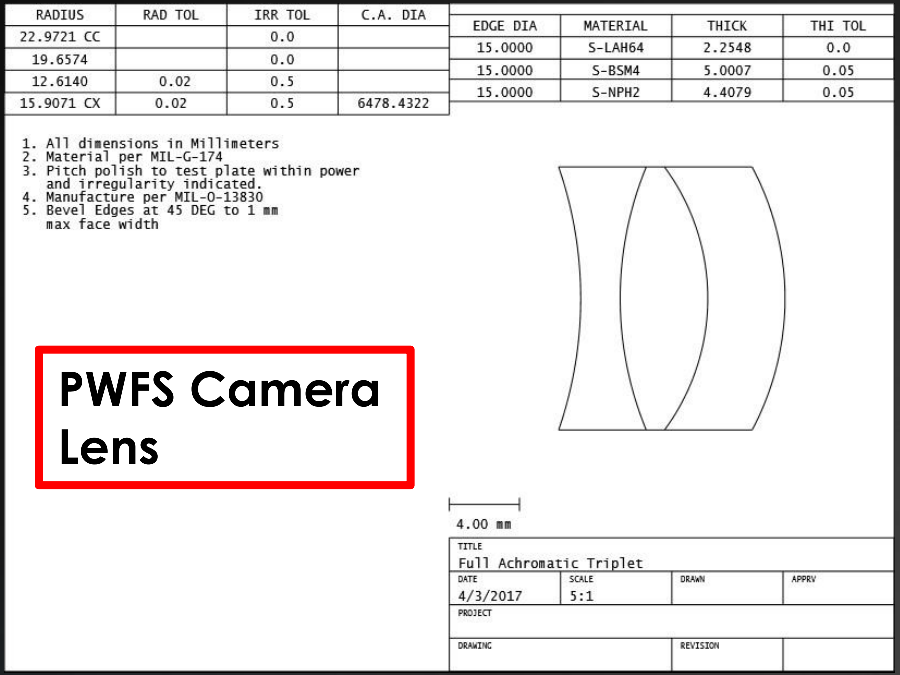
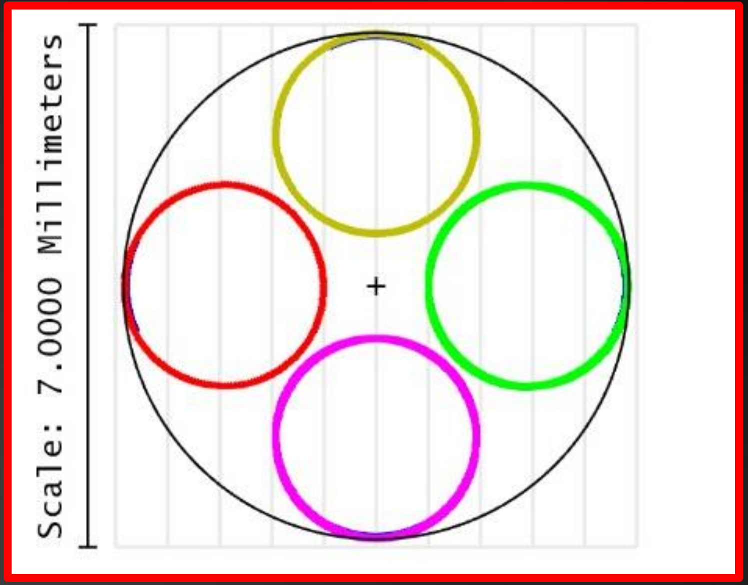
- Achromatic prism
- Designed by Arcetri
- Same pyramid in LBTAO and MagAO

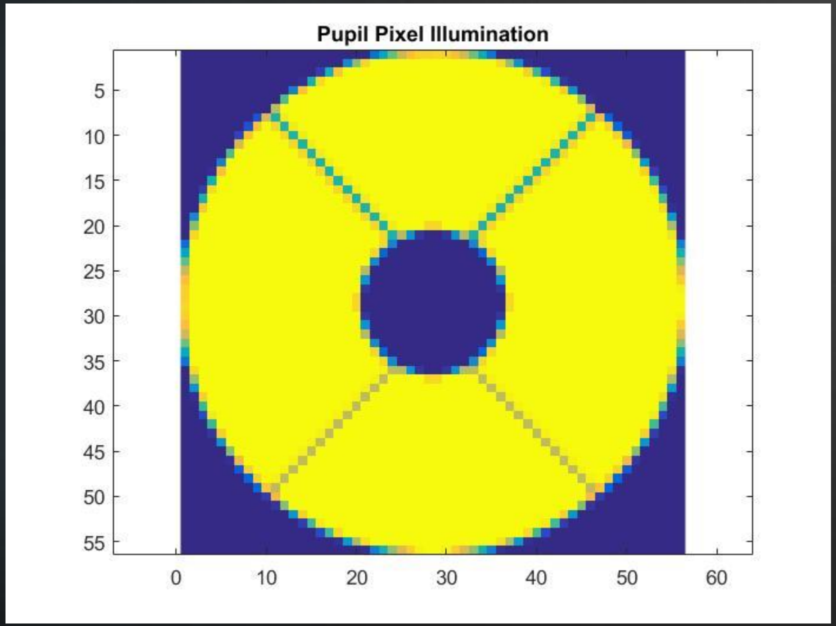






PWFS Camera Lens





% Illumination	# of Actuators
100%	1958
90%	166
80%	24
70%	46
60%	20
50%	18
< 50%	904

2232 Controlled modes
>
# of actuators on DM

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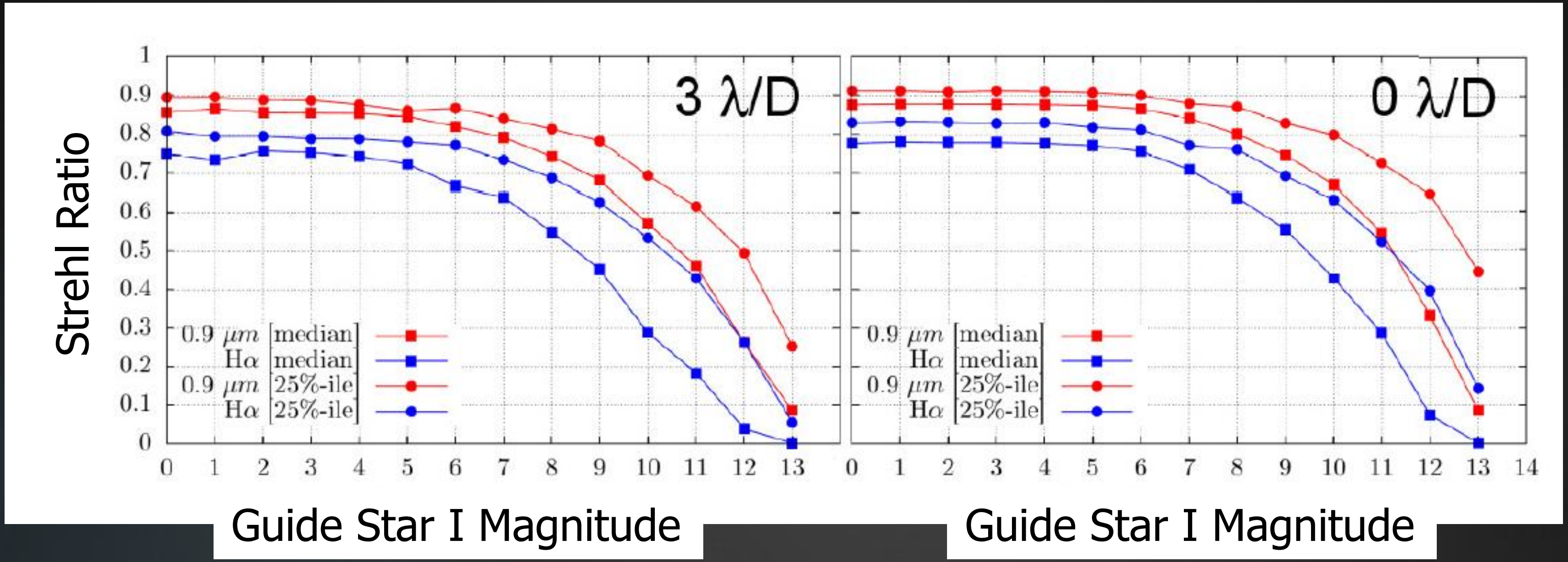
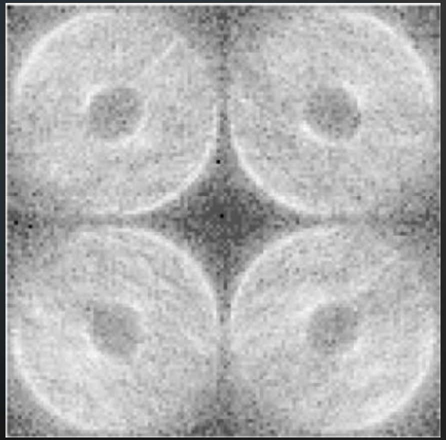
Expected performance of PWFS

Modulated | Unmodulated



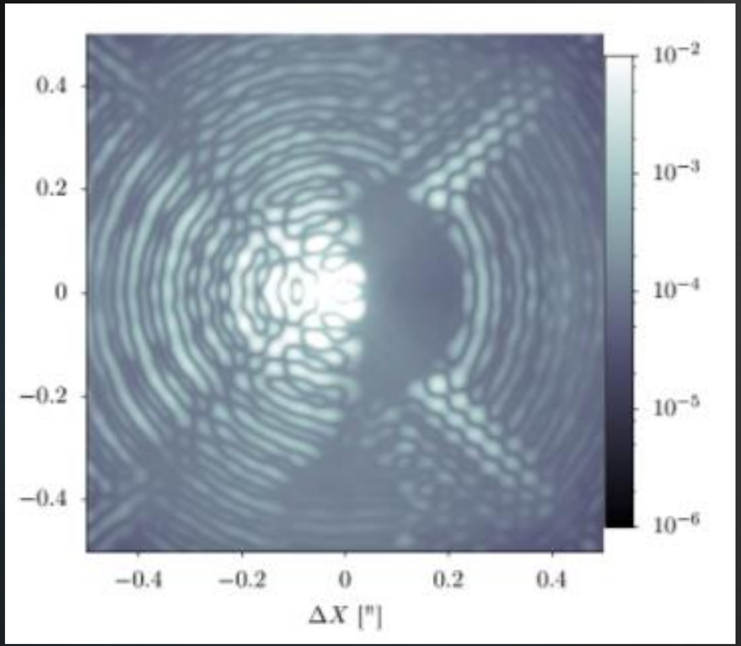


-Expected pupils on OCAM
- 8th mag guide star
-Log stretch

MagAO-X Raw Contrast Performance

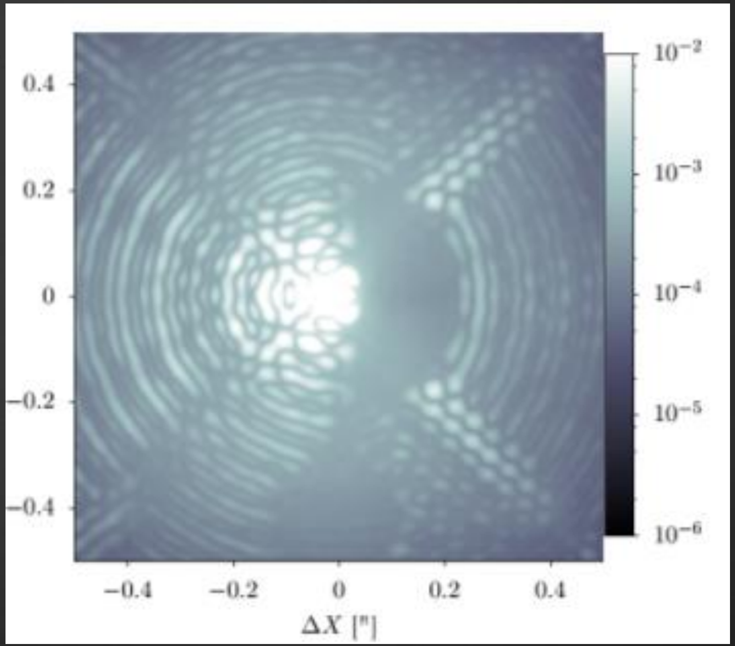
- 30 Second exposure times
- 25 %-ile seeing conditions

~10^-4 Contrast



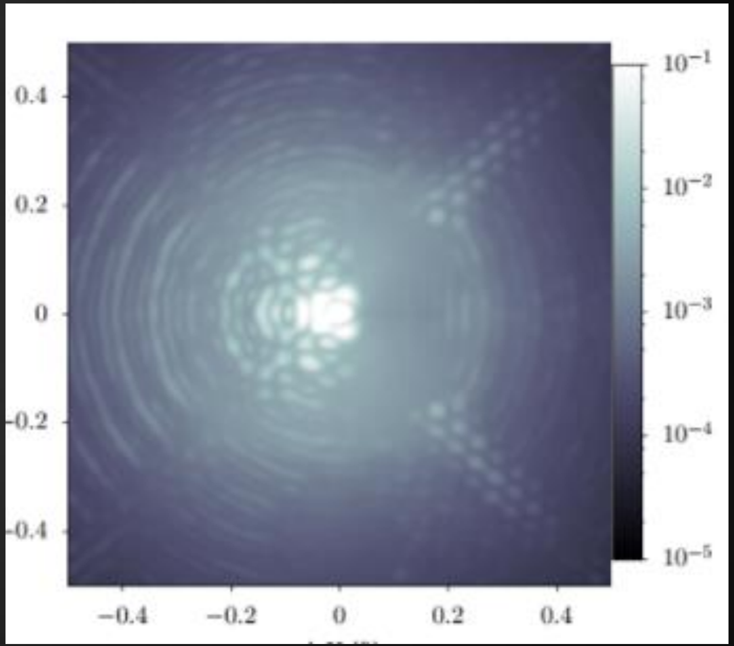
8th Mag GS

Better than 10^-3 Contrast



10th Mag GS

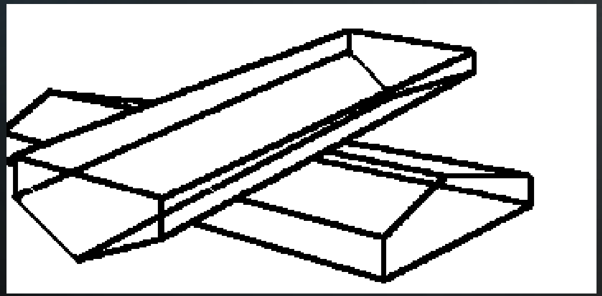
Better than10^-2 Contrast



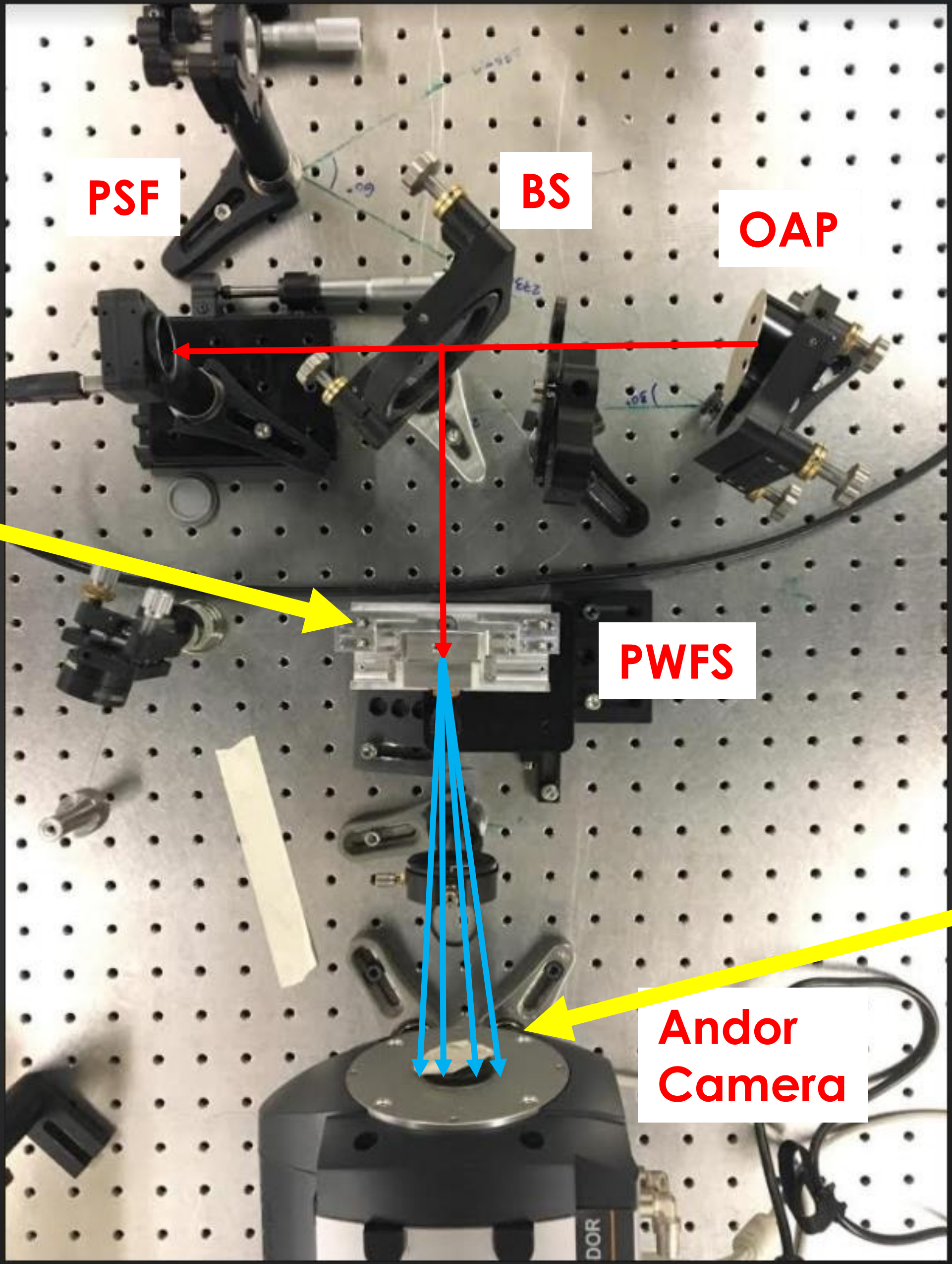
12th Mag GS

vAPP design by David Doelman

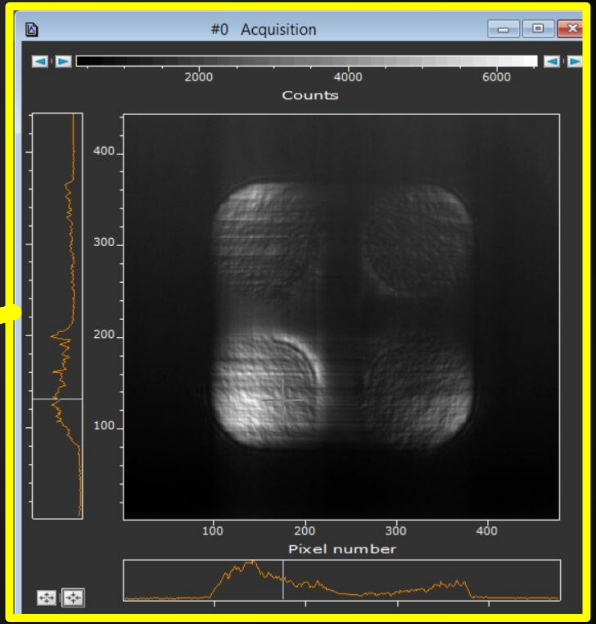
WFS Testbed



Olivier Guyon, Nemanja Jovanovic, SCExAO team



Unmodulated Pyramid Pupils



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3PWFS Simulations

U.S. AIR FORCE

Trying to understand difference in sensitivity and contrast for extended object wavefront sensing and imaging.

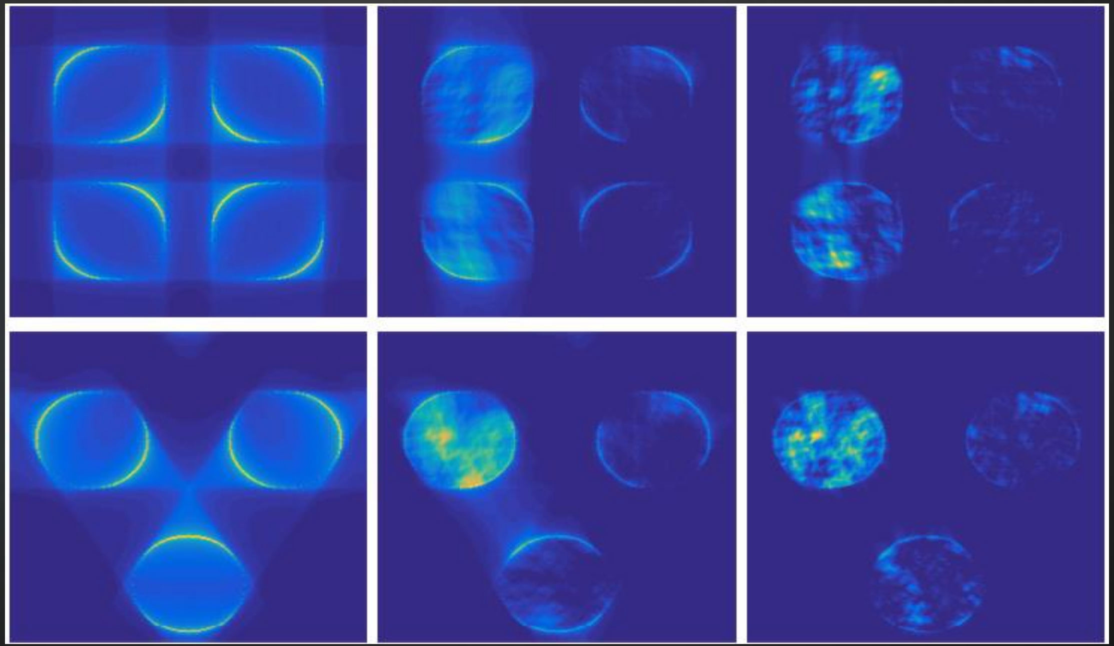
- 3PWFS
- 4PWFS
- Reflective/refractive

GMT

Path-finding for a reflective 3PWFS for GMagAO-X for GMT

Benefits:

- Easier to manufacture
- Potential detector savings
- Potential gains in SNR



4PWFS Refractive

3PWFS Refractive

- 0 Radian RMS
- 1 Radian RMS
- 3 Radian RMS

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Logo Conceptual Design

Acknowledgements

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Jhen Lumbres

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MagAO-X

Logo PDR Approved

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