PYRAMID WAVEFRONT SENSING UPDATE FOR MAGAO-X

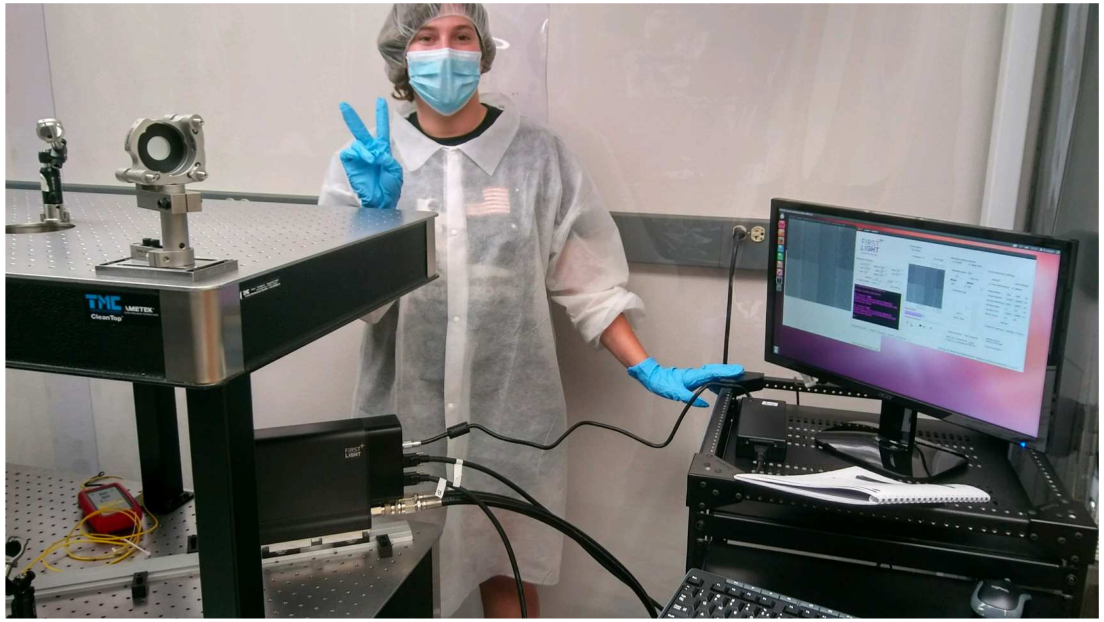
LAUREN H SCHATZ[1], JARED MALES[2], MICHAEL HART[1], LAIRD CLOSE[2], KATIE MORZINSKI[2], OLIVIER GUYON[1,2,3,4], MADISON JEAN[1] ,CHRIS BOHLMAN[2], KYLE VAN GORKOM[1], ALEXANDER HEDGLEN[1], MAGGIE KAUTZ[1], JUSTIN KNIGHT[1], JOSEPH D. LONG[2], JENNIFER LUMBRES[1], KELSEY MILLER[1], ALEXANDER RODACK[1]

[1]College of Optical Sciences, University of Arizona. [2]Steward Observatory, University of Arizona. [3]National Astronomical Observatory of Japan, Subaru Telescope, National Institutes of Natural Sciences, Hilo, Hawaii.[4]Astrobiology Center, National Institutes of Natural Sciences, Tokyo, Japan.

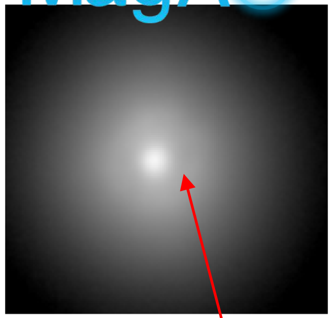
Center for Astronomical Adaptive Optics

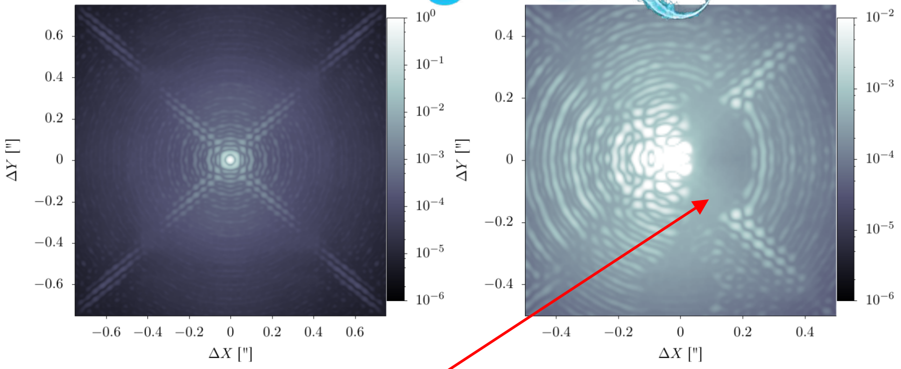
OUTLINE

- MagAO-X Pyramid Wavefront Sensor Design
  - Optical design of system
  - Lens Results
  - Lab Results
- PYRITE
  - GMagAO-X motivation
  - 3 PWFS vs 4 PWFS
  - PYRITE simulator



MOTIVATION





c/o Kate Follette

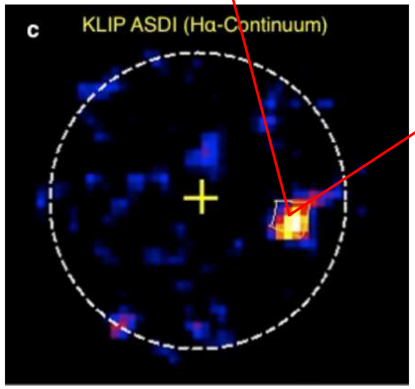
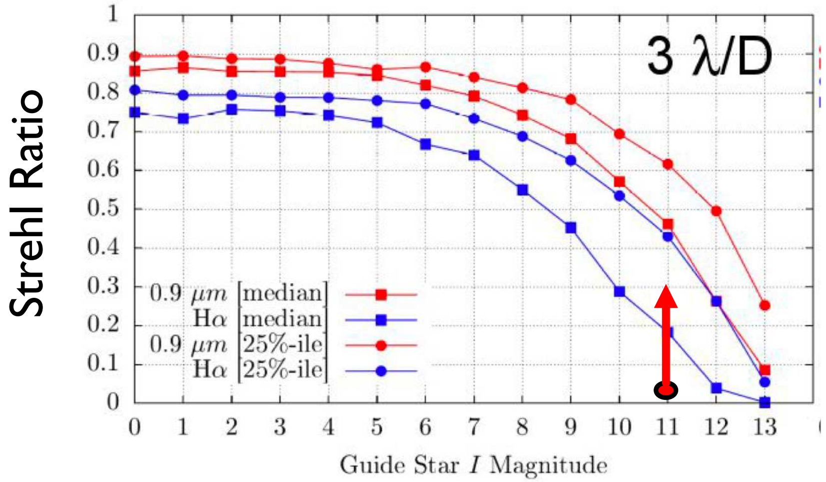
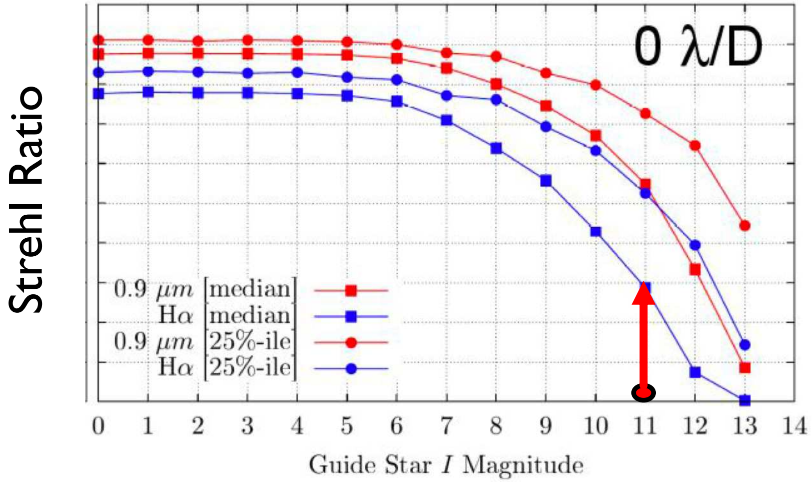


Image of LkCa 15b taken by Kate Follette (Sallum et al., Nature, 2015)

High airmass and 11th mag GS demand high performance.

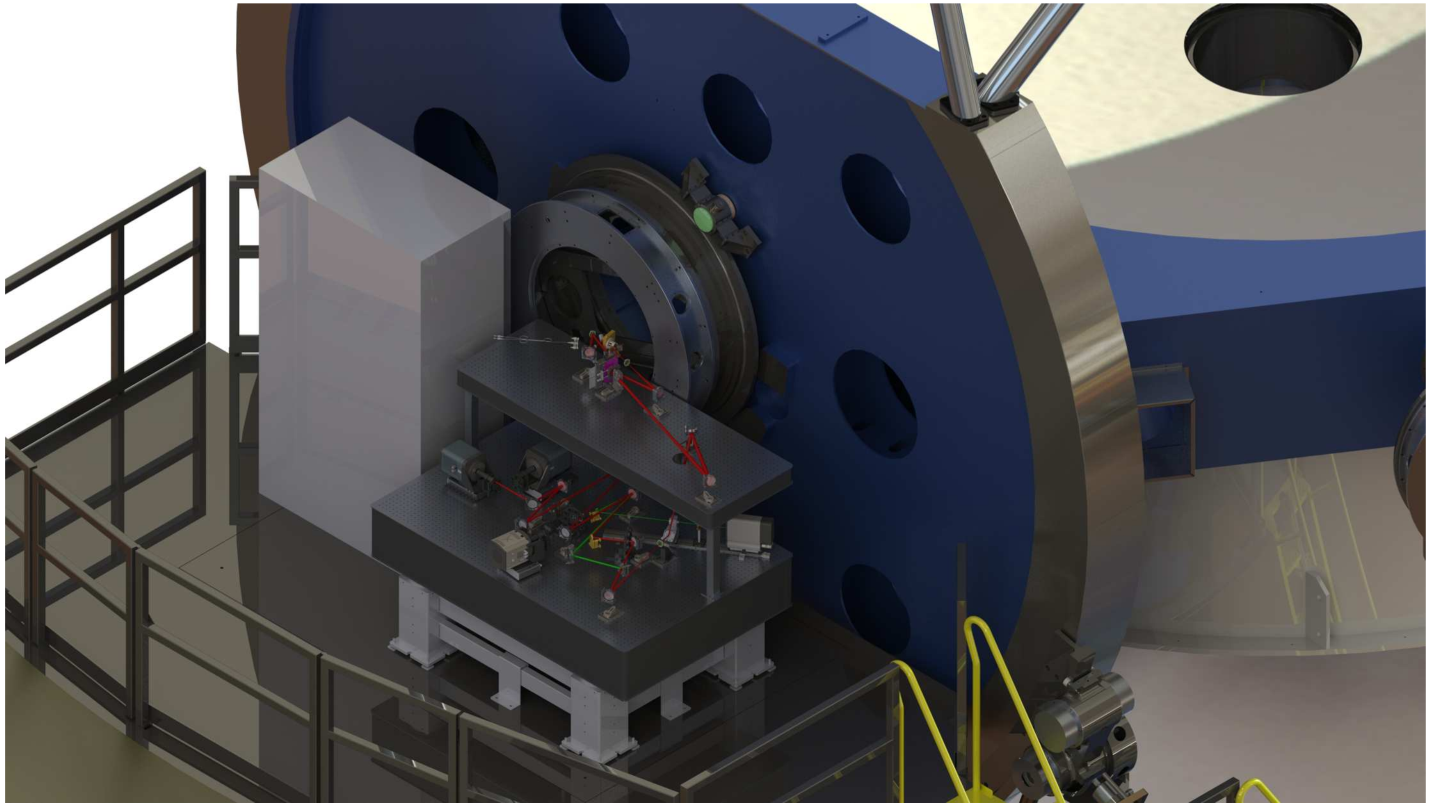




MAGAO-X

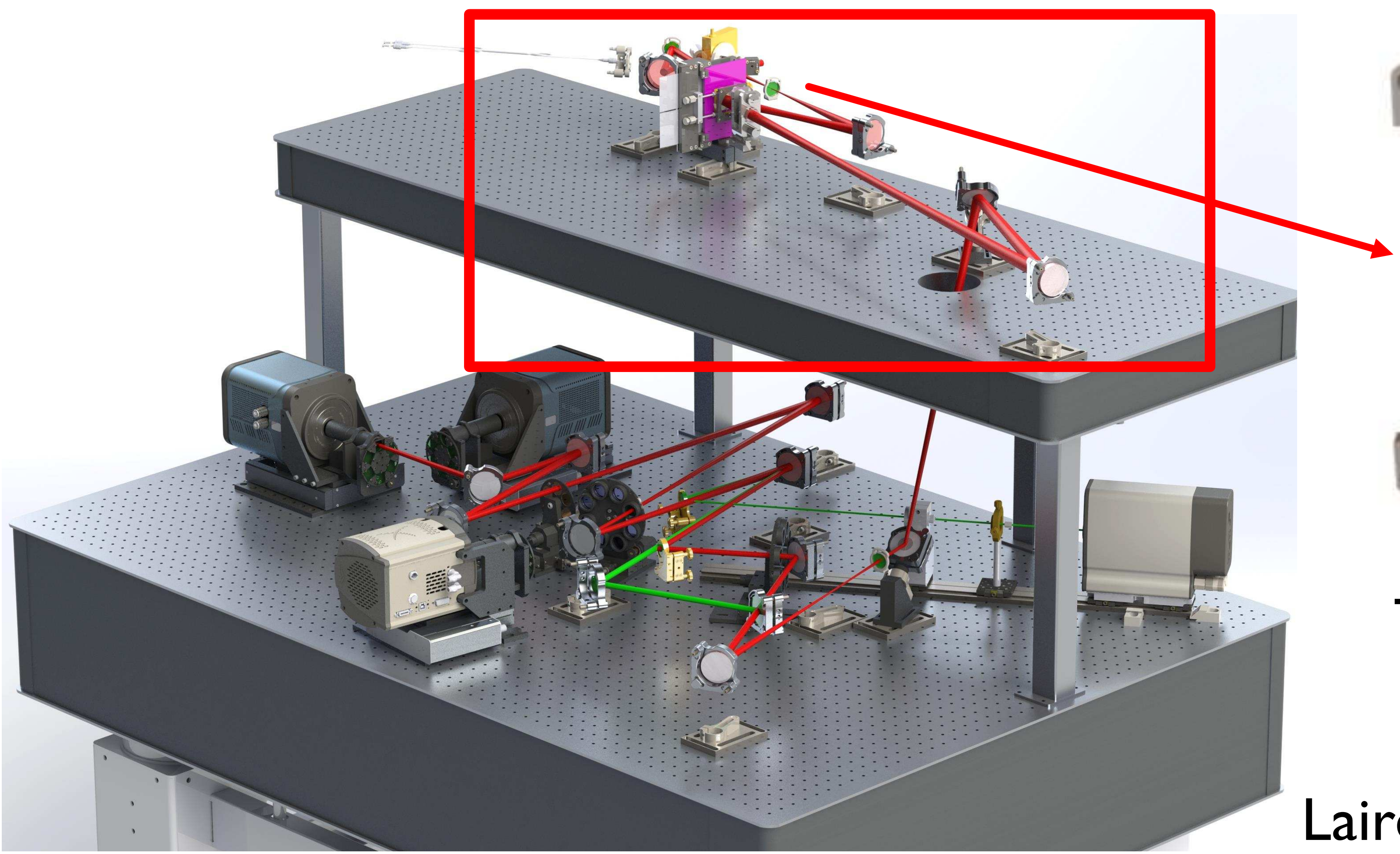
<u>MagAO-X: Magellan **Extreme** Adaptive Optics System</u>

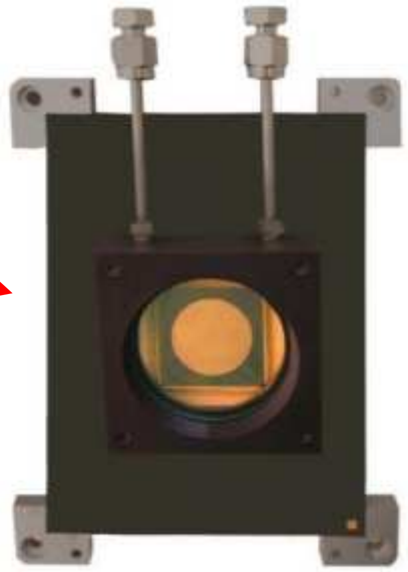
- P.I. Dr. Jared Males, Steward Observatory
- First light planned: Early 2019
- 2,000 actuator Boston Micromachines Deformable Mirror
- 3.6 kHz correction speed
- Pyramid Wavefront Sensor
- Coronagraph
- Imagers and Spectrographs



Laird Close, Corwynn Sauve

MAGAO-X



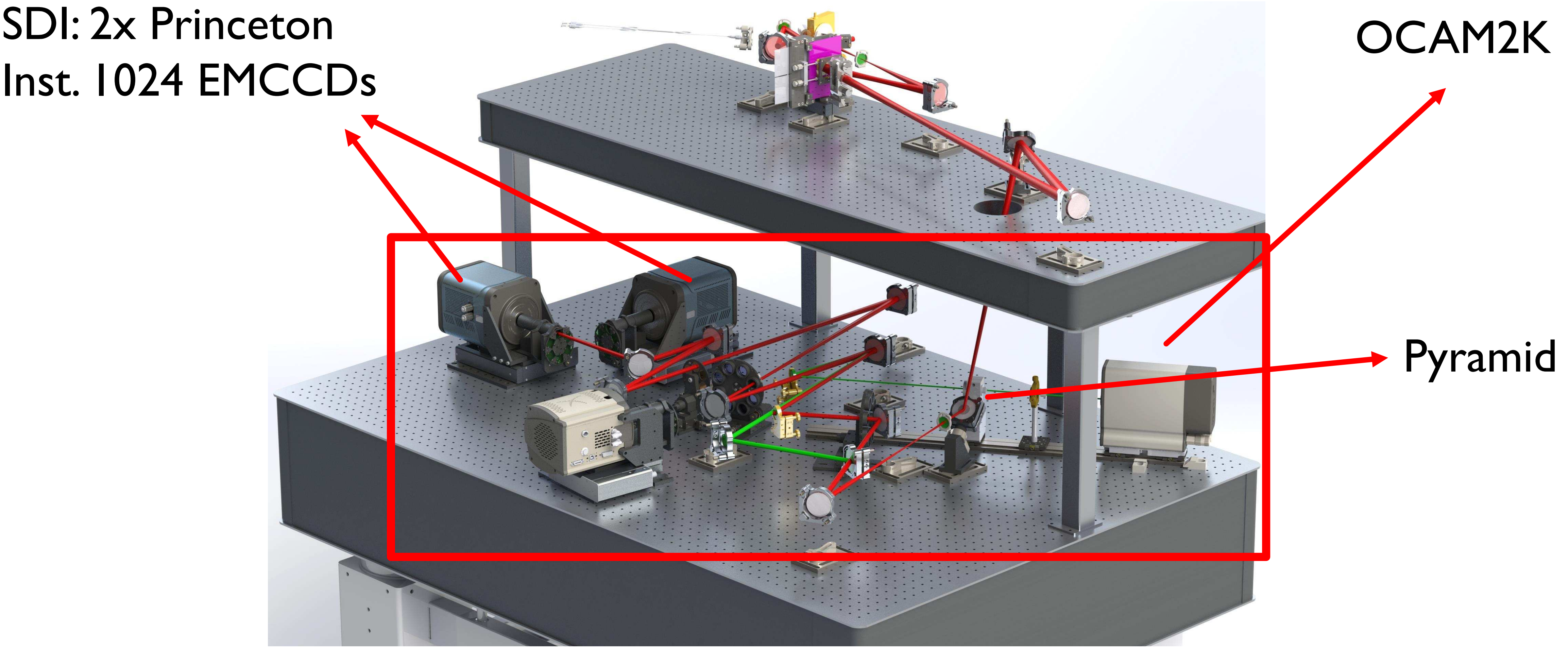


BMC 2K
Tweeter DM

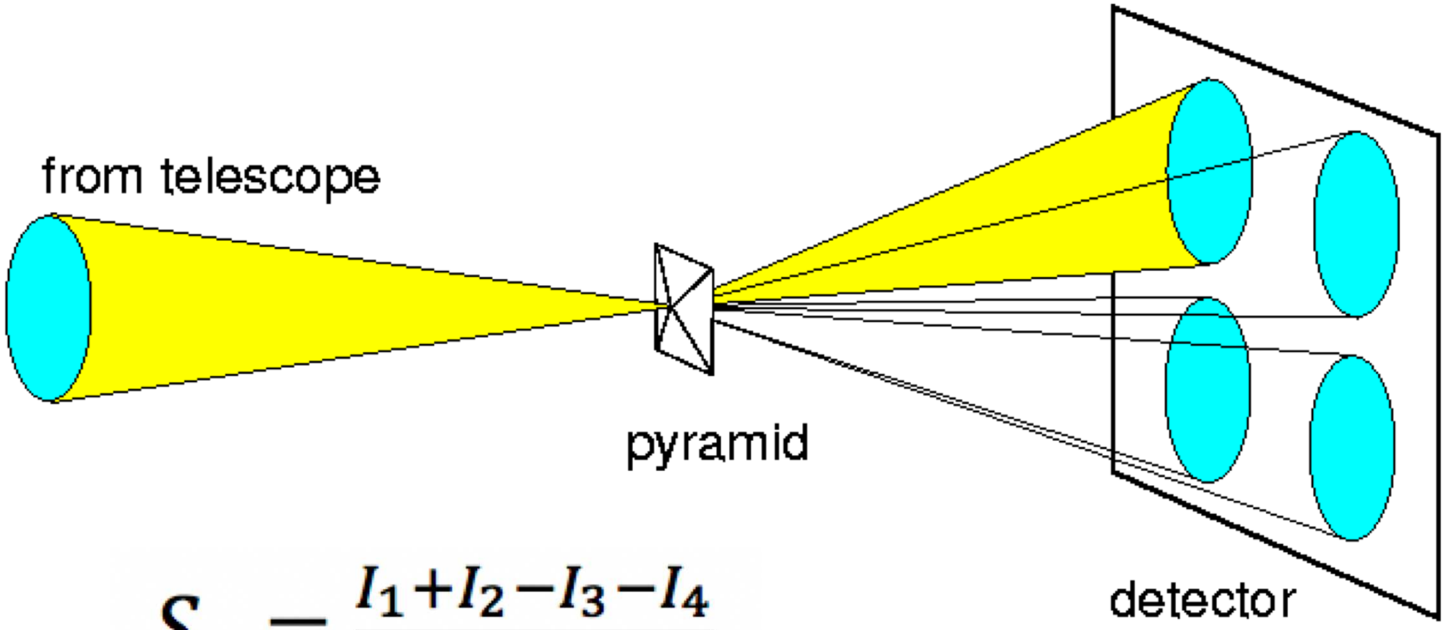
Custom locking kinematic optical mounts

Laird Close

MAGAO-X

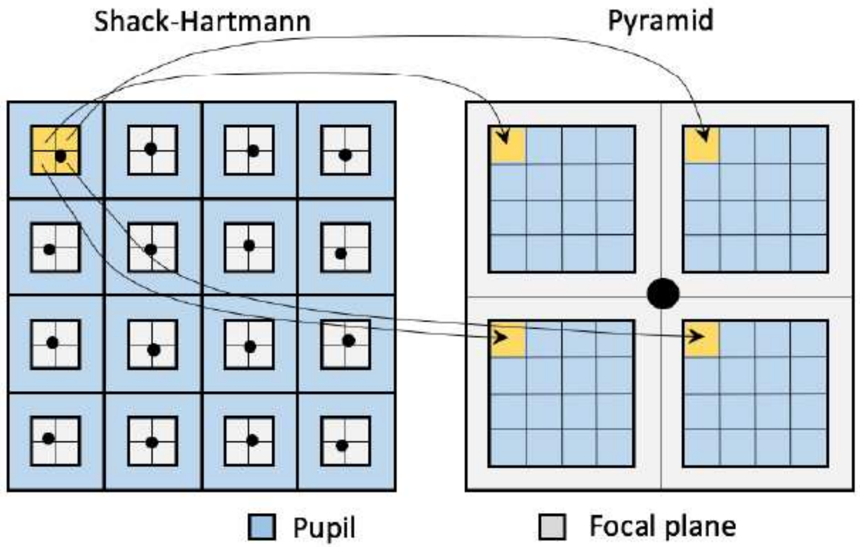


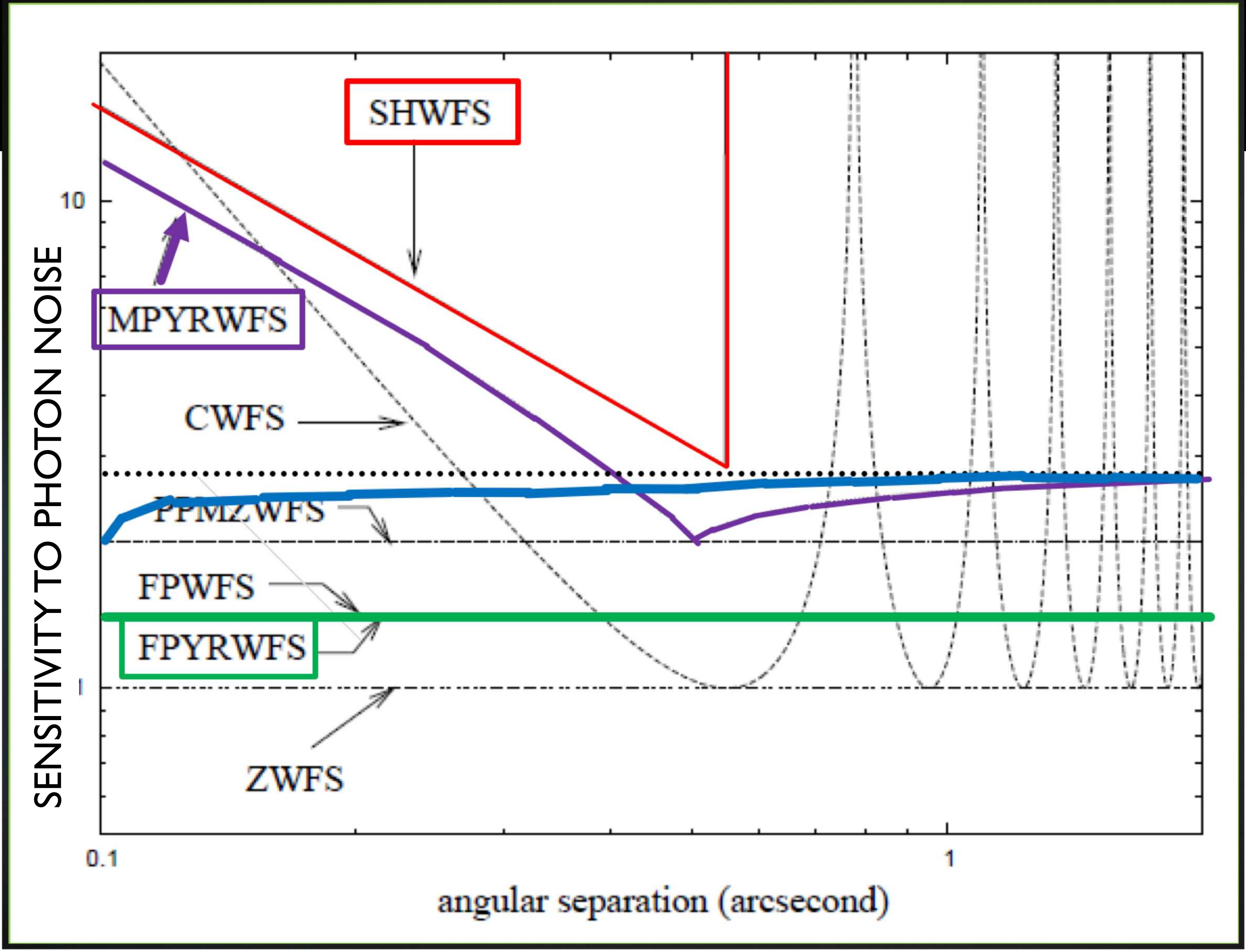
PYRAMID WAVEFRONT SENSING



$$S_x = \frac{I_1+I_2-I_3-I_4}{I_1+I_2+I_3+I_4}$$

$$S_y = \frac{I_1-I_2-I_3+I_4}{I_1+I_2+I_3+I_4}$$

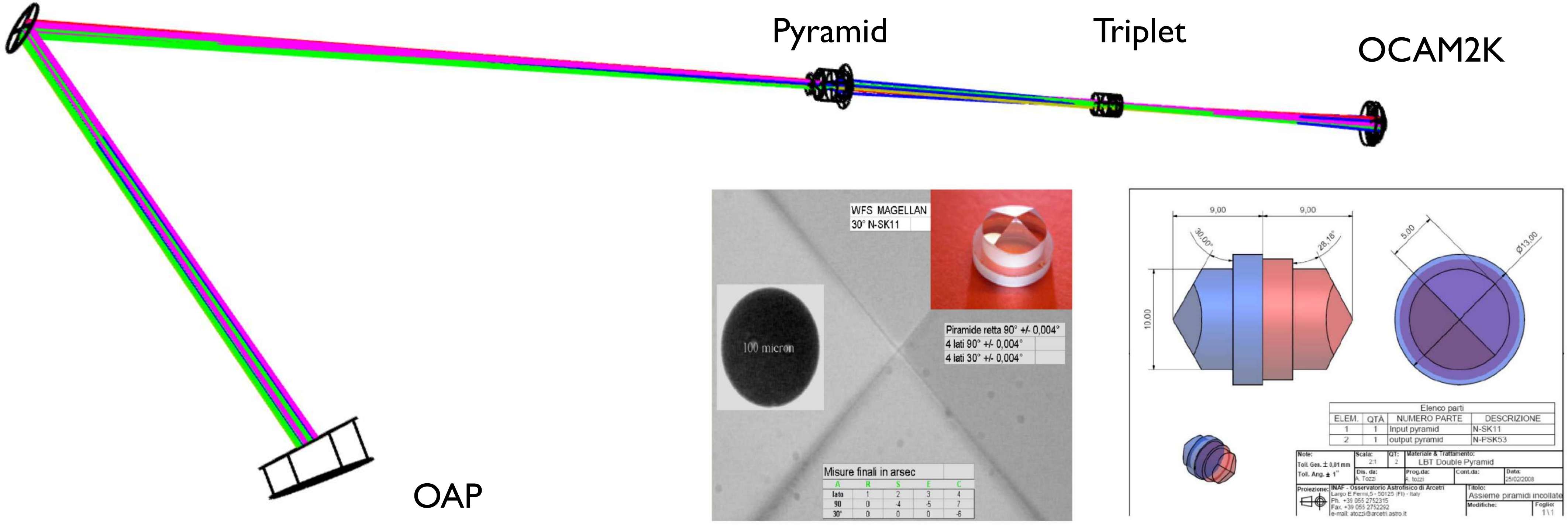




Purple: 0.5 arcsec modulation
Blue: Real modulation 60mili arcsec
Green: No modulation

Guyon 2005

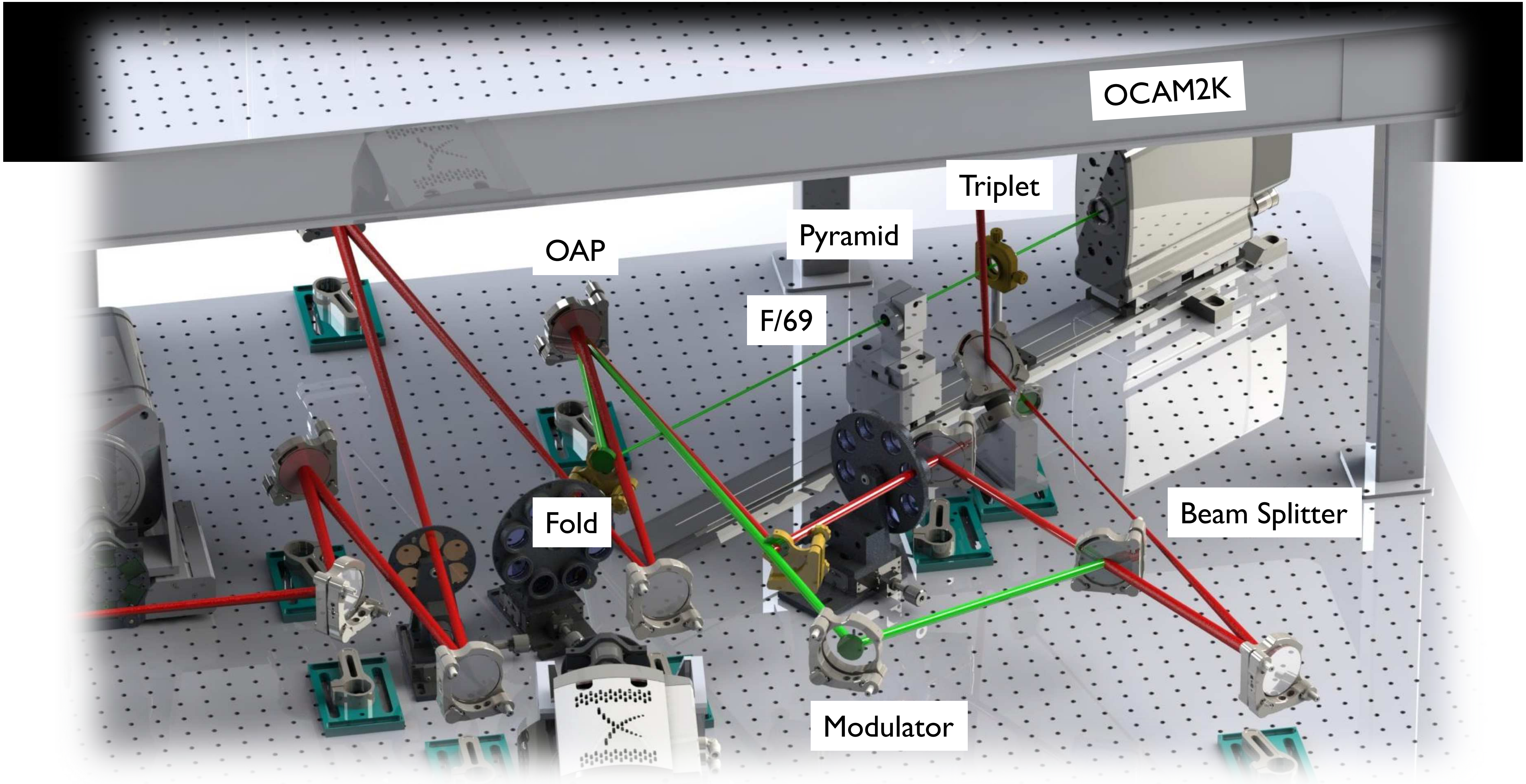
PYRAMID OPTICAL DESIGN



Designed and Manufactured by Arcetri

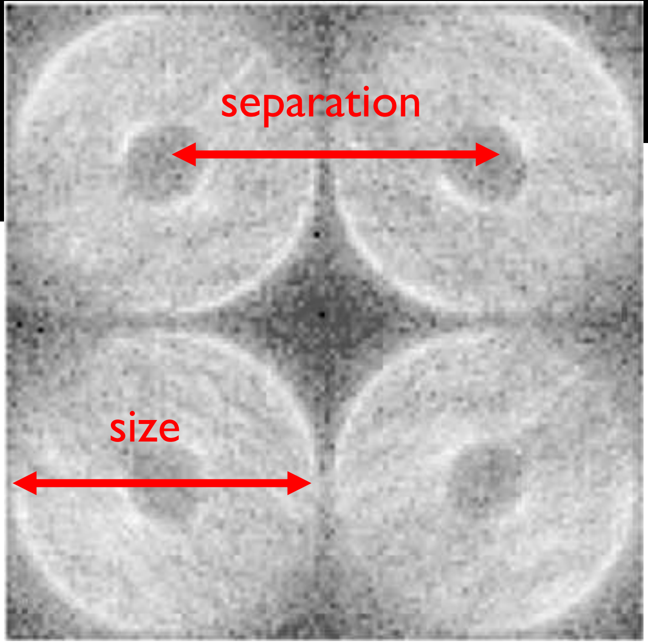
200 mm

Schatz et. al. in prep

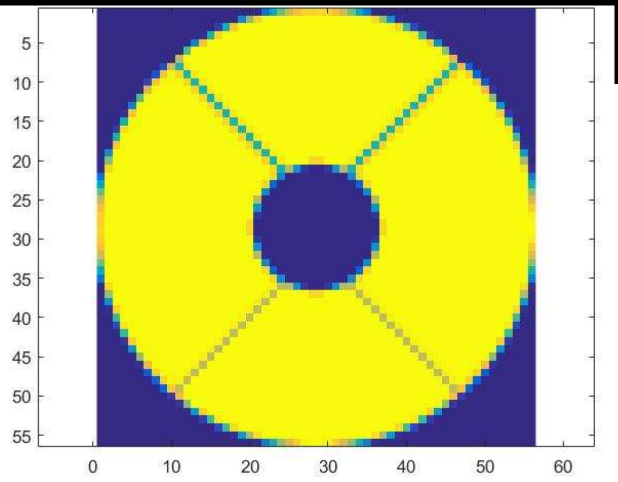

OCAM2K
Triplet
Pyramid
OAP
F/69
Fold
Beam Splitter
Modulator

Laird Close

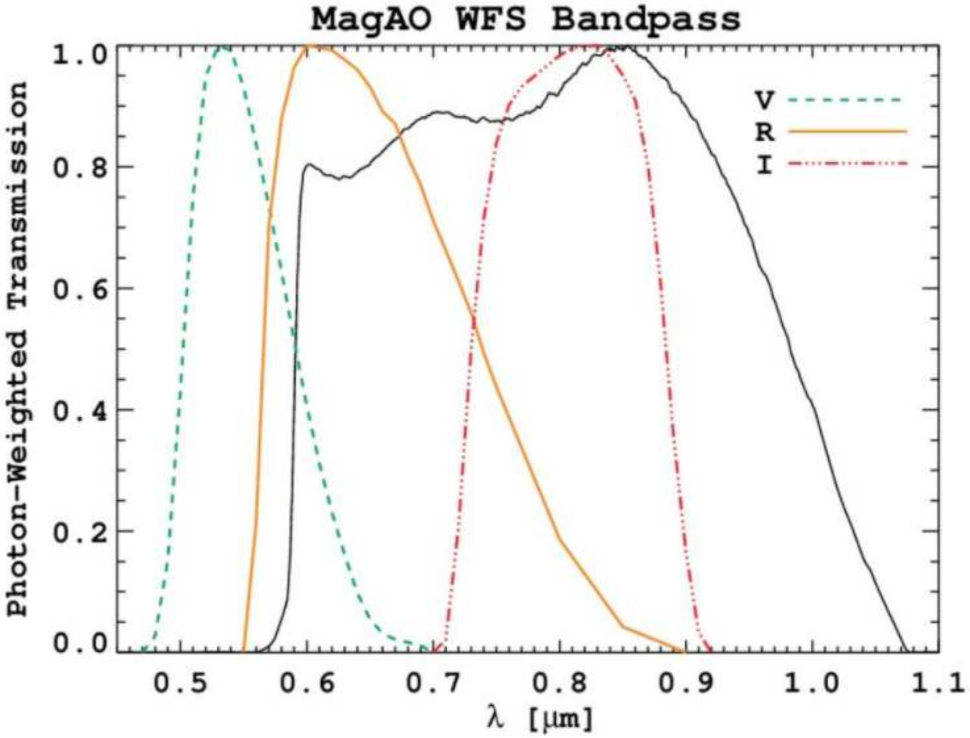
SYSTEM DESIGN



Expected Pixel Illumination



MagAO-X bandpass same as MagAO



Parameter	Requirement
Wavelength Range	600-1000 nm
Pupil Size	56 pixels; 2.688 mm
Pupil Separation	60 pixels; 2.880 mm
Pupil Tolerances	Δ < 1/10th pixel; 4.8 μm
Lens Diameter	10mm < D < 20 mm

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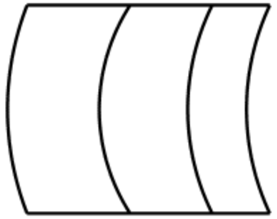
LENS DESIGN

Parameter	Requirement	As Built
Wavelength Range	600-1000 nm	600- 1000 nm
Pupil Size	56 pixels; 2.688 mm	2.696 mm
Pupil Separation	60 pixels; 2.880 mm	2.857 mm
Pupil Tolerances	Δ < 1/10th pixel; 4.8 µm	Δ_{size} =8 µm, Δ_{sep} =-23 µm,
Lens Diameter	10mm < D < 20 mm	D=10.1 mm



Radius	Thickness	Material
13.76800	4.40900	S-NPH2
9.18400	4.24900	S-BSM4
11.24350	2.82400	S-LAH64
11.75473	0.00000	

Manufactured by Rainbow Optics

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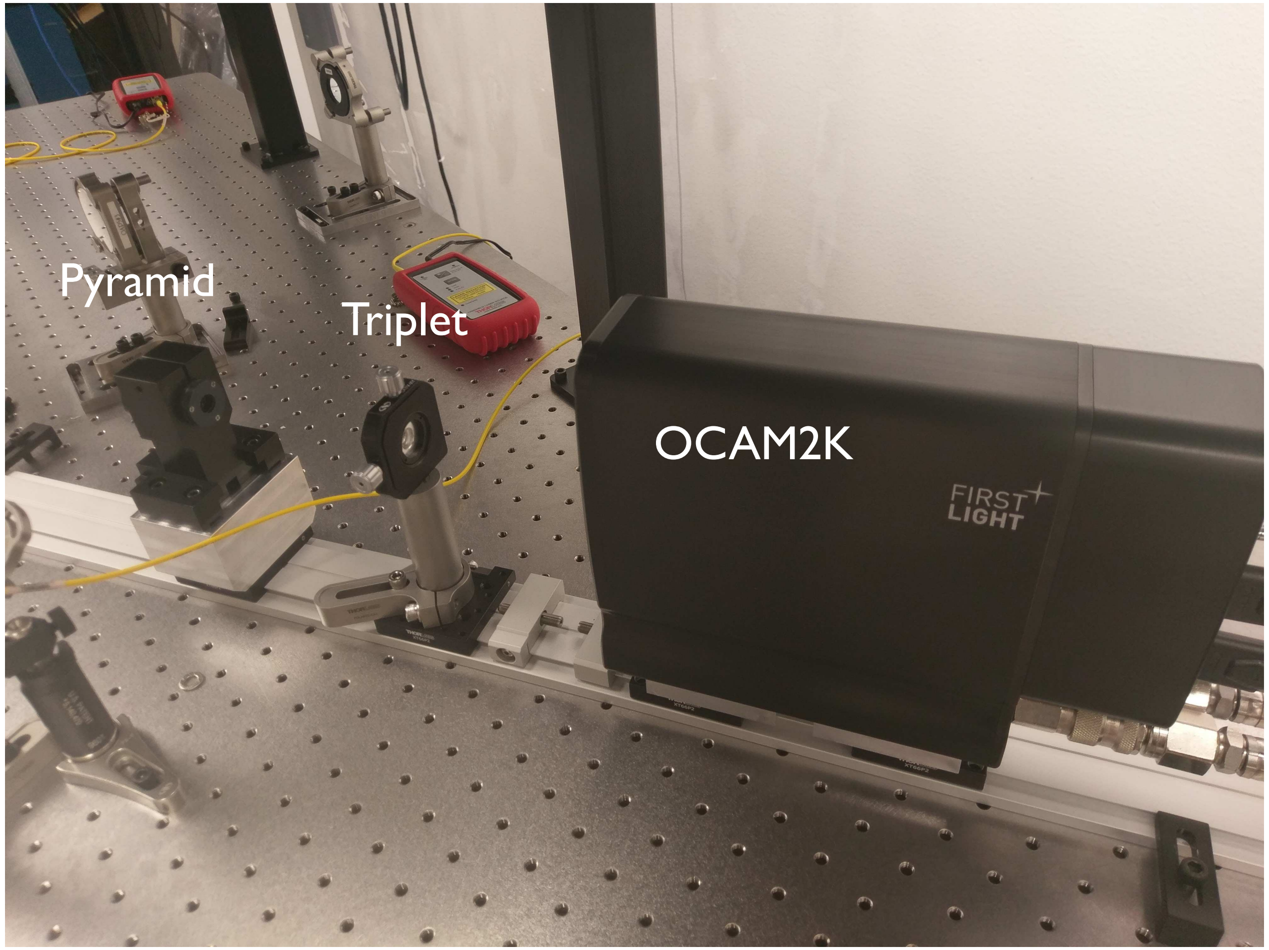
ALIGNMENT



Madison Jean
Optical Science Undergrad

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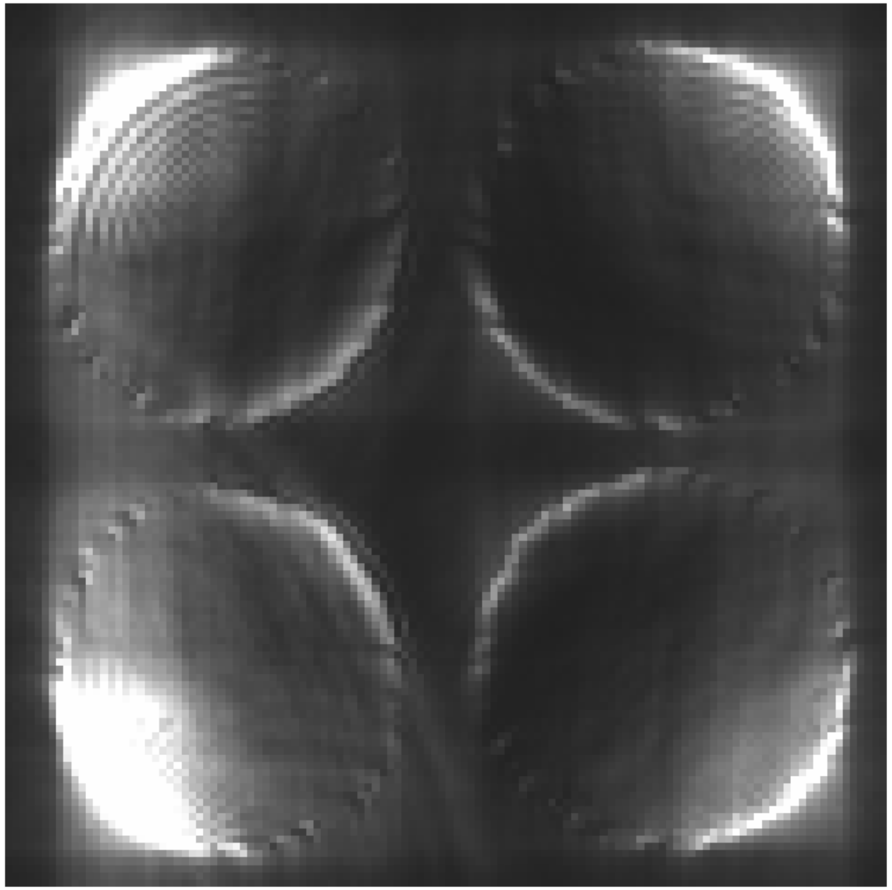
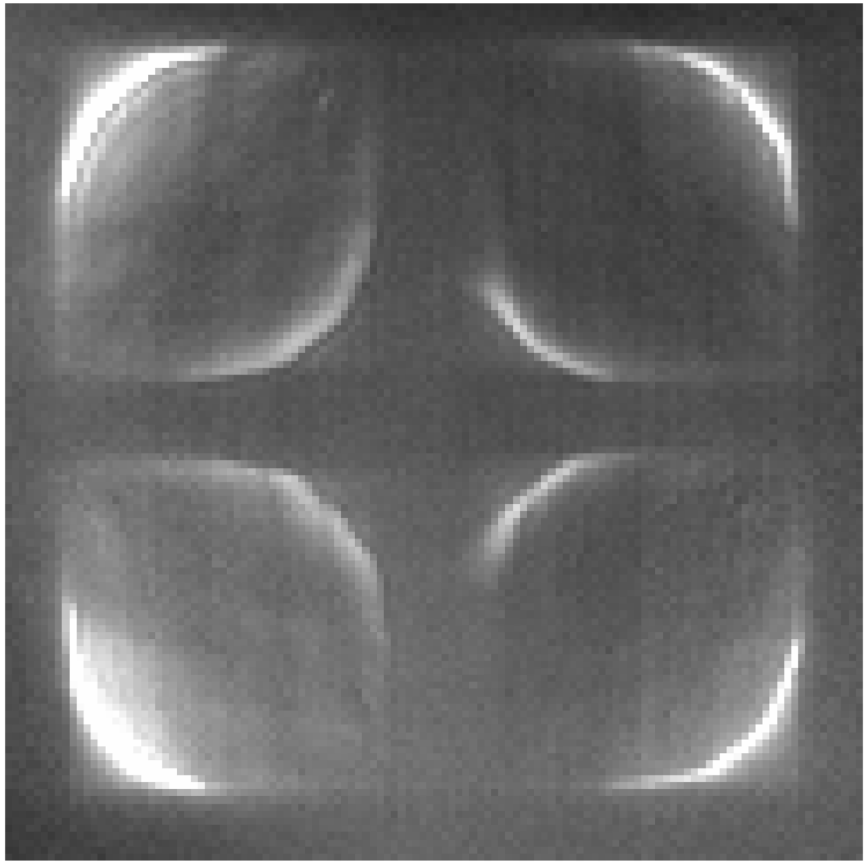
INITIAL RESULTS



HeNe Laser Full Pupils



White Light, Stopped Down

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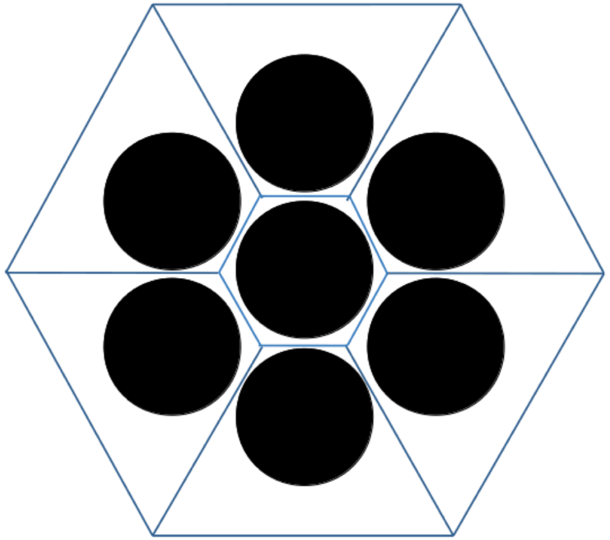
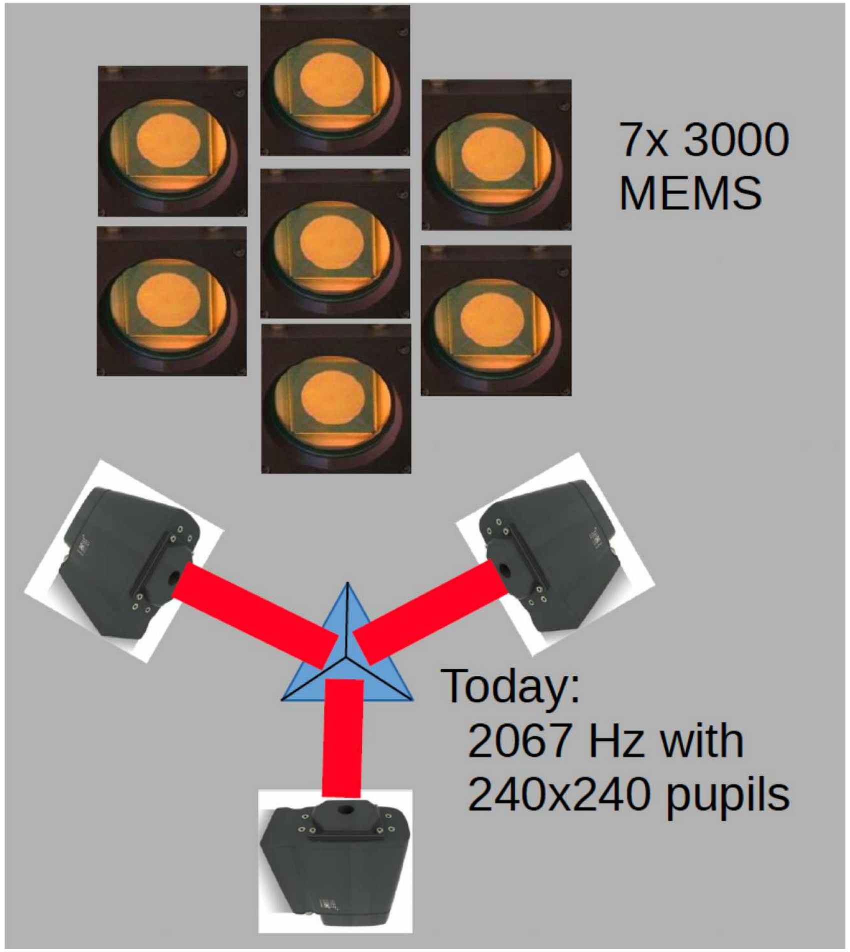
THE GIANT MAGELLAN TELESCOPE EXTREME ADAPTIVE OPTICS SYSTEM: GMAGAO-X

- 7x 3,000 actuator deformable mirrors
- 3 OCAM2K detectors
- 240 x 240 mode 2kHz on OCAM2k

Look out for Jared's Poster tonight! 10702-341





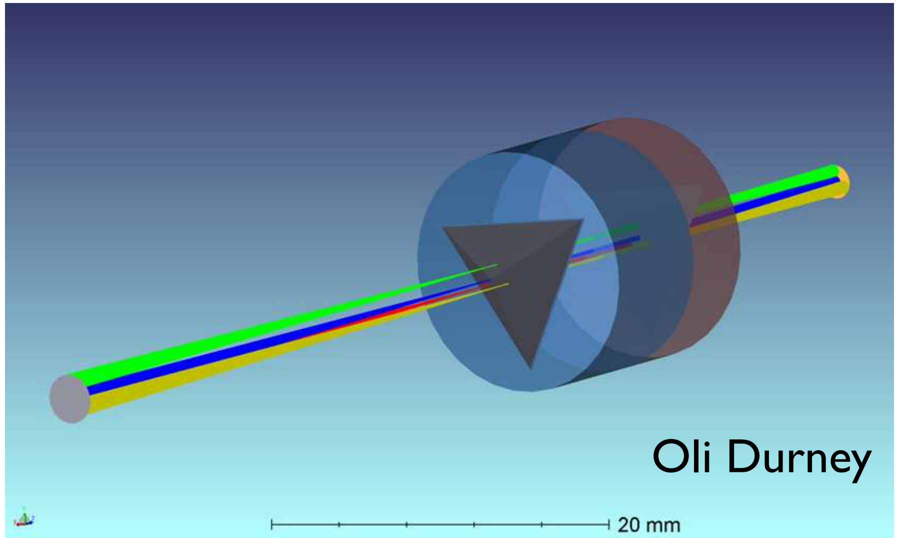
3PWFS VS 4PWFS

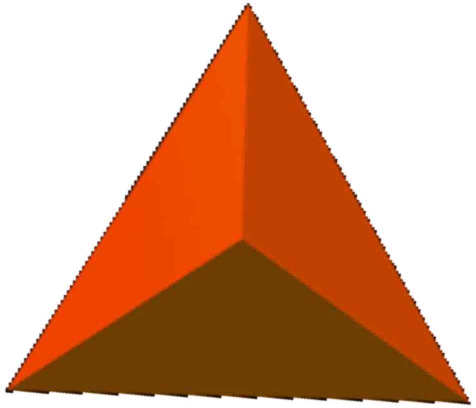
Benefits of Three Sided PWFS:

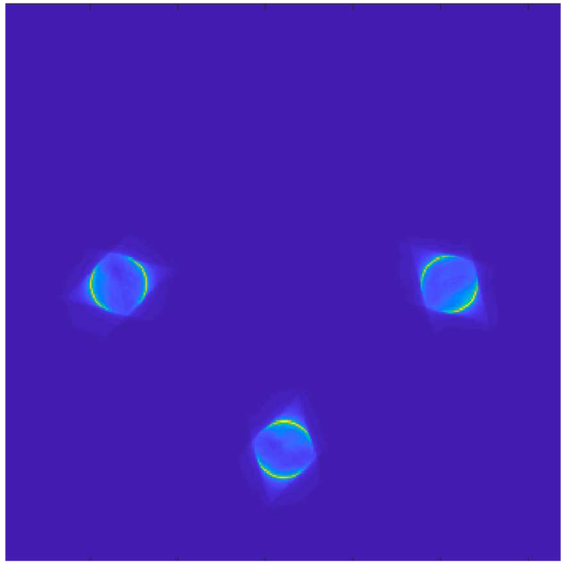
- Easier to manufacture
- Less pixels = less read noise

Benefits of Reflective vs Refractive:

- Multiple detectors
- Faster, less read noise







4 sided

$$S_x = \frac{I_1 + I_2 - I_3 - I_4}{I_1 + I_2 + I_3 + I_4}$$

$$S_y = \frac{I_1 - I_2 - I_3 + I_4}{I_1 + I_2 + I_3 + I_4}$$

3 sided

$$S_x = \frac{I_2\left(\frac{\sqrt{3}}{2}\right) - I_3\left(\frac{\sqrt{3}}{2}\right)}{I_1 + I_2 + I_3}$$

$$S_y = \frac{I_1 - I_2\left(\frac{1}{2}\right) - I_3\left(\frac{1}{2}\right)}{I_1 + I_2 + I_3}$$

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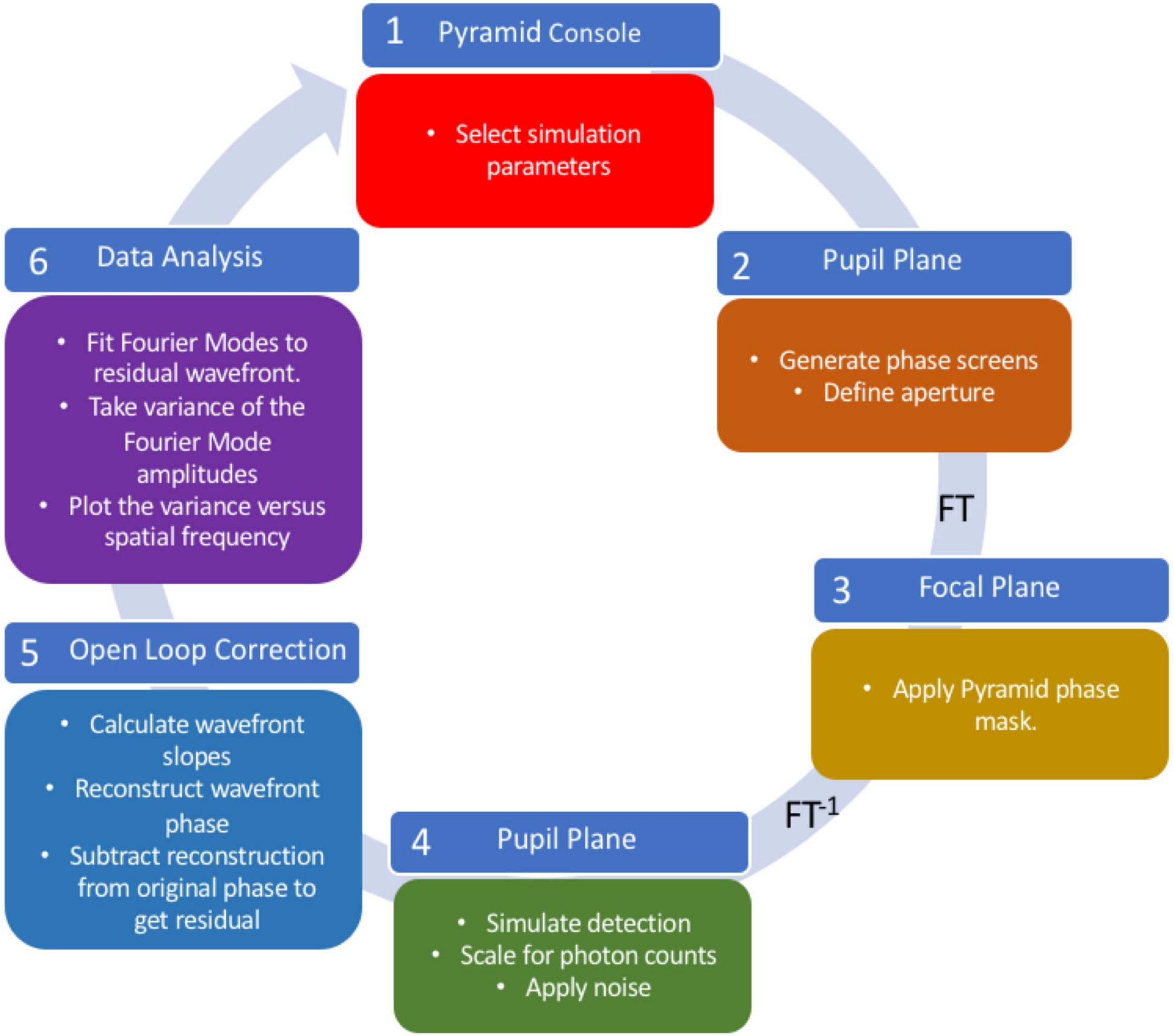
PYRITE

Pyramid Residual Wavefront Experiment

Robust Simulation Tool:

- Simulates atmospheric turbulence.
- Different Pyramid architectures.
- Reflective vs Refractive
- Manufacturing errors.
- Uses residual wavefront error as a metric.



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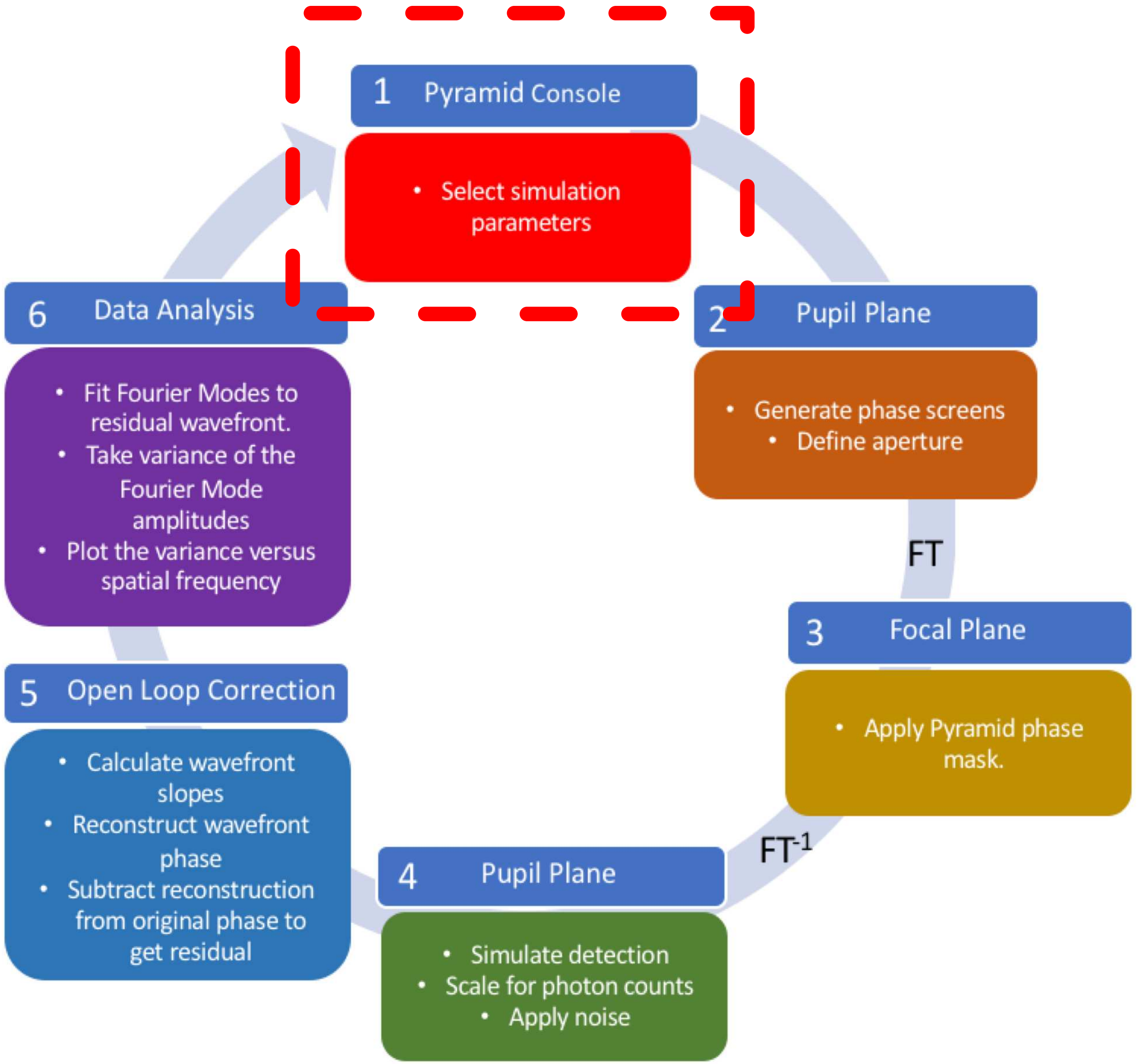

Run through a console script.
Can select:

- Number of photons
- Read noise
- # Pixels across pupil
  - 16, 32, 64

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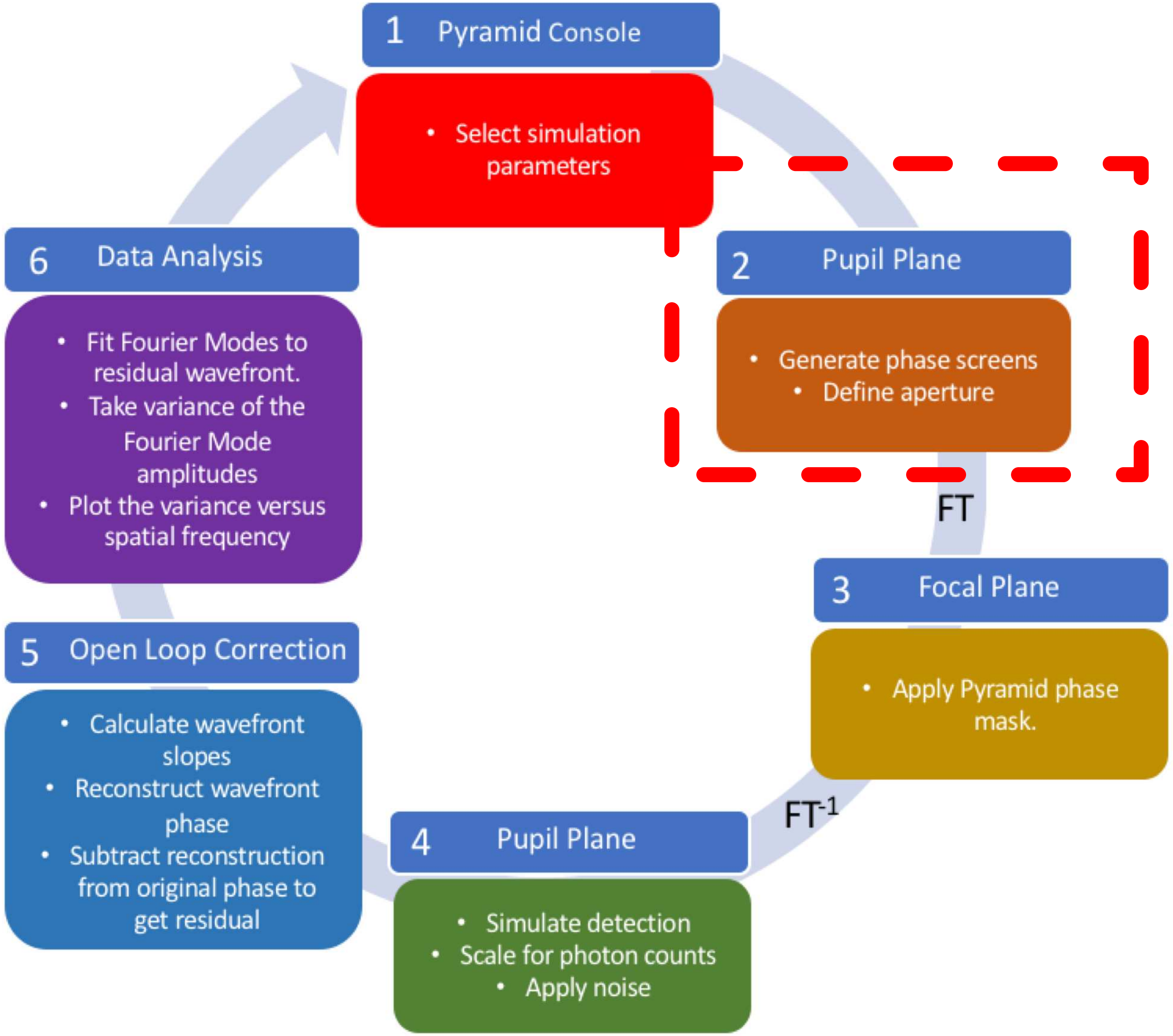

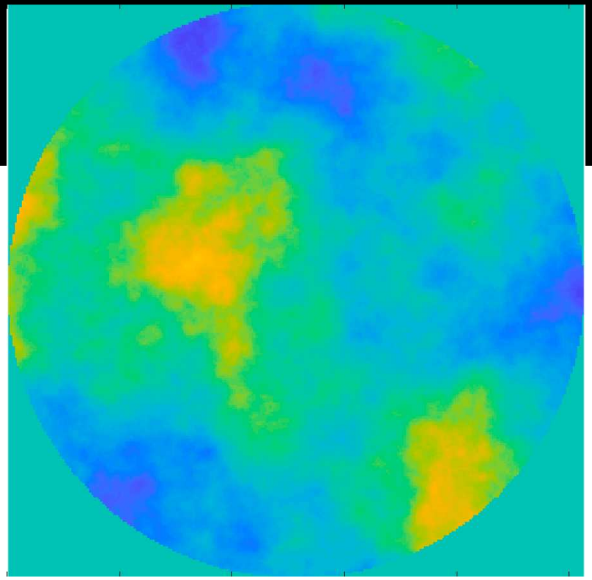

- Kolmogorov Turbulence Model
  - Random phase screens generated
  - Piston, tip/tilt removed.
- Plate Scale: $\frac{1}{10}\left(\frac{\lambda}{D}\right)$

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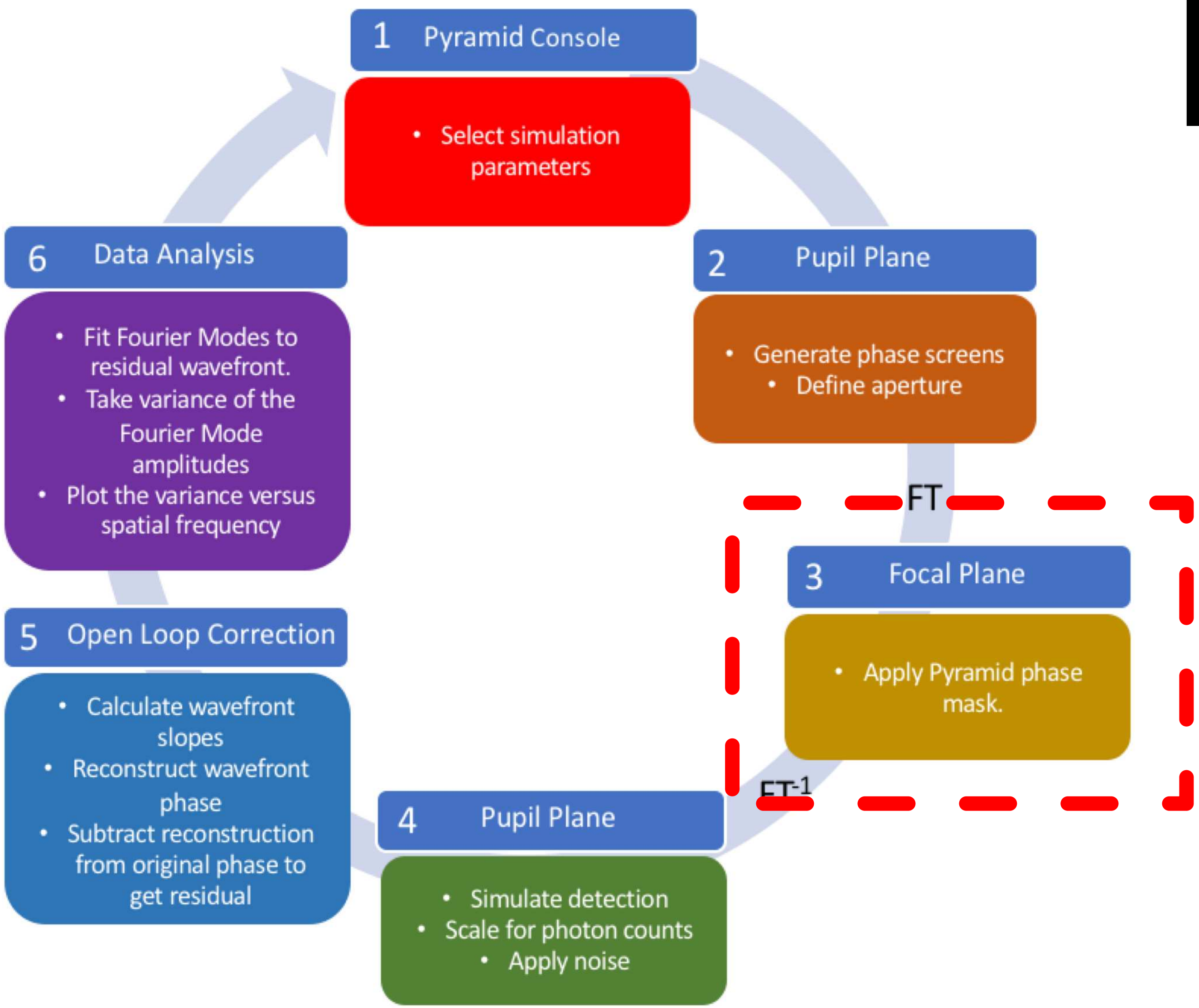
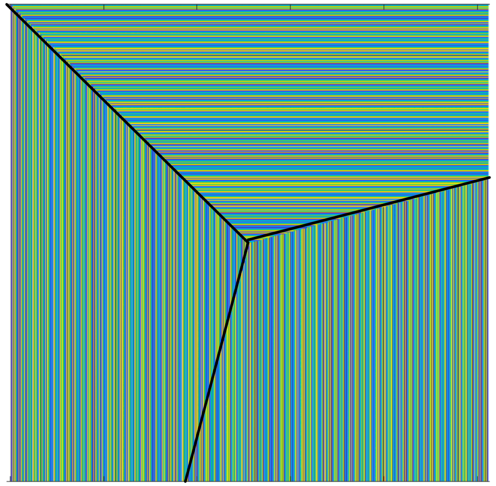
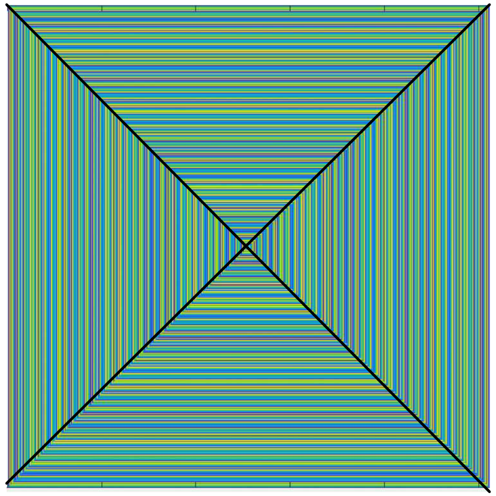
PYRITE

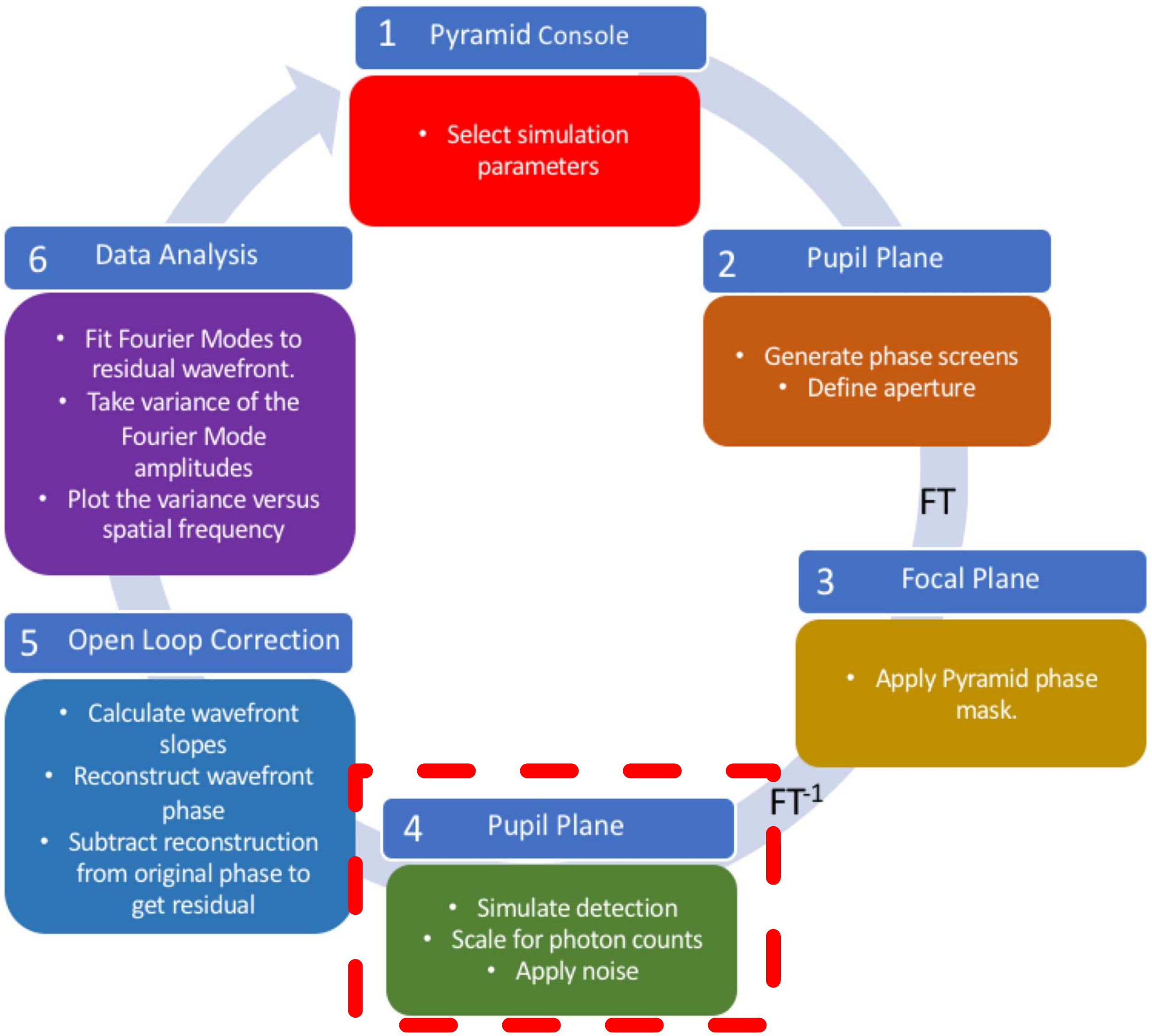


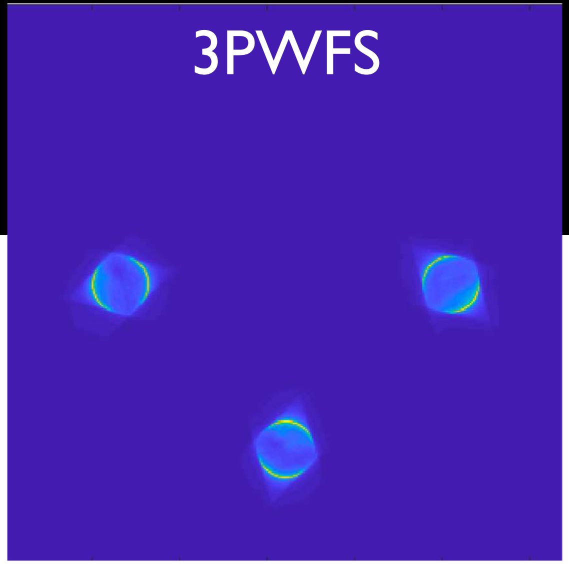
3PWFS



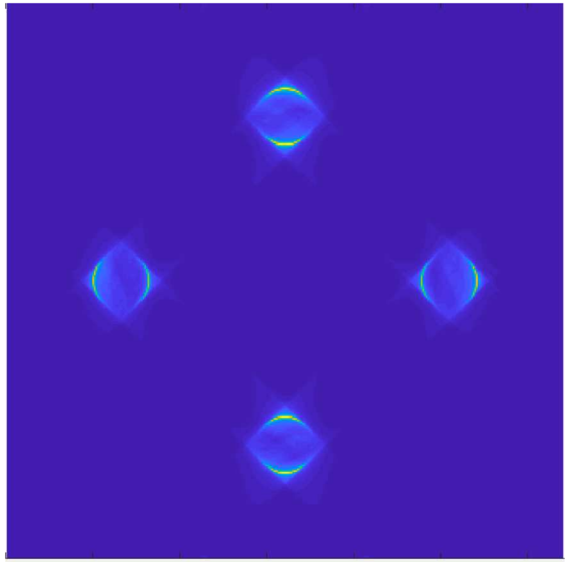
4PWFS



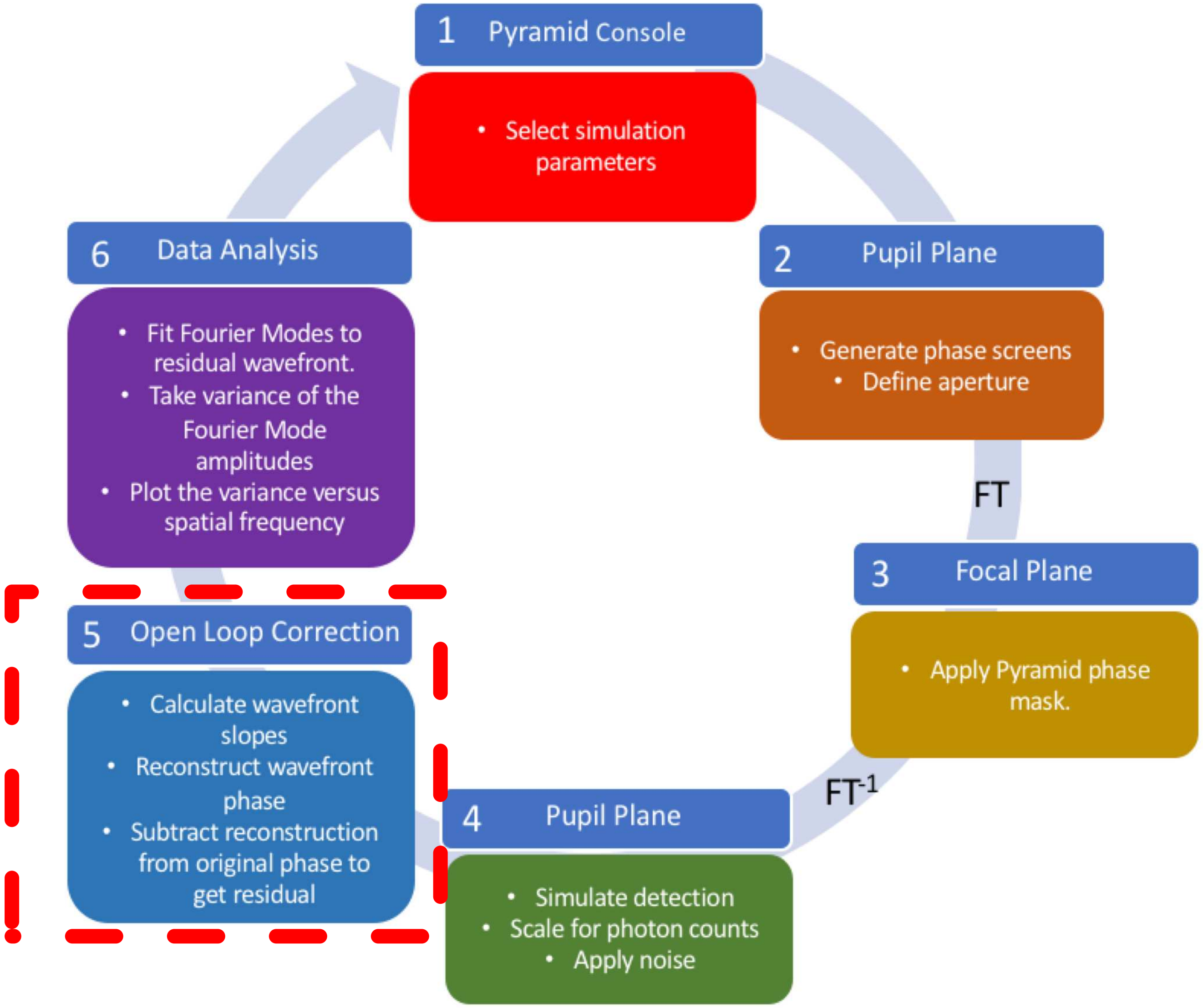

1 Pyramid Console
Select simulation parameters
2 Pupil Plane
Generate phase screens
Define aperture
FT
3 Focal Plane
Apply Pyramid phase mask.
FT-1
4 Pupil Plane
Simulate detection
Scale for photon counts
Apply noise
5 Open Loop Correction
Calculate wavefront slopes
Reconstruct wavefront phase
Subtract reconstruction from original phase to get residual
6 Data Analysis
Fit Fourier Modes to residual wavefront.
Take variance of the Fourier Mode amplitudes
Plot the variance versus spatial frequency


3PWFS

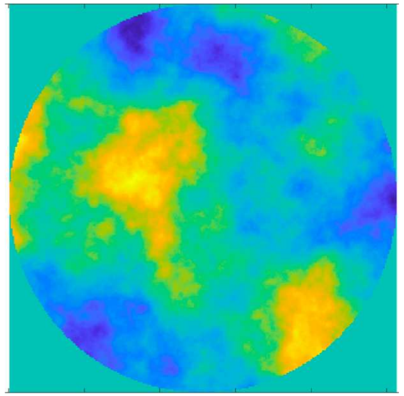
4PWFS



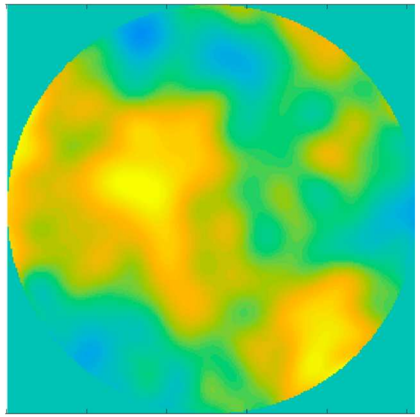
PYRITE



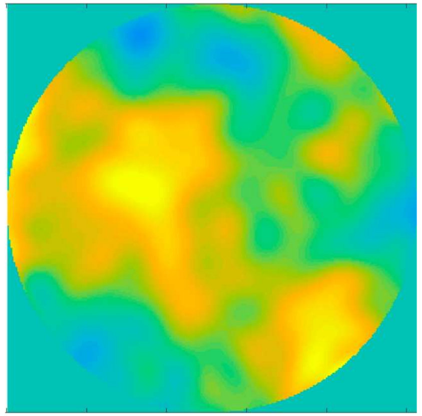
Input



3PWFS

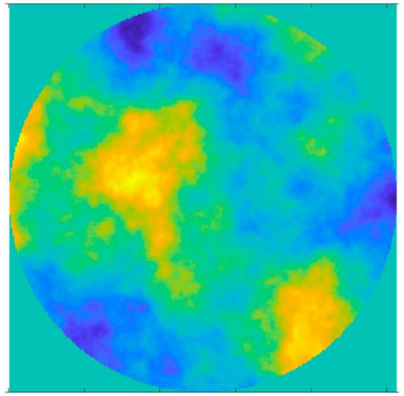


4PWFS

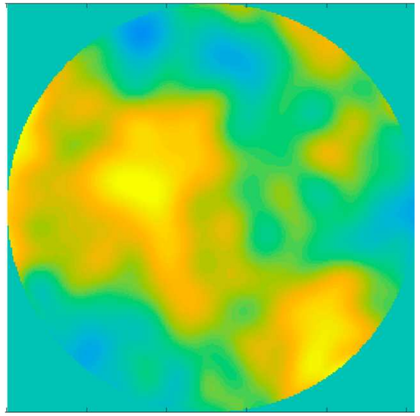


5) RESIDUAL WAVEFRONT

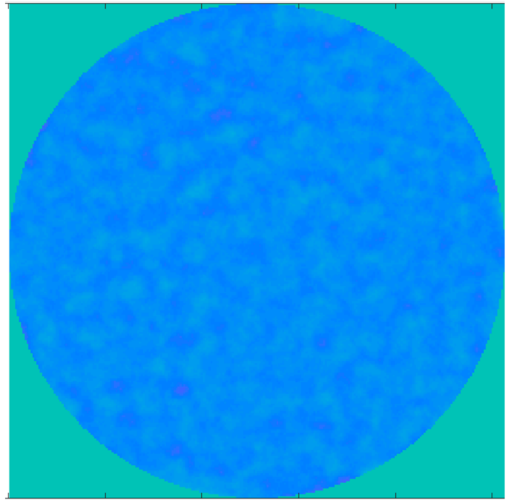
Actual



Reconstructed



Residual Wavefront



Fit with Fourier Modes to analyze power spectrum

TRADE STUDY

- 3PWFS vs 4PWFS
- Reflective vs Refractive Pyramid
- Manufacturing Errors vs No Errors
- Read Noise
- Guide Star Magnitudes

PYRAMID WAVEFRONT SENSING UPDATE FOR MAGAO-X

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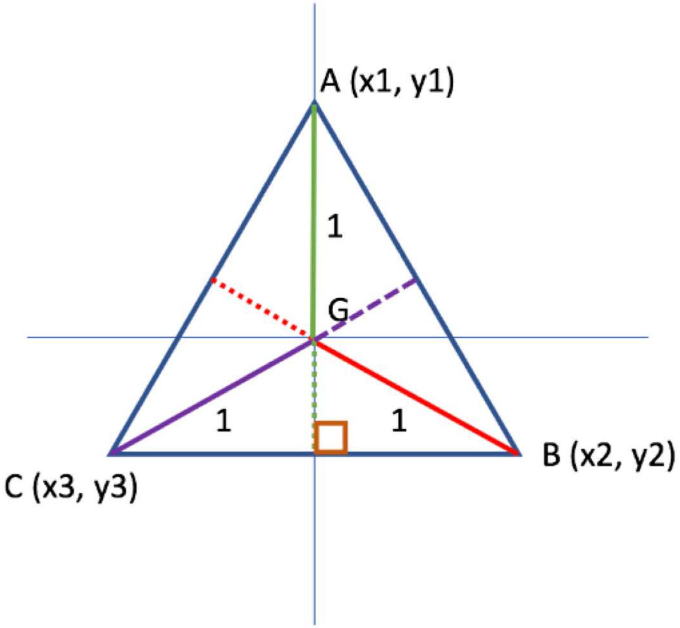
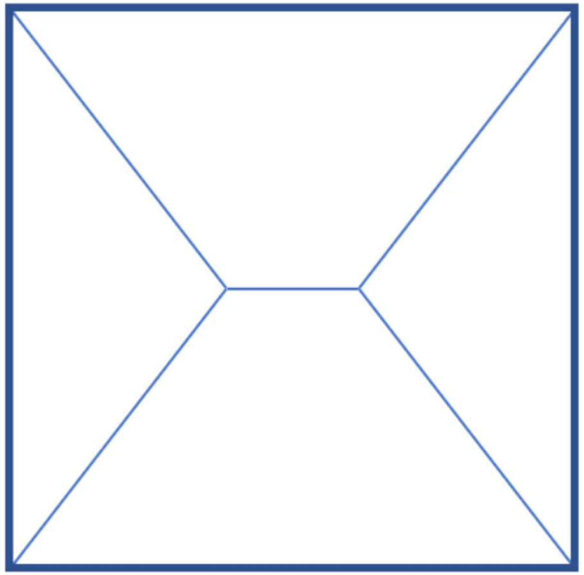
MagAO-X PYRITE MagAO ARIZONA CAAO Center for Astronomical Adaptive Optics

CANNED SLIDES





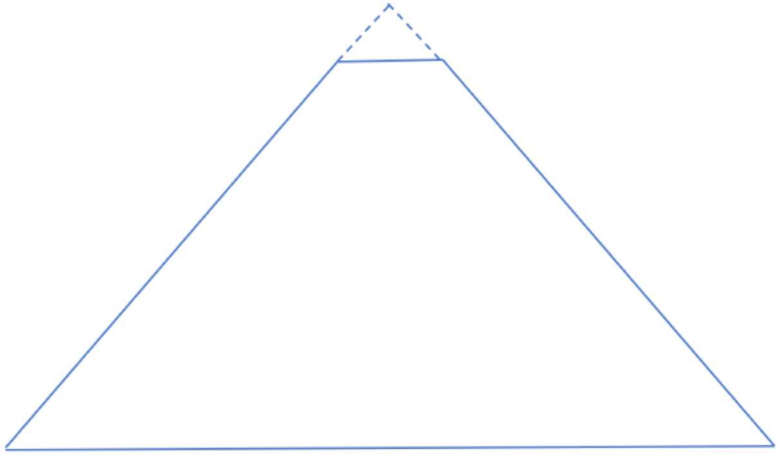


Figure 5. The roofing of a four sided pyramid tip.