MAPS

ARIZONA

UNIVERSITY OF TORONTO

NSF

WFS2020

Visible pyramid wavefront sensor for MAPS - **M**MT **A**daptive optics exo**P**lanet characterization **S**ystem

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For

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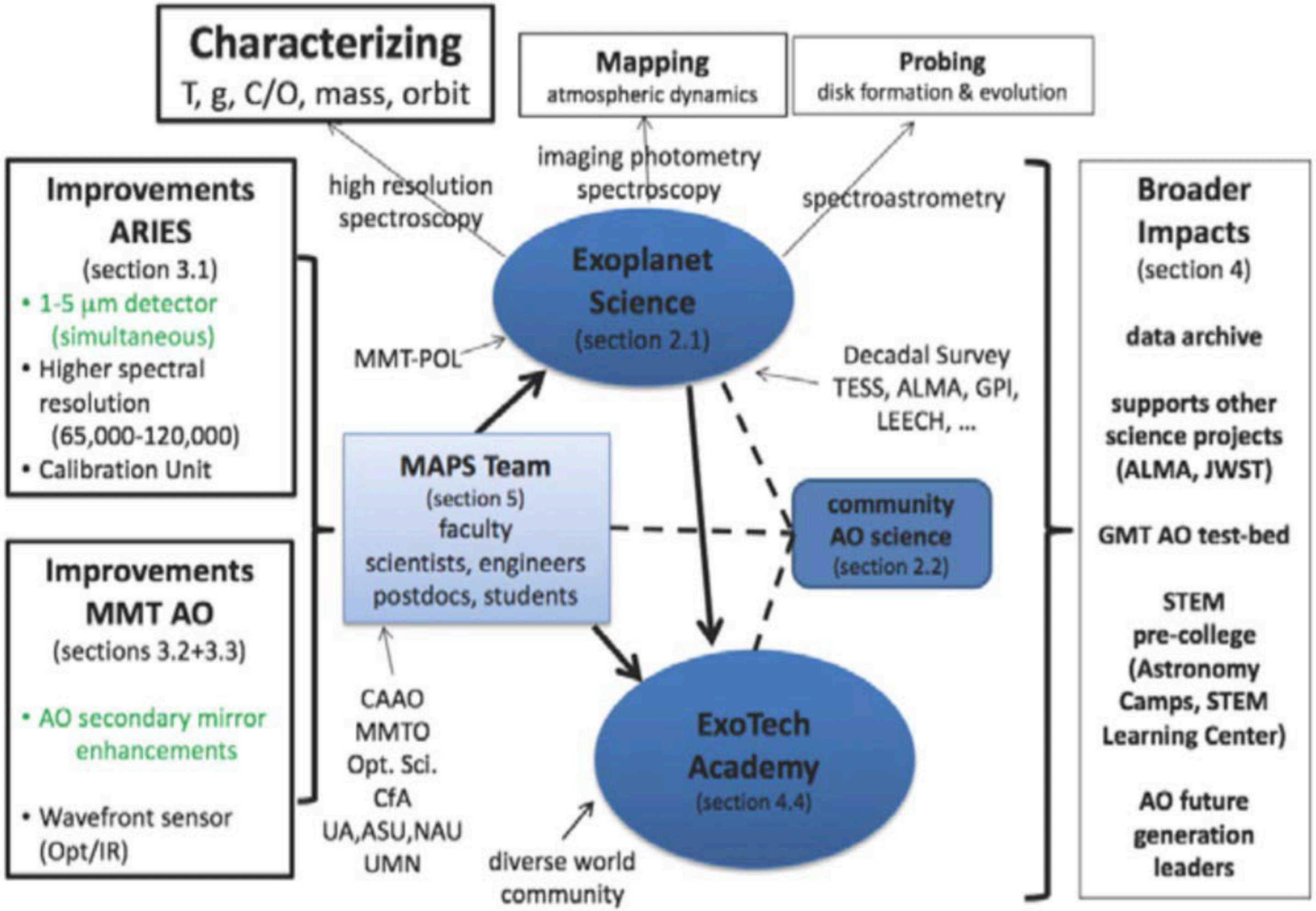
PI: Katie Morzinski

4 year NSF MSIP funded project

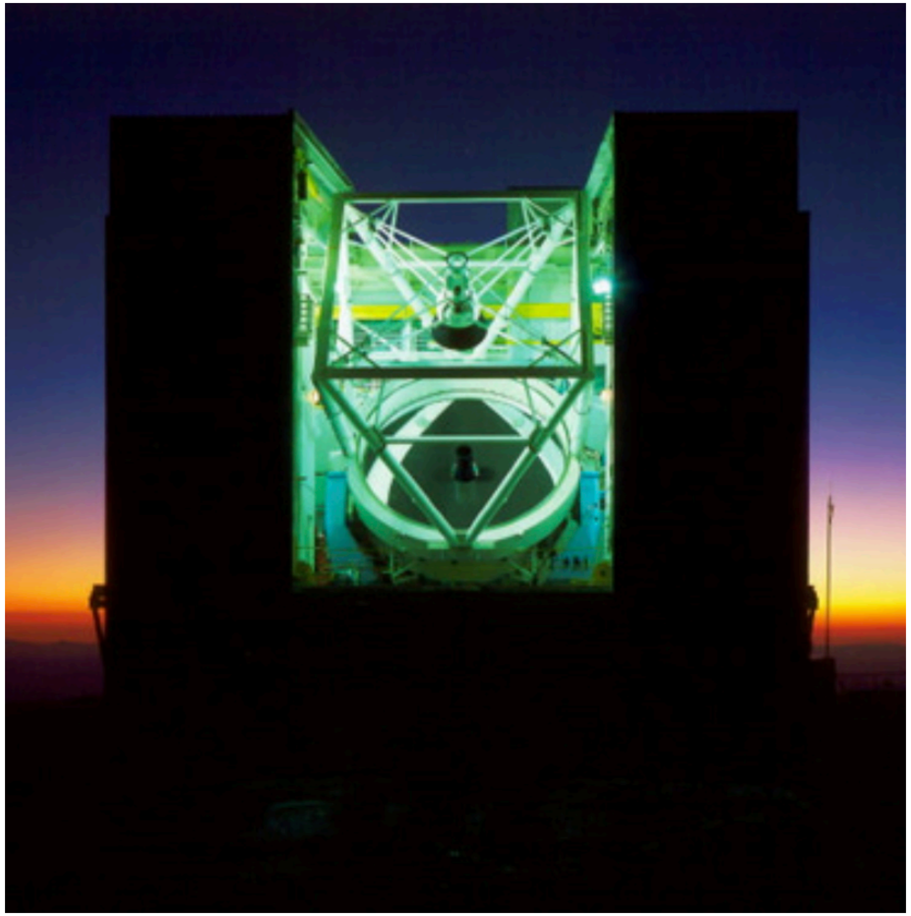
- upgrade of MMT - adaptive secondary mirror (ASM)
- Upgrade of ARIES (1-5 um imager and spectrograph) for 60,000 spectral resolution
- When built is comparable to ESO/CRIRES

60 MMT nights committed

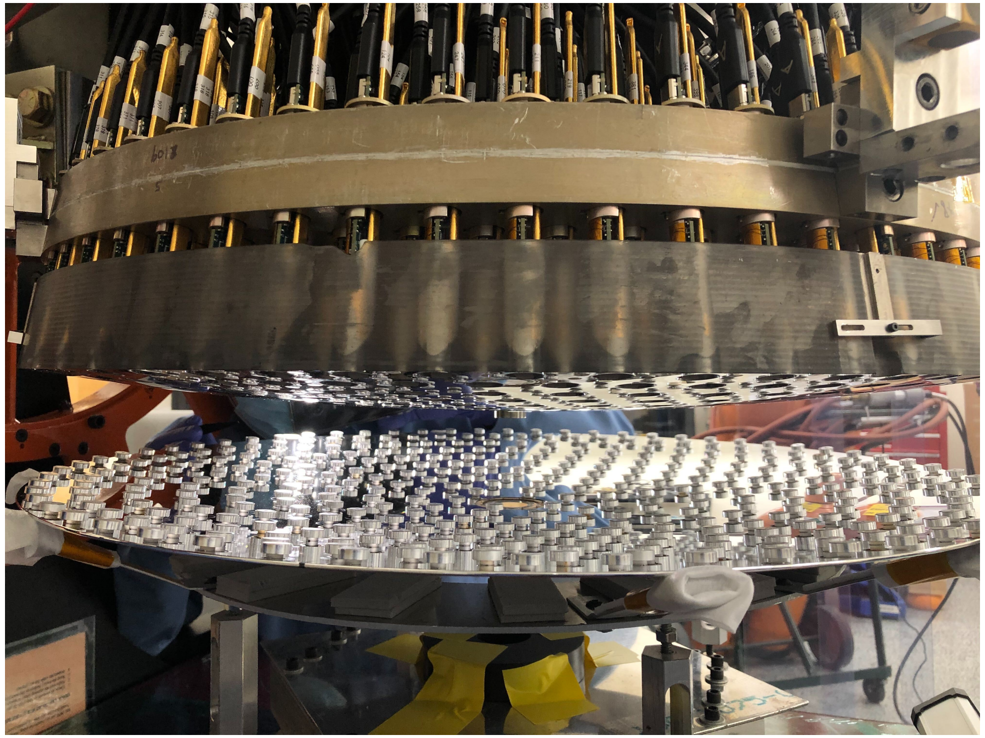


https://www.as.arizona.edu/~ktmorz/

MMT adaptive secondary mirror



MMT 6.5 m telescope, located in Arizona, US



336 adaptive optics secondary mirror (ASM)

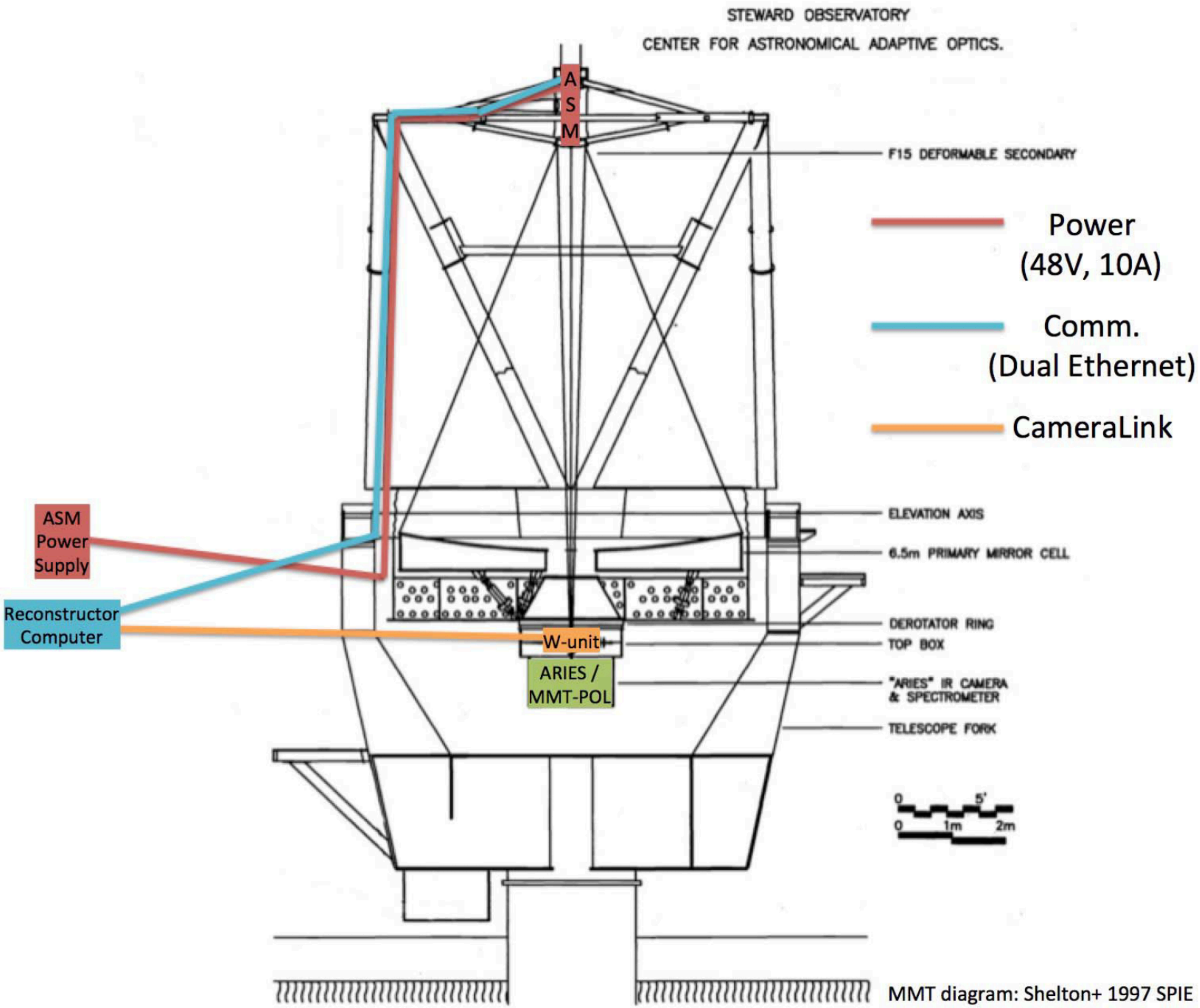
Control electronics and software developed by our University of Arizona team

Optimized for:

— higher modes of correction

— Low power emission

MAPS overview



MMT diagram: Shelton+ 1997 SPIE

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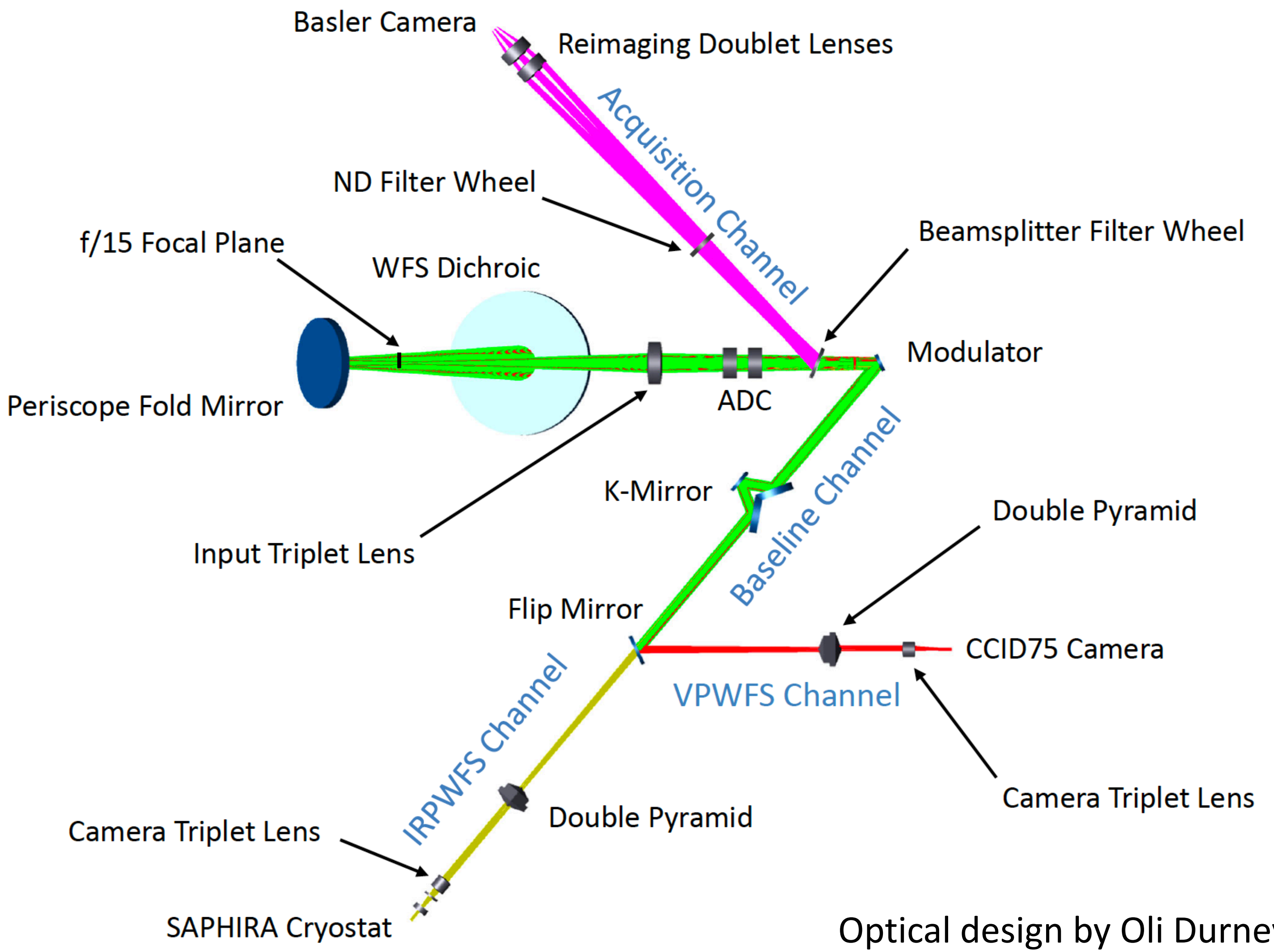
Optical design



Optical design by Oli Durney and Shaojie Chen

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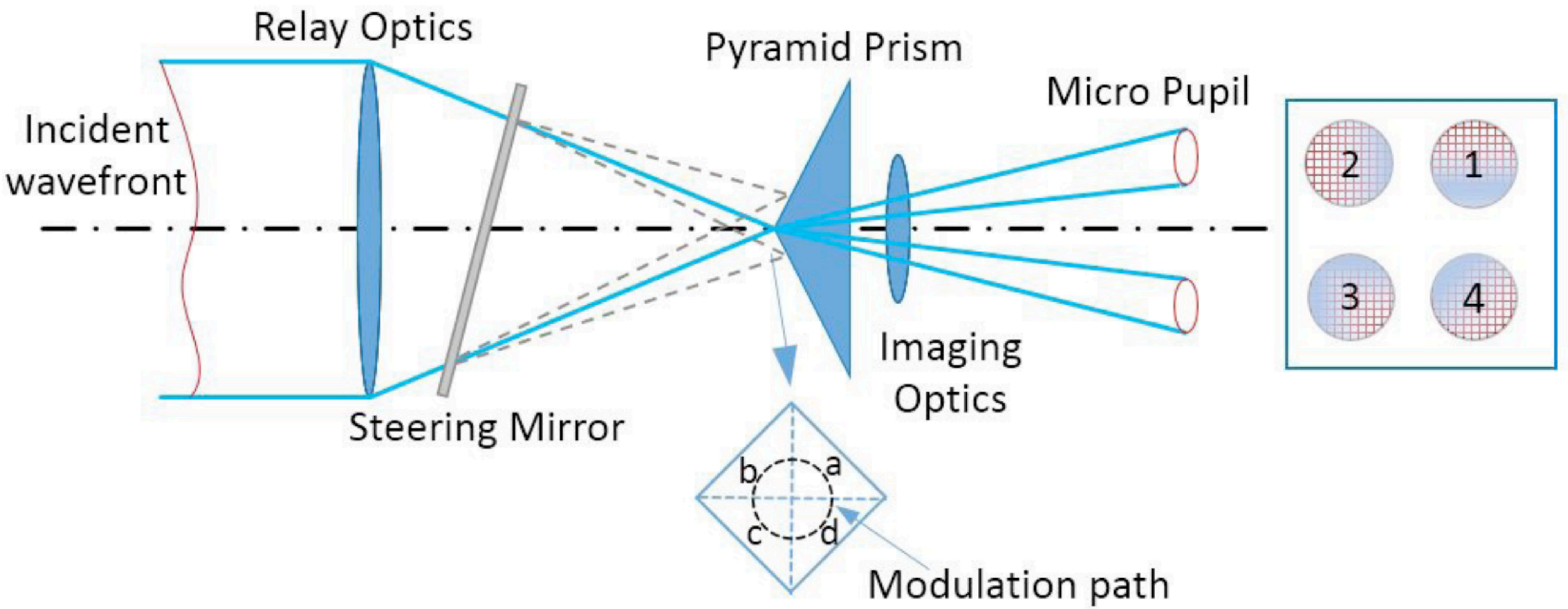
Pyramid wavefront sensor



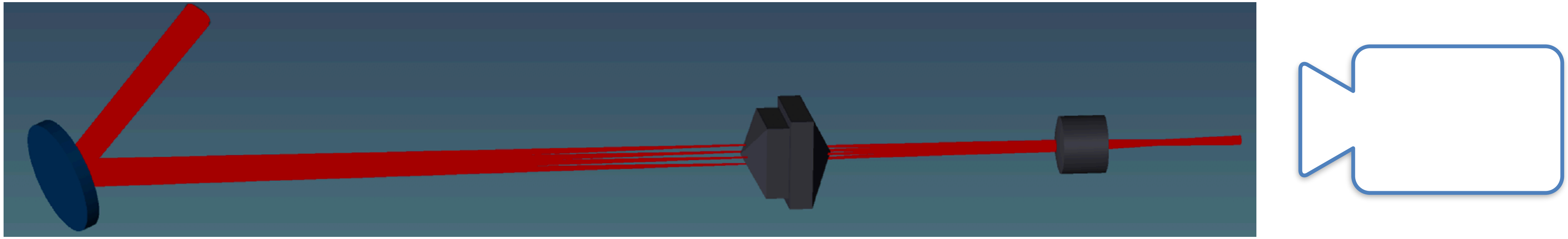
$$S_x(x,y) = \frac{I_1(x,y)+I_4(x,y)-[I_2(x,y)+I_3(x,y)]}{I_1(x,y)+I_2(x,y)+I_3(x,y)+I_4(x,y)}$$

$$\frac{\partial W(x,y)}{\partial x} \approx \frac{\pi V}{2f} S_x(x,y)$$

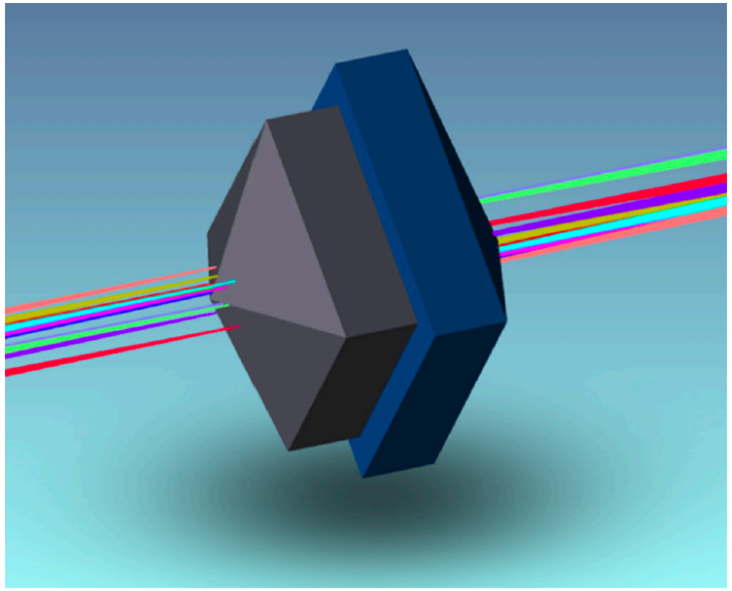
$$S_y(x,y) = \frac{I_1(x,y)+I_2(x,y)-[I_3(x,y)+I_4(x,y)]}{I_1(x,y)+I_2(x,y)+I_3(x,y)+I_4(x,y)}$$

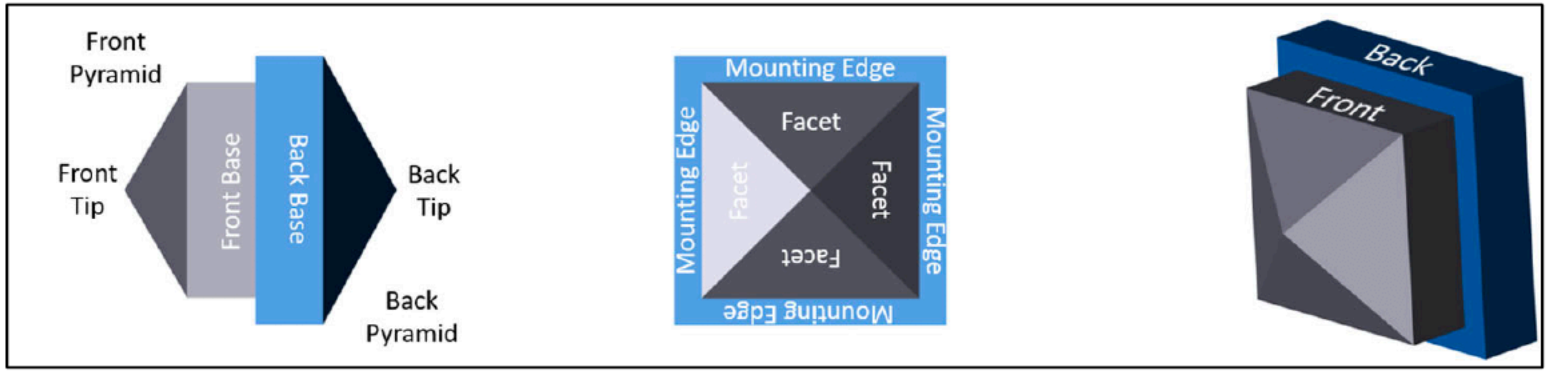
$$\frac{\partial W(x,y)}{\partial y} \approx \frac{\pi V}{2f} S_y(x,y)$$

Visible pyramid wavefront sensor



Flip mirror | Double pyramid | Camera triplet lens | CCID75





Optical design by Oli Durney and Shaojie Chen

Glass substrates: N-BAK1, N-KZFS5, and S-LAM60

Status: in procurement from WZOPTICS

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Specifications

Parameter	Requirement
Pupil Diameter [pixel]	30
Pupil Separation [pixel]	39
Waveband [μm]	0.6 – 1.0
Field of View [asec]	2.0 x 2.0
Modulation [λ/D]	≤ 10
Static Pupil Image Quality * [RMS pixel]	< 1/10
Dynamic Pupil Image Quality ** [RMS pixel]	< 1/10
Pupil Jitter [pixel]	< 1/10
Residual Pupil Chromatism [RMS pixel]	< 1/10
Pupil Distortion [RMS pixel]	< 1/10
Detector Size [pixel]	CCID75, 160 x 160
Region of Interest [pixel]	80 x 80
Pixel Pitch [μm]	21
Frame Rate [kHz]	1
Telescope Input f/#	f/15

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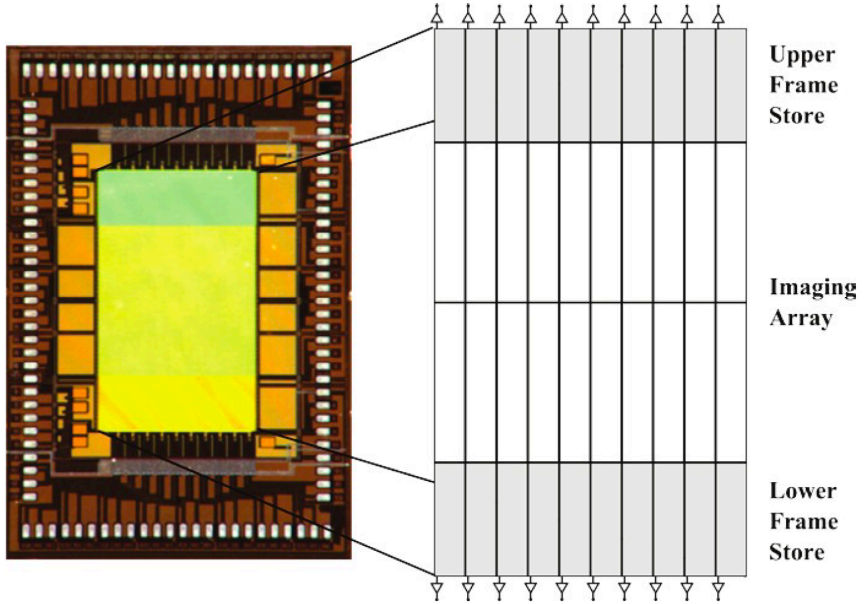
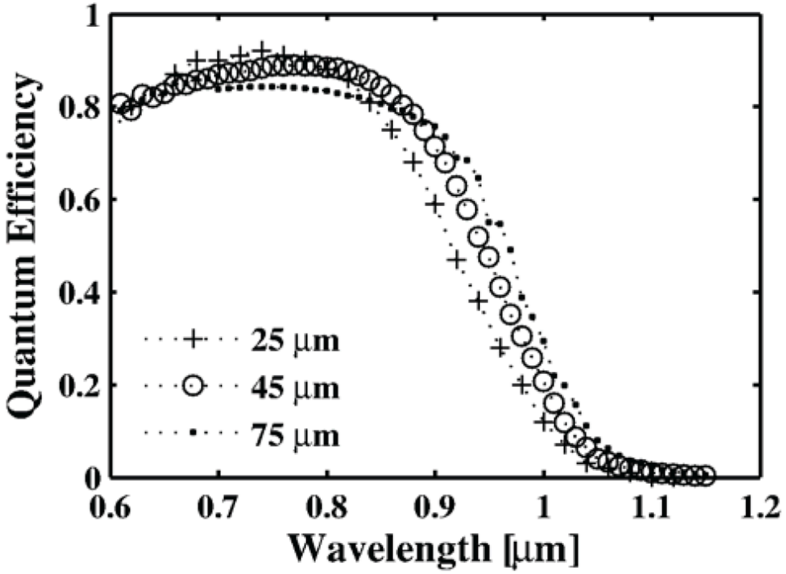
Visible wavefront sensor detector: CCID75



- 21 um pixel pitch
- Split frame transfer CCD
- High frame rate with 20 outputs
- Each output reads 16 x 80 pixels, i.e., 160 x 160 pixels
- Two storage areas: upper and lower
- 16-bit analog to digital conversion



Interface: Extended CameraLink	(green) = new columns
PED is 2.3 to 3.8um	
QE depends on CCD thickness	(orange) = significant difference from request

PROGRAM SEQUENCE 0 PWFS

Mode	Type Array	Guard Ring	Bin	Actual Readout	Actual Readout	Pixel Rate (MHz)	Max FR (KHz)	Max FR (kHz)	% diff	RON(e-)	RON(e-)
0	160 x 160	0	No	160 x 160	160 x 160	4.54	2150	2151	0%	4.4e-	4.2e-
1	128 x 128	0	No	128 x 128	160 x 128	3.85	2250	2287	2%	3.9e-	3.7e-
2	160 x 160	0	No	160 x 160	160 x 160	2.78	1350	1441	7%	2.7e-	2.7e-
3	96 x 96	0	No	96 x 96	160 x 96	2.78	2150	2303	7%	2.7e-	2.7e-
4	128 x 128	0	No	128 x 128	160 x 128	1.47	1025	1014	-1%	2.1e-	2.1e-
5	96 x 96	0	No	96 x 96	160 x 96	1.47	1204	1332	11%	2.1e-	2.1e-
6	96 x 96	0	No	96 x 96	160 x 96	1.01	850	931	10%	< 2.0e-	2.0e-
7	128 x 128	0	No	128 x 128	160 x 128	5.56	3150	3083	-2%	7e-	5.9e-

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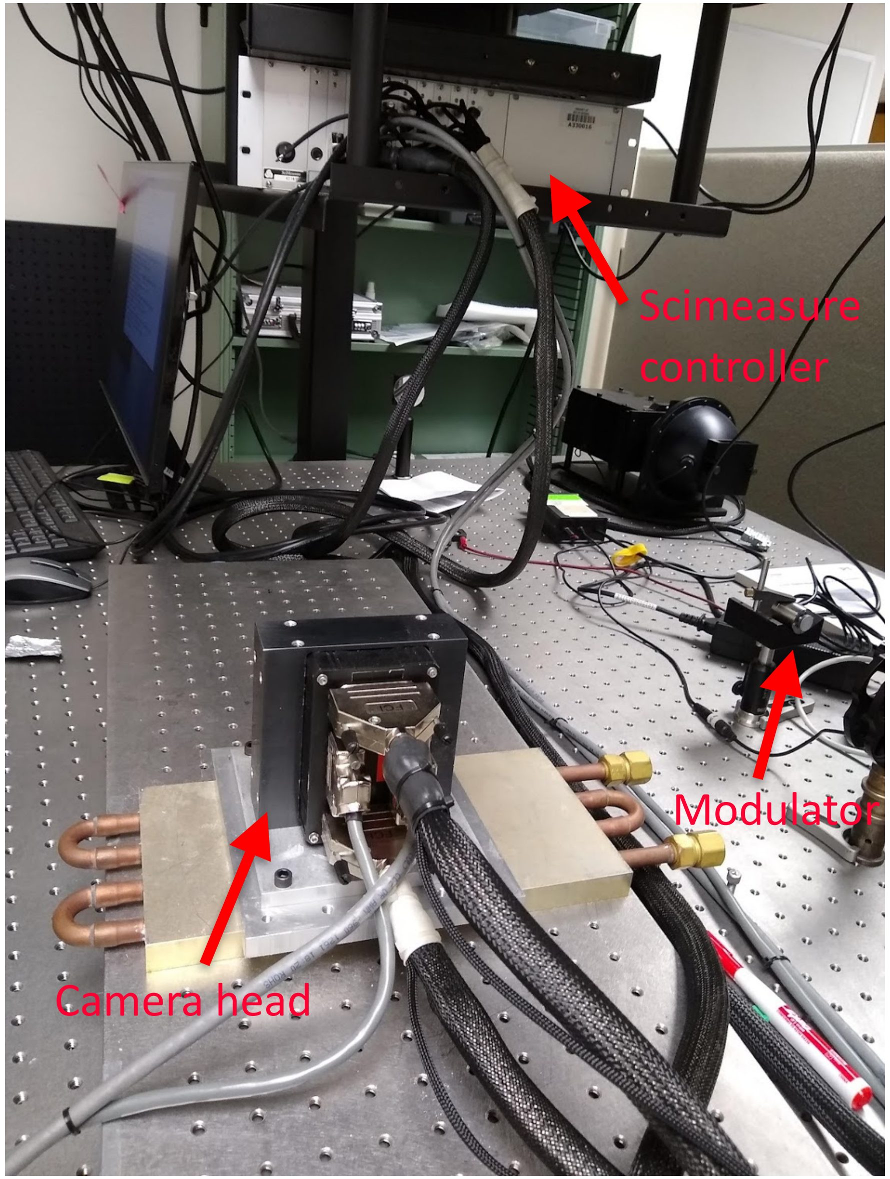
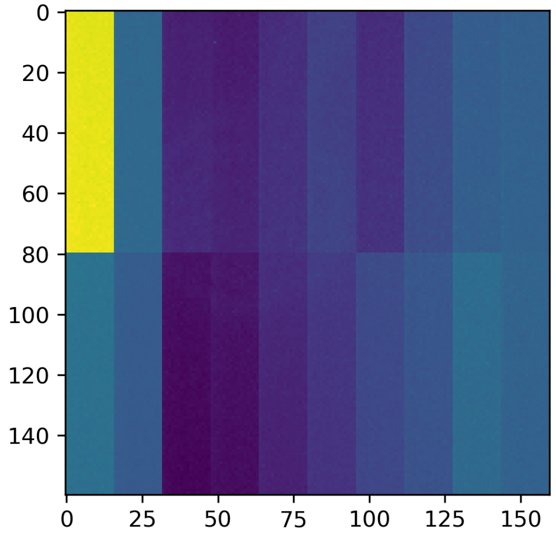
CCID75 lab installation and testing

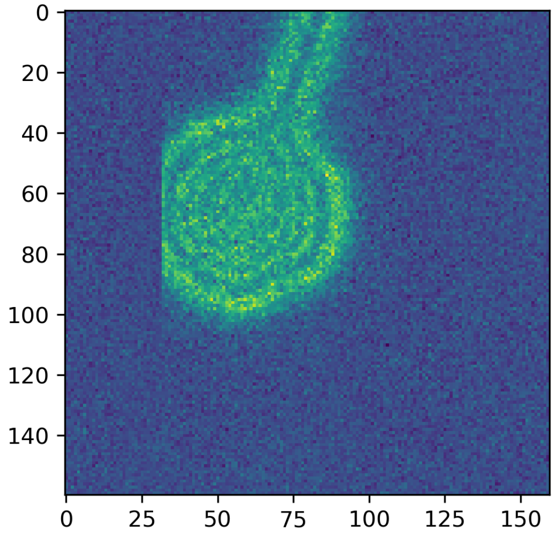


- Installed in Nov 2019
- SciMeasure's Little Joe controller
- EDT frame grabber
- Camera link cables are extended with VisionLink fiber extender

- 30 x 30 sub-aperture wavefront sensing
- Read: 96 x 96 pixels ROI (4 quadrants + separation)



Bias image



Scene image

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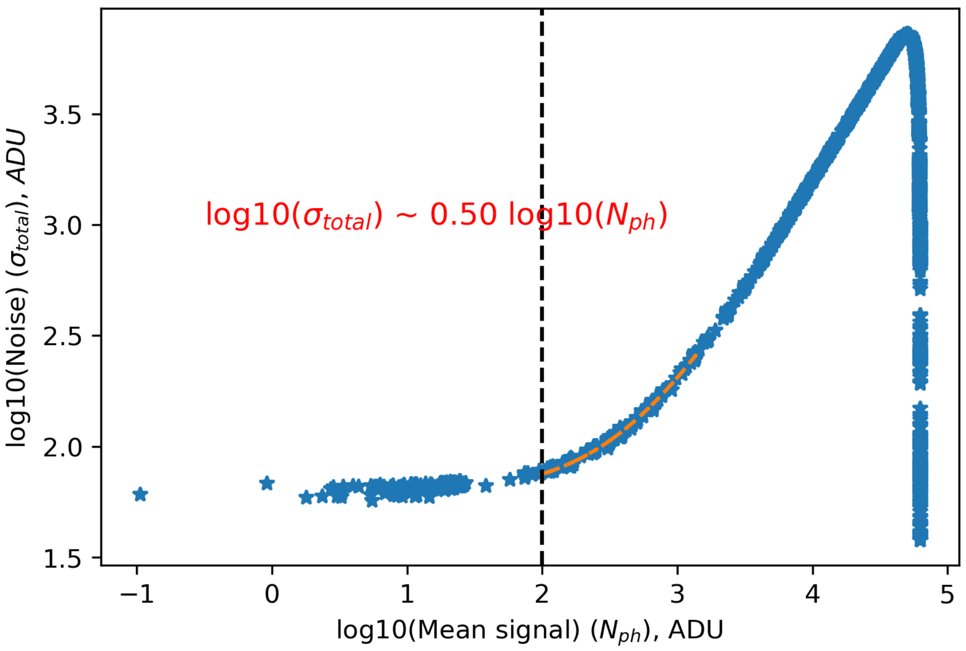
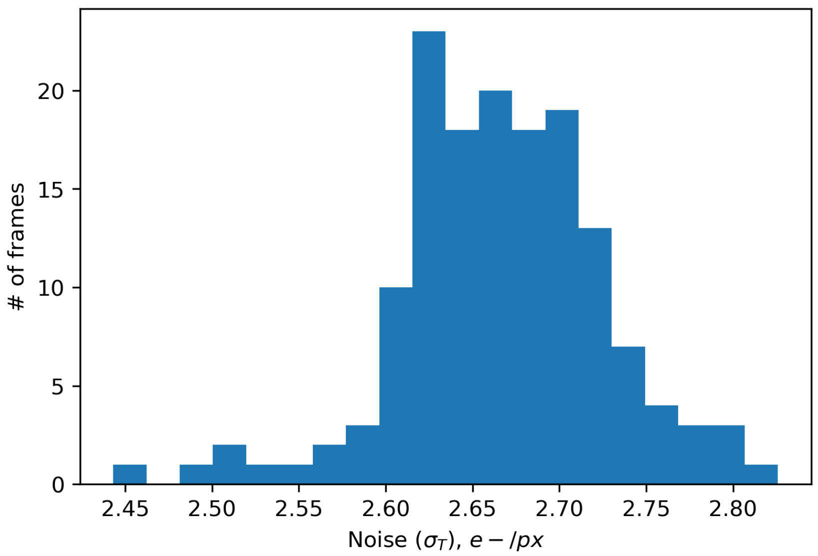
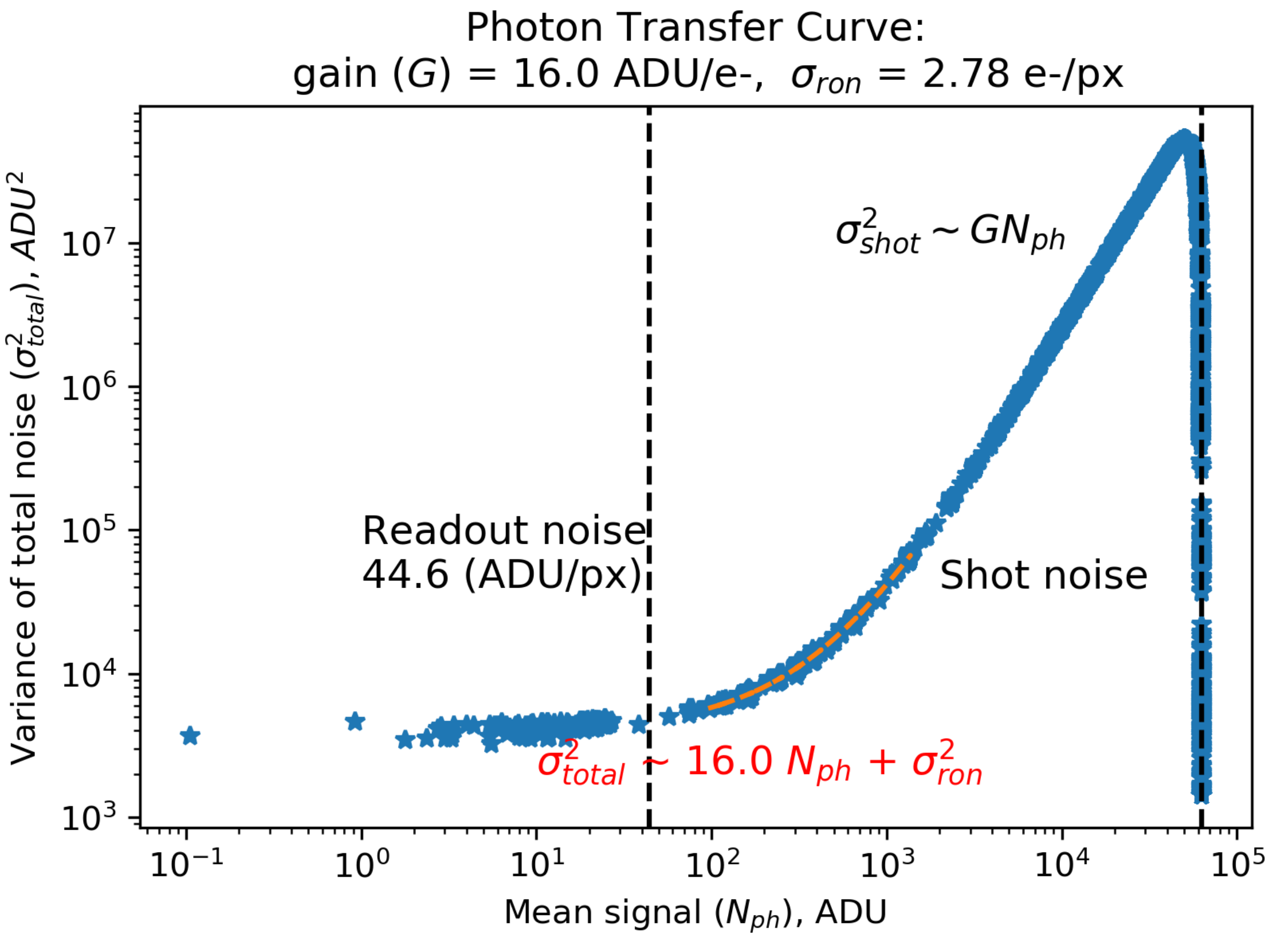
CCID75 photon transfer curve







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CCID75 readout noises for different readout modes

Readout mode	RON [e-/px] (measured)	RON [e-/px] (expected)	Total gain (ADU/e-)	Frame rate (KHz)	Clock speed (MHz)
RCL0 (G=0)	3.62	4.2	13.8	2.149	4.55
RCL2 (G=0)	2.77	2.7	15.8	1.44	2.78
RCL8 (G=1)	4.59	4.2	8.23	2.149	4.55
RCL16 (G=2)	8.0	4.2	0.94	2.149	4.55
RCL24 (G=3)	9.33	4.2	0.73	2.149	4.55

1. There are total 32 readout program modes
2. We yet to find out how to read binning modes on the chip

Tip-tilt modulator to increase dynamic range of WFS

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E-727.3SDAP:
Three-Channel digital Piezo Controller, with Strain Gauges with increased output power

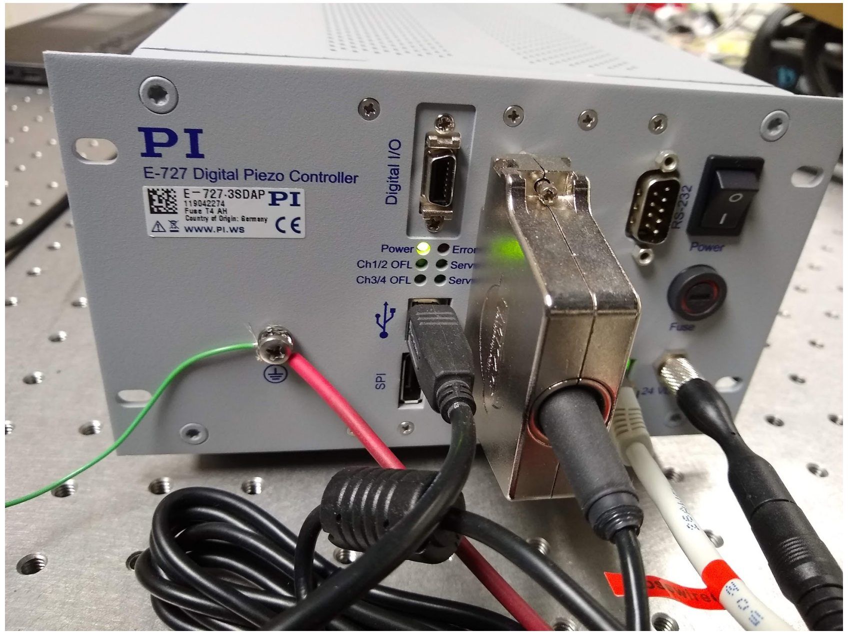
S-331.2SH:
High-Dynamics, High-Stiffness Piezo Tip/ Tilt Platform

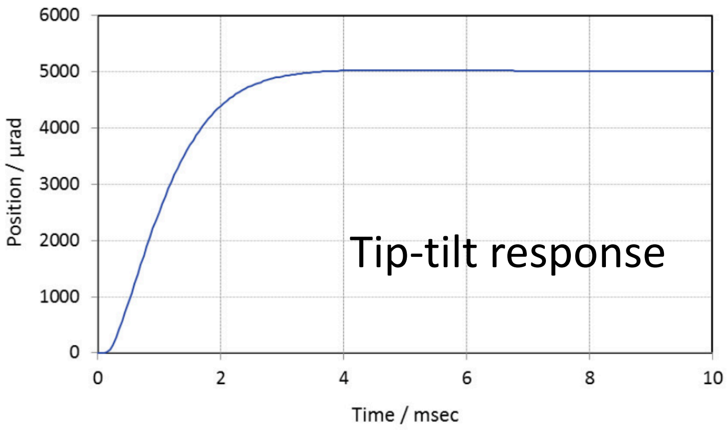
Edmund Optics:
#34-388, lambda/20 quality 15 mm mirror onto the S-331.2SH, epoxied.

Software: C/C++

Ethernet and TCP/IP protocol communication

WFS synchronization trigger output





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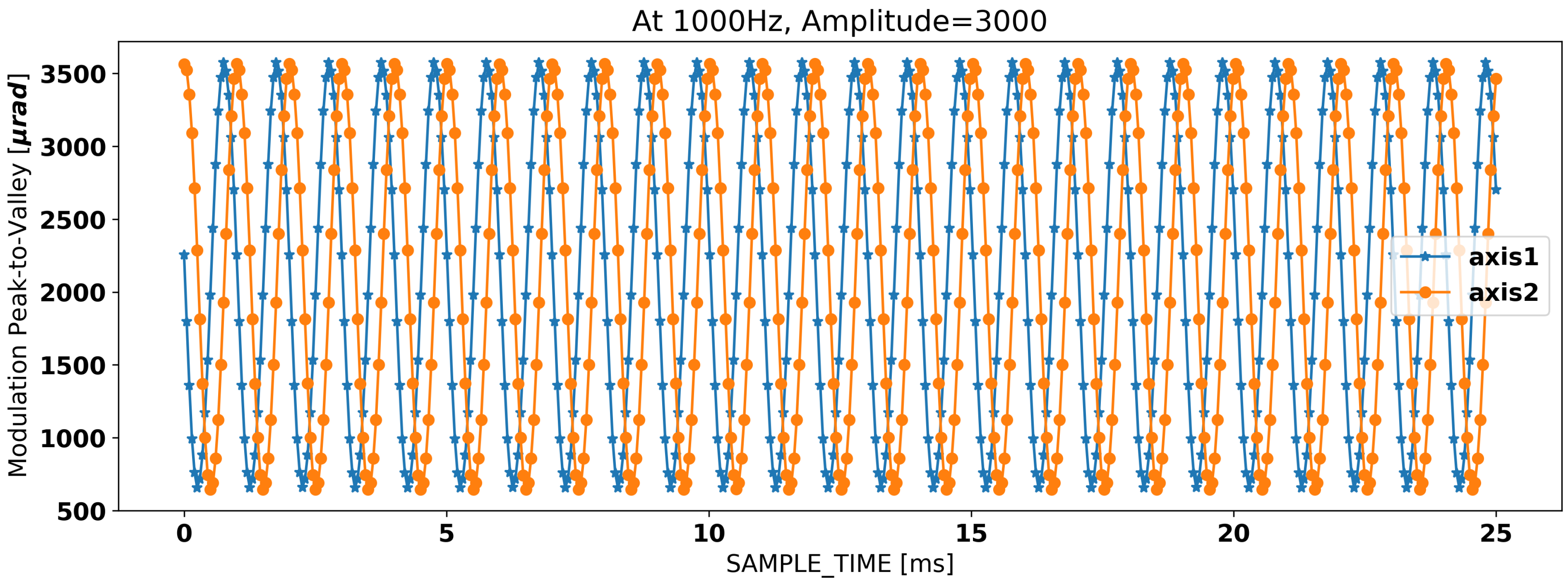
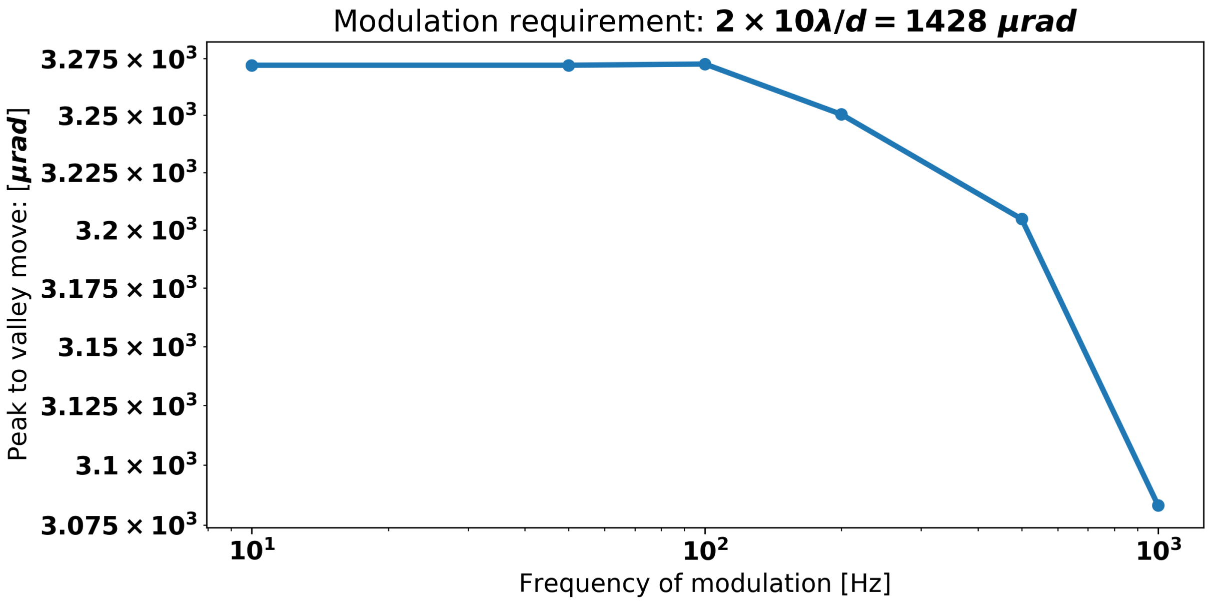
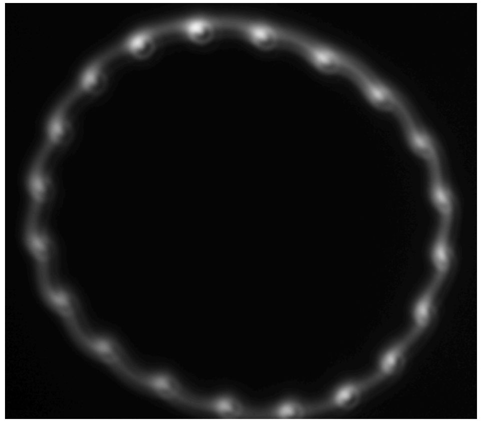
Tip-tilt modulator characterization



Lookup table prepared for various:

- frequency (with magnitude)
- amplitudes (with seeing)





1. Modulation at 3000 urad at 1k Hz
2. Recording of modulation was done at 15 Hz
3. This image is old, now wiggles are corrected.

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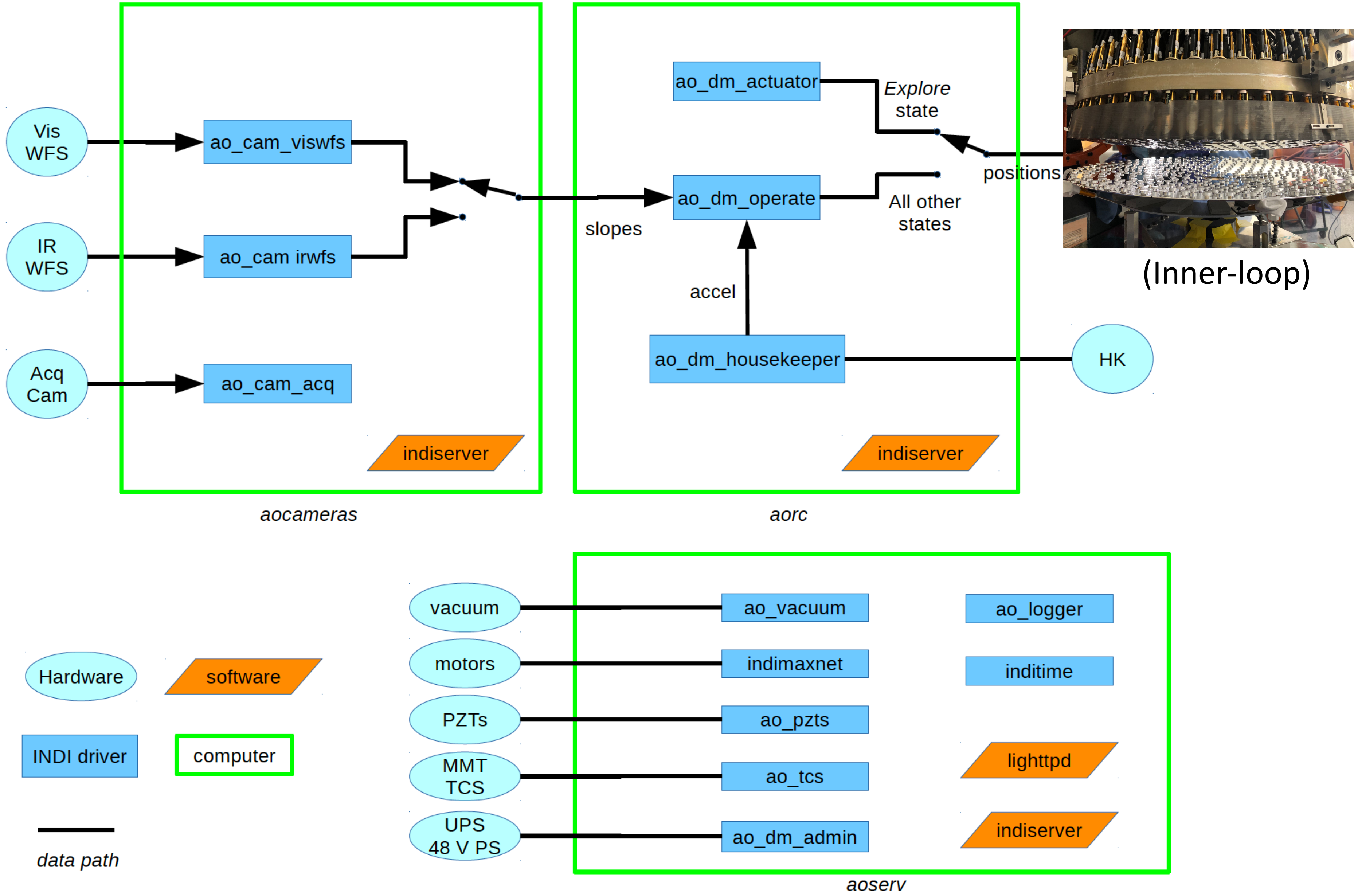
Computers and software modules



Current status and future tests

Current status:

- We have working CCID75, tip-tilt modulator and acquisition camera in the lab
- We measured quantum efficiency of CCID75 with a black body source (~70%)
- We have implemented software drivers for CCID75, tip-tilt modulator and acquisition camera.

Future:

- WFS frame synchronization between the modulator and WFS is not yet done.
- We will use PZT camera lens XY positional controller (1/10 px ; E-727.3CD For XY) but that is under procurement

Summary

- Deformable mirror
  - 336-actuator adaptive secondary mirror (ASM)
- Wavefront sensors: 2 pyramids
  - 1 visible PyWFS – CCID-75 detector
  - 1 IR PyWFS – SAPHIRA detector
  - Tip/tilt modulator for PyWFS
  - Visible-light acquisition camera
- Control and sampling
  - Closed loop: up to 1000 Hz, with 100 μs ASM comm. lag
- Science cameras
  - ARIES 1-5μm high-res spectrograph
  - MMT-POL 1-5μm imaging polarimeter

I-band Strehl vs. guidestar mag.