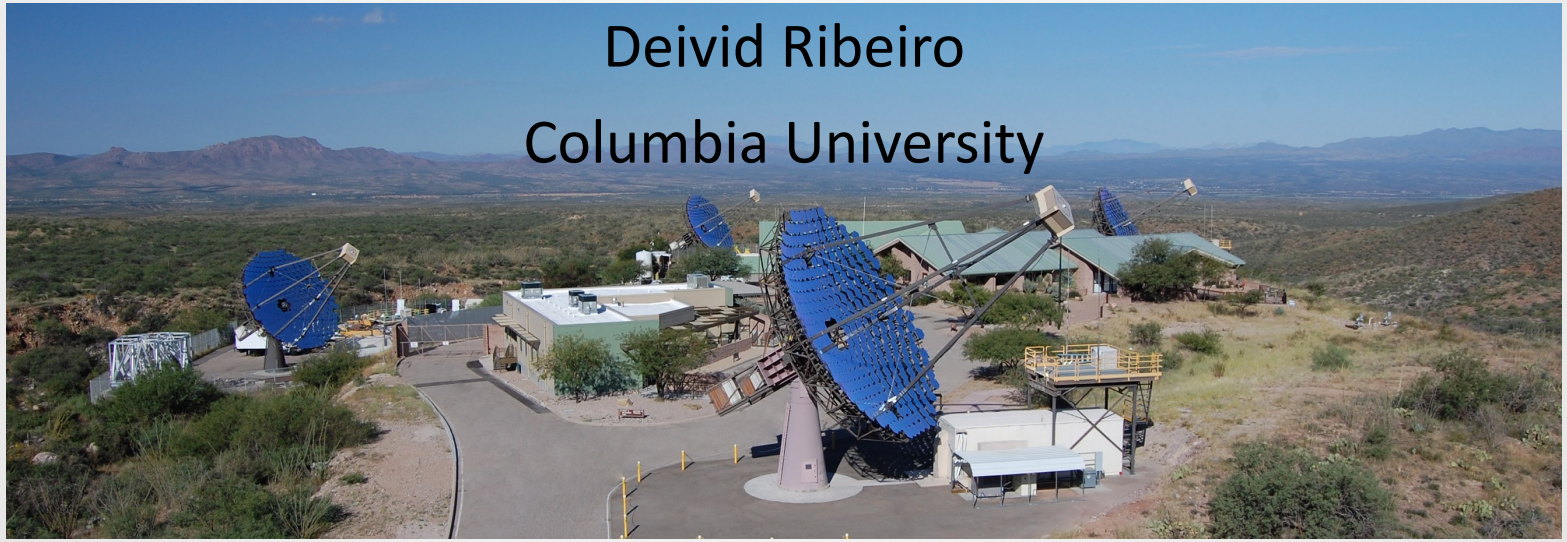
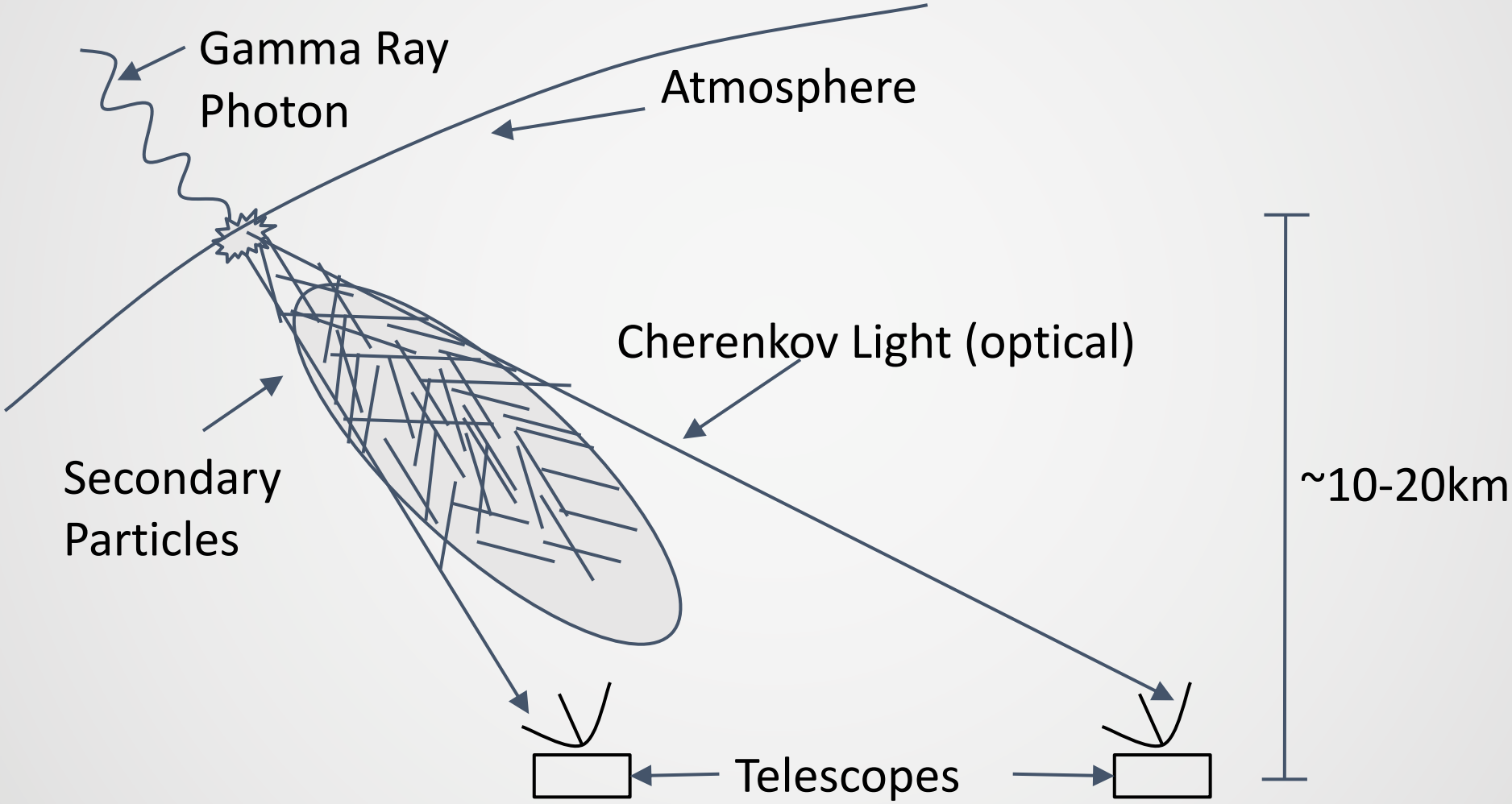
A Graduate Student's Life Building A Novel Dual-mirror Telescope

Deivid Ribeiro

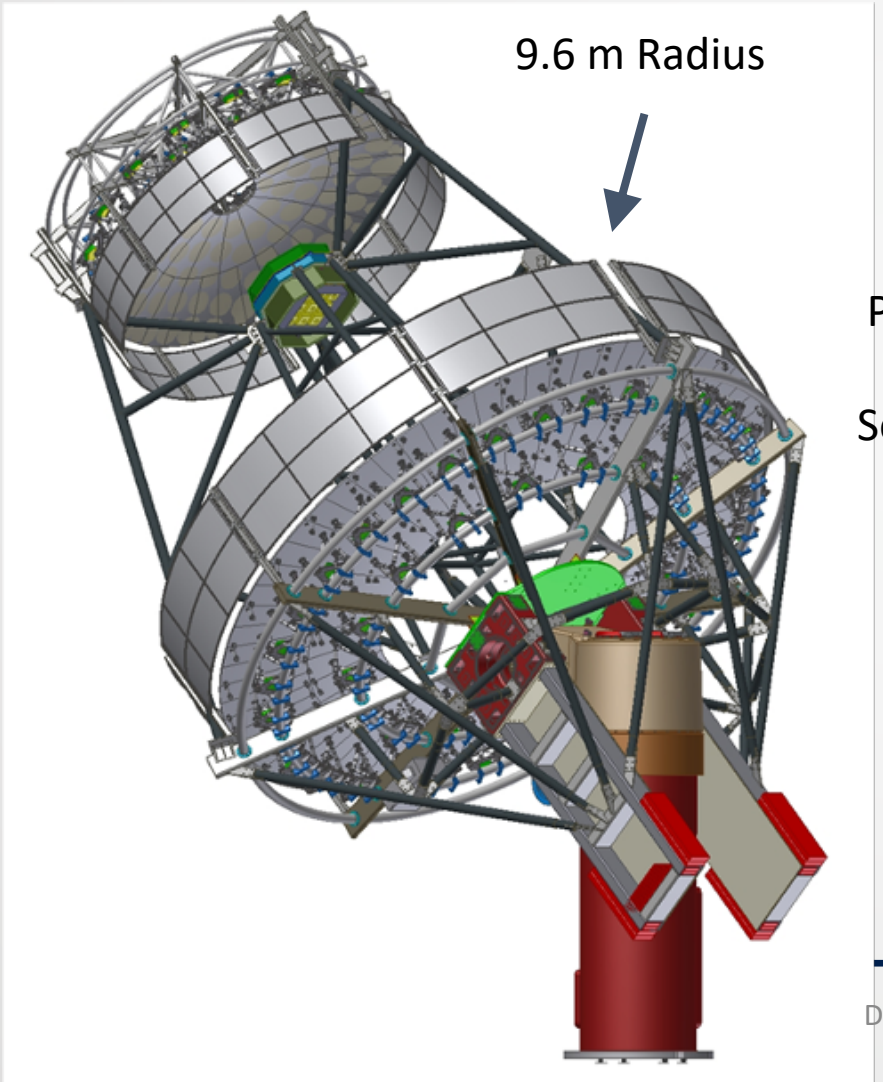
Columbia University



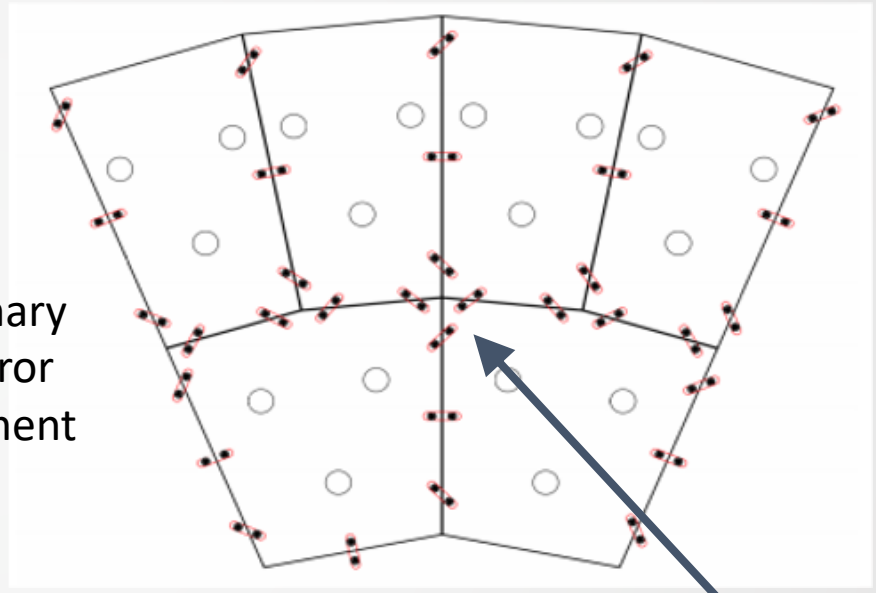
Cherenkov Radiation (200-700 nm)



Prototype Schwarzschild-Couder Telescope

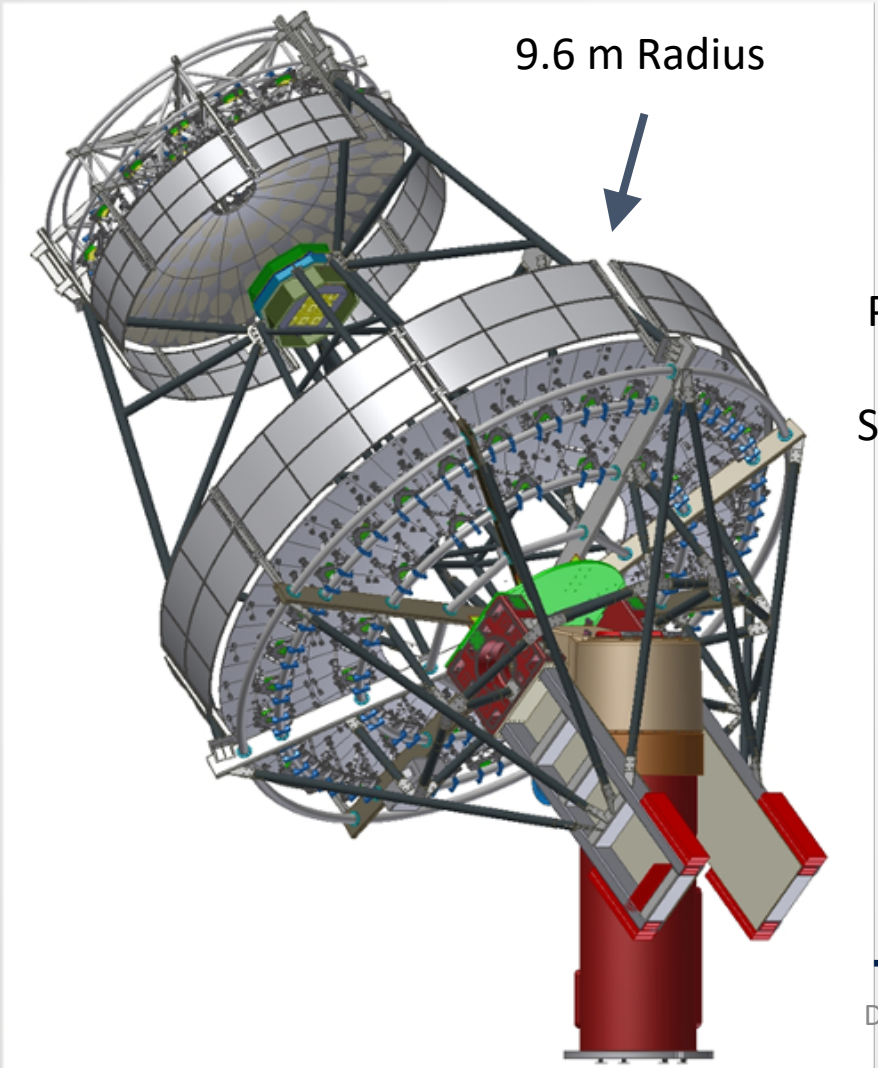


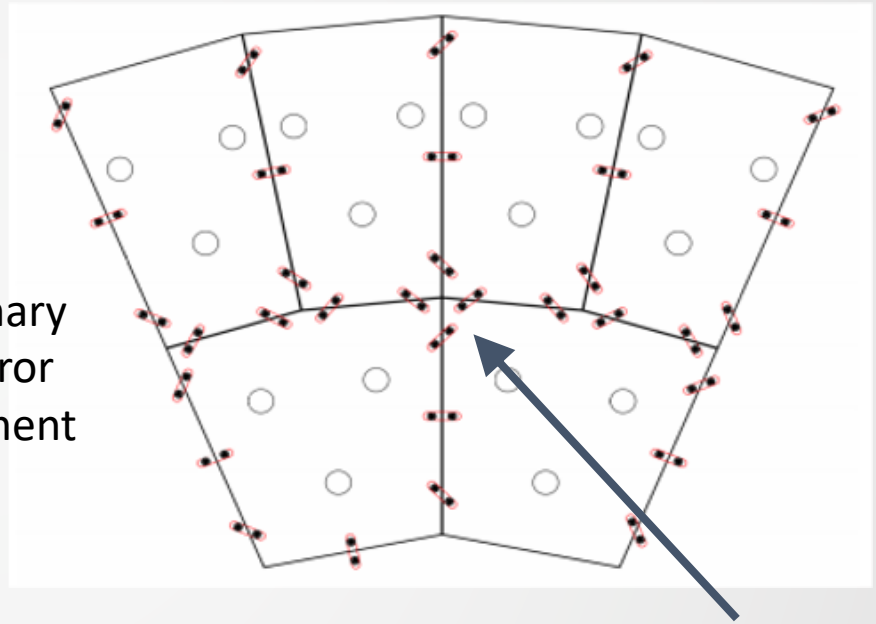
Primary Mirror Segment



Mirror Panel Edge Sensor (MPES)

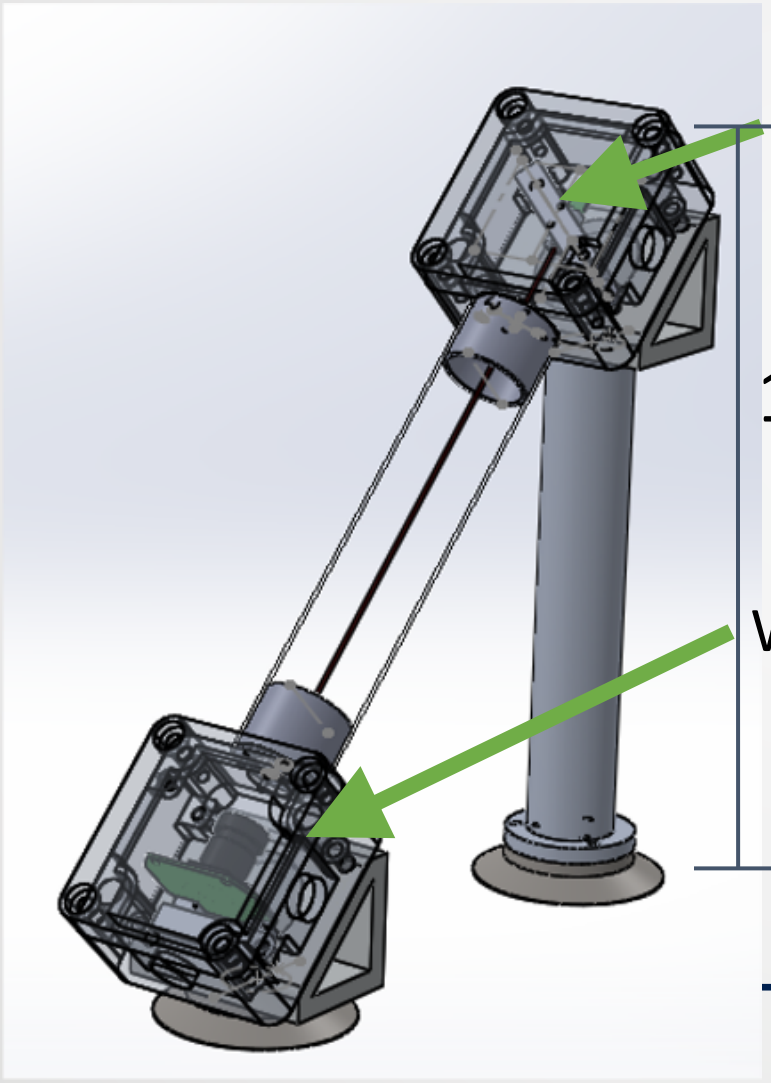
Prototype Schwarzschild-Couder Telescope

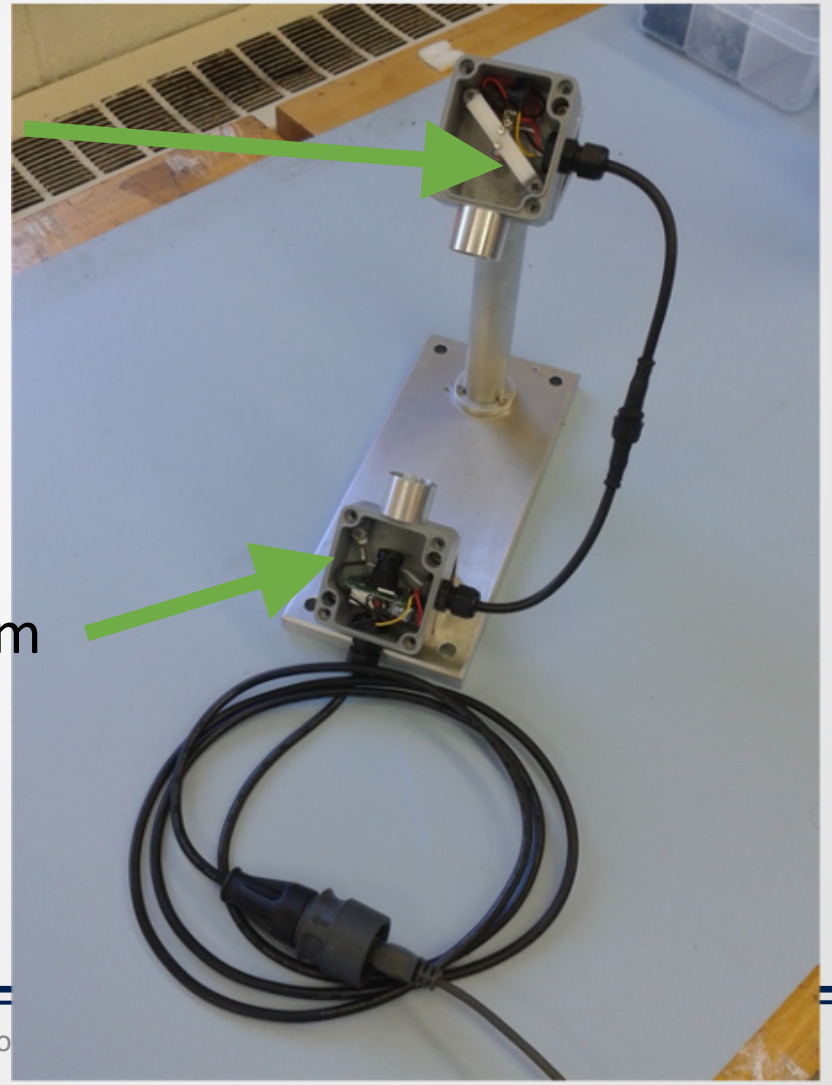




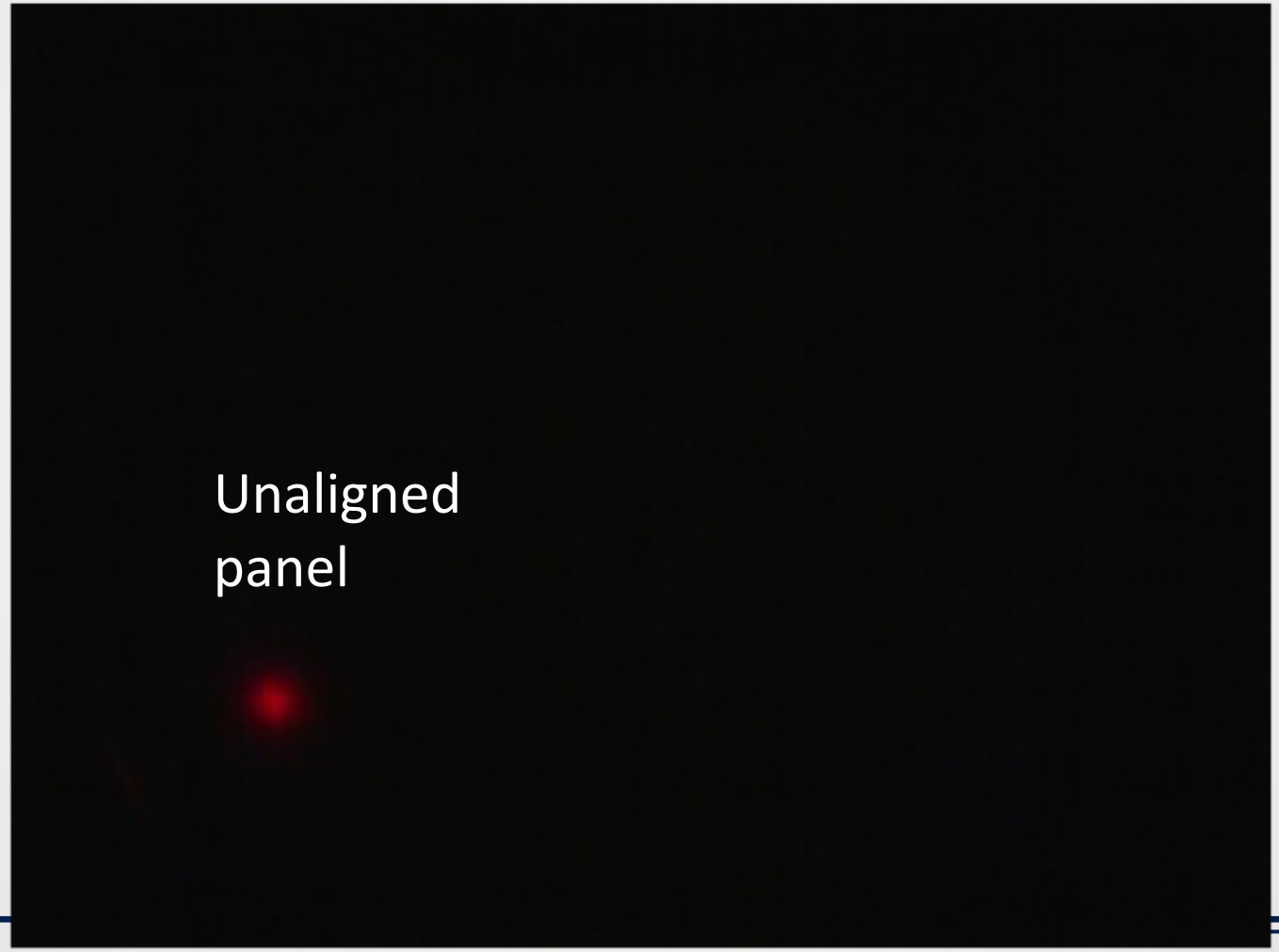
Maximum allowed misalignment between panels is 100 microns

Mirror Panel Edge Sensor

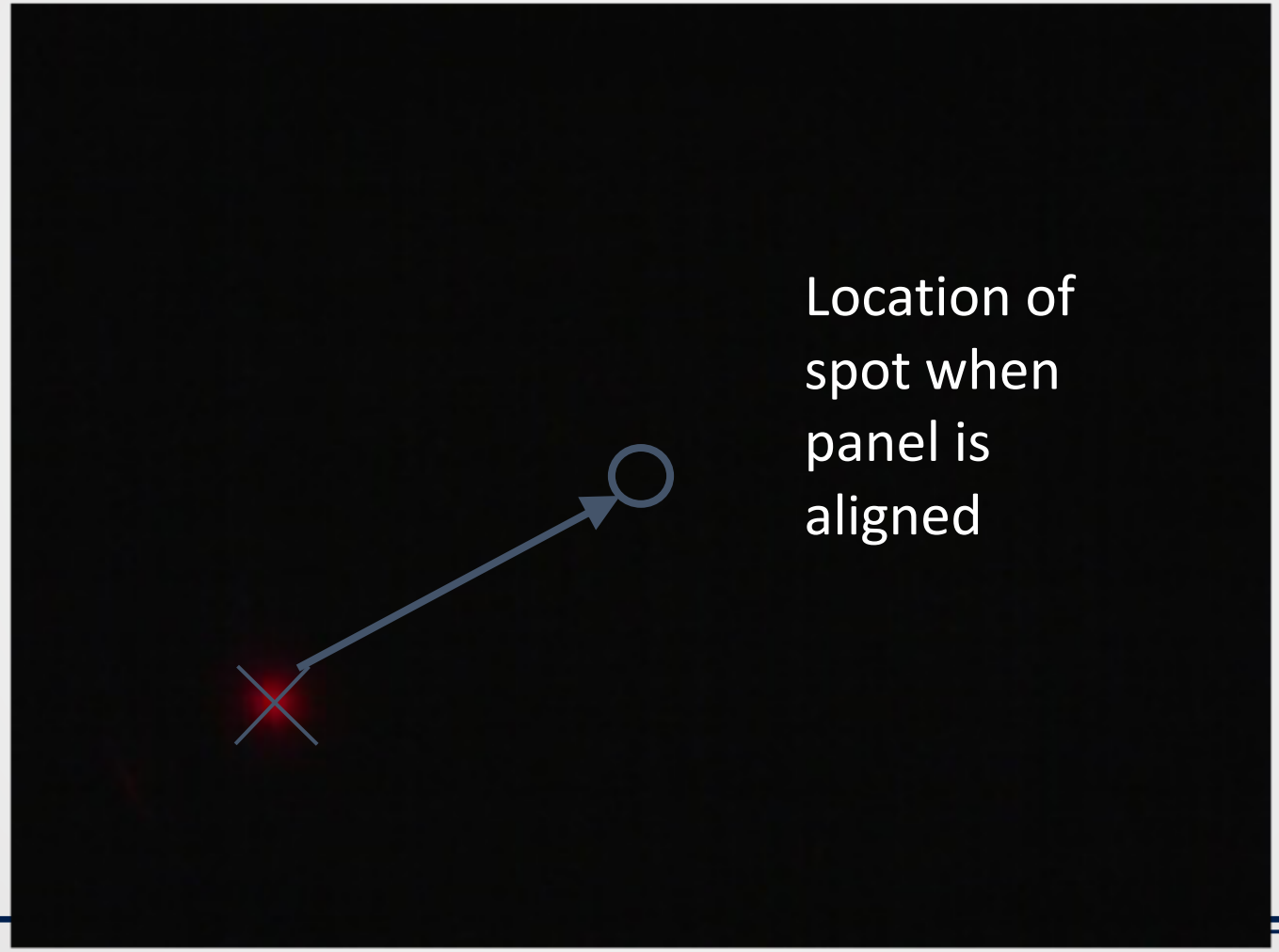




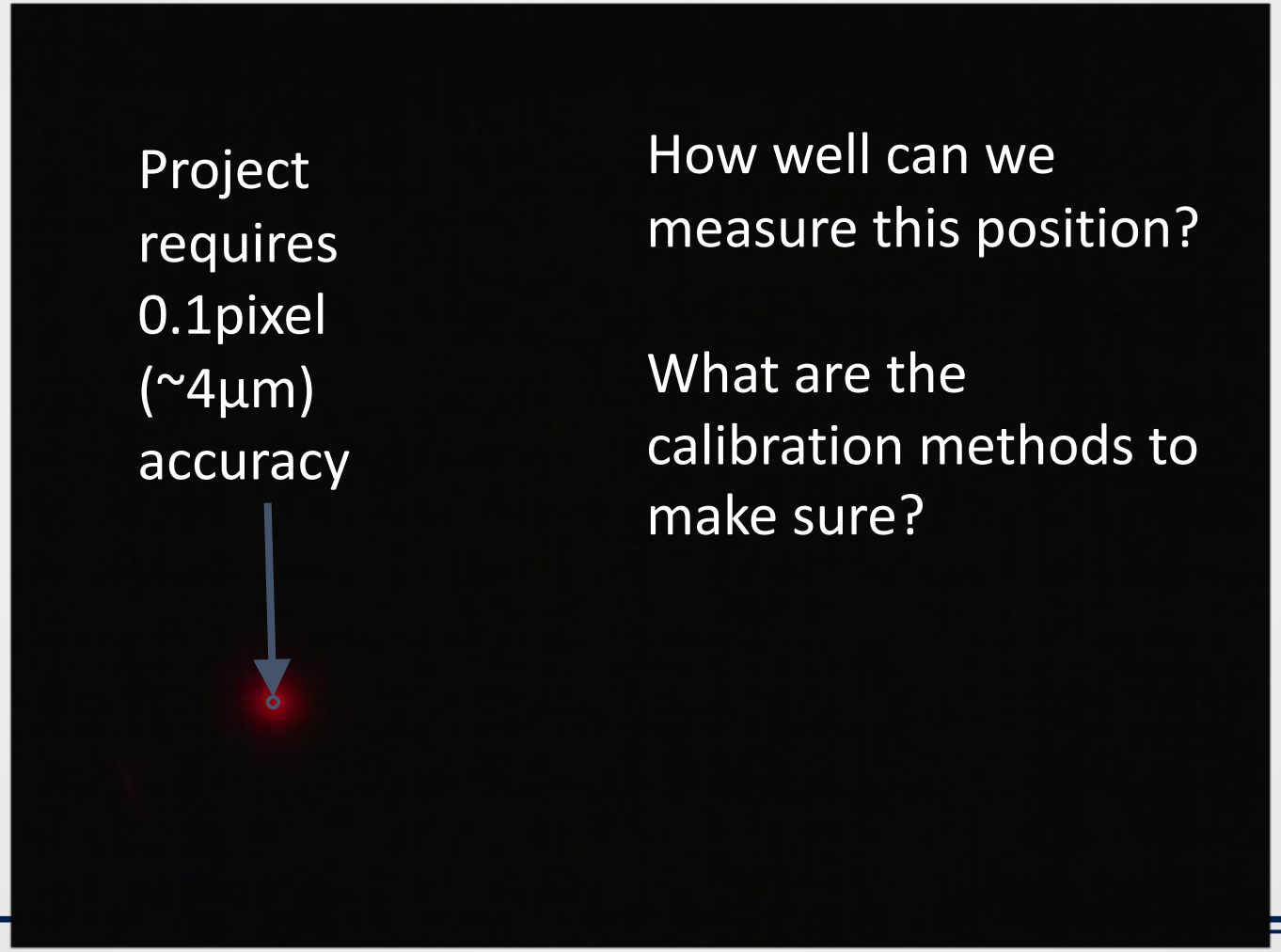
Alignment



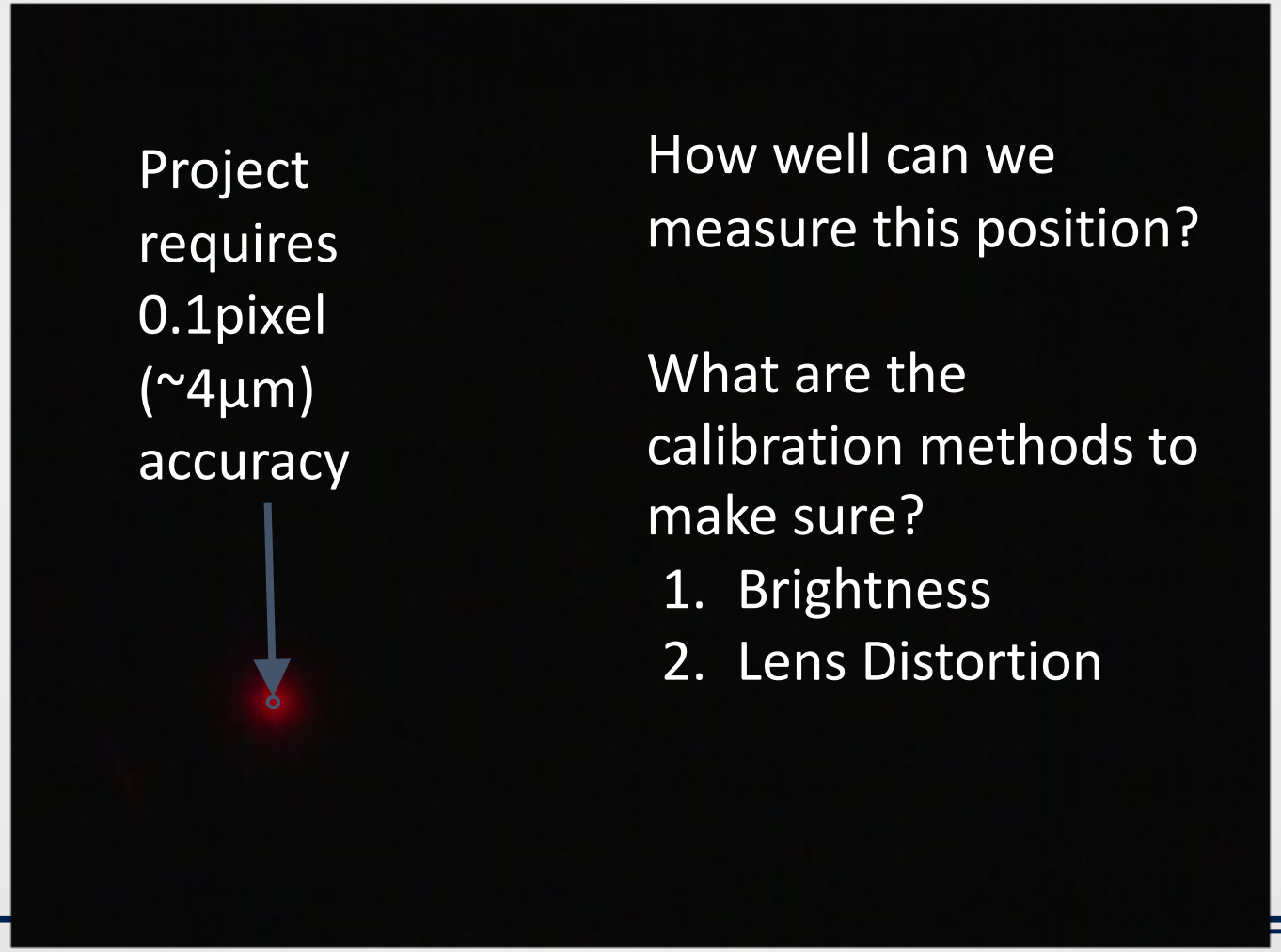
Alignment



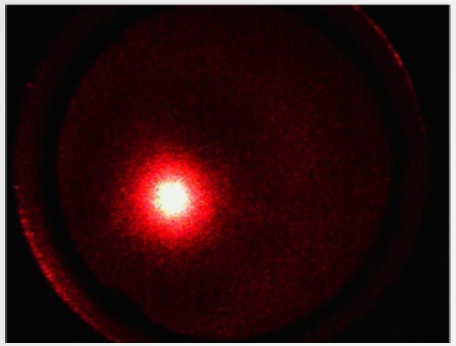
Alignment


Project requires 0.1pixel (~4µm) accuracy
How well can we measure this position?
What are the calibration methods to make sure?

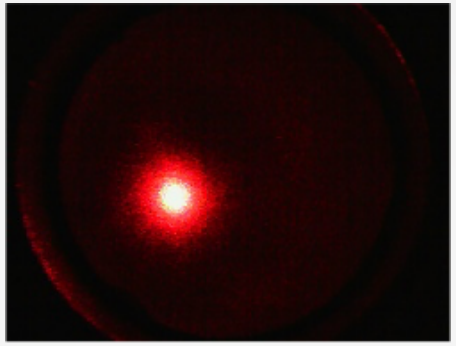
Alignment


Project requires 0.1pixel (~4µm) accuracy
How well can we measure this position?
What are the calibration methods to make sure?
1. Brightness
2. Lens Distortion

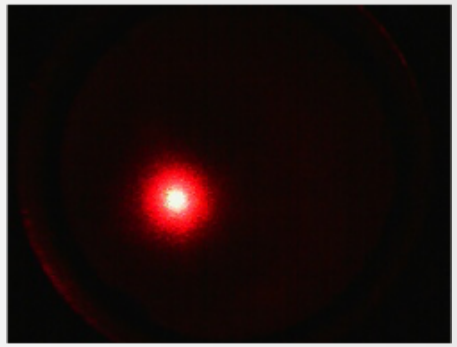
Exposure Control



-20 C



-10 C



0 C

10 C

20 C

Temperature affects image intensity.

Cold → Hot

All same camera exposure setting

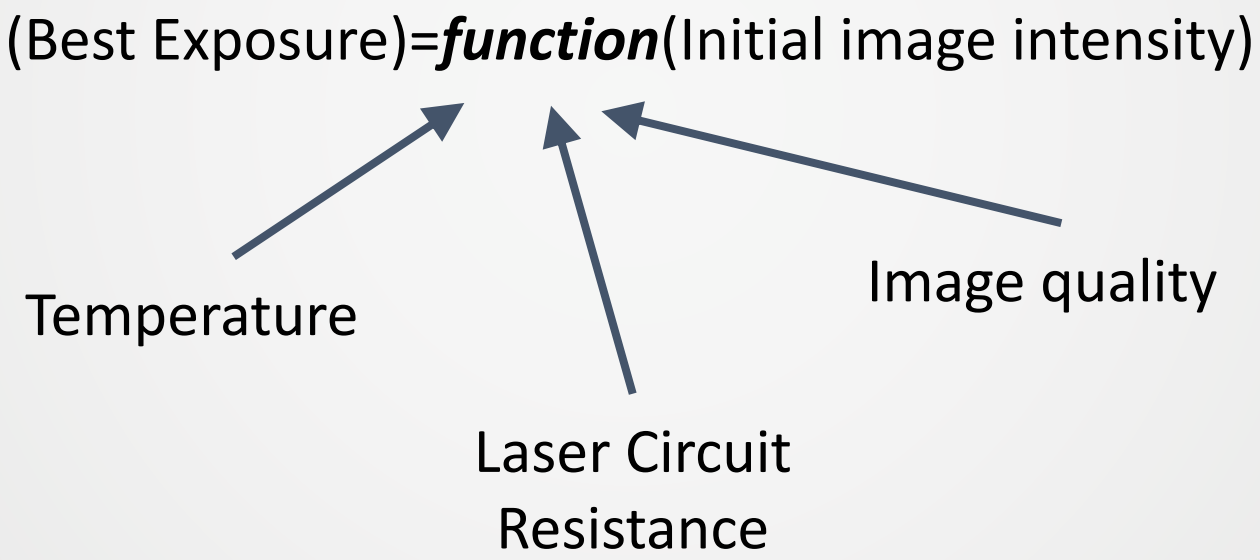
Exposure Control

- Camera has manual “Exposure Value” controlled by MPES software

(Best Exposure)=***function***(Initial image intensity)

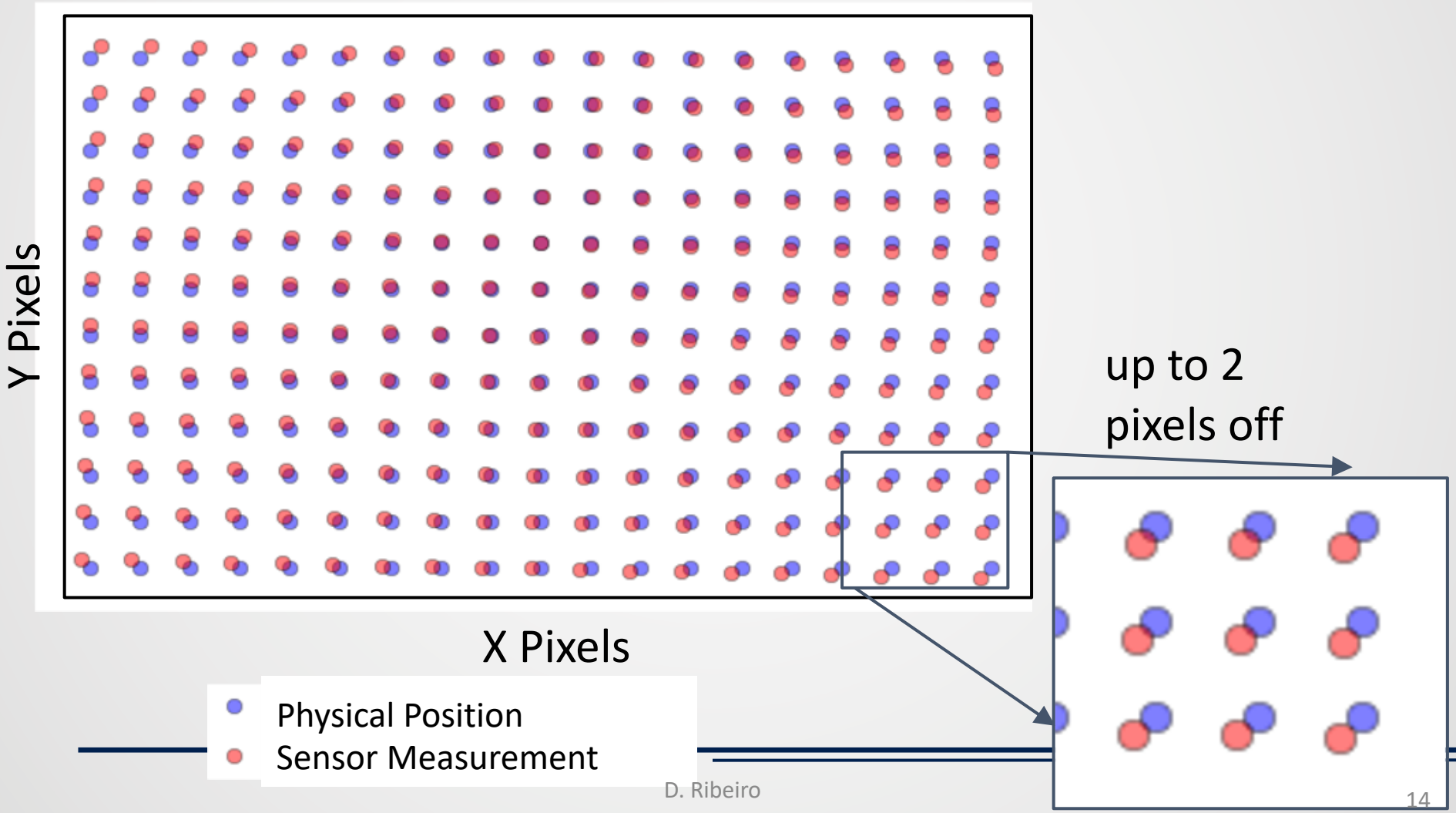
Exposure Control

- Camera has manual “Exposure Value” controlled by MPES software

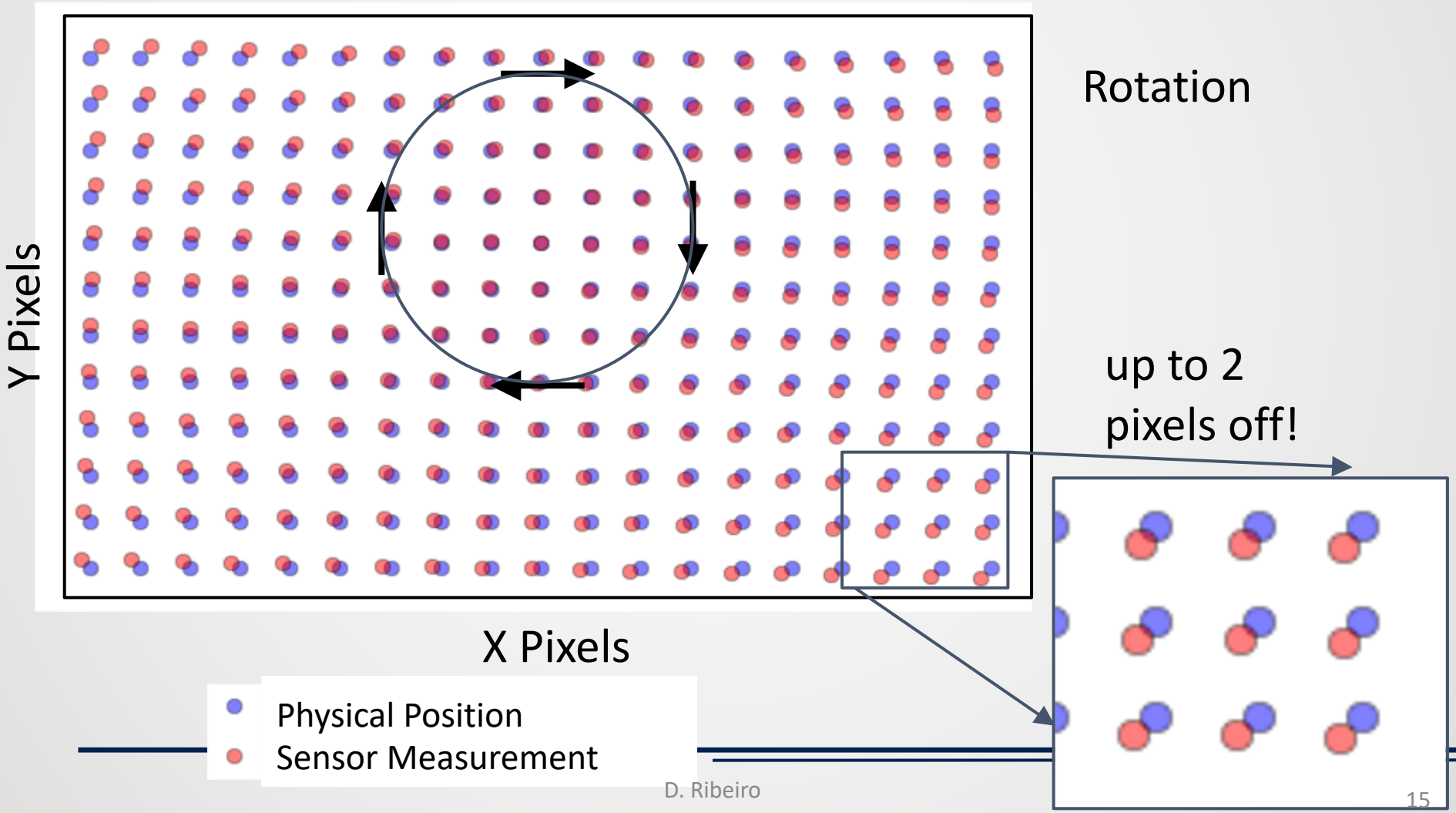


Lens Calibration

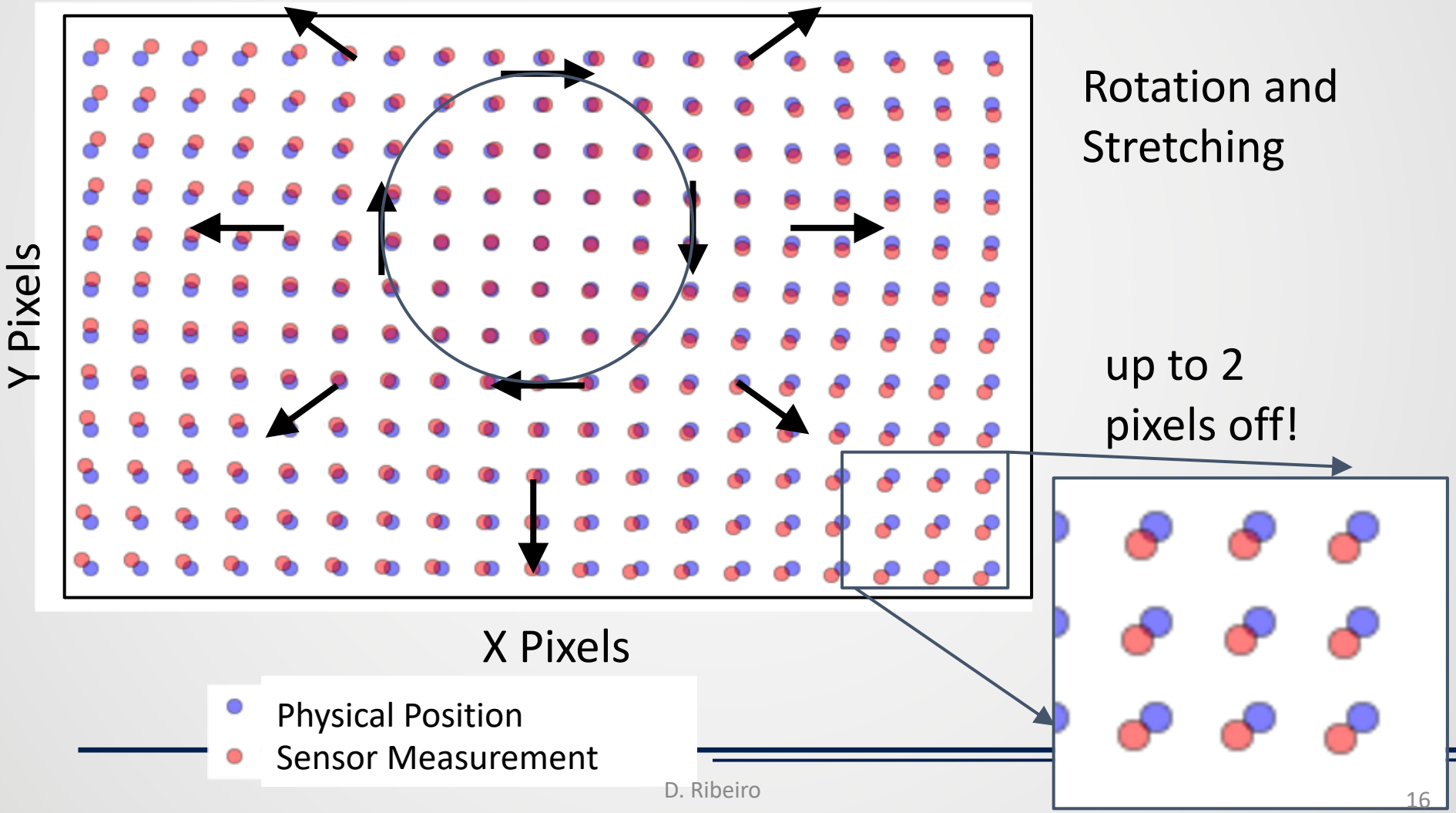
Lens Calibration



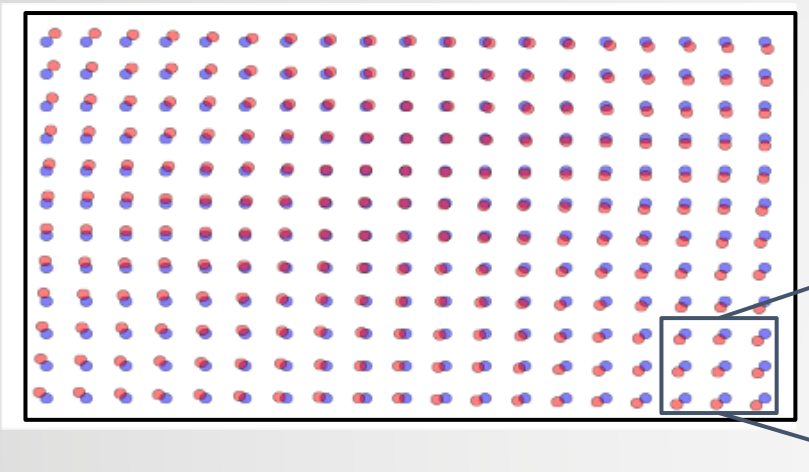
Lens Calibration



Lens Calibration

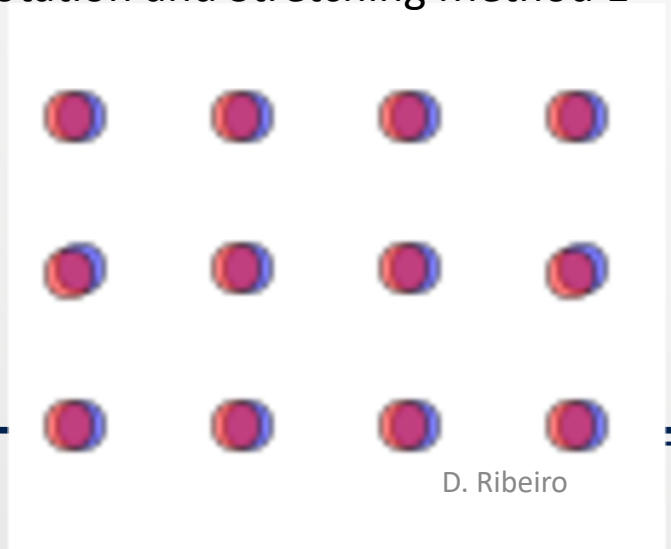


Calibration Methods



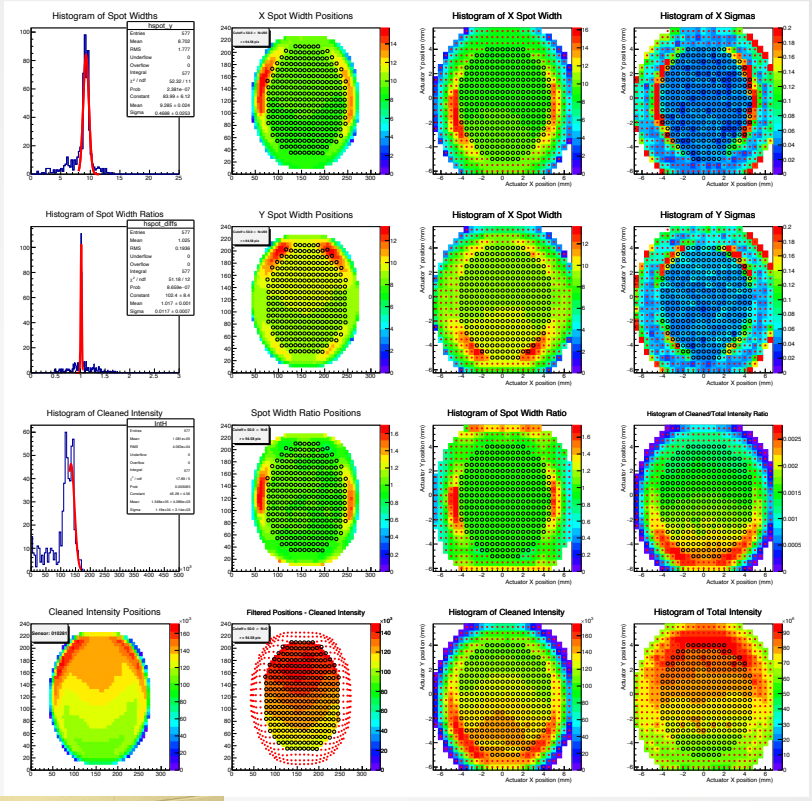
Physical Position
Rotation and Stretching Method 2

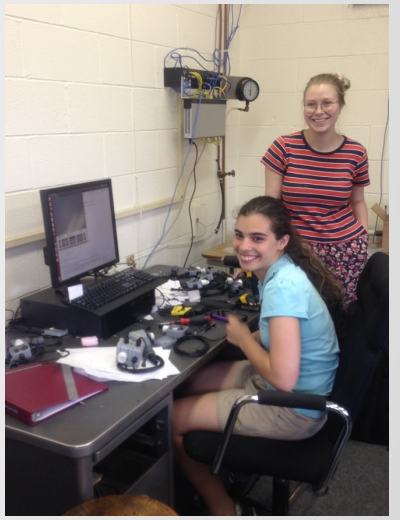
Physical Position
Rotation and Stretching Method 1



MPES Assembly

- Small army of undergraduates
- 375 MPES units built
- Calibration over 1.5 years
  - Measured FoV in 1 mm and 0.5 mm spacing for every unit
  - Generated diagnostic plots
  - Found plate scale (19.75 px/mm)





Columbia University's Bridge to the Ph.D. Program in STEM

The Bridge to the Ph.D. Program in STEM is designed to increase the participation of students from underrepresented groups in Ph.D. programs in STEM disciplines. The Bridge Program is an intensive research, academic, and mentoring experience for post-baccalaureates seeking to

Bridge to the Ph.D. Program in STEM Timeline

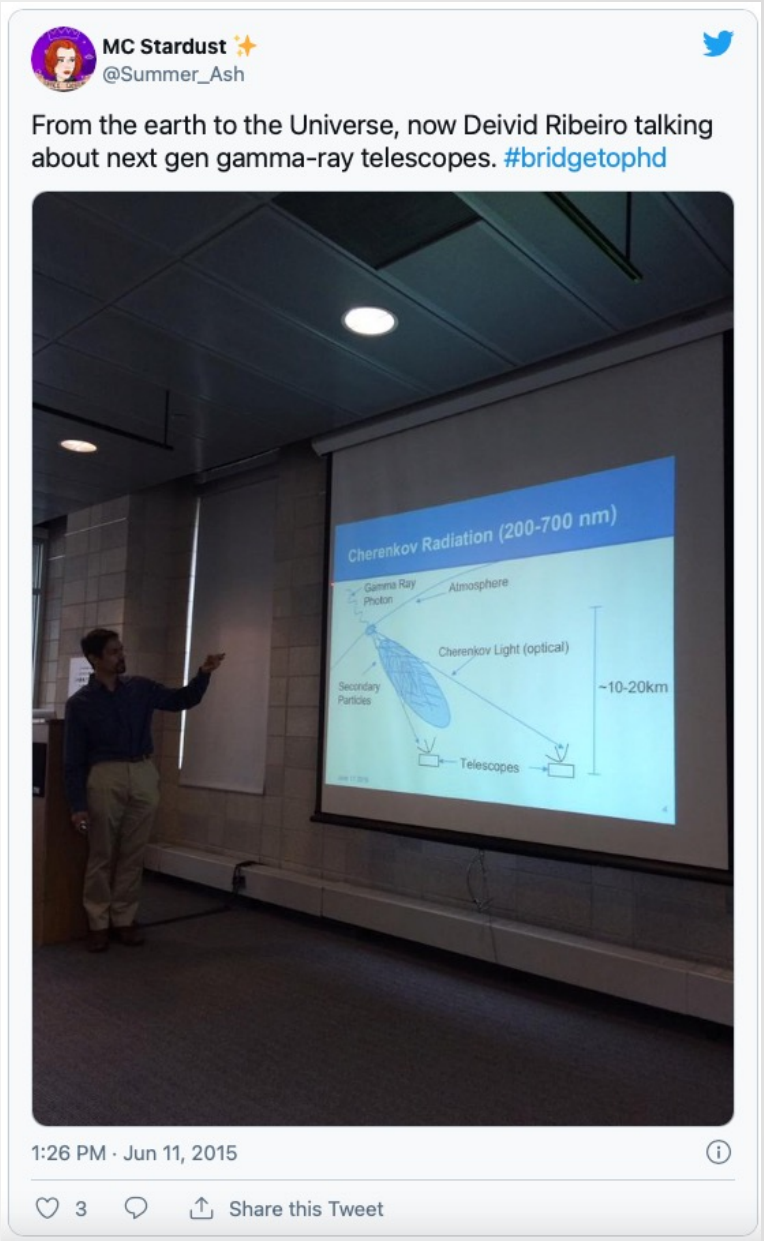
First Year of Bridge

- Late Summer
  - Arrive at Columbia University and participate in orientation and HR onboarding
  - Meet research advisers, other Bridge scholars, and Bridge administration and staff
  - Register for undergraduate or graduate courses
- Fall
  - Start research project(s)
  - Take undergraduate or graduate courses
  - *Participate in professional development workshops and seminars*
  - *Attend monthly meetings with the director*
  - Register for spring semester courses
- Spring
  - Continue research project(s)
  - Take undergraduate or graduate courses
  - *Attend professional development workshops and seminars*
  - *Attend monthly meetings with the director*
  - Register for fall semester courses
  - *Participate in the Year-end Annual Research Symposium*
  - Year-end evaluation

Second Year of Bridge

- Summer
  - Continue research project(s)
  - Take a preparatory course for the GRE General Test
  - Attend a GRE Physics Subject Test "boot camp" (for scholars in the Departments of Astronomy and Physics)
  - Develop preliminary lists of prospective graduate programs
  - Apply to graduate school open houses
- Fall
  - Begin the second year of coursework
  - Take the GRE General and Subject (if applicable) Tests
  - Prepare and submit applications for graduate programs and fellowships
- Spring
  - Continue the second year of coursework
  - Visit graduate programs and go on graduate interviews (if applicable)
  - End of program evaluation

Bridge Symposium



Graduate School!

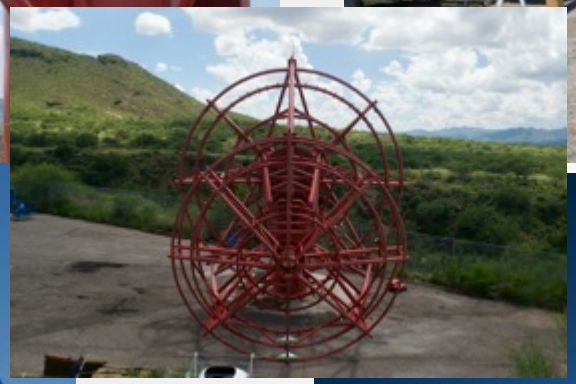
School

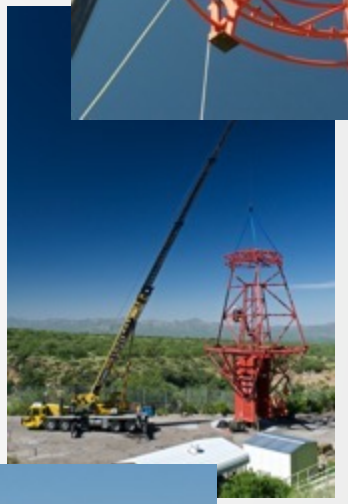
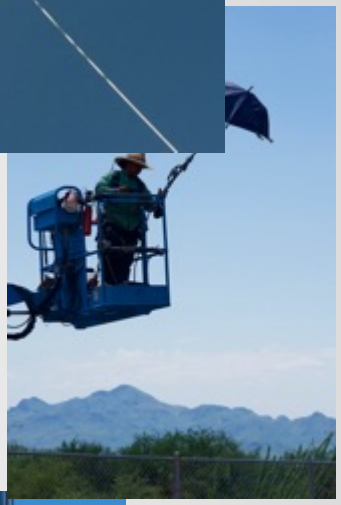
- Apply
- Get accepted!
- Begin coursework
- Prep for Qualifying Exam
  - At Columbia – this was a brutal 2 week obstacle course during Winter “break”
  - Faculty has received feedback😉

Research during first year

- Oversee MPES calibration
- Participate in installation of Secondary OSS




Stewart Platform

- Actuators on Stewart Platform
- 6 degrees of freedom
- Independent motion of each panel
- Control board for each panel

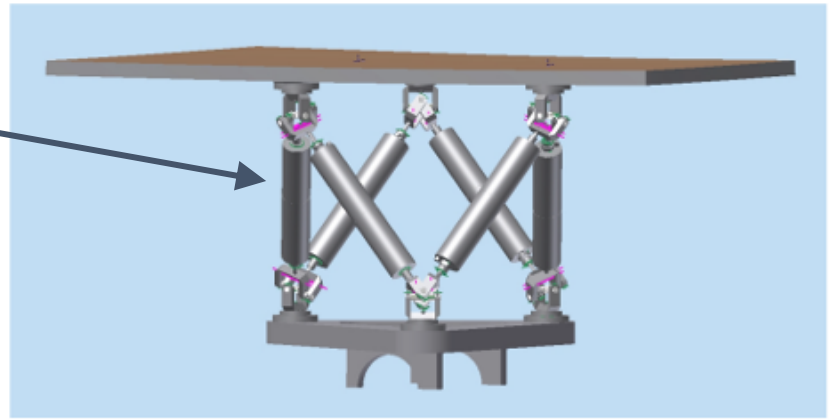
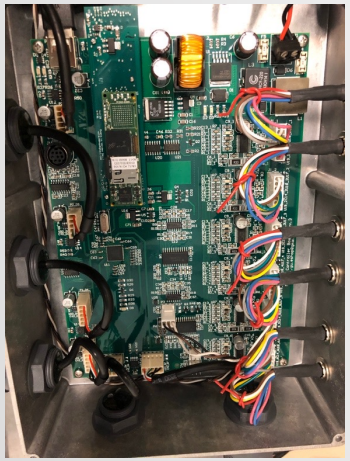
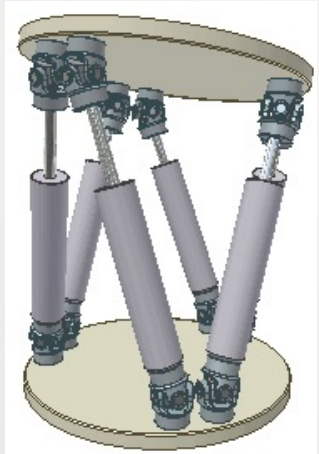


Figure 20. Mirror mounted to Stewart platform and base





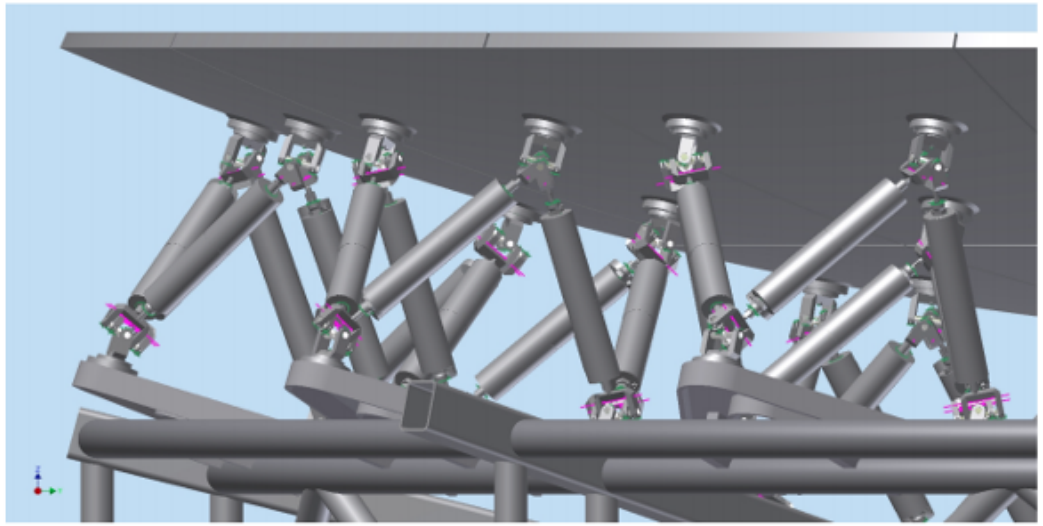
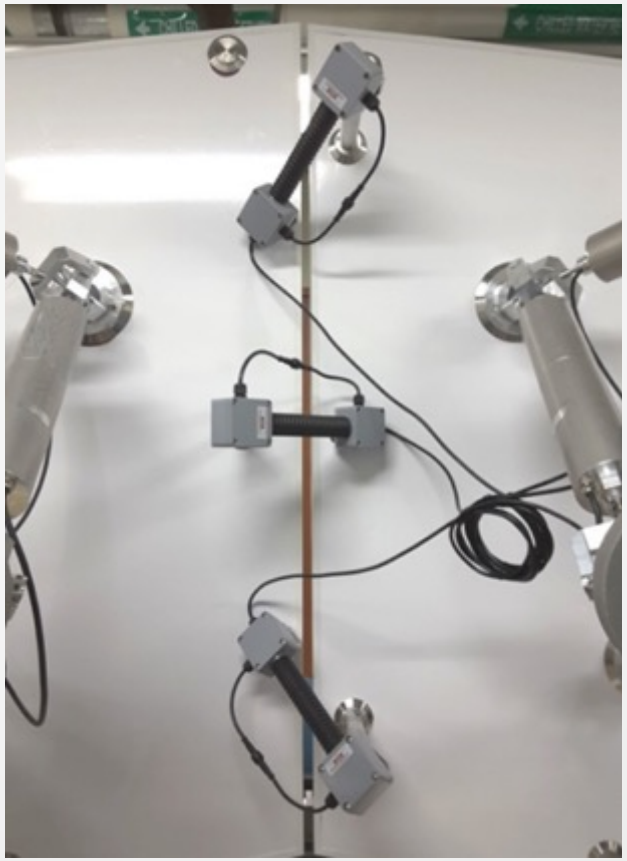


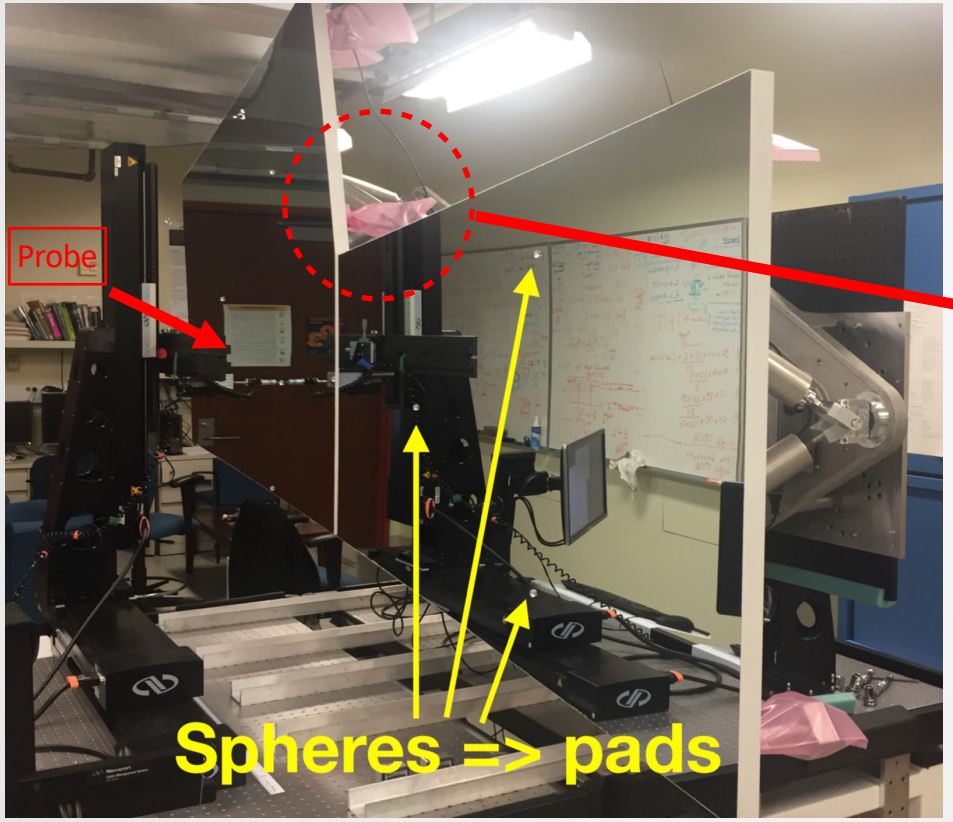
Figure 21a. Mirror mounting

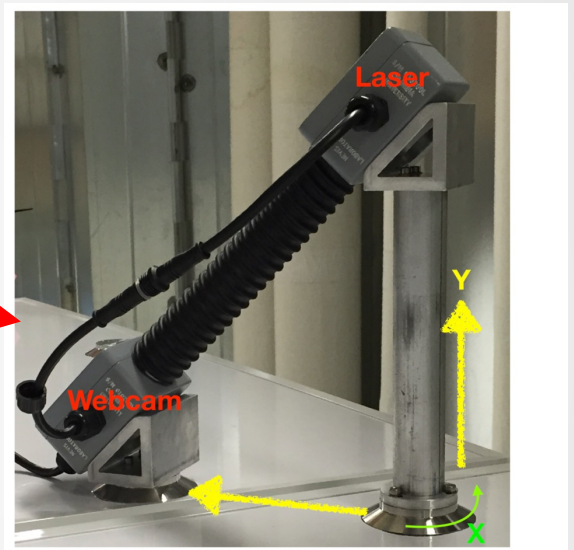
UCLA Mirror Lab Calibration

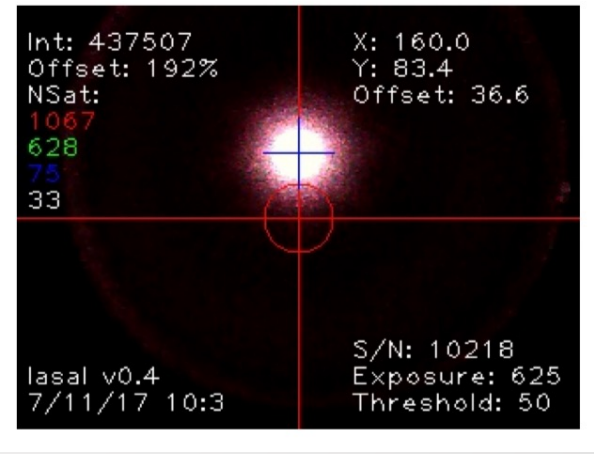
Measure and save the alignment targets!



UCLA Mirror Lab Calibration

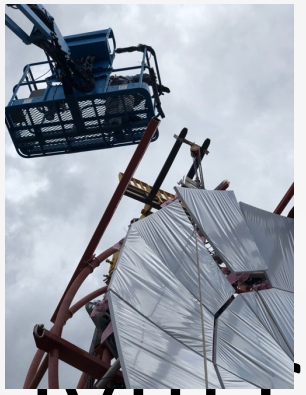






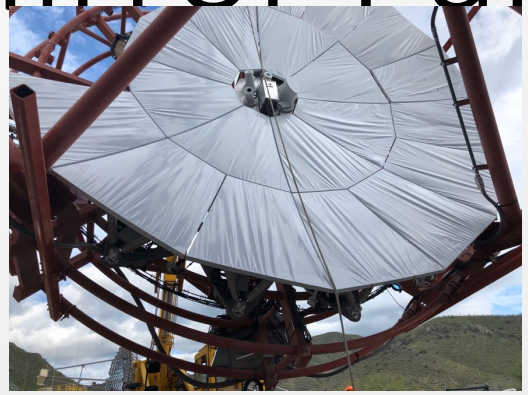






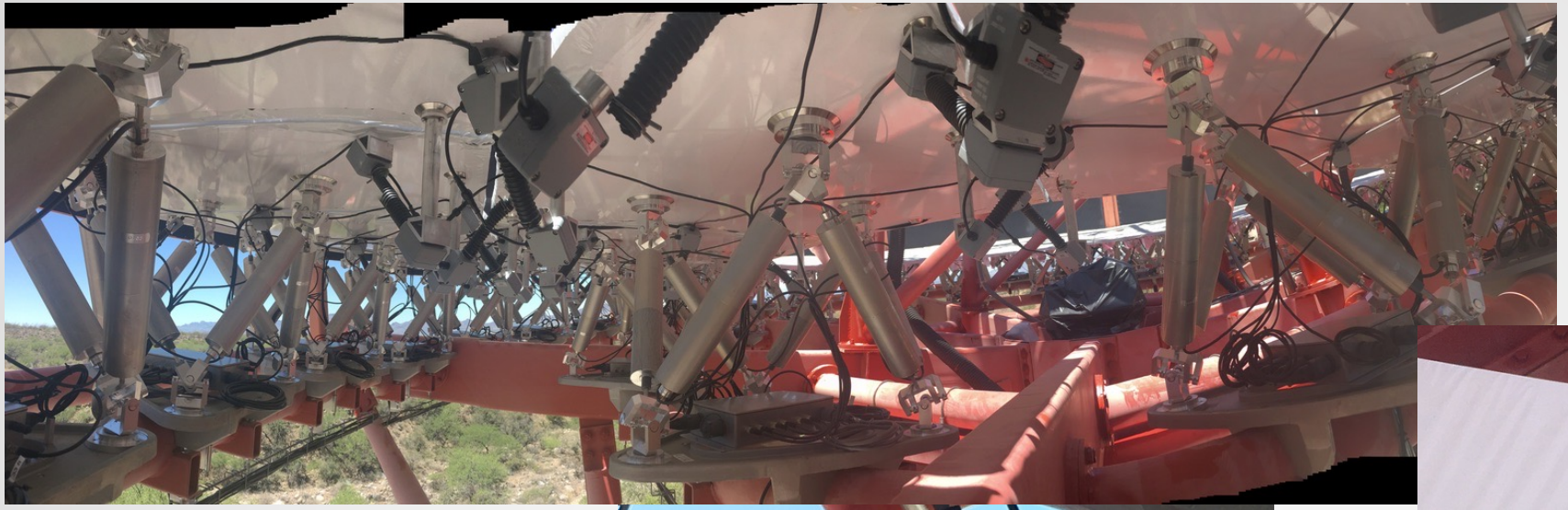
Install Mirror Panels!



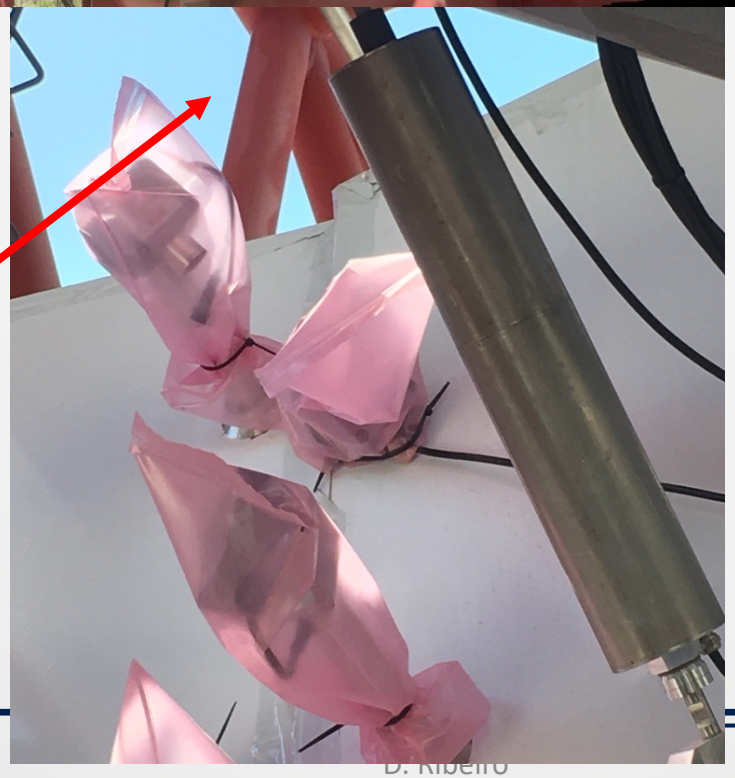



Storms and accidents

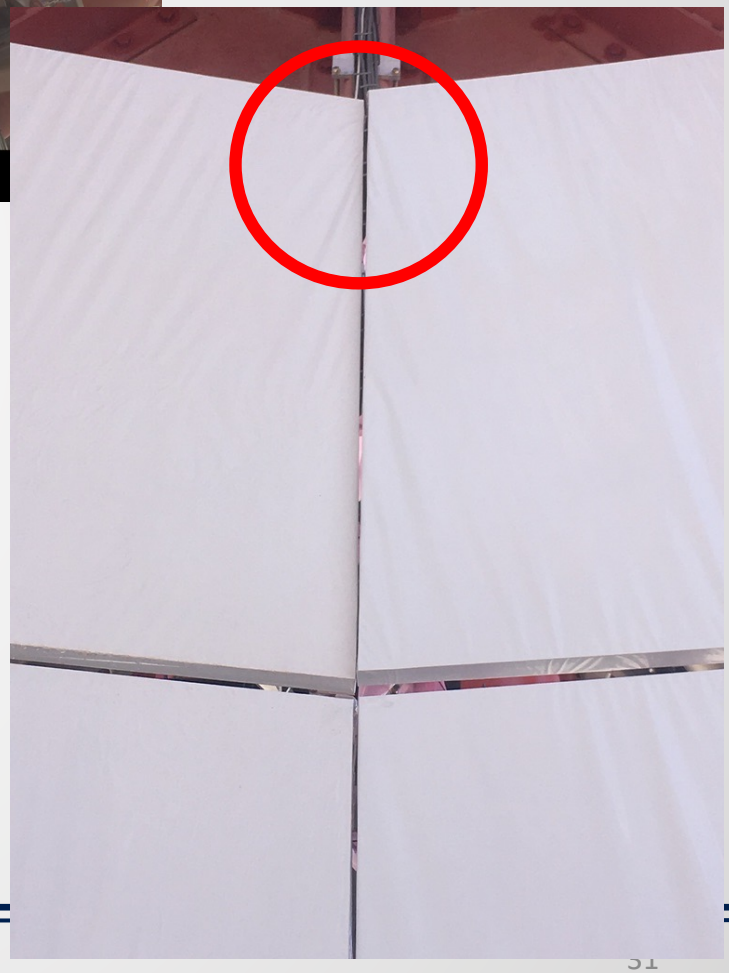
Move to AZ for 3 months

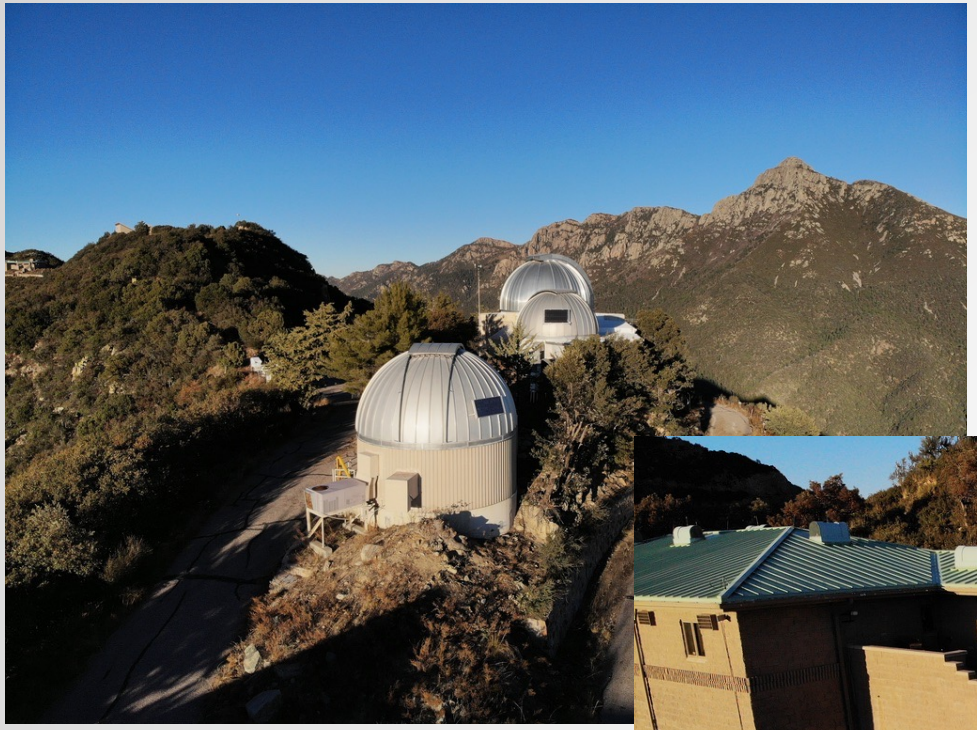


Tediously move every panel to the correct position using the sensors



Some are disabled due to OSS interference

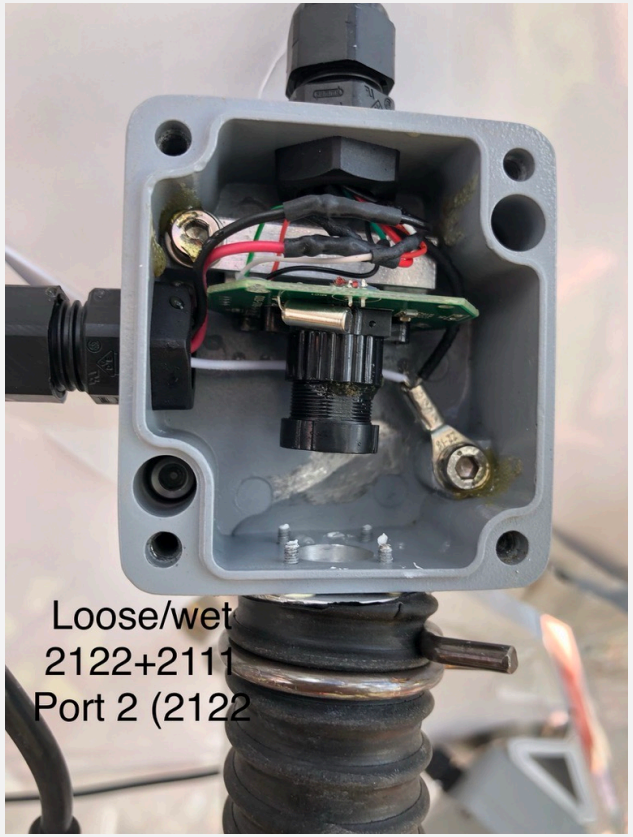


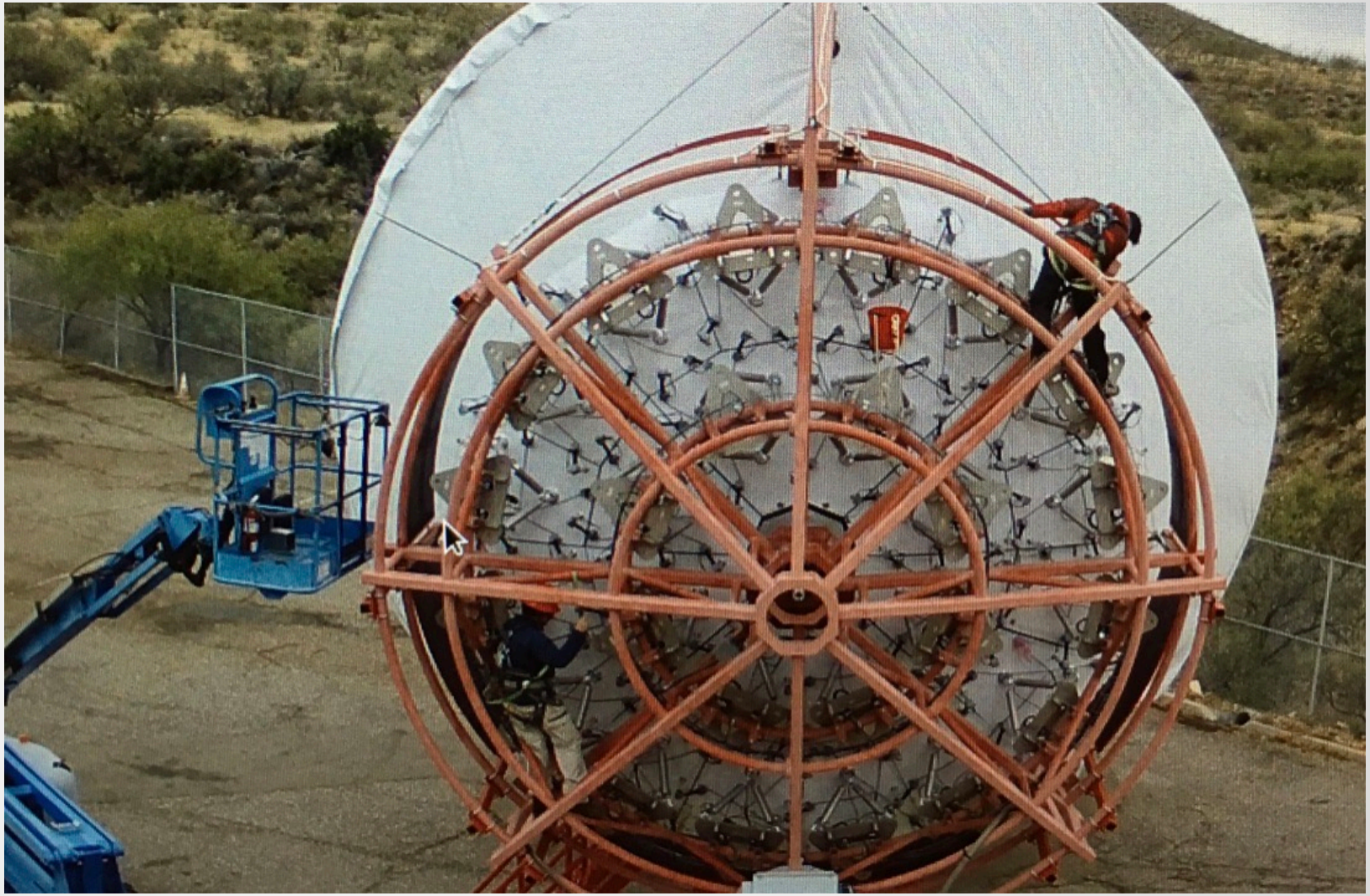


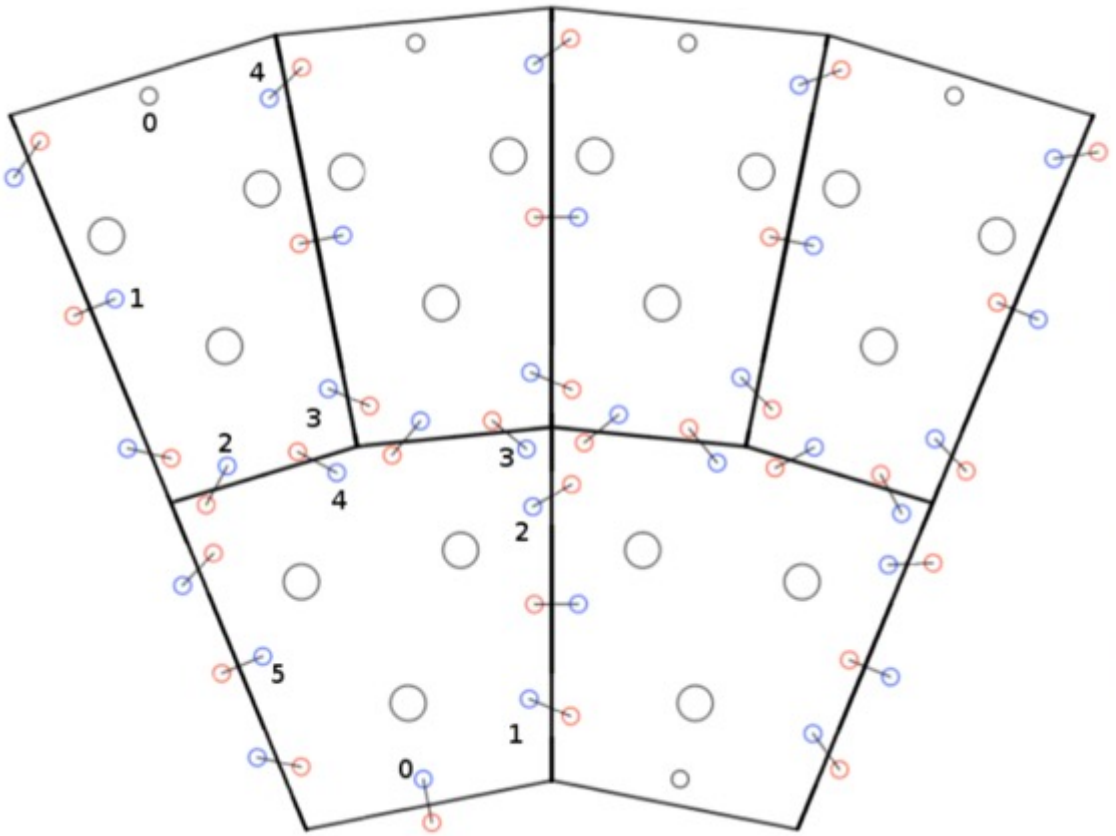


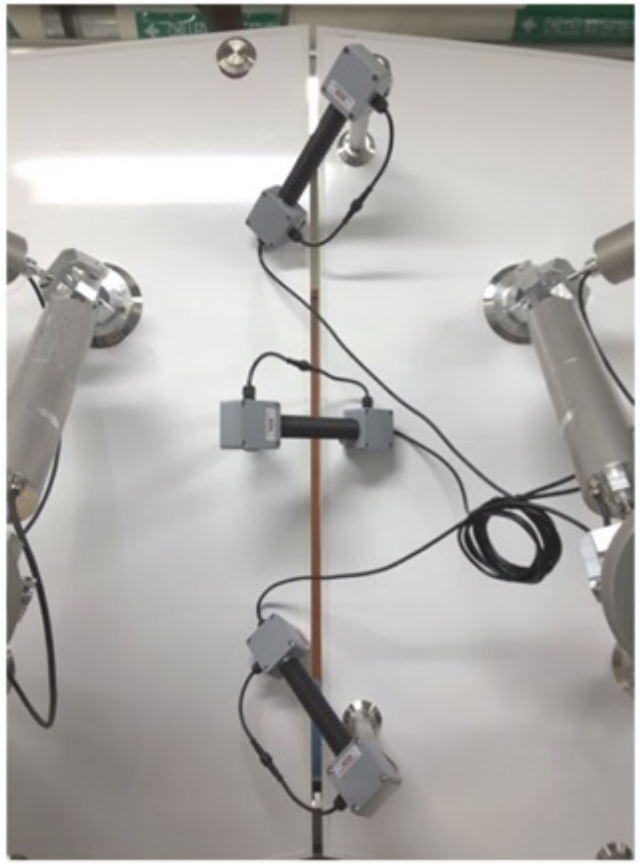


2422+2111
Port 5 (2111)

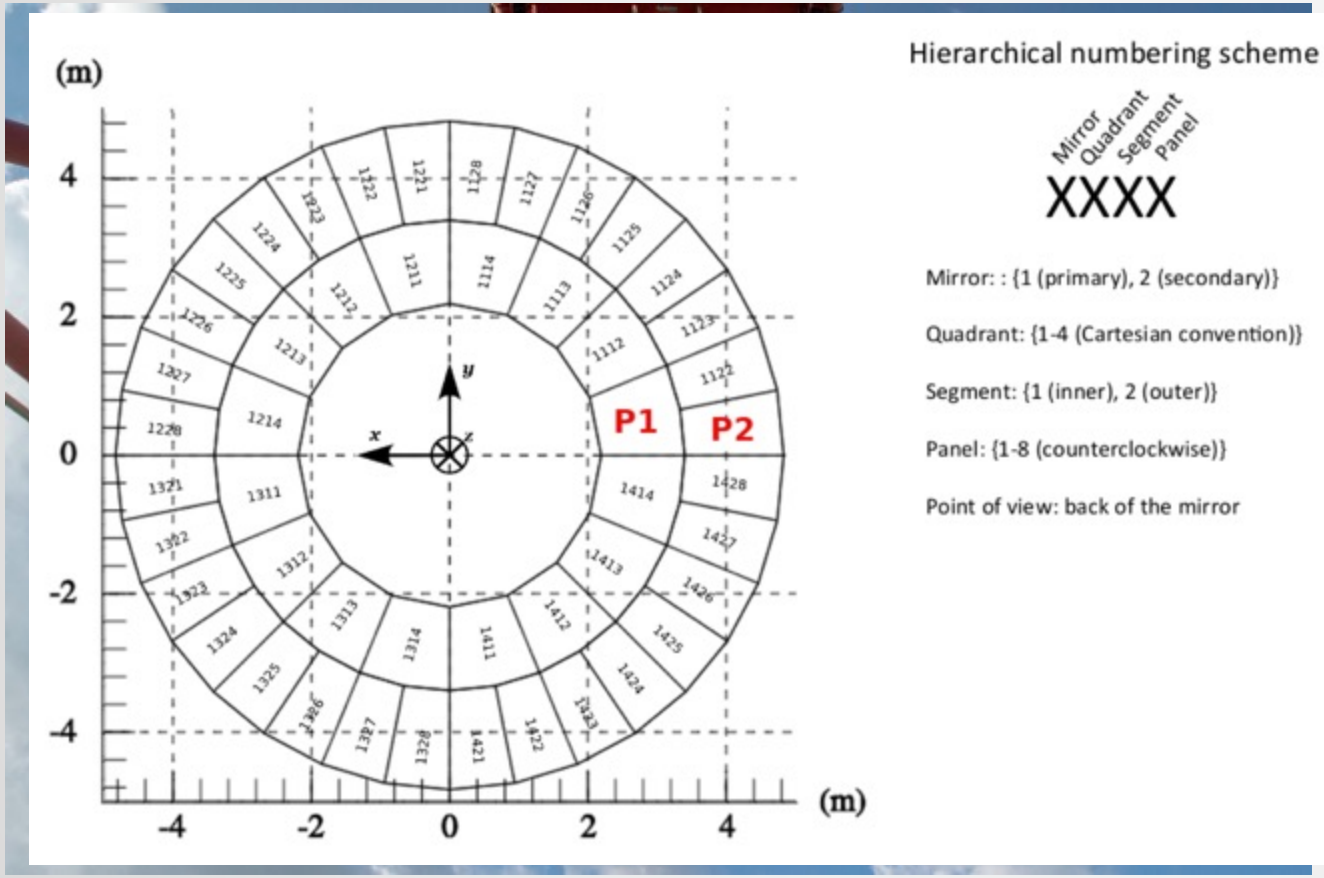

Loose/wet
2122+2111
Port 2 (2122




0
4
1
2
3
4
3
2
5
1
0



pSCT Optics Alignment



Hierarchical numbering scheme

Mirror Quadrant Segment Panel

XXXX

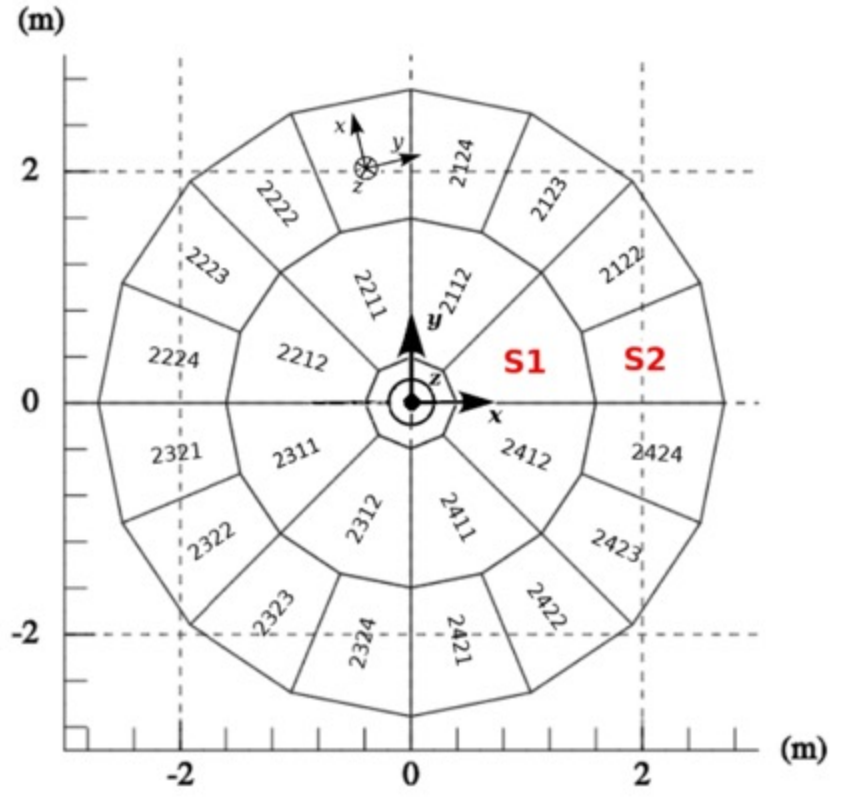
Mirror: : {1 (primary), 2 (secondary)}

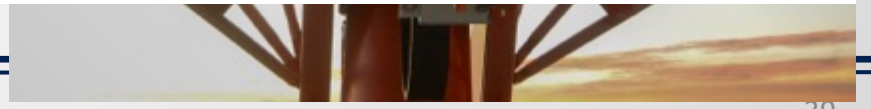
Quadrant: {1-4 (Cartesian convention)}

Segment: {1 (inner), 2 (outer)}

Panel: {1-8 (counterclockwise)}

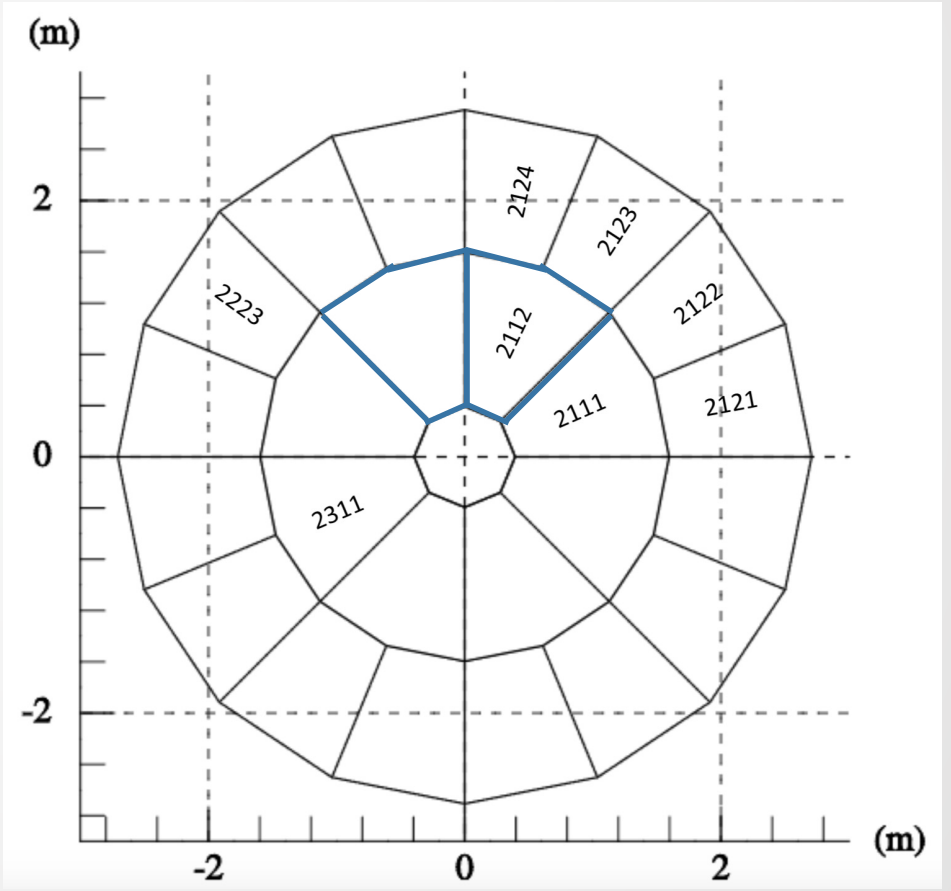
Point of view: back of the mirror





Methods of alignment

- Aligning one edge.
- Aligning one wedge.
- Aligning arbitrary edges.



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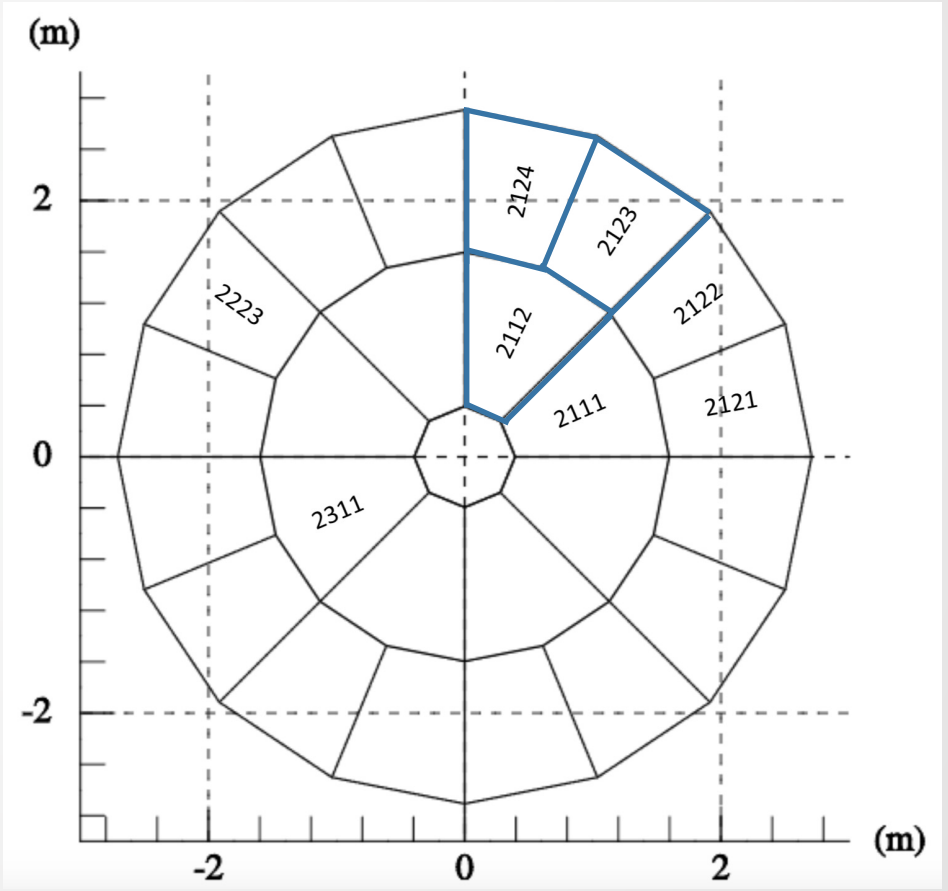

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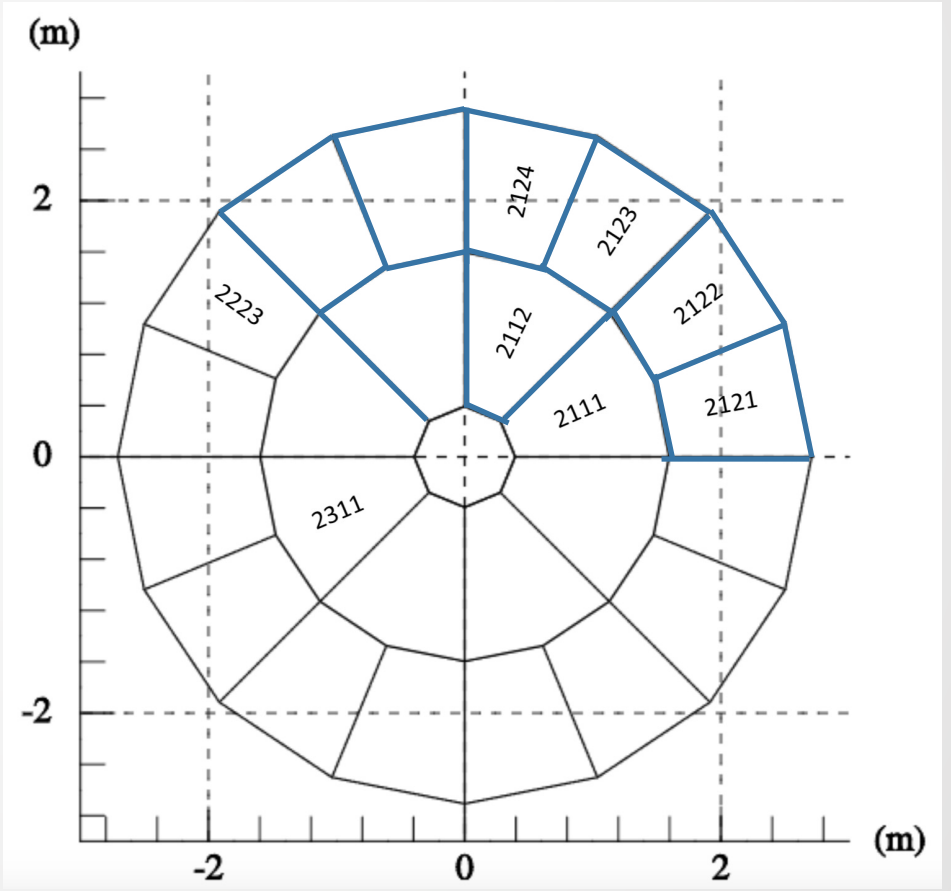
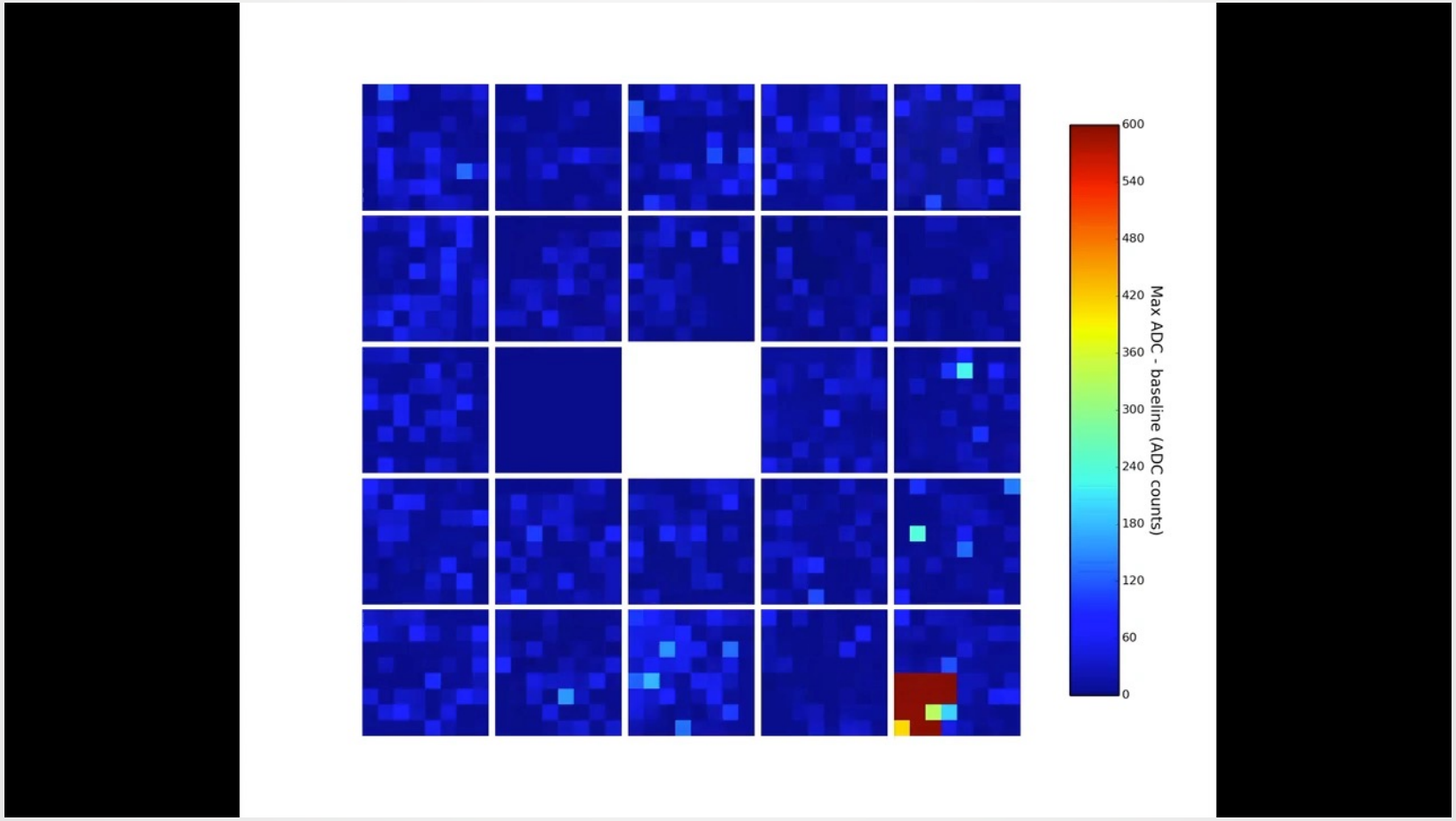
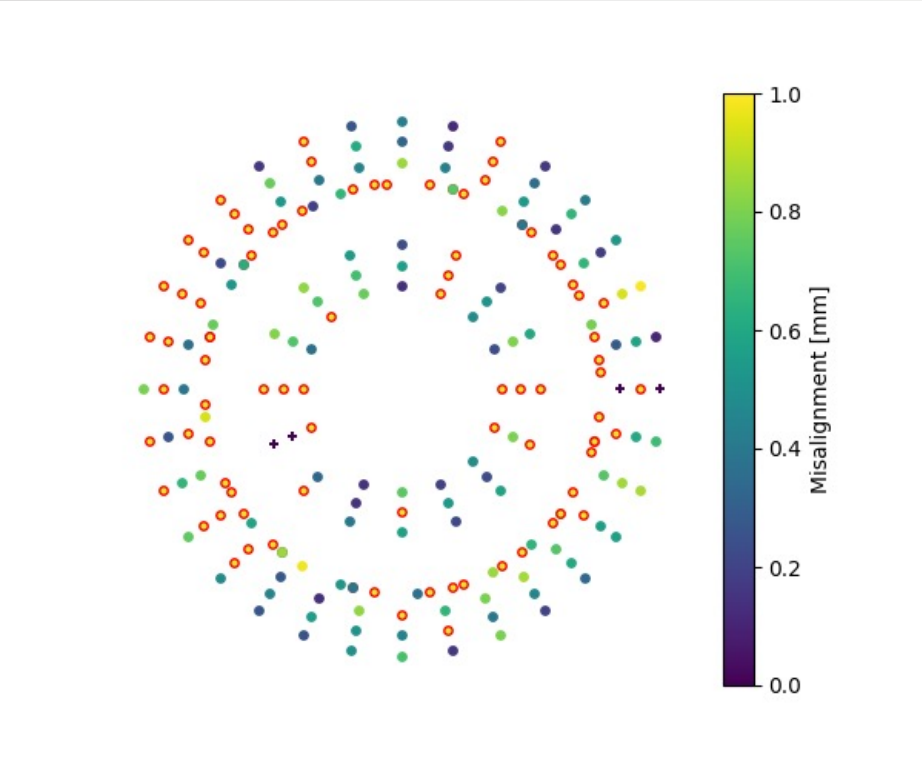
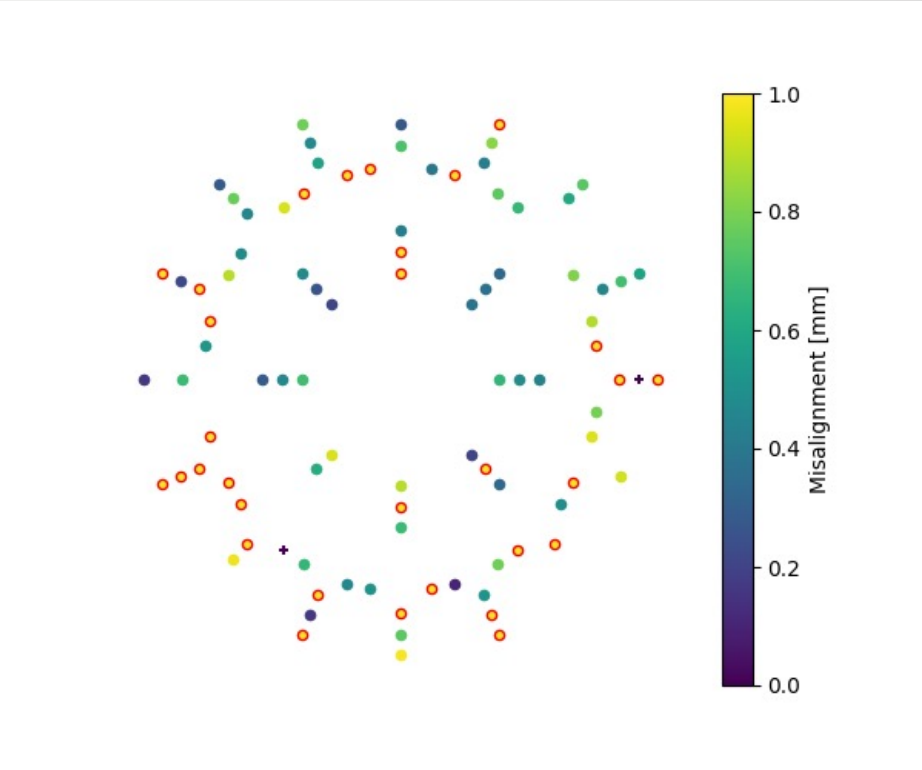


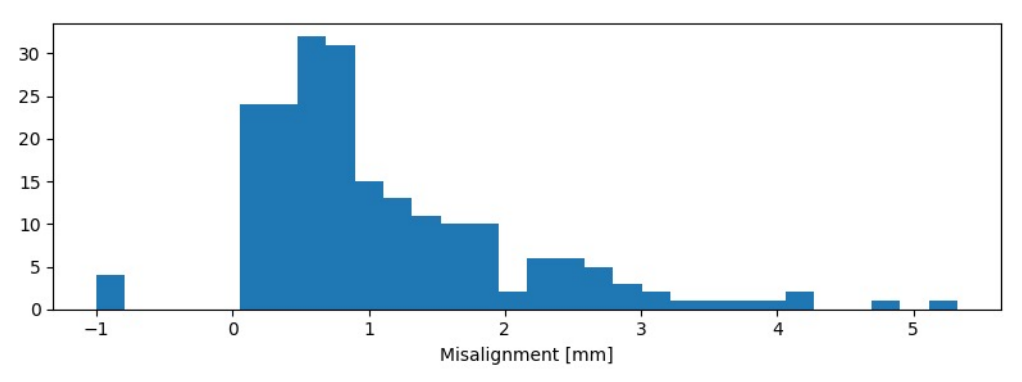
Inauguration

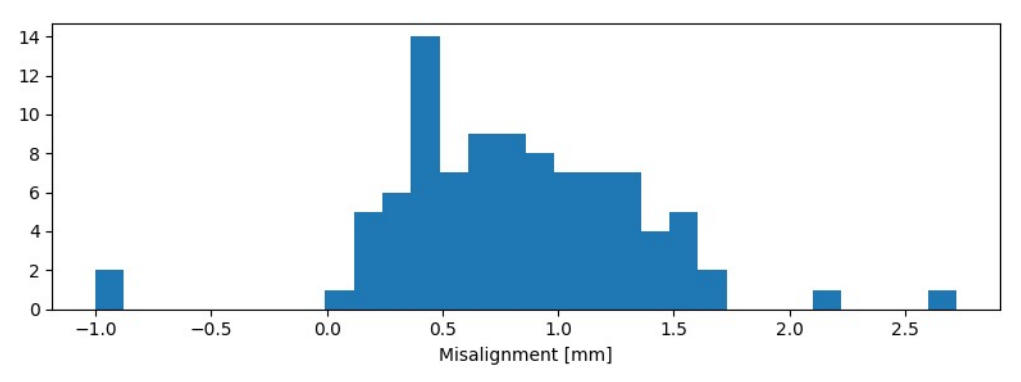
First Light!


600
540
480
420
360
300
240
180
120
60
0
Max ADC - baseline (ADC counts)

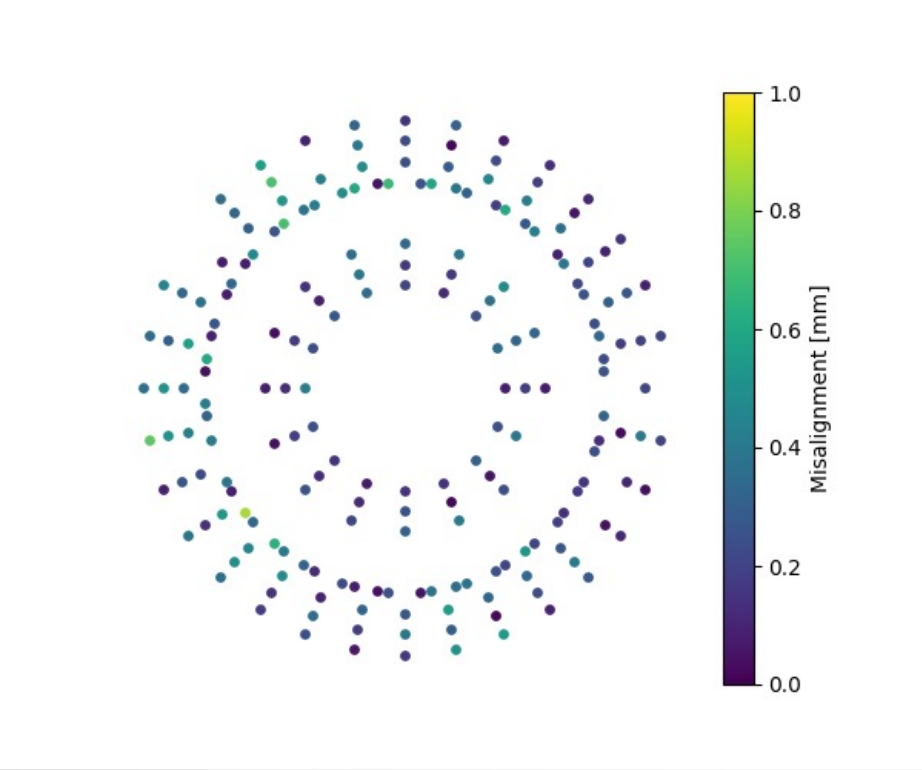

1.0
0.8
0.6
0.4
0.2
0.0
Misalignment [mm]

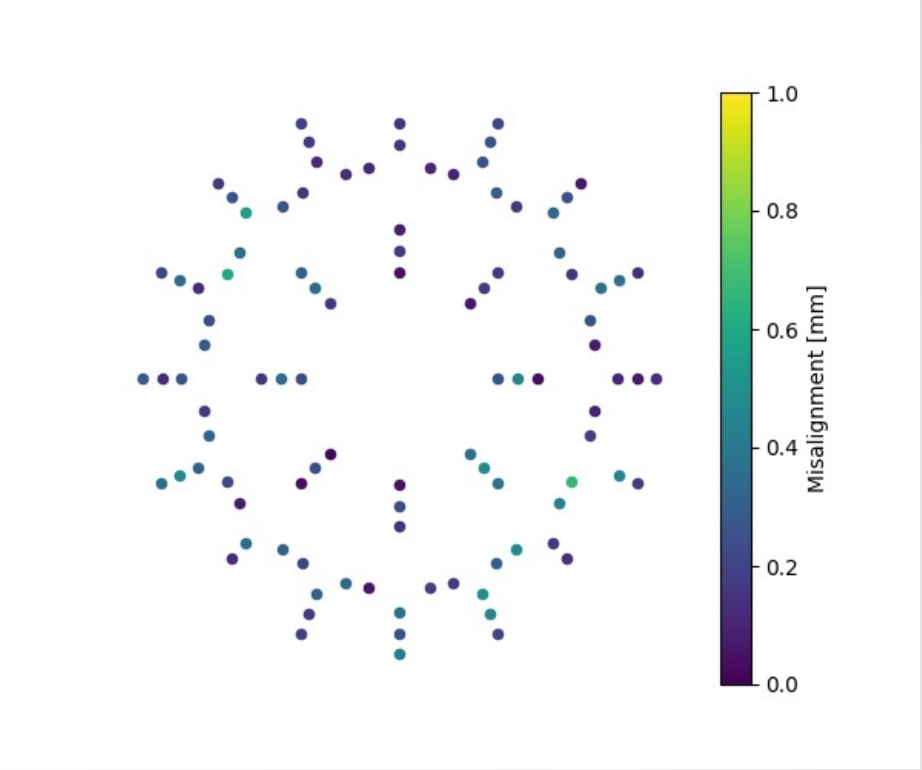

1.0
0.8
0.6
0.4
0.2
0.0
Misalignment [mm]

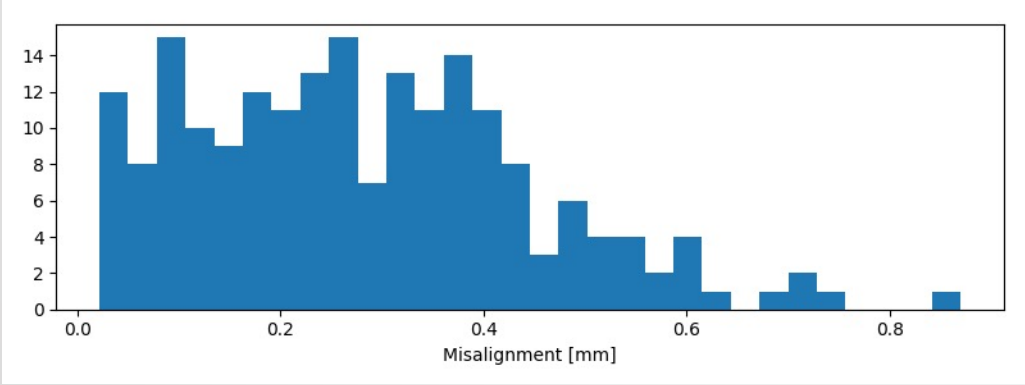

30
25
20
15
10
5
0
−1
0
1
2
3
4
5
Misalignment [mm]

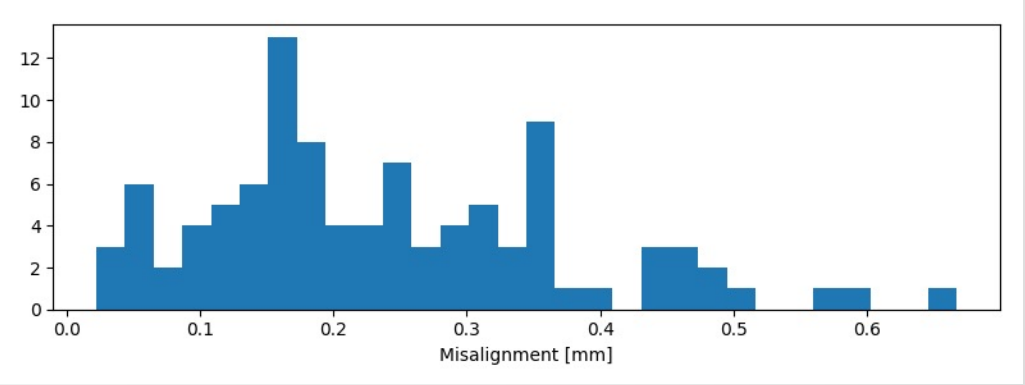

14
12
10
8
6
4
2
0
−1.0
−0.5
0.0
0.5
1.0
1.5
2.0
2.5
Misalignment [mm]

Several strategies later…

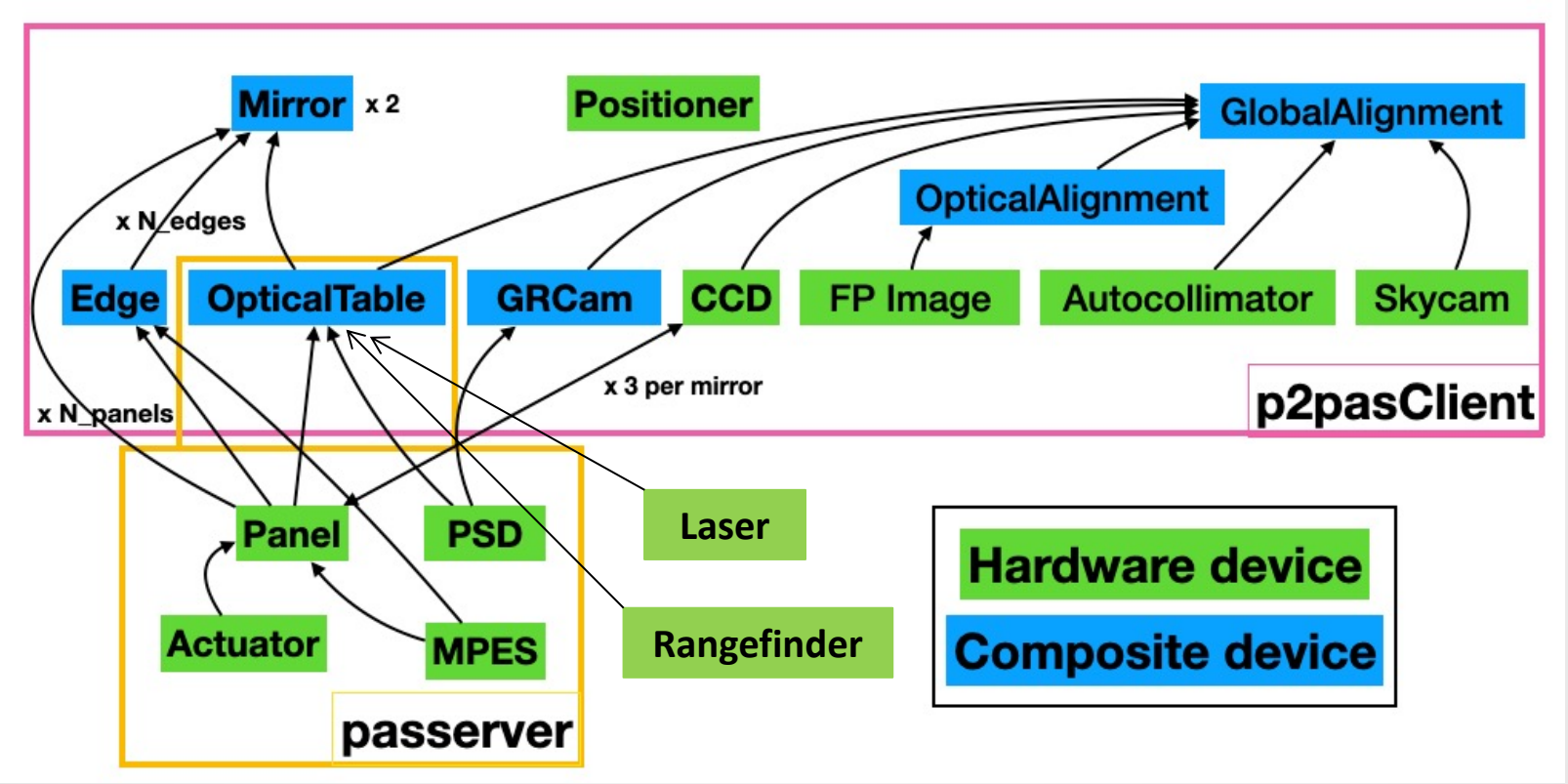

1.0
0.8
0.6
0.4
0.2
0.0
Misalignment [mm]


1.0
0.8
0.6
0.4
0.2
0.0
Misalignment [mm]

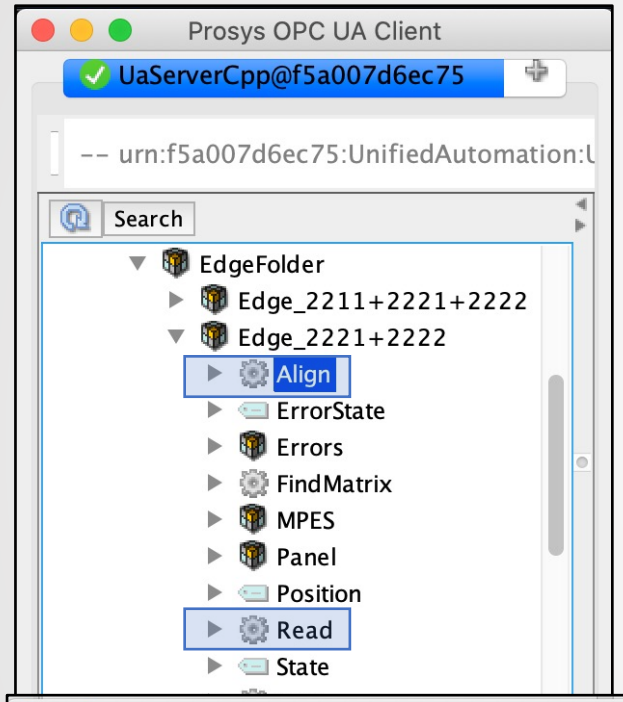

14
12
10
8
6
4
2
0
0.0
0.2
0.4
0.6
0.8
Misalignment [mm]


12
10
8
6
4
2
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Misalignment [mm]

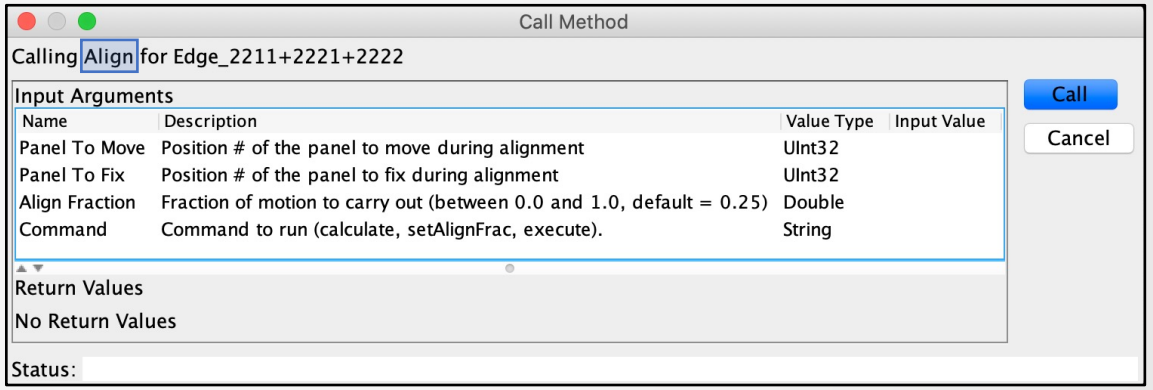
Overall Structure

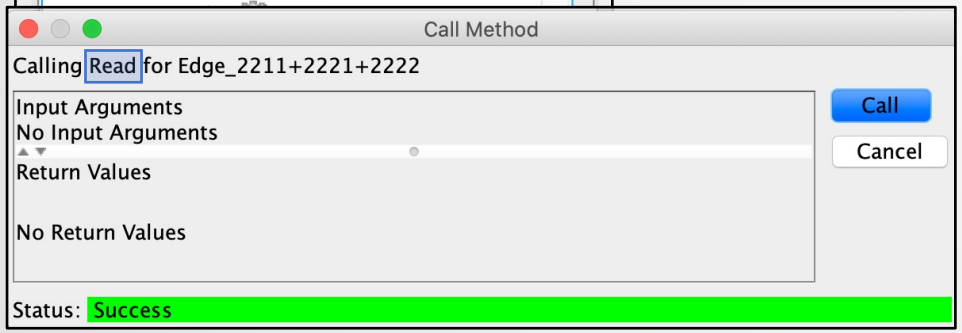


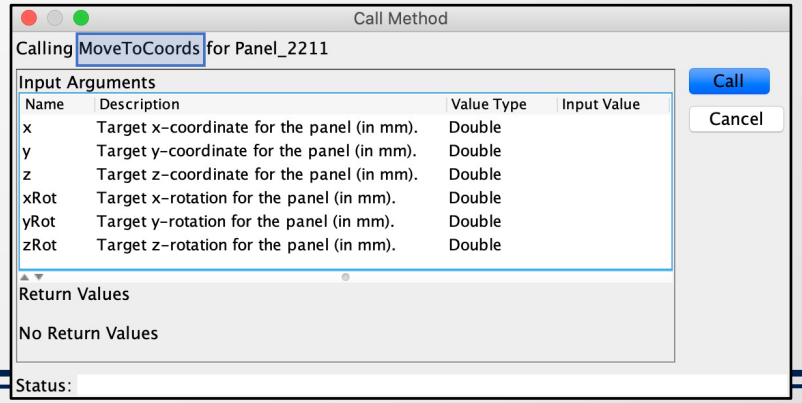
Software Capabilities



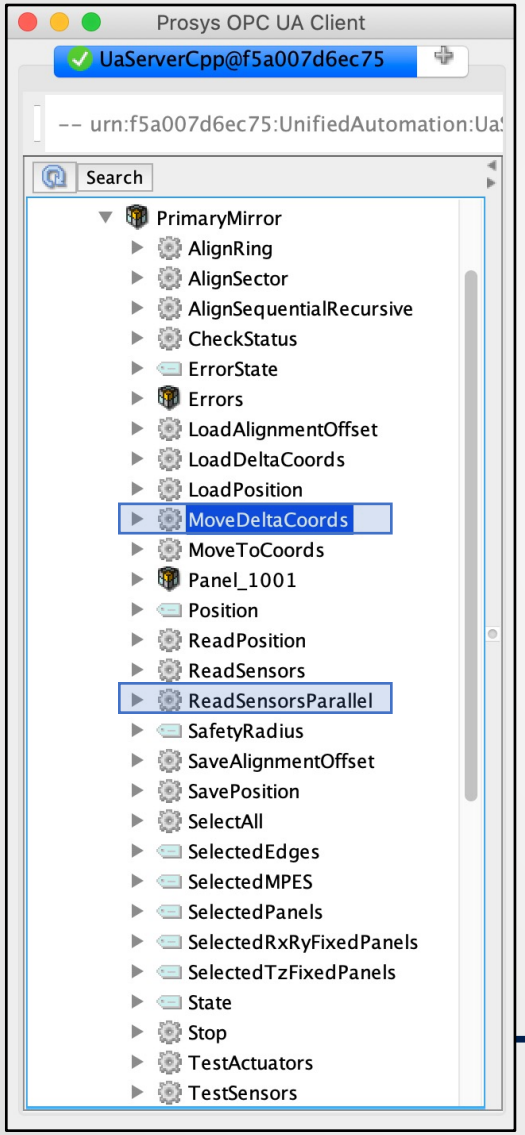
- Simple buttons to
  - **align** single edge,
  - **read** misalignments,
  - **move** individual panels.



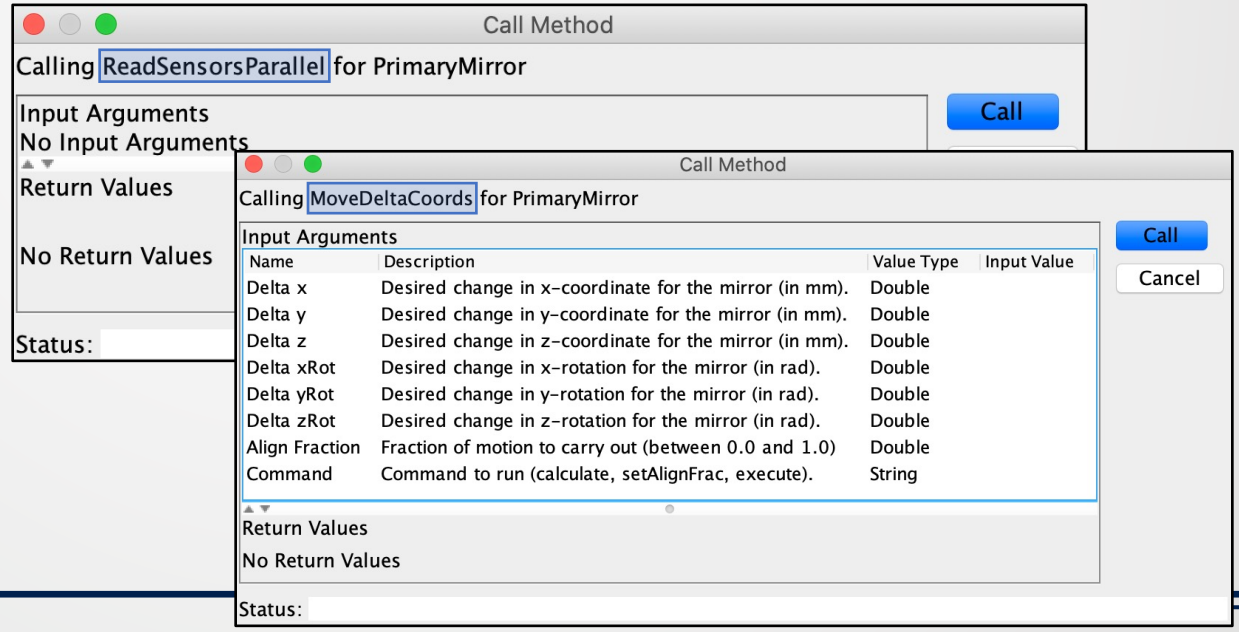


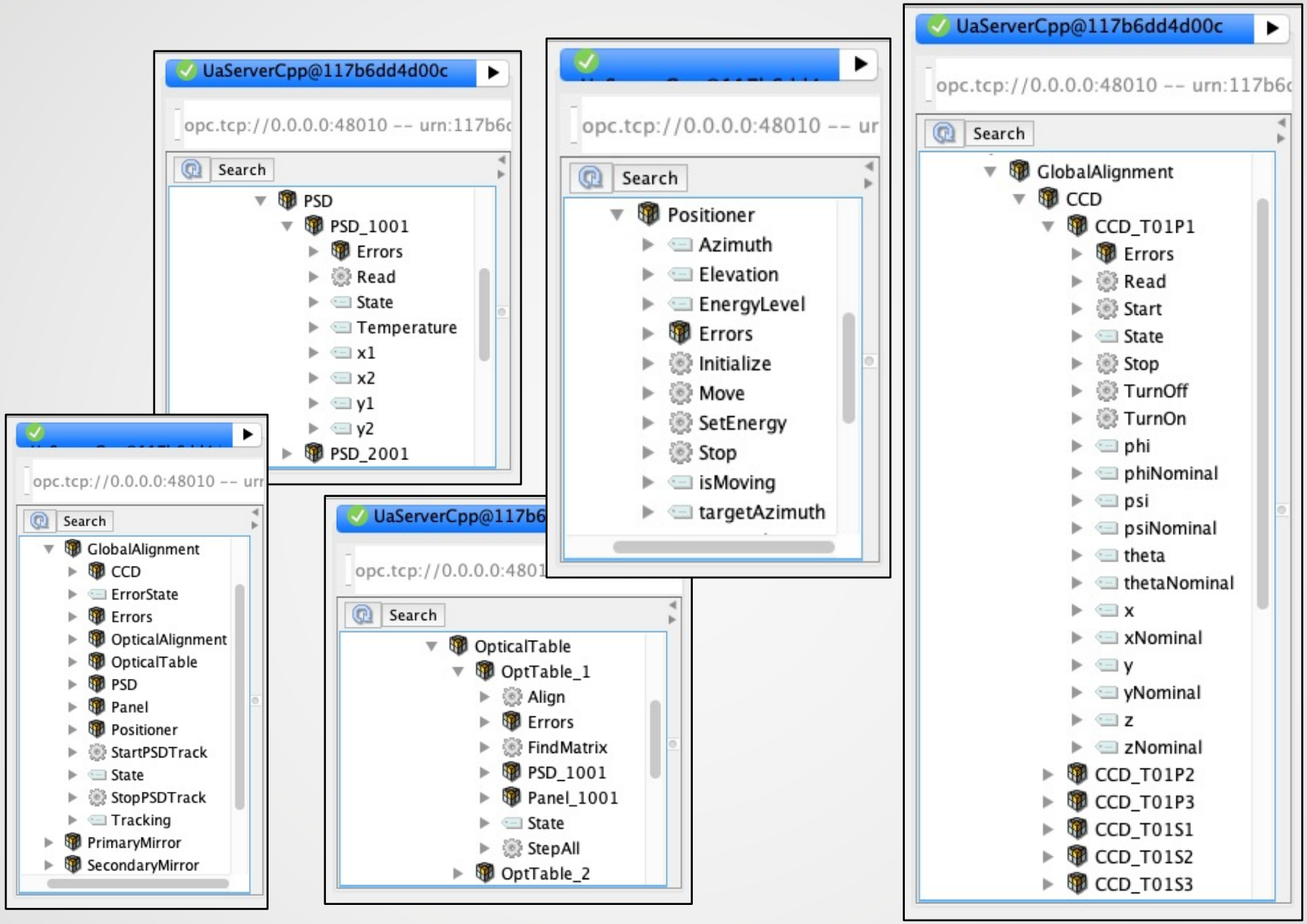


Software Capabilities

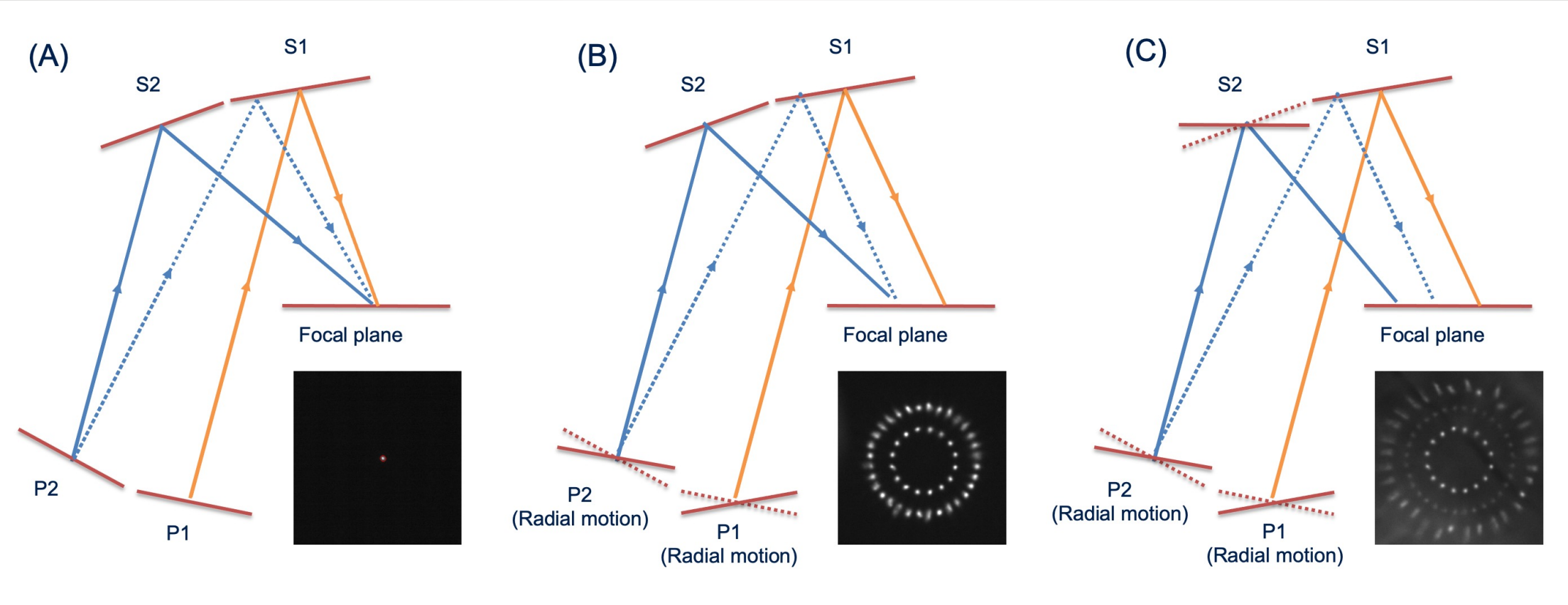


- Important features:
  - **Read** all sensors in *parallel* <5mins for >300 sensors!
  - **Move** all panels *simultaneously* in telescope reference frame!
  - **Save** any state and **reload** later, moving all panels to those coordinates.

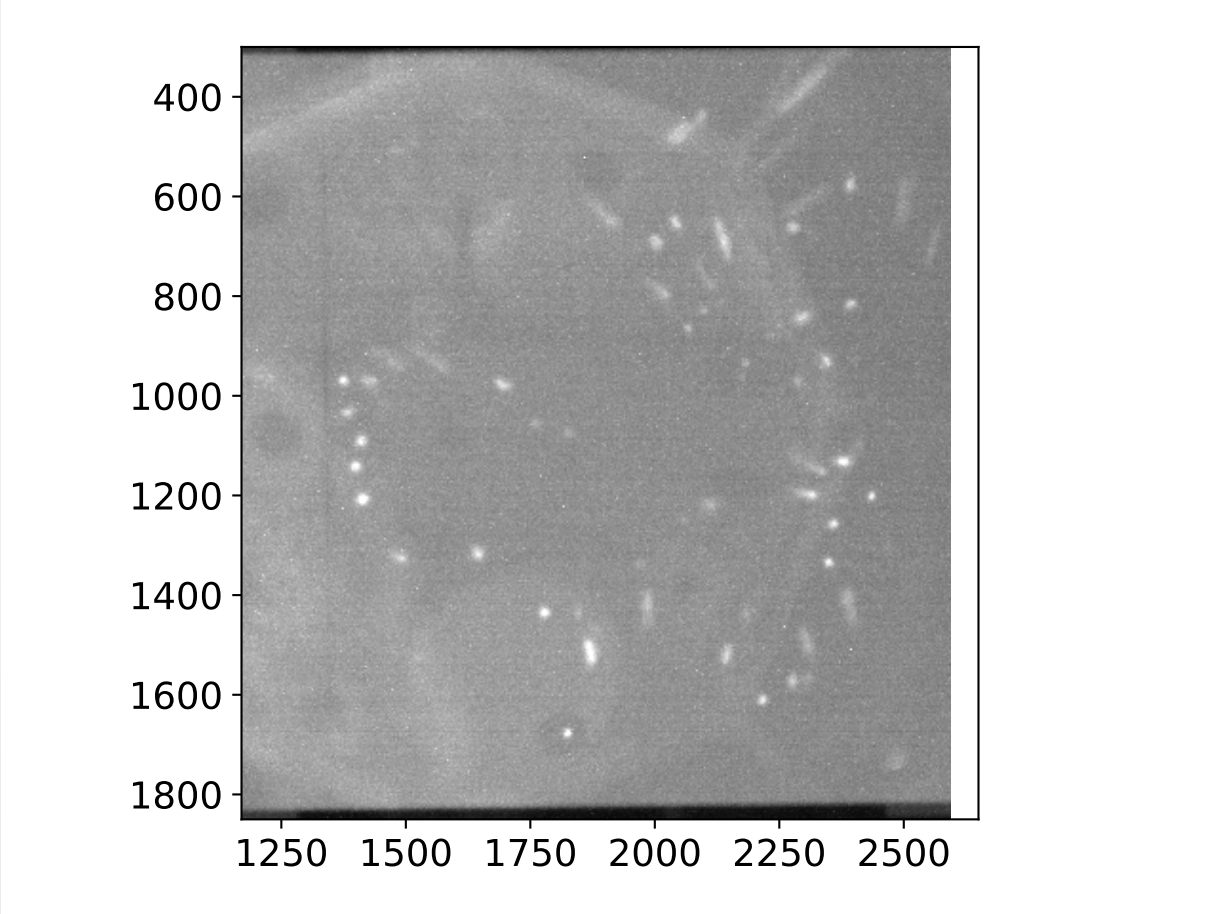



UaServerCpp@117b6dd4d00c
opc.tcp://0.0.0.0:48010 -- urn:117b6c
Search
PSD
PSD_1001
Errors
Read
State
Temperature
x1
x2
y1
y2
PSD_2001
opc.tcp://0.0.0.0:48010 -- ur
Positioner
Azimuth
Elevation
EnergyLevel
Errors
Initialize
Move
SetEnergy
Stop
isMoving
targetAzimuth
UaServerCpp@117b6dd4d00c
opc.tcp://0.0.0.0:48010 -- urn:117b6c
Search
GlobalAlignment
CCD
CCD_T01P1
Errors
Read
Start
State
Stop
TurnOff
TurnOn
phi
phiNominal
psi
psiNominal
theta
thetaNominal
x
xNominal
y
yNominal
z
zNominal
CCD_T01P2
CCD_T01P3
CCD_T01S1
CCD_T01S2
CCD_T01S3
opc.tcp://0.0.0.0:48010 -- urr
Search
GlobalAlignment
CCD
ErrorState
Errors
OpticalAlignment
OpticalTable
PSD
Panel
Positioner
StartPSDTrack
State
StopPSDTrack
Tracking
PrimaryMirror
SecondaryMirror
UaServerCpp@117b6
opc.tcp://0.0.0.0:4801
Search
OpticalTable
OptTable_1
Align
Errors
FindMatrix
PSD_1001
Panel_1001
State
StepAll
OptTable_2

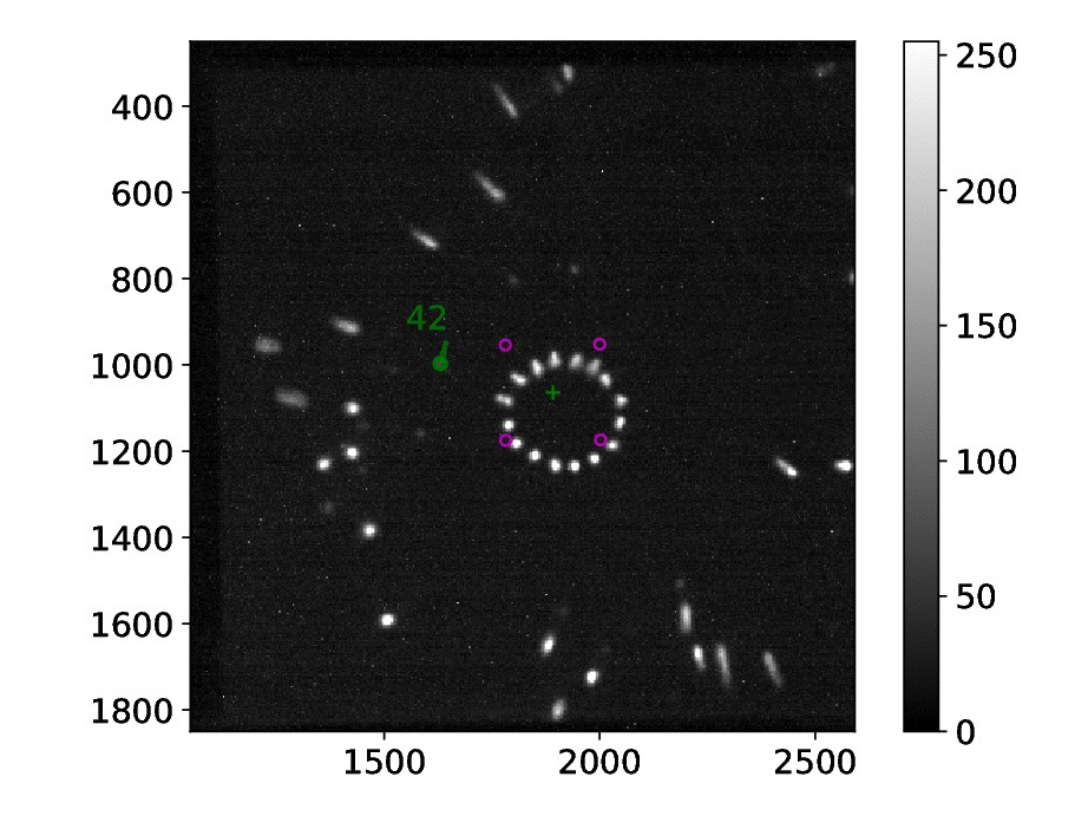
Optical Alignment Procedure

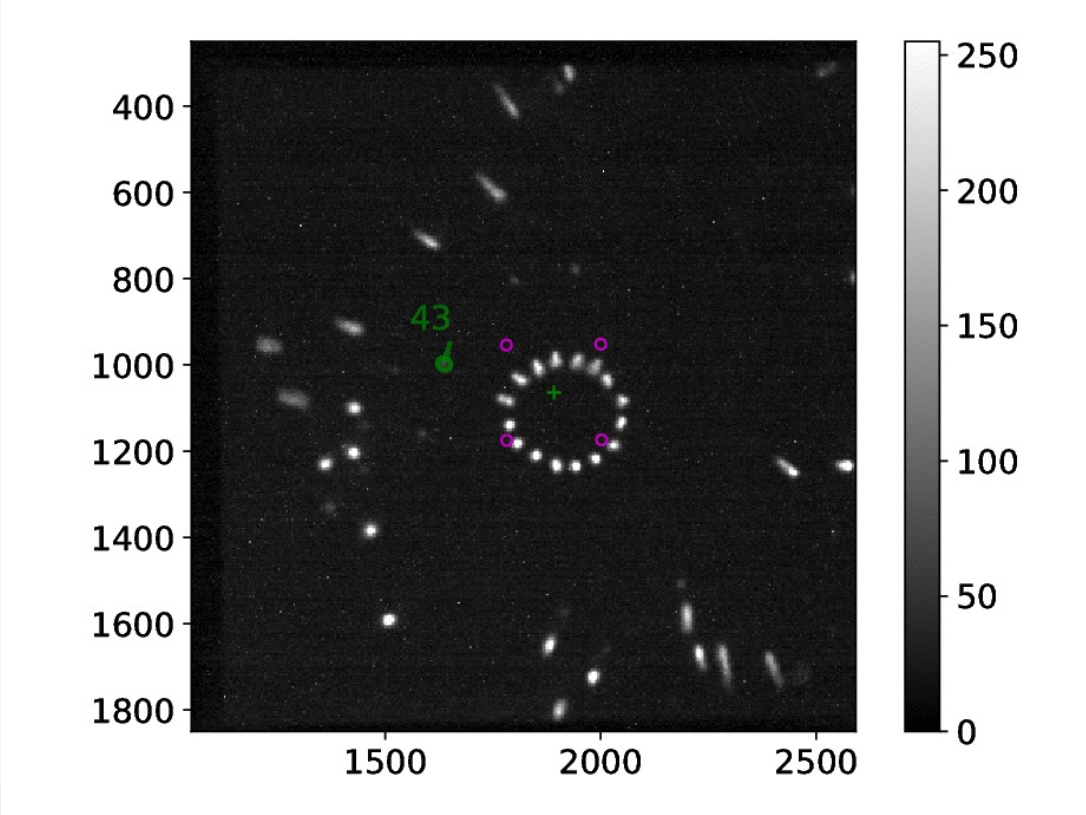


MPES Aligned State



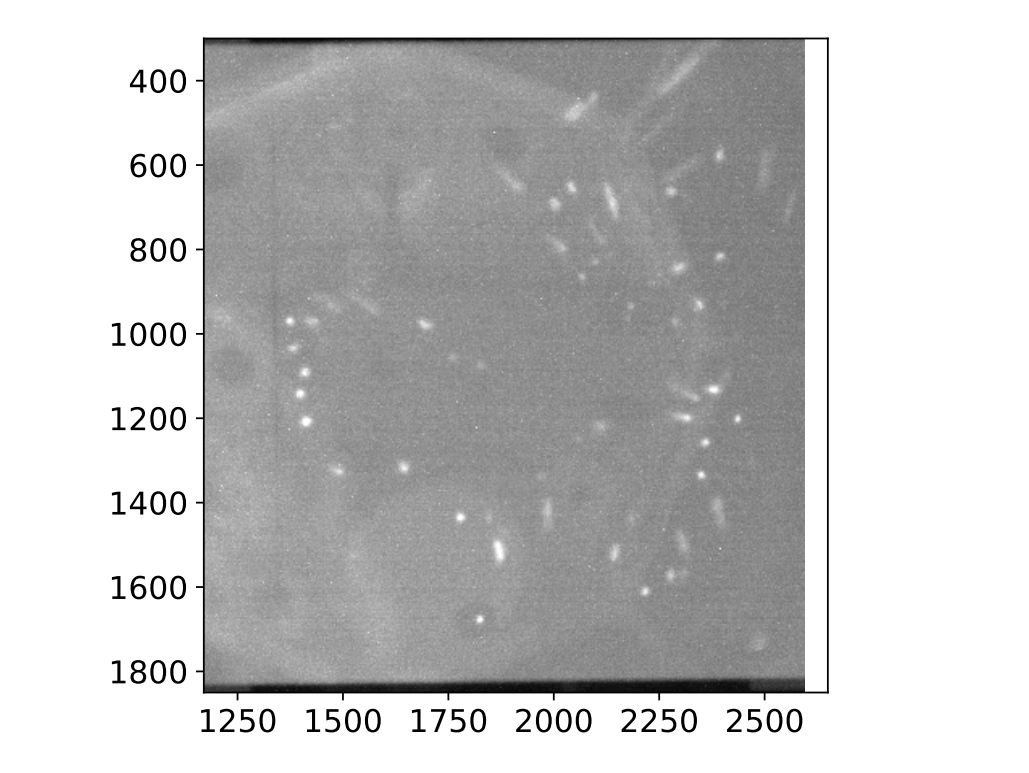
Response Matrix



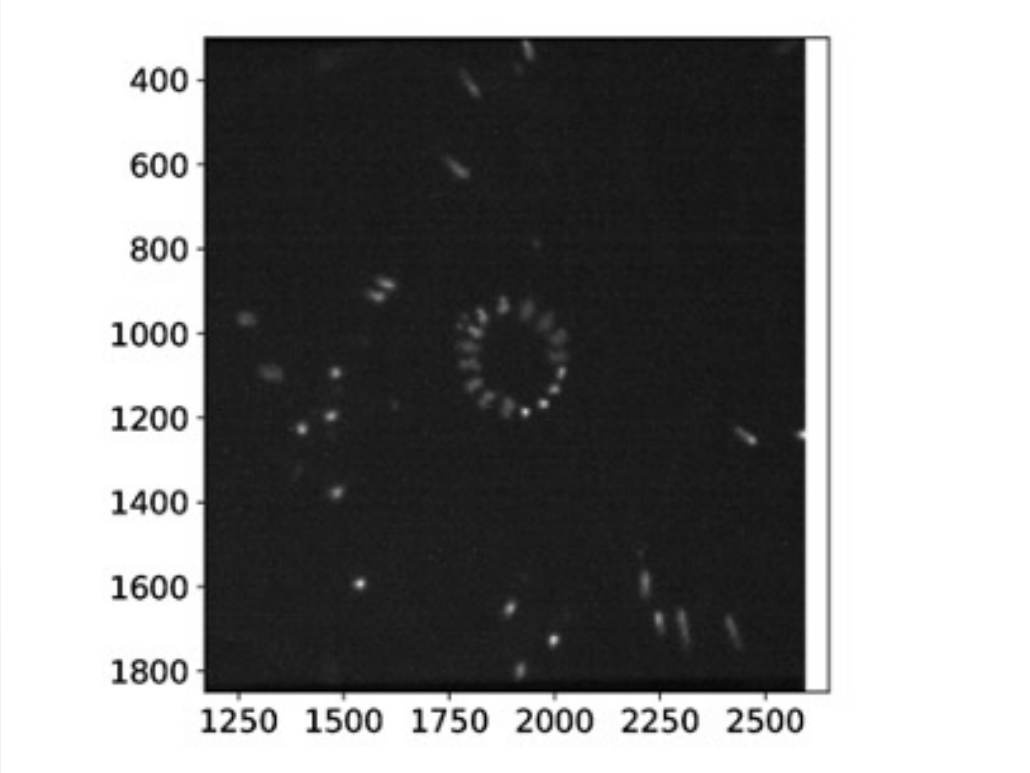


Optical Motion

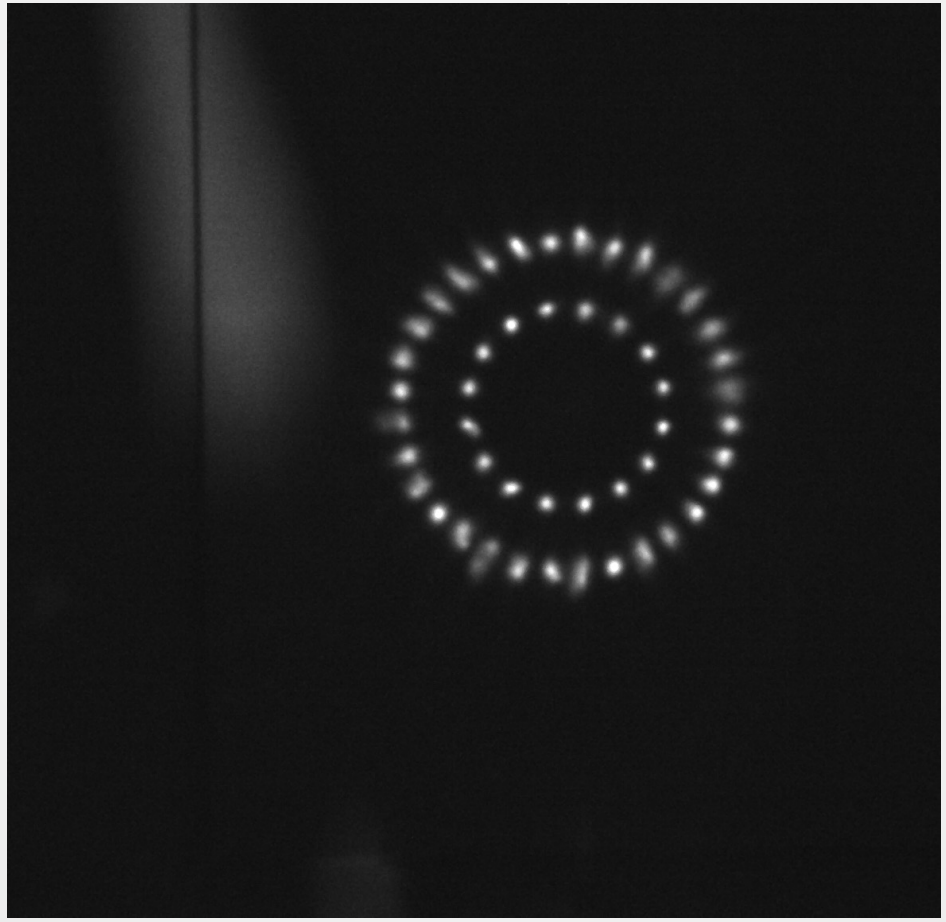
MPES Aligned State



P1 Ring



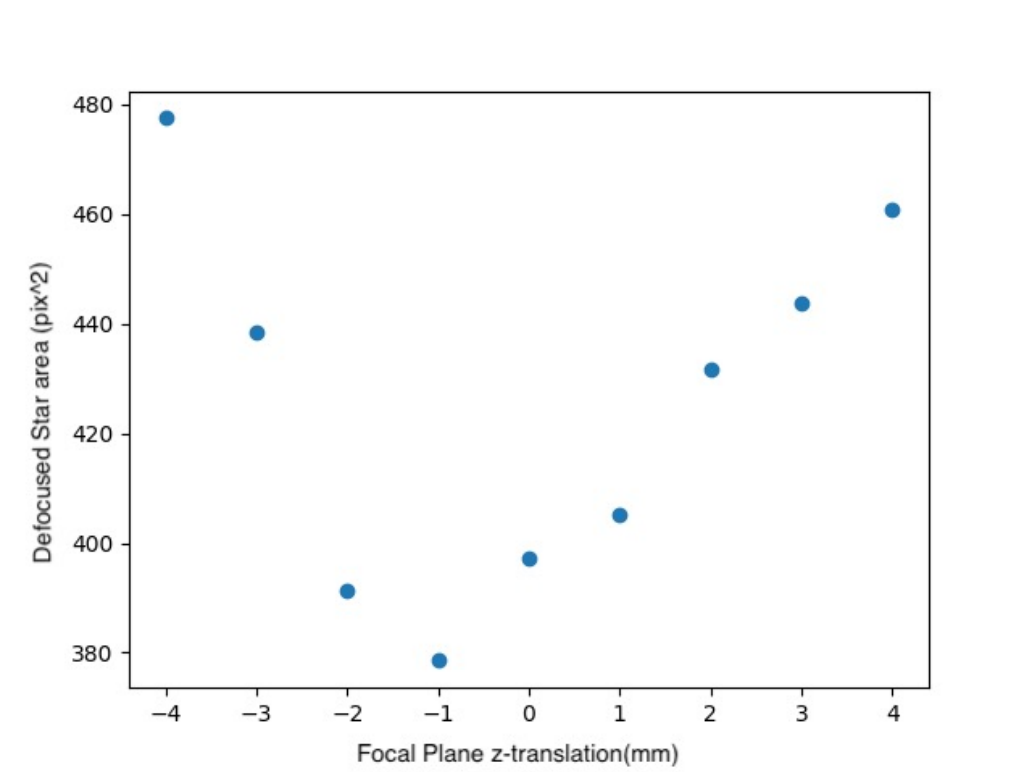
Alignment to Focus



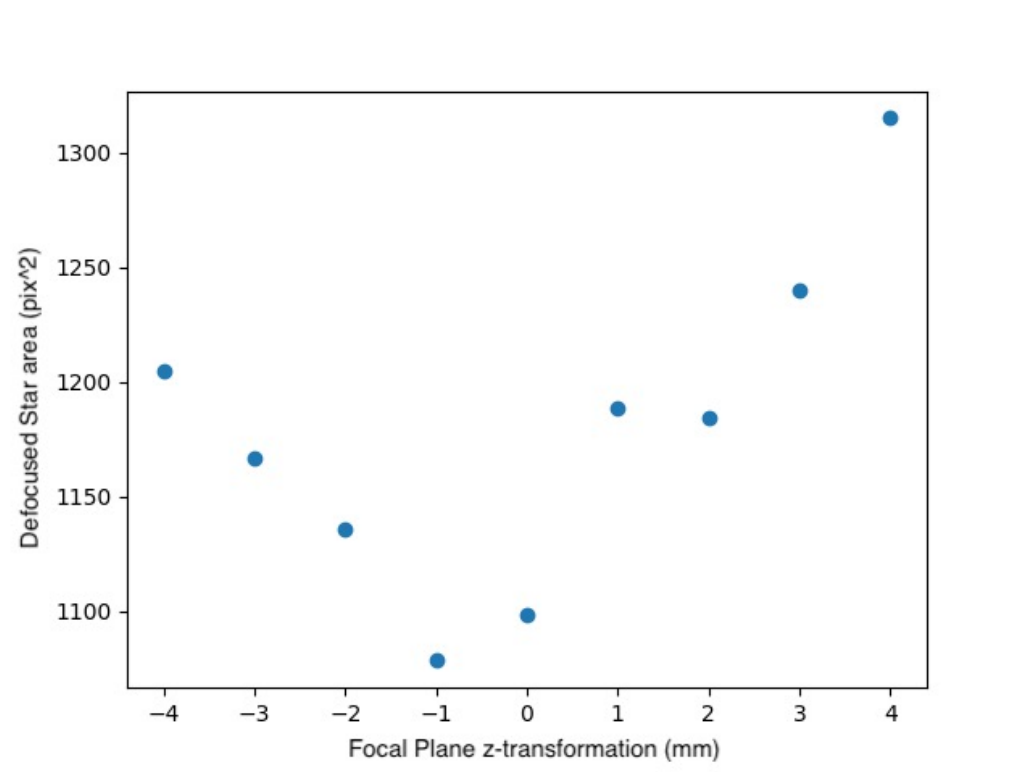
~1.5x camera pixel PSF

Finding Ideal Focal Plane Position

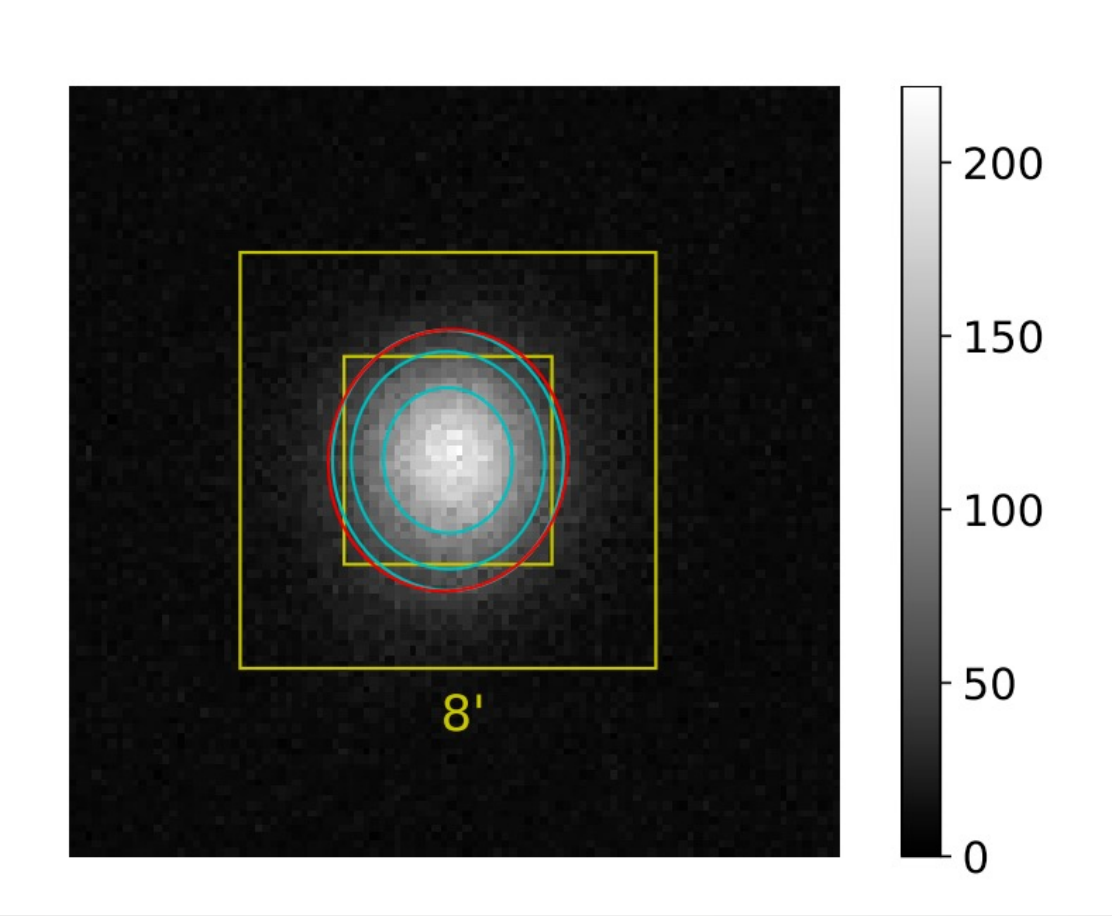
P1 Ring



S2 Ring



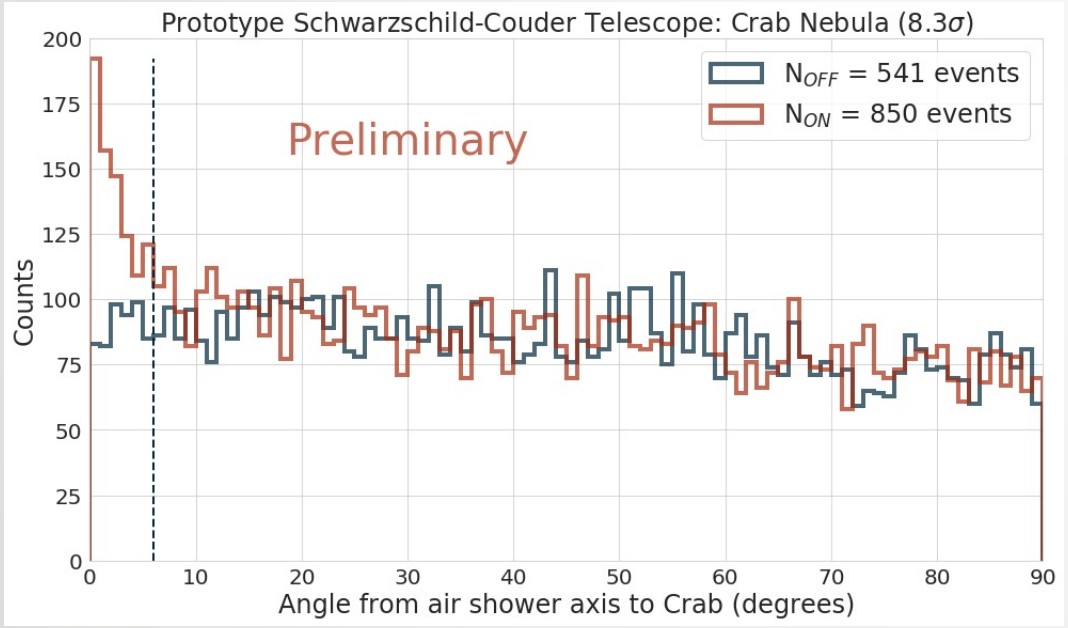
Prior to Crab Observations



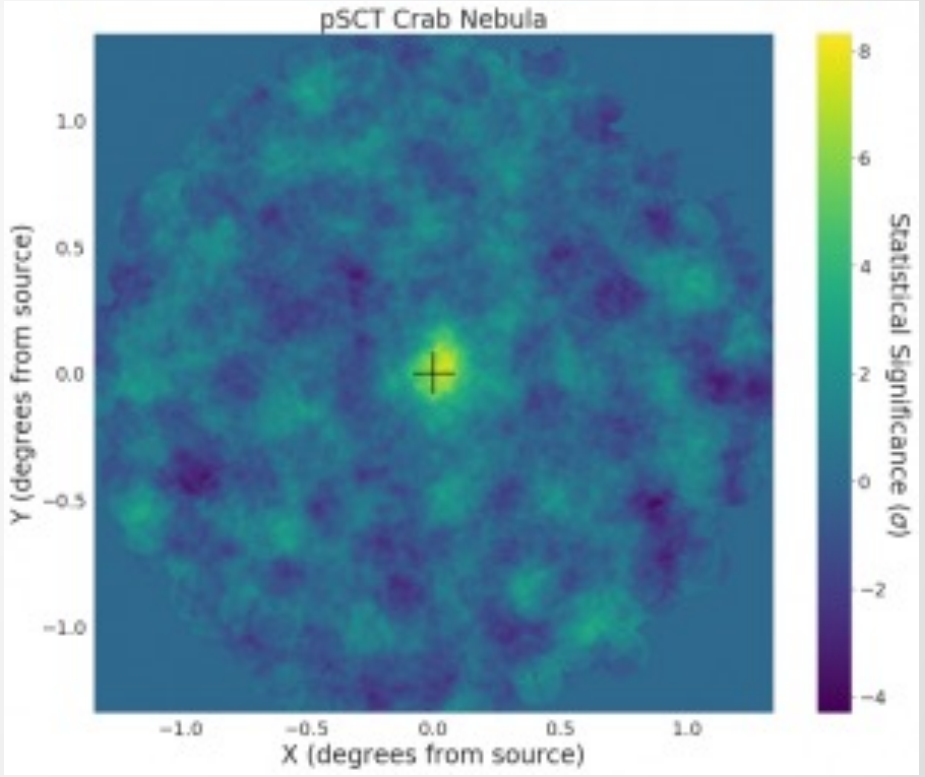
Crab Detection!

Adams, C. B., et al. (2020). *Astroparticle Physics*, *128*, 102562.

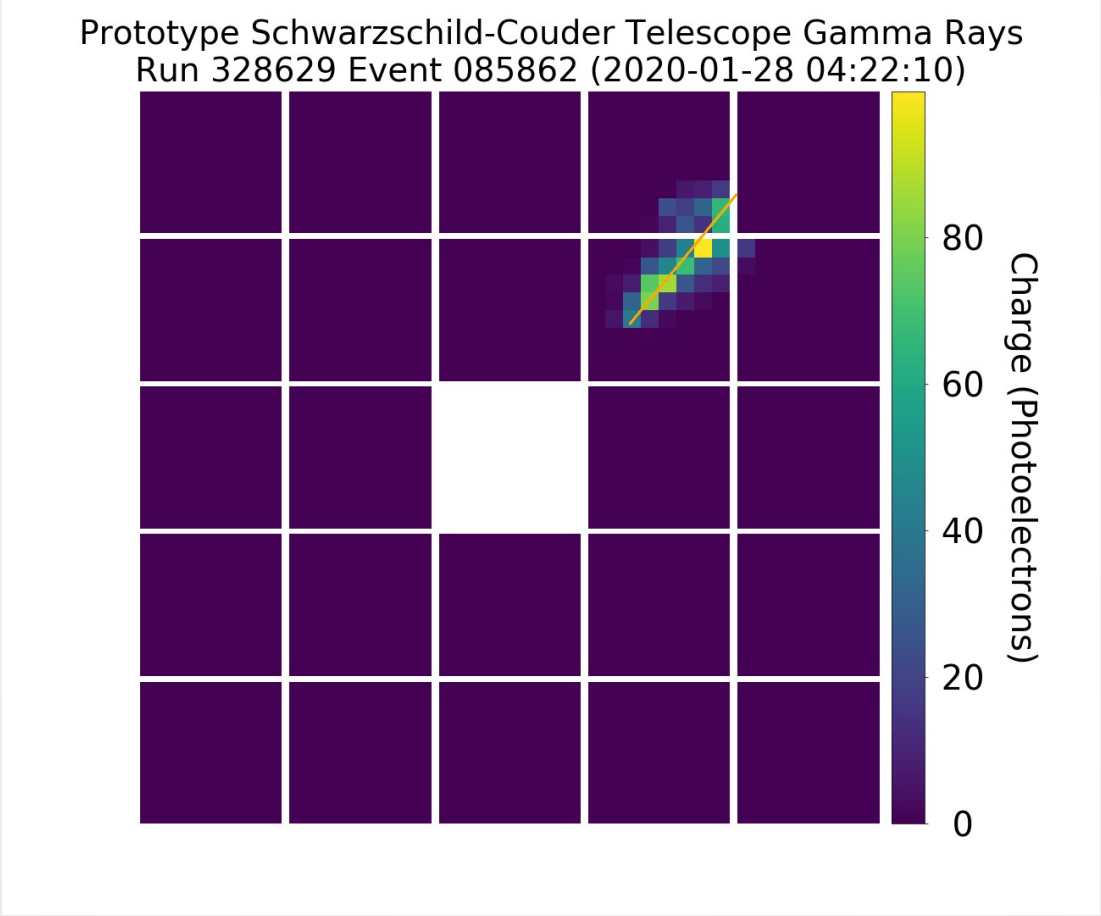
Alpha Plot



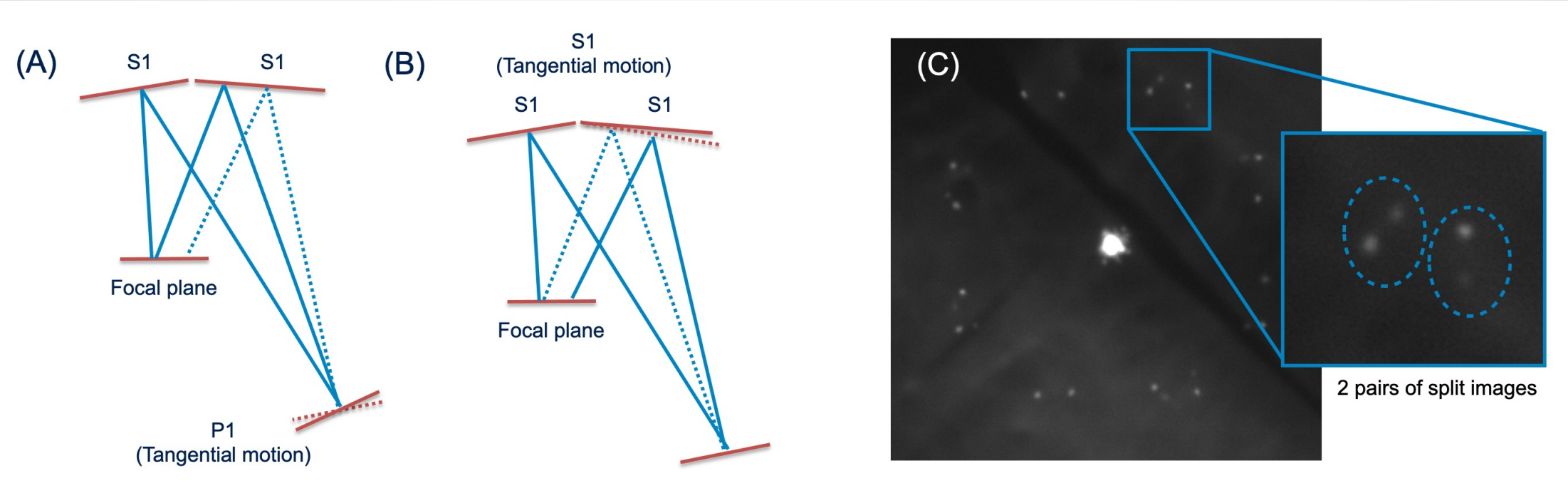
Significance Map



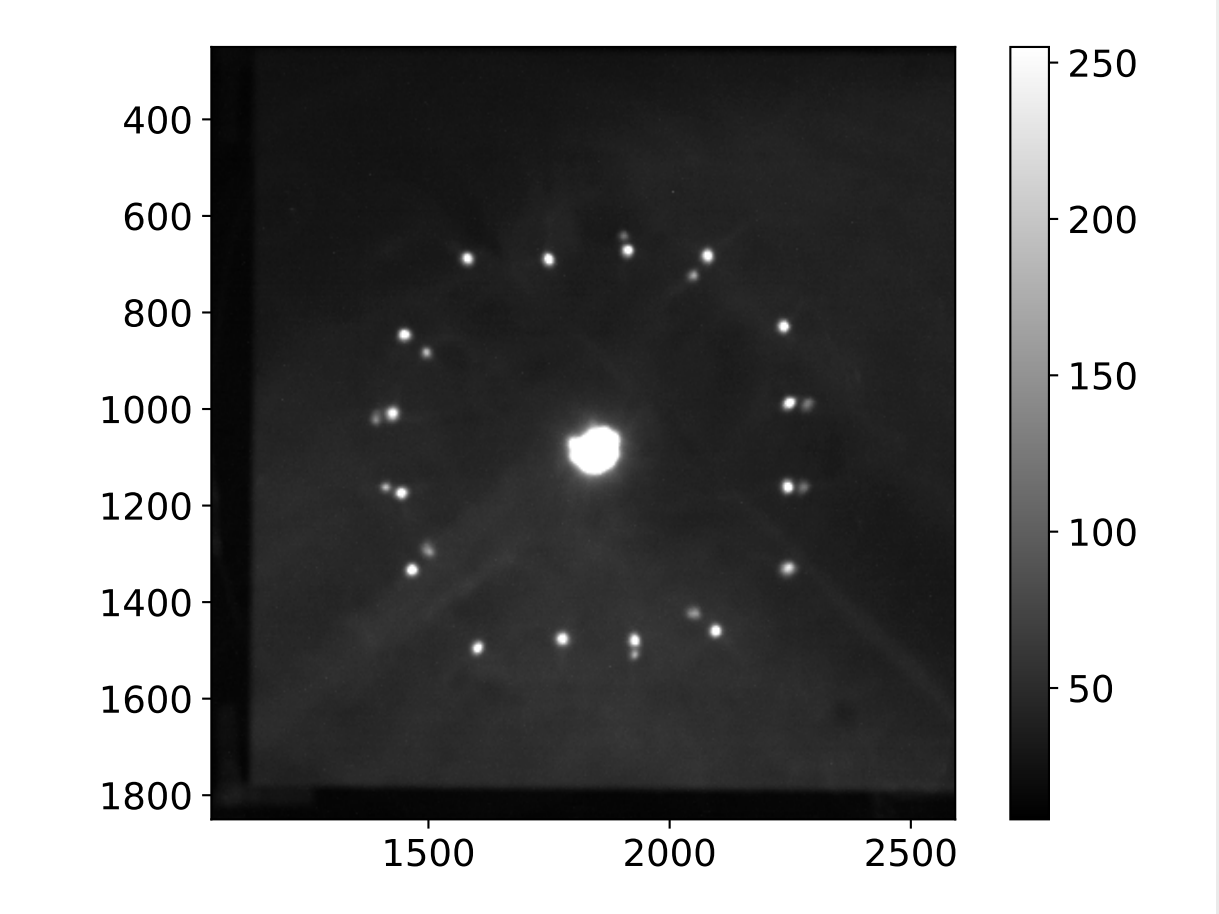
18 High Quality Gamma-Rays



S1 Alignment



Using Jupiter to Align S1



Alignment contributions

- Secondary OSS installation
- MPES assembly
- Secondary mirror calibration
- Secondary mirror installation
- Secondary mirror first order alignment
- Optical alignment
  - Panel response matrix calibration
  - Assembly of patterns
  - Focal plane z-position
  - Alignment of mirror optical axes for pattern symmetry.
  - S1 Alignment (special technique)
  - First order correction P1 and P2
  - Inspection of Off-Axis alignment
  - Measurement of PSF per elevation. Creation of de-focused database
- GAS
  - CCD & LED
    - Commission, inspection, implement software
  - Laser + PSD
    - Commission, inspection, implement software
    - Find response matrix for OT1 and OT2
- Full review of SCT network components
- VNC system installation for remote work

Remaining Tasks

- Returning soon to using the MPES for alignment
  - Update MPES target positions from optical alignment results
  - Use improved matrices that account for torque from MPES tubes
- Commission and use global alignment devices
- Measure off-axis PSF
- Draft paper on this work

As a Graduate Student,

- You get to…
  - Work on interesting projects
  - Build new things
  - Travel
  - Present at cool conferences
  - Explore your interests
  - Meet great people