



Software Development of Fiber Positioning Sequencer for Prime Focus Spectrograph of Subaru Telescope

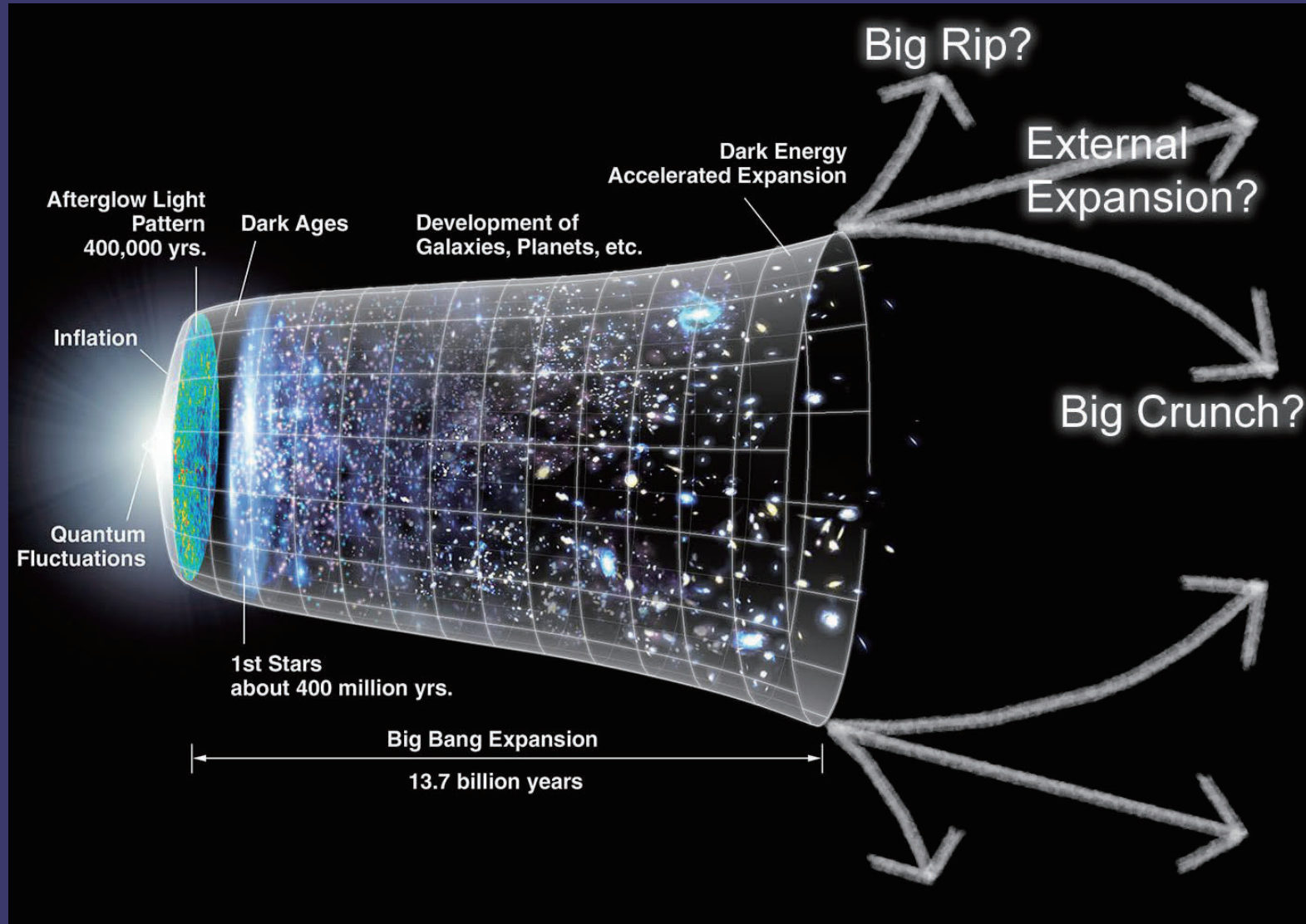
Introduction

- Prime Focus Spectrograph
 - 2394 fibers at focal plane
 - wavelength range from 0.38 micron to 1.26 micron
 - $\sim 1.25 \text{ deg}^2$ field.
- Major Components
 - PFI
 - MCS
 - SpS
- Engineering challenge of Fiber Positioning System
 - Allocate 2394 fibers within 120 seconds.
 - Distance error of fiber should be less than 10 micron





Major Science of PFS





THE DARK SIDE



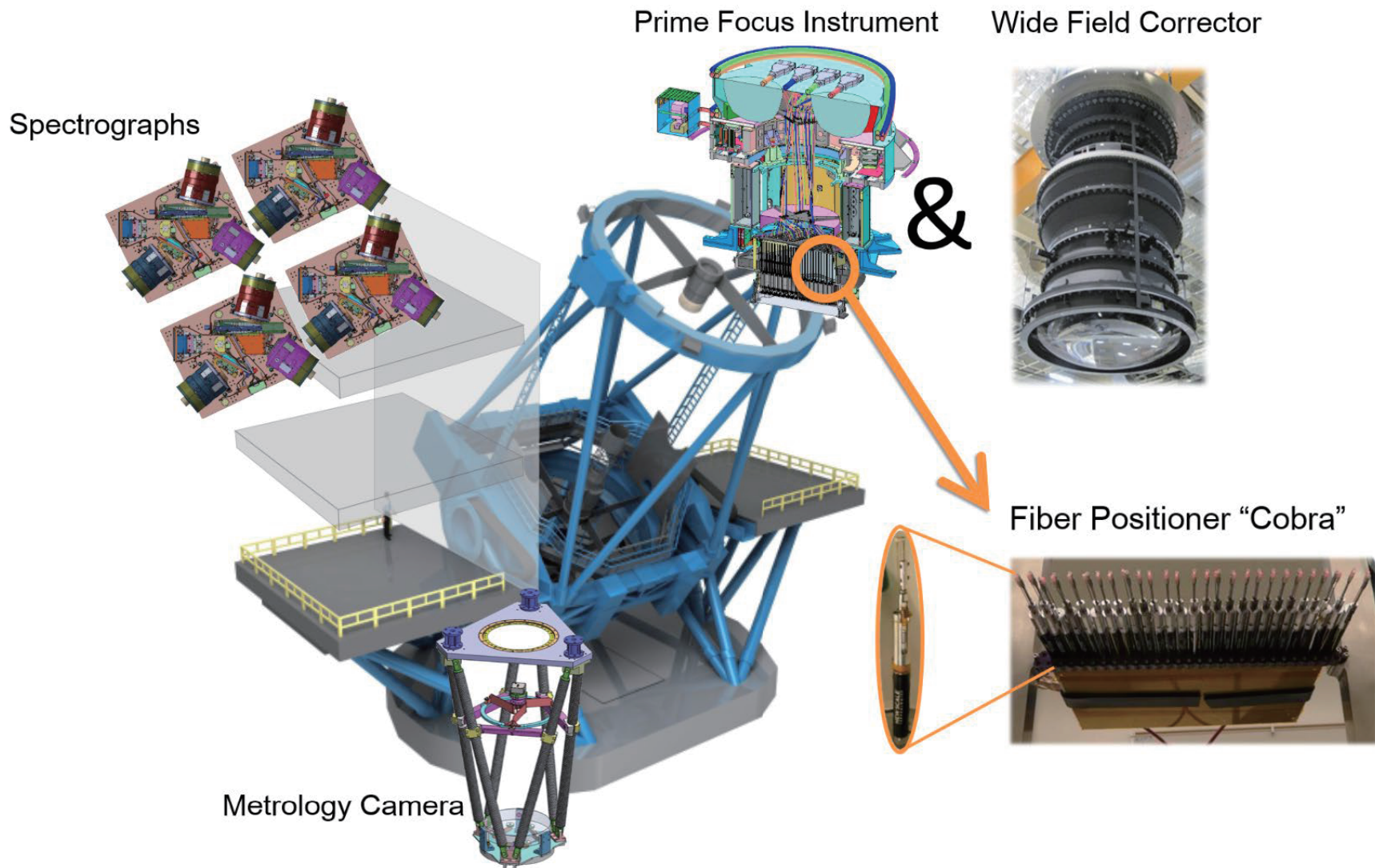


Credit:NAOJ





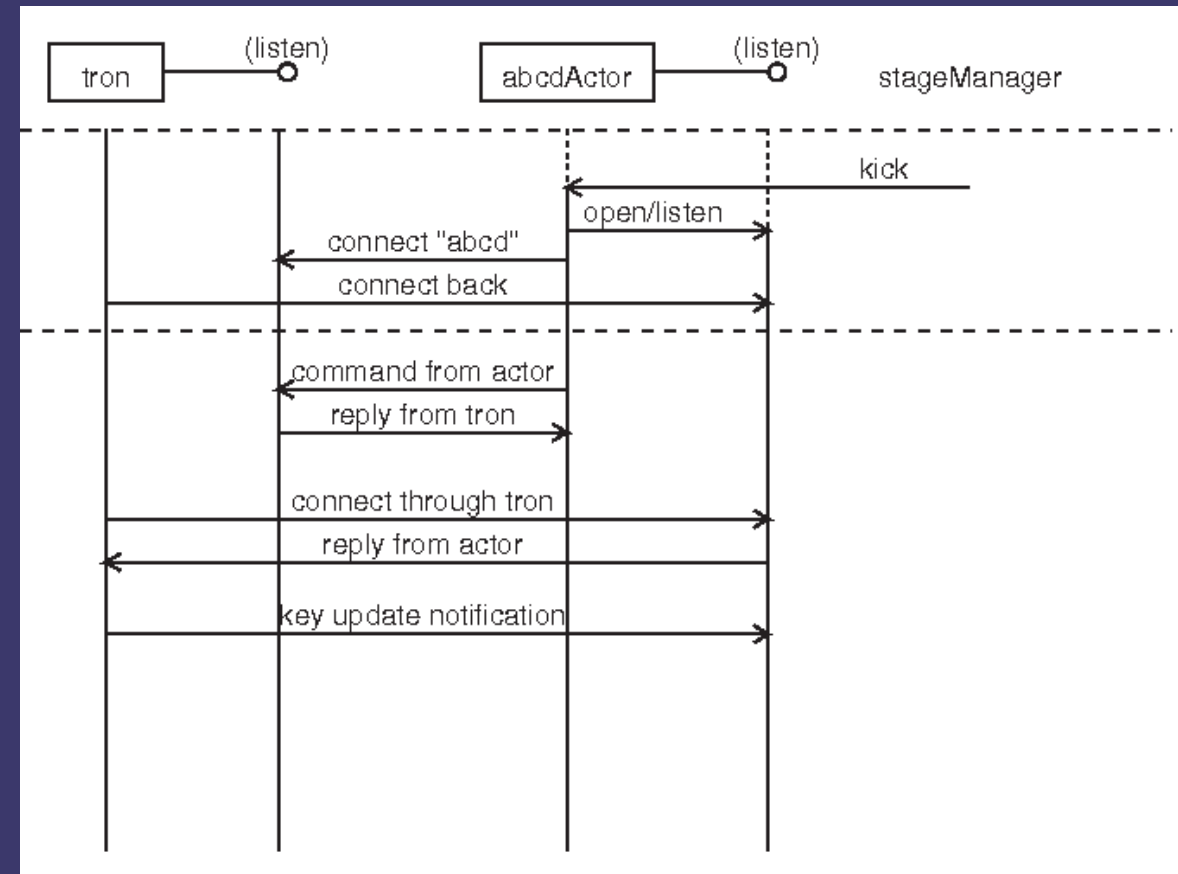
PFS主焦點多目標光纖系統

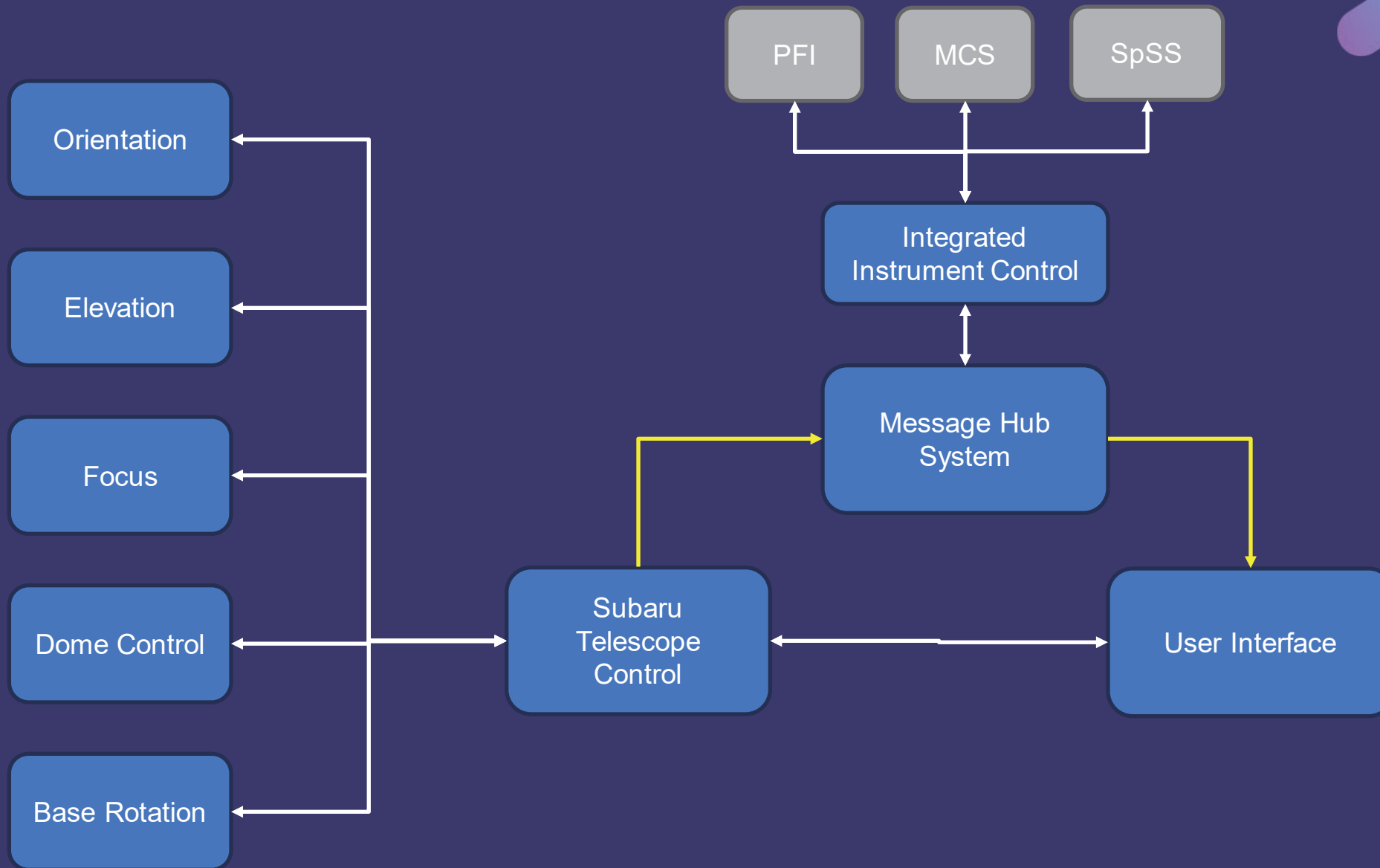


Software Development of Instrument Controls System

Message Hub System

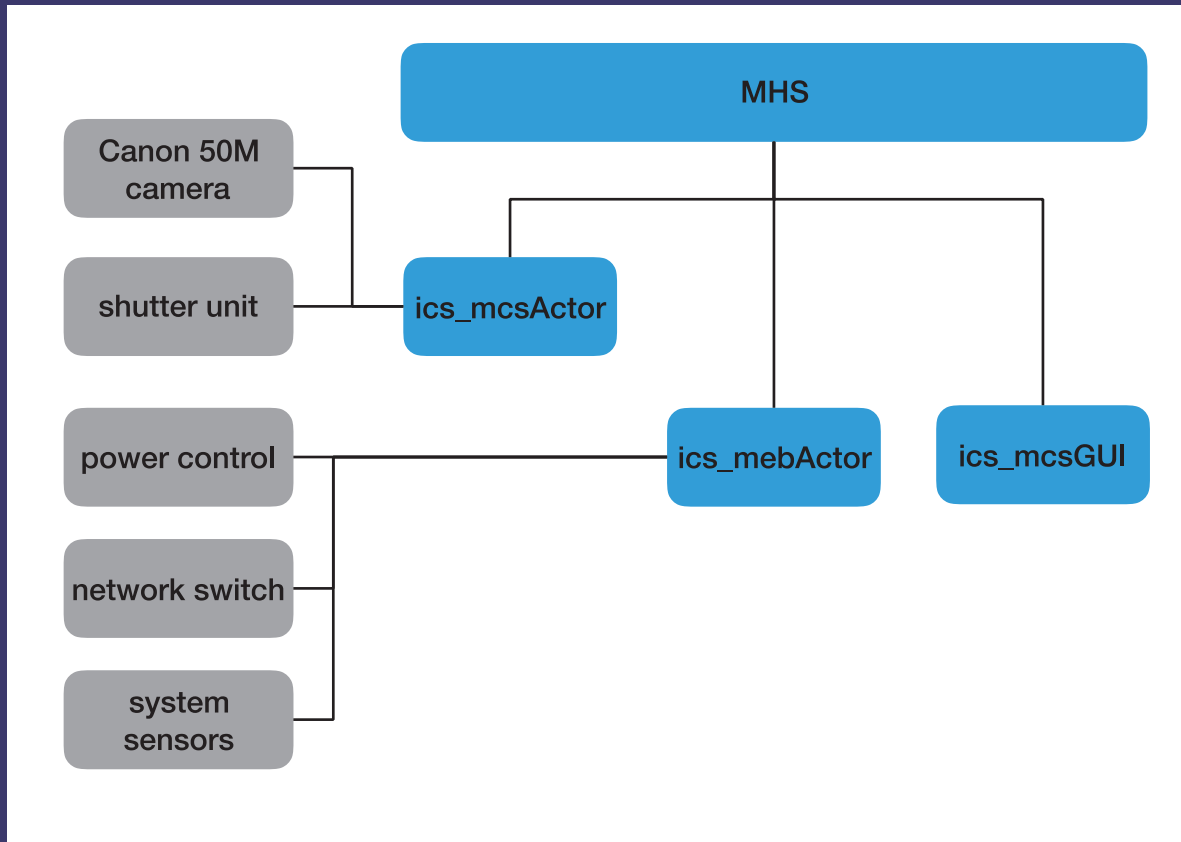
- 由普林斯頓大學咖發維護，該系統也應用在LSST 儀器控制。
- 全部由Python 寫成，主控程式稱為Tron 。
- 每一個控制的Python 子系統都稱為actor 。
- 子系統的啟動或停止由stageManager 控制。
- 透過TCP /IP 溝通。







Metrology Camera System



The screenshot shows the **mcsGUI.cwen** window. It features a grid of controls for various system components:

Top plate(C) 19.23	Carbon fiber tube(C) 19.88	Primary mirror(C) 20.55	Cover panel(C) 20.08
Coolant water in(C) 19.93	Coolant water out(C) 19.88	Electronic rack(C) 21.04	Flow meter 0
Camera Off Turn On	Shutter/Temp/Flow Off Turn On	Cisco On Reset	PC/Cooling Off Turn On

Below the controls is a text input field containing **meb temps status** and a **Send Command** button. A terminal window at the bottom displays the following log output:

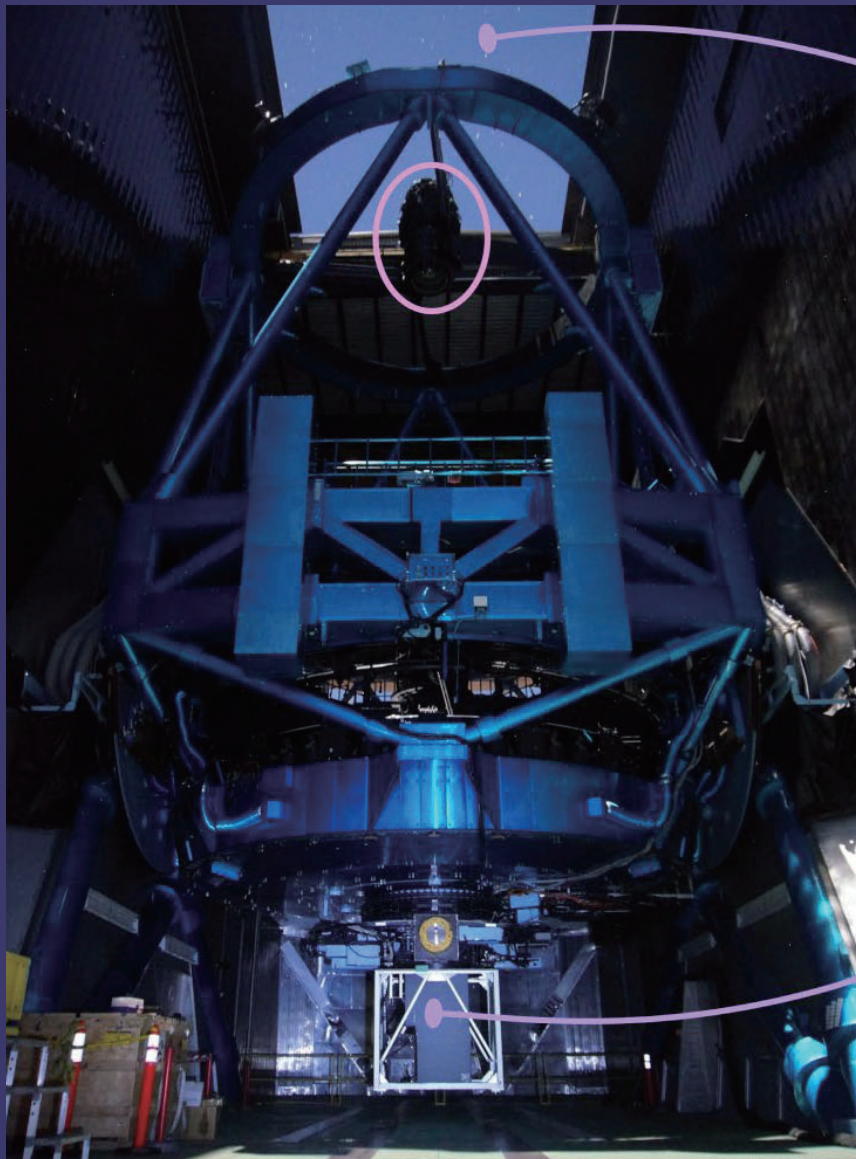
```
16:25:02.140919 cmdIn=meb flow status
16:25:04.144592 cmdOut=mcsgui.mcsgui 4 meb I flow="0.00"
16:25:04.145064 cmdOut=mcsgui.mcsgui 4 meb I flow="0.00"
16:25:04.145343 mcsgui.mcsgui 4 meb :
16:25:13.278455 cmdIn=meb temps status
16:25:13.846893 cmdOut=mcsgui.mcsgui 5 meb I temps=19.21,19.88,20.55,20.08,19.95,19.90,21.06
16:25:13.847345 cmdOut=mcsgui.mcsgui 5 meb I temps=19.21,19.88,20.55,20.08,19.95,19.90,21.06
16:25:13.847656 mcsgui.mcsgui 5 meb :
```



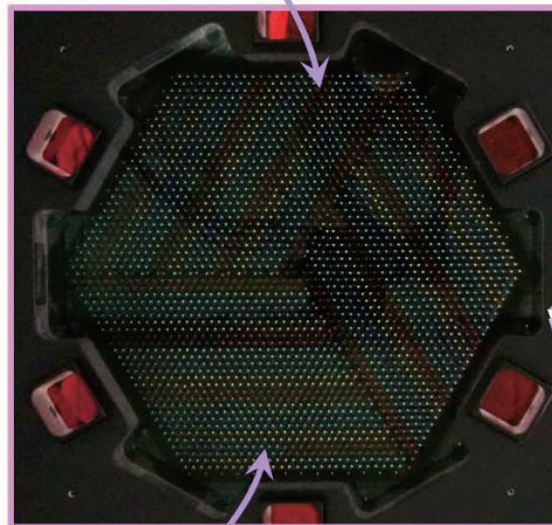
Calibration of Cobra Arms



Fiber Positioning System



Predict the object positions
on the prime focal plane
主焦点上の天体の位置を予測



Predict position
予測位置



Move Cobras while
measuring the
fiber position
ファイバーの位置を
測りながらコブラを
動かす

Measure the fiber position
on the prime focal plane
主焦点上のファイバーの位置
を測定





From single module to Cobra array





Cobra Geometry using Computer Vision

Hough Circle Transformation

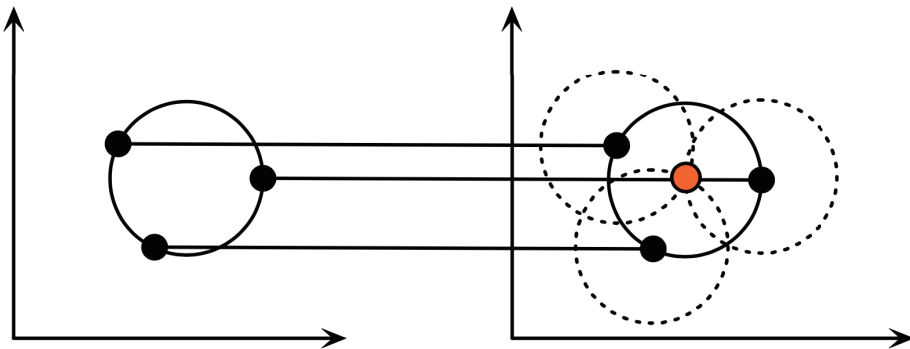
Search with fixed R

If the circles in an image are of known radius R , then the search can be reduced to 2D. The objective is to find the (a, b) coordinates of the centers.

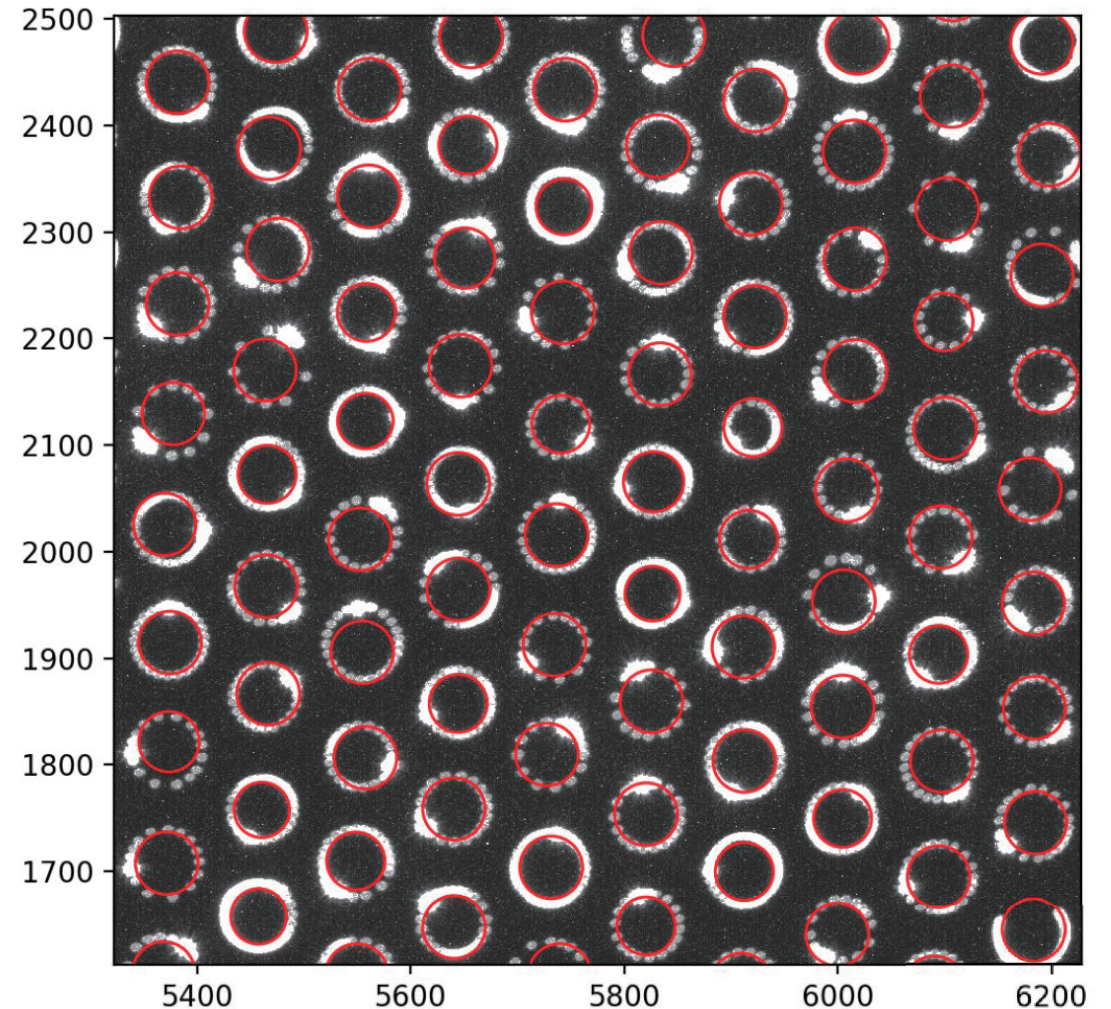
$$x = a + R \cos(\theta)$$

$$y = b + R \sin(\theta)$$

The locus of (a, b) points in the *parameter space* fall on a circle of radius R centered at (x, y) . The true center point will be common to all parameter circles, and can be found with a Hough accumulation array.

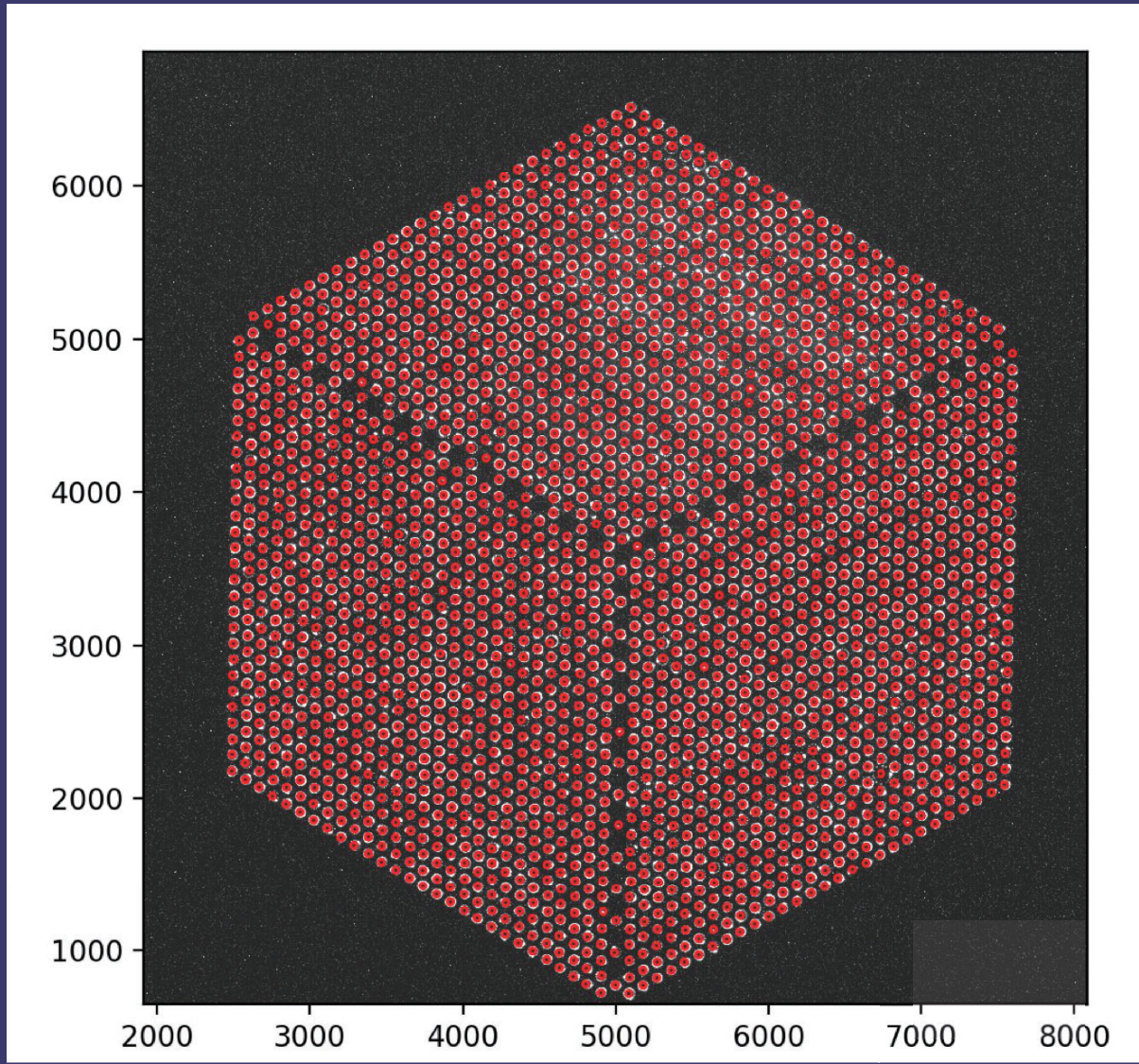
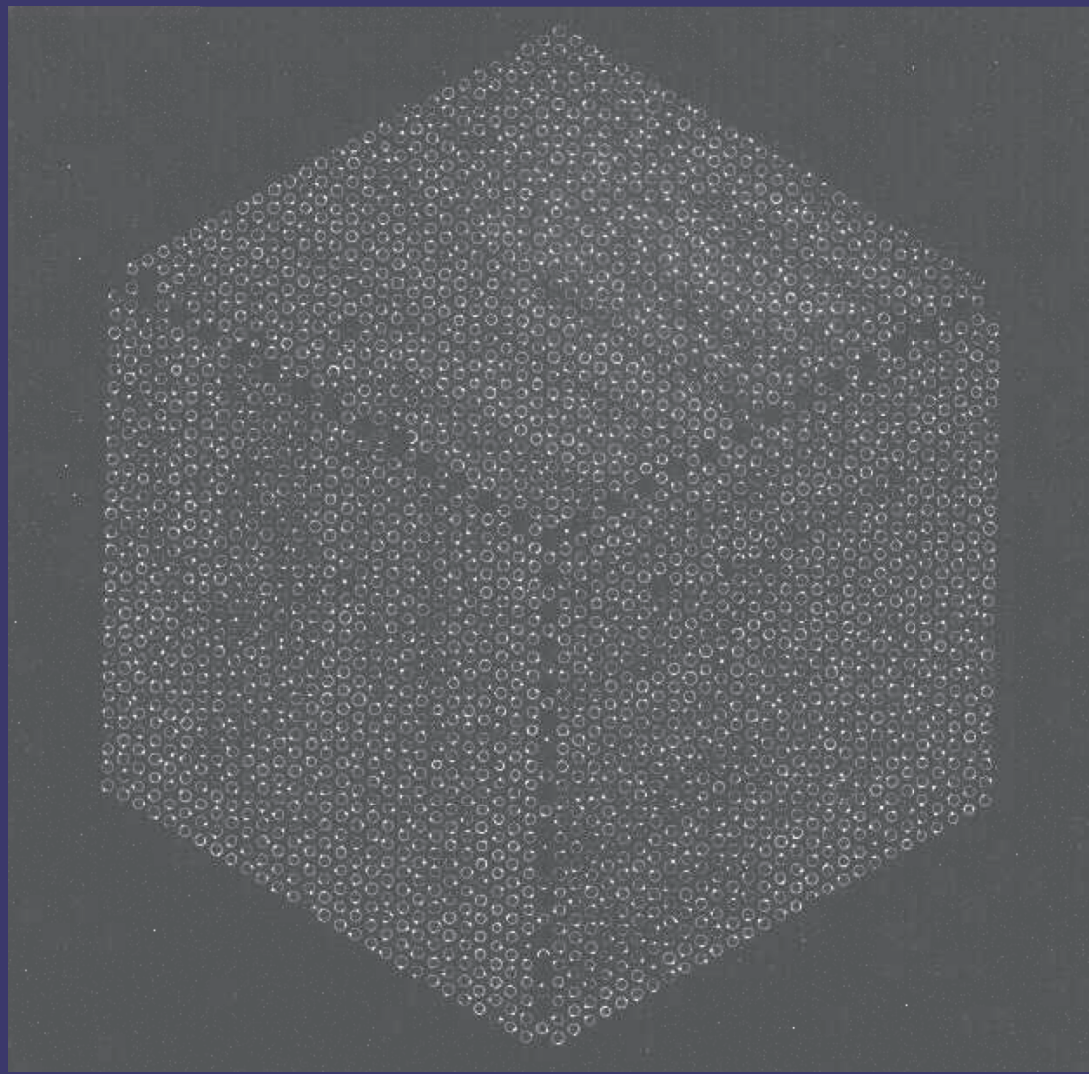


Each point in geometric space (left) generates a circle in parameter space (right). The circles in parameter space intersect at the (a, b) that is the center in geometric space.



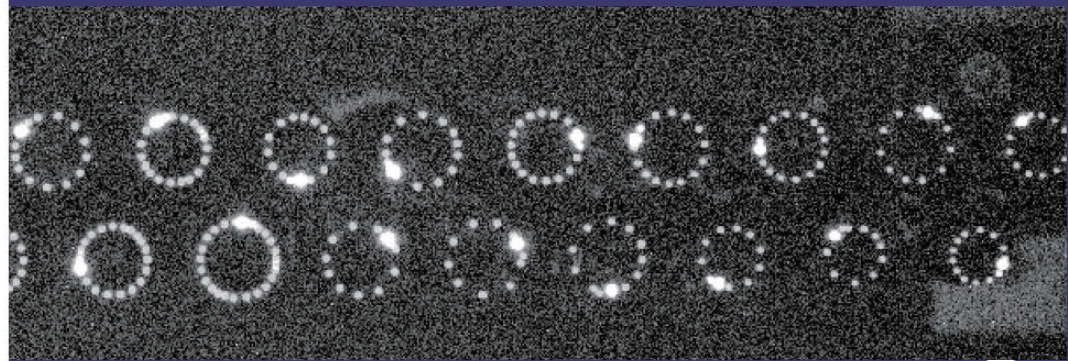
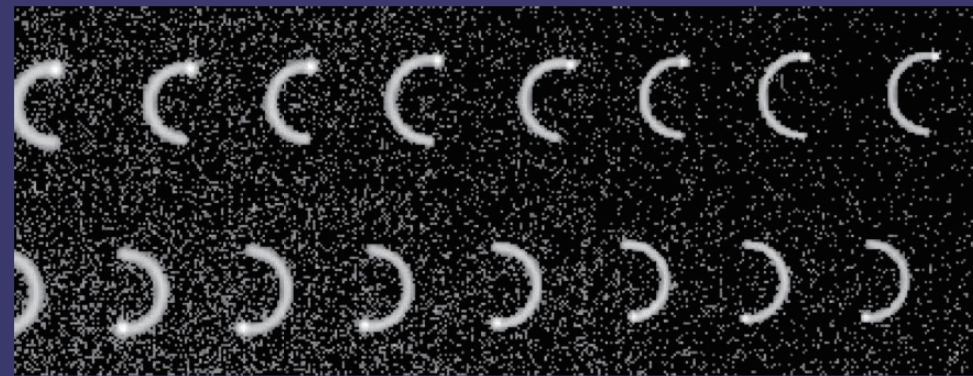
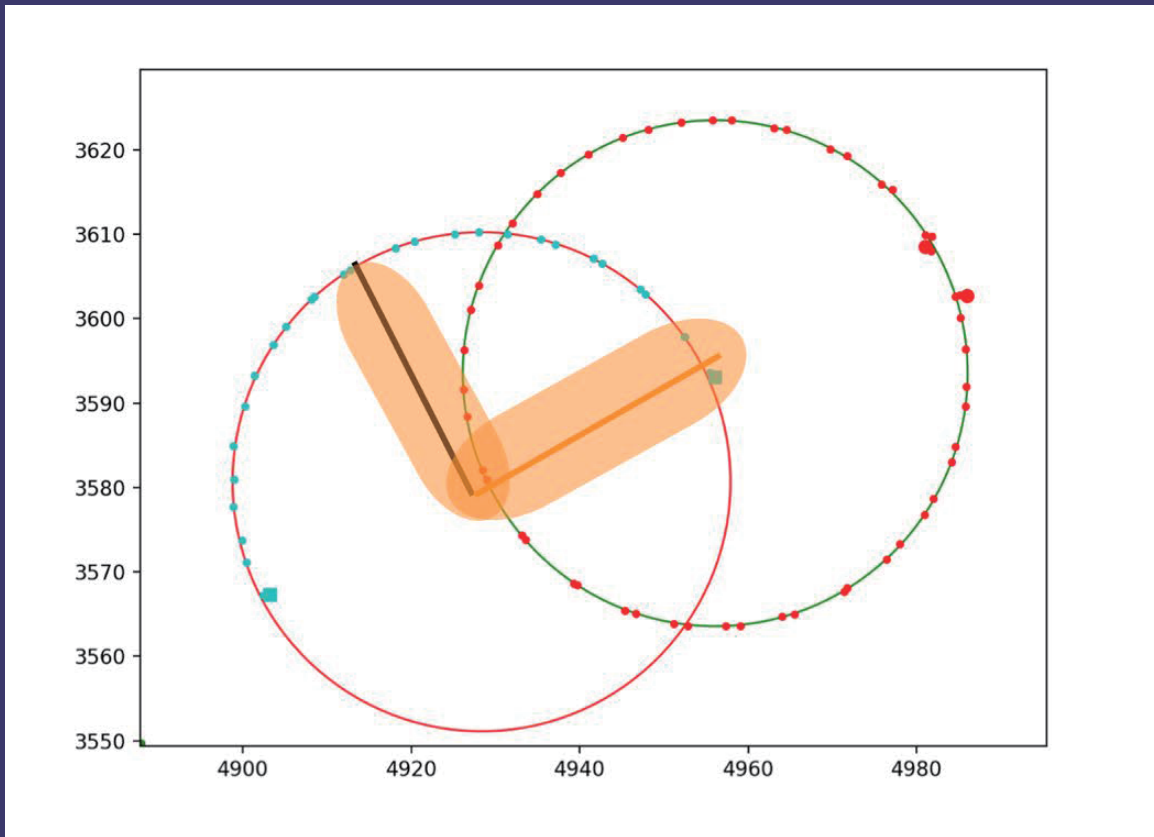


Cobra Geometry using Computer Vision



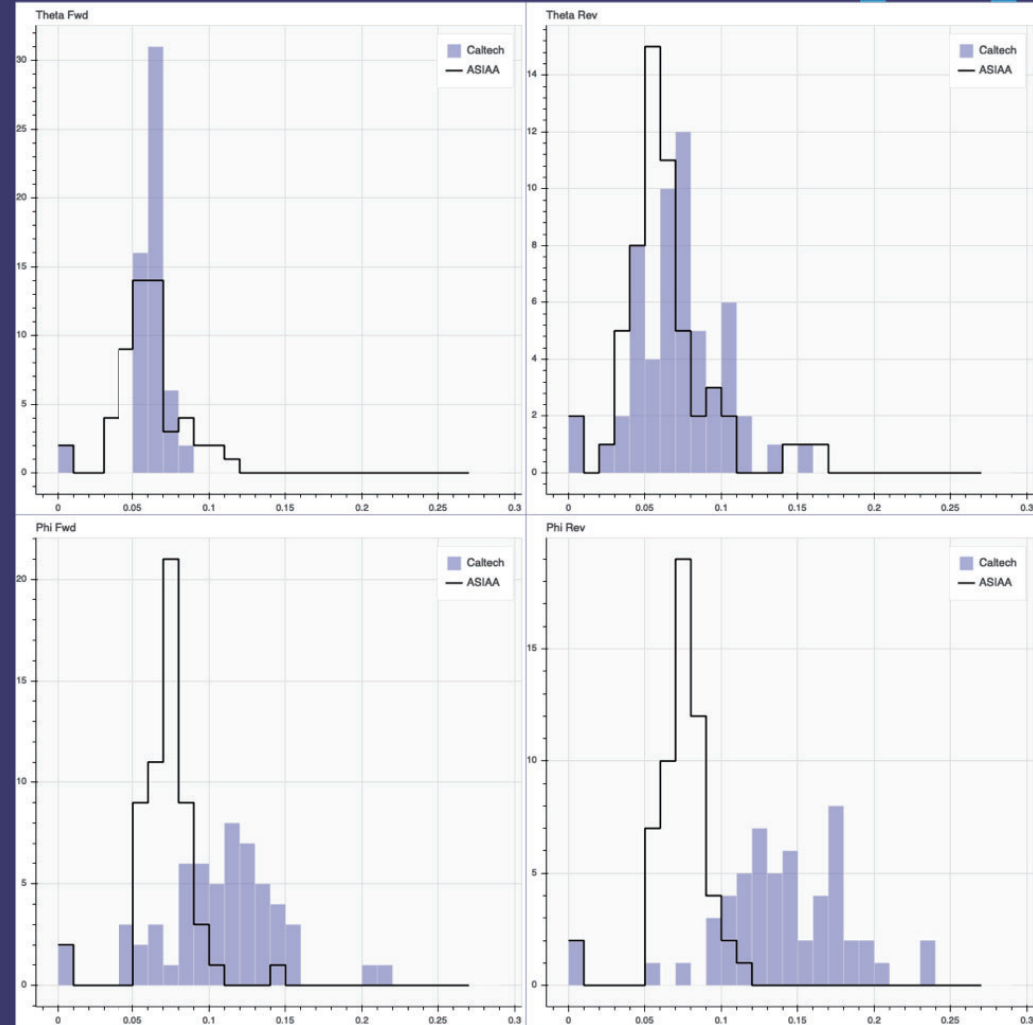
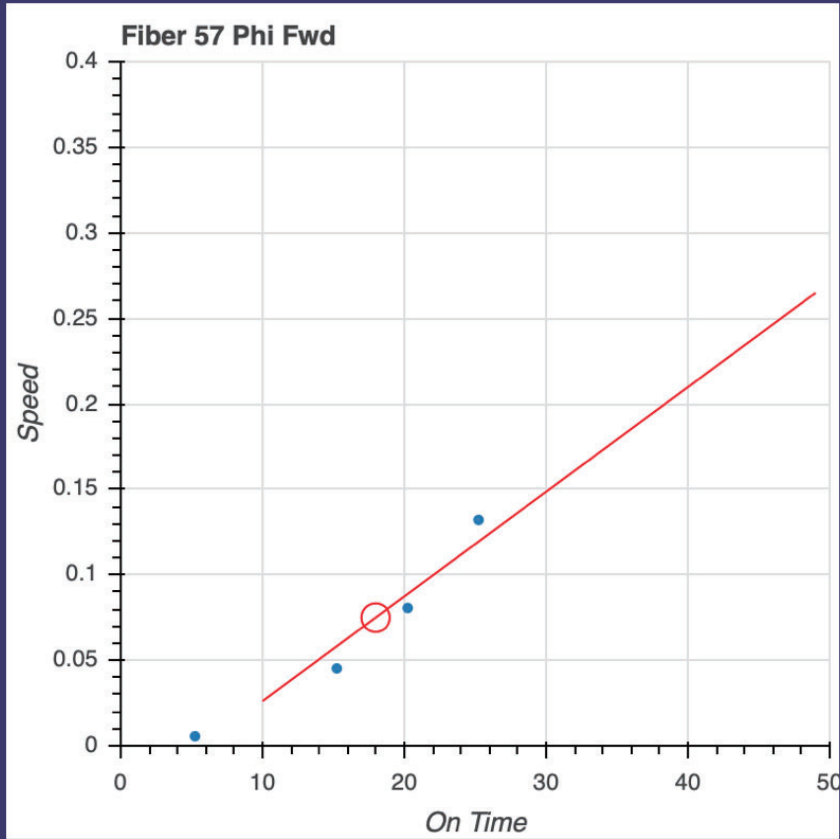


Motor Calibration : Arm Motion Range



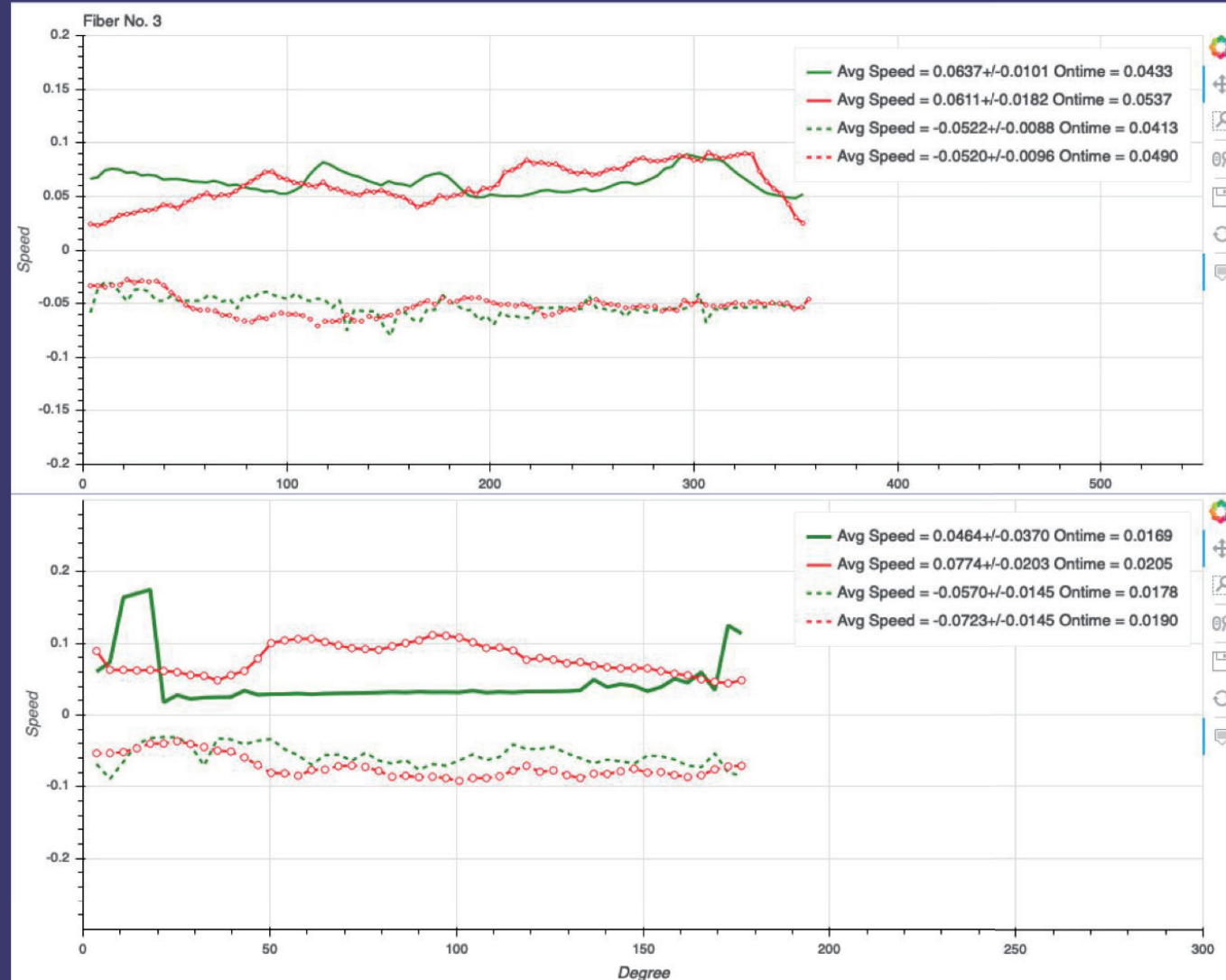


Motor Calibration : on-time optimization





Motor Calibration : Motor Map



Engineering Result

Major Testing Result

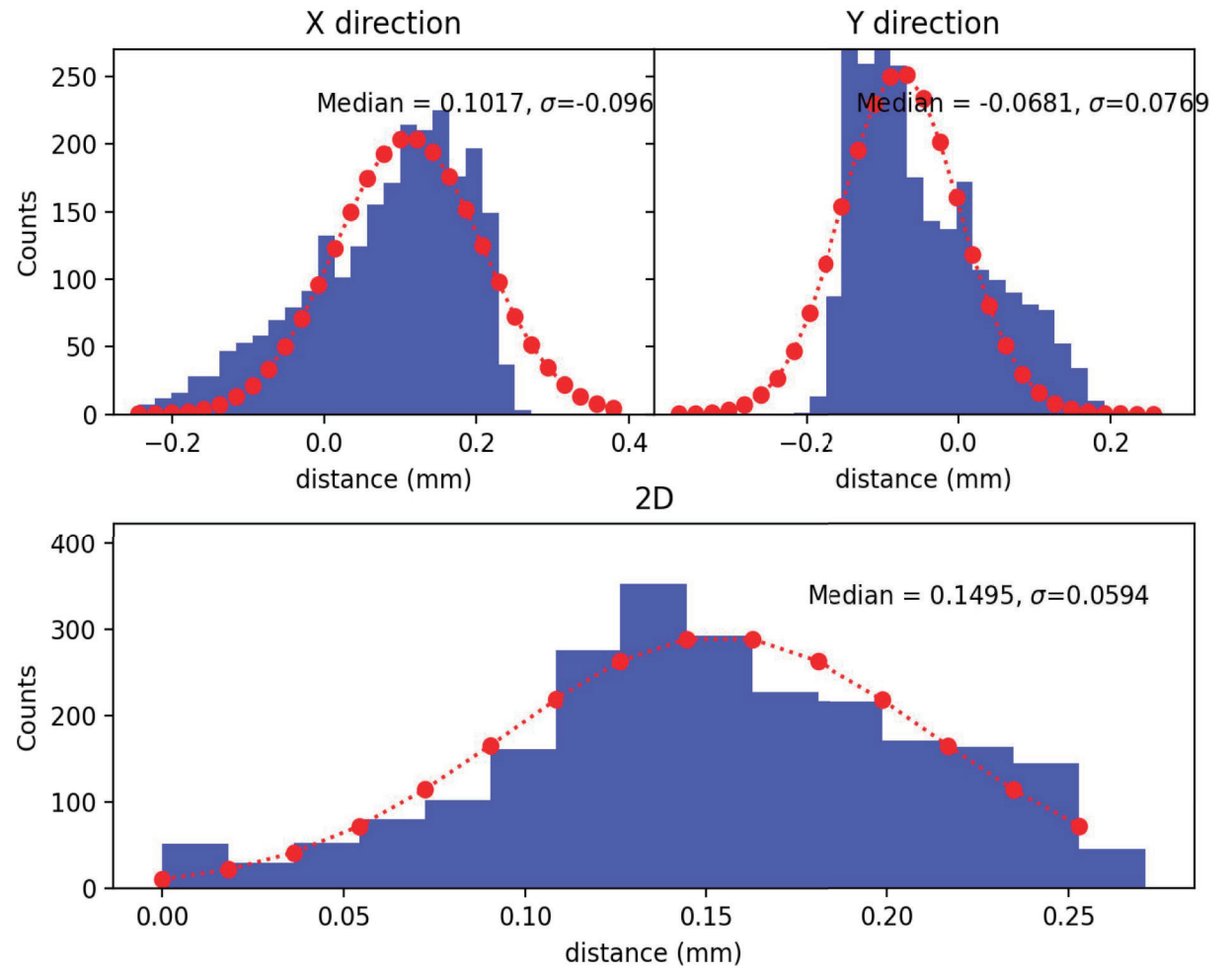
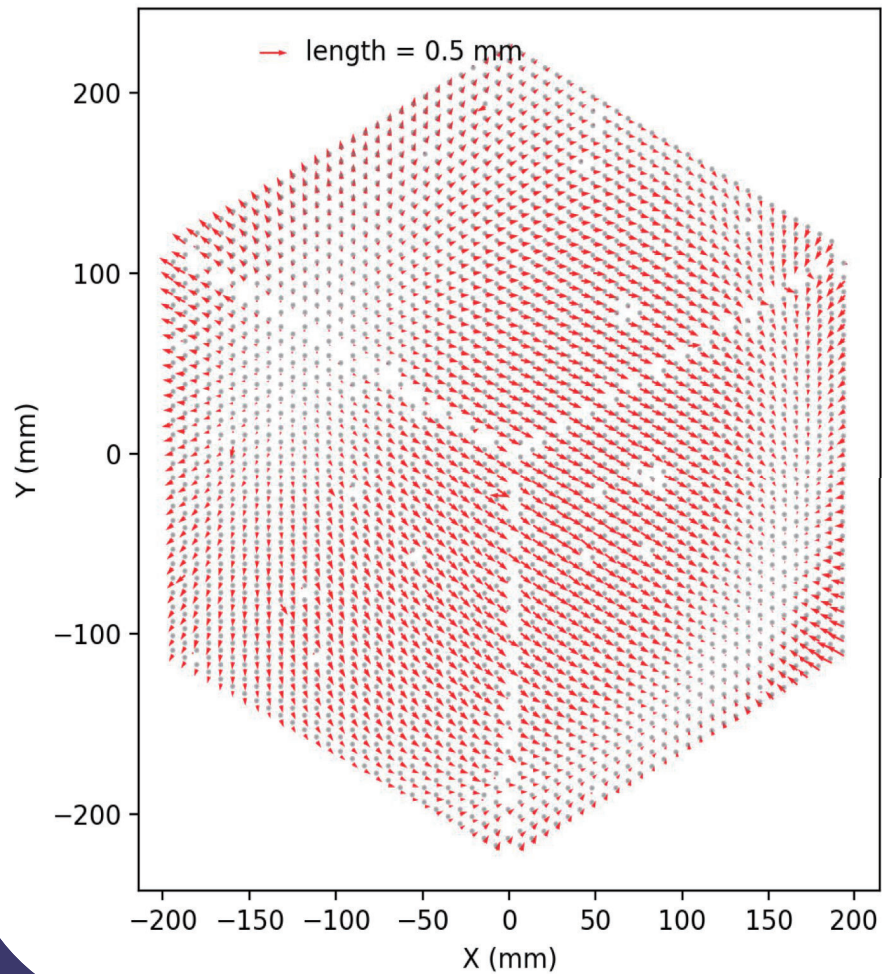
- Geometry Repeatability
- Convergence Performance
- Raster Scan Result with Spectrograph
- Convergence Optimization
 - Number of iteration
 - Total time





Geometry Repeatability

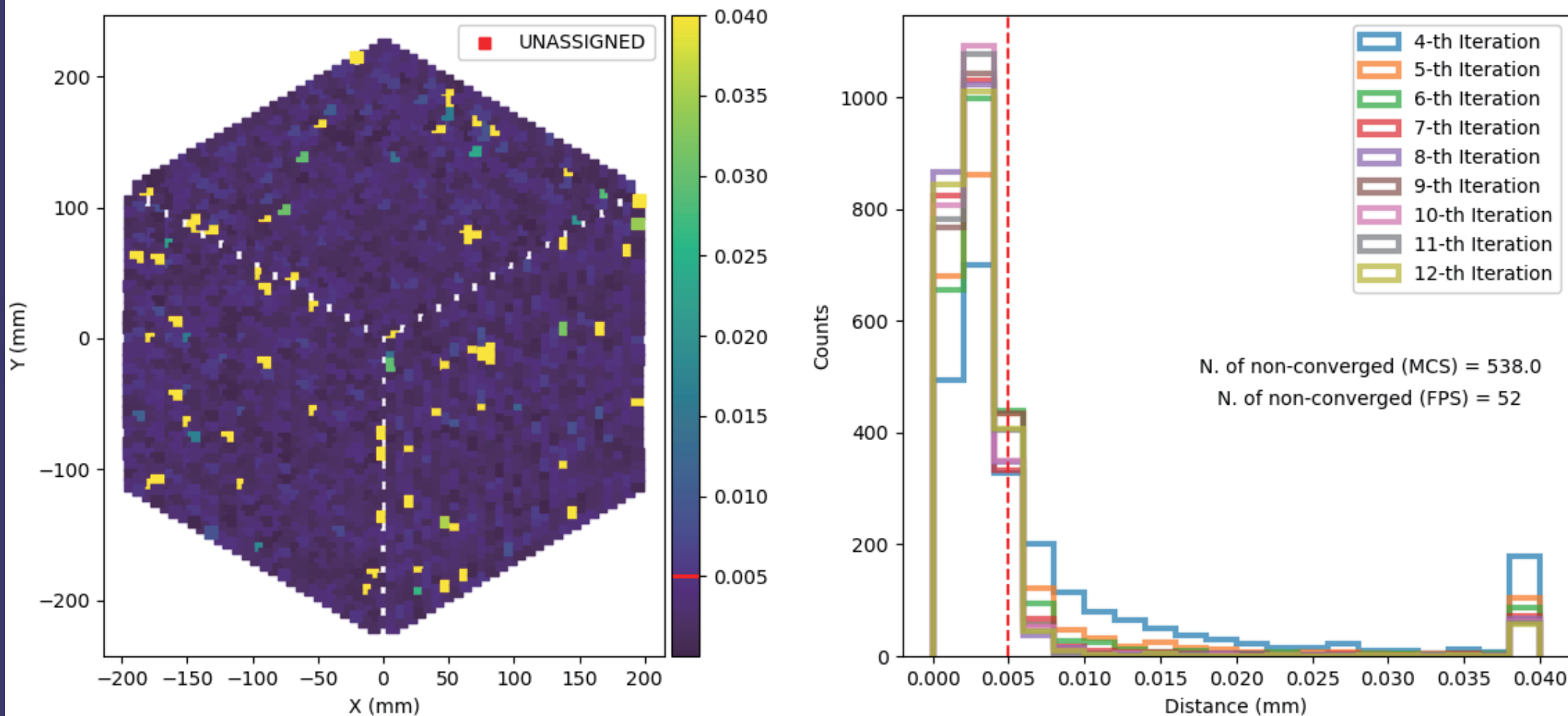
Cobra Centers (Nov - Sep)





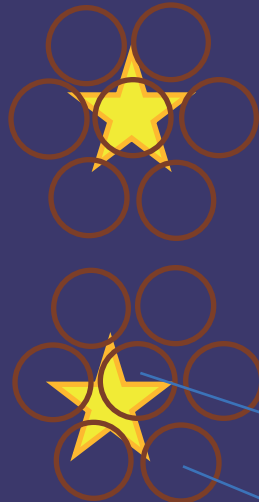
Convergence Performance

Cobra Convergence 96996

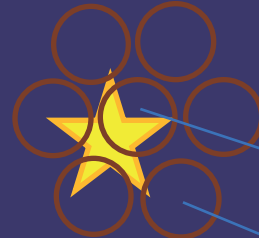


Raster Scan

- (1) Converge Cobras to the target
- (2) Take spectra at this pointing, and several p around it by moving the telescope.

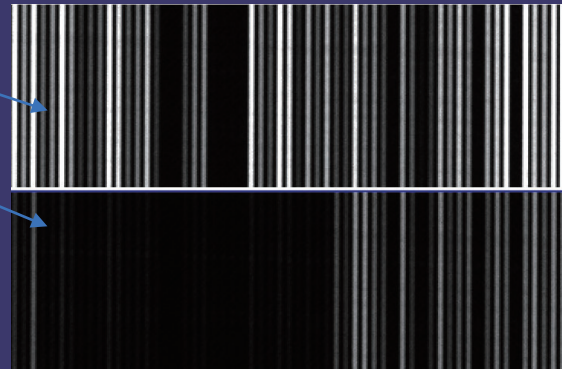


If the Cobra is moved to the target perfectly, the flux at the center is the brightest



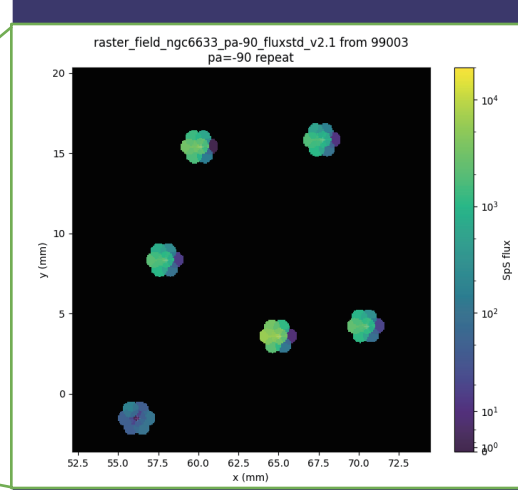
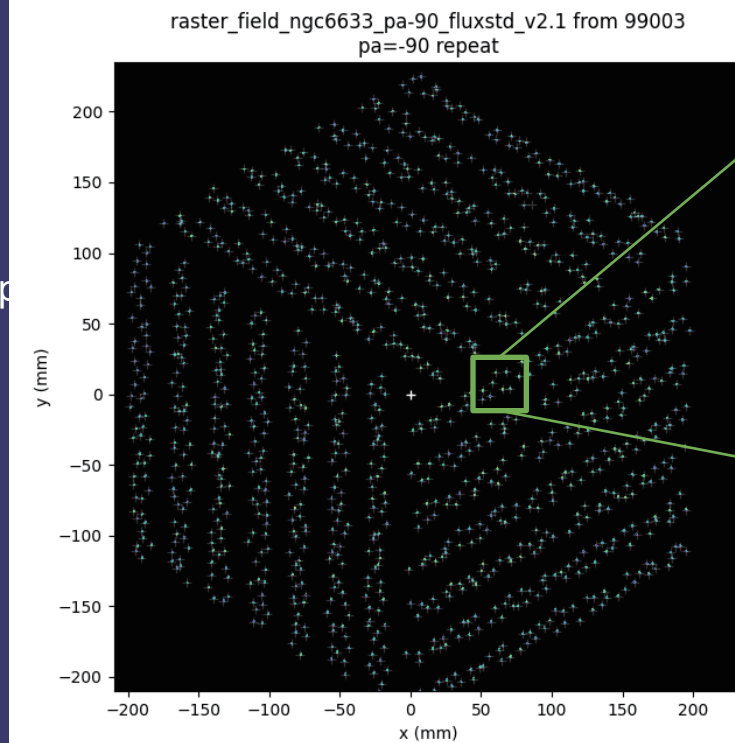
If the Cobra has offset to the target, the flux is distributed to more than one fibers.

a part of PFS at the center and nearby positions (spectrain the same colour scale)



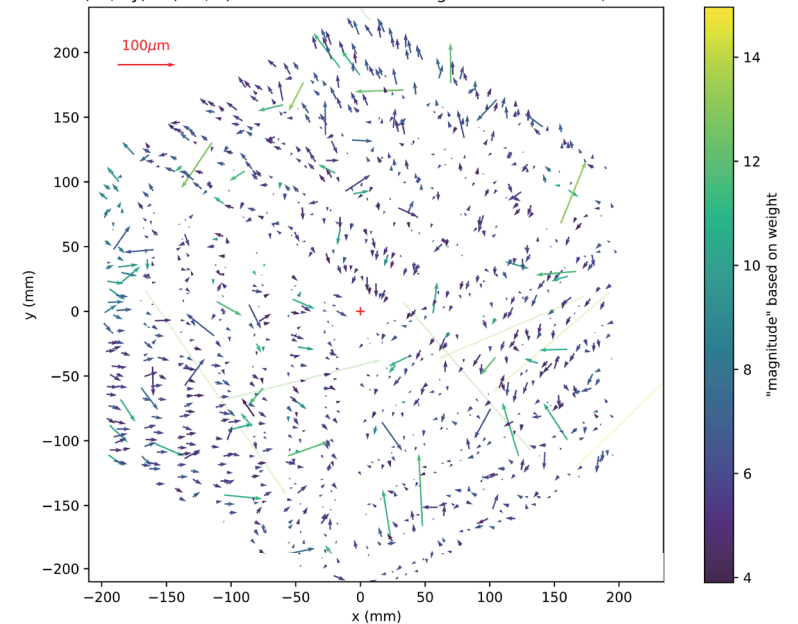
- (3) By measuring the CoG of the fluxes, estimate the offset to the actual star position
- (4) Improve coordinate transformation.

Vector plot showing measured offset. In this case, scale difference is dominant.



Flux map of one set of raster scan data. telescope movement is projected on PFI plane.

99003,99009 raster_field_ngc6633_pa-90_fluxstd_v2.1 mag < 15 (dx, dy) = (-10, 6) μ dtheta = -0.00415deg scales=-0.000426,7.38e-09



Convergence Optimization

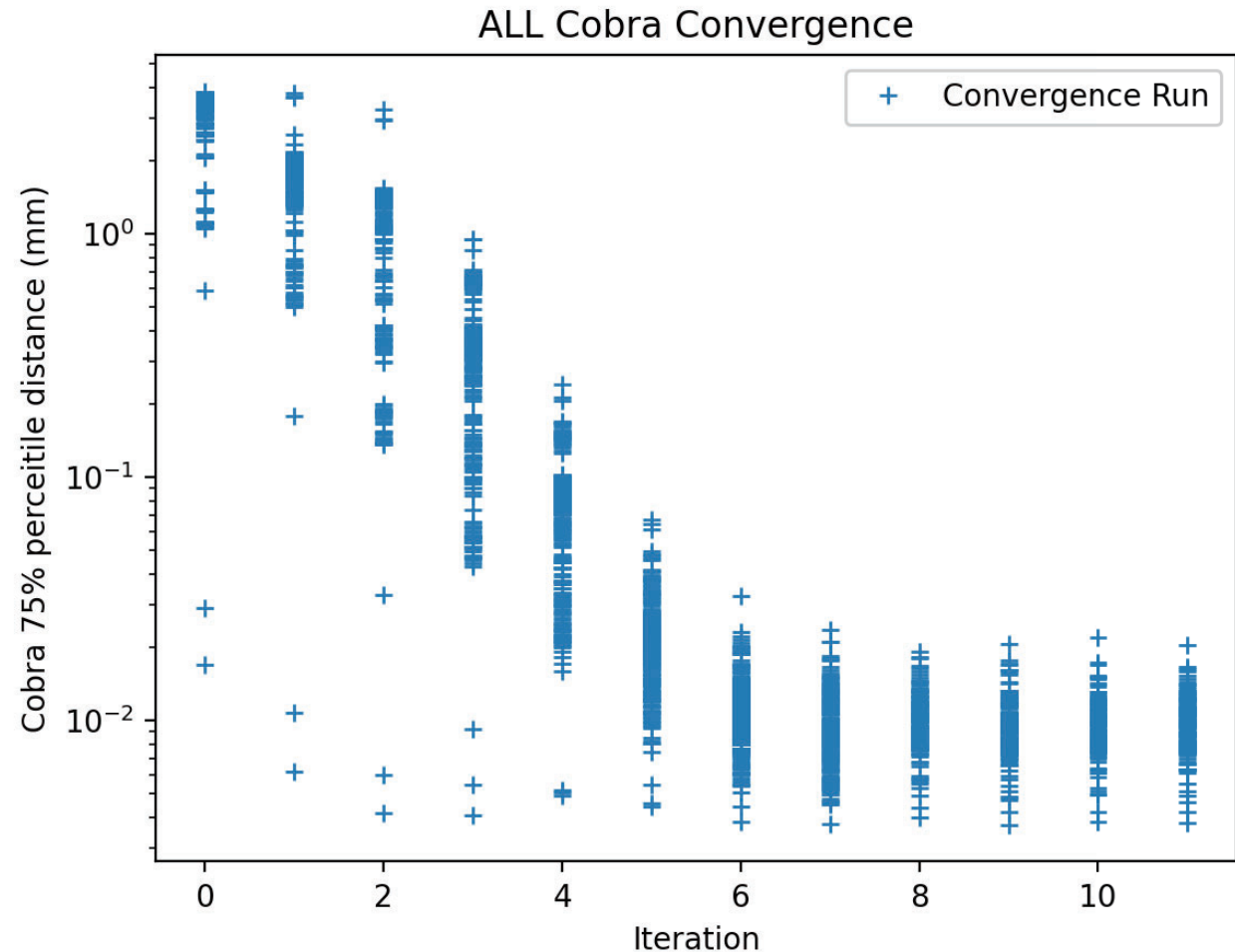
- Use the optimal number of iteration.
- Shorten the operation overhead
 - Not to produce engineering data
 - Use optimal exposure time
 - Use multi-core for centroid detection
 - Write image in the background (to be tested)





Convergence Optimization: Number of Iteration

- Combining all convergence data from engineering data of 2023, we see that convergence performance did not improve after 8th iteration.

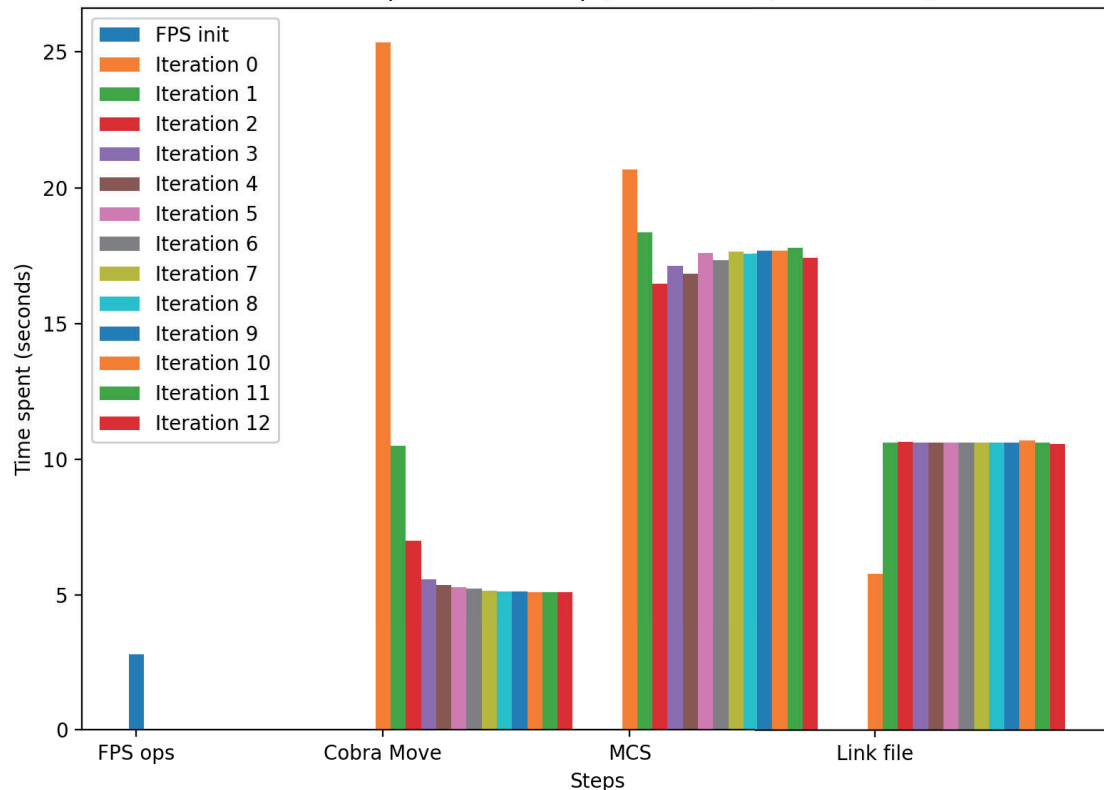




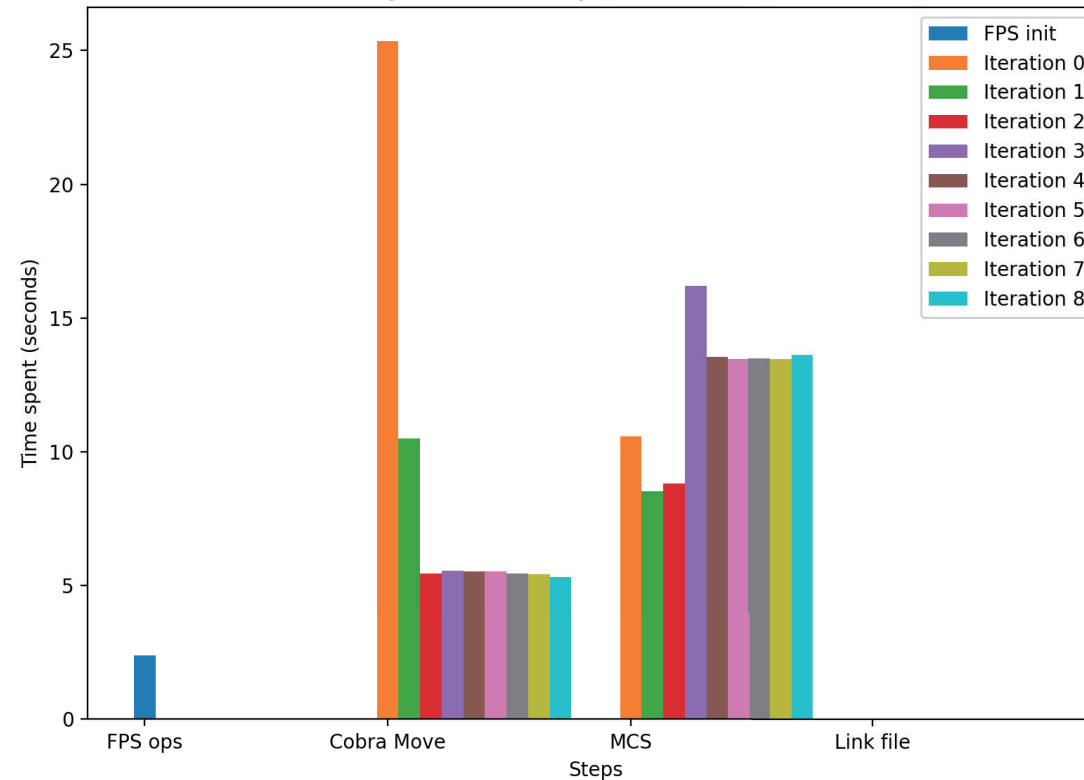
Convergence Optimization: Time Spend



FPS Time spent in each step (visit=100337, t=465.783s)



FPS Time spent in each step (visit=101659, t=191.997s)



Summary

- We deliver MCS and PFI in 2018 and 2021 respectively. After the delivery, we also joined the system integration activities.
- We deliver the control software for both MCS and PFI. Especially, the Fiber Positioning System.
- By calibrating cobra arms carefully, we are able to control those arms in a decent accuracy.
- We are still improving the system performance.
- PFS is expecting to start science operation in 2024!



Thanks

