Update on Adaptive Optics Scanning Laser Ophthalmoscope (AOSLO) for retinal imaging

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Tuesday, March 9, 2021

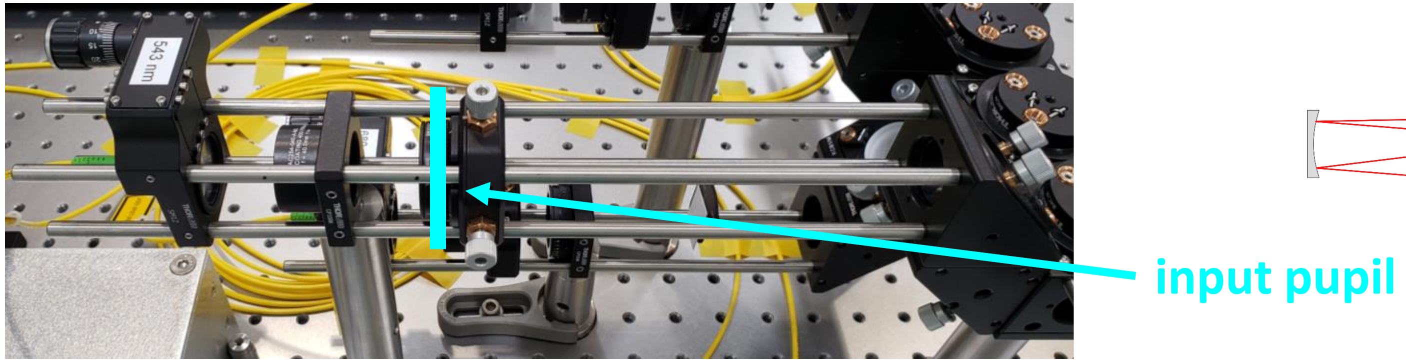
Active Perception Lab Meeting

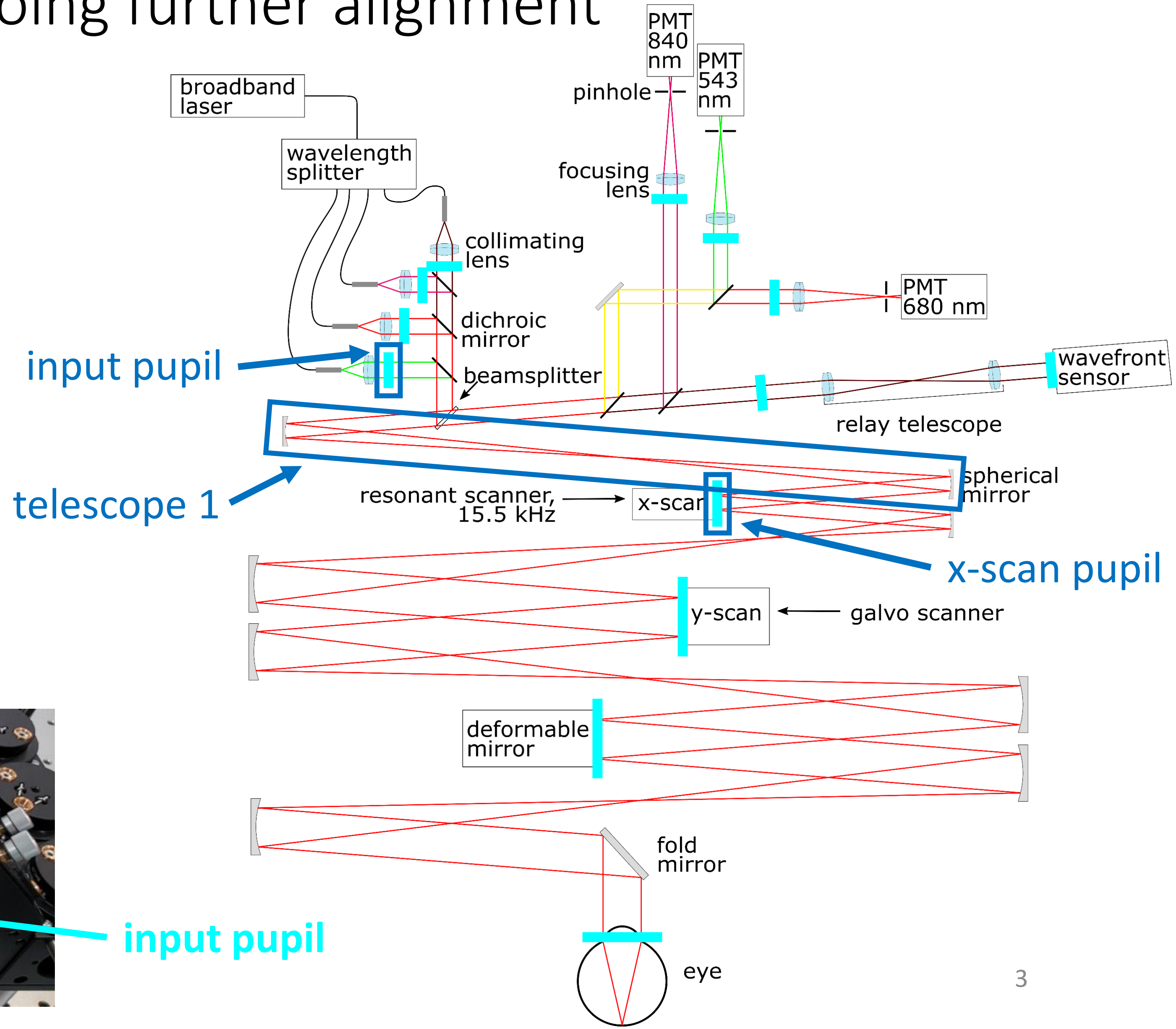
Outline

- Alignment updates
  - Measuring input collimation
  - Fine tuning telescope alignment
  - Realignment with new galvo
  - Pupil plane adjustments
- Hardware updates
  - Scanning and signal conditioning boxes
  - Detector installation
  - Bite bar fabrication
- Software updates
- Ongoing challenges and remaining tasks

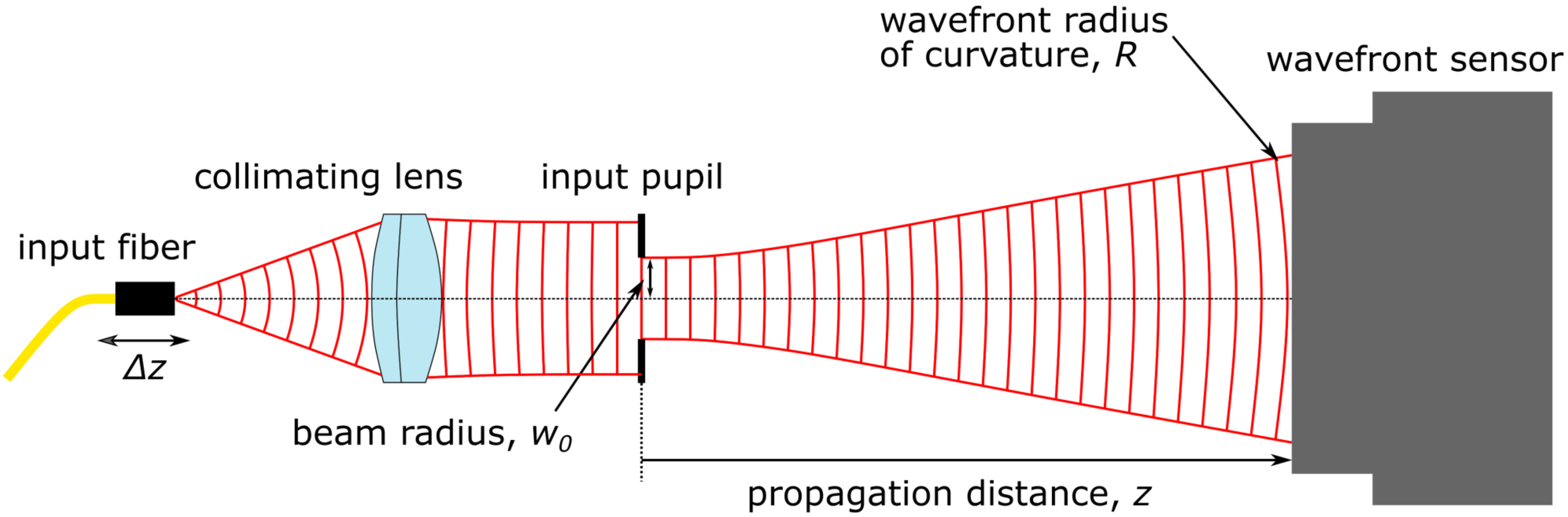
Measuring the input beam collimation is a necessary first step before doing further alignment

- Each telescope must be fine-tuned to achieve good alignment
- Collimated input light should yield collimated output light
- This process requires accurate measurement of the input beam collimation
- Challenge: input pupils are not accessible to the wavefront sensor





Using Gaussian beam propagation equations enables fine-tuning of input collimation



$$R = z\left[1 + \left(\frac{\pi (w_0)^2}{\lambda z}\right)^2\right]$$

This is wavelength dependent, so it was computed for each of the 4 wavelength channels

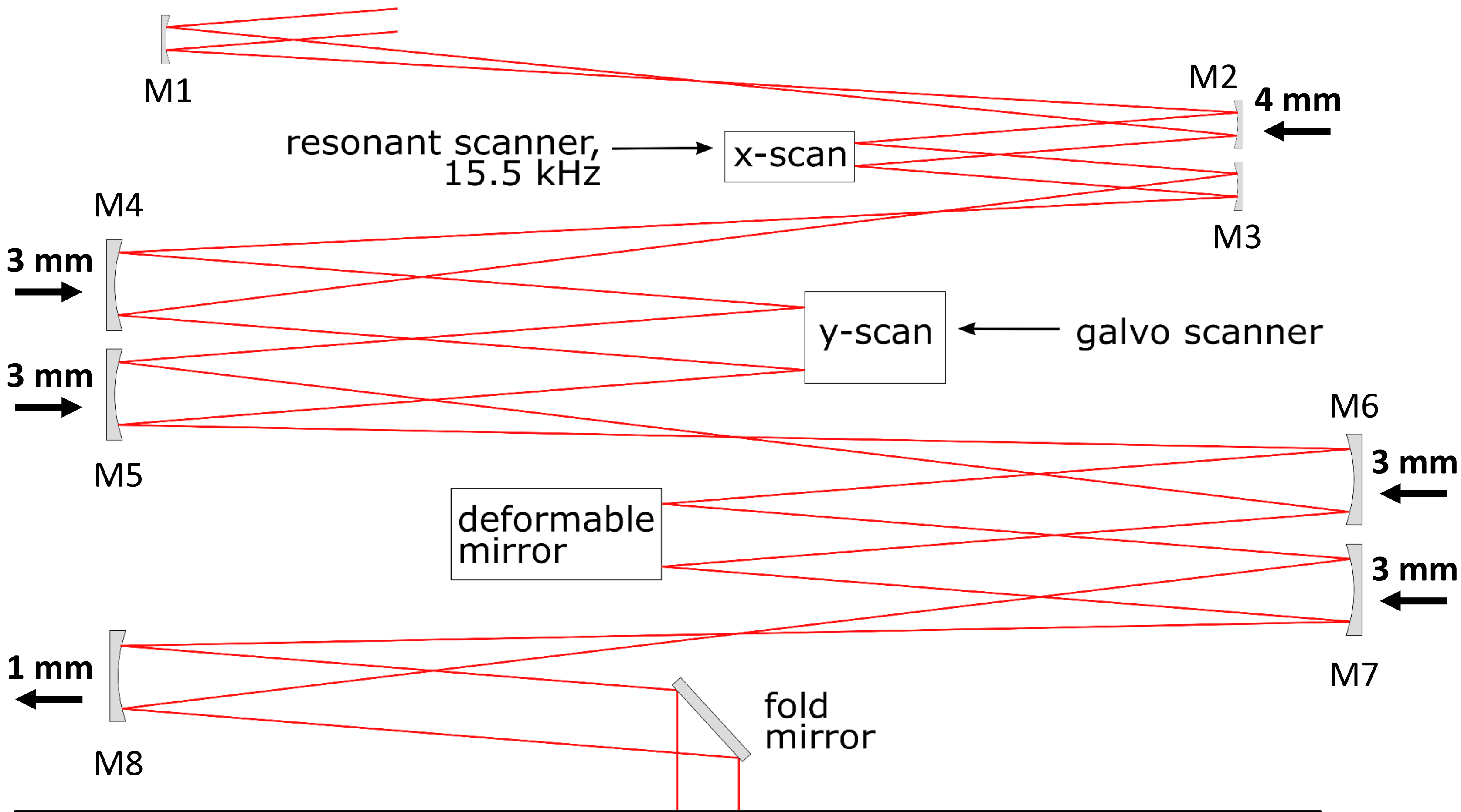
- Want wavefront to be planar at input pupil plane
- Wavefront sensor was placed at a distance of $\mathrm{z} = 400\ \mathrm{mm}$ from the pupil plane
- Wavefront radius of curvature was measured with wavefront sensor
- Fiber position Δz was adjusted until the correct value of R was obtained

Adjustments were made to telescopes to ensure collimated input and output

galvo scanner and deformable mirror were replaced with flat mirrors for these tests

- Small changes (1-4 mm) were made to the z-position of 6 spherical mirrors
- These adjustments resulted in excellent performance of the telescopes
- Wavefront at eye pupil:

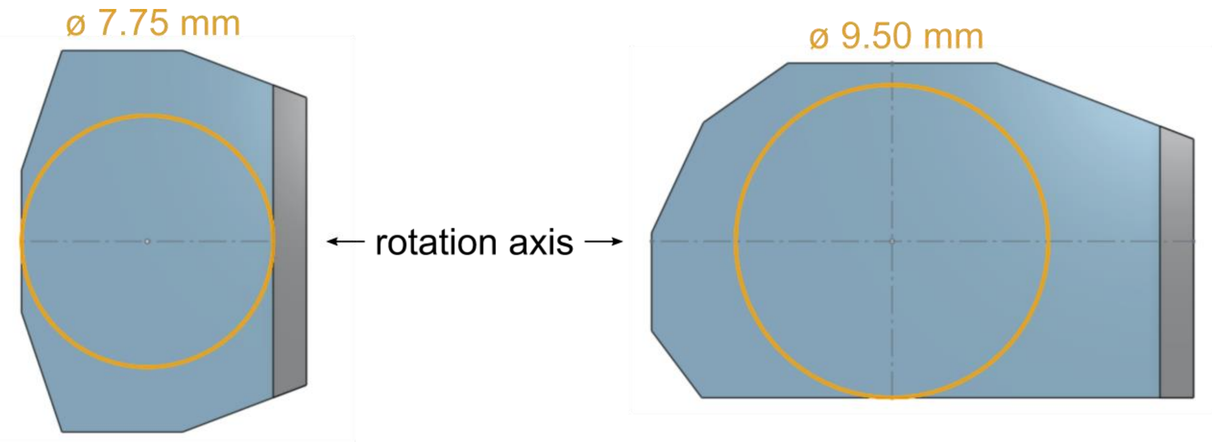
λ (nm)	RMS WFE (waves)	Sphere (D)
543	0.0442	0.003
680	0.0426	0.002
840	0.0452	0.004
940	0.0479	0.001



On-axis performance is diffraction-limited (RMS WFE < 0.07 waves) for all wavelength channels

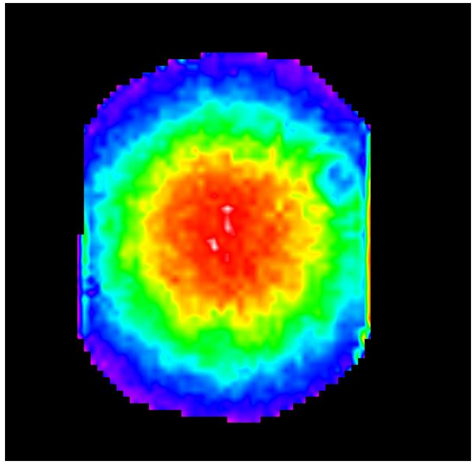
Installing the new galvo solved the beam-clipping issue

- After installing galvo, optical system was realigned
- The galvo cable was rebuilt because the new galvo uses a different connector style

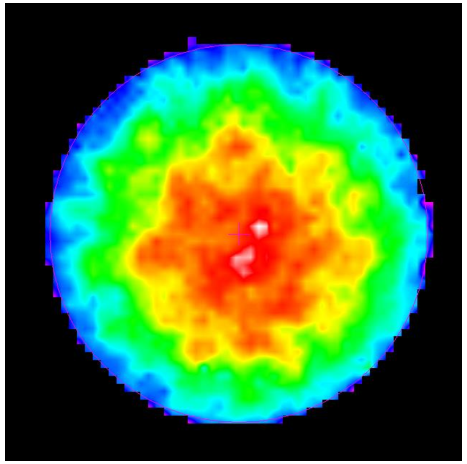


incorrect mirror (D05615)

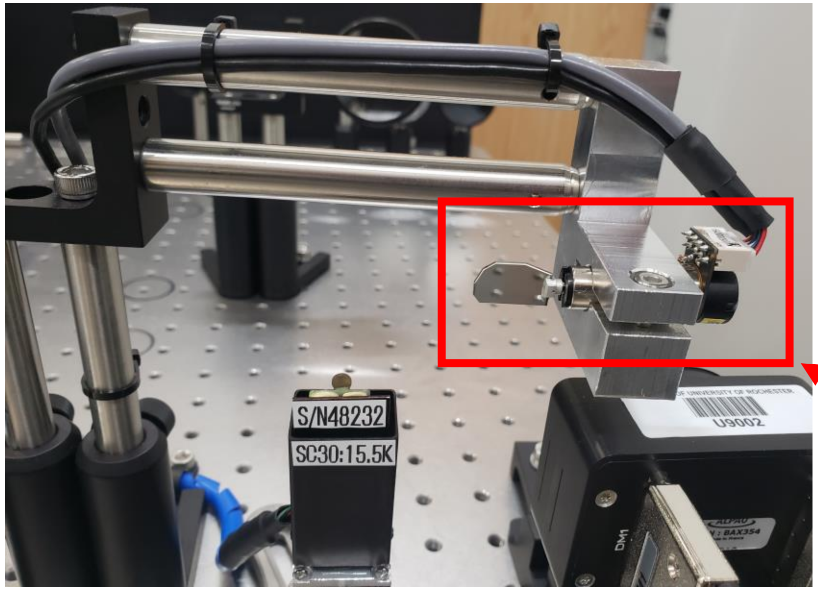
correct mirror (D05616)



beam profile with old galvo (clipping)



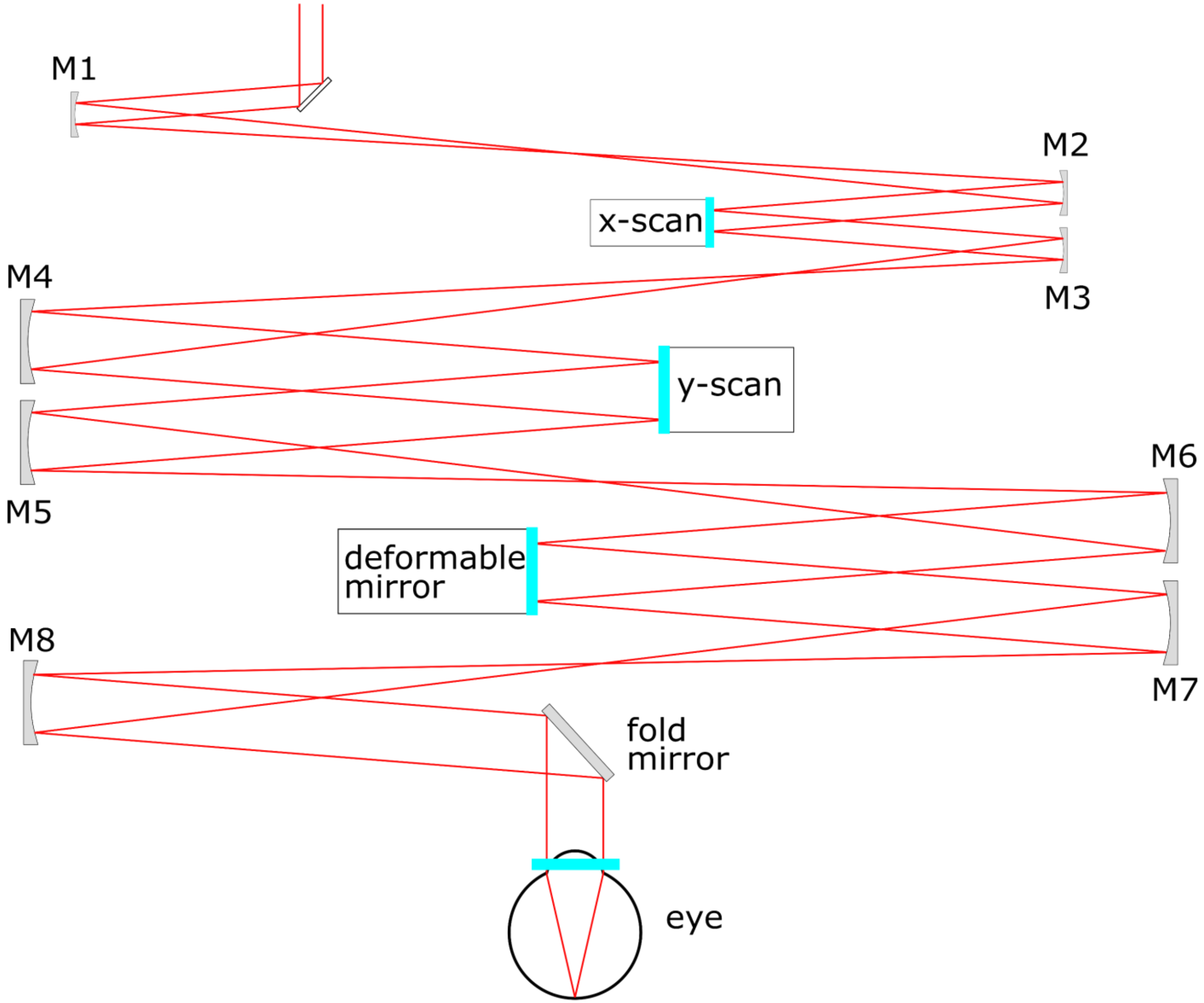
beam profile with new galvo



new galvo installed in custom mounting bracket

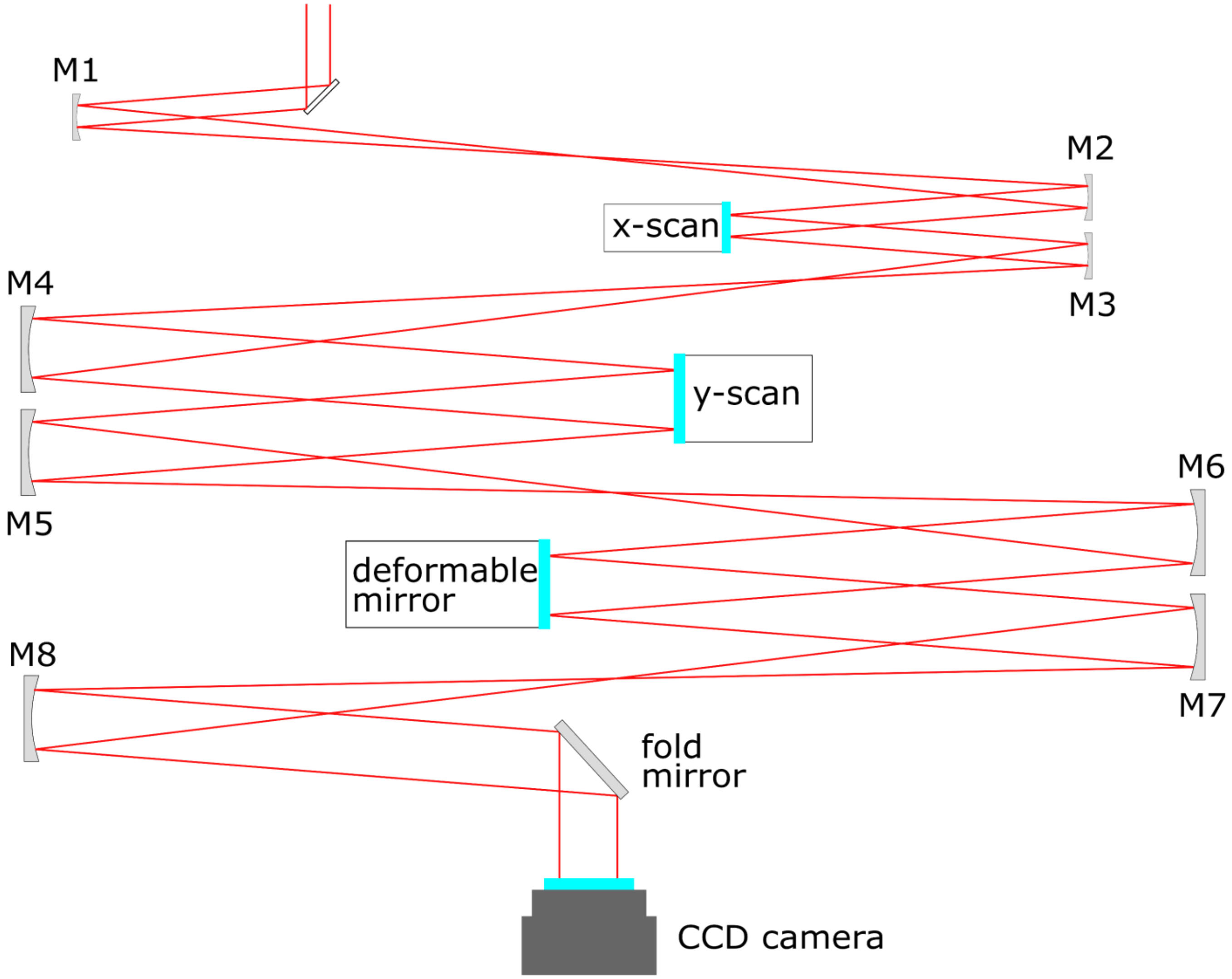
With new galvo installation complete, pupil planes can be aligned

- If pupil planes are not properly aligned, there will be scanning distortions in the image
- To align pupil planes, a CCD camera was placed at the eye pupil plane

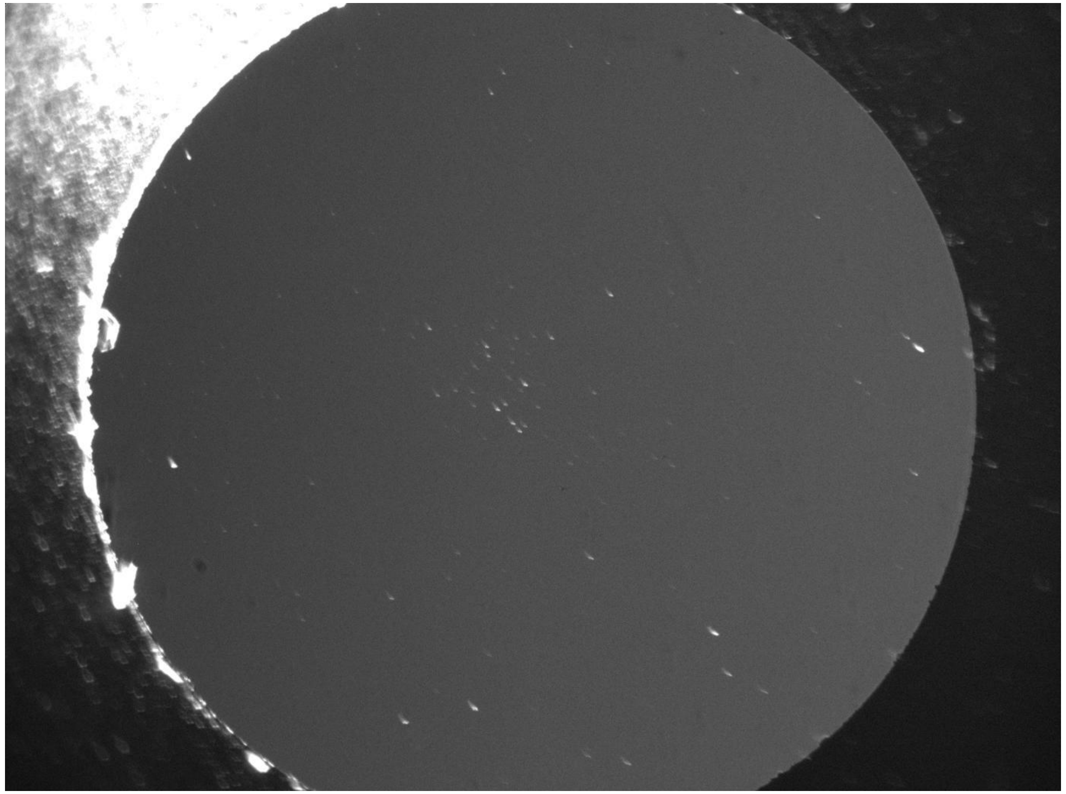


With new galvo installation complete, pupil planes can be aligned

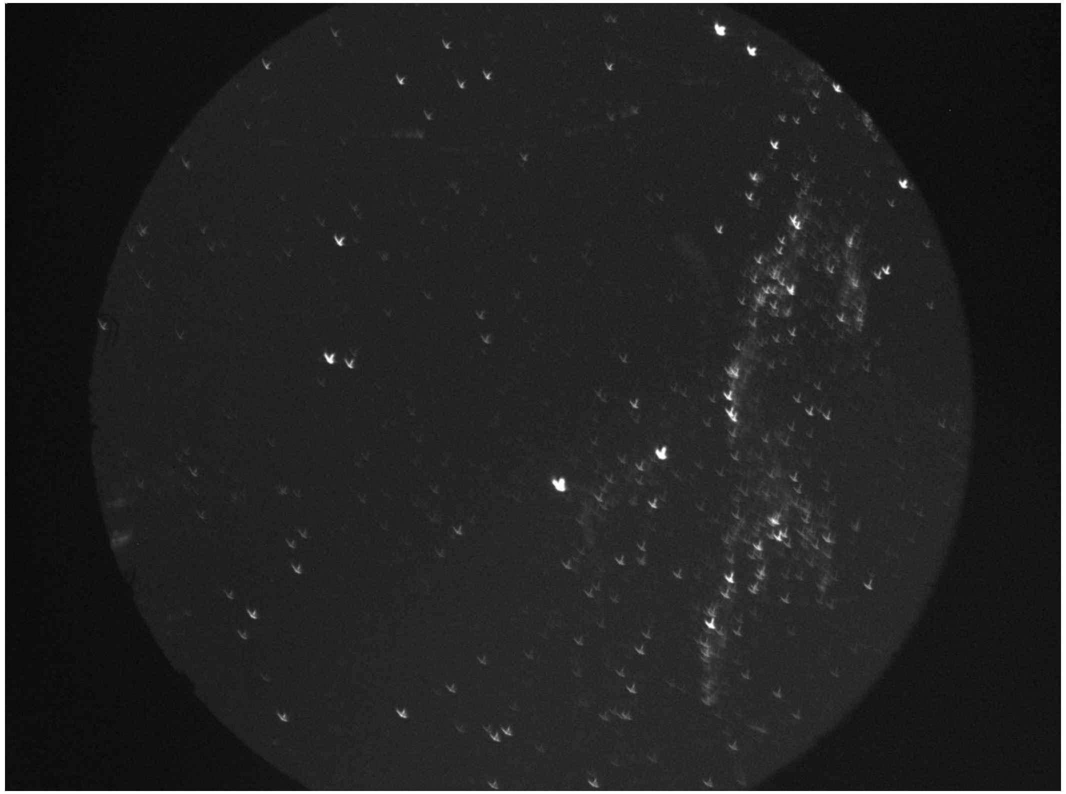
- If pupil planes are not properly aligned, there will be scanning distortions in the image
- To align pupil planes, a CCD camera was placed at the eye pupil plane
- When properly aligned, the deformable mirror and both scanners should be in focus on the CCD camera
- A flashlight is used to provide side illumination on the mirrors, making dust particles visible



Two out of three of the pupil planes have been aligned using this technique



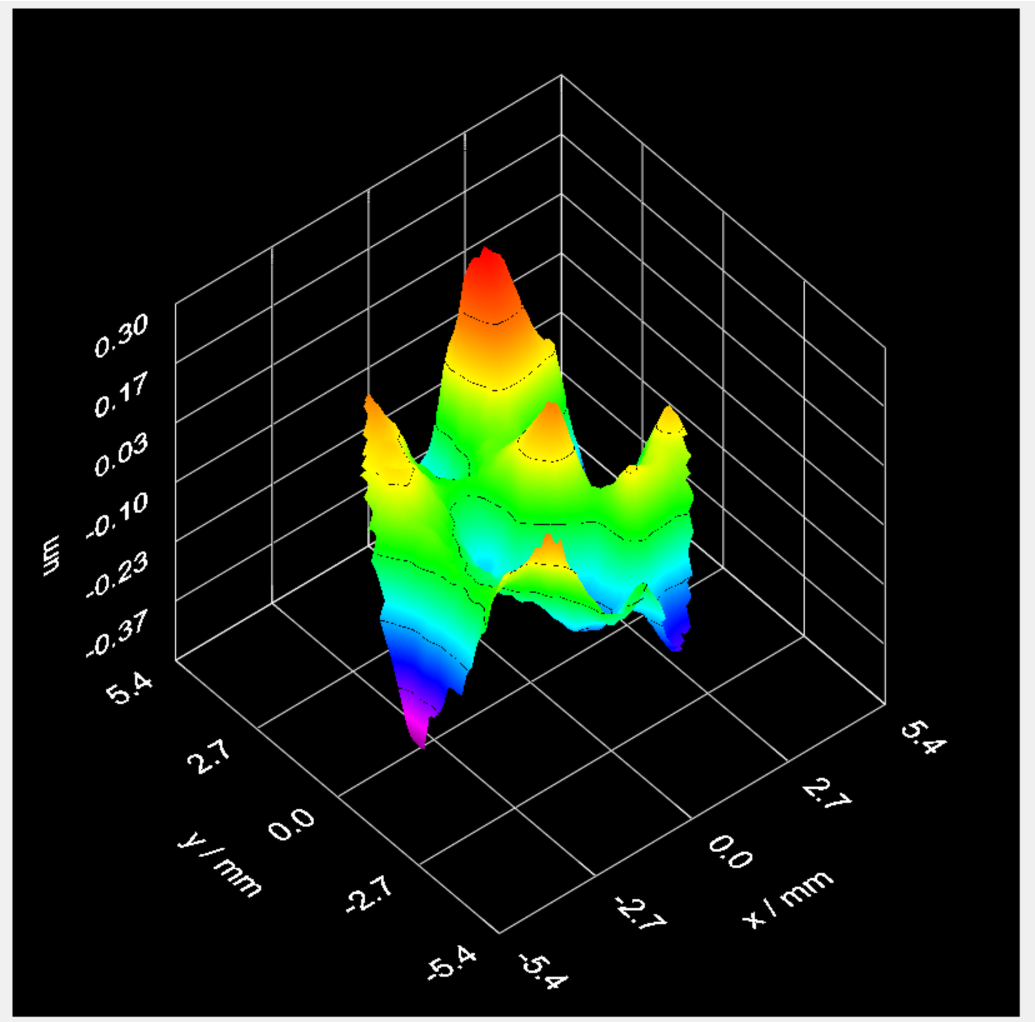
Dust particles on the deformable mirror in sharp focus



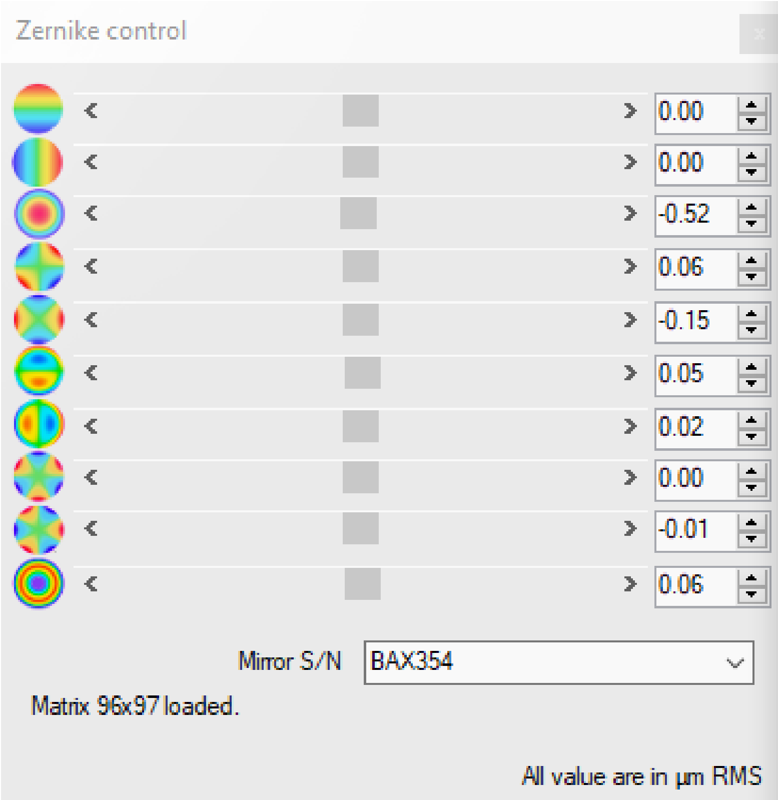
Dust particles on the galvo scanner mirror in sharp focus

- This process will be repeated for the remaining scanning pupil plane (resonant scanner)

Deformable mirror introduces some aberrations, which need to be corrected by adjusting mirror shape



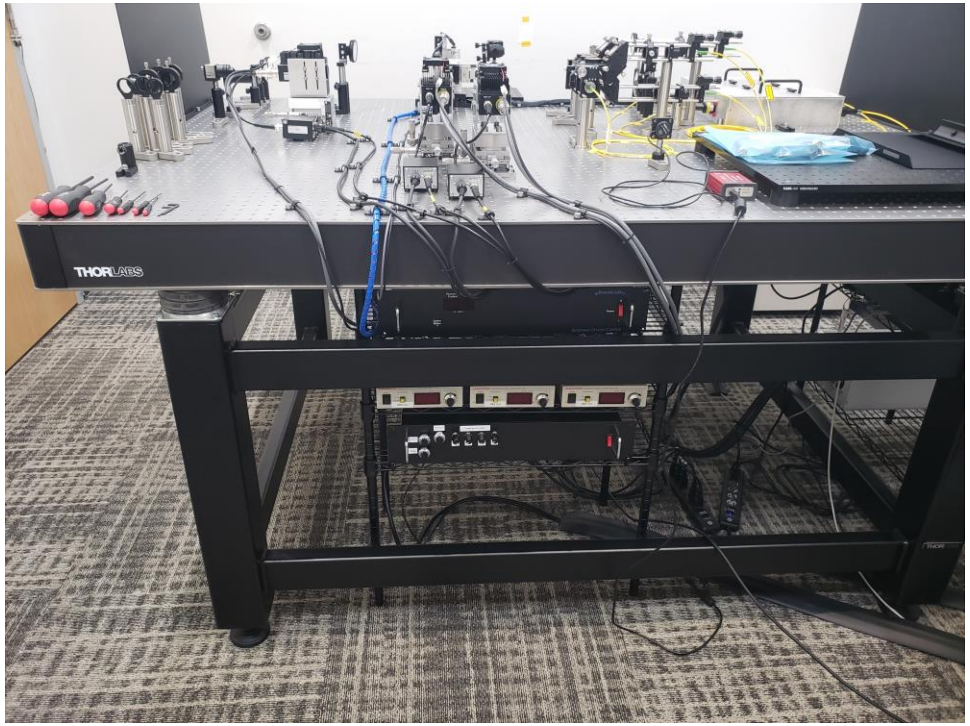
Residual wavefront error introduced by deformable mirror. RMS is 0.114 waves.



Interface for modifying the deformable mirror shape. This program only has low-order Zernike modes (tip/tilt, defocus, astigmatism, coma, trefoil, and spherical)

- Current challenge: the supplied deformable mirror interface only supports low-order Zernike modes
- Wavefront control software from Austin Roorda should enable more controls
- Working on installing this software

Scanning and signal conditioning boxes from Austin Roorda's lab have been installed



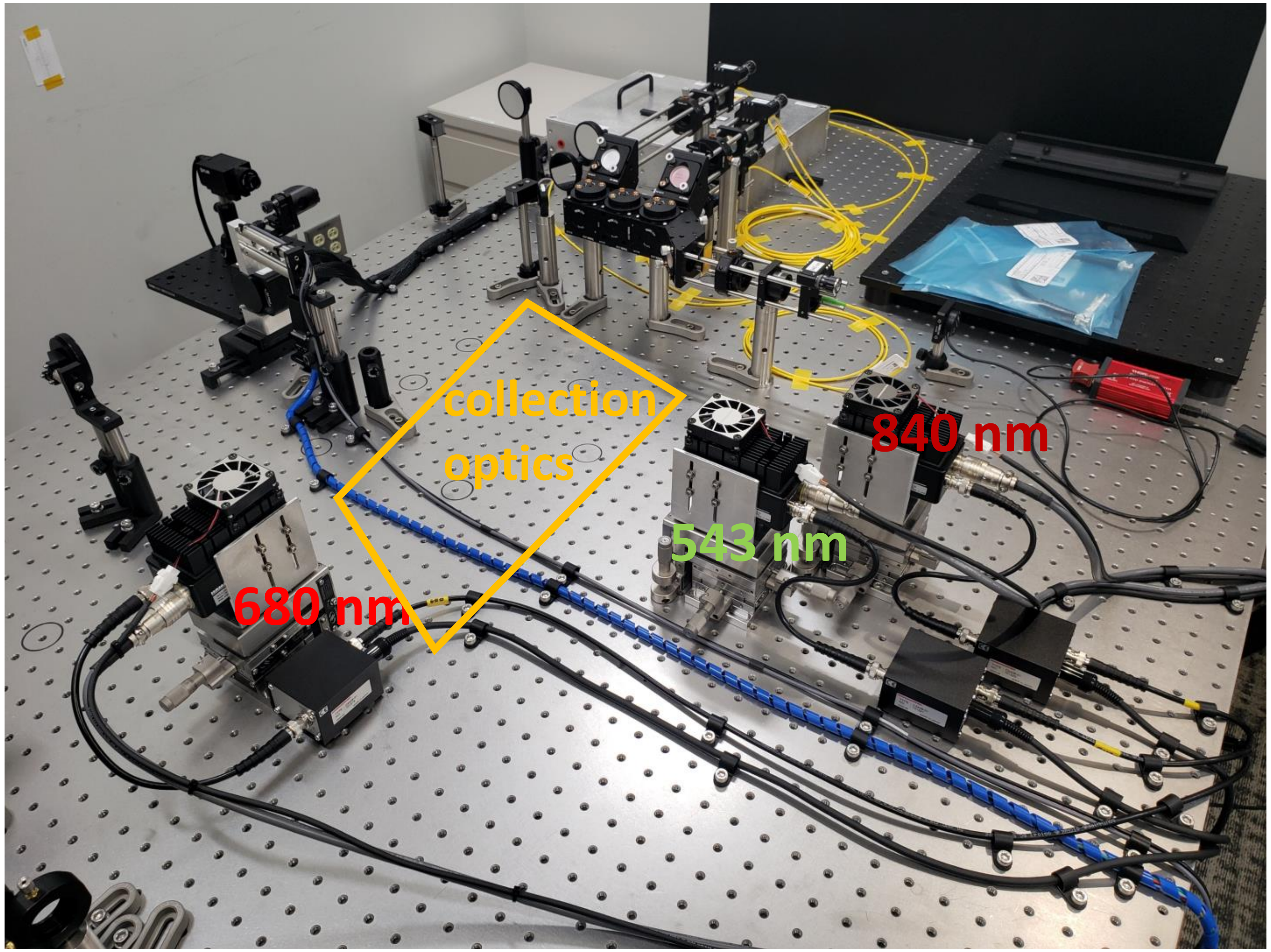
scanner drivers

PMT power supplies

timing and signal conditioning

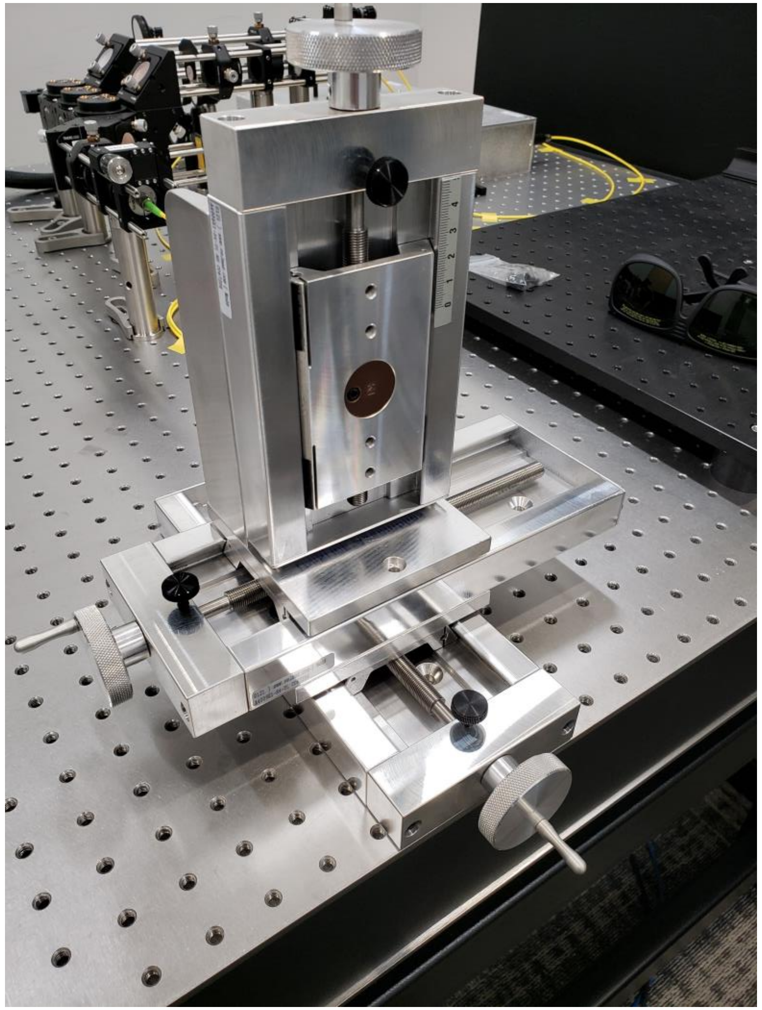
- We have received all the custom electronics from Austin Roorda's lab that we need to finish implementing the system
- All required cables have been installed

Detectors have been installed, but some collection optics still need to be installed

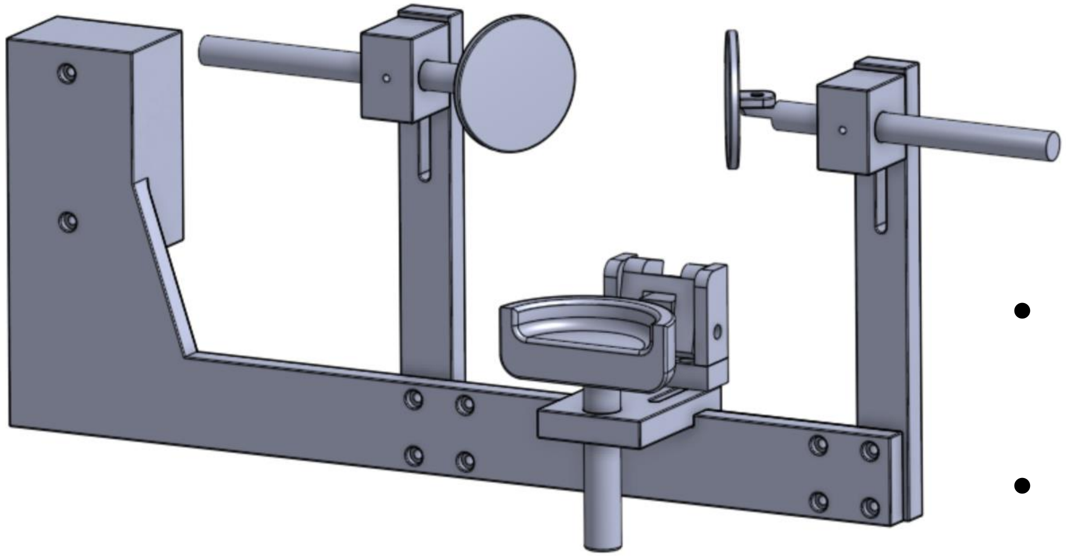


- Remaining collection optics to install and align:
  - Dichroic mirrors
  - Focusing lenses
  - Confocal pinholes
- Wavefront sensor also needs to be installed, but I am currently using it to test other parts of the system alignment

Bite bar fabrication is underway and 3-axis stage is ready



3-axis stage assembly for positioning subject



bite bar / chin rest assembly, which will attach to the 3-axis stage

- Marty is building this assembly for us
- Can be used with either bite bar or chin rest
- Will be compatible with the existing DPI/DDPI bite bars

We have the software required to run the system, but there is not thorough documentation for it

- Custom programs built by Austin Roorda's Lab for imaging and data acquisition have been installed on the computer
- Currently working on installing the custom software for controlling the deformable mirror and running the adaptive optics control loop
- From what I have heard from one of the engineers in the Roorda Lab, there are no user manuals for these custom programs
- I will need to figure out how to use the programs, so I think we should ask Austin Roorda if someone from his group can provide a few training sessions
    - Ideally, this would be someone in the lab who uses the software regularly for conducting human imaging experiments
    - I can then write up procedures so our lab knows how to use the software

Ongoing challenges

- Currently using the wavefront sensor camera for alignment, but I will soon need to install this in the system permanently: **do we have another camera I could use for alignment if necessary?**
- The current deformable mirror software does not allow full control of mirror surface shape, meaning there are residual aberrations that cannot be corrected: **need to get software from Roorda Lab installed and working.**
- I do not have a clear understanding of the light safety considerations for this system: **planning to attend retinal light safety presentation by Dr. Jennifer Hunter on March 19.**
- I would like some guidance on the IRB process for this study: **do we need to complete a separate IRB for this study? If not, what changes do we need to make to the existing IRB?**

Plan for working on remaining tasks

- **Optics**
  - Finish aligning pupil planes
  - Calibrate and install wavefront sensor
  - Install dichroics and focusing lenses
  - Align pinholes and detectors
  - Image resolution targets and distortion grids to assess performance
  - Adjust alignment as necessary
- **Software**
  - Install wavefront control software
  - Receive training on how to use software
  - Write documentation for other users in our lab
- **System integration**
  - Receive training on tuning the scanning hardware and electronics
  - Complete tests of the full system to validate imaging performance
  - Learn techniques and best practices for imaging with AOSLO systems
  - Develop imaging protocols that prioritize retinal light safety
  - Update IRB for this study
  - Install AOMs (acousto-optic modulators) to enable presentation of complex stimuli
  - Begin human imaging study

Questions, suggestions, and feedback