

Design and Prototyping of Optical Systems for Engineering Applications

Week 1

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EECE-5654
Northeastern University

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Week 1 Agenda

- Introductions
- Overview of the Course
- Administrivia
- Experiment 1

Me

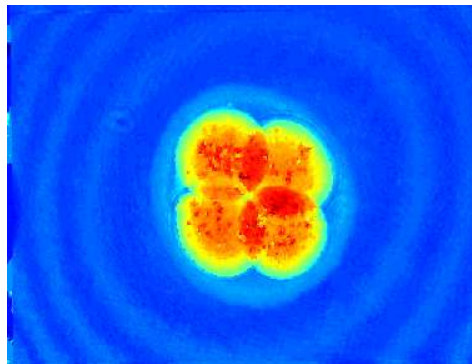
- Education
 - 1969: BS in Engineering Physics, University of Maine
 - 1973: MS in Physics, WPI
 - 1996: Ph.D. in Electrical Engineering, Northeastern
- Employment
 - 1973 — 1987: Raytheon Company (Laser Radar)
 - 1983 — 1987: Northeastern (Part-Time Lecturer)
 - 1987 — 2000: Northeastern (Research Scientist)
 - 2000 — Present: Northeastern ECE Faculty (MIE/BioE)
 - 2014 — 2020: Topical Editor for *Optics Letters*
 - 2014 — 2016: Associate Chair of ECE
- Home: Cambridge, with my Wife, Sheila
- Family: 2 Children, 3 Grandchildren
- Home Ski Area: Killington, Vermont

Personal History

- Raytheon (Jelalian)
 - Aircraft Wake LIDAR
 - Airborne LIDAR
- Northeastern University
 - LIDAR
 - MOKE Sensors
 - Landmine Detection
 - Hyperspectral Imaging (Biomed)
 - Light and Sound
 - Optical Quadrature
 - Multi-Modal Microscopy



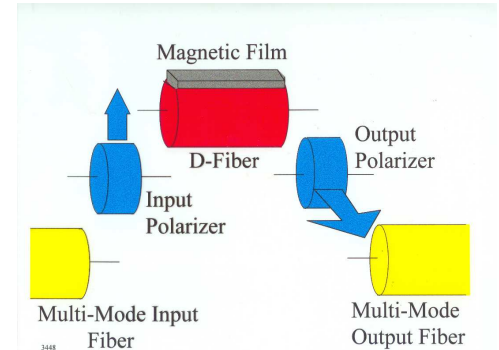
Severe Storms



Cell Counting



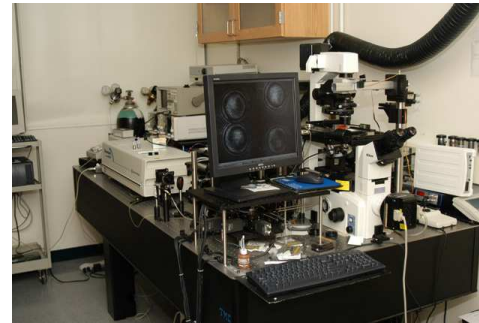
Coal-Dust Lidar



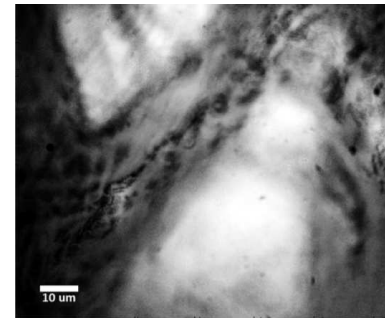
Magnetic Sensor

Our Current Research

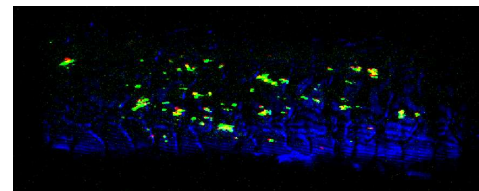
- Multi-Modal Microscopy
- Light and Sound
- Structured Illumination
- Collagen Orientation
- Stepwise 3-Photon Fluorescence in Melanin
- Lidar (Laser Radar)



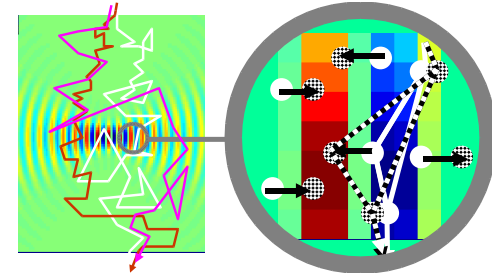
Multi-Modal



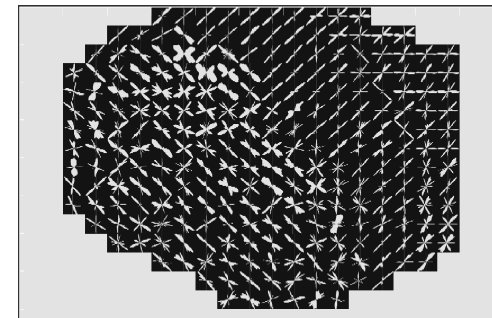
SIM



Melanin



Light and Sound



Collagen



Lidar

Engineers at Play



Introduce Yourself in 2 Minutes

- Name
- Academic History
- Interests in Optics
- Research Group

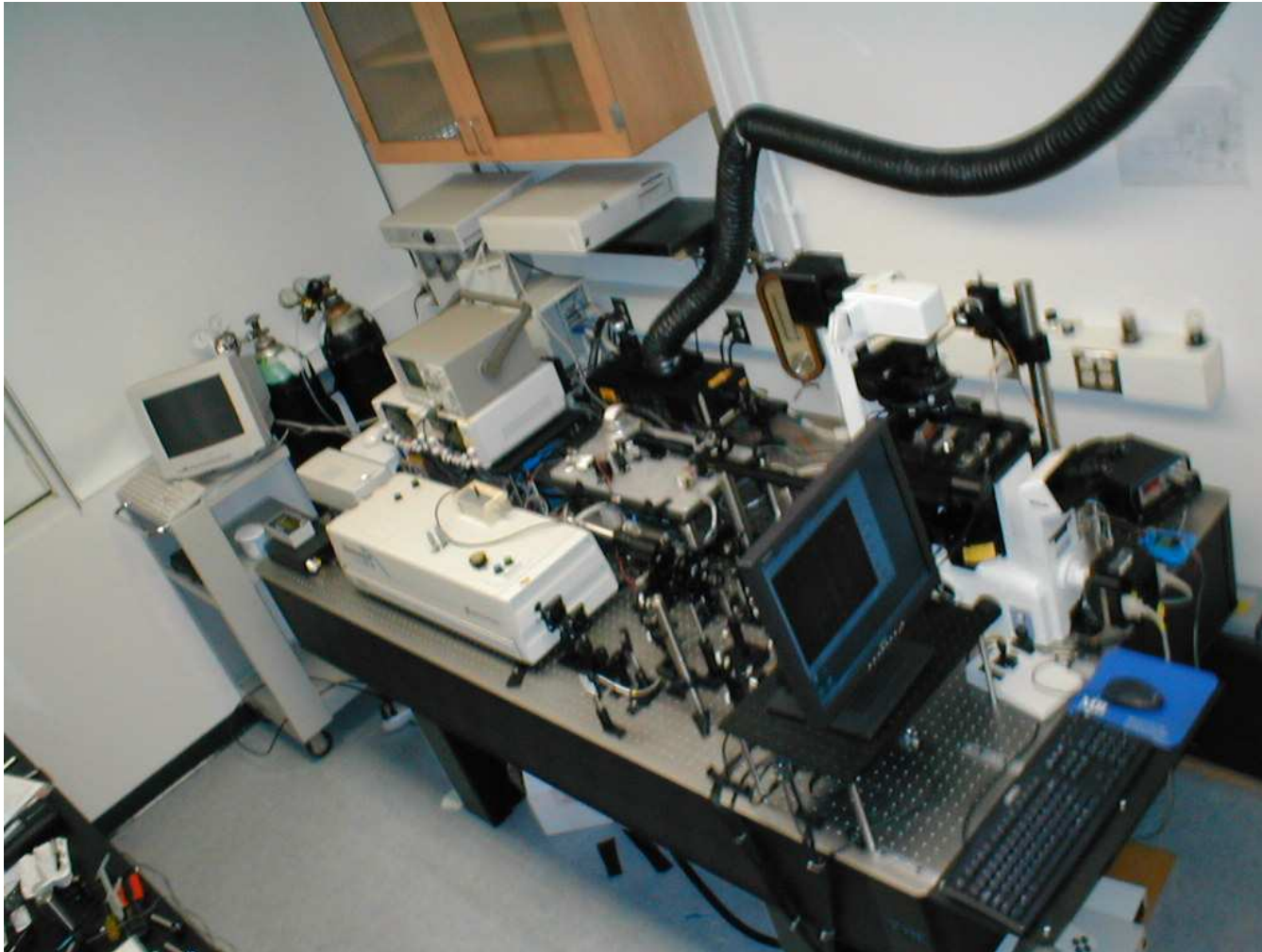
Course Components

- Lectures (Synchronously and Recorded)
- Slides (Available on the Website)
- Pre-Lab
- Lab Experiments
- Extra Lab Hours
- Reports
- Office Hours on Zoom
- Slides from EECE7105/4646
<https://www.ece.neu.edu/courses/eece4646/dimarzio/>

Tentative List of Experiments

- Imaging System
- Telescope
- Polarization T/R Beamsplitter
- Spectrometer
- Interferometer
- Your Idea Here

Learning Objective: Be Able to Build This



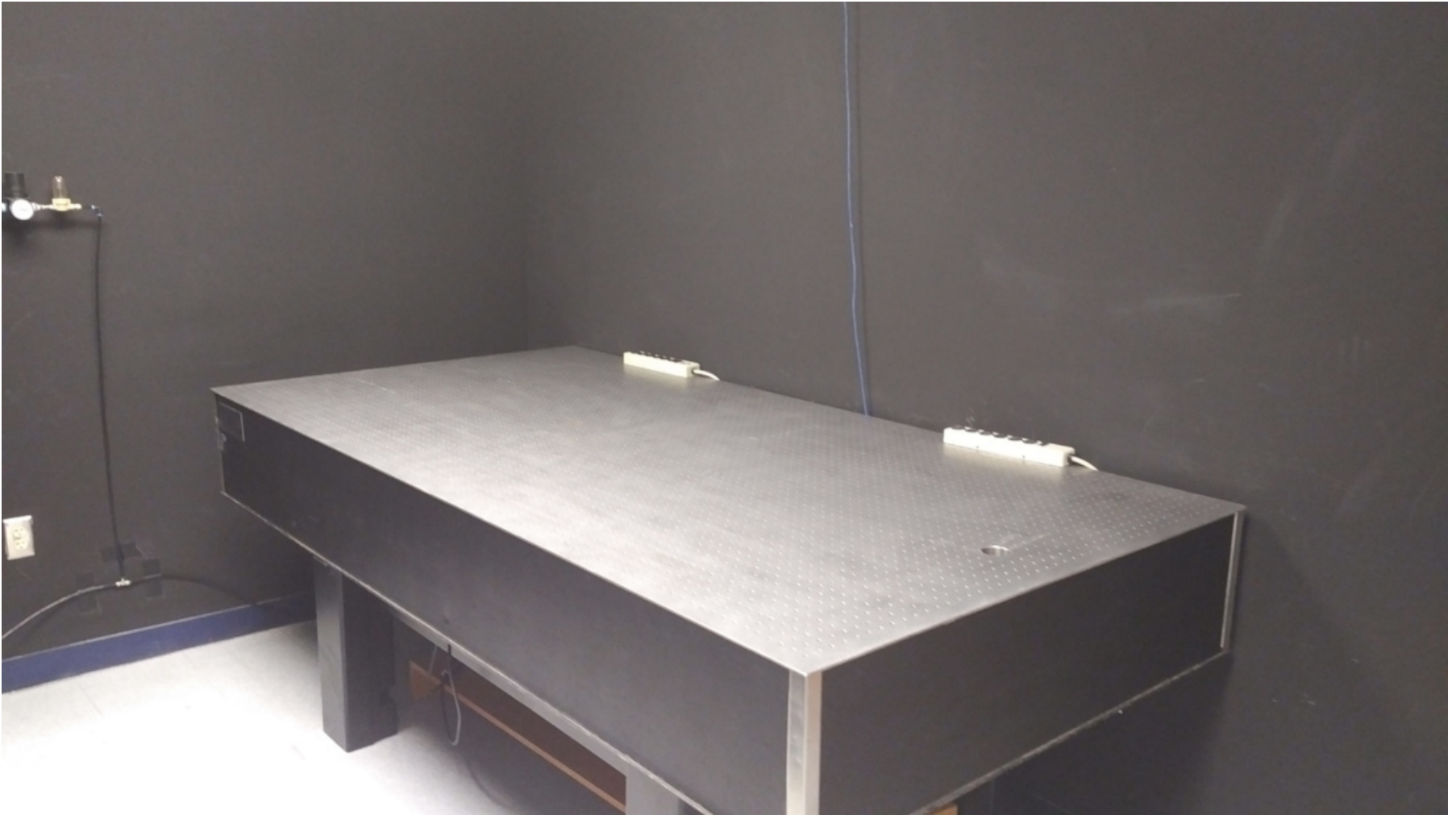
Course Activities

- Design Experiments
 - Use Basic Optical Concepts
 - Perform Trade-off Analysis
 - Design for Alignment
- Build Them and Collect Useful Data
 - Assemble Optical Systems
 - Align Them
 - Use the Tools of the Trade
- Compare Experiments to Theory
- Present Results Clearly (Each Group Every Week)

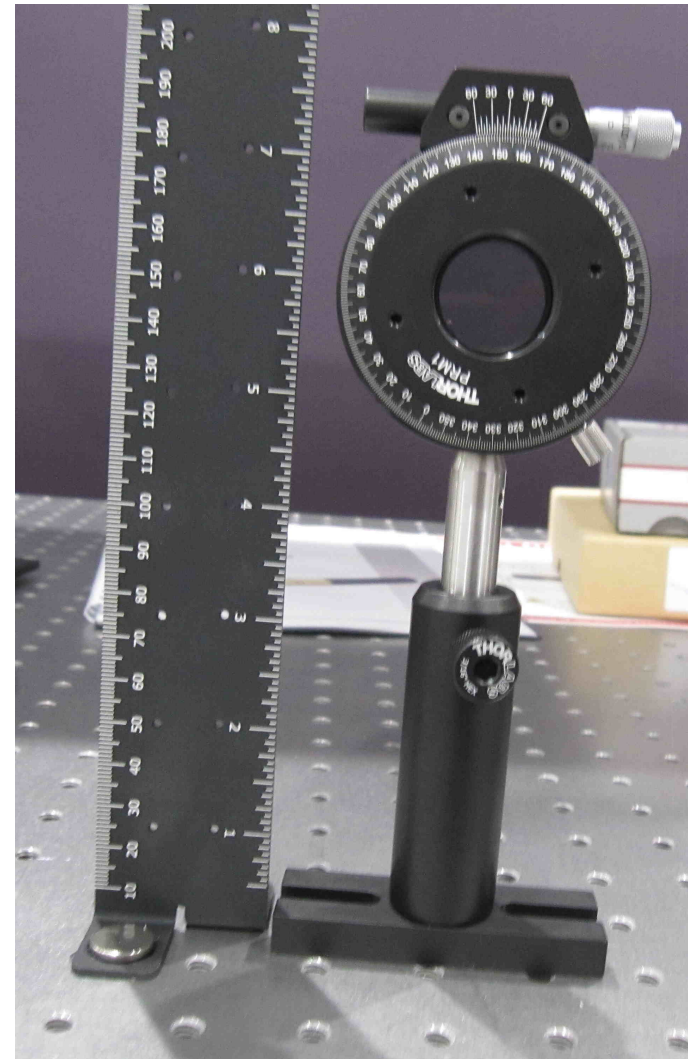
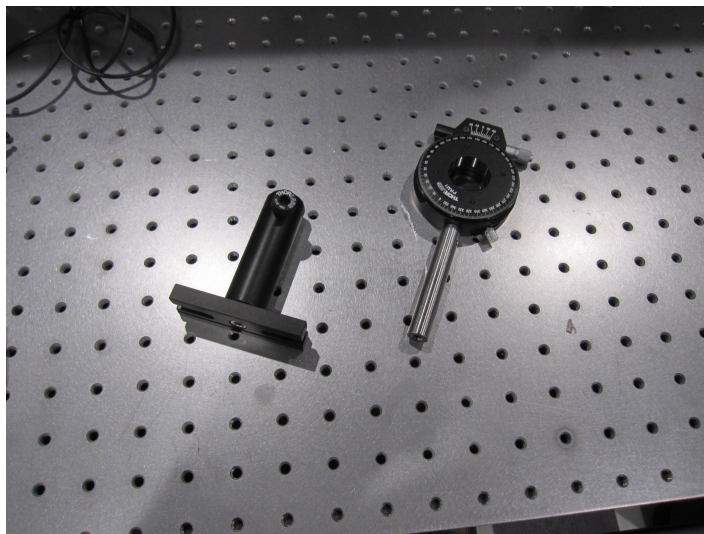
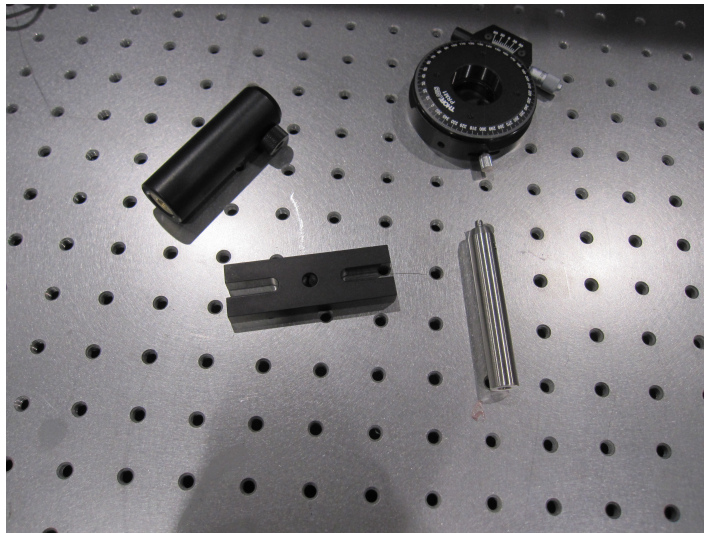
Administrivia

- Communication: Use Email First: (dimarzio@ece.neu.edu)
- Lab Location: 009 HA
- Office Hours on Zoom
TBD
- Graded Items: Pre-Labs and Lab Reflections.
- Lab Teams: Mix Levels (Self-organize)

Optical Breadboard

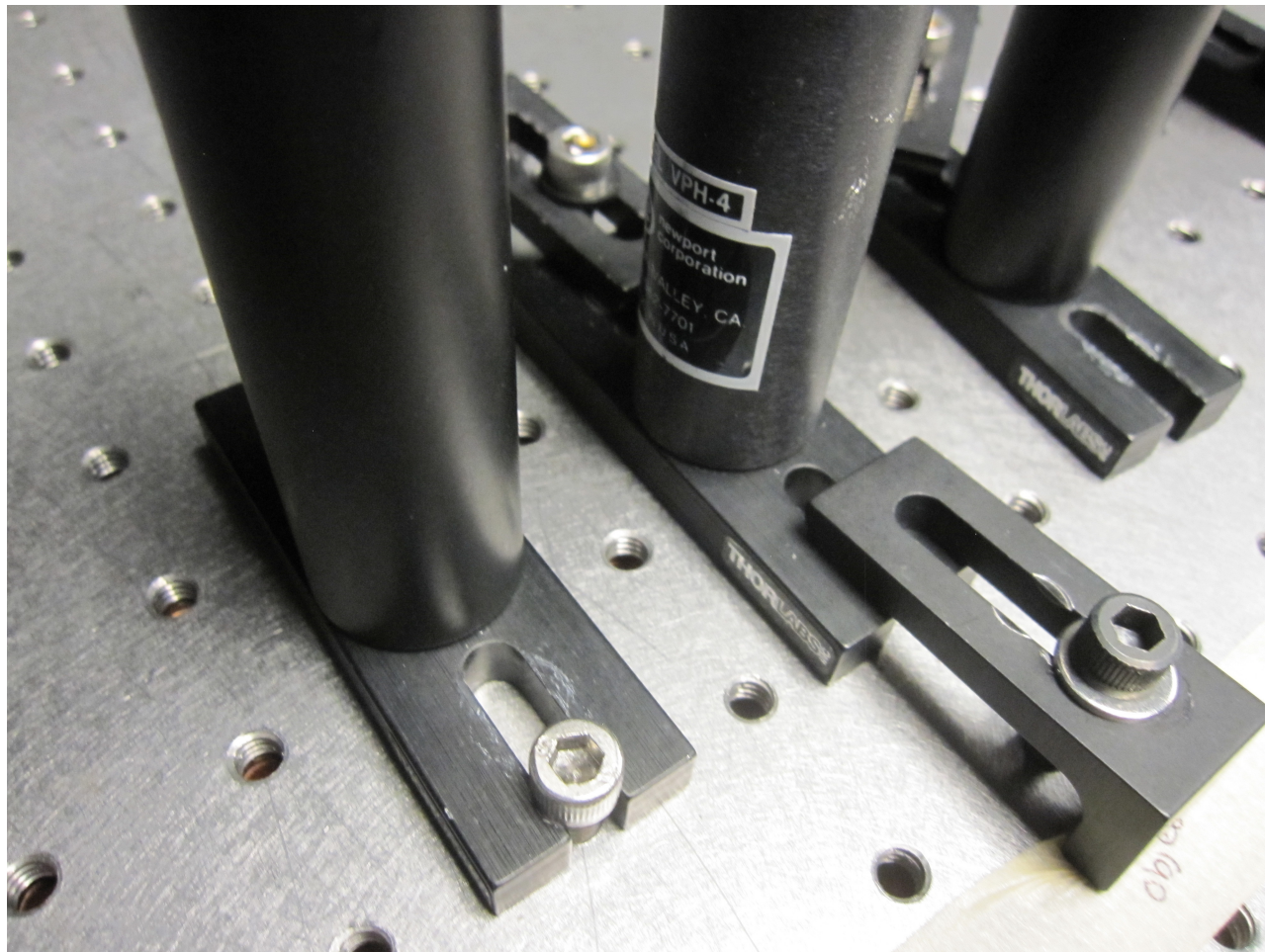


Basic Optical Assembly

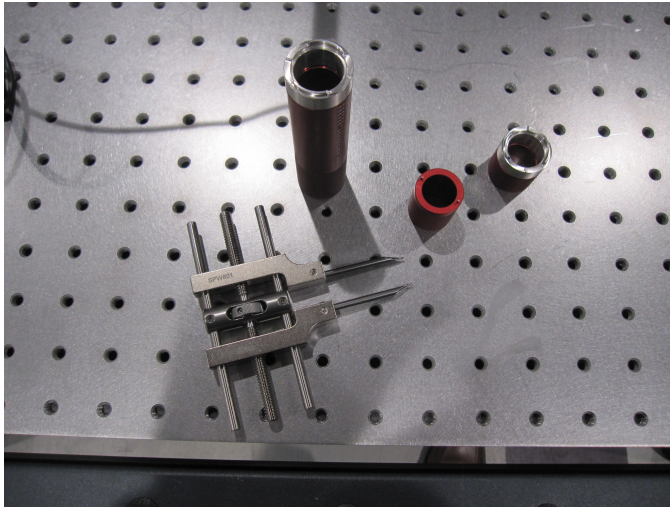


Angle Brackets

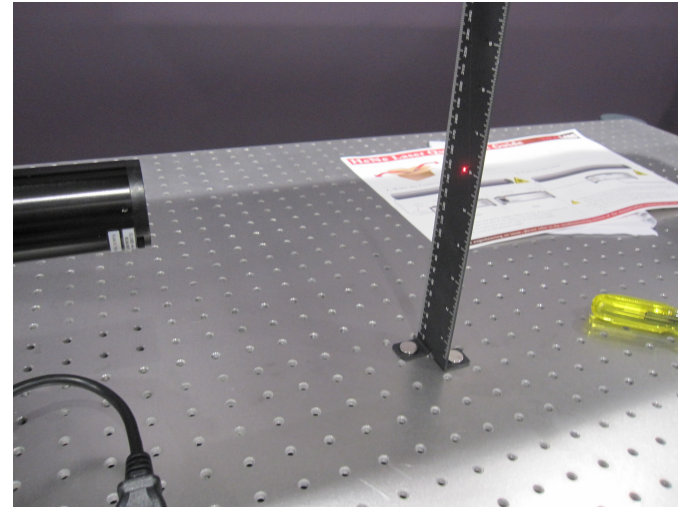
Remember the Washers, Please!



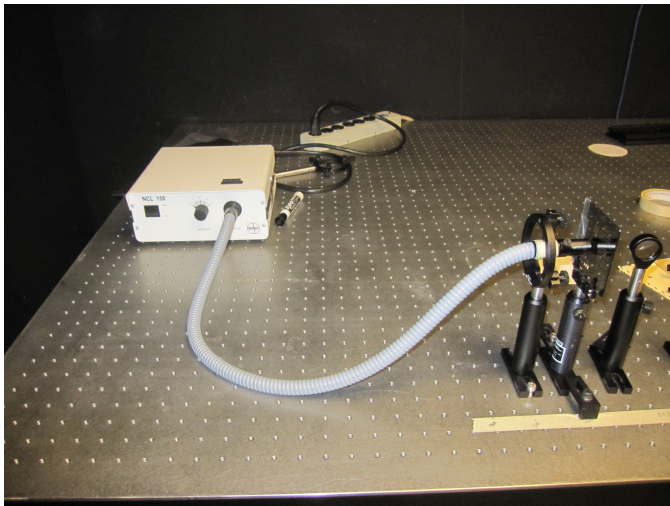
Some Useful Tools (1)



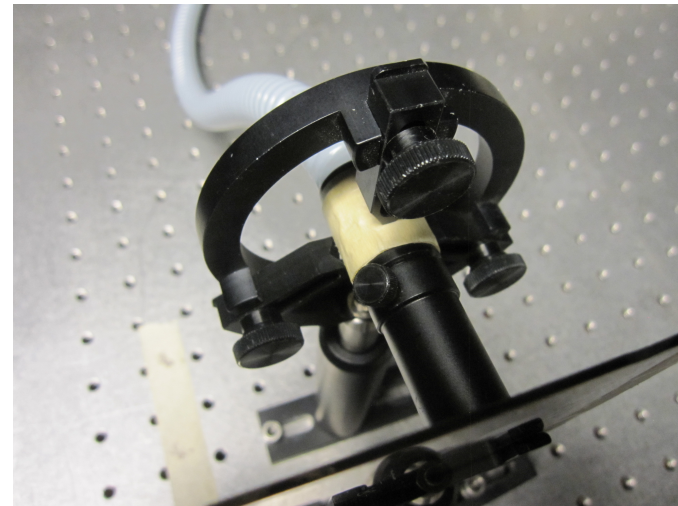
(A) Spanner Wrenches



(B) Alignment Aid



(C) Light Source



Fiber Mounting

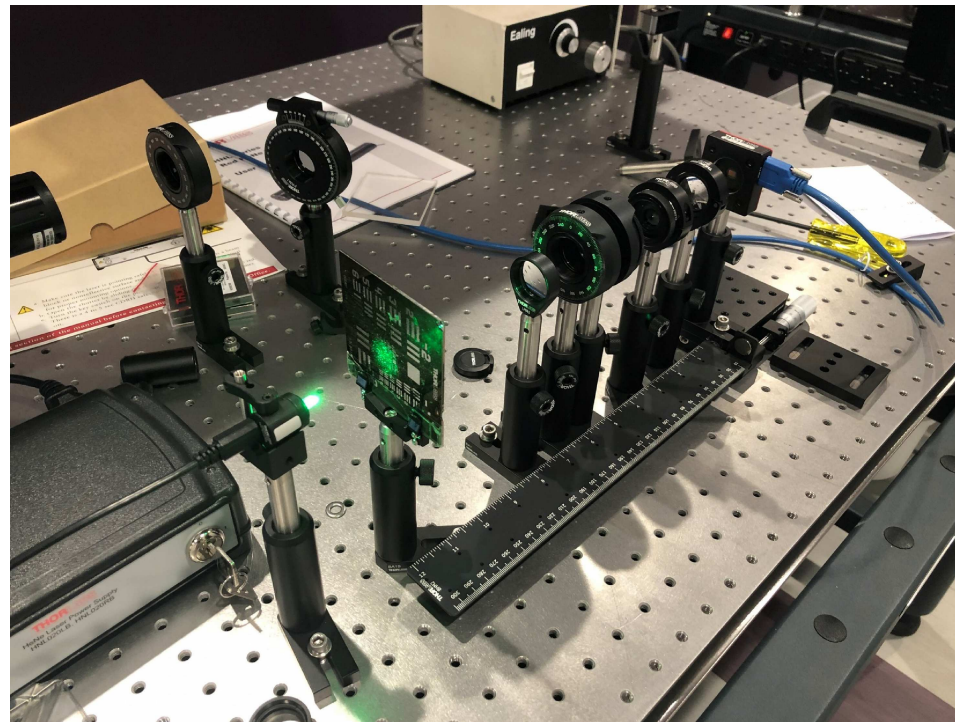
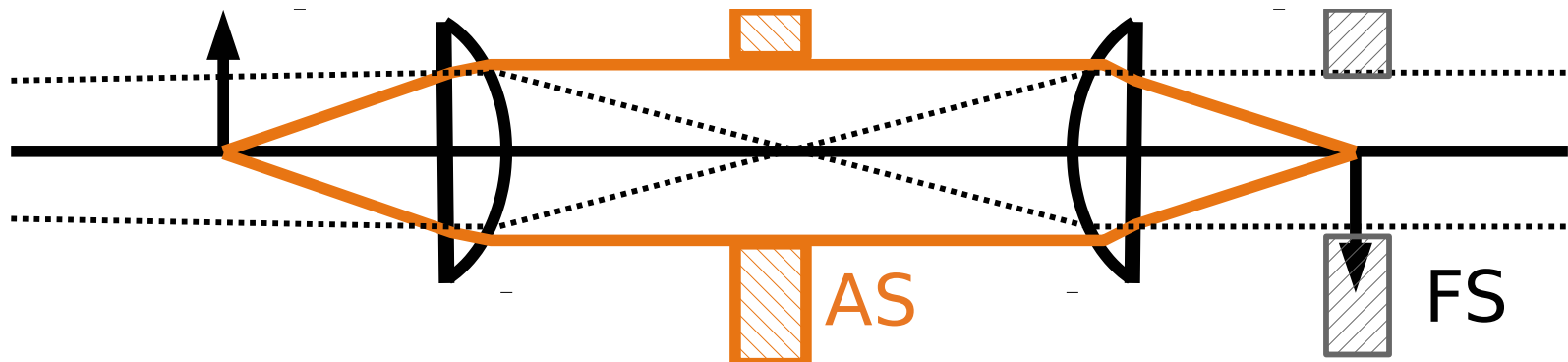
Some Useful Tools (2)

- A Flashlight
- White Cards
- Black Cardboard
- Tape
- A Laptop with Software Loaded (Camera, Spectrometer, Power Meter, and Matlab)
- The most useful tool of all is your eye.

Learning Objectives 1

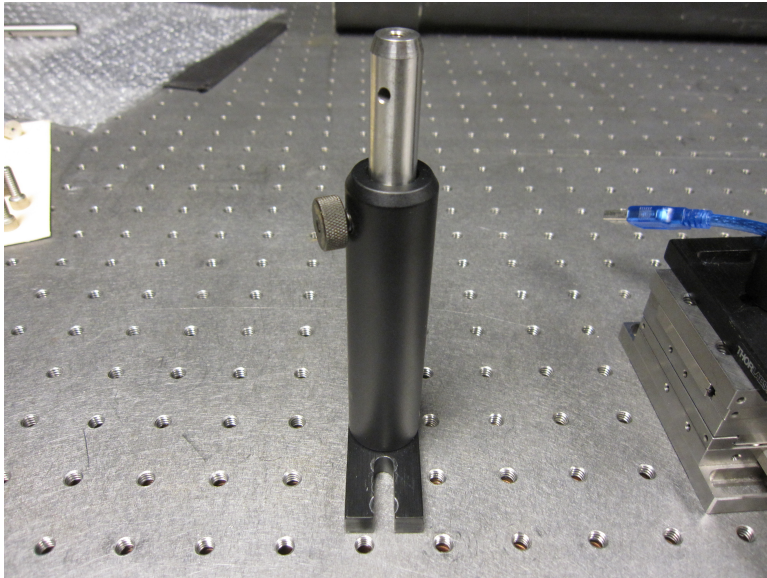
- Working on the Bench: Mounting Optics, Alignment
- Incoherent Sources: Tungsten, LED
- Imaging: Lens Equation, Telecentric Lenses
 - Numerical Aperture, Diffraction
 - Aberrations
- Linear Micropositioners
- Cameras: Pixels, Bit Depth and Dynamic Range
- Integration Time, Gamma
- Saturation, Clipping Blacks, Clipping Whites

Experiment 1 Setup



Sam Koblensky, Northeastern University

Lens Assembly



Base Plate: Many Styles
Post Holder, Post
(Pick Lengths to
Adjust Height and
Maintain Stability)
1/4–20 Screws



Lens, Lens Mount
8–32 Set Screw
Threaded Ring (Tighten Gently
with Spanner Wrench)
Don't Touch the Optics!
(Hold by the Edges)

Mounting Loose Optics



Retaining Ring (note slots)



Spanner Wrench

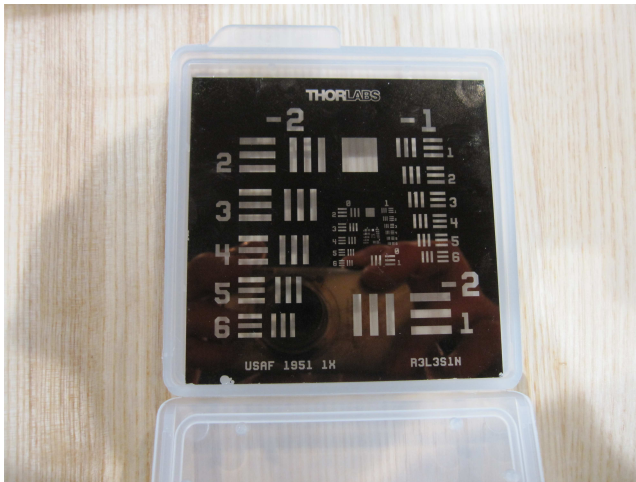


Pre-Mounted Lens



Screw into Mount on Post

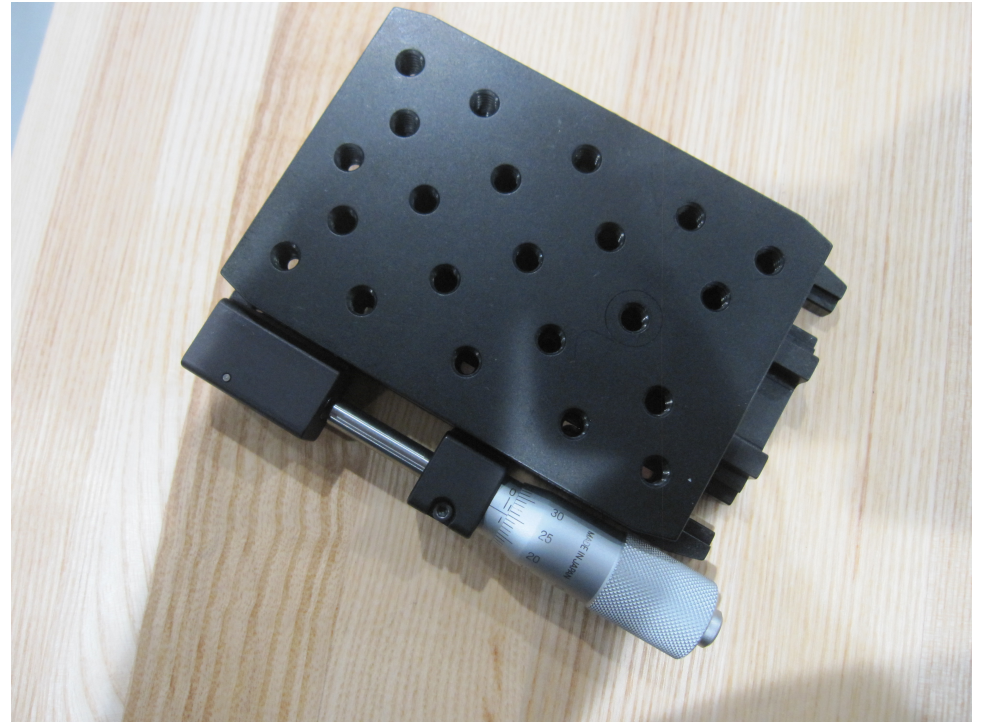
Mounting the AF Chart



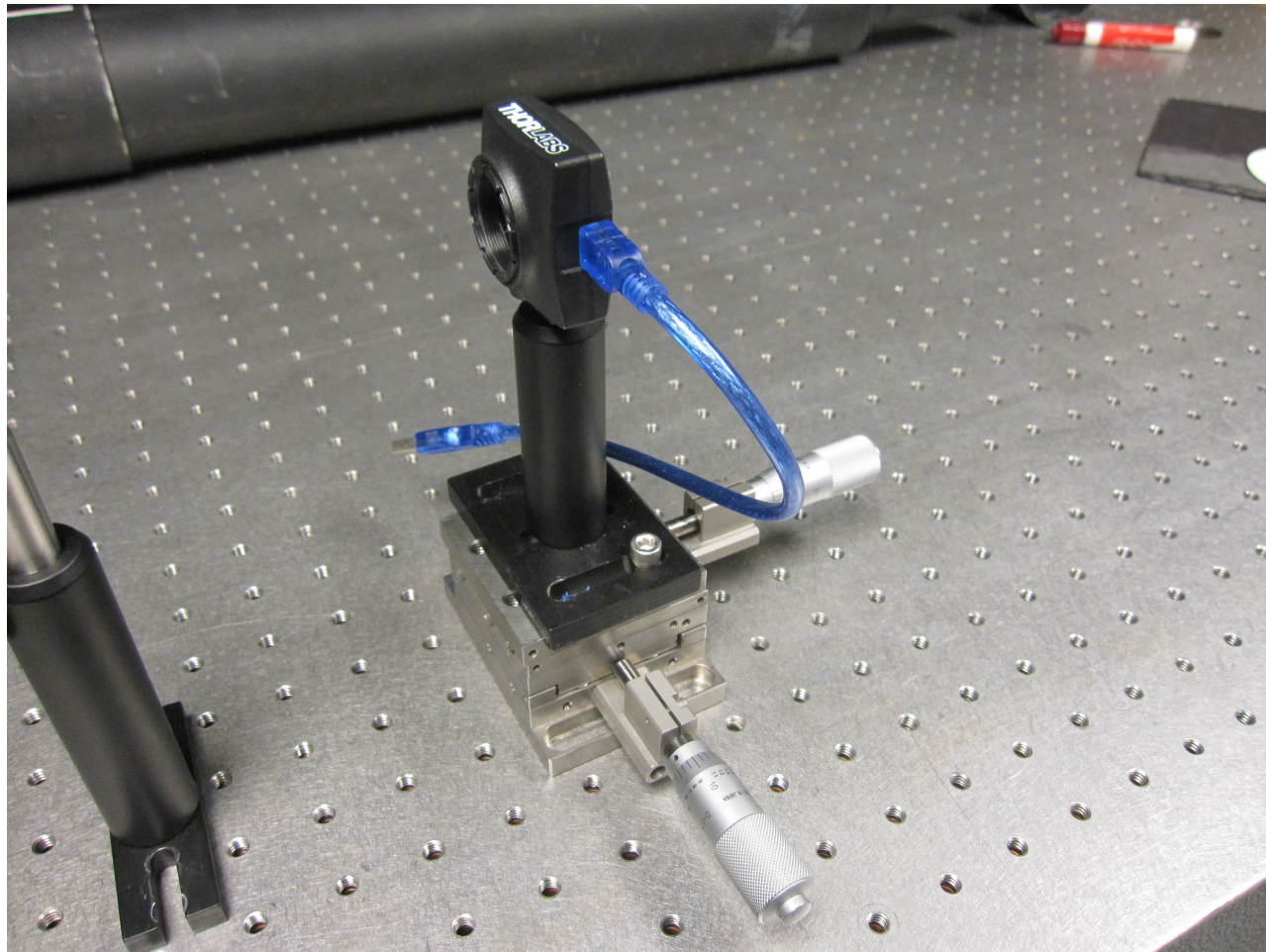
$$x = \frac{1\text{mm}}{2^{G+1+(E-1)/6}}$$

Micropositioning

- Much Better than Adjustment by Hand
- Quantitative
- But Expensive and Large
- Also 2-D and 3-D Assemblies



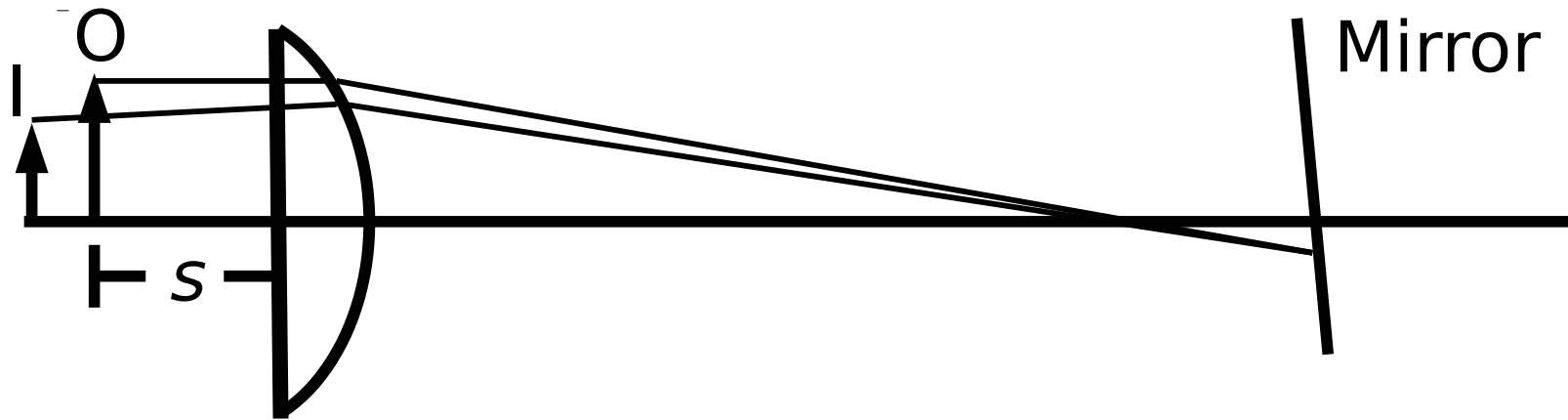
Camera on 2-Axis Stage



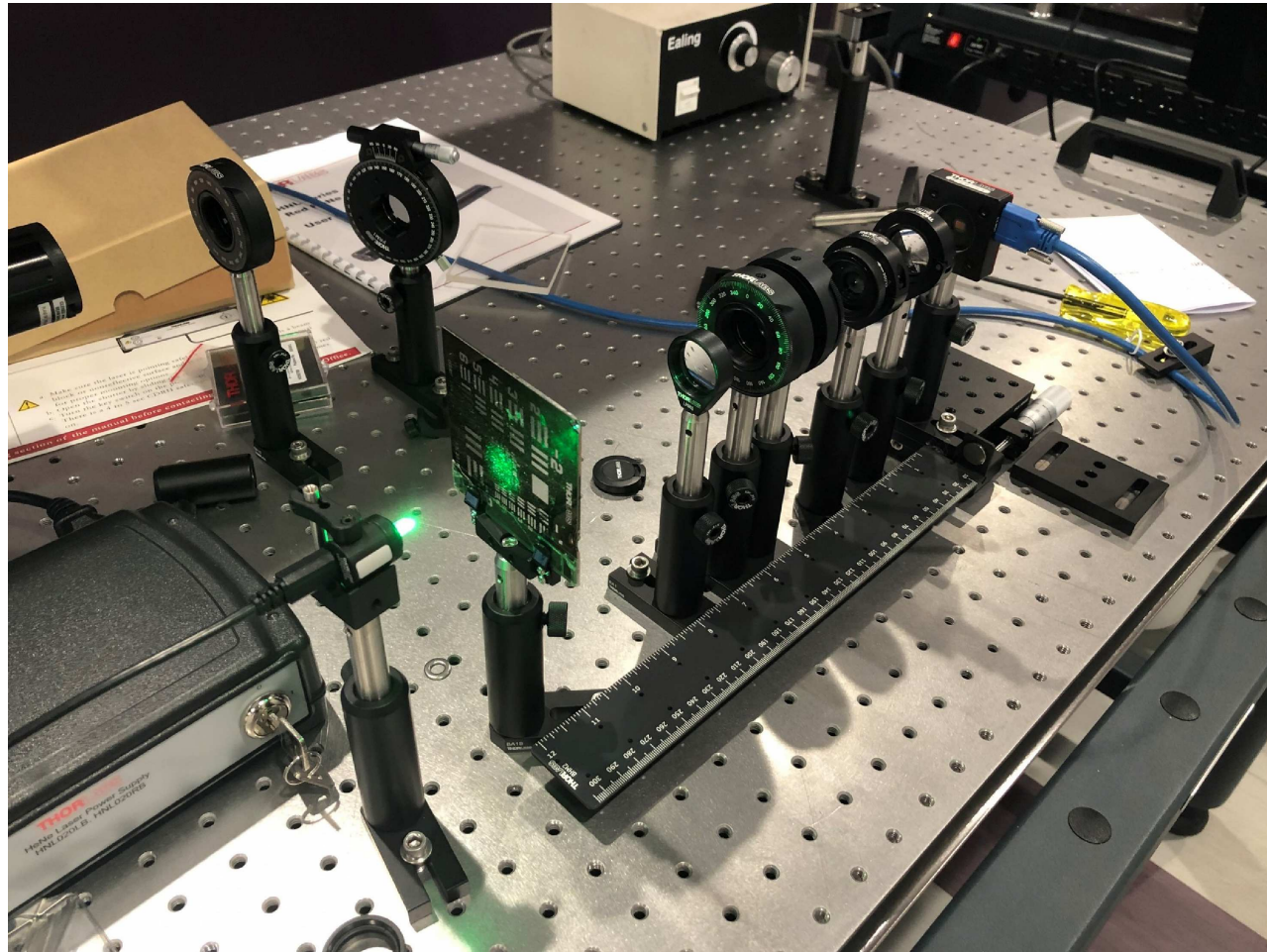
Keep Covered when not in use and don't touch!

Download Software: [Thorlabs Mono Zelux Scientific 1.6MP, USB3.0](#)

Autocollimation



Experiment 1



Sam Koblensky, Northeastern University

The Essential Math

- The Lens Equation

$$\frac{1}{s} + \frac{1}{s'} = \frac{1}{f}$$

- Magnification

$$m = -\frac{s'}{s}$$

- Telecentric System

$$s_1 = f_1 \quad s'_2 = f_2$$

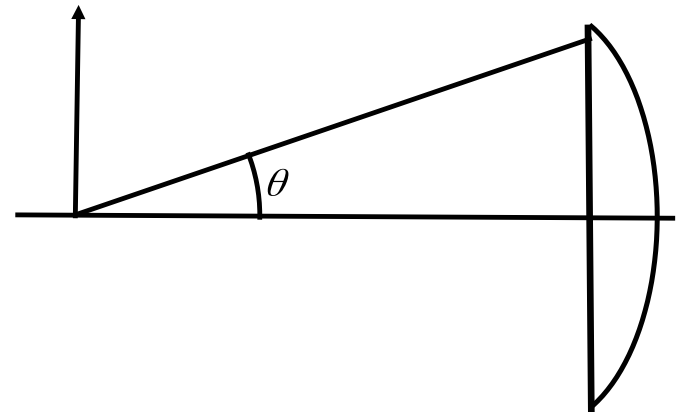
$$s'_1 + s_2 = f_1 + f_2$$

- Magnification

$$m = -\frac{f_2}{f_1}$$

- Numerical Aperture

$$NA = n \sin \theta$$



- Increasing NA
 - Diffraction Limit $\downarrow$
 - Aberrations $\uparrow$

Concepts

- Resolution (Diffraction) λ/NA

$$NA = n \sin \theta \quad \tan \theta = \frac{D}{2f}$$

- Resolution (Aberrations) increases with NA
- Imaging with Telecentric System
- Reflection and Transmission
- Operation of a Camera (Dynamic Range, Calibration, etc.)

Prelab 1

View <https://www.youtube.com/watch?v=4xZmGyMsQNo&t>

Design a telecentric imaging system. Decide on a “reasonable” magnification so that you can test the diffraction limit by imaging the Air–Force resolution chart. Also be sure that you can measure changes in the diffraction–limited spot using your camera. In other words, make sure that the smallest aperture will result in a point–spread function that subtends many pixels on the camera. Use plano–convex lenses and put them in “the right way.”

Calculate the numerical aperture using different diameters for an iris placed in the pupil plane. Calculate the diffraction limit using these numerical apertures.

Calculate the transverse spherical aberration. This will take a bit of work. Remember that the axial aberrations (in diopters) add. More specifically, calculate the total axial aberration using $L_s = \frac{1}{s'(x_1)} - \frac{1}{s'(0)}$ and then compute the transverse aberration $\Delta x(x_1) = x_1 \frac{\Delta s'(x_1)}{s'(0)}$. Do the same with both lenses installed “the wrong way.”

Optionally if ray–tracing software is available, plot spot diagrams and compare the results to the aberration calculations above.

Experiment 1 (1)

Set up the imaging system with a camera at the image plane and the Air–Force chart at the object plane. You’ll probably need to microposition the axial direction of at least one element of the system.

Use autocollimation to assure that the object is at the front focal plane of the first lens.

Collect an image. Is the magnification what you would expect? You will need to know the pixel size on your camera, and the size of different elements of the AF chart $x = \frac{1\text{mm}}{2^{G+1+(E-1)/6}}$.

Look at the “brightness” of the image. Adjust the light source to different values and look for the phenomenon of “clipping whites” where the brightest part of the image saturates the digitizer in the camera (or the full–well capacity of the pixel. Remove the AF chart and just look at the light source. Adjust it so the brightness is near but not too near the upper limit. Call this image *White*. Also block the light source and collect an image called *Dark*. Put the AF chart back without moving anything else and take an image called *Sample*.

The glass areas of the AF chart should transmit about $T_{Fresnel} = 0.96^2$ because about 4% of the light is reflected at each surface. Create an image of the transmission, $T_{experiment} = \frac{Sample-Dark}{White-Dark}$. Choose a good color axis and see how closely the transmission matches the theory.

Experiment 1 (2)

Move the resolution chart to different locations in x and y , and collect images with different apertures at each location. What is the smallest element of the resolution chart you can resolve? In other words, which is the smallest element where you can tell that there are three bars? Is it different for horizontal and vertical elements?

Notice the changes for different locations and aperture sizes. For at least one location, systematically collect images at a sequence of different aperture sizes so that you can complete the task in the “reflections” slide. If you have time, do this for more than one location.

Reflections 1

How close does the resolution match your expectation for different iris sizes? Answer this question first at the center of the field of view and then at the edges and corners. You may get different answers in the vertical and horizontal directions. Remember that the equations derived from spherical aberration are for the ray at the edge of the aperture stop. Most rays are considerably closer to the center and the equation will give a very pessimistic estimate of the resolution. On the other hand, imperfect alignment will result in larger aberrations.

Discuss changes in resolution and changes in contrast among your images.

Is the transmission of the glass about what you would expect?

Good Lab Behavior

- Don't touch the optics.
- Be gentle with front-surface mirrors.
- Keep the camera covered if not in use.
- Don't try to clean anything (yet).
- Don't turn on the lasers (yet).
- Use washers.
- Announce “Lights On” and “Lights Off” (mostly off)
- Clean up and put things away in the right place.