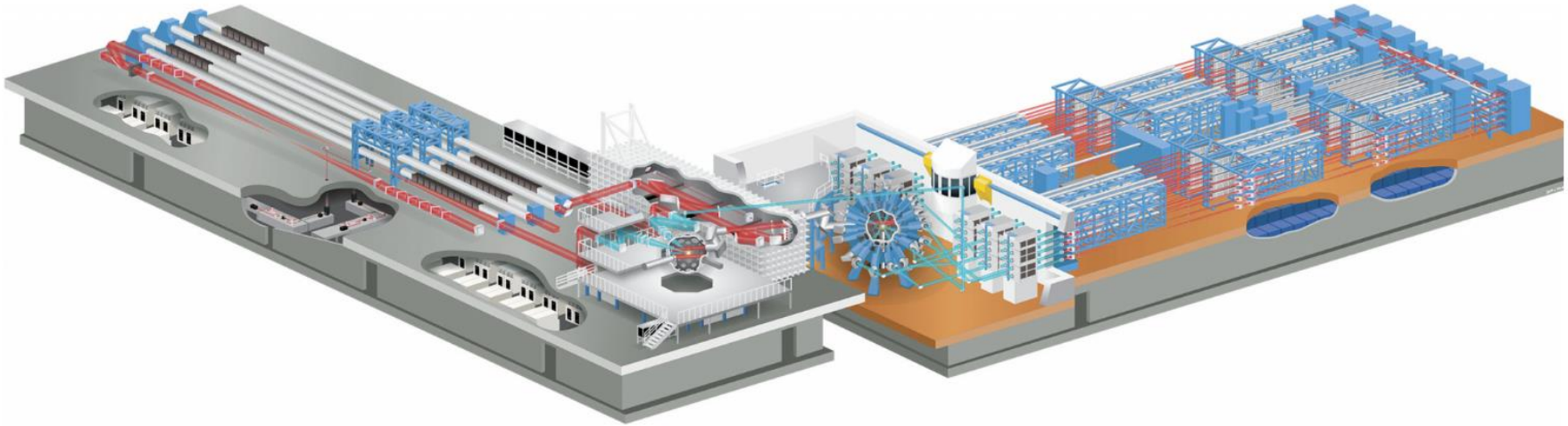


LLE OMEGA-60 Laser System Stability Monitoring

Linh Vu, Owen Wacha, Gyeongjae (Jay) Yoo, Makarii Yurkiv

Advisor: Professor Christopher Muir

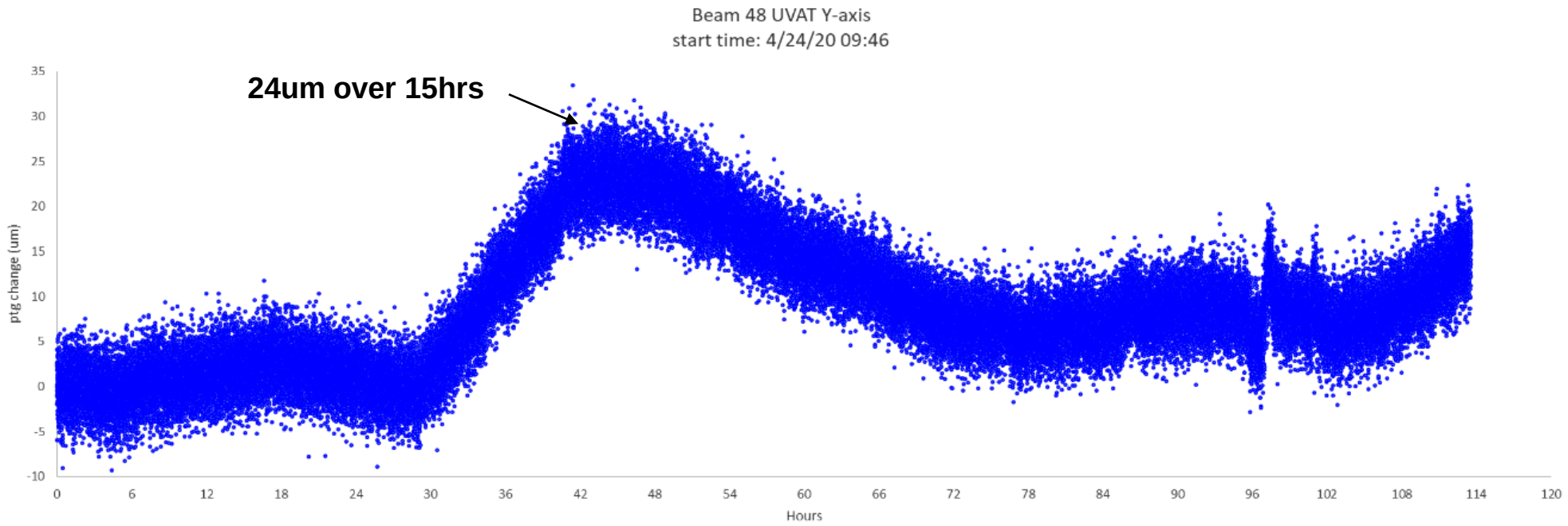
Sponsor: Professor Ethan Burnham-Fay

04/27/2023

Mechanical Engineering
University of Rochester

LABORATORY FOR LASER ENERGETICS
UNIVERSITY OF ROCHESTER

Problem Definition



Beam 48 Drift Plot (J. Kwiatkowski, 2020)

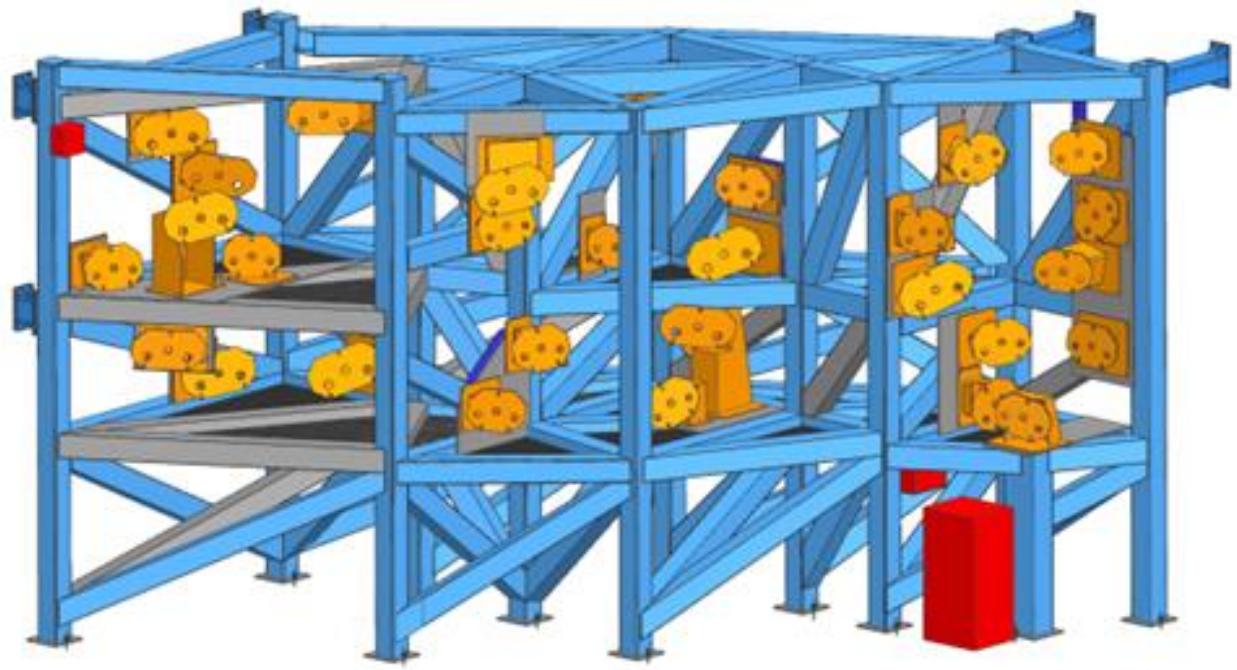
- LLE Omega-60 lasers are experiencing drifts.
- Leading theory is that thermal sources act on transport mirror structures, causing mirrors to tilt, resulting in drifts.

Deliverables, Requirements, & Specifications

Deliverables
- Appropriate experimental set-up to measure drift
- Technical Report with simulations and test data

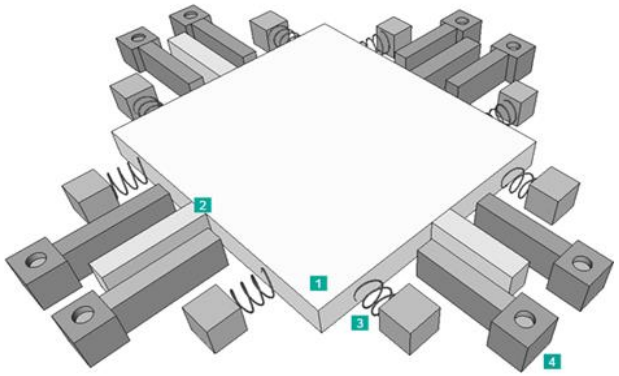
Requirements
- Improve LLE's understanding of drift sources.
- Model thermal effects on transport mirror structure.
- Test hypothesis of stray heat sources in the bay affecting the transport mirrors.

Specifications
- At least **1 µm** drift caused by a thermal source
- No more than **0.1°C** increase in ambient temperature due to measurement apparatus



LLE Transport Mirror Structure

Concepts



MEMS Inclinometer

Quad Cell

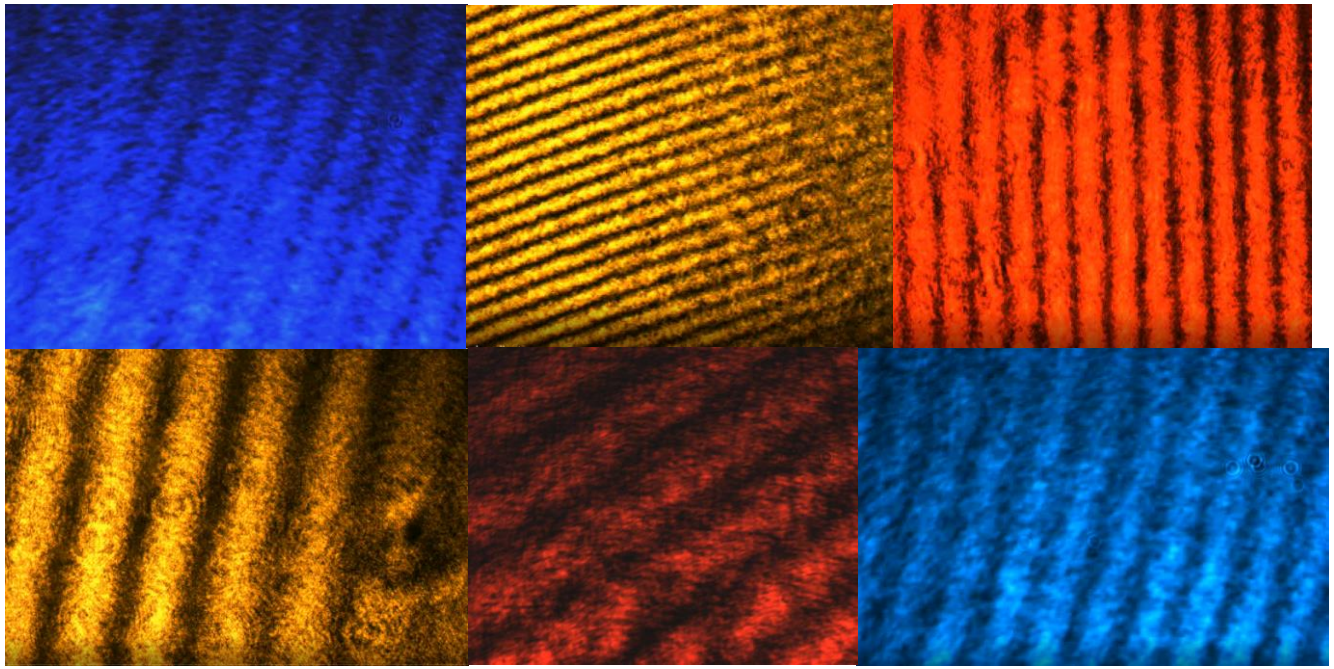
Autocollimator

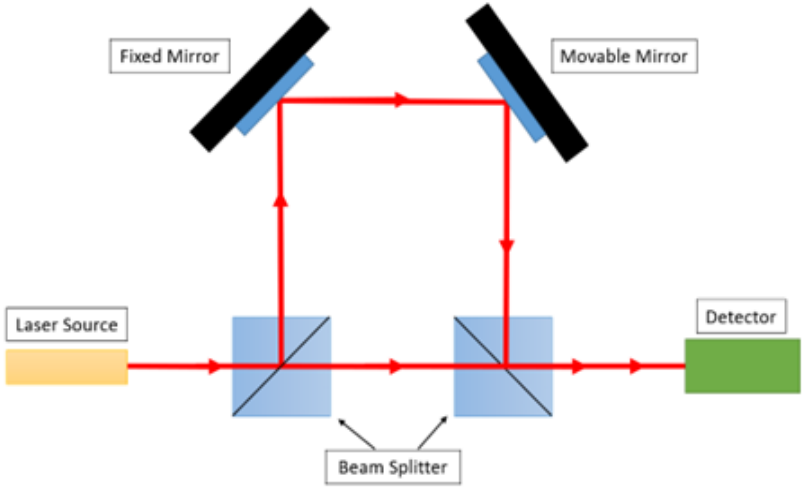
	Inclinometer	LQC	Autocollimator	Interferometer
Ease of implementation	0	-1	-1	-1
Applicability to OMEGA-60	0	+1	-1	+1
Resolution	0	+1	+1	+1
Ease of Access	0	0	+1	+1
Cost	0	+1	+1	+1
Total	0	+2	+1	**+3**

Pugh Matrix of Concepts

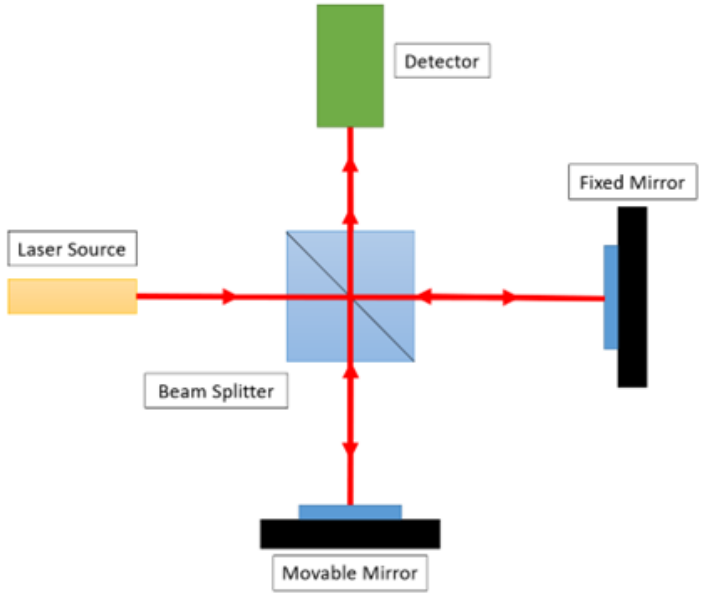
Concepts: Interferometer

- Measure small displacements and differences using light interference patterns (fringes).
- Can measure as small as a few nanometers.
- Fringe patterns (below) can be viewed and recorded using a camera.



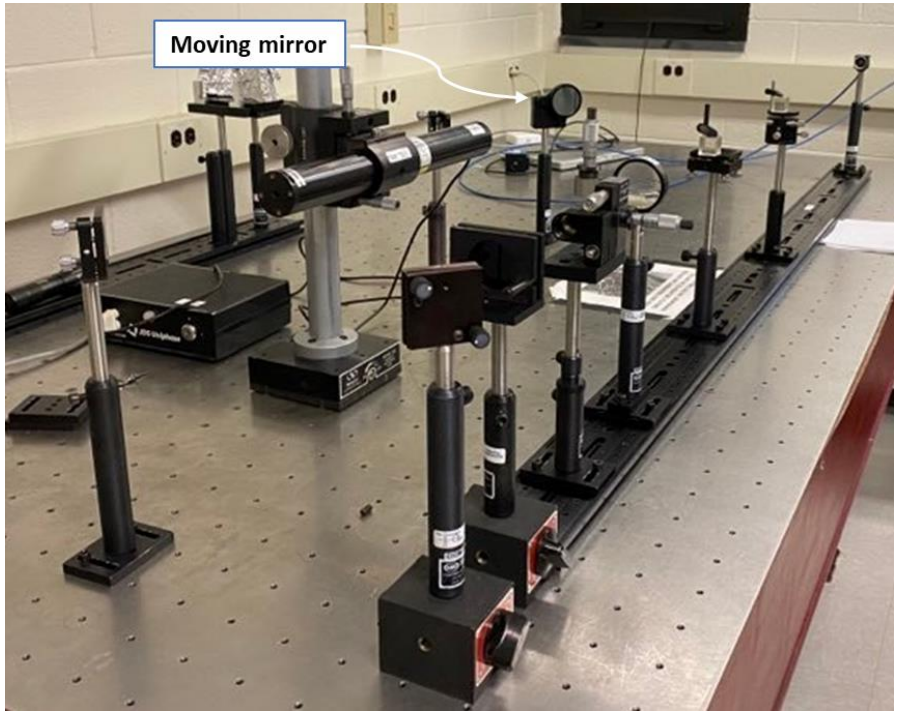


Mach-Zehnder Setup



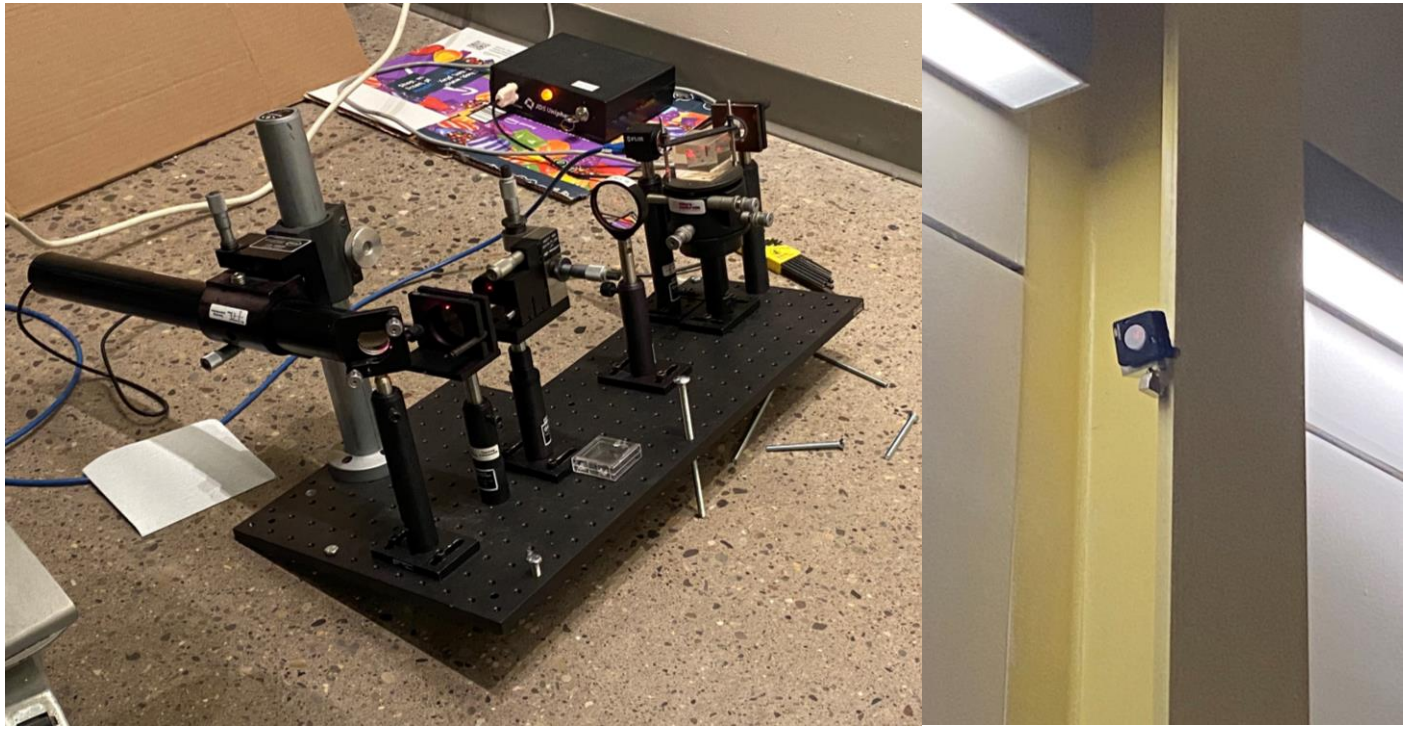
Michelson Setup

Test Plans



Mach-Zehnder Setup on Optical Bench experiment

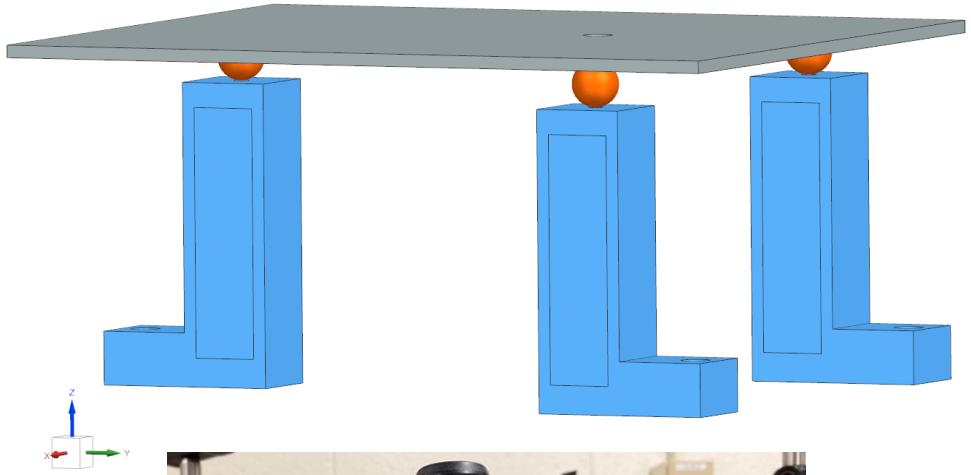
- Proof of concept
- Vibration isolated
- Temperature control

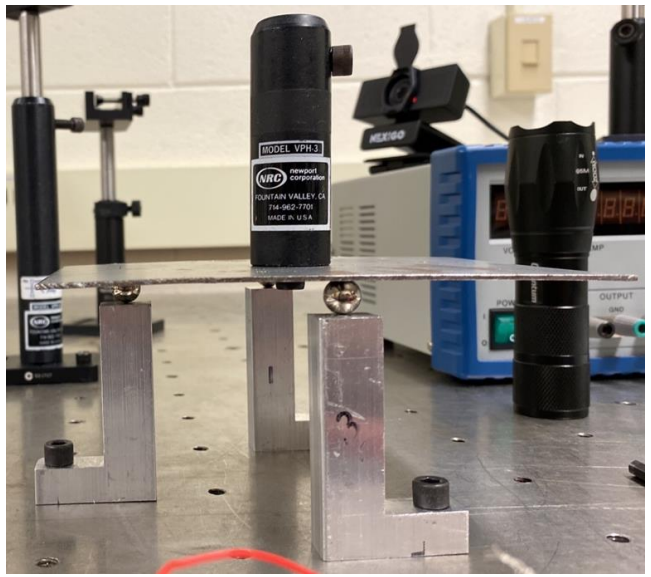


Michelson Setup on Rettner experiment

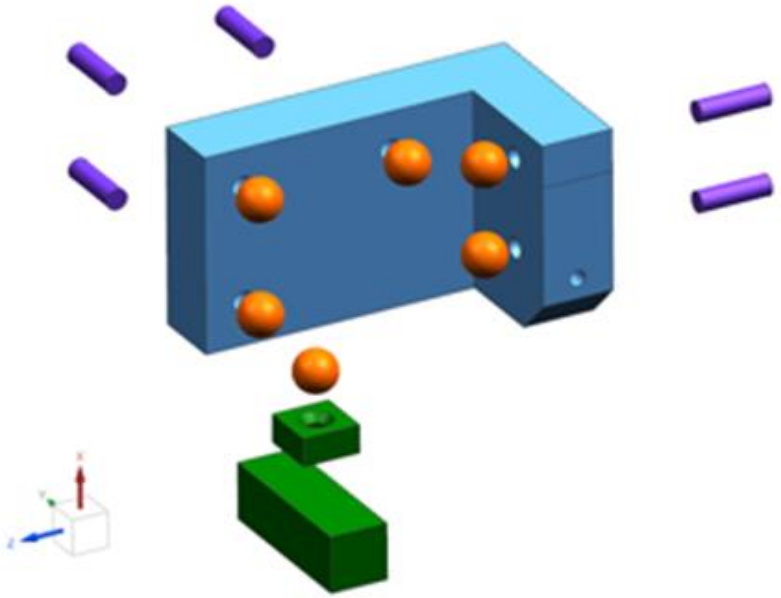
- Realistic
- Similar to LLE structure
- Long beam path

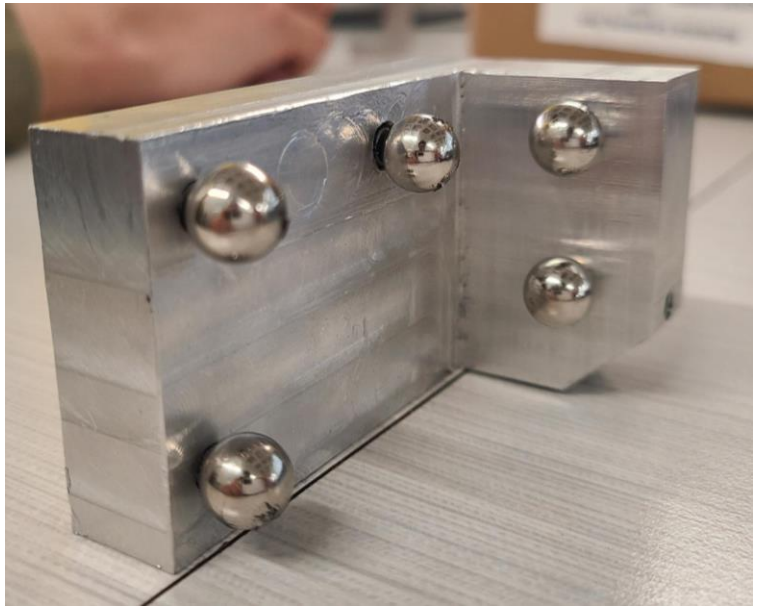
Design and Manufacturing





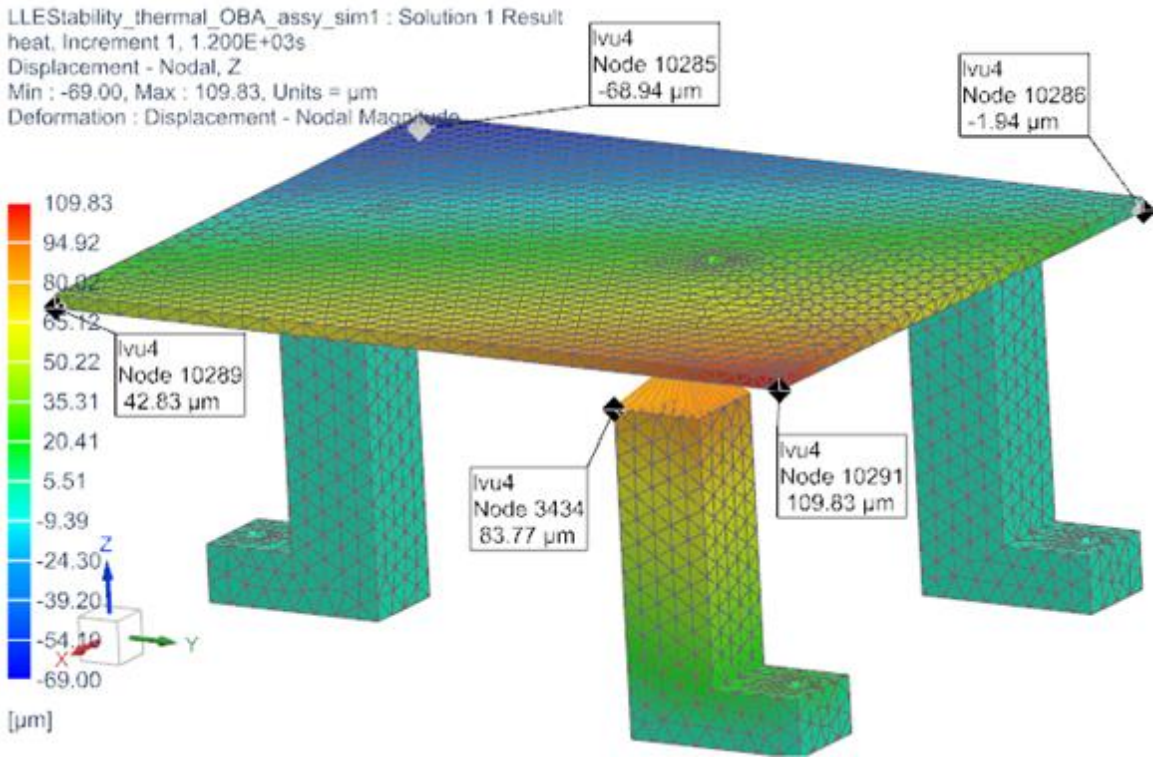
Optical Bench Kinematic 3-stage Platform

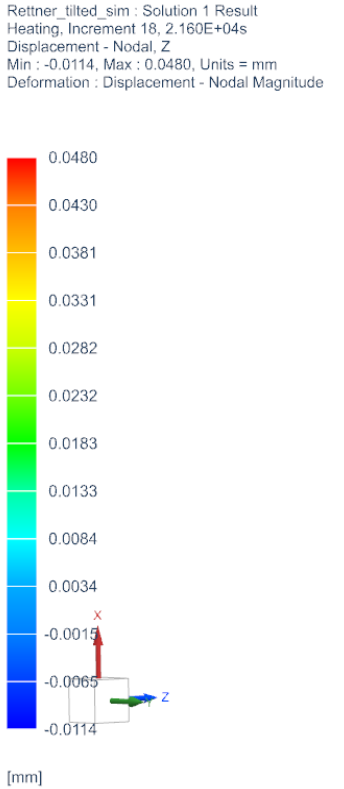


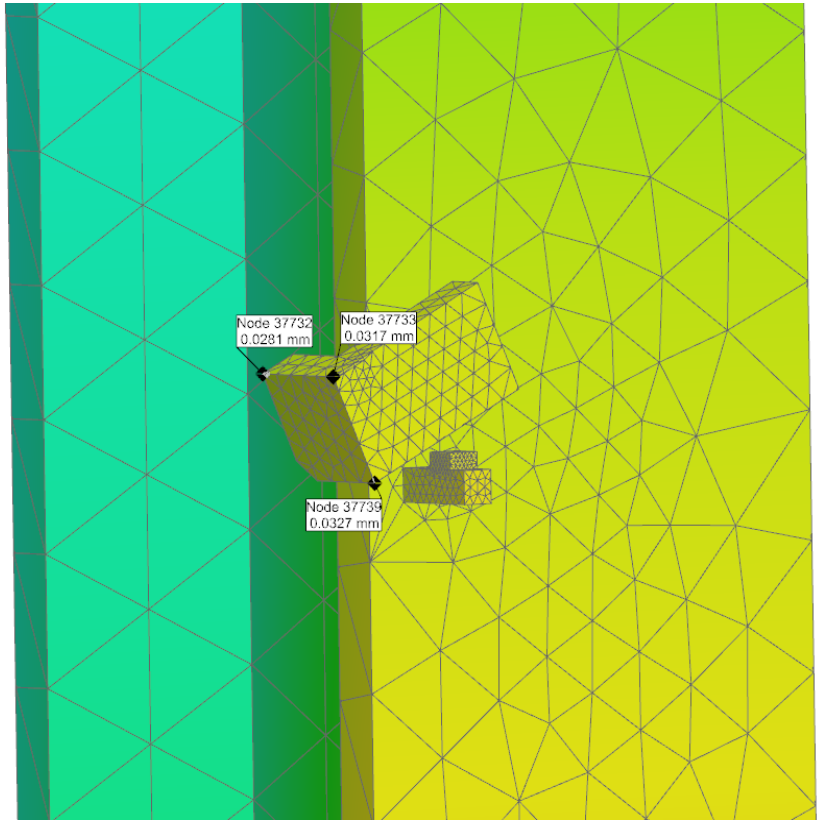


Rettner Kinematic Adapter

Finite Element Analysis: Experiments





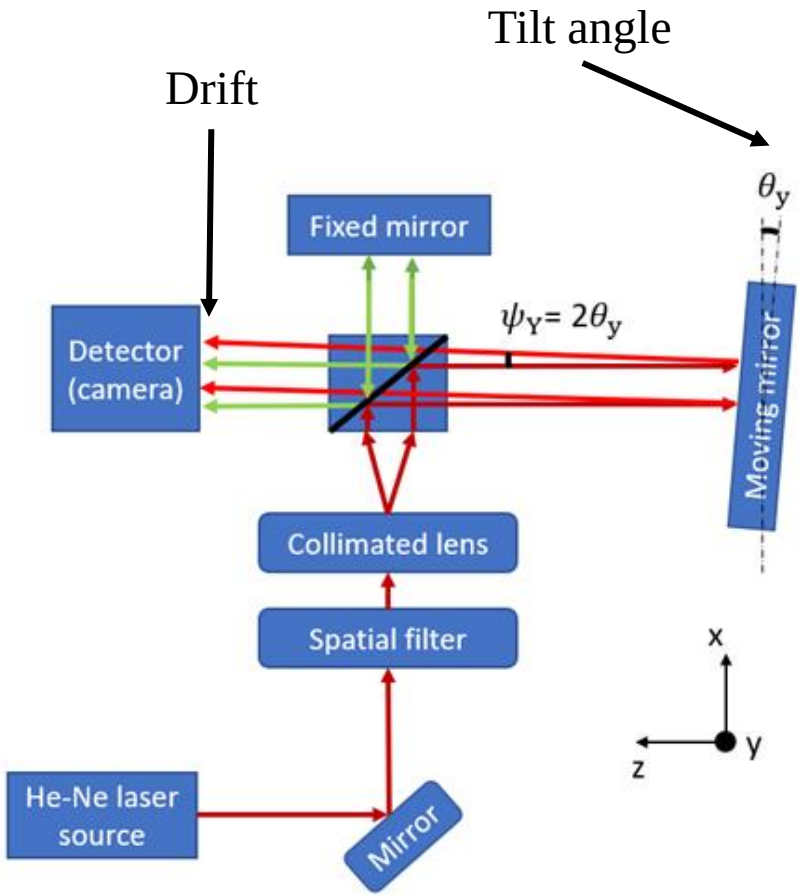


Optical Bench Setup FEA

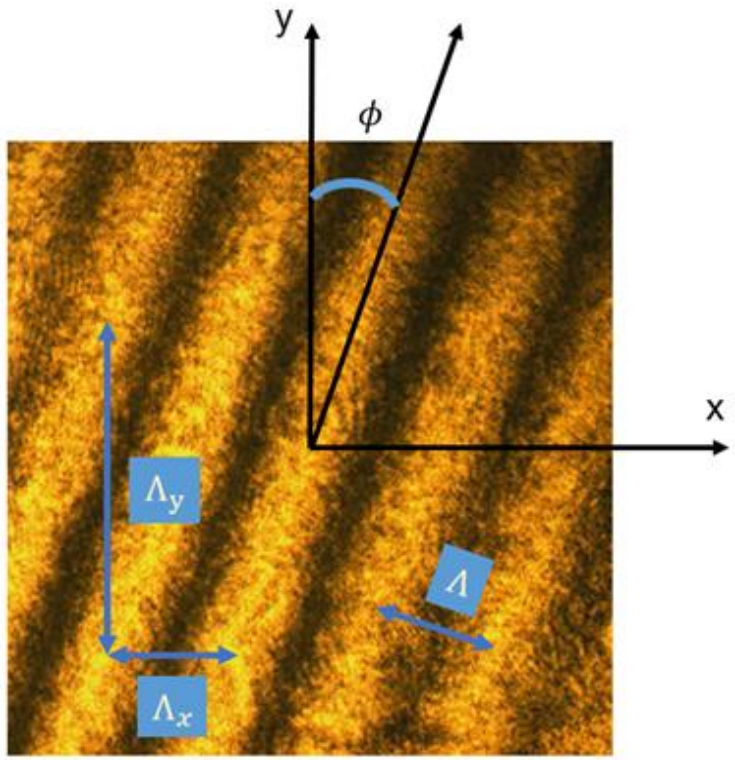
Rettner Setup FEA

	Tilt angle [deg]	Total drift [mm]
Rettner FEA	0.00485	2.002
Optical Bench FEA	0.0564	0.750

Experimental Results: Fringe Calculation



Michelson Setup on Rettner experiment



Fringe sample diagram

$$\Lambda_x = \Lambda \cdot \sqrt{(\tan\phi)^2 + 1} \quad (1)$$

$$\Lambda_y = \Lambda \cdot \sqrt{\frac{1}{(\tan\phi)^2} + 1} \quad (2)$$

$$\psi_{x,y} = 2 \cdot \theta_{x,y} \quad (3)$$

$$\theta_{x,y} = \frac{\lambda}{2\Lambda_{x,y}} \quad (4)$$

$$d_{x,y} = L \cdot \tan(2 \cdot \theta_{y,x}) \quad (5)$$

$$d_{total} = \sqrt{{d_x}^2 + {d_y}^2} \quad (6)$$

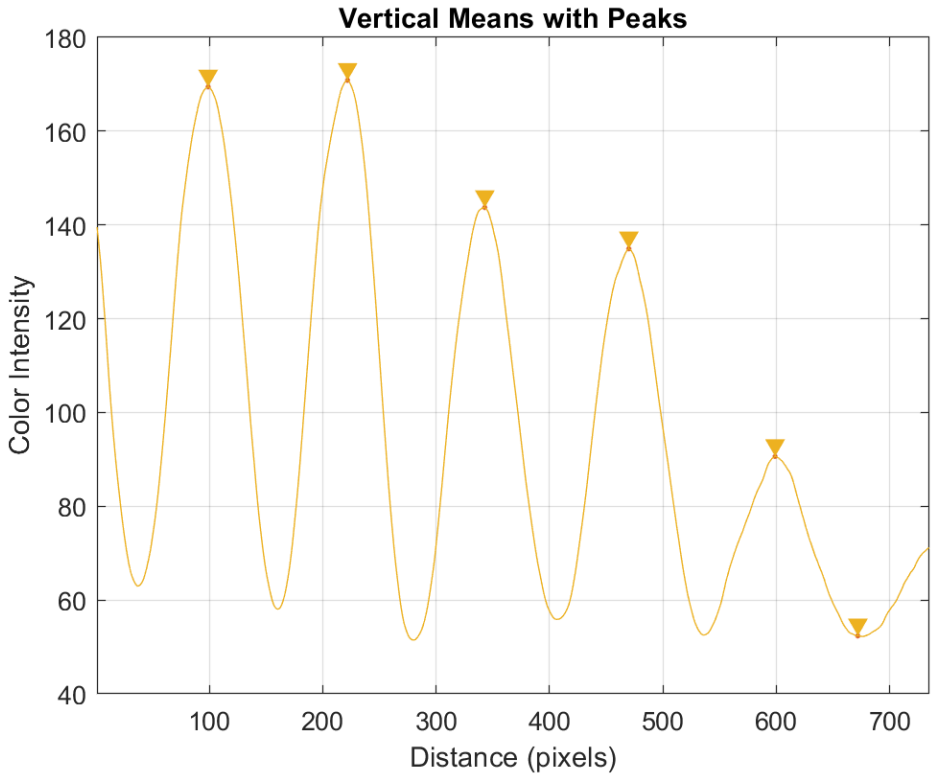
Drift calculation

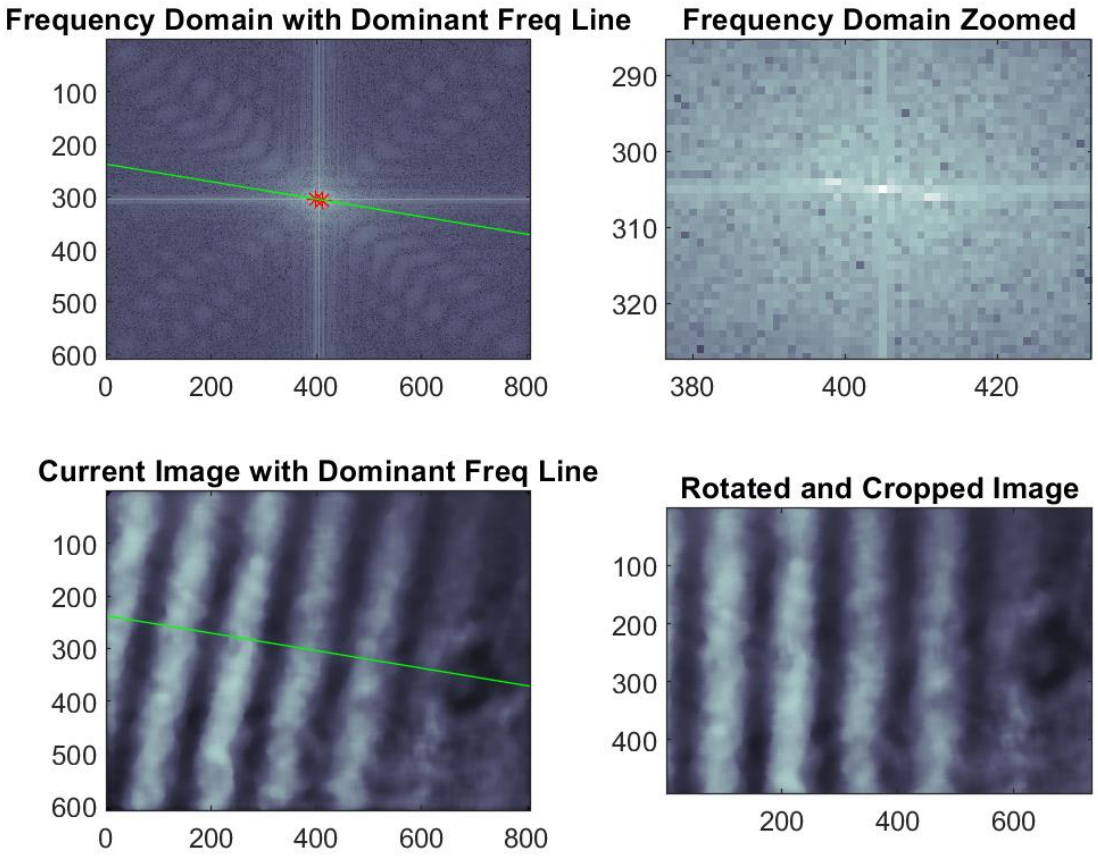
Given
Calculated

Experimental Results: Fringe Processing

Fringe Video Processing

- 2D-Fast Fourier Transform (FFT) to find angle from vertical
- Find fringe spacing from vertical mean of image



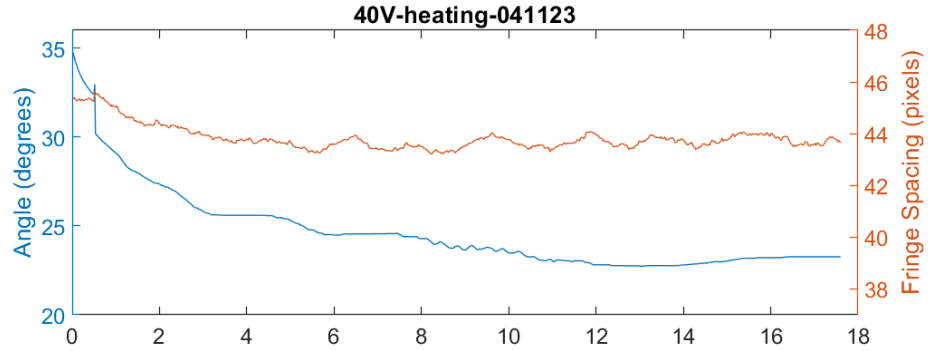


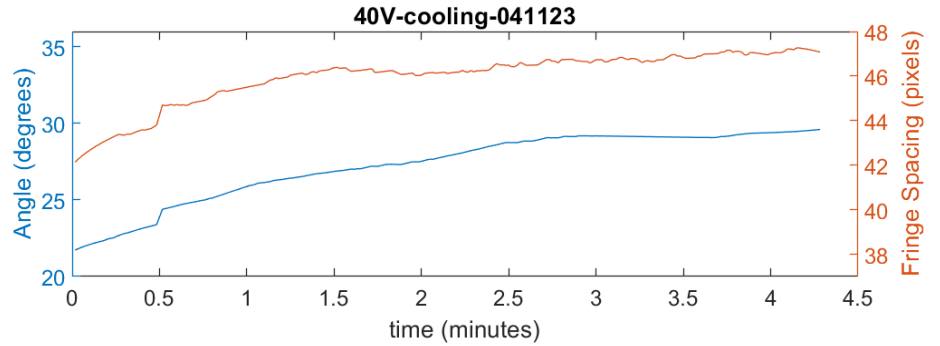
Experimental Results: Fringe Processing

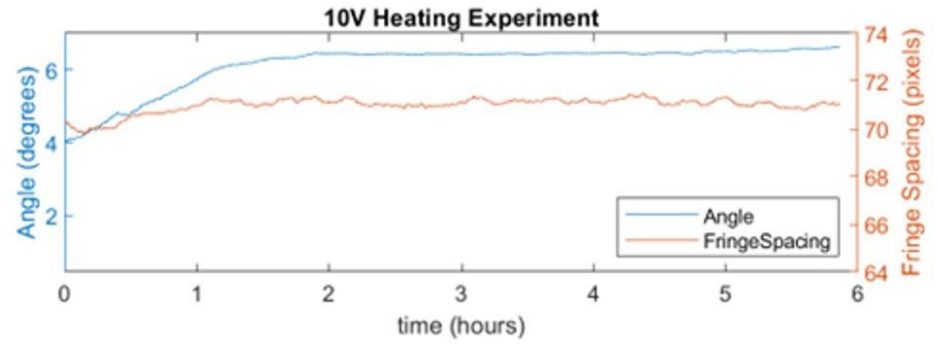
Optical Bench (left) and Rettner (right)

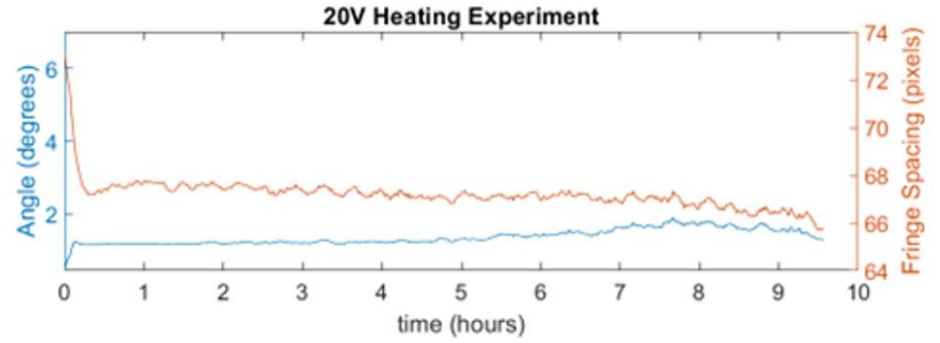
- Changes in angle and spacing following heating/cooling of mirror mount
- Table shows drift detected meets specification 1

Experiment		Tilt angle [deg]	Total drift [mm]
Optical Bench 40V/16.08W – 20min	FEA	0.056	0.750
	Heating Experiment	0.036	0.475
	Cooling Experiment	0.043	0.573
Rettner 10V/4.10W – 8h	Heating Experiment	0.004	1.577
Rettner 20V/33.6W – 6h	FEA	0.00485	2.002
	Heating Experiment	0.015	6.018





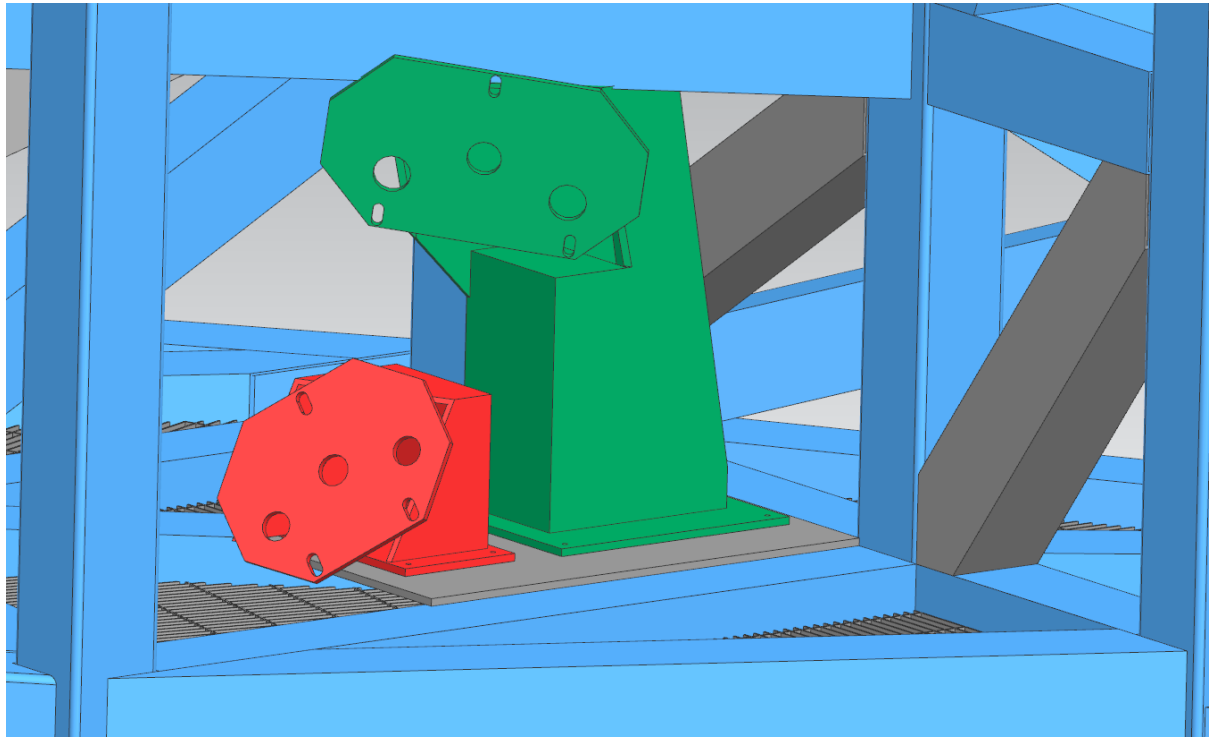




LLE Structure: Drift Data Analysis

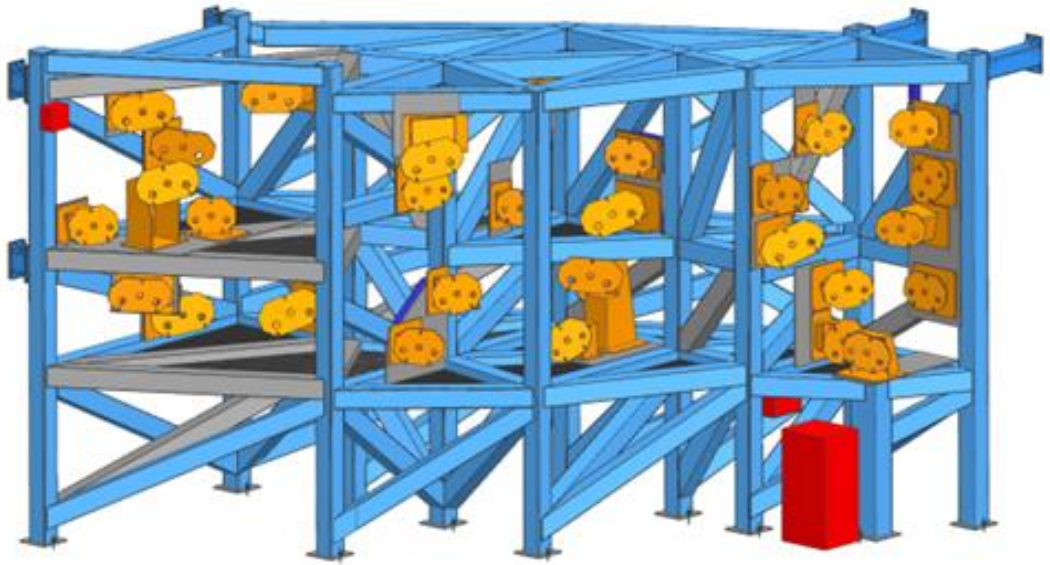
Beam	avg dx	median dr	avg dr	Avg Drift Rank	Med Drift Rank	Angle (degree	Family
29	-3.418	15.781	17.002	9	8	98.68985	NLME
20	-1.795	6.886	8.577	59	58	67.2933	NLME

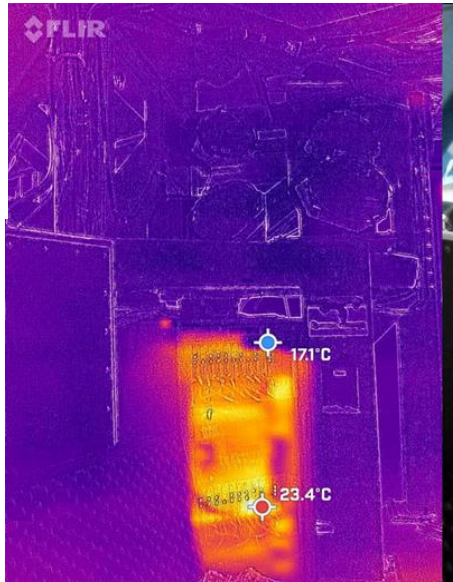
- Received drift data from LLE over 11 days.
- Data analyzed using Excel.
- Trends in data found and examined using CAD.
- Downward facing mirrors are 13% more likely to experience above median drift (95% significance level).

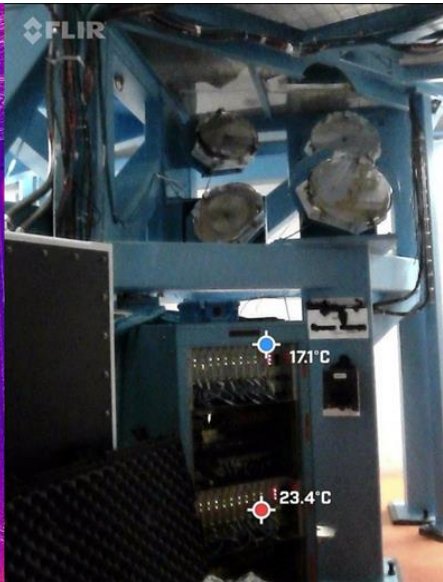


"North Lower Middle East" Mirror Family: 20 (red) and 29 (green)

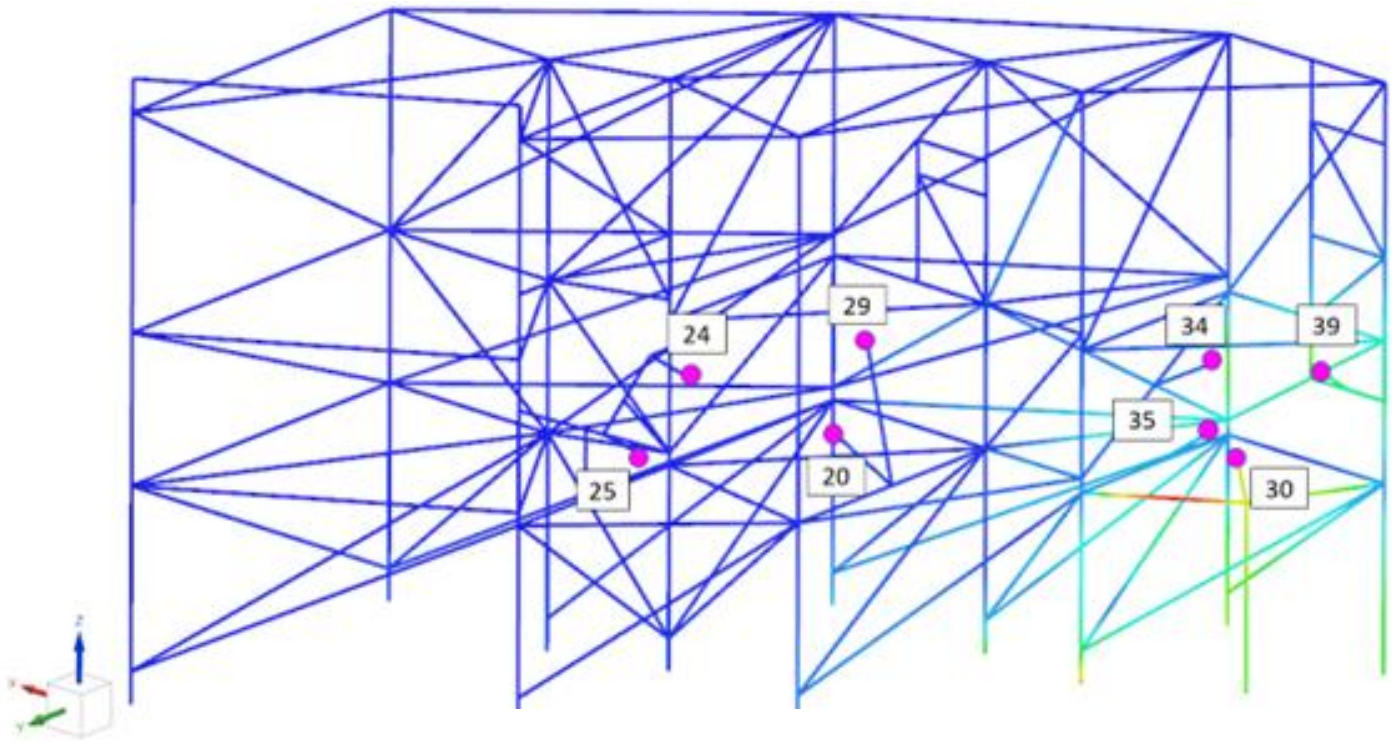
LLE Structure: Target Bay Visit 4/14 - Thermal Images Localized Heat Sources

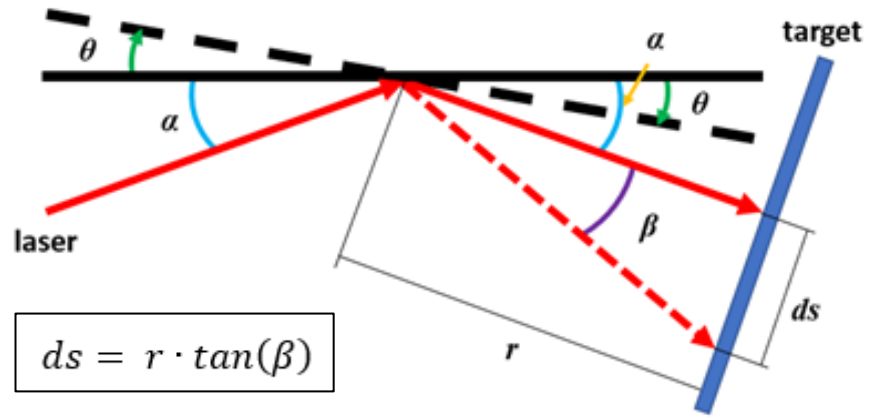






LLE Structure: FEA of North-End Structure





$$ds = r \cdot \tan(\beta)$$

Change in mirror tilt angles

Mirror ID	$d\theta_x$ [μdeg]	$d\theta_y$ [μdeg]	$d\theta_z$ [μdeg]
24	-0.2696	3.896	-2.007
25	-0.2604	3.613	-2.039
29	1.855	3.412	-10.34
20	1.855	3.412	-10.34
30	64.28	53.42	65.16
39	-65.03	-7.611	10.78
34	13.92	6.38	14.26
35	4.072	6.741	41.18

Drifts

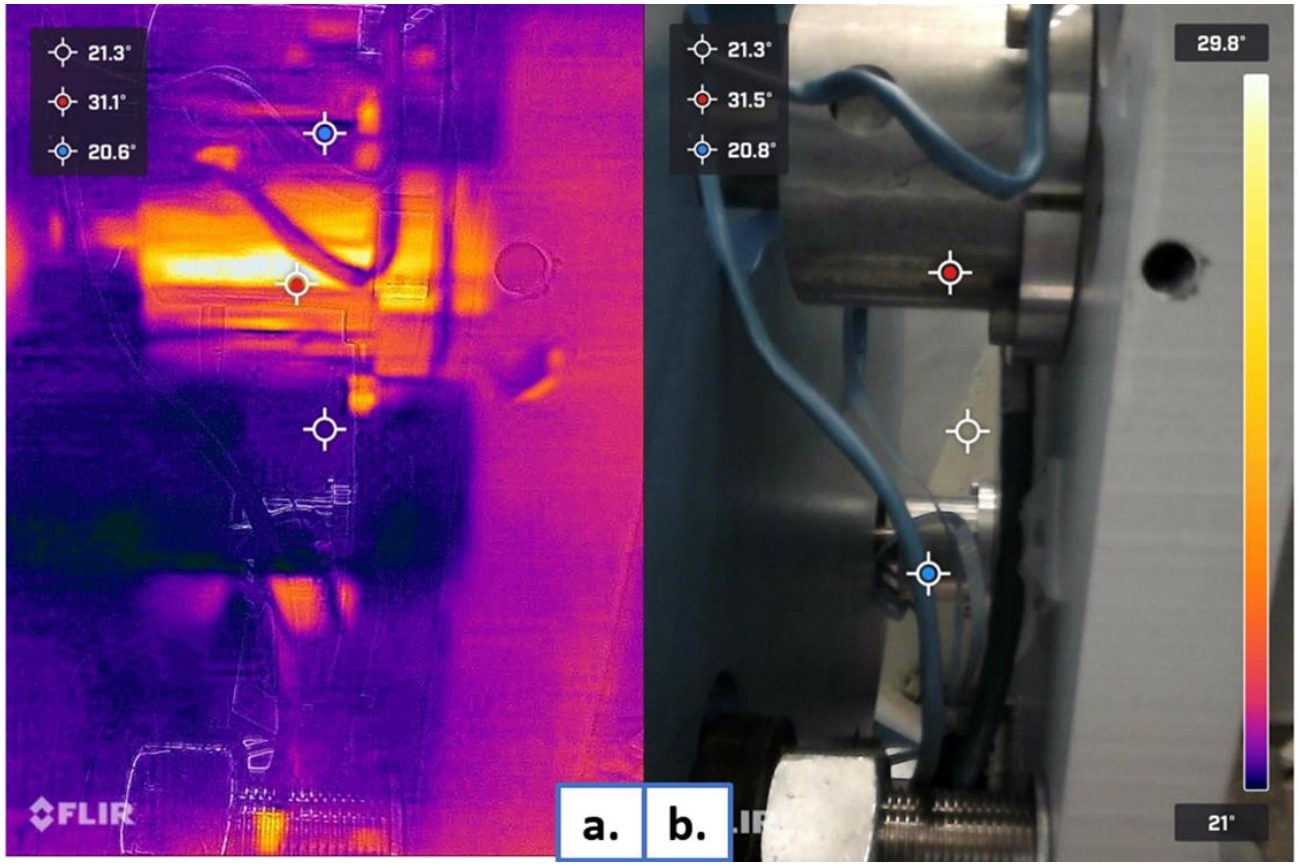
Mirror ID	dx	dy	dz	Magnitude
24	-0.07248	1.04742	-0.53957	1.18045
25	-0.07564	1.04951	-0.59229	1.20747
29	0.39325	0.72333	-2.19205	2.34157
20	0.42943	0.78987	-2.39370	2.55697
30	10.26102	8.52744	10.40149	16.91735
39	-8.15518	-0.95447	1.35188	8.32139
34	1.90825	0.87462	1.95486	2.86843
35	0.60623	1.00359	6.13080	6.24191

Future Work

- LLE FEA model: heat sources radiate or conduct heat to the structure
- Thermal images of all the transport mirrors

- Tests on sample mirror mount: motors and downward tilt

- Investigation of interesting mirror groups
- Alternative measurement methods: Quad cell



Mirror mount motors

Conclusion

- Set up a Michelson interferometer in Rettner Hall as an appropriate experiment to measure drift.
- Identified a drift source of **6mm** in experiment and **2mm** in FEA simulation.
- Identified that stray heat sources inside the target bay of OMEGA-60 that may have caused the drift.
- Analyzed and proposed other potential factors adding to the drift.
- Proposed future improvements.

Acknowledgements

Professors	Christopher Muir, Ethan Burnham-fay (SPONSOR), Edward Herger
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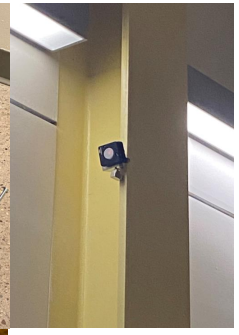
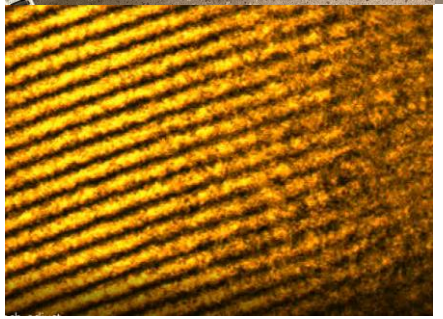
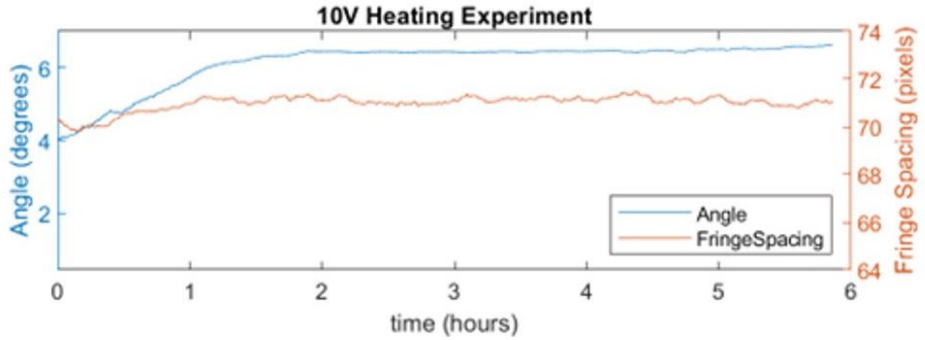
LLE Staff	Albert Consentino, Jeff Hart
TA	Robert Nowak
Peer	Charles Fleischmann, Riya Sharma, Jose Corredor





	Hours	Labor Cost
Jay	48	$4,800.00
Linh	154	$15,400.00
Makarii	96	$9,600.00
Owen	200.5	$20,500.00
Total	498.5	$49,850.00




Thank You