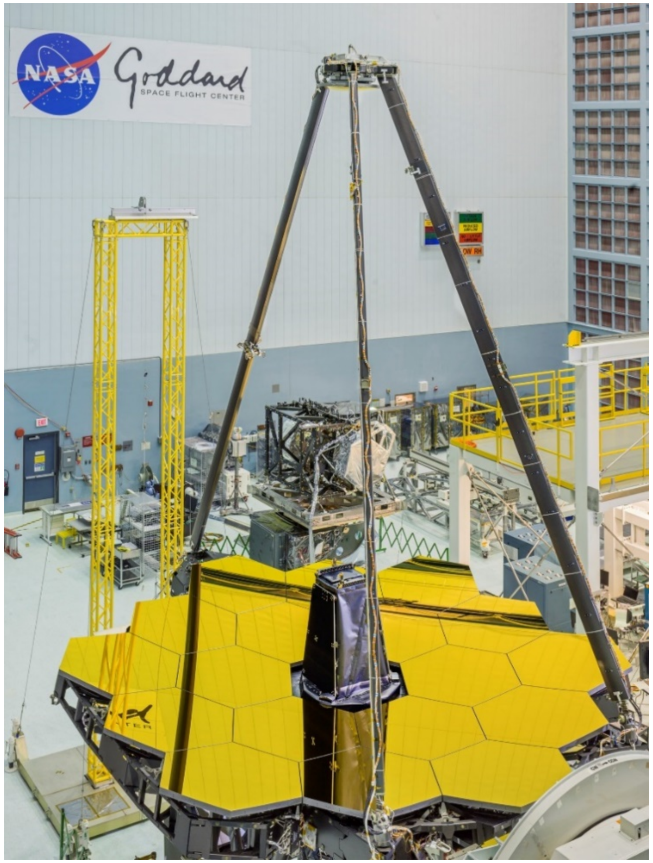

Picometer Level Spatial Metrology for Next Generation Telescopes

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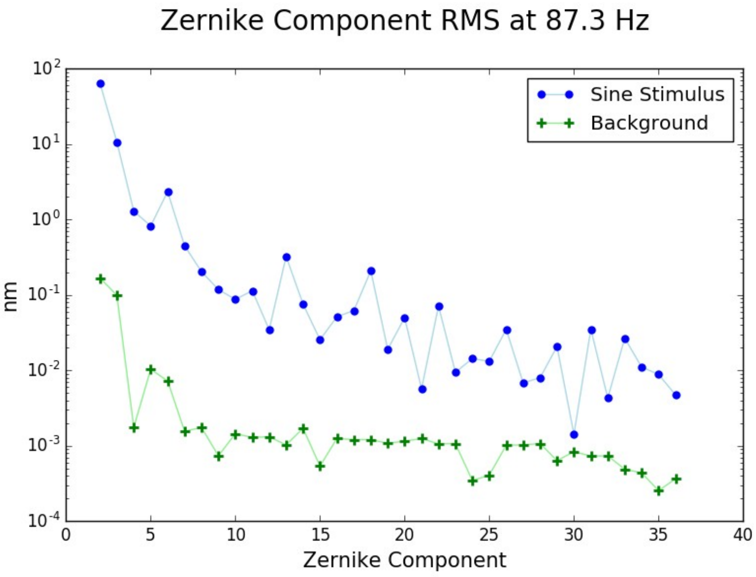
Background

- During the testing of the primary mirror segments for JWST, our team realized that some of the tools and techniques we had developed could be pushed further to achieve picometer resolution.
- We began developing incremental techniques for measuring, controlling, sensing to picometer levels
- Several recent peer reviewed papers have shown that we can measure this level of change, control it with actuators, and potentially even develop active architectures using these ideas
- We will show how the work on JWST evolved to systems applicable to measure picometer and even sub-picometer levels, show the results, and discuss implications for future telescope like LUVOIR and Habex

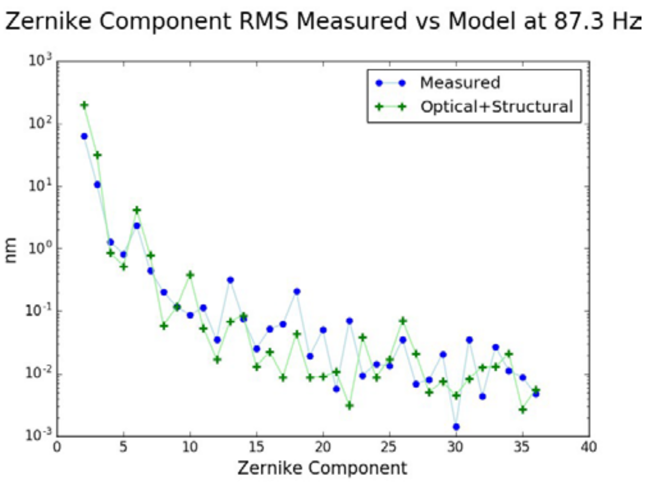
Goals of Ultra-stable Structures Effort

- Based on the JWST mirror segment results indicating we can detect picometer changes, we proposed to the SAT program to study Ultrastable systems to the picometer level
  - New Interferometer
  - Ultrastable chamber with window
  - Calibrators and Algorithms
- Measure the building blocks of segmented telescope to picometer levels:
  - Composites
  - Mirror samples
  - Actuators
  - Joints
- Establish that we can actually measure to the levels needed and assess if the components and building blocks can be made stable enough

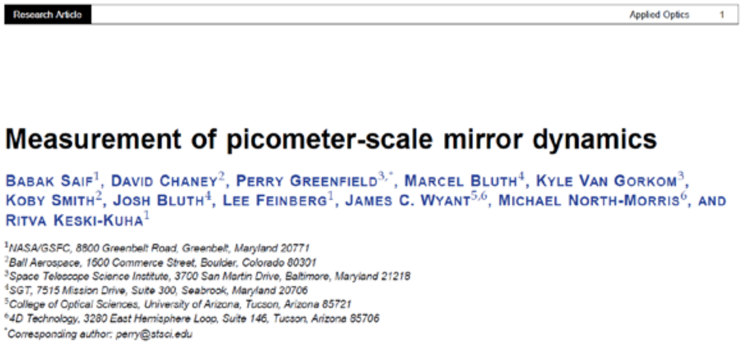
JWST PM Segment Dynamic Picometer Results



Plotted are the dynamic Zernike term RMS values for 2 different cases: 1) the case where a fixed frequency sinusioidal stimulus is present, and 2) the case where no such stimulus is present.



Plotted is the comparison between the measured Zernike RMS terms and the sum of the corresponding opti- cal and structural dynamic models terms.



Research Article Applied Optics 1

Measurement of picometer-scale mirror dynamics

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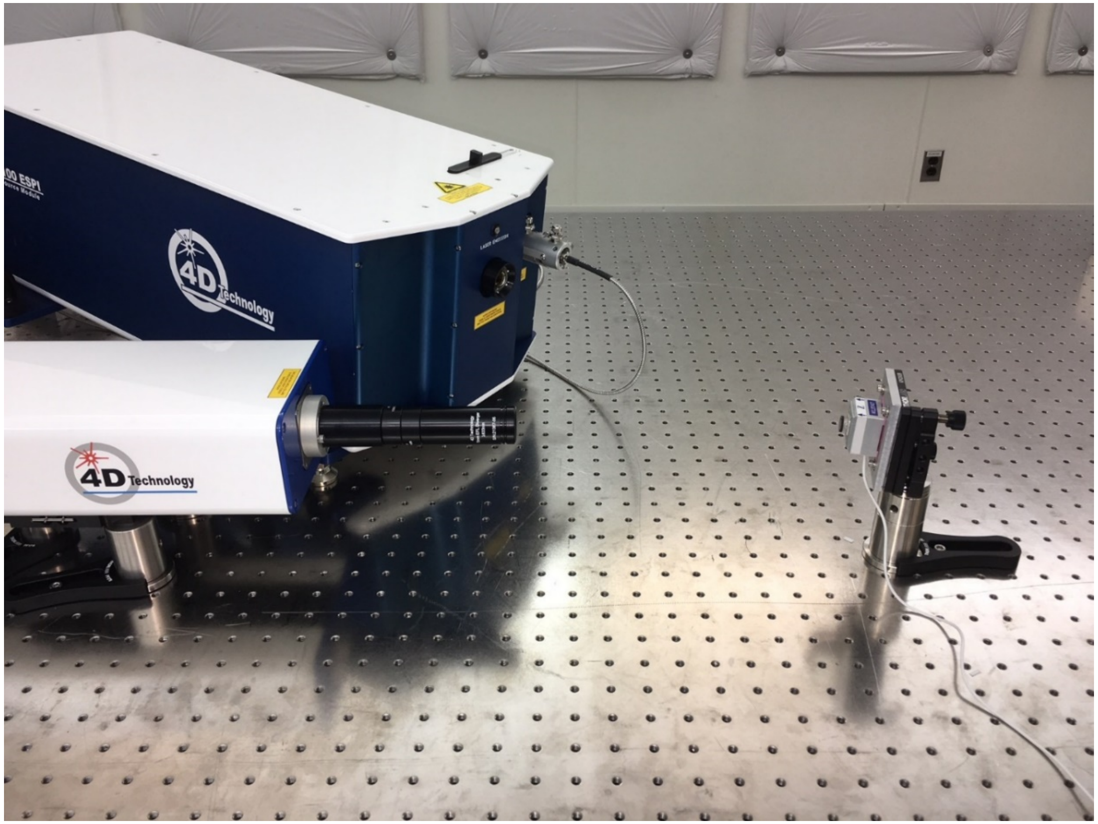
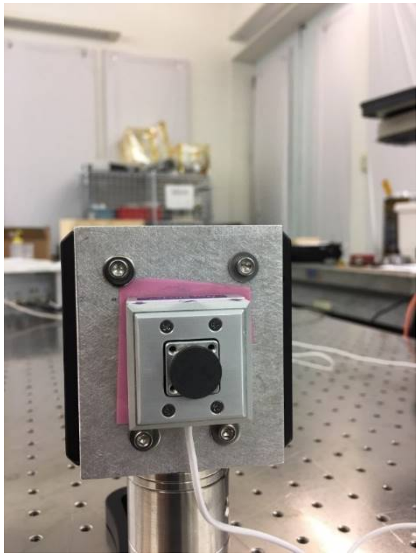
New Interferometer
ESPI+HSI in One Device

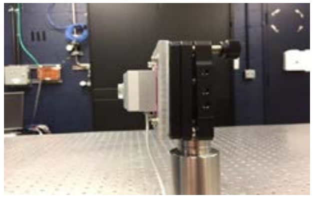
New High Speed Speckle Interferometer Design and built by GSFC/4D technology

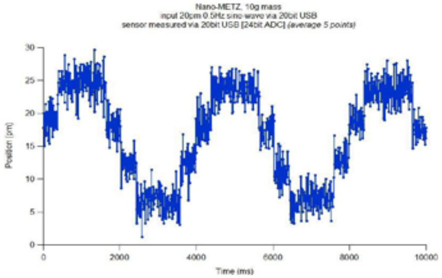




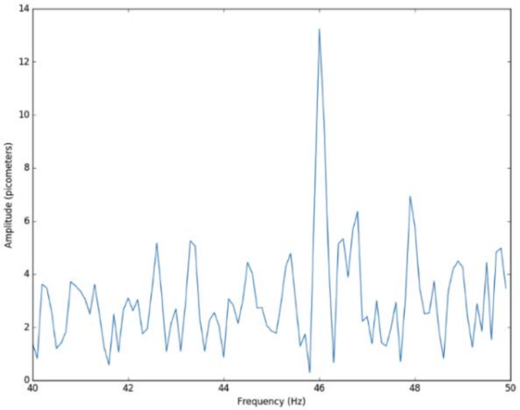
Picometer Actuator Characterization

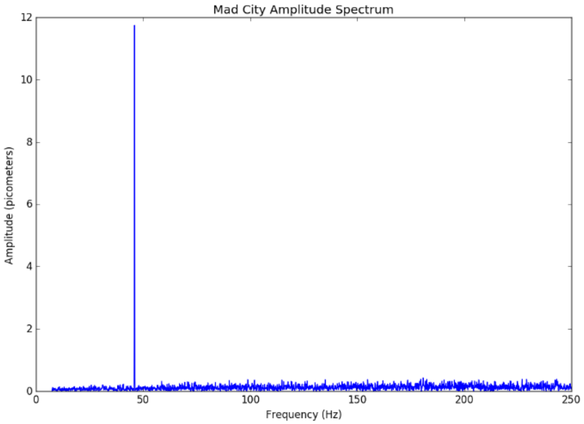
- We identified an actuator that we planned to use as a calibrator
- Closed loop piezo actuator being characterized using the same methods used on segments
  - Was measured at vendor using an AFM
  - Provides crosscheck of the temporal phase unwrapping methodology
- Results were so promising, we realized this type of actuator could form the foundation of an ultrastable control system



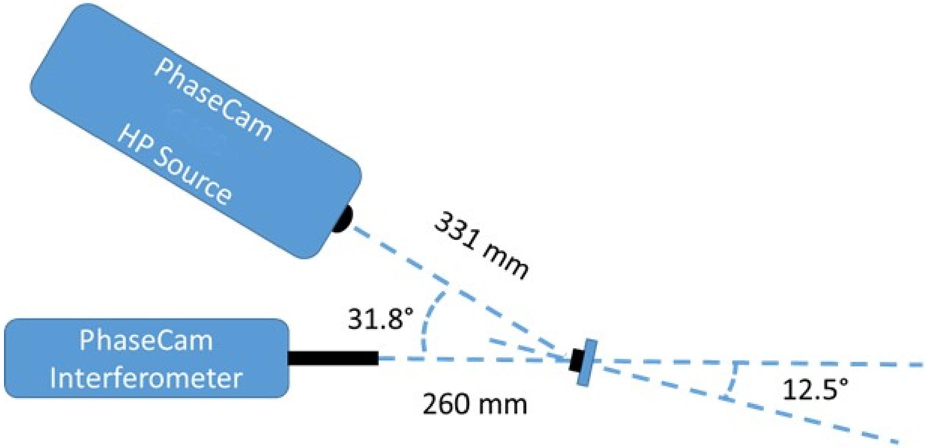


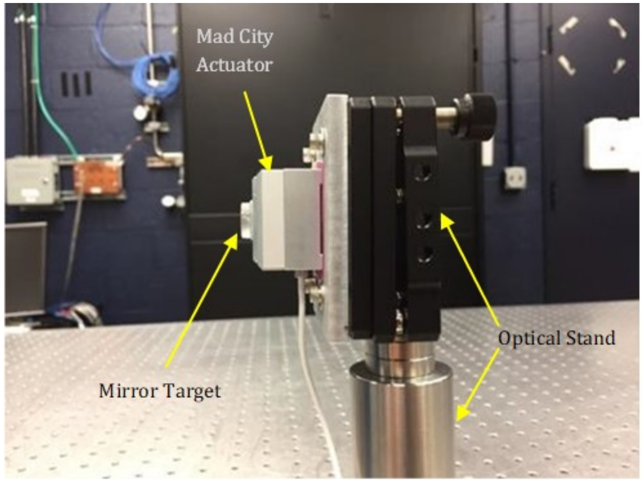
Vendor Measurements Matched our Laser Metrology

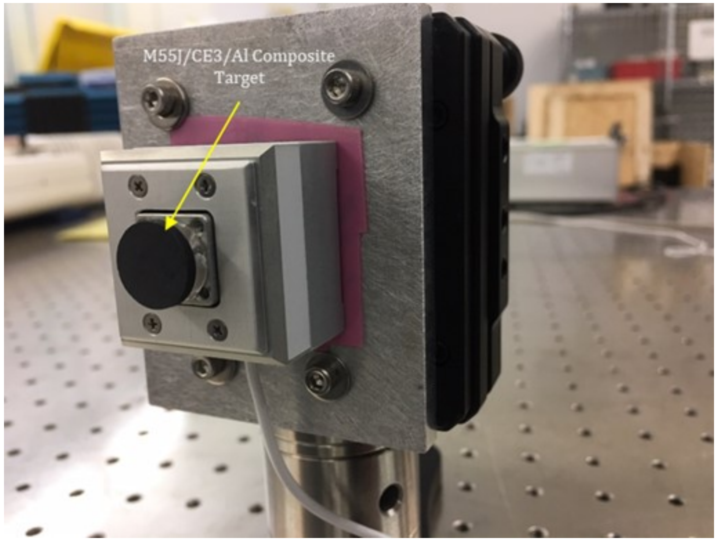


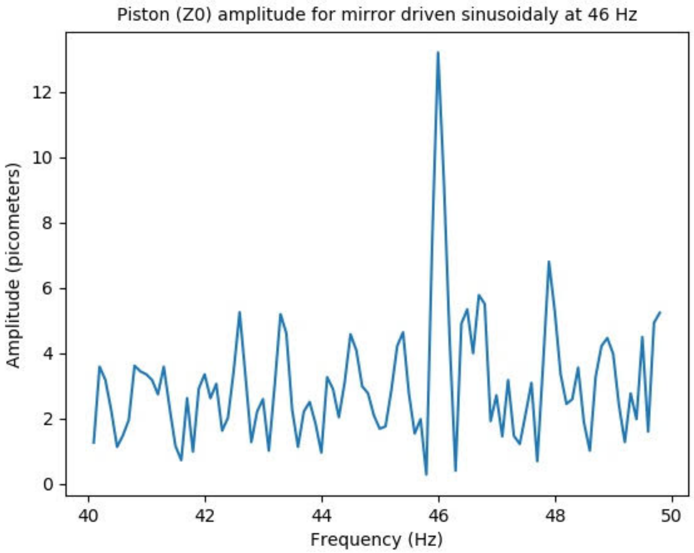


First ever picometer measurements of a non-specular surface

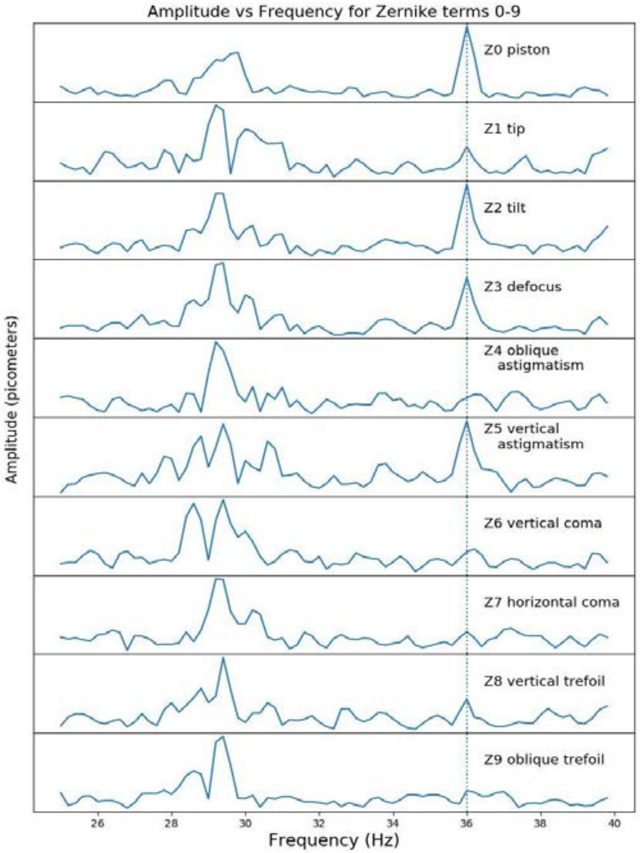








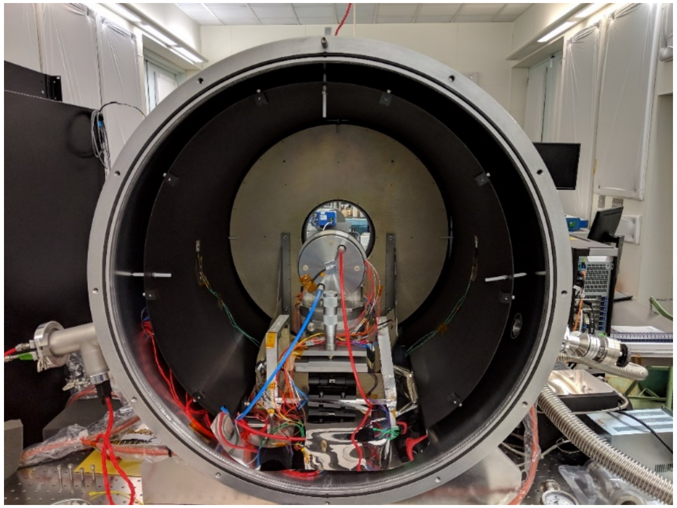
Carbon Fiber Results
100pm motion



Surface Zernike Term		Amplitude (pm)	Standard Deviation (pm)	Probability of Null
Z0		82.87	4.548	0.0000
Z1		0.28	0.077	0.0012
Z2		1.23	0.151	0.0000
Z3		0.29	0.037	0.0000
Z4		0.05	0.018	0.0376
Z5		0.22	0.022	0.0000
Z6		0.02	0.013	0.4182
Z7		0.01	0.013	0.7045
Z8		0.06	0.015	0.0001
Z9		0.02	0.014	0.4048

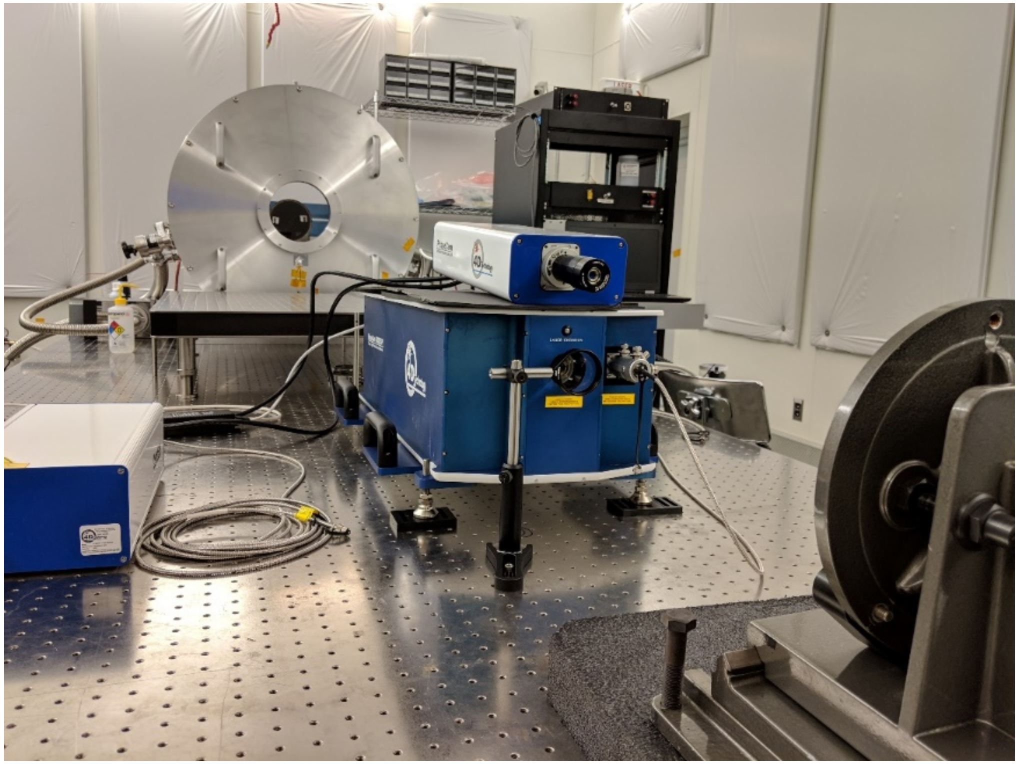
Tabulated outcome of the surface analysis results from the test

Ultra-stable Test System
Milli-Kelvin Thermal Control With Window

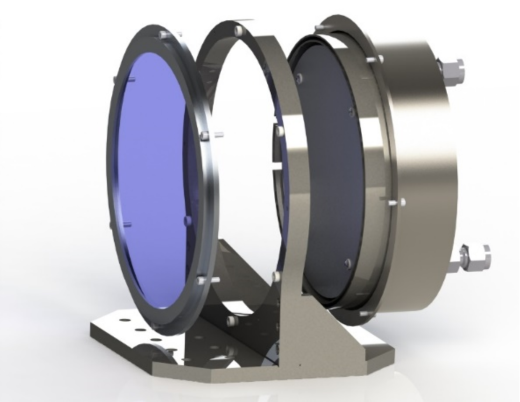


Average surrogate test article thermal stability achieved:

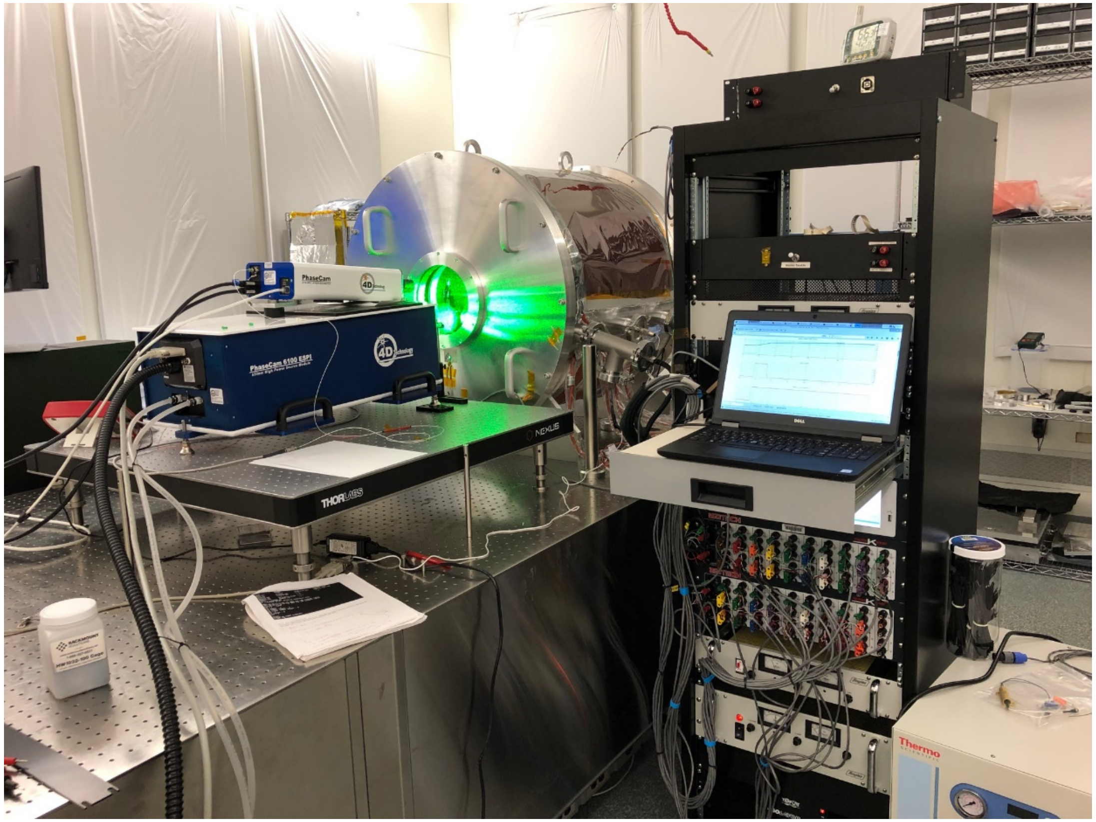
23.5°C +0.0004 / -0.0002C over 80+ hours (+0.4mK / -0.2mK)



Ultra-Stable Chamber

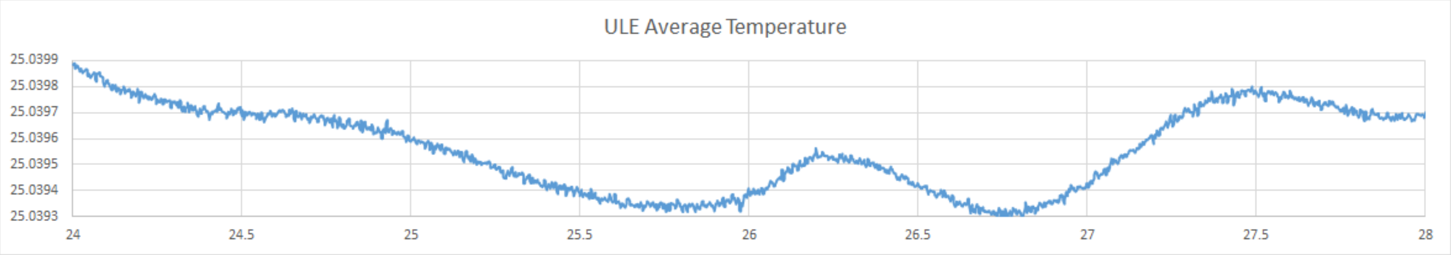


Diffuse ULE Mirror



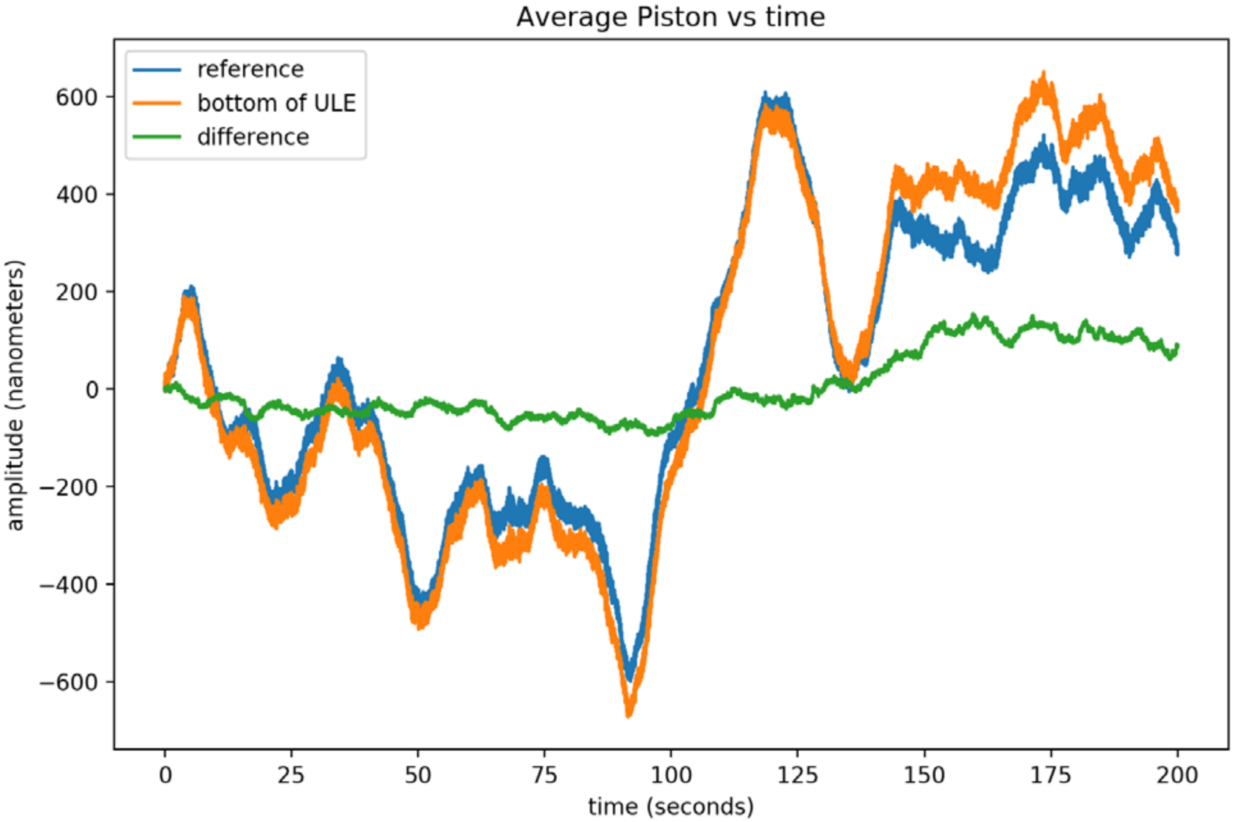
The final thermal sensing and control functional test of ULE Test Sample resulted in the thermal stability 0.0006K (0.6mK) P-V over 4+ hours.

(This validation test data was gathered from 06 June 2019 while the Chamber sink temperature varied between 19.95 and 19.96°C or 10mK variations)



.6mK ptv
.3mK p/hr

ULE Mirror



Averaged time series plot of 98 runs of the reference compared to the difference between the reference and the target at the bottom of the ULE Mirror. ULE mirror not thermally controlled.

Summary

- The ability to sense and control at picometer levels on spatial systems has now been shown at small scales. More work is needed to study drift and larger system complexity
    - NASA is developing the tools so it can act as an independent evaluator of industry’s ideas for components which NASA can ultimately transfer to industry for larger scale systems
- Longer term, these efforts open the possibility of other applications ranging from characterizing gravitational wave system mount stability to characterizing structures for X-ray systems
- To search for life by statistically sampling Exo-earths, we will likely need a large ultra-stable telescope that makes use of these efforts.