Ultra Stable SAT

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Topics

- Objectives
- Accomplishments
  - Segment Deformation Dynamics Measurements
  - Ultra Stable Thermal Demonstration
  - Interferometer design and manufacturing
  - Picometer calibration actuator characterization
- Next steps: building block demonstrations
  - ULE ultra stable control and stability
  - Nano-composite characterization
  - Active systems (segment to segment) components
  - Other ultra stable characterization possibilities

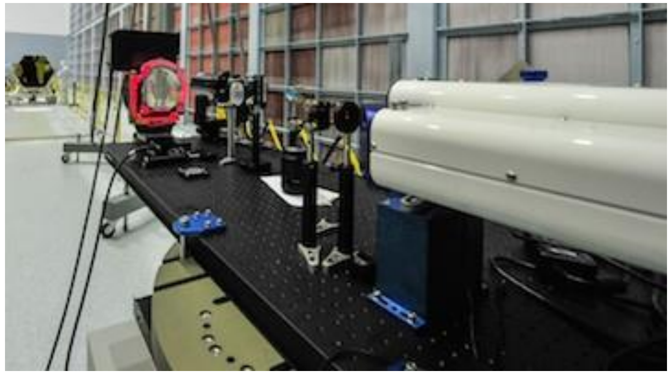
Goals of this effort

- Develop picometer spatial interferometry for characterizing ultra stable systems
  - Demonstrate picometer dynamic measurements can match a structural model sufficiently to gain confidence in our stability deformation predictions
  - Develop a next generation interferometer that can combine speckle methods on non-specular surfaces with picometer metrology techniques
  - Develop the algorithms, software, and analytic processes
- Develop an ultra stable test configuration including milli-Kelvin temperature control integrated to the optical metrology
- Test the building blocks of LUVOIR components to advance their TRL levels at the component level in relevant environments (eg, TRL3/4)
  - Mirror material and thermal control
  - Stable composites
  - Actuators
  - Other components (future)

Basic premise of the approach

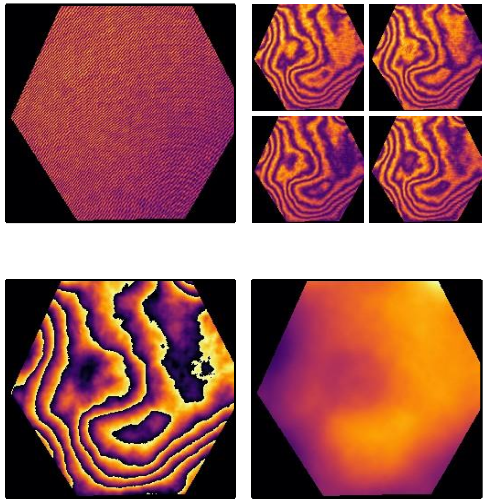
- Make use of high speed instantaneous phase shifting interferometry
- Perform temporal phase unwrapping through algorithmic methods
- Fit 2-d phase data to Zernike polynomials taking advantage of the statistics of large samples
- Don’t use corner cubes or retros which require attachments that can creep or shift – directly measure what you care about
- For dynamics, stimulate source using stinger to reduce noise in the frequency domain
- For stability, can use calibration systems that are frequency based combined with linearity checks
- For thermal stability, requires a very stable test chamber (at the level of control planned for LUVOIR so milli-Kelvin)
    - Opportunity to demonstrate milli-Kelvin control using nested loop control methods
- Requires a Kilohertz interferometer
    - First was developed to test JWST segments used in initial phase
    - Second will be speckle capable with a high speed laser for non-specular measurements of unpolished surfaces like composites and not require corner cubes
- Requires high speed computational algorithms that can unwrap lots of data and analyze it both temporally and in the frequency domain
    - This is actually one of the most complicated parts!

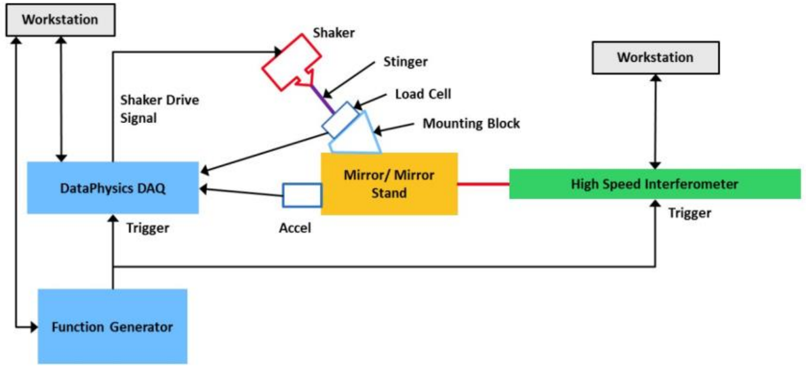
Picometer measurement of mirror dynamics



This photograph shows all the optical elements in the test setup including the HSI, CGH (framed in red), and test mirror (hexagonal mirror on the far left).

Single HSI frame comprises 4 interlaced phased- shifted interferograms which are converted (with an ellipse- to- circle correction to account for phase error) into a wrapped phase image that can be unwrapped to a surface profile.





This schematic diagram shows the relationship of the components of the test setup.

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Measurement of picometer-scale mirror dynamics

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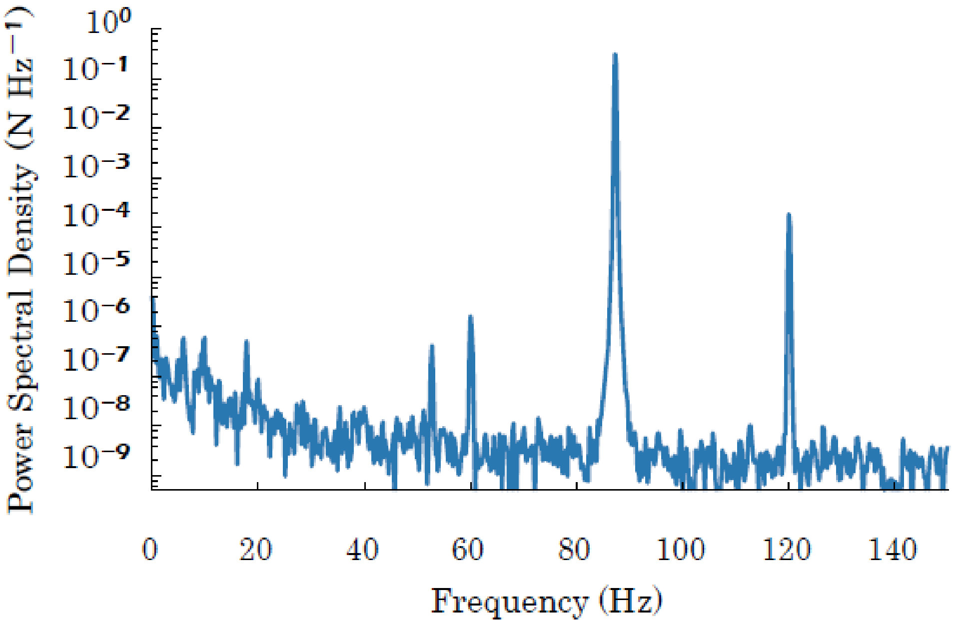
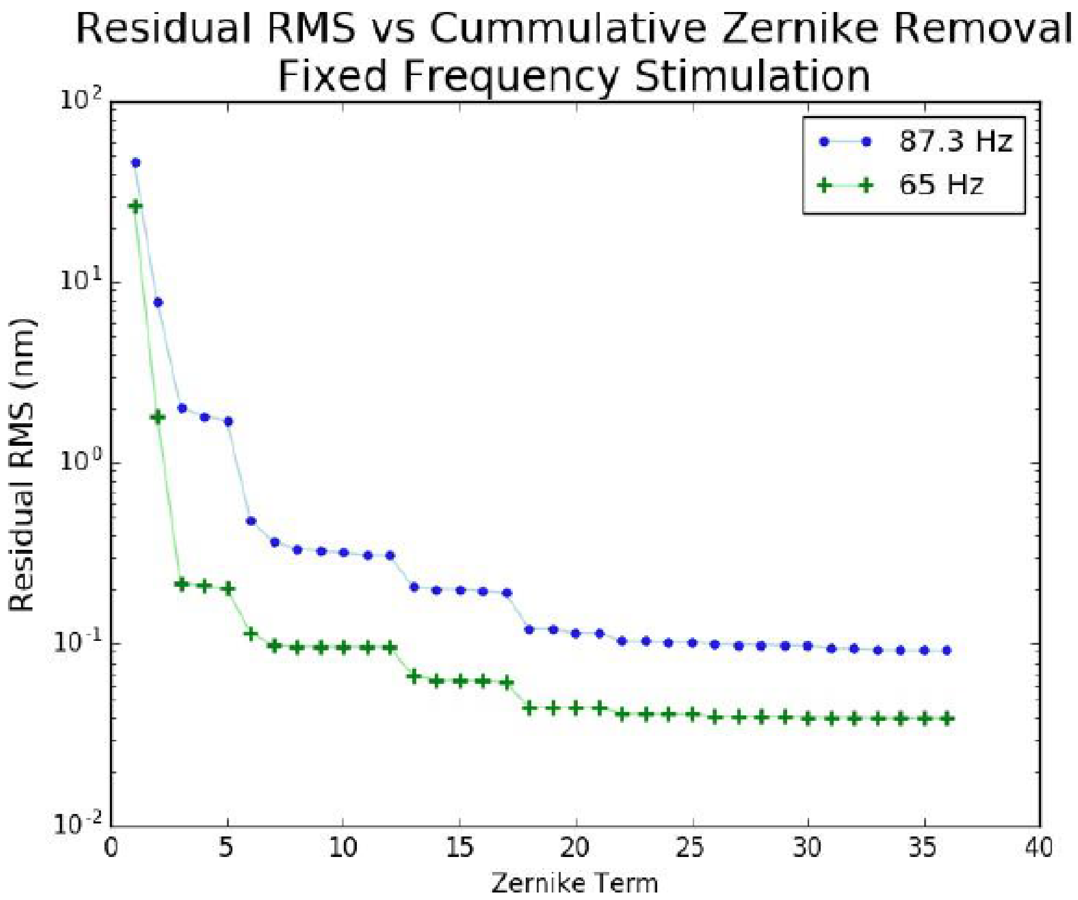
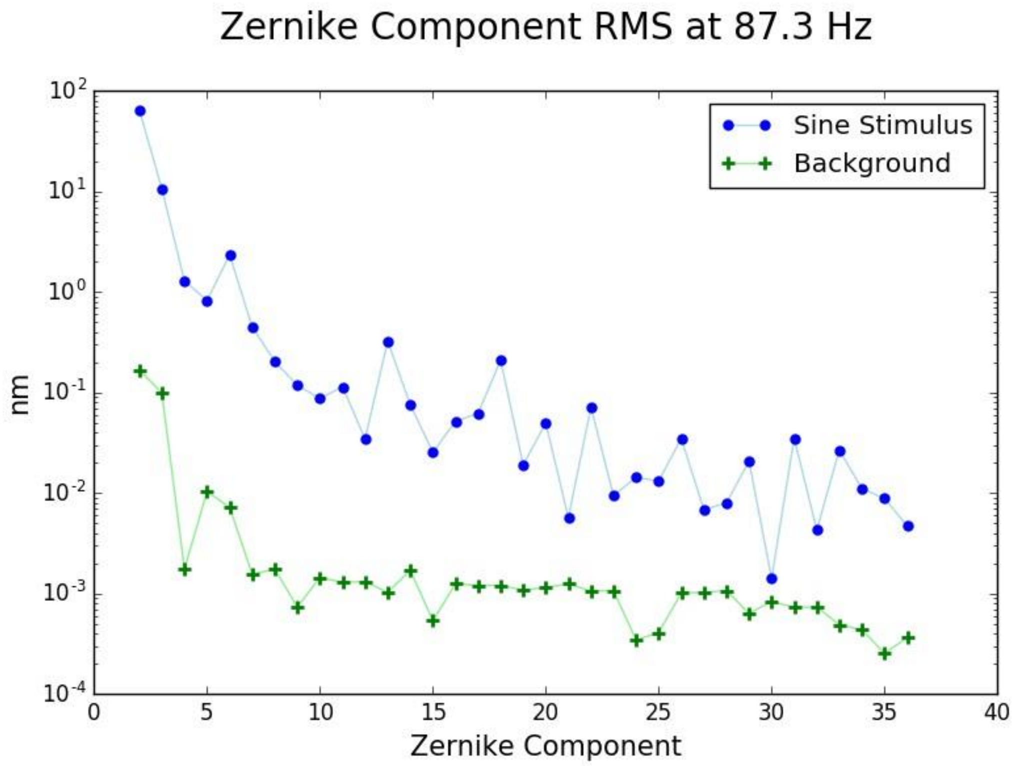
Data Analysis



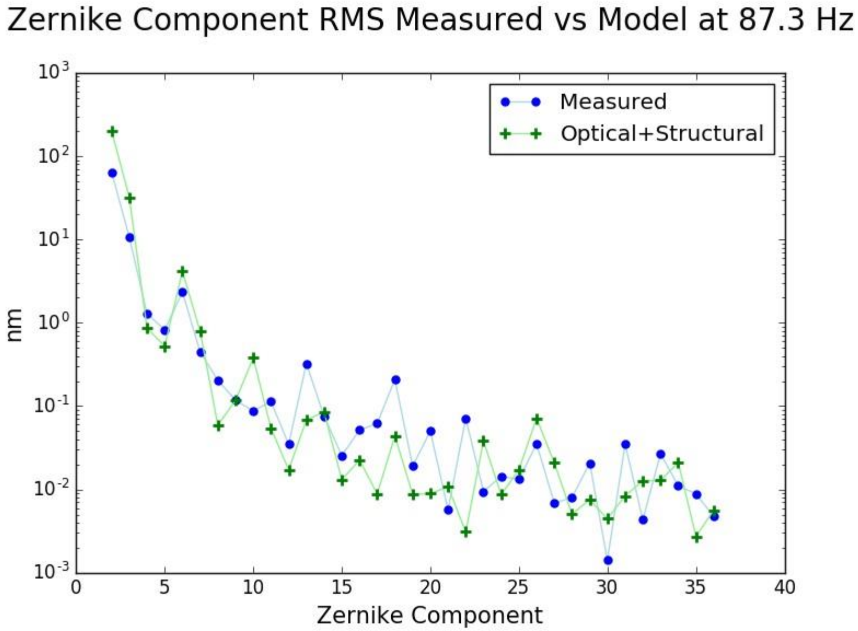
Sine Dwell at 87.3 Hz



Results



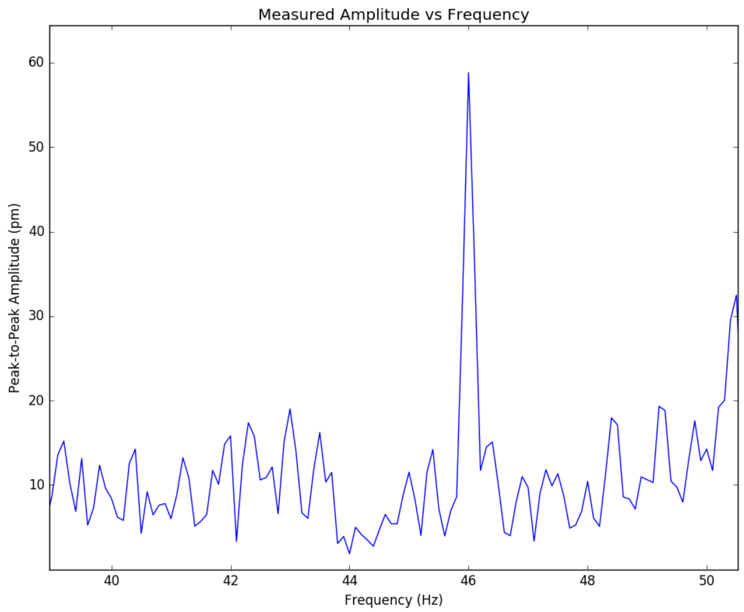
Plotted are the dynamic Zernike term RMS values for 2 different cases: 1) the case where a fixed frequency sinusioidal stimulus is present, and 2) the case where no such stimulus is present.



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

Picometer Actuator Characterization

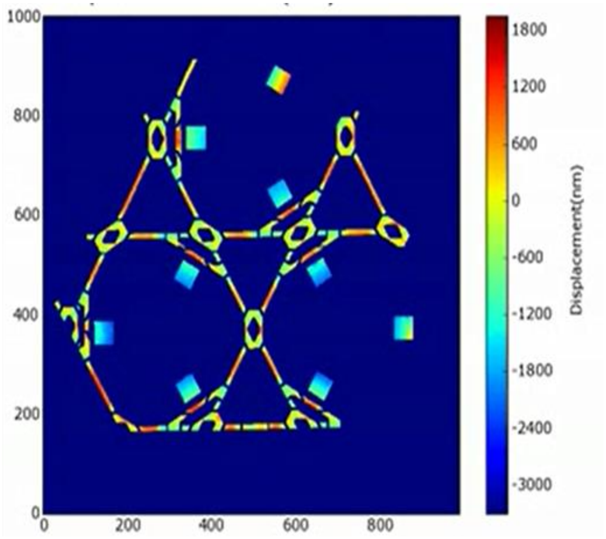
- Closed loop piezo actuator being characterized using the same methods used on segments
  - Was measured at vendor using an AFM
  - Provides crosscheck of the temporal phase unwrapping methodology
- Can provide an in situ calibration source
- Possible actuator candidate for future missions
- Achieved +-25pm in lab environment
  - Demonstrates method for measuring actuators at this scale
  - Expect we can do even better
- Next step is characterizing in ultra stable vacuum system (see next slides)



Next Generation: Structural/Thermal Strain Measurements

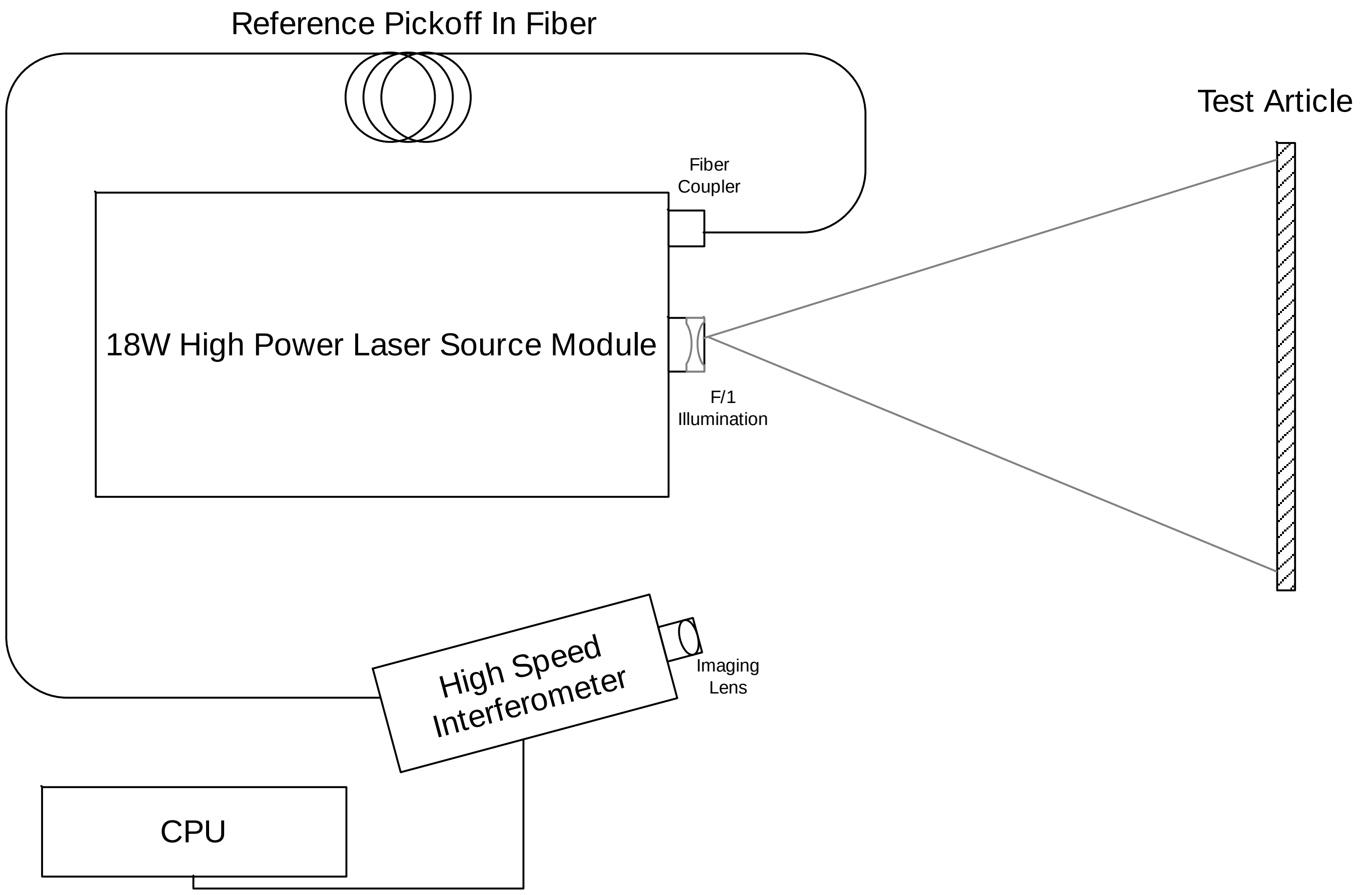
- Thermal response of structure key in maintaining alignment in space.
- Speckle interferometry – change in shape of diffuse structures.
- Requires significant laser power

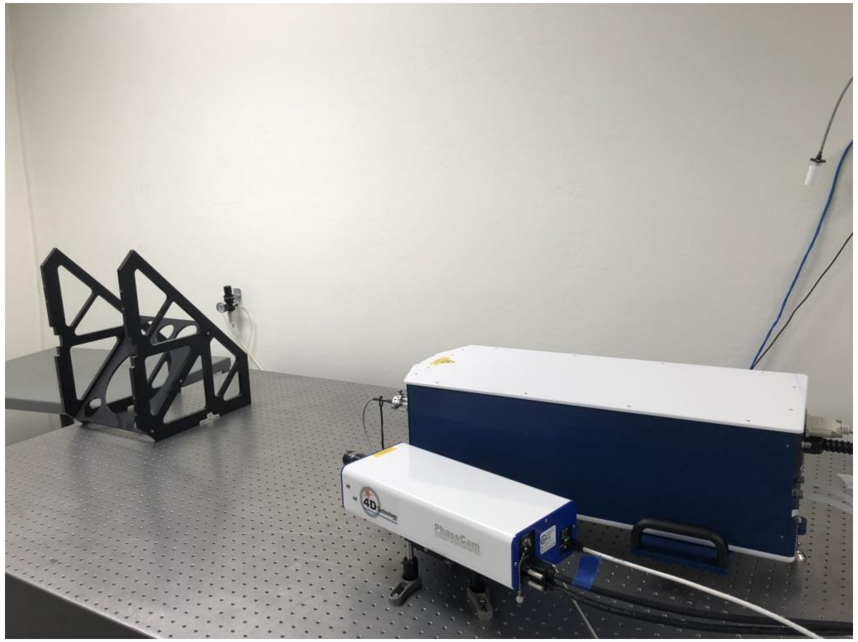
100's nm/days



Babak Saif, et al. "Measurement of large cryogenic structures using a spatially phase-shifted digital speckle pattern interferometer," Appl. Opt. 47, (2008)

New High Speed ESPI

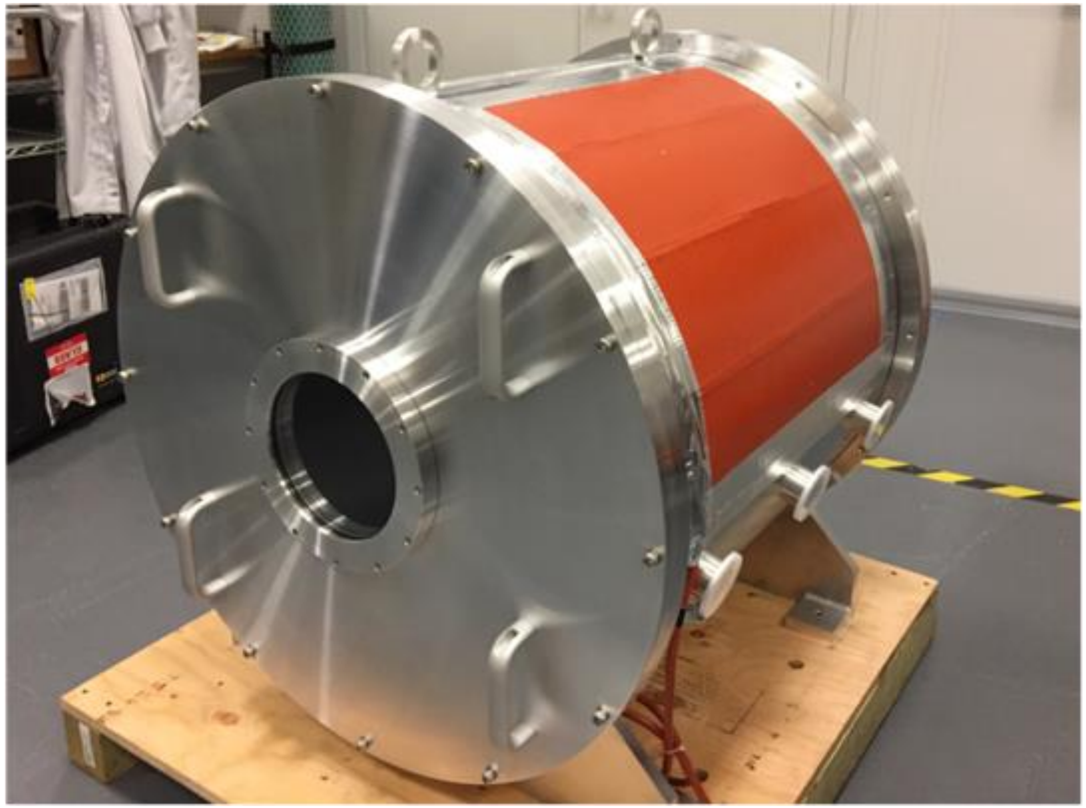




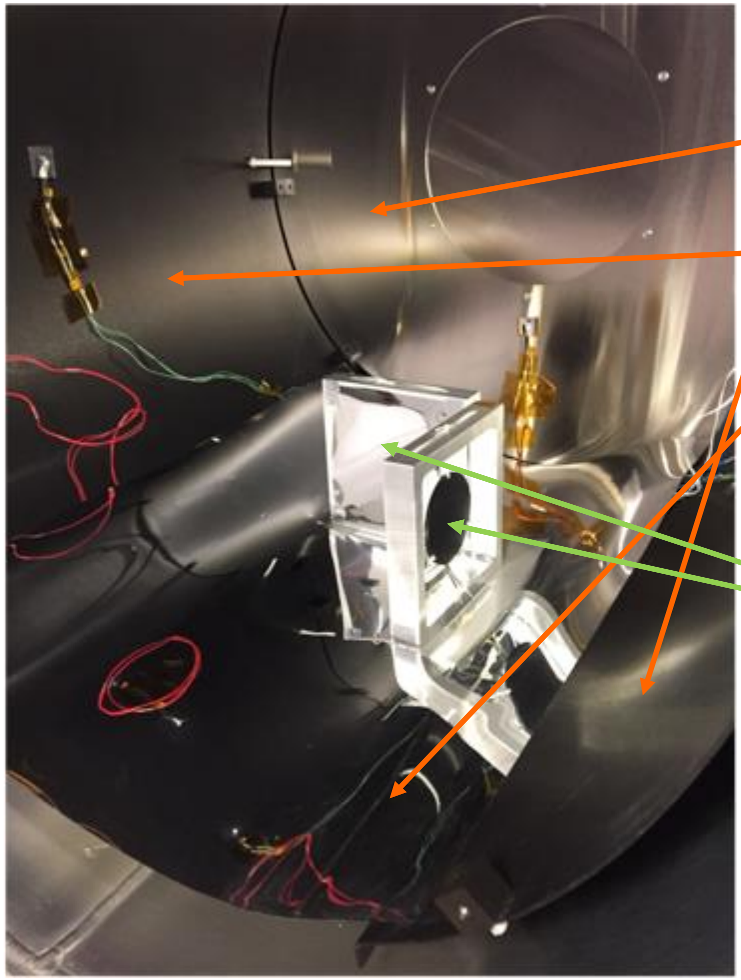
Calibration Using Picometer Actuator (picture from Babak)

- Using the HSI and temporal phase unwrapping to test a closed loop piezo actuator that will serve as the calibration source in our in-vacuum chamber testing
- Testing in air initially
- Vacuum compatible actuator to be used as part of vacuum calibration gauge

Ultra-Stable Chamber Configuration



- An aluminum vacuum chamber assembly
- Vacuum system is capable of <E-5Torr using Ion pump for vibration free operations.



<u>Internal Thermal radiation shields</u>

End panels: Low emissivity

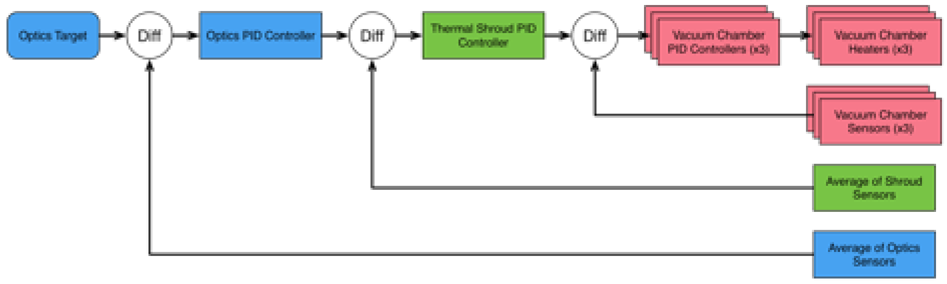
Cylinder: High emissivity

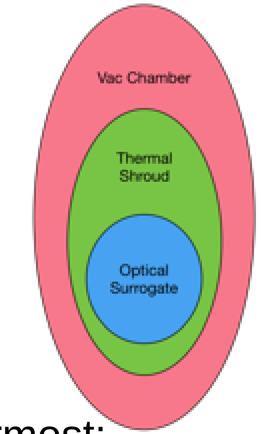
Bottom (Below test bench): Low emittance SLI

<u>Test Article Surrogates</u>

High emissivity Aluminum Disk Used as a ‘stand-in’ thermometers.

High Precision Thermometry and Control System

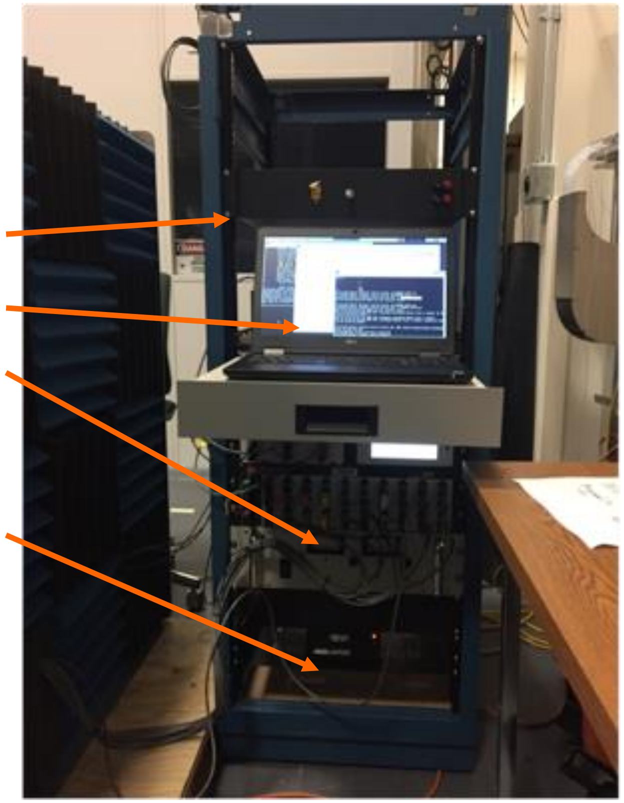




* 3 layers thermal control from innermost to outermost: optics, thermal shroud, vacuum chamber
* all controllers are independently tunable

Ultra-Stable Chamber Electronics Rack

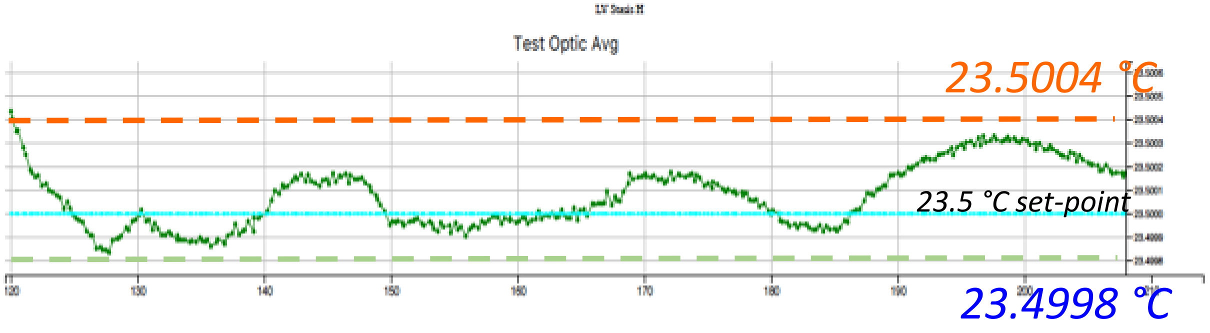
Heater Power Drive Module
Logic Control Laptop
High Precision Thermometry system
Heater Power Supply



Average surrogate test article thermal stability achieved:

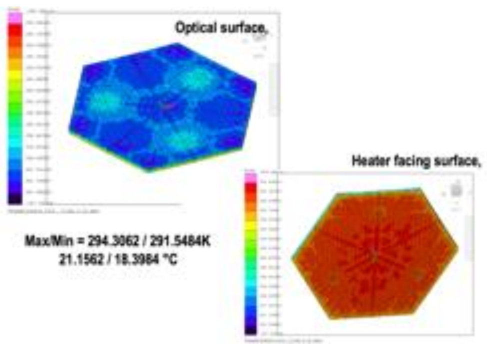
23.5°C +0.0004 / -0.0002C over 80+ hours (+0.4mK / -0.2mK)

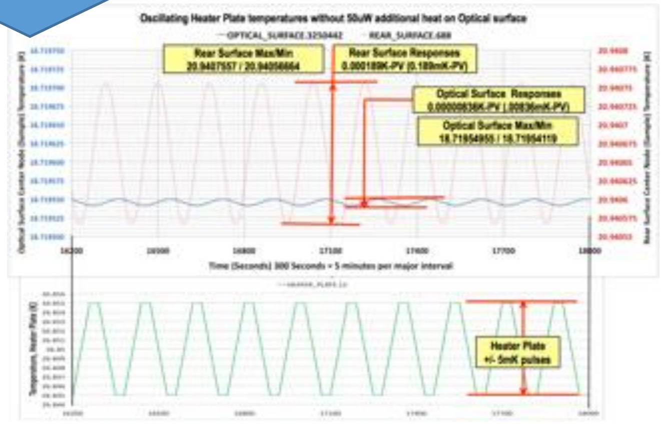
- 23.5°C nominal set point
- Test data from 02 June 13:38:20 to 12 June 2017 14:14:30
- Local ambient temperature ranged between 18.5 and 22.0°C

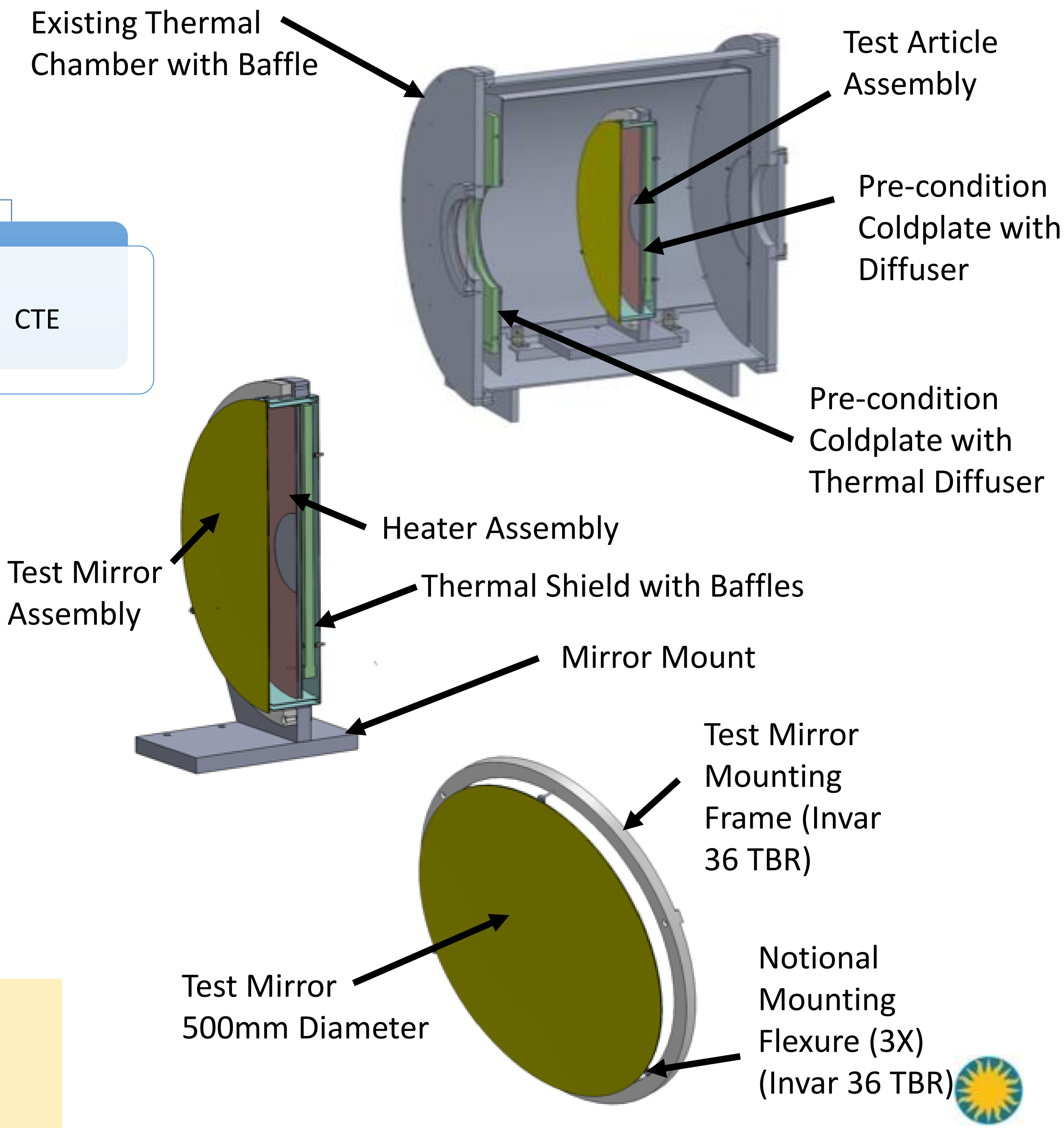


Ultra Stable Mirror Demonstrator System

- **Thermal** – 'Flat' ULE Substrate
  - Thermal Sensor mounting demonstrator
  - Heater Stability Demonstrator
- **Dynamic** – ULE Spherical Optic
  - High Frequency Picometer Actuator
- CTE







<u>REFERENCE:</u>

<u>ATLAST ULE Mirror Segment Performance Analytical Predictions Based on Thermally Induced Distortions</u>

(SAO Eisenhower, M. Park, S. ; 2015, SPIE)

Summary/Future Plans

- Team has made excellent progress in it's first year:
  - First picometer spatial metrology demonstration tied to a structural model comparison
  - Application of picometer spatial metrology to a picometer class actuator for use as a calibration gauge
  - Development and testing of an ultra stable milli-Kelvin chamber
  - First of a kind speckle HSI interferometer procured, designed, and to be delivered this winter
- Plans for coming year
  - Integrate ultra stable test chamber with interferometer and calibration source
  - Make first measurements of test materials
  - Demonstrate feasibility of picometer level thermal stability
  - Begin fabrication of Nanocomposite test articles