Ultra Stable SAT

Babak Saif, Lee Feinberg, GSFC
Sang Park, SAO
Perry Greenfield, StScI
Marcel Bluth, SGT
Presented by Ritva Keski-Kuha/GSFC

Topics

- Objectives
- Accomplishments
  - Demonstration of rough surface measurements of a change to 10 pm level
  - Work in progress to measure ULE substrates, dynamics and drift, under Ultra Stable Thermal control
  - Interferometer design modification due to acquired experience

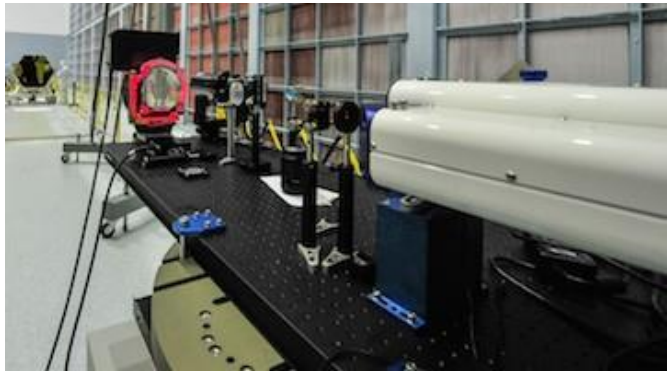
Goals of this effort

- 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 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 components to advance their picometer stability dynamics and drift.
  - Mirror material and thermal control
  - Stable composites
  - Actuators
  - Other components (future)

Basic premise of the approach

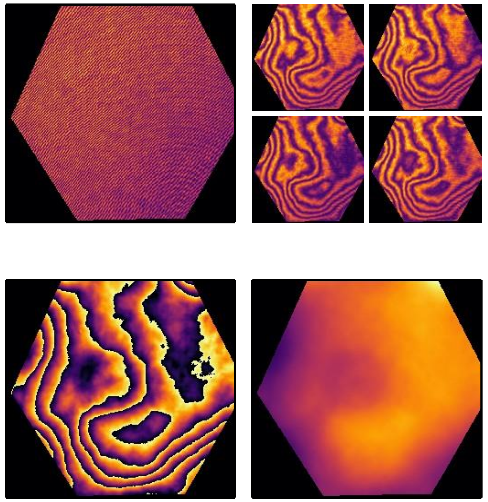
- Make use of high speed instantaneous phase shifting interferometry
- Perform temporal phase unwrapping through algorithmic methods
- Fit 2-d phase data to Zernike polynomials taking advantage of the statistics of large samples
- Don’t use corner cubes or retros which require attachments that can creep 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 milli-Kelvin control/stability
    - 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 is a 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!

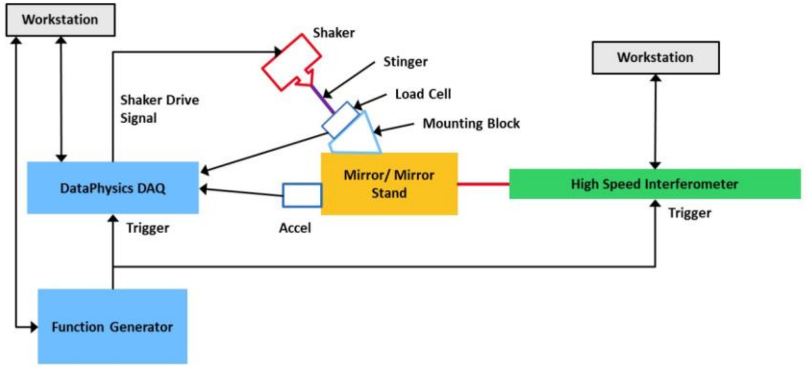
Picometer measurement of mirror dynamics



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.

Research Article Applied Optics 1

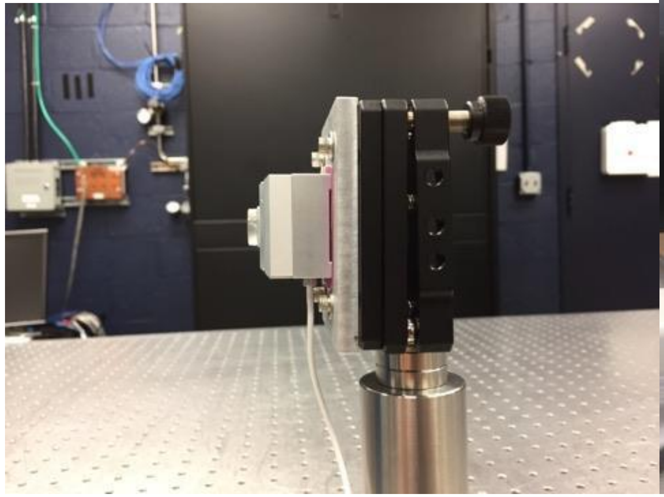
Measurement of picometer-scale mirror dynamics

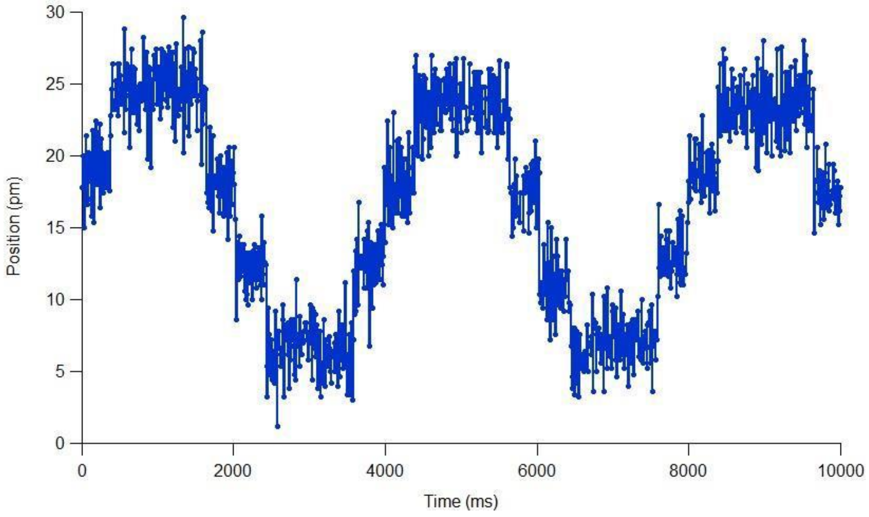
BABAK SAIF[1], DAVID CHANEY[2], PERRY GREENFIELD[3,*], MARCEL BLUTH[4], KYLE VAN GORKOM[3], KOBY SMITH[2], JOSH BLUTH[4], LEE FEINBERG[1], JAMES C. WYANT[5,6], MICHAEL NORTH-MORRIS[6], AND RITVA KESKI-KUHA[1]

[1]NASA/GSFC, 8800 Greenbelt Road, Greenbelt, Maryland 20771
[2]Ball Aerospace, 1600 Commerce Street, Boulder, Colorado 80301
[3]Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, Maryland 21218
[4]SGT, 7515 Mission Drive, Suite 300, Seabrook, Maryland 20706
[5]College of Optical Sciences, University of Arizona, Tucson, Arizona 85721
[6]4D Technology, 3280 East Hemisphere Loop, Suite 146, Tucson, Arizona 85706
*Corresponding author: perry@stsci.edu

Picometer Actuator Characterization

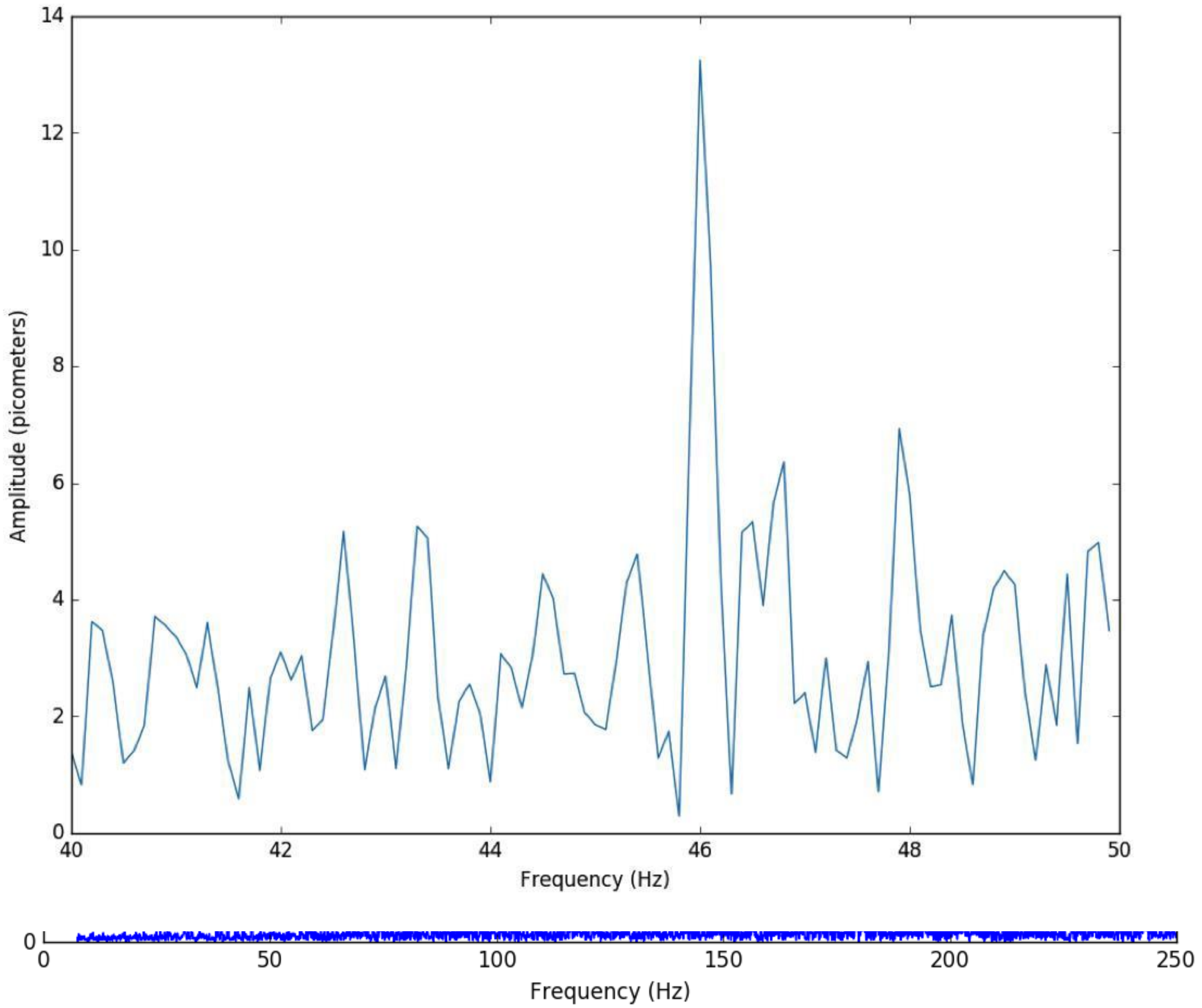
- Closed loop piezo actuator being characterized using the same methods used on segments
  - Was measured at vendor using an AFM
  - Provides crosscheck of the temporal phase unwrapping methodology
- Can provide an in situ calibration source
- Possible actuator candidate for future missions





Measurements of Mirror Under Sine Wave Stimulus

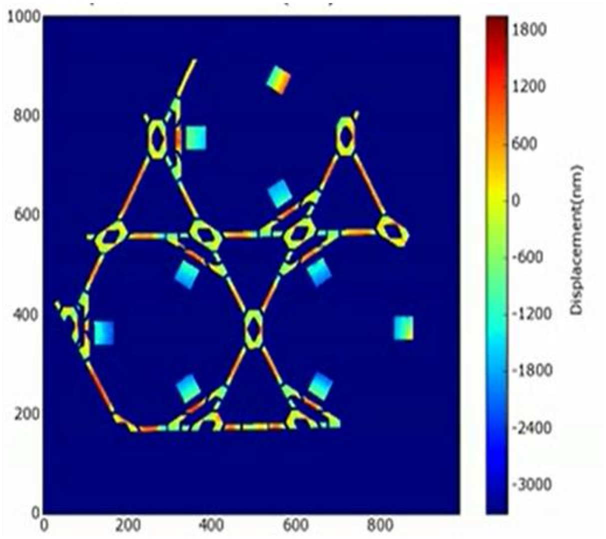
Achieved 13+/- 2.6 pm for mirror sample



Next Generation: Structural/Thermal Strain Measurements

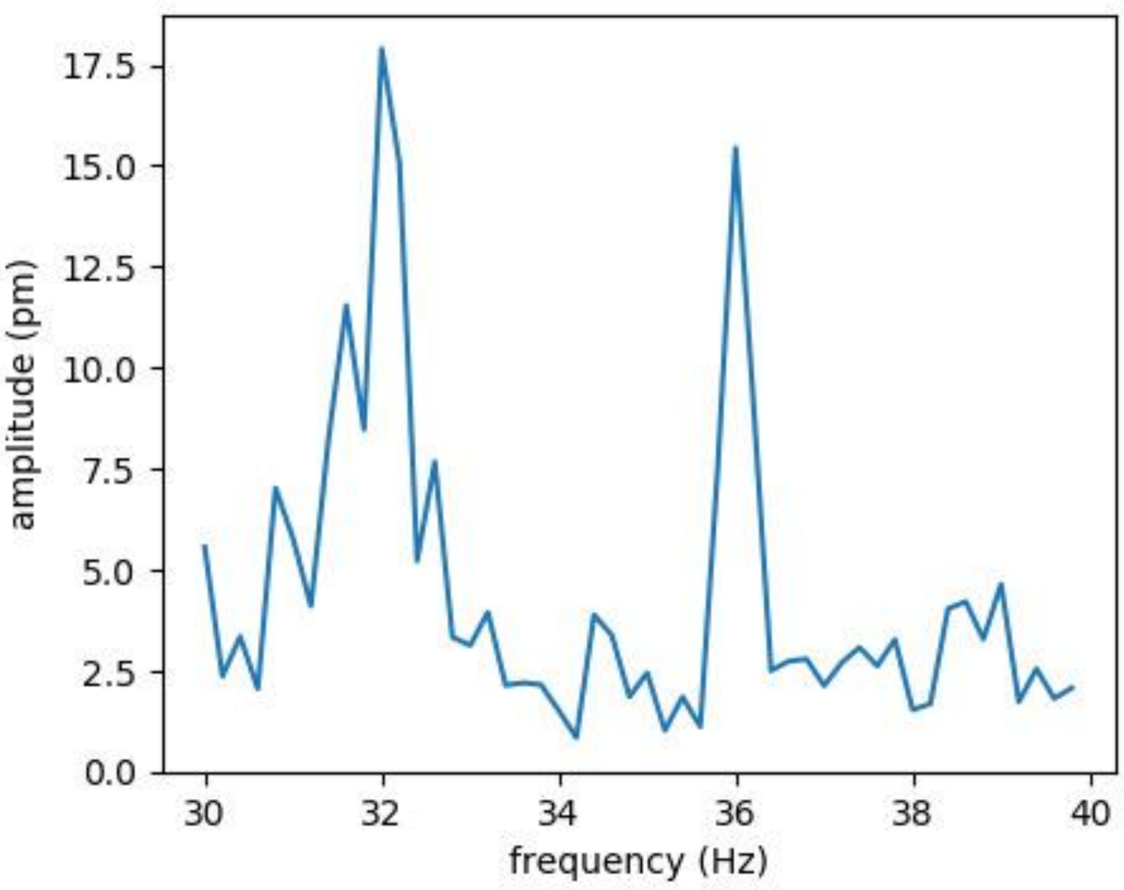
- Thermal response of structure key in maintaining alignment in space.
- Speckle interferometry – change in shape of diffuse structures.
- Requires significant laser power

100’s nm/days



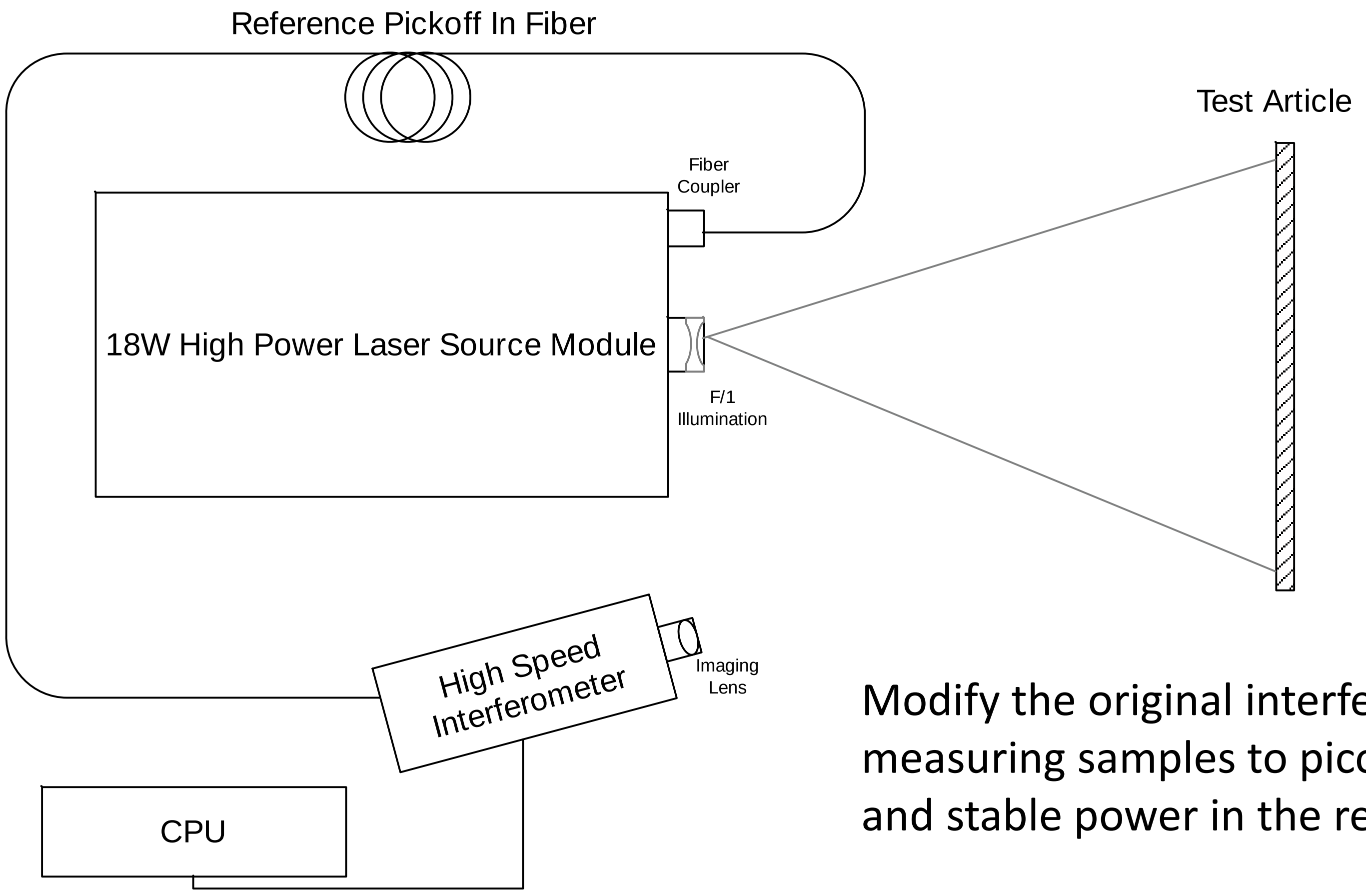
Babak Saif, et al. "Measurement of large cryogenic structures using a spatially phase-shifted digital speckle pattern interferometer," Appl. Opt. 47, (2008)

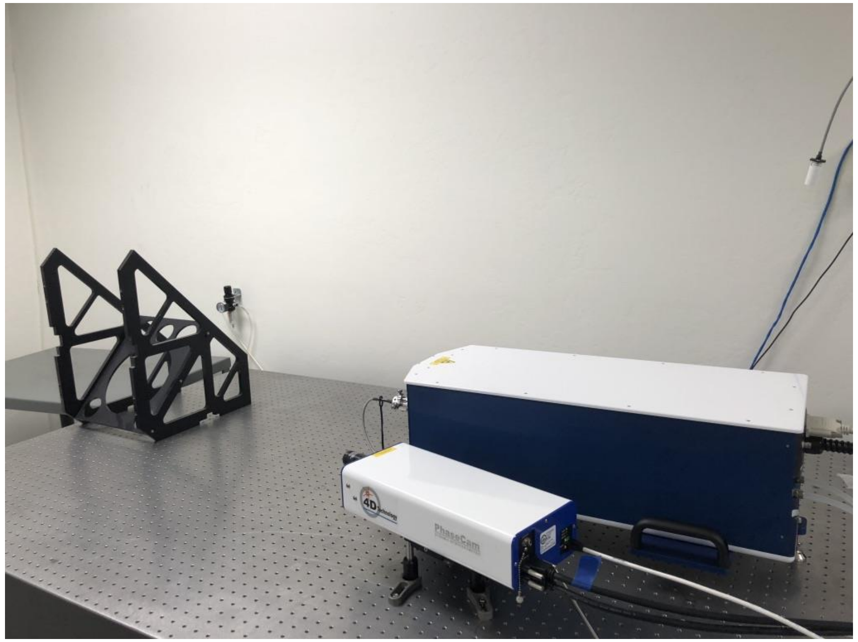
Carbon Fiber Sample Motion



Achieved 16pm amplitude for carbon fiber sample.

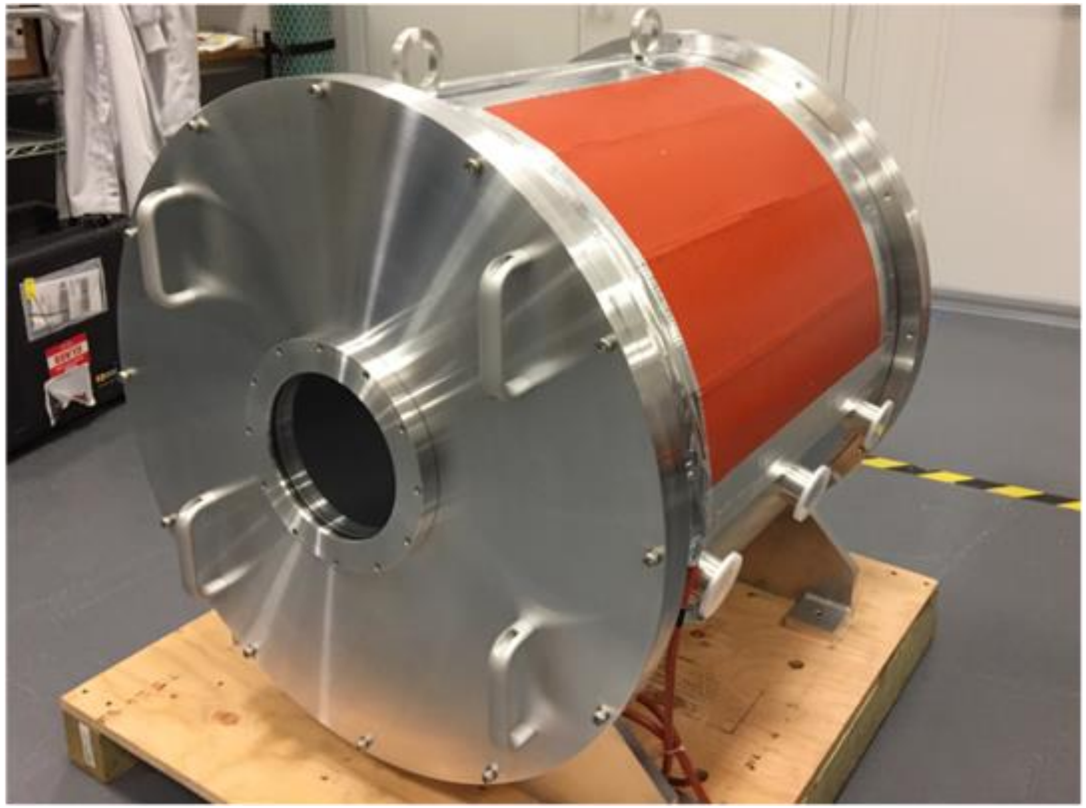
New High Speed ESPI



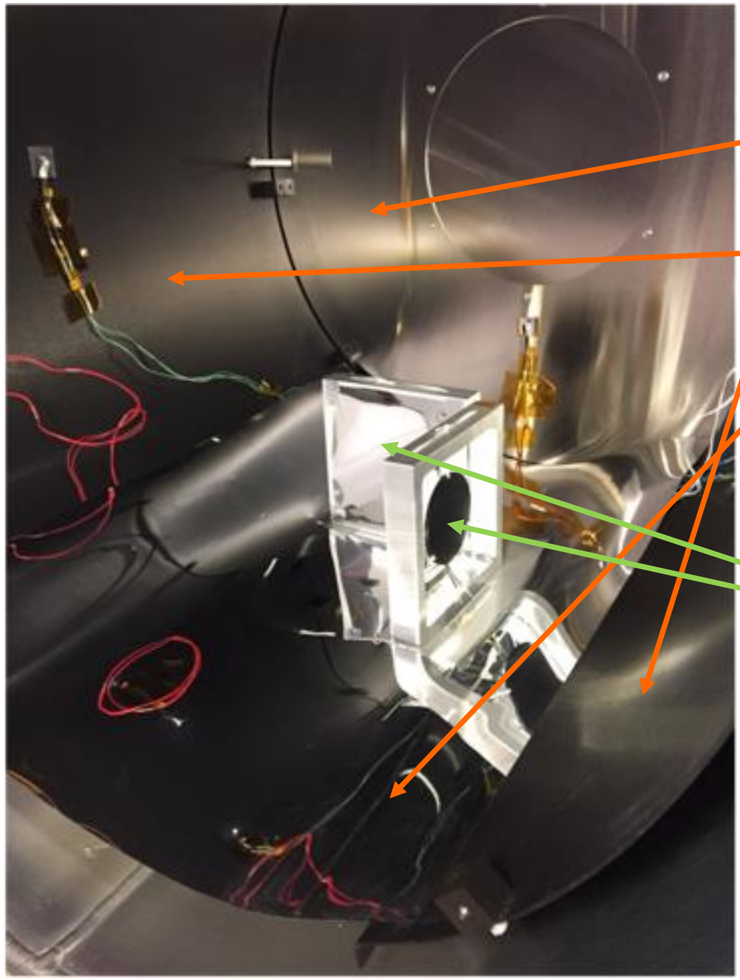


Modify the original interferometer design using experience acquired measuring samples to picometer level including providing continuous and stable power in the reference arm.

Ultra-Stable Chamber Configuration



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



Internal Thermal radiation shields

End panels: Low emissivity

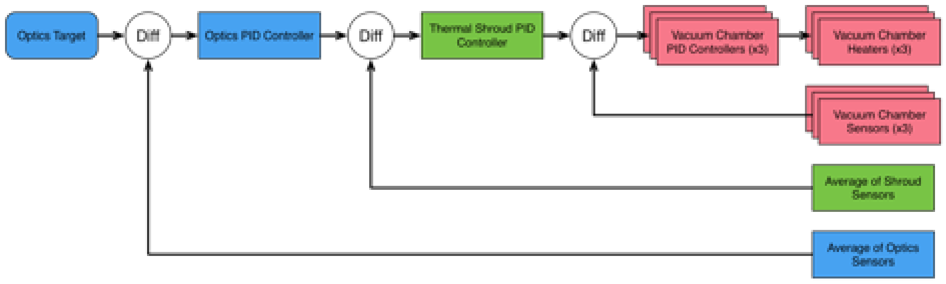
Cylinder: High emissivity

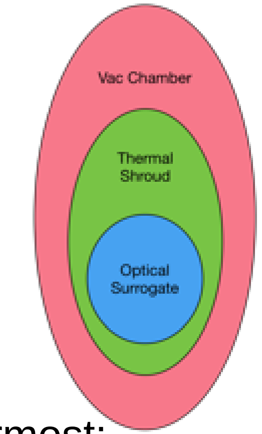
Bottom (Below test bench): Low emittance SLI

Test Article Surrogates

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

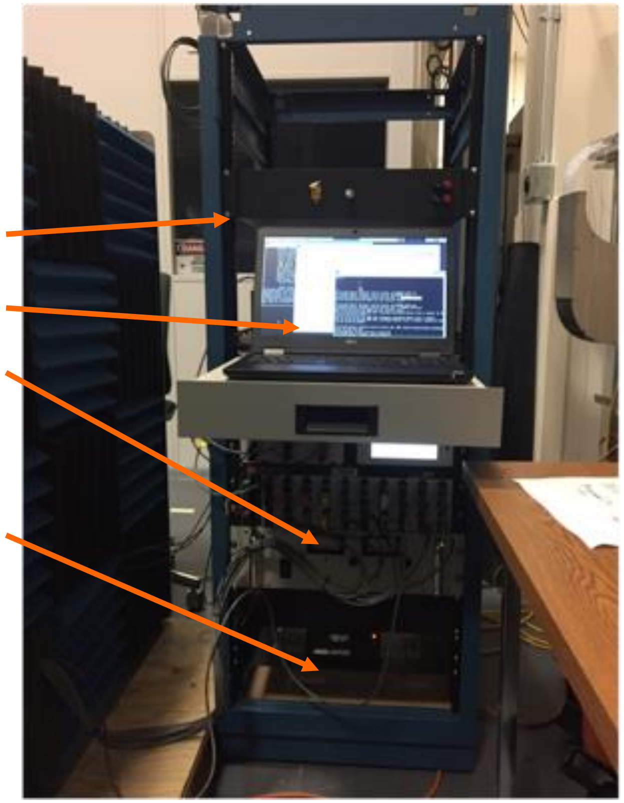
Ultra-Stable Chamber Electronics Rack

Heater Power Drive Module

Logic Control Laptop

High Precision Thermometry system

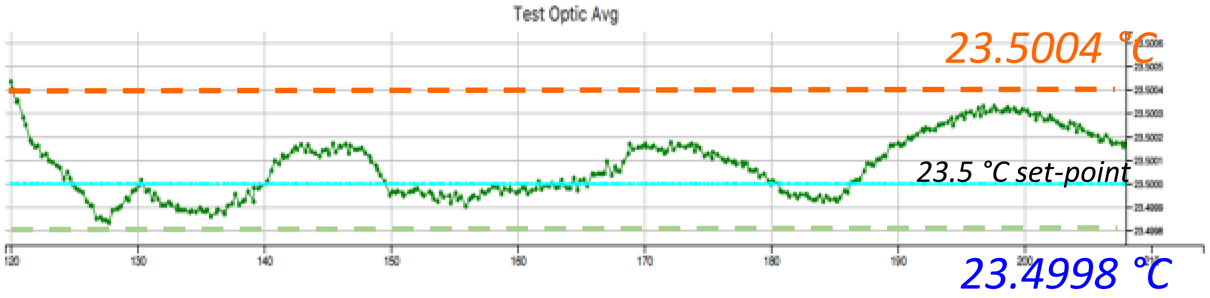
Heater Power Supply



Average surrogate test article thermal stability achieved:

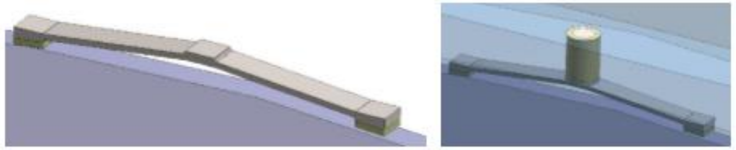
23.5°C +0.0004 / -0.0002C over 80+ hours (+0.4mK / -0.2mK)

- 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

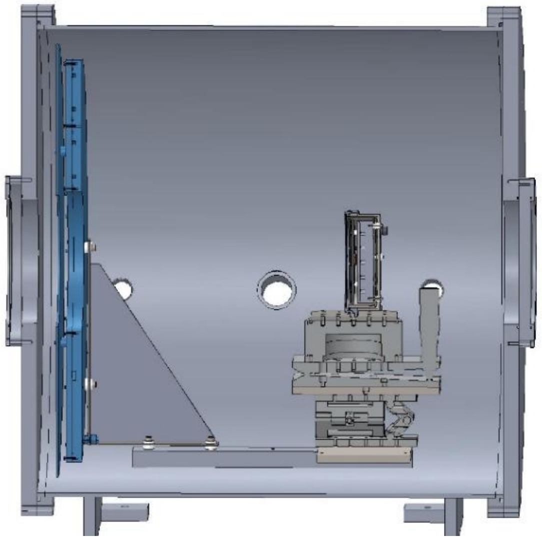


150 mm Diameter ULE Mirror Assembly

Mirror assembly



Microflexure



Test configuration

Summary/Future Plans

- Team has made excellent progress:
  - 10 pm measurements of rough surfaces/carbon fiber sample was achieved by high speed speckle interferometer.
  - 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 delivered.
  - Vacuum compatible actuator to be used as part of vacuum calibration gauge for diagnostic purposes.
- Plans for coming year
  - Perform drift measurements and dynamics measurements on ULE substrate in the chamber
  - Complete modifications to the original interferometer design using experience acquired measuring samples to picometer level.
  - Make first measurements of test materials
  - Demonstrate feasibility of picometer level thermal stability
  - Begin fabrication of Nanocomposite test articles