Ultra-Stable Picometer-Scale Mirror Assembly Demonstrator

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AGENDA

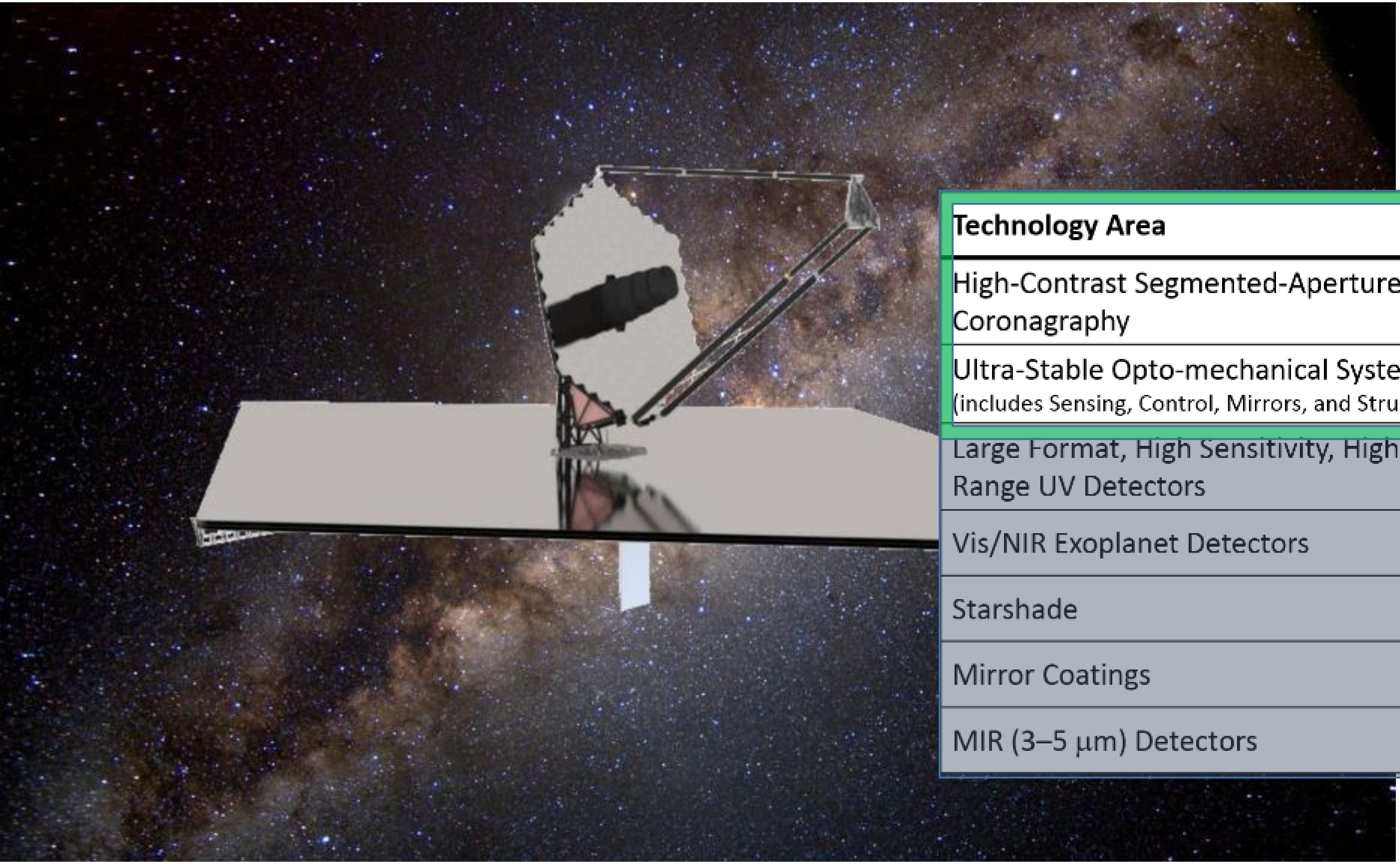
- Background Intro
- Brief Overview of LUVOIR
- Picometer Milli-K Class Studies
- Picometer Metrology and Milli-K Sense and Control Demonstrators
- Discussions/Questions

Background and Introduction

- LUVOIR: In order to achieve the high-contrast imaging required to satisfy the primary science goals of this mission would require, roughly, 10 pico-meter wavefront RMS stability over a wavefront control time step of approximately 10 minutes.
- The LUVOIR Optical Telescope Assembly will require active thermal management to maintain operational temperature while on orbit. Furthermore, the active thermal control must be sufficiently stable to prevent time-varying thermally induced distortions in the OTA.

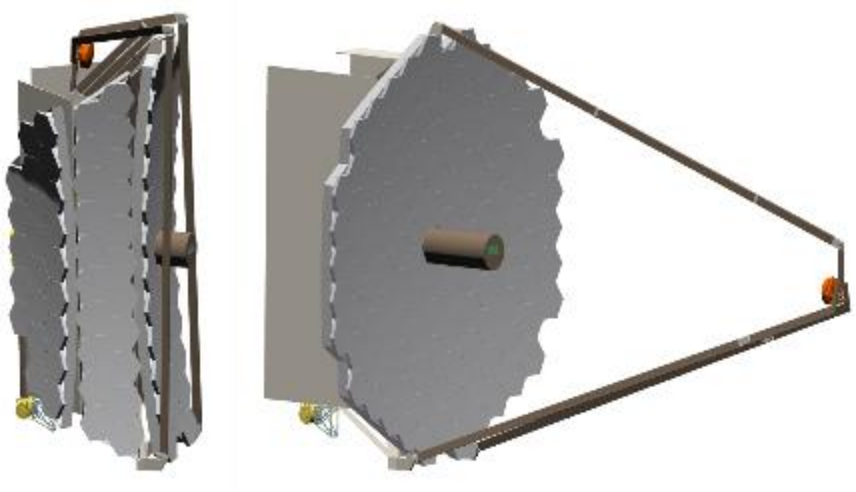
- **Ultra-Stable Picometer-Scale Mirror Assembly (USPS-MA) Demonstrator is a part of the technology development of picometer-class metrology system and an ultra-stable thermal sensing and control system.**

LUVOIR Technology Prioritization List

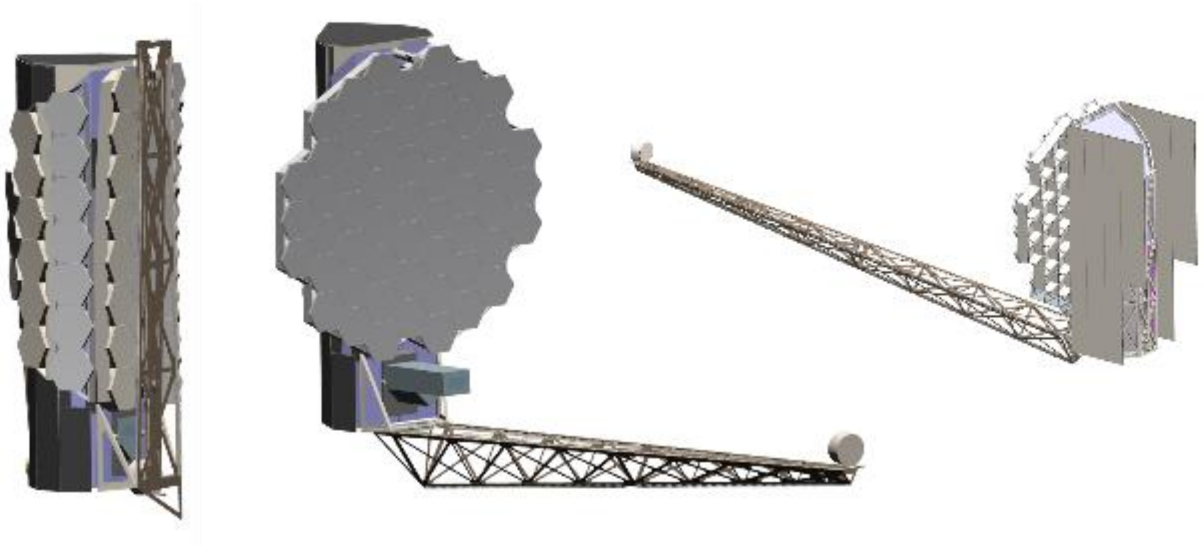


Technology Area	Difficulty	Urgency
High-Contrast Segmented-Aperture Coronagraphy	CRITICAL	CRITICAL
Ultra-Stable Opto-mechanical Systems (includes Sensing, Control, Mirrors, and Structures)	CRITICAL	CRITICAL
Large Format, High Sensitivity, High-Dynamic Range UV Detectors	HIGH	HIGH
Vis/NIR Exoplanet Detectors	HIGH	MED
Starshade	HIGH	MED
Mirror Coatings	MED	MED
MIR (3–5 μm) Detectors	LOW	LOW

LUVOIR Telescope Architectures 15m “A” and 8m “B”

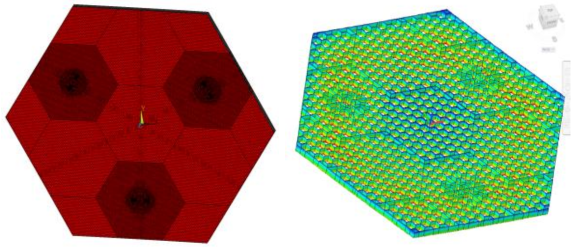


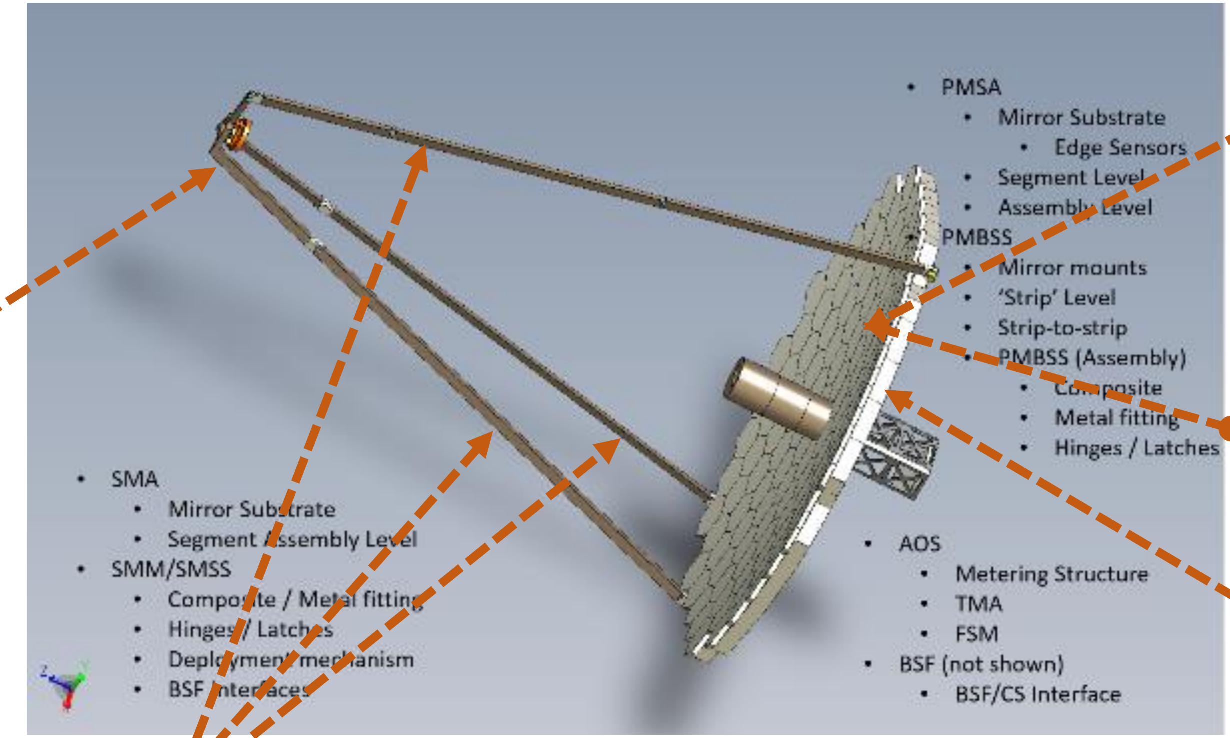
The ‘LUVOIR-A” is a three-mirror anastigmat telescope with 120 segmented primary mirrors with a fine-steering mirror contained in a housing along with its tertiary mirror assembly. The Architecture A concept has 4 serviceable science instruments mounted on the Backplane Support Frame (BSF), structurally attached to the Primary Mirror Backplane Support Structure (PMBSS). The secondary mirror is designed to be located off of the Secondary Mirror Support Structure (SMSS).

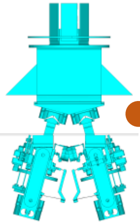


The ‘LUVOIR-B” is an off-axis, unobscured telescope. The Architecture B concept has 3 science instruments mounted on a similar structural architecture of the LUVOIR-A where the Backplane Support Frame (BSF) is structurally attached to the Primary Mirror Backplane Support Structure (PMBSS). The secondary mirror is designed to be located off of a unique Secondary Mirror Support Structure (SMSS).

Supporting Studies Performed to Date

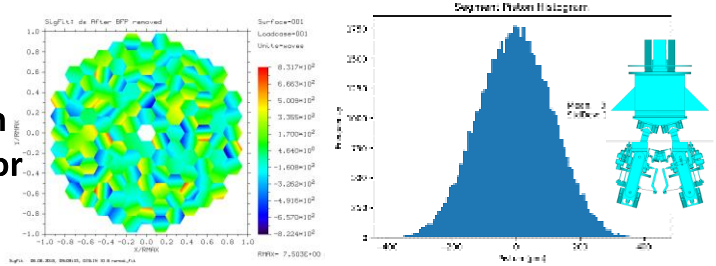




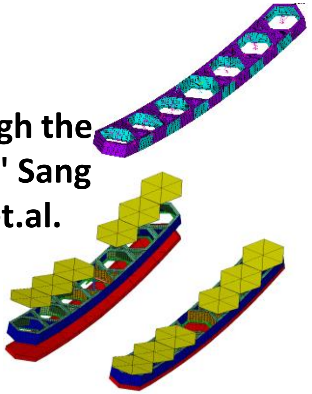


Mirror Substrate Stability
Reference: **ATLAST ULE mirror segment performance analytical predictions based on thermally induced distortions** Michael J. Eisenhower Sang C. Park et. al. *Proc. SPIE* 9602, September 22, 2015

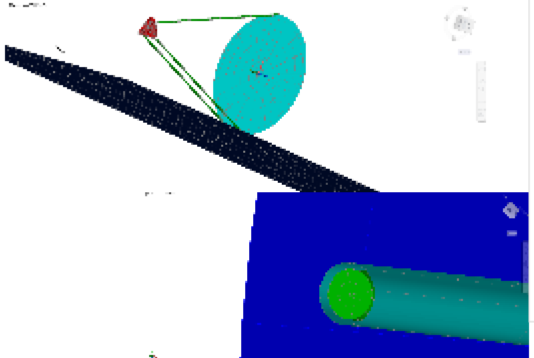
Global WFE Contribution from the PMSA Actuator Systems

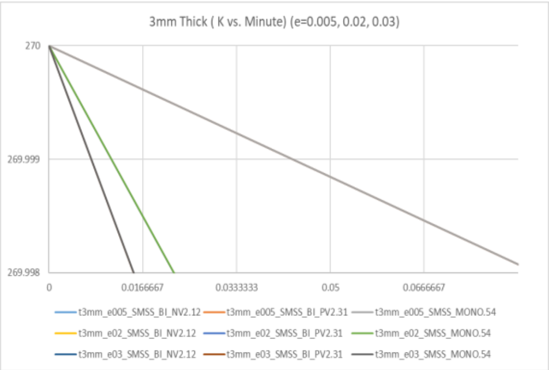


"LUVOIR backplane thermal architecture development through the composite CTE sensitivity study," Sang C. Park, Michael J. Eisenhower, et.al. SPIE 10398, (5 September 2017)



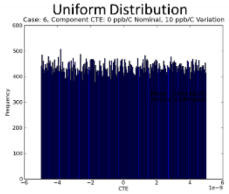
LUVOIR SMSS Transient Response Analysis



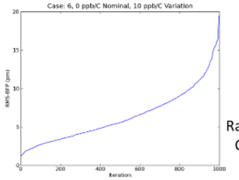


Example: All parts have same nominal CTE: X ppb/K
All parts have a variation in CTE: Y ppb/K
All CTE in the range: (X-Y/2) ppb/K to (X+Y/2) ppb/K
We vary X and Y
Entire structure subject to +1mK dT
Below is example of X=0ppb/K, Y=10 ppb/K

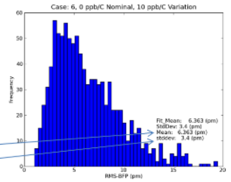
Input CTE Variation
Uniform Distribution



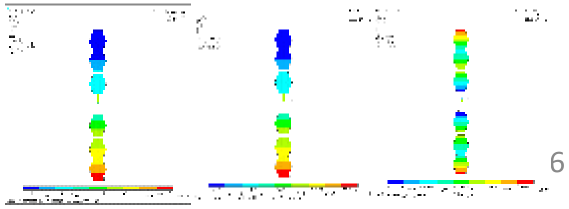
Output Surface RMS – BFP (pm)



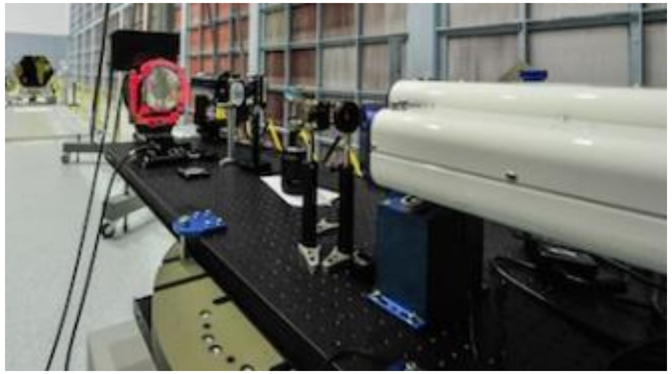
1k Random Cases



95% Confidence: Nominal + 2 Sigma
6.363 + 2(3.4) = 13.163 pm SFE

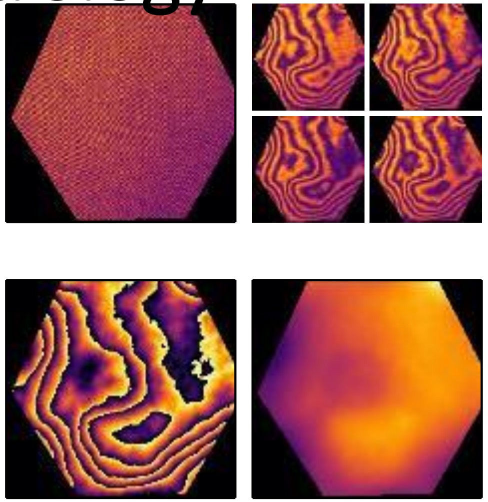


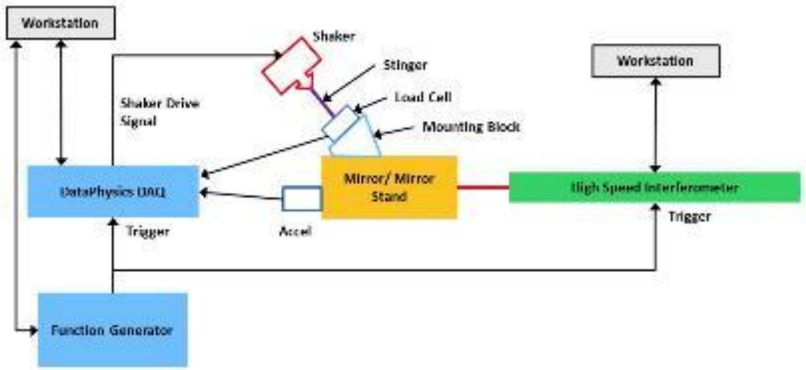
More to Follow, See Next Presentation: Picometer-Scale Metrology



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]

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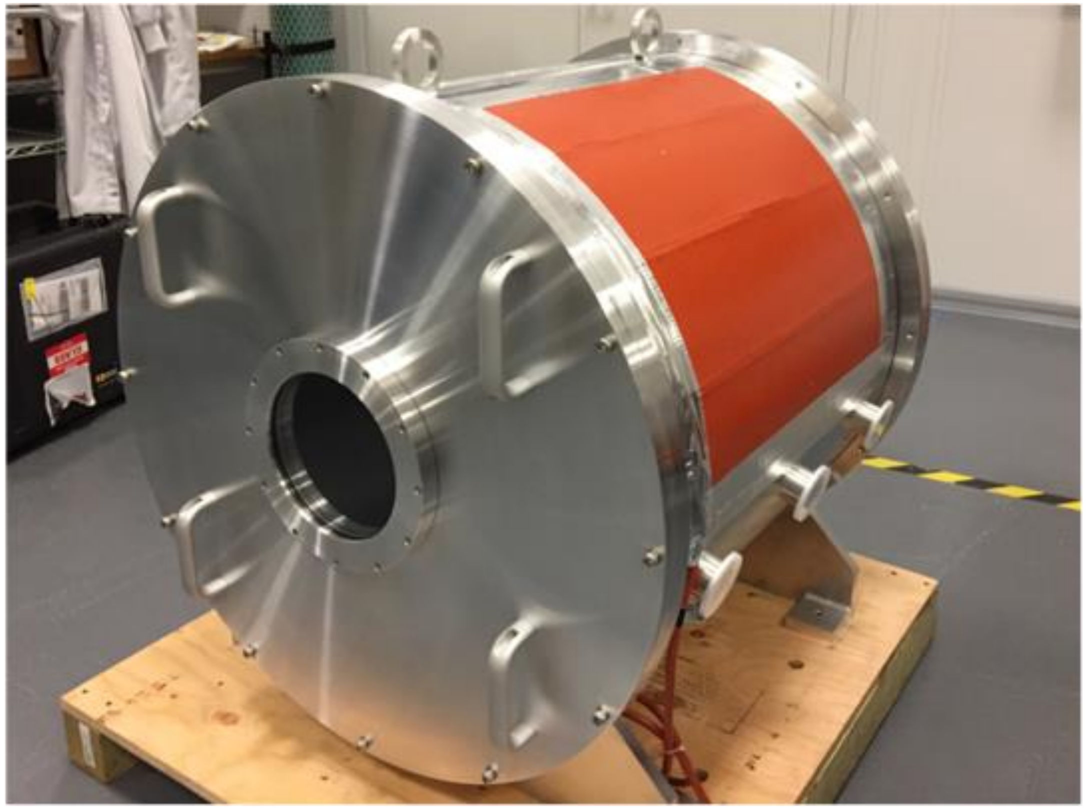
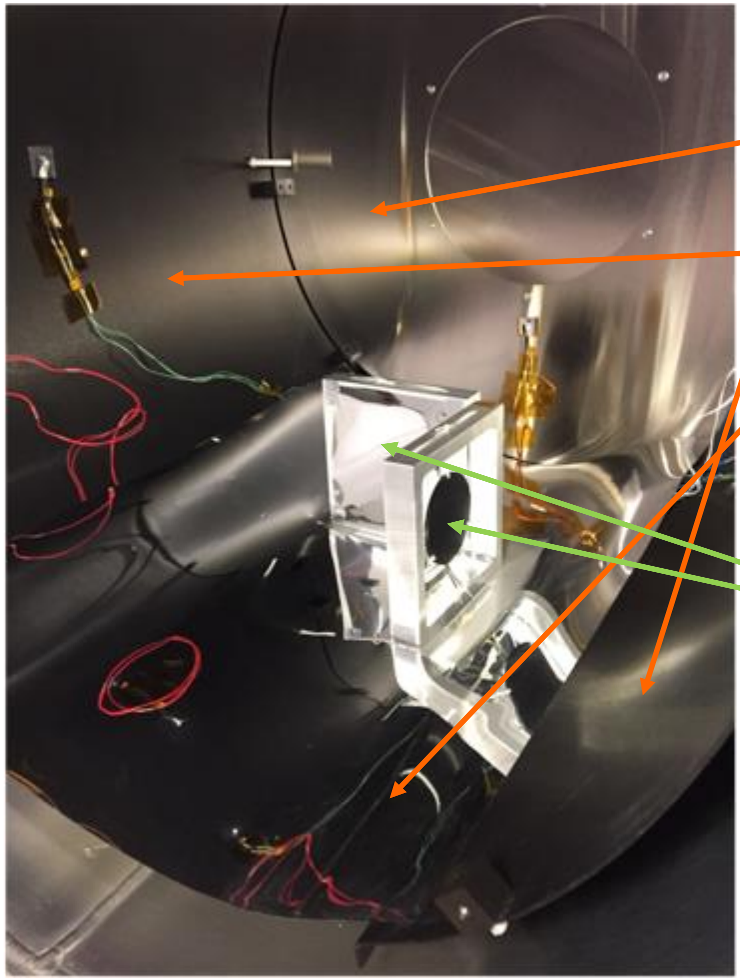
Ultra-Stable Chamber Configuration



- An aluminum vacuum chamber assembly
- Vacuum system is capable of lower than 1.0E-5 Torr using Ion pump for vibration free operations.



<u>Internal Thermal radiation shields</u>

End panels: Low emissivity

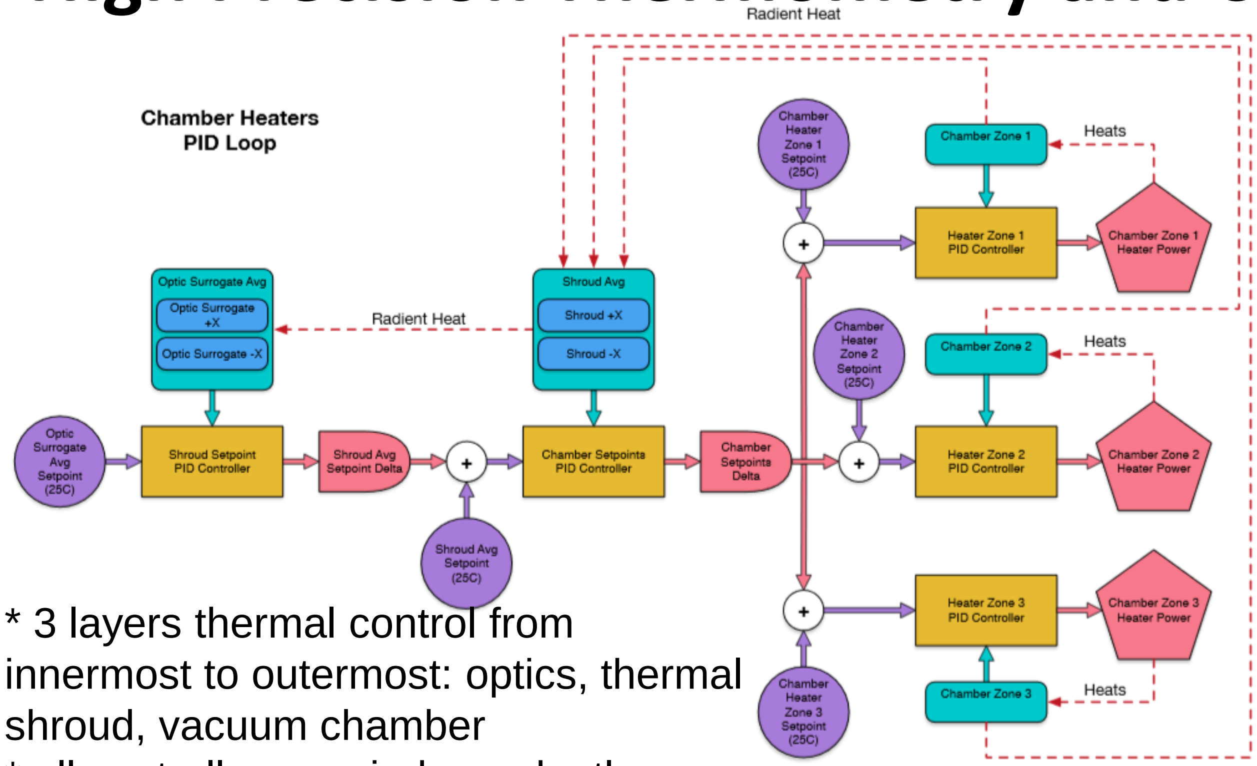
Cylinder: High emissivity

Bottom (Below test bench): Low emittance SLI

<u>Test Article Surrogates</u>

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

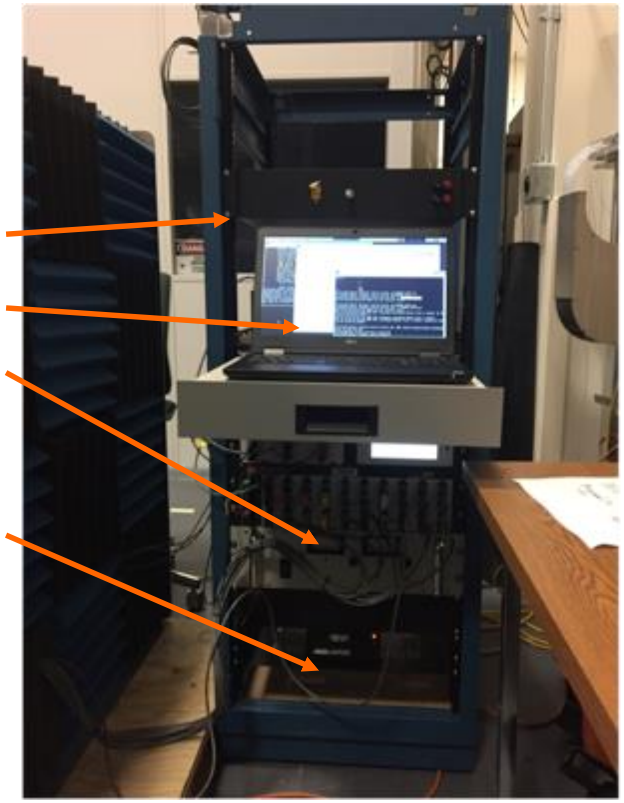
High Precision Thermometry and Control System



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

Ultra-Stable Chamber Electronics Rack

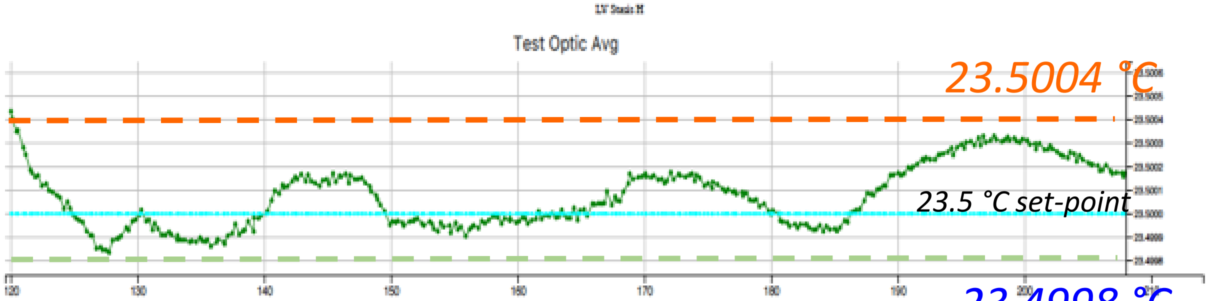
Heater Power Drive Module
Logic Control Laptop
High Precision Thermometry system
Heater Power Supply



Average surrogate test article thermal stability achieved:

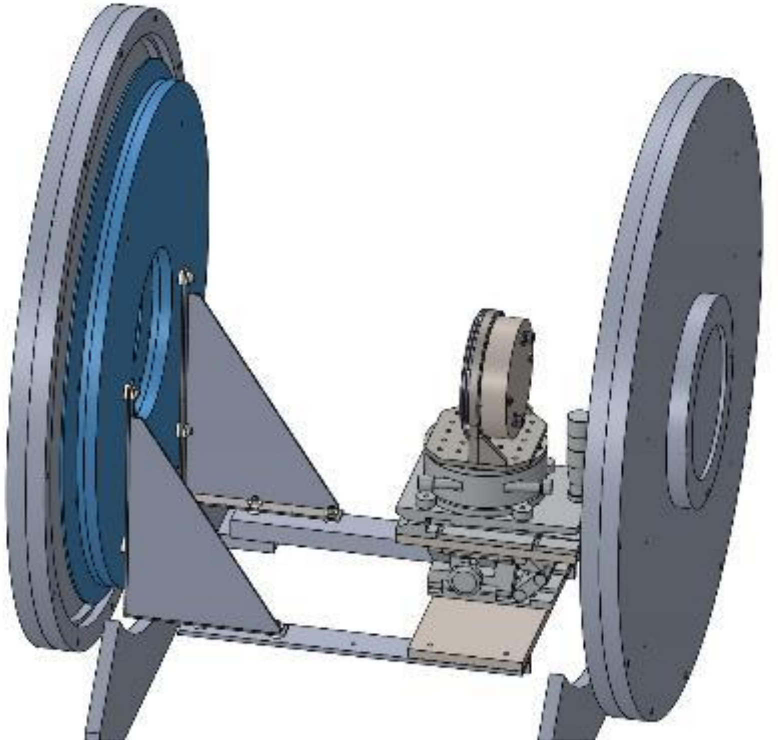
23.5°C +0.0004 / -0.0002C over 80+ hours (+0.4mK / -0.2mK)

- 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



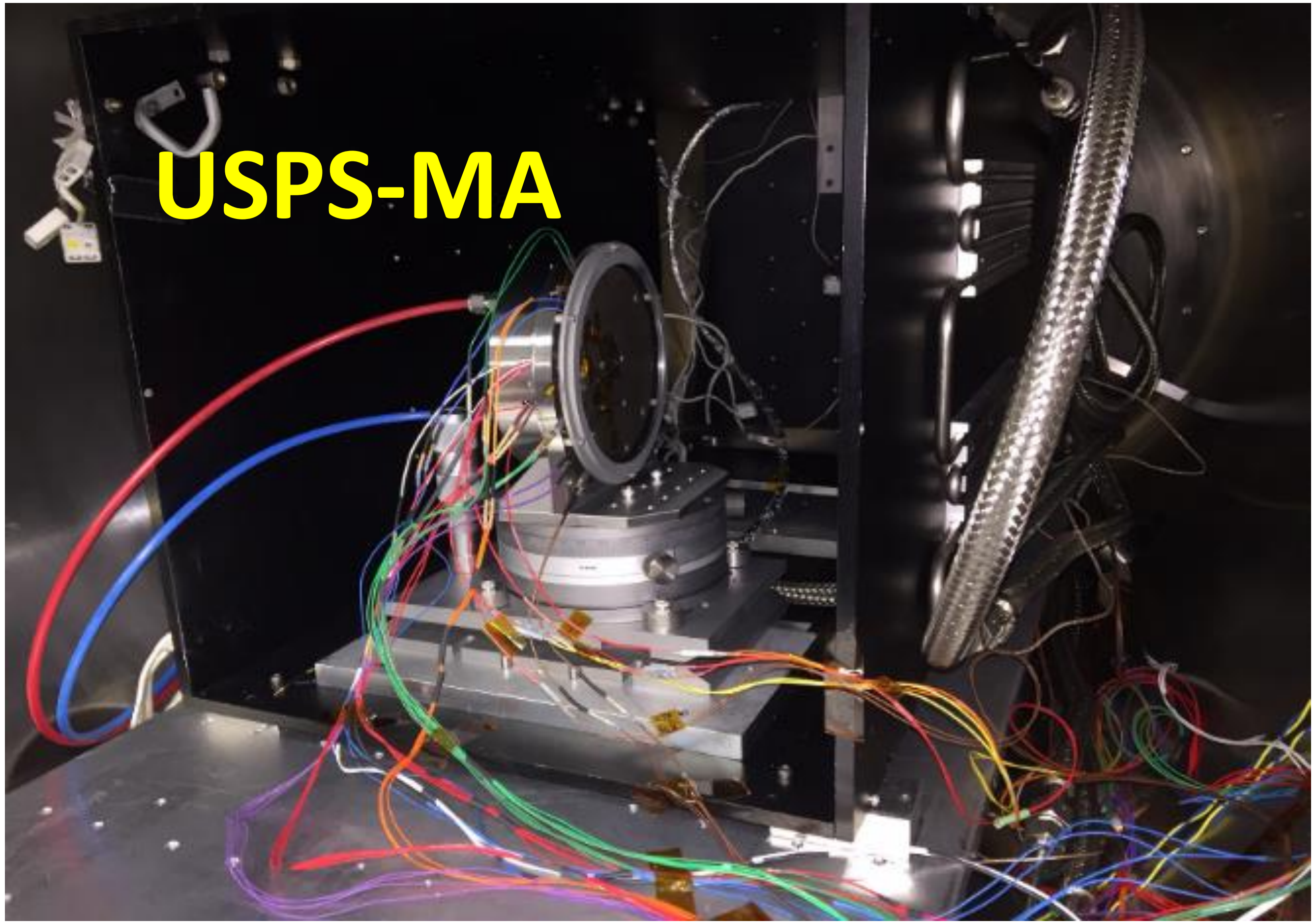
Sensing Noise is roughly 0.050milli-K p-v (50uK)

Ultra-Stable Picometer-Scale Mirror Assembly (USPS-MA) Demonstrator

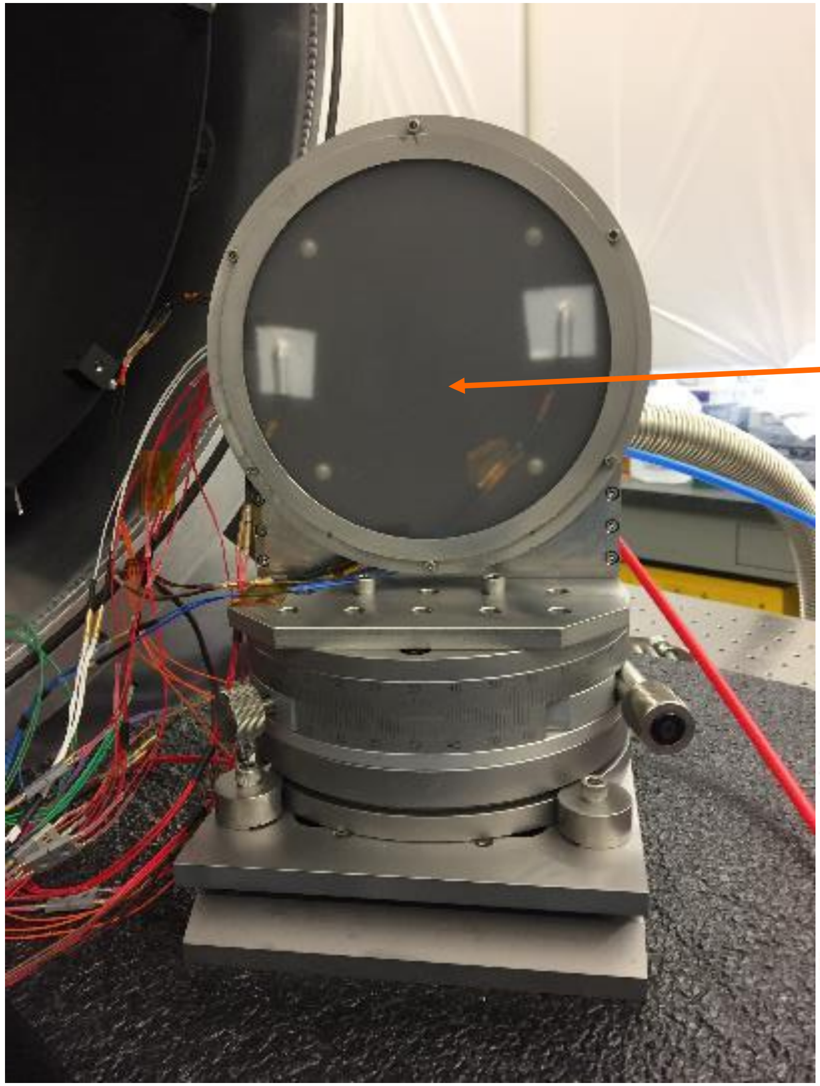


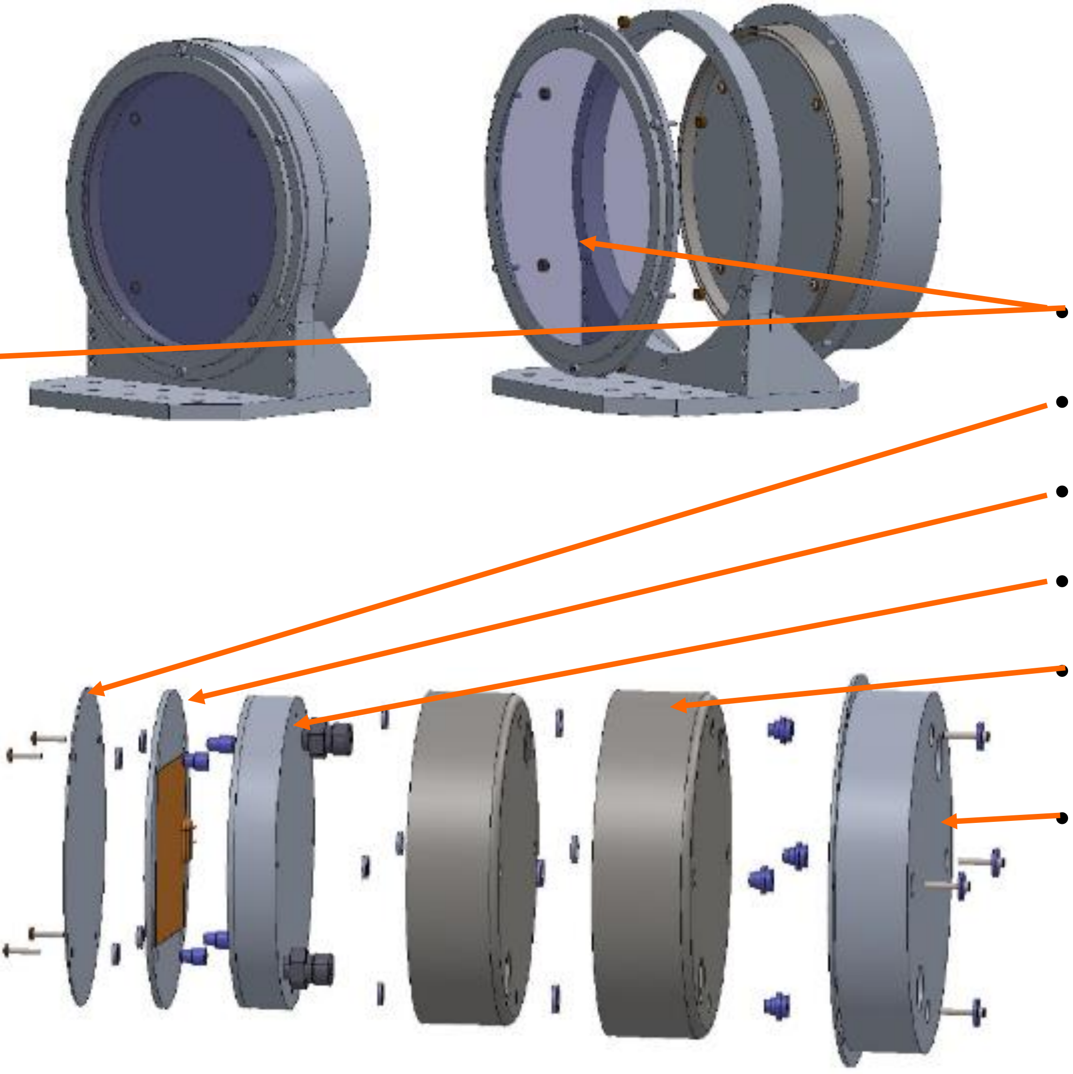
Internal view of the USPS-MA

Test Configuration with the 6-DOF optical stages for the proper orientation with respect to the optical window in the SAO ultra-stable Thermal vacuum chamber



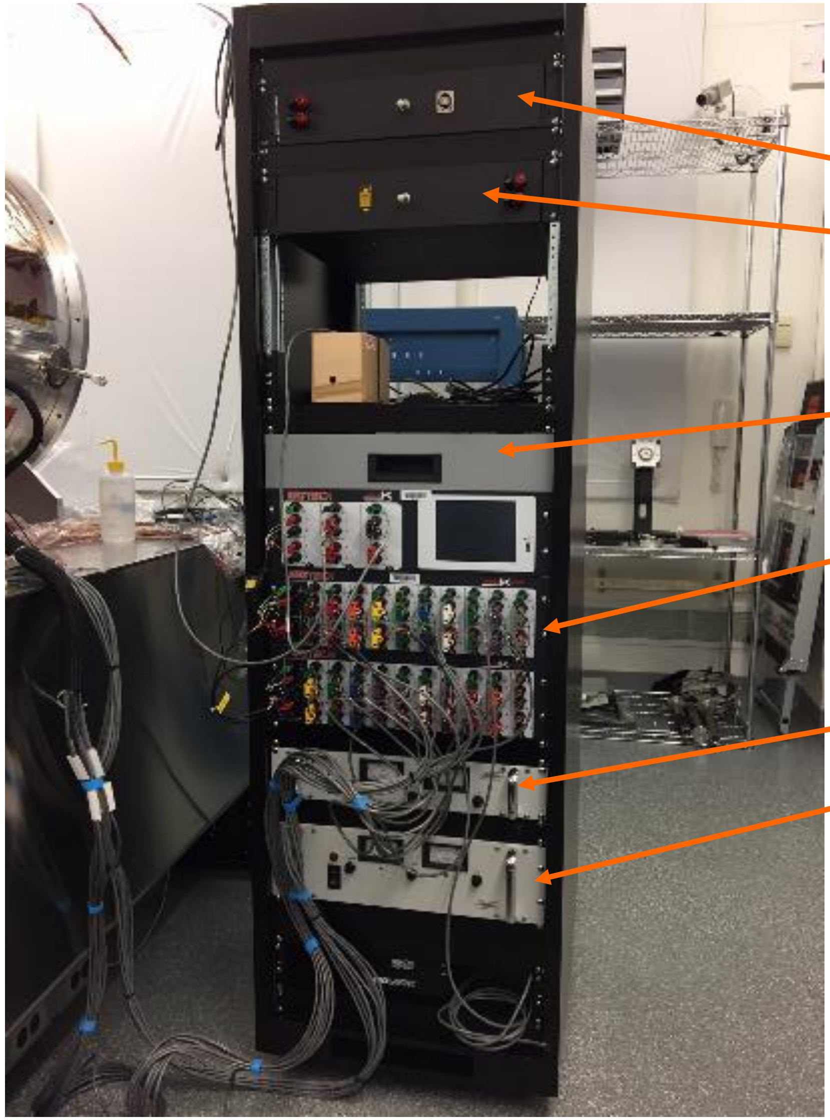
Ultra-Stable Picometer-Scale Mirror Assembly (USPS-MA) Demonstrator: DETAILS





- ULE Mirror Substrate
- Diffuser Plate
- Heater Plate
- Coldplate (Liquid)
- Thermal Radiation Shields (2x)
- Housing

Ultra-Stable Picometer-Scale Mirror Assembly (USPS-MA) Demonstrator: Electronics



Upgraded Ultra-Stable Chamber Electronics Rack

Heater Power Drive Module (Chamber)
Heater Power Drive Module (Mirror Assembly)

Logic Control Laptop

High Precision Thermometry system (Expanded to 20 Channels)

Heater Power Supply (Mirror Assembly)
Heater Power Supply (Chamber)

Discussions

- To meet the 10 pm over 10 minutes WFE goal for LUVOIR, the current state of art thermal sensing and control capabilities will be pushed to its limits.
- Refinements of Optical Error Budget allocation will dictate thermal control requirements
- In order to add margins to the future design challenges associated with the ultra-stable telescope components, further technology developments should be considered in the areas of:
  - **Temperature specific near-zero and lower variability ULE CTE**
  - **Lower composite CTE** such as uses of nano-carbon tube technologies
  - **Better manufacturing control of the variations in Composite CTE**.
  - **Finer, sub-milli-K thermometry system** with improved heater control logics.
  - **Higher thermally insulating composite surface finishes, low emittance** values that would match the effective emissivity of a MLI thermal blanket,

QUESTIONS

Thanks!

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