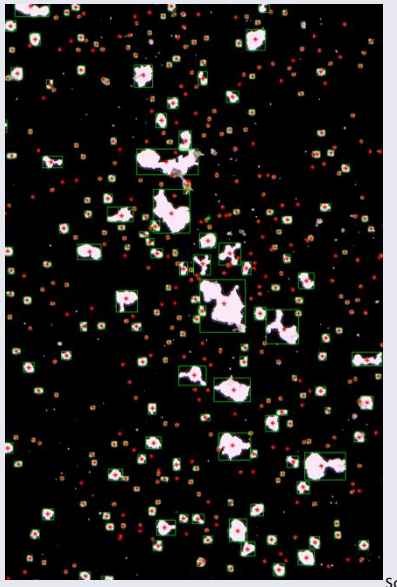
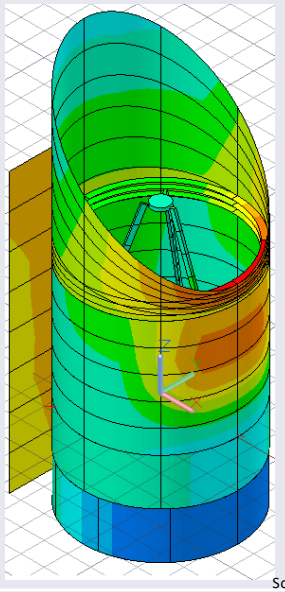
ROSES D.19 Critical Technologies for Large Telescopes: Systems Technologies for Architecture BaseLinE (STABLE) Study

NORTHROP GRUMMAN

Tiffany Glassman
Jon Arenberg
George Harpole
Todd Lawton
Jim Tucker
& the whole STABLE team

11/20/2024

STABLE Study Topics

Study Topic	Micrometeoroid (MM) Impact Mitigation	Telescope Temperature Control	Ultra-Stable Telescope Structure Materials & Modeling	Improvement of Thermal Expansion Test Capability
	 Source: NG	 Source: NG	 Source: NG	 Image courtesy of Kratos
Lead	Jonathan Arenberg (NG)	George Harpole (NG)	Todd Lawton (NG)	Jim Tucker (Kratos)
Supporting	NG, Heliospace, NeXolve, WSTF, STScI	NG, JPL	NG, GSFC, Kratos, JPL	NG
Effect of Maturation on HWO Program	• Inform architecture trades for baffle configuration • Increase TRL & MRL of baffle by establishing effective methods for MM mitigation	• Inform architecture trades for baffle configuration and telescope thermal control • Reduce thermal control risk, increasing TRL of thermal control and producibility/MRL	• Reduce thermal instability risk, increase TRL of stable telescope structure • Improve MRL of backplane with potential to reduce schedule and cost	• Increase TRL of material characterization, decreasing risk • Improve MRL of all telescope components requiring picometer stability

All images cleared in case 24-1474

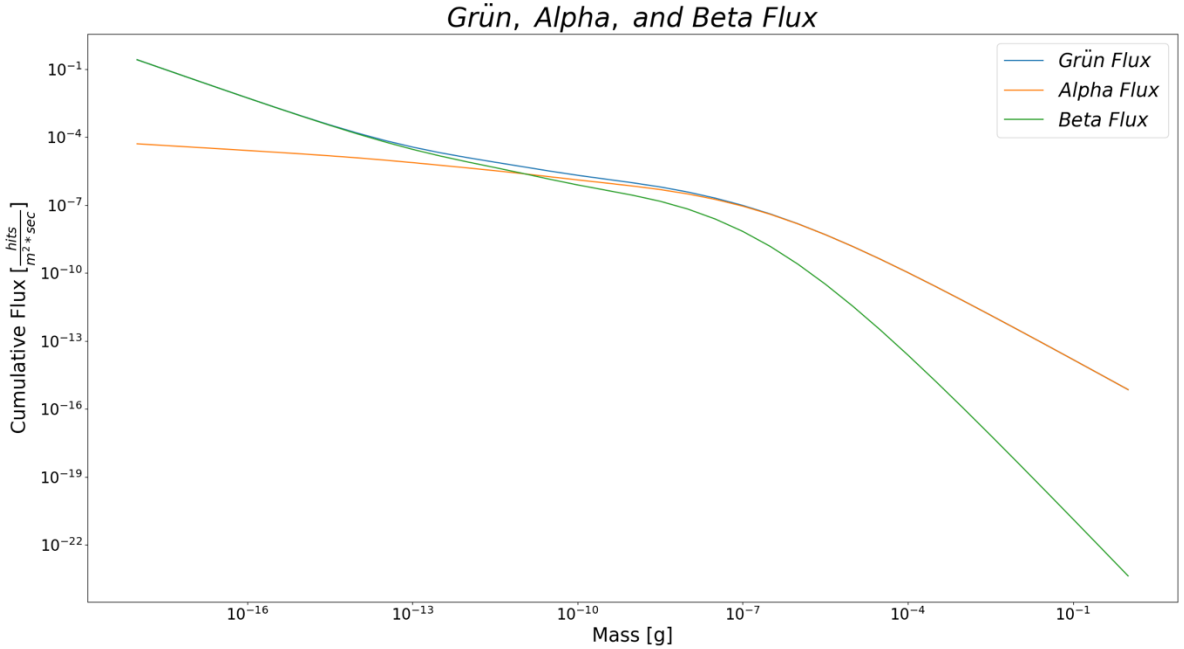
Study 1: Micrometeoroid (MM) Impact Mitigation

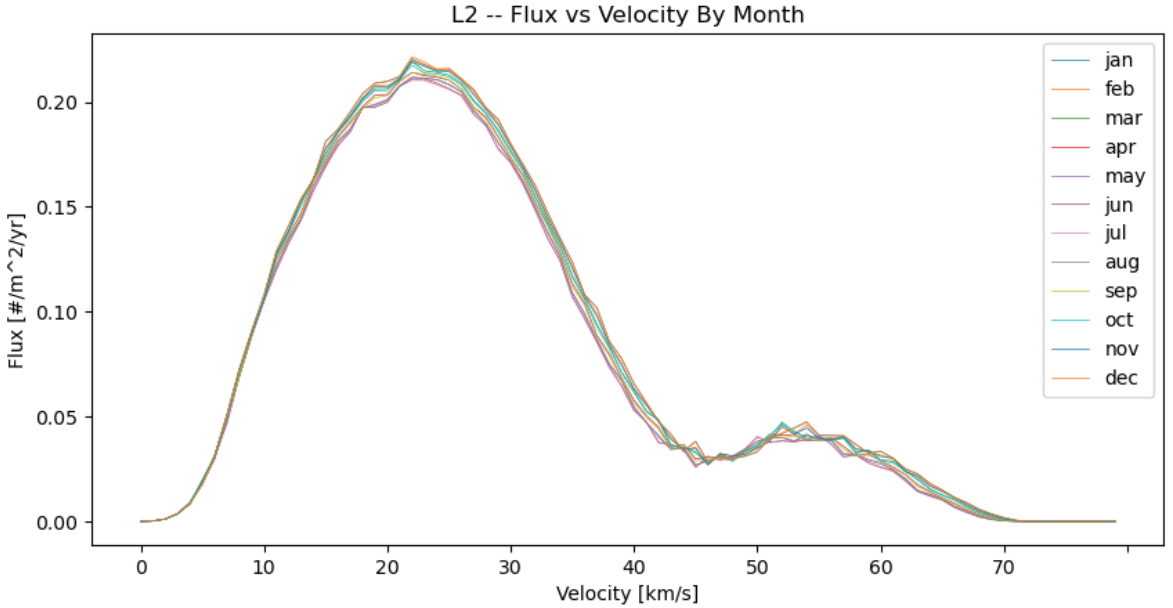
Co-I Jon Arenberg (NG)

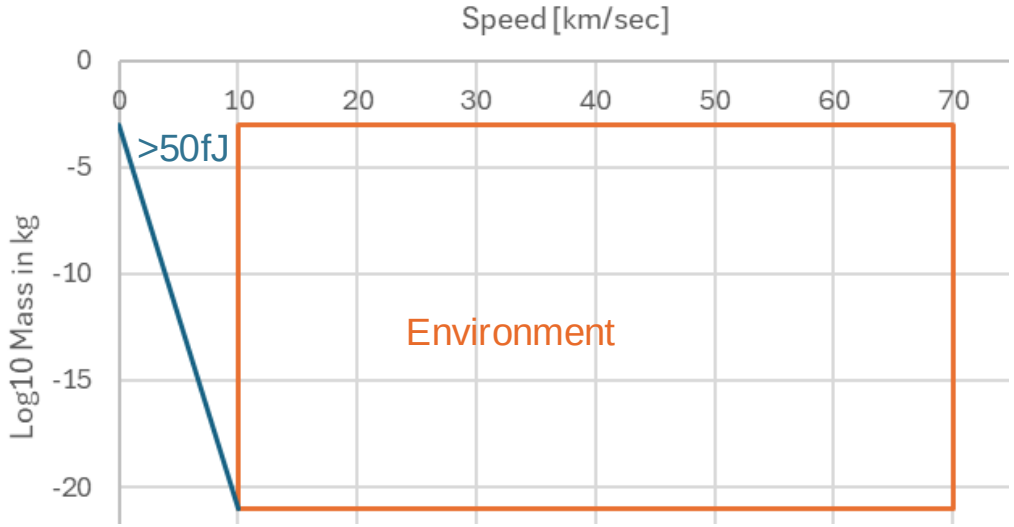
Introduction

- HWO needs a shield to protect the mirror from damage and to minimize the effect of impacts on the dynamic stability of the telescope
- We have developed a physics-based model of MM penetration of thin shielding material and have conducted preliminary testing
- Need physics-based model (first principles) that has been validated with ground tests and can be used to extrapolate to the flight environment
  - Understand the physics so we can account for uncertainties
  - Natural particles are different than test particles in species, mass, and velocity
- In this study, we will conduct further hypervelocity tests of a range of material options (including materials with environmental exposure), correlate the model to the results, and develop requirements for the shield configuration

MM Environment





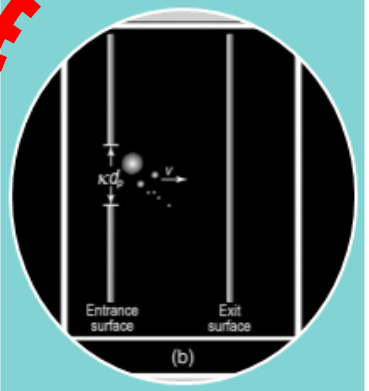


We calculated that the energy stored in 1 pm of displacement (using JWST values for the structure as a starting place) is 50 femto-Joules (fJ)

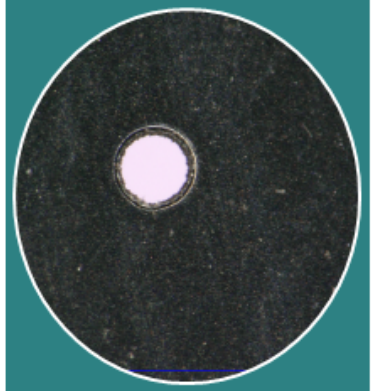
The entire natural MM flux lies WELL above this disturbance threshold

Grün, Eberhard, et al. *Icarus* 62.2 (1985): 244-272.
Sommer. *Planetary and Space Science* 236 (2023): 105751
Miller. *Contract Num*: 16852/02/NL/JA (2024)
Arenberg. *Proc. SPIE* 11115, (2019): 1B

Current Knowledge is Insufficient for Shield Design



Fragmentation Model (Species, Mass)



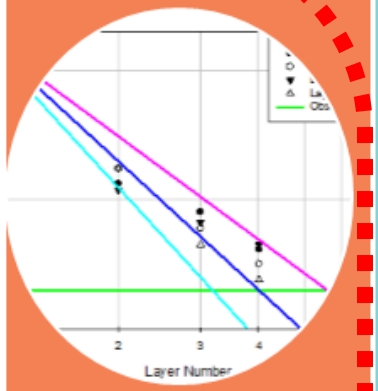
Shield Materials



Environmental Changes to Material Properties

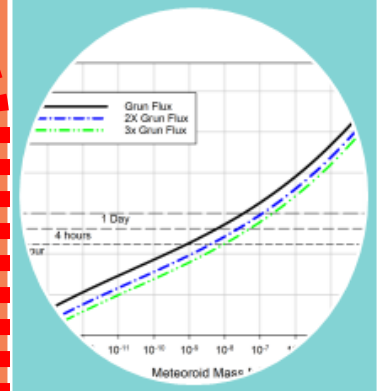


Design (Layers, spacing)



Requirements Definition and Figures of (De)merit

Verification

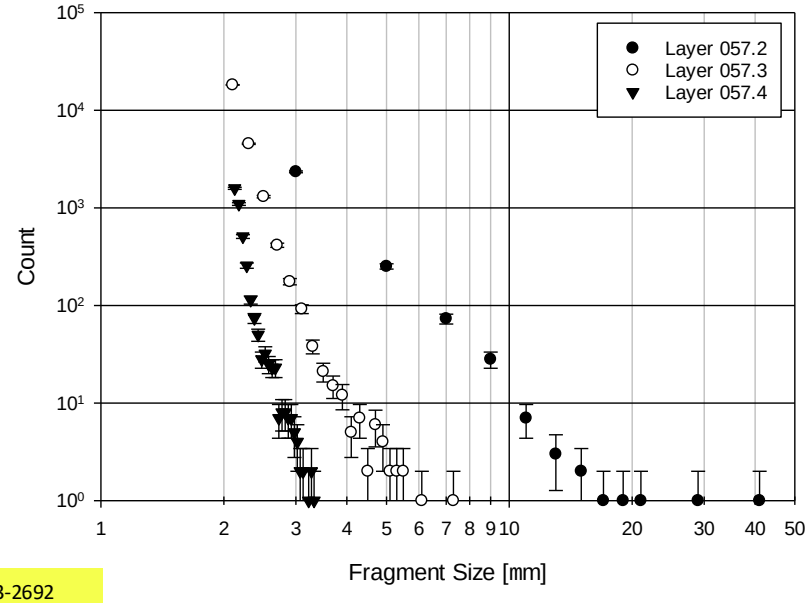


Environment (Mass, Flux, Direction, Species, Velocity)

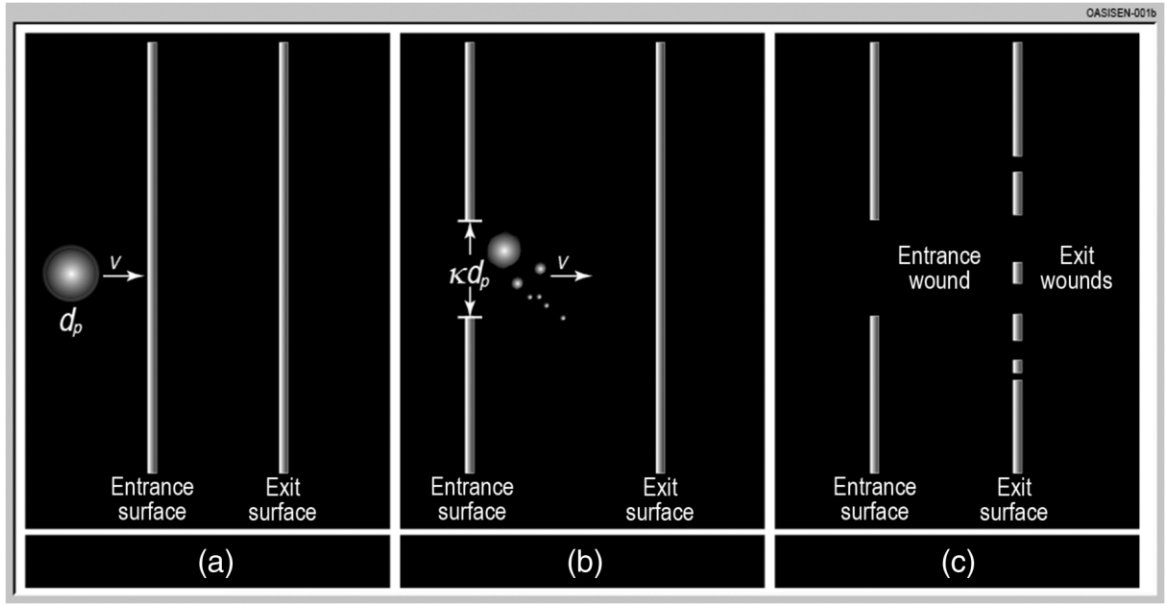
Images source: NG

Model of Fragmentation, Ionization, & Mass and Momentum Conservation

- Understand the fragmentation mechanisms
  - Earlier experiments showed that the radial distribution of fragments is well matched by a Rayleigh distribution and is more dependent on target material properties than any other parameter
- Understand conversion of MM to plasma
  - Literature and flight observations suggests threshold is ~6-8 km/sec
  - Initial analysis suggests this is independent of mass



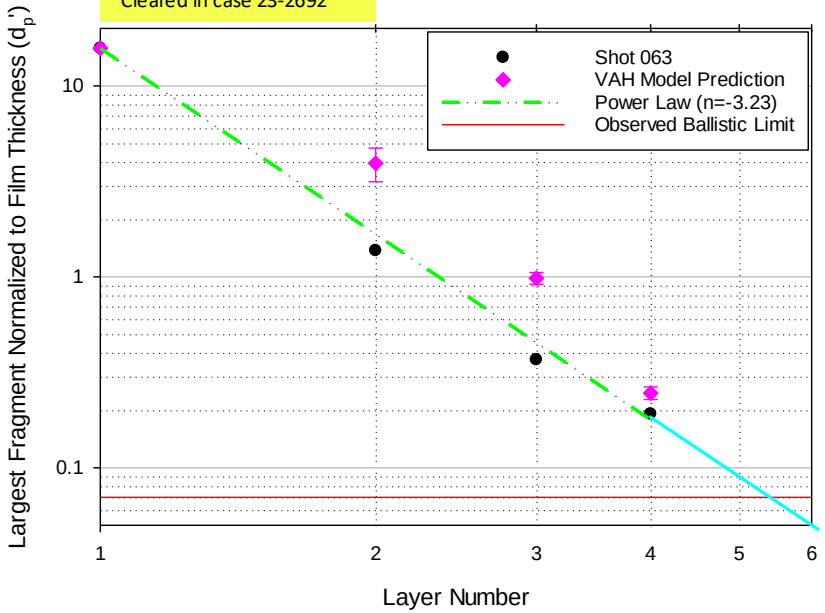
Cleared in case 22-0412



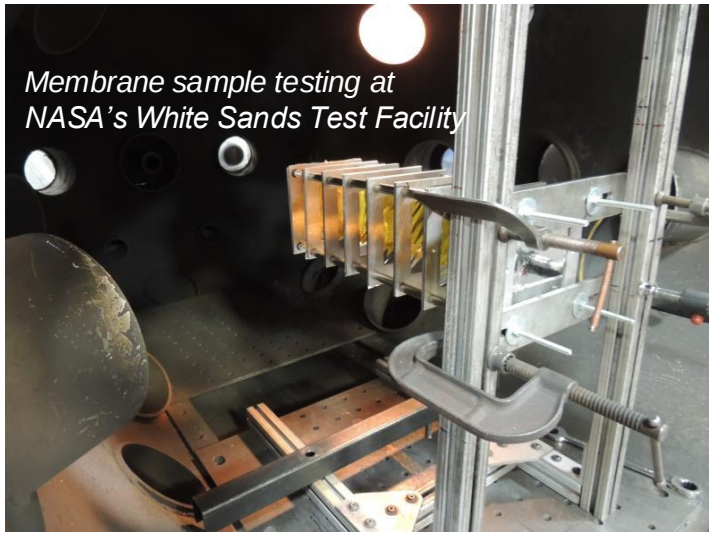
Villarreal, Arenberg, & Harris. JATIS 8(4) 044006 (2022)

Images source: NG

Cleared in case 23-2692

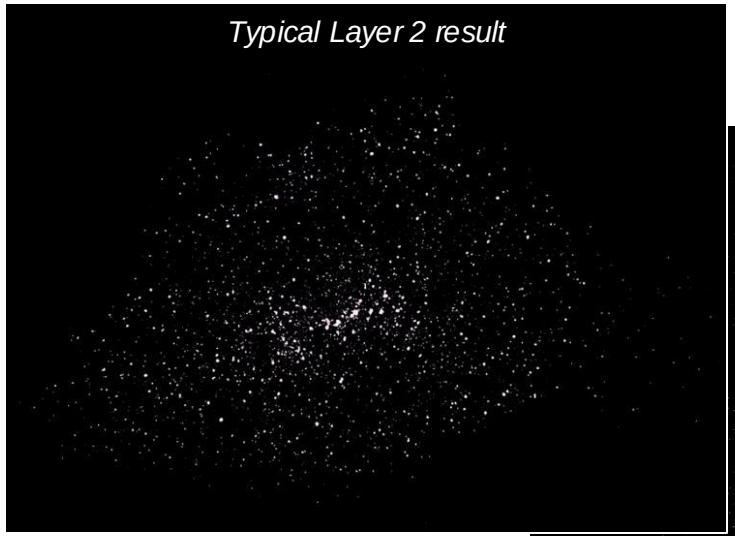


Hypervelocity Testing

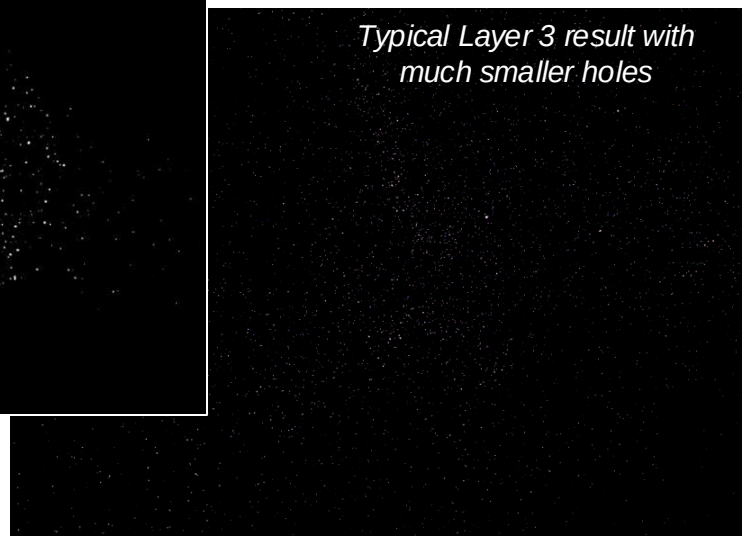


Membrane sample testing at NASA's White Sands Test Facility

Previous test setup and photos of results on layers 2 & 3



Typical Layer 2 result



Typical Layer 3 result with much smaller holes

Images source: NG

Current test plans:

Test series 1: Pristine membranes

Test series 2: Membrane aging

Test series 3: Prototype shields and system design

Series	Impactor (~0.2 mm diam)	Target Materials	Temperature	Impactor Velocity	Env Exp
1	Ruby (Al_2O_3) & Metallic	CP-1 & Reinforced CP-1	Low (100K), Room Temp, Hot (350-380 K)	4 km/s & ≥7 km/s	No
2	Driving Case from Test 1	CP-1 Blk & Reinforced CP-1 Blk	Driving Temp from Test 1	4 km/s & ≥7 km/s	Yes
3	Driving Case from Tests 1&2	Prototype Shield	Flight-like Temps	4 km/s to max	Yes

Study 2: Telescope Temperature Control

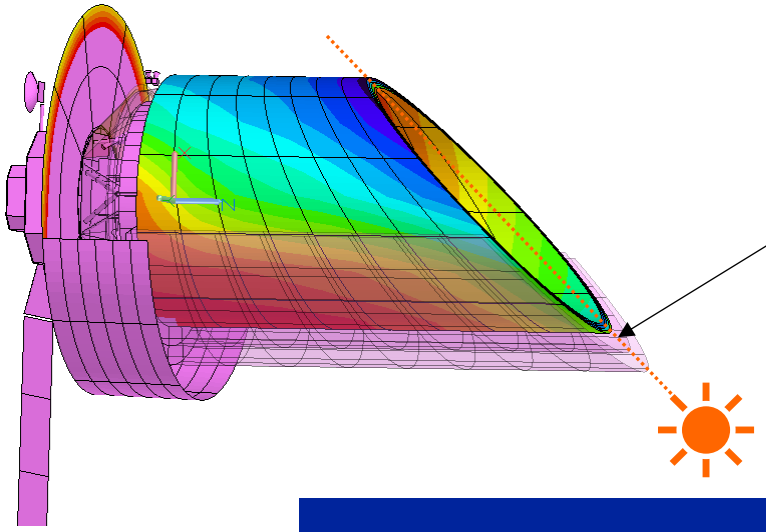
Co-I George Harpole (NG)

Introduction

- Holding the HWO telescope dimensionally stable to the required levels necessitates maintaining it at a near-constant temperature
- This can be accomplished by minimizing both radiative and conductive thermal disturbances
- In this study, we model the baffle performance to inform the design and then perform a sub-scale test to validate the model
- Later in the study, we will also test a concept for improved cable guard heating with direct contact with the shielding

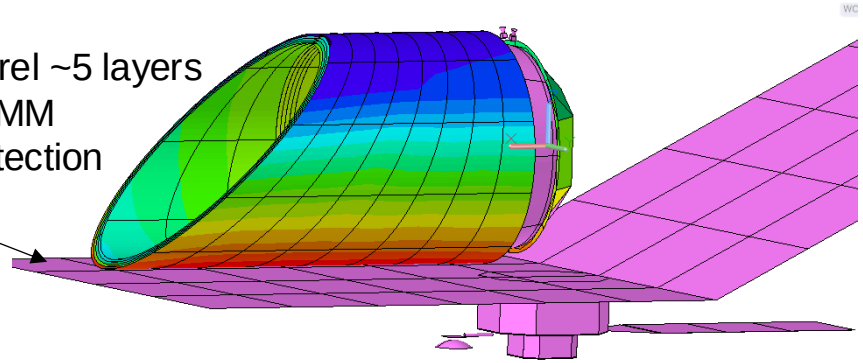
Barrel Architecture Concept

- The HWO baffle was assumed to need heaters to stabilize its temperature and minimize impact on Primary Mirror (PM)
- Any such heaters must be insulated (interior and exterior) to avoid huge heat losses
- However, the interior insulation alone may be sufficient to isolate PM from changes in barrel exterior temperature
  - Per our initial analysis, multi-layer insulation (MLI) with e* = 0.01 is sufficient, but spaced single-layer insulation (SLI) is even better
- Looking at the concept of a baffle consisting of a ~5-layer barrel and a 1- or 2-layer shield
  - No view of the barrel interior from the sun or shield
  - No direct sun view of the barrel exterior
  - The PM and barrel interior view is constant, deep space
- In this case, barrel heaters are not needed because of low barrel exterior temperatures (due to the shield), insulating capability of the barrel, and the 100% deep space view



Shade is 1-2 layers, wrapped halfway around barrel or flat

Barrel ~5 layers for MM protection

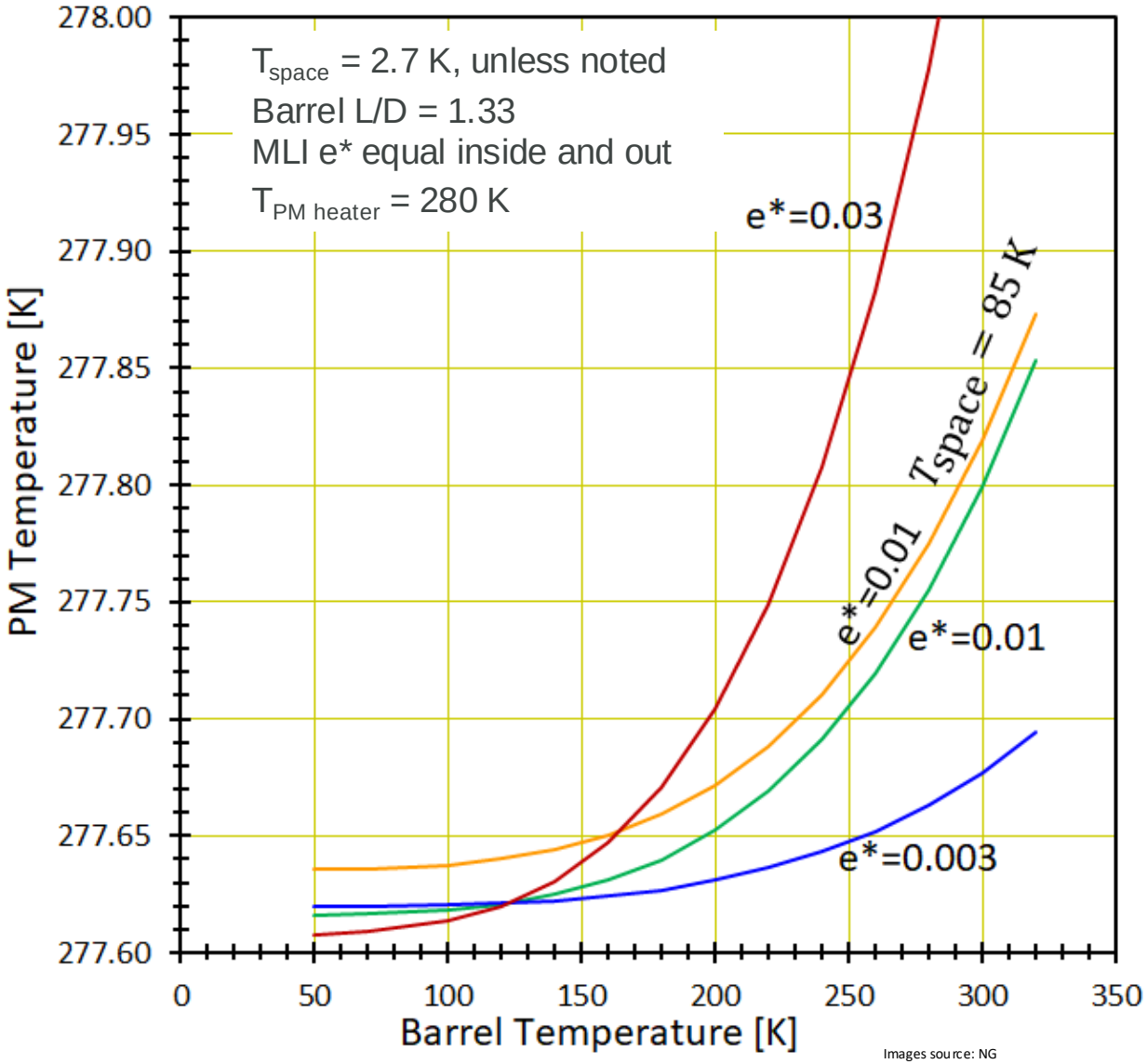


Trade actively-controlled barrel heaters for a shade and no heaters (all passive)

Images source: NG

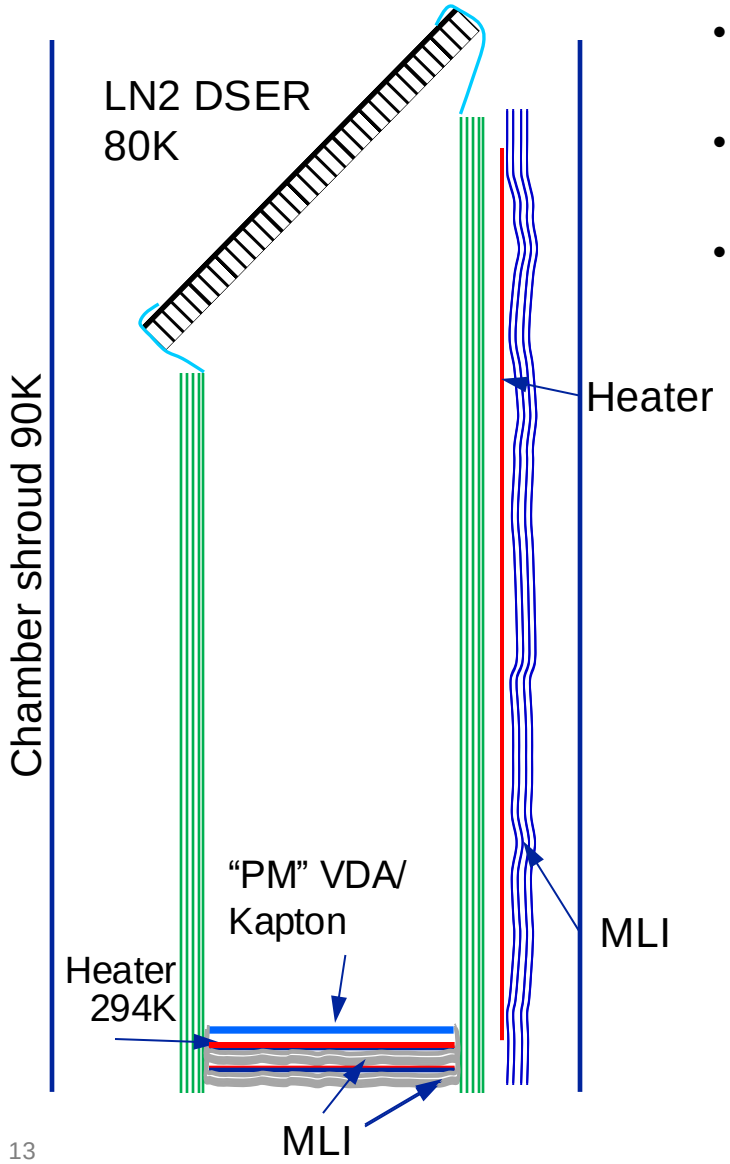
Insulated Barrel Plus Shade Enables Stable Mirror Temperatures

- The sensitivity of the Primary Mirror temperature (T_{PM}) to changes in the temperature of the barrel exterior ($T_{Barrel_exterior}$) varies with the heat transmissibility (e*) of the barrel
- If $T_{Barrel_exterior}$ varies from 50K to 150K, dT_{PM} = 12 mK with e* = 0.01, but only 3.6mK with e* = 0.003
- The sensitivity of the PM temperature to changes in the barrel temperature ($dT_{PM}/dT_{Barrel_exterior}$) is roughly proportional to e* and is lower when the barrel is colder

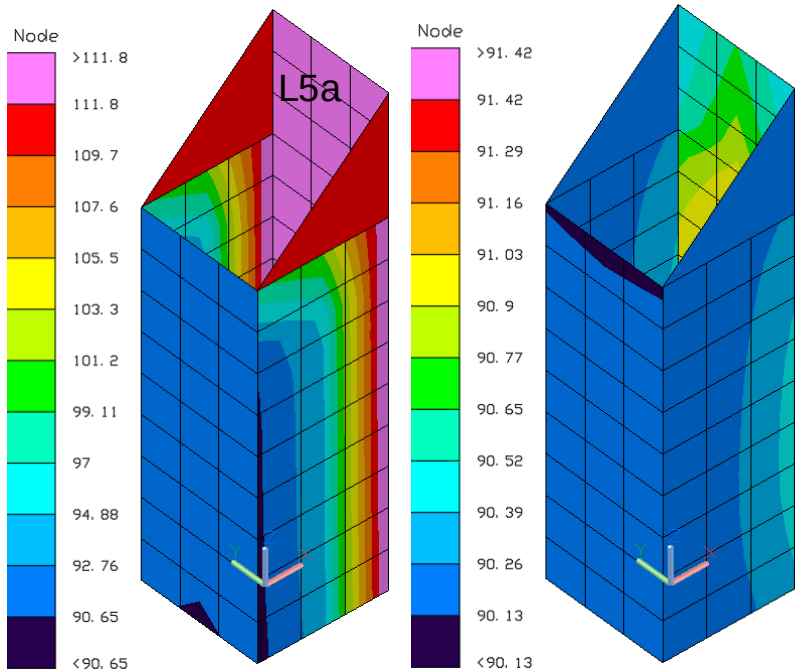


Images source: NG

Test of Scale-Model Barrel



- Model was used to predict the barrel exterior temperature, which is highest when the telescope is 90° to the sun
- The sun-side maximum temperatures range 118 to 207 K for different shade configurations
- Test will vary the barrel exterior temperature from no heat to this maximum temperature predicted and measure the impact on the PM simulator temperature



Layer 5 200K Case Layer 5, Floating Case

- Model of test configuration with varying temperature on sun-facing surface of barrel
- Shows very little change in PM simulator temperature

T_L5a [K]	T_PM [K]	ΔT
Floating	291.18052	
100	291.18065	0.0001
150	291.18230	0.0018
200	291.18657	0.0061

Images source: NG

Study 3: Ultra-Stable Telescope Structure Materials & Modeling

Co-I Todd Lawton (NG)

Introduction

- Creating a structure that is stable at the level of picometers, requires understanding the behavior of the base materials, joints, bonds, latches, etc. even in the presence of an active control system, to levels that are orders of magnitude more precise than was needed for JWST
- The goal of this study is to determine what improvements need to be made in the analysis, manufacturing, and testing of the structure to achieve this level of improvement
- This study will address four areas that can improve the stability, predictability, and manufacturability of composite structures
  - Damping Test
  - Picometer Analysis
  - Material and Manufacturing Optimization
  - Microdynamics Investigation
- These tasks work towards a future goal of building subscale test articles to validate picometer level performance

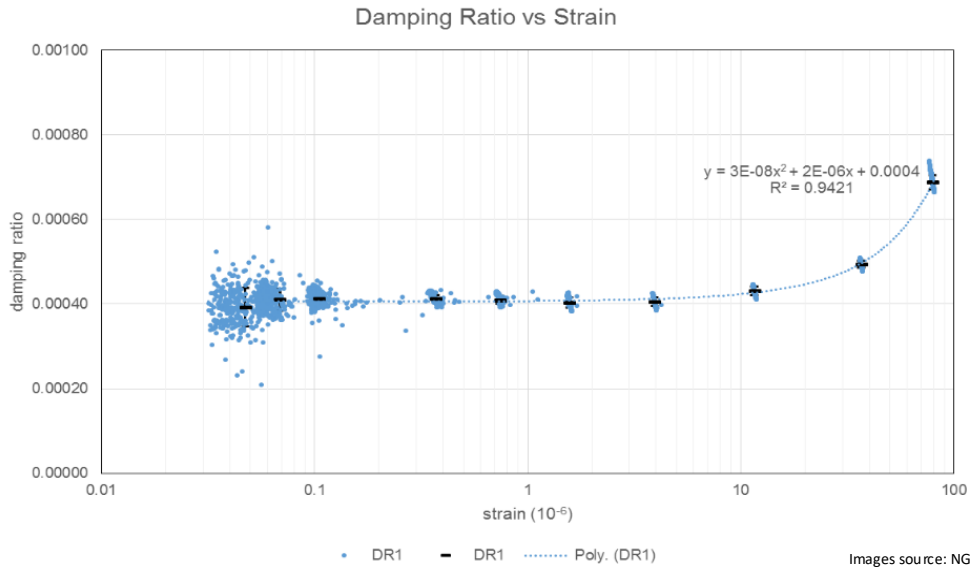
Damping Test

Previous Progress:

Tested performance of damping foil on flight-like composites at launch and on-orbit loads and found:

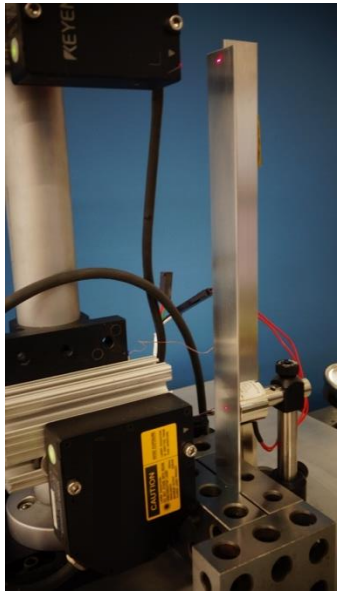
- Damping foil is effective at appreciably increasing the damping ratio
- The ratio does not vary significantly over frequency and strain ranges tested
- Damping ratio plateaus with foil coverage
- Aging effects investigated do not impact damping performance

However, a sub-element test was inconclusive about the impact of damping foil



Images source: NG

Al sample in test setup was used to prove out process



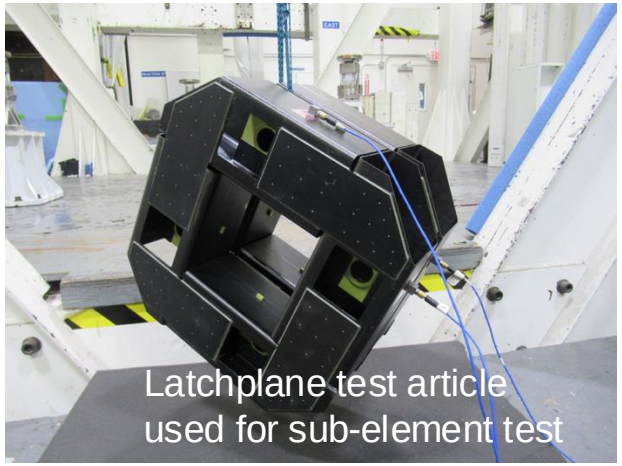
Approach for current study:

Analysis of test setup

- Determine what in the test setup caused the measured damping
- If possible, bring test frequency down to <250 Hz

Damping test

- Perform updated damping test to evaluate effects of improvements

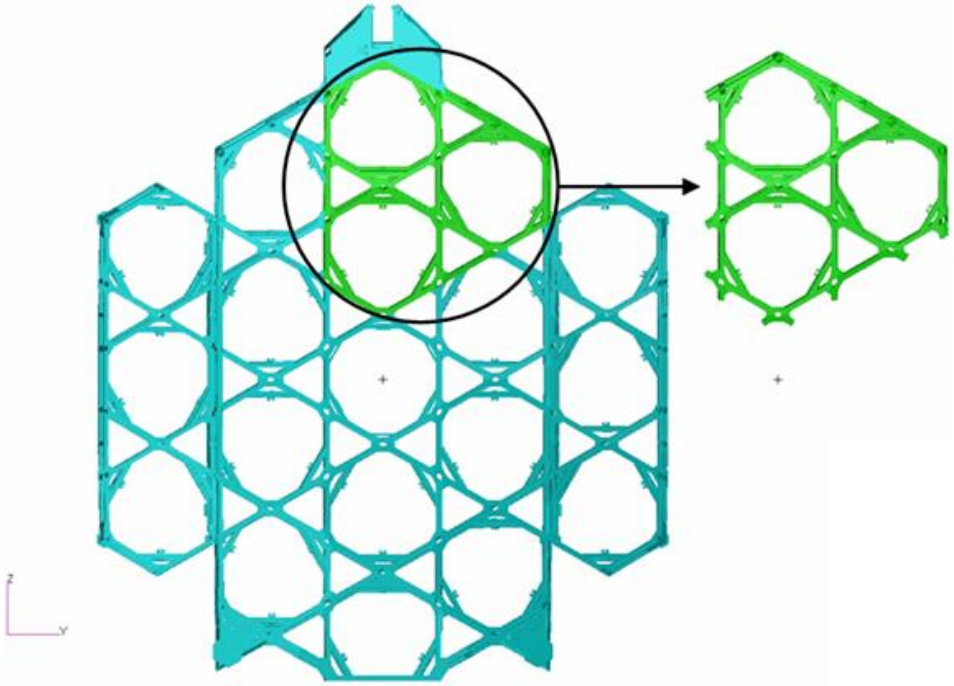


Improve structural damping, reducing large launch loads and mitigating small on-orbit loads

Picometer Analysis

- Tune JWST model for new environment
- Determine if model has numerical accuracy to predict picometer movements
  - Apply loads at levels that should produce picometer movements
  - Apply loads at nanometer + picometer levels – can you get linear changes at picometer level?
  - Difference between states i.e., 20 to 25C, 20 to 25.001C same as 25 to 25.001C, similar to studies with load states
- Study mesh refinement for picometer measurements
  - Similar to BSTA “gold standard” studies
- Study material variability for picometer movements
  - What capability do we need out of the manufacturing/ metrology processes?
  - This will help us identify manufacturing and work in progress testing requirements – by only targeting the necessary areas, we can reduce cost and schedule

Overall modeling and manufacturing expected to be based on the same approach used on JWST:
Coupon testing – DOTA – linear DAVEs – BSTA – Pathfinder – Flight Backplane



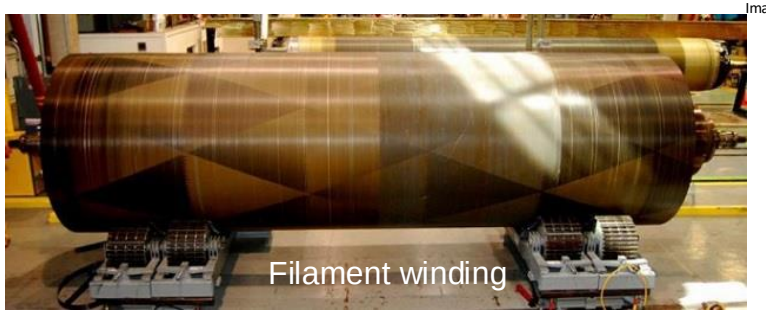
Images source: NG

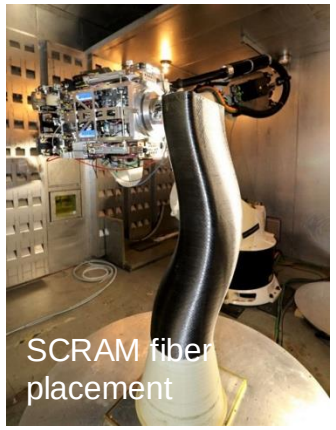
Develop understanding of how to numerically model a structure to be stable at the picometer level

Material and Manufacturing Optimization

- Research material options and compare to M55 as the “standard”
  - Expected drivers to include stiffness, performance at operating temperatures, CTE, and stability
- Research manufacturing methods (including assembly approach)
  - Review JWST, RST data for cost & schedule
  - Look for cost/scheduling savings opportunities
  - Look at automated manufacturing capabilities
- Down select material/manufacturing method(s) and create coupon(s)
  - Based on lessons learned from the modeling study and lurching data
- Test at GSFC ULTRA STABLE LAB
  - Obtain data to validate/refine models

Images source: NG





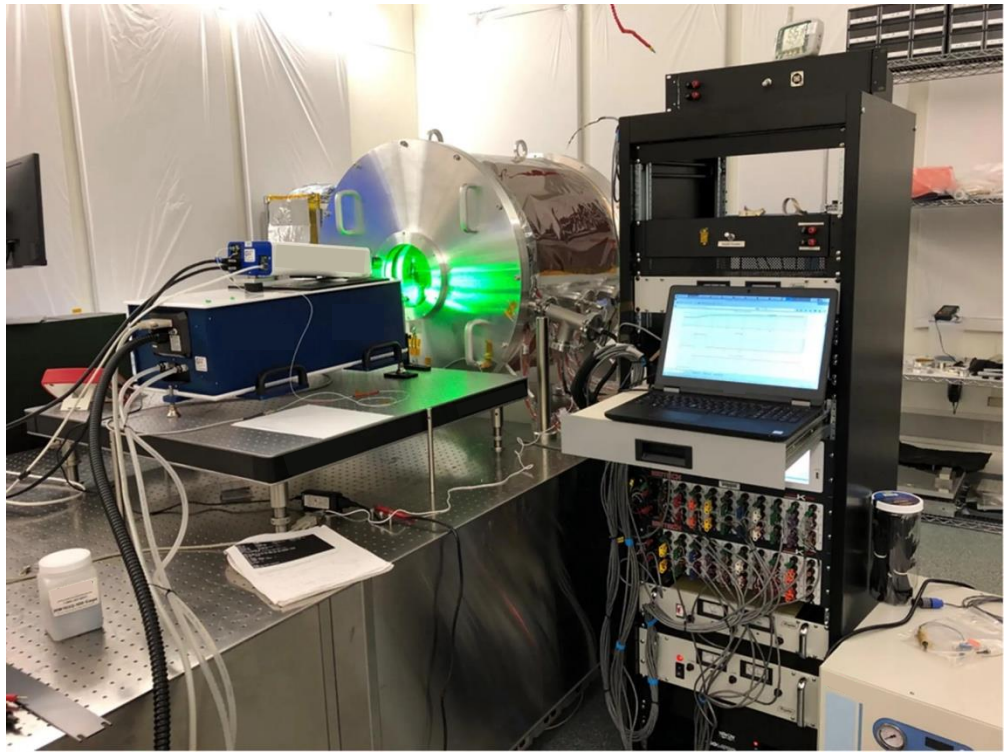


Image courtesy of NASA

NASA’s ULTRA STABLE LAB

Develop materials and processes that will support timely and cost-effective delivery of stable structures

Microdynamics Investigation

- Study will start by investigating past lurching evidence
  - JWST flight data
  - Past CTE measurements
- Modeling effort
  - How can we model this (step input functions)
  - At what point does it matter?
    - How large do the lurches have to be to impact the distortions?
    - How does the number of lurches matter (randomly pick 10%, 20%, 30%, etc. of structure and have it lurch)
    - Is there a point where it no longer matters – enough randomness in various directions might cancel itself out

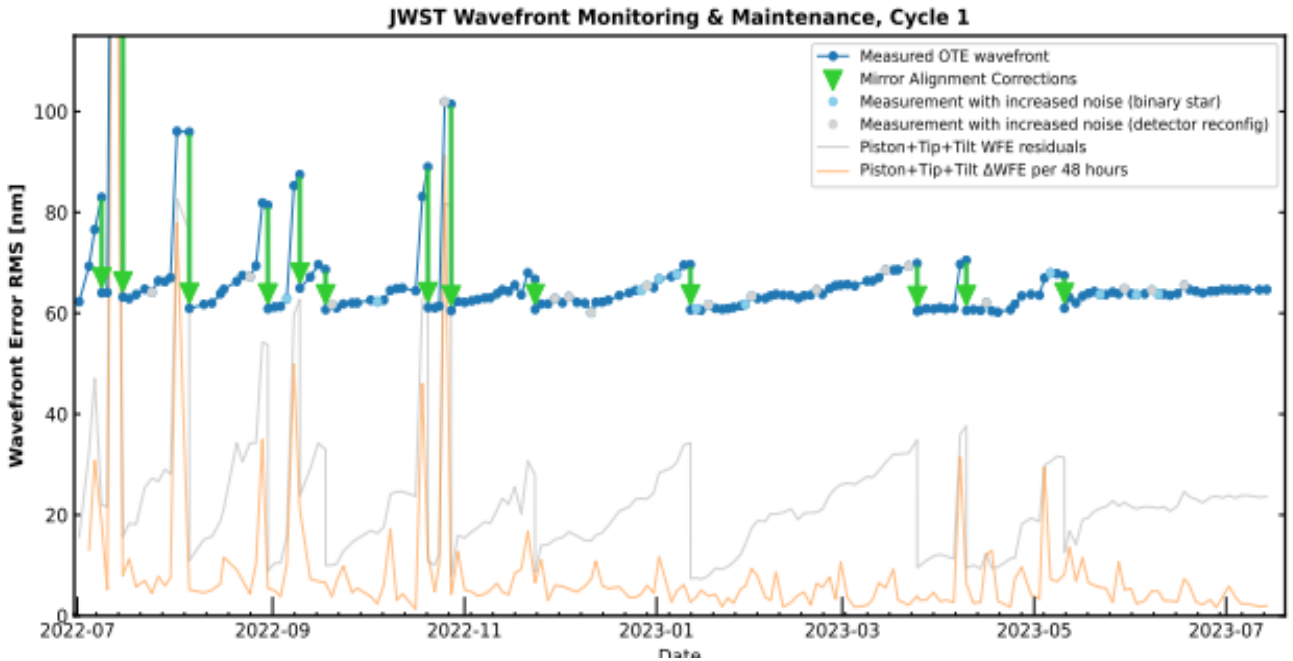


Image from "OTE Science Performance Memo 2: WST-STScI-008497"

Develop methods to model structure lurching, to perform tests to validate models, and to better understand the effects of non-linear responses to loads

Study 4: Improvement of Thermal Expansion Test Capability

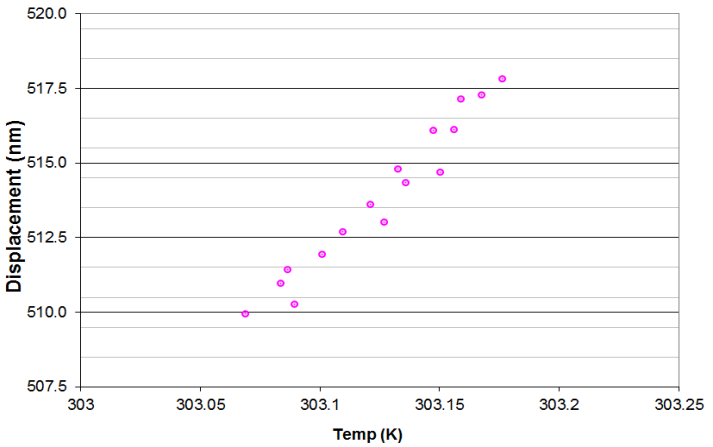
Co-I Jim Tucker (Kratos SRE)

Introduction

- Goal of this effort is to improve CTE measurement accuracy to order of 0.1 ppb over a 2K thermal delta
- This is ~two orders of magnitude better than the legacy JWST capability (IMF)
- The basic optical system used in the IMF (differential, double-pass heterodyne distance measuring interferometer) has demonstrated performance that will meet these goals, so this approach was retained
- Steps to achieving desired CTE resolution:
  - Improve heterodyne interferometer system resolution
  - Improve testbed environmental control
- Maintain legacy capability including high throughput, being material agonistic, and being scalable to large structures
- Strategic decisions are also made with awareness to the cost of potential implementation

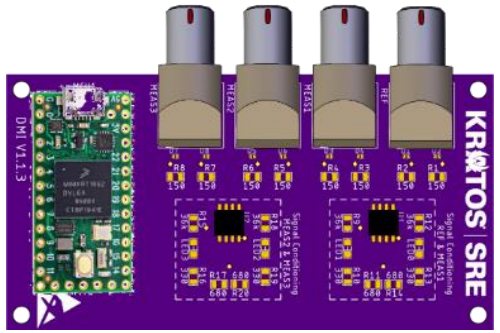


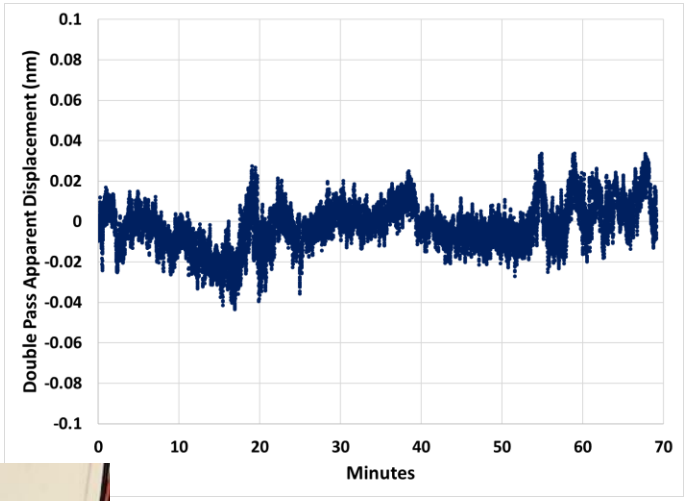
Images courtesy of Kratos



Progress to Date

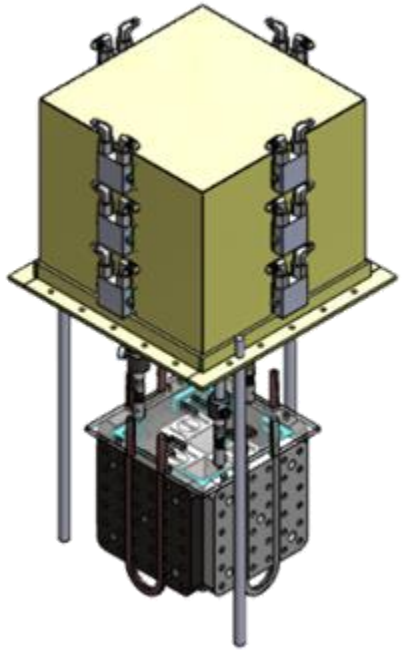
- Heterodyne interferometer system improvements:
  - Optical amplification: Design of a multi-pass beam system that allows optical amplification.
  - Electronics: USB addressable heterodyne reader with 1 KHz update rate and numerical resolution in the 10's of pm.
  - Acquisition parameters and data treatment: phase wrapping statistical algorithms (developed by Marcel Bluth) and analysis guiding trades between data density and update rates.
- Environmental control improvements:
  - New CTE testbed with thermal control using recirculating liquid baths and thermoelectric coolers (RT only capable) so that it does not contribute to mechanical vibration and noise
  - Massive specimen thermal shroud to facilitate finer and more stable control.
  - Creation of an OPD model (by Marcel Bluth)





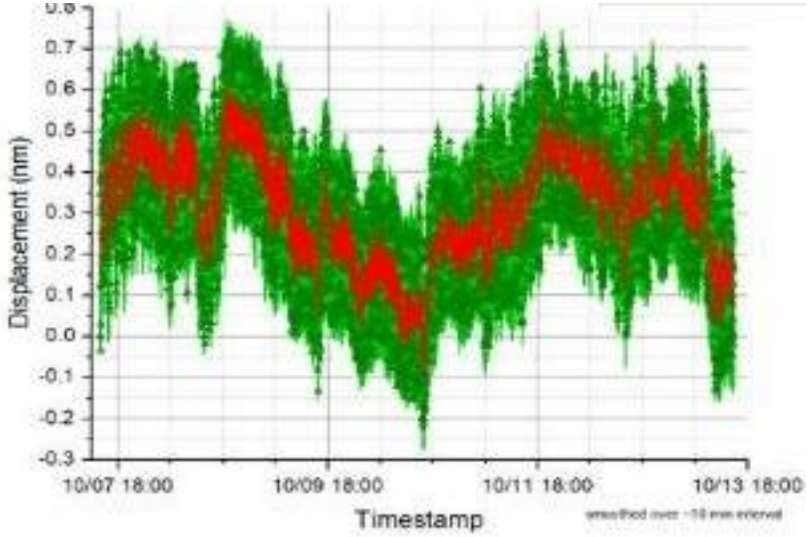


Images courtesy of Kratos



Gaps to be Addressed by STABLE (Heterodyne Interferometer)

- Instability of the heterodyne beat frequency from the COTS orthogonally-linear-polarized dual-frequency lasers
  - Rapid changes in the laser beat frequency can confound counting statistics and diminish resolution by an order of magnitude or more as the beat frequency moves in and out of harmonic relationships with data acquisition frequency.
  - Currently addressed using an algorithm to sample data at two different frequencies and using the standard deviation of results to select the “best” data set to report. (significantly reduces data update rate)
- Laser pointing stability (see next slide)
- 1 KHz data rates are adequate for long-term specimen testing but insufficient for structure testing where higher frequency modal sampling is required. 10 to 20 KHz data rates will be pursued.

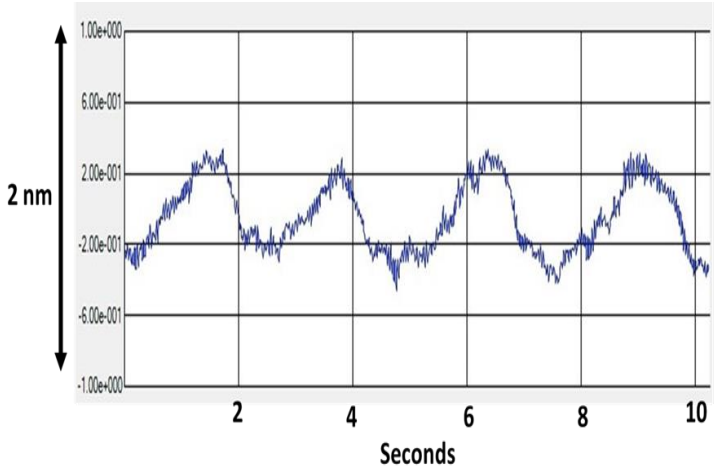


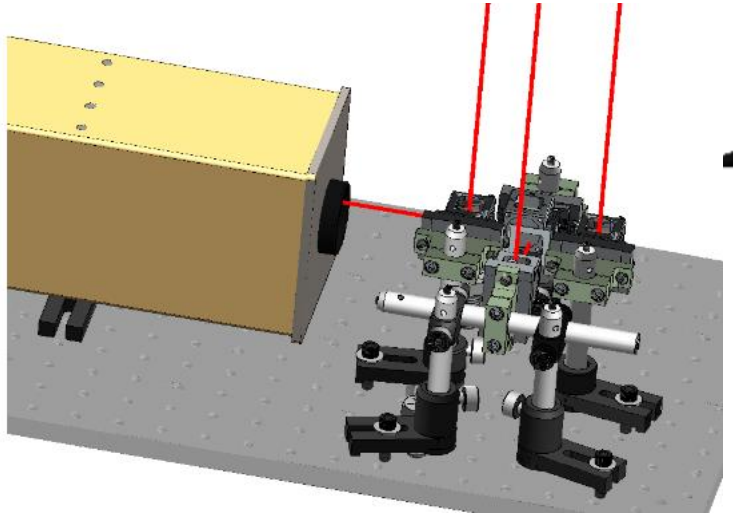


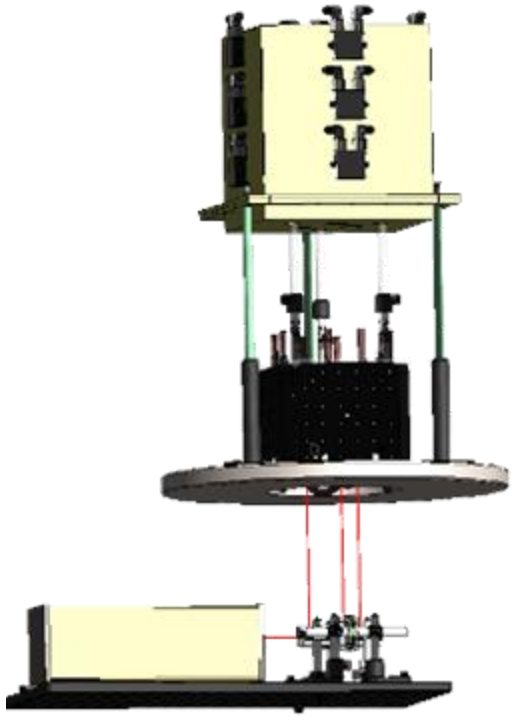
Images courtesy of Kratos

Gaps to be Addressed by STABLE (Environmental Control)

- Optics Environment:
  - OPD analysis suggested some specific areas to address:
  - Laser pointing stability
    - Pointing stability of the laser beam distribution system
    - Thermal isolation of the interferometers from specimen temperature
    - Laser beat frequency (see previous slide)
- Mechanical Environment:
  - Even in the most pristine thermal environments achieving pm resolution for more than a few seconds was challenged by the mechanical environment.
  - Studies are ongoing to identify best isolation practices.







Images courtesy of Kratos


NORTHROP
GRUMMAN