Advanced UVOIR Mirror Technology Development for Very Large Space Telescopes

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Objective

Define and initiate a long-term program to mature six inter-linked critical technologies for future UVOIR space telescope mirrors to TRL6 by 2018 so that a viable flight mission can be proposed to the 2020 Decadal Review.

- *Large-Aperture, Low Areal Density, High Stiffness Mirrors:* 4 to 8 m monolithic & 8 to 16 m segmented primary mirrors require larger, thicker, stiffer substrates.
- *Support System:* Large-aperture mirrors require large support systems to ensure that they survive launch and deploy on orbit in a stress-free and undistorted shape.
- *Mid/High Spatial Frequency Figure Error:* A very smooth mirror is critical for producing a high-quality point spread function (PSF) for high-contrast imaging.
- *Segment Edges:* Edges impact PSF for high-contrast imaging applications, contributes to stray light noise, and affects the total collecting aperture.
- *Segment-to-Segment Gap Phasing:* Segment phasing is critical for producing a high-quality temporally stable PSF.
- *Integrated Model Validation:* On-orbit performance is determined by mechanical and thermal stability. Future systems require validated performance models.

We are pursuing multiple design paths give the science community the option to enable either a future monolithic or segmented space telescope.

Approach

Technology must enable mission capable of doing both general astrophysics and ultra-high contrast observations of exoplanets.

Outstanding team of academic, industry & government with expertise:

- UVOIR astrophysics and exoplanet characterization,
- monolithic and segmented space telescopes, and
- optical manufacturing and testing.

Integrate science & systems engineering to:

- derive engineering specifications from science measurement needs and implementation constraints;
- identify technical challenges in meeting these specifications;
- iterate between science and systems engineering to mitigate challenges; and
- prioritize the challenges.

Systematically mature TRL of prioritized challenges using

- design tools to construct analytical models and
- prototypes/test beds to validate models in relevant environments.

Goals

Defined quantifiable goals for each of the six key technologies:

Large-Aperture, Low Areal Density, High Stiffness Mirror Substrates:

- make a sub-scale mirror via a process traceable to 500 mm deep mirrors

Support System:

- produce pre-Phase-A point designs for candidate primary mirror architectures; and
- demonstrate specific actuation and vibration isolation mechanisms

Mid/High Spatial Frequency Figure Error:

- 'null' polish a 1.5-m AMSD mirror & subscale deep core mirror to a < 6 nm rms zero-g figure at the 2 C operational temperature.

Segment Edges:

- derive edge specifications traceable to science requirements; and
- demonstrate an achromatic edge apodization mask.

Segment to Segment Gap Phasing:

- develop models for segmented primary mirror performance; and
- test prototype passive and active mechanisms to control unconstrained, damped and constrained gaps to ~ 1 nm rms.

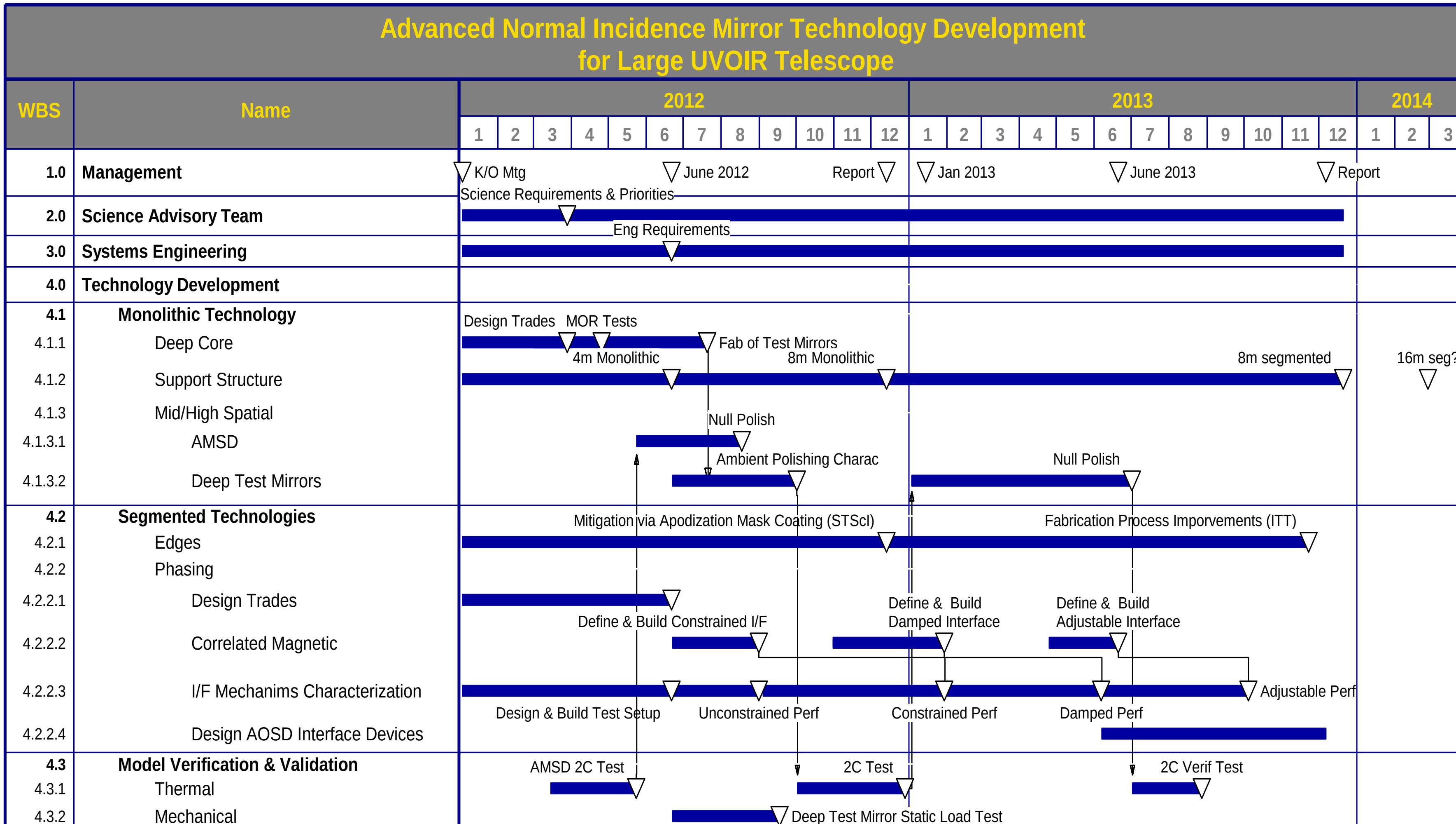
Integrated Model Validation:

- validate thermal model by testing the AMSD and deep core mirrors at 2 C; and
- validate mechanical models by static load test.

Work Breakdown Structure

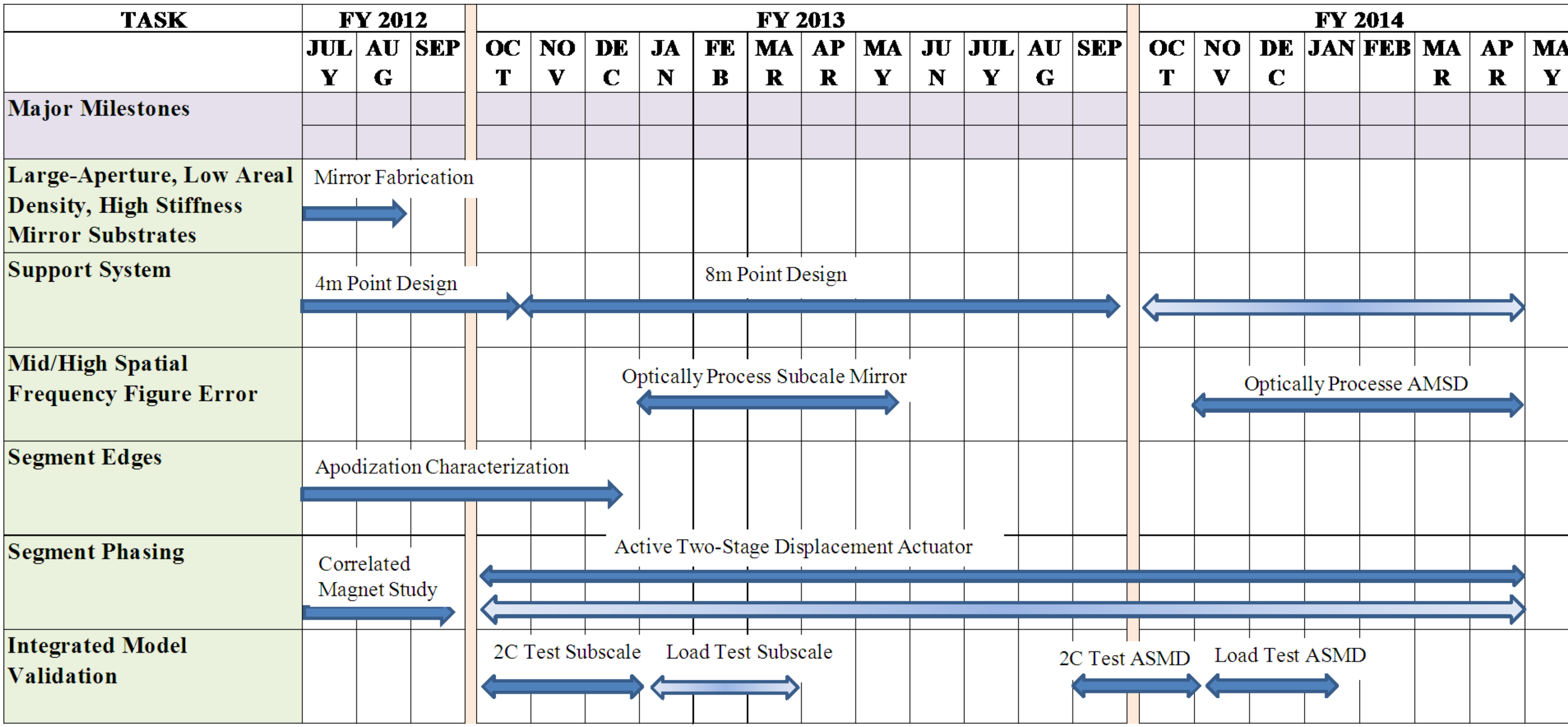
Project is managed according to WBS.

Each quantitative Milestone is scheduled.

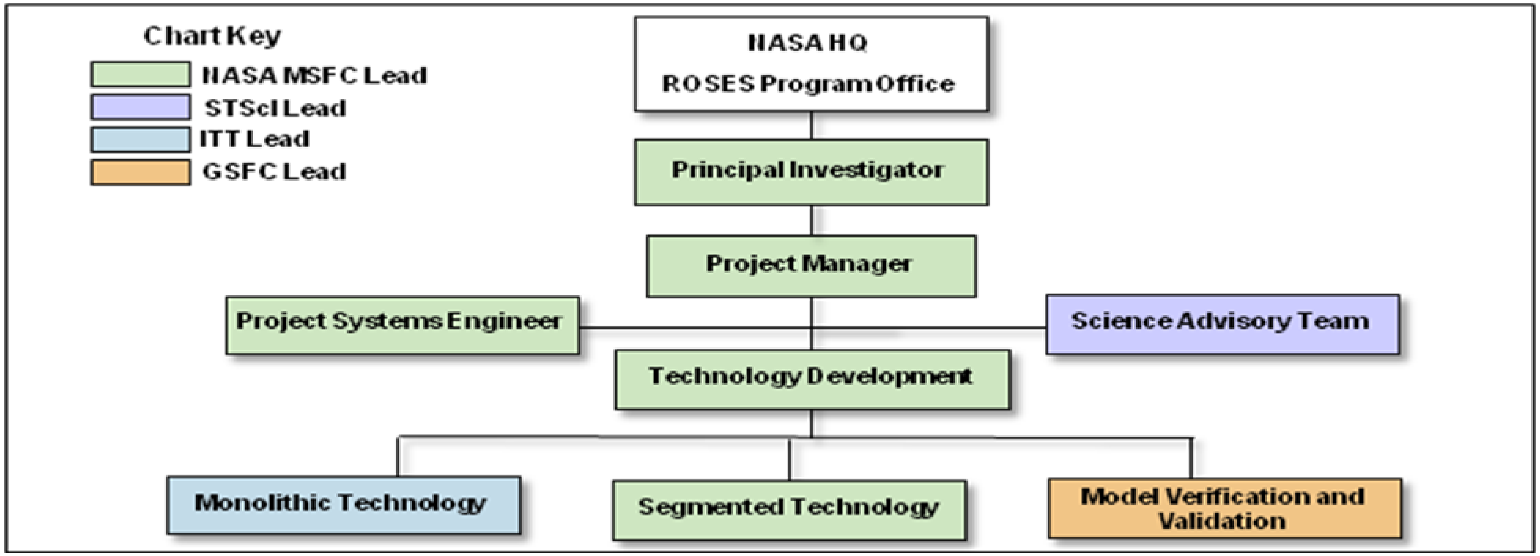


Milestone Project

Project was rephased from 2 years to 3 years.



Project Organization



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WBS Task Discussion

WBS 2.0 Science Advisory Team

Science team works with Engineering to:

- derive (and/or confirm) engineering specifications for advanced normal incidence mirrors which flow down from the astrophysical measurement needs and flow up from implementation constraints;
- collaborate with systems engineering to mitigate these challenges via architectural implementation trades; and
- prioritize which challenges should be solved first.

The Science Team has meet 4X by telecon and once face-to-face in FY12.

WBS 3.0 Systems Engineering

Systems Engineering working with Science:

- derives engineering mirror specifications to achieve on-orbit performance requirements;
- identifies technical challenges in meeting these specifications;
- prioritize technology development using a systems perspective to determine which technologies will yield the greatest on-orbit performance improvement; and
- define metrics, evaluate their TRL, and assess their advance.

WBS 3.0 Systems Engineering

Systems Engineering will

- develop thermal & mechanical models of candidate mirror systems including substrates, structures, and mechanisms;
- validate models by test of full- and subscale components in relevant thermo-vacuum environments.

Specific analyses include:

- maximum mirror substrate size, first fundamental mode frequency (i.e., stiffness) and mass required to fabricate without quilting, survive launch, achieve stable pointing and maximum thermal time constant;
- segment edge dimensions and roll; and
- segment-to-segment gap dimensions, phasing and stability.

WBS 4.0 Technology Development

WBS 4.0 develops technology

- 4.1 Monolithic Mirror Technology
- 4.2 Segmented Mirror Technology
- 4.3 Model Verification and Validation

Enables our 4 baseline options:

- 4-m monolithic mirror launched by an EELV;
- 8-m monolithic mirror launched by a HLLV;
- 8-m segmented mirror launched by an EELV; and
- 16-m segmented mirror launched by a HLLV.

Same technology can also enable 8-m on HLLV.

WBS 4.1 Monolithic Technologies

Monolithic mirror technology is required to manufacture, test, launch, and operate a 4 or 8-m monolithic mirror also 2-m class mirror segments.

WBS 4.1 matures the 3 key monolithic mirror challenges:

4.1.1	Deep Core Mirror Substrate
4.1.2	Mirror Support Structure
4.1.3	Mid/High Spatial Frequency Surface Errors

WBS 4.2 Segmented Technologies

Segmented mirror technology is required to assemble, align, phase, and operate a segmented mirror as an integrated unit to UVOIR tolerances.

WBS 4.2 matures the 2 key segmented mirror challenges:

- 4.2.1 Edge Control
- 4.2.2 Gap Phasing Control

WBS 4.3 Model Verification & Validation

Models are required to predict on-orbit performance for pointing stability, jitter, and thermal-elastic stability, as well as vibro-acoustics and launch loads. Performance data is required to verify and validate models.

WBS 4.3 matures the 2 key modeling challenges:

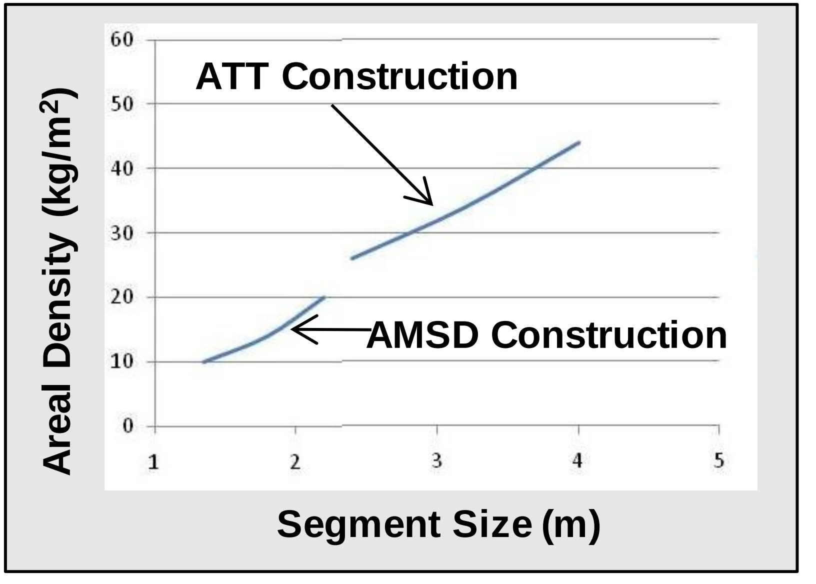
- 4.3.1 Thermal Model Verification
- 4.3.2 Mechanical Model Verification

WBS 4.1.1 Deep Core Substrate

Need: 500 mm thick mirror substrate.

4 m PM requires substrate with areal density of <60 kg/m^2 & ~200 Hz first mode. Analysis indicates this can be achieved with a 500 mm thick mirror. For 8-m, this is an upper thickness limit.

SOA: 300 mm deep substrates



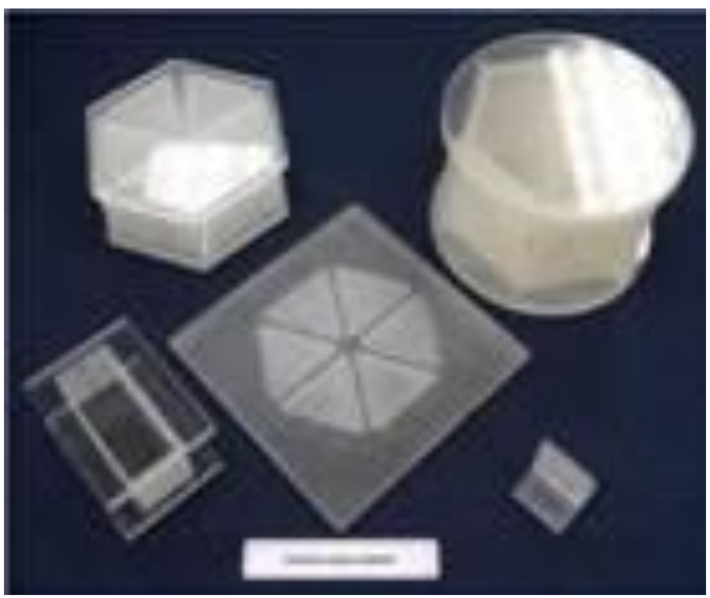
Starting: TRL3/4

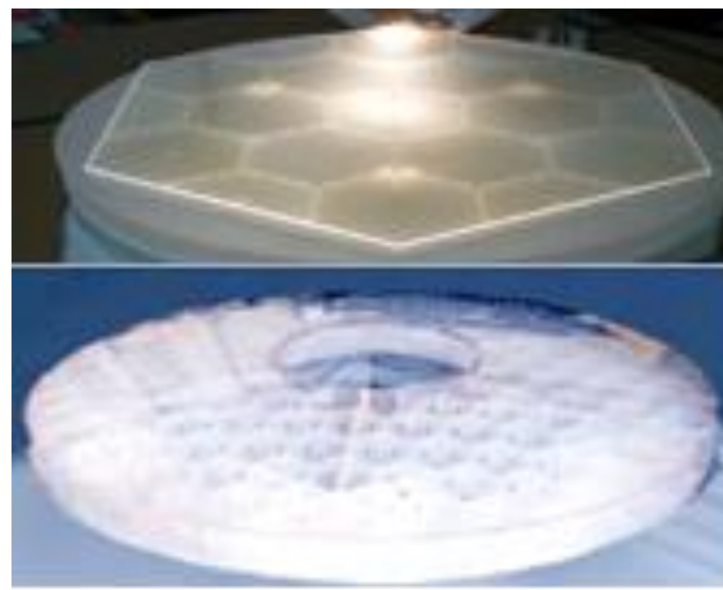
2.4 m is TRL9 (HST), Kepler is1.4m – both are sub-scale.

WBS 4.1.1 Deep Core Substrate

Milestone: demonstrate innovative process to make glass cores with required areal density that can be scaled to 500 mm deep.

Approach: manufacture 40 cm dia x 400 deep subscale (‘cut-out’ of a 4 m dia x 400 mm deep mirror) using 3 ‘stacked’ cores with full size cells and ribs and pocket milled face and back sheets with full sized pockets, ribs and thickness.





WBS 4.1.2 Support Structure

Need: System to support mirror during launch and deploy it into an on-orbit strain free state; maintain operational wavefront and pointing stability.

SOA: Kepler 1.4 m support system

Starting: TRL3/4

Kepler support system is TRL9, but it is sub-scale.

Milestone: Pre-Phase-A point designs for potential 4-m and 8-m monolithic primary mirrors and an 8-m segmented mirror.

Approach:

- Design structure based on substrate designs, launch vehicle constraints and performance requirements.
- Design, build & demonstrate a two-stage active strut/actuator.

WBS 4.1.3 Mid/High Spatial Frequency

Need: < 10 nm rms surface mirror at 2C

SOA:

- AMSD at <10 nm rms and ATT at <20 nm rms at 20C
- Hubble, 7.8 nm rms at 20C
- 4m & 8m ground telescope mirrors at ~ 10 nm rms at 20C

Starting: TRL4 for 1.5 m; TRL 3 for 4 m or larger.

- AMSD, ATT & HST are sub-scale & not at operational temperature.
- Ground 4m & 8m mirrors are full size, but not flight areal density.

Milestone: polish traceable substrates to UVOIR tolerances at their anticipated operating temperature of 2 C.

Approach:

- Create mechanical and thermal models
- Test AMSD mirror at 2C and cryo-null polish via traceable process
- Demonstrate on 4.1.1 sub-scale mirrors process (traceable to 2m, 4m or 8m mirrors) to polish without introducing quilting

WBS 4.2.1 Edge Control

Need: TBD by Science and Systems Engineering

SOA: Keck is 2 mm (but substrates are 400 Hz); JWST is close to 5 mm; AMSD was10 mm; QED & Zeeko SBIRs did 2 mm

Starting: TRL3 to 6 depending on Requirement

Milestone:

Define Requirement

Demonstrate apodization concept via a test article.

Approach:

Write an amplitude apodization mask on the edge of a mirror and test its impact on edge diffraction.

WBS 4.2.2 Gap Phase Control

Need: < 5 nm rms segment to segment stability

SOA: JWST, passive, 20 nm 50 Hz rocking mode; Keck, active, < 20 nm rms 50 Hz; ITT AOSD, active, < 10 nm rms 30 Hz; LAMP, active, classified in Vacuum.

Starting: TRL3/4

UVOIR Requirement not achieved.

Milestone:

Demonstrate Active Strut (WBS 4.1.2)

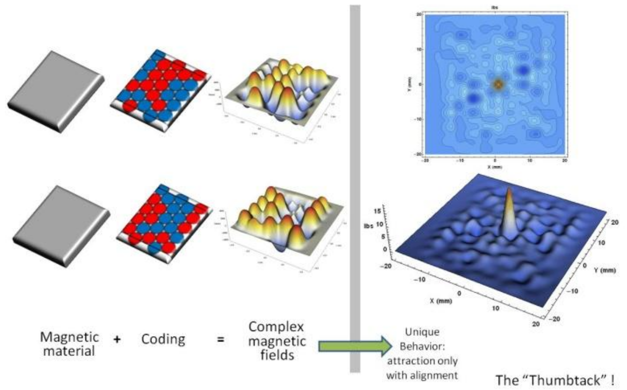
Quantify utility of Correlated Magnetic Interfaces

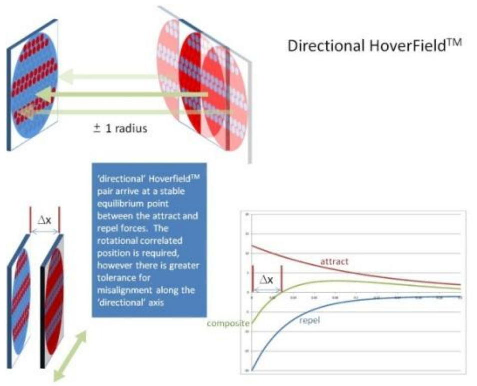
Approach: design, build and test dynamic dampening devices on sub-scale test-bed and on ITT AOSD test-bed.

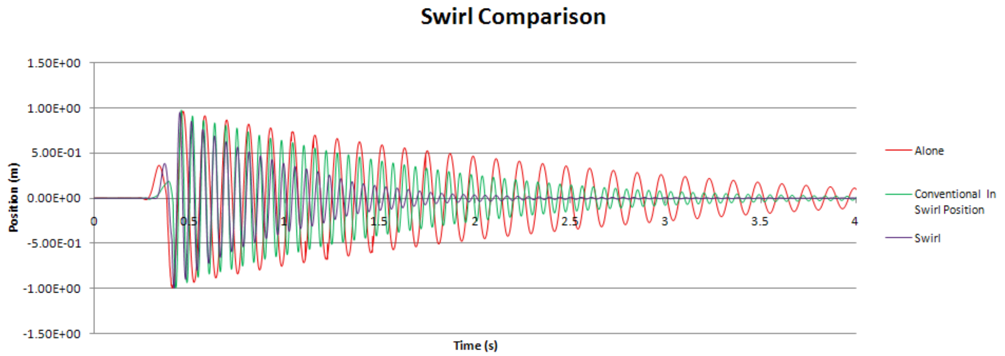
Correlated Magnetic (CM) Interface

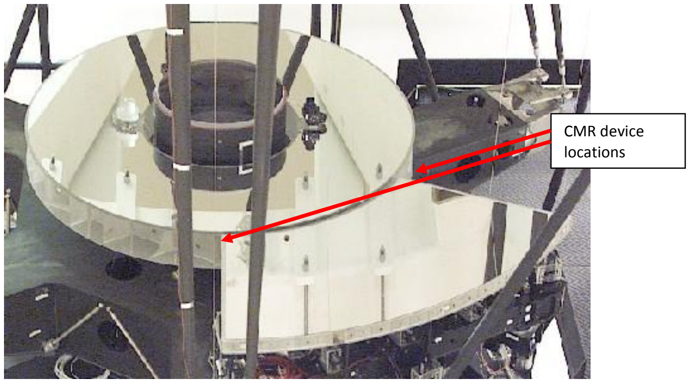
CMs are useful for vibration isolation & motion constraint.

CM can be designed to constrain interface to a single symmetry point; rotate about a symmetry point; or move linearly in one direction but not the orthogonal direction – similar to a mechanical flexure.









WBS 4.3 Integrated Modeling

Need: Predict on-orbit performance

SOA:

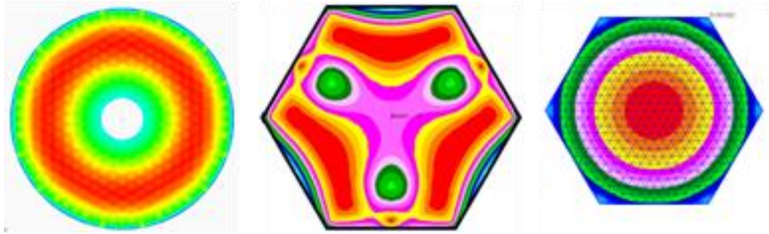
JWST (AMSD, Flight PMSAs, BSTA 4% match);
Air Force Structural Vibration Modeling and Verification (SVMV)

Starting: TRL4/5

UVOIR Requirement not achieved.

Milestone:

Validate Thermal Model
Validate Mechanical Model



Approach:

Thermal model predicts AMSD figure sensitivity of 5 nm rms/K. Prediction will be validated at the MSFC XRCF. Additionally, thermal figure stability will be quantified.

Mechanical model will be validated via static load test.