Advanced Mirror Technology Development (AMTD) Project:
Overview and Year 4 Accomplishments

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AMTD is a funded NASA Strategic Astrophysics Technology (SAT) project

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Accomplishments since Tech Days 2015

• Continuing Science Driven Systems Engineering: deriving Telescope Stability Requirements for Coronagraph $10^{-10}$ Contrast Leakage.

• Harris Corp fused and slumped 1.5-meter ULE© mirror which is currently in polishing. (Scheduled for cryo-test in Mar/Apr)

• Schott polished 1.2 m Zerodur® mirror which has been cryo & mechanical tested for model validation.

• Using Arnold Mirror Modeler to perform HabEx 4-meter mirror trade studies.

• 4 Student Interns

• 8 Publications

• Predictive Thermal Control for Stable Telescopes
Recent Publications


AMTD driven by NASA’s need for Mirror Technology

Astro2010 Decadal Study recommended technology development (page 7-17) for a potential future:

- Exoplanet Mission (New-Worlds Explorer)
- UVOIR Space Telescope (4 meter or larger)

2012 NASA Space Technology Roadmaps & Priorities: Top Technical Challenge C2 recommended:

- New Astronomical Telescopes that enable discovery of habitable planets, facilitate advances in solar physics, and enable the study of faint structures around bright objects …

2014 Enduring Quests Daring Visions recommended:

- 8 to 16-m LUVOIR Surveyor with sensitivity and angular resolution to “dramatically enhance detection of Earth-sized planets to statistically significant numbers, and allow in-depth spectroscopic characterization.”
Objective

AMTD’s objective is to mature to TRL-6 the critical technologies needed to produce 4-m or larger flight-qualified UVOIR mirrors by 2018 so that a viable mission can be considered by the 2020 Decadal Review.

AMTD is not developing technology for a specific mission.

AMTD technology is relevant for high-contrast imaging & spectroscopy architectures:

- single aperture monolithic mirror telescope - HabEx,
- single aperture segmented mirror telescope – LUVOIR,
- sparse aperture, and
- interferometers.
Multiple Technology Paths

Just as JWST’s architecture was driven by launch vehicle, future mission’s architectures (mono, segment or interferometric) will depend on capacities of future launch vehicles (and budget).

Since we cannot predict future, we must prepare for all futures.

To provide the science community with options, we are pursuing multiple technology paths for both monolithic and segmented aperture telescopes.

All potential UVOIR mission architectures (monolithic, segmented or interferometric) share similar mirror needs:

- Very Smooth Surfaces $\leq 10$ nm rms
- Thermal Stability Low CTE Material
- Mechanical Stability High Stiffness Mirror Substrates
‘The’ System Challenge: Dark Hole

Imaging an exoplanet, requires blocking $10^{10}$ of host star’s light.

An internal coronagraph (with deformable mirrors) can create a ‘dark hole’ with $< 10^{-10}$ contrast.

Ultra-smooth, Ultra-Stable Mirror Systems are critical to achieving and maintaining the ‘dark hole’

Krist, Trauger, Unwin and Traub, “End-to-end coronagraphic modeling including a low-order wavefront sensor”, SPIE Vol. 8422, 844253, 2012; doi: 10.1117/12.927143
To accomplish our objective, we:

- Use a science-driven systems engineering approach.
- Mature technologies required to enable highest priority science AND result in a high-performance low-cost low-risk system.
Phase 1 & 2

Goals, Objectives & Tasks
Goals

To accomplish Objective, must mature 6 linked technologies:

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 & deploy on orbit in a stress-free & 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 & thermal stability. Future systems require validated models.
Technical Approach/Methodology

We mature these technologies simultaneously because all are required to make a primary mirror assembly (PMA); AND, it is the PMA’s on-orbit performance which determines science return.

PMA stiffness depends on substrate and support stiffness.

Ability to cost-effectively eliminate mid/high spatial figure errors and polishing edges depends on substrate stiffness.

On-orbit thermal and mechanical performance depends on substrate stiffness, the coefficient of thermal expansion (CTE) and thermal mass.

Segment-to-segment phasing depends on substrate & structure stiffness.
Phase 1: Goals, Progress & Accomplishments

Systems Engineering:
• derive from science requirements monolithic mirror specifications
• derive from science requirements segmented mirror specifications

Large-Aperture, Low Areal Density, High Stiffness Mirror Substrates:
• make a subsection mirror via a process traceable to 500 mm deep mirrors

Support System:
• produce pre-Phase-A point designs for candidate primary mirror architectures;
• 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:
• demonstrate an achromatic edge apodization mask

Segment to Segment Gap Phasing:
• develop models for segmented primary mirror performance; and
• test prototype passive & active mechanisms to control gaps to ~ 1 nm rms.

Integrated Model Validation:
• validate thermal model by testing the AMSD and deep core mirrors at 2°C
• validate mechanical models by static load test.
Phase 1: Key Accomplishments

- Derived from Science Requirements, Specifications for Primary Mirror Wavefront Error and Stability
  - Surface < 10 nm rms (low ~5 nm, mid ~5 nm, high ~3 nm)
  - Stability < 10 picometers rms per 10 minutes
- Demonstrated, at the 0.5-m scale, the ability to make mechanically stiff, i.e. stable, UVOIR traceable mirrors:
  - <6 nm rms surface
  - 60-kg/m²
  - 400-mm deep-core substrate using the stack-core low-temperature-fusion/low-temperature-slumping (LTF/LTS) process.
- Developed Tools for Integrated Modeling & Verification
Phase 2: Tasks

Refine engineering specifications for a future monolithic or segmented space telescope based on science needs & implementation constraints.

Mature 4 inter-linked critical technologies.

*Large-Aperture, Low Areal Density, High Stiffness Mirrors*
Fabricate a 1/3rd scale model of a 4-m class 400 mm thick deep-core ULE© mirror – to demo lateral scaling.

*Support System – continue Phase A design studies*

*Mid/High Spatial Frequency Figure Error*
Test 1/3rd scale ULE© & 1.2 m Zerodur Schott mirror at 280K

*Integrated Model Validation – continue developing and validating tools*
Phase 2: Tasks

Monolithic Mirror Substrate Technology
- Fabricate and test A-Basis allowable required for mirror
- Design 1/3-scale model of a 4-m x 400-mm class ~150Hz ULE® mirror
- Design support structure for Zerodur 1.2m mirror

Mirror Preparation
- Fabricate & polish 1/3-scale model ULE mirror & support structure
- Fabricate support structure & Polish Zerodur mirror

Thermal Characterization
- “Qualify” (i.e., test) two candidate lightweight primary mirrors (1.5m Harris & 1.2m Zerodur Schott) in X-Ray & Cryogenic Facility at MSFC
  - Characterize their optical performance from 230K to ambient
- Expose to representative vibration and acoustic launch environments & conduct modal test of 1.5m Harris & 1.2m Zerodur Schott
Summary of Following Presentations

AMTD Phase 2 Status of ULE® Mirror
   Review accomplishments, lessons learned & status of 1.5 m mirror which is currently in polishing and schedule for testing in March 2017.

AMTD Test Results of Schott 1.2m ELZM mirror
   Present cryogenic and mechanical test results of the Schott 1.2 m extreme-lightweight Zerodur© mirror

Schott ELZM mirror thermal model predictions and test data correlation.

Arnold Mirror Modeler status and use on 4-meter point design trade study for HabEx

Update on derive Systems Specifications for Telescope WFE Stability based on Coronagraph Contrast Leakage

Predictive Thermal Control SAT Goals and Objectives
Conclusions

AMTD uses a science-driven systems engineering approach to define &
execute a long-term strategy to mature technologies necessary to enable
future large aperture space telescopes.

Because we cannot predict the future, we are pursuing multiple technology
paths including monolithic & segmented mirrors.

Demonstrated capability of ‘stack & seal’ process:
• Make 40-cm deep mirrors
• Lateral scalability to 1.5-m diameter
• Validated Non-Linear Visco-Elastic Modeling

Continuing improvement of Arnold Mirror Modeler for rapid design of mirror
substrates and support systems to enable point design trade studies.

Developing integrated modeling methods to derive engineering specifications
from science requirements.

Validate by Test Integrated Model Performance Predictions.