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Active Space Telescope Systems: A New Paradigm

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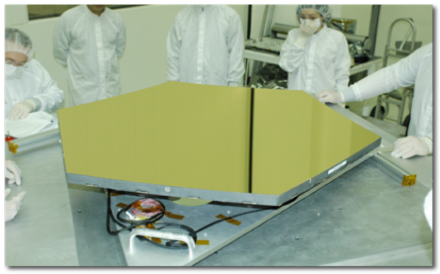
Abstract

- New active optics technologies are rapidly maturing that will enable outstanding scientific performance for the next generation of astronomical space telescopes, while dramatically reducing cost drivers such as risk, mass and manufacturing time. Using these technologies, NASA can, with further development, field high-performance space telescopes at a cost, risk and development schedule substantially below historical norms
- Elements of this new system architecture have been developed, in some cases through TRL 6, at the Jet Propulsion Laboratory
- The primary new ingredients of active optics flight systems are:
  - Lightweight, easily replicable, mirrors or mirror segments, incorporating actuators which can control the segment figure on orbit
  - A robust Wavefront Sensing and Control system to establish the overall figure, phasing, and alignment
  - A real time, high dynamic range, high precision control system which maintains the rigid body alignment of the segments to the required precision

Lightweight, Active Mirrors

- Successful development of lightweight active mirrors using two different technological approaches has been demonstrated:
  1. Lightweight low-expansion glass mirrors
  2. Actuated Hybrid Mirrors
- Development of meter-class, Actuated Hybrid Mirrors (AHMs) specifically addresses the problem of how to provide tens of square meters of optical quality, lightweight, space-qualifiable optics with a reasonable cost and fabrication time. These AHMs, shown below, are a combination of three distinct technologies:
  1. A metallic nanolaminate facesheet that provides a high optic quality reflective surface;
  2. A SiC facesheet that provides structural support and houses actuators to provide an adaptive surface figure; and
  3. Wavefront Sensing that provides active figure control
- AHM replaces passive mass with actuators and controls, while maintaining a high level of optical performance (low-scatter and diffraction-limited imaging)



An Actuated Hybrid Mirror (AHM) lightweight active mirror segment equipped with surface figure actuators to provide wavefront error correction. Configuration is in the form of a 1.2-m hexagon, with no central obscuration. This could be one segment of a multi-segment ATLAST-type telescope.

References and Acknowledgments

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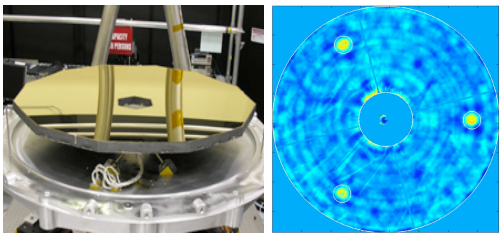
Advantages of Active Optics Systems

- Active optics in general lower optical performance risk
  - Provide on-orbit correction for any optical train error
    - Fabrication errors — allows looser fabrication tolerances
    - Alignment errors — allows build to mechanical tolerances rather than optical tolerances
    - Thermal prediction errors — compensate unpredictable environmental effects
    - Testing errors — errors in test hardware need no longer prevent spec performance on-orbit
  - Demonstrate spec performance during ground testing, in multiple configurations
    - Tolerant of gravity — can test to spec with optical axis horizontal or vertical
    - Tolerant of temperature changes
    - Test to hyperbolic or parabolic figure, depending on test configuration (ACF, null, integrated telescope)
- Active optics shorten system build time and reduce system cost
  - Looser fabrication tolerances reduce component fabrication time and cost
  - Alignment to mechanical tolerances reduces or eliminates optical alignment required during assembly
  - Overall Integration & Test (I&T) time greatly reduced
  - Final testing demonstrates spec performance
- Active Hybrid Mirrors in particular lower mirror costs through replication-based manufacture
  - Only part requiring optician-quality labor is the precision mandrel, the tool on which the reflecting surface is deposited
    - Mandrel needs smooth surface, but figure tolerances are quite loose
    - Mandrel for a large mirror (to 1.5 m) requires 6 months
  - After mandrel is complete, AHM total build time, incl. surface bonding and a functional test of actuators, is 14 weeks
  - On a production line, replicated AHMs can be completed on 6-8 week centers
  - Mandrel and other tooling can be reused many times
- AHMs are light weight and durable
  - 15-20 kg/m² including wiring and actuation
  - SiC substrate strength and toughness far exceeds that of glass
  - Representative AHMs have been successfully shock and vibe tested
- Wavefront Sensing used for active mirror control also provides detailed, accurate system knowledge for improved science data processing

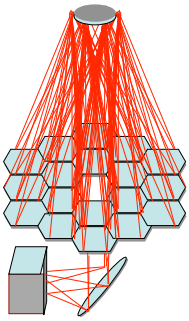
AHM Performance



Actuated hybrid mirrors (AHM) of less than 15 kg/m² have demonstrated 40 nm total WFE (gravity effect included), limited by mandrel polishing residual errors.

See an Actual AHM Mirror Here at the AAS !

We have a 40-cm test mirror at the *Exoplanet Exploration Program* display in the Exhibit Hall



Segmented Telescopes: Laser Metrology Truss

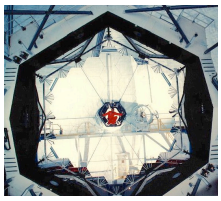
A laser metrology truss, as demonstrated on the SIM STB-3 testbed, can provide continuous monitoring for rigid body control of the alignment of optical elements/ segments: it is desirable to avoid the difficulties of verifying a 'set and forget' alignment system. Gauges work with the individual optical element/segment actuators for I&T, postlaunch alignment, and maintenance of the performance throughout operations.

Going Cold

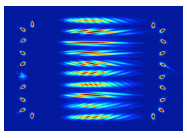
- Active mirrors at cold temperatures for IR astronomy offer the potential to reduce or eliminate "cryo figuring," by using actuators to correct WF error induced by cooling mirrors to cryogenic temperatures
- For cryo applications, bare polished SiC mirrors (no nanolaminate) is the best option
  - SiC has isotropic properties and high strength well suited to cryo optics
  - SiC has low CTE at ambient, and extremely low CTE at cryo temperatures
  - Actuators have demonstrated stroke sufficient to correct cryo cooldown-induced figure errors, operating at a temperature range of 10-65K

Wavefront Sensing and Control

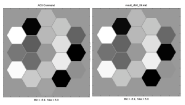
- Measurement and control of wavefront (WF) errors utilizes technologies developed by JPL for JWST and other missions
- Initial capture of large WF errors after launch uses Shack-Hartmann WF sensing to sense initial mirror figure errors
- Segmented mirrors are efficiently phased in white light using Dispersed-Fringe Sensing, which uses spectra to modulate the large piston errors between segments
- Ultimate accuracy is attained using Phase Retrieval WF sensing, processing defocused images taken in the science cameras themselves to create high-resolution WF maps.
- Typical WF sensing and control performance specifications:
  - Total WF error capture range > 10 µm, 10 mrad
  - Mirror figure capture range > 30 waves (Peak to Valley)
  - Final total WF accuracy < 1/14 wave (RMS)



Keck-II Telescope Phasing Demonstration



Dispersed-Fringe Image



Measured and commanded WF

Astronomy Applications

- ATLAST, a set of design concepts for the next generation UVOIR space observatory
- A 4-meter class segmented telescope for UV spectroscopy
- An 8-meter SAFIR- class cryogenic telescope for far-infrared and submillimeter studies
- Applications to smaller, monolithic systems, e.g.:
  - Balloon-borne telescope; Secondary payloads; ISS platform