Next Generation Space Telescope Integrated Performance Modeling

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NGST

Overview

- Integrated Modeling
- Optical control timeline
- Optical control algorithms
- Optical performance
- Issues

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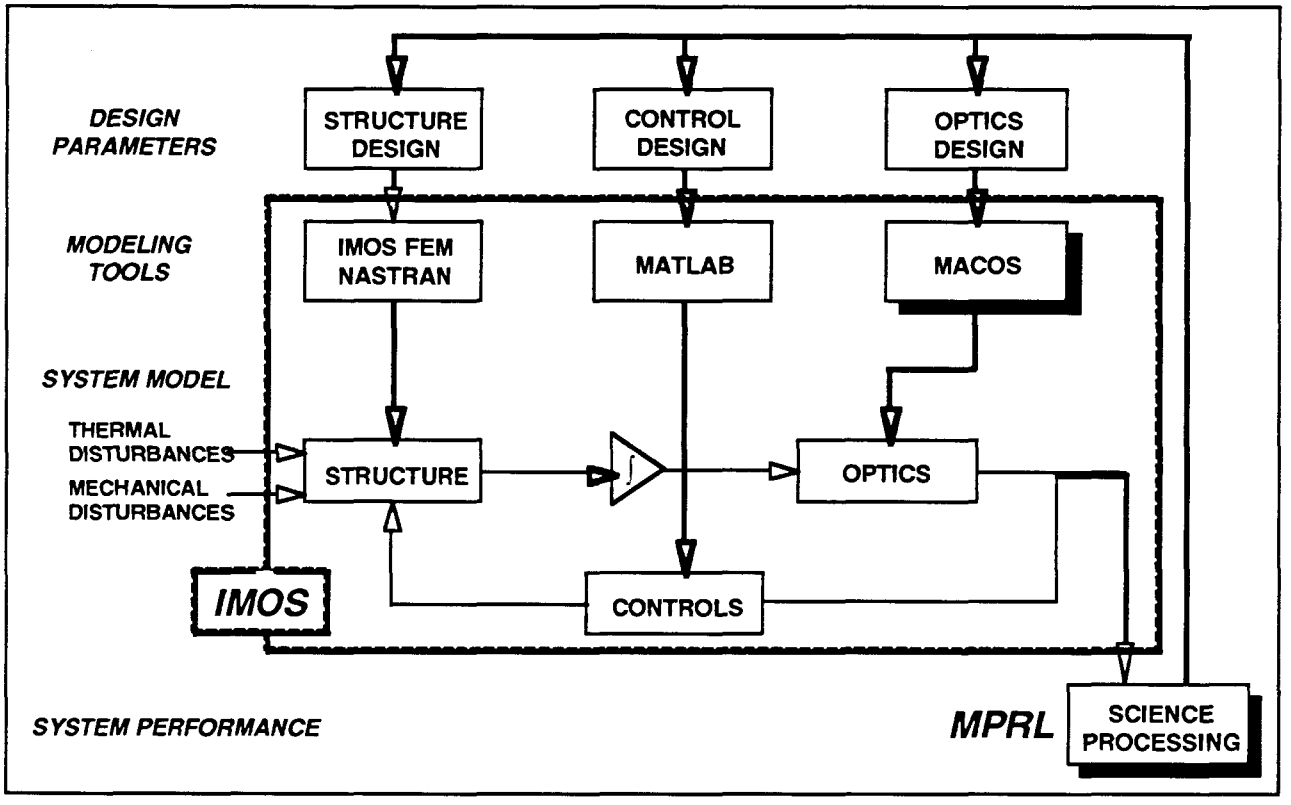
Integrated Modeling



- End-to-end system performance model
- Quantify thermal, structural, control, optics and system issues in terms of science impact
- Testbed for control and alignment algorithms

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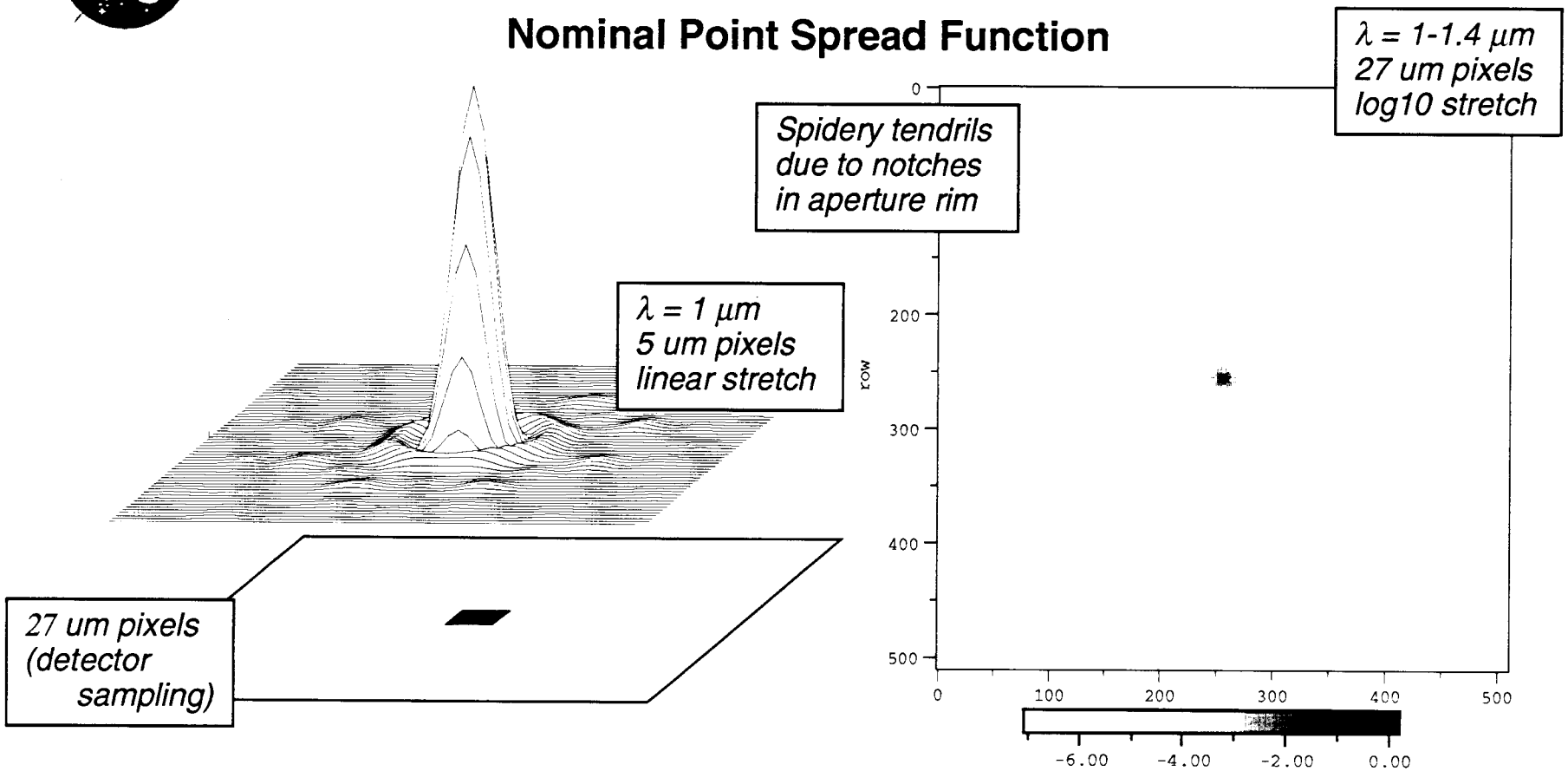
Nominal Point Spread Function



- **Central pixel contains:**
  - **50% of total energy at $\lambda = 1\ \mu m$** **5% at $\lambda = 4\ \mu m$**
  - **18% at $\lambda = 2\ \mu m$** **2% at $\lambda = 6\ \mu m$**
- **All cameras diffraction limited across full field**
  - **SR = 75% (relative to annular aperture) in Near IR camera**
  - **WFE = 21 nm on-axis**

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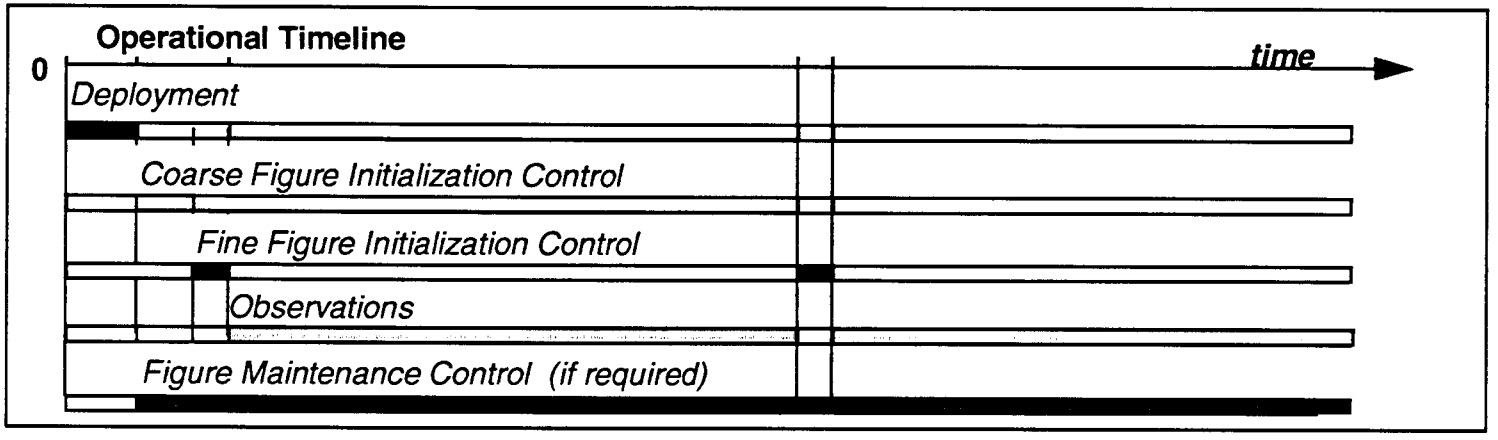
NGST Optical Control Timeline



- **Figure Initialization Control occurs following deployment, periodically thereafter**
  - Observe bright star in Near IR camera, spectrometer
  - Align SM to PM and SIM
  - Phase PM segments
  - Set DM
- **Passive figure during observations**
  - Rely on passive structural stability
  - Dynamic and thermal isolation
- **Figure Maintenance Control is an option if passive structural stability is not adequate during observations**

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Coarse Initialization Control

While observing bright star in Vis/IR camera...

Single-segment scan-in spot
Focus sweep
Coma sweep

Repeat for SM, all segments

Pairwise...

Coalign with center segment
Cophase using dispersed fringe

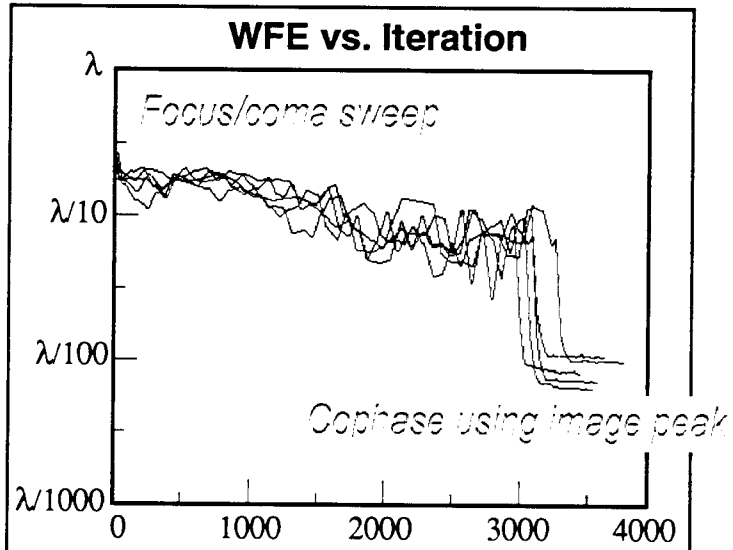
Repeat for all outer segments

Pairwise...

Coalign with center segment
Cophase using image peak

Repeat for all outer segments

Fine Initialization Control...



Simulated PSR sub-mm telescope

- *5 Monte Carlo trials*
- *No dispersed fringe sensing*
- *7 hex segments*
- *3DOF/segment actuation*
- *F/0.4 PM, F/10 system*
- *6DOF alignment errors + noise*

- **Coalignment/Cophasing with Dispersed Fringe Sensing**
  - **Semi-autonomous operation**
  - **Phase PM to λ/4**
  - **Requires excellent actuator repeatability or direct metrology of segments**

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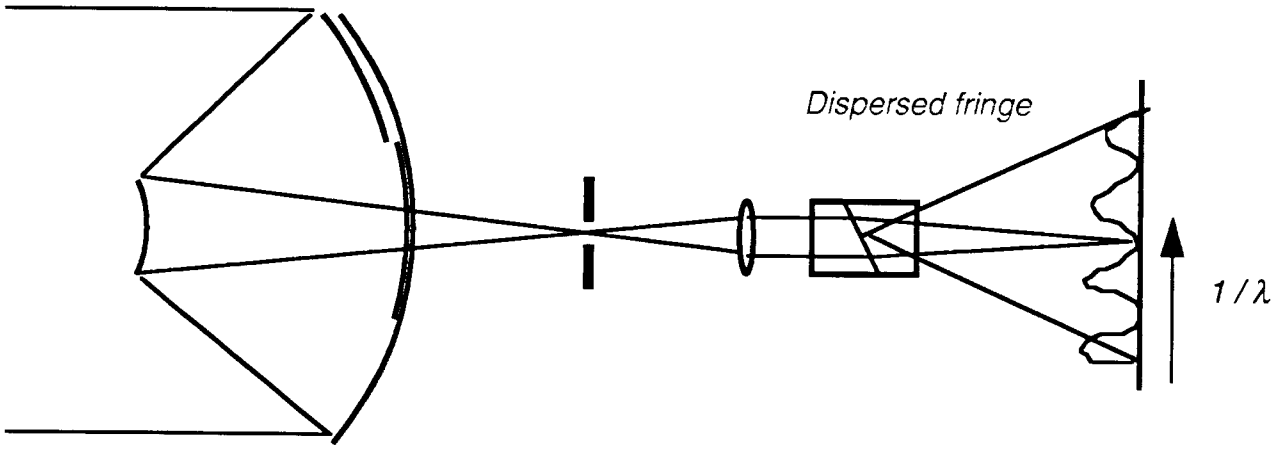
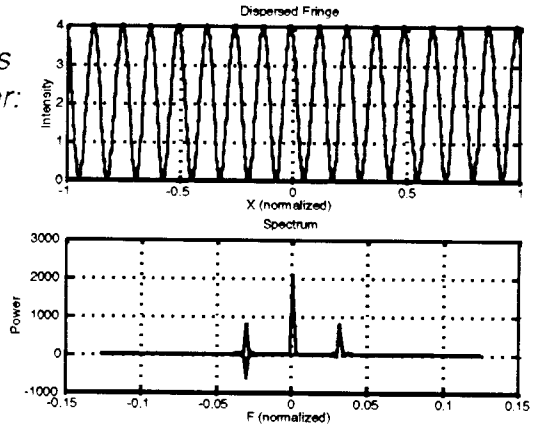
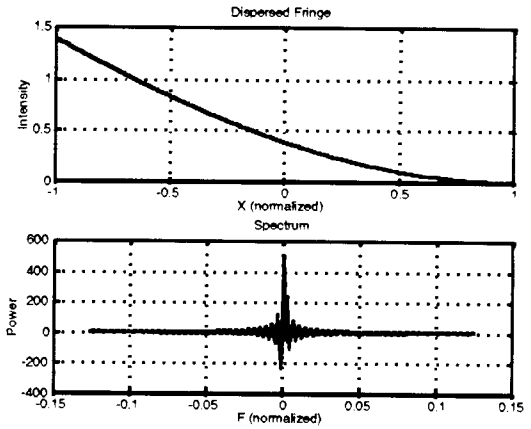
Coalignment/Cophasing: Dispersed Fringe



32.1 waves phase error:



0.4 waves phase error:



- **Dispersed-fringe "phase sensor" uses Vis/IR Camera with GRISM in 1 filter wheel slot**
- **Provides instant readout of relative phase of 2 coaligned segments**

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Fine Initialization Control

While observing bright star in Vis/IR camera...

Take defocussed images

Send to ground

Phase diversity processing
Optimal DM, segment commands

Send to space

Implement commands

Repeat until converged

Resume observations...

- Ground computer processes defocused pupil images to determine wavefront phase
  - Phase diversity algorithm(phase retrieval, prescription retrieval, curvature sensing,...)
  - Phase used to compute optimal control displacements for PM segments and DM
  - Control uplinked and process iterated

- **Optimal control moves segments to minimize segment edge discontinuities; DM then compensates smooth WF**
  - **Final steps actuate DM alone to beat segment actuator noise floor**
- **Does not require large motions of segments**
- **OTA phased to diffraction limit at 2 um in under 1 hour**

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Initialization Control Example

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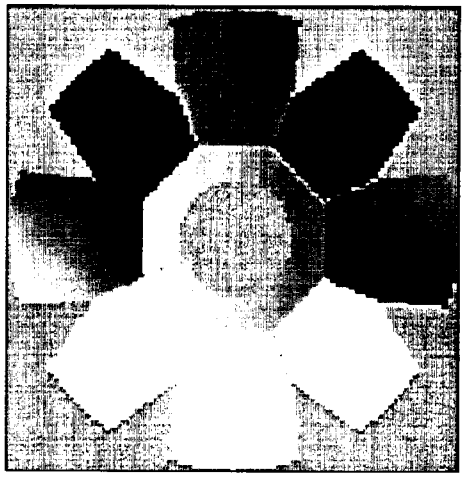
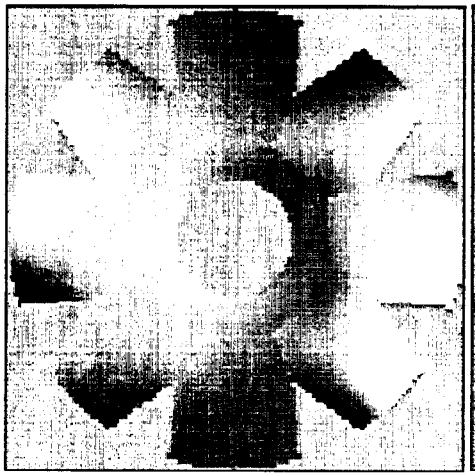
8-Petal configuration
8 meter aperture
F/1.25 primary
F/24 system
$\lambda = 1.0\ \mu m$ (0% bandpass)
Random segment errors
Phase sensing
Optimal controller
No sensing error
No actuation error

Initial Error



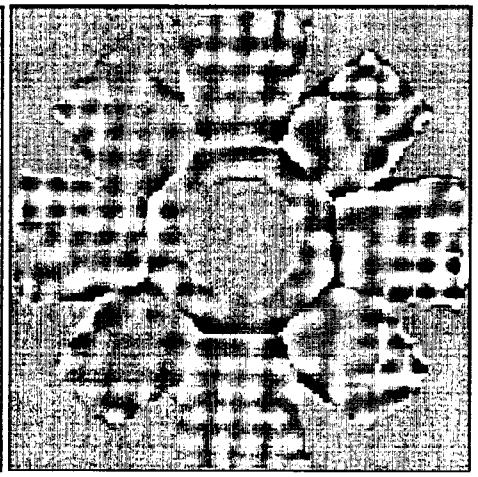
WFE = 612μm

Following segment control

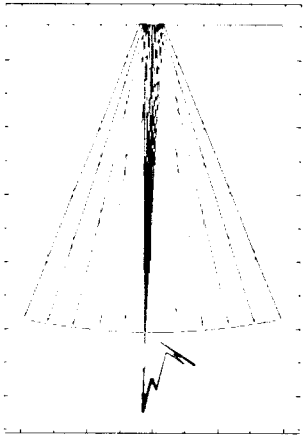


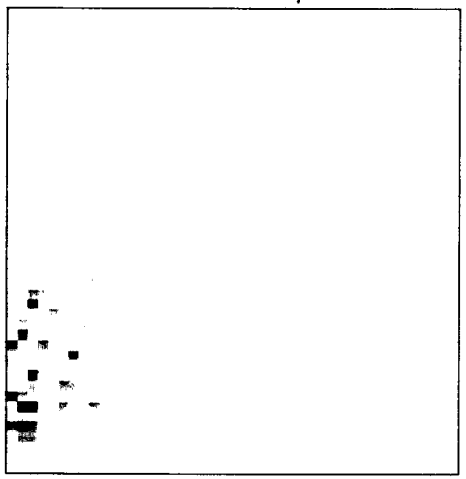
WFE = 173 nm

Following DM control

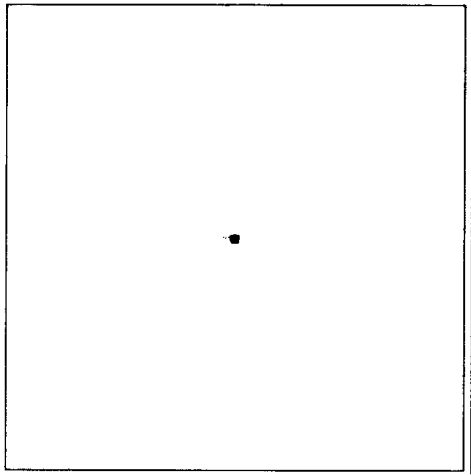


Final WFE = 12 nm

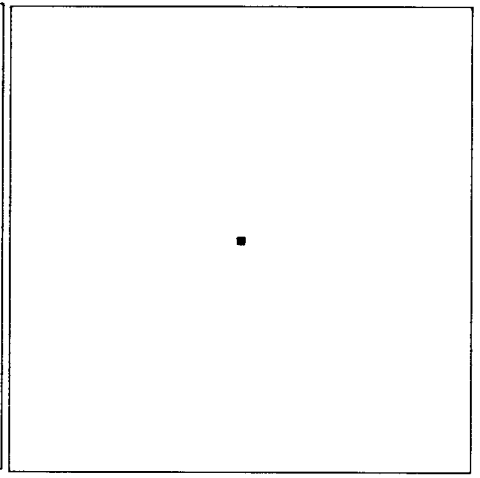




SR = 0



SR = 0.5



SR = 1.02

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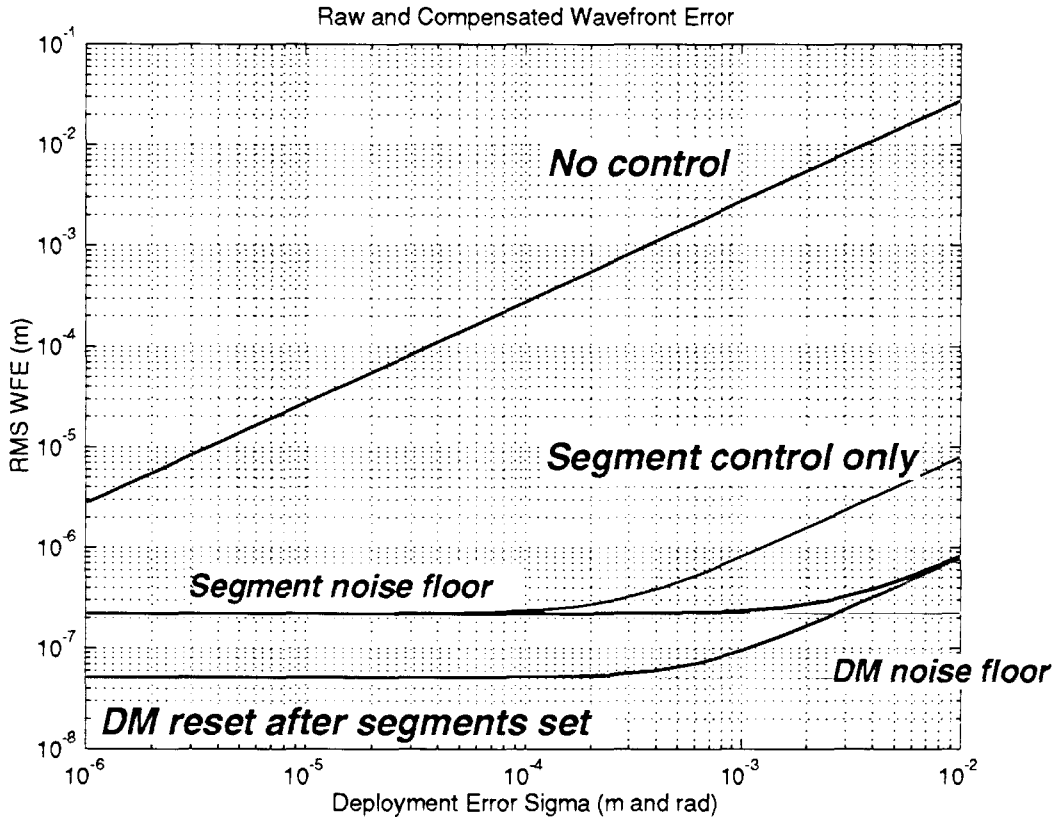
Effect of Random Deployment Errors



NGST 8-Petal configuration
8 meter aperture
F/1.25 primary
F/24 system
$\lambda = 1.0\ \mu m$ (0% bandpass)
Random initial segment state errors
Optimal WF controller
Set DM and segments together
Follow up with DM only
Phase sensing
Results via covariance analysis

Deployment error in 6DOF
Uniform variance
Segment actuation in 3DOF
Segment actuation error 8e-8 rad & m
DM actuation error 1e-9 m
Sensing error 1e-12 m

- **Segment control reduces WFE by 3e3, minimizes edge discontinuities**
- **DM control reduces WFE by an additional factor of 10**
- **DM control after segment actuation provides lower noise floor**

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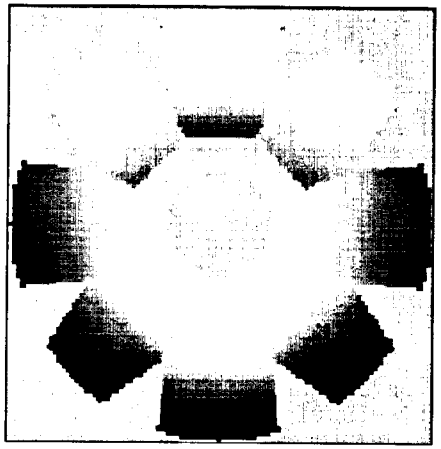
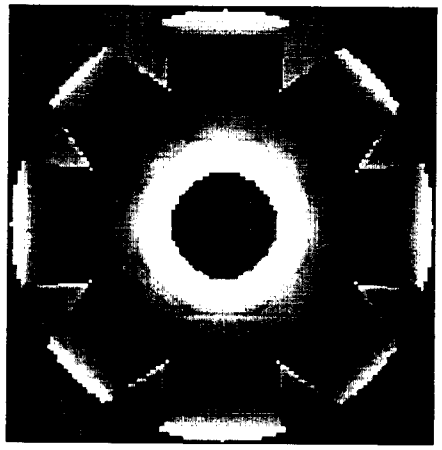
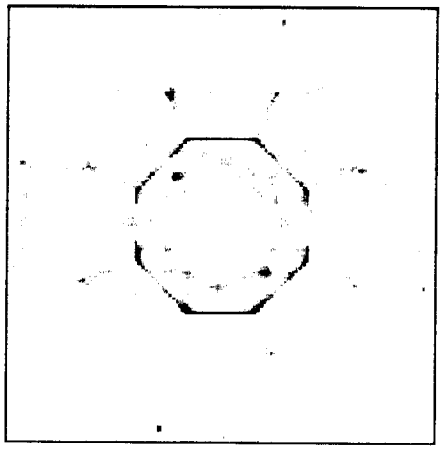
Thermal Response: Ground-to-Orbit, With Control



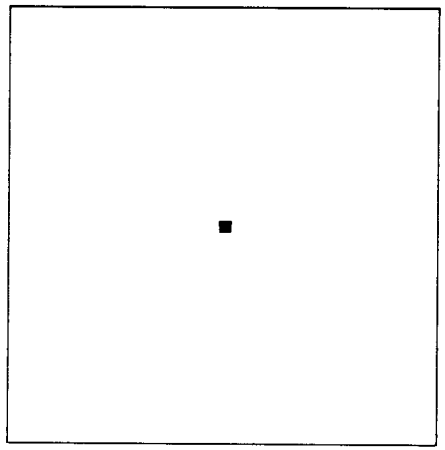
Raw on-orbit WFE
WFE = 34 μm
Segment decenter 50 μm
Segment piston 150 μm



Following segment control
WFE = 717 nm
4DOF/segment actuation

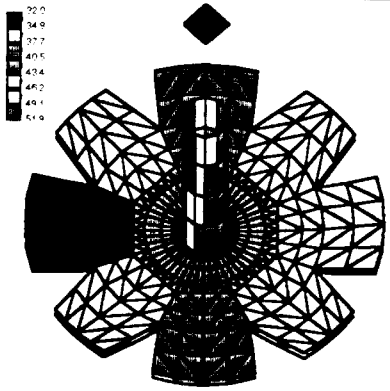


Following DM control
WFE = 33 nm



Following DM control
SR = 96 %

- **"Cold-figured" primary: telescope segments, backup structure figured at 90°K**
  - **LN2 facility required for testing**
- **Beryllium PM facesheet, composite backup structure**
- **Optical control improves cold-figured PM WFE performance to within requirements**
  - **Segment control improvement factor = 47**
  - **DM control improvement factor = 22**
  - **Total control improvement factor = 1120**



Facesheet CTE = 0.5 ppm
(integrated 90°K to 30°K)
Orbit T = 32 - 46 °K
Support structure CTE = -0.5 ppm
Segment actuator CTE = 13.4 ppm

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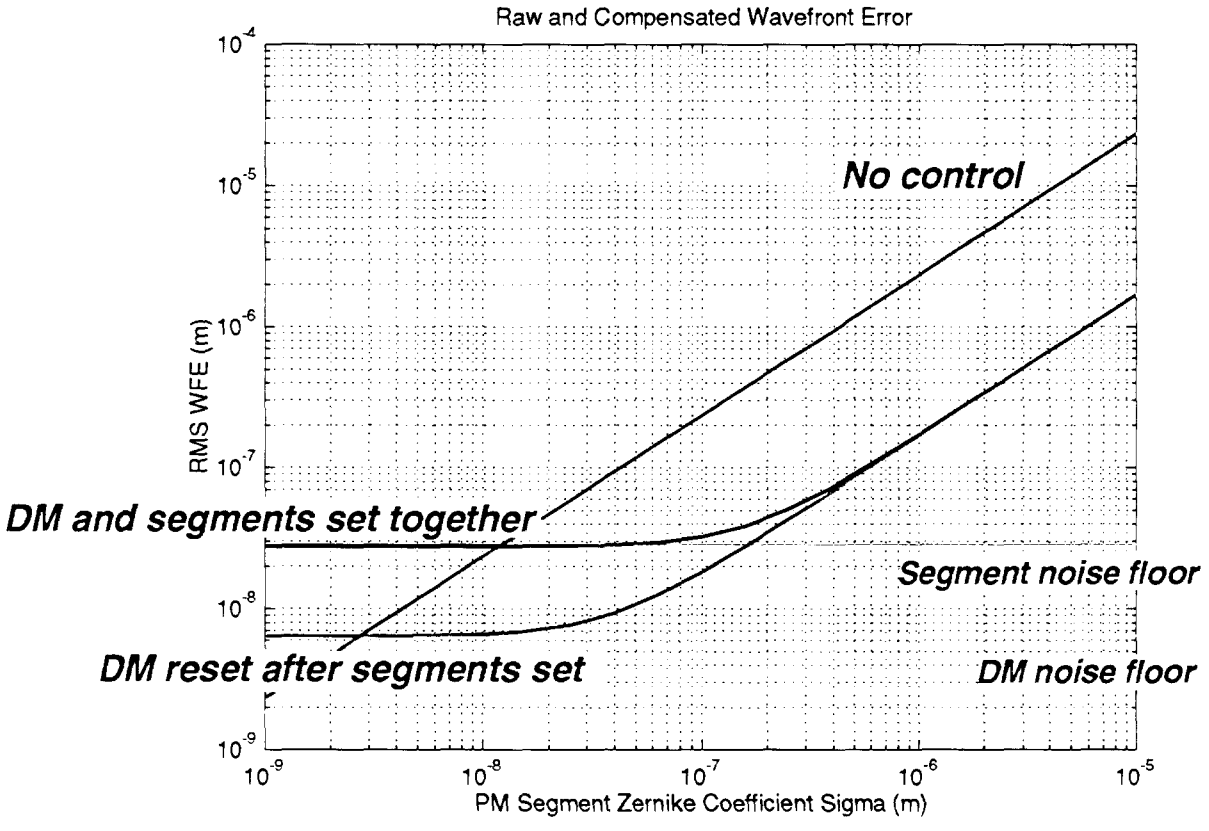
Effect of Random Segment Figure Errors



NGST 8-Petal configuration
8 meter aperture
F/1.25 primary
F/24 system
$\lambda = 1.0\ \mu m$ (0% bandpass)
Random initial segment state errors
Optimal WF controller
Set DM and segments together
Follow up with DM only
Phase sensing
Results via covariance analysis

Random Zernike segment figure errors
2nd and 3rd order Zernikes only
Zernikes centered at PM vertex
Uniform variance
Sensing error 1e-12 m
Segment actuation error 1e-8 rad & m
DM actuation error 1e-9 m

- **Segment control minimizes edge discontinuities**
- **DM + segment control reduces WFE by factor of 10**
- **DM control after segment actuation provides lower noise floor**

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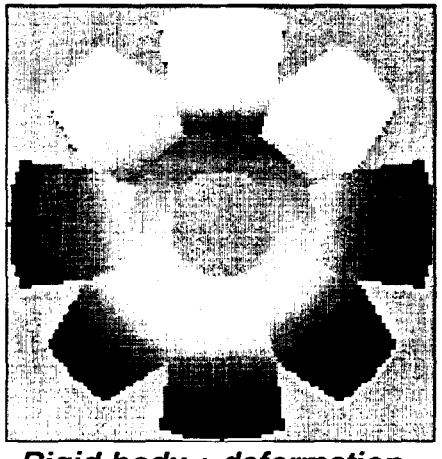
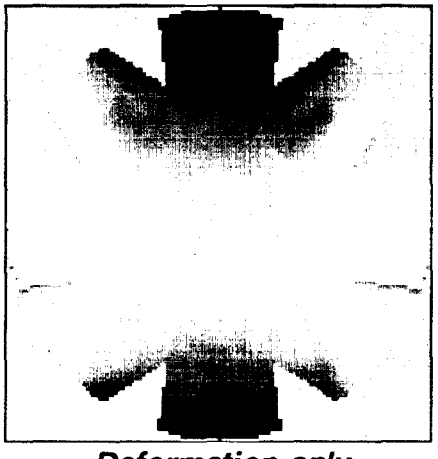
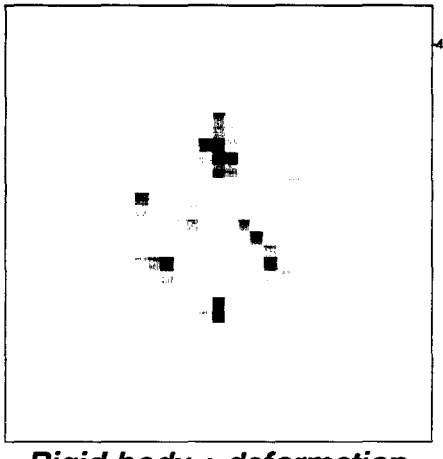
Thermal Response: On-Orbit Worst Case



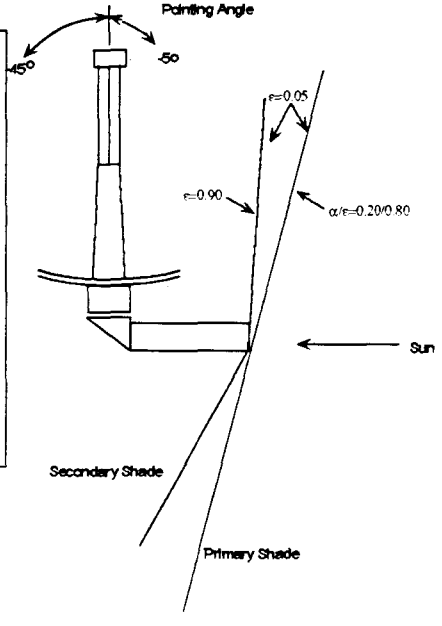
Rigid-body + deformation
WFE = 953 nm
(nom = 19 nm)



Deformation only
WFE = 20.3 nm
(nom = 19 nm)



Rigid-body + deformation
SR = 0.033 %
$\lambda = 1\ \mu m$



- **Worse-case attitude change**
  - OTA initialized at cold condition
  - Slew and equilibrate at hot condition
- **WFE does not meet objective**
  - Better thermal design, insulation: reduce by 8?
  - Reduced observing envelope: reduce by 4?
  - Figure maintenance control: eliminate RB part

Beryllium PM
On-orbit attitude change
Perfect optics at Cold condition
Cold condition = -5° pitch
Hot condition = 20° pitch
DT = 1.5 °K max on sunshade
DT < 1.5 °K max in structure
DT =1.2°K on mirror
Facesheet CTE = 0.016 ppm
Support structure CTE = -0.28 ppm
Segment actuator CTE = 13.4 ppm

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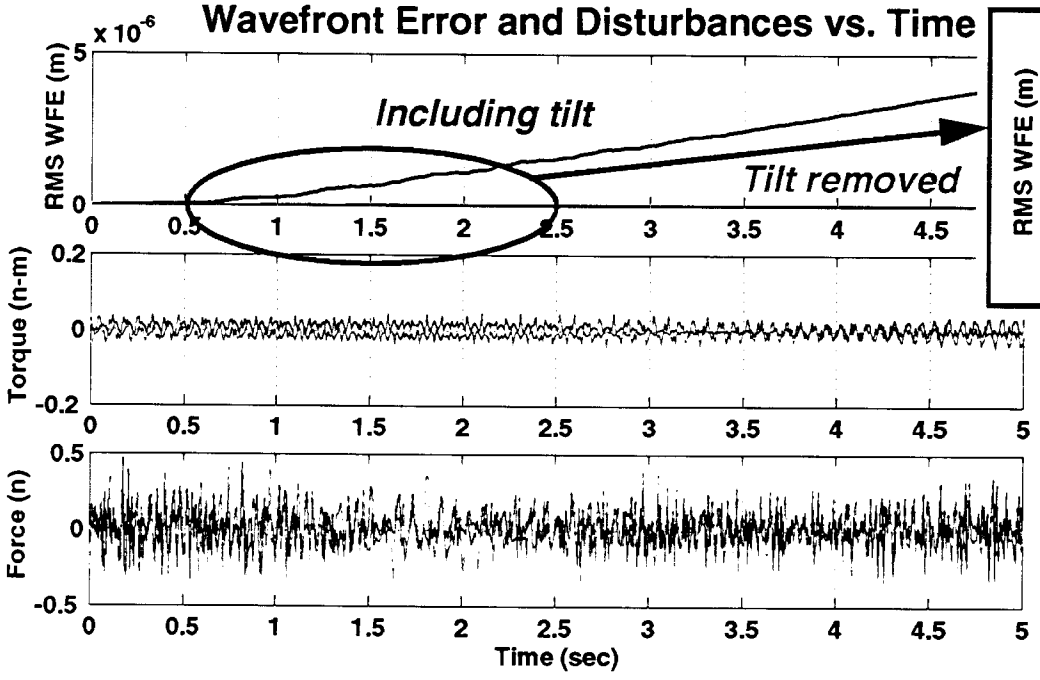
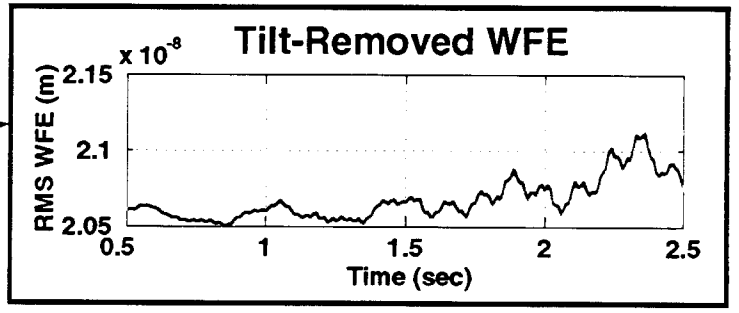
Vibration Response





IMOS FEM
- *OTA, SSM, SIM included*
- *1229 nodes, 7374 DOF*
- *Simulation modes 0.8 to 33 Hz*

MACOS optics
- *1844 rays*

Open-loop ACS
- *ACS noise included*
- *No isolator*
- *Wheel speeds 1320 rpm*

Sampled at 100 Hz

- Disturbance profile includes
  - ACS noise (roll axis uses star trackers for guiding)
  - Reaction wheel imbalance and bearing noise -- based on HST wheels
    - Reaction wheel momentum capacity 16× smaller than HST wheels
    - Noise amplitude reduced by 4×
- Single case -- PSDs with stochastic wheel response will show performance envelope

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Optical Control Issues and Options

- Cryogenic deformable mirror
  - Actuator spacing vs. figure error spatial frequency
  - Actuator stroke vs. figure error magnitude
  - Reliability
  - *Deform PM segments?*
- Cryogenic segment actuators
  - Dynamic range, accuracy
  - Thermal stability
  - *Metrology?*
- Wavefront sensing
  - Noise performance
  - Autonomy
  - Phase diversity: best algorithm
  - *Dedicated WF sensors?*
- Thermal deformation from ground to on-orbit
  - Cold-figuring of PM segments
  - CTE isotropicity
  - Operational temperature range
  - *Deform PM segments?*
- Thermal stability of structure on-orbit
  - Improved materials and thermal design
  - Improved insulation, shielding
  - *Figure maintenance control?*
- Vibration from SSM
  - Structural stiffening, damping
  - Reaction wheel quality
  - *Active isolation?*