Wide-Field Infrared Survey Telescope (WFIRST) Integrated Modeling

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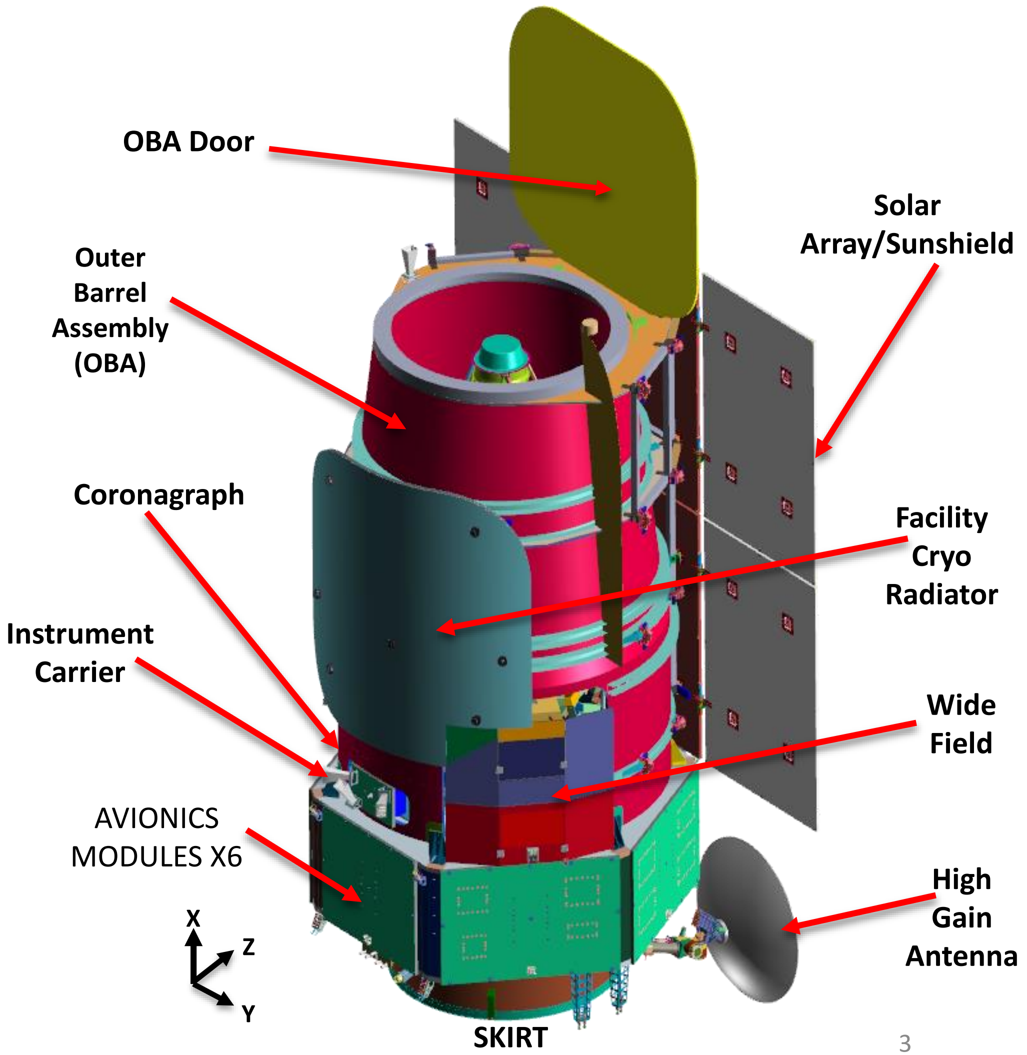
WFIRST IM Team

Agenda

- Intro to WFIRST and Integrated Modeling
- WFIRST Stability Requirement Summary
- Instability Mitigation Strategies
- Dynamic Jitter Results
- STOP (Thermal Distortion) Results
- STOP and Jitter Capability Limitations
- Model Validation Philosophy

WFIRST Introduction

- Observatory is designed to allow rapid slew/settle for Wide Field Instrument (WFI) survey, while allowing long-term Coronagraph Instrument (CGI) observations.
  - CGI has internal control system to correct for slow-varying, thermal-induced errors.
- By design, the instruments are shielded from the Sun by the solar array-sunshield (SASS) and Outer Barrel Assembly (OBA).

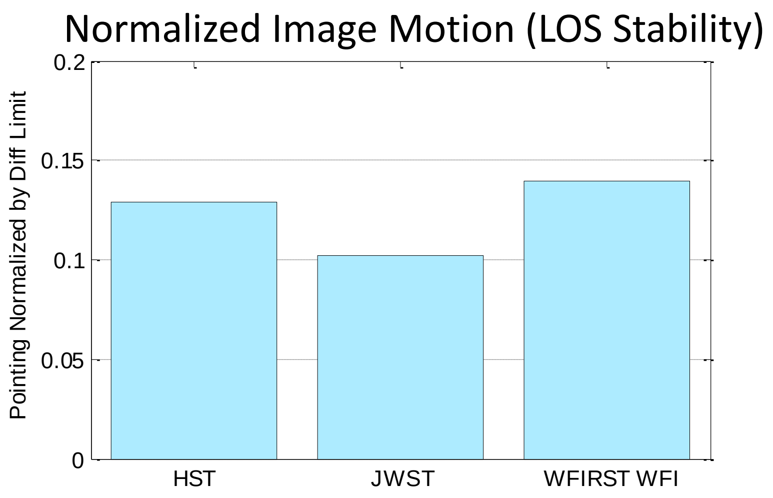


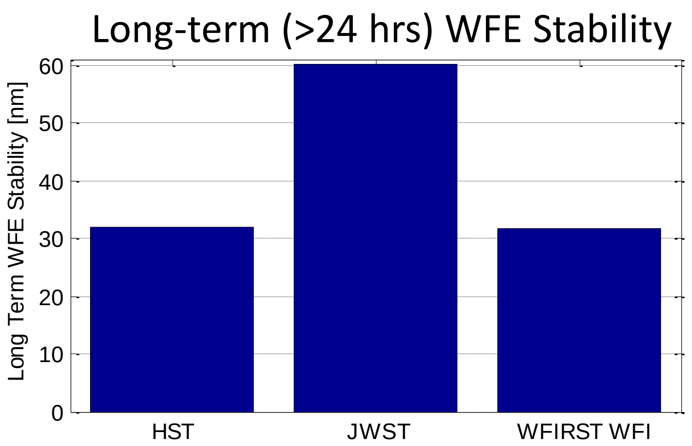
Introduction to WFIRST Integrated Modeling

- Modeling and analysis work that crosses discipline boundaries and requires observatory level coordination
  - Thermal distortion analysis: structural-thermal-optical performance (STOP) analysis
  - Dynamic jitter analysis: disturbance, structural, and optical analysis
- Ground to orbit effects
  - cool-down and gravity release
- On-orbit variation
  - dynamic jitter, thermal variation, moisture desorption, and material creep
- Uses tools and processes that have been flight validated on other NASA Goddard missions (Solar Dynamic Observatory, Global Precipitation Mission, Landsat-8, Neutron Star Interior Composition Explorer) and used extensively on James Webb Space Telescope (JWST), that have been enhanced to meet WFIRST needs
  - Enhanced to model large monolithic glass optics and cold alignments
  - Also working closely with JWST on lessons learned

Wide Field Instrument (WFI) Stability Requirements

- WFIRST WFI has similar line-of-sight (LOS) stability and long-term wavefront error (WFE) requirements as the Hubble Space Telescope (HST).
  - Image motion requirements are reasonable: 10-20% of resolution limit (or pixel size)
  - JWST has a larger WFE stability requirement due to larger and more complex (segmented) primary mirror.
  - High confidence in meeting these requirements given HST and JWST experience.
- Driving WFIRST WFI stability requirement is 1 nm within 180-sec (largest possible exposure window).
  - Derived from weak lensing ellipticity knowledge requirement.
  - WFE occurs within exposure window cannot be corrected during post-processing.
- Primary mirror (PM) stability is the dominant contributor to observatory stability performance.
  - Telescope thermal and dynamic environments must be made stable to meet stability requirements.





Coronagraph Instrument (CGI) Stability Requirement Summary

		Need From Observatory	CGI Control	CGI Reqt (TBR)
Pupil shear drift during observation		0.001 mm	—	0.001 mm
LoS drift (RMS per axis, equiv on sky)		8 mas	Fine Steering Mirror (FSM)	0.2 mas
LoS jitter (RMS per axis, equiv on sky)		12 mas	FSM	0.4 mas
RMS WFE drift	Focus	10 nm	Focus Mechanism	0.07 nm
	Astigmatism	1.2 nm	Deformable Mirror	0.05 nm
	Coma	1.2 nm	Deformable Mirror	0.01 nm
	Spherical	1 nm	Deformable Mirror	0.01 nm
RMS WFE jitter	Focus	0.07 nm	—	0.07 nm
	Astigmatism	0.05 nm	—	0.05 nm
	Coma	0.01 nm	—	0.01 nm
	Spherical	0.01 nm	—	0.01 nm
	Trefoil	0.02 nm	—	0.02 nm

Without CGI Control

Post CGI Compensation

CGI achieves required stability using active control with Observatory stability driven by WFI requirements.

Slew-Settle Requirements

- Thermal settling is not required, and only dynamic settling time is considered.
- Jitter settling is met by limiting wheel speed operational range.
- ACS slew-settle time is driven by actuator capability, control algorithm formulation, and damping of appendage modes (i.e. SA, HGA boom).

	Slew Time Requirement (6 wheels)
Gap Filling Slew	The Observatory shall slew in less than 23 seconds for a gap filling slew of ≤212 arcsec, with all wheels functioning.
Long Field Slew	The Observatory shall slew in less than 78 seconds for a long field slew of 0.82 degree, with all wheels functioning.
Short Field Slew	The Observatory shall slew in less than 56 seconds for a short field slew of 0.41 degree, with all wheels functioning.
Large Microlensing Slew	The Observatory shall slew in less than 92 seconds for a slew of 1.16 degrees, with all wheels functioning.
180 Degree Slew	The Observatory shall slew in less than 3700 seconds for a slew of 180 degrees, with all wheels functioning.

	Settle Time Requirement
<1 Degree Settle Time	The Observatory shall settle within 10 seconds, average value over a science sector, for slews <1 deg.
1 to 10 Degrees Settle Time	The Observatory shall settle within 10 seconds plus 1 second per degree of slew, average value over a science sector, for slew angles between 1 and 10 deg.
>10 Degrees Settle Time	The Observatory shall settle within 20 seconds for slews >10 deg.

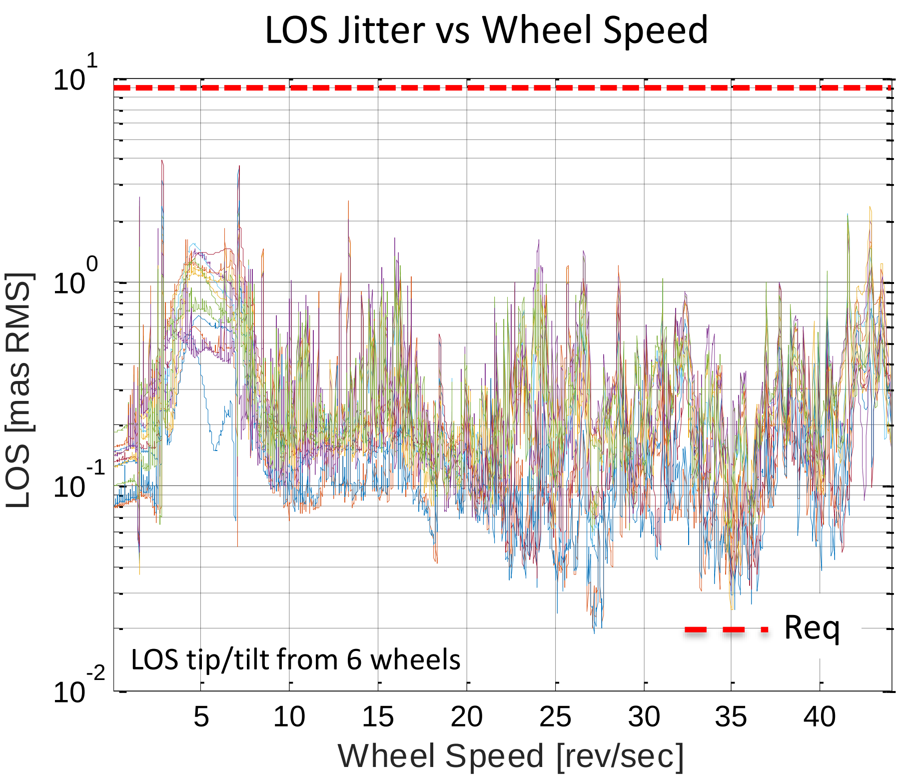
Stability Mitigation Tools

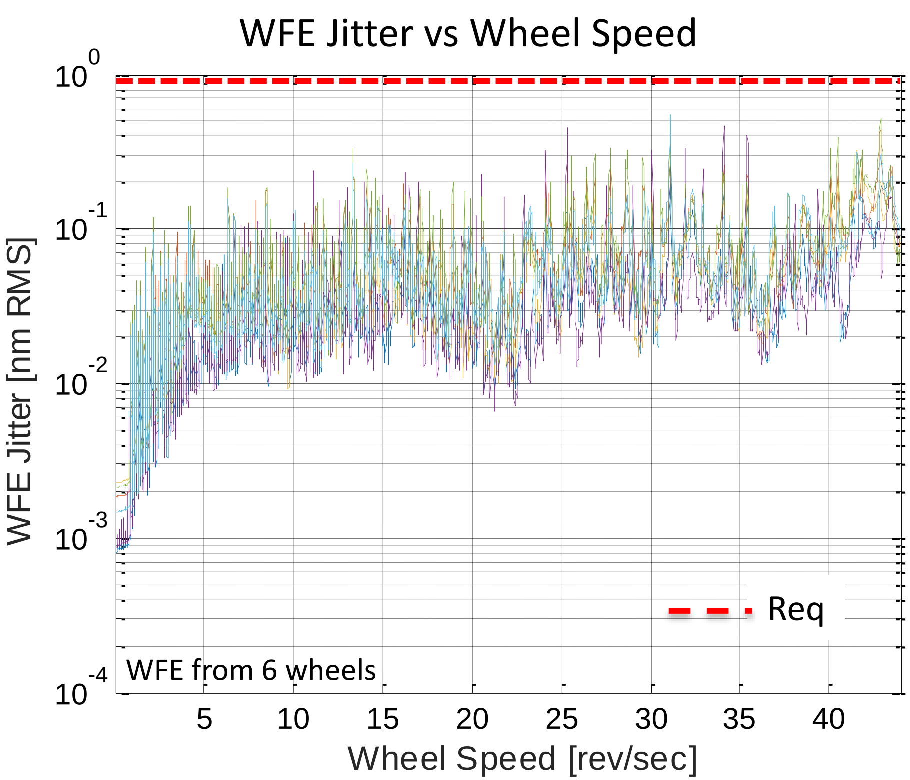
- Ground-to-orbit
  - Cool-down effects: cold alignments and cool figuring
  - Gravity release: characterization of gravity effects and pre-launch alignments based on analysis of gravity release
  - Sufficient flight compensation to correct for residual alignment errors
- Thermal Variation
  - Active thermal control
  - Use proportional heaters on Payload thermal control system (TCS)
  - Minimize changes in Sun vector direction in the Observatory frame
  - WFI has no real-time compensator
  - CGI can use steering mirror, focus mechanism, and deformable mirrors (DMs) to correct for slow-varying thermal induced errors
- Material Stability
  - Use flight alignment mechanisms for alignment error compensation
  - Plan for periodic on-orbit alignment adjustments

Dynamic Stability Mitigation

- Primary mitigation strategy for wheel-induced jitter is passive isolation
  - Analysis shows 2-stage isolation meets requirements for an acceptable wheel speed range
  - Supplemented by targeted damping if necessary
- Payload vibration isolation system (PVIS): between spacecraft bus (reaction wheel, high gain antenna actuator) and Payload (telescope/instruments)
  - Baseline approach is to modify existing WFIRST D-struts to achieve the best isolation performance possible.
- Reaction wheel assembly (RWA) isolation system
  - Potentially, ops concept modifications (wheel speed limits during certain observations, scheduling least sensitive science campaigns after slews, …)
- High gain antenna (HGA) gimbal actuator
  - Avoid stepping HGA during science exposure
  - Implement boom damper
- WFIRST has fixed solar array/sun shield
- General strategies to mitigate effects from other disturbance sources
  - Other disturbances are instrument mechanisms and thruster firings
  - Avoid moving mechanisms and firing thrusters during science exposures
  - Implement dampers for appendage modes to reduce settling time

WFI Jitter Results during Observation

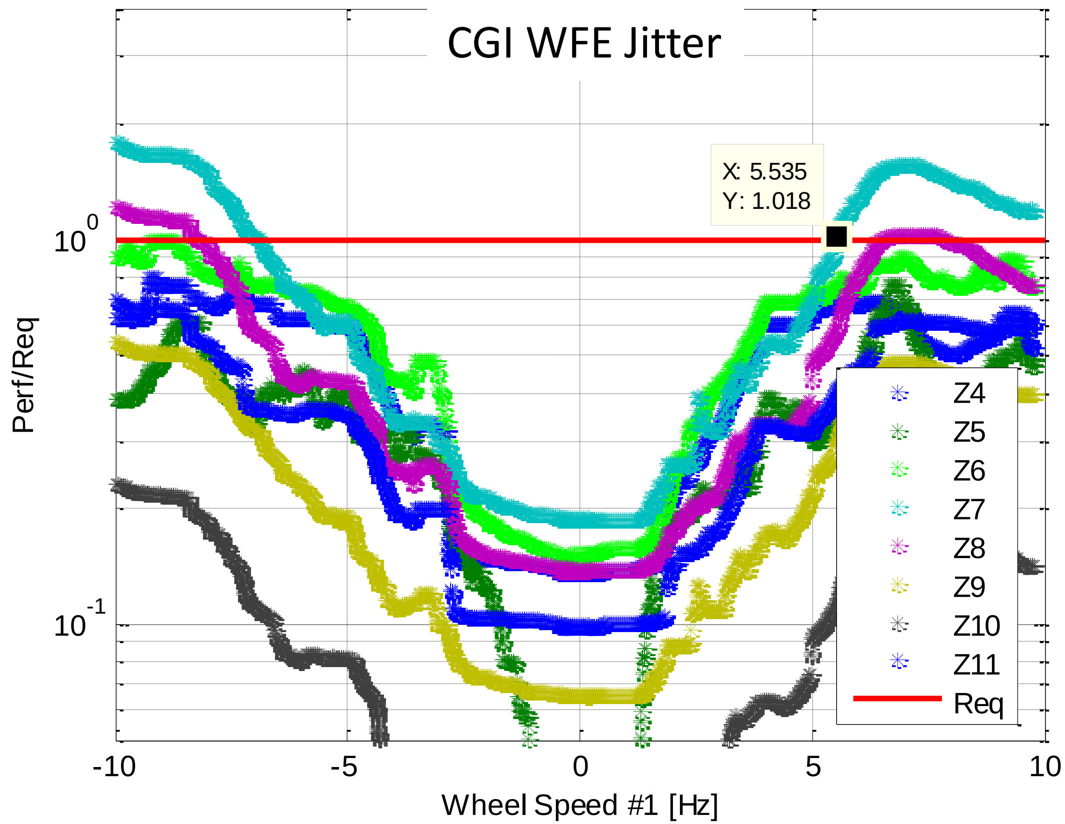




- Limit wheel speed range to <40Hz to meet WFI LOS and WFE jitter requirements.
- Point in time results show WFI results meet requirements with accepted Model Uncertainty Factors (MUFs).
- When idealized isolator model is replaced with wheel vendor isolator model, some performance degradation is expected.
  - Only need to meet requirement 95% of the time.

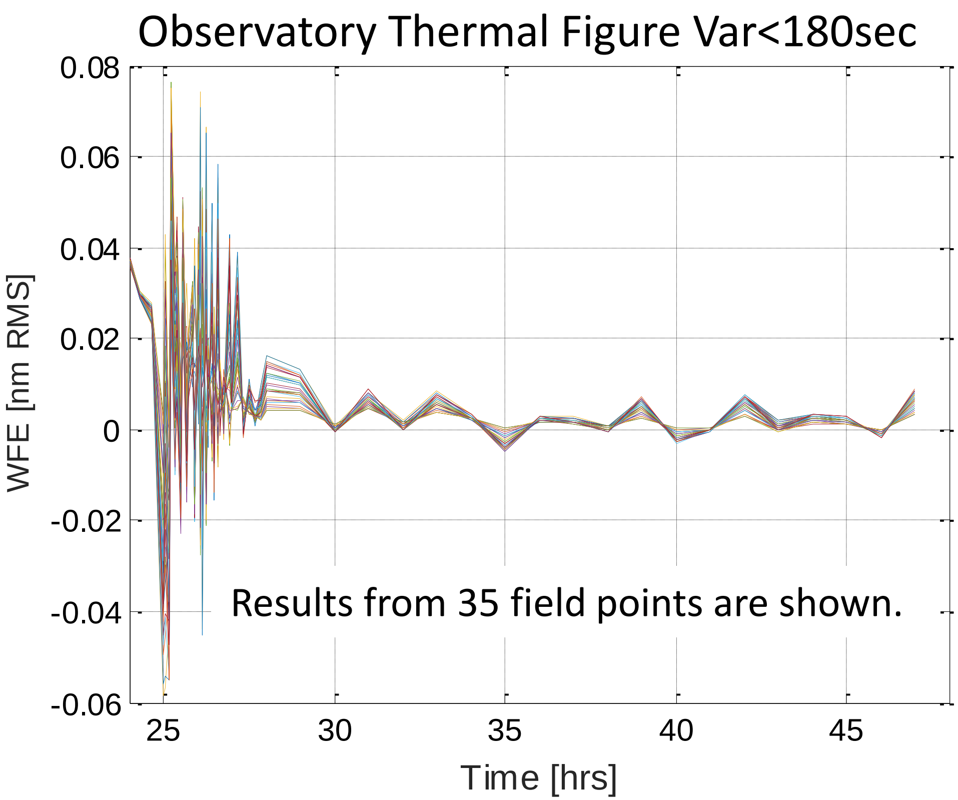
CGI Jitter Results during Observation

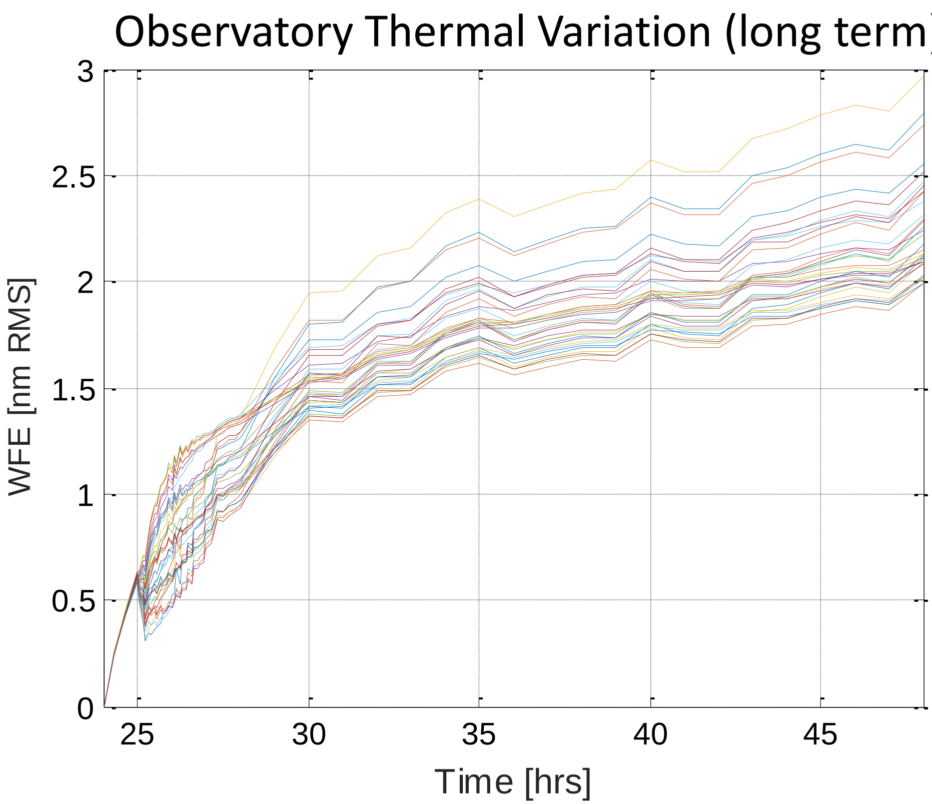
- Processed CGI wheel-induced jitter results with realistic wheel speed profiles.
- Normalized CGI Zernike jitter predictions by their requirements.
- Assumed 2-hour observation periods and only need to meet requirements 70% of the time.
- Point in time results show acceptable CGI results with reduced confidence.
  - CGI WFE jitter requirements can be met for some wheel speed ranges (+/- ~5.5 Hz).
  - CGI LOS jitter requirement is met through internal closed-loop control system.



CGI jitter requirements are challenging but achievable.

WFI STOP Results





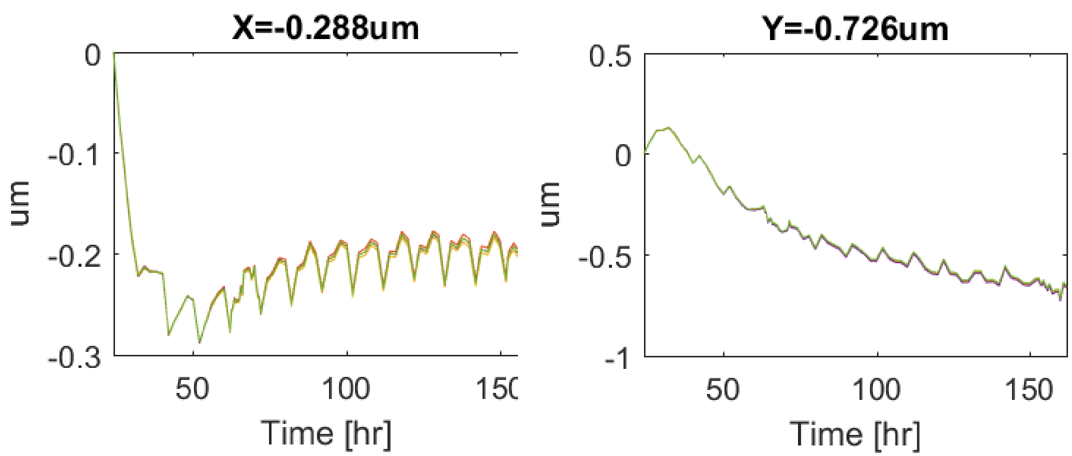
Current Best Estimate: 0.08 nm RMS
Requirement: 0.4 nm RMS

Current Best Estimate: 2.97 nm RMS
Requirement: 26.5 nm RMS

WFI thermal stability requirements are met with large margins after a worst-case slew.

CGI STOP Results

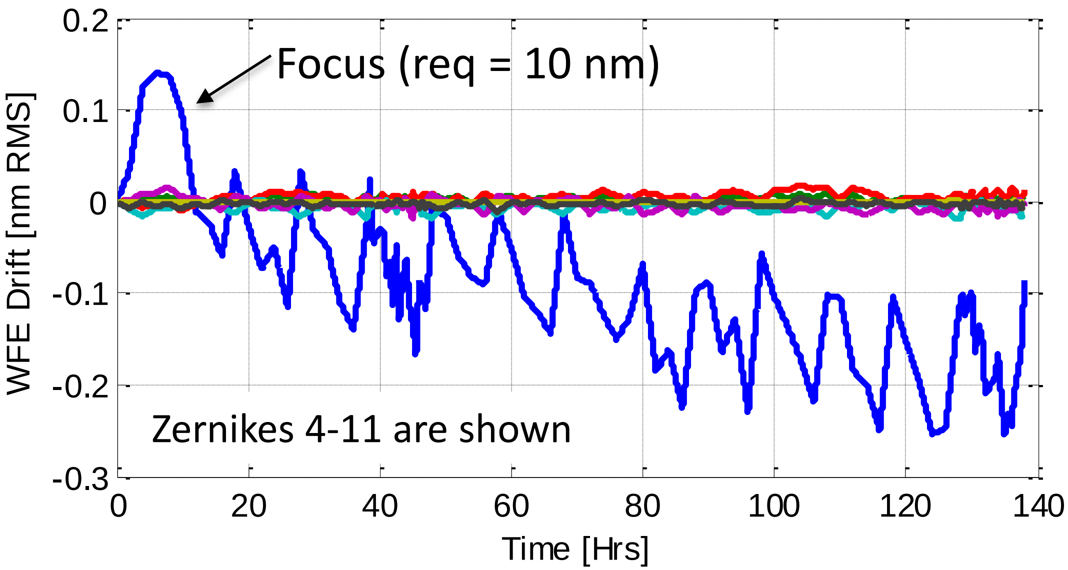
CGI WFE Pupil Drift over ~140 hours



Pupil drift estimate: 0.726
Pupil drift requirement: 1.0 um

CGI thermal stability requirements are met with good margins.

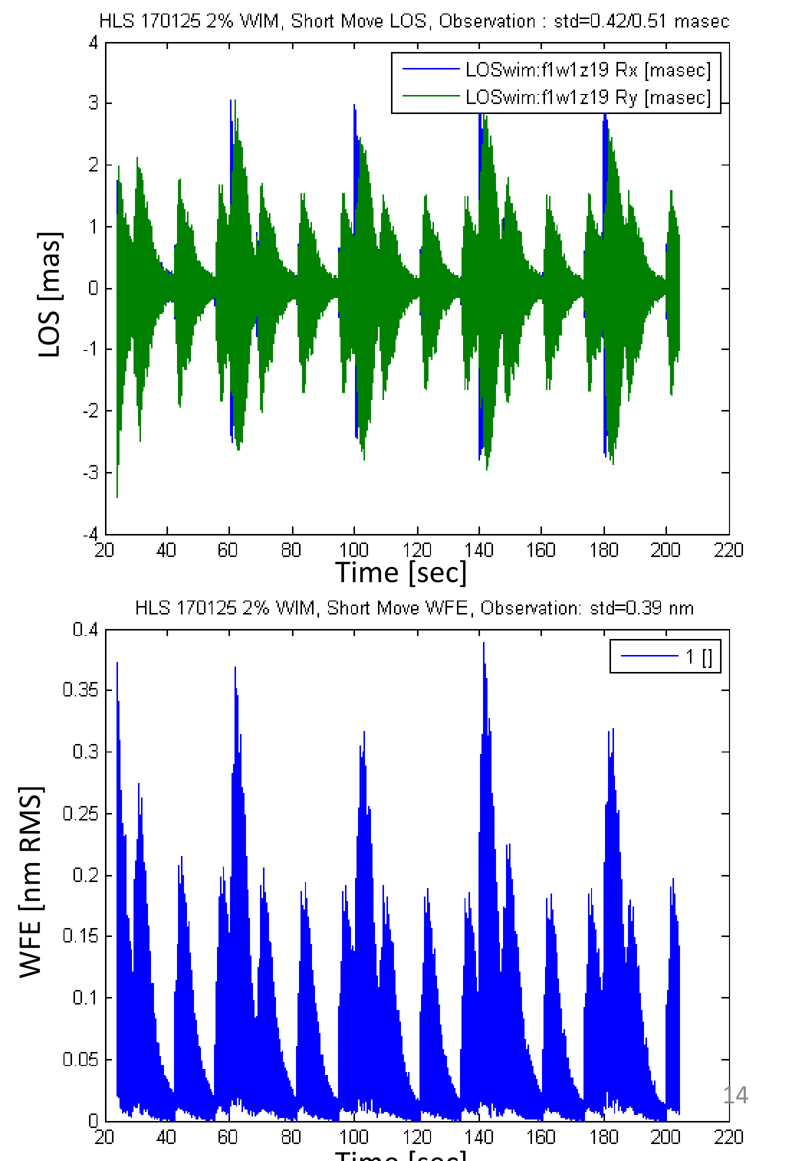
CGI WFE Drift over ~140 hours



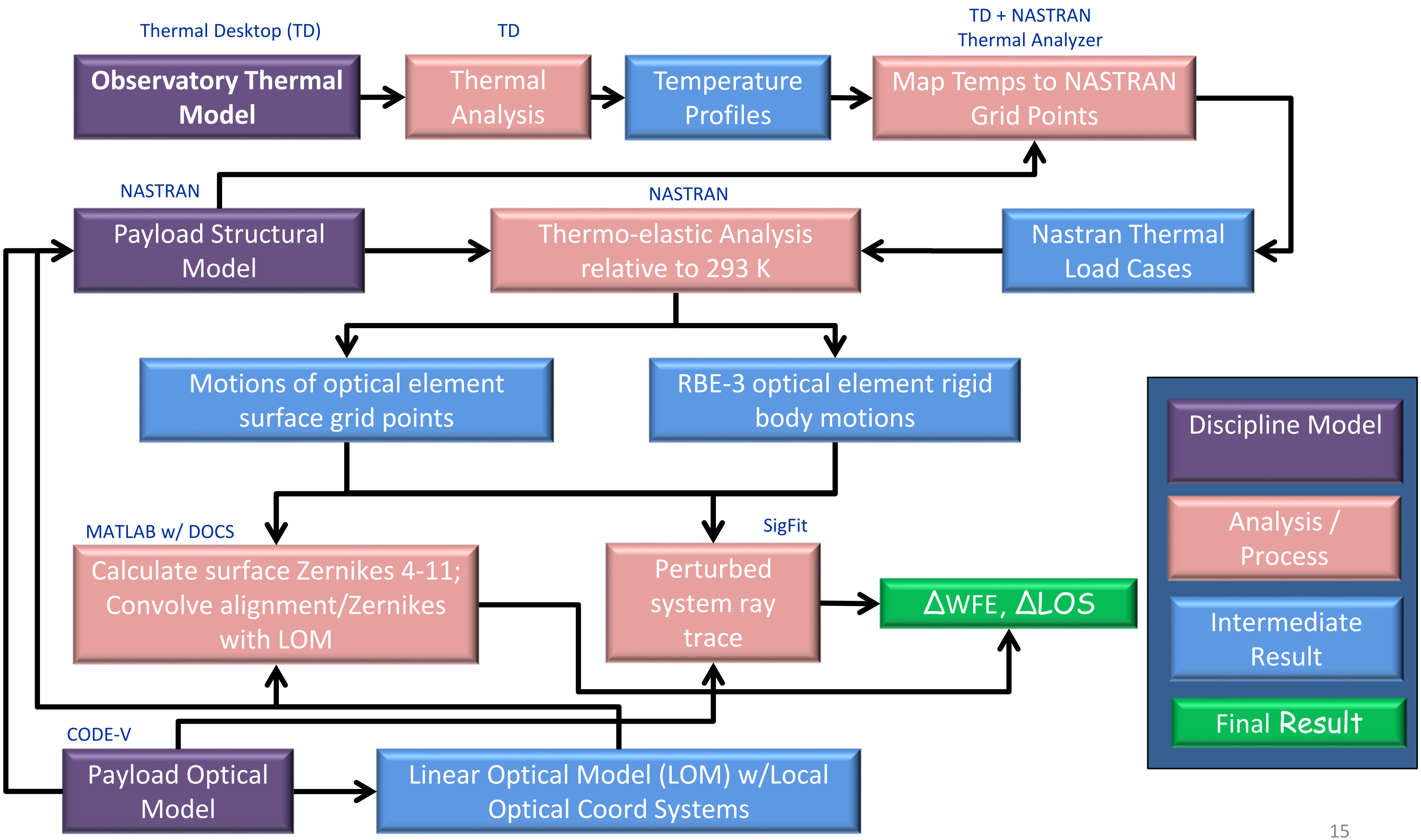
Peak drift estimate: 0.25 nm RMS
All Zernike requirements >= 1.0 nm RMS

HGA-induced Jitter

- When pointed inertially, there is a small amount of Earth relative motion (~1-2 deg/day).
  - Plots shown LOS (0.4 mas RMS) and WFE (0.4 nm RMS) jitter generated from stepping the HGA actuators at this rate to maintain contact with Earth.
- HGA boom damping, micro-stepping, and low-detent motors are assumed in these jitter results.
  - Micro-stepping requires constant power to actuators
  - Without low detent, microstepping will provide ~2x jitter reduction.
  - With low detent, microstepping will provide 5-10x jitter reduction but will require gravity off-load during ground deployment testing



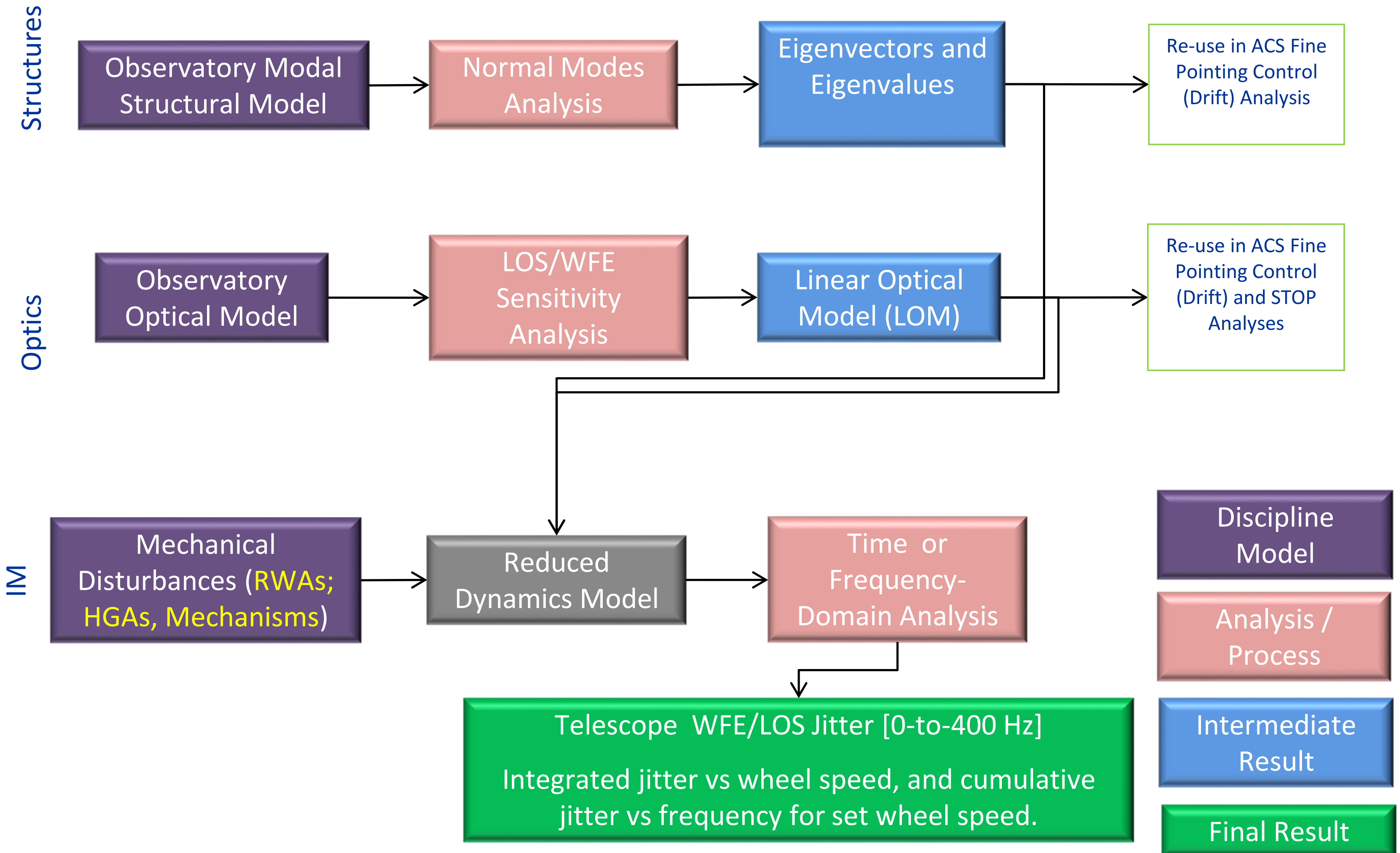
WFIRST STOP Process



STOP Capability Limitations

- STOP analysis drivers
  - Finite resolution (mesh size) drives model run time and model integration time.
  - Design maturity limits model fidelity.
  - Computing power limits model and analysis run time.
- Experimental validation
  - Cannot test to sub-nanometer level due to facility noise
  - Rely on over-drive testing
  - Design in linearity to allow extrapolation (i.e. ball joint to flexures, see MCR replies, may use flexures instead of latches…)
- Material and joint behavior are not drivers
  - There are extensive material database and joint characterization based on heritage flight programs
  - WFIRST plans to perform material and joint characterization as part of our test program

WFIRST Jitter Process



Jitter Capability Limitation

- Model accuracy degrades at frequencies above 100 Hz.
  - Only know system dynamic response to within some bound
  - Rely on isolators to reduce sensitivity to modeling errors
- Require accurate characterization of isolators to validate flight performance predicts.
  - Internal isolation modes and structural flexibility limit isolation performance at high frequencies
  - Important to manage mechanical shorts such as cables or heat straps across the isolator interface (e.g. design soft cables)
- Measure and characterize input disturbances to high precision
- If additional isolation performance is needed, active cancellation is an option
  - Active control increases robustness to modeling uncertainty but with added risk, cost, and complexity.
- Same model size and test limitations as STOP

Model Validation

- Sub-nanometer accuracy: A model will be defined to have sub-nanometer accuracy when it achieves a specified probability of predicting the magnitude of a sub-nanometer change in optical response within a specified error bound when acted on by flight level thermal and mechanical disturbances
- The specified error bound is represented by a multiplicative MUF
  - Separate MUFs for Thermal, Thermal Distortion, Moisture Desorption, Gravity Release, and Jitter
  - Based on historical accuracy of discipline modeling tools
  - Validated as far as possible via analysis and test
- WFIRST will do this by creating models that:
  1. predict sub-nanometer optical response when acted on by flight level disturbances,
  2. match the measured response to (possibly non-flight-level) disturbances within a specified error bound, and
  3. are shown to be valid to extrapolate from test disturbance amplitudes to flight disturbance amplitudes

Concluding Remarks

- Tools, processes, and analysis capabilities developed on NASA GSFC past missions are being utilized on LUVOIR.
- Due to LUVOIR size and tight stability requirements, an active, non-contact vibration isolation system may be required for jitter performance.

BACK-UP SLIDES

WFIRST
WIDE-FIELD INFRARED SURVEY TELESCOPE
DARK ENERGY • EXOPLANETS • ASTROPHYSICS

WFIRST IM team has extensive experience

IM team has established a tight working relationship across organizations and disciplines, and with system teams.

Mission System
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Payload System
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Spacecraft System
M. Vess

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(A. Liu)

IM Lead
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GSFC

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- B. Pasquale (Design lead)
- J. Howard (LOM)
- A. Jurling (WFS&C)

Structural
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- P. Baird (Dynamics)
- S. Godo (STOP)
- N. Nicolaeff (STOP)

Thermal
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- C. Cottingham (Payload lead)
- H. Peabody (Lead Obs. Analyst)
- C. McDonald (Payload analyst)

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- L. Sacks (LOM/STOP)

Harris

- R. Egerman (Overall Technical Lead)
- P. McCarthy (Optical)
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- F. Forkl (Thermal)

JPL

- R. Demers (Flight System Lead)
- C. Noecker (System)
- I. Poberezhskiy (System)
- H. Tang (Optics Lead)
- D. Braun (Mechanical lead)
- H. Pham (Thermal Lead)
- O. Alvarez-Salazar (LOS control)

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WFIRST Disturbance Sources

Mechanism		Active during	
		WFI Science Exposure	CGI Science Exposure
Spacecraft	Reaction Wheel Actuators	Y	Y
	High Gain Antenna	N (settling)	N
	Thrusters	N	N
WFI	Element Wheel Assembly	N	N
	Internal Fold Mirror	N	N
	Fold 1 Mechanism TBR	N	N
	RCS Mechanism	N	N
CGI	Fast Steering Mirror	N	Y
	Deformable Mirror	N	Y
	CGI Focus Corrections	N	Y

RWA and HGA are by far the most significant jitter source, and has been the focus of investigation through Phase A; other sources will be analyzed in Phase B