



Optics in NASA Astrophysics

ICSO, 2018

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Topics

- **General Astrophysics Missions and Studies**
 - Missions in Operation
 - Missions in Development
 - Decadal Survey Mission Studies
 - Decadal Survey Probe Studies
- **Key Missions with an Optical Focus:**
 - TESS
 - WFIRST
 - LISA
 - JWST

Astrophysics Missions in Operation

<p>Hubble 4/90 NASA Strategic Mission</p>  <p>Hubble Space Telescope</p>	<p>Chandra 7/99 NASA Strategic Mission</p>  <p>Chandra X-ray Observatory</p>	<p>XMM-Newton 12/99 ESA-led Mission</p>  <p>X-ray Multi Mirror - Newton</p>	<p>Spitzer 8/03 NASA Strategic Mission</p>  <p>Spitzer Space Telescope</p>	<p>Gehrels-Swift 11/04 NASA MIDEX Mission</p>  <p>Swift Gamma-ray Burst Explorer</p>	<p>Fermi 6/08 NASA Strategic Mission</p>  <p>Fermi Gamma-ray Space Telescope</p>
<p>Kepler 3/09 NASA Discovery Mission</p>  <p>Kepler Space Telescope</p>	<p>NuSTAR 6/12 NASA SMEX Mission</p>  <p>Nuclear Spectroscopic Telescope Array</p>	<p>SOFIA 5/14 NASA Strategic Mission</p>  <p>Stratospheric Observatory for Infrared Astronomy</p>	<p>ISS-NICER 6/17 NASA Explorers Miss. of Oppty</p>  <p>Neutron Star Interior Composition Explorer</p>	<p>ISS-CREAM 4/17 NASA Research Mission</p>  <p>Cosmic Ray Energetics And Mass</p>	<p>TESS 4/18 4/2018 NASA MIDEX Mission</p>  <p>Transiting Exoplanet Survey Satellite</p>

Astrophysics Missions in Development

<p>TESS NASA Mission 4/2018</p>  <p>Transiting Exoplanet Survey Satellite</p>	<p>Webb NASA Mission 2020</p>  <p>James Webb Space Telescope</p>	<p>Euclid ESA-led Mission 2021</p>  <p>NASA is supplying the NISP Sensor Chip System (SCS)</p>	<p>IXPE NASA Mission 2021</p>  <p>Imaging X-ray Polarimetry Explorer</p>
<p>GUSTO NASA Mission 2021</p>  <p>Galactic/ Extragalactic ULDB Spectroscopic Terahertz Observatory</p>	<p>XARM JAXA-led Mission 2021</p>  <p>NASA is supplying the SXS Detectors, ADRs, and SXTs</p>	<p>MIDEX/MO NASA Mission 2022/ 2023</p>  <p>Arcus, FINESSE, or SPHEREx CASE, COSI-X, or ISS-TAO</p>	<p>WFIRST NASA Mission Mid 2020</p>  <p>Wide-Field Infrared Survey Telescope</p>

Decadal Survey Planning

Large Mission Concept Studies

	Community STDT Chairs	Center Study Scientist	Study Lead Center	HQ Program Scientist
Habitable Exoplanet Imaging Mission www.jpl.nasa.gov/habex	Scott Gaudi Sara Seager	Bertrand Mennesson	JPL	Martin Still
Large UV/Optical/IR Surveyor asd.gsfc.nasa.gov/luvoir	Debra Fischer Bradley Peterson	Aki Roberge	GSFC	Mario Perez
Lynx X-ray Surveyor wwwastro.msfc.nasa.gov/lynx	Feryal Ozel Alexey Vikhlinin	Jessica Gaskin	MSFC	Dan Evans* Rita Sambruna
Origins Space Telescope asd.gsfc.nasa.gov/firs	Asantha Cooray Margaret Meixner	David Leisawitz	GSFC	* Dan Evans is on detail to OMB through July Kartik Sheth 2018

Decadal Survey Planning

Probe Mission Concept Studies

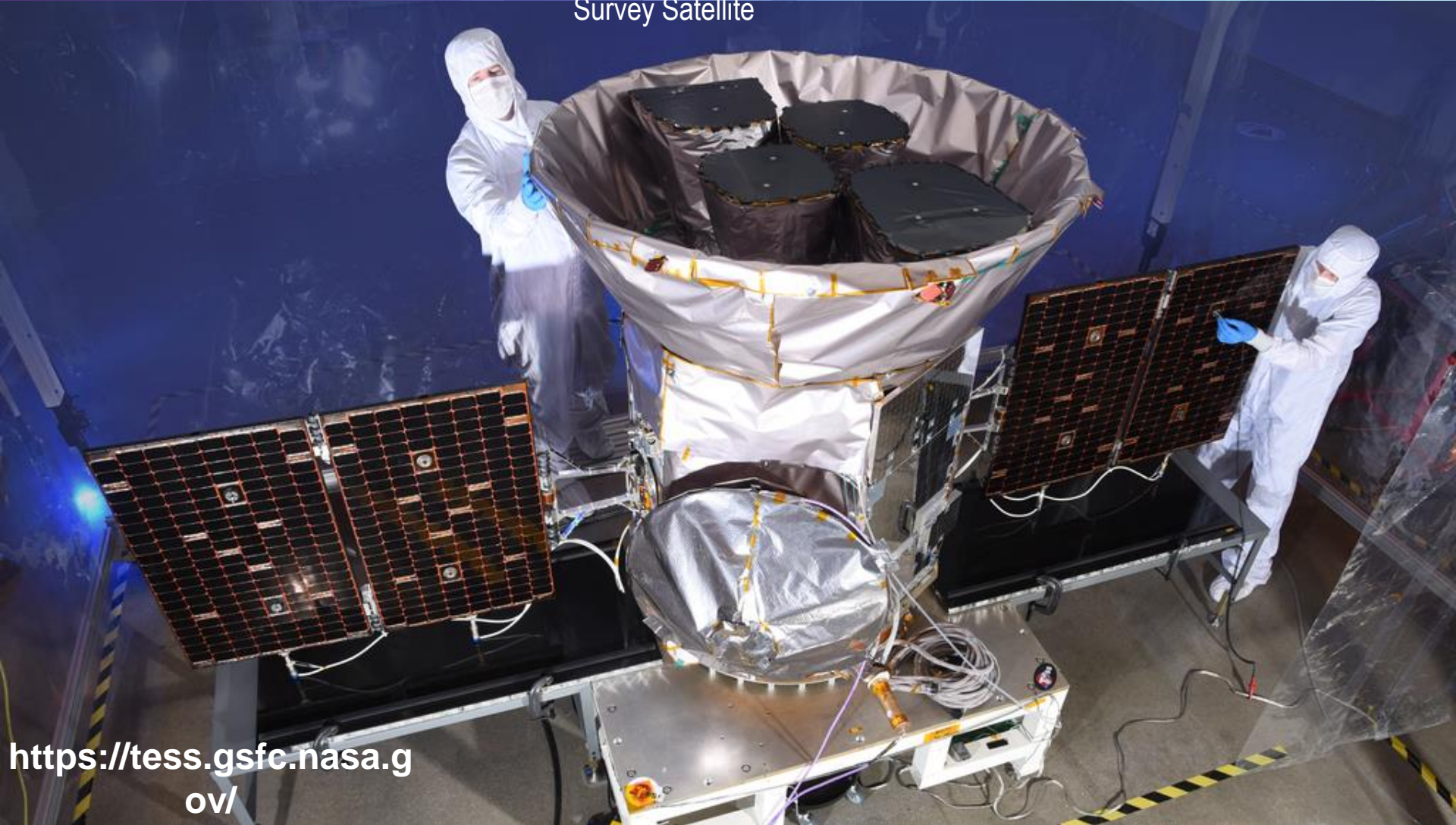
PI	Affiliation	Short title
Jordan Camp	NASA GSFC	Transient Astrophysics Probe
Asantha Cooray	Univ. California, Irvine	Cosmic Dawn Intensity Mapper
Bill Danchi	NASA GSFC	Cosmic Evolution through UV Spectroscopy Probe
Jason Glenn	Univ. of Colorado	Galaxy Evolution Probe
Shaul Hanany	Univ. of Minnesota	Inflation Probe
Richard Mushotzky	Univ. of Maryland	High Spatial Resolution X-ray Probe
Angela Olinto	Univ. of Chicago	Multi-Messenger Astrophysics Probe
Peter Plavchan *	Missouri State Univ.	Precise Radial Velocity Observatory
Paul Ray	Naval Research Lab	X-ray Timing and Spectroscopy Probe
Sara Seager *	MIT	Starshade Rendezvous Mission

* Partial Selections

The Selection Document and Probes Implementation Plan are posted at
<https://science.nasa.gov/astrophysics/2020-decadal-survey-planning>

TESS

Transiting Exoplanet
Survey Satellite



<https://tess.gsfc.nasa.gov/>

<https://tess.mit.edu/>

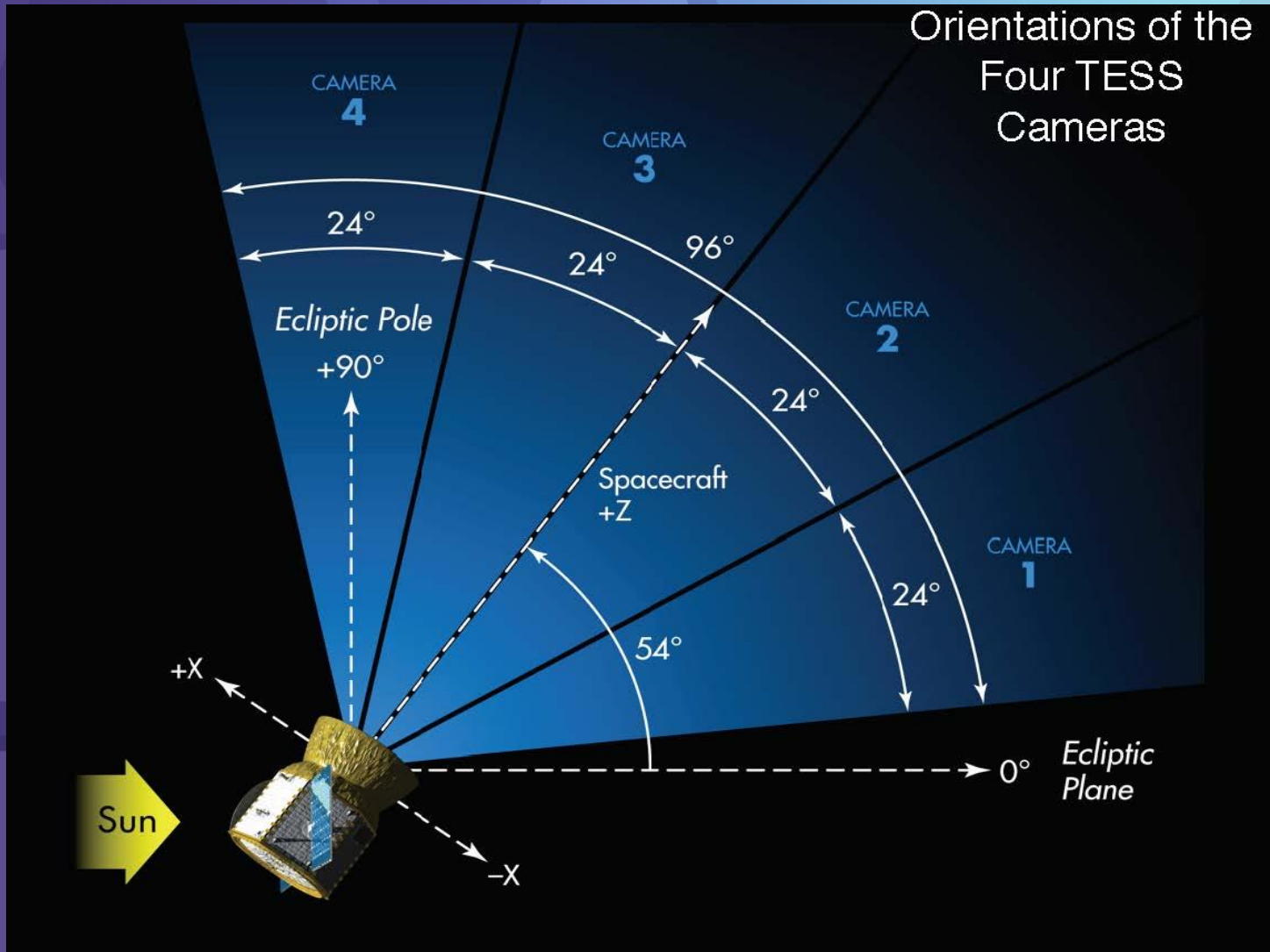
TESS

Transiting Exoplanet Survey Satellite

Launched April 18, 2018

<https://tess.gsfc.nasa.gov/>
<https://tess.mit.edu/>





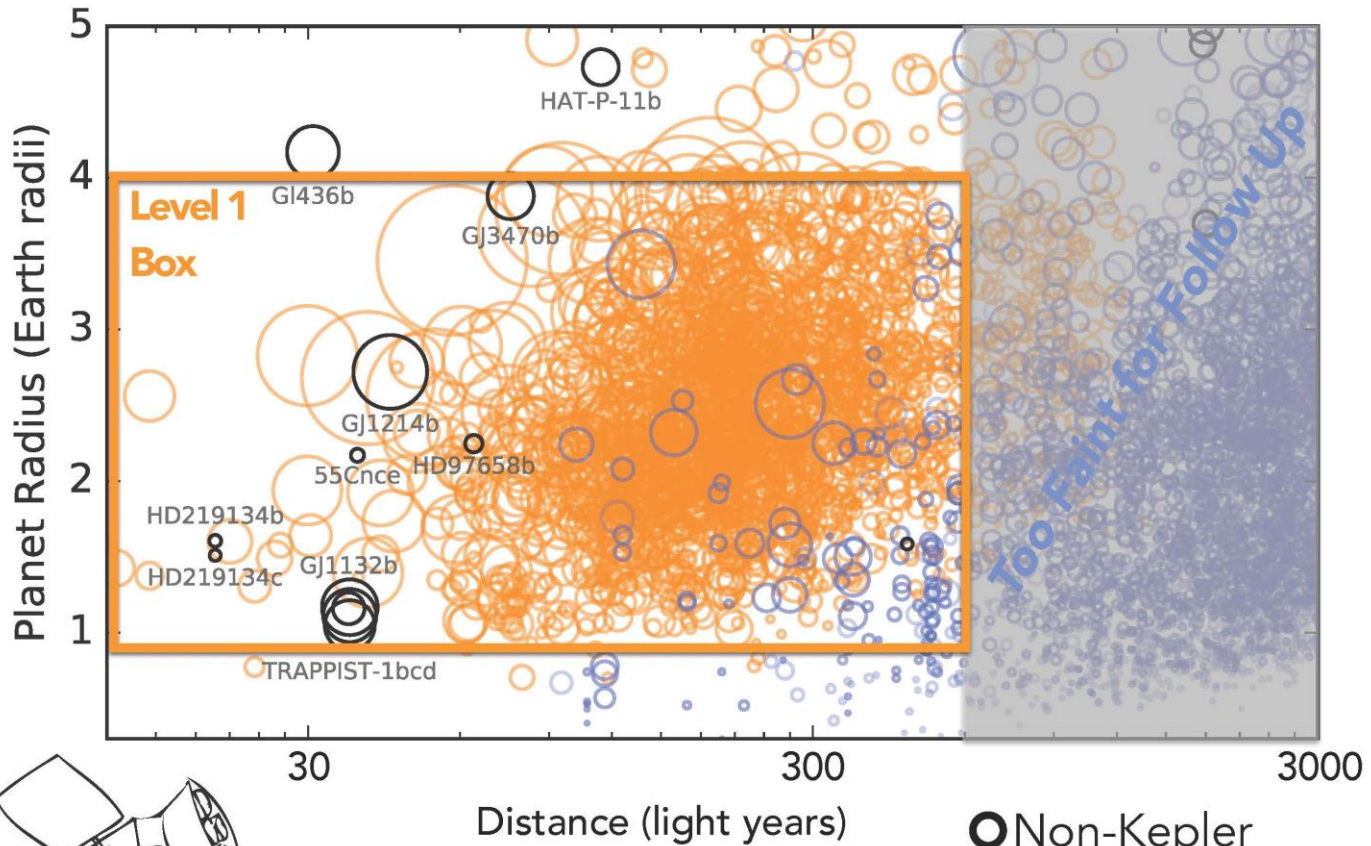
One TESS Camera:
24 degrees

30-minute exposure
full frame images (FFI)
(>30 million stars and galaxies in survey...)

1300 successive FFI's for
each sky segment
(27 days)

- Moon $\sim 0.2 \text{ deg}^2$
 \Rightarrow 10,000
moons would
fit inside the
TESS FOV

Kepler FOV
 $\sim 100 \text{ deg}^2$



- Non-Kepler
- Kepler/K2
- TESS (expected)

circle size = transit
depth

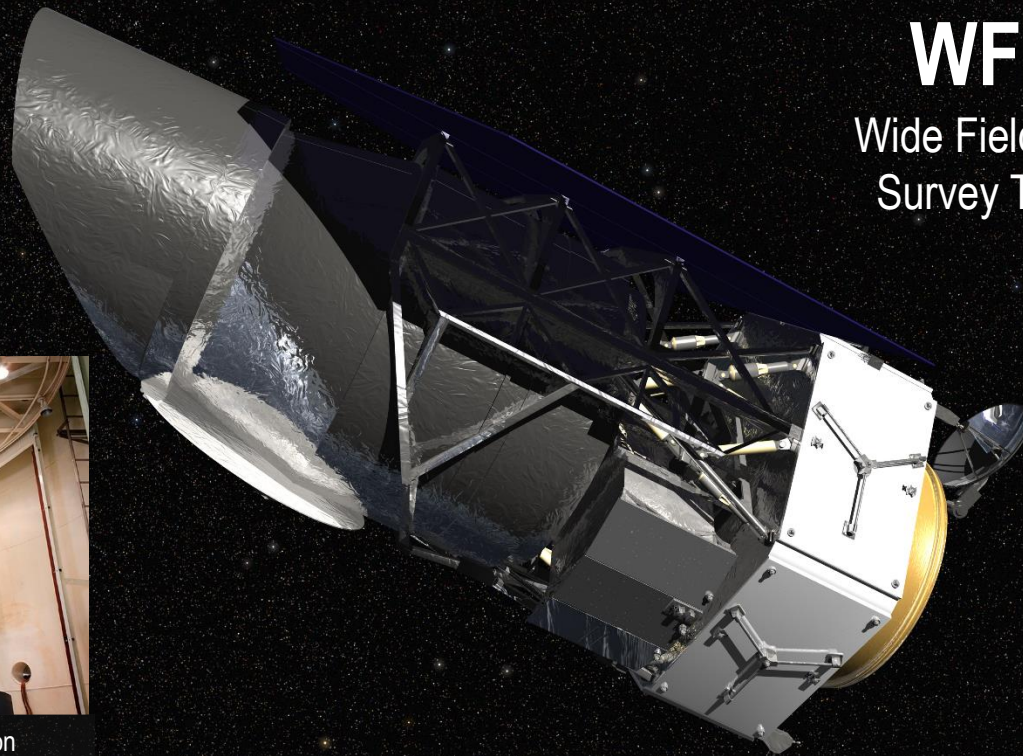
TESS — Discovering New Earths and Super-Earths in the Solar Neighborhood

WFIRST

Wide Field Infrared
Survey Telescope



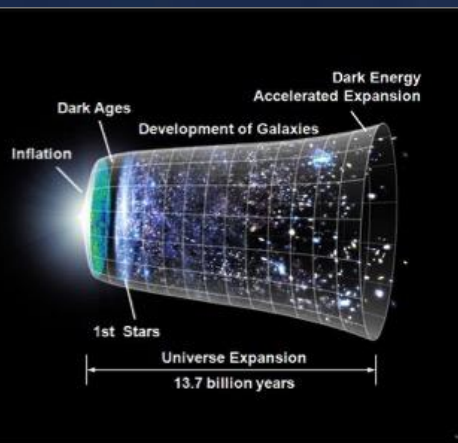
Primary mirror assembly / Harris Corporation



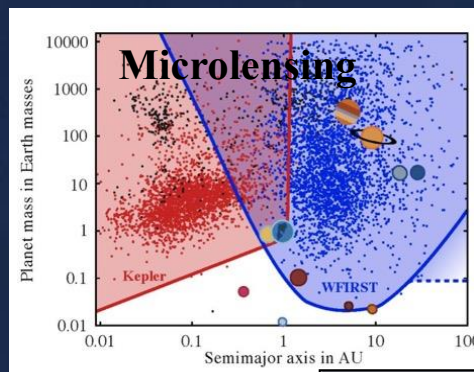
Introduction

- Highest ranked large space mission in 2010 Astrophysics Decadal Survey
- Use of existing 2.4m telescope hardware components enable:
 - Hubble quality imaging over 200x more sky than WFC3/IR
 - Exoplanet studies with a coronagraph at 10^{-8} - 10^{-9} contrast

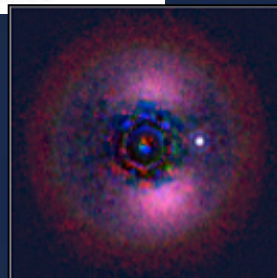
Dark Energy



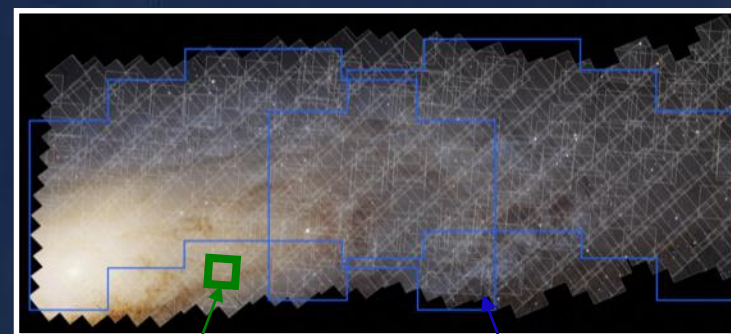
Exoplanets



Coronagraph Technology Demonstration



Astrophysics



WFIRST Mission Summary

Mission Life: 5 years (+ ~3 month checkout)

Mission Orbit: Sun-Earth L2

Launch Vehicle: carrying multiple options

- Delta IV Heavy, Falcon Heavy, New Glenn and SLS

Mission Classification: Class A, CGI is Class C (technology demonstration)

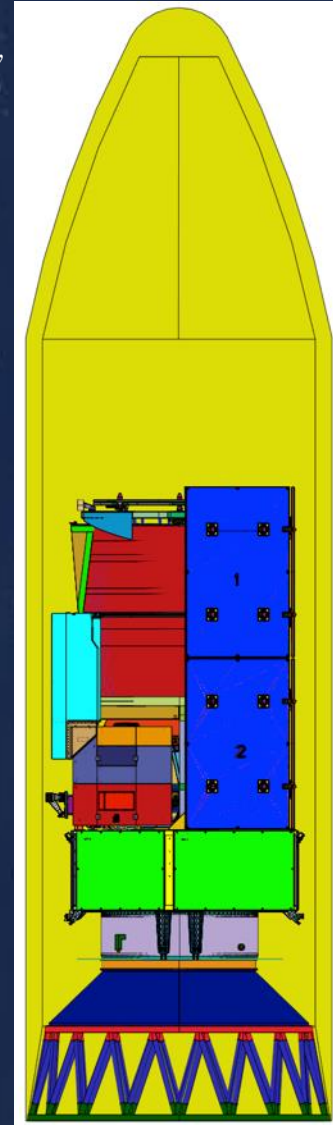
Observatory:

- 2.4 m primary mirror Telescope
- Wide Field Instrument (WFI) & Coronagraph Instrument (CGI)
- Designed to facilitate I&T and enable servicing
- Compatibility with a potential future Starshade mission

Ground System:

- Mission Operations Center and Science Operations Center
- Instrument Engineering Centers
- Ground Stations: White Sands + DSN, ESA & JAXA stations

*Observatory
shown in
Delta IV
fairing*

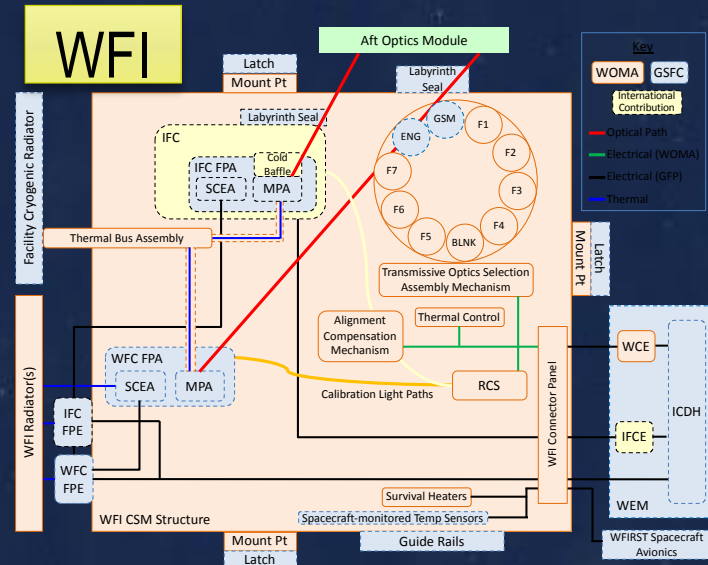
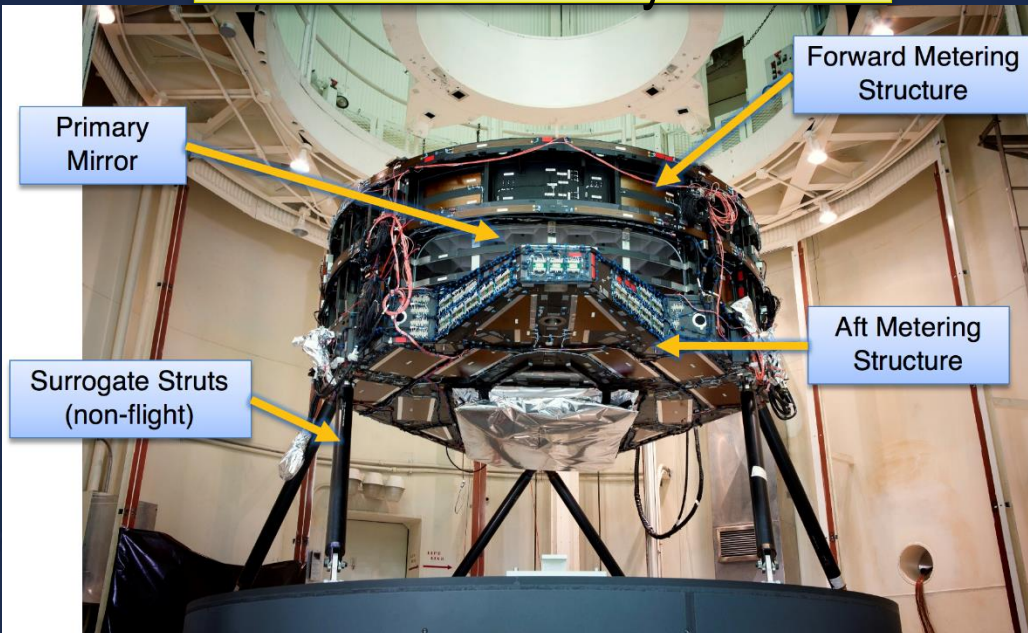
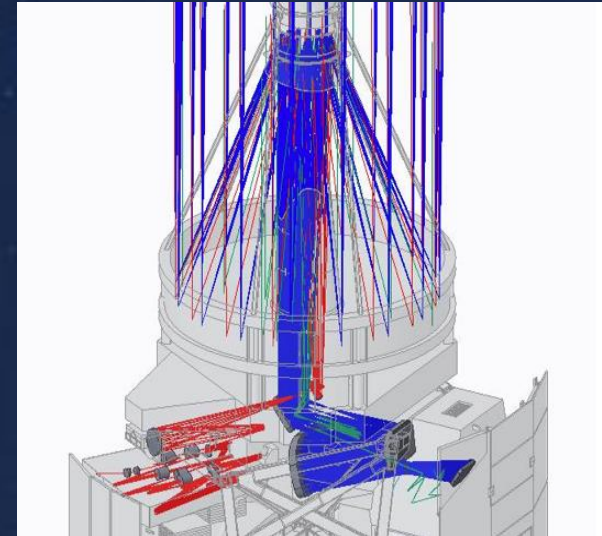


Primary Mirror and Wide Field Instrument

Key Parameters

- PM Diameter: 2.4 m
- PM Base Radius: ~5.7 m
- WFC Platescale
(110 mas/pixel → f/7.9)
- Field of View (FOV):
200x Hubble WFC3
~0.4° x 0.8° (18 * 7.5'x7.5')

Inherited Primary Mirror

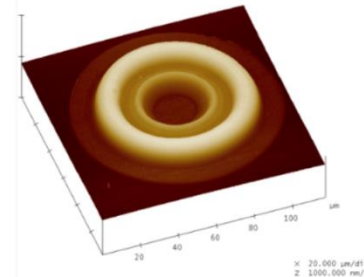


Coronagraph Instrument

WFIRST Coronagraph Instrument (CGI) will demonstrate in space coronagraph technology required for characterization of rocky planets in the Habitable Zone, significantly reducing the risk for future Exo-Planet missions

- High-Contrast Broadband Imaging
- High-Contrast Imaging Spectroscopy
- High-Contrast Extended Source Imaging and Polarimetry

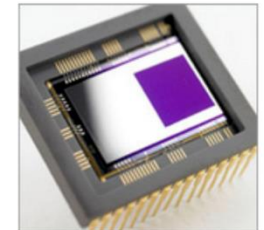
HLC mask image with an atomic force microscope



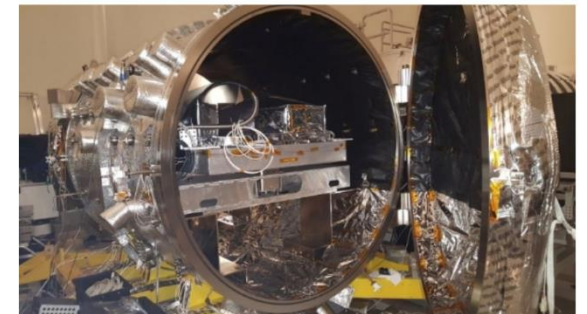
SPC mask image with an atomic force microscope



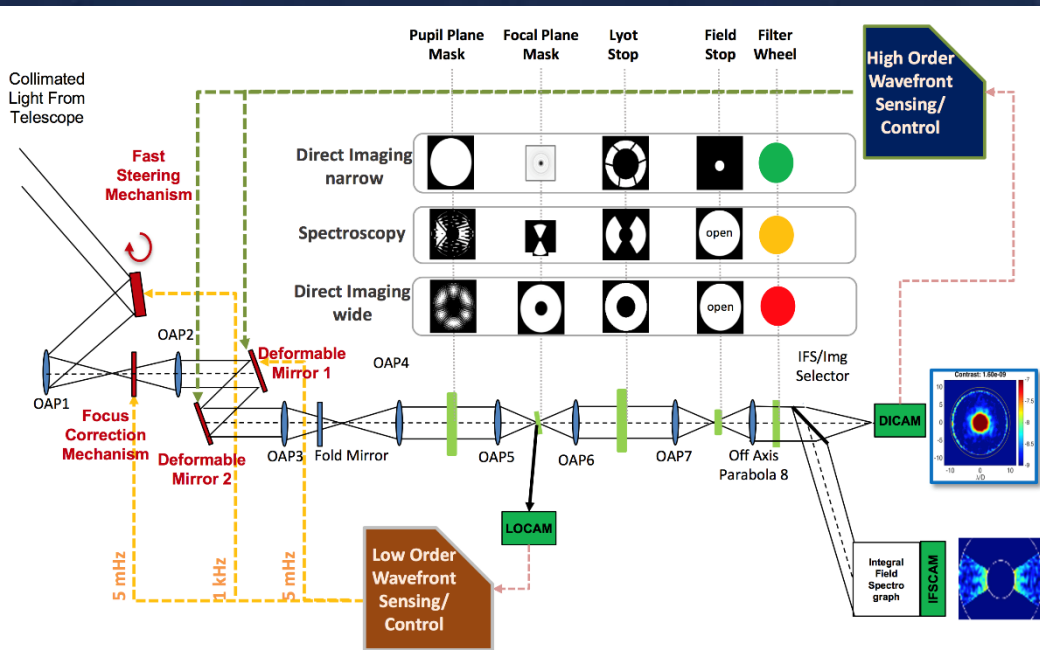
Xinetics 48 x 48 DM used in JPL's HCIT



E2V EMCCD used in photon-counting mode

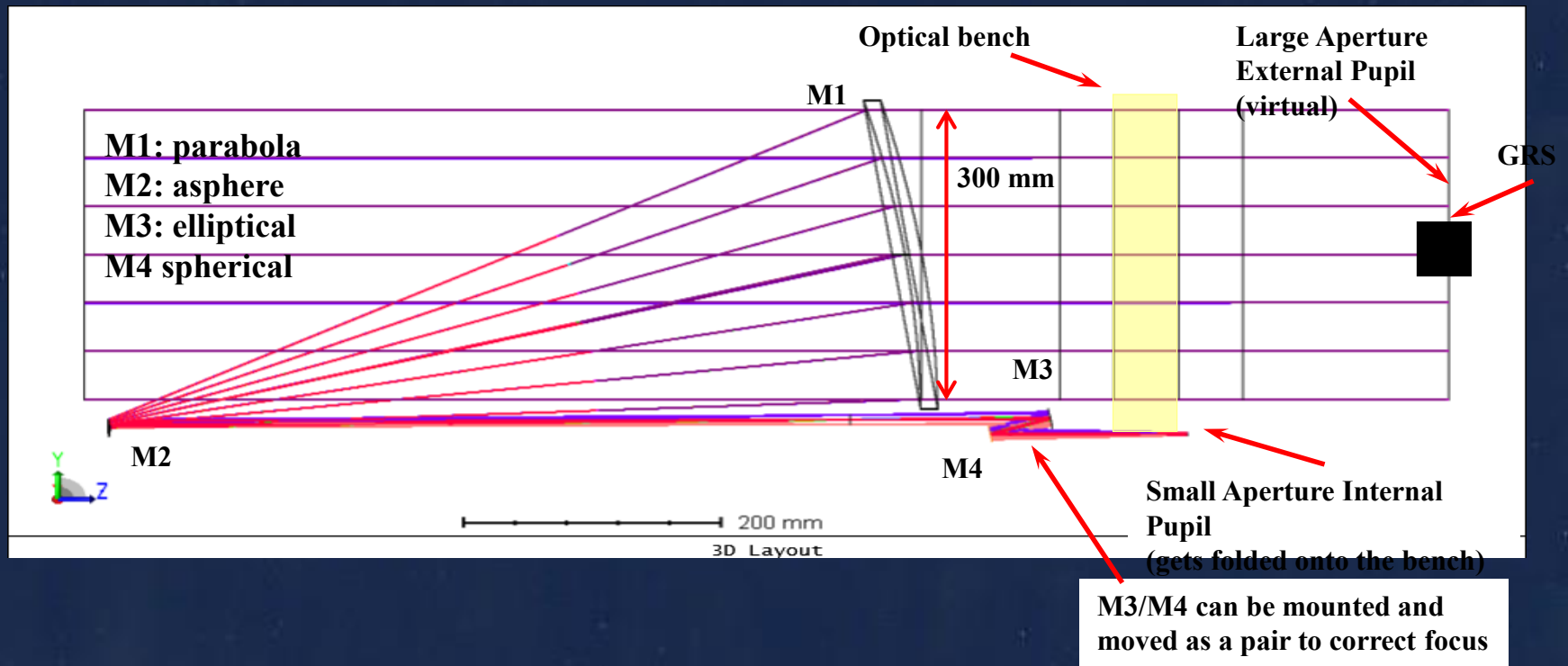


Testbed



GSFC is studying a 4 mirror, telescope pointed LISA telescope design

Opto-mechanical challenges for picometer per rt. Hz stability



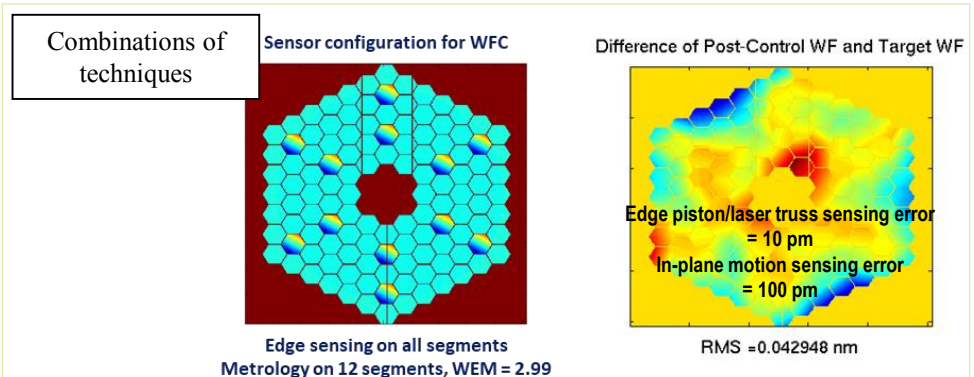
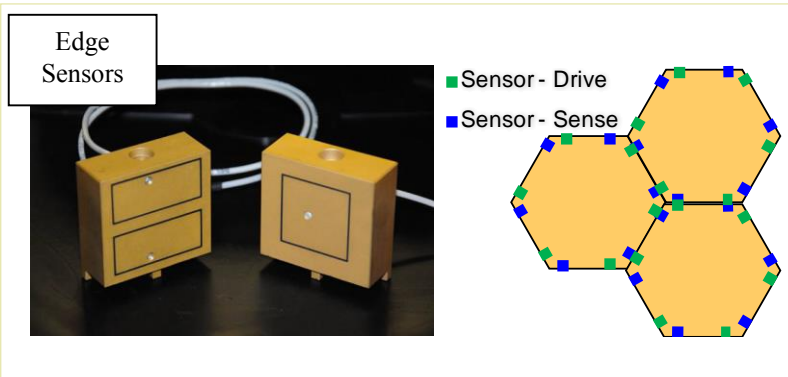
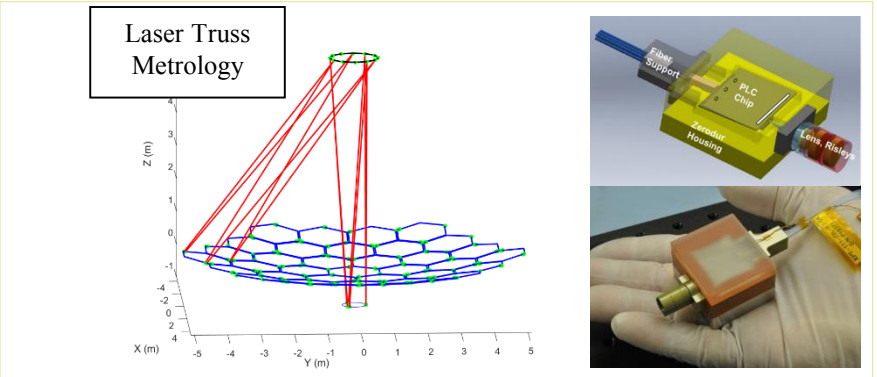
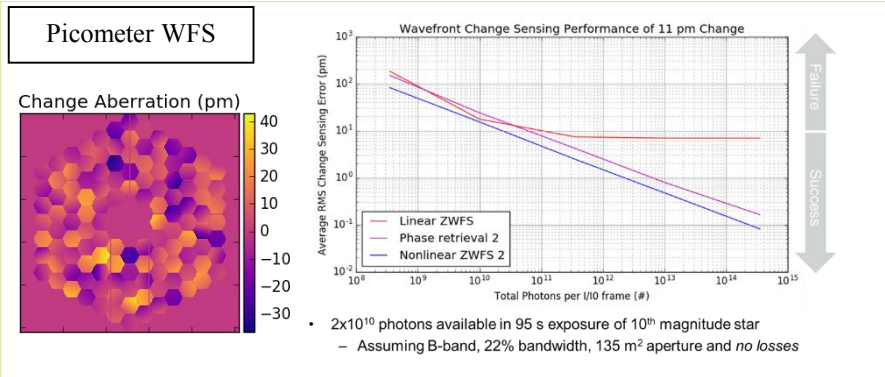
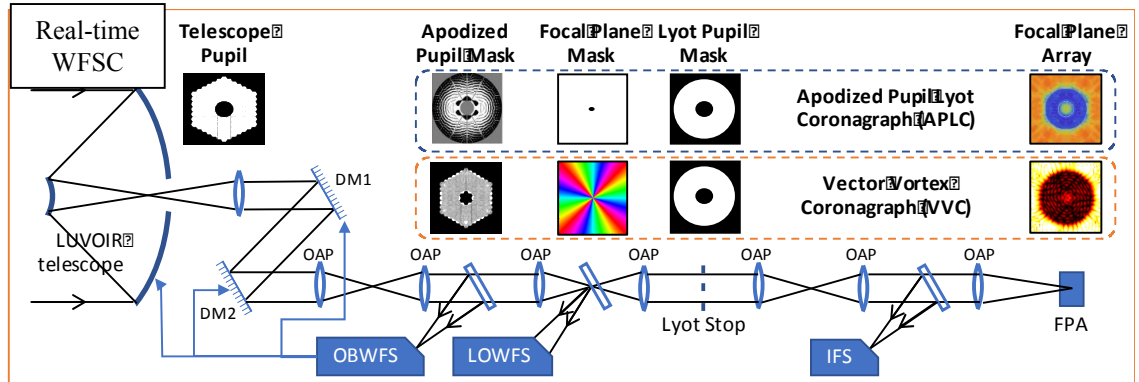
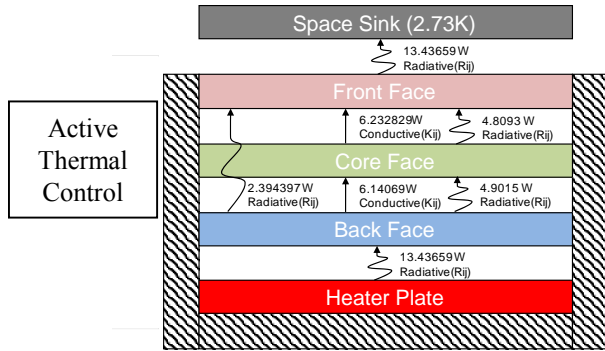
From Jeff Livas, LISA Symposium meeting, July 2018

LUVOIR Decadal Study: Technology Prioritization

Priority	Technology Gap Name	TRL
1	Ultra-stable Opto-mechanical Systems Architecture	2
1a	Segment Phasing & Control	3
1b	Dynamic Isolation Systems	4
1c	Mirror Segments	5
1d	Wavefront Sensing & Control	4
2	High-contrast Segmented Aperture Coronagraphy	3
2a	Segmented-aperture Coronagraph Architecture	3
2b	Deformable Mirrors	4
2c	High-contrast Imaging Post-processing	4
3	Instrument Technologies	4
3a	Large-format, Ultra-low noise, High-dynamic Range UV / VIS / NIR Detectors	4
3b	Next-Gen Microshutter Arrays	4
4	High Reflectivity Broadband FUV-to-NIR Mirror Coatings	3

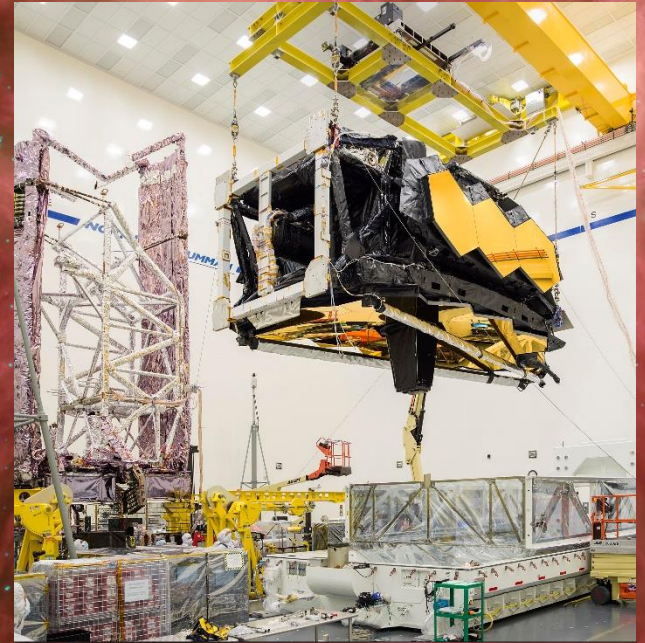
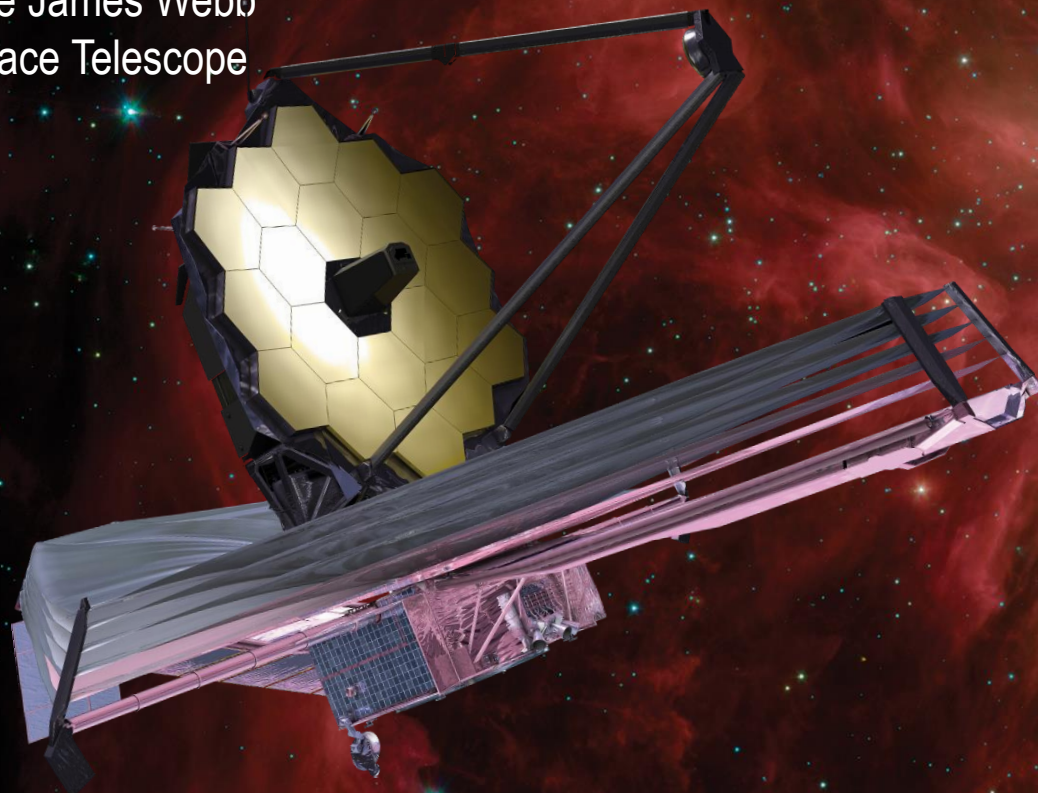


Active Control Methods for Ultra-Stability



Webb

The James Webb
Space Telescope



March 2018, Webb prepares for additional testing at Northrop Grumman in Redondo Beach, CA



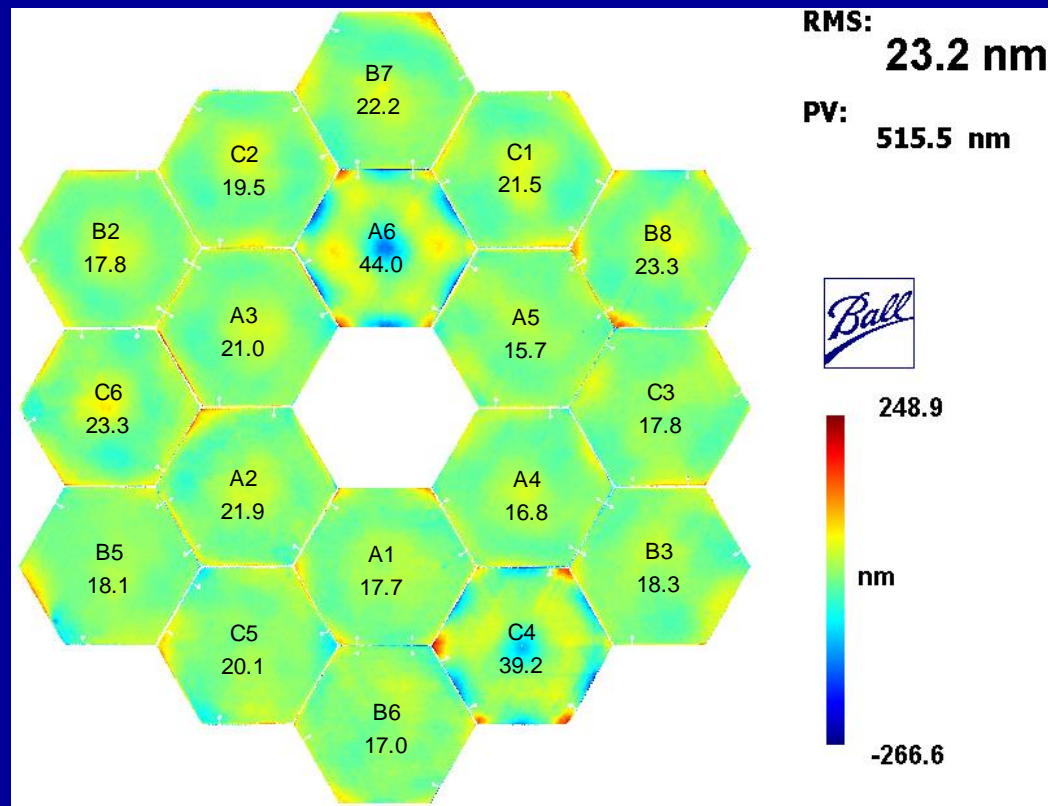
Movie

Measured Primary Mirror Cryogenic Surface Figure Error meets requirements

6 PMSAs ready for cryo testing



Requirement	=	25.8 nm rms
Total Measurement + Uncertainty	=	25.0 nm rms



Composite Primary Mirror meets requirements

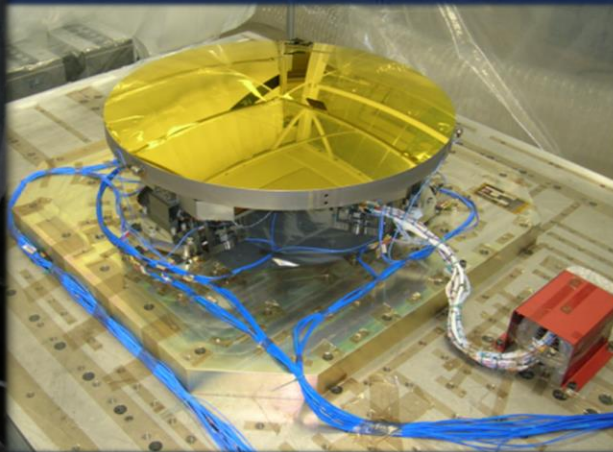
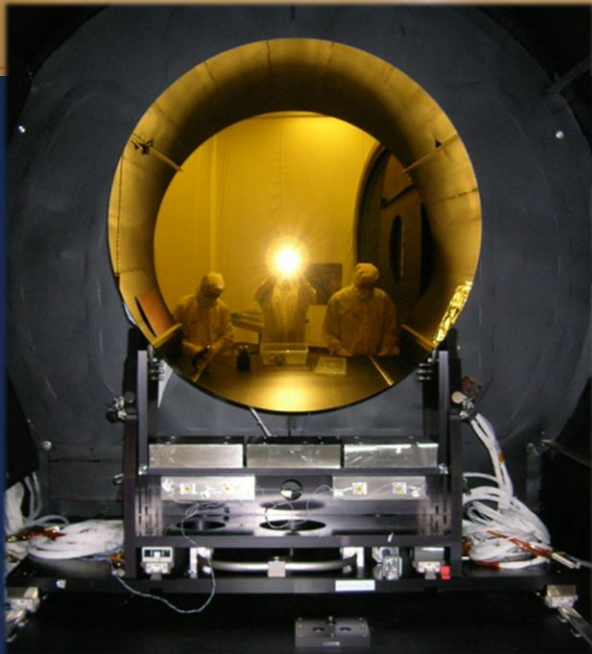
Flight Secondary Mirror



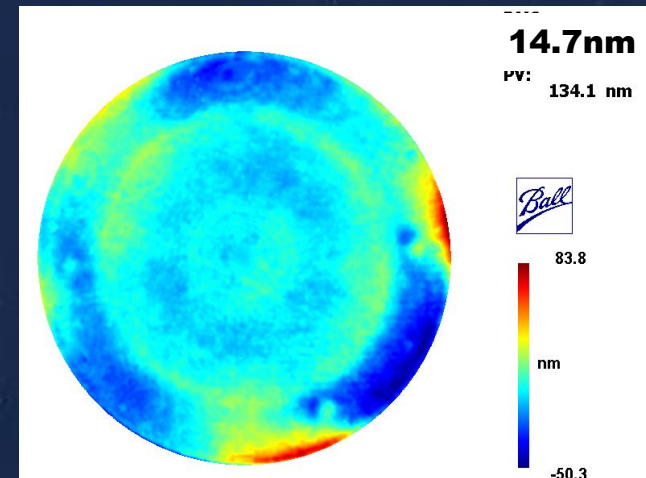
SMA SFE: 19.8nm RMS SFE (including measurement uncertainty) vs. 23.5nm req't

On convex mirror 0.7 meters in diameter.

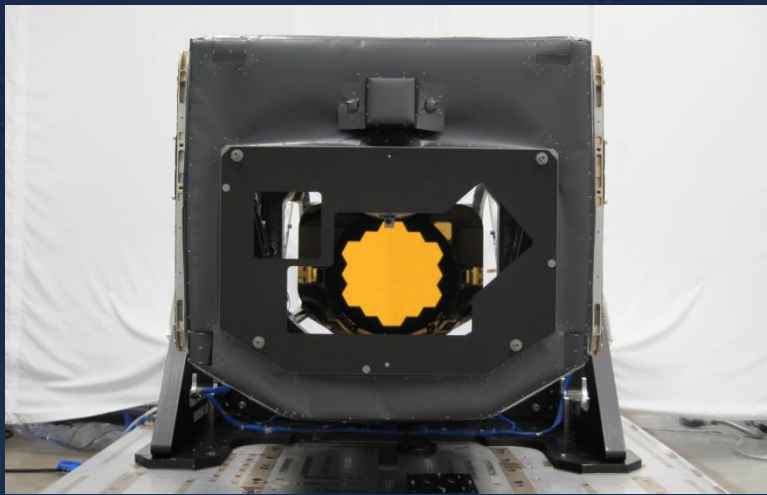
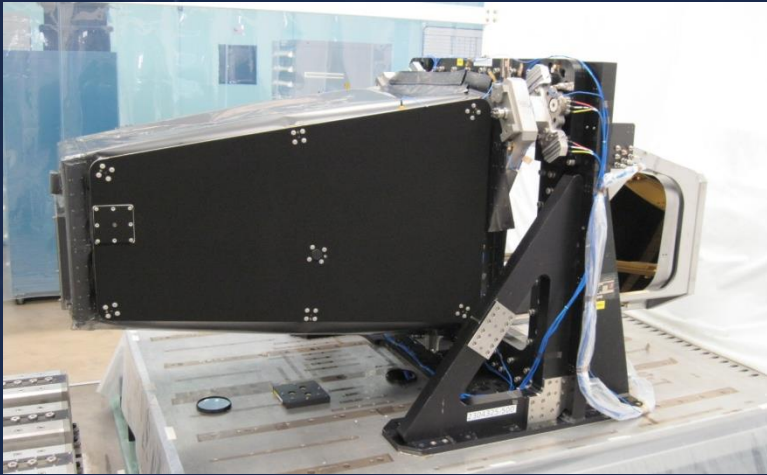
One of the more challenging tasks on the program, and therefore, one of the more spectacular achievements.



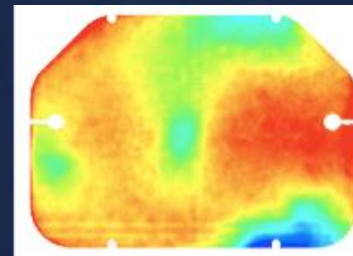
20K SMA Measured Surface Figure



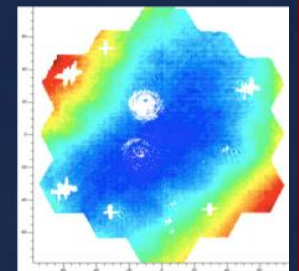
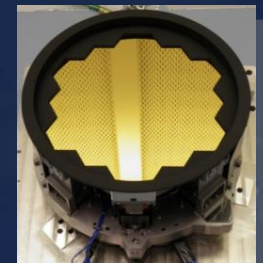
The fully integrated Aft Optics Systems (AOS)



Mirror	Measured (RMS SFE)	Uncertainty (RMS SFE)	Total (RMS SFE)	Requirement (RMS SFE)
Tertiary	18.1 nm	9.5 nm	20.5 nm	23.2 nm
Fine Steering	13.9 nm	4.9 nm	14.7 nm	18.7 nm

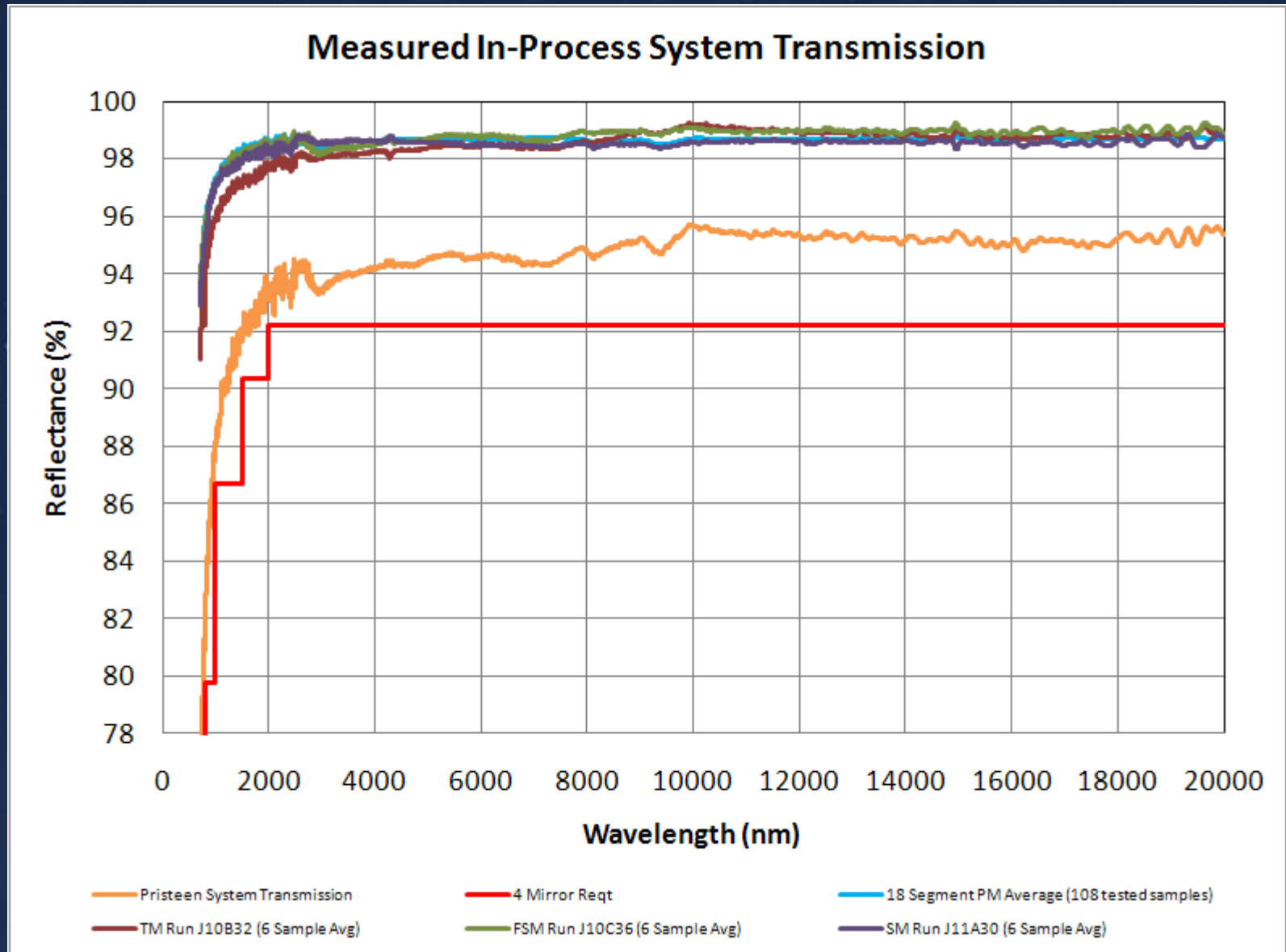


Tertiary Mirror

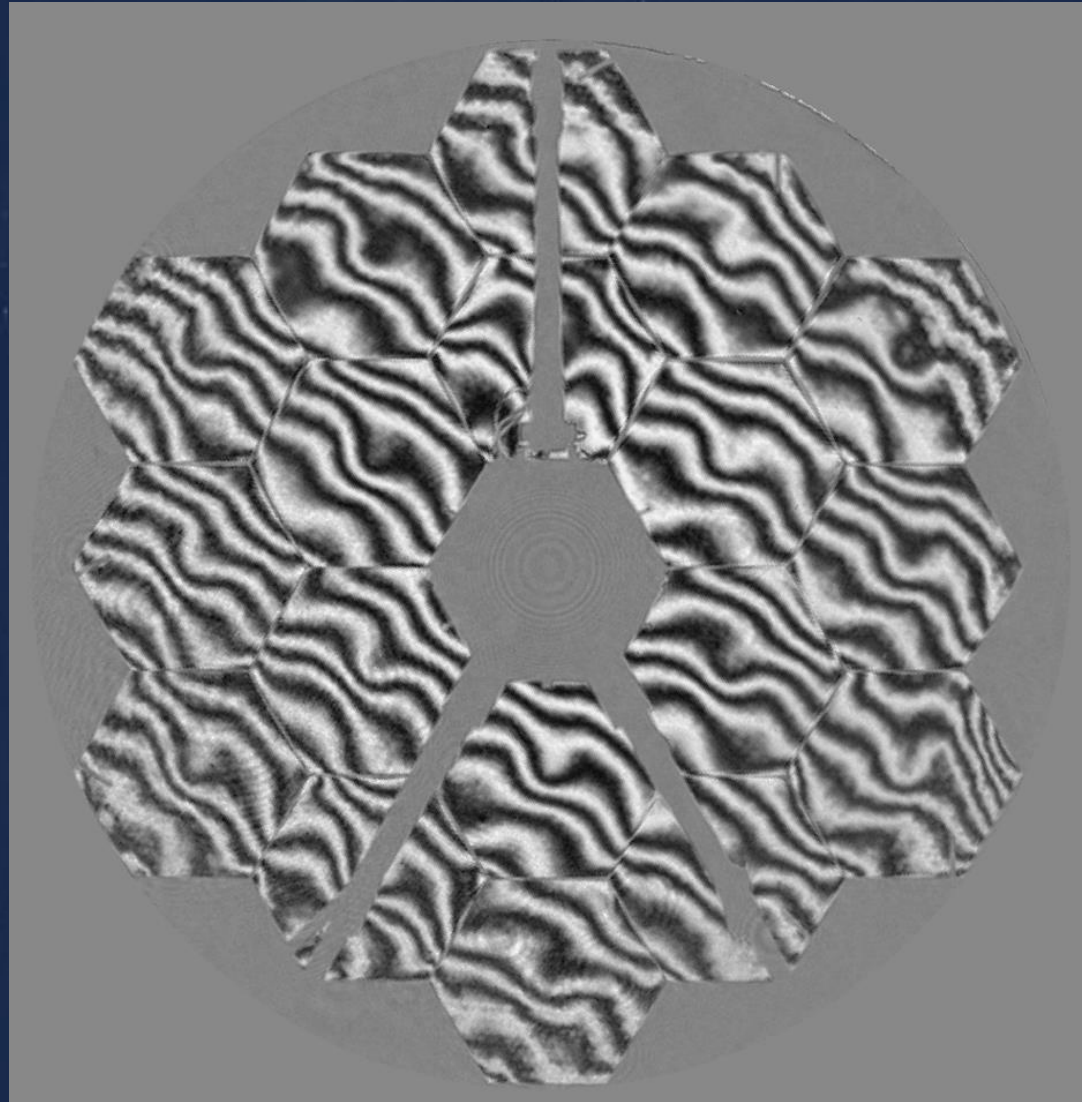


Fine Steering Mirror

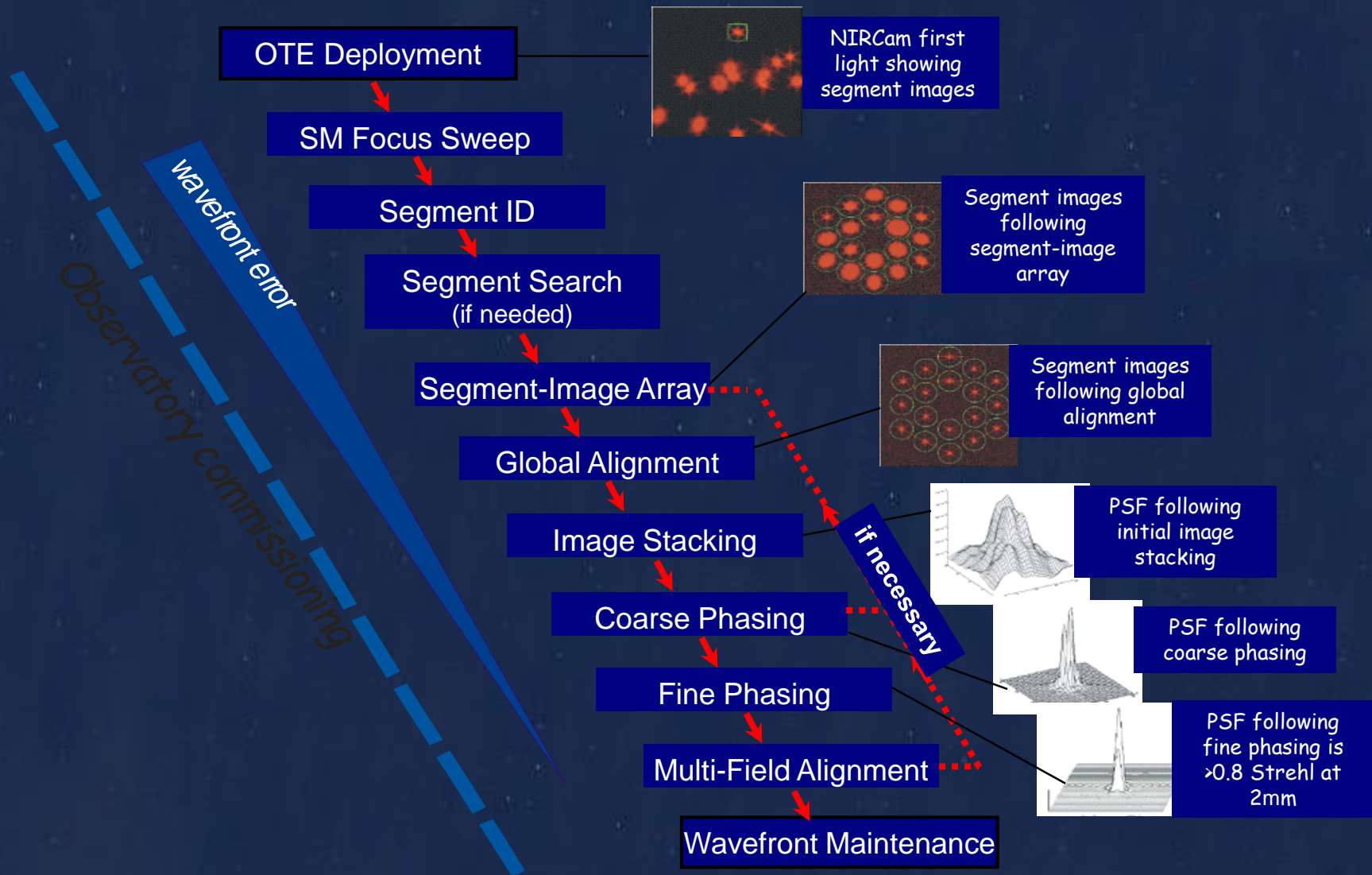
System transmission meets requirements



Phased Primary Mirror Interferogram



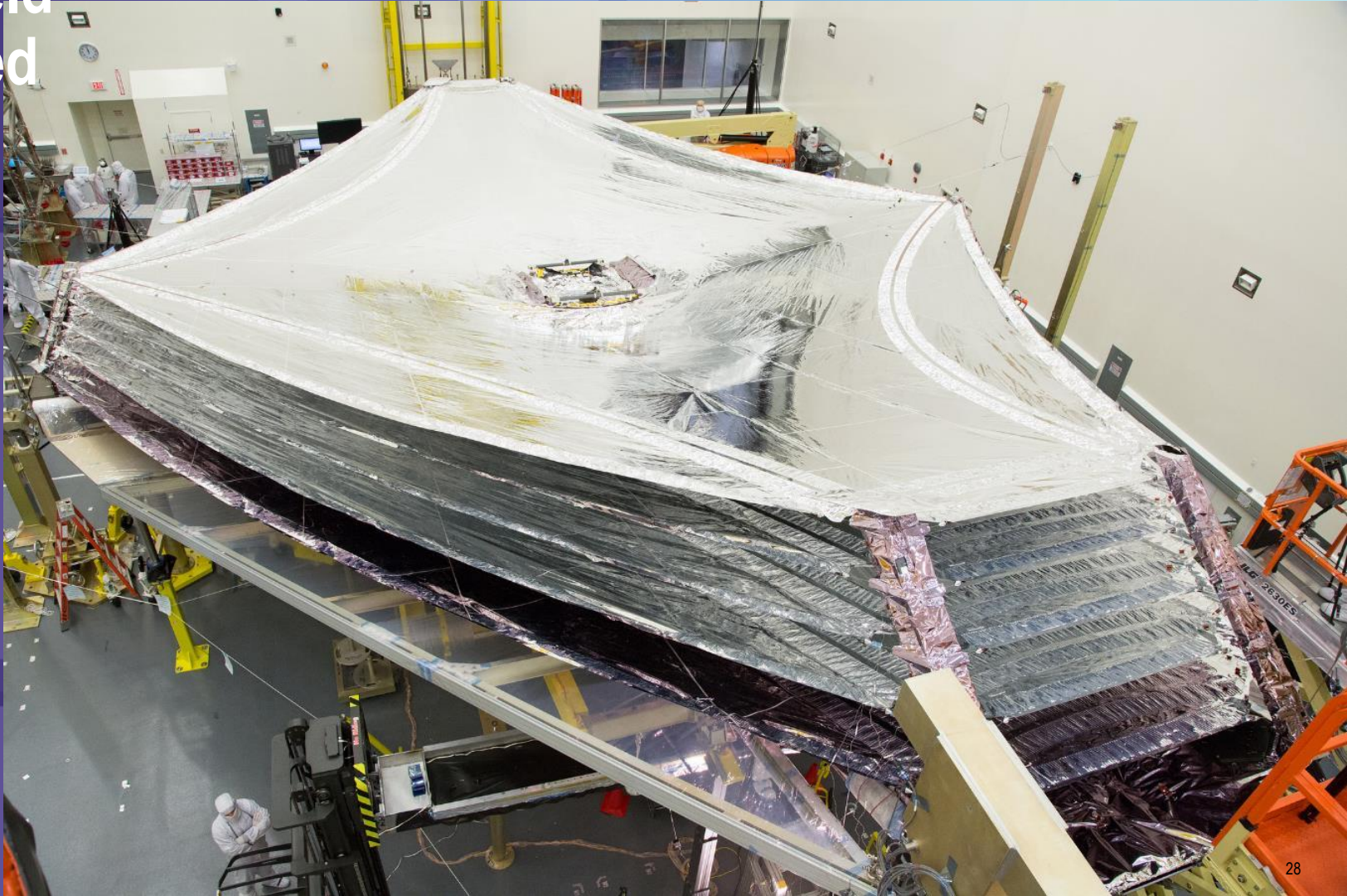
JWST Wavefront Sensing & Control Process



Webb Sunshield Deployed

Fall 2017

Webb Sunshield Deployed



Webb Mission Status

Webb Observatory Elements at Northrop Grumman (NGAS) Redondo Beach, CA

Spacecraft
Element

Sun-Shield

Spacecraft



Optical Telescope
Element
(with instruments)