LUVOIR ARCHITECTURE “A” ENGINEERING STATUS

Presented to:
The LUVOIR STDT

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We will study two architectures in depth...

- Architecture A (first half of 2017)
  - 15-m diameter aperture
  - Five instrument bays:
    - Optical / NIR Coronagraph (A)
    - UV Multi-object Spectrograph ("LUMOS")
    - High-definition Imager (will also perform guiding / wavefront sensing)
    - *UV Spectro-polarimeter (CNES Contributed)*
    - *Empty Bay for future expansion / contribution*

- Architecture B (late 2017 into 2018)
  - ~9-m diameter aperture
  - Three instrument bays:
    - Optical / NIR Coronagraph (B)
    - UV Multi-object Spectrograph ("LUMOS")
    - Optical / NIR Multi-resolution Spectrograph
      - Will need to include guiding and wavefront sensing capabilities

Study Schedule (2017):

- √ **1/17–24 – Telescope Instrument Design Lab (IDL)**
  - **Pre-work 1/10**
- √ **2/6–10 – HDI IDL**
  - **Pre-work 1/31**
- ◎ **3/20–24 – Coronagraph IDL**
  - **Pre-work 3/14**
- ◎ **5/15–19 – LUMOS IDL**
  - **Pre-work 5/9**
- ◎ **6/7–13 – Instrument Accommodation & ΔTelescope IDL**
  - **Pre-work 6/1**
- ◎ **7/10–14 – LUVOIR “A” Mission Design Lab (MDL)**

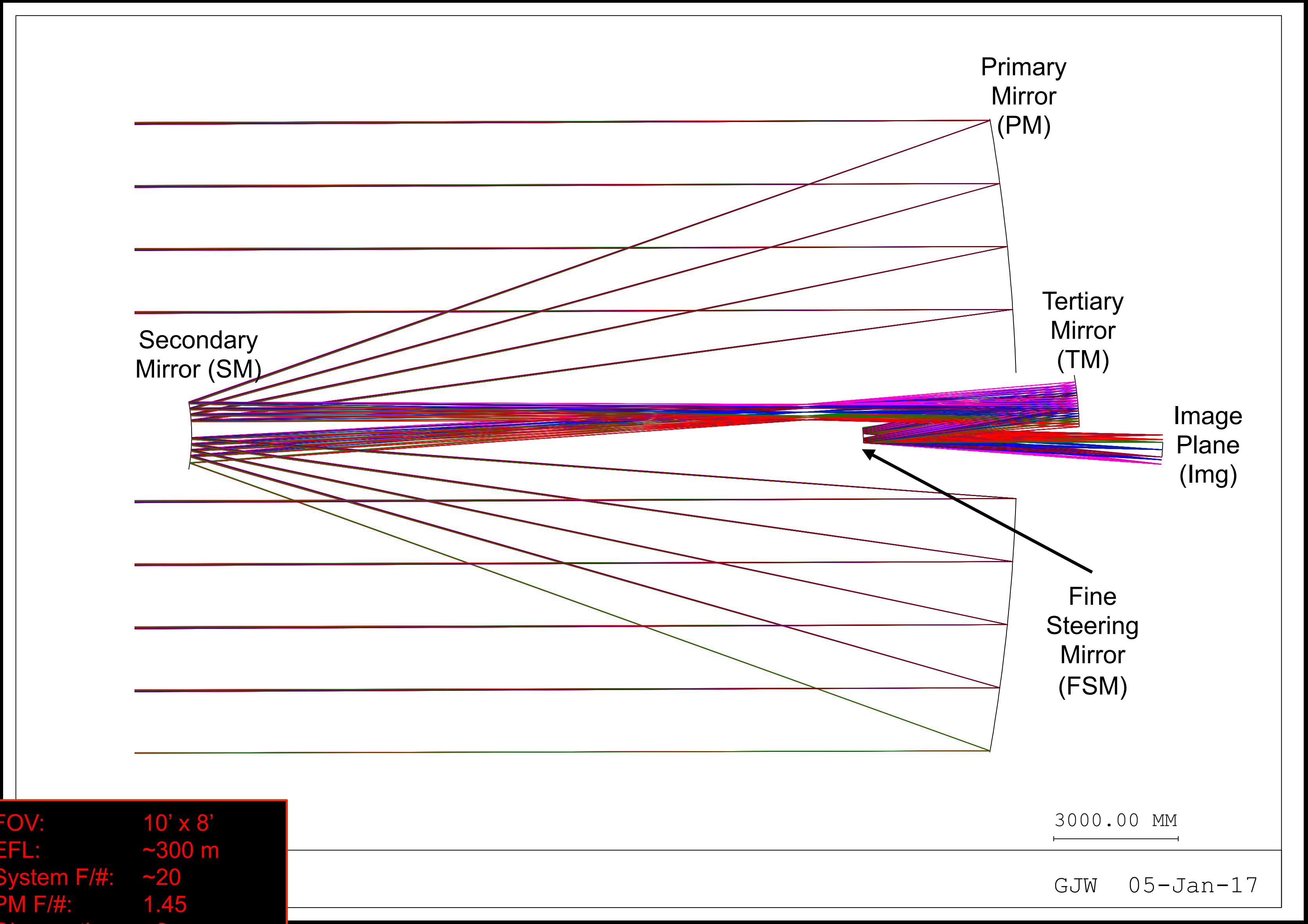
- ◎ June – Dec.: Prepare Interim Report on Architecture A
- ◎ Sept.: Kick-off Architecture B IDLs

Telescope Design

LUVOIR “A” Science Measurement Concept

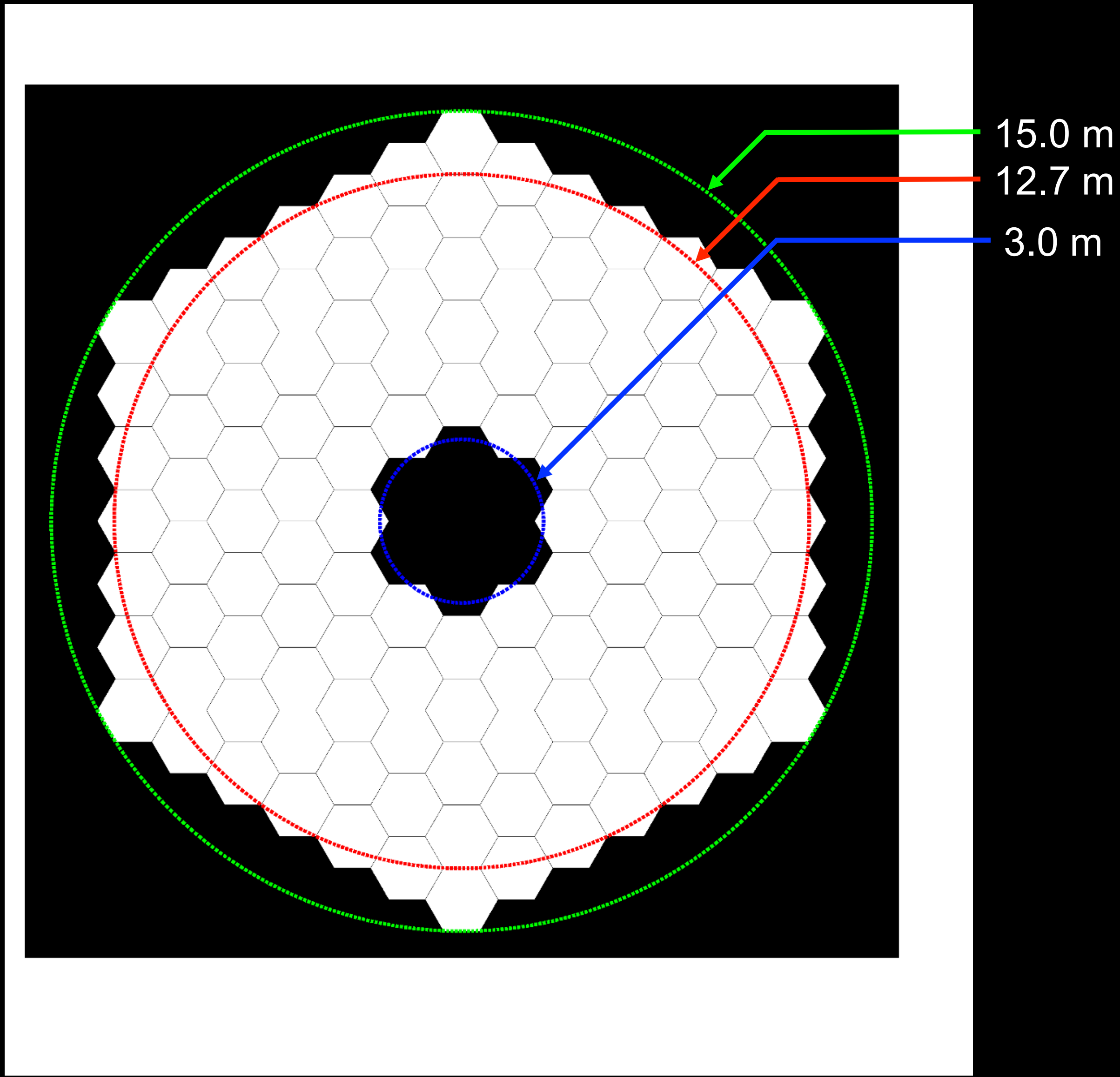
- FOV: 10 arcmin x 8 arcmin
- Wavelength:
  - 100 nm – 2.5+ μm
  - 90 nm blue cutoff stretch goal (largely dependent on coating technology development)
  - Optics & coatings should not preclude observations as red as 5.0 μm
- Diffraction-limited at 500 nm
- Spatial resolution:
  - Limiting instrument (*LUMOS*) has a spatial resolution of 30 mas for an assumed 25 μm resolution element
  - Implies a telescope focal length ≥ 172 m
- Aperture diameter:
  - Largest that can fit in an 8.4-meter x 27.4-meter fairing
  - Deemed to be 15-m by LUVOIR Engineering Team
- Operating temperature: 270 K

LUVOIR "A" Telescope Optical Design

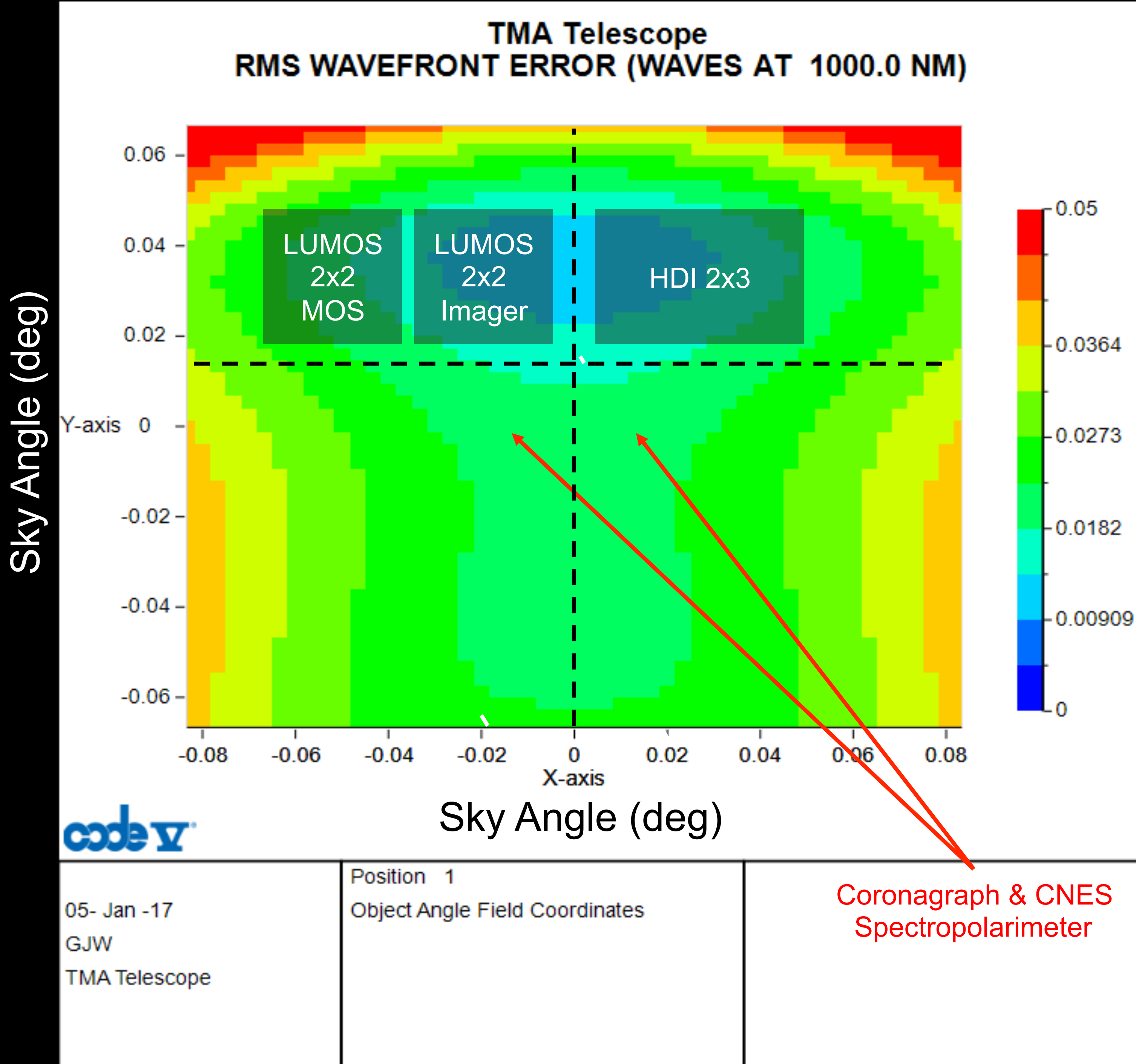


FOV:	10' x 8'
EFL:	~300 m
System F/#:	~20
PM F/#:	1.45
Obscuration:	~3 m

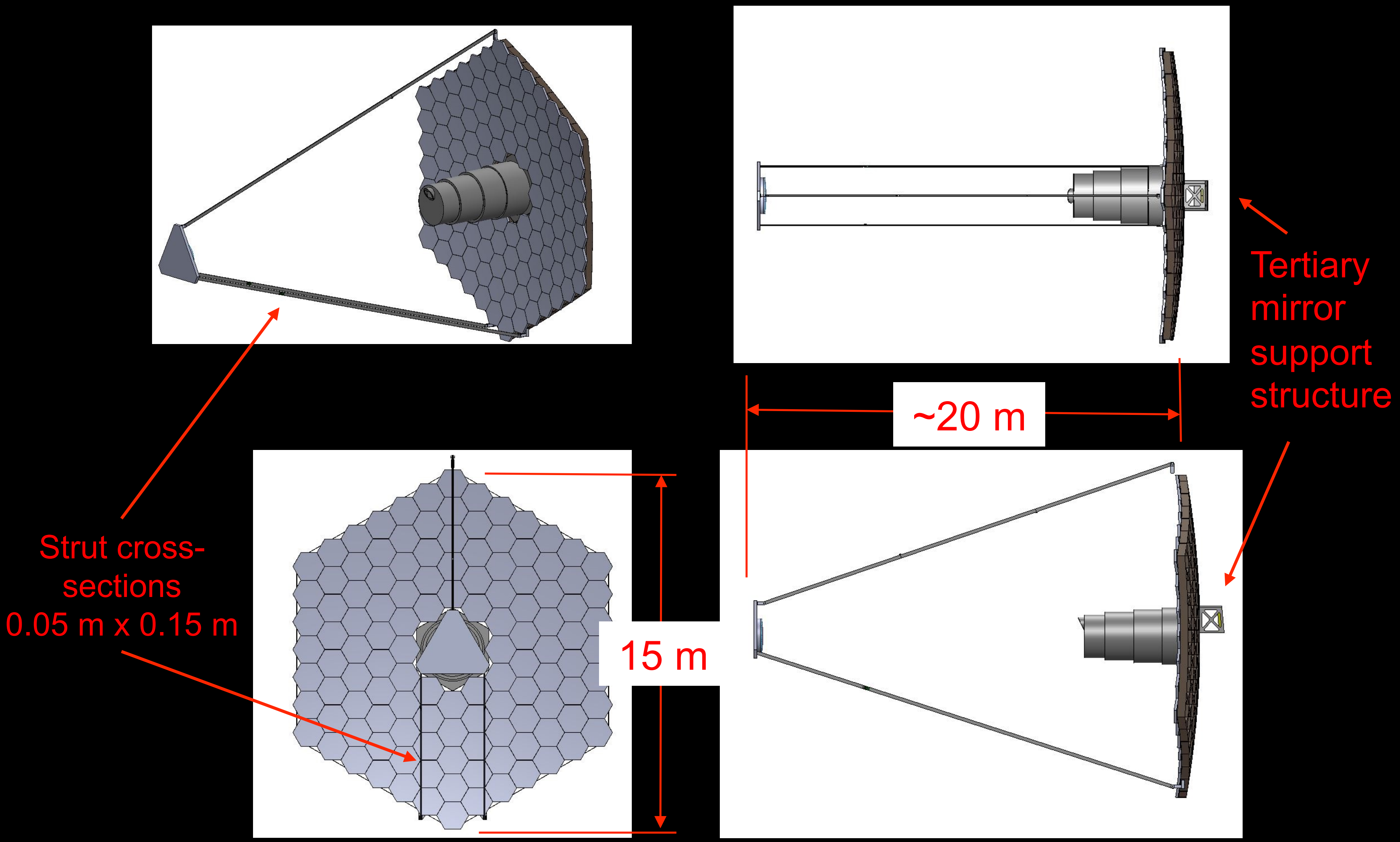
LUVOIR “A” Telescope Aperture



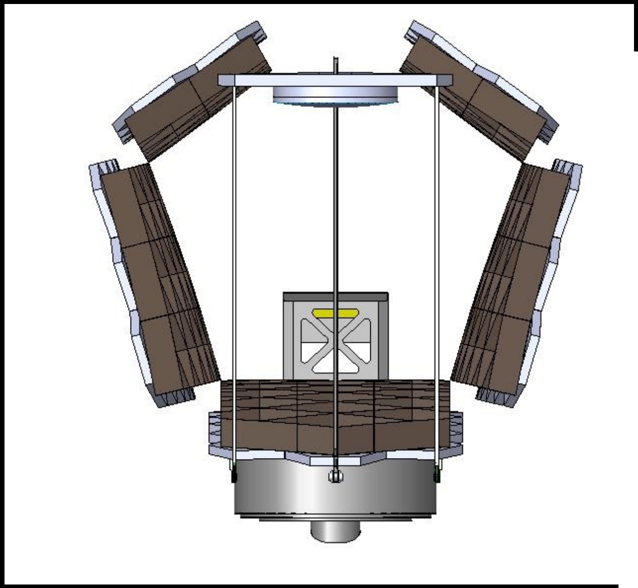
- 1.15-m flat-to-flat segments (120x)
- Central ring of array removed to accommodate Aft-optics & Secondary Mirror Obscuration
- Effective area is ~135 m^2
- 15-m circumscribed diameter / 12.7-m inscribed diameter
- Assumes 6 mm gaps

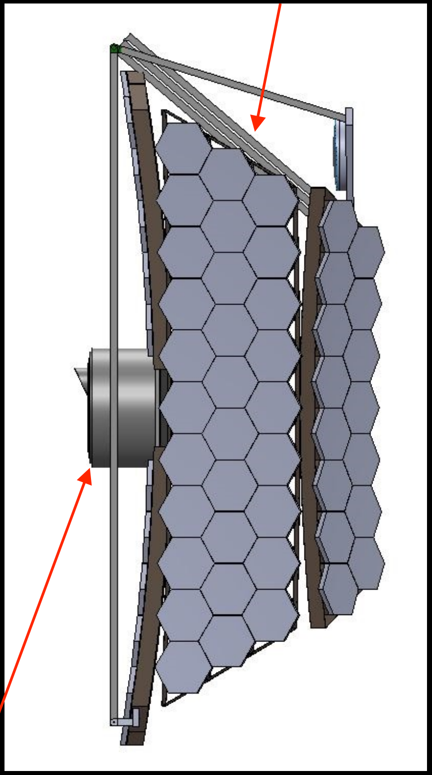

TMA Telescope
RMS WAVEFRONT ERROR (WAVES AT 1000.0 NM)
Sky Angle (deg)
0.06
0.04
0.02
Y-axis 0
-0.02
-0.04
-0.06
-0.08
-0.06
-0.04
-0.02
0
0.02
0.04
0.06
0.08
X-axis
Sky Angle (deg)
LUMOS 2x2 MOS
LUMOS 2x2 Imager
HDI 2x3
0.05
0.0364
0.0273
0.0182
0.00909
0
Position 1
Object Angle Field Coordinates
05- Jan -17
GJW
TMA Telescope
Coronagraph & CNES Spectropolarimeter

Mechanical Design Details (1)



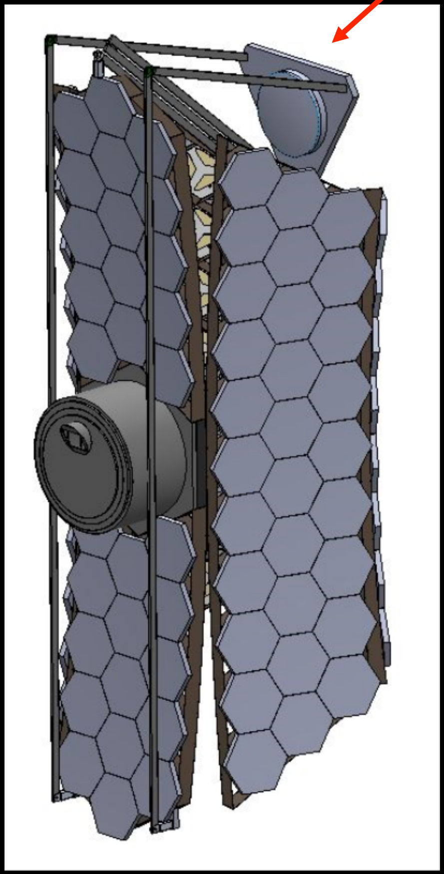
Mechanical Design Details (2)

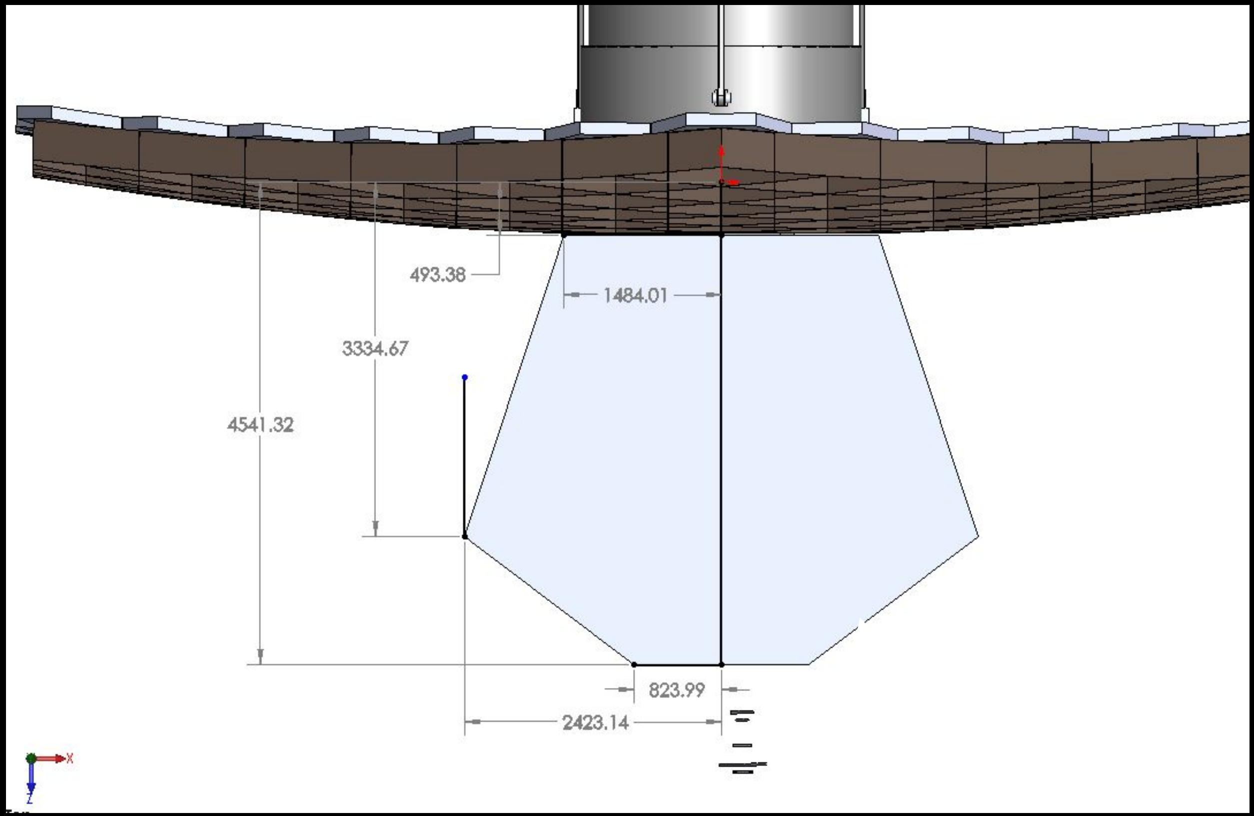




Mechanical Design Details (3)

Secondary Mirror





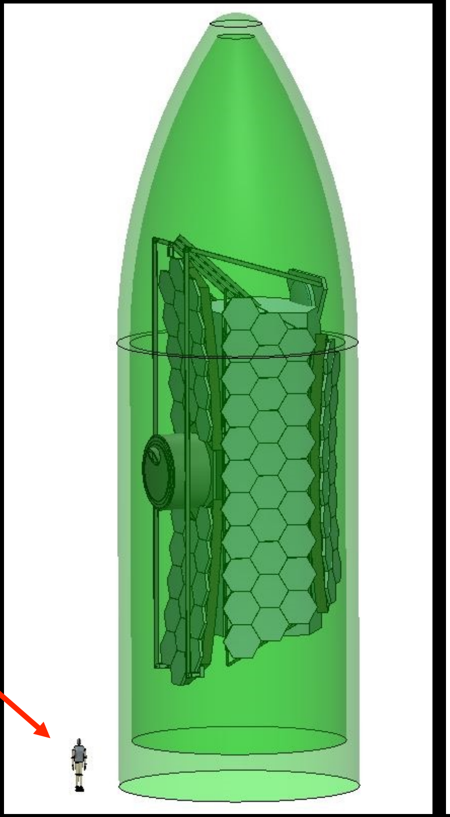
Footprint for Backplane Support Frame (BSF) and Instruments, given OTE stowed arrangement

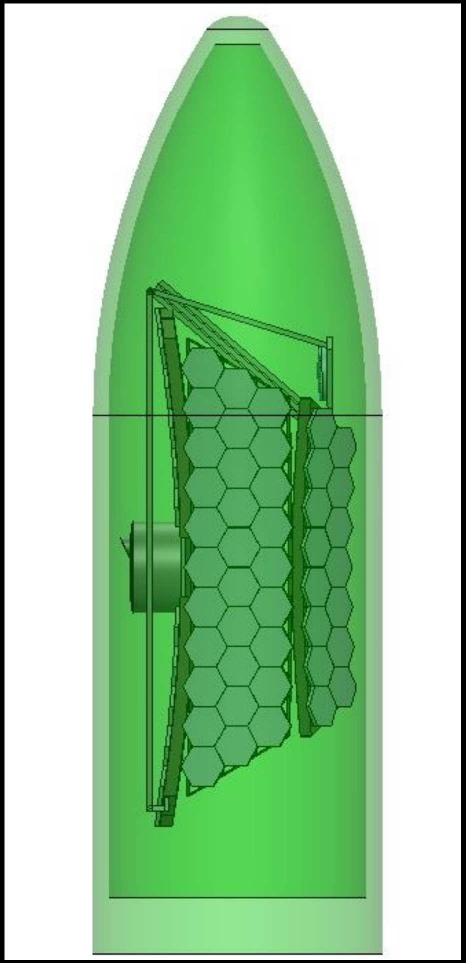
Mechanical Design Details (4)

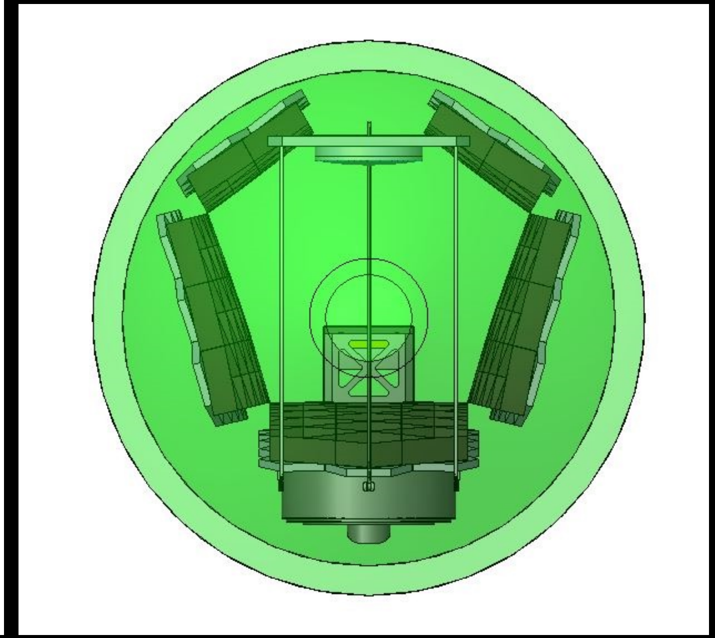
Not Shown:

- Sunshield and deployment system
- Spacecraft bus
- Primary Mirror “frill”

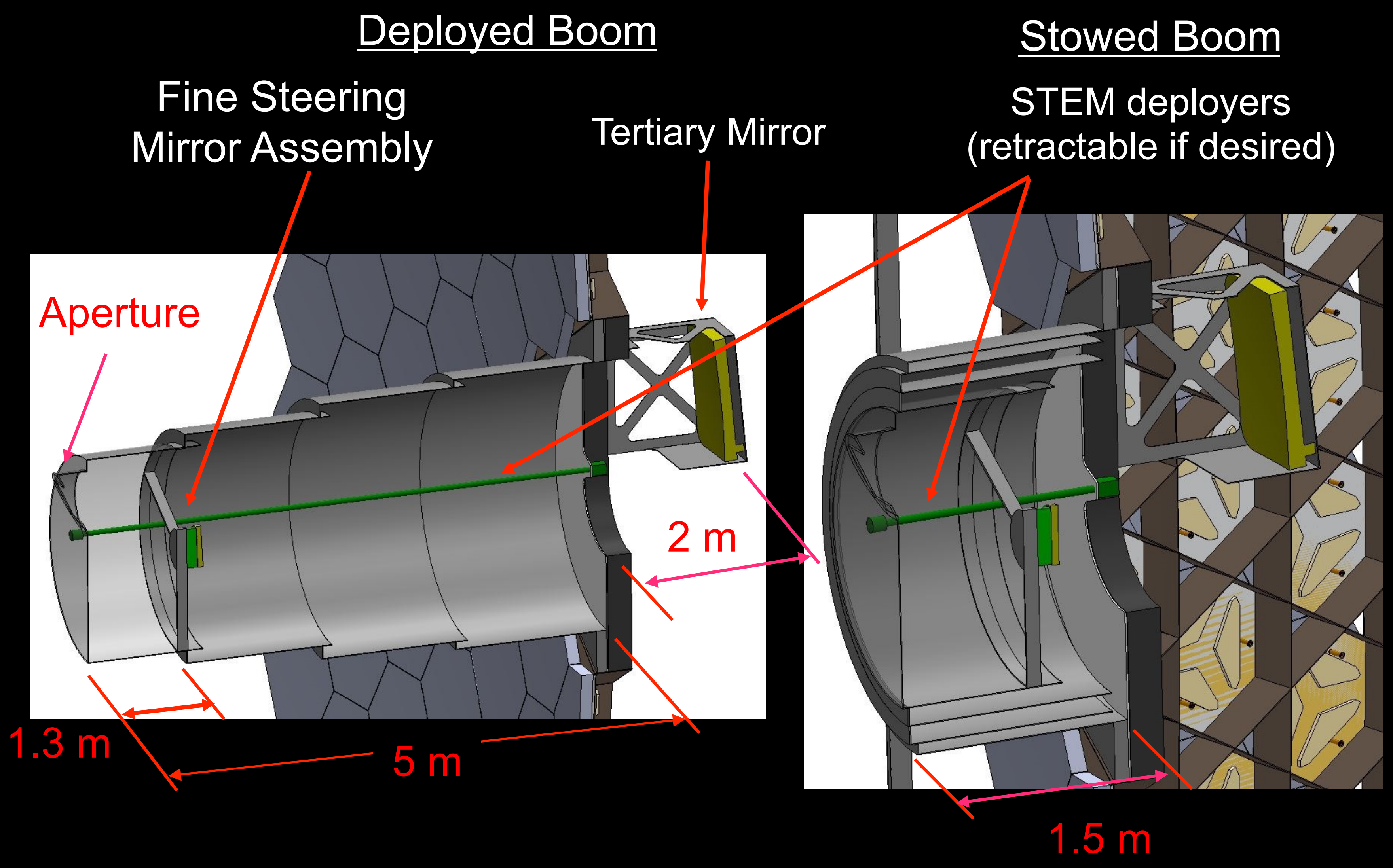
6’ tall Fairing Guard



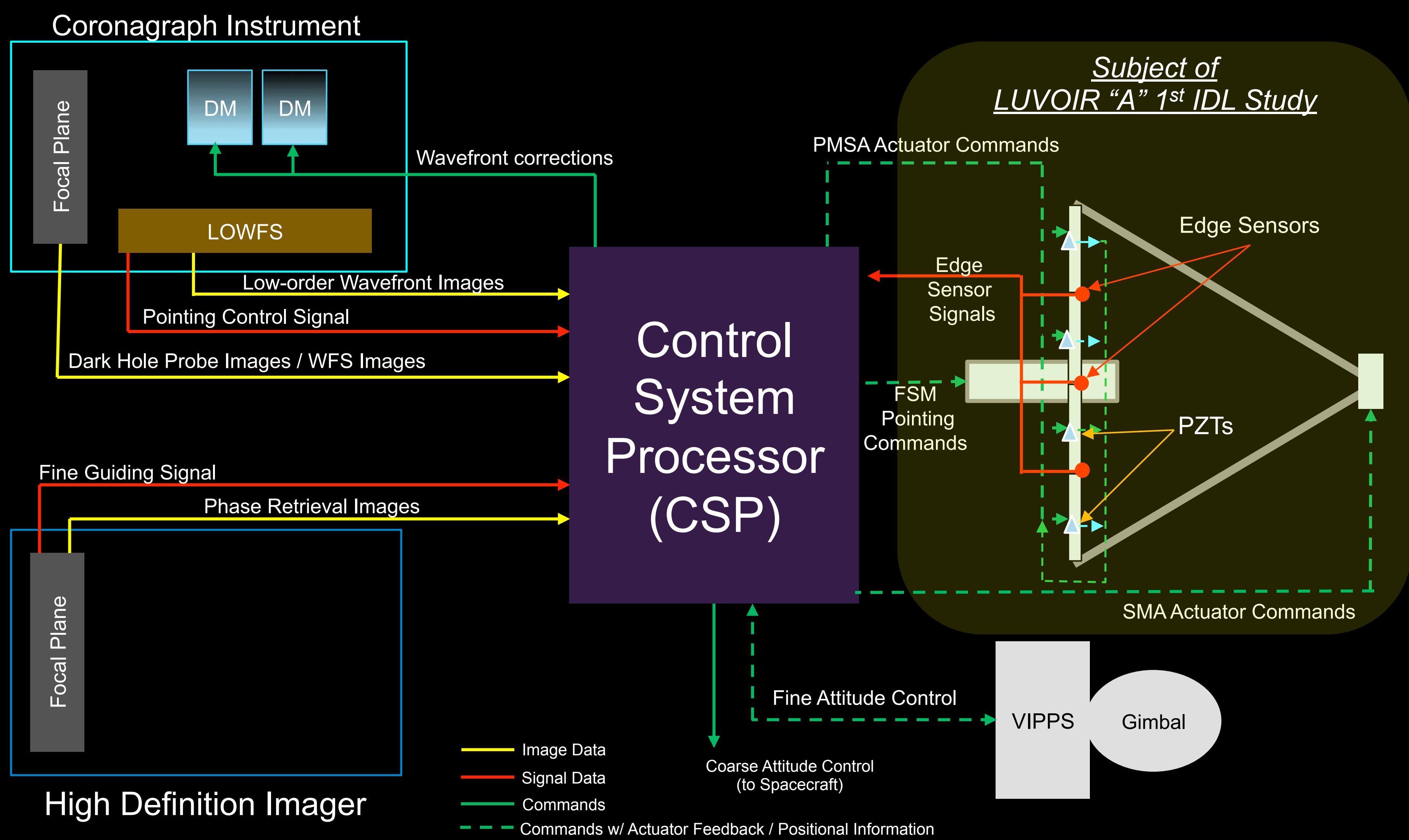




Mechanical Design Details (5)



Control System Block Diagram (So Far)



Concept for PM Segment Phasing (1)

- Introduced a closed-loop control system at the primary mirror segments to maintain segment-to-segment phasing
- Edge sensors on each segment measure picometer-level rigid-body motions at high speeds
- In response, piezoelectric (PZT) actuators move PM segments at picometer level
- Closed-loop system creates a “virtual monolith”

Concept for PM Segment Phasing (2)
Edge Sensors

- Capacitive edge sensors
  - Two sensors per edge shared between segments: 622 sensors total
  - Provide 6-degree of freedom motion of each segment

- Similar sensors are being developed for ground-based systems (TMT, EELT, GMT) and have been used on Keck

- Challenge for LUVOIR is in the electronics
  - Need high speed (~450 Hz) readout with picometer-level accuracy at low power

- Lab-based system has demonstrated ~10 pm sensing at lower speeds with custom electronics

Concept for PM Segment Phasing (3)
Segment Actuators

- Average the 450 Hz edge sensor measurements at a rate of 5:1 to generate a 90 Hz control signal for PM segments

- LUVOIR PM segments use exact same actuator design as JWST, except fine stage mechanical actuator is replaced with a PZT actuator
  - One PZT per actuator → 6 PZTs per PM segment for fine control of six degrees of freedom

- On JWST, a mechanical linkage is used to “step-down” physical actuator displacement to PM segment motion
  - i.e. if actuator moves 100 microns, the mirror only moves ~1 micron

- We will use the same linkage for the PZTs such that a 0.250 nm PZT step (which is easy) corresponds to ~2 pm motion of the mirror segment

Priority Telescope "To-Do"

- Add mechanical design fidelity to:
  - Primary mirror backplane
  - Primary mirror segment mechanical structure (heater, whiffles, delta frame, actuators, mounting points)
- Perform dynamic stability analysis
  - For launch loads on stowed configuration
  - For jitter disturbance on deployed configuration
- Re-visit thermal control system
  - Incorporating new backplane wing sections
  - Incorporating actuator drive electronics in each primary mirror segment assembly
- Add fidelity to mechanisms
  - Launch locks, deployment motors, latches, snubbers, etc.
- Perform straylight analysis and size baffling

High Definition Imager Design

HDI Technical Overview (1/2)

- Two-channel Imaging Instrument:
  - UV/Vis Imaging (200 nm - ~1.0 μm)
    - Diffraction-limited performance at 500 nm
    - Nyquist sampled at 400 nm
  - NIR Imaging (~1.0 μm – 2.5 μm)
    - Diffraction-limited performance at 1.2 μm
    - Nyquist sampled at 1.2 μm

- Each channel will contain a suite of spectral filters:
  - Narrow (R ~50-100)
  - Medium (R ~20-40)
  - Broadband (R ~3-5)
  - At least one slitless grism/prism option with R ~200-500

- Field-of-view: 2 x 3 arcmin
  - Both channels view the same patch of sky

HDI Technical Overview (2/2)

- Exposure times:
  - For most extragalactic sources and stellar population observations:
    - Total observation times of up to 200 hrs.
    - Composed of many exposures of 500-1000 s each
  - High-speed photometry will require exposures of 50 – 100 ms
    - Will only be required over a small area of the focal plane array (perhaps a single SCA of the entire FPA)

- Dynamic Range:
  - Desire the ability to define a region of the focal plane with reduced sensitivity (or faster readout) for both astrometry and solar system observations

HDI Special Modes :

- High-Precision Astrometry (for measuring exoplanet mass)
  - Astrometric precision of < 5×10^{-4} pixels
  - Requires a Pixel Calibration System to calibrate pixel geometry

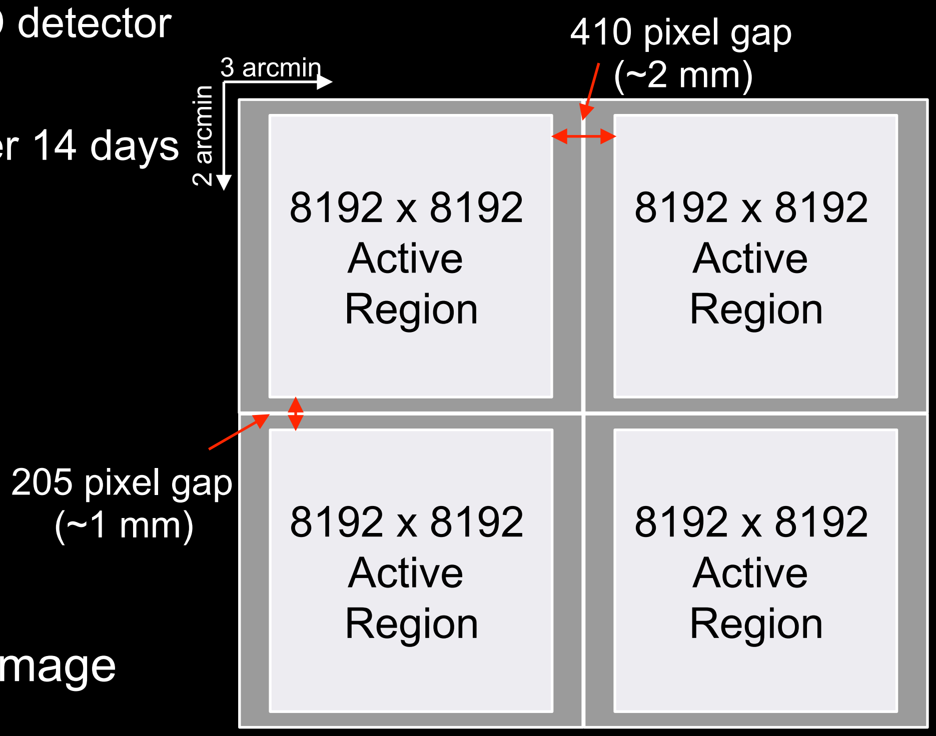
- Fine-guiding
  - HDI is the primary fine-guidance sensor for the LUVOIR observatory
  - Similar to WFIRST operation
    - Requires ability to define regions of focal plane with faster readout
    - Should have capability in both UV/Vis and NIR channels

- Image-based Wavefront Sensing (i.e. phase retrieval) for telescope commissioning and maintenance
  - Similar to role played by NIRCam on JWST
  - Requires inclusion of:
    - Weak-lenses for generating defocused images
    - Dispersed Hartmann Sensor (DHS) gratings for coarse piston sensing
    - Pupil Imaging Lens (PIL) subsystem

HDI Detector Concept – UV/Vis Channel

- CMOS Detector
  - Pixel size = 5 μm
  - Nyquist sampled at 400 nm
    - Defined as: 1 pixel = λ / (2*D)
    - λ = 400 nm; D = 15.08 m; ◊ 1 pixel = 2.74 mas
  - Read noise: ~2.5 e-
  - Dark Current: Assume 0.001 e-/pix/s
  - Assume same QE as WFC3 UVIS CCD detector
  - Operating temperature ~120 K
  - Pixel sensitivity to be stable to ~1% over 14 days

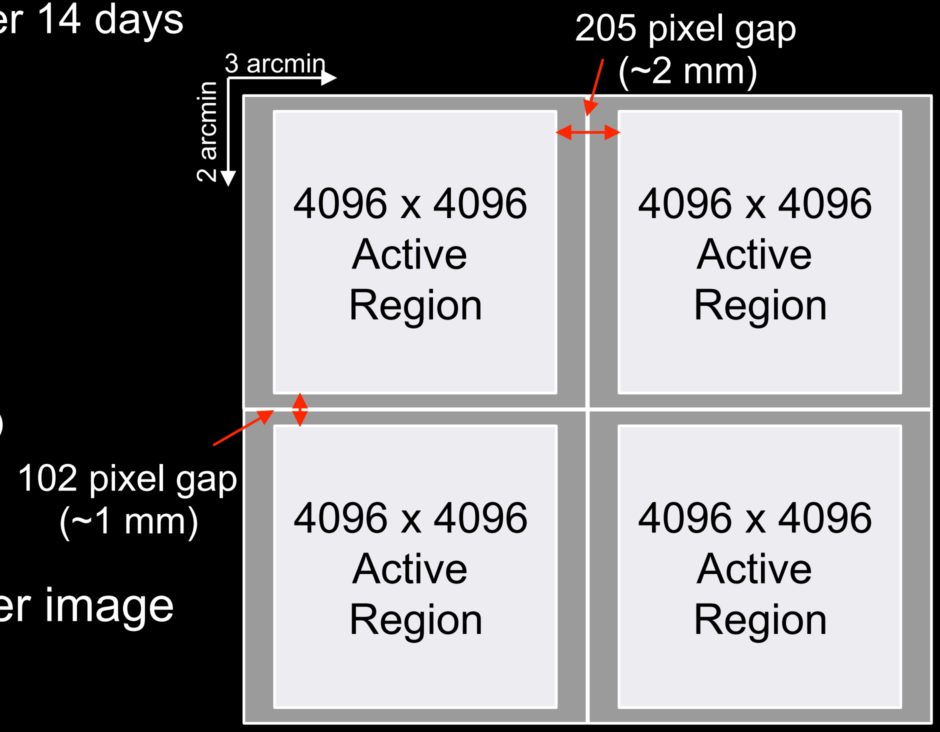
- For an 8k x 8k detector technology:
  - Use 5 x 8 tiling of arrays:
    - FOV = 1.90 x 3.12 arcmin
    - 40,960 x 65,536 pixels = 2.68 Gpix
    - 209 x 342 mm focal plane array (including gaps)
  - Gaps are as shown at right:



- Assume 16 bits/pixel: 5.4 Gbytes per image

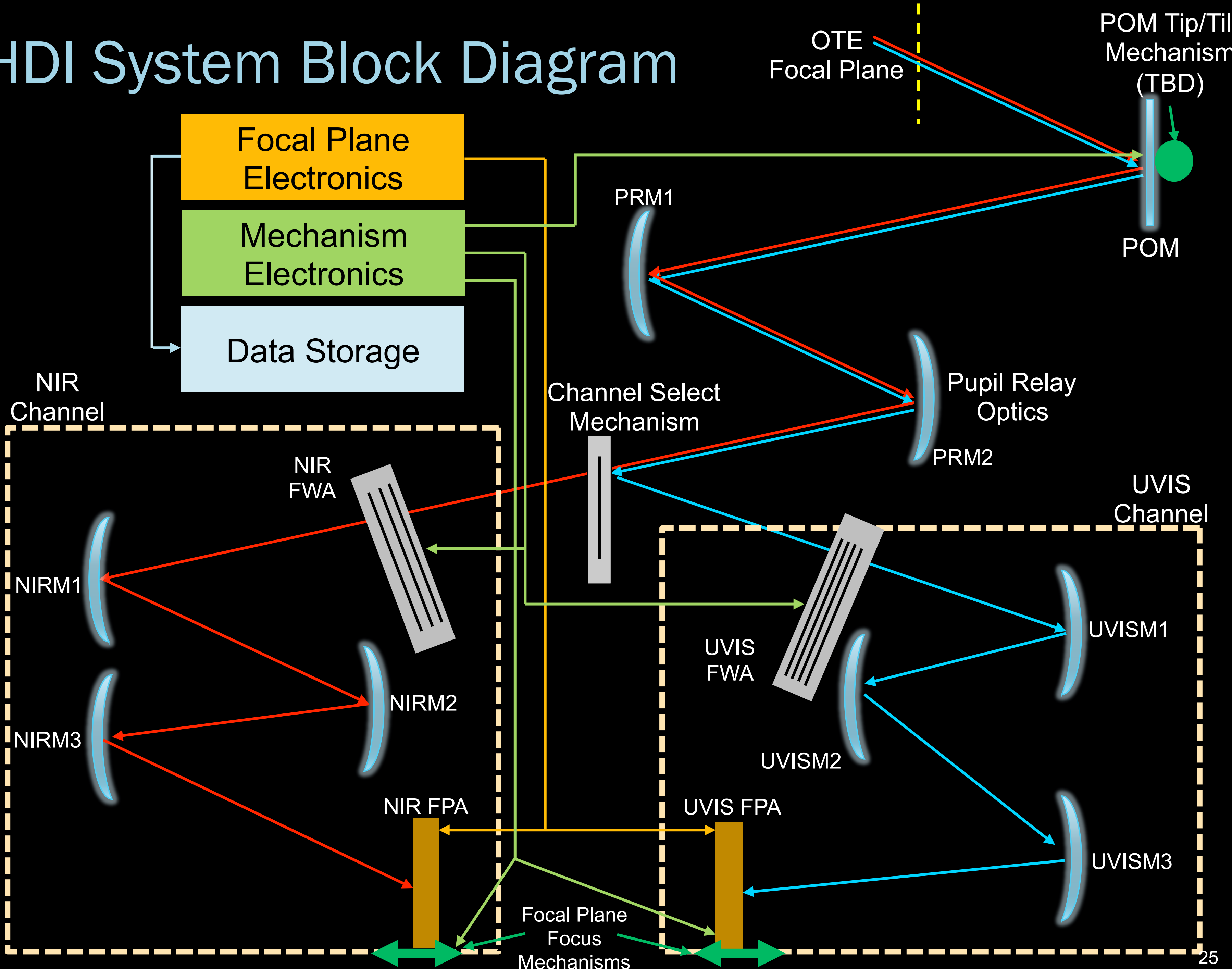
HDI Detector Concept – NIR Channel

- H4RG Detector
  - Pixel size = 10 μm
  - Nyquist sampled at 1200 nm
    - Defined as: 1 pixel = λ / (2*D)
    - λ = 1200 nm; D = 15.08 m; ◊ 1 pixel = 8.2 mas
  - Read noise, dark current, QE adopted from WFIRST H4RG specs
  - Operating temperature ~70 K
  - Pixel sensitivity to be stable to ~1% over 14 days



- For an 4k x 4k detector technology:
  - Use 4 x 5 tiling of arrays:
    - FOV = 2.28 x 2.91 arcmin
    - 16,384 x 20,480 pixels = 335 Mpix
    - 167 x 213 mm focal plane array (including gaps)
  - Gaps are as shown at right:
- Assume 16 bits/pixel: 0.671 Gbytes per image

HDI System Block Diagram



HDI Thermal Design

- Three thermal zones within the instrument using passive cooling:
  - 260 K
    - Instrument housing
    - Pupil relay optics
    - UVIS channel optics
  - 120 K
    - NIR channel optics
    - UVIS focal plane
  - 70 K
    - NIR focal plane

Priority HDI “To-Do”

- Resolve a small volume allocation violation
  - A few millimeters of the NIR channel thermal shroud encroaches beyond the allocated instrument volume
- Finalize optical design
  - Grisms, weak lenses, pupil imaging lens, etc.
  - Investigate optimizing the design for UVIS throughput
- Re-visit thermal design and radiator sizing for the three thermal zones
  - 120 K may be colder than is needed for UVIS detector
- Re-visit number of elements and element type in the channel select mechanism