Laser Metrology for Coronagraphs

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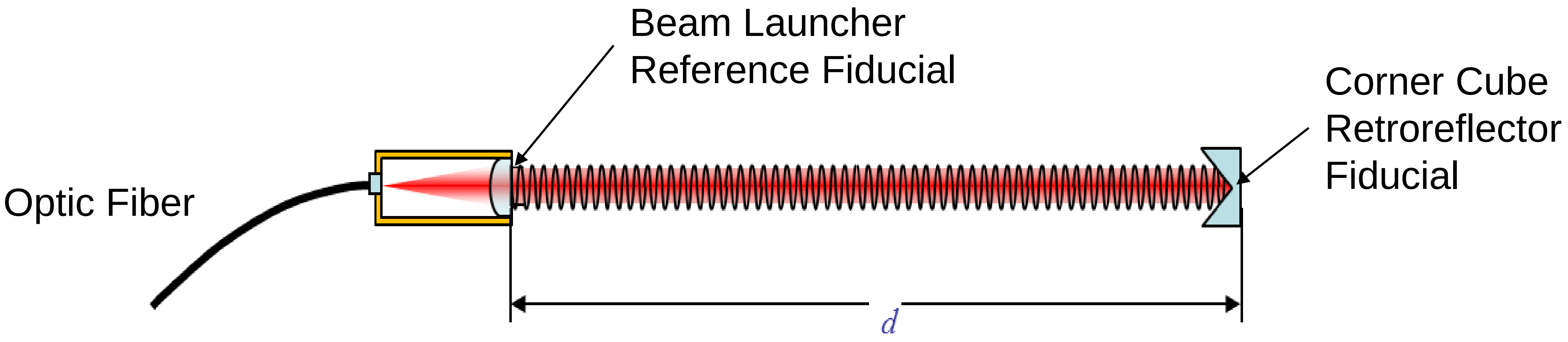
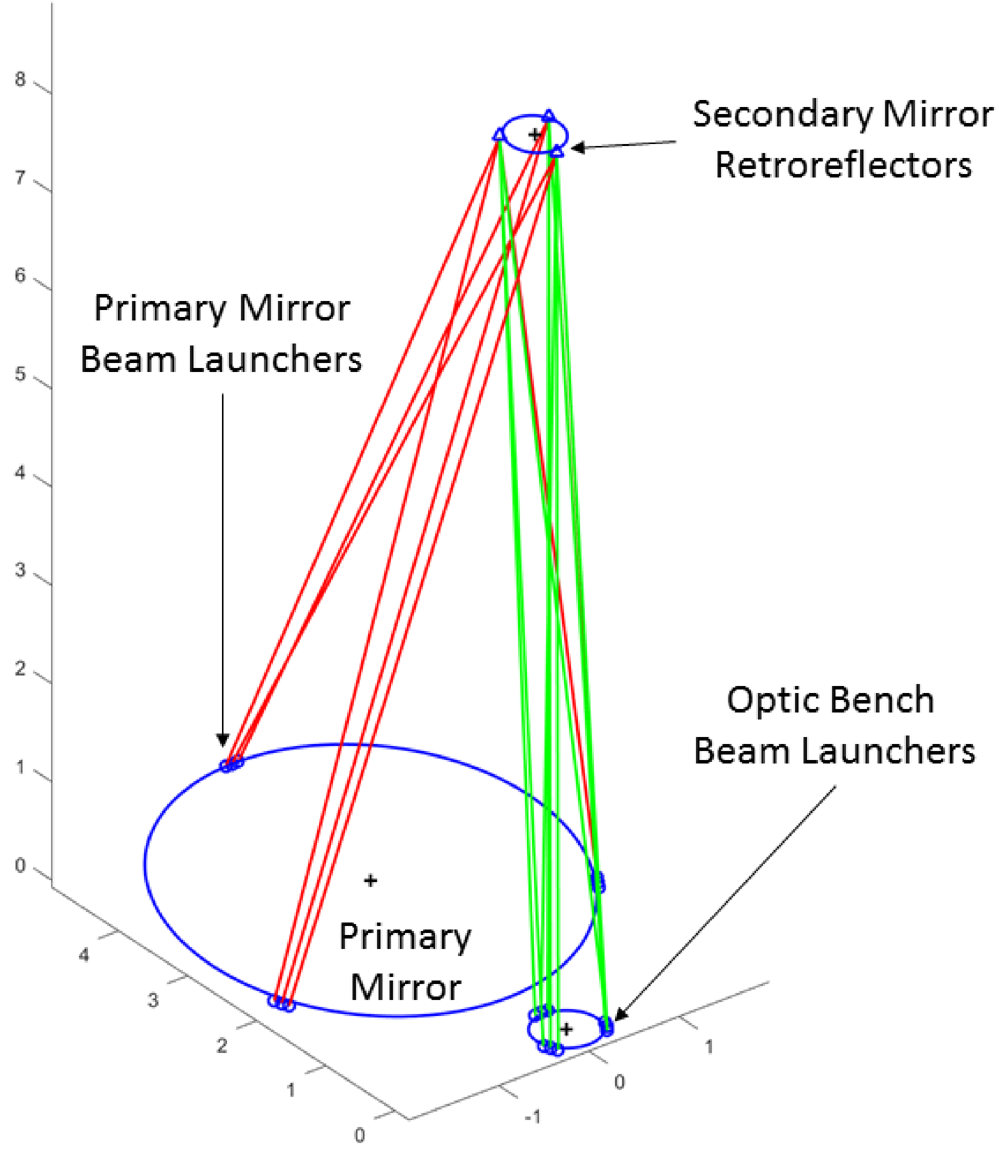
Laser Metrology Overview



- A collimated beam from the beam launcher propagates through free space and is reflected back from a corner cube (which may be many meters away) to the beam launcher where it couples back into fiber optics.
- 1 µW per gauge : 1500 nm wavelength : supplied from a single laser
- A reference beam is also reflected from the beam launcher to eliminate sensitivity to the fiber path.
- The laser frequency is stabilized to a molecular line.

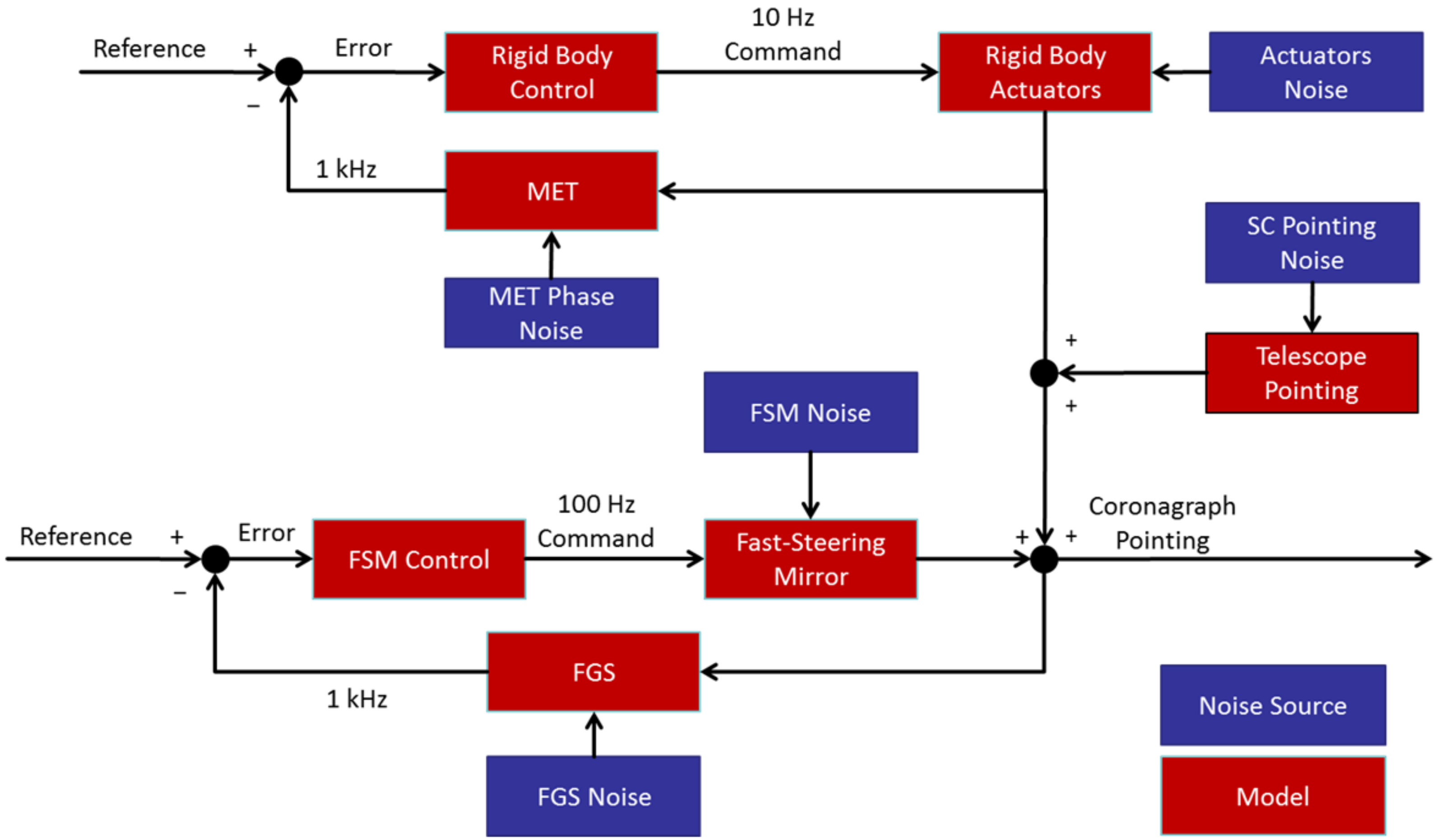
HabEx Metrology Truss



HabEx 4 meter unobscured aperture telescope.

- The primary and secondary mirrors are mounted on rigid body actuators and are actively controlled in closed loop with laser metrology.
- The secondary mirror motion is measured in six degrees of freedom relative to the optic bench with a laser truss (green).
- The primary mirror is also controlled relative to the optic bench via the primary to secondary laser truss (red) and the secondary to optic bench truss (green).
- A truss needs a minimum of six beams to sense six degrees of freedom. The truss in this design uses nine beams for redundancy.
- Maintains alignment during spacecraft slews
- Maintains alignment for general astrophysics instruments.

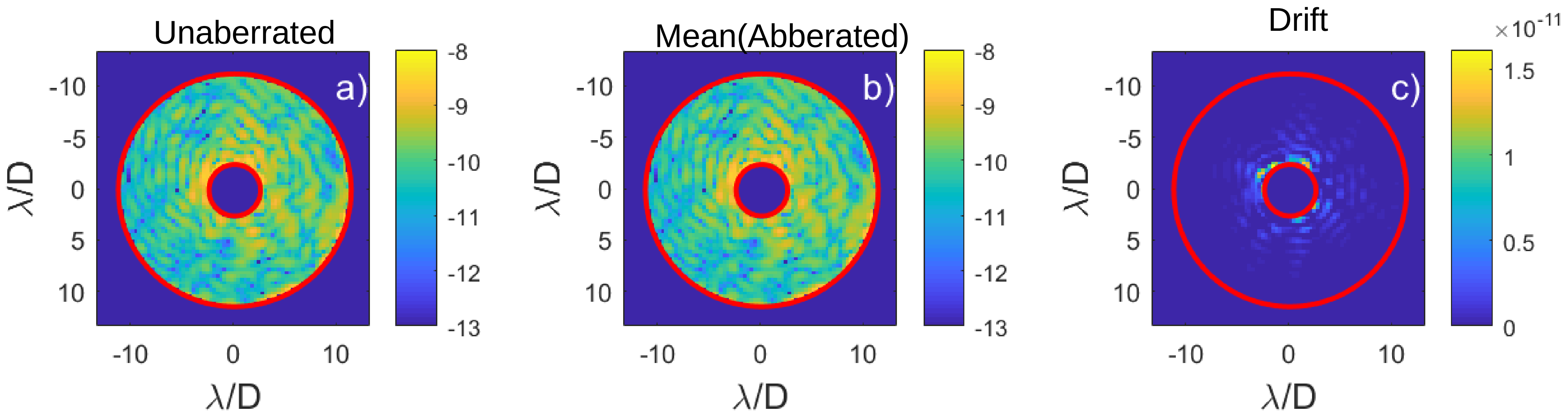
Active Control



Because laser metrology is only sensing the alignment of the primary and segment relative to the optic bench, MET must be supplemented by a line-of-sight control loop. A Fine Guidance Sensor (FGS) measures starlight rejected by the coronagraph to detect misalignment between the stellar image and the coronagraph mask. The line-of-sight error is then corrected with a Fine Steering Mirror (FSM) located upstream of the deformable mirrors. The LOS control loop corrects for spacecraft (SC) pointing errors as well as residual errors from the MET control loop and LOS errors from optics downstream of the tertiary mirror.

HabEx Use Case

Exposure #1 ➪ 30° roll ➪ Exposure #2 ➪ difference image

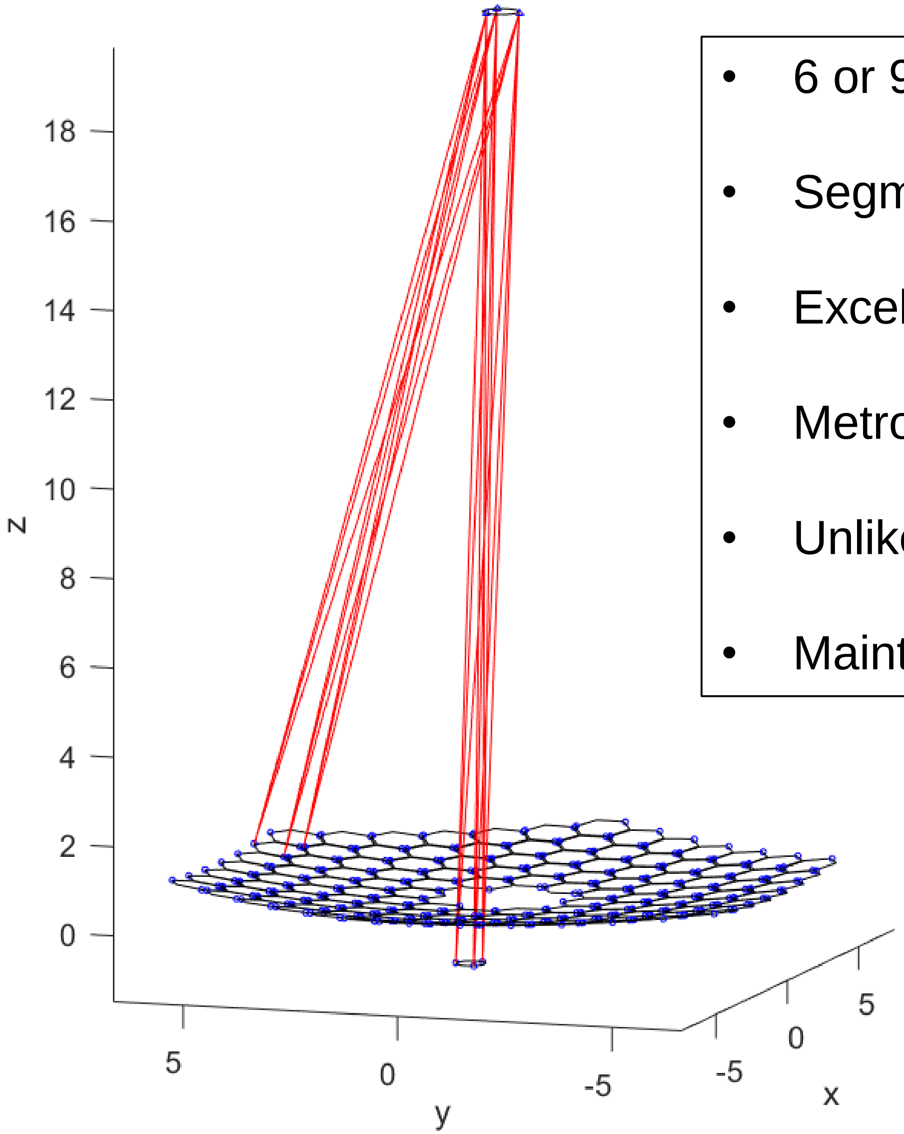


a) Simulation of an unaberrated HabEx coronagraph for the baseline 4 meter, unobscured monolith with a charge 6 vector-vortex coronagraph. The dark hole was tuned for 2×10^{-10} raw contrast between IWA = 2.5 λ/D and OWA = 11 λ/D (red circles). The image is displayed on a logarithmic scale.

b) b) Mean of 100 instantiations of the contrast with the metrology system in closed loop control with rigid body actuation of the primary and secondary mirrors simulating a long exposure. Aberrations are the result of 150 pm rms gauge drift causing rigid body motion of the primary and secondary mirrors. This level of control requires 0.020°C rms thermal control for typical laser metrology gauges.

c) c) The difference between the unaberrated contrast and the degraded contrast due to laser metrology drift on a linear scale. The contrast drift is at least an order of magnitude smaller than the background speckle.

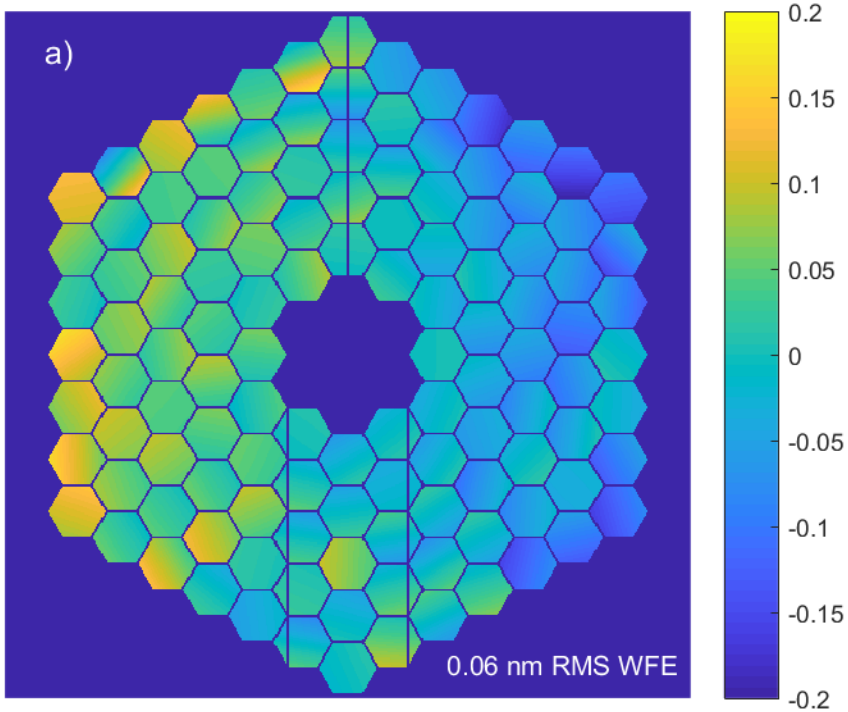
Laser Metrology Truss for LUVOIR

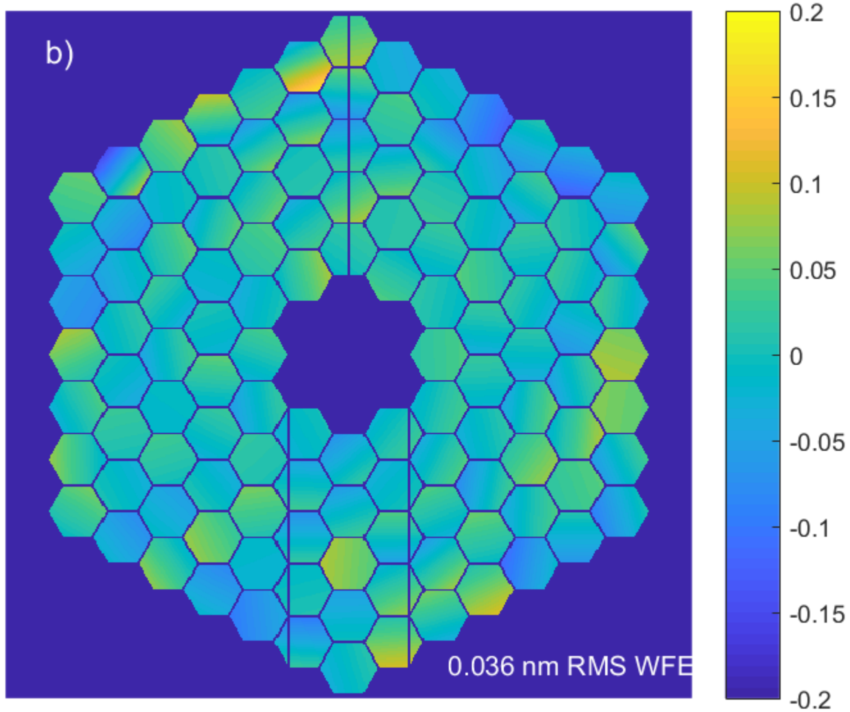


- 6 or 9 Laser gauges per optic
- Segments and secondary mirror are referenced to the tertiary mirror
- Excellent sensitivity in the optically significant degrees of freedom (θ_X, θ_Y, ΔZ)
- Metrology is always maintaining alignment while slewing between targets.
- Unlike edge sensors, each segment is independently controlled.
- Maintains alignment for general astrophysics instruments.

A minimum of 726 Beam Launchers are required to control all 6 degrees of freedom of the segments and secondary mirror.

Metrology Residual Error and LOS correction



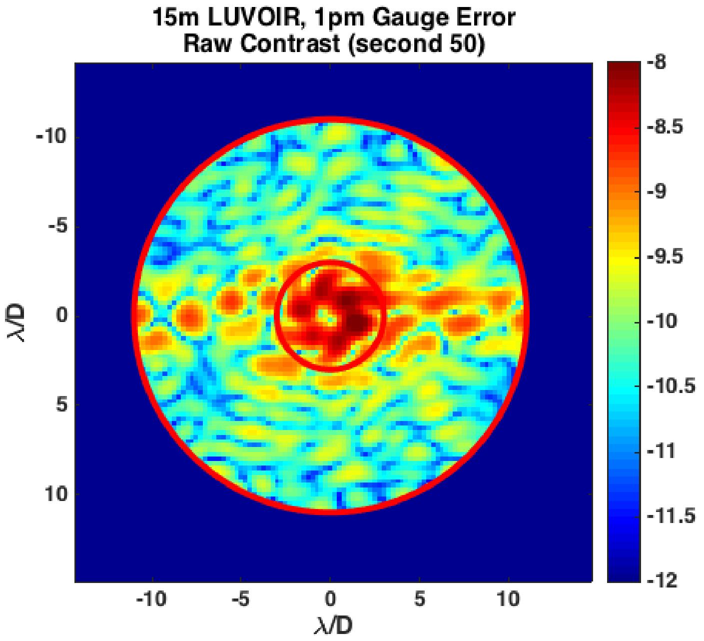


LUVOIR wavefront error as a function of metrology gauge error. A Monte Carlos simulation of the LUVOIR MET errors resulted in 6 pm of wavefront error per pm of laser gauge error. The simulation includes both the segmented primary and the secondary mirror. In figure 8a), misalignment of the secondary mirror introduces a line-of-sight error, here seen as a global wavefront tilt. When laser metrology is combined with a line-of-sight control around the host star, the line-of-sight error is reduced as illustrated in figure 8b). A Zernike polynomial description of the primary mirror is not helpful; a Zernike polynomial decomposition of the wavefront error due to secondary mirror misalignment is, however still relevant. In particular, MET is very effective in controlling low order Zernike terms. It is worth noting that it would take single digit µK control of low CTE carbon-fiber struts, averaged over the secondary support struts, to maintain the same level of secondary mirror stability.

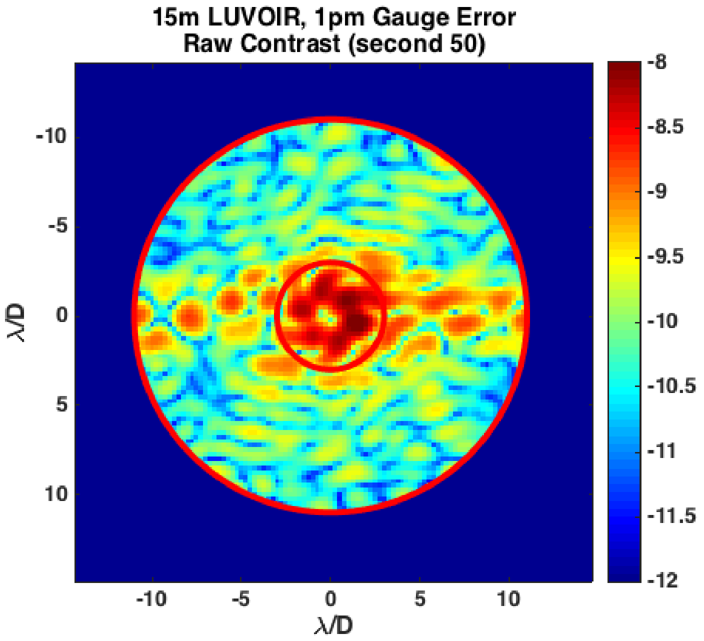
LUVOIR Simulation 1 pm Metrology Gauge Error

Unabberated contrast = $5x10^{-10}$
Charge-4 vector vortex coronagraph with 10% bandwidth centered at 550 nm

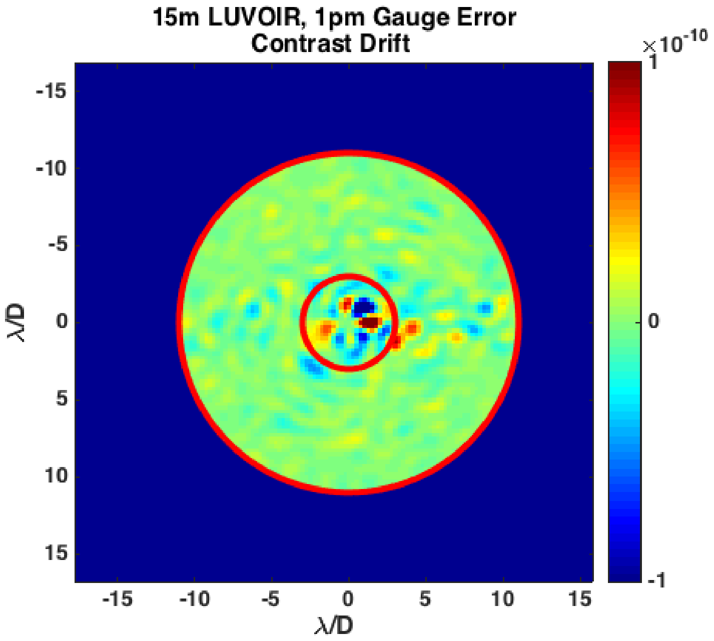
Exposure #1 ⇨ 30° roll ⇨ Exposure #2 ⇨ difference image



Exposure 1 : log(contrast)
Average of 50 instantiations with random gauge errors



Exposure 2 : log(contrast)
Average of 50 instantiations with random gauge errors



Contrast drift

Contrast drift results in ~10% change in contrast.

Next Steps

1. Optimize the phase meter for thermal drift . Goal : 5 pm @ 1 Hz

2. Reduce the beam launcher size
    - Improves thermal stability
    - Reduces segment gaps
    - Reduces launch stress on segments

3. Reduce the beam launcher thermal sensitivity to less than 1 nm/°C

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