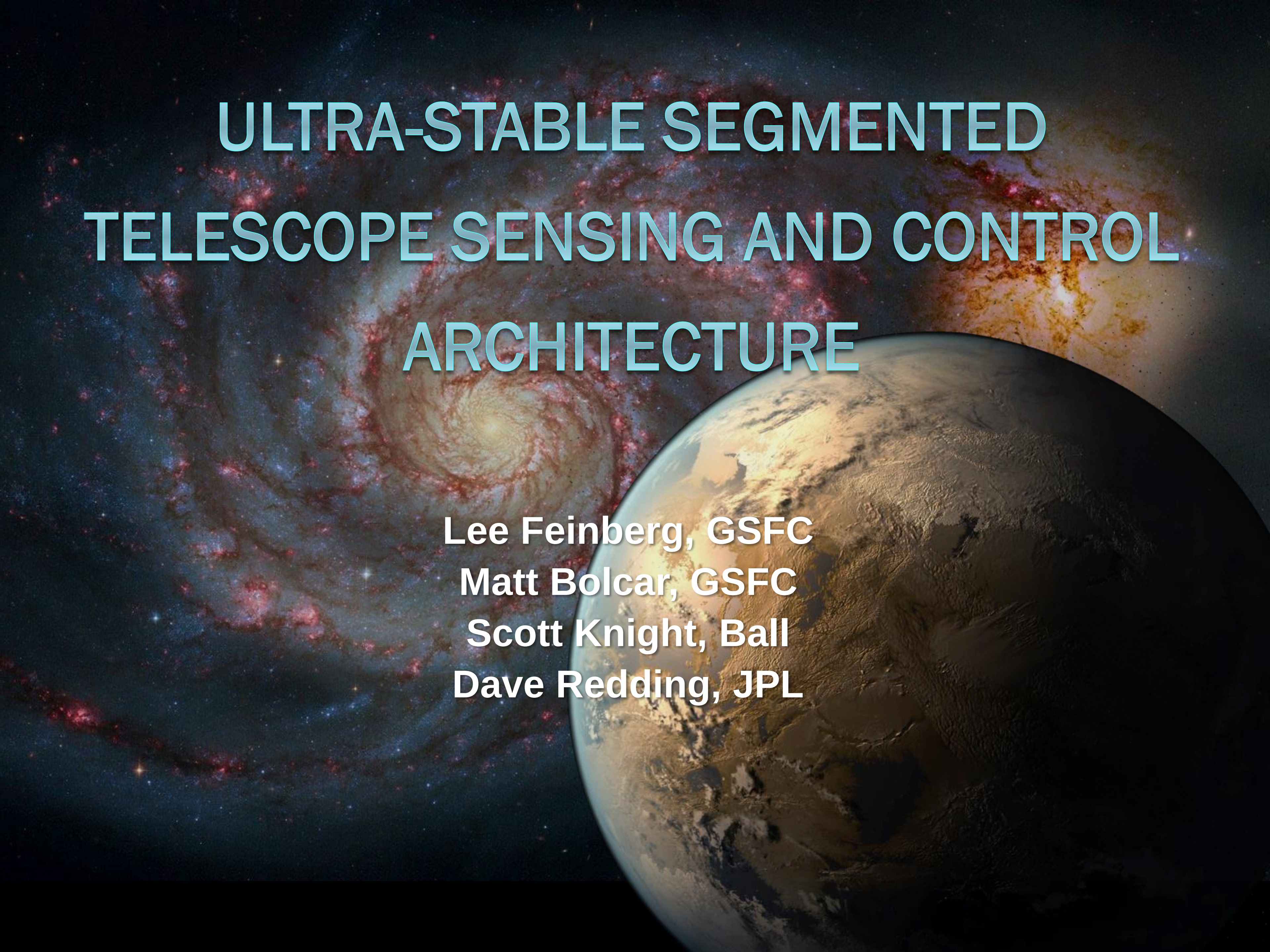

ULTRA-STABLE SEGMENTED TELESCOPE SENSING AND CONTROL ARCHITECTURE

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Topics

- Introduction
- Requirements/Drivers
- LUVOIR 15m Architecture (Summary)
- LUVOIR 15m Stability Architecture
  - Block Diagrams
  - Sensing
  - Control
- Summary

Intro

- The LUVOIR team is conducting two full architecture studies
  - Architecture A – 15 meter telescope that folds up in an 8.4m SLS Block 2 shroud is nearly complete
  - Architecture B – 9.2 meter that uses an existing fairing size will begin study this Fall
- This talk will summarize the ultra-stable architecture of the 15m segmented telescope including the basic requirements, the basic rationale for the architecture, the technologies employed, and the expected performance
- This work builds on several dynamics and thermal studies performed for ATLAST segmented telescope configurations. The most important new element was an approach to actively control segments for segment to segment motions which will be discussed later.

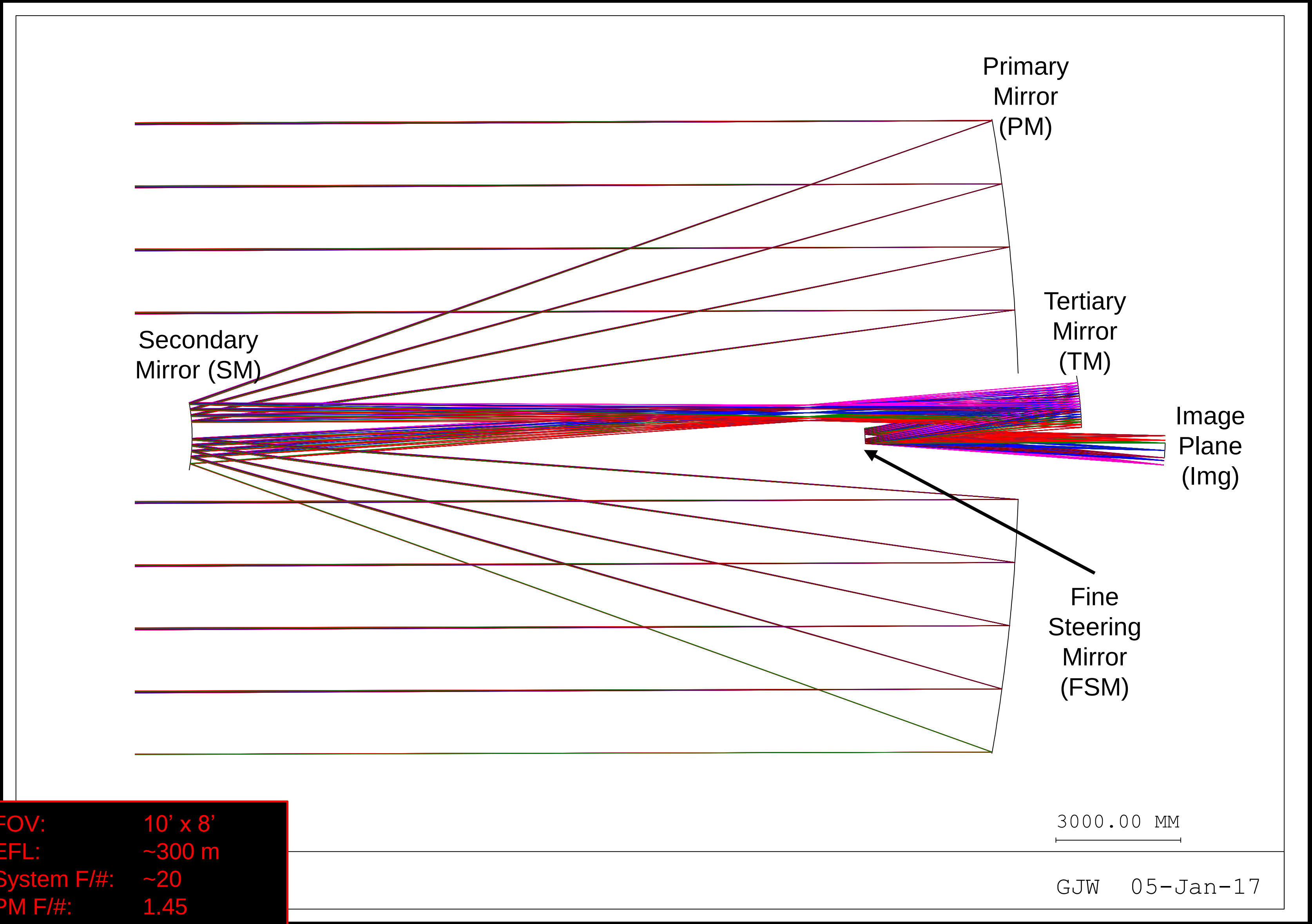
Requirements for Stability

- Driving requirement is to detect Exo-earths with 10^-10 system contrast which means contrast stability of 10^-11
- Equates to about 10 picometers RMS between updates but the driving requirement is for tip, tip and piston of segments as these are the most sensitive terms
  - Work is ongoing (Zimmerman) to evaluate this for an APLC with the 15m segmented architecture
  - Guyon et al have shown that the Contrast goes with the Variance and thus the stability requirement goes with 1/# of segments for uncorrelated (random) segment motions
  - Further sensitivity studies planned but these degrees of freedom are believed to be the most sensitive based on their wavefront contribution and the fact that they fall in between the IWA and OWA
- Update time driven by source magnitude
  - If we only sense piston, tip, tilt, studies by JPL (Moore/Redding) indicate a Zernike sense can close the loop in approximately:
    - <5 seconds for a 6^{th} magnitude star
    - <2 minutes for a 10^{th} magnitude star
    - Will set 2 minutes as a goal for this piston, tip, tilt time between updates

Potential Requirement Relaxation

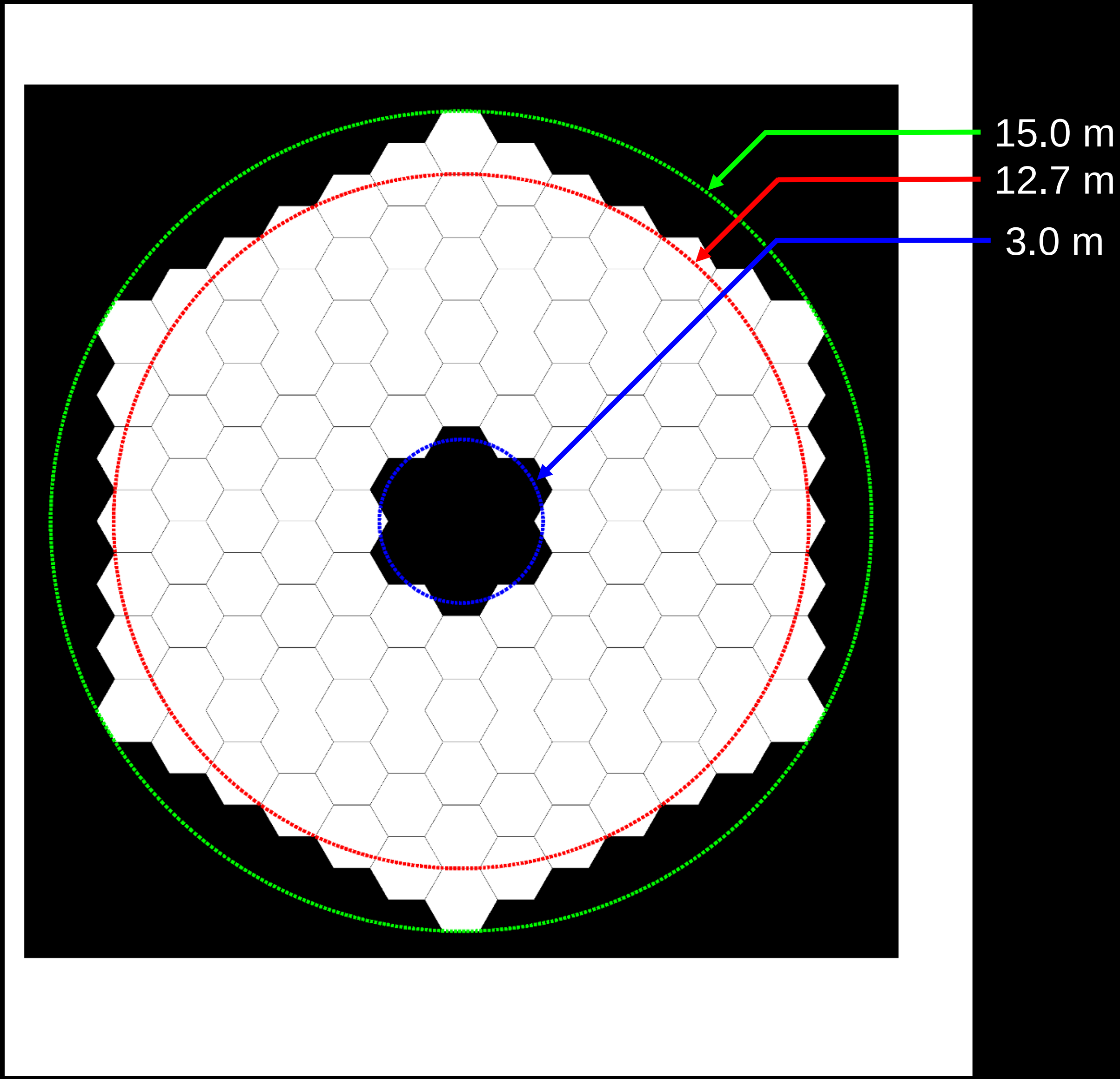
- Some novel coronagraph approaches may be able to relax the telescope stability
  - Vector Vortex – relaxes certain symmetric aberrations, still sensitive to piston, tip, tilts and not shown to work well with a central obscuration like LUVOIR (See work by Mawet)
  - Non-telecentric Microlens IFS – Promising idea to relax contrast and contrast stability but modeling and testbedding still ongoing to validate approach (See paper by Q. Gong)
- Another novel approach to relax the timescale of updates is to use an artificial laser guide star which provides sufficient S/N to reduce updates to milliseconds (work led by Cahoy/MIT and Guyon and Males (UofA)
- Another area of potential relaxation is PSF calibration methods as being employed on WFIRST
  - May also be able to filter key spatial frequencies like that corresponding to the piston, tip, tilt
- While many of these are promising, for purposes of this LUVOIR Architecture A, we don't assume these novel approaches to relax requirements but focus on picometeter class stability
  - We will revisit this for Architecture B this Fall based on maturity and applicability

LUVOIR "A" Telescope 15m Optical Design



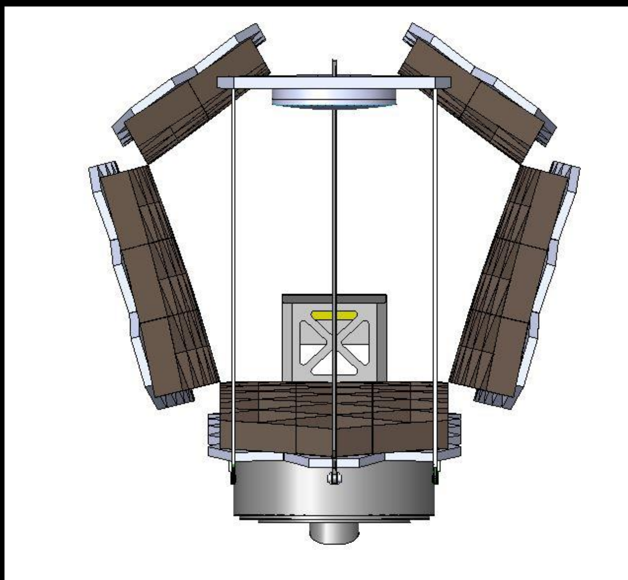
FOV:	10' x 8'
EFL:	~300 m
System F/#:	~20
PM F/#:	1.45
Obscuration:	~3 m

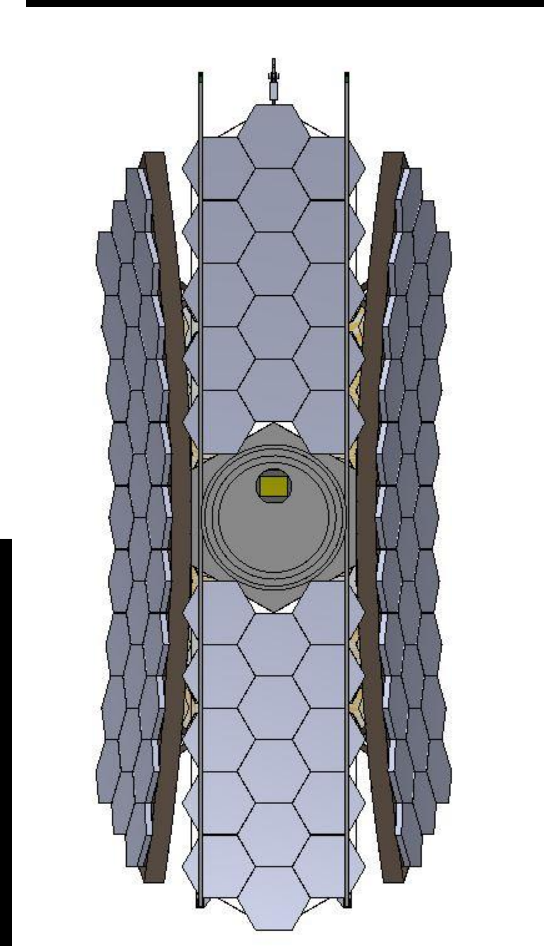
LUVOIR "A" Telescope Aperture



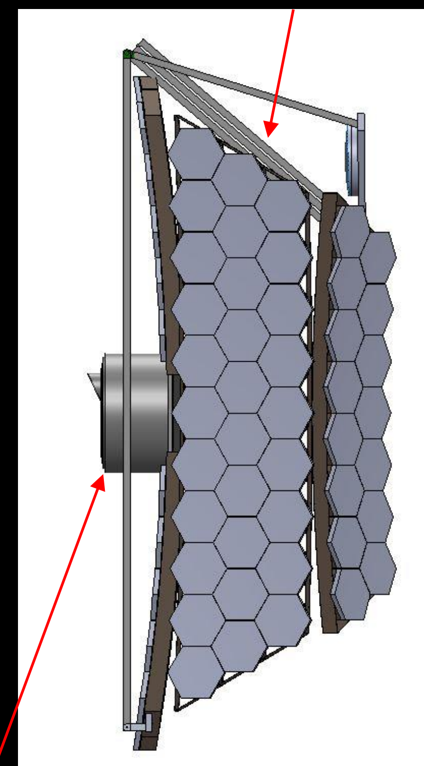
- 1.15-m flat-to-flat segments (120x)
- Central ring of array removed to accommodate Aft-optics & Secondary Mirror Obscuration
- Effective area is ~135 m^2
- 15-m circumscribed diameter / 12.7-m inscribed diameter
- Assumes 6 mm gaps

Mechanical Design Details (2)





Folded segments of SMSS



Stowed Telescoping Boom is 1.5 m deep

Architecture Approach for 15m

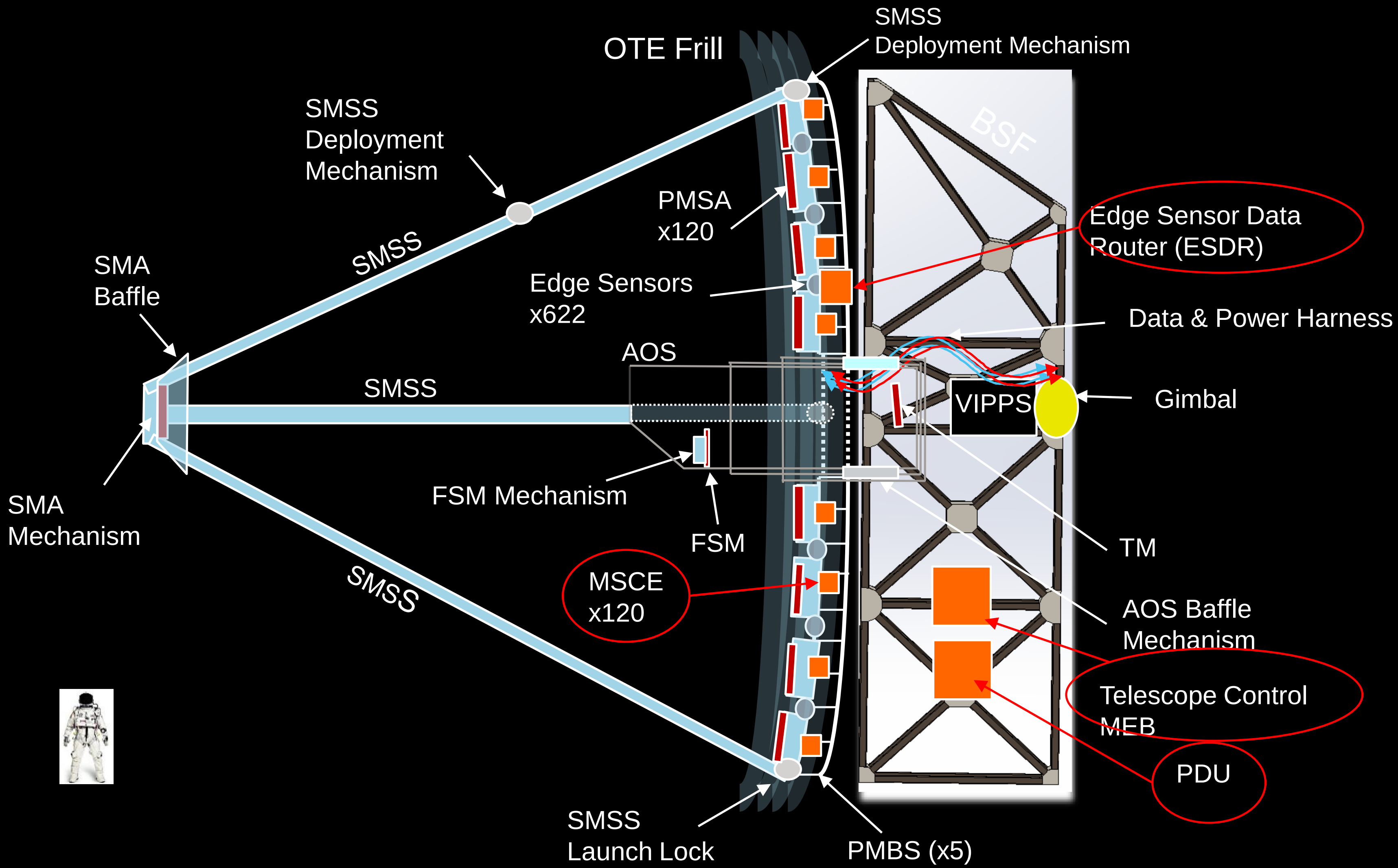
Segment level

- Assume stiff mirrors (>250Hz) and picometer thermal stability achieved with 1mK heater plate (as demonstrated for ATLAST 9.2m)
  - See Paper by Eisenhower et al

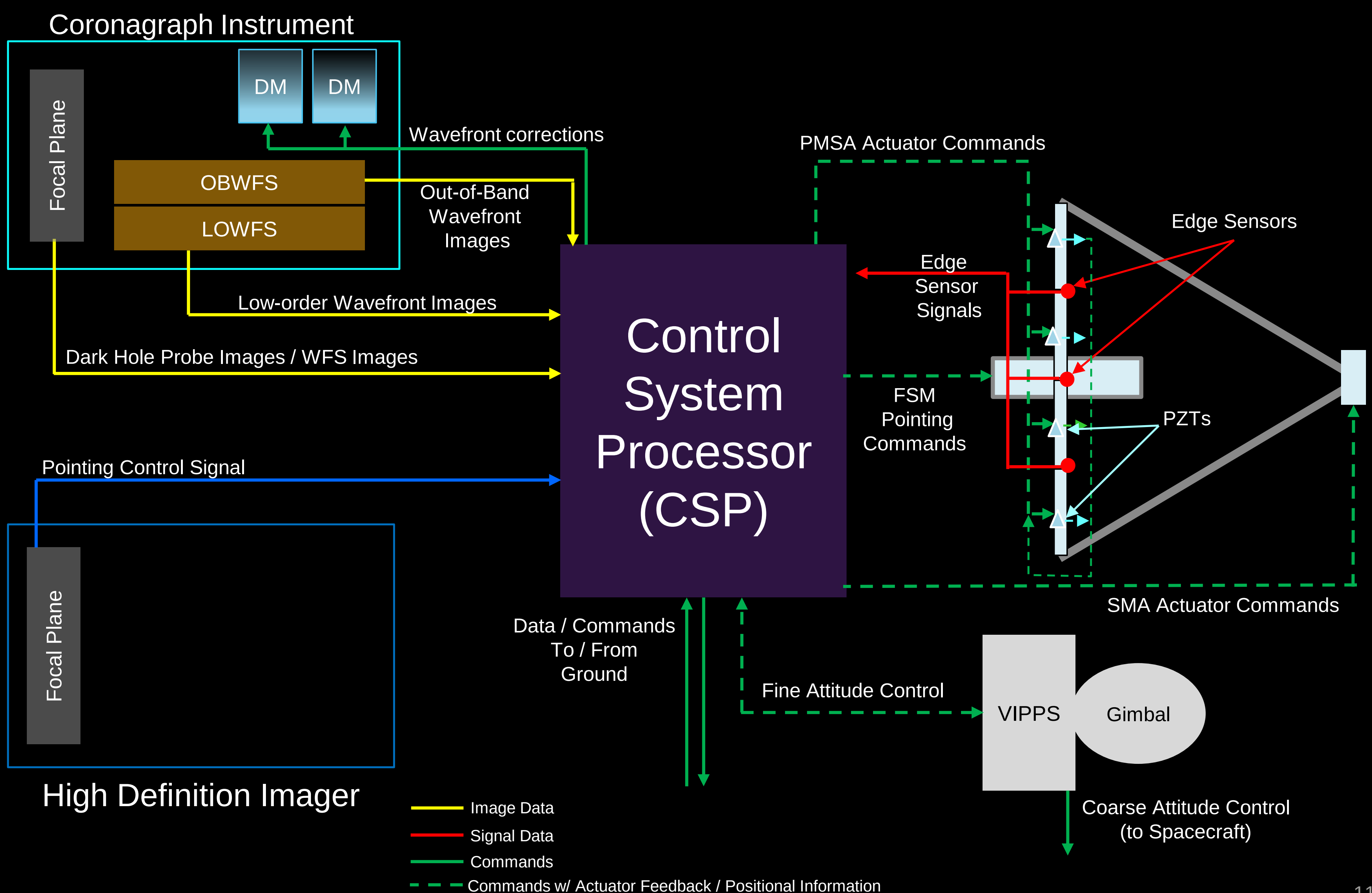
Segment to Segment

- Use a Non-Contact Isolation approach (eg, Disturbance Free Payload) to sufficiently isolate the telescope for dynamics (>1hz)
  - Modeling for 15m ongoing, based on success of pm stability for 9.2m ATLAST which also achieved excellent SM stability
- Use a Zernike Sensor for the outer loop (2 minute update for piston, tip, tilt)
- Use edge sensors and piezos to control drifts (1hz to 2 minutes)
  - Baseline was 450hz readout – allows averaging (20x reduction in noise) so .1pm measurement requires 2 pm resolution and stability over 2 minutes
  - Capacitive edge sensors chosen due to heritage from ground telescopes including TMT testbed results and relative simplicity
    - Laser truss also assessed here as alternative
- Achieve good <1pm stability between edge sensors and piezos over 2 minute intervals
- Can use the edge sensors with feed forward control as a backup approach for segment tip/tilt (roughly 40hz mode)

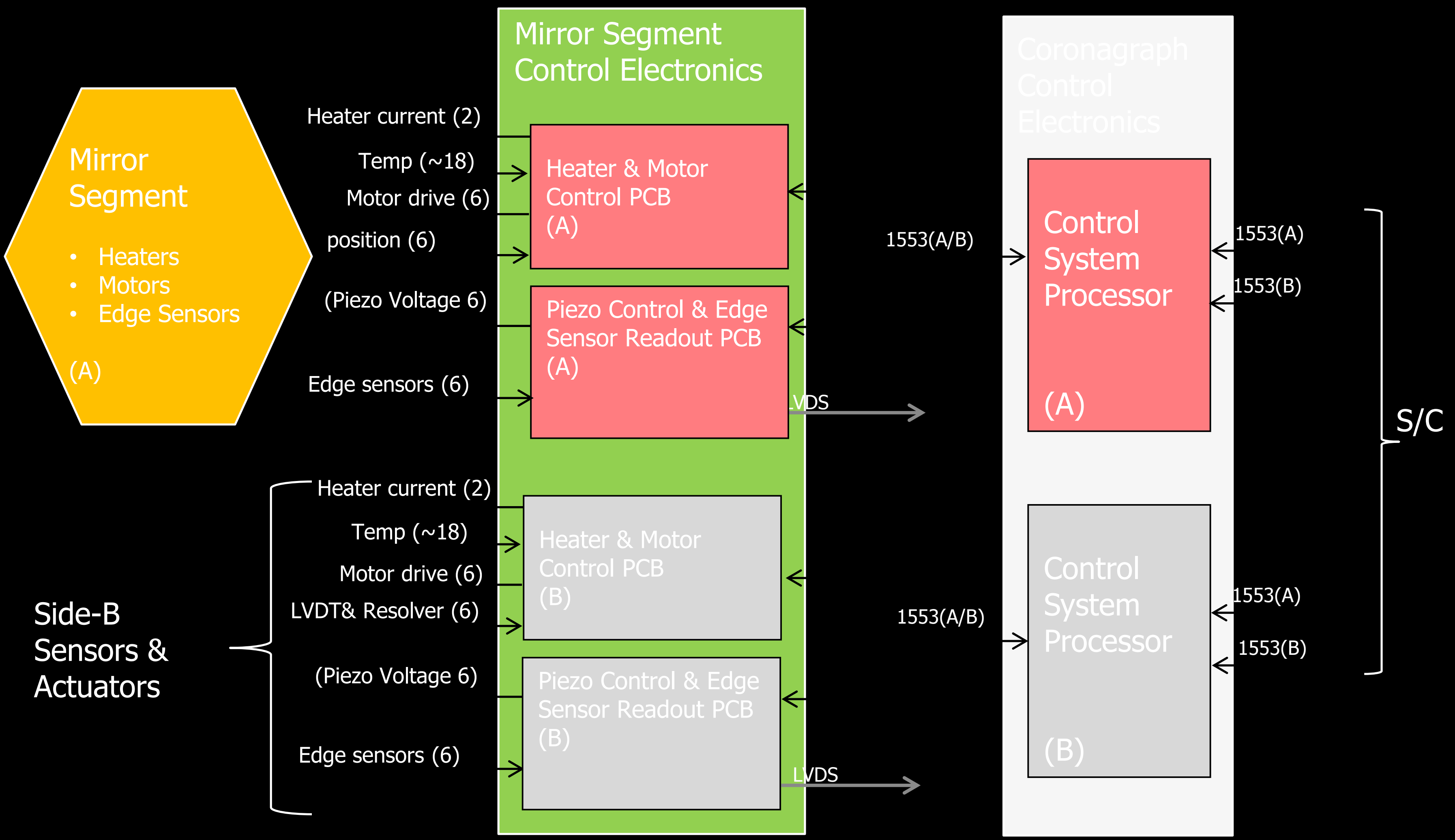
LUVOIR "A" Telescope System Block Diagram



Control System Processor (CSP)

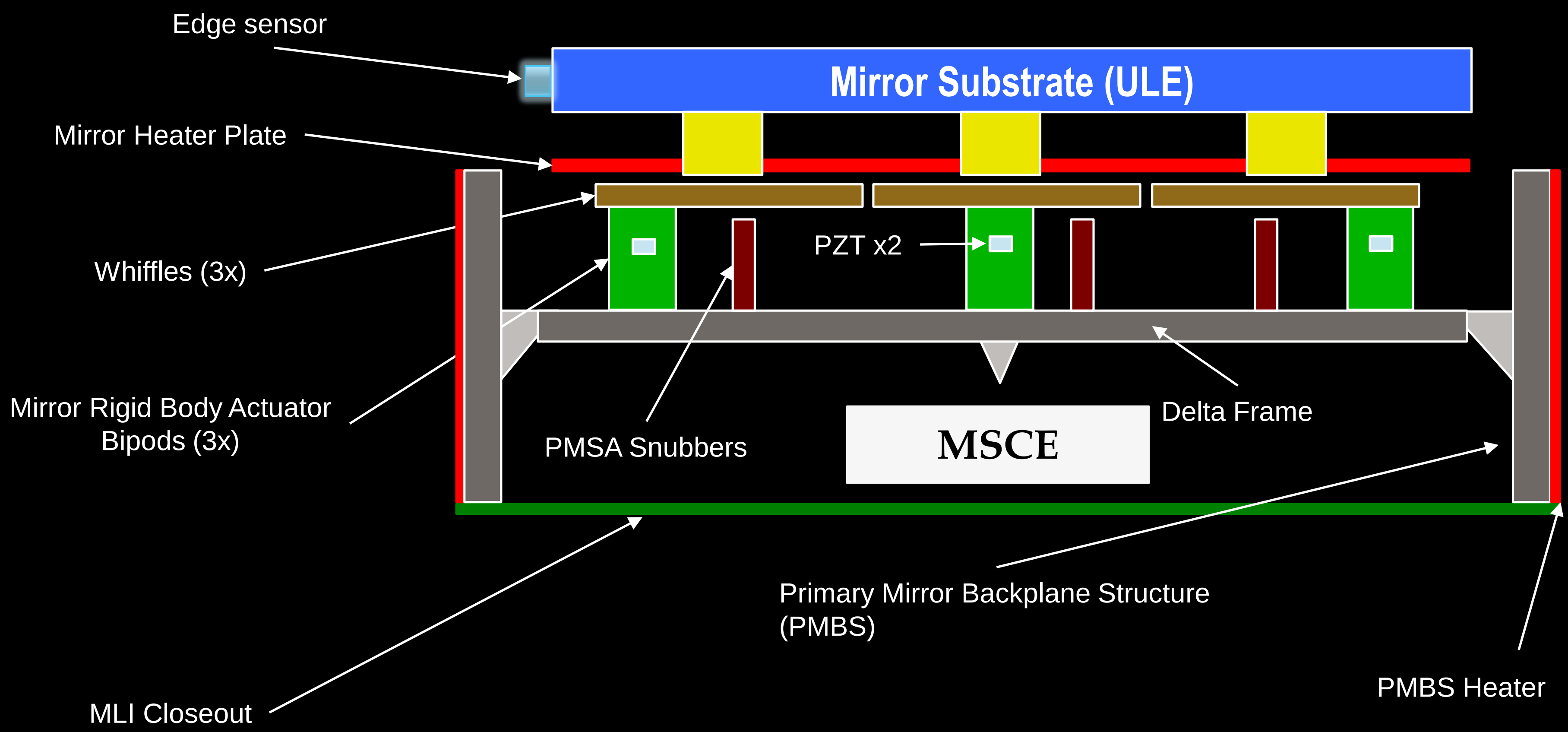


Distributed Architecture



A key finding was that the heat dissipated for the piezo and edge sensor readout can be used as part of the heat required to maintain 270C operations thus minimizing the heater power required (similar power)

LUVOIR "A" PMSA Block Diagram



Key stability in design is segment level and from edge sensor to piezos

Dynamic range required for piezo has been budgeted to be 3 nm's which includes backplane hinge effects

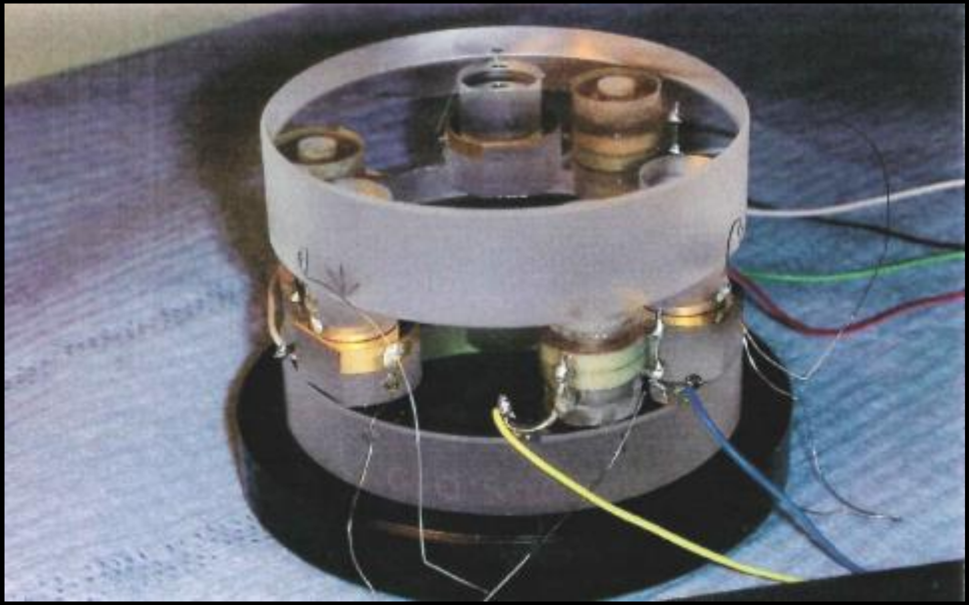
Mirror Segment Stability

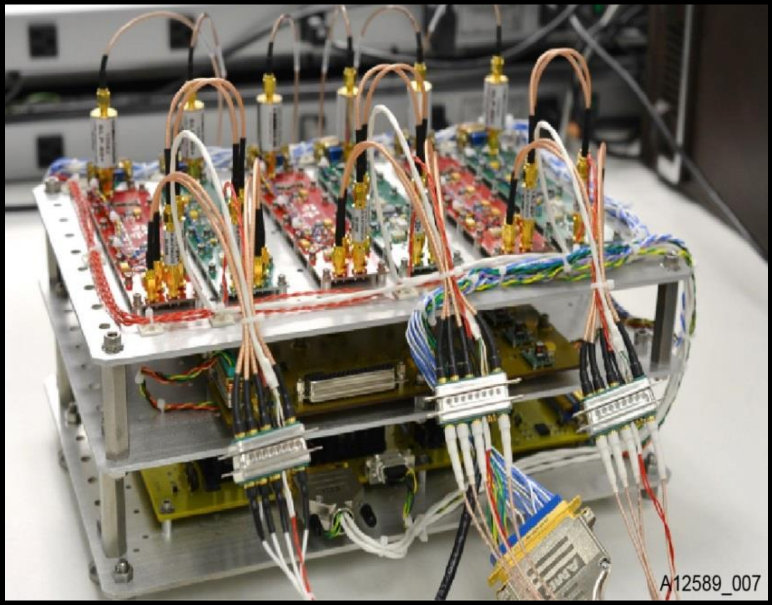
- Very stiff mirror (300hz) avoids deformation modes
- Use 1 mK Thermal Control as Discussed in Eisenhower et al (SPIE)
- Recent Demontration by our team of MicroKelvin sensing and <1mK Control supports the notion that this is achievable
  - More work ongoing to demonstrate this on a mirror

Baseline Sensor: Custom Capacitance Sensor

This sensor was developed for use for gap sensing in an etalon for a tunable filter for a LIDAR instrument

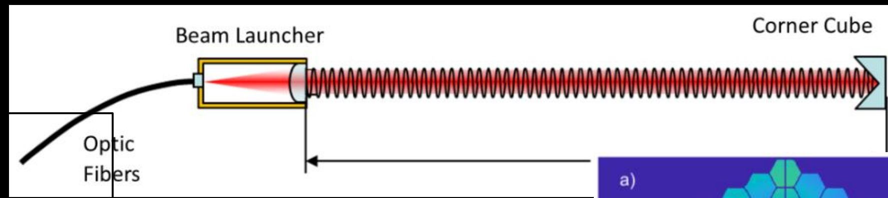
- 3 Sensors and 3 PZT stacks to control piston tip and tilt of etalon in the presence of dynamic disturbance
- Etalon control reqt was 16 pm, 7-11pm achieved from 0 to 60Hz
- Harris AOSD testbed and TMT testbeds have demonstrated full dof control to nanometer level (global solution)





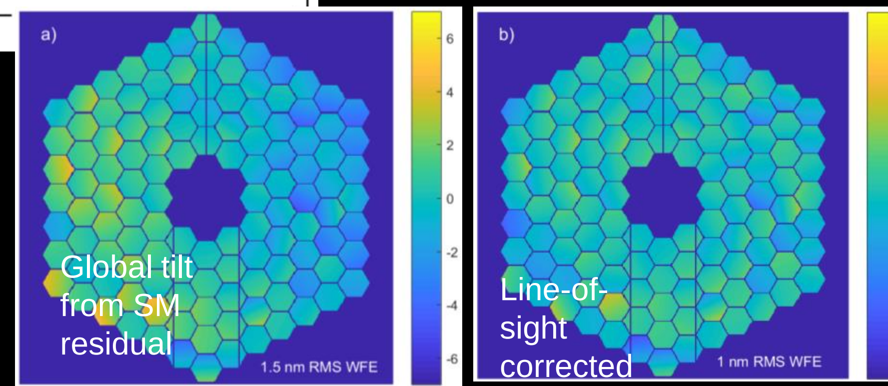
Ball Brassboard, Scott Knight of Ball

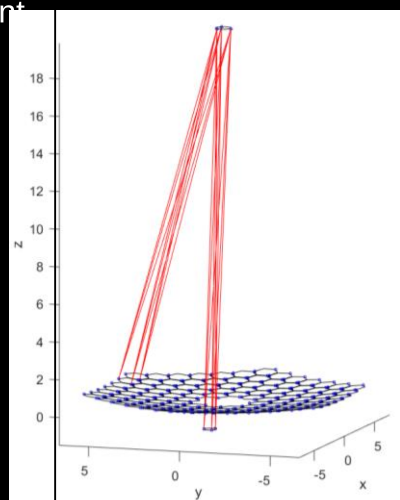
Alternative Sensing Method: Laser Metrology



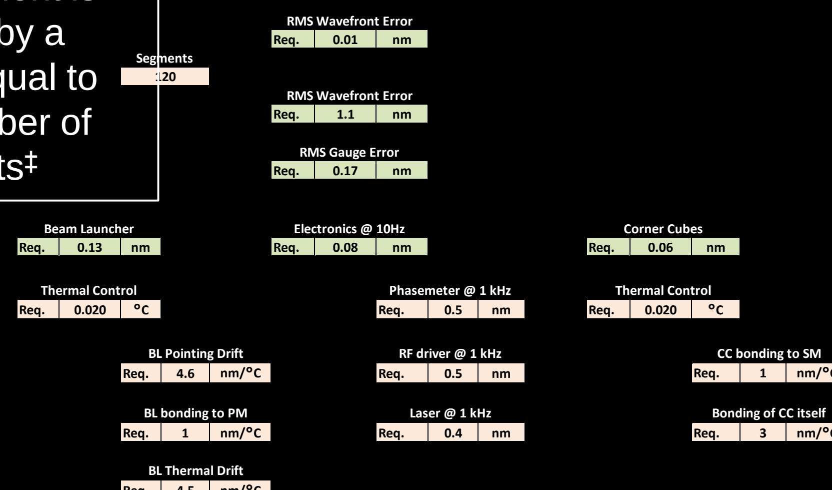
Summary

- Segments and secondary are referenced to the optical bench
- Optics rigid body modes are in closed loop with metrology
- Global tip/tilt is removed with the fine guidance sensor
- Minimum of 6 gauges/segment for 6 rigid body degrees of freedom
- 726 gauges from a single stabilized laser source
- Controlling alignment at the optic minimizes high order aberrations and beam walk
- No coupled modes between segments





Phasing requirement is relaxed by a factor equal to the number of segments‡

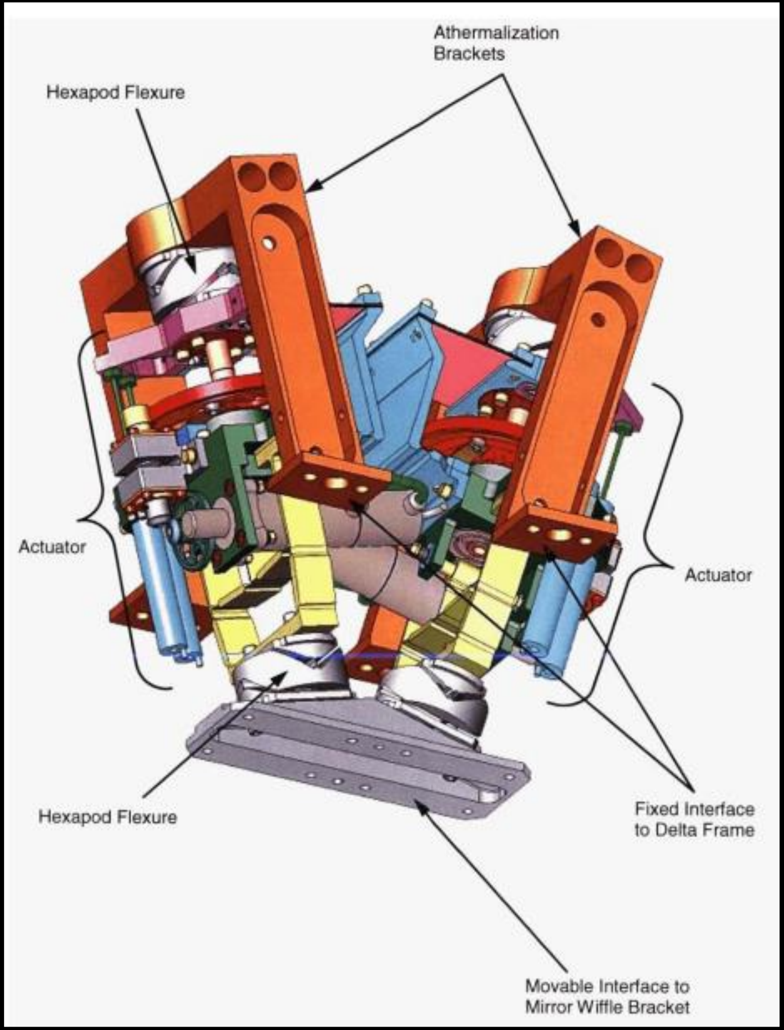


‡Guyon,O., Coronagraphic performance with segmented apertures

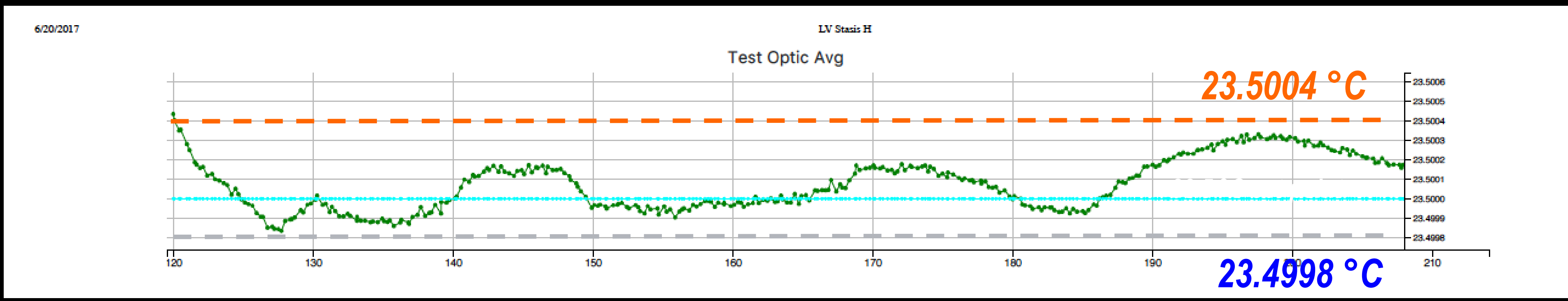
Current technology meets 10^{-11} contrast drift requirement

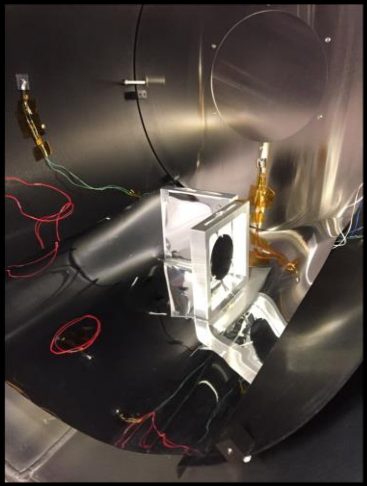
Example actuator approach used in baseline

- Three bipod assemblies make up one Hexapod.
- JWST actuators can achieve 8nm steps
- Fine stage added to achieve smaller steps
- Option to put piezo before final linkage thus relaxing step resolution by 114:1 (so 114pm piezo motion is 1pm of actuator motion)
- Demonstration in work….



Demonstration of Ultra-Stable Control Shown on Test Chamber (sensing and control to support 1mK is achievable)





Surrogate Test Article
(Next Phase will Demontrate Control on a Mirror)
Sang Park/SAO under Effort Led by B. Saif/GSFC

Gives us confidence that thermal control to milli-Kelvin as needed by segment and piezo to edge sensor is feasible

Conclusion

- The ultra stable architecture for the 15m LUVOIR telescope has been developed that greatly leverages work by ATLAST studies and from TMT edge sensing
  - New wrinkle is to include edge sensors and piezo control which relaxes backplane requirements and inoculates the design to creep, CME effects
  - Also provides backup approach for segment tip/tilt
- Analysis underway to confirm dynamics configuration and thermal stability from edge sensor to piezo
  - Thermal demonstration and ATLAST 9.2m results give us confidence that these are solvable
- Based on active segment control technologies that have heritage from ground telescopes (edge sensors and piezos), flight missions, and the added fidelity needed has been demonstrated or will soon be