Proposed LISA Telescope Design

J. Livas[a], S. Blake[b], A. Davis [a], R. DeRosa[a], I. Escudero Sanz[b *], M. Fickett [a], E. Fitzsimons[c], P. Fulda [d], J. Gleason [d], W. Hayden [a], M. Hersh[a], J. Howard [a], J. Ivanov [a], R. Keski-Kuha[a], S. Kulkarni [d], J. Lehan [a], H. Li [a], G. Mathews [a], P. McNamara[b] , L. Mondin[b], G. Mueller [d], P. Patel[b], S. Sankar[a], L. Seals [a], Andrew Weaver [a], Alexander Weaver [d], M. Wells[c], M. Wilson [a]

[a]NASA-GSFC, 8800 Greenbelt Rd, Greenbelt, MD-20771, USA; [b]ESA-ESTEC, Keplerlaan 1, Noordwijk, NL-2201AZ; [c]UK Astronomy Technology Centre, Royal Observatory, Edinburgh, UK EH9 3HJ, [d]University of Florida, Gainesville, FL, 32611, USA

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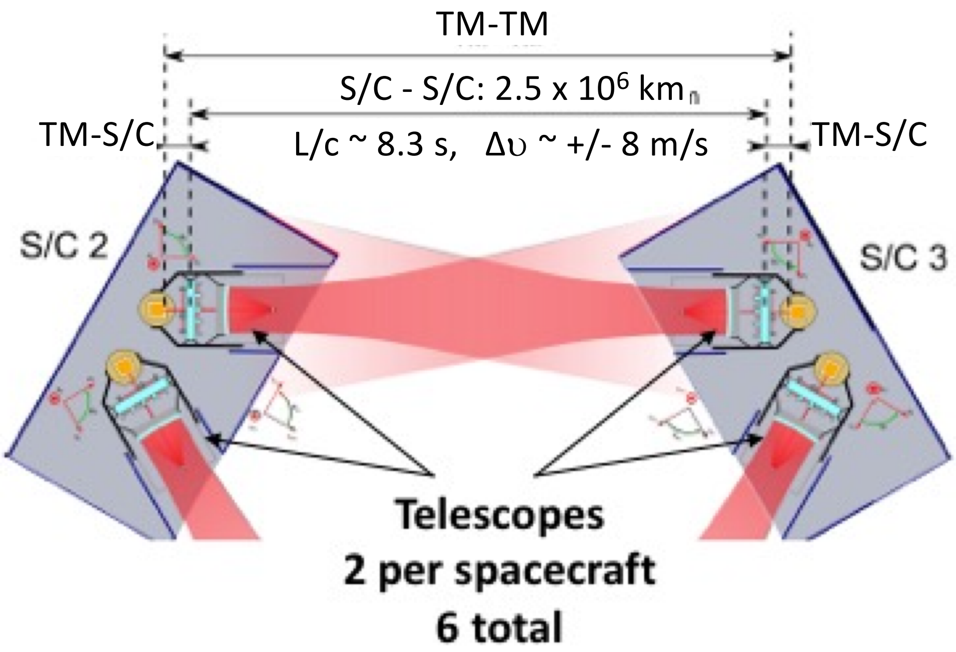
Telescope Functional Description

- Efficiently deliver power on-axis to the far spacecraft
- Simultaneous transmit and receive (TX/RX)
- Afocal beam expander
    - **300 mm dia. large beam**
    - **2.24 mm dia. on bench**
    - **134X magnification**

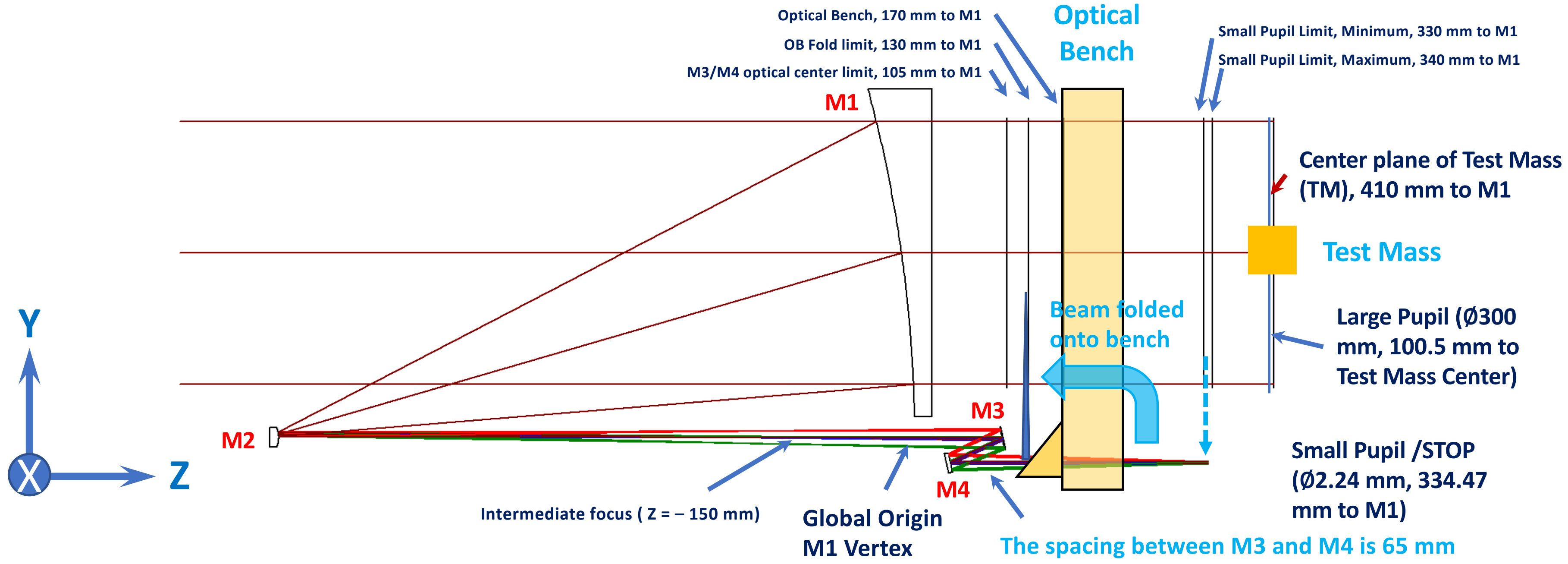
- **Application is PRECISION LENGTH MEASUREMENT, not image formation**
    - **Keep optical pathlength stable to ~ 1 pm/√Hz over the measurement BW**
    - **Minimize phase noise from coherent transmitter backscattered light**
    - **Minimize tilt to length (TTL) coupling**



Key Challenges/design drivers

- Dimensional Stability
  - Low CTE material and thermal stability at the 1 x 10^{-5} K/√Hz level, using baffles fixed to the spacecraft that act as a passive thermal filter
  - Spacecraft is stable at the 1 x 10^{-3} K/√Hz level per LISA Pathfinder experience.
- Coherent backscattered light
  - Adopt unobstructed design
  - Low scatter coatings and dimensionally stable structure so scattered light phase is stable
  - Keep spacing between the telescope and optical bench stable
- Tilt-to-length (TTL) coupling
  - Careful design to minimize pathlength differences with field angle
  - Careful alignment of measurement axes (bench to bench and bench to GRS) such that spacecraft tilts do not couple to the length measurement (movable aperture stops help during integration)
  - Wavefront errors projected into the far-field will also couple TX angular jitter into an apparent length signal

725-V7a-M4-Flat Design Layout



Global Coordinate System

- Origin at M1 Vertex
- Z-axis: parallel to optical axis (object and image space)
- Y-axis: perpendicular to optical axis, within screen
- X-axis: perpendicular to optical axis, into screen

	Type	Conic	Radius (mm)	Clear Aperture (mm)	Edge Diameter (mm)
M1	Parabola	-1	-1475.246	345.3	365
M2	Hyperbola	-1.0928	-25.813	6.4	25.4
M3	XY Polynomial	0	Infinity	24.6	27.4
M4	Flat	0	Infinity	21.0	27.4

”freeform” optic

M1 Clear Aperture Analysis

Stop Size Calculation

Nominal STOP Diameter (mm)	2.24
Design Tolerance (mm)	+/- 0.0075
Alignment/Interface Margin (mm)	+/- 0.170
Oversized STOP (Worst Case, mm)	**2.5875**

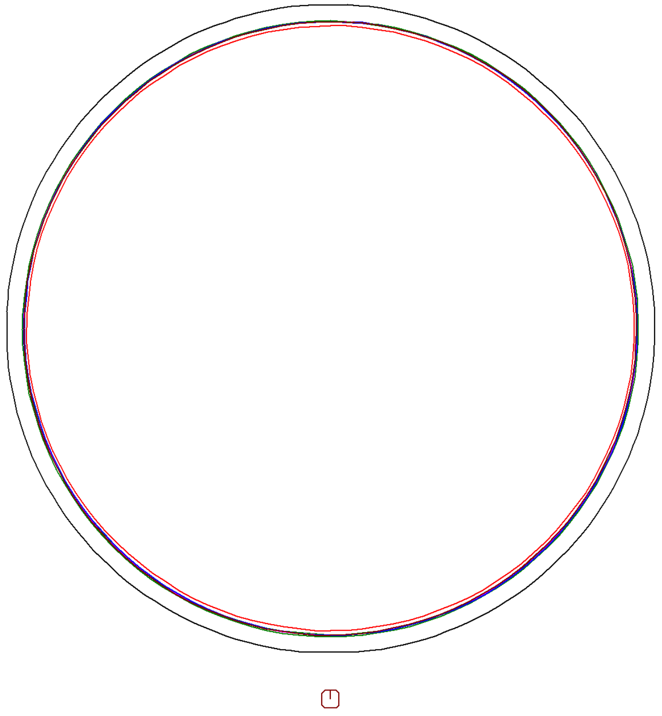
+/- 0.140 Rx clip
worst case expected

M1 Footprint Analysis

STOP SIZE (mm)	M1 Footprint (Y, X, mm) Science FOV (20 μR)	M1 Footprint (Y, X, mm) Acquisition FOV (225 μR)
2.2400	299.4, 299.4	300.2, 300.3
2.5875	345.9, 345.9	346.7 346.8

M1 Clear Aperture Analysis

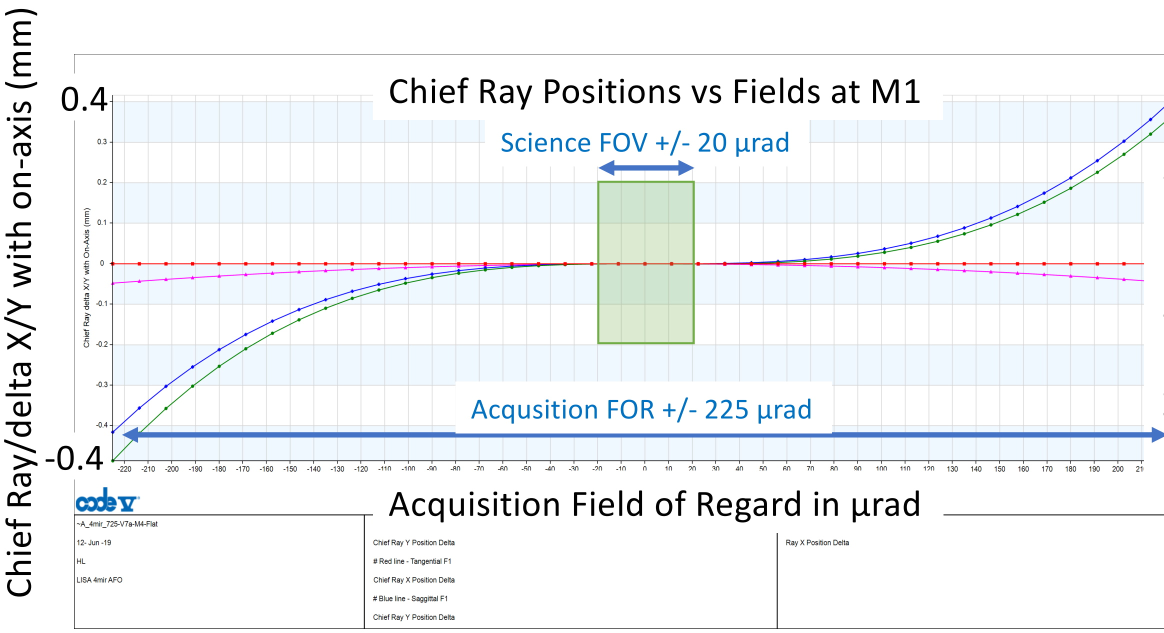
M1 Footprint (diameter, mm)	**346.8**
Clear Aperture Radius Margin (Alignment/Tolerance, mm)	3
Coating Radius Margin (included above, mm)	2
Mechanical Edge Radius Margin (mm)	4.1
M1 Physical Diameter (mm)	**365**

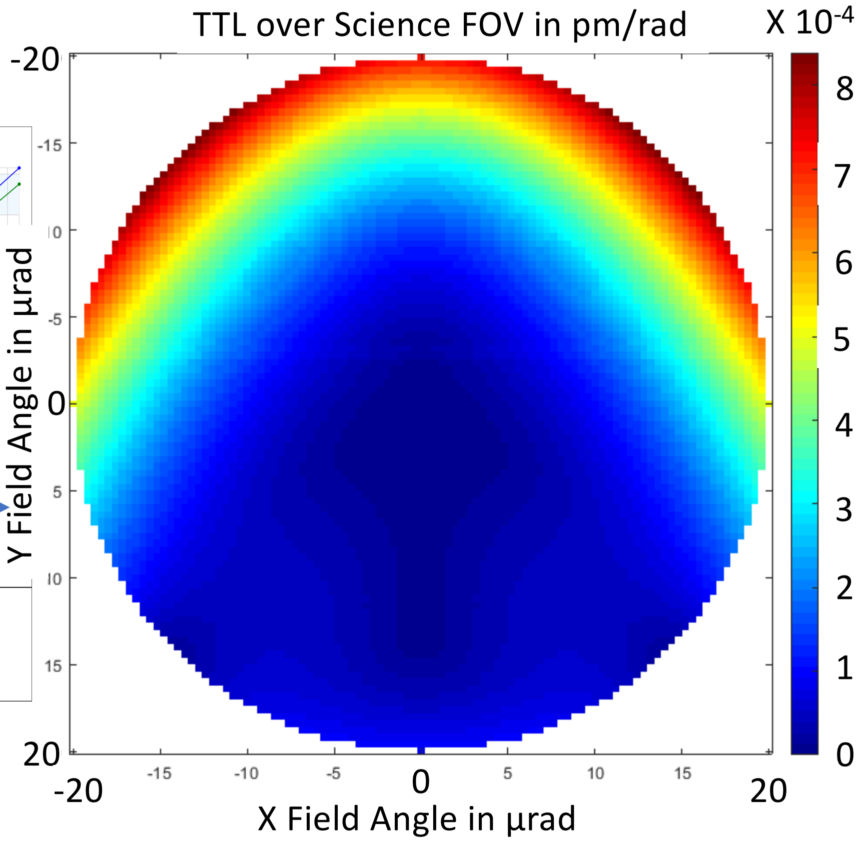


M1 Footprint Plot

- Physical Diameter 365 mm
- Footprint 346.8 mm
- Mirror center 210 mm to M1 vertex
- On-axis chief ray Y position 210 mm to M1 vertex

Pupil wander/dOPL vs. Field

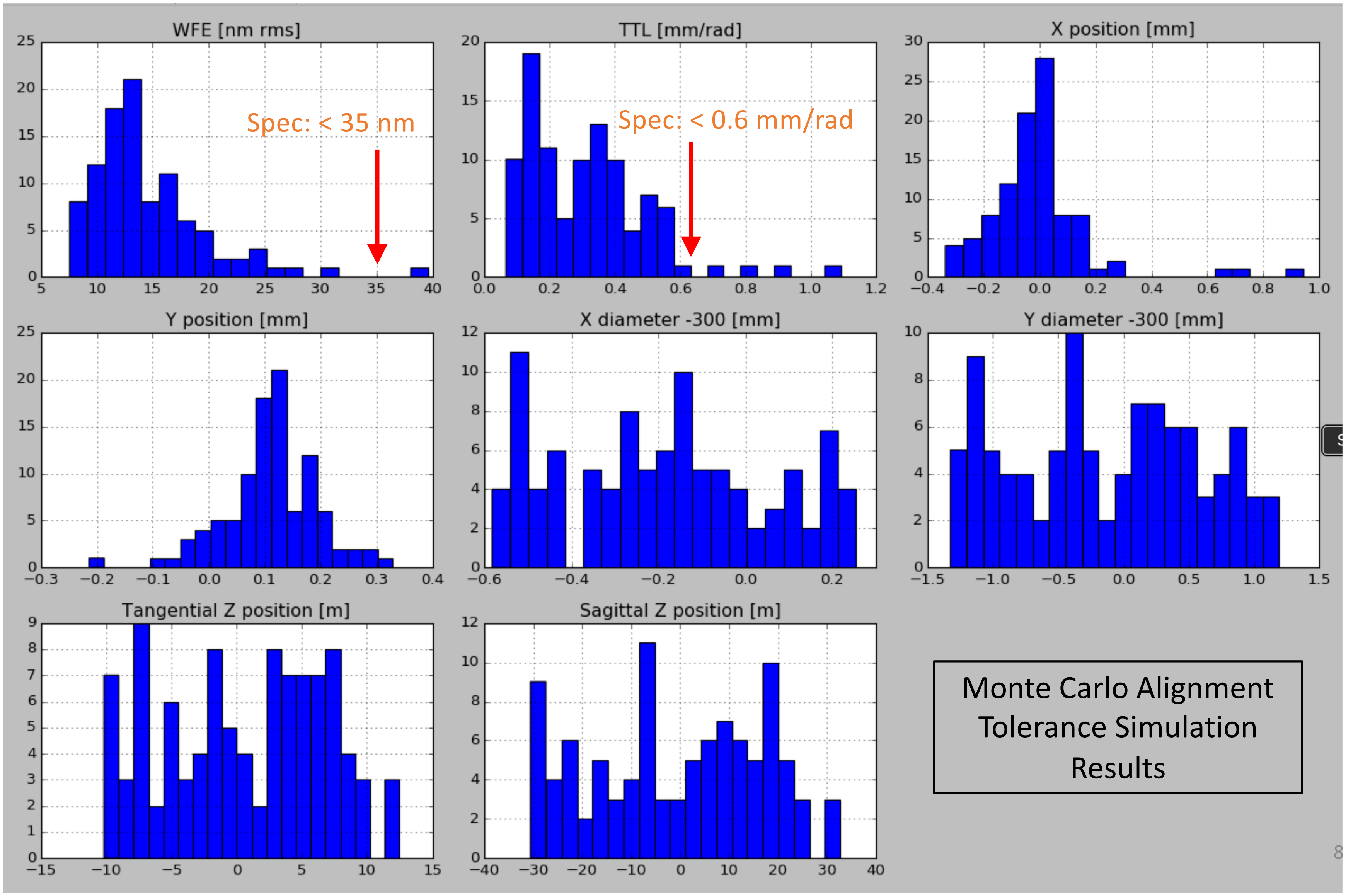




"Intrinsic" optical path length variation nearly eliminated by design.
Max over science field of view is 10^{-3} pm/rad = 1 fm/rad.

Alignment Tolerances

- Cassegrain tolerancing inputs are at the edge of metrologists’ advice
  - few microns in ROC, 0.01% in conic, few microns in position
  - Driven by angles of incidence, need a longer telescope or a smaller primary to significantly alter
- M3/M4 tolerancing inputs are much more relaxed, angular alignment requirements are difficult but within the realm of “routine” (2 arcsec = 10 µrad requirement)
- If these inputs are satisfied, then the image of the stop places well and the boresighting is tightly controlled (keeps TTL of integrated system to an acceptable level)
  - Magnification variation produces +/- 1.5 mm spread in beam sizes
  - WFE within requirements

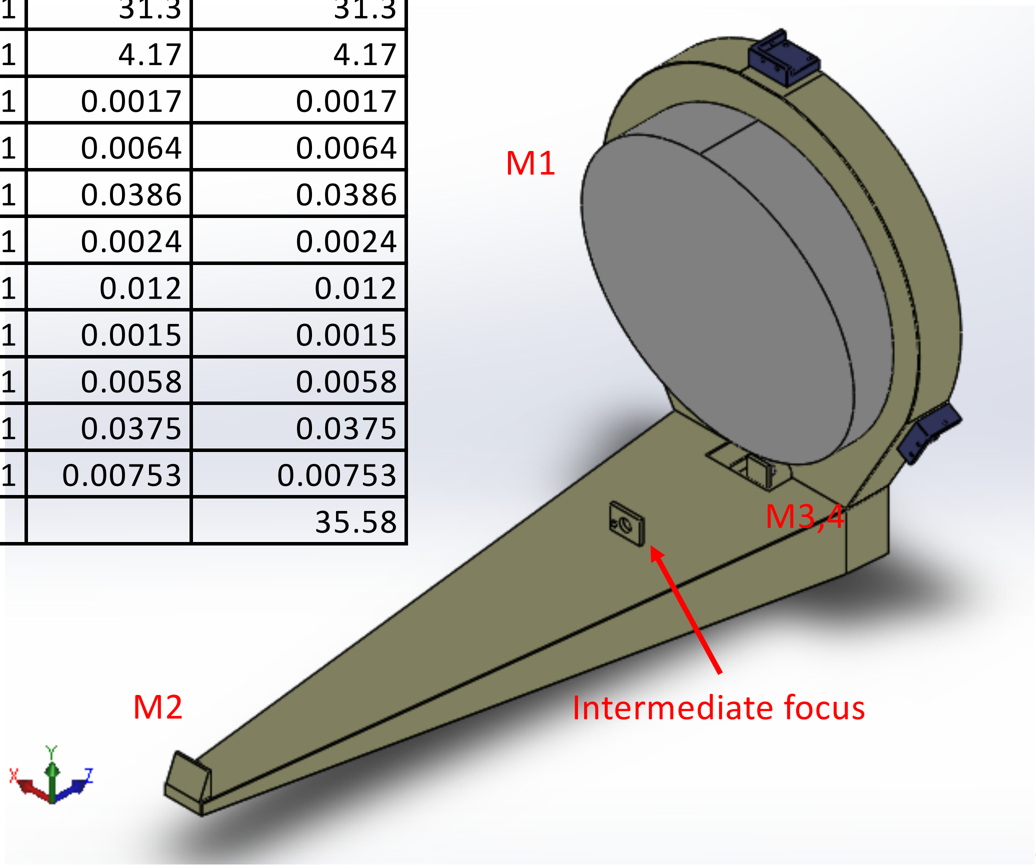


Monte Carlo Alignment Tolerance Simulation Results

Mechanical Design Overview

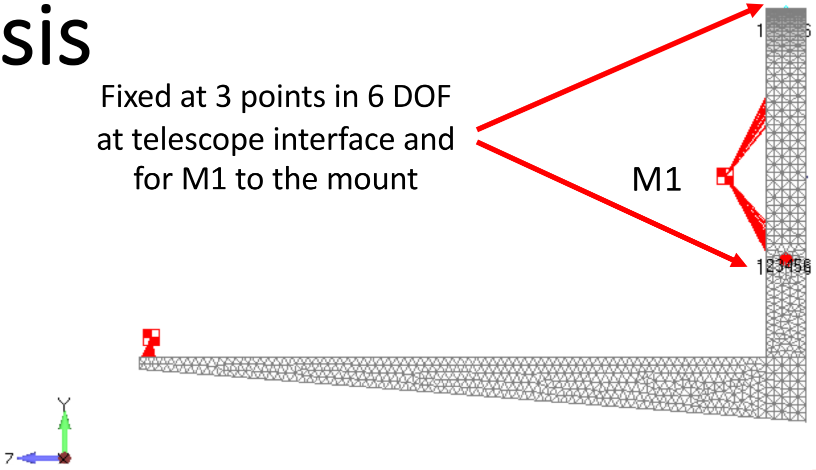
Component	**Material**	**QTY**	**Mass (kg)**	**Total (kg)**
One Arm Structure	Zerodur	1	31.3	31.3
M1	Zerodur	1	4.17	4.17
M2	Zerodur	1	0.0017	0.0017
M2 Adapter	Zerodur	1	0.0064	0.0064
M2 Mount	Zerodur	1	0.0386	0.0386
M3	Zerodur	1	0.0024	0.0024
M3 Mount	Zerodur	1	0.012	0.012
M4	Zerodur	1	0.0015	0.0015
M4 mount	Zerodur	1	0.0058	0.0058
M3,M4 Stage	Zerodur	1	0.0375	0.0375
Int Image Aperture	Zerodur	1	0.00753	0.00753
				35.58

Further reduction in mass appears possible by light-weighting M1 mounting backplane (see next slide)

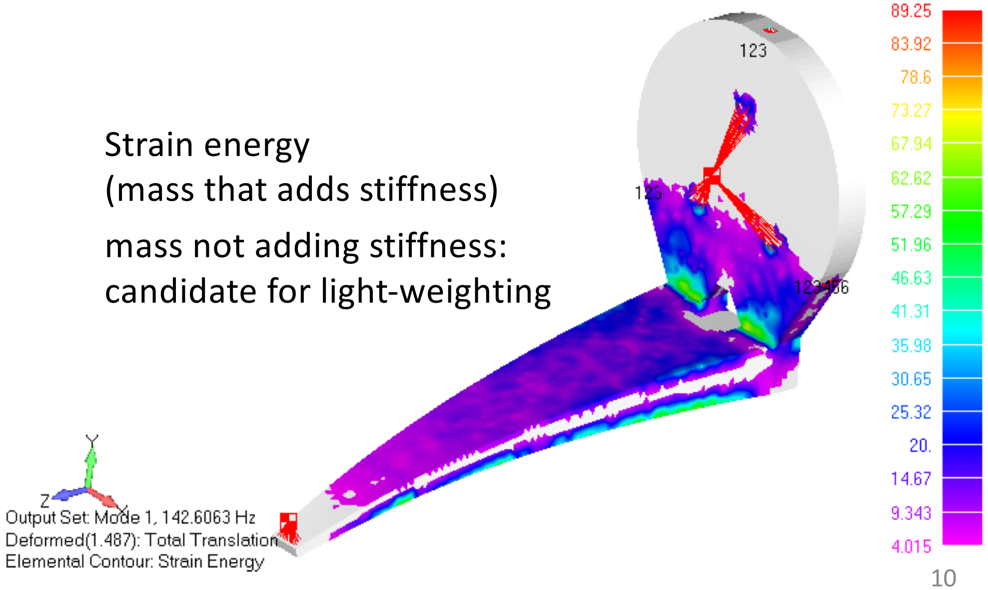


Preliminary FEM Analysis

- Single arm design
- Mass 30.3 Kg (Zerodur)
- First mode 142 Hz (diving board)
  - Goal is 100 Hz + 15% margin = 115 Hz
  - Second mode is 333 Hz
- M2 mass
  - Nominal ~.05Kg
  - 3x (account for alignment mechanism) ~.15Kg
- Output in global coordinate system
- M3/M4 mass/distortions not included
  - Fluid optical design
  - Sag should be negligible wrt to M2
  - Will update as optical design matures



Fixed at 3 points in 6 DOF
at telescope interface and
for M1 to the mount

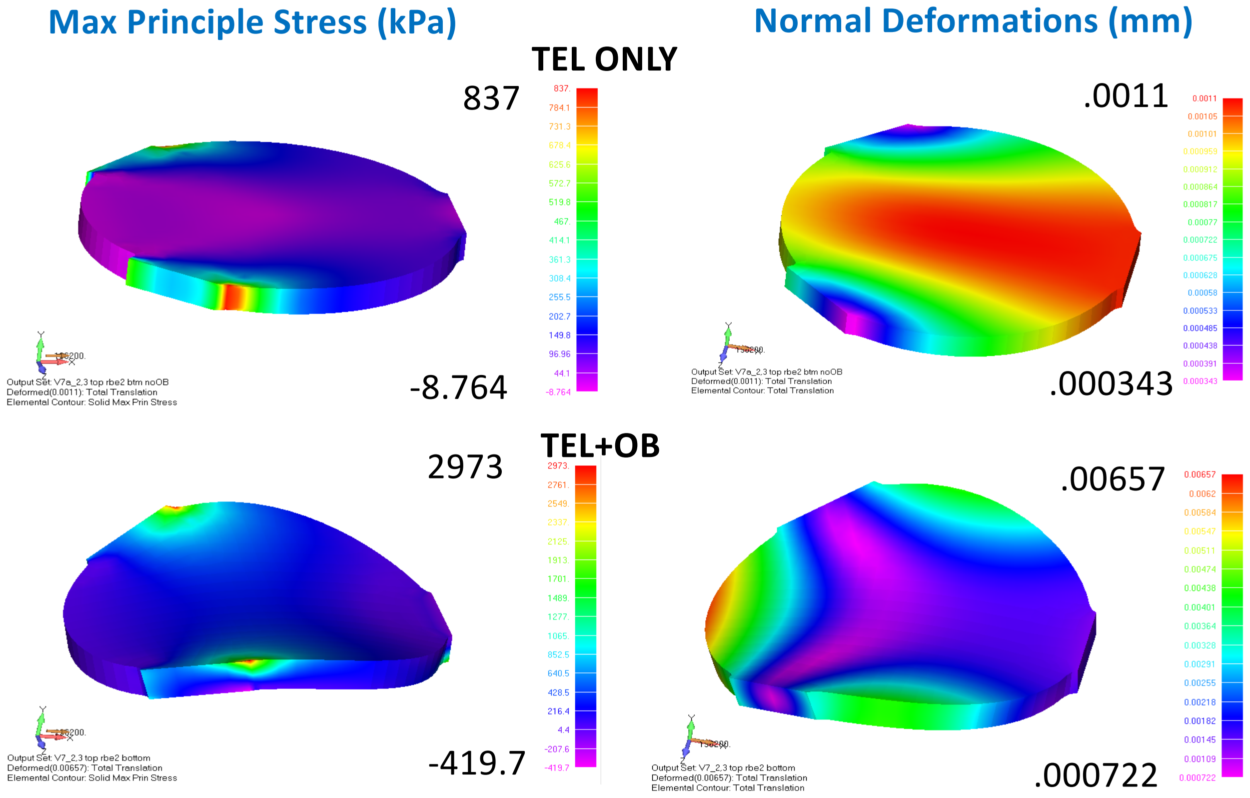


Strain energy
(mass that adds stiffness)

mass not adding stiffness:
candidate for light-weighting

Preliminary FEM Analysis

- ~3x increase in telescope plate stress due to OB. Similar trends when looking at out of plane distortions across telescope face.
- Magnitude depends on (amongst other things) stiffness at supporting structure interface. The stiffer that interface the less loads will be reacted by the telescope.



Output Set: V7a_2,3 top rbe2 btm noOB
Deformed(0.0011): Total Translation
Elemental Contour: Solid Max Prin Stress

Output Set: V7a_2,3 top rbe2 btm noOB
Deformed(0.0011): Total Translation
Elemental Contour: Total Translation

Output Set: V7_2,3 top rbe2 bottom
Deformed(0.00657): Total Translation
Elemental Contour: Solid Max Prin Stress

Output Set: V7_2,3 top rbe2 bottom
Deformed(0.00657): Total Translation
Elemental Contour: Total Translation

Summary

- Proposed design meets key requirements
  - Dimensional Stability
  - Coherent backscattered light
  - “Intrinsic” tilt-to-length coupling
  - Can accommodate dynamic stop placement during alignment
- Tertiary mirror design is a freeform optic, but with small (< 2 microns RMS) deviations from a sphere
- Alignment requirements are tight, but possible
- Mechanical design with all-glass construction meets stiffness requirements
- Tolerance and mechanical analysis is ongoing
- Next step is to procure a structural thermal model (STM) and 2 engineering development units (EDU) for testing