Solar 3D printer for Moon Base
Preliminary Design Review

Thomas Schneider

OPTI 523

Initial System Requirements

Telescope FOV: at least 32 arcminutes

Primary Mirror Diameter: 2 meters

Secondary Mirror Diameter: 0.5 meters

Mirror Reflectance: Greater than 80% from 250nm to 1000nm

Telescope F/#: 2

Mirror Materials: Zerodur or ULE

Primary Mirror Mount: Must be able to achieve 50 nm rms from surface irregularities, self-weight deflection and mound induced deflection for zenith to horizon pointing

Mirror Mount and Secondary mirror support Material: Low CTE Graphite Epoxy

Operational Position Stability: less than 1 arminute tip/tilt, and 50 µm decenter

Angle of incidence at Fiber Optic interface: 14.5 degrees

Beam Width at Fiber Optic interface: less than 350 µm

Focal plane spot size at printing surface: 50 µm

System Survival Requirements

Operational Environment

Temperature: -100C to 100C

Gravity: 1/6 Earth gravity

Survival:

Shock: 40G

Temperature: -100C to 100C

Limitations

Weight limitations: Less than 50 kg

System Changes for Feasibility and simplification

Primary Mirror: 1 meter diameter

Secondary Mirror: removed

Mirror Reflectance: 400-1000 nm

RMS error: <100 nm

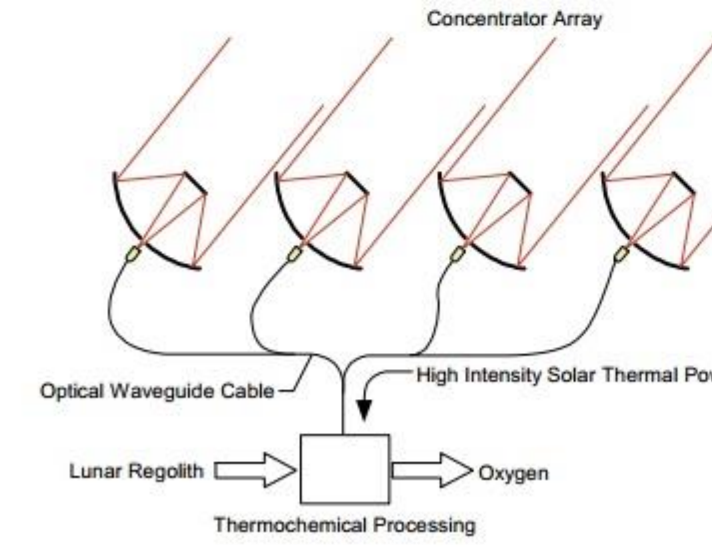
Weight Limitation: 50 kg for mirror, 100 kg for mount

Effective light collection area: 0.785 meters

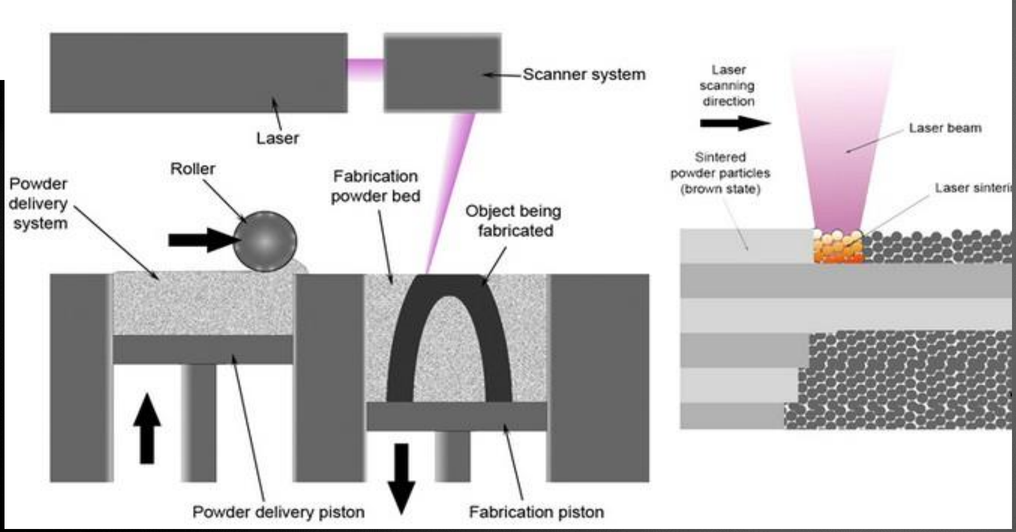
With reduction in wavelength and surface area the final throughput of the system can no longer exceed 1 kW.

This may pose a problem with melting the substrate, but can be compensated for by slowing down the feedrate for the 3D printer positioning system

Design Concept



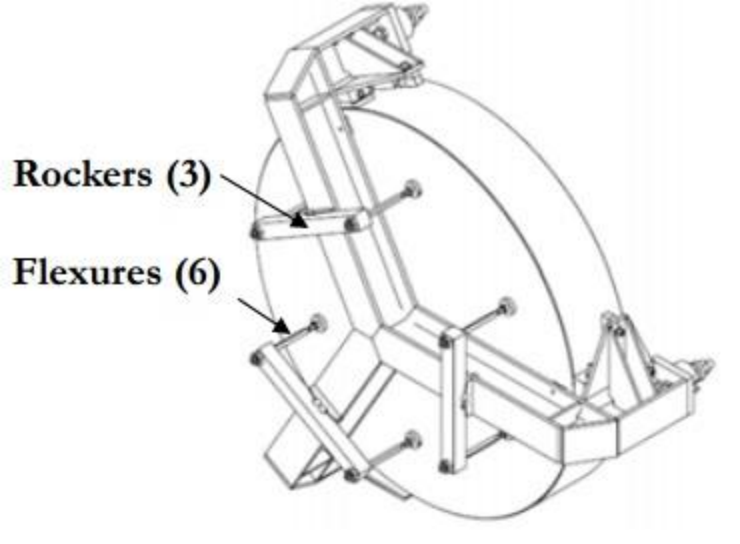
Primary mirror gathers sunlight and passes the light through a fiber optic cable to the 3D printer area, where the light is focused into a beam 50 microns wide



Design Choices – Mirror Mount

Vertical mount preference: Six point contact

- Self weight deflection calculations for a six-point mount when pointed to zenith
  - $\delta_{V\,max} = C_{SP} * \left(\frac{\rho g}{E}\right) * \frac{r^4}{h^2} * (1 - \nu^2)$
  - To achieve necessary rms limitation 2 meter mirror weight too high
  - 1 meter mirror will have rms≈30nm



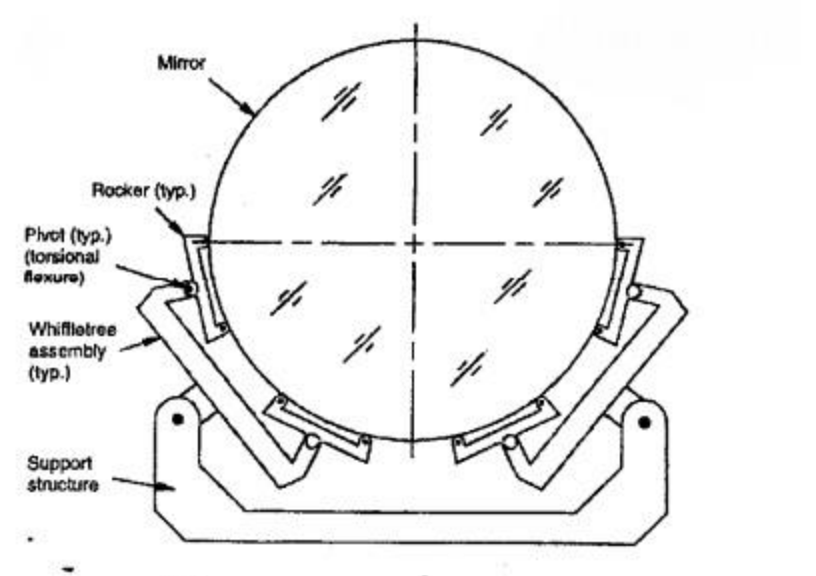
Design Choices – Mirror Mount

Horizontal Mount choice: Whiffle-tree mount

- Self-weight calculations for whiffle tree mount when pointed to horizon
  - $\delta_{H\ rms} = (a_0 + a_1\gamma + a_2\gamma^2) * \left(\frac{2\rho g}{E}\right) * r^2$
  - Required RMS could not be achieved with 2 meter mirror
  - 1 meter mirror will have rms≈33 nm

Total rms from self weight deflection will be:

$$\delta_{rms} = \sqrt{(\delta_{V\ rms} cos\theta)^2 + \delta_{H\ rms} sin\theta)^2}$$



Design Choices – Primary Mirror

Primary mirror radius of curvature of 4 m, with a conic constant of -1.005

- Eliminates the need for a secondary mirror
- Meets the requirements for fiber acceptance angle of 14.5 degree (angle at focal point is 14 degrees)
- Allows for looser tolerances on Primary mirror pointing and stability

Primary mirror with silver coating

- Helps mitigate chromatic aberrations
- Higher reflectance than aluminum from 400 nm
- Loss of reflectance below 400 nm

Design Choices – Mount Materials

For the mirror mount, a standard uni-direction carbon fiber reinforced plastic will be used.

- Low CTE of 0.57
  - For temperature variation of ±100 Celcius, ΔL will result in 0.1 mm change in lateral fiber optic location
- Strength and rigidity
  - Change in fiber location of less than 50 microns at horizon
  - Change in fiber location of less than 2 microns at zenith

Design Choices – Adhesive Bonds

Use RTV112 for binding rockers to the mirror

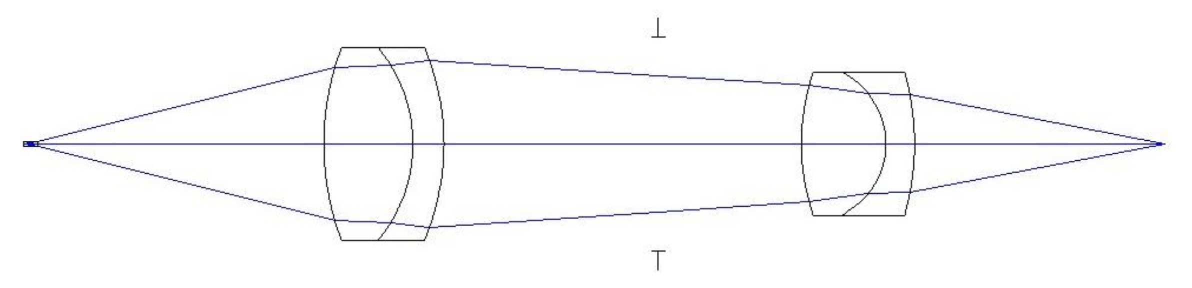
- Thickness of 100 microns
- Shear stress due to thermal expansion/contraction
  - $\tau = \frac{Ga}{2t}(\alpha_1 - \alpha_2)\Delta T = 0.87$ kPa per bond
- Stress from 40 G shock
  - $\sigma = \frac{m*40g}{A} = 0.82$ MPa per bond (below the tensile strength of 2.24 MPa, and within the safety factor)

Design Choices – Printer Lenses

Use achromatic doublets to reduce chromatic aberations

- Use BK7 and SF5 due to their ability to transmit light from 400-1000 nm
- Lenses to be supported in a barrel, placed vertically
- Can make small adjustments to final lens for focal plane fine adjustments
- Barrel made from copper due to high thermal conductivity
  - Should help mitigate heat build up in barrel

Barrel will be located in an enclosed area, so not subject to outside temperature variations



Design Choice – Lens Tolerances

Required tolerances for a 50 micron spot from Zemax

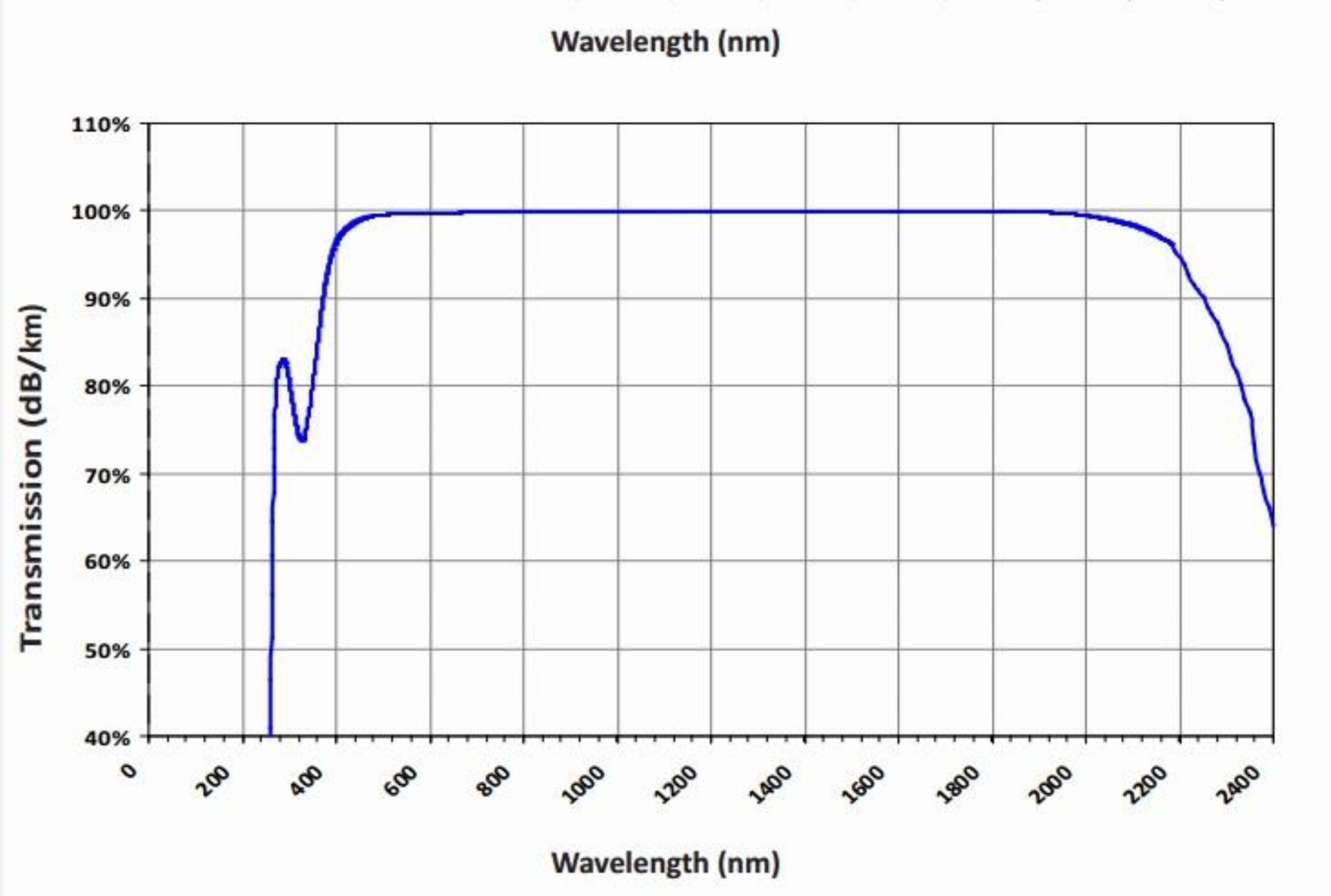
- Lens element spacings – less than 0.05 mm
- Lens element decenters – less than 0.1 mm
- Lens element tilts – less than 0.4 mm
- Individual Lens specifications
  - As long as each individual lens is made to high precision optical quality standards, then tolerances will not be an issue

Design Choices – Fiber Optic Cable

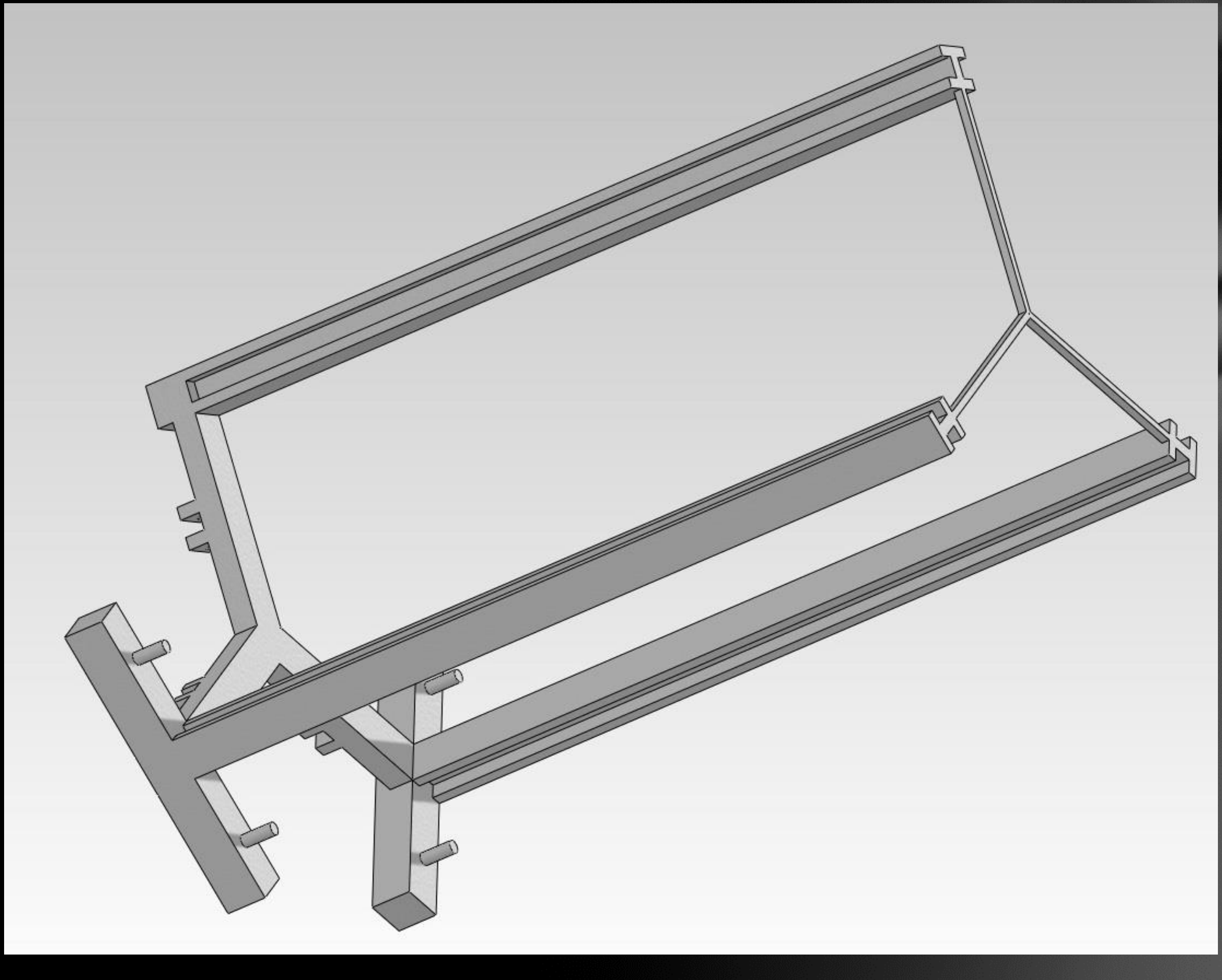
Fiber cable specifications

- Needs little to no attenuation from 400-1000 nm for a distance of 500m
- Pure fused silica core/fluorine doped silica cladding will provide optimal performance
- Gold coating will perform under required temperature variances (works from -263 to 700 C)
- Fiber with gold coatings can be procured at diameter of up to 400 microns
- Fibers with acceptance angles up to 30 degrees can be procured

Design Choices – Fiber Optic Cable



Preliminary Mount and Mirror Design



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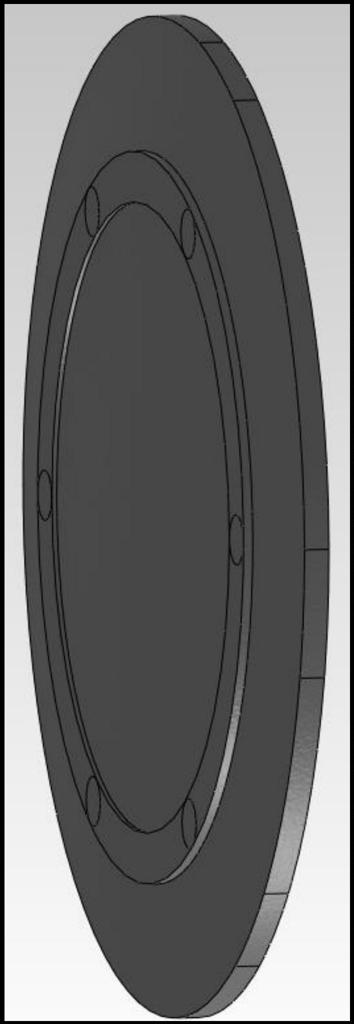

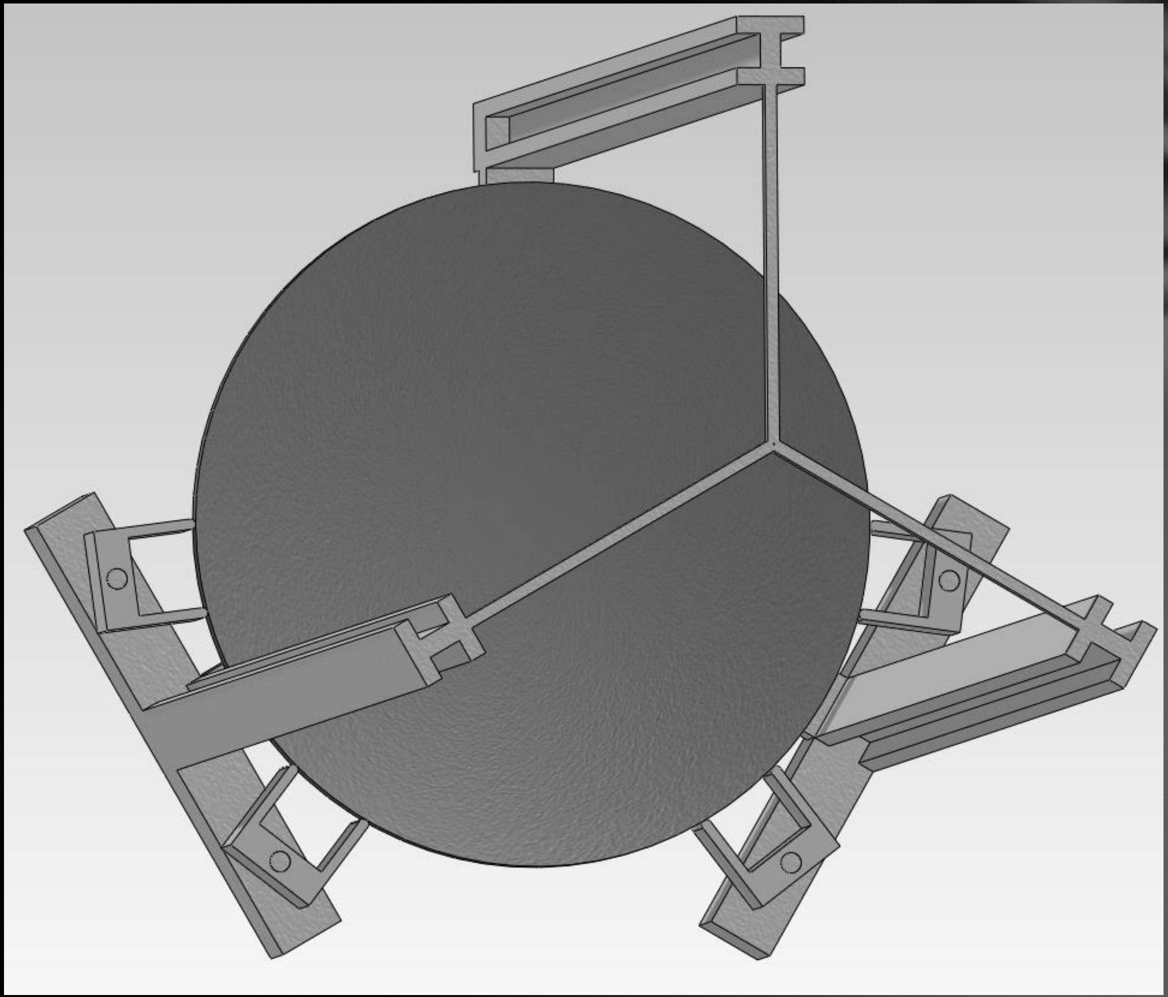

Additional Calculations

What Finite Element Analysis has shown

- Deflection of fiber location on telescope mount
  - 1.95 microns at zenith
  - 50 microns at horizon

Hand Calculations

- Deflection of fiber location on due to temperature variance
  - $\Delta L = \alpha L \Delta T = 108$ microns (Along the optical axis)
- System Throughput:
  - 93% of light between 400 and 1000 nm will get through
  - Total throughput of ~700kW

Remaining Work

Perform Finite Element Analysis of all models

Finalize Lens design (able to achieve 60 micron spot size with wavelength from 400-2000nm so far)

Finalize Lens Barrel Design

Calculate throughput of the system

Finalize mount design

Finalize Fiber interfaces, specifically material

Define manufacture and assembly procedure