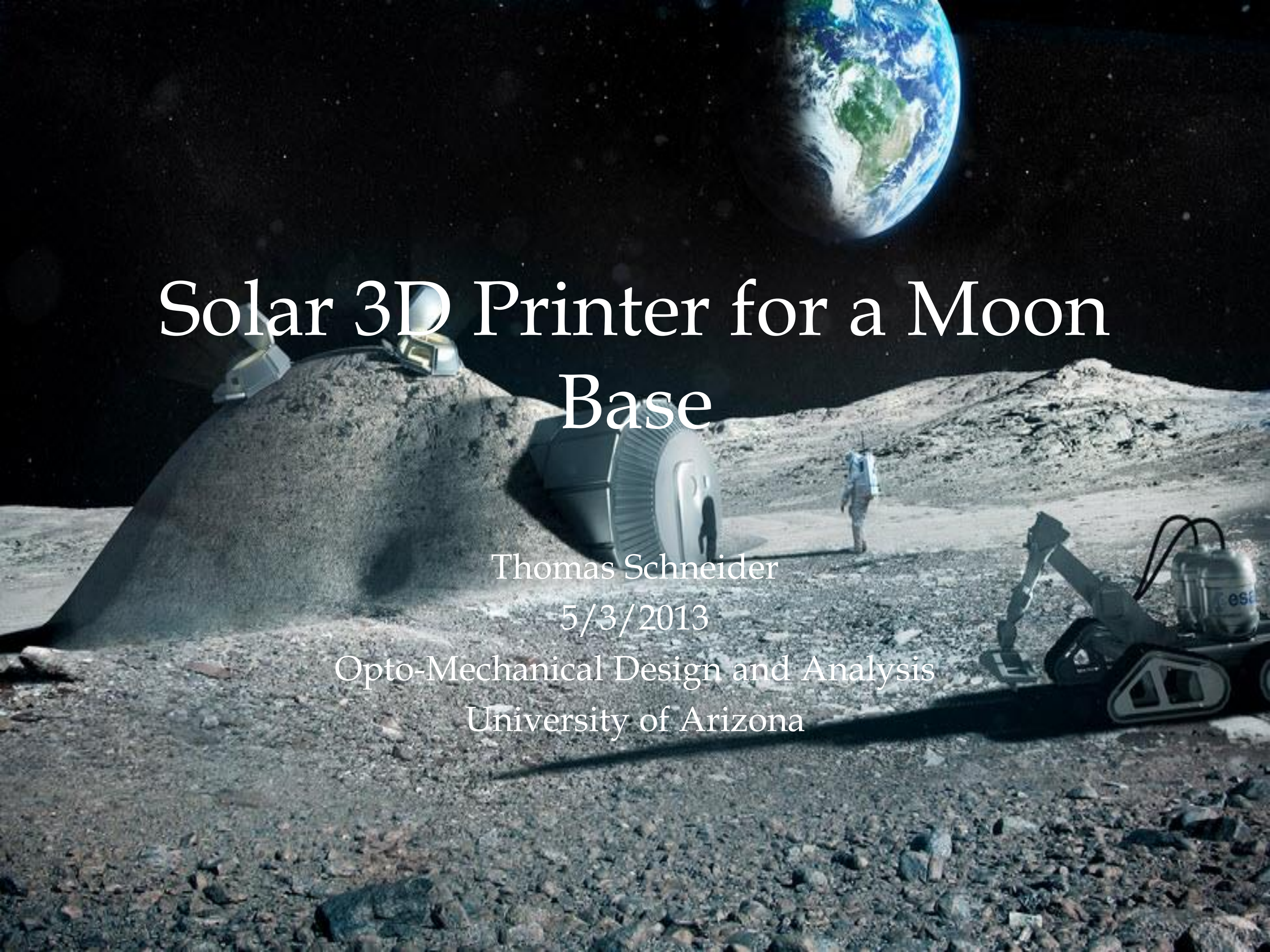

Solar 3D Printer for a Moon Base

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5/3/2013
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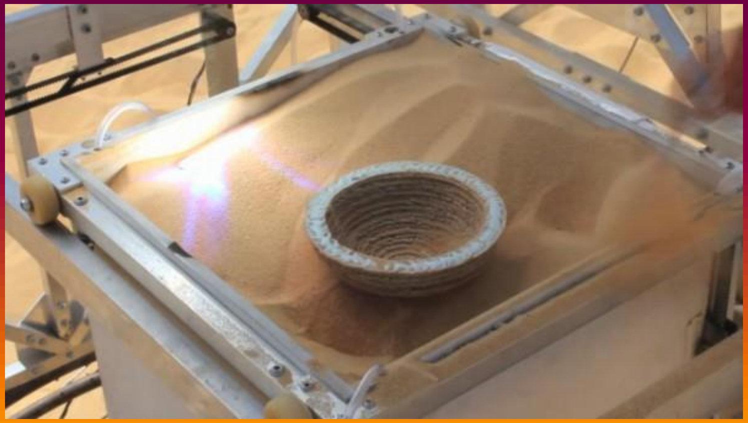
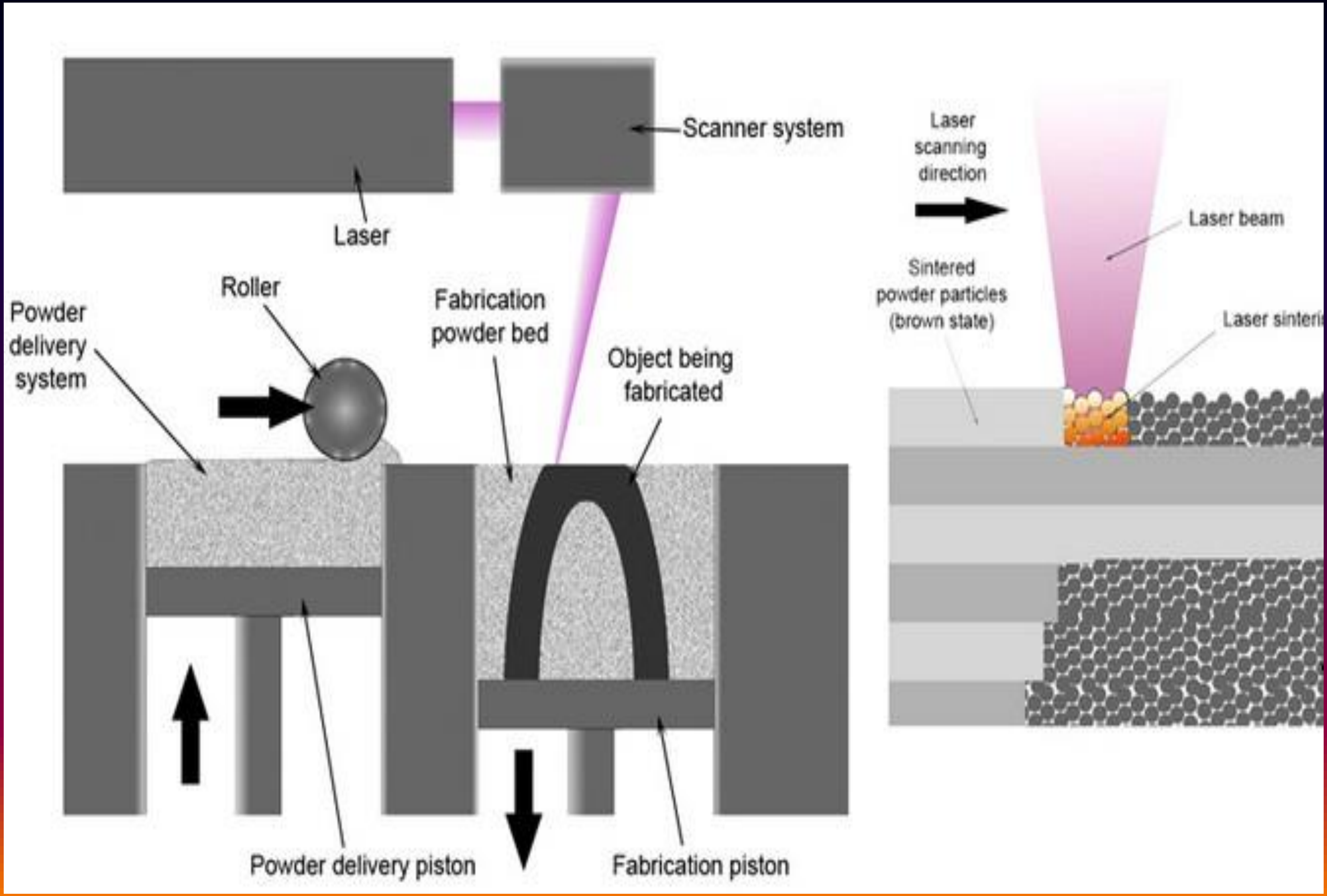
3D Printing Overview

- Focus lasers on a substrate
- Build object one layer at a time
- Most use synthetic polymers
- Art project able to build objects with Fresnel Lens and sand

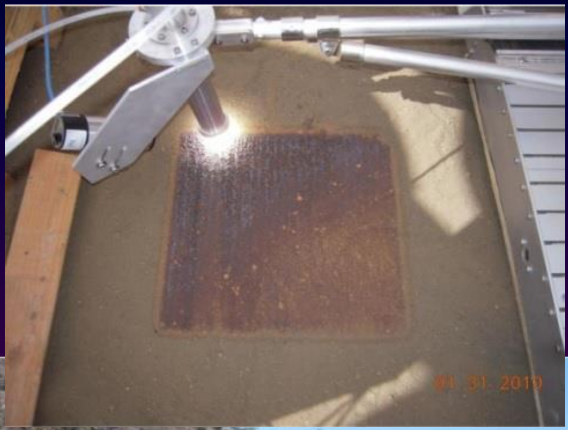



Scanner system
Laser
Roller
Powder delivery system
Fabrication powder bed
Object being fabricated
Powder delivery piston
Fabrication piston
Laser scanning direction
Laser beam
Sintered powder particles (brown state)
Laser sinteri

Solar Sintering

- Developed by Takashi Nakamura and tested on Mauna Kea at second PISCES field test
- Able to sinter lunar simulant at 1100 degrees Celsius
- Use fiber optics to guide collected solar energy
- Able to achieve average output of 657 W (32 percent efficient
- Array weighed 1400 pounds

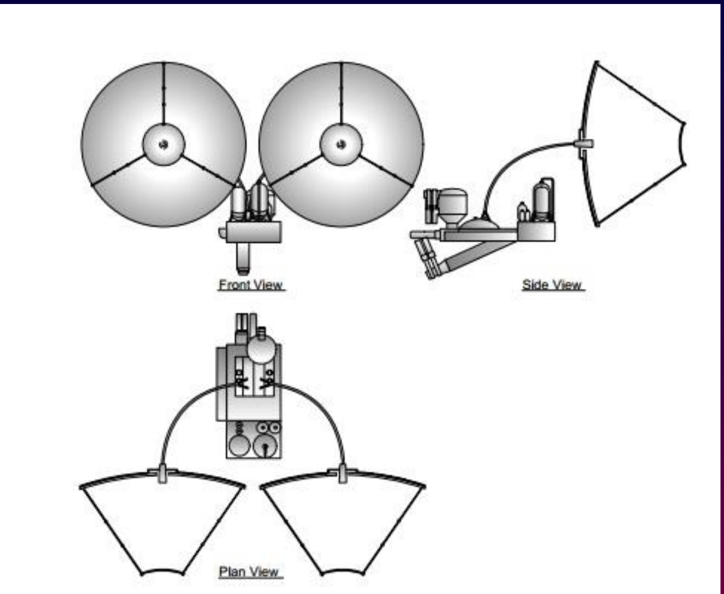
Solar Sintering



A Solar 3D printer for the Moon

- Important for establishing permanent Lunar settlement
- 3D solar printer can make precision objects without transportation costs
- Uses in-situ resources found on the Lunar surface

Requirements from for PILOT concept



- 2 - 2 meter Primary and 0.5 meter Secondary mirror in Cassegrain configuration
- 169 – 2 mm diameter fused silica cores
- Fiber Acceptance Angle – 14.5 degrees
- Overall Reflectivity – 95 percent
- Total Focused Power – 7.272 kW
- Total System Weight – 34.16 kg

Requirements for Project

- Primary Mirror Diameter - 1 meters
- Telescope f/# - f/2
- Mirror Reflectance - Greater than 95% from 400nm to 1000nm
- Mirror Materials: ULE
- Primary Mirror Mount: Must be able to achieve 100 nm rms from surface irregularities, self-weight deflection and mound induced deflection
- Mirror Mount and fiber 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

Project Operational and Survival Requirements

Operational Environment

- Temperature: -100C to 100C
- Gravity: 1/6 Earth gravity

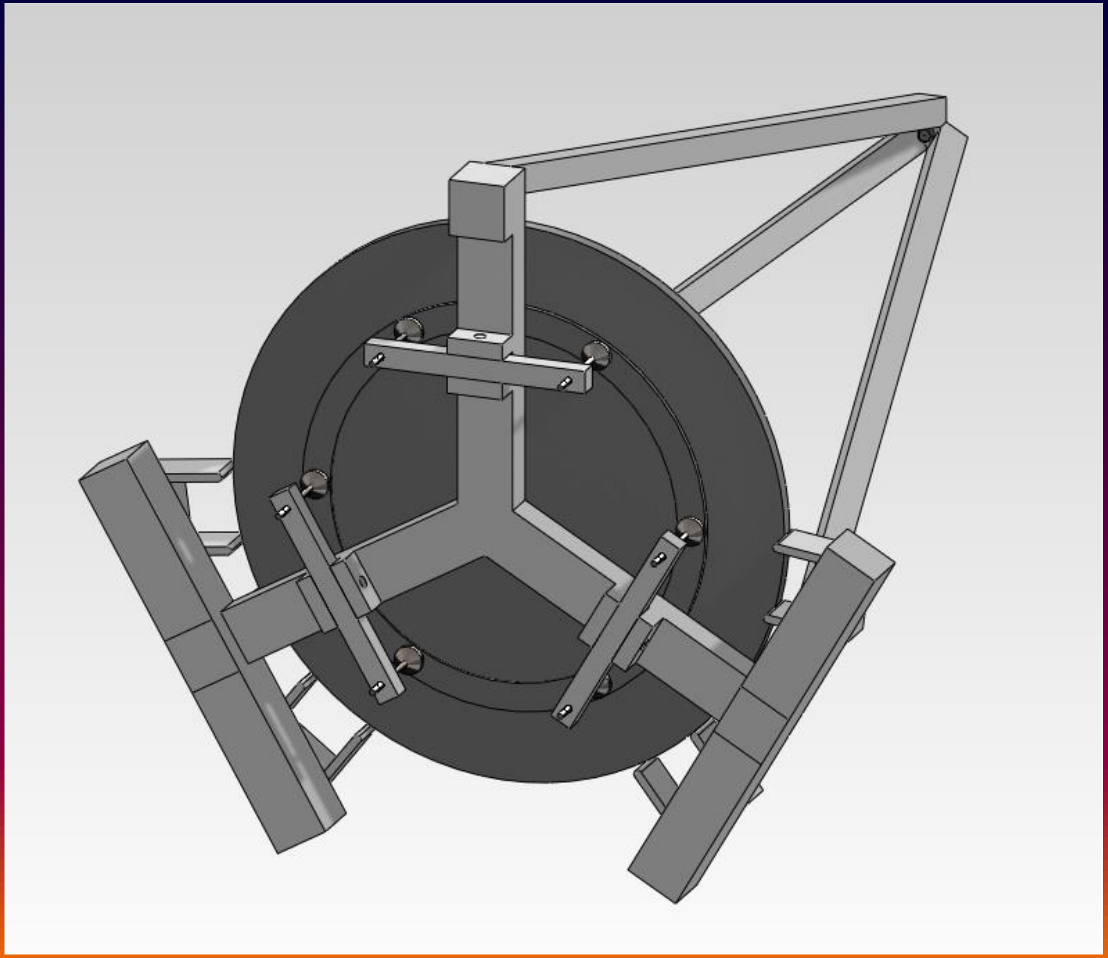
Survival:

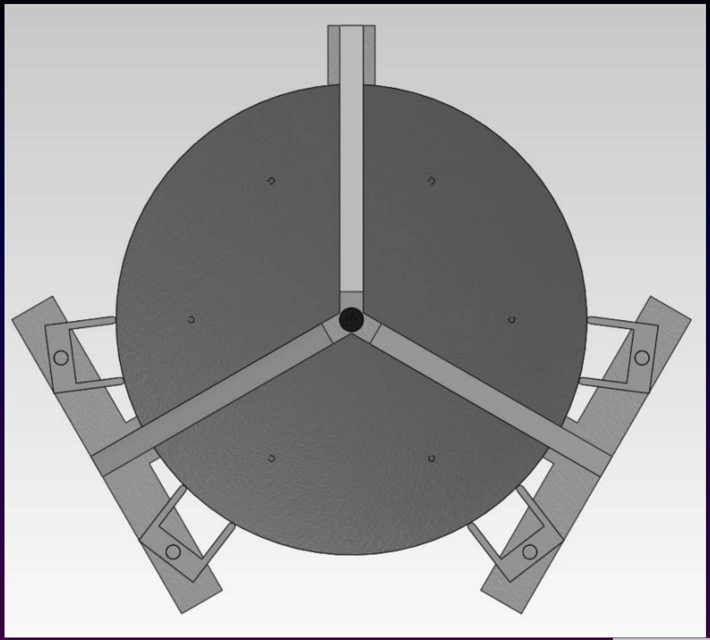
- Shock: 40G
- Temperature: -100C to 100C

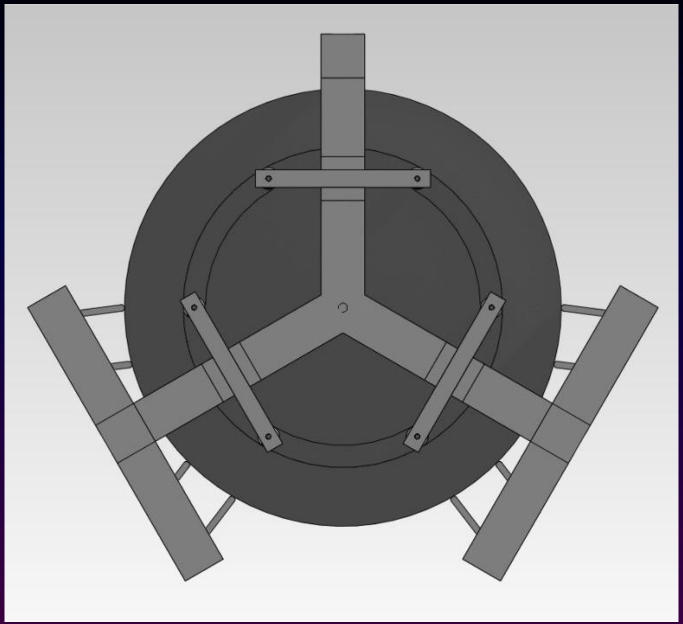
Limitations

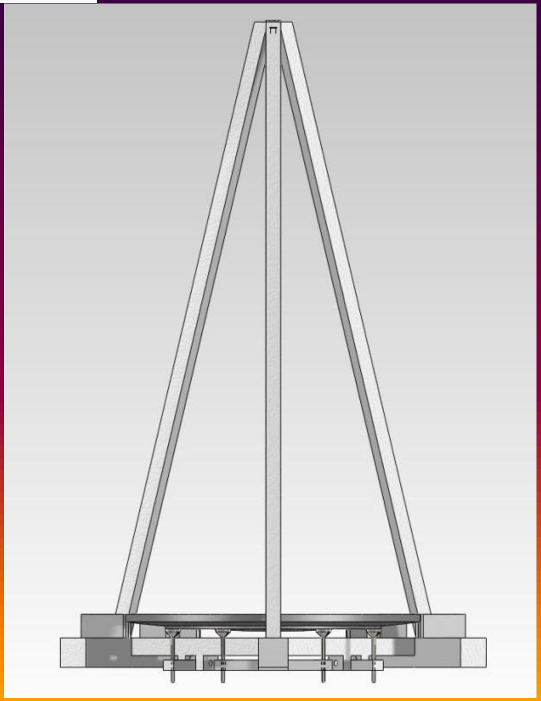
- Weight limitations: Less than 150 kg

System Design

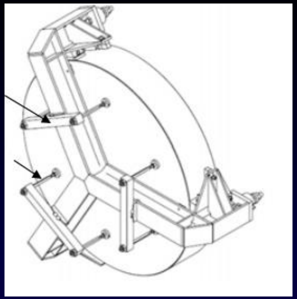






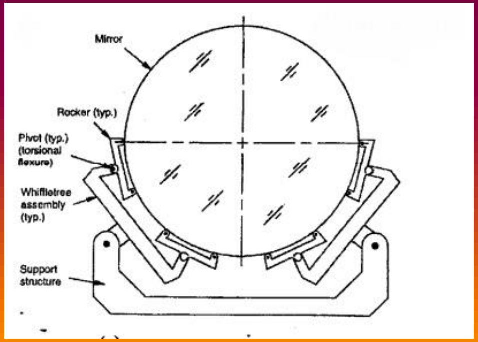


Total System Mass: 122 kg



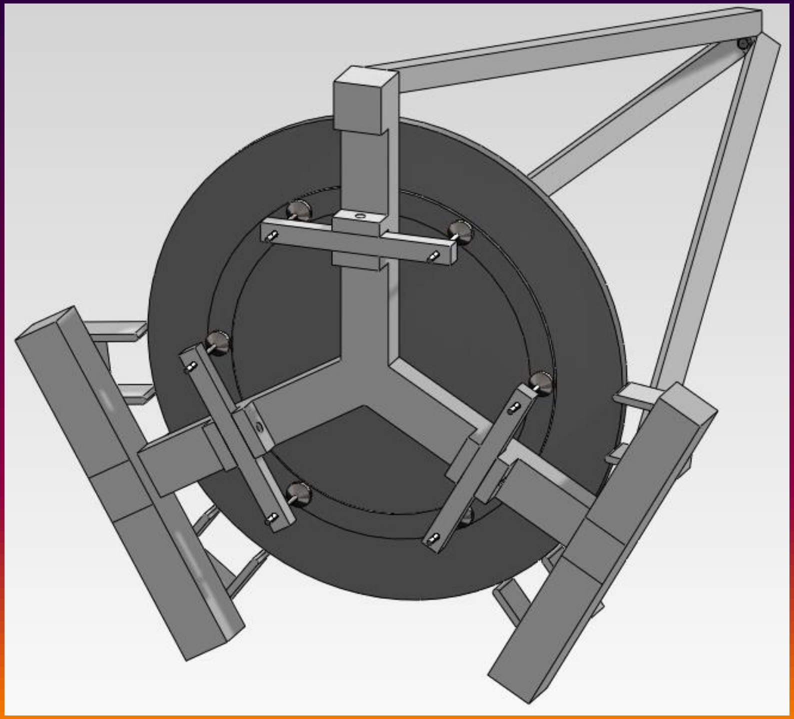
System Design

- Use a six point mirror mount to support mirror back
- Use a four point whiffle tree mirror mount to support mirror at horizon
- Mirror design
  - Hyperbolic Primary with conic constant of -1.005
  - Curved back to reduce weight
  - 1 meter diameter, 25.4 mm thick ULE
  - 4 meter Radius of Curvature
  - Silver Coating
  - Mirror Mass – 45 kg



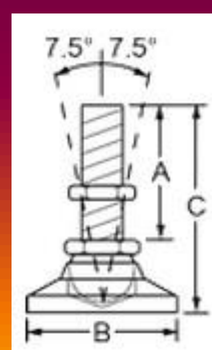
System Design

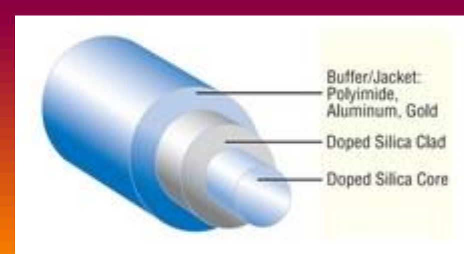
- Unidirectional low CTE CFRP (CTE of 0.57 ppm/K) for all parts except swivel leveling mounts
- Zenith Mirror Supports
  - Height – 60 mm
  - Width – 100 mm
  - Length – 631.43 mm
  - Spaced at 120 degrees
- Fiber support rods
  - Height and Width – 50 mm
  - Length – 2144.38 mm
- Horizon Mirror Supports
  - Height – 100 mm
  - Width – 100 mm
  - Length – 721.69 mm
- Mass
  - Mount – 67 kg
  - Back Rocker - 3.87 kg
  - Base Rockers – 4.8 kg
  - Swivel Leveling Mounts – 1.38 kg

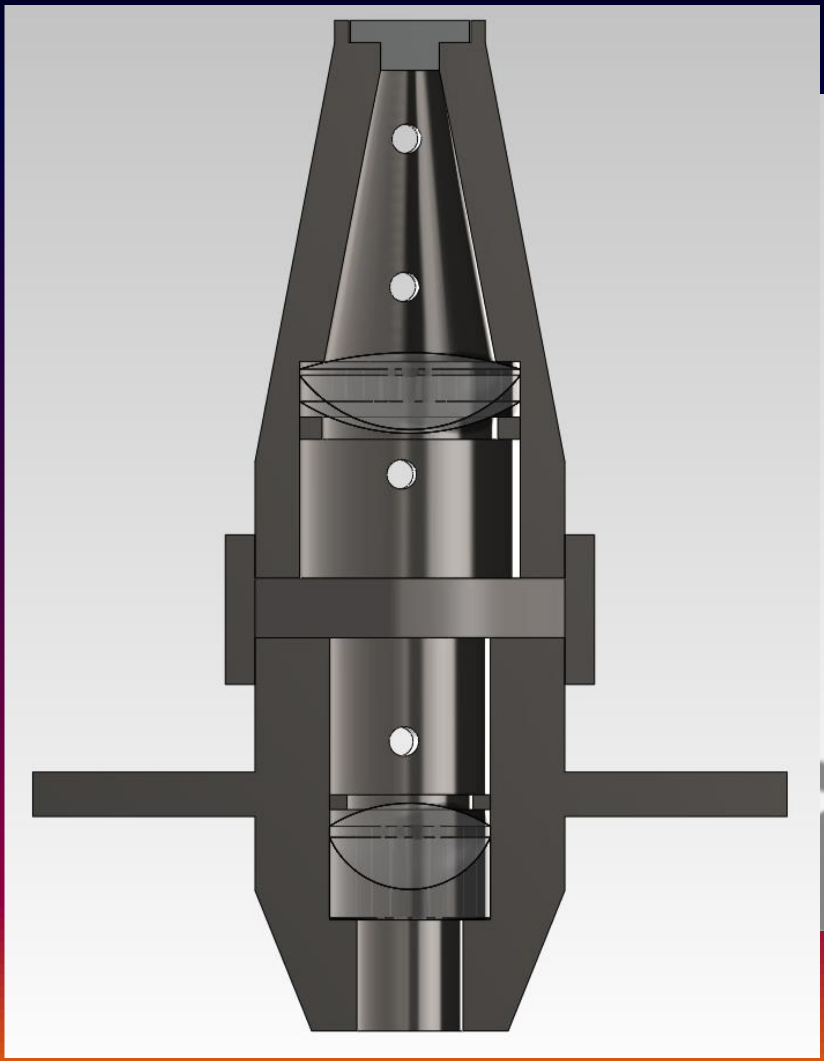
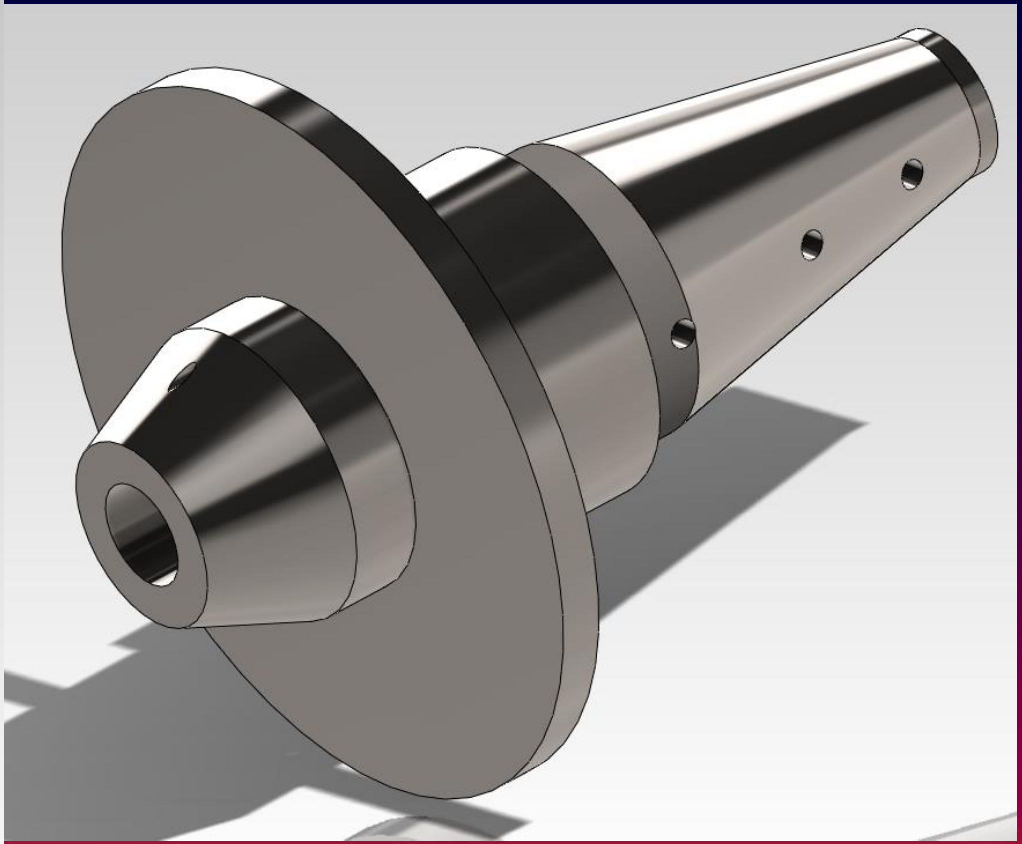


System Design

- Titanium swivel leveling mounts
- Fiber material – Fused pure silica with a fluorine doped silica cladding
  - 400 micron diameter fiber with gold coating
- RTV 112 adhesive for bonding swivel leveling mounts to mirror
- Bond diameter of 50 mm and thickness of 0.5 mm
- Fiber interface – 25 mm diameter, through top of supports, made from Beryllium
- Fiber material – Fused pure silica with a fluorine doped silica cladding





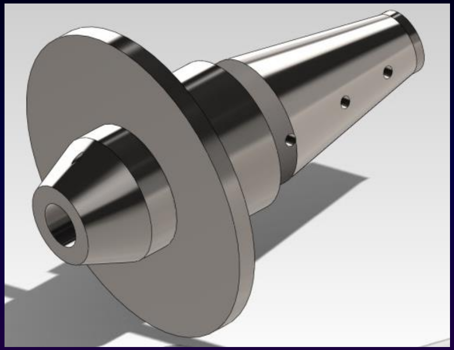



System Design

- Printing Lens Specifications

Specifications					
Lens	**Material**	**ROC1**	**ROC2**	**CT**	**Diameter**
1A	BK7	25.488	-9.447	5.246	7.5
1B	SF5	-9.447	-14.009	0.235	7.5
2A	BK7	10.307	-6.024	5.92	5.5
2B	SF%	-6.024	-104.627	2	5.5
Tolerances					
Lens	**Tip/Til**	**Decenter**			
Lens 1	0.4	0.5			
Lens 2	0.4	0.1			

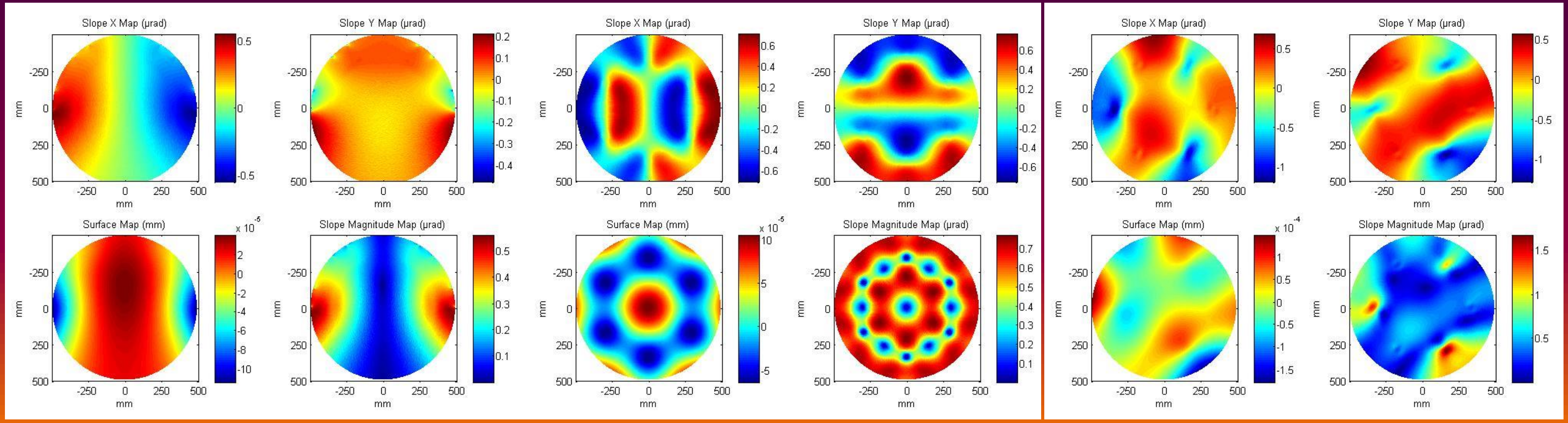
System Design



- Printing Lens Barrel
  - Material Titanium Ti-8Mn annealed
  - Fiber retainer made from Beryllium
  - Vents along the side for heat dissipation
  - Can be produced on a metal lathe
  - Adjustment Ring for focus adjustment
  - Stability rod maintains lens orientation during adjustment
  - Vent holes along the side for temperature stabilization
  - Barrel and Lens Mass - .085 kg

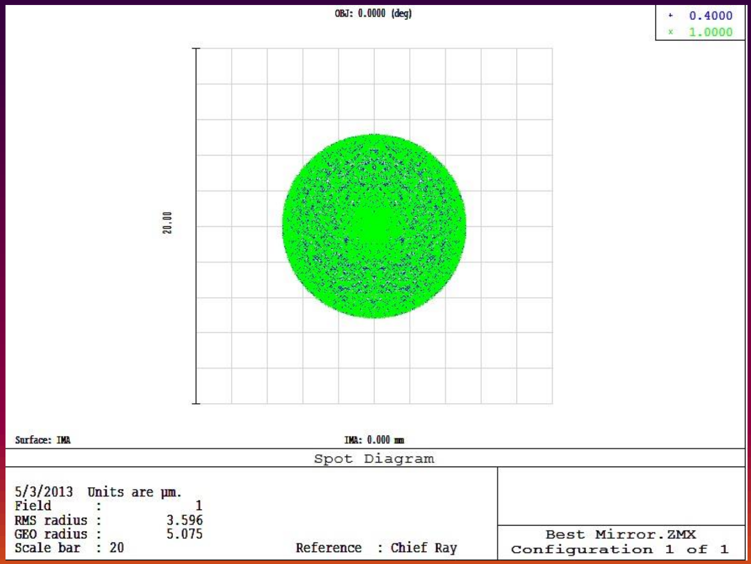
System Performance - Mirror

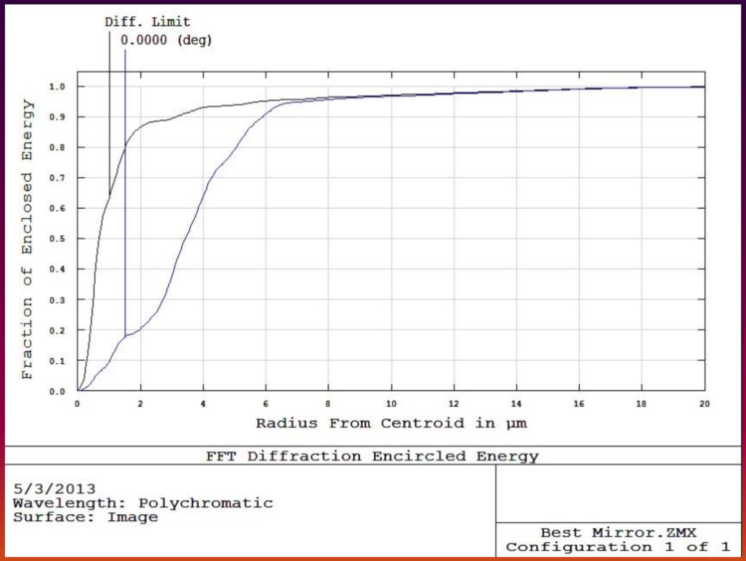
	RMS Contribution
Manufacturing Surface Error	20 nm
Self-weight Deflection at Zenith	37.9 nm
Self-weight Deflection at Horizon	26.5 nm
Thermal Deflection	64 nm
Mount Induced Deflection	57 nm
RSS	99.42 nm



System Performance - Mirror

- Nominal spot size at focal point – 10 microns
- Encircled Energy > 90 % at 6 micron radius
- Beam Angle – 14 degrees





System Performance – Mount Induced Deflection at Fiber interface

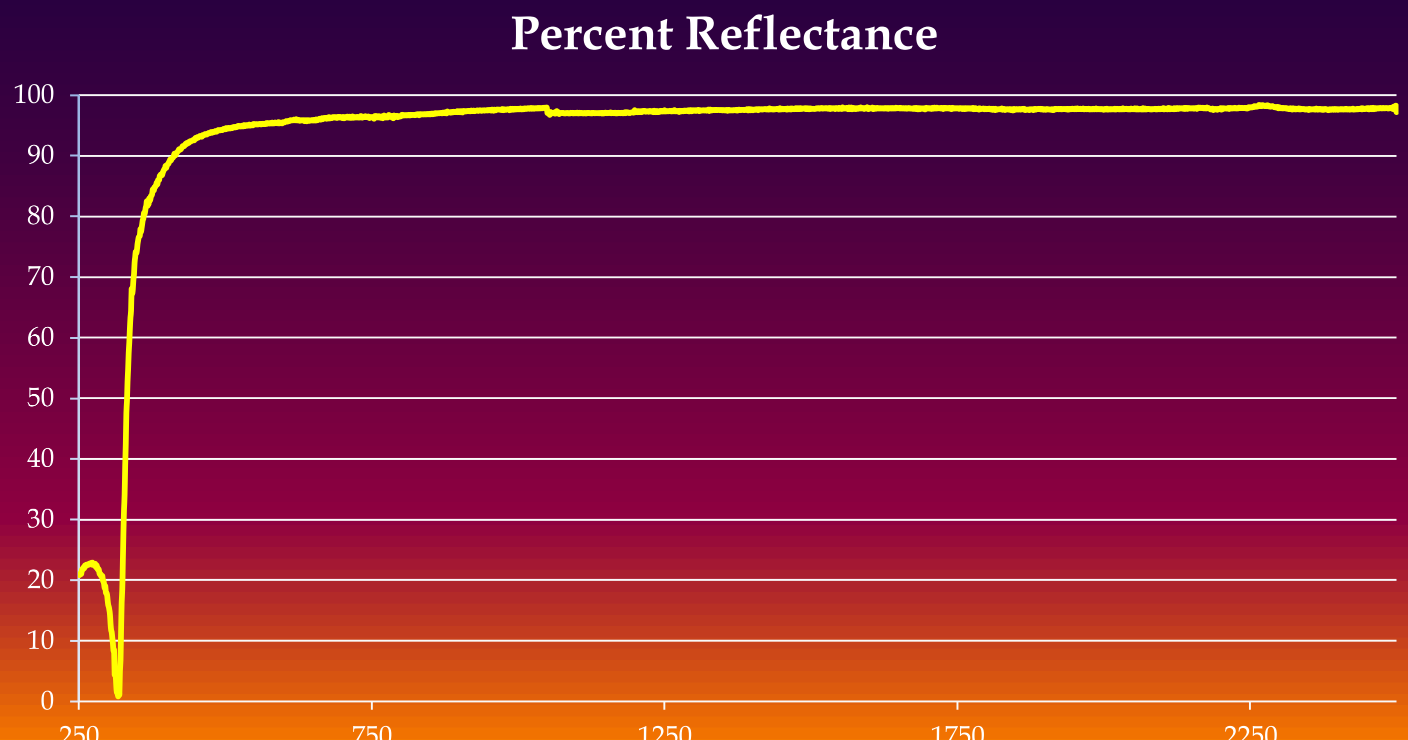
Type of Deflection	Deflection RSS	
Mount at Zenith	9.63E-06	mm
Mount at Horizon	0.0149	mm
Telescope weight at Horizon	0.00149	mm
Telescope weight at Zenith	0.000746	mm
Rocker Deflection	0.00135	mm
Horizontal Rocker	0.00169	mm
Thermal Deflection (Along Optical Axis)	0.111	mm
RSS - Decenter Deflection	0.0151	mm
RSS - Total Deflection of focal point	0.112	mm

Deflection along the focal plane is 111 microns, well within tolerances for the beam acceptance

Able to maintain 1 arcminute tip/tilt and 50micron decenter

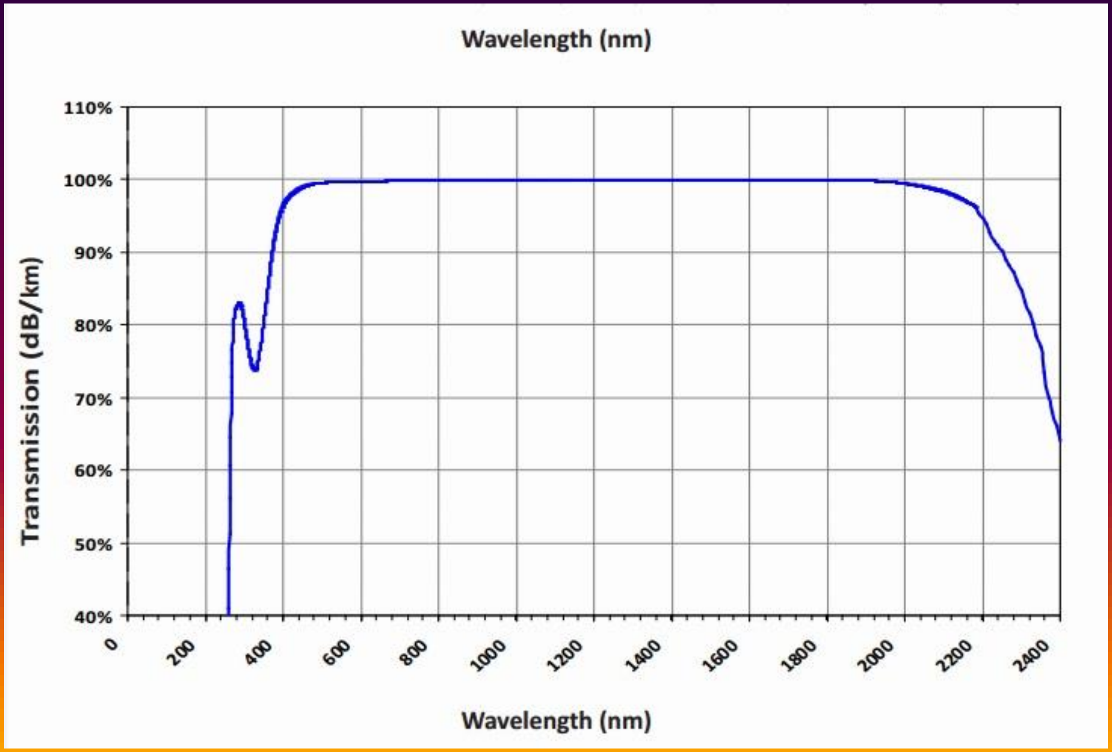
System Performance - Transmission

- Using a silver coating performance between 400-1000 nm is optimal



System Performance – Fiber Transmission

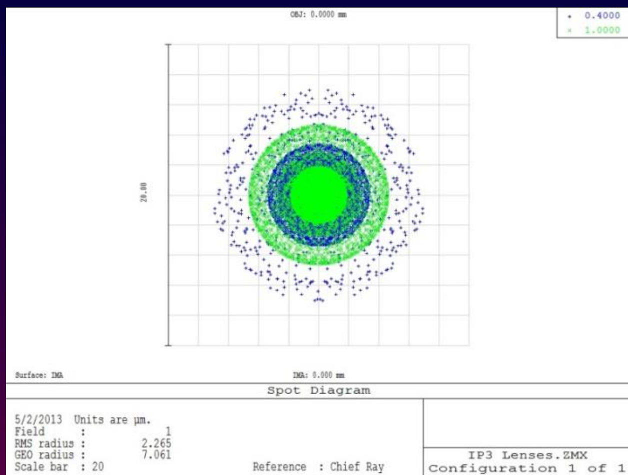
- Using a pure fused silica core/fluorine doped silica cladding will provide good performance

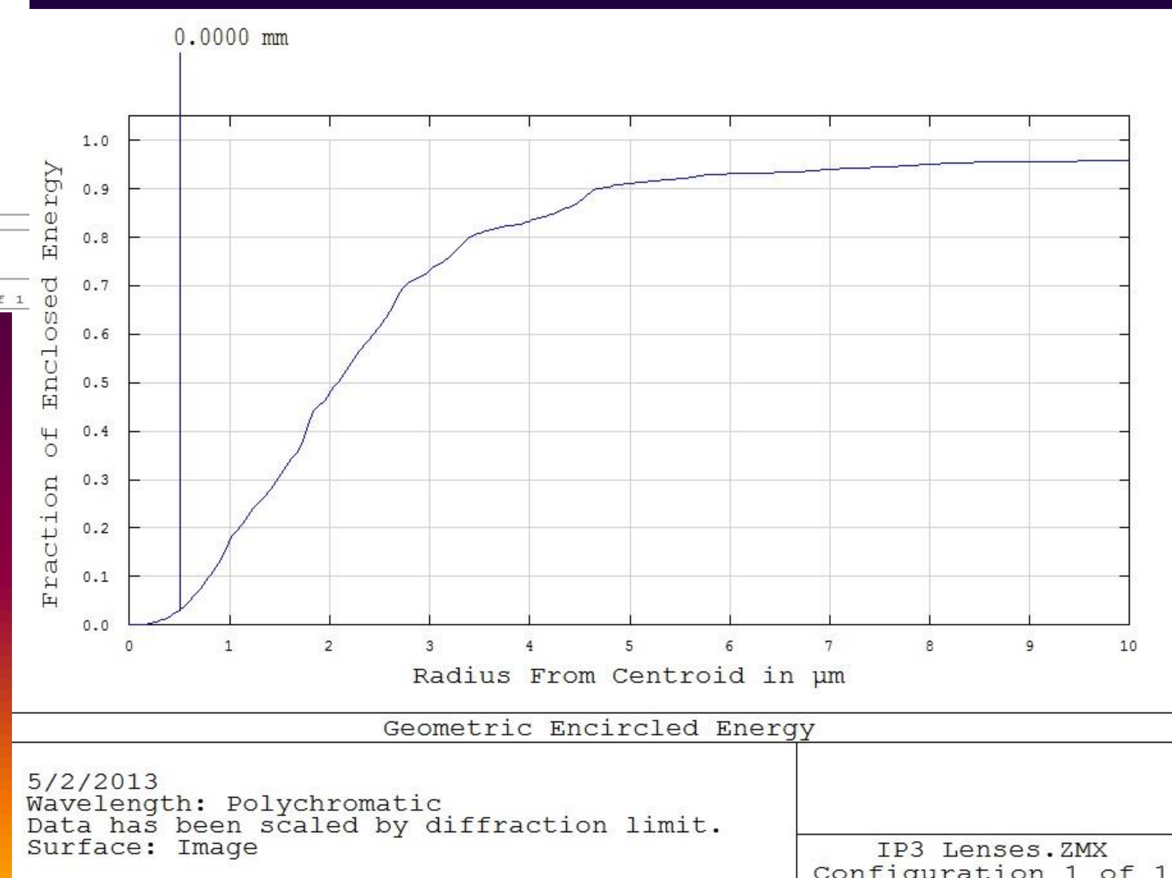


System Performance - Lenses

- Achromatic doublet lenses able to maintain spot size below 50 microns
- Broad Band AR coating provides average transmission > 99.5% from 400-1000 nm per surface
- Nominal Spot Size < 15 microns
- Encircled energy > 95% within 10 micron radius
- Lens tolerances are not too strict
  - Precision manufacturing tolerances
  - Element decenter an tilt tolerances greater than 0.05mm

System Performance – Focal Plane





System Performance – Total transmission

Surface	Power
After Mirror	612.60 W
Entering Fiber	609.54 W
Exiting Fiber	597.35 W
Lens 1 Surface 1	594.36 W
Lens 1 Surface 2	591.39 W
Lens 2 Surface 1	588.43 W
Lens 2 Surface 2	585.49 W
Image Plane	585.49 W

System Performance - Survivability

- Stress of 250 kpa per bond under 40G shock is within the bond strength of 2.24 Mpa
- Applying preload force of 1.27 N on lens 1 and 1 N on lens 2 ensures survival from 40 G shock
- Temperature requirements are met for Mirror and mount through materials
- Lenses and lens barrel will be located inside an enclosure, so temperatures will not fluctuate
- Gold coated fiber optic able survive temperatures from -269 to 700 degrees Celsius
- Fiber interfaces made from Beryllium, for low CTE and high thermal conductivity

Materials and Cost

- Carbon Fiber – up to 250 $ per pound
  - Mount Weight 75 kg
  - Cost of material 41250 dollars plus cost of manufacture
- Swivel Leveling Mounts
  - Custom made from titanium
  - Cost of material ~100 dollars plus manufacture cost
- Corning ULE
  - No price disclosed
  - Mirror will probably be the most costly aspect
- Achromatic Lenses
  - Price quote would be needed from optical design companies
- Fiber
  - Price quote needed for 500m of Gold coated fiber
- Manufacturing will be the most costly aspect (except maybe transport)

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Thanks for Attending the Presentation

Any Questions?