Shared Aperture Diffractive Optical Elements (ShADOE) Lidar System Development

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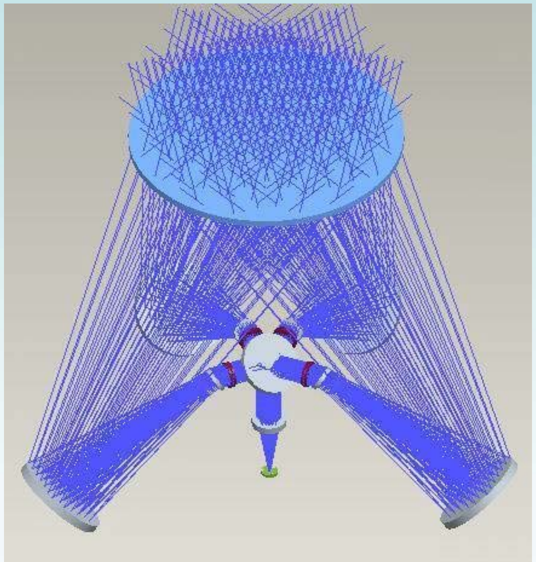


Outline

- Background & Objectives
- Optical Design
- Mechanical Design
- Optical Performance
- Tolerance to Space Radiation
- Hybrid design
- Summary

Wind Mission Requirements

	Study Baseline	Units
Vertical depth of regard (DOR)	0-24	km
Vertical resolution: Tropopause to top of DOR (18-24) Top of BL to tropopause (2-18) Surface to top of BL (0-2)	 3 2 0.5	 km
Vertical Sampling (max)	0.25	km
Number of LOS wind measurement perspectives for horiz wind[A] calculation	2=pair	-
Allowed angular separation of LOS wind pair, projected to a horizontal plane	30-150	Degree
Maximum allowed horizontal separation of LOS wind pair	50	km
Along track repeat distance	350	km
Along track integration per LOS (max)	80	km
Along track sampling (max)	10	km
Number of horizontal wind tracks	2	-
Velocity error Tropopause to top of DOR (18-24) Top of BL to tropopause (2-18) Surface to top of BL (0-2)	 4 3 2	 m/s
Minimum wind measurement success rate	TBD. Define for cloud free	%
Data product latency	1.33 ; 2.75	Hours
Vertical location accuracy of LOS wind measurements	0.2	km
Horizontal location accuracy of LOS wind measurements	10	km
Maximum design horizontal wind speed: Above BL Within BL	 100 50	 m/s

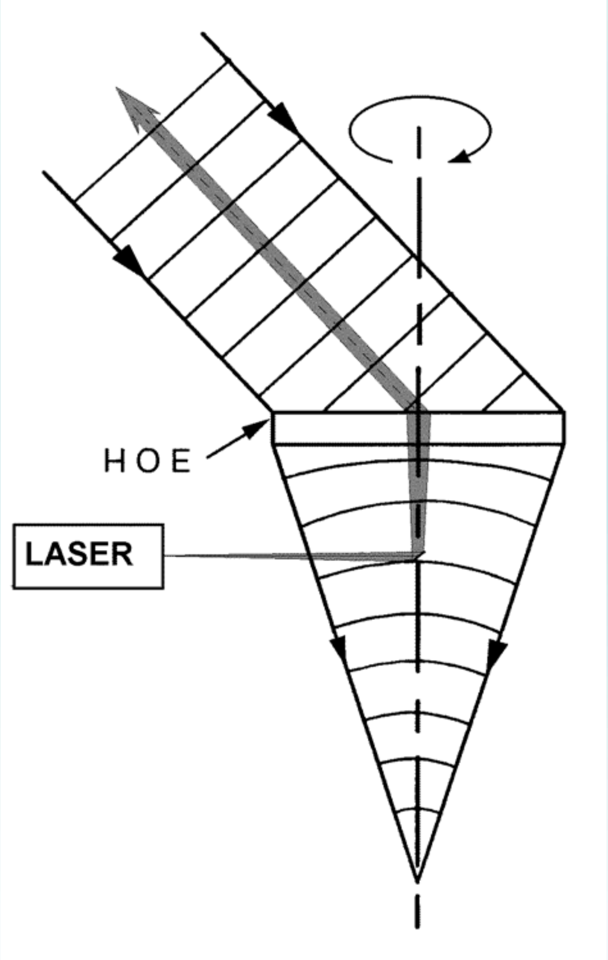
Scanning requirements: Fore/Aft views to target sample volume provide horizontal wind information x 2 tracks = 4 FOVs

Competing Technologies (prior art)

- Conventional telescope w/ rotating mount
- Multiple telescopes
- Scanning flat mirror
- Rotating wedge prism
- Rotating Fresnel prism
- Rotating HOE
- Multiplexed HOE / SHADOE

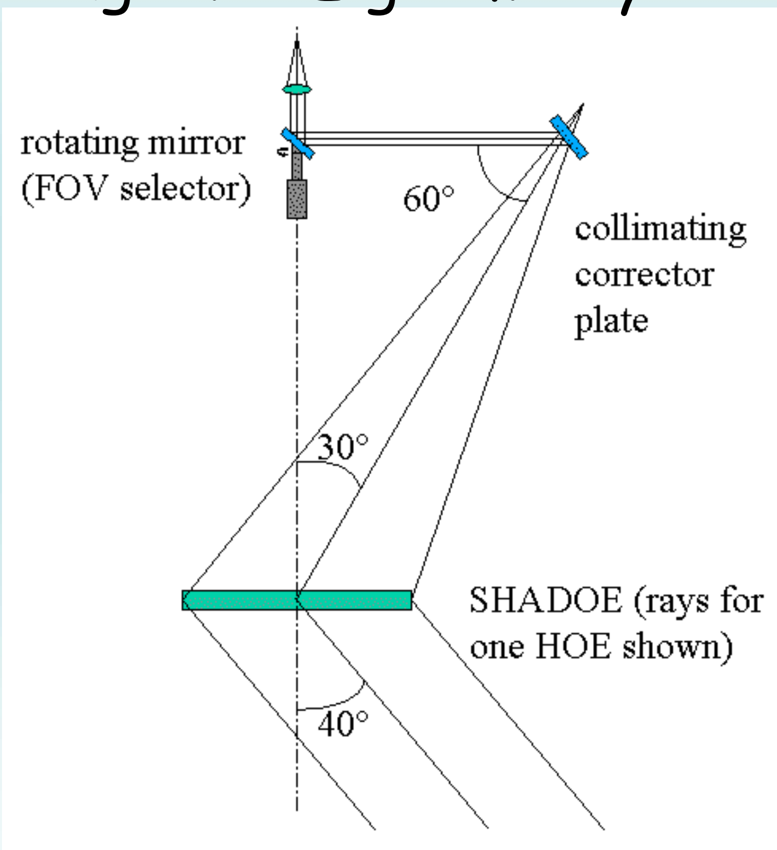
Holographic Optical Element Scanning Telescope

Holographic Airborne Rotating Lidar Instrument Experiment (HARLIE)

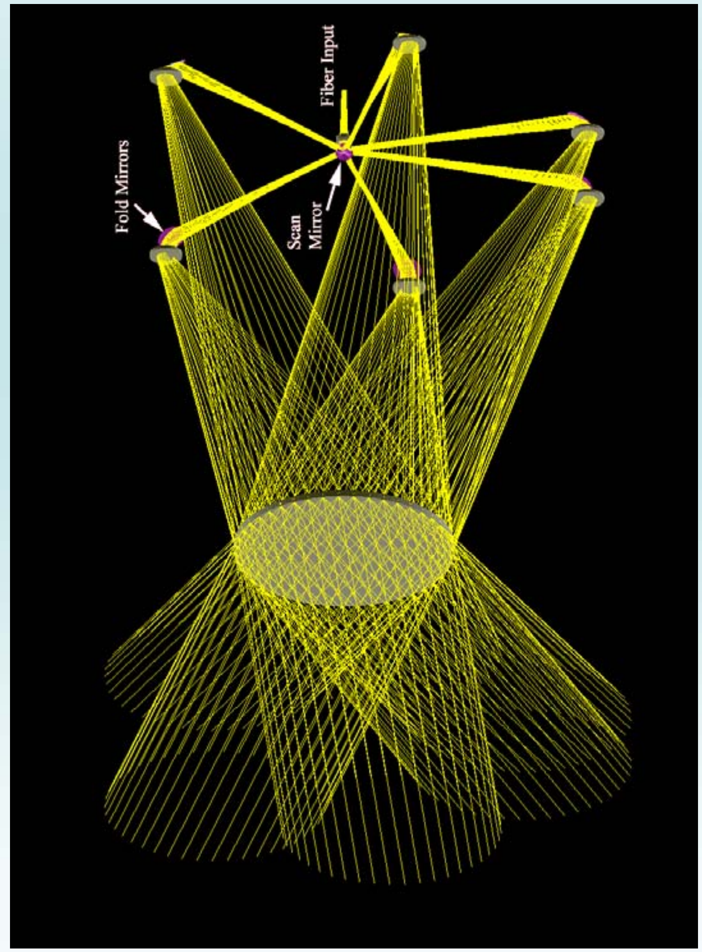


Angle multiplexed HOEs

Single HOE geometry



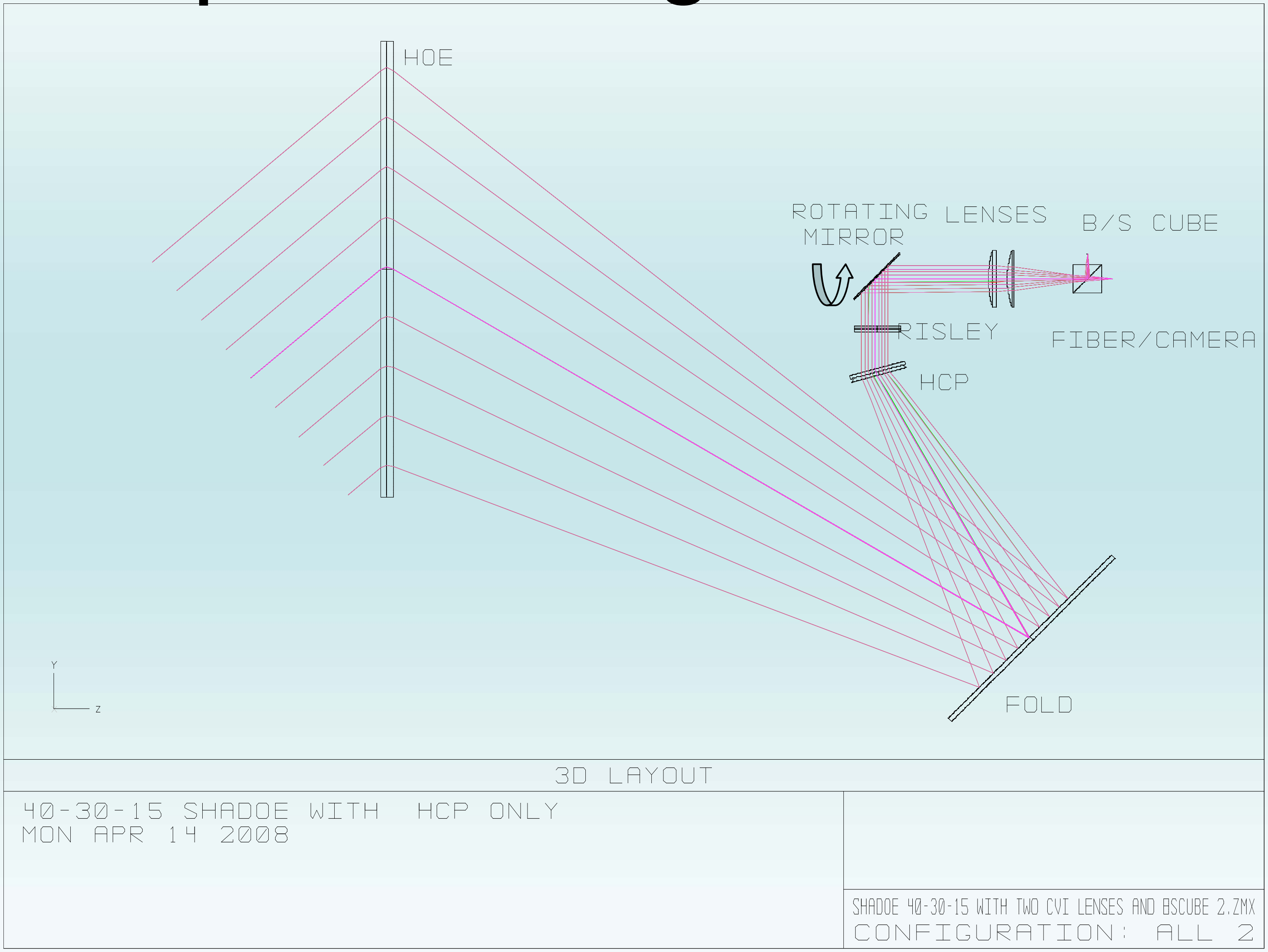
6 HOE exposure geometry



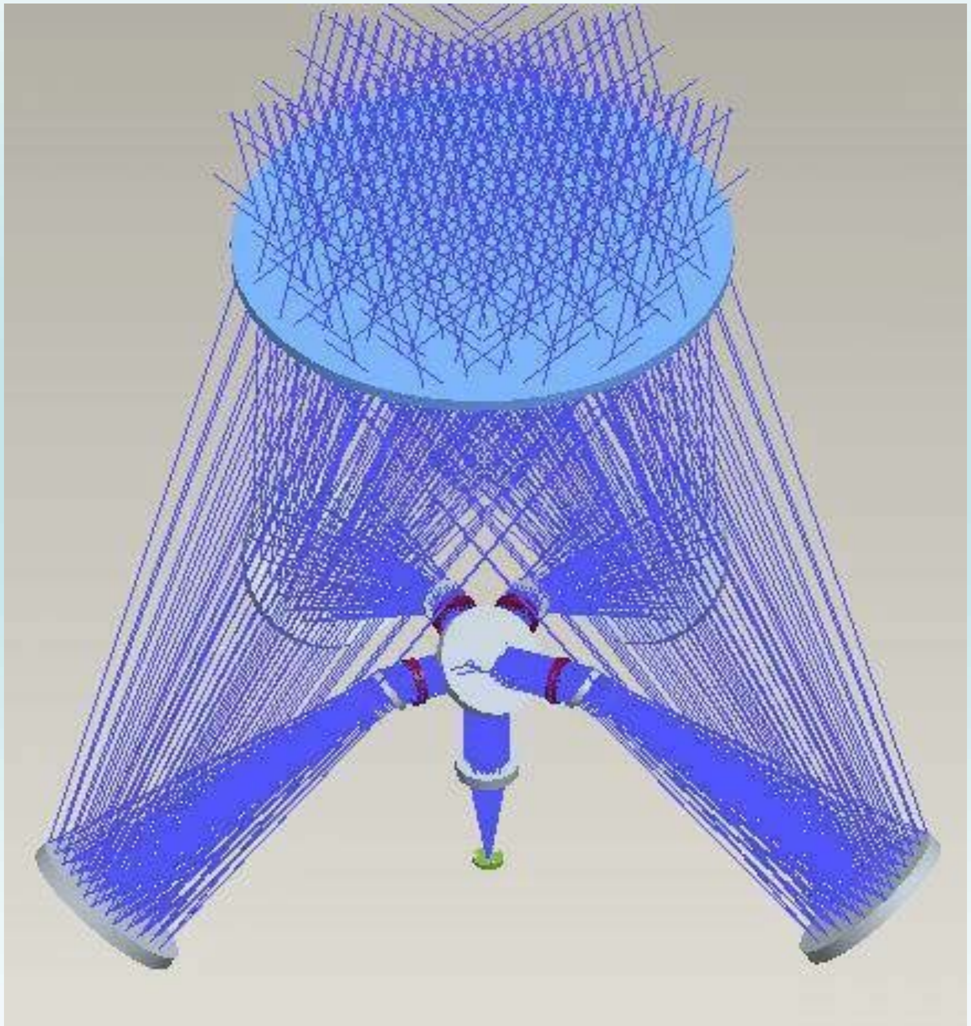
ShADOE ACT Objectives

- Enable lidar along 4 lines of site for atmospheric Doppler and surface mapping applications from space using ShADOE technology to minimize telescope weight & motion
- Investigate radiation effects
- Demonstrate FOV < 100 microrad at 355 nm.
- Demonstrate 355 nm ShADOE breadboard telescope system
- Demonstrate diffraction limited FOV (<30 microrad for 20 cm diam.) at 2054 nm.
- Conceptually design a multi-wavelength ShADOE telescope for use with 355 & 2054 nm.
- Advance the ShADOE TRL from 2 to 4.

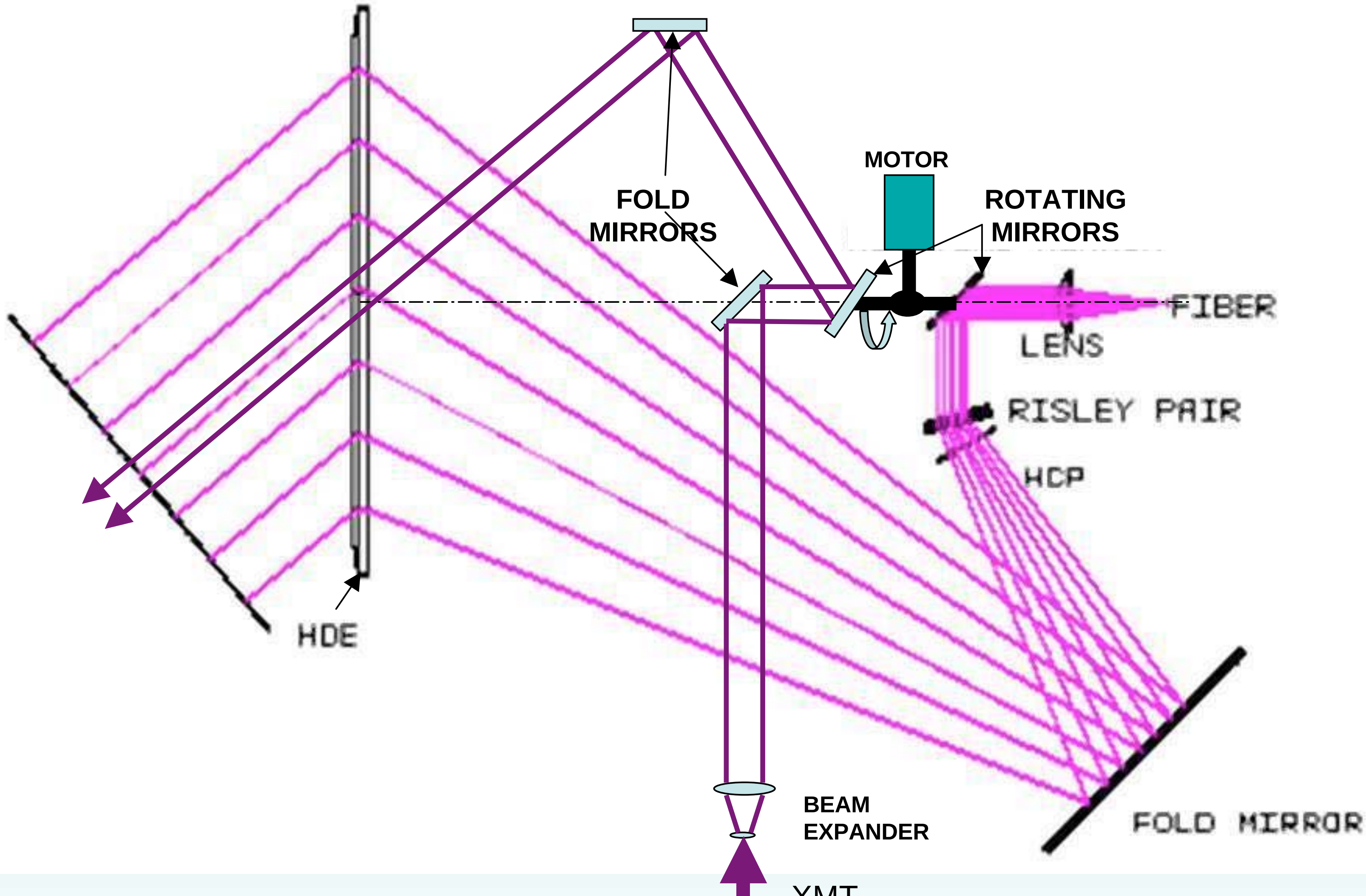
Optical Design – One Path



ShADOE Multiplexed Telescope

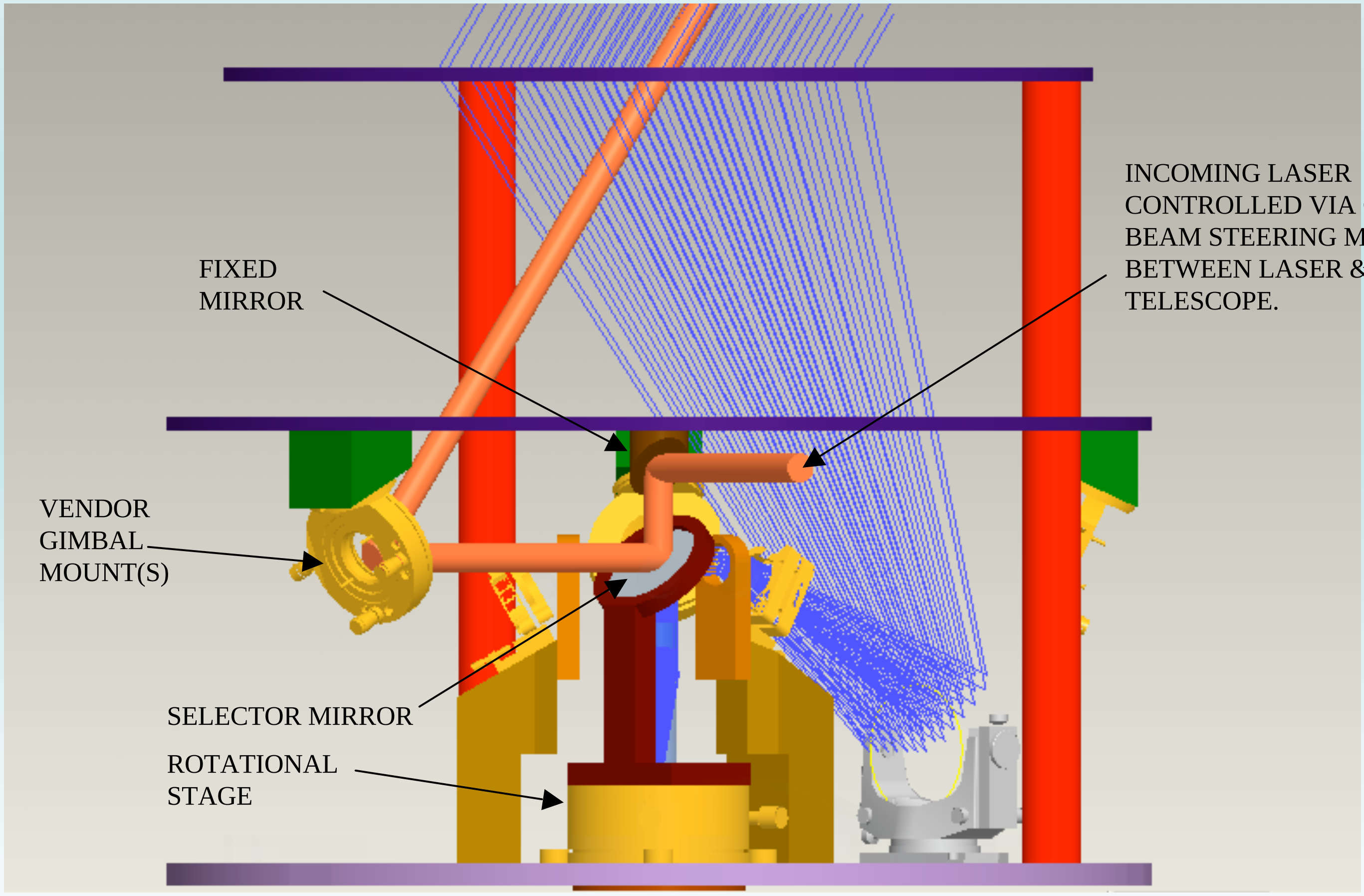


COAXIAL TRANSMITTER AND RECEIVER



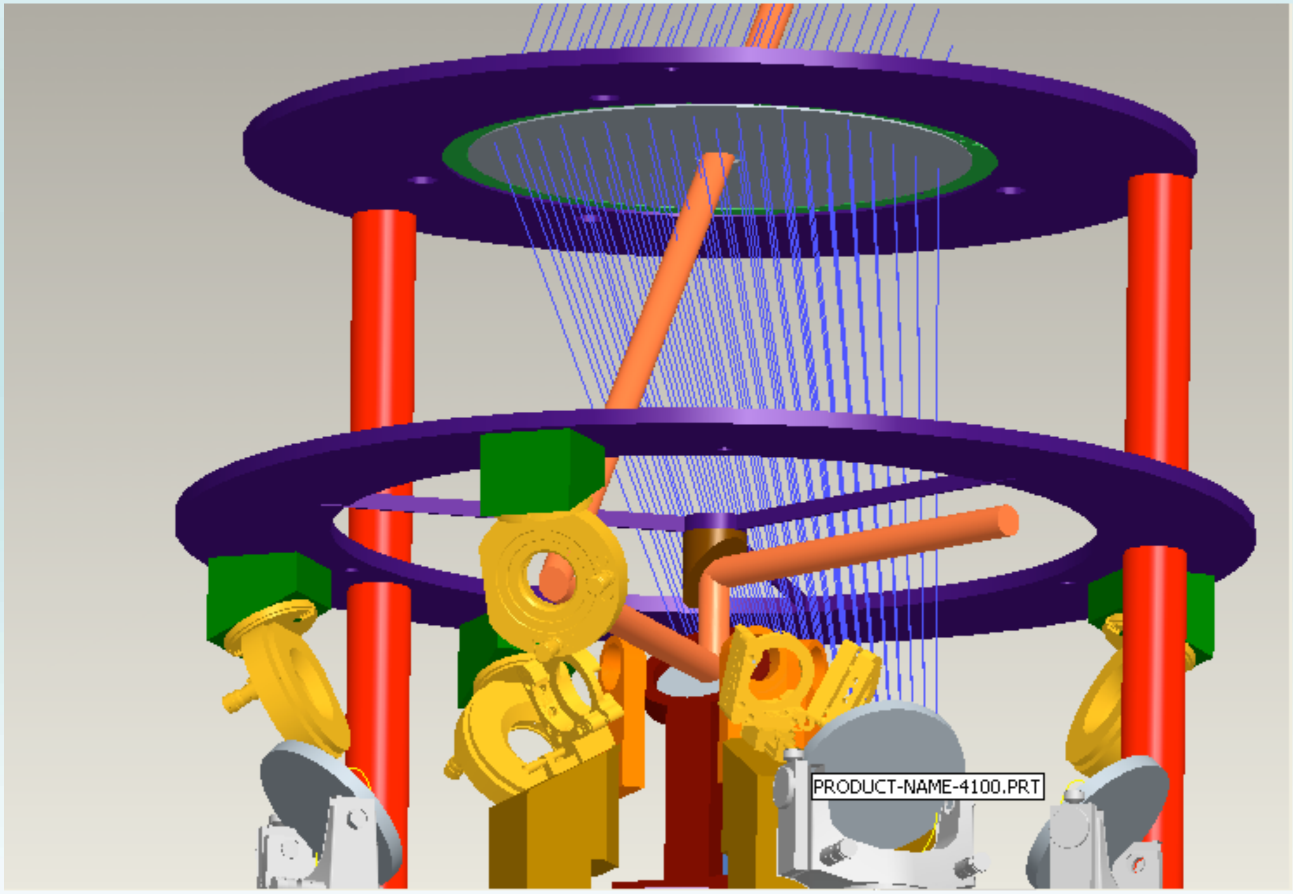
ShADOE Telescope Breadboard

Updated design-laser path (1OF2)



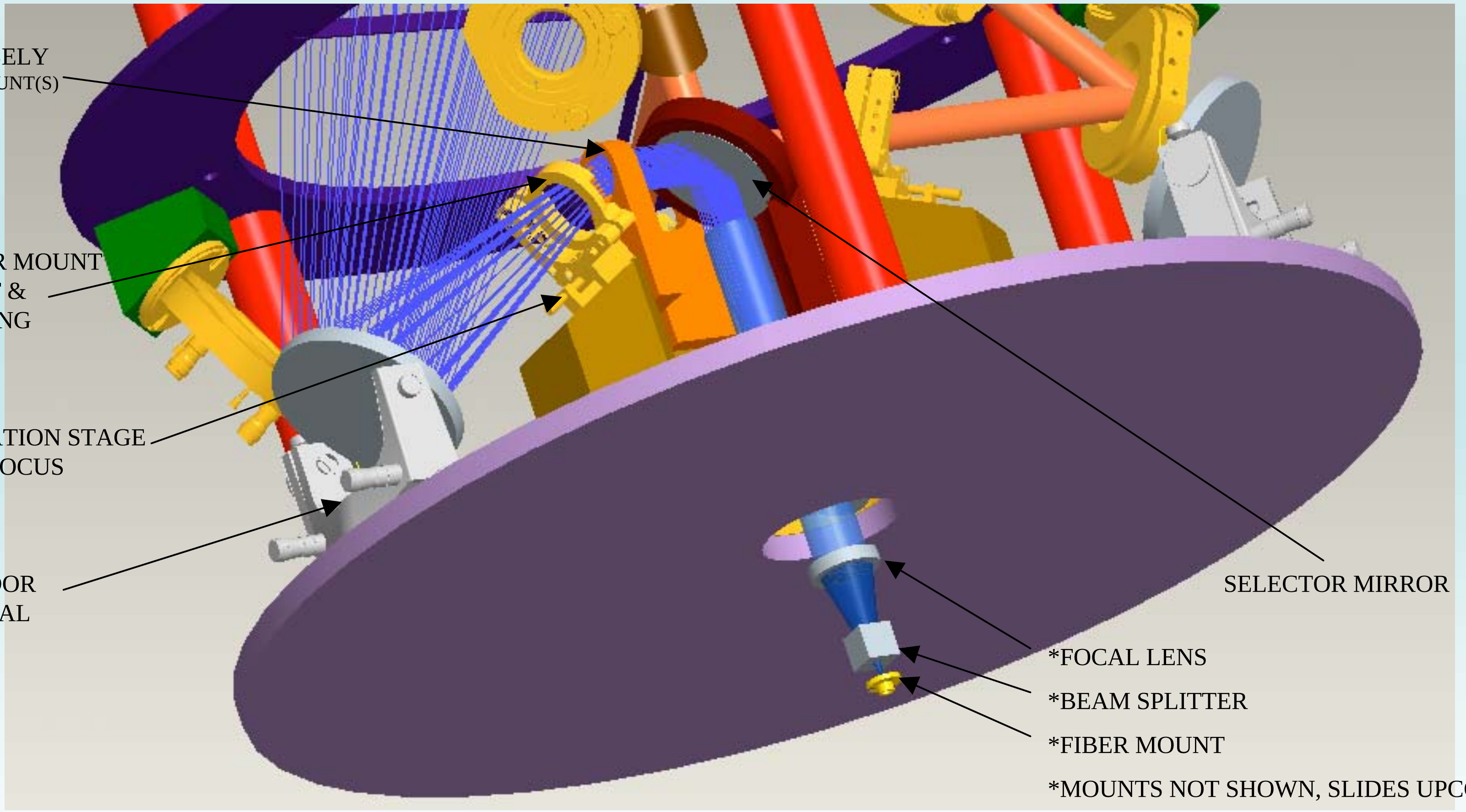
ShADOE Telescope Breadboard

Updated design-laser path (2OF2)

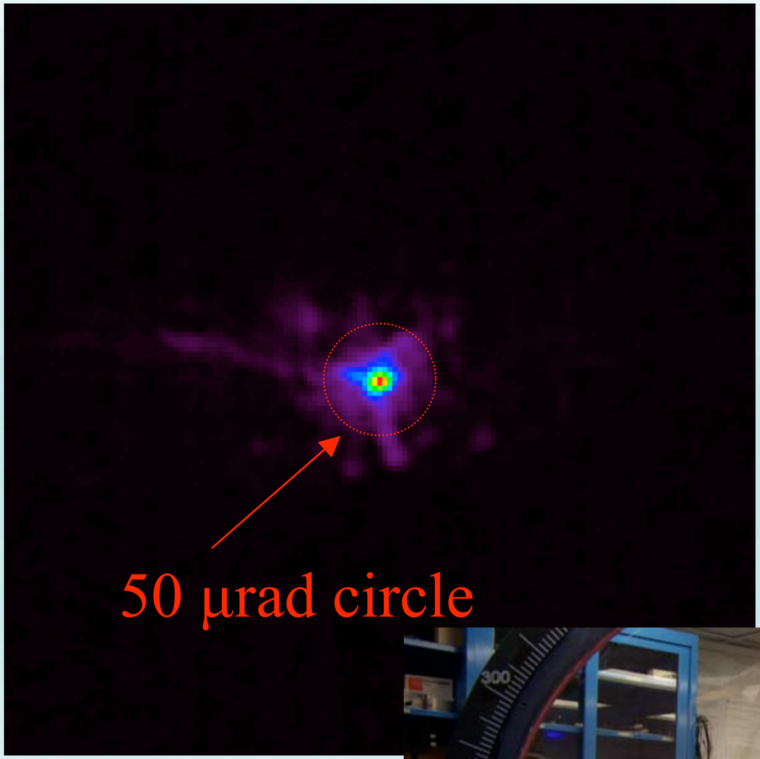


ShADOE Telescope Breadboard

Updated design-returned light



Holographic Image Correction

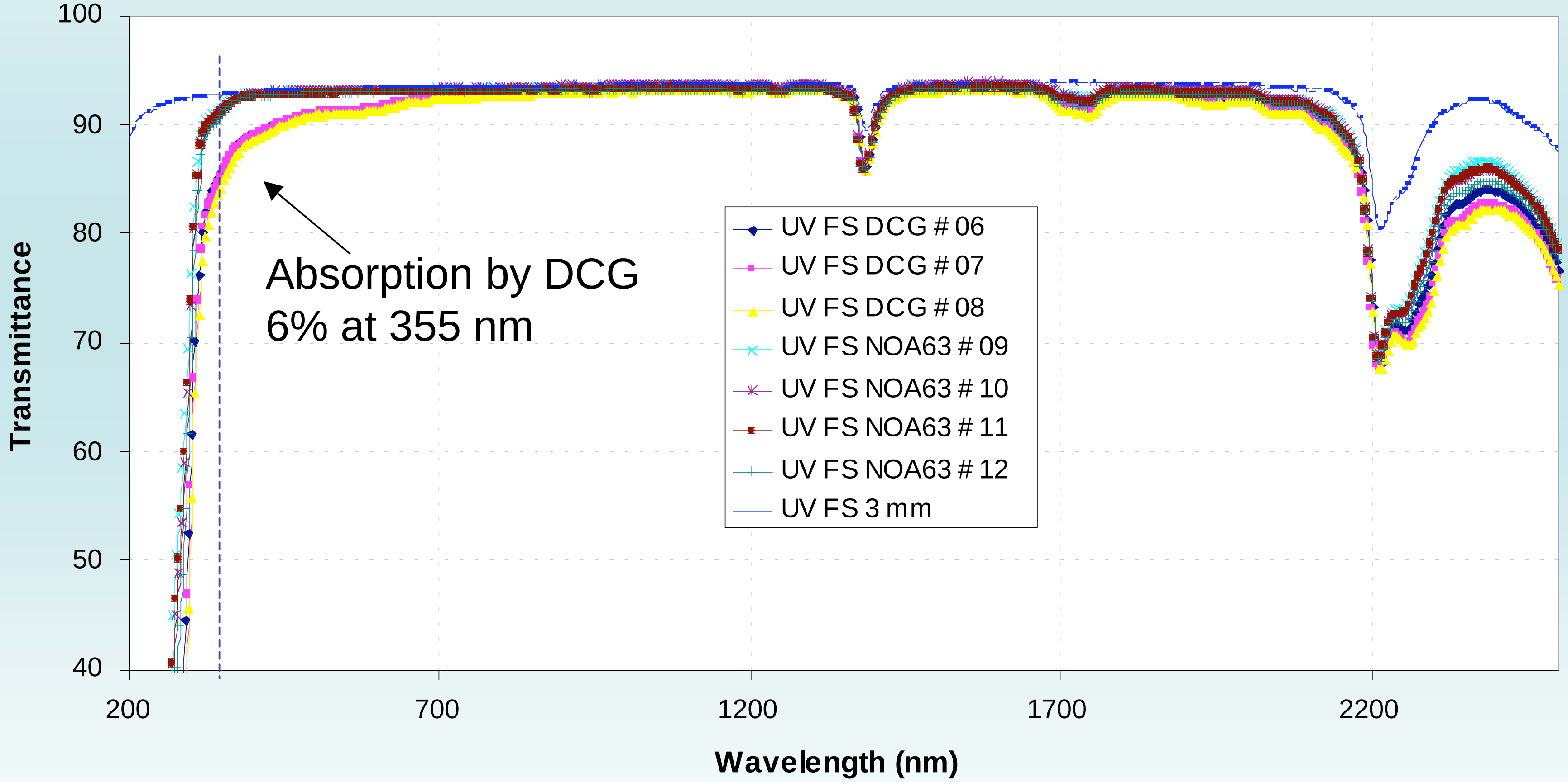


- Image blurred slightly due to atmospheric scintillation
- Bright core is 15-20 µrad wide with some halo/scatter around the core
- Phase retrieval analysis indicates ~0.5 wave error at 355 nm
- 93% of the energy within 50 µrad diameter circle
- For comparison, uncorrected HOEs have spots on the order of 200 urad.

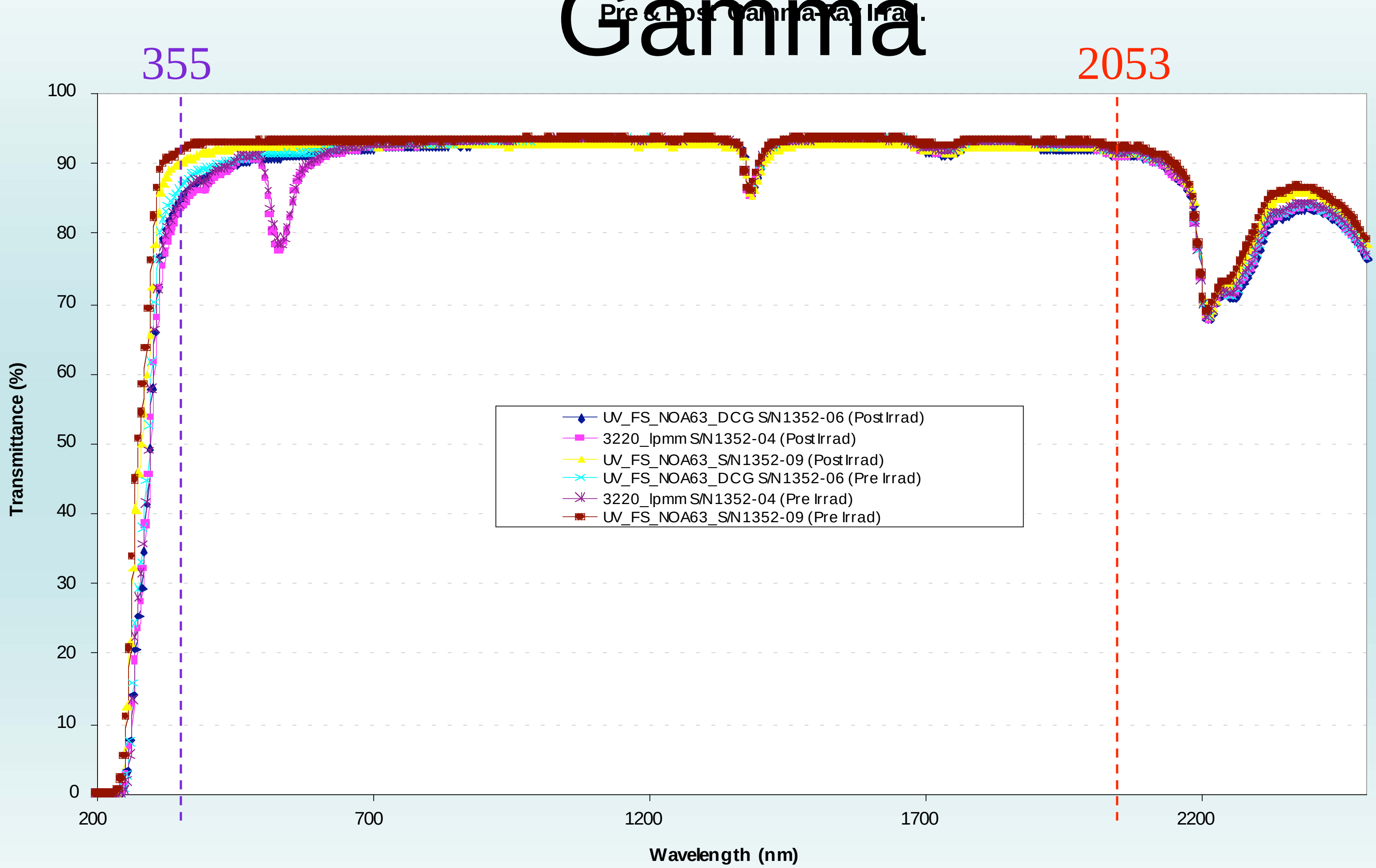
Materials Evaluation

- **Motivation**: evaluate HOE materials for space qualification
- **Radiation Types**:
  - Gamma (to simulate up to 2 MeV electrons)
  - Proton (5, 20, and 200 MeV)
  - 355 nm UV laser – damage thresholds, long term exposure effects, and thermal effects
- **Initial Findings**: Gamma and high E proton measurements demonstrated need for better substrate material; inconclusive for DCG.
- **Recent Findings**: Repeated radiation tests using UV-grade fused silica substrates.
  - No measurable effect from Gamma or high E proton radiation.
  - Epoxy damages first from high energy UV.
  - DCG only absorbs 6% at 355 nm, 0% at 2053 nm.
- **Status**:
  - Completed Gamma, high, med, low E protons, UV damage thresholds
  - Performing thermal blooming threshold test in response to mid-power density UV

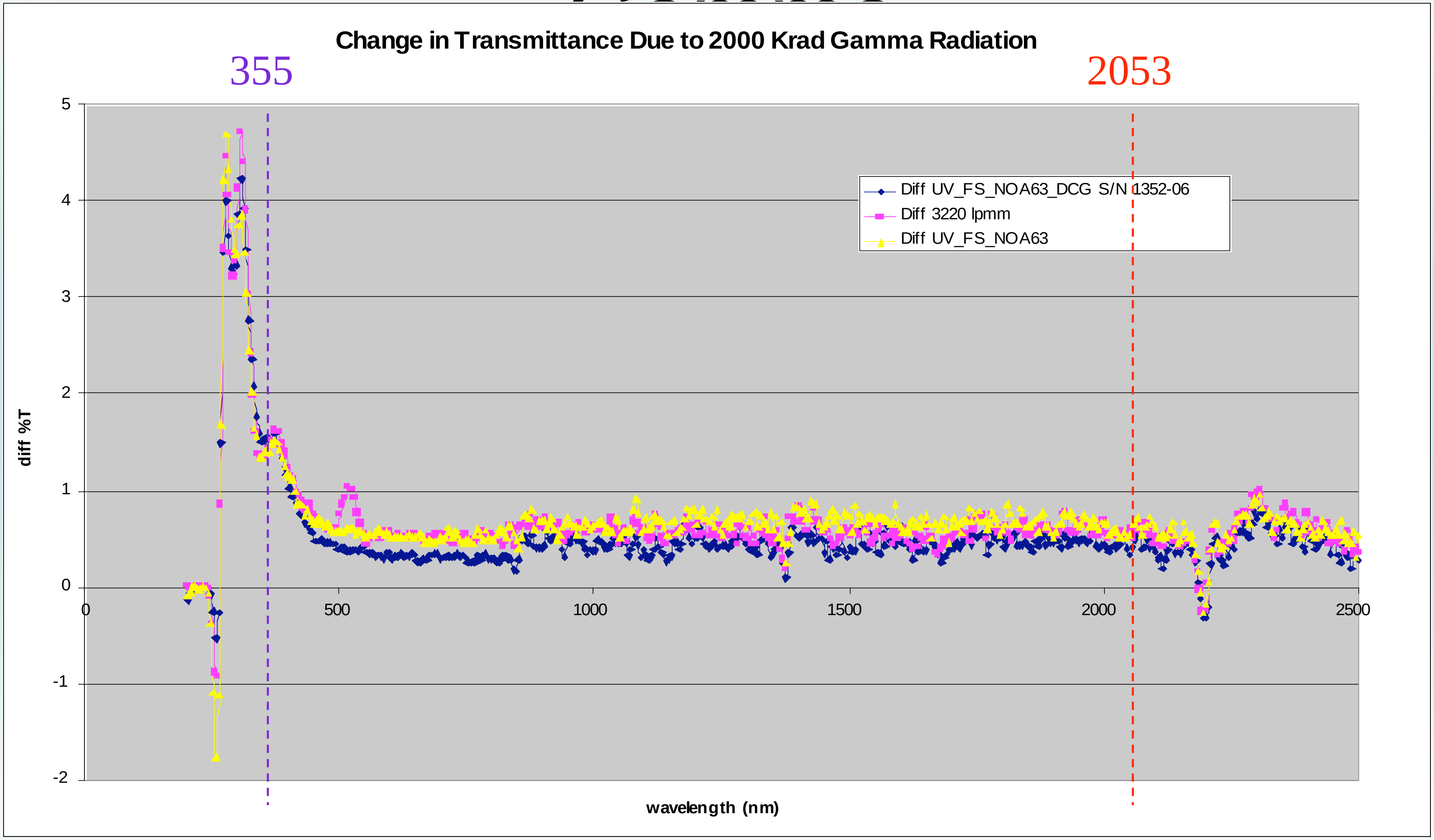
Pre-RadiationTransmission Spectrum – UV FS samples



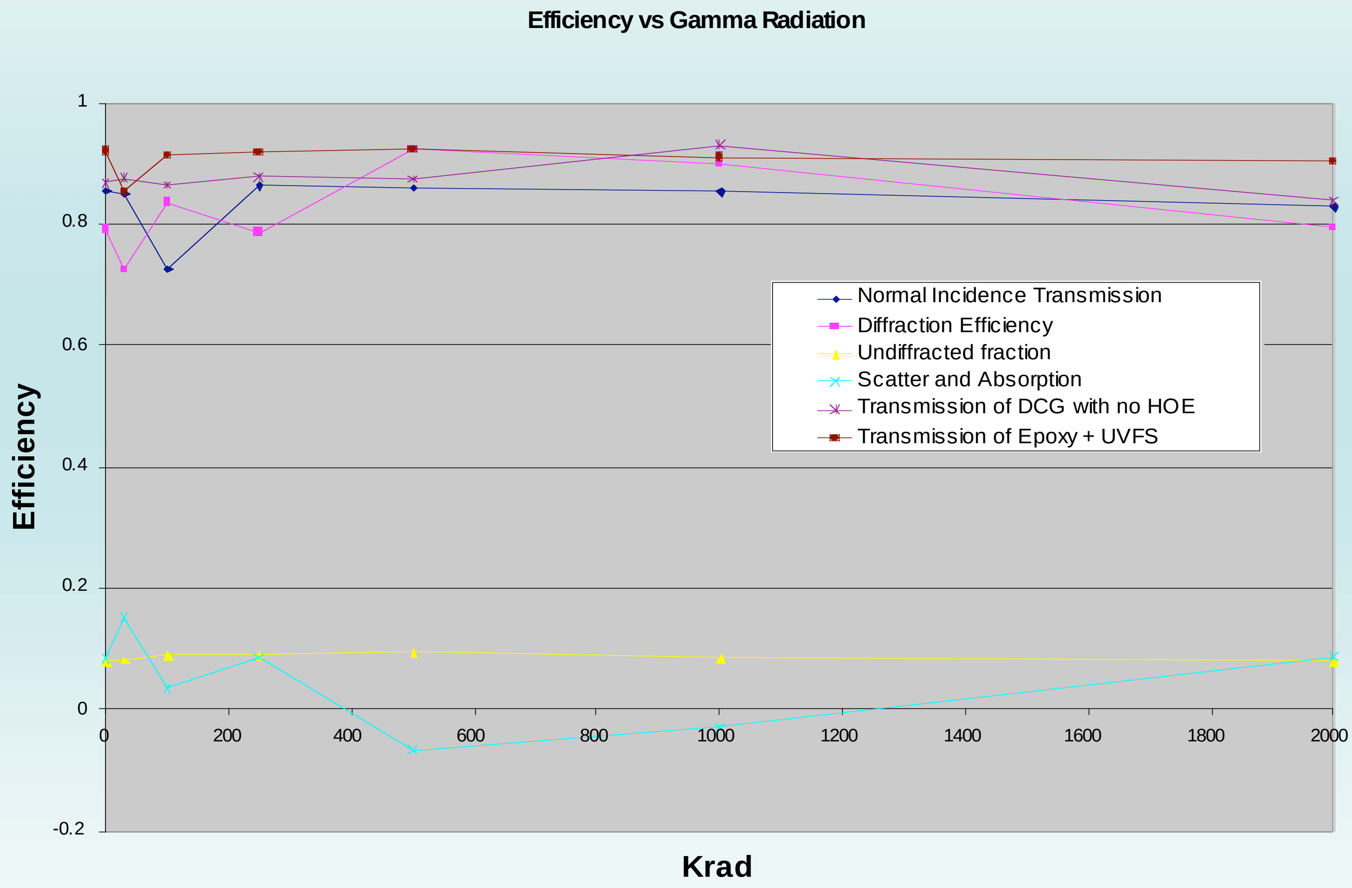
UVFS Post 2000 krad Gamma



UVFS Post 2000 krad Gamma



UVFS Post-Gamma 355 nm response: No measurable effect



High Power UV Damage Thresholds

Sample	Exposure Time	Power Density
UVFS only	10 min	>>3.3 W/cm^2
JGS2 only	10 min	>>3.3 W/cm^2
JGS2 + epoxy	10 min	1.0 W/cm^2
JGS2 + DCG	10 min	1.0 W/cm^2
JGS2 HOE	10 min	1.0 W/cm^2

High UV Energy Density Damage Test

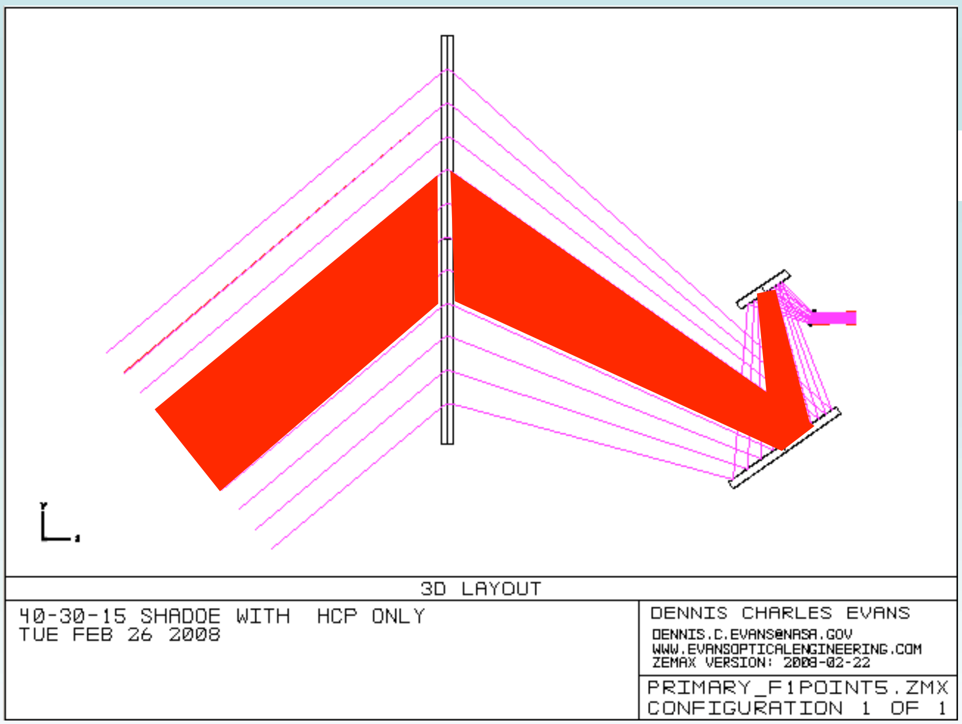
Single Pulse Energy Density (J/cm^2)	Total Energy Density (J/cm^2)	Peak Power Density (MW/cm^2/pulse)	No of Shots
0.297	5.94	49.5	20
0.326	4.89	54.33	15
0.354	3.54	59	10
0.425	2.13	70.83	5
1.274	6.37	212.33	5
1.433	1.433	238.83	1

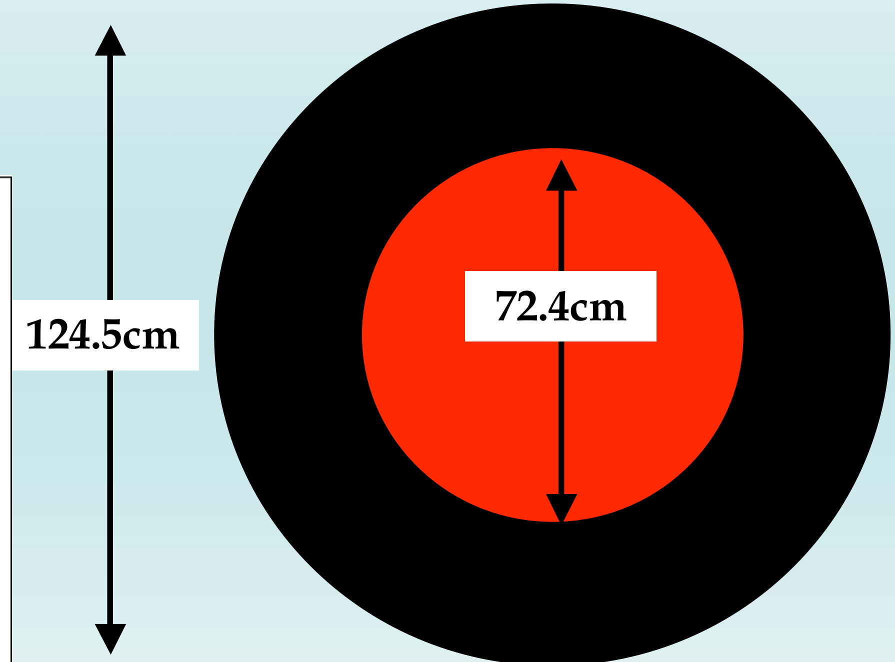
NWOS Instrument Design Study

- The NPOESS Integrated Program Office sponsored a study in the GSFC Instrument Design Lab to explore accommodation of a hybrid wind lidar on the next generation NPOESS (nominal launch date 2024 following NASA/NOAA demo mission).
- The NPOESS Wind Observing Sounder (NWOS) study examined several concepts to minimize the mass, volume and power requirements of the hybrid instrument, including the potential use of a 2 wavelength, 4 FOV ShADOE telescope.
- Results from the ShADOE ACT program were used to develop a baseline concept for this option.
- The study, supported by GSFC, LaRC and NOAA, was carried out February 21-25, 2008.

Hybrid design from IDL Study

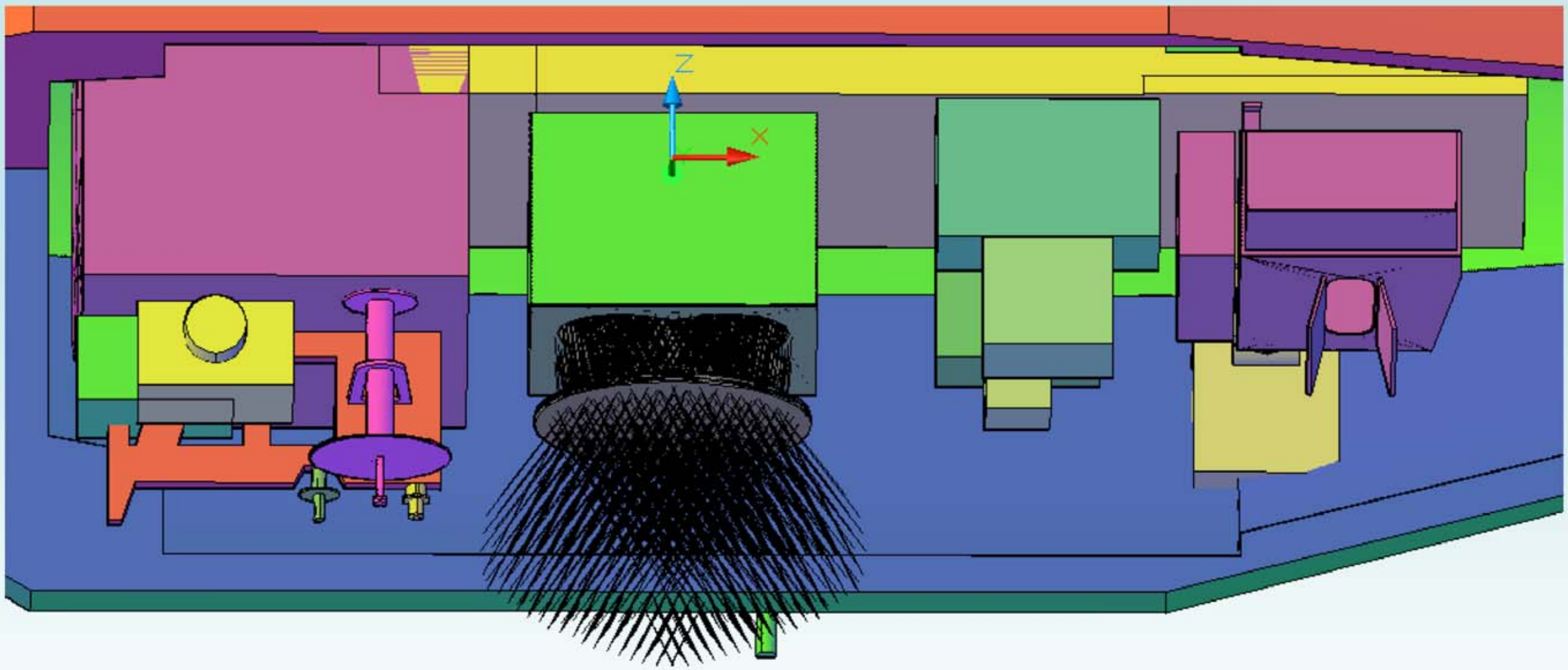
- 2 micron equivalent to 50 cm telescope
- 355nm equivalent to 70cm telescope
- Optical Efficiency = 0.9
- Hologram Efficiency = 0.75
- Overall Efficiency = 0.9 x 0.75 = 0.675





NWOS ShADOE Concept

- A 4 FOV, Multi-wavelength (355 nm and 2 micron) ShADOE based wind lidar is shown re-designed, scaled & refolded to fit on the NPOESS nadir deck



Summary

- Requirements derived from demo Doppler Lidar Wind Mission recommended in the NRC Earth Science Decadal Survey (January 2007).
- ShADOE promises to reduce weight, power & torque versus conventional mechanically rotated telescope system.
- Hybrid ShADOE concept explored in next-gen NPOESS instrument design study.
- Laboratory testing of the ShADOE/HCP prototype shows very good results can be obtained using the holograpically corrected ShADOE in the uv.
- Extensive materials test plan implemented to evaluate effects of radiation (gamma, proton) and uv exposure on HOE materials.
  - HOE samples made using UV fused silica substrates show little effects of gamma and proton exposure levels up to 2 Mrad
  - UV laser damage thresholds > 1 W/cm^2 over 10 minutes; >1.4 J/cm^2 single shot. Optical epoxy is limiting material for high energy pulsed UV – does not prevent its use but affects optical design of transmit optics.
- Preparing for delivery of final optics set, expected this summer.

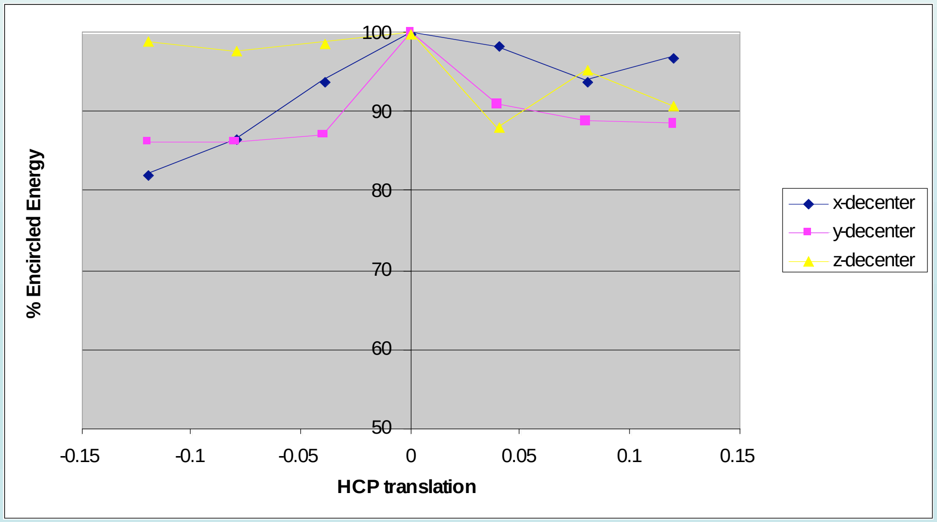
End ACT I

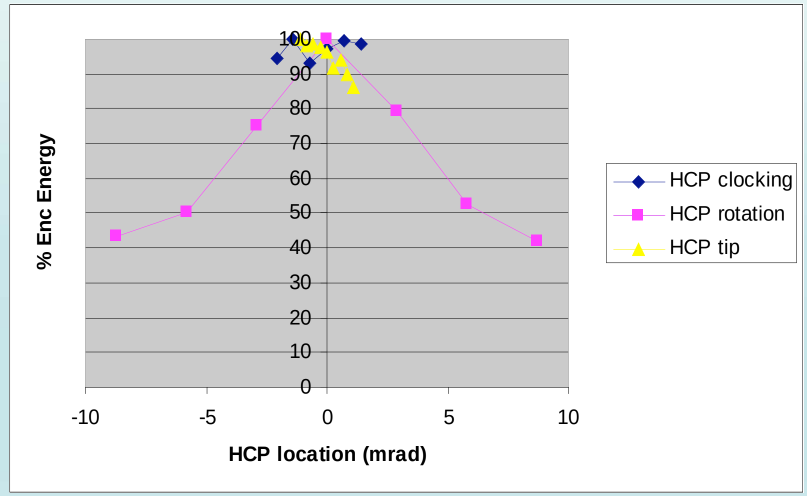
Backup

Conclusions from Phase Retrieval

- Wavefront error of the system is ~0.5 waves at 355 nm
- This is a vast improvement over the single HOE primary and would allow a smaller instrument FOV.
- The largest aberration is astigmatism

Sensitivity Analysis of Current HCP





Using these sensitivities to select step size and range for adjustments in the mounts.

Creating an error budget to understand the impact of mechanical tolerances, uncertainties and likely changes (i.e. rotating system from side to face up) on the encircled energy.

HCP Positioning Tolerances

Parameter	Value based on Enc. Energy Calc.	Estimate	Basis
Mechanical positioning tolerances on corrector plates, relative to primary ShADOE optic.		**As below**	**Proximity of corrector plate to focal plane and spatial scale of wavefront errors. To correct 1000 waves/m (175 µrad blur) of error at the HOE requires ~1/10th wave positioning error (at HOE) times system magnification. Secondary optics are 91.4 cm from the HOE, for a magnification of ~10X.**
ΔX, ΔY, Translation along X & Y axis	40 µm	10 µm	Based on above argument: .04m/fringe * 1/10th wave * 1/10X magnification. Define X-axis as in the diffraction plane, normal to Z axis.
ΔZ , Translation along Z axis	120 µm	40 µm	Wavefront corrective structures in the HCP must match the corresponding wavefront errors in the converging beam to within 10 µm in X&Y according to the above. The position of the wavefront error structures in X,Y change in proportion to the position along Z by $\Delta X = \Delta Z * A/(2f)$, where A is the primary aperture diameter (40 cm) and f is the primary focal length (1 m).
Tip (rotation about X axis)	1 mrad	1 mrad	The main effect is the equivalent z-axis translation near the edge of the HCP. The maximum tip angle is $\Delta\varphi = \Delta Z/(a/2)$ where a is the HCP aperture diameter. a = 4cm.
Tilt (rotation about Y axis)	1 mrad	1 mrad	This is just like tip except in the plane of diffraction. On one edge of the HCP the errors will be partially concelled because of the converging beam, but errors will double on the opposite side, so we go with half the maximum tip error.
Rotation about Z axis (clocking error)	1 mrad	0.5 mrad	Moves the perimeter of the HCP 10µm, equivalent to X-Y translation error.

1st SHADOE with HCP