An Off-Axis Hartmann Sensor for Measurement of Wavefront Distortion in Interferometric Detectors

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ACIGA

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SUB CRUCE LUMEN

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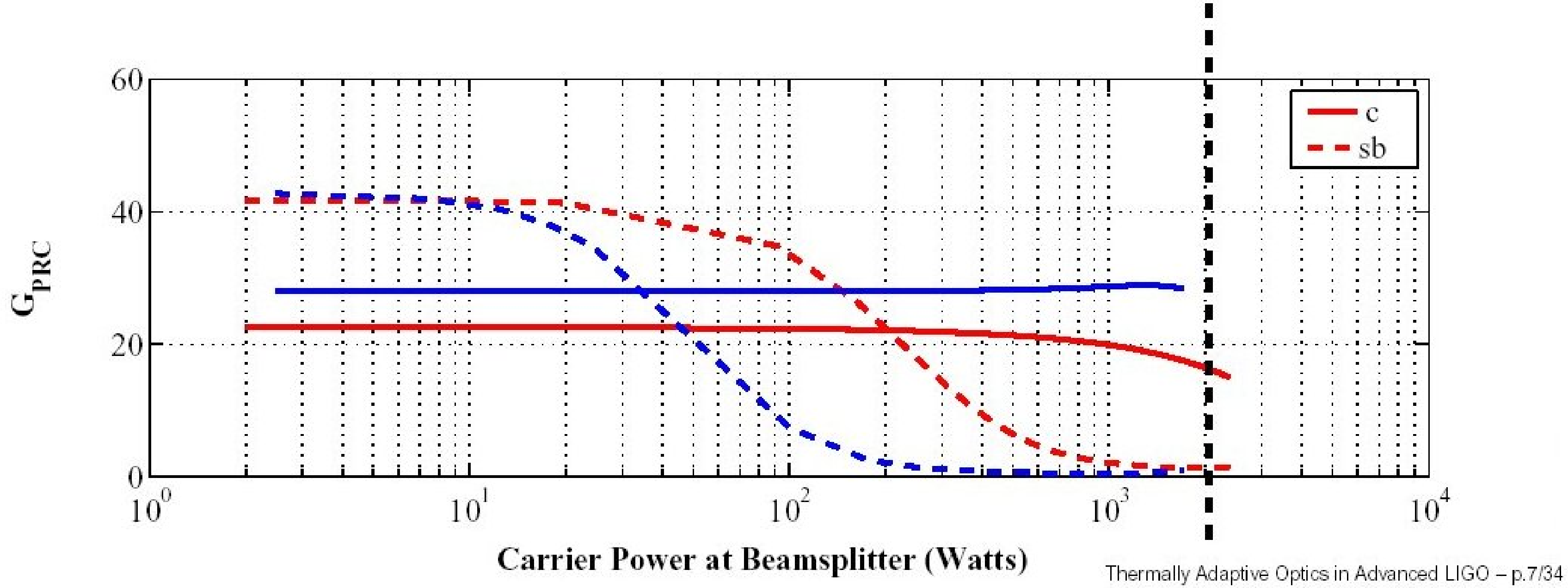
Outline of Talk

- Discuss the thermal lensing problem
- Off-Axis Hartmann Sensor – Two Stages
  1. Phase distortion measurements with a Hartmann sensor
  2. Off-axis tomographic analysis of phase measurements
- Installation of sensor at AIGO

Objectives of research

- Improve operation of advanced interferometers by reducing thermally induced wavefront distortion.
- Develop a sensor to measure the distortion and correction in the ACIGA High Optical Power Test Facility.

Crux of thermal problem



Courtesy of Ryan Lawrence and David Ottaway, MIT

- Absorbed power causes ‘thermal lensing’
- Prediction of MELODY model of Advanced LIGO
- Sideband power is scattered out of TEM_{00}
- Instrument failure at approximately 2 kW
- Adv. LIGO cannot achieve desired sensitivity unaided

How to maintain cavity finesse?

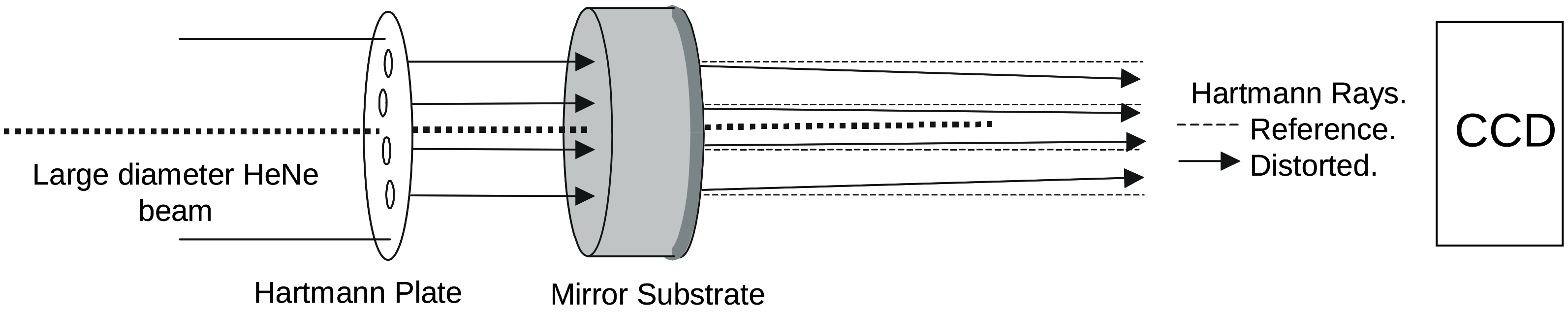
- Measure distortion with wavefront sensor
- Employ active compensation system
- Sensor cannot interfere with core optics or GWI laser beam.

OFF-AXIS WAVEFRONT SENSOR

Why use a Hartmann wavefront sensor?

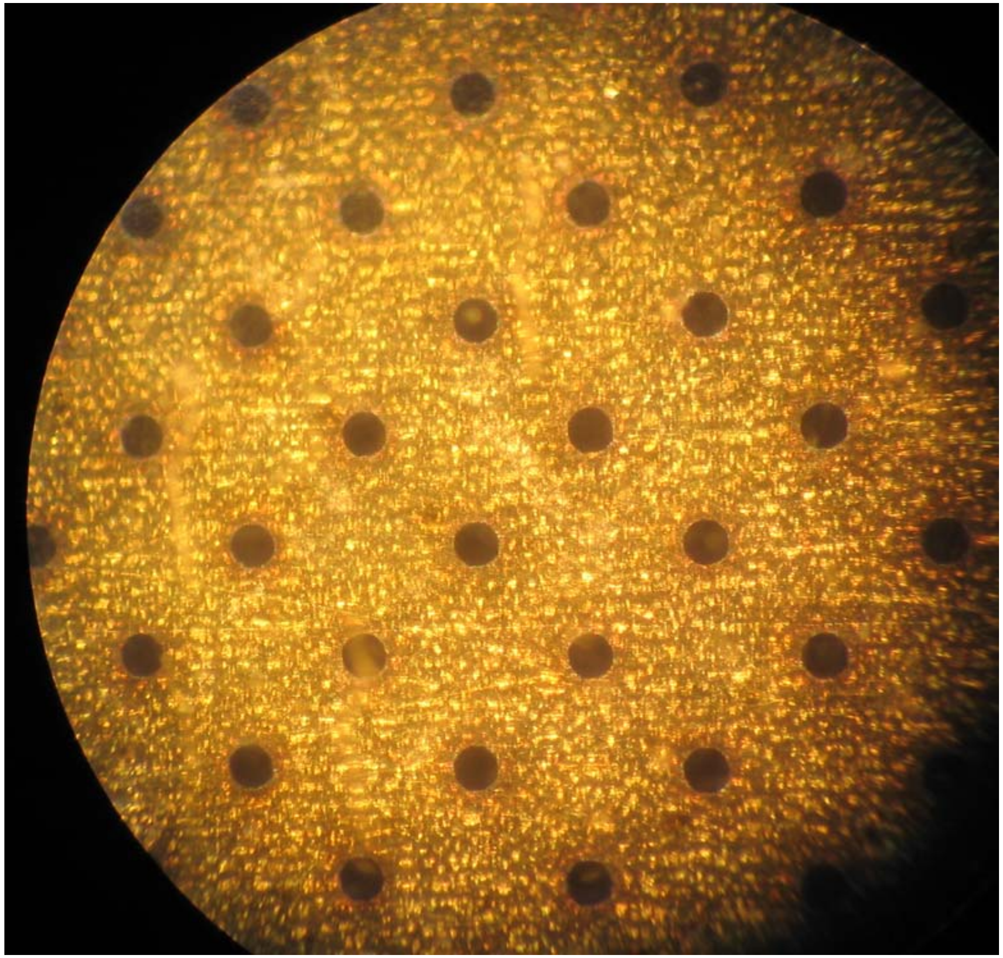
- Interferometry
- Shack-Hartmann
- Hartmann
  - Easiest to align
  - Cheap
  - In principle, can measure a wavefront change of less than $\lambda/1000$

Hartmann wavefront sensor



- Record spot positions on CCD
- Wavefront changes $\rightarrow$ spot positions change
- Gradient of wavefront change proportional to displacement of spot.
- Measurement of the gradient of the phase distortion allows one to reconstruct the distortion itself

Current Hartmann Plate

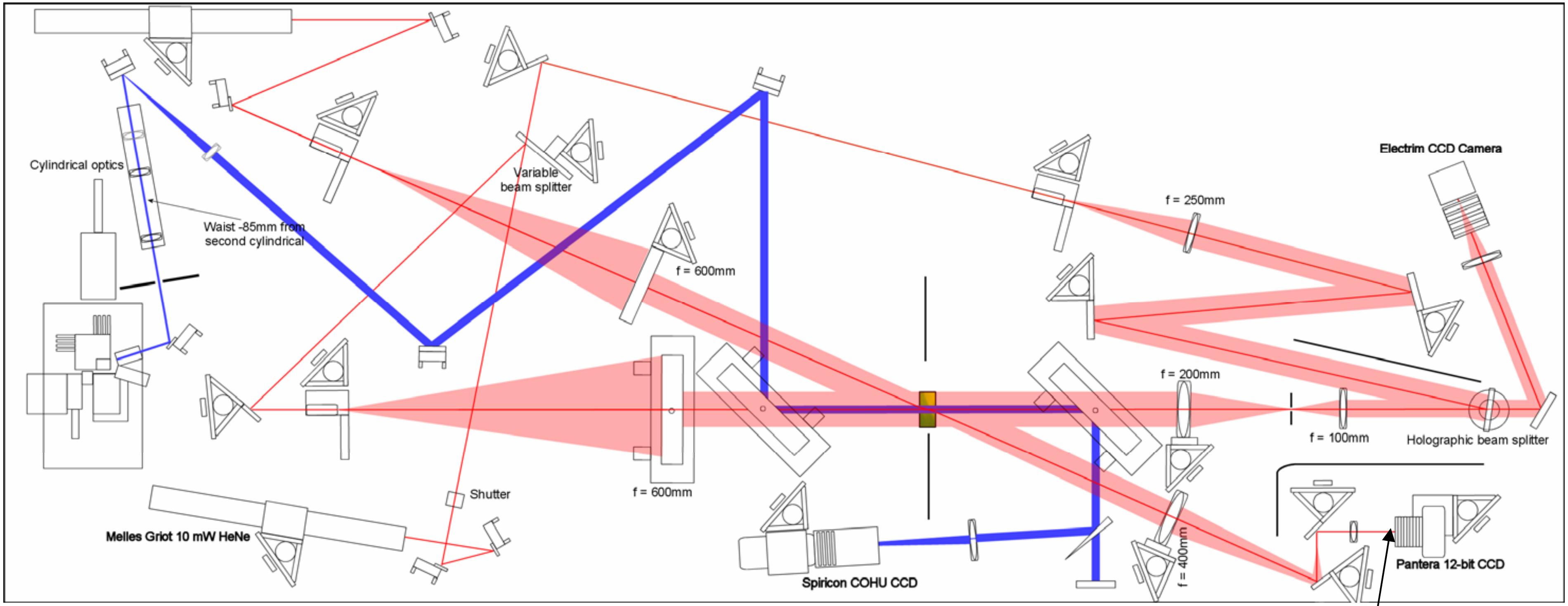


- Square arrangement
- Hole size: 150 microns
- Pitch: 570 microns

Future plate:

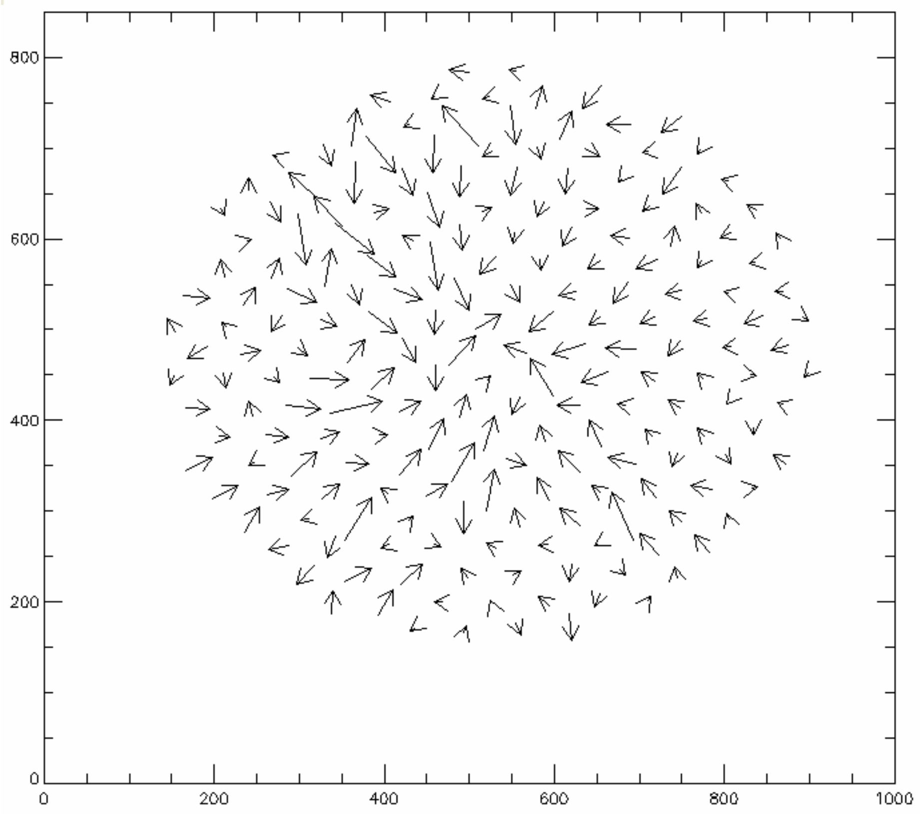
- Hexagonal arrangement
- Hole size: 150 microns
- Pitch: 430 microns

Off-Axis Bench Top Test

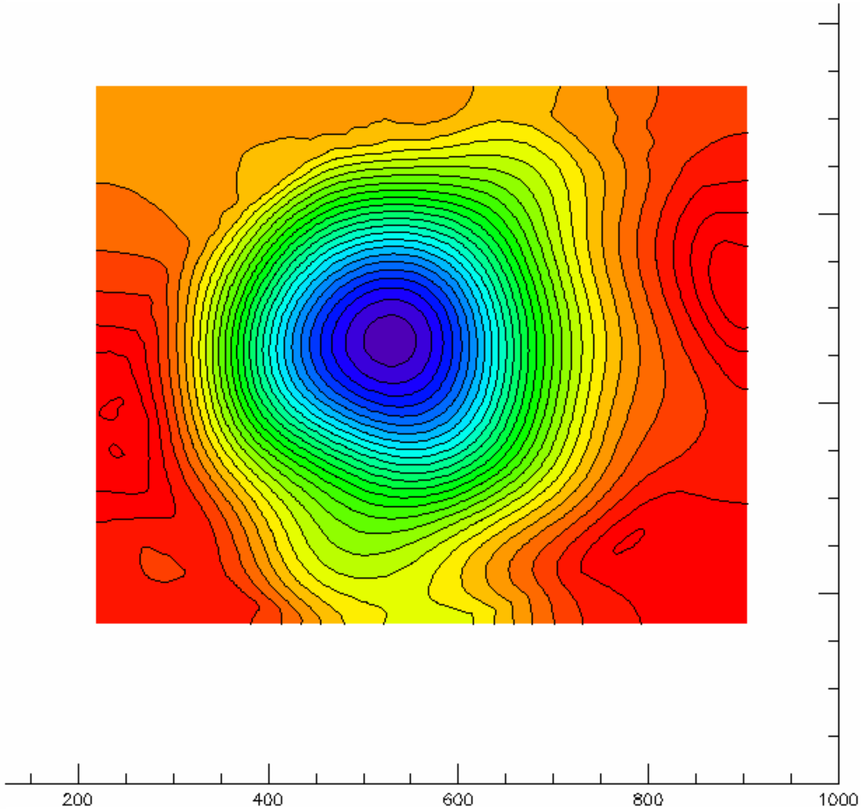


Hartmann plate

Hartmann Phase Reconstruction

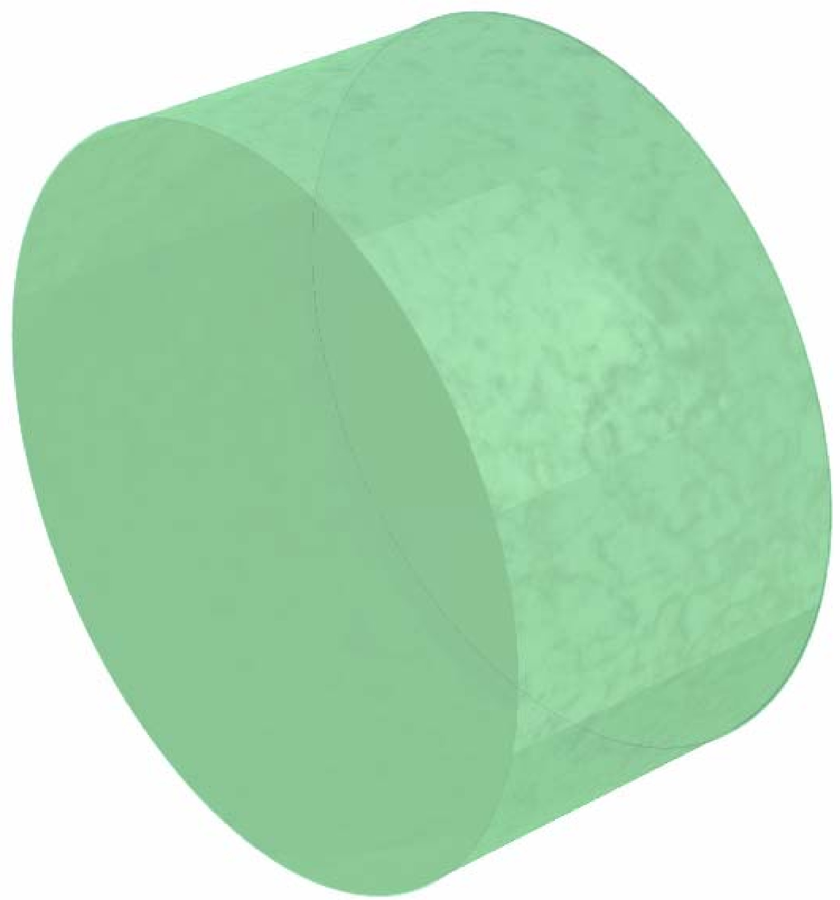


Gradient field



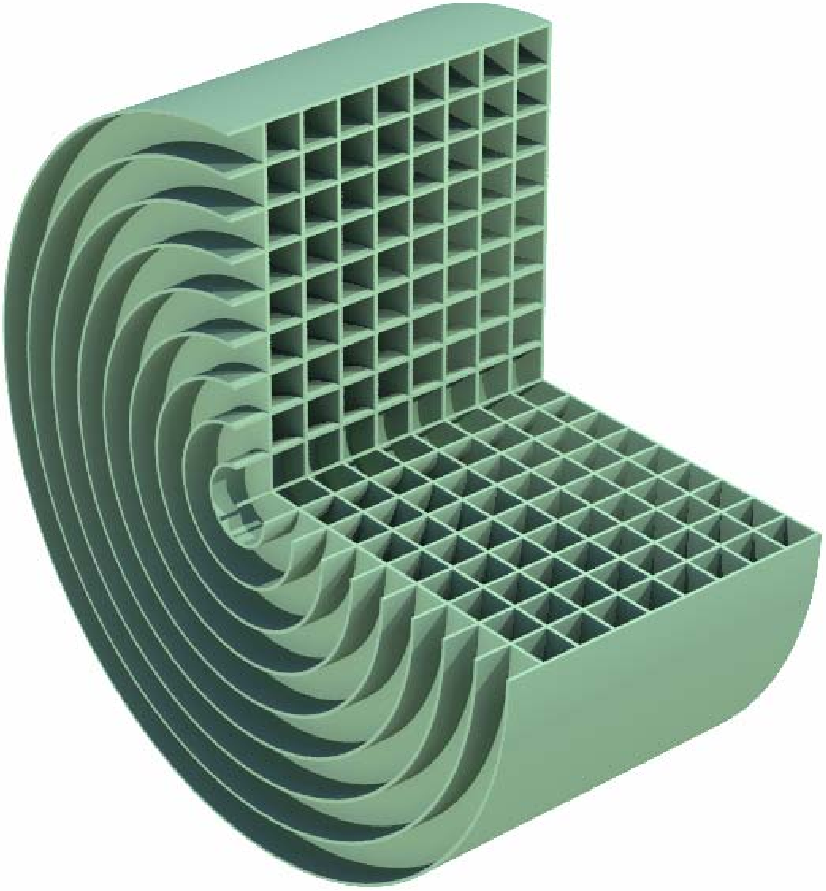
Reconstructed phase map

Determine wavefront distortion using optical tomography



Cylinder of transparent material with internal temperature/refractive index distribution

Determine wavefront distortion using optical tomography

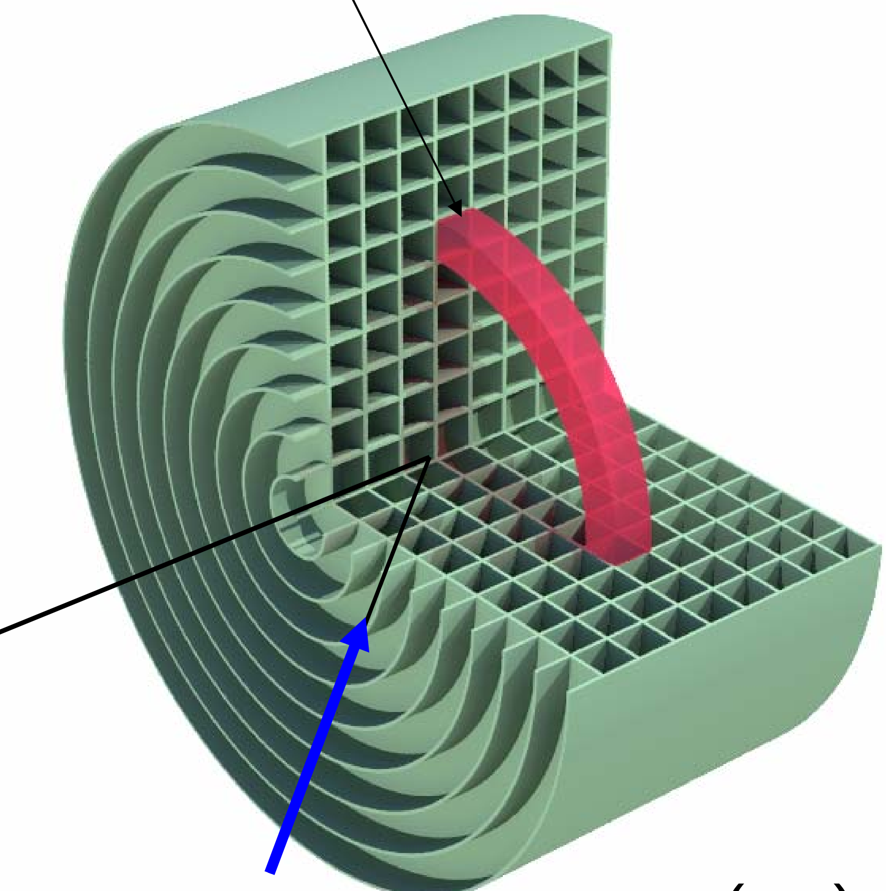


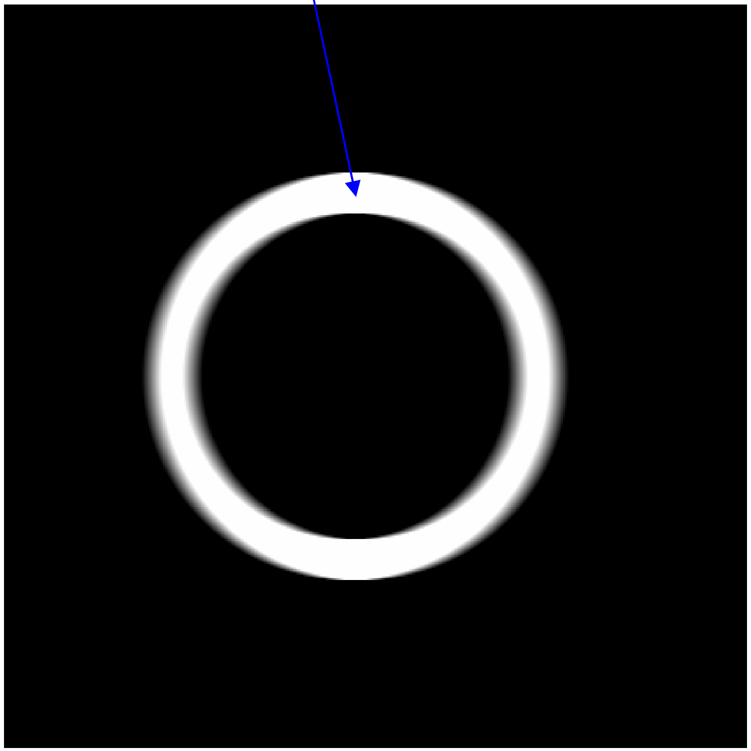
Divide into annular volume elements (voxels)

Determine wavefront distortion using optical tomography – related spaces

Original voxel – uniform refractive index

Phase distortion caused by this voxel - *Off Axis Projection*





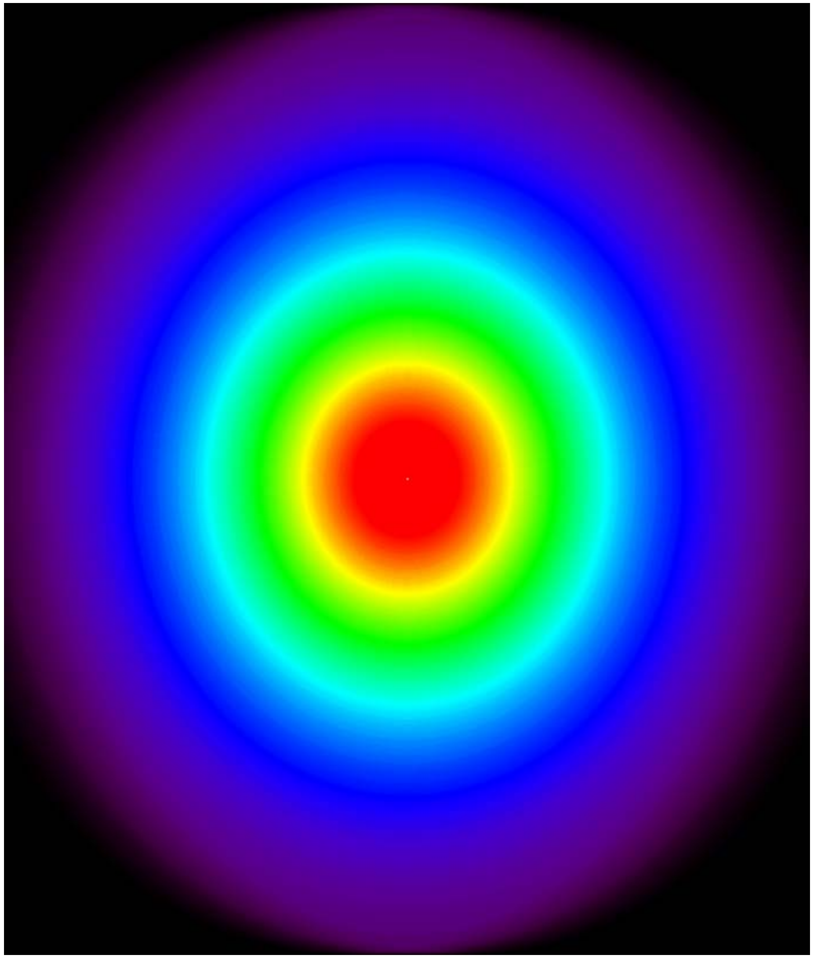
Off axis viewing angle, θ

$$n(r, z) \leftrightarrow \phi(x, y)$$

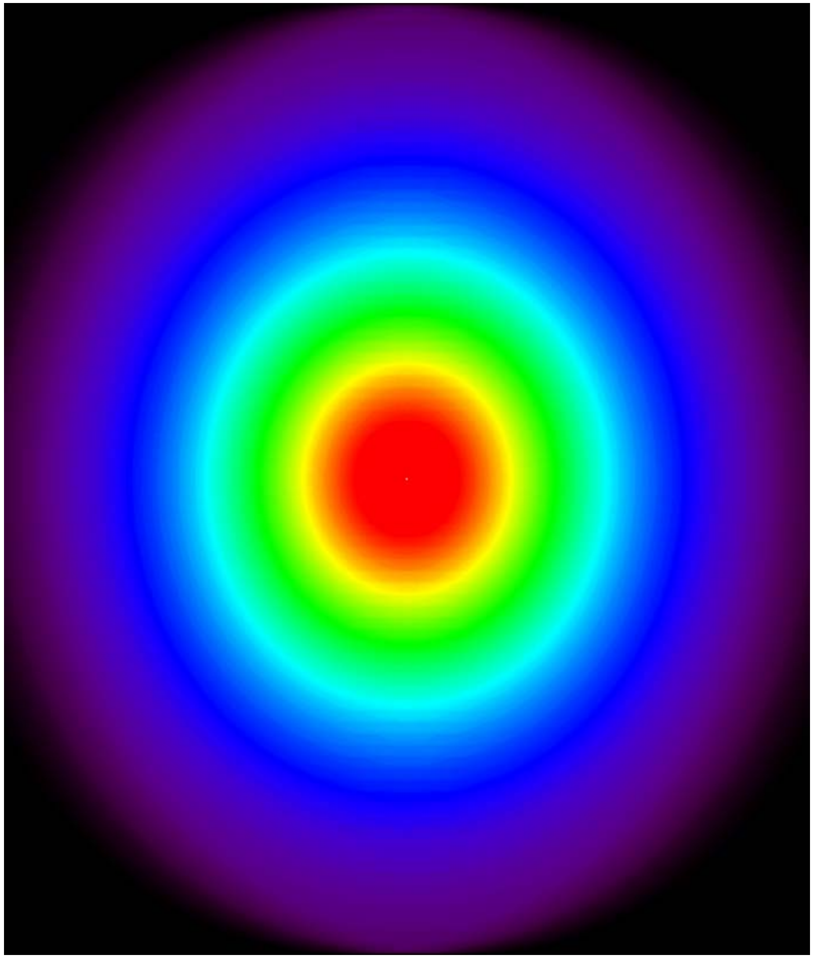
Simulation of tomography

- Temperature distribution in ITM of AdLIGO-like system modelled using Hello-Vinet equation
- Off-axis optical path distortion (OPD) through this distribution determined
- OPD used as input data for a least-squares-fit to voxel projections
- Internal temperature distribution reconstructed
- On-axis OPD determined from reconstruction and compared to OPD predicted by theory

Simulation results

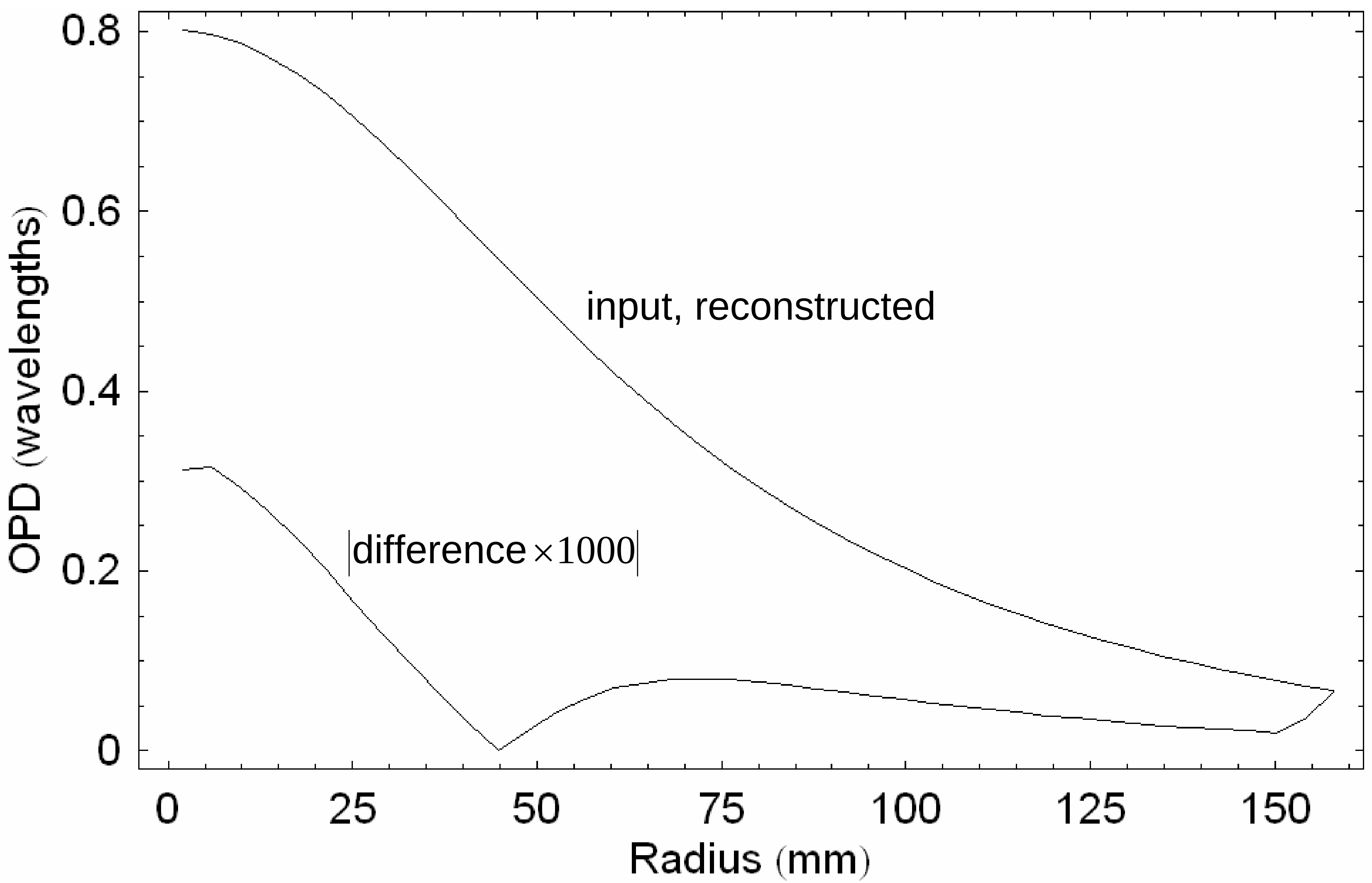


Original off-axis OPD



Best fit with voxel projections

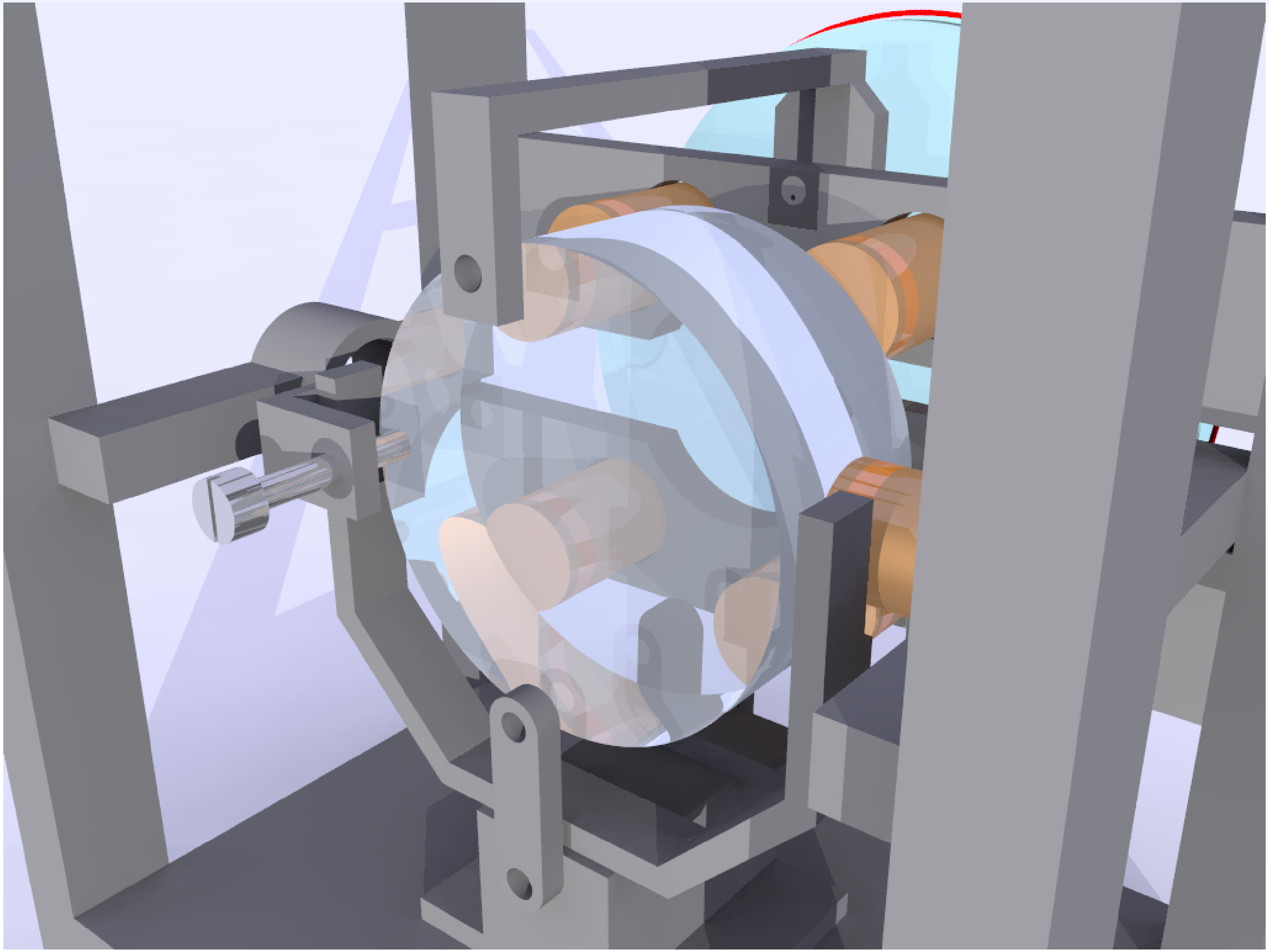
Tomographic analysis is accurate



Implementation of tomography

- Hartmann sensor used to measure OPD gradient field
- Gradient field used to reconstruct phase distortion (OPD) using iterative process
- Tomographic analysis determines temperature distribution from reconstructed OPD
- On-axis OPD determined from reconstructed temperature distribution

Installation at AIGO



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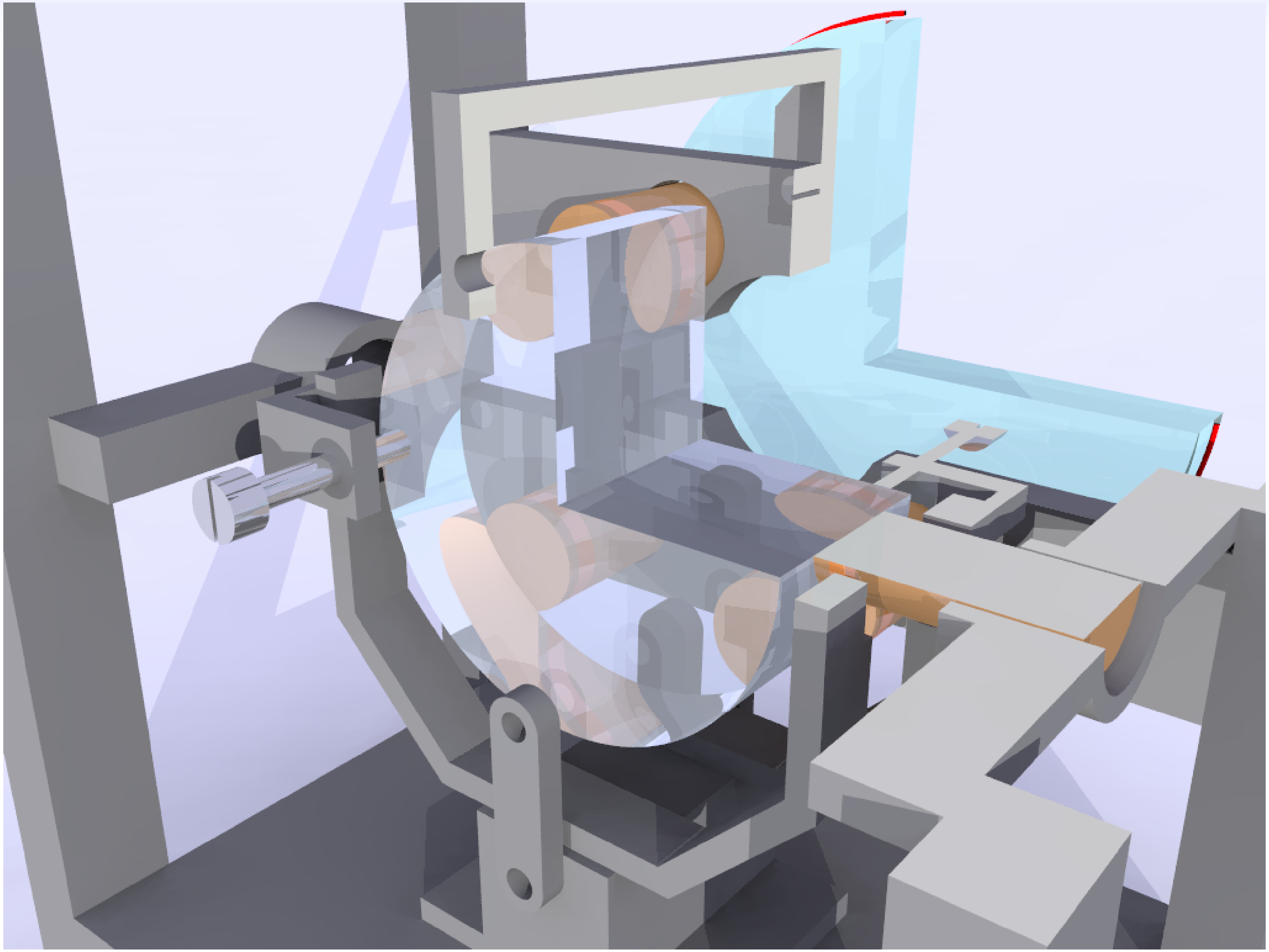

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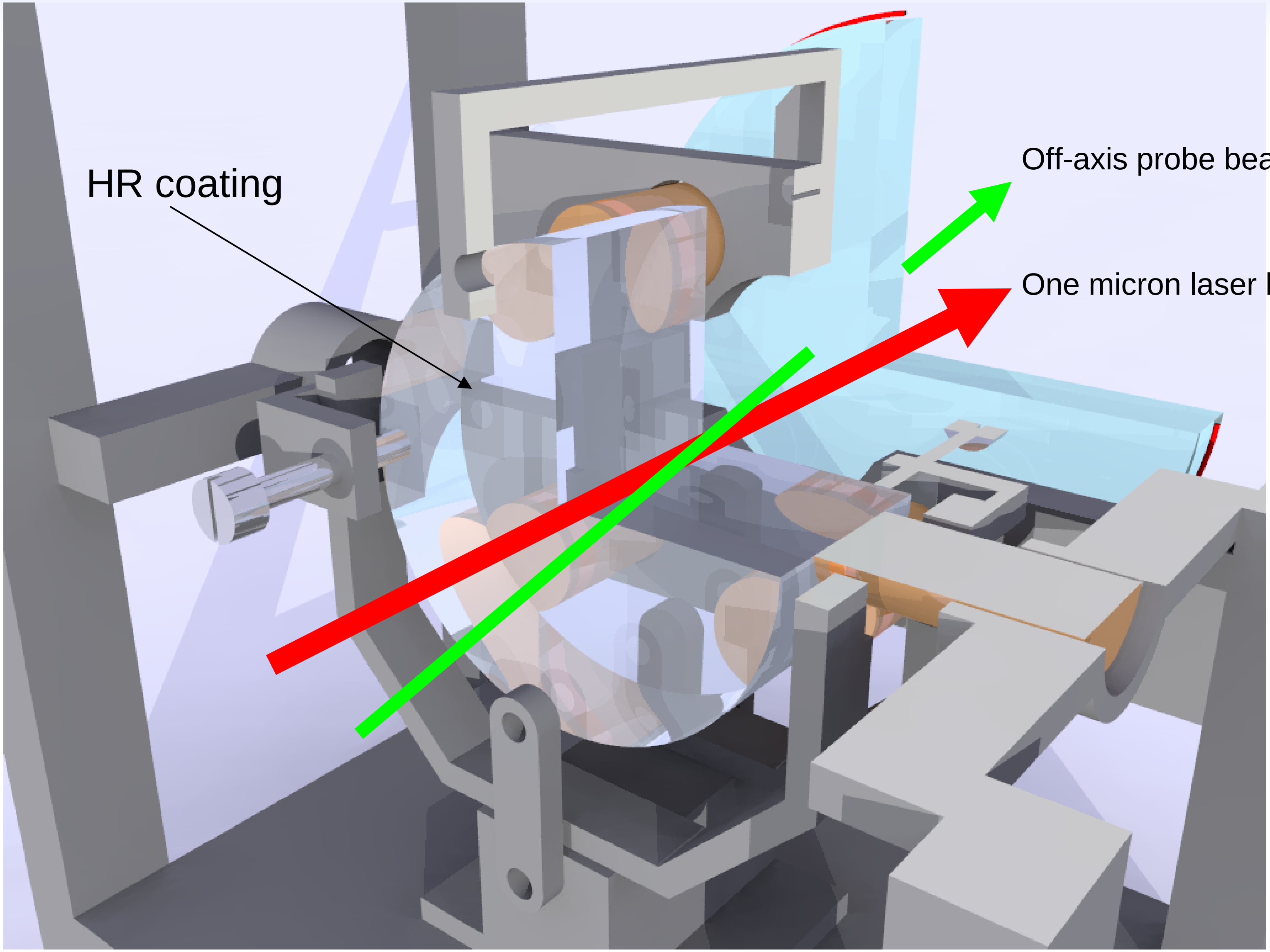
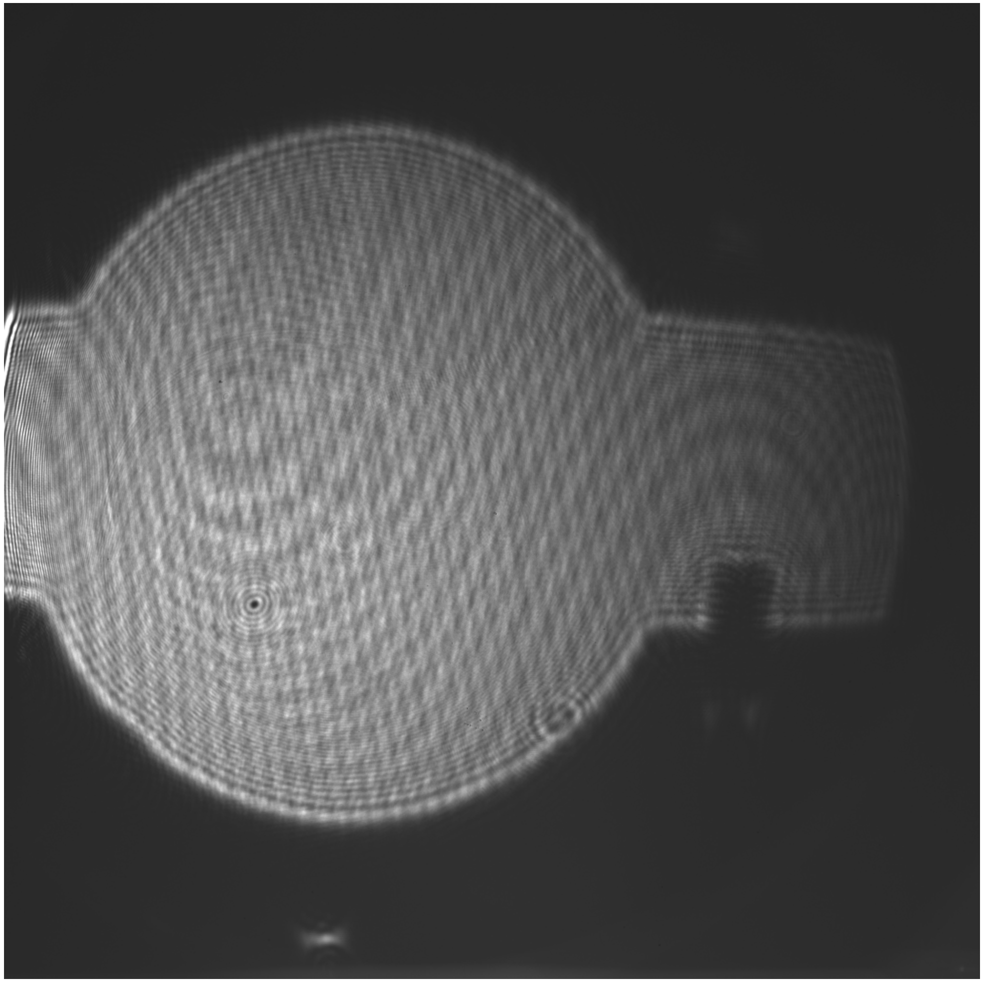
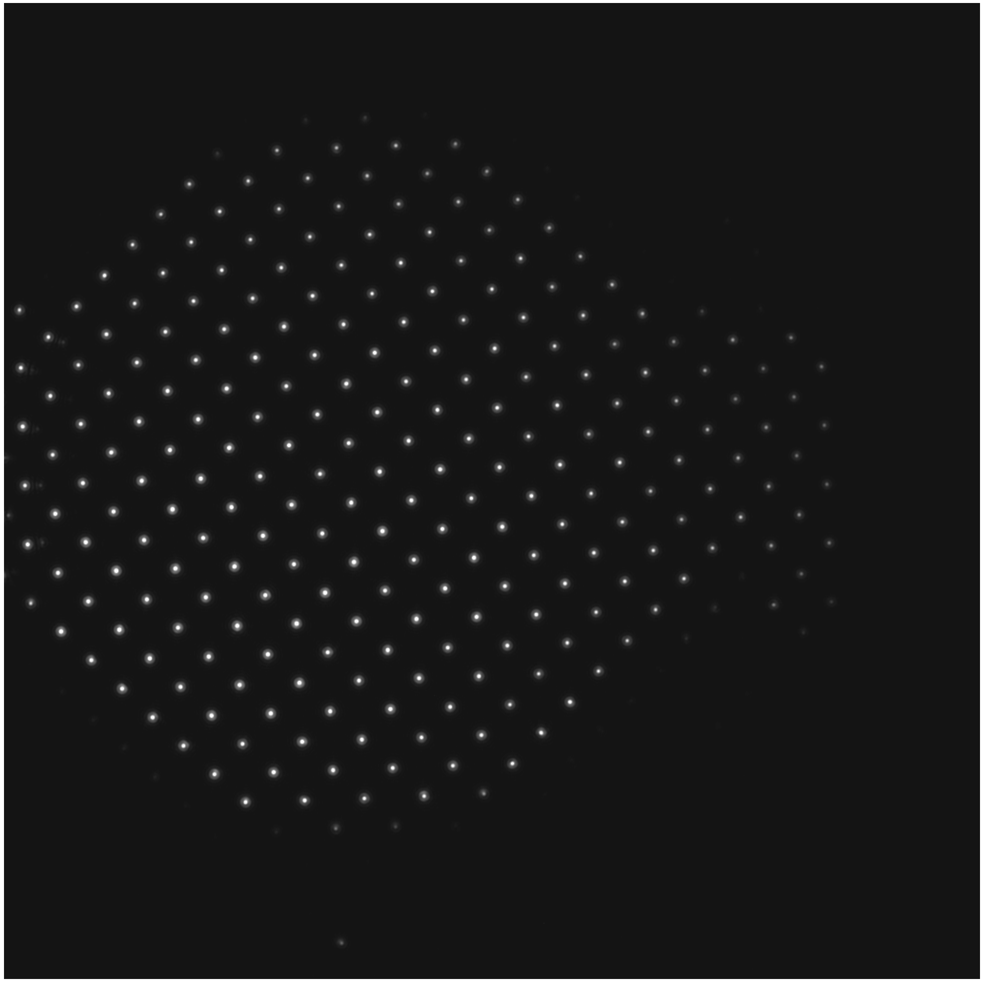


Installation at AIGO - Update



- Interference fringes on illumination pattern.
- Caused by a combination of aberrations on the input beam and reflections from the vacuum tank input windows.
- Intensity variations adversely affect the Hartmann sensor
- Use a short coherence length source

Installation at AIGO - Update



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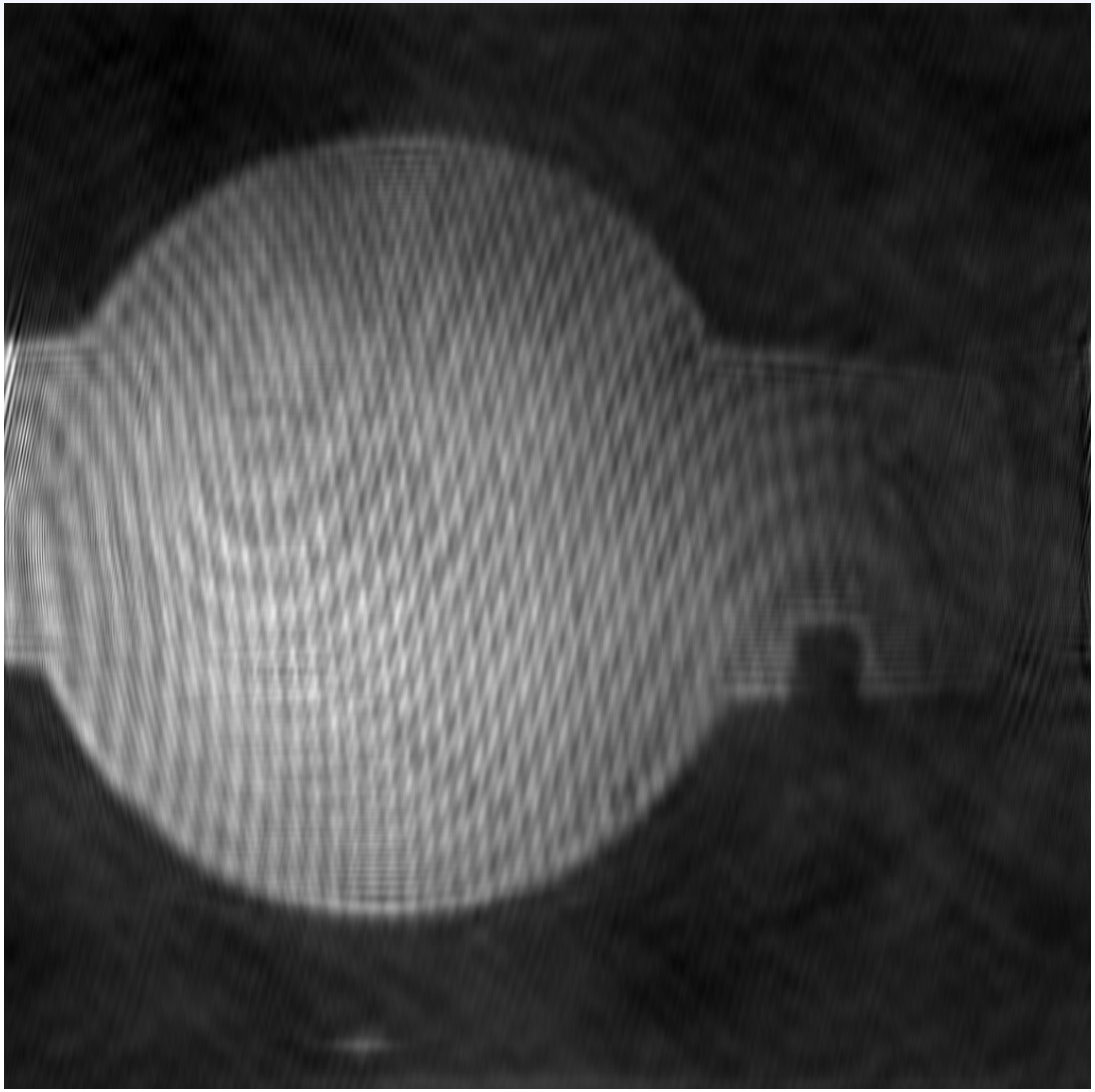
Conclusion

- Single view, off-axis Hartmann, tomographic wavefront sensor has sufficient accuracy to measure cylindrically symmetric refractive index distributions in advanced interferometers
- Accuracy of ~ $\lambda/1000$ (simulation).
- Current precision (Adelaide) ~ $\lambda/250$
- Current precision (AIGO) ~ poor.
- Acquire short coherence length source
- Acquire correct Hartmann plate
- Can extend to non-cylindrically symmetric distributions – use multiple views and azimuthal voxelation

Compensation Plate Effect



Compensation Plate Effect