ADAPTIVE THERMAL COMPENSATION OF TEST MASSES

LIGO-G010238-00-R

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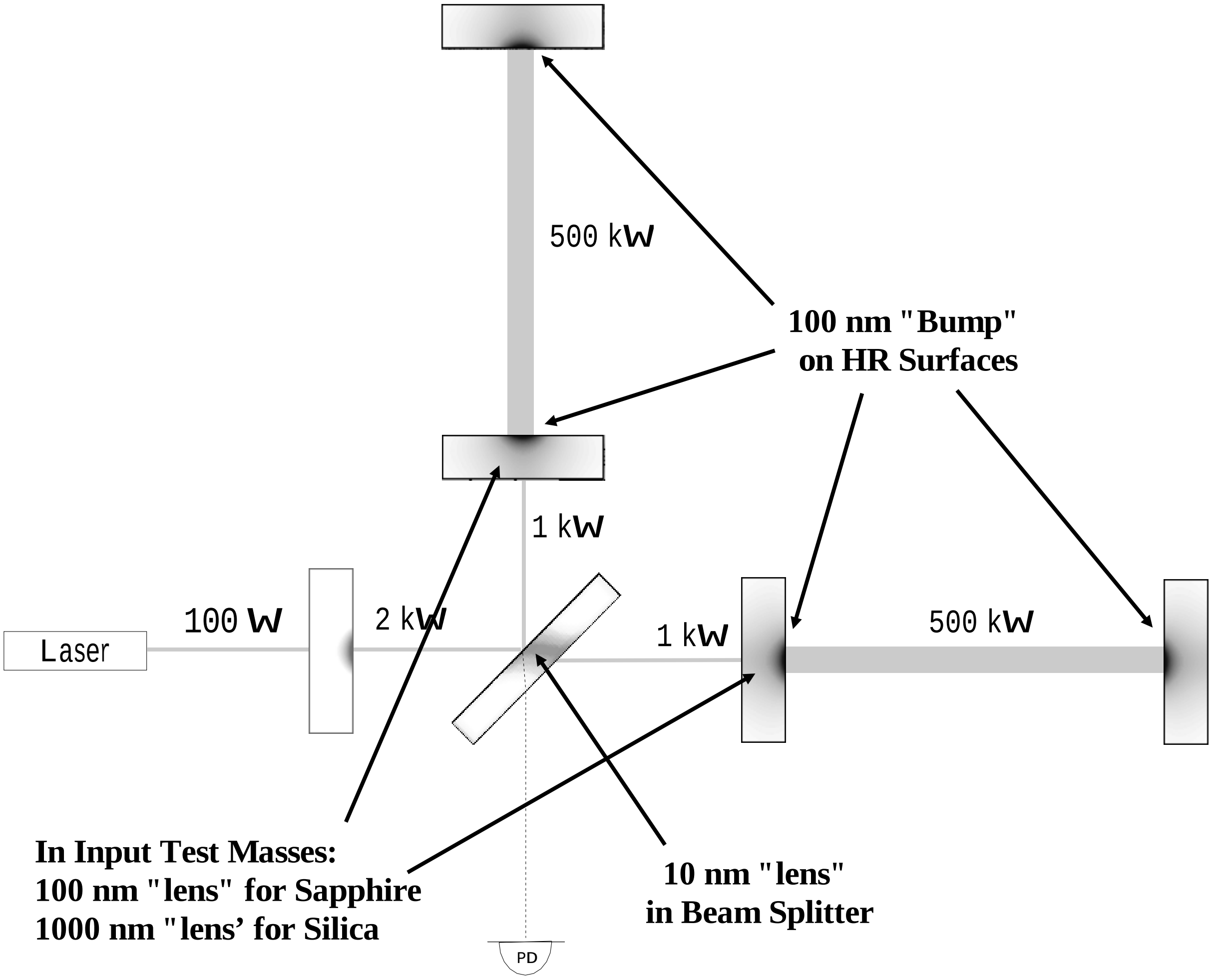
Introduction:
Thermal Effects in LIGO II



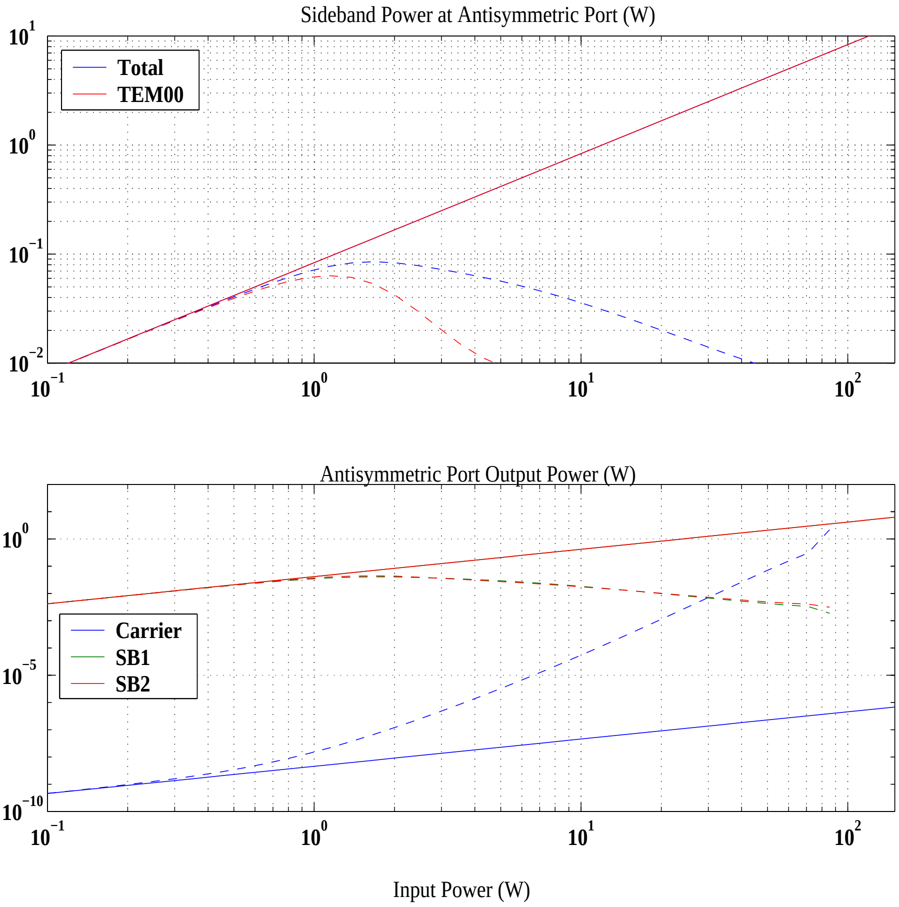
100 nm "Bump"
on HR Surfaces

In Input Test Masses:
100 nm "lens" for Sapphire
1000 nm "lens' for Silica

10 nm "lens"
in Beam Splitter

- Note: the nominal sag of Test Masses is 1μm over the clear aperture (100nm over the beam diameter).

Thermal Effects in LIGO: Melody Model



- LIGO I with low absorption (Heraeus SV) Fused Silica (0.3 ppm/cm).
- Start to see sideband power loss at 1 Watt input power.
- Cold curvature optimized.

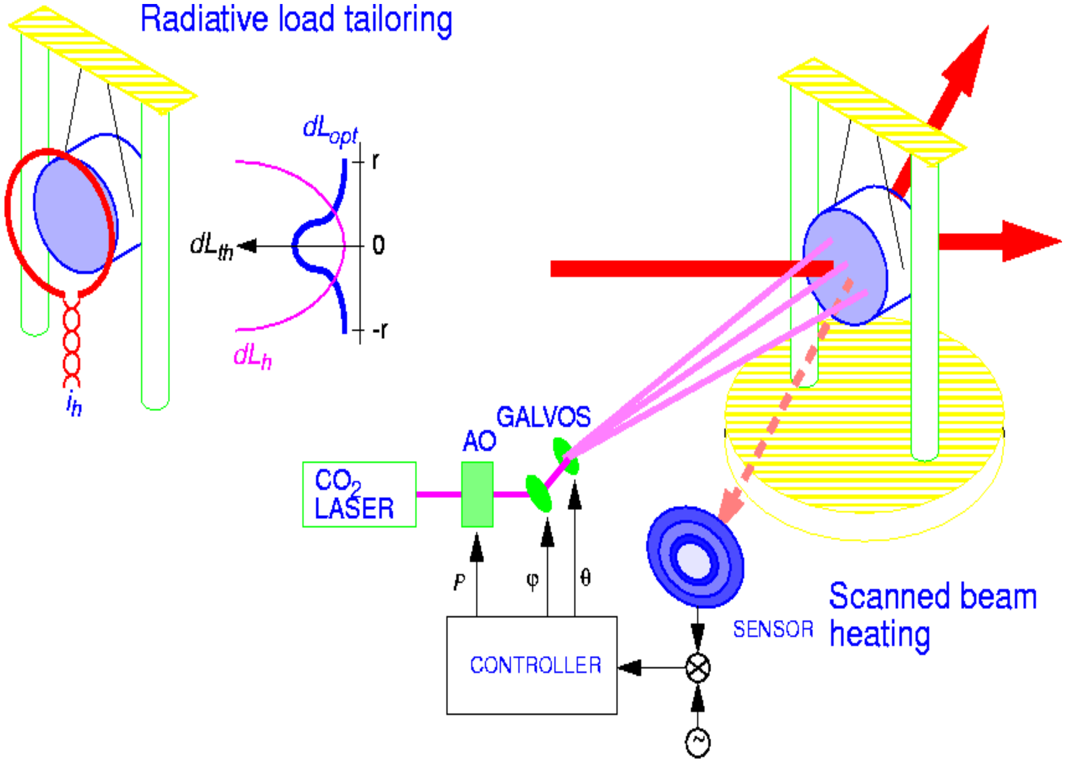
Fixing Thermal Effects in LIGO II
Use "Thermal Compensation"

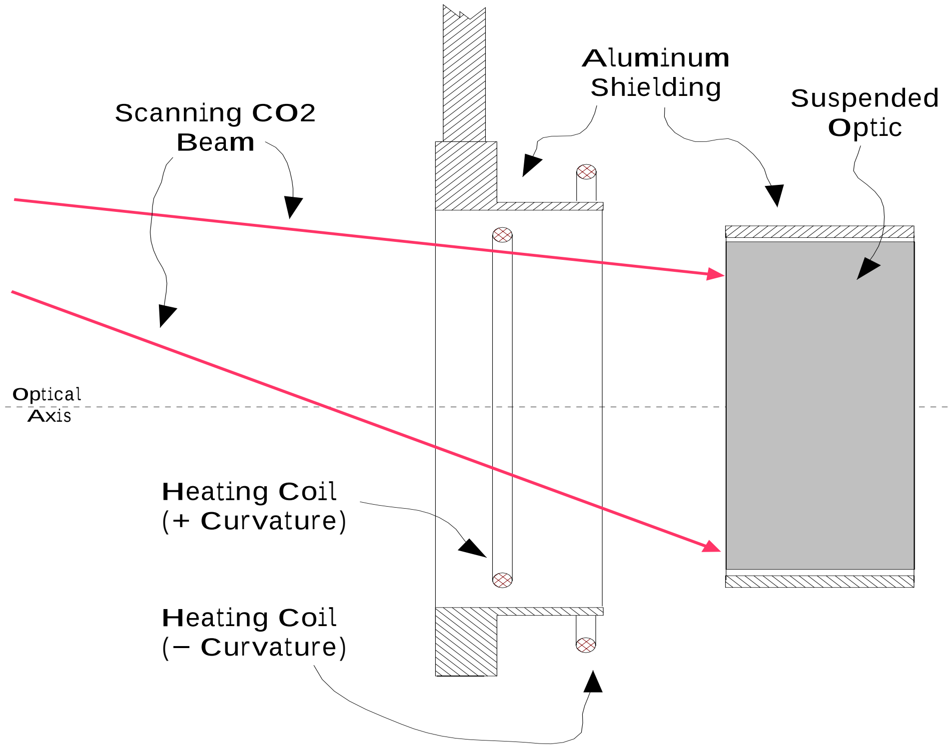
- Directly control the optical properties of a test mass by depositing energy (radiatively) in a well defined pattern.

- Can only *add* optical path (you can put heat in, but you can't extract it).

- Two methods: Static (heating pattern tailored to generate a wavefront of fixed shape)

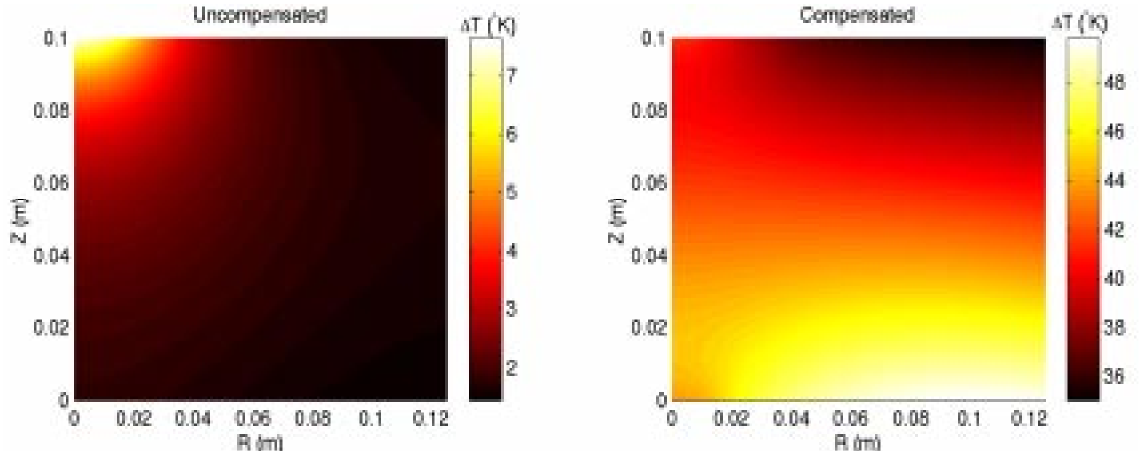
  Dynamic .(adjustable heating pattern, able to generate an "arbitrary" wavefront)

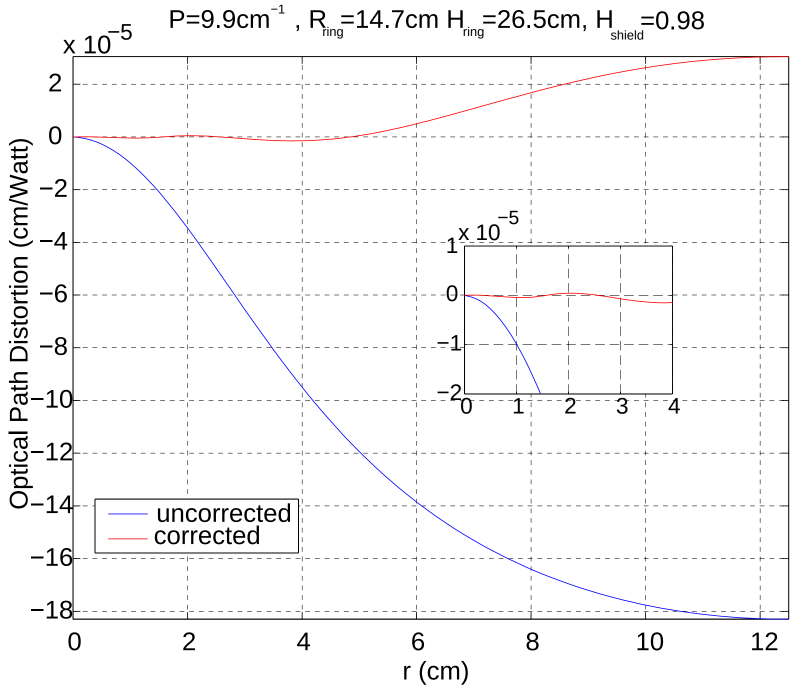

Radiative load tailoring
dL_{opt}
r
0
-r
dL_{th}
dL_h
i_h
GALVOS
AO
CO_2 LASER
P
φ
θ
CONTROLLER
SENSOR
Scanned beam heating


Aluminum Shielding
Suspended Optic
Scanning CO2 Beam
Optical Axis
Heating Coil (+ Curvature)
Heating Coil (− Curvature)

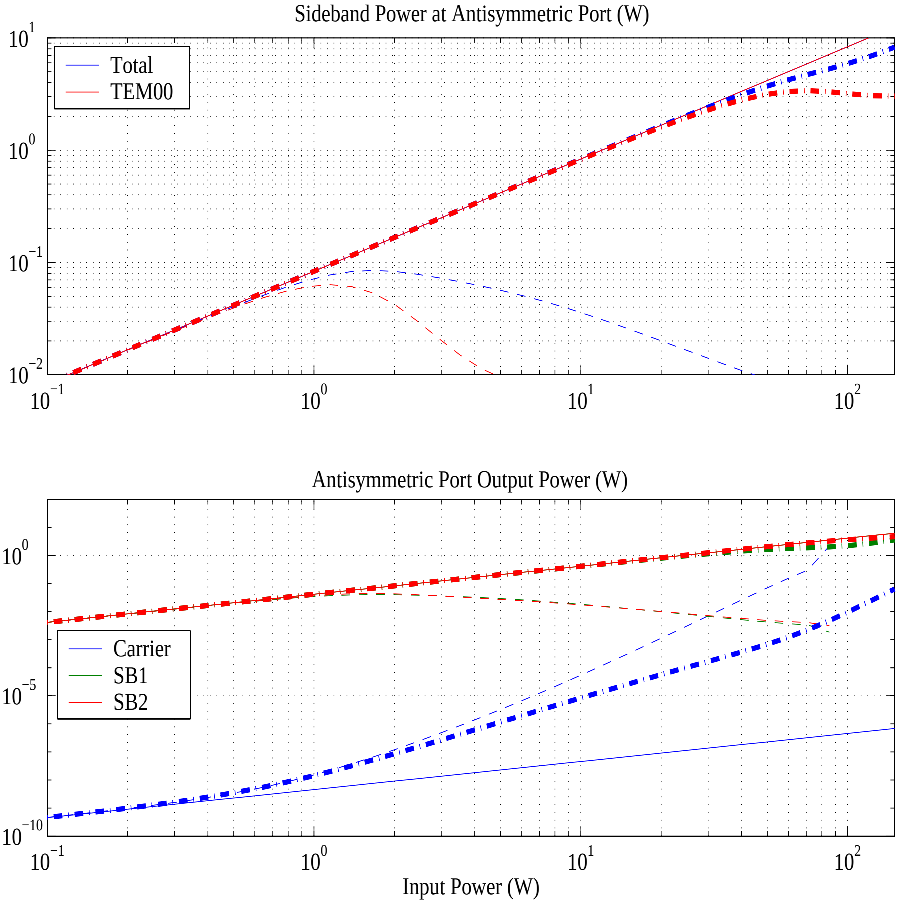
Shielded Ring, Insulated Optic

(Fused Silica ITM)





So What?

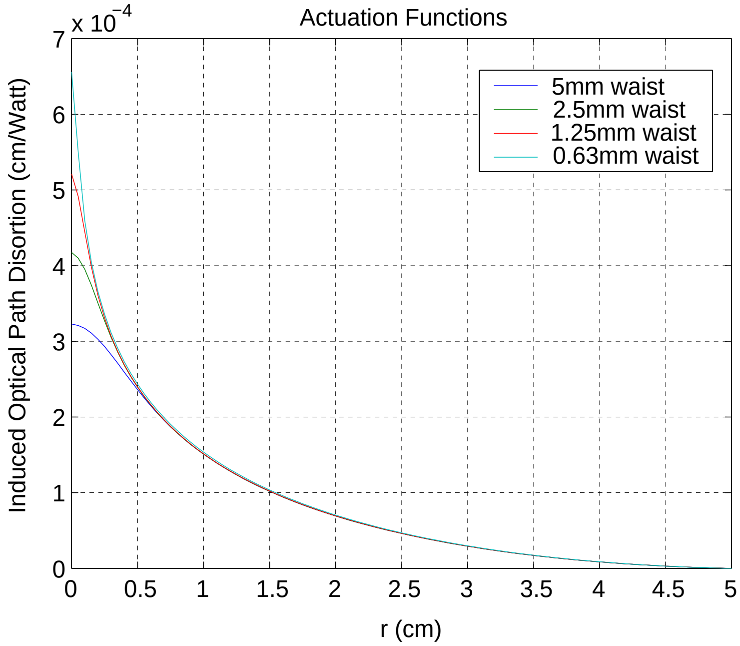


- Same situation as shown originally (slide 2), now with “realistically” compensated fused silica ITM’s.

- Optic curvatures are “cold optimized”.

- Beamsplitter lens *uncompensated.*

Dynamic Thermal Compensation Theory



- Work in a basis of 2D functions that are orthogonal over the measured aperture (e.g. Zernike polynomials, $Z_{nm}(r,\theta)$).

- Work in the basis of "actuation functions" ($\mathcal{A}_k(r,\theta)$, the net distortion generated by the laser actuating with unit power on the kth scan point).

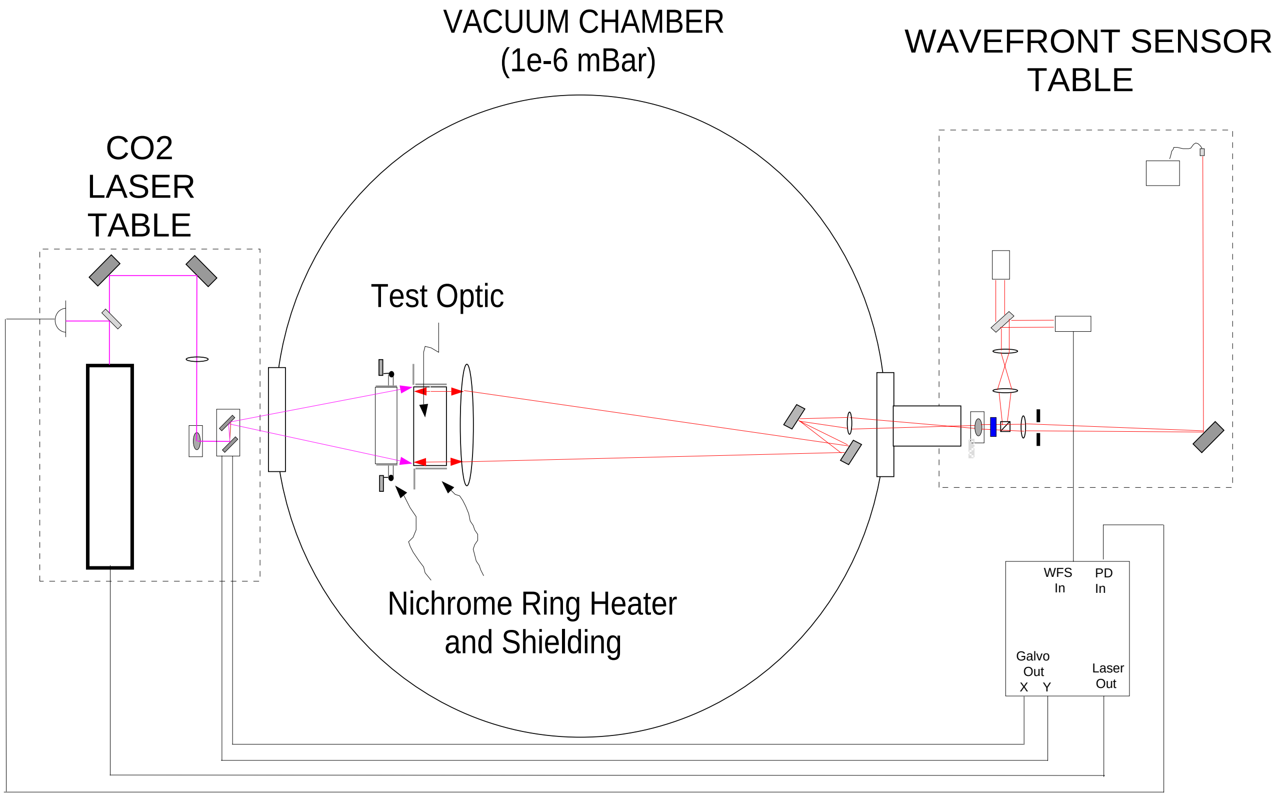
In either case, you calculate (or measure) the *response matrix* $\underline{A}$:

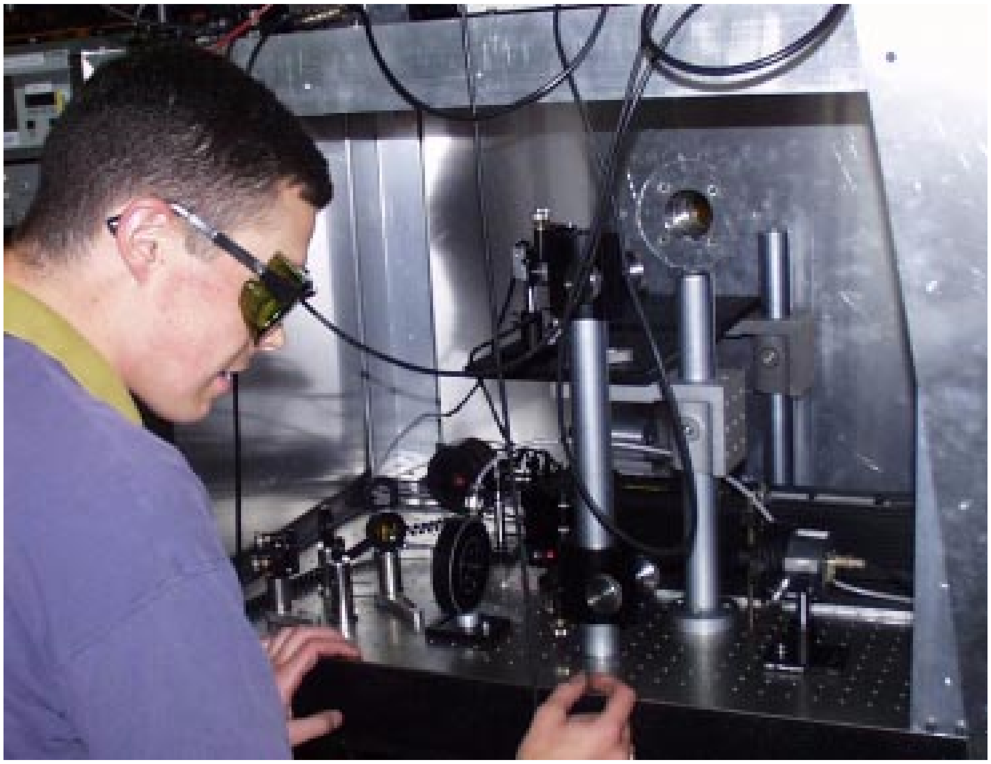
$$\vec{d} = \underline{A} \cdot \vec{P}$$

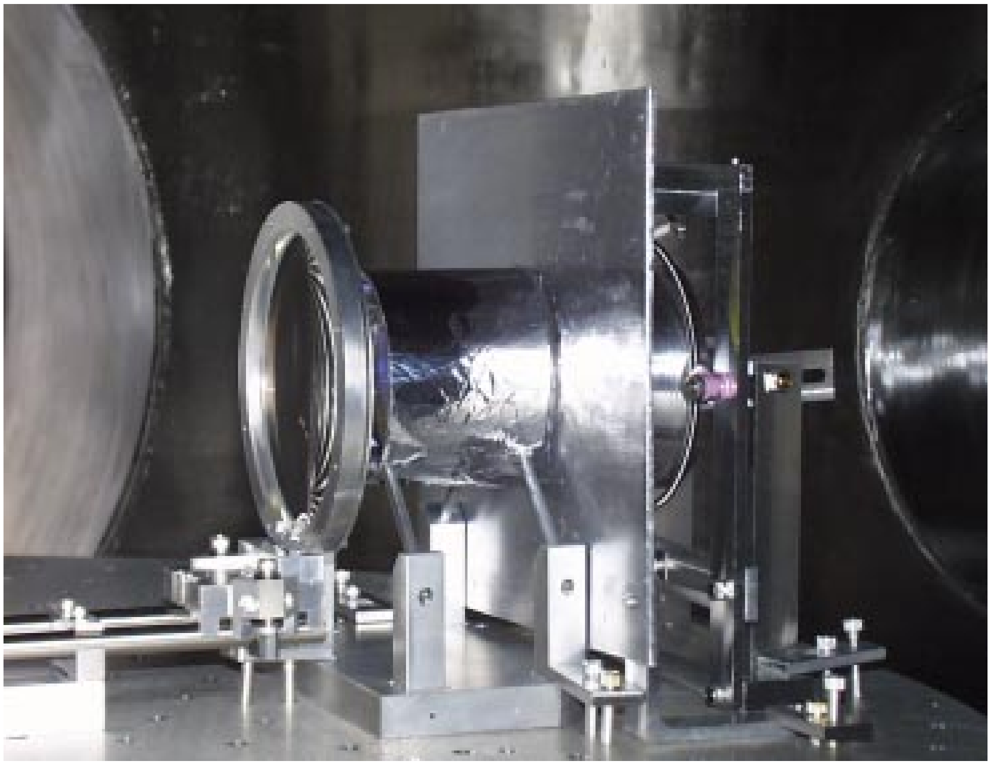
Then invert to get the *actuation matrix* $\underline{A}^{-1}$, so that:

$$\vec{P} = \underline{A}^{-1} \cdot \vec{d}$$

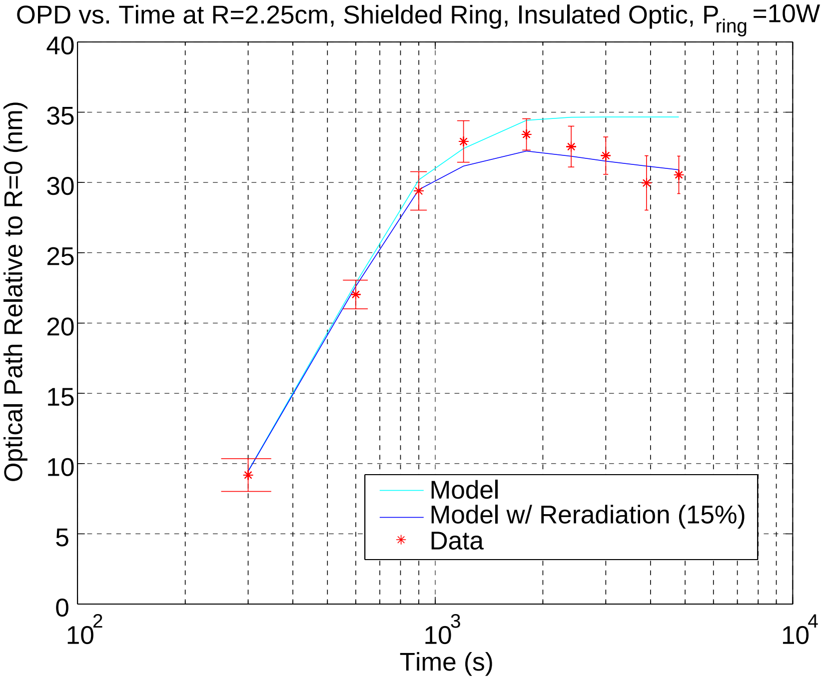
The Experimental Effort

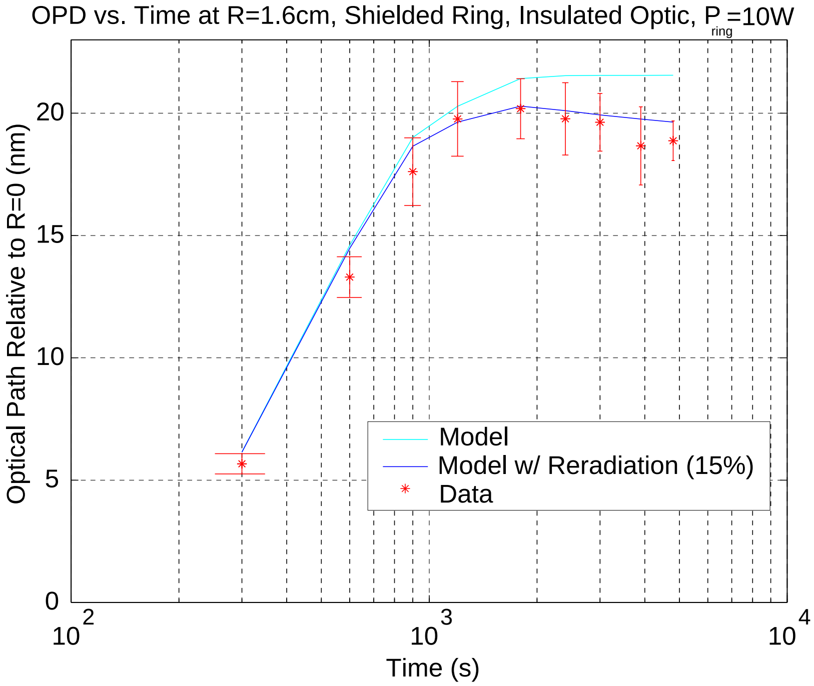






The Data (So Far)
Shielded Ring, Insulated Optic





Scanning Laser Thermal Compensation

Data (Phil Marfuta, '01)

- Actuator beam waist of 5mm, Optical aperture radius of 2.5cm, maximum power of 2.5 Watts.

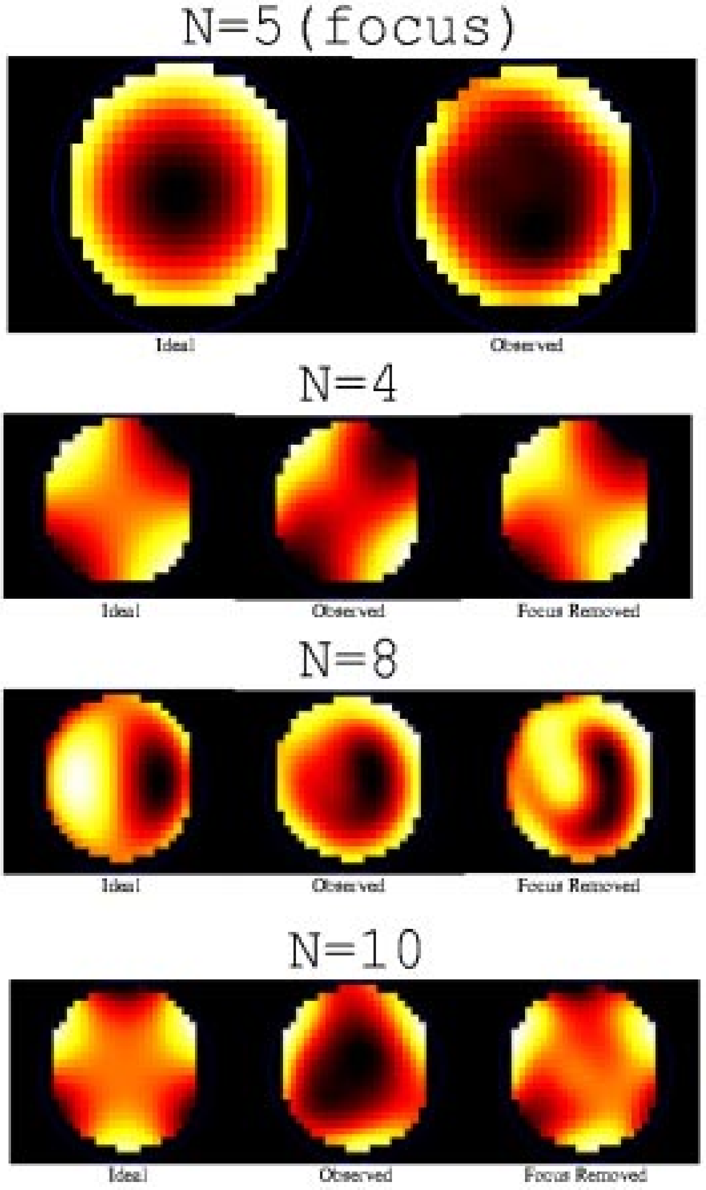
- Demonstrated Zernikes up to Z_{33} (N=10). Higher order terms could not be generated.

- Persistent focus term, approximately constant for each data run.

⇒ Explained by thermoelastic "bowing" of the test optic.

Deformations Induced by Scanning Laser

Data (Phil Marfuta, '01)



Conclusions

- Two and three dimensional finite element models have been built to determine both temperature and thermoelastic deformation fields in cylindrical optics under arbitrary heating.

- Heating ring model: for LIGO I layout with cold curvature optimized fused silica optics, maximum input power increased from 1 Watt to 60 Watts (limited uncompensated beamsplitter?).

- Heating ring experiment: a prototype ring has been built, and its effect on optical path has been measured.

- Scanning laser model: the framework for developing the actuation basis is in place, still need to determine an optimum scan resolution.

- Scanning laser model: Zernikes are a bad idea. Laguerre-Gauss polynomials or actuation functions alone might be better.

- Scanning laser experiment: Initial tests complete. Second round of tests to begin in September 2001.

- Also: through the time response of optical path to the probe beam, thermophysical parameters (thermal conductivity, thermal expansion, etc.) can be extracted from optical samples (e.g. sapphire). *Careful characterization and control of the probe beam required!*