Status Report: Adaptive Thermal Compensation & Determination of Thermophysical Constants

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LIGO Science Collaboration Meeting

LIGO Livingston Observatory
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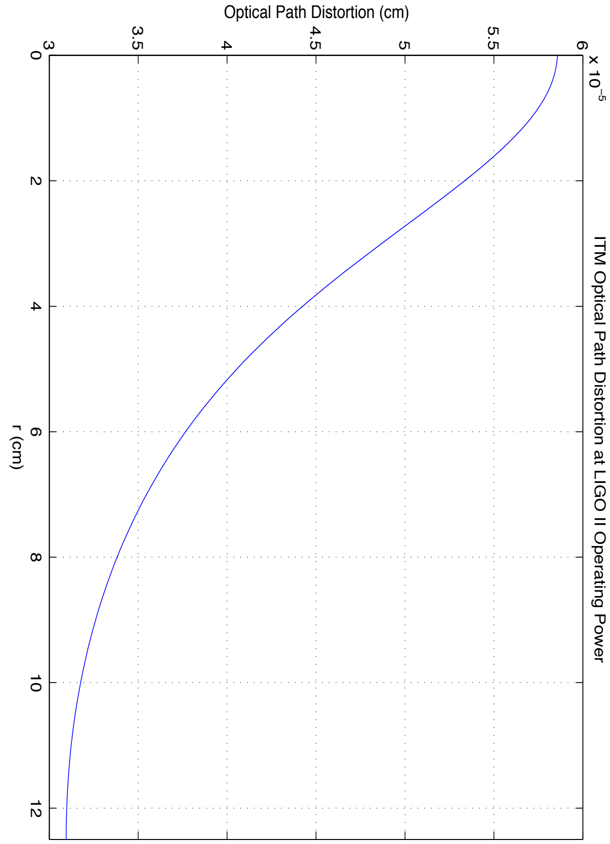
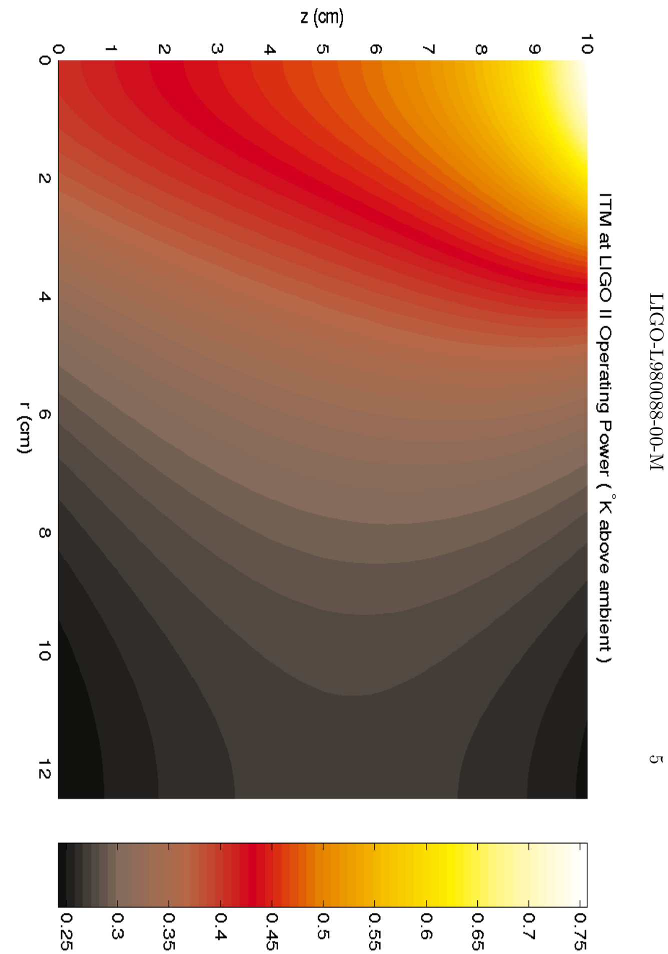
FEA model: uncorrected SiO_2 ITM





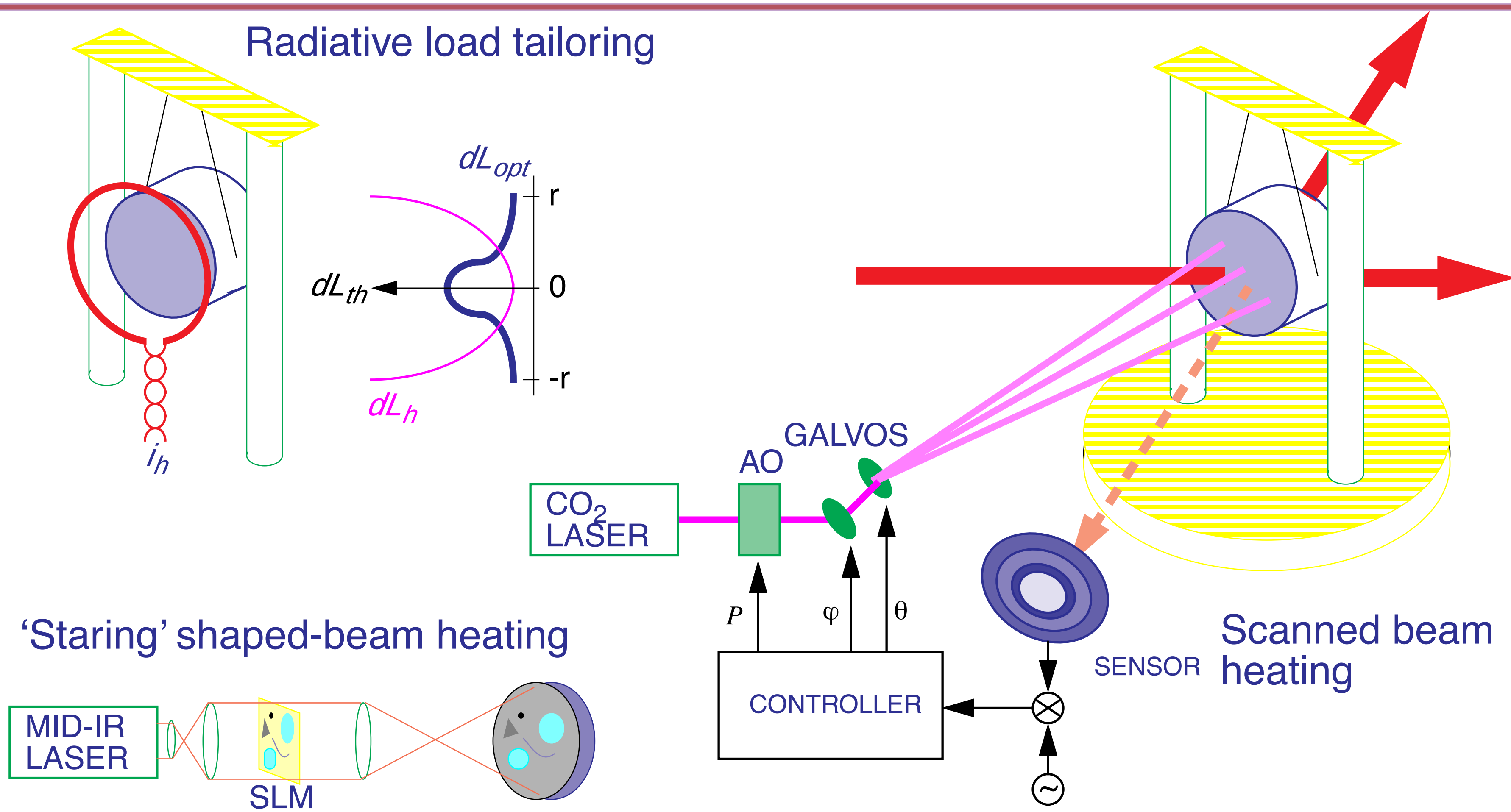
Adaptive Compensation of Thermal Lensing in Advanced LIGO Core Optics

- Thermal distortions expected to limit AdLIGO
  - ◊ Thermal lens aspherical; refocusing, curvature 'preload' not adequate
  - ◊ Cold-start 'bootstrap' problem
  - ◊ Strong possibility of spatially inhomogeneous absorption in Al_2O_3
- Test mass & coating improvements not guaranteed adequate
- Real-time not especially difficult w/current technology
  - Scanning "Phase Camera" (Adhikari, MIT)
  - Staring "Bullseye WFS" (Mueller, UF)
  - Hartmann & Schack-Hartmann methods (Veitch & McLelland, ACIGA)
- Actuation tricky; can't "touch" anything (no PZT mirrors, etc.)

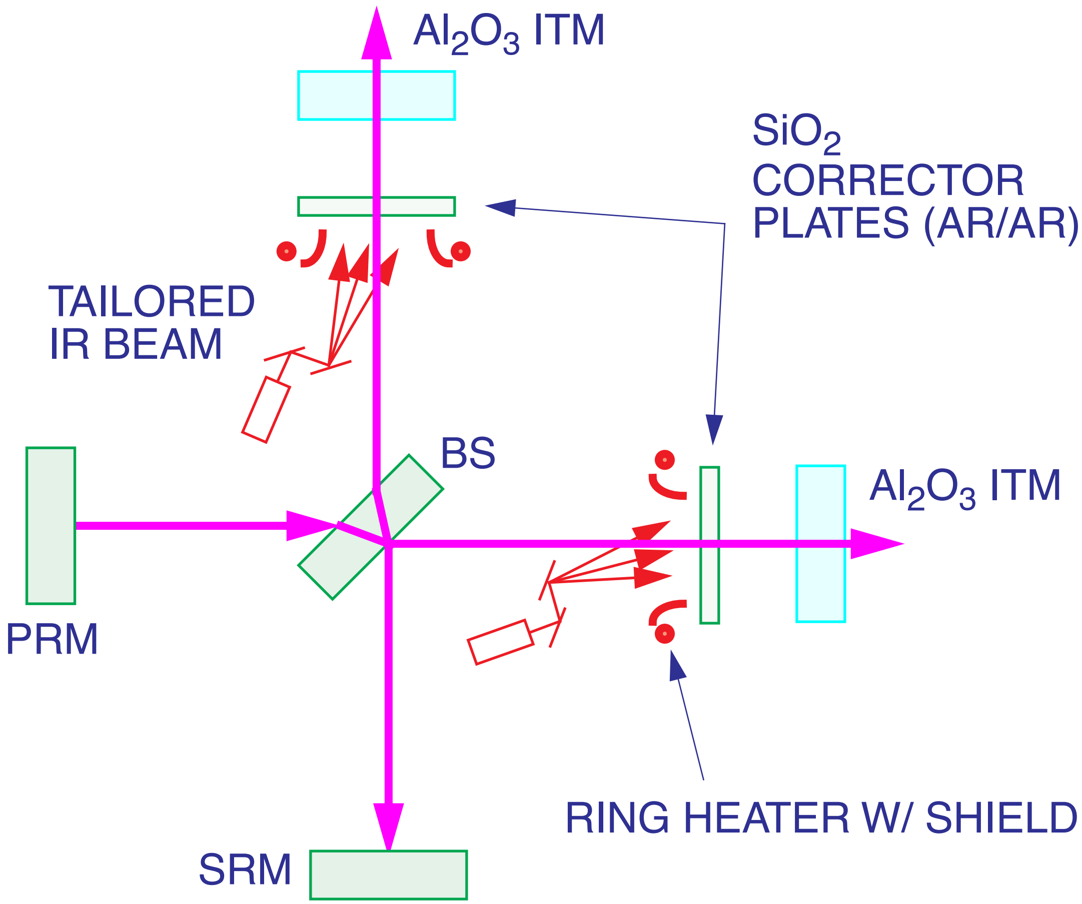
Thermal Actuation

- Thermal actuation on core optics (Lawrence, MIT)
  - Noncontact actuators with low spurious phase noise potential
  - Time constants & spatial scales matched to disturbances
- Radiative ring heater ("Toaster")
  - Simple nichrome ring near optic, aided by passive low-emissivity shield
  - Purely axisymmetric, but efficient and low potential for spurious noise
- Directed beam heating ("Star Wars")
  - Can deal with (nearly) arbitrary error function (e.g., absorption 'hot spots')
  - Potential for noise if directed at main cavity optics
  - Not efficient for first-order effect (simple lensing)
- USE BOTH on TRANSMISSIVE OPTICS (not cavity mirrors)

Thermal OPD Actuators

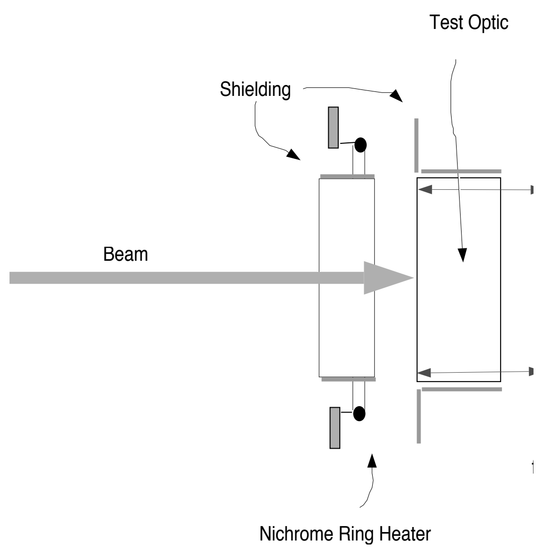


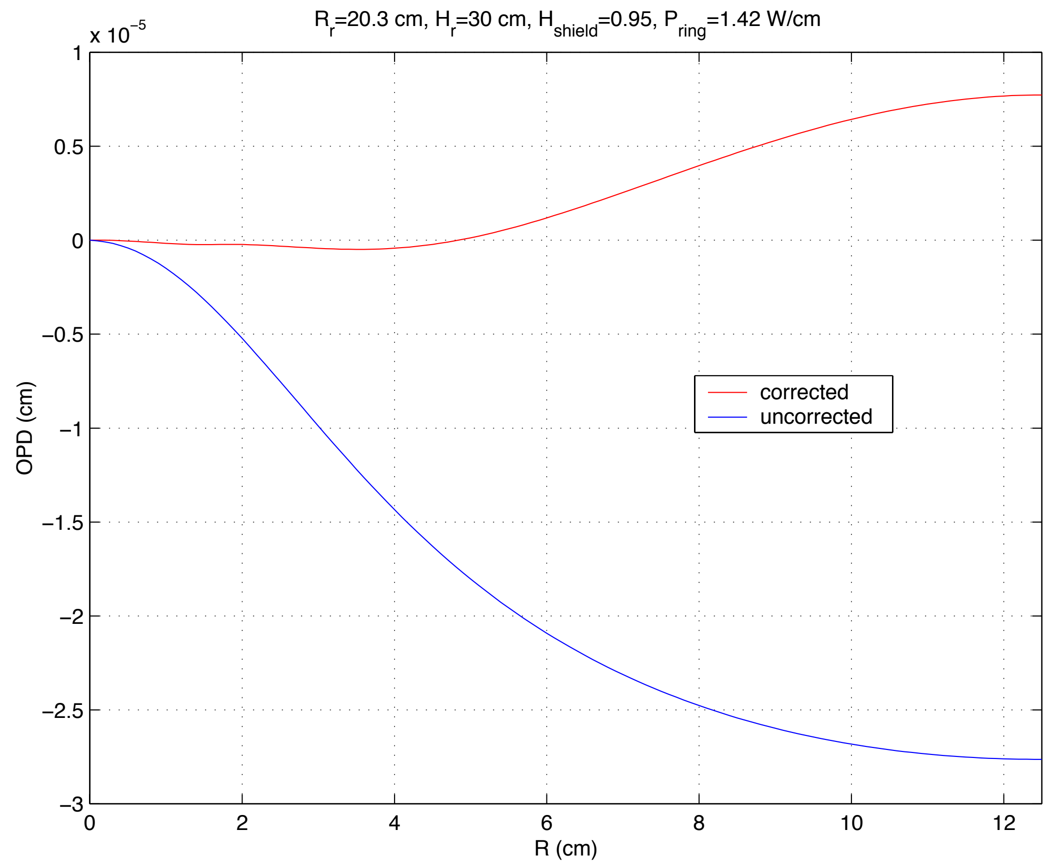
Proposed Implementation: Corrector Plates w/ Dual Actuators



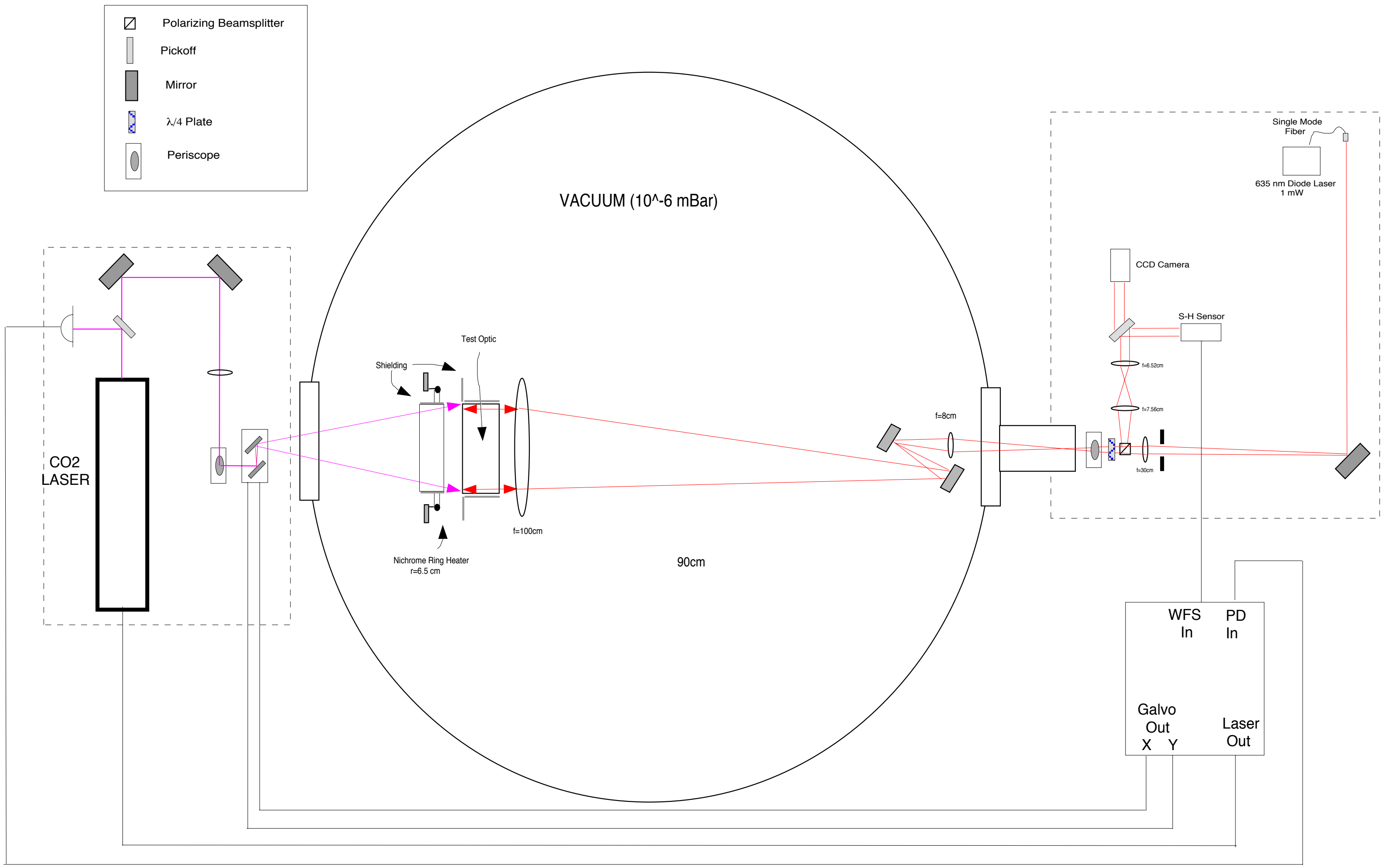
- minimize cavity mirror ΔT
- minimize IR beam noise influence
- thin plate gives added “bowing” leverage
- use fused silica for dn/dT, low k (spatial contrast)
- alternate: use PRM and BS (harder to model!)

FEA model w/correction: ring heater + cylindrical radiation shield





ATC Experiment



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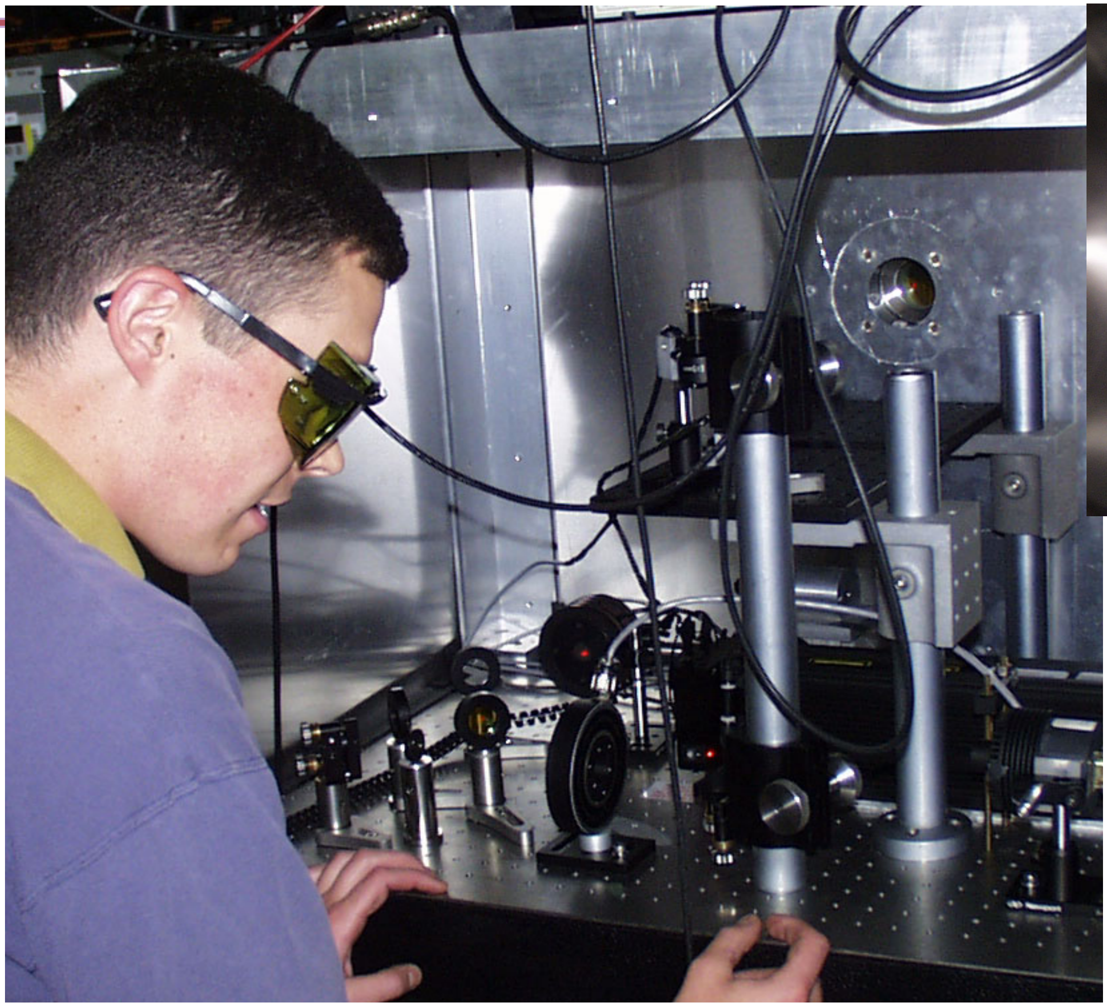
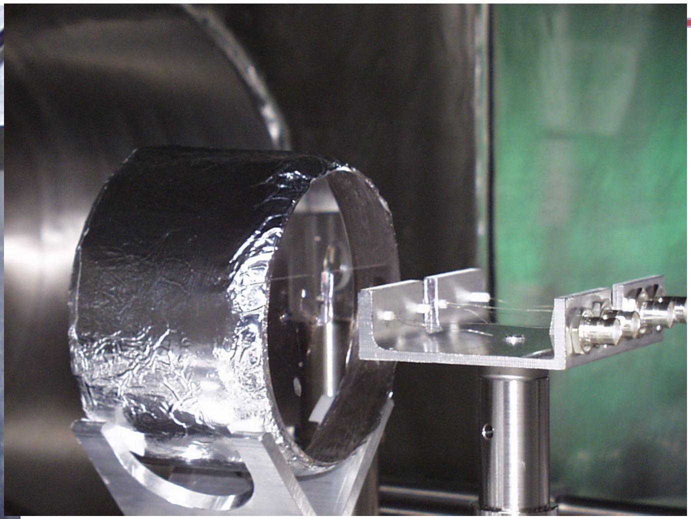
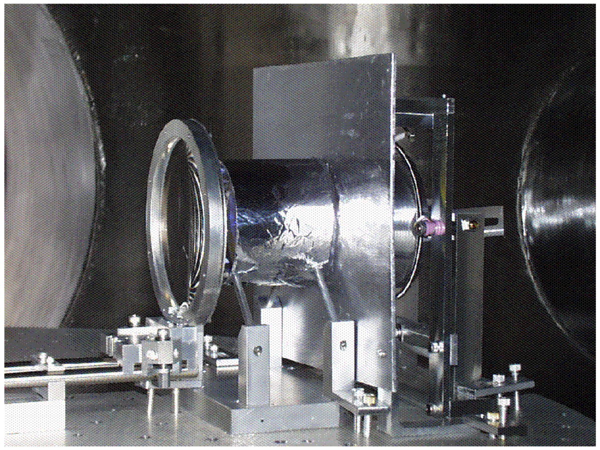
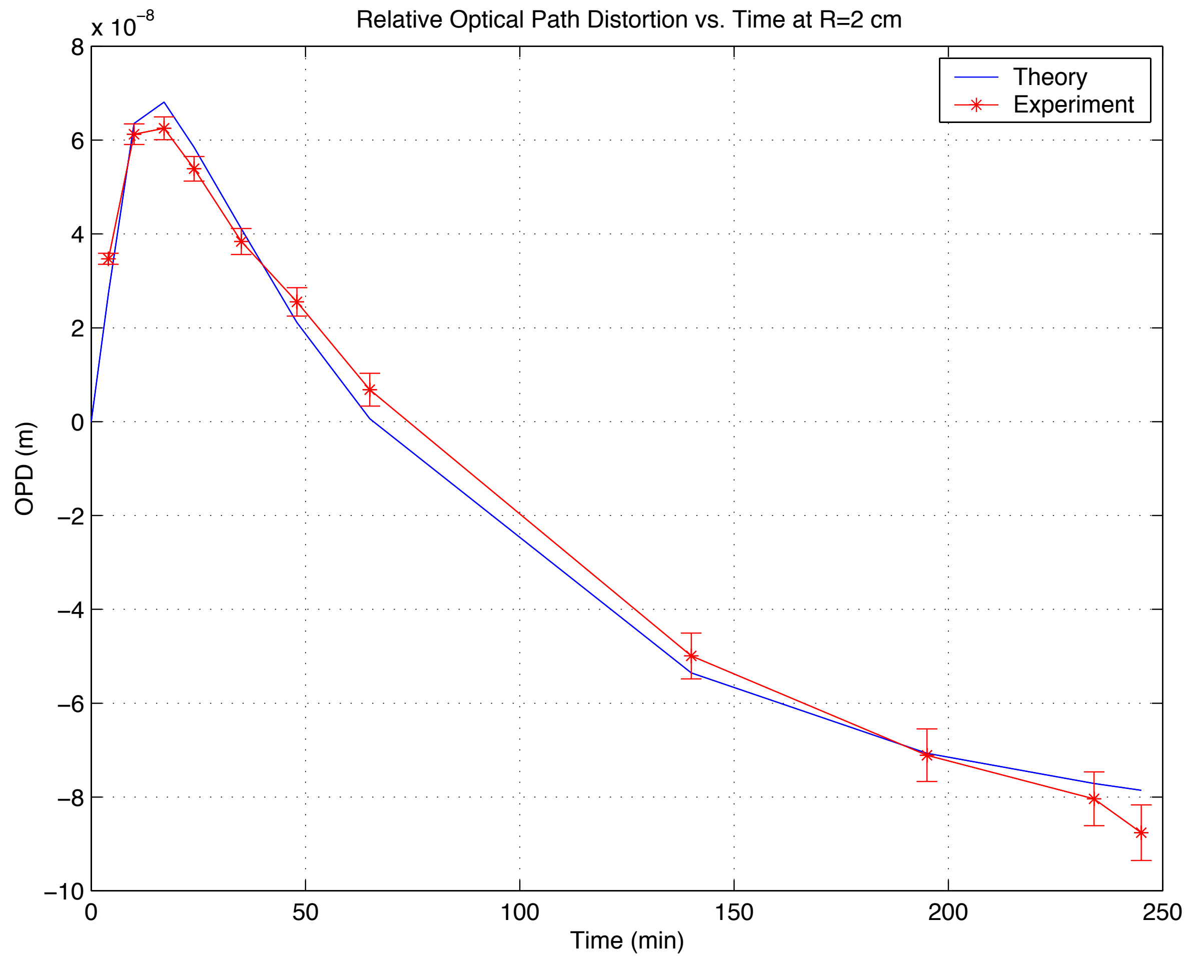




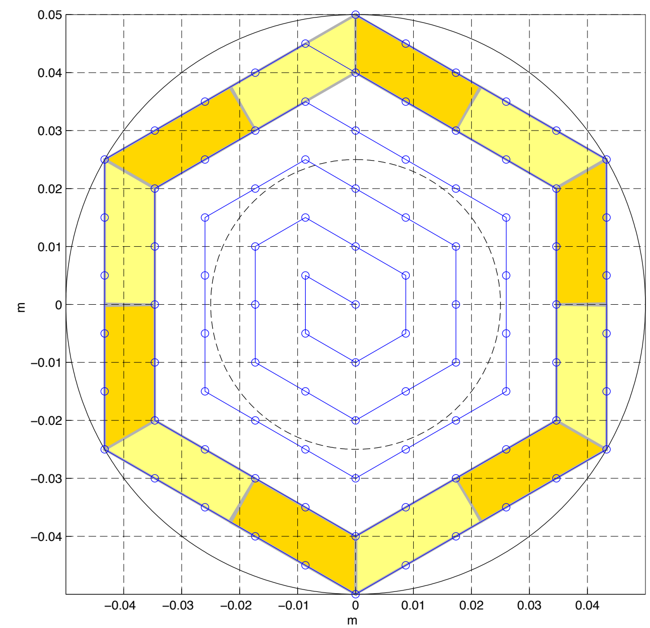


OPD vs. t, ring heater w/SiO_2 test optic



Tailored Beam Heating Progress

- Tailored beam actuation (RCL & undergrads)
  - ◊ FEA of actuation "kernel" (R. Bennett thesis), showed edge effects negligible
  - ◊ Developed actuation basis & generated "arbitrary" Zernike distortions (P. Marfuta thesis); found hard to control net lens ('power') with finite heat
  - ◊ Efficient "spiral" scan pattern (minimum move/settle time for galvos)
  - ◊ Inversion (distortion map --> heat map) converges well if outer periphery is lumped into single zone



Other Progress

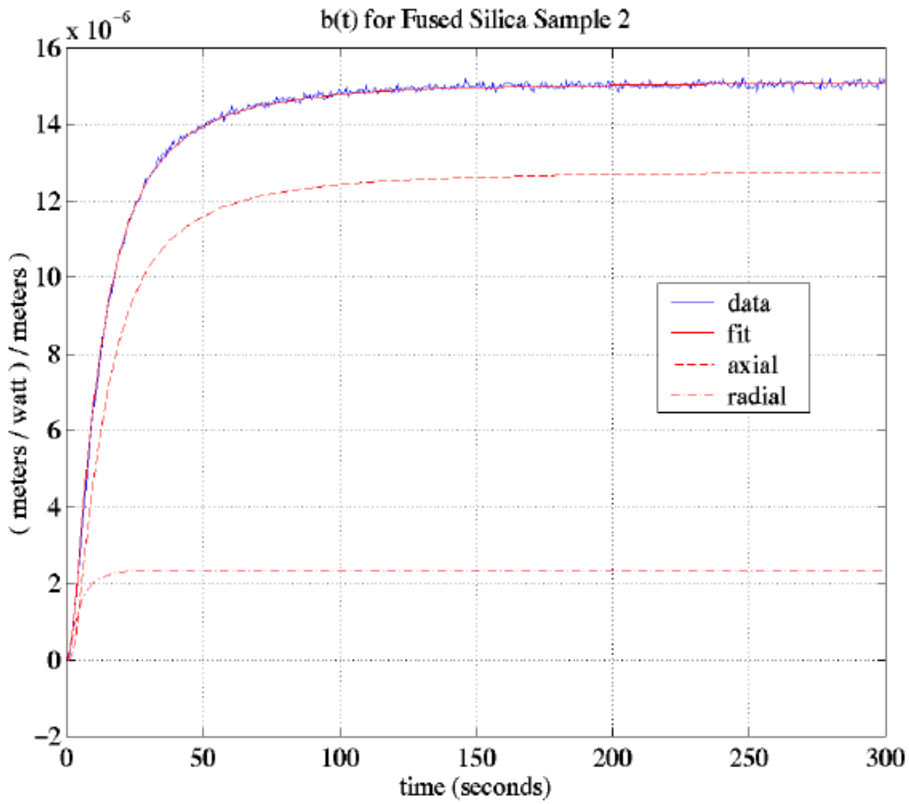
- Interferometer modeling (RCL)
  - ◊ Applied Melody to case of 150W in LIGO I with SV glass ; thermal compensation makes it work! (LIGO-P010023)
  - ◊ Added angled optics (e.g., beamsplitters) to Melody (LIGO-T020001)
  - ◊ Added anisotropic material (e.g., sapphire) capability to Melody (LIGO-T020001)
- Sensing & interpretation (SH sensors are deceptive!)
  - ◊ Imaging of optic at SH CCD plane is critical (test target & second CCD)
  - ◊ Edge diffraction causes bias (throw away periphery, use big optics)
  - ◊ Don't trust "wavefront reconstruction" algorithm; use raw gradients
  - ◊ Calibrate magnification using tilted mirror for pure shear
- Still need measurements of absorption inhomogeneity

Thermophysical Constants

- Radial OPD gradient vs. time in “impulse response” (space & time) will project k_{th} and α independently
- Prior attempts to also include dn/dT were not so easy
- Results sensitive to systematics from SH sensors, “wavefront reconstruction” errors
- Now have anisotropic formalism for influence kernel, use only wavefront gradients
- Waiting for “good” C-axis sapphire, but initial silica test looks consistent with model

Fused Silica Constants

@ 60C temperature



Measure:

$d\phi/dr = a(t)\ r + b(t)$

Isotropic Fit:

k_{th}= 1.47(±.03) W/m/K

$\alpha = 6.39(\pm.13)\times10^{-7}$ /K

Anisotropic Fit:

k_{th_r}= 1.48(±.08) W/m/K

k_{th_z}= 1.13(±.24) W/m/K

$\alpha_r = 5.07(\pm1.04)\times10^{-7}$ /K

$\alpha_z = 6.83(\pm0.40)\times10^{-7}$ /K

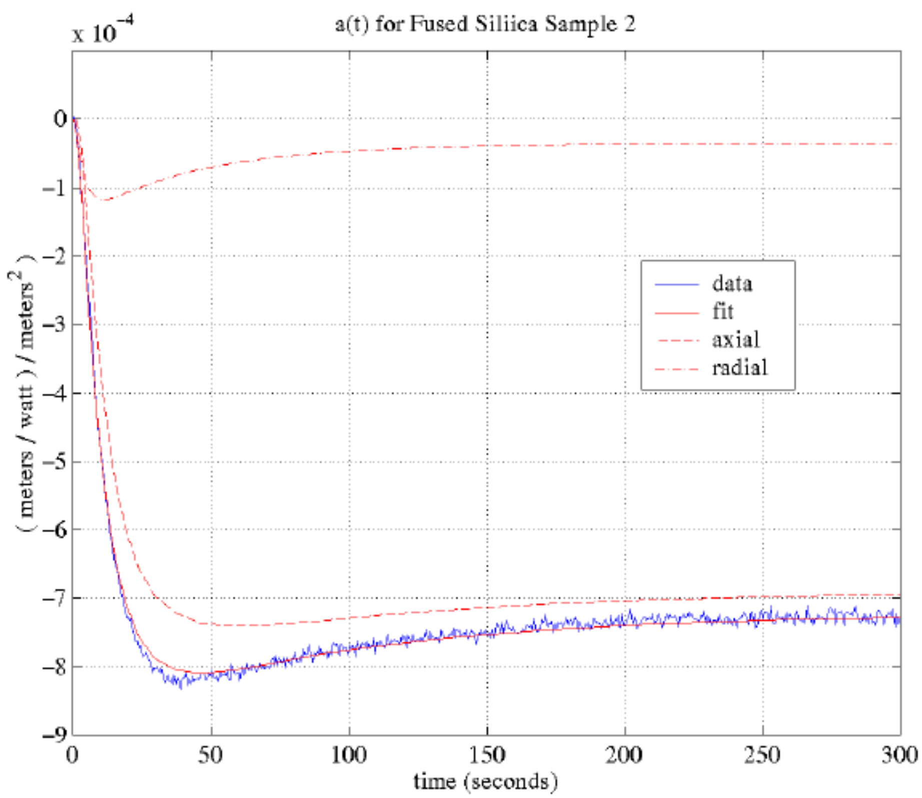
Published Values:

k_{th}= 1.42 W/m/K (CRC)

$\alpha = 5.5\times10^{-7}$ /K (??)

Fused Silica Constants (cont'd)

@ 60C temperature



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Future Track

- Now: Second pass at sapphire k_{th}, α
- Next: Retest toaster, beam actuators on silica
  - ◊ Significantly enhanced models
  - ◊ Better control of systematics in SH sensing
  - ◊ With more IFO performance modeling -> RCL Ph.D. thesis
- Transitioning work to other team members
  - ◊ Dave Ottaway + student + part-time optomech engineer
- 4Q'02: deliver "toaster" design to Gingin
- 2Q'03: deliver prototype dual-actuator system to Gingin