Thermal Optical Distortions and Compensation in GW Interferometers

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Interferometers designed to detect gravitational waves are highly susceptible to thermal misalignment:

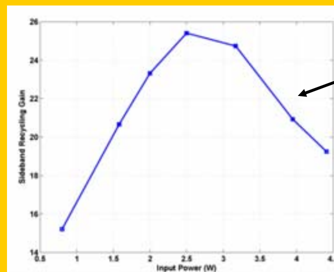
•they use optical cavities ~10-1000 m long

•these cavities are close to marginal stability (g≈1)

•they store ~10-1000 kW optical power

Thus, even small heating due to light absorption creates significant thermal lensing.

RF sideband power vs. input power in the LIGO power recycling cavity. As the input power increases, thermal lensing distorts the cavity, limiting the storable RF power.



Thermal lensing impairs detector performance by reducing:

•arm cavity mode power gain and structure profile

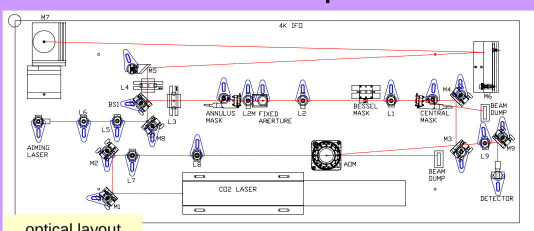
•heterodyne sideband power and overlap with optical carrier

•contrast at Michelson dark port

•coupling of GW signal through output cavity

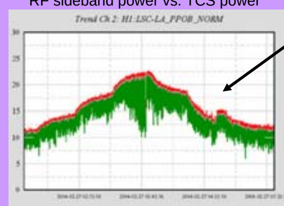
A thermal compensation system (TCS) can independently set the thermal lens, allowing good thermal alignment at any input power.

Methods of Compensation



optical layout

RF sideband power vs. TCS power



LIGO CO_2 laser projector

one heating pattern

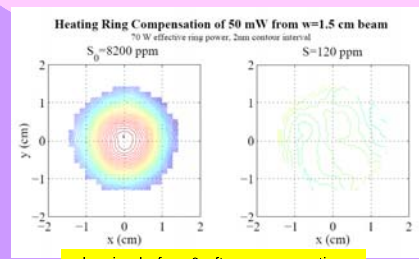
as installed

A CO_2 laser projector can reside outside the detector vacuum and produce a variety of easily modified profiles. However, the system is complex and low noise operation requires effort.

An incandescent ring heater resides inside the vacuum near the optic. This simple device gives good performance for axisymmetric thermal lensing and low noise, but is not as flexible.

heater & mirror in vacuum

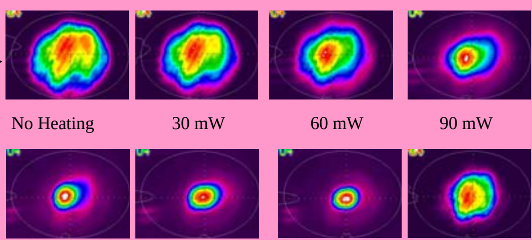
MIT prototype ring heater



lensing before & after compensation

TCS Performance

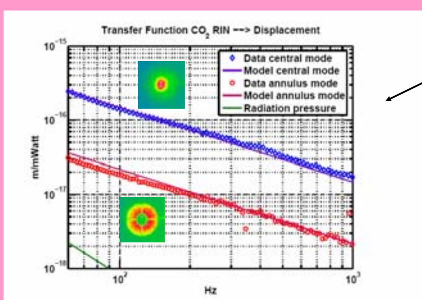
The optical heterodyne sideband mode structure in LIGO as it is tuned through optimal overlap with the optical carrier beam. At 90 mW the heterodyne control signal is maximized.



The dark port signal in the GEO600 detector, at Garching, Germany, with and without thermal radius of curvature correction of the cavity end mirror.

~1% ~0.05%

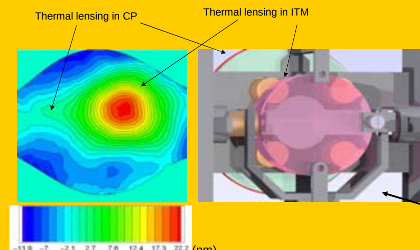
(H. Lück *et al*, 2004 Class. Quantum Grav. 21 S985-S989, 2004)



$$\langle\Delta z\rangle = \frac{P}{2\pi f C\rho}\left(\frac{1}{\pi w^2}\left[(1+\eta)\alpha\left(1-\frac{\pi}{2\mathcal{F}}(n-1)\right)-\frac{\pi}{2\mathcal{F}}\frac{dn}{dT}\right]+\frac{6\alpha}{h^2}C^{\rm cm}_{\rm mm}\right)\mathrm{RIN}$$

Measured coupling of TCS noise to detector output in LIGO, for the two heating patterns shown. Data agree well with analytical predictions (e.g. formula for central mode model).

Future Work



Hartmann sensor image of thermal lens in mirror and compensation plate at the Gingin facility (Western Australia). Image courtesy of the University of Adelaide.

Advanced detectors will have even higher optical power and more need for TCS. Research includes:

•separate thermal compensation optics

•low-absorption coatings

•advanced optical substrate materials

•*in-situ* lens monitors

•passive compensation (negative dn/dT optics)

•real-time reconfigurable projectors

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