Advanced Ligo: Non gaussian beams

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Related documents:

http://www.cco.caltech.edu/˜kip/ftp/beamreshaped020903.pdf

Physical Review D Vol.67 (2003) ID 102004

Proposal for a Tabletop... Ligo technical note

Motivations for our proposal

In Advanced Ligo the sensitivity limit is dominated by thermoelastic noise. By better averaging over the mirror thermal noise, we obtain similar improvements as by cryogenics techniques.

Advantages:

- the design or construction of the interferometer is almost not affected
- some level of reduction is provided for a variety of perturbations, such as Brownian and coating thermal noise and also for the thermal lensing effect
- if thermoelastic noise is sufficiently reduced in the region of maximum sensitivity, QND techniques may be successfully applied to further improve the response of the detector.

Scaling laws for T

Standard Thermal Noise: $S_{bare}(f) \sim T$

Thermodynamical Fluctuations:

$$S_{bare}(f) \sim T^2 \Longleftarrow < \delta T > = \sqrt{\frac{k_B T^2}{\rho C V}}$$

Coating Mechanical Loss: $S_{bare}(f) \sim T$

Scaling laws for w

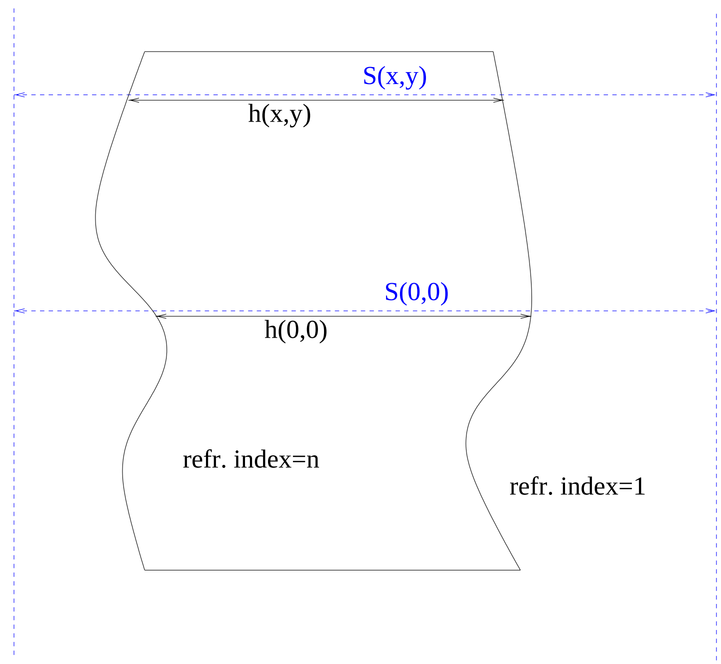
Standard Thermal Noise: $S_{coupled}(f) \sim w^{-1}$

Thermodynamical Fluctuations:

$$S_{coupled}(f) \sim w^{-3} \Longleftarrow < \delta x^2 > = \alpha^2 \delta T^2 \left[\frac{K_{th}}{C\rho}\tau\right]$$

Coating Mechanical Loss: $S_{coupled}(f) \sim w^{-2}$

Influence on thermal lensing

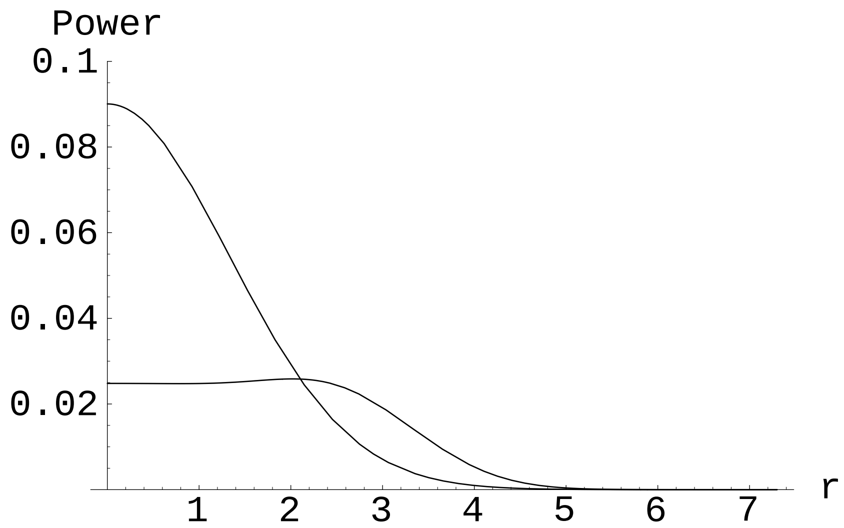


$$S(x,y) - S(0,0) = nh(x,y) - nh(0,0) - (h(x,y) - h(0,0))$$

$$\Delta S(x,y) = \left[\frac{\mathrm{d}n}{\mathrm{d}T} + \alpha(n-1)\right] \int_0^{h(x,y)} \Delta T(x,y,z)\mathrm{d}z$$

$$\int_0^h [\Delta T(x,y) - \Delta T(0,0)]\mathrm{d}z \simeq -\frac{P_{abs}}{2\pi K_{th}} \frac{x^2+y^2}{w^2}$$

The flat top beam



The power spectral density of thermoelastic noise is reduced by $\sim 1/3$. The comparison is done with the Gaussian beam which has the same diffraction loss.

What scales unfavorably?

1. larger sensitivity to alignment

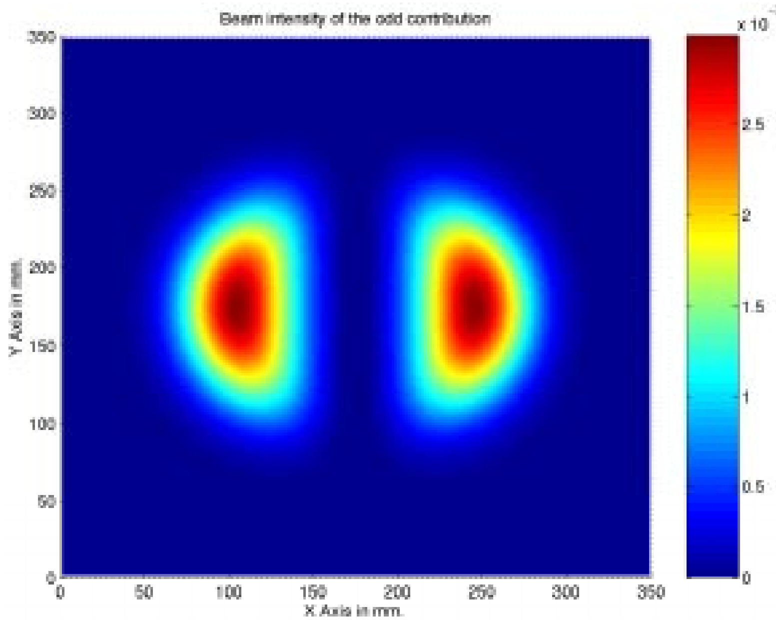
$$\frac{P_{DP}}{P_{BP}} = \left(\frac{k w_{BL}(L)\theta}{2\sin\eta_{BL}}\right)^2 = 0.2196(\frac{\theta}{\mu rad})^2$$

$$\frac{\eta_{BL}}{\eta_{FT}} = \frac{0.17}{0.04}$$

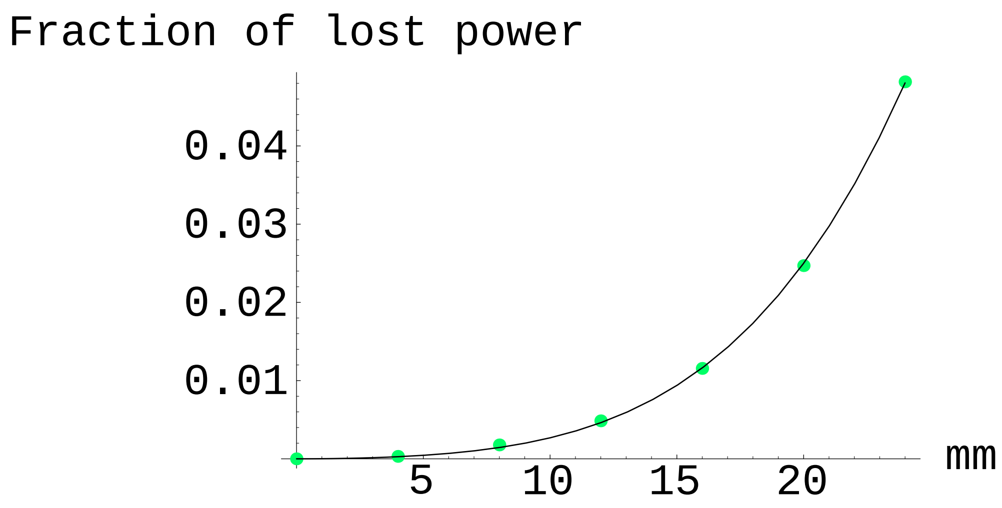
2. moderately increased response to transverse displacement of the mirrors
3. stricter constraints are necessary for the figure errors of the mirrors

Sensitivity to angle error

$$
\begin{aligned}
v_{tilt} &= \alpha_0 u + \alpha_1 u_{odd} + \alpha_2 u_{even} \\
\alpha_0^2 &= \frac{P_u}{P_{tot}} = 1 - \alpha_1^2 - \alpha_2^2 \\
\alpha_1^2 &= \frac{P_{odd}}{P_{tot}} = 5.1426\left(\frac{\theta}{\mu\text{rad}}\right)^2 \\
\alpha_2^2 &= \frac{P_{even}}{P_{tot}} = 4.12\left(\frac{\theta}{\mu\text{rad}}\right)^4
\end{aligned}
$$



Sensitivity to lateral displacement



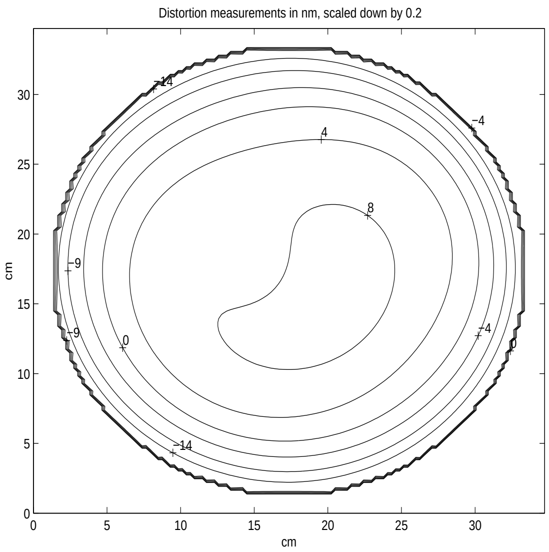
$$\frac{\Delta P}{P} = [1.49(\frac{\delta x}{mm})^2 + 0.01(\frac{\delta x}{mm})^4]10^{-5}$$

Sensitivity to figure errors

The measured height error $\delta z(x, y)$ of a beamsplitter substrate is used.
The lost power is

$$\frac{P_{DP}}{P_0} = 0.0297\epsilon^2 + 0.0064\epsilon^4$$

$$\delta z_{fid}(x, y) = \epsilon \delta z(x, y)$$



Priorities

A tabletop experiment that can demonstrate the technique, verify the behaviour of the flat top beams and build experience in their production and control.

In order to characterize the sensitivity of the interferometer, when non gaussian beams are supported inside the cavities, a series of experiments with a simple Fabry-Perot should be done.

The predicted behaviour should be explored in more and more complex situations.