Thermal noise and high order Laguerre-Gauss modes

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GWADW meeting, Isola d'Elba
May 27th – Jun 2nd , 2006

LIGO-G060331-00-Z

Introduction

- Mirror thermal noise will limit the interferometers sensitivities around few 100 Hz

- Thermal noise is smaller with more uniformly distributed power

  => Spherical-spherical cavities instead of flat-spherical cavities (Virgo case)
  => Flat beams

- Flat beam issues:
  - Production of flat beams
  - Production of "Mexican hat" mirrors
  - More coating thermal noise?

⇒ What can be gained with high order Laguerre-Gauss modes?
  - Advantage: use classical mirrors

Mirror thermal noise

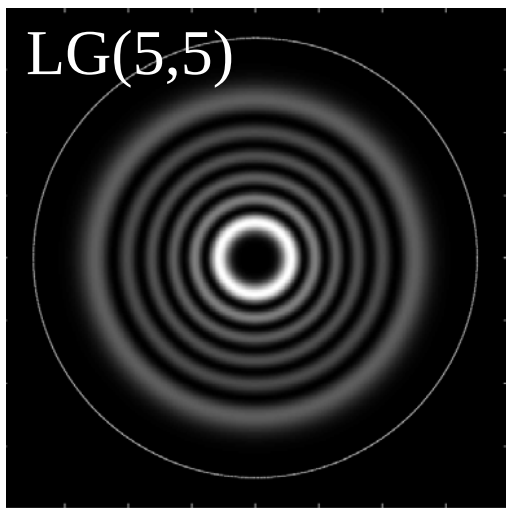
Mirror bulk thermal noise estimated with the BHV model (Phys. Lett A 246 (1998) 227)

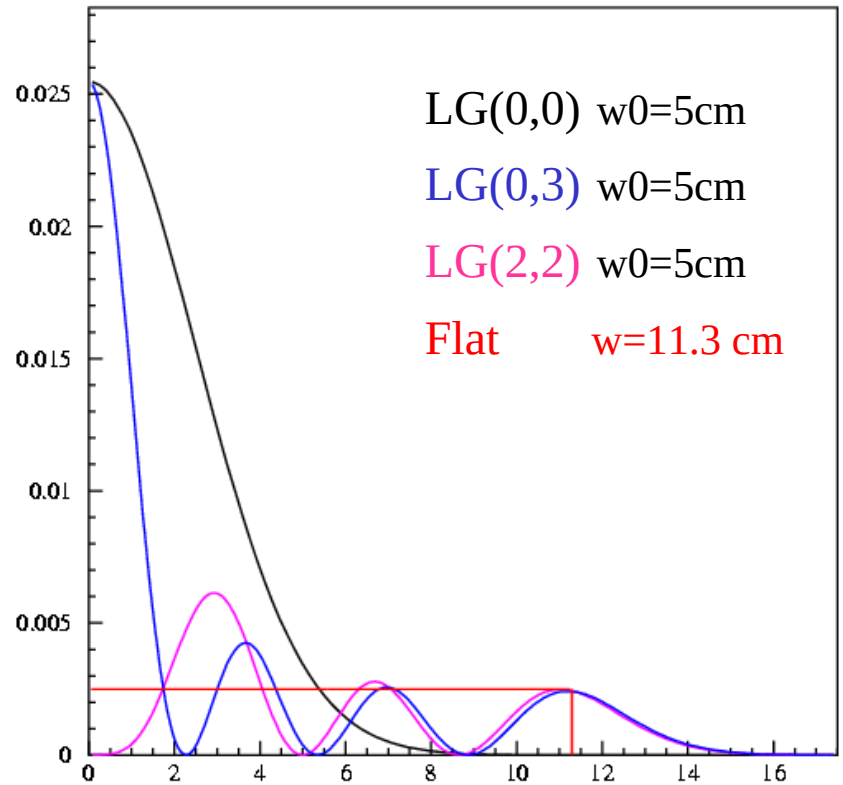
Displacement noise PSD: $S_x(f) = \frac{4k_B T}{\pi f} \phi U$

Loss angle

U: Strain energy of the mirror under a pressure distribution having the profile of the readout beam

Thermal noise smaller for flatter profiles



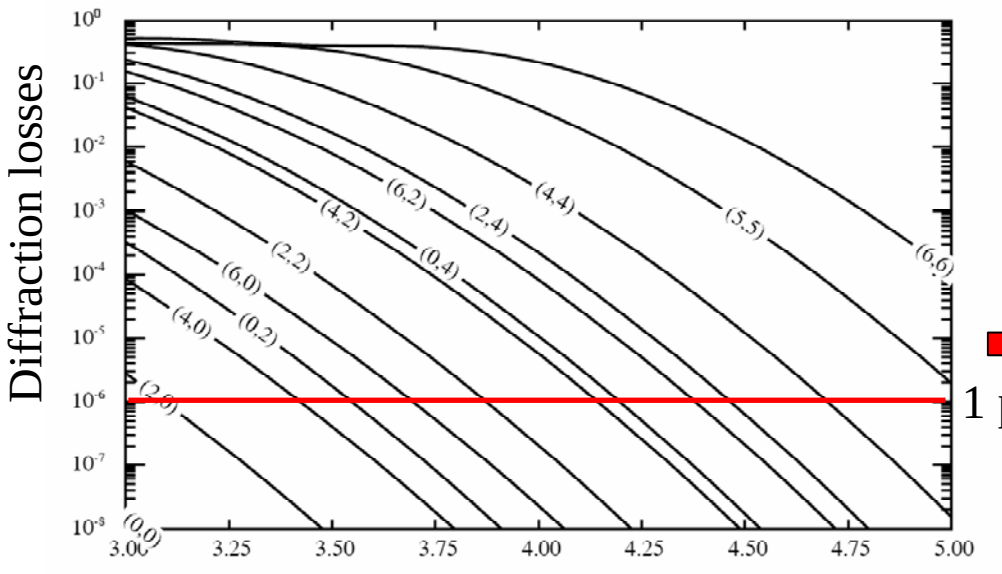


Diffraction losses

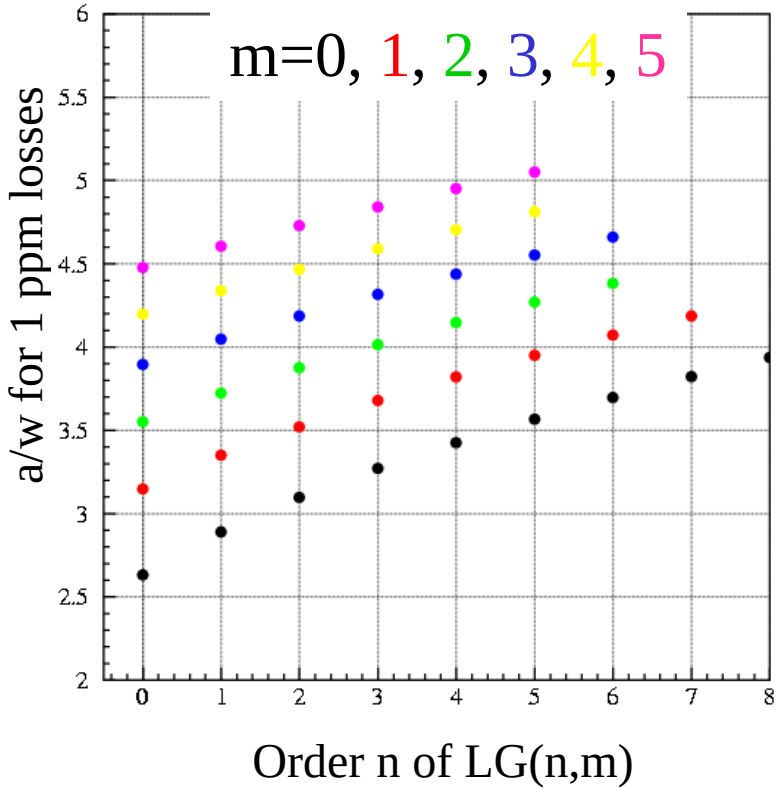
- Potential problem with high order modes: diffraction losses

⇒ Ensure that diffraction losses stay below 1 ppm

a/ spherical-spherical cavities with Virgo type mirrors (∅35 cm)
b/ for each mode adjust the beam size so that diffraction losses = 1 ppm



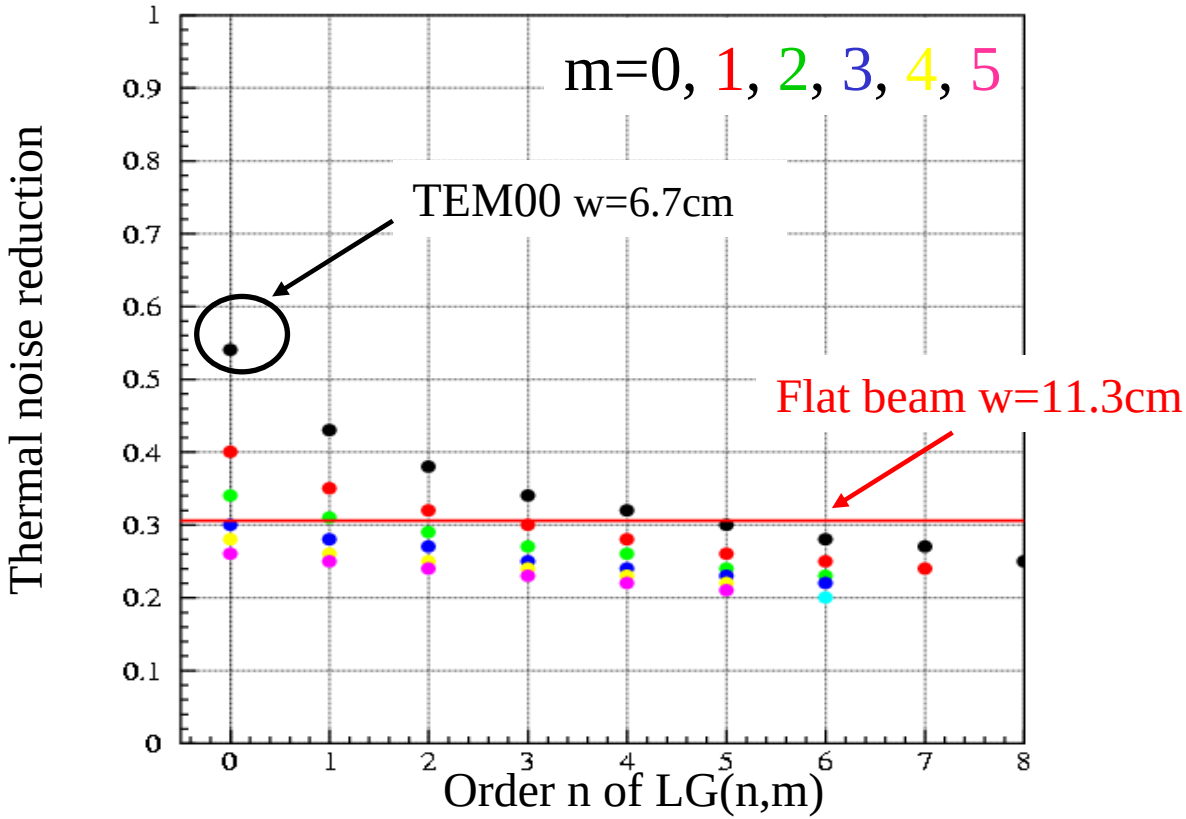
1 ppm



Thermal noise reduction

Reduction of thermal noise with respect to present Virgo configuration

Ratio of thermal noise for: LG(n,m) in spherical-spherical cavity / TEM00 w=2cm



=> Thermal noise reduced by a factor 3 to 5 with respect to present Virgo configuration

=> Can reach results even better than flat beams !

Advantages / Issues

- Optics:
  - Mirrors uniformity on large diameter
  - Large but standard optics (spherical mirrors, mode cleaners,…)
  - Cavities compatible with TEM00 beam

- Production of high order Laguerre-Gauss modes:
  - With a fiber laser: Bragg fibers can produce LG modes?
  - Diffractive optical elements (DOE) ?

- Error signals:
  - Longitudinal locking: in principle no difference with TEM00
  - Alignment: higher order modes more sensitive to misalignments

Alignment/matching issues

- Mis-alignments
- Beam waist mis-matching

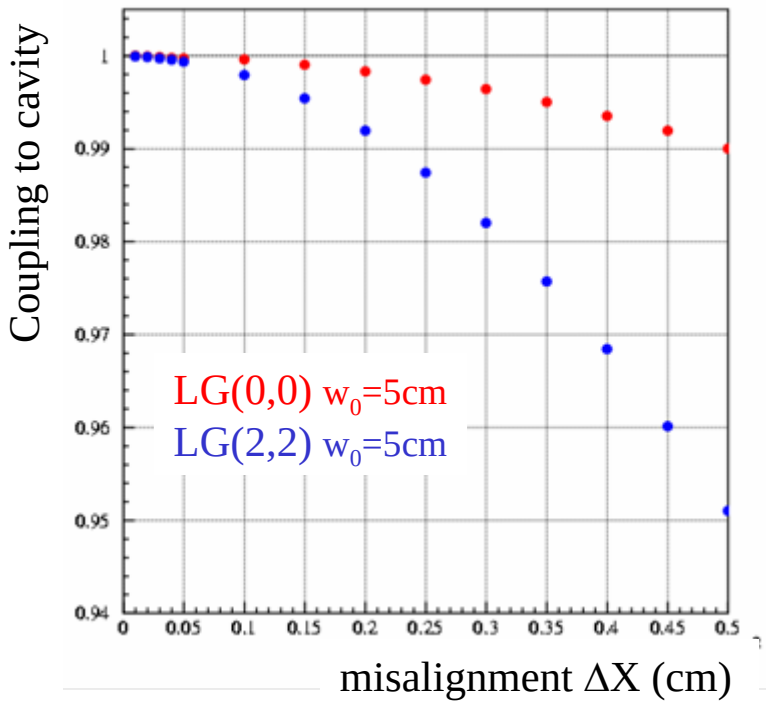
Dominantly couples to non-degenerated modes
=> can be cleaned up by output mode cleaner

Losses larger than for (0,0) mode
=> more stringent constraints on misalignments / matching

Example LG(2,2) vs (0,0) mode:

- alignment:
  should be 2-3 times more precise

- waist:
  should be 4 times more precisely matched



Conclusions

- High order LG modes seem to be a good alternative to flat beams
  - Thermal noise can be comparable to or even lower than flat beams
  - Standard spherical optics can be used
  - Losses: slightly larger constraints on alignment than with TEM00
  - Not too risky: optics compatible with standard TEM00 beam