KEEPING BEAMS IN SHAPE FOR NEXT GENERATION GRAVITATIONAL-WAVE DETECTORS

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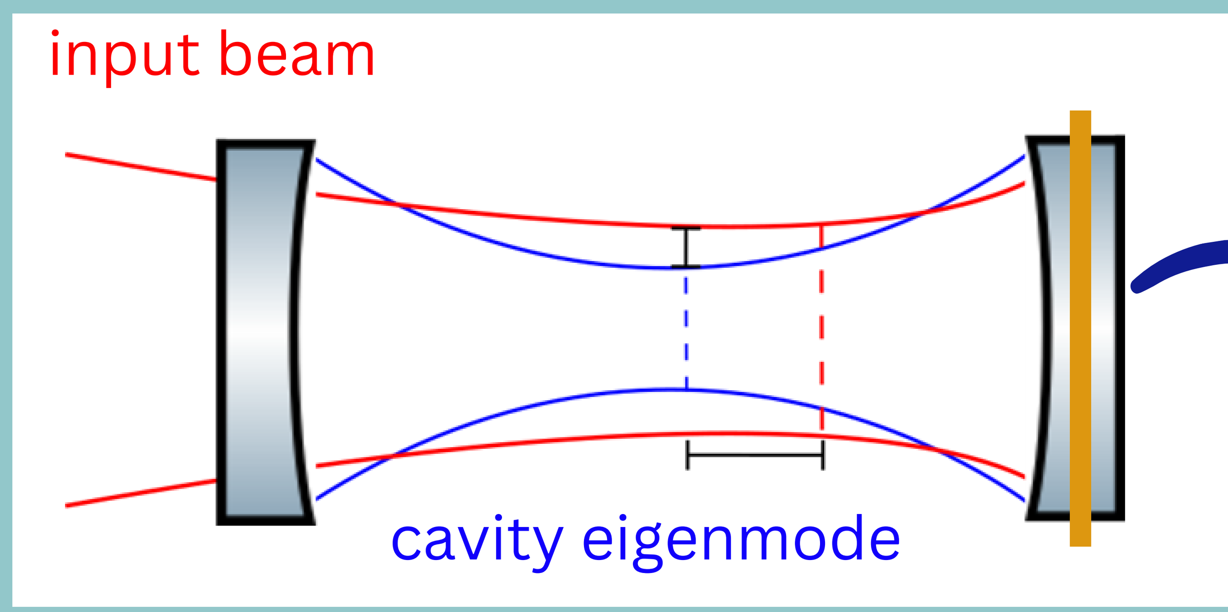
INTRODUCTION

In order to improve sensitivity, next-generation gravitational-wave (GW) detectors plan to increase circulating power by up to 8 times and decrease quantum noise by about 2.5 times [1]. However, higher-circulating powers lead to more thermal effects which impact the spatial modes of circulating beams leading to mode mismatch. This mode mismatch turns into significant optical losses which are the largest limitation to the efficiency of quantum noise reduction [2,3]. We present multiple schemes to compensate mode mismatch using a single phase camera [4] that can be used in next-generation detectors.

MODE MISMATCH

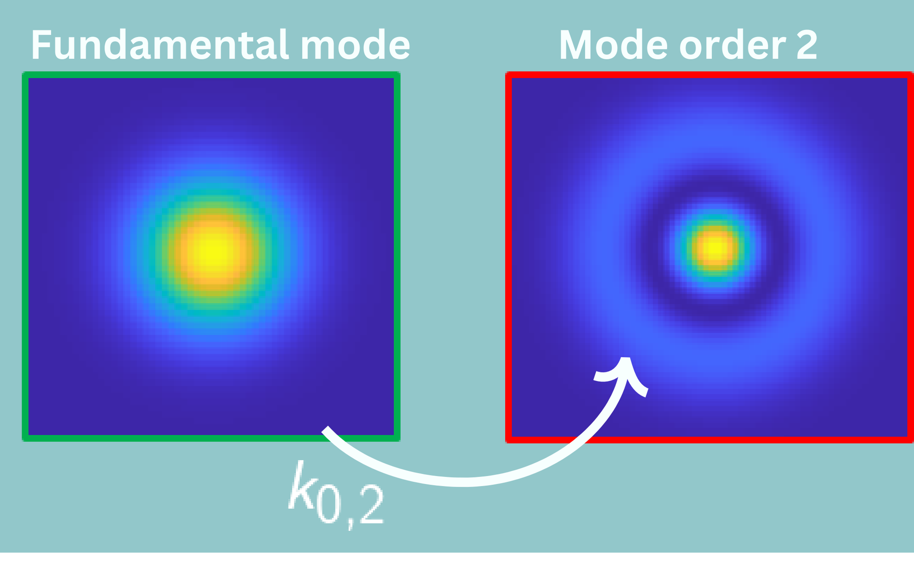
MODE MISMATCH is when the input beam's waist position and/or size doesn't match the one of the cavity.



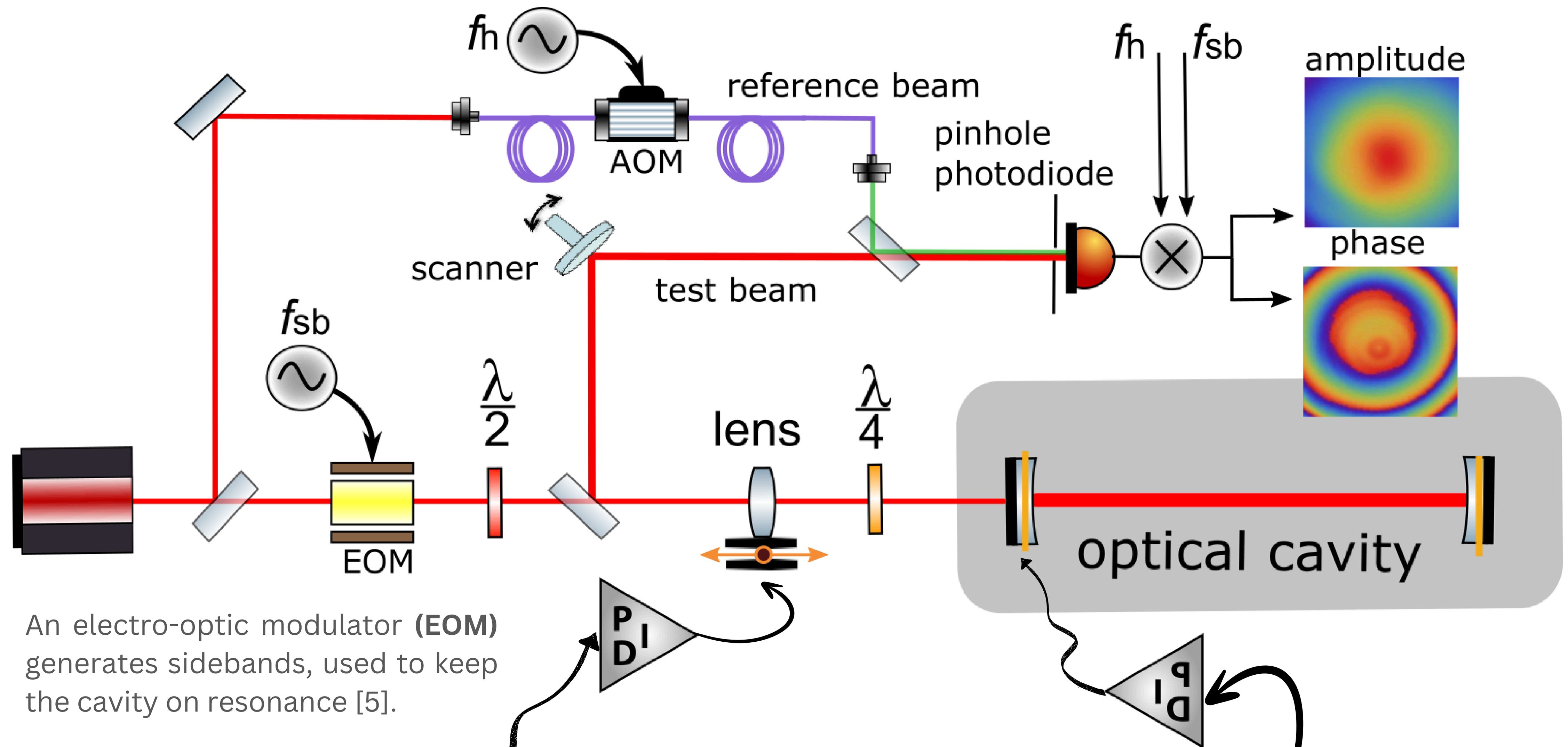
In GW detectors, ring-heaters surround the mirrors. The heating around the edges compensates the absorption of the beam at the centre, changing the radius of curvature (RoC) of the mirror.

With mode mismatch, power is lost from the fundamental mode to second-order modes with coupling coeffiecient:

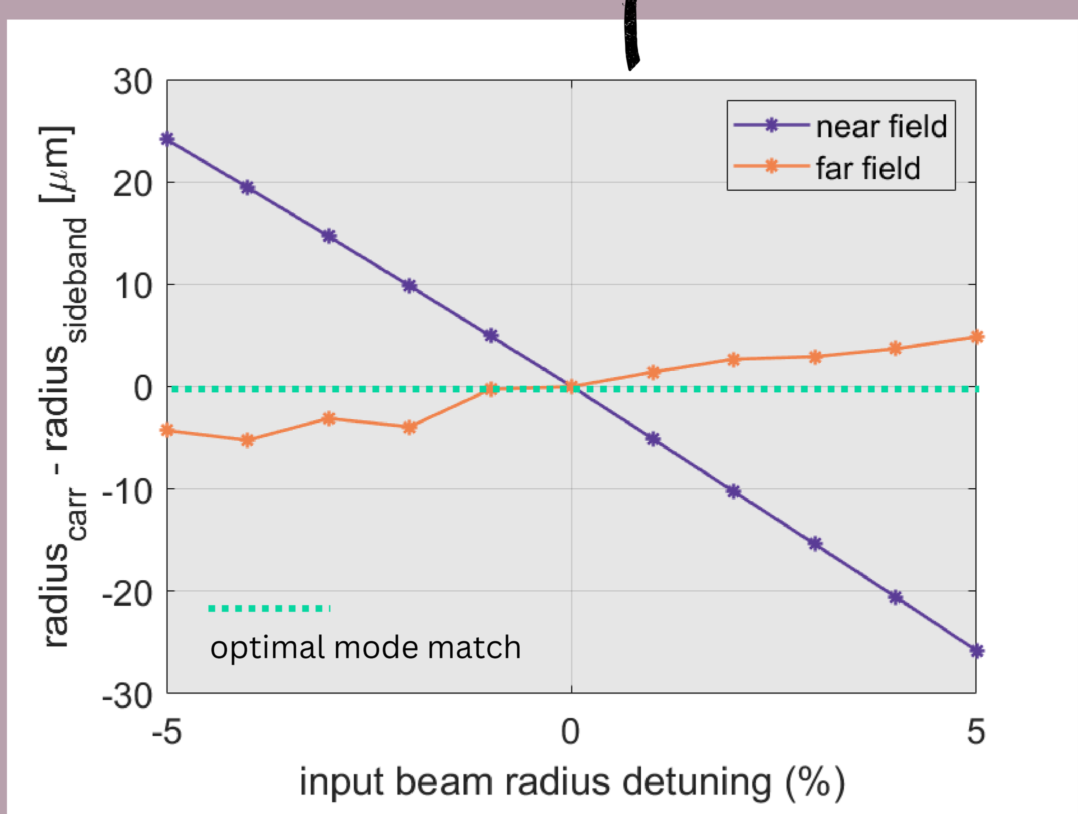
$$k_{0,2} = \frac{1}{4}(\Delta_{pos} - i\Delta_{size})\sqrt{2}$$



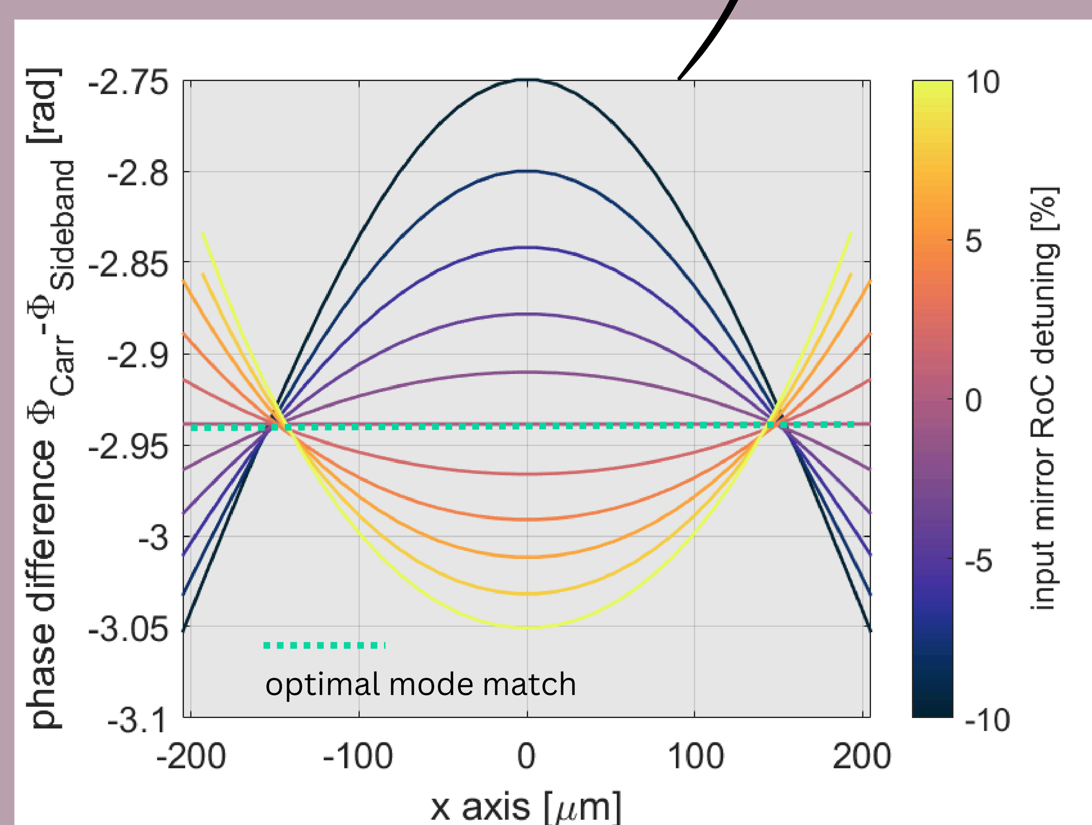
OPTICAL SCHEME AND ERROR SIGNALS



An electro-optic modulator **(EOM)** generates sidebands, used to keep the cavity on resonance [5].



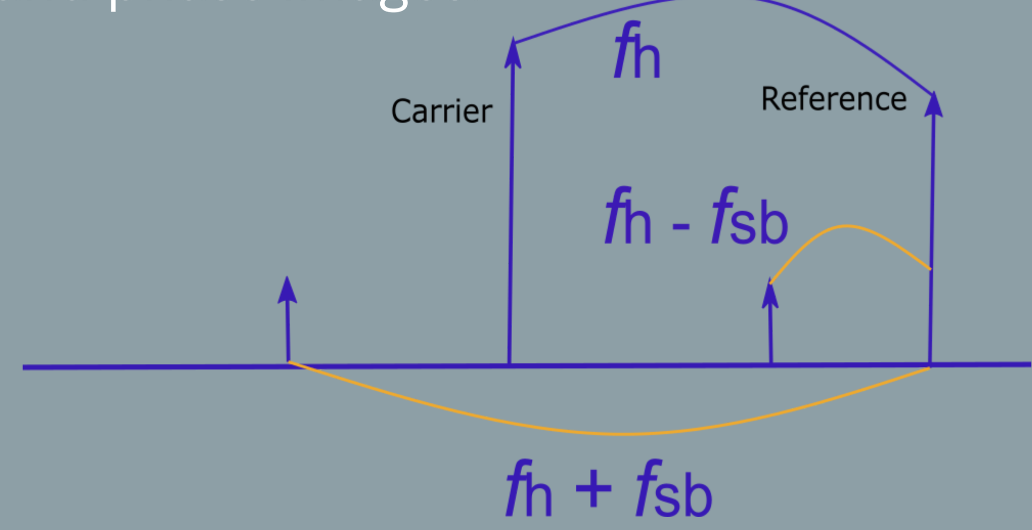
For a change in the Input beam size, the error signal is the difference between the fitted carrier and sideband radii. The signal slope changes with Gouy phase.



For actuation of the Input mirror RoC, the error signal is the phase cross section of the differential phase images between carrier and upper or lower sideband.

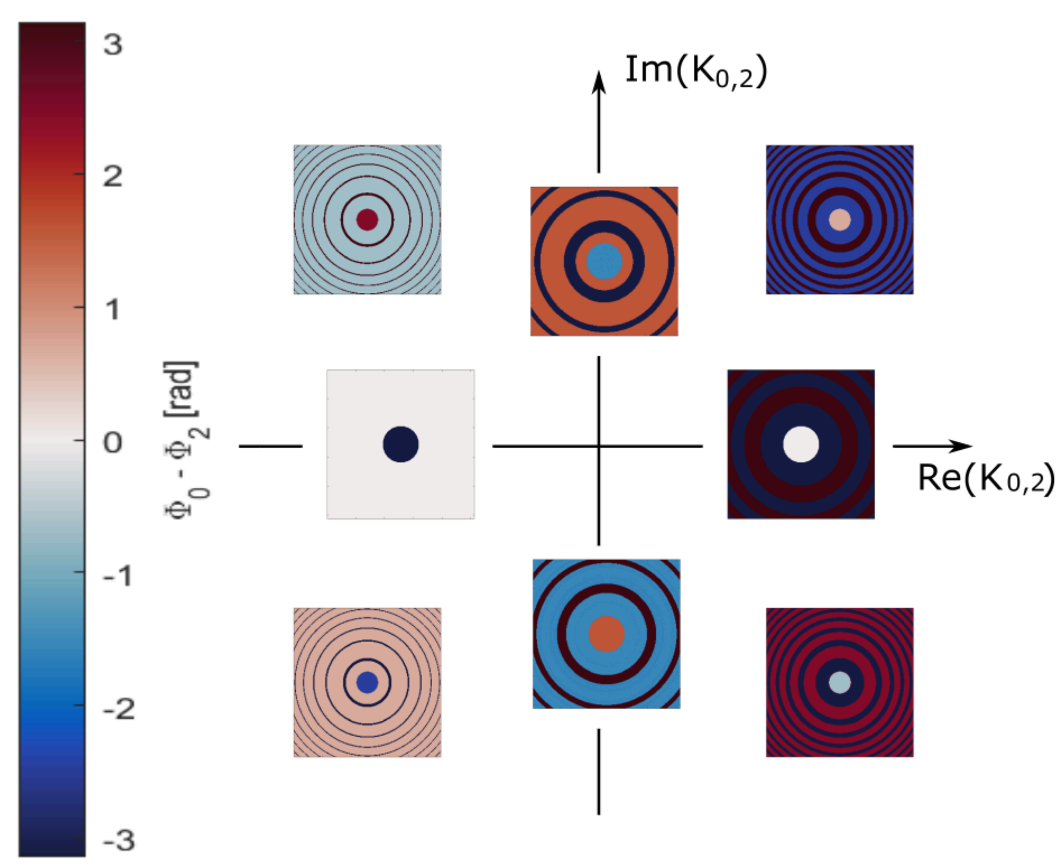
PHASE CAMERA

An acoustic optical modulator **(AOM)** frequency shifts a pick-off of the main beam. The frequency shifted beam (fh) acts as a reference beam and interferes with the test beam at a beam-splitter. The radio-frequency beat notes are measured by a fast photodiode. In order to image multiple pixels, the beam is scanned over the photodiode with a piezo scanner.
The signal is demodulated with a local-oscillator in an FPGA to obtain amplitude and phase images.



MODE DECOMPOSITION

The phase camera images can be used to decompose the beam in a sum of (higher-order) modes with complex coefficient $k_{n,m}$[6], giving direct access to $k_{0,2}$.



The value of $k_{0,2}$ directly determines the mode mismatch, and can, for example, be used to drive two ring heaters in a cavity.

CONCLUSION

We show how comparing the carrier with the non-resonant sidebands provides error signals that can be used in a feedback loop to automatically mode-match a beam to a cavity.
This research is crucial to develop the mode sensing and control systems of next generation GW detectors. Additionally, these techniques can be directly applied to the Virgo detector using the two already installed phase cameras.

REFERENCES

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