

# ANGULAR TRAPPING OF A MIRROR USING RADIATION PRESSURE

By

**David B. Kelley**

B.S. Massachusetts Institute of Technology, Cambridge, MA, 2010

DISSERTATION

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY IN PHYSICS

Syracuse University

October 2015

# ANGULAR TRAPPING OF A MIRROR USING RADIATION PRESSURE

By

**David B. Kelley**

B.S. Massachusetts Institute of Technology, Cambridge, MA, 2010

DISSERTATION

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY IN PHYSICS

Syracuse University

October 2015

Approved : \_\_\_\_\_

Prof. Stefan Ballmer

Date : \_\_\_\_\_

## ABSTRACT

Alignment control in gravitational-wave detectors has consistently proven to be a difficult problem due to the stringent noise contamination requirement for the gravitational wave readout and the radiation-pressure induced angular instability in Fabry-Perot cavities (Sidles-Sigg instability [1]). I present the development, implementation, and measurement of a dual-carrier control scheme which uses radiation pressure to control a suspended mirror, trapping it in the longitudinal degree of freedom and one angular degree of freedom.

Copyright © 2015 David B. Kelley  
All rights reserved.

# Contents

List of Tables	vi
List of Figures	vii
Preface	viii
Acknowledgments	ix
1 Introduction	1
1.1 Basic layout of aLIGO . . . . .	1
Bibliography	3

# List of Tables

# List of Figures

1	Simplified LIGO Layout . . . . .	2
---	----------------------------------	---

# Preface

The work presented in this thesis stems from my participation in the LIGO Scientific Collaboration (LSC). This work does not reflect the scientific opinion of the LSC and it was not reviewed by the collaboration.

The theory of optical trapping in two degrees of freedom in chapter 1 is based on A. Perreca *et al.*, “Multi-dimensional optical trapping of a mirror,” *Phys. Rev. D* **89** (2014) 122002.



# Acknowledgments

Thank you for the music.....

*to*  
*my parents and Emma*

# Chapter 1

## Introduction

The Advanced Laser Interferometer Gravitational-Wave Observatory (aLIGO) is part of an international effort to detect gravitational waves. The search will resume later this year with the two aLIGO sites in Washington and Louisiana, which will ramp up to full design sensitivity over the following few years.

### 1.1 Basic layout of aLIGO

In its simplest form, aLIGO is a Michelson interferometer with Fabry-Pérot cavities for arms (see figure [1](#)). In each Fabry-Pérot cavity, the mirror closer to the Michelson beam splitter is called the input test mass (ITM) and the other mirror is called end test mass (ETM).

When a gravitational wave passes through the detector, it causes changes in the distance between the ETM and ITM in each cavity. Because the wave is quadrupolar, the changes in the x direction will have the opposite sign of the changes in the y direction. This causes a relative phase shift in each of the arms in opposite directions. When they recombine at the beam splitter, the phase shifts cause changes in the interference between the two beams, changing the amount of power at the the output port. We can detect these power fluctuations to reconstruct the phase shift and thus the strain,  $h = \Delta L/L$  experienced by the interferometer due to the gravitational wave. We then use techniques like matched filtering to compare the strain signal from the interferometer to models of expected signals to search for events hidden in the noise background of the interferometer.

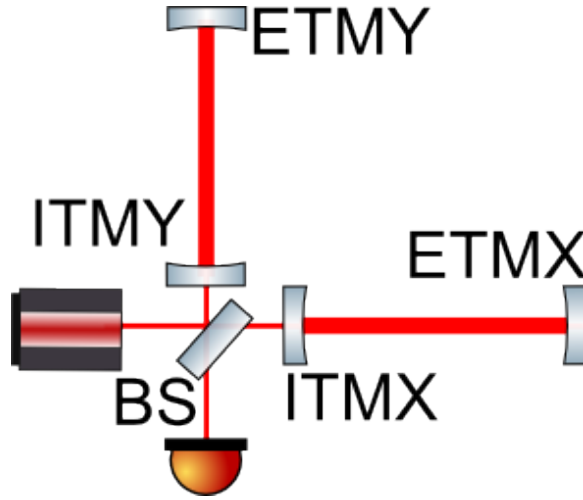


Figure 1 : In its simplest form, aLIGO is a Michelson interferometer with Fabry-Pérot cavities for arms. Light from the laser is split by the beam splitter (BS), then enters the arm cavities through the input test masses (ITMX and ITMY). Power builds up in the cavity between input and end test masses (ETMX and ETMY). When a gravitational wave passes through the detector, it shifts the phases of light in the two arms in opposite directions. Because the cavity is over-coupled ( $r_{ITM} < r_{ETM}$ ), light leaves the arm cavities and goes back to the BS. The phase-shifted light from the two cavities interferes at the BS, producing the error signal that we measure with a photodiode.

# Bibliography

- [1] J.A. Sidles and D. Sigg. Optical torques in suspended fabryperot interferometers.  
*Phys. Lett. A*, 354(3):167 – 172, 2006.

## Curriculum Vitae

Title of Dissertation

Angular trapping of a mirror using radiation pressure

Full Name

David B. Kelley

Place and Date of Birth

Poughkeepsie, New York

December 3, 1987

Colleges and Universities,

Years attended and degrees

Massachusetts Institute of Technology

2006–2010, B.S.

Syracuse University

2010–2015, Ph.D.

Publications

Awards and Fellowships

2010 Fellowship??

Major Department

Physics