Squeezing Enhanced Power Recycled Michelson Interferometer

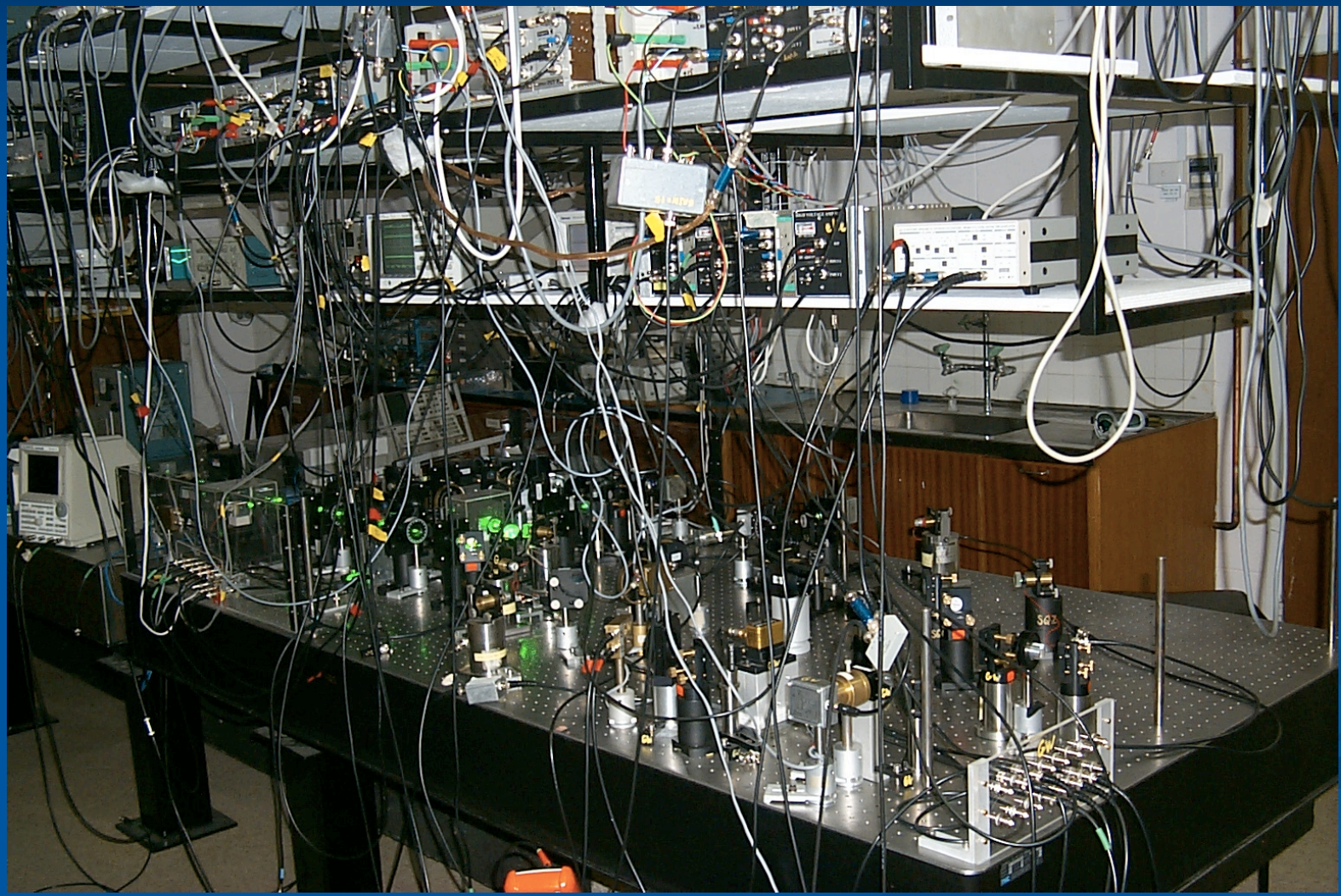
Kirk McKenzie

Completed as part of an honours degree at ANU

Supervisors: Dr. Daniel Shaddock[1]
Prof. David McClelland[1]
Dr. Ben Buchler[2]
Dr. Ping Koy Lam[2]

Location: Gravitational Waves Research Facility[1]
ANU Quantum Optics group[2]
Australian National University

Experiment



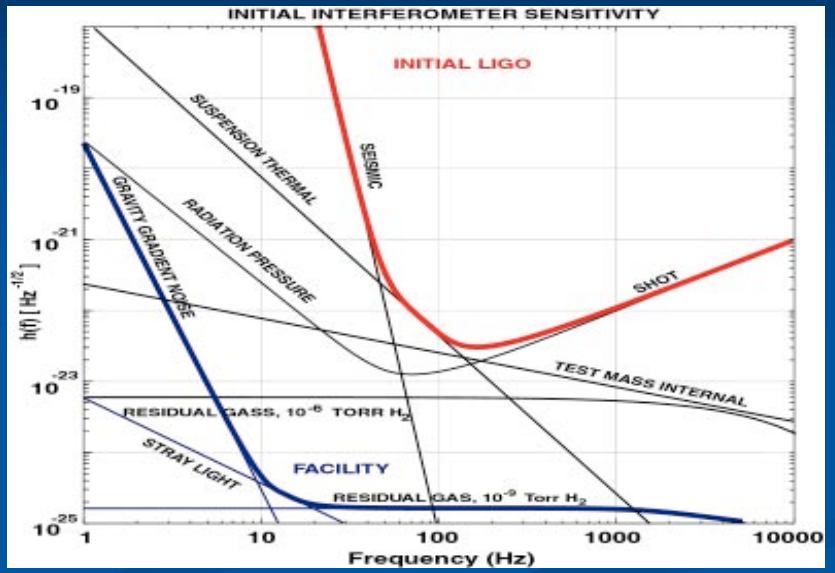
Overview

- Motivation
- Correlated and anti-correlated noise
- Quantum noise in a gravitational wave detector
- Squeezed light
- Application to gravitational wave detectors
- Experiment and results

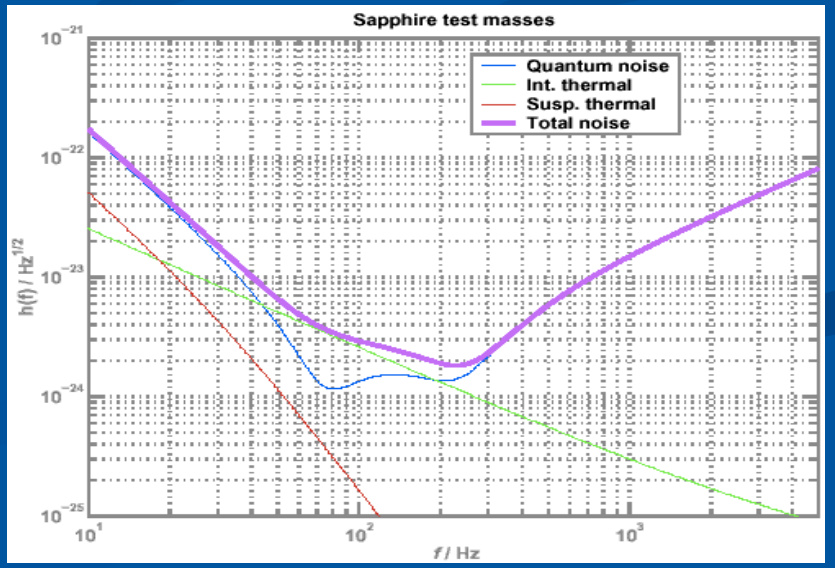
Motivation

- LIGO limited by Shot noise at f > 200Hz
- Advanced LIGO expected to be limited by quantum noise at most frequencies
- Quantum noise reduction in gravitational wave detectors proposed 1981 by C.M.Caves[1]
- **Never before done experimentally**

LIGO



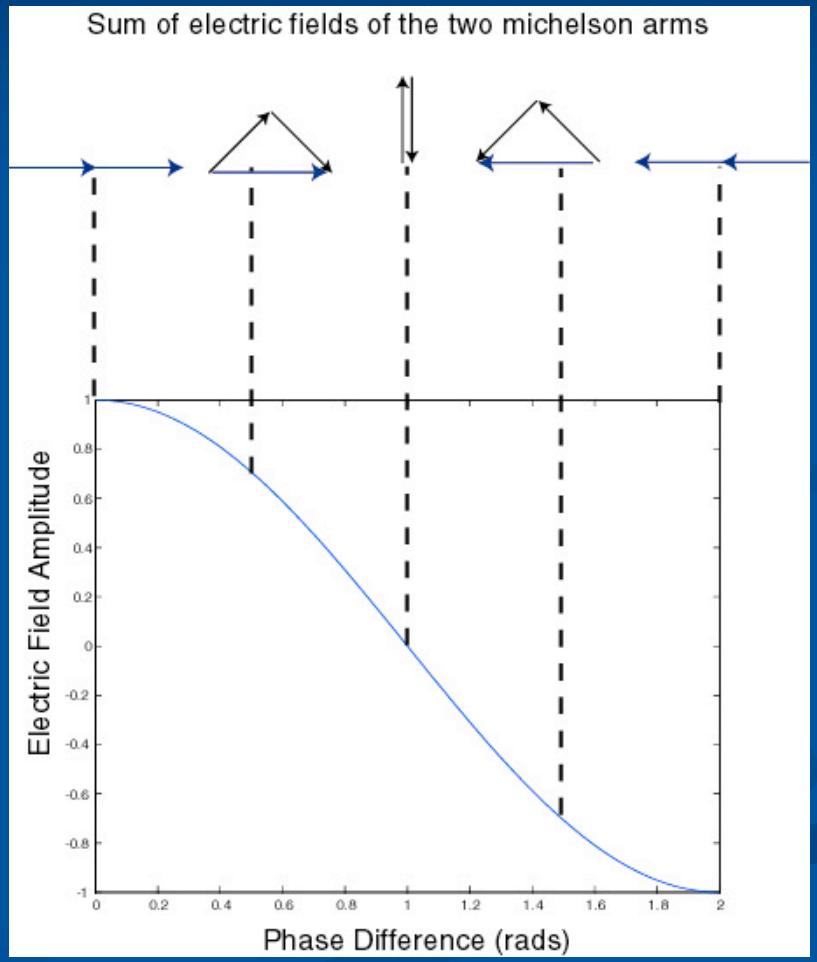
Advanced LIGO



1 C.M.Caves, Phys. Rev. D 23, P 1693 (1981).

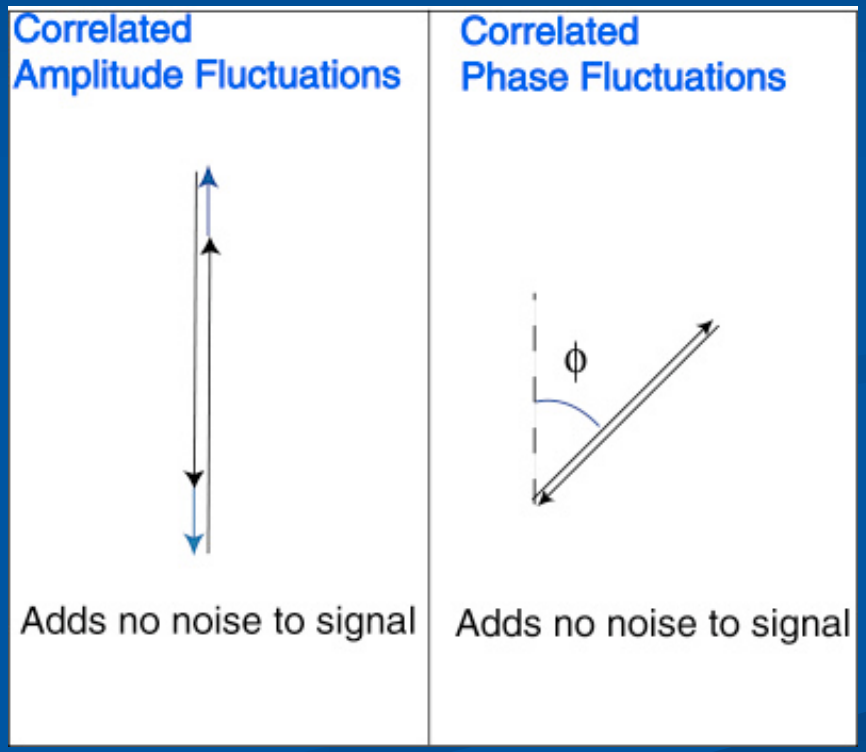
Michelson Interferometer

- The electric field at the output is a vector sum of the electric fields in each arm
- The angle between the vectors is the phase difference at the beam-splitter
- GW detectors operate on a ‘dark fringe’



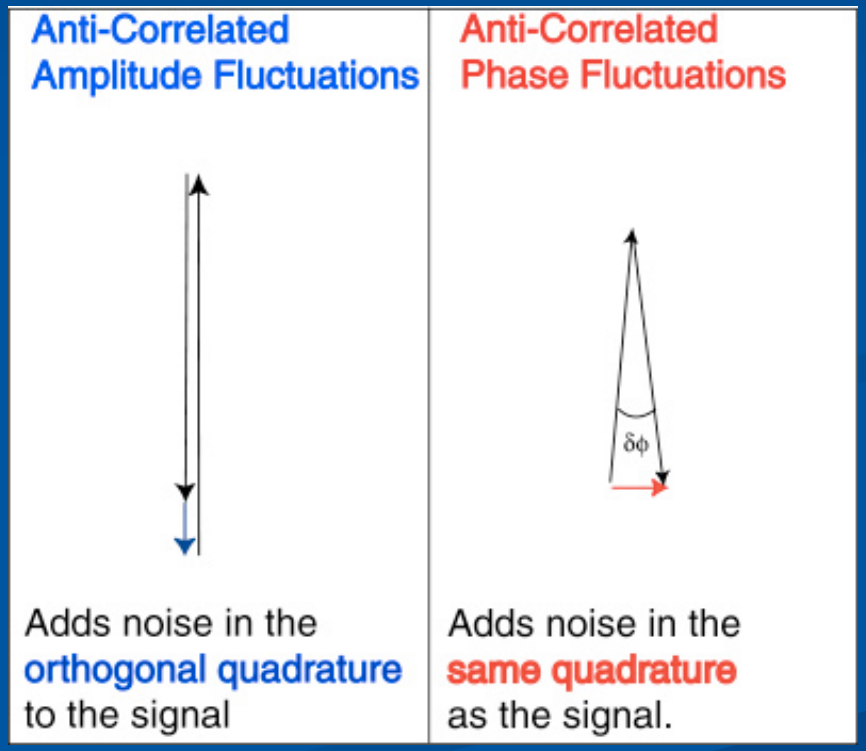
Noise in a Michelson

- Correlated noise
  - eg. Laser power fluctuations
- No correlated noise couples to photo-detector in an ideal interferometer on a dark fringe
- Quantum noise on input beam has no effect



Noise in a Michelson II

- Anti-correlated noise
  - eg. Quantum vacuum noise
- Anti-correlated noise couples onto signal !
- GW signal - from an anti-correlated effect
- Quantum vacuum noise can be reduced using squeezing

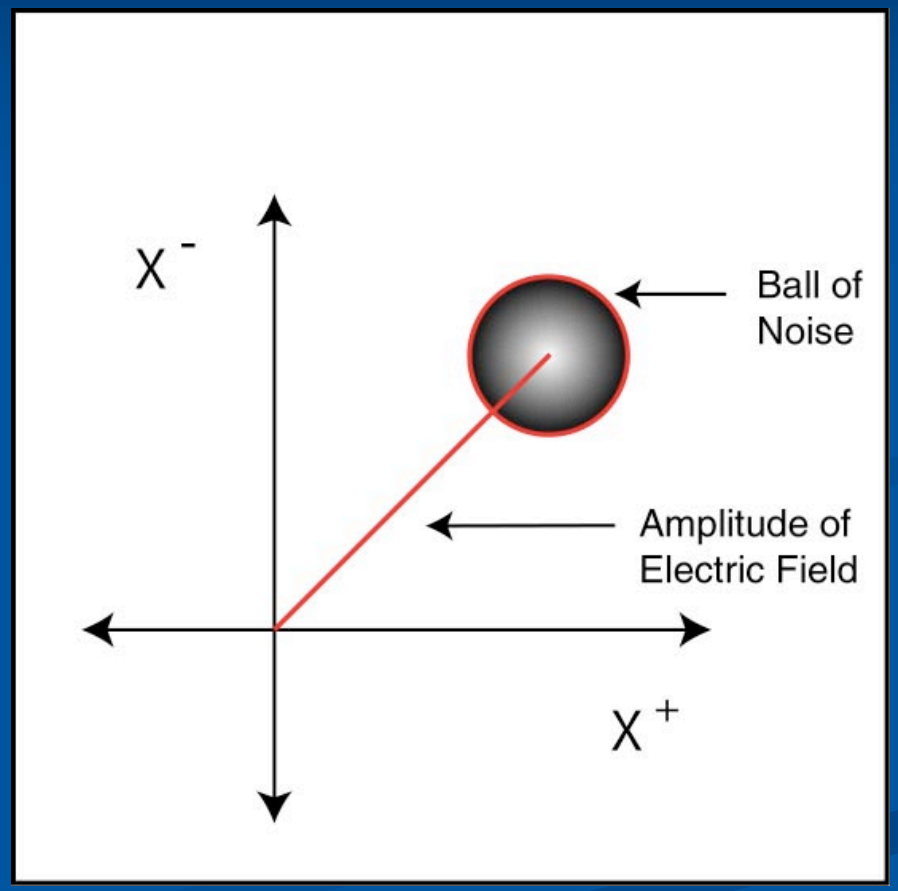


Quantum Vacuum Noise I

- Light has intrinsic random QM fluctuations
- Described by the Heisenberg uncertainty principle

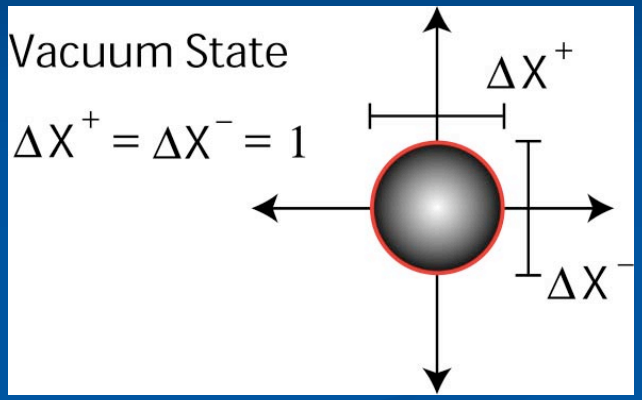
$$\Delta X^- \Delta X^+ \geq 1$$

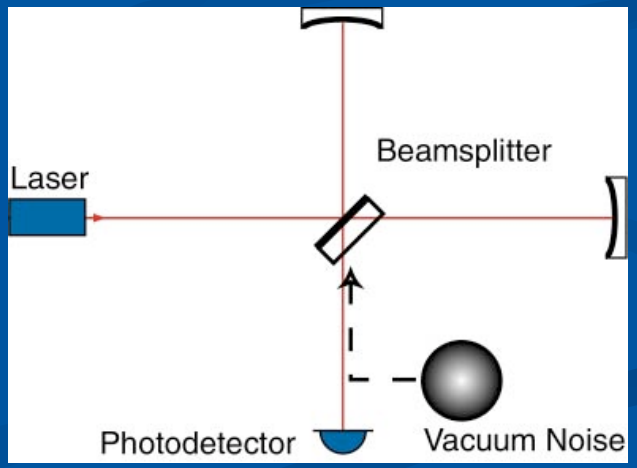
- The two non-commuting quadratures:
  - Phase quadrature, X^-



Quantum Vacuum Noise II

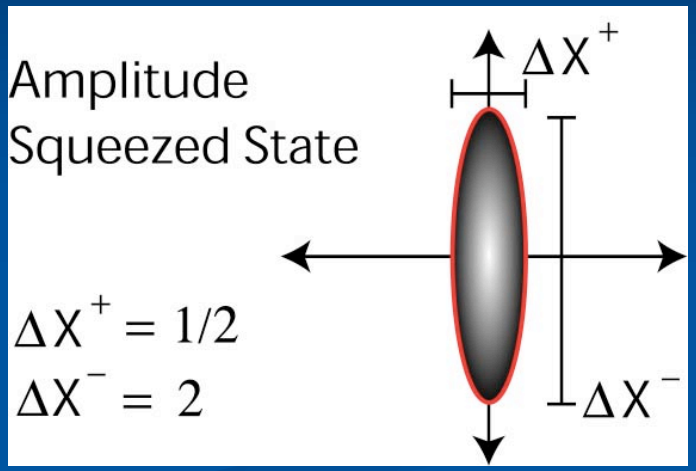
- Laser contributes only correlated noise
- Anti-correlated noise couples-in at the beamsplitter: Vacuum fluctuations
- Phase quadrature fluctuations: Shot Noise
- Amplitude quadrature fluctuations: Radiation Pressure Noise

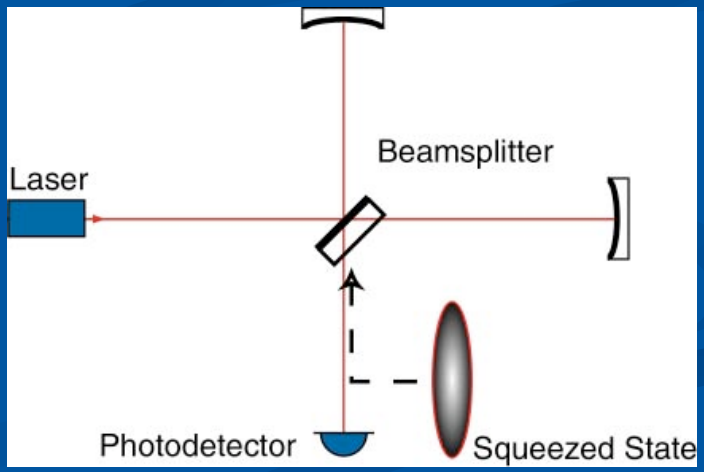




Squeezing

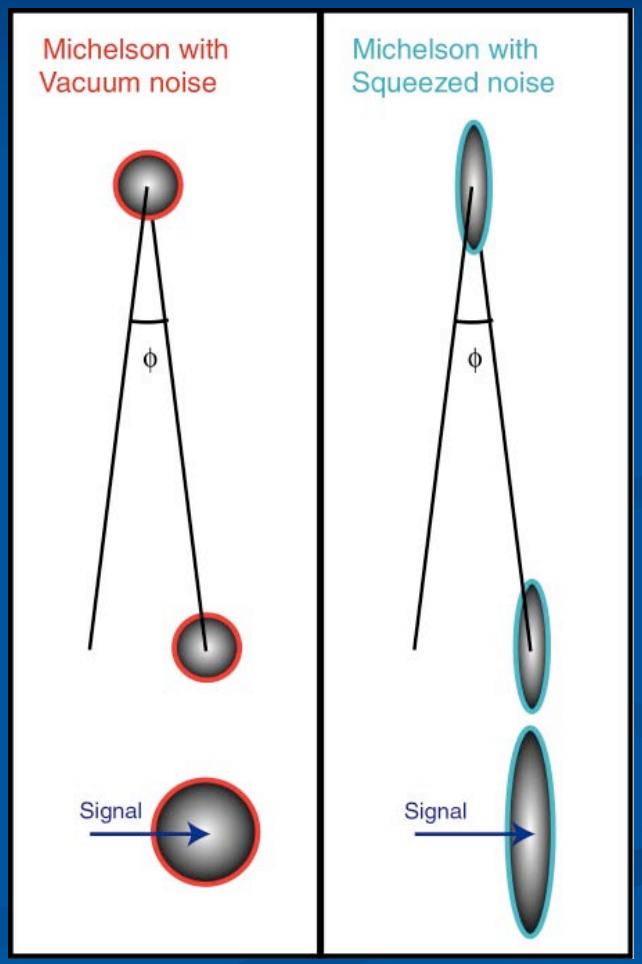
- Reduce noise in one quadrature at the expense of increasing the other quadrature noise
- Inject squeezed vacuum in the dark port of Michelson





Squeezing in a Michelson

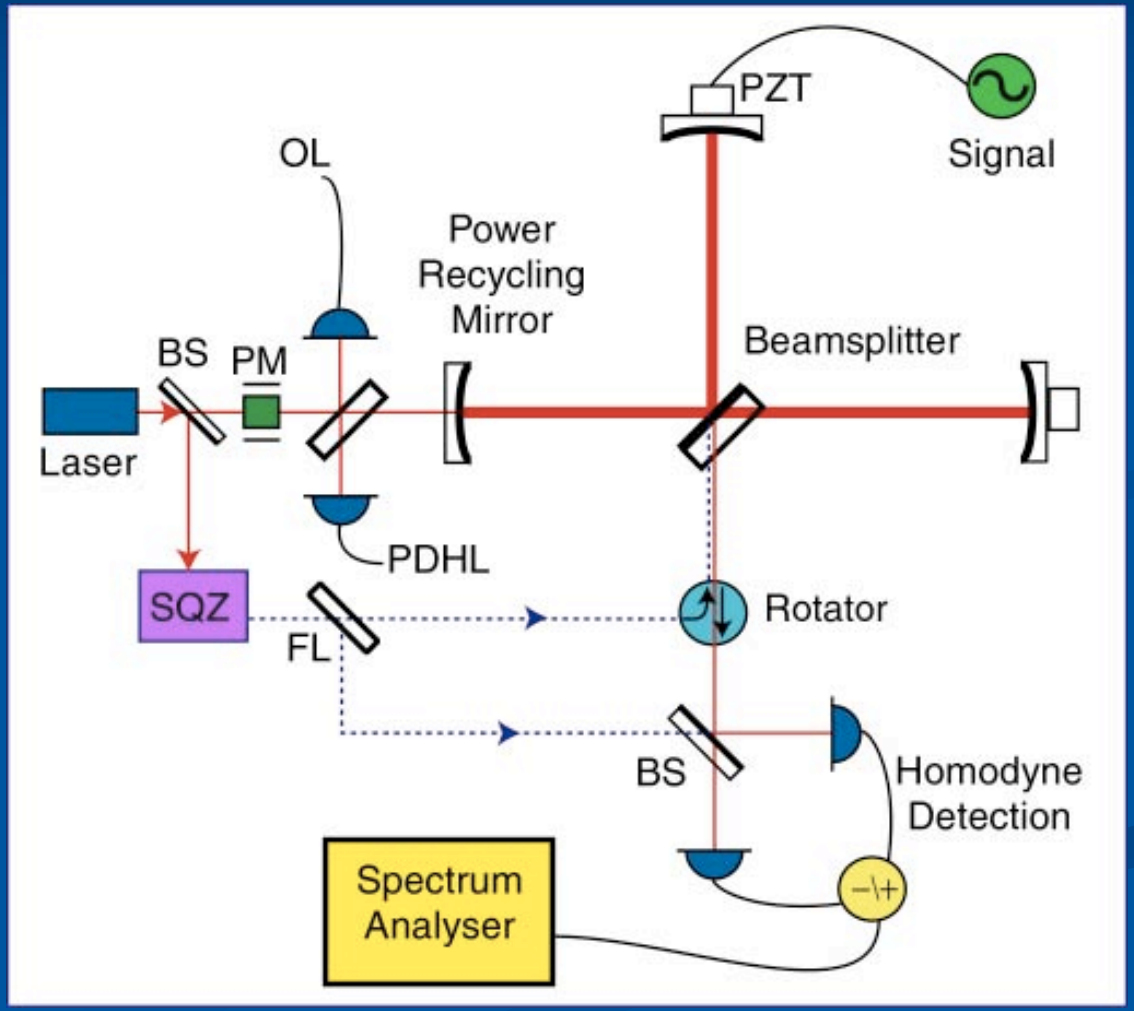
- Local Oscillator selects the phase quadrature
- Amplitude squeezed light reduces noise in phase quadrature[1]



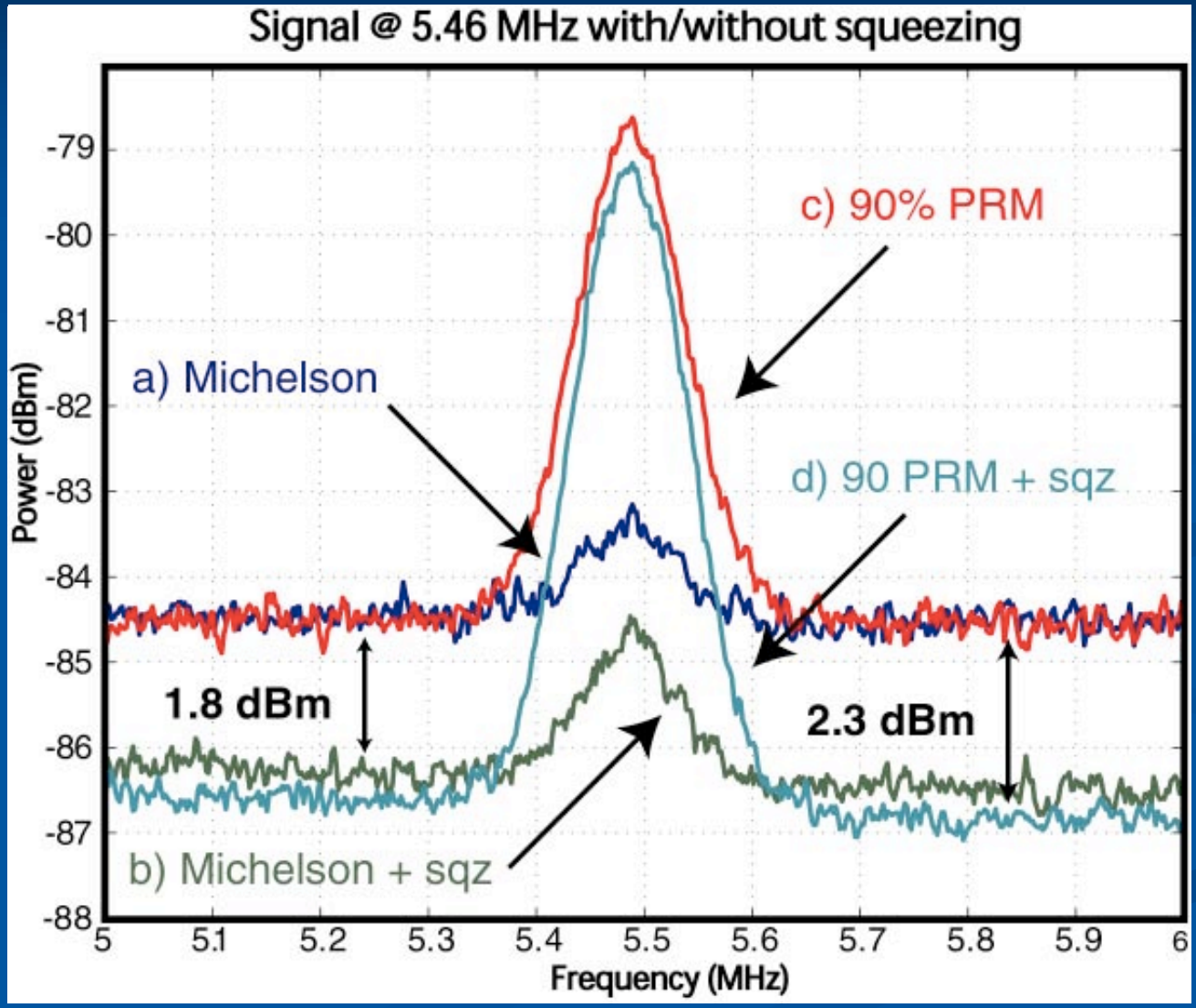
1 Shot noise regime

Experimental Setup

- Power Recycling
- Inject Squeezing in the Dark port
- Use already built Squeezer
- Realistic configuration, compatible control scheme



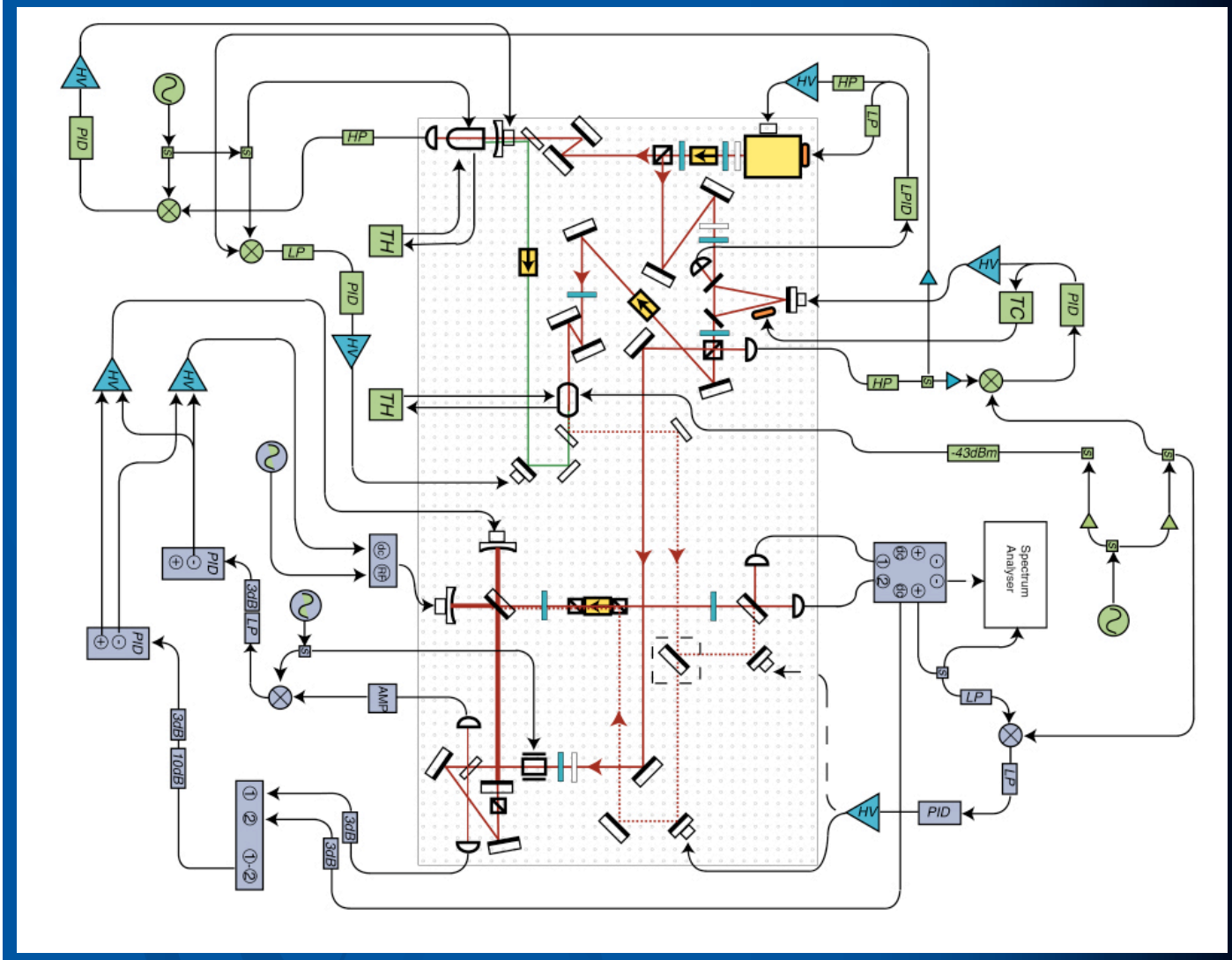
Results



K.McKenzie, D. A. Shaddock, D. E McCelland, B.C. Buchler, P. K. Lam, **Physical Review Letters**, accepted 2002

Control

- PRM with Squeezing, three degrees of freedom
  - Differential mode
  - Common mode
  - Squeezing phase
- Differential mode uses Offset Locking
  - Proposed for Advanced LIGO
  - No modulation required
  - Compatible with Squeezing
- Four other degrees of freedom in the squeezer


HV
PID
HP
LP
LPID
TH
TC
-43dBm
Spectrum Analyser
AMP
3dB
10dB
PD
PD1
PD2

Conclusions

- Experimental demonstration of Shot noise reduction in a power recycled Michelson using squeezing
- Injection optics for squeezed light are compatible with full scale detectors
- Compatible control scheme
- Shot noise reduction of 2.3 dB