Experimental Plan for Extraction of Ponderomotive Squeezing

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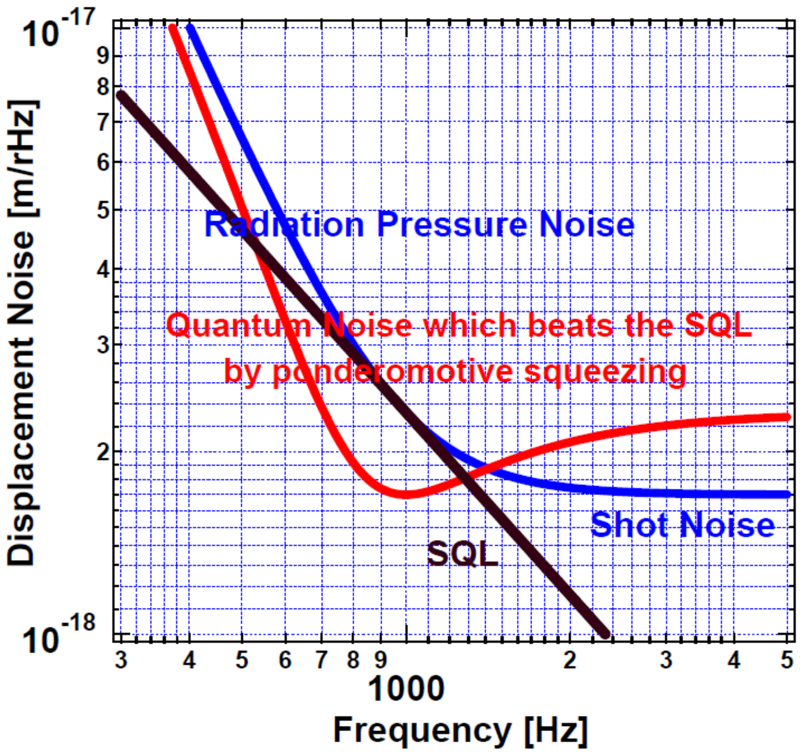
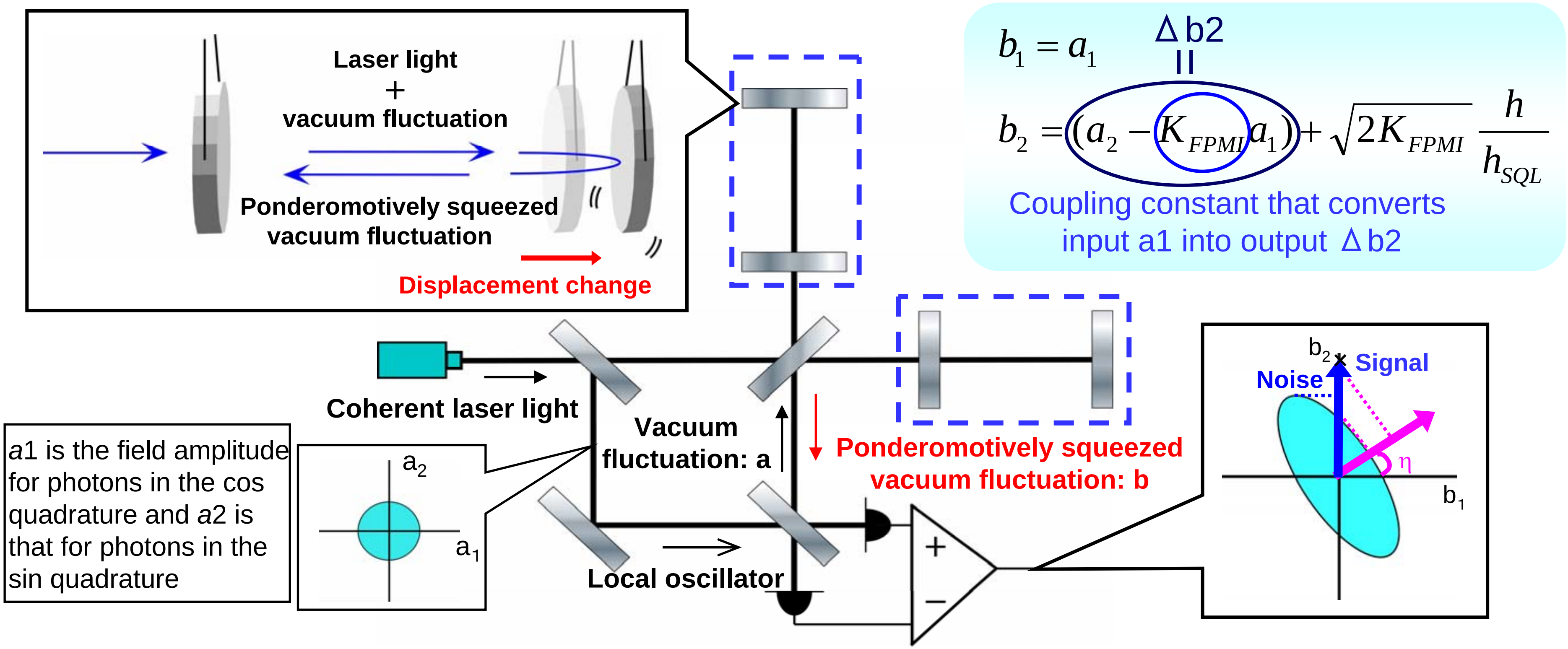
1. Introduction

- Advanced detector sensitivity will be limited by quantum noise at almost all frequencies
  - » Radiation pressure noise is dominated at lower frequencies
  - » Shot noise is dominated at the higher frequencies
    - – The point at which shot noise equals radiation pressure noise is called the standard quantum limit (SQL)
- The SQL can be overcome by installing quantum nondemolition (QND) devices in an interferometer
  - » **Generation of correlation between shot noise and radiation pressure noise by ponderomotive squeezing**
    - – **Use of homodyne detection which is one of the QND devices**



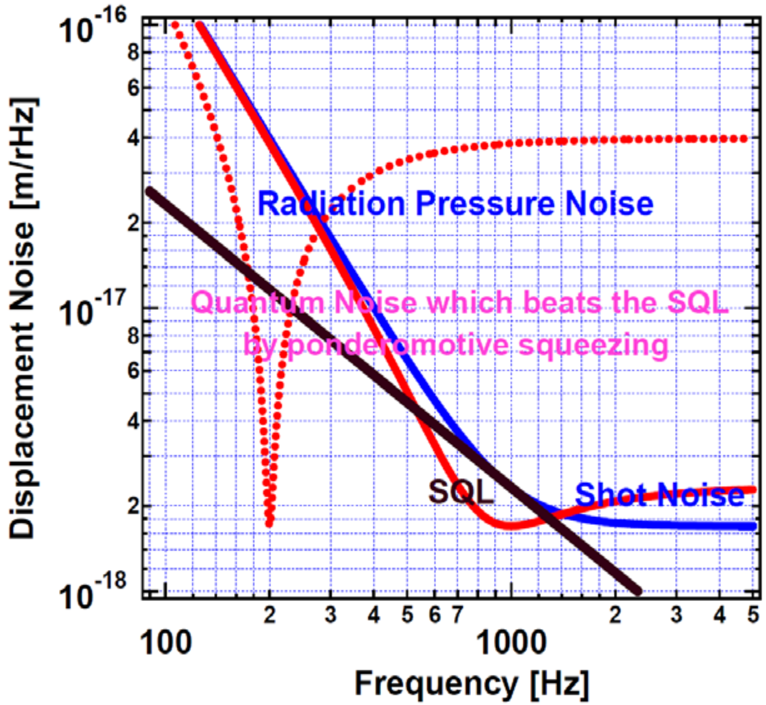
Ponderomotive Squeezing

- What is “Ponderomotive Squeezing” ?
  - » The vacuum fluctuations are squeezed by back-action because of amplitude for vacuum fluctuations and laser light
    - – Correlations between radiation pressure noise in one quadrature and shot noise in the other are generated



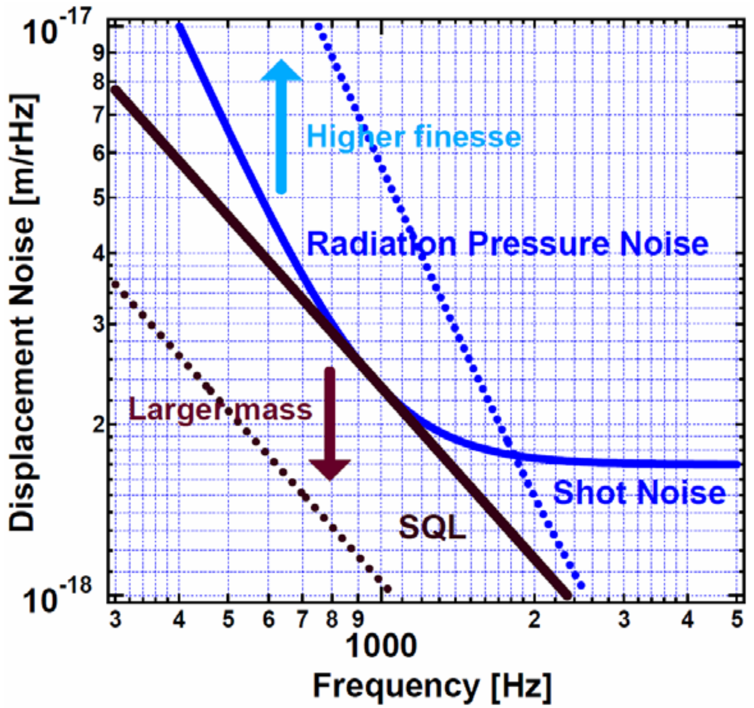
2. QND Research

- Purpose of our QND research
  1. Extraction of the ponderomotive squeezing
  2. Beating the SQL using the ponderomotive squeezing

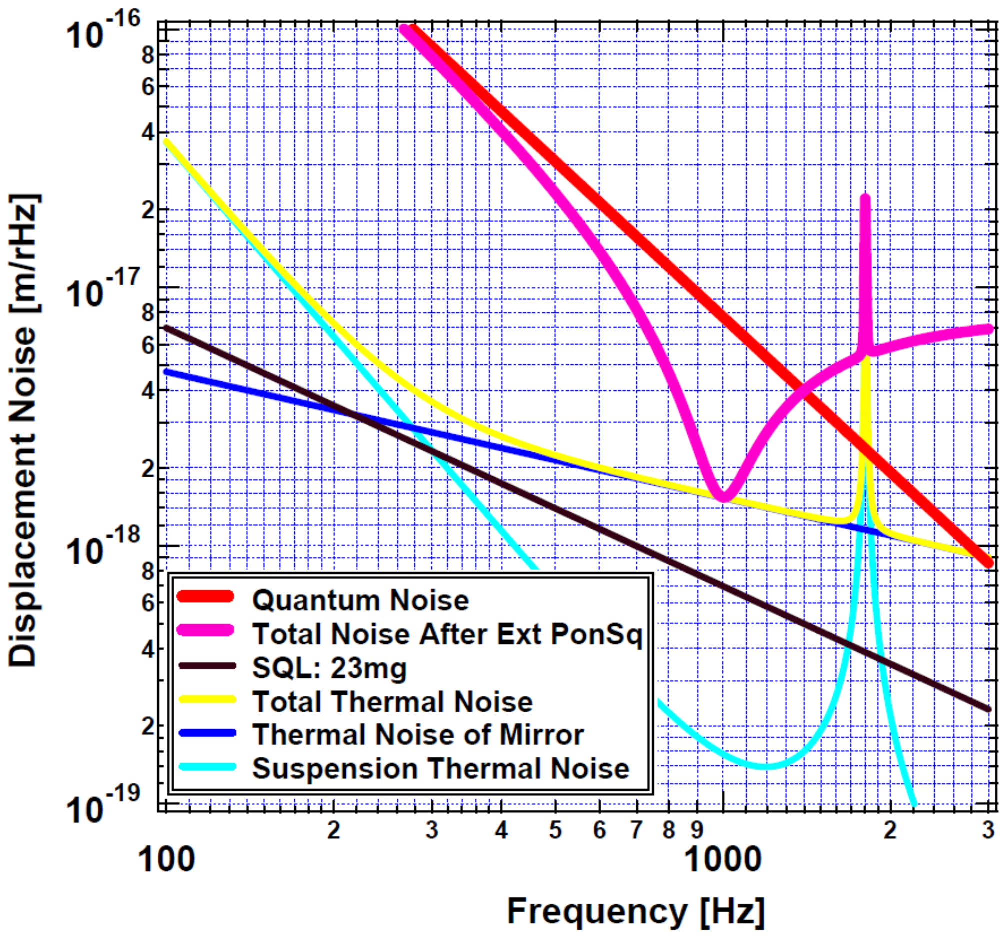


Conceptual Design

- **Conceptual design**
  - » Interferometer configuration
    - – Fabry-Perrot Michelson interferometer installing homodyne detection
    - – The Fabry-Perot cavities are on resonant condition
  - » Condition of the extraction of the ponderomotive squeezing as easy as possible
    - – Small mirror mass
      - • Radiation pressure noise $\propto 1/m$ (m: mirror mass)
      - • Radiation pressure noise is larger
    - – High finesses
      - • Radiation pressure noise $\propto \mathcal{F}$ ($\mathcal{F}$: finesse)
      - • Radiation pressure noise is larger



Experimental Parameters & Noise Budget



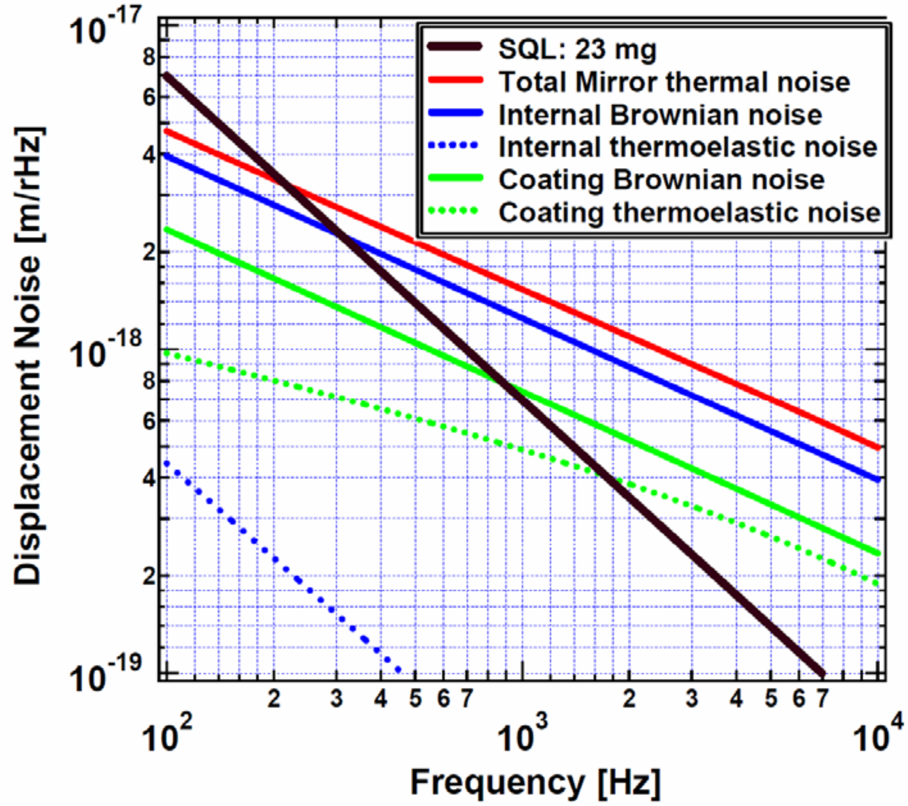
Laser power	200 mW
Injected power into the interferometer	120 mW
Finesse	7500
Front mirror mass	200 g
End mirror mass	23 mg
Diameter of the end mirror	3 mm
Thickness of the end mirror	1.5 mm
Beam radius on the end mirror	500 μm
Q factor of substrate	10^5
Loss angle of coating	4×10^{-4}
Temperature	300 K
Length of the fiber	1 cm
Thickness of silica fiber	10 μm

Mirror Thermal Noise Calculation Ⅰ

- Mirror Thermal Noise
  - » Internal and Coating Brownian Noise
    - – The noises are derived from dissipation which homogeneously exist in each material
  - » Internal and Coating Thermoelastic Noise
    - – The noises are derived from thermoelastic dissipation
- Mirror Thermal Noise Calculation
  - » Reduction of Brownian Noise as possible as we can
    - – Internal Brownian Noise
      - $1/\omega^{1/2}$ (ω: beam radius)
    - – Coating Brownian Noise
      - $1/\omega$ (ω: beam radius)
  - » Keeping good Aspect Ratio(=Diameter/Thickness), 2/1

Mirror Thermal Noise Calculation Ⅱ

- **Calculation parameters**
  - » Common parameters
    - – Beam radius: 500 μm
    - – Mirror diameter: 3 mm
    - – Mirror thickness: 1.5 mm
    - – Temperature: 300 K
  - » Parameters about substrate
    - – **Mirror loss angle : 10^{-5}**
  - » Parameters about coating
    - – **Coating loss angle: 4×10^{-4}**
    - – Coating material: SiO_2, Ta_2O_5



Suspension/Spring Thermal Noise

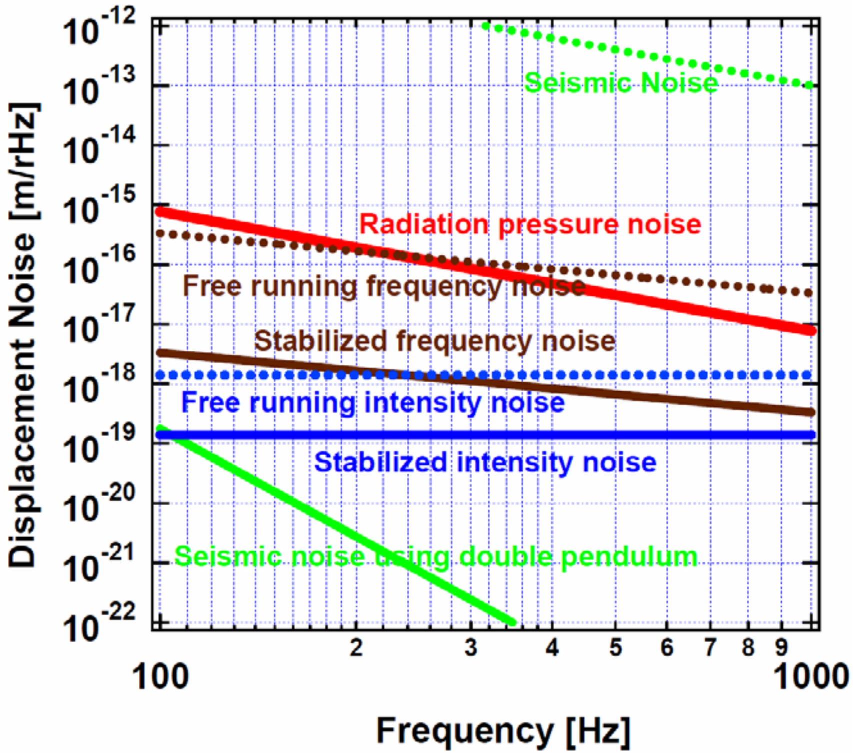
- Suspension thermal noise of the end mirror
  - » Suspension design of the end mirror
    - – End mirror: mass 23 mg, diameter: 3 mm, thickness: 1.5 mm
    - – Silica fiber: length 1 cm, thickness: 10μm
  - » The suspension assumed to be ideal suspension, such as LIGO or TAMA suspension
    - – Dilution factor is small, Dilution factor: 0.02
    - – Dilution factor: $V_{El}/(V_{GW}+V_{El})$
      - V_{El}: elastic energy stored in the wire
      - V_{GW}: gravitational potential energy
  - » In reality, fiber thickness against the mirror mass is thick
    - – The result is probably smaller than realistic suspension thermal noise

Requirement of reduction of other noises

Requirement of reduction of other noises

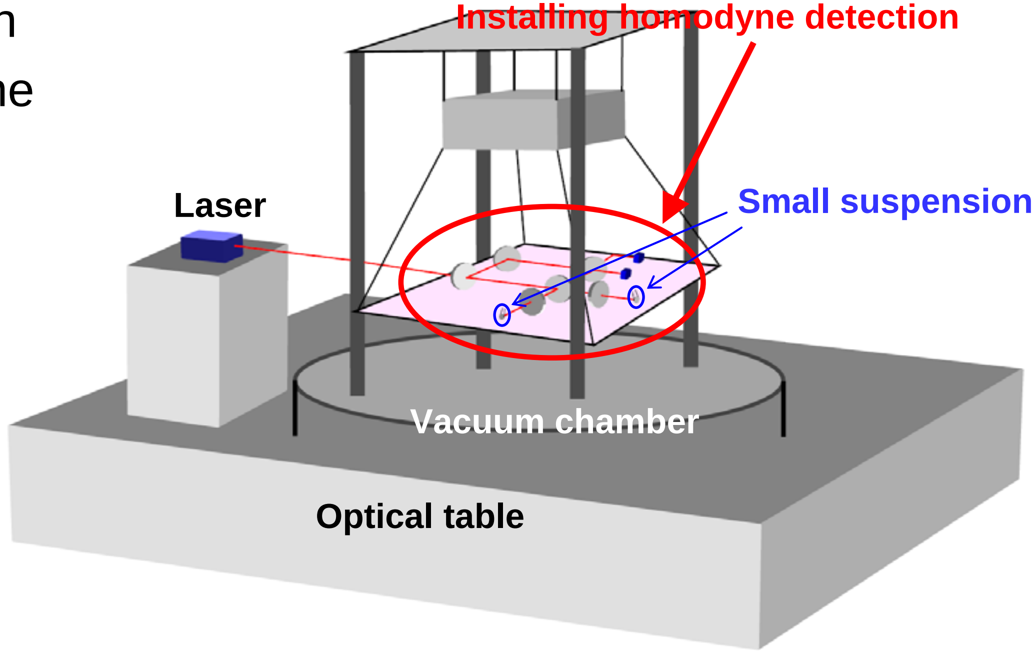
» Design sensitivity: 8×10^{-18}@1 kHz
- Main other noises should be reduced below 8×10^{-19}

» Main other noises
- Seismic noise: $10^{-7}/f^2$ [m/rHz] (f≧0.1)@NAOJ
  - 10^{-13} [m/rHz]@1 kHz
  - Vibration isolation of 10^{-6} to 10^{-5} should be necessary
- Laser frequency noise: $3.3\times10^{-14}/f$ [m/rHz]
  - Frequency noise: $10^4/f$ [Hz/rHz]
  - CMRR: 1/100 should be realized
- Laser amplitude noise: 1.4×10^{-18} [m/rHz]
  - Intensity noise: 1×10^{-7} [/rHz]
  - Residual RMS deviation: 1.4×10^{-11}[m]
  - Intensity noise of a factor of 10 should be stabilized
- Residual gas
  - 10^{-4} Pa



Experimental Setup

- Preliminary experimental setup
  - » The interferometer is suspended by double pendulum
  - » End mirror is suspended by single pendulum
    - – Small suspension system is developing
  - » All of the setup other than laser will be installed in the vacuum chamber



3. Summary & Future Plan

Summary

- » The purpose of the QND research is to extract the ponderomotive squeezing
- » Conceptual design is to use Fabry-Perot Michelson interferometer installing homodyne detection
- » Experimental parameters are almost decided
  - – From calculation of the noise budget

Future Plan

- » Suspension thermal noise should be calculated
- » Small suspension system and small mirror will be developed
- » The interferometer will be built

The End