Development for Observation and Reduction of Radiation Pressure Noise

S. Sakata, O. Miyakawa, A. Nishizawa, K. Numata, E. Nishida,
H. Ishizaki, A. Furusawa, S. Kawamura

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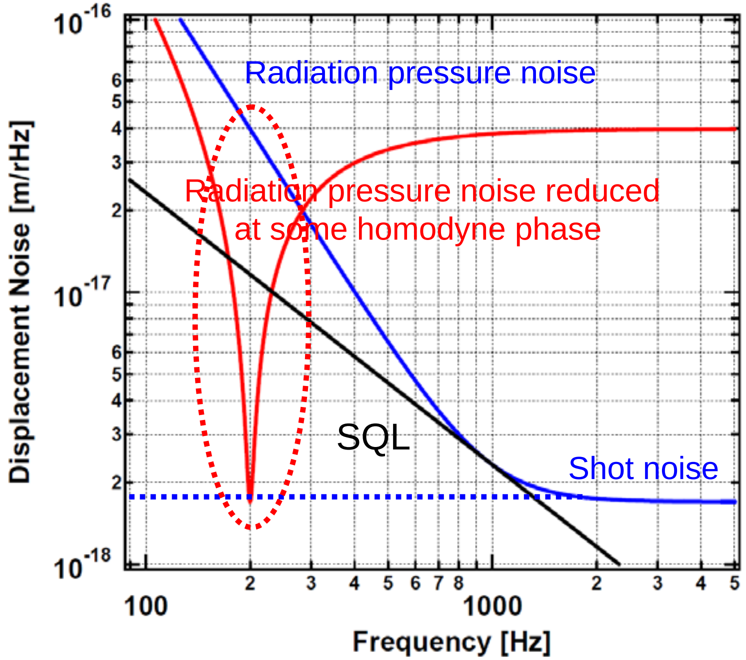
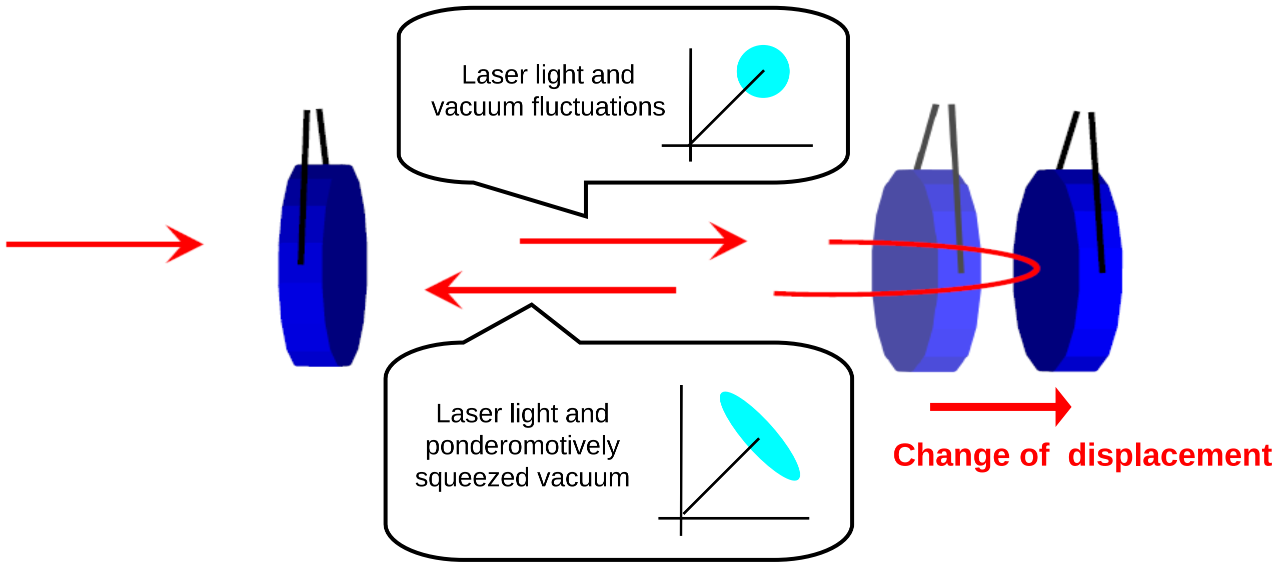
1. Objectives and Scope

- **Objectives**
  - » Observation of radiation pressure noise
  - » Reduction of radiation pressure noise
    - – Measurement of ponderomotively squeezed vacuum fluctuations at the best homodyne phase
- **Scope**
  - » Fabry-Perot cavities with tiny mirrors and high finesse



Ponderomotive squeezing

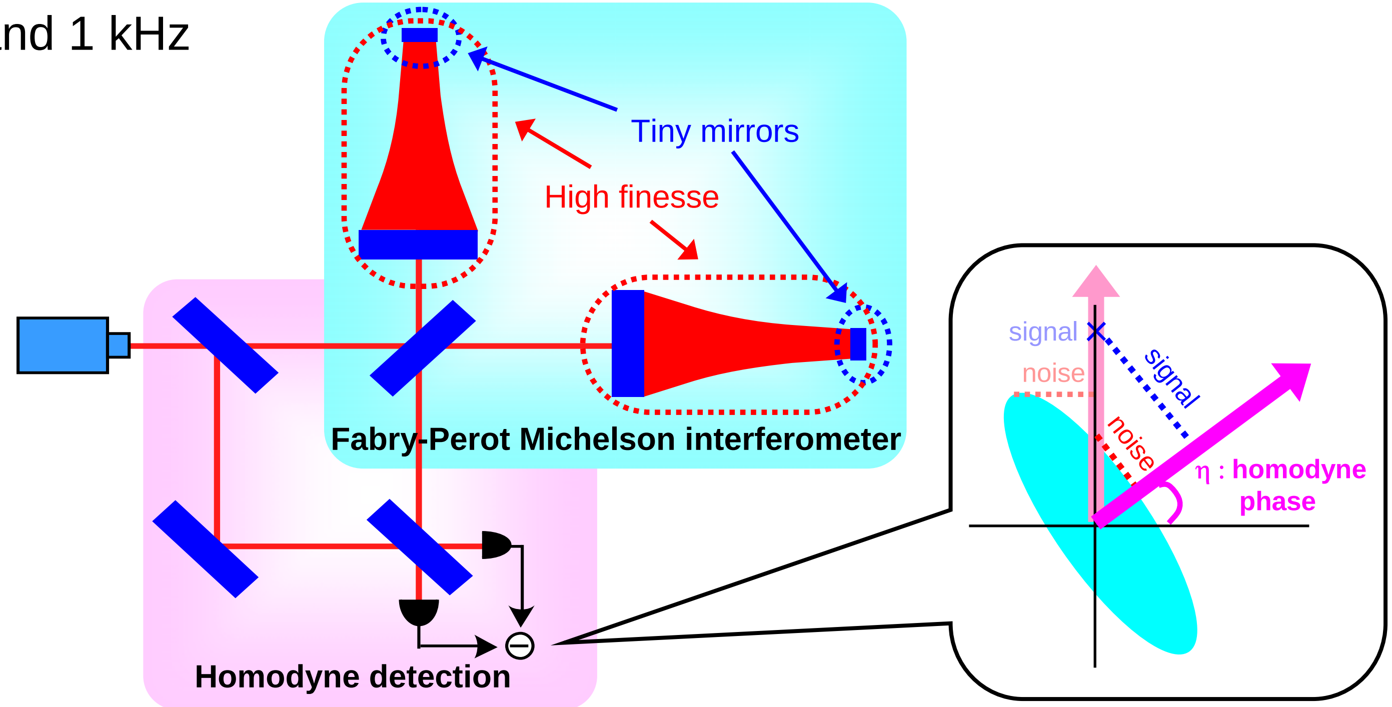
- Ponderomotive squeezing
  - » Amplitude fluctuation is correlated with phase fluctuation
    - – Displacement changed by back-action of laser light and vacuum fluctuations
  - » Squeezing with frequency dependence



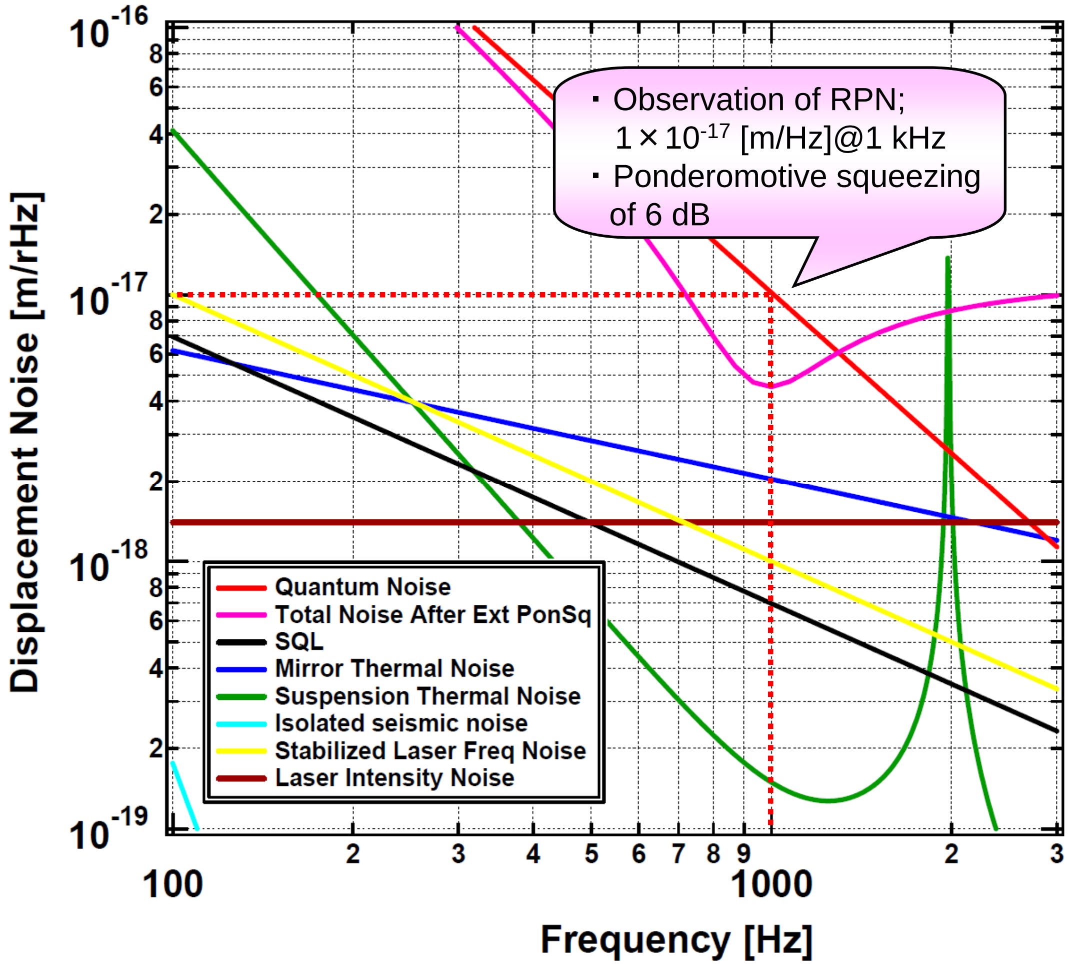
Conceptual design

Conceptual design

- » Fabry-Perot Michelson interferometer with homodyne detection
  - – Fabry-Perot cavities with tiny mirrors and high finesse
- » Observation and reduction of radiation pressure noise between 300 Hz and 1 kHz



Noise Budget



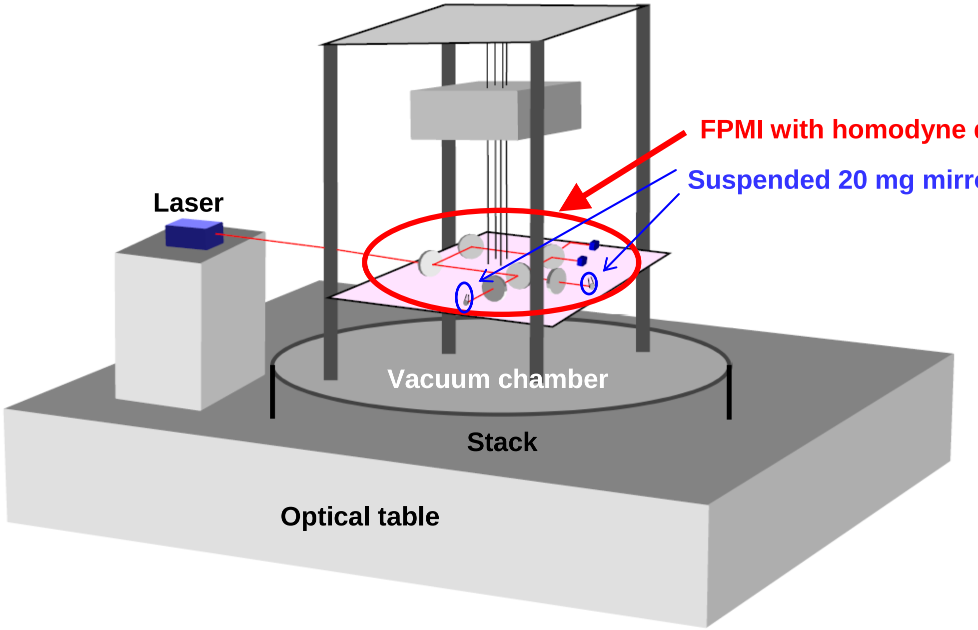
Laser power	200 mW
Injected laser power	120 mW
Finesse	10000
End mirror mass	20 mg
Diameter of end mirror	3 mm
Thickness of end mirror	1.5 mm
Front mirror mass	14 g
Reflectivity of end mirror	99.999 %
Reflectivity of front mirror	99.94 %
Optical loss	50 ppm
Beam waist of end mirror	340 μm
Mechanical loss of substrate	10^{-5}
Mechanical loss of coating	4×10^{-4}
Length of silica fiber	1 cm
Diameter of silica fiber	10 μm

2. Experiment and Current status

- Step1
  - » Assembly of experimental setup
    - – 20 mg mirror suspended by a 10μm silica fiber, Fixed front mirror
- Step2
  - » Achievement of sensitivity of 1×10^{-18} [m/Hz] at 1 kHz
    - – Replacement to suspended front mirrors
- Step3
  - » Observation of radiation pressure noise
    - – Replacement to high reflectivity mirrors
- Step4
  - » Reduction of the radiation pressure noise

Experimental setup

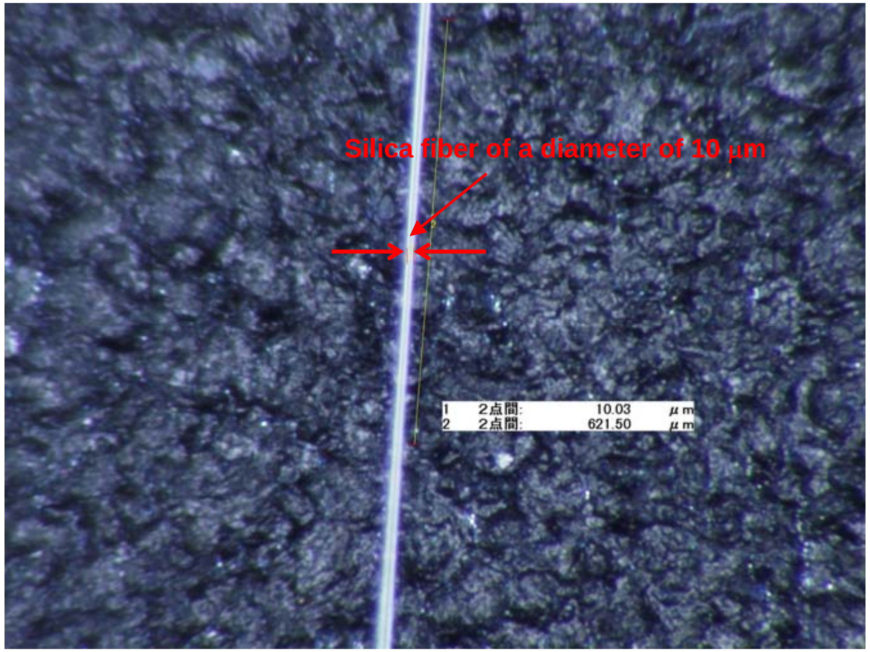
- Experimental setup
  - » Fabry-Perot Michelson interferometer with homodyne detection is suspended by a double pendulum
    - ✓ Assembly of a Fabry-Perot cavity
      - 20 mg mirror suspended by a 10μm silica fiber



20 mg mirror and 10 μm silica fiber

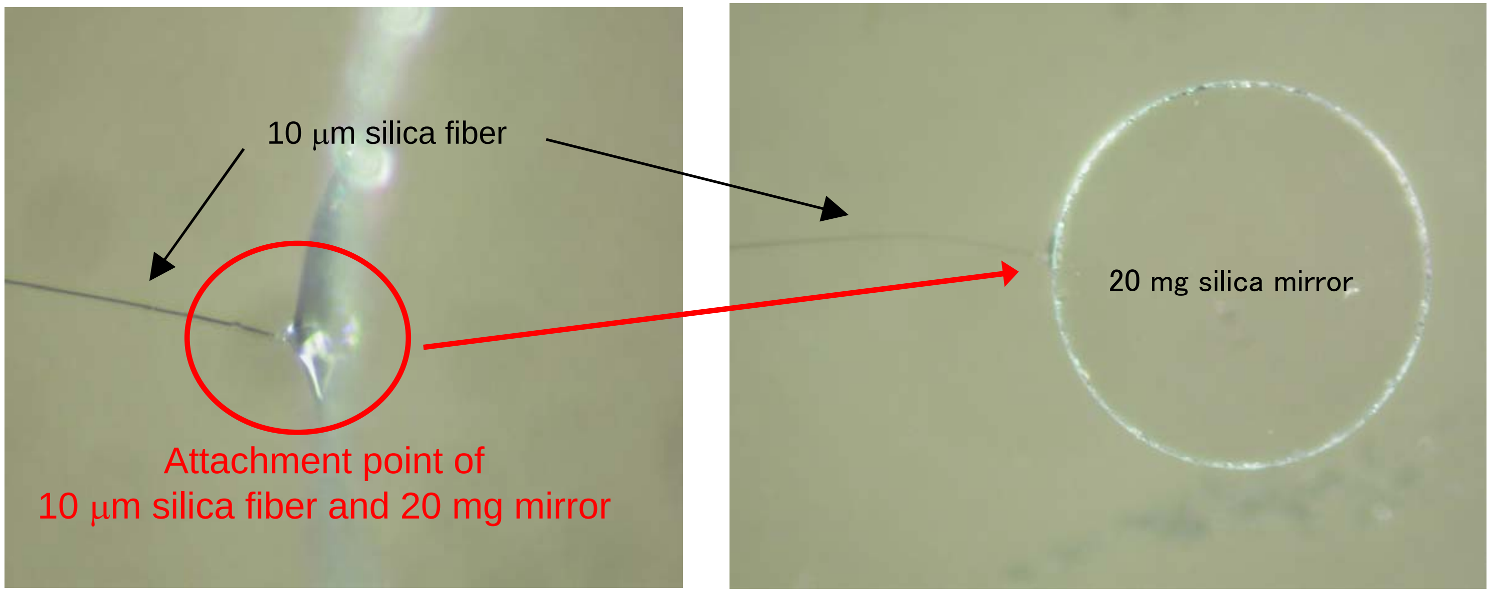
- 20 mg mirror with a diameter of 3mm

- Silica fiber of 10μm in diameter
  - » For lower suspension thermal noise



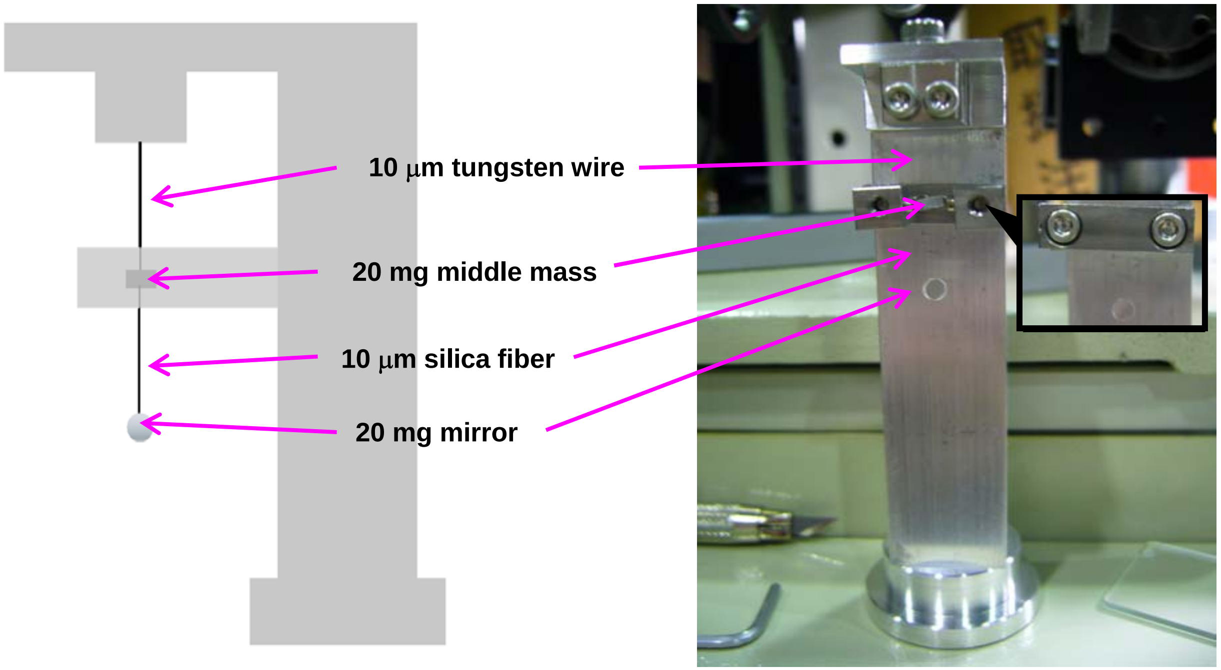
Silica fiber attached on 20 mg mirror

- Silica fiber attached on 20 mg mirror
  - » Glued with UV cured resin
    - – Q-factor of suspension with the suspended mirror should be measured
  - » We may investigate welding using CO2 laser



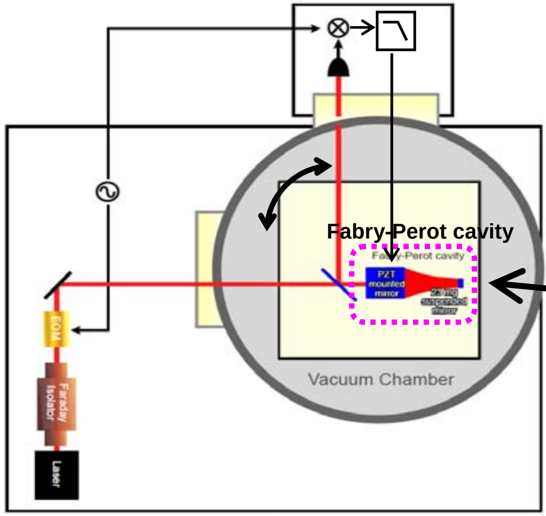
20 mg mirror suspension

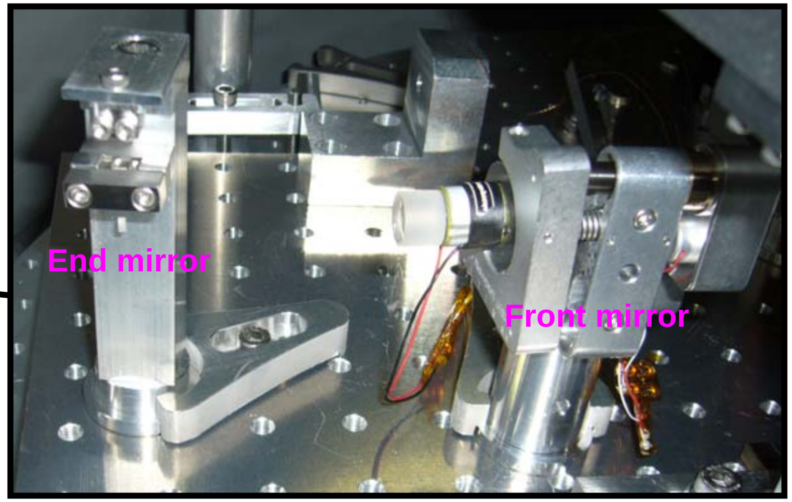
- Double suspension with 20 mg mirror
  - » Middle mass of 20 mg is damped using eddy current damping
    - – Very high Q-factor of suspension



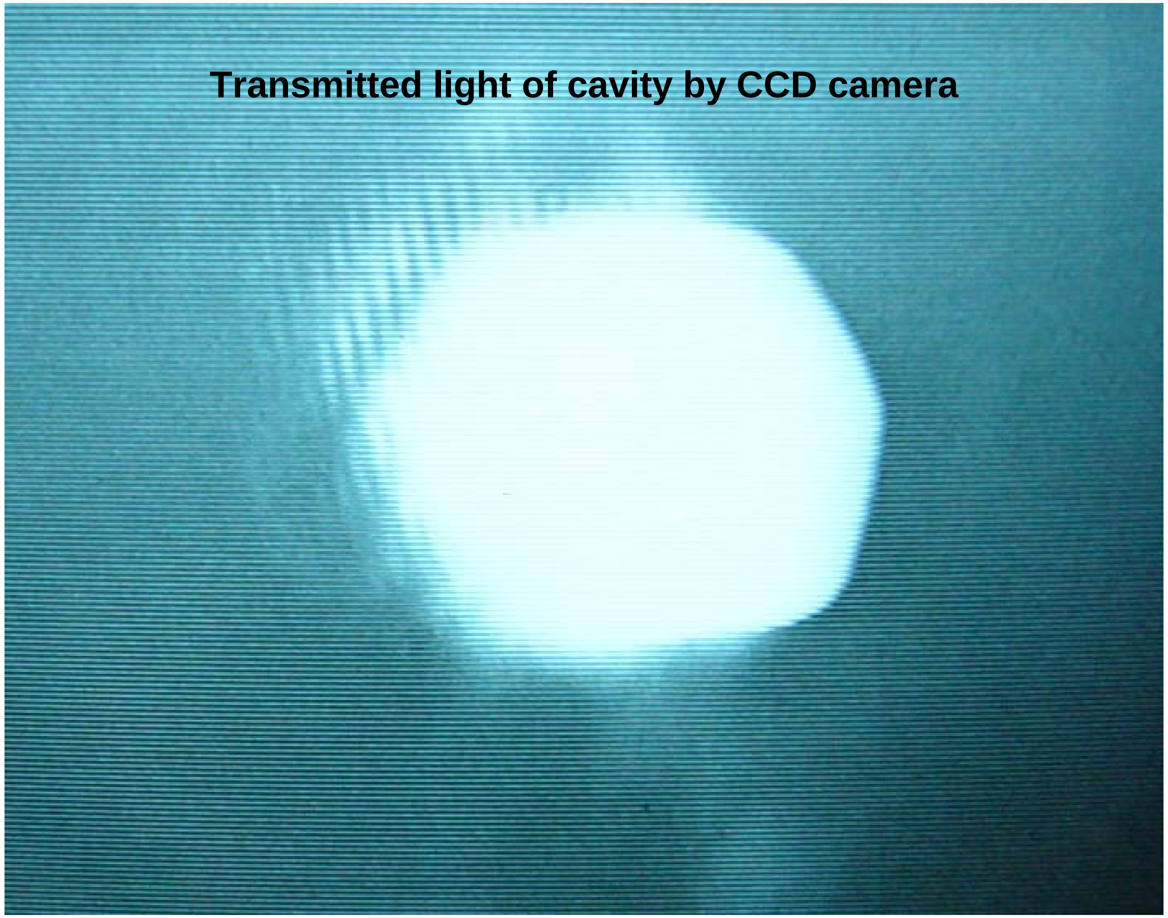
Fabry-Perot cavity

- Fabry-Perot cavity
  - » Cavity length; 6cm, Finesse; 1400
    - – Front mirror; fixed mirror mounted on PZT
    - – End mirror; suspension with 20 mg mirror
      - Effective diameter of the mirror; 2 mm
  - » Optical table is suspended by a double pendulum



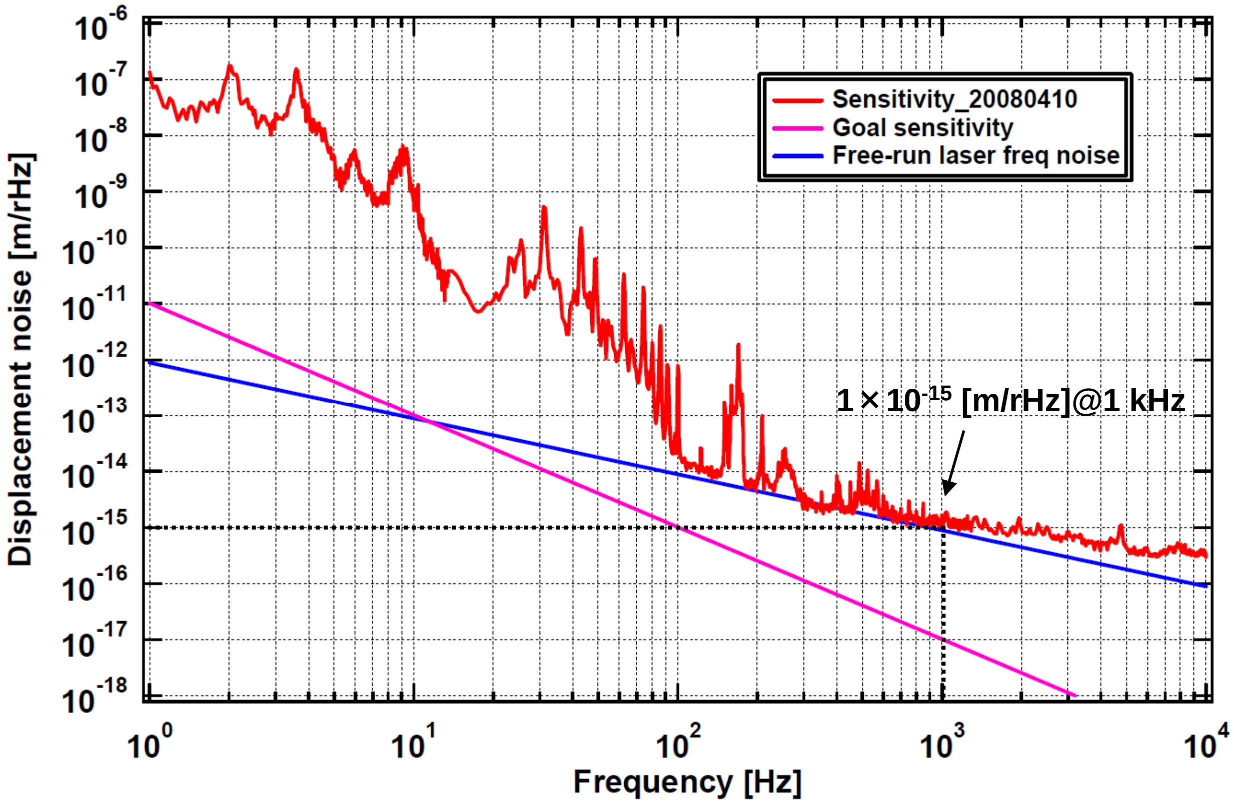


Cavity is locked



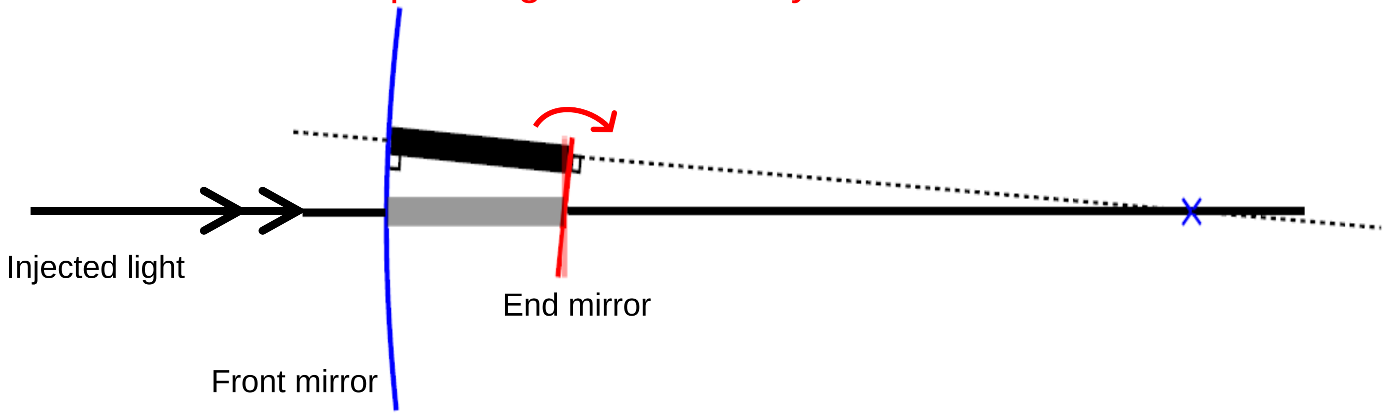
Current sensitivity

- Current sensitivity; 1×10^{-15} [m/rHz]@1 kHz
  - » A factor of 10 at 100 Hz, 100 at 1 kHz to reach the goal sensitivity
    - – Laser power is a factor of 100 smaller than the maximum laser power because of angular anti-spring effect by radiation pressure



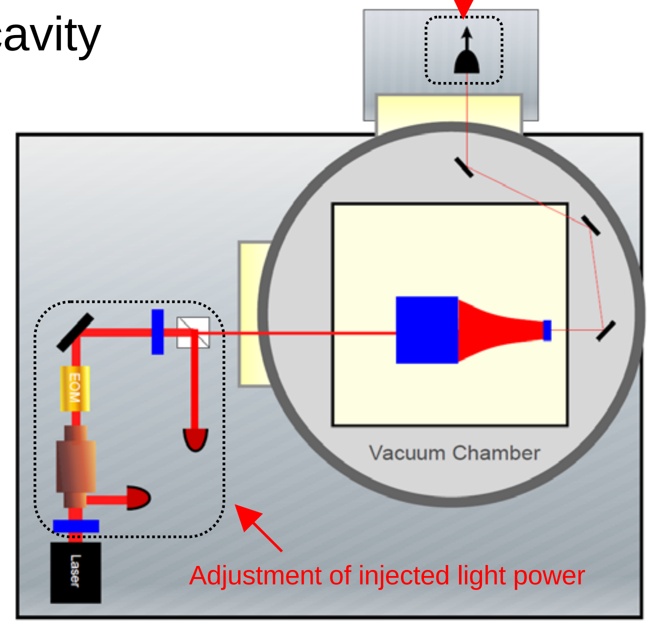
3. Angular anti-spring effect by radiation pressure

- Principle of angular anti-spring effect by radiation pressure
  - » Resonant axis is changed from center of mirror because of mirror fluctuations
    - – Tiny mirror is suspended by single silica fiber
    - – Rotation is increased by radiation pressure → angular anti-spring effect
  - » Torque by radiation pressure is a factor of 100 larger than restoring force
    - – If maximum laser power goes into cavity



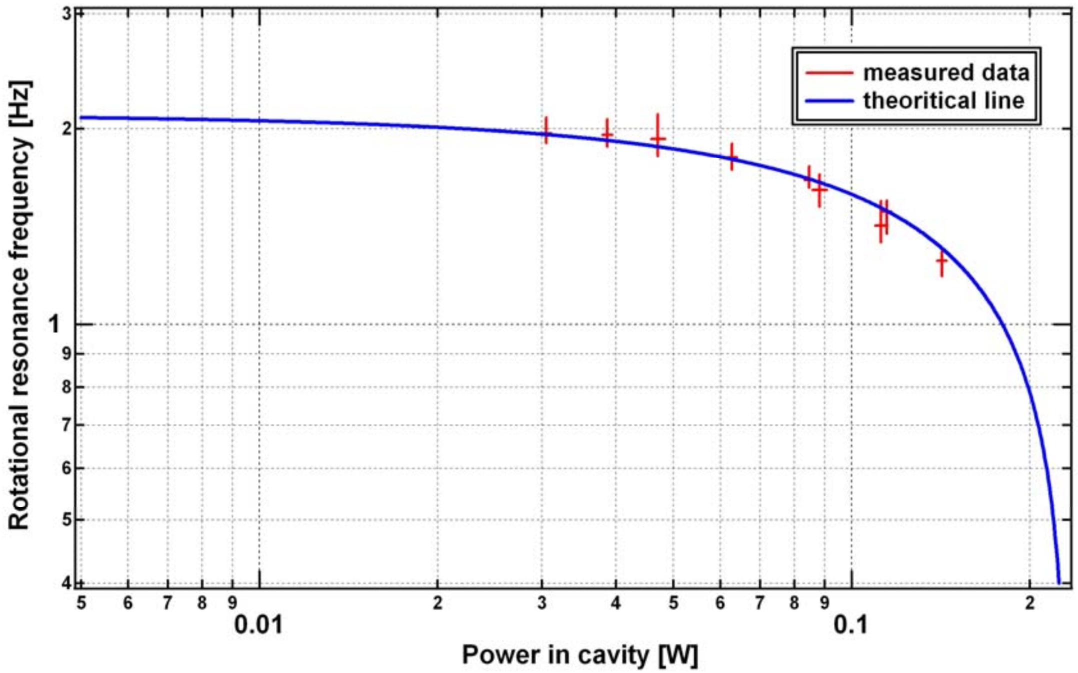
Measurement of angular anti-spring effect

- Measurement of angular anti-spring effect
  - » Radiation pressure force is smaller than restoring force
    - – Injected laser power is adjusted to make the cavity stable
  - » Measurement of rotational resonance frequency of suspended mirror at some power in a cavity
    - – QPD is put on transmitted port
  - » Resonance frequency became smaller with higher laser power



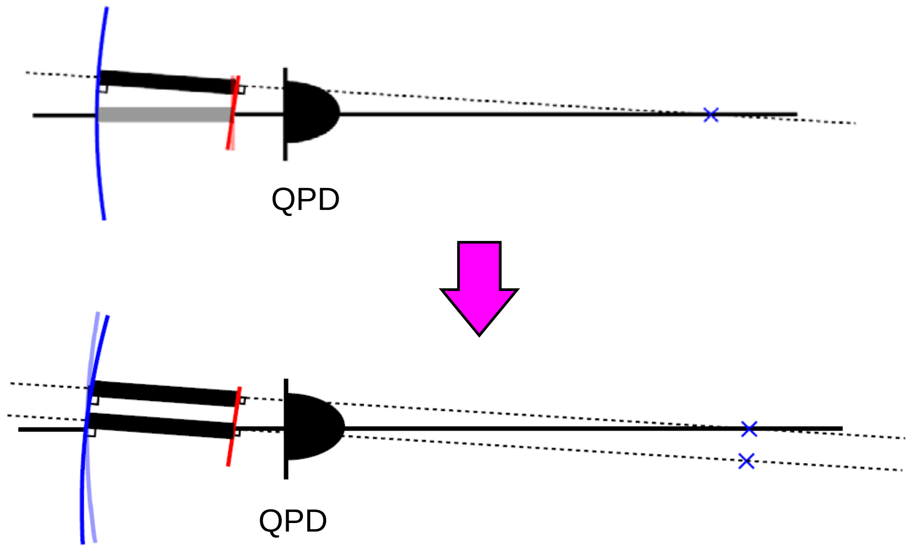
Preliminary result

- Plot of rotational resonance frequency over power in cavity
  - Power calibration is fit
  - The angular instability is observed with the increased power



Solution for angular instability by radiation pressure

- Solution for angular motions by radiation pressure
  1. QPD is put at transmitted light port to read how much resonant axis is moved from the center
  2. Center of curvature is moved to get back the axis to the center
  3. Feedback the QPD signal to front mirror



Summary and Future plans

Summary

- » Observation and reduction of radiation pressure noise between 100 Hz and 1 kHz
  - – Radiation pressure noise level of 1×10^{-17} [m/rHz] at 1kHz
  - – Ponderomotive squeezing of 6 dB is expected
- » Current status
  - – 20 mg mirror is suspended by single 10 μm silica fiber
  - – Current sensitivity is 1×10^{-15} [m/rHz] at 1kHz
  - – Measurement of anti-spring effect by radiation pressure

Near future plans

- » Fabry-Perot Michelson interferometer will be built
  - – Reach a sensitivity of 1×10^{-18} [m/rHz] at 1kHz
    - Front mirror will be suspended

The End