QRPN Experiment with Suspended 20mg Mirrors

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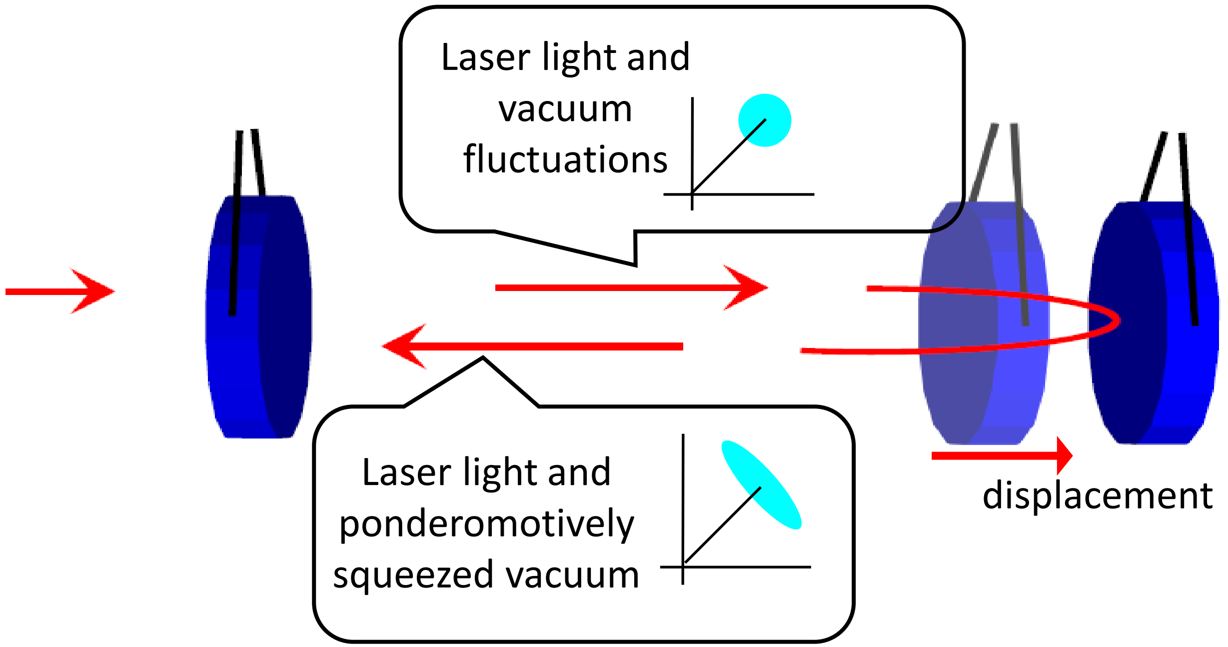
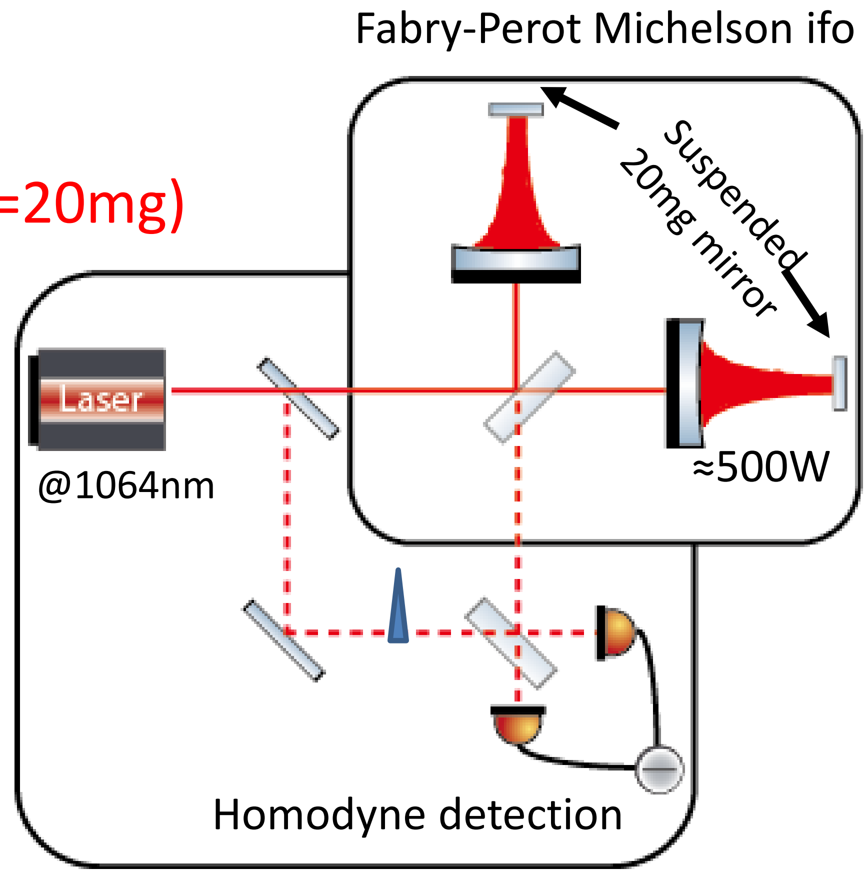
Objectives

- Observation/Reduction of Quantum Radiation Pressure Noise
  - Back-action correlates amplitude and phase fluctuations
  - Ponderomotive squeezing



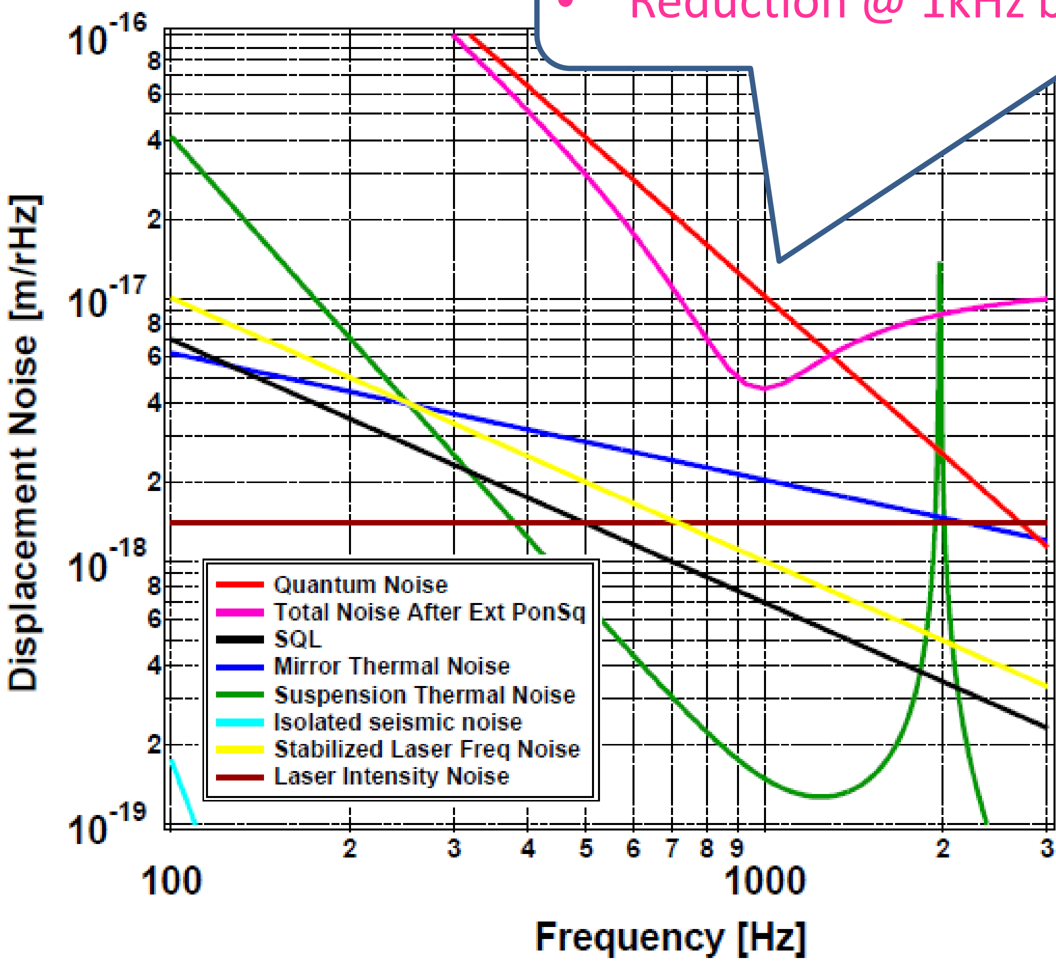
Approach

- Topology
  - Fabry-Perot Michelson interferometer
  - Homodyne detection
- Key elements
  - High Finesse cavities (*F*=10000)
  - Tiny suspended end mirrors (*m*=20mg)



Design Sensitivity/Parameter

- Observation of QRPN around 1kHz
- Reduction @ 1kHz by 6db ponderomotive squeezing

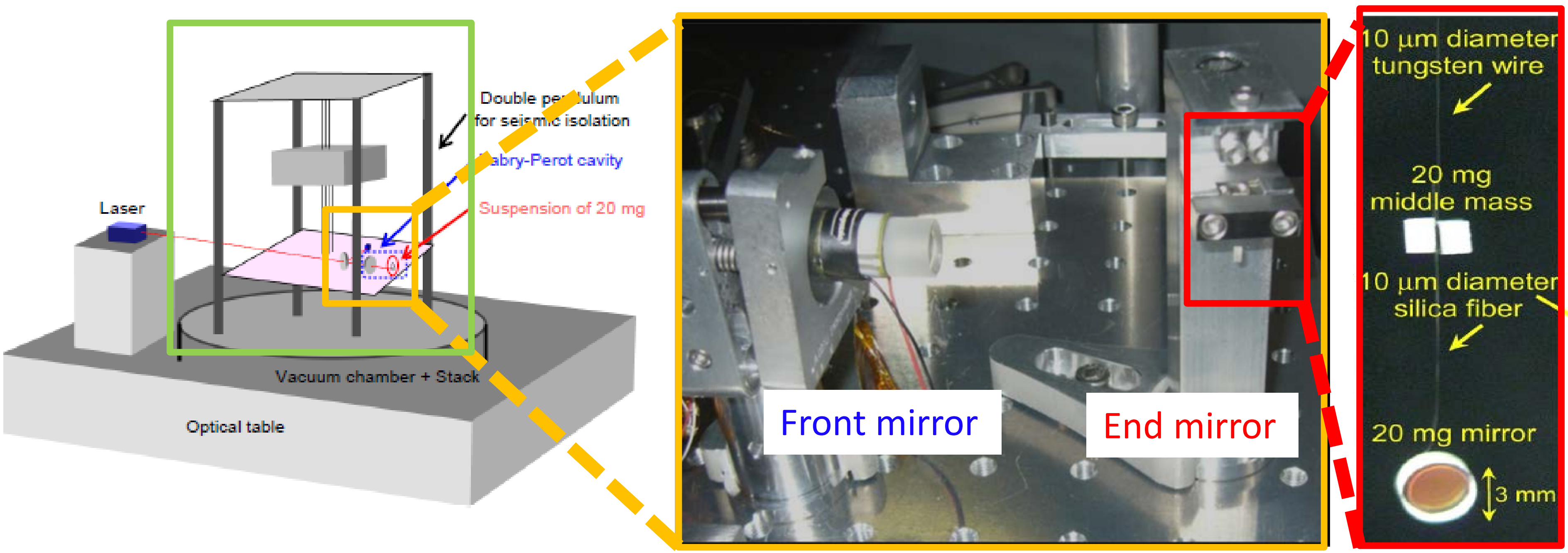


Laser power	200 mW
Injected laser power	120 mW
Finesse	10000
End mirror mass	20 mg
Diameter of end mirror	3 mm
Thickness of end mirror	1.5 mm
Front mirror mass	14 g
Reflectivity of end mirror	99.999 %
Reflectivity of front mirror	99.94 %
Optical loss	50 ppm
Beam waist of end mirror	340 μm
Mechanical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

S.Sakata et al. J.Phys.: Conf. Ser. **122**, 012020 (2008)

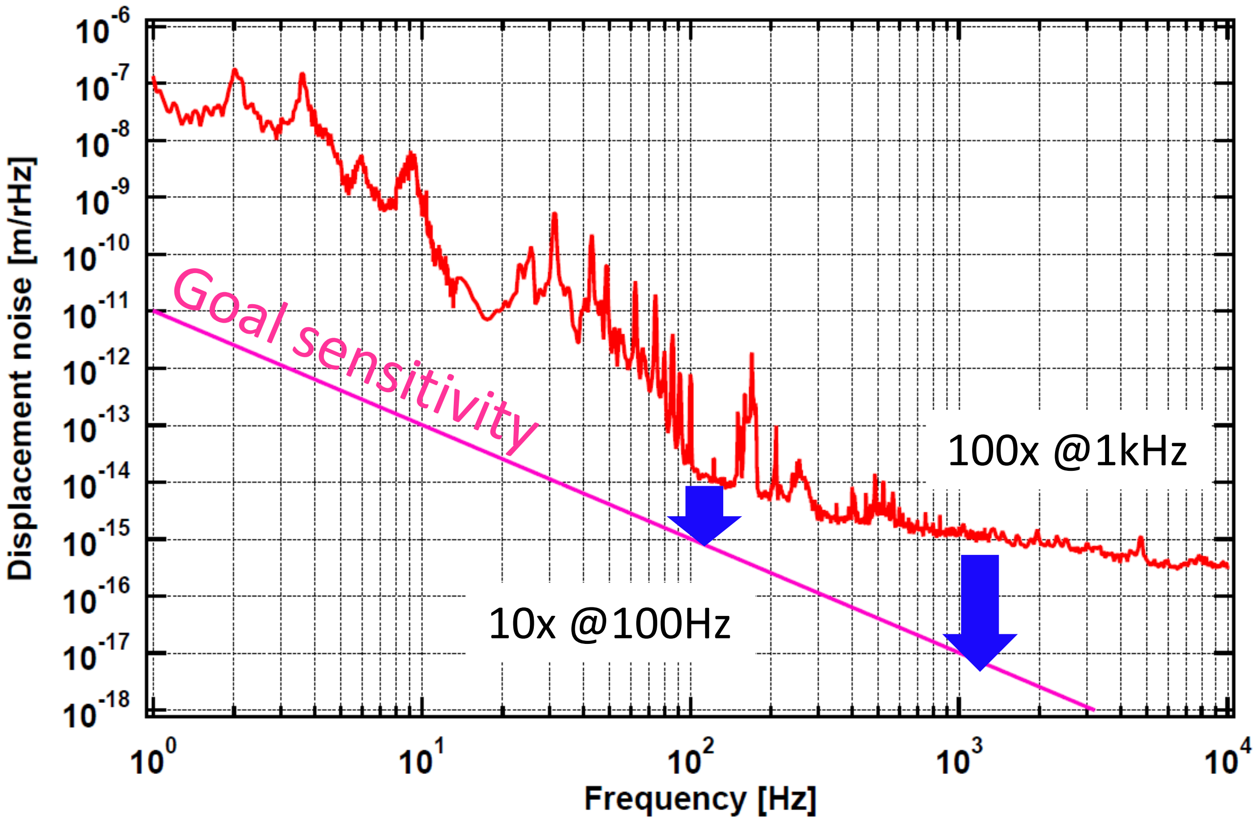
Initial Experimental Setup

- Seismic isolation for core optics is provided by a double pendulum
- Fabry-Perot-cavity under vacuum
- Front mirror: fixed mirror mounted on a Piezo actuator
- End mirror: 20mg mirror suspended by a 10μm diameter silica fiber

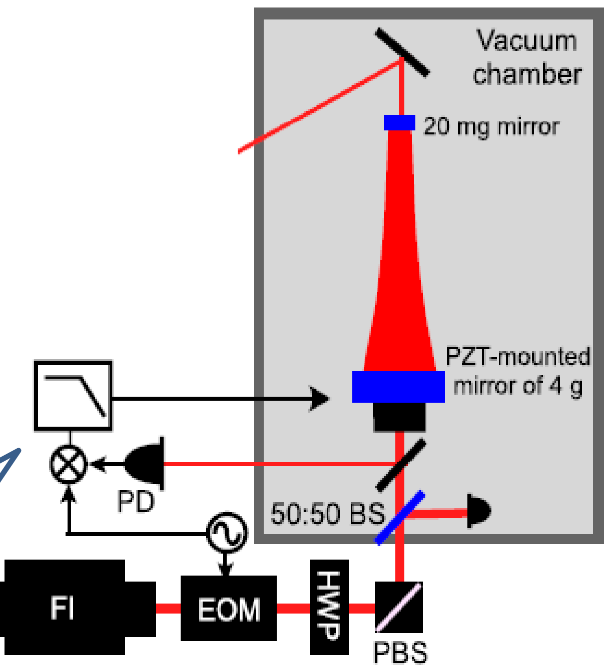


S.Sakata, Ph.D. thesis, Ochanomizu University (2008)

Achieved Sensitivity



Cavity parameter:
Finesse = 1400
L = 70mm
RoC_1 = 2m
RoC_2 = inf

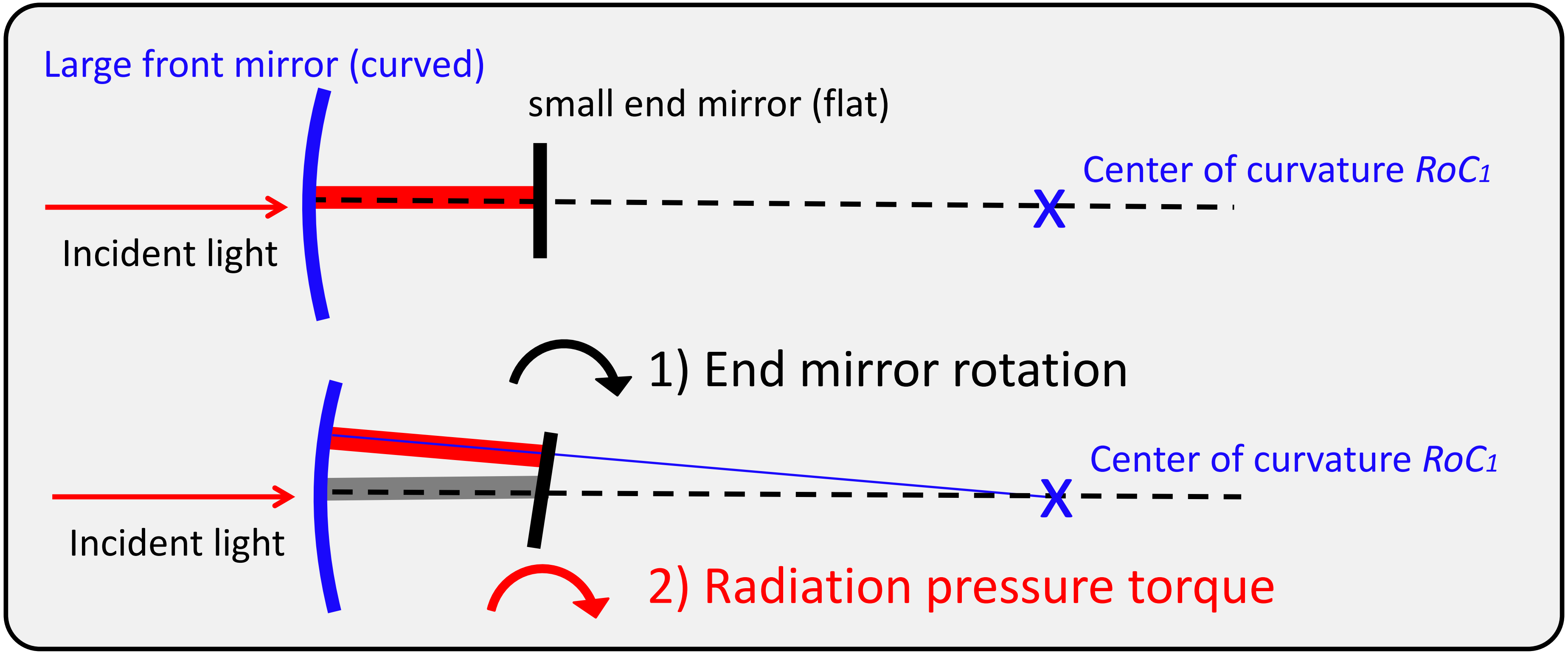


- Stabilized via PDH-scheme
- Sensitivity via calibrated feedback signal

S.Sakata, GWADW (2008)

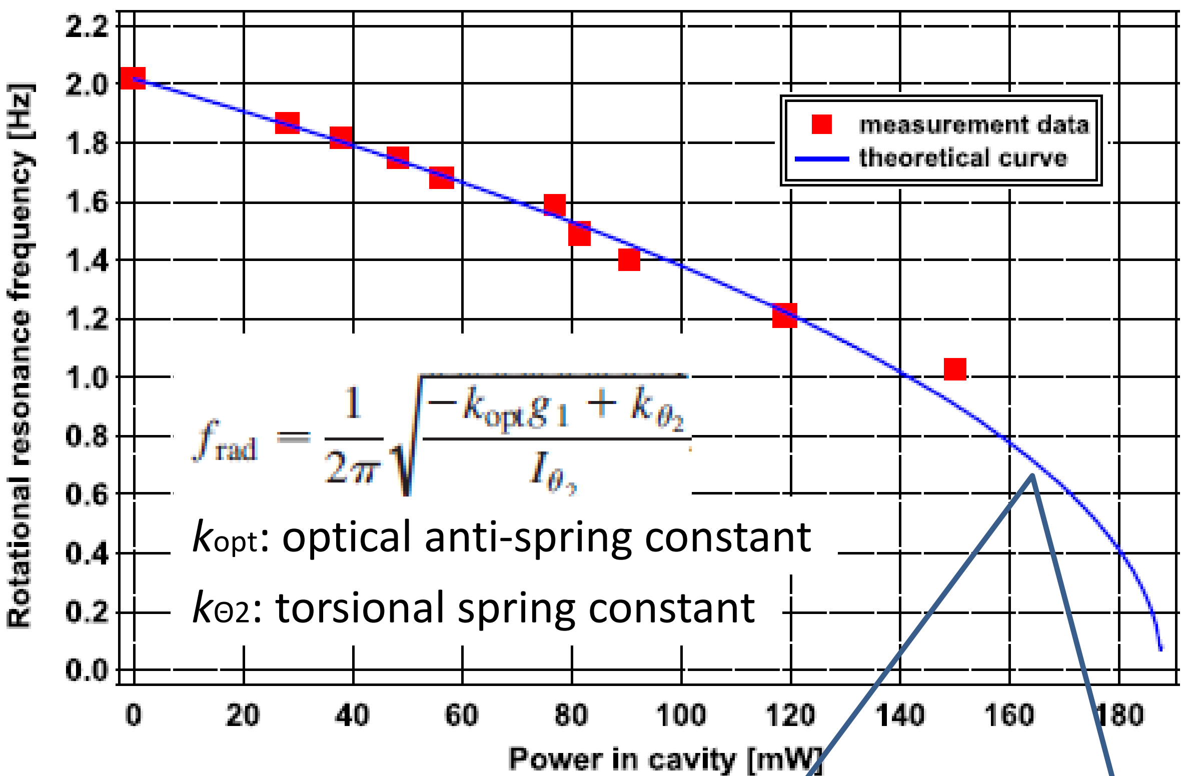
Angular Anti-Spring in Suspended Cavities

- Optical axis is shifted by mirror rotation (yaw/pitch)
  - Torque by radiation pressure
  - For high circulating power: optical torque > restoring force
  - Cavity becomes instable (angular anti-spring effect)



[see e.g. J.A.Sidles, D.Sigg, Phys. Lett. A 354, 167 (2006)]

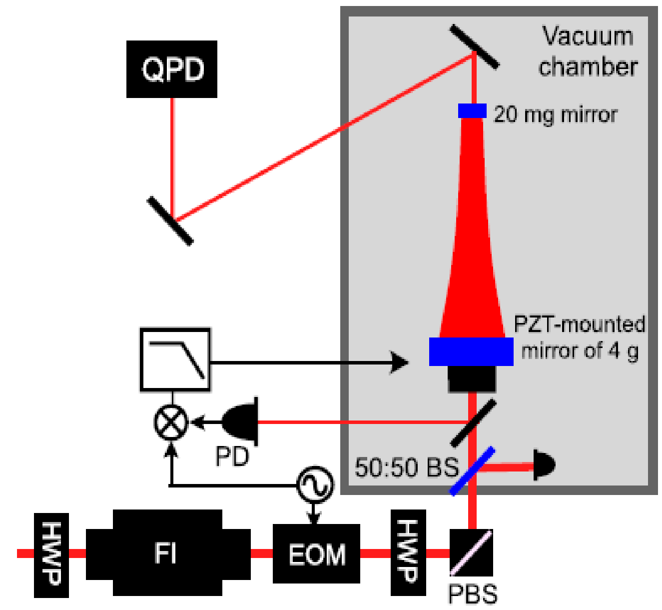
Measurement of Angular Anti-Spring (Yaw)



$$f_{\rm rad} = \frac{1}{2\pi}\sqrt{\frac{-k_{\rm opt}g_1 + k_{\theta_2}}{I_{\theta_2}}}$$

$k_{\rm opt}$: optical anti-spring constant

$k_{\Theta 2}$: torsional spring constant



- Optical anti-spring increases with laser power
- Observed via a decrease in yaw eigenfrequency
- Data was taken until near instability (≈190mW)

Cavity parameter:

Finesse = 1400

L = 70mm

R_1 = 2m

R_2 = inf

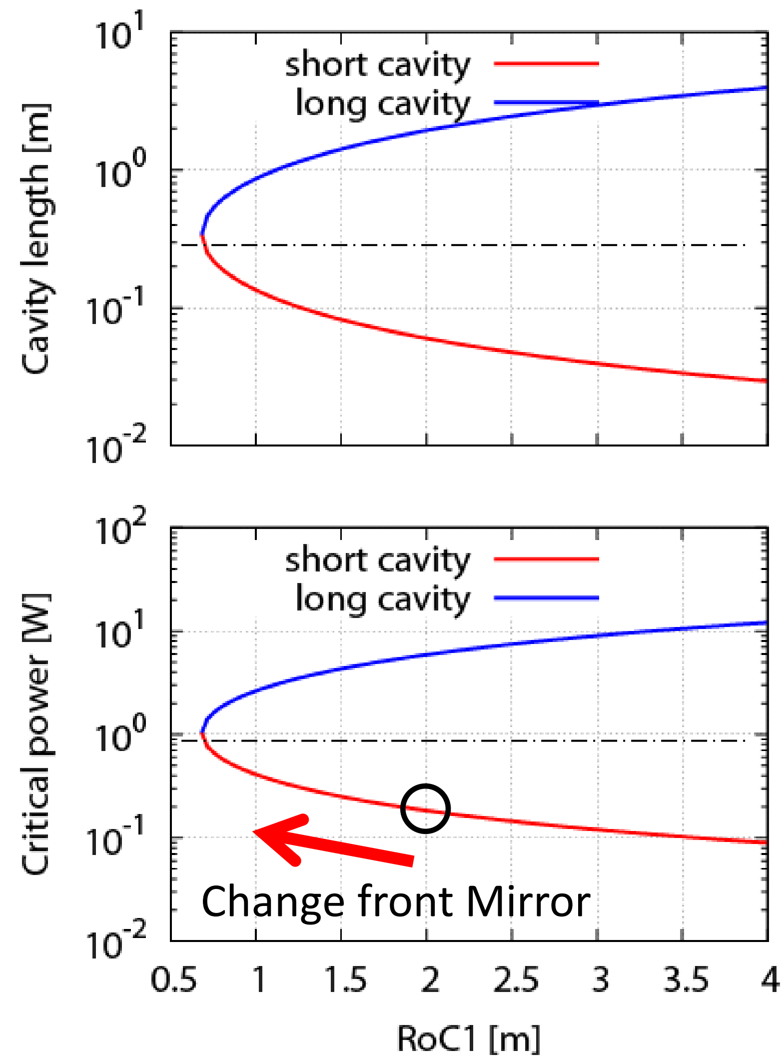
S.Sakata et al. Phys. Rev. D **81**, 064023 (2010)

How to Cope the Angular Anti-Spring

Optimize the cavity geometry:

- ➢ Change cavity g-factors
- ➢ Change RoC of the front mirror

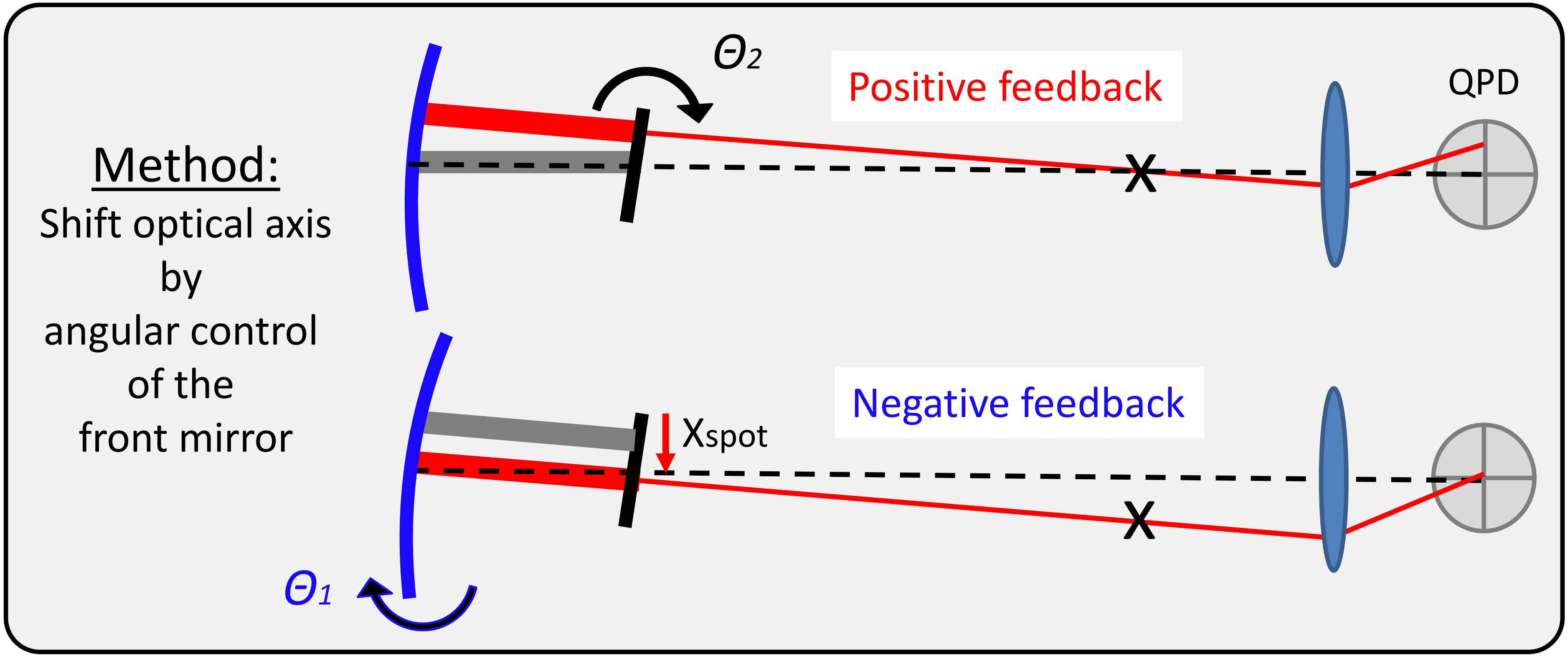
- Restriction:
  - ➢ Using a flat end mirror*
  - ➢ Beam radius of 340µm (coating TN)
  - ➢ Reasonable cavity length ≤ 0.3m
- Result:
  - ➢ Going to smaller RoC1
  - ➢ Critical power still < 1W
  - ➢ Circulating Power in final design ≈ 500W
  - ➢ Angular control is required!



* A curved 20mg mirror is advantageous, but not available so far

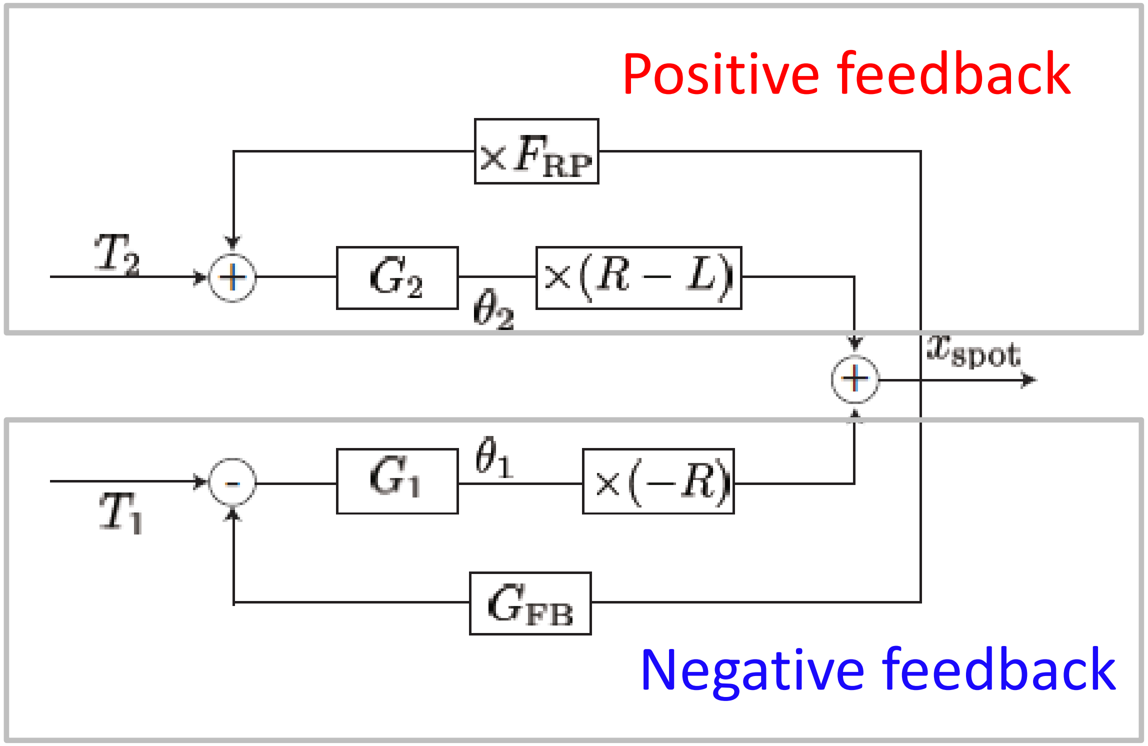
Angular Control – Idea

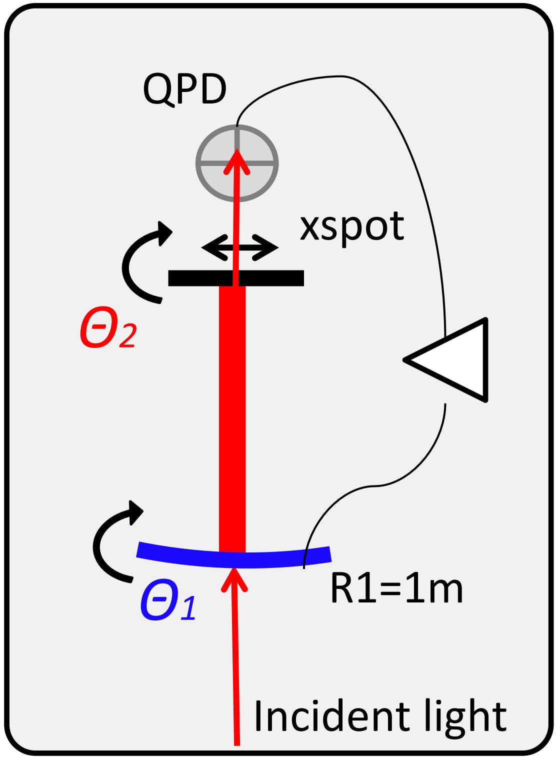
- Difficult to apply an external force to the small mirror directly
  - ➢ Idea: Control the small end mirror via radiation pressure



➢ Error signal is derived via a quadrant diode (QPD)

Angular Control - Model





Ti: torque, *Gi*: pendulum transfer function

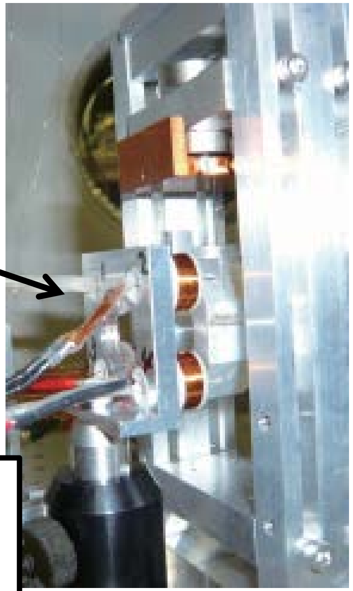
- Model for angular control to suppress x_{spot} (for final design):
  - G_{FB}: can provide sufficient gain at low frequencies (zero/pole @ 200/500Hz)
  - Need to suppress electronic noise around 1kHz (yaw to longitudinal coupling)

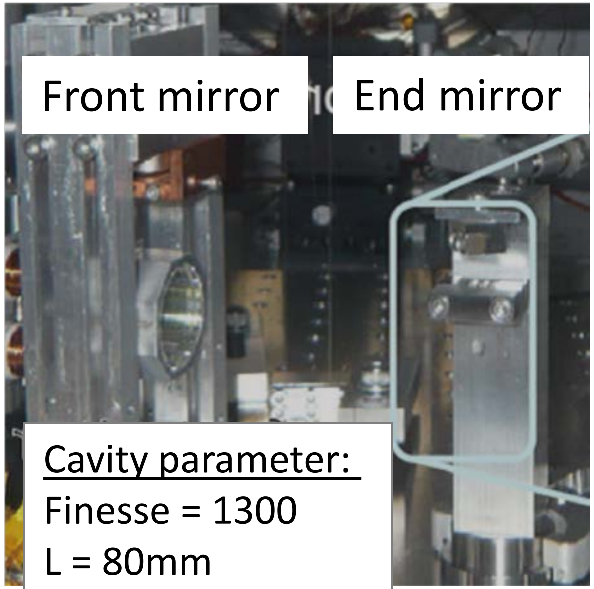
S. Sakata, internal document (2008)

T.Mori, Ph.D. thesis, The University of Tokyo (2012)

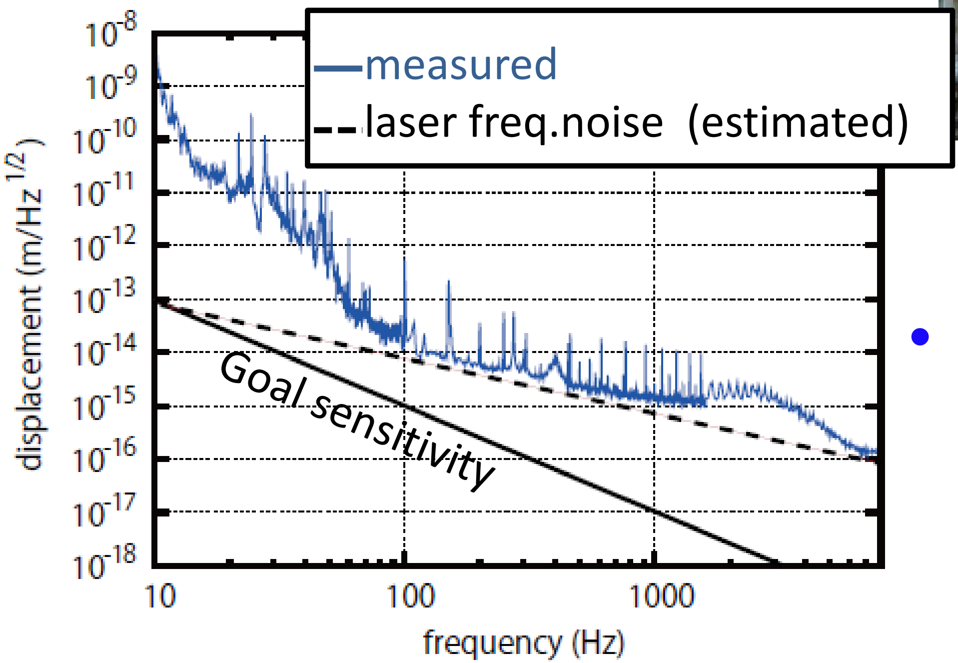
Results with a Fully Suspended Cavity

- Suspended front mirror
  - ➢ coil-magnet actuators
  - ➢ increase the actuation range
  - ➢ stable longitudinal lock (low power)
  - ➢ sensitivity comparable to prev. setup





Cavity parameter:
Finesse = 1300
L = 80mm
R1 = 1m, R2 = inf

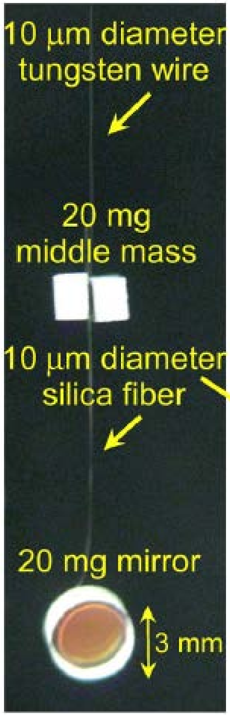


- Angular control via front mirror
  - ➢ control circuit was installed
  - ➢ stabilization of angular anti-spring via RP not demonstrated yet

T.Mori, Ph.D. thesis, The University of Tokyo (2012)

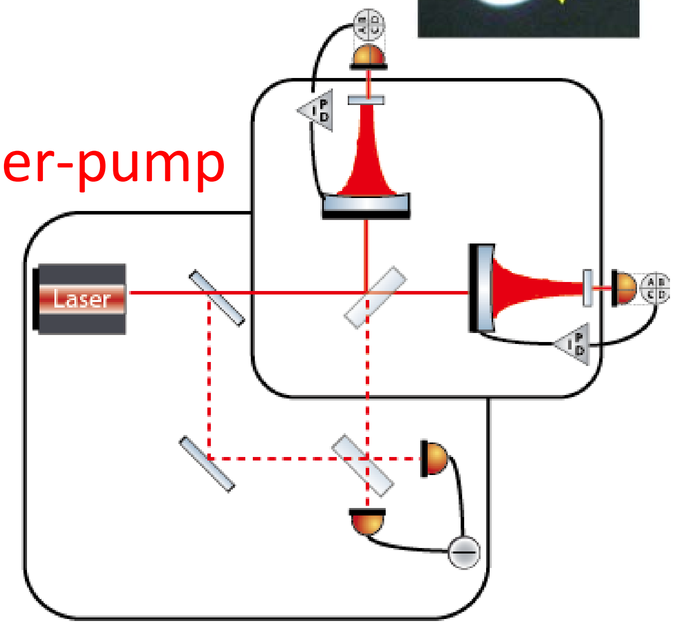
Summary

- Goal: Observation and Reduction of QRPN
  - Key element: 20mg mirror suspended by a 10µm silica fiber
- Fully suspended cavity locked stable (at low power)
  - Model/setup for angular control via radiation pressure



Outlook

- Demonstrate angular control (with preliminary setup)
  - Investigate feasibility for the final design
- Upgrade the vacuum system by an Ion-getter-pump
  - More stable working conditions
- Setting up the full interferometer
  - Common noise rejection



Thank you


The new lab

Arrival at ICRR, March 2012