Development of a laser interferometer for MHz gravitational-wave detection

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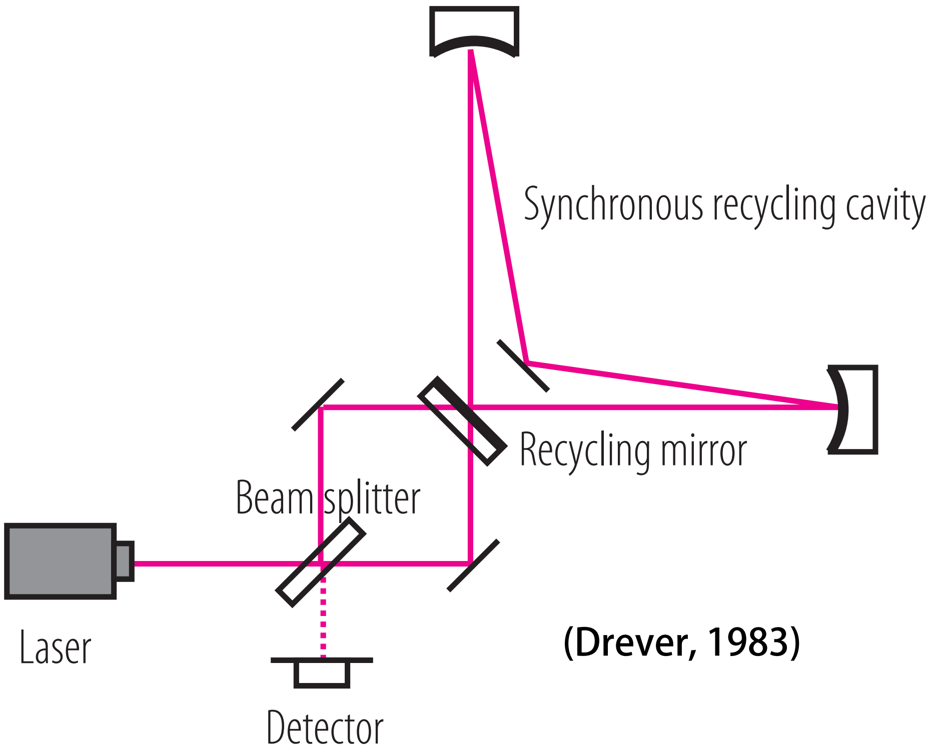
LIGO-G060309-00-Z

Contents

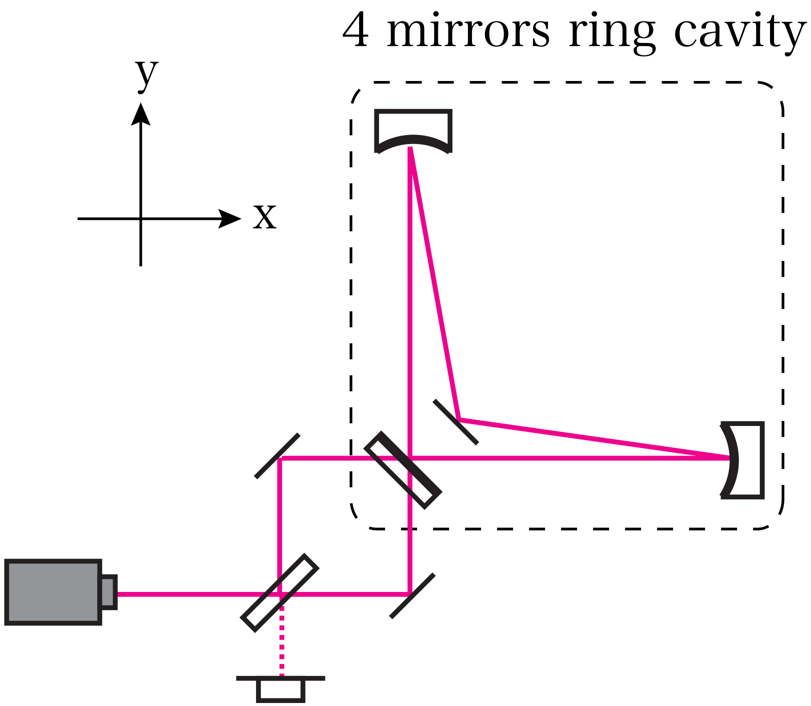
Overview

- Target: gravitational wave @ 100MHz
  (Source: cosmic background GW)
- Devices: synchronous recycling interferometers
  (Correlate the two interferometers)



(Drever, 1983)

Synchronous recycling cavity would work as follows:



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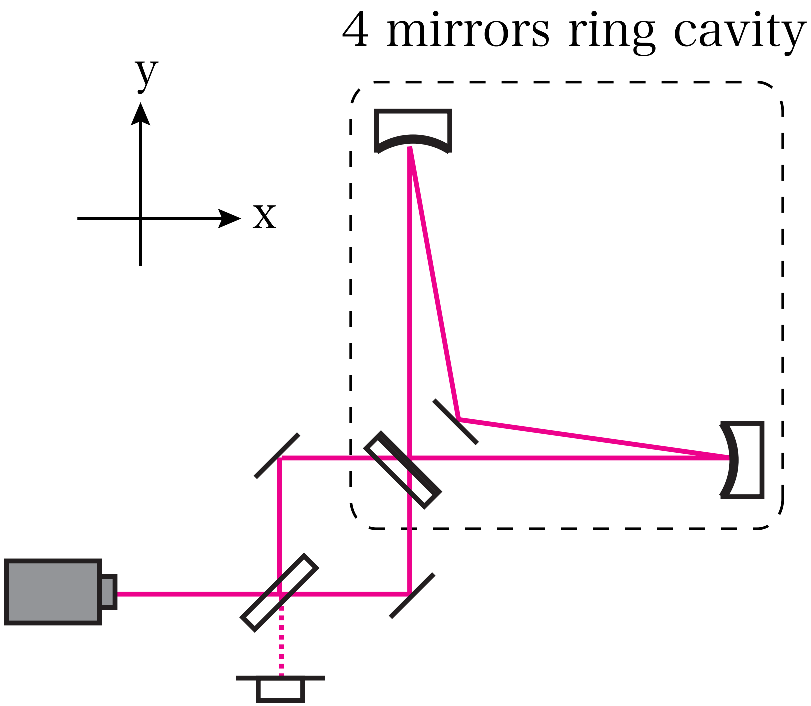

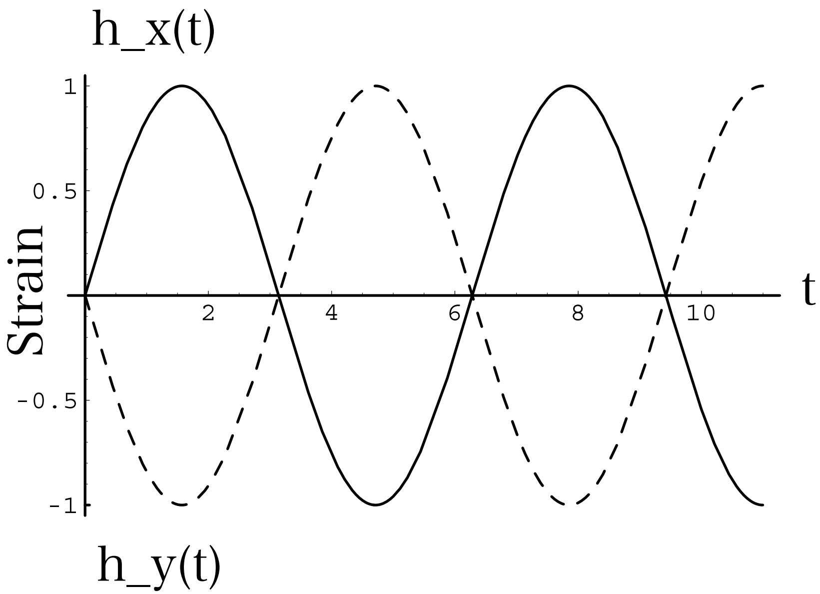

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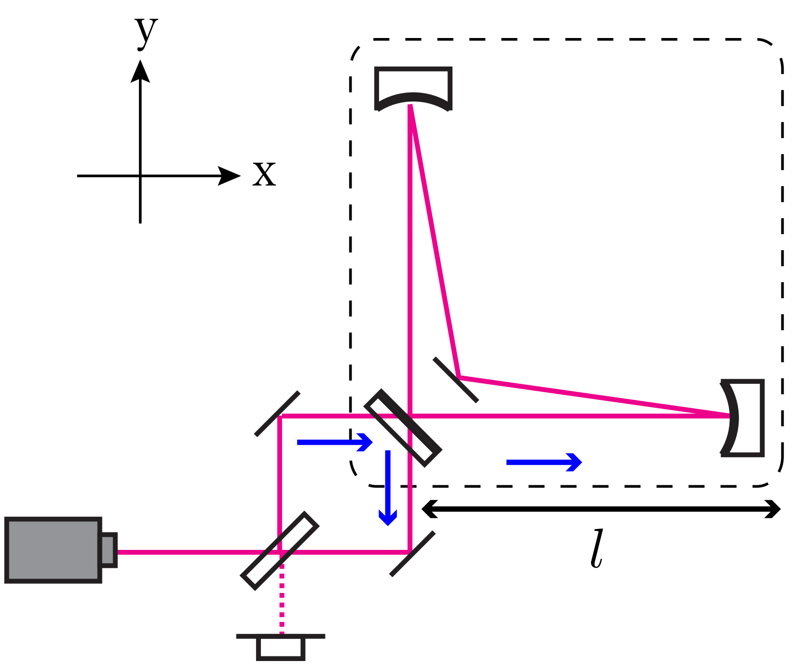

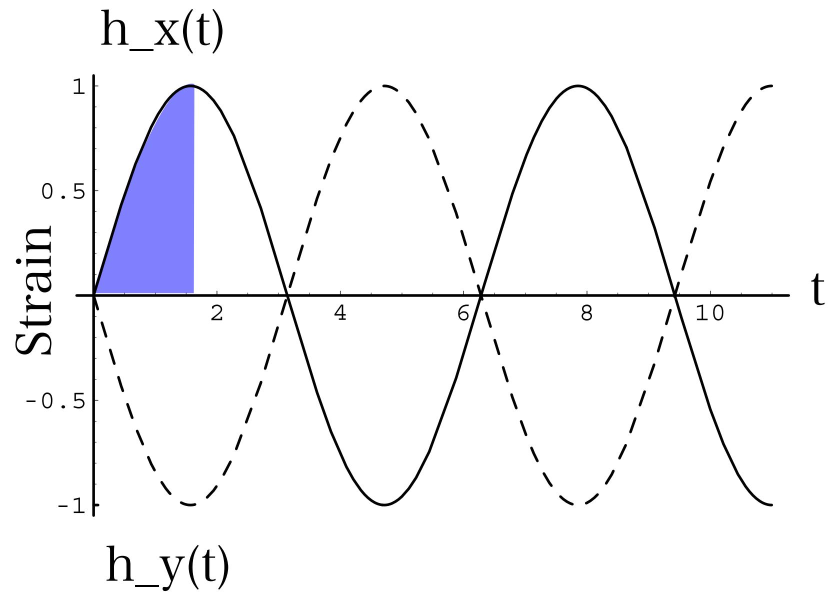

Gravitational wave at $f_{\mathrm{GW}} = \frac{c}{l}$

* Round-trip time for the ring-cavity: $t_{\mathrm{round}} = \frac{c}{4\,l}$

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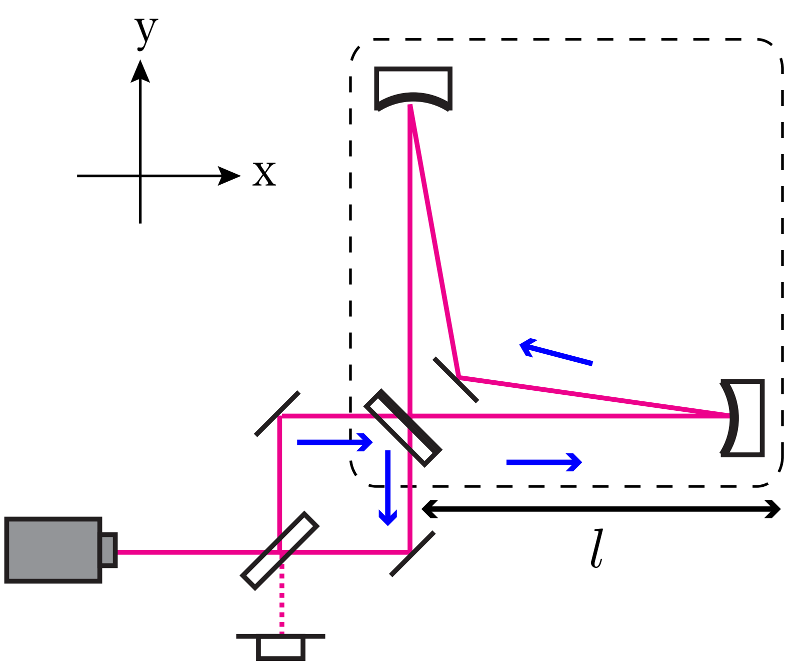

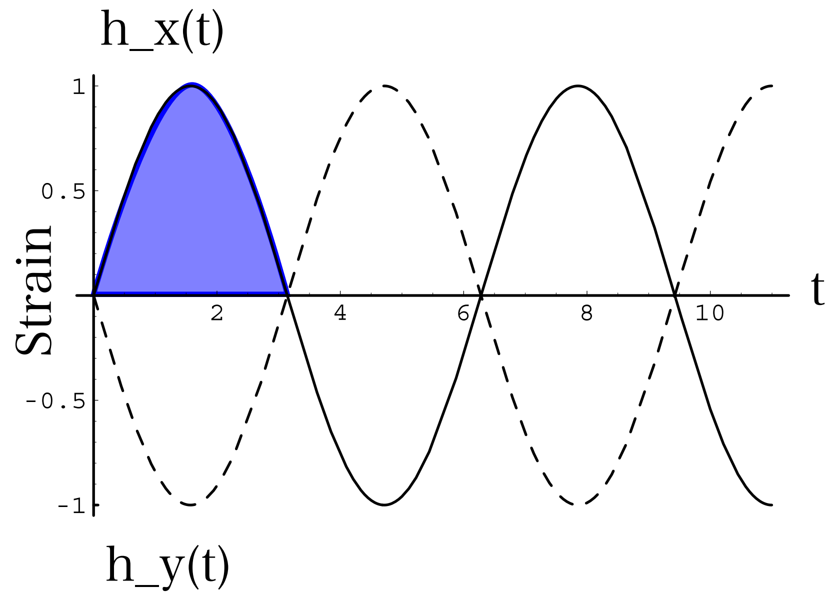

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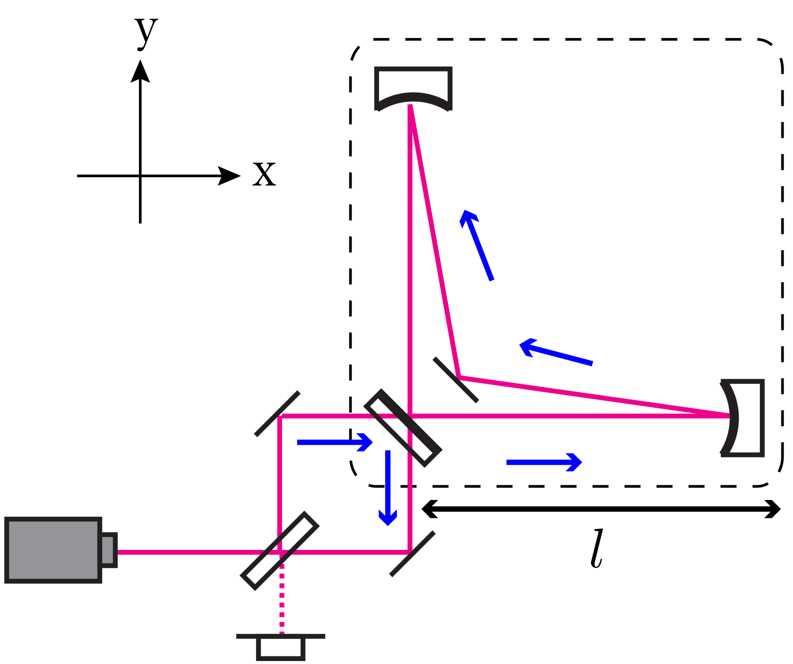

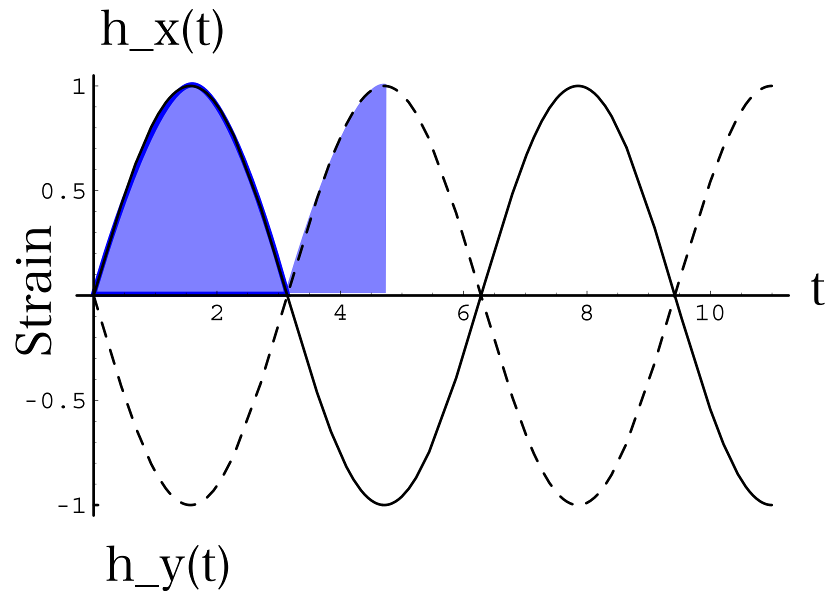

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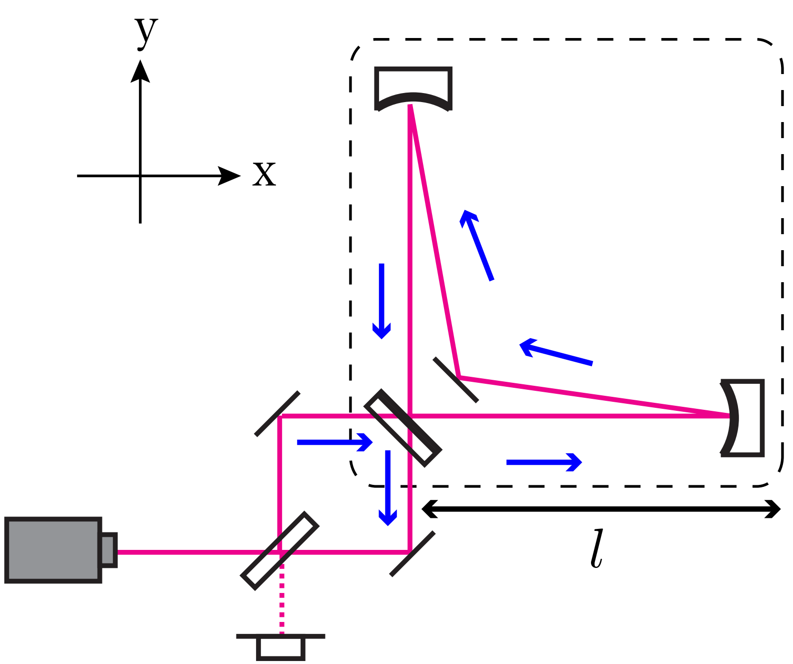

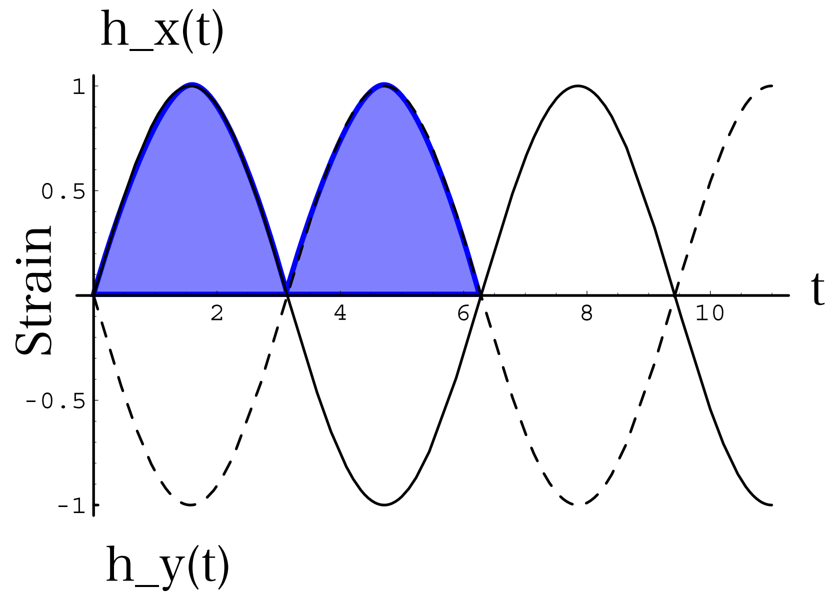

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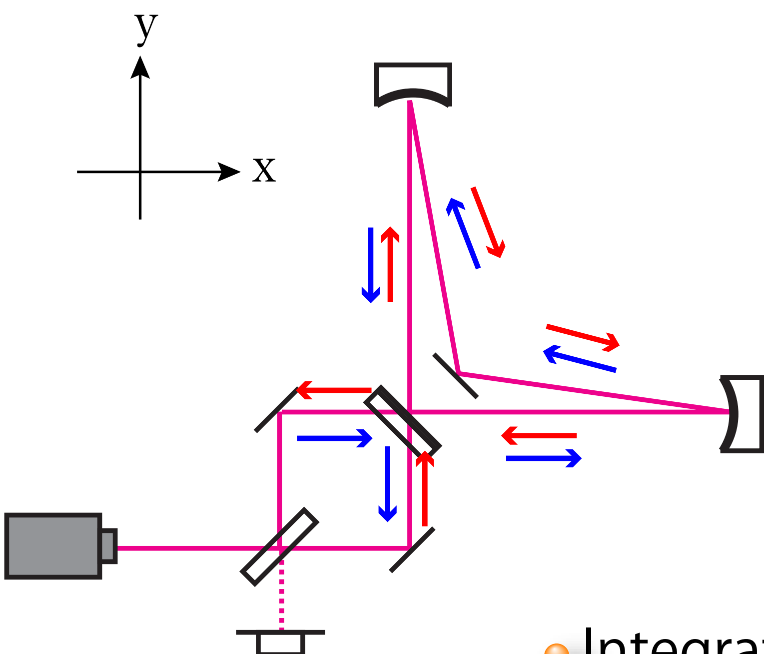
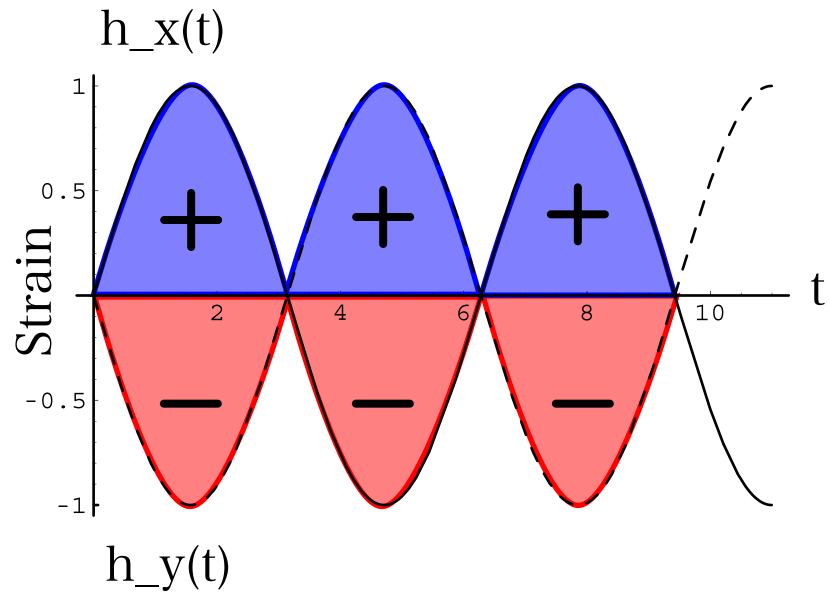
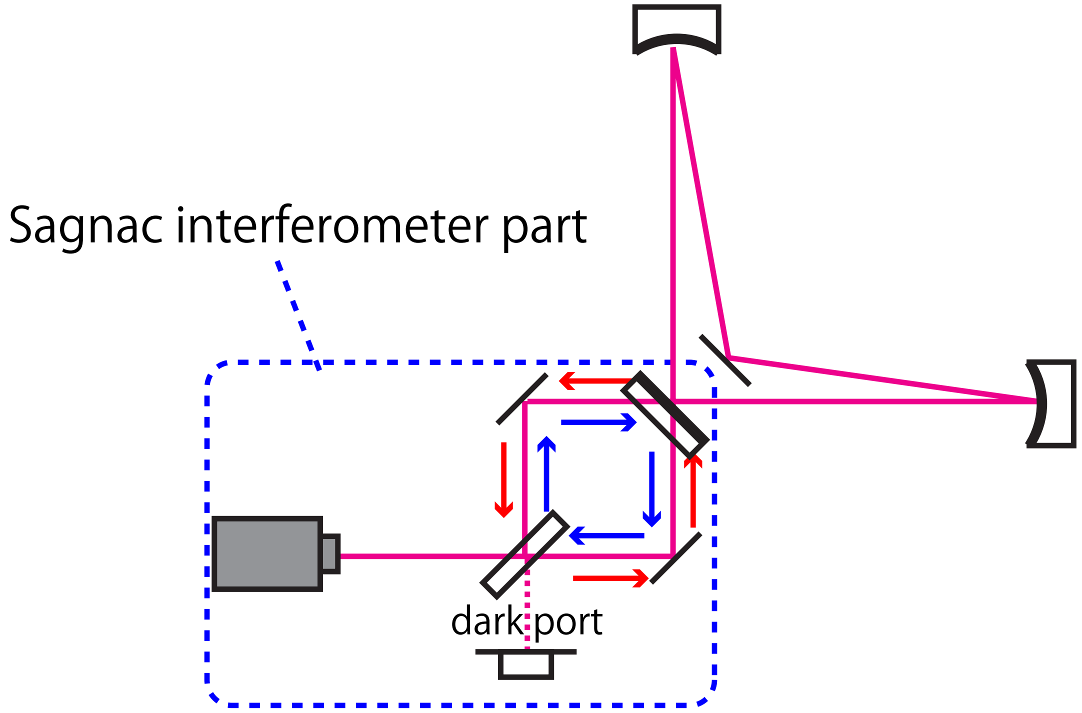




- Integrated phase amount: $\phi_{\mathrm{CCW}} = -\phi_{\mathrm{CW}}$

Sign of the phase amount would differ between counter-clockwise and clockwise light, then...

Sagnac part can detect the phase difference between ↑ & ↓



(Field at dark port) $\propto$ (phase difference)

Gravitational wave sideband at dark port

Agenda to reach final goal sensitivity

Start

The cavity really acquires lock?
100MHz siganls can be really obtained?
How about noises?

↓

1st IFO with low finesse ($\tilde{h} \simeq 10^{-18}\,\mathrm{Hz}^{-1/2}$)

↓

2nd IFO with low finesse, observation for a few weeks

↓

Two IFOs with high finesse ($\tilde{h} \simeq 10^{-21}\,\mathrm{Hz}^{-1/2}$)

↓

Observation for a few months ($\tilde{h} \simeq 10^{-26}\,\mathrm{Hz}^{-1/2}$)

Agenda to reach final goal sensitivity

Start

Our reach

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2nd IFO with low finesse, observation for a few weeks

Two IFOs with high finesse ($\tilde{h} \simeq 10^{-21}\,\mathrm{Hz}^{-1/2}$)

Observation for a few months ($\tilde{h} \simeq 10^{-26}\,\mathrm{Hz}^{-1/2}$)

Sciences of 100MHz gravitational wave

- **Big-bang nucleosynthesis**

  Upper limit of cosmic GW background @ 100MHz :

$$\tilde{h} < 10^{-33}\,\mathrm{Hz}^{-1/2}$$

Estimation from (for example) `Phys.Rev.D60:123511`

- **This experiment**

  Correlate the outputs of two IFOs for a few months,

$$\tilde{h} \simeq 10^{-26}\,\mathrm{Hz}^{-1/2}$$

(by some practical reason)

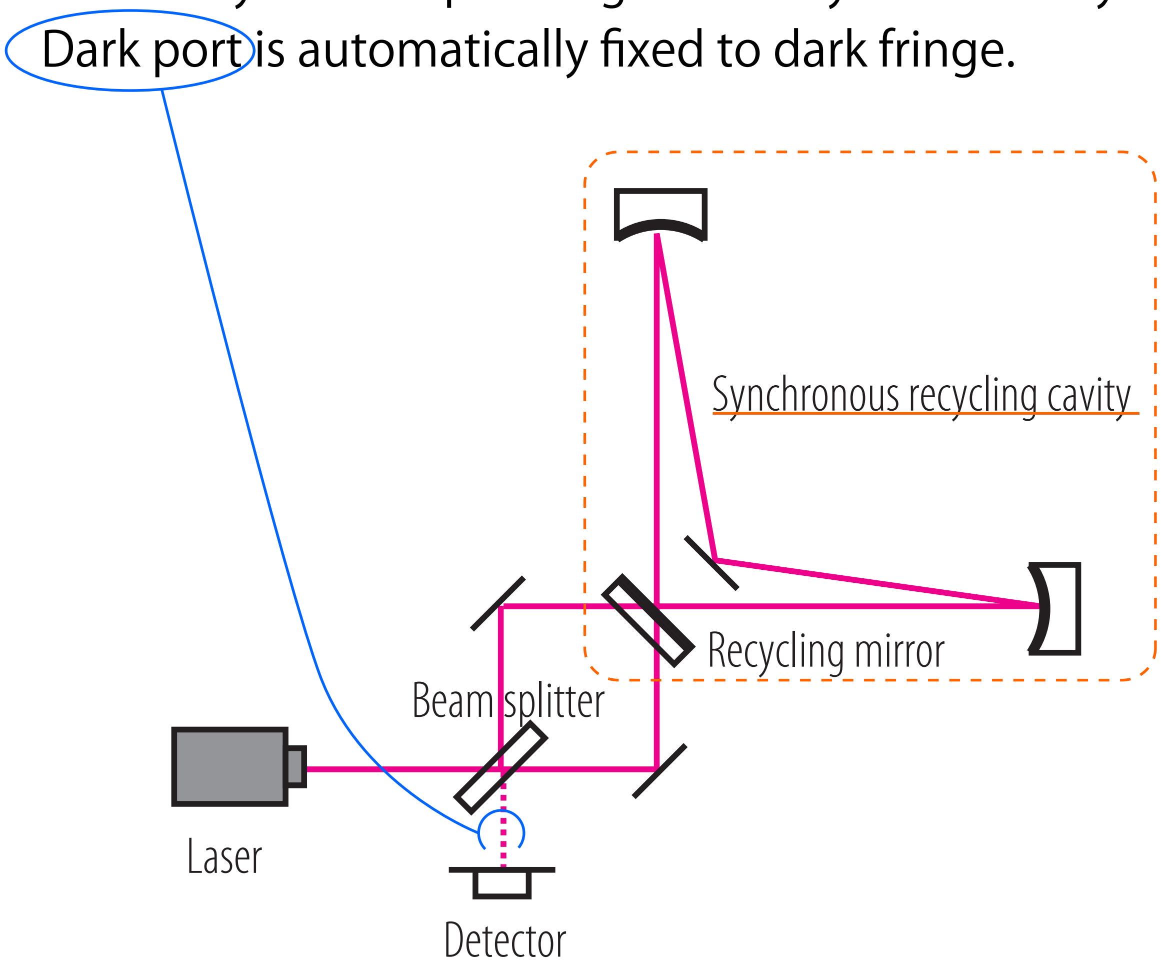
It's larger than theoletical limit, but we believe the direct measurement is significant.

2. Design

Lock acquisition (1)

- **Simple; Only 1 degree-of-freedom (in pinciple)**

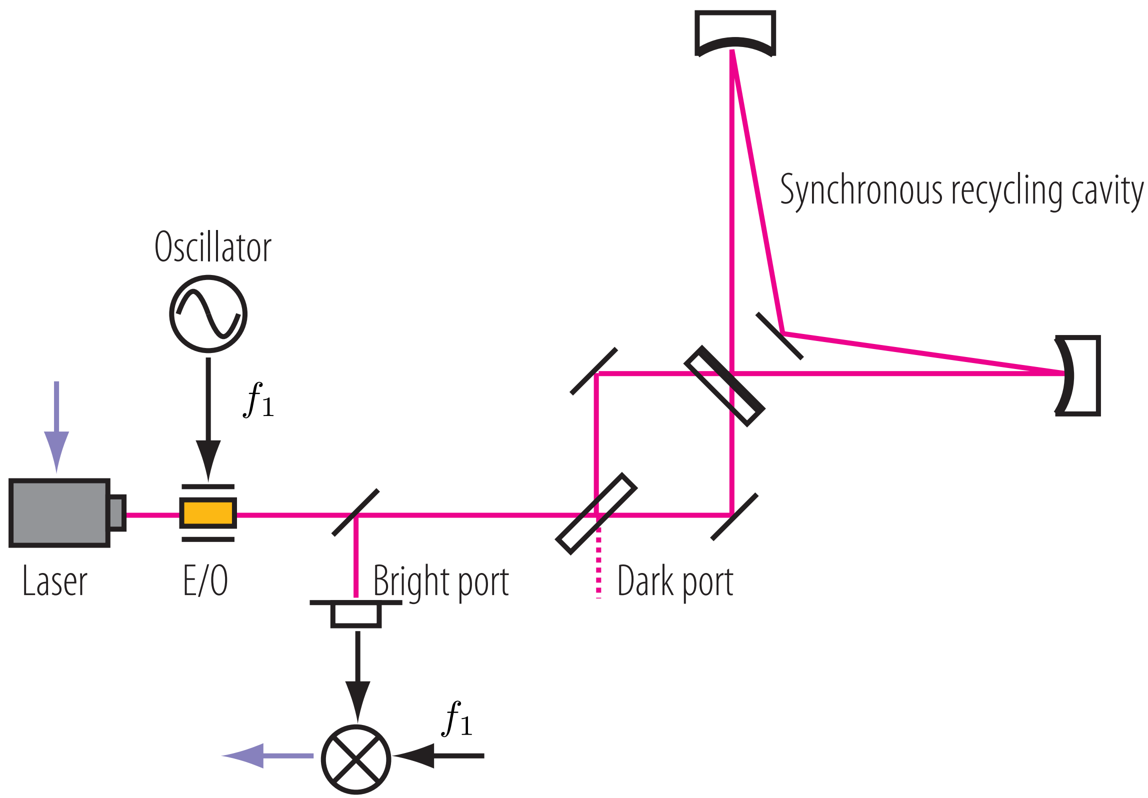
  The cavity is corresponding to a Fabry-Perot cavity.
  Dark port is automatically fixed to dark fringe.



Lock acquisition (2)

Obtain error signal at bright port (Pound-Drever-Hall method)

Aquire feedback to laser frequency



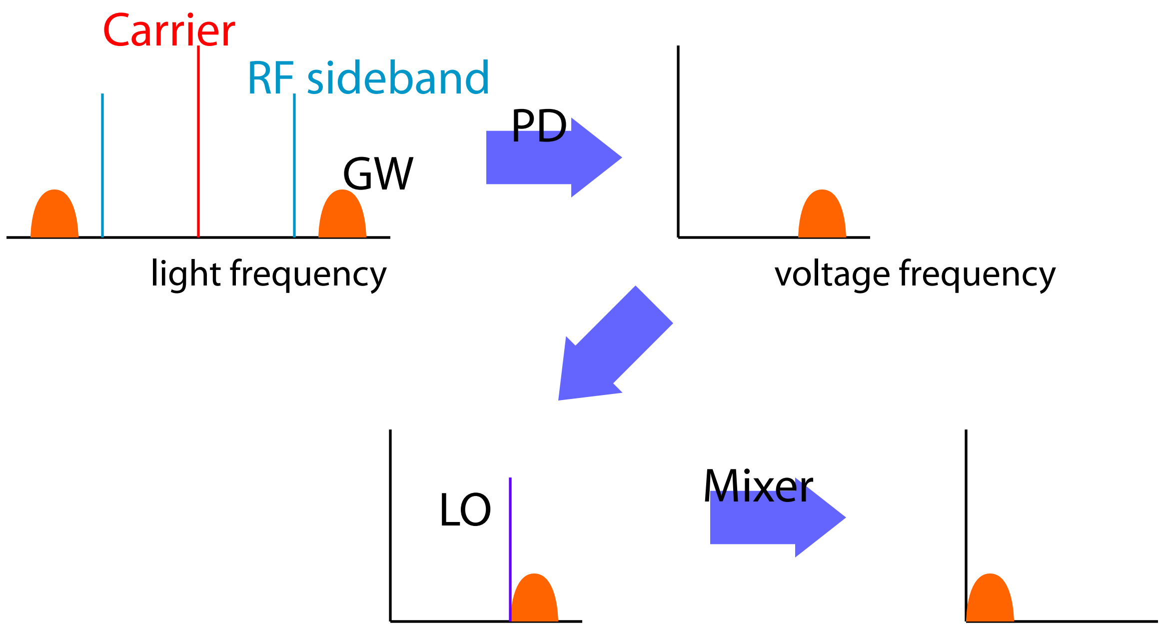
Signal readout sheme

GW sideband ($f_{\rm GW}$) beats against RF sideband ($f_{\rm RF}$) at dark port,

then photodetector provides signal at $f_{\rm GW} - f_{\rm RF}$.

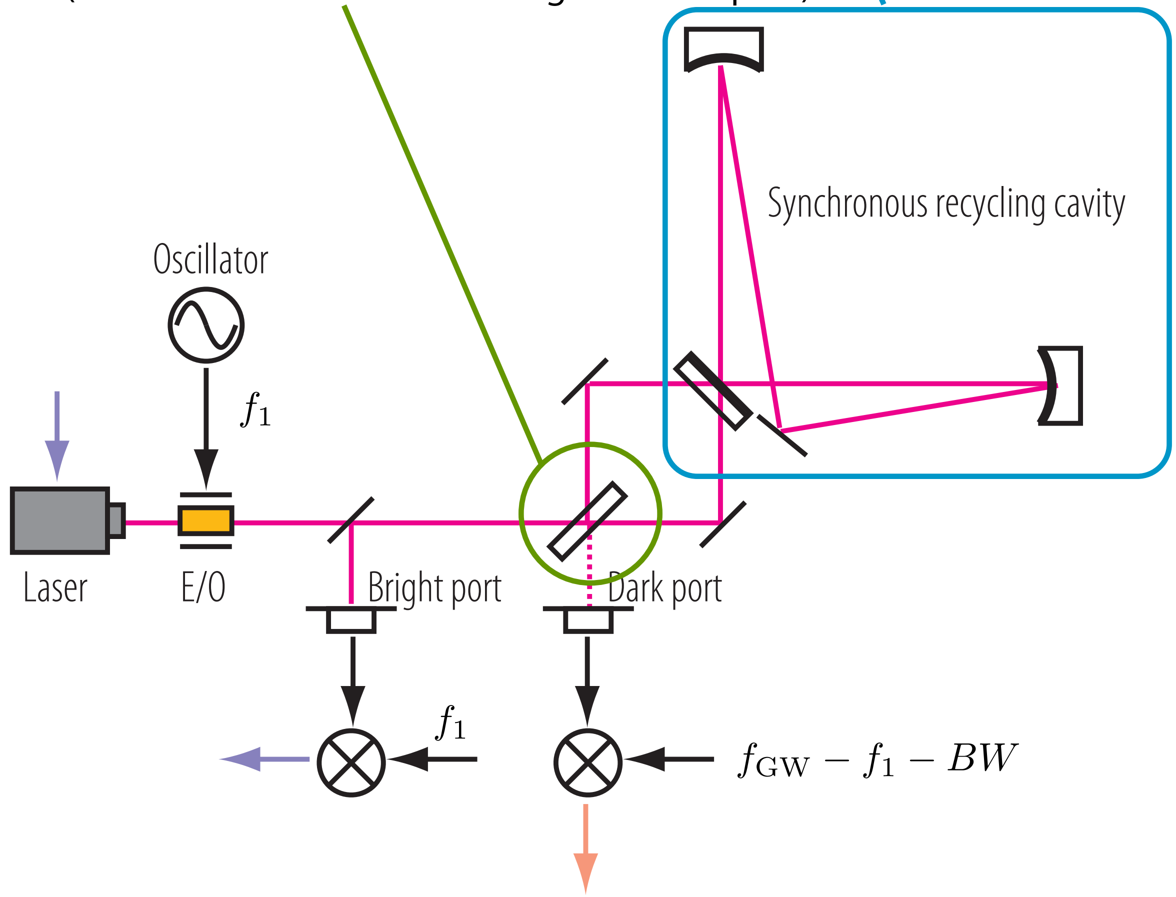
The signal beats against local oscillator at $f_{\rm GW} - f_{\rm RF} - BW$, (bandwidth)

then baseband signal is obtained.

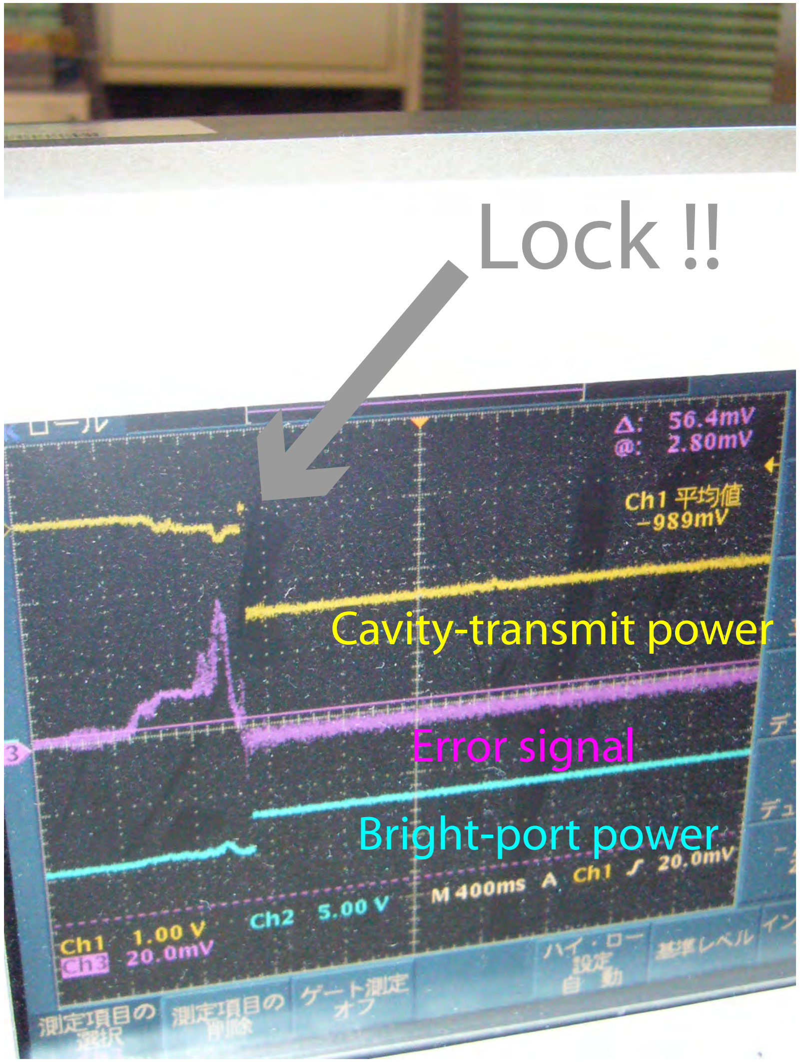


3. Current status

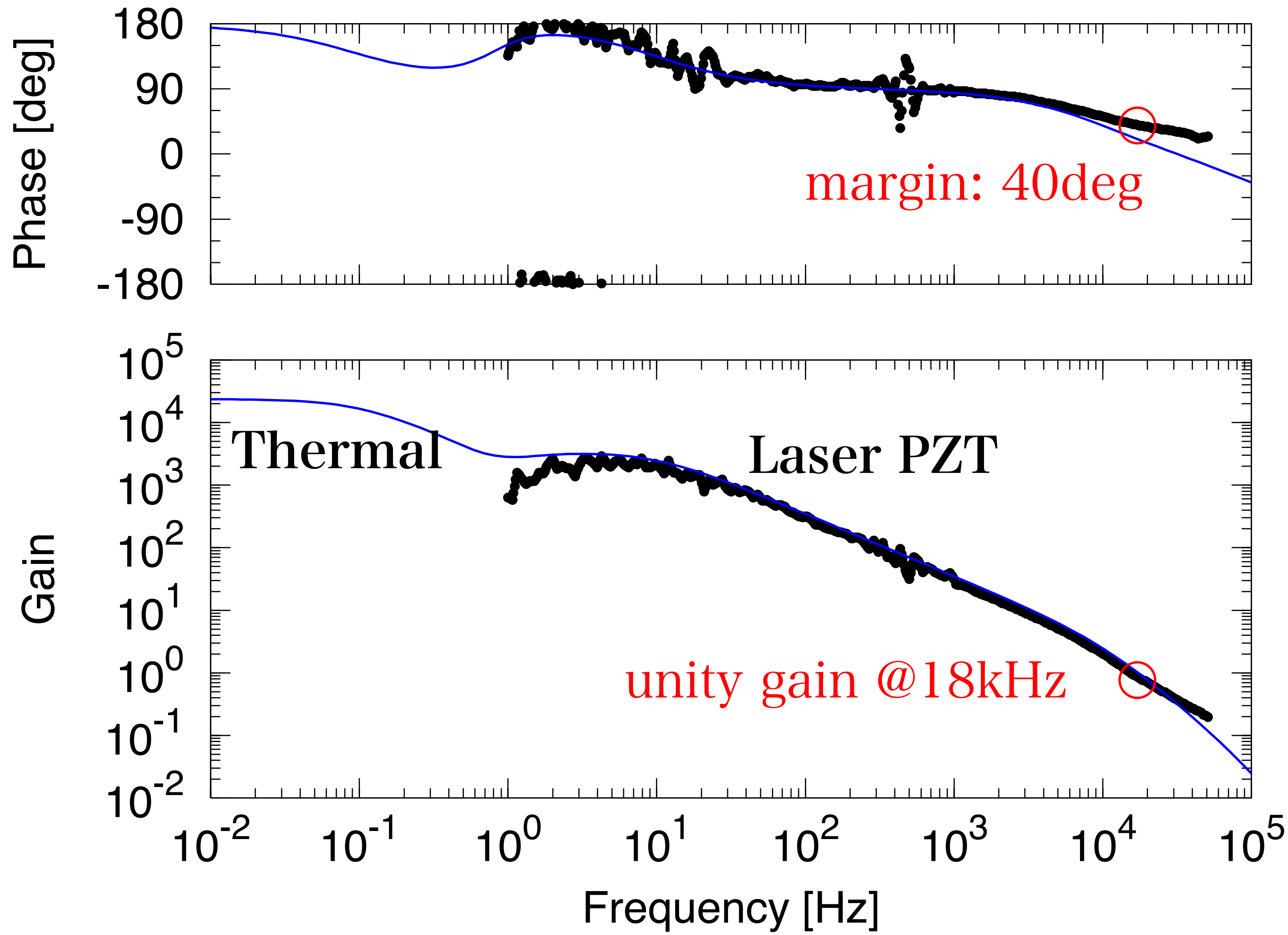
- Finesse: around 100 (using available mirrors)
- Beamsplitter: $R/T \neq 50/50$
  (Use RF sideband "f1" as LO light at Darkport)



Cavity lock aquisition



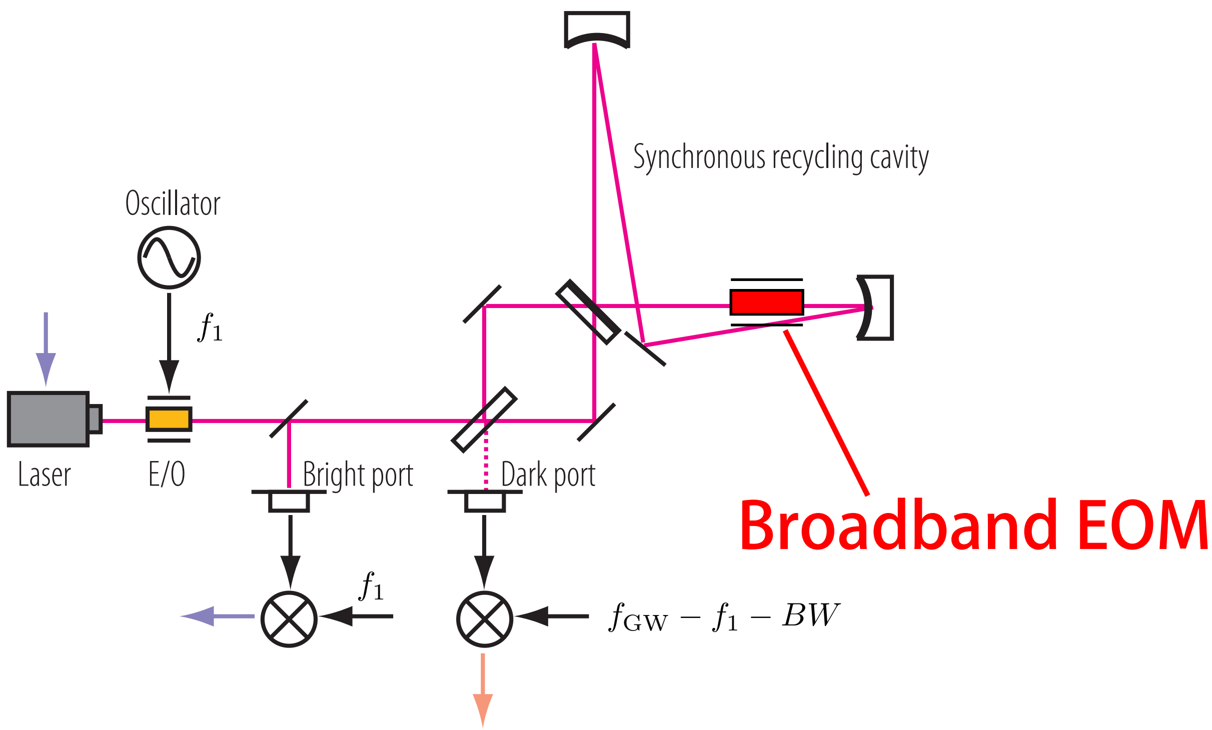
Open-loop Transfer function



Calibration of signals at dark port

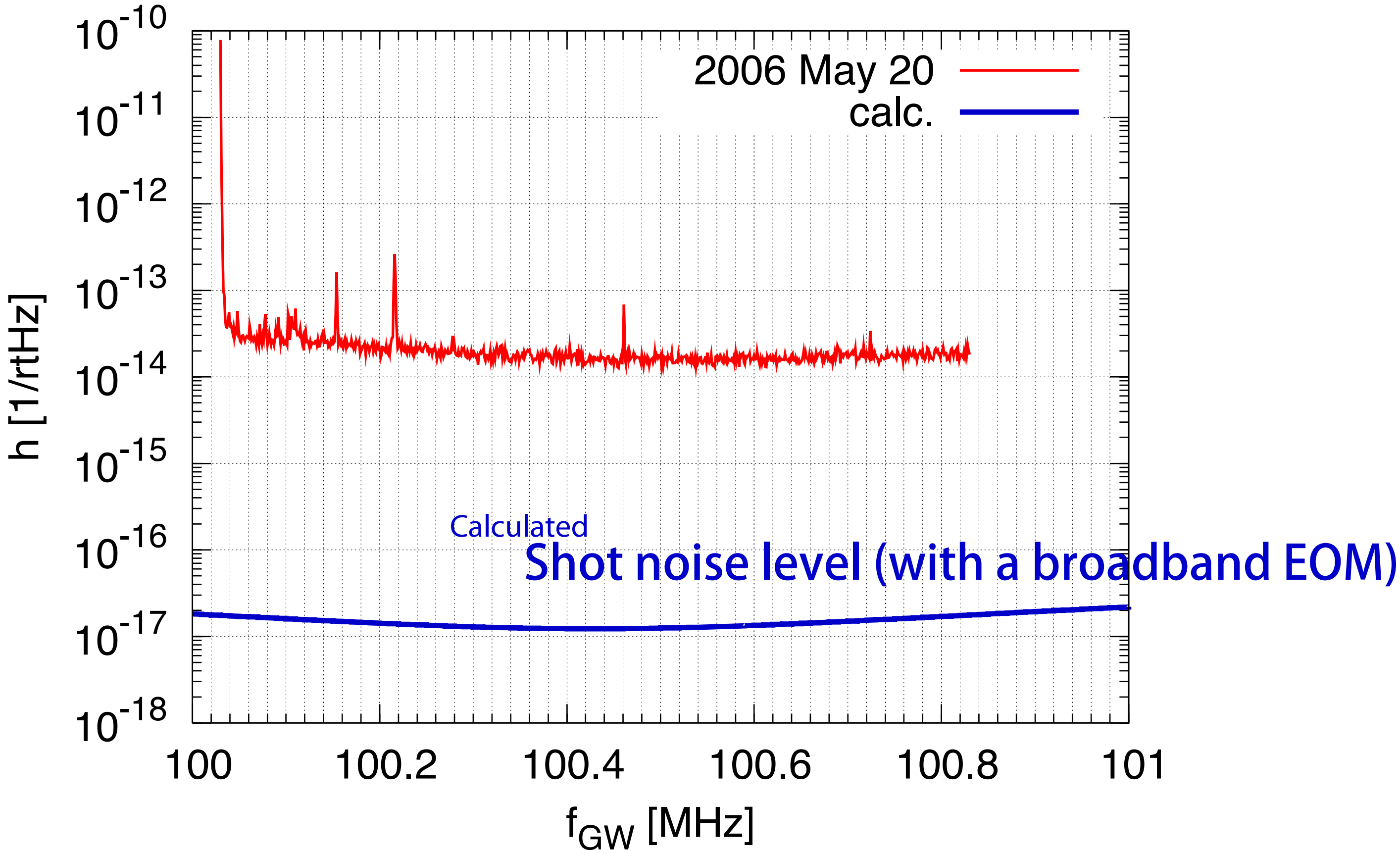
- Impossible to acutuate cavity mirrors @ 100MHz
- Put a broadband EOM inside the cavity

(Even though its finesse would decrease...)



Sensitivity (preliminary)

- **Measurement:** $\tilde{h} \simeq 10^{-14}\,\mathrm{Hz}^{-1/2}$



*** PD at dark port seems to have very little gain.
Repair the PD, the sensitivity would be better soon!

4. Summary & Future works

- To detect 100MHz cosmic gravitational wave background, we are going to construct two synchronous recycling IFOs.
- Synchrononus recycling cavity really acquires lock.
- So far, the sensitivity is about 1e-14 /rtHz around 100MHz.
  (preliminary)

~ Next steps ~

- Noise hunting
- Calculate good alignment of two IFOs