The cancelation of displacement- and frequency- noise using four mach-zehnder interferometer

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- Review of DFI
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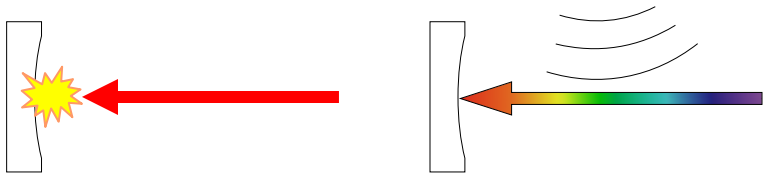
Introduction

- DFI (Displacement- and frequency-noise Free Interferometer) can take away all kinds of displacement noises.
  - DFI does not sense all displacement noises : seismic, thermal and radiation pressure noises. Therefore, in theory, DFI is limited by only the shot noise
- DFI was suggested by
  Kawamura & Y.Chen, 2004 *Phys. Rev. Lett.* **93**, 211103 and
  Y.Chen & S.Kawamura, 2006 *Phys. Rev. Lett.* **96**, 231102
- The configuration suggested by
  Y. Chen, *et al.*, 2006 *Phys. Rev. Lett.* **97** 151103
  is being constructed in NAOJ
- For both ground- and space-based gravitational wave (GW) detectors

Difference between displacement noises and GW effect

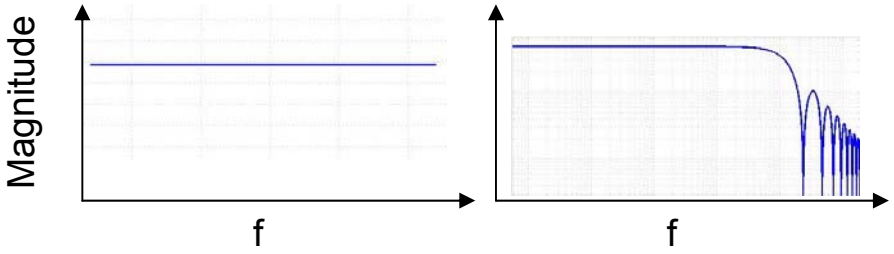
- Laser IFOs respond to mirror displacements and GWs differently



- An example for MI case

Response to mirror displacements

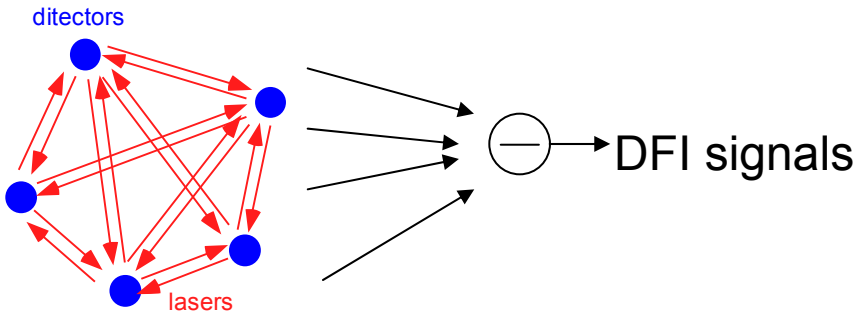
Response to the GWs



In the low frequency region, GW effects and mirror motions can not be distinguished, but when the gravitational wave lengths and cavity lengths are comparable, they can be distinguished

Principle of DFI

- In a multiple IFO system, one can take their signal combination so that the displacement noises are canceled

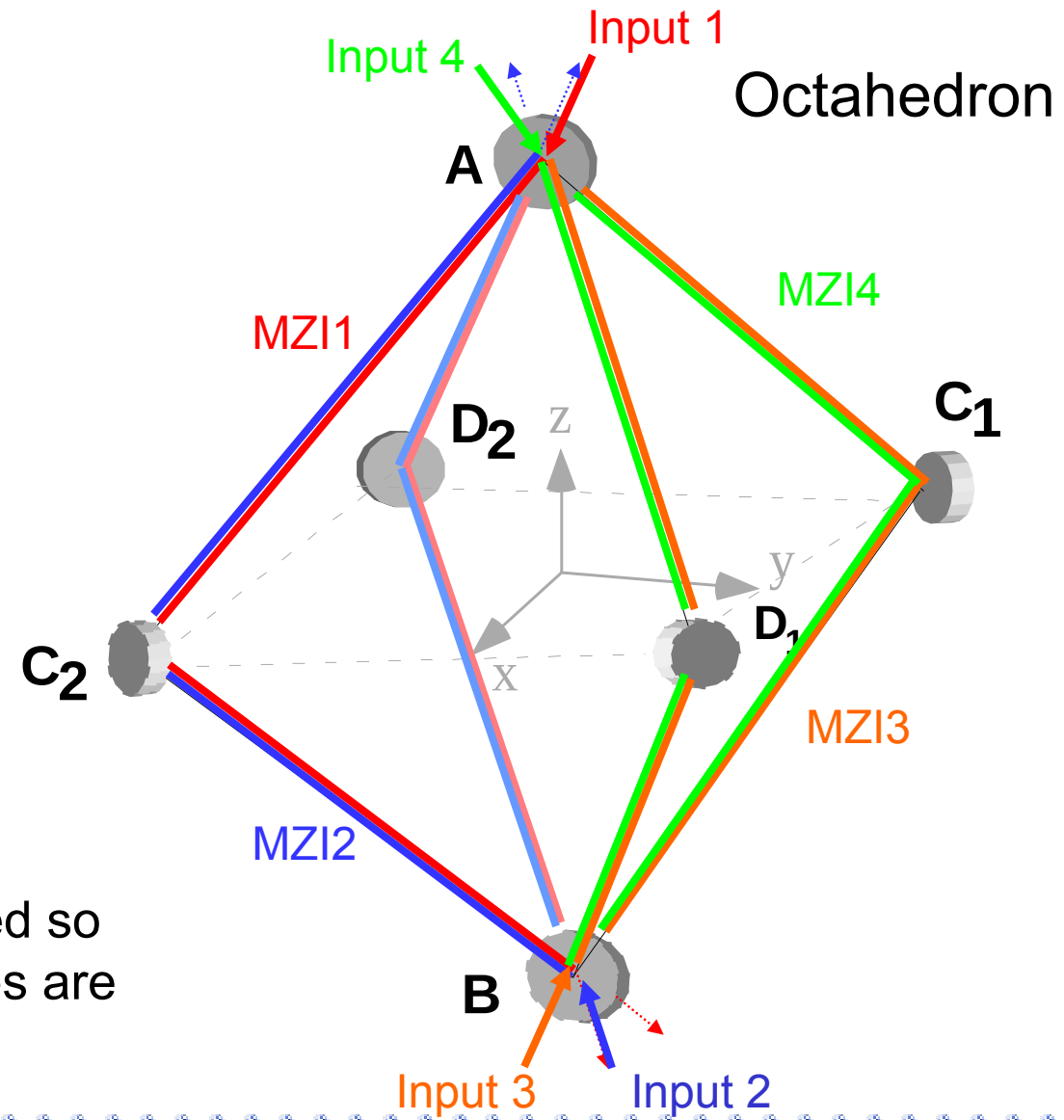


All the displacement noises can be canceled, while GW signals are surviving

In the low frequency region, GW signals are canceled because the displacement noises and GW effects can not be distinguished

DFI configuration for the experiment

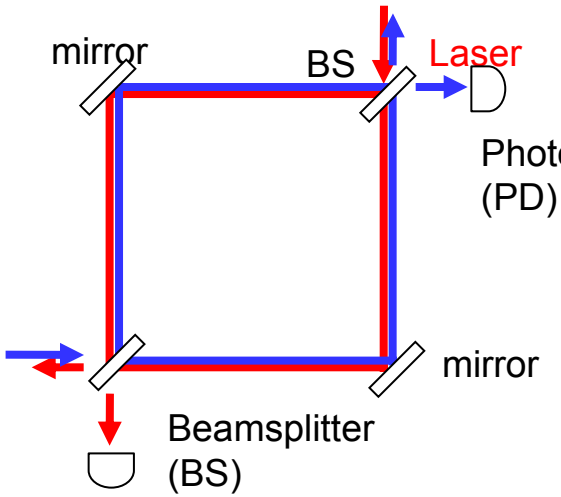
- DFI consists of four Mach-Zehnder Interferometers (MZI)

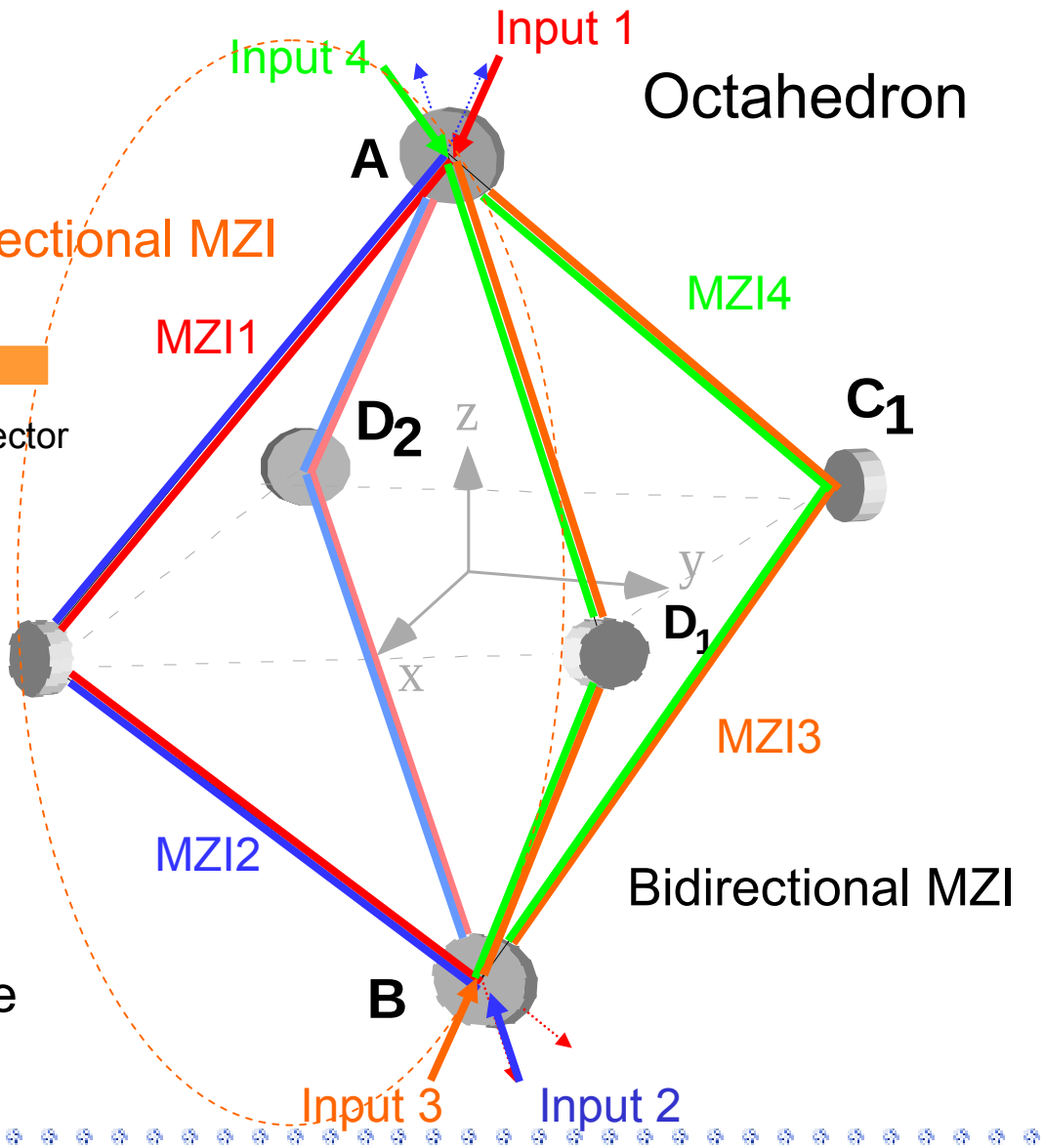


- Four signals are combined so that the displacement noises are canceled

DFI configuration for the experiment

- DFI consists of Four Mach-Zehnder Interferometers (MZI)



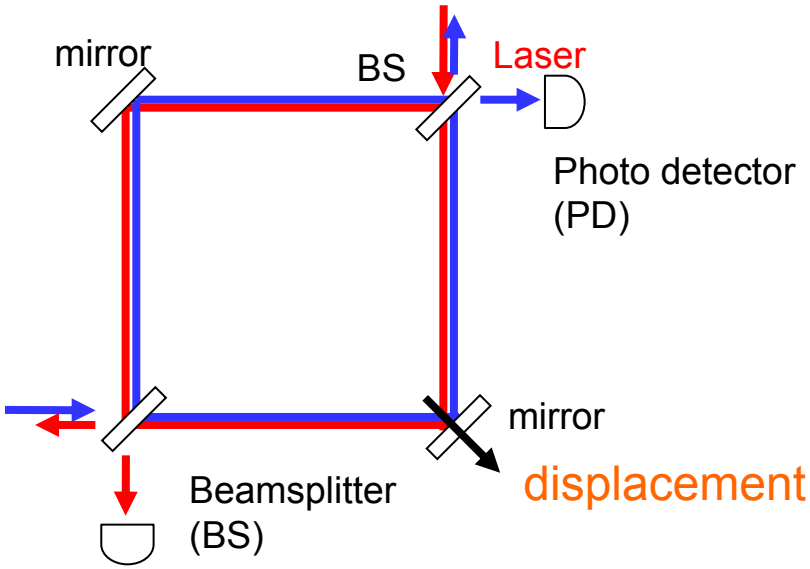


- Four signals are combined so that the displacement noises are canceled

Bi-directional MZI (1)

- Mirror displacements are canceled

Mirror displacement
MZI1=δL
MZI2=δL
MZI1-MZI2=0



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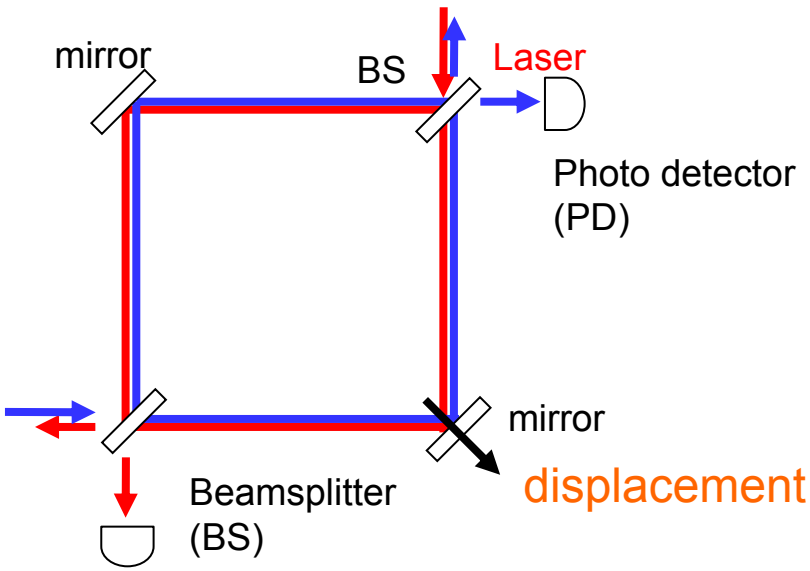
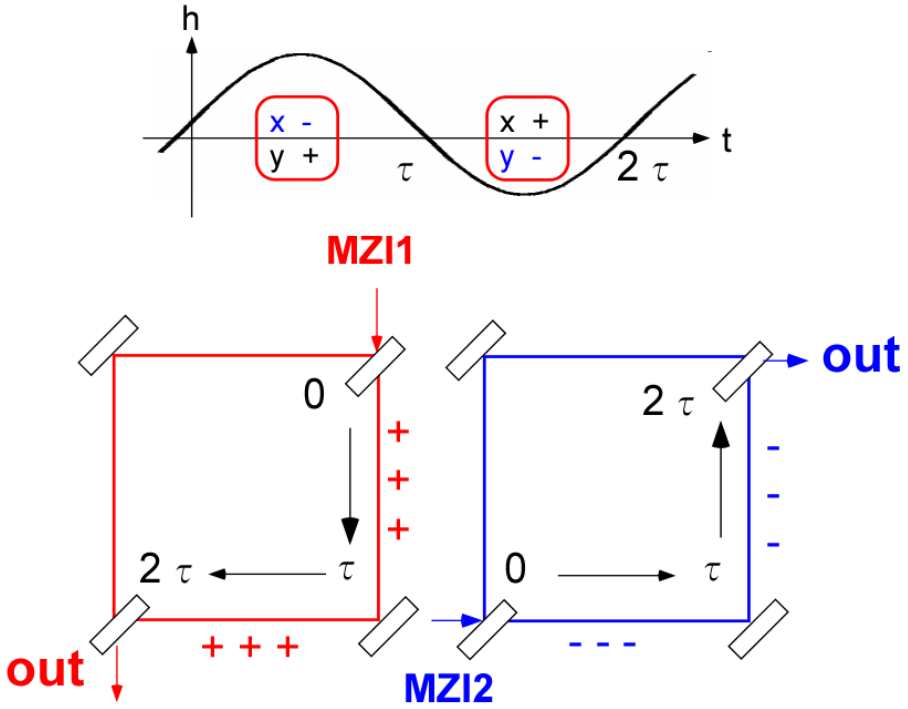
Bi-directional MZI (2)

- GW signals are not canceled





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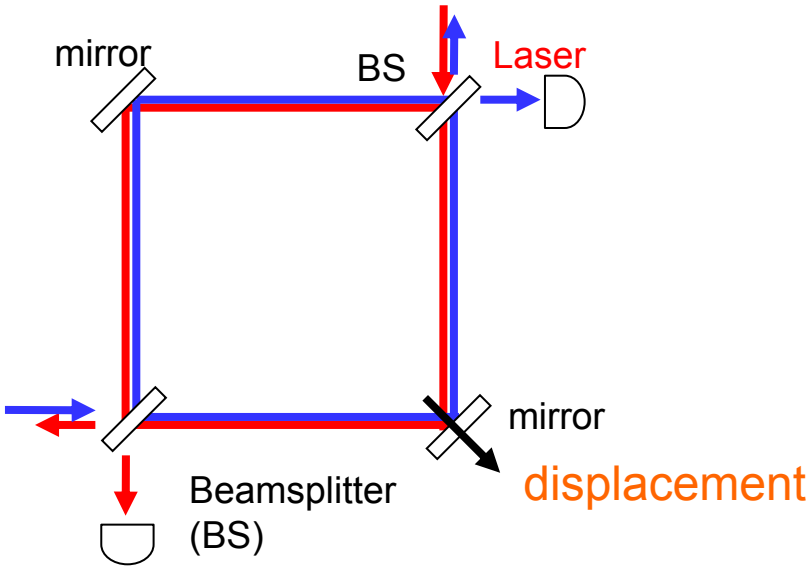

Response to the GW
MZI1 = +δL
MZI2 = -δL
MZI1-MZI2= 2δL

GW signals are not canceled by the subtraction

One more bidirectional MZI is necessary to cancel the displacements of the BSs
→3D configuration

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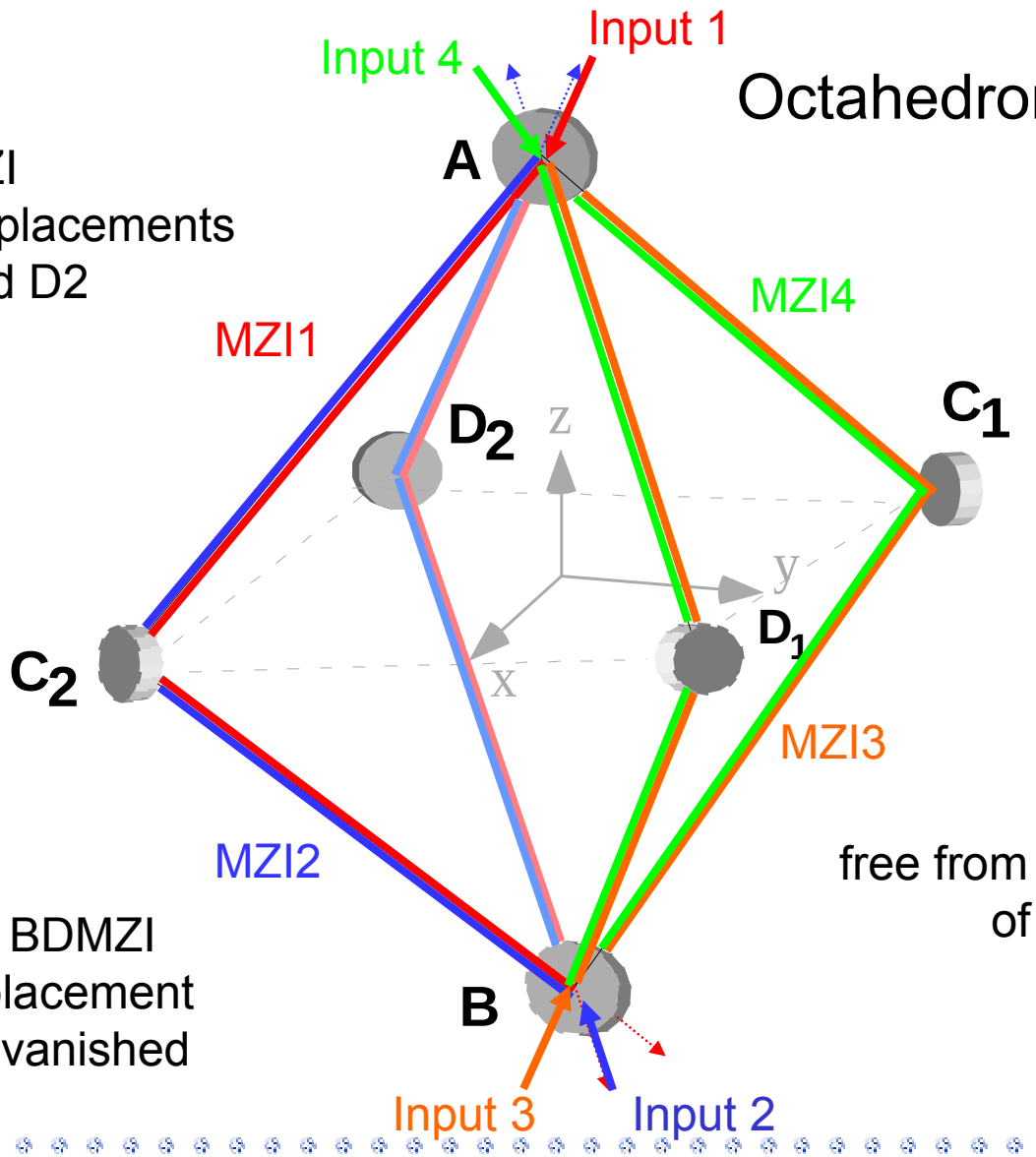
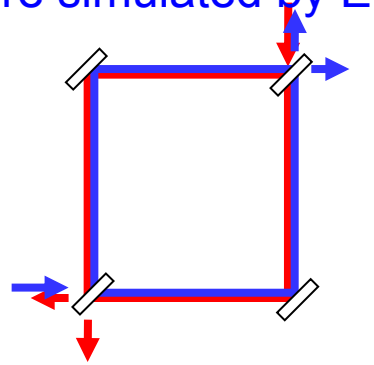
DFI configuration for the experiment



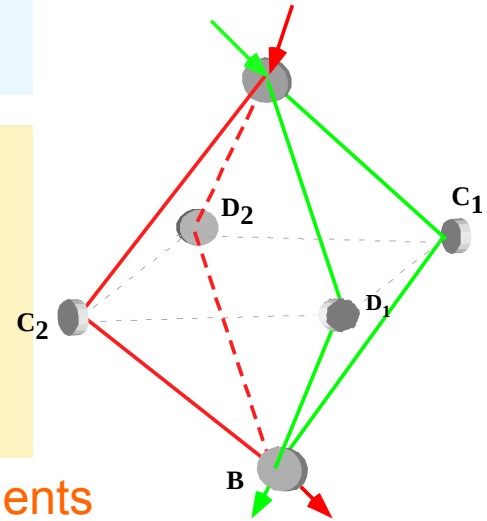
Three proof-of-principle experiments

1. 2D Bidirectional MZI experiment using EOMs
   - Confirm the cancelation of mirror displacement
   - Confirm the surviving GW signals
2. BS displacement cancelation experiment using an EOM
   - Confirm the cancelation of BS displacement
   - No GW signals were simulated

Optical displacements were simulated by EOMs



3. BS displacement cancelation experiment using a PZT
   - Confirm the cancelation of BS displacement
   - No GW signals were simulated

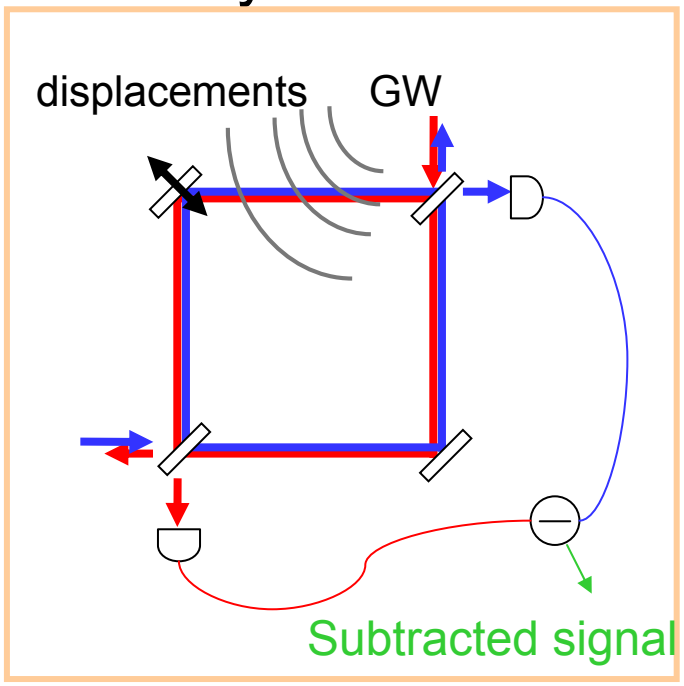


Optical displacements were simulated by PZT

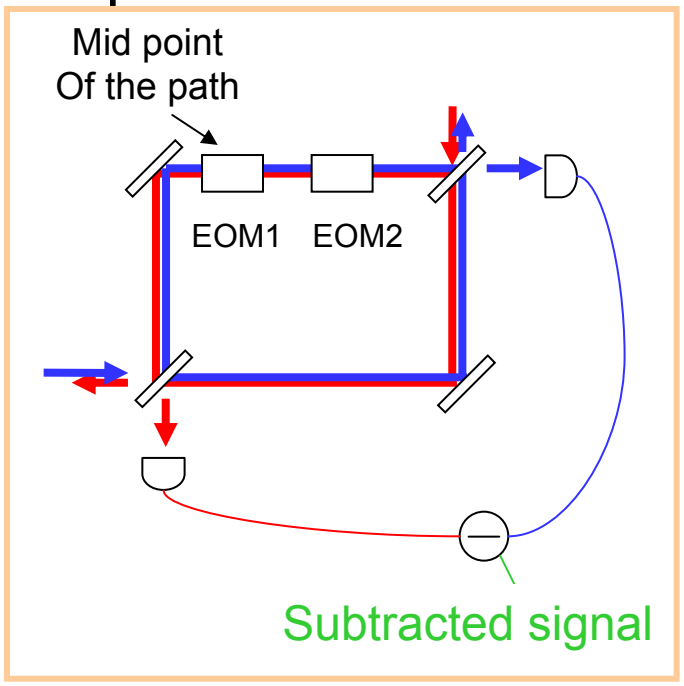
Three proof-of-principle experiment 1

- 2D bidirectional MZI

In reality



Experiment



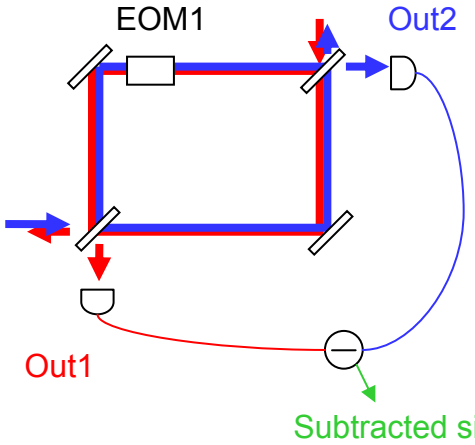
We looked for

the cancelation of the mirror displacements

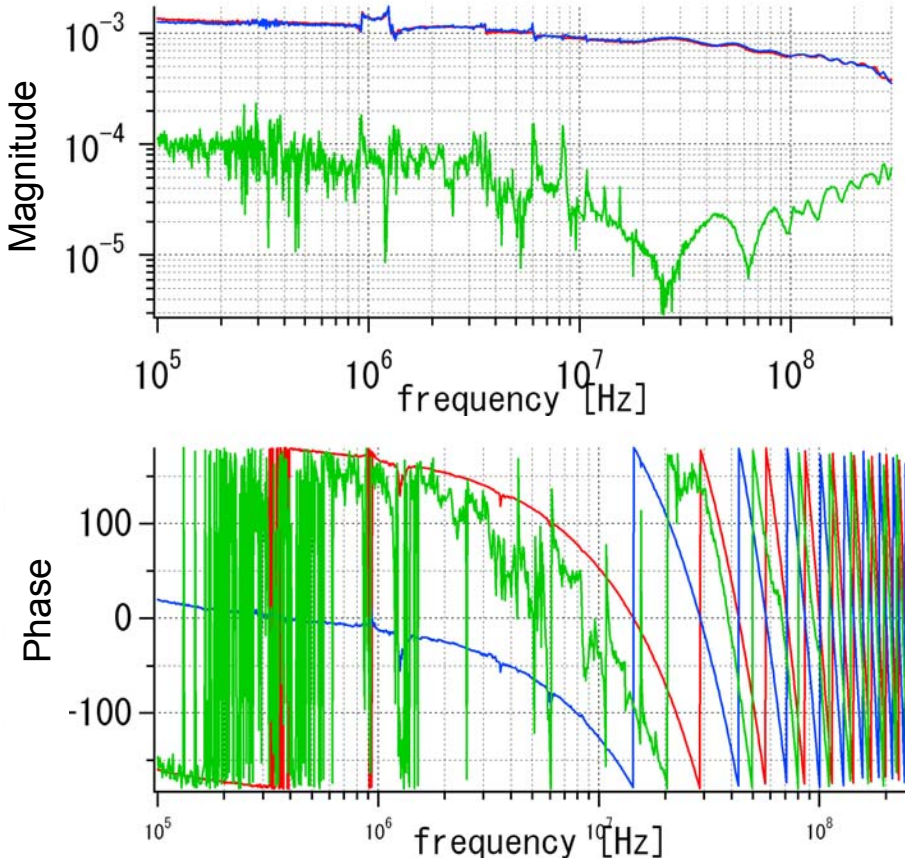
the survived GW signals

Three proof-of-principle experiment 1

- 2D bidirectional MZI



Transfer function from EOM1 to Out1
Transfer function from EOM1 to Out2
EOM1 to subtracted signal

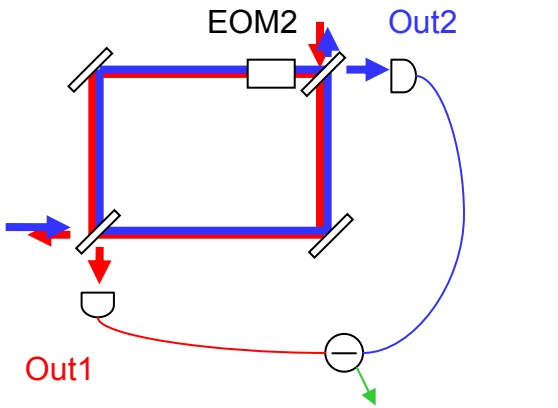


Cancelation of about 40dB was attained

S. Sato, *et al,* 2007 *Phys. Rev. Lett.* **98** 141101

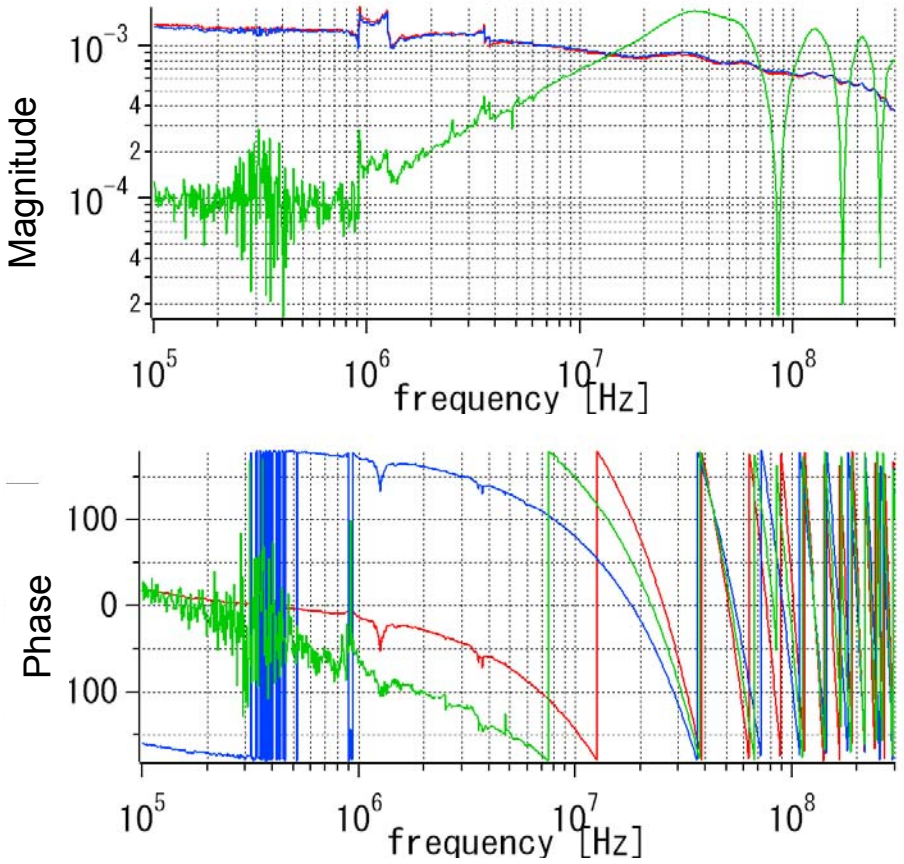
Three proof-of-principle experiment 1

- 2D bidirectional MZI



Transfer function from EOM2 to Out1
Transfer function from EOM2 to Out2
EOM2 to subtracted signal

GW signals survived after the subtraction

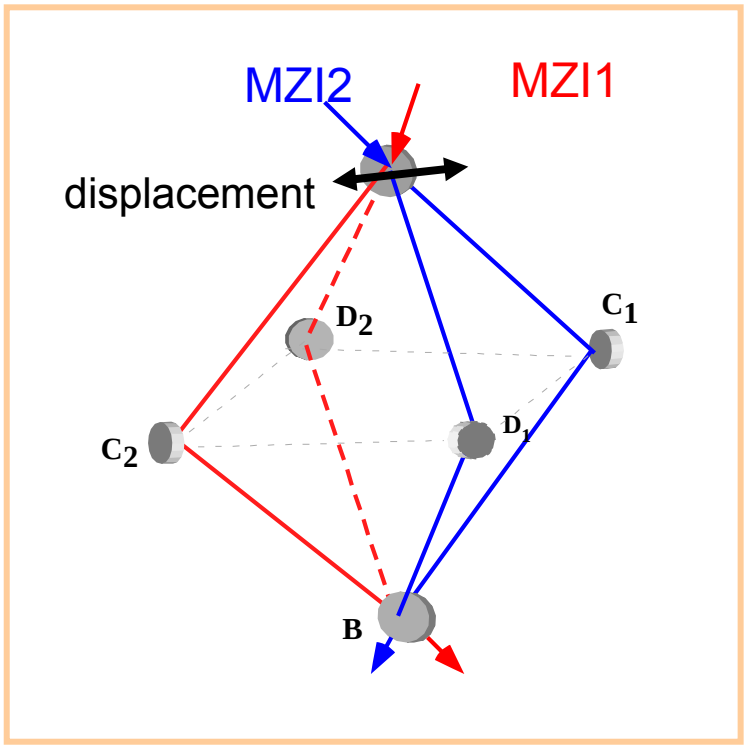


S. Sato, *et al,* 2007 *Phys. Rev. Lett.* **98** 141101

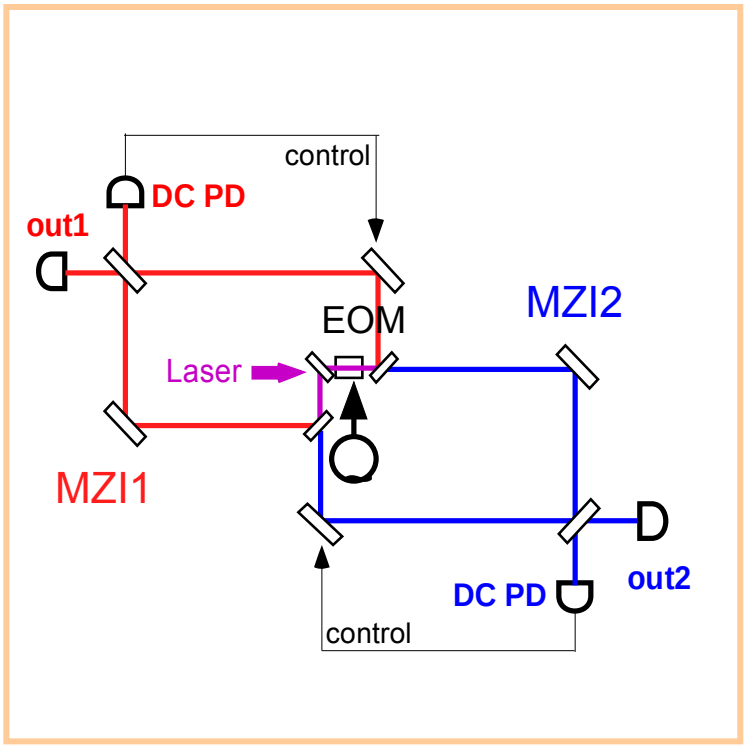
The proof-of-principle experiment 2

- BS displacement cancelation using an EOM

In reality

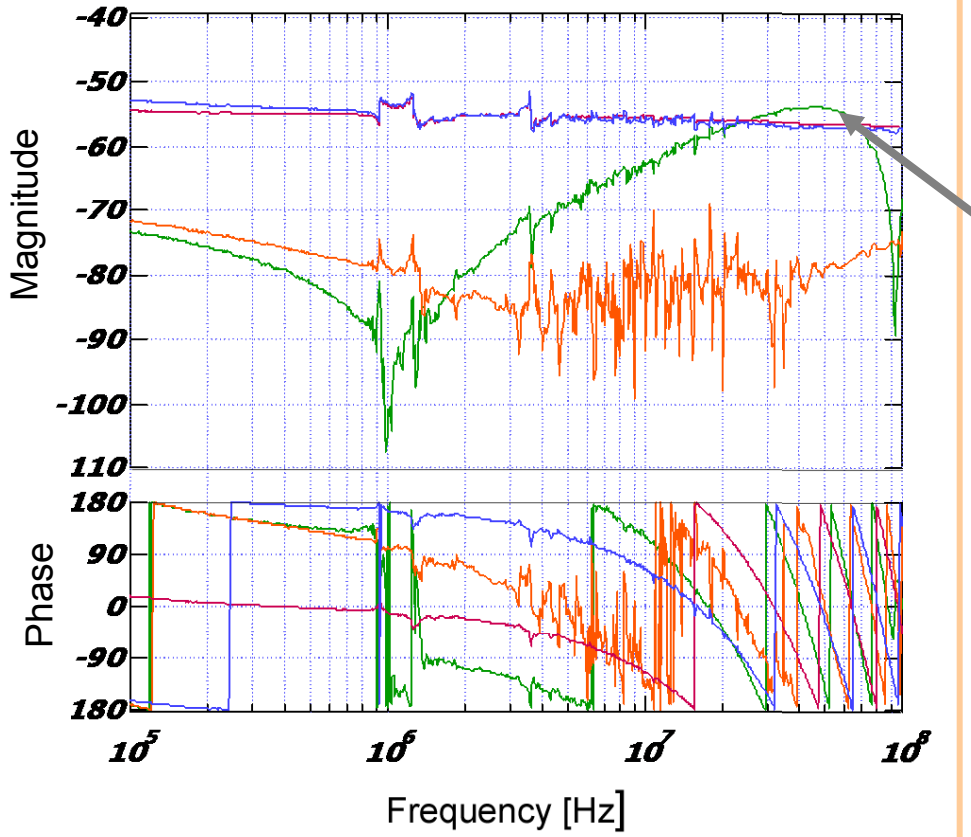


experiment



The proof-of-principle experiment 2

- BS displacement cancelation using an EOM



Cancelation of about maximum 50dB was attained

It looks like summed in spite of the subtraction of the same gain TFs.
It is because of the phase difference.

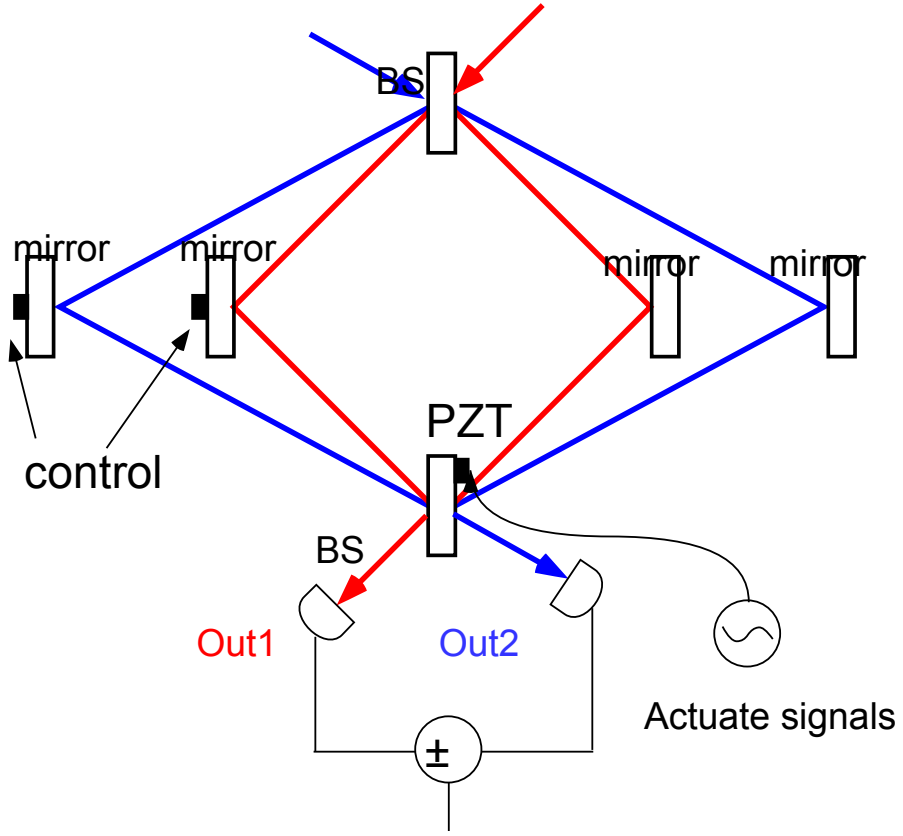
From EOM to Out1
From EOM to Out2
Adjusted for the max cancelation
Adjusted for a broadband cancelation

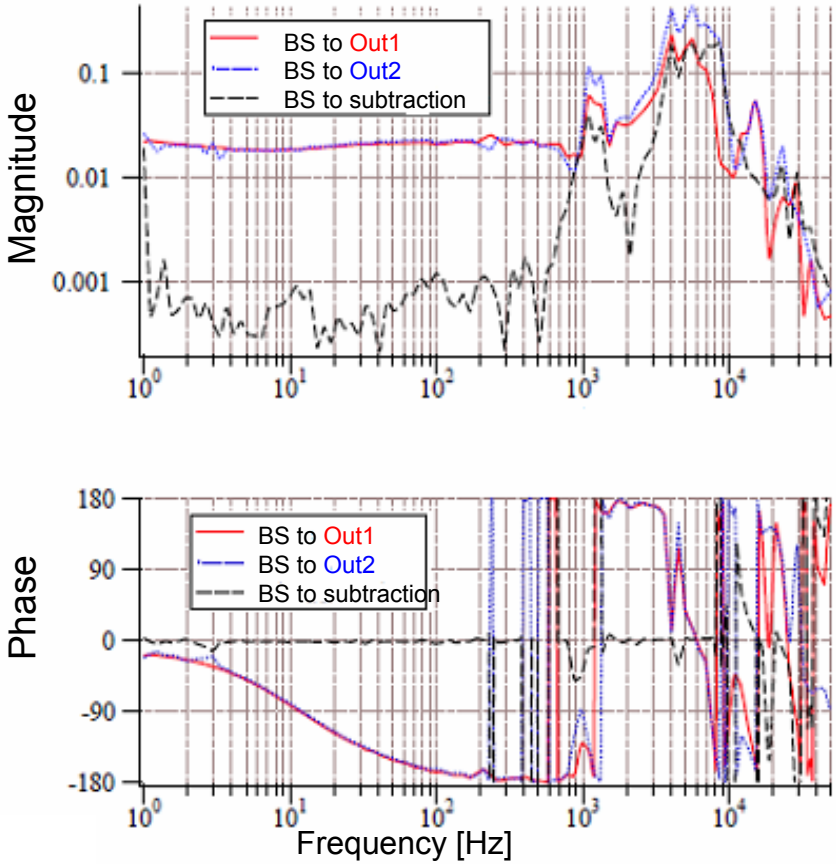
The proof-of-principle experiment 3

BS displacement cancelation using a PZT

One of two BSs was actuated by a PZT

The signal cancelation was observed





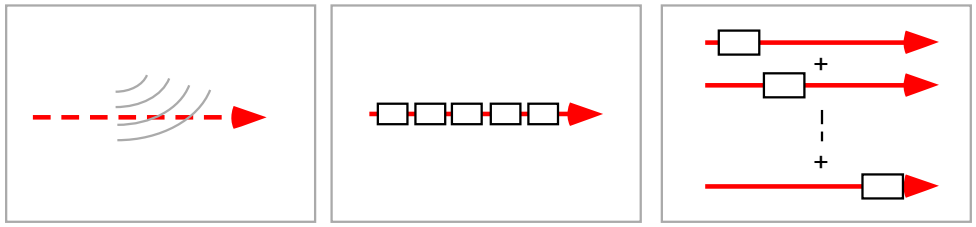
This experiment is to test how much cancelation can be attained for the real displacements

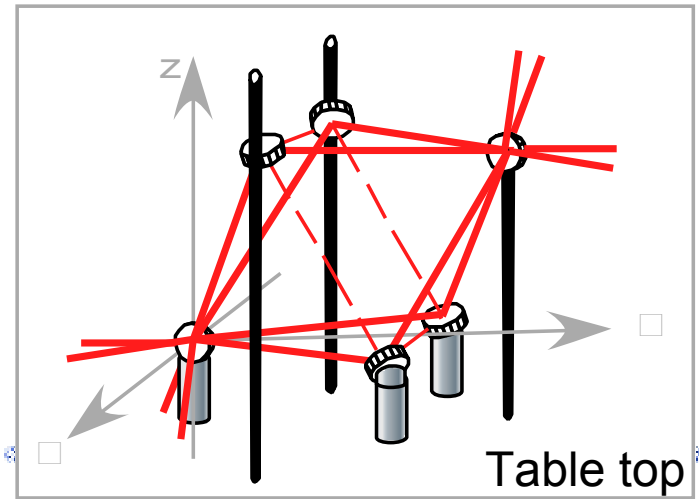
GWs are not simulated because they will be canceled in the low frequency

3D DFI experiment

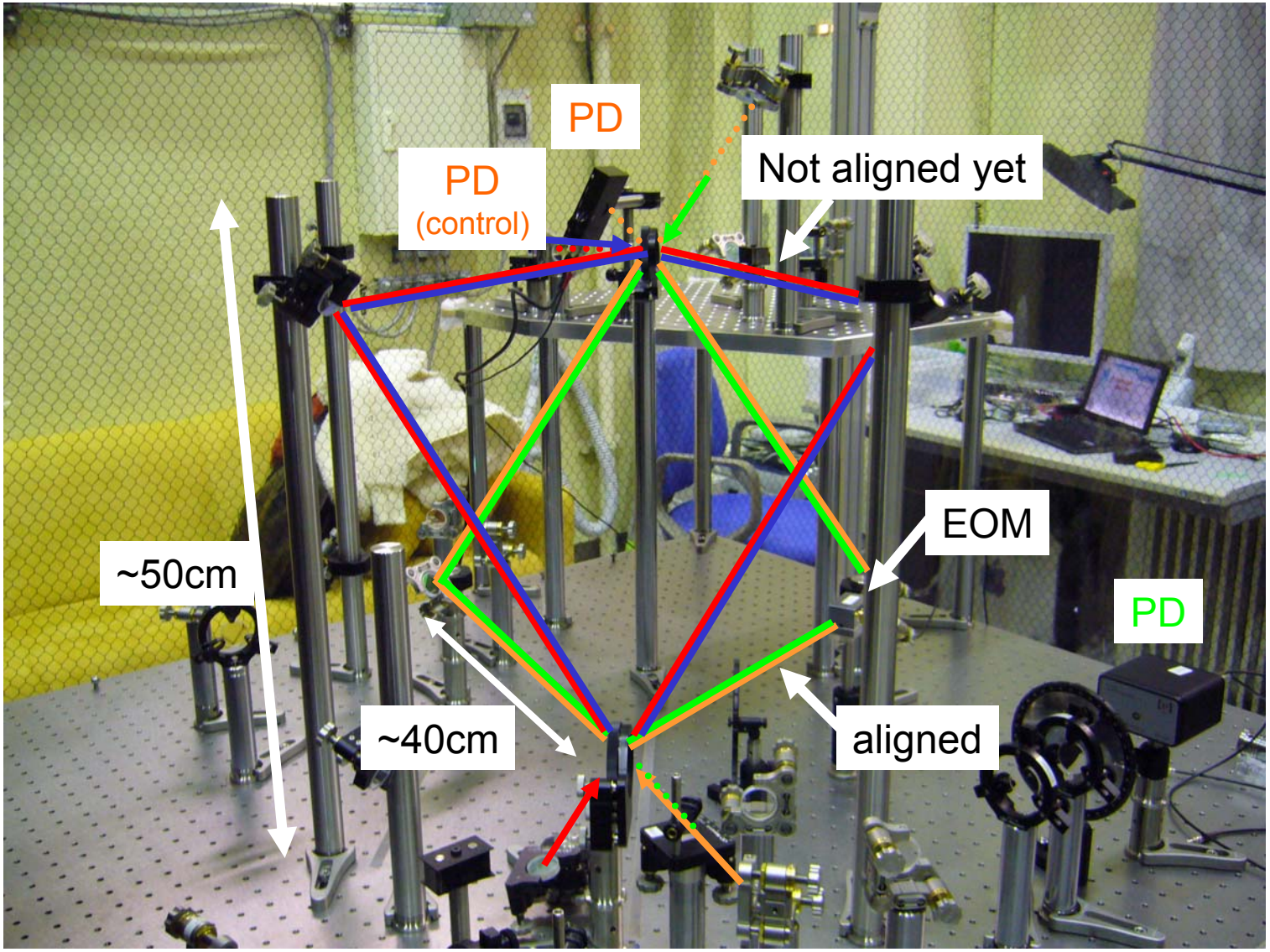
- A DFI of the complete 3D configuration is being construced
- Four signals from each IFO will be combined
  - All the displacements are canceled
  - GW signals are not canceled
- Optical displacements will be simulated by EOMs
  - Mirrors can not be actuated in a high frequency region by PZTs
- GW effects will be simulated by using multiple EOMs
  - The laser path should be filled by EOMs to simulate the GW effect, however, many EOMs are expensive and may disturb the contrast

→ One EOM will be put at a position on the path + put at the next point +…

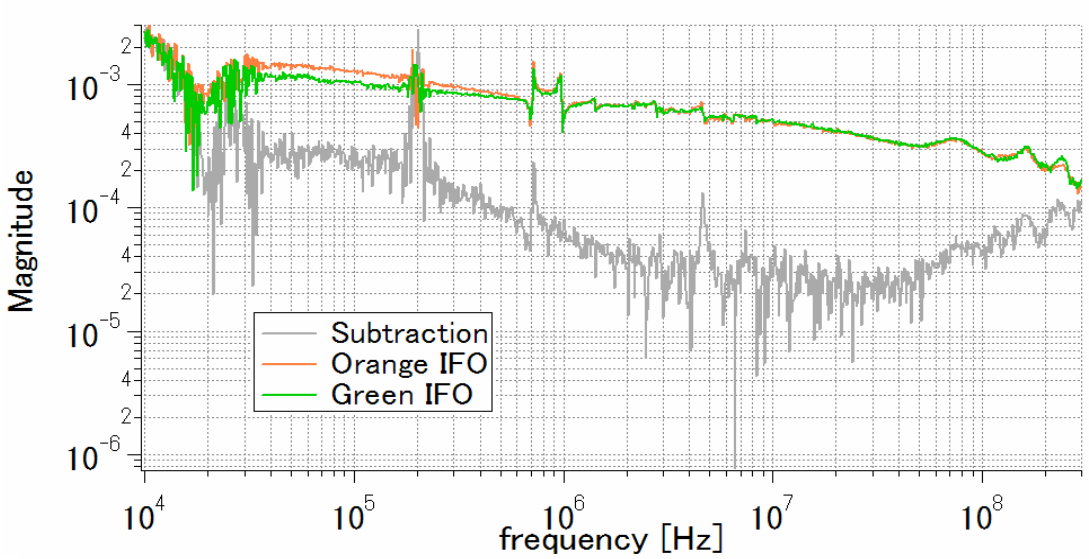


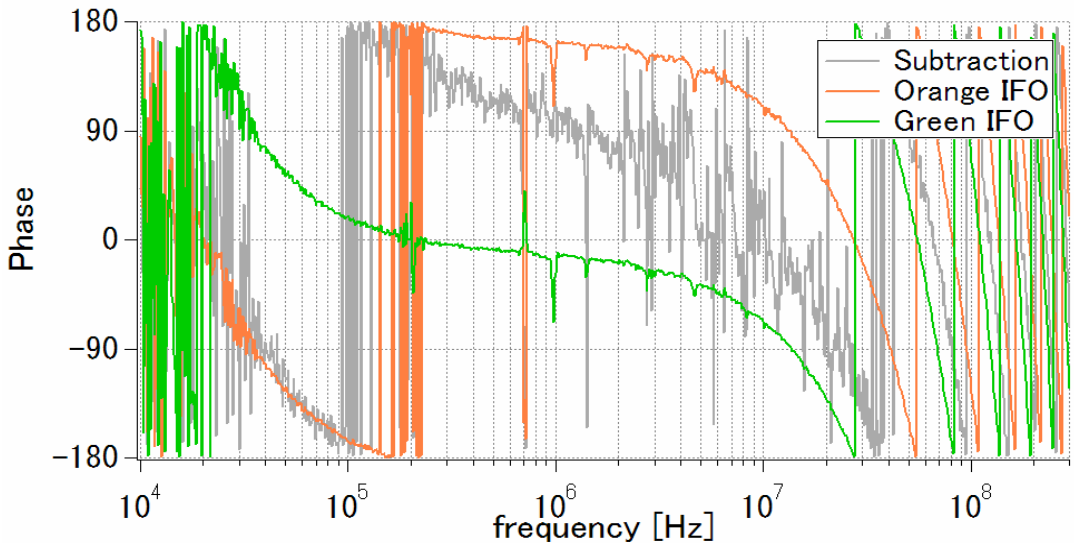


3D DFI experiment



Subtracted signals of 3D IFO





Transfer function from the EOM to two IFO outputs and subtraction output

The signal suppression was observed In the 3D configuration

To do

- To Align the two other MZIs
- To obtain and combine the four signals
- To look for the displacement cancelation and survived GW signals

- To isolate from the vibration due to the long posts
  - one BS and two mirrors are held by the long posts which vibrate at about 200Hz

Summary

- Three proof-of-principle experiments were done
  - 2D Bidirectional MZI
  - to cancel BS displacement cancelation (EOM)
  - to cancel BS displacement cancelation (PZT)

- 3D DFI is underway
  - The DFI setup is built
  - one set of BDMZI signal was obtained