Displacement and frequency noise Free Interferometer (DFI)

Ando Lab Seminar

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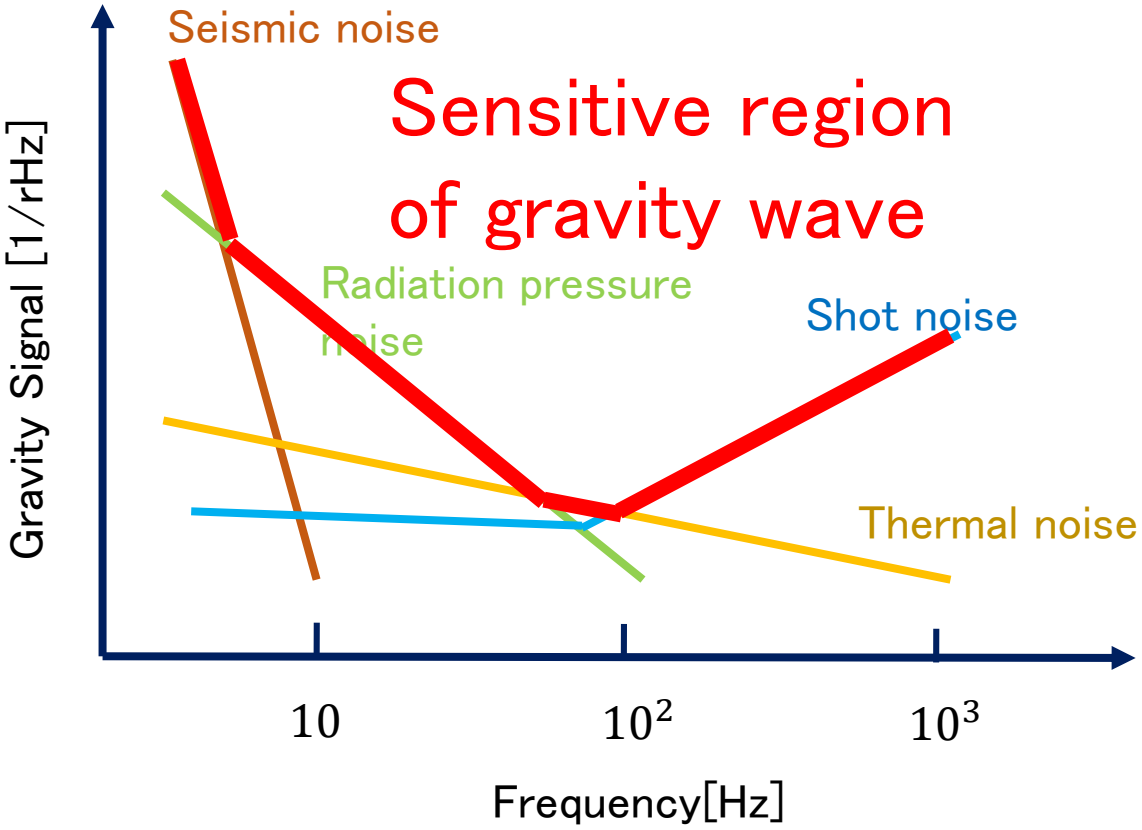
Wada Shotaro

Introduction

There are various noises when we try to detect a gravitational wave



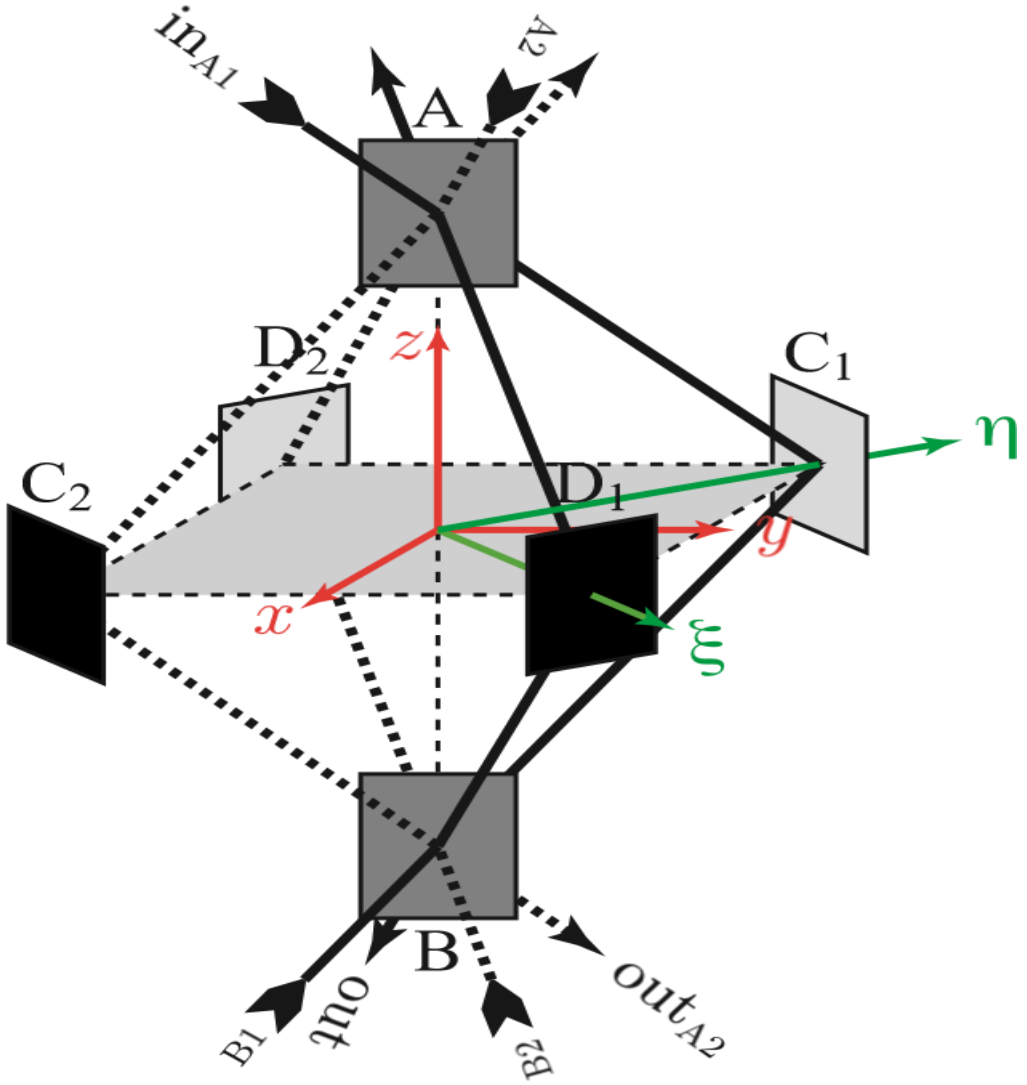
We want a detector which have lower noises

What is DFI ?

DFI is displacement and frequency noise free interferometer

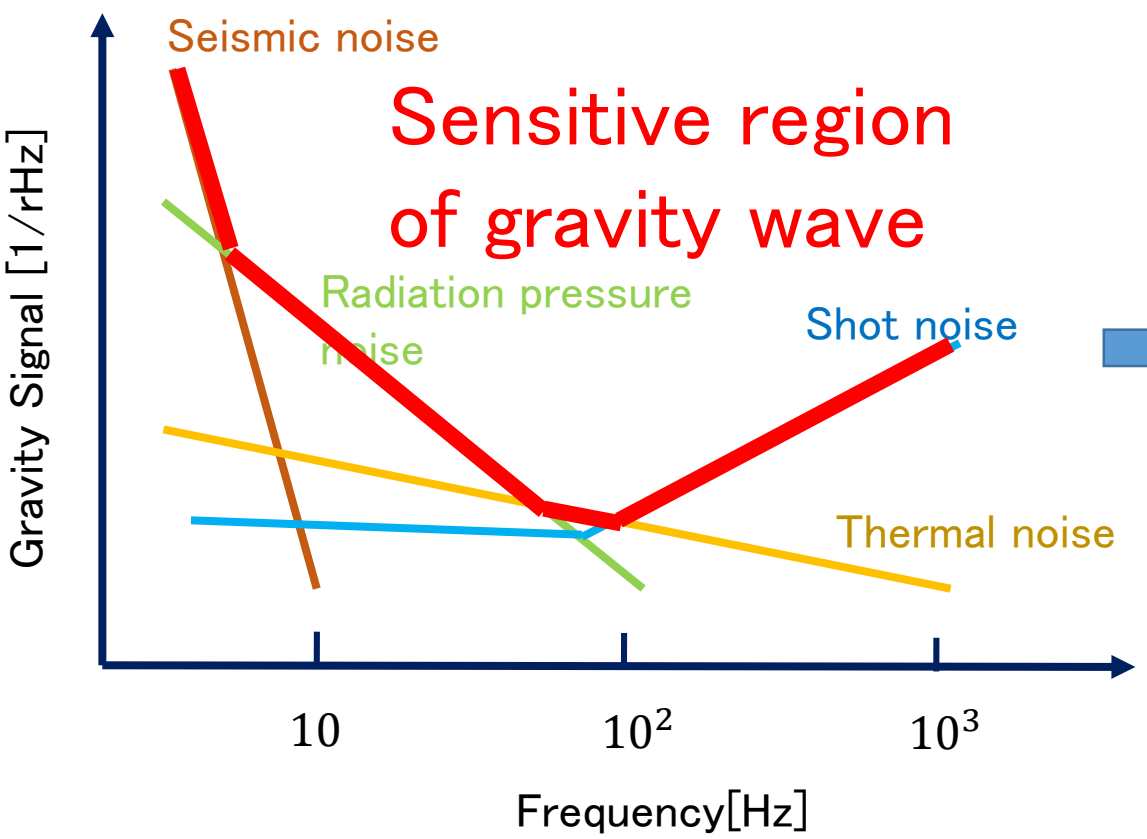
It can cancel displacement noise and frequency noise

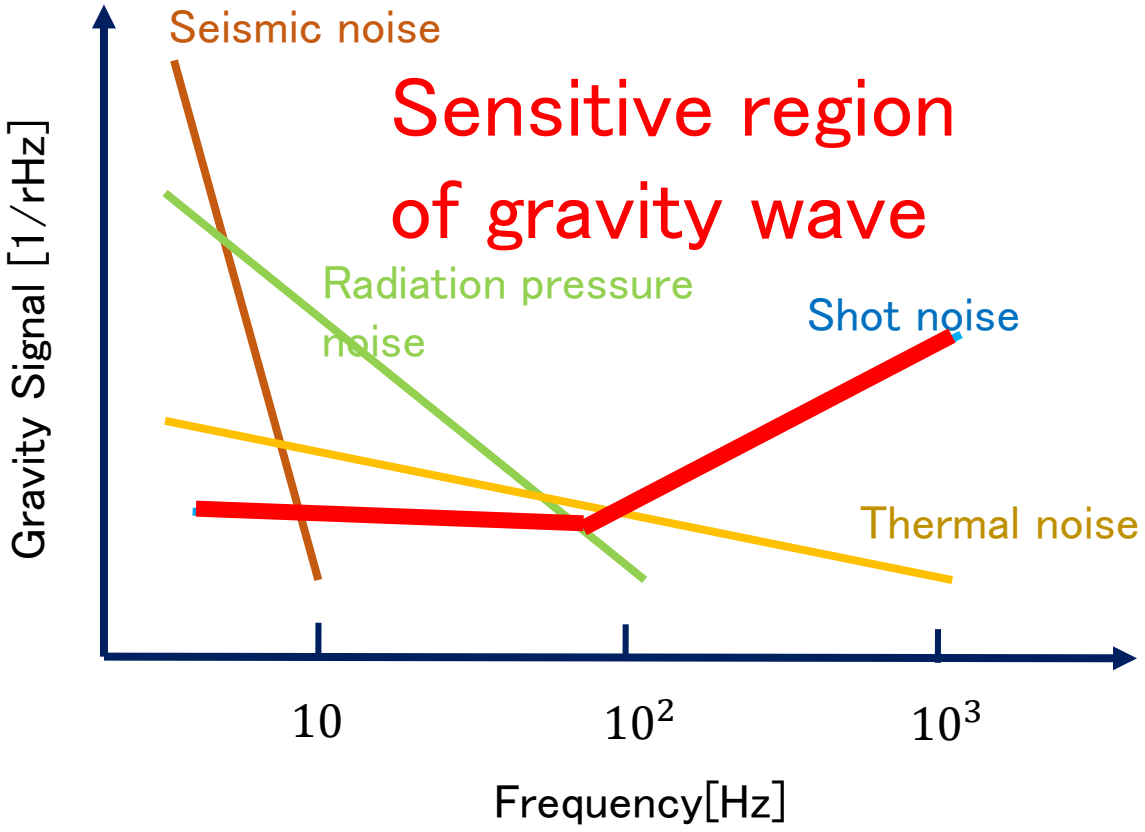
e.g. thermal noise, seismic noise, radiation pressure noise ..



One of the DFIs(4 Mach–Zehnder interferometers)

What is DFI ?





Sensitive region is decided by shot noise

Reference reports

1. Displacement-Noise-Free Gravitational-Wave Detection (2004)
   ➡ The principle of the DFI

2. Displacement-and Timing-Noise-Free Gravitational-Wave Detection (2006)
   ➡ This report is considered about frequency noise as well as displacement noise

3. Interferometers for Displacement-Noise-Free Gravitational-Wave Detection (2006)
   ➡ This report propose the concrete configuration of DFI

1. Displacement-Noise-Free Gravitational-Wave Detection (2004)

This report is the first report which presented idea of DFI

Displacement-Noise-Free Gravitational-Wave Detection

Seiji Kawamura[1]

Yanbei Chen[2]

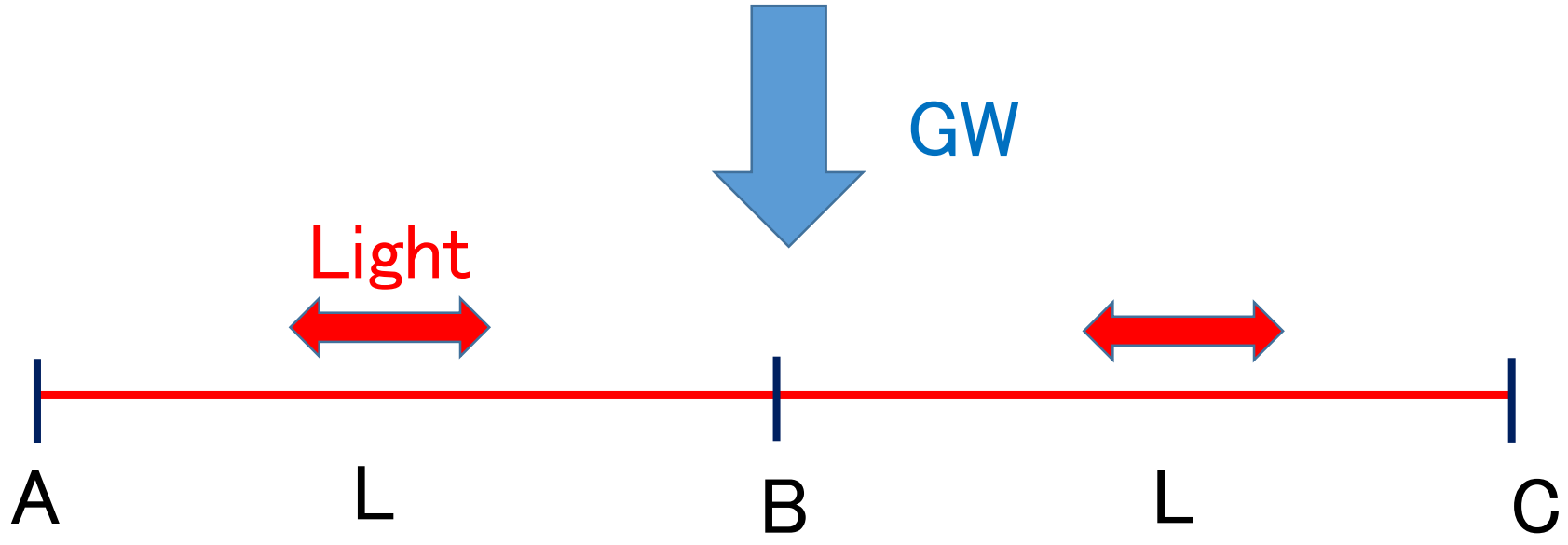
[1]*TAMA Project, National Astronomical Observatory of Japan, Mitaka, Tokyo, Japan*
[2]*Theoretical Astrophysics, California Institute of Technology, Pasadena, California 91125, USA*
(Received 18 May 2004; published 18 November 2004)

We present a new idea that allows us to detect gravitational waves without being disturbed by any kind of displacement noise, based on the fact that gravitational waves and test-mass motions affect the propagations of light differently. We demonstrate this idea by analyzing a simple toy model consisting of three equally-separated objects on a line. By taking a certain combination of light travel times between these objects, we construct an observable free from the displacement of each object, which has a reasonable sensitivity to gravitational waves.

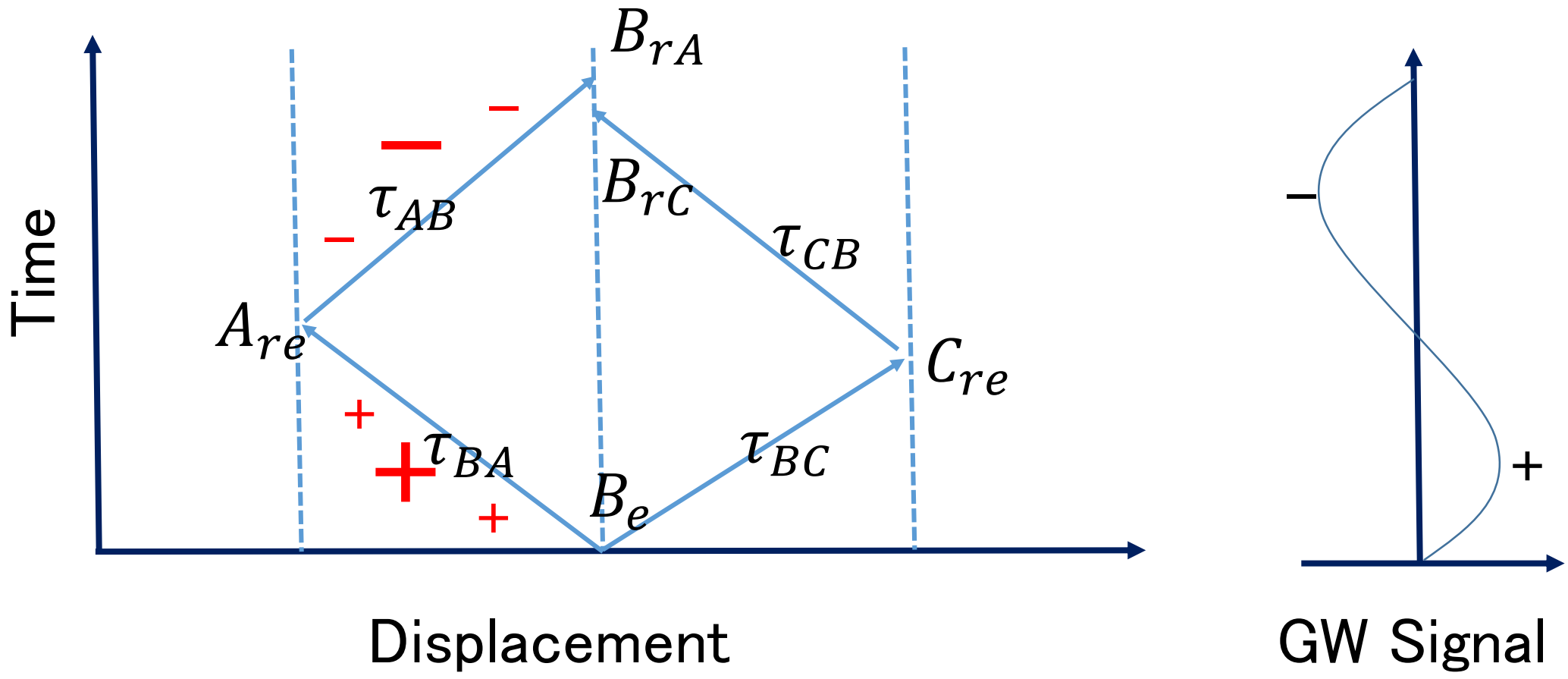
DOI: 10.1103/PhysRevLett.93.211103 PACS numbers: 04.80.Nn, 06.30.Ft, 95.55.Ym

1. Displacement-Noise-Free Gravitational-Wave Detection

We consider a following figure

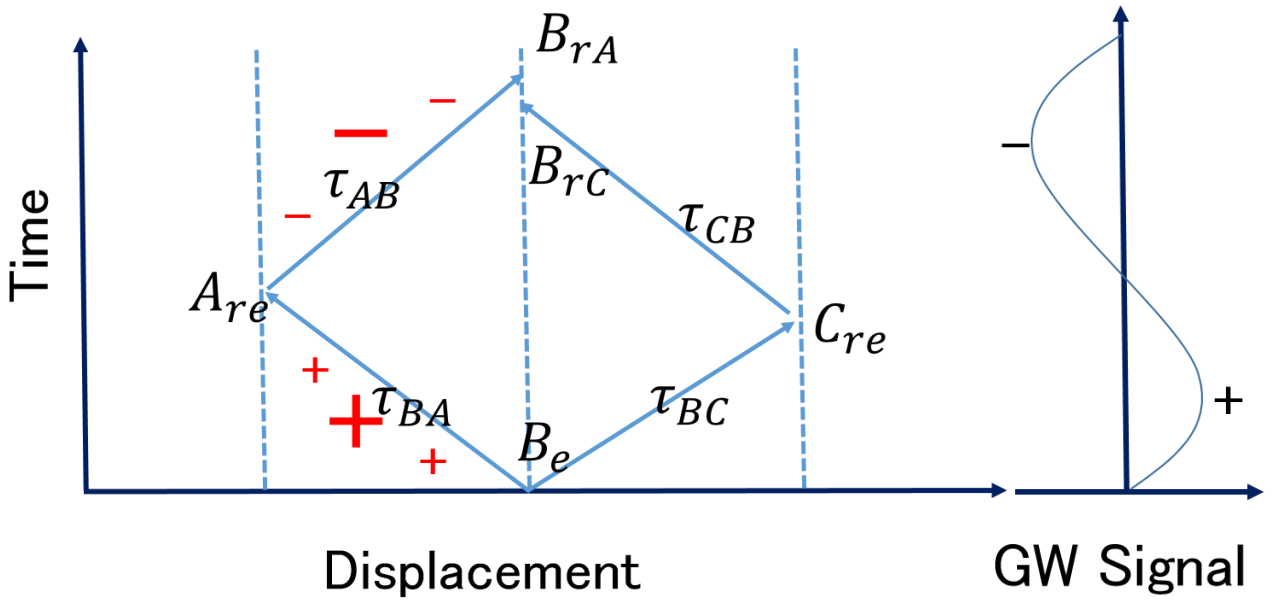


1. Displacement-Noise-Free Gravitational-Wave Detection



1. Displacement-Noise-Free Gravitational-Wave Detection

$$\tau_{BA} = +S_g + (B_e - A_{re})/c$$
$$\tau_{AB} = -S_g + (B_{rA} - A_{re})/c$$
$$\tau_{BC} = +S_g + (C_{re} - B_e)/c$$
$$\tau_{CB} = -S_g + (C_{re} - B_{rC})/c$$



$$\tau_0 = \tau_{BA} - \tau_{AB} + \tau_{BC} - \tau_{CB} = 4S_g$$

only GW's effect

(with approximation that $B_{rA} \approx B_{rC}$)

1. Displacement-Noise-Free Gravitational-Wave Detection

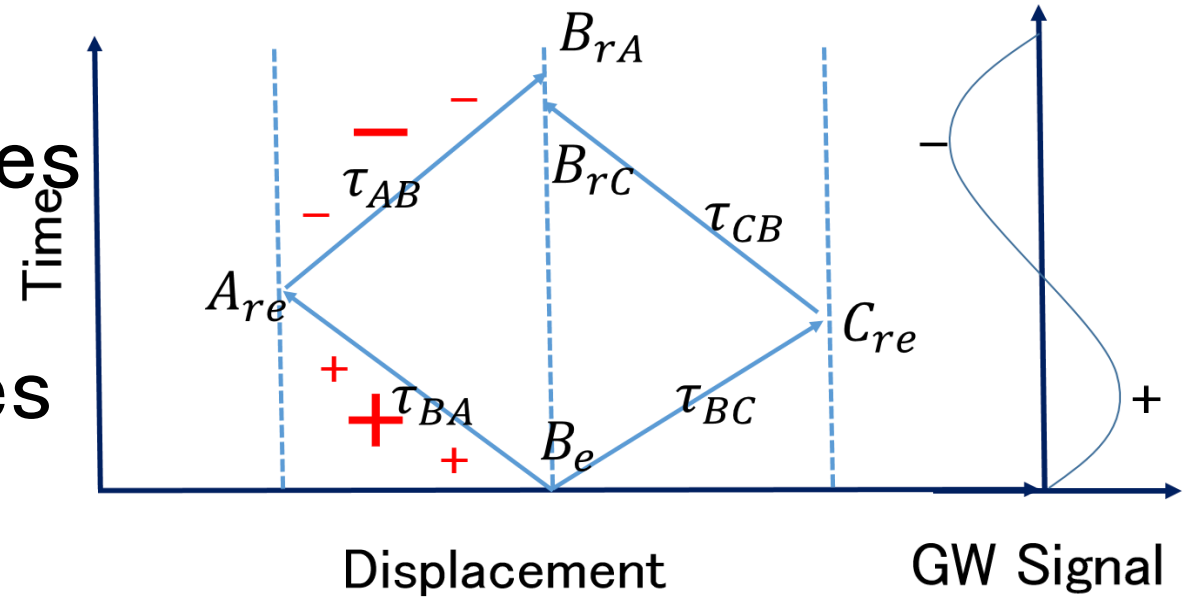
Contribution of light travel times

・Displacement noise

⟶ at the instance light reaches the detectors

・GW

⟶ at the all time light travels from detectors to detectors



This difference enables DFI

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DFI signal expression

$$s(\Omega) = \sum_k \sum_{j \neq k} A_{(jk)}\, \tilde{\tau}_{(k)} + \sum_k \sum_{j \neq k} B_{(jk)} \cdot \tilde{x}_{(k)} + \left[\sum_k \sum_{j \neq k} G_{(jk)}\, e^{-i\Omega e_z \cdot X_{(k)}} \right] : \sum_p \tilde{h}_p\, e^p$$

Frequency noise term

Displacement noise term

GW signal term

necessary condition $\sum_{j \neq k} A_{(jk)} = 0$ $\sum_{j \neq k} B_{(jk)} = 0$

GW signal of DFI

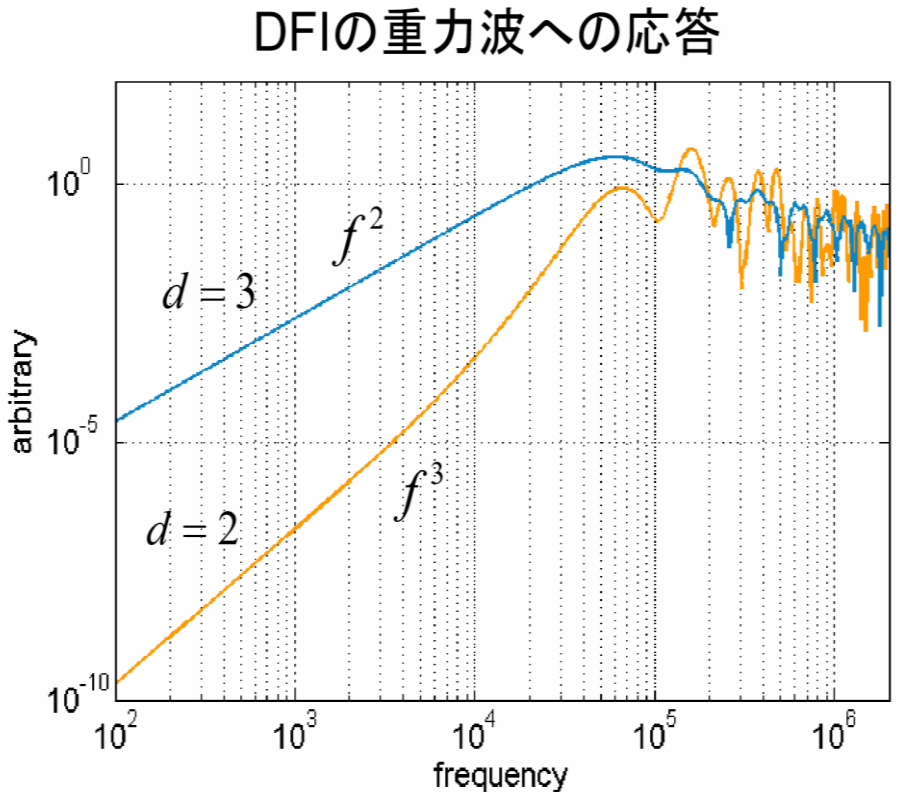
1D :when $\sum_{j\neq k} A_{(jk)} = 0, \sum_{j\neq k} B_{(jk)} = 0,$

$$\sum_{k}\sum_{j\neq k} G_{(jk)}\, e^{-i\Omega e_z \cdot X_{(k)}} = 0$$

→No DFI signal

2,3D :we define $\mathrm{T} \equiv \frac{s}{h}$

$$\mathrm{T} \sim (fL/c)^p L/c \quad f \ll c/L \quad p = \begin{matrix} 3 & 2D \\ 2 & 3D \end{matrix}$$



3D is better

Condition to realize DFI

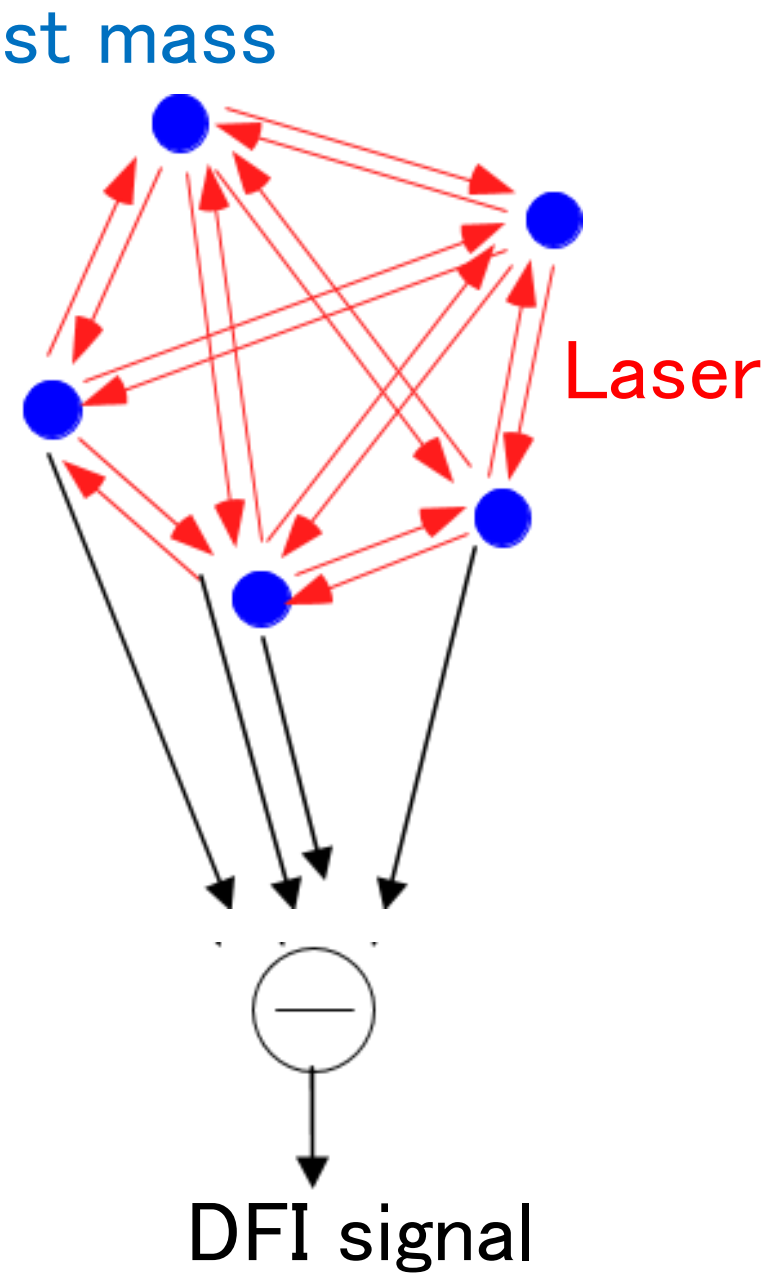
N : a number of detectors
d : dimensionality

Displacement noise → Nd
Laser noise → N
Signal → N(N−1)

Necessary condition $N(N-1) \geq N(d+1) \rightarrow N \geq d+2$

(signal channel)≥(noise channel)

→ d=3 → N≥5



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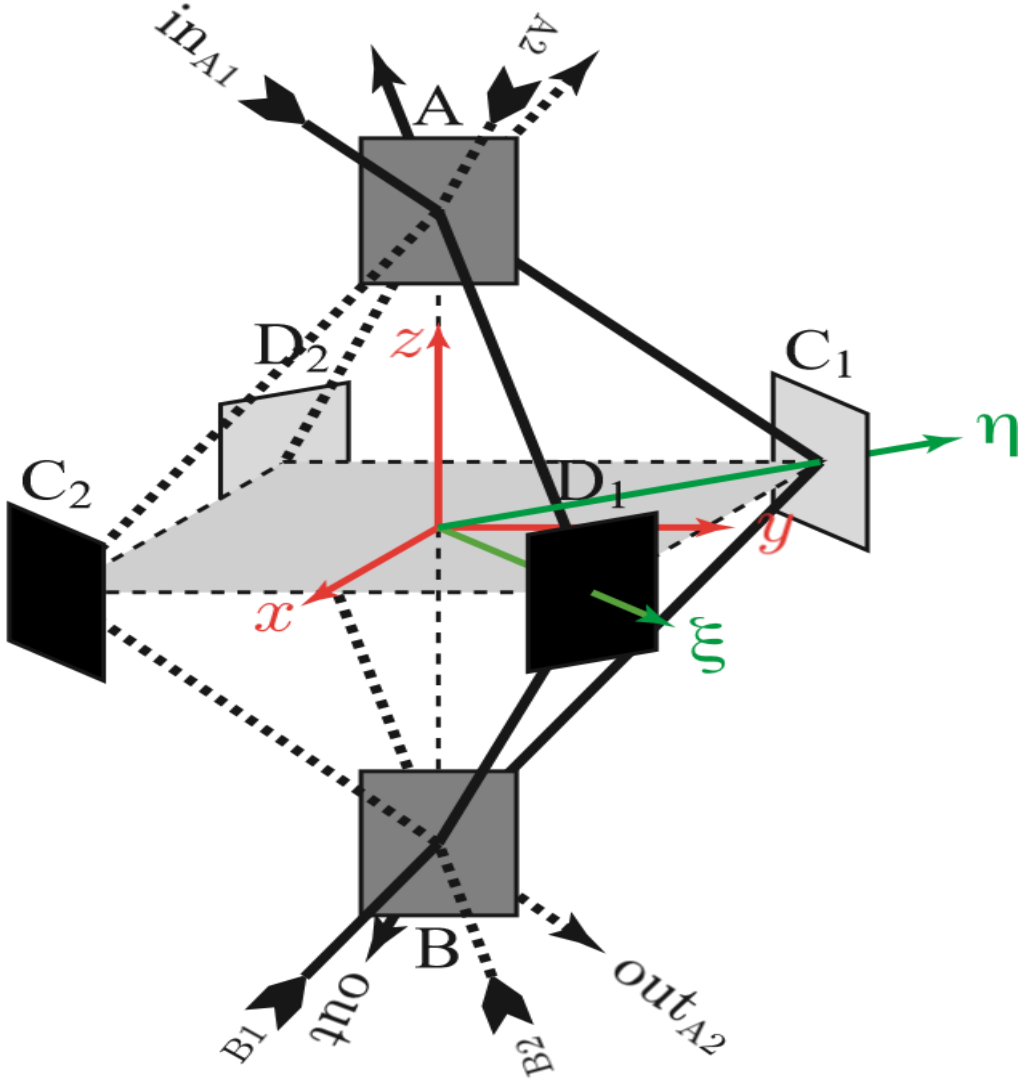
Mach–Zehnder interferometer

A and B are Beam Splitter
C_1, C_2, D_1, D_2 are mirror

There are four Mach–Zehnder interferometers

All edge lengths are equal to 2L
→laser noise is cancelled



Displacement noise

MZ1−MZ2

→ Displacement of C2 and D2 are cancelled

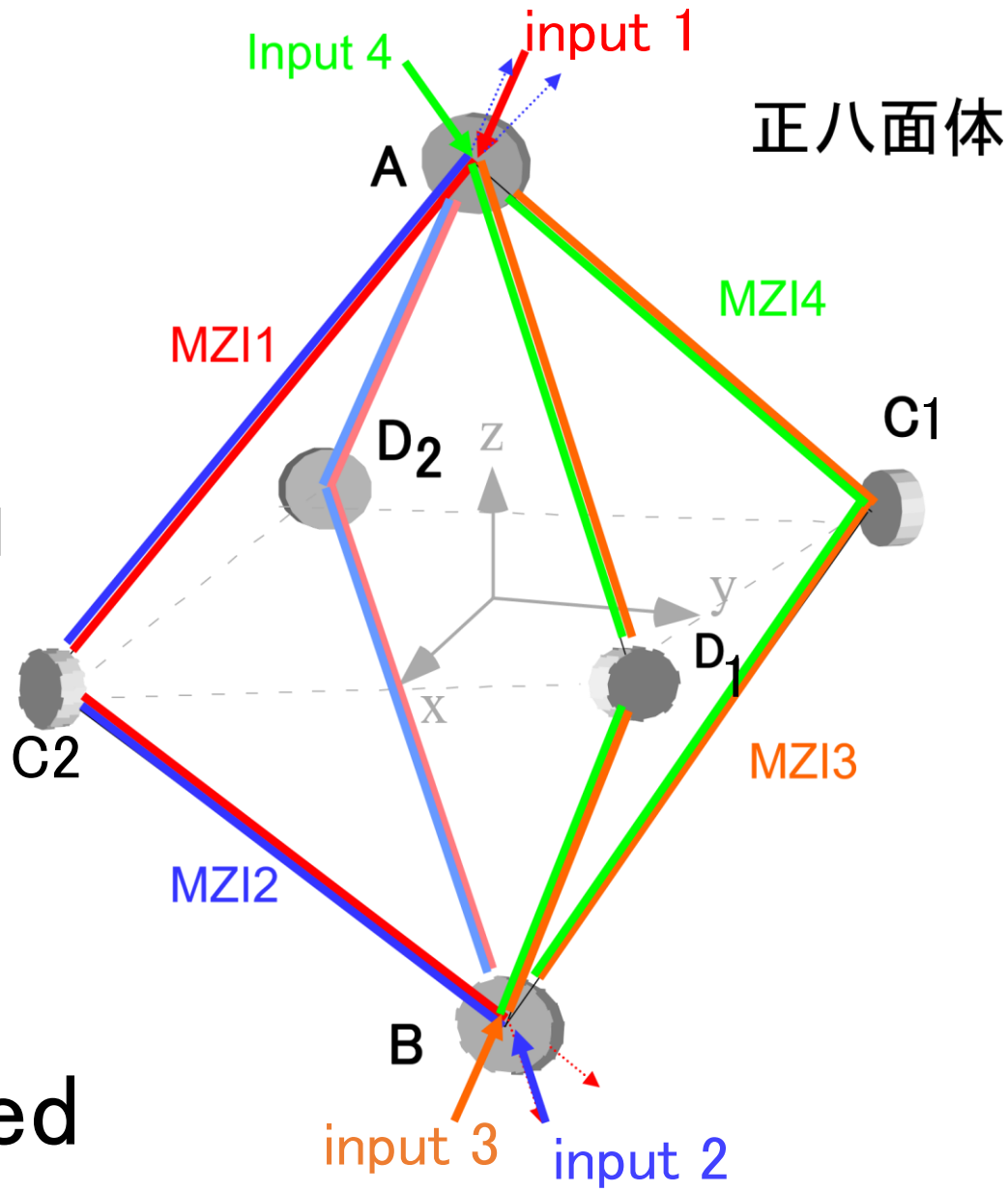
MZ4−MZ3

→ Displacement of C2 and D2 are cancelled

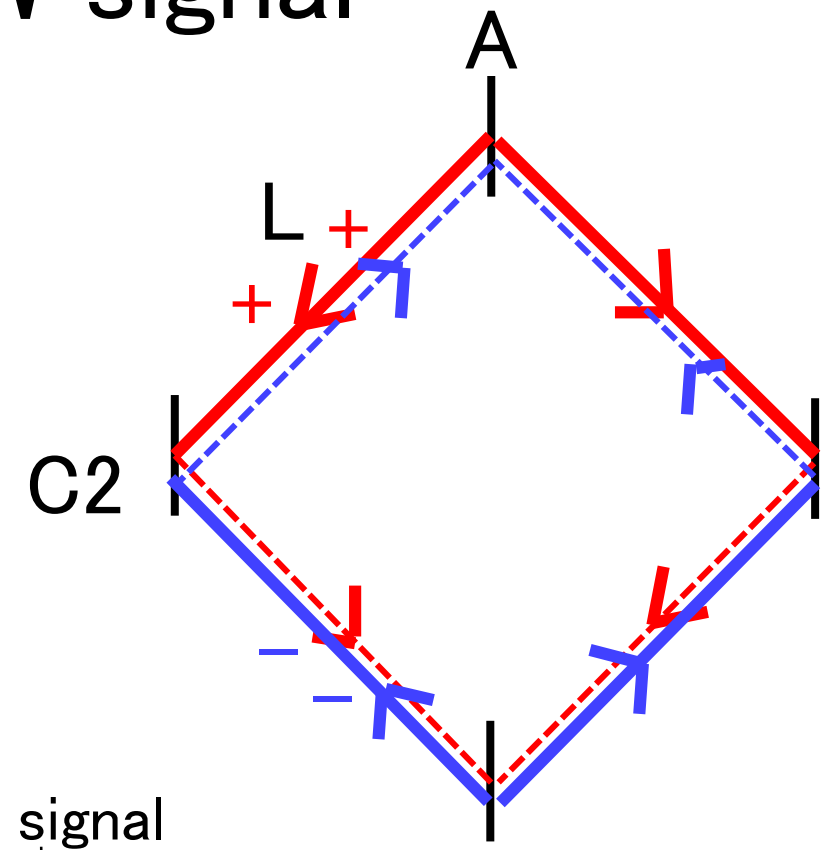
(MZ1−MZ2)−(MZ4−MZ3)

→ Displacement of A and B are cancelled

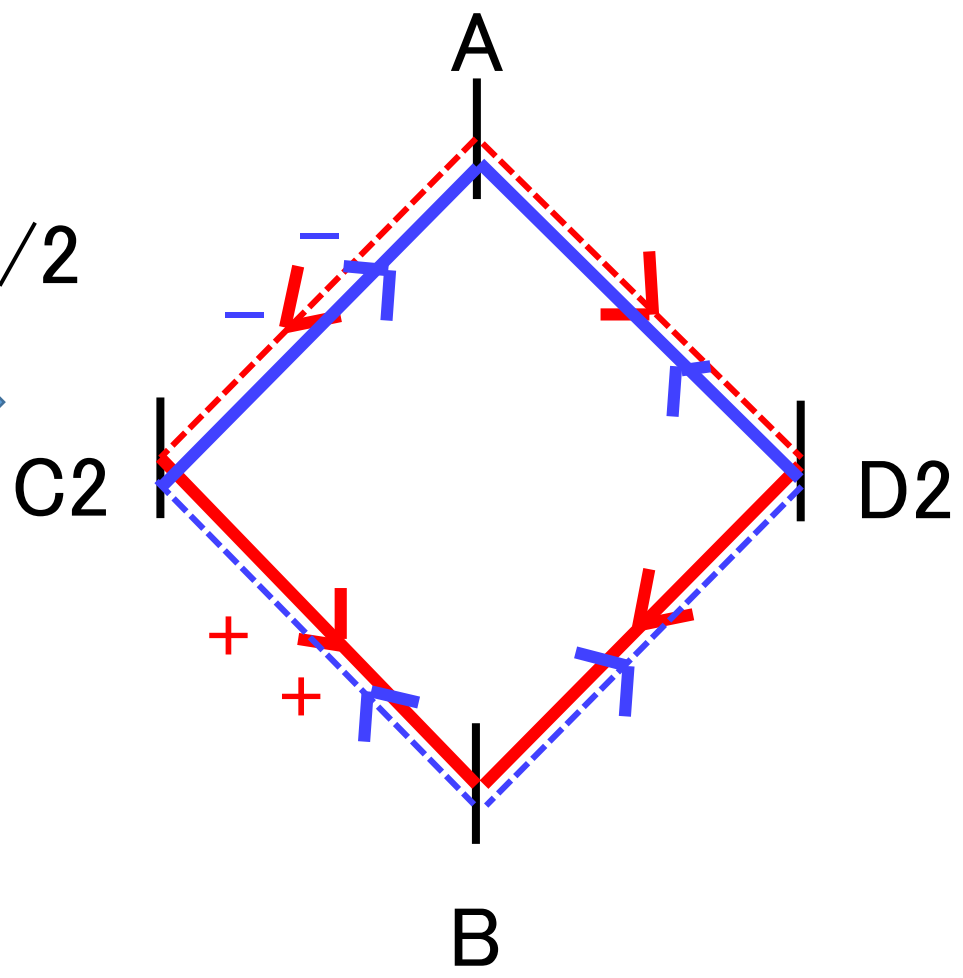
Displacement noise are cancelled

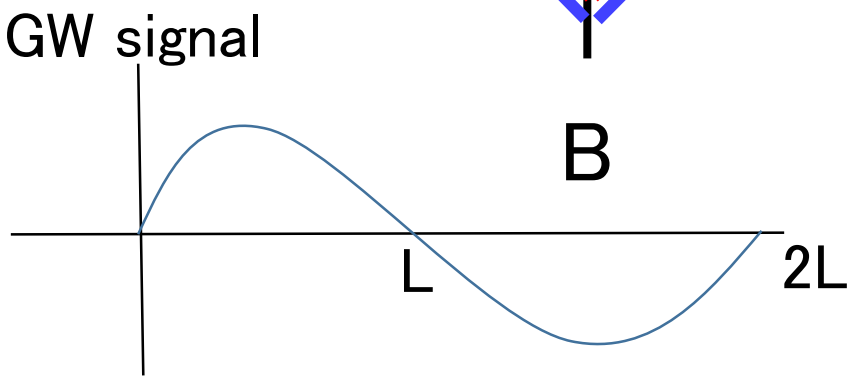


GW signal



After T/2





GW signal is not cancelled

Summary

- DFI is displacement and frequency noise free interferometer

- 3-dimensional configuration has a better sensitivity in a low frequency than 2-dimensional one

- To realize DFI, $N \geq d+2$ must be satisfied

- 4 Mach-Zehnder interferometers of DFI is proposed

END