Displacement-Noise-Free Interferometry

~True Potential~

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GWADW at Ft Lauderdale

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1. **Invention of DFI** **[2004-2006]**

   ~ Kawamura, Chen, et al

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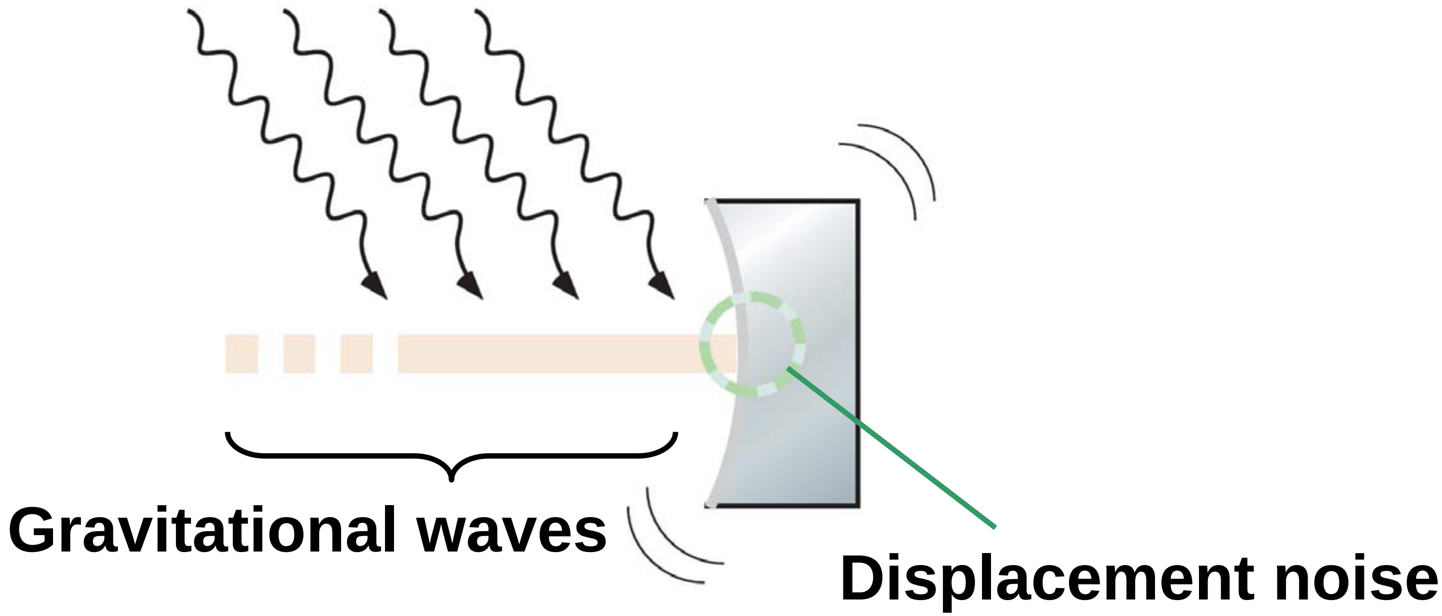
   ~ Kokeyama, Sato, et al

3. **Recent study** **[2008-2009]**

   ~ Nishizawa, Vyatchanin, et al

DFI

[Kawamura PRL 04]



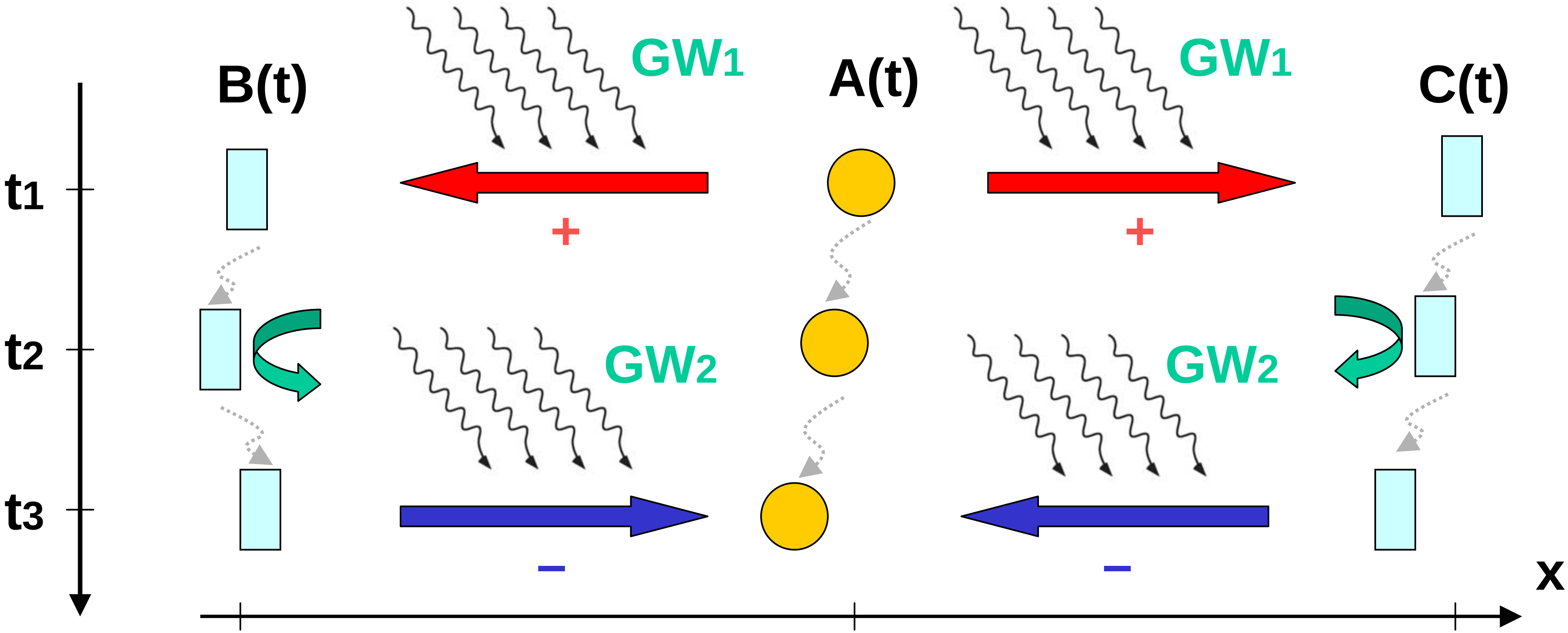
There is a difference between GW and disp. noise.

GW : probed during the light travel

disp: probed at the reflection

⇨ There is a way to distinguish them!!

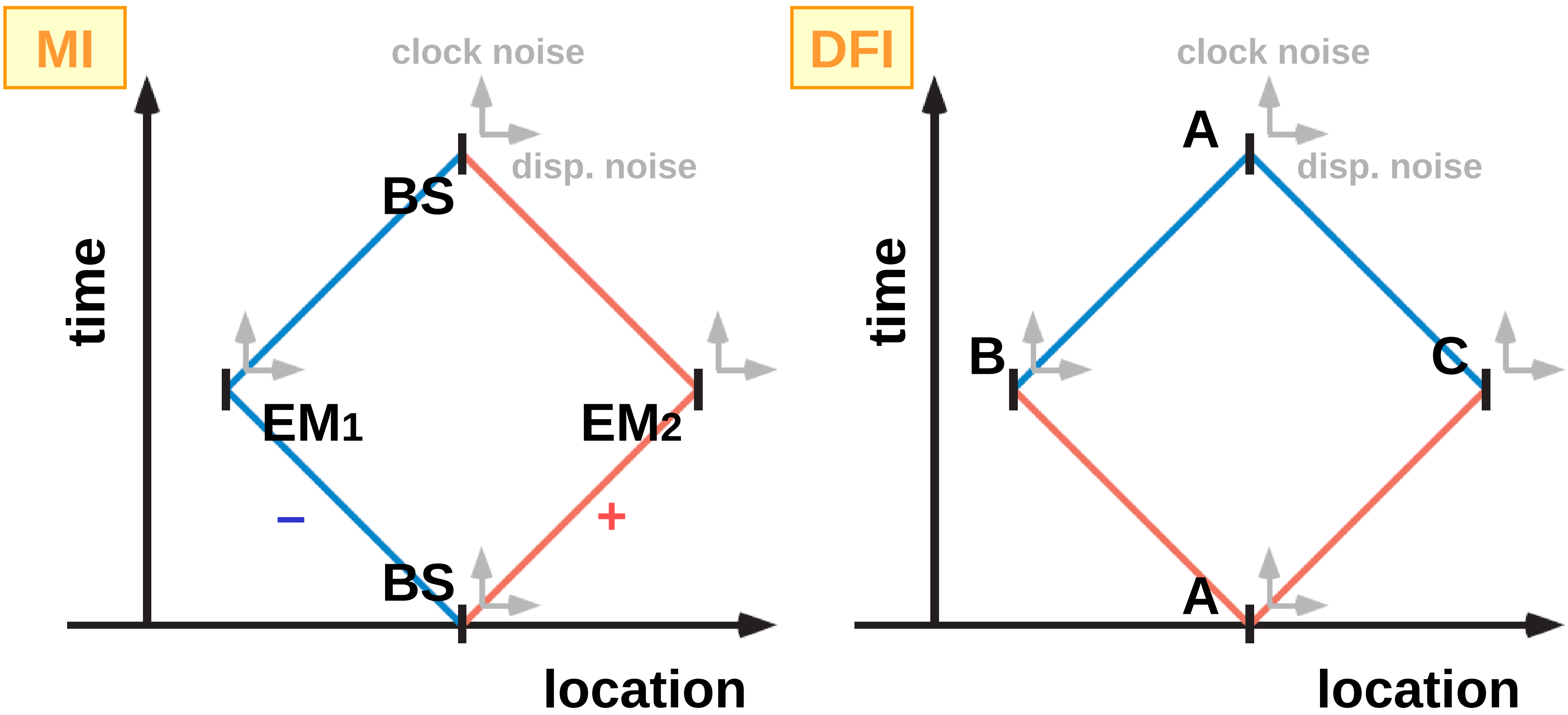
How can we distinguish GW and disp-noise?



$[A(t_1)-B(t_2)] + [C(t_2)-A(t_1)] - [A(t_3)-B(t_2)] - [C(t_2)-A(t_3)] + GW_1 - GW_2$

displacement free + GW + clock noise

DFI vs Michelson ifo



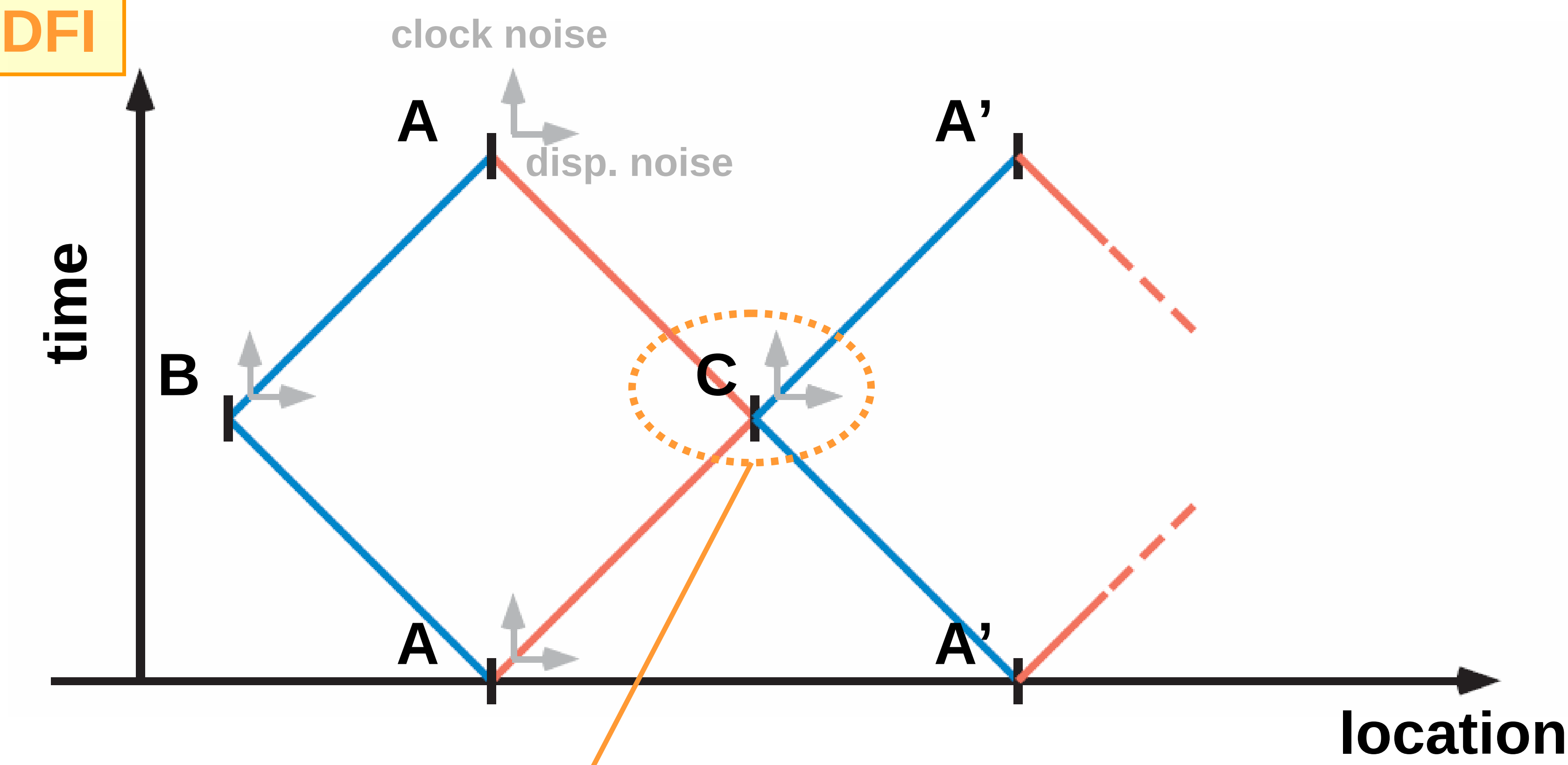
MI : no clock noise (freq noise), but disp. noise

DFI : no disp. noise, but clock noise

Actually we want to cancel both.

Displacement-noise and Frequency-noise free

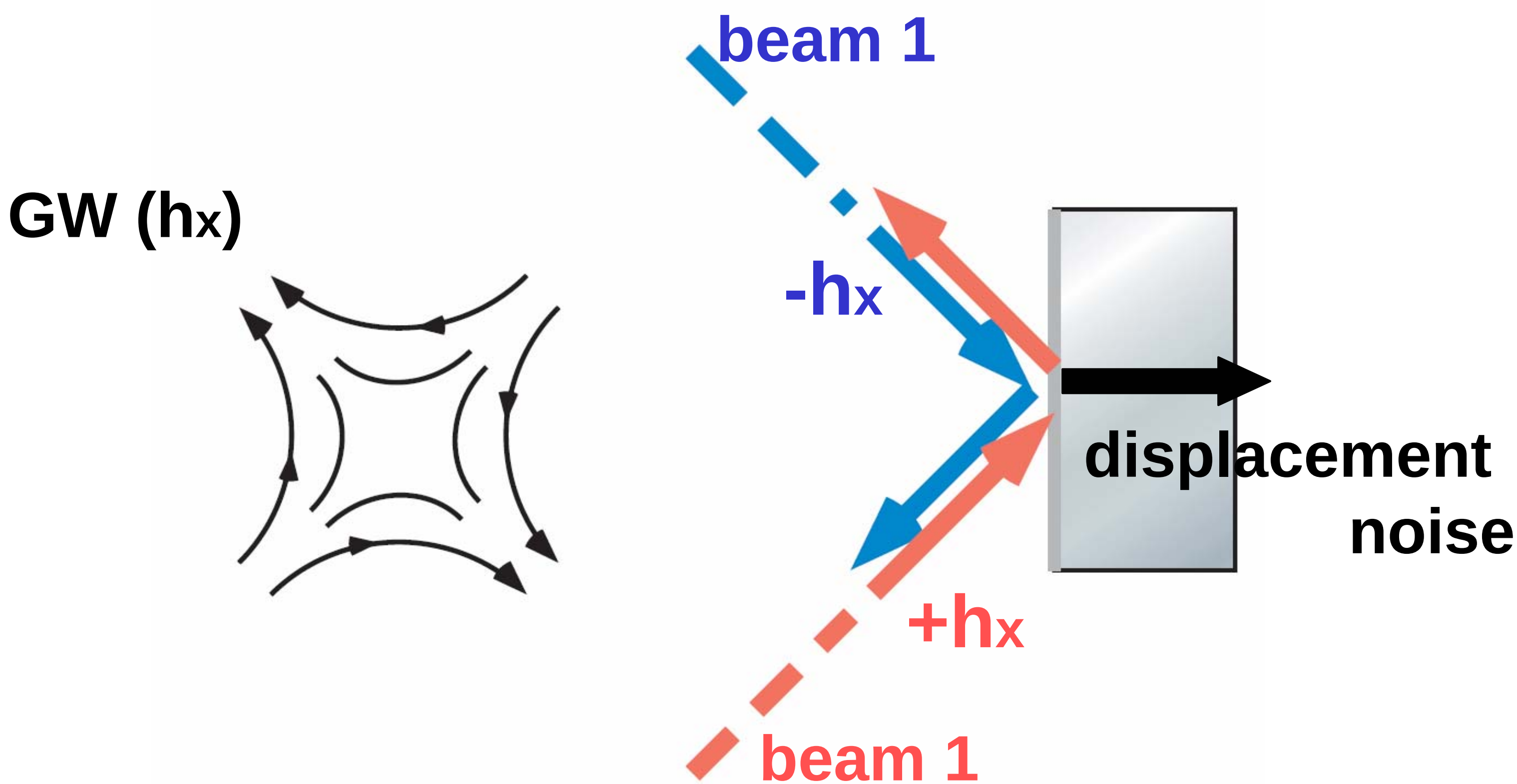
true-DFI



Both disp noise and freq noise are cancelled (for C).

- We should do the same for all the components
- GW signal should not be cancelled

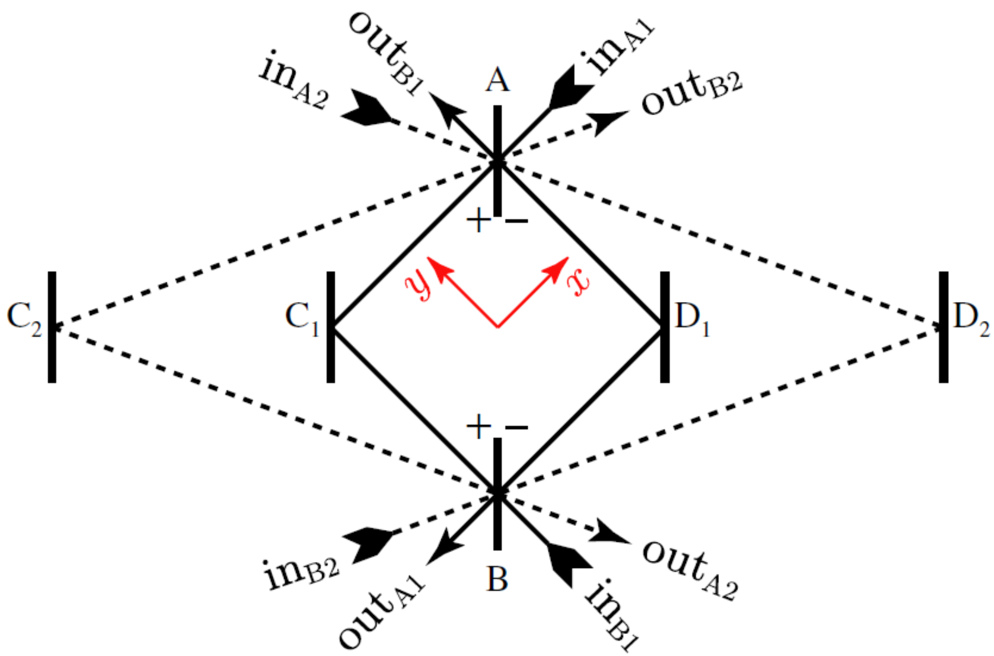
Separation of GW and disp noise



- Sign of GW is opposite between beam 1 and beam 2
- After subtraction, GW signal is prop to frequency

Bi-directional Mach-Zehnder ifo

[Chen PRL 2006]



1st subtraction (mirror disp)
bi-directional measurement
(ex. AC_1B – BC_1A)

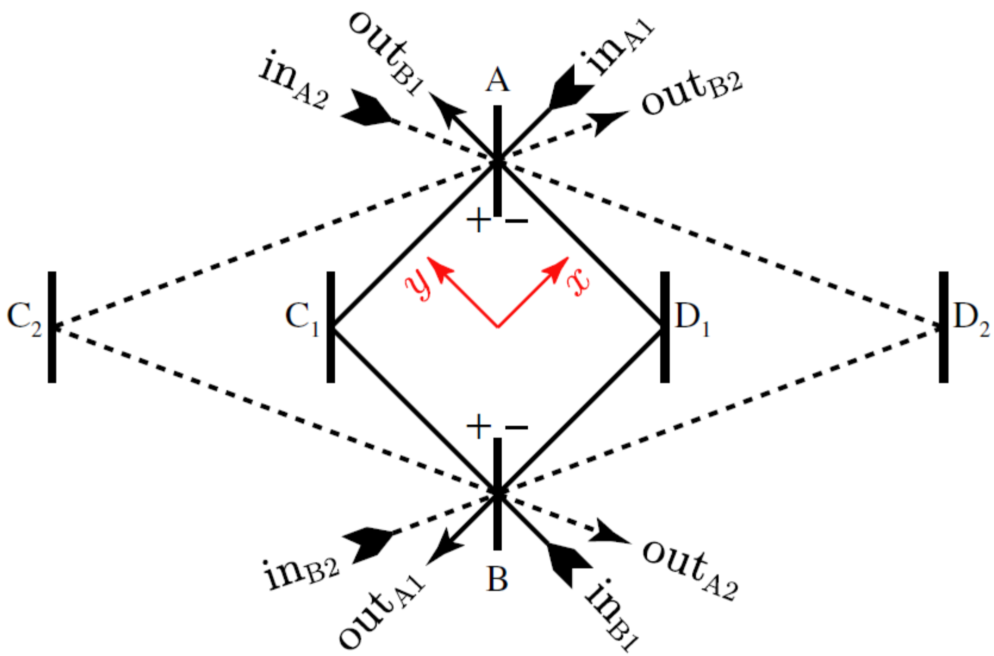
2nd subtraction (freq noise)
MZ interferometer
(ex. AC_1B – AD_1B)

3rd subtraction (BS disp)
2 MZ combination
(ex. AC_1B – AC_2B)

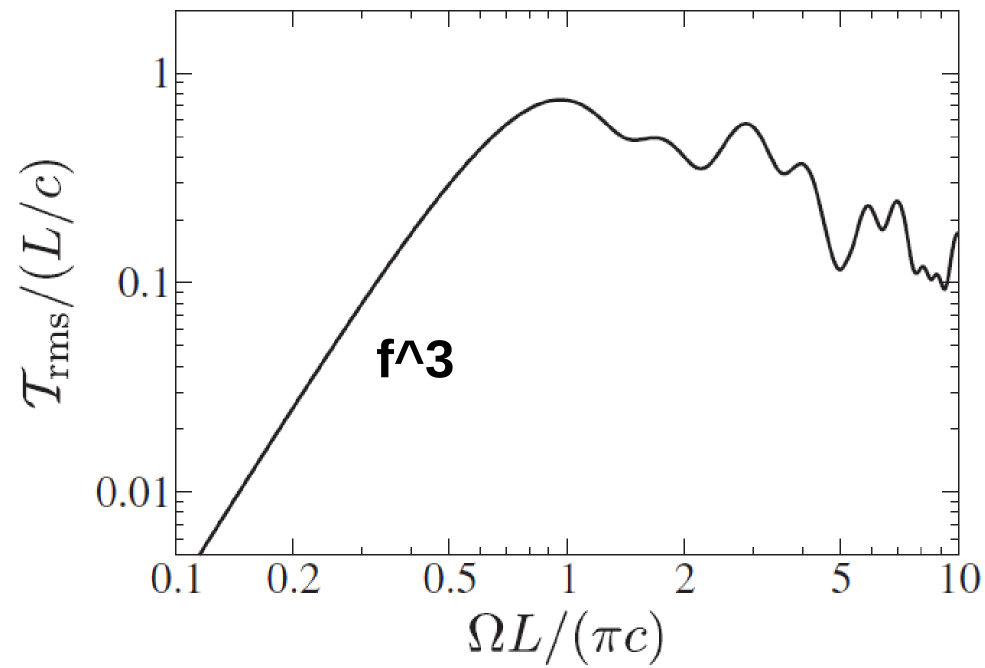
→ **Signal is proportional to f^3 (bad)**

Bi-directional Mach-Zehnder ifo

[Chen PRL 2006]



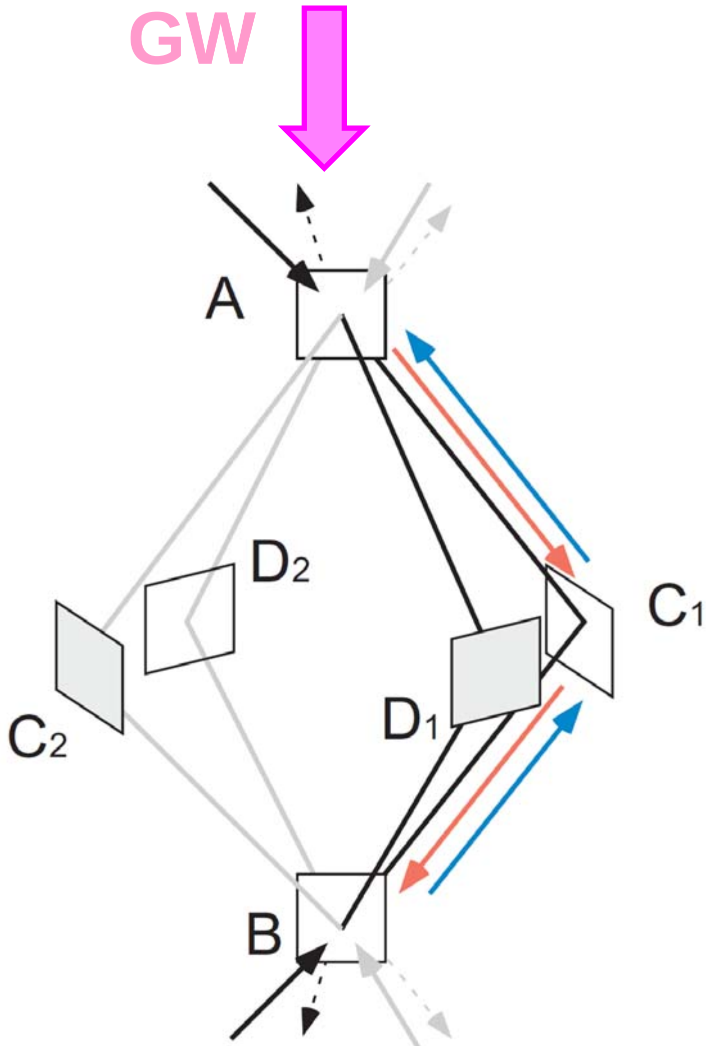
Signal response

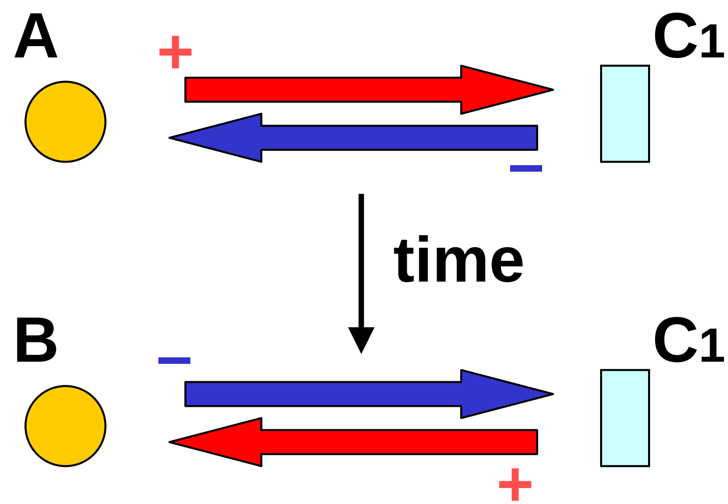


Signal is proportional to f^3 (bad)

3D DFI

[Chen PRL 2006]





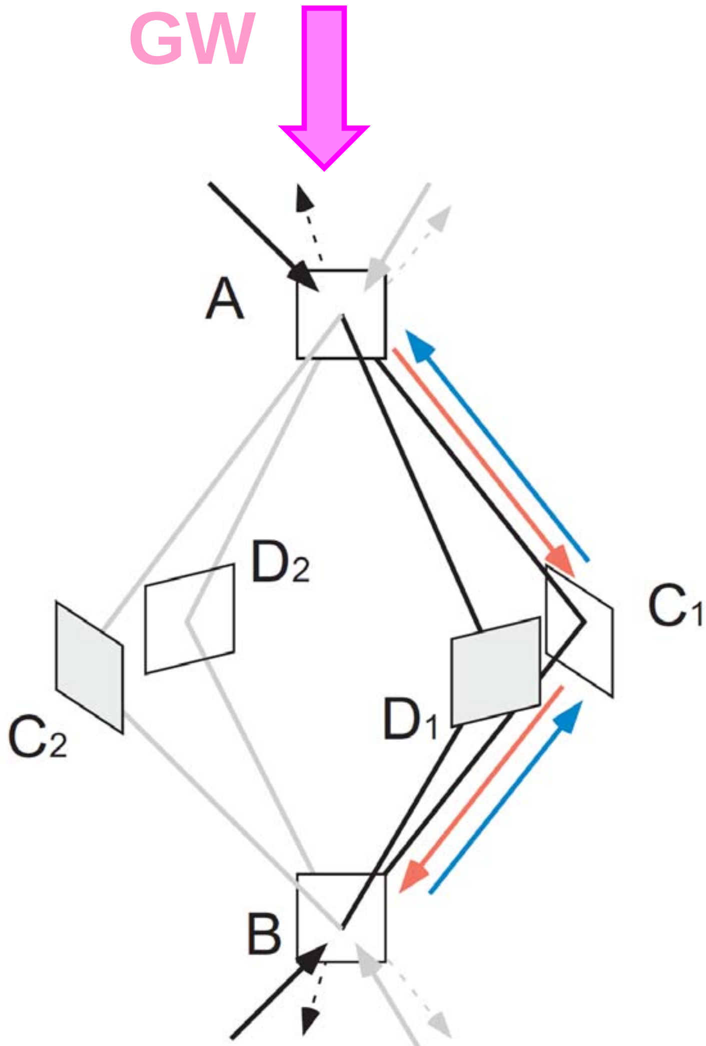
1st subtraction
DFI between A-C_1

2nd subtraction
A-C_1 and B-C_1 at different time

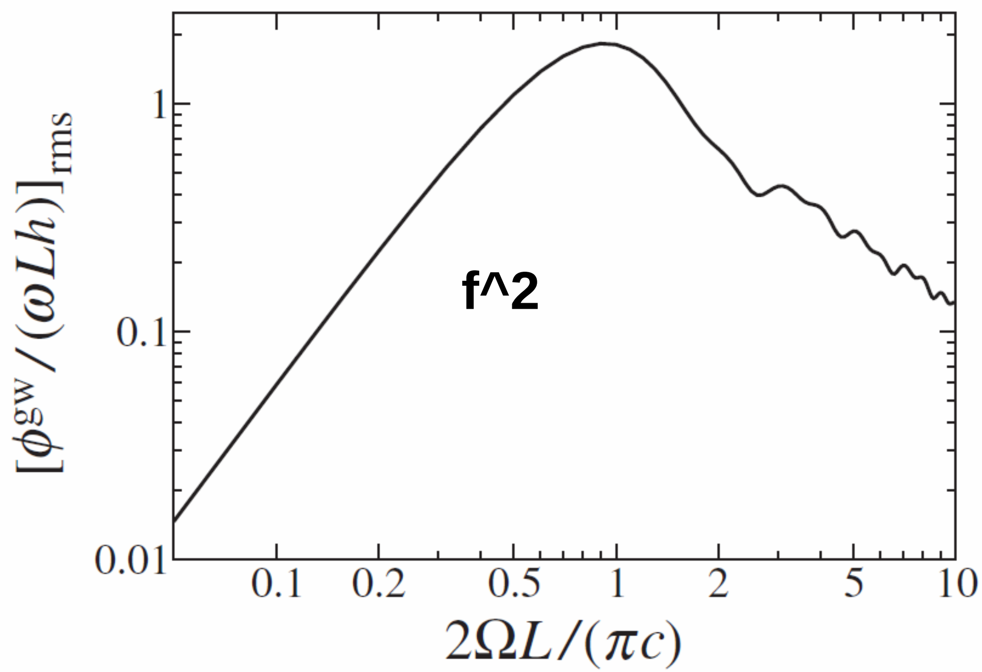
Signal is proportional to f^2 (bad)

3D DFI

[Chen PRL 2006]



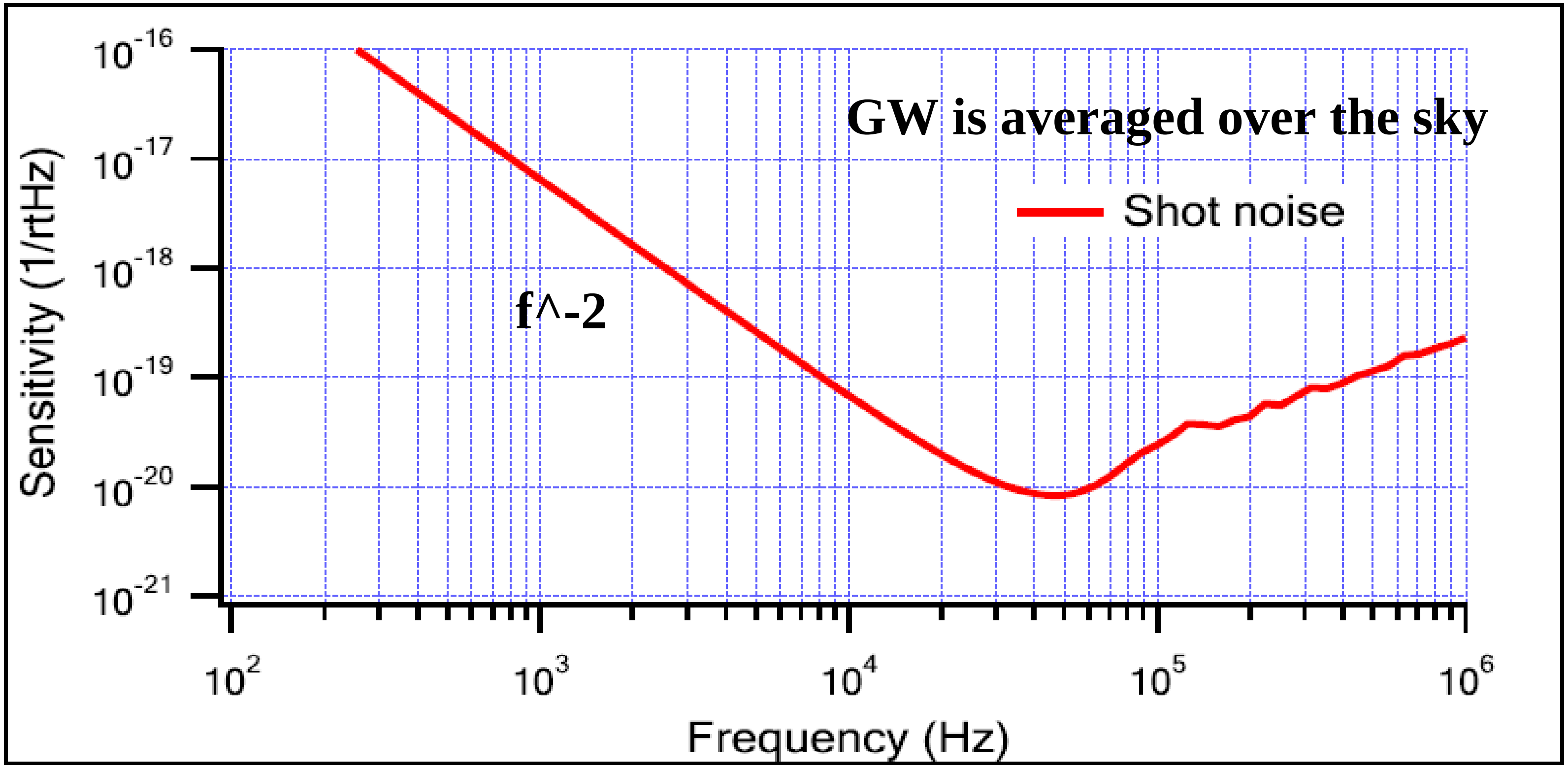
Signal response



Signal is proportional to f^2 (better)

3D-DFI noise spectrum

L=4km, I=10W each



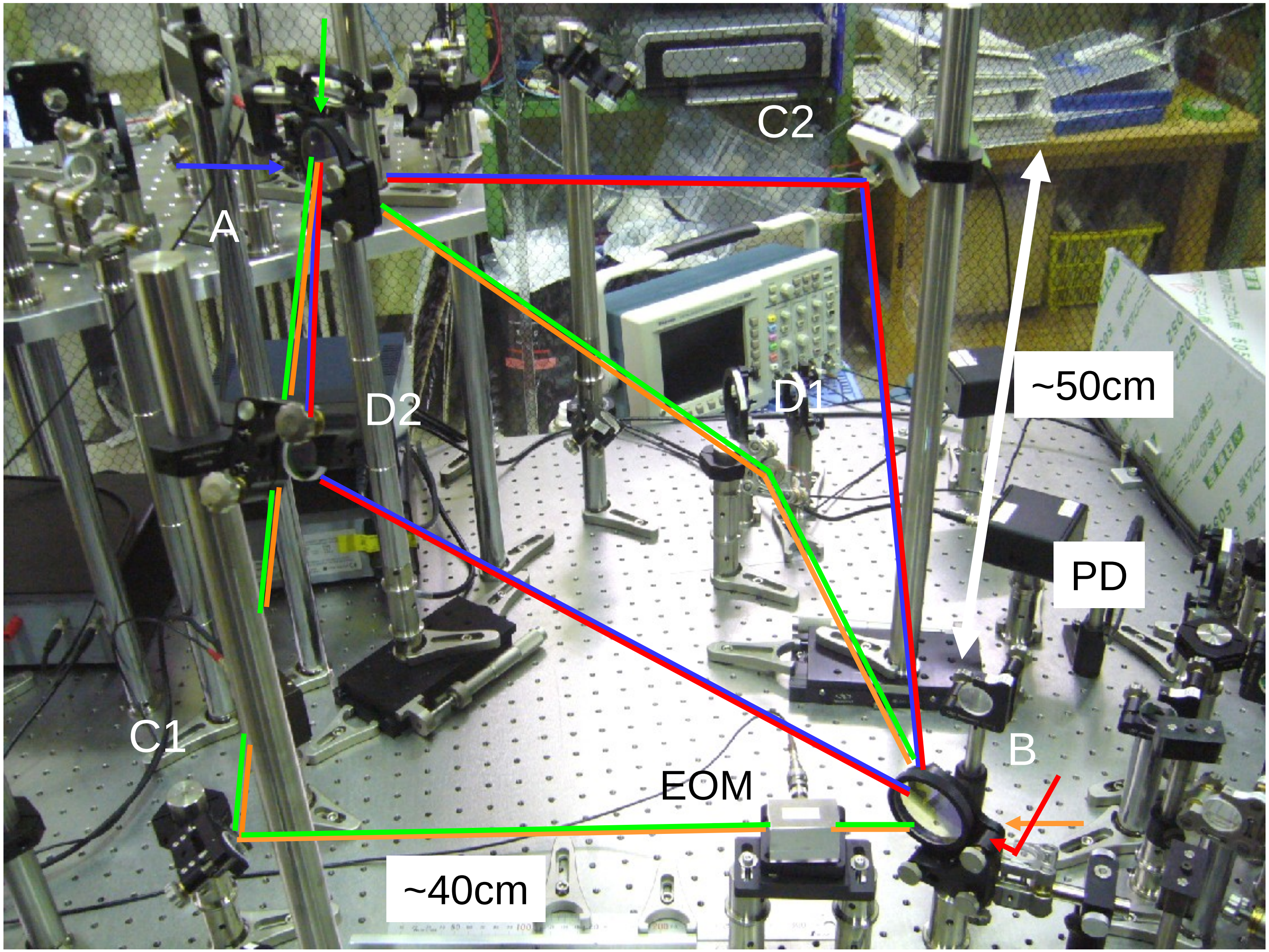
- No displacement noise at any frequency
- Shot noise is bad at low frequency

After the discovery…

- R&D experiments in Japan
  - 2D DFI
  - 3D DFI
- Effort to find a better configuration
  - time-delay device
  - narrow-band DFI
  - DFI with rigid platform
  - resonant-type DFI

3D DFI table-top experiment

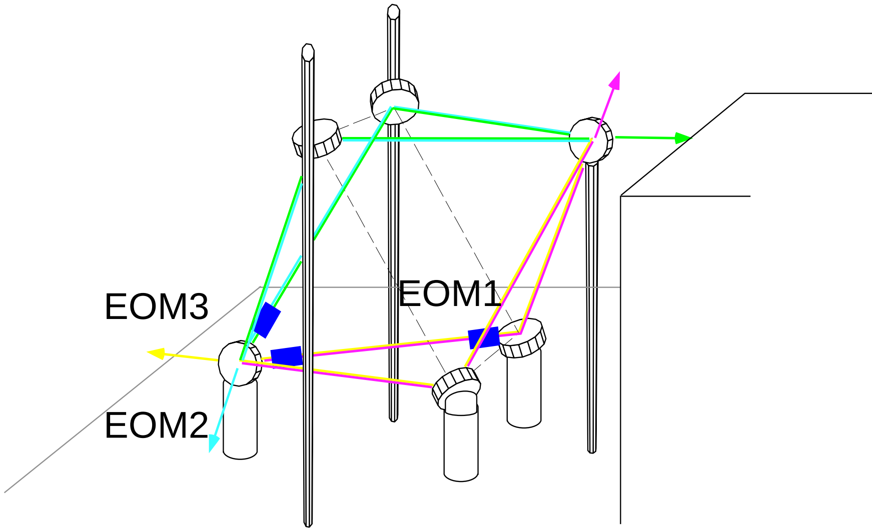
[Kokeyama 2009]



- Alignment in 3D
- High frequency (~MHz)
- TF measurement using EOMs

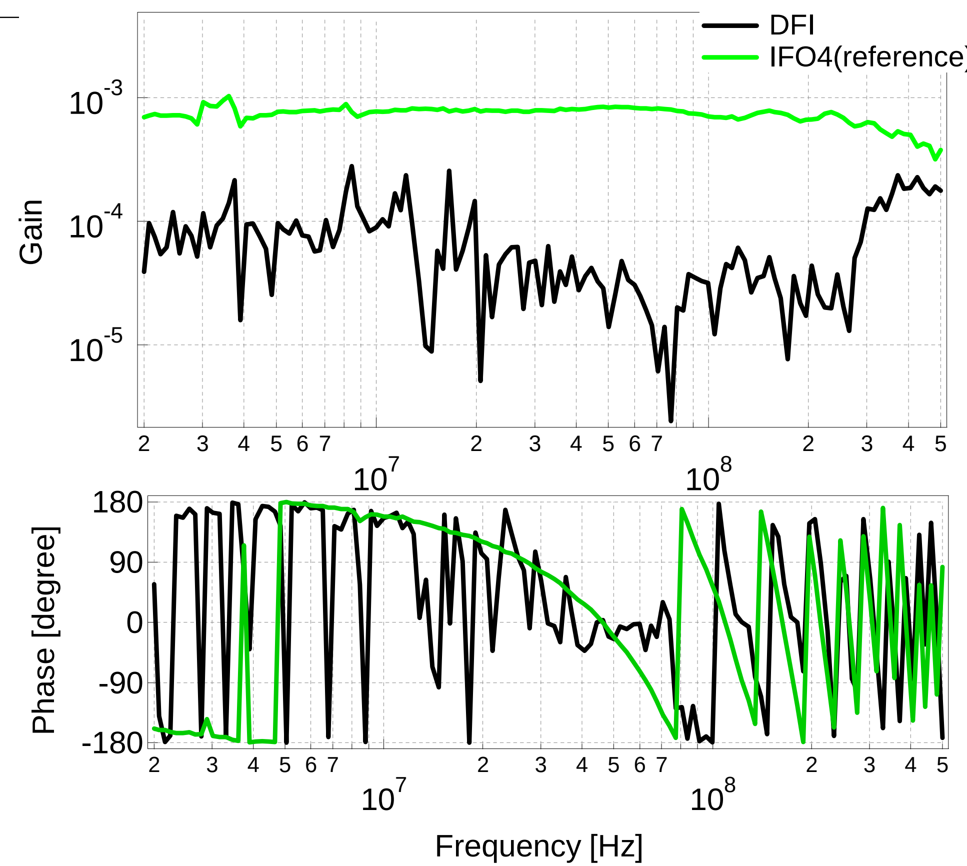
Verification of noise cancellation

[Kokeyama 2009]



Mirror: EOM1
BS: EOM2&EOM3

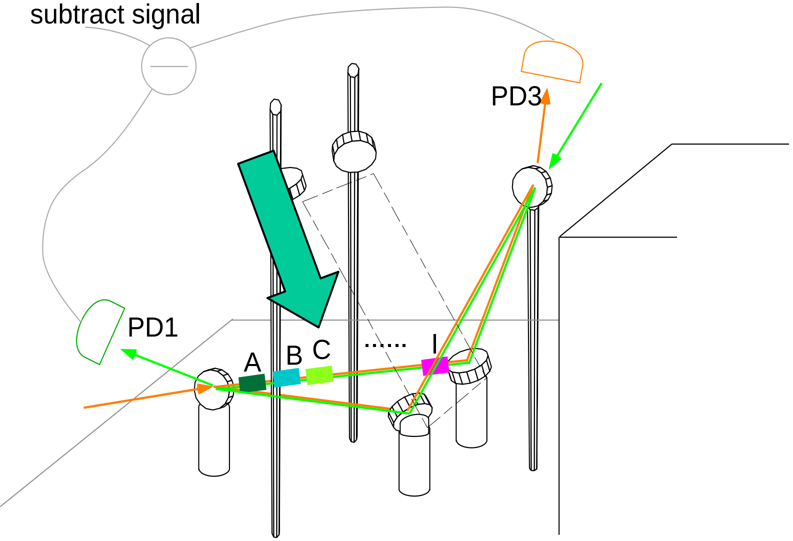
TF : EOM1 to output



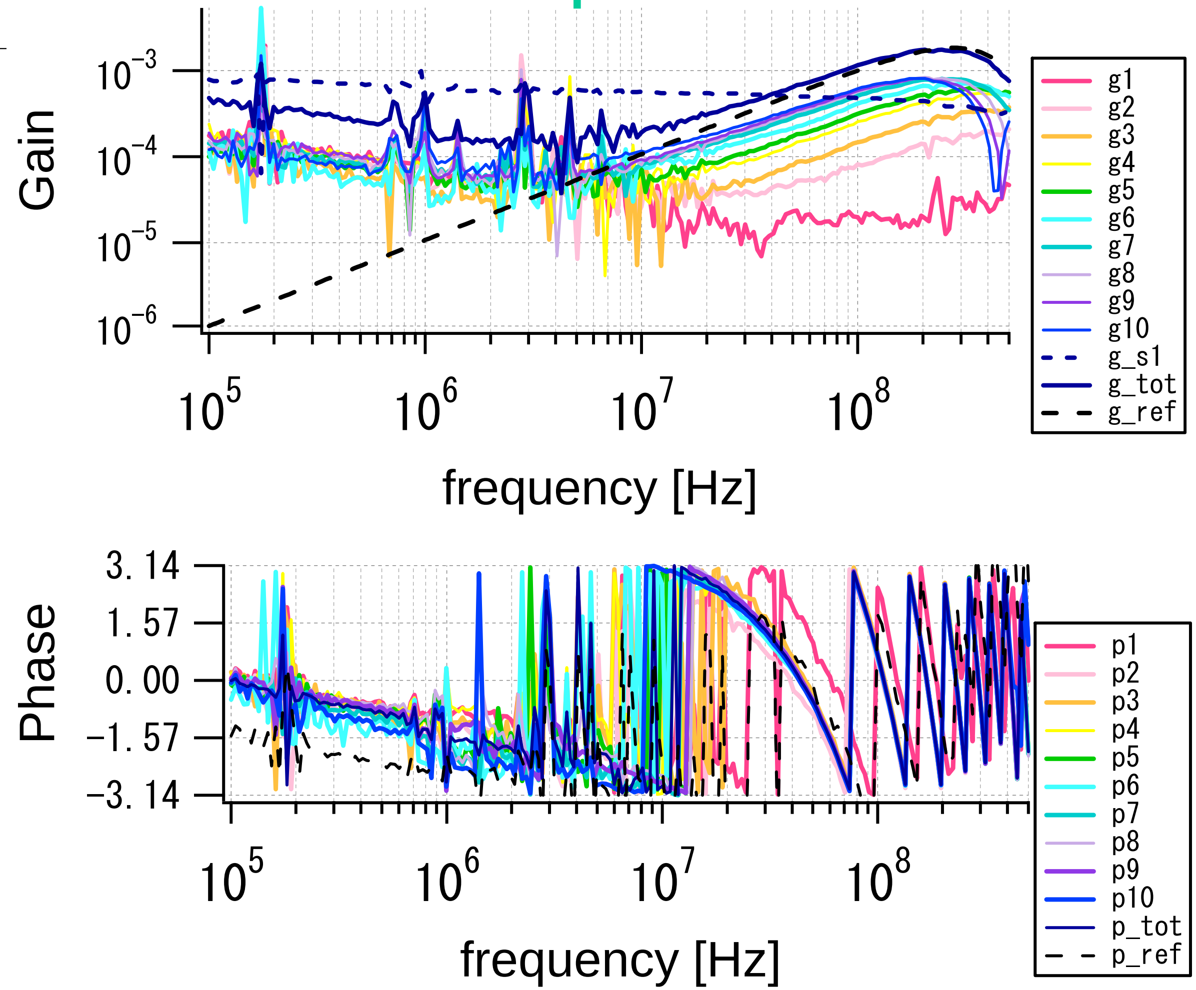
Displacement components is reduced by 20~30dB

Verification of GW non-cancellation

[Kokeyama 2009]



TF : each EOM to output

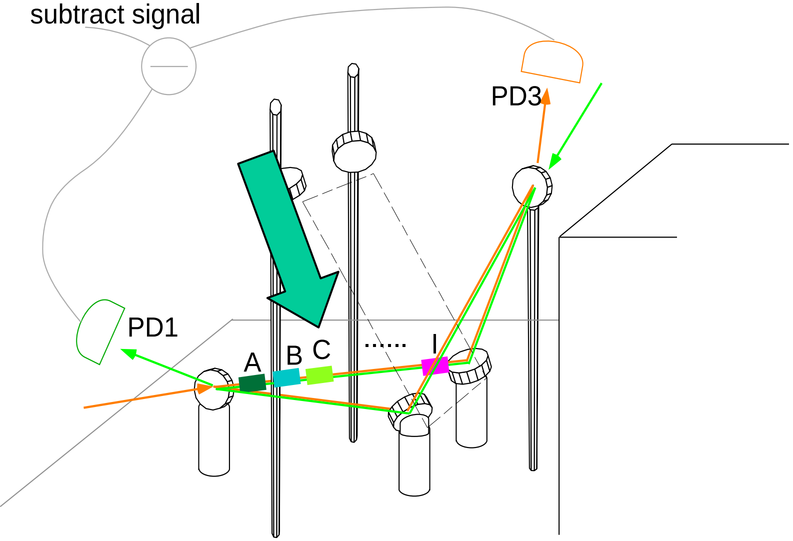


GW: EOM
(different phase at different location)

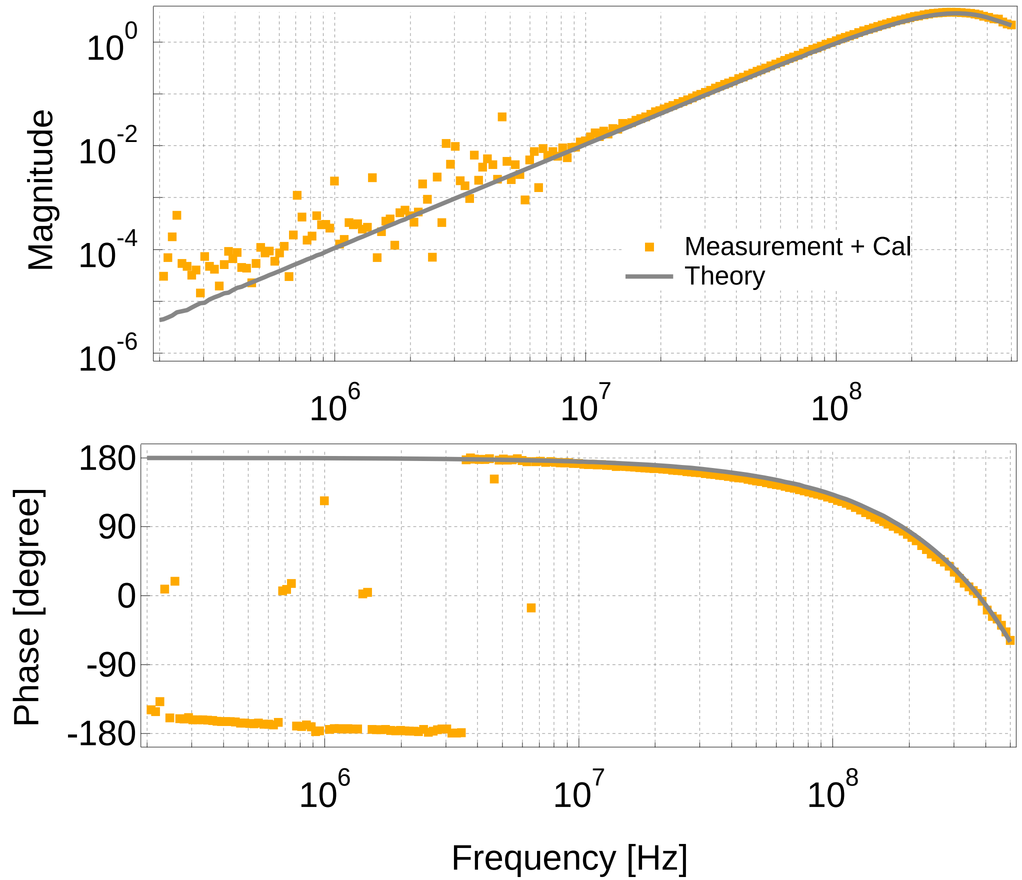
GW signal can be imitated by combining these outputs

Verification of GW non-cancellation

[Kokeyama 2009]



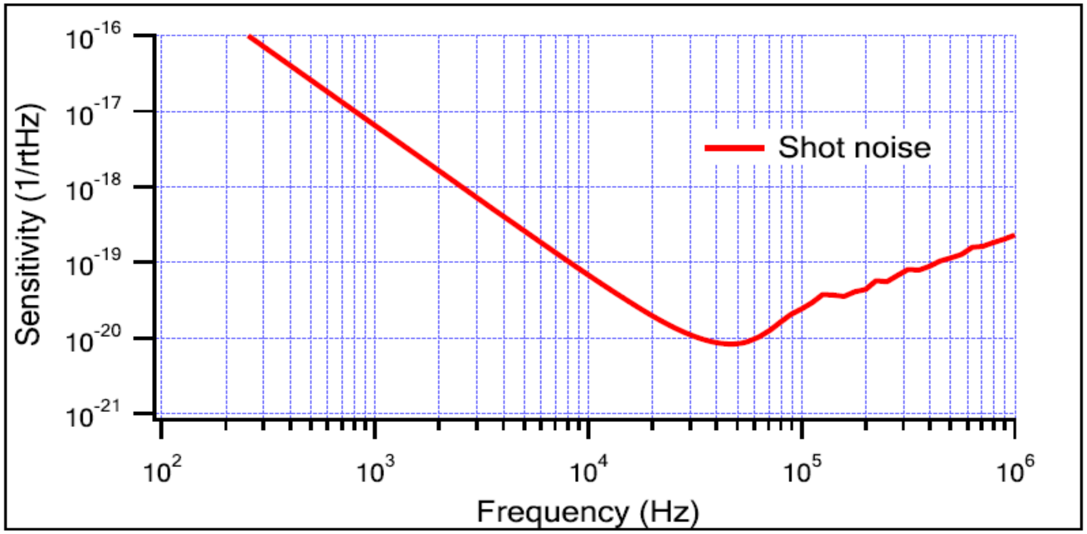
TF : combination of 10 EOMs



GW: EOM
(different phase at different location)

After the calibration, DFI signal response is obtained.

Weak-response problem



Even with the 3D DFI, shot noise ∝ f^-2

Moreover…

Yanbei's theorem

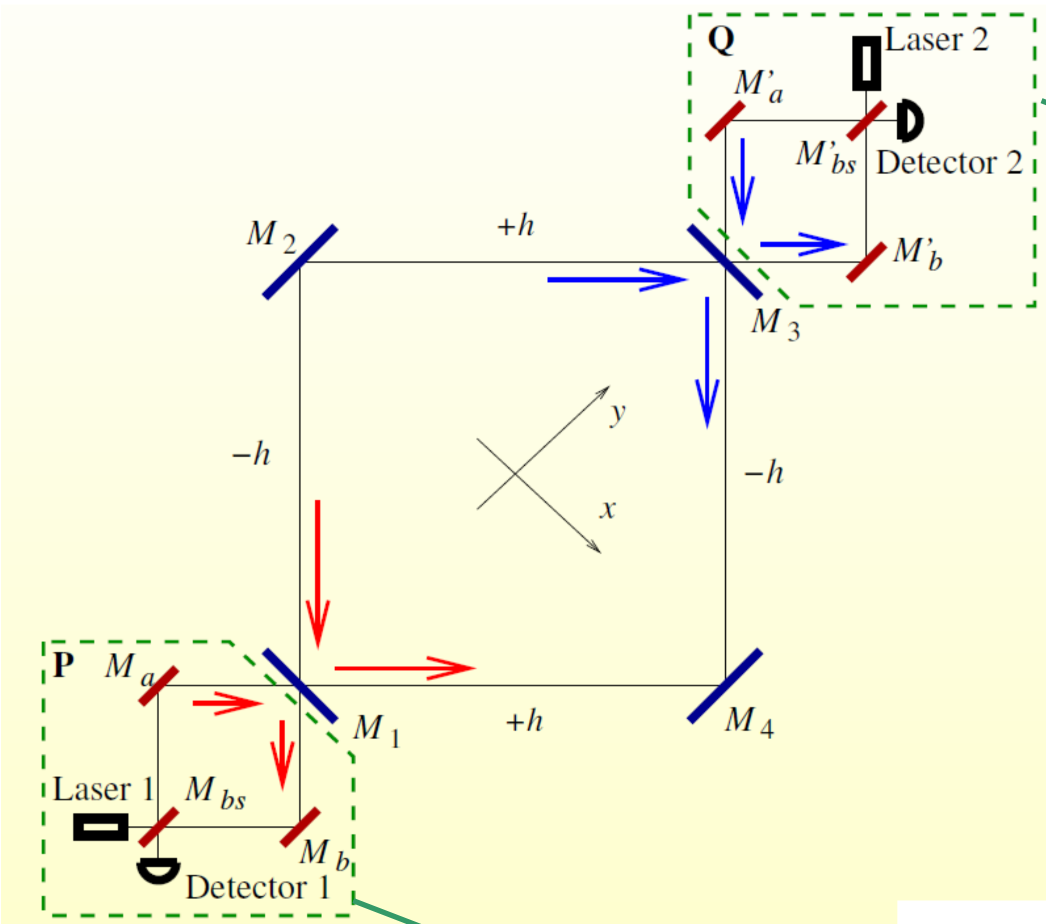
1D : impossible
2D : f^-3
3D : f^-2

one possible ways to circumvent the problem

Make a cavity and ignore disp noise outside the cavity

Resonant speed-meter DFI

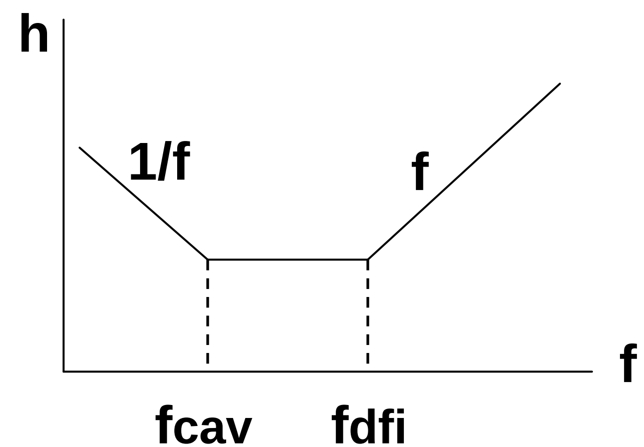
[Vyatchanin 2009]



disp noise of PF is suppressed by finesse

noisy platform

DFI



noisy platform

This configuration gives 1/f DFI sensitivity curve.

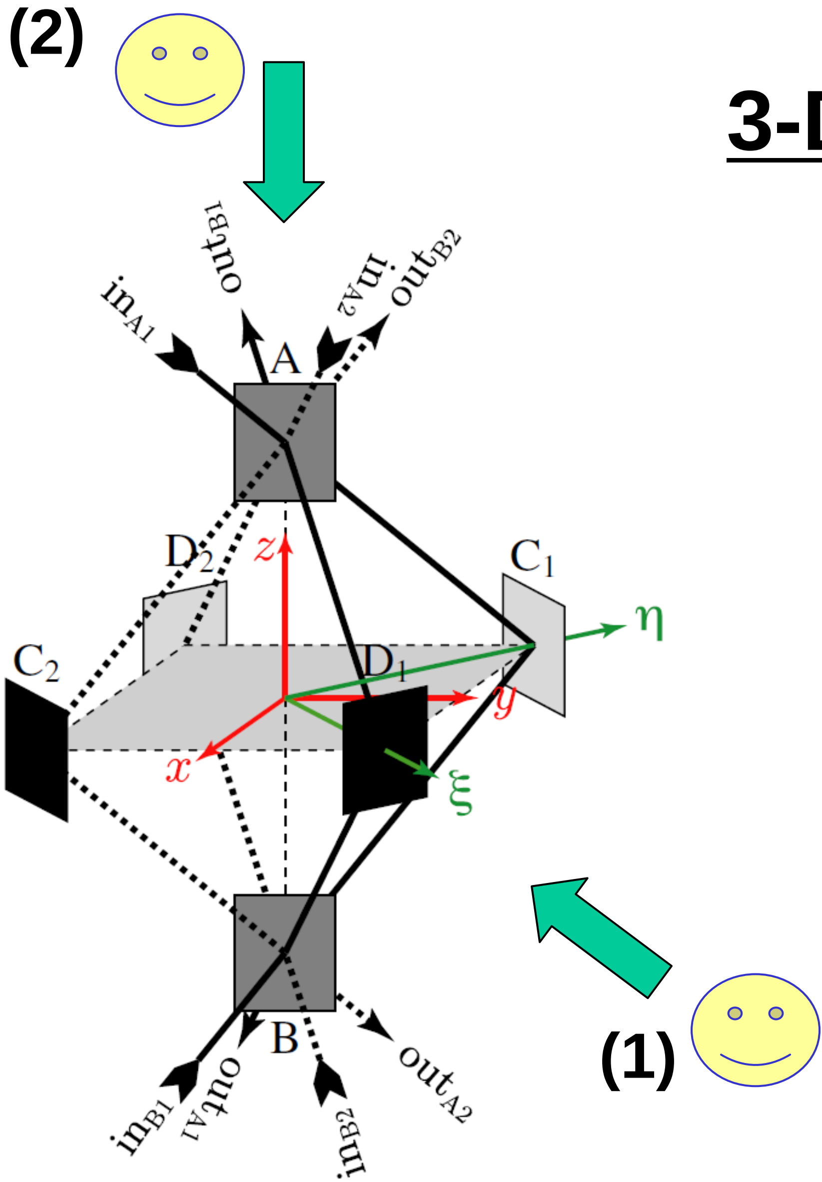
Is this good enough?

Summary and discussions

- 3D DFI with f^-2 slope is so far the best for complete DFI
- R&D experiments done
- Resonant partial-DFI seems nice with 1/f slope
- Is it possible to make the slope better?
- DFI might be useful for a space-based GW detector
- Maybe with atomic interferometer…

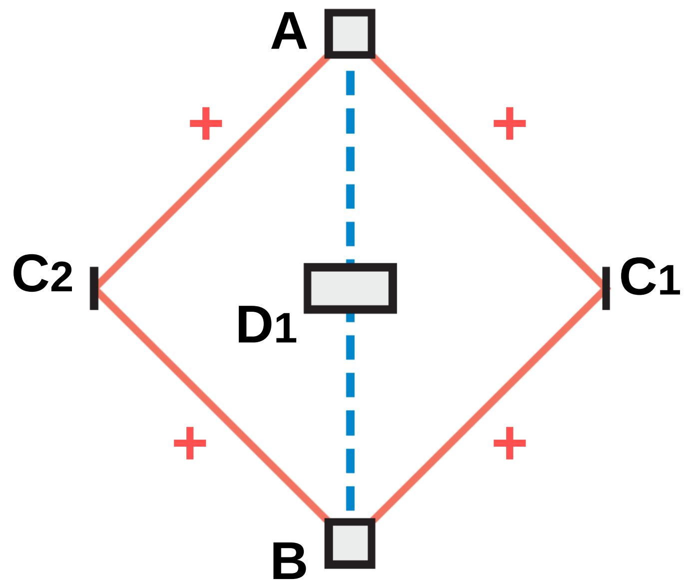
End of the slides

3-D DFI



[Chen PRL 2006]

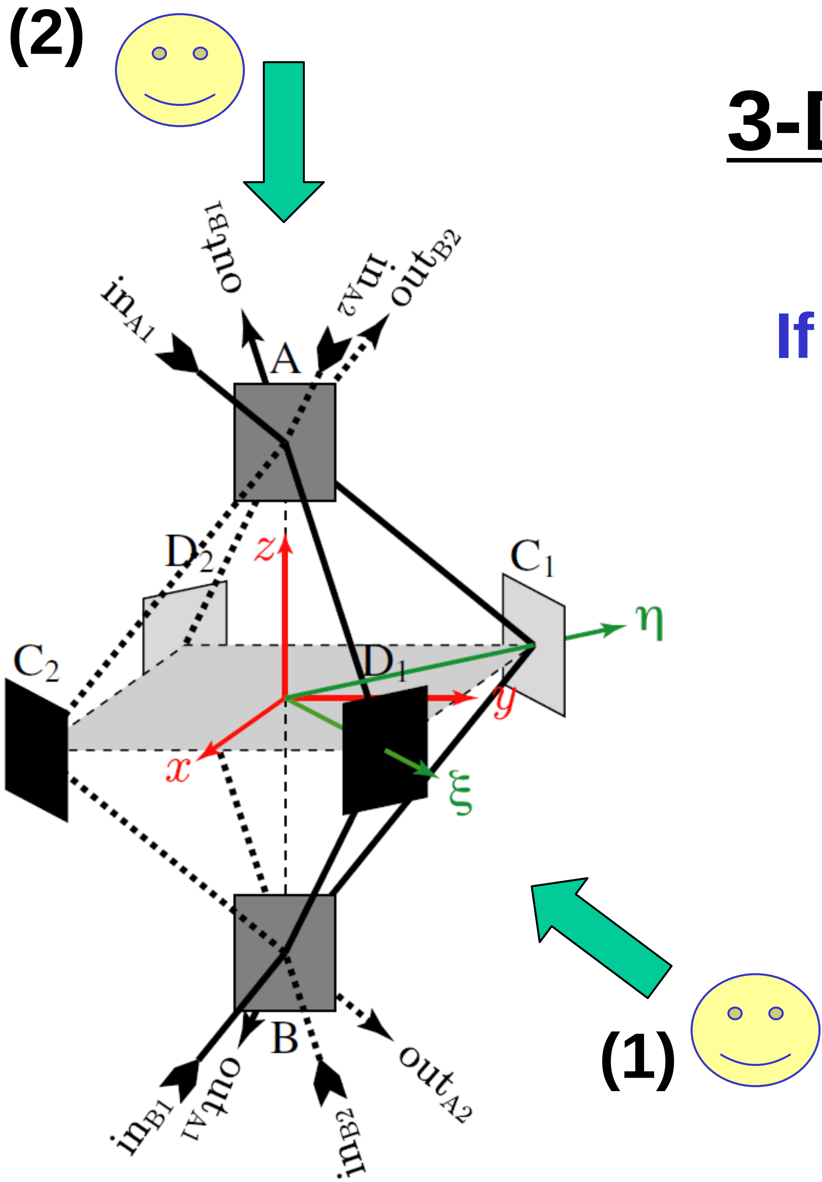
GW from (1)'s direction



ACjB is no MZ (no GW).
ADjB's GW cancels with BDjA's.

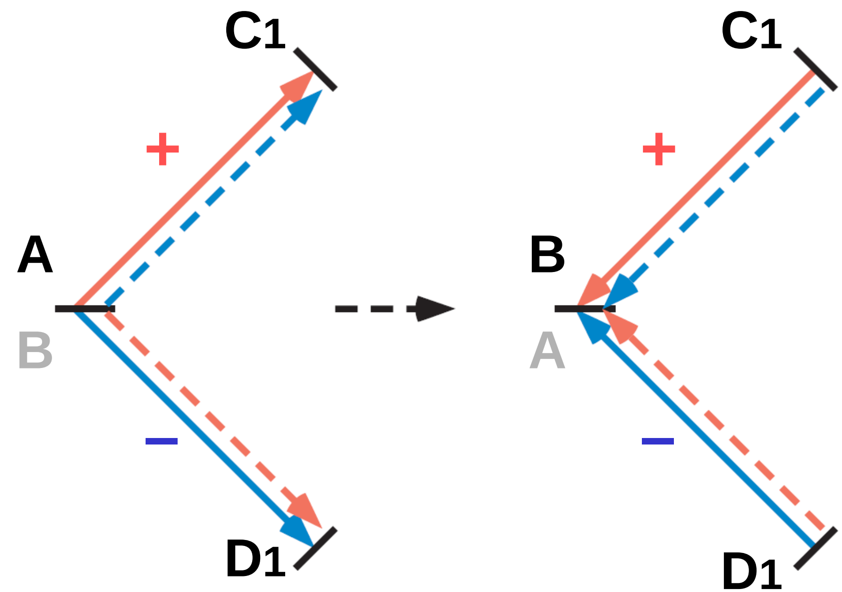
No response to GW from (1)'s direction.

3-D DFI



[Chen PRL 2006]

If GW comes from (2)'s direction



like a Michelson interferometer

Signal is proportional to f^2