Retrospective view of my path in this half a year

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Institute for Cosmic Ray Research,
University of Tokyo
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Abstract

- My main work is “QND experiment”.
- But, in this half a year, I did a lot of other things.
  (Some works has not yet been done…)
- This year, I worked in
  - Kamioka (January),
  - Caltech (February - March 1st half),
  - Sendai, Miyagi (March 2nd half),
  - Kamioka (April 1st half)
  - Kashiwa (April 2nd half - May 1st half),
  - Elba, Italy (May 2nd half),
  - Glasgow, Scotland (June).
- I will talk on what I did in this half a year.

Outline

2016	What I did	Others
Jan	KAGRA	
Feb	Caltech	- LIGO announced the first detection of the GW.
Mar	~~JPS meeting (@Sendai)~~	- First iKAGRA observation (3/25-3/31) - GW workshop (@Tamarokuto)
Apr	KAGRA DC1	- Second iKAGRA observation (4/11-4/25)
May	~~GWADW (@Italy)~~	
Jun	Speed meter (@UGlasgow)	- LIGO announced the second detection of the GW. - LISA announced their result.

Paper work 1 about QND exp.

Paper work 2 about QND exp.

Paper work about Caltech experiment

Introduction

- In KAGRA, thanks to reduction of the “seismic” noise and thermal noise by underground and cryogenic technique, the design sensitivity is mainly limited by quantum noise as shown in Fig. 1.
- Quantum noise is composed of radiation pressure noise and shot noise.

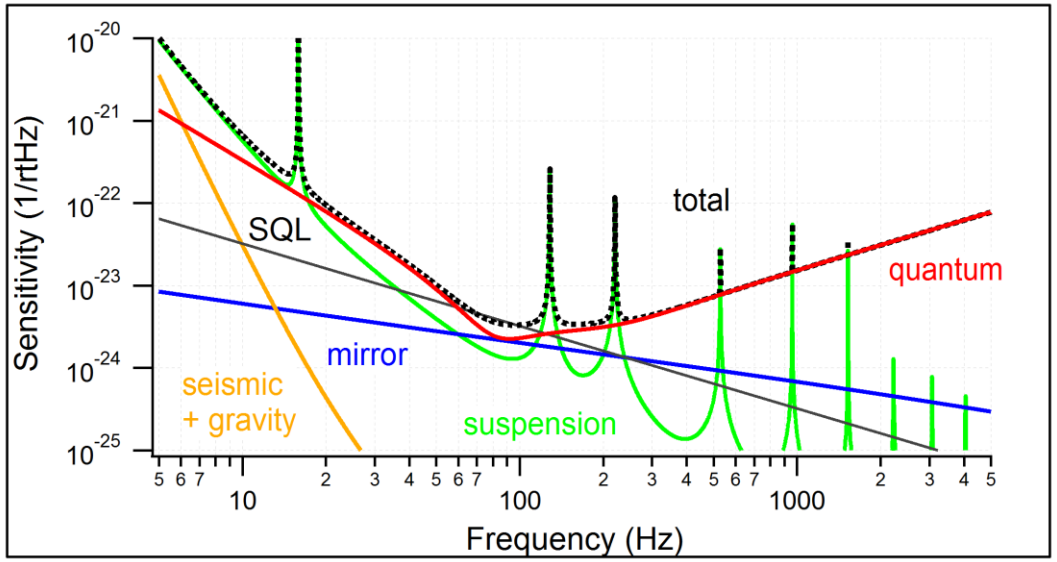

Fig. 1: Estimated noise budget of bKAGRA. (K. Somiya, CQG)

Introduction

- In order to reduce quantum noise, KAGRA is going to use the resonant sideband extraction, optical spring (detuning), **ponderomotive squeezing technique and homodyne detection** (DC readout).
- We (Yutaro and I) have the experiment in ICRR (Kashiwa) to demonstrate ponderomotive squeezing technique, which reduce radiation pressure noise.
- In our experiment, the cavity consisting of suspended tiny 23-mg mirror as shown in Fig. 2 is used to enhance and observe, first of all, radiation pressure noise.

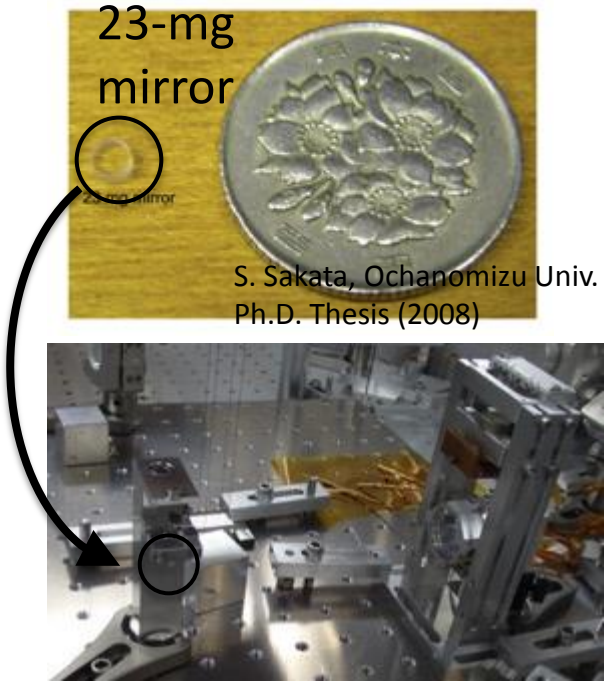

Fig 2. Tiny 23-mg mirror and Our cavity.

Introduction

- My main work is this experiment, which is called “Quantum Non-Demolition (QND) experiment”.
- Usually, my talk’s subject is this “QND experiment”.
- However, in this half a year, I did many things other than “QND experiment”.
- Today, instead of “QND experiment”, I will talk mainly on what I did in this half a year.

January

2016	What I did	Others
Jan	KAGRA	
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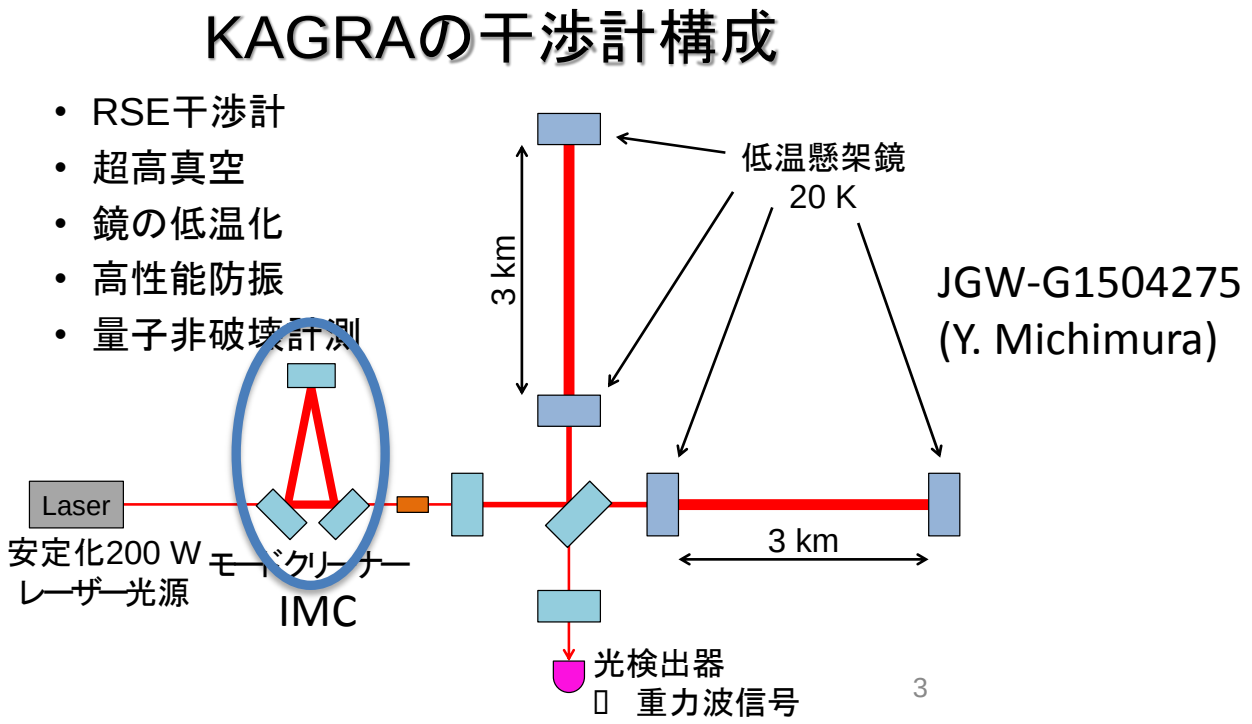
January

- In January, I was mainly in KAGRA site.
- My main work was Input Mode Cleaner (IMC) commissioning.



January

- IMC had been locked in the end of Dec. 2016.

IOO (IMC)

masayuki.nakano - 18:[illegible]6, Sunday 27 December 2015 (559)

IMC locked!!!!!!!!!!!!!!

[Kawamura, Kokeyama, Enomoto, Nagano, Nakano]

FINALLY THE IMC GOT LOCKED!!!!!!!

The IMC continued to be locked for several minutes and looked so stable. The attached movie (not a still image!) is the transmission light from MCo.

I have to go to a great dinner tonight, so I will report detail later.

Images attached to this report

Non-image files attached to this report

img2231.mov

Comments related to this report

takashi.uchiyama - 1[illegible]40, Monday 28 December 2015 (560)

Great job!!

Thank you.

tomotada.akutsu - 11:03, Monday 28 December 2015 (561)

Good jobs!

ayaka.shoda - 11:17, Monday 28 December 2015 (562)

Congrats!!!

masayuki.nakano - 17:28, Monday 28 December 2015 (565)

1.Configulation

January

- For stable operation of iKAGRA, it is necessary to make IMC more stable.
- To realize this, following things were done,
  - alignment tuning,
  - control loop optimization,
  - mirror angle control installation,
  - and more.

(These IMC works were kept doing till April mainly by Nakano-san and Enomoto-kun.)

January

As a result,

- In the end of Dec. 2015
  - Although IMC was locked in low finesse mode for 5 minutes, we could not lock IMC in high finesse mode.
- In Apr. 2016
  - IMC was kept locked in high finesse mode for longer than 4 hours typically.

February

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Jan	KAGRA	
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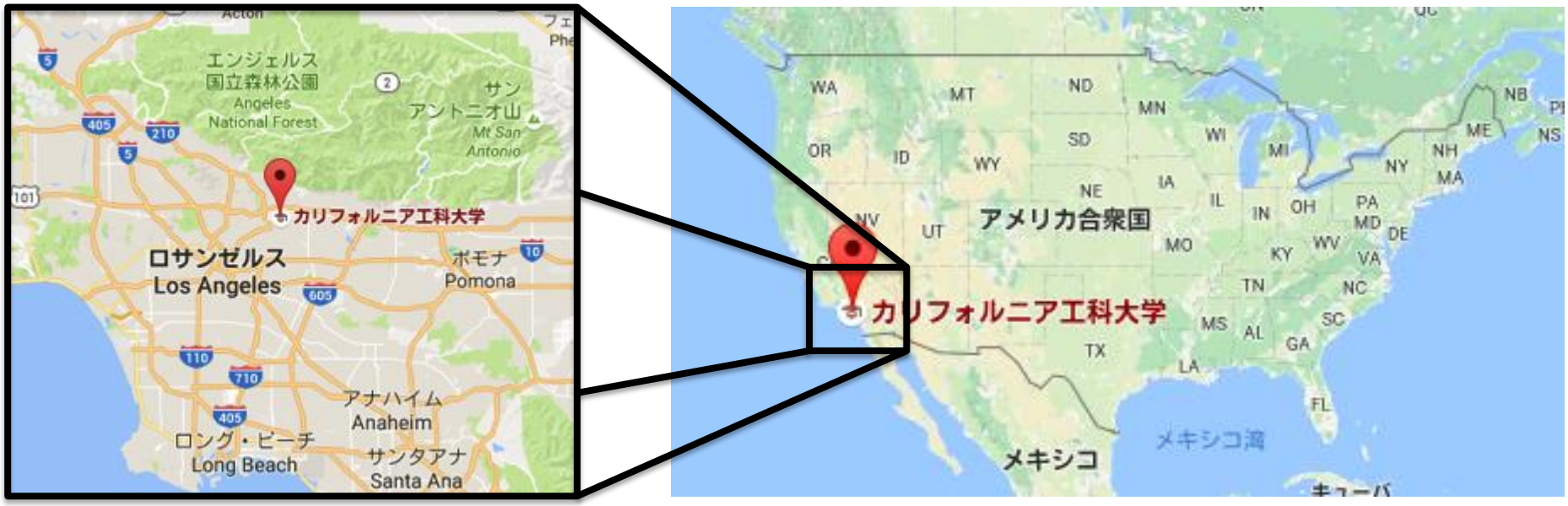
Paper work about Caltech experiment

February

- From Feb. 1st to Mar. 9th, I was in California Institute of Technology (Caltech).
- Caltech is at Pasadena, Los Angels, US.



February

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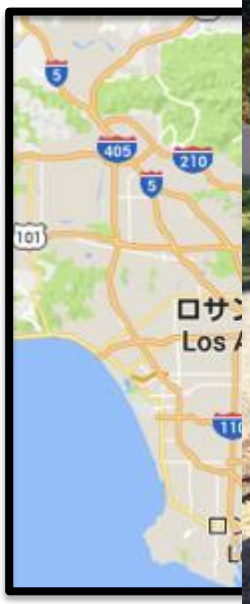
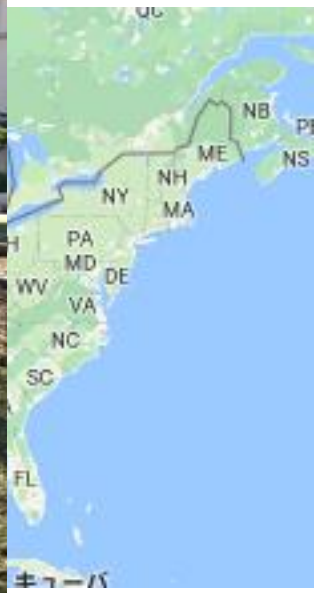
- Caltech is at Pasadena, Los Angels, US.





February

- Thanks to LIGO visitor program, I could stay in Caltech.
  - https://www.ligo.caltech.edu/page/visitor-program
- My mentor was Rana X. Adhikari.
- My vice-mentor was Koij Arai.
- My co-worker was Antonio Perreca.


Rana

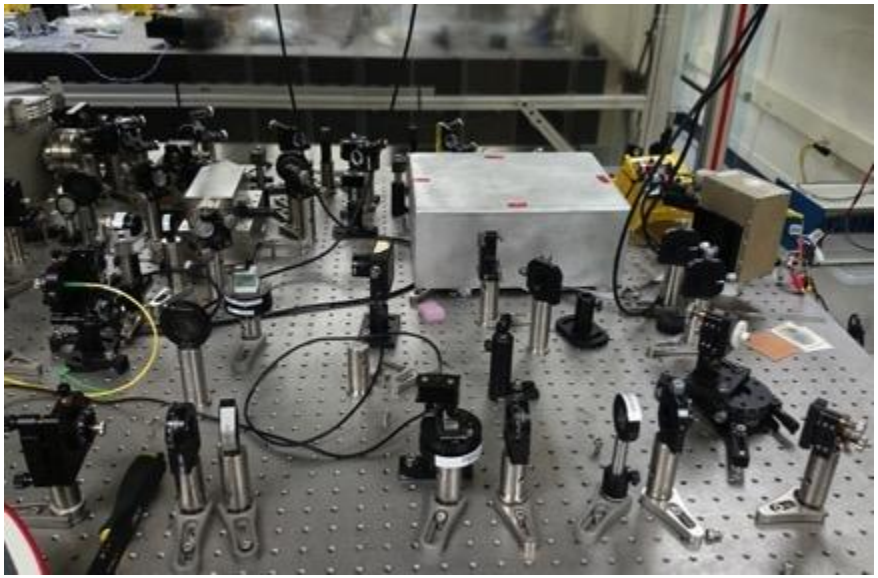

Arai-san


Antonio

February

- If you visit Caltech, you will work for,

- 40-m prototype (40 m) or - table-top experiments



Enomoto-kun worked for 40 m in his stay.

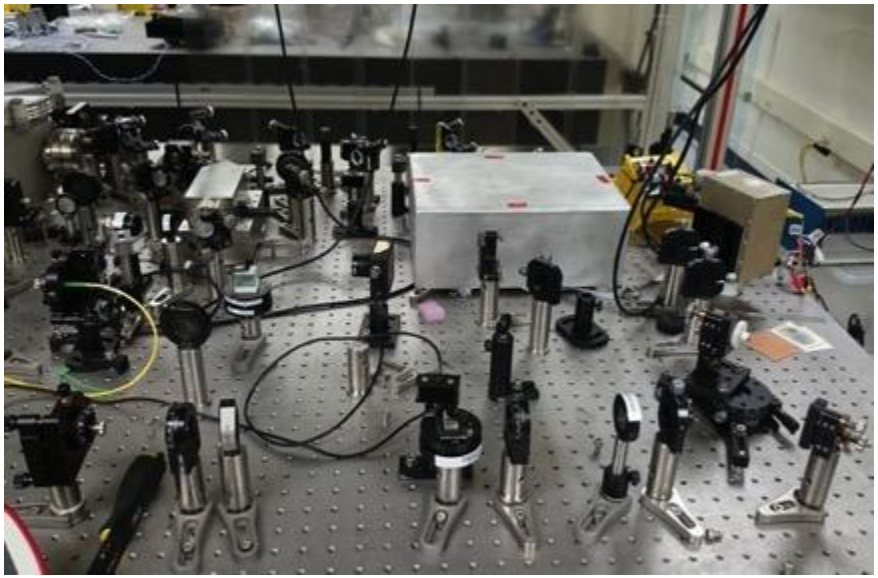
I worked for a table-top experiment.

February

- If you visit Caltech, you will work for,

- 40-m prototype (40 m) or - table-top experiments

Enomoto-kun worked for 40 m in his stay.



I worked for a table-top experiment.

February

- Table-top experiment's purposes are R&D of the technique for Advanced LIGO (aLIGO) or next-generation gravitational wave detectors.
- For example, output mode cleaner, crackling noise, direct measurement of thermal noise, cryogenic technique, **photodiode quantum efficiency (PD QE) enhancement** and so on are studied.
- Among these experiment, I worked for the **PD QE enhancement experiment**.

February

PD QE experiment

- Introduction
  - In order to improve gravitational wave detectors, squeezed light is or is going to be used.
  - The squeezing level of the squeezed light is decreased by optical loss, which is explained as the injection of the vacuum fluctuation.
  - Thus optical loss should be reduced.
  - One of the essential losses is the imperfect PD QE.

February

PD QE experiment

- Introduction
  - In aLIGO, special custom PDs, which have very high QE (~0.99), are used.
  - However, special custom PDs are not off-the-shell.
  - If, we can enhance the PD QE with a technique which does not require special products, the technique is useful.

PD QE experiment

- Method
  - For reducing the the light reflected by the PD, i.e. the light is not absorbed by the PD and lost, we recycle the light with reflectors as shown in the following figure.
  - We call this technique photon recycling.

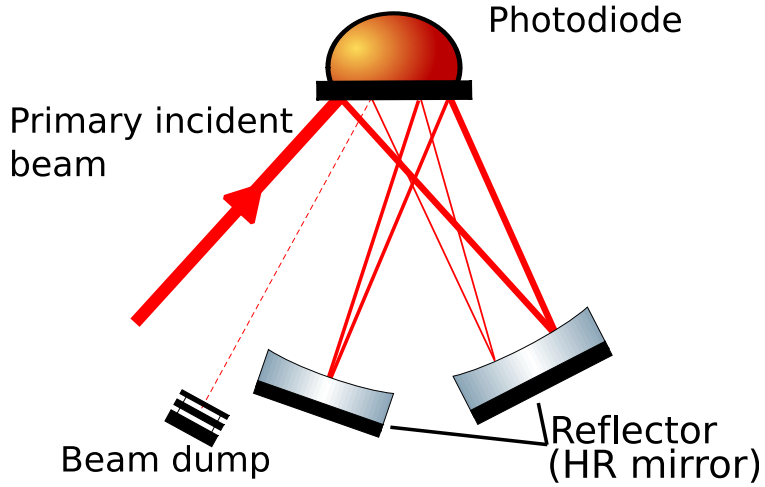


Fig. Principle of the photon recycling.

February

PD QE experiment

- Experimental setup
  - This experiment started with my visit.
  - So, I set up the whole experiment shown as follows.

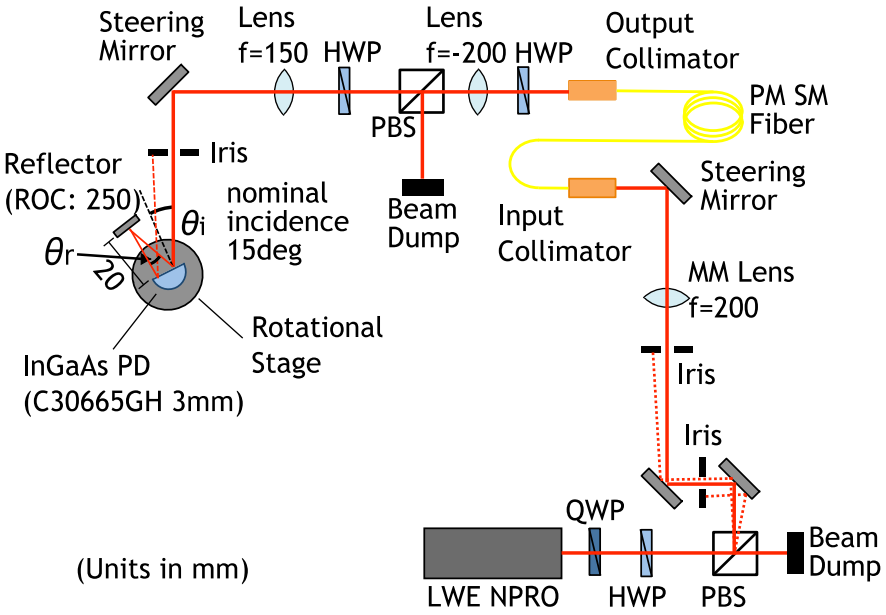


Fig. Experimental setup.
We used InGaAs PD.

February

PD QE experiment

- Experimental setup

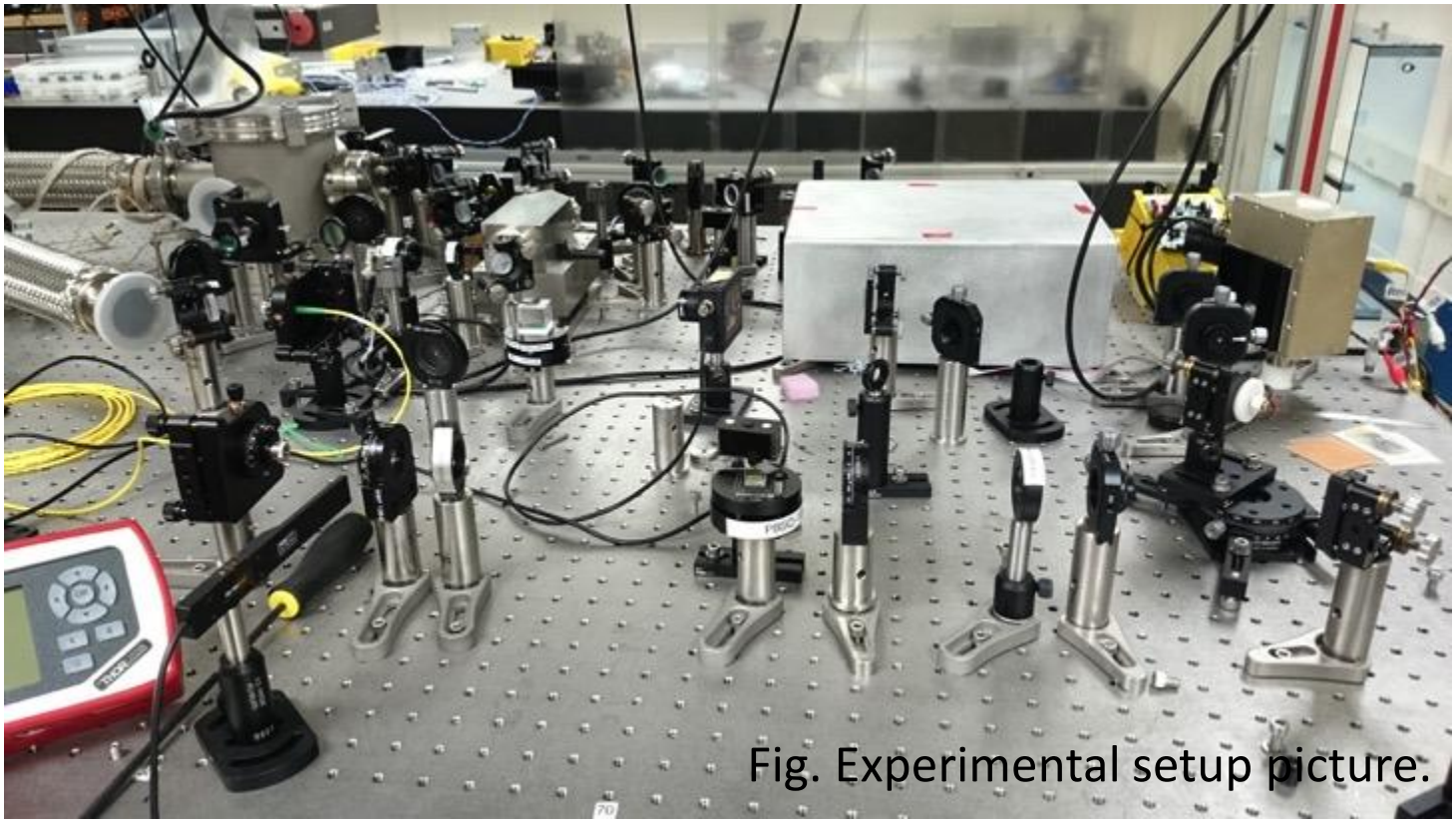


Fig. Experimental setup picture.

February

PD QE experiment

- Result
  - The measured QE is shown as follows.

- The original QE of the InGaAs PD is measured to be about 0.90.

- The QE is enhanced up to 0.94.

(Please note that these measurements have systematic error of 3%)

- The enhancement is about 4%.

- We also confirmed that the photon recycling does not induce significant back scattering to upstream.

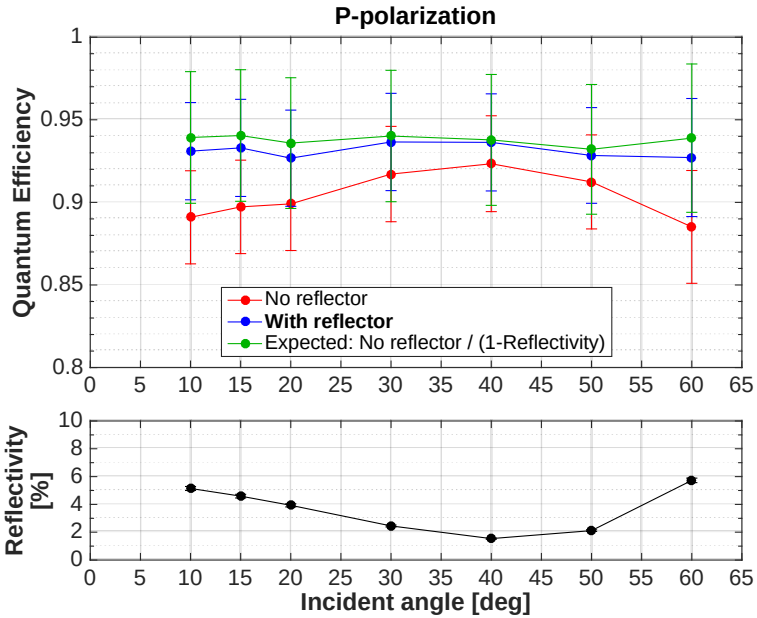


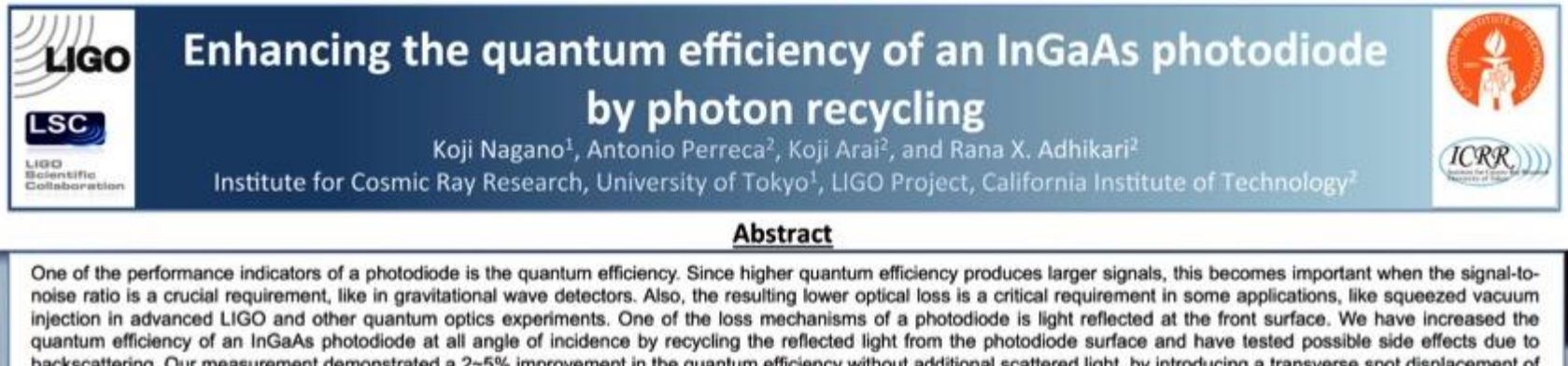
Fig. Measured QE and reflectivity of the InGaAs PD. LIGO-G1600514

February

PD QE experiment

- Conclusion
  - We demonstrated that the photon recycling enhanced the InGaAs PD QE about 4% without inducing significant back scattering.
  - We presented this result in the LVC meeting as a poster (LIGO-G1600514) and we are writing a paper about this work.

LIGO-G1600514



Enhancing the quantum efficiency of an InGaAs photodiode by photon recycling

Koji Nagano[1], Antonio Perreca[2], Koji Arai[2], and Rana X. Adhikari[2]
Institute for Cosmic Ray Research, University of Tokyo[1], LIGO Project, California Institute of Technology[2]

Abstract

One of the performance indicators of a photodiode is the quantum efficiency. Since higher quantum efficiency produces larger signals, this becomes important when the signal-to-noise ratio is a crucial requirement, like in gravitational wave detectors. Also, the resulting lower optical loss is a critical requirement in some applications, like squeezed vacuum injection in advanced LIGO and other quantum optics experiments. One of the loss mechanisms of a photodiode is light reflected at the front surface. We have increased the quantum efficiency of an InGaAs photodiode at all angle of incidence by recycling the reflected light from the photodiode surface and have tested possible side effects due to

February

- Other things
  - During my stay in Caltech, the first detection of the gravitational wave is reported.
  - There are a few events related to the first detection.

March

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Jan	KAGRA	
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Paper work 2 about QND exp.

Paper work about Caltech experiment

March

- On Mar. 10th, I returned home from Caltech.
- After that, I went JPS annual meeting, which is held in Sendai, Miyagi.
- In JPS annual meeting, I had a presentation about "QND experiment", especially the angular control of the cavity.
- For detail, please see
  - our presentations on JGD doc
    - "重力波検出器KAGRAのための量子雑音低減法の開発(4)" JGW-G1504506, etc.
  - papers
    - K. Nagano et al., *Physics Letters A*, **380**, 983, 2016
    - Y. Enomoto et al., *Class. Quantum Grav.*, **33**, 145002, 2016
    - K. Nagano et al., JGW-P1605264 (submitted to Physics Letters A)

March

- Another topic in March is the first observation of iKAGRA.
- iKAGRA test run in Mar. and Apr. is summarized by Michimura-san.
  - JGW-G1605155, JGW-T1605101, JGW-T1605177
- During test run of iKAGRA, members of ICRR, NAOJ, and KEK worked as “expert shift workers”.
- Expert shit workers’ tasks are, for example, monitoring the status of pre mode cleaner, IMC, and main interferometer (simple Michelson), digital system, taking logbook, and so on.

March

- Other things
  - Gravitational-wave workshop was held in Tama-Rokuto Kagaku-kan (多摩六都科学館).
  - The speaker of this workshop was Kokeyama-san.
  - I was a TA.

March

- Other things
  - Gravitational-wave workshop was held in Tama-Rokuto Kagaku-kan (多摩六都科学館).
  - The speaker of this workshop was Kokeyama-san.
  - I was a TA.
  - In this workshop, one problem occurred.
  - The plane which Kokeyama-san had been going to take was delayed and she could not arrive in time.
  - As a result…

March


宇宙からのメロディ
重力波
-ミニ重力波検出装置をつくってみよう-
東京大学宇宙線研究所　特任助教
苔山　圭以子
(こけやま　けいこ)
多摩六都科学館
3/26, 2016

March


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3/26, 2016
東京大学宇宙線研究所 修士1年
長野 晃士

April

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Paper work 2 about QND exp.

Paper work about Caltech experiment

April

- In the beginning of April, I worked in KAGRA site again.
- That time, we had a small commissioning between Mar. run and Apr. run.
- In this small commissioning, the main interferometer configuration was changed to dark fringe locking from mid fringe locking.
- Moreover, many things was also done.
- As a result, the sensitivity got 5 times better.

April

- Other things
  - From April, I started to write the application for DC1.
  - My research project title is “重力波検出器KAGRAおよび次世代重力波検出器のための量子雑音低減法の開発”.

May

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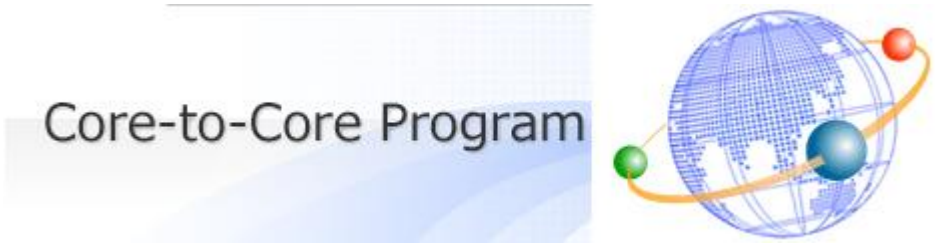
May

- In May, GWADW was held in Elba, Italy.
  - My trip was supported by JPS Core-to-Core Program.



- In GWADW, I felt that LIGO people were full of confidence because “they had done it” and laid out a future plan seriously.
  - For example, Si substrate for cryogenic operation (120 K), longer arm length (40 km) and so on.

May

- For detail, please see our report on KAGRA mailing list (kagraj) or presentation files uploaded on the GWADW webpage.
  - https://agenda.infn.it/conferenceDisplay.py?confId=10512

    (On “Timetable” page, some presentations were uploaded.)
- I had a poster presentation in GWADW.
  - JGW-G1605215

    (Related Enomoto-kun’s poster is JGW-G1605222.)

June

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June

- From the end of May to the end of June, I was in Glasgow, Scotland with Enomoto-kun.
  - This trip was also supported by JPS Core-to-Core Program.
- We visited the speed meter interferometer (speed meter) group in University of Glasgow.

June

- Our mentor was Stefan Hild.
- Our main co-worker was Sebastian Steinlechner.

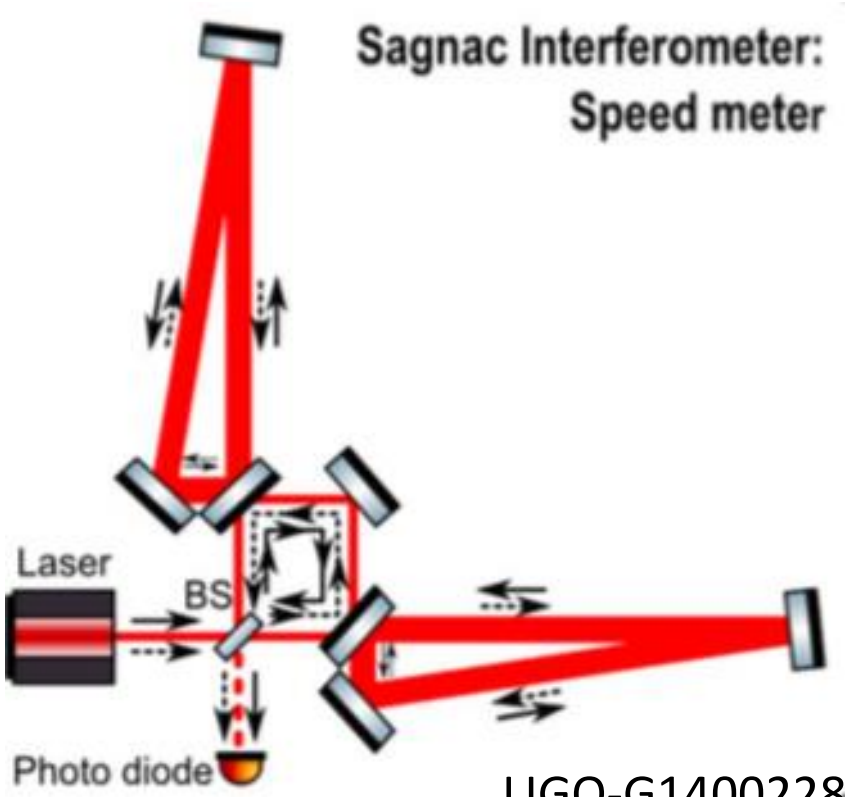
(Left) Stefan
(Right) Sebastian

June

- What is speed-meter interferometer?

June

- What is speed-meter interferometer?



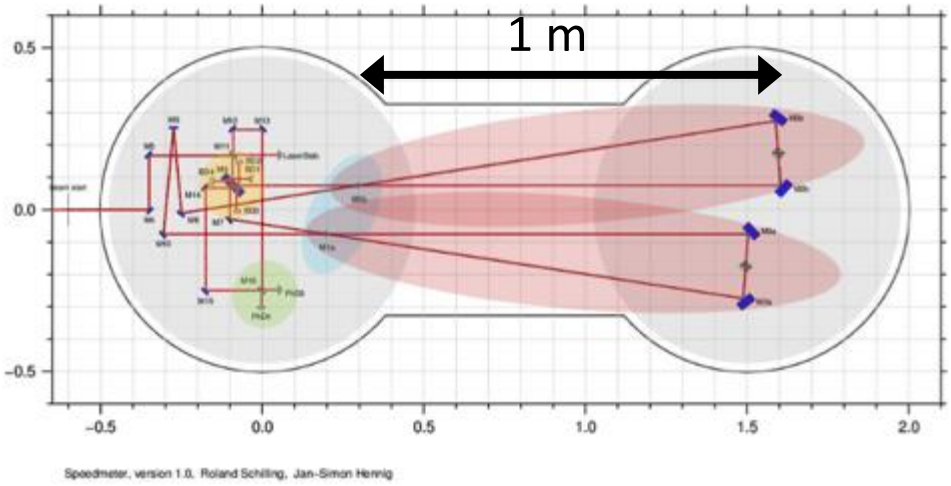
LIGO-G1400228

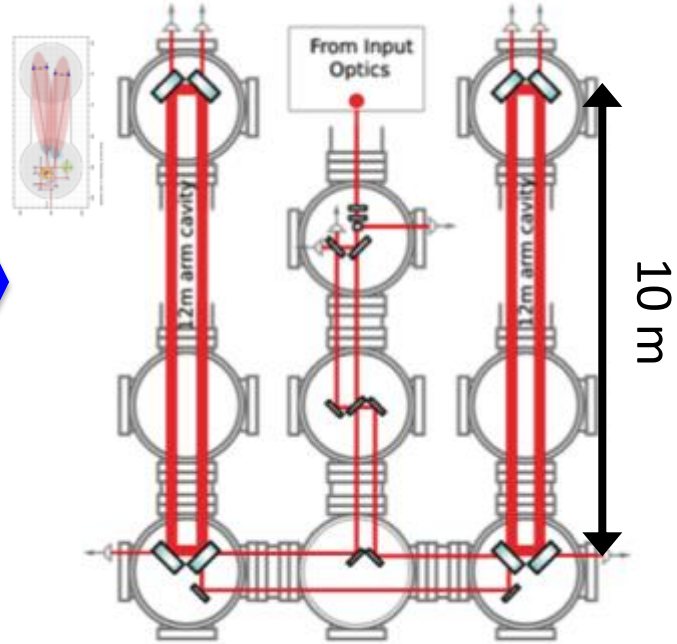
June

- Speed meter measures the momentum of the test mass instead of the position of that, which is measured by the ordinary interferometer.
- Speed meter has the QND potential. In other words, speed meter can reduce quantum noise. In especially, radiation pressure noise is cancelled and reduced in speed meter.
- Einstein Telescope (ET) may adopt speed meter topology, “possibly”.
- However, the experimental demonstration of speed meter has not yet been done.

June

- In UGlasgow, the 1-m speed meter prototype of the 10-m speed meter prototype is under construction to demonstrate the QND potential of the speed meter topology.



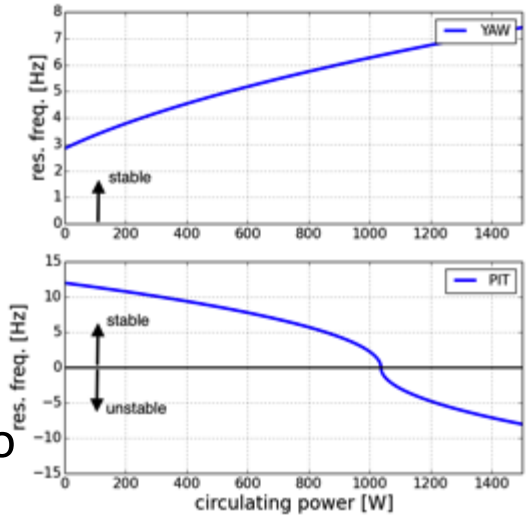


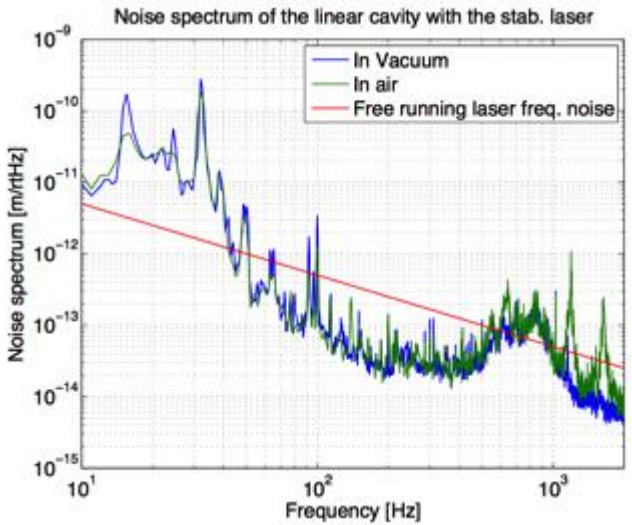
(Left) 1-m prototyme layout
(Right) 10-m prototype layout

LIGO-G1400228

June

- In UGlasgow we did mainly two things:
  1. Estimated how seriously the optical angular anti-spring in 1-m speed meter prototype.
     - Moreover, we proposed a way to circumvent the angular instability.
  2. Evaluated the effect of the frequency stabilization system.





June

- In the end of our stay, we participated the speed meter workshop in the Highlands.
  - http://www.physics.gla.ac.uk/igr/speedmeter/index.php?L1=workshop2016

Conclusion

- In this half a year, I did many things.
- I worked hard.

Conclusion

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Future plan

Future plan

2016	What I will do	Others
Jul		- GW workshop (@Ocha-dai)
Aug		- Face-to-face meeting (@UToyoma)
Sep		- JPS autumn meeting (@Miyazaki)
Oct		- LIGO O2 (around here?)
Nov		
Dec		

MASTER THESIS!!!

Paper work about Caltech experiment

(Till when?)

Paper work 2 about QND exp.

(Till when?)

End