ICRR
Institute for Cosmic Ray Research
University of Tokyo

KAGRA

# The Input Optics for iKAGRA

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- Background
- Overview of iKAGRA input optics
- Summary of PSL test in ICRR
- IOO Installation in the KAGRA tunnel
- Plans

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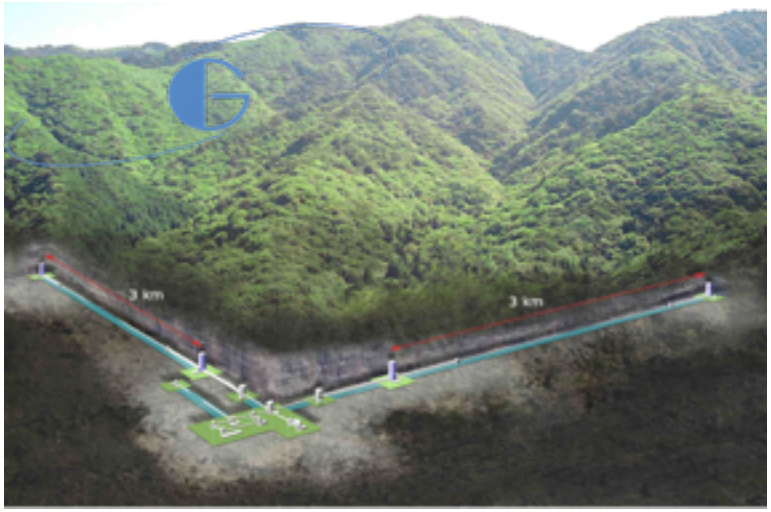
# Background

We are developing the input optics for **iKAGRA**. iKAGRA specifications are below.

- **Configuration**
  - √ 3 km Fabry Perot Michelson Interferometer
- **Laser Power**
  - √ 2W
- **Purpose**
  - √ To gain experience in operating a large interferometer



# Objectives of Input Optics

- Provide a laser beam stable enough for locking the Fabry-Perot Michelson Interferometer stably.
  - √ **Frequency stability**
  - √ **Reduction of the beam jitter**
  - √ **Mode matching**

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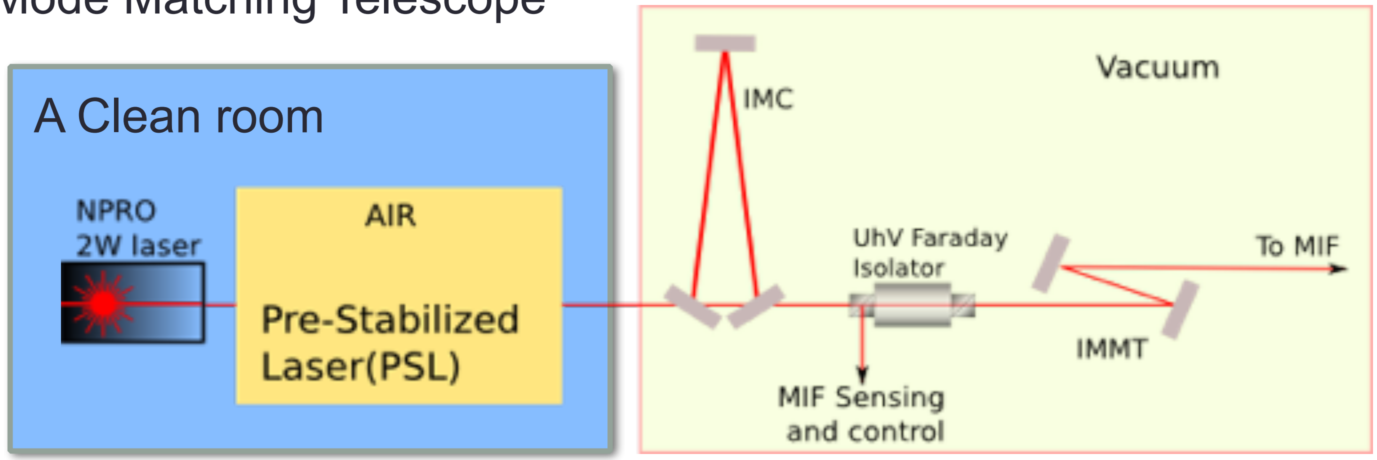
# Overview of iKAGRA input optics

- **In-air optics (In a clean room)**
  - ✓ A Laser Source
  - ✓ EOMs for IMC and MIF control
  - ✓ Steering mirrors (SMs) for align the beam
  - ✓ The frequency stabilization system with FRC
  - ✓ IMC mode matching lenses
- **In-vacuum optics**
  - ✓ 53 m long Input Mode Cleaner (IMC)
  - ✓ A vacuum compatible high power faraday isolator
  - ✓ An Input Mode Matching Telescope



# Pre-Stabilized Laser (PSL)

- Laser Source
  - ✓ A monolithic Nd:YAG crystal NPRO (Non-Planar Ring Oscillator) laser.
  - ✓ The power is 2 W
- Pre-mode cleaner (PMC)
  - ✓ The cavity length will be controlled with a PZT on the end mirror by Pound-Driver Hall signal.
  - ✓ 40 cm long triangular cavity.

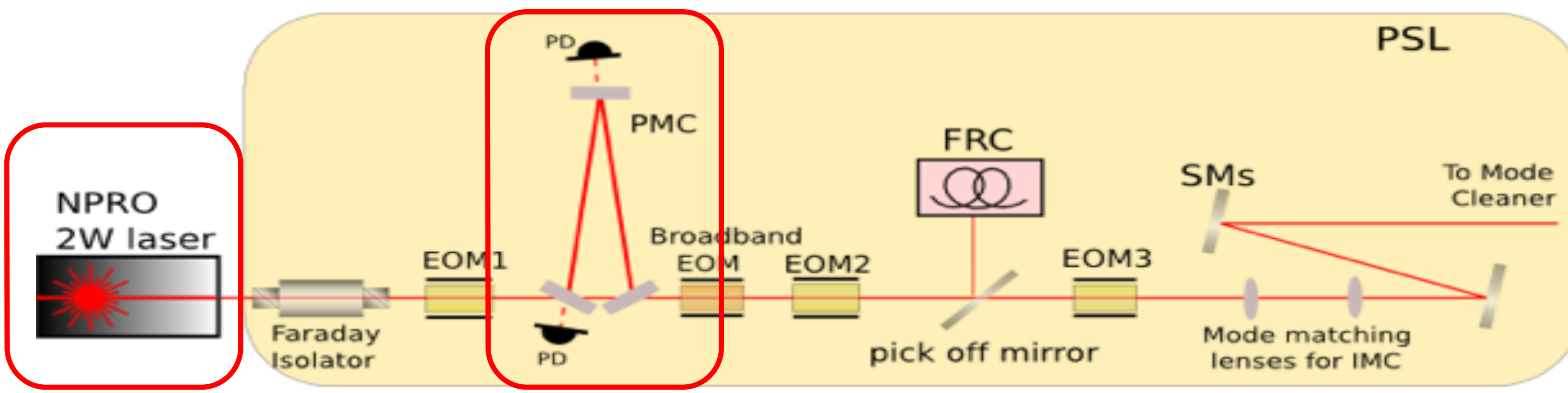



Fig.2 Pre-Stabilized Laser

# Pre-Stabilized Laser (PSL)

- Electro-optic Modulators (EOMs)
  - ✓Providing the phase modulations for each cavity length control
    - EOM1 : For PMC
    - EOM2 : For FRC and IMC
    - EOM3 : For main interferometer
    - Broadband EOM : For frequency stabilization
- Fiber Ring Cavity (FRC)
  - ✓Used for frequency stabilization as a reference cavity.

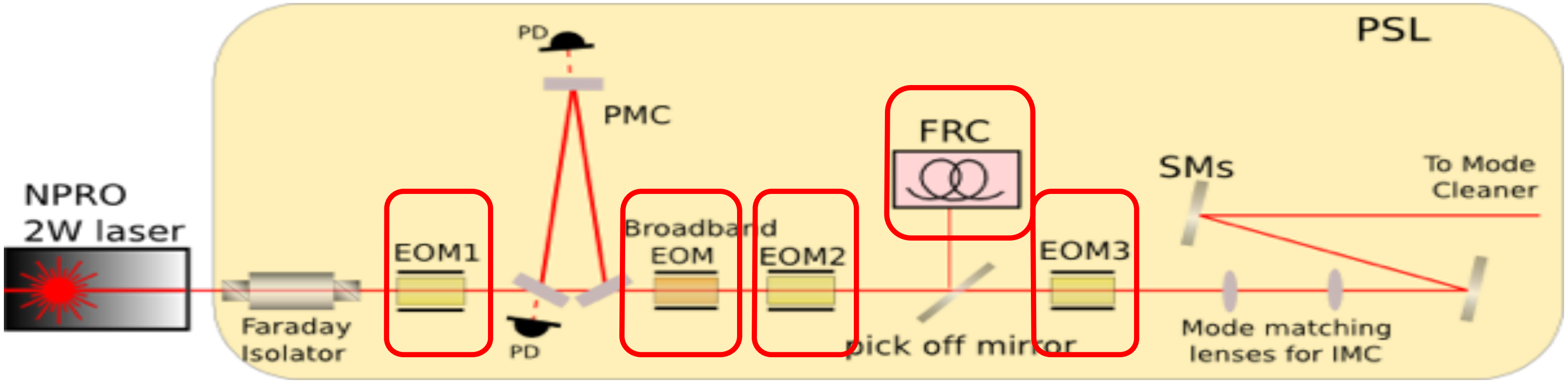
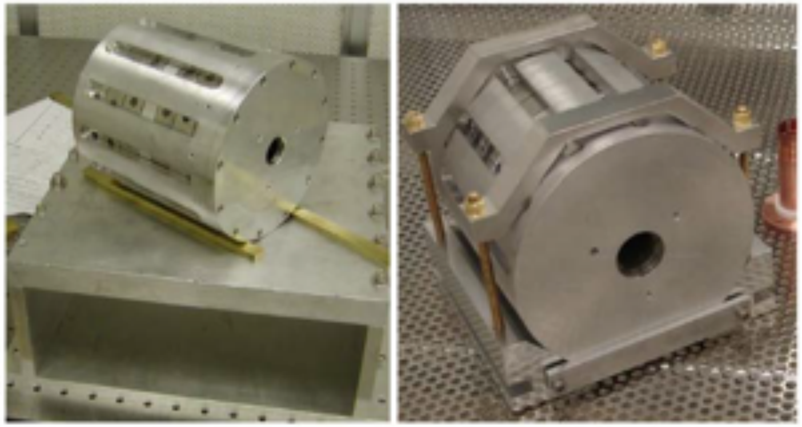



Fig.2 Pre-Stabilized Laser

# IMC, IFI, IMMT

- Input Mode Cleaner (IMC)
  - A triangular cavity with suspended mirrors.
  - Round trip length is 53 m, Finesse is 500, FSR is 5.625 MHz
  - Use the Wave Front Sensing technique for alignment control
- Input Faraday Isolator (IFI)
  - ✓Vacuum compatible high isolation ratio.
  - ✓We don't have to suspend it in the sense of phase noise caused by back scattered light
  - ✓We ordered to the Florida University.



- Mode Matching Telescope
  - ✓We don't need any curved mirrors or lenses for mode matching for the FPMI.
  - ✓We just use flat mirrors for the mode matching telescope.

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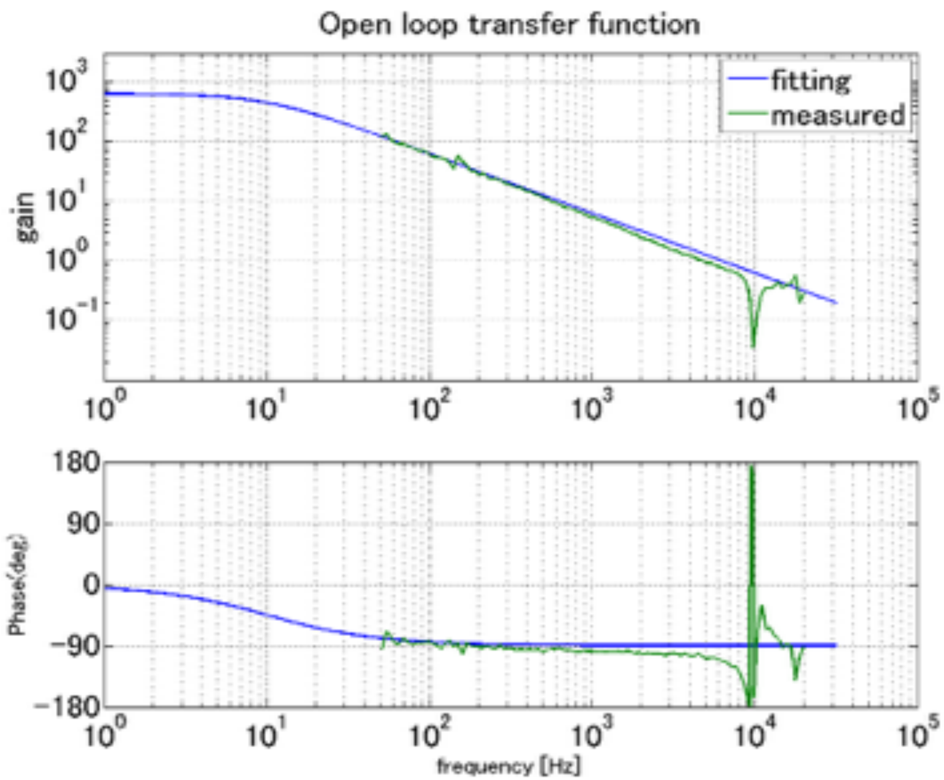
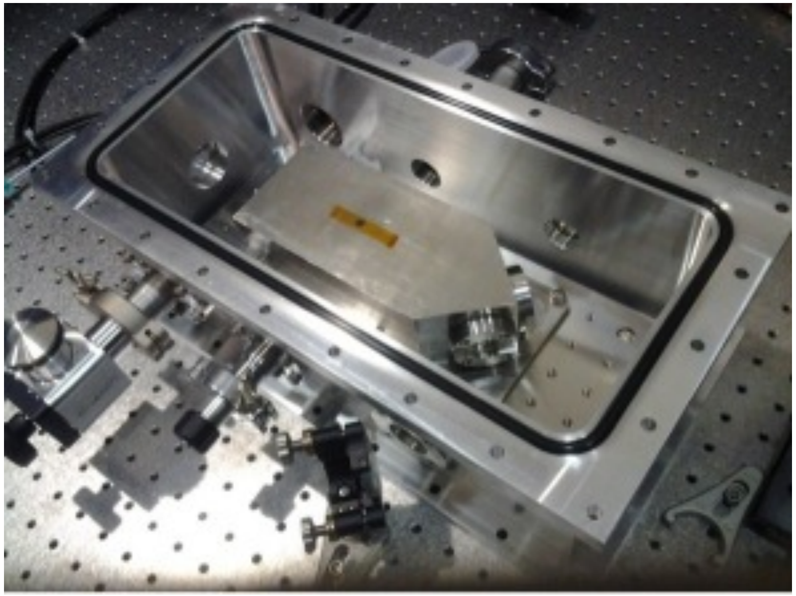
# Pre-Mode Cleaner

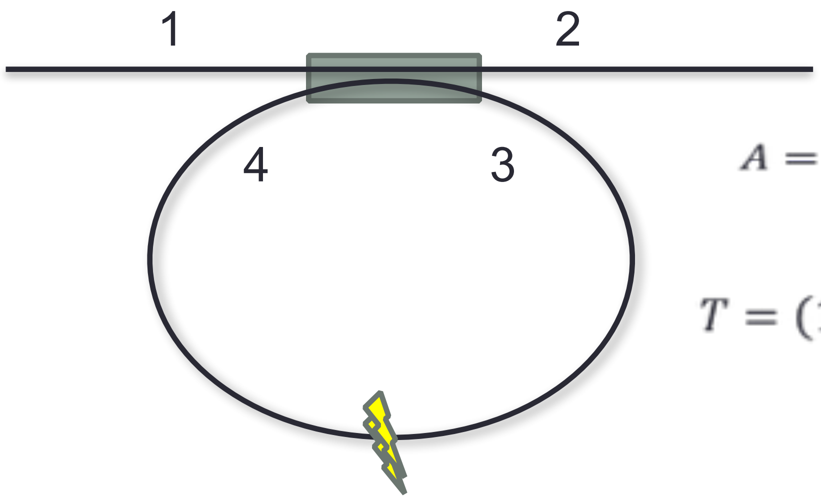
- cavity length : 40 cm
- The cavity frequency following to the laser frequency by the PDH control. An actuator is a PZT attached on the end mirror.



- UGF:4.2kHz
- **The lock itself is stable, but the dynamic range of the PZT is not large enough.**
- **We have to make it larger somehow (change PZT, temperature control, etc.)**

# Fiber Ring Cavity (FRC)




$$A = (1-\kappa)(1-r)(1-a)\,e^{-2\alpha L};\ \text{loss factor}$$

$$T = (1-r)\left(1 - \frac{\kappa\,(1-\kappa-A)}{(1-\kappa)\,(1+A-2A^{1/2}\mathrm{Cos}[\beta L])}\right)$$

$$f_{\mathrm{FSR}} = \frac{c}{n\,L},$$

$$\Delta\nu = \frac{c\sqrt{\frac{(1-\sqrt{A})^2}{\sqrt{A}}}}{L\,n\,\pi}$$

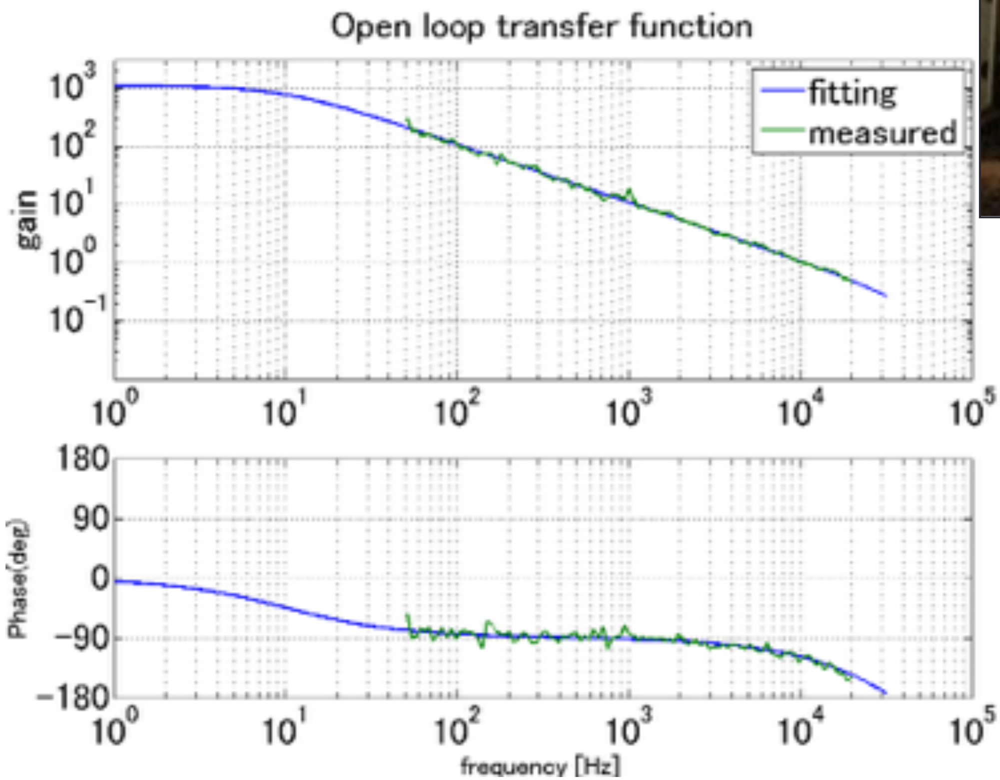
$$\mathcal{F} = \frac{\pi}{\sqrt{\frac{(1-\sqrt{A})^2}{\sqrt{A}}}}$$

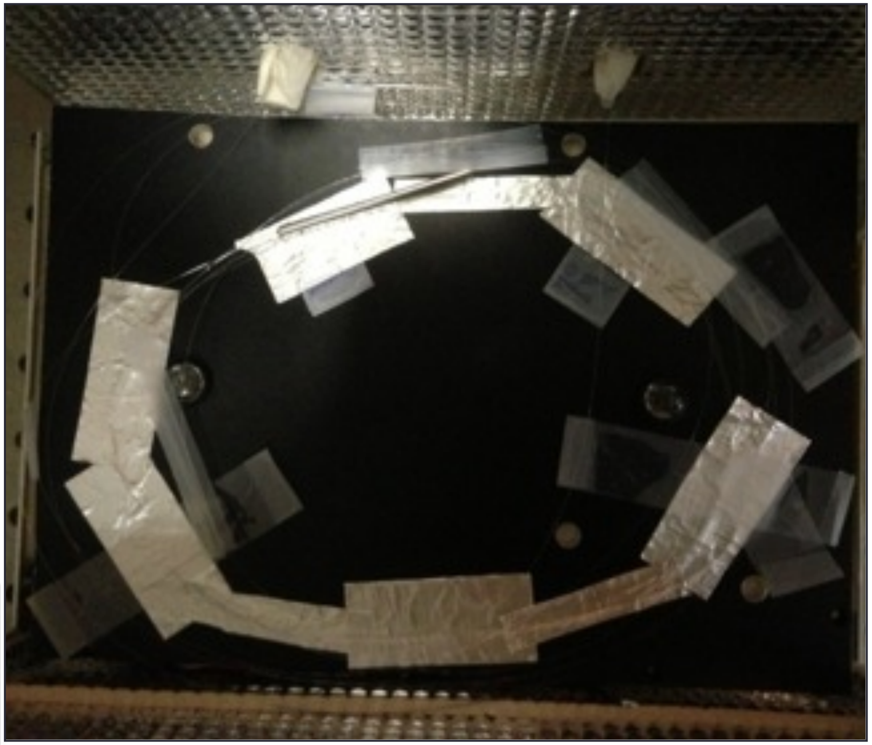
$\kappa$ : Coupling Ratio
$r$ : Insertion Loss
$a$ : Splicing Loss
$\alpha$ : Fiber Loss
$L$ : Cavity Length
$\beta$ : Wave number

**Ref. "All-single-mode fiber resonator", L.F. Stokes, et al., Opt. Lett. 7, 288 (1982).**

# FRC Control

- cavity length : 5.3m
- The laser frequency follows the cavity frequency of FRC with the PDH control. The actuators are laser temperature, laser PZT, broadband EOM.



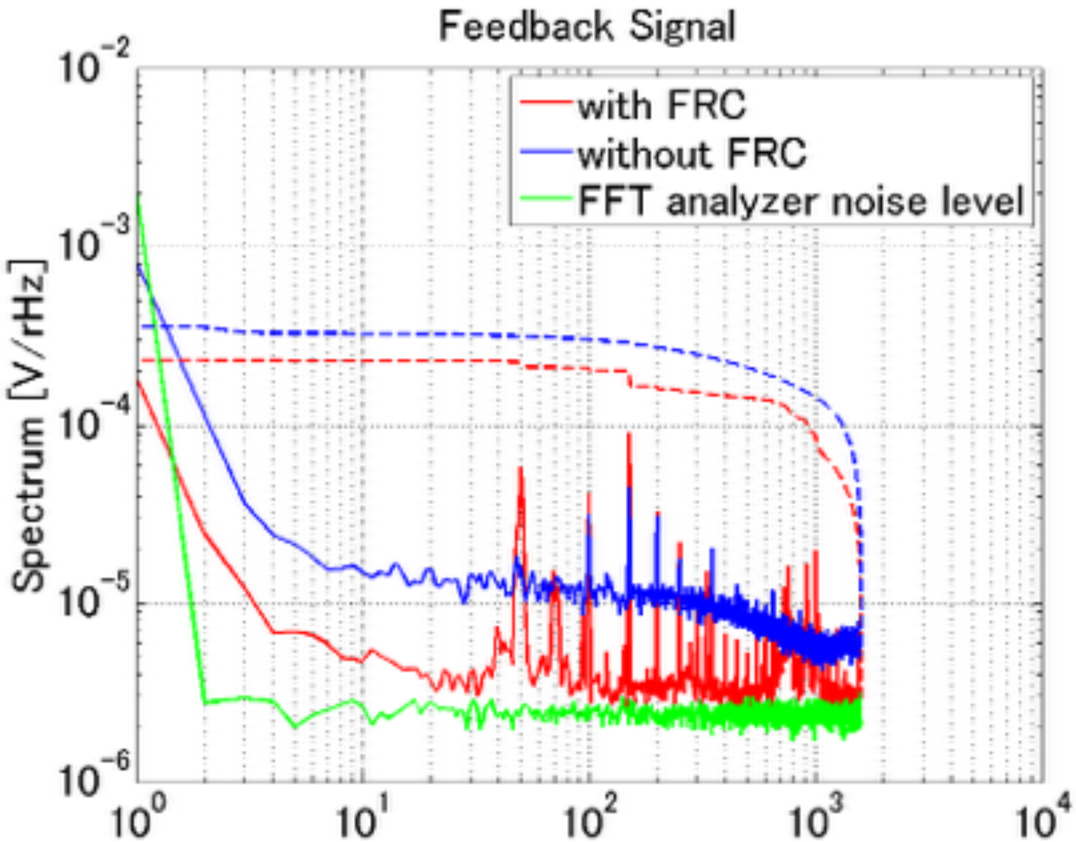
- UGF:10kHz
- Up to now, the broadband EOM haven't been installed yet. UGF might become faster after installing
- **The lock is not stable enough. (At most 2 hours).**

# Frequency Stabilization System(FSS) by FRC

- We tested the frequency stabilization system with FRC
- We used the PMC feedback signal as the frequency sensor.

✓ With FFS, laser frequency become more stable by factor of 2

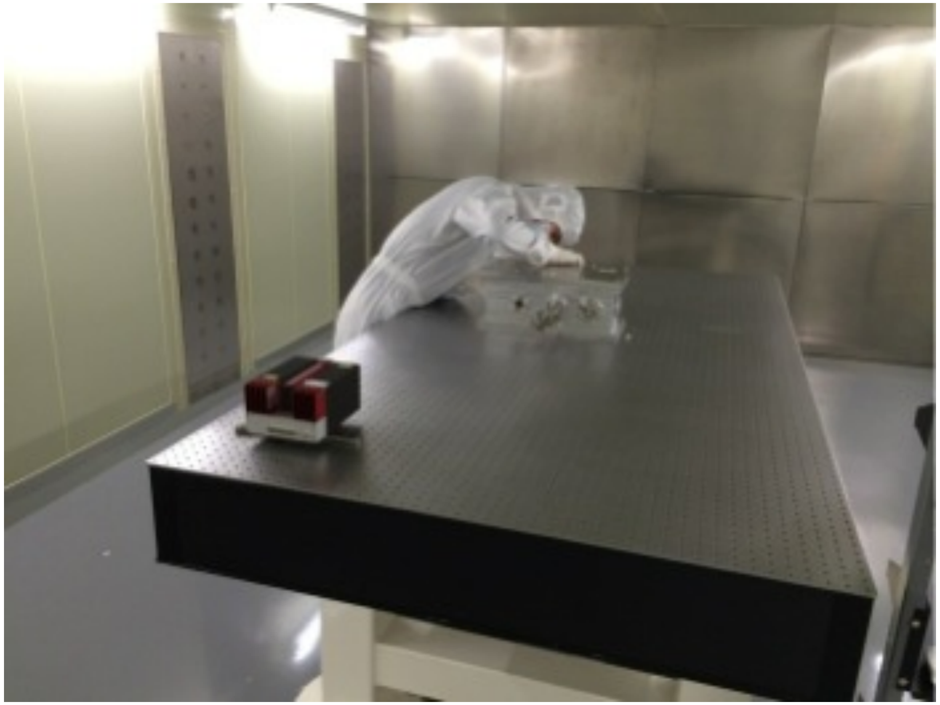
✓ You can see the large noise around 1 kHz and 50 Hz HAM noise. The frequency stability would improve by hunting these noises.



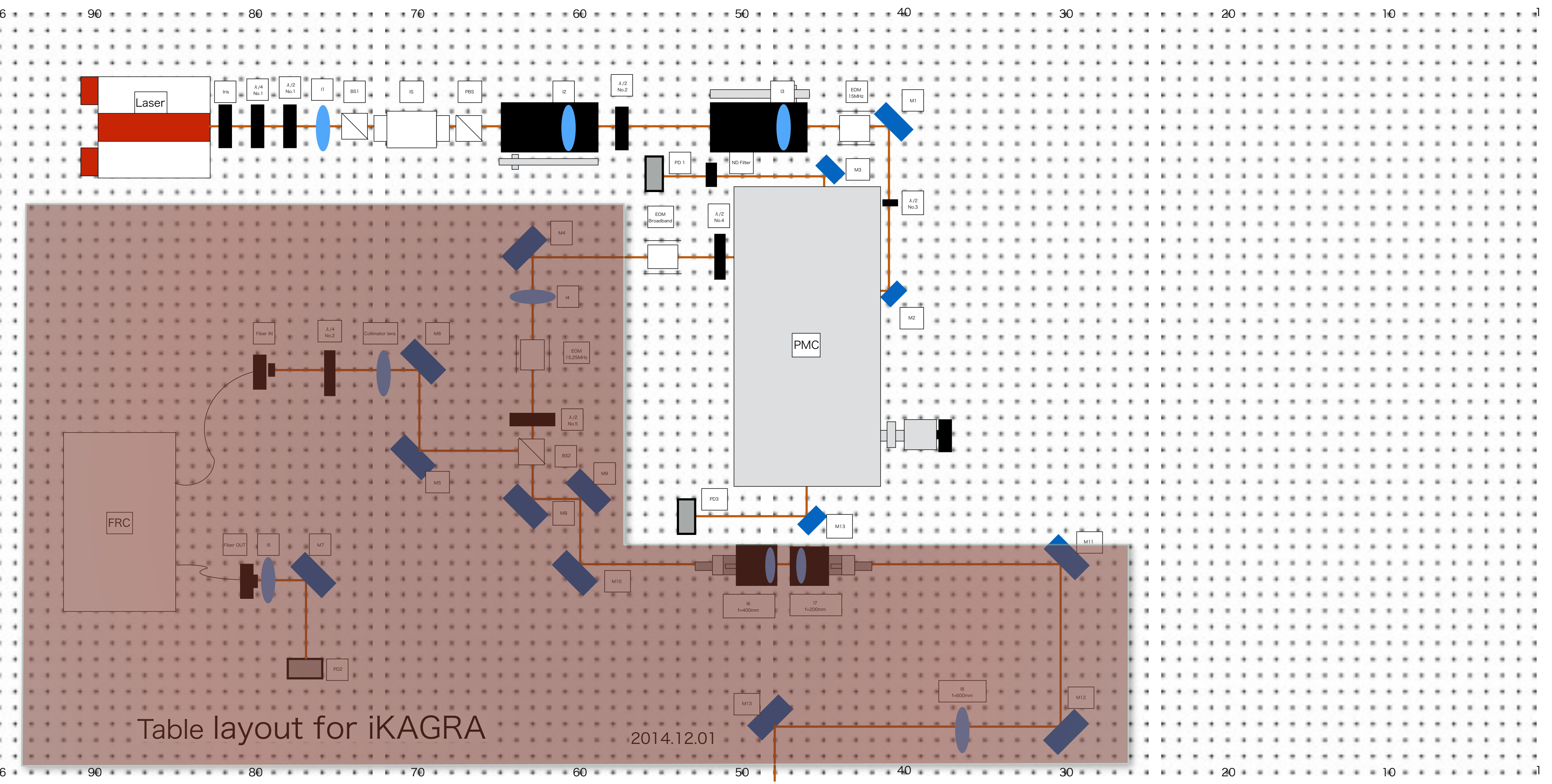
# Contents

# Laser room

- The Laser room is cleaned up so closely.
- We wear a clean suit in the laser room



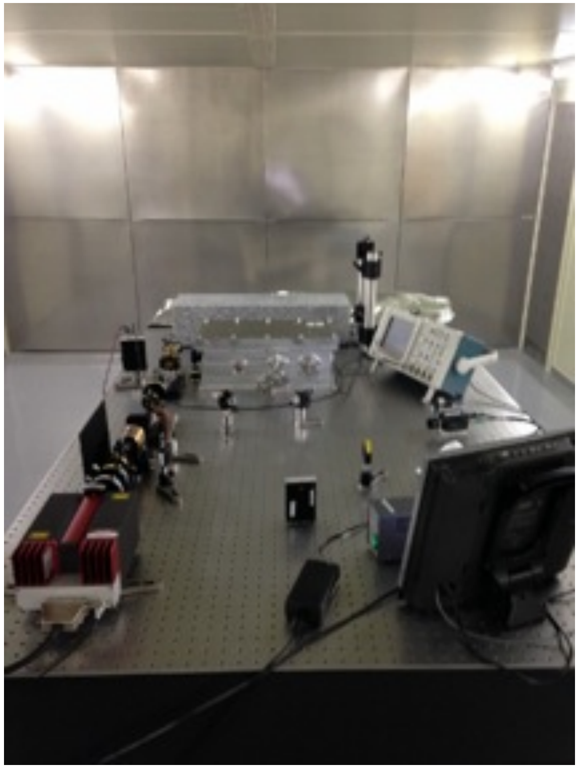
# PSL table

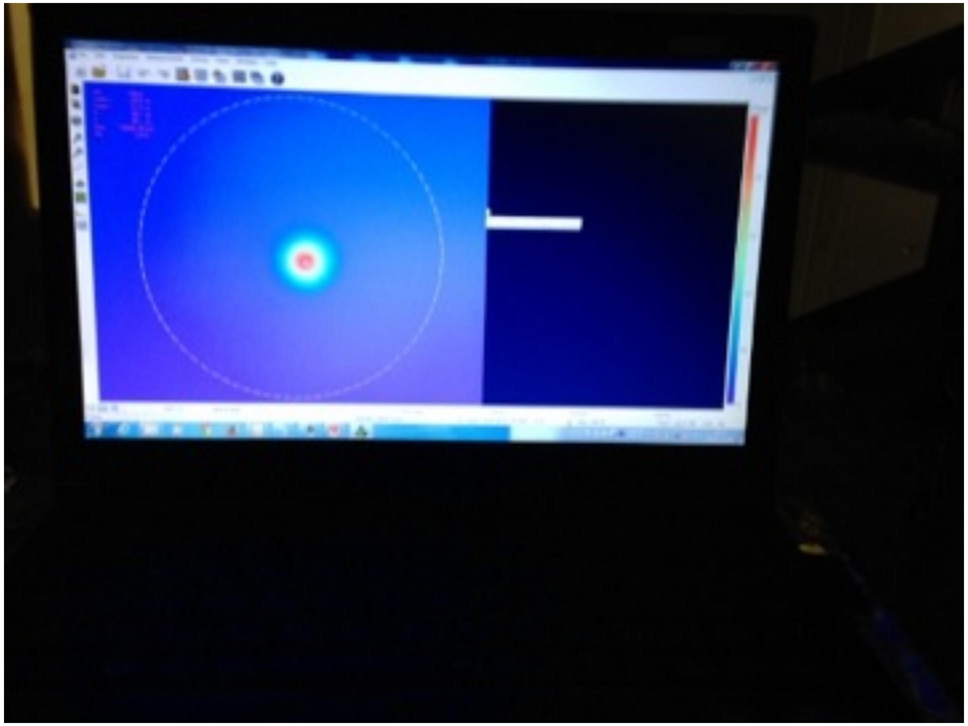



Written by Kataoka (Tokyo Tech)

# PSL table

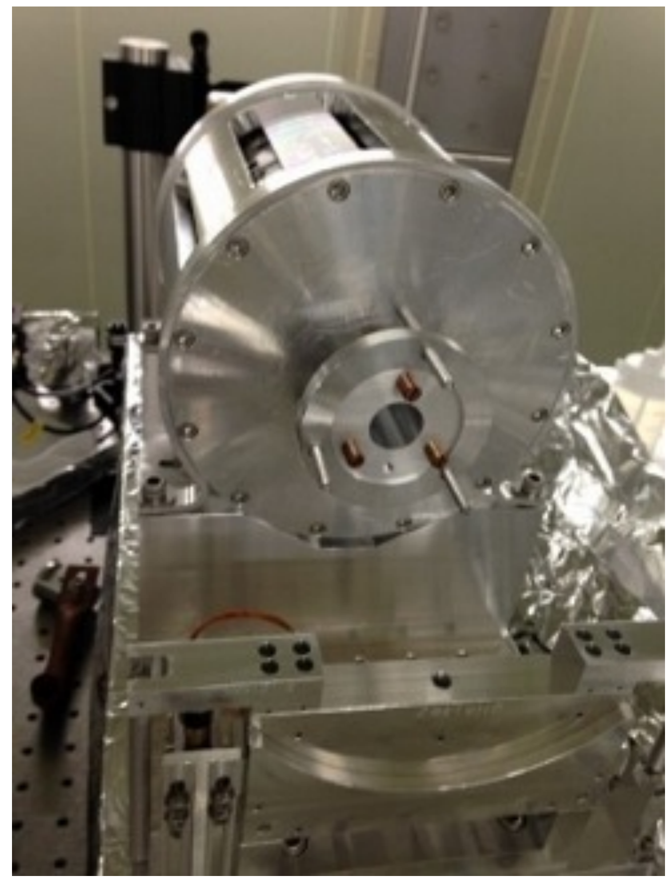
- The PMC is locked **for 27 hours**.
  - Unfortunately, the temperature stability in the room is not so good as our expectation. That means we have to increase the dynamic range of the control.





# Faraday Isolator

- The Faraday isolator is under assembling on the PSL table.



# Input Mode Cleaner

- The suspensions are assembled in NAOJ.
- The VIS and IOO team starts the installing the suspensions into vacuum chambers.

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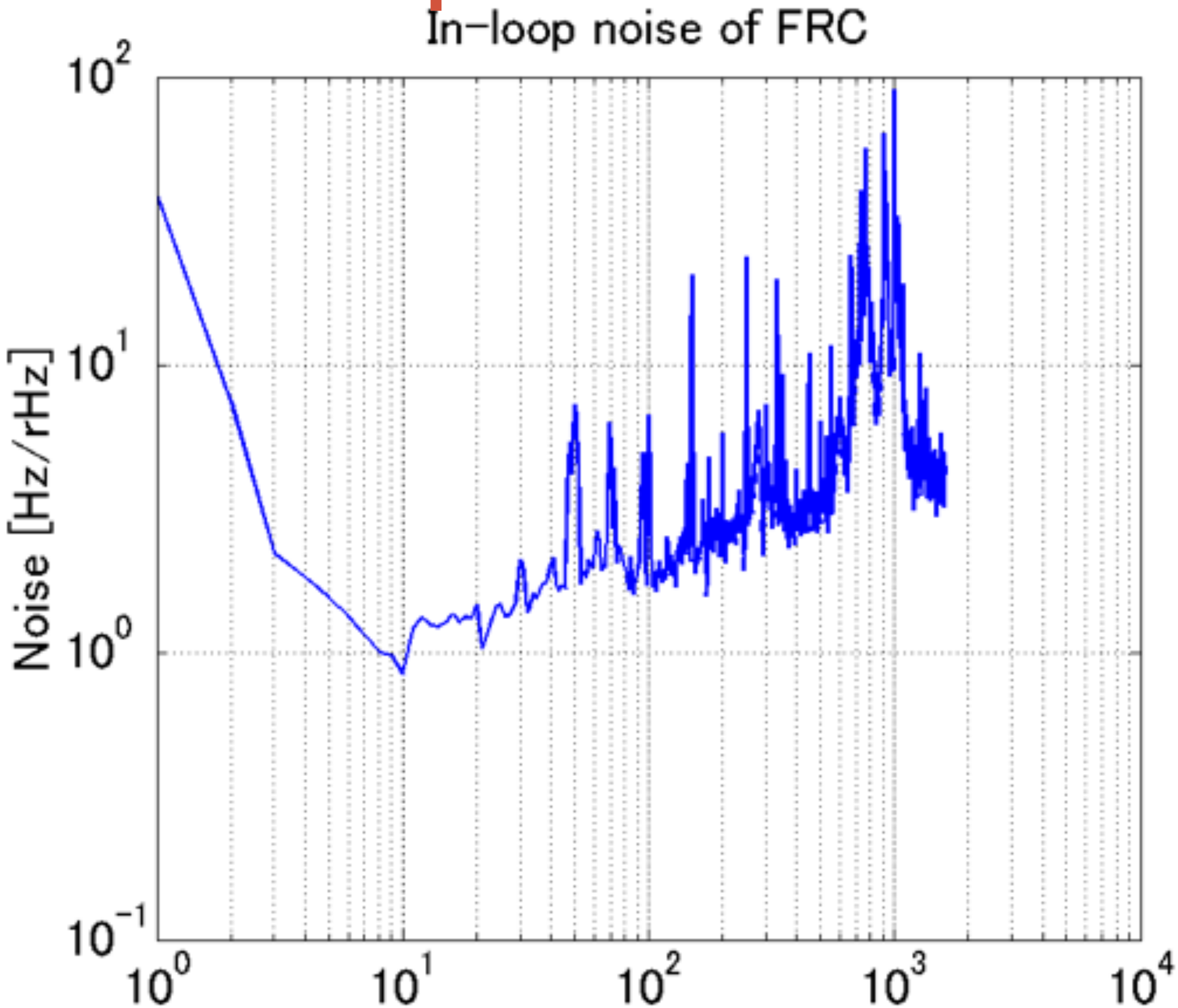
# Plans

- Finish the construction of the PSL table
  - Installations of EOMs, FRC, mode matching lenses and so on.
  - Initial alignment of the beam to the IMC.
  - Improvement of the PMC dynamic range
- Finish the assembling of IFI
- Finish the installation of IMC suspensions
- IMC locking.

End

# FRC In-loop noise

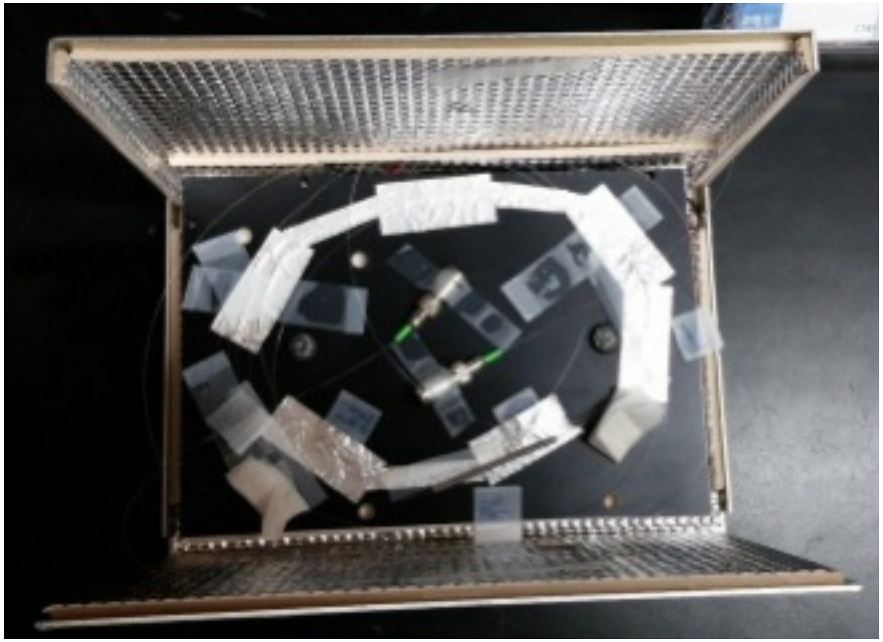


# PMC parameters

| | |
|---|---|
| *Shape* | *triangular* |
| *Spacer* | *Invar* |
| *Mirror Curvature* | *300 mm* |
| *Round-trip length* | *40 cm* |
| *FSR* | *768.75 MHz* |
| *Finesse* | *230(p)* |
| *Transmissivity* | *43%(p)* |
| *UGF* | *~4 kHz* |
| *PZT resonant frequency* | *9.3 kHz* |

# FRC fabrication: Final design for iKAGRA

## 3rd Fiber Ring Cavity



Splicing Loss : 0.01 dB, $a \cong 0.0023$

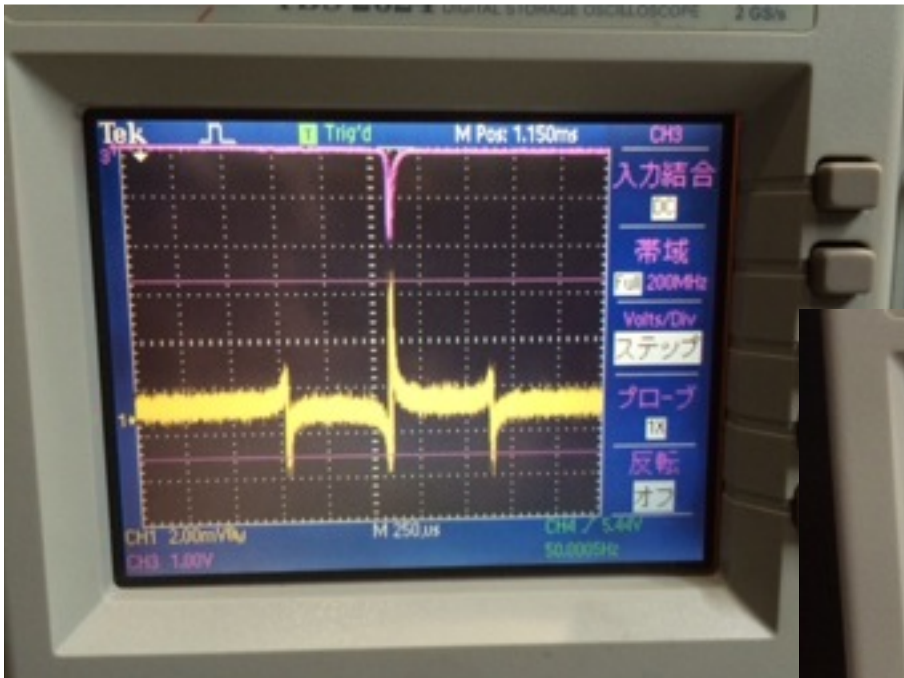
Gooch & Housego SM Coupler (99.9 % : 0.1 %)

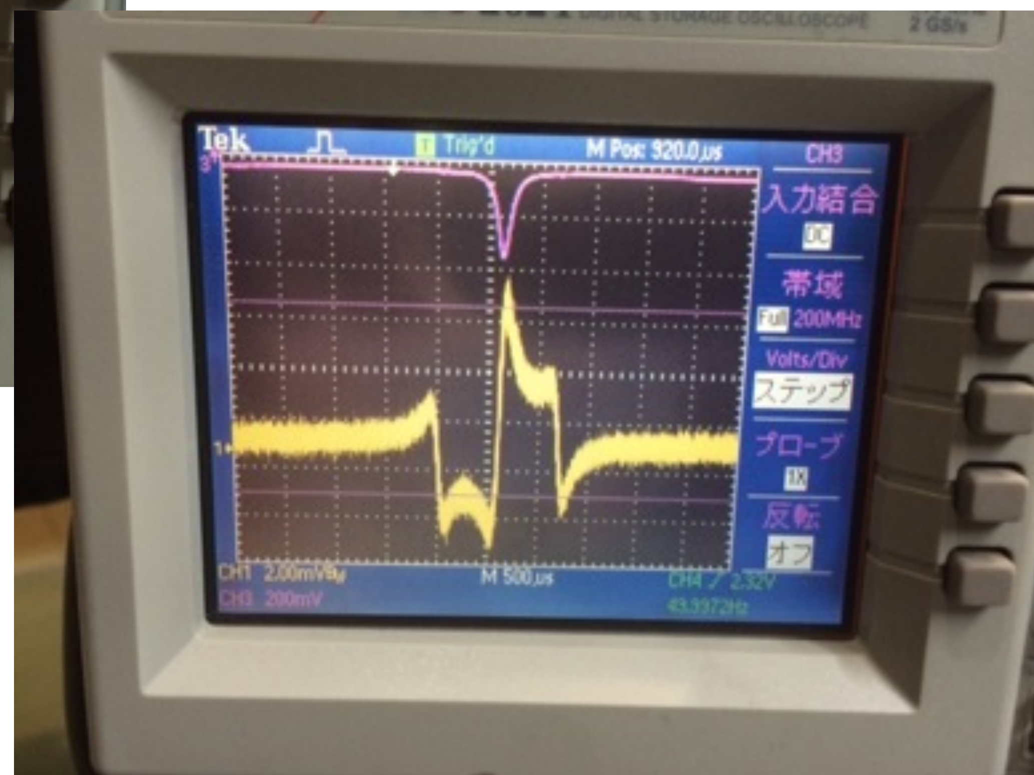
Reducing line-width 3times

↓

Length: 5.8 m
$f_{FSR}$ = 35 MHz
$\Delta\nu$ = 80 kHz
Finesse = 540
Contrast: 27 %

# PDH signal

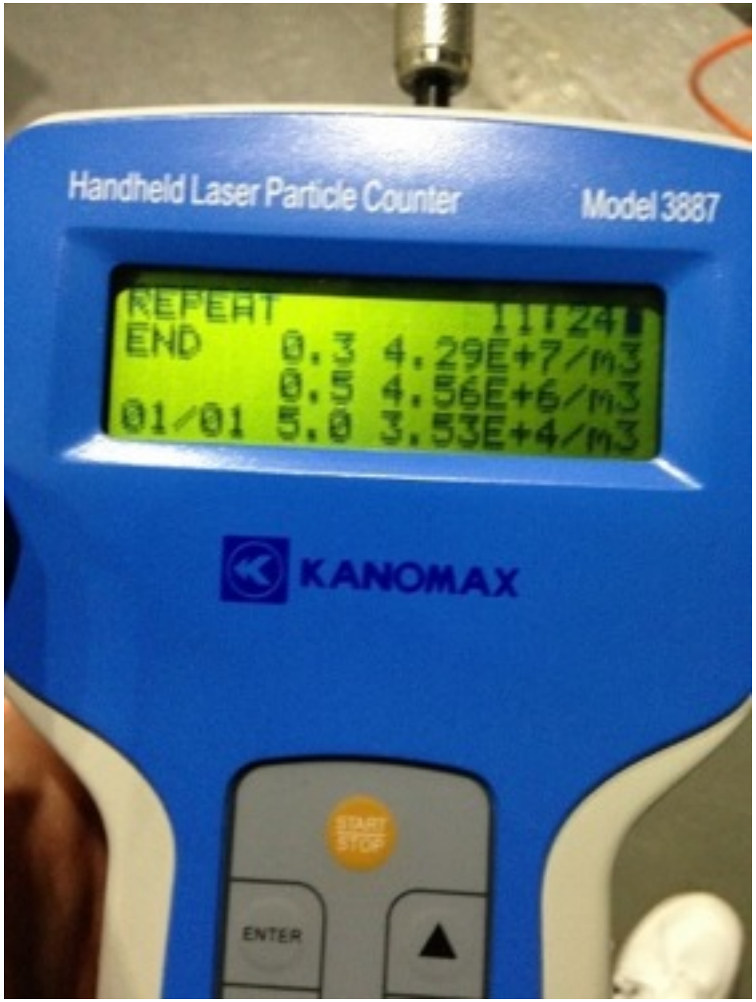

Tek
Trig'd
M Pos: 1.150ms
CH3
入力結合
DC
帯域
Full 200MHz
Volts/Div
ステップ
プローブ
1X
反転
オフ
M 250μs


Tek
Trig'd
M Pos: 320.0μs
CH3
入力結合
DC
帯域
Full 200MHz
Volts/Div
ステップ
プローブ
1X
反転
オフ
M 500μs

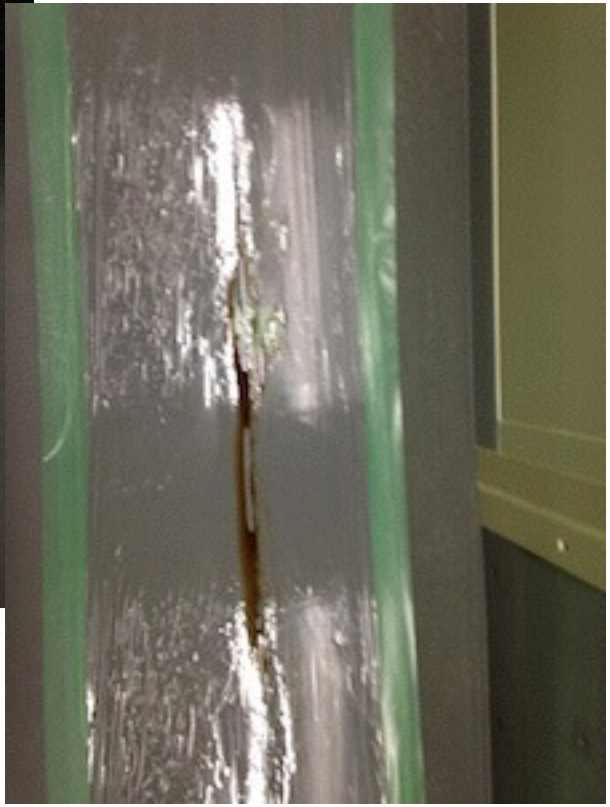
# The Particle Number

**Inside**


**Outside**

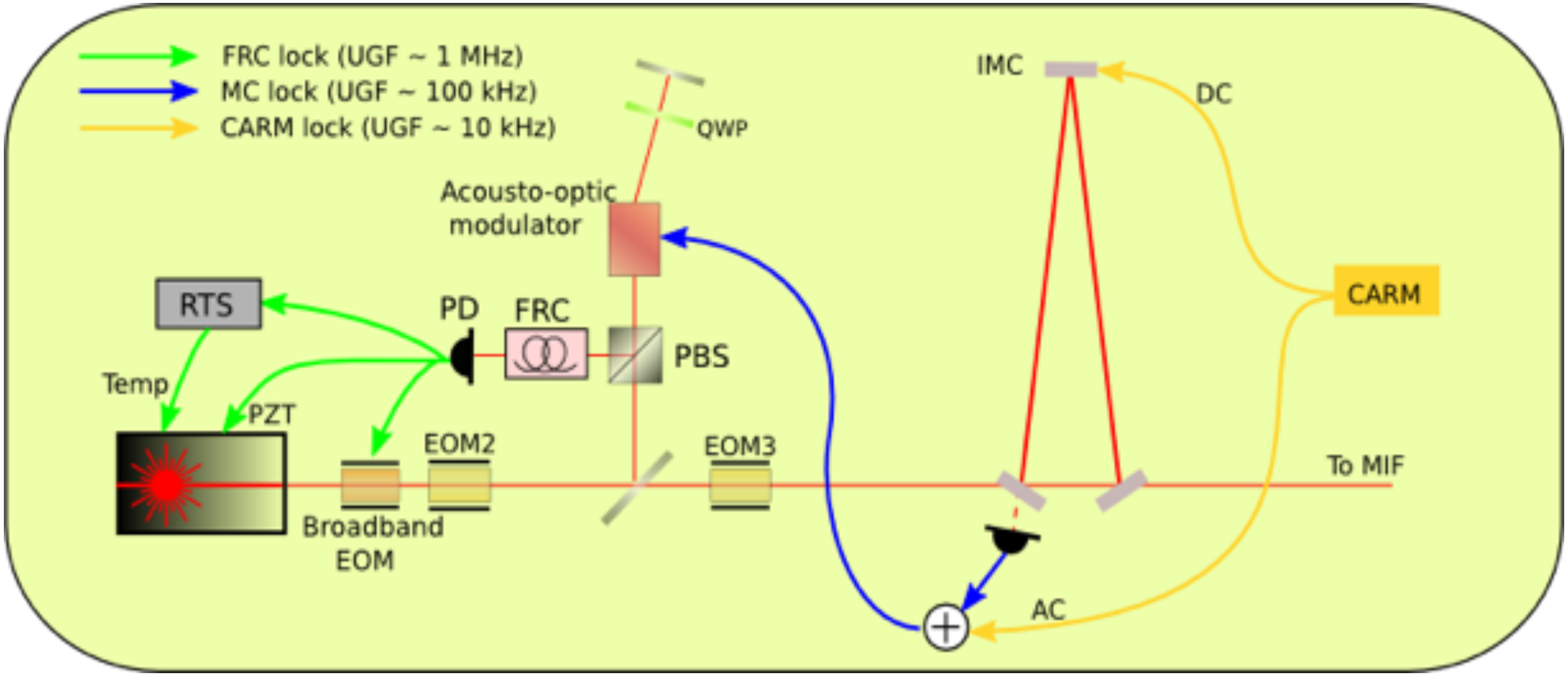


# dirty water inside the room



# Frequency Stabilization

- The frequency noise stabilization servo will be a multiple loop system.
- Using the Fiber Ring Cavity as a reference cavity
  - ✓FRC is easy to use and the alignment is stable.
- This system will be tested at ICRR.




Frequency Stabilization Servo Topology