# CLIO

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  - *(ii) Open cryostat system*
  - *(iii) Ultra-low vibration refrigerator.*
  - *(iv) Cryogenic mirror suspension.*
  - *(v) Thermal noise limiting displacement noise.*

- **Summary -**

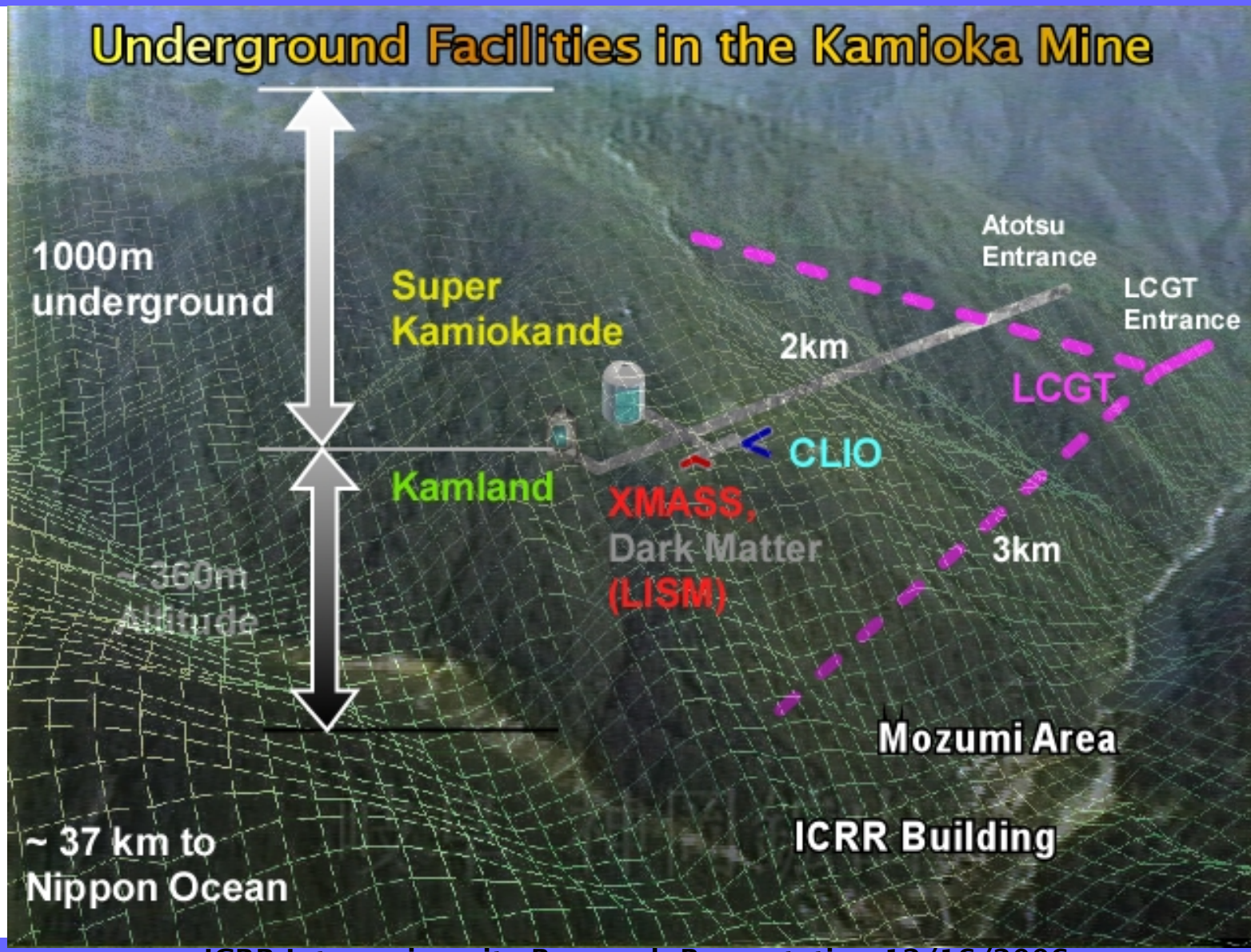
# CLIO Design

# CLIO Overview

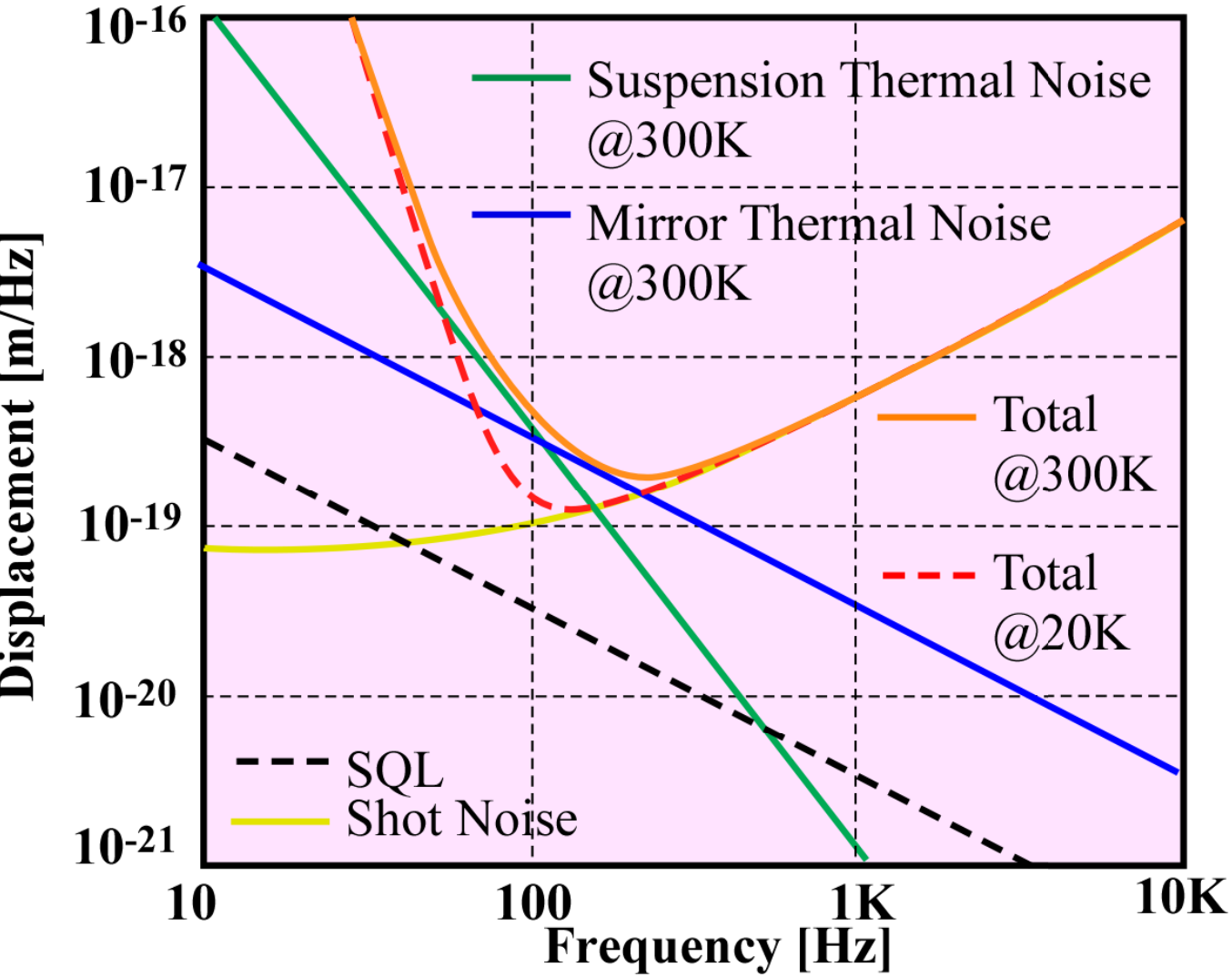
## Cryogenic Laser Interferometer Observatory

- *100m base-line Locked-FP style Proto-Type for LCGT.*
- *Technical combination of R&Ds done at CLIK(2000-02), LISM(1999-2002), KEK-cryogenic-facility (1996-2006).*
- *Reduced thermal noise limited sensitivity is targeted using sapphire mirrors and sapphire suspension fibers.*
- *Stable operation (GW observation) is expected owing to the low seismic noise of KAMOIKA mine.*

# Site


Underground Facilities in the Kamioka Mine
1000m underground
Super Kamiokande
Kamland
~ 360m Altitude
~ 37 km to Nippon Ocean
Atotsu Entrance
LCGT Entrance
2km
LCGT
CLIO
XMASS, Dark Matter (LISM)
3km
Mozumi Area
ICRR Building

# 1st Targeted Displacement Noise



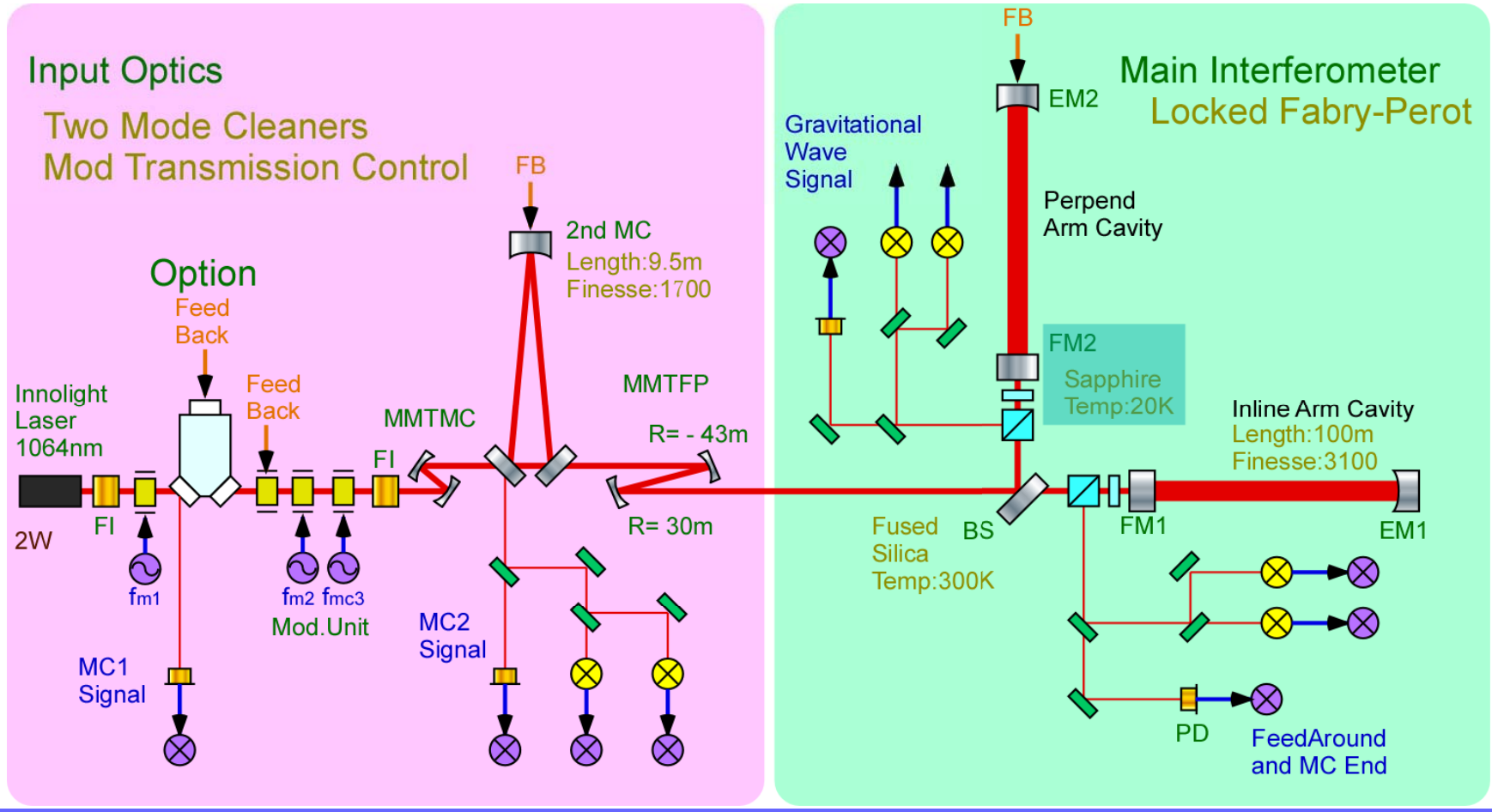

**Laser power :**
*200mW for one arm*
**Mirror Mass :**
*1.8 kg*

*Thermal Noises limit the sensitivity around 100Hz, and they will be reduced after cooling.*

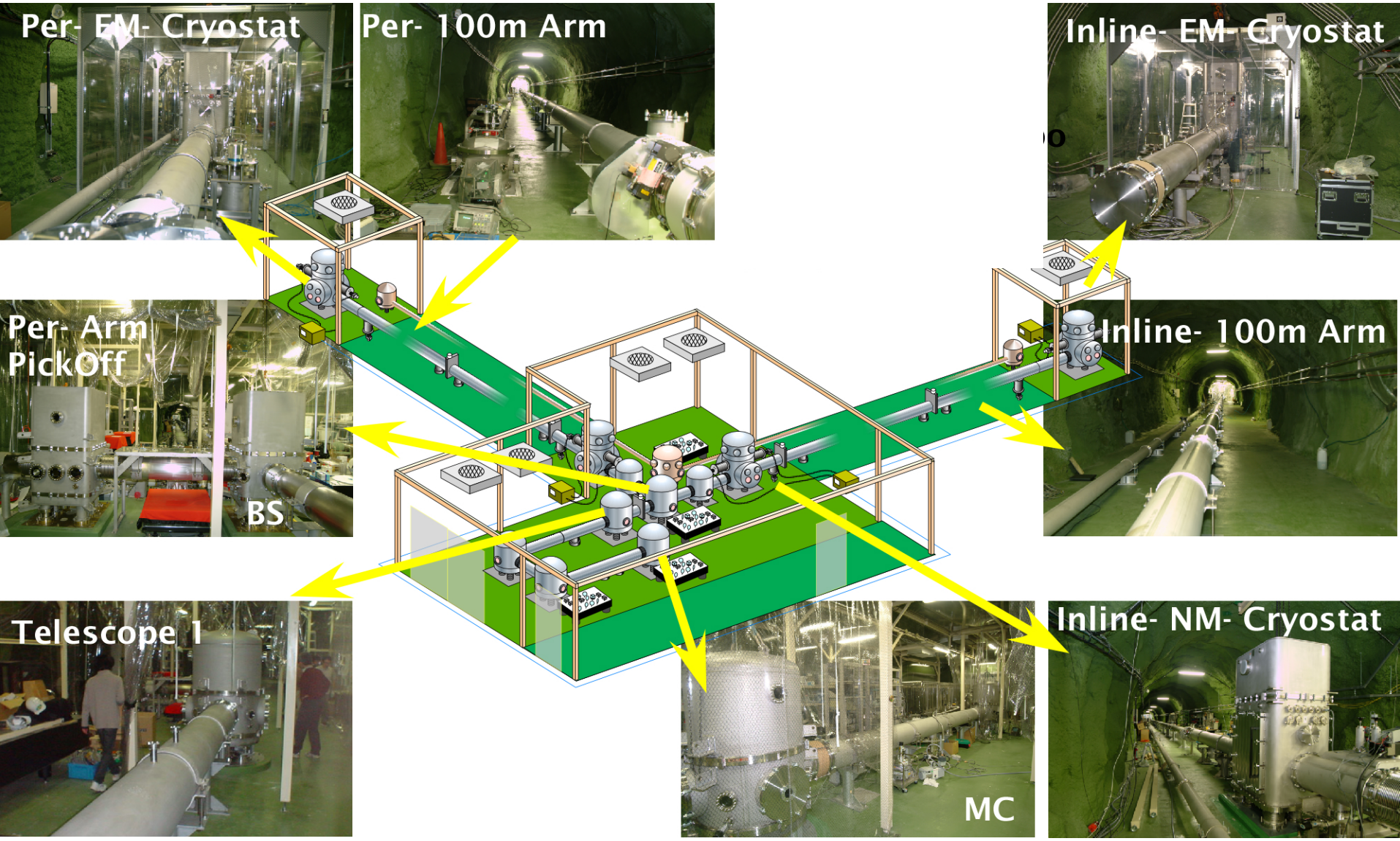
# Optical Configuration

-Locked Fabry-Perot Configuration- (Easiest as an IFO)

*One arm is used for frequency stabilization.*
*The other arm is used for GW detection.*



# Outlook of CLIO

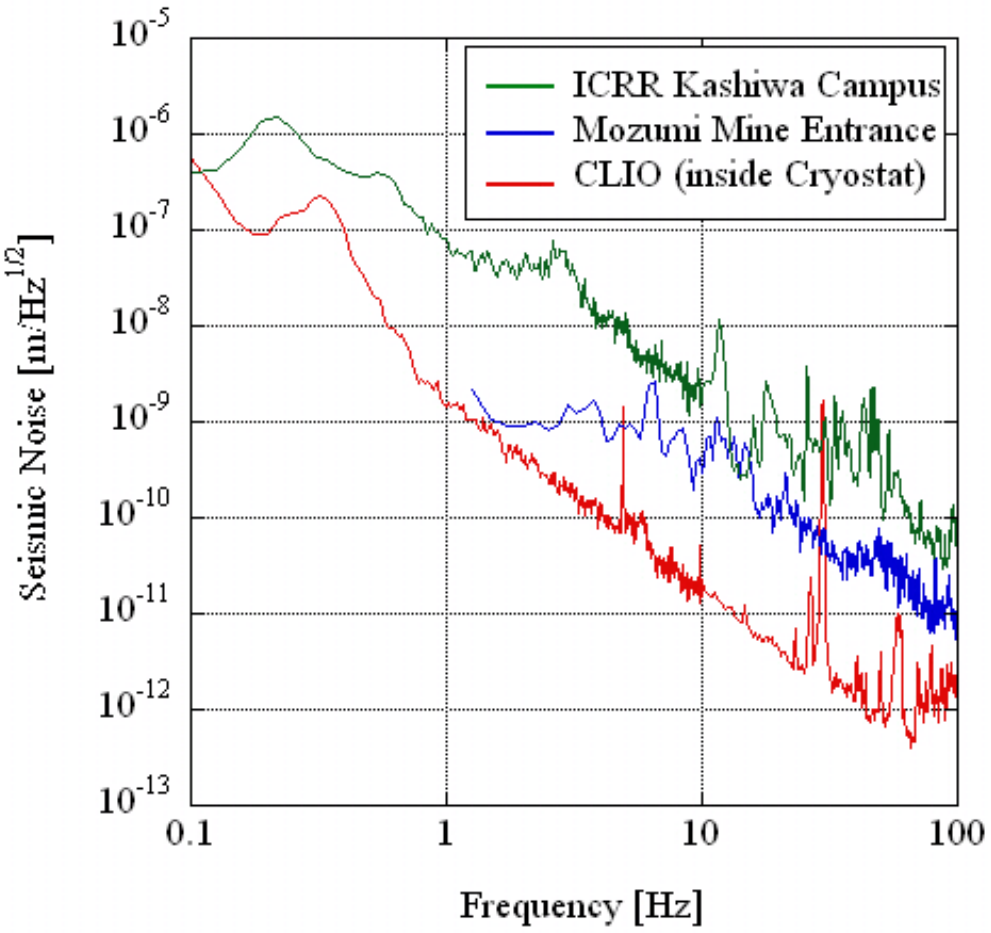


# Highlight of CLIO

# Highlight of CLIO

- *Underground.*
- *Open cryostat system.*
- *Ultra-low vibration refrigerator.*
- *Cryogenic mirror suspension.*
- *Thermal noise limiting displacement noise.*

# Underground




*-Difference between the seismic noise on the surface and in the ground of the isolated area is distinguishing above 1 Hz.*

*-Even at LIGO(LHO), the wind sometimes disturbed GWD operation.*

*- Stable operation without alignment control is demonstrated for ?? hours. (Normally, GWDs on the ground without alignment control is impossible.)*

# Cryostat *- Requirements -*

## - Temperature -

below 10K at the inner shield, below 100K at the outer shield.
Below 100K at the radiation shield duct. ---> OK

## - Heat transfer -

mW level is expected, but … (see Tomaru's talk)

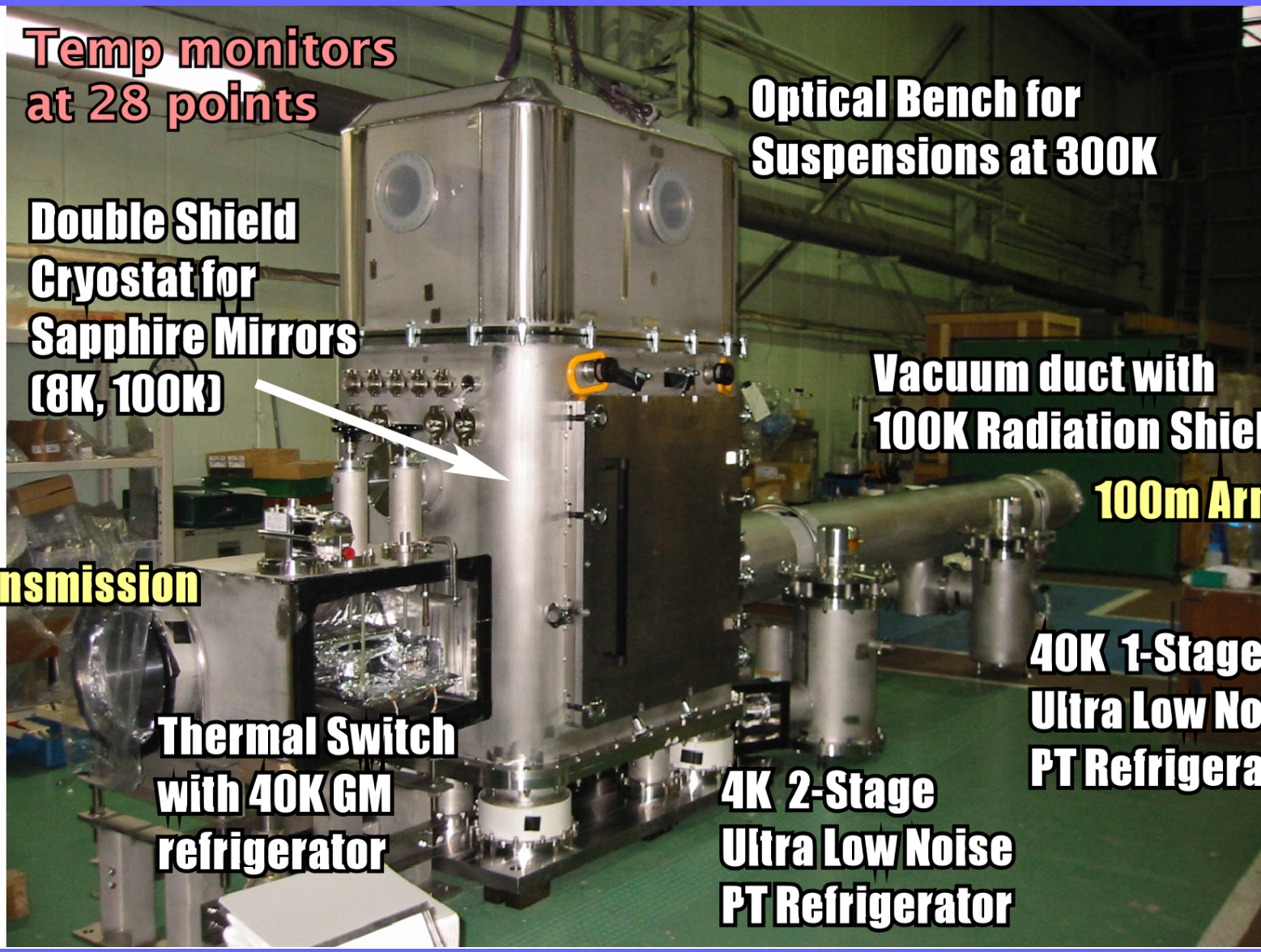
## - Cooling time -

Within 5 days (only cryostat) ---> OK

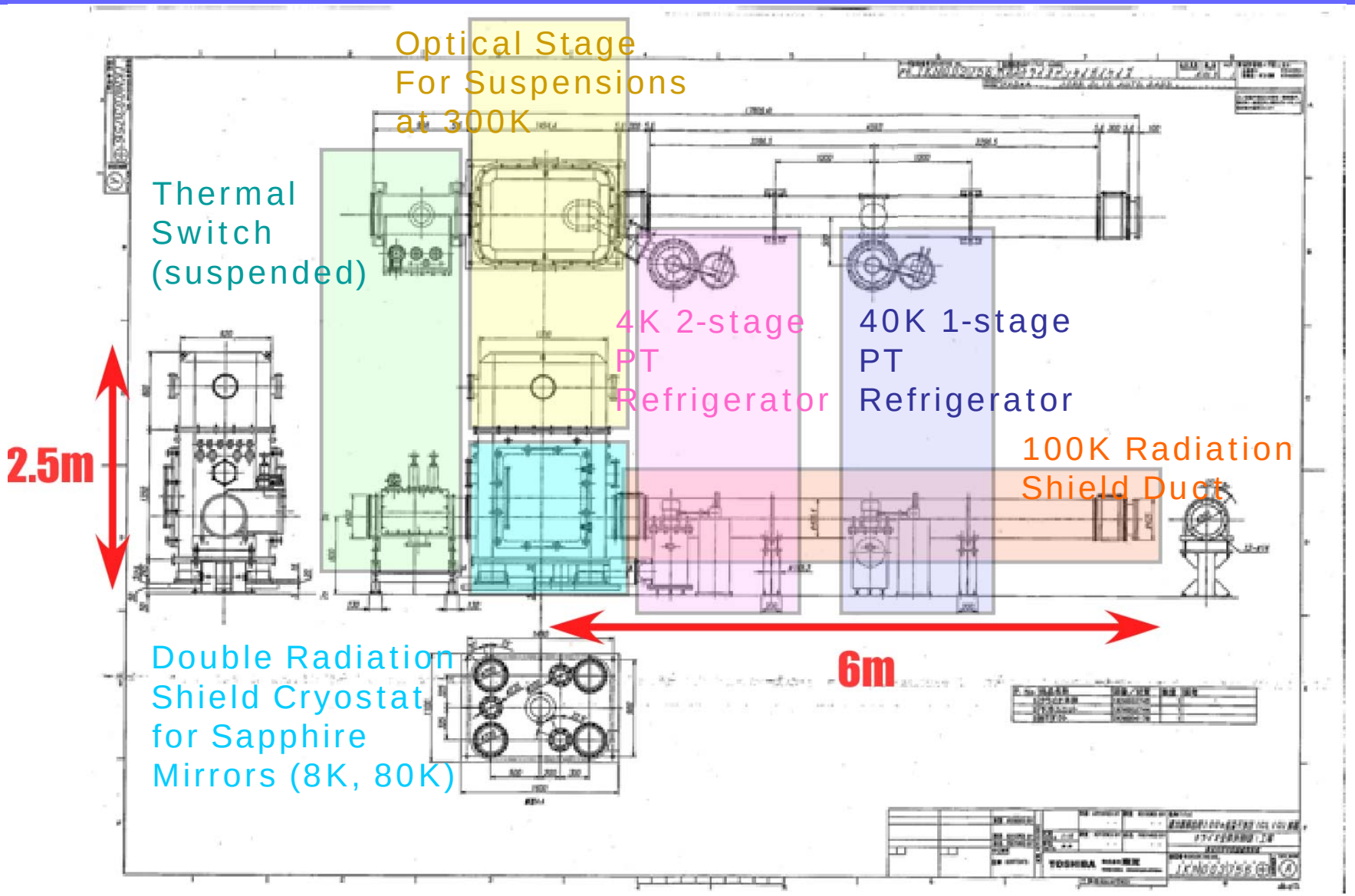
## -Vibration level –

Below 10 times of the KAMIOKA mine seisimic noise level at the optical bench. ---> OK

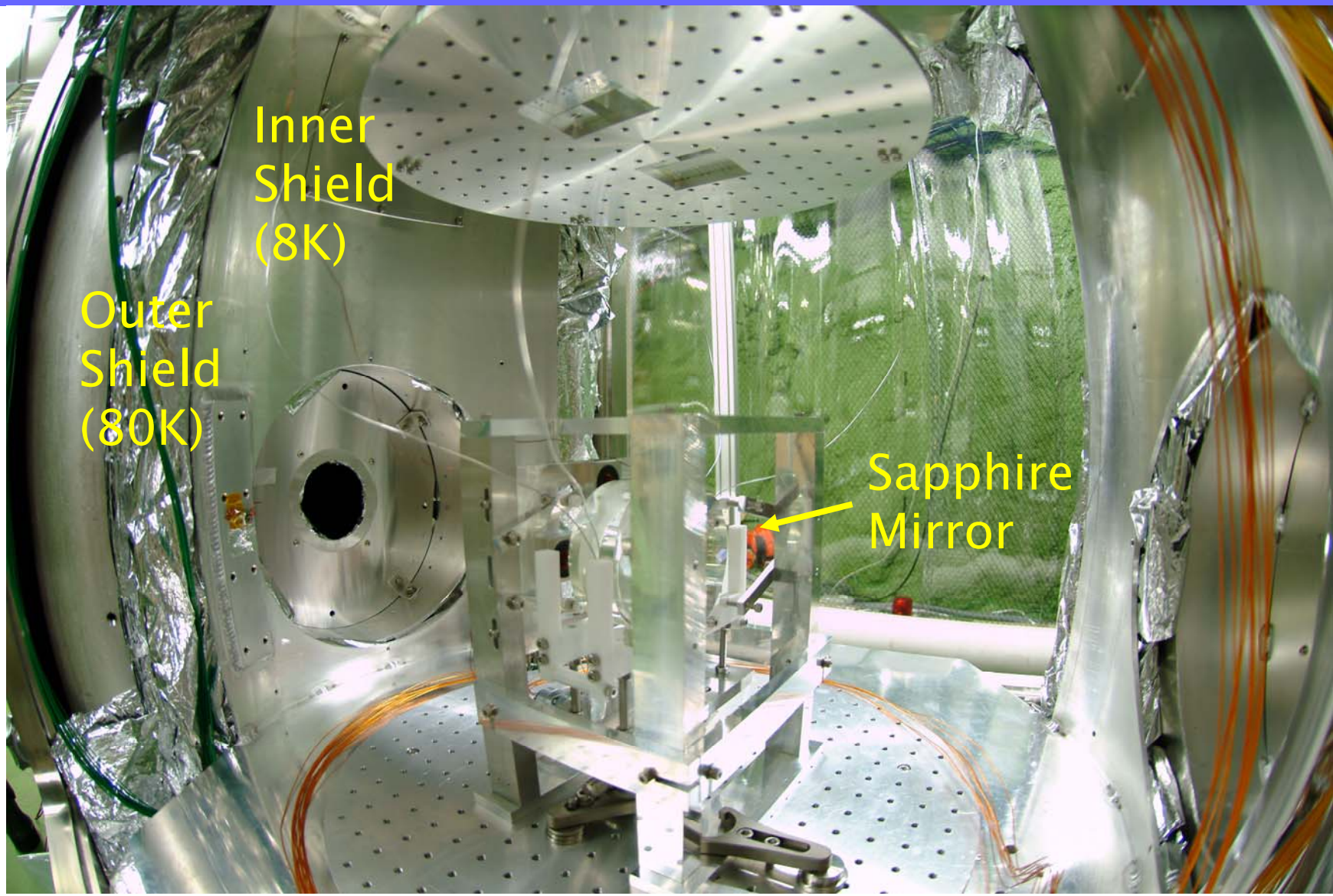
# Cryostat *- outlook -*



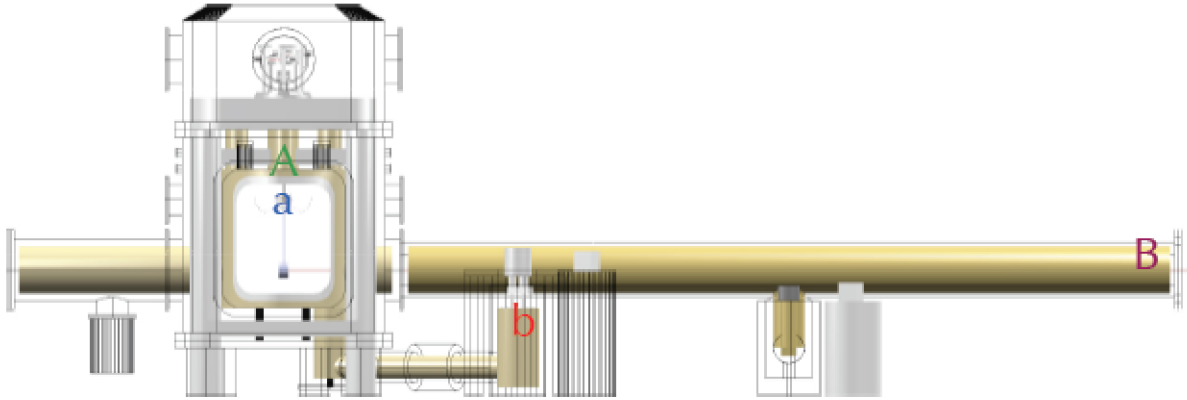
# Cryostat - *structure* -

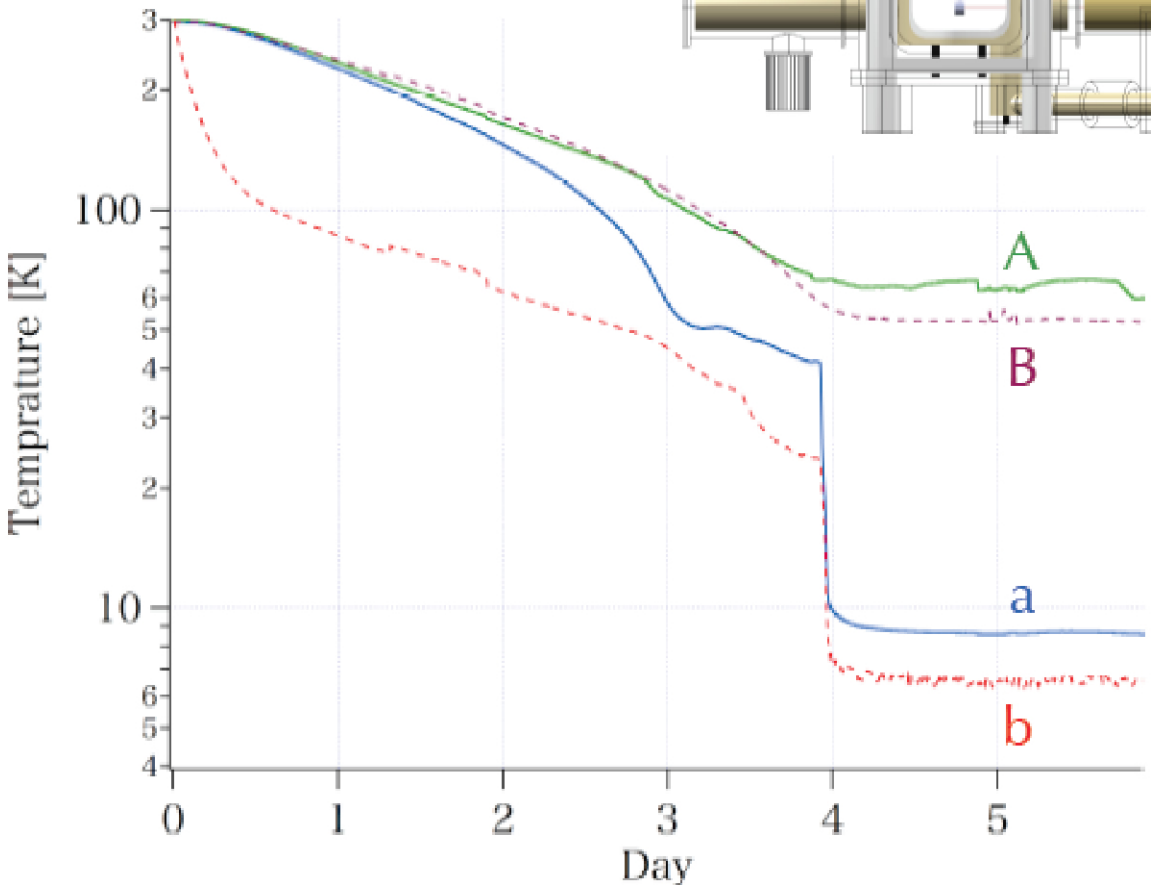


# Cryostat *- inside -*



# Cryostat *- cooling performance -*




*Outer Shield Top(80K)*

*End of Pipe(60K)*

*Inner Shield Top (8.4 K)*

*Refrigerator Cold Stage*

# Ultra-Low Vibration Refrigerator
## *- Requirements -*

## - Temperature and cooling power-

Small cooling power reduction compared with the original refrigerator performance (0.5W at 4K head, 15W at 40K head) ---> OK

## - Vibration level -

Below 10 times of the KAMIOKA mine seisimic noise level (accounting for 1/100 Z-X coupling) at the optical bench. ---> OK

# Low Vibration Refrigerator

## *- outlook -*

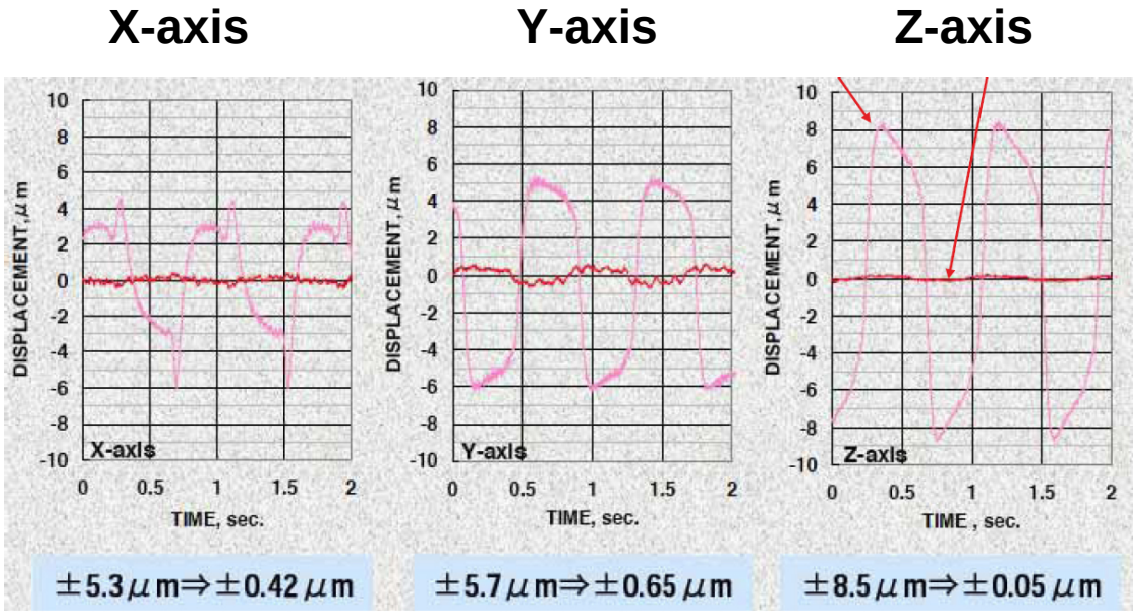
- 40 K Cold Head
- Bundles of Al wires
- 40K vibration reduction stage
- 4 K Cold Head
- FRP Pipe Rod
- 4K vibration reduction stage
- Soft thermal conductive bundle of wires

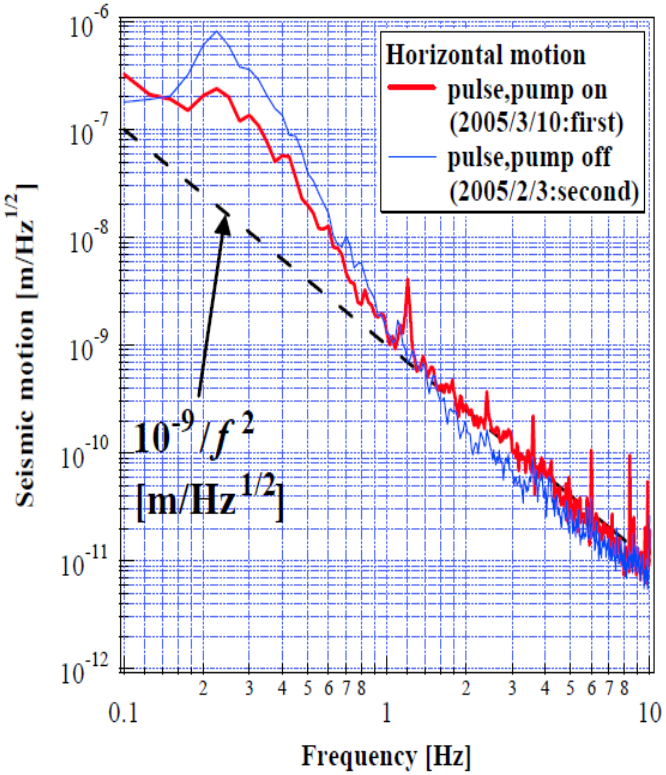
- Cryocooler table fixed on the ground
- Valve unit on a frame
- Valve unit table fixed on the ground
- He gas flexible tube

# Ultra-Low Vibration Refrigerator
## *- vibration reduction performance -*

*Vibration of the 4K vibration reduction stage in time.*

*Vibration on the 300K stage in the Cryostat in the KAMIOKA mine*




*The values show mainly the operation frequency vibration.*

# Ultra-Low Vibration Refrigerator

## *- cooling power -*

*- Cooling power reduction was very small -*

| | 1st Stage | | 2nd Stage | |
|---|---|---|---|---|
| Original Cooling Head | 41.2K | @15W | 4.15K | @0.5W |
| Reduction Stage | 43.7K | | 4.43K | |

# Cryogenic Mirror Suspension
## - Requirements -

*- Temperature -*

*around 20K at the sapphire mirror ---> almost OK*

*- Heat transfer of suspension wires -*

*mW level is satisfied enough, but… (see Tomaru's talk)*

*- Cooling time -*

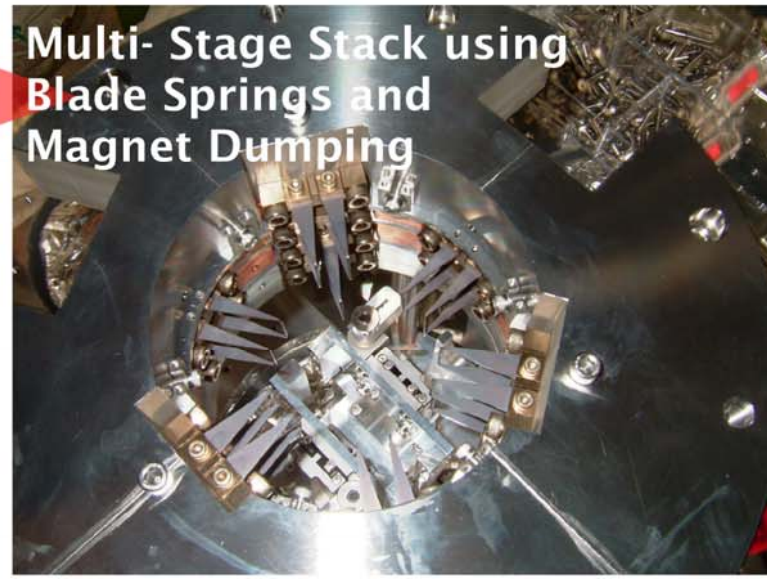
*Within 7 days (including all suspension system) ---> OK*

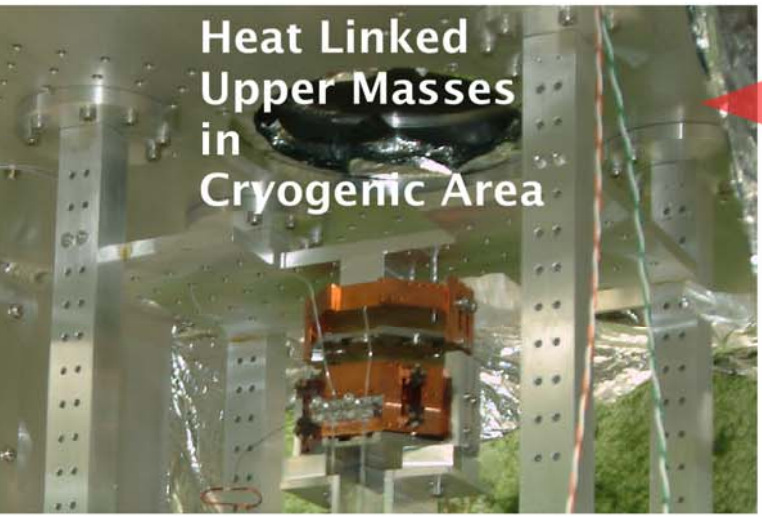
*-Seismic noise isolation –*

*Below 1/10 times compared with the targeted sensitivity ---> on going*

# Cryogenic Mirror Suspension

## *- structure at 300K area -*

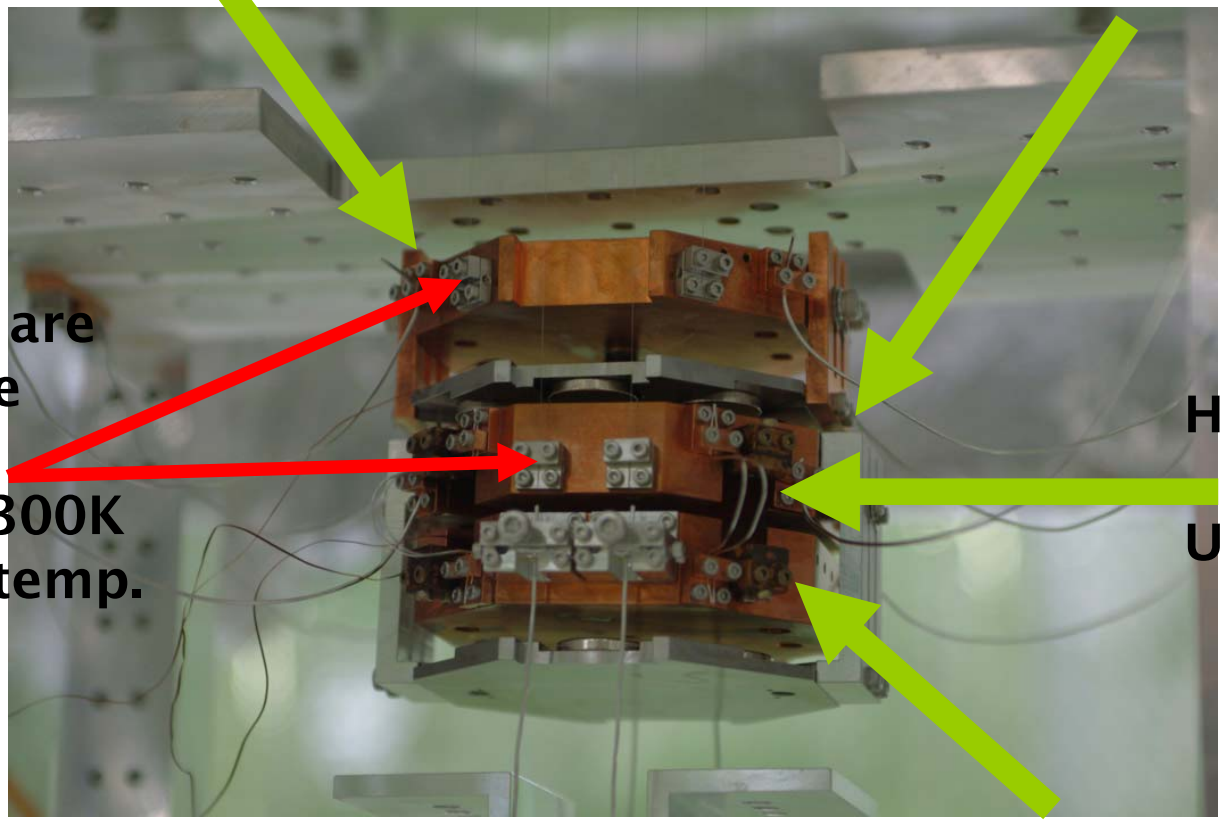




# Cryogenic Mirror Suspension

## *- close up of upper masses -*

Magnet base and Heat Link Wires (HLWS)

Upper mass1 (UM1) and magnet base for the upper mass 2 damping. They are also with HLWs.



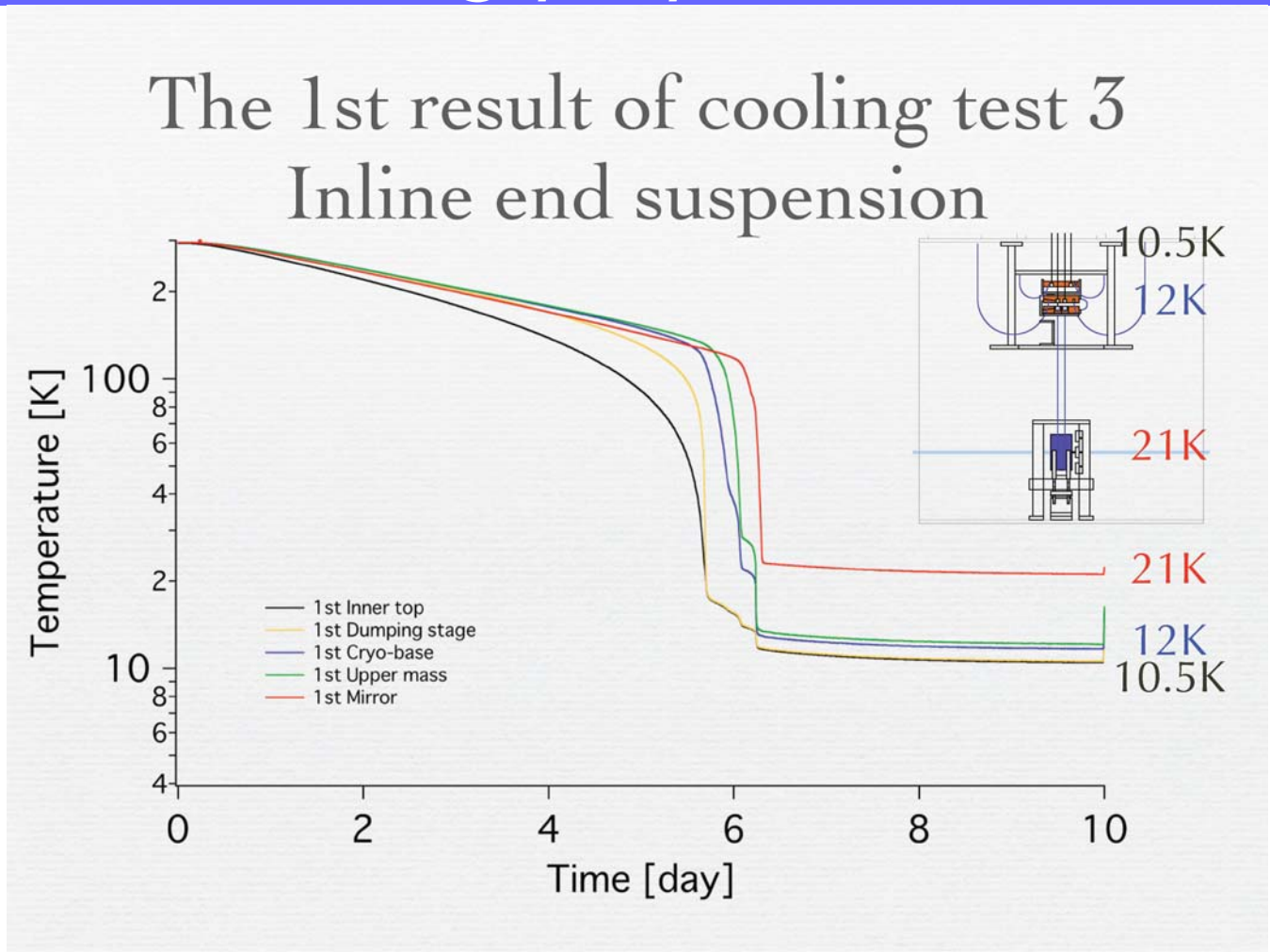
Bolfa wires are used for the suspension between a 300K and a cryo temp. object

HLWs between

UM1 and UM2

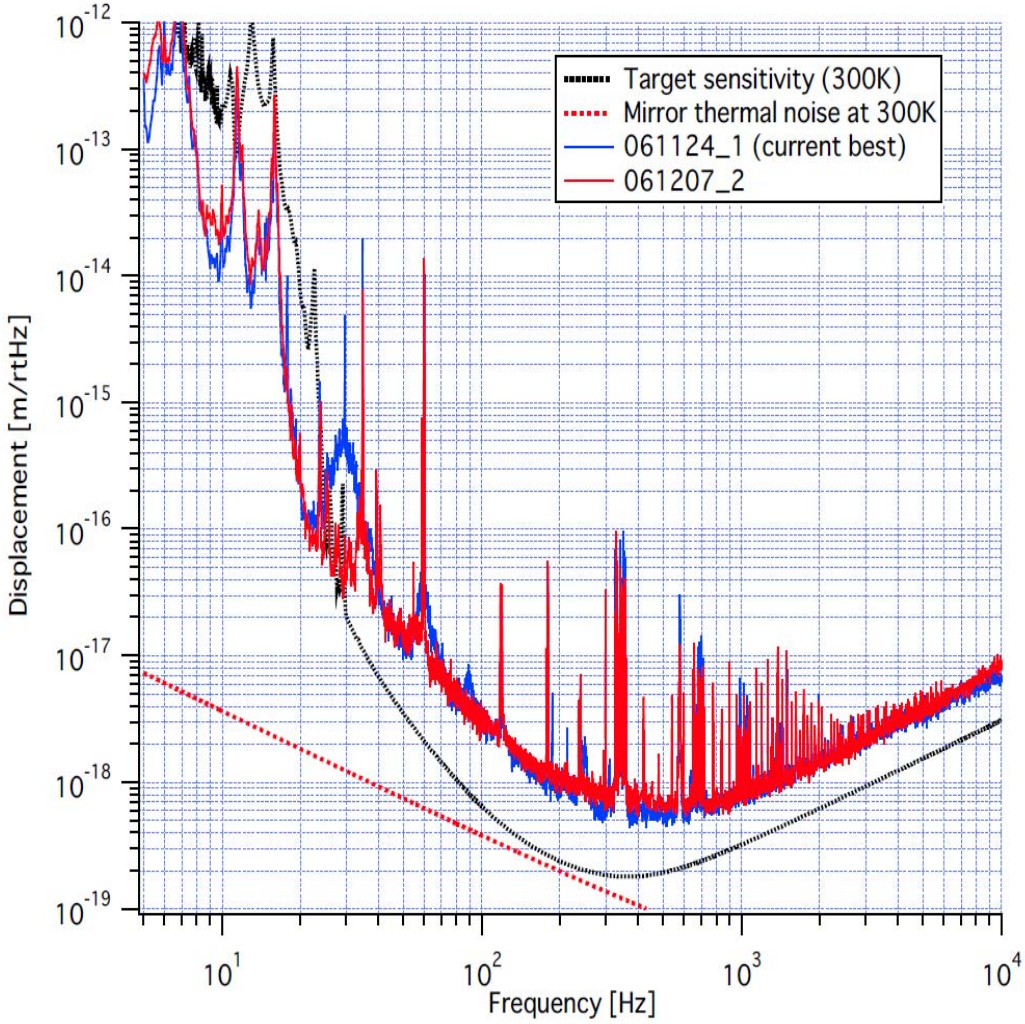
Upper mass 2 (UM2) from which the sapphire mirror is suspended. The UM2 is suspended by blade springs from the UM1.

# Cryogenic Mirror Suspension
## *- cooling performance -*




**Mirrors were cooled around 20K**

# Displacement Noise
## *- current best -*

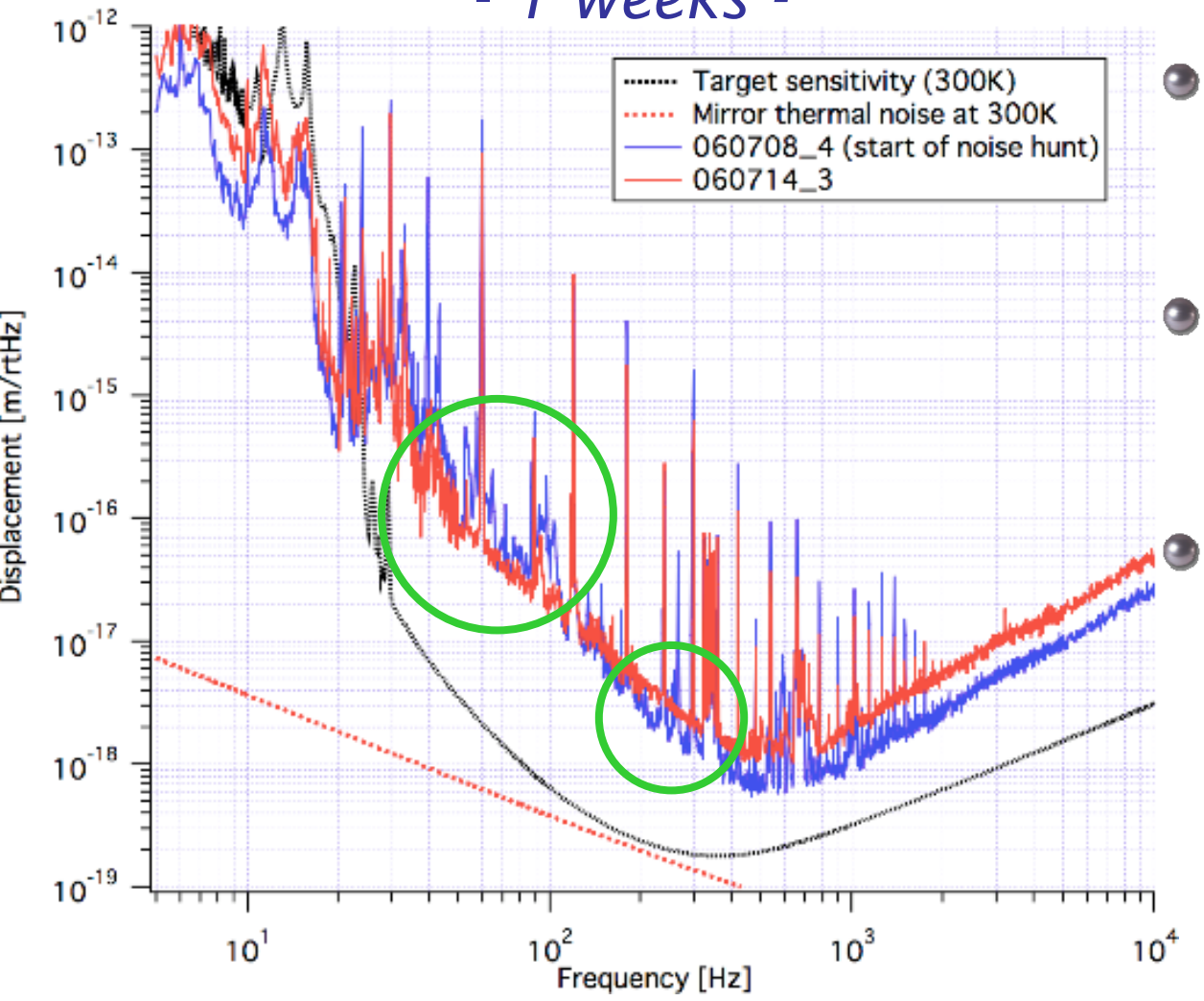



- Noise hunting started from July.
- Almost white noises dominated the displacement except for 60Hz and wire resonances above 40Hz.
- Some Within 4 times level compared with 1st targeted displacement level.

# Displacement Noise

## *- toward thermal noise limit 1 -*

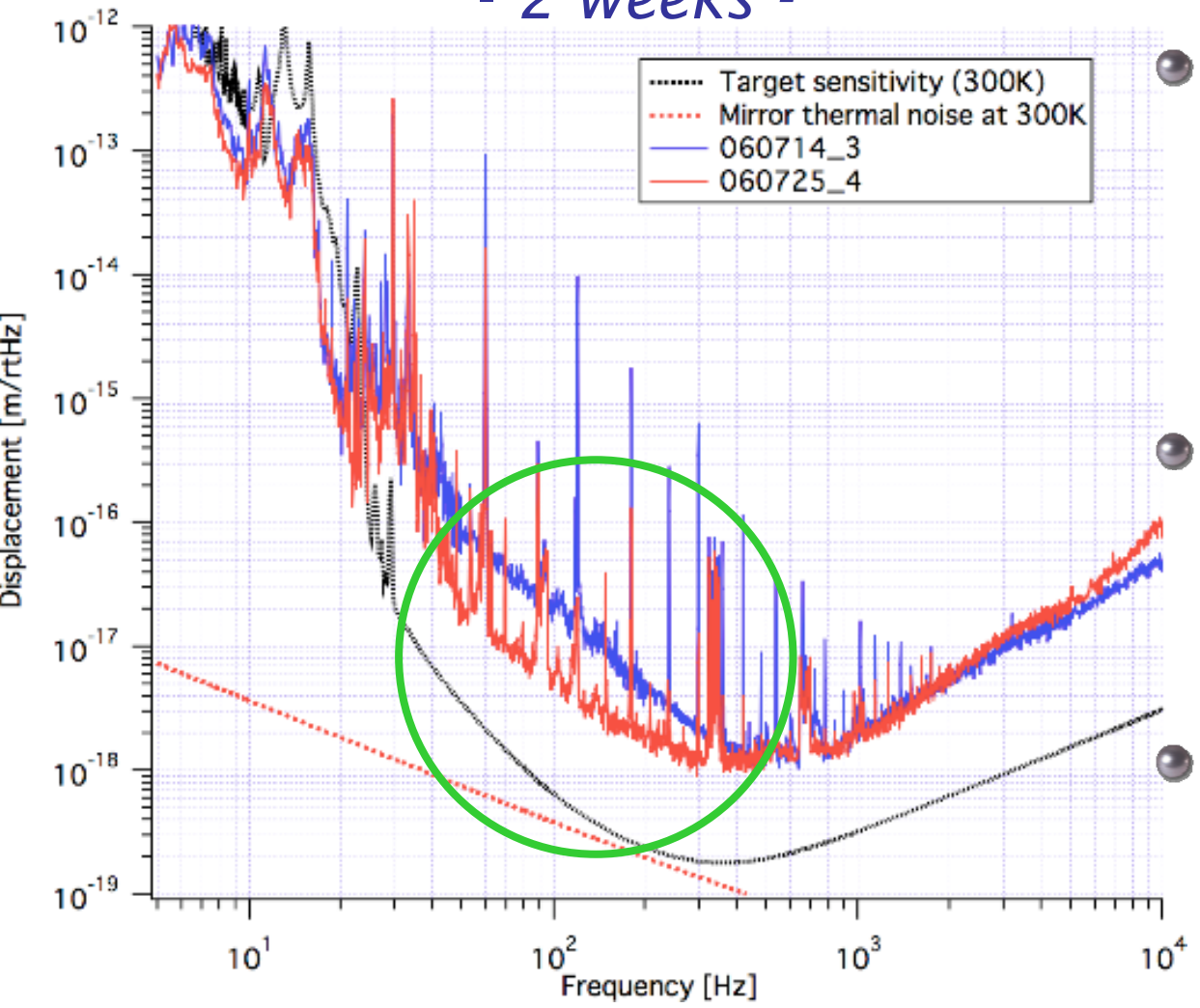
*- 1 weeks -*




- Stop all the vacuum umps for the cryostats.
- Stop the air fan of the experiment room.
- Some structures was reduced or vanished.

# Displacement Noise
## *- toward thermal noise limit 2 -*

*- 2 weeks -*



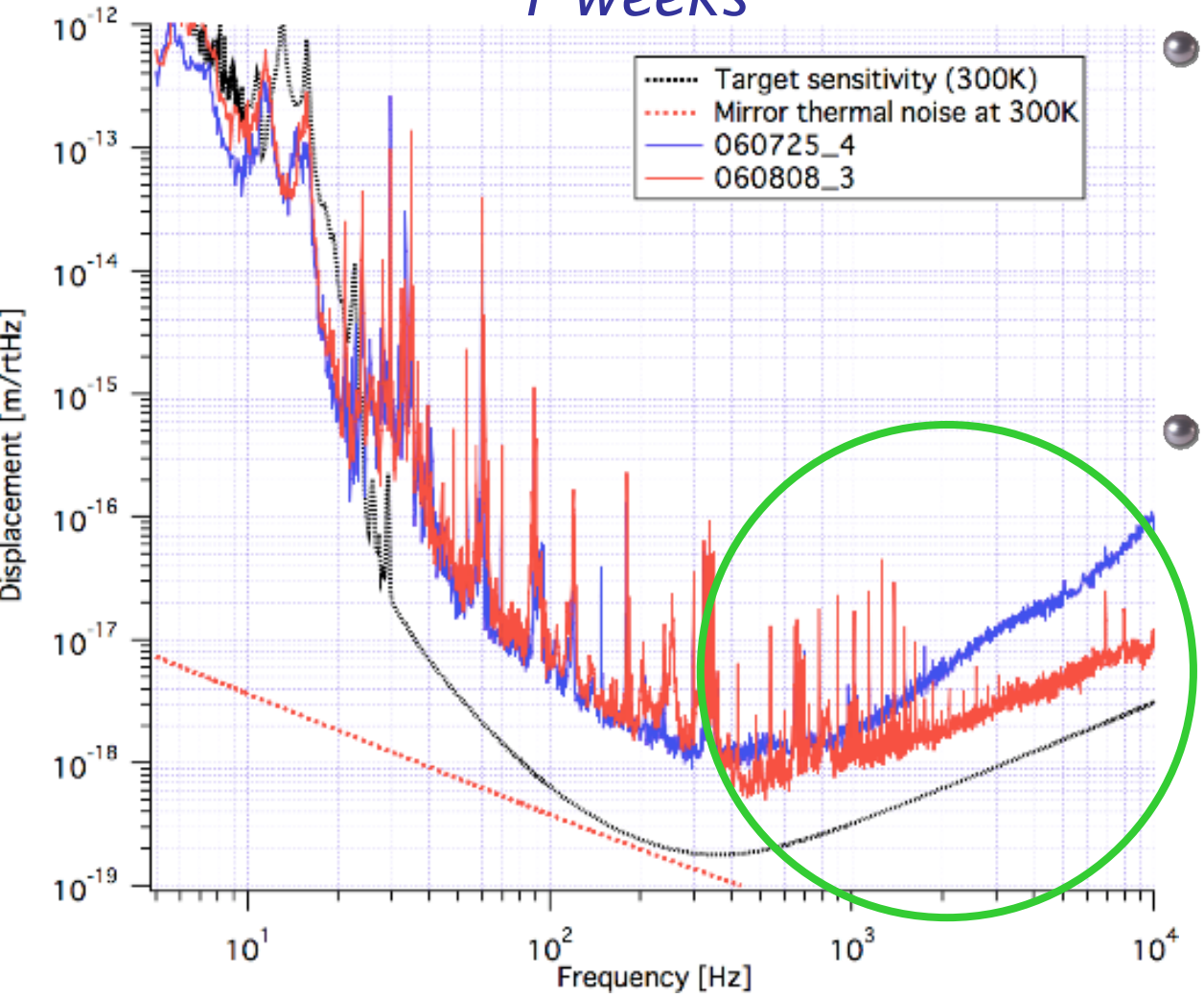

1 ohm bypass was inserted parallel to the coil actuator, in order to reduce the actuator efficiency.

The actuator efficiency was reduced less than 7 times than before.

The sensitivity from 40Hz to 400Hz was improved.

# Displacement Noise
## *- toward thermal noise limit 3 -*

*- 1 weeks -*



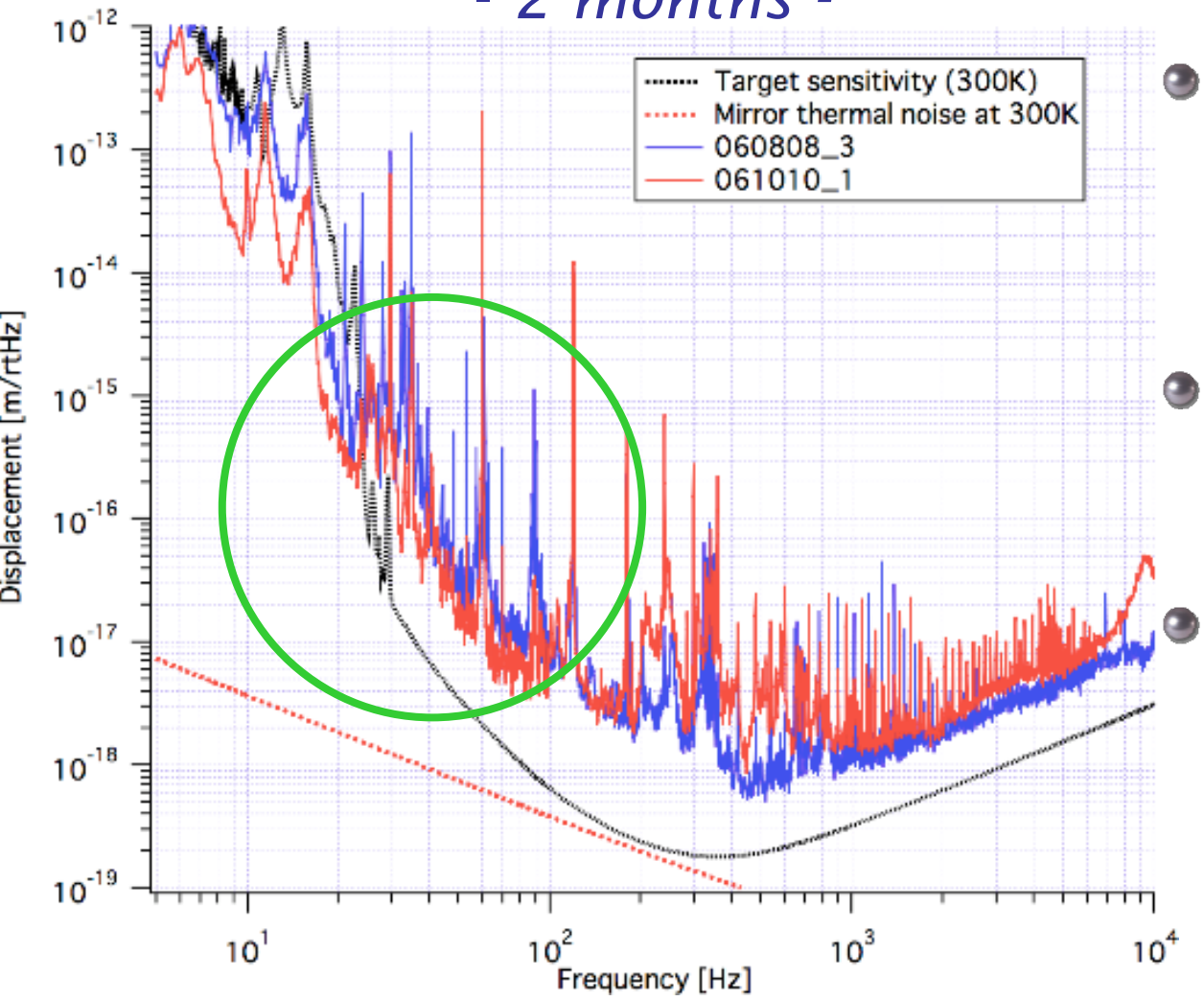

The servo gain balance of the primary cavity and the mode cleaner cavity was changed.

The sensitivity higher than 400Hz was improved.

# Displacement Noise

## *- toward thermal noise limit 4 -*

*- 2 months -*



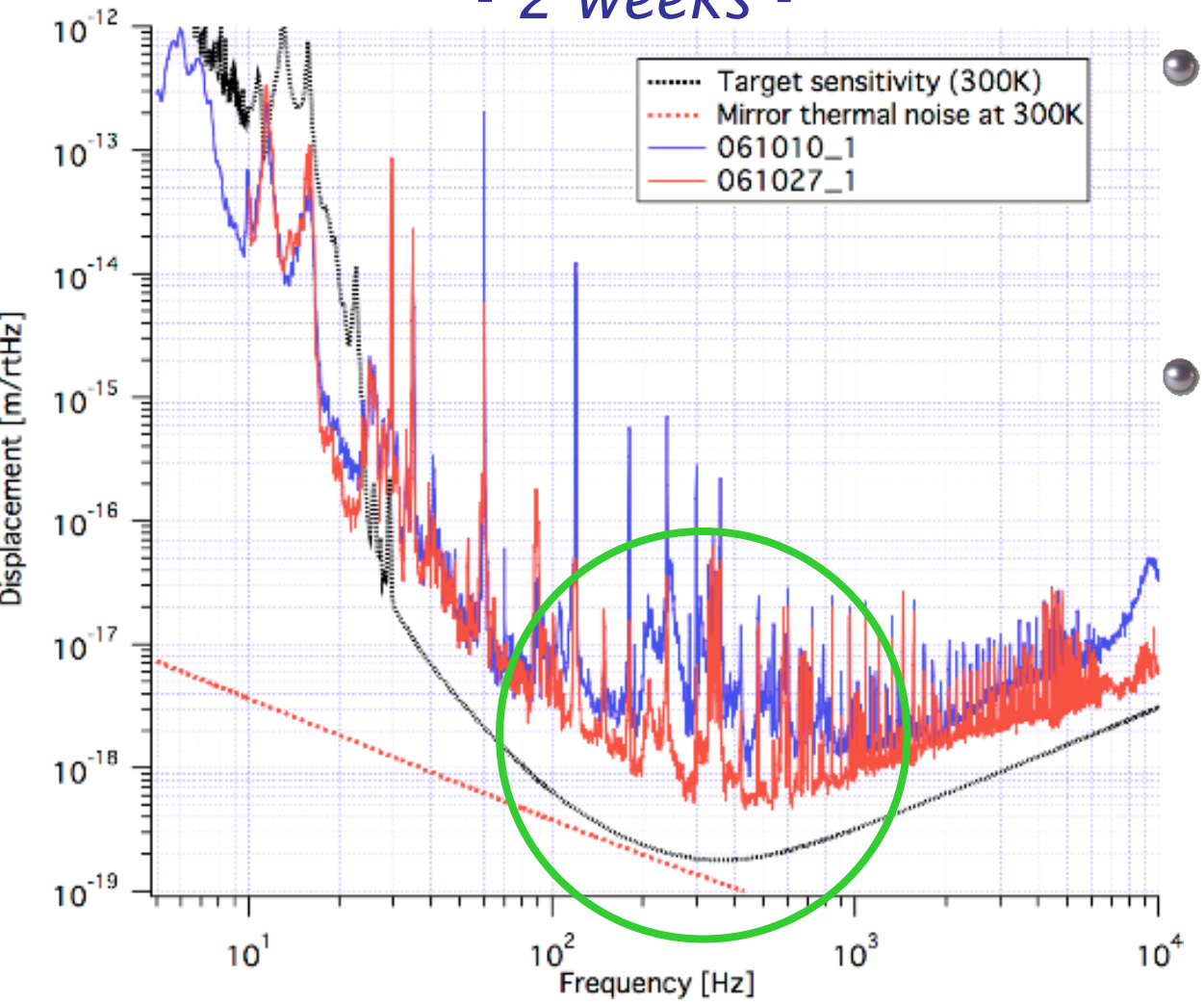

The optics for the reflected light were on the vibration isolation tables.

The bellows for the stack system were used at this time.

The sensitivity from 5Hz to 100Hz was improved.

# Displacement Noise
## *- toward thermal noise limit 5 -*

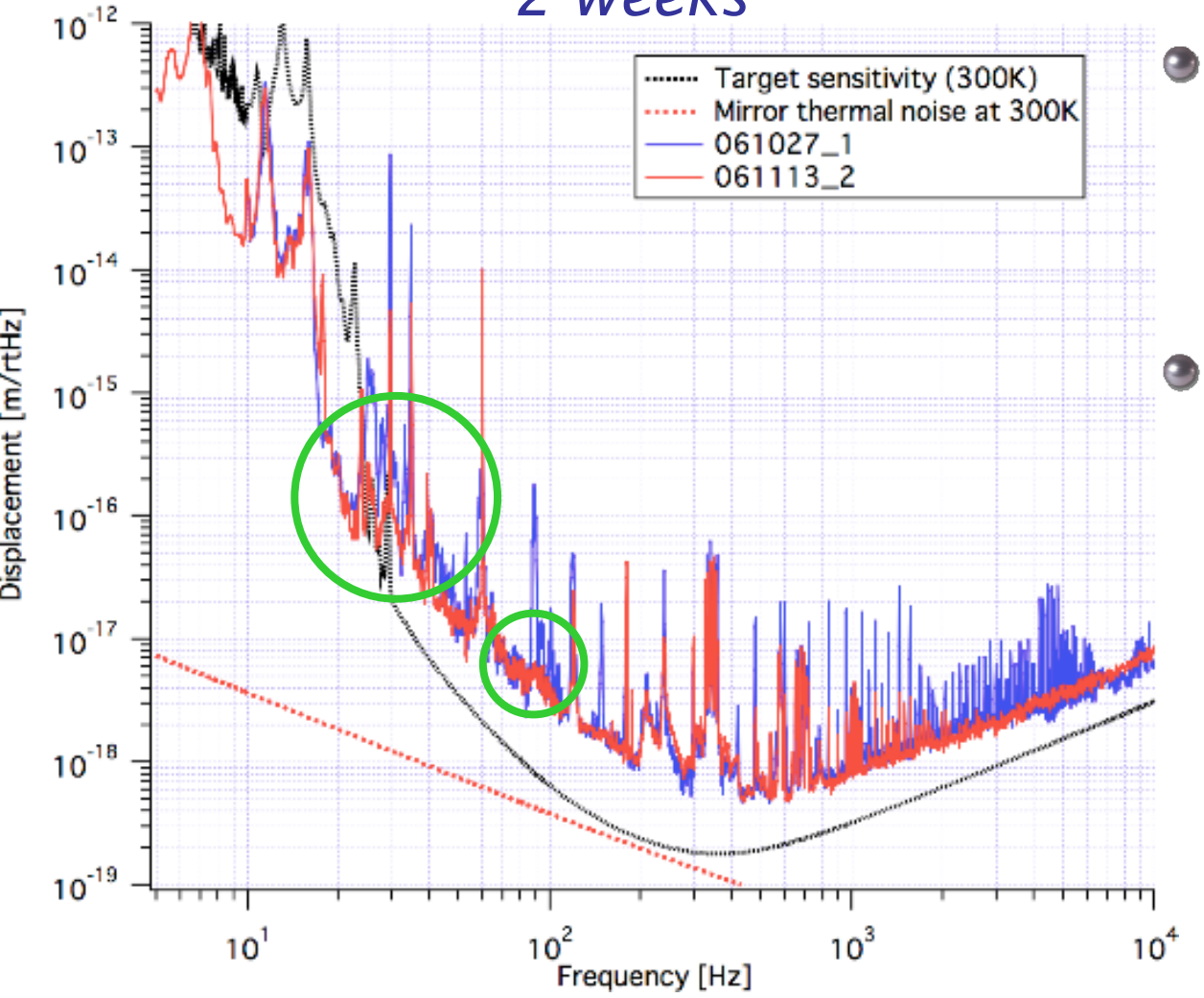
*- 2 weeks -*




- The optics of the reflected light were housed made of aluminum plates.
- The sensitivity higher than 100Hz was improved.

# Displacement Noise
## *- toward thermal noise limit 6 -*

*- 2 weeks -*

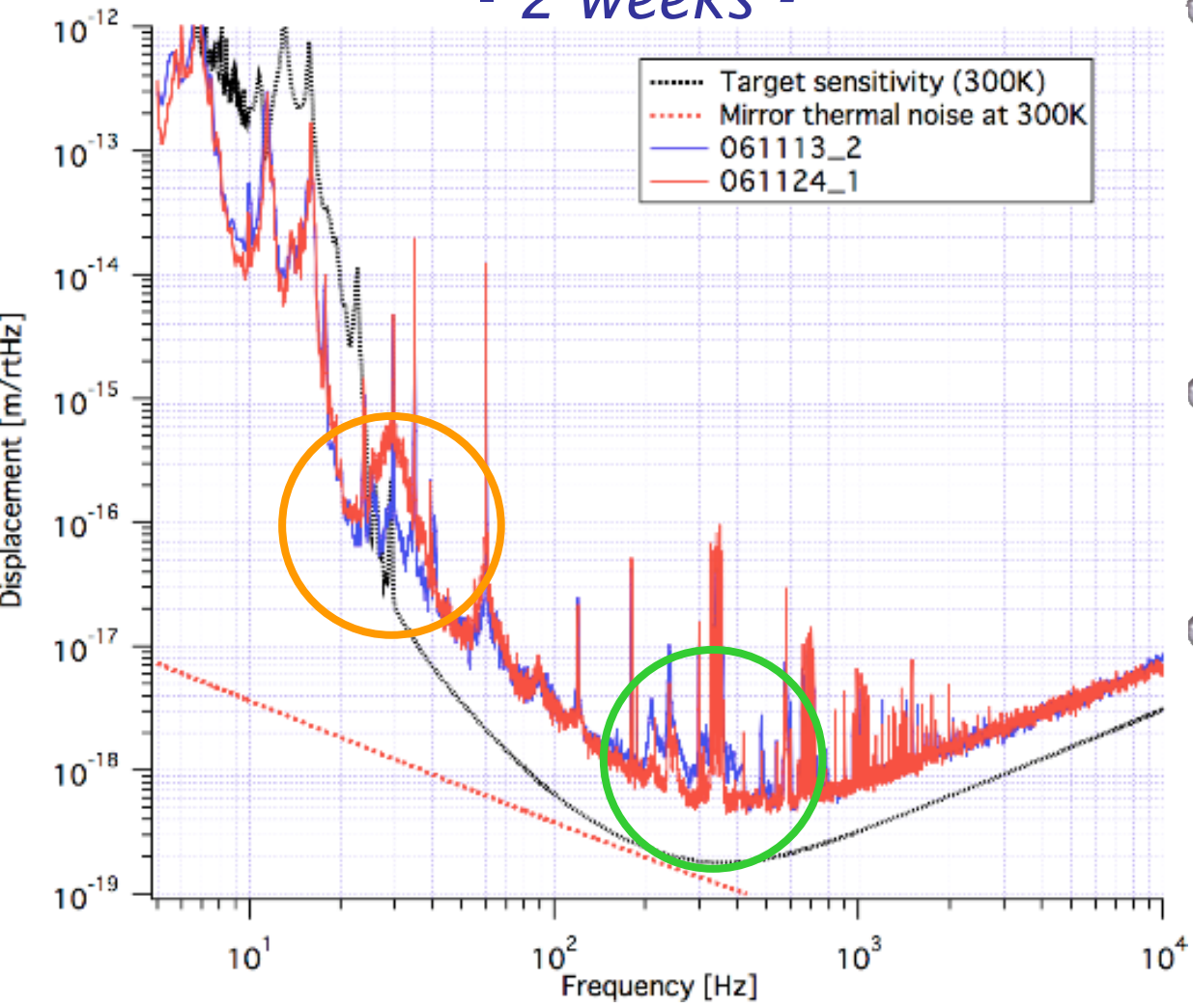



- The coil actuator was on the bellows for vibration isolation.
- Some structures between 20Hz to 100Hz were reduced.

# Displacement Noise

## *- toward thermal noise limit 7 -*

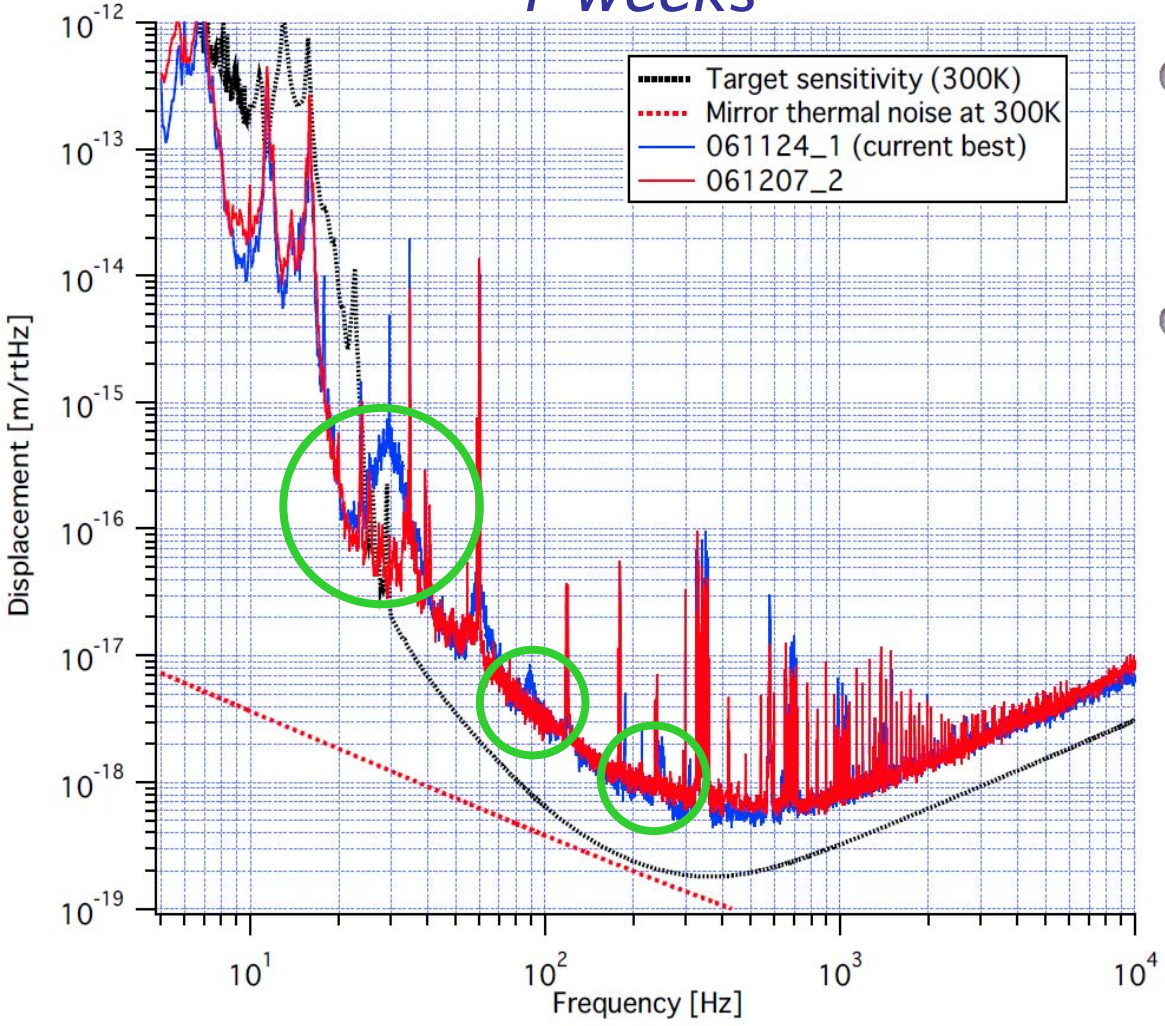
*- 2 weeks -*




- The transmitted light through the inline end mirror was scattered in the tank.
- Rotary pump in the middle of 100m duct was turned off
- The structures from 200Hz to 400Hz was reduced.

# Displacement Noise
## *- toward thermal noise limit 8 -*

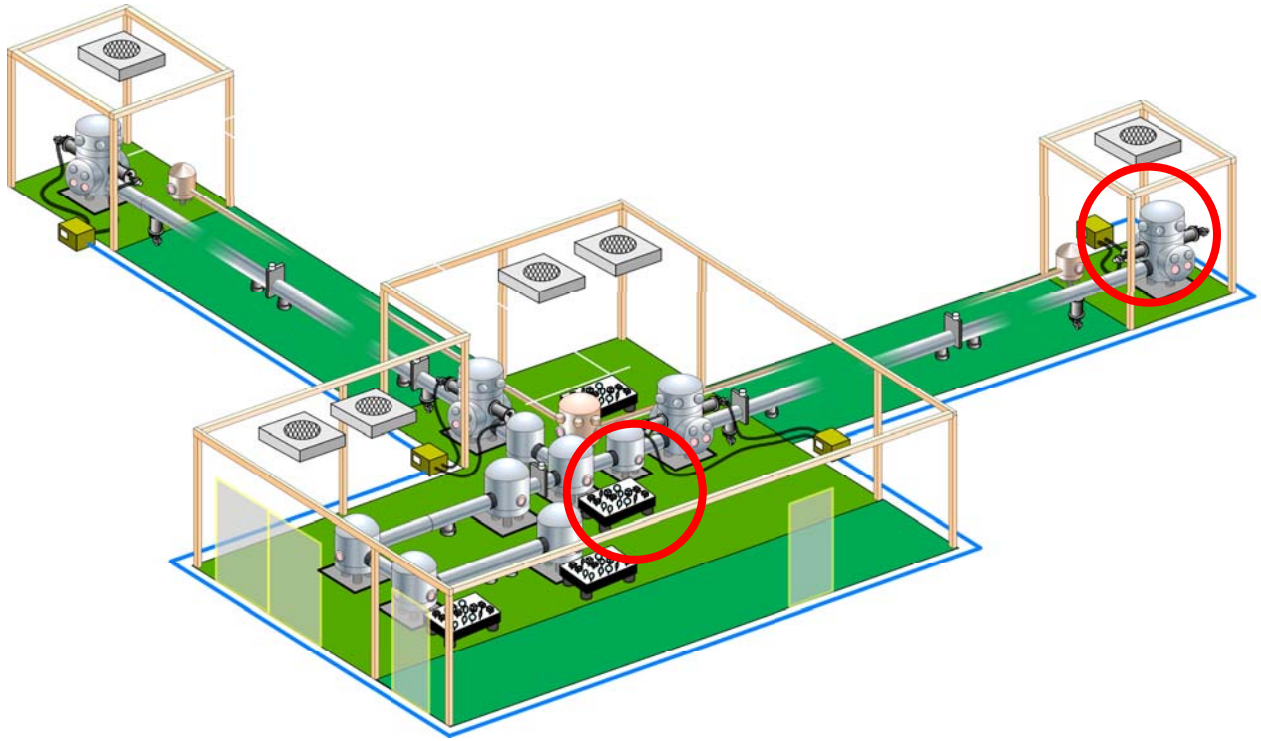
*- 1 weeks -*



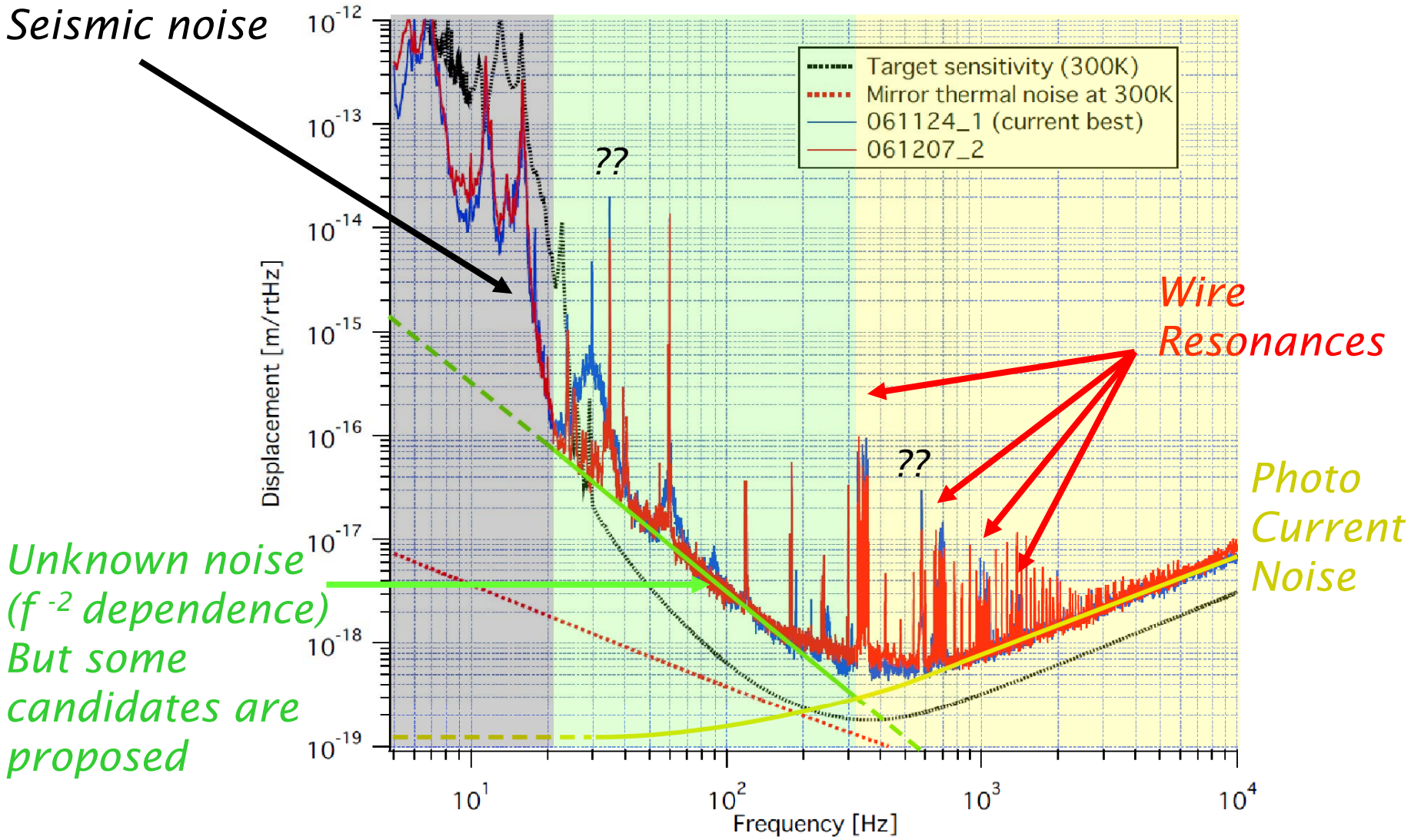

- Rotary pump in the middle of 100m duct was turned off
- The structures around 30Hz was reduced.

# Displacement Noise
## *- what we learn ? -*

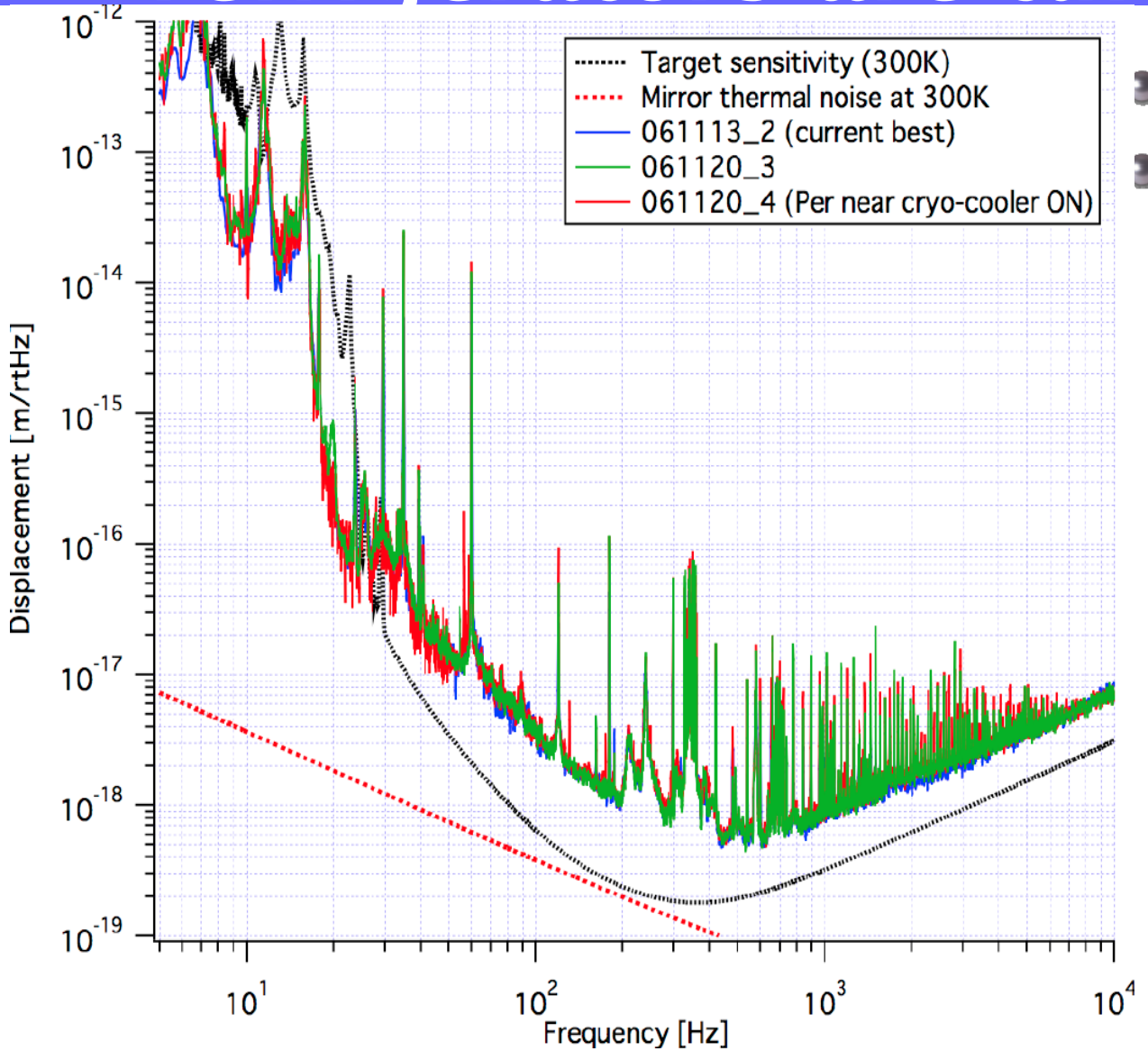
*-What we knew did not limit the sensitivity.*
*-What we did not know and not be prepared did limit the sensitivity (Sound, Vibration of PD optics, Scattered light from in the duct)*



# Displacement Noise
## *- noise estimation -*

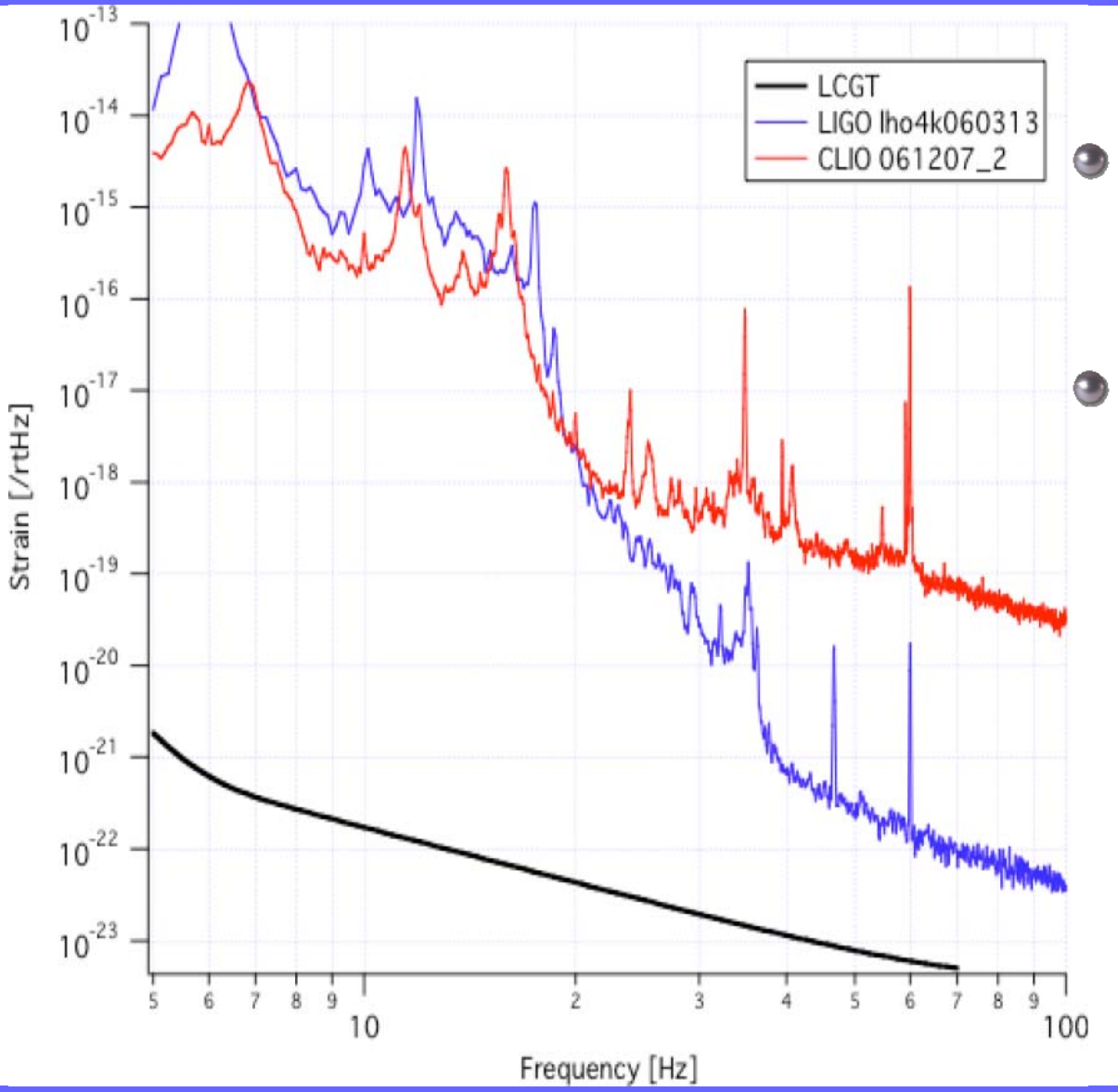


# How change when the refrigerators are turned on ?




- No change.
- Note that the sensitivity is not current best (but very near) and that mirrors themselves are not cooled.

# How about “strain” sensitivity ?




- Below 20 Hz CLIO strain is less than LIGO.
- GWs from pulsars and bursts GWs could be competitive scientific subjects with the present km-scale GWDs.

# Summary of CLIO

- *CLIO cryogenic system requirements for the cryostat, the cryogenic mirrors and the ultra-low vibration refrigerators are almost accomplished except for the miss-estimation of the radiation heat from the radiation shield. The practical remedy for this, however, was presented in Tomaru's talk.*

- *Displacement noise of CLIO is within 4 times of the targeted level. Some improvements of suspension wires and electronics are necessary.*

- *During noise hunting of CLIO, many practical unexpected noise sources were firstly identified in a Japanese GWDs. Especially less than 30Hz, CLIO displacement is world best, and our experiences should contribute the present and the future world km-scale GWD performance.*