Current status of CLIO

Cryogenic Laser Interferometer Observatory

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&
CLIO/TAMA collaboration

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Rikkyo University
2009/03/29

Introduction of CLIO

- *Laser interferometric GW detector with 100m arm cavities.*
- *Sited in Kamioka mine.*
- *Cryogenic cooled sapphire mirrors.*
    - *Under 20K.*
- *Constructed during 2002-2006.*
- *Full operation has started in 2006/02/18.*

LCGT & CLIO

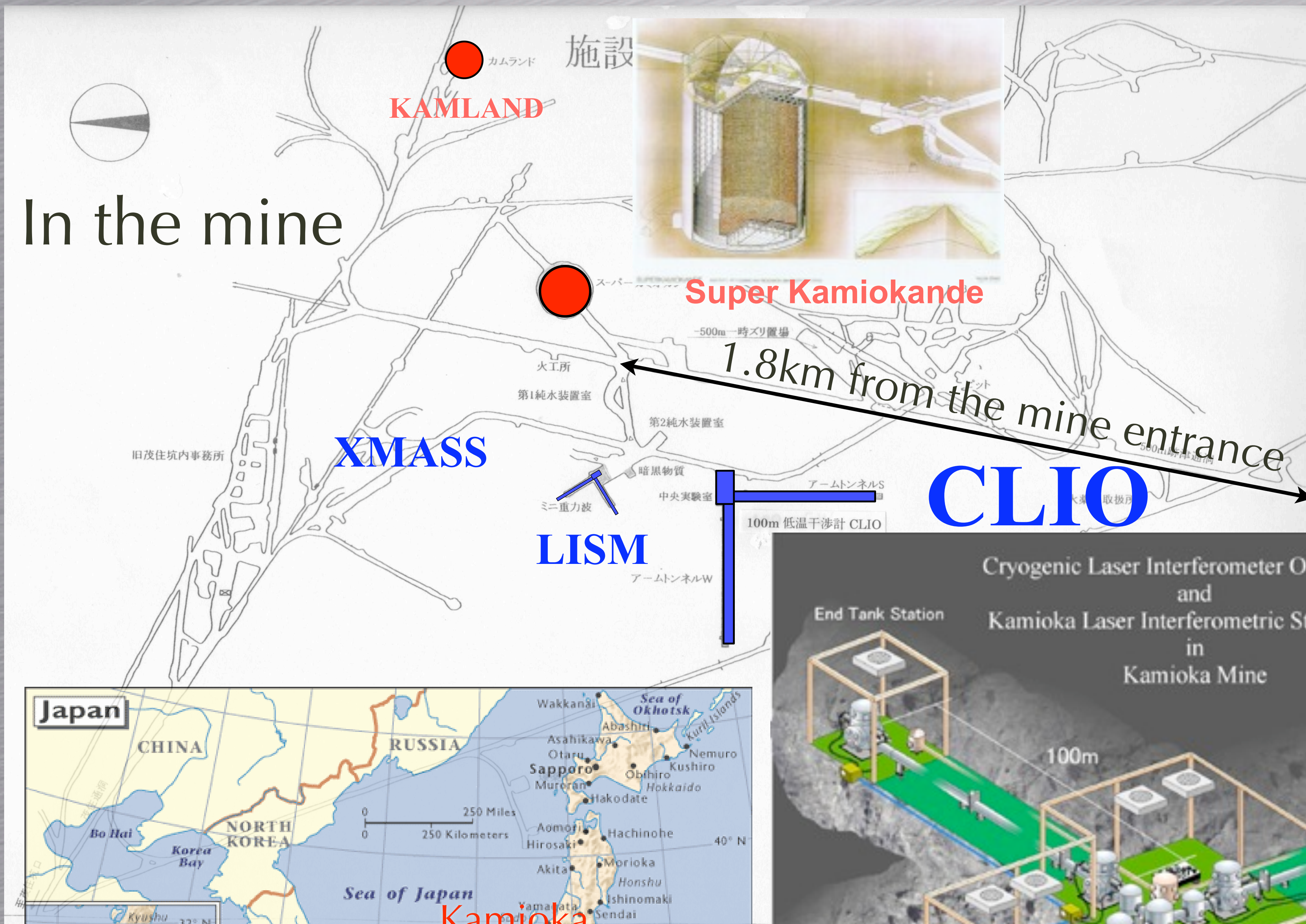
- *LCGT is a future project in Japan.*
  - *Large-scale Cryogenic Gravitational wave Telescope*
- *Laser interferometric GW detector with 3000m arm cavities.*
- *Sited in Kamioka mine.*
- *Cryogenic cooled sapphire mirrors.*
  - *Under 20K.*
- *GW from NS-NS binary coalescence can be detected several times in a year.*

Purpose of CLIO

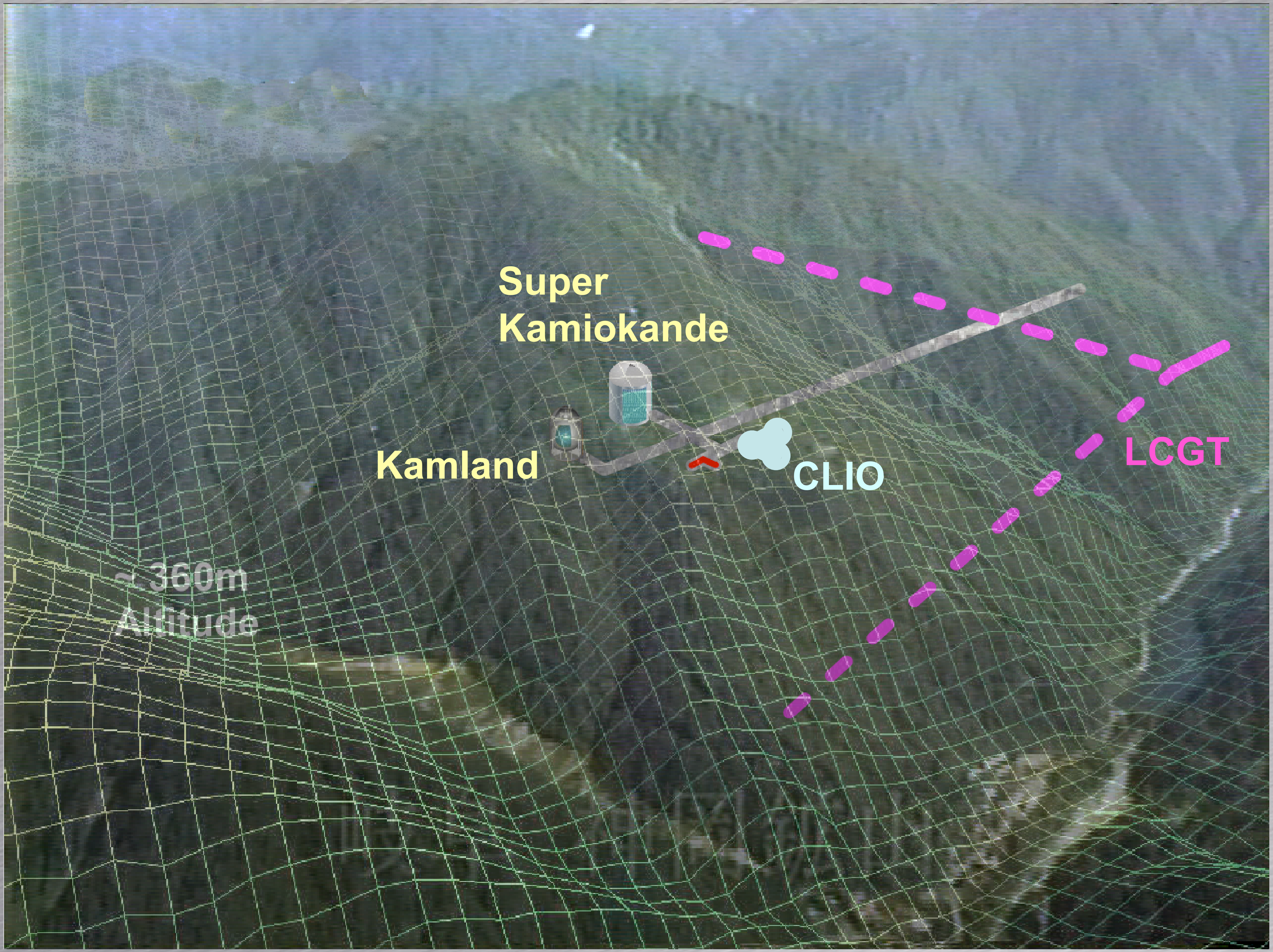
- *We wish the first detection of GW and starting the GW astronomy by LCGT.*
- *LCGT is a future project in Japan.*
- *The underground site and the cryogenic mirrors are key features of LCGT.*
- *The prime purpose of CLIO is demonstration of the keys.*

Where is Kamioka?

In the mine



Sky view of CLIO



New tunnel for CLIO

2002/12

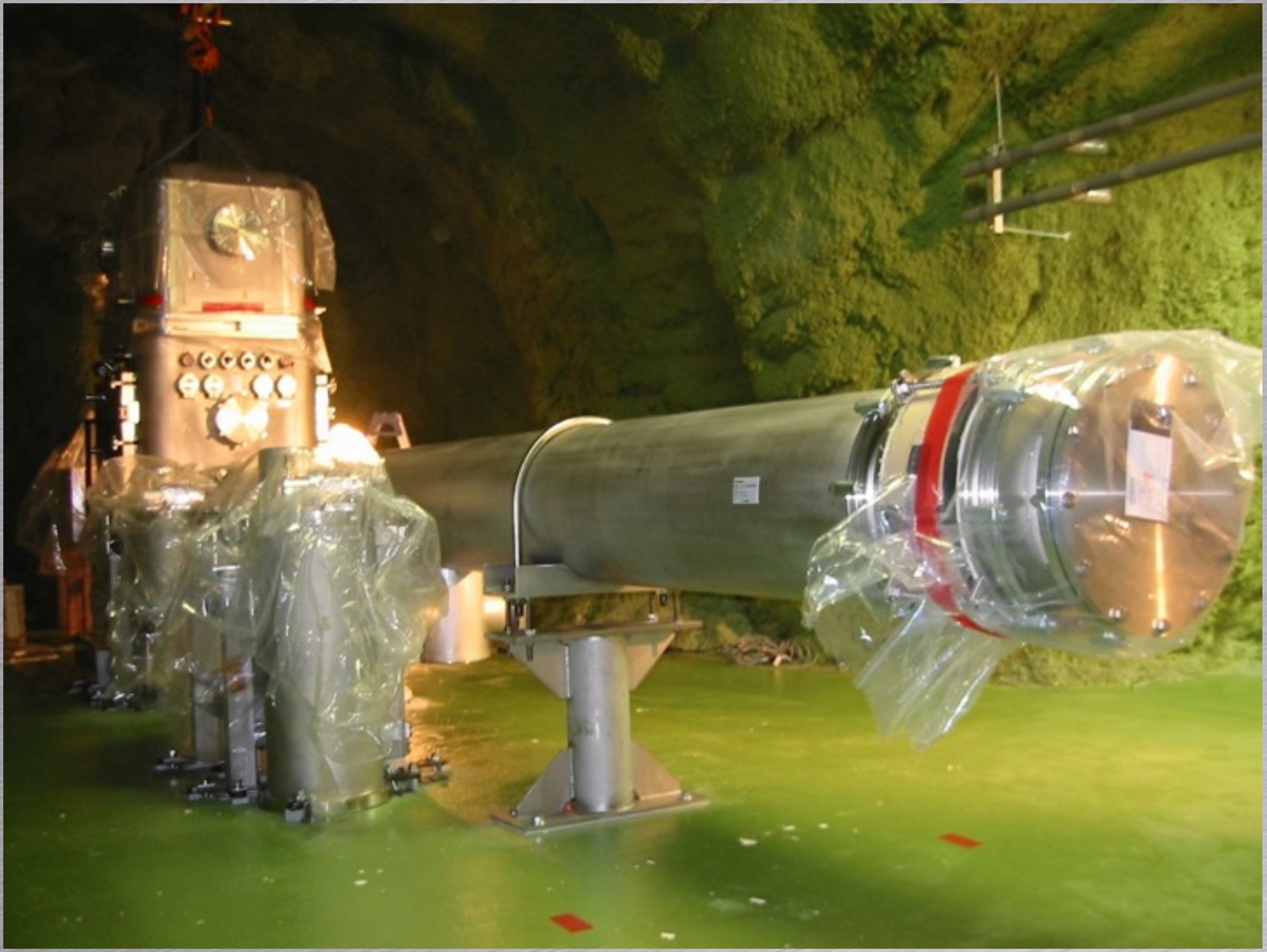
Strain meter

2003/08.

Start of CLIO construction

Mode Cleaner install. 2003/12.

The 1st cryostat install



The inline end cryostat has been installed. 2004/09.

One arm has been completed.

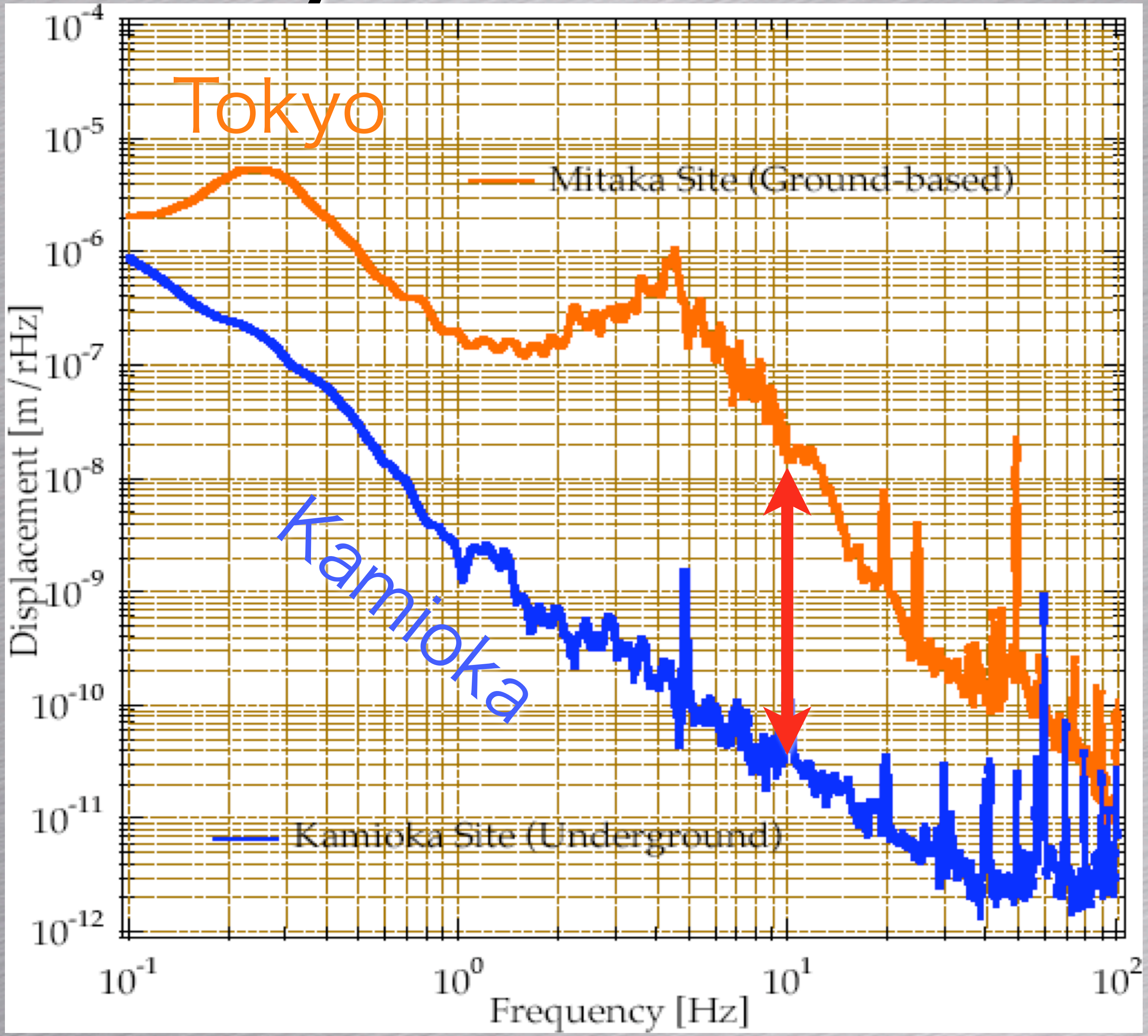
Perpendicular arm has been completed. 2005/02.

Vacuum system completed

2005/06

I would like to thank Mr. Sato (Ultra Finish Technology), Mr. Imura (SETEC) and Mr. Ichimura (TI) for assembling the vacuum system.

Why Kamioka?



Amplitude of seismic motion

More than 100 times smaller seismic noise.

Quite stable temperature & humidity.

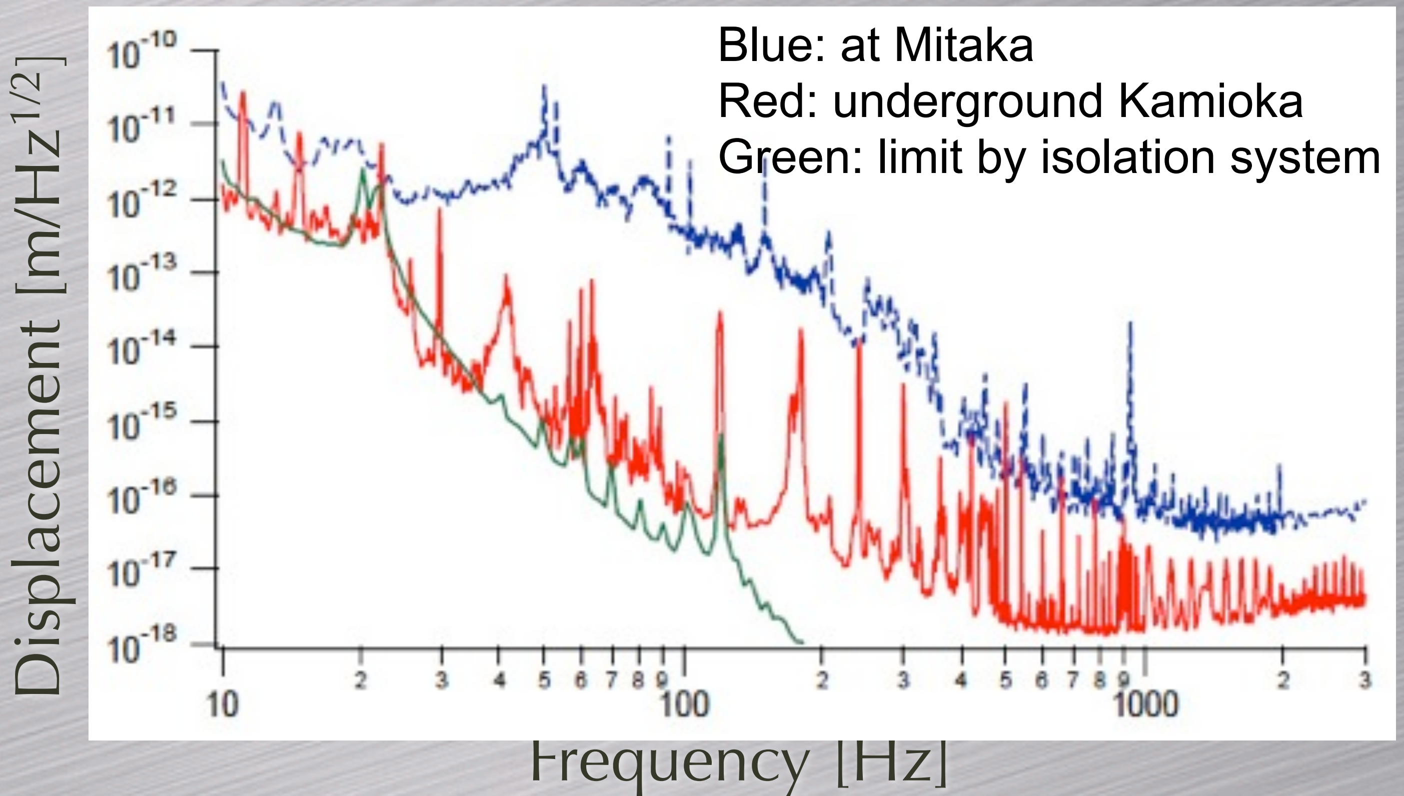
Kamioka observatory

- Kamioka observatory, ICRR.
- Established in 1983 for Kamiokande experiment.
- We are supported a lot of things, infrastructure, safety management, facility and so on.

http://www-sk.icrr.u-tokyo.ac.jp/index-e.html

LISM project

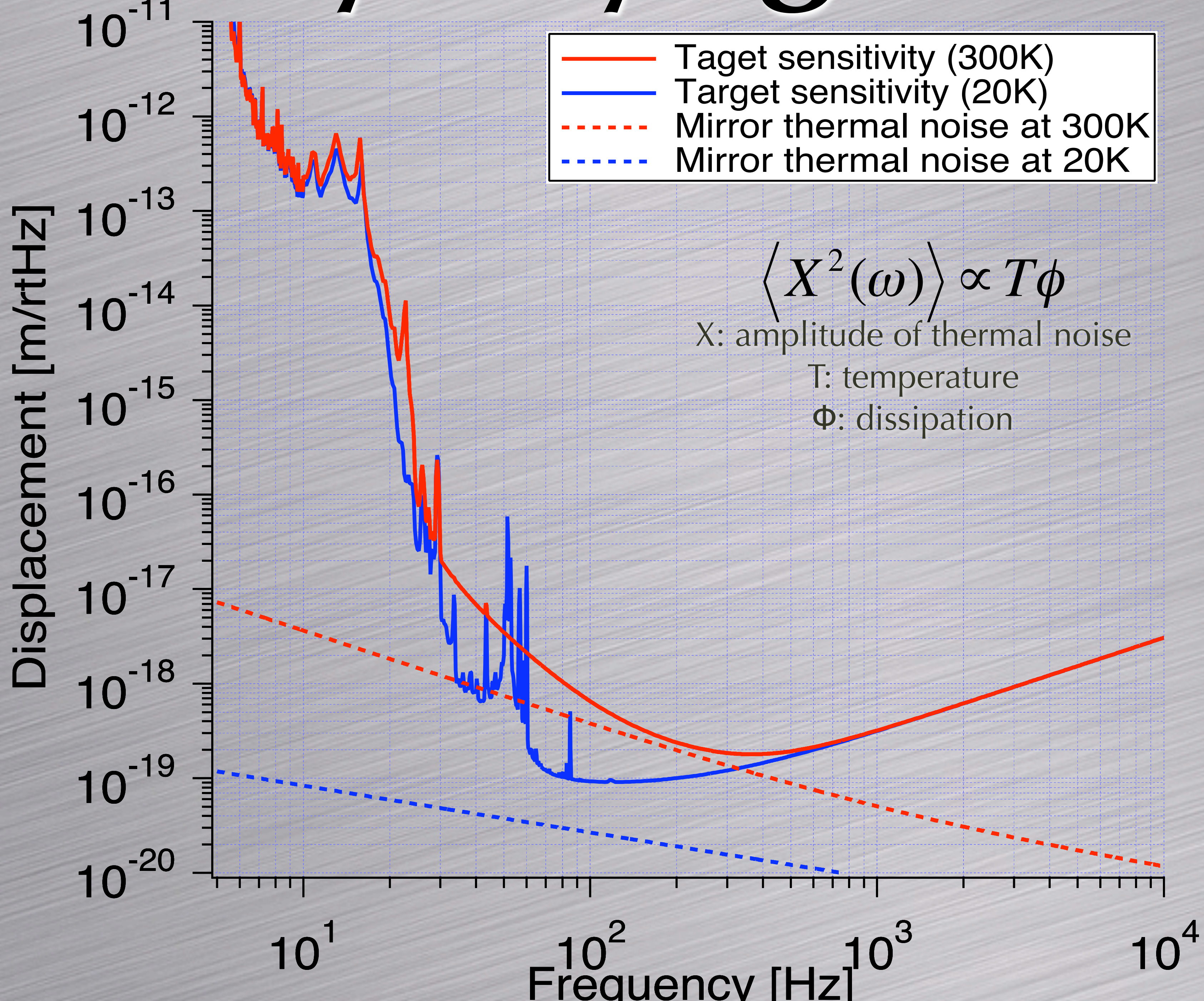
- LISM project (1999-2003)
- Pioneer of GW detector in underground site.
- 20m prototype at NAOJ Mitaka replaced to Kamioka mine.



LISM displacement sensitivity

10^{-16}m/Hz$^{1/2}$ at 100Hz

Why cryogenic?



CLIO target sensitivity curve

10 times smaller thermal noise is available.

The best solution for thermal lensing effect.

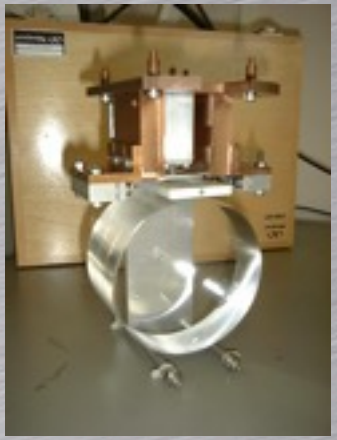
Difficulties of cooling

- Mirrors are always heated by laser absorption.
  - Mirrors are in high vacuum (10^{-5}Pa) and low temperature.
    - No convection and no radiation for heat transfer.
  - Mirrors are vibration isolated.
  - Low suspension thermal noise is necessary.
- Contamination, mirror control and so on.

Difficult but challenged!

History of cryogenic mirrors Japan original!!

1997 Stating of feasibility study at KEK. Sapphire mirror & fiber suspension.

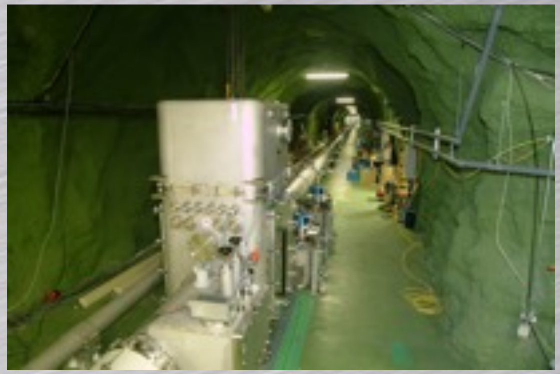


10cm

2001 CLIK: Control of cryogenic Fabry-Perot cavity at Kashiwa.

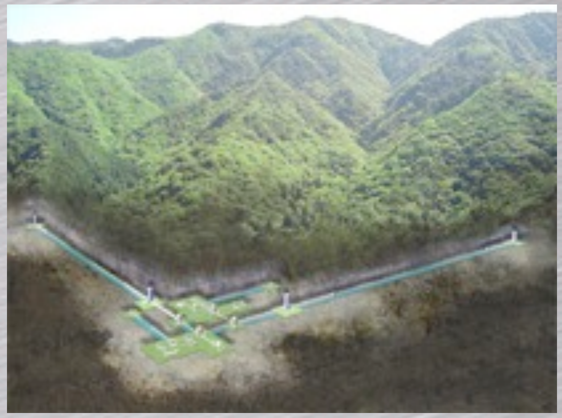
7m

2002~ CLIO: Sensitivity of cryogenic GW detector.



100m

201? LCGT: Detection of Gravitational wave.

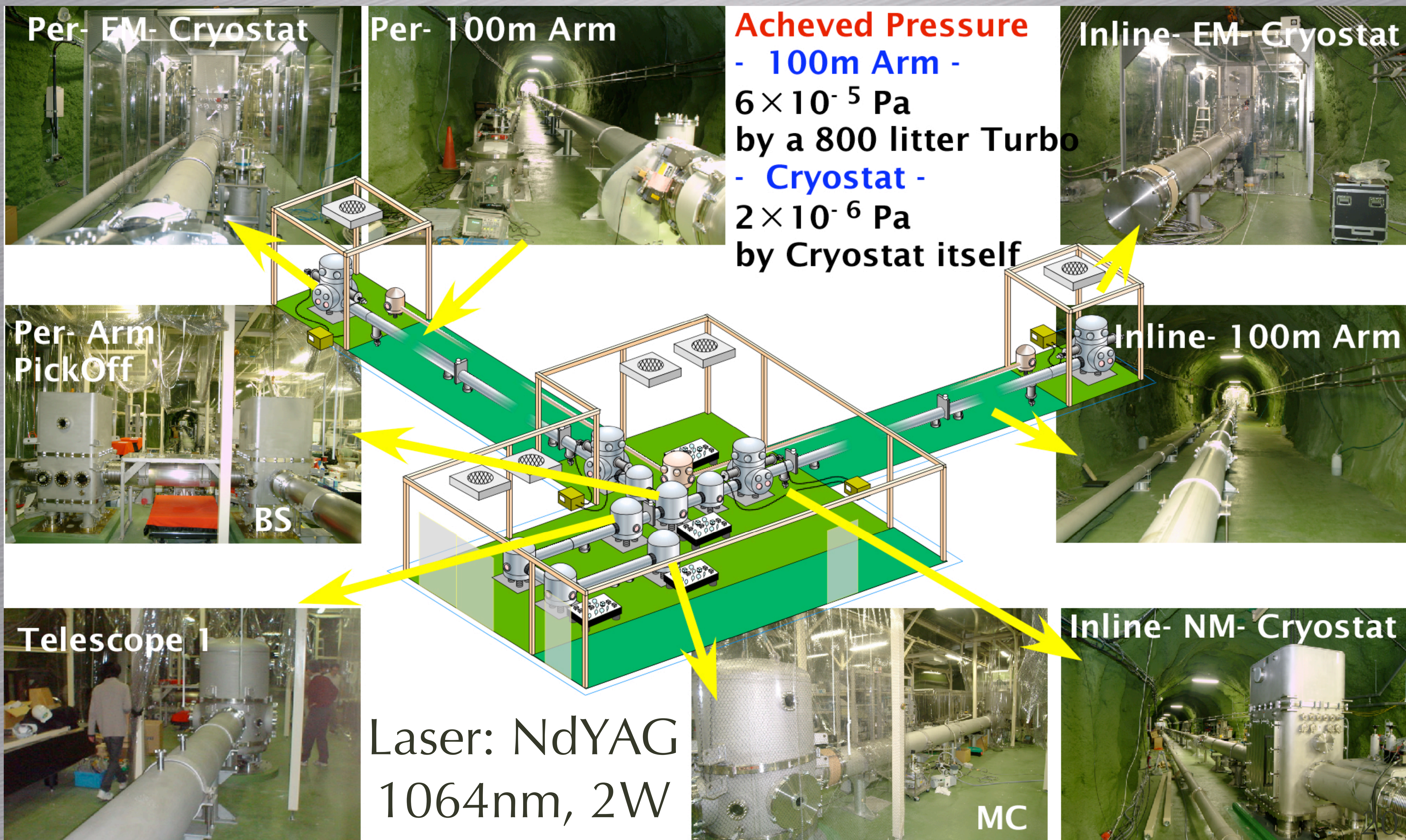


3000m

History of CLIO

- *Constructed during 2002-2006.*
- *Full operation started from 2006/02/18.*
- *2006: Noise hunting at 300K.*
  - *not reached the mirror thermal noise.*
  - *80 hours data take in 2007/02.*
    - *Vela pulsar(22Hz) upper limit: 5.3×10^{-20}.*
- *2007: Full cryogenic operation.*
  - *All mirrors were cooled about 14K.*
  - *Sensitivity did not improved.*
- *2008: Noise hunting at 300K.*
  - *Toward the mirror thermal noise again.*

CLIO



Acheved Pressure

- 100m Arm -

6×10^{-5} Pa

by a 800 litter Turbo

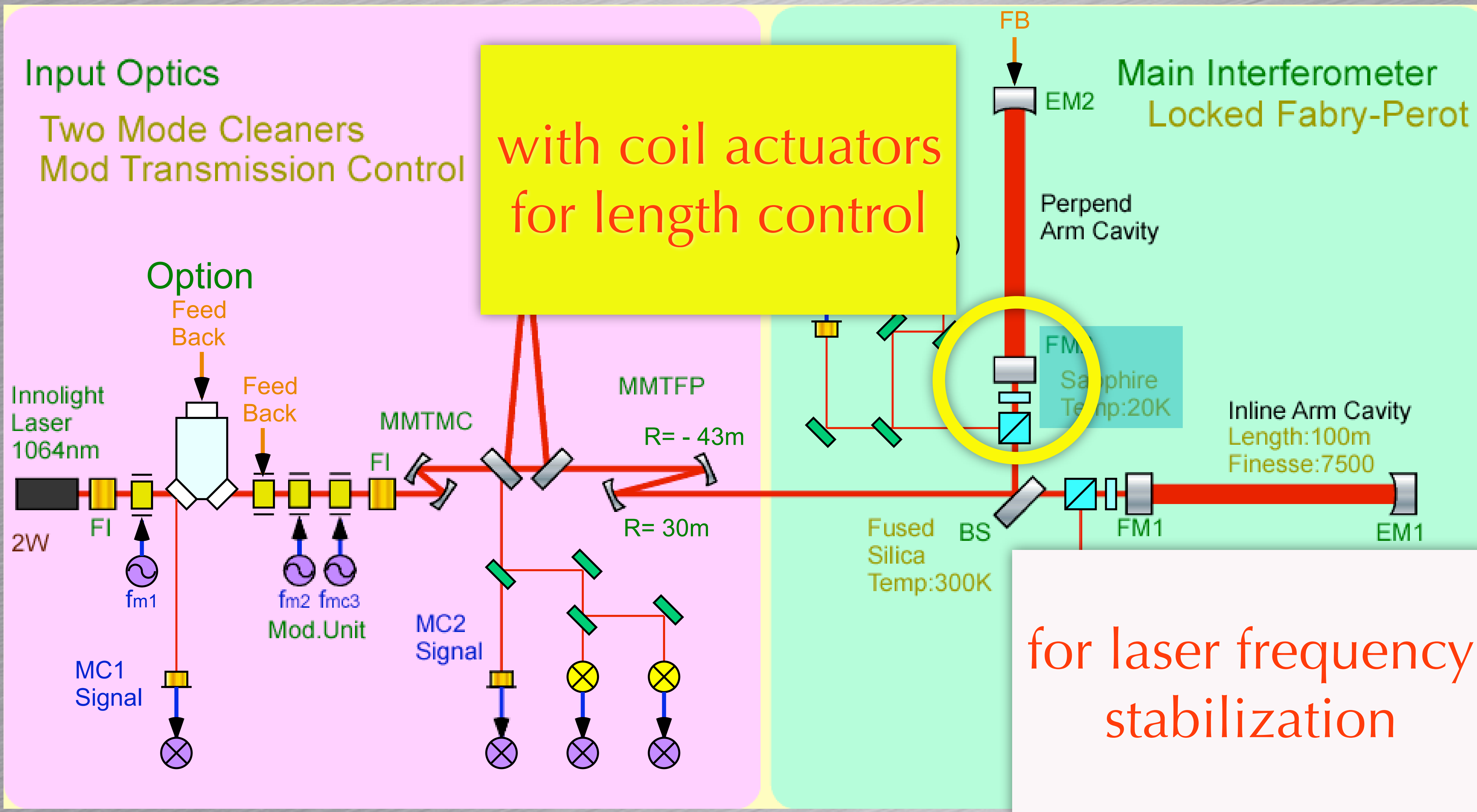
- Cryostat -

2×10^{-6} Pa

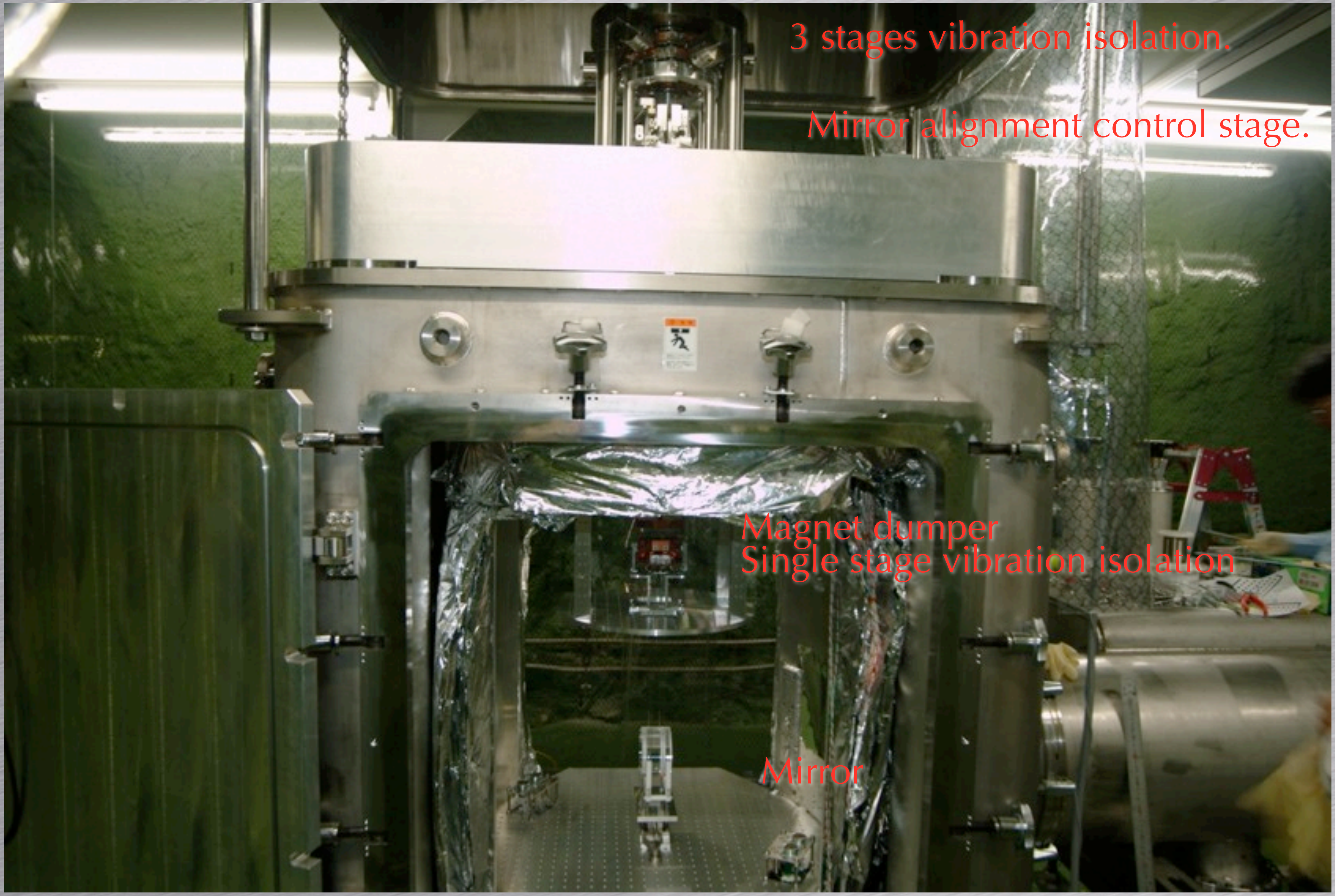
by Cryostat itself

Laser: NdYAG
1064nm, 2W

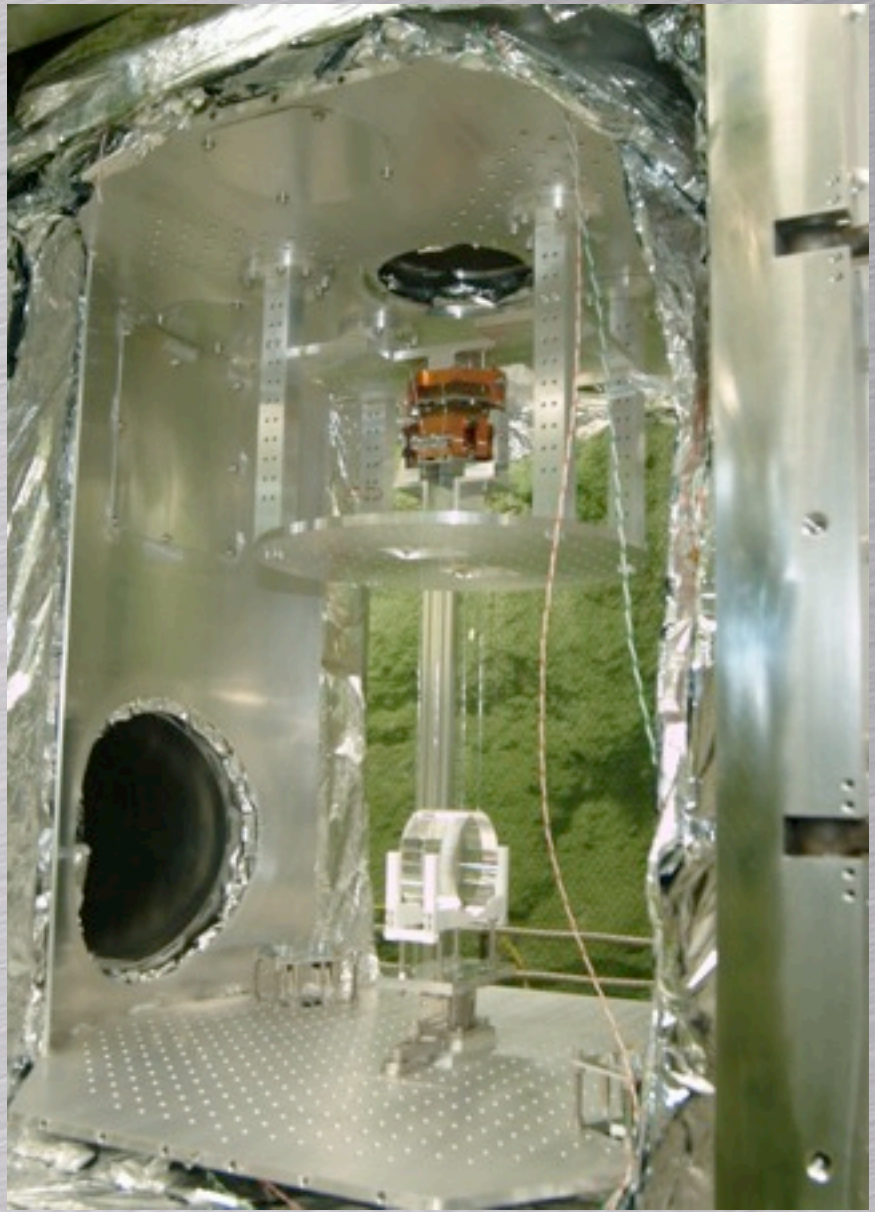
Optical configuration



Cryostat and Suspension

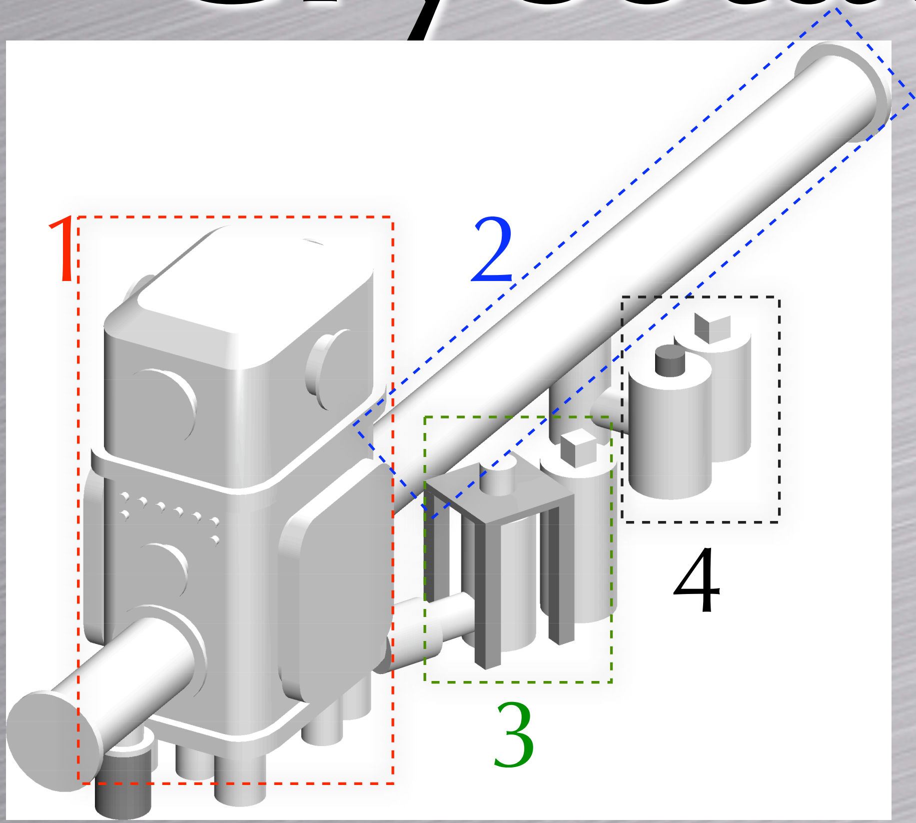


Suspension

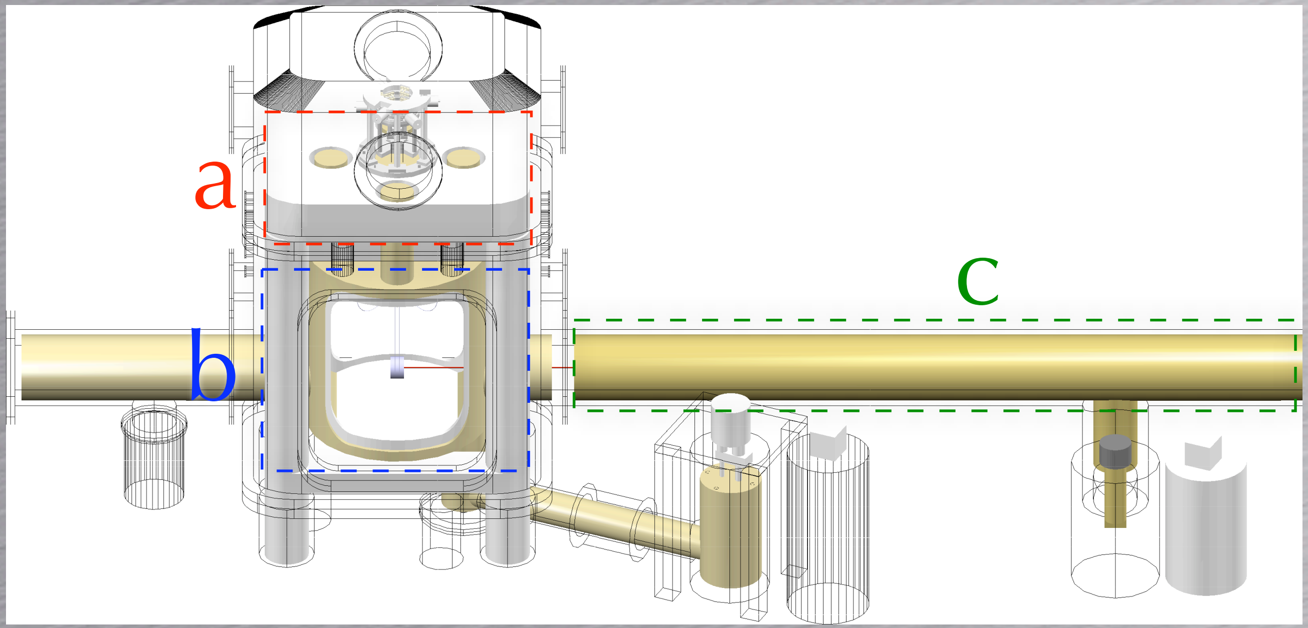


Sapphire mirror
Φ100×60

Cryostat component



Outside of the cryostat
(for the end mirror)

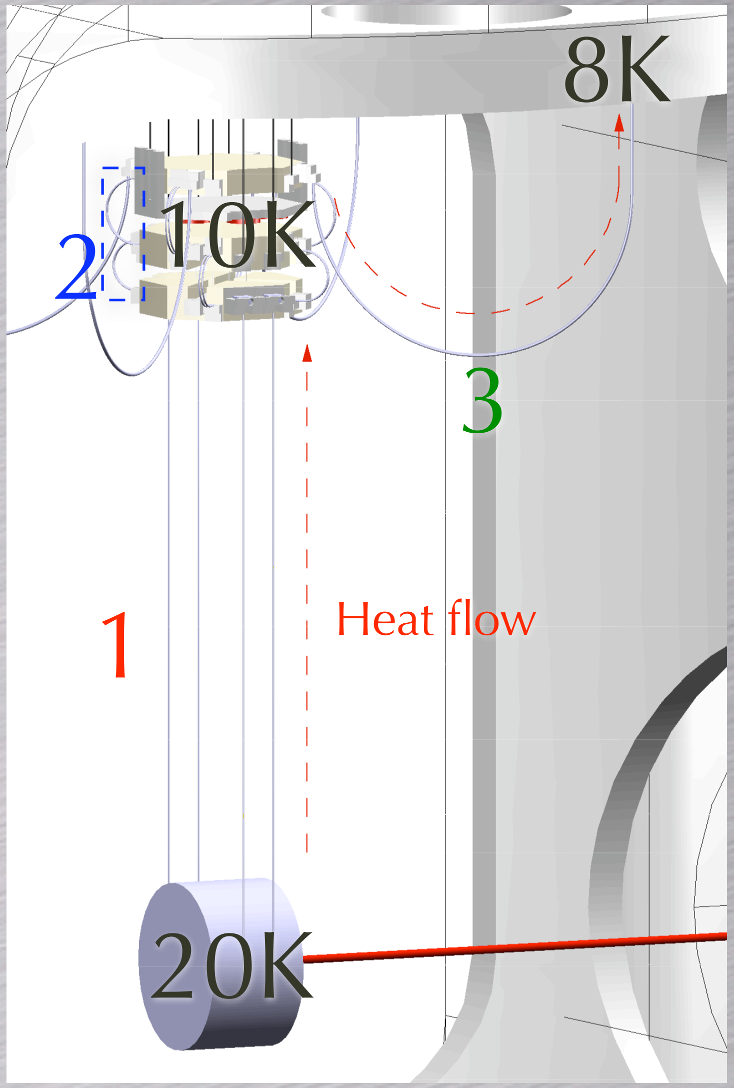


Inside of the cryostat

- 1: Mirror tank
  - 1300×900×2500, weight: 4t
- 2: Cryogenic vacuum pipe
  - In oder to reduce radiation heat.
  - ϕ300×500
  - The tanks for the near mirror have two cryogenic vacuum pipes at the both sides.
- 3: 4K 2 stage PT refrigerator, 0.5W at 4K.
- 4: 80K PT refrigerator, 100W at 80K.
- a: Suspension stage
  - The suspension base is put on this stage.
  - 300K
- b: Radiation shields
  - There are two shields in the tank.
  - Outer (gold): 100K, Inner (silver): 8K.
- c: Radiation shield
  - There is one shield in the pipe.
  - 100K

Cooling the mirror

- Only thermal conductivity can be used for heat transfer.
- Heat links must be connected between the suspension and the cryostat shield.
- The heat links also transfer vibration at the shield to the suspension. Vibration isolation of the heat link is necessary.



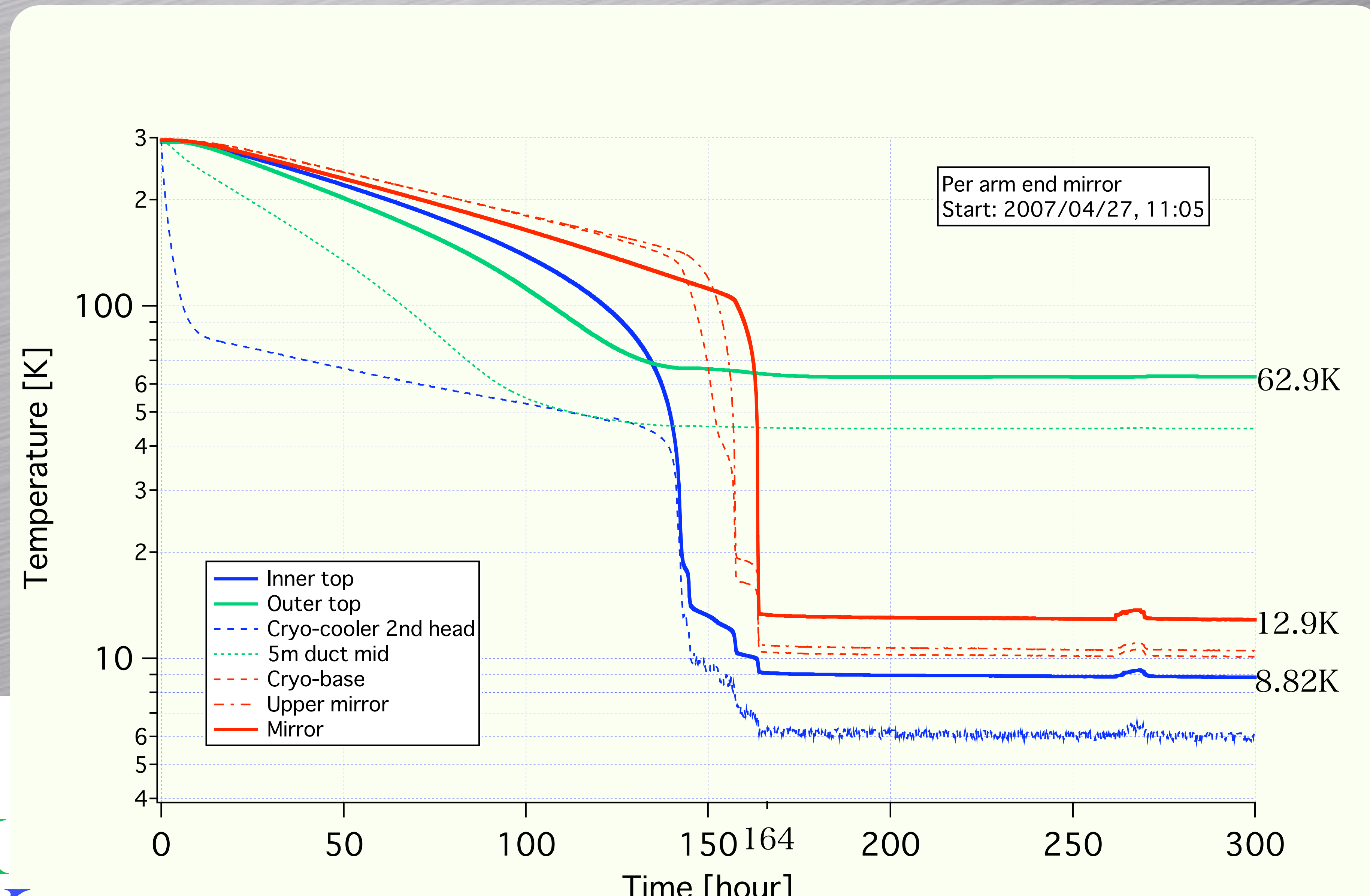
1 : Sapphire fiber or Aluminum wire

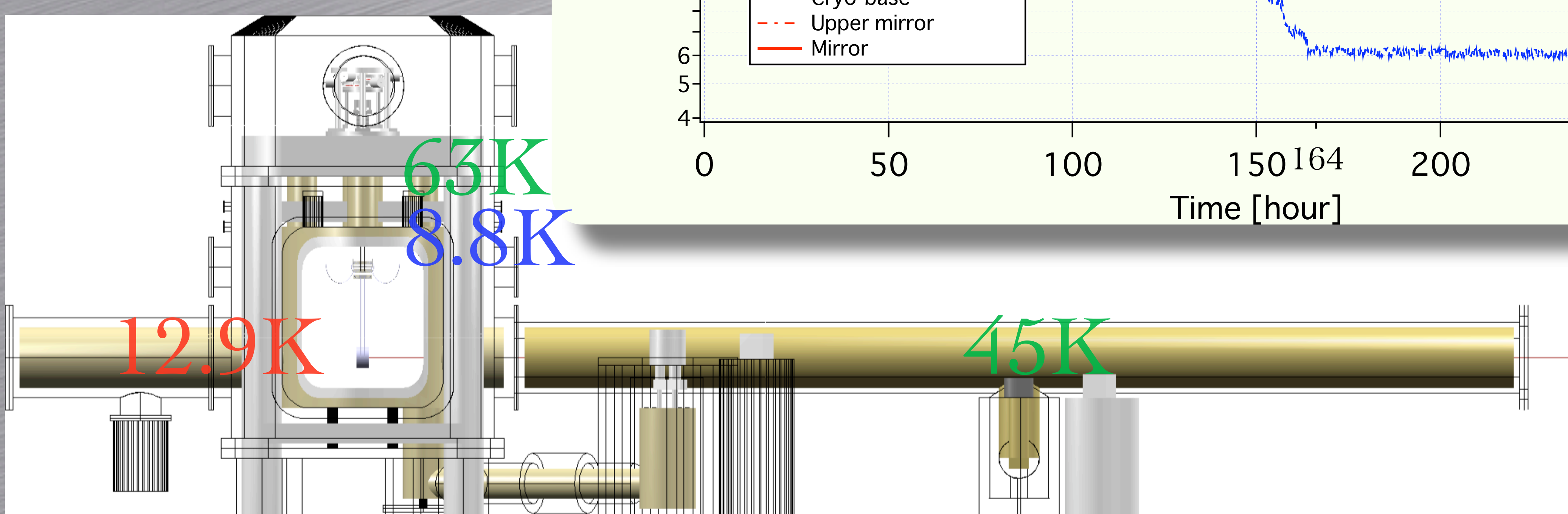
2 : Aluminum wire

3 : Aluminum wire

Heat in the mirror goes to the shield through the thermal conductors 1, 2 and 3.

Cooling example



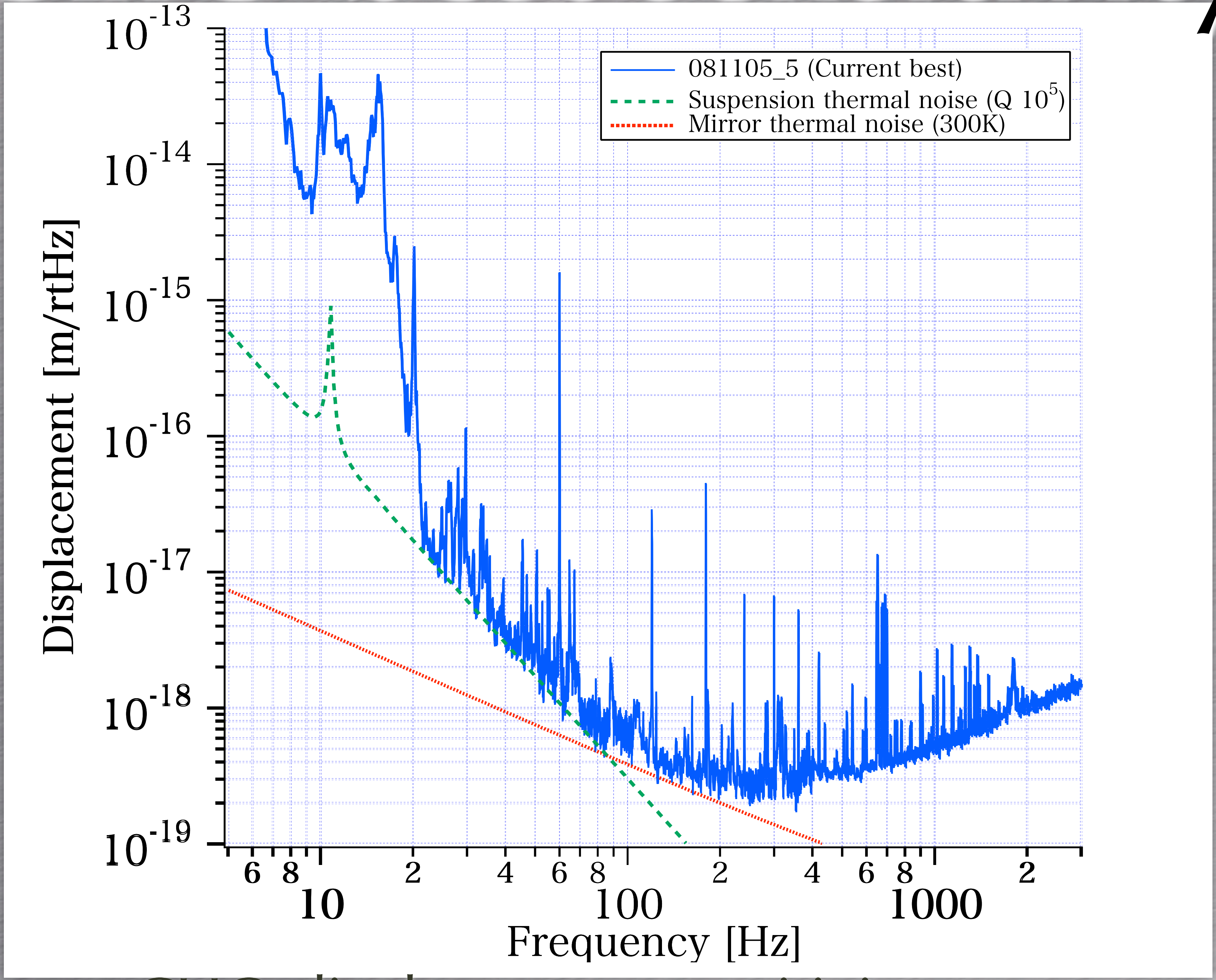


Summary of cooling in 2007

Mirror	Cooling time	Mirror temp	Heat in the suspension	Heat at the 1st cooling 2006/02
Inline end	176hour start 07/06/22,10:00	13.5K	40mW	N/A
Inline near	174hour start 07/06/22,10:00	13.4K	36mW	N/A
Per arm end	164hour start 07/04/27,11:05	12.5K	62mW[#1]	116mW
Per arm near	193hour start 07/08/16,12:30	13.8K	29mW	109mW

#1; No shield for radiation from the outer shield at 63K.

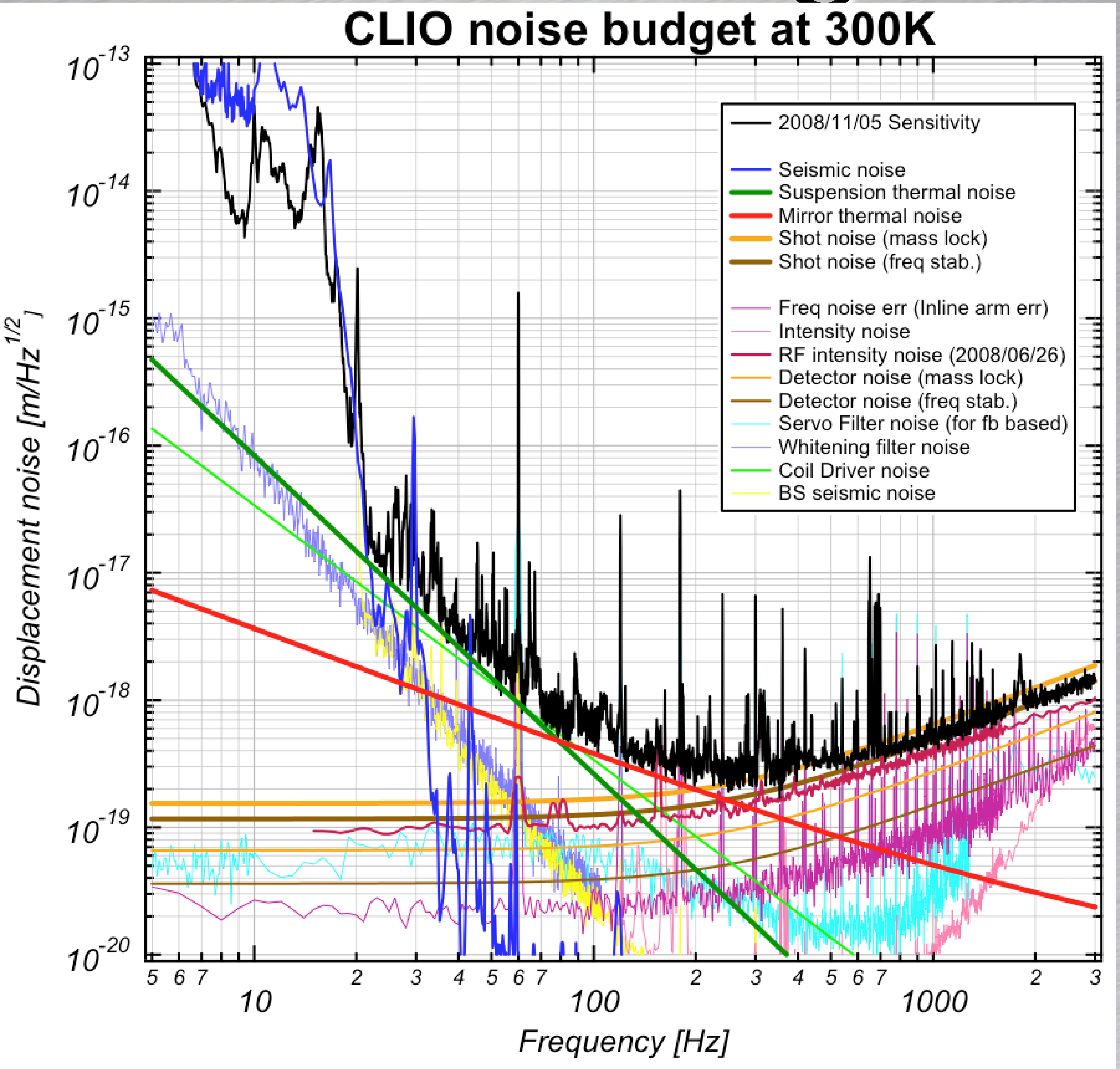
CLIO best sensitivity



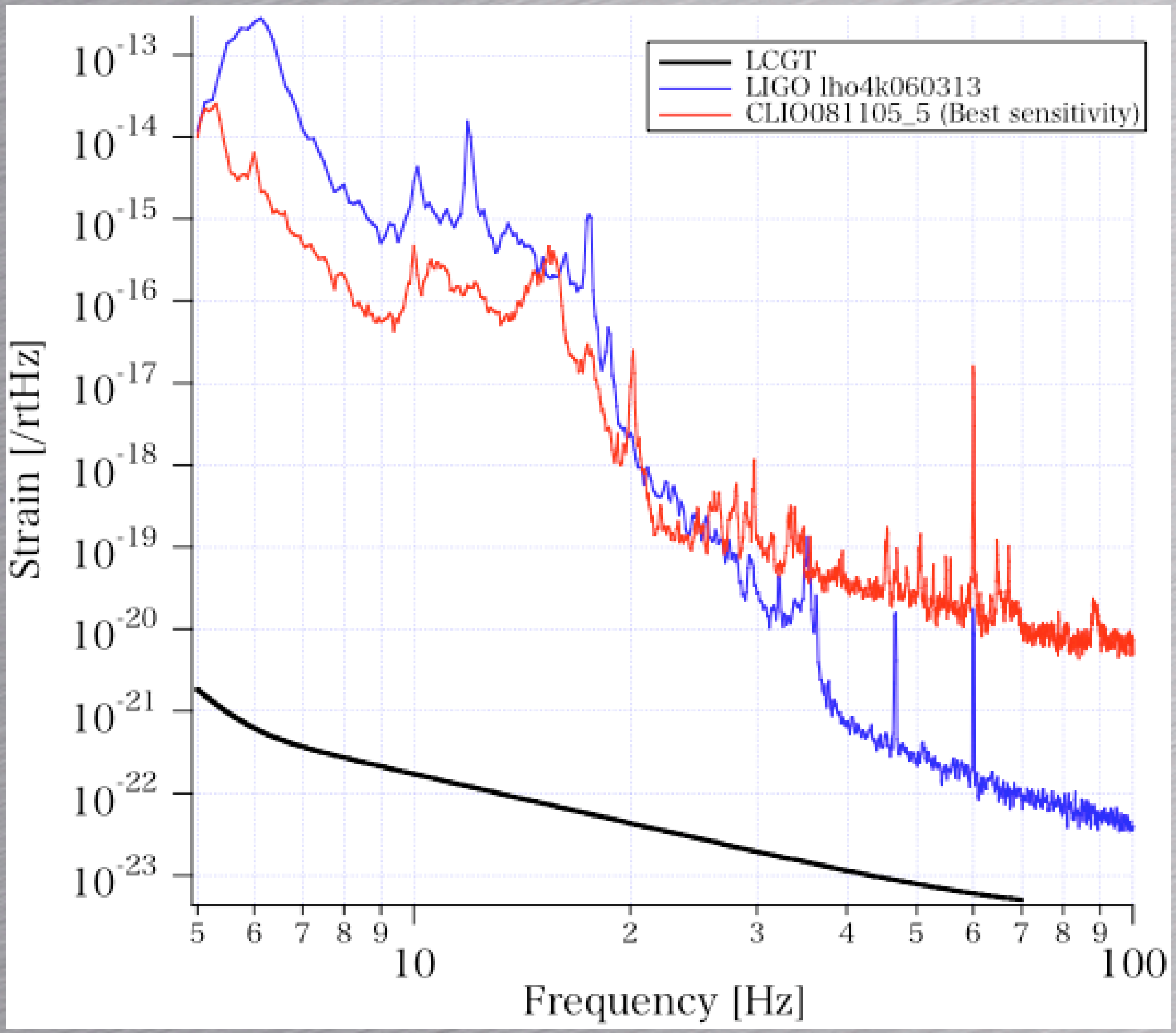
CLIO displacement sensitivity curve

Reach the thermal noises!!

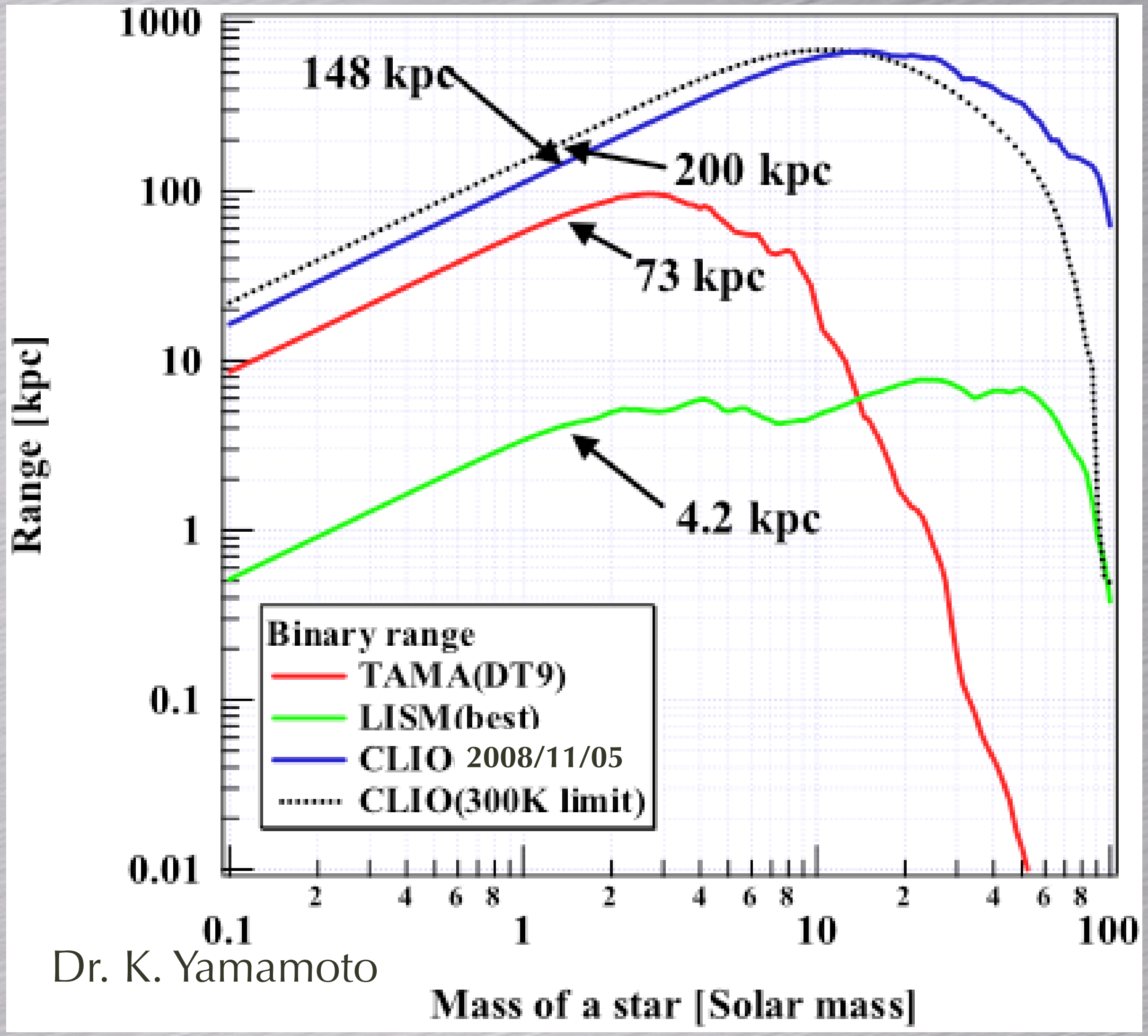
Noise budget



GW sensitivity



Strain sensitivity



Observation range for compact star binary coalescence

Comments about sensitivity

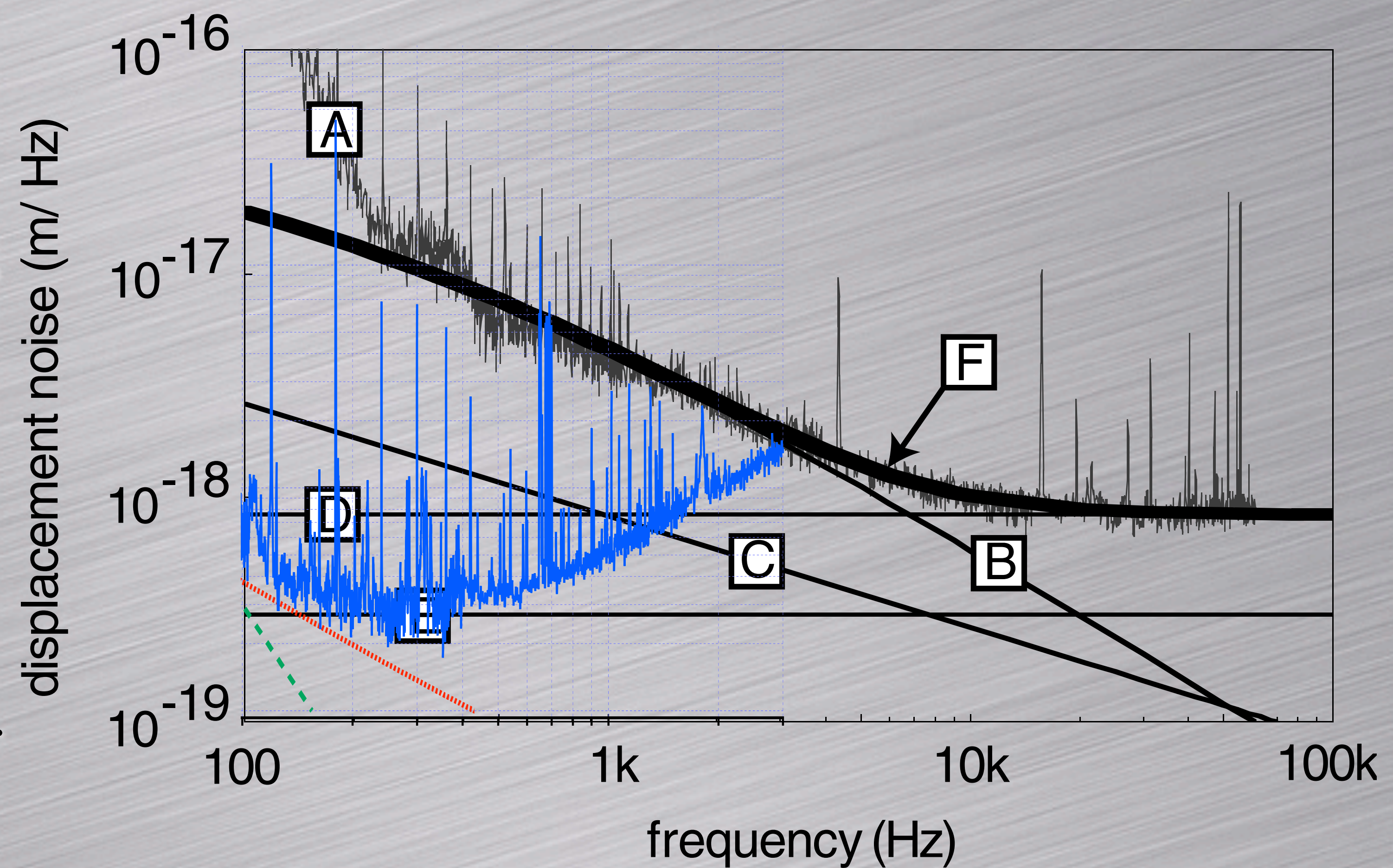
- DC ~ 20Hz: limited by the seismic noise.
  - -110dB of Vibration isolation ratio at 20Hz.
  - Comparable “strain sensitivity” with LIGO 4km.
  - Less than 0.1% of Vertical - Horizontal coupling (1% assumed for design).
  - Value of Kamioka site was shown again following LISM.
- 20 ~ 80Hz: limited by the suspension thermal noise.
  - 10^5 of pendulum Q measured by wire resonances at 700Hz.
  - (May be) the 1st observation by a GW laser interferometer.
- 80 ~ 200Hz: limited by the mirror thermal noise.
  - Major dissipation source is thermoelastic damping of the sapphire substrate.
  - The amplitude is determined by material properties and the beam spot size.
- Above 200Hz: the laser shot noise.
  - Unfortunately laser power was down to half at that time.
  - We got new one. Recovering interferometer is going now.

CLIO is a fundamental noise limited interferometer.

We are ready to see the thermal noise reduction by cooling.

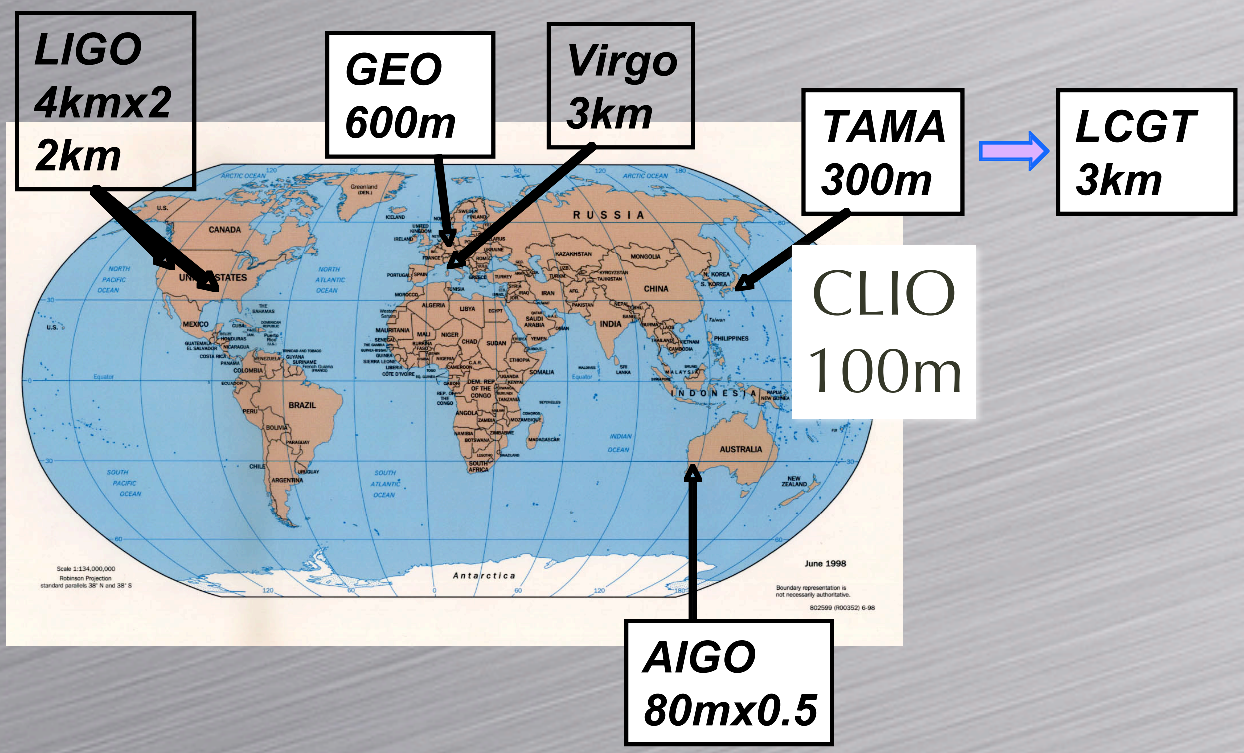
Sapphire mirror thermal noise

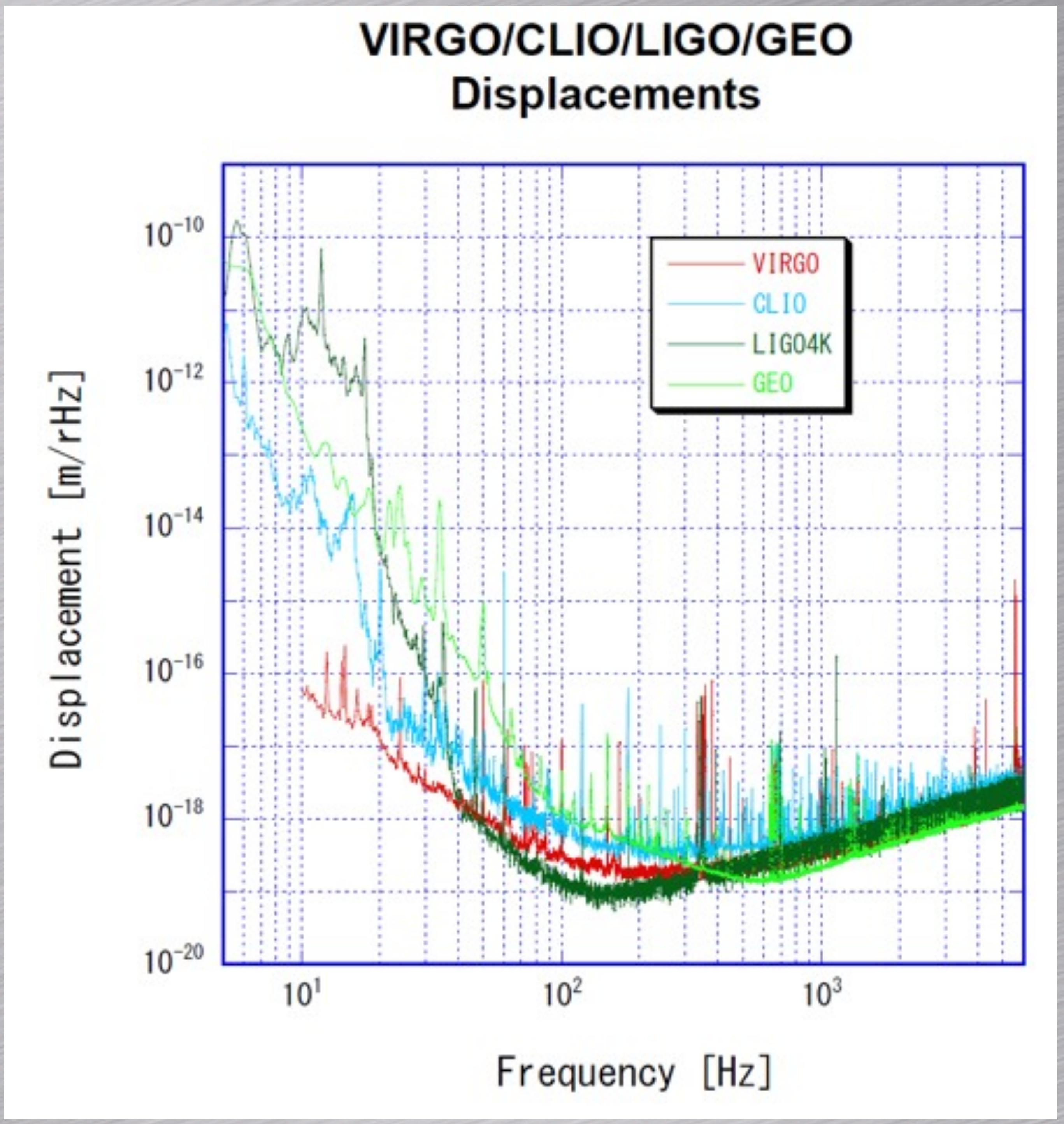
- Sapphire mirror thermal noise caused by thermoelastic damping has already observed.
- The measured amplitude is consistent with theoretical prediction.
- Difference is only beam spot size.
  - CLIO: 4.9mm and 8.5mm.
  - Black et al.: 0.16mm.



Eric D. Black et al., "Thermoelastic Damping Noise from Sapphire Mirrors in a Fundamental-Noise-Limited Interferometer", PRL 93 241101 (2004).

Compare with others





- CLIO displacement sensitivity is comparable with other detectors.
- VIRGO uses very low frequency vibration isolation system.
- LIGO & VIRGO uses larger beam spot and fused silica mirrors for small thermal noise.
- Long base-line is necessary to catch up “GW sensitivity”.

2009

- 300K
  - Recover the sensitivity after the laser replacement.
  - Short term observation for data analysis group.
  - Preparation for mirrors cooling with TAMA members.
- 20K
  - Cool the mirror one by one.
  - Try to see the thermal noise reduction!!

Summary

- CLIO is a laser interferometric GW detector with 100m arms.
- Kamioka site and the cryogenic mirrors are key features of CLIO and LCGT.
- Low seismic motion in Kamioka mine provides CLIO good sensitivity in low frequency region.
- The prime purpose of CLIO is sensitivity improvement by cooling the mirror about 20K.
- CLIO reached the suspension and mirror thermal noise at the room temperature in 2008.
- In 2009, we will cool the mirrors again.