CLIO Development in KAMIOKA and LCGT

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CLIO Overview

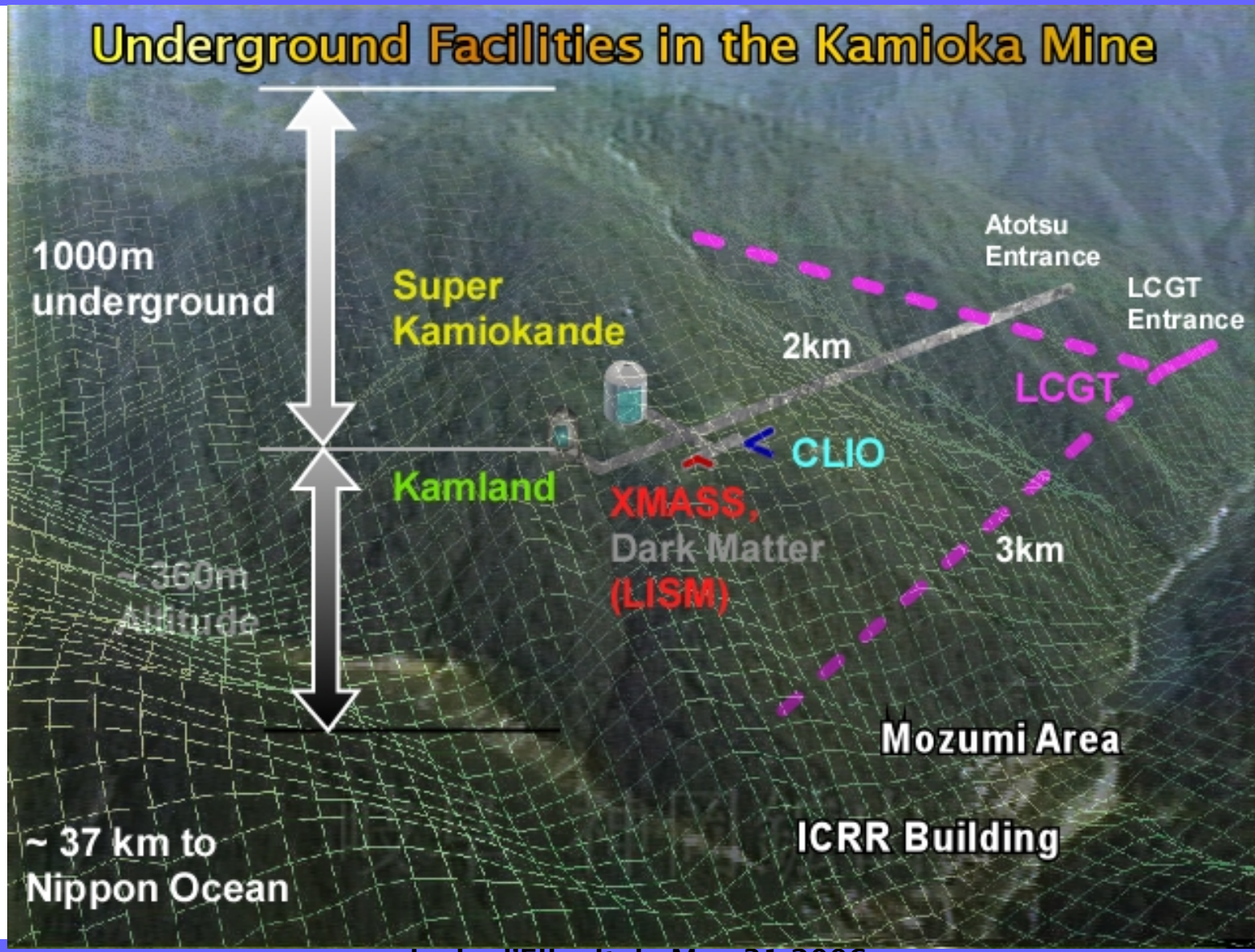
Cryogenic Laser Interferometer for Gravitational Wave

- 100m base-line Locked-FP style Proto-Type for LCGT.
- Reduced thermal noise limited sensitivity is targeted using sapphire mirrors and sapphire suspension fibers.
- Stable operation is expected owing to the low seismic noise of KAMOIKA mine.

Laser Strain-meter for Geophysics

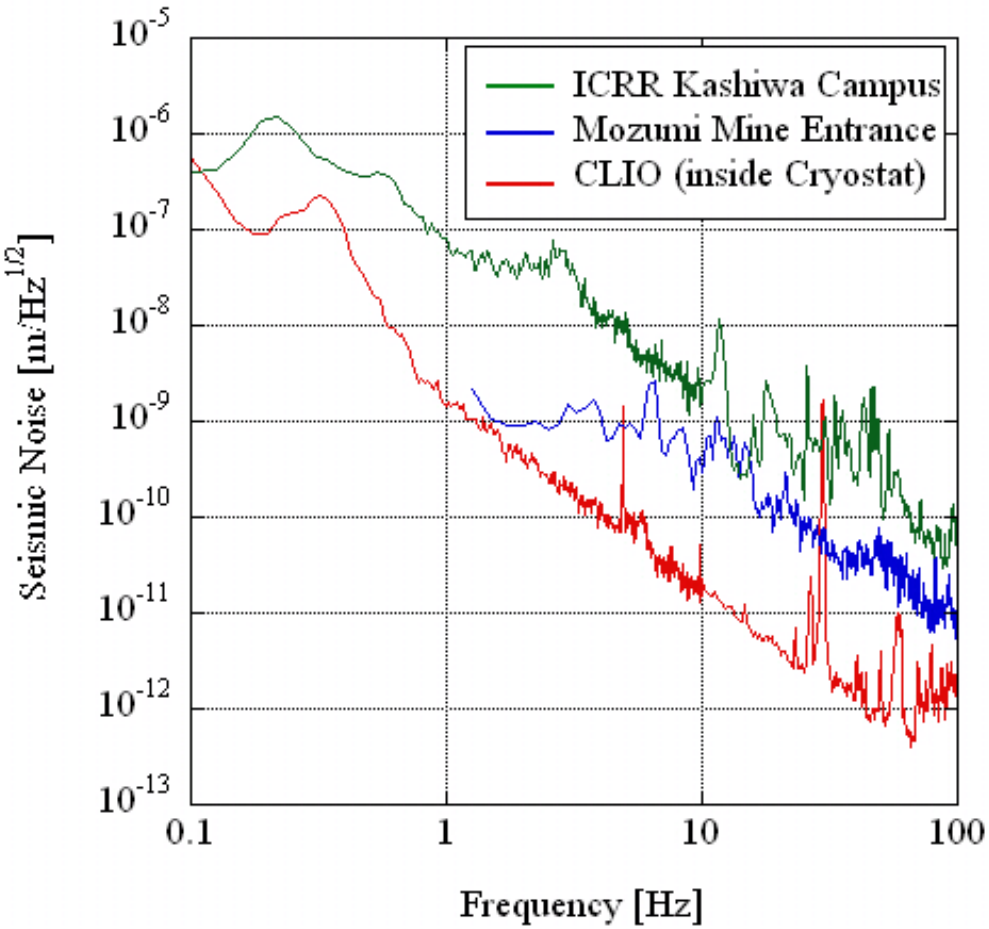
- 3 interferometers for the common, sheer, and absolute ground strain measurement with the world best sensitivity in the KAMOIKA mine.

Site


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

Design and Construction

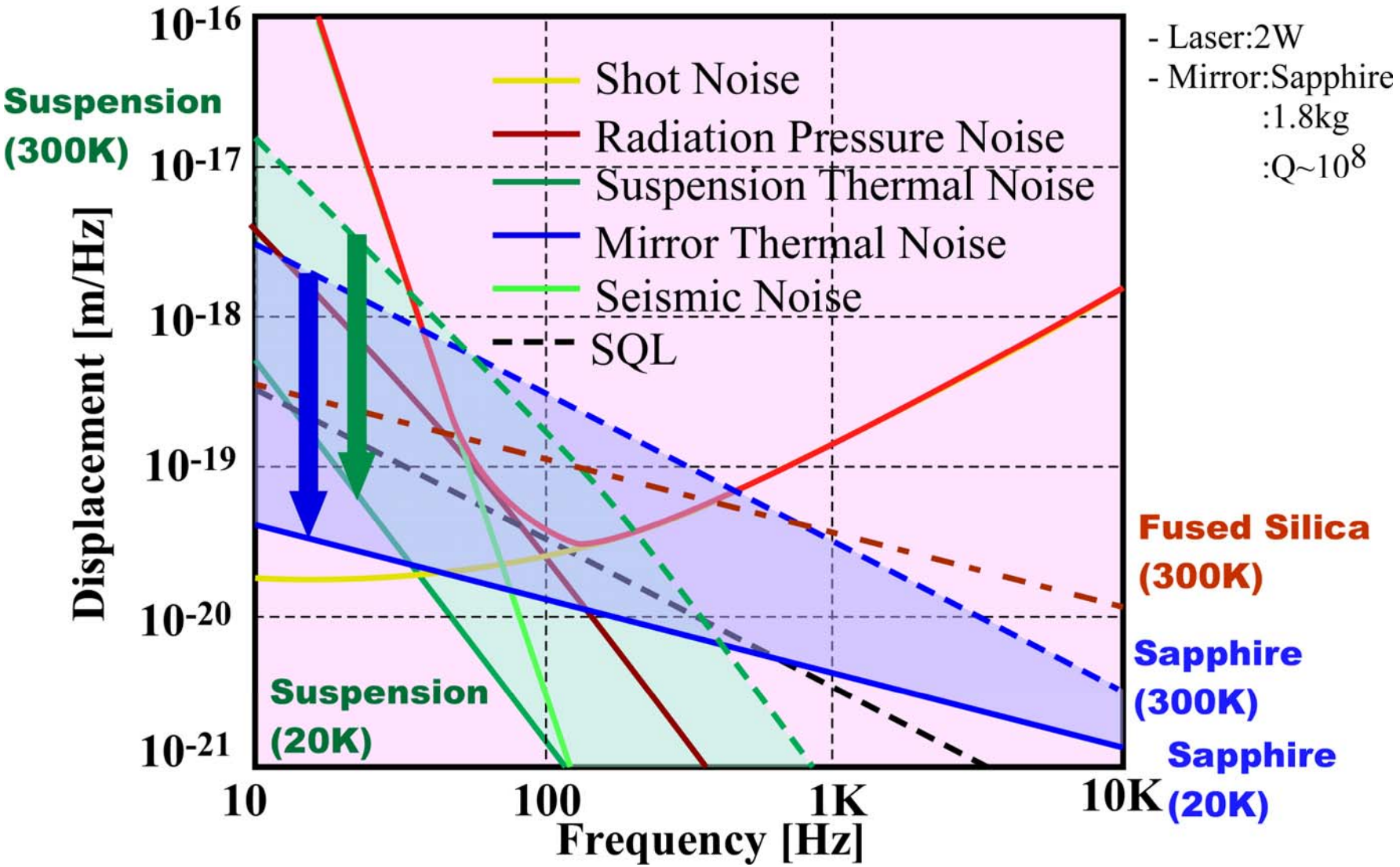
Seismic Noise Depth Dependency



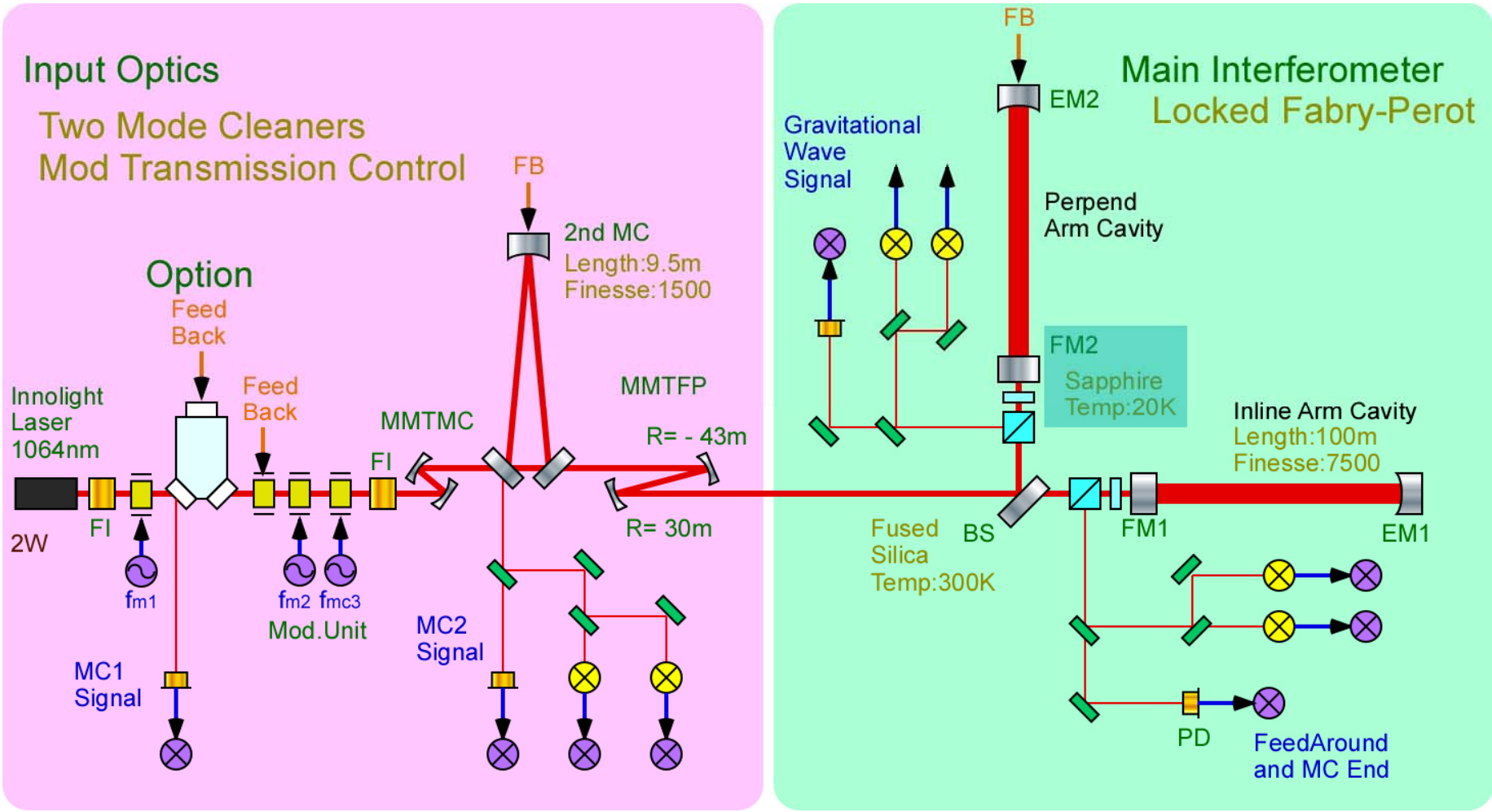
-Difference between the seismic noise on the surface and in the ground of the isolated area is distinguishing above 1 Hz.

- Although the CLIO has 1000m ground (rock) cover, 100m ground cover is verified to be enough to obtain the same seismic noise level with CLIO.

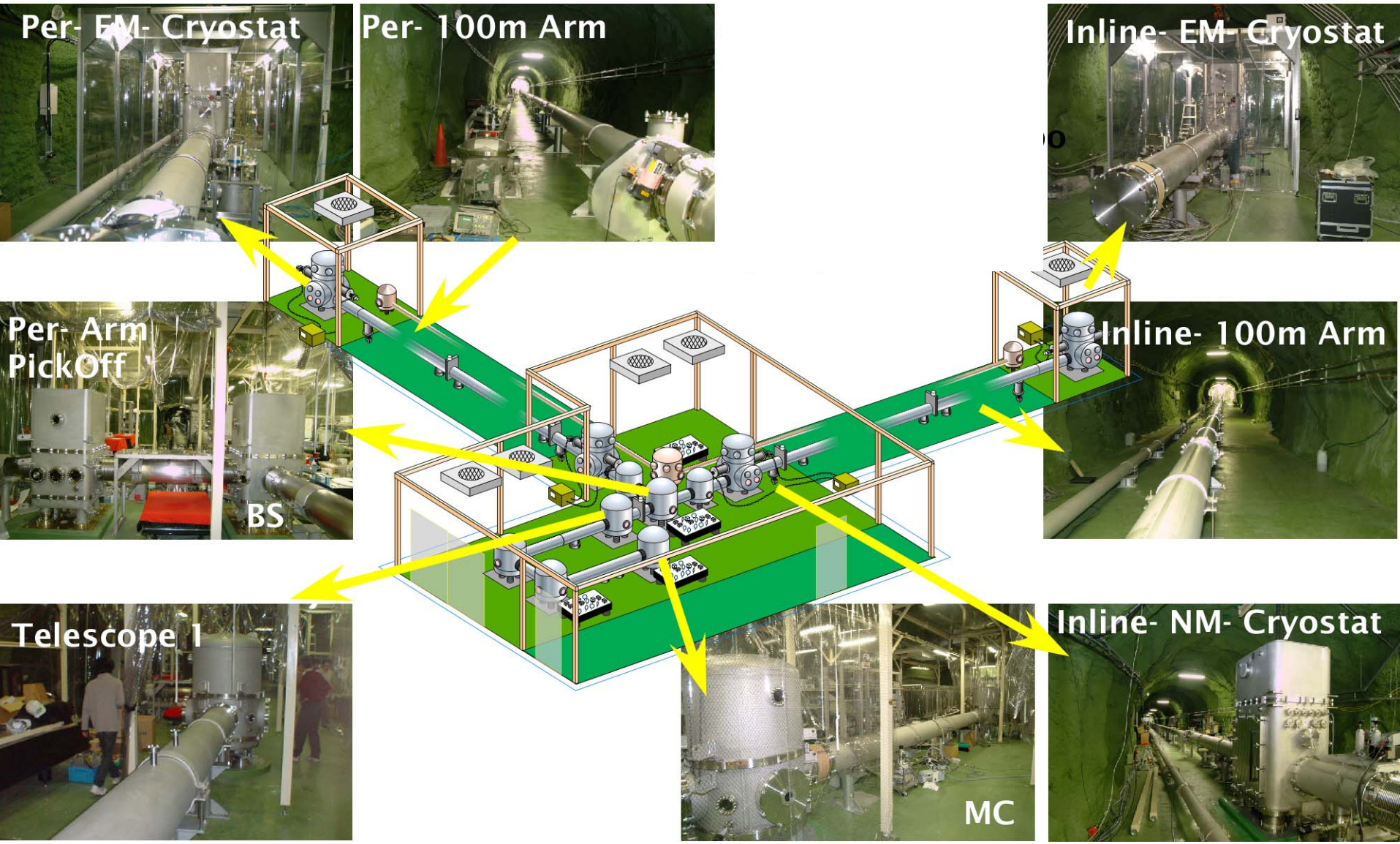
Targeted displacement noise



Optical Configuration



Completed vacuum system and cryostats (2005/5/17)



Mode Cleaner

-Dimension -

Length 9.5m

-Optical Property -

Finesse 1500

-Control -

Mod. Frequency

12.0MHz

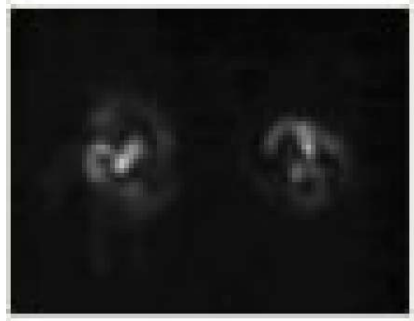
UGF 14dB Loop Gain @200kHz

2 Gain Up @ 300kHz

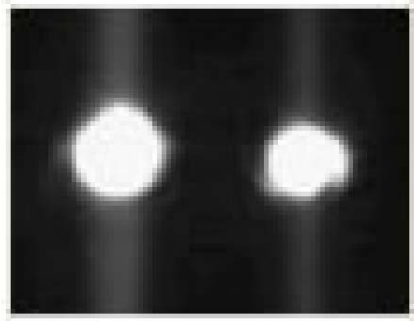
Feedback

PZT, Ext EOM, Thermal

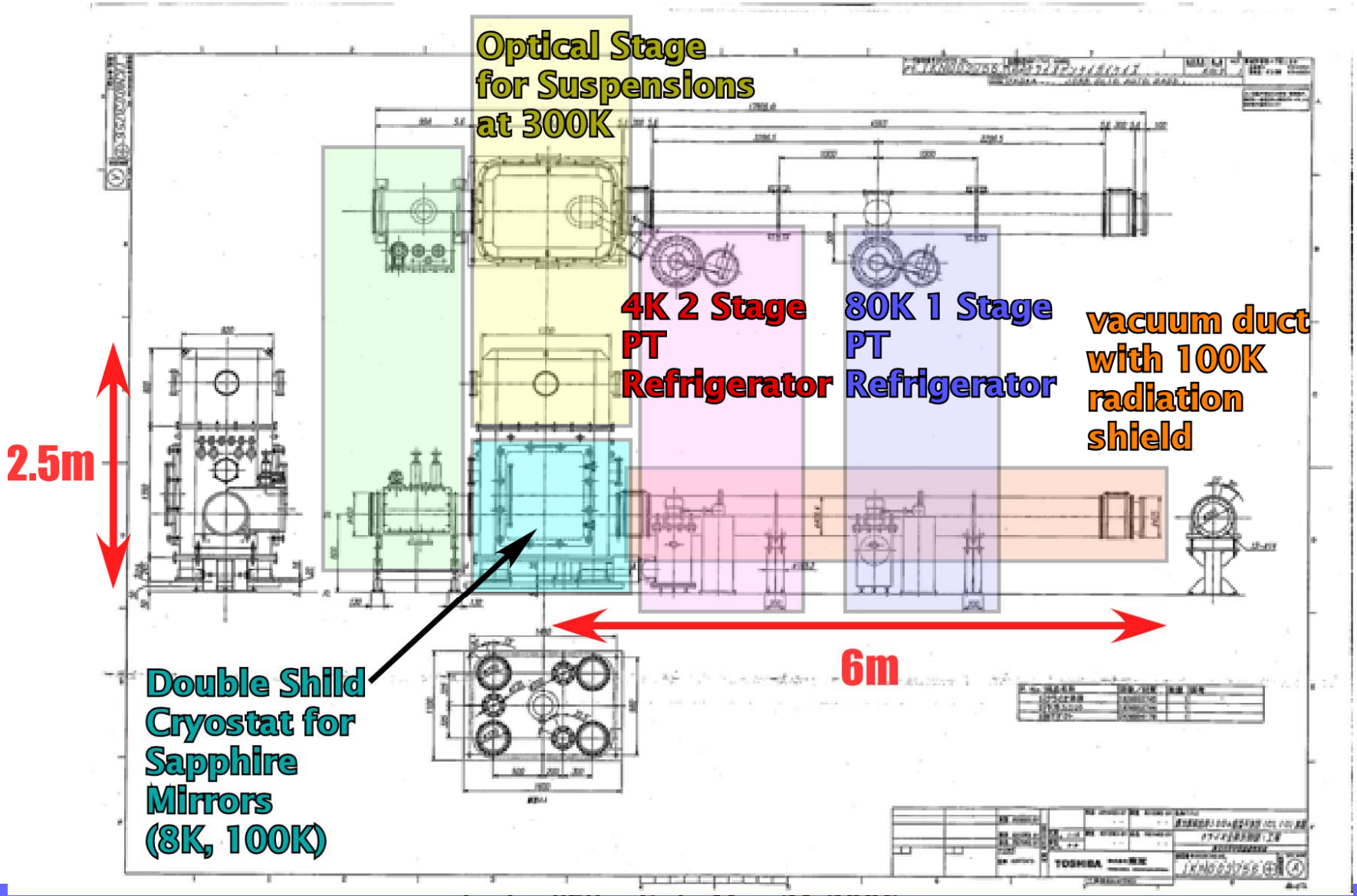
Cavity Reflected Light



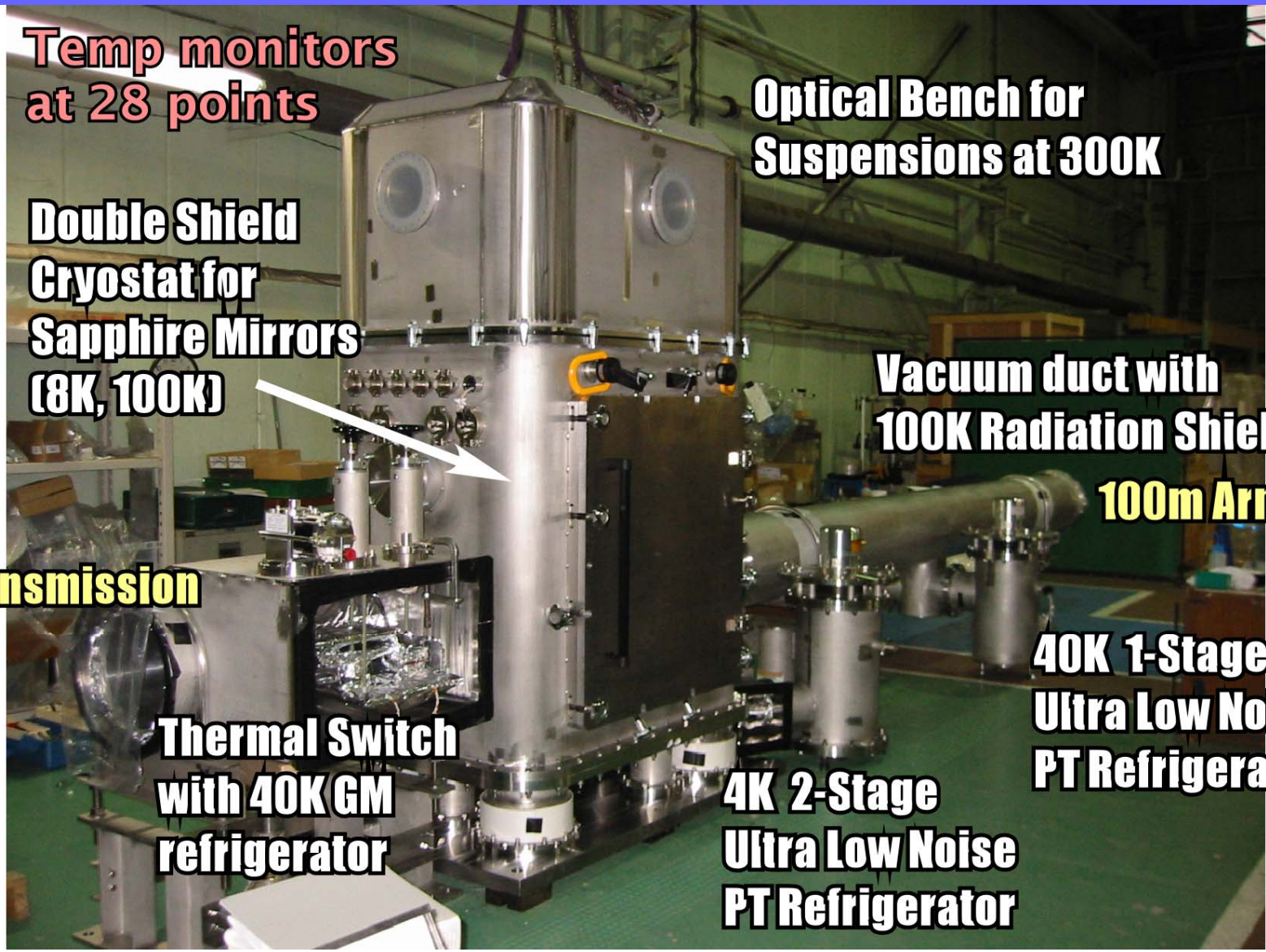
3.4%



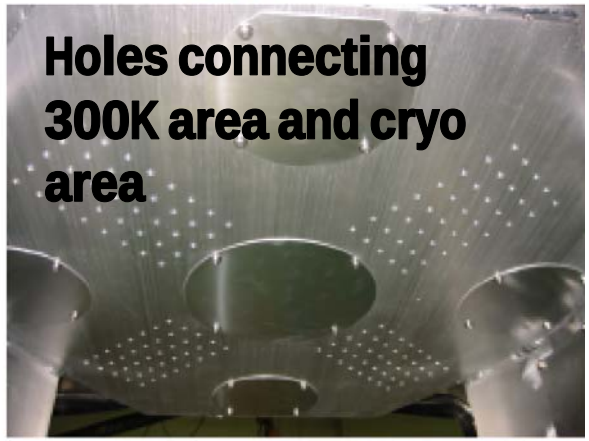
Cryostat Side Views



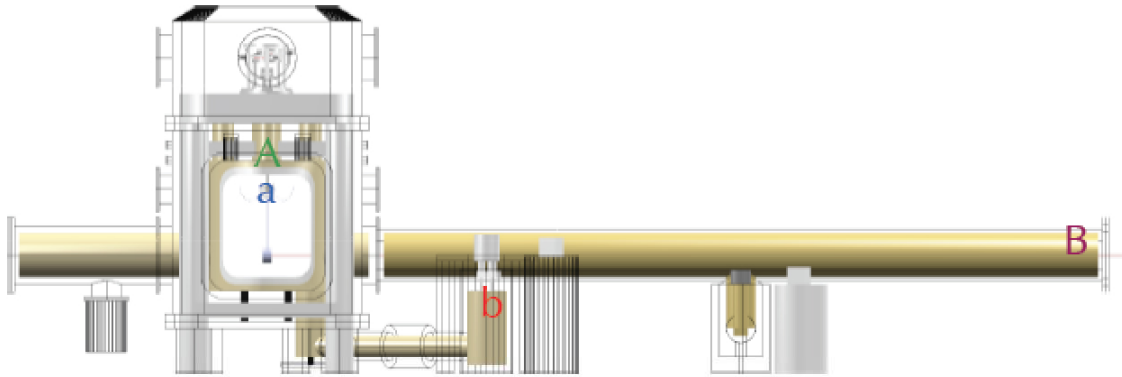
Cryostat for an end mirror

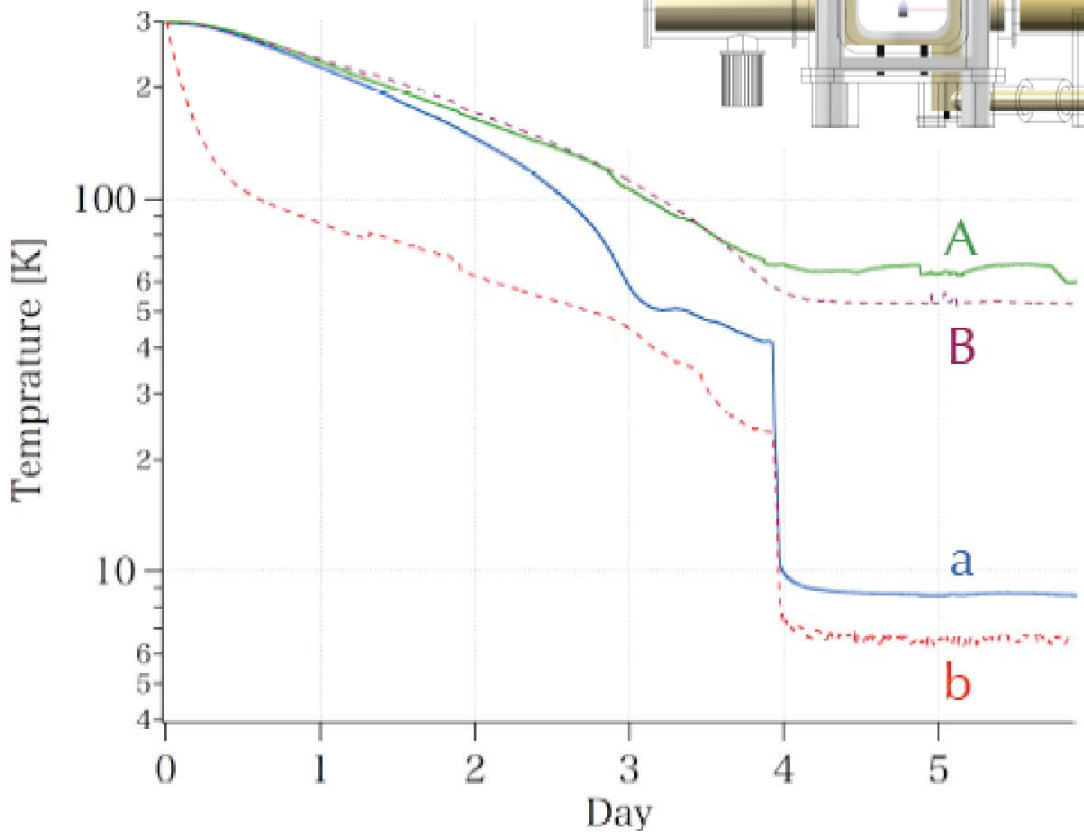


Inside the cryostat



Cooling test and achieved temperature





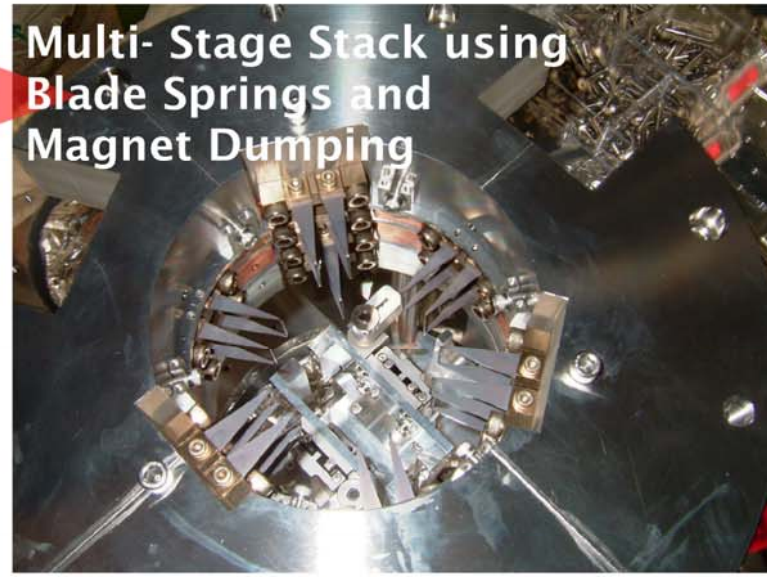
Outer Shield Top

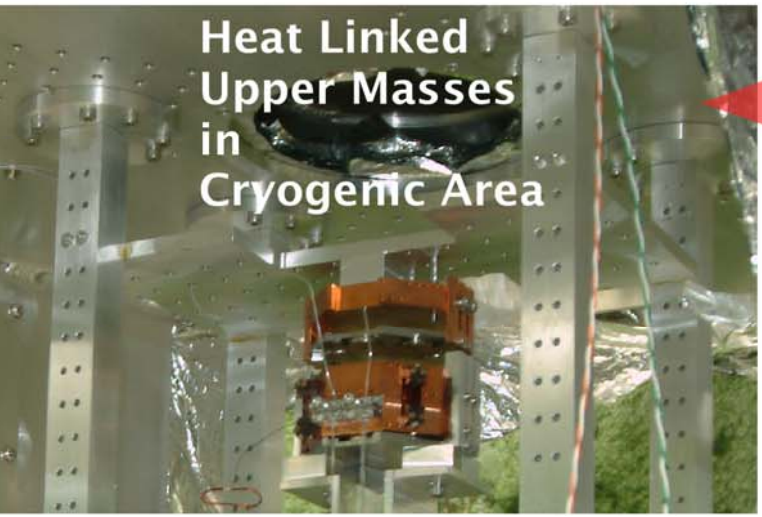
End of Pipe

Inner Shield Top (8.4 K)

Refrigerator Cold Stage

6-stages suspension
(3 Spring stacks and triple pendulum)

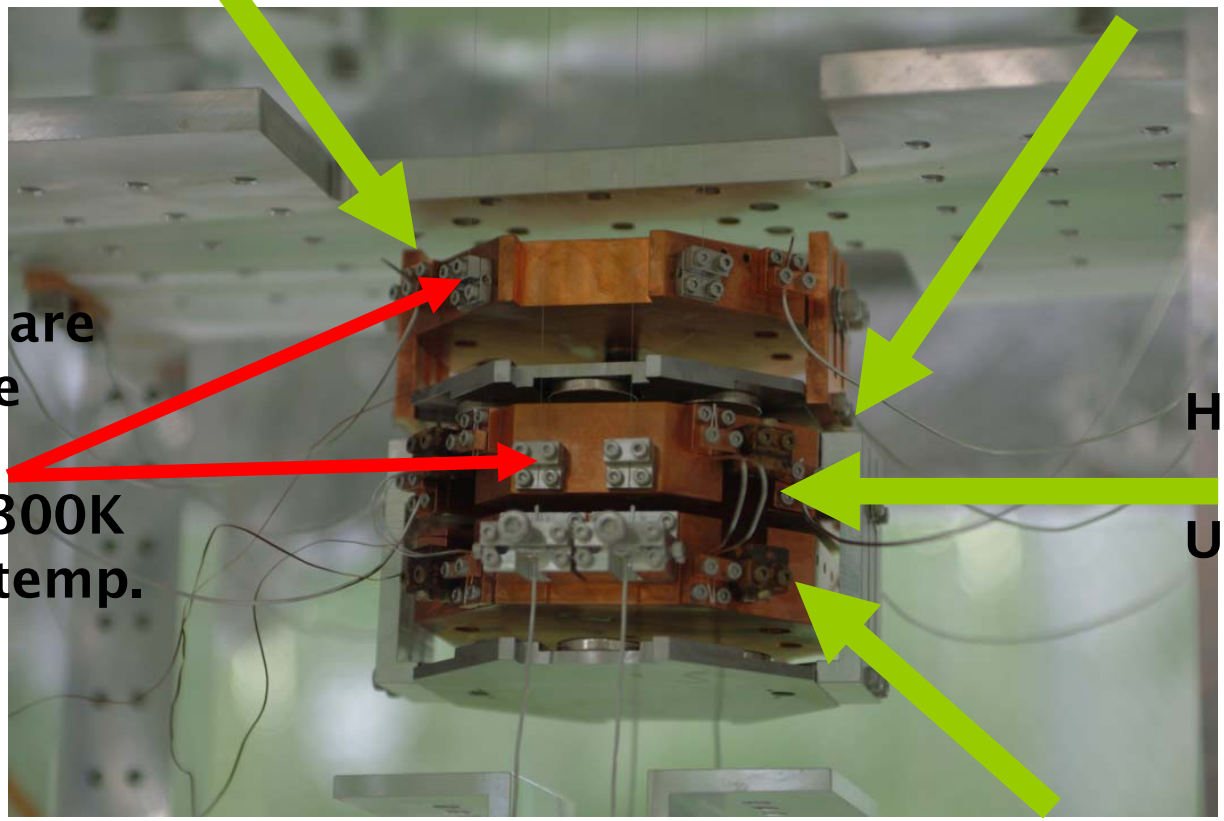




Upper masses and magnet base

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.

A kind of refrigerator and their vibration level

	Vibration Sources	Vibration Level
Gifford MacMaphon Ref.	• Stepping Motor • Displacer • Pressure Wave • He gas flow	10^{-4} m/rHz @1Hz and its harmonics
Commercial GM type Pulse Tube Ref.	• Pressure Wave • He gas flow • Rotary Valve	$5*10^{-6}$ m/rHz @1.5Hz and its harmonics
KEK&Sumitomo Refined GM type Pulse Tube Ref.		$5*10^{-8}$ m/rHz @1.5Hz and its harmonics

Seismic noise is 10^{-9} m/rHz @1Hz in the Kamioka mine.

Low vibration PT refrigerator by KEK and SUMITOMO

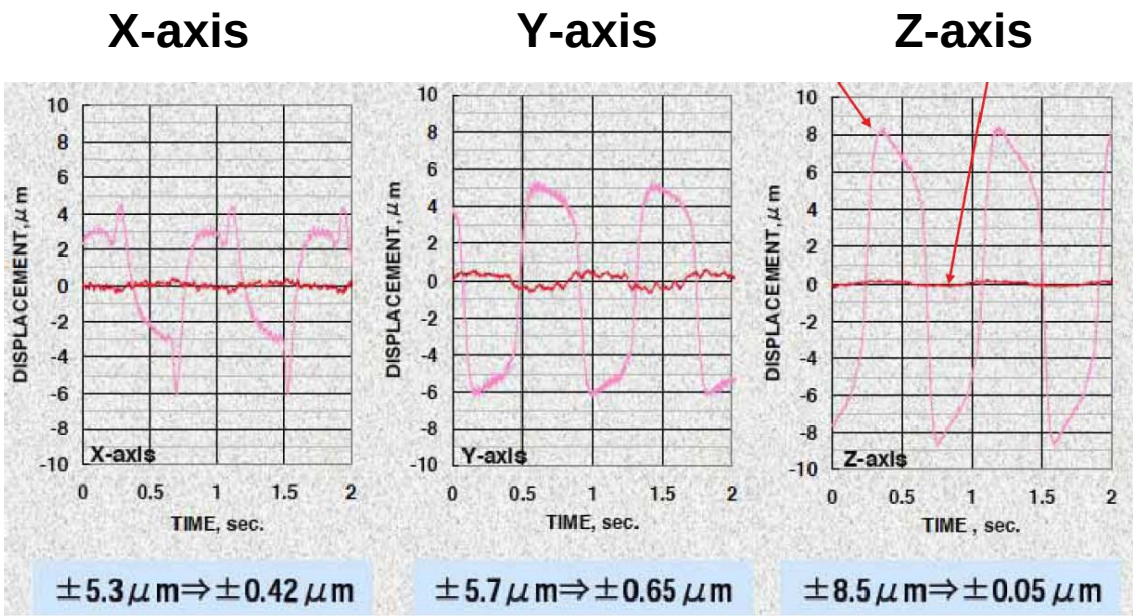
- 40 K Cold Head
- Bundles of Al wires
- 40K vibration reduction stage
- 4 K Cold Head
- FRP Pipe Rod
- 4K vibration reduction stage
- Soft thermal conductive bundle of wires

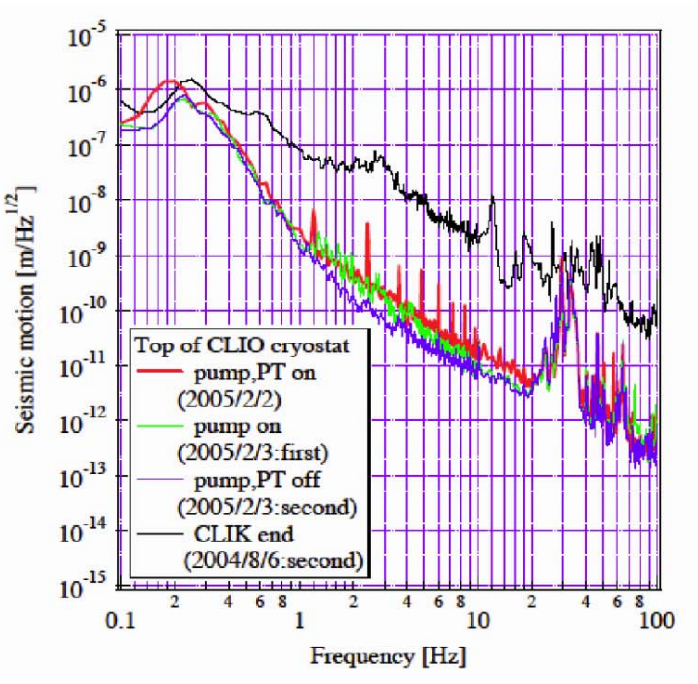
- Cryocooler table fixed on the ground
- Valve unit on a frame
- Valve unit table fixed on the ground
- He gas flexible tube

Vibration reduction effect

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.

Cooling power comparison

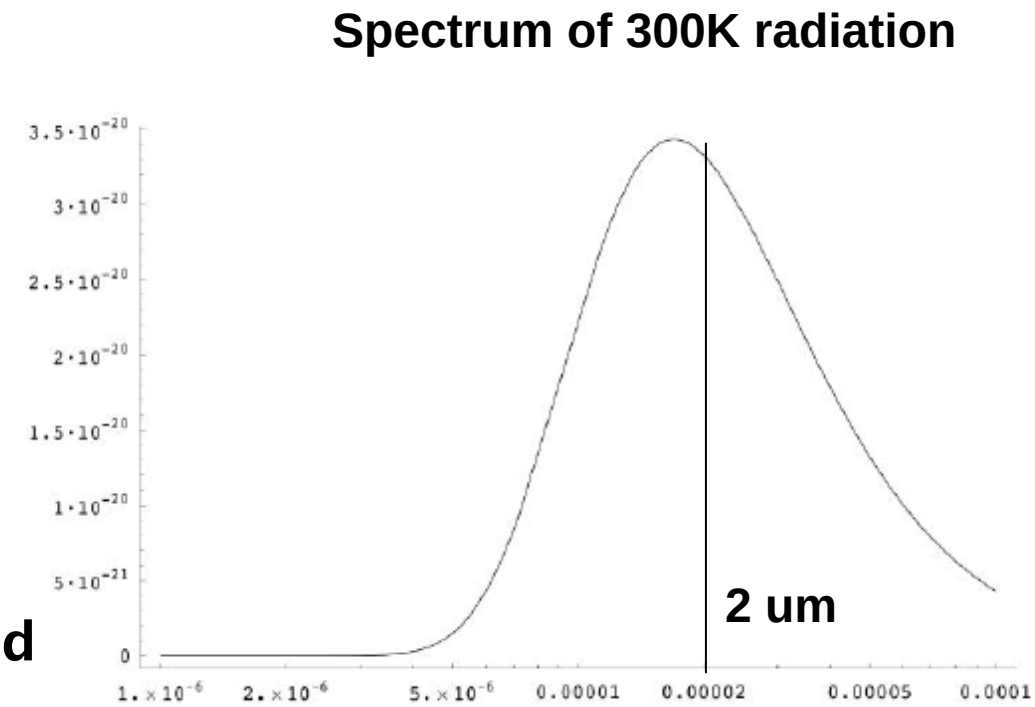
Cooling power reduction was very small

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

Current Status

Semi-Full operation of CLIO @ 20K as an Interferometer

We operated CLIO as a Locked FP interferometer, with 3 of 4 Sapphire mirrors that were cooled at 20K and 1 mirror that stayed around 40K because of the huge 300 K radiation from an edge hole of a 5-m radiation shield duct.

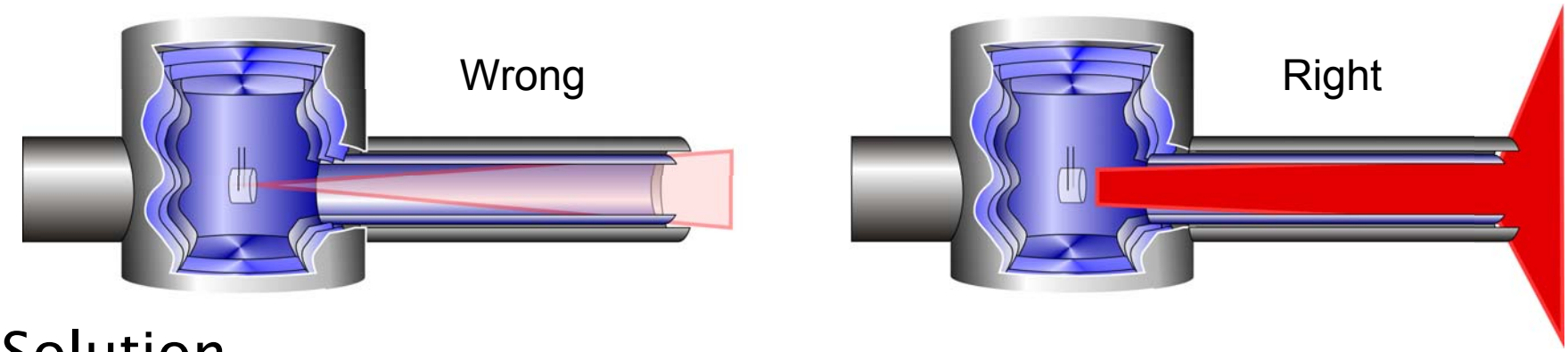


We missed estimating the contribution of the 300K radiation reflection inside the radiation shield duct!!

300 K Radiation Contribution

(1)300K radiation was proved to be 100 times amount of the estimated radiation (1.7mW -->100mW !).

(2)300K Radiation whose wave length is around 2um can easily reflect and reach inside the cryostat (R ~ 0.9@2um).



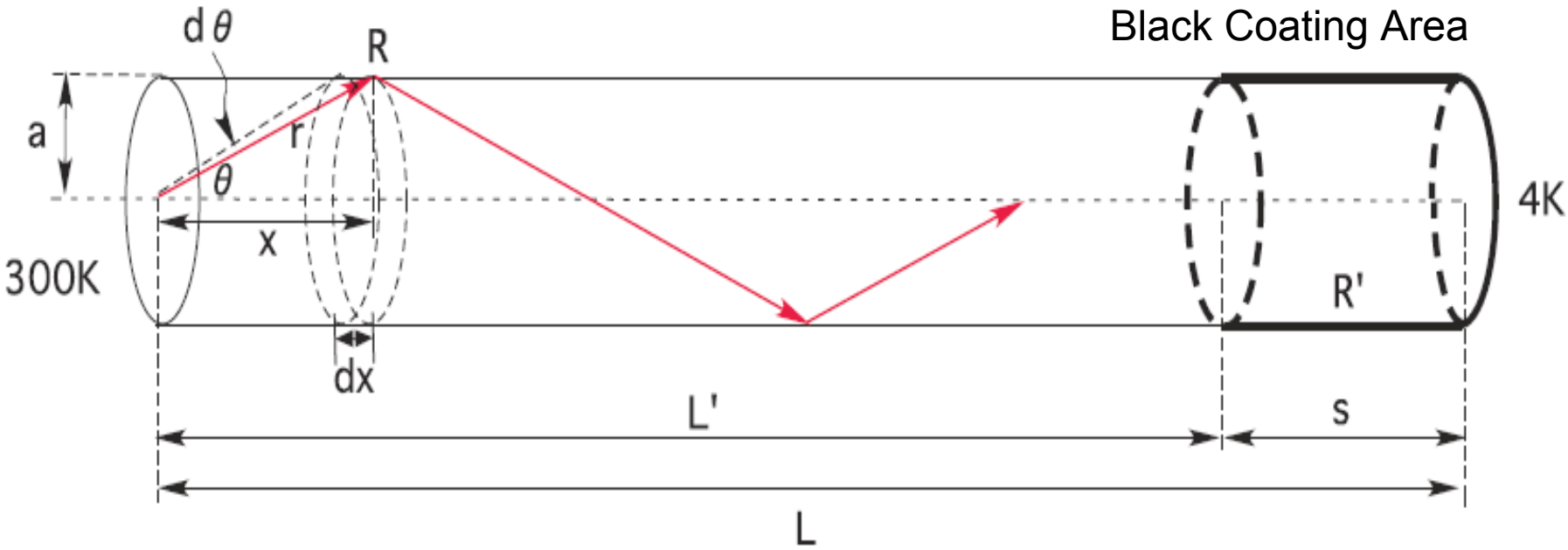
Solution

(1) Black material for 300K radiation, such as UB-NiP, should be formed in side the radiation duct

(2)Optical baffle is effective for um wave radiation?

Reflected 300 K radiation contribution

Black coating on the half length area inside the radiation shield can reduce the amount of radiation to be 1/100.



Direct Radiation

$$P_{th} = P_0 \frac{d\Omega_{th}}{2\pi} = P_0 \frac{a^2}{2L^2}$$

Reflected Radiation Total

$$N(x) = 1 + n\left(\frac{L-x}{2x}\right)$$

$$P_{ref} = P_0 \int_0^L R^{N(x)} \frac{d\Omega}{2\pi} = P_0 \int_0^L R^{N(x)} \frac{a^2}{(x^2+a^2)^{3/2}}\, dx$$

T.Tomaru

300 K Radiation reduction using black coating

Contribution of the reflected radiation

	$R = 0.90$	$R = 0.95$	$R = 0.97$
$(P_{ref} + P_{th})/(P_{th})$	307	622	898
P_{ref}/P_0 の割合	14 %	28 %	40 %

Reduction of the reflected radiation using a black area (R~0.1) at 300K side of the duct. $(P_{ref} + P_{th})/P_{th}$

length of "s"	Reflectance of Aluminum		
	$R = 0.90$	$R = 0.95$	$R = 0.97$
0.5 m	92	122	137
1 m	37	44	47
2.5 m	8.7	9.2	9.4
5 m	2.0	2.0	2.0

T.Tomaru

300 K Radiation reduction using black coating

Reduction dependency on the black area reflectance and its length

length of "s"	Reflectance of Black area				
	0.05	0.1	0.2	0.3	0.4
1 m	36	44	63	88	120
2.5 m	3.8	6.1	12	20	31
5 m	1.4	2.0	3.5	5.8	9.5

Short summary

-5m black coating area whose reflectance is ~ 0.1 is effective to reduce the reflecting 300K radiation contribution.

-In the case that 0.1 reflectance is unobtainable around 2um, the longer area should be coated.

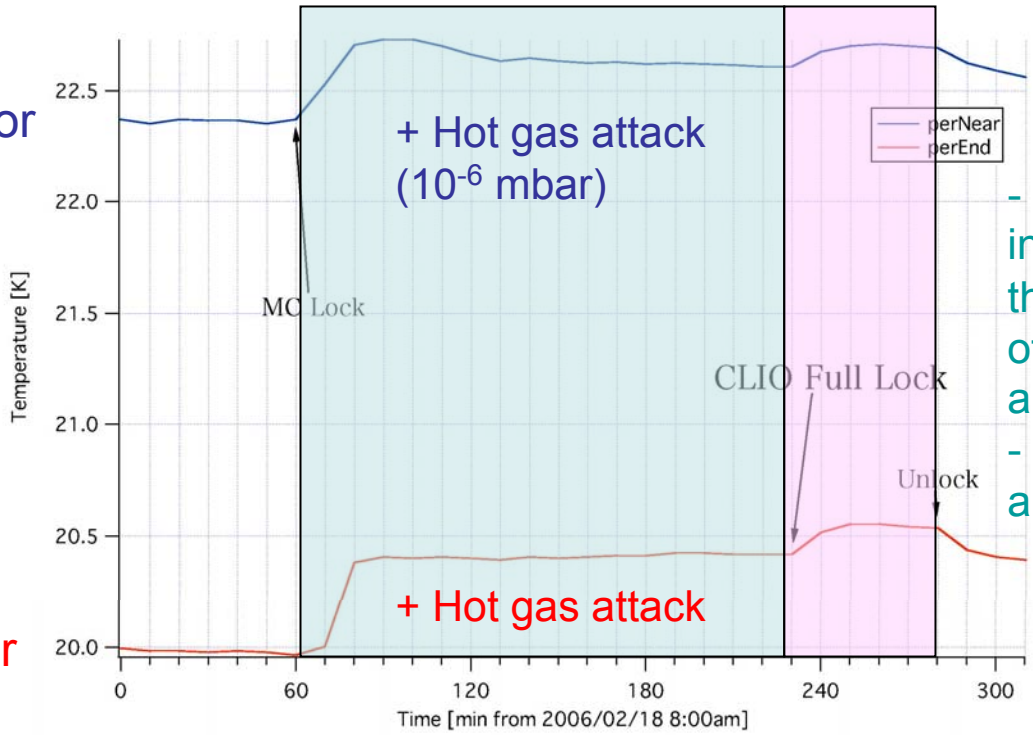
T.Tomaru

Sapphire Mirror Temperature

The present sapphire mirror substrate produced by some Japanese company is known to be bad. CSI Hemlight substrate are now prepared. An American company " Rubicon Technology Inc" might produce bigger and higher quality sapphire substrate than CSI.

PerArm Near Mirror

Substrate absorption



+ Coating absorption

- Accounting of the temp increase difference, the estimated absorption of substrate and coating are comparable (~ 3mW).
- 1000ppm/cm substrate absorption.

PerArm End Mirror

Non

+ Substrate and coating absorption

Gate Valve open FP Lock FP unlock

Sapphire Mirror Contamination

Because of high vacuum pressure level of 10^{-6} mbar, the cavity reflectance decreased especially during the temperature range below 70 K.

Inline Cavity Reflectivity ~1% (300K – 70K) → 5% (20 K).

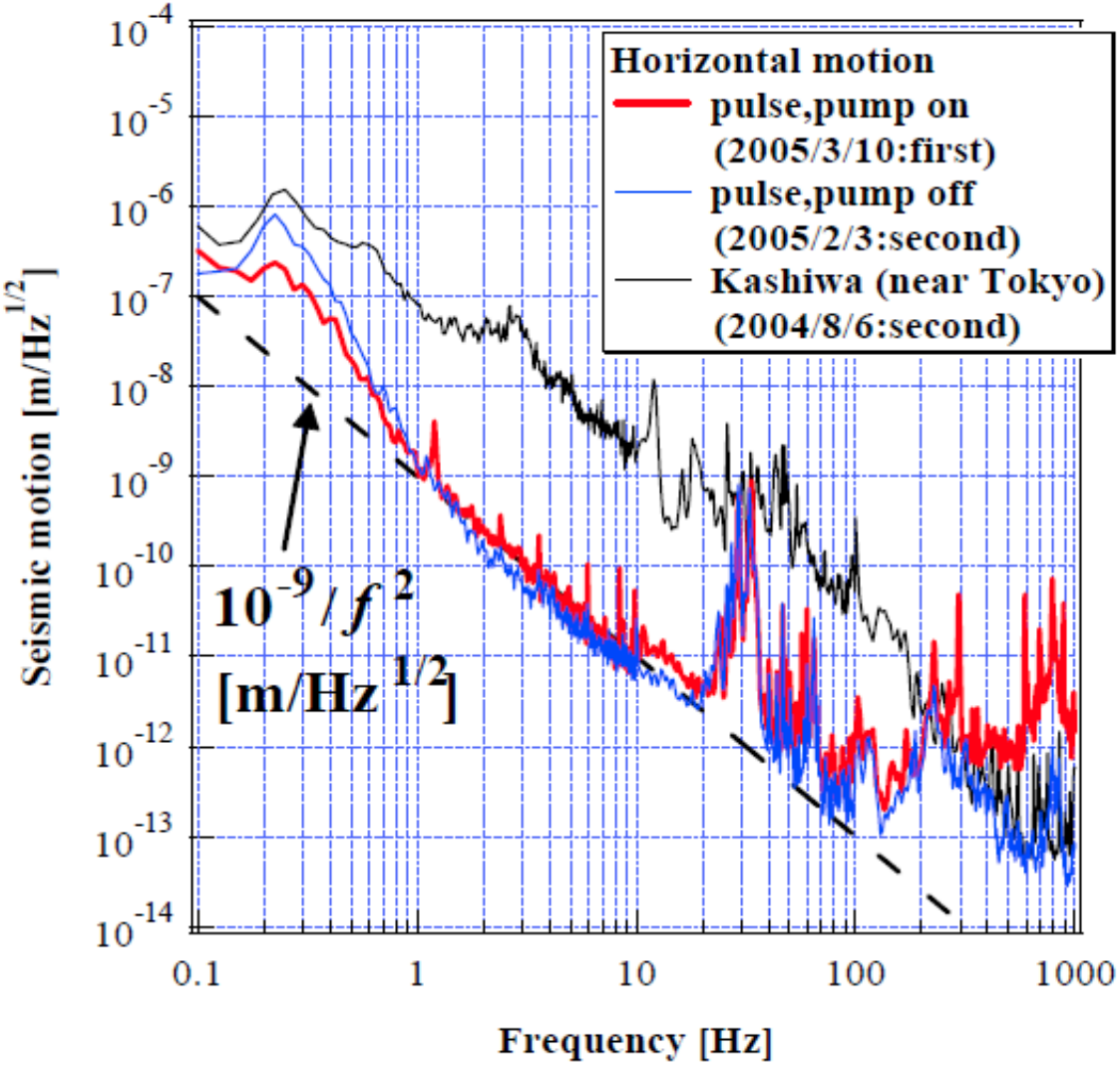
We don't know whether it took place suddenly or gradually and it keep getting worse or not.

(Mirror reflectance is 0.999)

This cavity reflectance degradation could be recovered when the mirror was wormed up.

But, we cannot improve the vacuum soon due to financial reason.

Seismic Noise with the working refrigerator



- Vibration noise increase due to the refrigerator operation was limited at 1.2Hz.

- Vacuum pump noise is observed.

- 30Hz sharp peaks come from optical bench support structure resonances.

Full operation of CLIO at ~20 K as an Interferometer

Optical Parameters

Output Power of MC : ~100mW

Cavity Reflectances : Inline ~20% PerArm ~85%

Finesse of the cavities : ???

Modulation Frequency for Arms : 15.8044 MHz

Used laser power for the Photo detectors : ~30 mW

Control Parameters

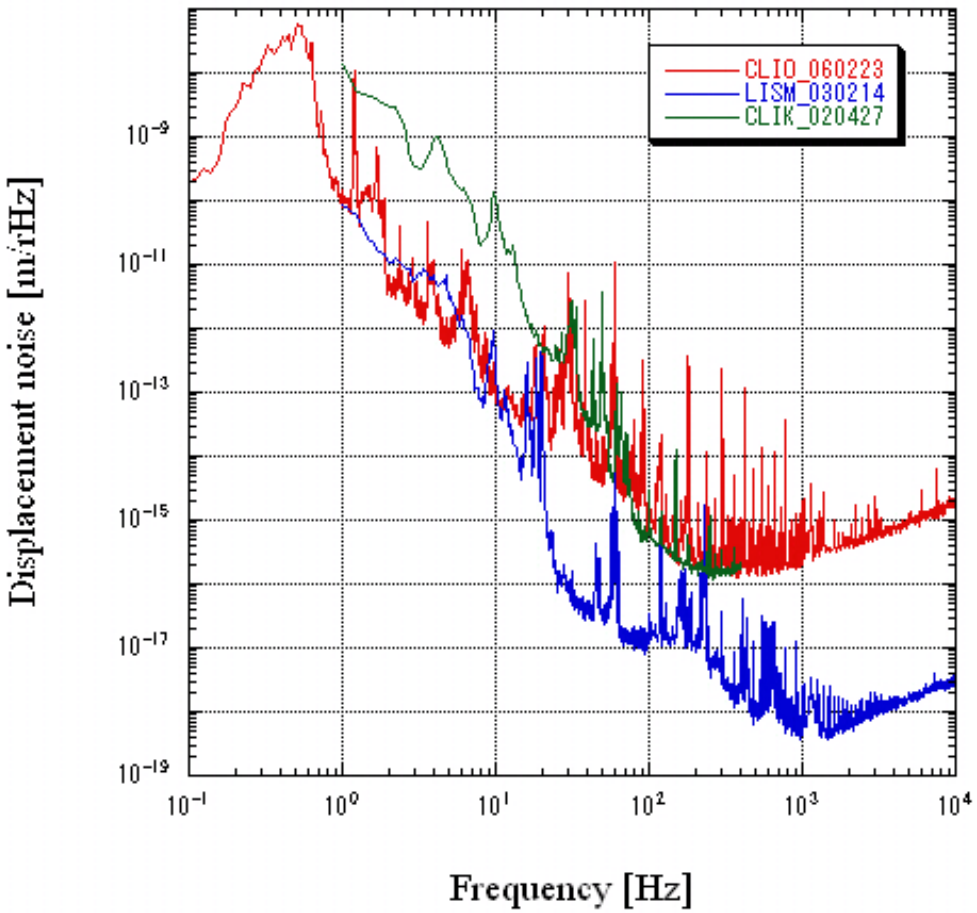
Primary Cavity Servo(PCS) UGF : 50 kHz (Gain UP at 10kHz and 30kHz)

Secondary Cavity Servo UGF : 300 – 500 Hz (Gain UP at 100Hz)

No alignment control at present

Because thermometers are fixed directly on mirrors and cavity reflectances are so bad, the measured displacement is bad. But, stable (days drift of alignment is negligible)!!

Displacement of CLIO at ~20K



Full operation of CLIO at 300 K as an Interferometer

Optical Parameters

Output Power of MC : ~100mW

Cavity Reflectances : Inline ~1% (10% with mod.),
PerArm ~4% (10% with mod.)

Finesse of the cavities : 3000

Modulation Frequency for Arms : 15.8044 MHz

Used laser power for the Photo detectors : ~30 mW

Control Parameters

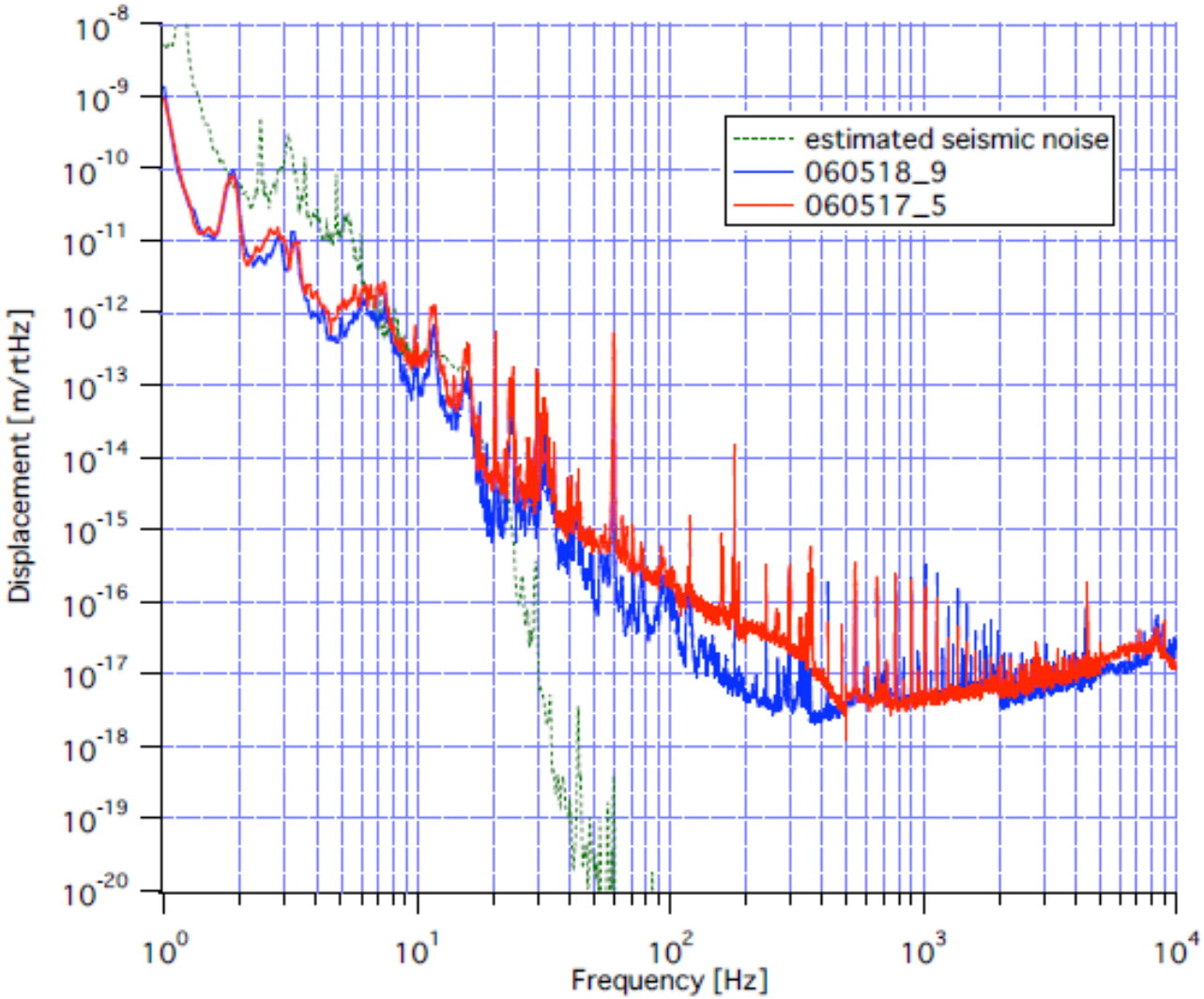
Primary Cavity Servo(PCS) UGF : 50 kHz (Gain UP at 10kHz and 30kHz)

Secondary Cavity Servo UGF : 300 – 500 Hz (Gain UP at 100Hz)

No alignment control at present

Sensitivity enhancement just started 2 weeks ago!!

Displacement of CLIO at 300K



Status Summary of CLIO

-Low vibration PT Refrigerators showed harmless vibration enhancement at the suspension point of the mirror.

-Radiation from the 300K area was miss-estimated. So we now prepare the remedy for this problem.

-CLIO was succeeded to be operated as an interferometer using cryogenic mirrors (3 at 20K and 1 at 40K).

-CLIO displacement noise enhancement is now undergoing.