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Hot radiation reflected by cold wall in a cryogenic interferometer

Kazuaki Kuroda

ICRR, The University of Tokyo

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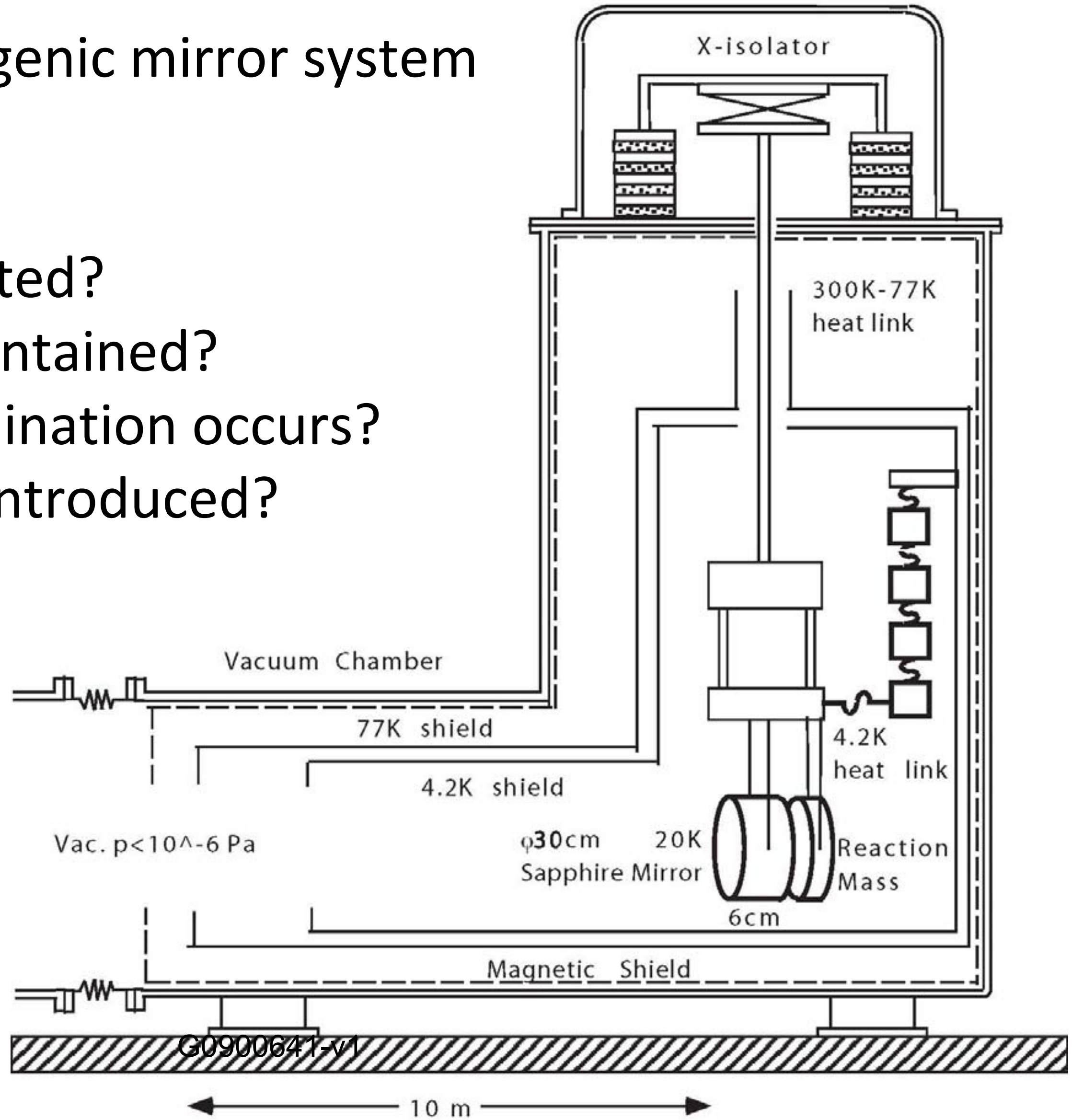
- Cooled interferometer
- Radiation shield inside a radiation shield
- Long run of refrigeration
- Reduction of thermal noise of bad Q suspension
- Proposal of the usage of CLIO for Newtonian noise subtraction

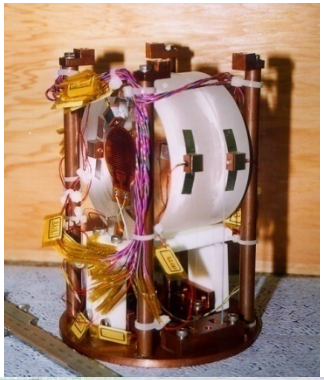
Cooling technique of cryogenic mirror (0)

Original idea of cryogenic mirror system
--basic questions—

1)How heat is extracted?
2)How good is Q maintained?
3)How much contamination occurs?
4)How large heat is introduced?

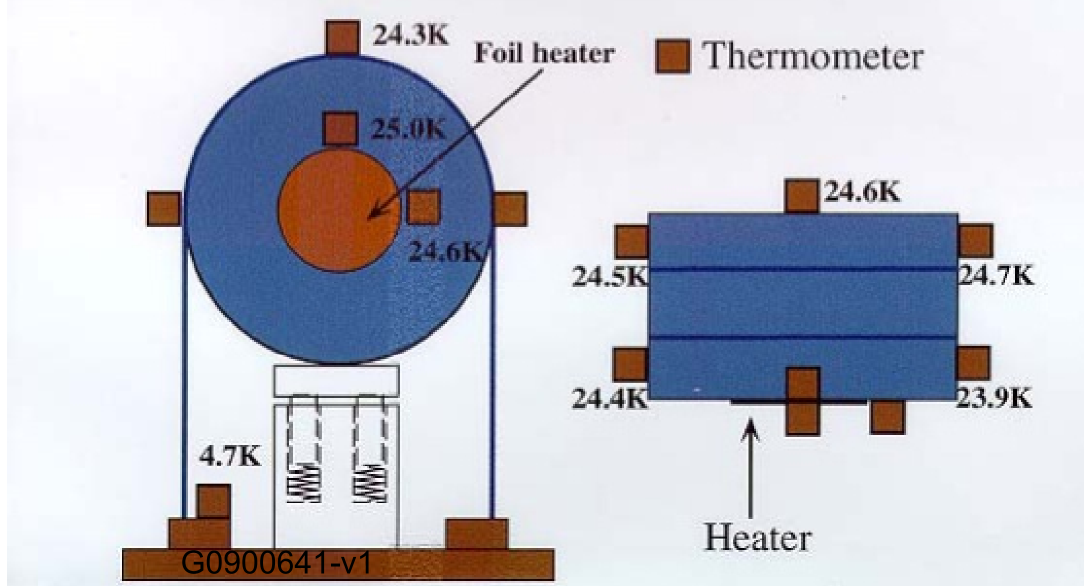


Cooling technique of cryogenic mirror (1)

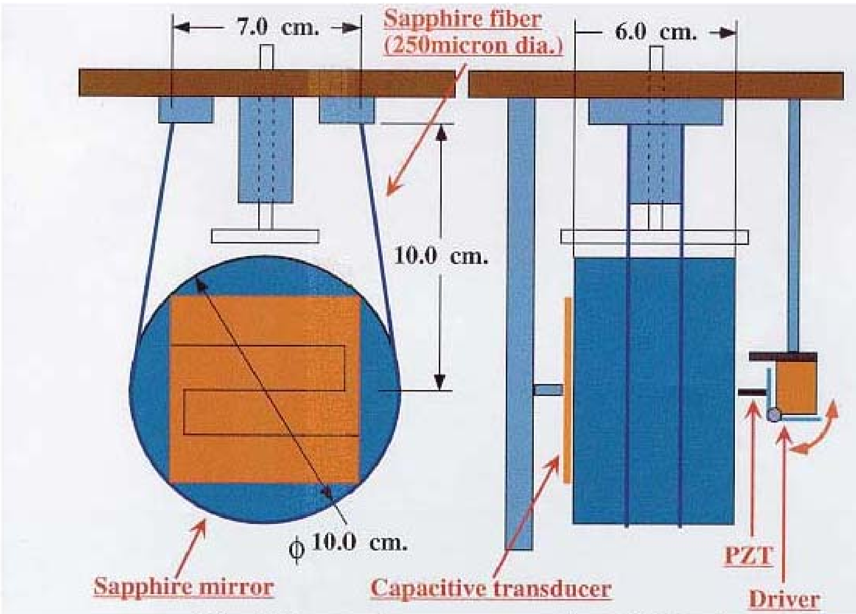


Heat produced by the absorption inside the Substrate is extracted through heat flow along the suspension fibers.
The heat flow was large enough to be applicable to the practical high power laser interferometer.

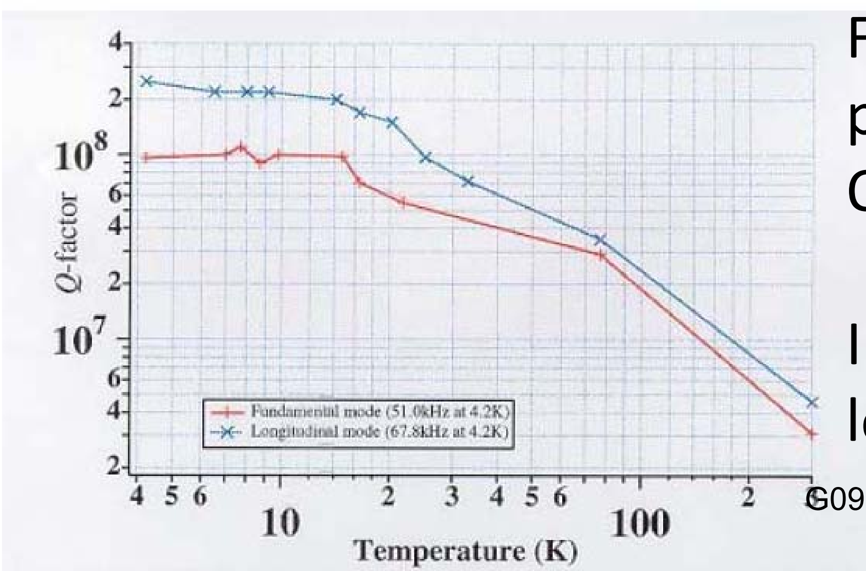
Simulation of the heat flow through sapphire fiber



Cooling technique of cryogenic mirror (2)



Thermal noise is proportional to mechanical Q / temperature T

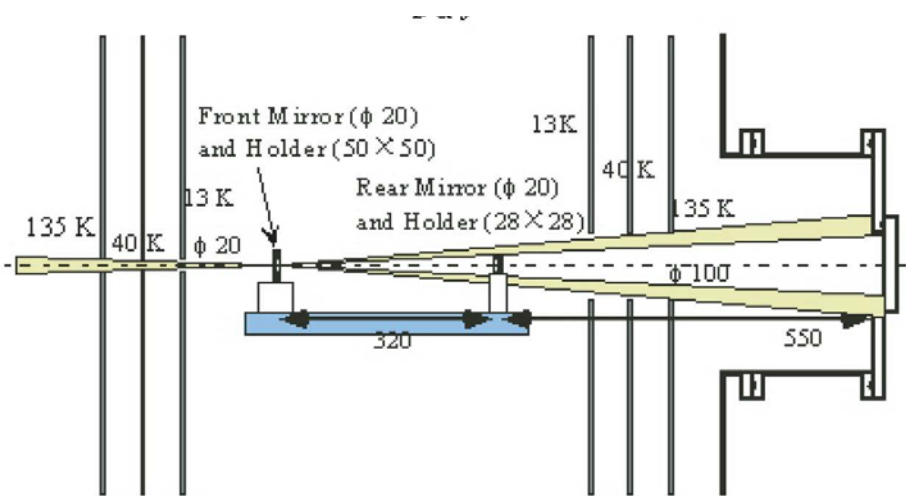


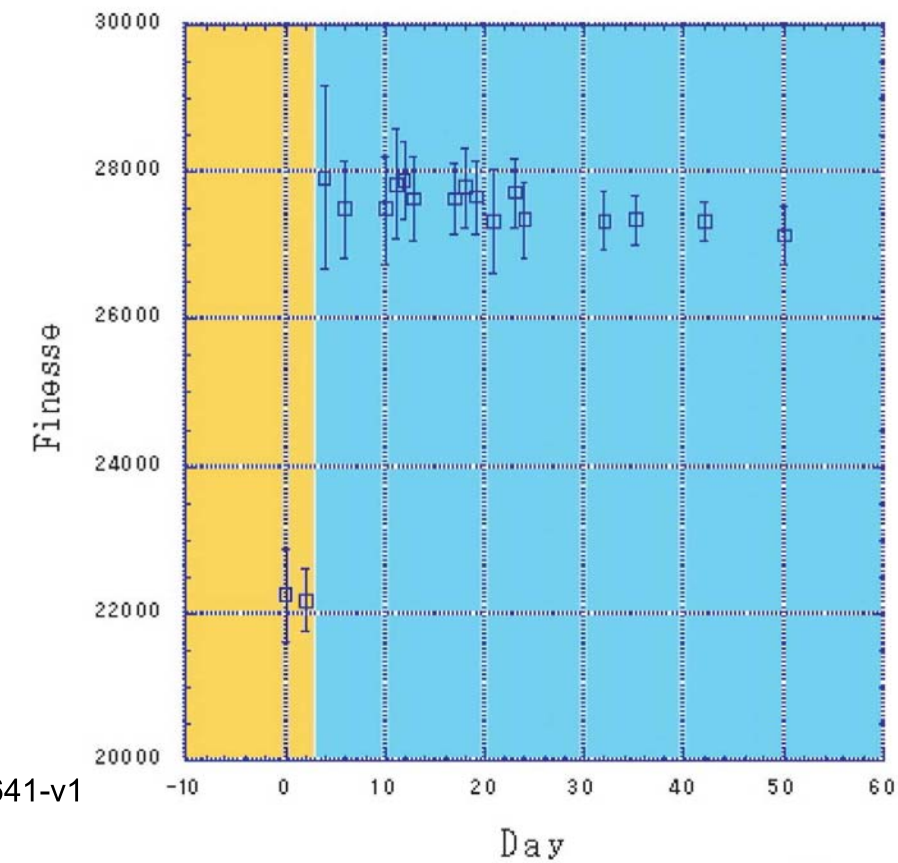
Fortunately, every sapphire sample piece showed better mechanical Q at cryogenic temperature.

Improvement by cooling was 2 orders less compared with room temperature.

Cooling technique of cryogenic mirror (3)

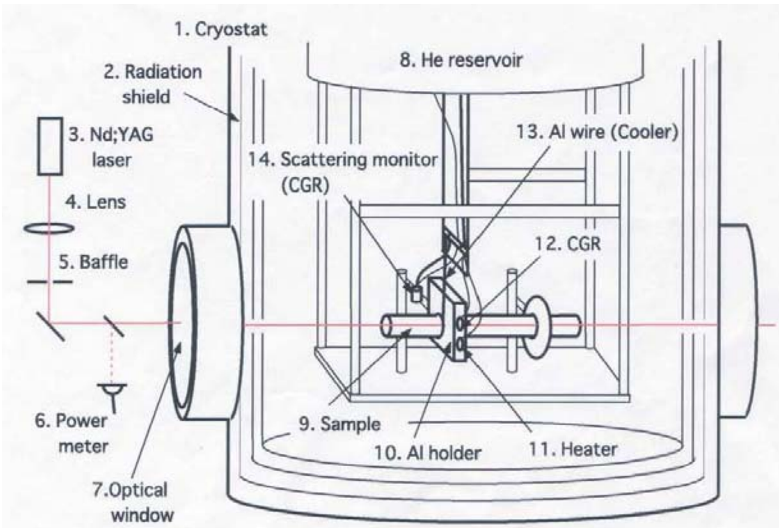
Hot vacuum duct emits hot residual gas molecules
that may deposit on the cooled surface of the mirror.
We simulated using high finesse cavity, the one of which
Mirror was exposed to a hot wall inside the vacuum chamber.
Two months change of the finesse was small enough to be neglible.





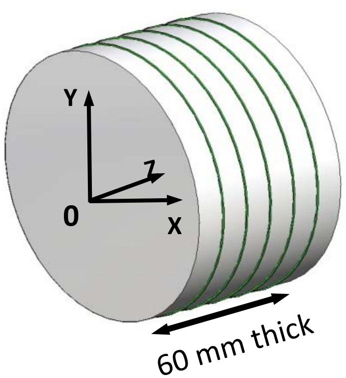
Cooling technique of cryogenic mirror (4)

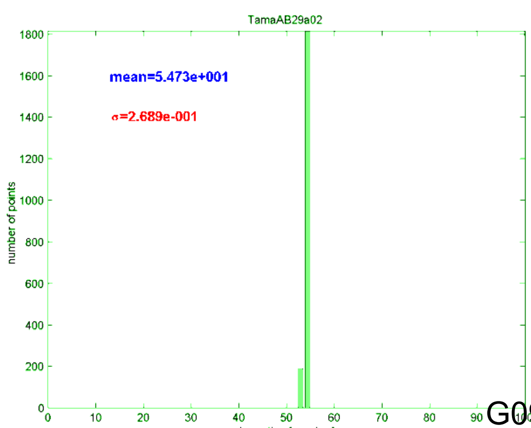
The optical absorption of sapphire bulk material was relatively large and we measured Experimentally its absorption rate.
With the existing measurement, it was 90ppm/cm for CSI crystal purchased in 1998

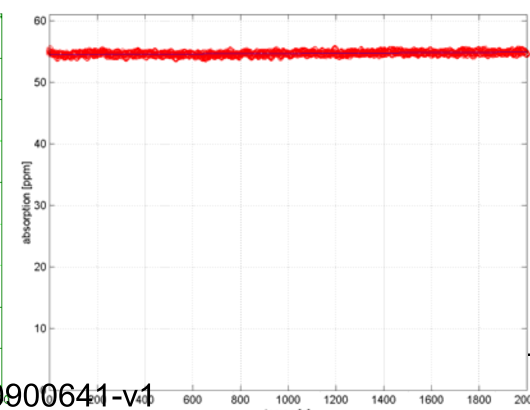


Sample	UWA	Stanford	VIRGO	LCGT (5K)
Hemex	55+-4	140	-	-
Hemlite	-	-	-	90 - 99
CSI White	3.1 - 3.5	120	-	-
CSI White	-	41	-	-
CSI White	-	68	142+-15	-
CSI White	-	58	90+-10	-
CSI White	-	-	-	88 - 93

ppm/cm





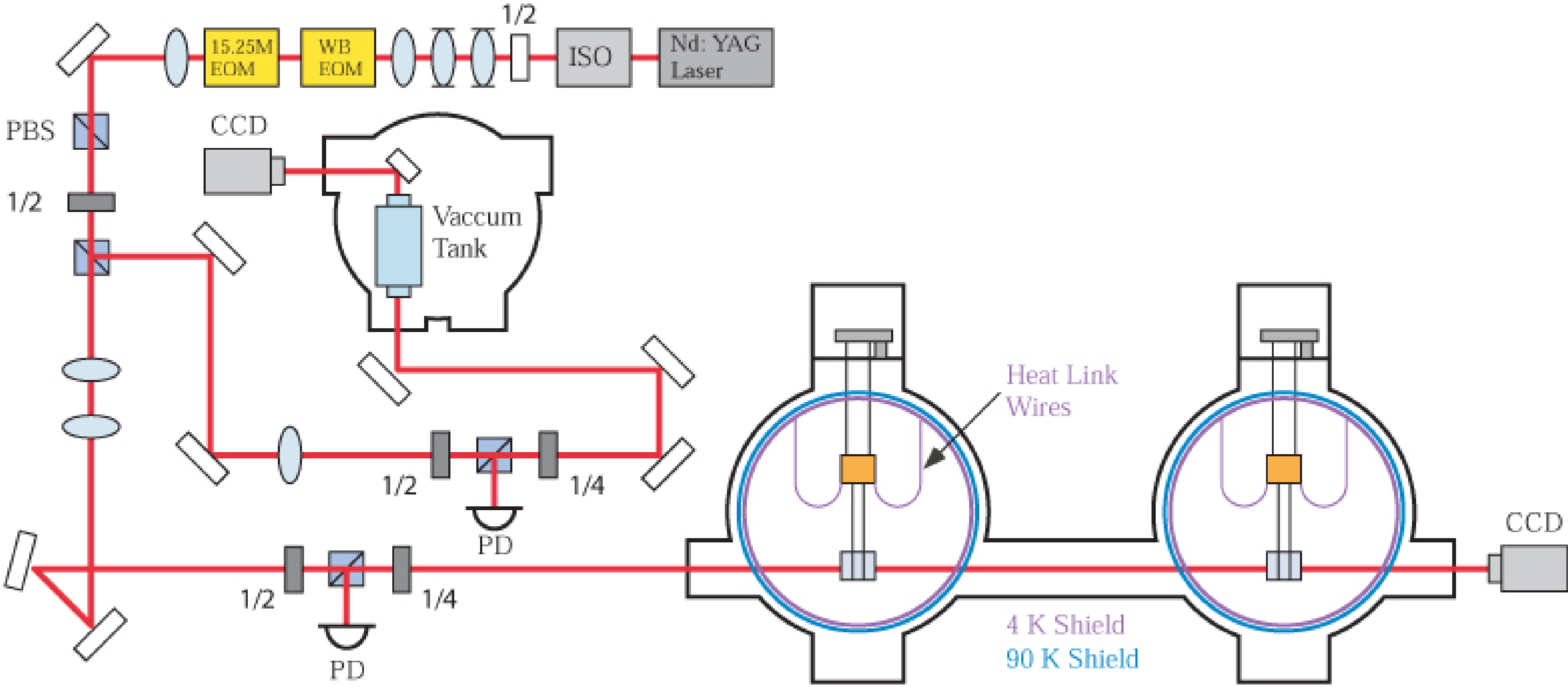


LMA measurement of pieces purchased in 2005.

54.7 +/- 0.3 $ppm.cm^{-1}$

Cooled interferometer (1)

The second step was to show some feasibility of cryogenic laser interferometer. Mirrors are cooled by refrigerators through heat link wires connected to the upper suspension mass.



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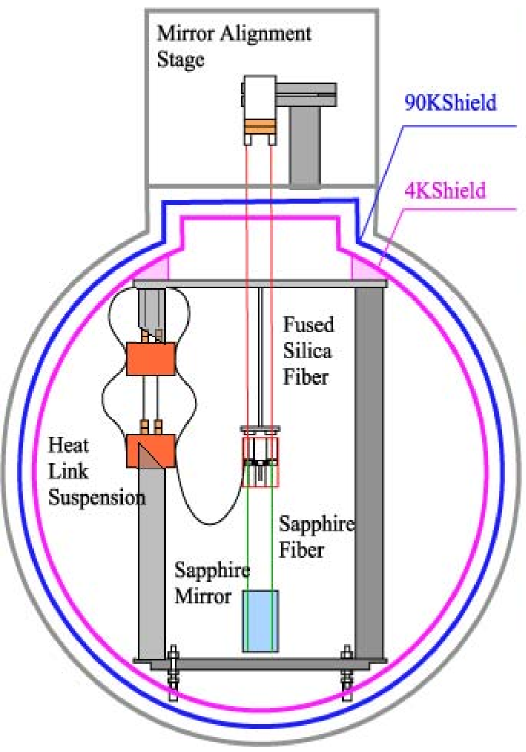
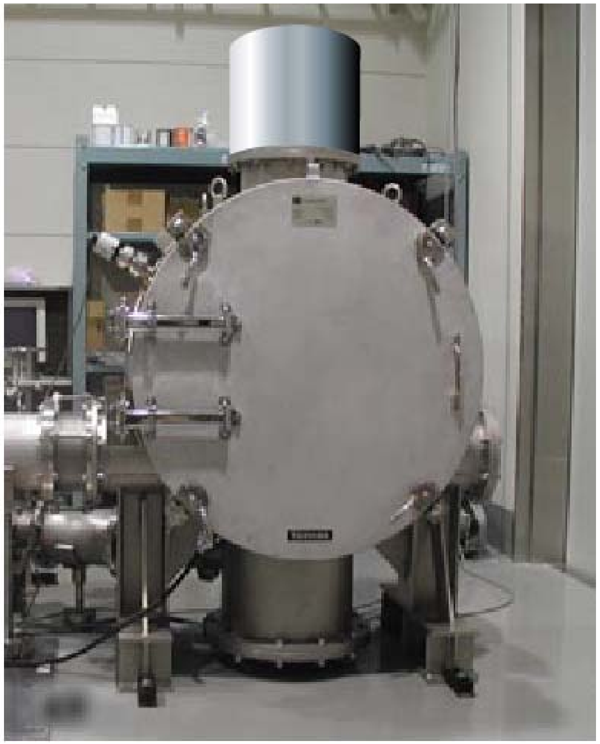
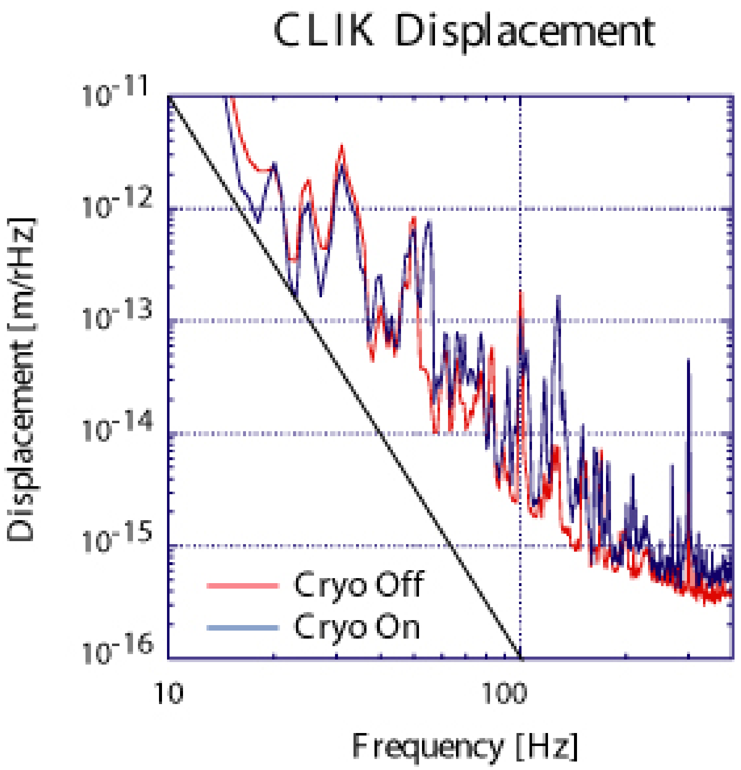
Cooled interferometer (2)

A Fabry-Perot cavity was firstly locked at cryogenic temperature and requirements on refrigerator were studied in 2001.







This result makes us to develop quieter refrigerator and softer heat link design.

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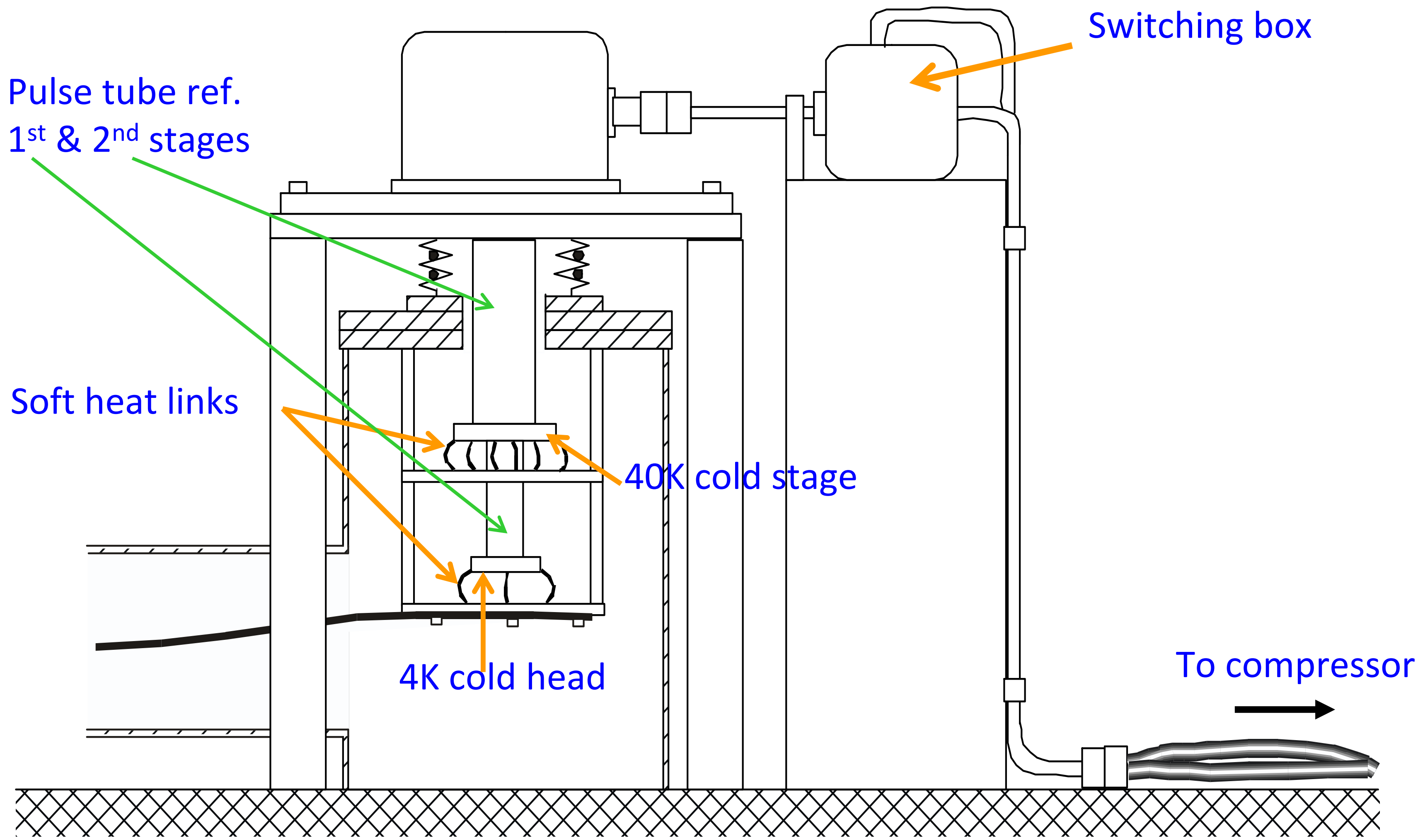
Quiet refrigerator was developed (design in 2003)

F-6: Class. Quantum Grav. (Accepted), Pr-1: Proc. 28th ICRC (2003),
patent: Pa-3 Tomaru et al., 2003; Suzuki et al., 2003.



Construction of CLIO site was started at the time of the Super-Kamiokande accident in 2002

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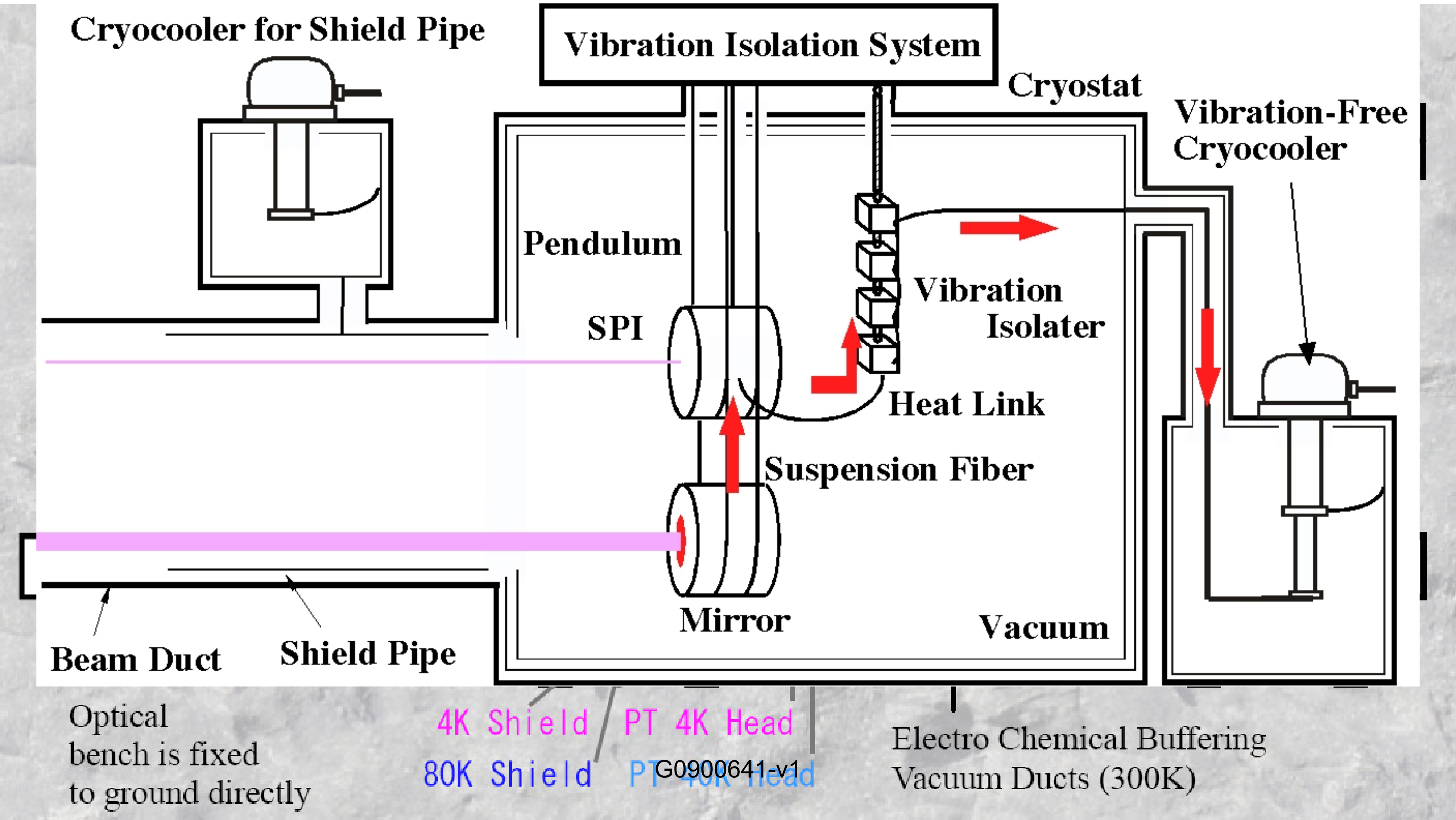
Radiation shield inside a radiation shield(1)

Four main mirror tanks are cooled down to 4 K. The connection tubes are maintained at room temperature.



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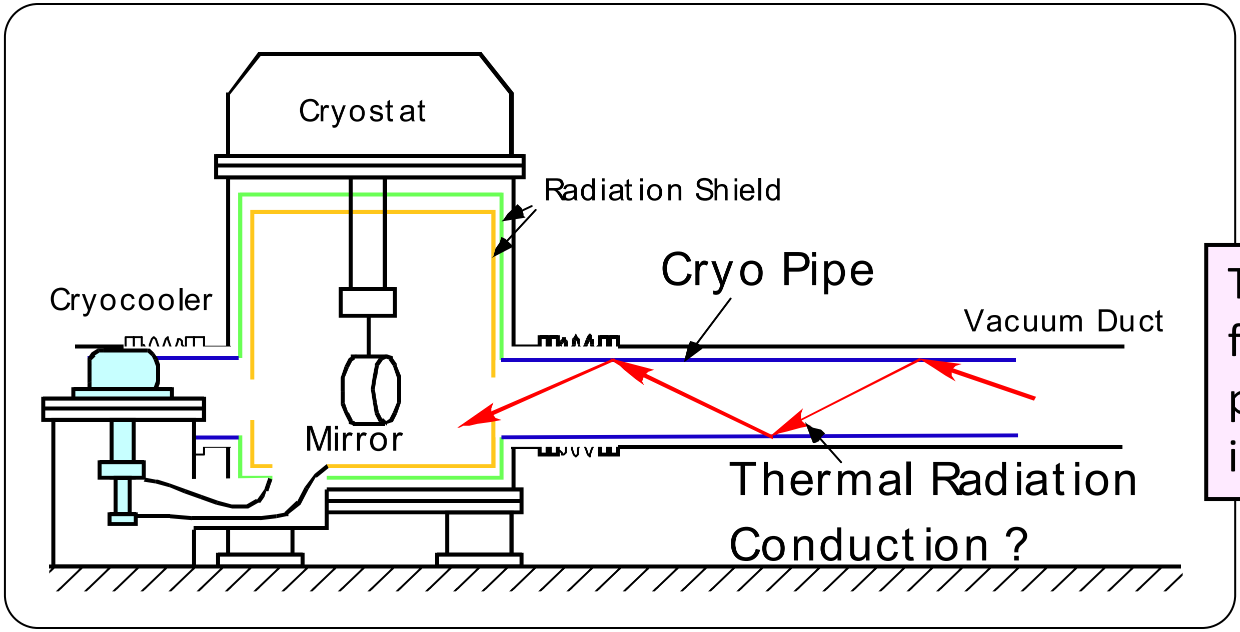
Radiation shield inside a radiation shield (2)



Thermal radiation from a 300K beam port conducted in Al cryo-pipe ?

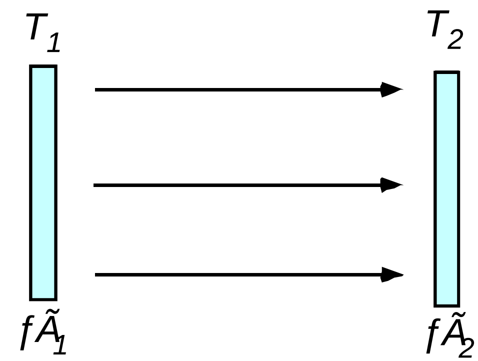
Radiation shield inside a radiation shield(3)

In general thermal radiation calculation:

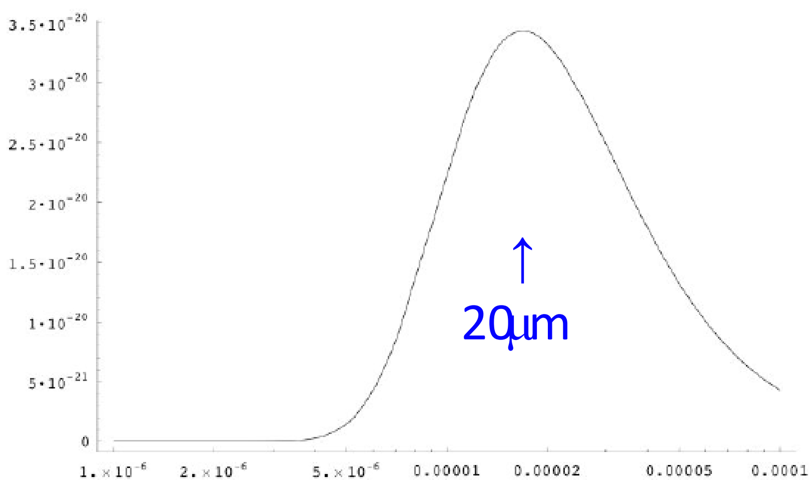
$$P = \frac{\varepsilon_1 \, \varepsilon_2}{\varepsilon_1 + \varepsilon_2 - \varepsilon_1 \, \varepsilon_2} \, \sigma \left(T_2^4 - T_1^4 \right) A \, \frac{\Omega}{2\pi}$$

Stefan-Boltzmann law

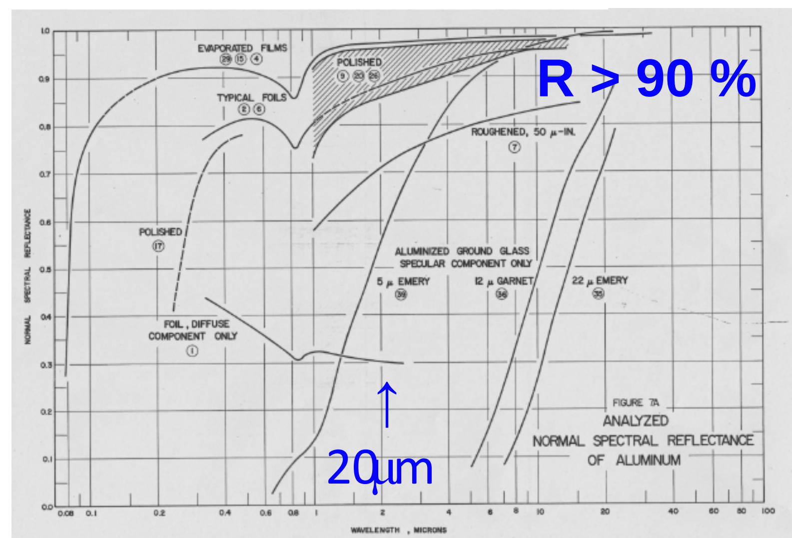
Surface to surface



300K Black body radiation:



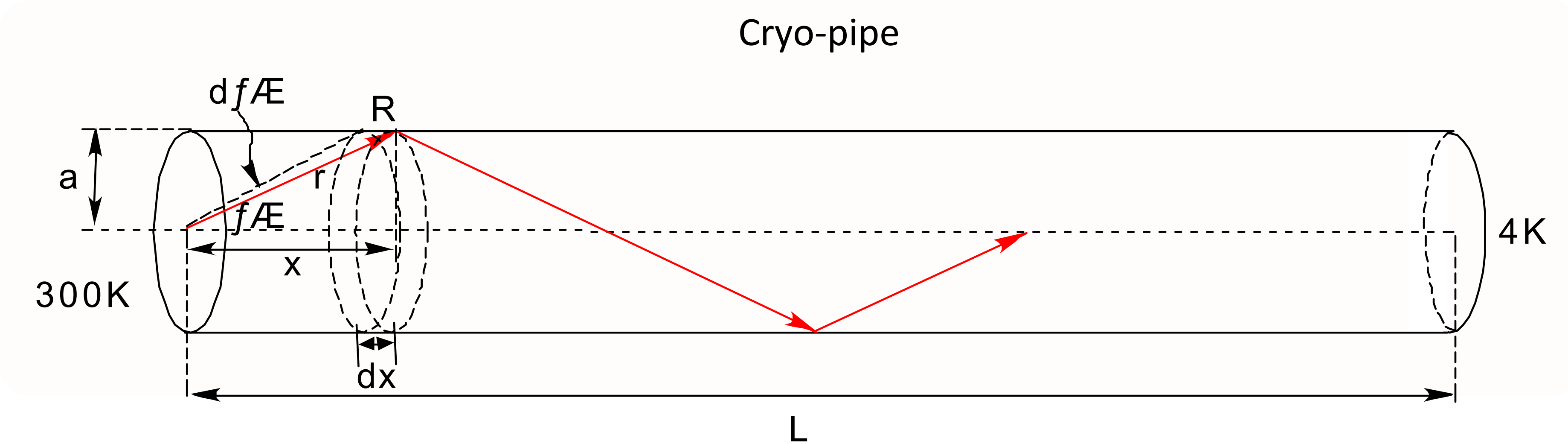
Reflectivity of aluminum



Thermal radiation can reflects at shield pipe surface as IR

Radiation shield inside a radiation shield(3)

Simulation: *Ray trace model*



Calculation result including reflection effect (CLIO case)

Reflectivity of Al	$R=0.90$	$R=0.95$	$R=0.97$
$\left(P_{ref}+P_{dir}\right)/P_{dir}$	**307**	**622**	**898**

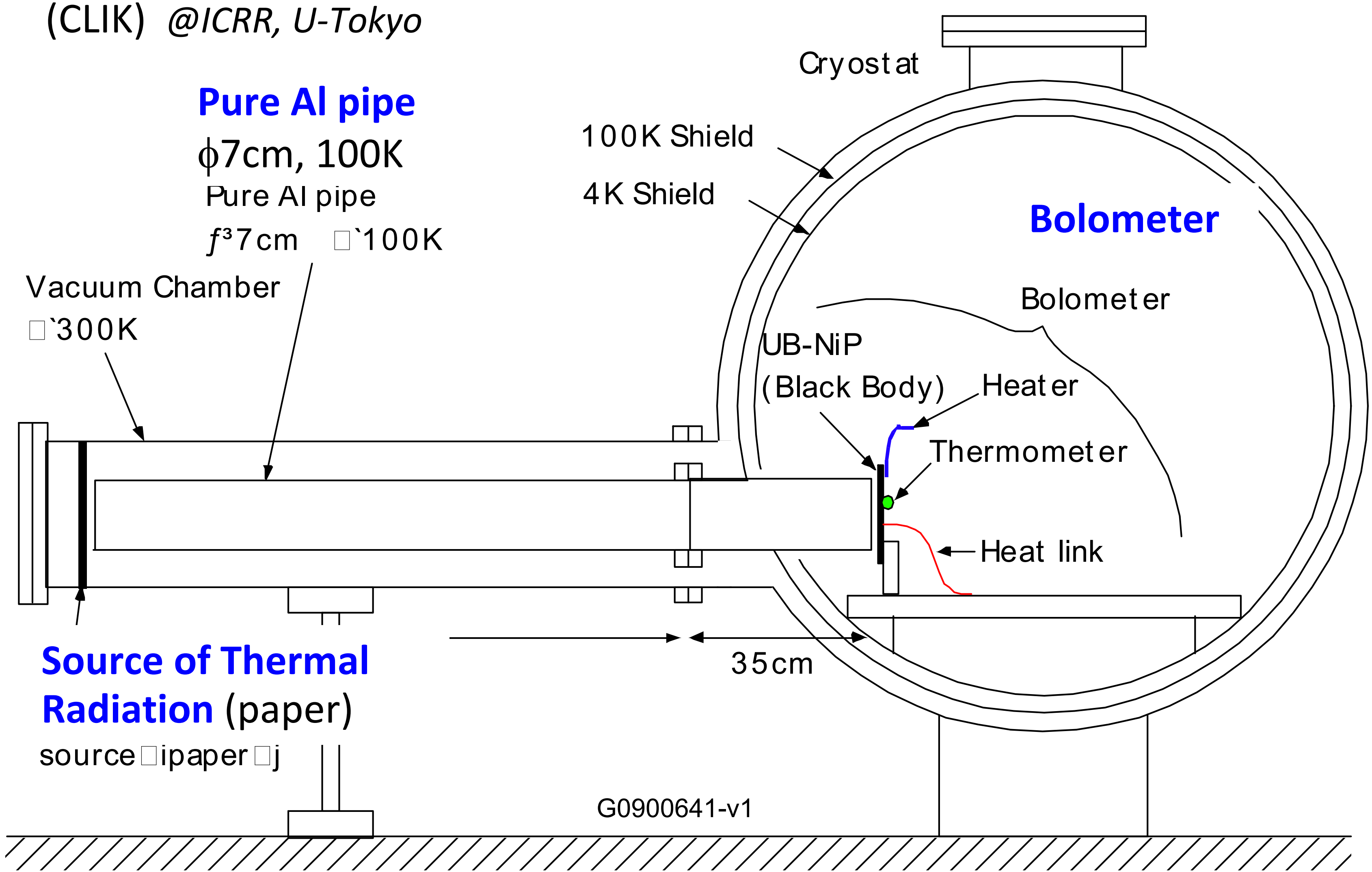
Thermal radiation source $\rightarrow$ *Vacuum duct consist of stainless steel* $\varepsilon=0.1@300K$

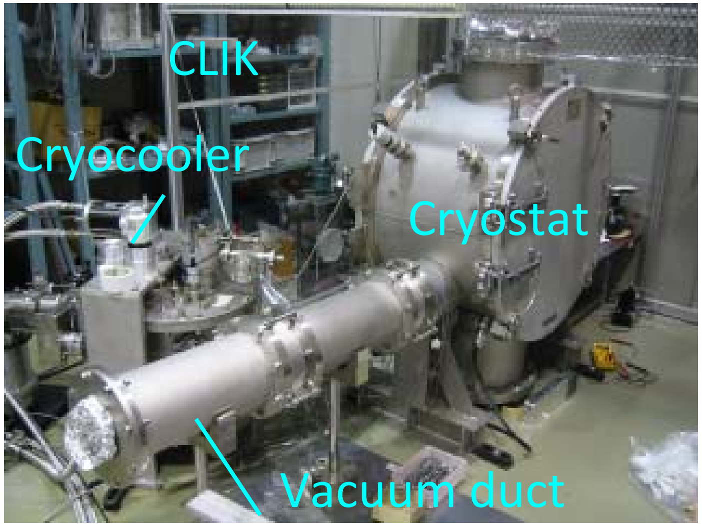
Absorbed power in cryostat $\rightarrow$ *100% (black body)*

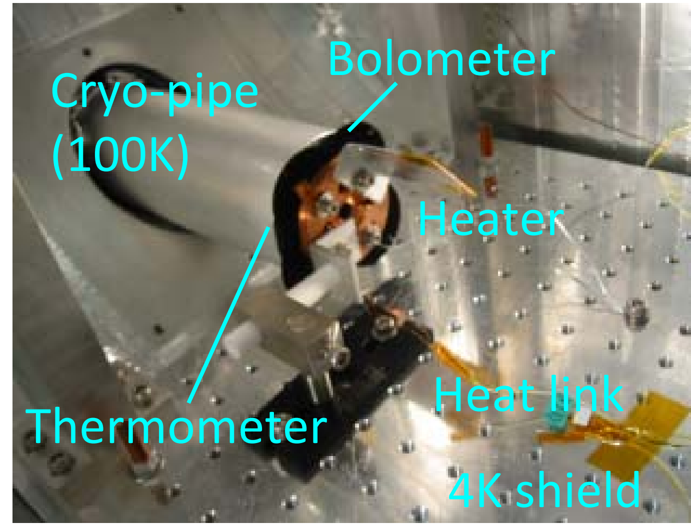
Radiation shield inside a radiation shield(4)

Experimental Verification

Prototype Cryogenic Interferometer
(CLIK) *@ICRR, U-Tokyo*







Result

Estimated value by SB law: 0.53mW

Measured Result : 390mW

-> Estimated IR reflectivity of Al pipe: 95.0%

x 740

This IR reflectivity was almost consistent with reflectivity of this pipe, measured by using IR laser.

Thermal radiation conduction effect was verified.

Apply this result to the LCGT …

Limitation: heat conduction of a main mirror suspension (820mW)

ϕ800mm x1 case : **5W**

ϕ250mm x2 case : **820mW**

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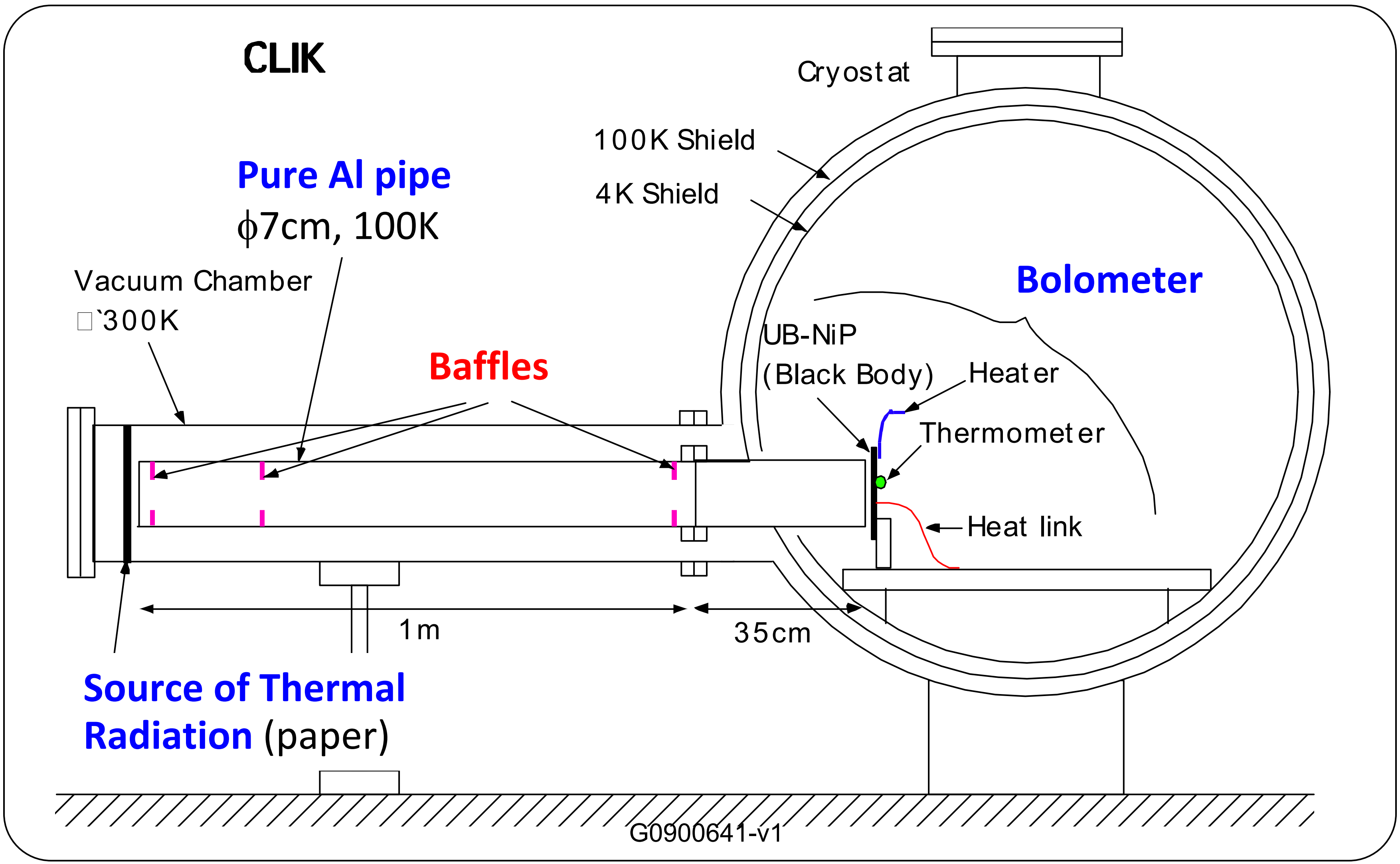
Too Large

Heat Load Reduced by infrared optical baffles

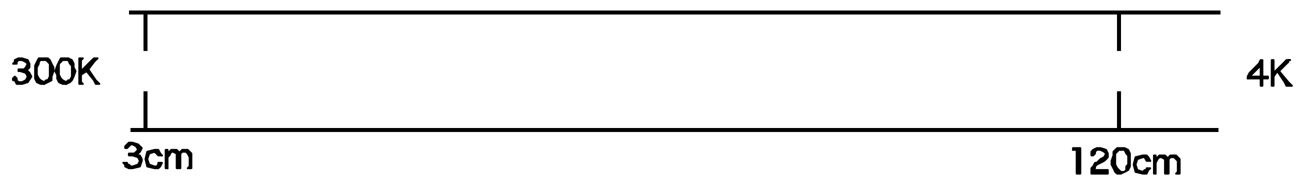
Introduction of Al baffles



Radiation shield inside a radiation shield(4)

Al baffles with aperture of
1/3 of cryo-pipe diameter

Using 2 baffles



Measured result: 7.9mW

-> **Reduction rate: 98%**

Acceptable

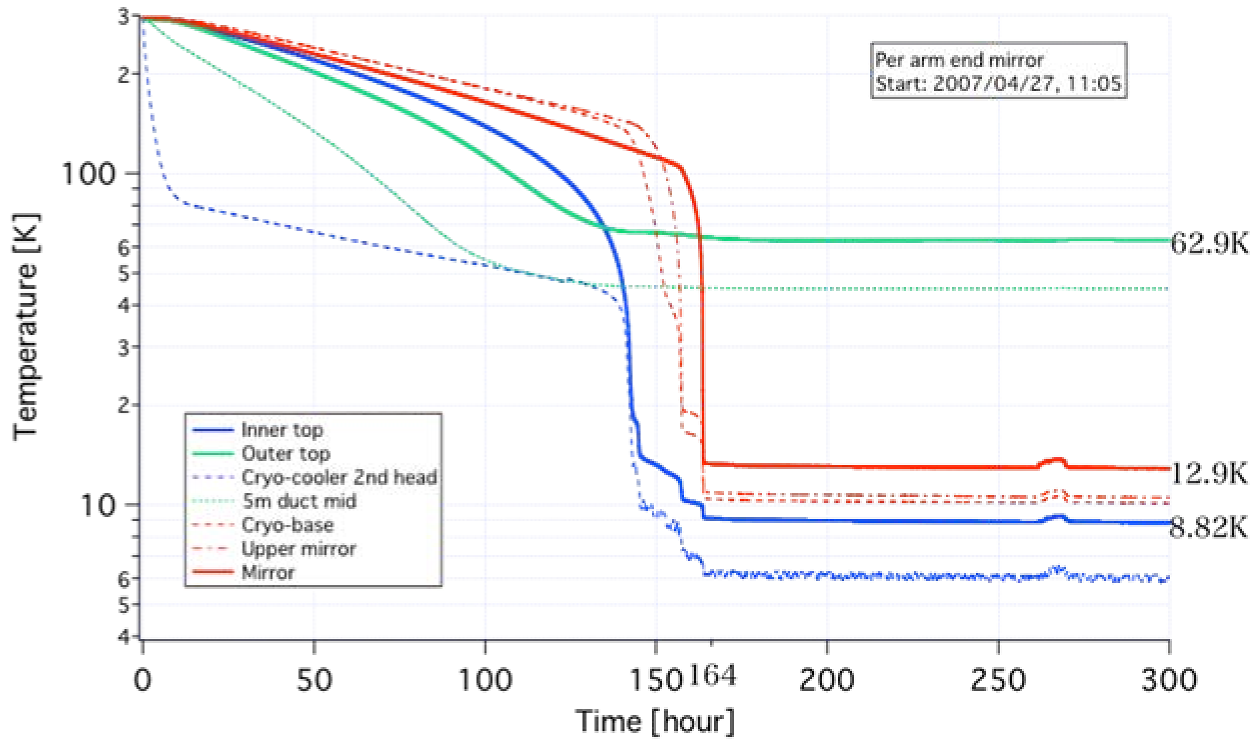
Applying this result to the LCGT …

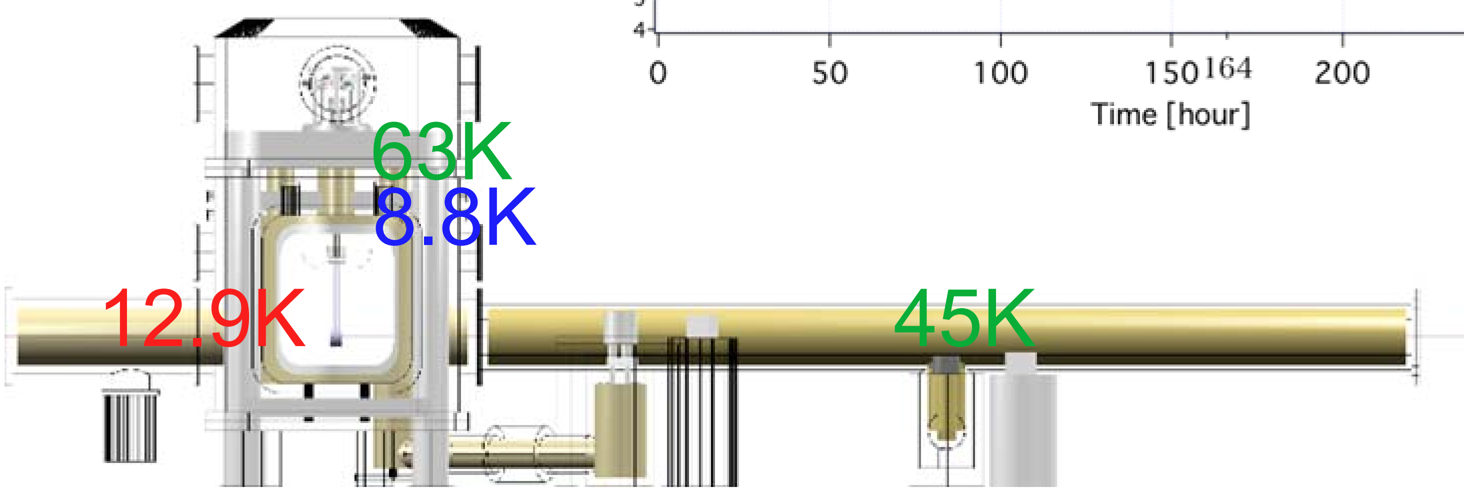
Limitation: heat conduction of a main mirror suspension (820mW)

ϕ800mm x1 case : **5W -> 700mW**

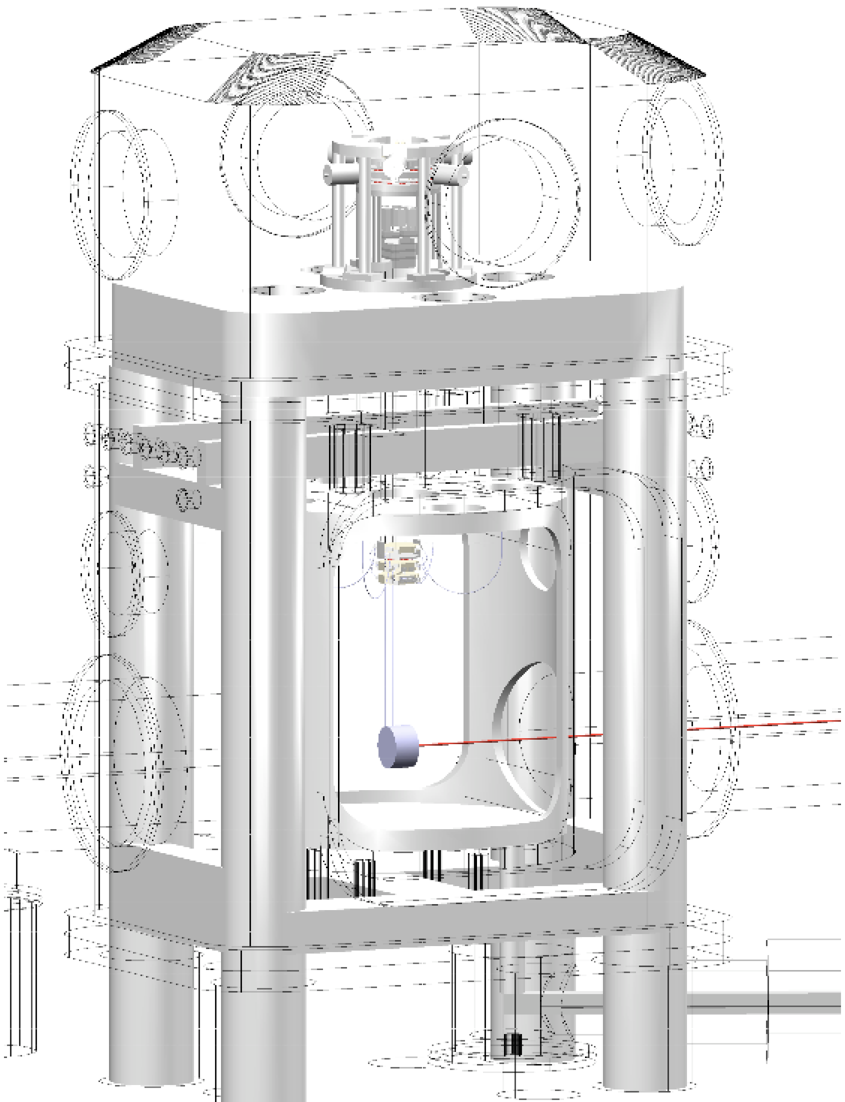
ϕ250mm x2 case : **820mW -> 620mW** (too small aperture)

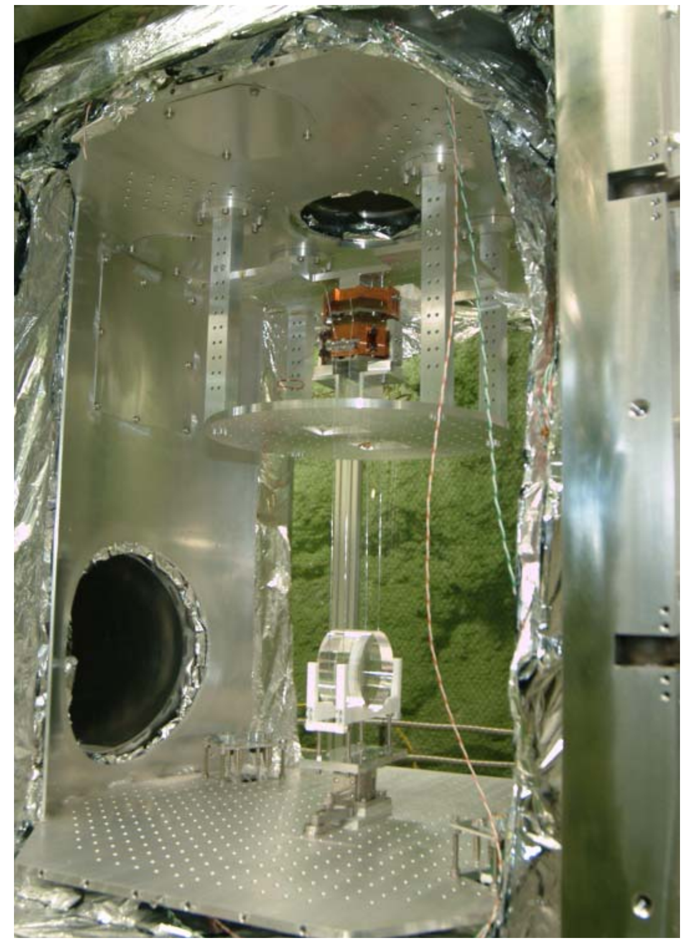
Cooling test and achieved temperature





Cryogenic suspension





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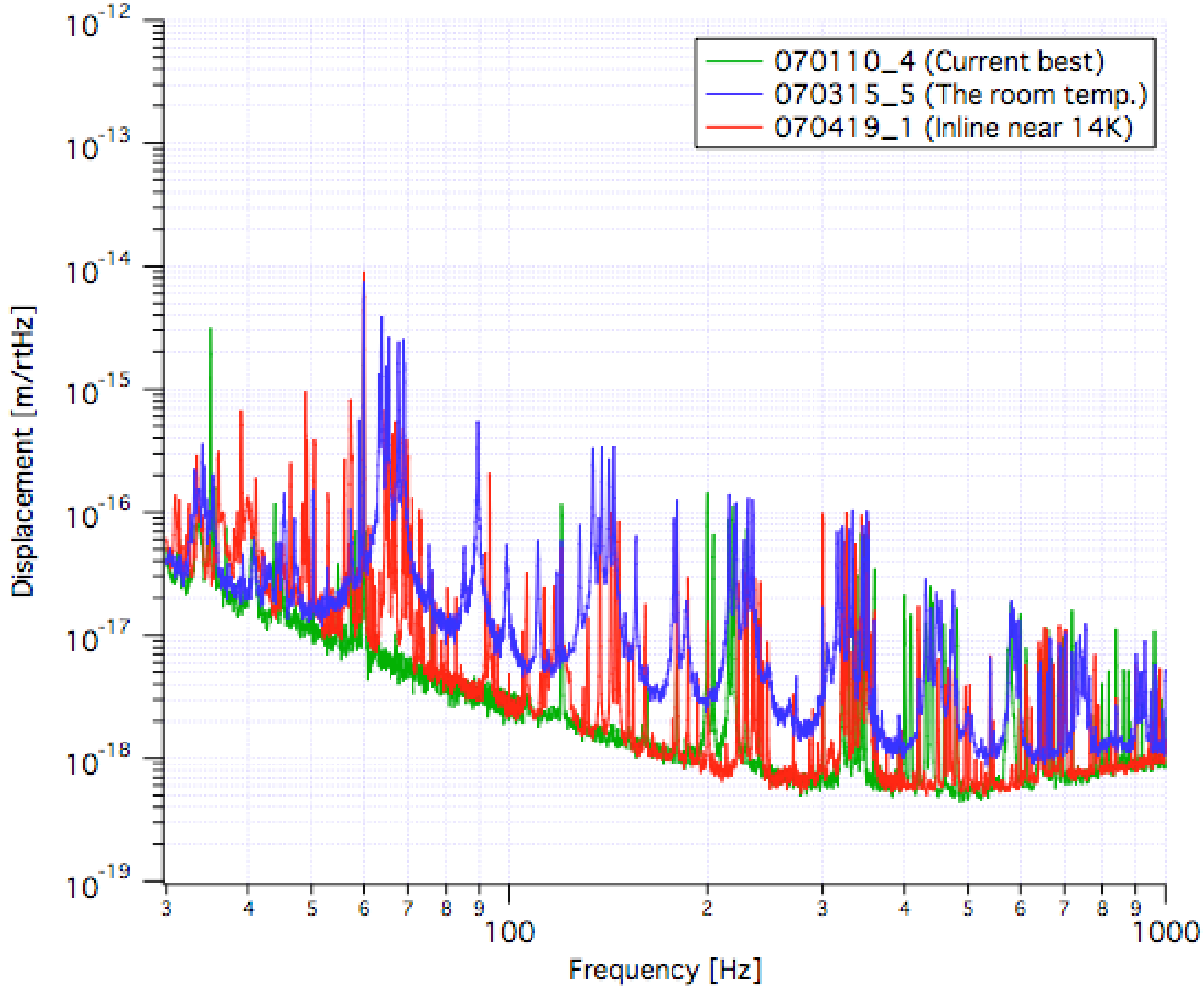
Cooling summary

	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.

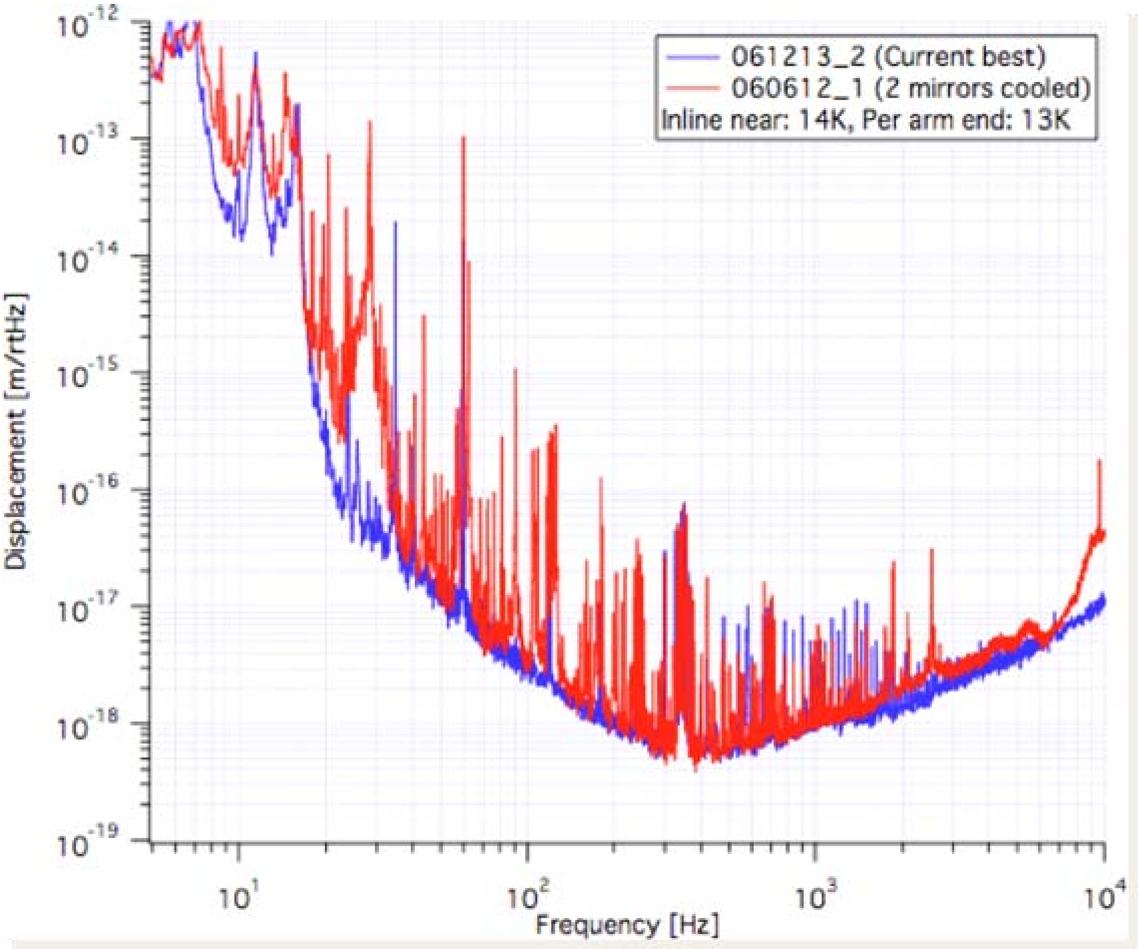
Reduction of thermal noise of bad Q suspension

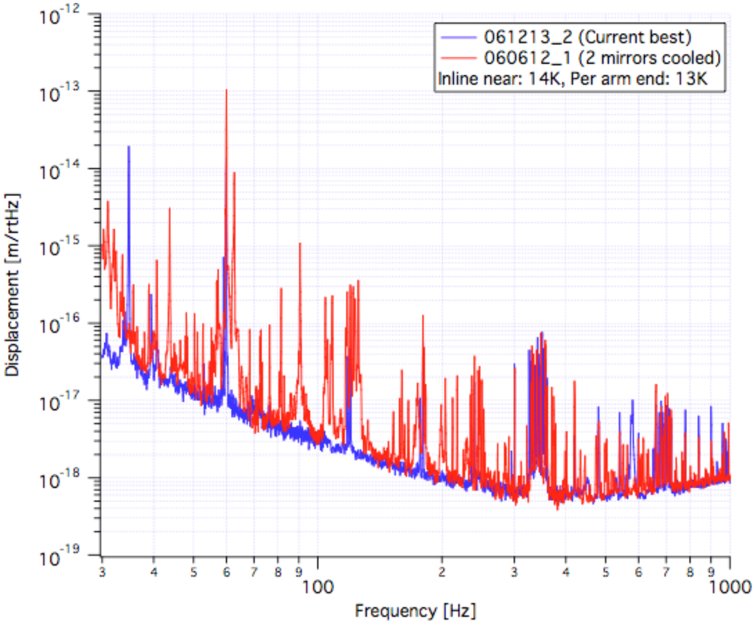


Inline near mirror was suspended by Φ1.0 Al wire.

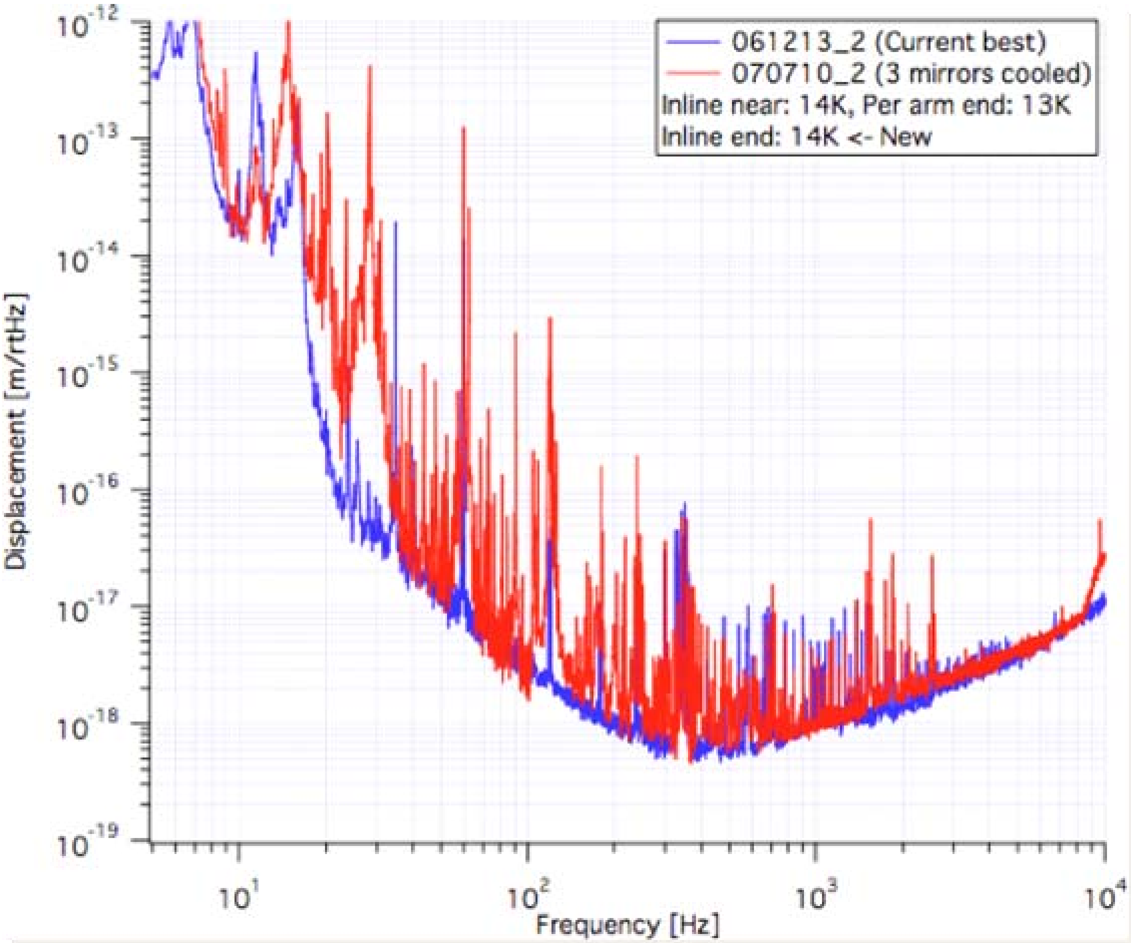
This is the first observation of sensitivity improvement by cooling.

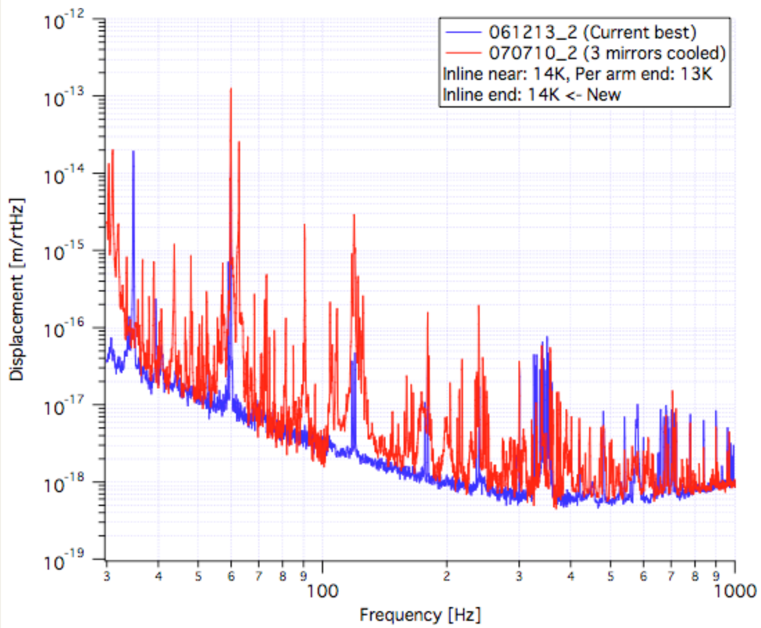
Long run of refrigerator system
- 2 mirrors are cooled -



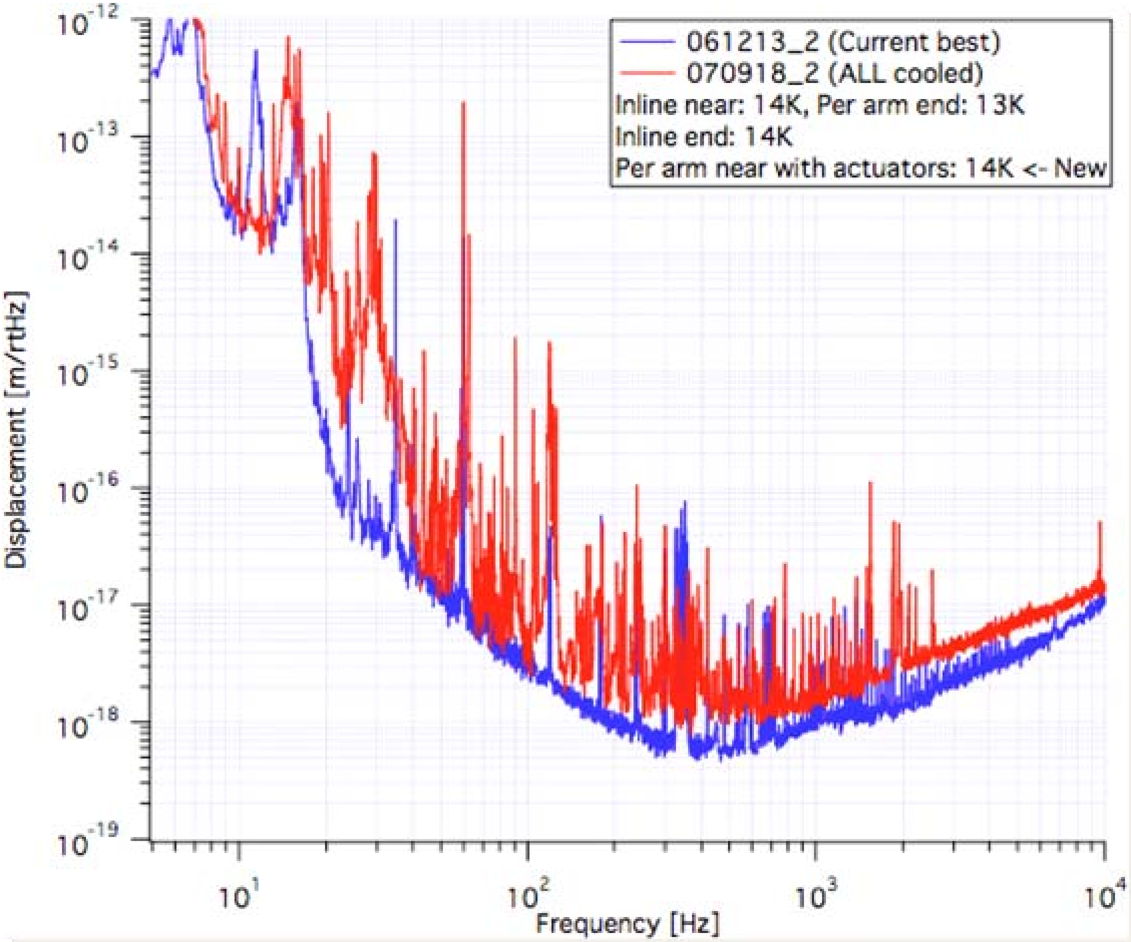


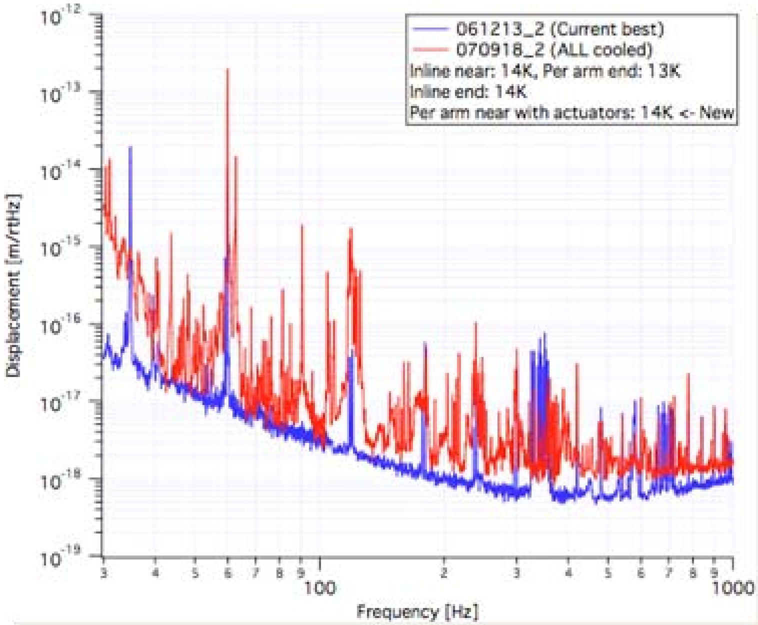
Long run of refrigerator system
- 3 mirrors are cooled -





Long run of refrigerator system
- All mirrors are cooled -





Tuning has not finished yet.

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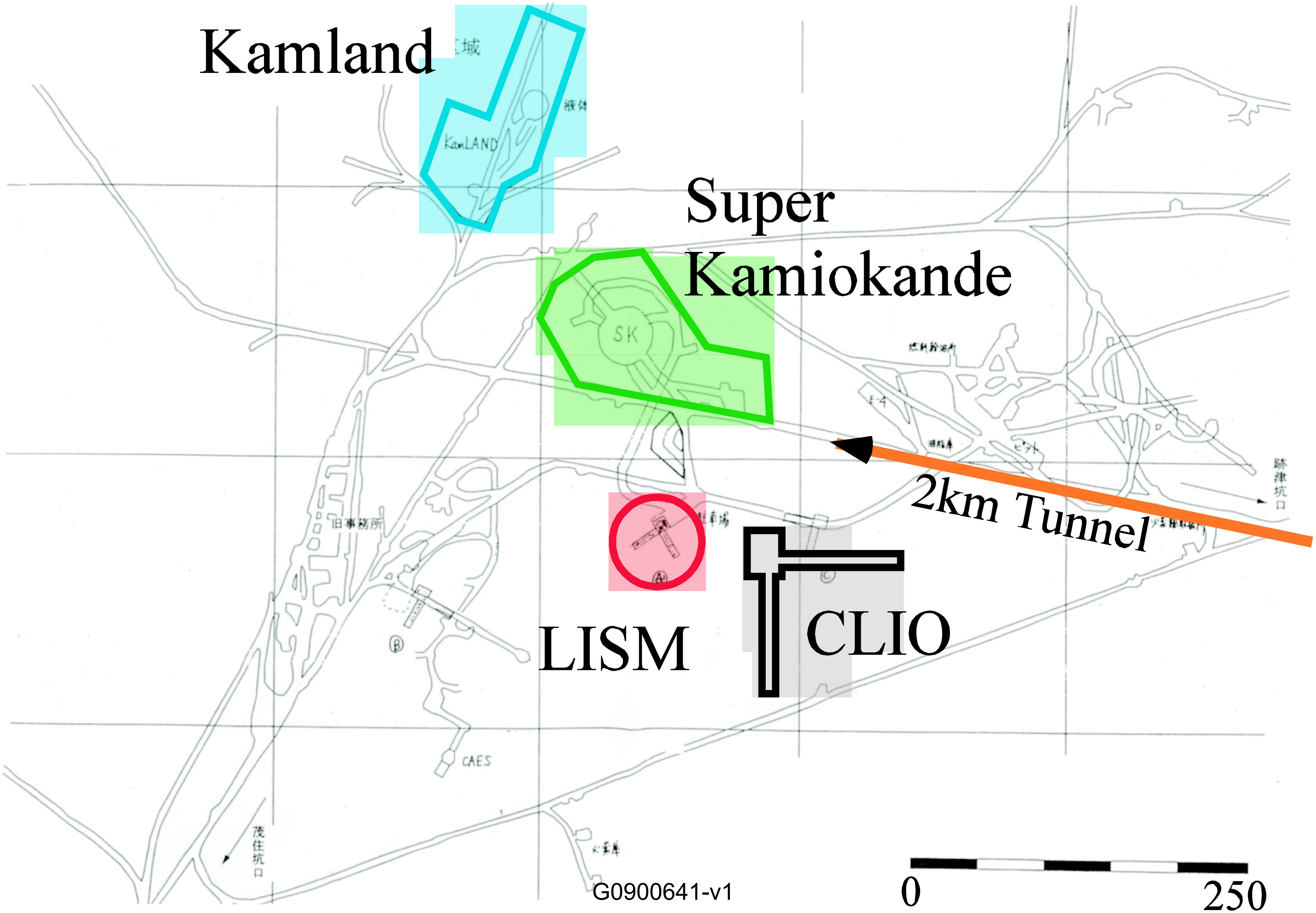
Proposal of the usage of CLIO for Newtonian noise subtraction

- CLIO presents a sensitivity enough to measure Newtonian noise subtraction measurement in 3 dimensional configuration
- Seismometers can be installed around the underground of the mine as well as outside of the site
- Main point of this measurement uses naturally earthquakes occurring

There are many caves that can be used to place sensors



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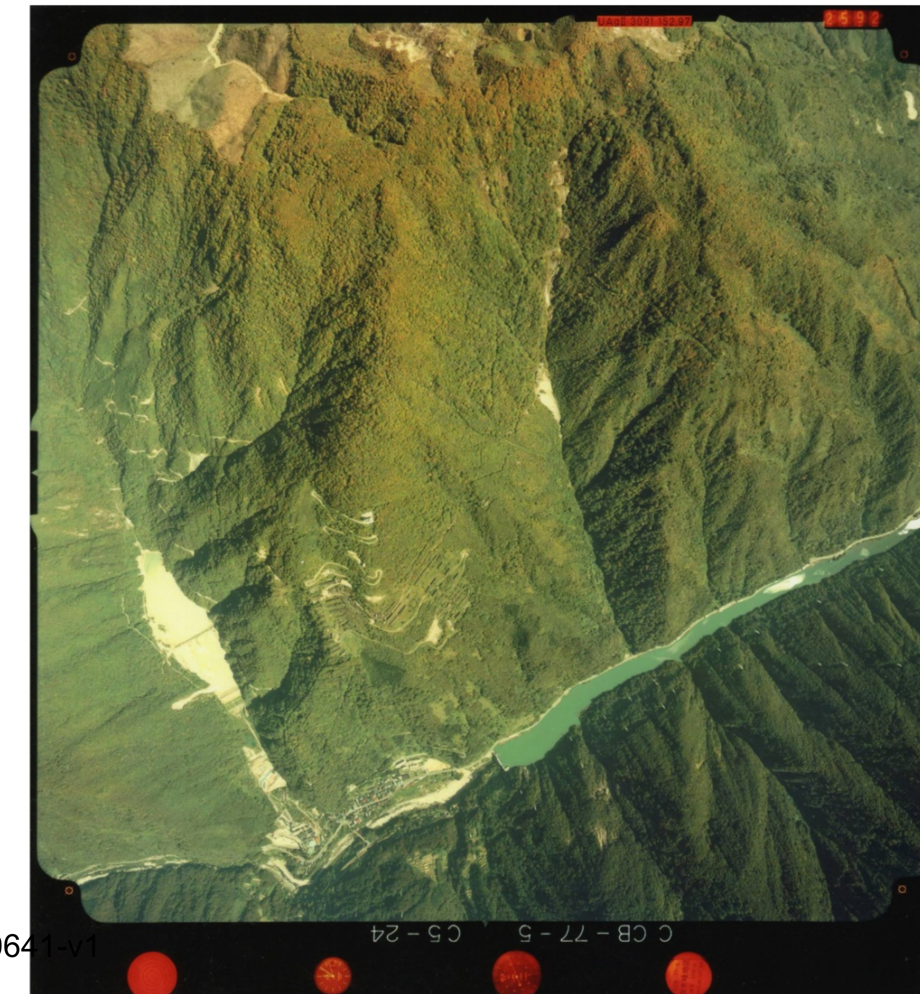
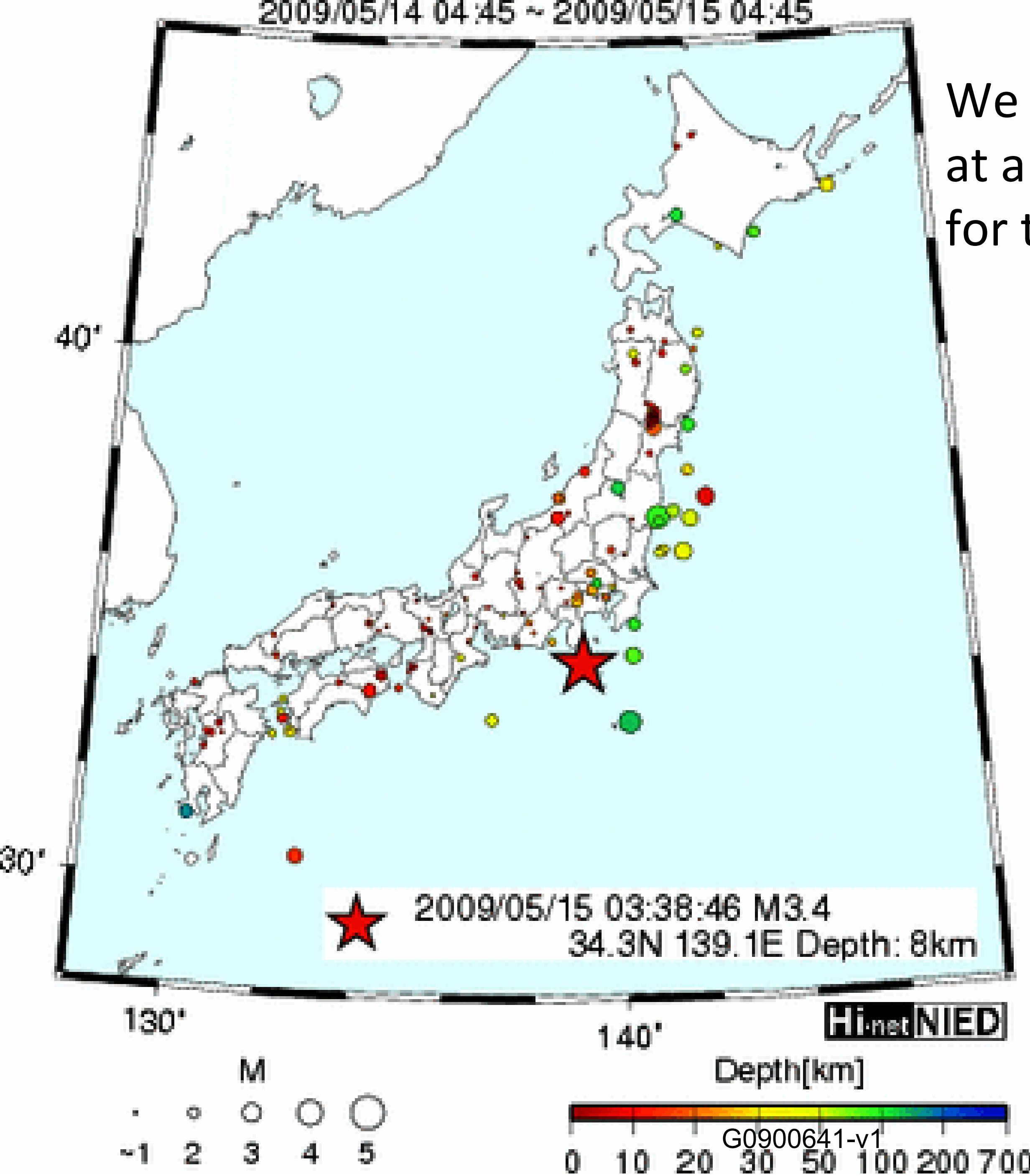
Contour of the mountain is well known and it is not difficult to search more precisely





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We always have earthquakes
at any time necessary
for the measurement.

Summary

- Cryogenics is applied to CLIO by existing techniques
- Close to its completion of the R&Ds
- After commissioning of CLIO, CLIO can be used for Astro- watch with other available detectors
- Also CLIO can be utilized as the test of Newtonian noise contraction scheme
- Welcome to adventurous researchers to augment the present commissioning and to conduct the Newtonian experiment

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