CLIO

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TAMA/CLIO/LCGT collaborators

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Brief history of R&D in Japan

1975 — Resonant antenna (Phys Dept, UT)

1980 — Cryogenic resonant Ant. (KEK)

TENKO-10 (ISAS, Initiation of laser interferometer)

1990 — *Research Fund by Government Total $9.3 M*

TENKO-100 (ISAS, FP verus Delay Line)

NAO 20m (NAOJ, Laser Technique)

LISM (Kamioka, Underground)

Research Fund for basic Res Total $15.6 M

2000 — TAMA 300 (Mitaka, 300 m scale system

Research fund for priority area Total $14.3 M

CLIO 100 (Kamioka, Cryogenics)

LCGT funding request $ 155 M

2010

Underground of Kamioka research facility

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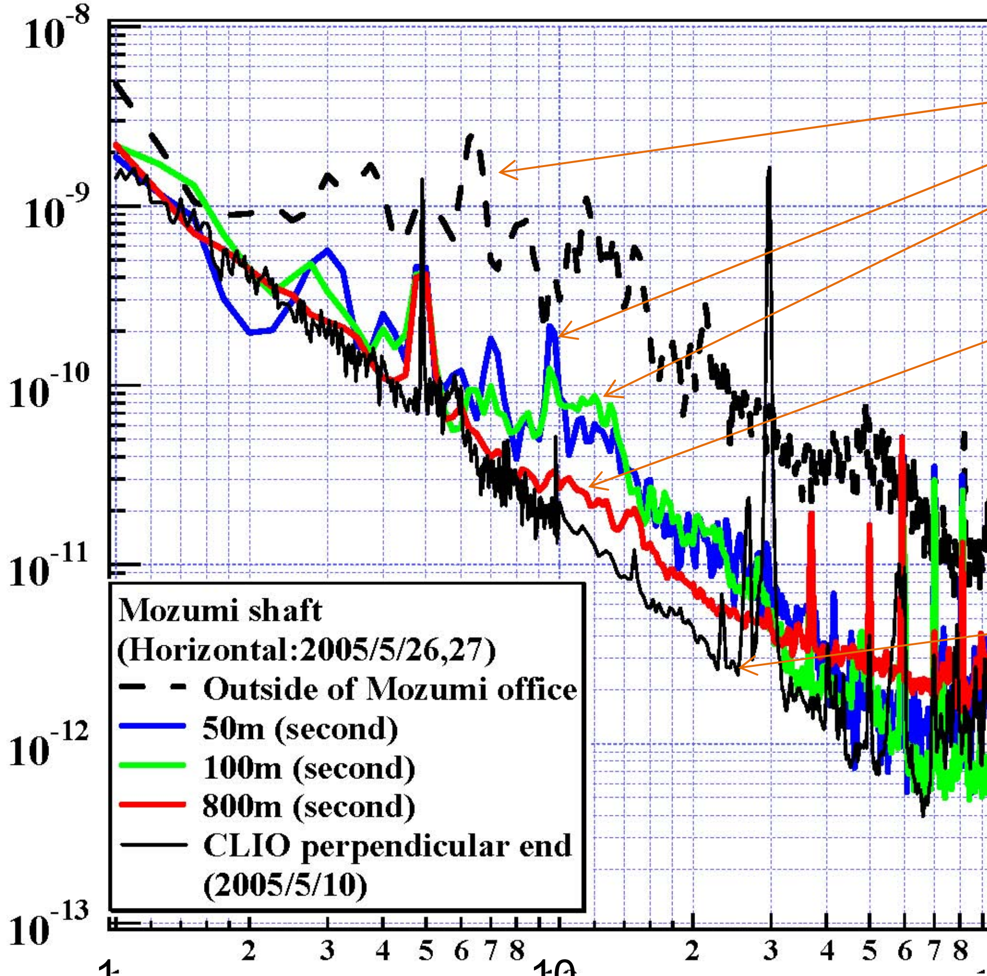
Merit of Underground

Seismic vibration spectrum
reduces by deeper intrusion

m/RHz



Frequency Hz

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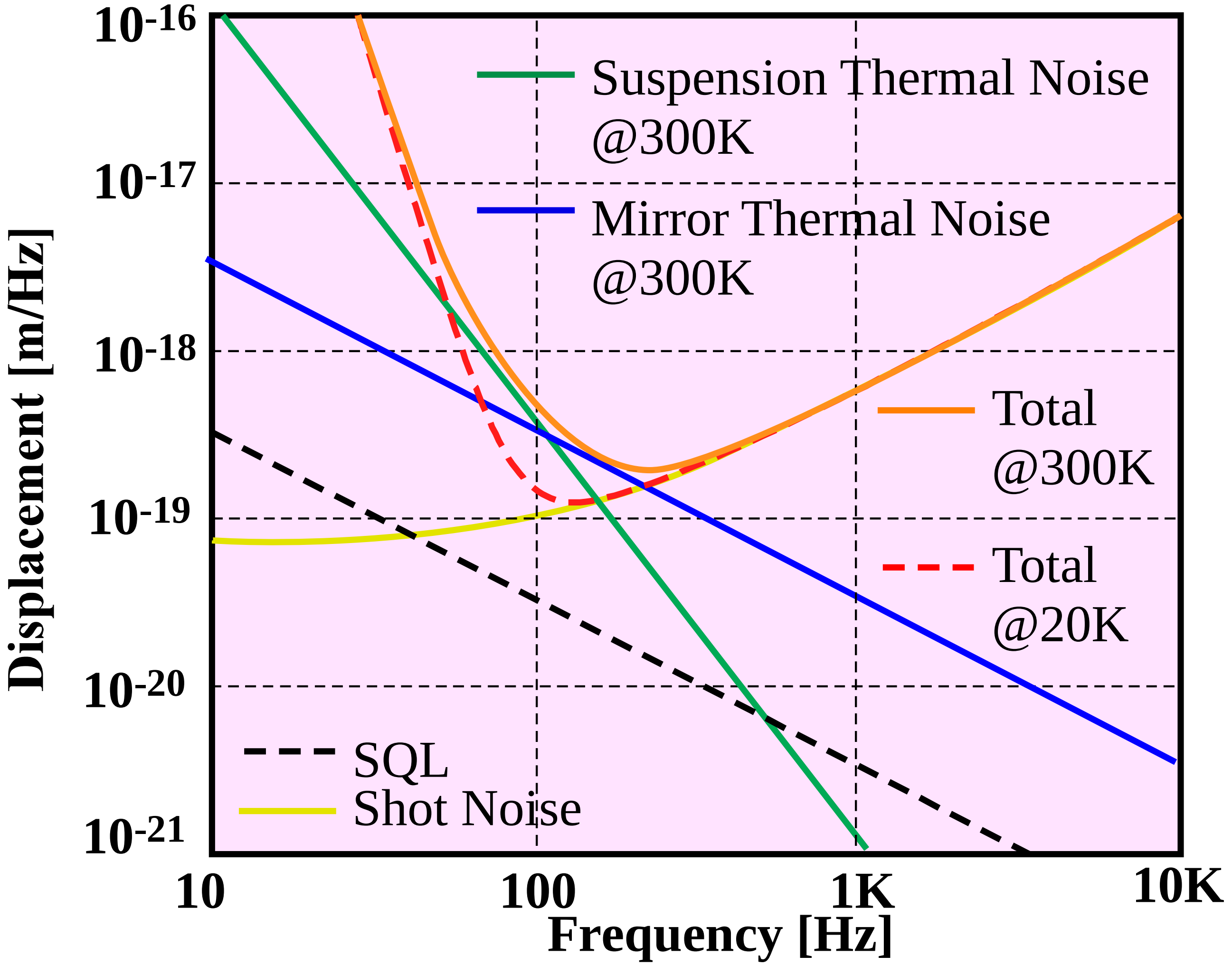
Measured by K Yamamoto

Objective of CLIO



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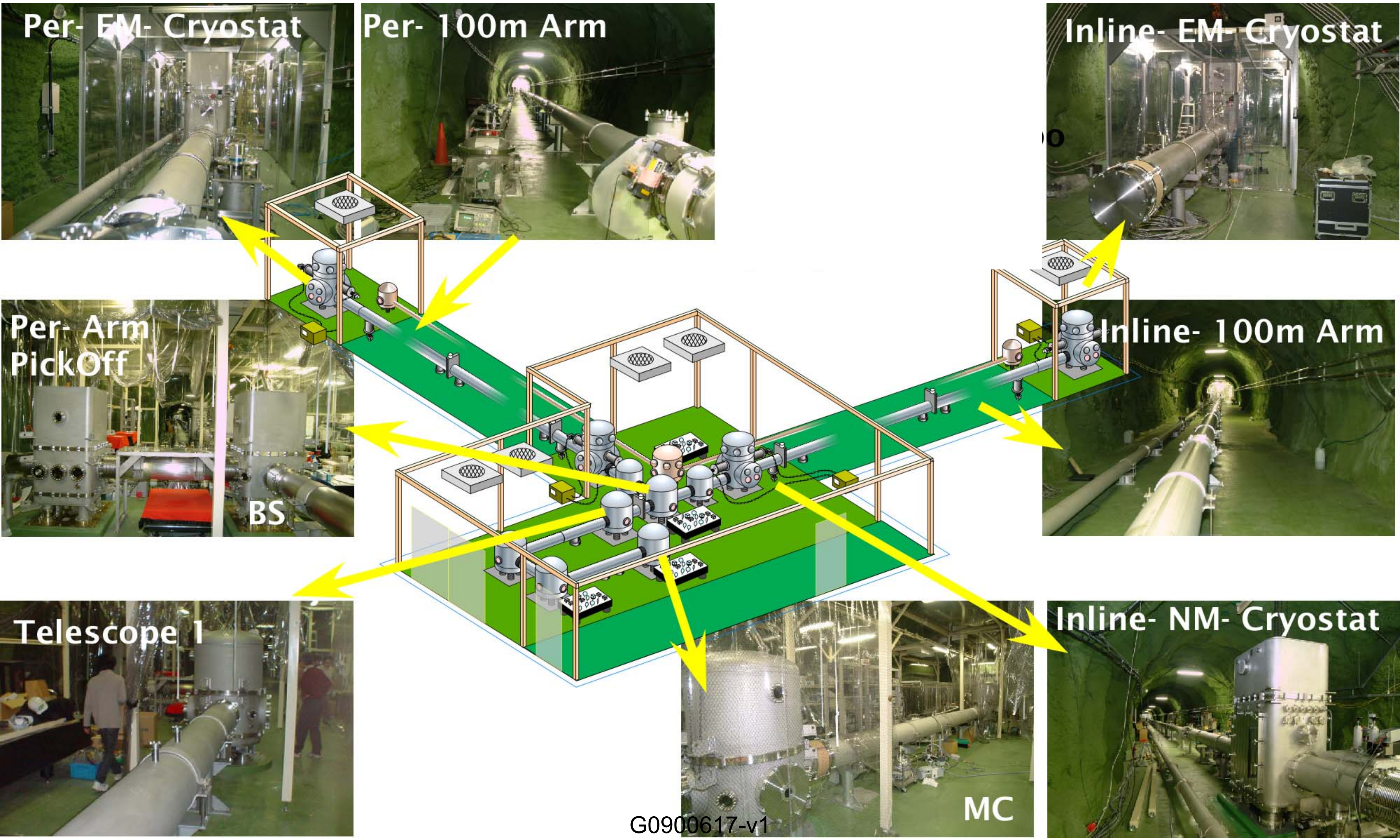
Laser power :
250mW for one arm
Mirror Mass :
1.8 kg

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

Schematic view of CLIO



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R&D of CLIO for LCGT (1)

- Cooling test of main mirrors of CLIO was successfully achieved in 2006 (last Amaldi meeting)
- The reduction of low Q mode thermal vibration of suspended wire was demonstrated by cooling the mirror system
- Technical problem that had not been recognized at the time of CLIO construction was heat invasion from hot vacuum duct, which was fixed

R&D of CLIO for LCGT (2)

April 2008~December 2008

The target is to achieve the sensitivity limited by thermal noise. There are two types of thermal noise.

(i) Mirror thermal (thermo elastic) noise(100Hz-300Hz□

(ii) Pendulum thermal noise(below 100Hz)

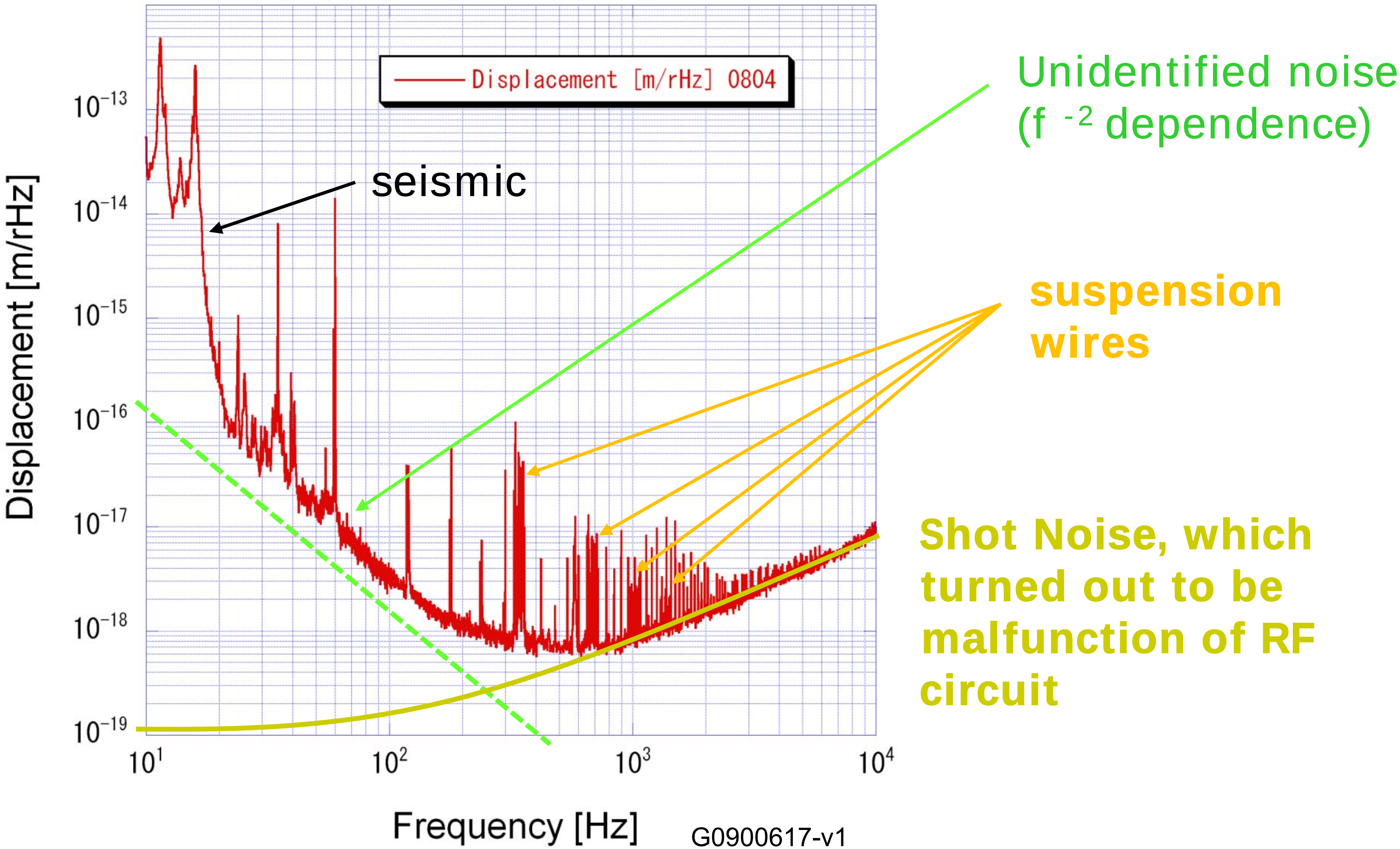
However,

Pitching noise motion of the mirror coupled with misalignment of beam centering hided this thermal noise. In case Q is lower than expected, it is easier to see pendulum thermal noise (drawback from getting higher sensitivity, though)

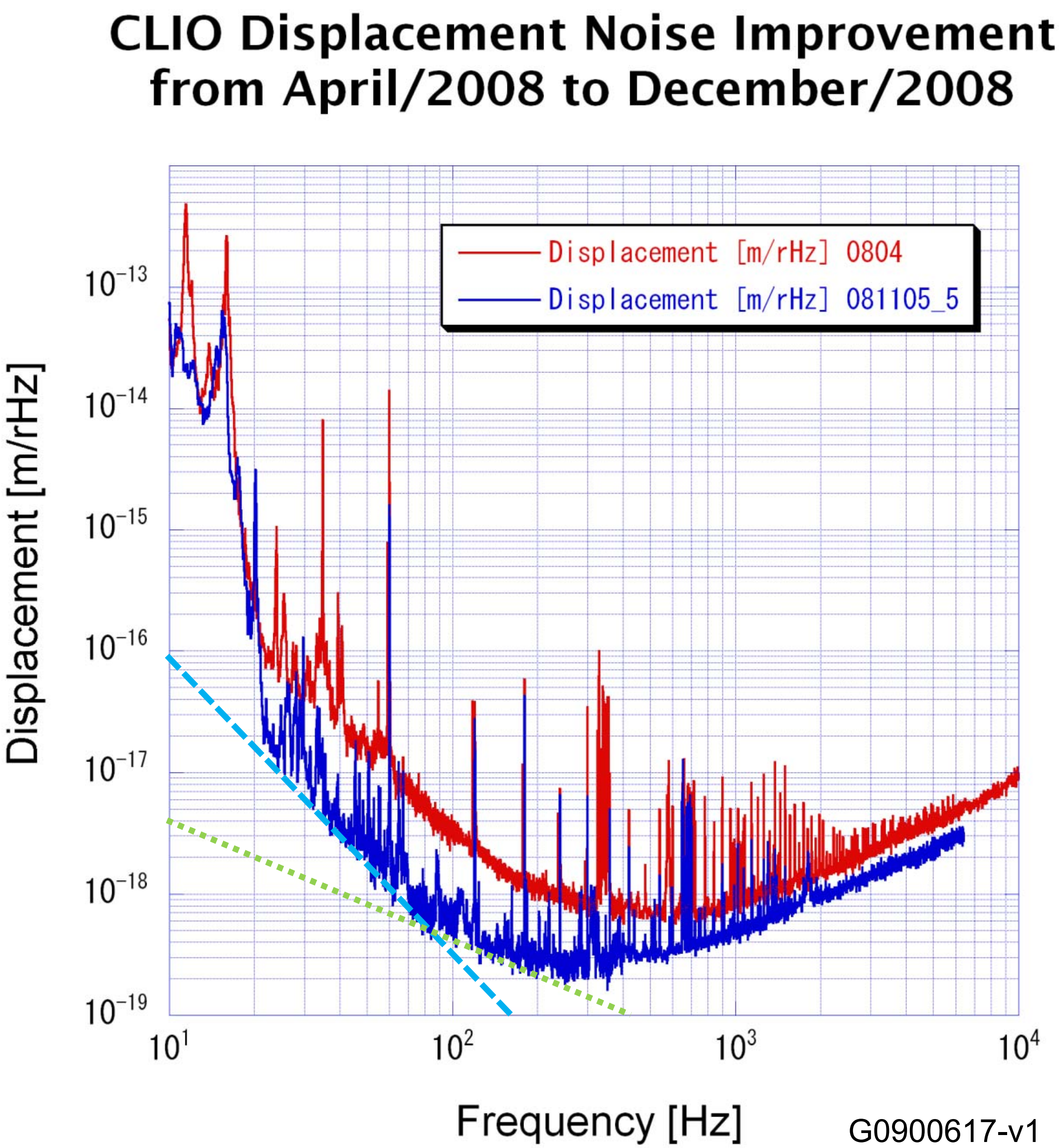
Since January 2009 □within 1.5year□

Clearly show the reduction of the above thermal noise by lowering the temperature. Preparation for cooling is ongoing, now.

Factors limiting previous sensitivity (Apr.08)



Current best at room temperature



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By finer wires shift wire resonances from the best region

Fix the malfunction of RF circuit over 400Hz, which assists to achieve shot noise level

Identified noise source appearing from 20Hz to 400Hz (Seiji's one day work)

Further more,

Correct beam centering reduces noise arising from pitching of the mirror (20Hz- 400Hz)

Broken blue line shows pendulum thermal noise

Broken green line shows mirror thermal noise

Thermal noise source (1)

Eddy Current Damping

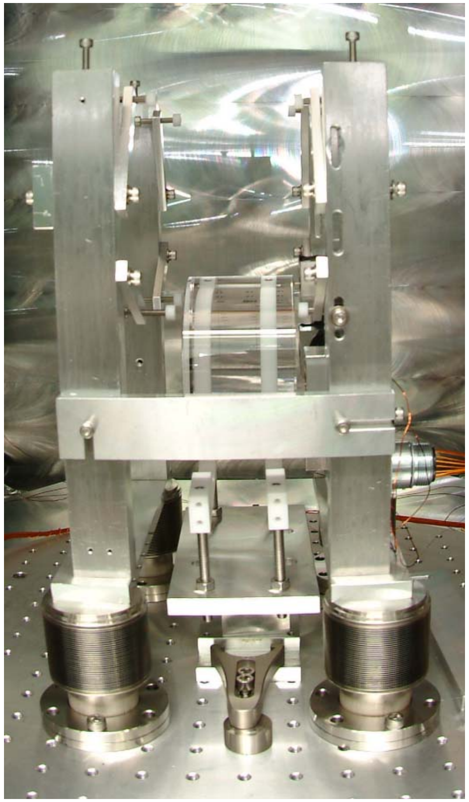
- Length control is applied to 100mFP cavity
  Finesse 3140←R=0.999000±20 ppm)

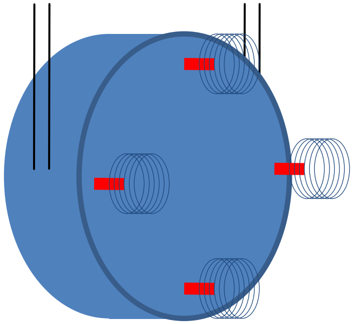
- The control is made by electro-magnetic actuation--- the bar magnet was neogium and sized 2mm in diameter and 10mm in length. The mirror mass is 1.8 kg.

- Due to cryogenic, supporting frame was made of all metal, typically aluminum alloy (cooled down to about 10K, the mirror is maintained at 20K). Especially the holder of the actuation solenoid was pure aluminum.

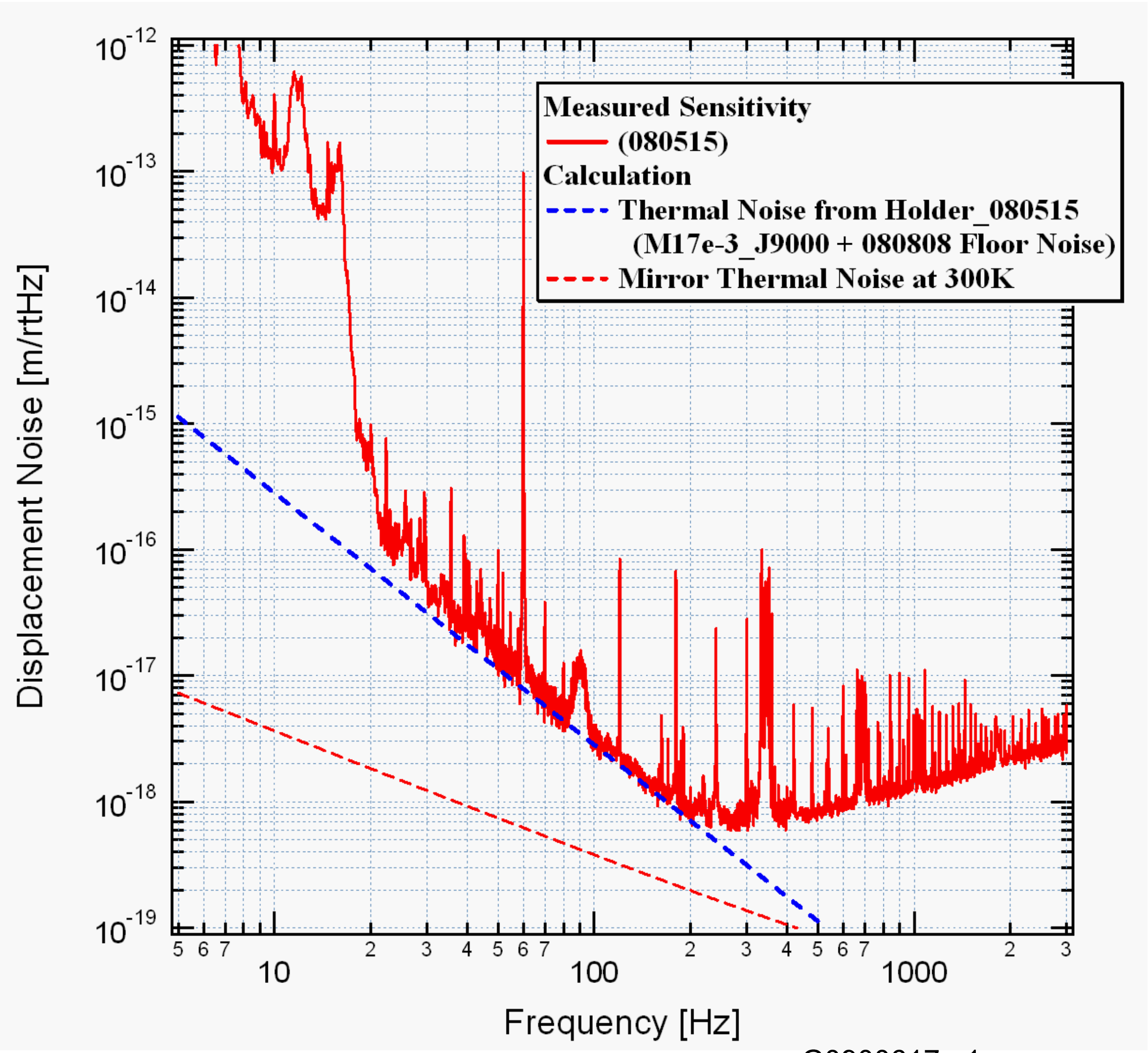
- The magnetic field of the bar magnet produced Eddy Current in the holders, which behaved as damping that dissipates energy causing thermal noise source. (equivalent mechanical Q was reduced accordingly)

- This phenomena is represented by fluctuating force exerted by Johnson noise current produced by conductivity resistance of aluminum.





Thermal noise (1) –theoretical check



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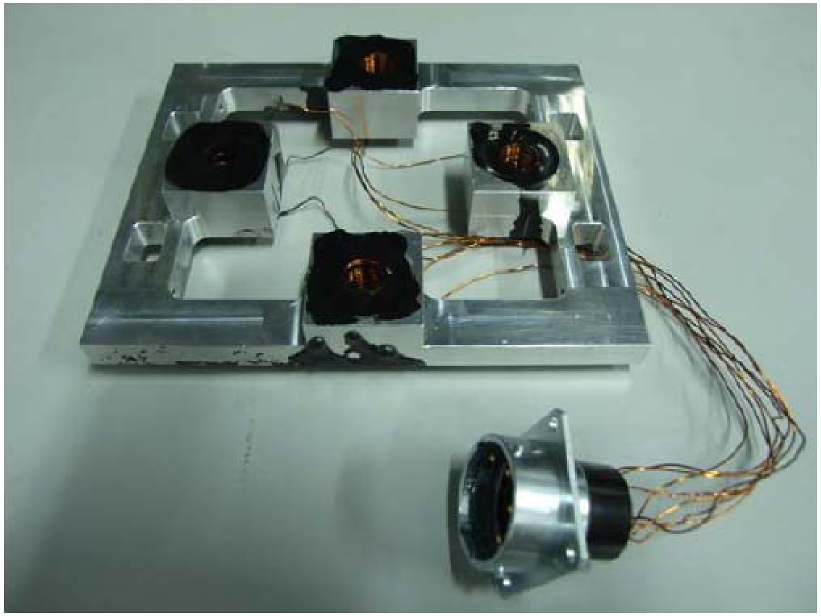
- Theoretical guess explained the data.

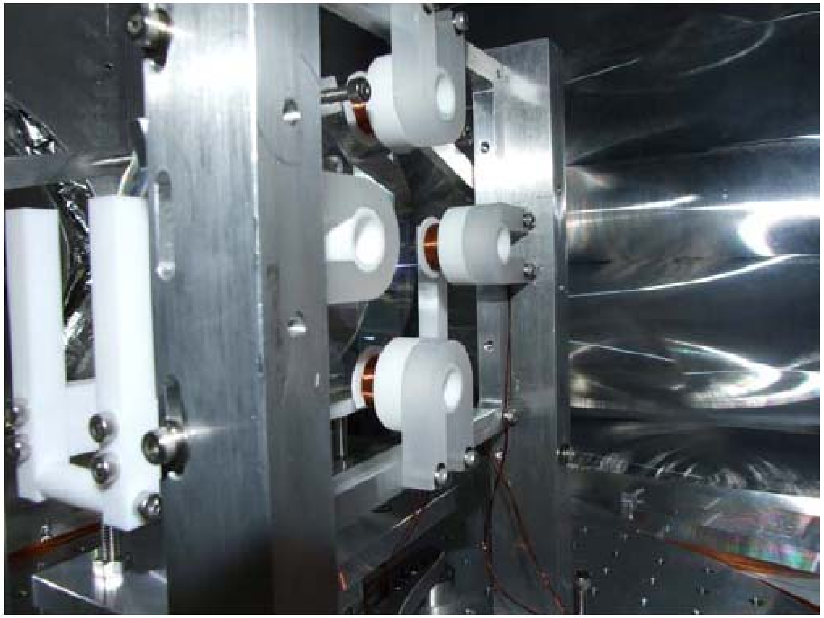
Experimental Check

Check (i)

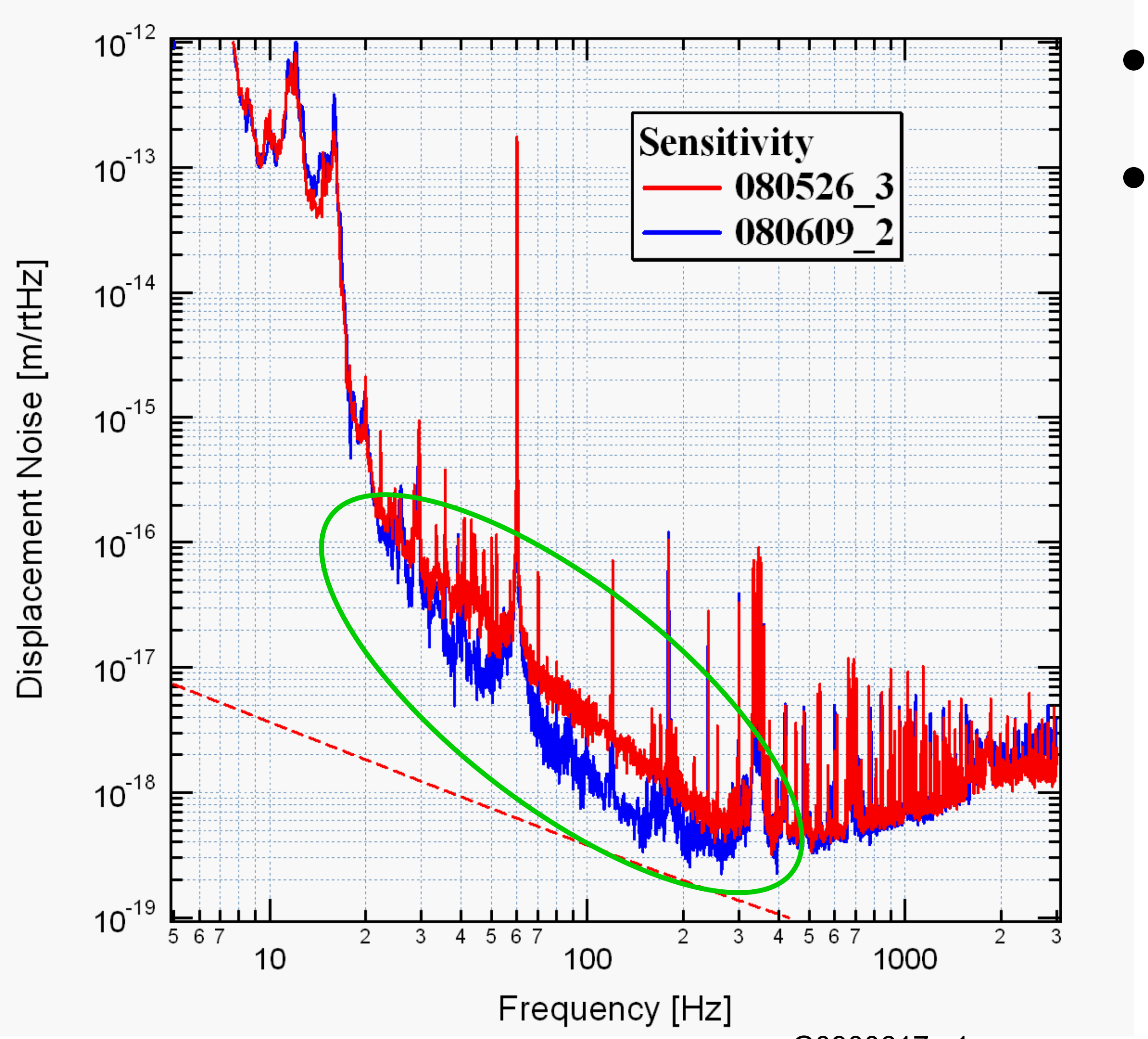
Repalcement of the material of solenoid holder from aluminum to ceramic (and plastic)

....this replacement is not final because good thermal conductivity at cryogenic temperature is required





Thermal noise (1) ---result



- Sensitivity improved
- limit of the sensitivity is the next problem

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Thermal noise (1)—Experimental check□

Reduction of pendulum Q due to eddy current and fluctuation-dissipation theorem

Estimated Q reduced by Eddy Current Damping & pendulum thermal noise by the theorem by K Agatsuma

$$F = \alpha I$$
$$V = \alpha v$$

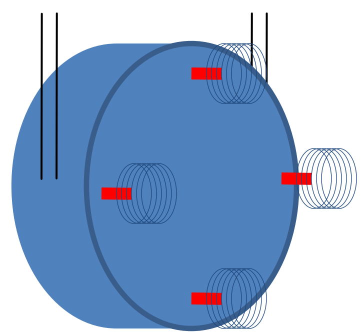
$$G = \frac{4k_B T\omega_0}{m\omega^4 Q} \qquad \sqrt{G}\,[\mathrm{m}/\sqrt{\mathrm{Hz}}]$$

F:external force on the mirror[N/A]
Z:toal impeadance of the solenoid and resistance of the external circuit
N:No.of pairs of magnet-solenoid
m:mirror mass [kg]
Q:mechanical Q of pendukum
G:power spectrum [m^2/Hz]

α は Coil-magnet actuator の Coupling 率 [N/A]

$$m(-\omega^2 + \omega_0^2)\tilde{x} = N\alpha\tilde{I}$$
$$Z\tilde{I} + i\omega\alpha\tilde{x} = 0$$
$$m(-\omega^2 + \omega_0^2)\tilde{x} + i\frac{N\alpha^2\omega}{Z}\tilde{x} = 0$$

$$Q = \frac{m\omega_0 R}{N\alpha^2} \qquad G = \frac{4k_B T N\alpha^2}{m^2\omega^4 R}$$



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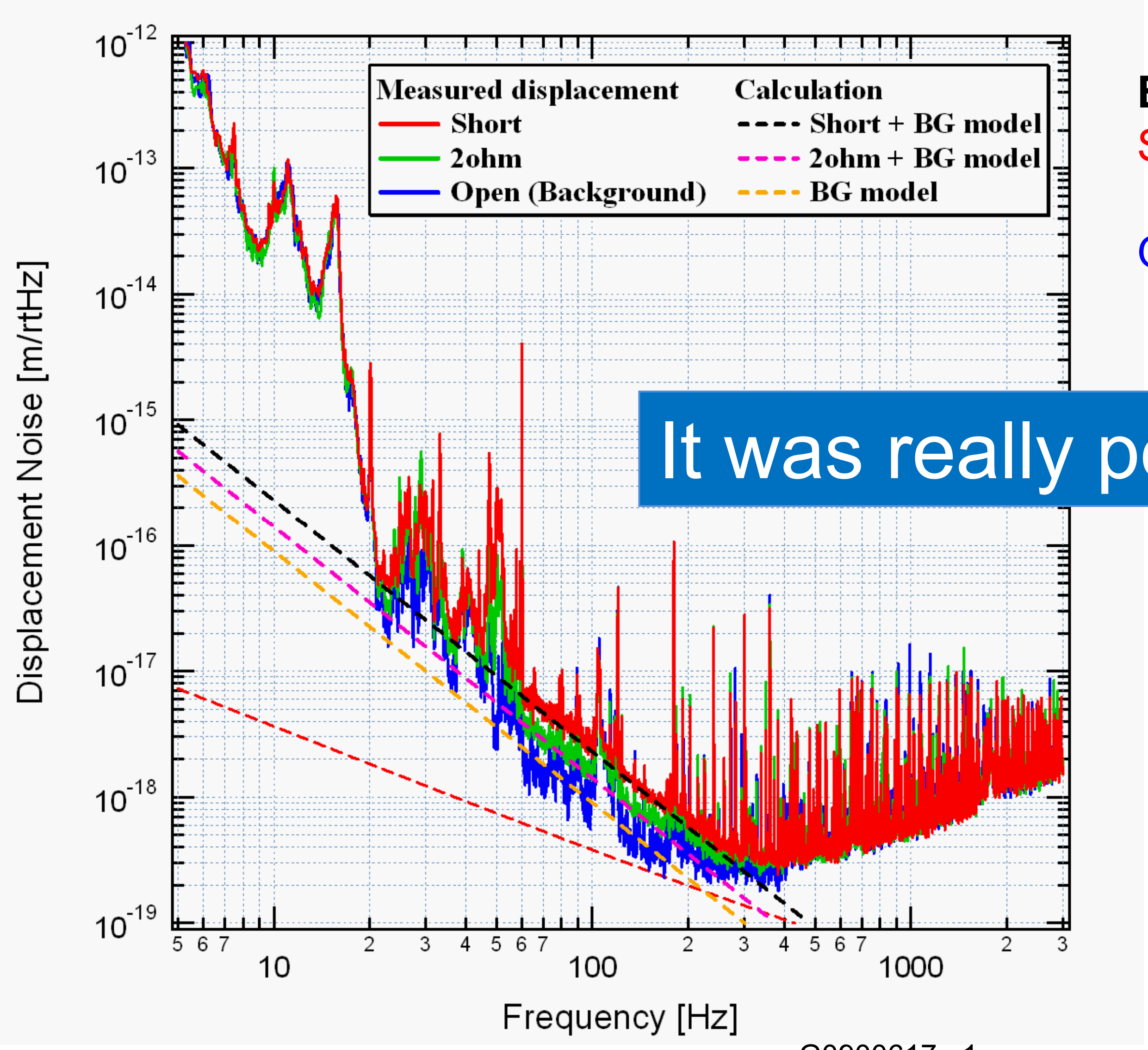
Magnitude of eddy current was changed by resisters in the external circuit in three stages□short, 2ohm, open□

Thermal noise (1) --Experimental check (ii)

pendulum thermal



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It was really pendulum thermal!

Expected noise@100Hz

Short : 2.3 x 10^{-18} [m/rtHz]

2 Ohm : 1.5 x 10^{-18} [m/rtHz]

Open : 1 x 10^{-18} [m/rtHz]

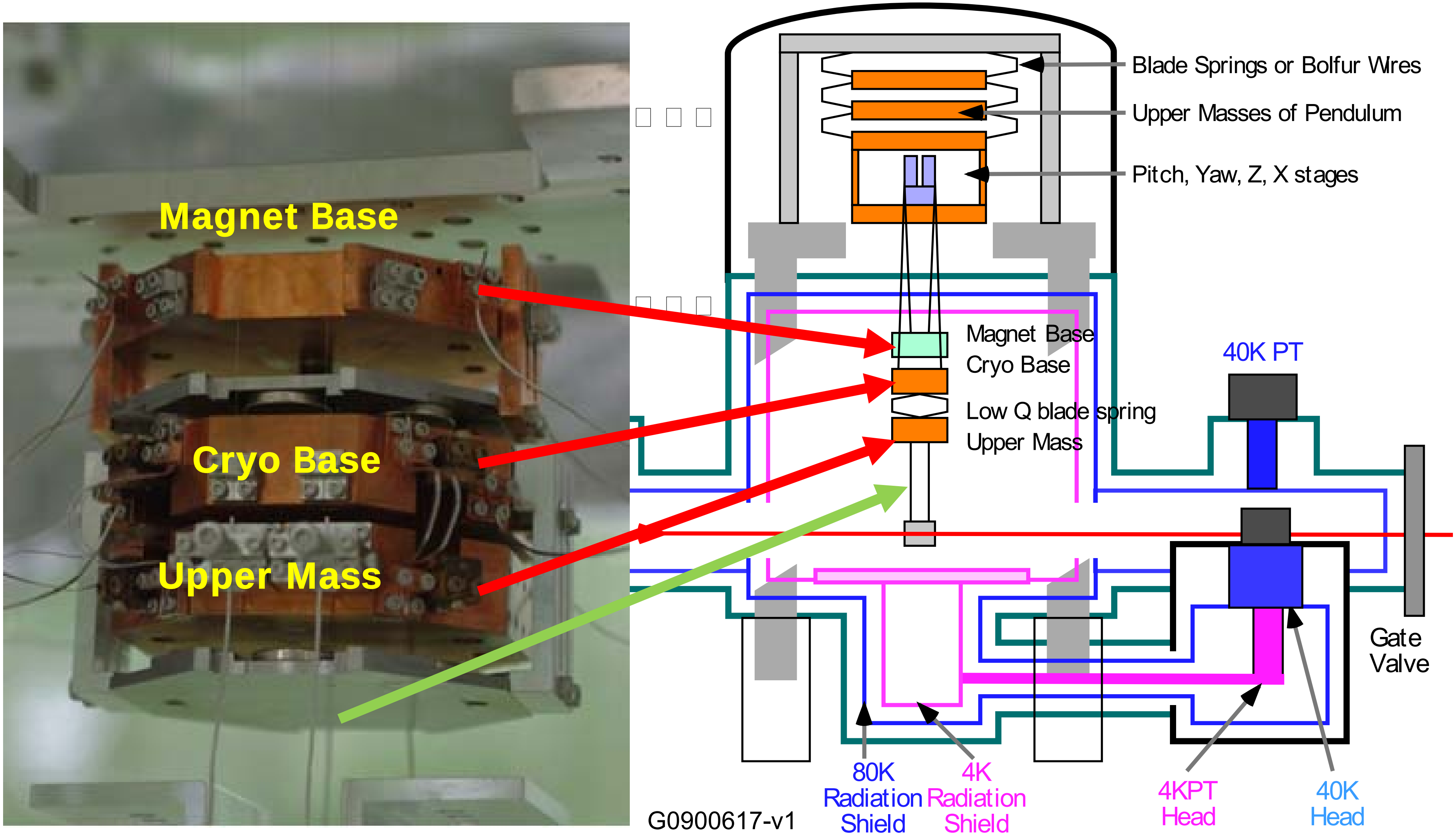
Comaprison in wide frequency band

Noise spectrum considering noise floor

□ observation agrees with theory

Thermal noise (2)

-Search for the noise source limiting spectrum (20Hz-200Hz)



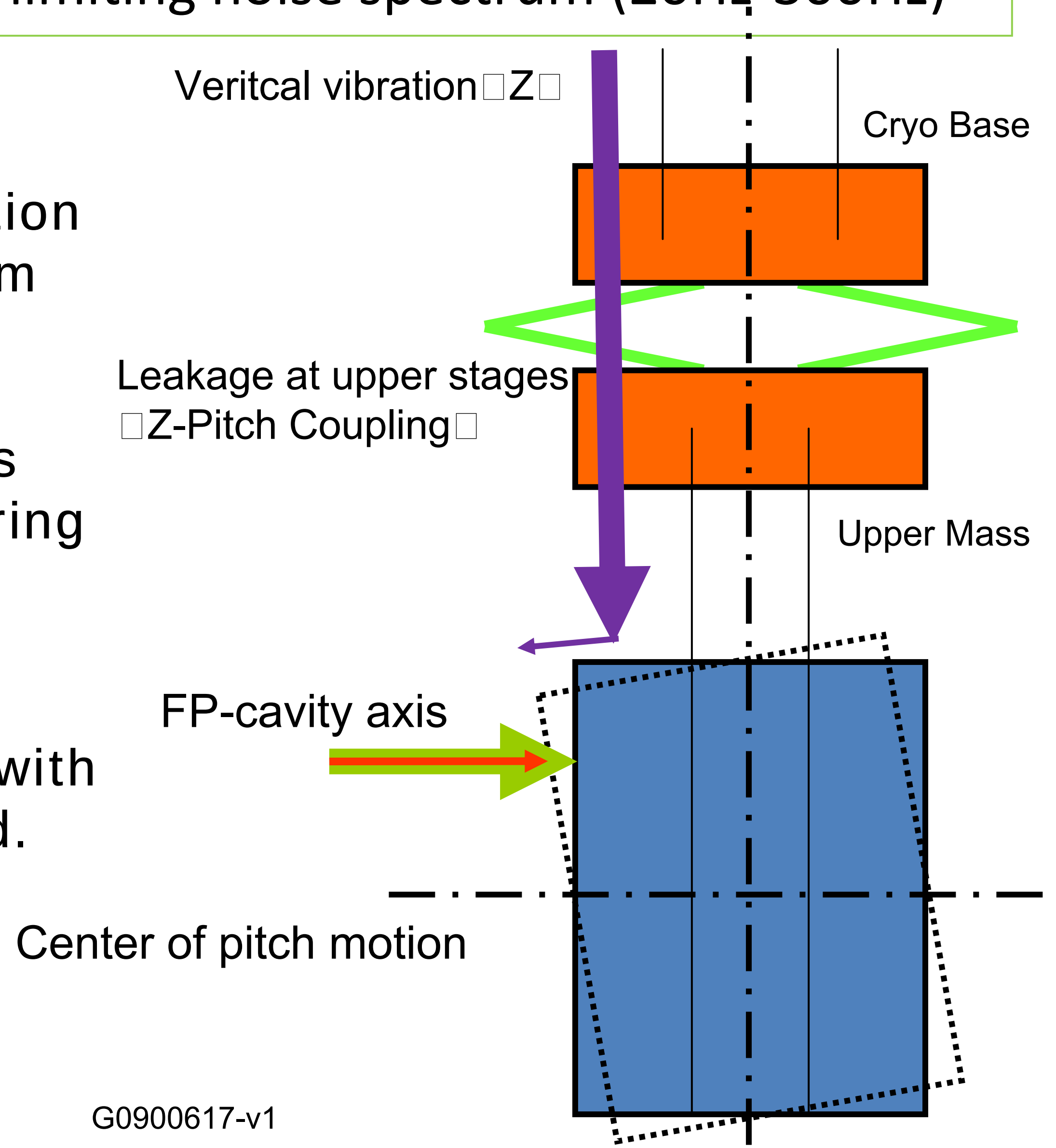
Thermal noise (2)

Search for noise source limiting noise spectrum (20Hz-300Hz)

- Vertical vibration leaks appearing as pitching motion by miss-alignment of beam centering

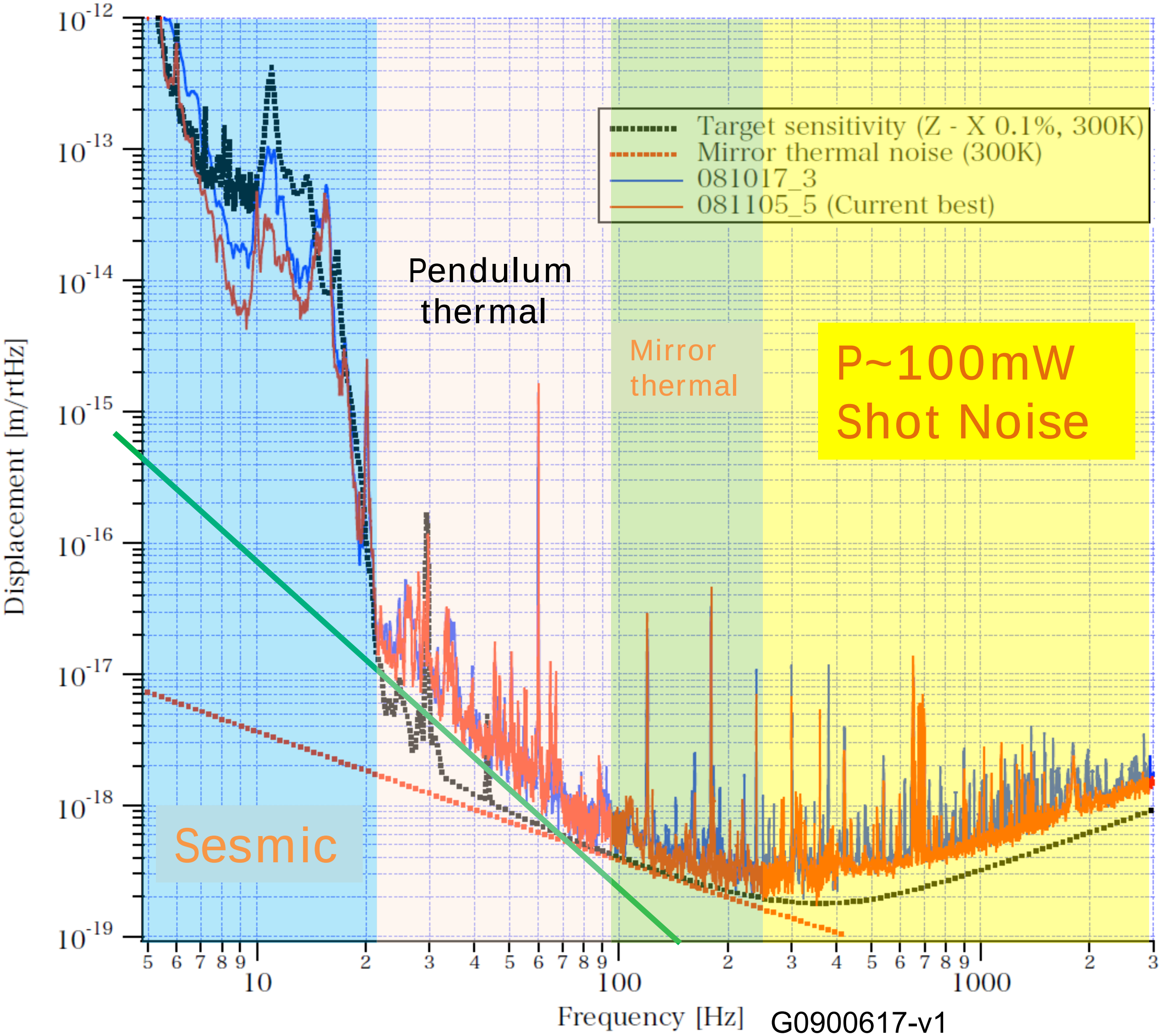
- This spectrum structure was wiped out by better centering

- After this adjustment, unidentified monotonous noise curve (20Hz-70Hz) with a slope of (-5/2) appeared.



Thermal noise (2)

What is noise source governing the spectrum (20Hz-70Hz)?



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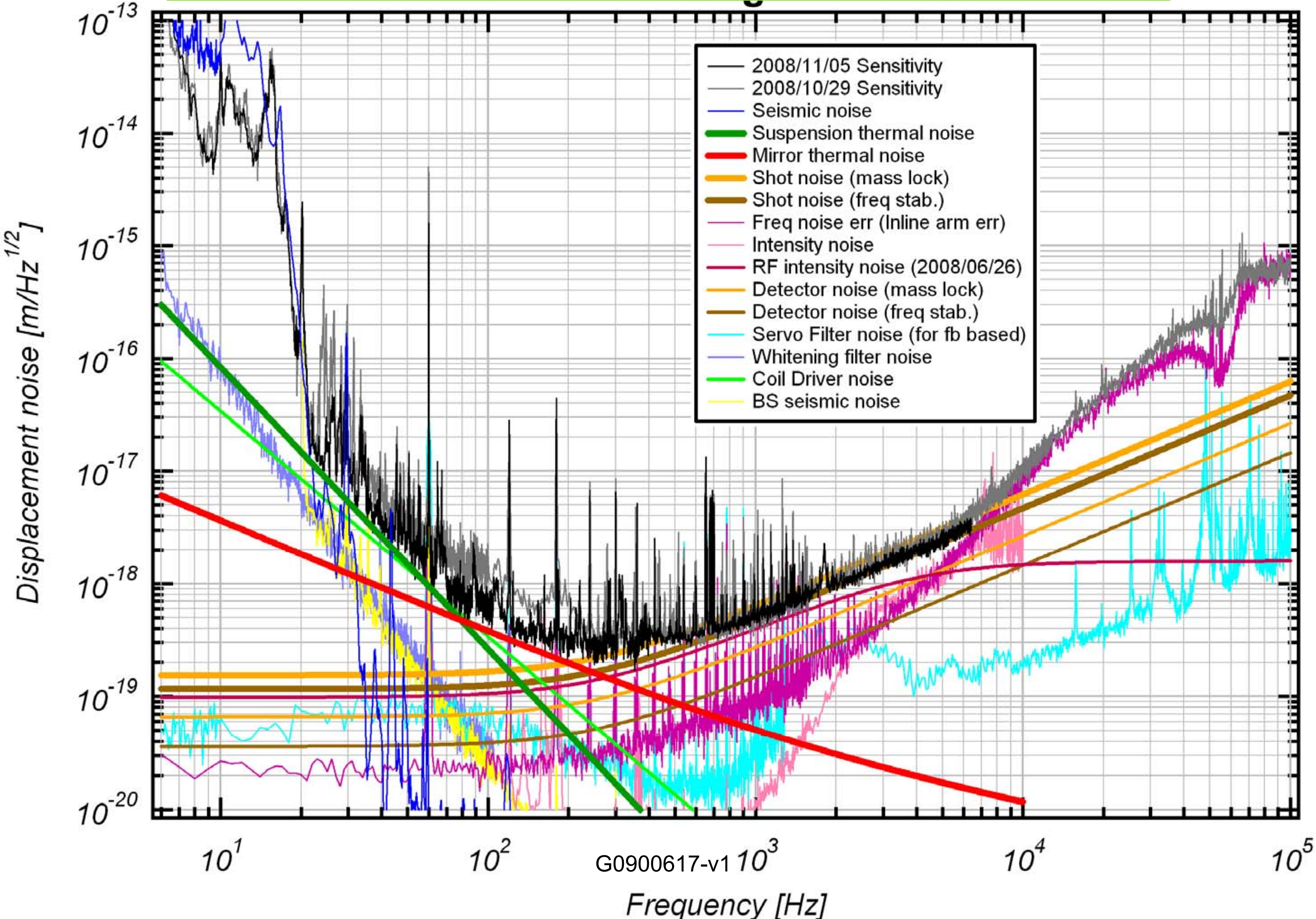
- Another candidate of the noise source is the leakage of pitching thermal noise motion (we know the Q of the pitching mode) (green line)
- The magnitude is also consistent with the estimated pendulum thermal using estimated Q by measuring violin mode
- The spectrum (70Hz-250Hz) is close to the estimation of the mirror bulk thermal noise (red broken line)

The observation of thermal noise limit is highly probable.

Noise budget at room temperature



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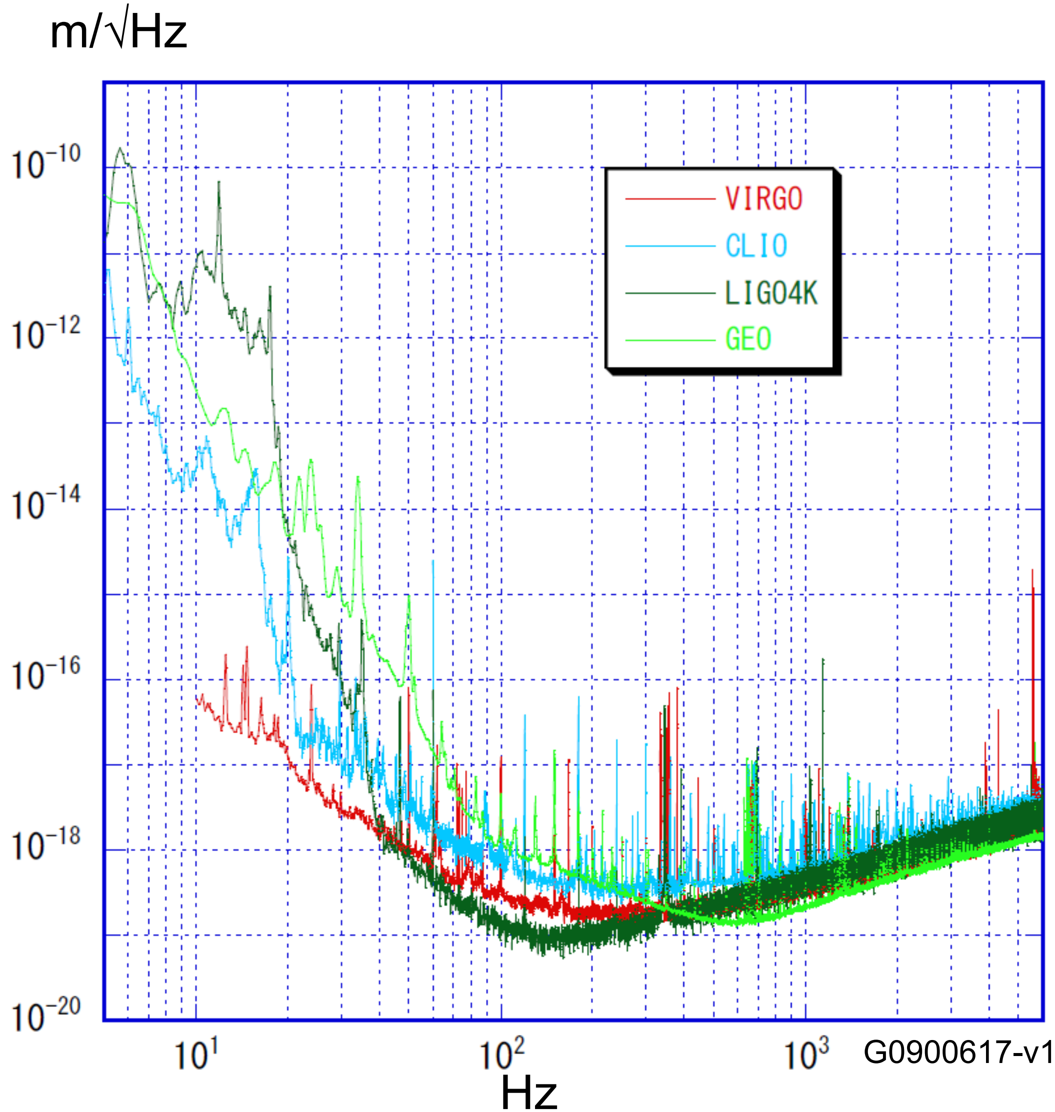
Comparison with other interferometers

- VIRGO GEO LIGO-



- Displacement noise is comparable with other interferometeres
- Virgo utilizes Super Attenuator
- LIGO has smooth noise curve
- GEO has best shot noise by its advanced detection scheme.
- Note that this graph compares not sensitivity for GW but displacement noise.

Limt on GW from PSR J0835-4510□Vela Pulsar□

- T.Akutsu et. al.,Class. Quantum Grav. 25 (2008) 184013. -

- *In Feb.2006, we have done one week data taking for targeting GWs from Vela pulsar (PSR J0835-4510) because the CLIO "strain" sensitivity around 22Hz was comparable with VIRGO and LIGO 4K at that time.*
- *Vela has the largest spin-down upper limit ~ 5 x 10^{-24} among the known pulsars.*
- *We analyzed the data using the Matched Filtering Method. Parameters are listed below. To keep the S/N loss less than 2%, we used 102 parameters templates (6 for A, 17 for ψ).*
- *We obtained ~ 5.3 x 10^{-20} assuming 10% calibration error. (99.4% conf)*

α	:08h 35m 20.61149s	Right ascension of the source
δ	:-45d 10m 34.8751s	Declination of the source
λ	:36.25° N	Polarization angle
ϕ_r	:9h 26m 40.4s (MJD : 54144)	Deterministic phase
Ω_r	:$2\pi/(0.9973\times 24\times 3600)$	Rotation angular velocity of the Earth
γ	:135°	Measured counterwise from East to the bisector of interferometer arms
ξ	:90°	Angle between interferometer arms

unknown parameters

$A=[0,\pi]$	: Inclination angle
$\psi=[-\pi/4,\pi/4]$	: Polarization angle

Laser development for CLIO

- Collaboration research between Mio group and Adelaide Univeristy-

- Increasing sensitivity at higher frequency of CLIO
- Innolight 2W laser was running at 1.6 W at the time of thermal noise hunting. We had been troubling with this (The worst condition in December, 2008) It was replaced by a new one in this March.
- The Adelaide laser was developed for an auxiliary laser for TAMA and is now being inspected for the requirement of CLIO by Mio research group. It is applied to CLIO as soon as the requirement is satisfied.

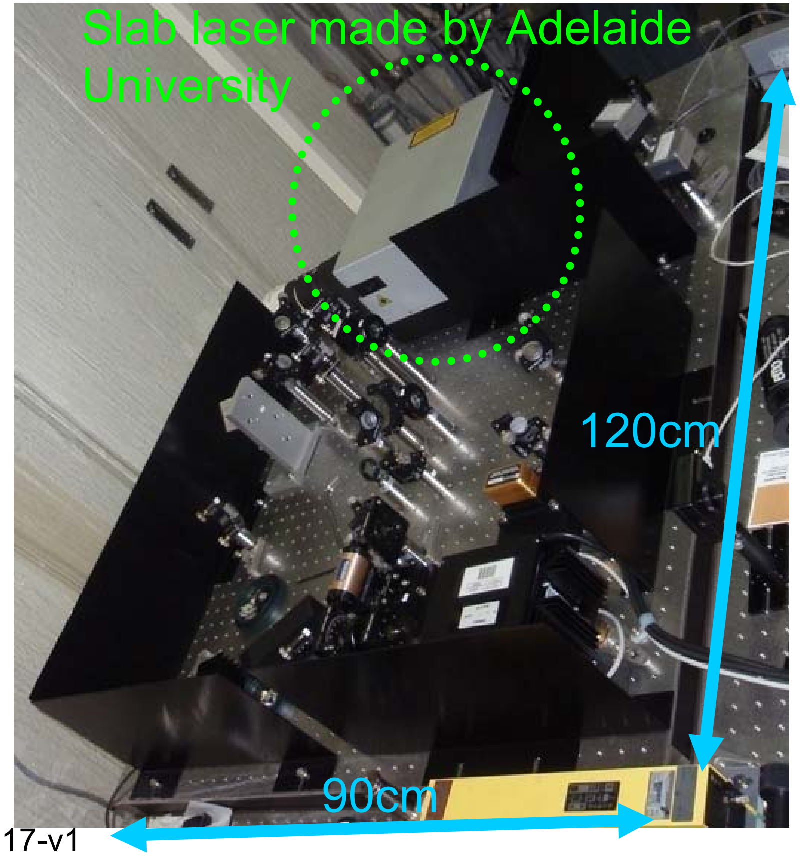
Laser development for CLIO

- Collaboration research between Mio group and Adelaide Univeristy-

- Adjustment of the slab laser developed at Adelaide University

- Mounted on a optical board of 90×120cm^2 considering for transportation into CLIO site

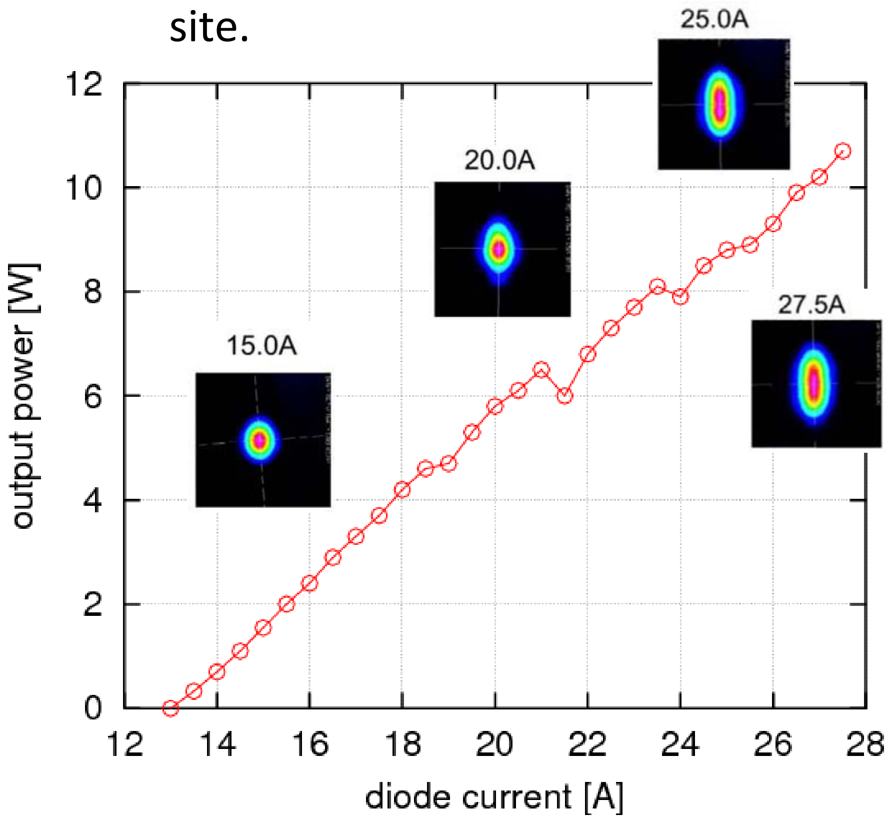
- Before
  - Re-ingition and starting of the characteristic measurement of the slab laser
- At present
  - Optics design for injection locking
- In future
  - Narrowing the single mode oscillation by injection locking
  - Evaluation of the characteristic and stability control



Laser development for CLIO

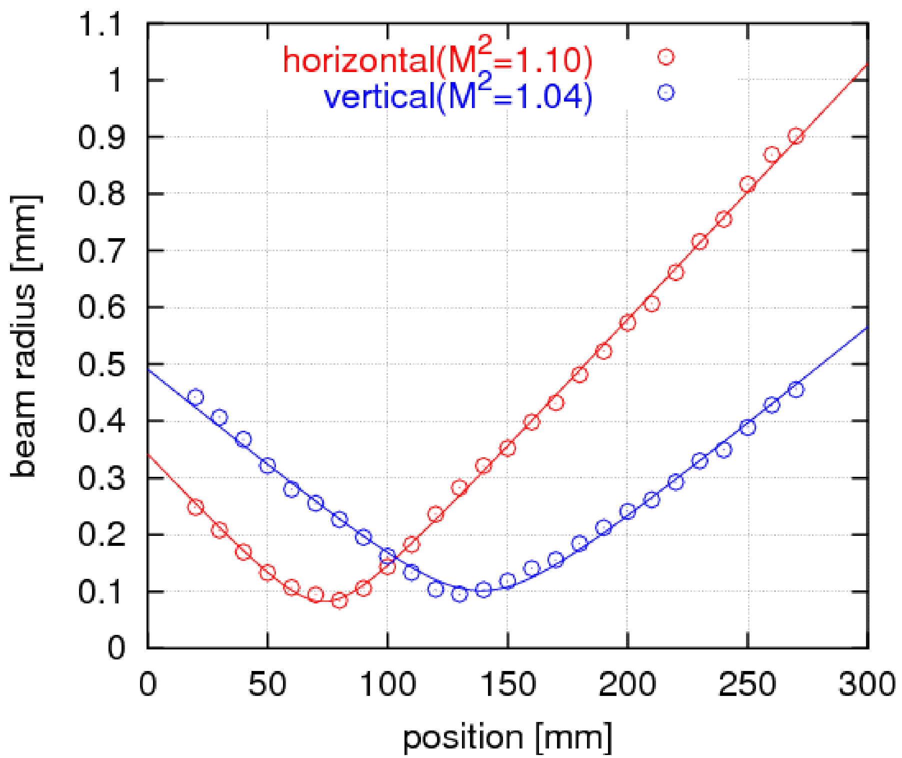
- Collaboration research between Mio group and Adelaide University-

- Power in bi-directional oscillation in a ring cavity configuration
  - Original power was attained at the time when it was imported to TAMA site.



- Measurement of M^2
  - M^2=1.04(vertical),1.10(horizontal)

（measured after passing a lens）



Augmented CLIO Collaboration

i) Review of activities of Japanese GW groups in December, 2008 at NAOJ

- Critical phase for funding of LCGT (technically and politically)

- In total, Japan is in behind of the world due to the limitation of both budget and manpower, notwithstanding partial technical achievements

ii) Strategy being discussed and reported to the executive members of LCGT

- Augmentation of manpower of CLIO

- Temporarily suspending R&D of TAMA and focusing resources on CLIO

- First priority of the establishment of cryogenic technique of laser interferometer

Summary of this talk

- CLIO is the practical test interferometer for the cryogenic mirror of LCGT
- The first step of thermal noise at room temperature has been achieved
- We are now conducting the second step to demonstrate the reduction of its thermal noise by cooling the mirror system
- Cryogenics is not all the R&D of LCGT but an important item to be achieved as soon as possible.