R & D of CLIO

Cryogenic Laser Interferometer Observatory

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&

CLIO/TAMA collaboration

GWADW2010

Kyoto

2010/05/18

Introduction of CLIO

- *Prototype of an advanced GW detector.*
  - *e. g. LCGT.*
- *Laser interferometric GW detector with 100m arm cavities.*
  - *Locked Fabry-Perot Michelson Interferometer.*
- *Sited in Kamioka mine.*
- *Cryogenic cooled sapphire mirrors.*

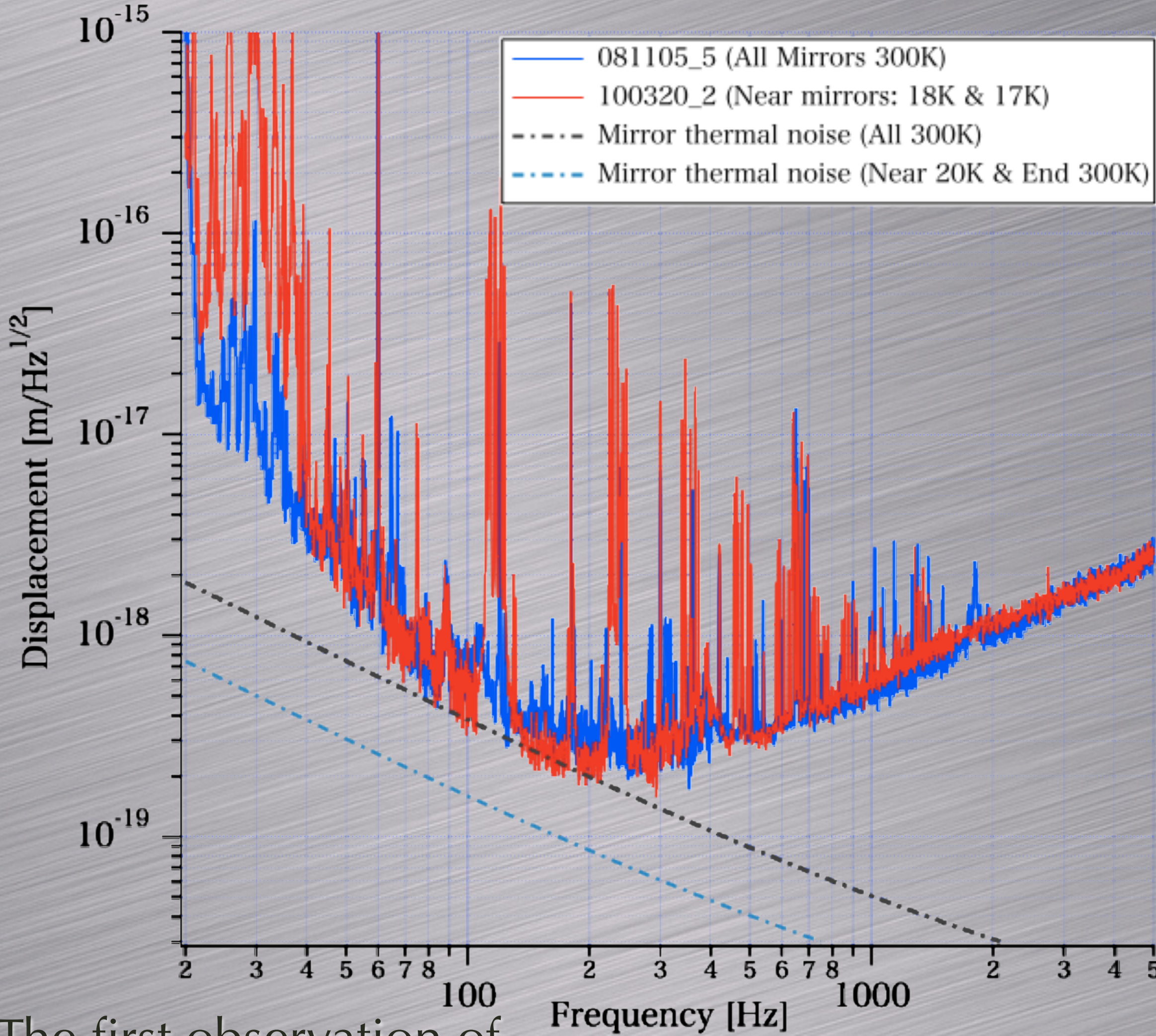
Demonstration of thermal noise reduction by cryogenic cooled mirrors.

Sensitivity

- We will compare two sensitivity curves.
- Difference is temperature of the mirrors.
- **Room temperature (081105_5).**
  - All four mirrors were at 300K.
  - Measured at 2008/11/05.
- **Cryogenic (100320_2).**
  - Two **near mirrors** were cooled at about 20K.
  - Two **end mirrors** were at the room temperature.
  - Measured at 2010/03/20.

Result

- 2008: 300K design sensitivity achieved.
- 300K mirror thermal noise dominates the sensitivity around 150Hz.
- 2009: Both near mirrors were cooled at about 20K.
- 2010: Sensitivity around 150Hz were improved.
- Total mirror thermal noise were reduced.



The first observation of

Mirror thermal noise reduction by cryogenic mirrors.

Cryogenic mirror

- Cool test mass and its suspension in cryogenic temperature (typical 20K).
- Provide low thermal noise.
  - Mirror thermal noise is a serious issue for advanced detectors.

$$\left\langle X^2(\omega) \right\rangle \propto T\phi$$

X: amplitude of thermal noise
T: temperature
Φ: dissipation

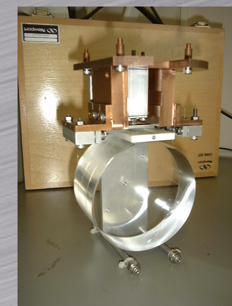
- Prevent thermal lensing effect.
  - High thermal conductivity of mirror substrate.

Difficulties of cooling

- Mirror is always heated by laser absorption.
  - Thermal conduction is the only method for cooling.
    - 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!!



10cm

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

2001 CLIK: Control of cryogenic Fab Perot cavity at Kashiwa.

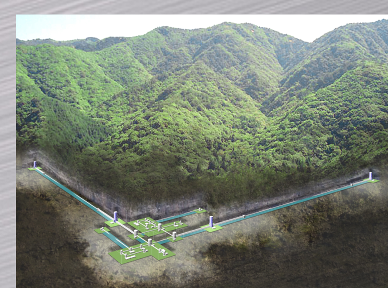
7m

100m

2002~ CLIO: Sensitivity of cryogenic GW detector.

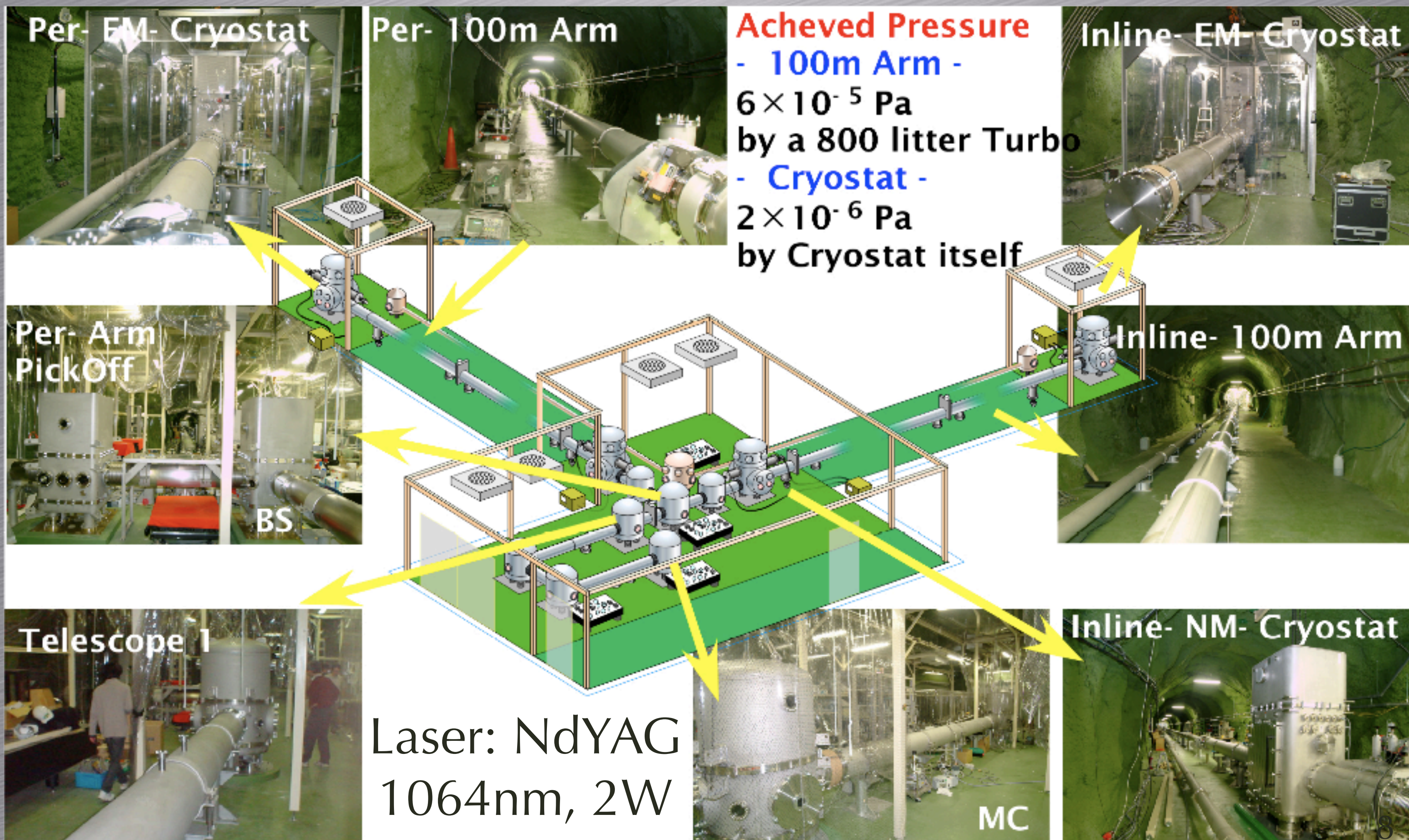
2010: We are here now!!

201? LCGT: Detection of Gravitational wave.



3000m

CLIO



Acheved Pressure

- 100m Arm -

6×10^{-5} Pa

by a 800 litter Turbo

- Cryostat -

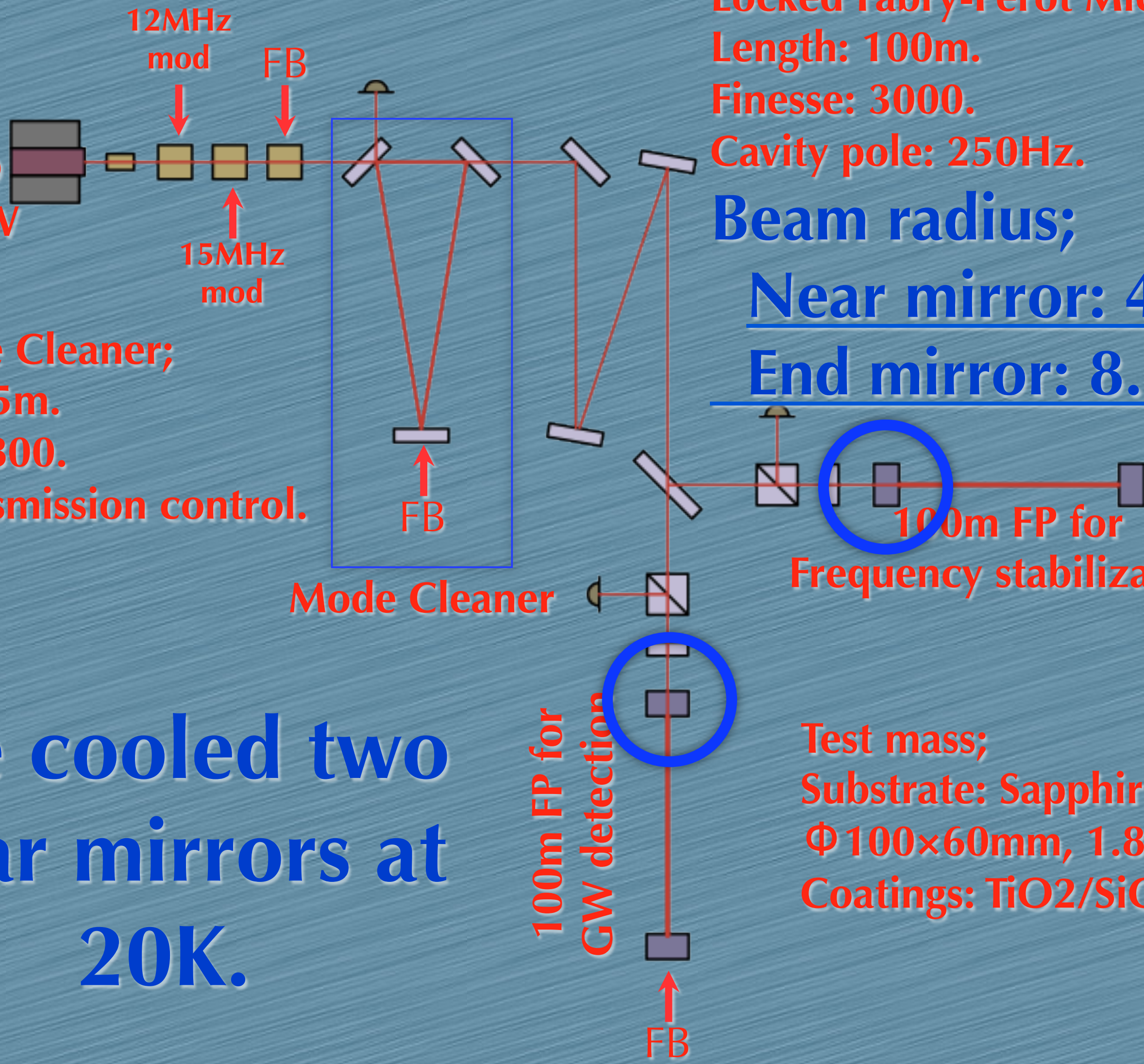
2×10^{-6} Pa

by Cryostat itself

Laser: NdYAG

1064nm, 2W

CLIO Optical configuration



Locked Fabry-Perot Michelson
Length: 100m.
Finesse: 3000.
Cavity pole: 250Hz.

Beam radius;

Near mirror: 4.9mm.

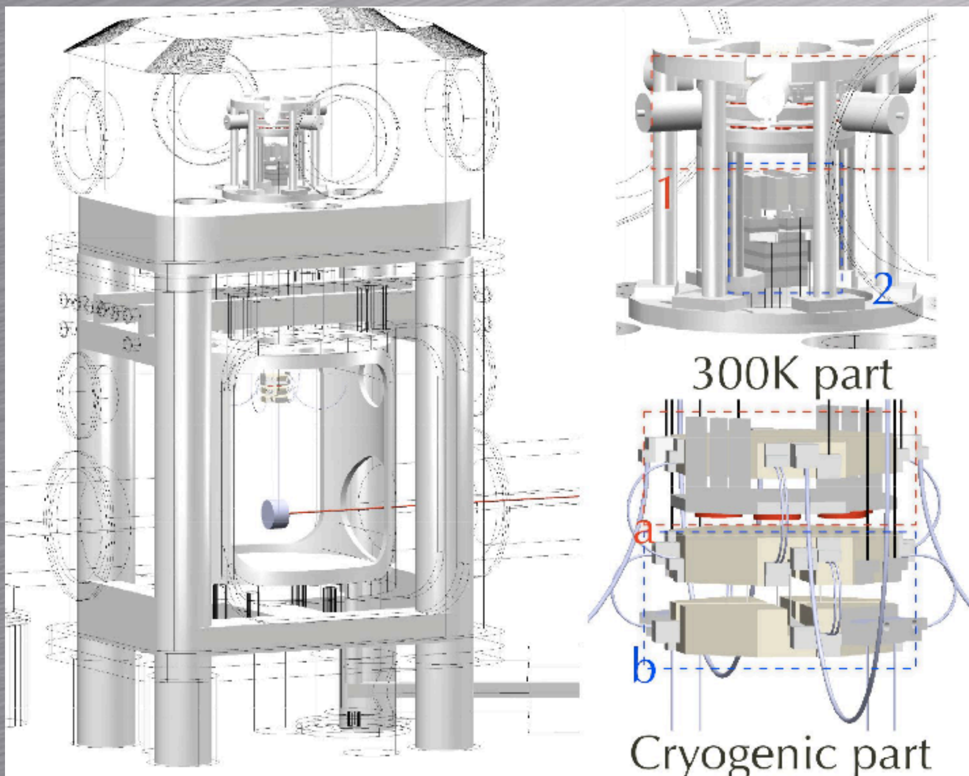
End mirror: 8.5mm.

One Mode Cleaner;
Length: 9.5m.
Finesse: 1800.
Mod. transmission control.

Test mass;
Substrate: Sapphire.
Φ100×60mm, 1.8kg.
Coatings: TiO_2/SiO_2.

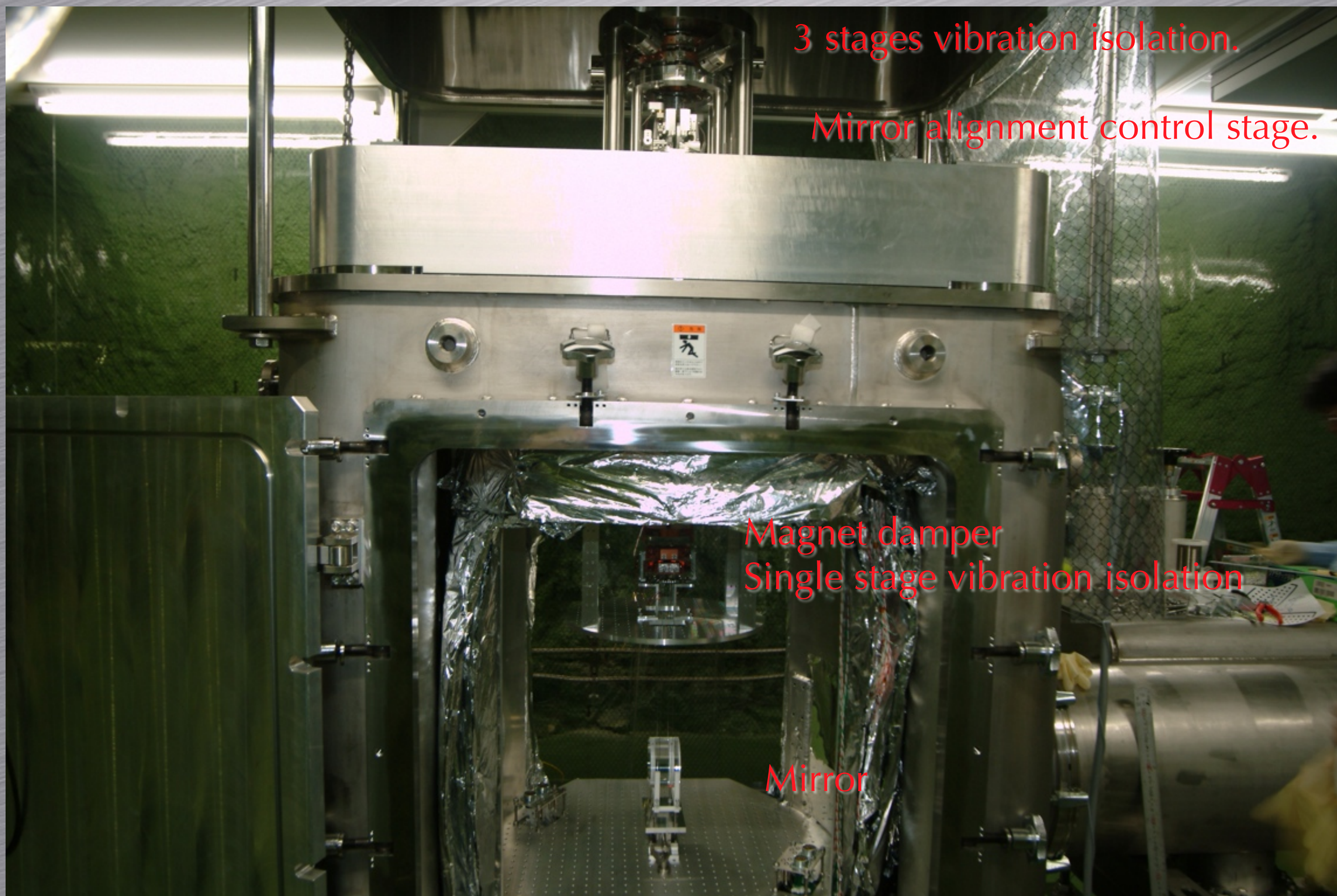
We cooled two near mirrors at 20K.

Mirror suspension system

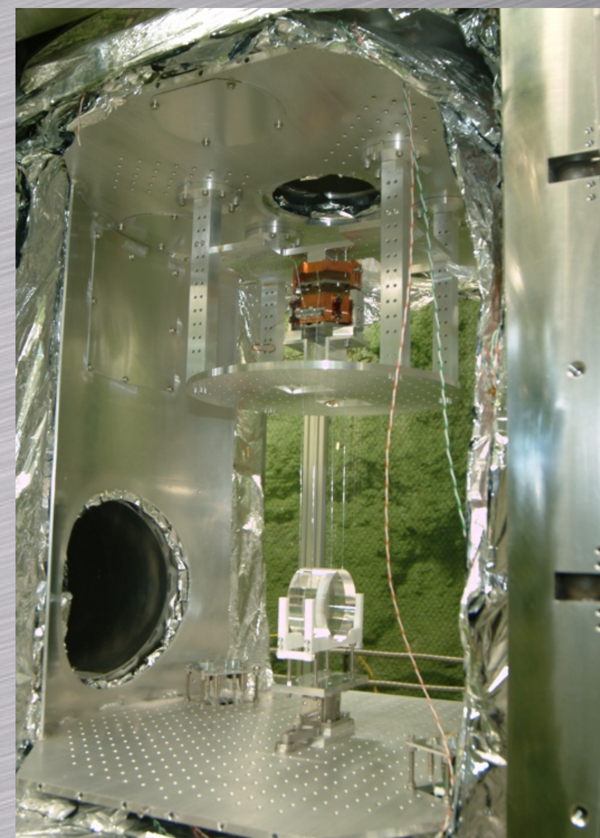


- *Sapphire mirror*
  - *Φ100×60, 2kg.*
- *6 stages vibration isolation.*
  - *3 stages in 300K.*
  - *3 stages in cryogenic.*

Cryostat and Suspension



Suspension

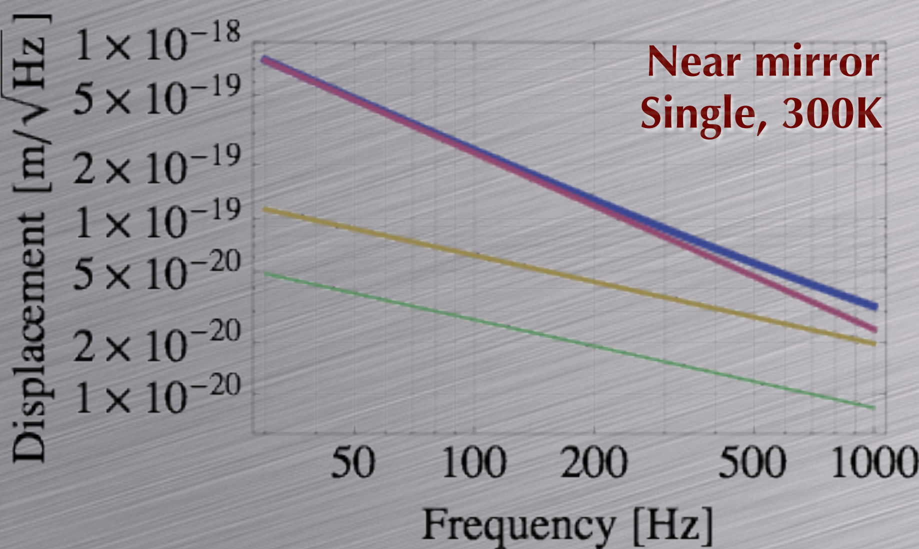


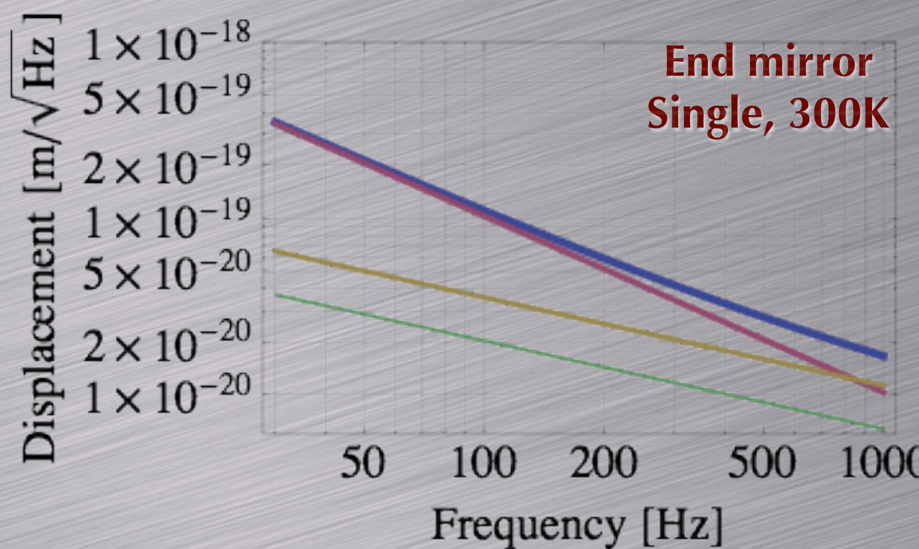
Sapphire mirror
Φ100×60

2009: Cryogenic experiment

- To see the sensitivity improvement with the cryogenic mirror.
- Only two near mirrors were cooled at about 20K.

Mirror thermal noise damping mechanisms

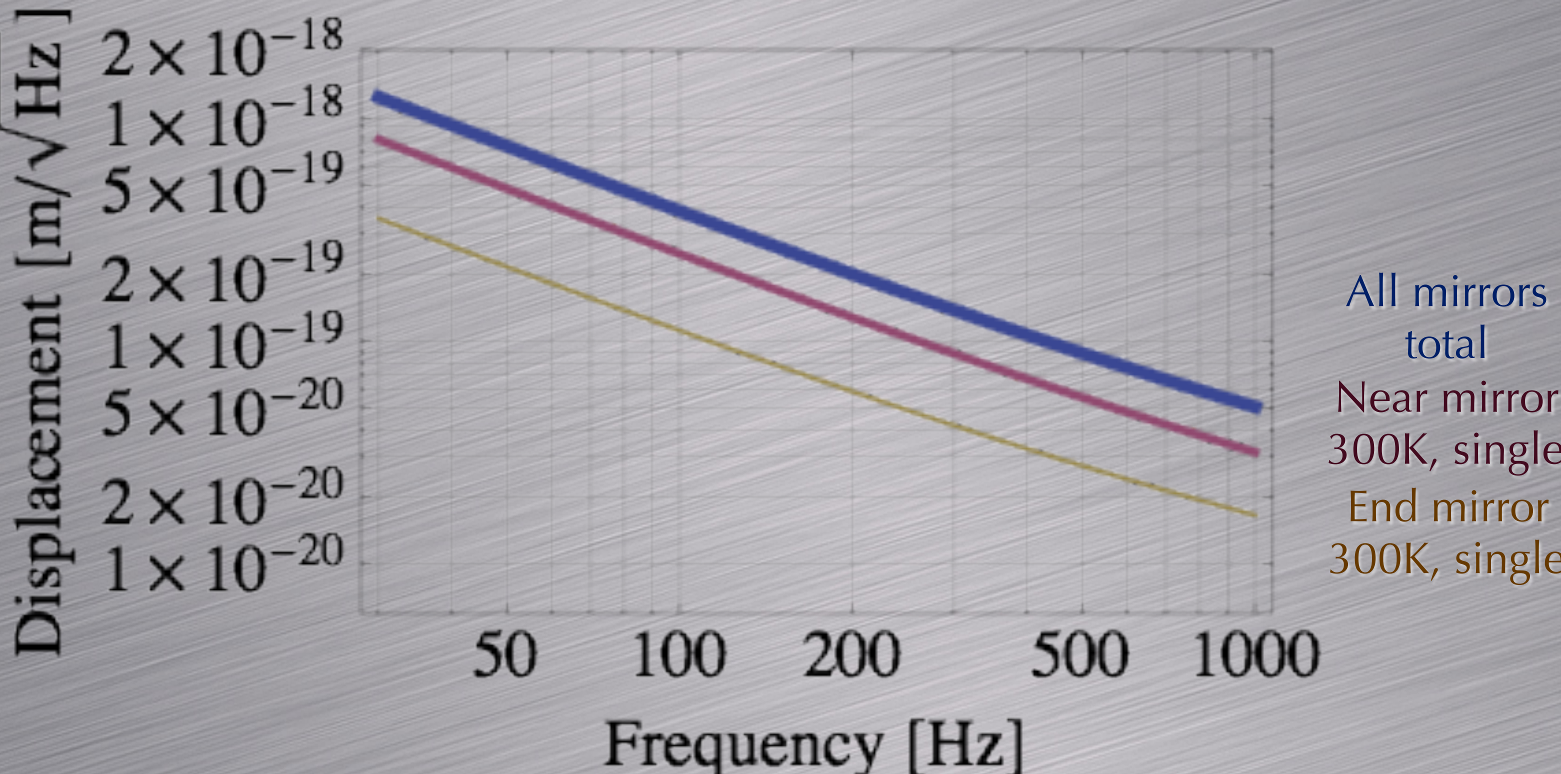




1. **Thermoelastic damping** is the dominant source of the mirror thermal noise.
2. Amplitude of the near mirror and the end mirror to the mirror thermal noise is **different**.
3. The difference is caused by the different **beam spot size** at the each mirrors.

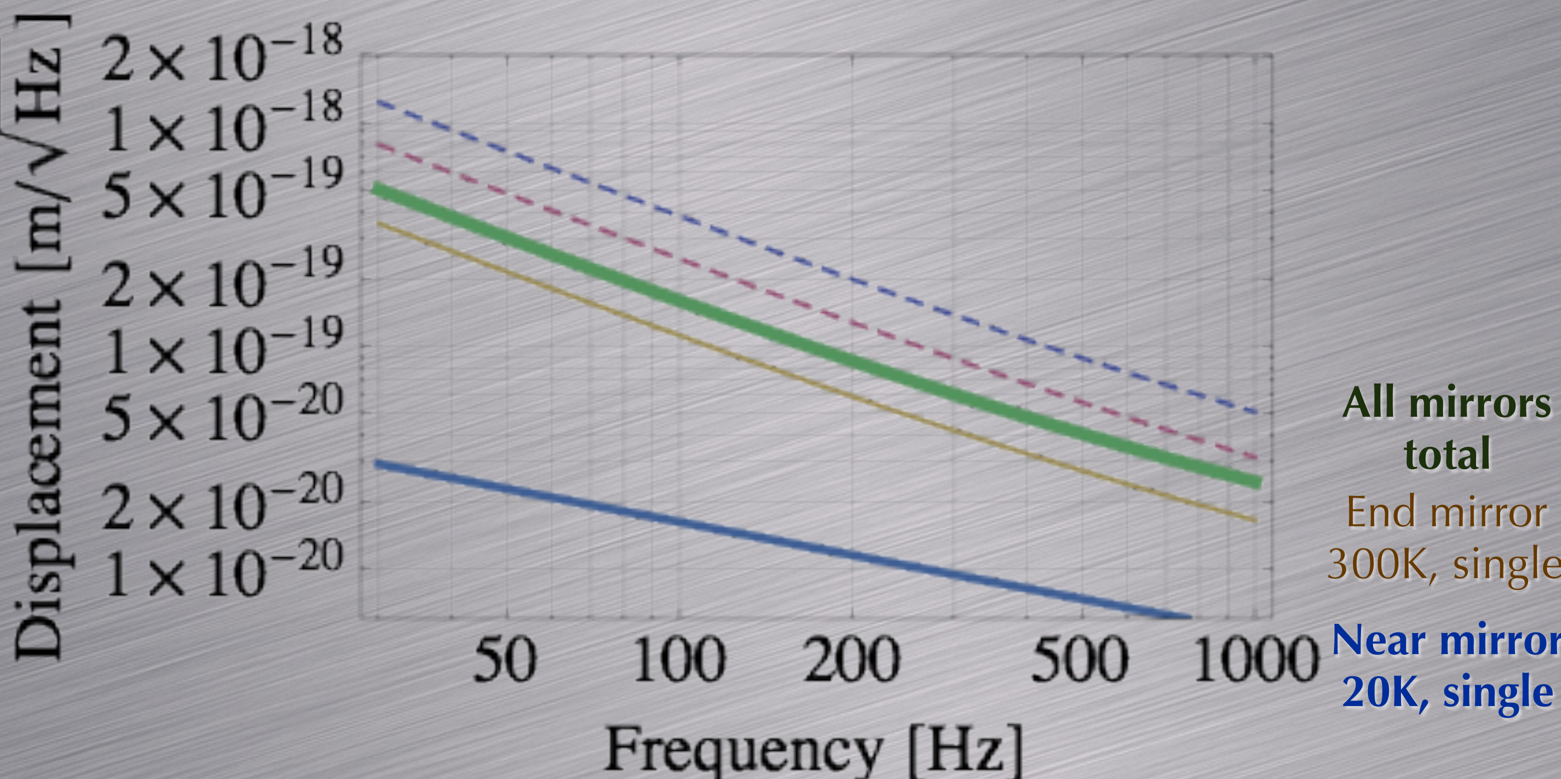
BLUE: Total
RED: Thermoelastic
YELLOW: Coating structure
GREEN: Substrate structure

Mirror thermal noise
All mirrors 300K



Near mirror thermal noise is 2.2 times larger than end mirrors.
We decided to cool the near mirrors at fast.

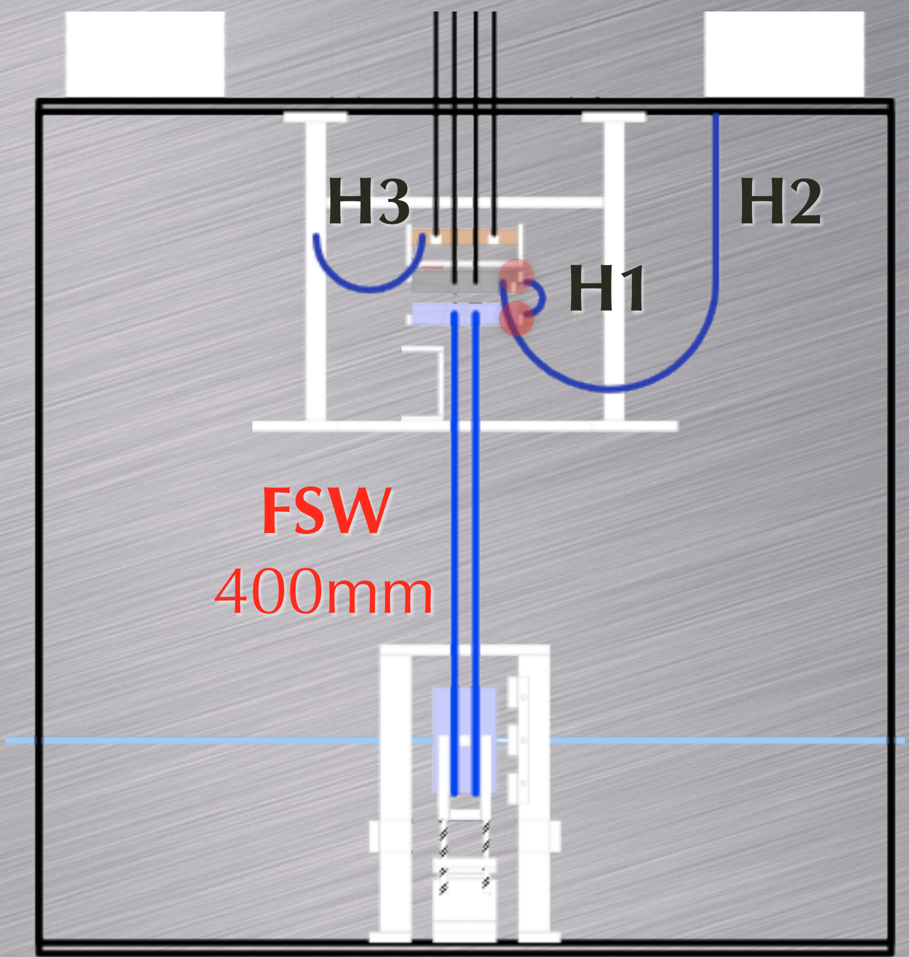
Mirror thermal noise
Cool near mirrors at 20K

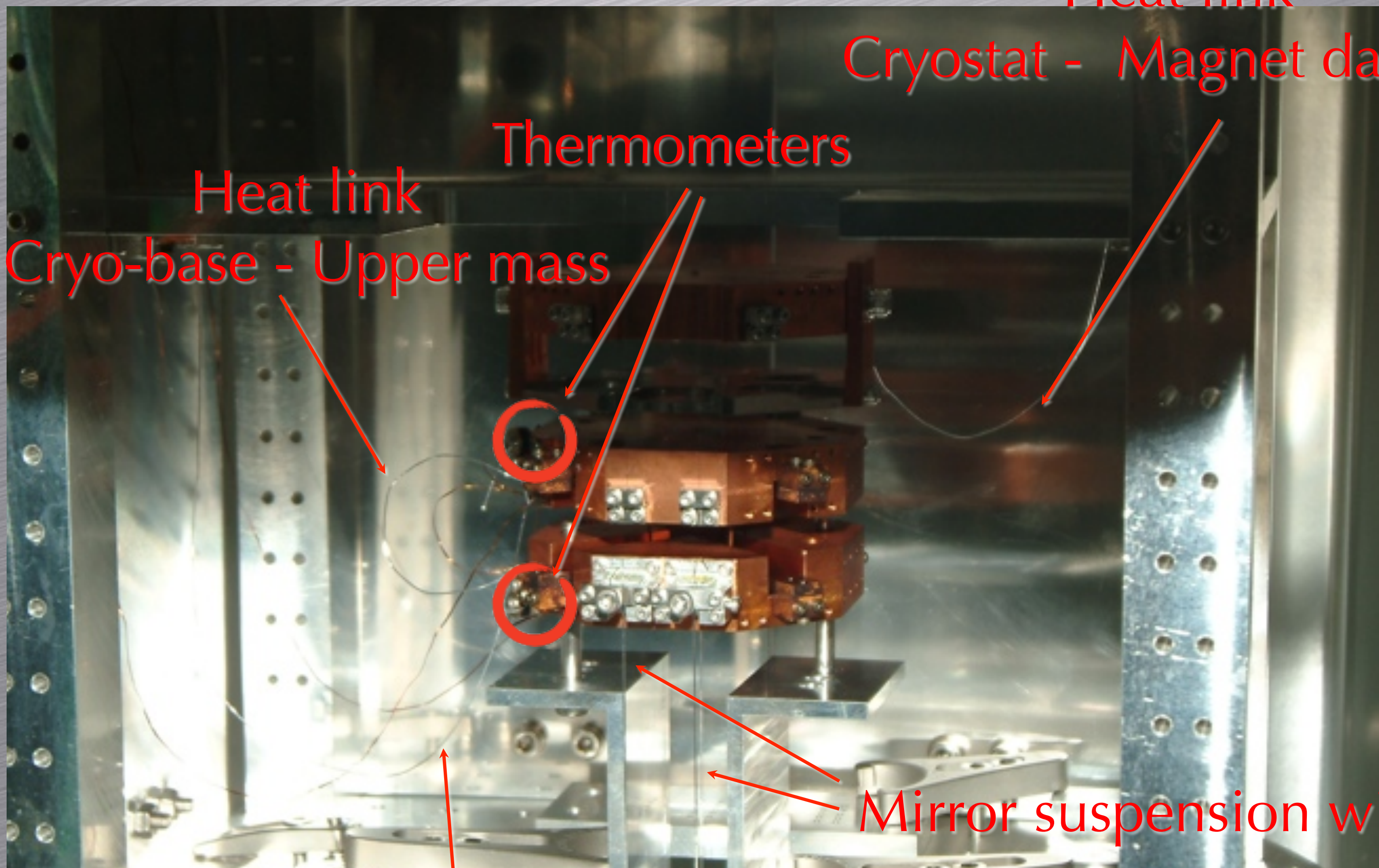


Near mirror thermal noise decreases to 1/15.
Total mirror thermal noise decreases to 1/2.4.

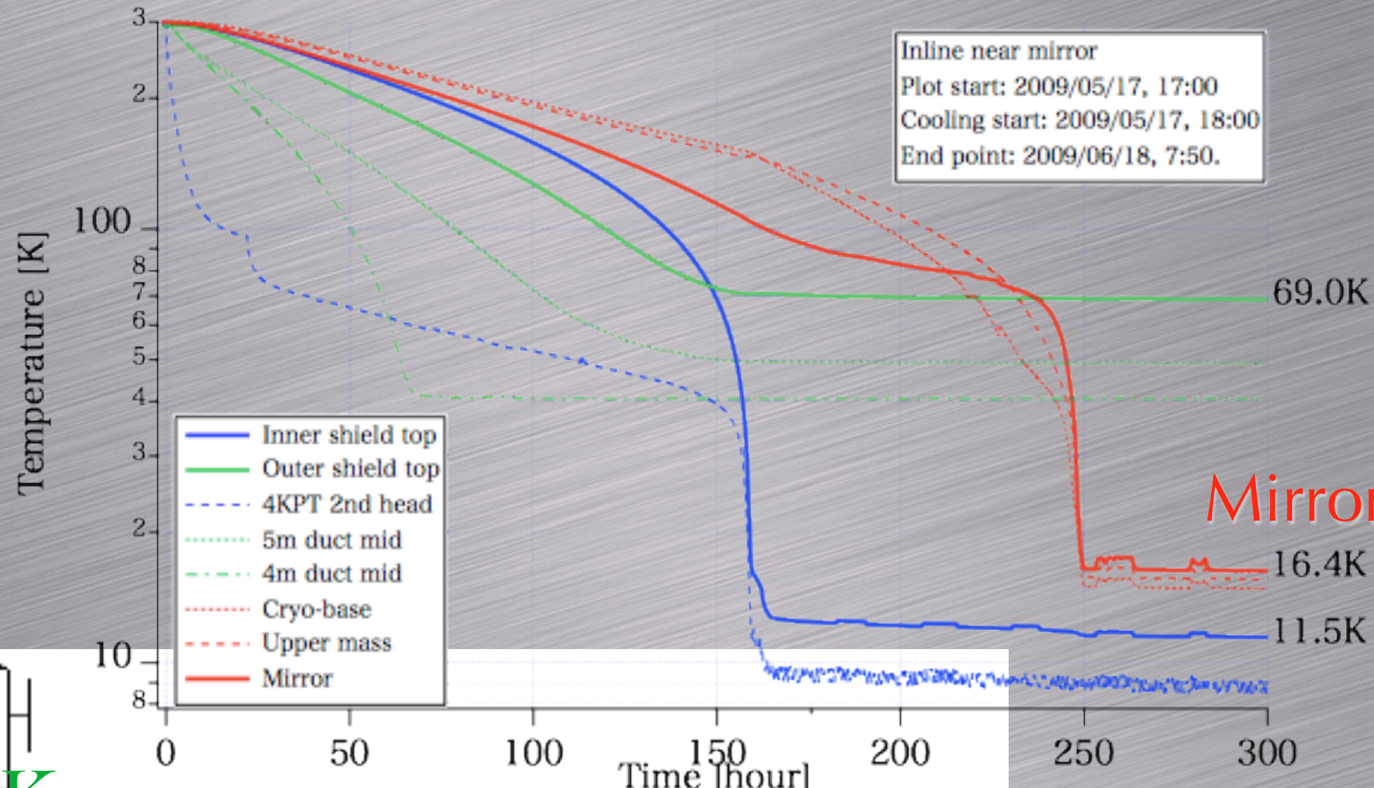
Suspension

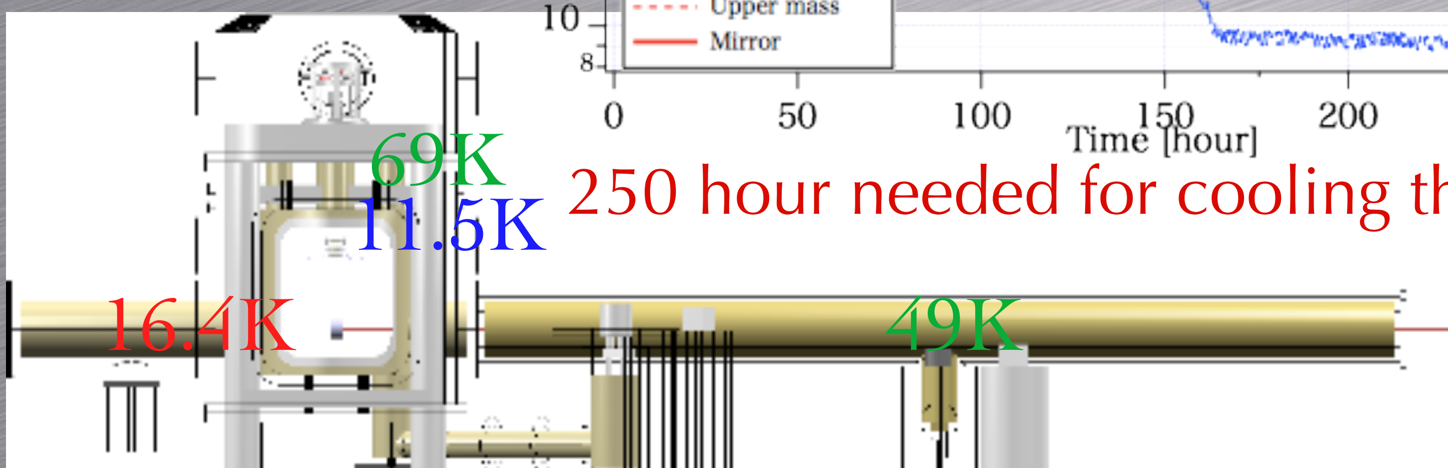
- **Final suspension wire(FSW).**
  - **300K: Bolfur of Φ0.05.**
  - **Cryogenic (Near): Al wire of Φ0.5.**
  - Increased noise floor around 20Hz - 400Hz.
- **Three heat link wires(H1-3).**
  - **Cryogenic (Near): Al wire of Φ0.5.**
- Two thermometers for monitoring.
  - Attached on clamping points of H1.
- Suspended mirror was housed in a cage prevent from radiation heat.




Heat link
Cryostat - Magnet damper
Thermometers
Heat link
Cryo-base - Upper mass
Mirror suspension wire
Heat link
Cryostat - Cryo-base

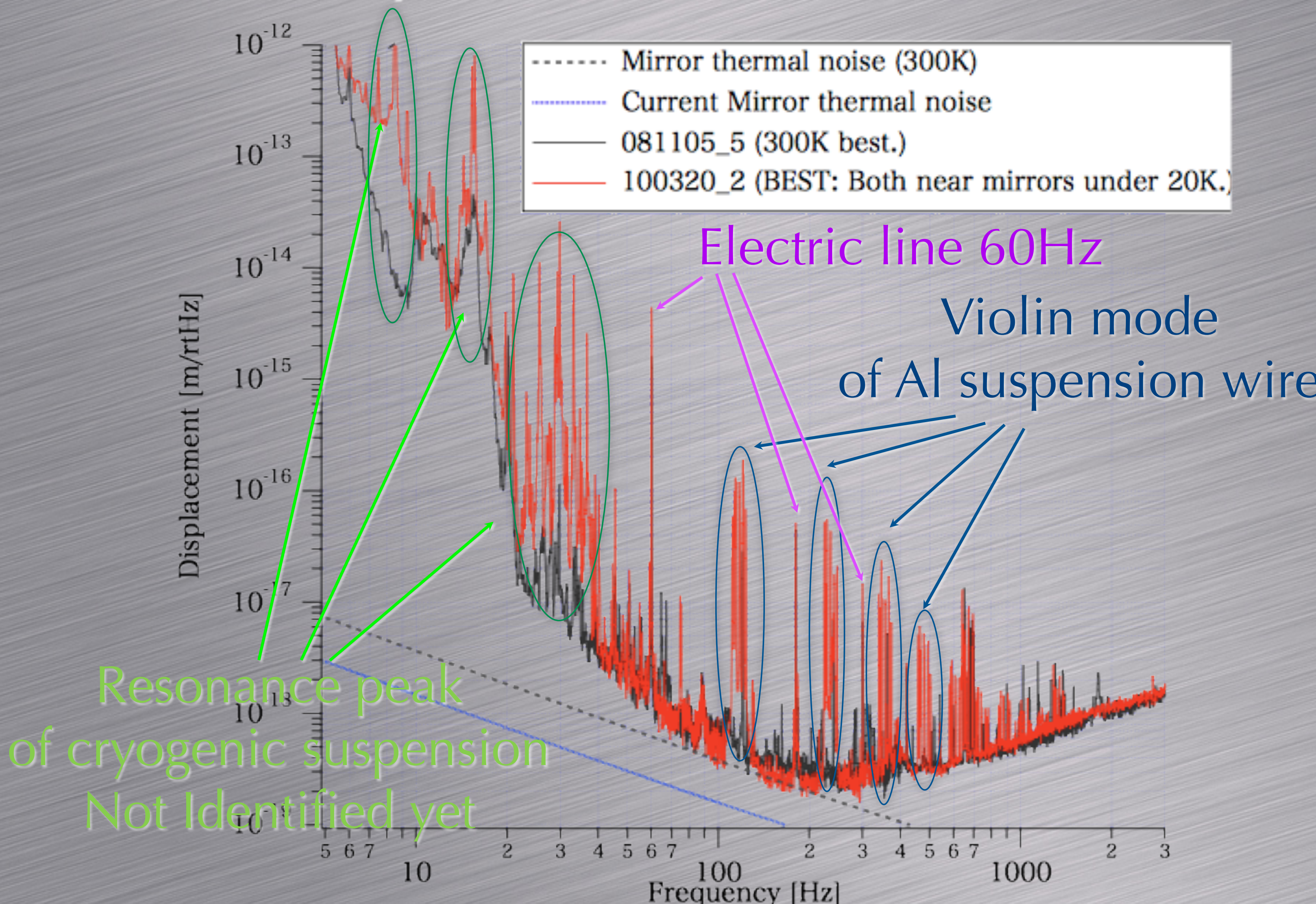
Cooling example



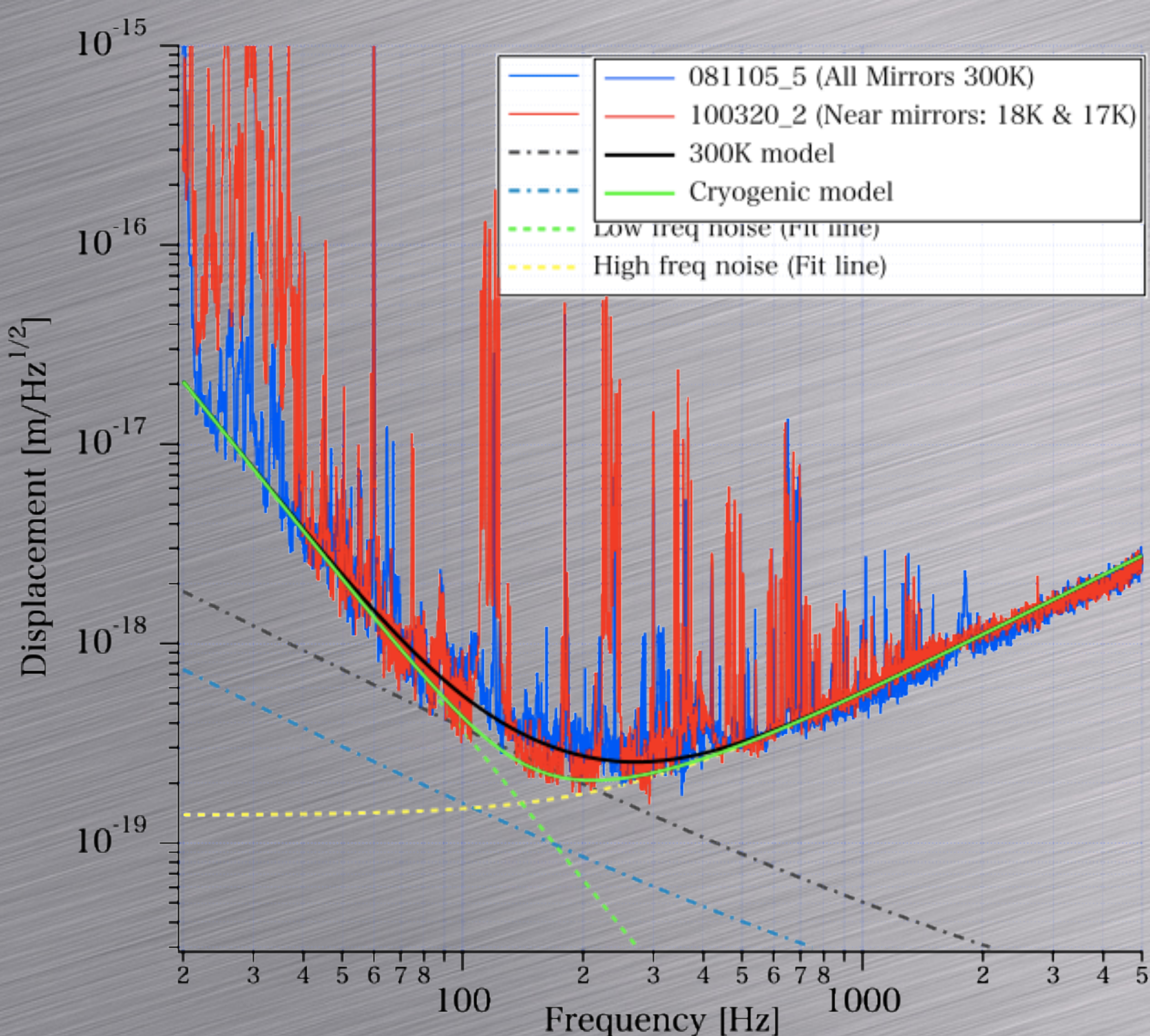


250 hour needed for cooling the mirror.

Sensitivity with and without cooling

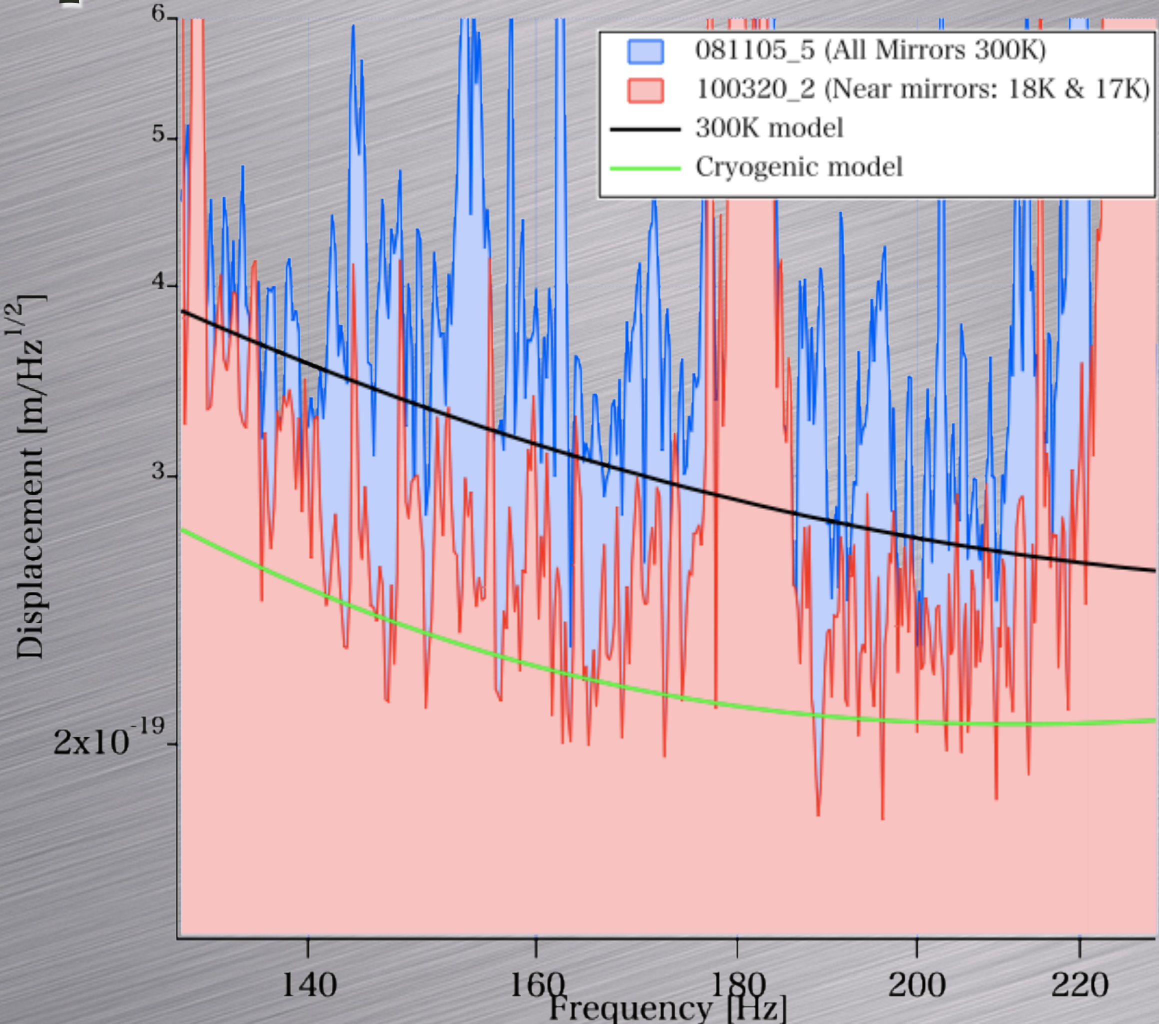


Compare with noise model



- Is this sensitivity improvement consistent with the mirror thermal noise reduction?
- Consider only 3 noise floors.
- **Low freq noise: $f^{-2.5}$**
  - Suspension thermal noise.
- **High freq noise: cavity pole 250Hz.**
  - Shot noise.
  - RF intensity.
- **Mirror thermal noise.**
  - all mirrors at 300K.
  - only near mirrors at 20K.

Compare with noise model 2



The cryogenic sensitivity breaks 300K mirror thermal noise limitation.
The sensitivity improvement is consistent with thermal noise reduction

Summary

- CLIO is a laser interferometric GW detector with 100m arm cavities.
- Goal of the CLIO project was to demonstrate thermal noise reduction by means of the cryogenic mirrors.
- CLIO achieved design sensitivity of room temperature in 2008.
- Then we cooled two near sapphire mirrors at about 20K.
- Expected sensitivity improvement has been observed.
- We have confirmed that this improvement shows thermal noise reduction by the cryogenic mirrors.
- The cryogenic mirror will be utilized for LCGT.