LSC-Virgo Meeting
26 July, 2007
G070574-00-R

Status of the Japanese Projects

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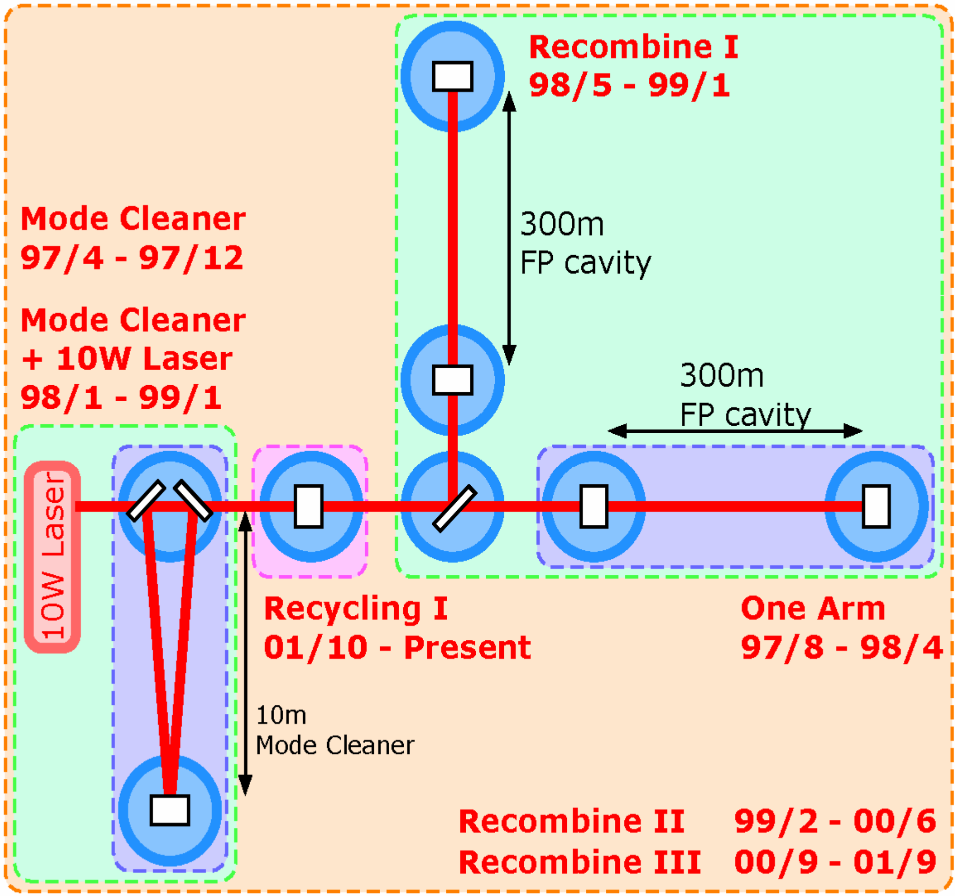
Status of TAMA

Present representative of TAMA is Emeritus Prof. Yoshihide Kozai, the former director of NAOJ and the director of Gunma Observatory.
He also represents the gravitational wave research of Japan.
Kuroda was a member of steering committee of TAMA during 1995-2003 and now Kuroda is the PI of LCGT project.

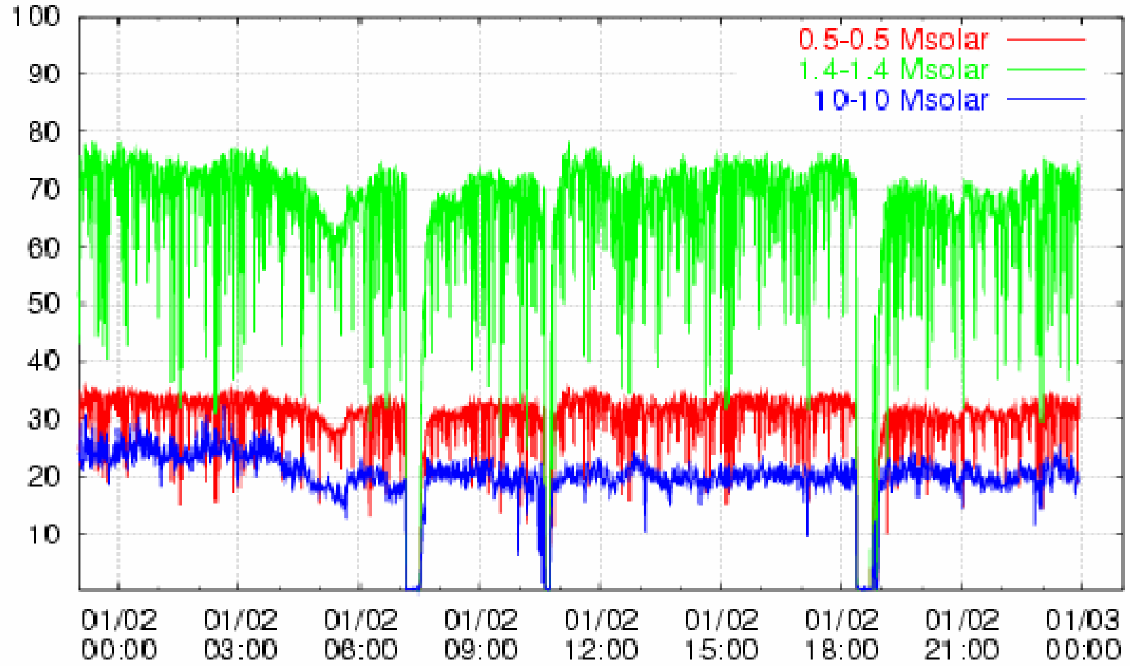
Brief History of TAMA300

1995 Project started
1997 One arm cavity locked
1999 FPMI operation started
DT1(11hr) ,DT2(31hr)
2000 World best sensitivity
h = 5E-21/rHz
DT4(167hr)
2001 DT6(1038hr)
Power Recycled FPMI
2002 First Coincidence Run
with LIGO(S1) and GEO600
2003 DT8(1158hr)
with LIGO(S2)
2003/4 DT9 with LIGO(S3)
and GEO600
Full Automatic Operation
2004. Noise hunting
TAMA-SAS



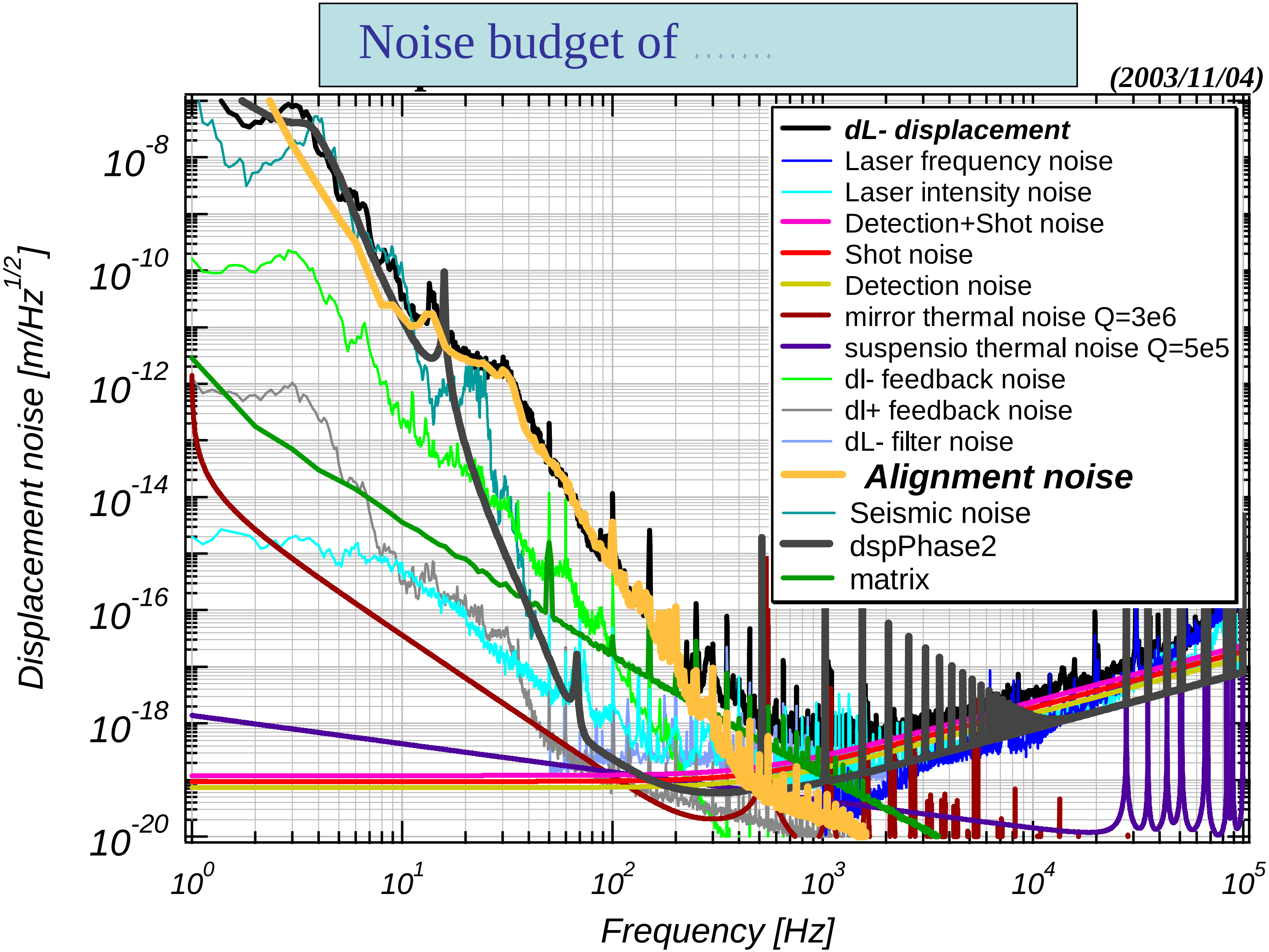
Long term operation

- Operation more than 100 days / Observation data more than 1700 hr
  - ~ Efficiency of 81.3%(Data taking run 8)
- Collaborative observation with LIGO and GEO600
- Improvement of observation system
  - ~ Automatic (Operator free) operation
  - ~ Alarm system / remote monitoring / remote control



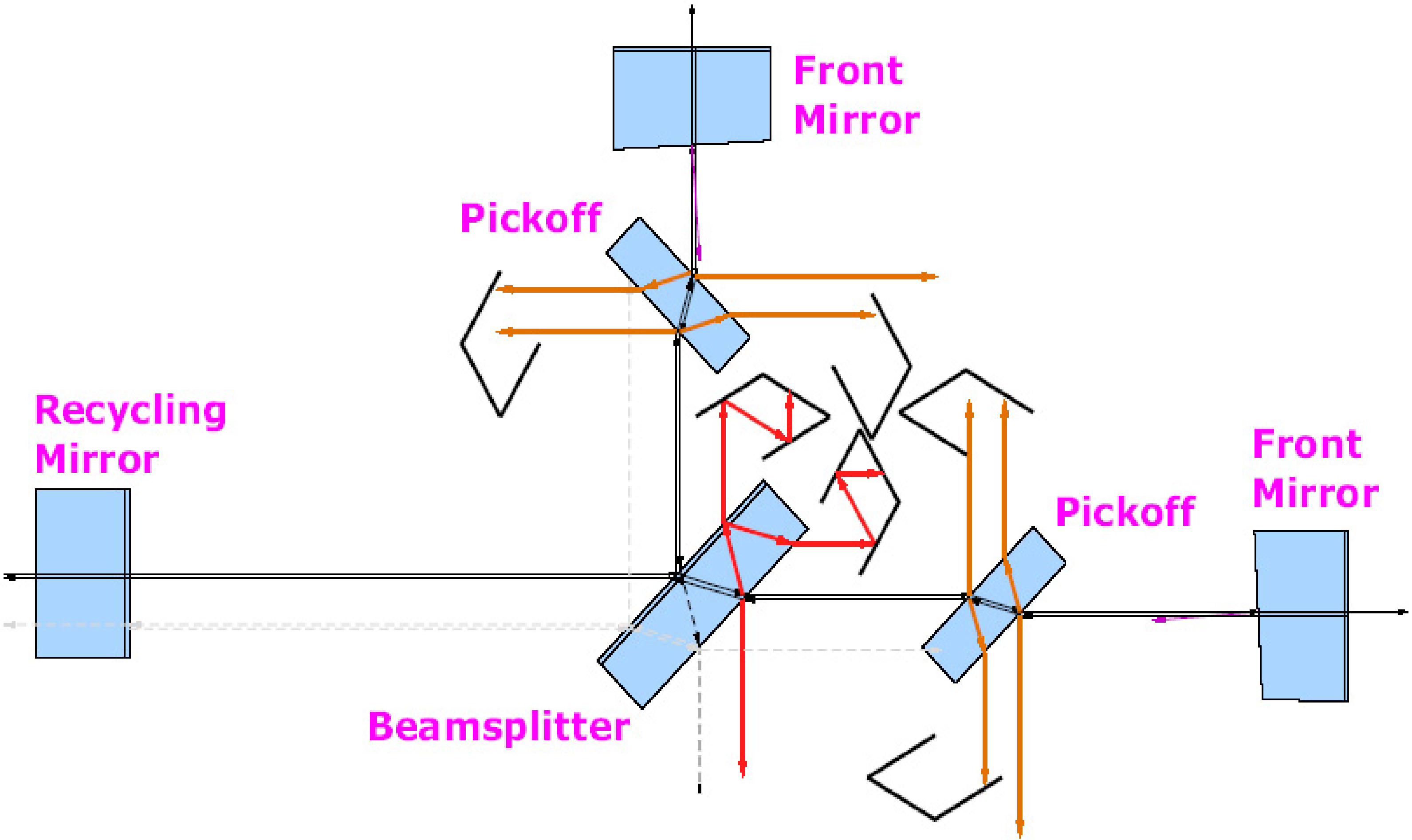
Time series of sensitivity

Current best at Low Frequencies

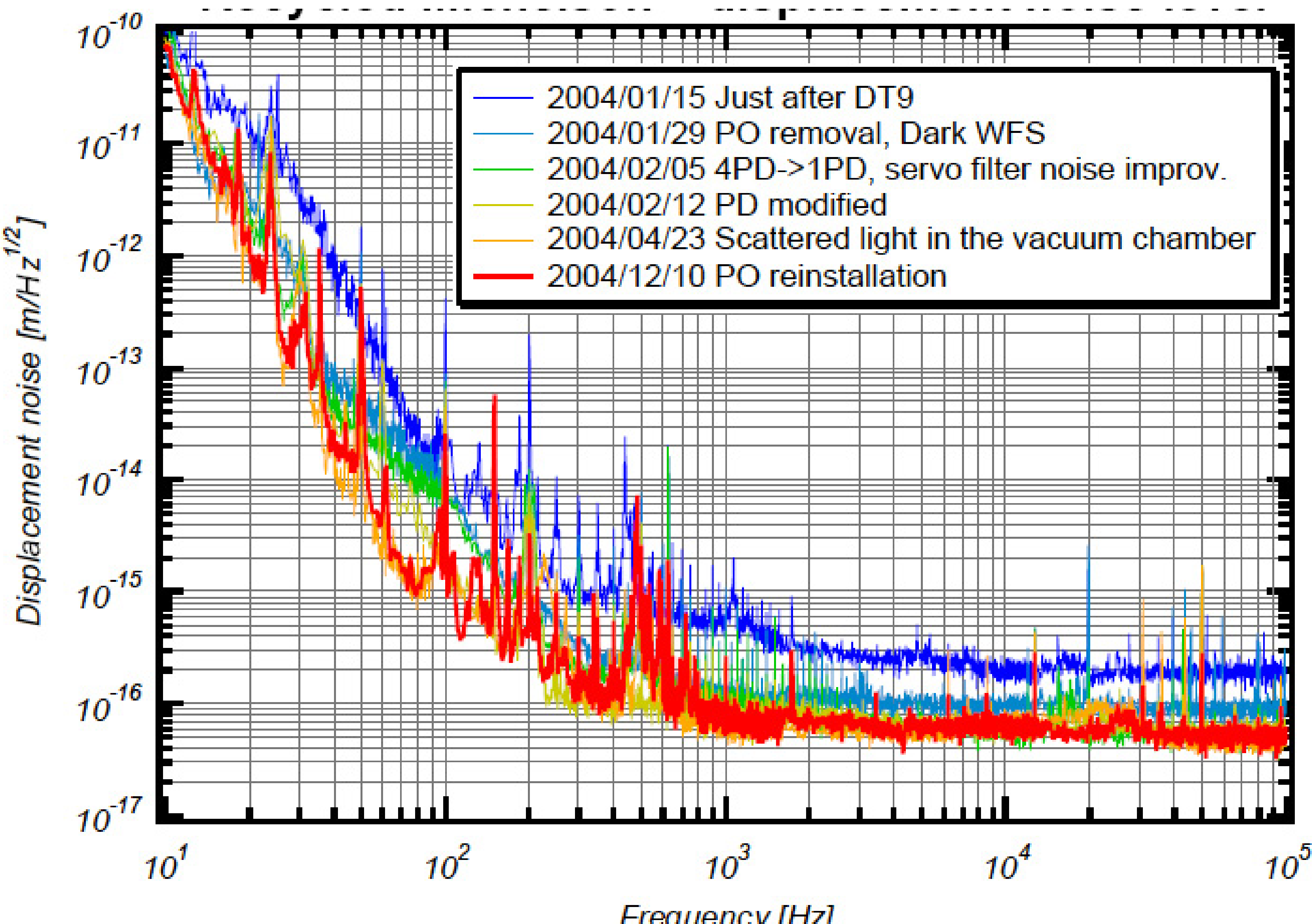


Identifying scattering noise in 2004

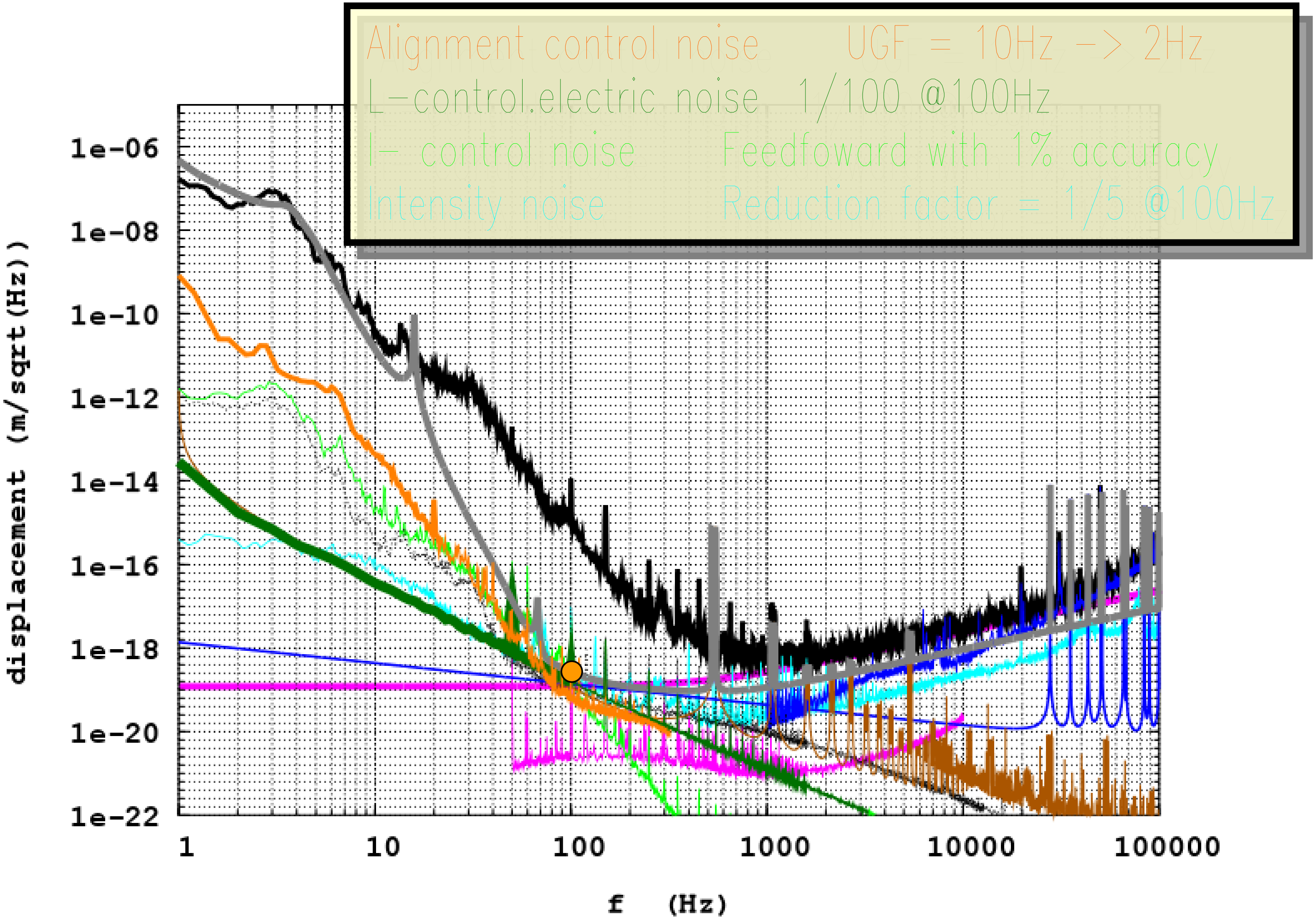
To find the scattering noise source at mid-frequencies, all reflected and possible stray beams were killed in the center Michelson part.



Noise reduction by one order in Michelson part without Fabry-Perot cavities

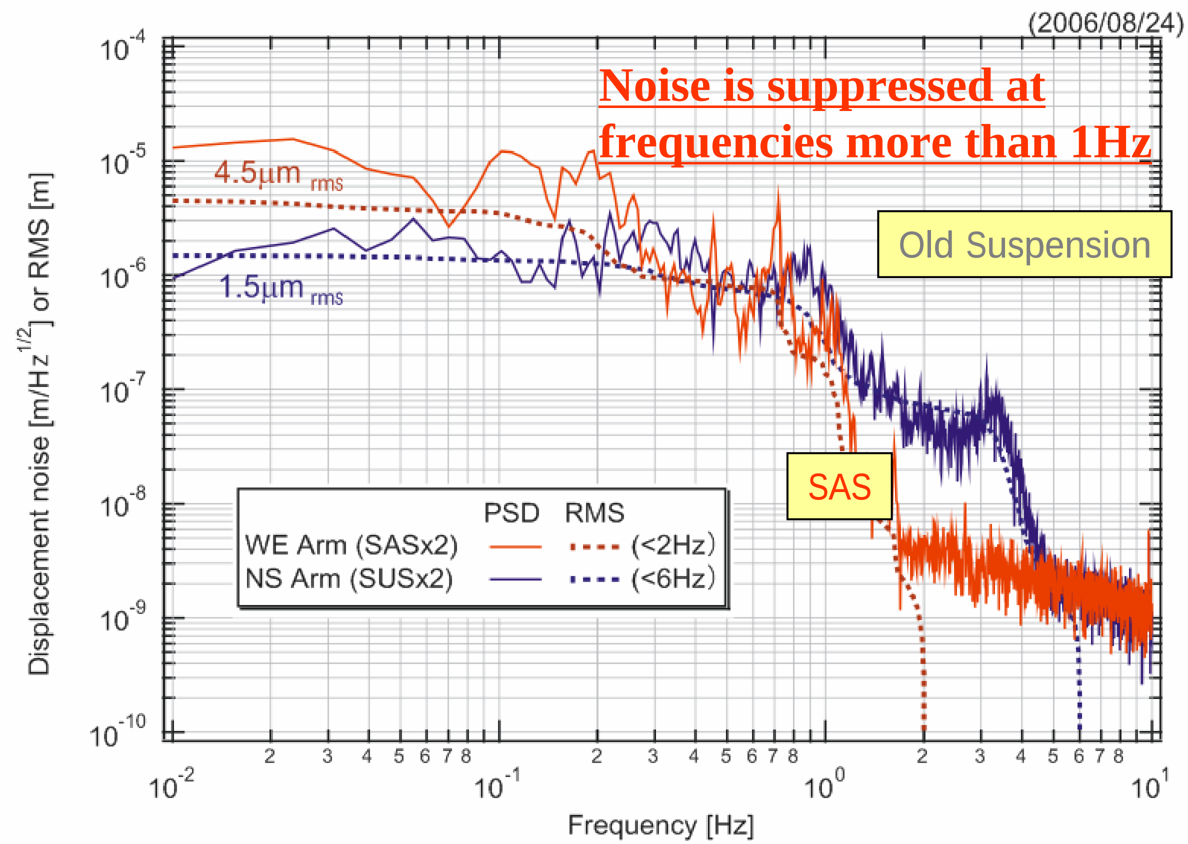


For Higher sensitivity at low frequencies



Introduction of SAS in 2005-06

Successful lock of 300mFP cavities and a noise curve was taken as a Fabry-Perot Michelson interferometer.

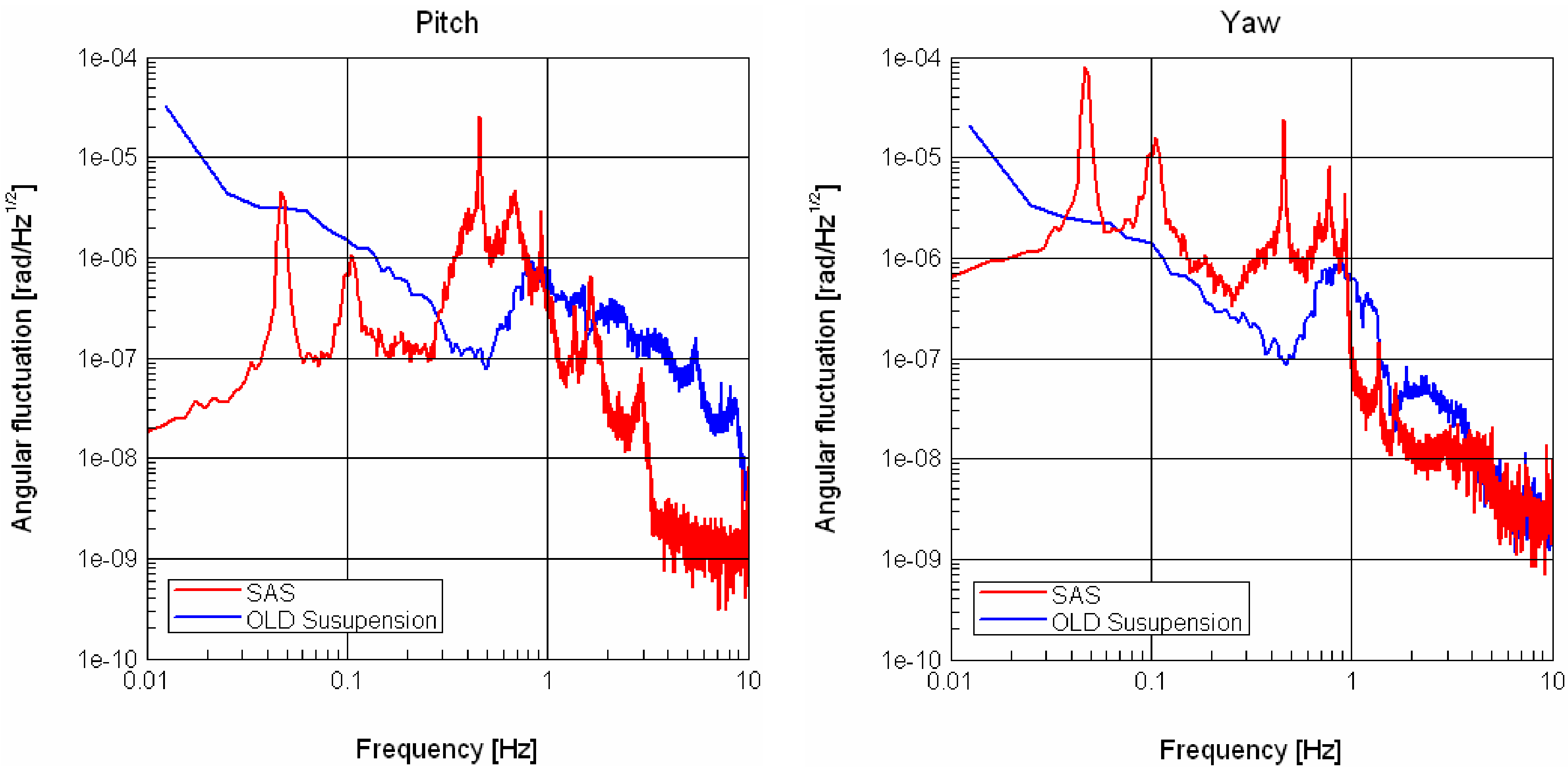


Step1

Angular performance by SAS

By R. Takahashi at Amaldi 7

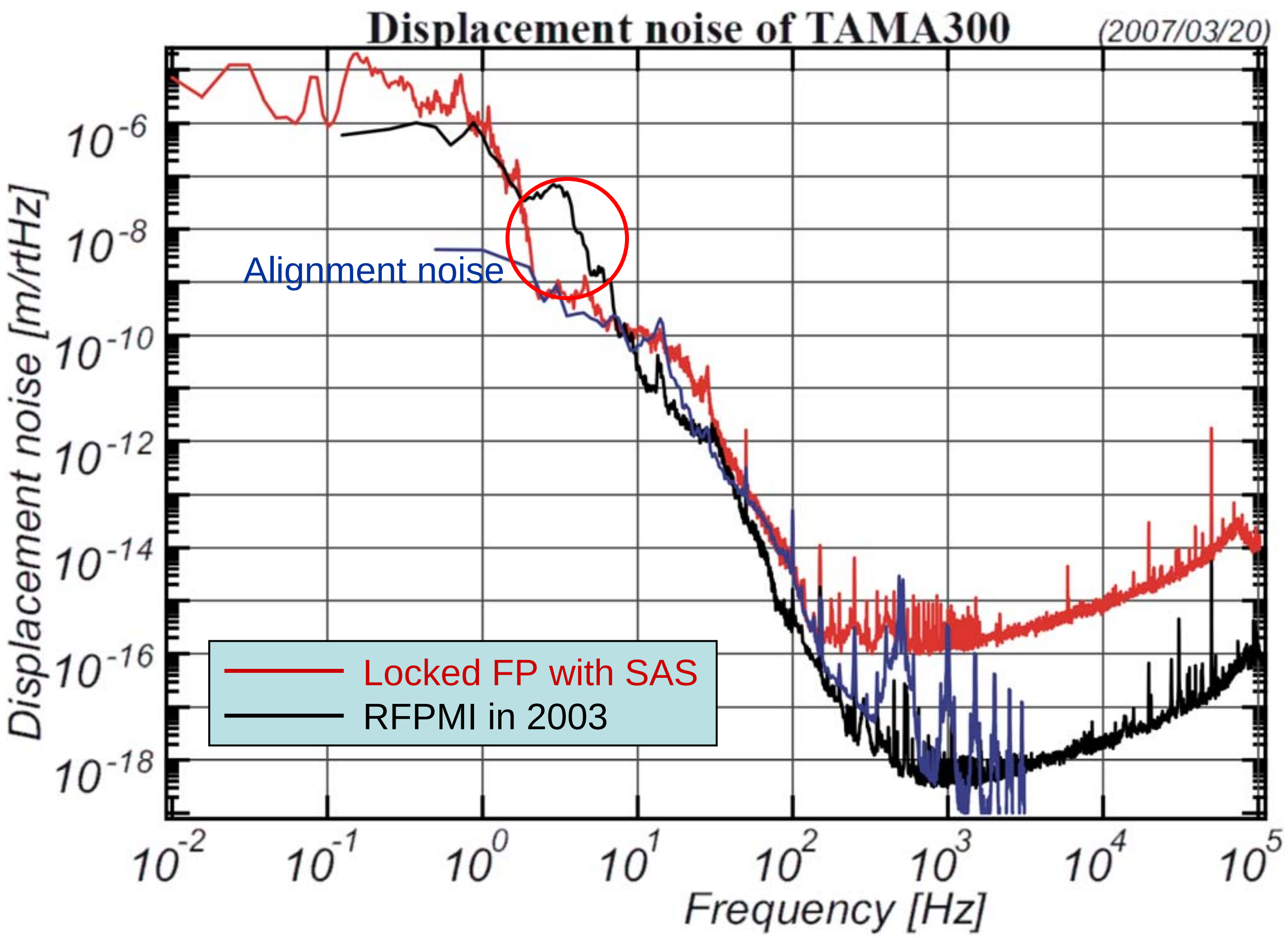
- Measured by local optical lever.
- Angular fluctuation of the test mass was improved at >1Hz.
- It is possible to set the bandwidth of the alignment control to be lower than 2Hz. . Expected reduction of the alignment noise which limited the former sensitivity of TAMA300.



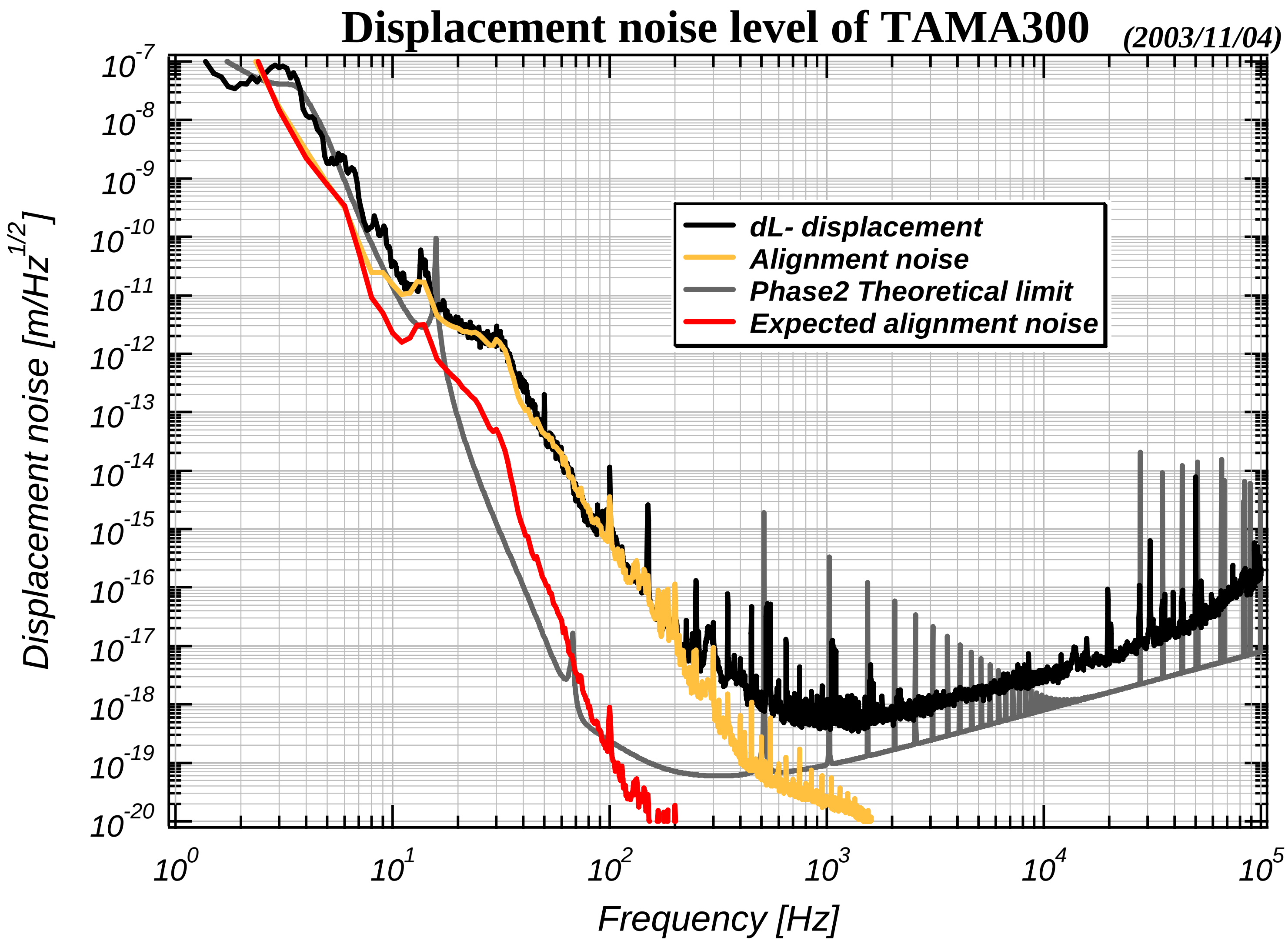
By R. Takahashi at Amaldi 7

Step2
Evaluation by Locked FP using four SASs

- Improved displacement noise at 2~7Hz.
- Still alignment noise is dominant at 2~100Hz.



Possible alignment control noise reduction



4000 times improvement at 100Hz

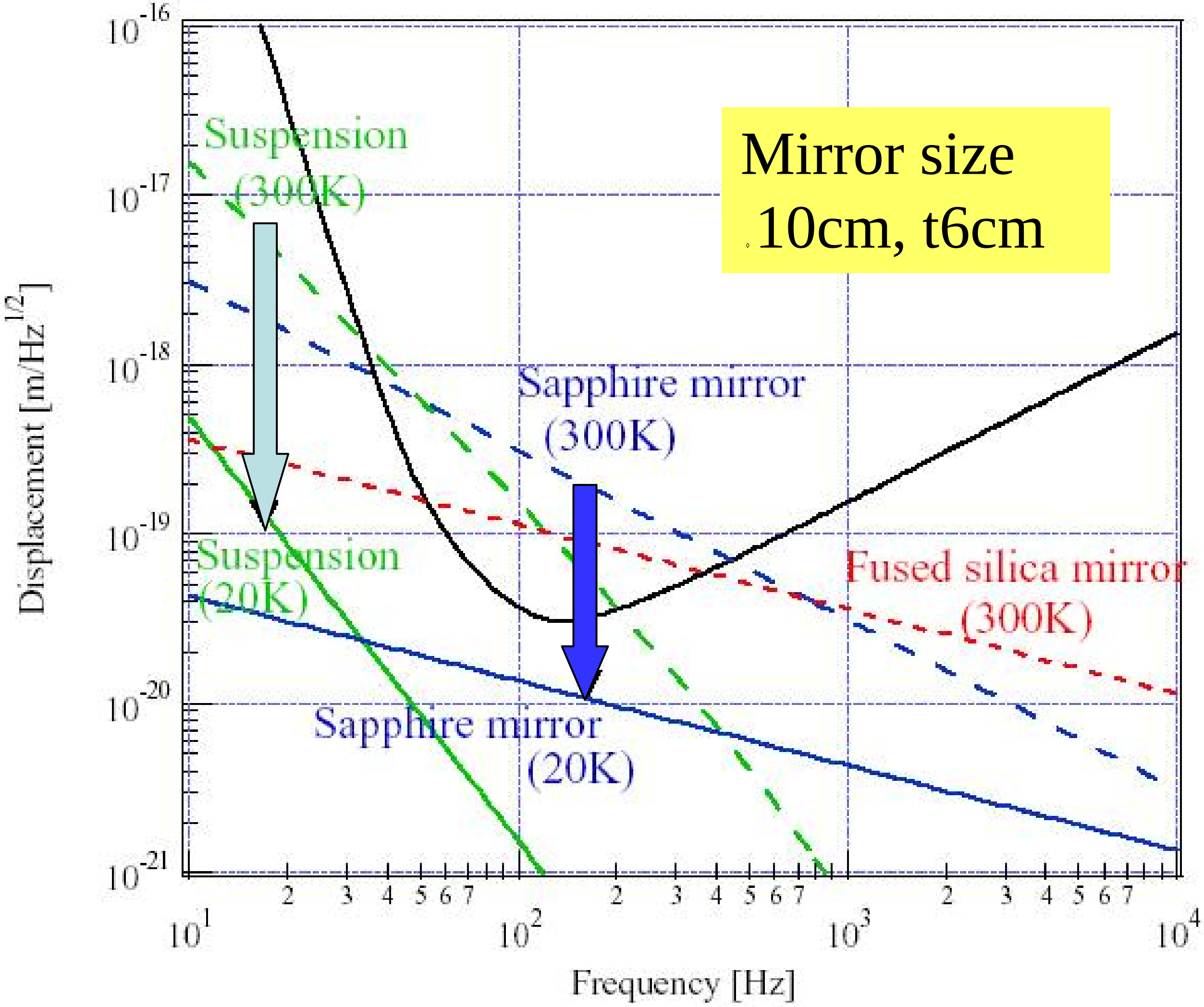
Summary of

- Control system for SAS was established.
- Length fluctuation of the 300-m cavity was improved at >1Hz.
- Angular fluctuation of the test mass was improved at >1Hz.
- Recycled FPMI with SAS was successfully locked and now the final tuning is being done.

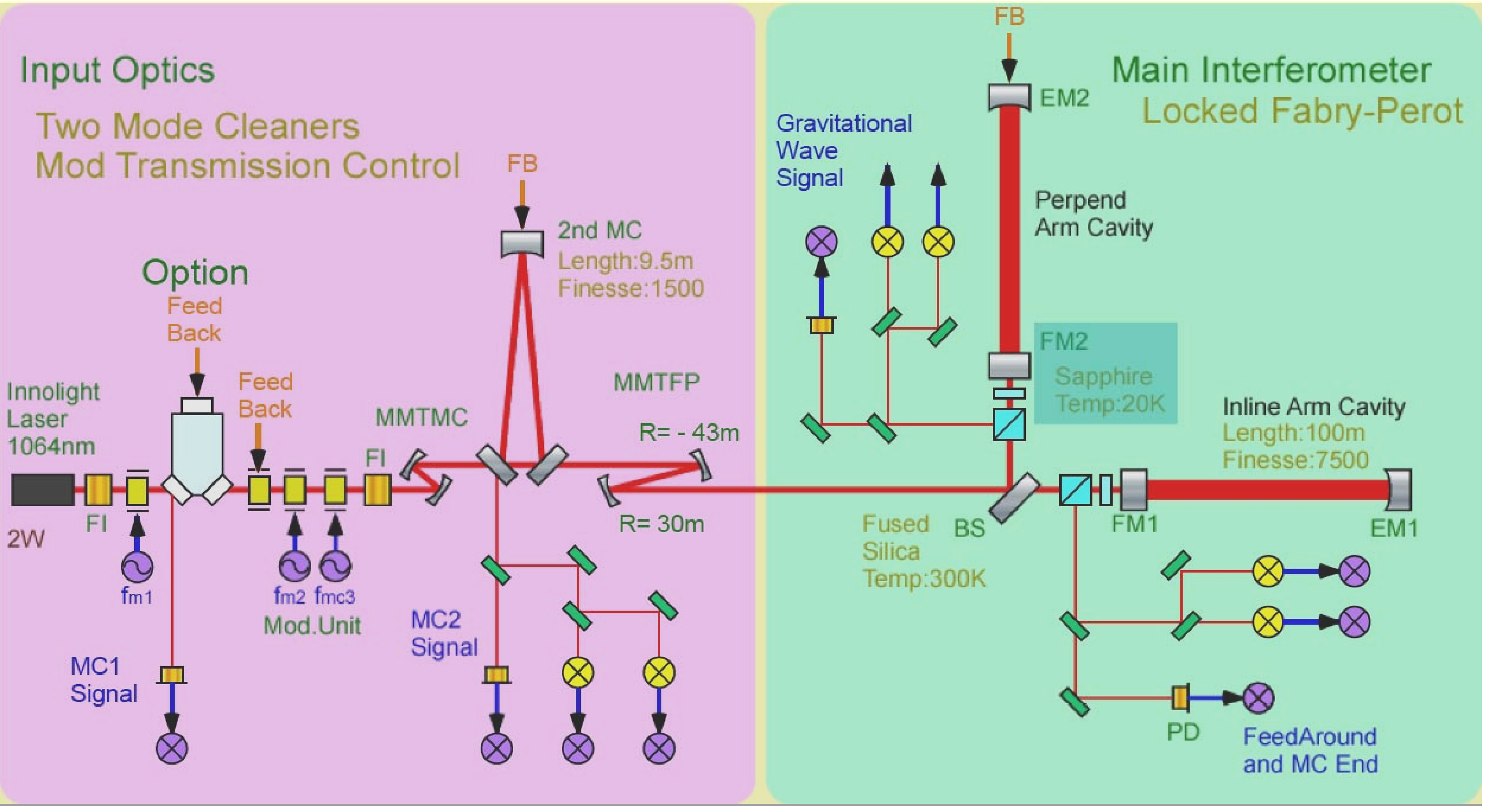
CLIO

CLIO is a 100m baseline cryogenic interferometer placed underground at Kamioka

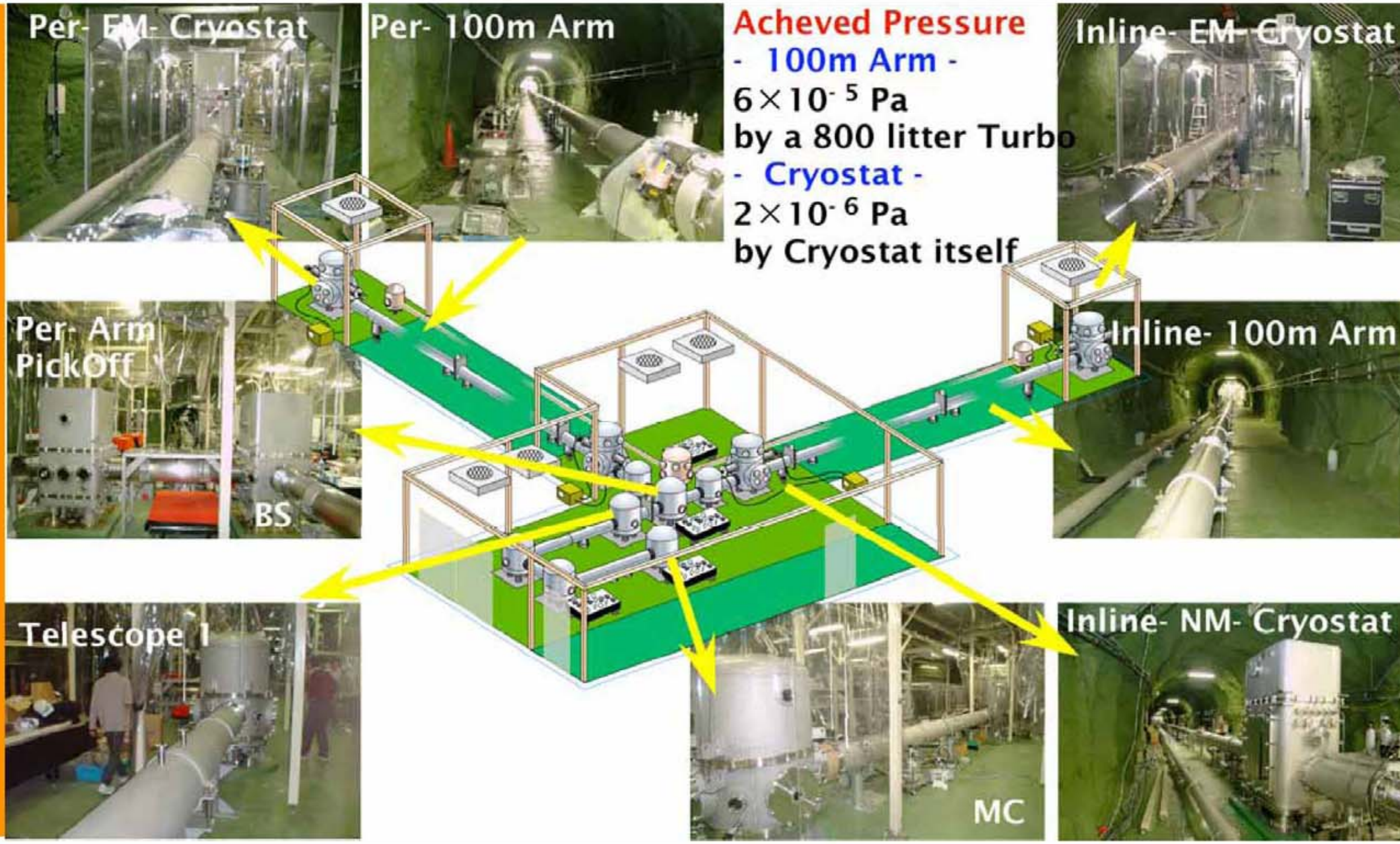
Expected reduction of thermal noise by CLIO (300K – 20K)



CLIO is a locked Fabry-Perot Interferometer

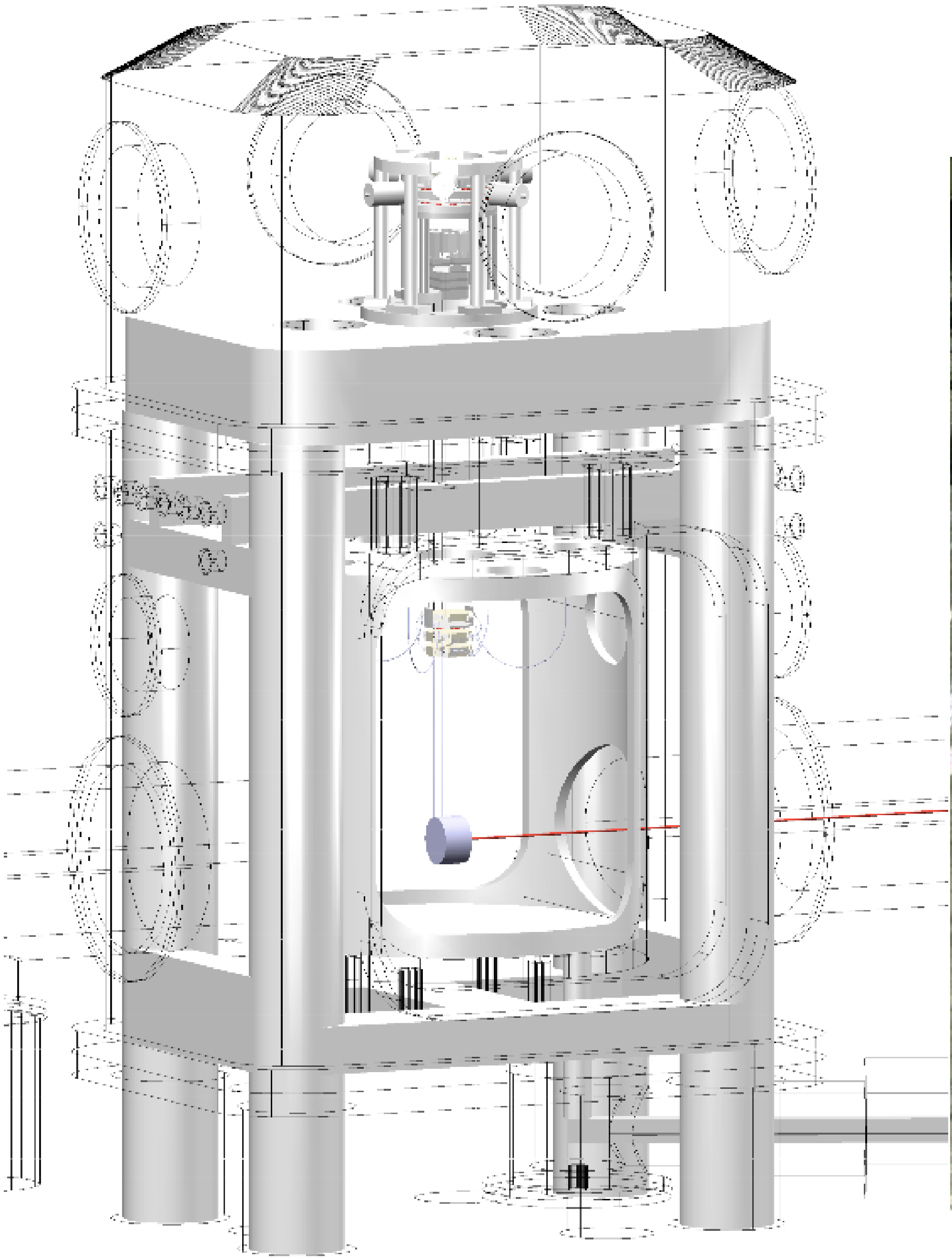


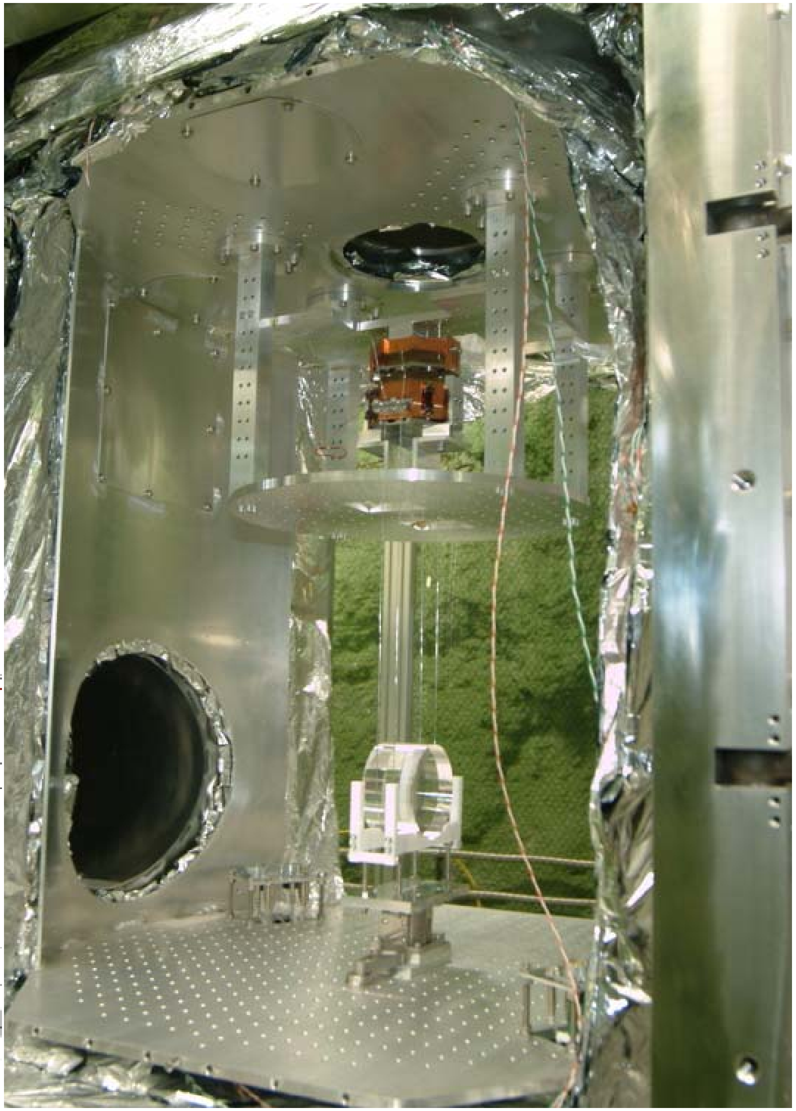
Construction of CLIO



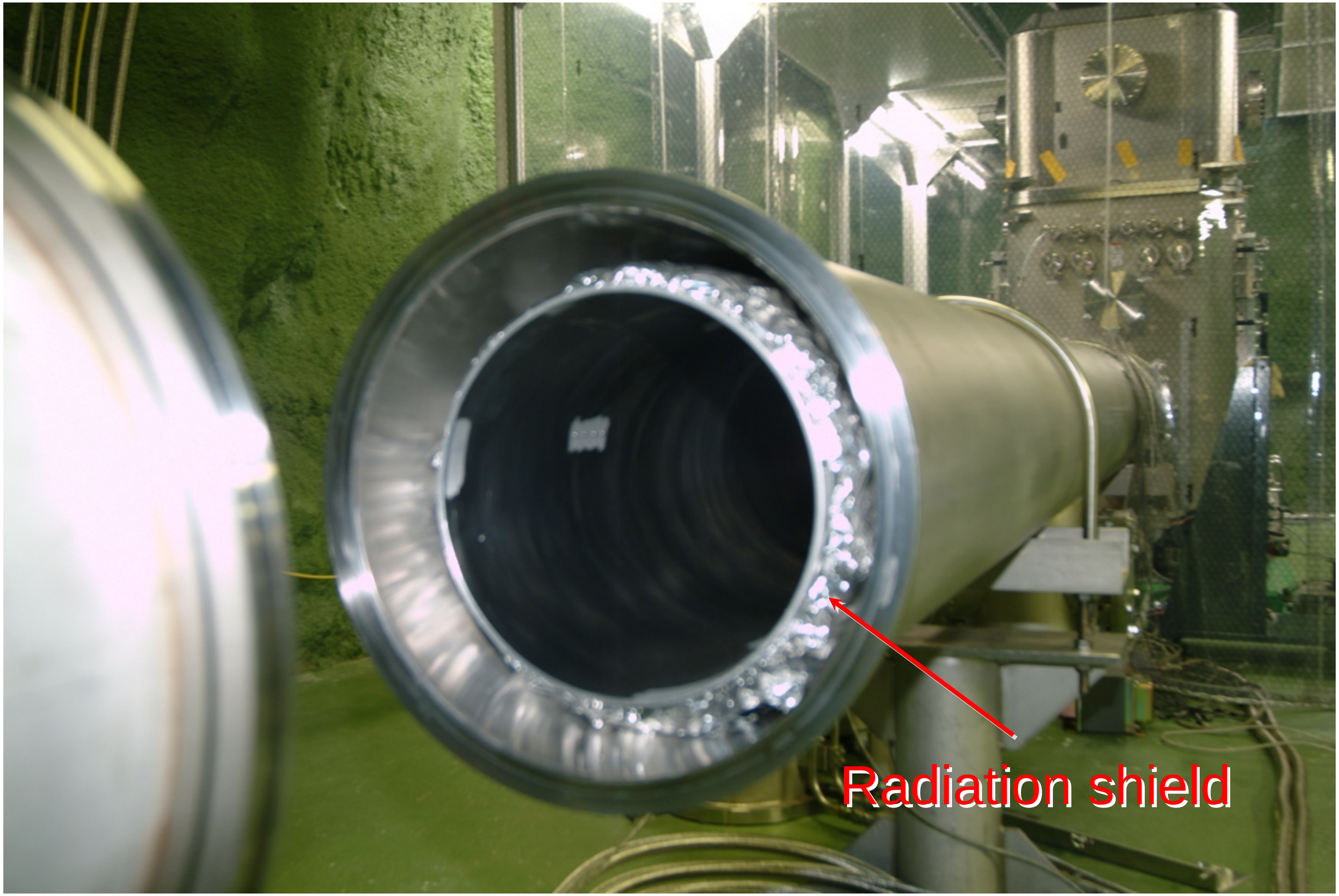
Acheved Pressure
- 100m Arm -
6×10^{-5} Pa
by a 800 litter Turbo
- Cryostat -
2×10^{-6} Pa
by Cryostat itself

Internal view of mirror suspension

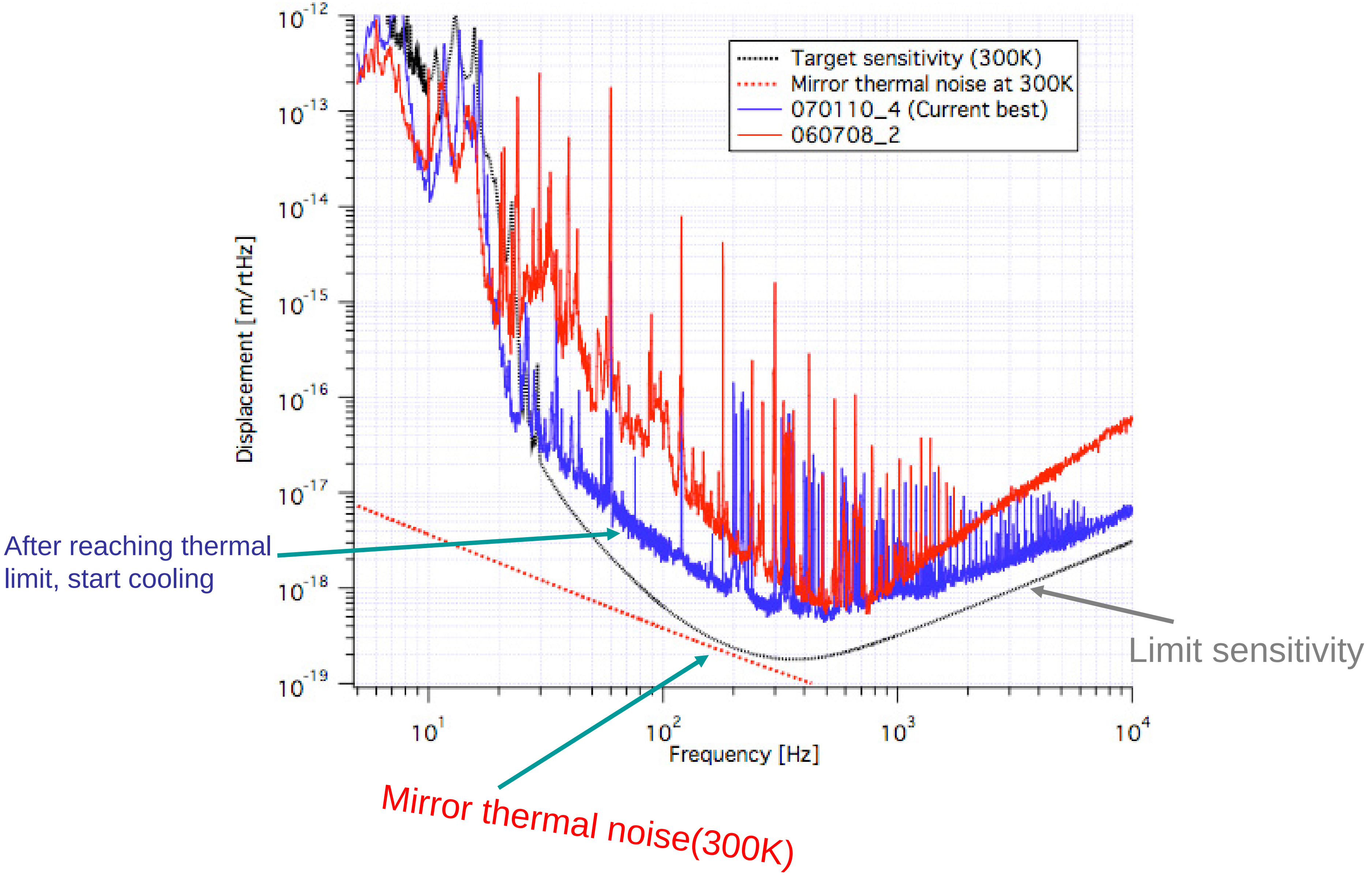




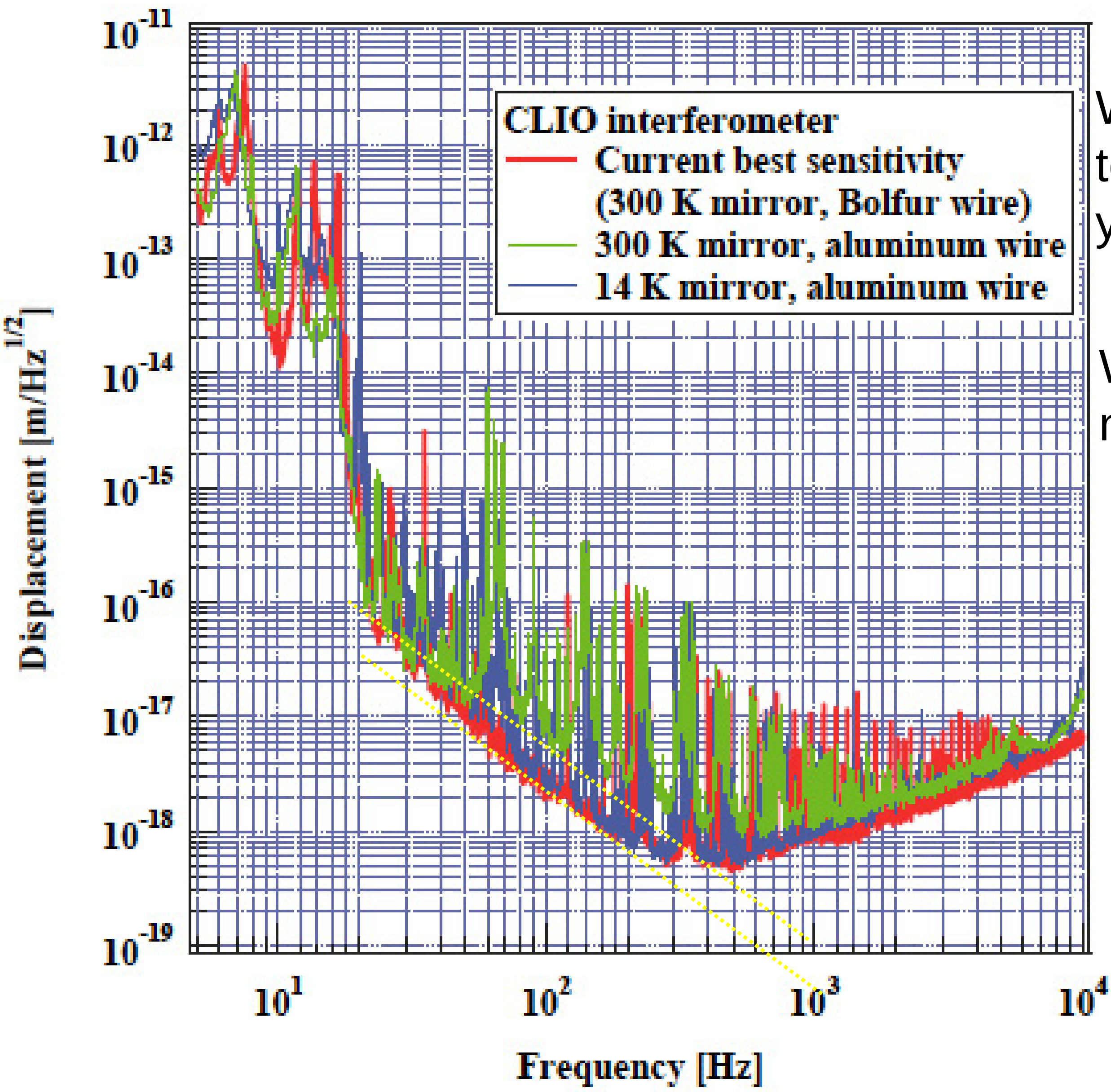
Cryostat and 5m pipe



Current sensitivity of CLIO



Effort to attain ultimate sensitivity of CLIO



We have not attained room temperature thermal noise, yet.

We are checking suspicious noise sources one by one.

The plots shows that thermal noise of lossy suspension wire might be reduced by cooling. (only three mirrors were cooled at this time)

Summary of CLIO and limiting factor of sensitivity

- 30Hz-300Hz f-inversely square dependence
  - Mechanical noise sources
    - Mirror vibration (main mirrors, pick-off mirrros, BS): not f^{-2}
    - Injection / detection port: detection optical line was enclosed against acoustic noise
    - Optical windows: ? If so, more complicated structure may apper
  - Electrical noise sources
    - Actuator system (amplifier noise, thermal noise of the circuit,…) magnet bars were replaced with smaller ones
    - Magnetic force (bar magnets, closed loop of suspension wires) ferromagnetic parts were removed near test masses
    - Electrostatic force ? may depend on repeated vacuum opening process
  - Physical noise sources
    - Stray light estimation by exciting the center part of the beam tube
    - Residual gas (spot sources) ? vacuum pressure changed
    - Radiation pressure (DC) observed repulsion of test masses by light power
    - Newtonian gravitational force difficult to increase to explain the present
  - Data taking
- 300Hz- photon shot noise / calibration
- We have still no answer.

LCGT

Necessity of LCGT

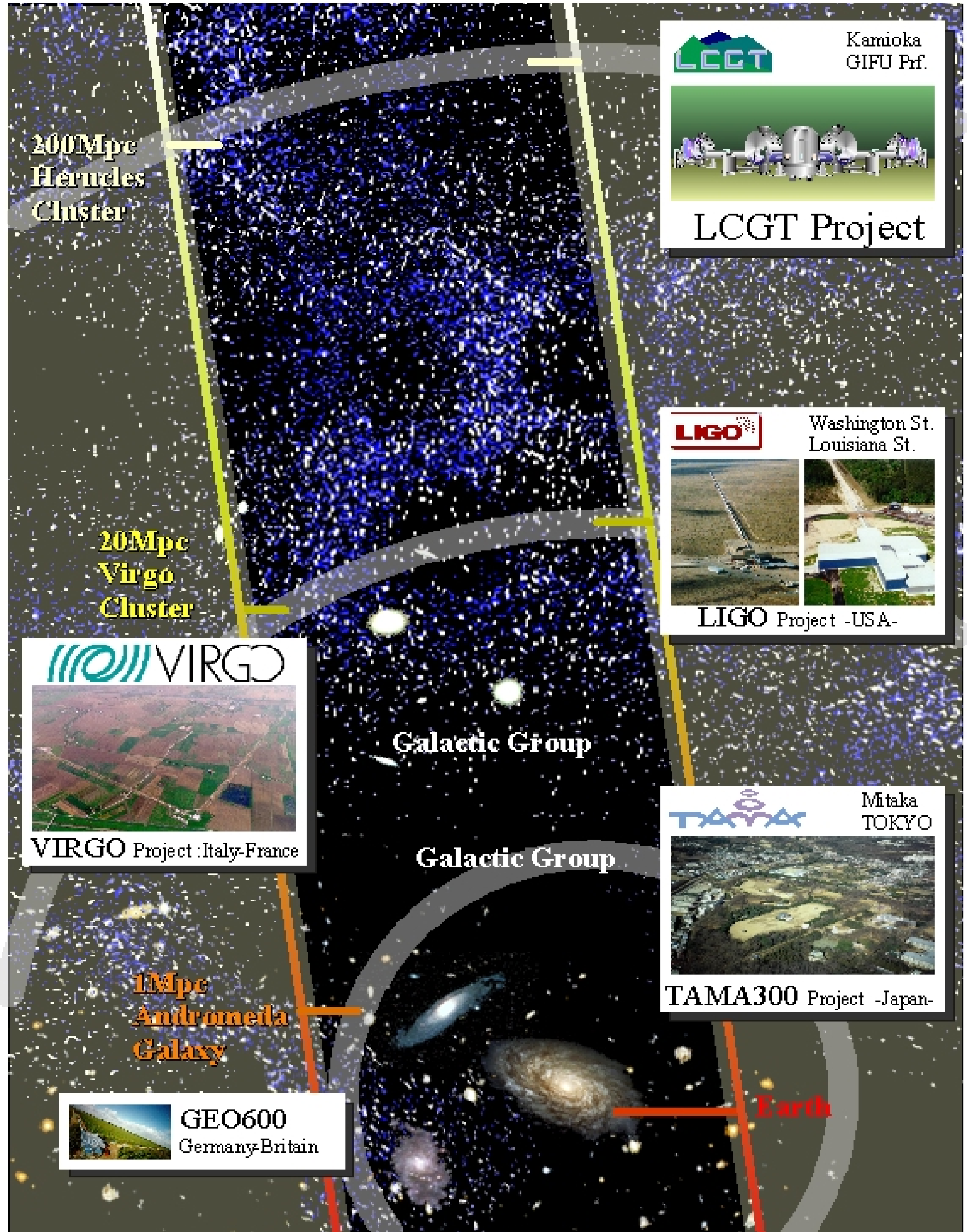
LIGO (USA), VIRGO (French-Italian), GEO (Germany-England), TAMA (Japan) are in operation.

Occurrence of neutron star binary is estimated to be 10^{-5} for matured galaxy per year . There are 0.01 galaxies for 1 cubic Mpc. Present detectors (..-scale) cover up to Virgo cluster.20Mpc). More than several years are needed to detect the event.

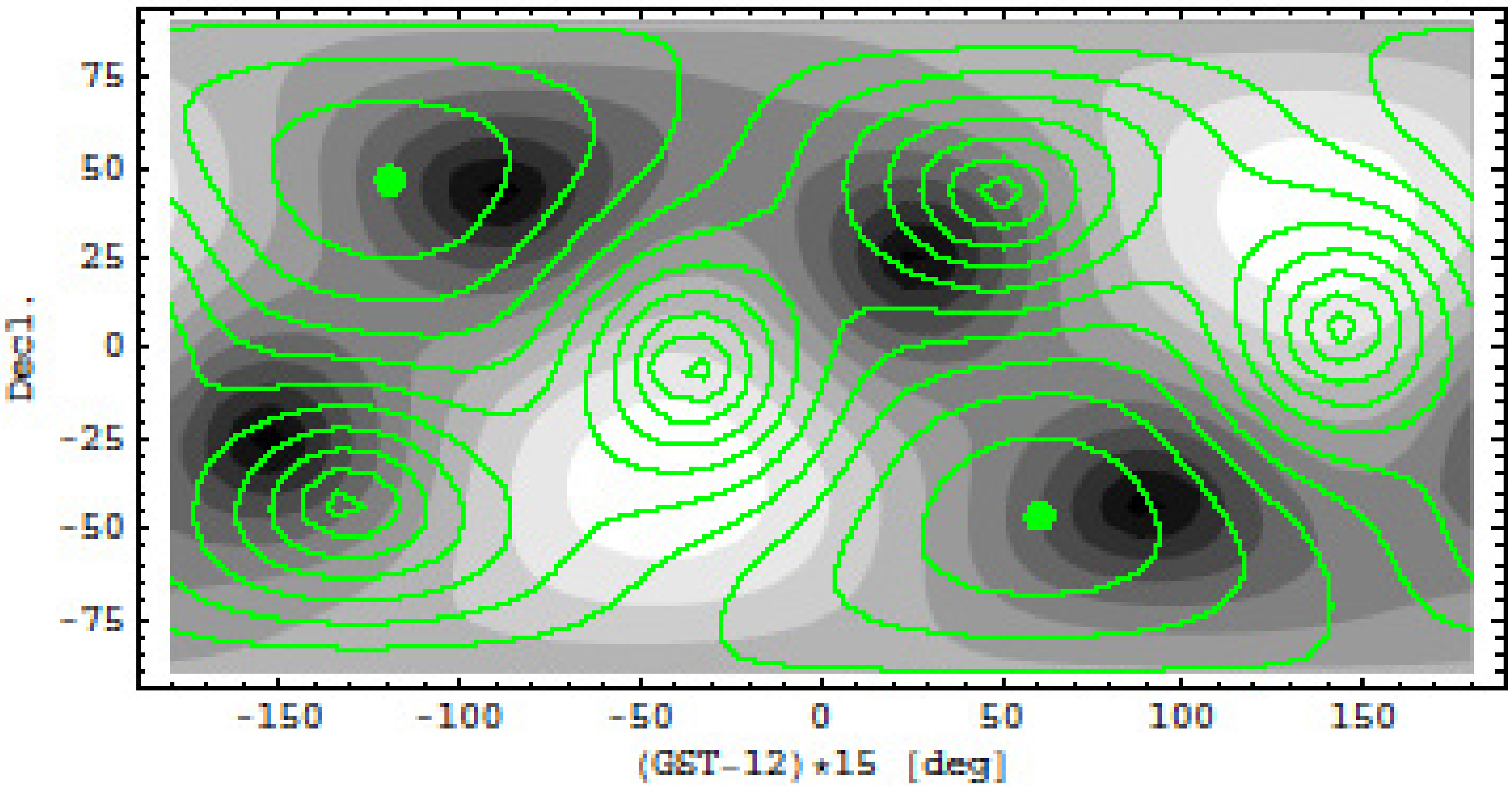
Therefore, we need more sensitive detector. LCGT can detect an event occurring at 180Mpc on average and observes 8 events a year.

1pc=3.3light year

View Ranges of Gravitational Wave Detectors



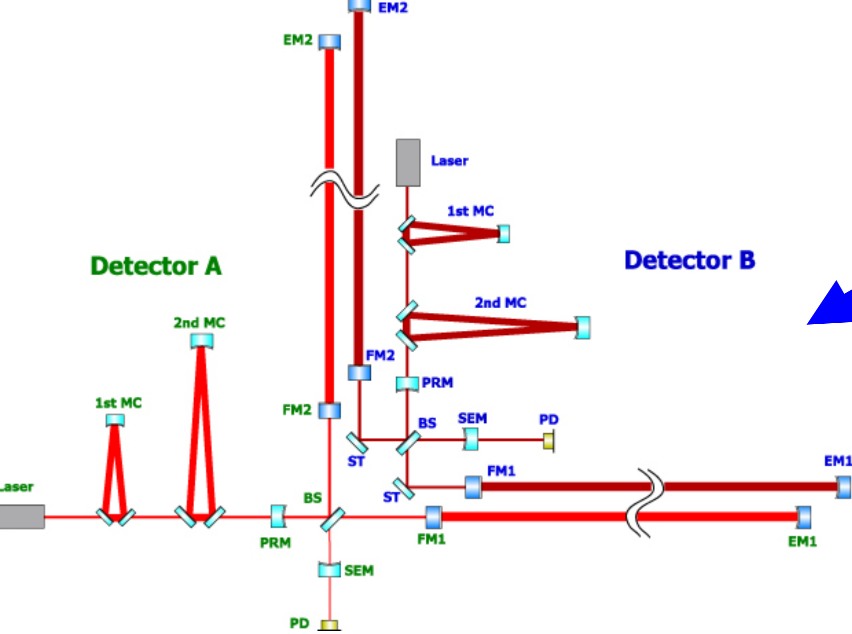
International Network of GW observation



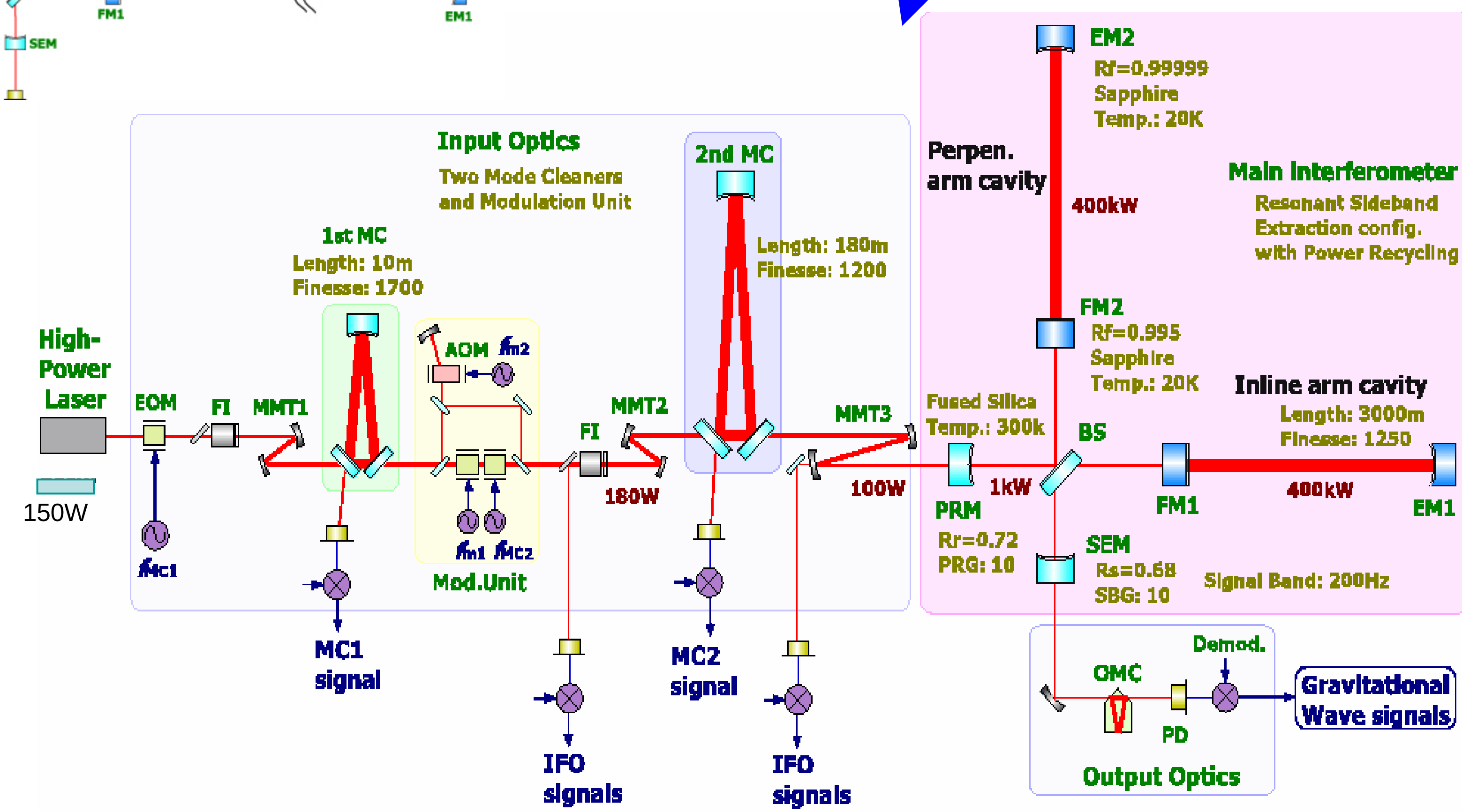
LCGT plays an complementary role with LIGO.
LCGT: grey, LIGO (Hanford): green contour

Optical design of LCGT

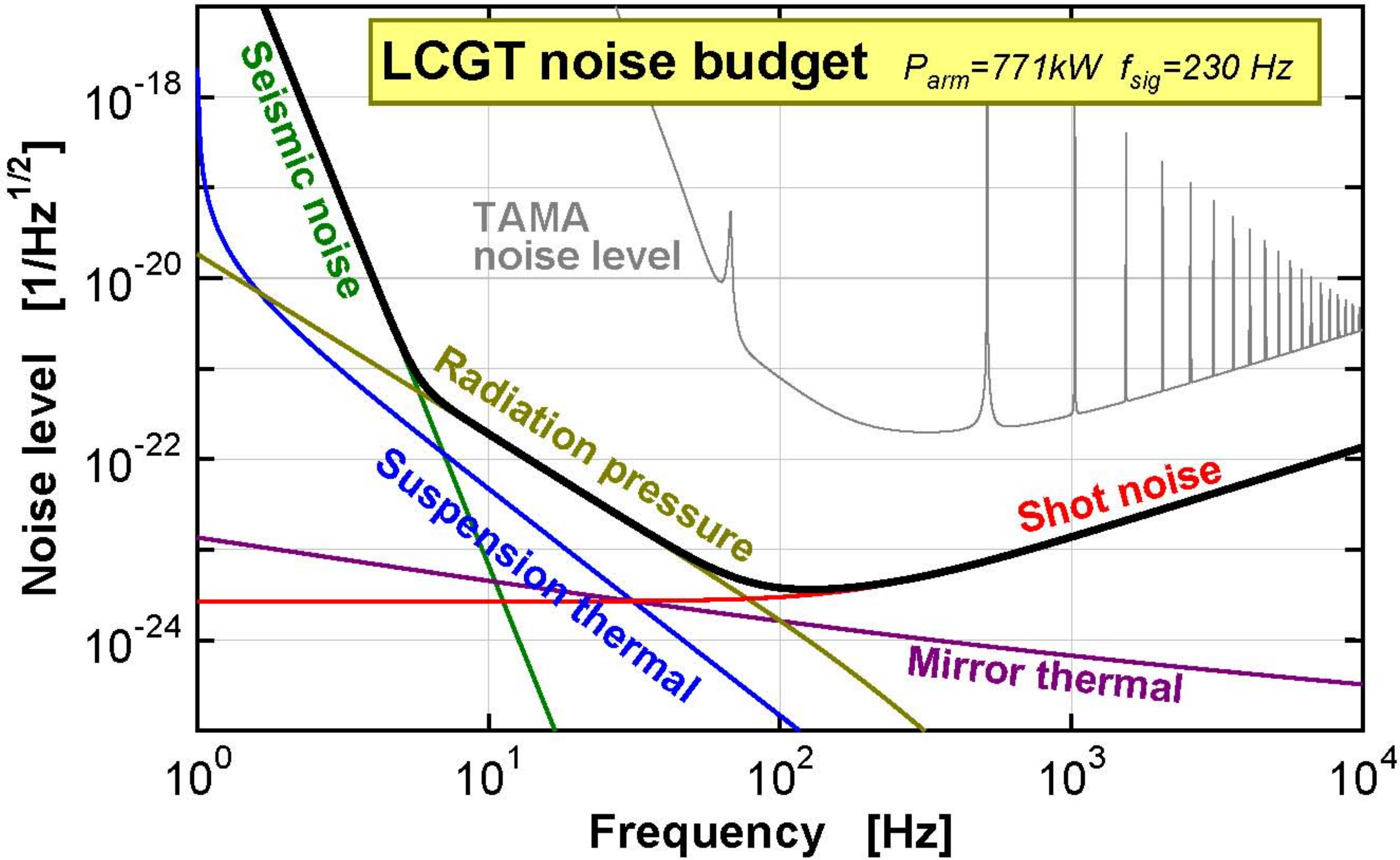
Two interferometers are arranged not to interfere in the same vacuum system.



Optical design of the basic interferometer

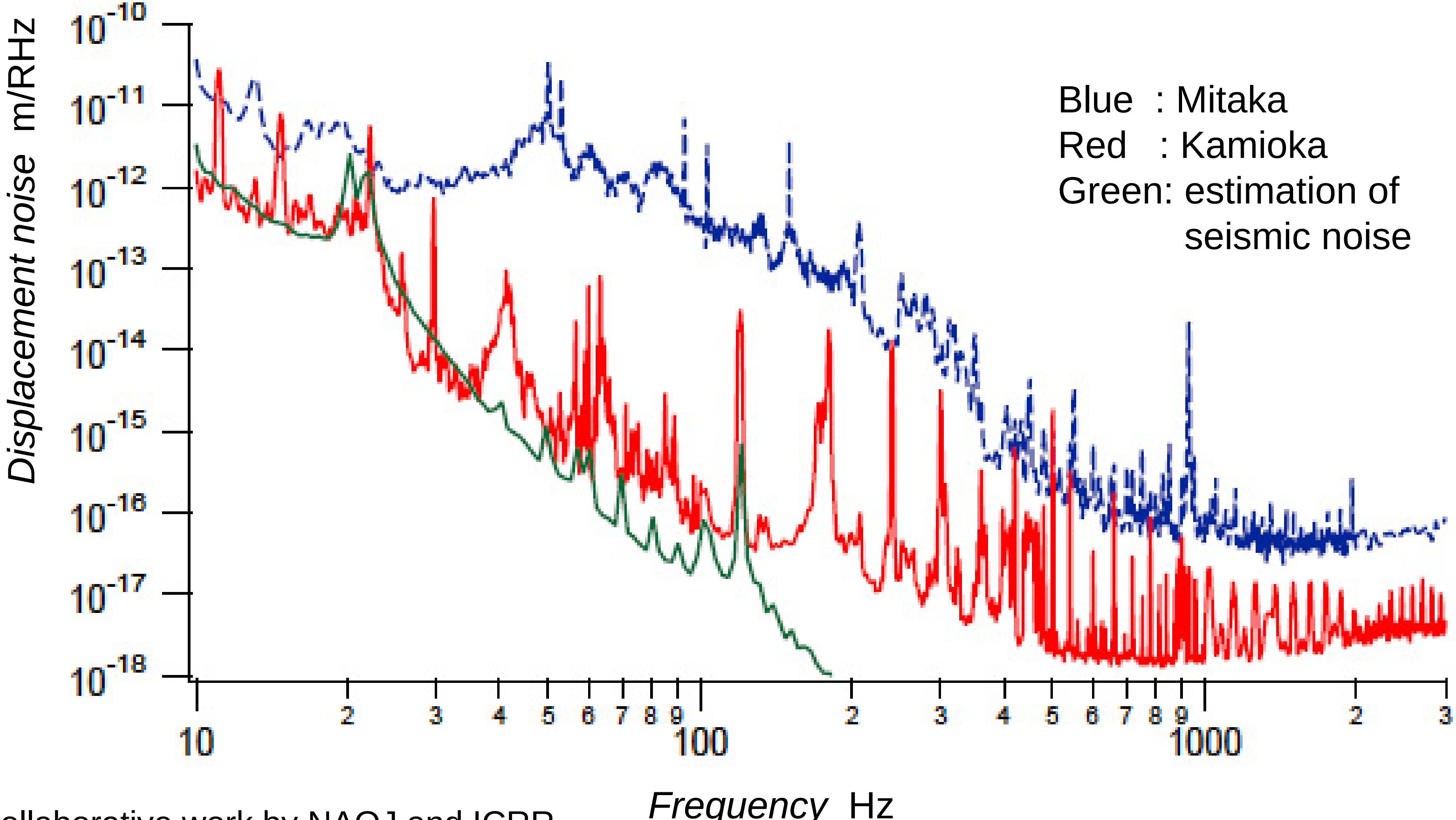


Design Sensitivity



LCGT placed underground at Kamioka

A 20m prototype, LISM, was moved from TAMA site to Kamioka underground. Sensitivity was nonlinearly improved by 4 orders at 100 Hz.



Collaborative work by NAOJ and ICRR

Why do we use cooled sapphire mirrors?

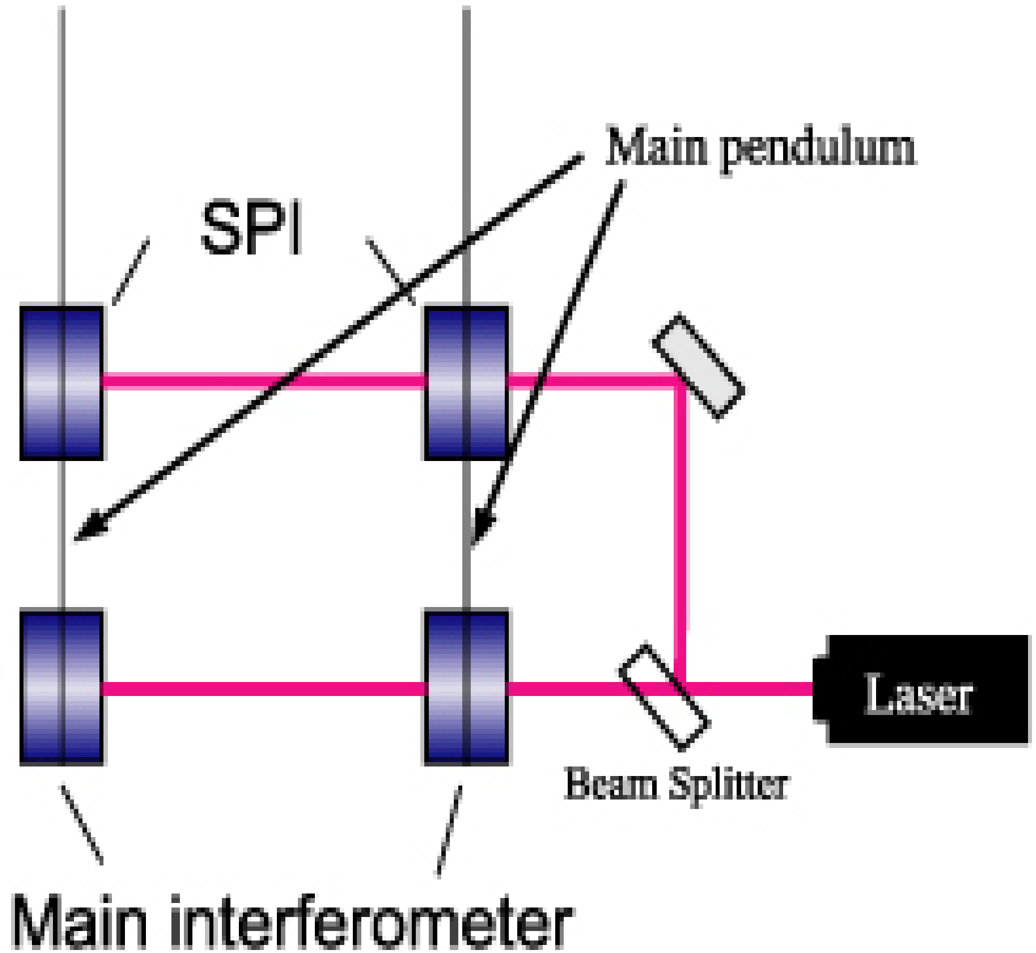
- It is a direct way to reduce thermal noise
- It produces less thermal lens effect
  - due to high thermal conductivity and low thermal expansion rate (sapphire)
- It can avoid the optical parametric instabilities
  - due to higher elastic wave speed (sapphire) and small beam size (cryogenic)
- It is free from large optical coating loss
  - due to low temperature

Large heat production is avoided by RSE

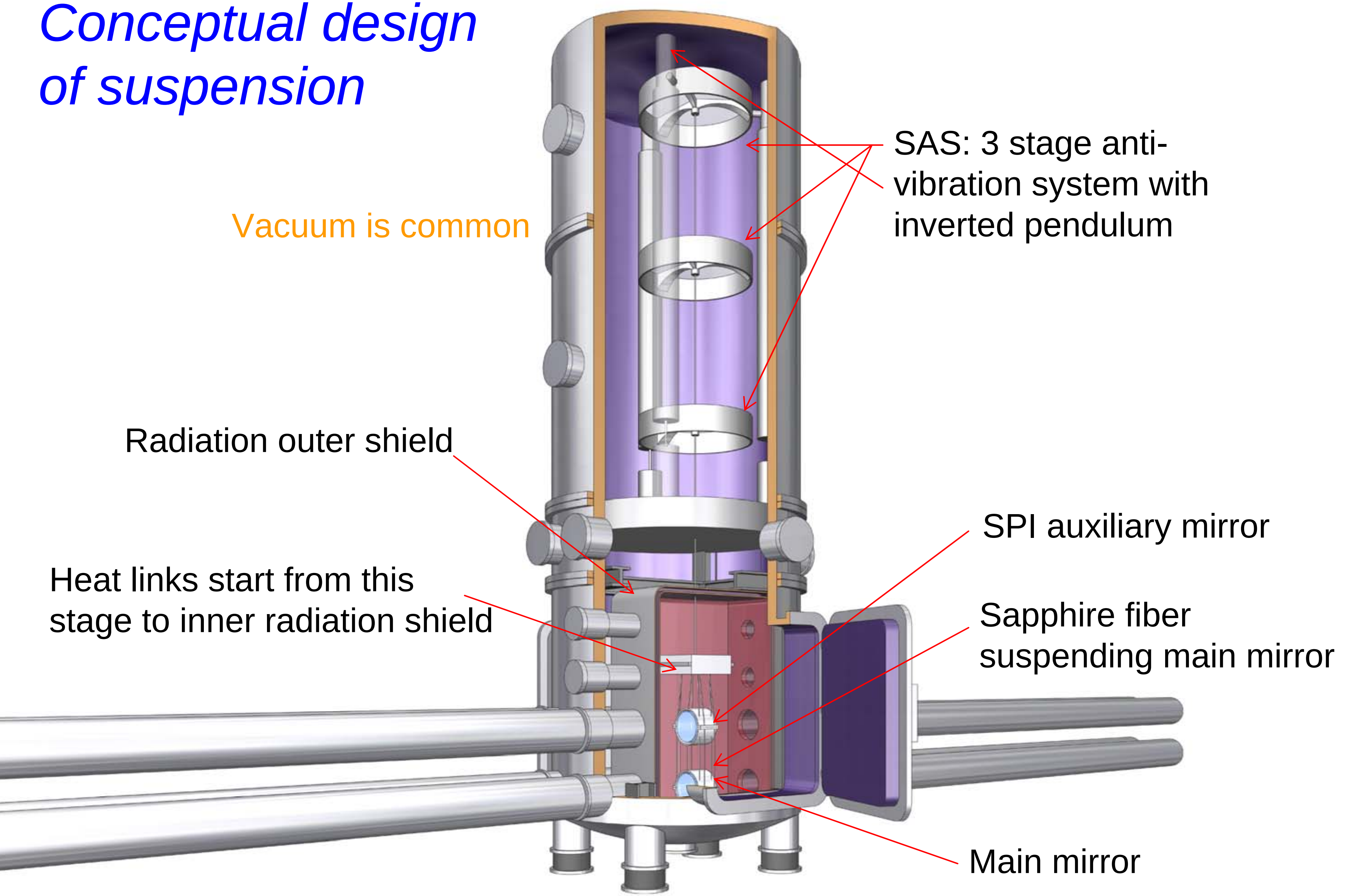
- Broad band RSE (Resonant Side band Extraction method) is applied.
- Power recycling gain is set 11.
- Finesse of the cavity is 1550, which means that observational band becomes to be lower than required.
- RSE keeps the observation frequency band unchanged.

Refrigerator noise is avoided by SPI

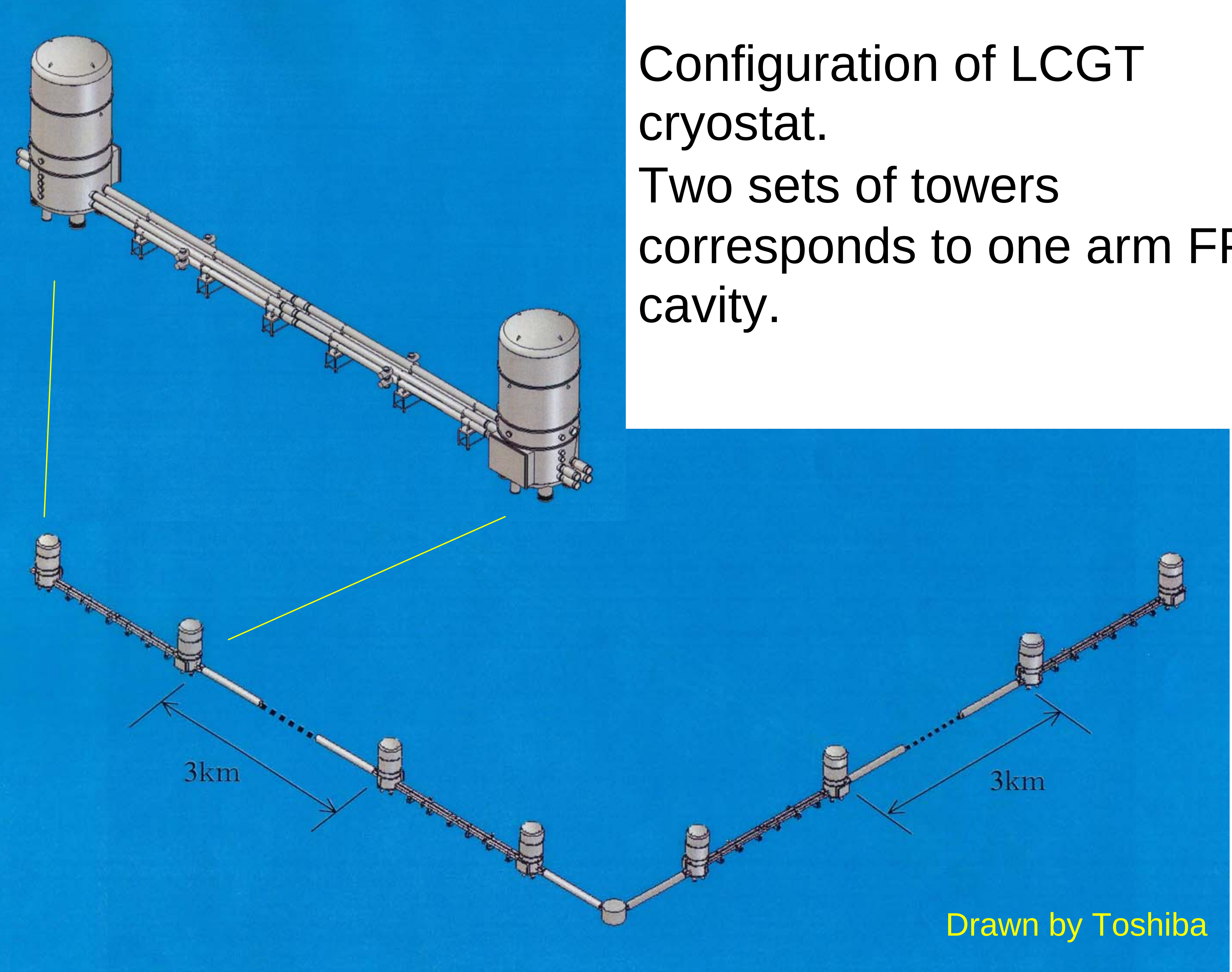
Test mass of LCGT is connected to a cooling system by a heat link that possibly introduces mechanical noise. A suspension point interferometer (SPI) is introduced to maintain high attenuation of seismic and mechanical noise without degrading high heat conductivity.



Conceptual design of suspension

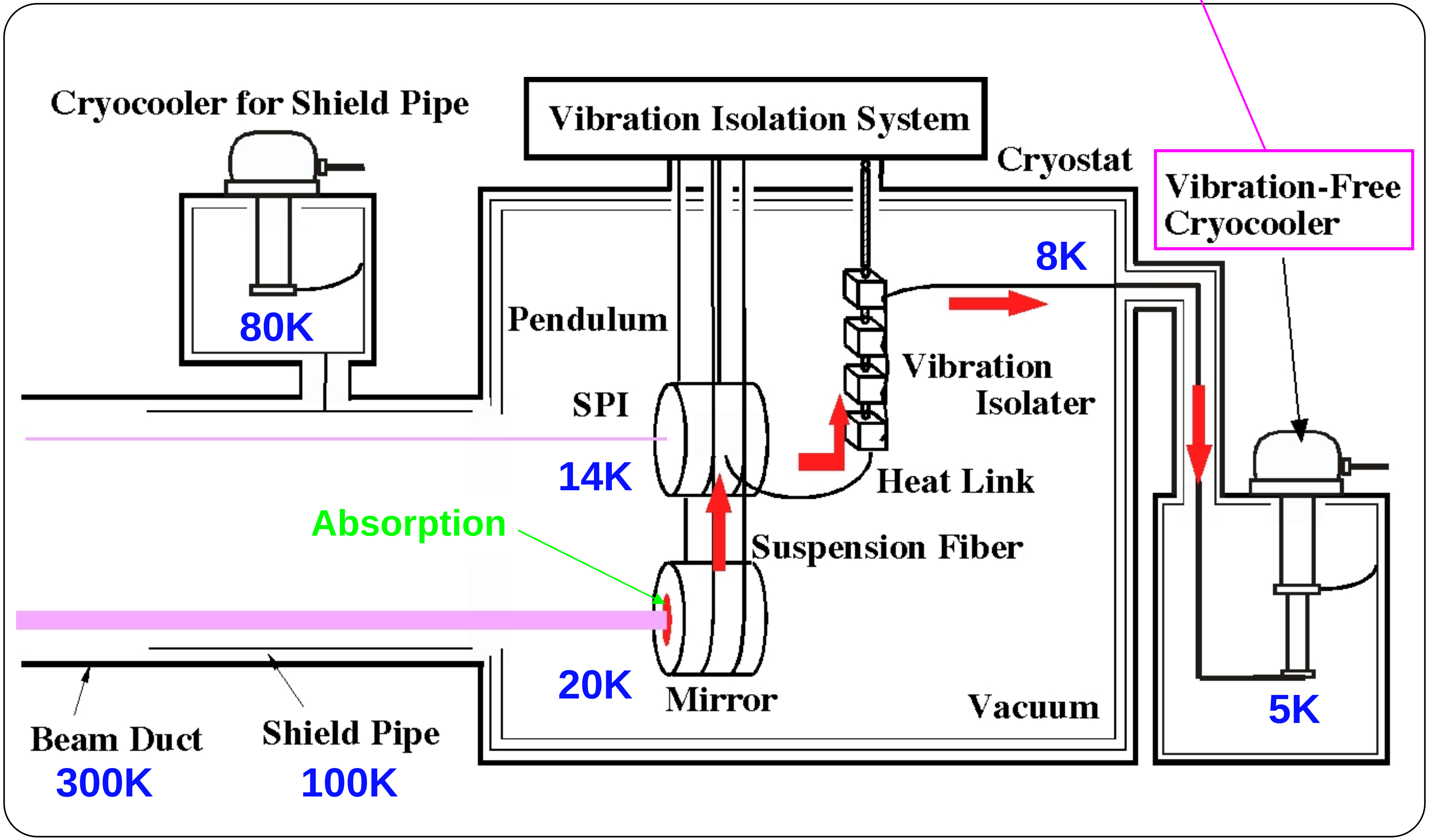


Configuration of LCGT cryostat.
Two sets of towers corresponds to one arm FP cavity.



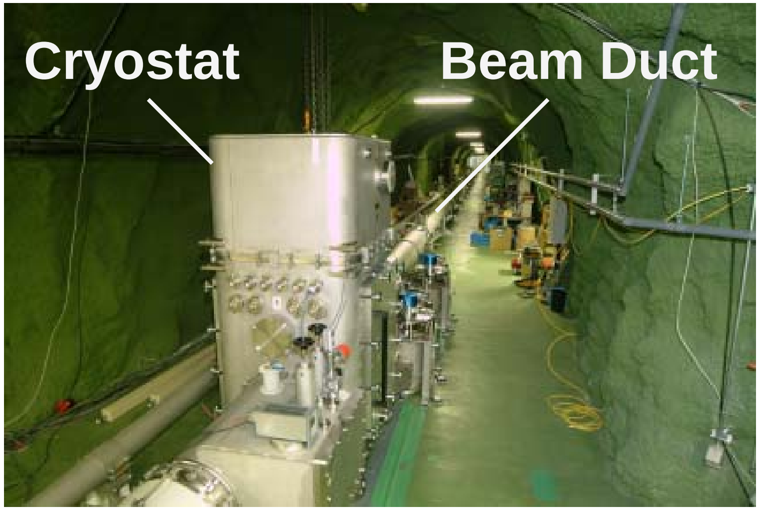
Cooling System

T. Tomaru et al., Cryocoolers 13 (2005) 695.
R. Li et al., Cryocoolers 13 (2005) 703.



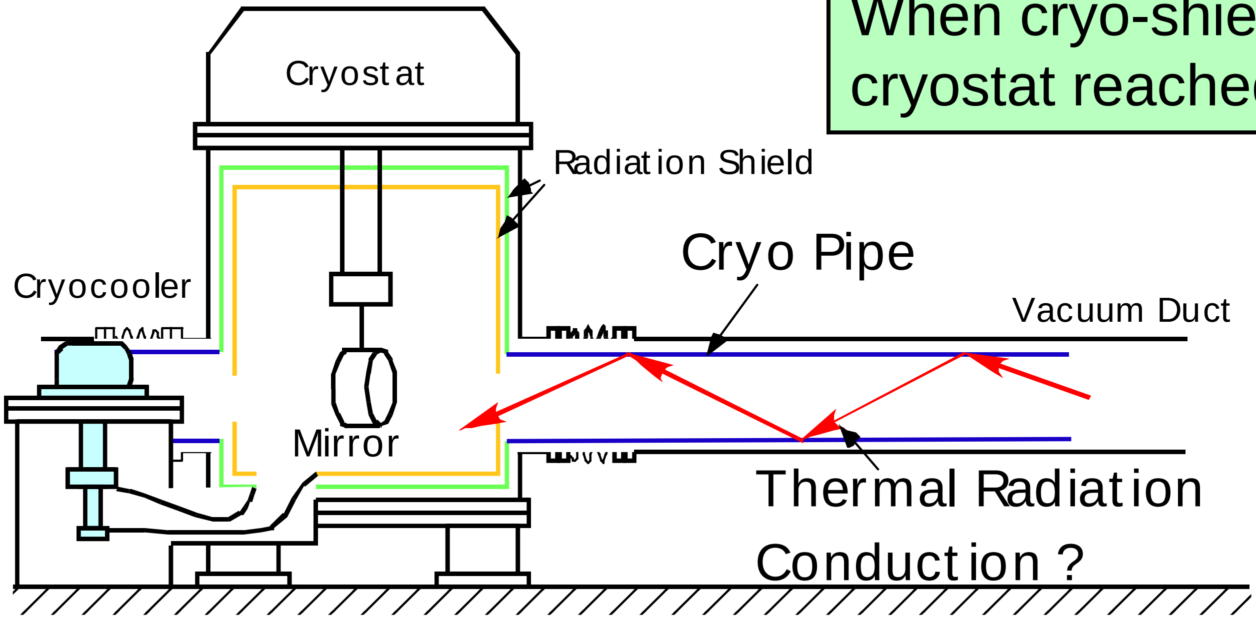
Tomaru et al. Amaldi7

New Revealed Heat Load in CLIO



Designed heat load:
~ a few mW @ 8K shield
Initial cooling test:
12.6 K @ 8K shield
Estimated heat load > 3W
~1000 times larger than design

When cryo-shield-pipe was closed, cryostat reached design temperature.



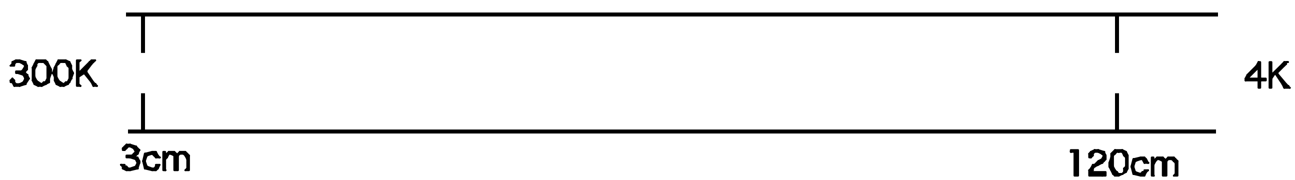
Thermal radiation from a 300K beam port conducted in Al cryo-pipe ?

Tomaru et al. Amaldi7

Tomaru et al. Amaldi7

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

Using 2 baffles



Measured result: 7.9mW

-> **Reduction rate: 98%**

Acceptable

Apply 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)

International Collaborations

- TAMA-LIGO
  - Attachment 1 (Locking system, 1997)
  - Attachment 2 (Mirror imperfection, 1998)
  - Attachment 4 (e2e simulator, 2000)
  - Attachment 5 (SAS technology, 2000)
  - Attachment 6 (sapphire, under process, 2007)
- TAMA-VIRGO (Pwr Recycling, 1998)
- LCGT-ACIGA (R&D, 2001)

New comers are welcomed!!

Summary

- We have acquired interferometer techniques (power recycling, Fabry-Perot Michelson, control system) by TAMA.
- LISM confirmed underground significance.
- CLIO proves the feasibility of cryogenic mirror, soon.
- LCGT will certainly detect gravitational wave events in a year.
- We are doing the best for funding of FY 2008.