CLIO-100

Institute for Cosmic Ray Research
Shinji Miyoki

ICRR
K.Kuroda,MOhashi,T.Uchiyama,K.Yamamoto,K.Kasahara,H.Ishitsuka
KEK
T.Tomaru, N.Sato, T.Suzuki, T.Haruyama, A.Yamamoto, T.Shintomi
NAOJ
D.Tatsumi
AIST
S.Talada

3rd TAMA Symposium
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ICRR

Ultimate Gravitational Wave Telescope on the Earth

Proceeding Projects
(GW detection rate is low except for LISA)

Planed Projects
(2-3 / year event rate is expected)

Advanced LIGO (USA)

EURO (Europe)

LCGT (JAPAN)

DECIGO (JAPAN)

How to obtain 10 times Sensitivity

Assuming ever obtained best displacement of ~10^{-19} [m/rHz] and almost established tech,

●Extend arm length to 30 ~ 40km.

---- maybe impossible on the earth, but space?

Assuming fixed 3 ~ 4km arm length,

●Decrease displacement noise by 1/10.

---- higher performance is required for each technique.

LCGT trial

Distinctions of LCGT Project

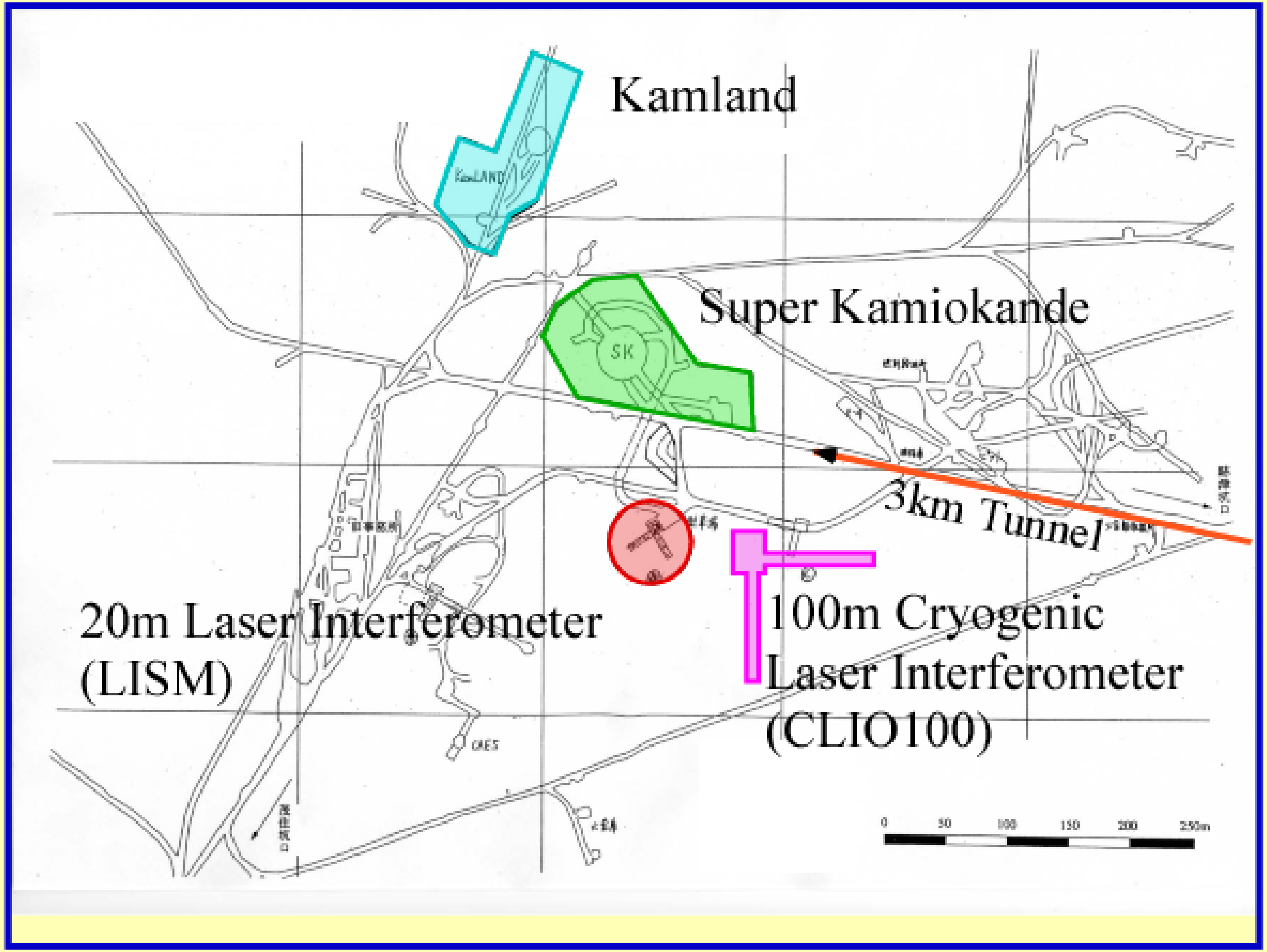
- Set in Kamioka Mine (1000m Underground)
  - Stable operation as a GW telescope depends on seismic noise < 1Hz.
  - Lower seismic noise is preferable to realize 1/10 displacement than that ever realized.
- 3km Fabry-Perot Cavity
  Fabry-Perot Michelson style
  using RSE and Power Recycling
- Thermal Noise Reduction by Cooling
  - Thermo Elastic Noise of Sapphire reduction by cooling
- Veto analysis by 2 detectors

◆Suspension Point Interferometer

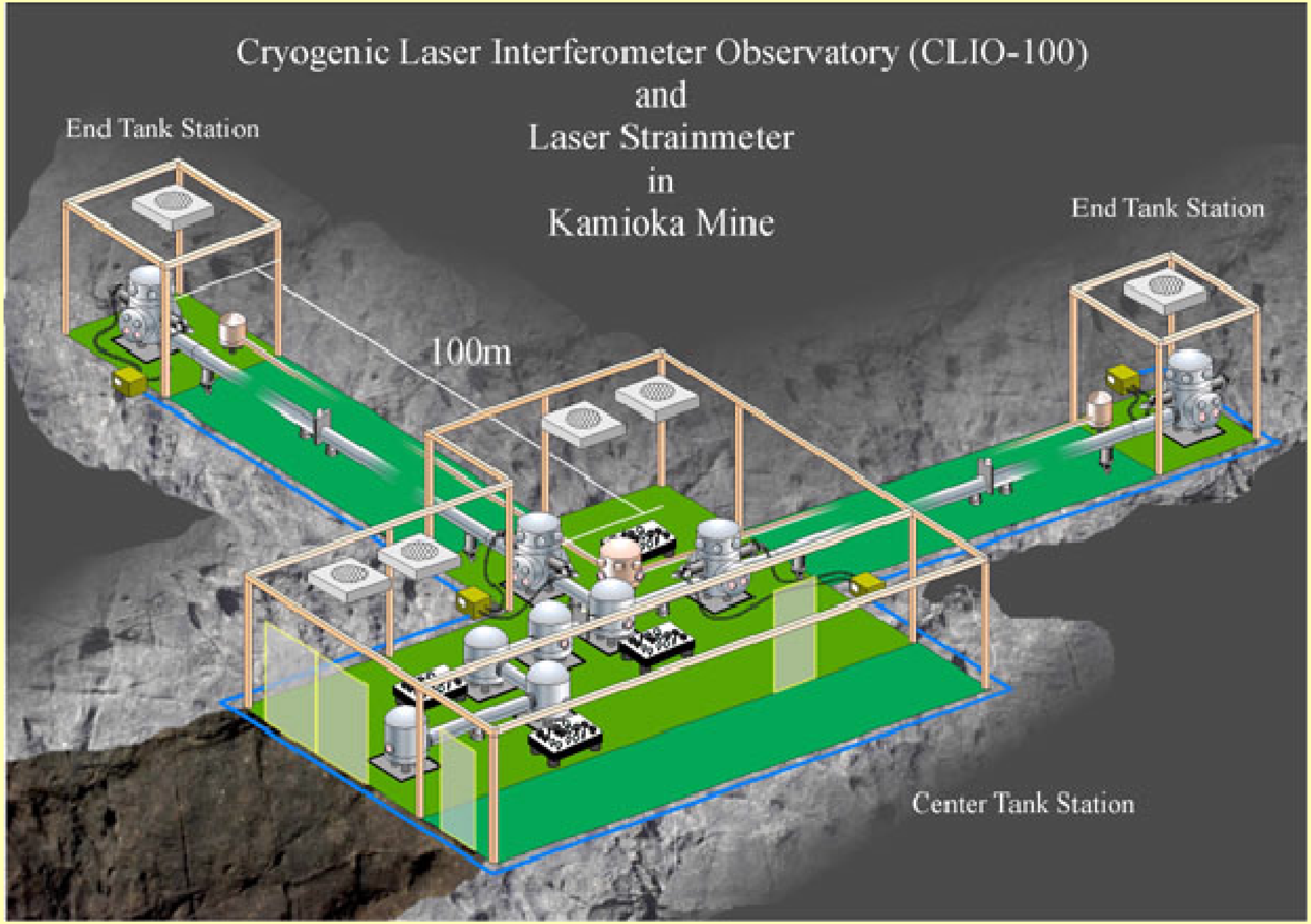
Goal of CLIO

maybe

Site of CLIO-100

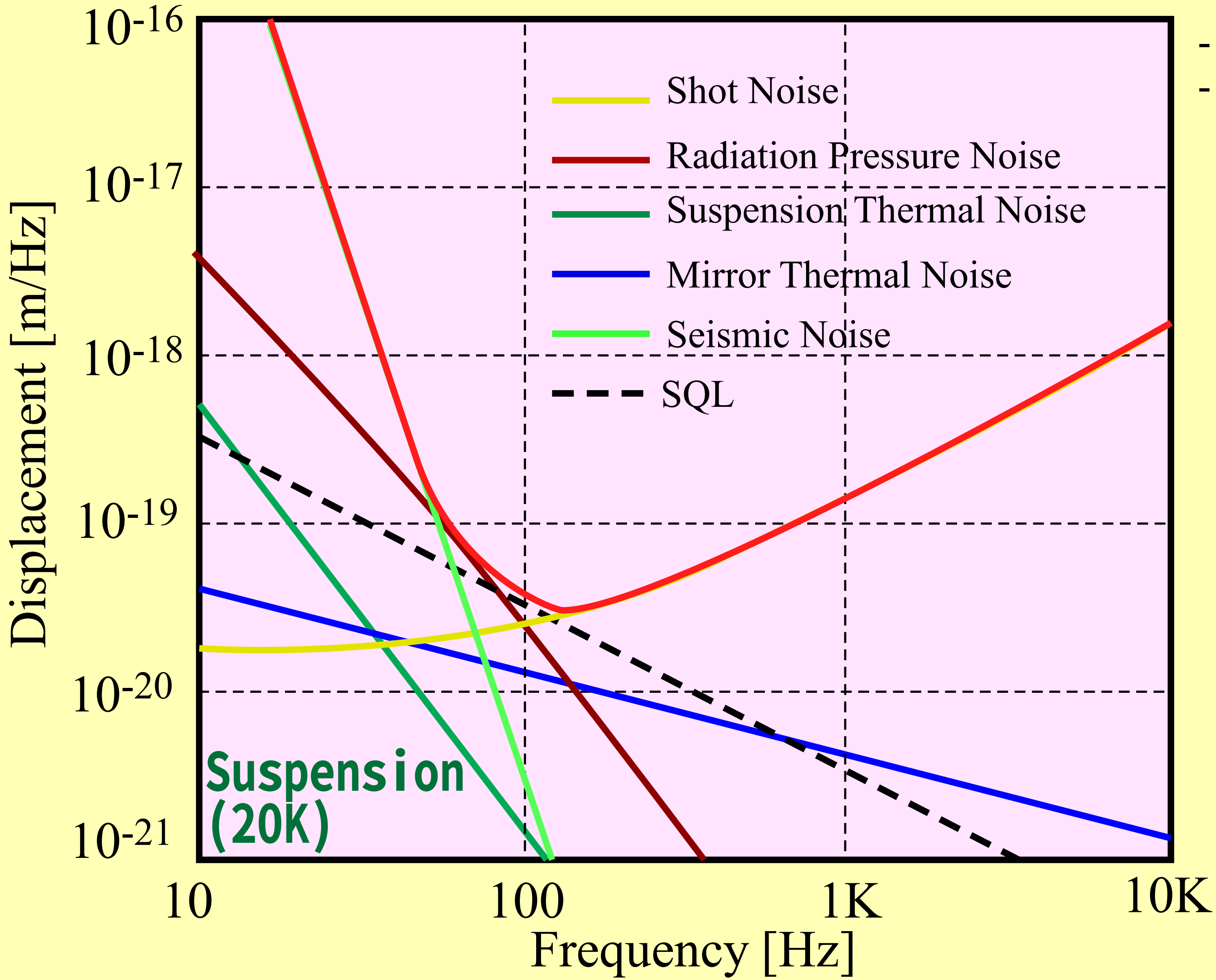


CLIO-100


Cryogenic Laser Interferometer Observatory (CLIO-100)
and
Laser Strainmeter
in
Kamioka Mine
End Tank Station
End Tank Station
100m
Center Tank Station

Target Displacement

- Below 10^{-19} [m/rHz] level.



- Laser:2W
- Mirror:Sapphire
  :1.8kg
  :Q~10^8

How to Reduce Thermal Noise

■ Enlarge Beam Size
Heavy Mirror

- merit -

Only "super" big mirror is required.

- demerit -

Can we make a "super" mirror?
Special optics can widen size for a normal size mirror, keeping good quality.

- solution -

Substrate : SiO2 or Sapphire.
Size : 50cm --- 1m.
30cm for Special Optics?

■ Cryogenic Mirror

(Q,κ,α are also change to minimize thermal noise)

- merit -

All thermal noise are reduced.

Sapphire's Q, κ, α are change to minimize thermal noise. (SiO2 has zero α at special temperature)

- demerit -

Cooling system is required.
Seismic noise through heat link path.
Cryogenic mirror easily contaminated by particle adsorption.
Allowable heat generation is limited.

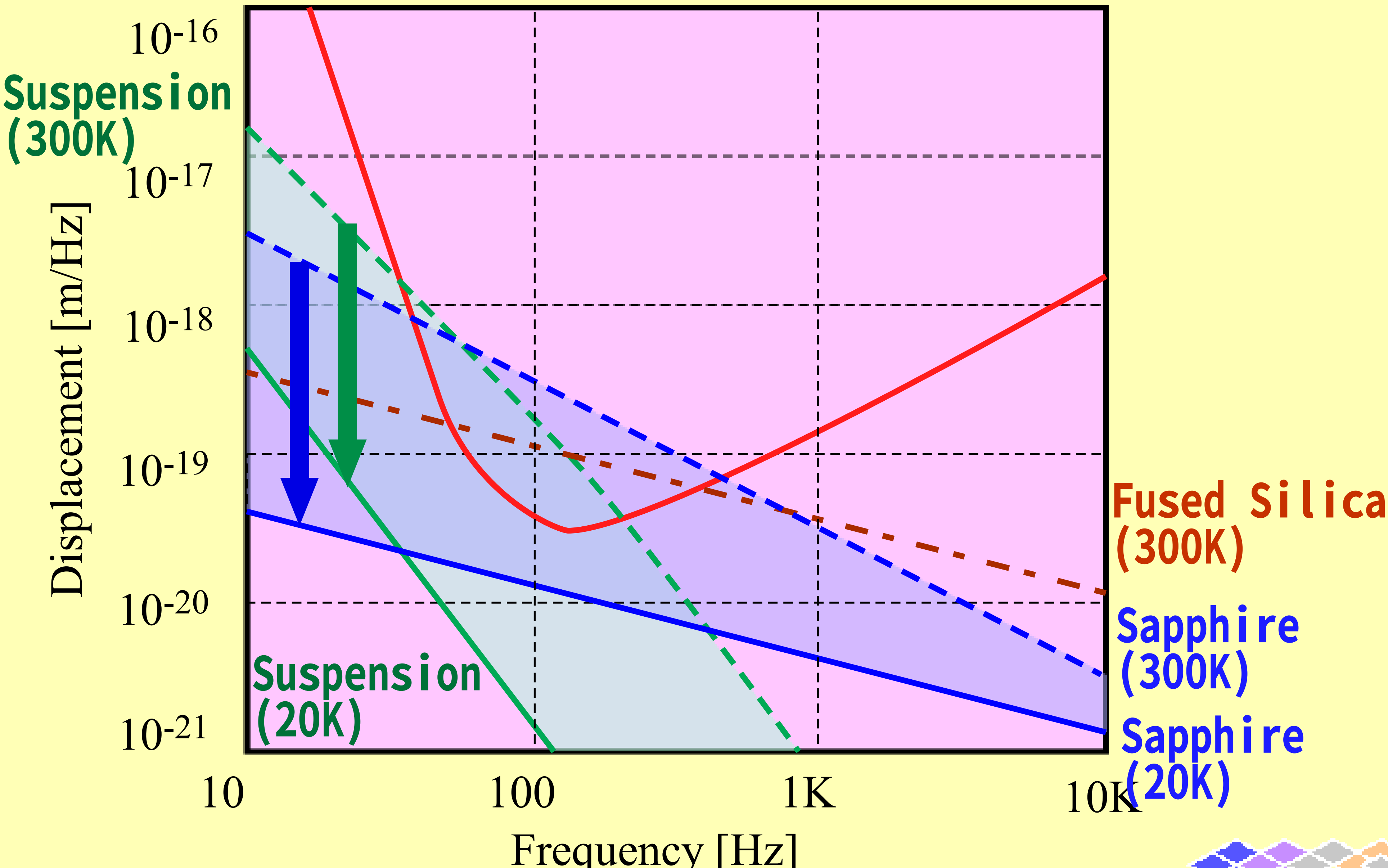
- solution -

Substrate : Sapphire
Size : 30cm-50cm

LCGT Selection

Estimated Thermal Noise

■ Verification of thermo elastic noise reduction by cooling



Thermal Noises

- Thermal Noises
  - Brownian Noise -
  - Thermal Noise due to additional loss (Magnets, coating, standoff)
  - Thermo Elastic Noise -

$$
\begin{aligned}
h_{\mathrm{mirror(thermo)}} &= \frac{2}{L}\sqrt{\frac{2}{\sqrt{\pi}}}\alpha^2(1+\sigma)^2 k_B {T_m}^2 \frac{1}{(\kappa\rho C)^{1/2}}\frac{1}{\omega^{1/2}} \\
&= 9.4\times10^{-25}[/\sqrt{\mathrm{Hz}}]\left(\frac{\alpha}{5.6\times10^{-9}/\mathrm{K}}\right)\left(\frac{T_m}{20\mathrm{K}}\right) \\
&\quad\times\left(\frac{1.57\times10^4\mathrm{W/m/K}}{\kappa}\right)^{1/4}\left(\frac{4.0\mathrm{g/cm^3}}{\rho}\right)^{1/4}\left(\frac{0.69\mathrm{J/kg/K}}{C}\right)^{1/4} \\
&\quad\times\left(\frac{3\mathrm{km}}{L}\right)\left(\frac{100\mathrm{Hz}}{f}\right)^{1/4}
\end{aligned}
$$

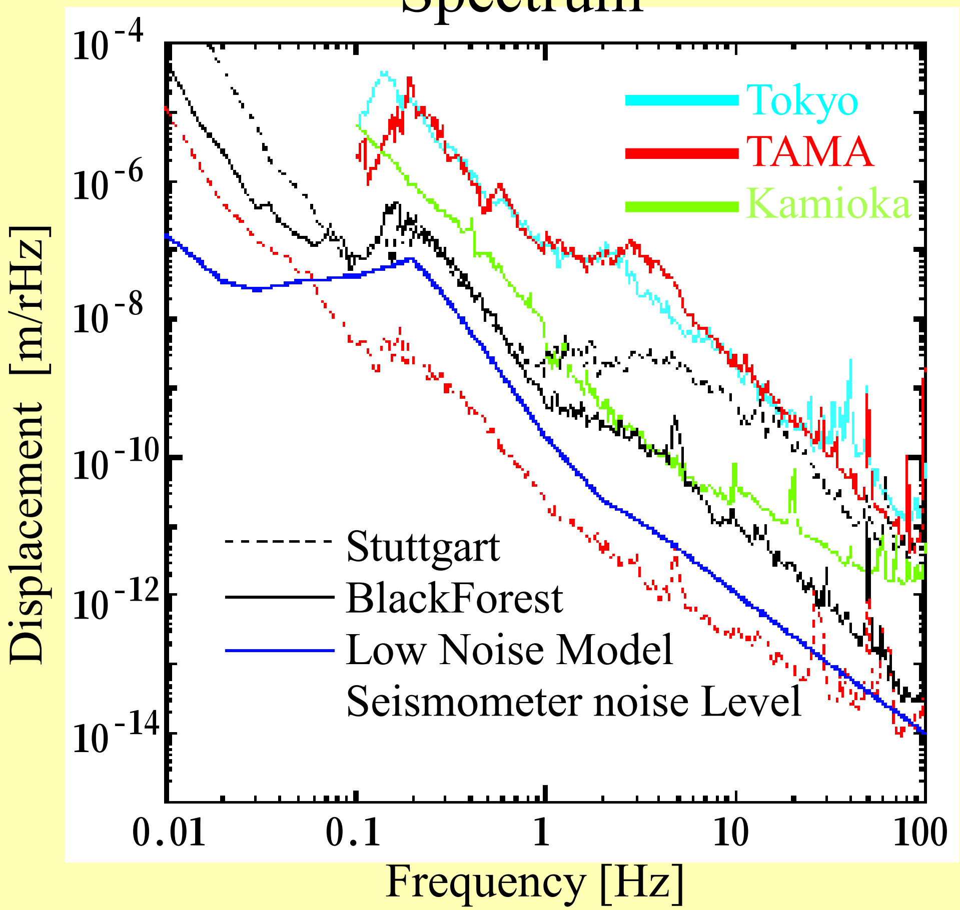
If $T_m\downarrow$, $\alpha\downarrow$ and $\kappa\uparrow$, then h_{thermo} drastically$\downarrow$.

Low Seismic Noise in KAMIOKA Mine

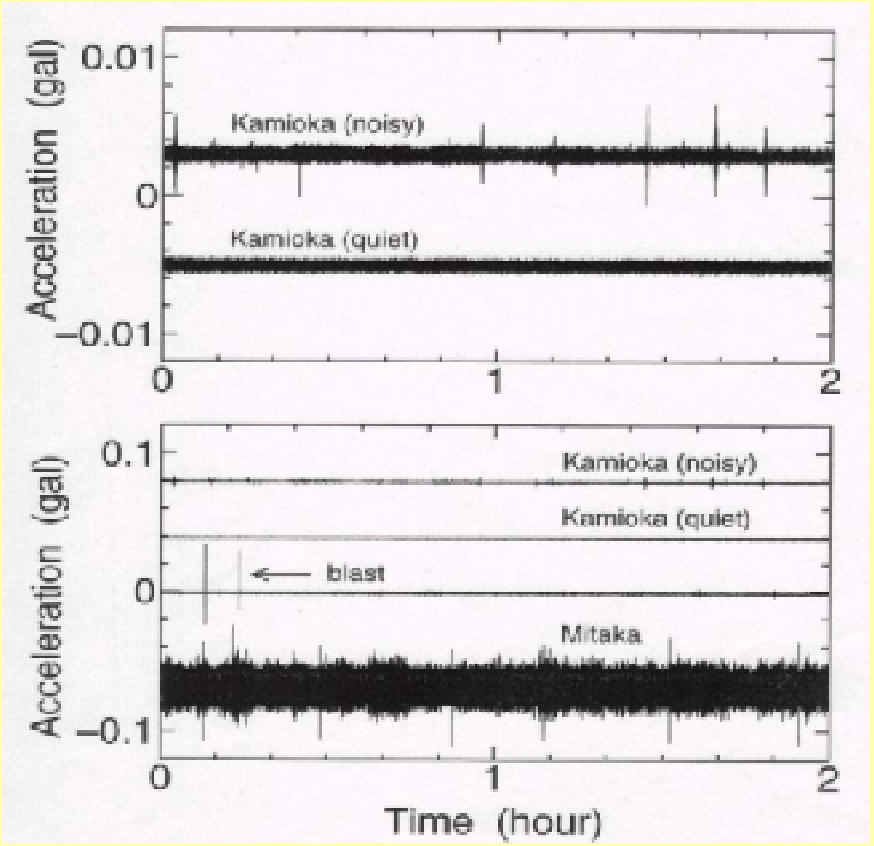
- Low Seismic Noise
  - 1/100 compared with TAMA site
  - 1/10 compared with Isolated Earth Surface around lower frequency range.

→ Avoid the control noise due to alignment control.

Spectrum



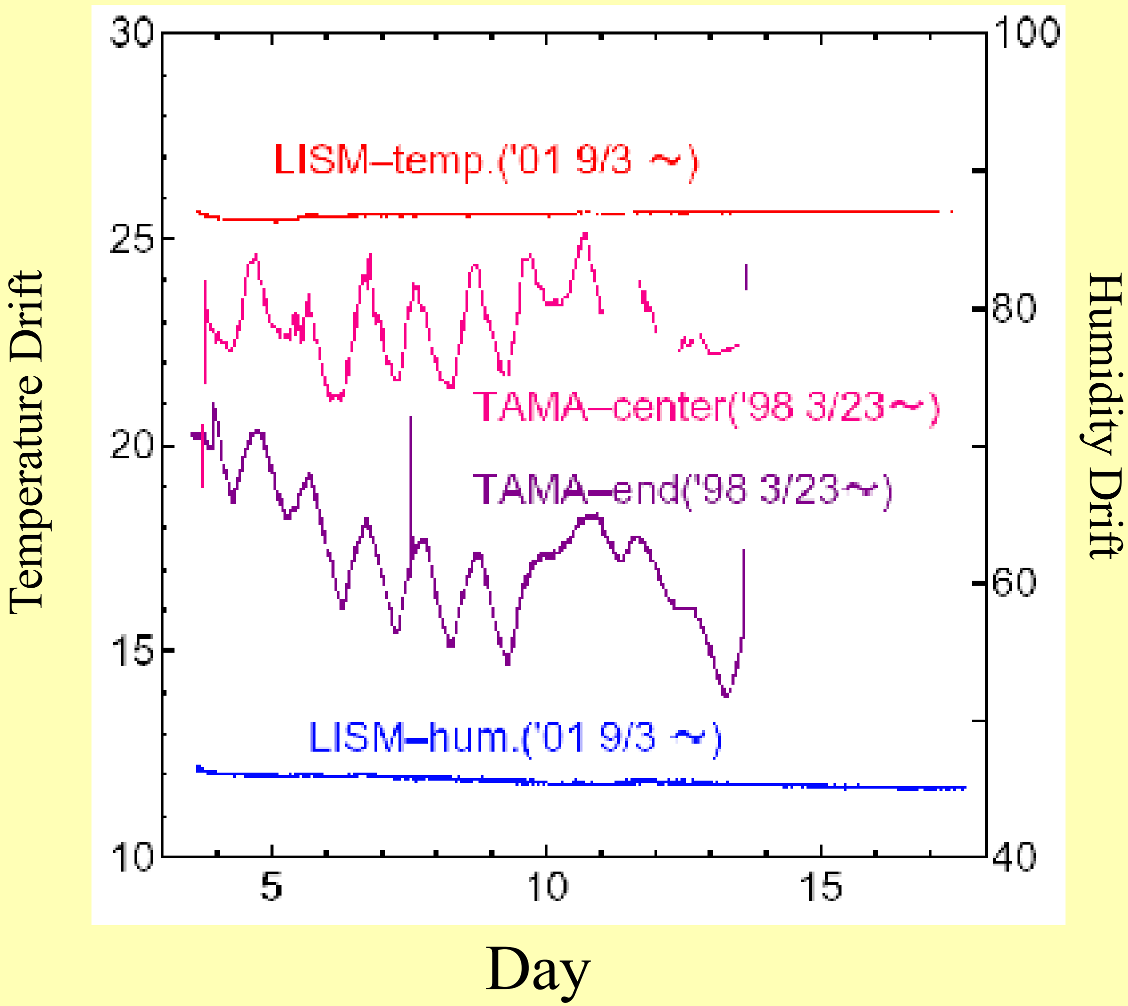
Acceleration (Time Domain)



by Araya

Stable Environment of KAMIOKA Mine

- Low Thermal Drift ⇨ Low Dynamic Range, less control noise

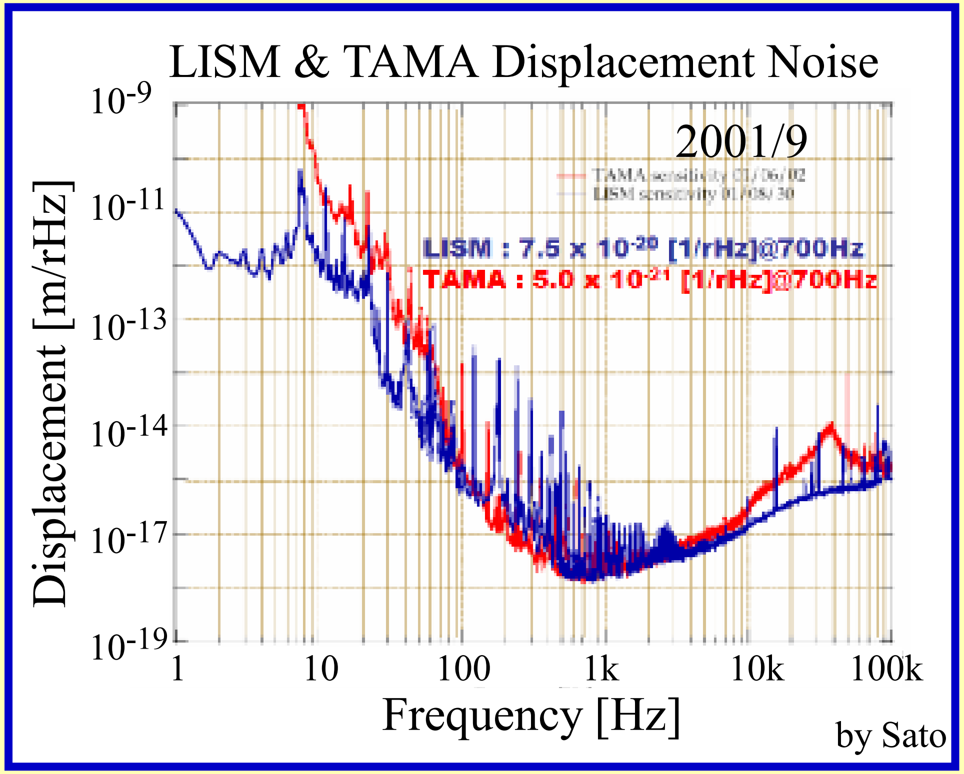


- ●±0.1degree/Day
- ●±1%/Week
- ●5000m/sec Sound Velocity of Rock

by Araya

Verification of KAMIOKA Environment

- Long term Operation of 20m Laser Interferometer(LISM)



Q:How compare the stability of a small and a large scale interferometer?

A: The storage time

LISM fabry-Perot cavity (0.001 sec) is 3 times longer than TAMA, 1/7.5 times smaller than LCGT, -1/2-1/3 times smaller than LIGO.

-Same level displacement @100Hz-1kHz in spite of less isolation systems.
-120 hours successive operation without alignment control.
-Common mode seismic noise reduction was observed less than 20 Hz.

LISM Interferometer

- Entrance of ATOTSU

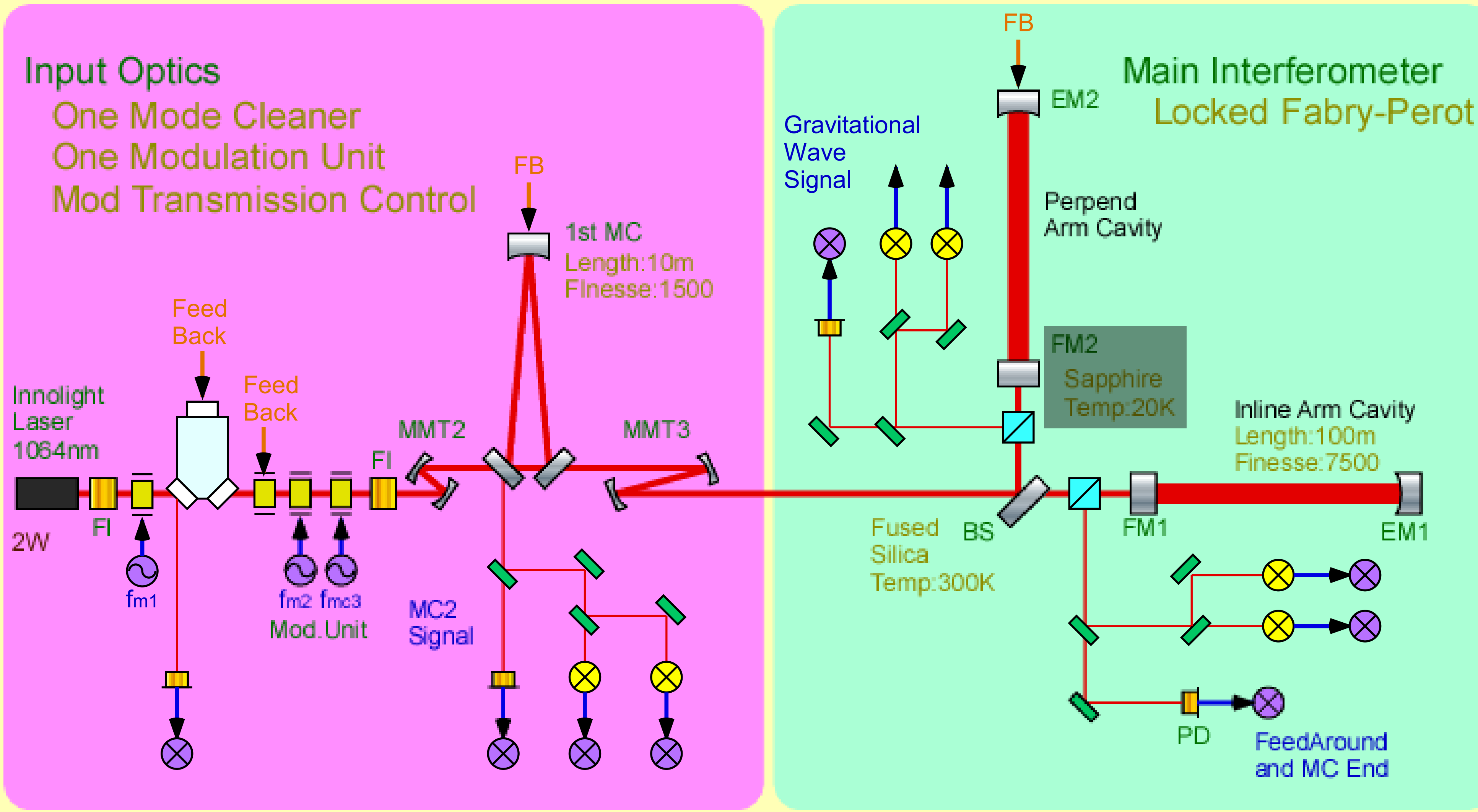
- Cave for LISM

- LISM Center Room

- LISM Optics Bench

Optical Layout

■ Locked Fabry-Perot Style



Most component designs and techniques are planted from TAMA300.

Laser Stability (Frequency)

Frequency Stabilization

- Original Stability -

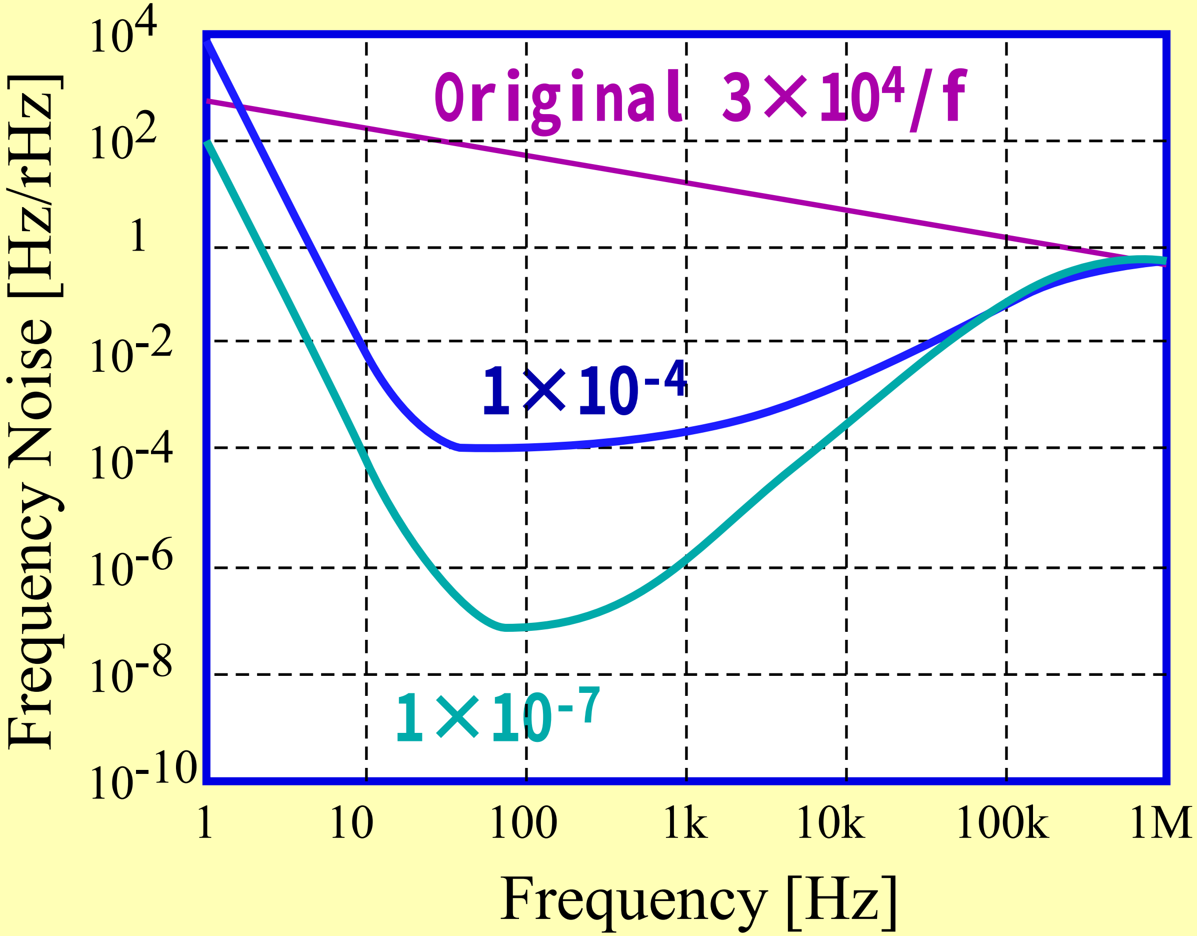
3×10^{4} / f [Hz/rHz]

- 1st Stb. -

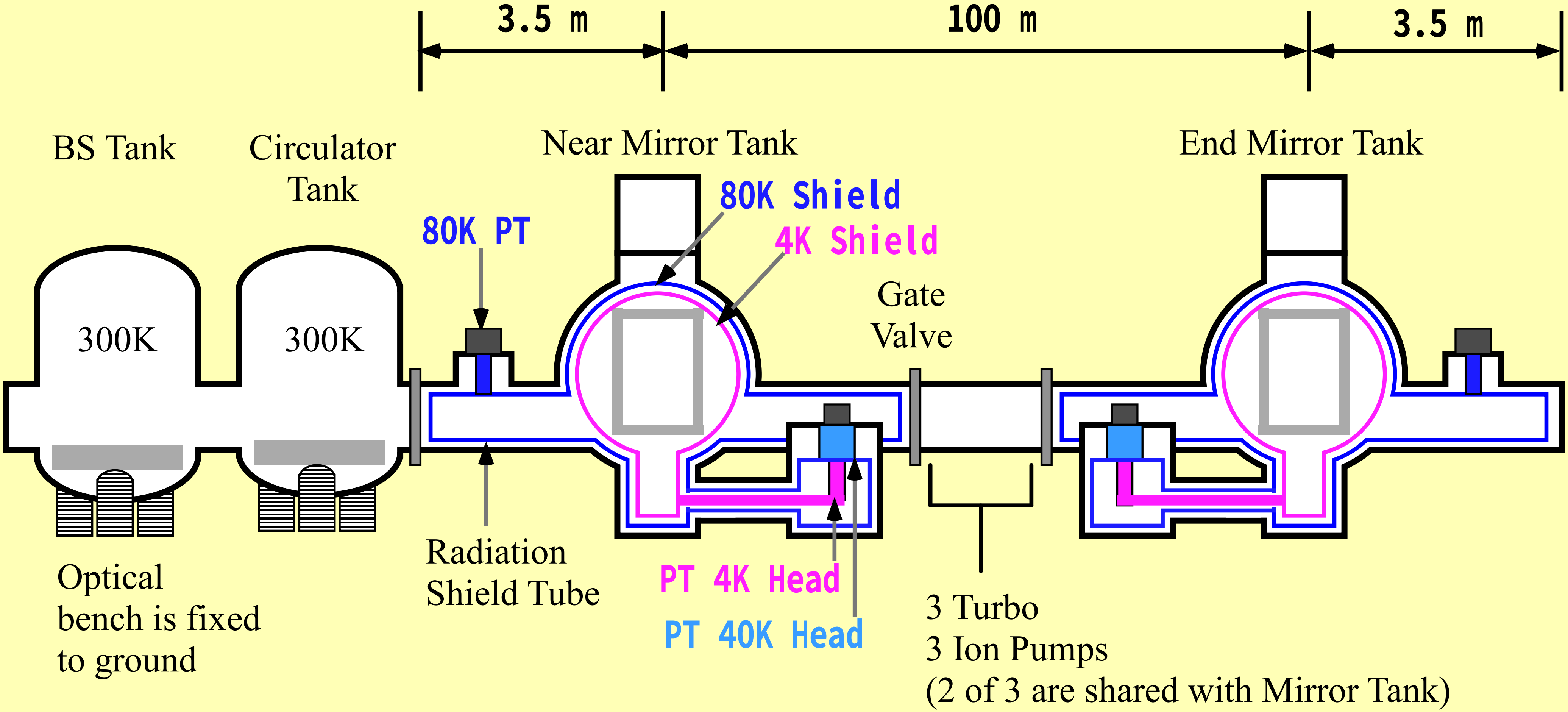
MC1(10m Finesse = 1700),
UGF 1MHz,
fedback to Laser PZT, Thermal and Ext EOM.
down to 1×10^{-4} [Hz/rHz] .

- 2nd Stb. -

Inline Arm Cavity
(100m Finesse = 7500),
UGF 100kHz,
fedback to MC1 End Mirror,
Feedaround in 1st loop.
down to 1×10^{-7} [Hz/rHz].



Cryogenic Vacuum System



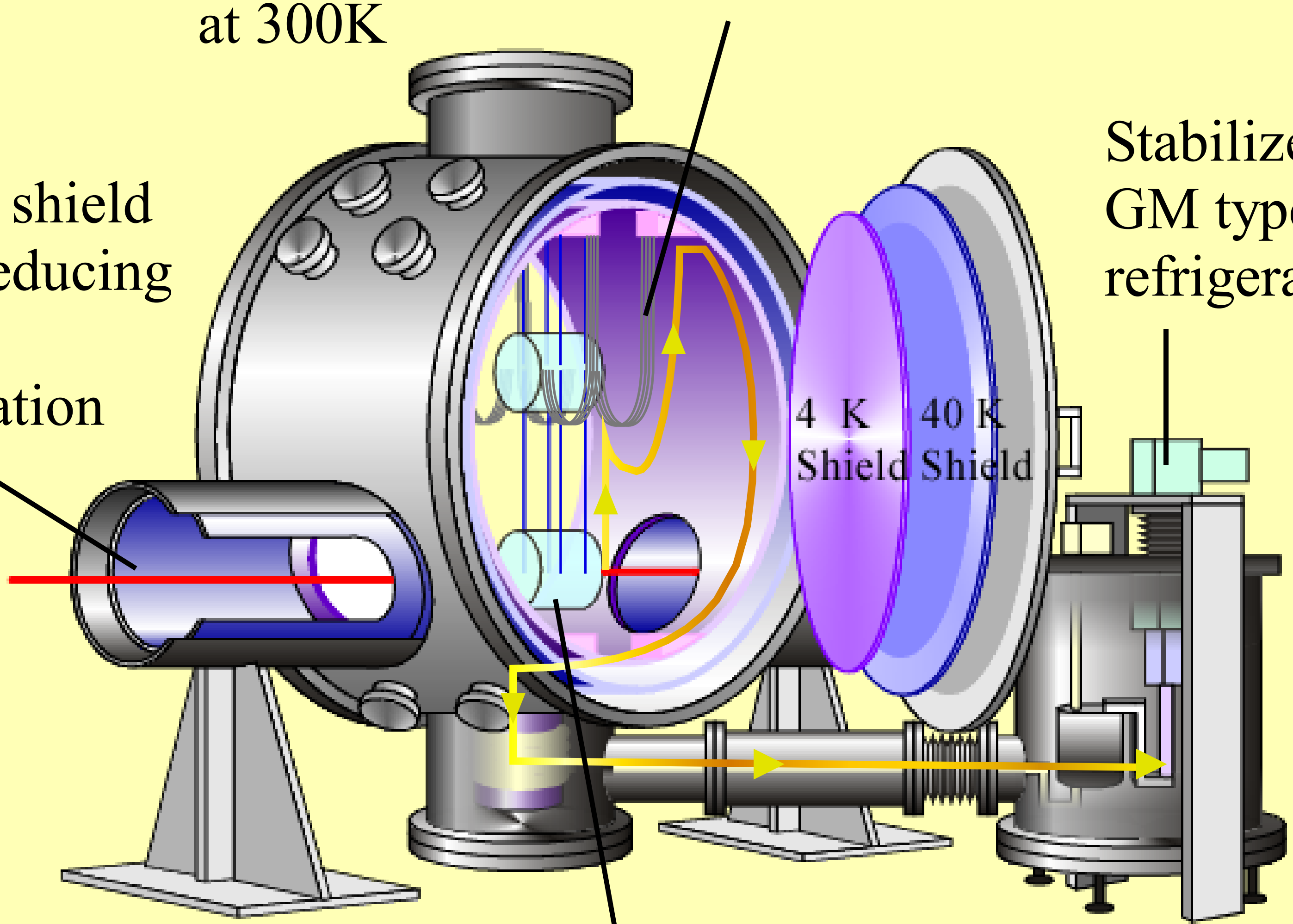
Cryogenic System

Rough Mirror
Control Stage
at 300K

Aluminum heat link wires
(Isolated by one or two stage pendulum)

Radiation shield
tube for reducing
cryogenic
contamination

Stabilized 2 Stage
GM type Pulse Tube
refrigerator



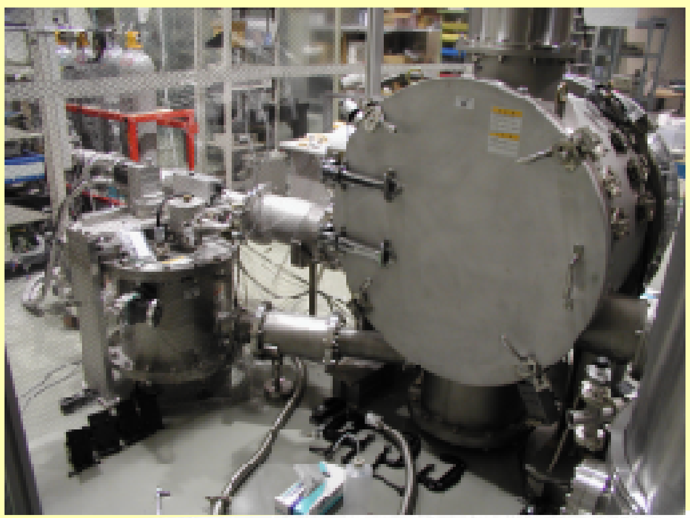
A sapphire mirror
suspended by sapphire fibers

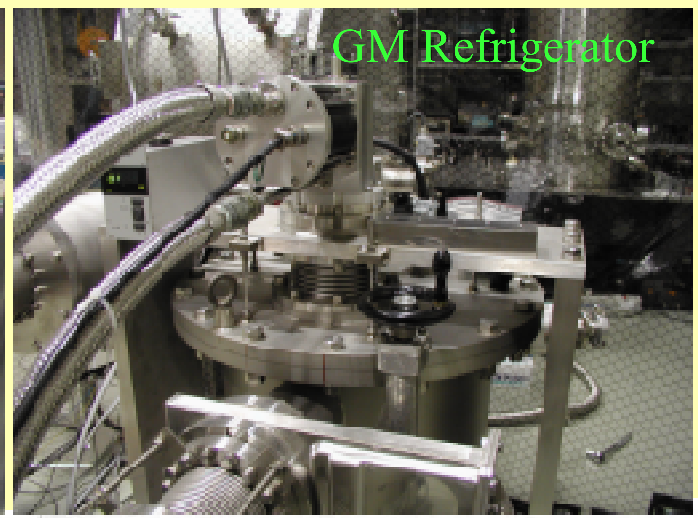
Model : C L I K Test Bench

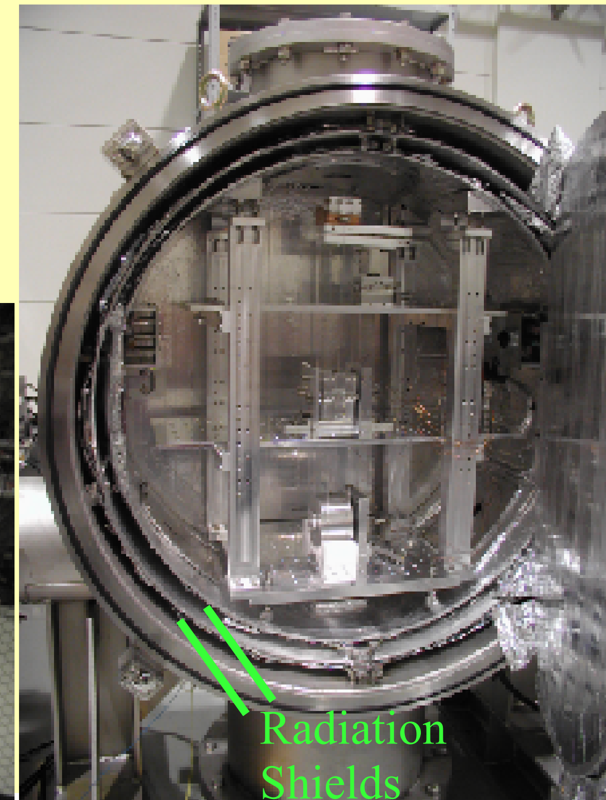
- Demonstration of Cryogenic Laser Interferometer in minimum scale

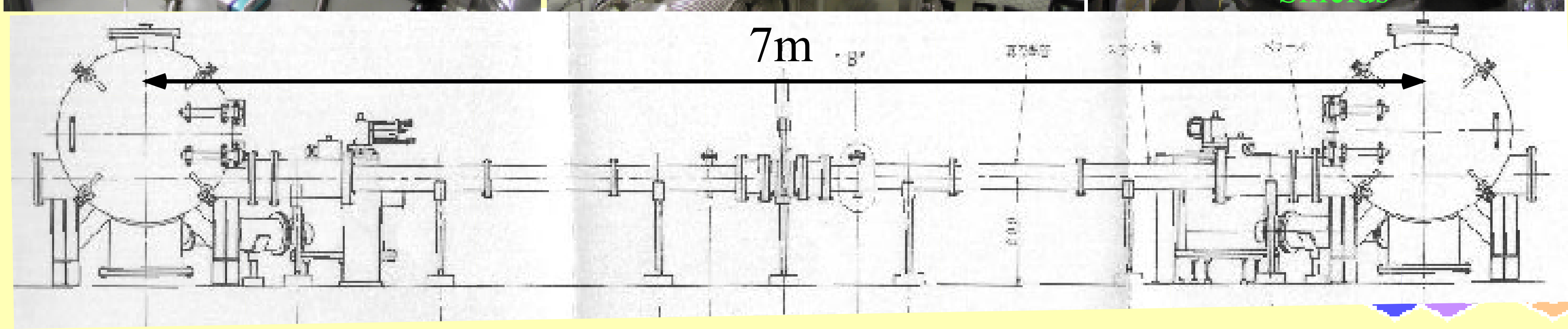
（Cooling system） --- 0.7W @ 4K Shield

- Thermal conductive cooling using refrigerator and isolated conductor.
- Two radiation shields.(4 K and 90 K)
- Radiation tube for reducing cryogenic contamination







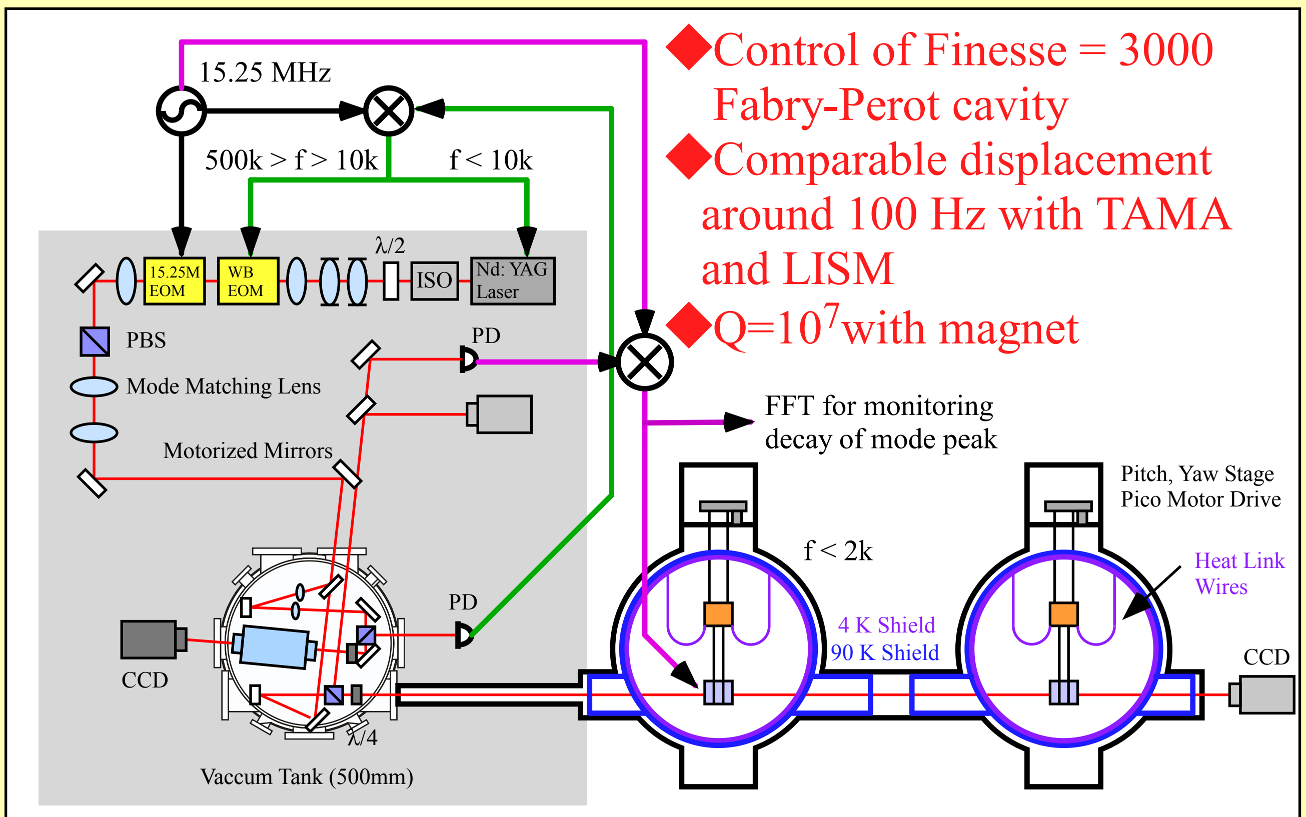


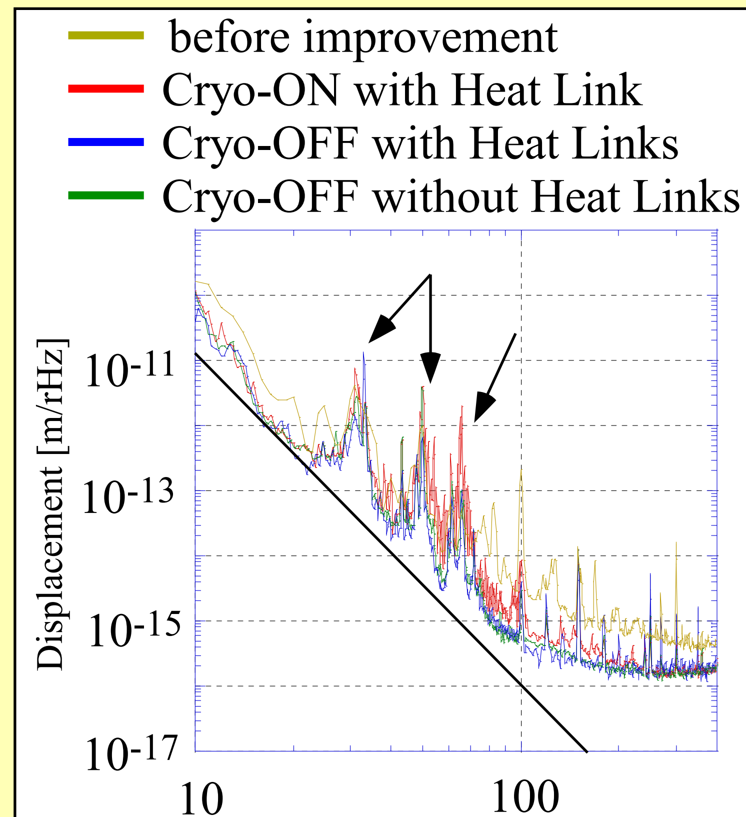
C L I K Demonstrations

Demonstration of Cryogenic Laser Interferometer in minimum scale

(Mirror Cooling and its suspension)

- Cryogenic Sapphire Mirror (20K)
- 2 Stage suspension at Cryogenic Temp.
- Mirror control using magnet-coil actuator at 20K
- U shape pure Al heat links wires
- Cooling by sapphire fiber
- Wire connecting 300K and 10K stages
- Rough alignment control of a mirror from a 300K stage





Present Status and Schedule of C L I O-100

- The tunnel housing has been finished.


- The power line, water, electric instrument will be finished until March 2003.
- The infrastructure construction and optics installing is from April 2004.