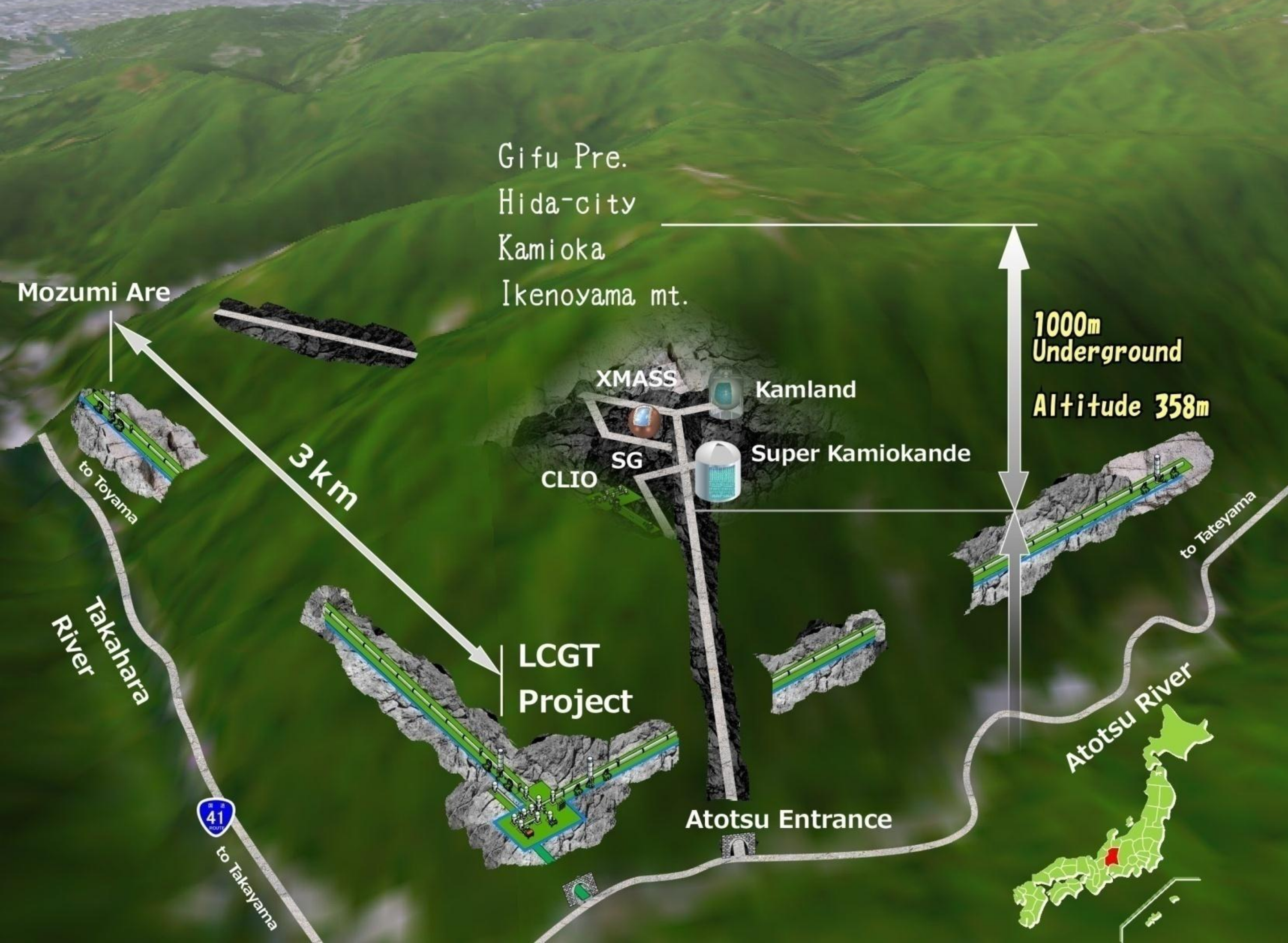
Large-scale Cryogenic Gravitational wave Telescope (LCGT) Project

Sinji Miyoki
Institute for Cosmic Ray Research and LCGT Collaboration
GW2010 @ Minnesota



LCGT Collaborators

ICRR, Univ. of Tokyo
ERI, Univ. of Tokyo
KEK, AIST, NAOJ, ECU, GSFS, Univ. of Tokyo.
Phys, Kyoto Univ.
Yukawa, Kyoto Univ.
DPRI, Kyoto Univ.
Phys. Univ. of Tokyo
Osaka Univ.
Nagaoka TS Univ.
Osaka City Univ.
Hiroshima Univ.
Tohoku Univ.
Hirosaki Univ.
Hosei Univ.
NICT Japan
Ochanomizu Woman Univ.
Nihon Univ.
Niigata Univ.
Rikkyo Univ.
Waseda Univ.
Ryukyu Univ.
MPQ, Germany
AEI, Germany
Caltech, USA
Univ. of Western Australia
Louisiana State Univ. USA
Rochester, USA
BNU, China
IHEP, China
UST, China
PMO, China
IUCAA, Moscow Univ.
EGO/LAPP
China Science Technology Univ.
NRMN, Taiwan
Maryland Univ. USA
Univ. of Birmingham, UK

LCGT and Advanced-GWDs Target is

(1) Direct Detection of Gravitational Waves

(2) Generation of Gravitational Wave Astronomy

LCGT Aspects

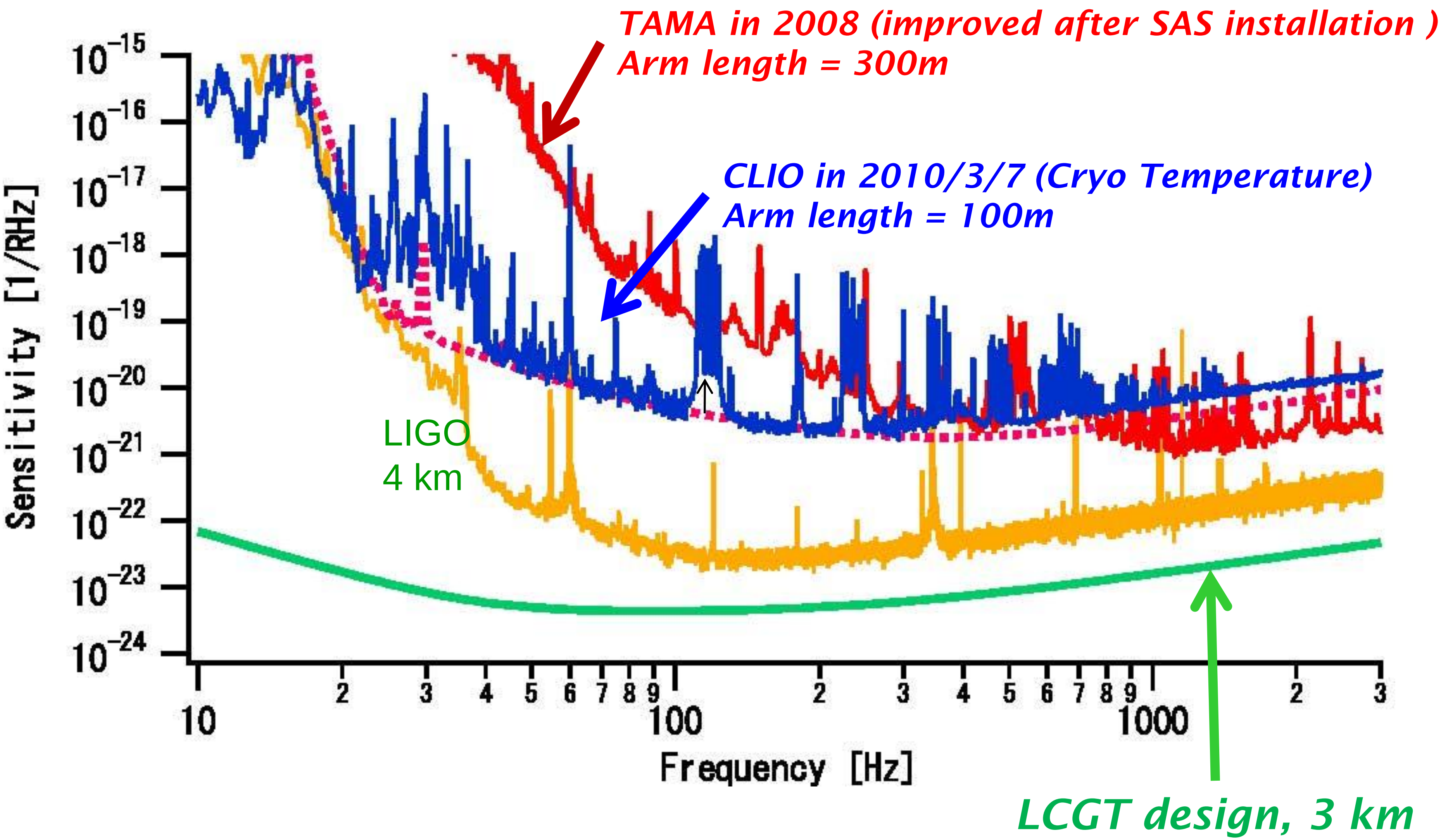
(1)Underground
→
Stable Operation owing to low seismic noise.

(2) Usage of Cryogenic Mirrors and suspensions.
→
Reduction of Thermal Noise

(3) Collaboration with Geophysical Laser Strain-meter set parallel with LCGT.

(1)(2) is planed to be introduced in ET Project.

Demonstrations of Techniques for LCGT



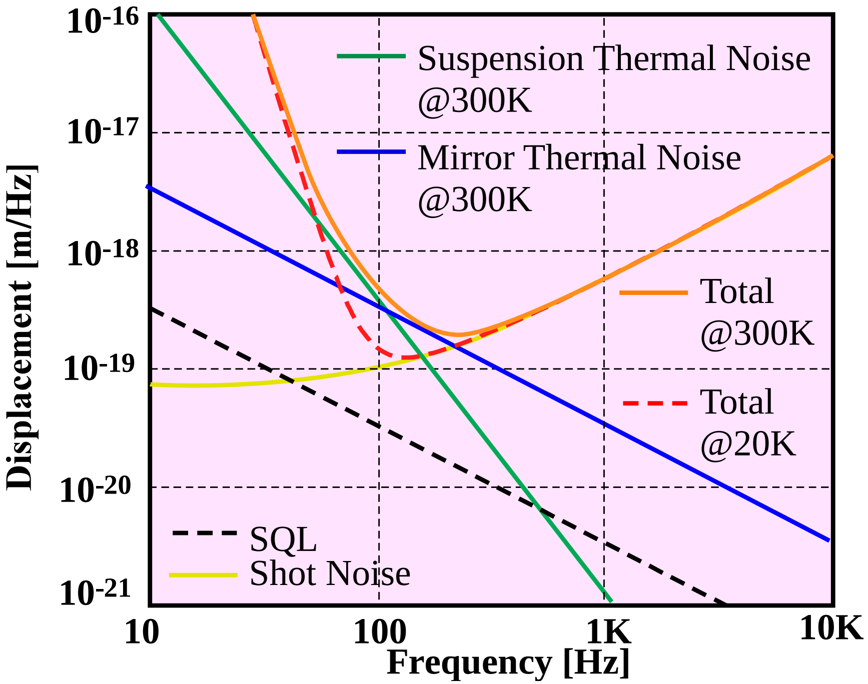
- Thermal noise reduction was demonstrated in CLIO.

CLIO Features

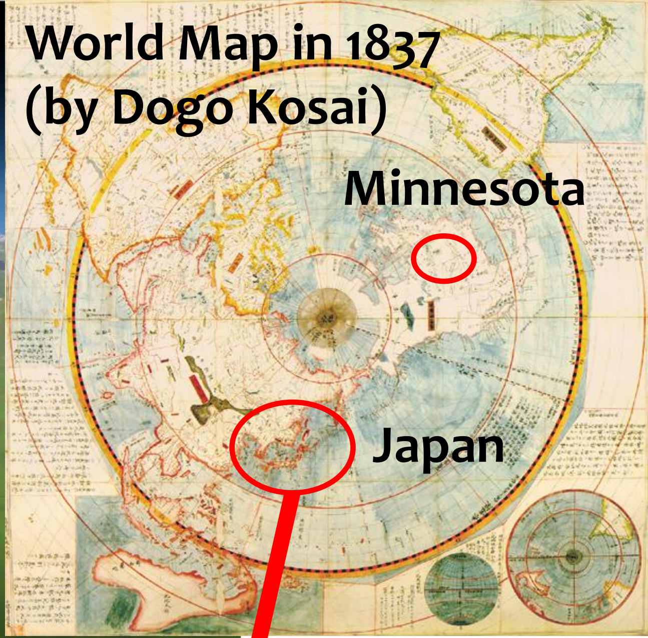
- 100m base-line Unrecombined Fabry-Perot Michelson Proto-Type for LCGT set in the Kamioka mine.

- Technical combination of products of
  - CLIK(2000-02) for cryogenic system development
  - LISM(1999-2002) for Underground IFO characterization
  - Ultra low vibration PT refrigerator developments at KEK(2004-2006)

- Demonstrate an improvement of sensitivity by reduction of the mirror and suspension thermal noise using mirror cooling technique.

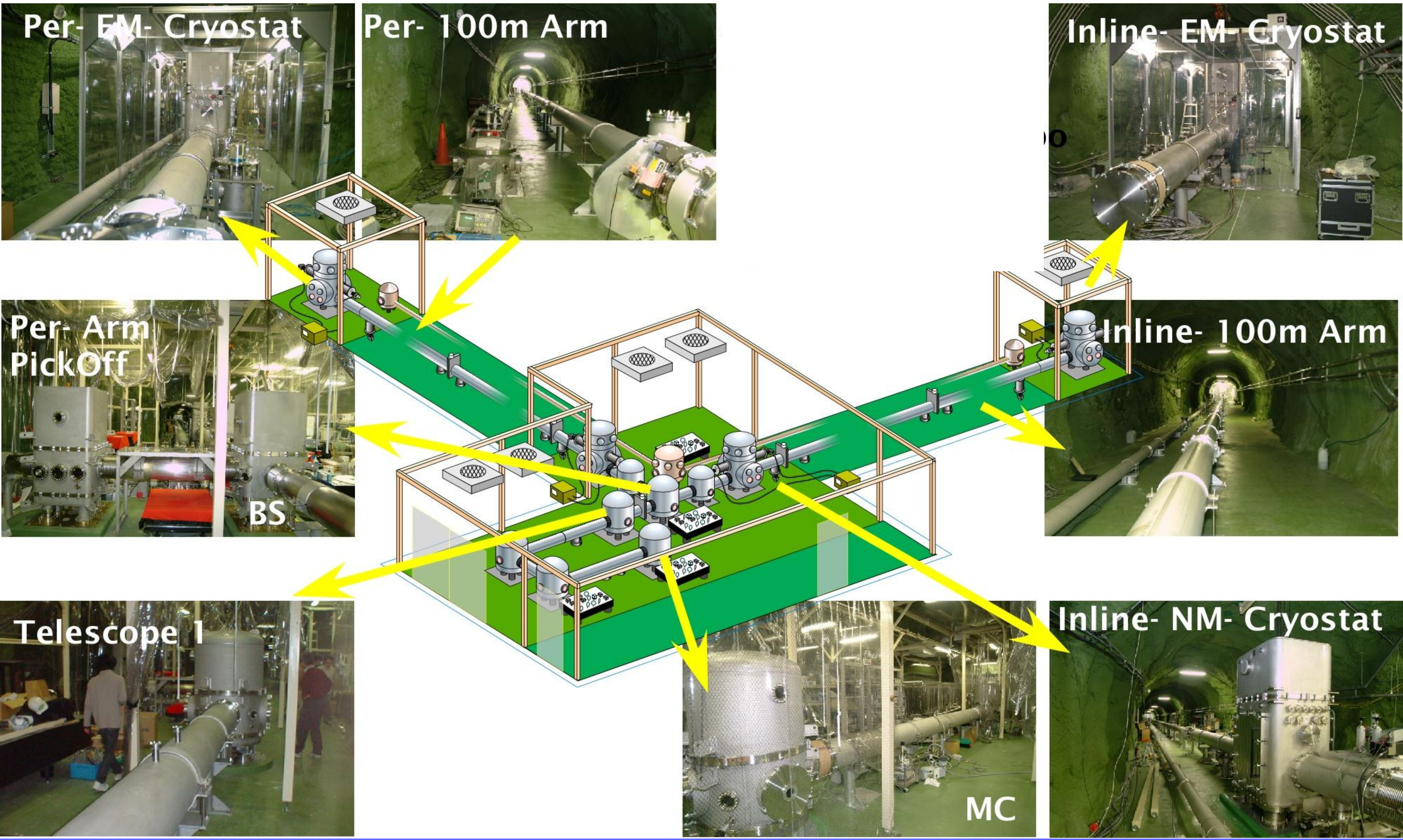


CLIO Location



Tour to CLIO

in the Kamioka mine near Super Kamiokande

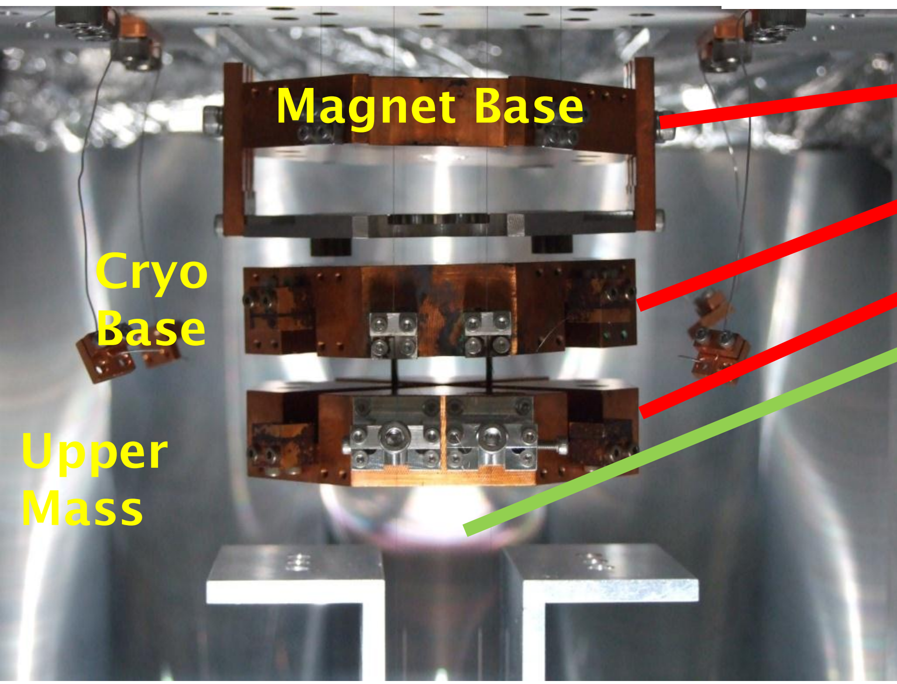


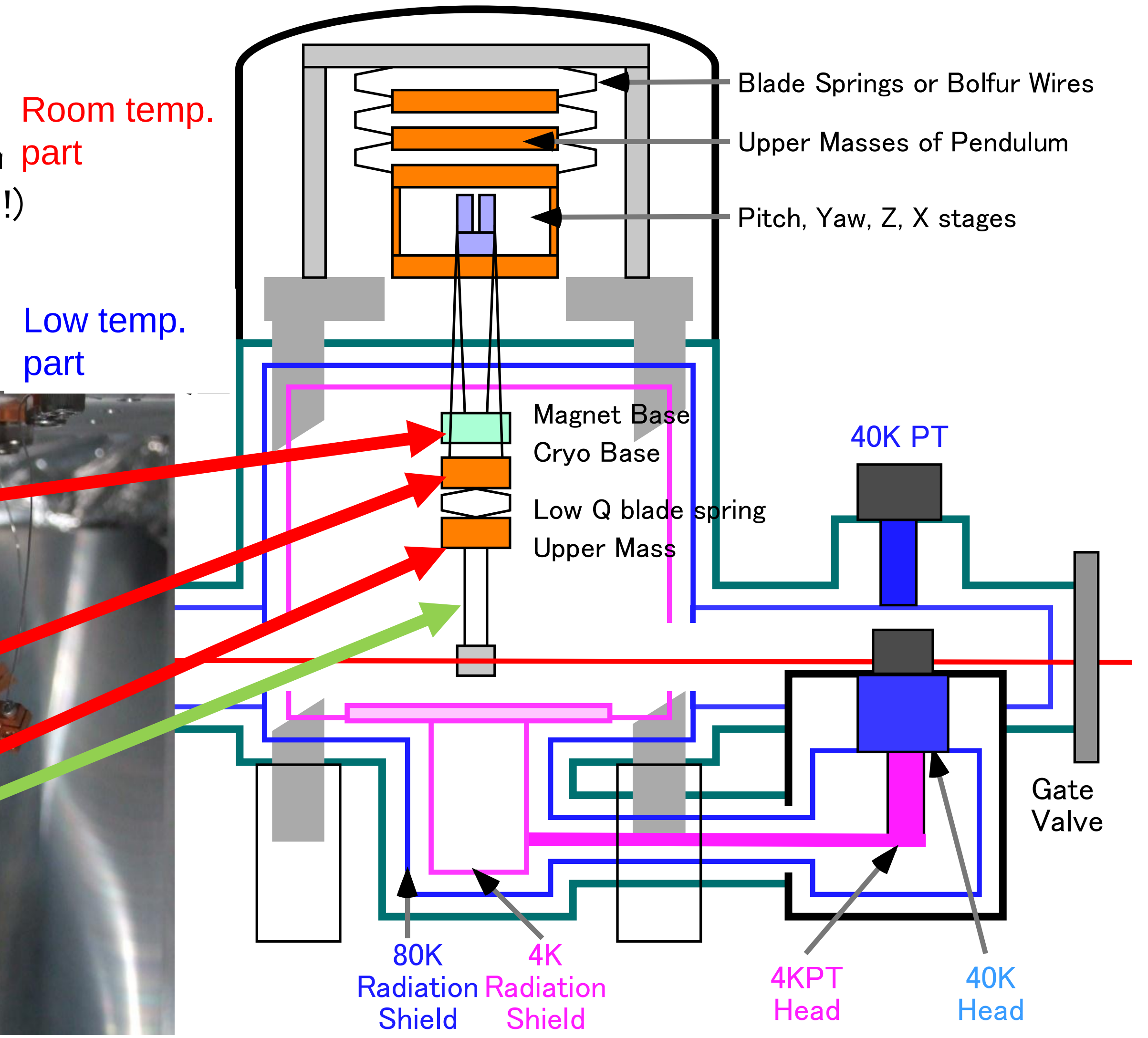
Cryogenic Mirror Suspension

- close up of upper masses -

●3 heat links between:
①Magnet Base and inner shield; 15cm
②CryoBase and inner shield; 31.5cm
③CryoBaseand and UpperMass; 11.5cm
φ 0.5mm pure aluminum wire (only one !)

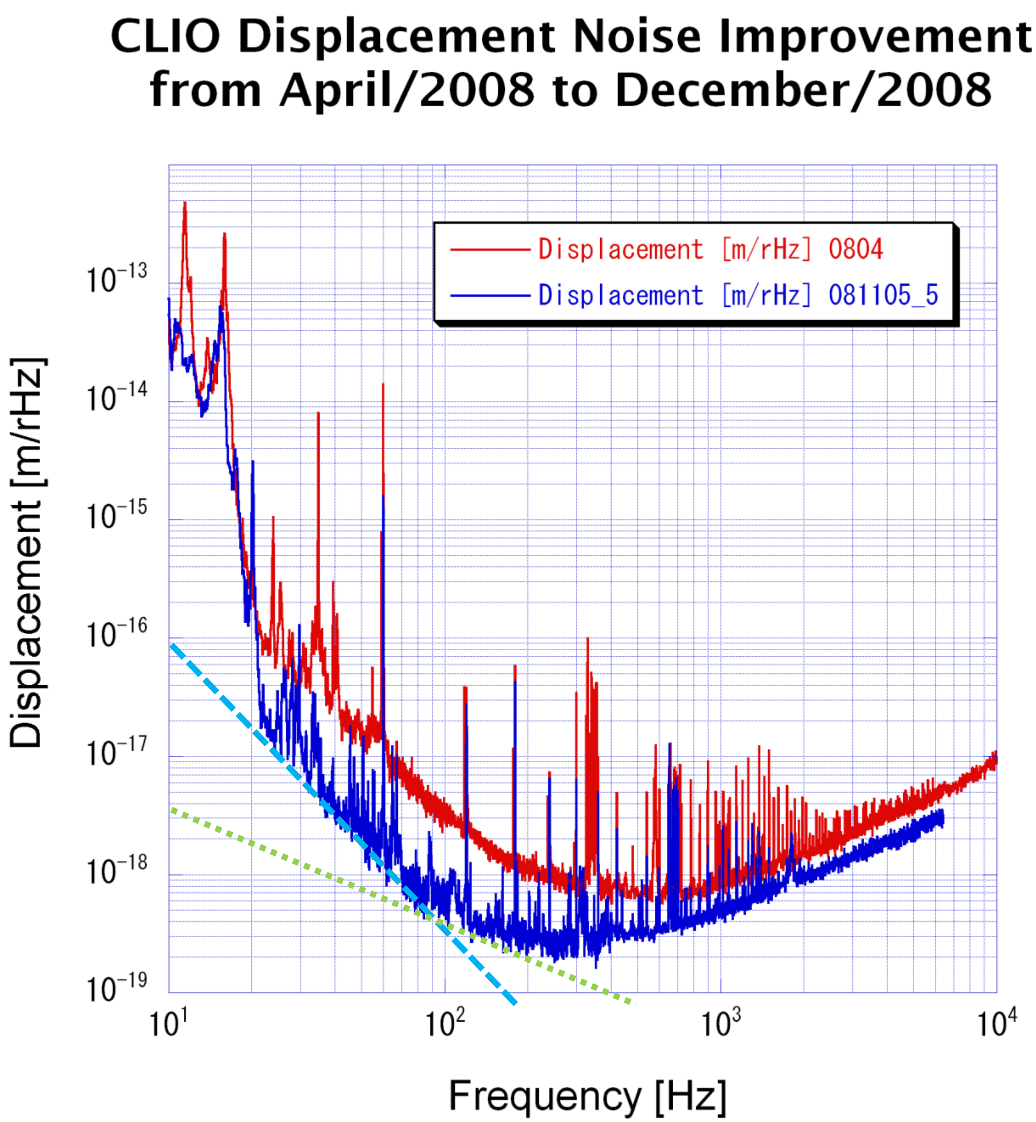
•It takes 7-10day to be cooled down.





Displacement in November 2008

- Almost thermal noise limited at 300K condition-

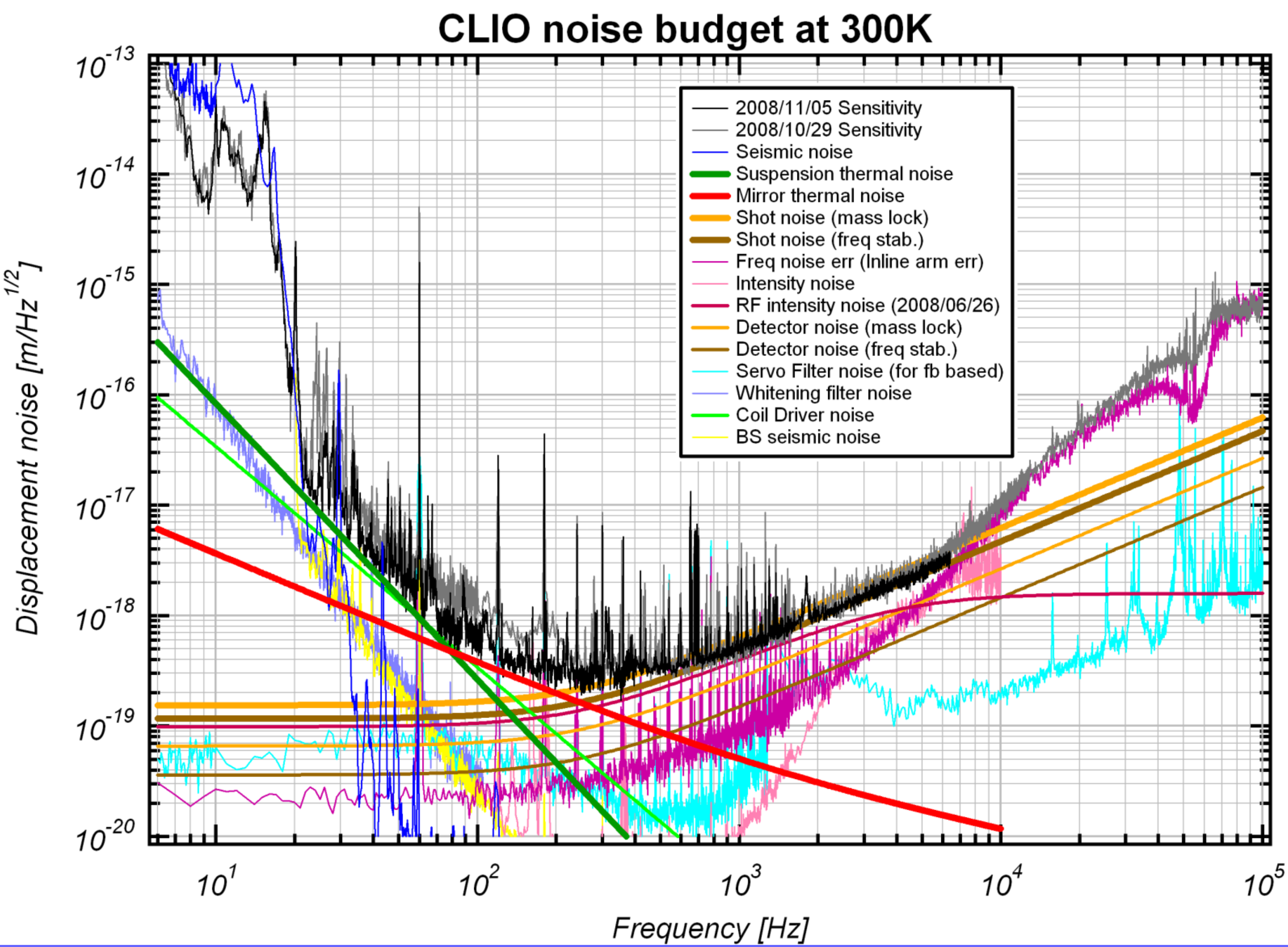


CLIO displacement touched the predicted thermal noise levels.

- Sapphire mirror thermoelastic noise
(80Hz~250Hz) Green Line
- Suspension thermal noise
(20Hz-80Hz) Blue Line

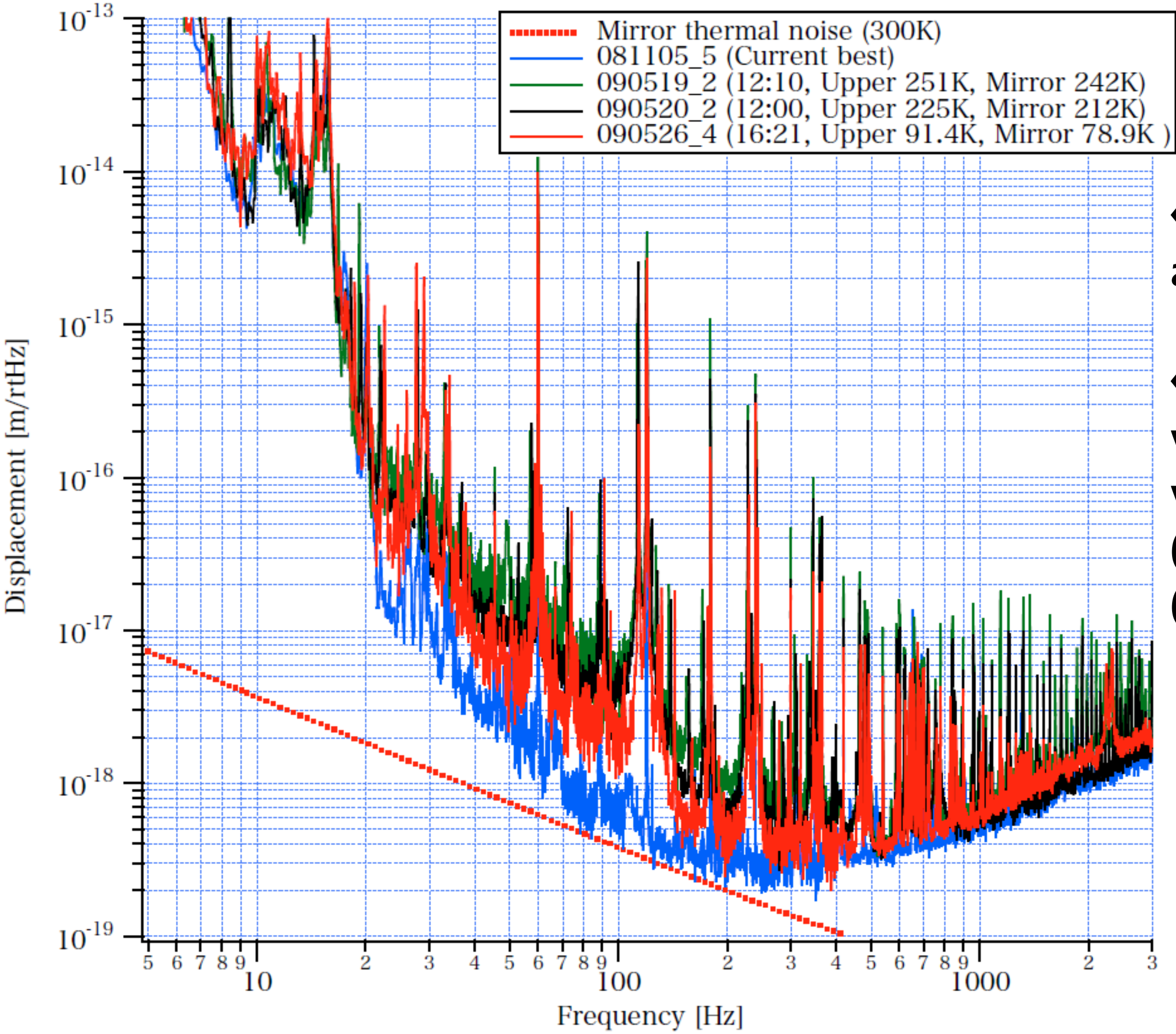
Mirror mass ~ 1.8kg

Noise Budget



Suspension thermal noise reduction

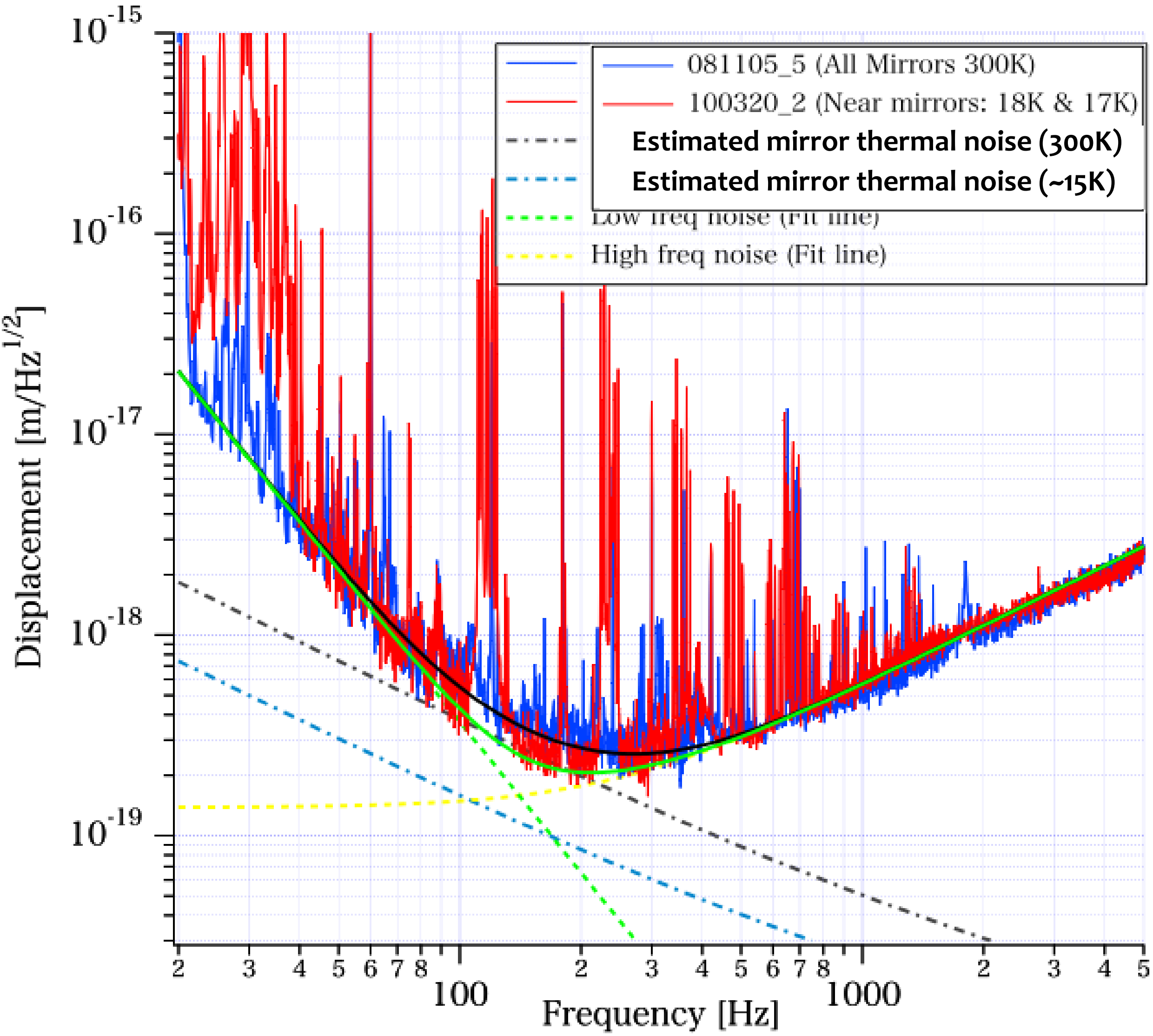
- Al wires thermal noise like noise -



♦Suspension wires are pure aluminum, not sapphire fibers.

♦ "Suspension thermal noise" was decreased, as the aluminum wires were cooled
(251K -> 225K ->91K)
(Green, Black, Red)

Mirror Thermo-elastic Noise Reduction



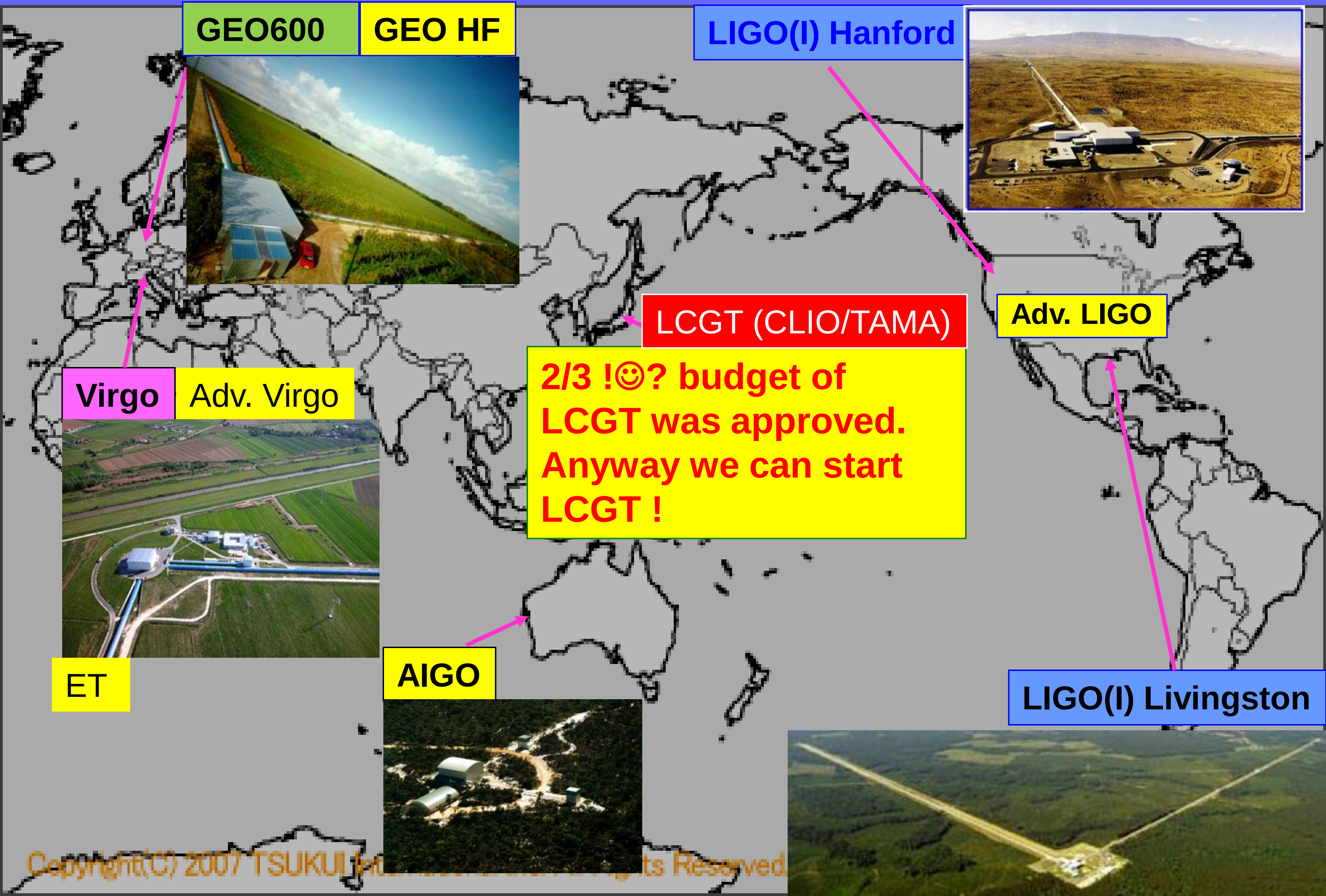
♦Only two input mirrors were cooled, accounting for smaller spot size on these mirrors.

♦ According to noise budget verification, main noise contributions are …

-Shot noise
-Suspension thermal noise
-Mirror thermo-elastic noise

♦Sapphire mirror thermo-elastic noise reduction seems to contribute the displacement noise improvement around 200Hz.

GW detection network

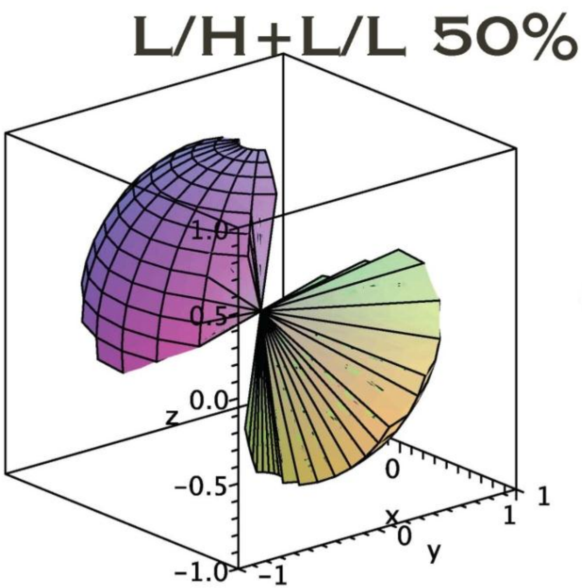


LCGT contribution in the world network for GW detection

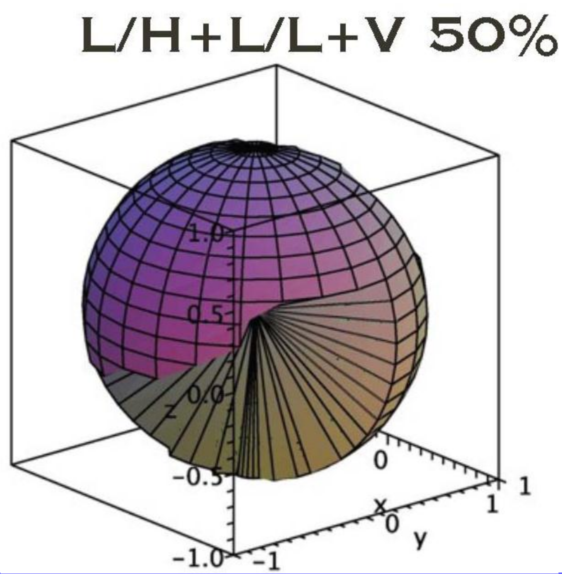
(1) Long distance between GEDs
(20 ms time flight among North America, Europe and Asia)
(2) Angular dependence of GWDs

LCGT and LIGO/H-LIGO/L-Virgo can cover almost 100% of the sky.

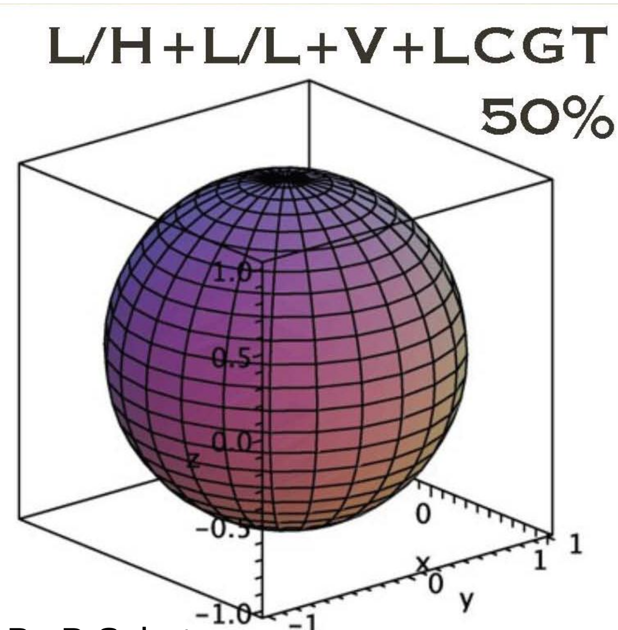
33% coverage



By global network

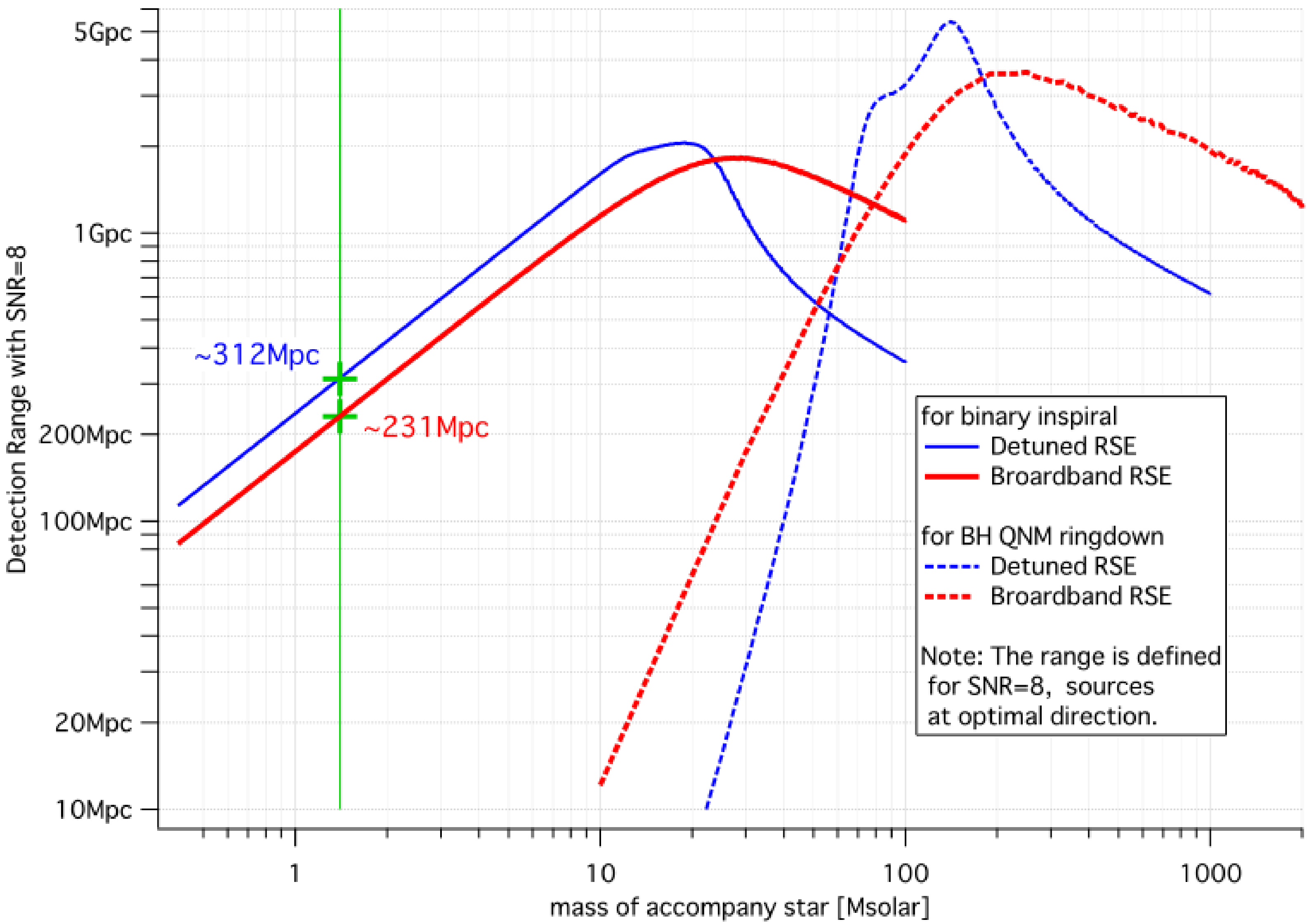


100% coverage

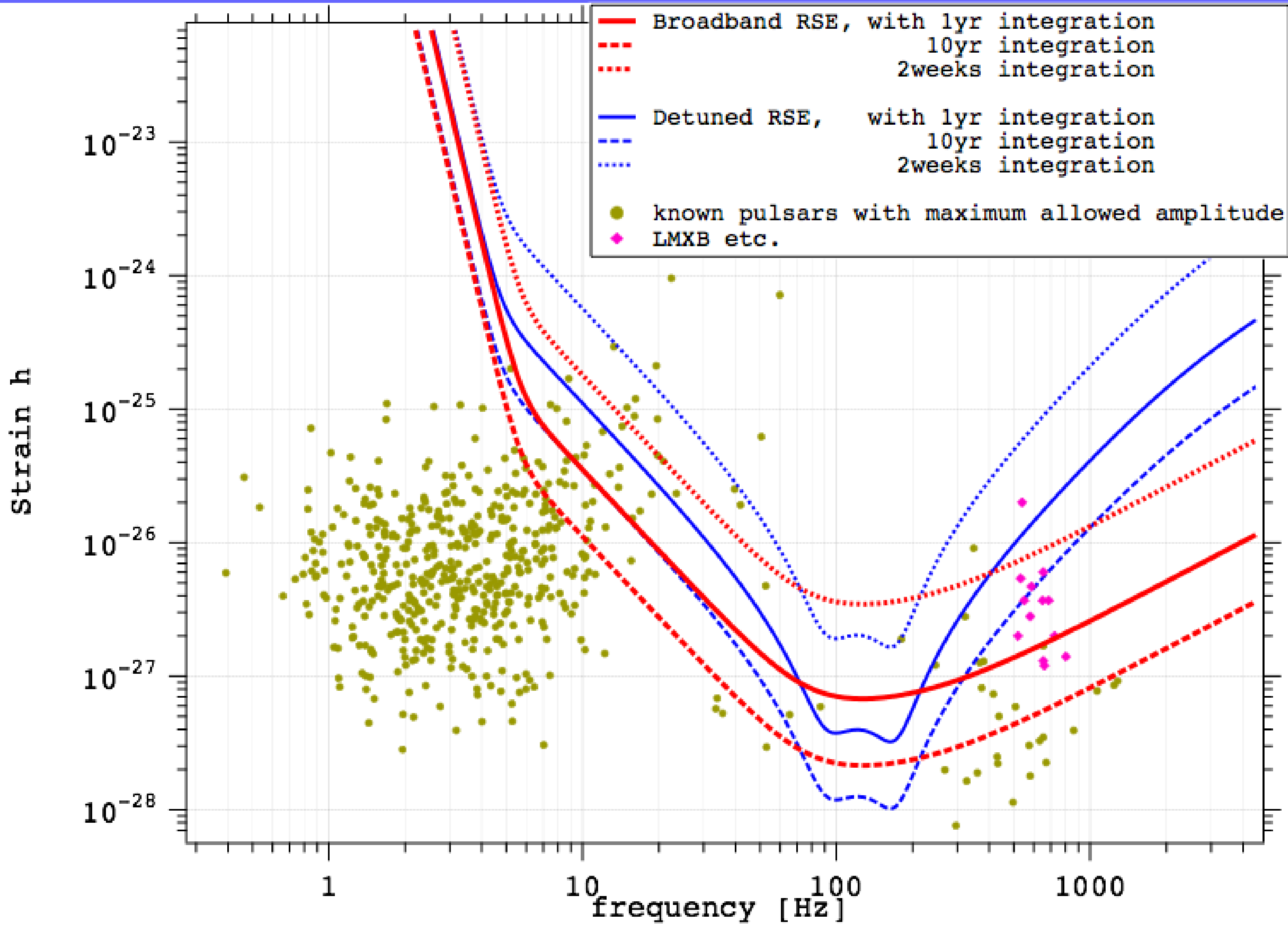


By B.Schutz
(@Fujihara seminar, May 2009)

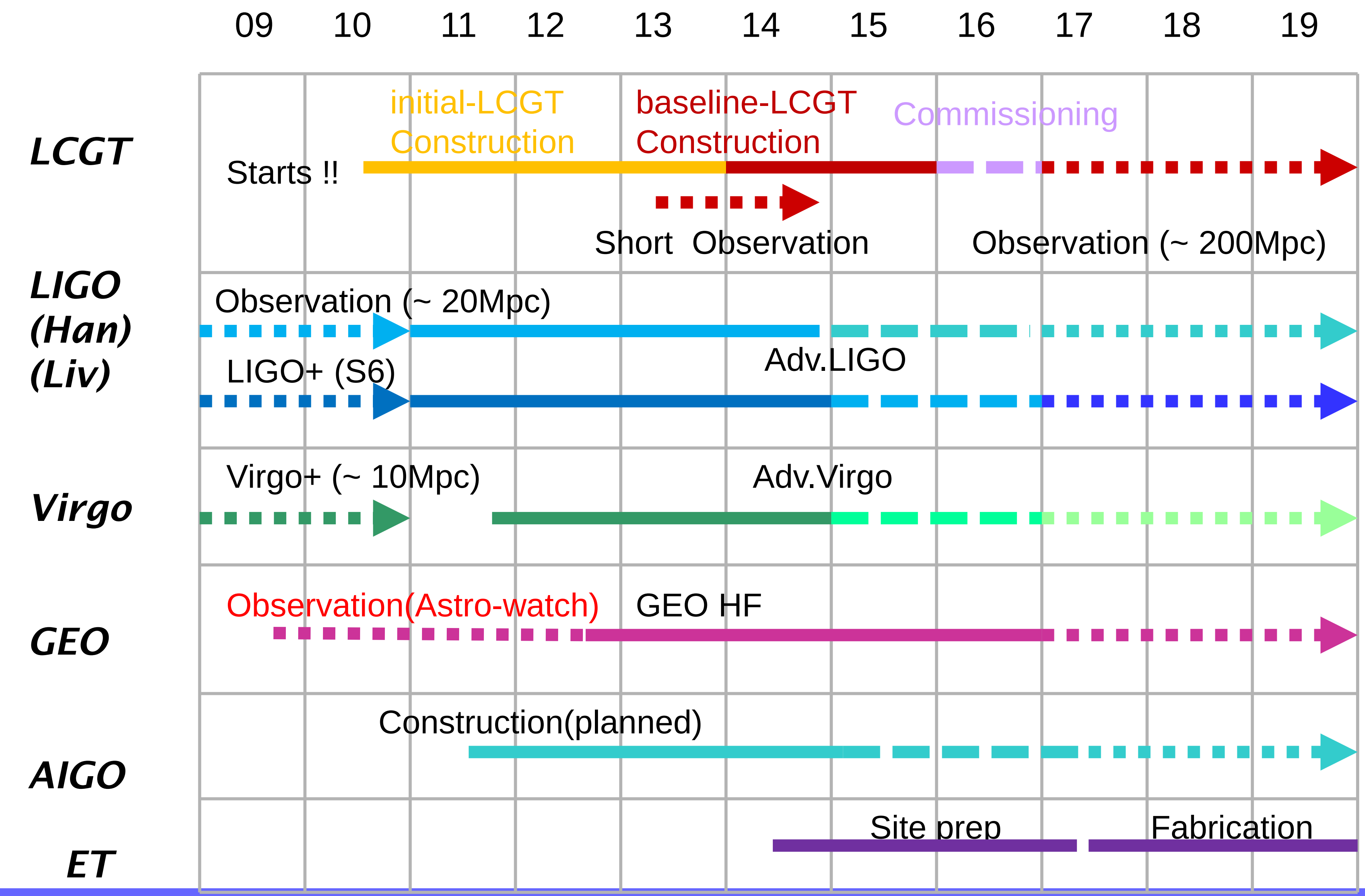
LCGT targeted sensitivity for compact stars coalescences



LCGT targeted sensitivity for pulsars



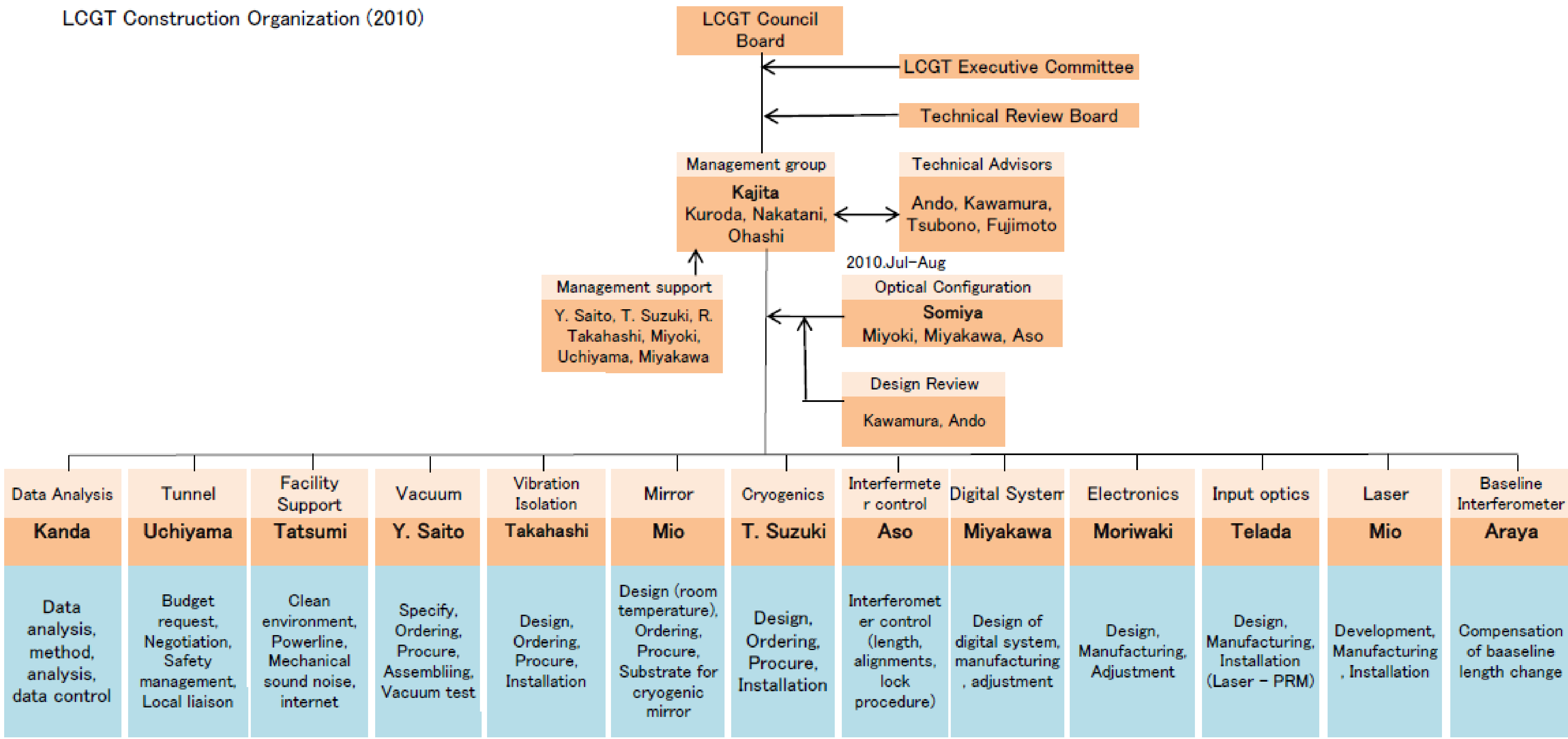
LCGT Construction Schedule



LCGT Organization (Under Construction)

PI : Takaaki Kajita (ICRR UT President)
PM : Ichiro Nakatani (Aichi Tech-U)

LCGT Construction Organization (2010)



initial-LCGT (2010~2013)

- Fabry-Perot Michelson Interferometer
  - Mirrors and suspensions are set at room temperature.
  - SiO_2 Mirrors.
  - 10W level laser sources
  - Negligible thermal distortion of mirror shape.
  - RF readout
  - Low frequency seismic noise isolation function in SAS are disable

- Targeted Sensitivity (for compact binary coalescences)
  - 5Mpc (SNR=8, Sky Averaged)
  - Displacement noise is limited by seismic and shot noise.

- Short Observation (for thrashing out problems)

baseline-LCGT (2013~2015~2016)

- **Toward the Targeted Sensitivity**
  - •Cryogenic mirrors and suspensions (sapphire or silicon)
  - •150W Laser (Mitsubishi-Amp or Fiber-Amp)
  - •RSE technique (Broadband or Detuned in Variable RSE)
  - •DC readout technique
  - •Output Mode Cleaner
  - •SAS full operation

MOUs with LIGO, VIRGO, etc

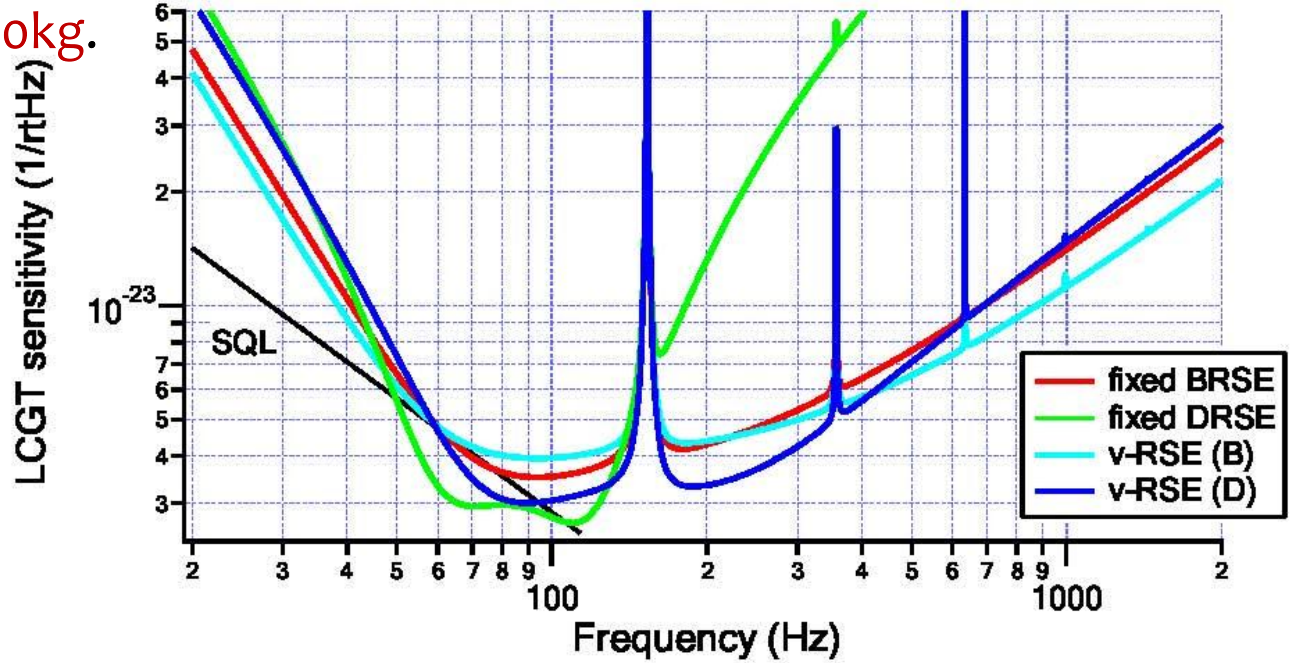
- **MOU with and (Support from) LIGO**
  - was discussed in September/2010 and will be concluded soon.
  - Some SiO2 mirror substrates that were not used for i-LIGO might be asked to introduce in i-LCGT to shorten the mirror manufacturing time.
  - ICRR UT has already MOU about digital control with LIGO Labo.

- **MOU with VIRGO**
  - Will be discussed in November 5th 2010 in Japan.(maybe 5 leaders in VIRGO will visit Kashiwa, ICRR UT.)
  - Concrete development items will be addressed in this meetings (cryogenics, SAS control, etc).

- **MOU with individual university, institute, etc**
  - Will be asked from LCGT side.

LCGT Important Parameters and Sensitivity

- In order to attain the sensitivity to catch the event at ~231Mpc (SNR=8), we need to reduce shot noise determined by 800kW optical power (400 kW).
- Thermal noise of the mirror, coating of the mirror, and suspension need to be suppressed by cryogenic temperature, 20K. Mechanical losses of these parts are required to satisfy this thermal noise limit; they are 10^{-8}, 4×10^{-4}, 10^{-8}
- Final sensitivity is limited by quantum noises in the observation frequency band, 230Hz. Radiation pressure noise is determined both by the optical power and by mass, 30kg.



LCGT Main IFO Part

- Revised design : Variable RSE

(⇔ We can shift to BRSE)

- Laser Power and wavelength

150W, 1064nm (→ 1550 nm ??)

- Mirrors

Silica (300K) → Sapphire/Silicon(20K)

- Finesse and Power in Cavity

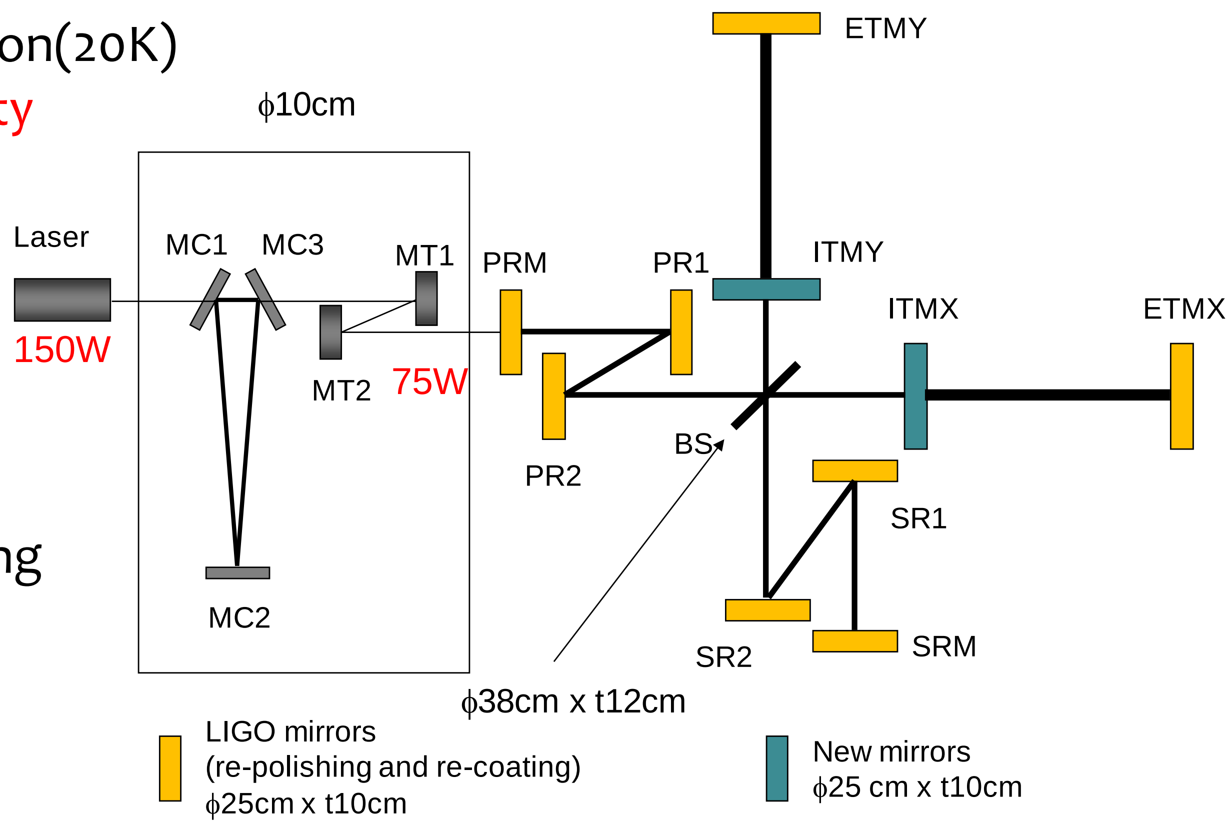
1550, 400kW

- One suspended Mode Cleaner (13~26 m)

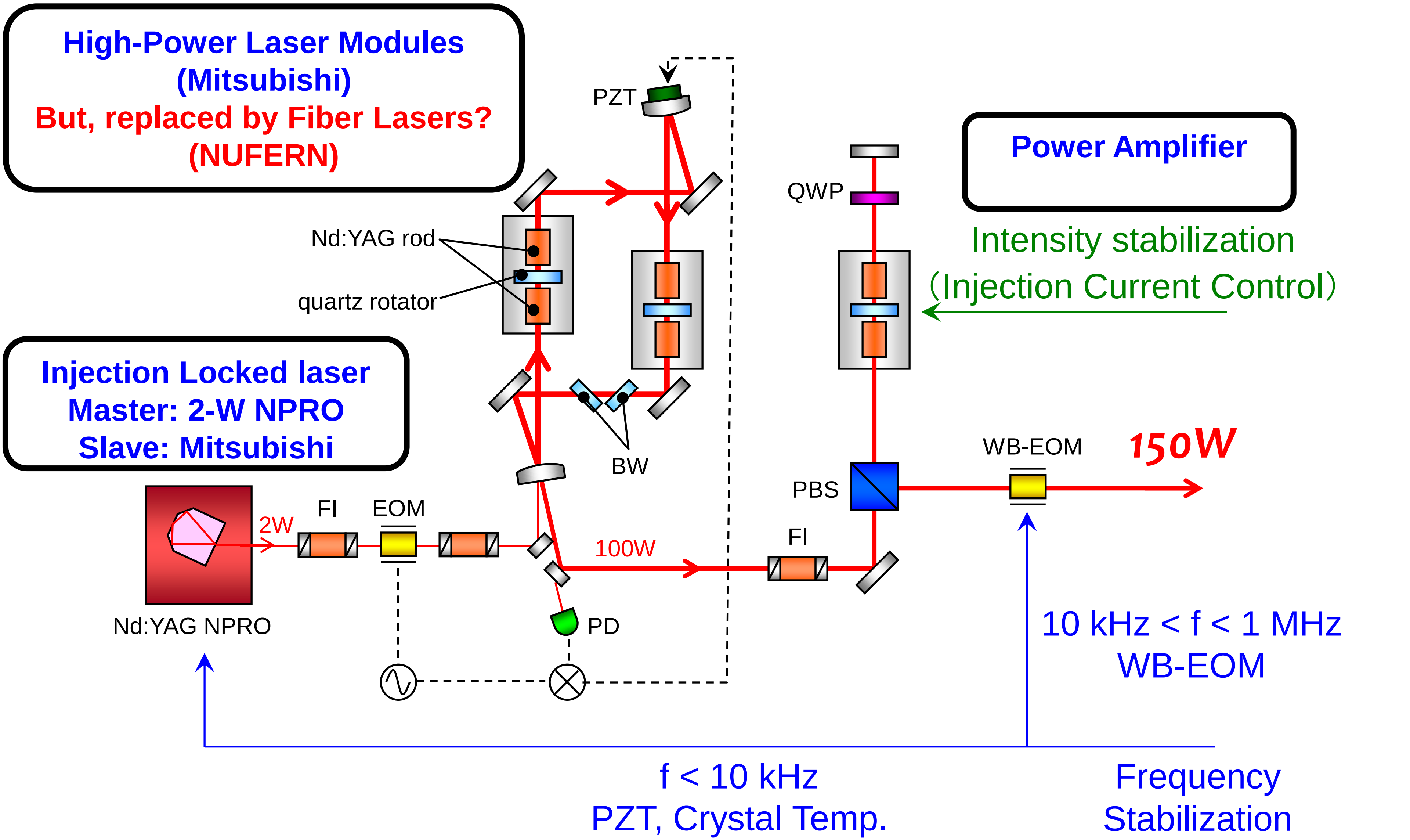
Rigid Pre-MCs will also be introduced.

- Folding structure

For Power and Signal Recycling Cavities

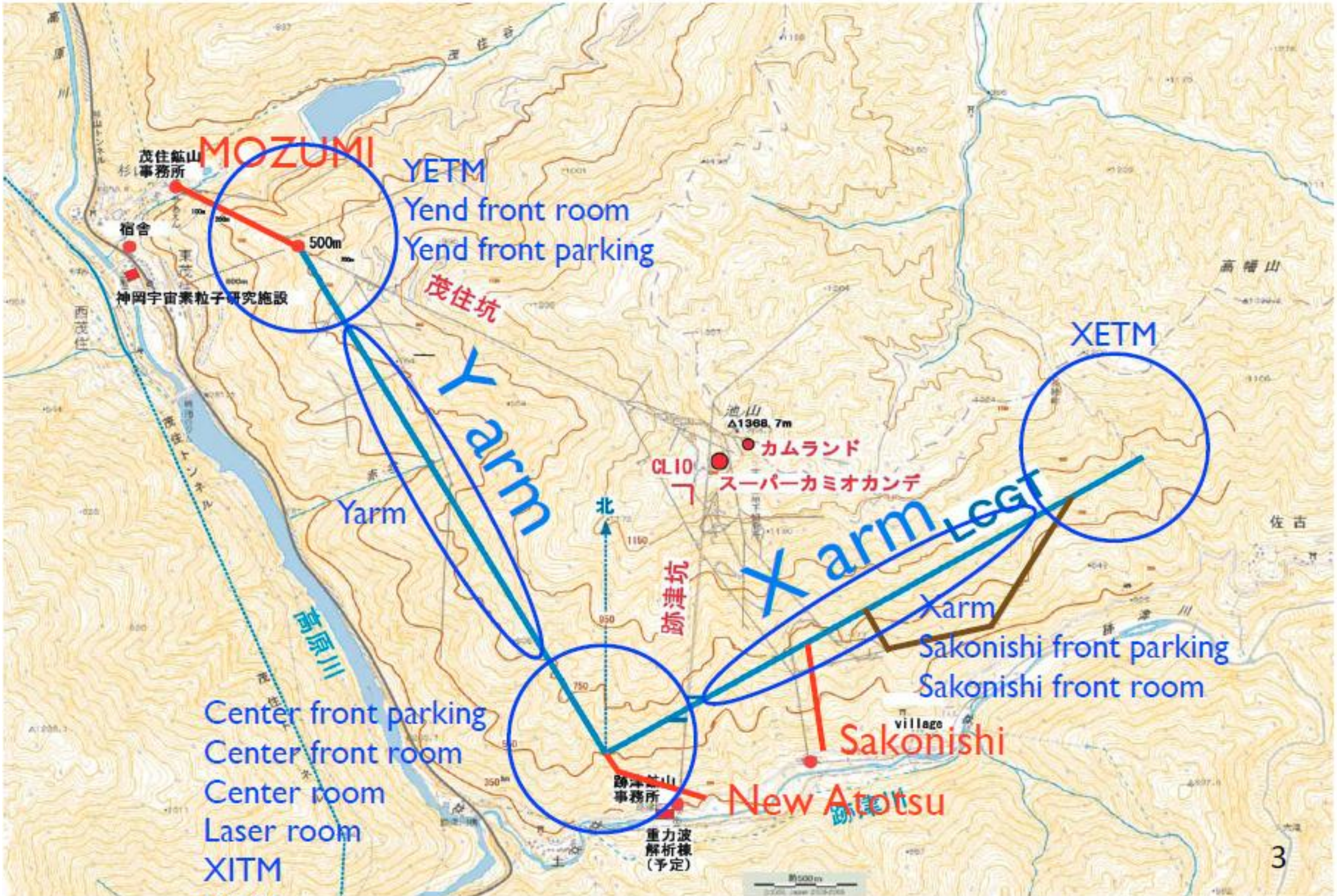


Laser



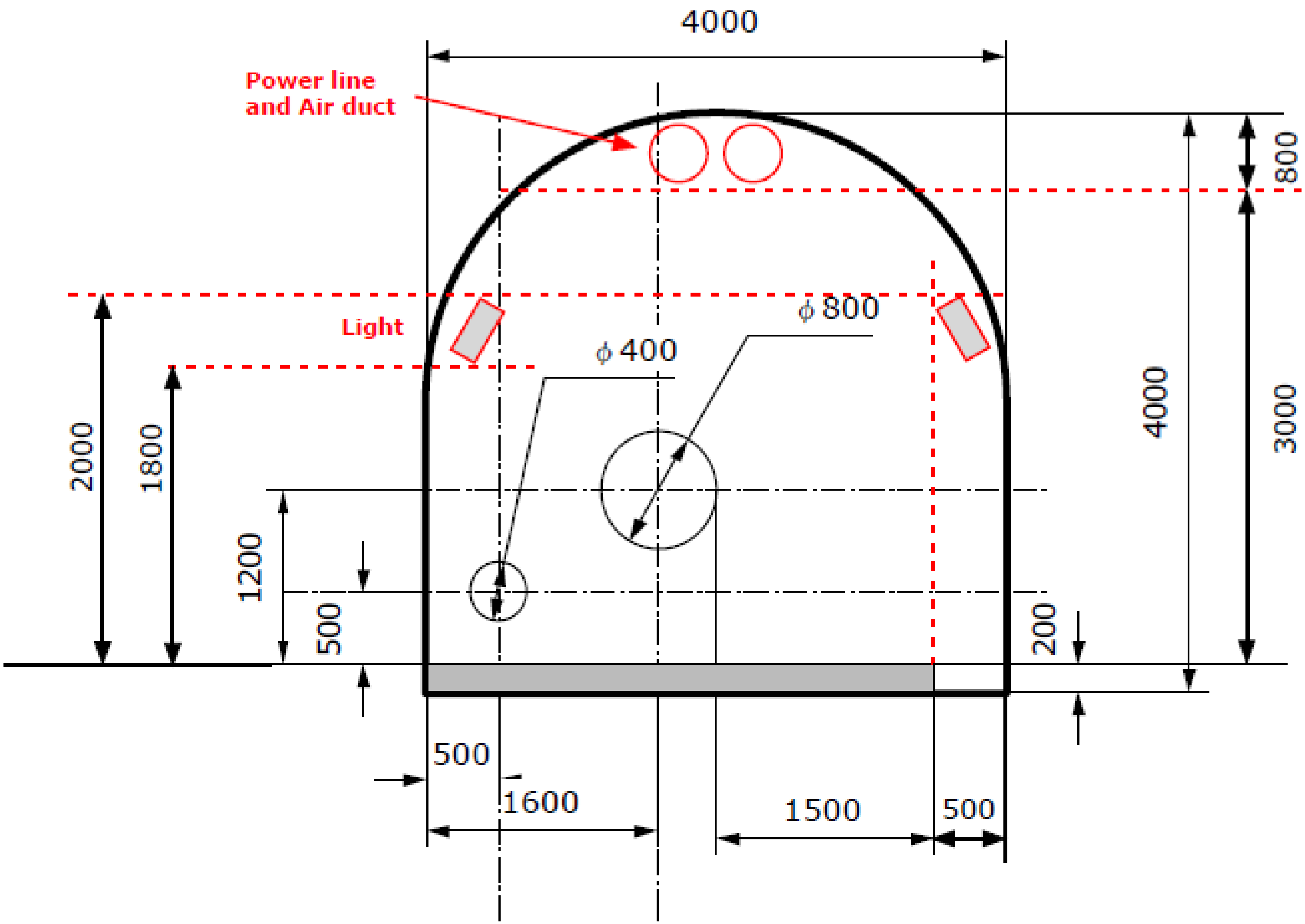
High-Power Laser Modules
(Mitsubishi)
But, replaced by Fiber Lasers?
(NUFERN)
PZT
QWP
Power Amplifier
Intensity stabilization
(Injection Current Control)
Nd:YAG rod
quartz rotator
Injection Locked laser
Master: 2-W NPRO
Slave: Mitsubishi
BW
WB-EOM
150W
PBS
2W
FI
EOM
100W
FI
Nd:YAG NPRO
PD
10 kHz < f < 1 MHz
WB-EOM
f < 10 kHz
PZT, Crystal Temp.
Frequency
Stabilization

Tunnel Alignments

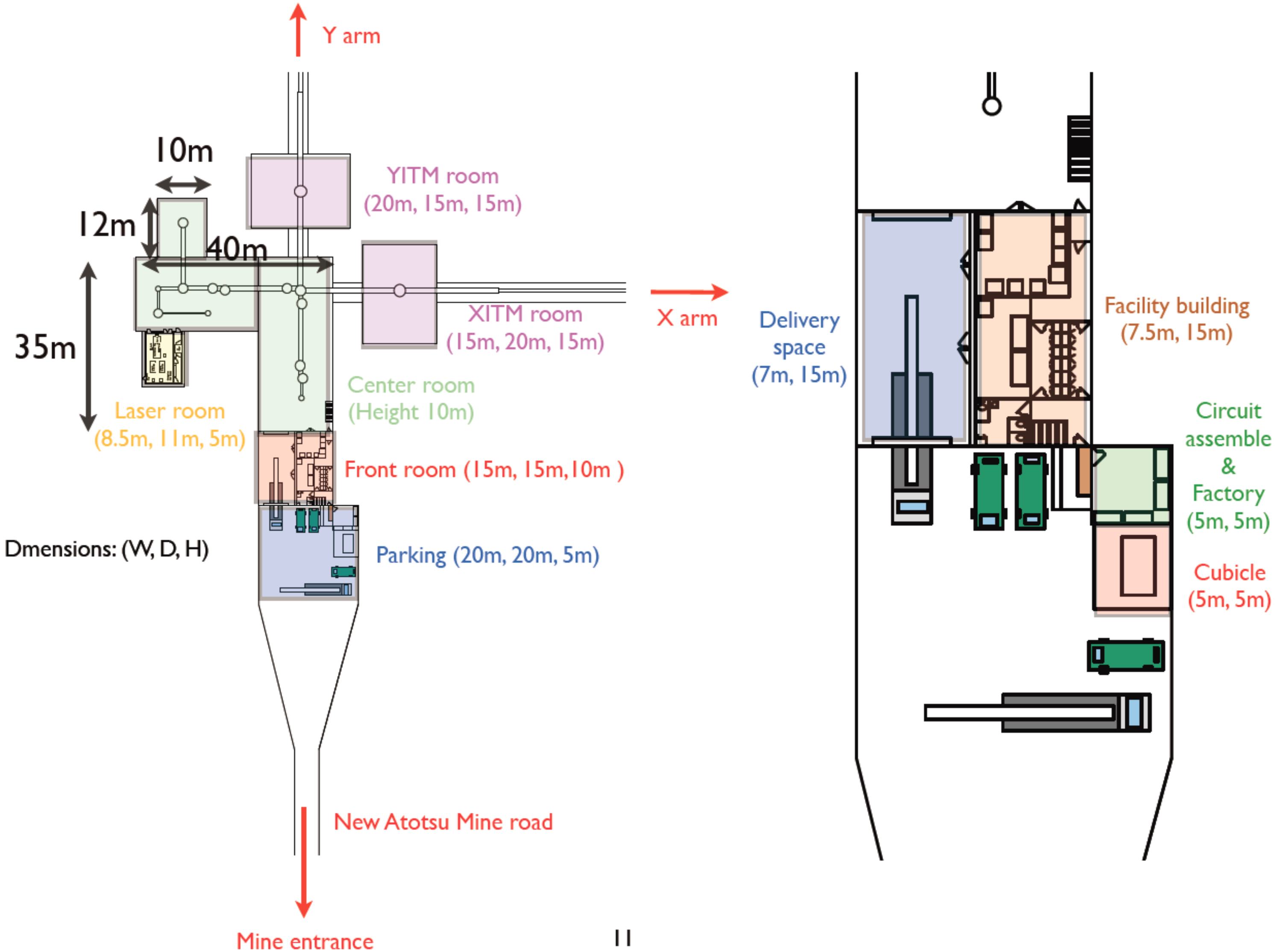


Tunnel Cross section

Figure of arm tunnel.

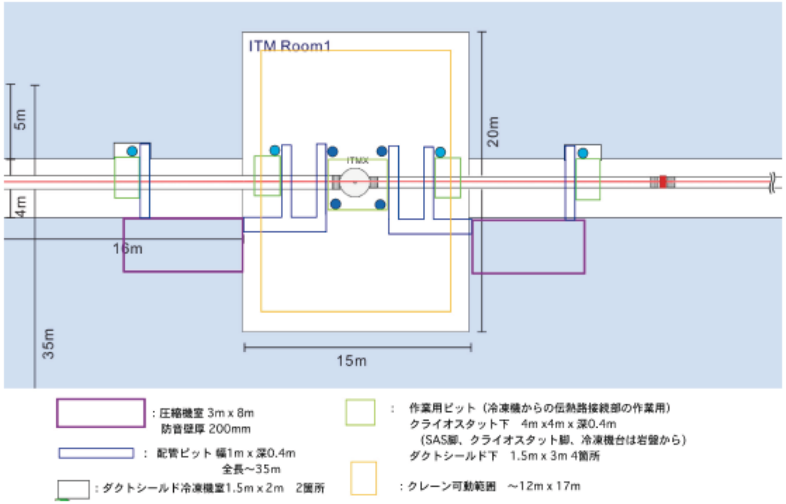


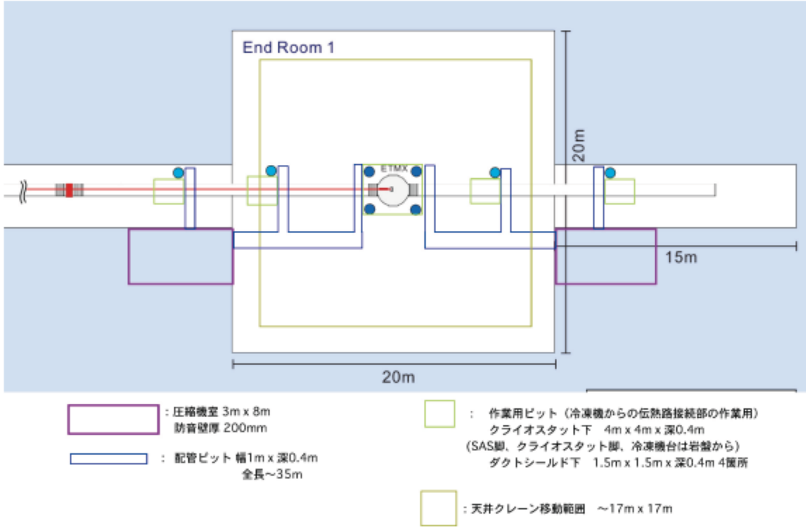
Center Station



ITM and ETM Area

- ITM room
  - 15m×20m×15m(W×D×H)
  - Crane
    - 10t?
    - 12m×17m.
- ETM room
  - 20m×20m×15m(W×D×H)
  - Crane
    - 10t?
    - 17m×17m.
- Compressor room(2spaces: 3m×8m×5m).
- There are pits(depth: ~0.4m).
  - For assemble work of cryostat and cryo-coolers units.
  - For He tube for refrigerators.
- Some stock rooms and assembling area.

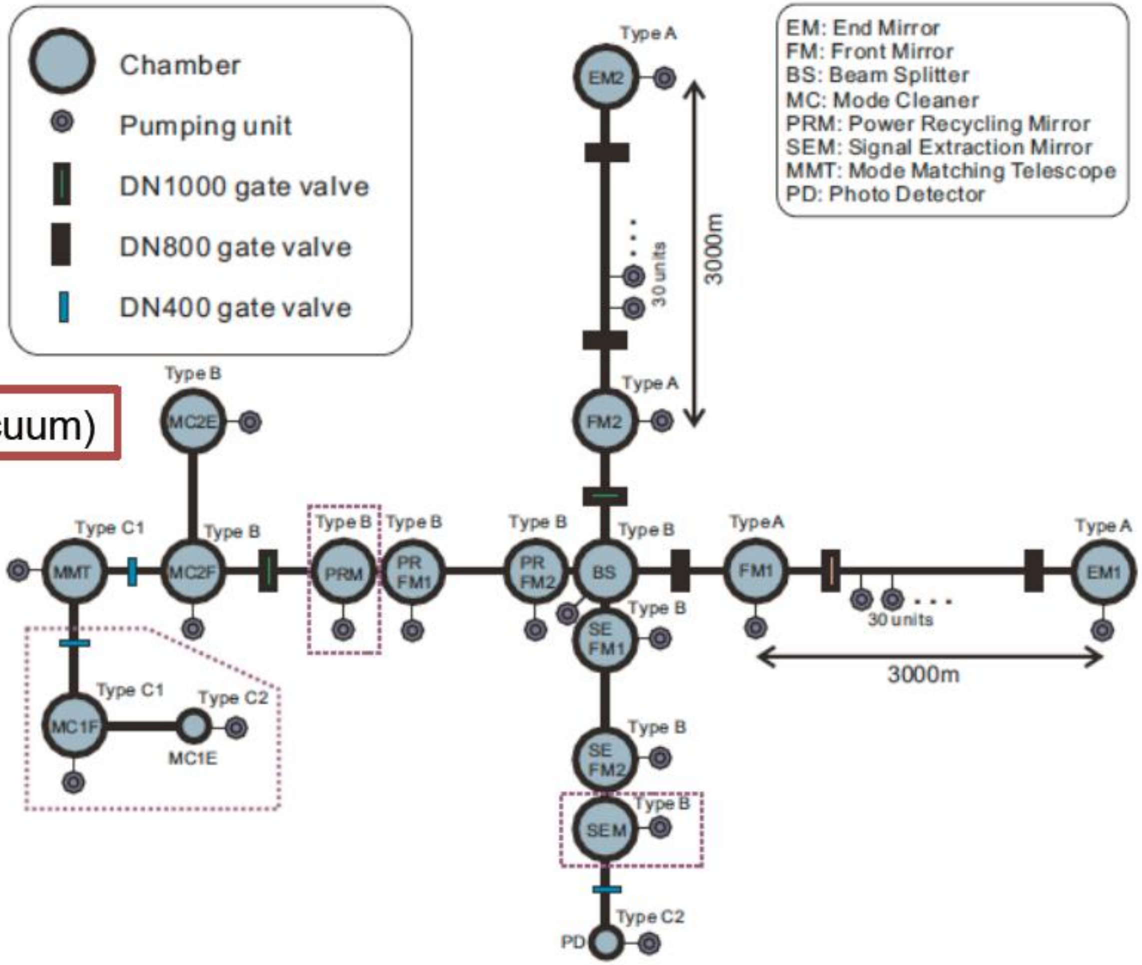




Vacuum Alignments

** for reducing noise due to a residual gas effect
** for maintenance minimizing

UHV (ultra high vacuum)



Vacuum Requirement

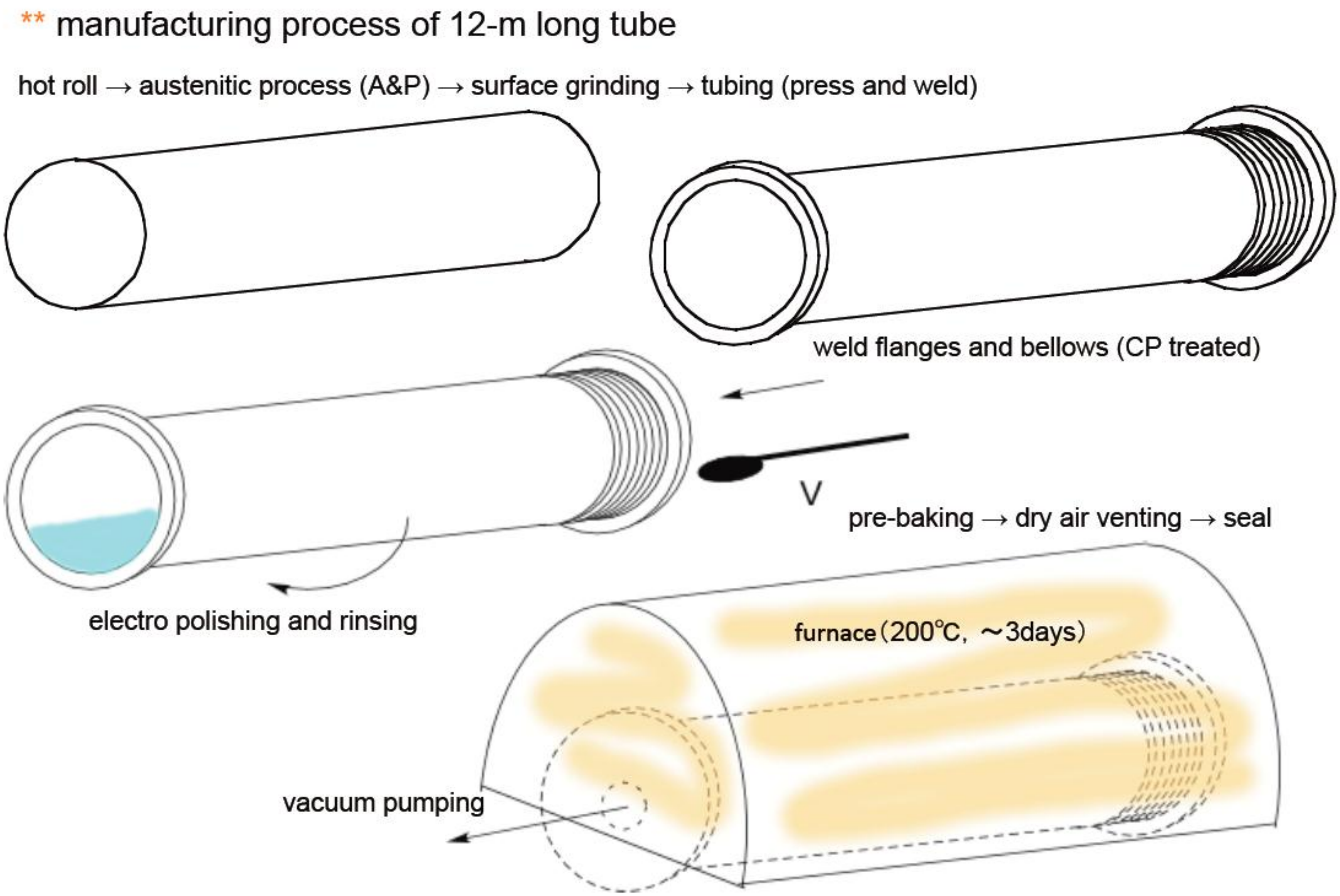
UHV (ultra high vacuum)

- beam tube (500 of 12-m long and 0.8 m in diameter each)
  - ** "*surface passivation*" of stainless steel prior to tunnel installation is required, so as to have an "*outgassing rate*" (per unit area for 50 hrs pumping) of the order of 10^{-8} Pa m^3 m^{-2} s^{-1}, or lower.
  - ** vacuum group have only one year to install all of the tubes! "*flange connection*" for tube installation is chosen.

- optical baffle (diamond-like-carbon/DLC coated)
  - ** based on the tube vibrating test in TAMA300, 500 of optical baffles are planned to place at "*every 12 meters*" along tubes, for phase noise reduction
  - ** measured outgassing rate of DLC is 4×10^{-9} Pa m^3 m^{-2} s^{-1},

- chamber (4 of 13 chambers are equipped with a cryogenic system)
  - ** installed materials, having low outgassing rate, should be chosen. careful investigation for *elastomer* and *plastomer* (generally large outgassing)
  - ** the amount of the adsorbed molecules on the "*cool-downed mirror*" is to be discussed and investigated, concerning

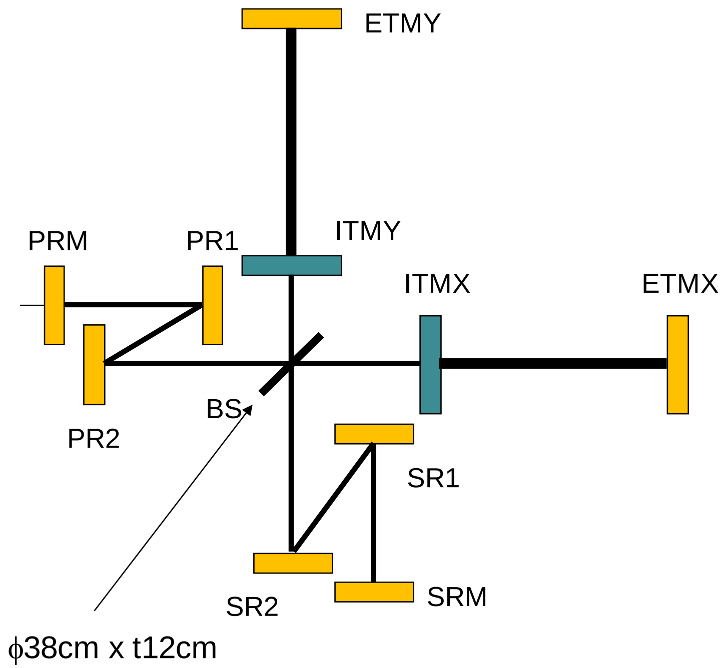
Vacuum Tube Production



Mirrors (Plan)

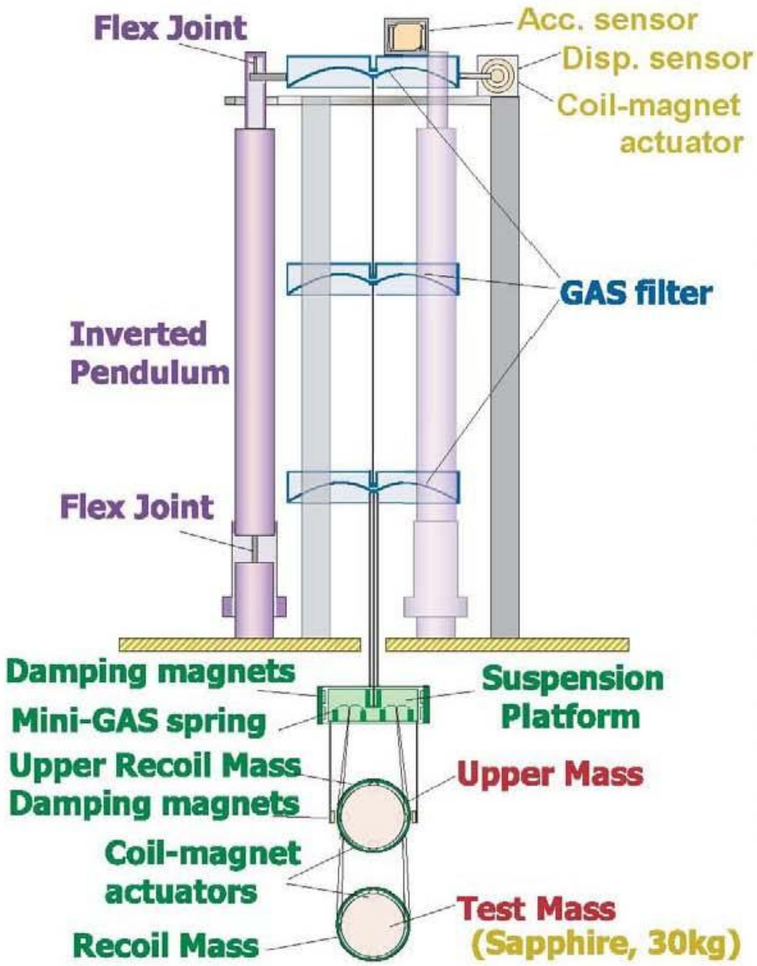
- **i-LCGT**
  - SiO2 Mirrors (substrate : ϕ250 x t100, 10kg) for PRM, STMs for folding in PRC, ETMs, SRMs and STMs in SRC.
  - Coating will be done in Japan.
  - Polishing might be by a company or RIKEN Group in Japan.

    On the other hand.
  - BS (ϕ380 x t120), ITMs are newly produced by “Asahi Glass” in Japan.
  - Polishing and Coating might be by CSIRO …

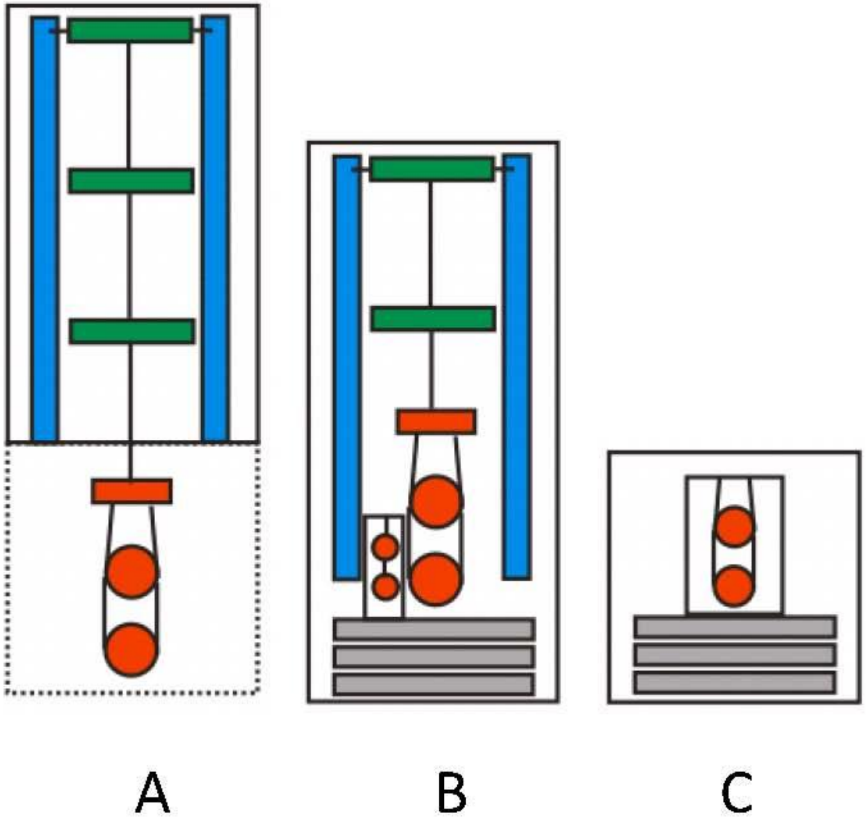


- **b-LCGT (= LCGT)**
  - Sapphire (or Silicon)
  - We are now negotiating with GT Crystal Systems.

Seismic Noise Attenuation System

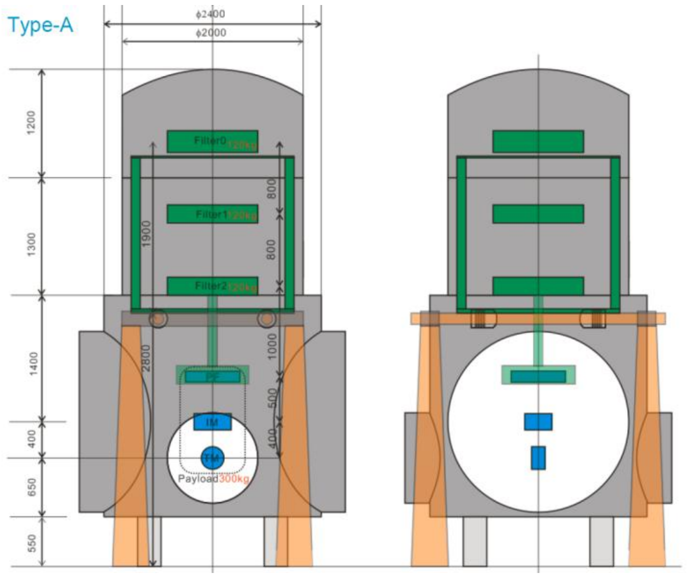


A)SAS(GASF 3stage)+cryo-sus:
ITM1, ITM2, ETM1, ETM2
B)SAS(GASF 2stage)+non-cryo:
BS, PRM, SRM, MCI, STMs, MCO, MCE
C)STACK+2stages: PD

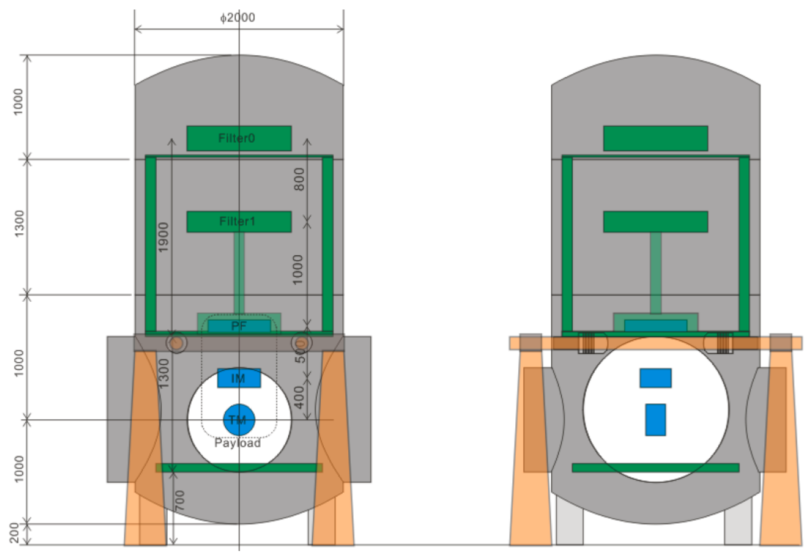


Kinds of SAS and Pendulums

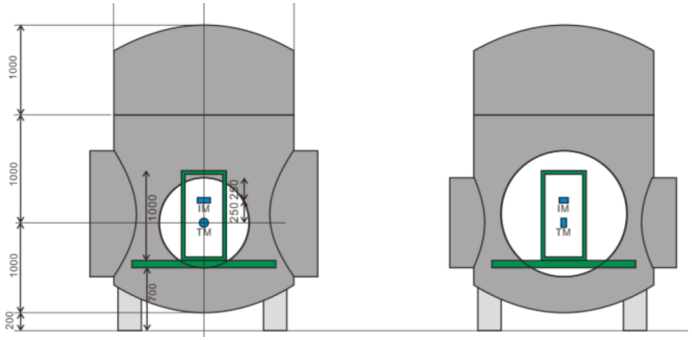
- **Type A**



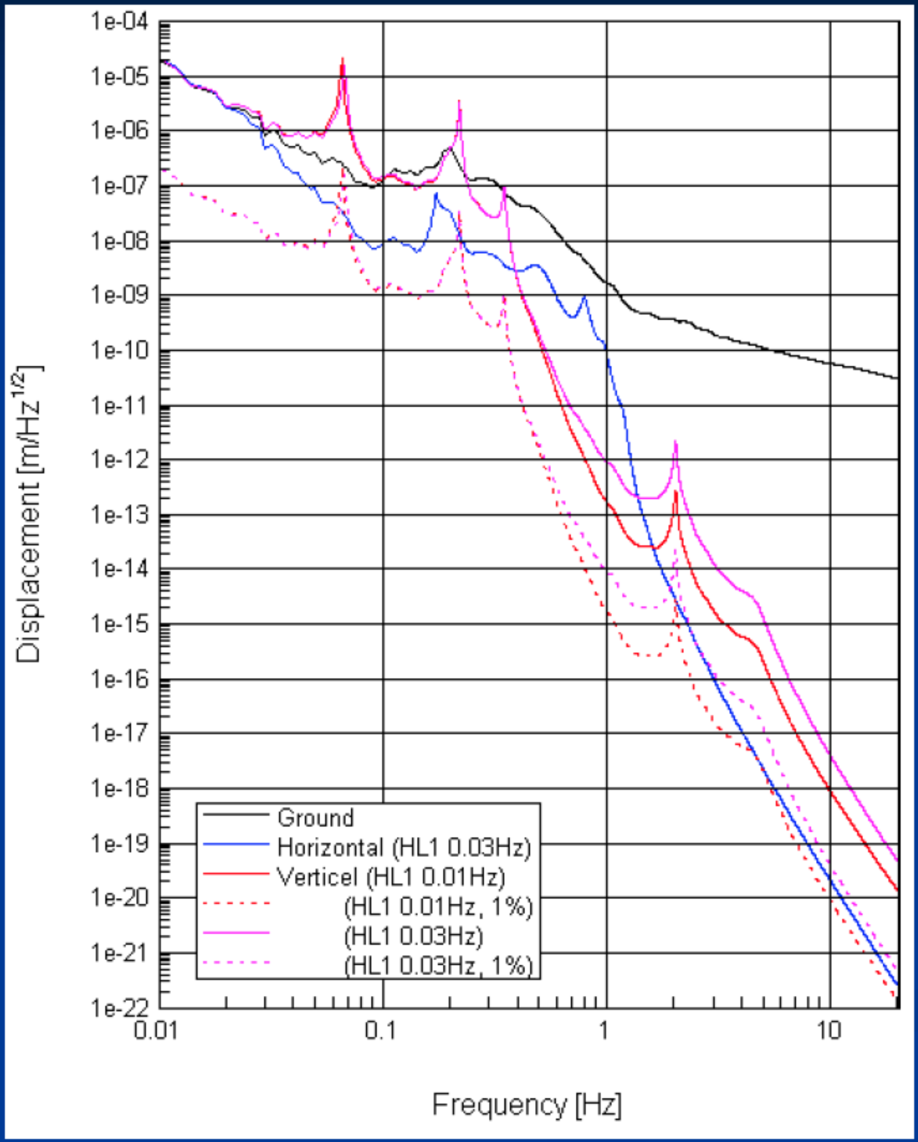
- **Type B**



- **Type C**



Isolation Performance (TypeA)



- The vertical isolation is better than the horizontal isolation around 1Hz because of 3 stage GAS filters.
- Since the final stage (TM) is suspended by 4 sapphire fibers of ϕ1.8mm, the vertical resonant frequency is about 100Hz.
- Heat links of 0.01Hz with 1% coupling from vertical mode satisfy demands at 5Hz. Heat links of 0.03Hz is NG but practically OK.

- **Type A**

Expected Residual RMS

			Type-A	Type-B	Type-C
Microseisms	normal	[μm]	1.0 (0.006)	1.0 (0.006)	1.0 (0.1)
		[μm/s]	0.08 (0.008)	0.08 (0.008)	0.2 (0.2)
	large	[μm]	0.7 (0.10)	0.7 (0.09)	2.0 (1.9)
		[μm/s]	0.12 (0.11)	0.11 (0.10)	2.3 (2.3)

Integration 0.01-4Hz
(Integration 0.1-4Hz)

Type-A,B vs. C

0.1 → 2 [μm] x20

0.1 → 2 [μm/s] x20

Cryostats

Quiet Cooling in vacuum

Vacuum for LCGT

- Optics of the interferometer must operate in a high vacuum because of sensing an extremely small signal. No optical window is required in the main cavity.
- All components have a common vacuum space and should reduce outgassing from their surfaces.
- Generally, metal surfaces have much smaller rate of outgassing than organic materials at 300K.
- A surface with low temperature also have a very small rate of outgassing.
- Super Insulator (SI) is effective thermal insulation for cryogenic parts. SI consists of 20~30 layers of aluminized polyester films.

ε : emissivity

1-ε : reflectivity

Straight pipe ε<<1

6 baffles

-> 99.4% reduction

SAS

Seismic Attenuation Syatem

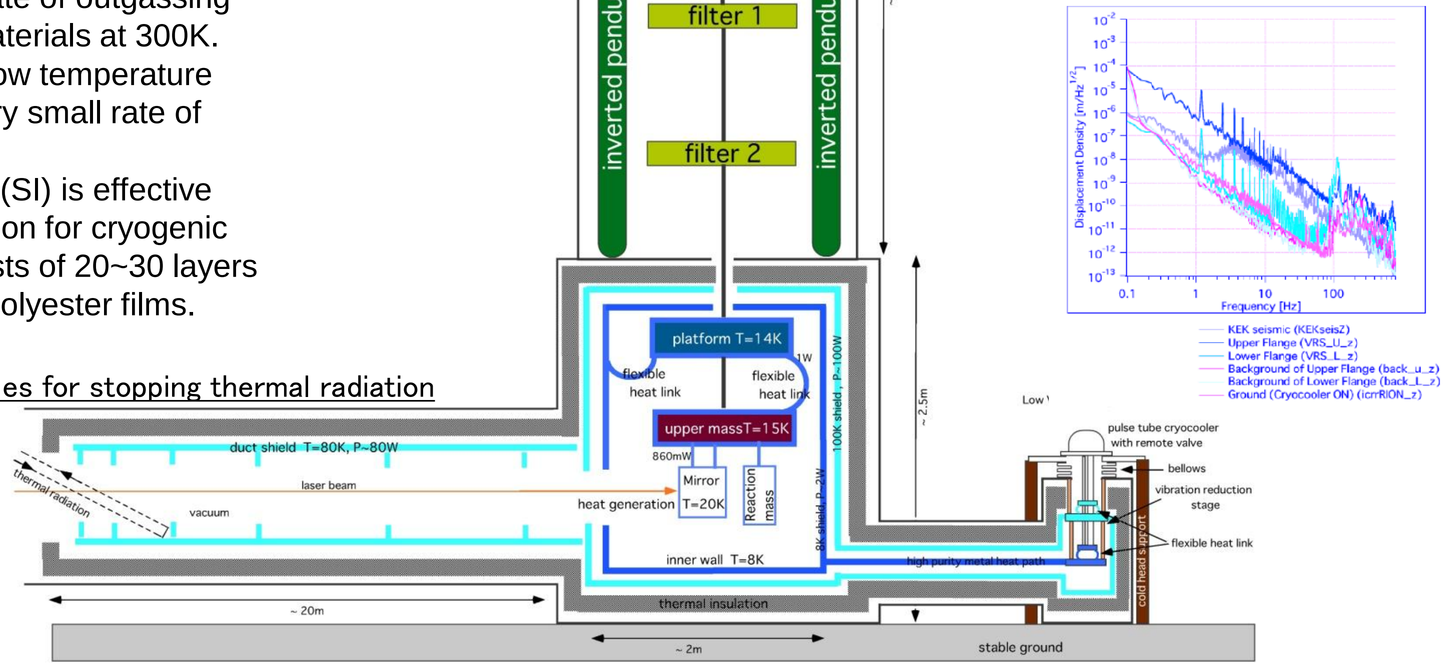
Baffles for stopping thermal radiation

Ultra low vibration cryocooler system

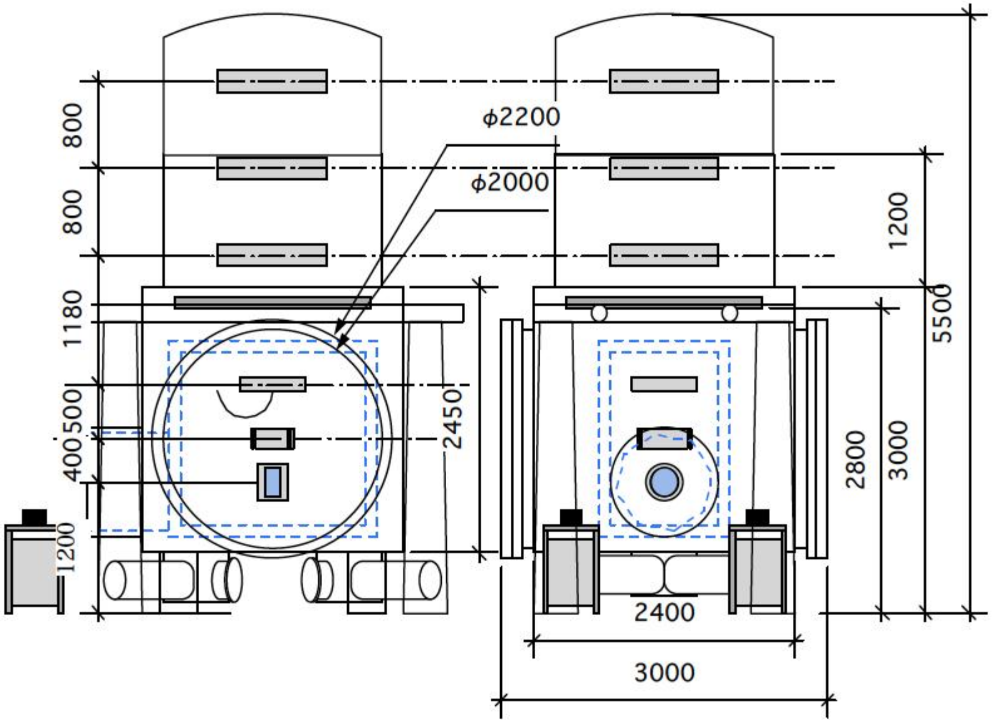
- Pulse tube cryocooler (PTC) + vibration isolator
- Two stage pulse tube with remote valve.
- Warm side of the cold head and the valve are tighten to the ground separately.
- A vibration reduction stage (VRS) is fixed in the vacuum chamber, which is also tighten to the ground.
- Warm side of the cold head and the vacuum chamber are connected by a soft bellows.
- The VRS and the cold stage of the cold head of the PTC are linked by flexible heat links made of thin wire bundle.
- The rms amplitude of the second stage of the VRS reduced to 50nm from the original amplitude of the 2nd stage of PTC. (z-direction, vertical)
- Horizontal directions are reduced to sub-micrometer rms amplitudes.

(Developed by KEK and SHI)

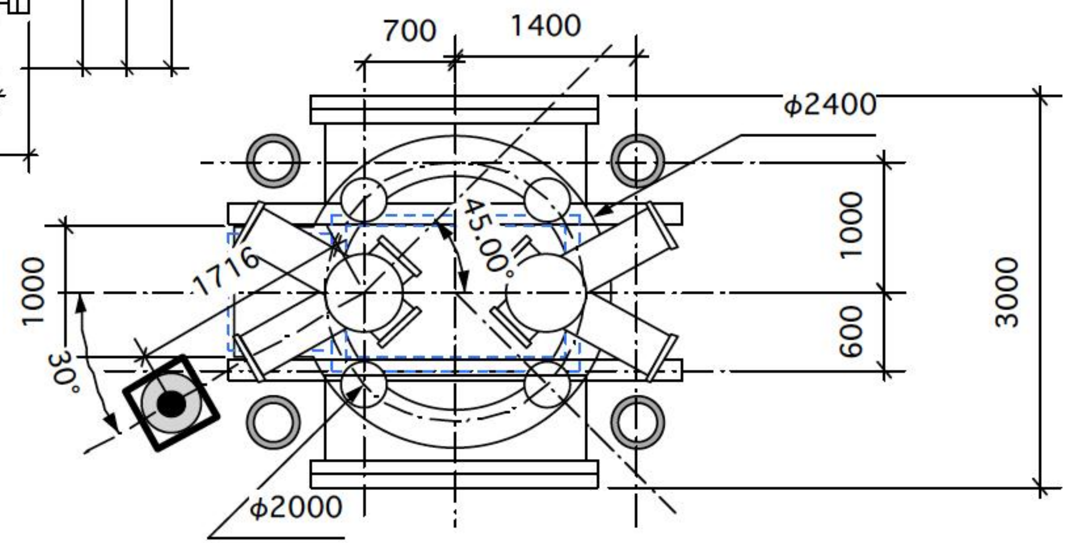
Vibration Spectra of Cryocooler System (Z)



Cryostats



- *Four PT cryocoolers will be attached with one cryostat*
- *1W for 5K cooling power is expected for one PT refrigerator.*



Requirements for Cryocooler

- Cooling power
  - Pulse tube cryocooler (PTC)   1W or more around 5K for cryostat
  - PTC   80W at 80K for duct shield
- Low vibration
  - At least as the same vibration level as the Kamioka ground motion
  - Same or similar vibration isolator used for CLIO cooler.
- Maintenance
  - On site service available
  - Response time < 24 hours

Baseline Interferometer

Plan

1. Two baseline-monitor interferometers (~1.5km) along LCGT
2. Sensors and benchmarks for monitoring environmental condition

Purpose and Targets

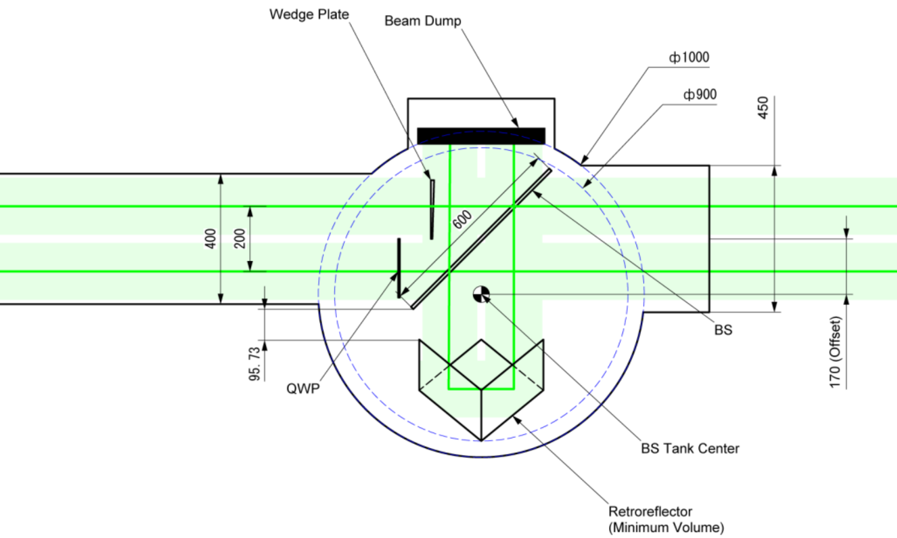
[Baseline interferometers]

1. Baseline monitor for LCGT (Tides, earthquakes, crustal deformation… in the middle of Niigata Kobe Tectonic Zone)
2. Fault-creep monitor for the Atotsu fault
3. Deep interior of Earth (Monitoring Earth's free oscillations)

[Sensors and Benchmarks]

1. Monitoring environmental condition (Thermometers, Barometers, Hygrometers, Broadband seismometers, and Accelerometers) and tunnel deformation (leveling and surveying)
2. Standard of length (collaboration with AIST)
3. Benchmarks for vacuum installation

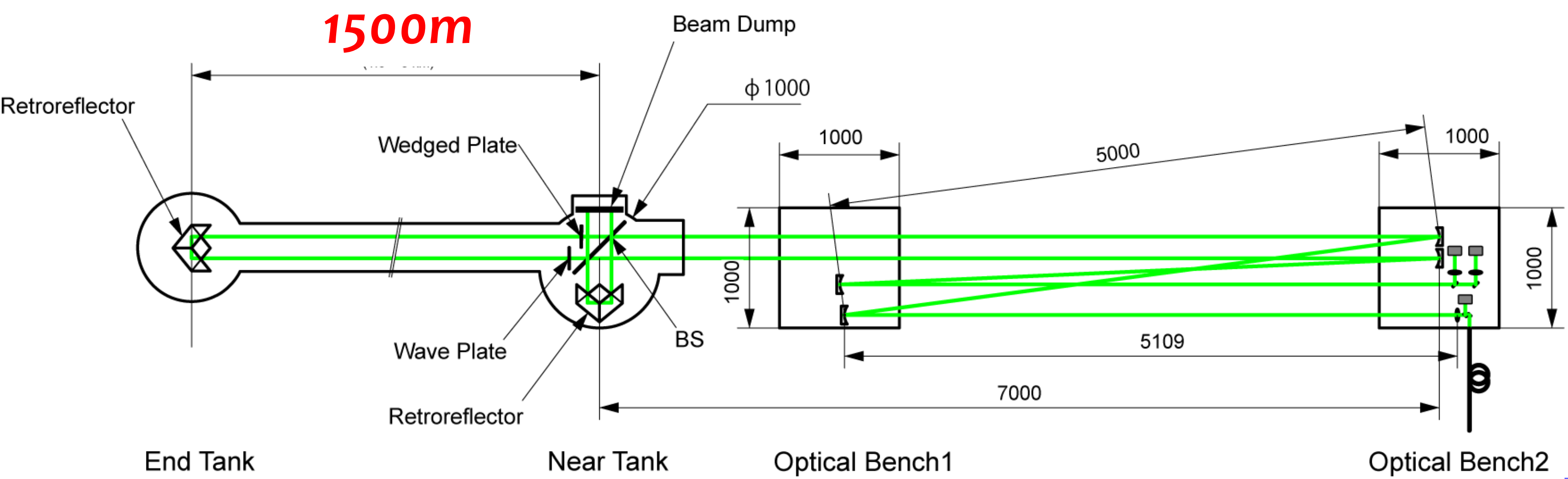
1500m Baseline IFOs in both arms



- Schedule

- 2011.10-2013.3 : Laser assemble (partially)
- 2011.10-2013.3 : Optics assemble (partially)
- 2012.11-2013.3 : Benchmark, vacuum installation
- (2nd tunnel)
- 2013.3-2013.7 : Benchmark, vacuum installation
- (1st tunnel)
- 2013.4-2013.9 : Laser and optics installation
- 2013.4-2013.9 : Data acq. sys. Installation
- 2013.10-2014.3 : Observation

09/17)



Summary

- *Fundamental techniques for LCGT have been prepared by TAMA and CLIO and LCGT Collaborators.*
- *LCGT finally started in September 2010.*
- *63% budgets was approved. A part of the rest 37% budget will be applied for 2011 start in this year 2010.*
- *Many LCG parts are under designing.*
- *5 years construction, and 2 years commissioning are planed. We hope observation from 2017.*