Large-scale Cryogenic Gravitational wave Telescope: KAGRA

Rencontres de Moriond 2015, Gravitation

Mar. 26. 2015

Takayuki TOMRU

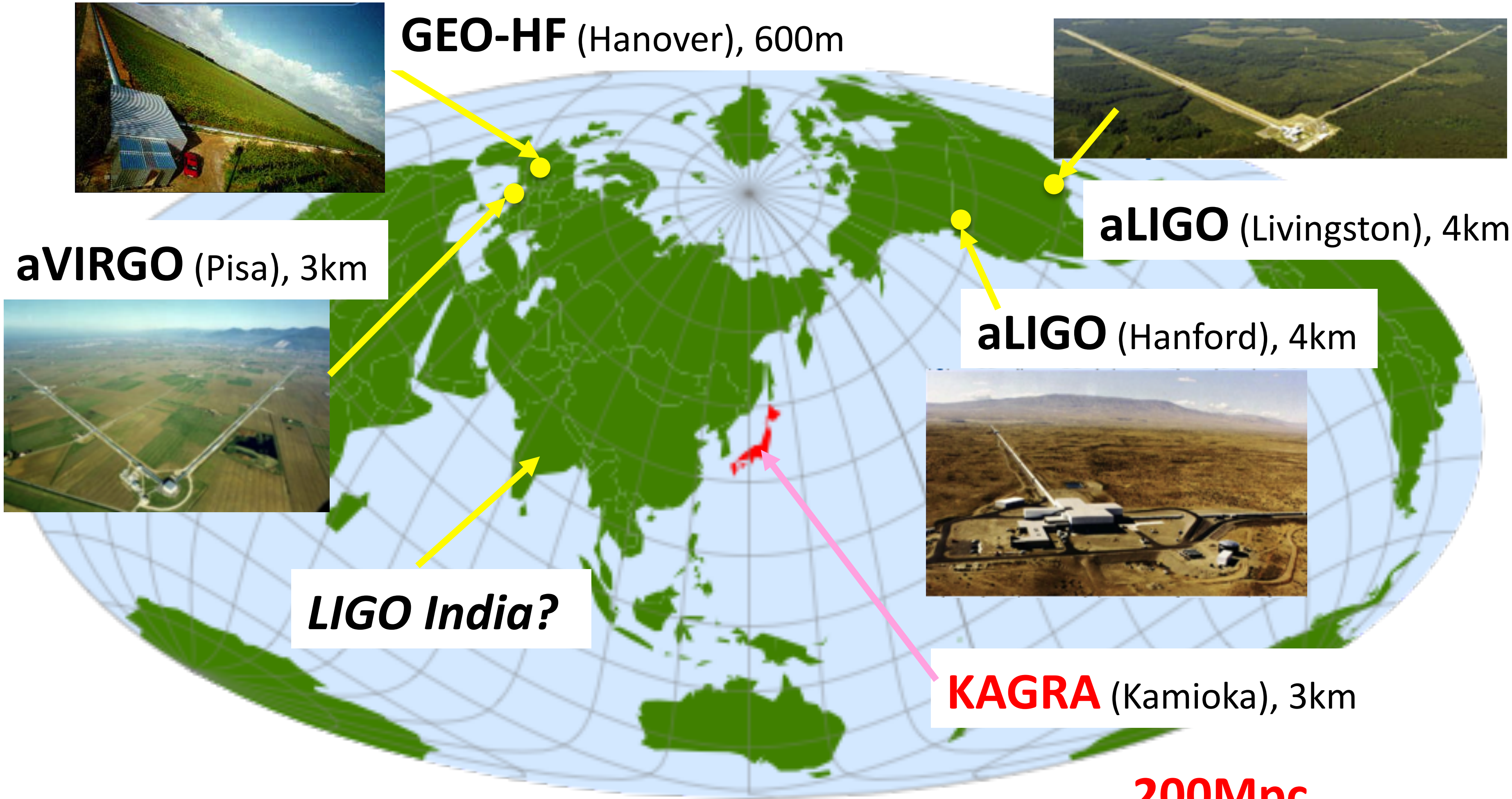
High Energy Accelerator Research Organization (KEK)

KAGRA: *KAmioka GRAvitational wave detector*

神楽　Traditional theatrical dance in Japanese Shinto religion

We selected this nickname from public offering.

2nd Generation GW Observation Network



Why do we need a GW telescope in Japan?

Sky Coverage

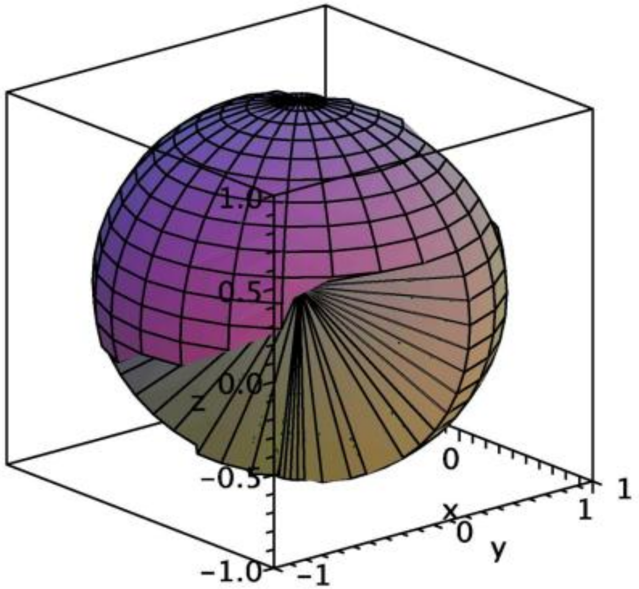
LIGO(H)+LIGO(L)+Virgo

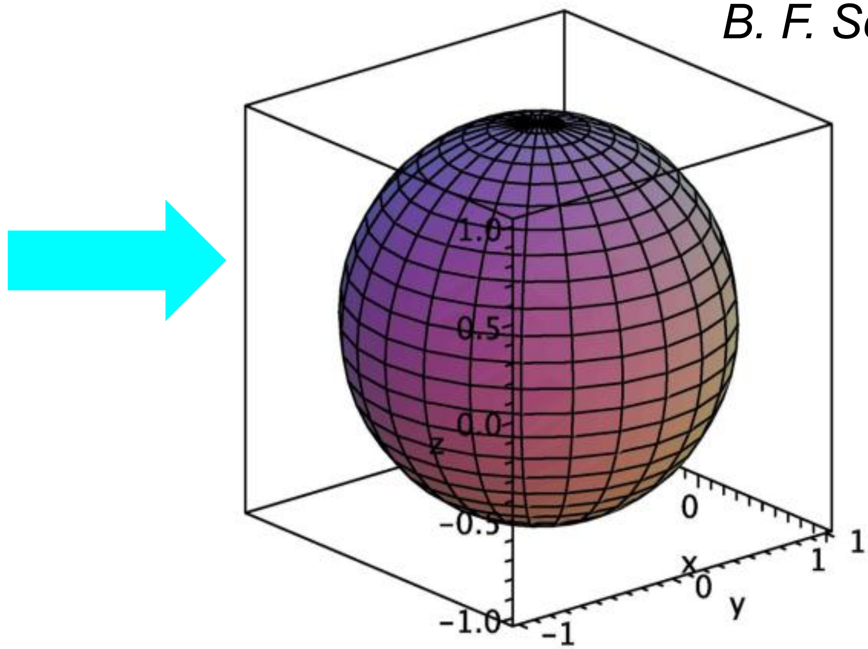
- Coverage at 0.5 M.S.: 72%
- 3 detector duty factor: 51%

LIGO(H)+LIGO(L)+Virgo+ KAGRA

- Max sensitivity (M.S.): +13%
- Coverage at 0.5 M.S.: 100%
- 4 detector duty factor: 82%

B. F. Schutz





Observation by KAGRA is critical to realize all sky surveying in new GW astronomy.

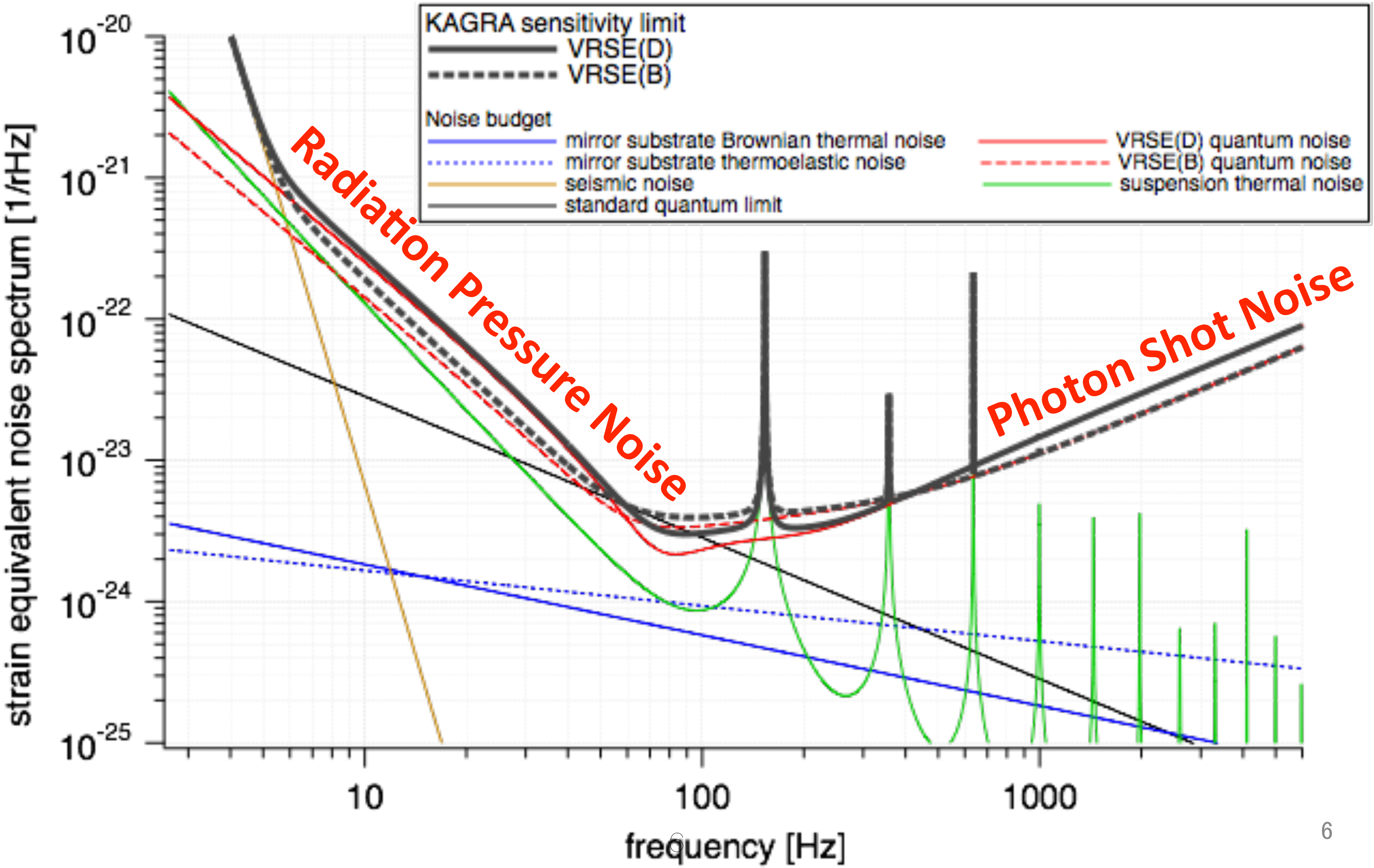
KAGRA collaboration

80 international institutions

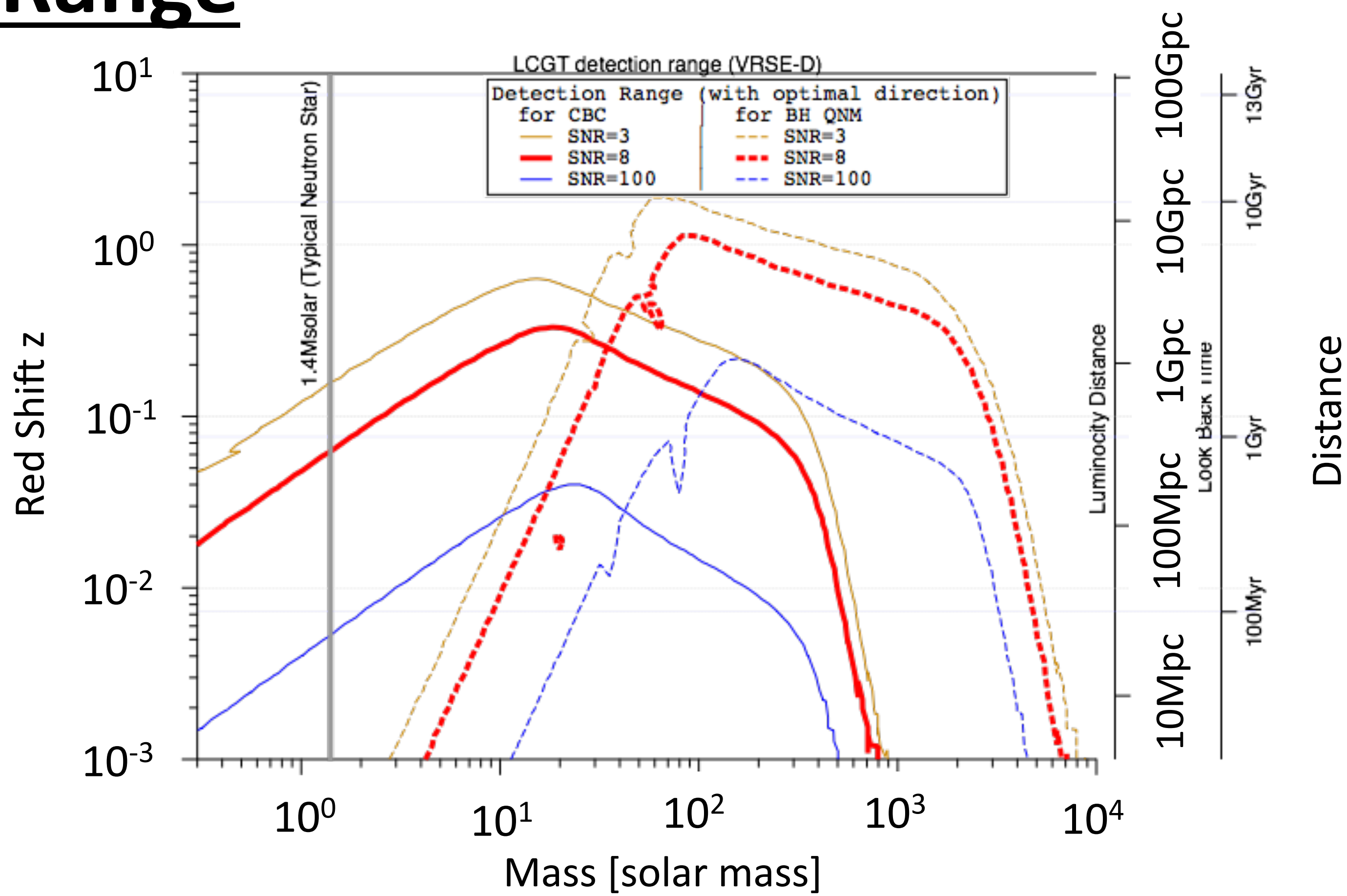
- the University of Tokyo, ICRR
- High Energy Accelerator Research Organization (KEK)
- National Astronomical Observatory of Japan (NAOJ)
- the University of Tokyo, Science
- the University of Tokyo, Frontier Science
- the University of Tokyo, Engineering
- Osaka City University
- Kyoto University
- University of Electro-Communications
- the University of Tokyo, ERI
- Hosei University, Science & Engineering
- Hosei University, Engineering
- National Institute of Advanced Industrial Science and Technology
- National Institute of Information and Communications Technology
- Osaka University
- Kyoto University
- Kyushu University
- Ochanomizuu University
- National Institute for Fusion Science
- Nihon University, ARISH
- Niigata University, Science
- Niigata University, Engineering
- Nagaoka University of Technology
- Nihon University, CIT
- Hirosaki University
- Tohoku University
- Rikkyo University
- Hiroshima University
- University of the Ryukyus
- Waseda University, ASE
- Waseda University, Education
- Teikyo University
- University of Toyama, Science
- University of Toyama, Engineering
- University of Toyama, ITC
- Yokohama City University
- Fukuoka University
- Aichi University of Technology
- Japan Student Service Organization
- Institute for Molecular Science
- Kavli Institute for the Physics and Mathematics of the Universe
- National Defense Academy of Japan
- Max-Planck-Institut
- California Inst. Technology
- University of Western Australia
- Louisiana State University
- Beijing Normal University
- Inter University Center for Astronomy & Astrophysics
- Moscow University
- LATMOS, CNRS
- University of Science and Technology of China
- Tsinghua University
- Industrial Technology Research Institute
- University of Maryland
- Columbia University
- University of the West of Scotland
- University of Sannio
- Rome University
- Shanghai Normal University
- National Tsing Hua University
- Korea University
- Inje University
- Seoul National University
- Myongii National University
- Korea Atomic Energy Research Institute
- Hanyang University
- Pusan National University
- Korea Institute of Science and Technology Information
- National Institute for Mathematical Sciences
- Kyungpook National University
- Kunsan National University
- Korea Institute for Advanced Study
- Sogang University
- Chinese Academy of Sciences
- The Pennsylvania State University
- Montana State University
- Indian Institute of Science Education and Research Thiruvananthapuram
- National Institute for Subatomic Physics
- University of Wisconsin-Milwaukee
- Warsaw U of Technology

Goal Sensitivity of KAGRA

h ~ factor x 10^{-24} [/√Hz] for observation band



Search Range



NS-NS binary Coalescence → **280 Mpc** at best direction

(~173Mpc in whole sky average)

→ about **10 event/yr**

Supernova → **typically 100kpc - 1Mpc**

Optical Configuration of KAGRA

Dual Recycled Fabry-Perot Michelson Interferometer

Typical 2nd generation GW detector configuration

Mode cleaner

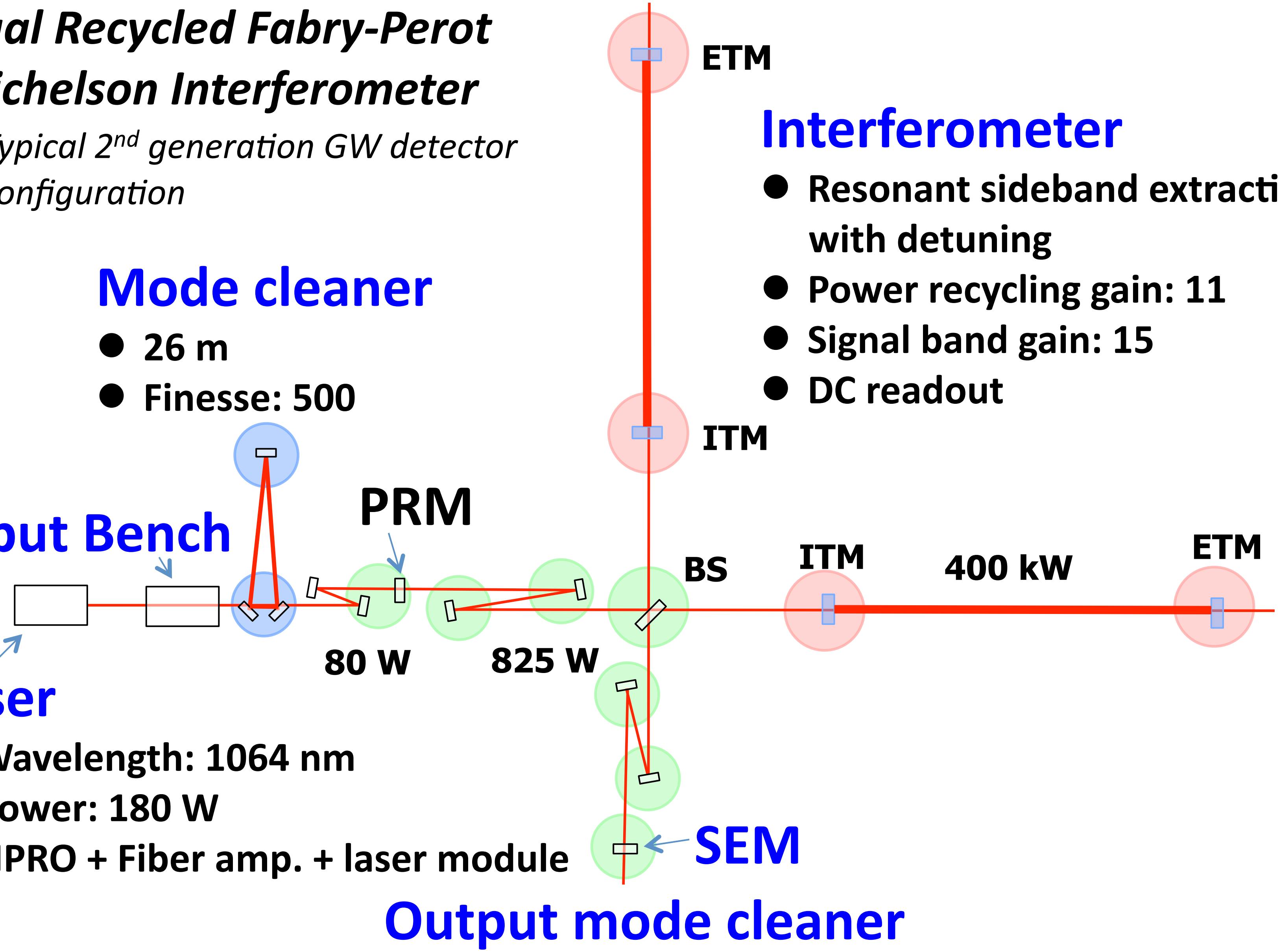
- 26 m
- Finesse: 500

Interferometer

- Resonant sideband extraction with detuning
- Power recycling gain: 11
- Signal band gain: 15
- DC readout

Laser

- Wavelength: 1064 nm
- Power: 180 W
- NPRO + Fiber amp. + laser module



Goal Sensitivity of KAGRA

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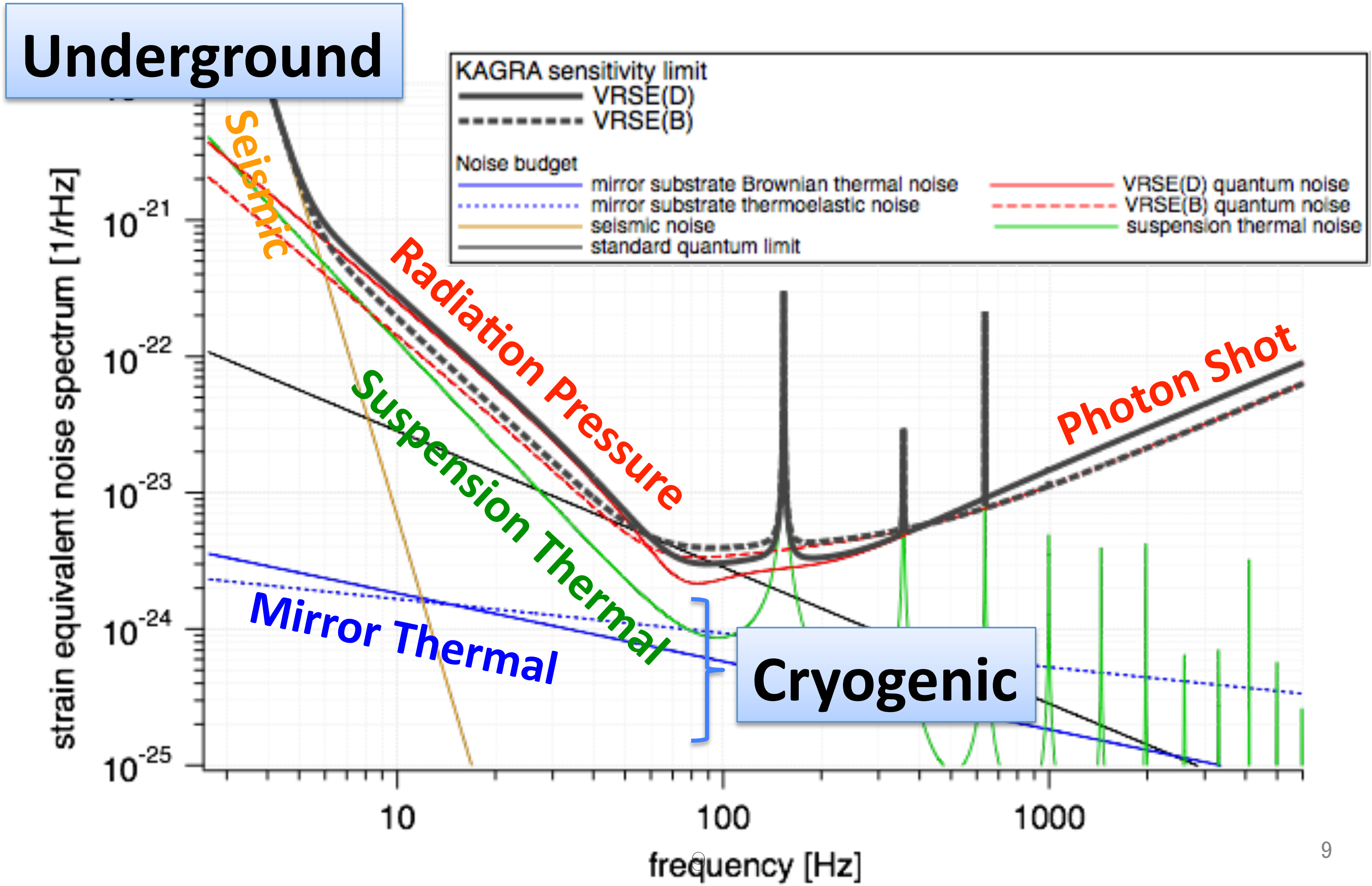
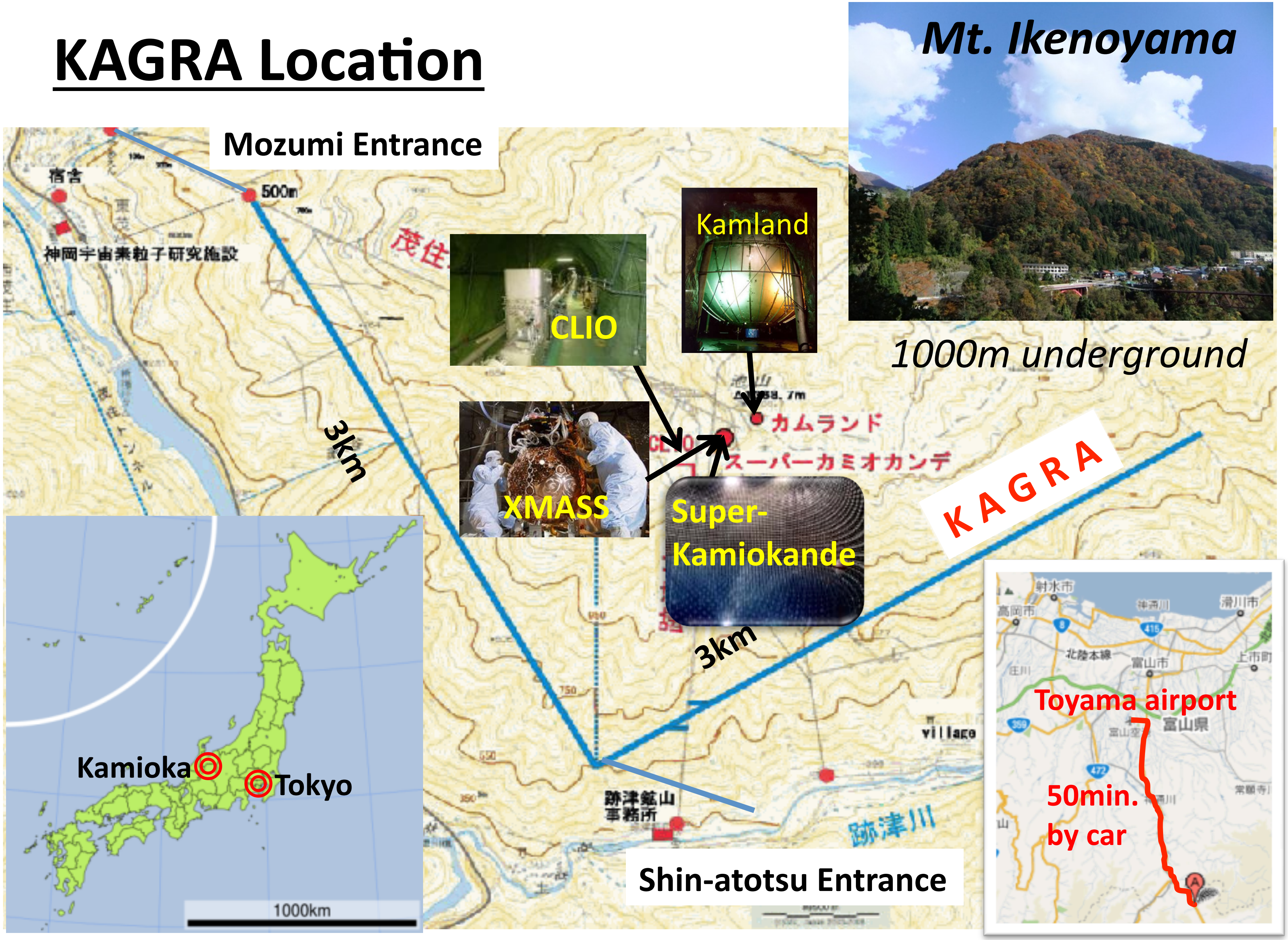



Cryogenic Mirror System
Features in
KAGRA
Underground

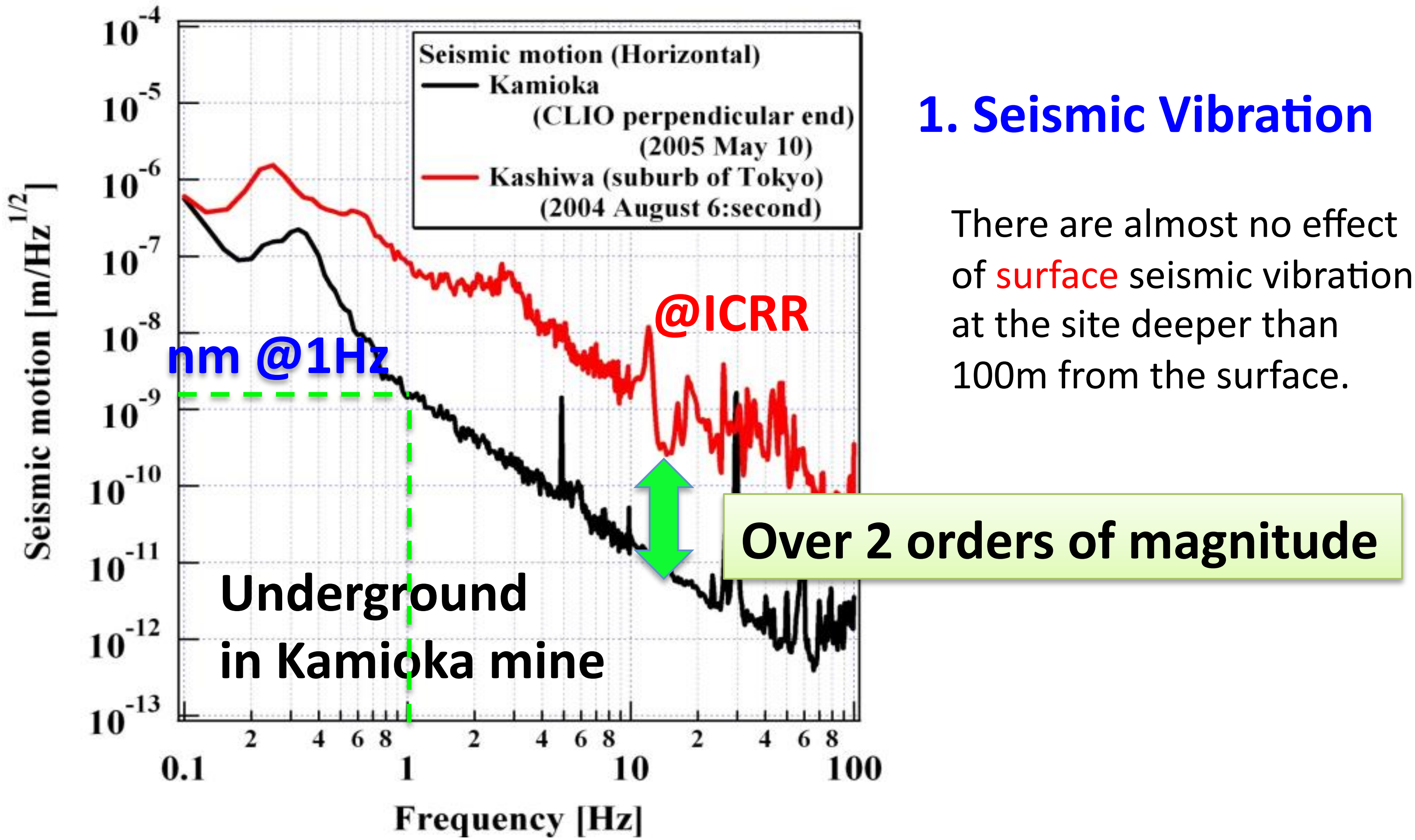
KAGRA Location



Avalanche

last week

Advantages in Kamioka Underground



1. Seismic Vibration

There are almost no effect of surface seismic vibration at the site deeper than 100m from the surface.

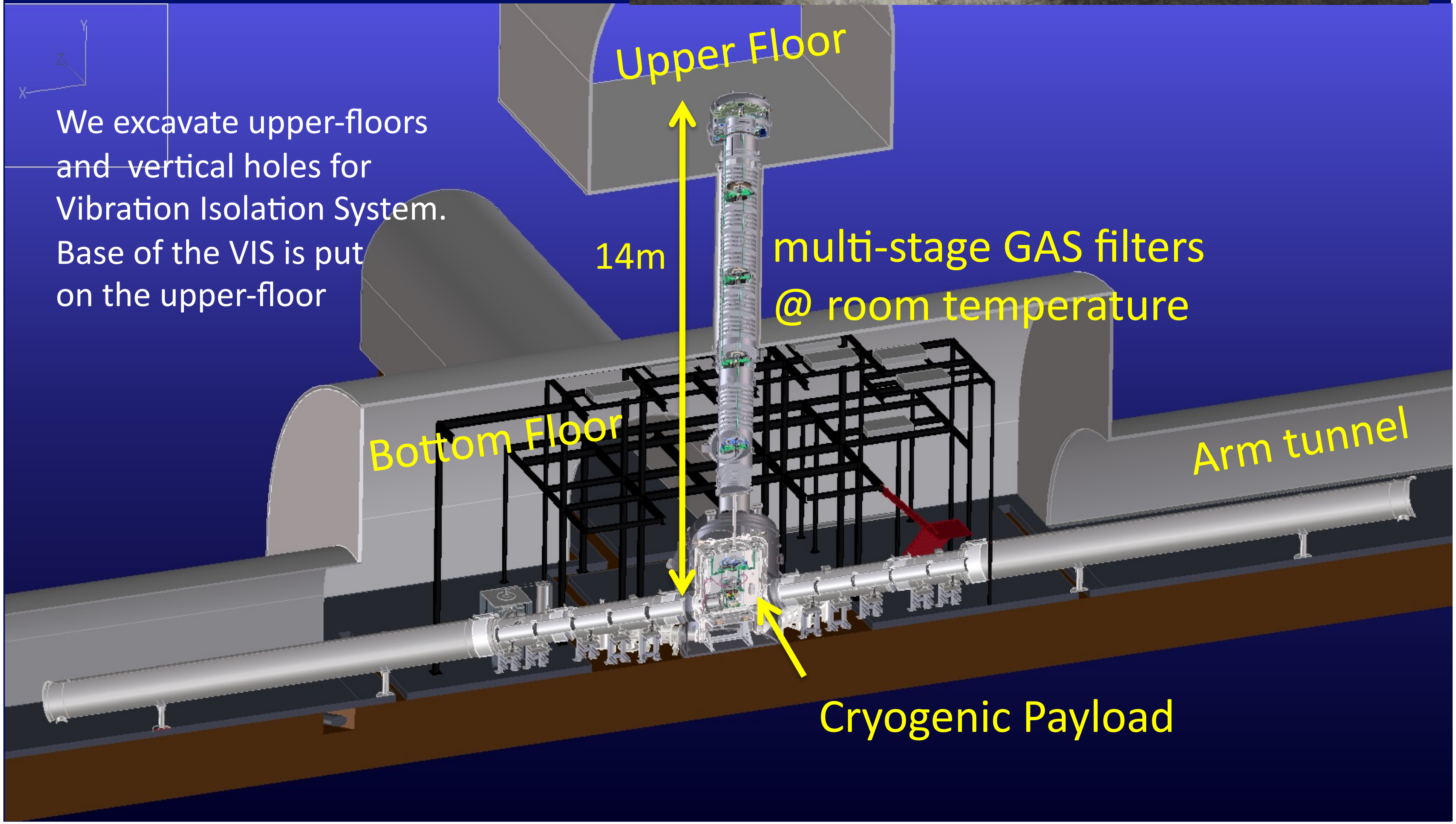
2. Very stable temperature

Only 1℃ temperature variation for a year.

-> Very stable device conditions are realized.

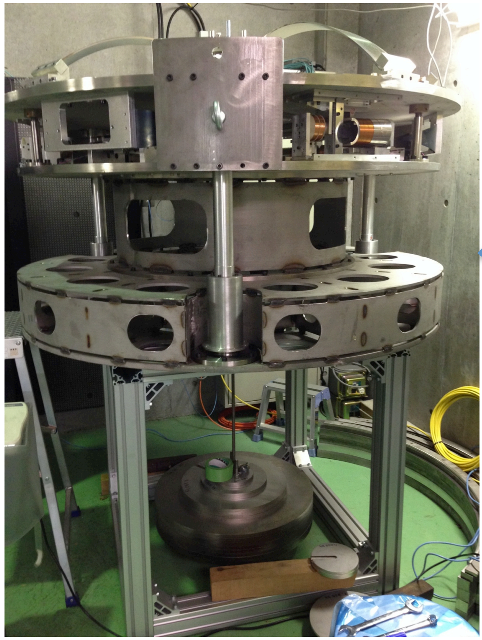
3. Frame-Free Suspension

We excavate upper-floors and vertical holes for Vibration Isolation System. Base of the VIS is put on the upper-floor



Seismic Attenuation System (SAS)

Developed in NAOJ

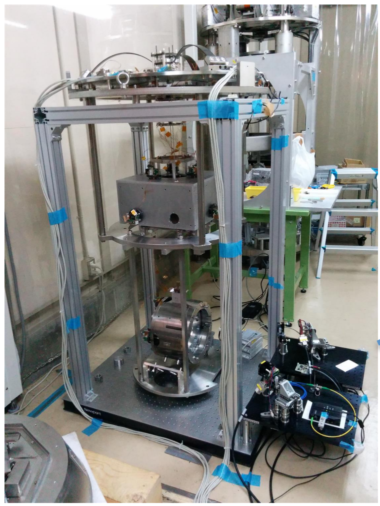


Pre-isolator

- Top Filter
- Inverted Pendulum

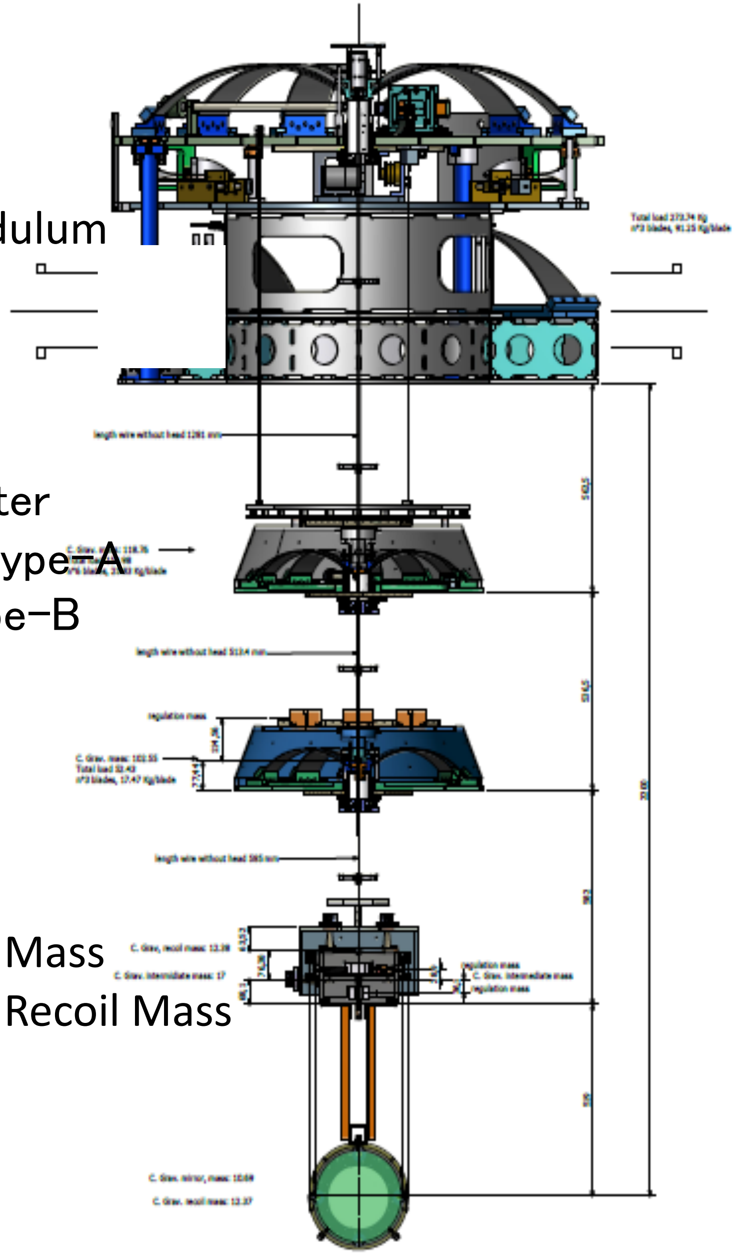
Filter chain

- Standard Filter
- Filter1~3 in Type-A
- Filter1 in Type-B
- Bottom Filter



Payload

- Intermediate Mass
- Intermediate Recoil Mass
- Test Mass
- Recoil Mass



Cryogenic Sapphire Mirror and Suspension

Thermal noise amplitude

$$\sqrt{x(\omega)^2} \propto \sqrt{\frac{T}{Q}}$$

Cryogenic mirror is most straightforward method to reduce thermal noises.

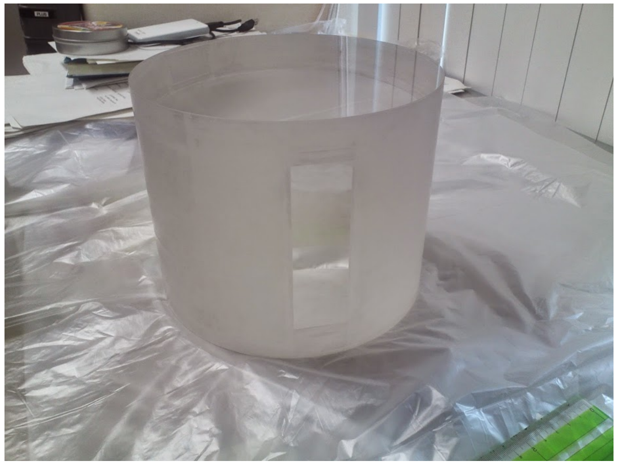
Moreover

Sapphire Mirror: $Q = 2 \times 10^8$

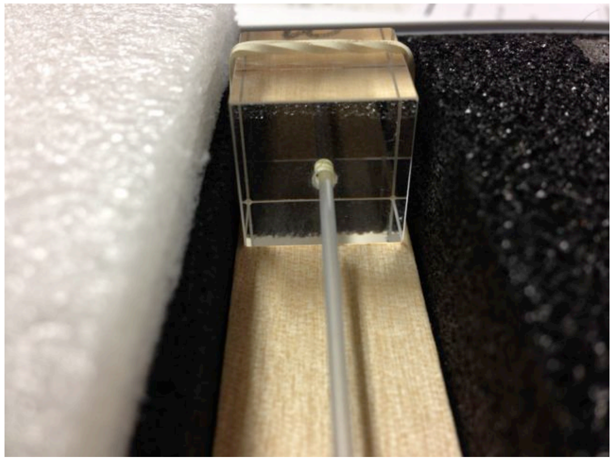
Sapphire Suspension: $Q = 1 \times 10^7$

@ 20K

Typical Q of sapphire at room temperature is ~10^6

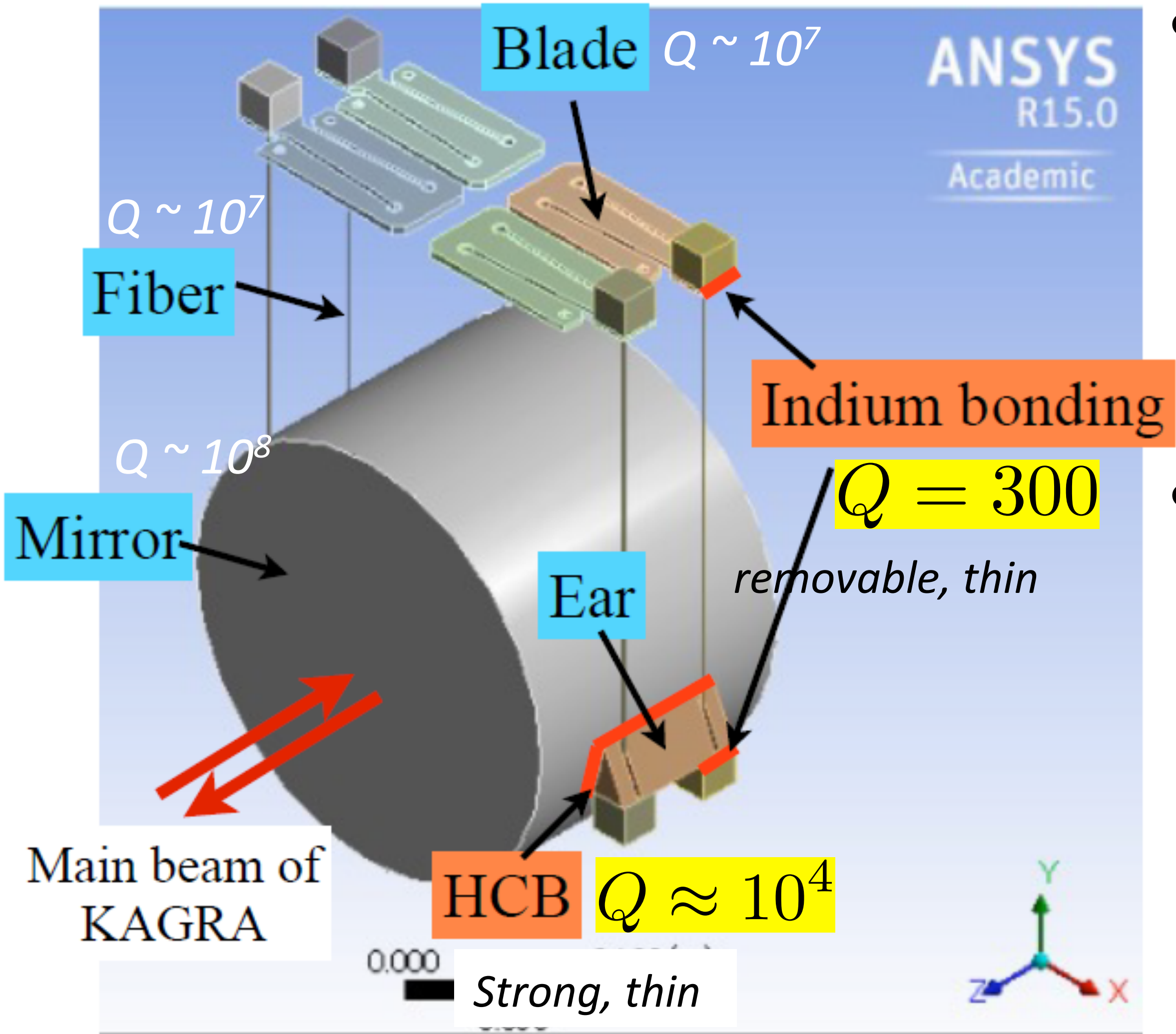


Sapphire substrate



Sapphire fiber w/ nail-head

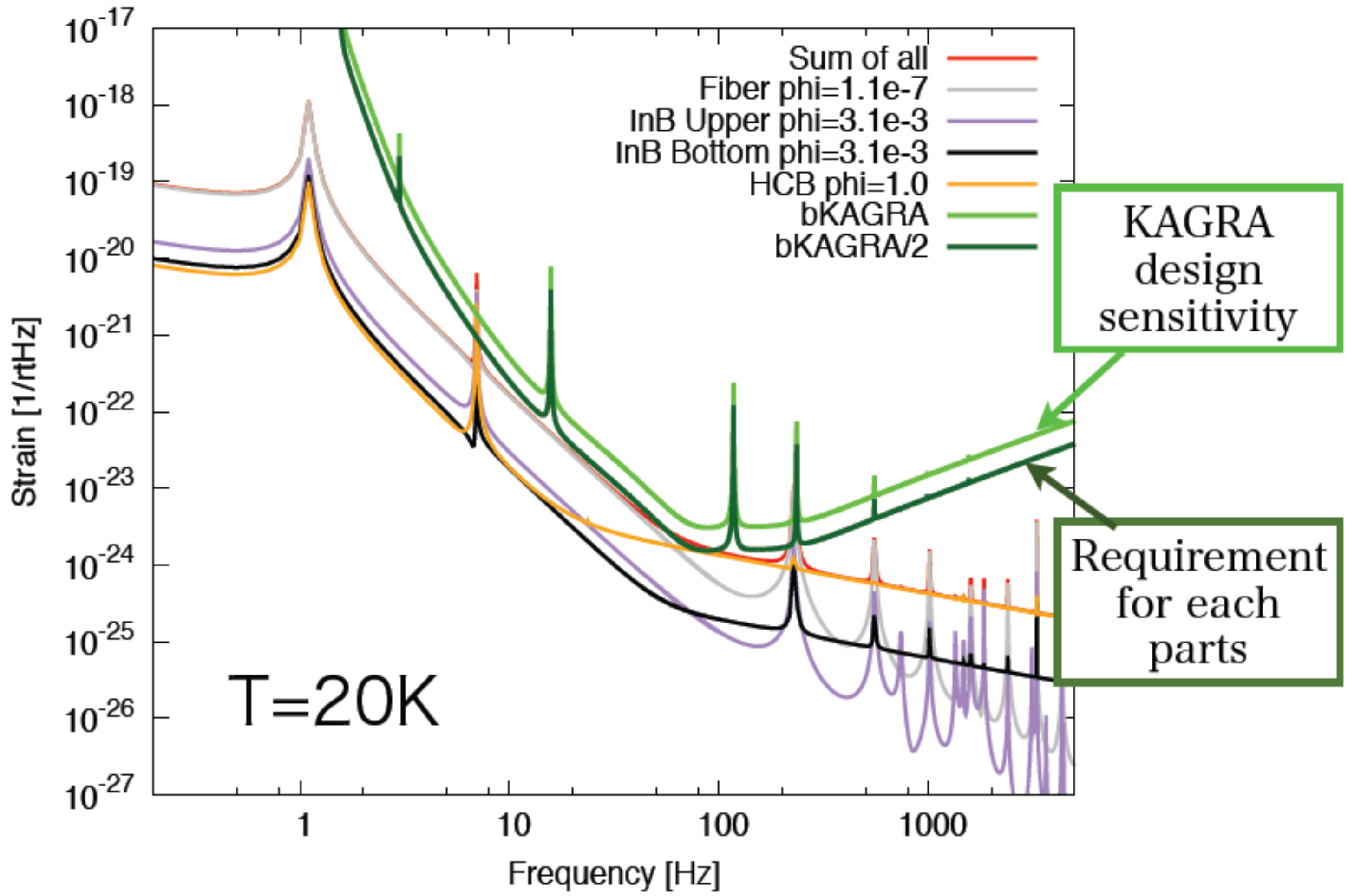
Practical Sapphire Mirror Suspension with High Q



- **Hydro-Catalysis Bonding (HCB)**
  - Kind of chemical bond
  - Strong bonding
  - Thin layer
- **Indium Bonding (IB)**
  - Welding
  - removable
  - Thin layer

 # Removable sapphire fiber connection is technically important when we meet the fiber trouble.

Thermal Noise Estimation for this Practical Suspension

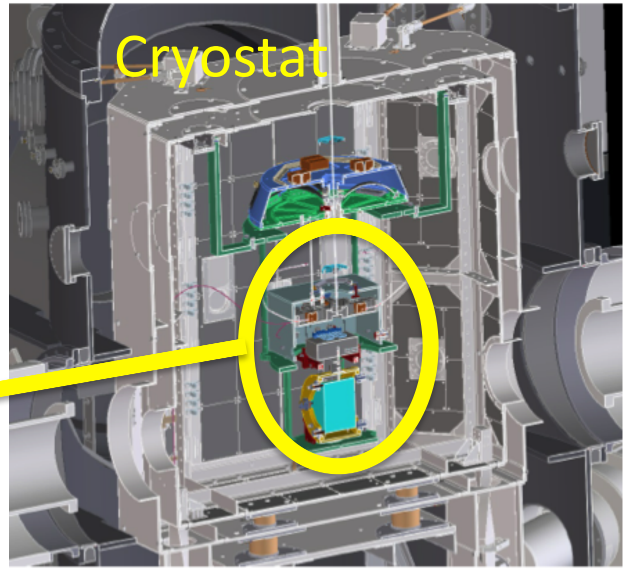


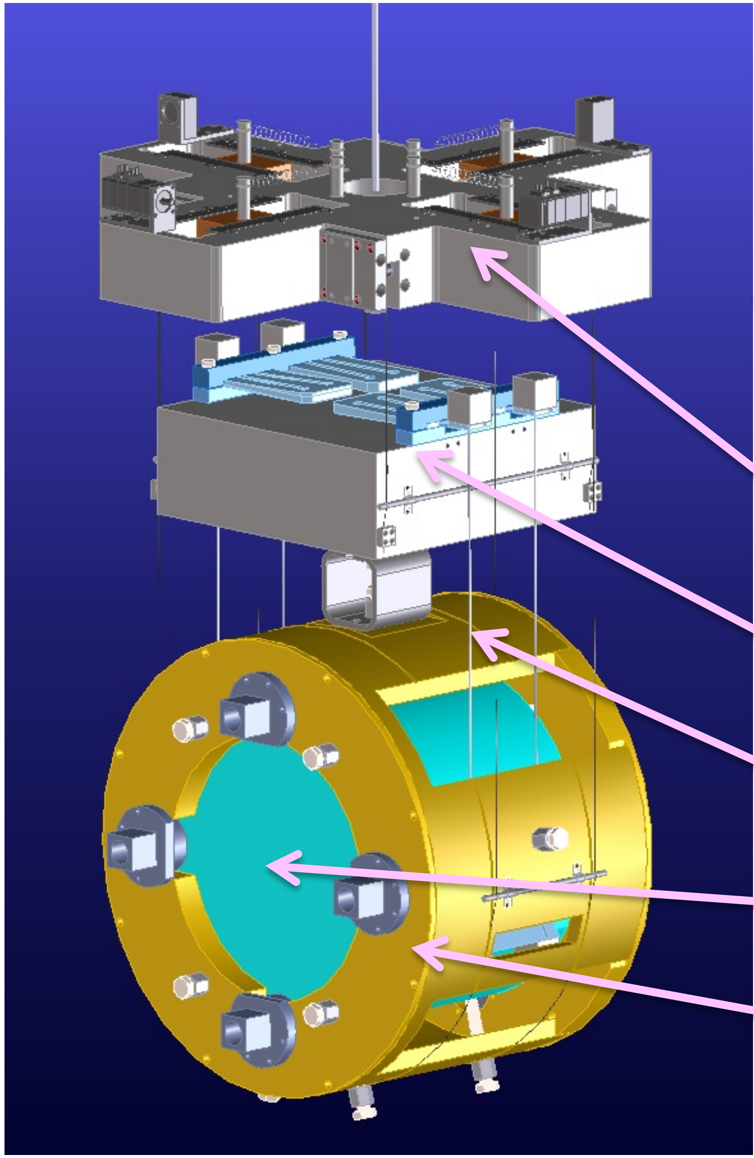
This suspension technique satisfies KAGRA requirement of thermal noises.

These studies are strongly supported by ELiTES program which is collaborative framework between Europe and Japan.

Cryogenic Payload

Under developing in KEK and ICRR





Upper intermediate mass (IM) w/ moving mass

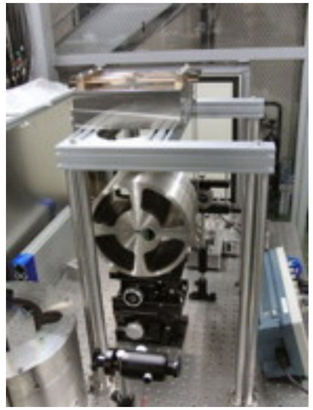
Bottom IM w/ sapphire blades

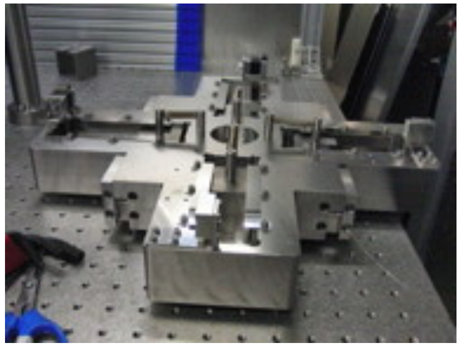
Sapphire suspension fibers

Sapphire Mirror

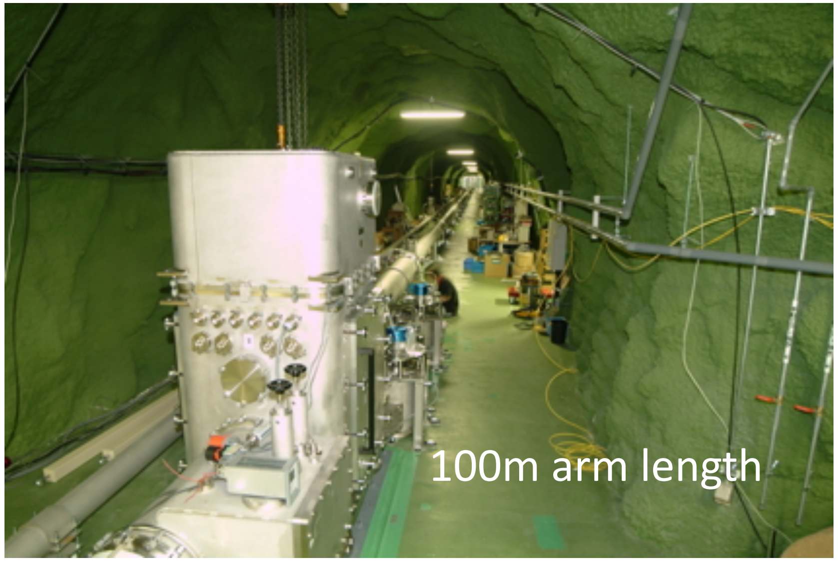
Recoil Mass

IM recoil mass and heat link are not shown.

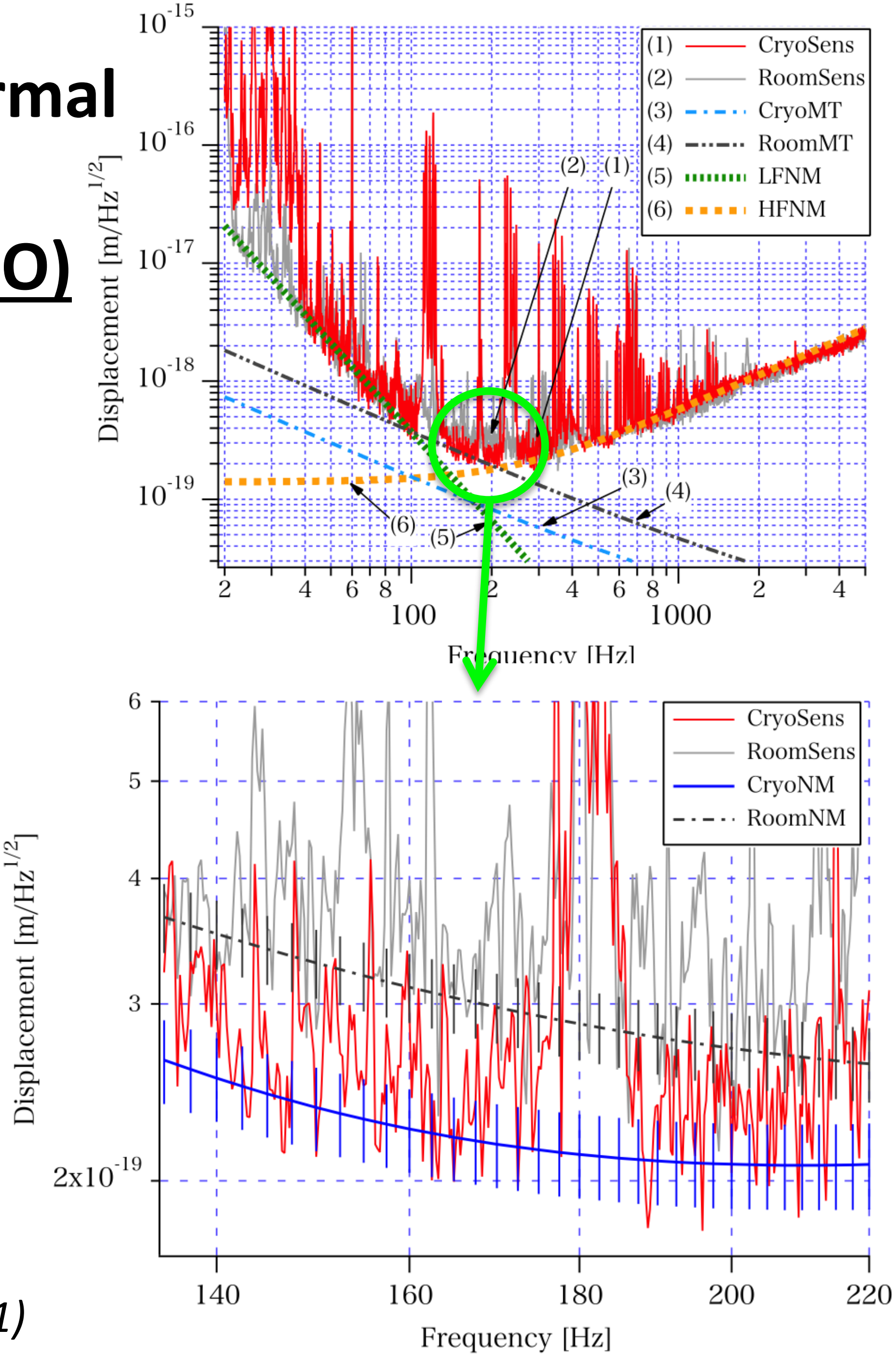




Demonstration of Mirror Thermal Noise Reduction in <u>Cryogenic Interferometer Prototype (CLIO)</u>



Reduction of sapphire mirror thermal noise at room temperature by cooling to 17K was demonstrated.



T. Uchiyama et al., PRL 108, 141101 (2011)

Present Status

Tunnel excavation was done at Mar. 2014

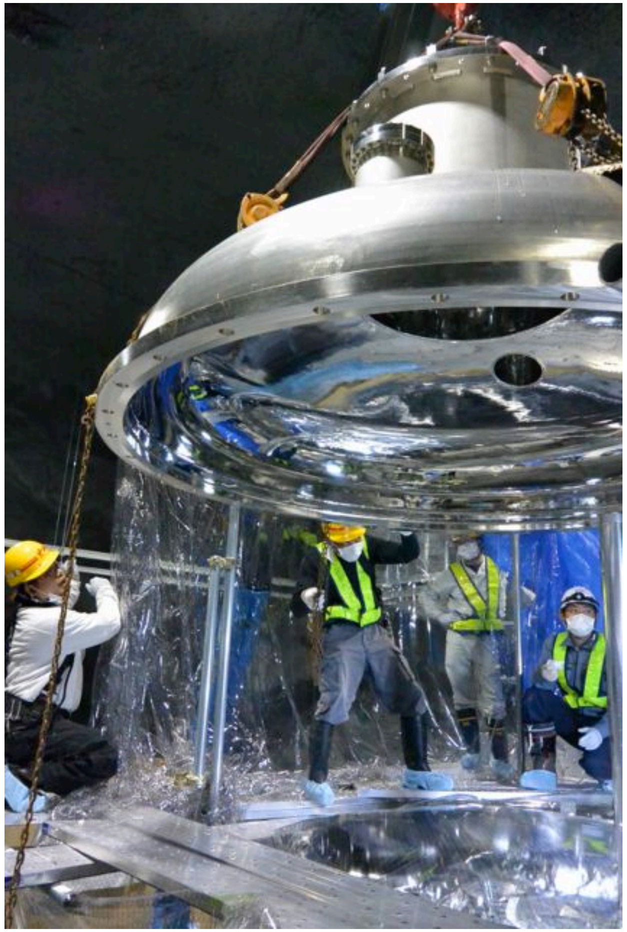
7km tunnel in total

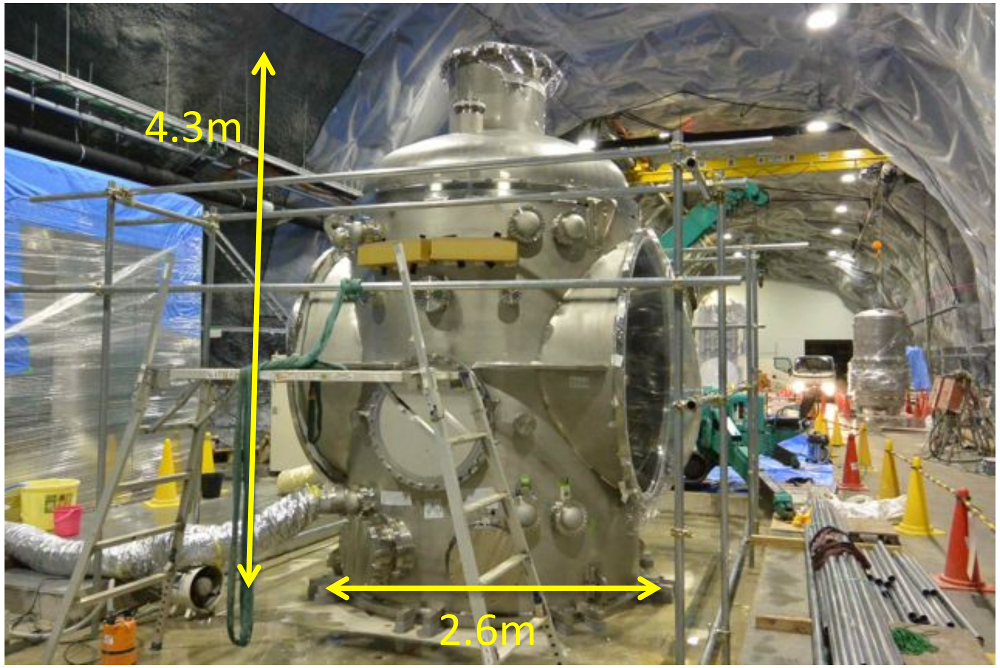
Cryostat Installation
Aug. 14, 2014

<- First device installation

Search KAGRA on YouTube

Cryostat Assembly





Assemblies of X-end, Y-end, Y-front cryostats has been done.
X-front cryostat is under assembly.

Vacuum Tubes and Tanks Installation

Beam tubes: φ800mm x12m x 478

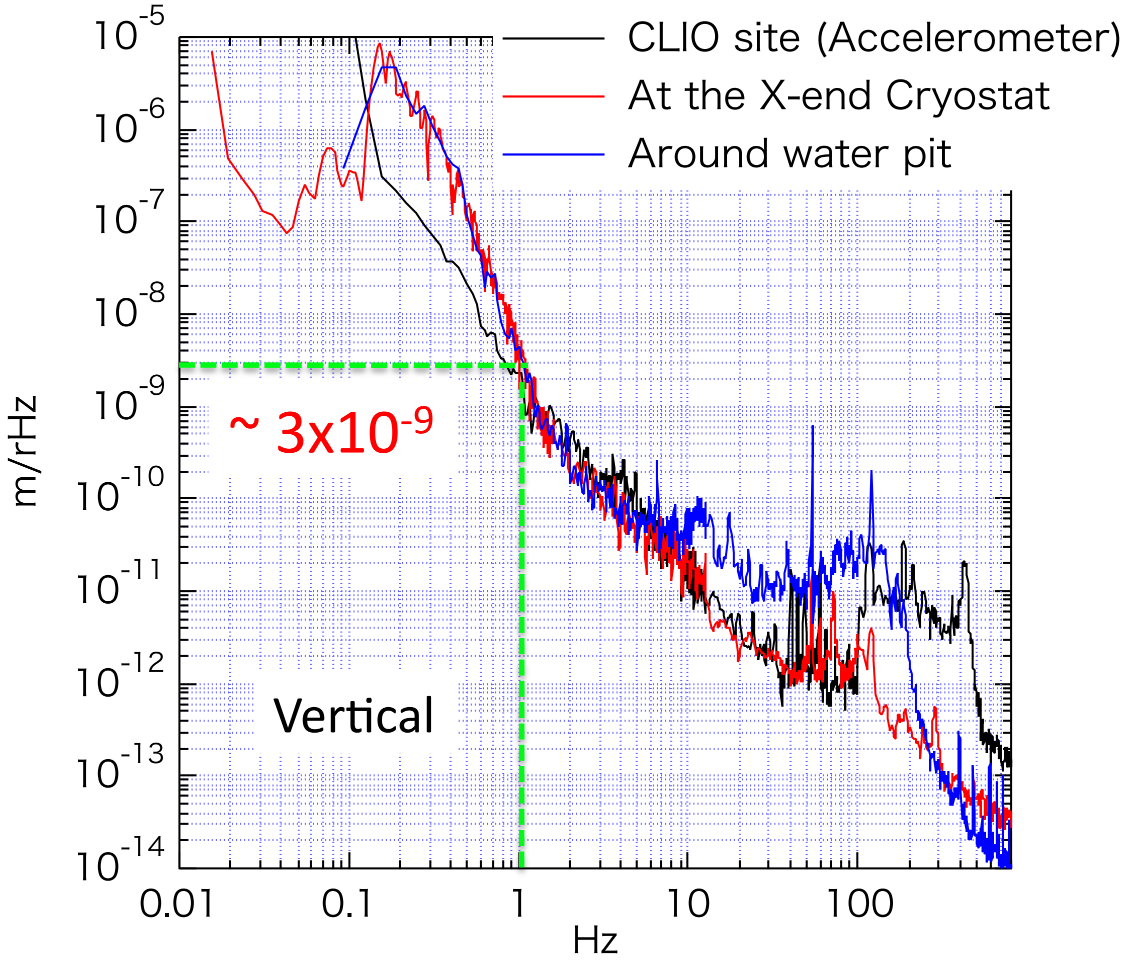
Mode cleaner and BS tanks

Most of vacuum tubes and tanks has been installed, and will be completed within this month.

We also confirmed no vacuum leakage;
$< 1 \times 10^{-12}$ [Pa m^3/sec]

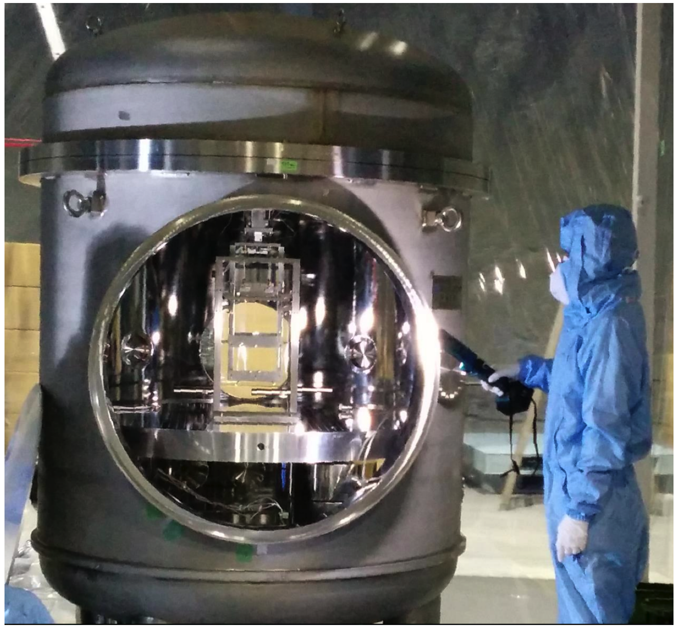
Issue: Water!

Vibration Measurement Results by Seismometer



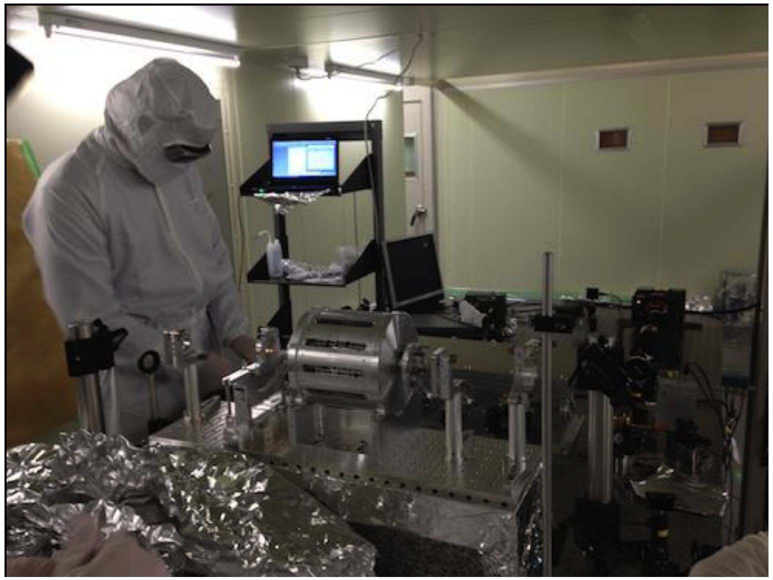
Seismic vibration at X-end cryostat is expected level, comparable with CLIO site.
In front of water pit where is about 10m from the cryostat location, we found excess over 10Hz.

Mode cleaner mirror suspensions have been installed.

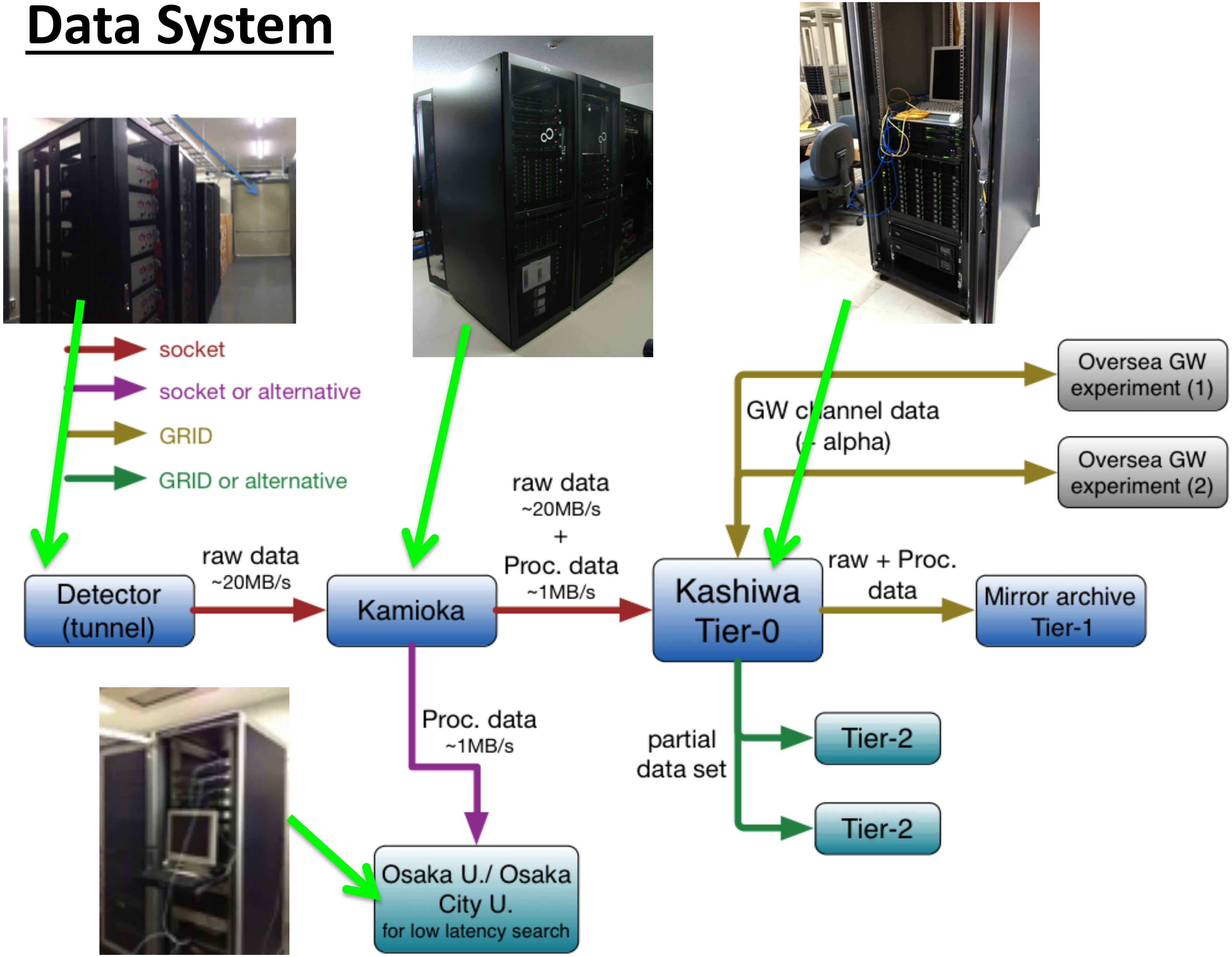


Clean Booths are under constructing

Input optics is under installation

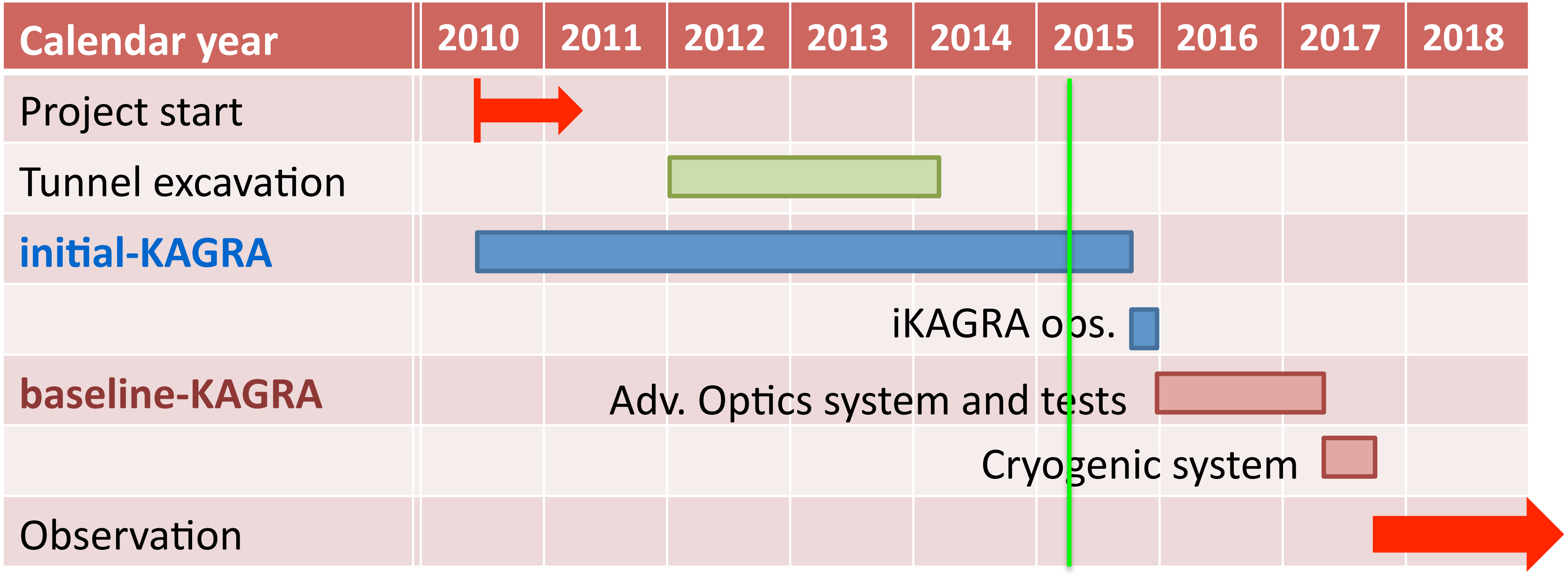


Data System

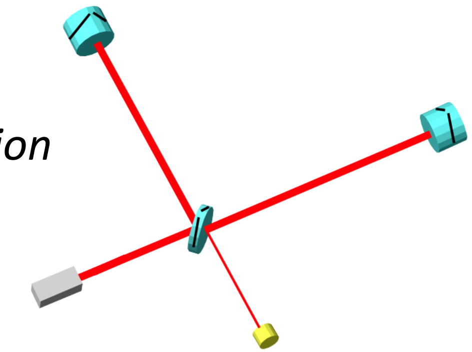


socket
socket or alternative
GRID
GRID or alternative
Detector (tunnel)
raw data ~20MB/s
Kamioka
raw data ~20MB/s + Proc. data ~1MB/s
Kashiwa Tier-0
GW channel data (+ alpha)
Oversea GW experiment (1)
Oversea GW experiment (2)
raw + Proc. data
Mirror archive Tier-1
Proc. data ~1MB/s
partial data set
Tier-2
Tier-2
Osaka U./ Osaka City U.
for low latency search

Schedule of KAGRA



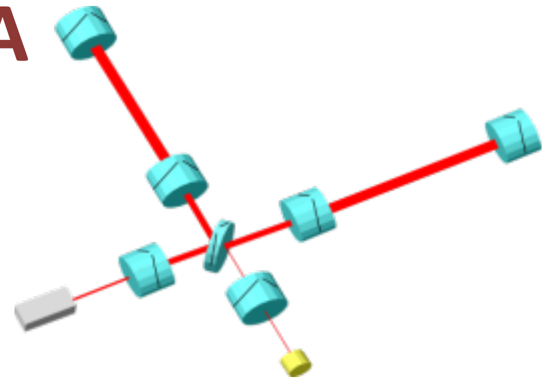
iKAGRA



basic operation test

- **Michelson interferometer**
- **Room temperature**
- **Simple seismic isolation system**

bKAGRA



- **Resonant sideband extraction**
- **Cryogenic Sapphire Mirror**
- **Advanced seismic isolation system**

Summary

- KAGRA is a new 2nd generation GW telescope under construction in Japan.
- KAGRA uses challenging technologies such like cryogenic mirror and underground site. These technologies will be advanced in 3rd generation GW telescope; Einstein Telescope.
- Tunnel excavation was done at Mar. 2014, and we installed large devices such like cryostats and vacuum chambers soon.
- Installation of major devices will be completed in 2015, and we will have iKAGRA basic test operation after then.
- Baseline KAGRA including cryogenic mirrors will be ready at the end of 2017.