LIGO seminar
Jul. 20, 2015
Caltech, Pasadena, USA

Status of KAGRA

Seiji Kawamura (ICRR, UTokyo)

JGW-G1503846-v1

Outline:

- Review of KAGRA
- Current status
- Schedule, Organization, Collaboration
- Summary

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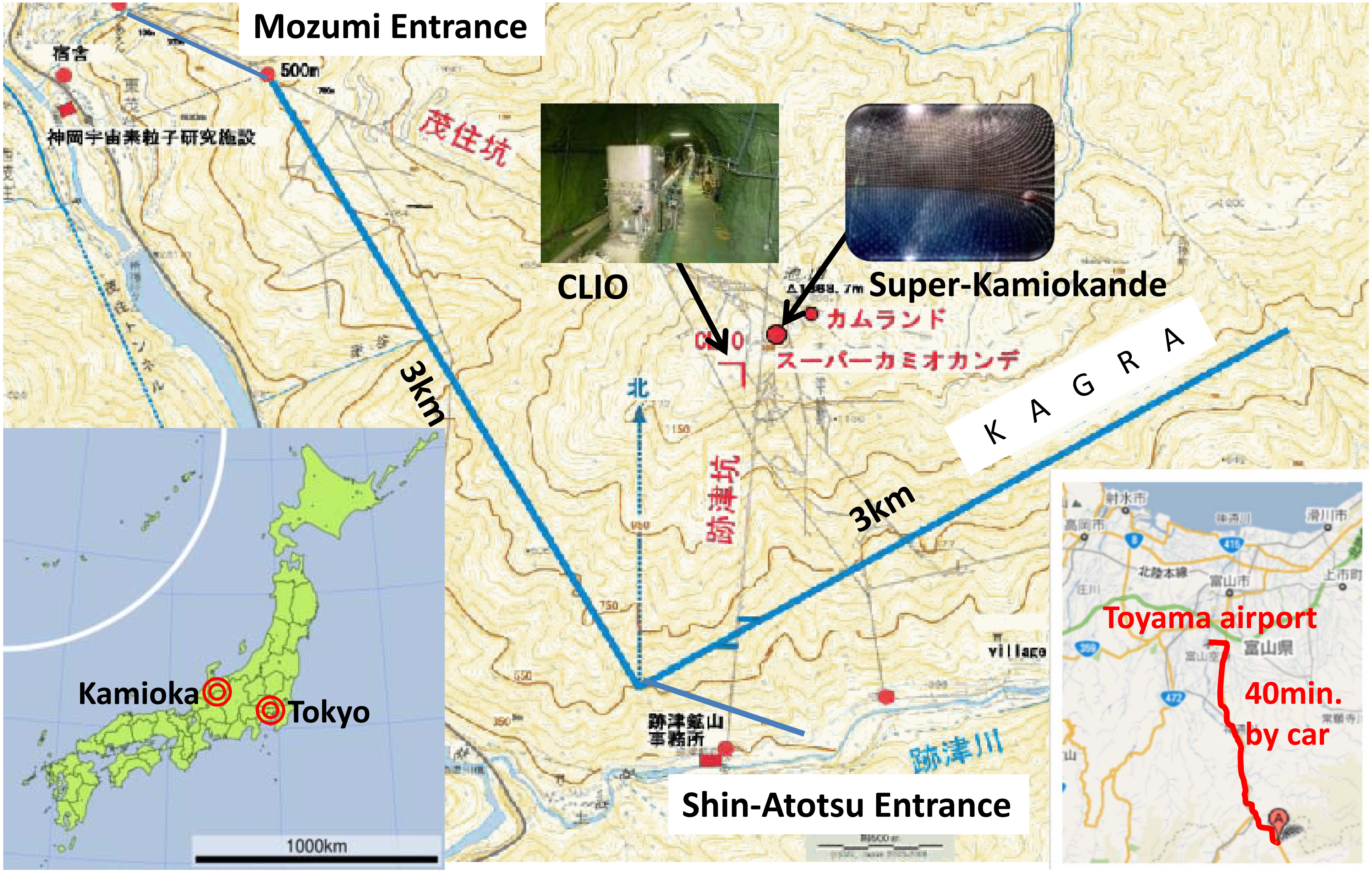
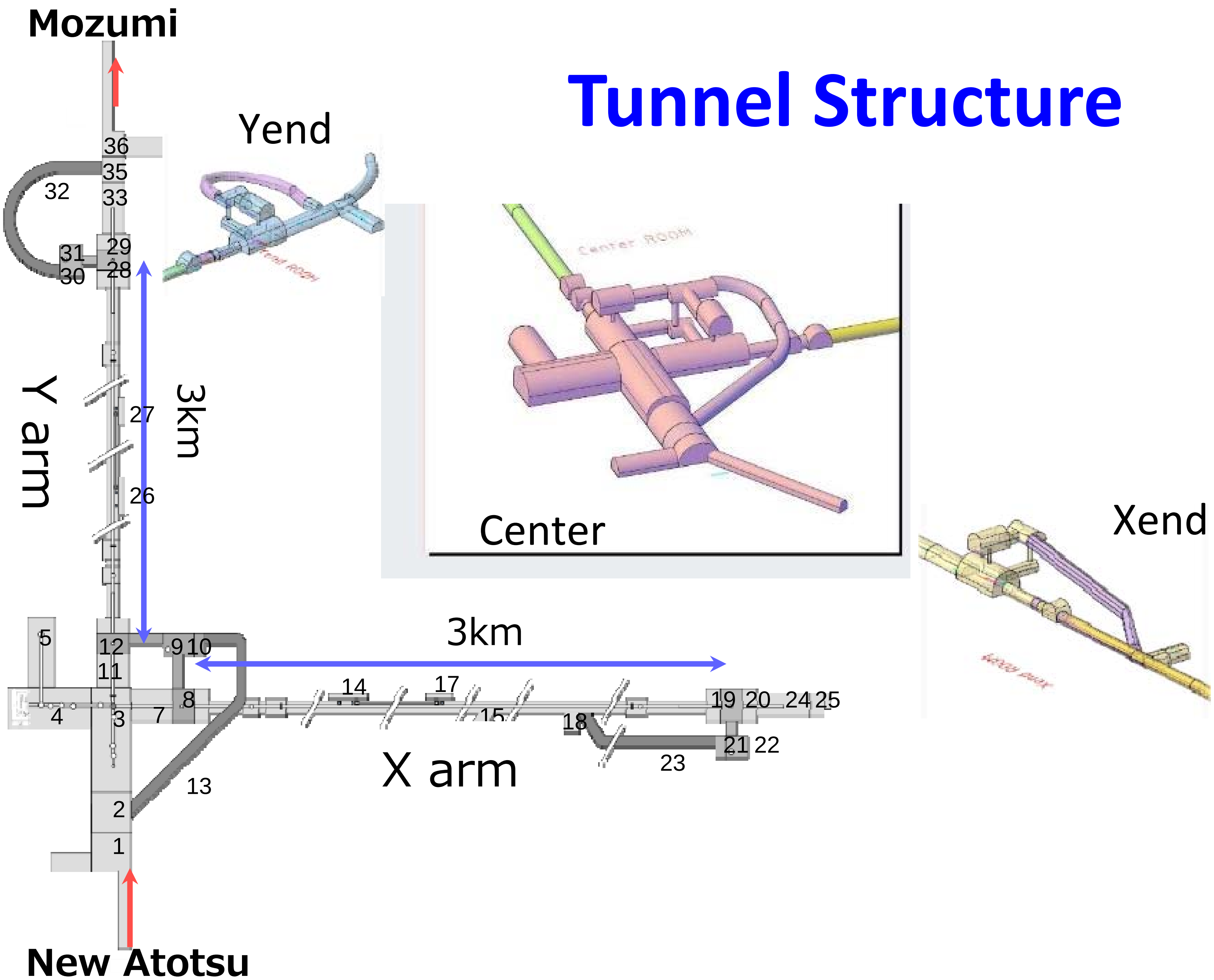
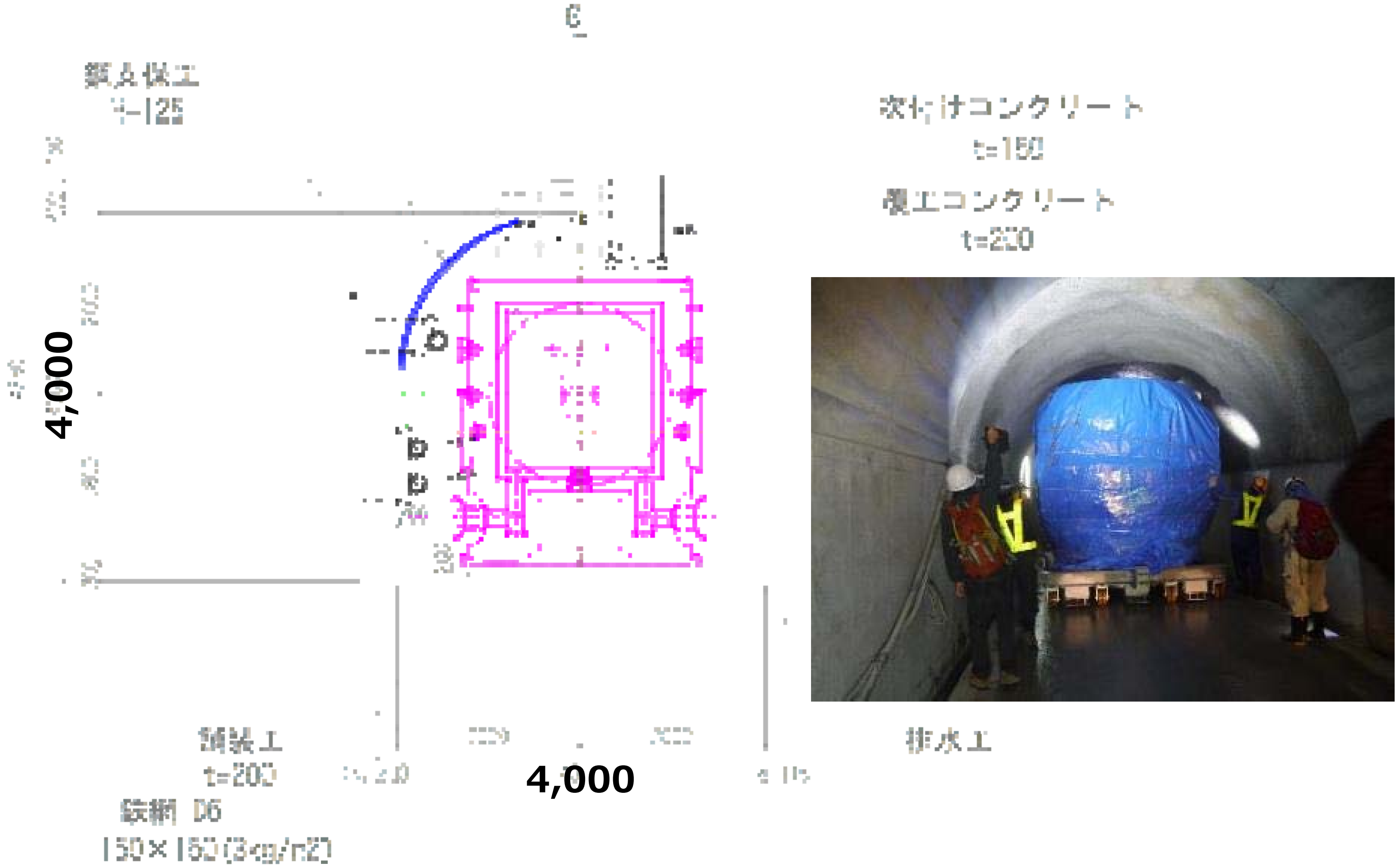
Location (Kamioka)



Tunnel Structure

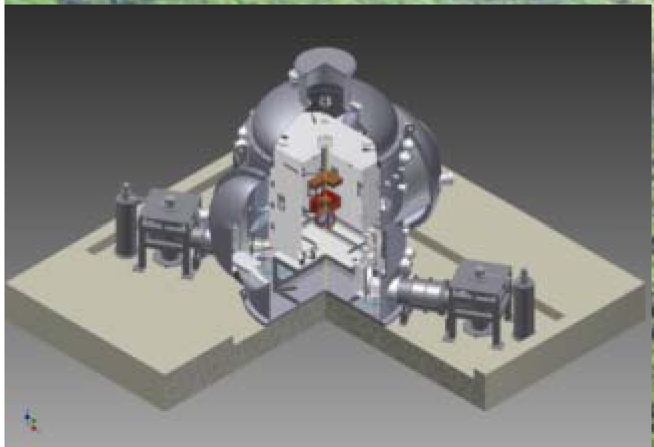


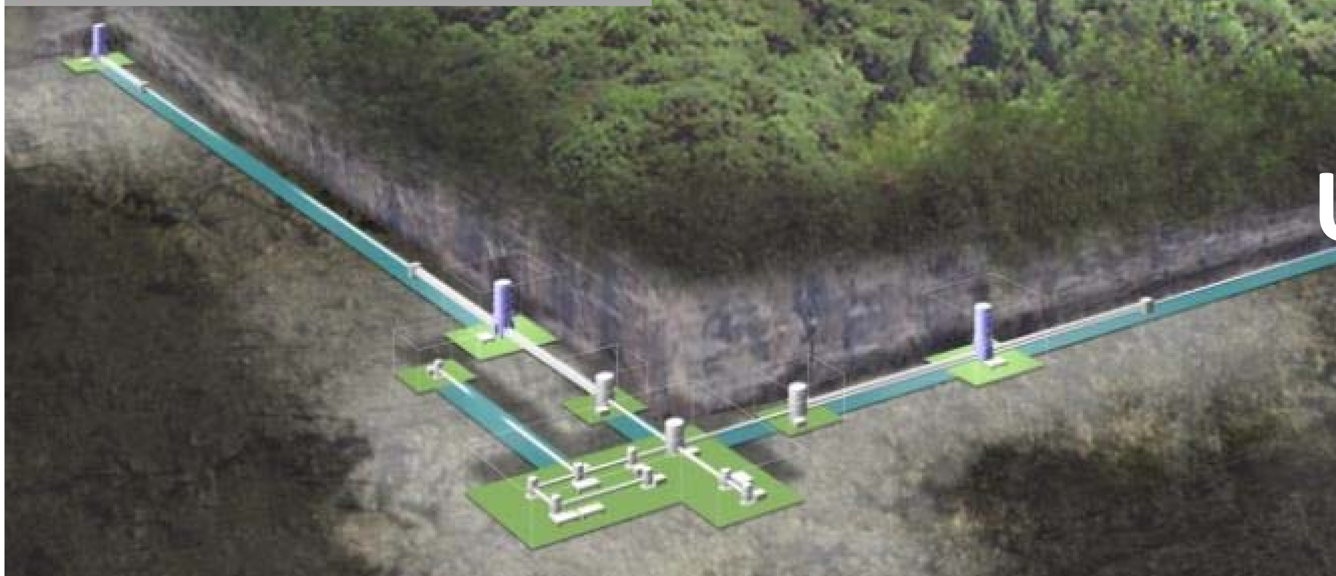
Standard cross-section of the tunnel



Key features of KAGRA

Cryogenic Mirror

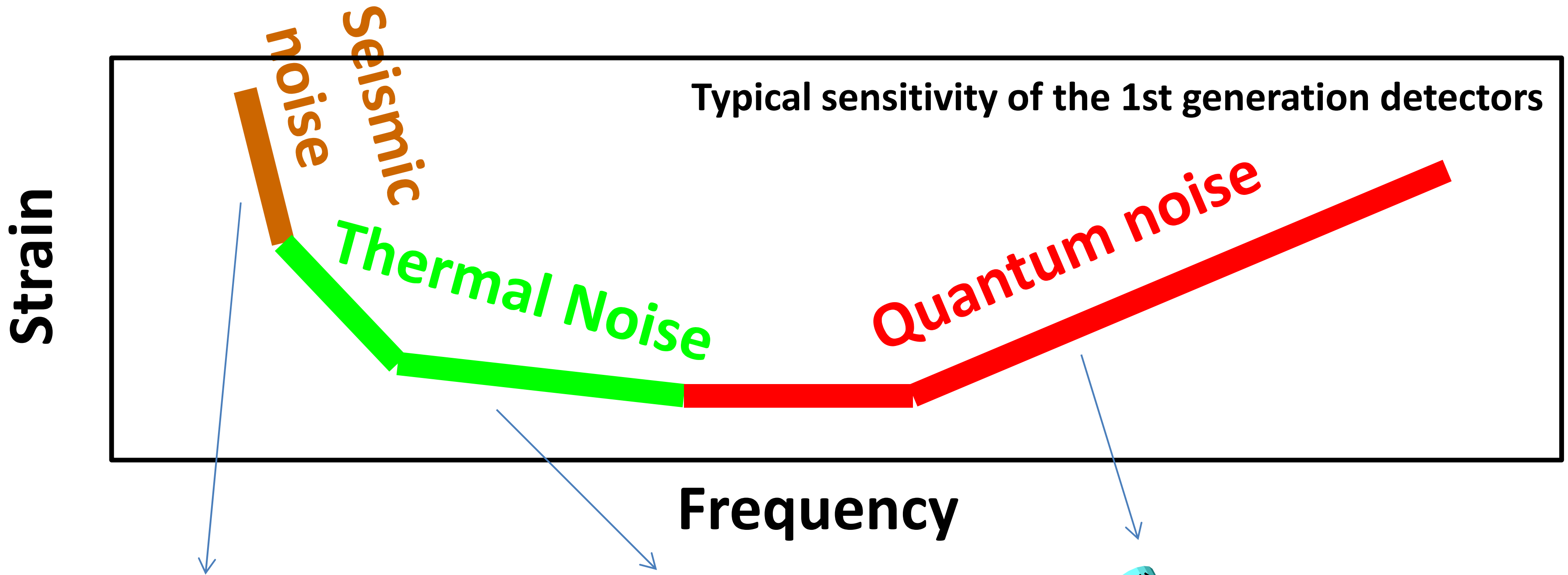




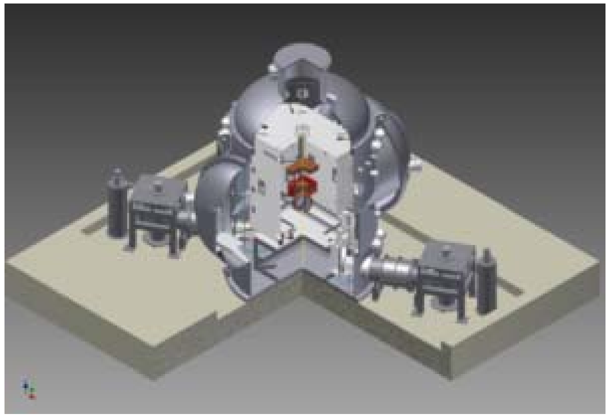
Underground

Technologies crucial for the 3rd-generation detectors;
KAGRA can be regarded as a 2.5-generation detector.

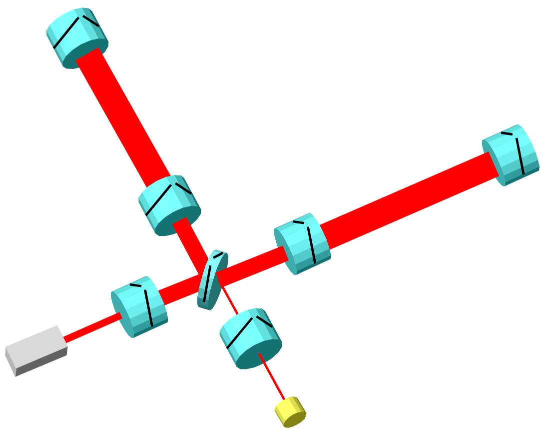
Two technologies + one



Underground

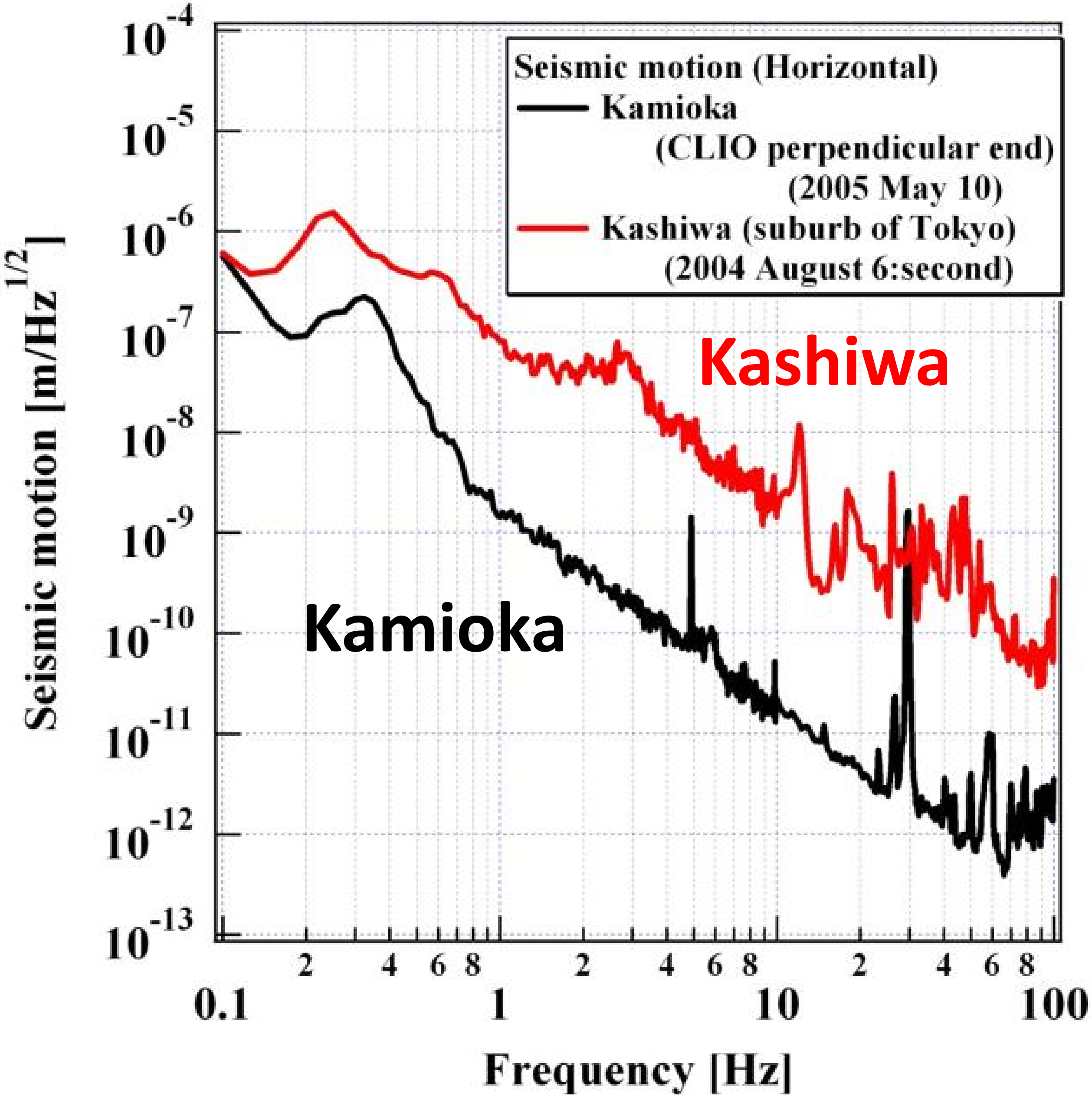


Cryogenic Mirror



Resonant Sideband Extraction

Ground motion in Kamioka mine



Further seismic isolation is still necessary

Vibration of mirrors:

10^{-11} $mHz^{-1/2}$

Should be improved by 7 orders of magnitude

10^{-18} $mHz^{-1/2}$ @10 Hz

Vibration isolation system

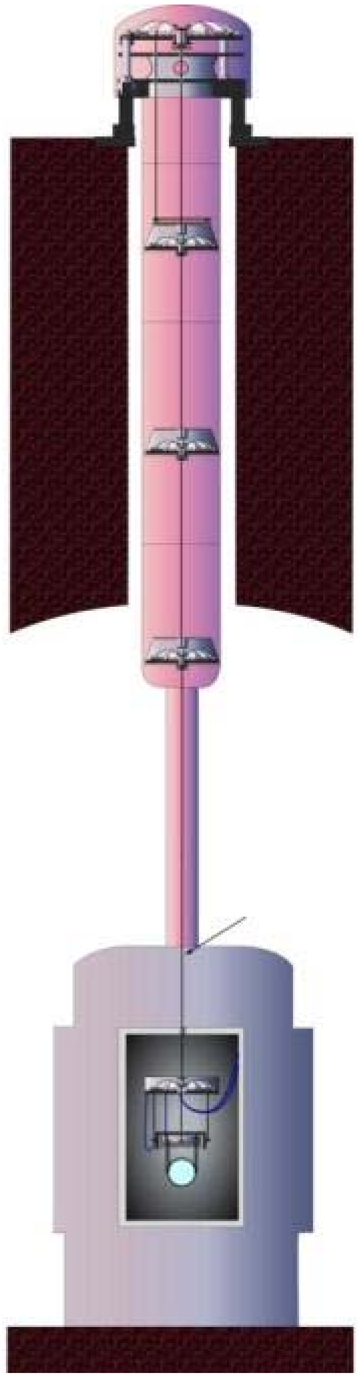
2nd floor

Inverted pendulum
Geometrical antispring (GAS) filter

Multi-stage pendulum
(with GAS filter)

1st floor

Another pendulum
(with GAS filter)
Mirror suspension



GAS filter

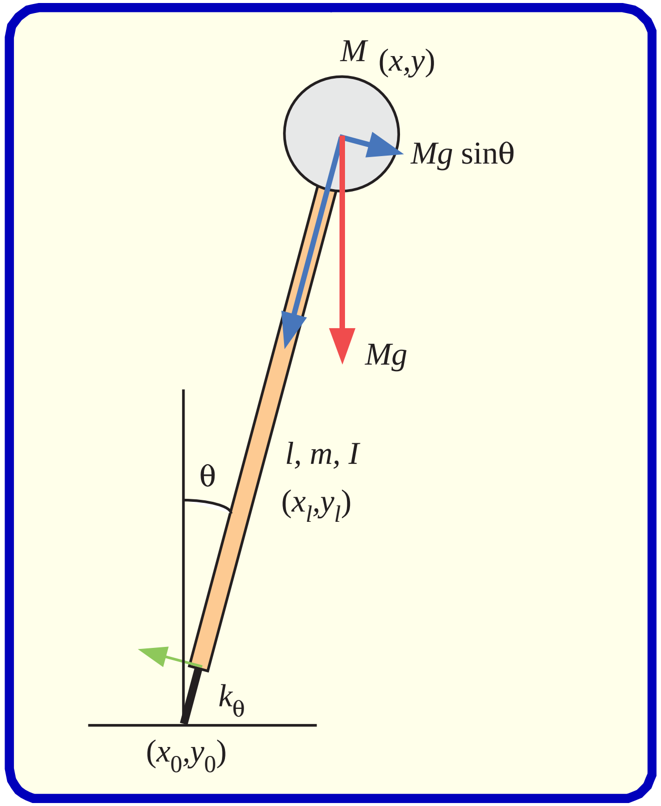
Two-layer structure to avoid the resonances of the tall structure.

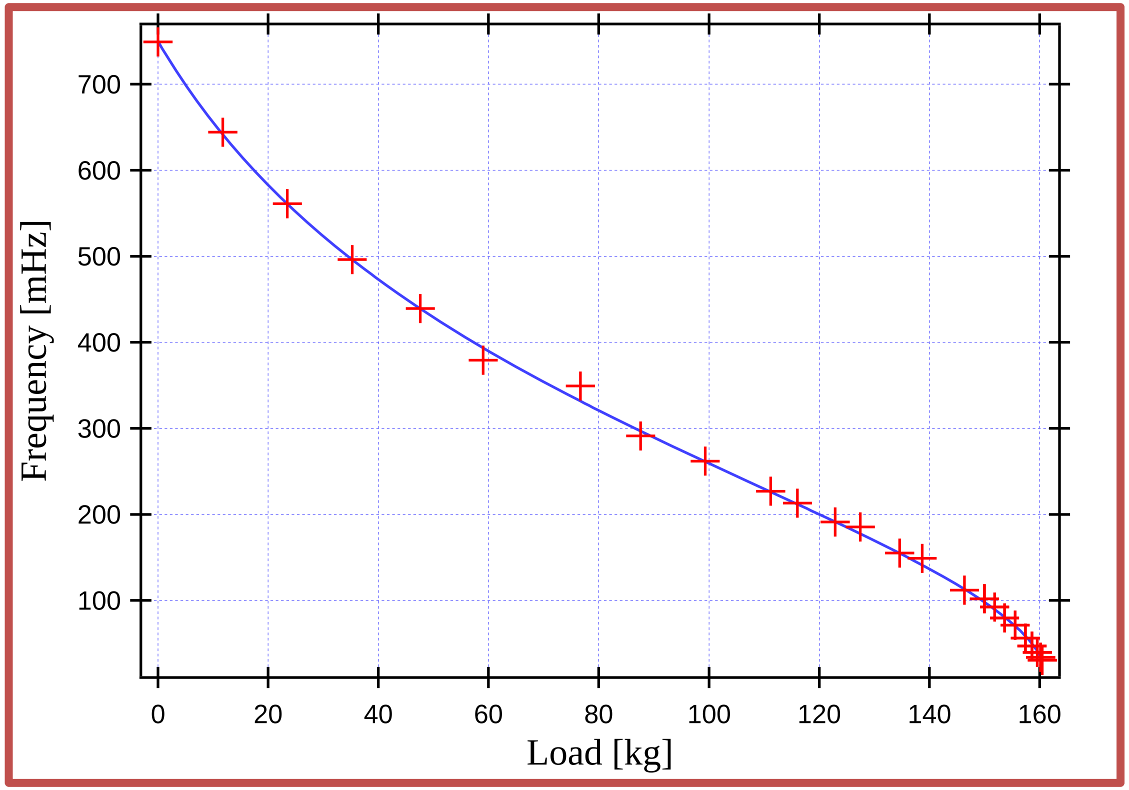
Inverted pendulum

Restoring force

= Spring force of Metal rod + antispring force of mass gravity

⇒ Lower resonant frequency





Vertical seismic isolation

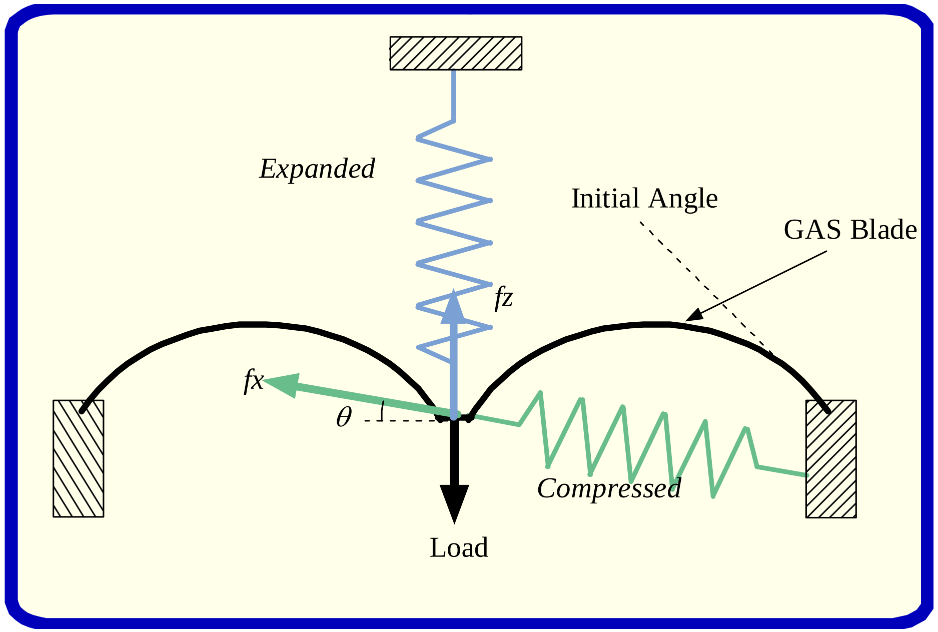
- **Coupling from vertical motion to horizontal motion exists because of:**
  - **earth curvature**
  - **mechanical coupling**
  - **Slope (1/300; for draining spring water)**

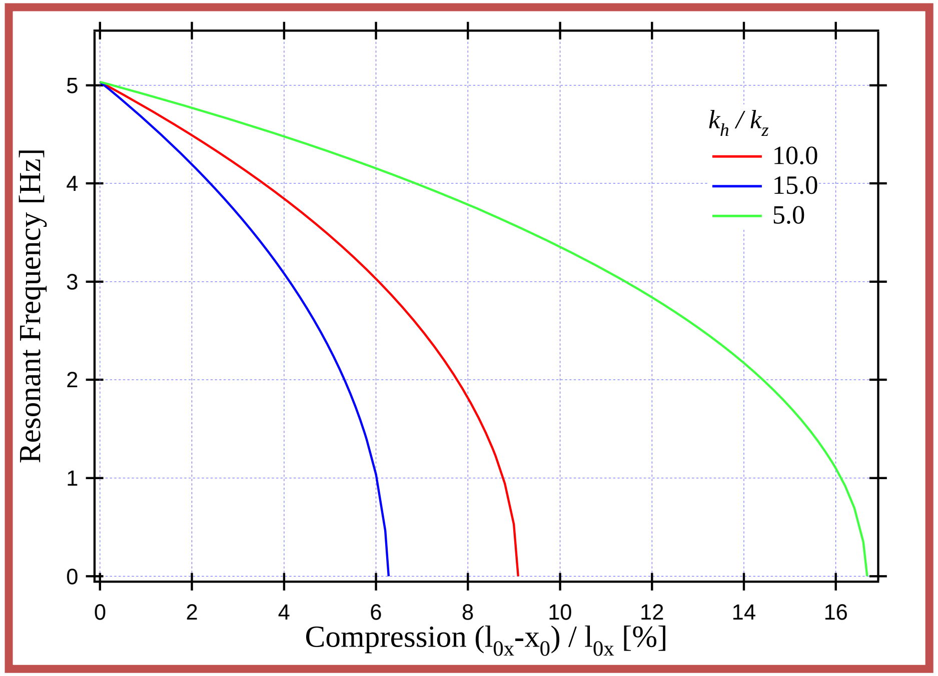
$\Rightarrow$ Vertical seismic isolation is necessary

Geometric Antispring (GAS) Filter

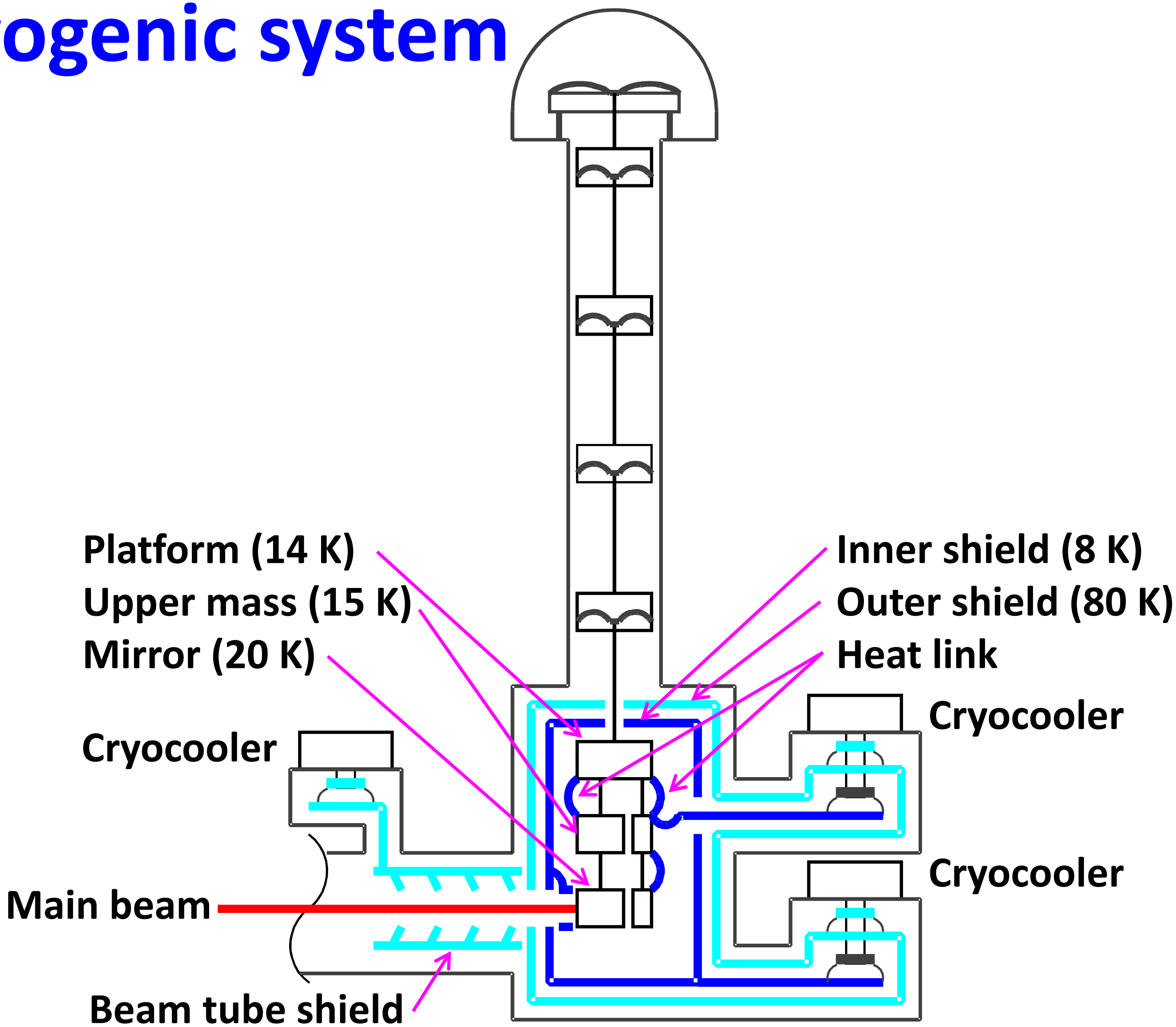
Restoring force
= Spring force of blade + antispring force of squeezed blades

⇒ Lower resonant frequency

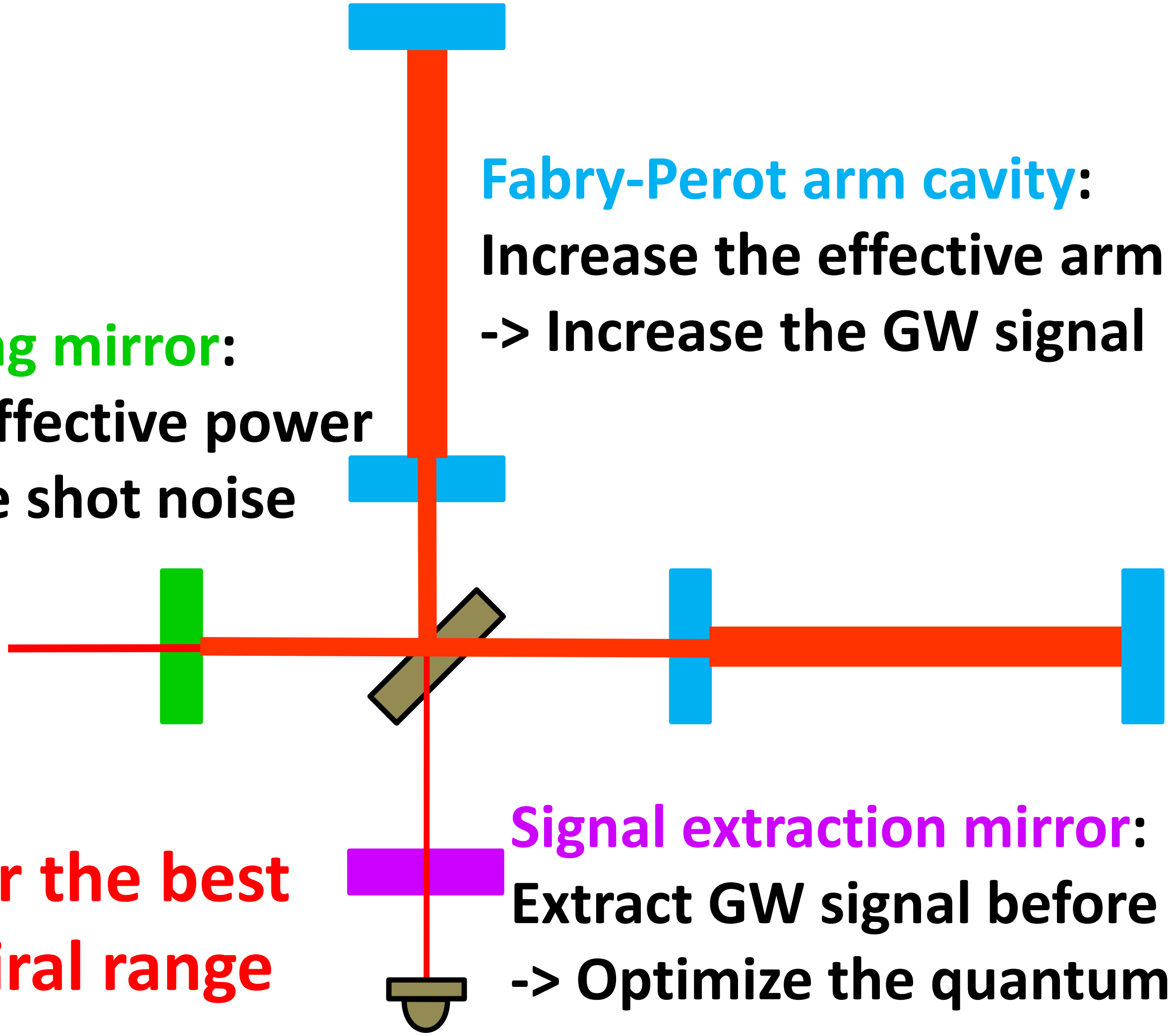




Cryogenic system



RSE interferometer



Fabry-Perot arm cavity:
Increase the effective arm length
-> Increase the GW signal

Power recycling mirror:
Increase the effective power
-> Improve the shot noise

Signal extraction mirror:
Extract GW signal before cancellation
-> Optimize the quantum noise

Detuned for the best NS-NS inspiral range

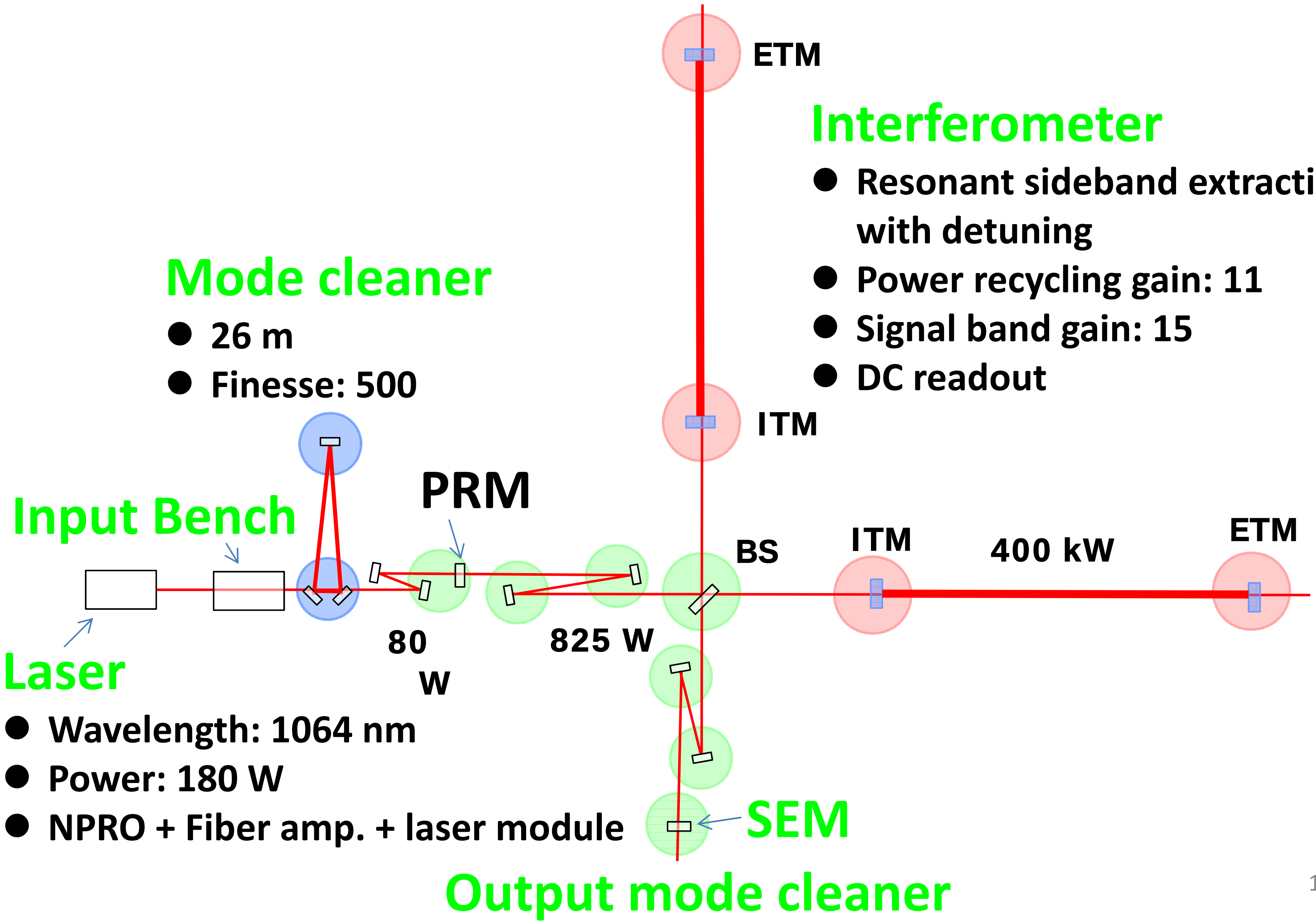
Optical configuration

Interferometer

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

Mode cleaner

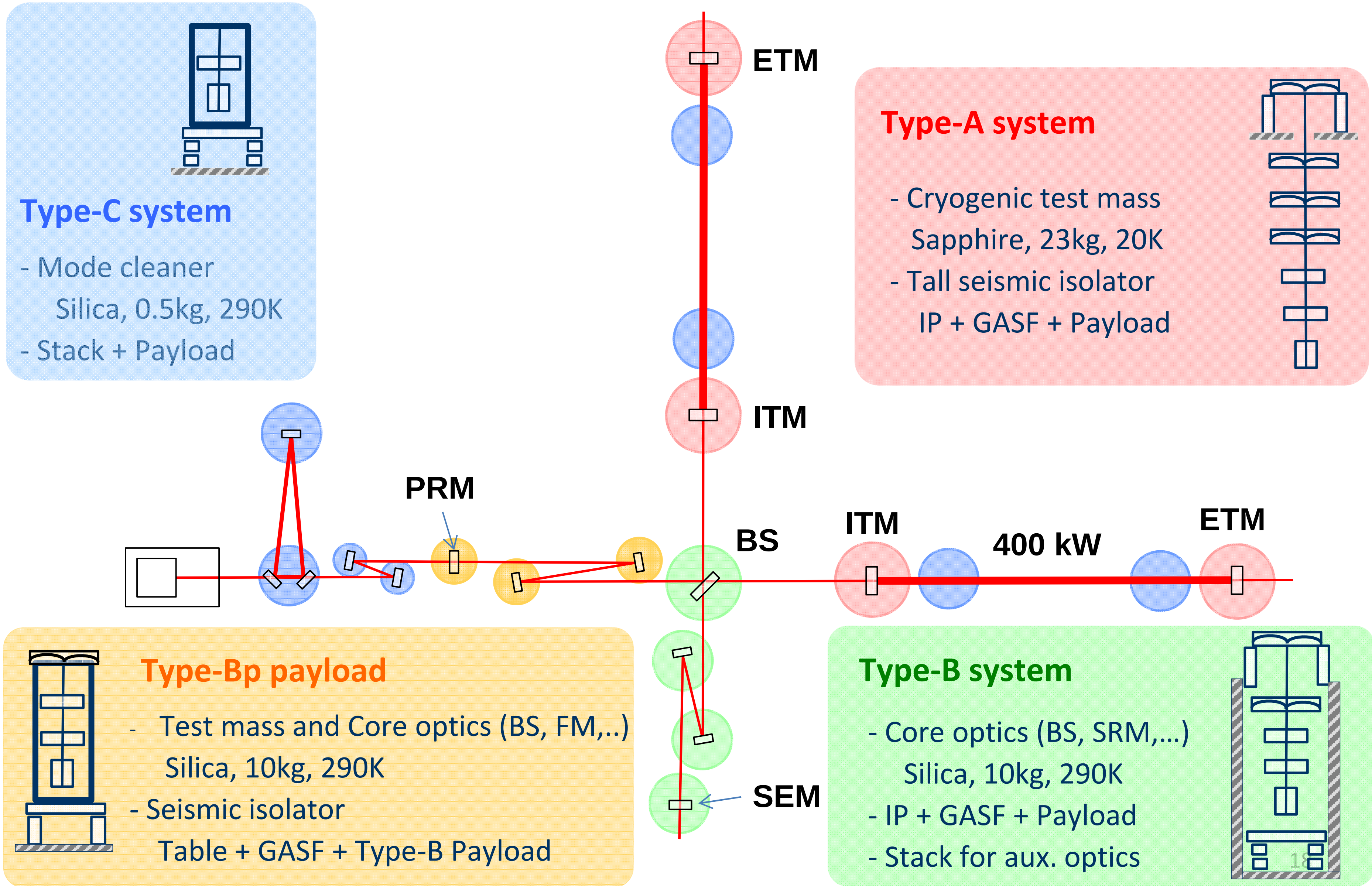
- 26 m
- Finesse: 500



Laser

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

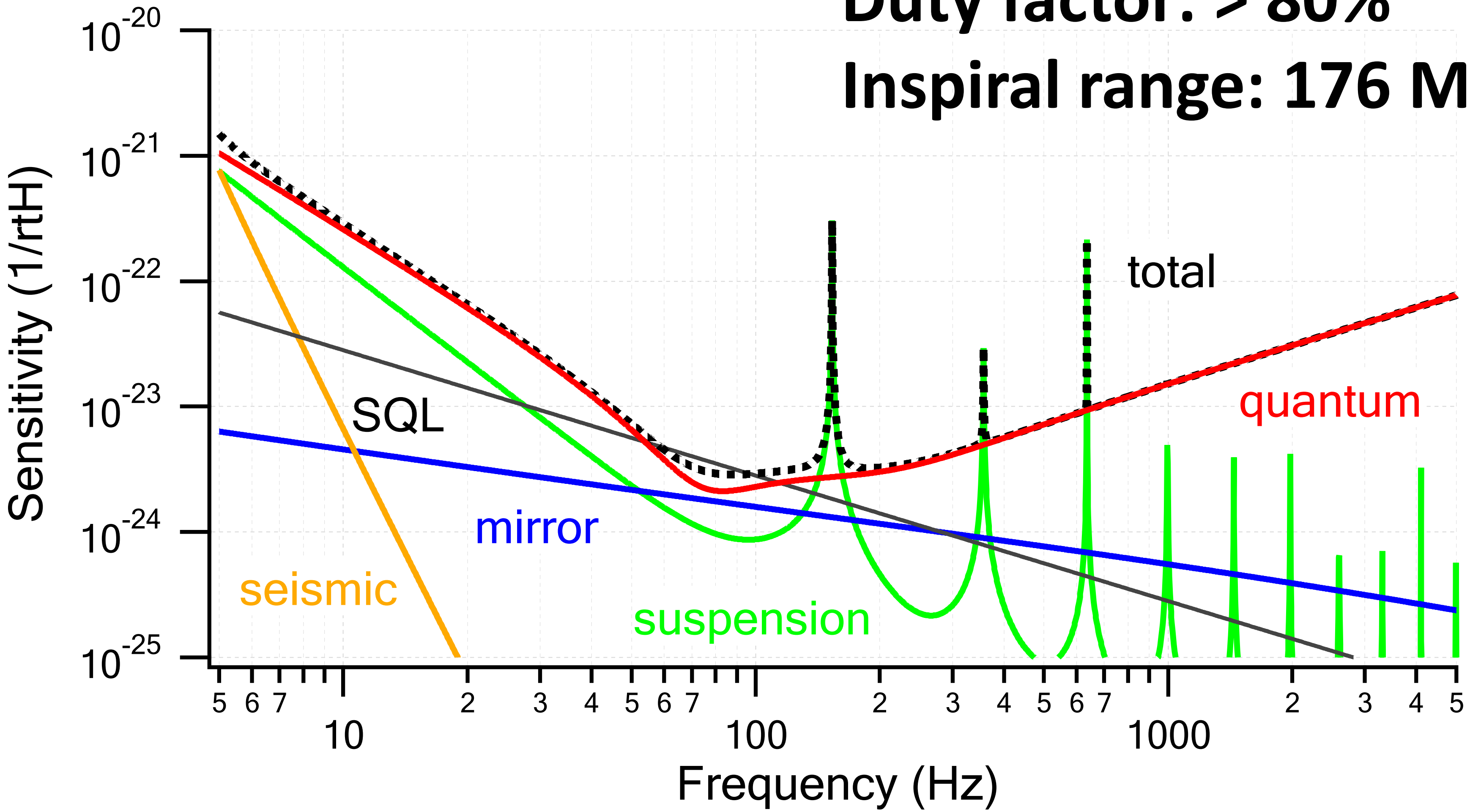
Mirror/suspension configuration



Ultimate sensitivity limit of KAGRA

Duty factor: > 80%

Inspiral range: 176 Mpc



Expected event rate for NS-NS coalescence

Inspiral range: 176 Mpc
(the same definition as LIGO/Virgo)

Assuming Inspiral rate per galaxy: ~100 Myr^{-1}

⇩

Expected event rate: ~10 yr^{-1}

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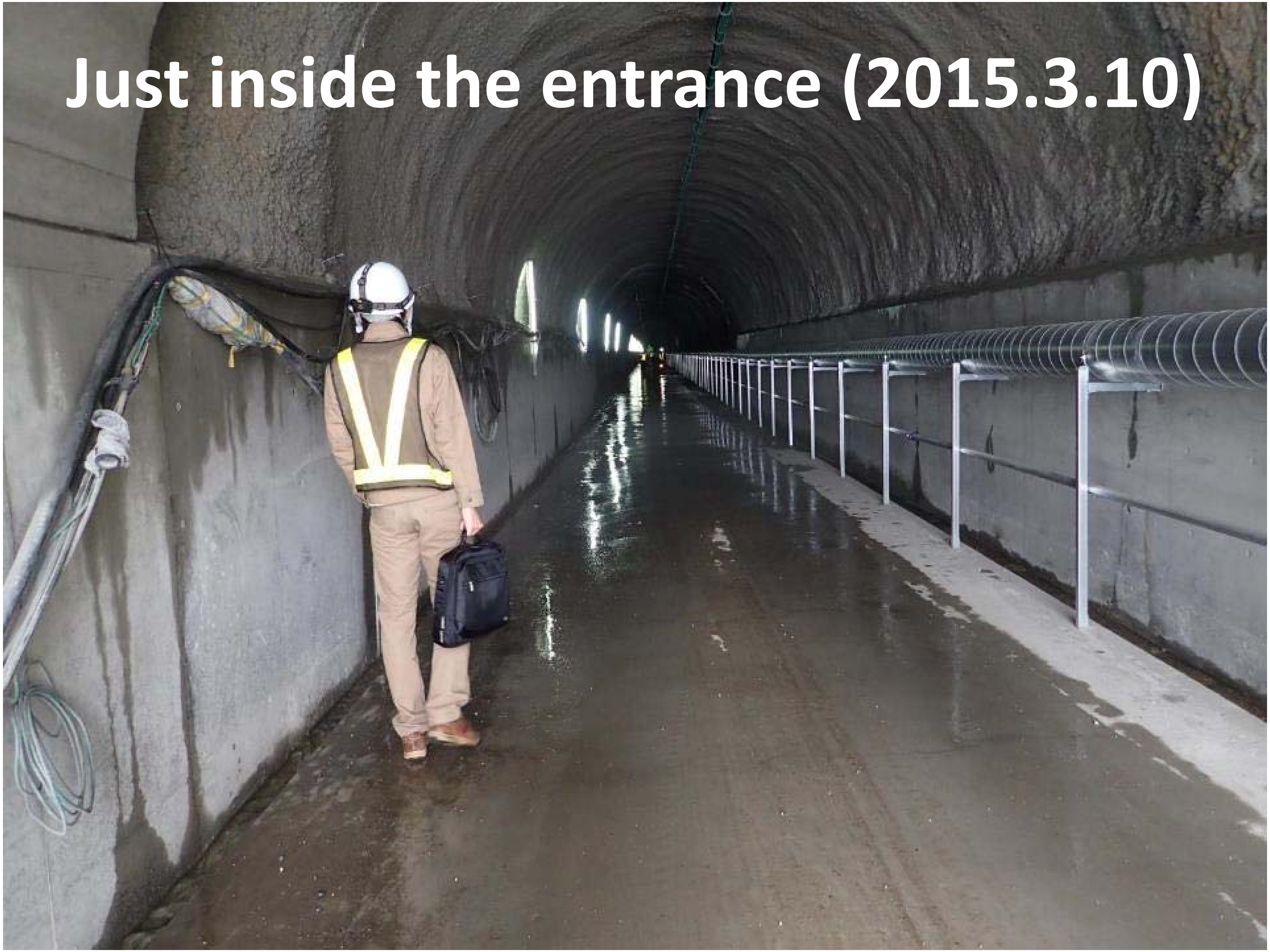
Shin-Atotsu entrance
(2015.3.10)


Just inside the entrance (2015.3.10)


500m away from the entrance
Close to the central area (2015.3.10)

Central area (2015.6.17)

Cryostat and shaft (2015.6.17)

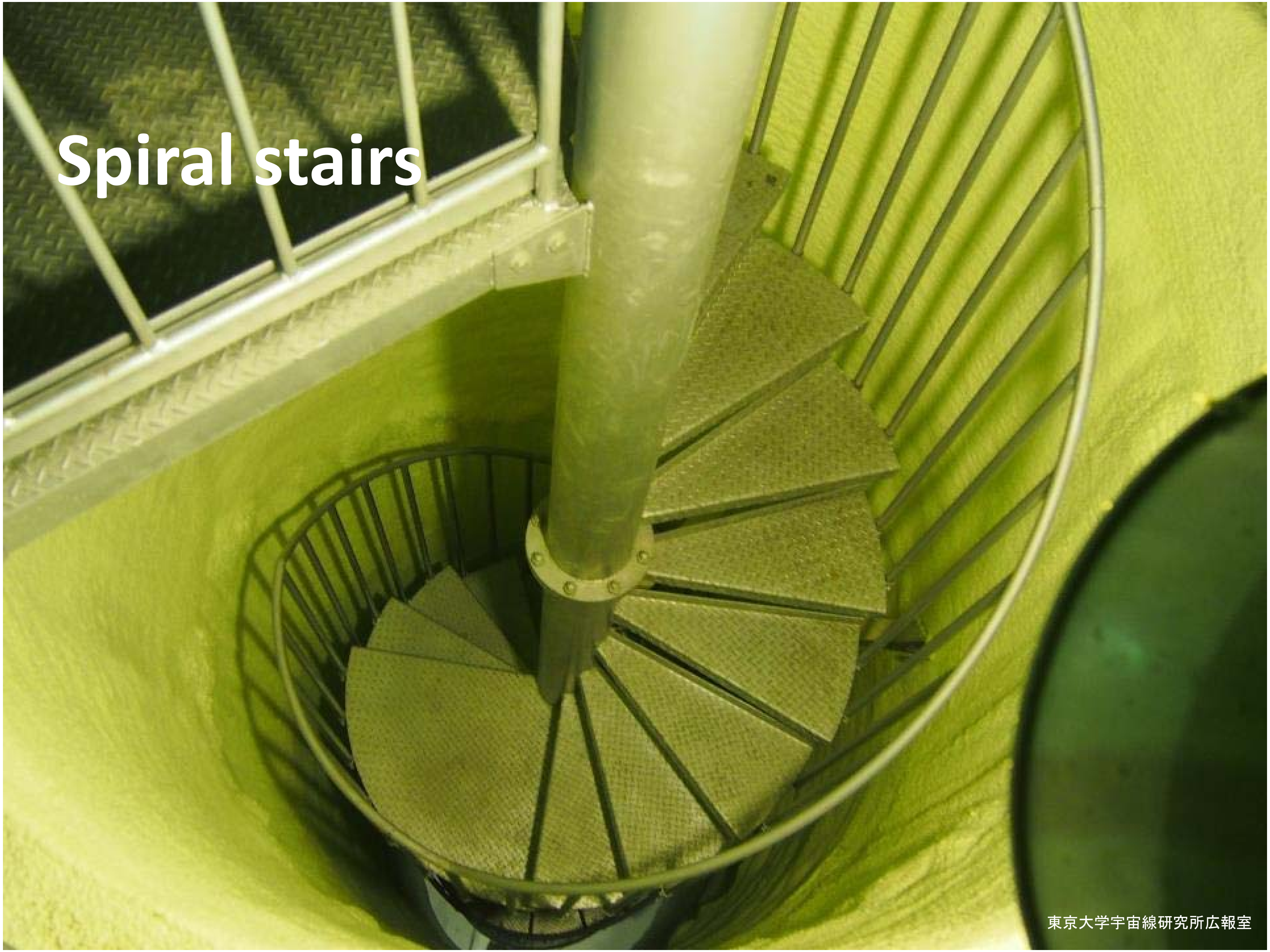
Computer room (2015.6.17)

Slope to the 2nd floor (2015.6.17)

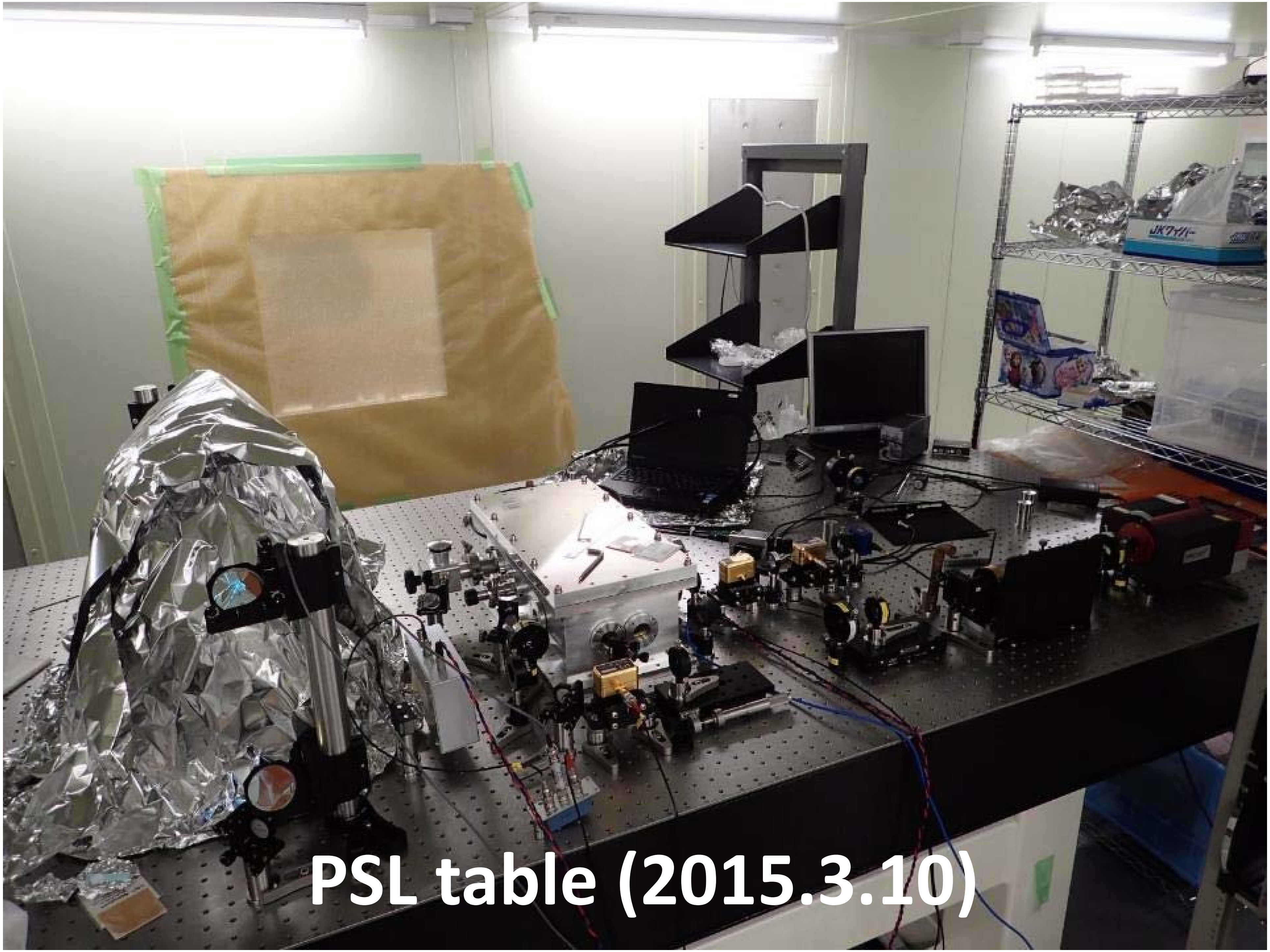
2nd floor (2015.6.17)

Vacuum system through the shaft (2015.6.17)

Spiral stairs



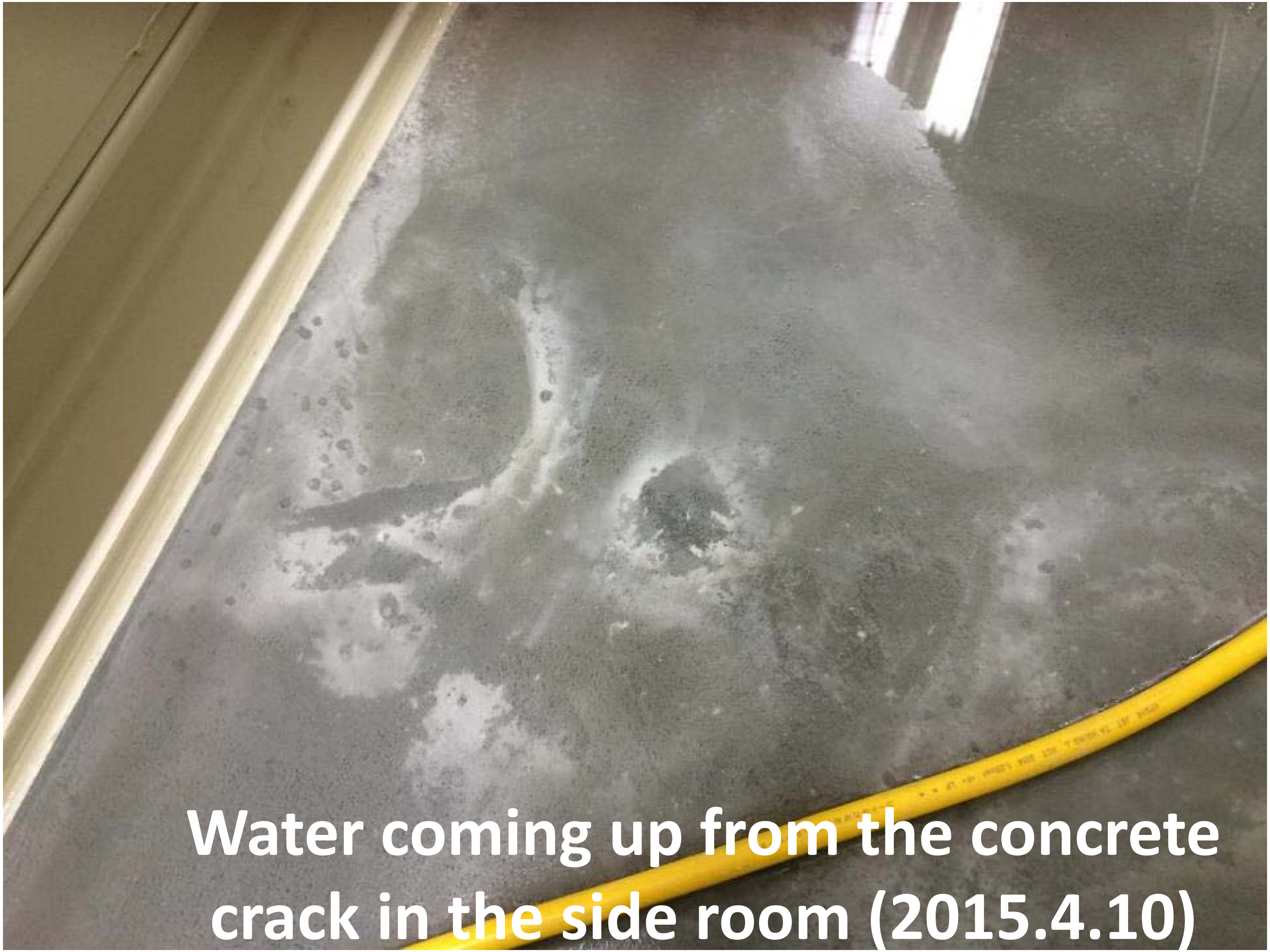
Laser clean room (2015.6.17)



PSL table (2015.3.10)

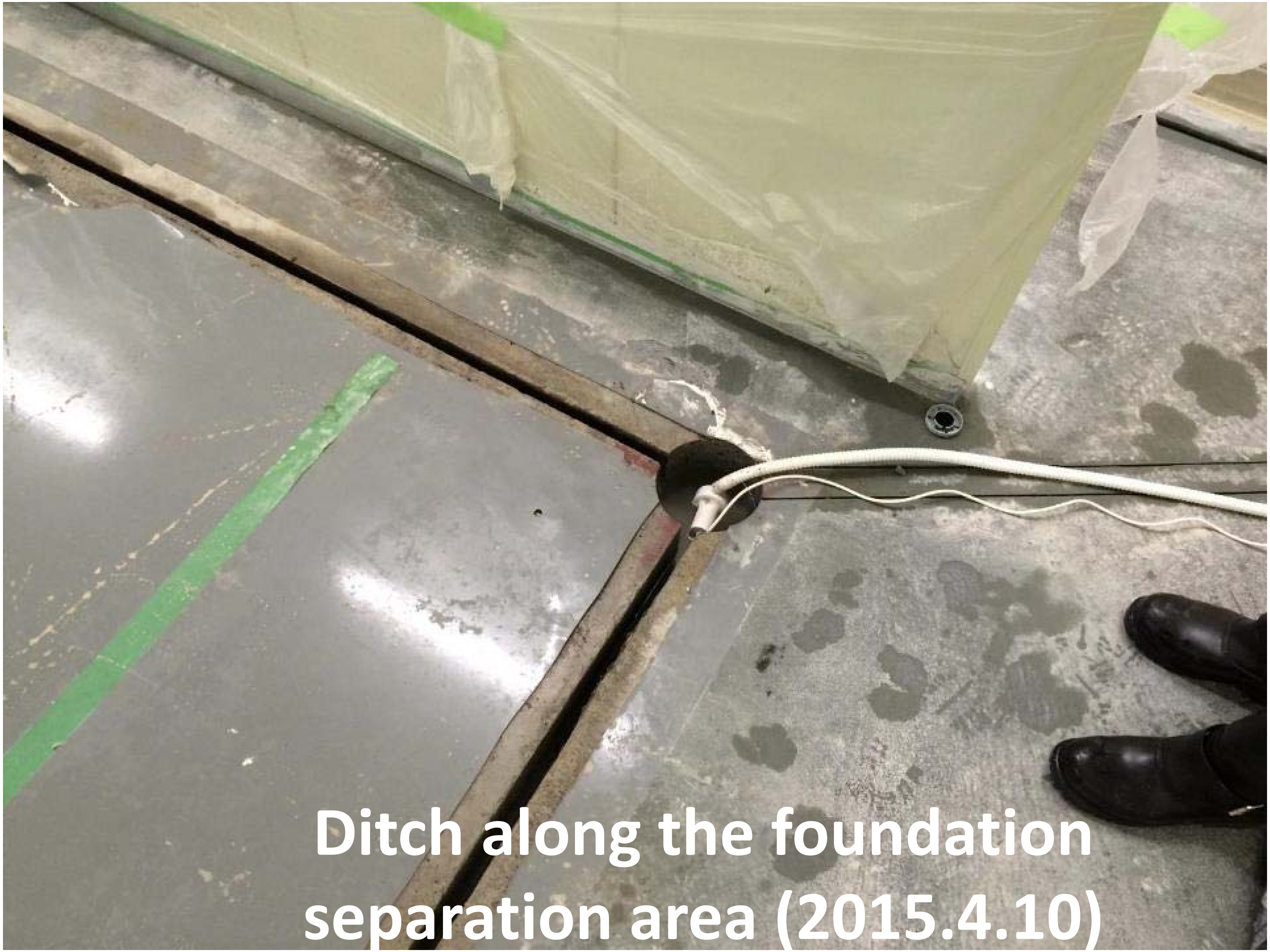
Fighting against water (2015.3.10)

Side of the clean room (2015.3.23)



Water coming up from the concrete crack in the side room (2015.4.10)

Protection for construction (2015.3.25)


Ditch along the foundation
separation area (2015.4.10)


Water drainage ditch (2015.4.21)

Pump in the hole (2015.4.21)


Clean room (2015.4.21)

Front room (2015.4.21)

Side room of the clean room
(2015.4.21)

PSL clean room (2015.6.17)

Draining ditch for spring water (2015.6.17)

Water pump for spring water (2015.6.17)

Vacuum chamber for input and output mode cleaner mirrors (2015.6.17)

Vacuum chamber for end mode cleaner mirror (2015.6.17)

Vacuum chamber for beam splitter (2015.6.17)

Vacuum chamber for iKAGRA input test mass (2015.6.17)

Beam tubes (2015.6.17)

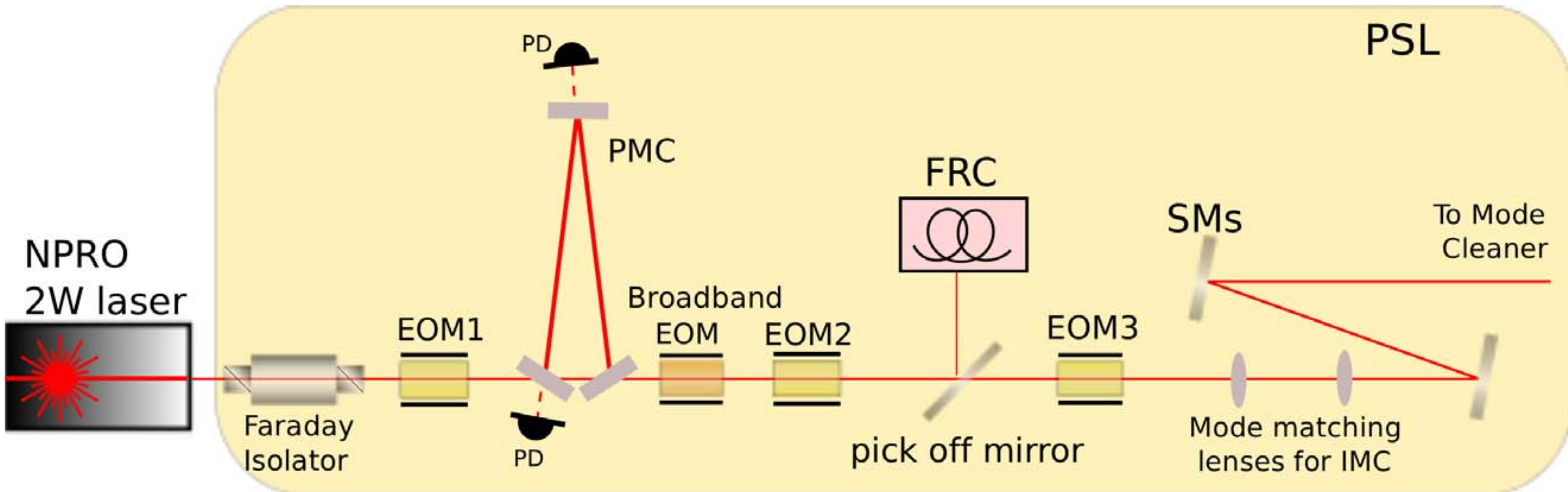
Electric car for driving in X-arm (2015.6.17)

Data analysis building

Control room in KAGRA research building (2015.6.17)

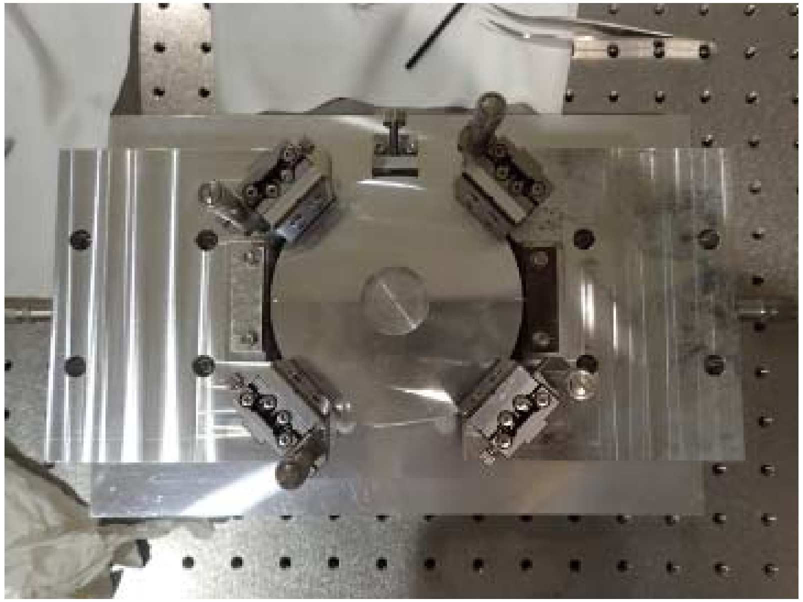
Pre-stabilized laser

- **Pre-mode cleaner: Locked**
- **Faber ring cavity: aligned, to be locked soon**



Input mode cleaner

- **Suspension system: Tested**
- **Magnets and standoff: being attached to MC mirrors**
- **MC Suspension: to be installed soon**

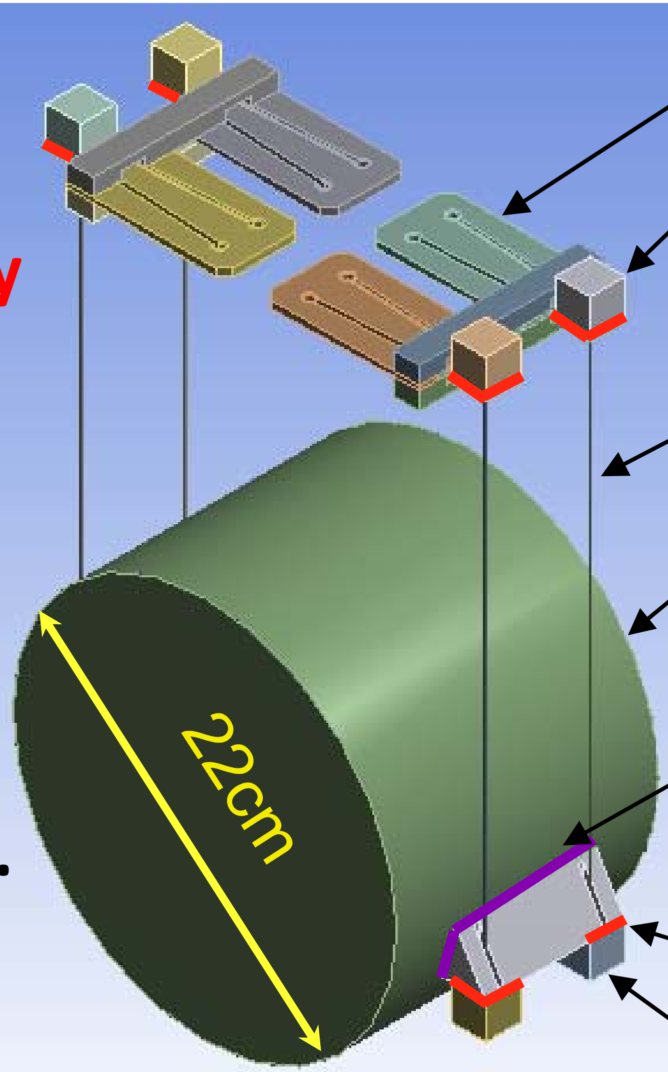


Cryogenic suspension

[Requirements]

- **Strength**
- **Heat conductivity**
- **Mechanical loss**

The component test showed the current design is OK. We plan to do the prototype test.



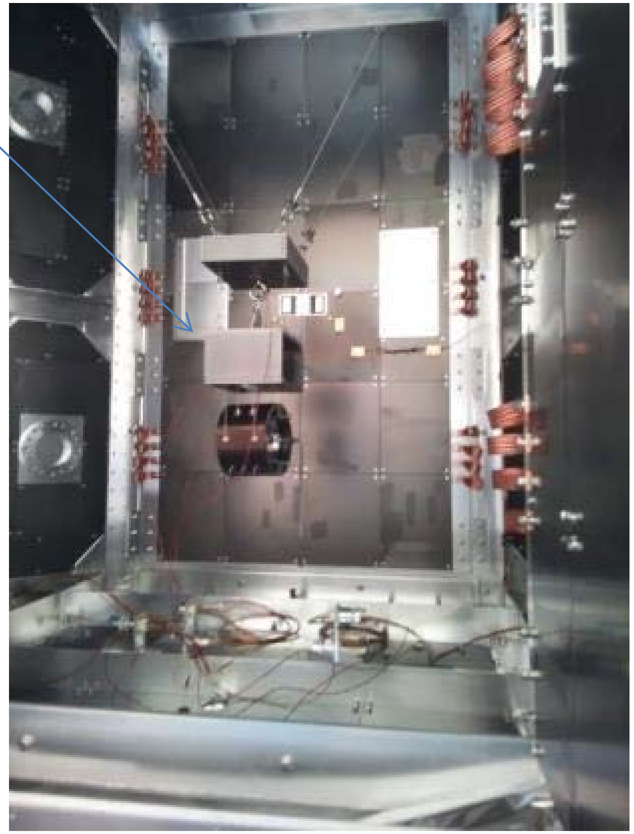
In collaboration with ET

Reduction of cooling time

- **Coating all the objects except Sapphire mirrors with DLC can reduce the cooling time from 2 months to 40 days.**
- **The effect was verified by experiment.**

Aluminum sphere coated with DLC

1/2 dummy payload coated with DLC



Other progress

- **The prototype of the payload including the bottom filter was assembled at NAOJ. The transfer function of the isolation system was measured, and the result agreed well with the model.**
- **All the mirrors for iKAGRA were manufactured and it was verified that the requirements were satisfied. A Sapphire mirror for bKAGRA with very low optical loss was test-coated as R&D for coating.**
- **The solid laser amplifier was successfully operated. The laser output power reached 210 W, although the quality of the beam was to be improved.**
- **A lot of progress on the data management system, detector characterization, and data analysis -> talks by Kanda, Hayama, Tagoshi, Oohara, and others**

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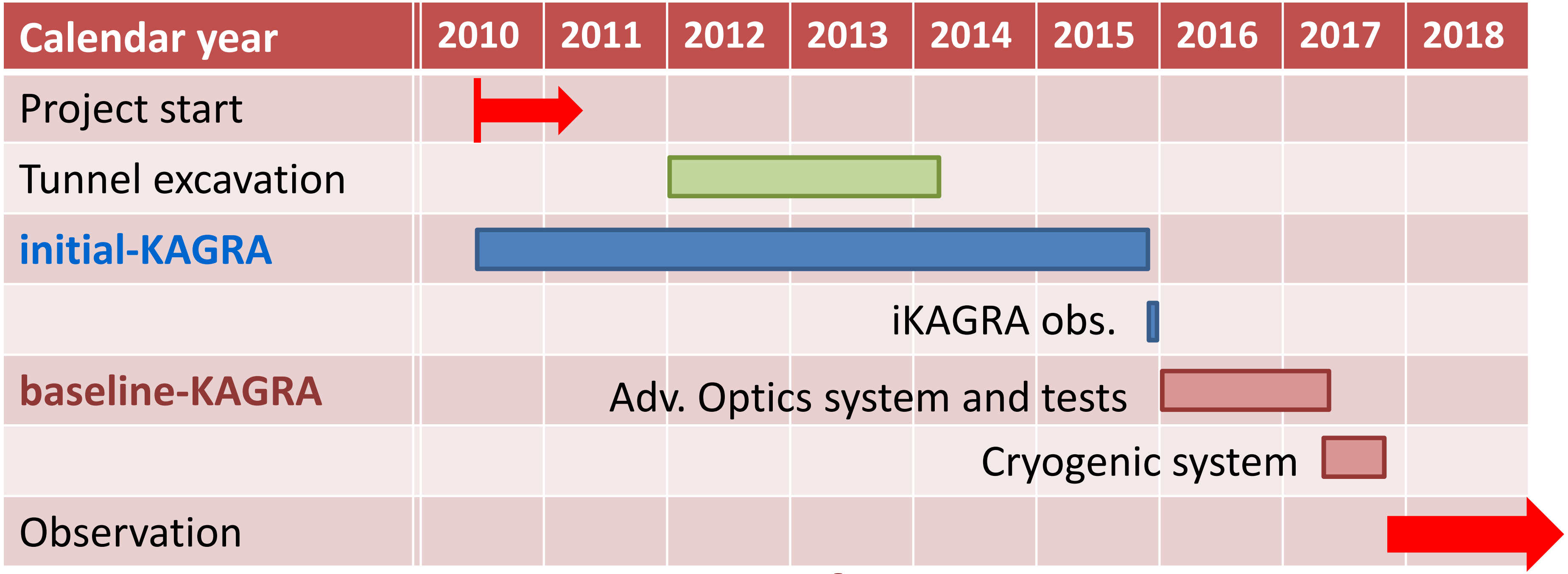
Schedule of KAGRA



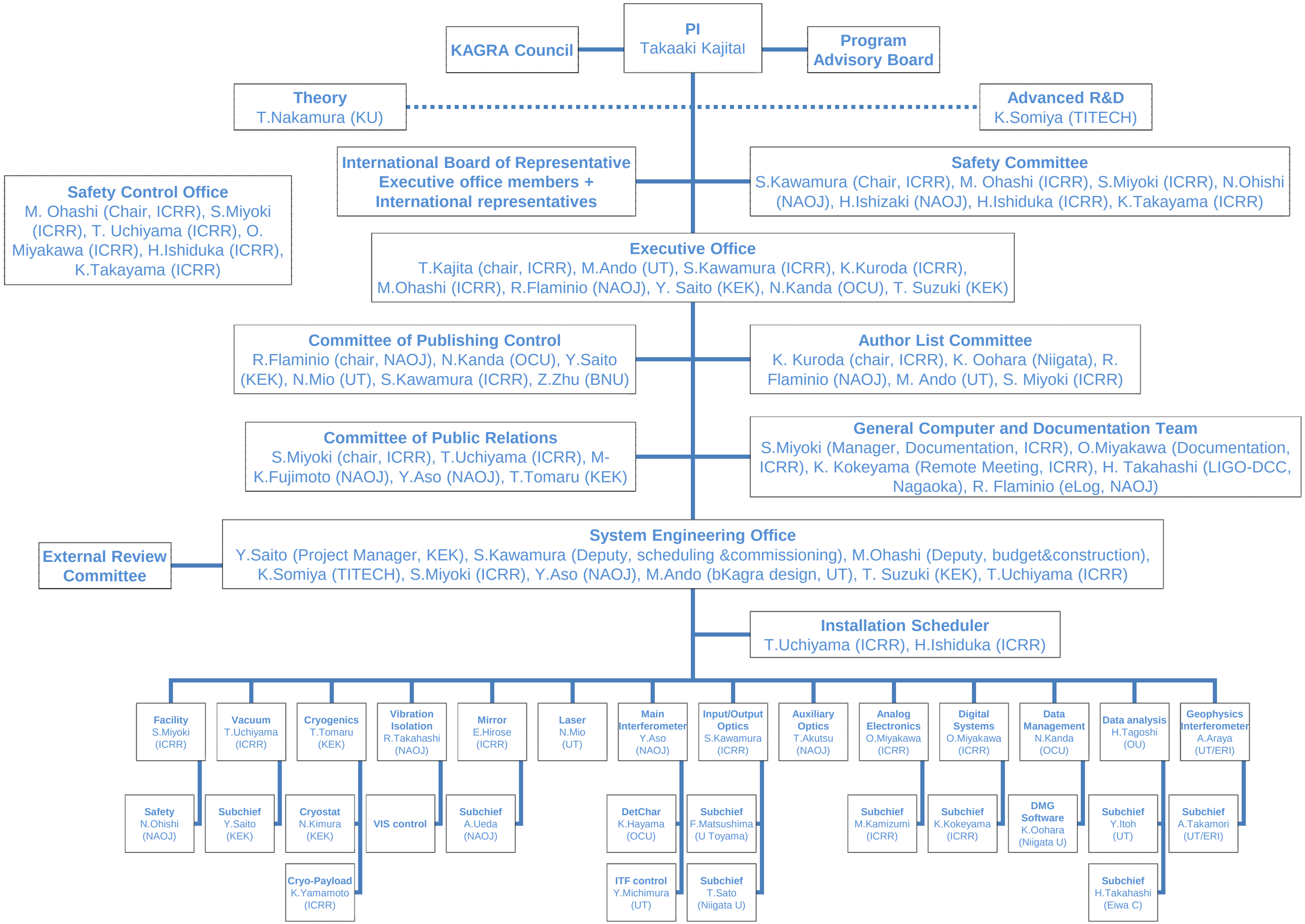
iKAGRA

bKAGRA

- **Michelson interferometer (changed)**
- **Room temperature**
- **Simple seismic isolation system**

- **Resonant sideband extraction**
- **Cryogenic temperature**
- **Advanced seismic isolation system**

KAGRA management structure



Summary of collaboration

- **242 members**
- **∼70 Universities/Institutes**
- **∼80 departments**

(as of May 1, 2015)

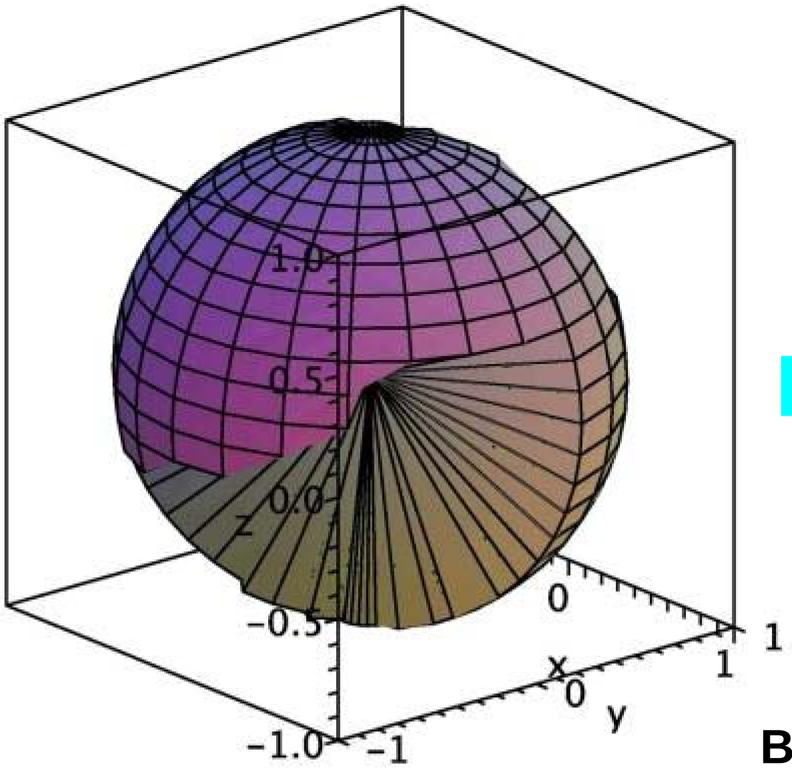
University/Institute/department with many members

- **ICRR, Univ. of Tokyo: 29 members**
- **NAOJ: 27 members**
- **KEK: 9 members**
- **Univ. of Tokyo (other than ICRR): 15**
- **Osaka City Univ.: 14**
- **Univ. of Toyama: 10**
- **Korea: 18 in total**

KAGRA in network

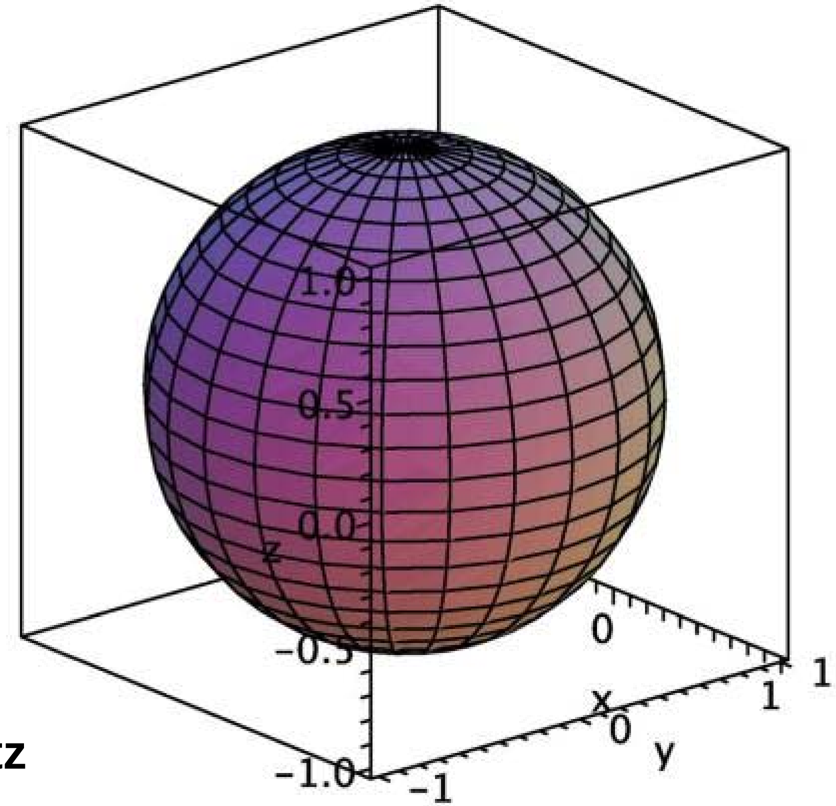
LIGO(H)+LIGO(L)+Virgo

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



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

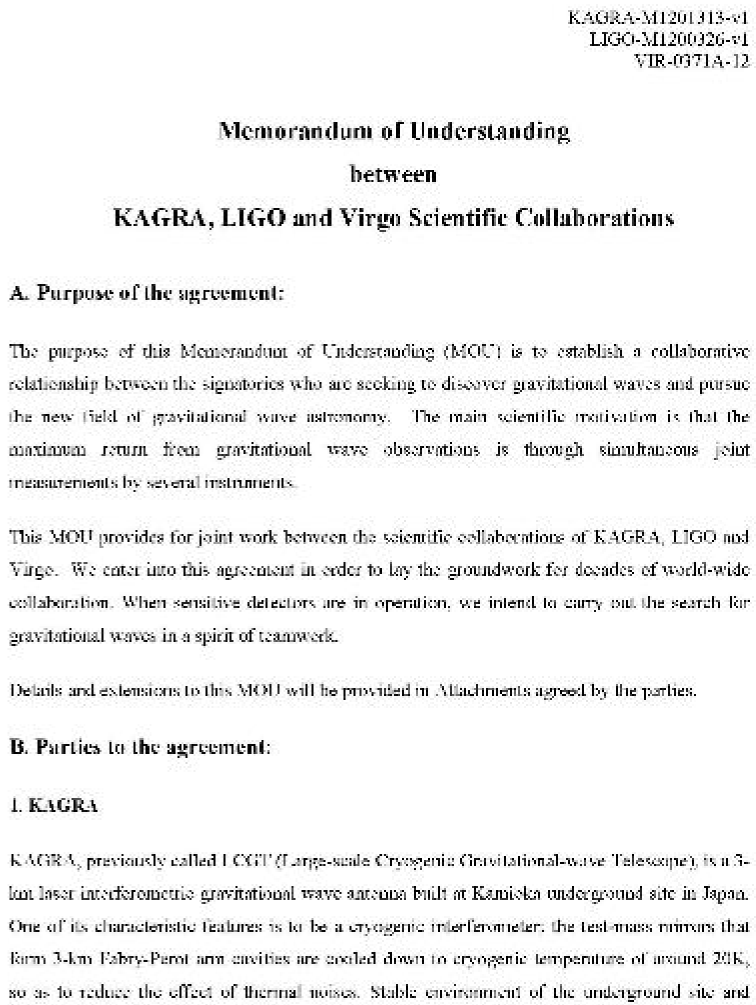
- Max sensitivity (M.S.): +13%
- Coverage at 0.5 M.S.: 100%
- 3 detector duty factor: 82%



B. F. Schutz

MOU with LIGO Scientific Collaboration (LSC) and VIRGO

- **MOU signed**
  - **General part (K-L-V)**
  - **Attachment A (K-L)**
    Technical collaboration
  - **Attachment B (K-L-V)**
    Data sharing and analysis
  - **Attachment C (K-V)**
    Technical collaboration


KAGRA-M1201313-v1
LIGO-M1200326-v1
VIR-0371A-12

Memorandum of Understanding

between

KAGRA, LIGO and Virgo Scientific Collaborations

A. Purpose of the agreement:

The purpose of this Memorandum of Understanding (MOU) is to establish a collaborative relationship between the signatories who are seeking to discover gravitational waves and pursue the new field of gravitational wave astronomy. The main scientific motivation is that the maximum return from gravitational wave observations is through simultaneous joint measurements by several instruments.

This MOU provides for joint work between the scientific collaborations of KAGRA, LIGO and Virgo. We enter into this agreement in order to lay the groundwork for decades of world-wide collaboration. When sensitive detectors are in operation, we intend to carry out the search for gravitational waves in a spirit of teamwork.

Details and extensions to this MOU will be provided in Attachments agreed by the parties.

B. Parties to the agreement:

1. KAGRA

KAGRA, previously called LCGT (Large-scale Cryogenic Gravitational-wave Telescope), is a 3-km laser interferometric gravitational wave antenna built at Kamioka underground site in Japan. One of its characteristic features is to be a cryogenic interferometer: the test-mass mirrors that form 3-km Fabry-Perot arm cavities are cooled down to cryogenic temperature of around 20K, so as to reduce the effect of thermal noises. Stable environment of the underground site and

JSPS core-to-core program

- **Core-to-core program is designed to create world-class research hubs in Japan by conducting collaborations with other countries.**
- **Five year program between FY2013 and FY 2017**
- **Budget**
  - **¥16M ($160K; assuming $1 ~¥100) for FY2013**
  - **¥16M ($160K) for FY2014**
  - **¥14.5M ($145K) for FY2015**

Country	Core Institute	Coordinator	Budget pattern
USA	Louisiana State University	Warren Johnson	1
Italy	European Gravitational Observatory	Michele Punturo	1
Germany	Albert Einstein Institute	Harald Lueck	1
UK	University of Glasgow	Sheila Rowan	1
Netherlands	NIKHEF	Jo van den Brand	1
France (Joined in 2015)	Centre National de la Recherche Scientifique	Gianpietro Cagnoli	1
Australia	University of Western Australia	David Blair	1
Korea	Korea University	Tai Hyun Yoon	2
China (1)	Beijing Normal University	Zong-Hong Zhu	2
China (2)	Shanghai Normal University	Xiang-Hua Zhai	2
Taiwan	National Tsing-Hua University	Shiuh Chao	2
India	IUCAA	Sanjeev V. Dhurandhar	2
Vietnam (Joined in 2014)	Hanoi National University of Education	Nguyen Quynh Lan	2

Pattern1: Sending side covers all the travel expenses.
Pattern 2: Sending side covers airfare and receiving side covers domestic travel costs.

Collaboration with ET

- Cryogenic mirror/suspension
  - Component test was performed and found to suffice the three requirements (strength, heat conductivity, and mechanical loss)
  - Prototype test will be performed soon.
  - Kieran Craig, who worked on the issue, will join KAGRA as a postdoc in August.
- Vibration isolation system
  - Inverted pendulum

ELiTES meeting

- **Collaboration meeting between ET and KAGRA**
- **Held once a year in Tokyo, Japan**

3rd ELiTES meeting in Tokyo on Feb. 9, 2015.

Collaboration with LIGO

- **Several KAGRA visitors to LHO/LLO to learn installation and commissioning**
- **LIGO speakers in KAGRA F2F meeting share experience of installation and commissioning**
- **LIGO kindly provided test masses for iKAGRA.**
- **University of Florida visited the KAGRA site to help assembly and adjustment of Faraday isolator.**
- **LIGO kindly made it possible that KAGRA members can get access to the LIGO documents including circuit diagrams, technical documents, etc.**

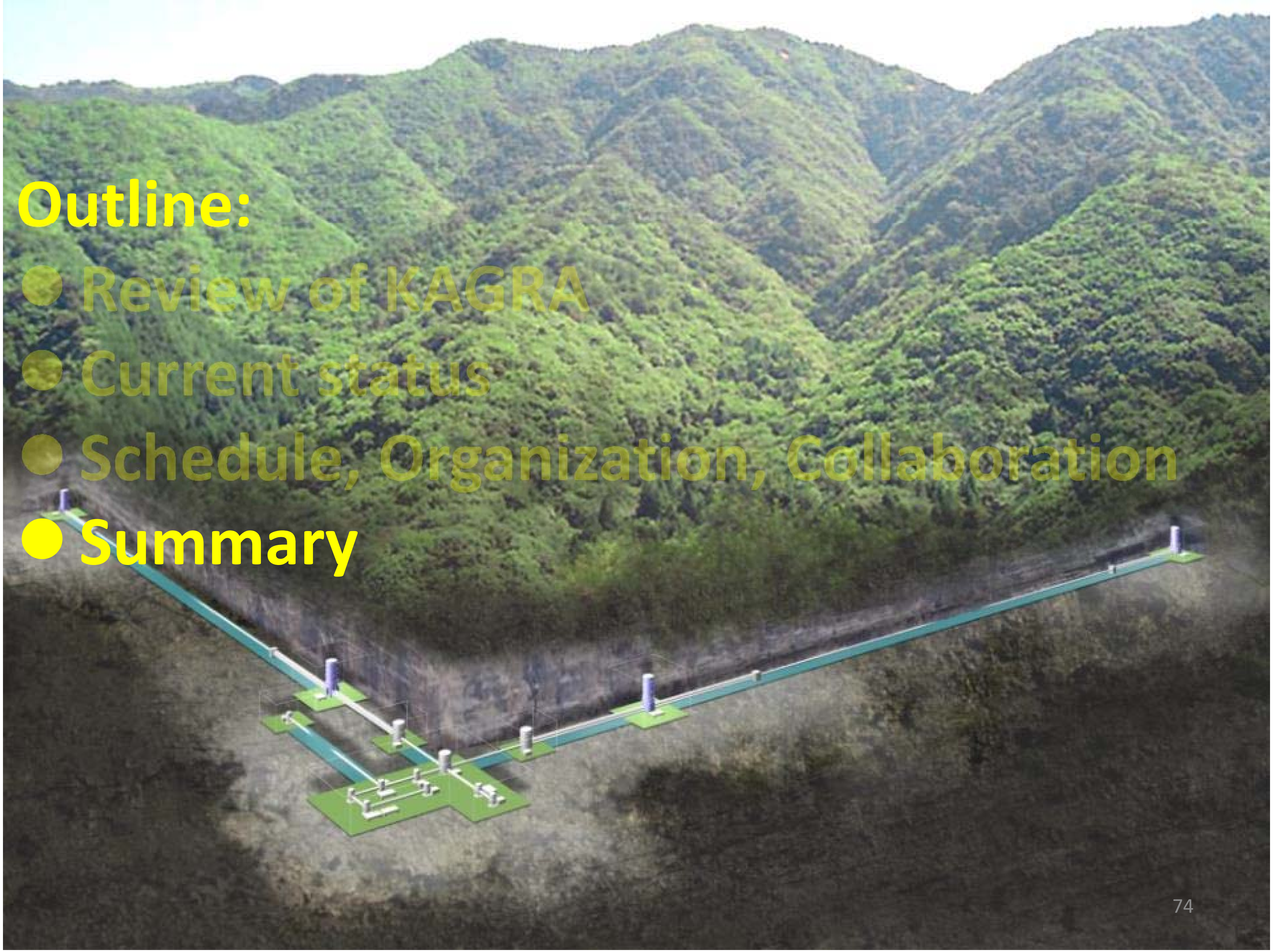
Collaboration with Korea

- **Instrument**
  - **Frequency stabilization system developed jointly by Tai Hyun Yoon (Korea Univ.) and ICRR has been installed for iKAGRA pre-stabilized laser system. He worked on this at ICRR as ICRR visiting professor for two months in 2013 and 2014.**
  - **Tilt sensor has been developed by Kyuman Cho (Sogang Univ.) . If it works well it could be used for bKAGRA mirror angular sensor. He worked on this at ICRR as ICRR visiting professor for almost two months in 2015.**
- **Data analysis and detector characterization**
  - **Code for data analysis has been developed jointly.**
  - **Tool for identifying noise source has been developed jointly.**
  - **Regular telecon and occasional F2F meeting is held now.**

Korea-Japan workshop on KAGRA

- **Held twice a year since 2012**
- **It could be evolved to international workshop on KAGRA; under discussion now**

8th Japan-Korea workshop in Gwangju, Korea on Jun. 27, 2015.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- **Most vacuum systems were installed.**
- **The water problem was mostly solved.**
- **We are now working on the pre-stabilized laser and mode cleaner for iKAGRA.**
- **We plan to have an observation run with iKAGRA at the end of 2015.**
- **We made progress on the cryogenic suspension, vibration isolation system, Sapphire mirrors, high-power laser, etc. for bKAGRA.**
- **We plan to start observation runs with bKAGRA at the end of 2017FY.**