KAGRA for the gravitational wave measurement

Yuki Inoue (Academia Sinica/KEK)
for
KAGRA collaboration

中央研究院
Academia Sinica

KAGRA collaboration

81 international institutions

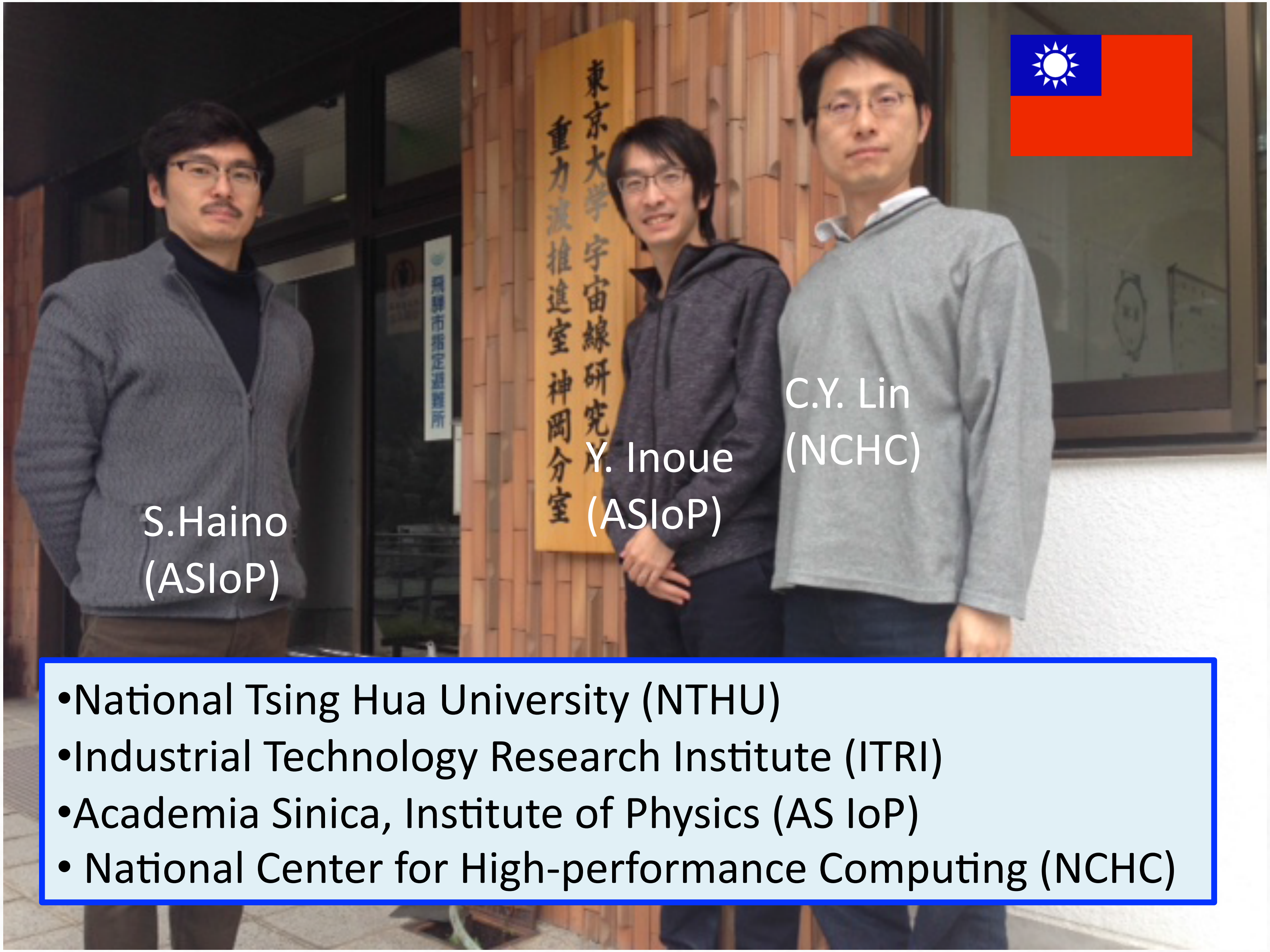
The University of Tokyo, ICRR
High Energy Accelerator Research Organization (KEK)
National Astronomical Observatory of Japan (NAOJ)
the University of Tokyo, Science
the University of Tokyo, Frontier Science
the University of Tokyo, Engineering
Osaka City University
Kyoto University
University of Electro-Communications
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
Academia Sinica
Rome University
Shanghai Normal University
National Tsing Hua University
Korea University
Inje University
Seoul National University
Myongji 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

International meeting in Korea

KAGRA in Taiwan



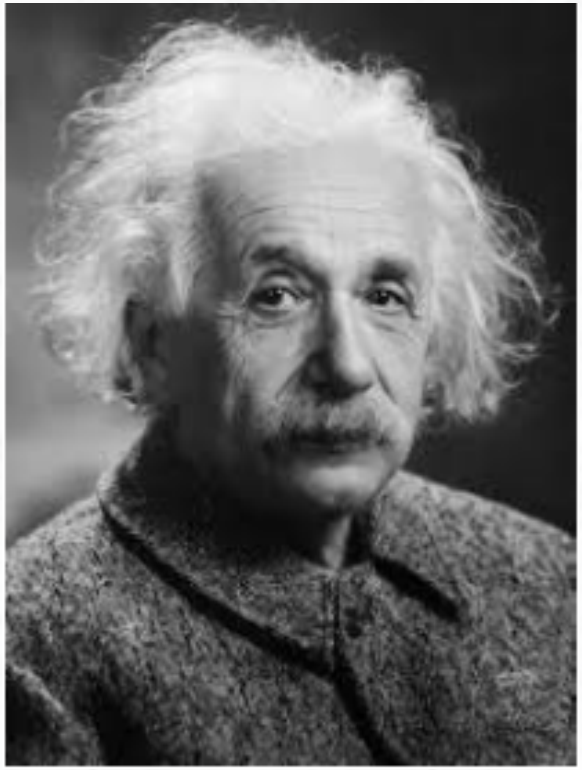
- National Tsing Hua University (NTHU)
- Industrial Technology Research Institute (ITRI)
- Academia Sinica, Institute of Physics (AS IoP)
- National Center for High-performance Computing (NCHC)

Outline

- Introduction
- KAGRA overview
- Results of iKAGRA
- Future plans
- Summary

SCIENCE OVERVIEW

Prediction of General rerativity



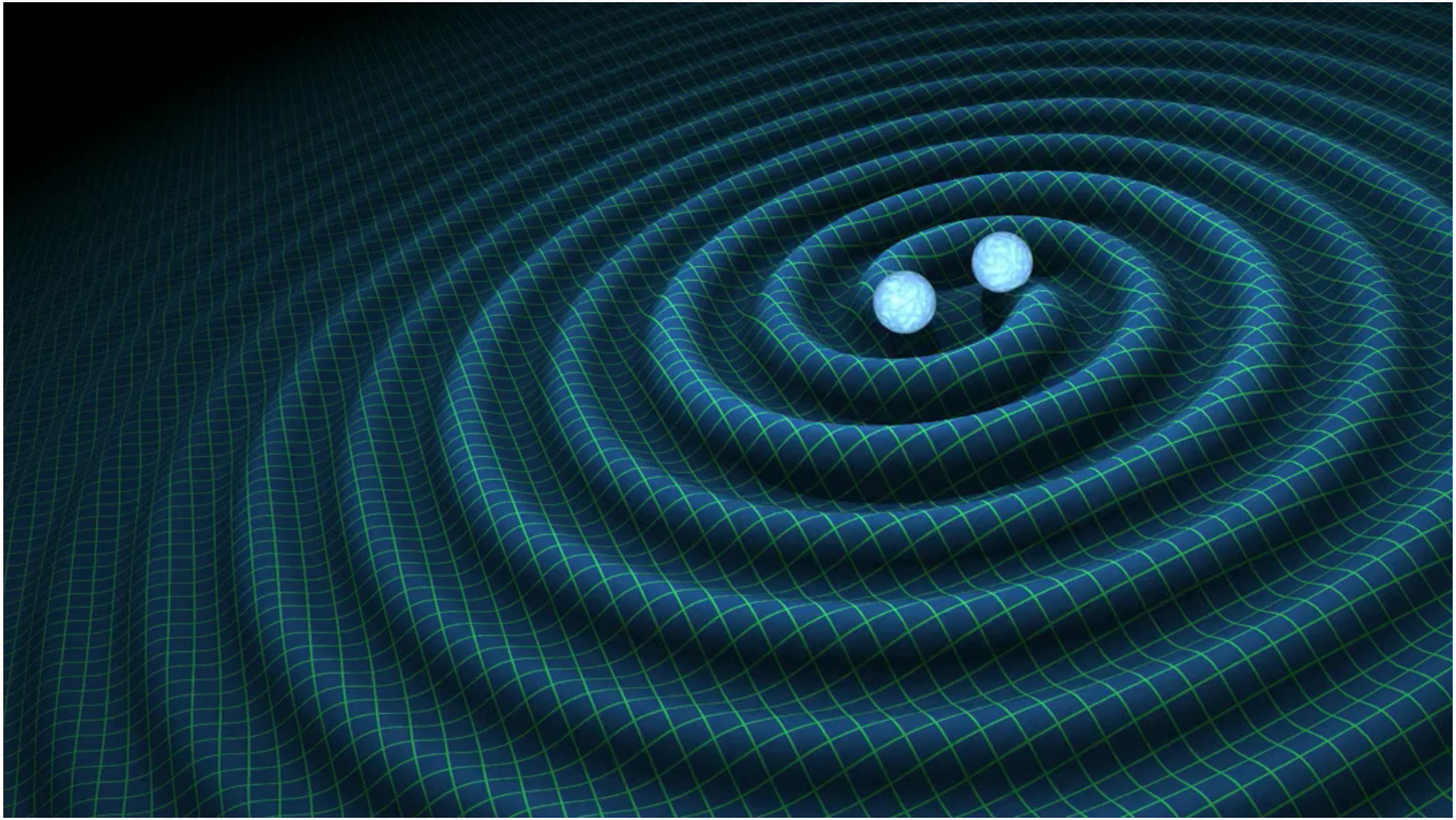
In 1916, Einstein proposed "General relativity":

Distortion of space-time

One of the most promising predictions

→ "Gravitational waves"

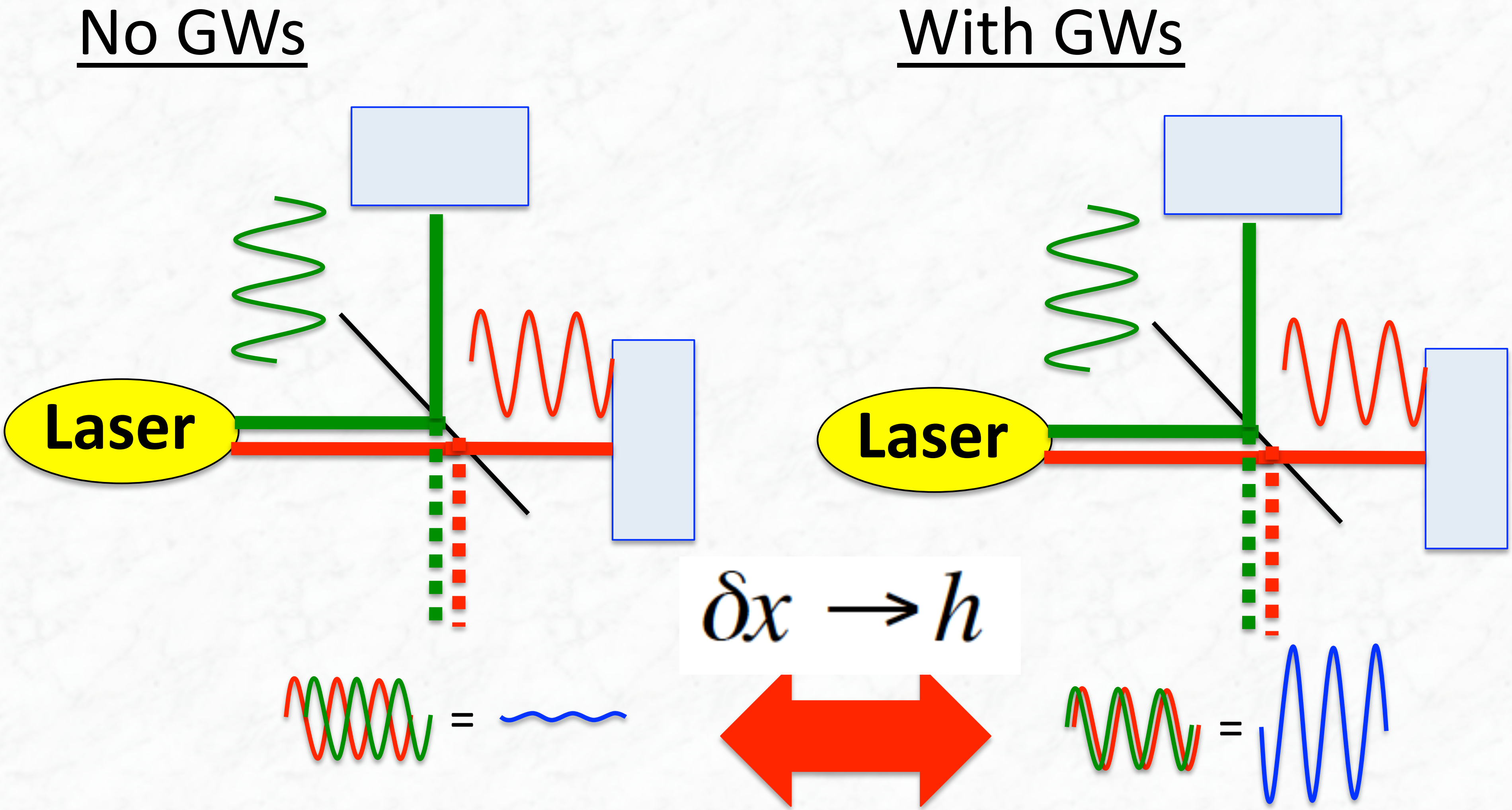
Gravitational wave



Sources

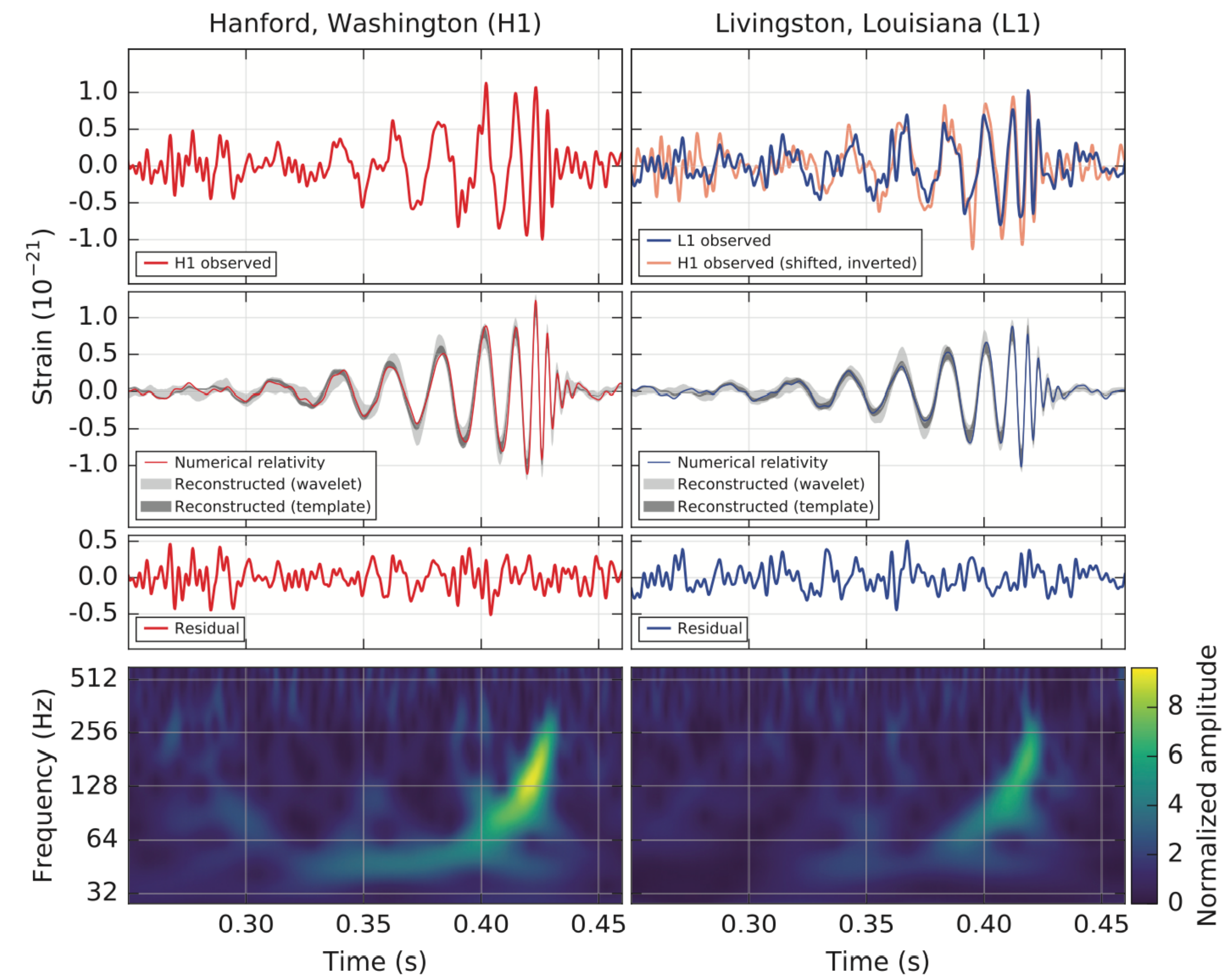
- Event like:
  - Compact Binary Coalescence (NS-NS, NS-BH, BH-BH)
  - Neutron star (NS), Black-hole (BH)
  - Supernovae
  - BH ring down
  - Pulsar glitch
- Continuous waves:
  - Pulsar rotation
  - Binaries
- Stochastic Background
  - Early universe (i.e.Inflation)

Simple principle of measurement



- The amplitude of interference fringe corresponds to that of GWs.

LIGO detection



- GW150914 and GW151226 are measured by LIGO.
- GWs are the measureable science targets!

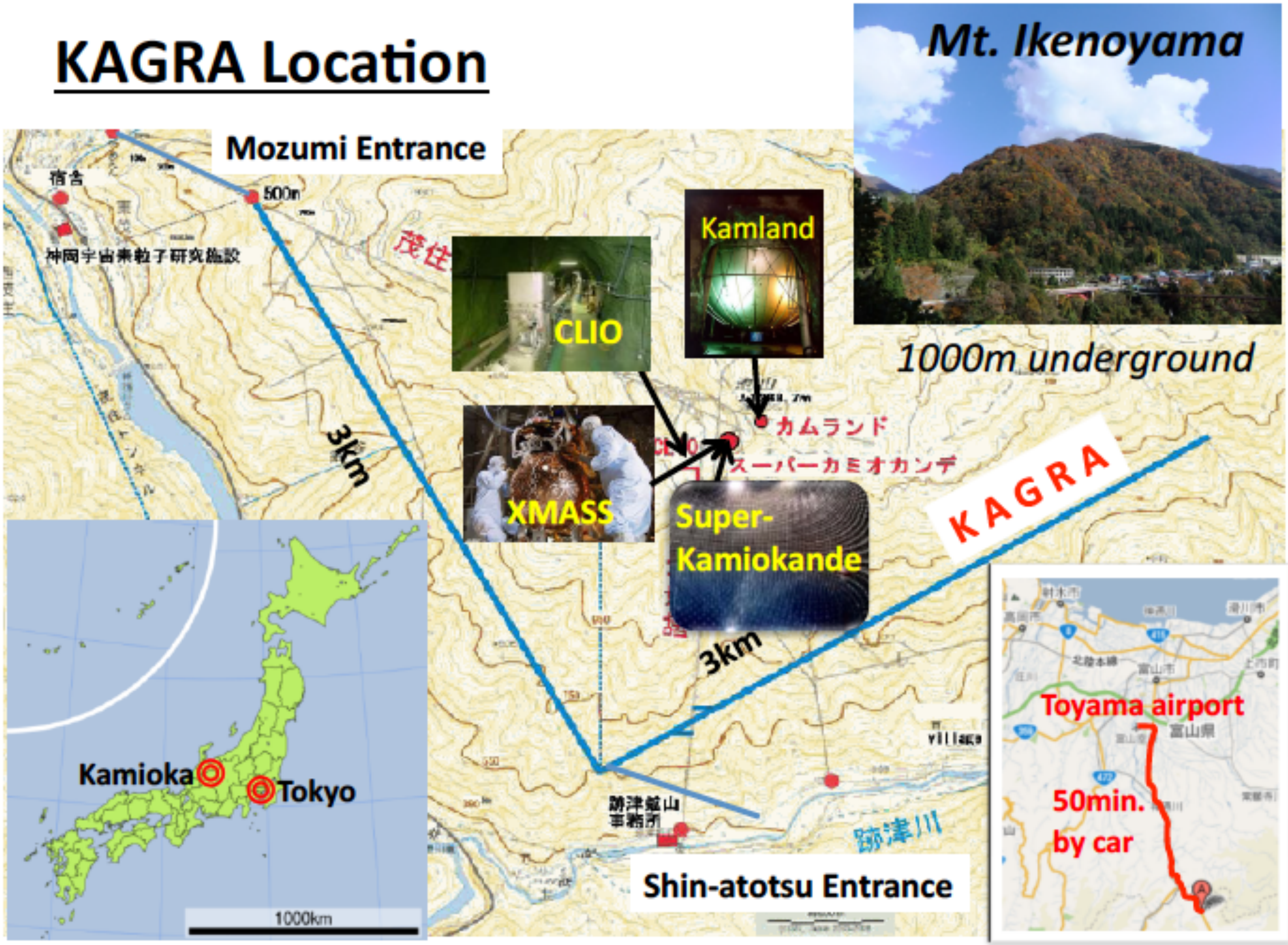
KAGRA

KAGRA: interferometric GW detector

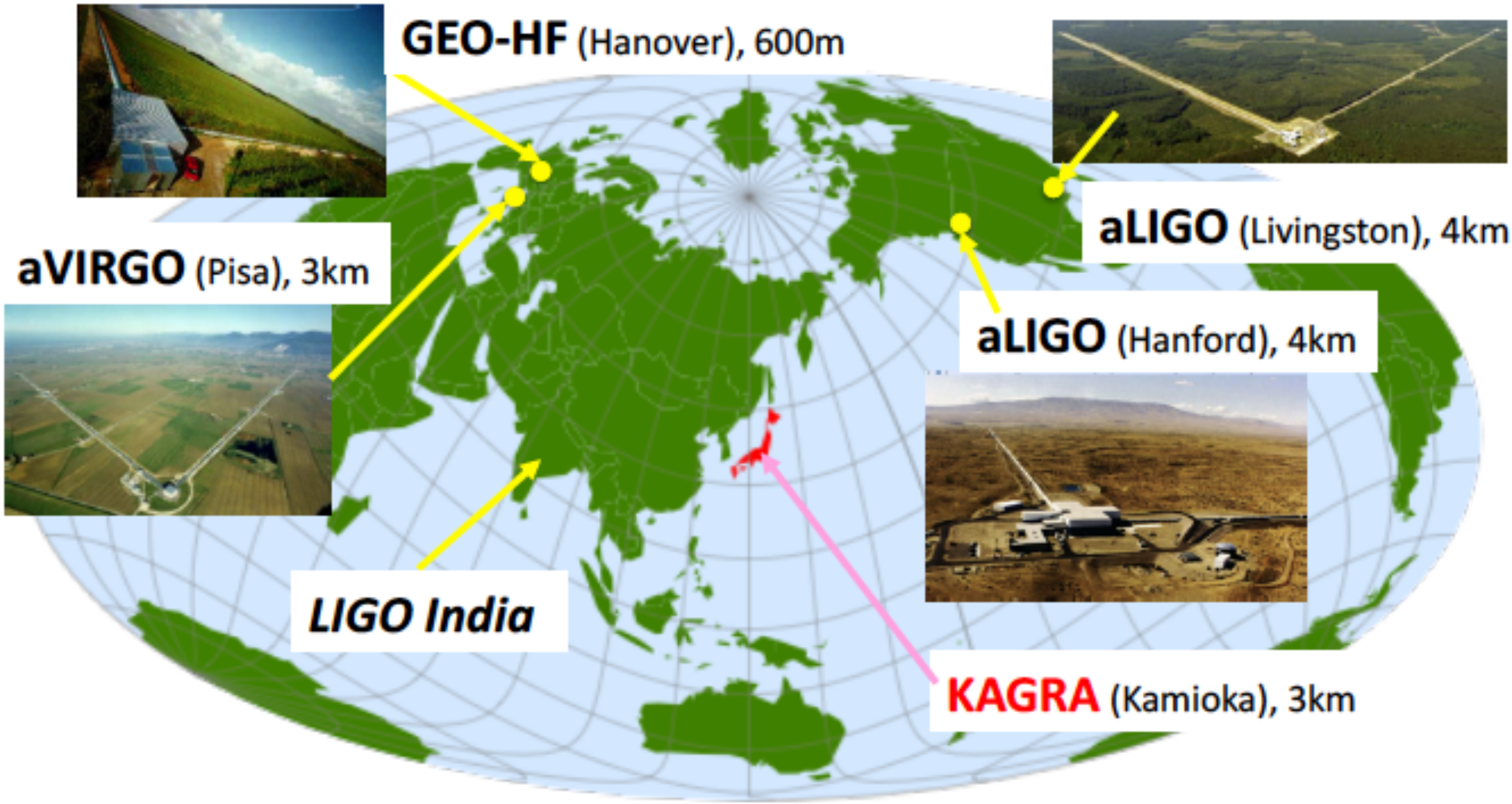
KAGRA specification

	KAGRA	AdvLIGO	Voyager
Wavelength	1064nm	1064nm	1550 nm
Power	825 W	5.2 kW	140 W
Finesse	1550	450	-
#reflection	987	287	-
Stored power	410 kW	745 kW	3 MW
baseline	3000 m	4000 m	4000 m
Temperature	20 K	Room	123 K
Site	Under ground	On ground	On ground

KAGRA Location

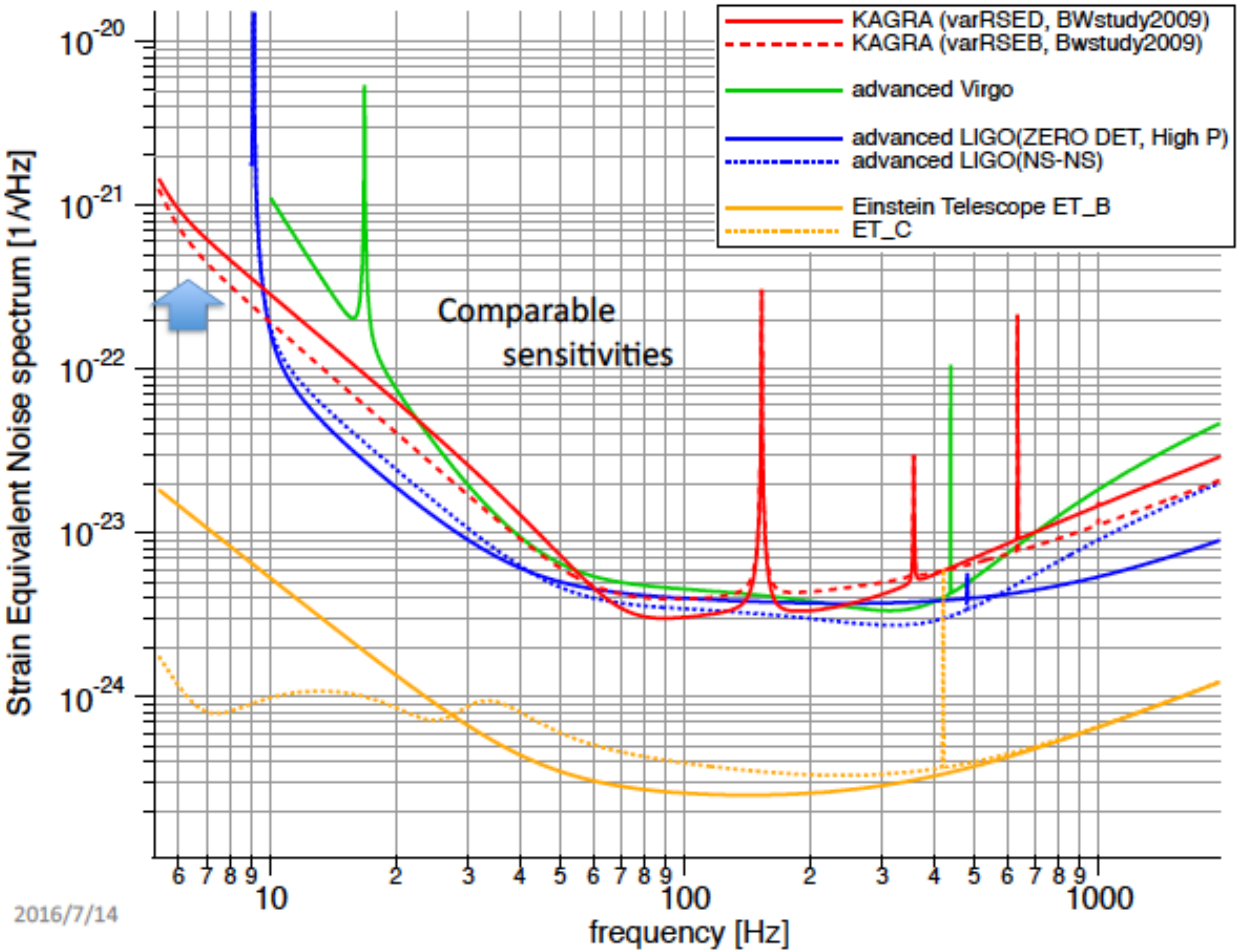


2nd Generation GW Observation Network



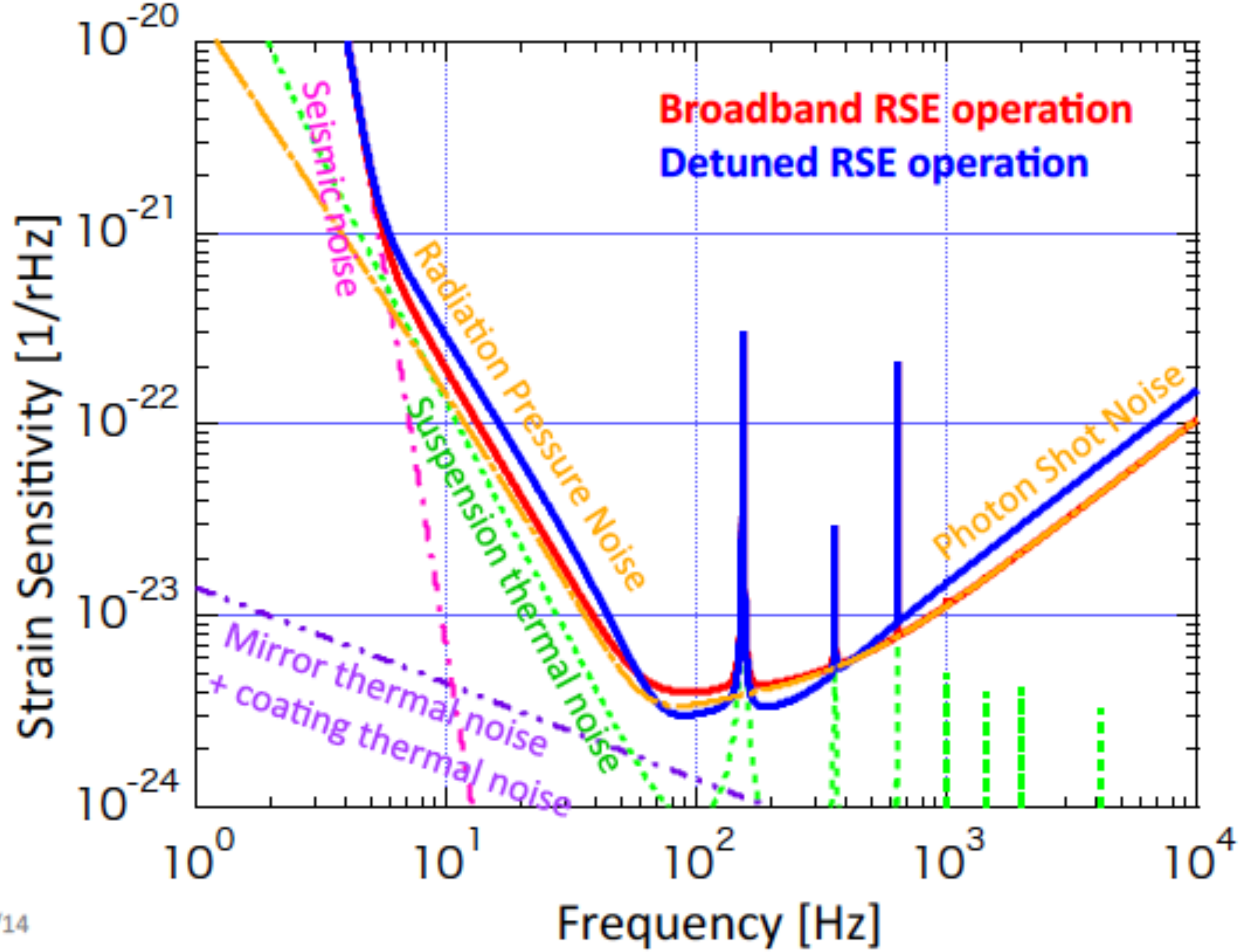
bKAGRA will be deployed in KAMIOKA mine at 2018!

Sensitivities of 2nd & 3rd Generation GW Telescopes



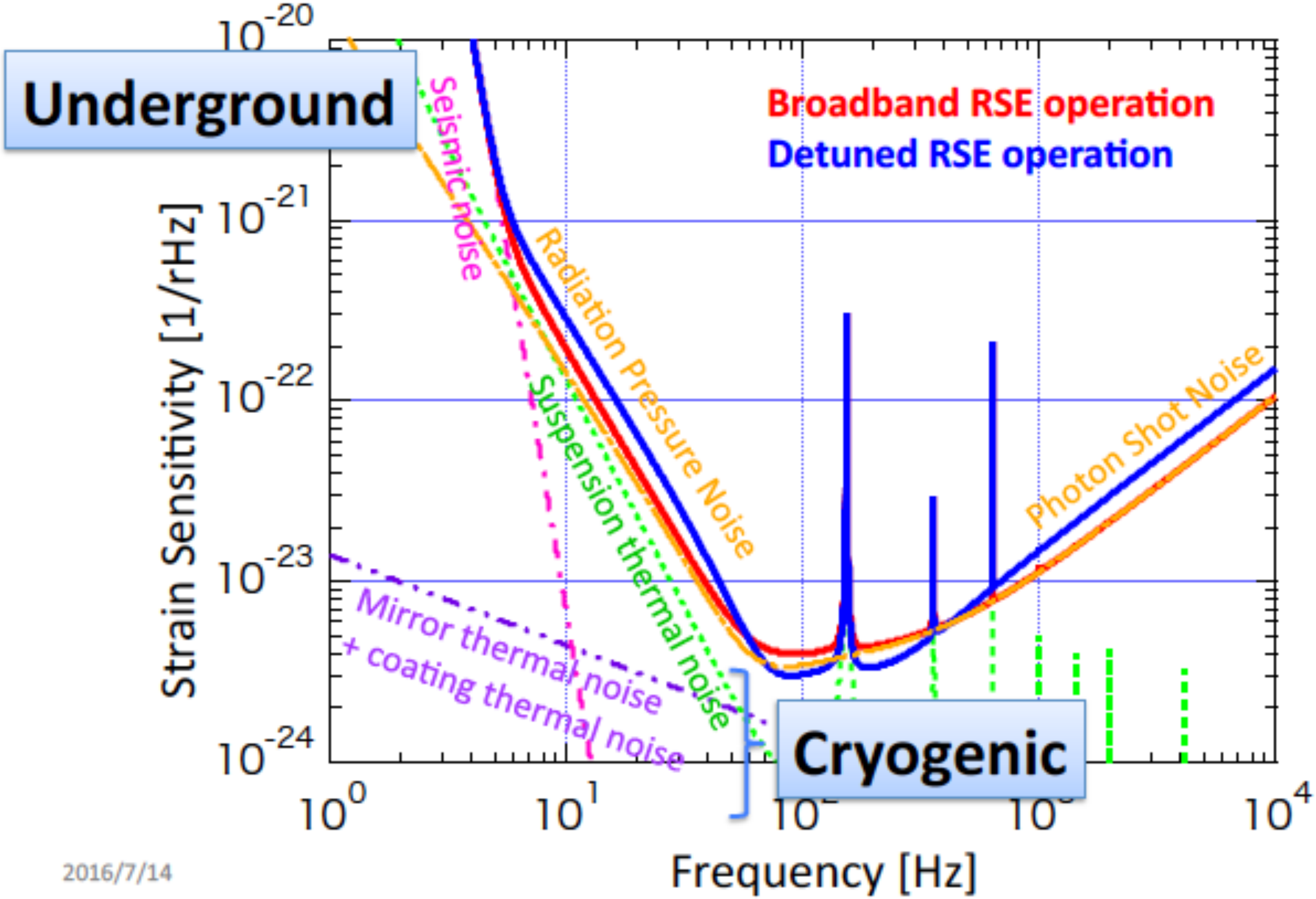
Noise Budget of KAGRA

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

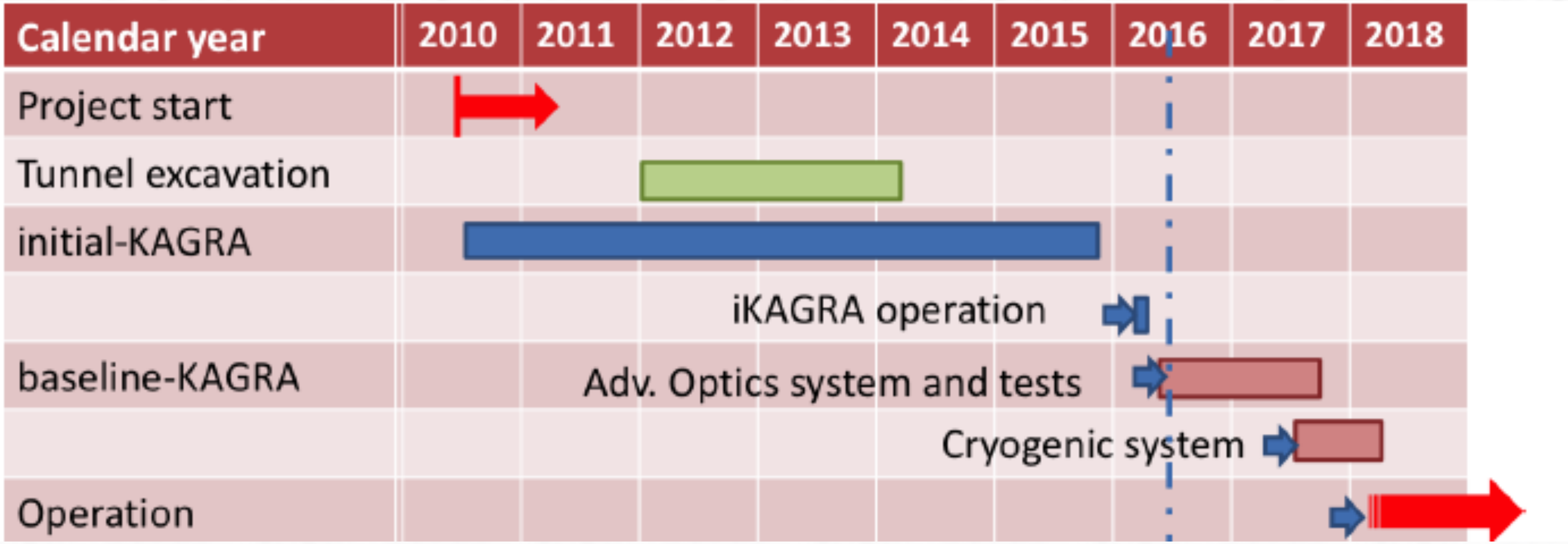


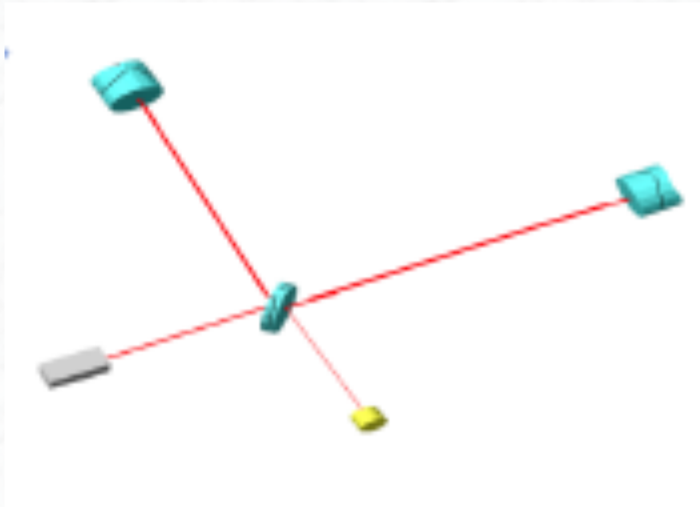
Noise Budget of KAGRA

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

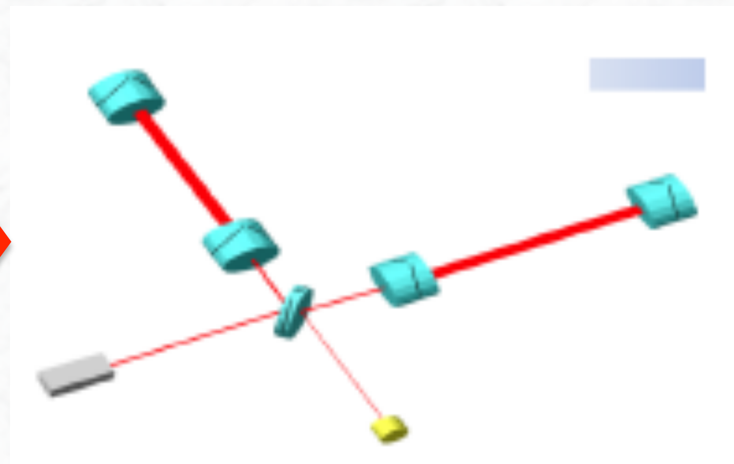


Timeline of KAGRA





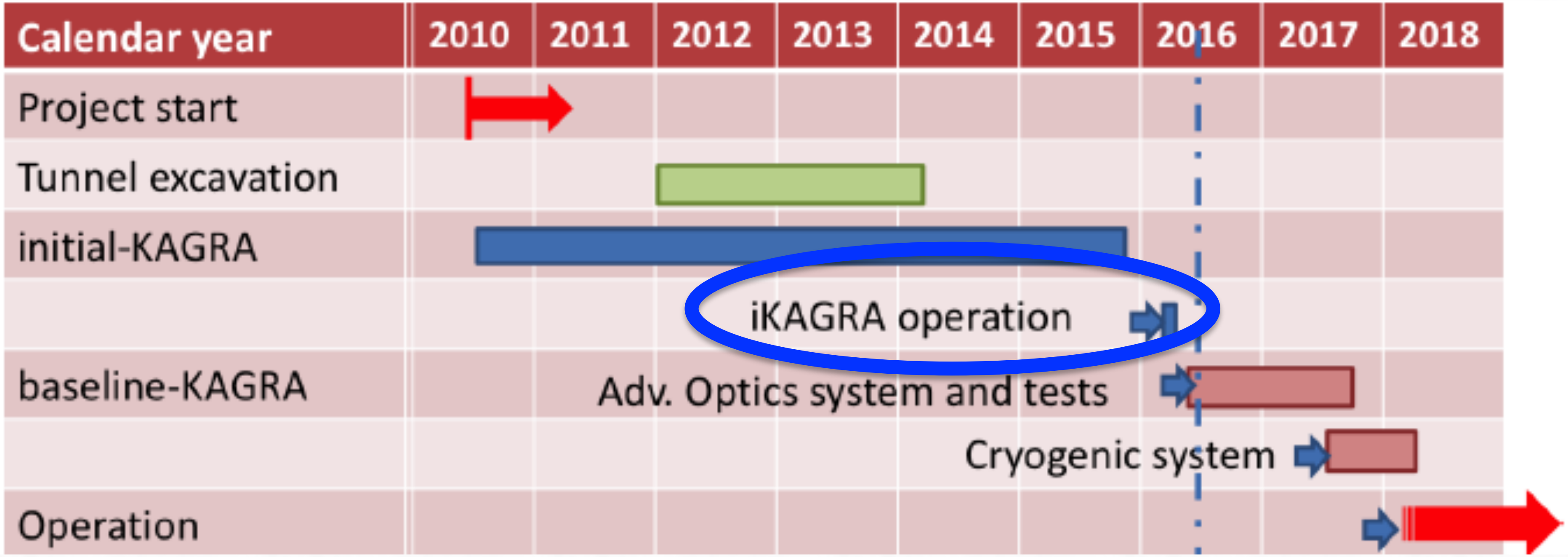
Michelson interferometer

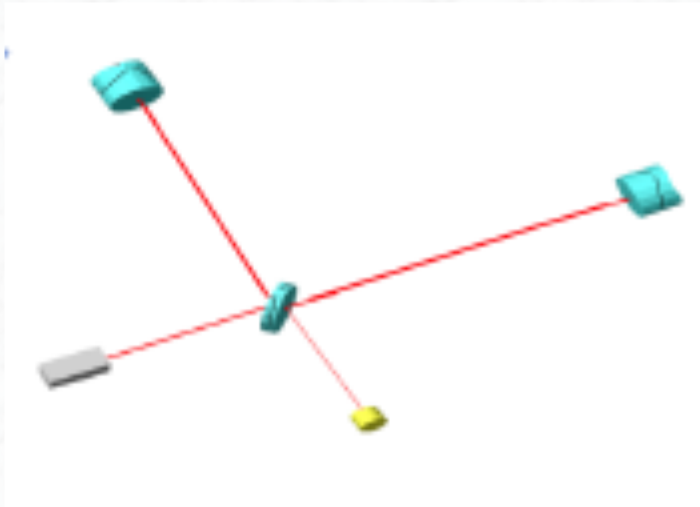


Cryogenic Michelson interferometer with Fabry-Perot cavity

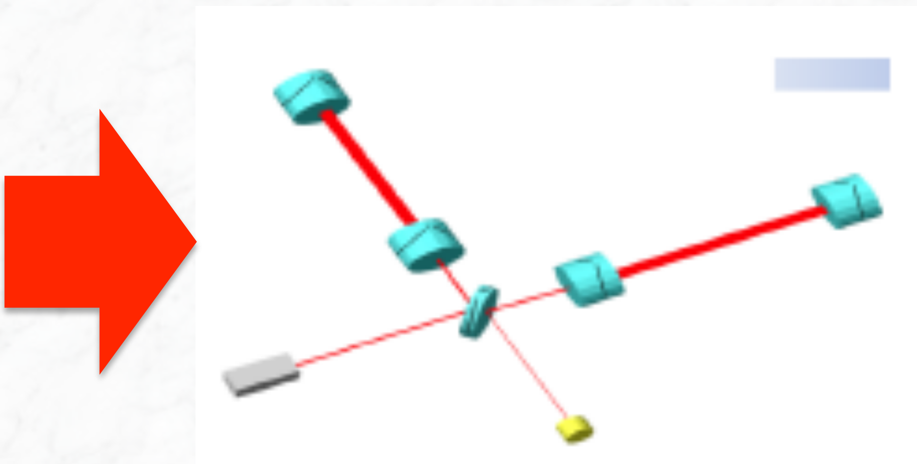
RESULTS AND PROGRESS OF iKAGRA

Timeline of KAGRA





Michelson interferometer



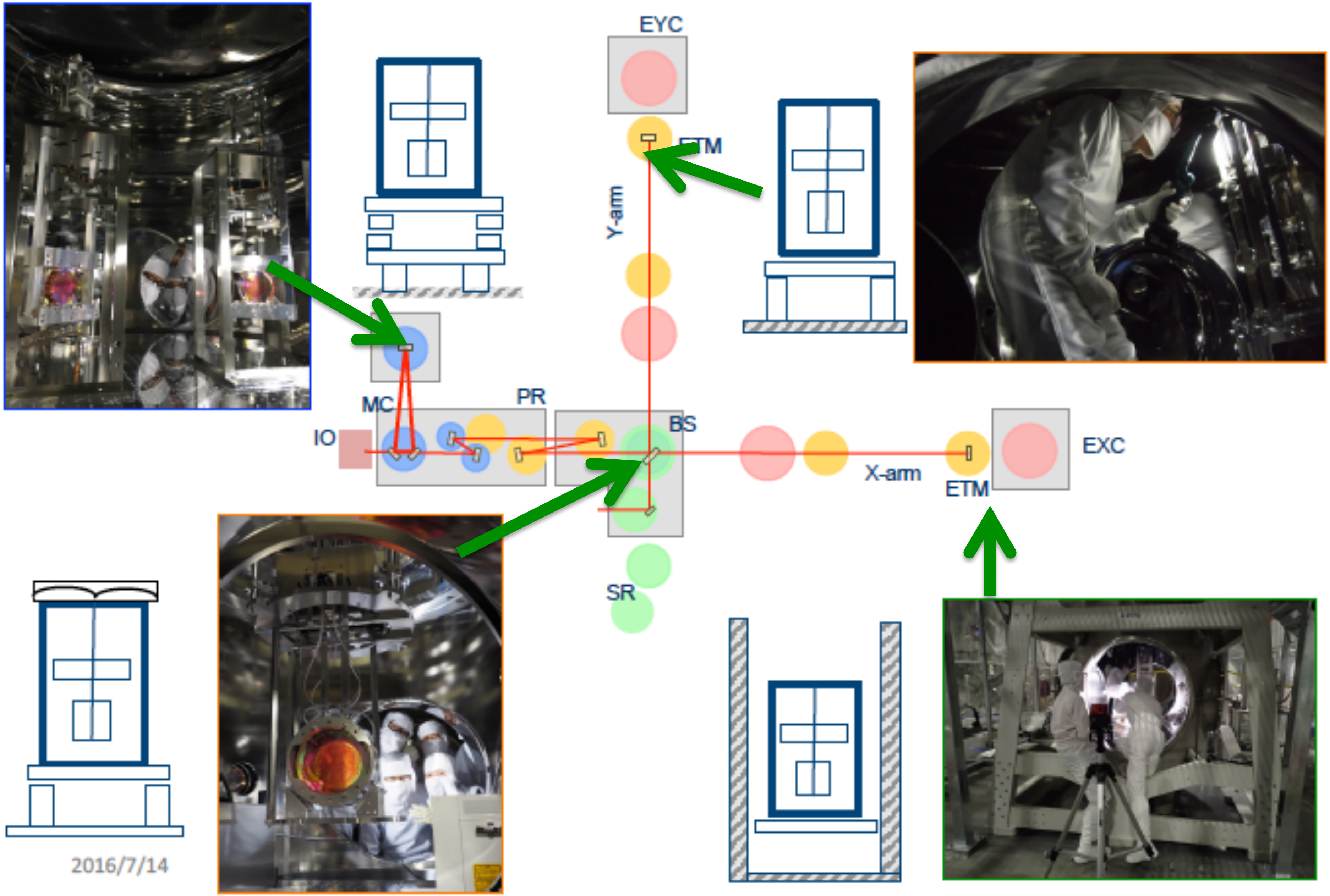
Cryogenic Michelson interferometer with Fabry-Perot cavity

Deployment of iKAGRA

- Setup
  - 3km Michelson interferometer
  - Laser power: 2W
- Schedule
  - iKAGRA 1st run: Mar. 25-31, 2016
  - iKAGRA 2nd run: Apr. 11-25, 2016
- Goal
  - Demonstration of 3 km Michelson interferometer
  - Construction of data aggregation and transfer
  - Validation of suspension and control system

160621_SAITO

iKAGRA commissioning



2016/7/14

Tunnel excavation was done at Mar. 2014

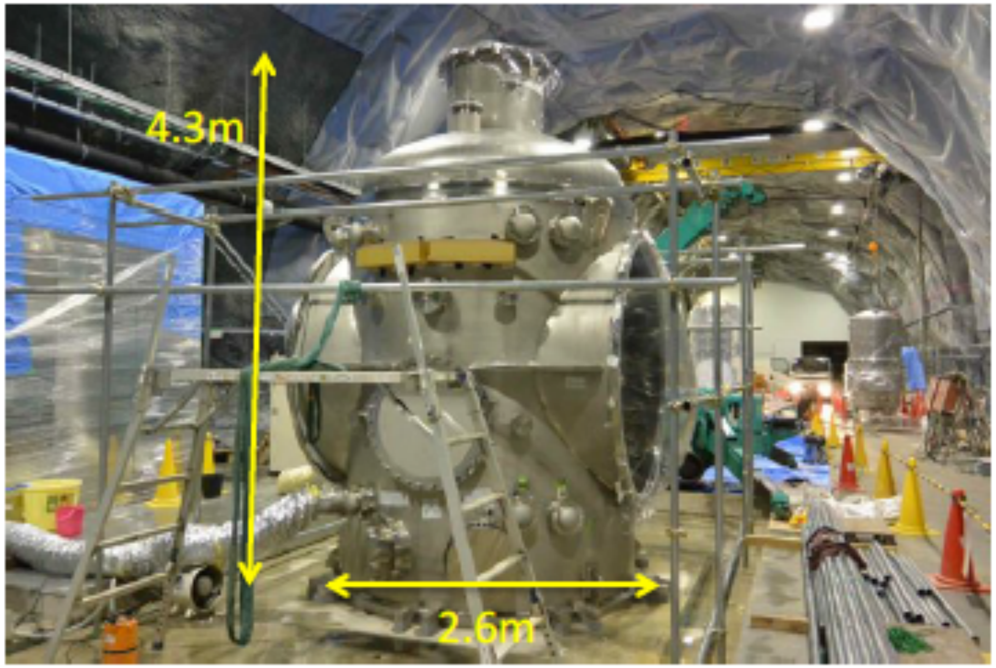
7km tunnel in total

Cryostat Installation Aug. 14, 2014

<- First device installation

Search KAGRA on YouTube

Cryostat Assembly

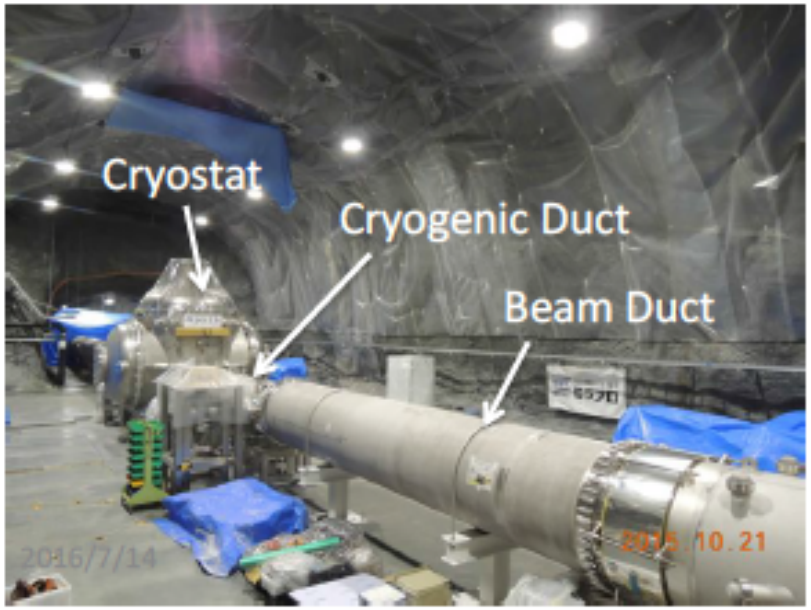


Assemblies of all of main cryostats has been done.

Vacuum Tubes and Tanks Installation

Beam tubes: φ800mm x12m x 478

Mode cleaner and BS tanks

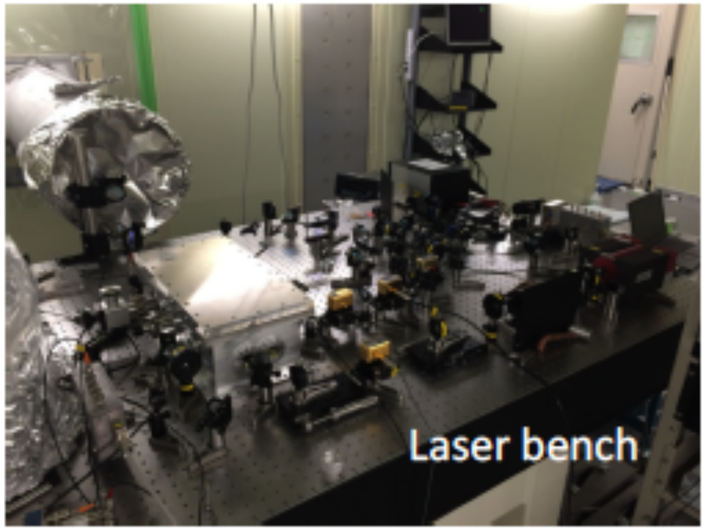


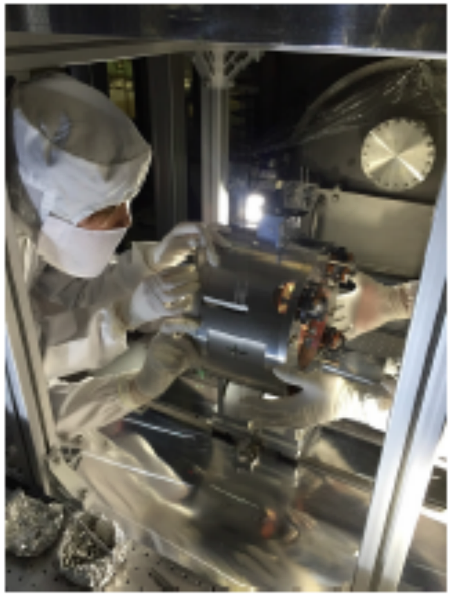
Most of vacuum tubes and tanks has been installed, and the installation will be completed in this year.

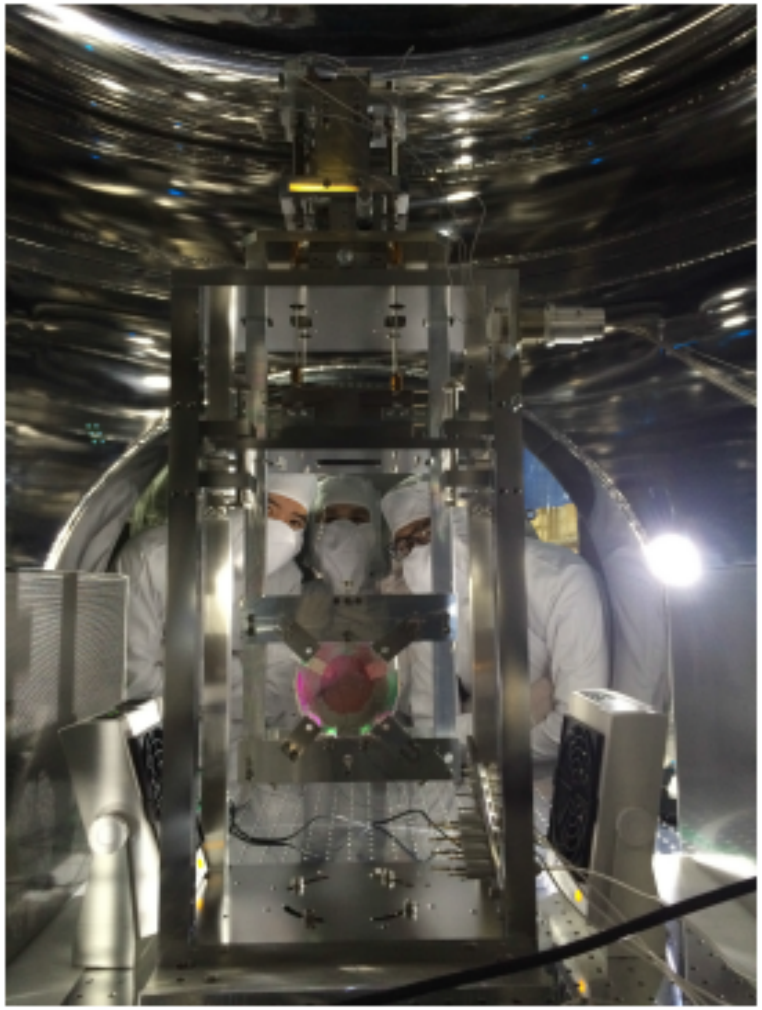
We also confirmed no vacuum leakage;
$< 1 \times 10^{-10}$ [Pa m^3/sec]

Installation of Input Optics & Vibration Isolators

Details: Nakano and Takahashi

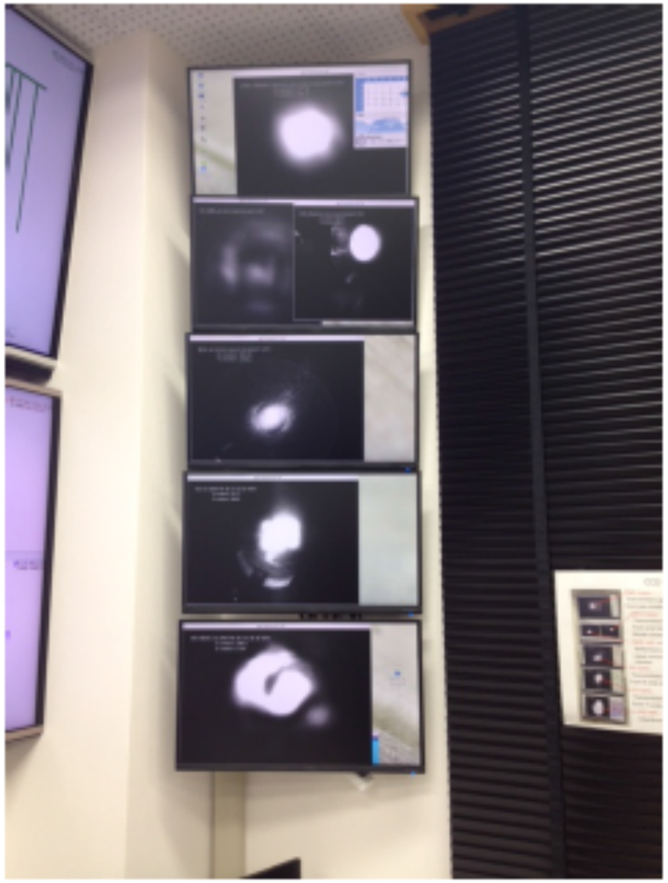






1st mirror (for mode cleaner) was installed in Oct. 2015.

Control room



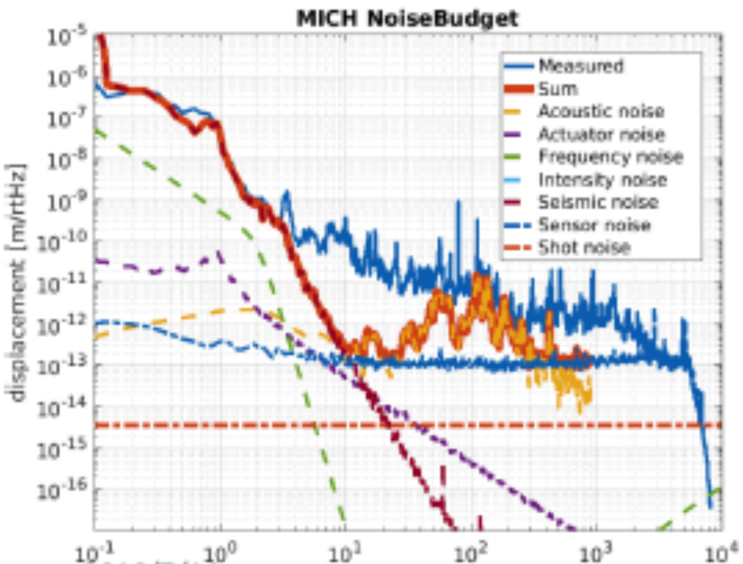
Mar. 25: iKAGRA operation was started.

iKAGRA 1st run: Mar. 25 - 31, 2016

iKAGRA 2nd run: Apr. 11 - 25, 2016

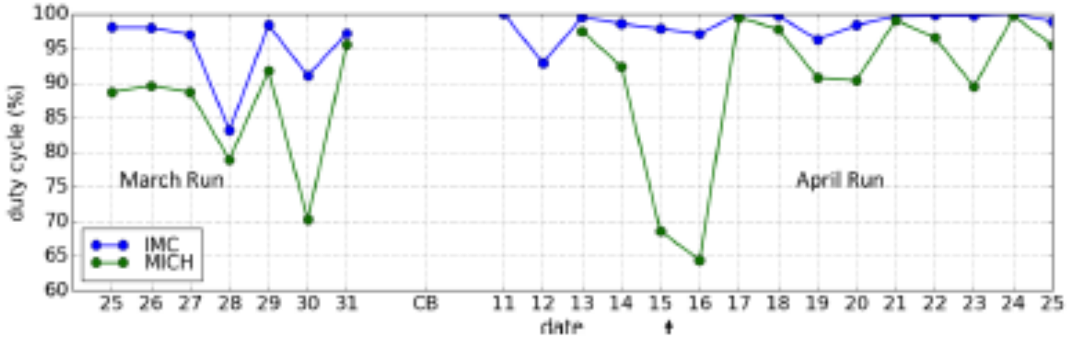
Typical Sensitivity

$6 \times 10^{-16}\,\mathrm{Hz}^{-1/2}@100\,Hz$

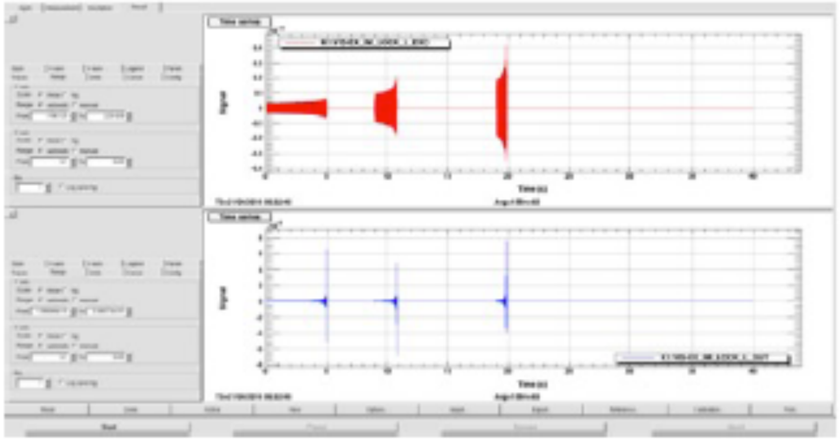


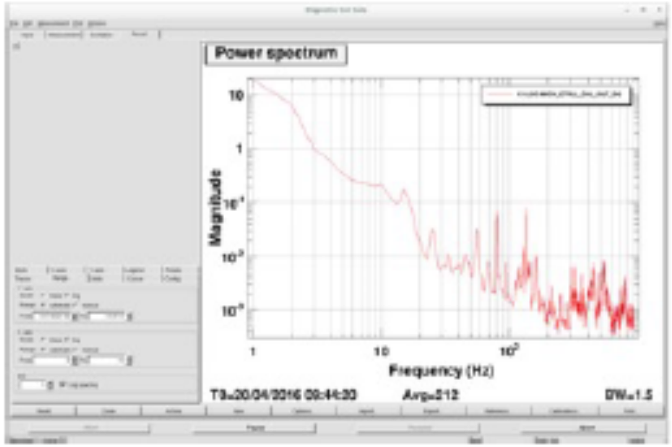
Duty Factor

1st run: 85.2%
2nd run: 90.4%



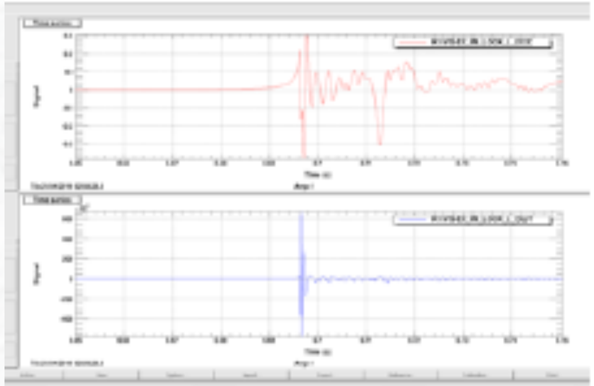
Injection tests



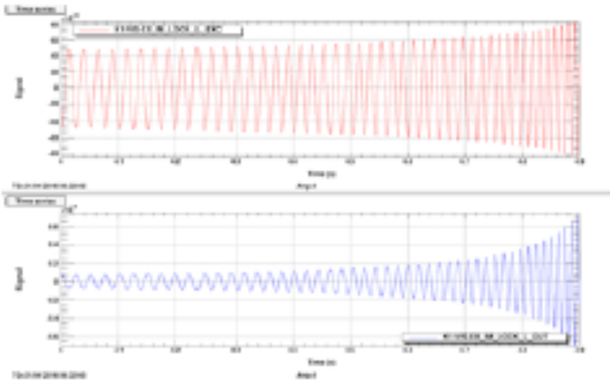


(red, top)Prepared waveform (blue, bottom)Injected waveform

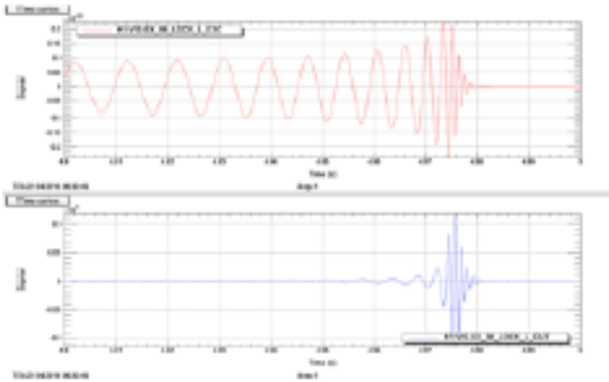
Supernova



CBC(Inspiral)



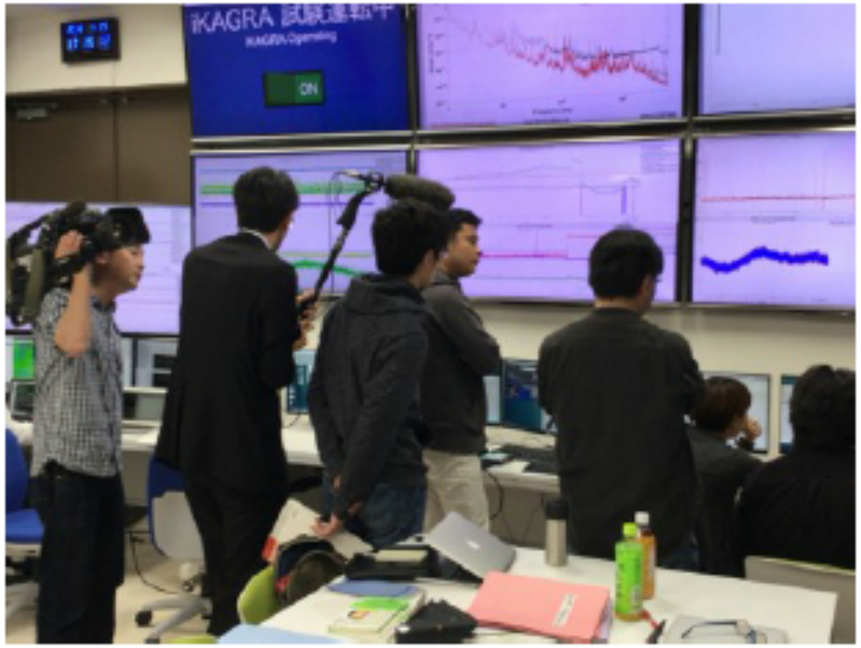
CBC(merger+ringdown)

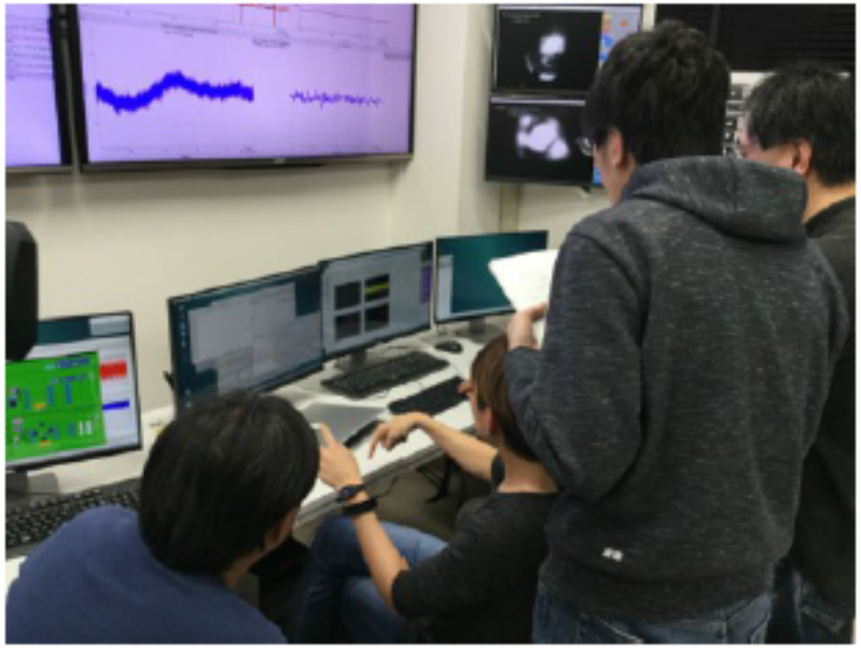


- We generate the pseudo signals with actuator.
- Analysis is ongoing.

Slide by Yokozawa san

Hardware injection -Pictures-

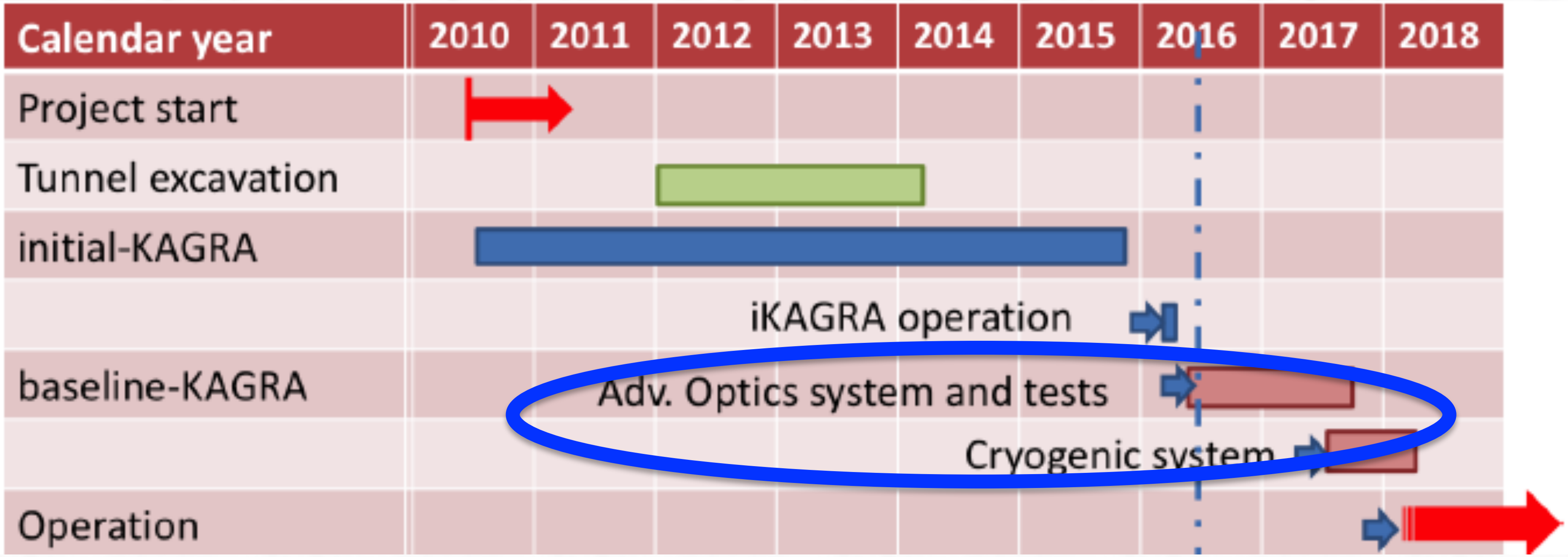


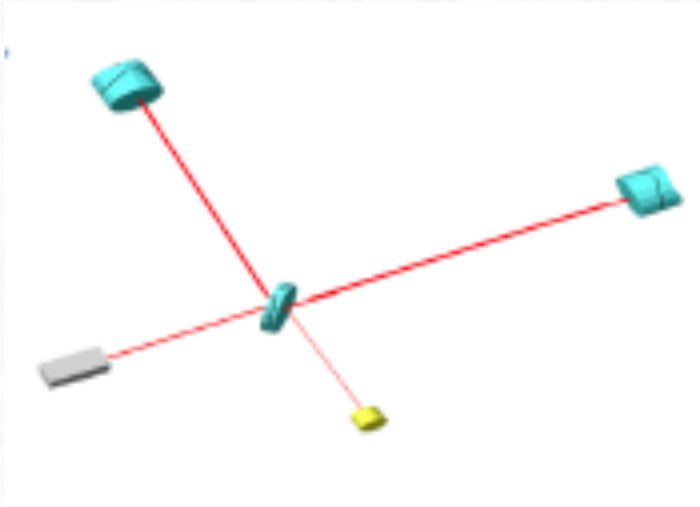


Slide by Yokozawa-san

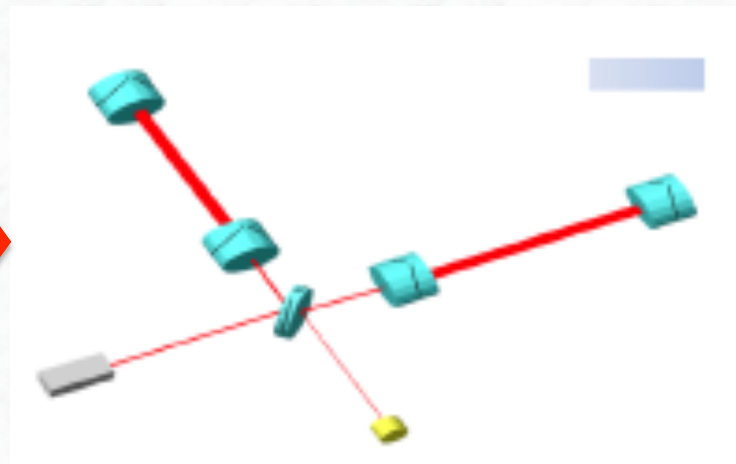
FUTURE PLANS

Timeline of KAGRA





Michelson interferometer



Cryogenic Michelson interferometer with Fabry-Perot cavity

Toward bKAGRA

Based on the experience of iKAGRA, we plan to proceed bKAGRA in 3 steps.

Phase-1 : Operation of a 3km cryogenic Michelson interferometer (-2018. 3).

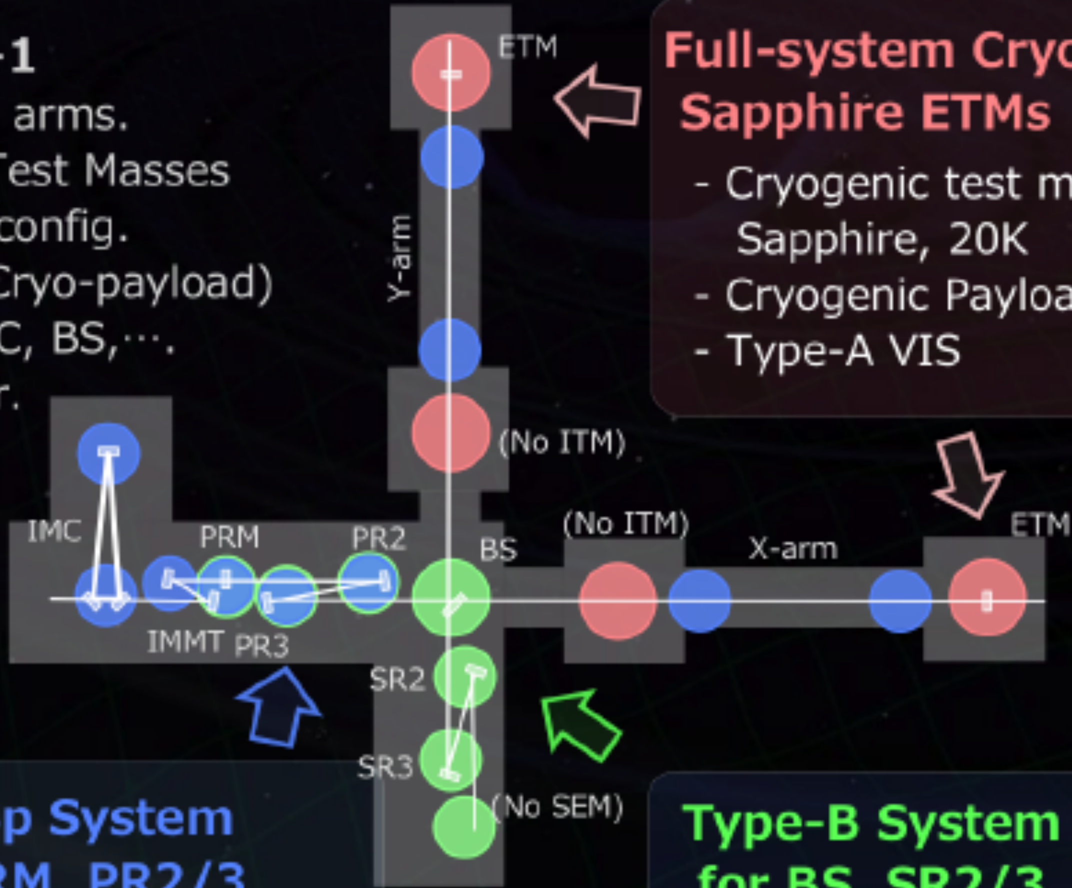
Phase-2 : Operation with full configuration: cryogenic and RSE (2018.4 – 2019 1Q??)

Phase-3 : Commissioning and Observation run (2019 2Q ??-)

bKAGRA Phase-1 (- 2018.3)

KAGRA

bKAGRA Phase-1
- PRMI with 3 km arms.
- Cryogenic End Test Masses suspended full config. (Type-A VIS +Cryo-payload)
- Final VIS for PRC, BS,….
- Low laser power.



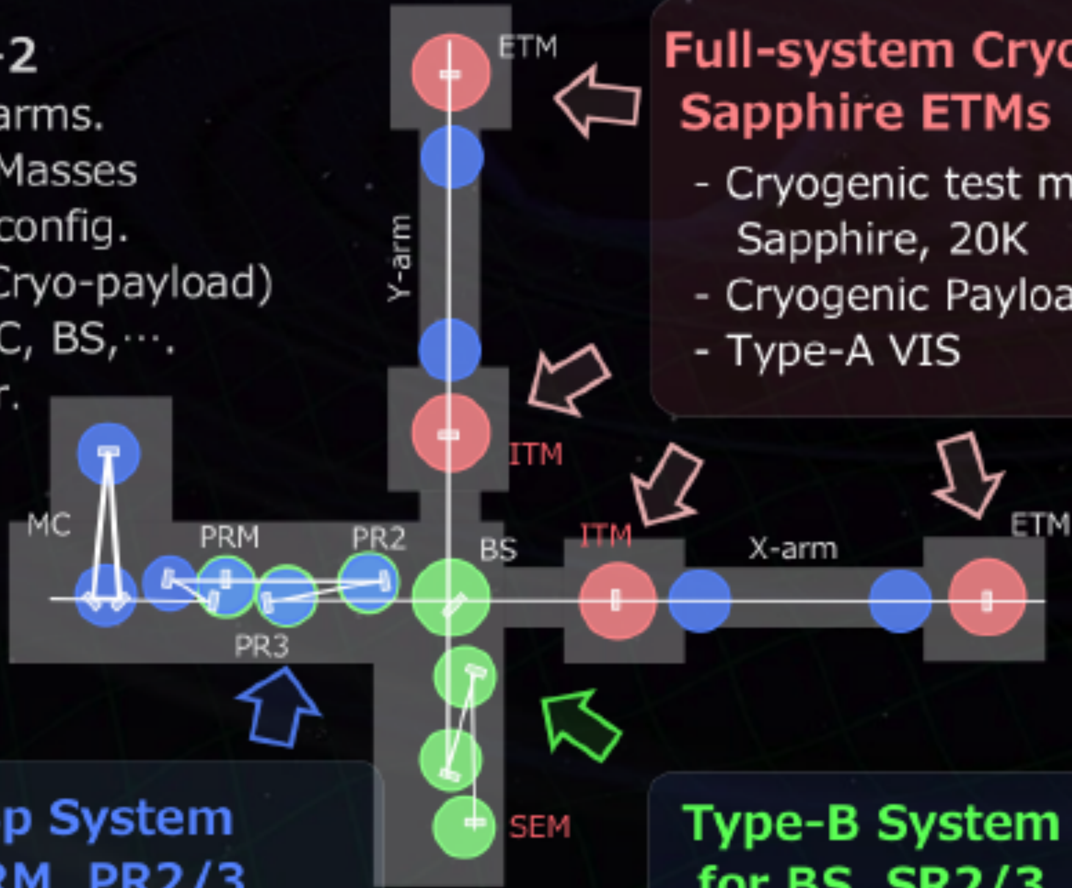
Full-system Cryogenic Sapphire ETMs
- Cryogenic test masses Sapphire, 20K
- Cryogenic Payload
- Type-A VIS

Type-Bp System for PRM, PR2/3
- Final Config.
- Room temp., 300K
- Power Recycling implementation is TBD

Type-B System for BS, SR2/3
- Final config.
- Room temp., 300K
- No SRM

bKAGRA Phase-2 (- 2019.3)

bKAGRA Phase-2
- RSE with 3 km arms.
- Cryogenic Test Masses suspended full config. (Type-A VIS +Cryo-payload)
- Final VIS for PRC, BS,….
- Low laser power.



Full-system Cryogenic Sapphire ETMs

- Cryogenic test masses Sapphire, 20K
- Cryogenic Payload
- Type-A VIS

Type-Bp System for PRM, PR2/3

- Final Config.
- Room temp., 300K
- Power Recycling implementation is TBD

Type-B System for BS, SR2/3

- Final config.
- Room temp., 300K
- No SRM

Taiwan contributions

Data management
and
Analysis

Cryogenic

Calibrator

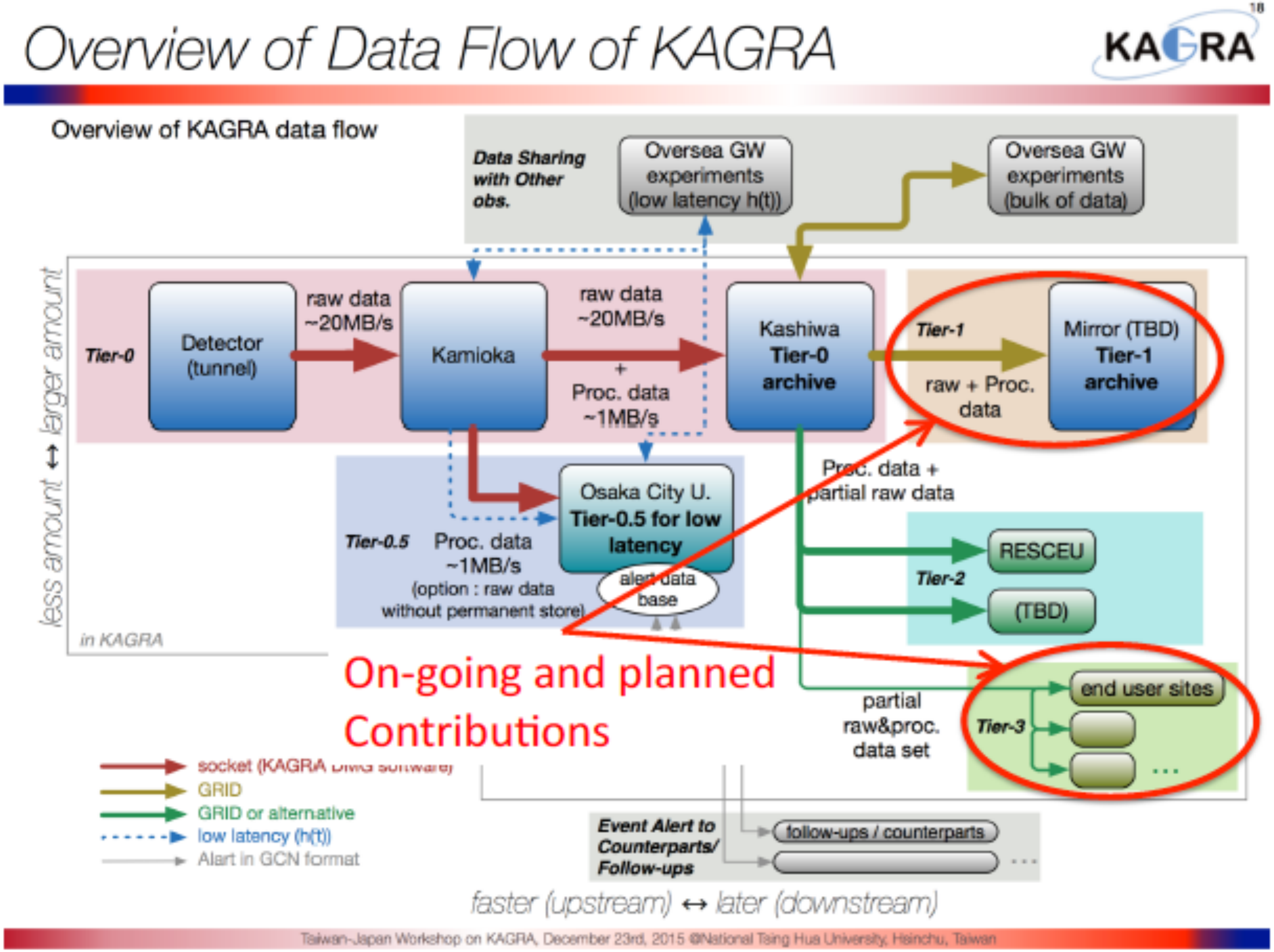
Taiwan contributions

Data management and Analysis

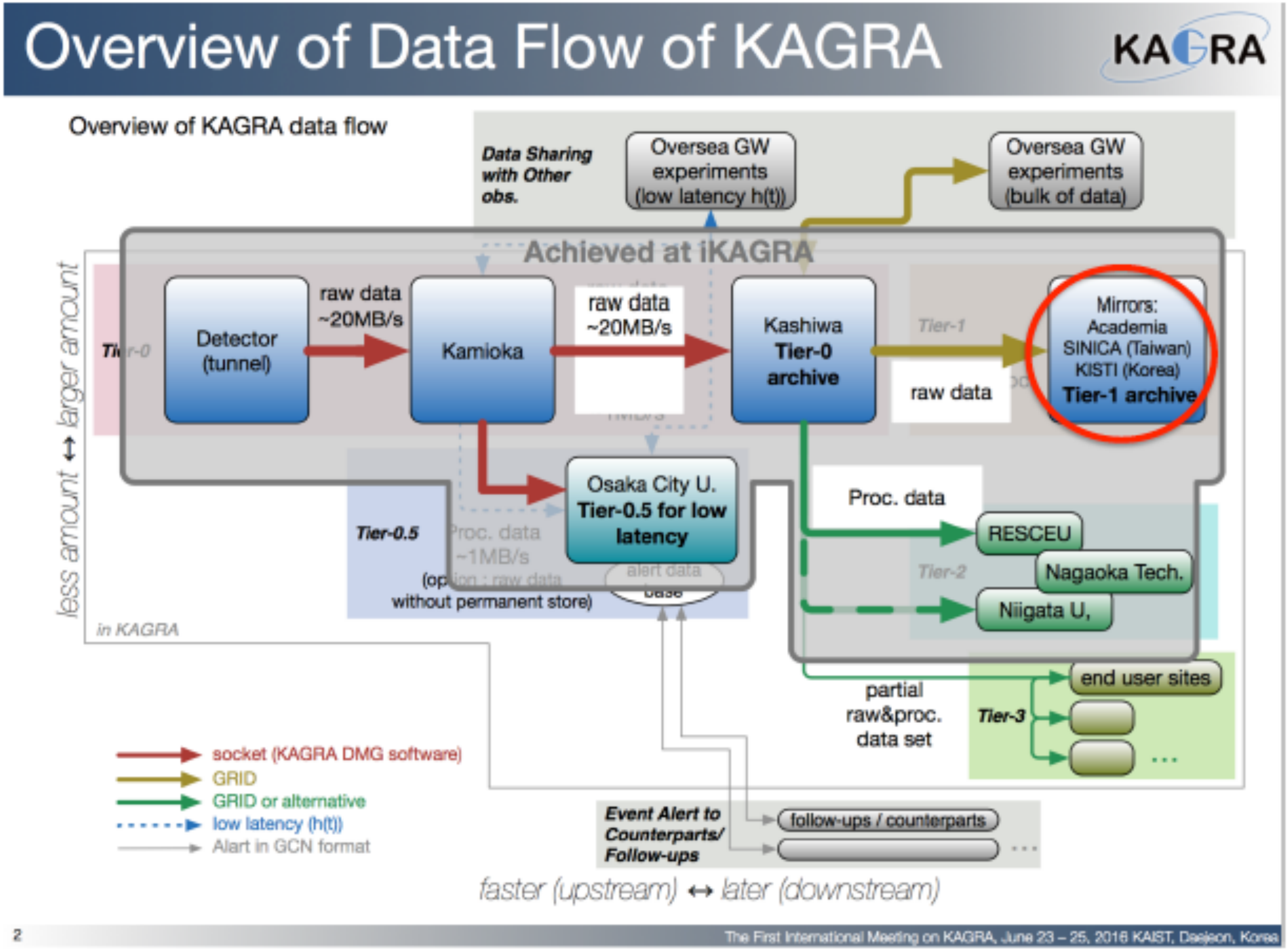
Cryogenic

Calibrator

Overview of Data Flow of KAGRA



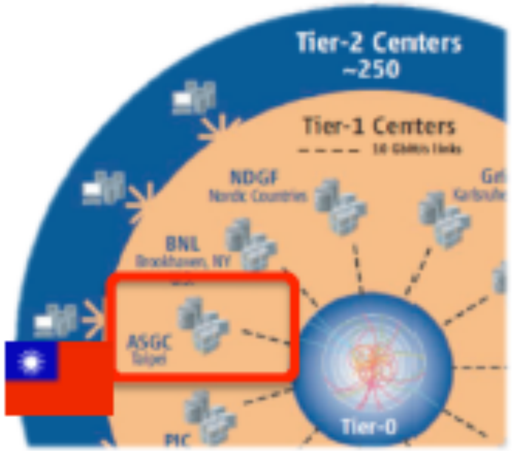
Slide by Kanda-san in Dec./2015



Slide by Kanda-san

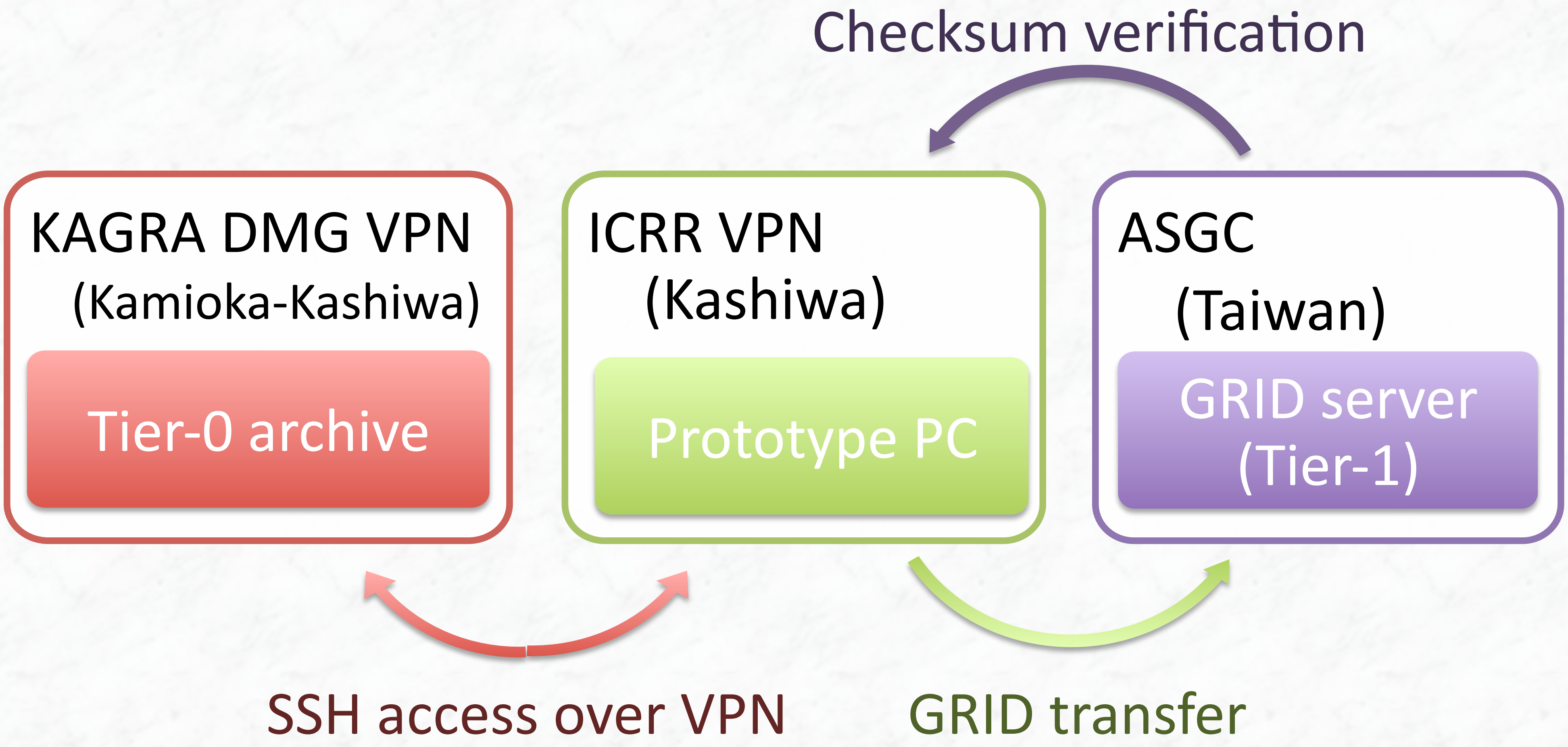
Data server in Taiwan

- ASGC (Academia Sinica Grid Center)
  The only LHC Tier1 center in Asia
  ~800 m^2 area
  ~20,000 CPU cores
  ~13 PB disk + 4 PB tape

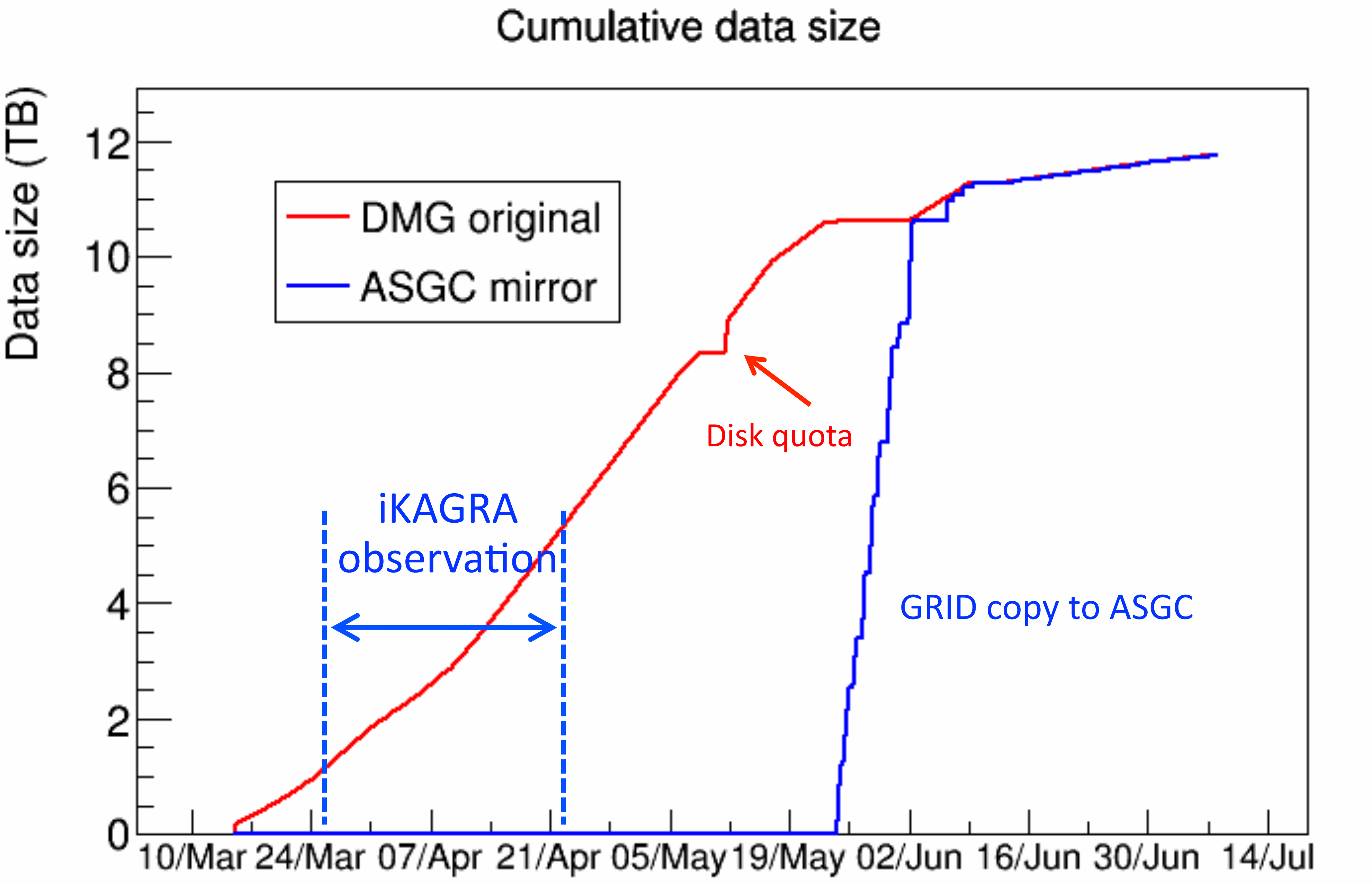


- Currently for iKAGRA, 220 TB disk space is allocated and 3 disk servers (Ceph FS, 16 cores, 96GB memory each) are working as GRID servers
- In the future, PB-level disk and the designated CPU nodes will be allocated in order to establish one of Tier-1 data mirror centers abroad of Japan

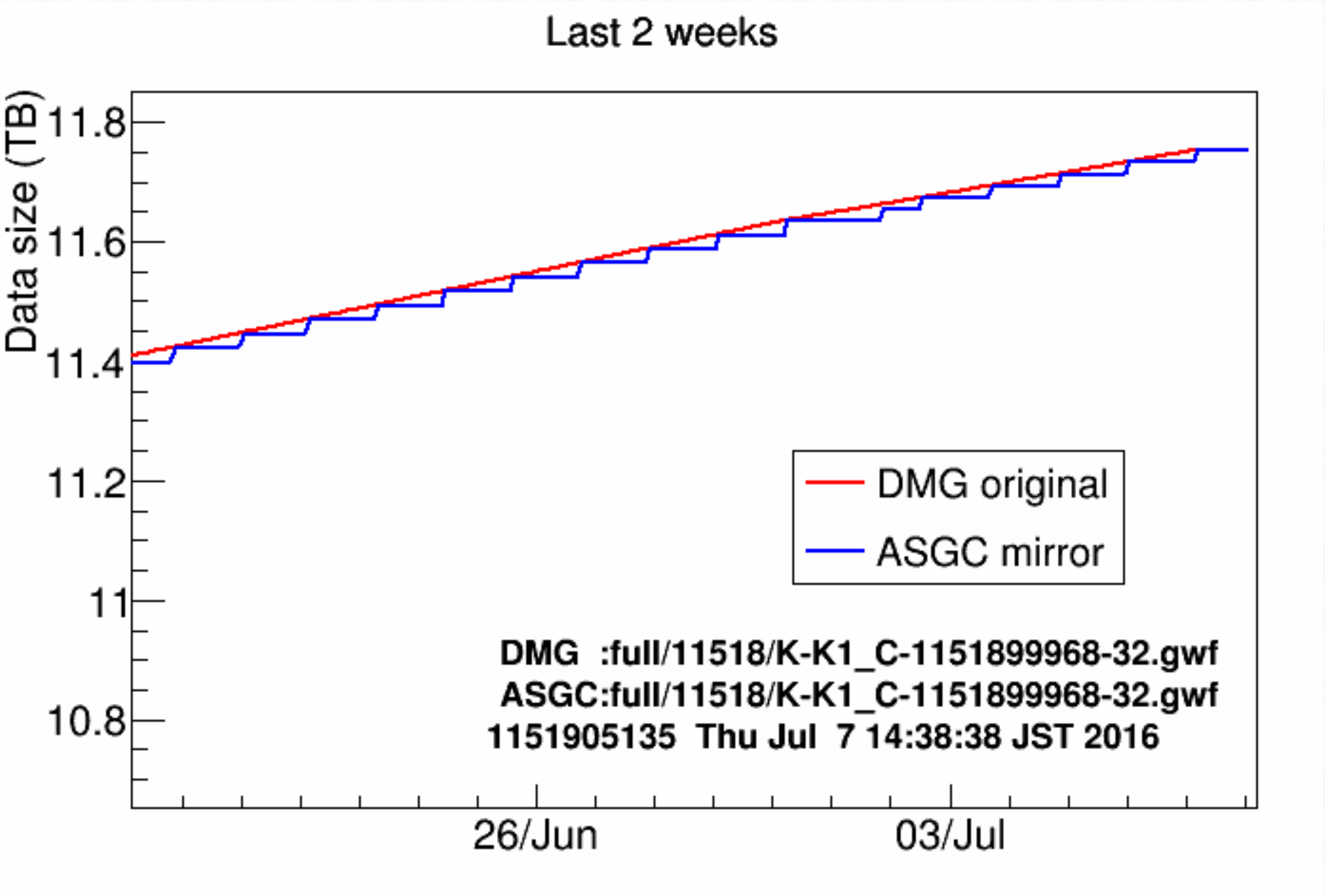
iKAGRA full data copy



Results of data transfer



Dater transfer (recent)



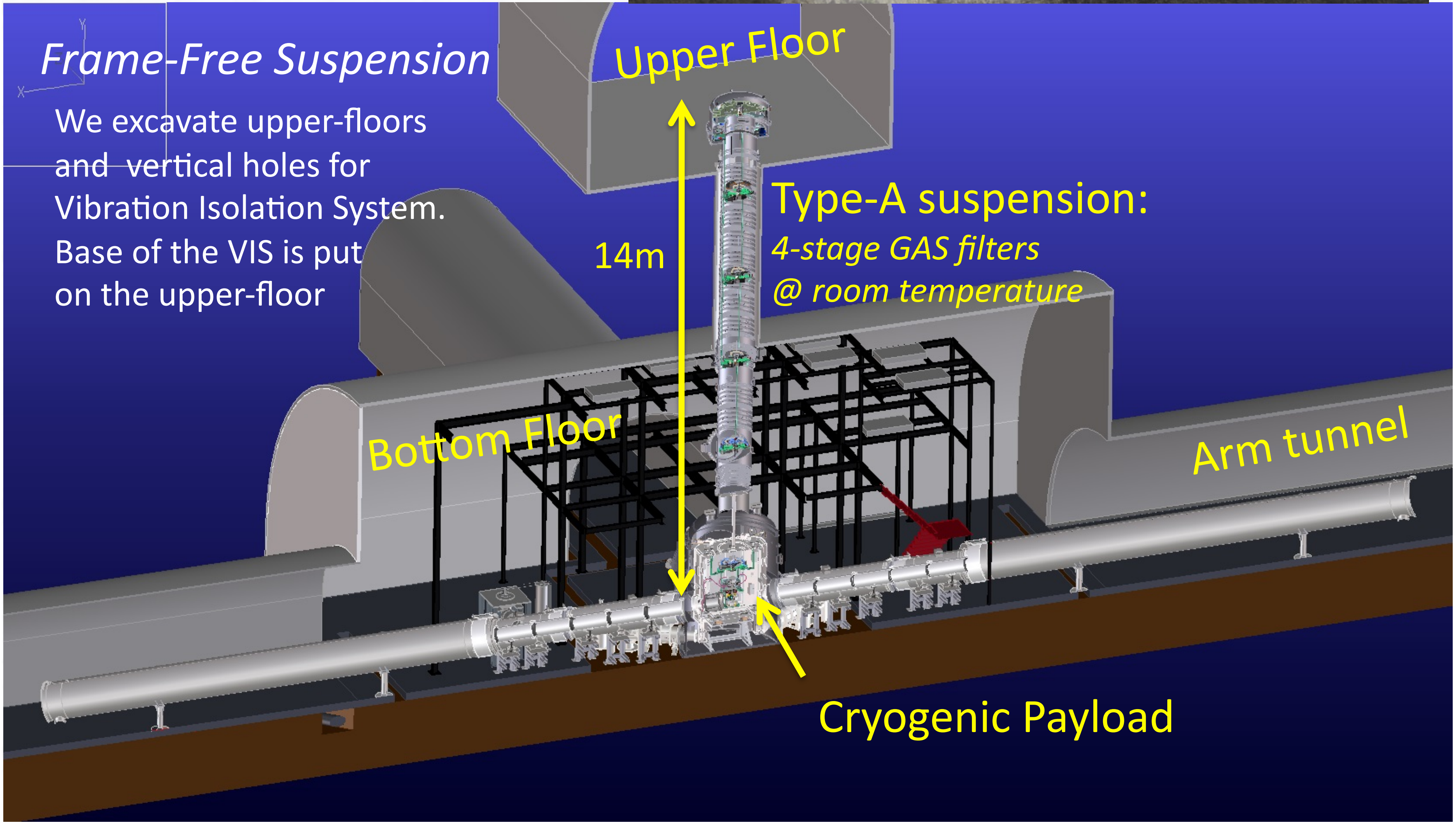
Taiwan contributions

Data management
and
Analysis

Cryogenic

Calibrator

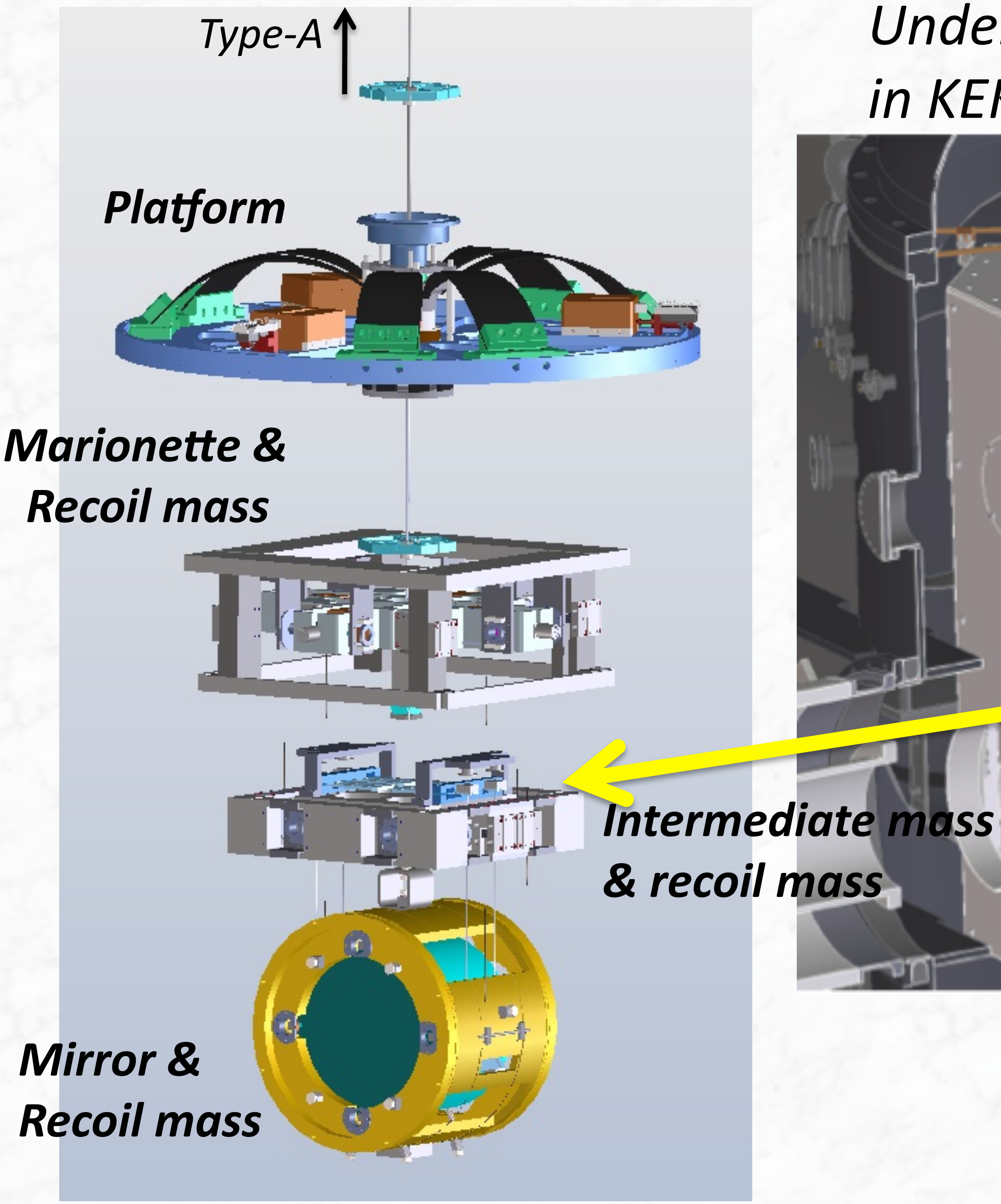
Main mirror



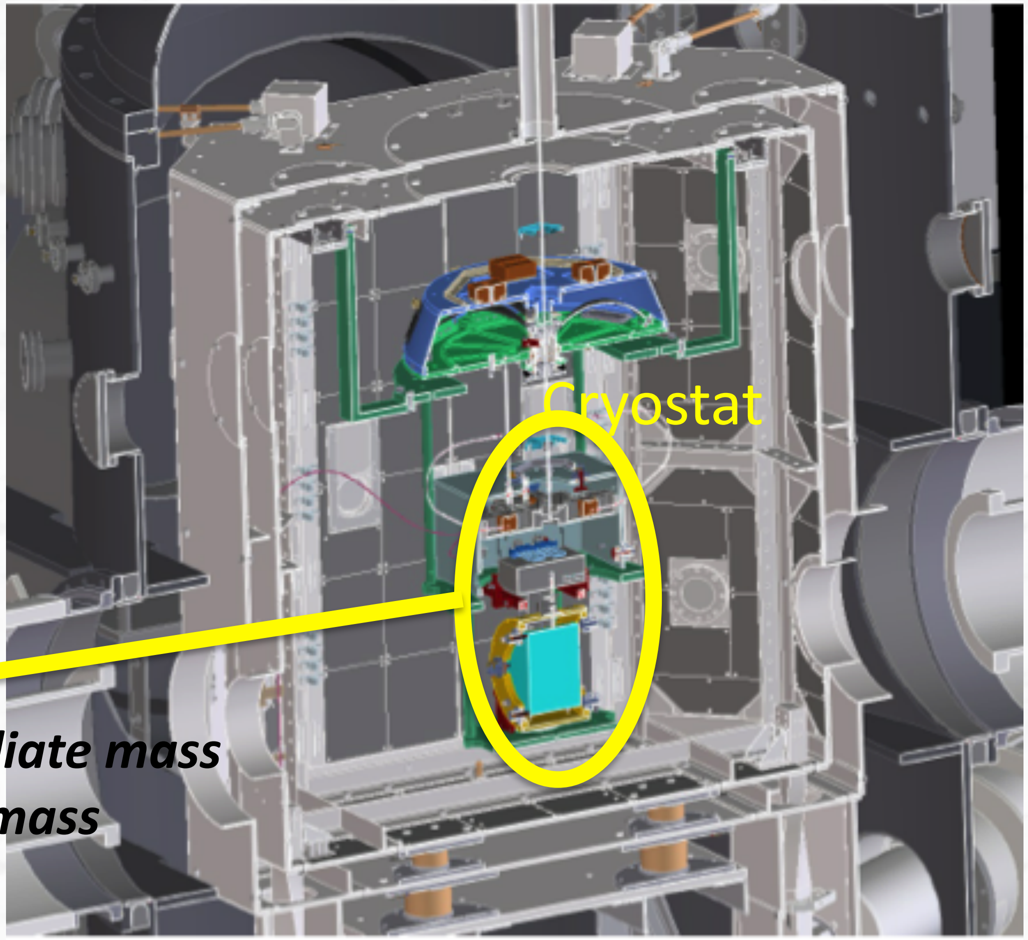
Frame-Free Suspension

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

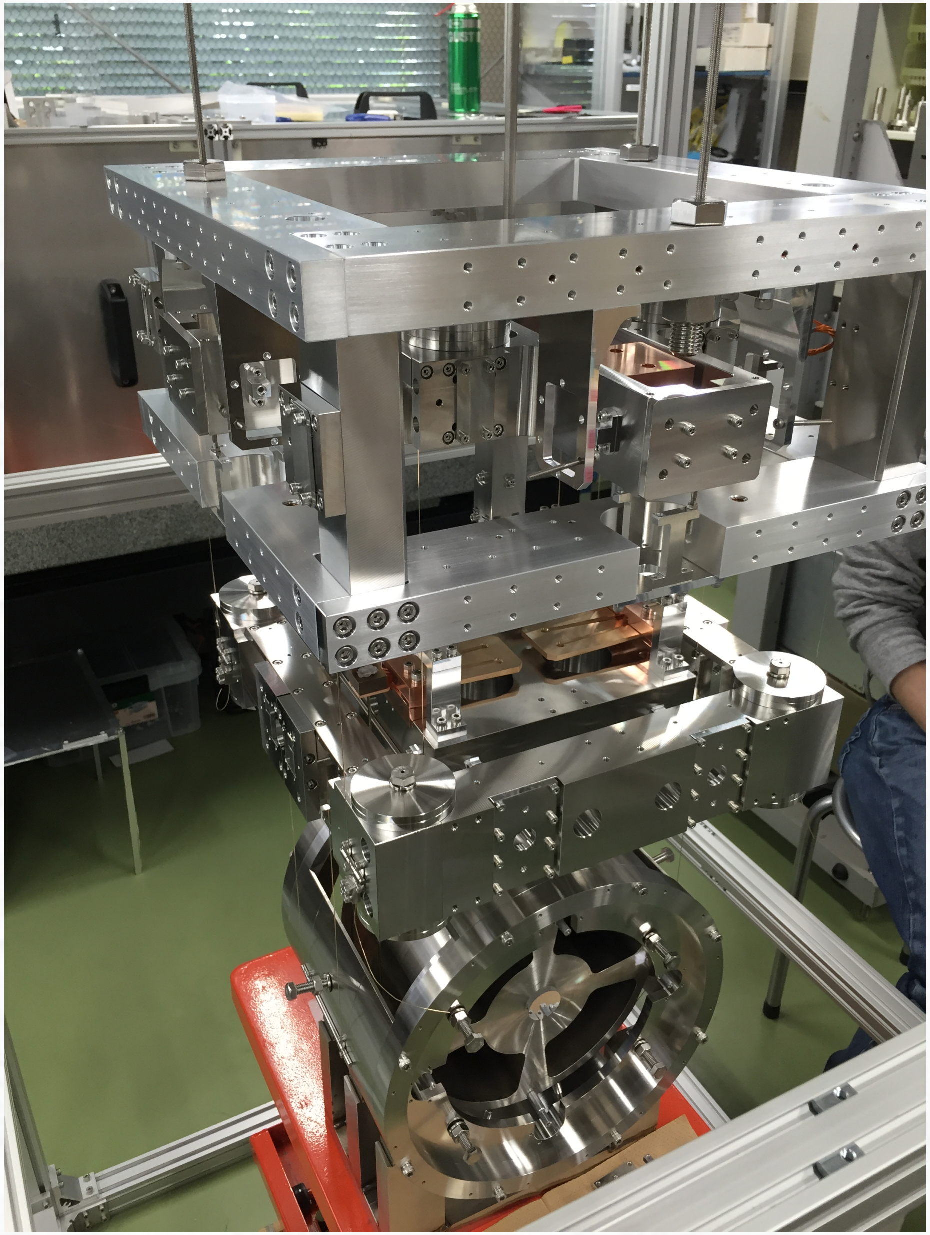
Cryogenic Payload

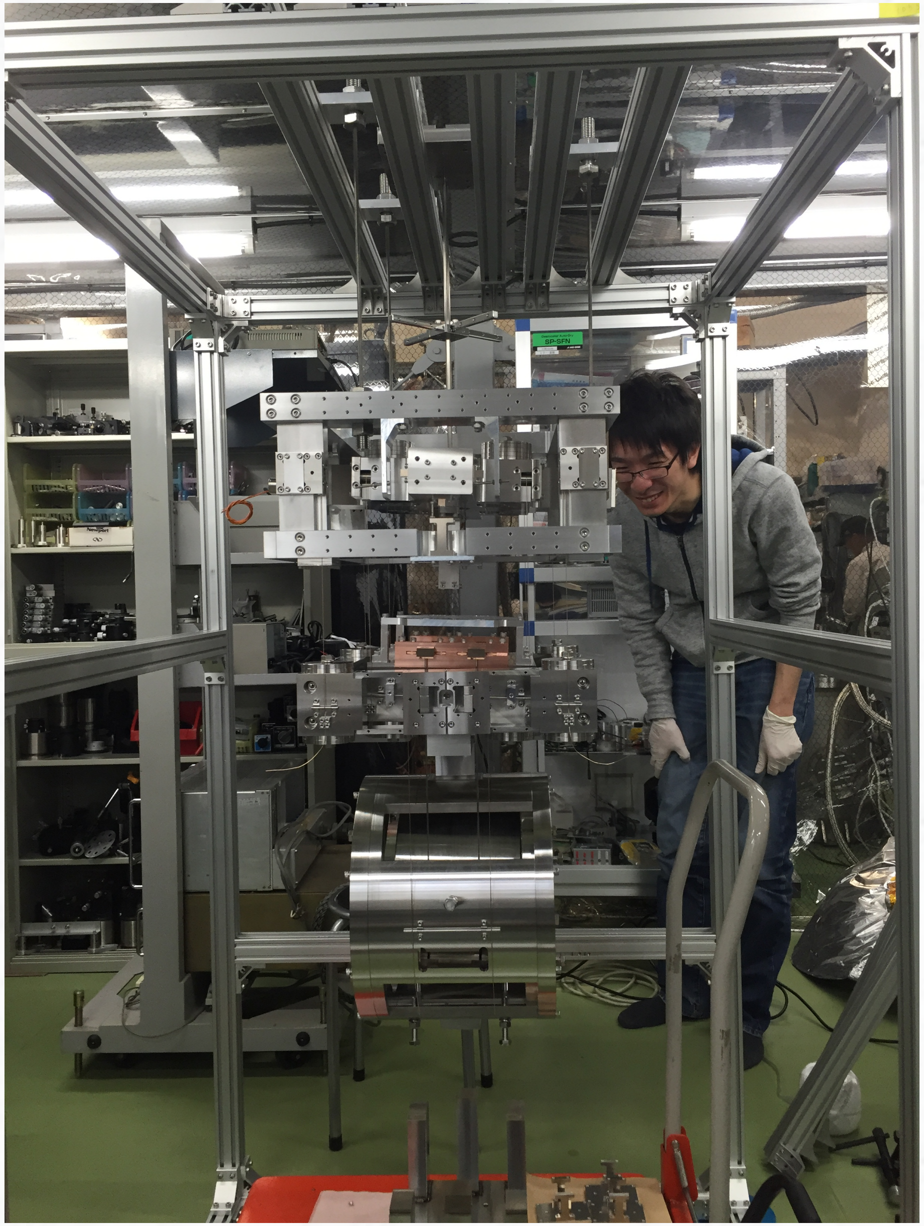


Under developing
in KEK and ICRR



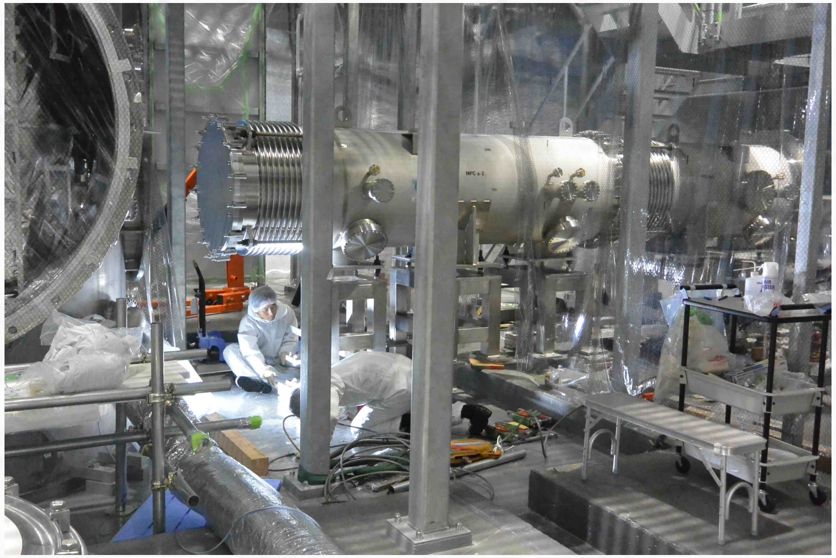
Assembling the Cryogenic Payload



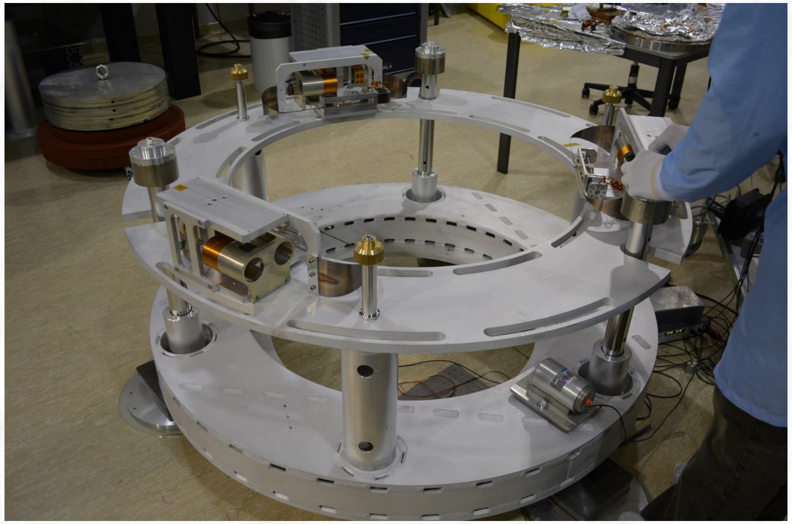


We have already rushed toward bKAGRA

XY-end cryostat assembly (Just now!)



Inverted pendulum for Type-A suspension



Vacuum chamber for Type-A

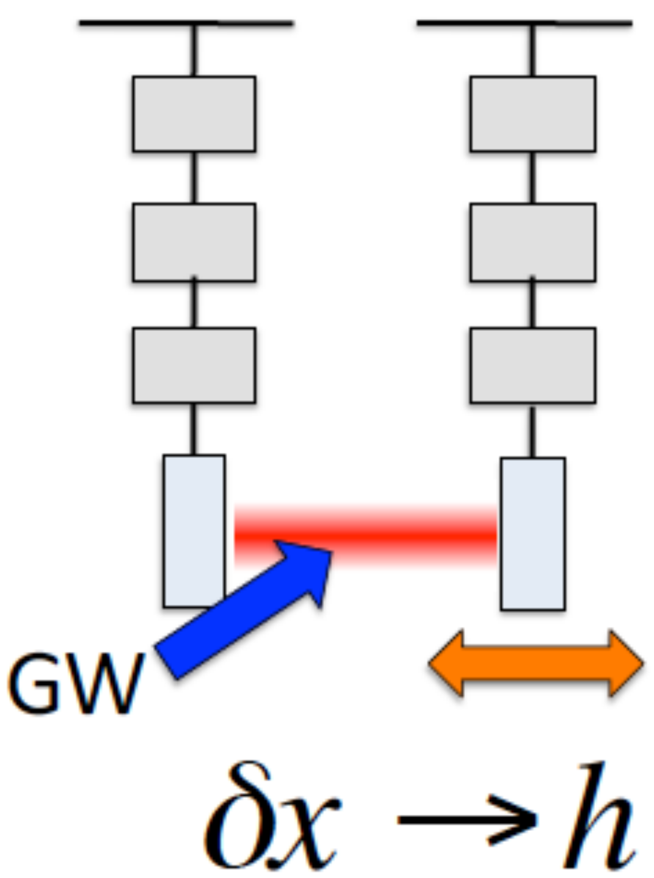
Taiwan contributions

Data management and Analysis

Cryogenic

Calibrator

Motivation

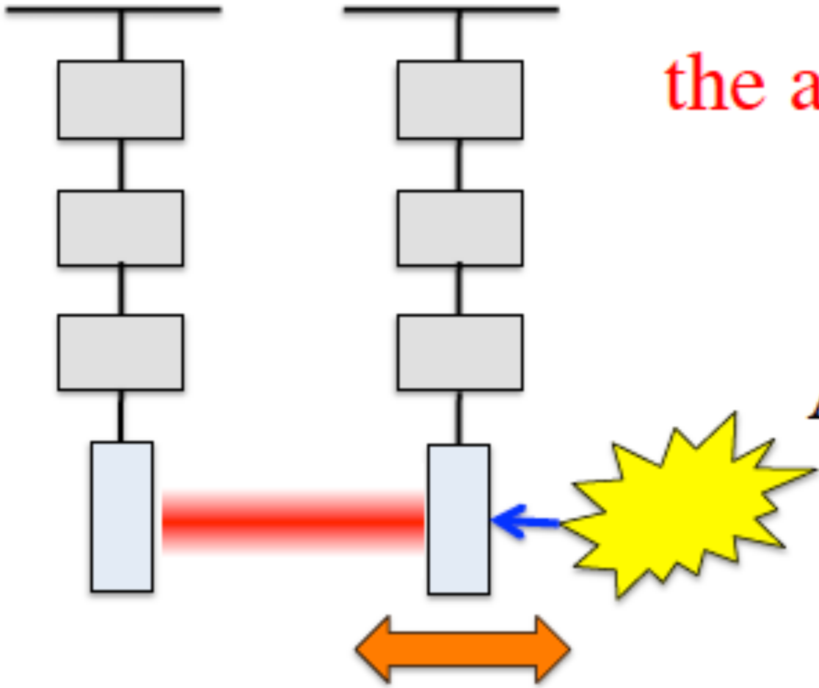


- Uncertainty of previous study
  - Amplitude: ~10 %
  - Phase: ~10deg
- Not enough to study the "Astronomy" and "Cosmology"
- Need the low-uncertainty detection of the waveform.

GW is measured as mirror displacement

We have to know the absolute displacement accurately!

Simple question

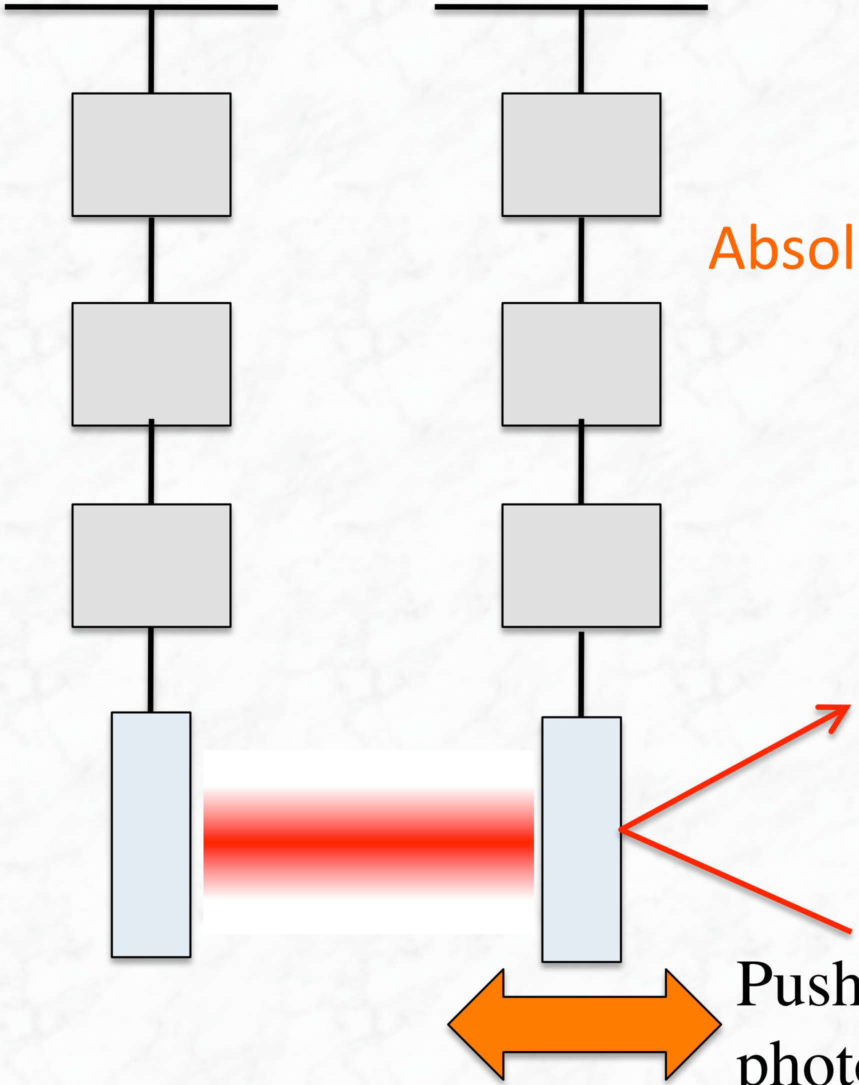


Q. How to know
the absolute mirror displacement?

A. Acting on the mirror with
well-known force!

Conventional method (LIGO)

Radiation pressure



Push the mirror with photon pressure

Absolute power — Transfer function — Geometrical factor

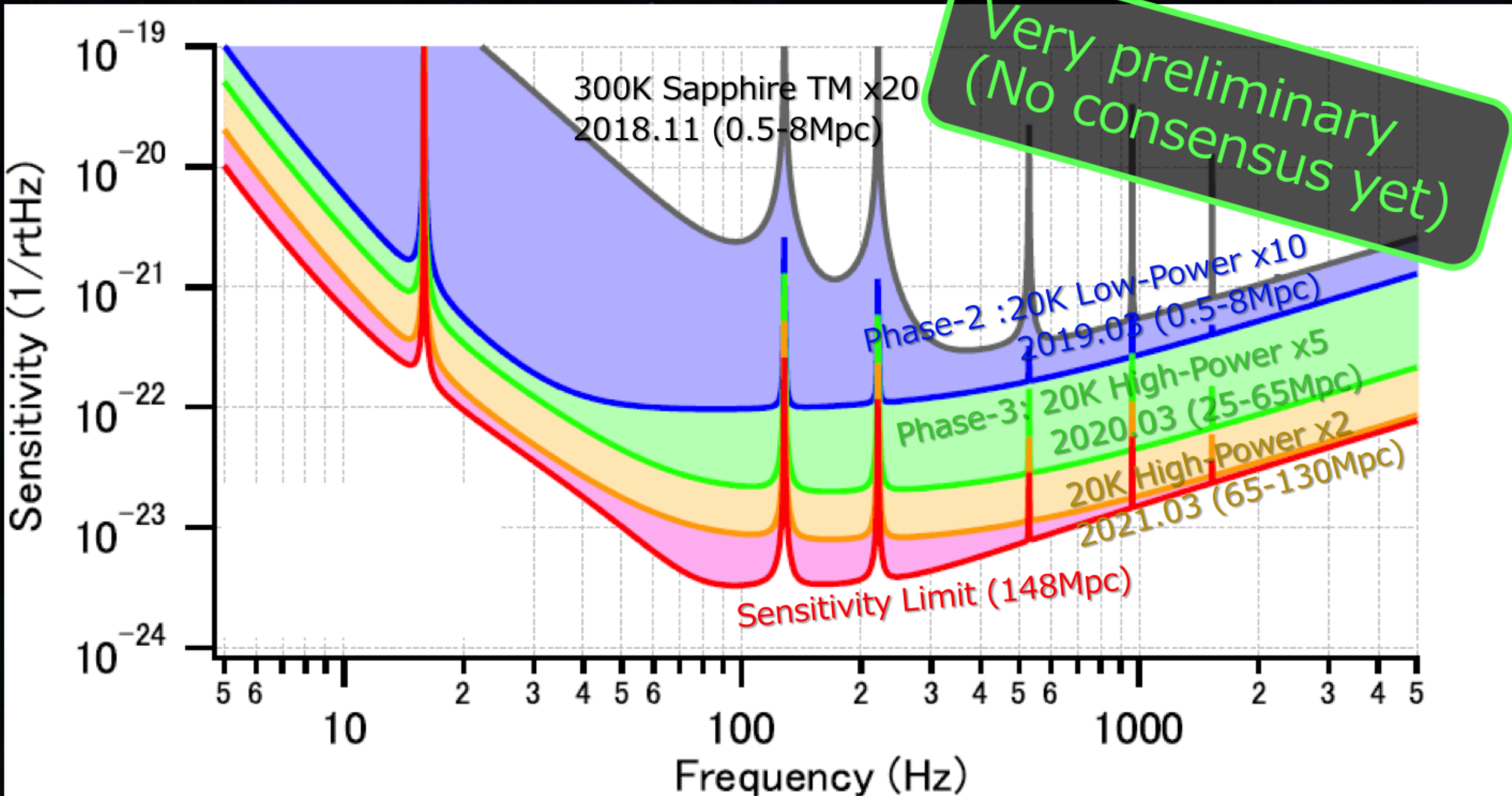
$$\delta x \sim \frac{2P(f)}{c} s(f) \left(1 + \frac{M}{I} \vec{a} \cdot \vec{b}\right) \cos\theta$$

Taiwan team plan to develop the calibration system.

Sensitivity Prediction

- Not a promise or consensus. Just for reference

By Somiya



SUMMARY

- The Gravitational waves are observable target.
- KAGRA is one of the GW detectors in Asia.
- The runs of iKAGRA ate finished and analysis is ongoing.
- The fabrication of bKAGRA in progress. Taiwan group contribute the analysis and calibrator development.
- The observation of bKAGRA will start in early 2018.