JGW-G1402630-v4

“Supernovae and Gamma-Ray Bursts 2014” in RIKEN during 25-27 Aug.

KAGRA : Construction Status in Summer 2014
&
its Science on SNe and GRBs

N.Kanda (Osaka City U.)
on behalf of KAGRA collaboration.

Plan of Talk about KAGRA

Brief overview of the project

- Detector
- Science target of Gravitational Wave (GW) detection

Construction status in 2014 Summer

- Tunnel excavation is finished !
- Preparing iKAGRA (1st total operation in normal temperature at December 2015)

Science in GW detection/measurement from SNe or GRBs

- What can be derive ?
- Chance of coincidence observation

What is Gravitational Wave ?

Gravity distorts the space-time !

Einstein Eq.

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = -\kappa T_{\mu\nu}$$

metric tensor

"flat" space-time (Minkowski)

$$g_{\mu\nu} = \eta_{\mu\nu} = \begin{array}{cc} \begin{array}{cccc} ct & x & y & z \end{array} & \\ \begin{pmatrix} -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} & \begin{array}{c} ct \\ x \\ y \\ z \end{array} \end{array}$$

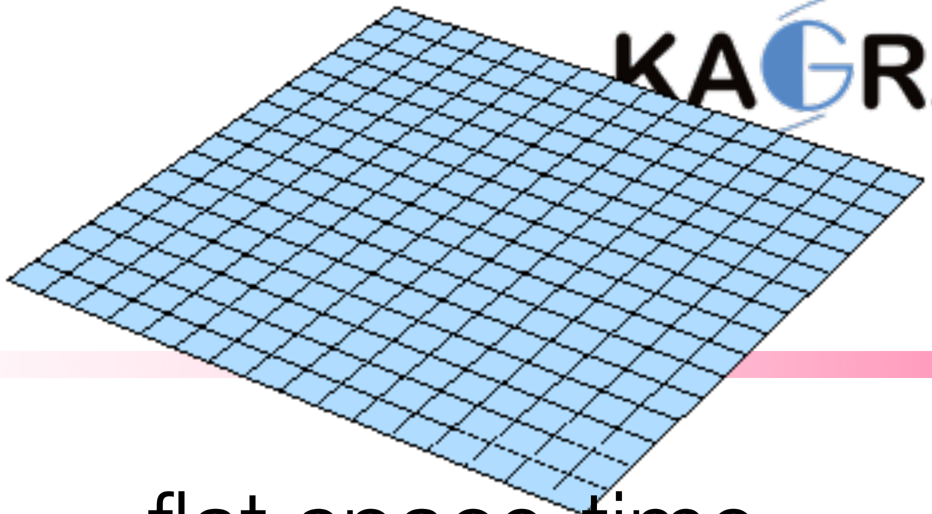
"curved (distorted)" space-time

$$g_{\mu\nu} \neq \eta_{\mu\nu}$$

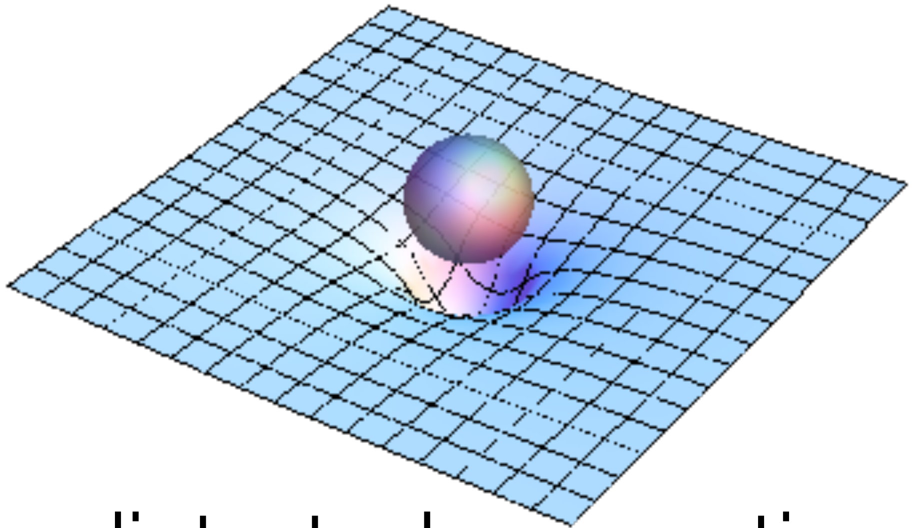
small perturbation 'h' --> Waves

$$g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu}$$

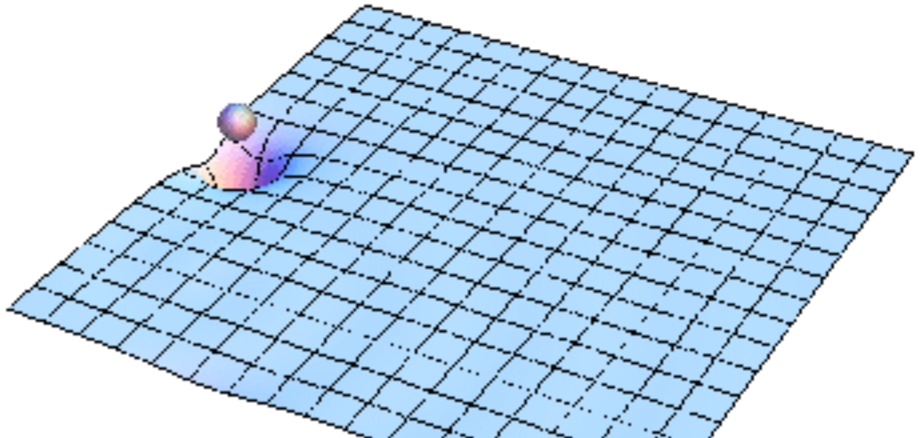
$$\left(\nabla^2 - \frac{1}{c^2}\frac{\partial^2}{\partial t^2}\right) h_{\mu\nu} = 0$$



flat space-time



distorted space-time
by mass = gravity



Gravitational Wave

propagation of distortion

What is Gravitational Wave ?

Gravity distorts the space-time !

Einstein Eq.

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = -\kappa T_{\mu\nu}$$

metric tensor

“flat” space-time (Minkowski)

$$g_{\mu\nu} = \eta_{\mu\nu} = \begin{array}{cc} \begin{array}{cccc} ct & x & y & z \end{array} & \\ \begin{pmatrix} -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} & \begin{array}{c} ct \\ x \\ y \\ z \end{array} \end{array}$$

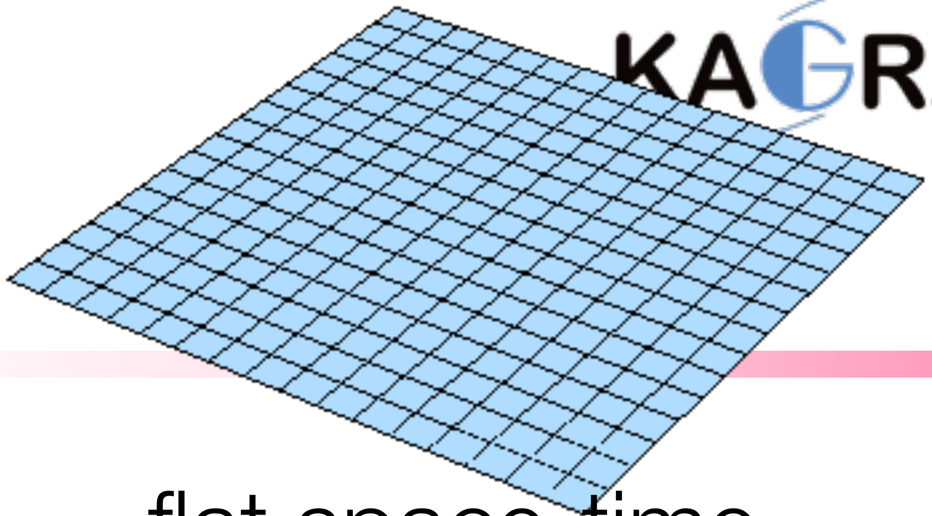
“curved (distorted)” space-time

$$g_{\mu\nu} \neq \eta_{\mu\nu}$$

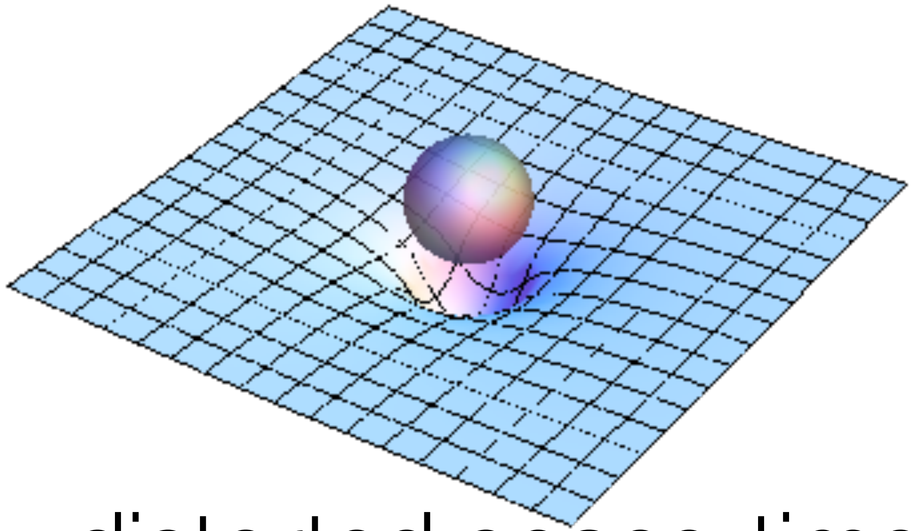
small perturbation ‘h’ --> Waves

$$g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu}$$

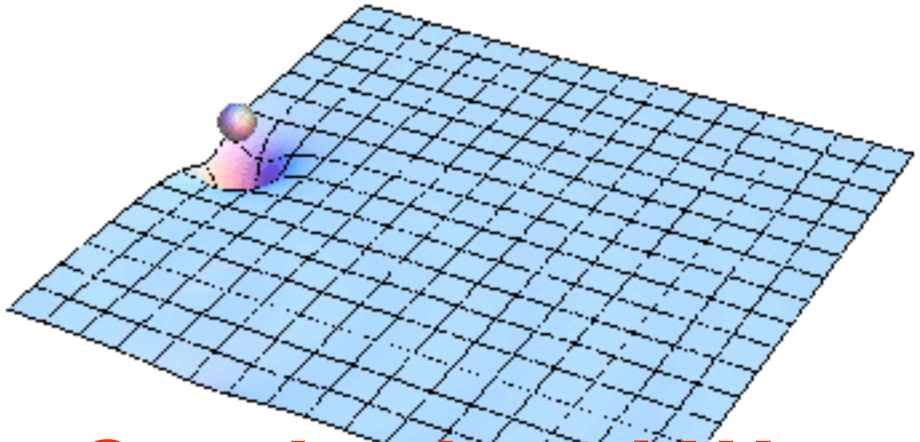
$$\left(\nabla^2 - \frac{1}{c^2}\frac{\partial^2}{\partial t^2}\right) h_{\mu\nu} = 0$$



flat space-time



distorted space-time
by mass = gravity



Gravitational Wave
propagation of distortion

GW radiation

Source

change (time derivative) of quadrupole moment of mass distribution

$$I_{\mu\nu} = \int dV (x_\mu x_\nu - \frac{1}{3}\delta_{\mu\nu} r^2)\rho(\vec{r})$$

Amplitude

inversely proportional to the distance between source and observer

$$h_{\mu\nu} \ = \ \frac{2G}{Rc^4}\ddot{I}_{\mu\nu}$$

Energy

total energy is given as :

$$E_{GW} \ \sim \frac{G}{5c^5} < \dddot{I}_{\mu\nu} \dddot{I}^{\mu\nu} >$$

Science of GW

Need direct measurement !!!

Why direct measurement ?

- We have to test GR in '**strong**' gravity field !
- Past experimental GR tests had been done in weak gravity field (in Solar system)
- Direct measurement of wave property is important as the test of a fundamental interaction .

GW waveform carry information of its sources !

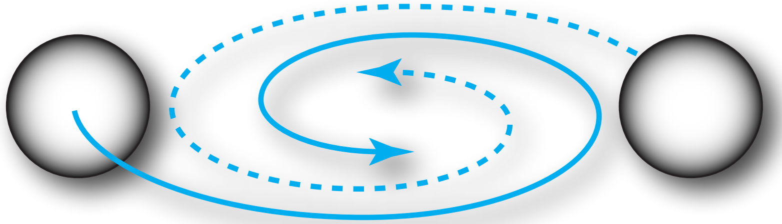
- New probe for astrophysics and cosmology
- Tagging GW events = seeing sources

Gravitational Wave Astronomy

Possible GW sources

Event Like

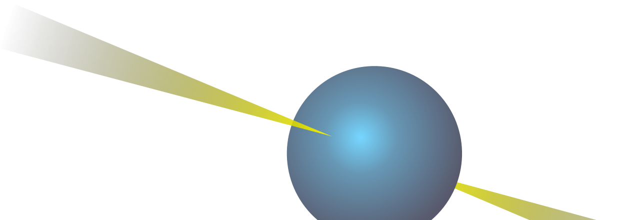
It will occur suddenly. Sometime it can be luminous!



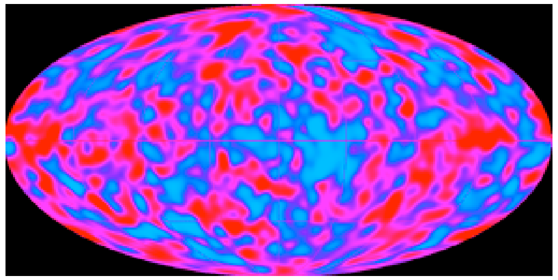
- **Compact Binary Coalescence** (**Neutron Star-NS**, NS-Blackhole, BH-BH)
- **Supernova** (Stellar-core collapse)
- BH QNM
- Pulsar glitch

Continuous

It exists anywhere, anytime in our universe …



- Rotating Pulsar
- Binary
- Stochastic Background



(+Unknown sources)

typical target : $h \lesssim 10^{-22} - 10^{-24}$

KAGRA Collaboration in the world

- Research organizations of laboratories and faculties of universities are 41 in Japan and 37 in overseas
- 158 researchers in Japan and 69 in abroad, 227 members in total

viewgraph by K.Kuroda

KAGRA overview

Underground

- in Kamioka, Japan

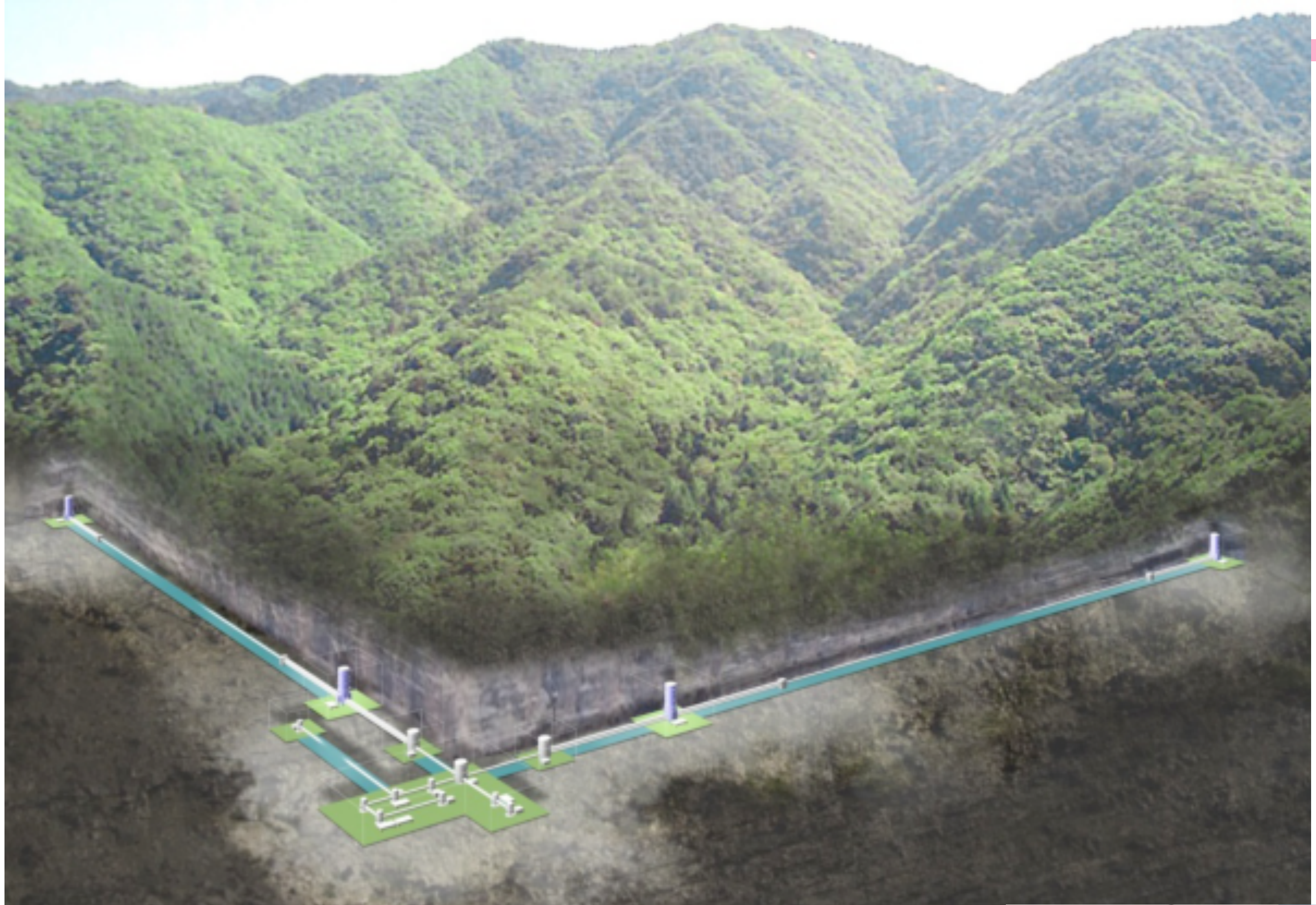
  Silent & Stable environment

Cryogenic Mirror

- 20K

  sapphire substrate

3km baseline



© ICRR, university of Tokyo

Plan

- 2010 : construction started
- 2015 Dec. : first run in normal temperature
- 2018 (or late 2017)- : with cryogenic mirror

KAGRA overview

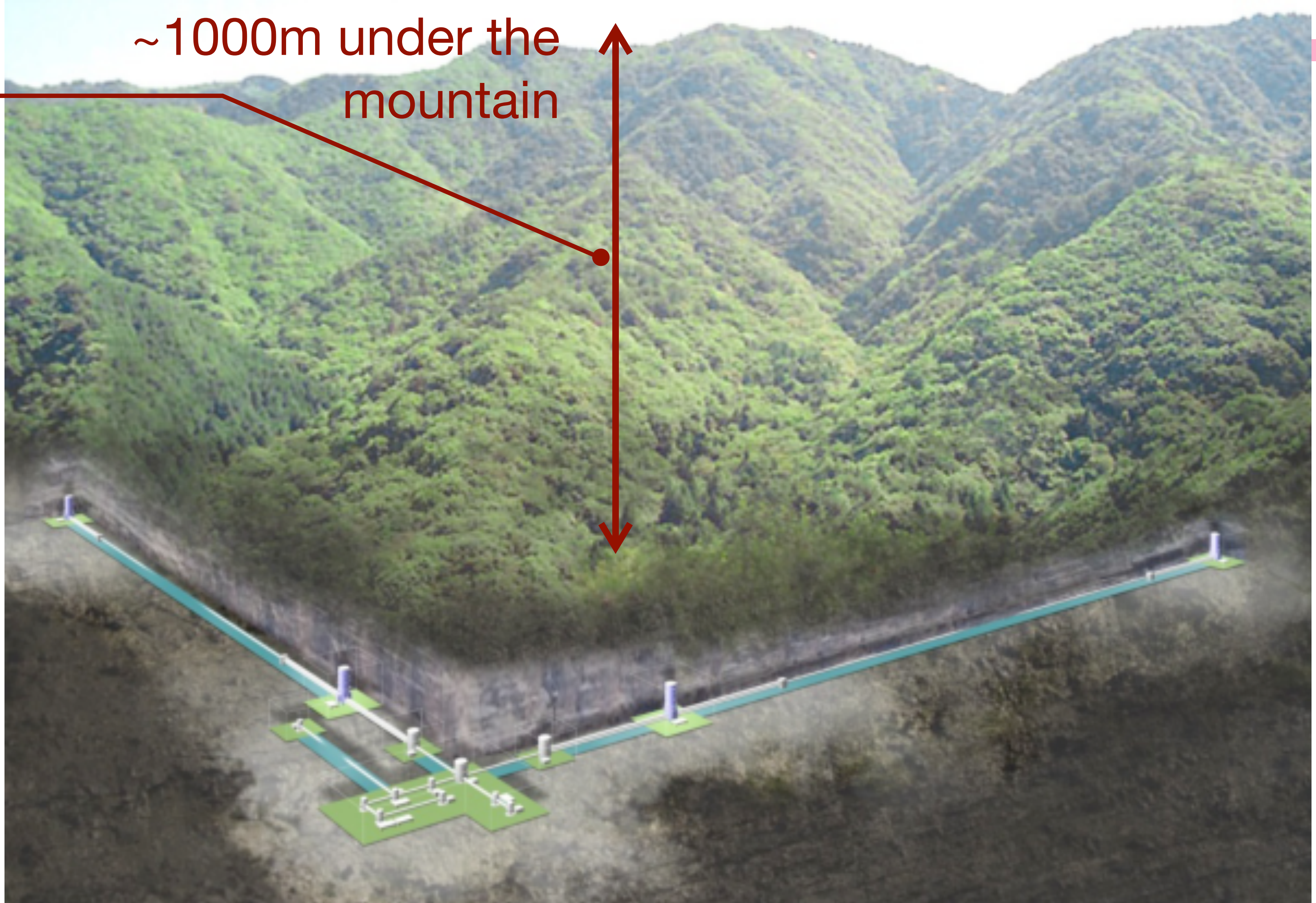
Underground

- in Kamioka, Japan
  Silent & Stable environment

Cryogenic Mirror

- 20K
  sapphire substrate

3km baseline



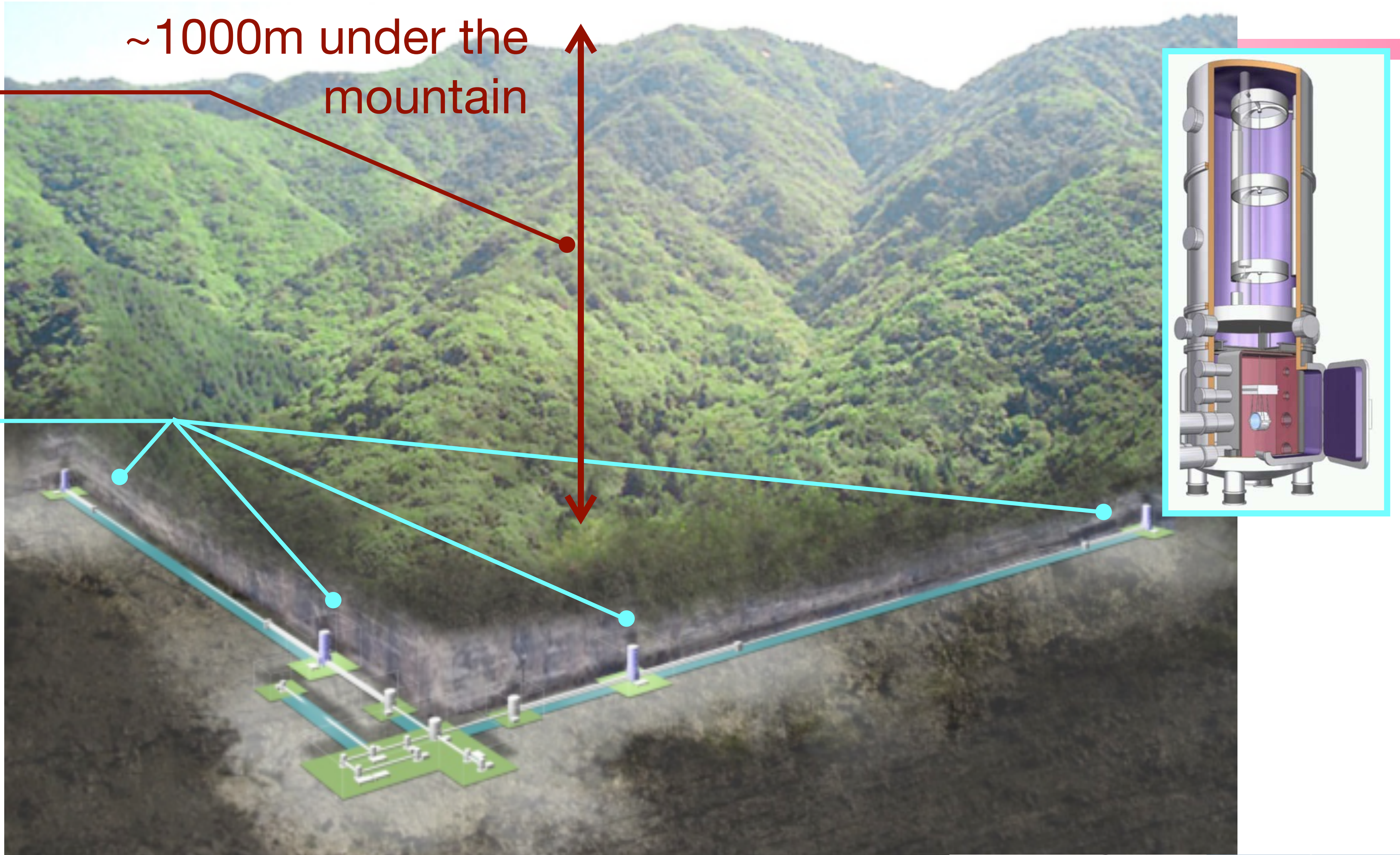
~1000m under the mountain

© ICRR, university of Tokyo

Plan

- 2010 : construction started
- 2015 Dec. : first run in normal temperature
- 2018 (or late 2017)- : with cryogenic mirror

KAGRA overview



Underground
- in Kamioka, Japan

  Silent & Stable environment

Cryogenic Mirror
- 20K

  sapphire substrate

3km baseline

© ICRR, university of Tokyo

Plan
- 2010 : construction started
- 2015 Dec. : first run in normal temperature
- 2018 (or late 2017)- : with cryogenic mirror

KAGRA overview

Underground

- in Kamioka, Japan

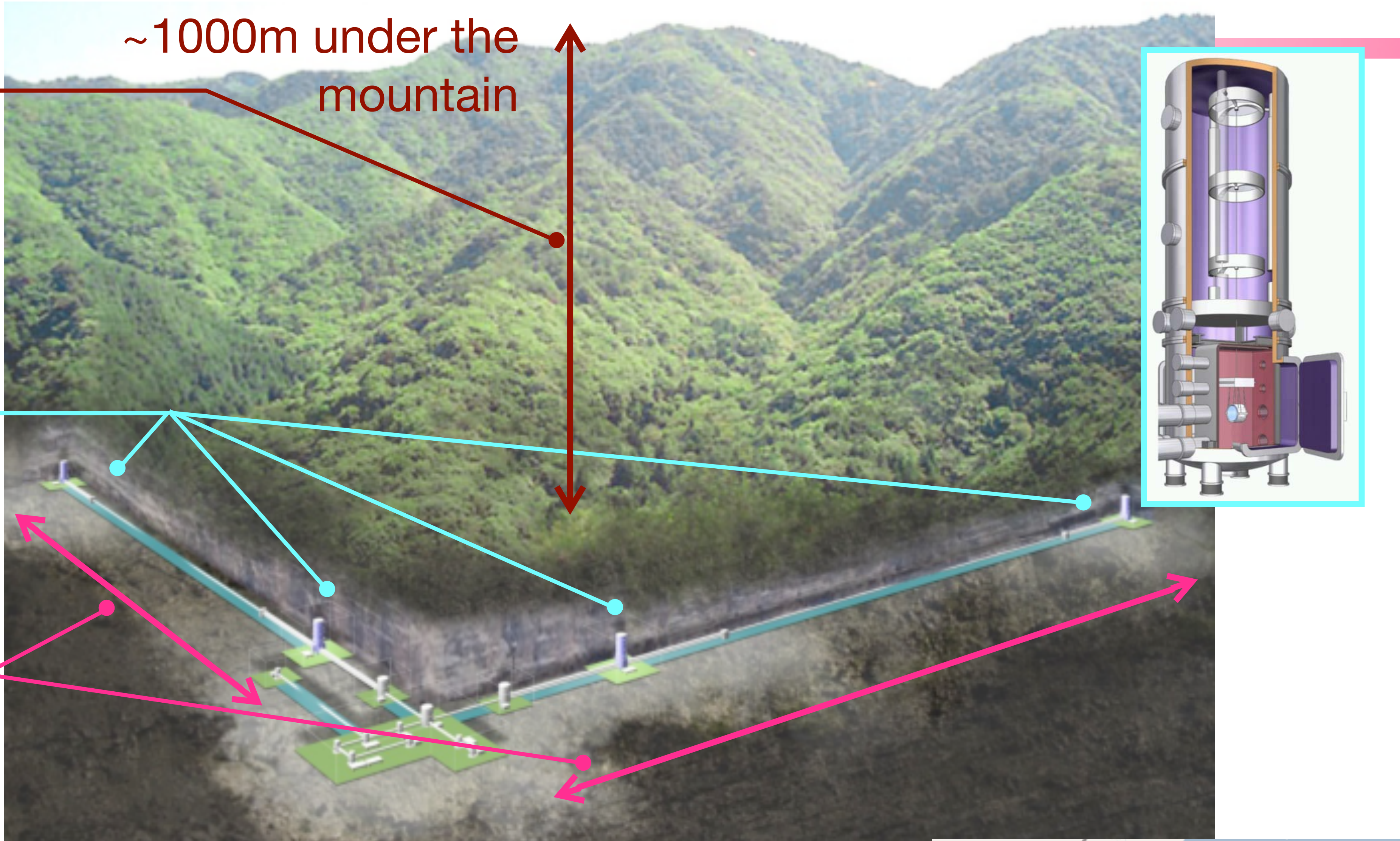
  Silent & Stable environment

Cryogenic Mirror

- 20K

  sapphire substrate

3km baseline



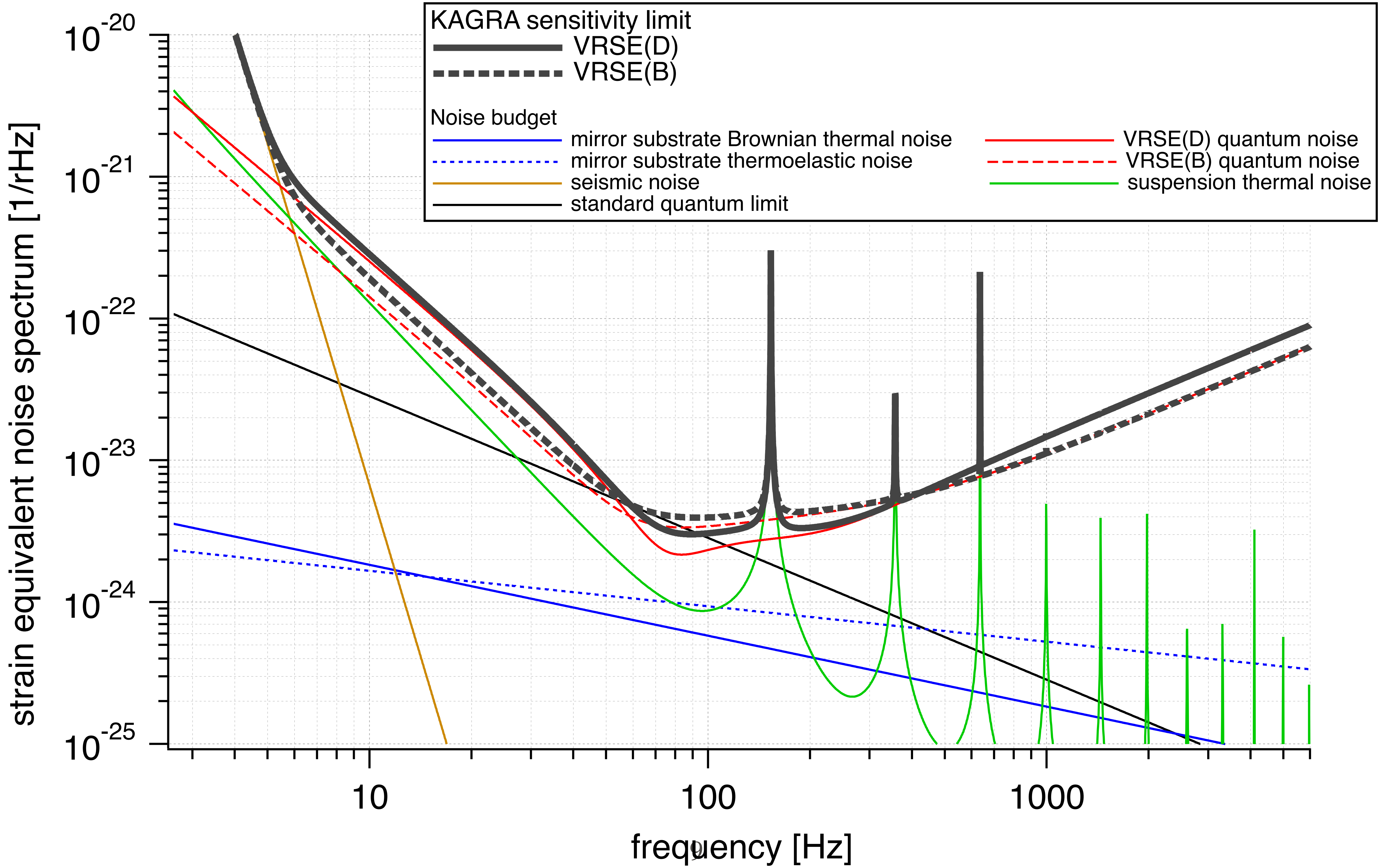
© ICRR, university of Tokyo

Plan

- 2010 : construction started
- 2015 Dec. : first run in normal temperature
- 2018 (or late 2017)- : with cryogenic mirror

Design Sensitivity of KAGRA

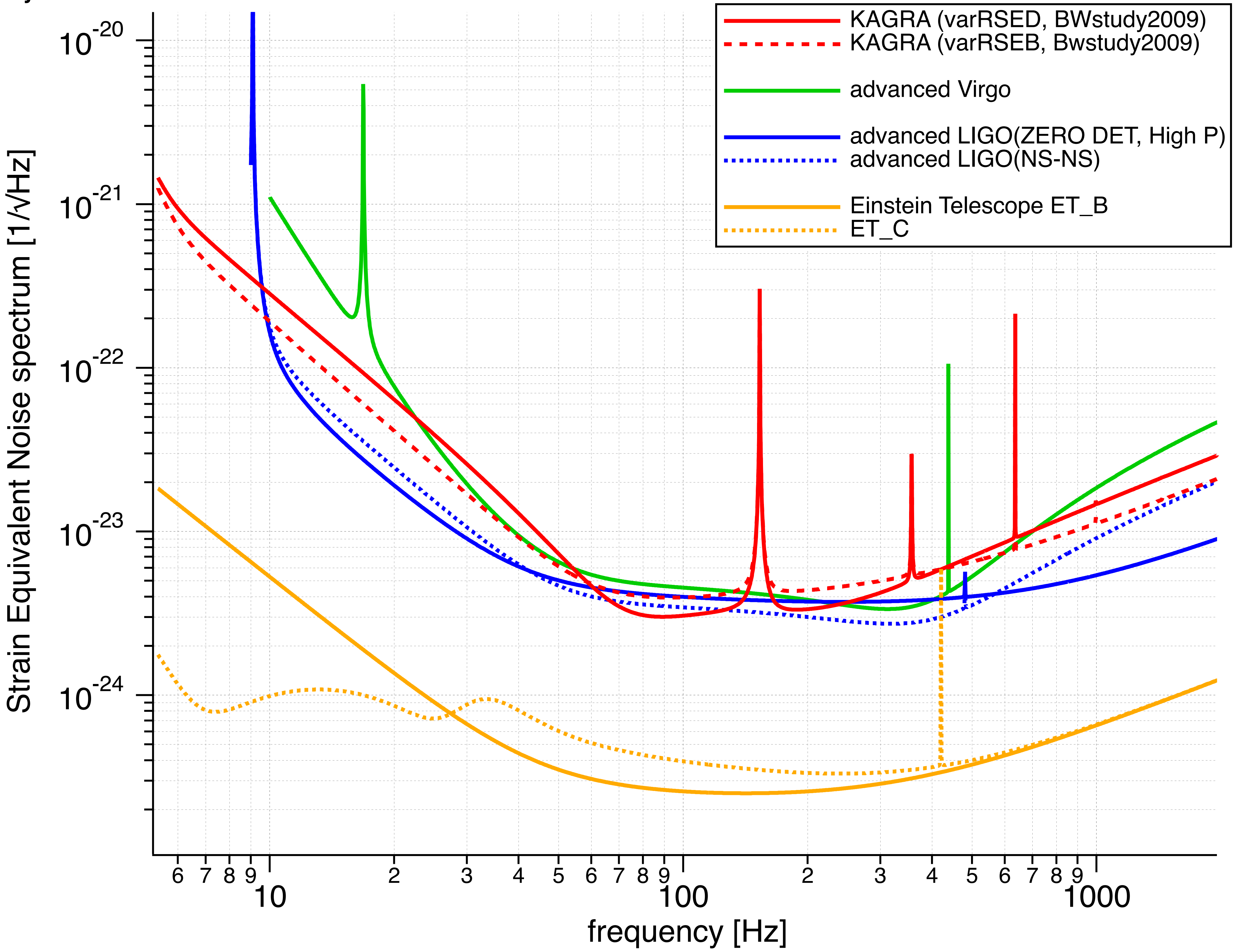
h ~ factor x 10^{-24} [/√Hz] for observation band



Design Sensitivity of KAGRA

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

with other projects



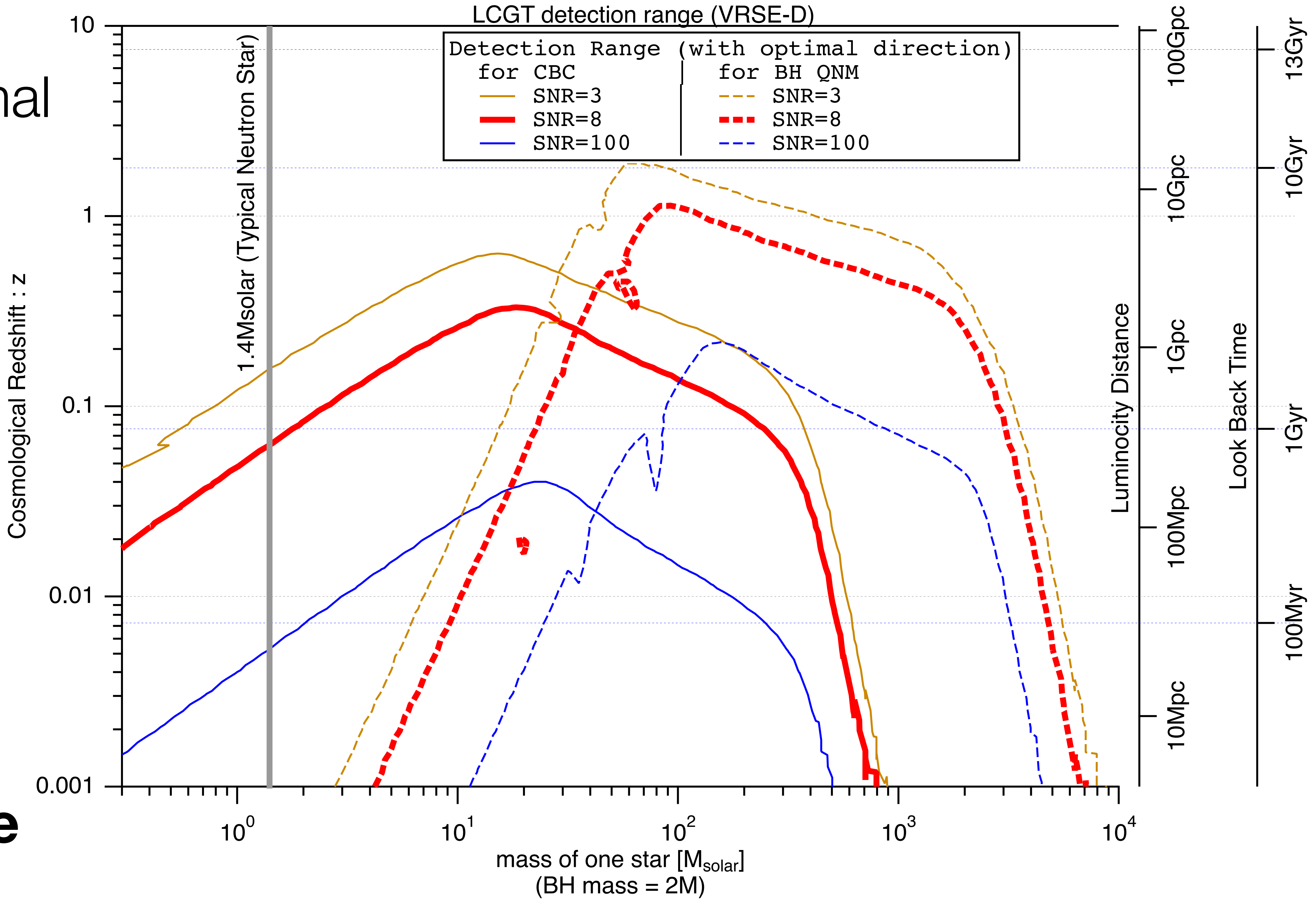
Detection Range

KAGRA's **NS-NS** detection range is **280 Mpc** for optimal direction and orbit inclination.

(~158Mpc in all sky average, LIGO definition)

-> 10 event/yr

For **supernovae**, the range may be **typically 100kpc ~1Mpc** or as like, **depending on the model** (waveform).



KAGRA Construction status

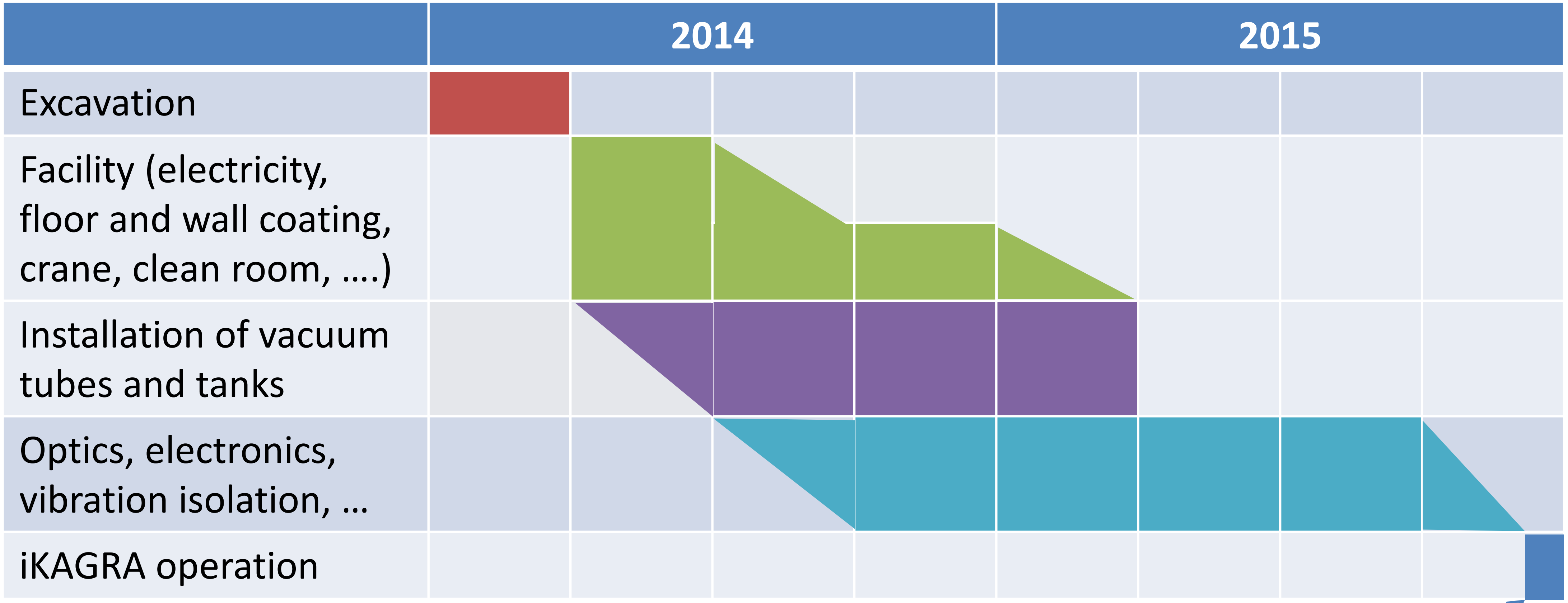
Tunnel excavation completed !

Floors are now ready. We will construct cubicles, clean rooms etc.

Cryostat installation will be start in this August 2014.

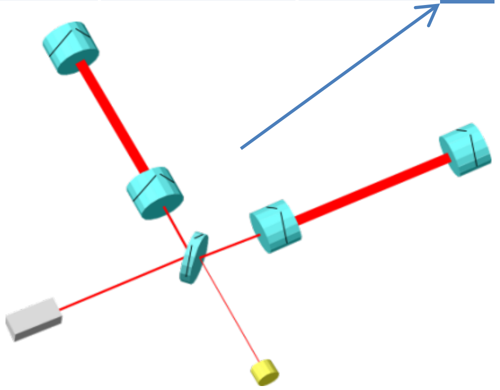
Electronics and digital control systems now stat their calibration and installation.

Data analysis software are developing rapidly.



	2014				2015			
Excavation	🟥							
Facility (electricity, floor and wall coating, crane, clean room, ….)		🟩	🟩	🟩	🟩			
Installation of vacuum tubes and tanks		🟪	🟪	🟪	🟪			
Optics, electronics, vibration isolation, …			🟦	🟦	🟦	🟦	🟦	🟦
iKAGRA operation								🟦

drawn by T.Kajita



3-km FPM interferometer with room temp. mirrors

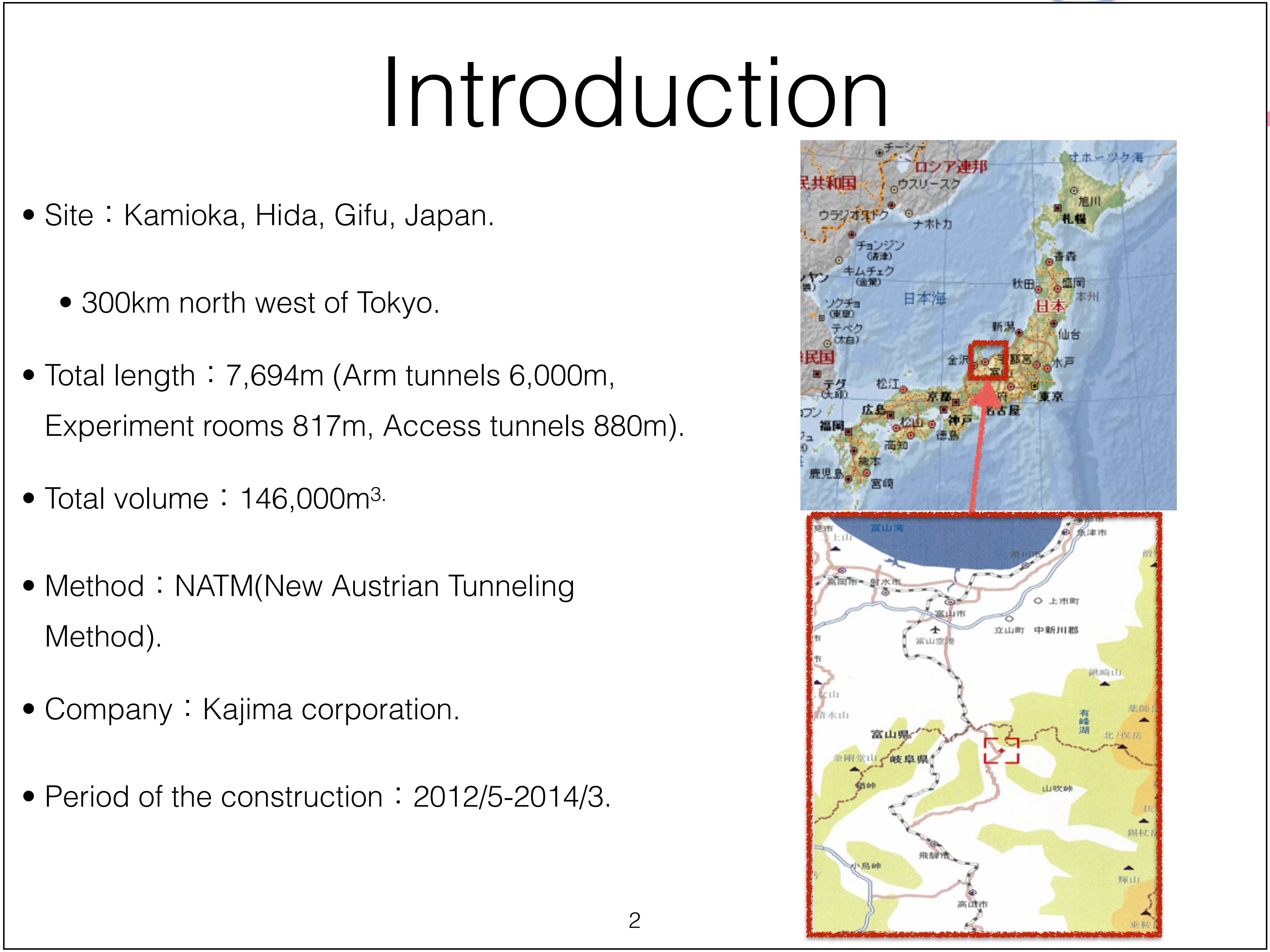
Most exciting news in the last one year

viewgraph by Y.Itoh

Tunnel excavation was finished on March 2014!!!

(Scheduled: 2014 Mar. 31 / Actually finished: 2014 Mar.31 !!!)

Tunnel



Introduction

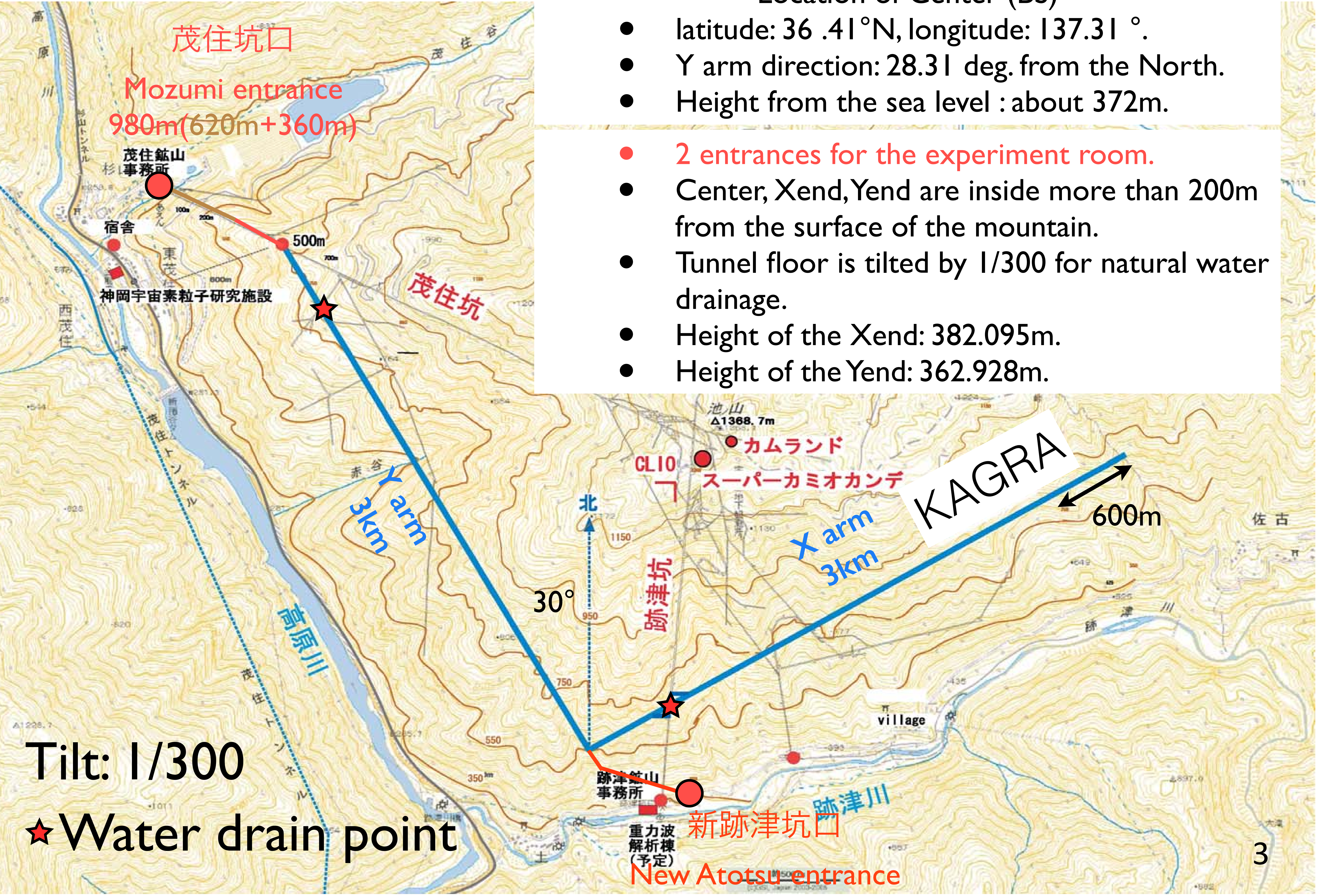
- Site：Kamioka, Hida, Gifu, Japan.
    - 300km north west of Tokyo.
- Total length：7,694m (Arm tunnels 6,000m, Experiment rooms 817m, Access tunnels 880m).
- Total volume：146,000m$^{3.}$
- Method：NATM(New Austrian Tunneling Method).
- Company：Kajima corporation.
- Period of the construction：2012/5-2014/3.

by T.Uchiyama

Location of Center (BS)

- latitude: 36 .41°N, longitude: 137.31 °.
- Y arm direction: 28.31 deg. from the North.
- Height from the sea level : about 372m.

- 2 entrances for the experiment room.
- Center, Xend, Yend are inside more than 200m from the surface of the mountain.
- Tunnel floor is tilted by 1/300 for natural water drainage.
- Height of the Xend: 382.095m.
- Height of the Yend: 362.928m.

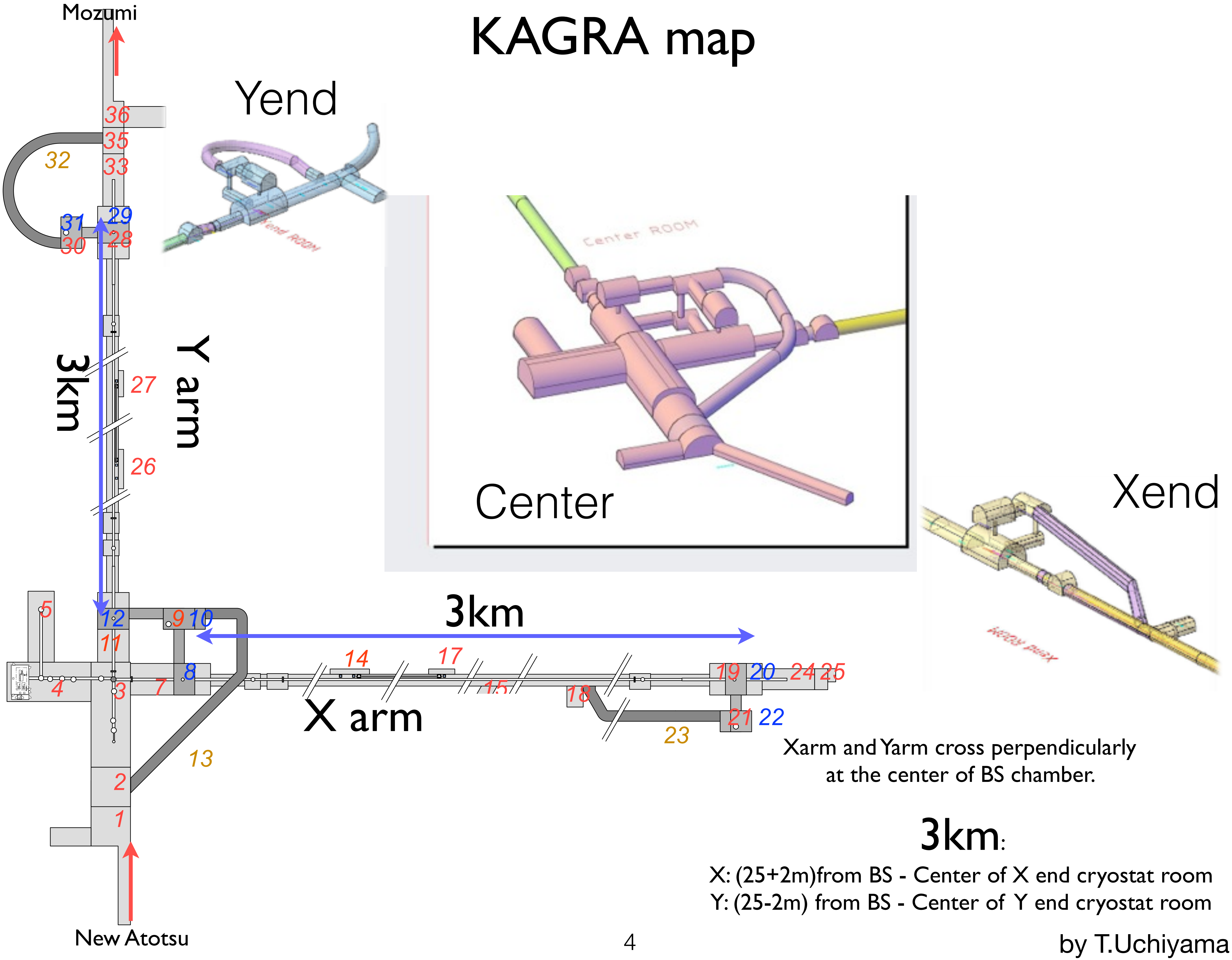


Tilt: 1/300

★ Water drain point

by T.Uchiyama

KAGRA map



Xarm and Yarm cross perpendicularly at the center of BS chamber.

3km:

X: (25+2m)from BS - Center of X end cryostat room
Y: (25-2m) from BS - Center of Y end cryostat room

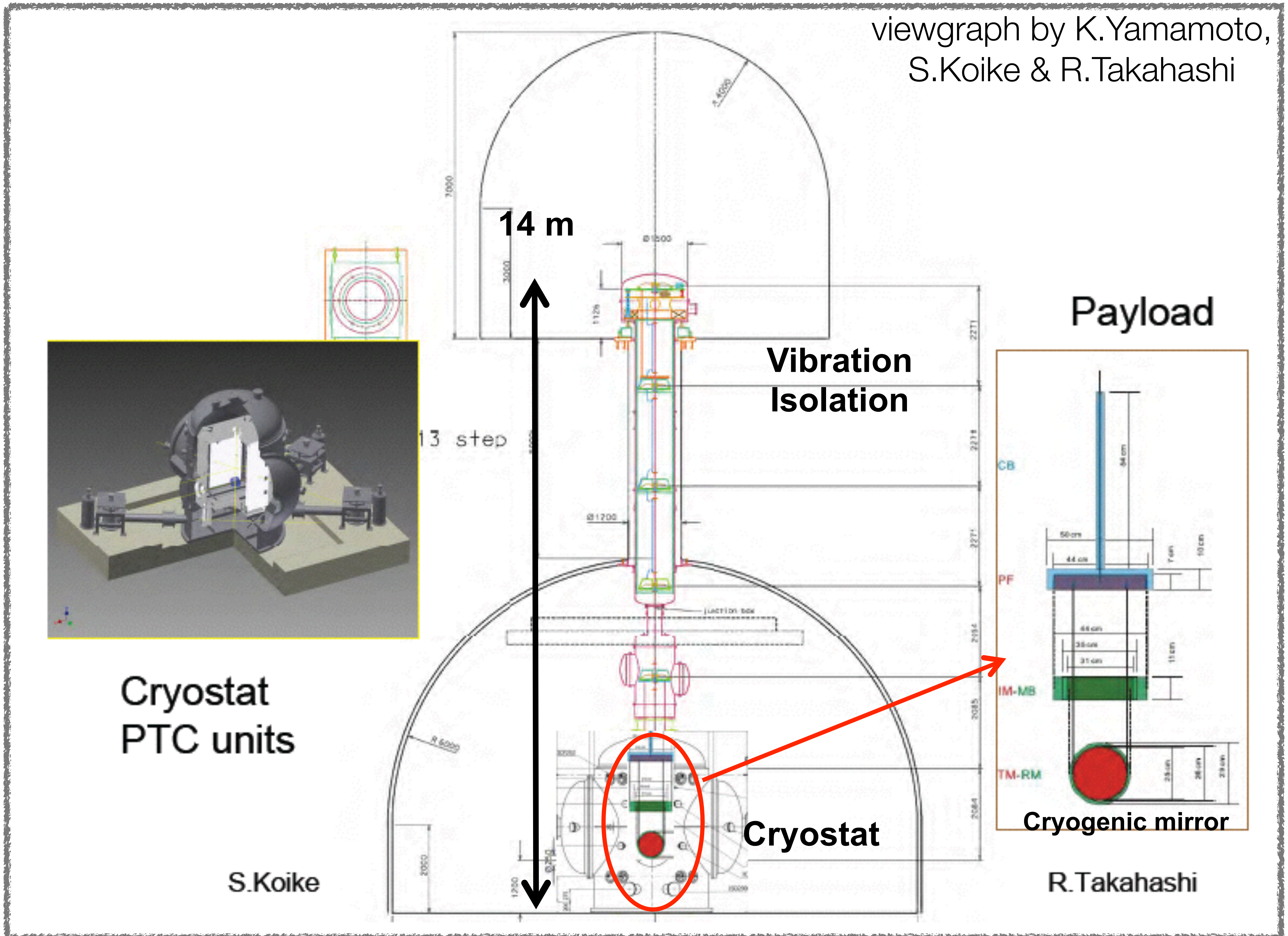
by T.Uchiyama

about one year ago …

Now ! (4th July, 2014)

Vibration isolation and cryostat

viewgraph by K.Yamamoto,
S.Koike & R.Takahashi



14 m

Vibration
Isolation

Payload

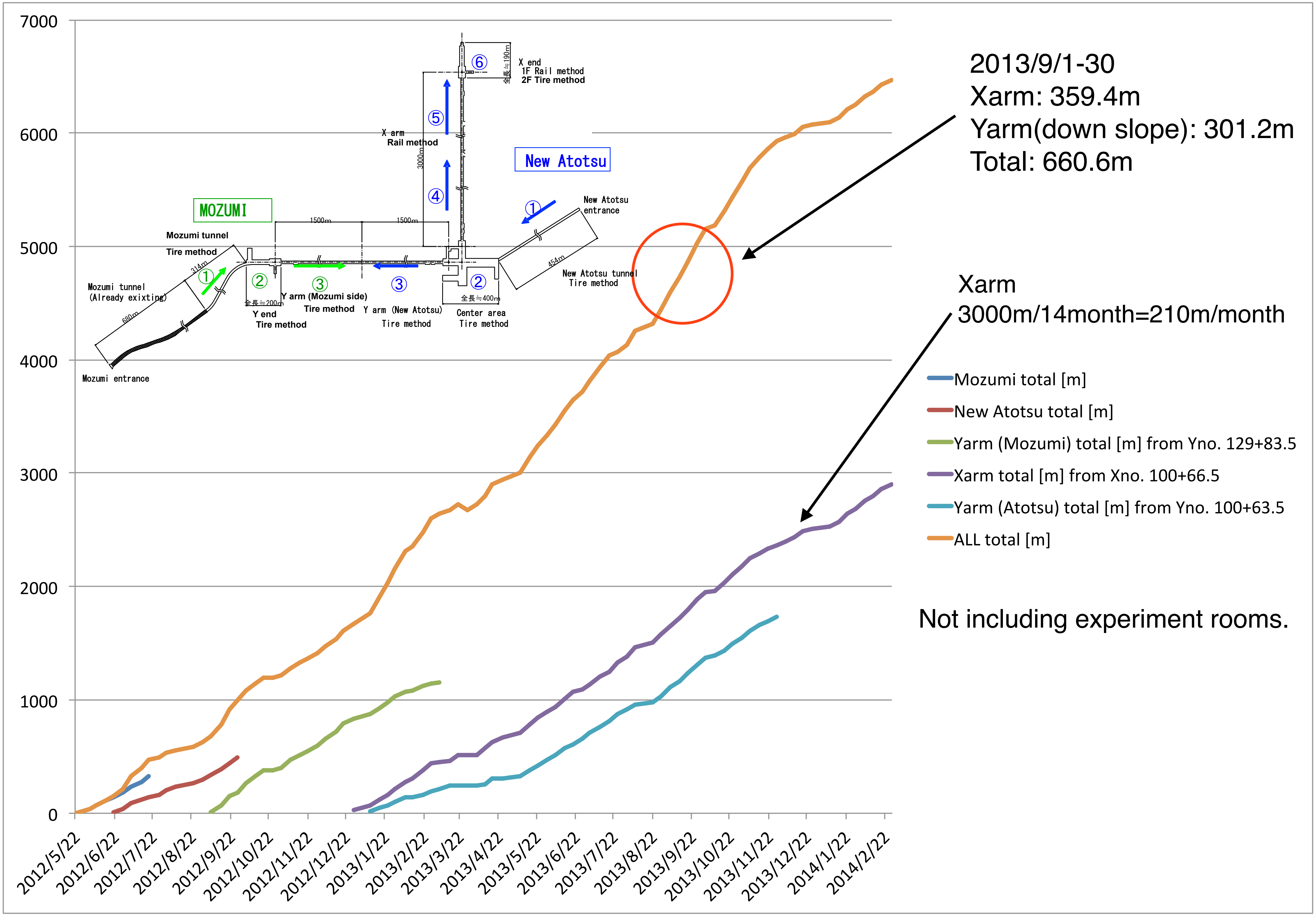
Cryostat
PTC units

Cryostat

Cryogenic mirror

S.Koike

R.Takahashi



2013/9/1-30
Xarm: 359.4m
Yarm(down slope): 301.2m
Total: 660.6m

Xarm
3000m/14month=210m/month

Not including experiment rooms.

by T.Uchiyama

Cryostat

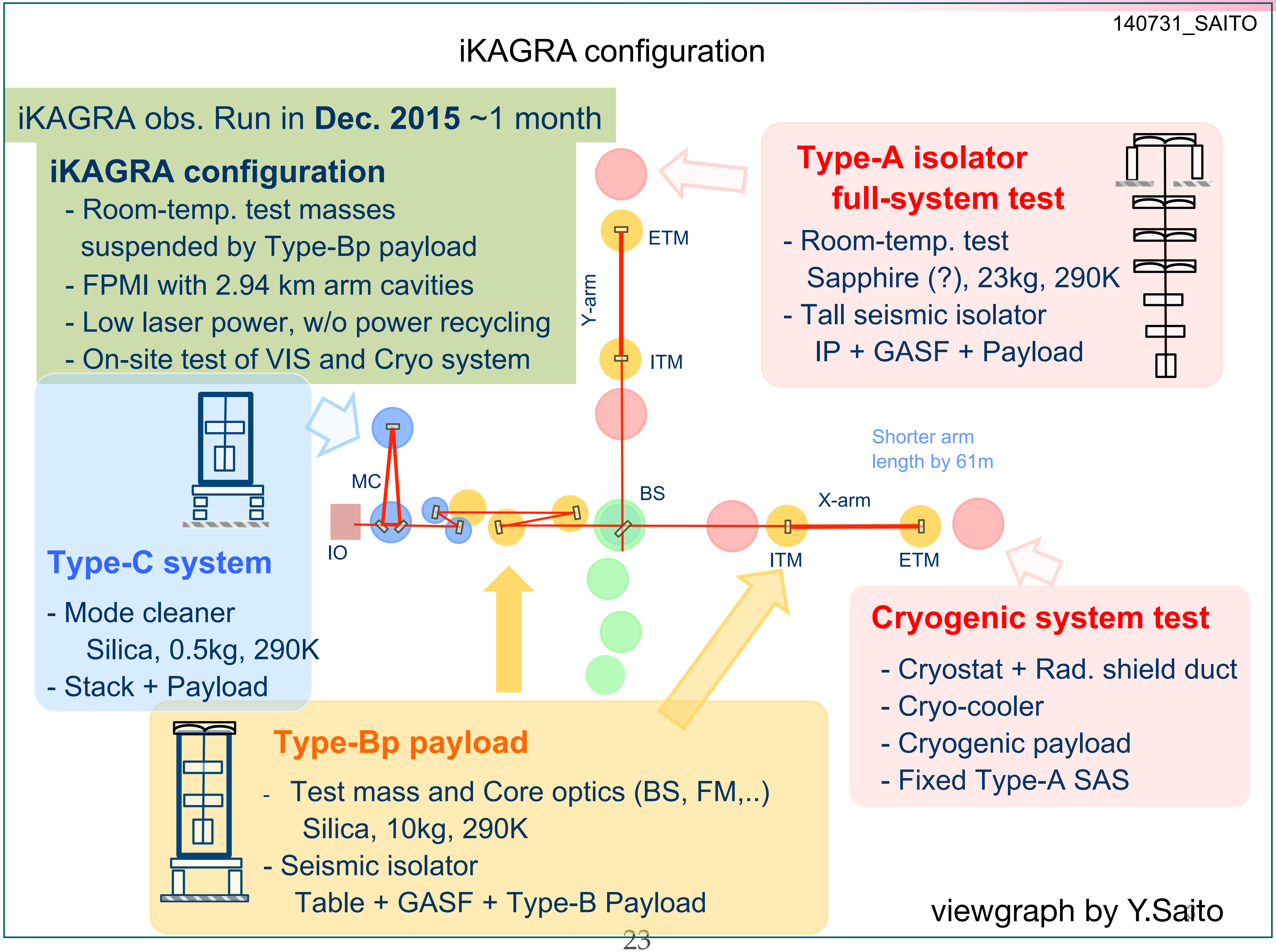
MC chambers and cryostats installation

Transportation of cryostat in Y arm

Installation of MC chambers
(center area)

viewgraph by T.Uchiyama

iKAGRA observation, December 2015



iKAGRA configuration

iKAGRA obs. Run in **Dec. 2015** ~1 month

iKAGRA configuration

- Room-temp. test masses suspended by Type-Bp payload
- FPMI with 2.94 km arm cavities
- Low laser power, w/o power recycling
- On-site test of VIS and Cryo system

Type-A isolator full-system test

- Room-temp. test Sapphire (?), 23kg, 290K
- Tall seismic isolator IP + GASF + Payload

Type-C system

- Mode cleaner Silica, 0.5kg, 290K
- Stack + Payload

Type-Bp payload

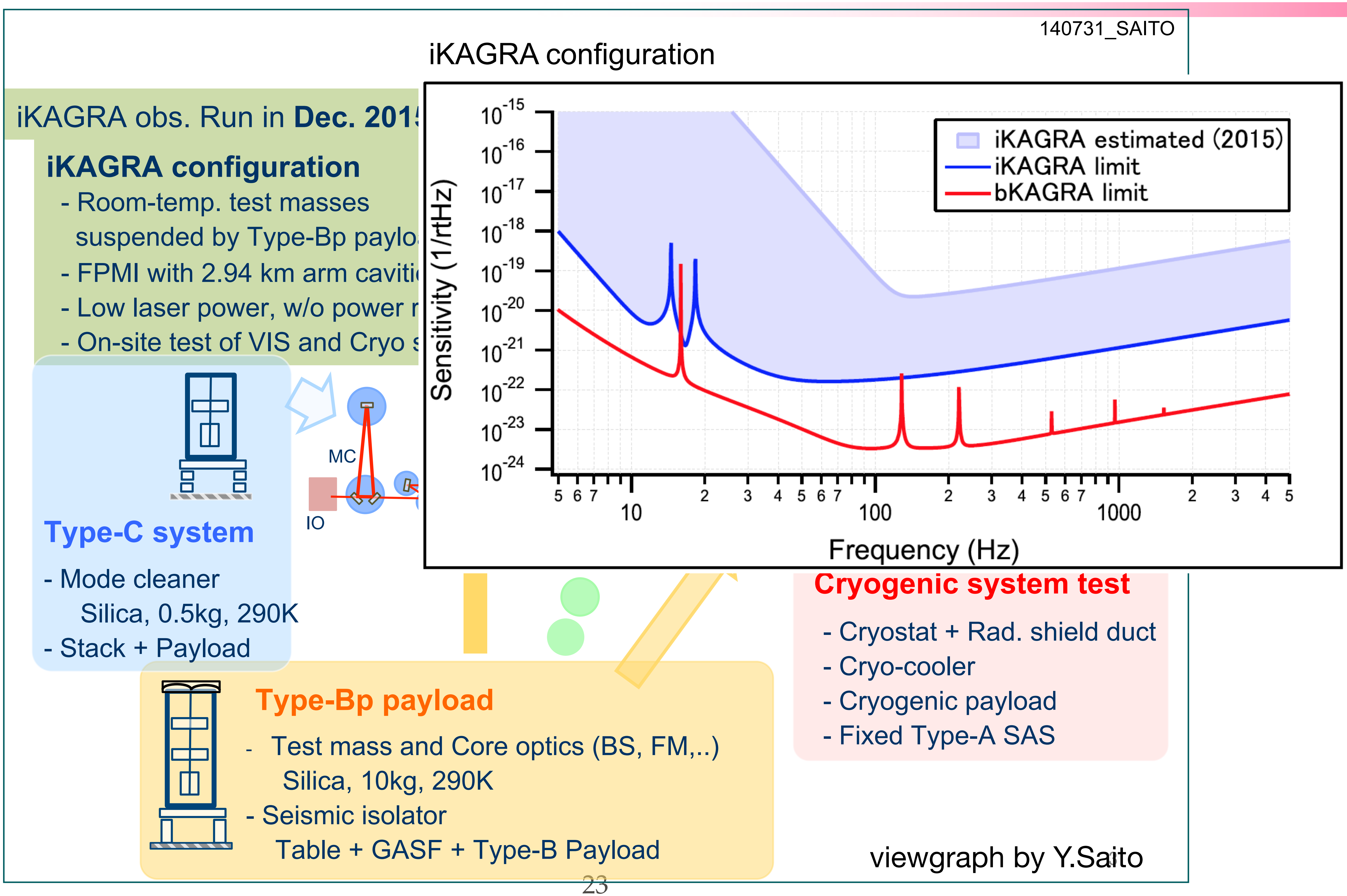
- Test mass and Core optics (BS, FM,..) Silica, 10kg, 290K
- Seismic isolator Table + GASF + Type-B Payload

Cryogenic system test

- Cryostat + Rad. shield duct
- Cryo-cooler
- Cryogenic payload
- Fixed Type-A SAS

viewgraph by Y.Saito

iKAGRA observation, December 2015



140731_SAITO

iKAGRA configuration

iKAGRA obs. Run in **Dec. 201**

iKAGRA configuration

- Room-temp. test masses suspended by Type-Bp paylo
- FPMI with 2.94 km arm caviti
- Low laser power, w/o power r
- On-site test of VIS and Cryo s

Type-C system

- Mode cleaner
  Silica, 0.5kg, 290K
- Stack + Payload

Type-Bp payload

- Test mass and Core optics (BS, FM,..)
  Silica, 10kg, 290K
- Seismic isolator
  Table + GASF + Type-B Payload

Cryogenic system test

- Cryostat + Rad. shield duct
- Cryo-cooler
- Cryogenic payload
- Fixed Type-A SAS

viewgraph by Y.Saito

Installation launch at Kamioka now

Digital control and analogue electronics start work shift partially in this July, on circuit tests, cabling, etc.

Cryostat installation started in this August.

Work shift for many apparatus in the tunnel are now organizing , and will be carried by collaborators soon.

New building (“Analysis build.”)

New building (“Analysis build.”)

at Jan.2014

Hardware of iKAGRA data system

@Kamioka surface bilding

- 200TiB lustre storage system (FEFS), separate MDT and OSS
- 1 data server
- 4 calculation nodes (8cores x 2CPUs) = 64cores
- 2 job management servers

VPN switch

placed at computer area beside the control room, 1st floor of analysis build.

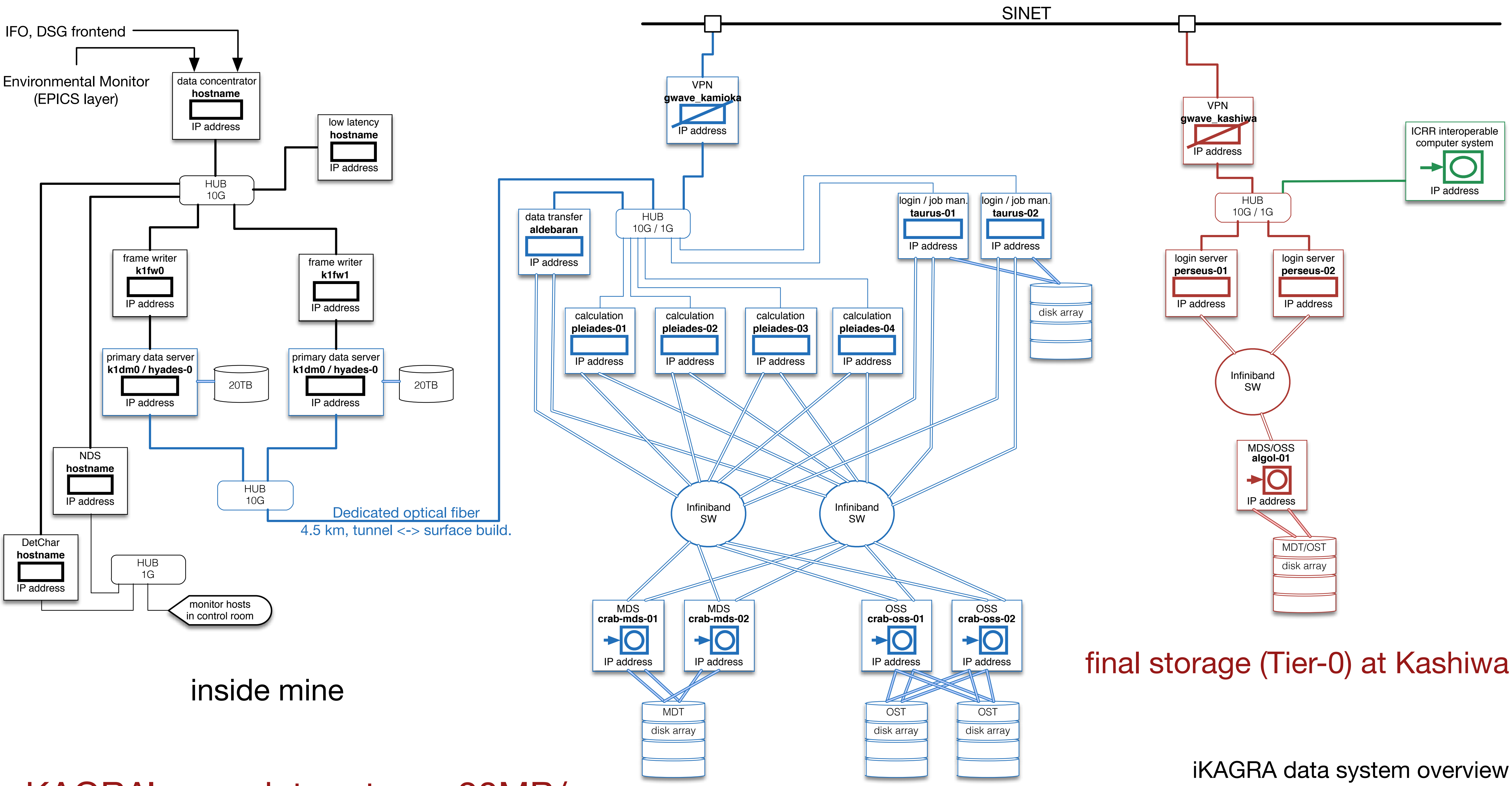
200 TiB 'lustre' file system

(pre-)main storage

@Kashiwa (ICRR building 6th floor)

- 100 TiB lustre storage system (FEFS), single storage for MDT+OSS
- 2 login server
- VPN switch

Data Acquisition, transfer and storage



KAGRA's raw data rate : ~ 20MB/s
(~630 TB/yr)

surface building at Kamioka

iKAGRA data system overview
Drawn by N.Kanda
last update : 2014/8/19

]

Data transfer test

Tunnel —(via dedicated optical fiber, 10GB) —> Analysis build. on surface

- using `scp`*, continuous transfer of dummy files, done by system vender (Fujitsu Co.Ltd.)

  It marked **~150MB/s.**
- using `scp`, 320MB frame data, intermittent transfer every16sec by T.Yamamoto

  ~**150MB/s** during data sending
- using via `socket` transfer** by Oohara

  ~ 1GB/s during data sending

Analysis build. on surface —(SINET)—> Kashiwa

- using `scp`, 320MB frame data, intermittent transfer every16sec by T.Yamamoto

  ~**50MB/s** during data sending
- using via `socket` transfer** by Oohara

  ~**50MB/s** during data sending

* scp including file I/O, transfer, encrypt, decrypt*
** socket transfer only data, exclude file I/O

Specification requirement : 40MB/s
KAGRA raw data : 20MB/s

Data Analysis Subsystem (DAS)

Chief: H.Tagoshi
Sub-chiefs: Y.Itoh, H.Takahashi
Core members: N.Kanda, K.Oohara, K.Hayama

Korean subgroup
Leader: Hyung Won Lee

Osaka Univ : H. Tagoshi, K.Ueno, T.Narikawa
Osaka City Univ : N.Kanda, K.Hayama, T.Yokozawa, H.Yuzurihara, T.Yamamoto, K.Tanaka, M. Asano, M. Toritani, T. Arima, A. Miyamoto
Univ Tokyo : Y.Itoh, K. Eda, J. Yokoyama,
Nagaoka Tech : H.Takahashi,
Niigaka Univ : K.Oohara, Y.Hiranuma, M. Kaneyama, T. Wakamatsu
Toyama Univ : S. Hirobayashi, M. Nakano

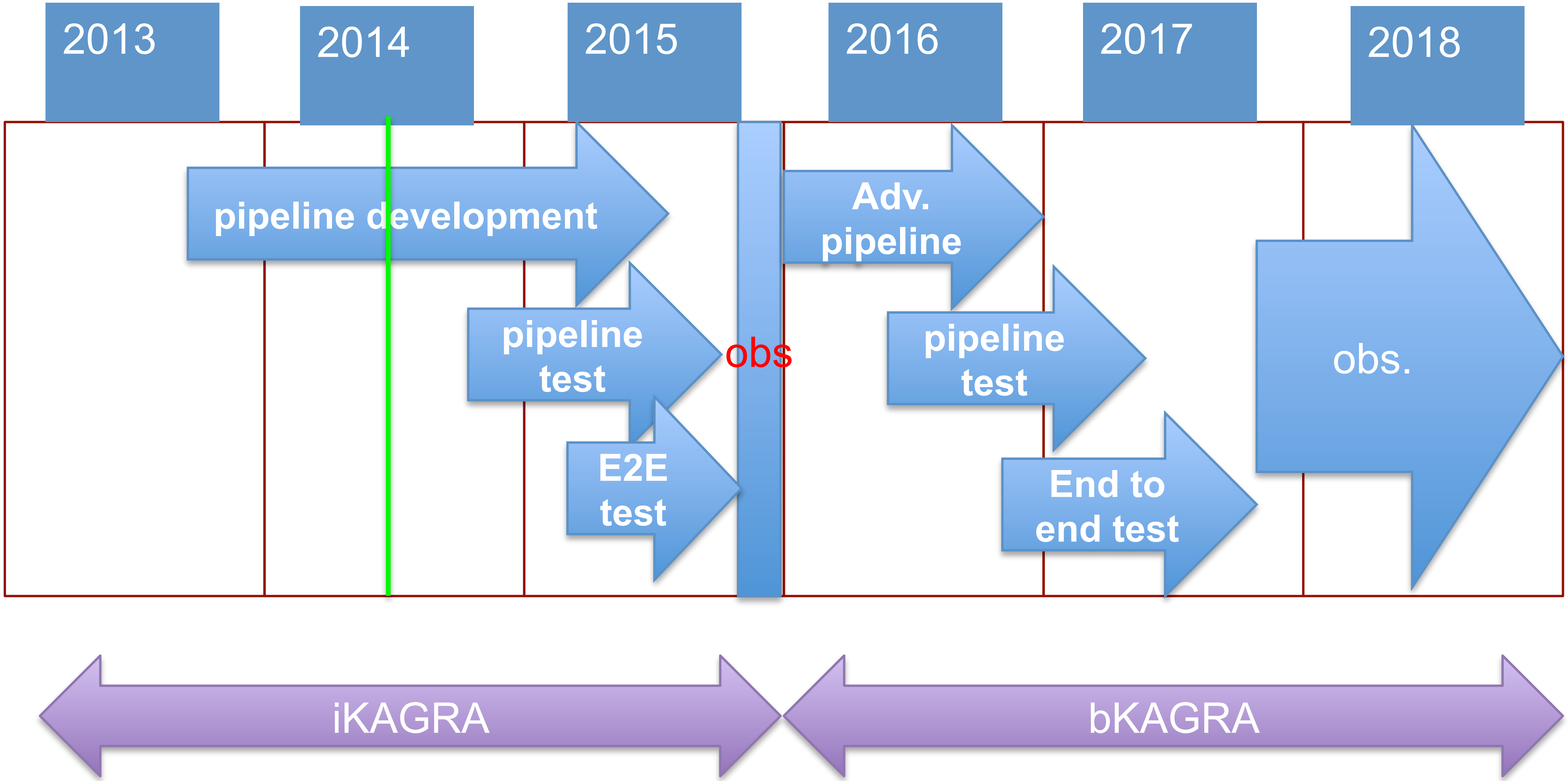
Inje Univ. : Hyung Won Lee, Jeongcho Kim
Seoul Nat. U.: Chunglee Kim

Total: 26 (Graduate students are included. Undergrad. are not included)

About 30 people in the mailing list.

viewgraph by H.Tagoshi, Y.Itoh

Schedule



iKAGRA target

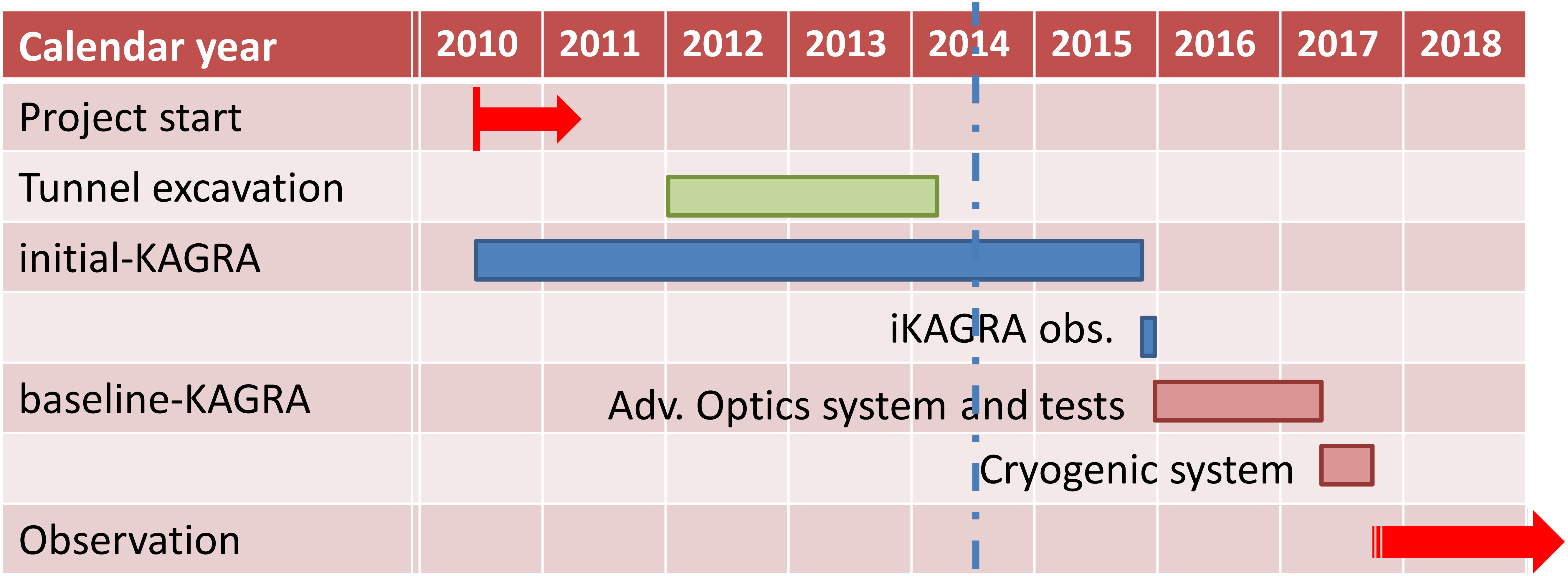
- Operation of the whole analysis pipeline which includes analysis of data and setting upper limits.
- Discovering local fortuitous GW events.

bKAGRA target

- Detection of GW signals
- Joint data analysis with LV
- GW astronomy

viewgraph by H.Tagoshi

Schedule to the observation era



drawn by T.Kajita

Science in GW detection/measurement from SNe or GRBs

What can be derive ?

- Information inside the objects :

  dynamics of SN core

  strong GW suspect the inner structure of the progenitor,

  NS-NS coalescence is one of the candidate of short-GRB progenitor.

- Population, formation

  if we will get enough statistics.

Chance of coincidence observation

- Convince the detection as true “event”
- Multi-messenger

GW waves : view of event detection ...

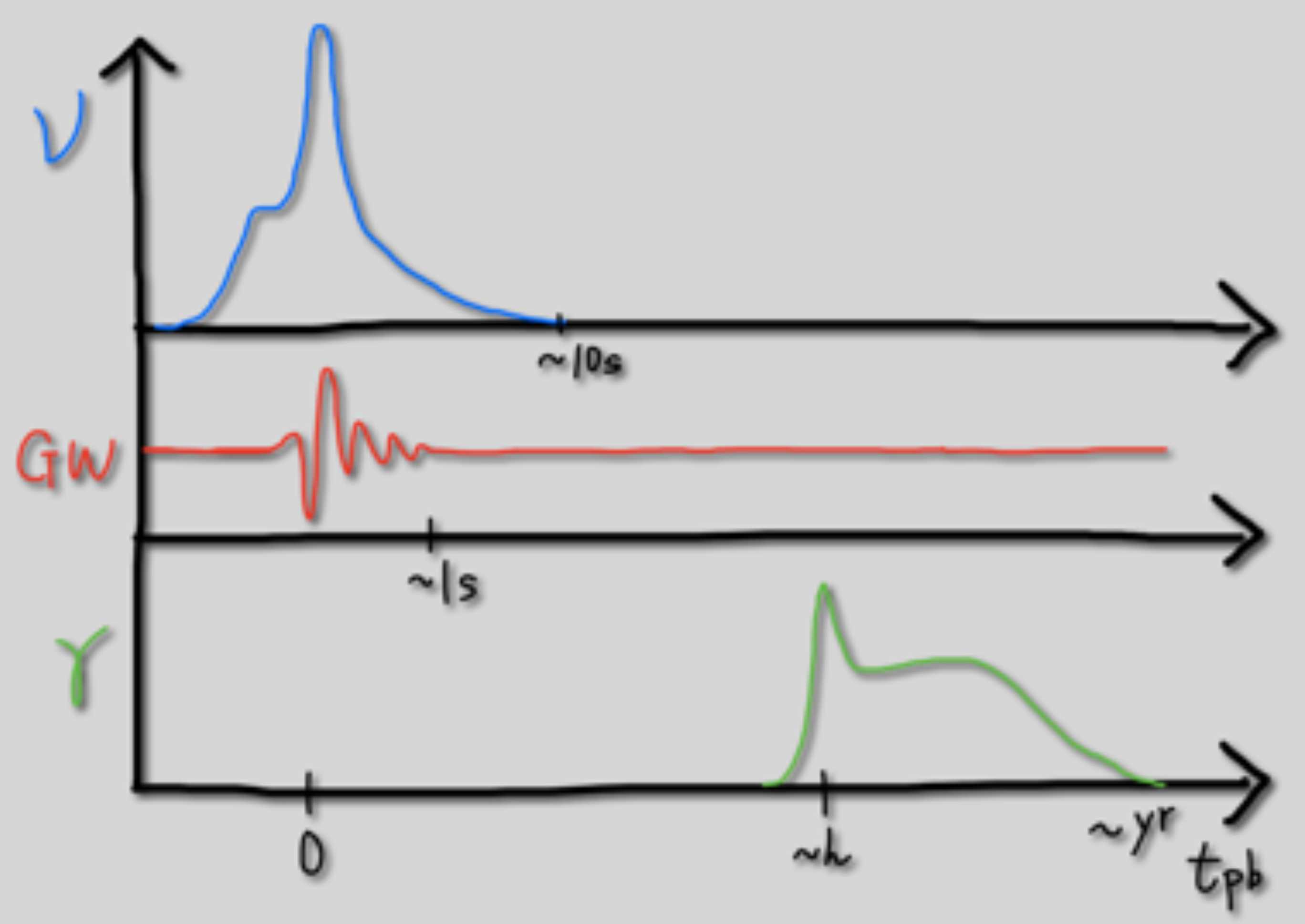
Features	Supernovae	Compact Binary Coalescence
GW waveform	"Burst" various prediction, but is **NOT well-known** or **hard** to give waveform **analytically**	"Chirp" Post-Newton + "Merger" Numerical Relativity + "Ringdown" Perturbation of BH (**analytical** + NR waveforms)
Detection (Signal Identification)	·**Excess power filter** (Integration of signal power), ·**Time-Frequency analysis** (Sonogram by Short-FFT, Wavelet etc.)	Matched filter between signal and templates (Winer **optimal filter**)
Typical Range for current detectors.	≲1Mpc	~200 Mpc
Follow-ups / Counterparts	EM (**visible-infrared**, X-ray, Gamma-Ray), **Neutrino**	EM (visible-infrared, **X-ray, Gamma-Ray**), Neutrino

Multi-messenger resolve the object
example : neutrino - GW coincidence

If we will have SNe in our galaxy or near by …

- Neutrino observation from SNe is promising.
- In some scenario, GW will emit. In other, no (strong) GW…

Comparison of Neutrino, EM and GW might explain the dynamics.



drawn by Y.Suwa

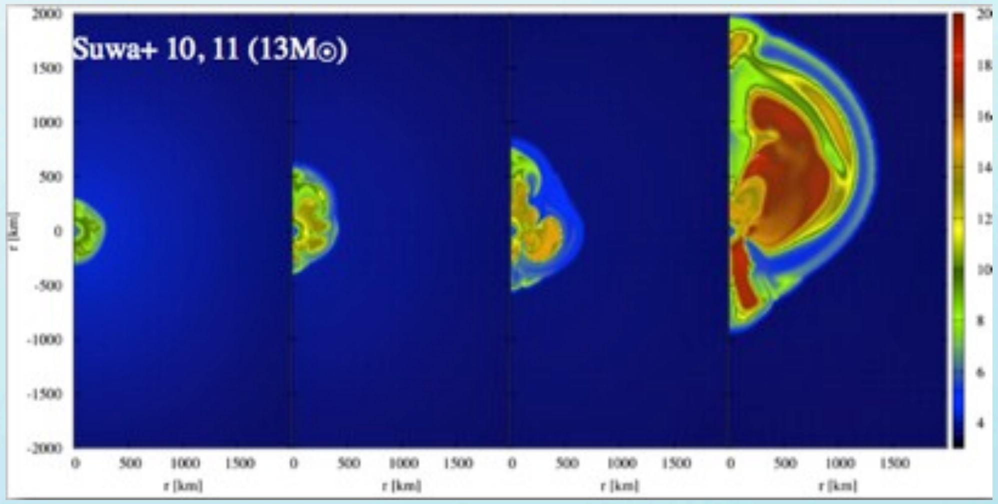
新学術「重力波天体」

Team SKE

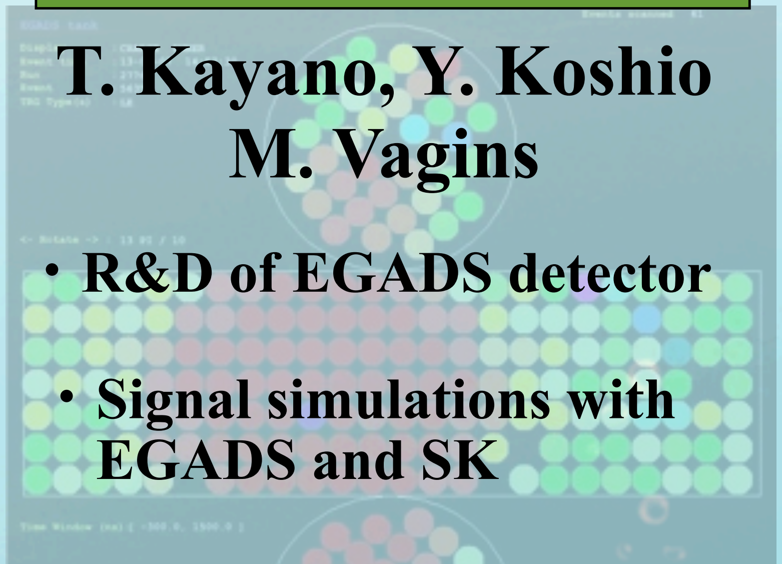
SNe Theory(A05)

Y. Suwa

- **Provide time correlated data, GW and neutrino**
- **Suggest signature signals physical phenomenon**

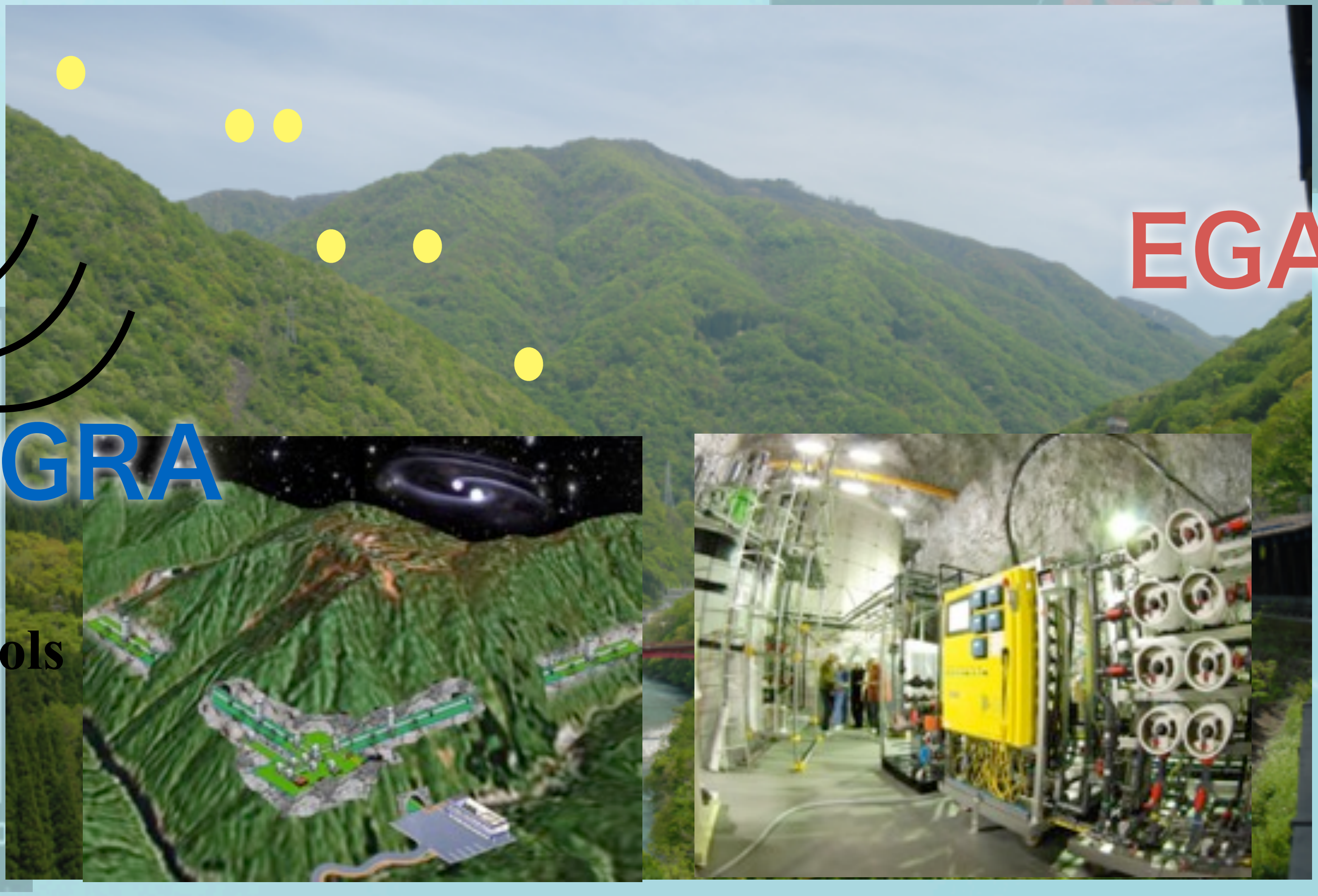


Neutrino analysis(A03)

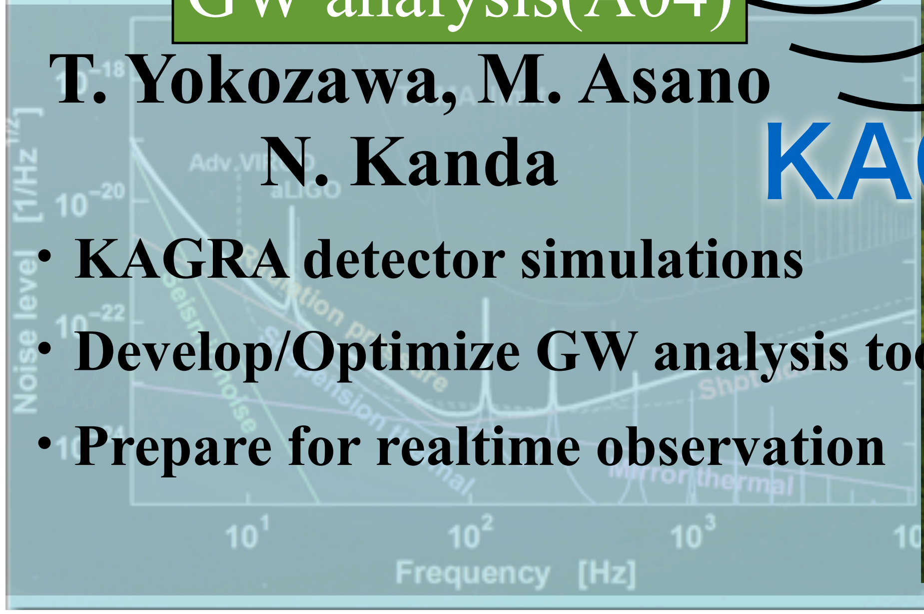


T. Kayano, Y. Koshio
M. Vagins

- **R&D of EGADS detector**
- **Signal simulations with EGADS and SK**



GW analysis(A04)



T. Yokozawa, M. Asano
N. Kanda

- **KAGRA detector simulations**
- **Develop/Optimize GW analysis tools**
- **Prepare for realtime observation**

viewgraph by T.Yokozawa

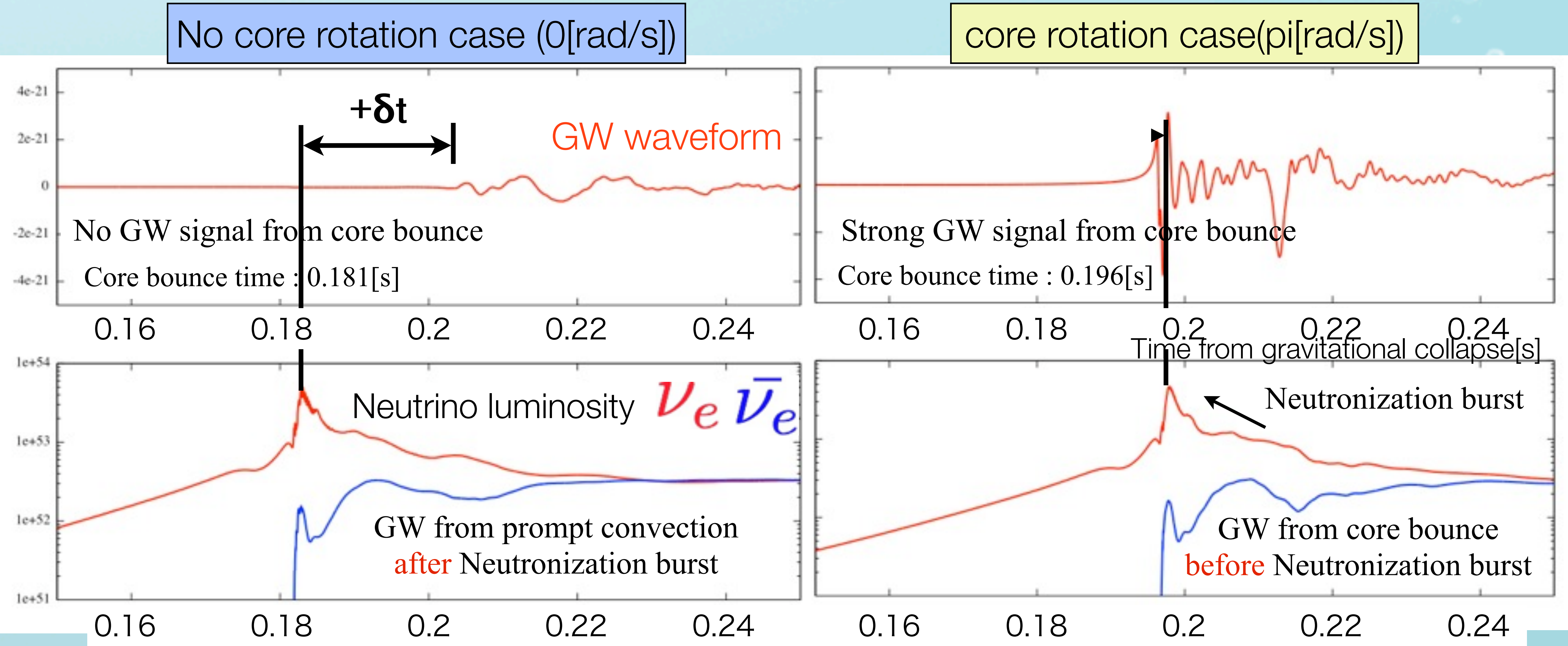
Motivation

- Focus on **GW observed time**(**t_obs_gw**) and **Neutronization burst time**(**t_obs_nburst**)
- Supernova detection simulation with KAGRA and EGADS detector

No core rotation
No GW signal from core bounce
GW from prompt convection after
Neutronization burst

↔

Strong core rotation
Strong GW signal from core bounce
GW from core bounce before
Neutronization burst



viewgraph by T.Yokozawa

Probing Rotation of SN core

with concurrent analysis of GW and Neutrino

Assumptions :

Core-collapse SN

Progenitor is rotating or is not rotating.

Colocate two detectors : KAGRA + EGADS

Expectation :

Neutrino burst at core collapse

Strong spike-like GW for rotating core bounce / no GW core-bounce for no rotating

-> Comparison of **GW and Neutrino make possible to suppose SN core rotation**

-> Understanding of the dynamics of SNe

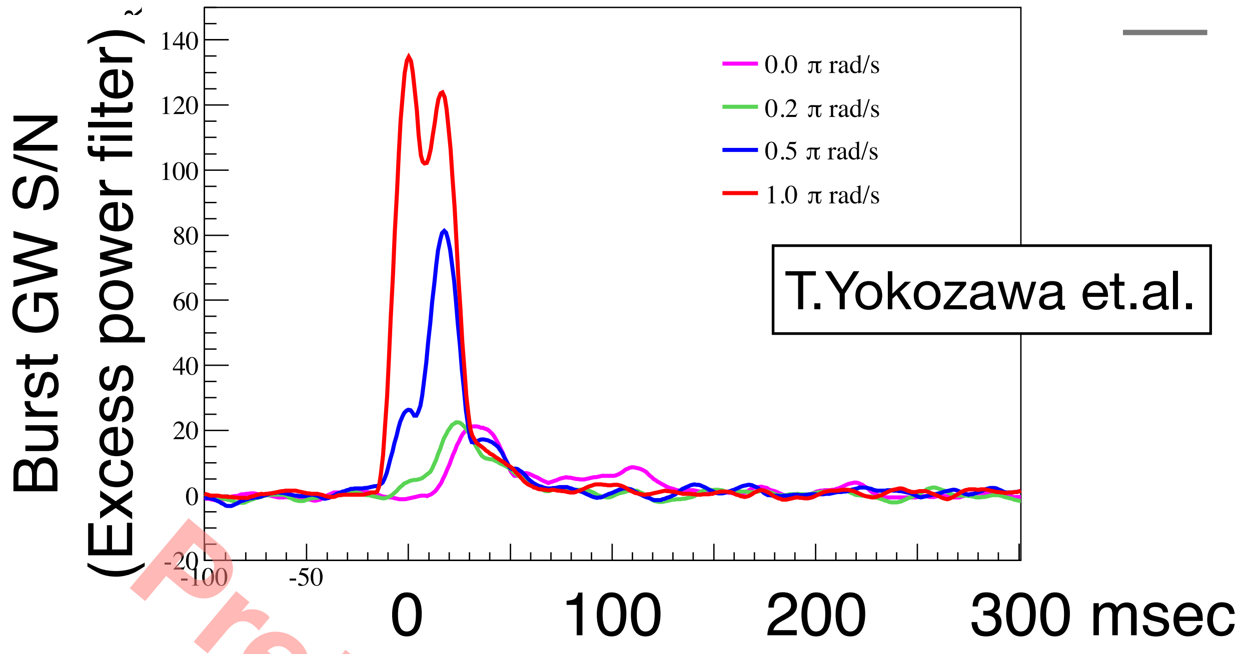


Fig. 4.— One example of the time variation of obtained SNR for each model. color shows the progenitor core rotation model, 0.0π(magenta), 0.2π(green), 0.5π(blu 1.0π(red) rad s^{-1}, respectively. The supernova distance is set to 1.0 kpc and on-directi KAGRA detector.

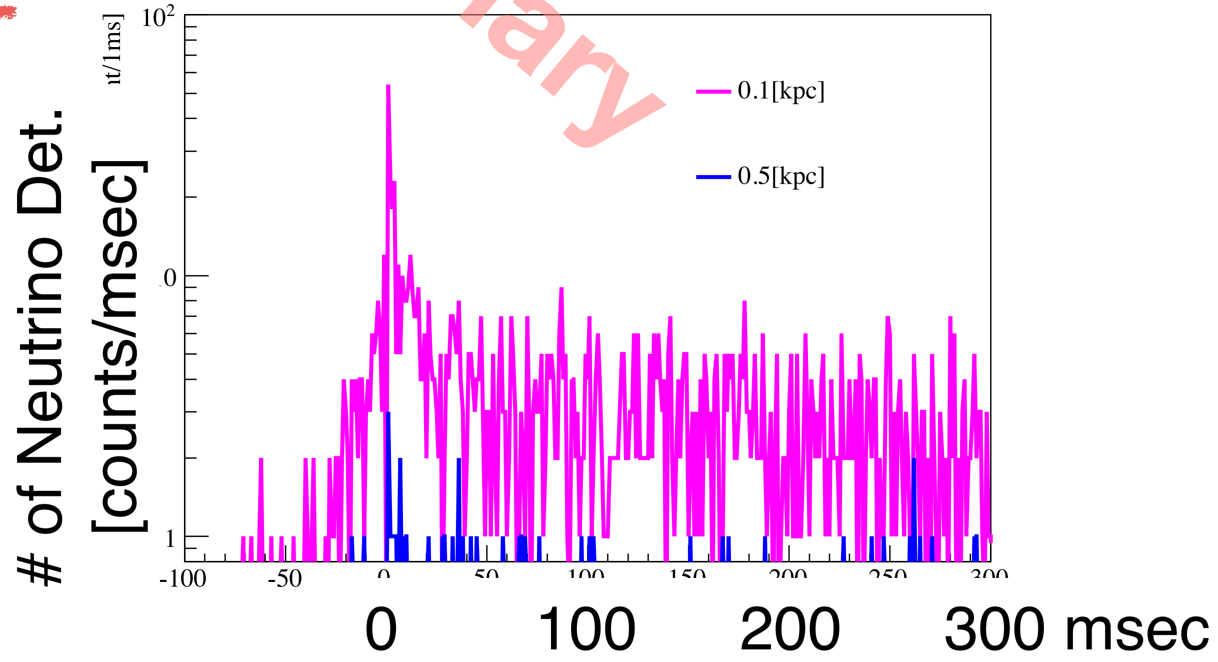
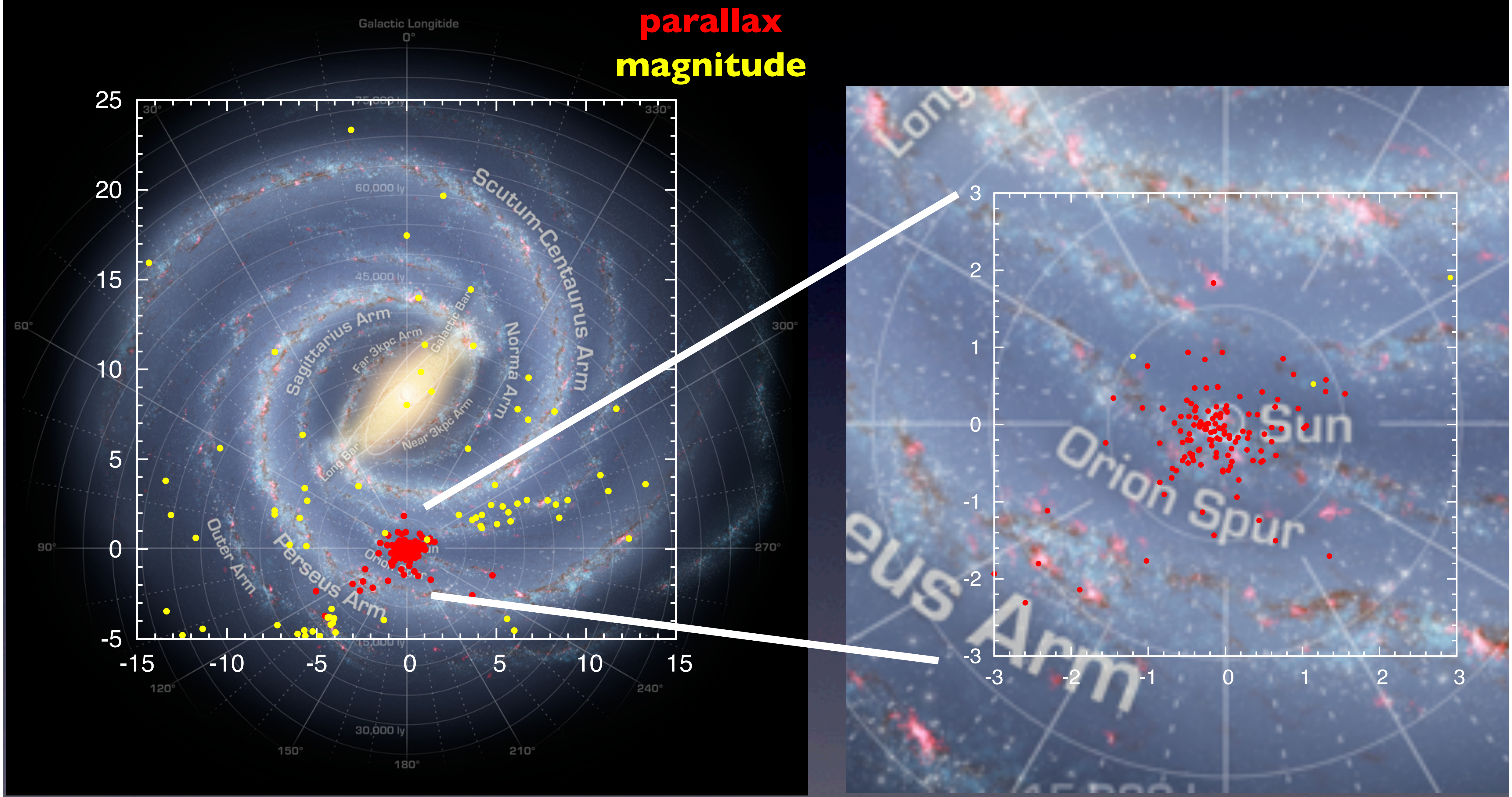


Fig. 13.— One example of the fluctuation of observed number of neutrino for the distance of 0.1 kpc(red) and 0.5kpc(blue). The 1.0 πrad s^{-1} model is used for this figure.

Is there a chance ?

viewgraph by M.Tanaka

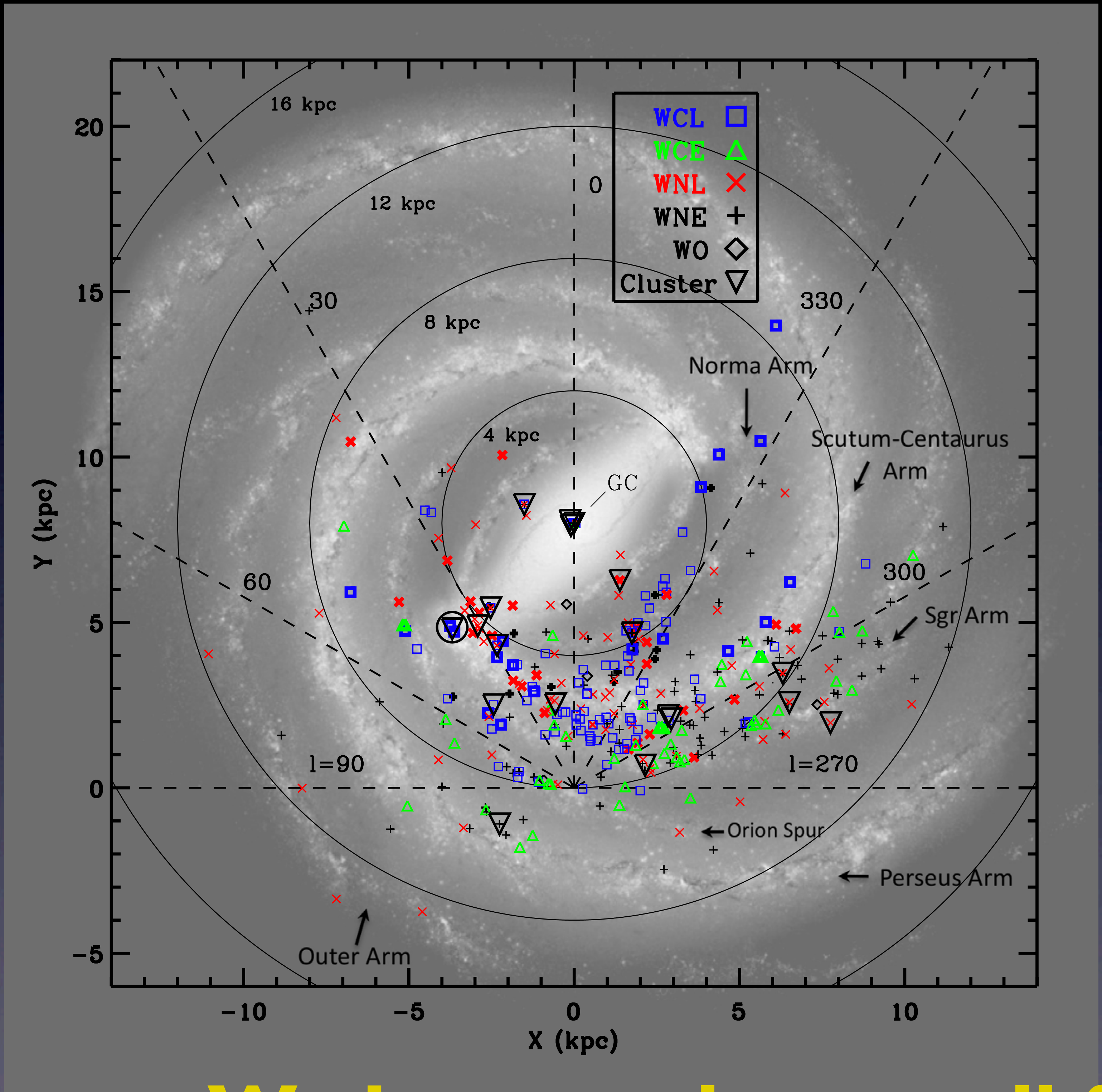
How many and where? : (I) RSG



We know only a small fraction!!

viewgraph by M.Tanaka

How many and where? : (2) WR



WR catalog

van der Hucht 2001, NewAR, 45, 135

Search in NIR

Mauerhan et al. 2011, AJ, 142, 40

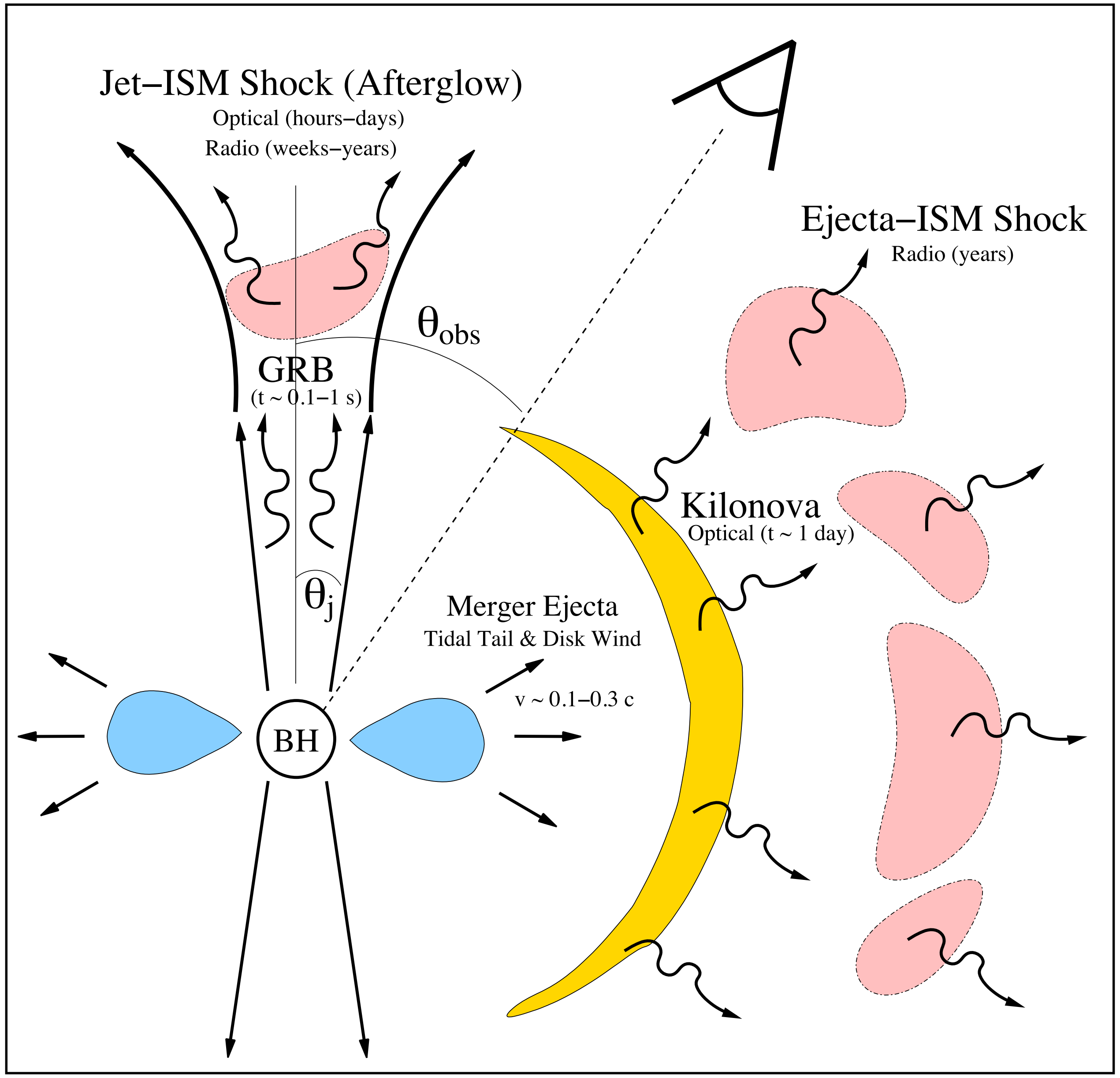
Shara et al. 2012, AJ, 143, 149

We know only a small fraction!!

GW and GRB : more chance of mutual follow-ups

NS-NS merger may emit EM radiation.

Features	**Supernovae**	**Compact Binary Coalescence**
Follow-ups / Counterparts	EM (**visible-infrared**, X-ray, Gamma-Ray), **Neutrino**	EM (visible-infrared, **X-ray, Gamma-Ray**), Neutrino

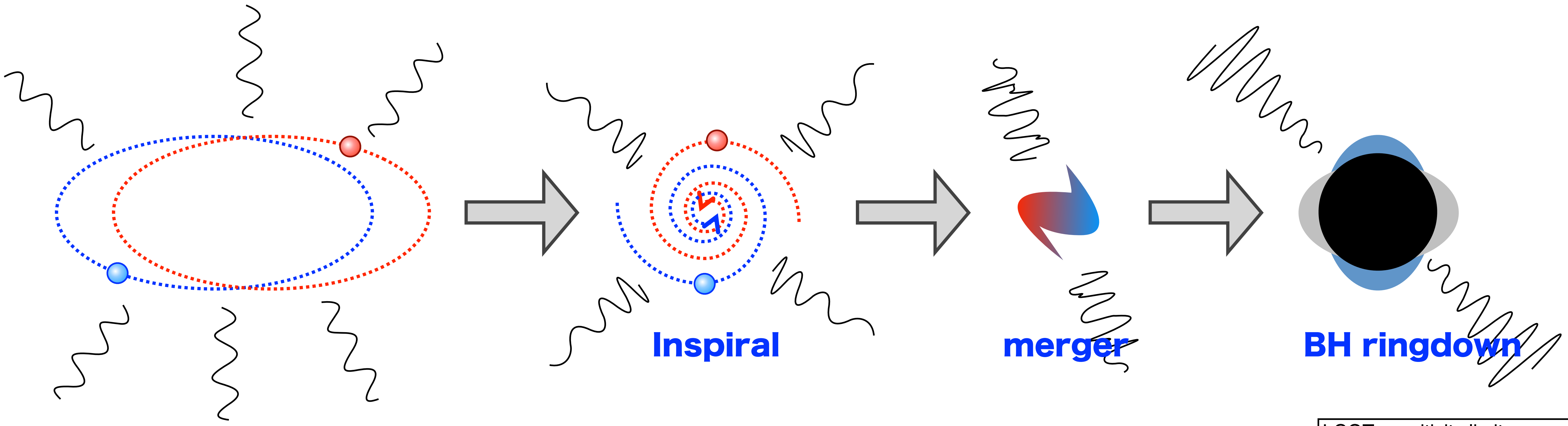


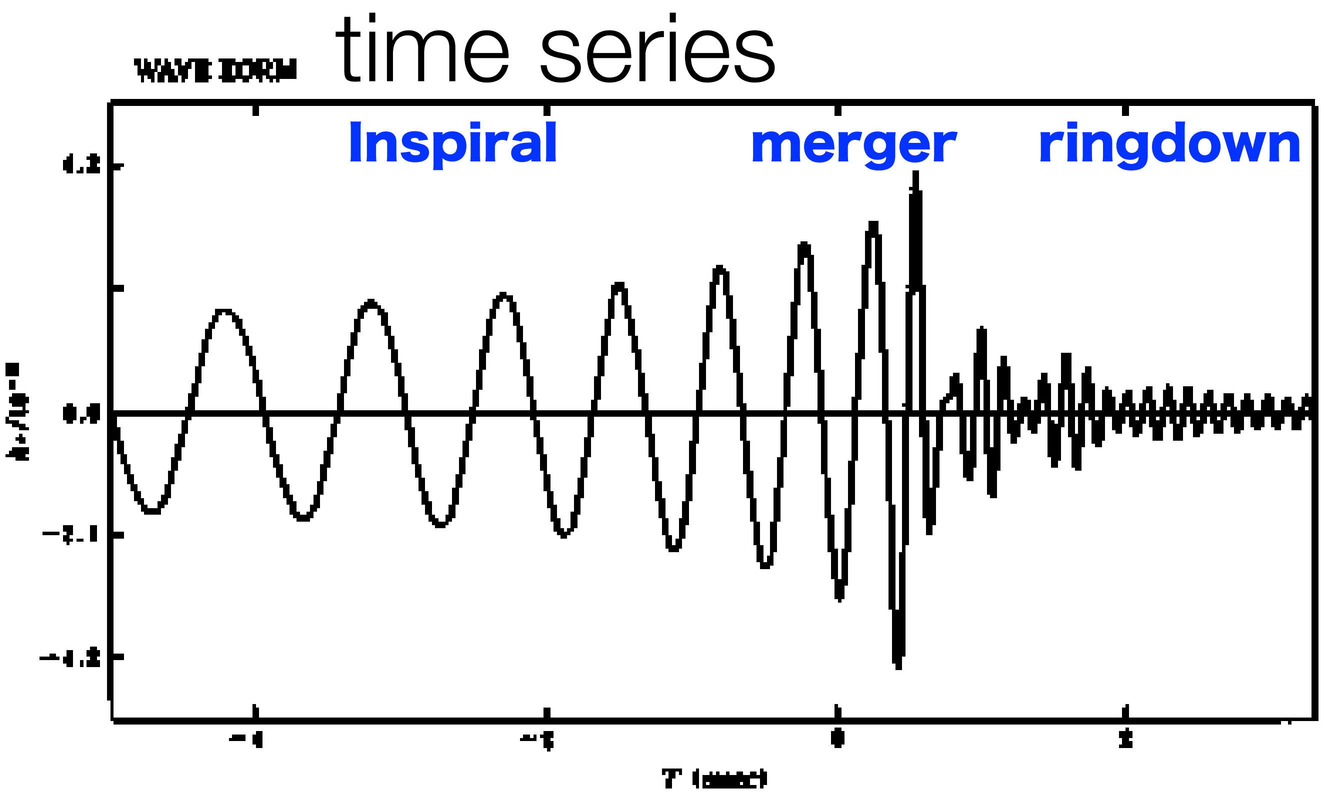
“Kilonova”

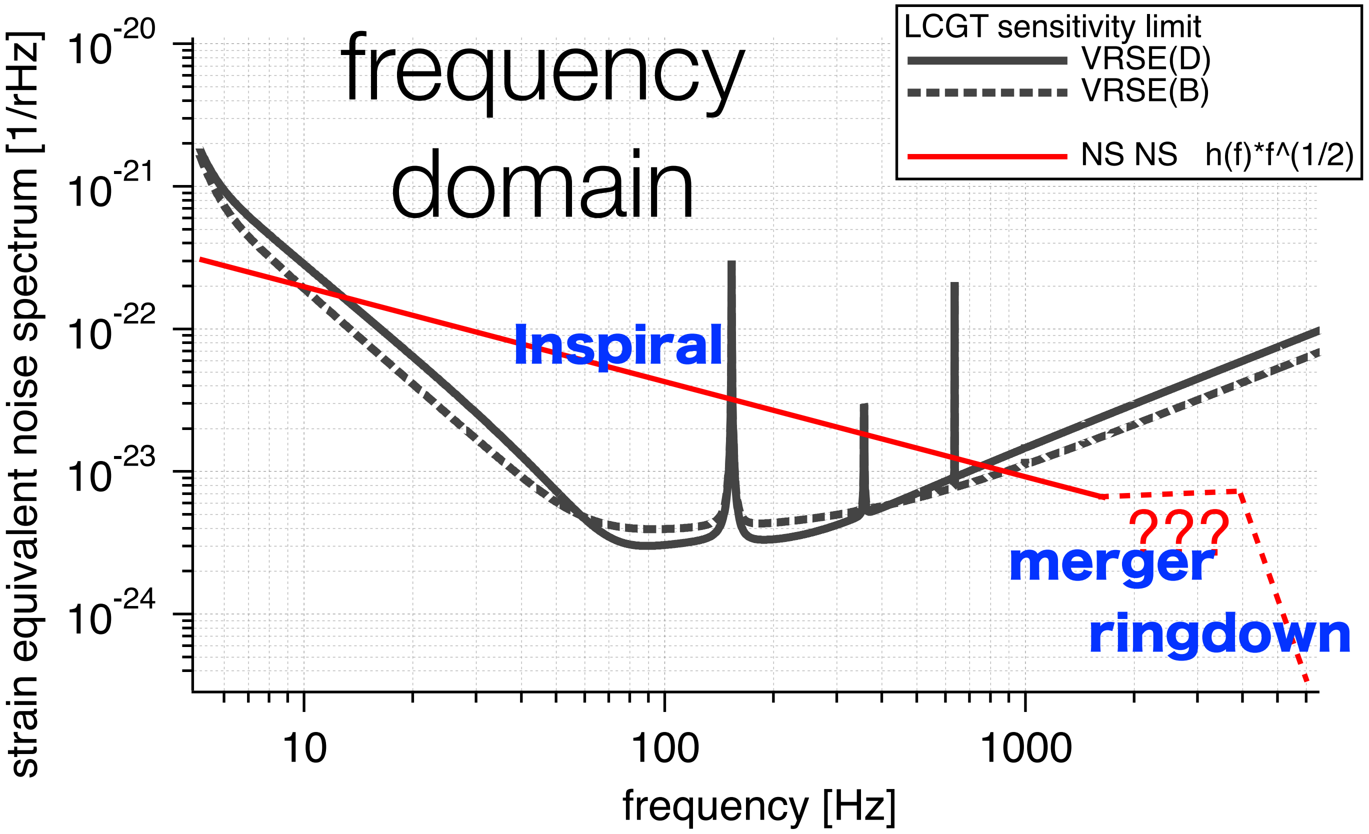
Metzger & Berger, 2011

EM Follow-ups are expected for GW. LIGO, Virgo already started these cooperative works.

GW signal (example: NS-NS Coalescence)







Summary

GW detection is ambitious project to confirm GR and to open the "GW astronomy".

KAGRA construction is progressing steadily.

SNe and GRB are very interesting source for GW!

not only for GW detection, but also counterpart / mutually follow-up observation.

It is expected to open new window!

GWPAW 2015

Gravitational **W**ave **P**hysics and **A**stronomy **W**orkshop

GWPAW is an annual open workshop (formerly called GWDAW) on the physics and astronomy of gravitational waves, techniques for their detection, and interpretation of data and results.

The workshop also focuses on **follow-ups/counterparts observations**, and
multi-messenger astronomy with GW.

Place: Osaka, Japan

Date: 17(Wed.)-20(Sat.), June 2015

KAGRA tour may arrange at 16th.