Status of KAGRA and for the Detection of Gravitational Waves from SNe

Nobuyuki Kanda (Osaka City U.)
KAGRA collaboration

30th Oct. 2013, Conference on Supernovae

YIPQS lon-term workshop “Supernovae and Gamma-Ray Bursts in Kyoto, 2013”

Plan of Talk

Gravitational Wave

- What ?
- How to detect

KAGRA

- Conceptual Design
- Schedule
- Construction Status

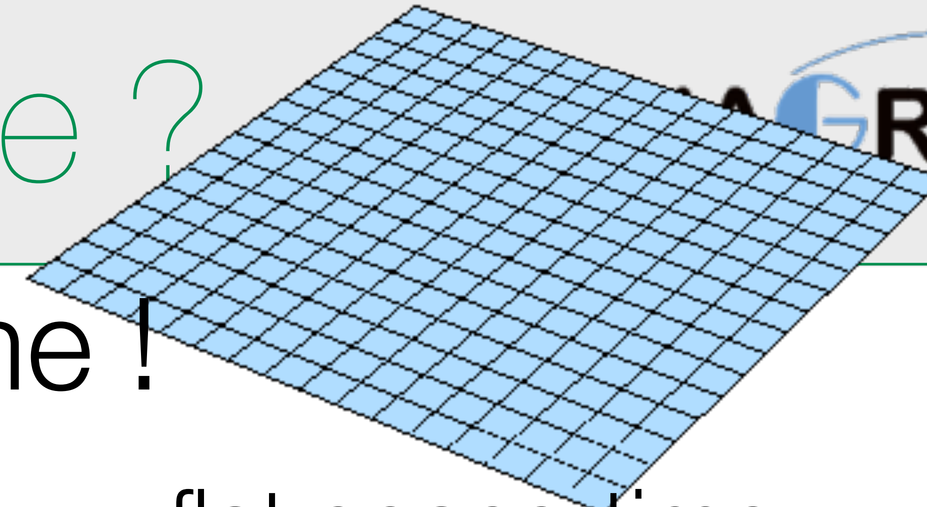
GW from SNe

- Possible Radiation Scenario
- What can be obtained from GW detection?

(GW and GRB)

What is Gravitational Wave ?

Gravity distorts the space-time !



flat space-time

Einstein Eq.

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

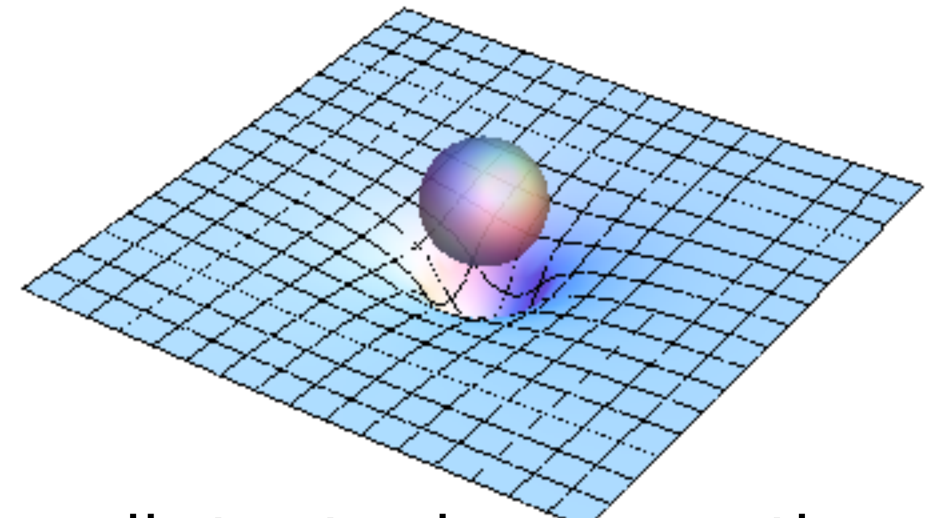
metric tensor

“flat” space-time (Minkowski)

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

“curved (distorted)” space-time

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

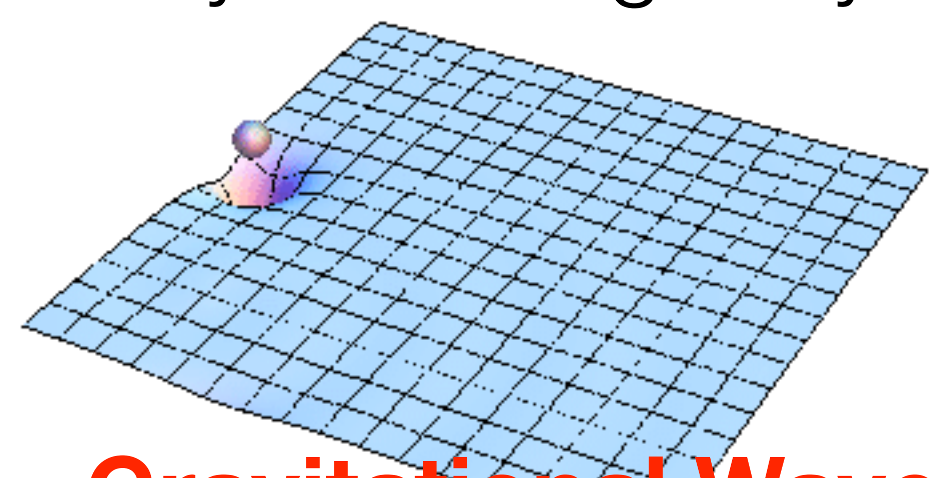


distorted space-time
by mass = gravity

small perturbation ‘h’ --> Waves

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

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



Gravitational Wave
propagation of distortion

GW radiation

KAGRA

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

Need direct measurement.

KAGRA

Why direct measurement ?

- We have to test 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

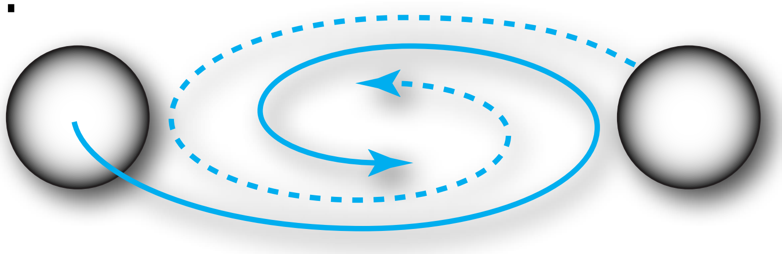
  Gravitational Wave Astronomy

Possible sources are also attractive for us:
black-hole, neuron star, supernovae, cosmic string, etc...

Possible GW sources

Event Like

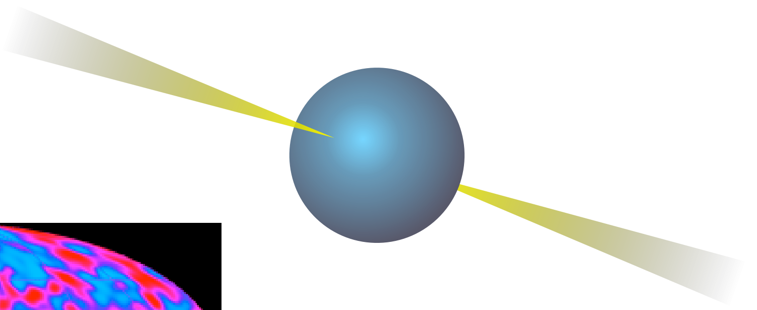
It will occur suddenly. Sometime it can be luminous!



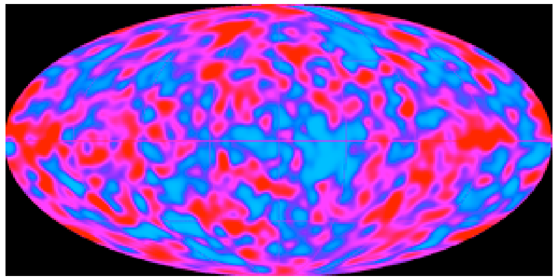
- **Compact Binary Coalescence**
  (**Neutron Star-NS**, NS-Blackhole, BH-BH)
- **Supernova**
  (Stellar-core collapse)
- BH QNM
- Pulsar glitch

Continuous

It exists anywhere, anytime in our universe ...



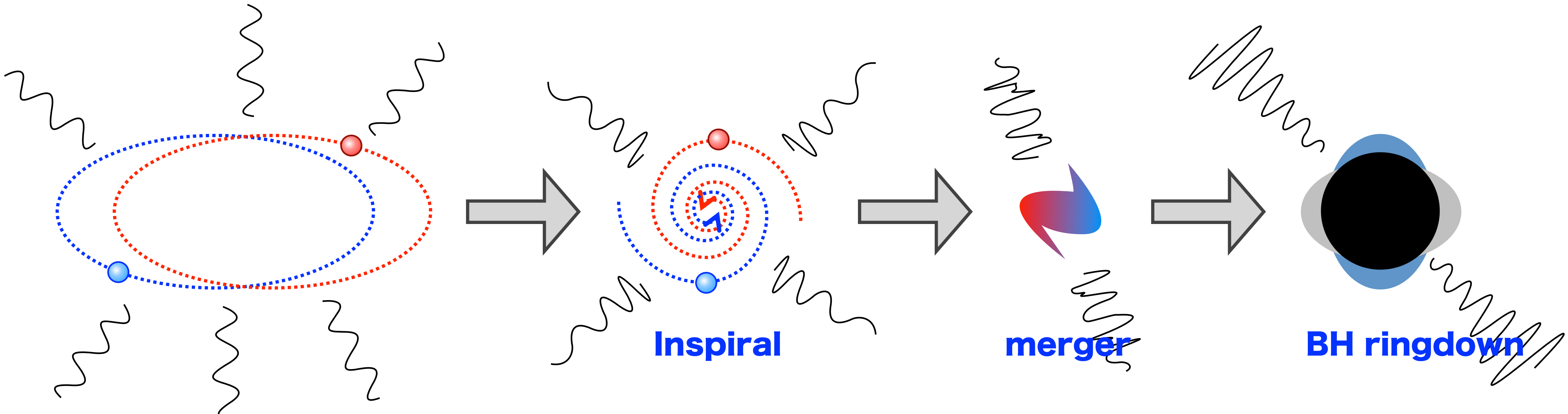
- Rotating Pulsar
- Binary
- Stochastic Background

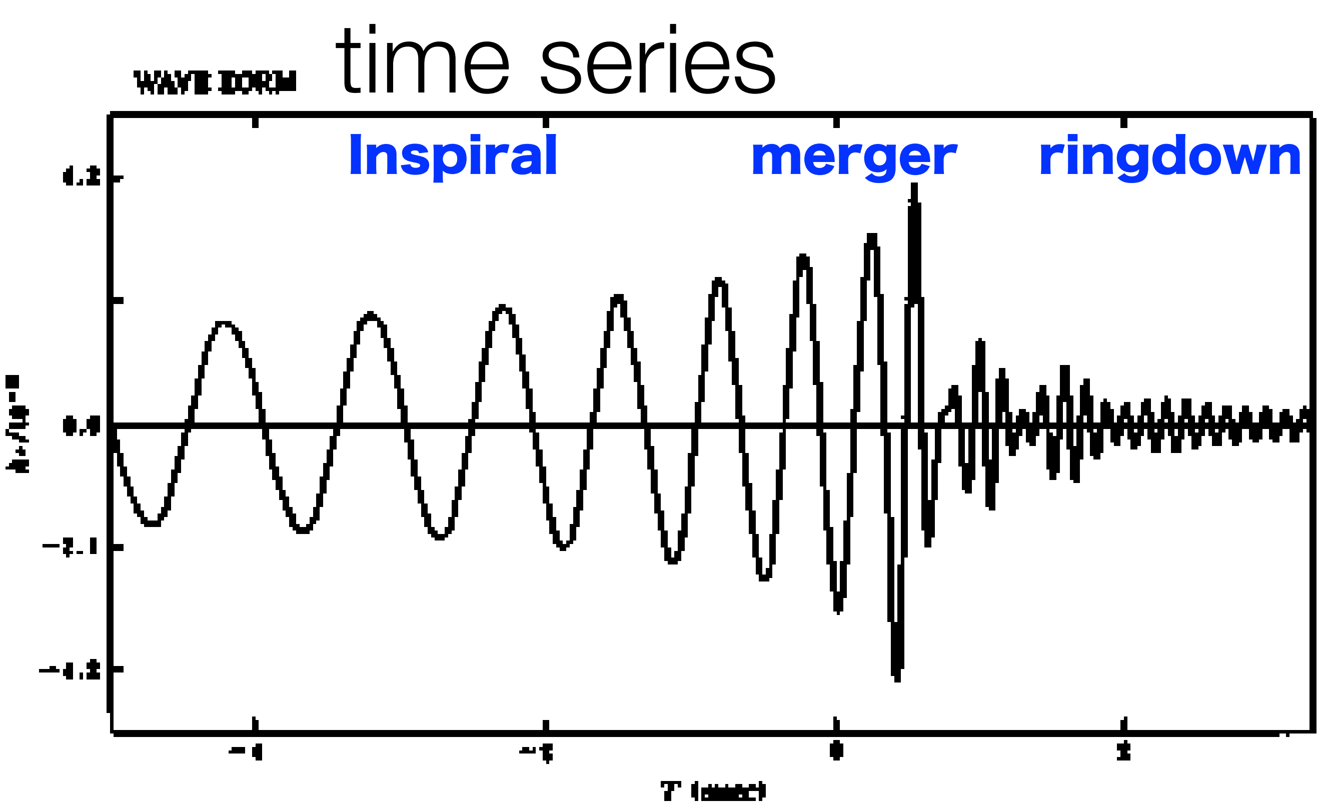


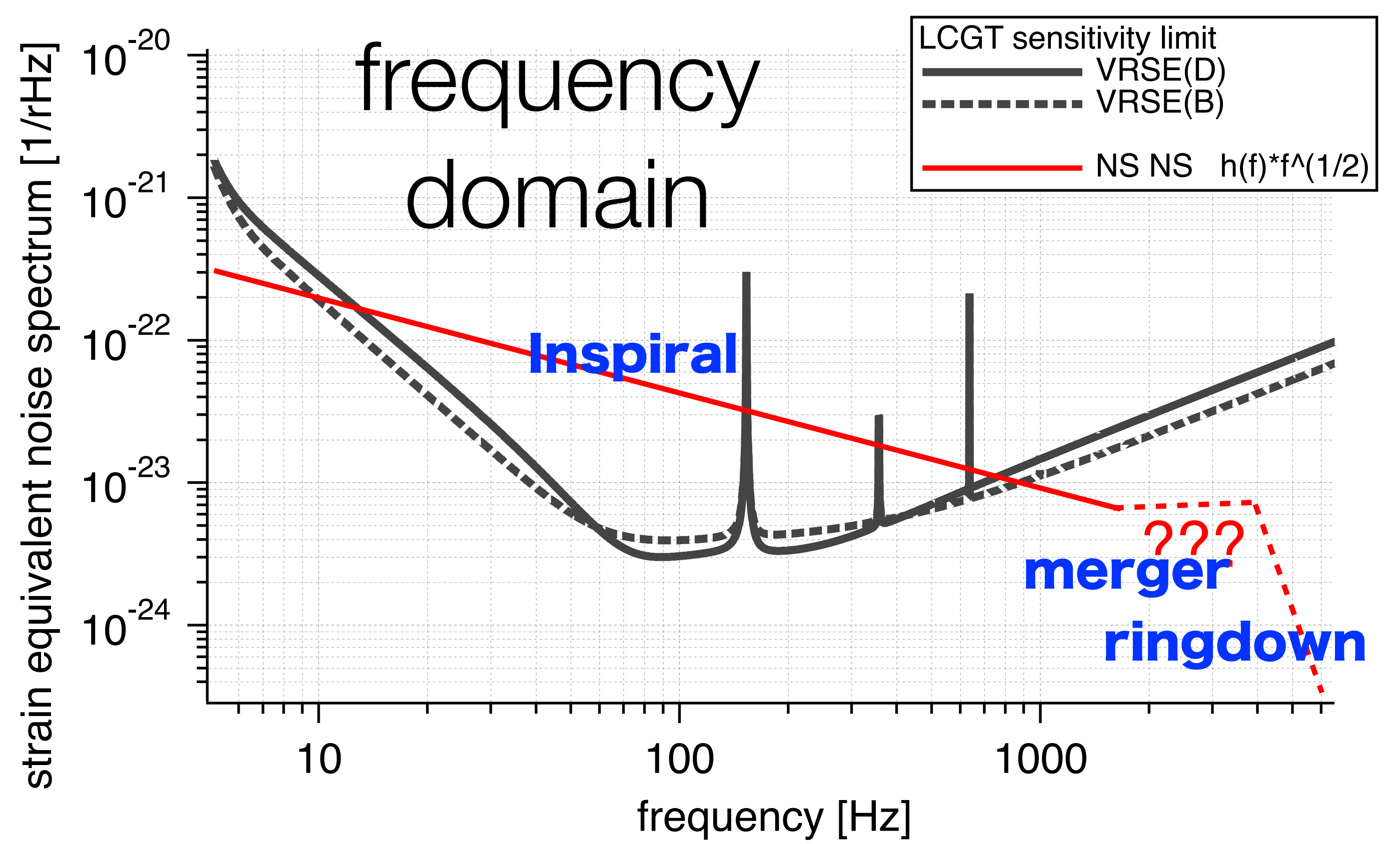
(+Unknown sources)

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

GW signal (example: NS-NS Coalescence)



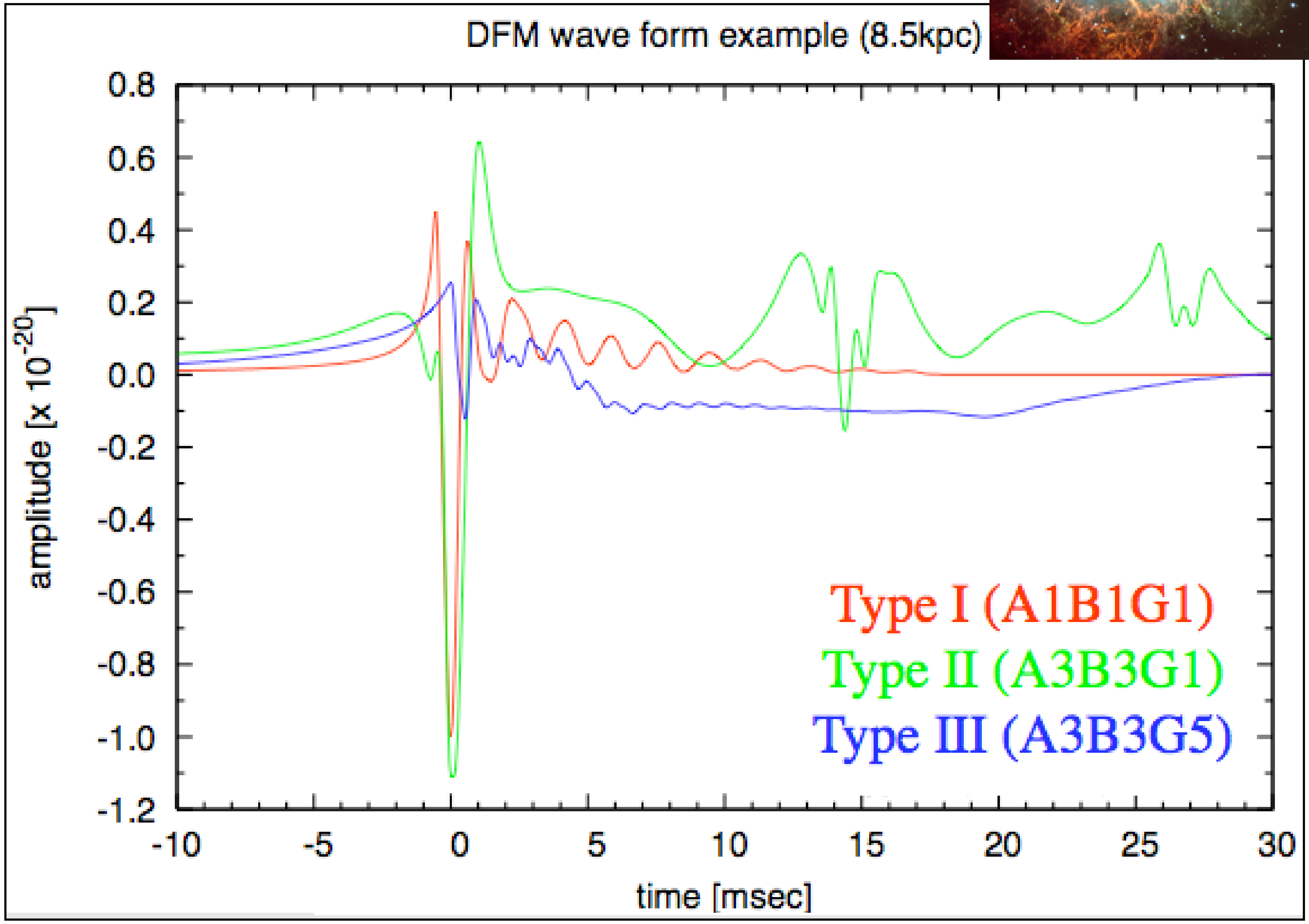




GW signal (example : Supernova)

Supernova (type II) will emit short duration GW (Burst wave) according to various processes in it.

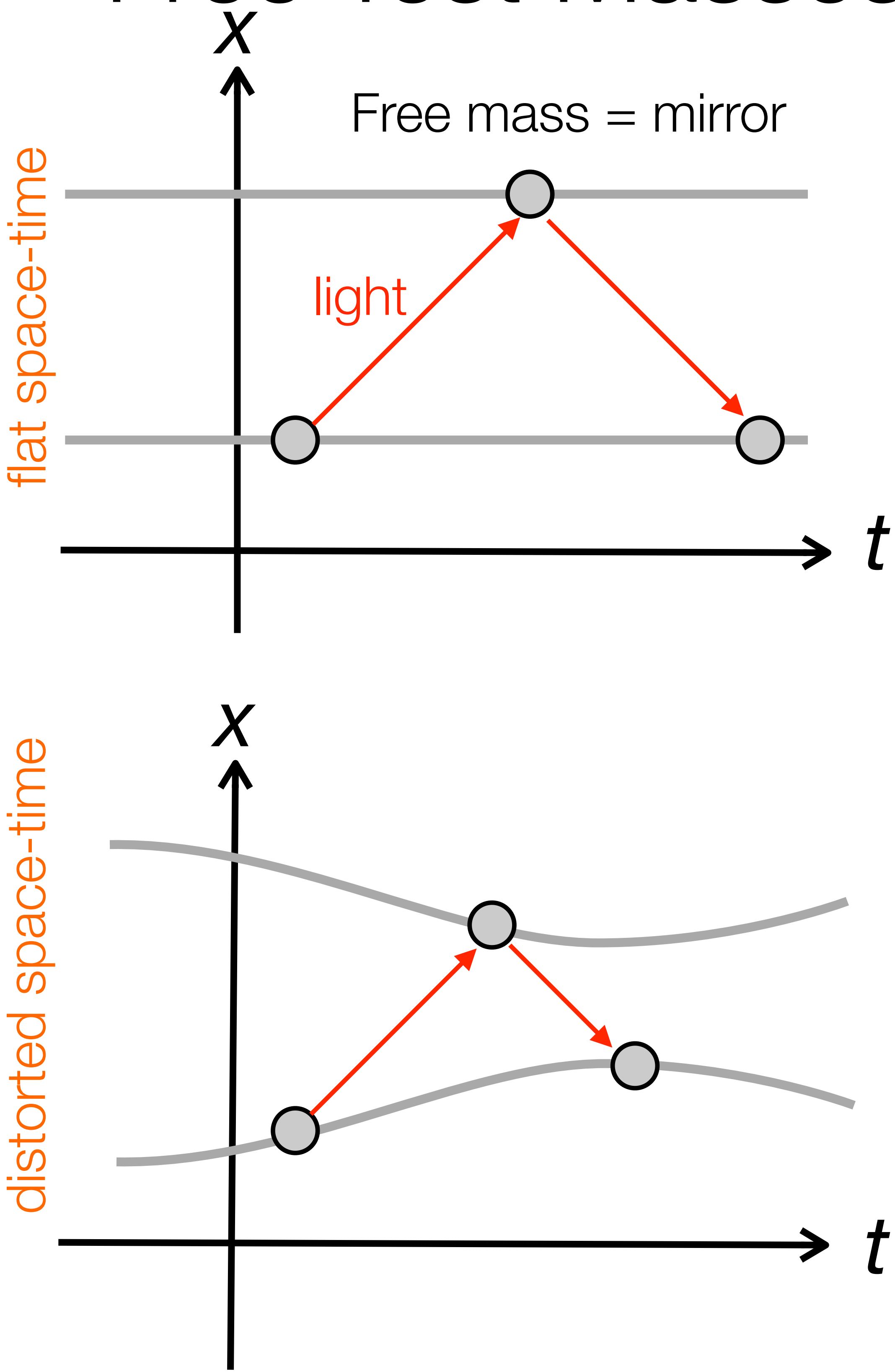
- Rotational Core collapse (Bounce)
- Convection
- Proto-neutron star formation and g-mode instability
- Standing-Accretion-Shock Instability
- ...

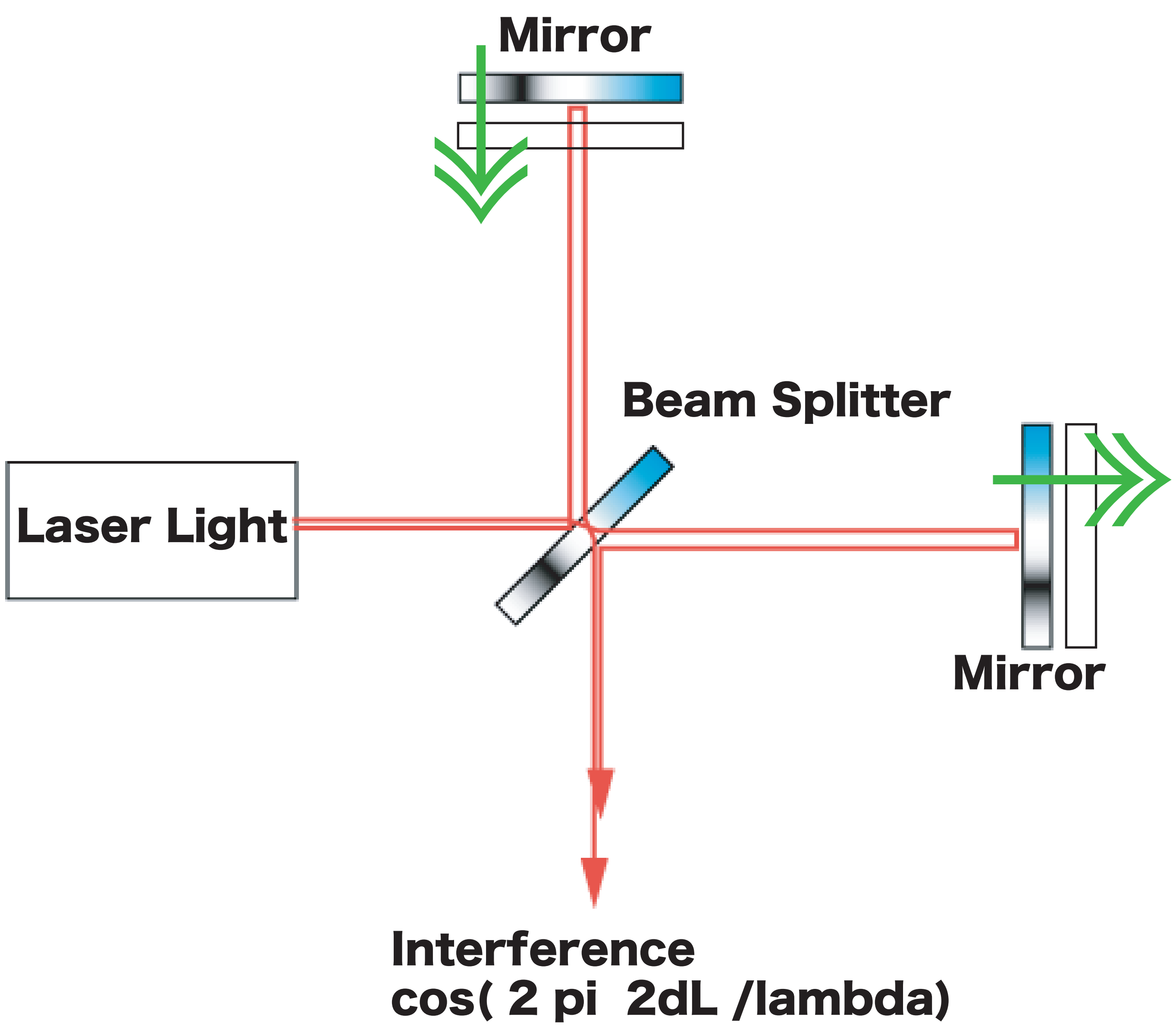


Dimmermeier et al.

How to detect GW

Free Test Masses & Laser interferometer

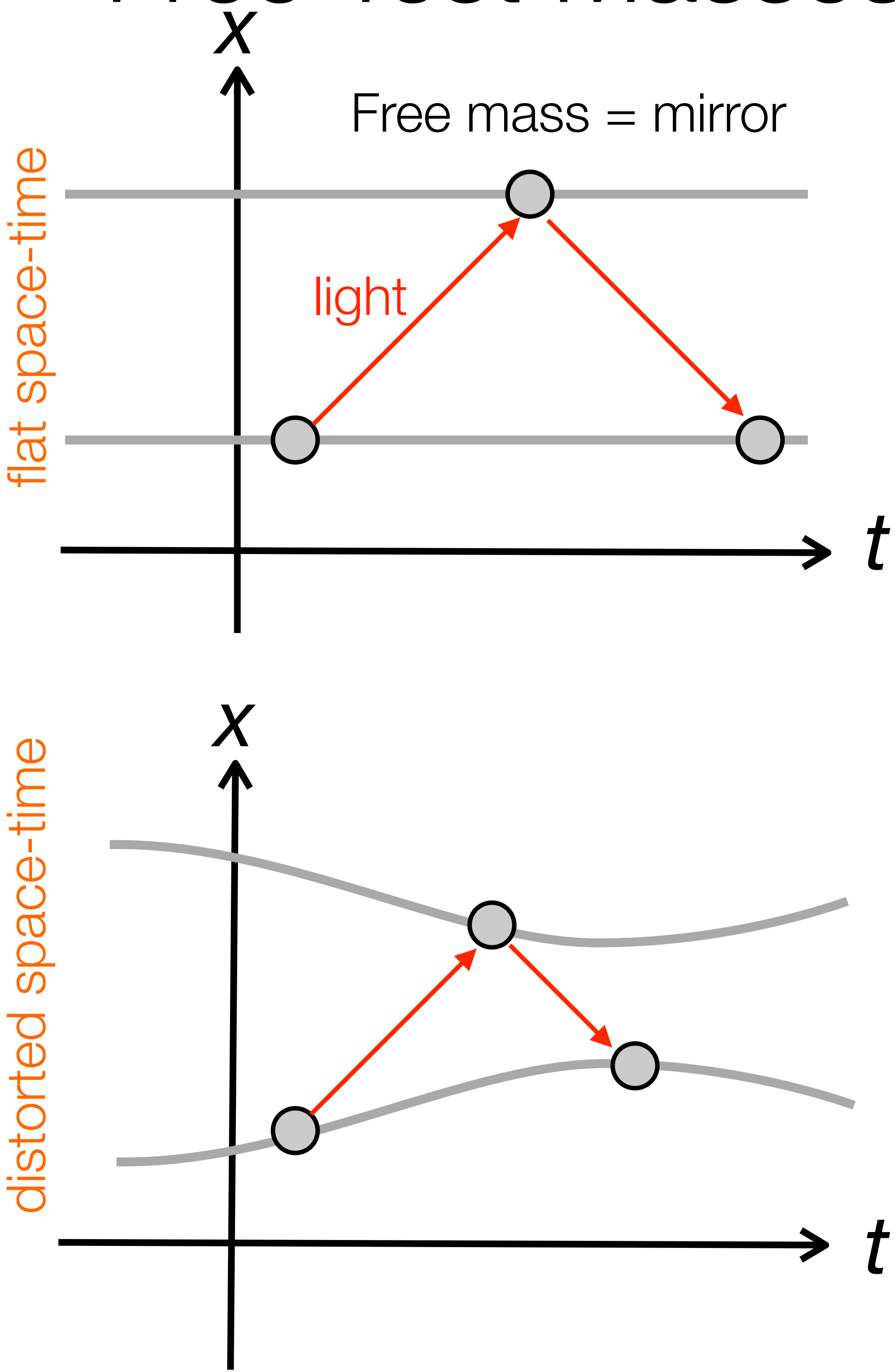


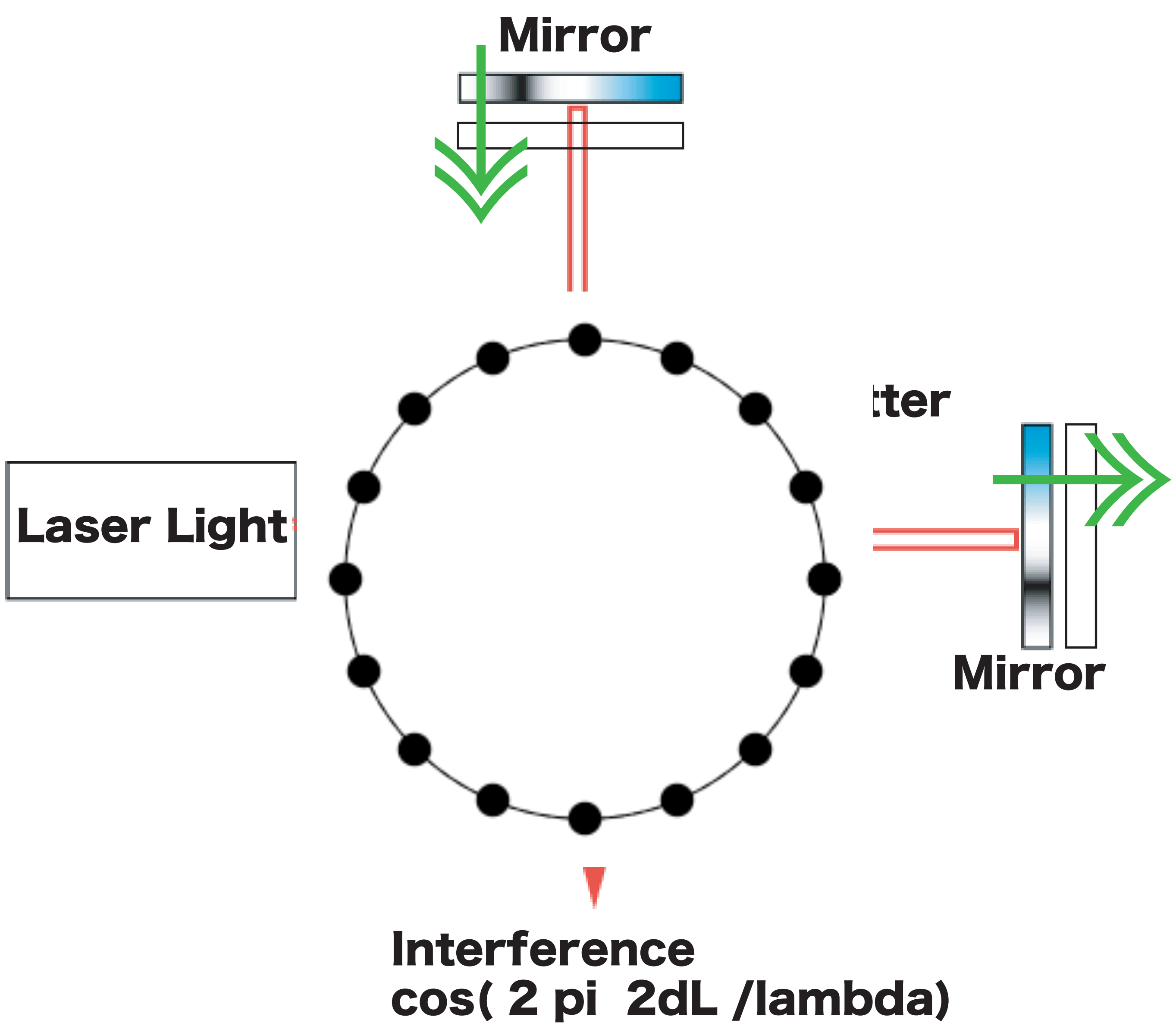


Michelson Interferometer

How to detect GW

Free Test Masses & Laser interferometer





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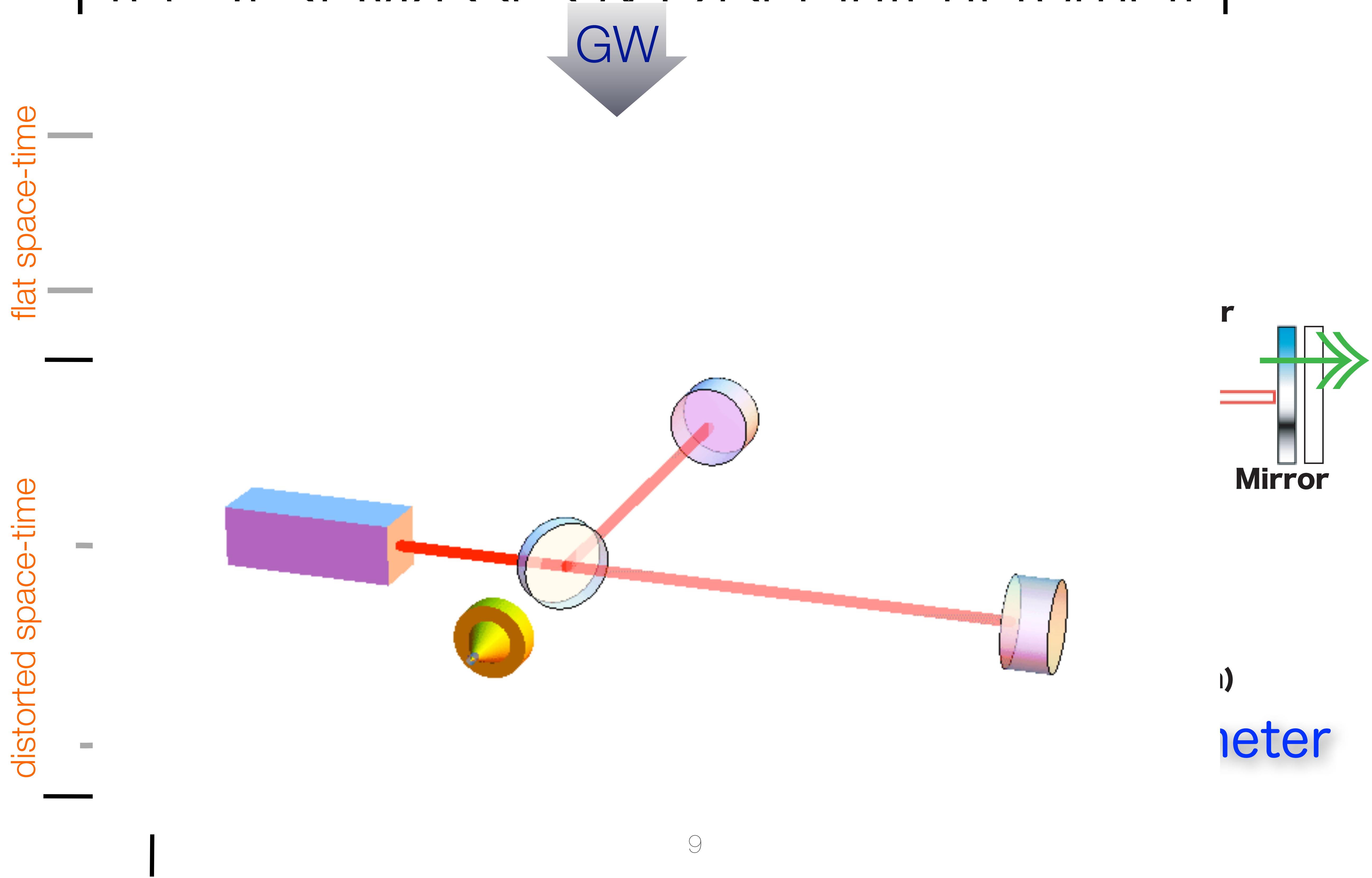


Schematic Figure

- Free mass --> suspended mirror

  To integrate strain 'h' --> long baseline arms.

- Limited size --> Folding arms / Storage cavity

- Against noises -->

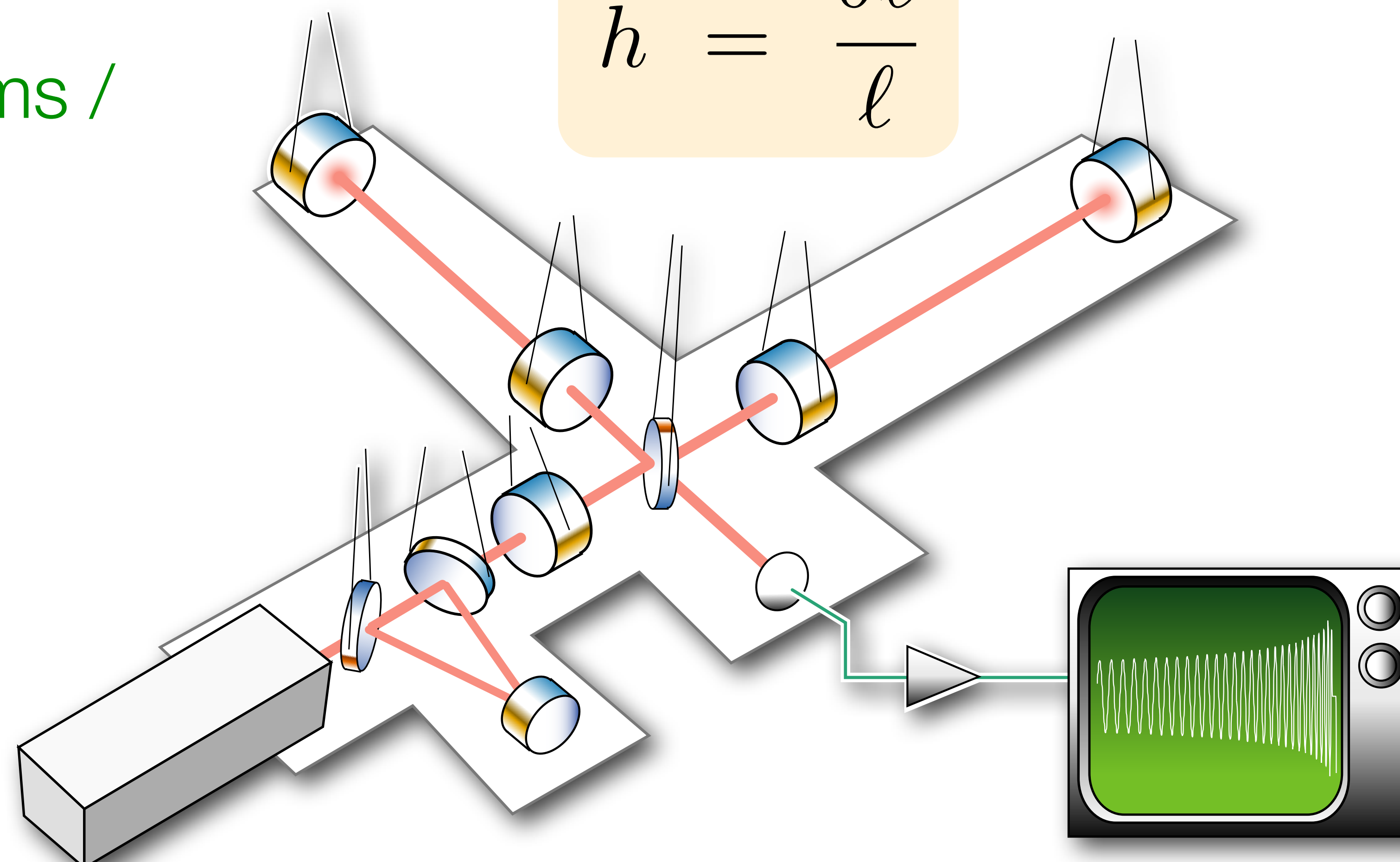
  high power laser

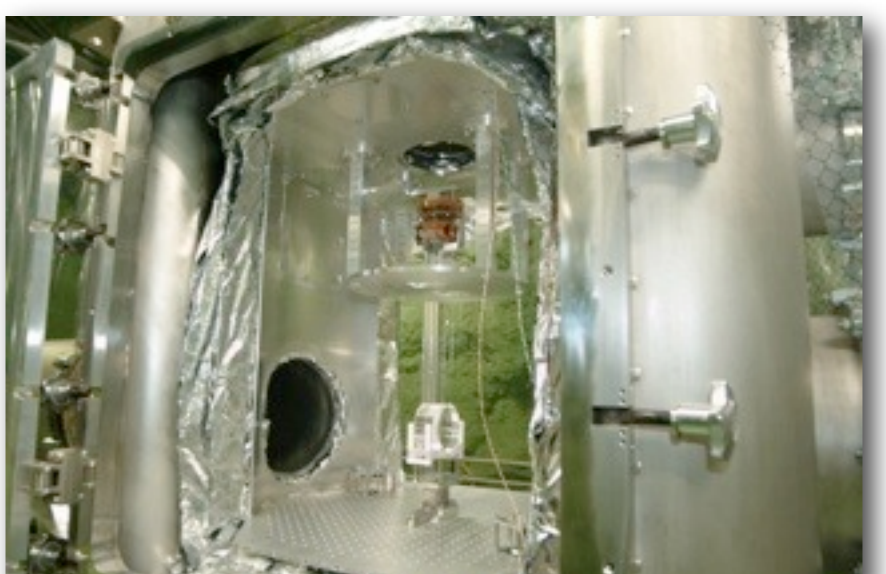
  Cooling

  etc..

merit on long base-line

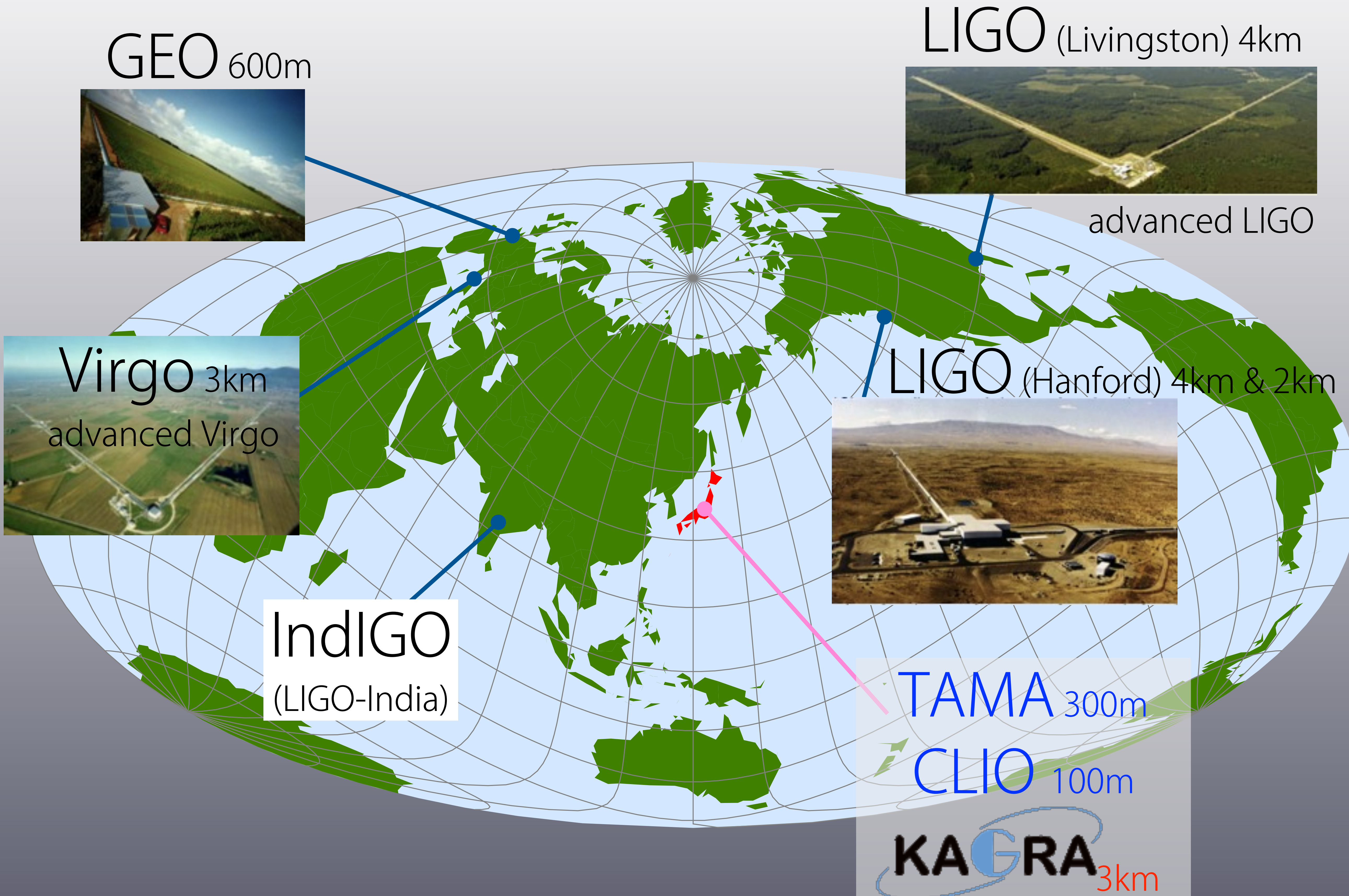
$$h = \frac{\delta \ell}{\ell}$$





<-- mirror and suspension of CLIO interferometer (prototype of KAGRA)

Global Network of GW detectors



KAGRA

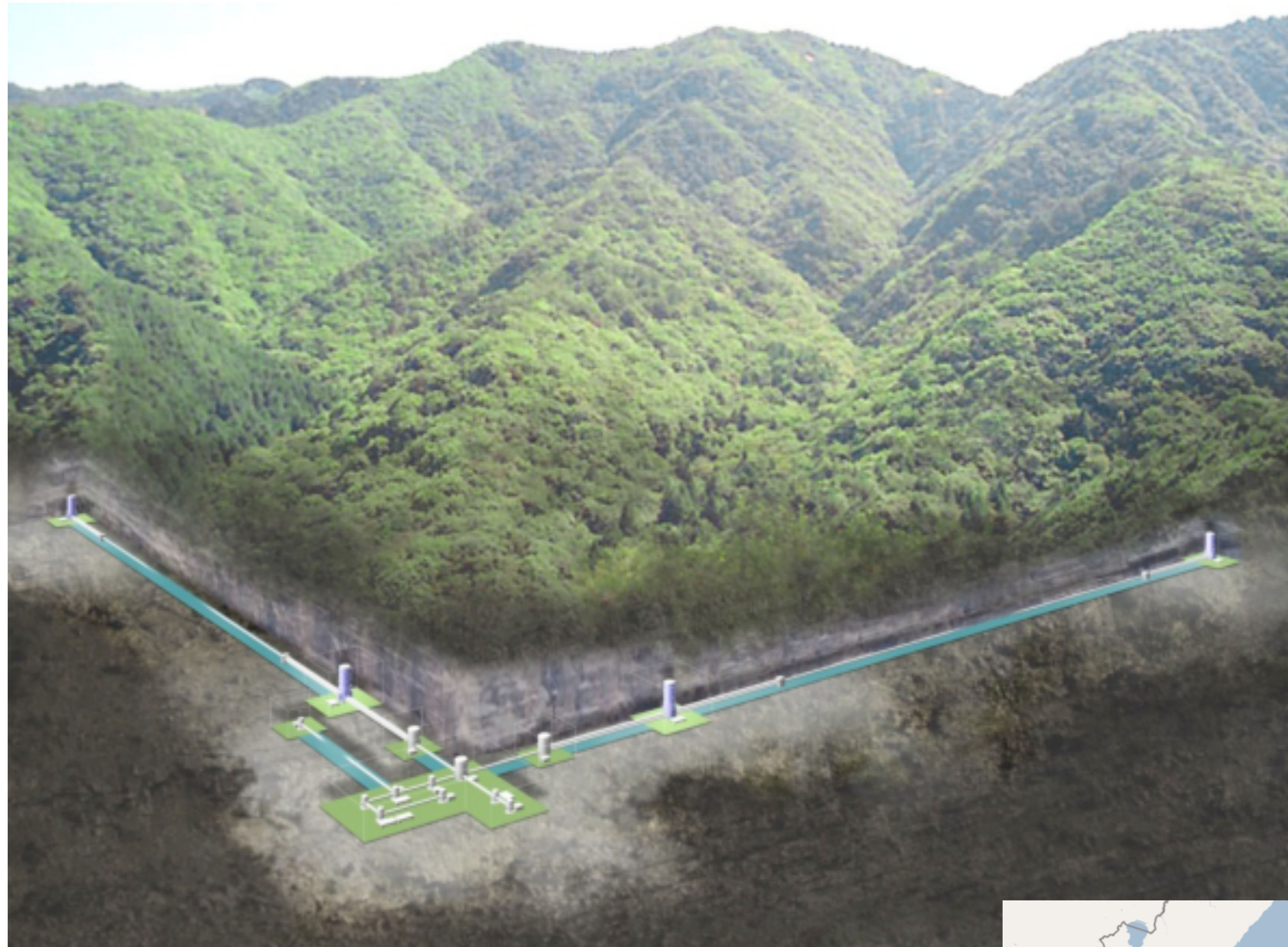
Underground

- in Kamioka, Japan
- Silent & Stable environment

Cryogenic Mirror

- 20K
- sapphire substrate

3km baseline



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Plan

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

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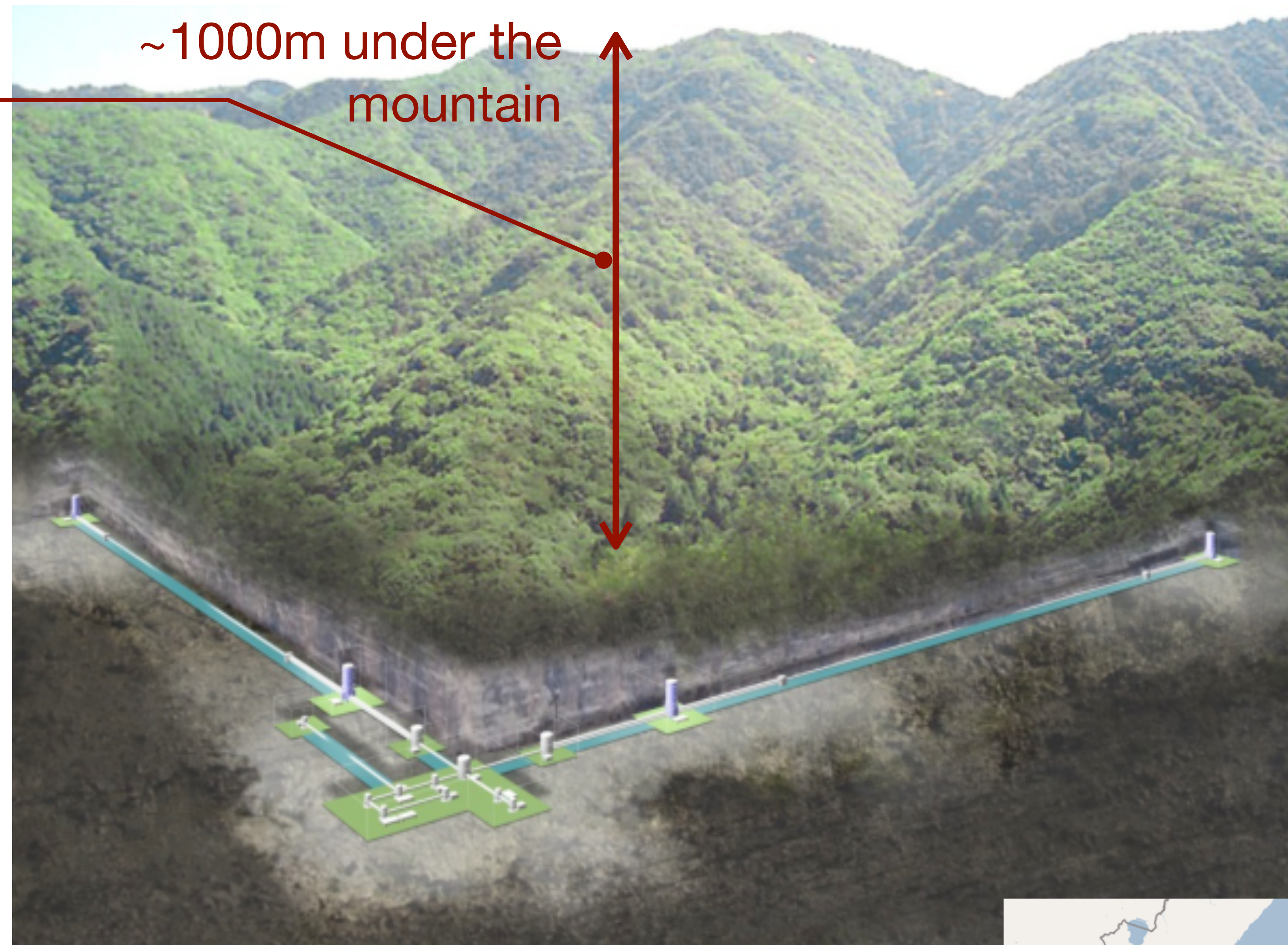

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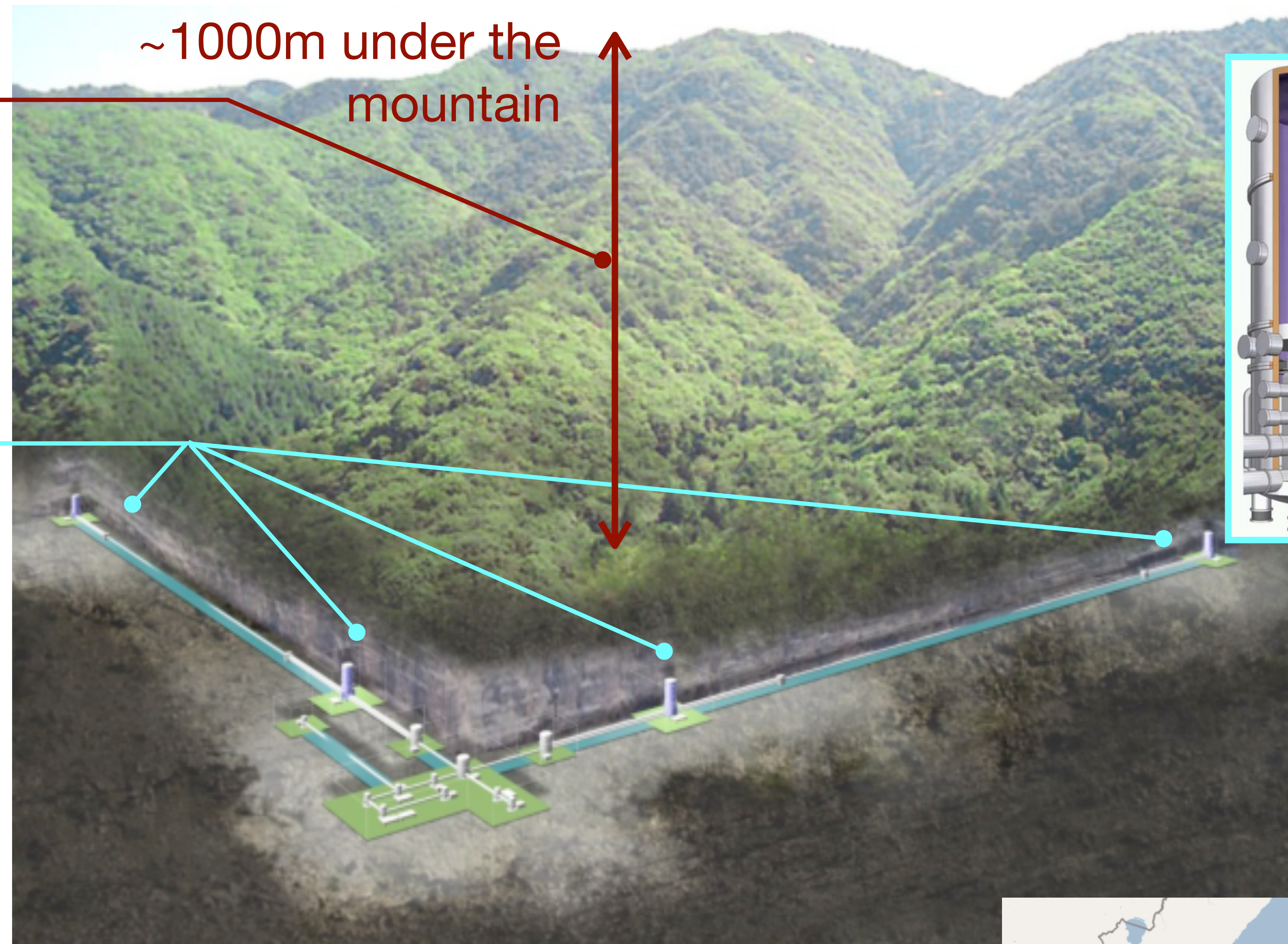

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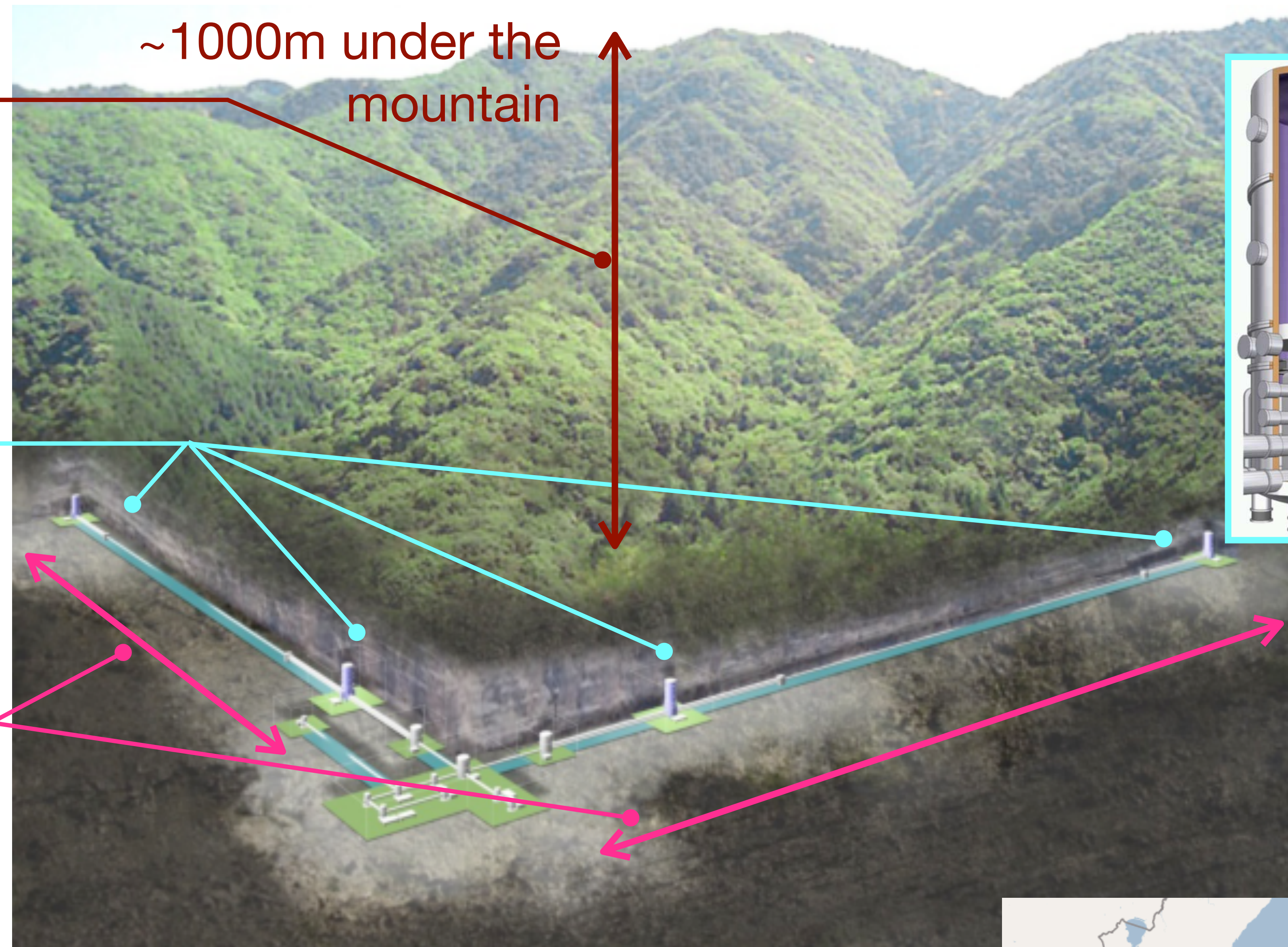

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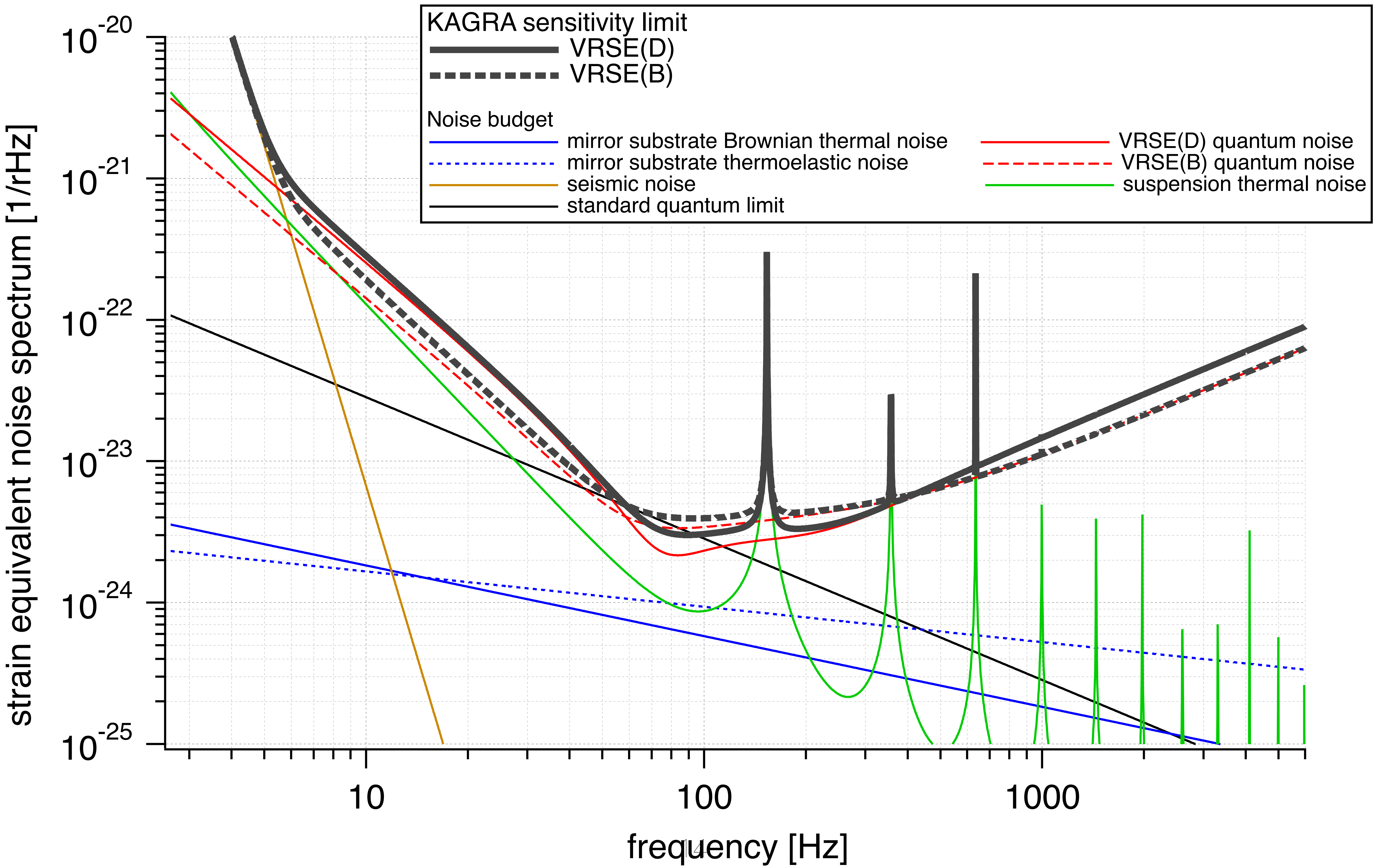
viewgraph by K.Kuroda

KAGRA Collaboration in the world

- Research organizations of laboratories and universities are 41 in Japan and 38 in overseas
- 158 researchers in Japan and 67 in abroad, 225 members in total

Sensitivity Limit of KAGRA

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



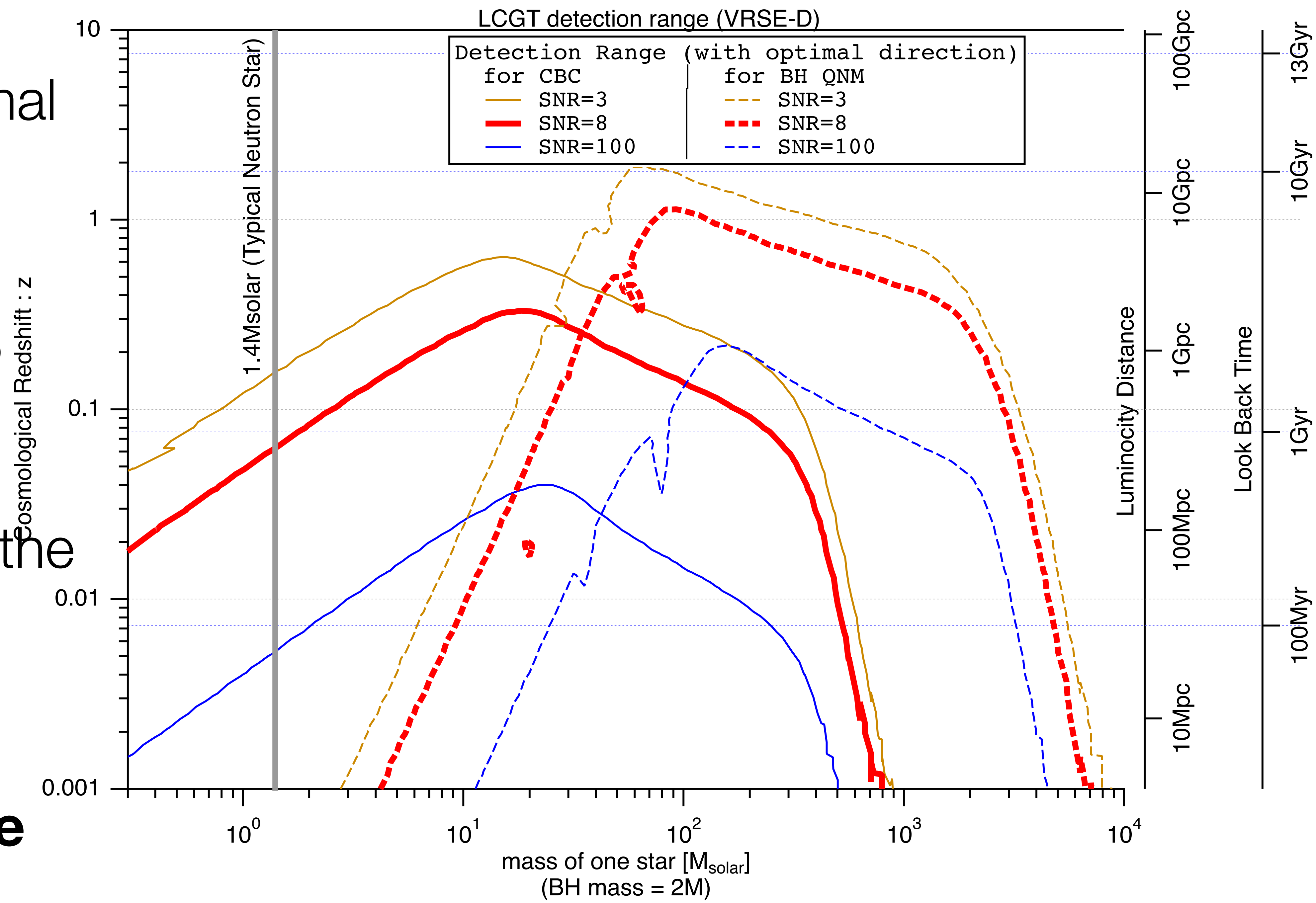
Detection Range

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

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

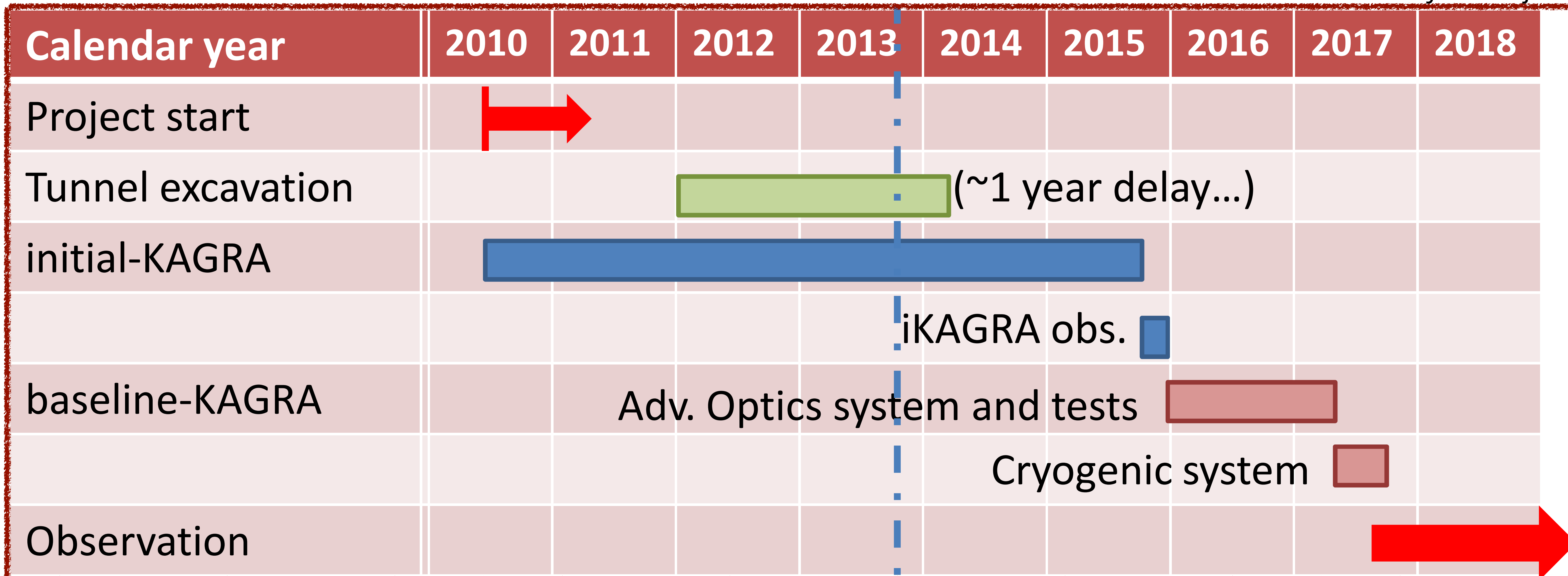
-> 10 event/yr

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

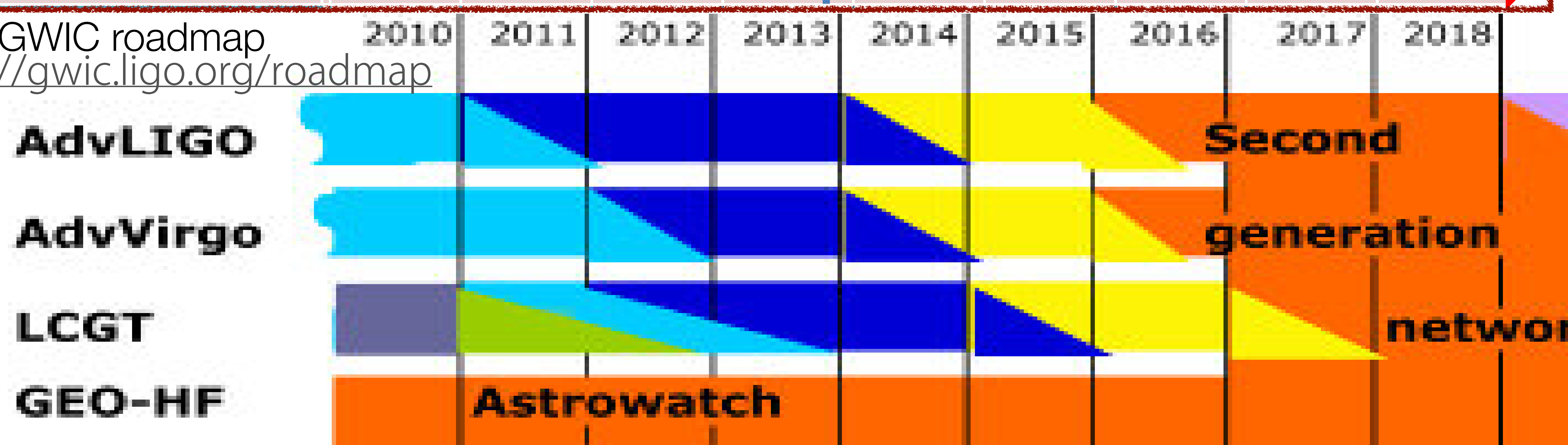


Schedule & Target

by T.Kajita

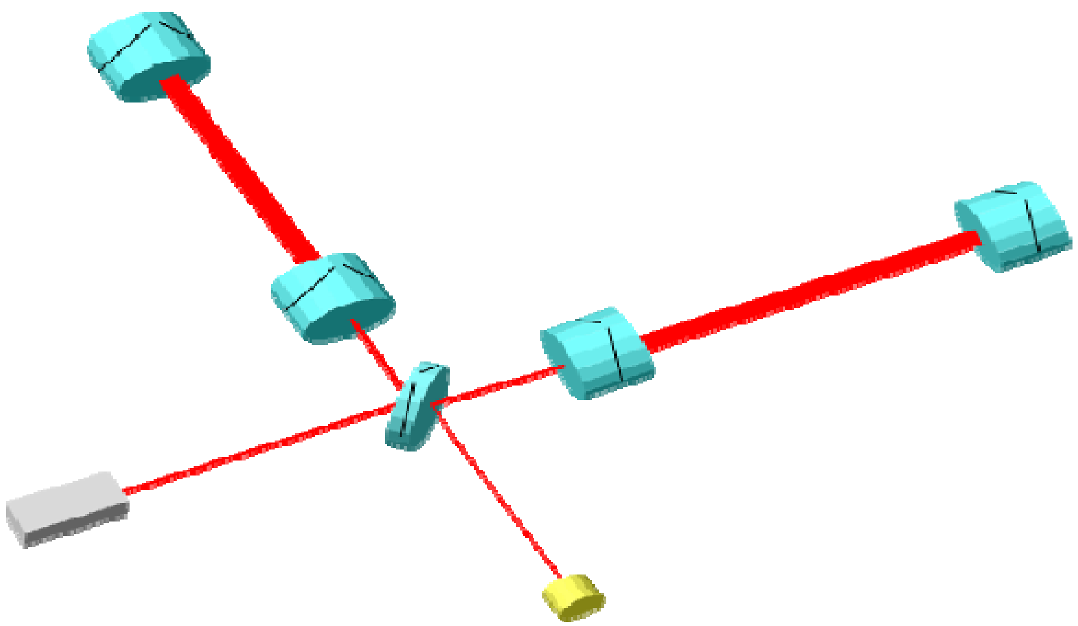


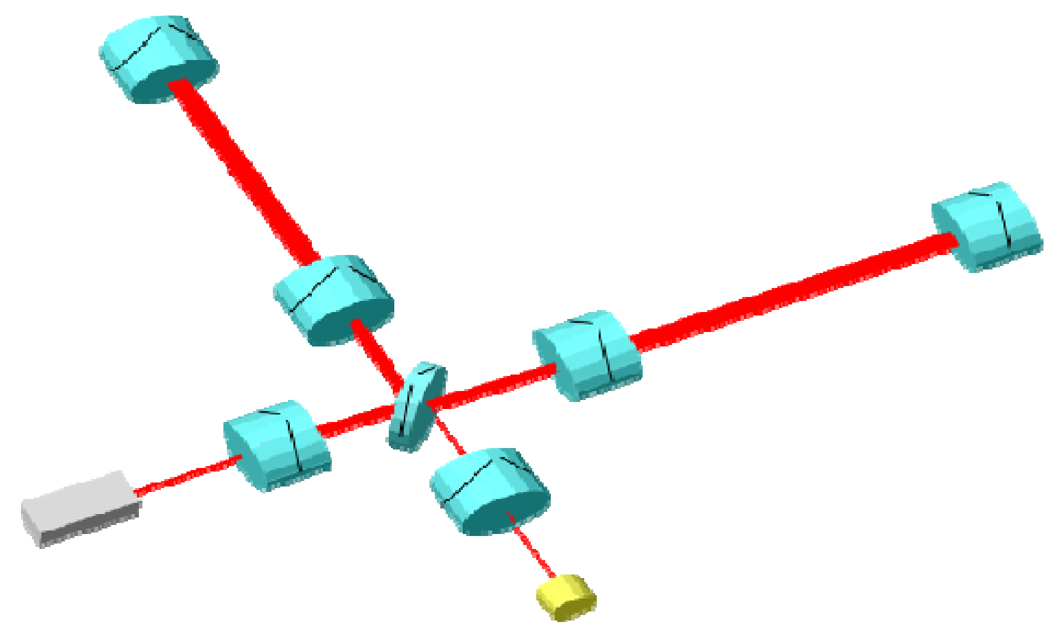
GWIC roadmap
https://gwic.ligo.org/roadmap



viewgraph by T.Kajita

iKAGRA (~ 2015) → *bKAGRA (2016 ~)*





- ◆Simple interferometer with:
  room temperature operation,
  10W class laser, and
  no power and signal recycling
- ◆ However, full end-to-end (relatively short) observation, in order to experience the operation and to understand the potential problems as soon as possible.

- ◆Advanced interferometer with:
  power and signal recycling, but still room temperature operation.

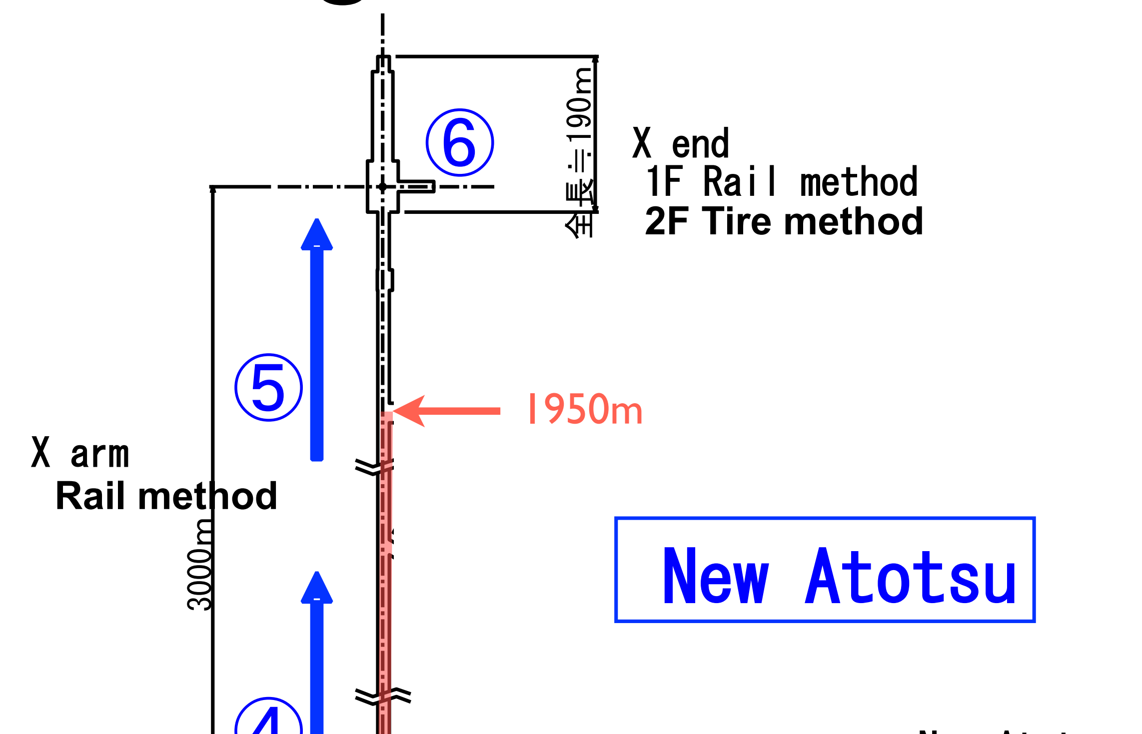
↓

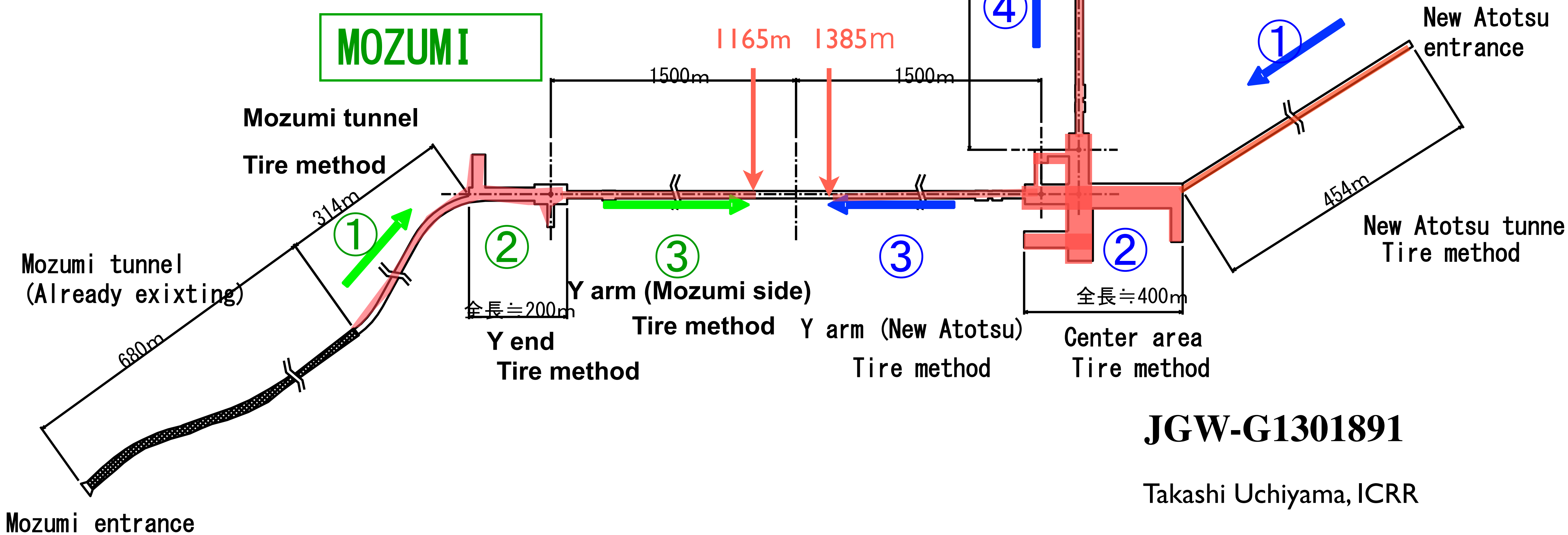
- ◆ Full bKAGRA with;
  power and signal recycling,
  cryogenic sapphire mirrors,
  and >150W laser.

by T.Uchiyama

Tunnel subgroup brief report for the KAGRA international collaboration meeting on 2013/10/09.

- Excavation from Mozumi entrance finished on 2013/03/06.
  - The Yend has been completed except for the vertical hole. Length of the Y arm tunnel is 1165m.
- Center area has been completed except for the vertical hole.
- The current progress of Xarm and Yarm are 1950m and 1385m, respectively.
- Yarm tunnel will be completed on 2013/12.
- The excavation will be completed on 2014/03.





JGW-G1301891

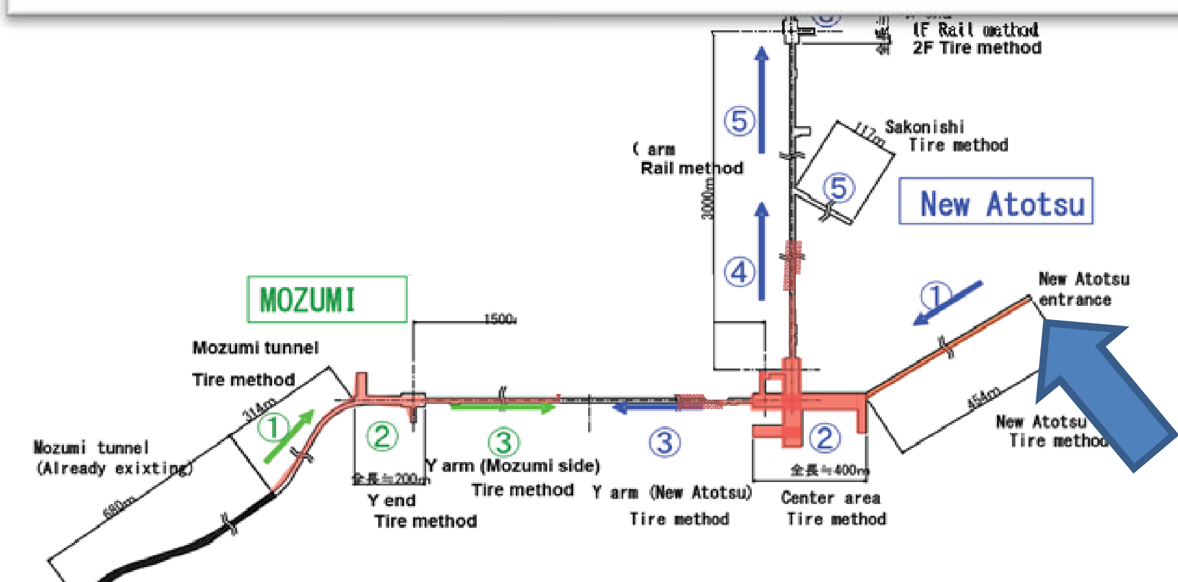
Takashi Uchiyama, ICRR

viewgraph by T.Kajita

New Atotsu entrance

End of April, 2012

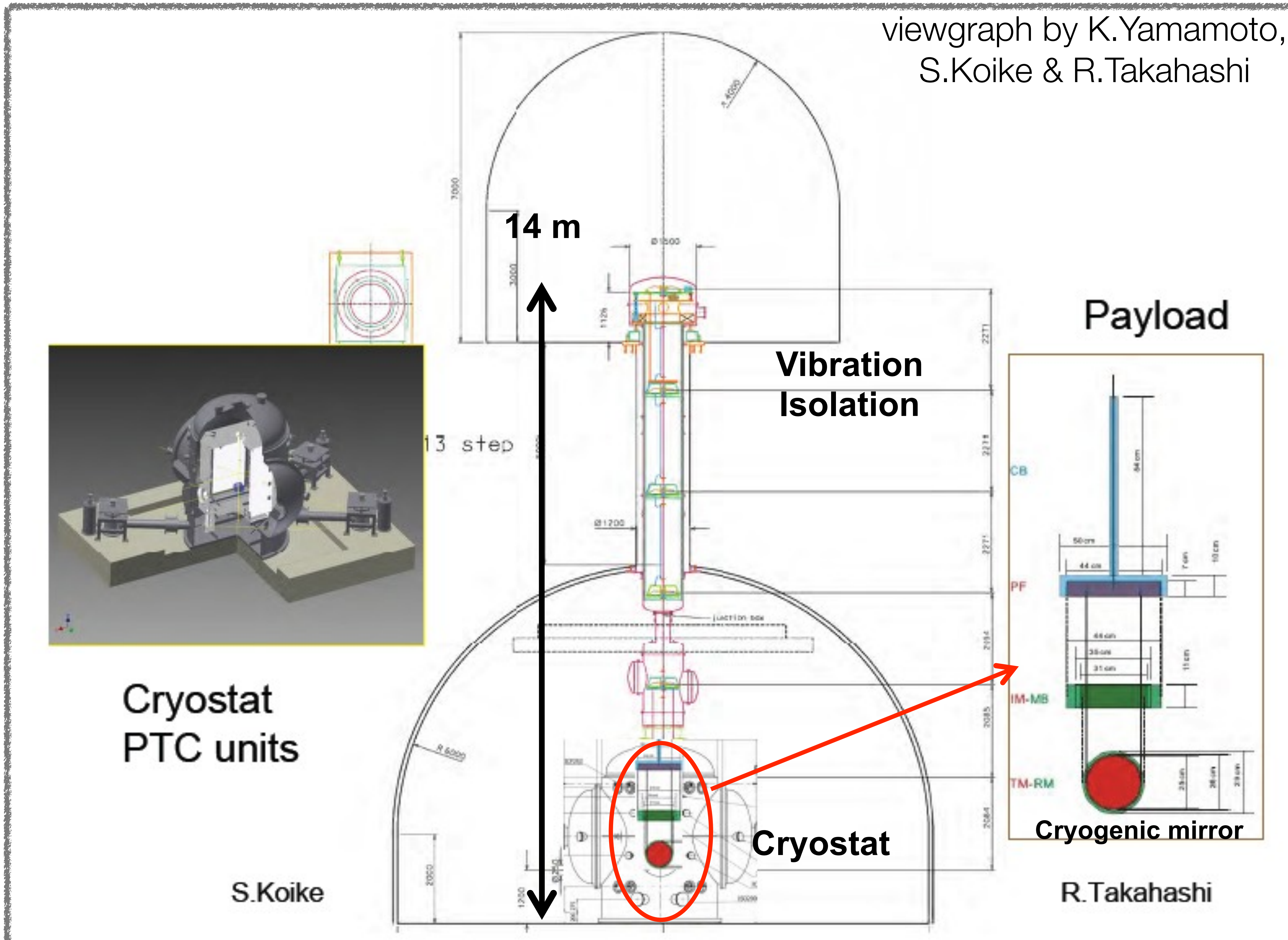
Mid June, 2012




ずり搬出中
ずり出し中
立入り禁止
上部回転灯の回転時は
ずり出し中です
この先立入り禁止となります

Vibration isolation and cryostat

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



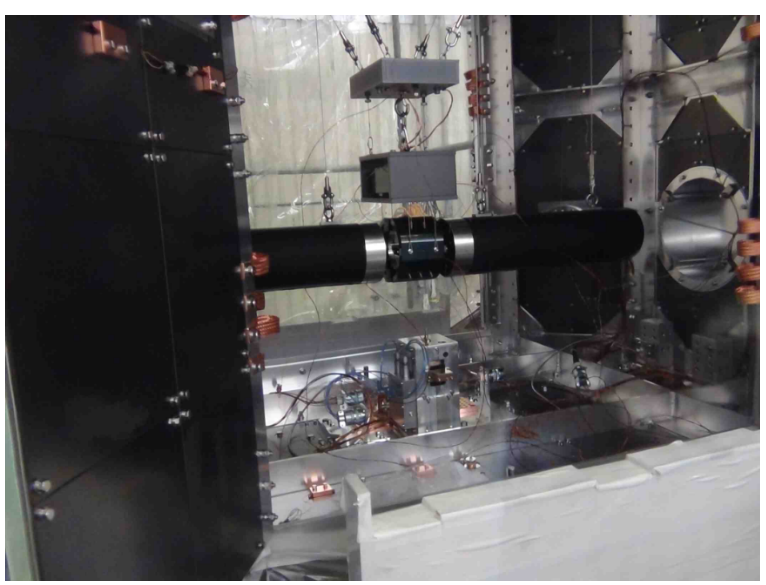
Cryostat

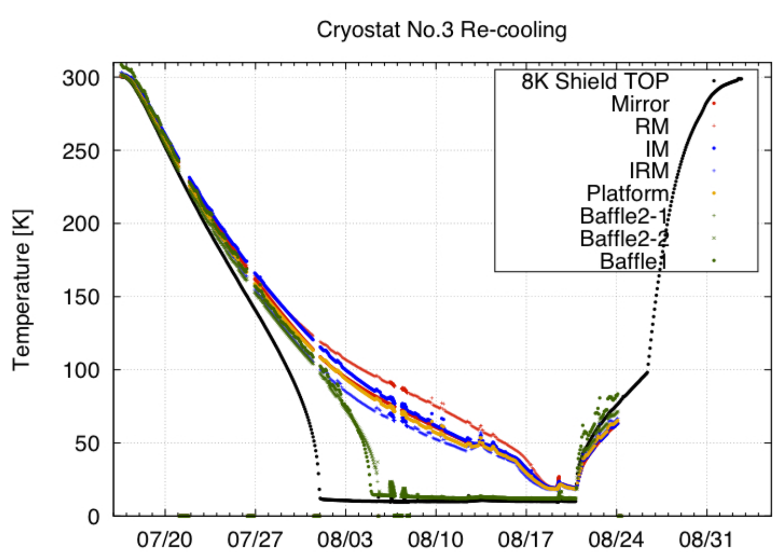
viewgraph by T.Suzuki

Cryostat #1, #2, #4 : Move to the Miyakawachou Storage (7/27, 7/28)

Cryostat #3 : Extra cooling test of 1/2 payload with dummy baffles in July and Aug.

Vibration measurement by Roma and ICRR accelerometers.
Waiting for transportation to Miyakawachou Storage.





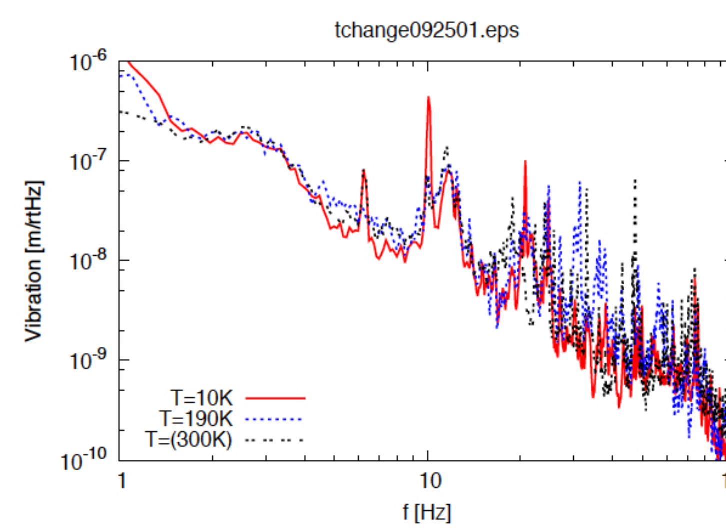


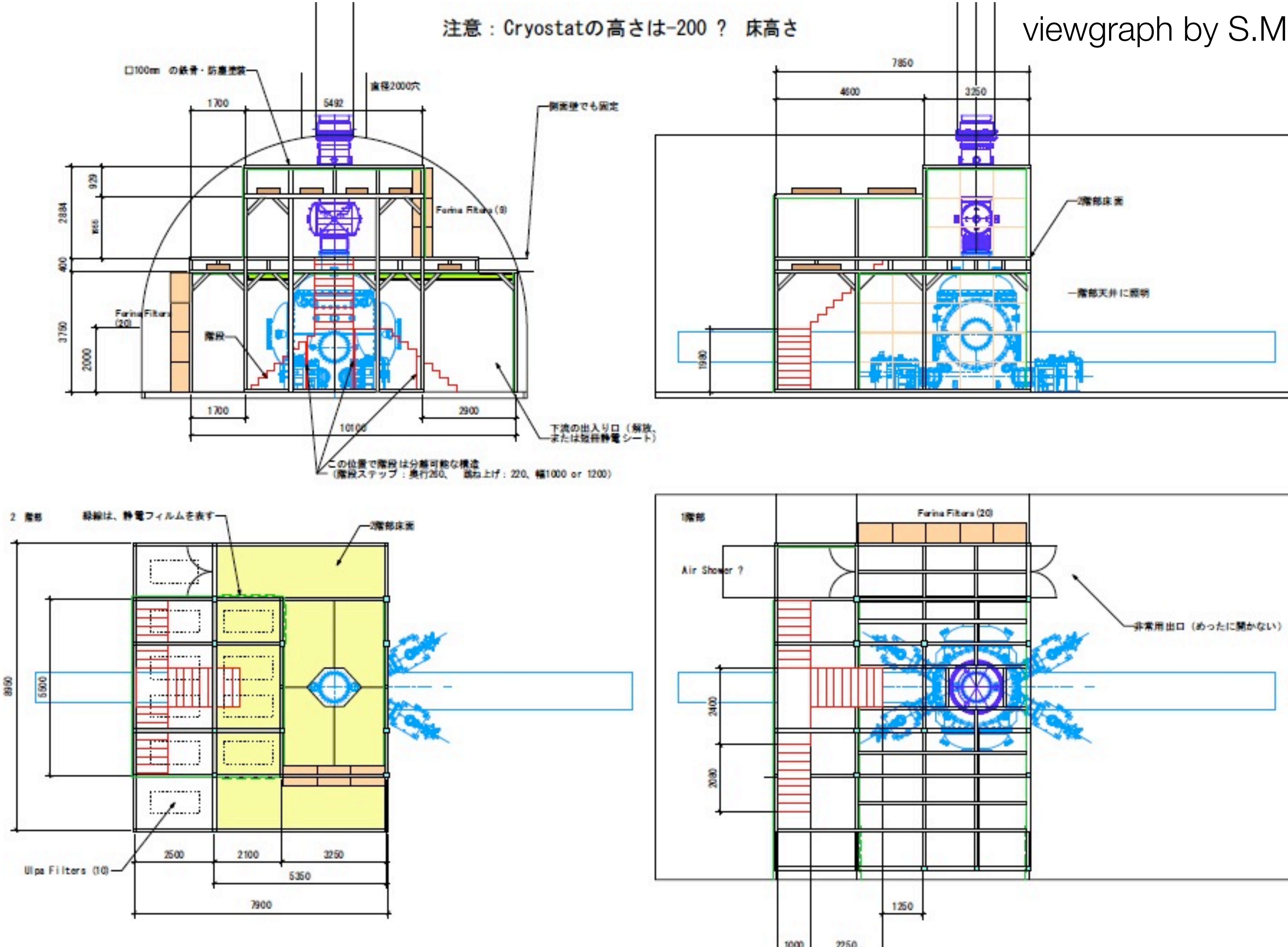
図 5: KAGRA クライオスタットの内部の振動測定結果 (水平成分)。PT(冷凍機) は OFF

Y. Sakakibara

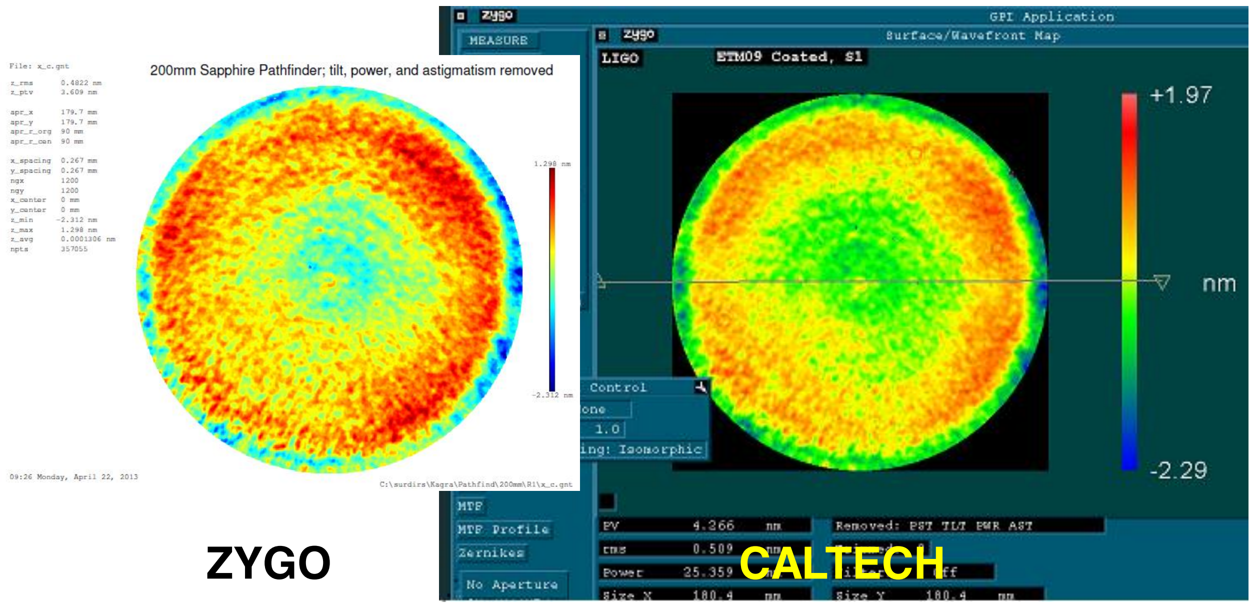
D. Chen

Clean Booth Plan for Cryostats

viewgraph by S.Miyoki



Optics (Mirror, Buffle)

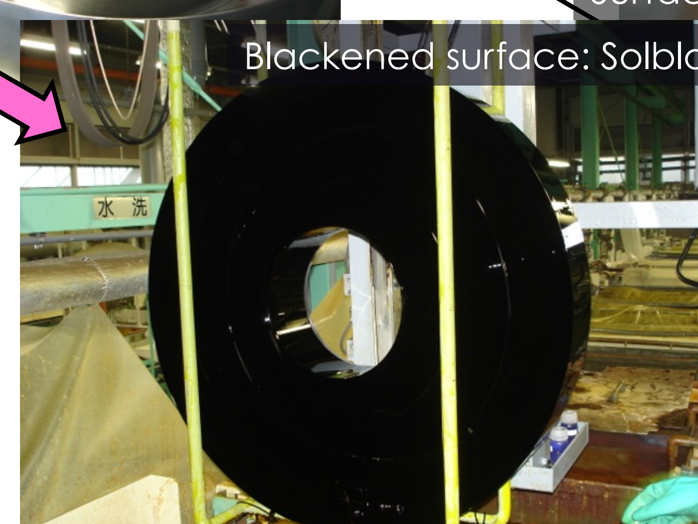


Sapphire test-polish was successful.

viewgraph by N.Mio

Example of a large baffle

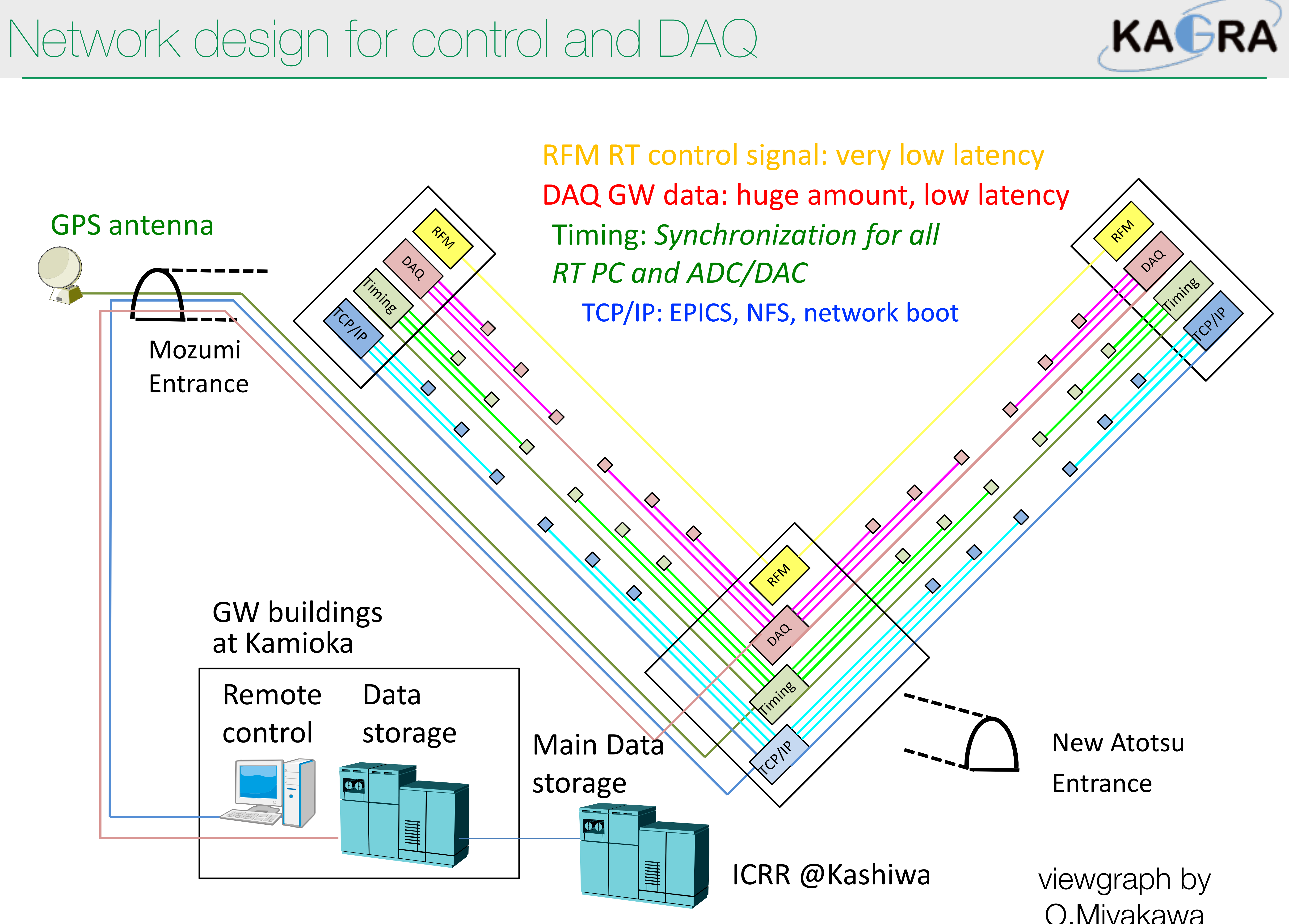
#3 Narrow-angle baffle
Material: A5052



ECB: low scattering
Solblack: Vacuum Compatibility (10^{-7} Pa), Cryogenic compatibility (<8K), Low reflectivity (~2%@1064nm), Applicable for a large work

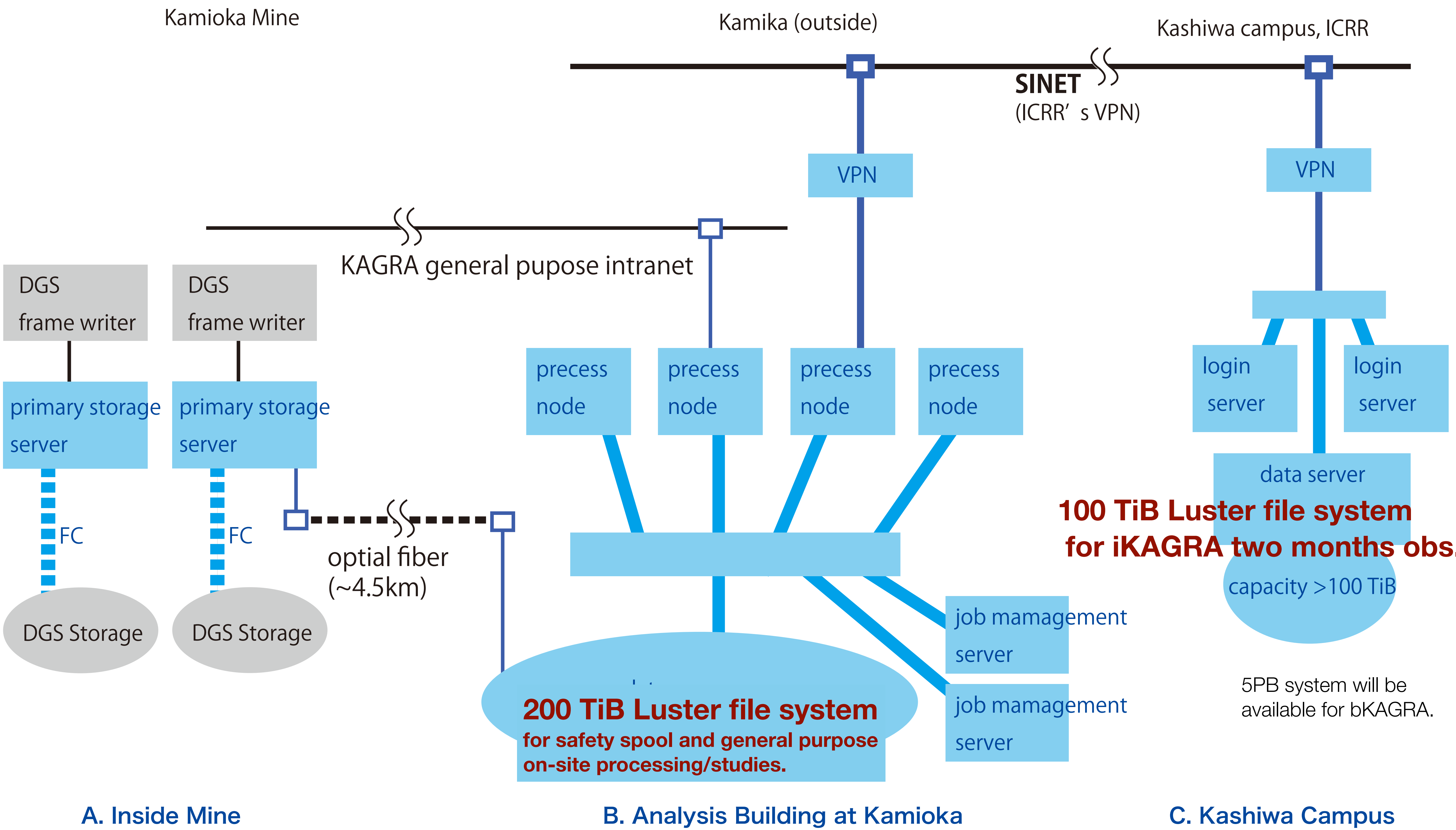
viewgraph by T.Akutsu

Network design for control and DAQ



iKAGRA Data System

The equipments will be installed at Kamioka and Kashiwa by the end of February 2014.



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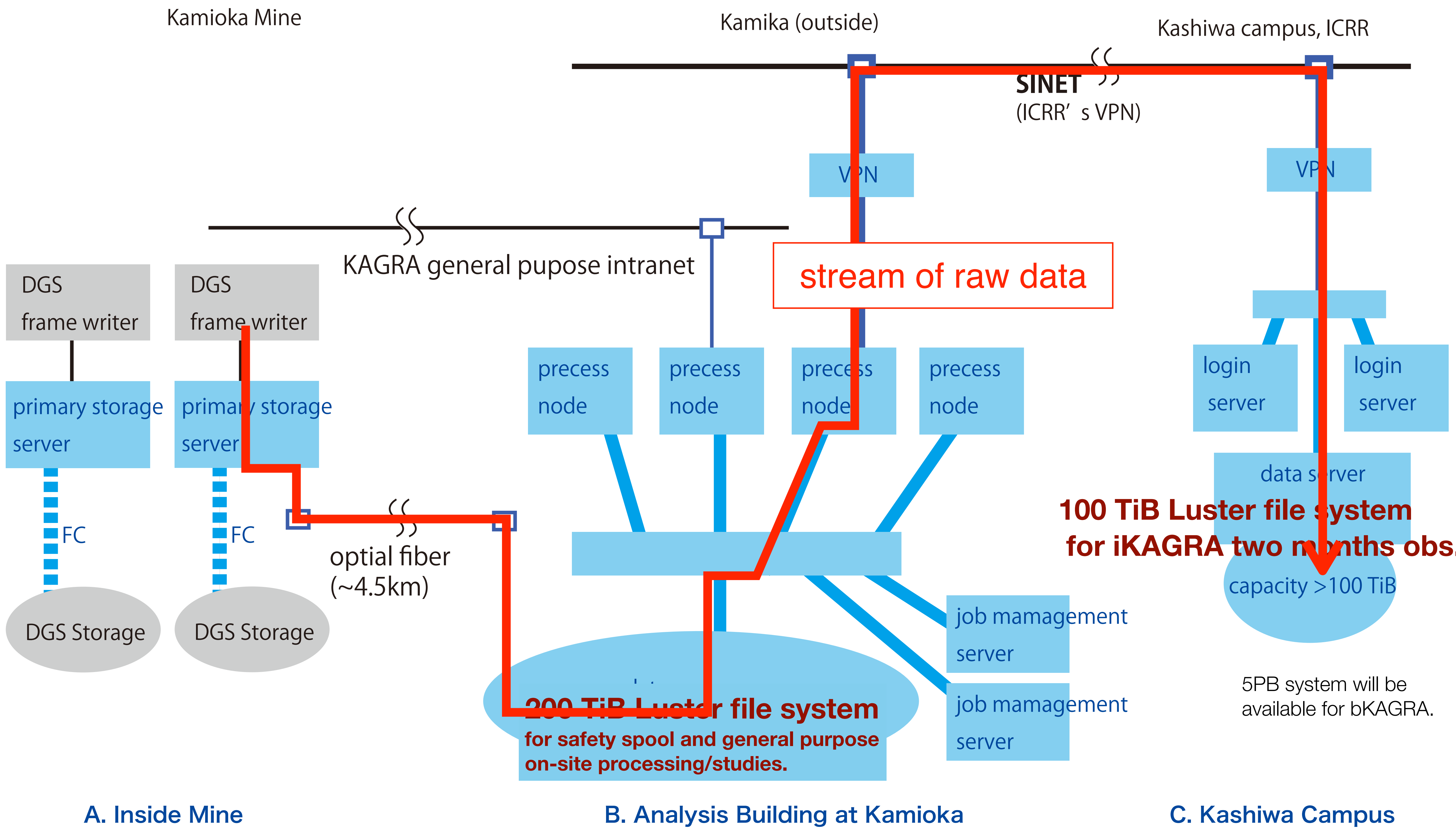


Amount of Data

phase	duration	data rate / duty	total expected amount	from -> to
iKAGRA	about 2~3 months at end of 2015	**20MB/s / 100%**	**100 TiB**	**Kamioka -> Kashiwa**
		1MB/s / 100%	5TiB	Kamioka -> Osaka City U./Osaka U.
commissioning	2016-2017	20MB/s / ?(5~10%)	?	Kamioka -> Kashiwa
		1MB/s / ?(5~10%)	?	Kamioka -> Osaka City U./Osaka U.
bKAGRA	2017 - (end of KAGRA)	**20MB/s / 100%**	**3PB / 5yrs**	**Kamioka -> Kashiwa**
		1MB/s / 100%	150 TiB / 5yrs	Kamioka -> Osaka City U./Osaka U.

iKAGRA : normal temperature operation at end of 2015

bKAGRA : cryogenic hi-sensitivity observation after mid of 2017 or 2018

Data analysis activities

Current activities:

- Development of data analysis package for KAGRA
- We have determined the name of data analysis library for KAGRA.

"KAGALI": KAGRA Algorithmic Library

篝

- We are now writing the data analysis white paper.

GW from supernovae

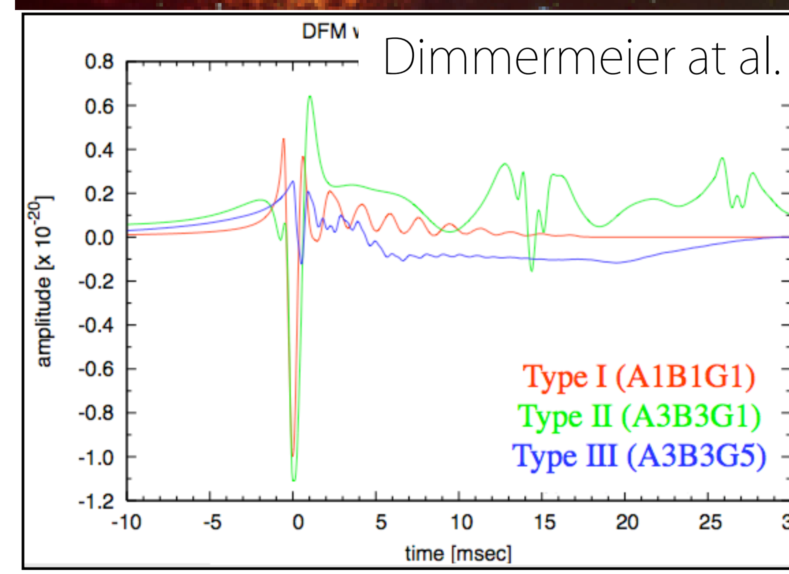
KAGRA

Supernova will emit GW
in various phase of its development.

- core bounce
- convection
- formation of proto-neutron star

  g-mode oscillation
- neutrino emission
- accretion

  cf: SASI (standing-accretion-shock instability)
- etc.



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KAGRA

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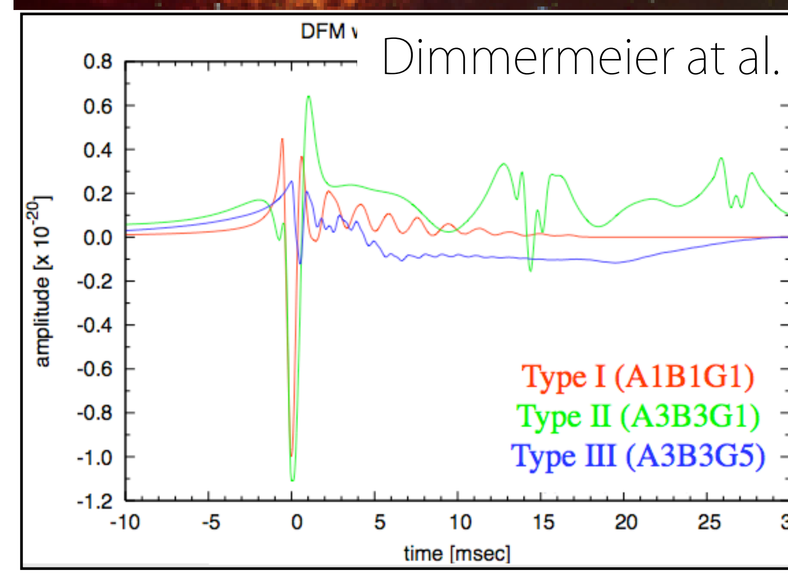


What is a key feature
from the view of GW detection and analysis ?

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

Detectability of GW from SNe

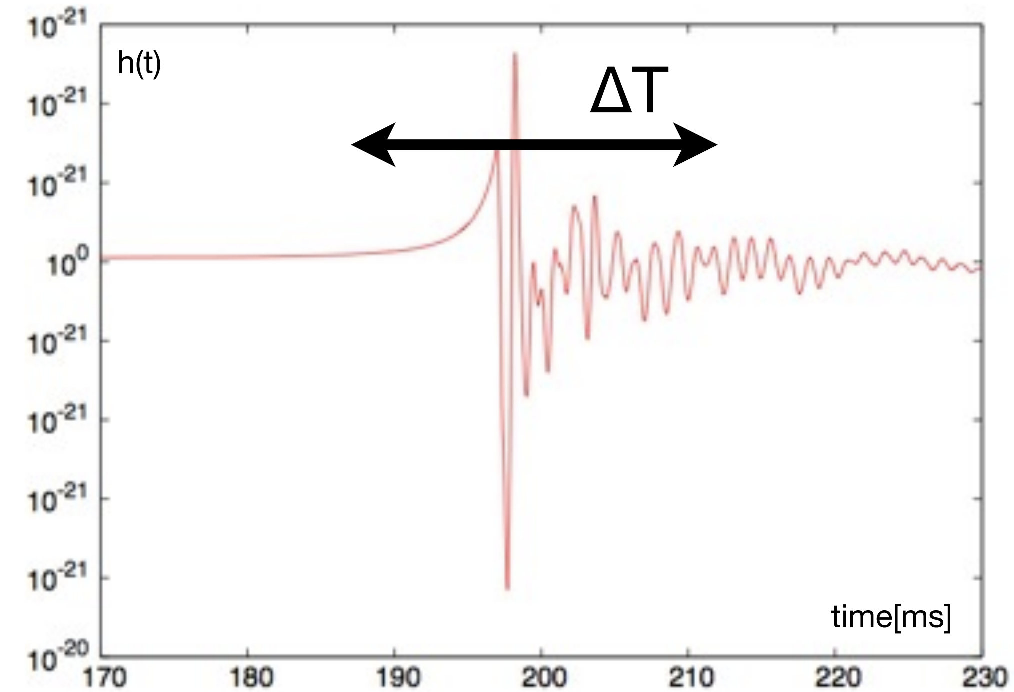
Typically, the detection range is roughly ≤1Mpc.

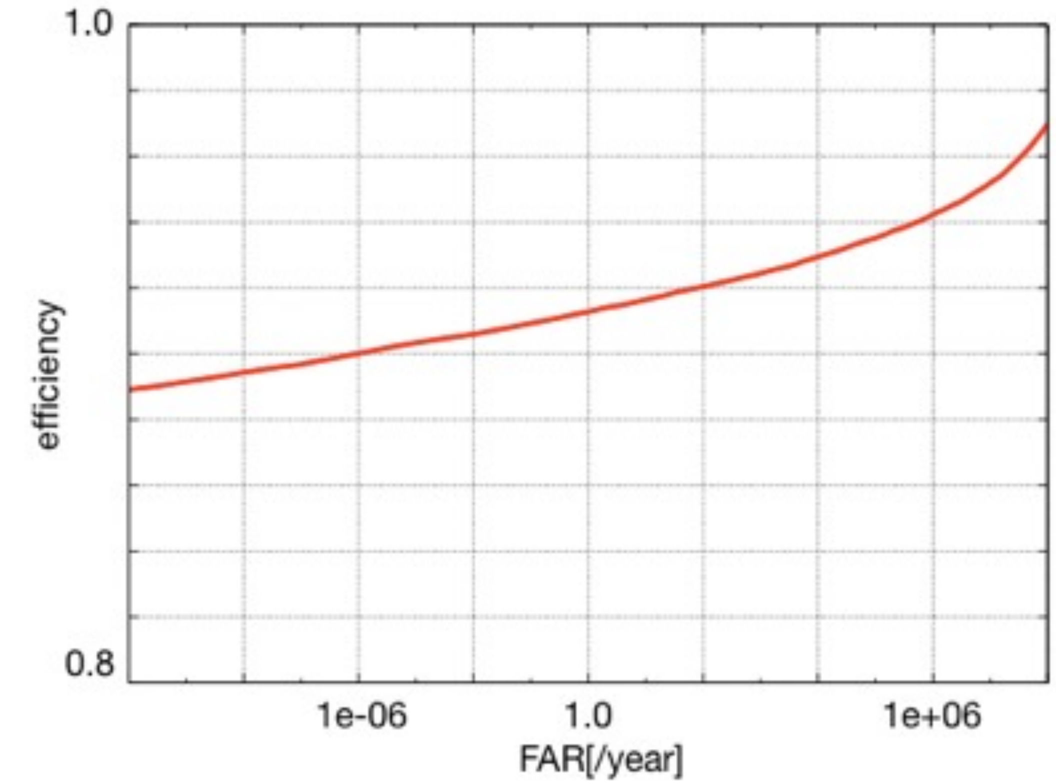
Excess power filter

- Integrate signal power between wider frequency band around certain arrival time.
- It may give most high S/N.
- Structure (waveform, accurate timing) of the signal might be lost.

Time-Frequency analysis

- There are many methods ! (Sonogram/Spectrogram with Short-FFT, Wavelet etc.)
- These are looks fine to give information in *t-f* domain.





example : ROC for the SNe at Galactic center in KAGRA study (See M.Asano's poster [P49])

Obtained from GW of SNe

What can be obtained from GW observation of SNe ?

Simply three things :

- Structure
- Dynamics
- Kinematics

Structure

If we will get the GW,

the SN is not spherical symmetry !

- There are some asymmetric development of SNe, at core? shock? convection?(density or temperature), etc.
- It is simply happy scenario for both GW experimentalists and theorists.

If we will NOT found any GW at close SN event(s),

the SN might be completely symmetric.

- ...It is terrible scenario for experimentalists (and current simulation predictions also!)..., but unhoped-for exciting situation...

It may hard to proof really no GW or detector disorder...

Structure

KAGRA

If we will get the GW,

the SN is <u>not spherical symmetry</u> !

- There are some asymmetric development of SNe, at core? shock? convection?(density or temperature), etc.
- It is simply happy scenar theorists.

GW or no-GW is simple, however, have to be confirmed for current our works.

If we will NOT found ar

the SN might be completely symmetric.

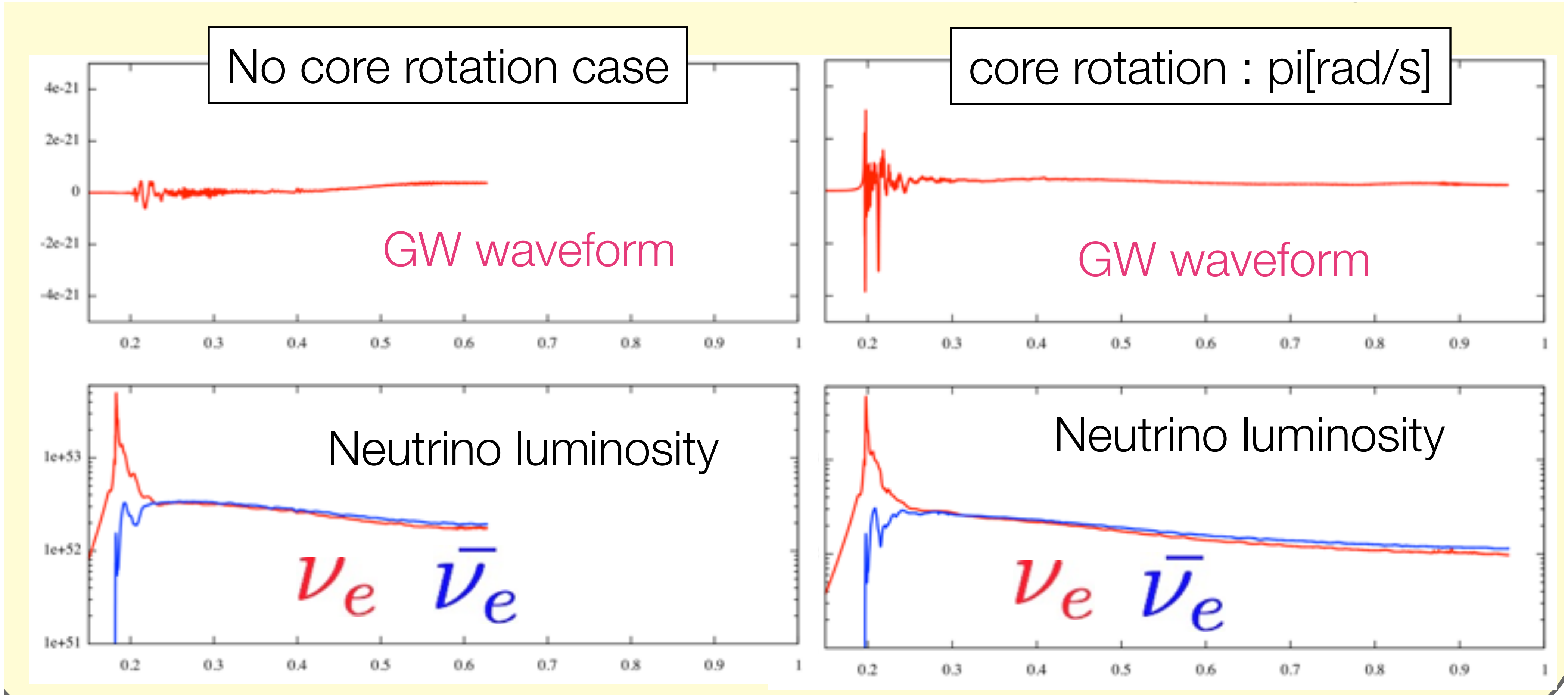
- ...It is terrible scenario for experimentalists (and current simulation predictions also!)..., but unhoped-for exciting situation...

It may hard to proof really no GW or detector disorder...

Dynamics

When strong GW will be emitted ?

- GW before neutralization burst suggest that the core is highly rotating.
- GW after neutralization burst, core does not rotate.



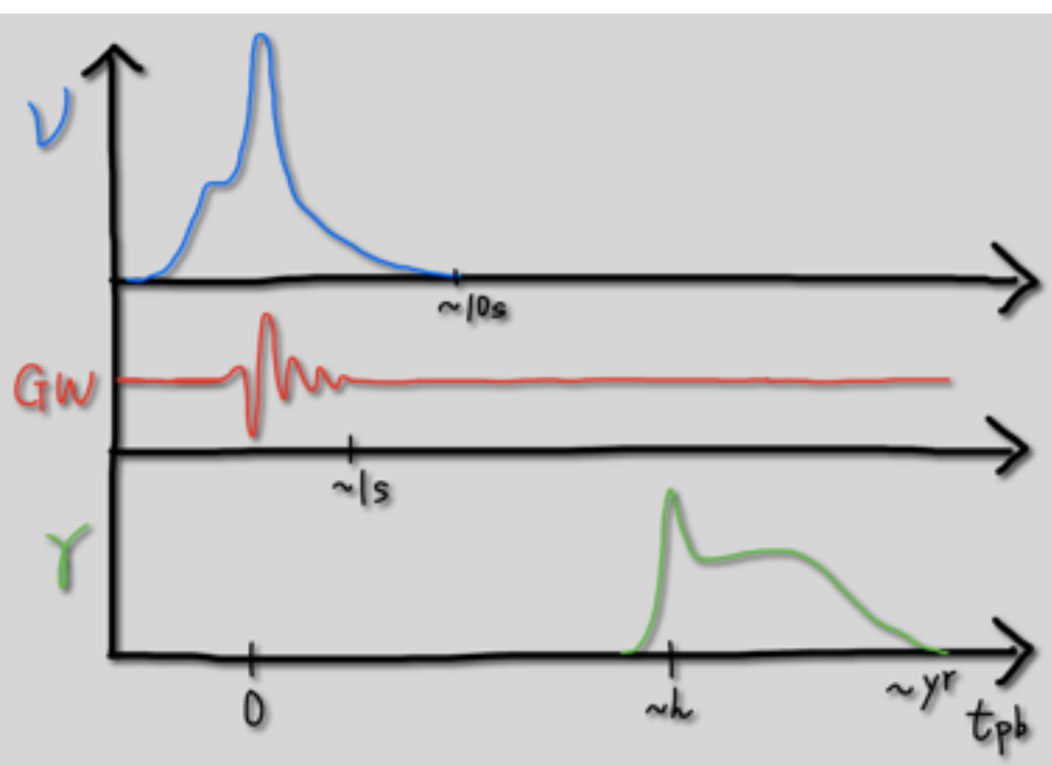
Simulation by Y.Suwa (drawn by T.Yokozawa)

Timing analysis is important !

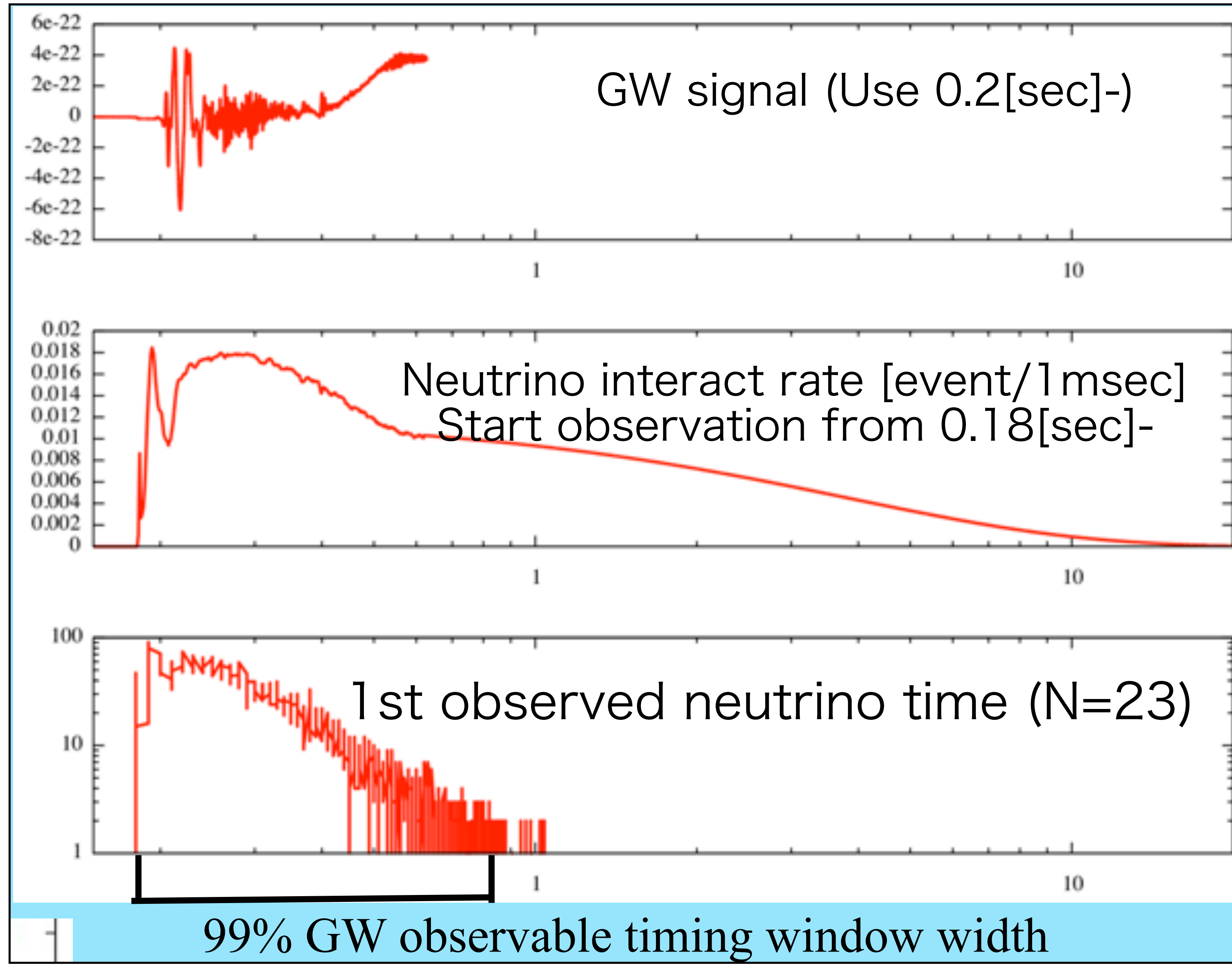
Timing of

- GW
- Neutrino
- EM

are important to know the dynamics of SN.



e.g. Neutrino and GW timing



See poster by T.Yokozawa in detail [P08]

Timing analysis is important !

KAGRA

Timing of

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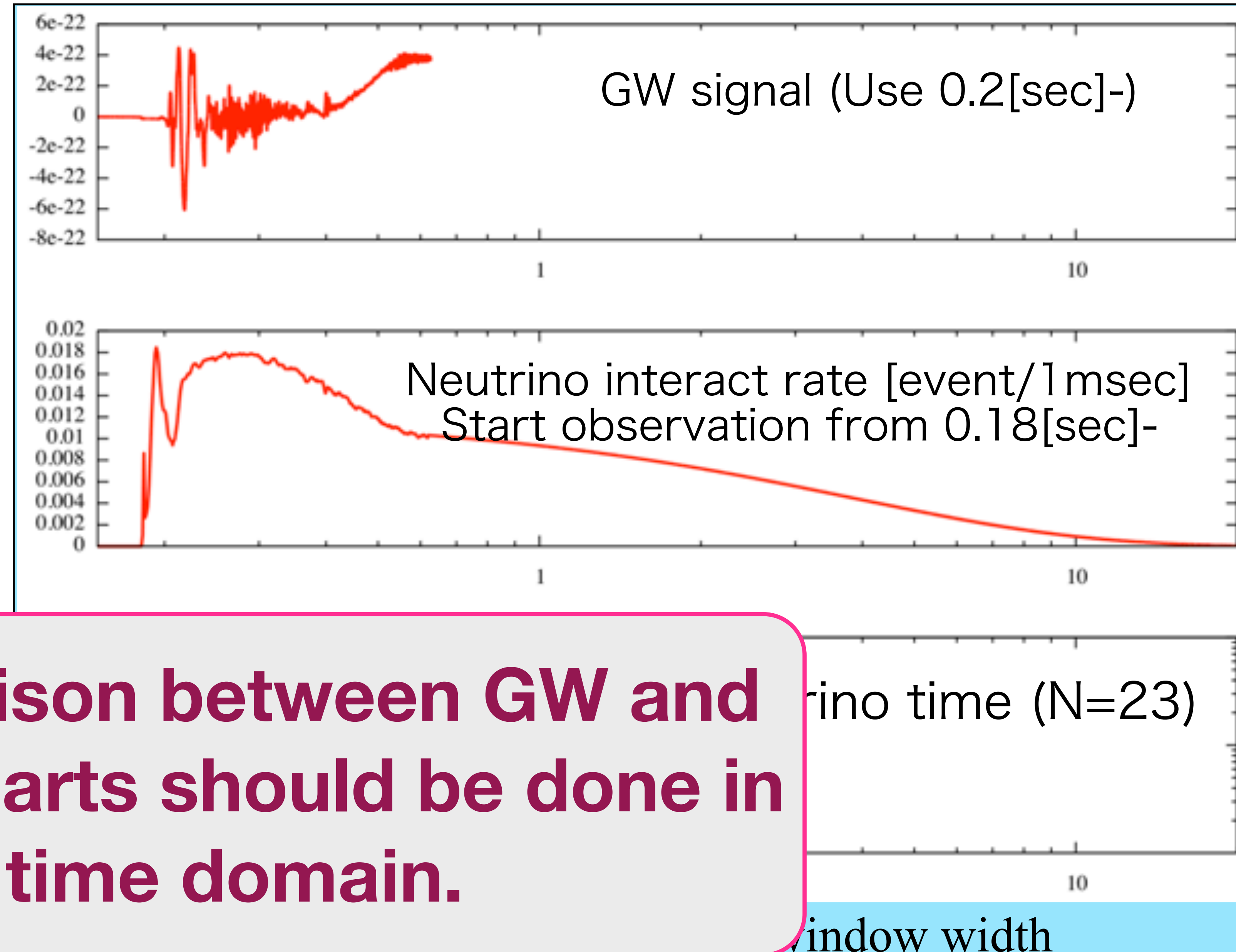
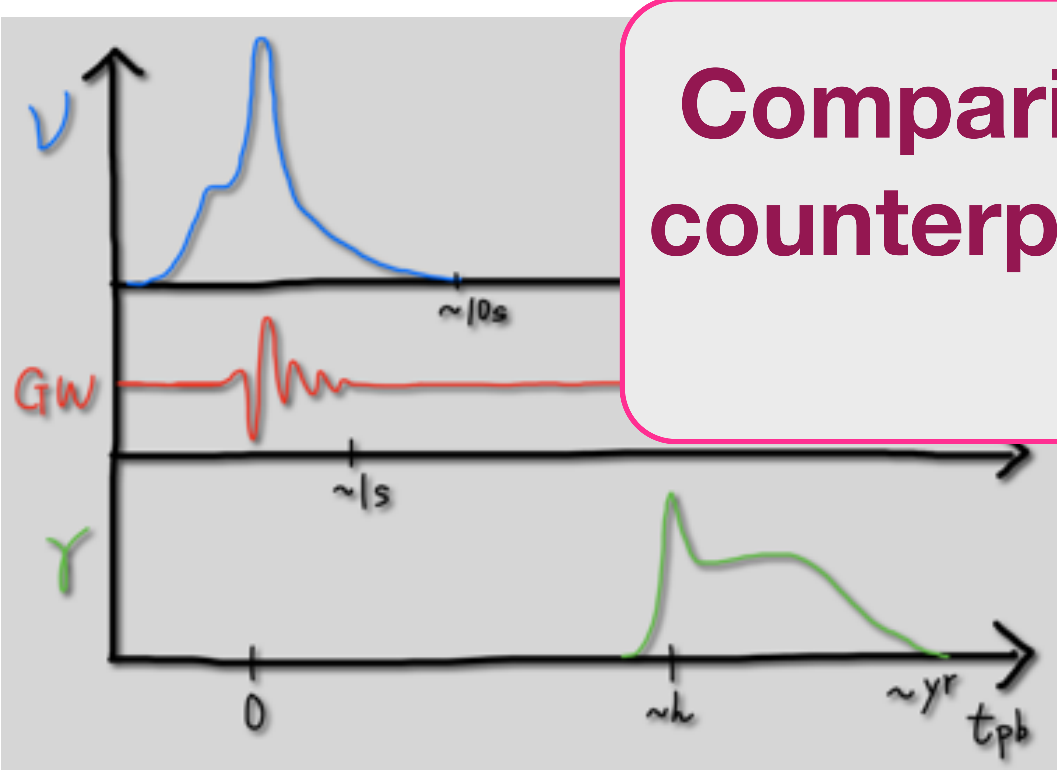
e.g. Neutrino and GW timing



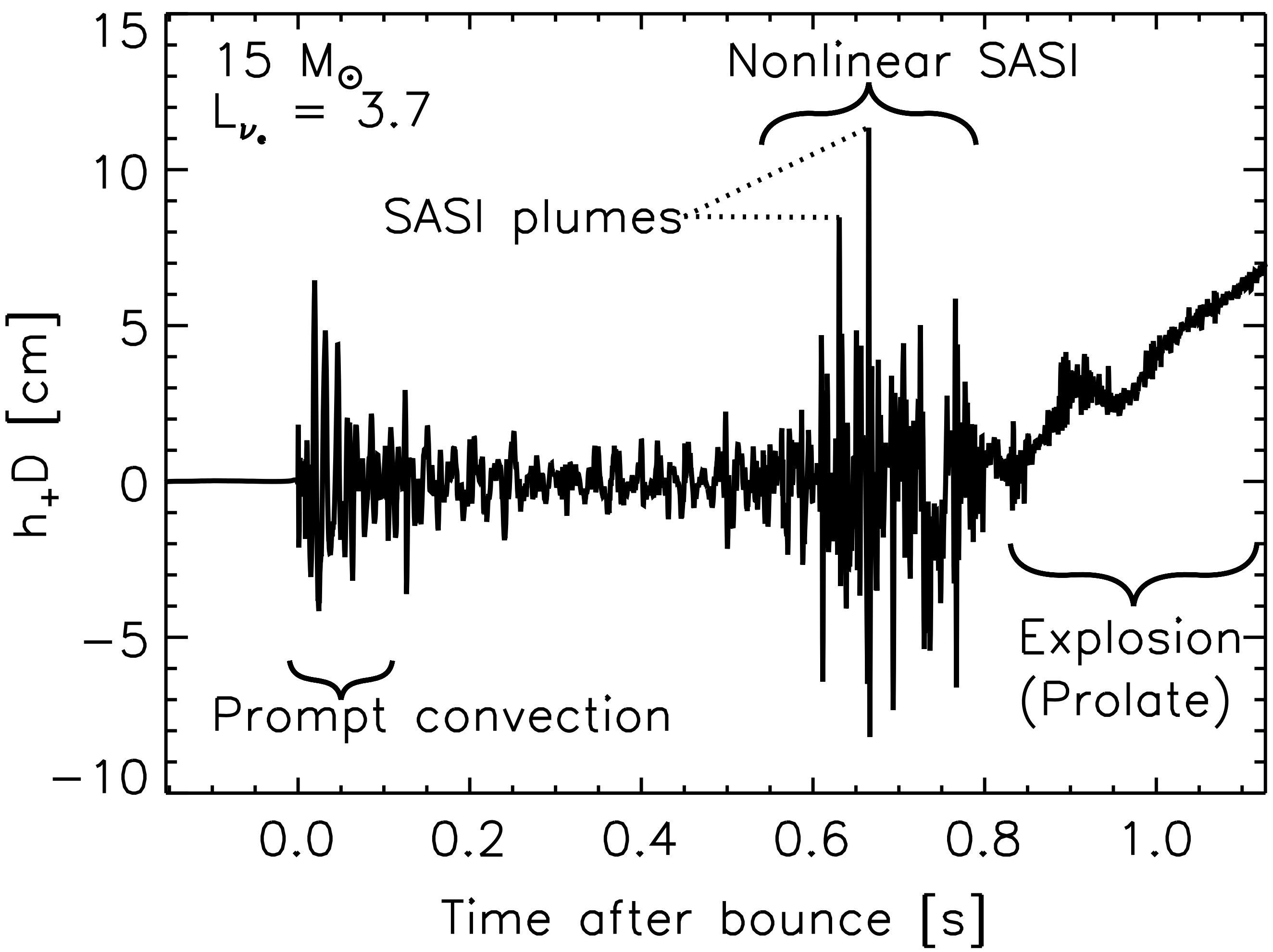
Comparison between GW and counterparts should be done in time domain.

See poster by T.Yokozawa in detail [P08]

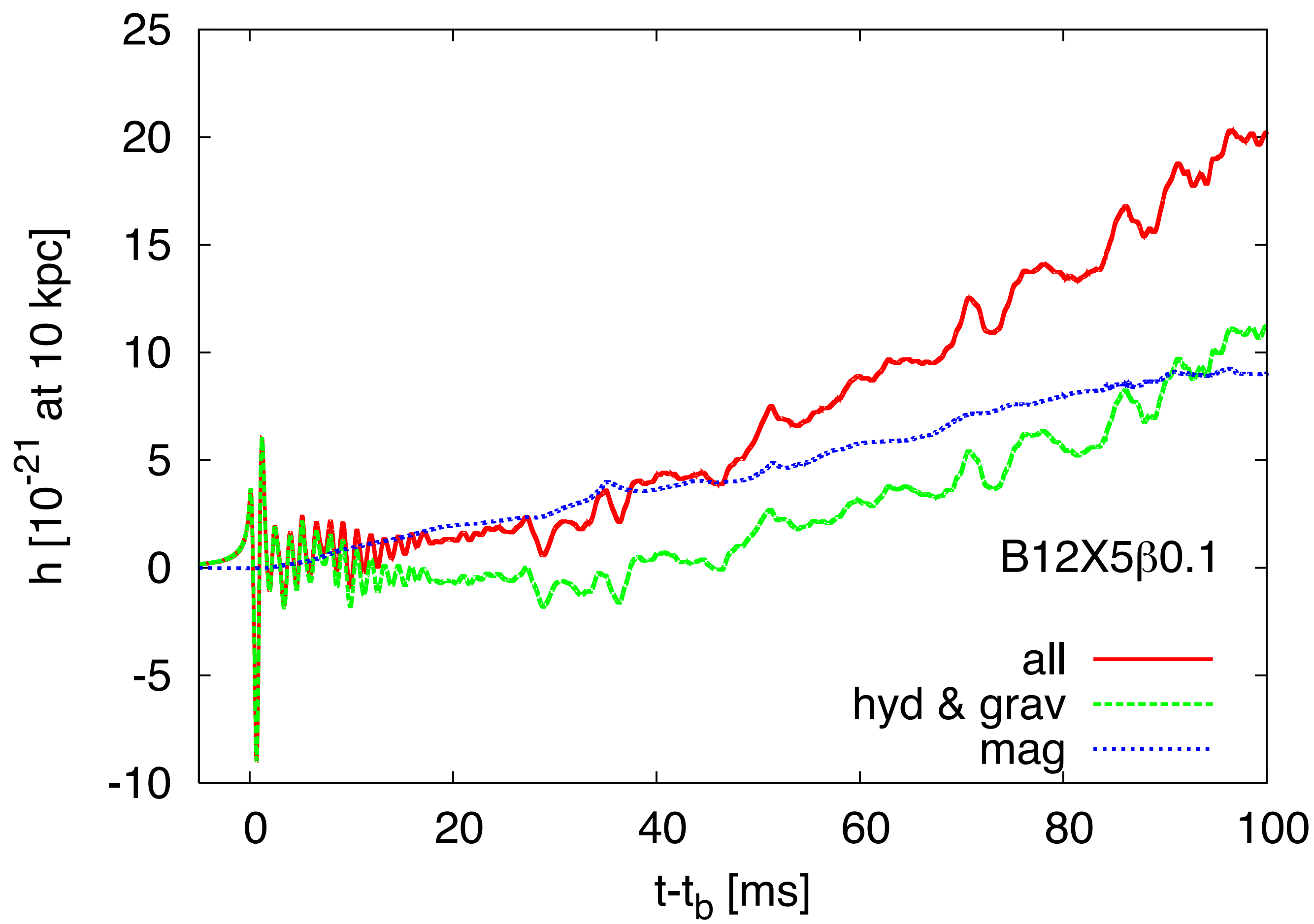


Kinematics

- Where dominant GW power come from ? core-bounce? convection? SASI?
- Does Magnet-Hydro Dynamics induce large mass ejecta ?



Murphy, Ott, Burrows, 2009

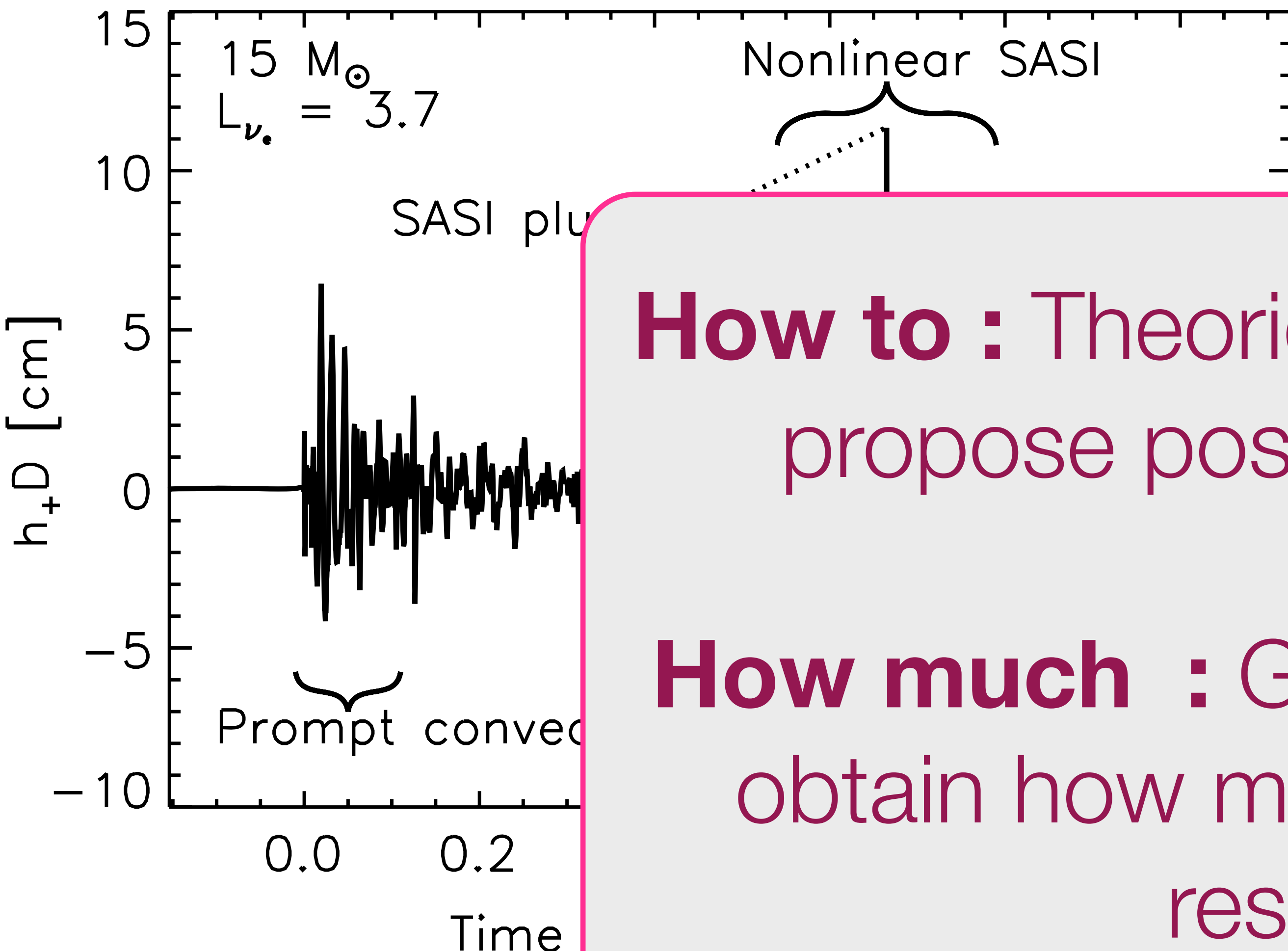


Takiwaki & Kotake, 2011

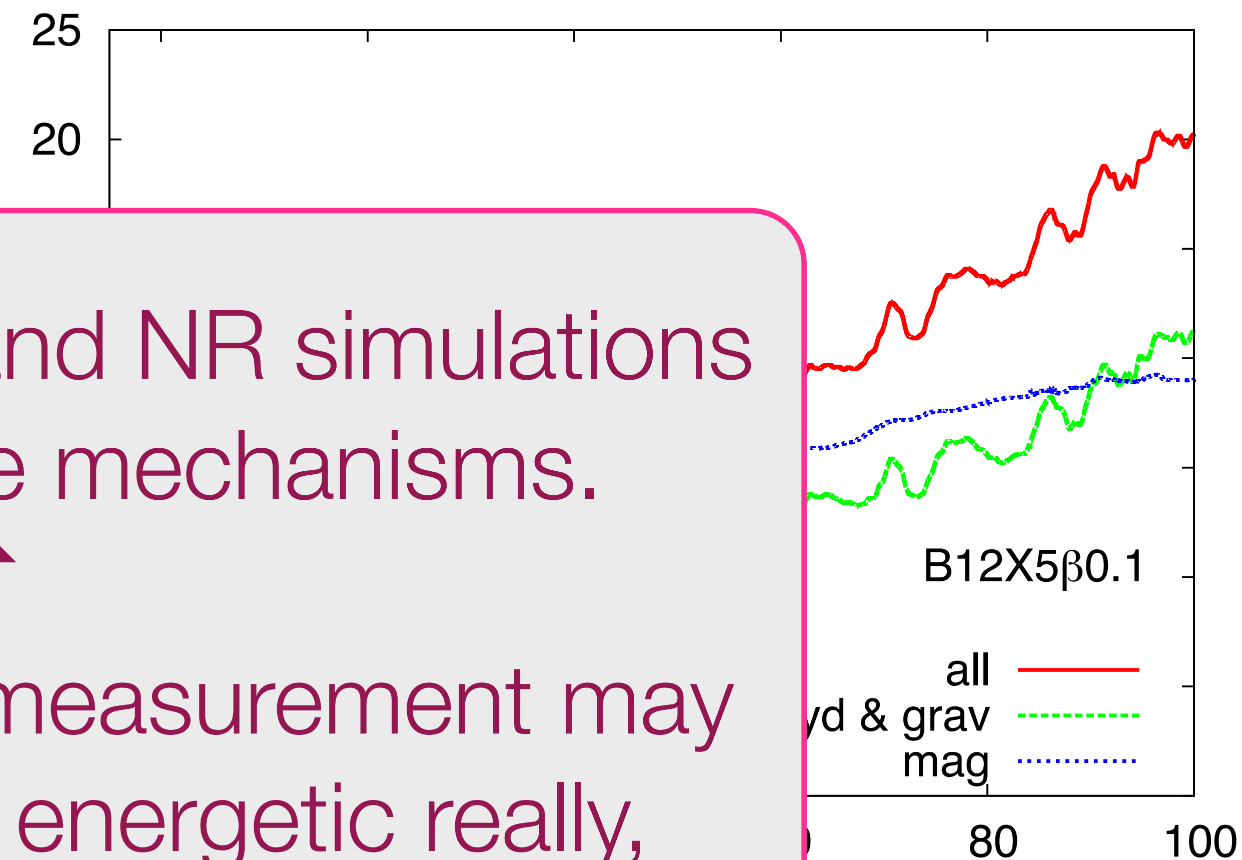
GW might suggest what is a dominant process to supply explosion energy of 10^{51} erg.

Kinematics

- Where dominant GW power come from ? core-bounce? convection? SASI?
- Does Magnet-Hydro Dynamics induce large mass ejecta ?



Murphy,



e, 2011

How to : Theories and NR simulations propose possible mechanisms.

↓↑

How much : GW measurement may obtain how much energetic really, respectively.

GW might suggest what is a dominant process to supply explosion energy of 10^{51} erg.

Obtained from GW of SNe !

KAGRA

- Structure : Symmetry or NOT
- Dynamics : Rotating or NOT
- Kinematics : Where come from explosion energy 10^{51} erg

Important key is 'timing' analysis.

(GW itself and between counterparts)

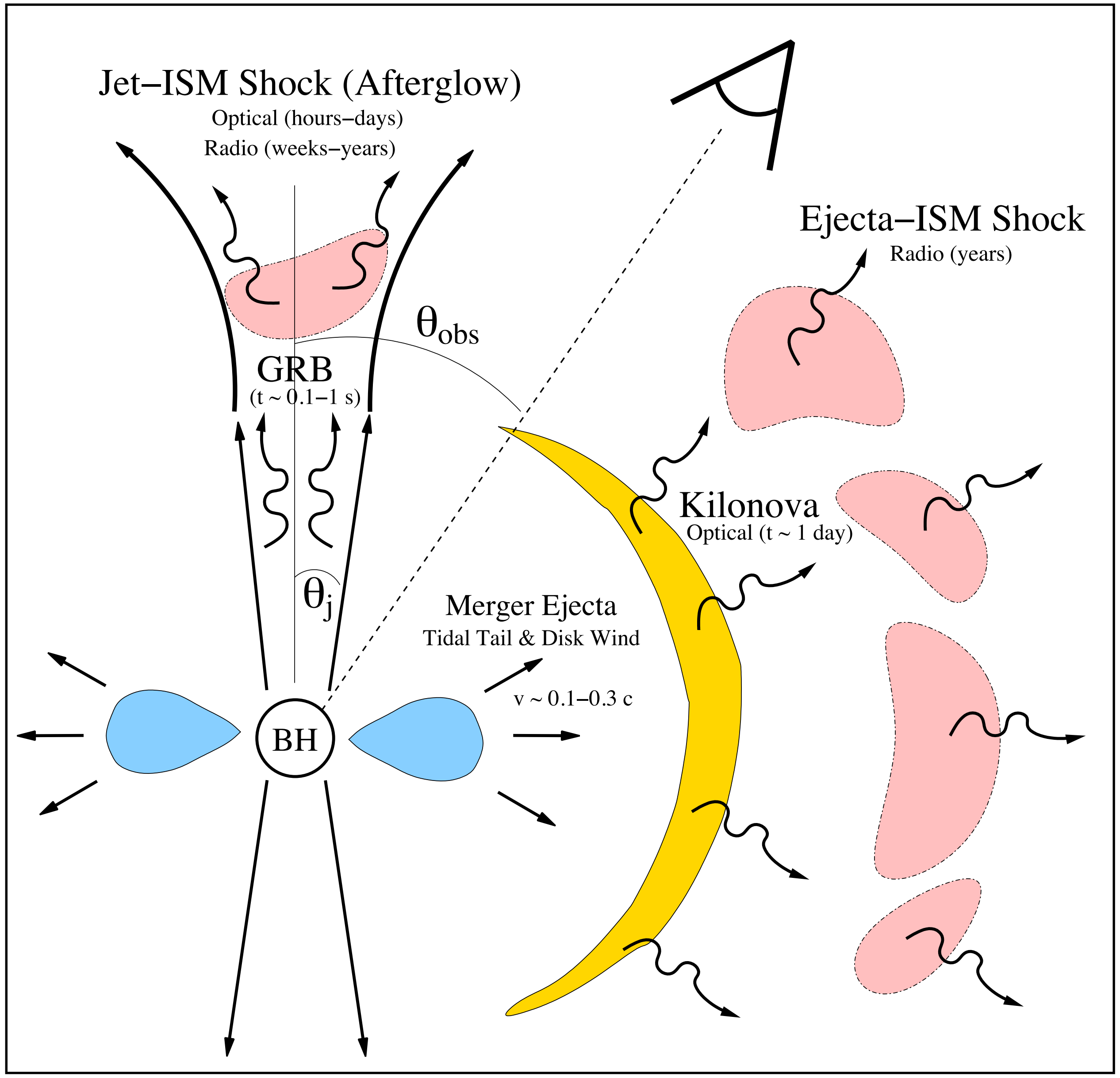
GW and GRB

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

NS-NS merger may emit EM radiation.

“Kilonova”

Metzger & Berger, 2011



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

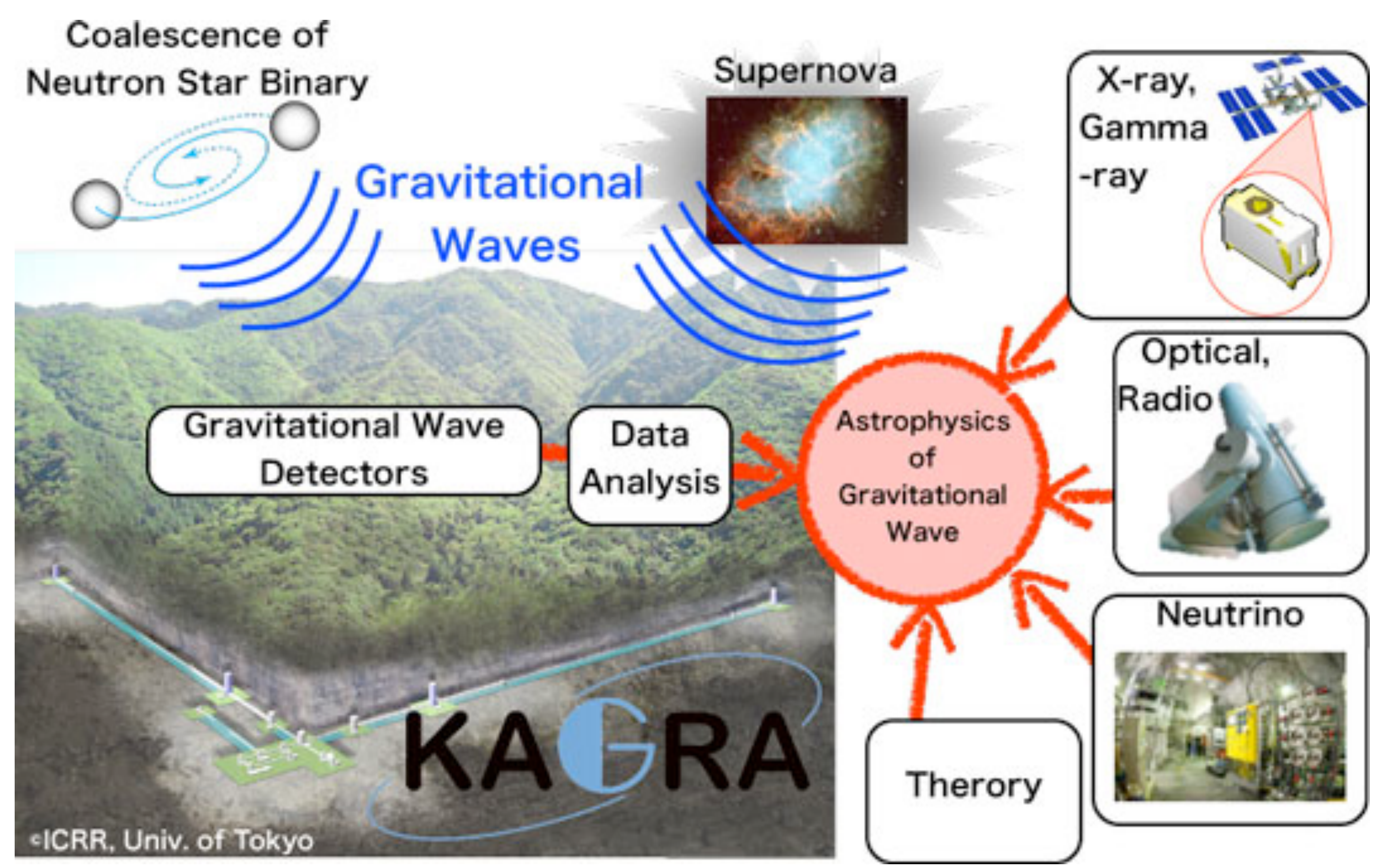
KAGRA also starts cooperation…

"New Developments in Astrophysics Through Multi-Messenger Observations of Gravitational Wave Sources" (Head : T.Nakamura)

by Grant-in-Aid for Scientific Research on Innovative Areas, MEXT Japan

Invite possible counterparts / follow-up channels of Japan !!

- X-ray and Gamma-ray
- Optical, Infrared and Radio
- Neutrino
- GW low latency analysis
- Theory for GW and counterpart



The project started in 2012.

KAGRA and these partners are 'open-minded' for also international partners.

Summary

- First GW detection is near future !
- KAGRA construction steadily

  iKAGRA ~ end of 2015

  bKAGRA 2018~ (or late 2017~)
- Supernova is promising GW source.

  GW is expected to give rich information for SN - its structure, dynamics and kinetics.