KAGRA

科研費 KAKENHI

新学術「重力波天体」

MEXT Grant-in-Aid for Scientific Research on Innovative Areas

New Developments in Astrophysics Through Multi-Messenger Observations of Gravitational Wave Sources

Nobuyuki Kanda (Osaka City U.)

on behalf of grant-in-aid for scientific research on innovative areas 'GW-Asrtro' 新学術「重力波天体」

and

(partially) on behalf of KAGRA collaboration

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Introduction ~ Gravitational Wave and Counterparts

Gravitational Wave …

- …is wave of fundamental interaction.
- …is a radiation from strong gravity filed
- …sources are compact and massive (=high density) objects with rapid motion

: e.g. Supernova, Black-hole, Neutron star, etc.

Such objects must be high-temperature.
—> High temperature induce EM and particle radiations!, thus…

EM and particle counterparts …

- … are naturally expected!
- e.g. X-ray or gamma-ray, Visible-Infrared, radio, neutrino

—> Different probes will make it clear the mechanism of sources.

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"New Developments in Astrophysics Through Multi-Messenger Observations of Gravitational Wave Sources"

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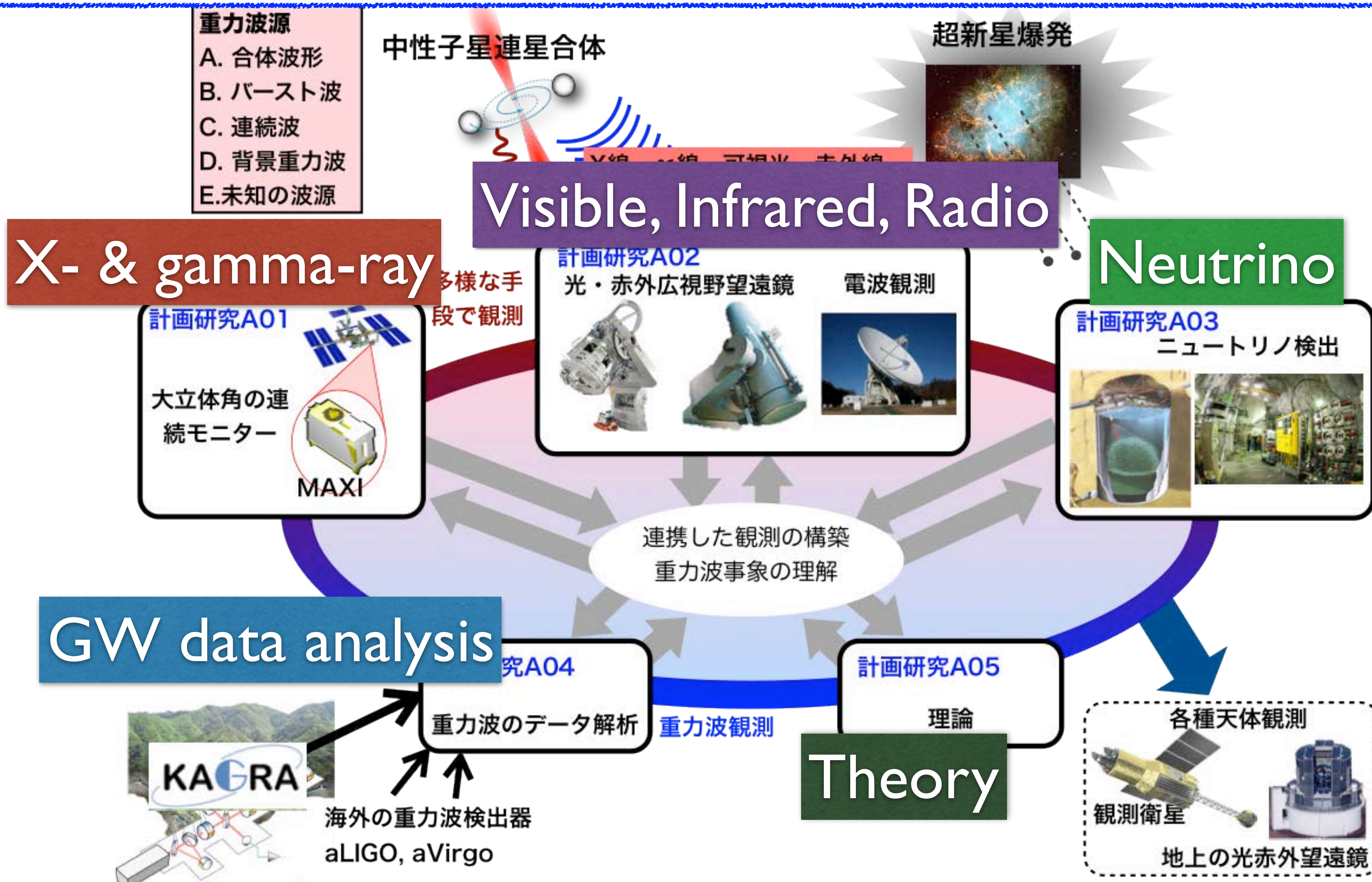
科研費 新学術領域研究「重力波天体の多様な観測による宇宙物理学の新展開」
領域代表: 京都大学 中村卓史, H.24-28年度 http://www.gw.hep.osaka-cu.ac.jp/gwastro/



Plan of Talk

Gravitational Waves

Note : GW direct measurement have not been achieved yet now (yr 2014).

- GW sources
- GW detectors

Innovative area 'GW-Astro (重力波天体)'

- 5 Research groups :
  X- and Gamma-Ray, Optical, Neutrino, GW data, GW theory

Typical case of Inter-group missions

- Neutrino-GW study on Supernova

Summary and Prospects

(If we will have a time —> Appendix : KAGRA photographs)

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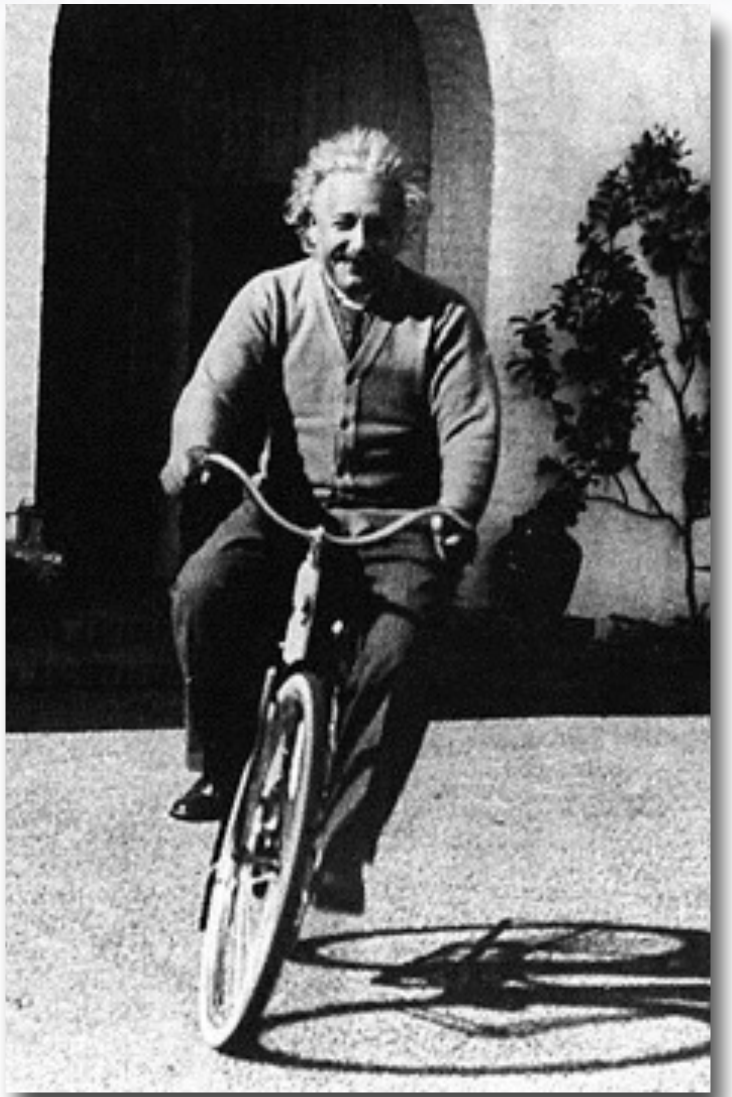
Gravity

by Newton

"action at a distance"

$$f = -G\frac{m_1 m_2}{r^2}$$



General Relativity
by Einstein

"distortion of space-time"

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

how space-time is exist　　energy, momentum

$R_{\mu\nu}$: Riemann curvature tensor
R : Scalar curvature

$g_{\mu\nu}$: metric tensor
$T_{\mu\nu}$: Energy-Momentum tensor

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)

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

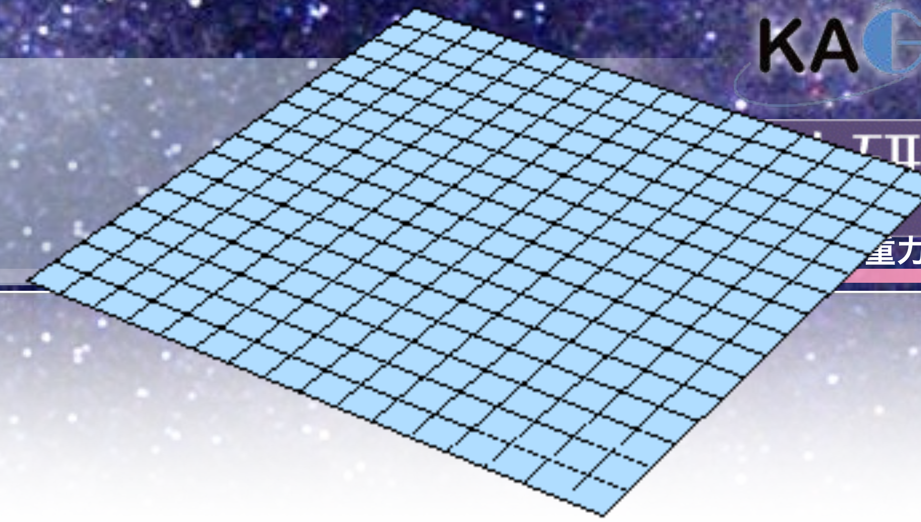
"curved (distorted)" space-time

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

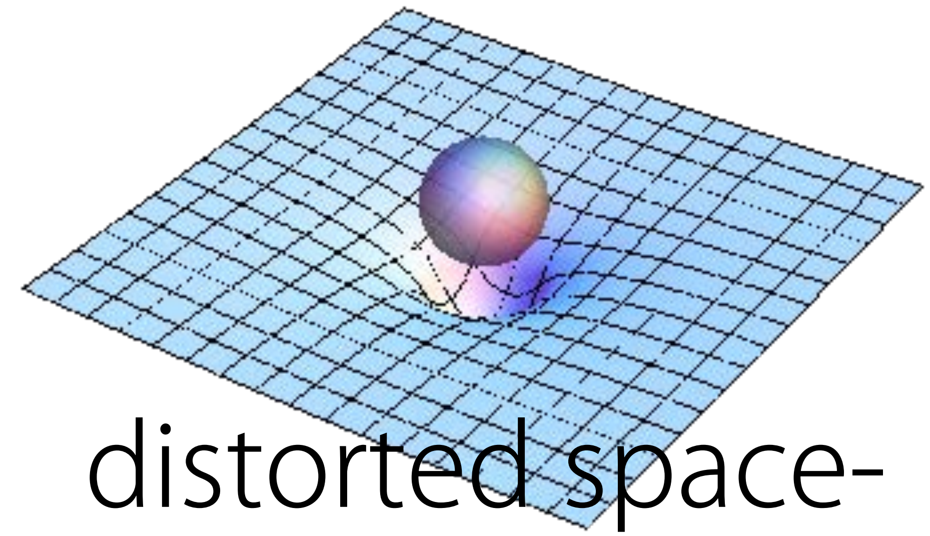
small perturbation 'h' --> Waves

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

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

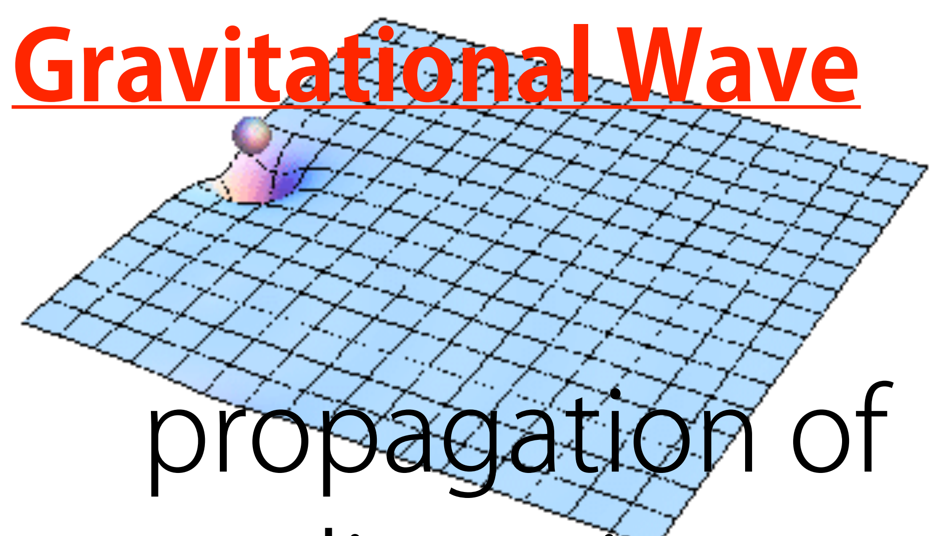


flat space-time



distorted space-time = gravity

Gravitational Wave



propagation of distortion

Direct measurement of GW

Aim of direct detection / measurement of GW!

- We have to test in '**strong**' gravity field !

  Past experimental GR (General Relativity) 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

- There will be many interesting sources of GW, which can be observed with counterparts : e.g. EM emission, particles.

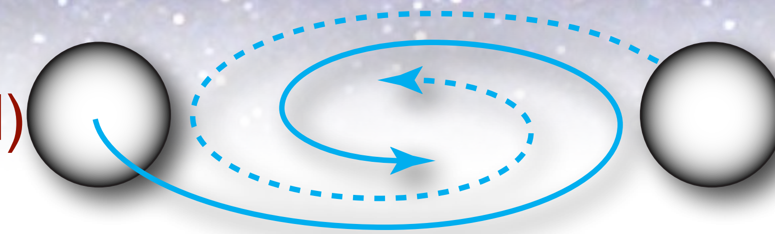
With what can we be convinced of detection of GW?

Need Counterparts !

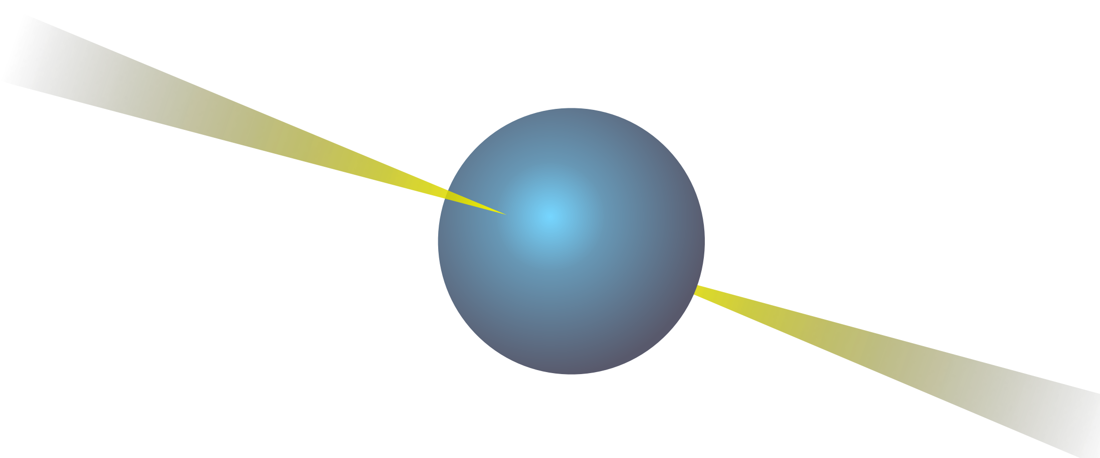
GW Sources

Event like:

- Compact Binary Coalescence (NS-NS, NS-BH, BH-BH)



- neutron star (NS), black-hole (BH)
- Supernovae
- BH ringdown
- Pulsar glitch

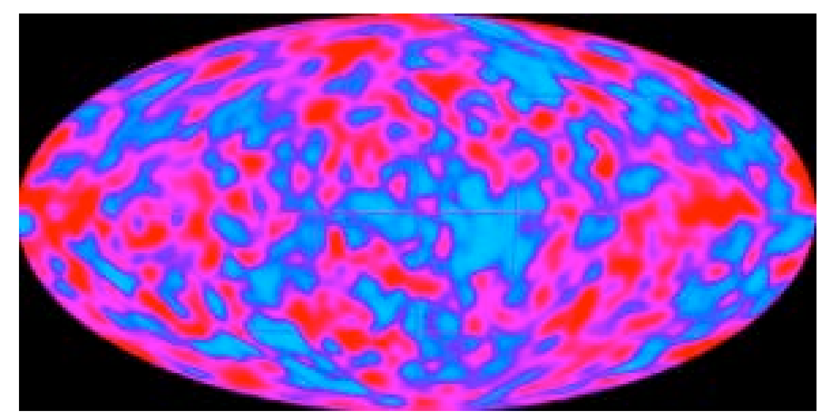


Continuous waves:

- Pulsar rotation
- Binaries

Stochastic Background

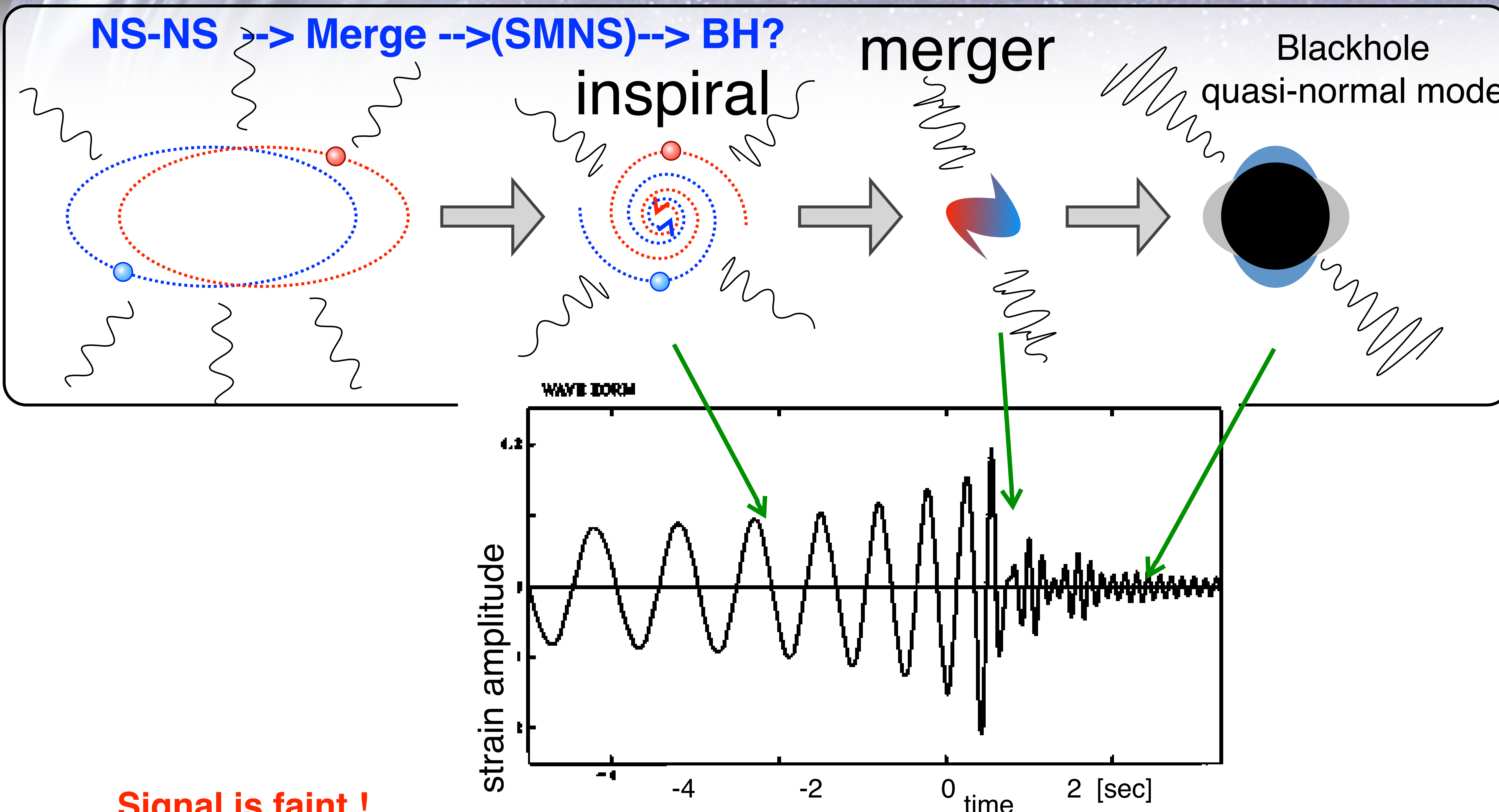
- Early universe (i.e. Inflation)
- Cosmic string
- Astronomical origin (e.g. many NS in galaxy cluster)



(& Unknown sources...)

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

typical source : Coalescence of Neutron Star Binary



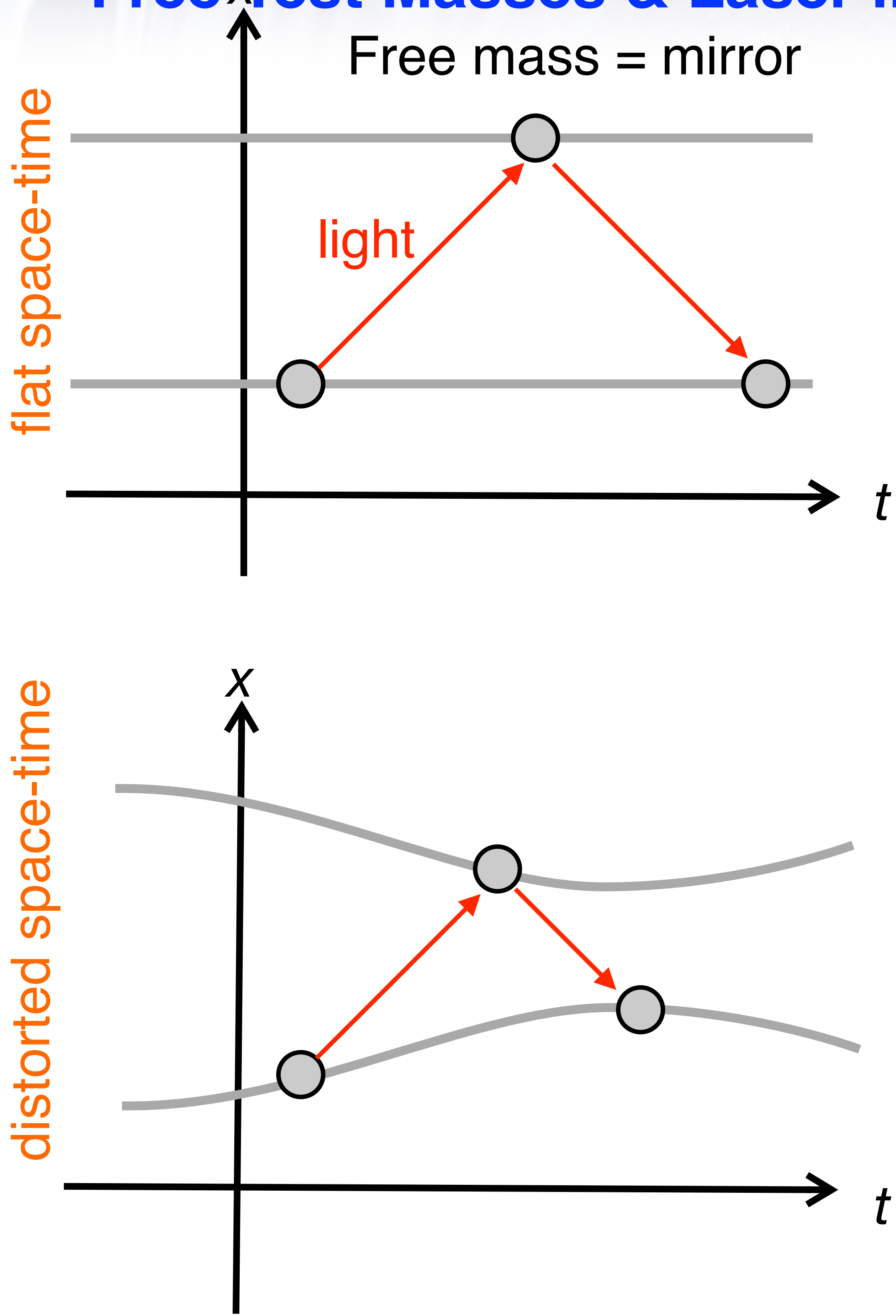
Signal is faint !

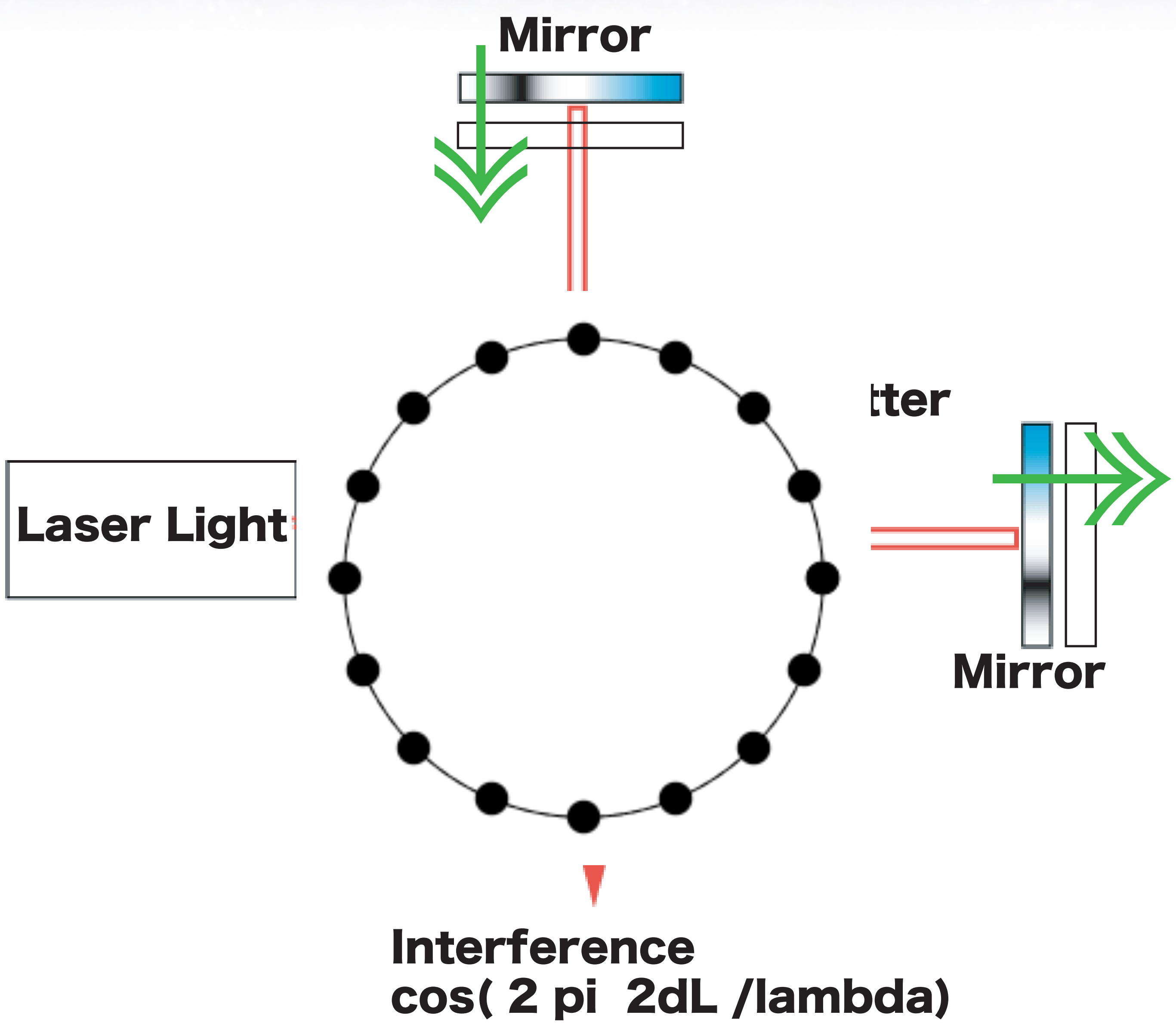
The amplitude is only ~10^{-24} for NS-NS at 200Mpc away!

(in frequency spectrum, ~$10^{-22\sim-23}$ [/√Hz] @10~100Hz)

How to detect GW : Laser interferometer (Free mass type)

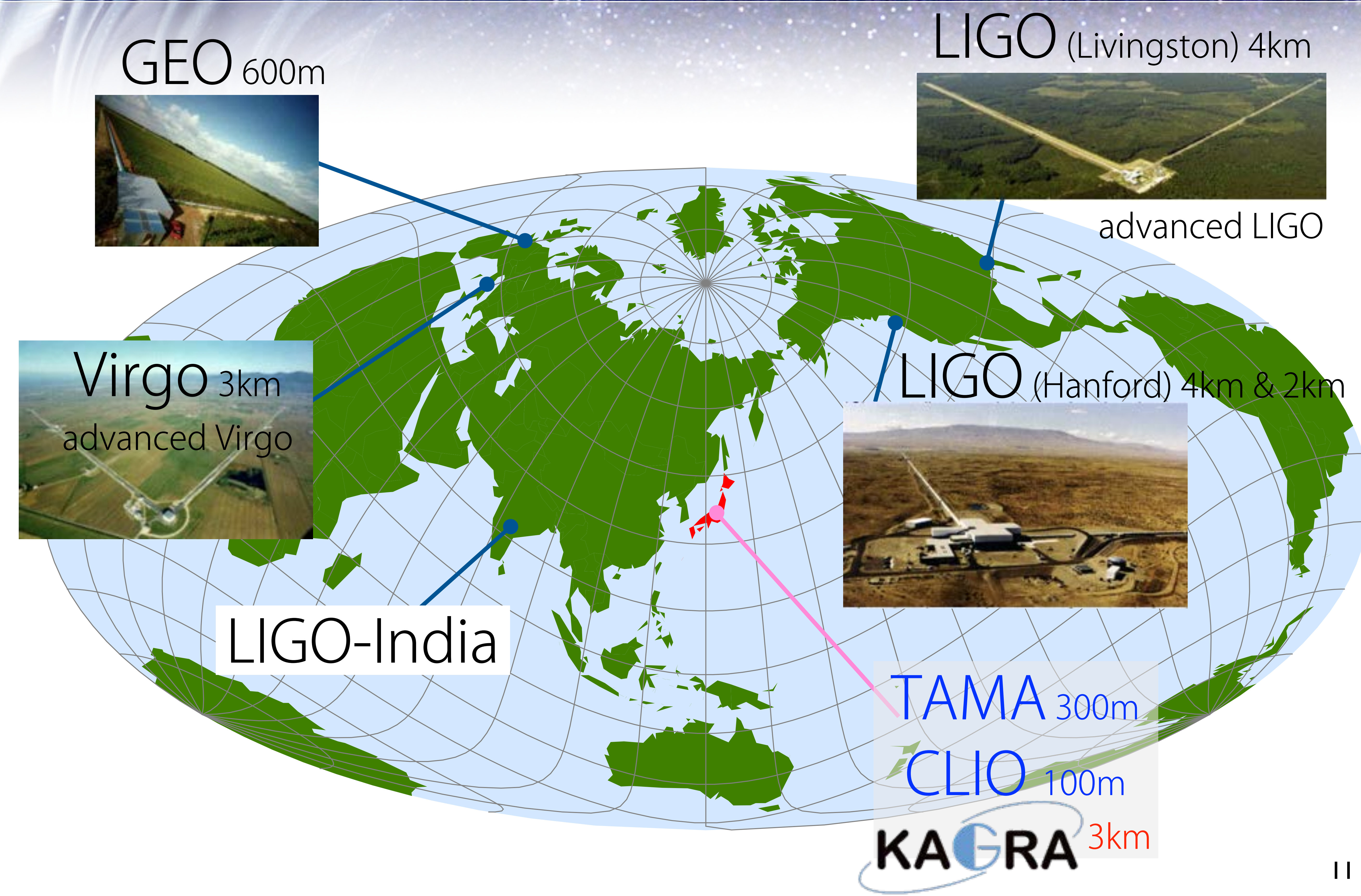
Free Test Masses & Laser interferometer





Michelson Interferometer

World-wide Network of GW detectors



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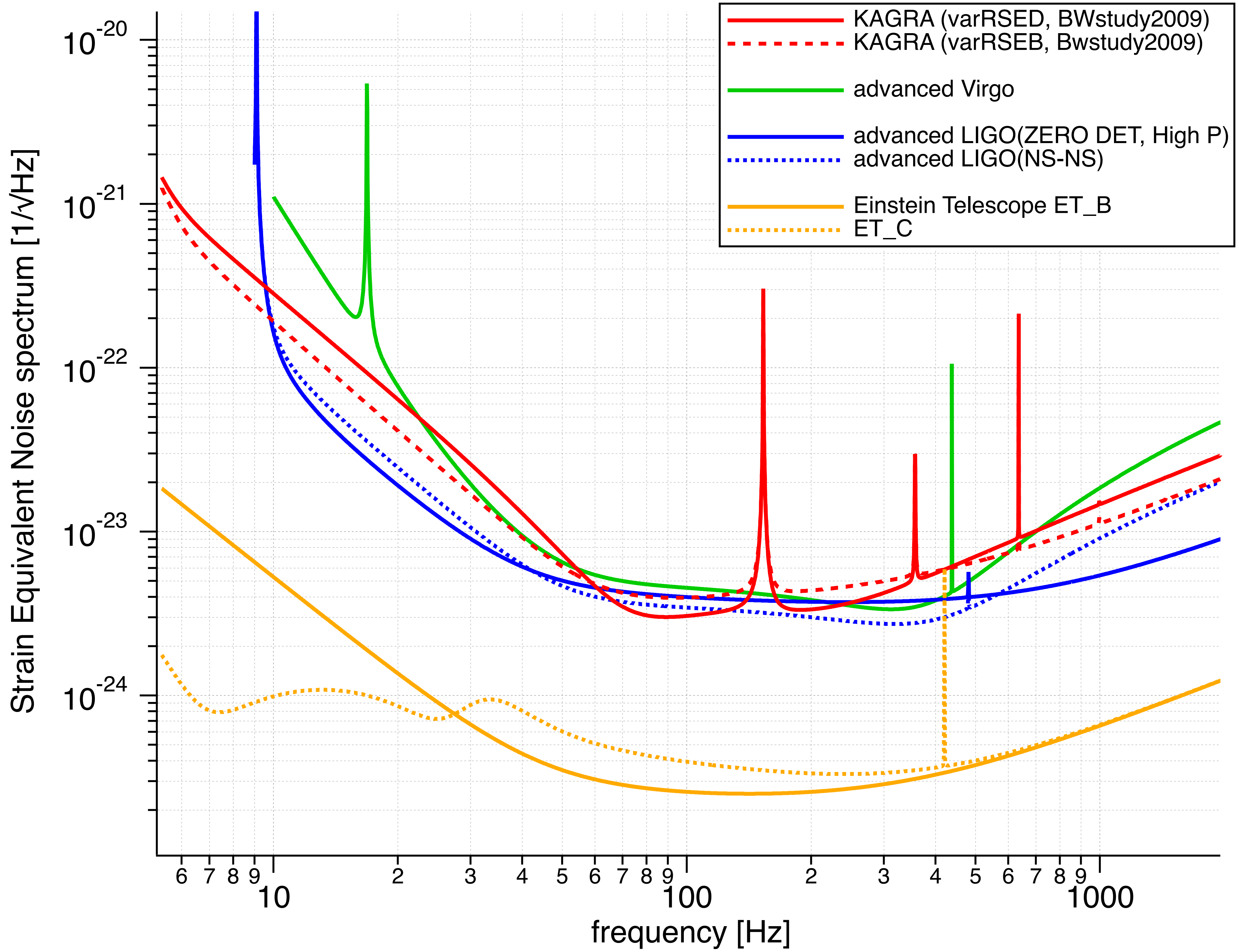
Sensitivity target of GW detectors



"2nd generation" aLIGO, aVirgo, KAGRA

"3rd generation" ET (Einstein Telescope)

Advanced LIGO will start in 2015, and will continuously upgrade its sensitivity.
Virgo has similar schedule.
bKAGRA operation (cryogenic) will be start in late 2017 or early 2018.

KAGRA

Underground

- in Kamioka, Japan
- Silent & Stable environment

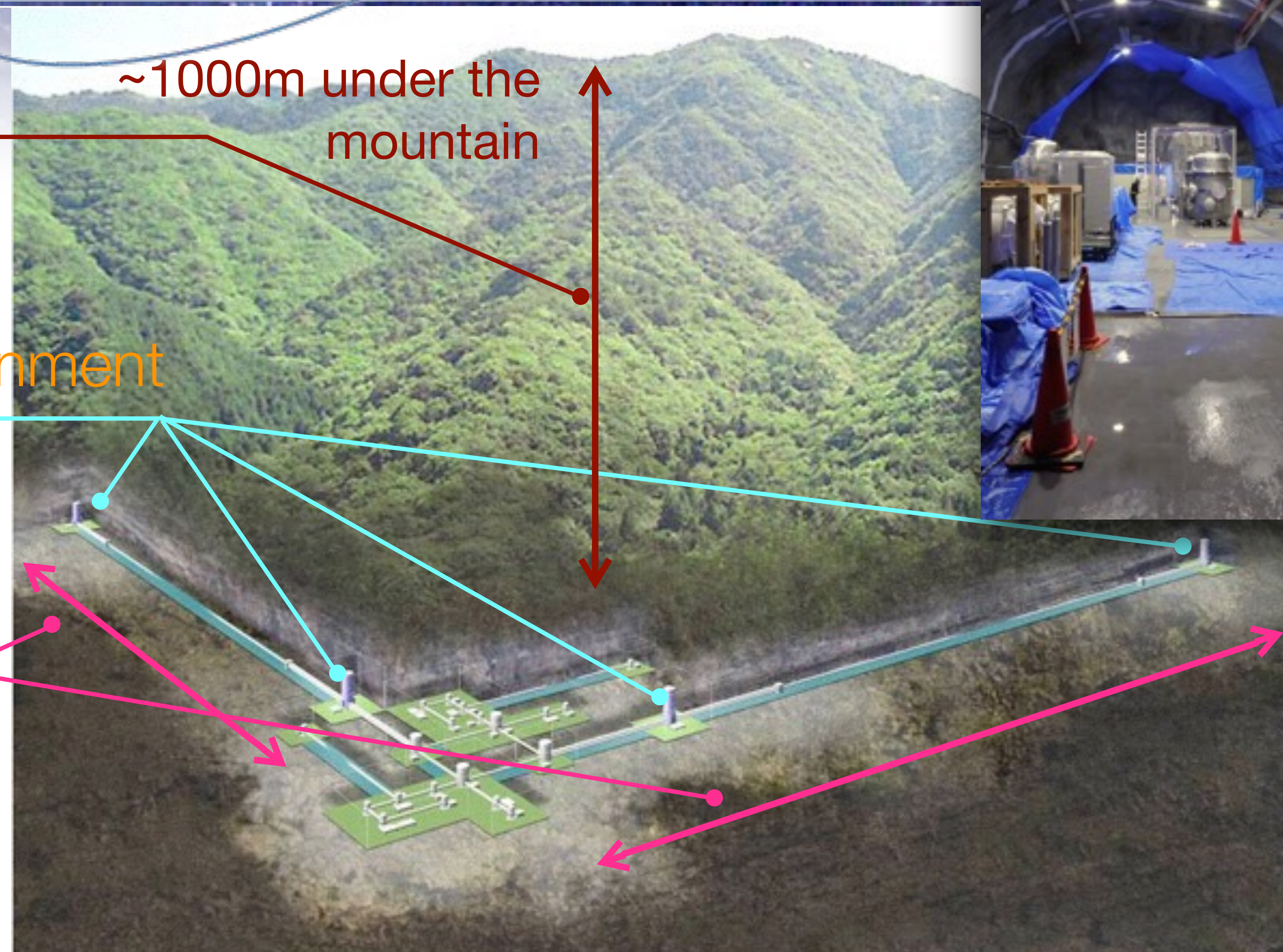
Cryogenic Mirror

- 20K
- sapphire substrate

3km baseline

Plan

- 2010 : construction started
- 2015 : first run in normal temperature
- 2017- : observation with cryogenic mirror



© ICRR, university of Tokyo

Tunnel excavation completed at March 2014

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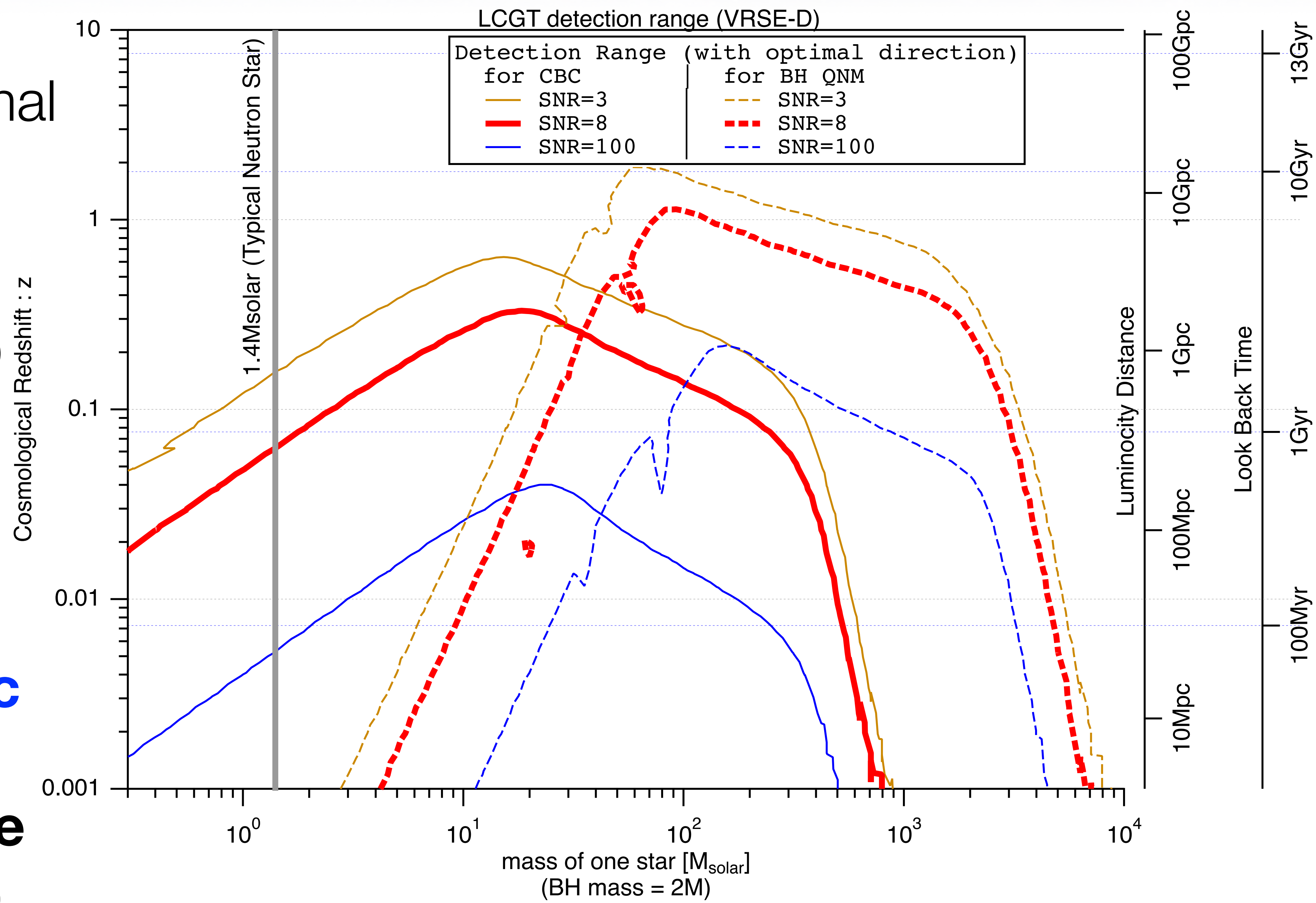
Detection Range

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).



This is opportunity !

- Using multiple GW detectors, …

  —> Arrival direction of GW will be determined.

  However, angular resolution is not good as identify the host galaxy.

- Mutual follow-ups by counterpart observations

  "Multi messenger "

- More knowledge induce / or be inspired by theoretical works.

Oversea projects started the cooperation between GW and astronomical observations.

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Innovative area 'GW-Astro (重力波天体)

"New Developments in Astrophysics Through Multi-Messenger Observations of Gravitational Wave Sources"

Project leader : Takashi Nakamura (Kyoto U.)

計画研究

• A01「重力波天体からのＸ線・γ線放射の探索」	X-Ray and Gamma-Ray observation
• A02「天体重力波の光学赤外線対応現象の探索」	Optical (Visible, Infrared) + Radio obs.
• A03「超新星爆発によるニュートリノ信号と重力波信号の相関の研究」	Neutrino
• A04「多様な観測に連携する重力波探索データ解析の研究」	GW data analysis (KAGRA + …)
• A05「重力波天体の多様な観測に向けた理論的研究」	Theory

総括班

- X00「重力波天体の多様な観測による宇宙物理学の新展開の総括的研究」

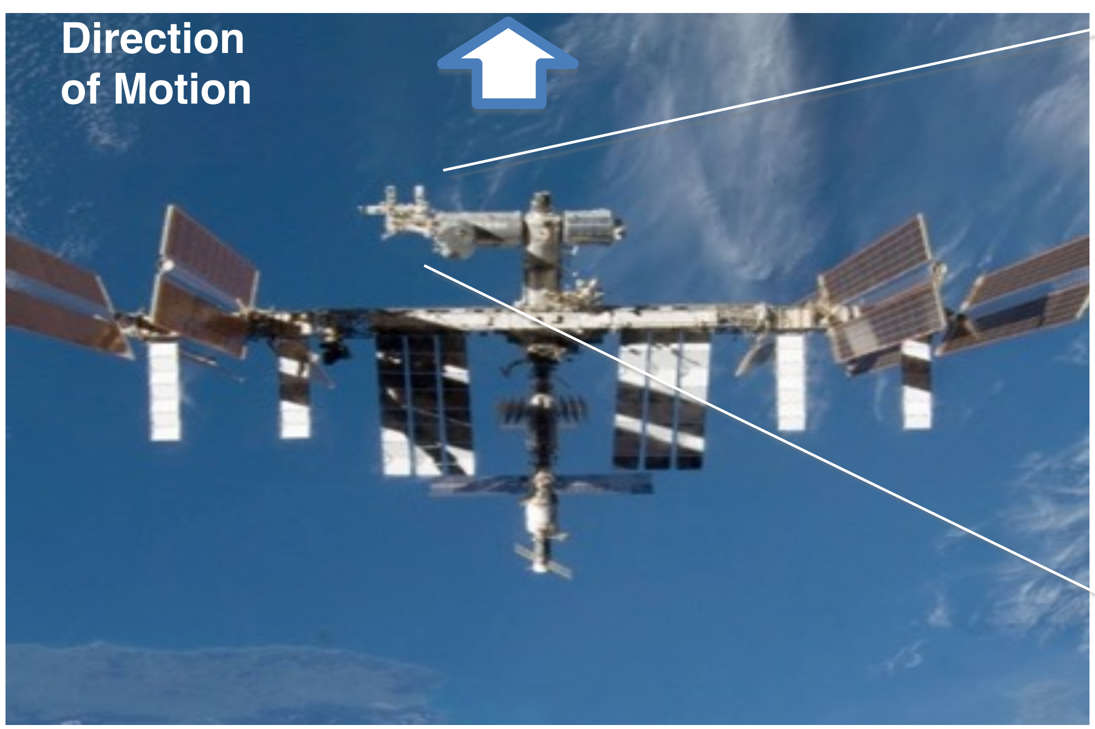
Research Group A01 : X-ray and gamma-ray

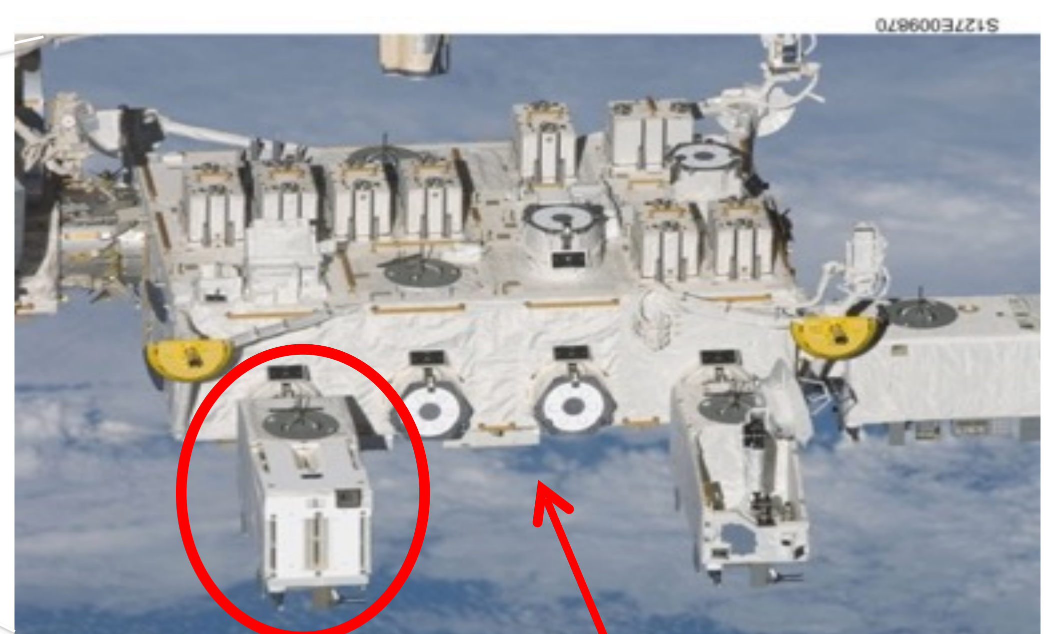
leader : Nobuyuki Kawai (Titech)

Target on X-ray < 10eV

- **Wide-FOV X-ray telescope will be necessary, since GW's angular resolution is wider as several 10 square-degree.**
- **ISS(International Space Station) MAXI(Monitor of All-sky X-ray Image) scans 80% of whole sky in 90 min.**

MAXI exchange the MoU (Memorandom of Understanding) with LIGO/Virgo





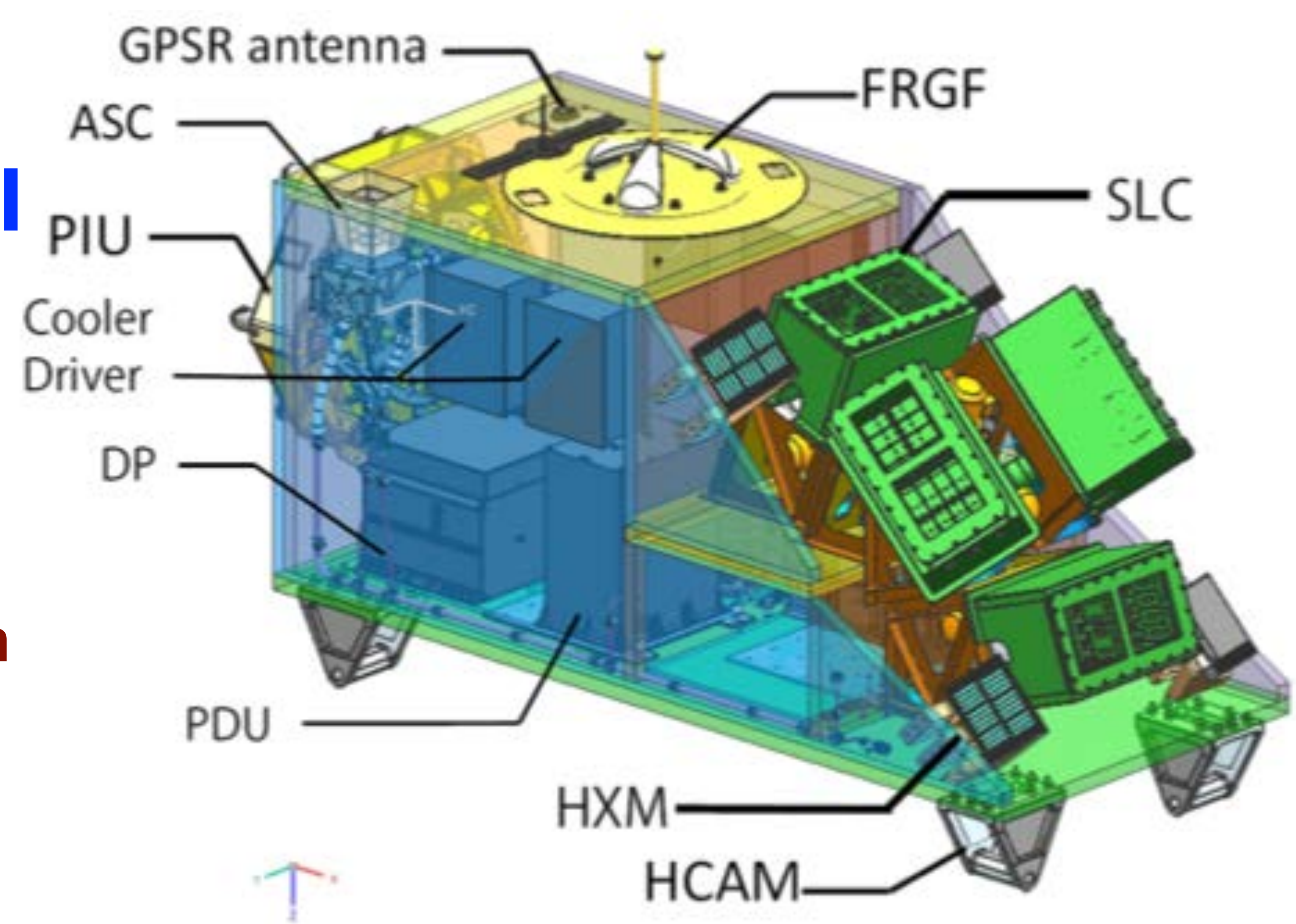
MAXI JEM EF

Research Group A01 : X-ray and gamma-ray

LIGO/Virgo Follow-up observation

on behalf of LIGO/Virgo EM follow-up consortium (MoU)
start at year 2015

Development of WF-MAXI



Study of Transient

- MAXI、Suzaku、Fermi
- targets : SNe, Blackhole, Neutron
  Star Binaries, GRB etc.
- Cooperation with A02 group

Research Group A02 :

Develop an optical-infrared-radio observation network for GW transient follow-up

leader : Michitoshi Yoshida (Hiroshima U.)

1. **Kiso wide-field Camera (optical imager)** → Doi
2. **OAO-WFC (wide-field infrared camera)** → Morokuma
3. **IFU for the spectrograph of Kyoto 3.8m telescope** → Yanagisawa
4. **50cm robotic telescope in Tibet** → Ohta
5. **Establish a transient observation network by utilizing existing facilities: Mini-TAO, IRSF, Kanata, Yamaguchi 32m radio tel., etc.** → Utsumi

leader : Michitoshi Yoshida (Hiroshima U.)

Schematic overview of A02 project

Detection of EM counterpart of GW transient
with wide-field observations
Multi-mode observations ➔
physics of EM counterpart

The nature of GW transient

GW alert
LIGO/Virgo/KAGRA

alert

Wide field obs.
➔EM counterpart
Rapid identification
alert to other facilities

X-γ obs. (A01)

Coop.

Neutrino obs. (A03)


OAO IR WFC


Kiso 6x6 deg^2 Camera


MOA-II 1.5x1.5deg^2 Camera

Yamaguchi32m
NRAO 45m

Multi-wavelen.
➔detailed study
identification
emission mechanism

Multi-mode obs.
➔detailed study
redshift -> distance
emission mechanism

World-wide obs.
➔long term monitor
event evolution

IRSF

miniTAO

HinOTORI 50cm

Kanata

Kyoto 3.8m

Subaru

theory (A05)

Coop.

J-GEM collaboration

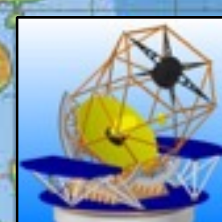
(Japanese Collaboration for Gravitational-Wave Electro-Magnetic Follow-up Observation)

A part of the project "Multi-messenger Observations of GW sources"
* collaborating with the KAGRA data analysis team
* science cases: GRBs, supernovae, blazars, etc.

Main features:
- 5 deg^2 opt. imaging w/ 1m
- 1 deg^2 NIR imaging w/ 1m
- opt-NIR spectroscopy w/ 1–8m
- opt-NIR polarimetry

- 1m Kiso Schmidt telescope
  6 deg^2 camera ➔ 36 deg^2
- 1.5m Kanata telescope
- 50cm MITSuME
- 91cm W−F NIR camera of NAOJ
  1 deg^2 NIR camera
- Yamaguchi 32m radio telescope

50cm telescope
(Hiroshima Univ. 2014)



3.8m telescope
(Kyoto Univ. 2015)

Subaru @Hawaii

IRSF (Nagoya Univ.) @ South Africa

MOA−II (Nagoya Univ.) @ New Zeeland

miniTAO (Tokyo Univ.) @ Chile

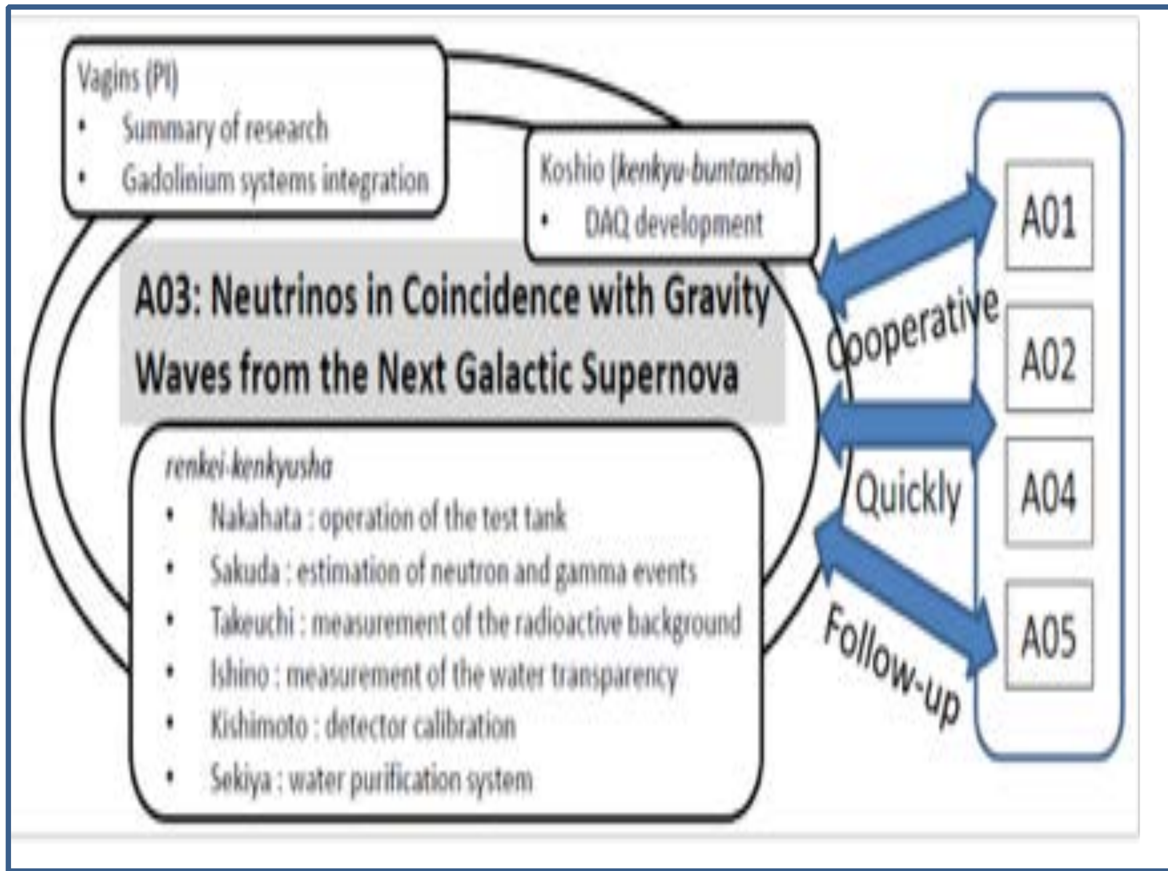
Research Group A03: Neutrinos

leader : Mark Vagins (IPMU)

- Special features of SN neutrinos and GW's
  - Provide image of core collapse itself (identical t=0)
  - Only supernova messengers which travel without attenuation to Earth (dust does not affect signal)
  - Guaranteed full-galaxy coverage
- What is required for maximum SN ν information?
  - Sensitivity to nearby explosions (closes gap in Super-Kamiokande's galactic SN ν coverage)
  - Deconvolution of neutrino flavors via efficient neutron tagging
    - By converting an existing R&D facility into the world's most advanced SN ν detector, we expect to collect

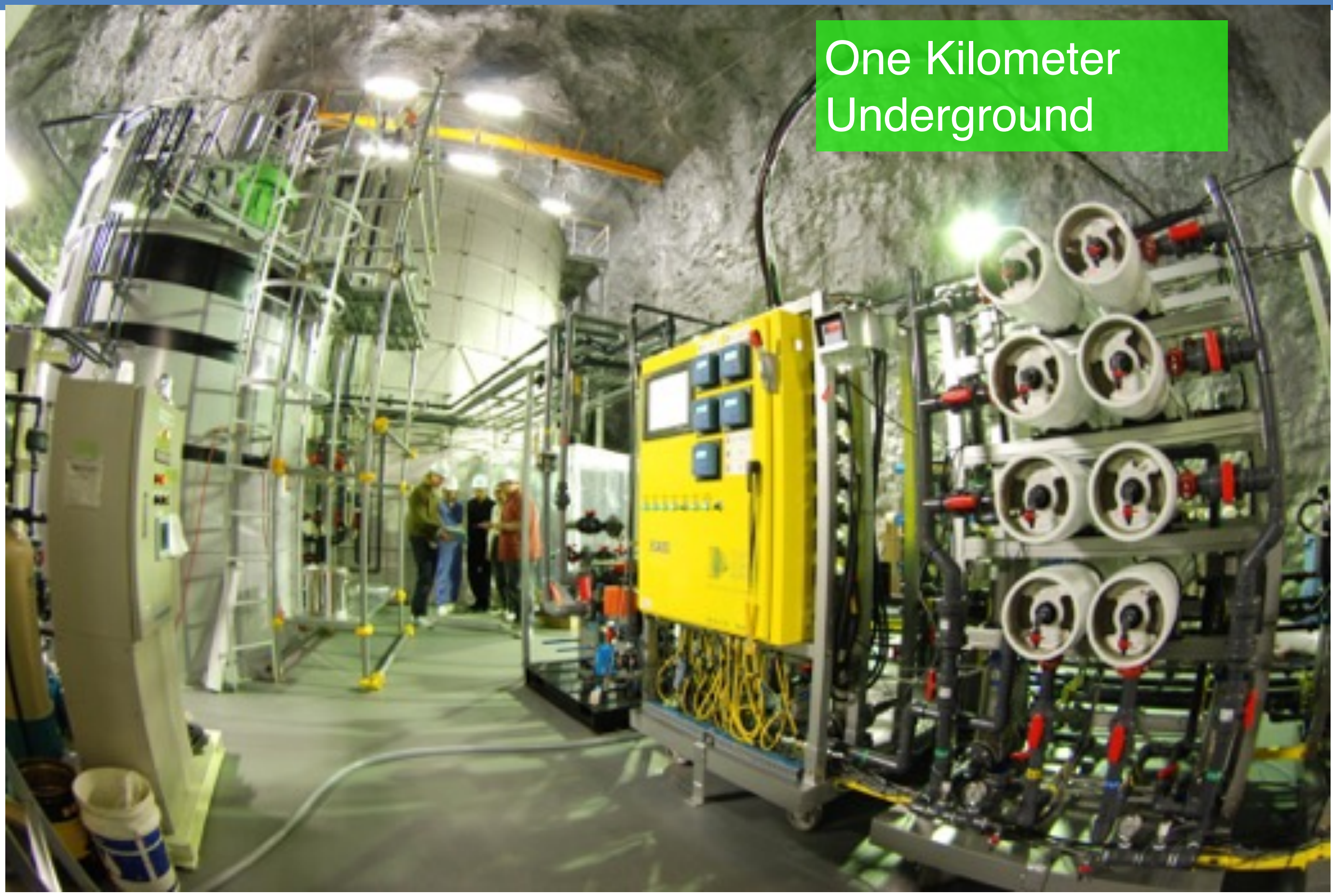
~30 ν events @ galactic center (30,000 light-years)
~90,000 ν events @ Betelgeuse (500 light-years)

Our target: send out announcement within ***<u>one second</u>*** of the SN neutrino burst's arrival!



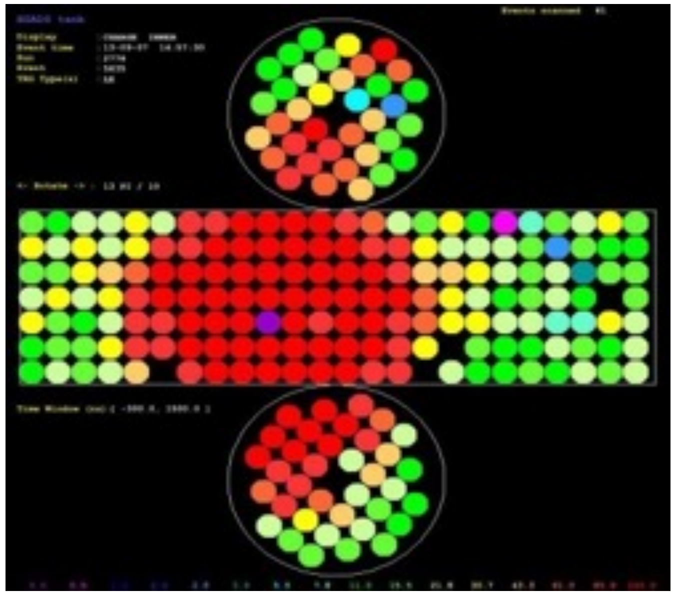
A03: EGADS Detector Has Been Built and Operated

EGADS experimental hall
in Kamioka mine



EGADS = Employing Gadolinium
to Autonomously Detect Supernovas

Inside of EGADS tank during PMT installation;
August 2013.



Event display of cosmic ray muon;
September 2013.

A03: Notable Recent Publication

Astrophysical Journal, 778 (2013) 164

OBSERVING THE NEXT GALACTIC SUPERNOVA

SCOTT M. ADAMS[1], C.S. KOCHANEK[1,2], JOHN F. BEACOM[1,2,3], MARK R. VAGINS[4,5], & K.Z. STANEK[1,2]

Draft version November 1, 2013

ABSTRACT

No supernova in the Milky Way has been observed since the invention of the optical telescope, instruments for other wavelengths, neutrino detectors, or gravitational wave observatories. It would be a tragedy to miss the opportunity to fully characterize the next one. To aid preparations for its observations, we model the distance, extinction, and magnitude probability distributions of a successful Galactic core-collapse supernova (ccSN), its shock breakout radiation, and its massive star progenitor. We find, at very high probability ($\simeq 100\%$), that the next Galactic supernova will easily be detectable in the near-IR and that near-IR photometry of the progenitor star very likely ($\simeq 92\%$) already exists in the 2MASS survey. Most ccSNe (98%) will be easily observed in the optical, but a significant fraction (43%) will lack observations of the progenitor due to a combination of survey sensitivity and confusion. If neutrino detection experiments can quickly disseminate a likely position ($\sim 3°$), we show that a modestly priced IR camera system can probably detect the shock breakout radiation pulse even in daytime (64% for the cheapest design). Neutrino experiments should seriously consider adding such systems, both for their scientific return and as an added and internal layer of protection against false triggers. We find that shock breakouts from failed ccSNe of red supergiants may be more observable than those of successful SNe due to their lower radiation temperatures. We review the process by which neutrinos from a Galactic core-collapse supernova would be detected and announced. We provide new information on the EGADS system and its potential for providing instant neutrino alerts. We also discuss the distance, extinction, and magnitude probability distributions for the next Galactic Type Ia supernova. Based on our modeled observability, we find a Galactic core-collapse supernova rate of $3.2^{+7.3}_{-2.6}$ per century and a Galactic Type Ia supernova rate of $1.4^{+1.4}_{-0.8}$ per century for a total Galactic supernova rate of $4.6^{+7.4}_{-2.7}$ per century is needed to account for the SNe observed over the last millennium, which implies a Galactic star formation rate of $3.6^{+8.3}_{-3.0}\ M_{\odot}\ yr^{-1}$.

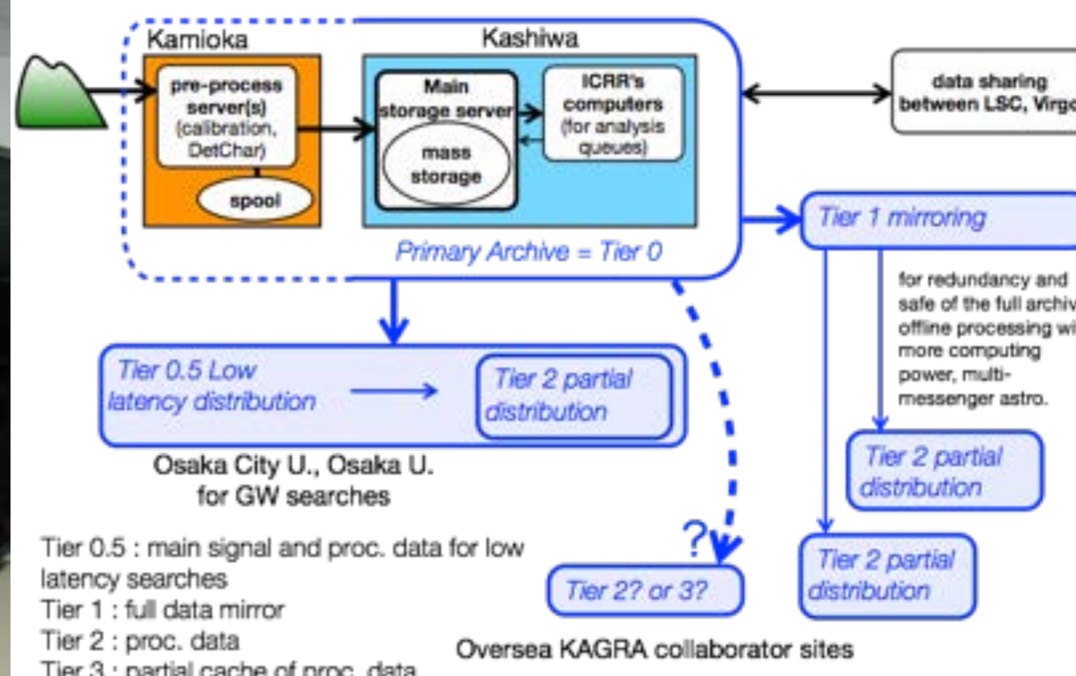
Research Group A04 : GW data analysis

Data analysis of KAGRA

leader : Nobuyuki Kanda (Osaka City U.

- **<u>Low Latency Event Search</u>**
- **Construction of event search pipelines (Software & Hardware)**

(also include the world wide cooperation between GW detectors)



Data spool and transfer system at Kamioka

Computing for low latency event search at Osaka City U./Osaka U.

Research Group A04 : GW data analysis

We should prepare iKAGRA observation :1st KAGRA operation in normal temperature,
<u>at December 2015!</u>

Data transfer and software for event search (pipeline) is in preparation.

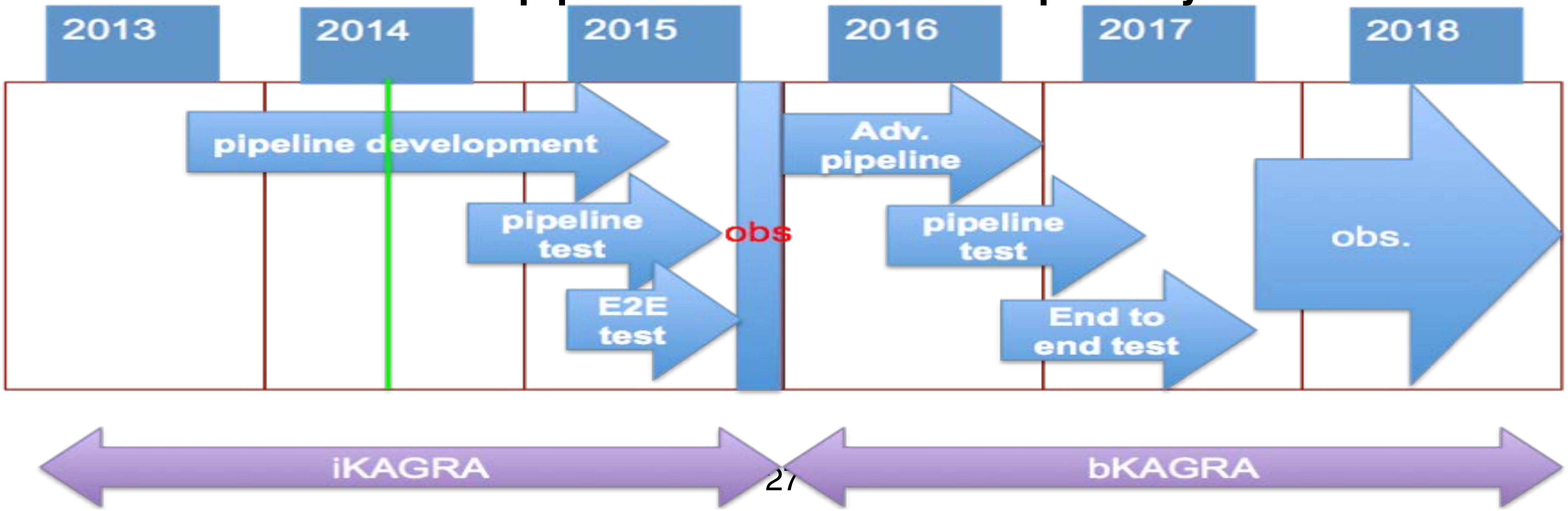
- **Development of KAGALI (KAGRA Algorithmic Library)**
- **Pipelines for corresponding GW sources**

CBC (Compact Binary Coalescence), Burst wave, Continuous wave

Human resource !

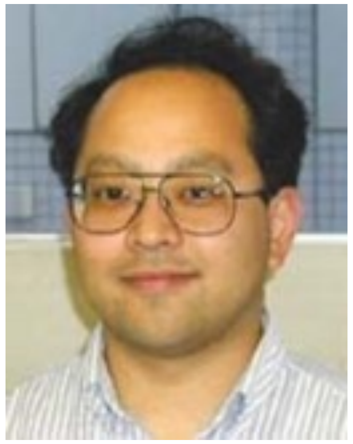
- **Younger researchers (Post-docs, Graduate students) are now working on.**
- **KAGRA data analysis group : 26 persons**

Pipeline development schedule
1st test of pipeline will start in 2014 partially.



Research Group A05 : Theoretical study for astrophysics through multimessenger observations of gravitational wave sources

leader : Takahiro Tanaka (Kyoto U.)

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柴田大 京都大学基礎物理学研究所
Masaru Shibata

固武慶 福岡大学理学研究科
Kei Kotake

PD researchers

Atsushi Nishizawa Kyoto university
Hiroyuki Nakano, YITP, Kyoto university
Hayato Motohashi, RESCEU, The Univ. of Tokyo
Hidetomo Sawai, Waseda university

Objective

Once gravitational waves are detected, we can study various important unsolved problems in Physics/astrophysics:

① Test of GR in the strong gravity regime

② Test of modified gravity
③ Properties of nuclear matter
④ Gamma ray burst
⑤ Supernovae

Furthermore, if we find unexpected phenomena by gravitational waves, a completely new frontiers that human-beings have never seen before will open. Developing the theoretical study on the promising gravitational wave sources, we also pursue new sources of gravitational waves as follows:

(1) Possibility of simultaneous observation or mutual follow-up observation using other methods than gravitational waves, revealing the properties of electromagnetic or neutrino signals emitted from the various gravitational wave sources.
(2) Proposal to data analyses: fast data analysis for quick follow-up, and how to take into account new knowledge about the theoretical template.
(3) Developing gravitation wave physics widely: Reinforcing the network of researchers which covers wide research area related to gravitational wave physics.
(4) Encouraging young researchers.

Organization

To achieve the mentioned objective, we develop 5 key projects

a) Discovering new gravitational wave sources and making templates. (Nakamura)
b) Physics of supernovae (Yamada)
c) Physics obtained from simultaneous observation (Ioka)
d) Proposal to data analysis (Seto)
e) Connection to cosmology and gravity (Tanaka)

Activities:

① 公募研究(Koubo kenkyu)

② Organizing workshops

JGRG

Contribution to the long term workshops at YITP

"Gravity and Cosmology 2012" (Nov.18-Dec.22, 2102) (chair: Tanaka)

"GWs and Numerical Relativity 2013" (May 19-June 22, 2013)(chair: Shibata)

YKIS (June 3-7, 2013)

コンパクト連星合体からの重力波・電磁波放射とその周辺領域(Feb 12-14, 2015)

合宿meeting (every year)

etc. etc.

③ Regular TV conference (Friday AM10:30-12:00)

Synergy : Inter-group missions !

There are possibilities of GW and counterparts…

- Neutron Star Binary Coalescence

GW + EM (X or gamma, Optical) + neutrino

—> neutron star's EoS, radius, etc. —> Nuclear Physics
—> Astrophysics, Cosmology

- Stellar-core-collapse of Supernova

GW + EM + **neutrino**

—> Science of Supernova
—> Particle physics

Co-operating with
Neutrino analysis(A03)
GW analysis(A04)
SNe Theory(A05)

—> Science of pulsar

- Cooperation with theory

A01-A05 study on extended emission of GRB,
A05-A04 study on detectability of POP-III BH binaries,
'kilo-nova' (maybe A02-A05-A02 issue)
etc.

viewgraph by T.Yokozawa

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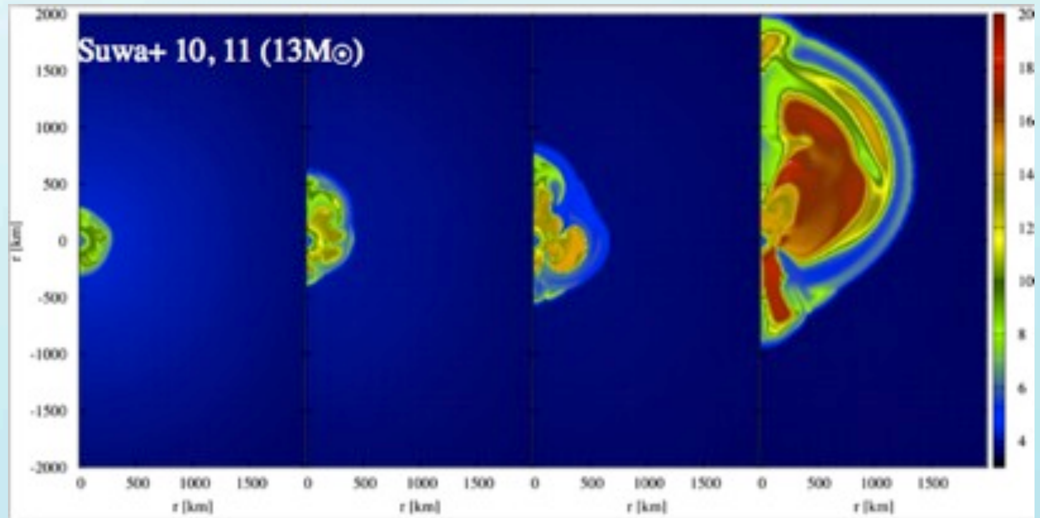
Team SKE

SNe Theory(A05)

Y. Suwa

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



Neutrino analysis(A03)

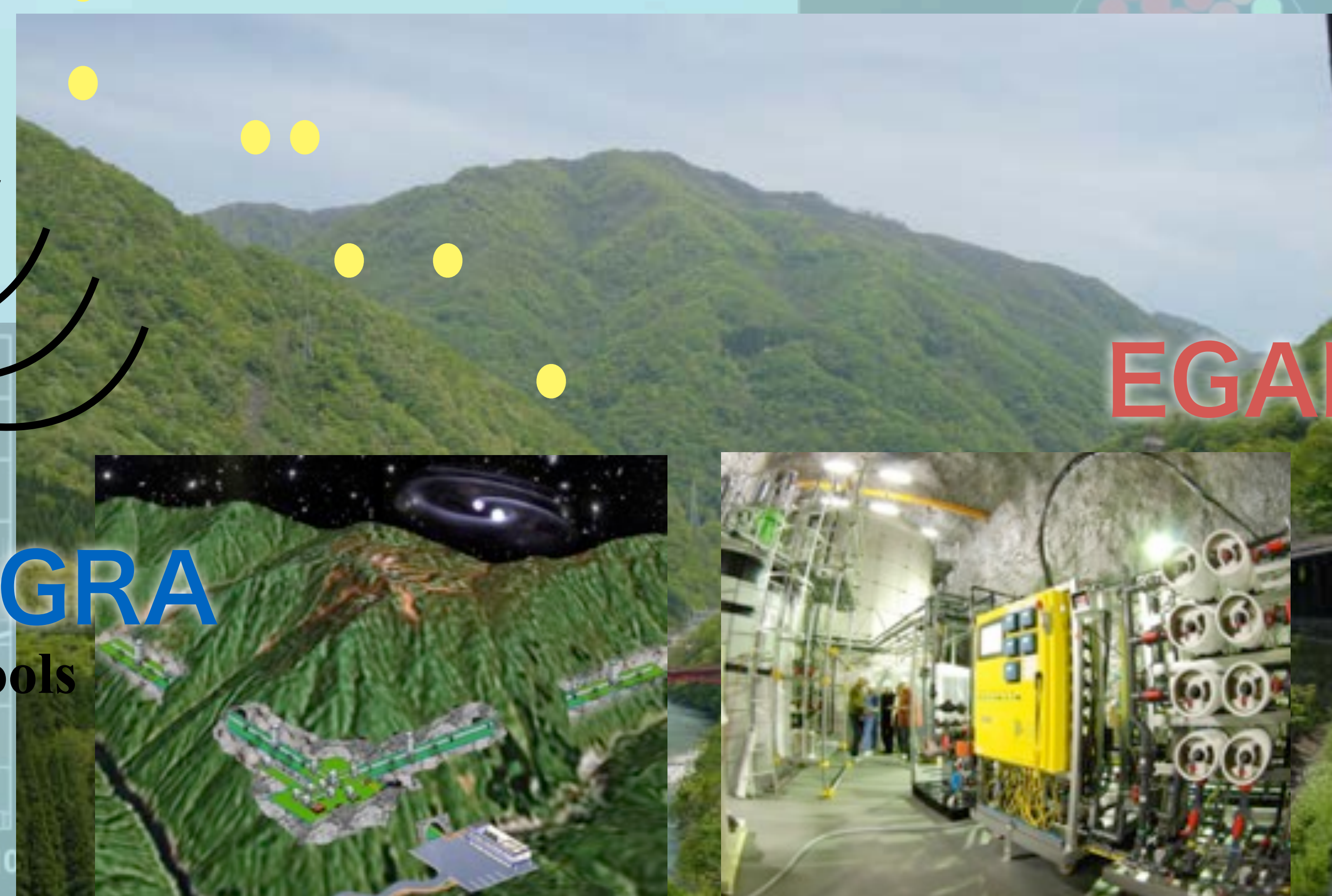
T. Kayano, Y. Koshio
M. Vagins

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

GW analysis(A04)

T. Yokozawa, M. Asano
N. Kanda

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



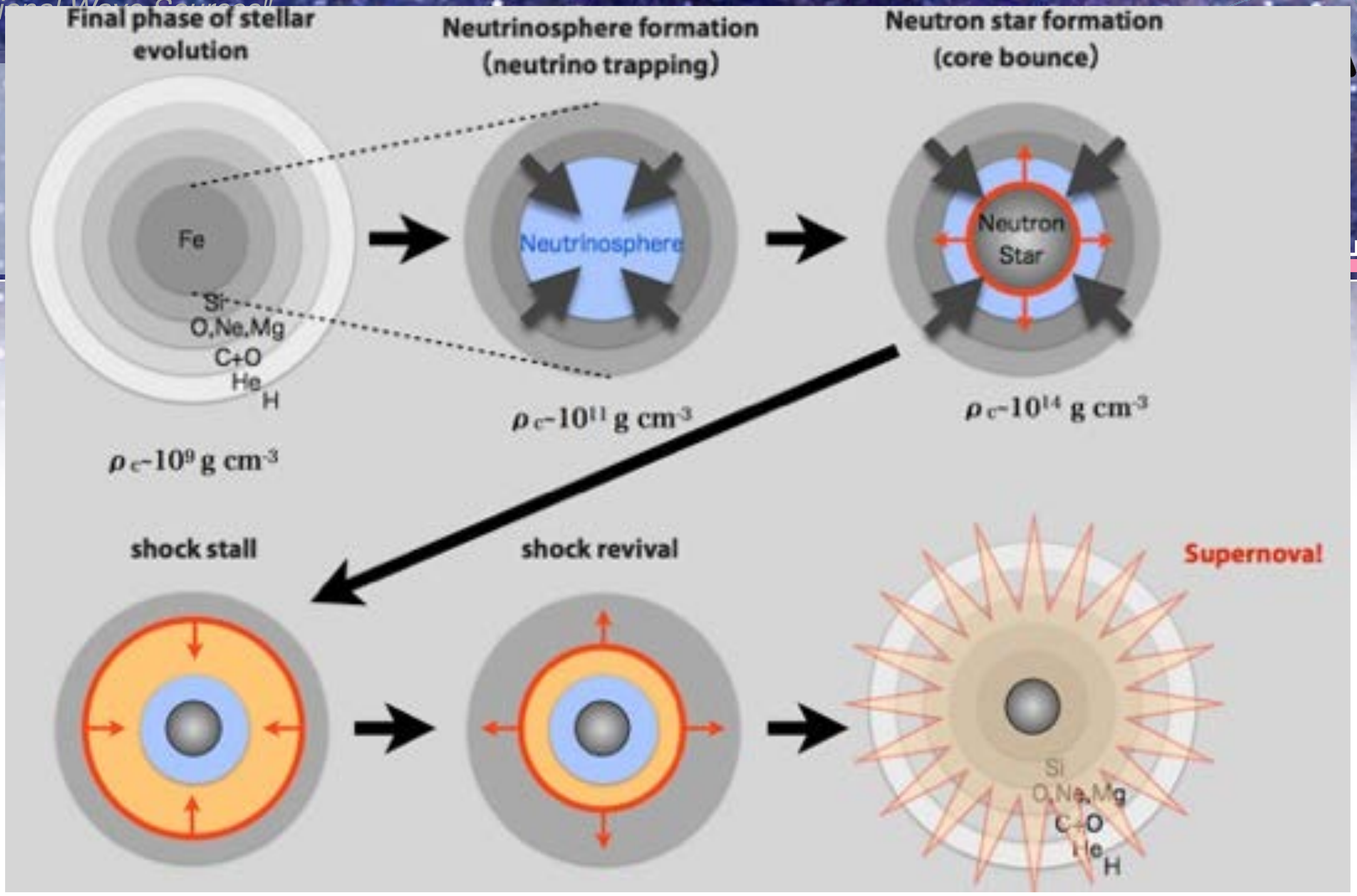
12

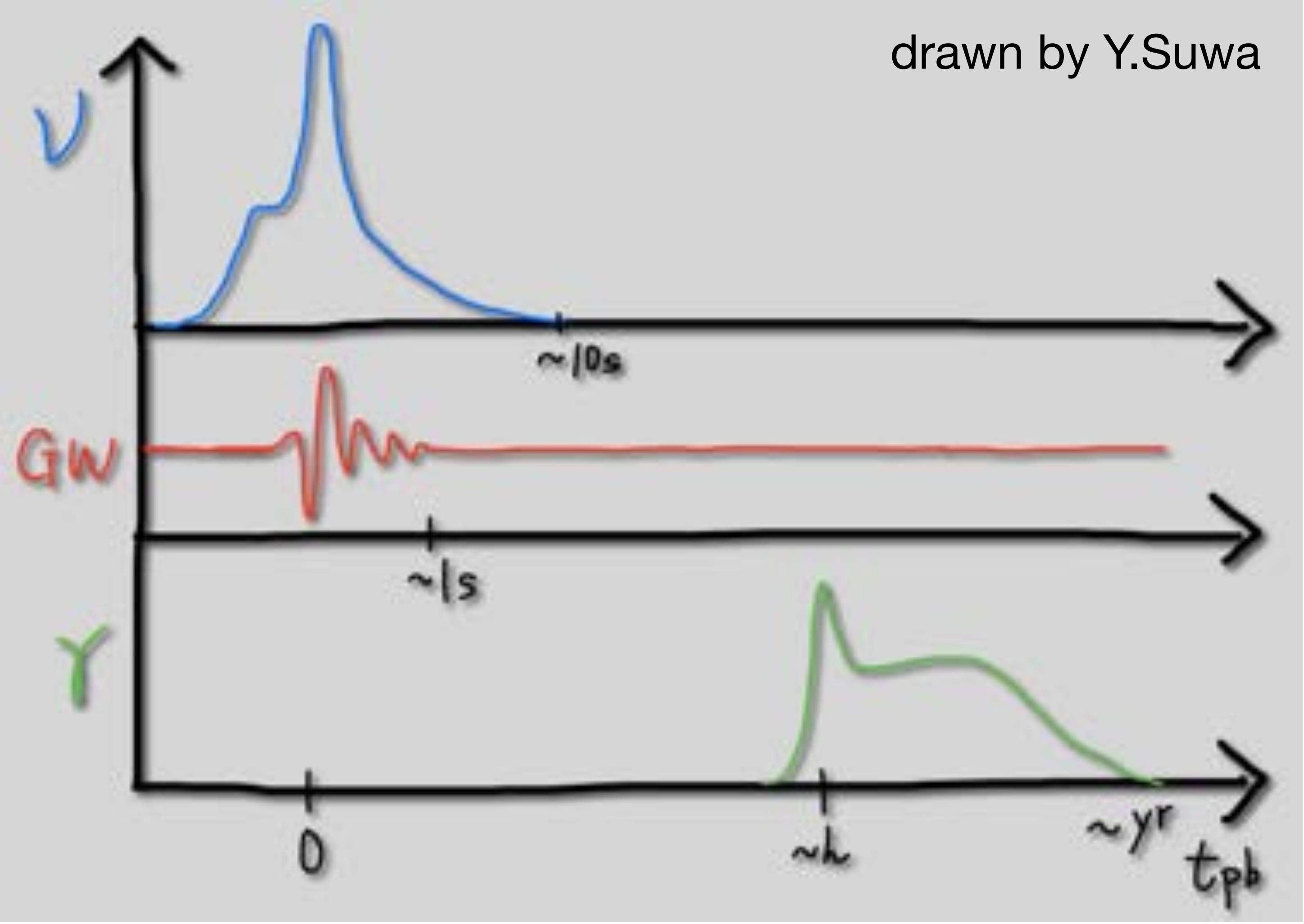
* Following several slides are of SKE studies using simulation data, with remarkable contribution by T.Yokozawa, H.Asano, Y.Suwa.

Supernova

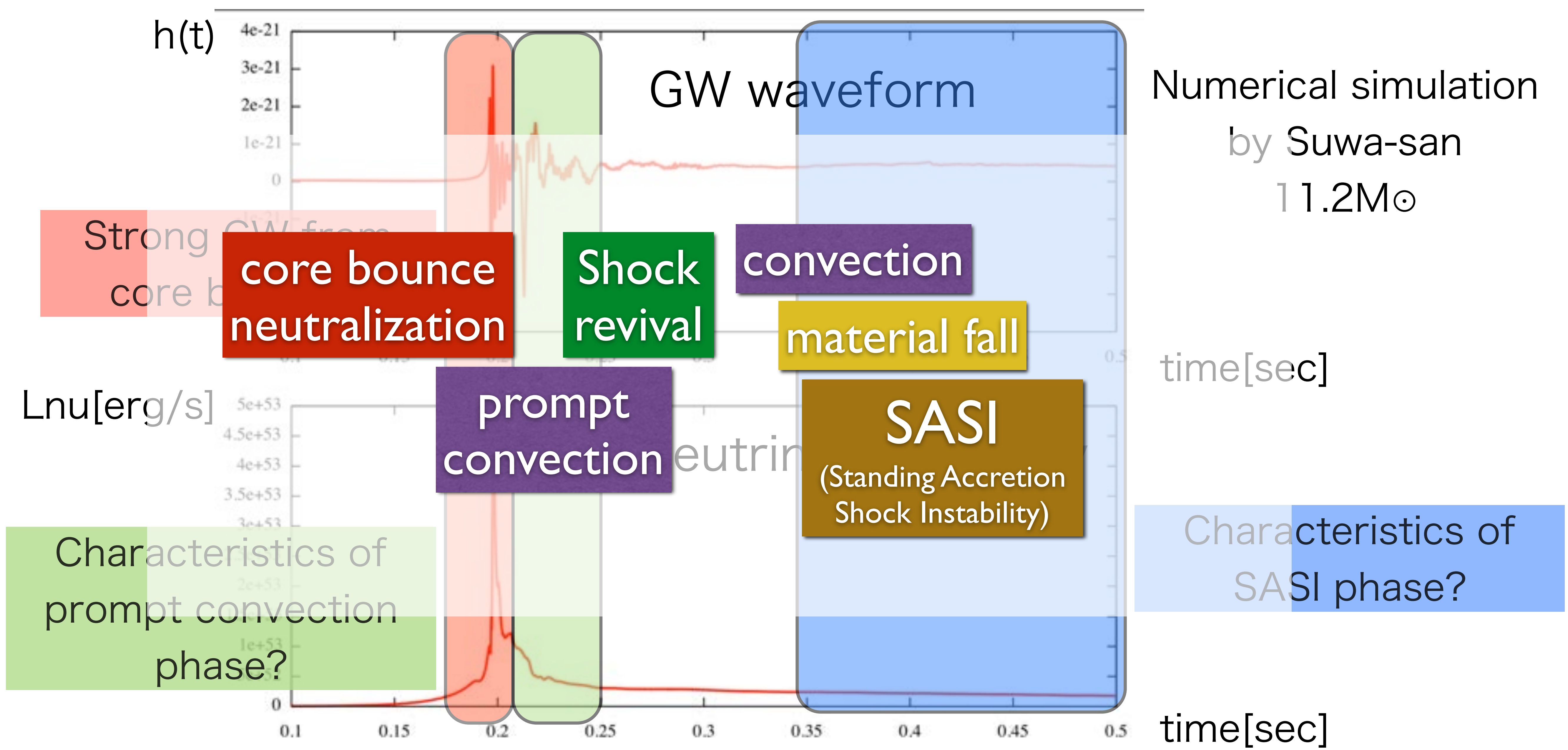
Type II (Stellar-core collapse) will emit …

- GW
  in various phase of its evolution :
  e.g. core bounce, convection,
  typical duration is order of
  msec ~ 1 sec
- Neutrino
  at 'neutralization', thermal
  development, duration as like 10 sec
- EM
  at outer structure,
  longer duration as ~day ~ year



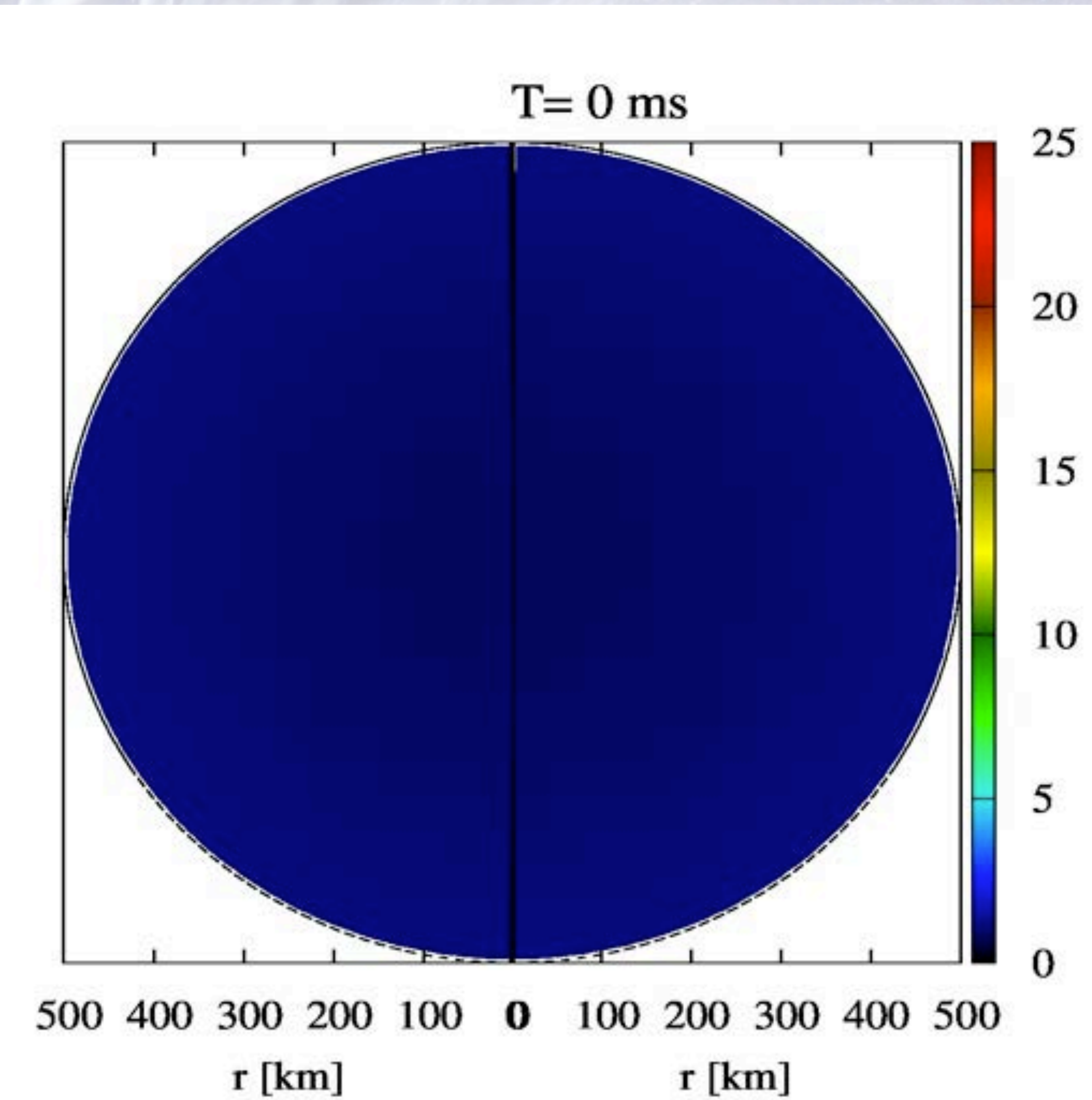


Epoche of GW and/or neutrino emission

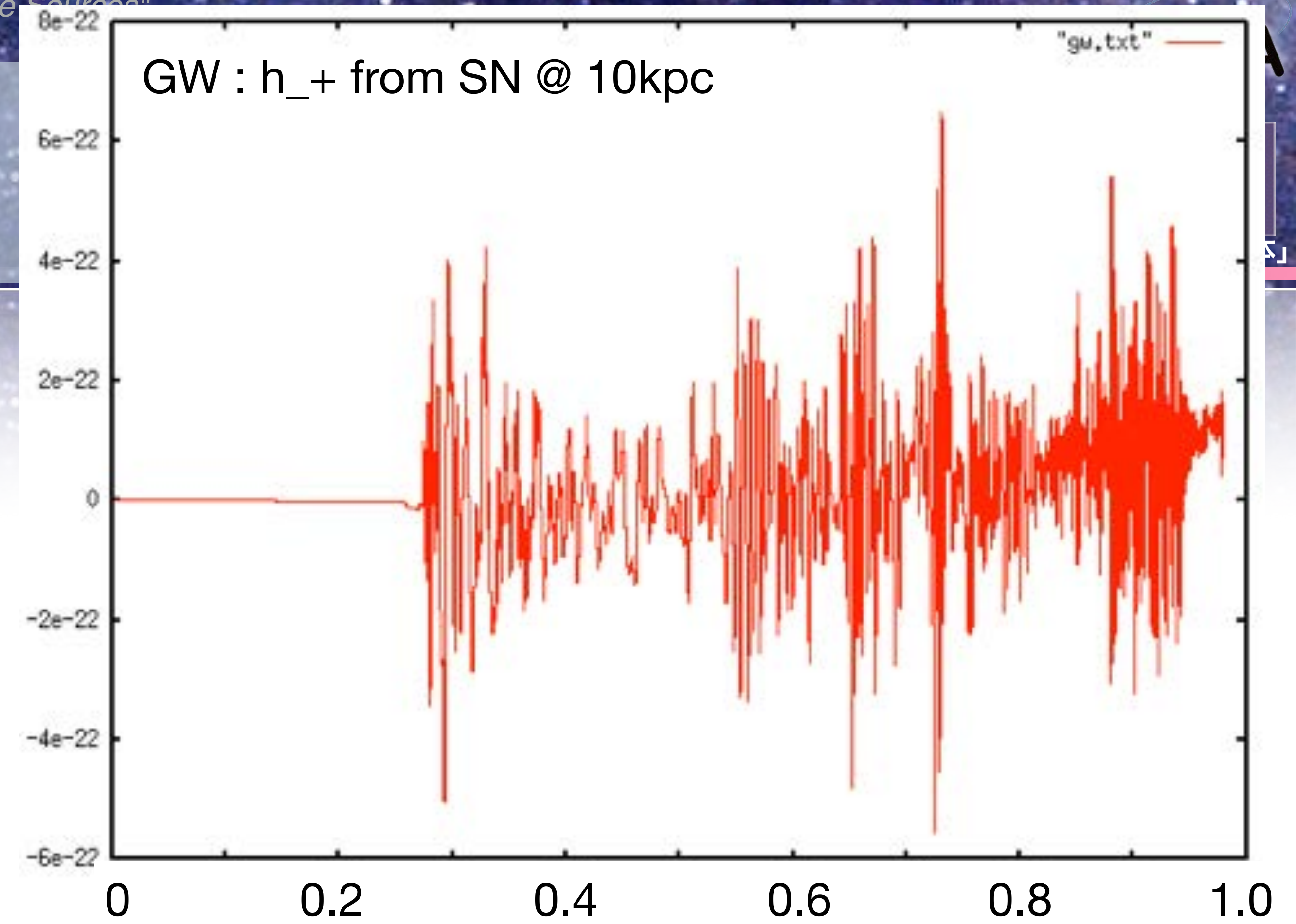


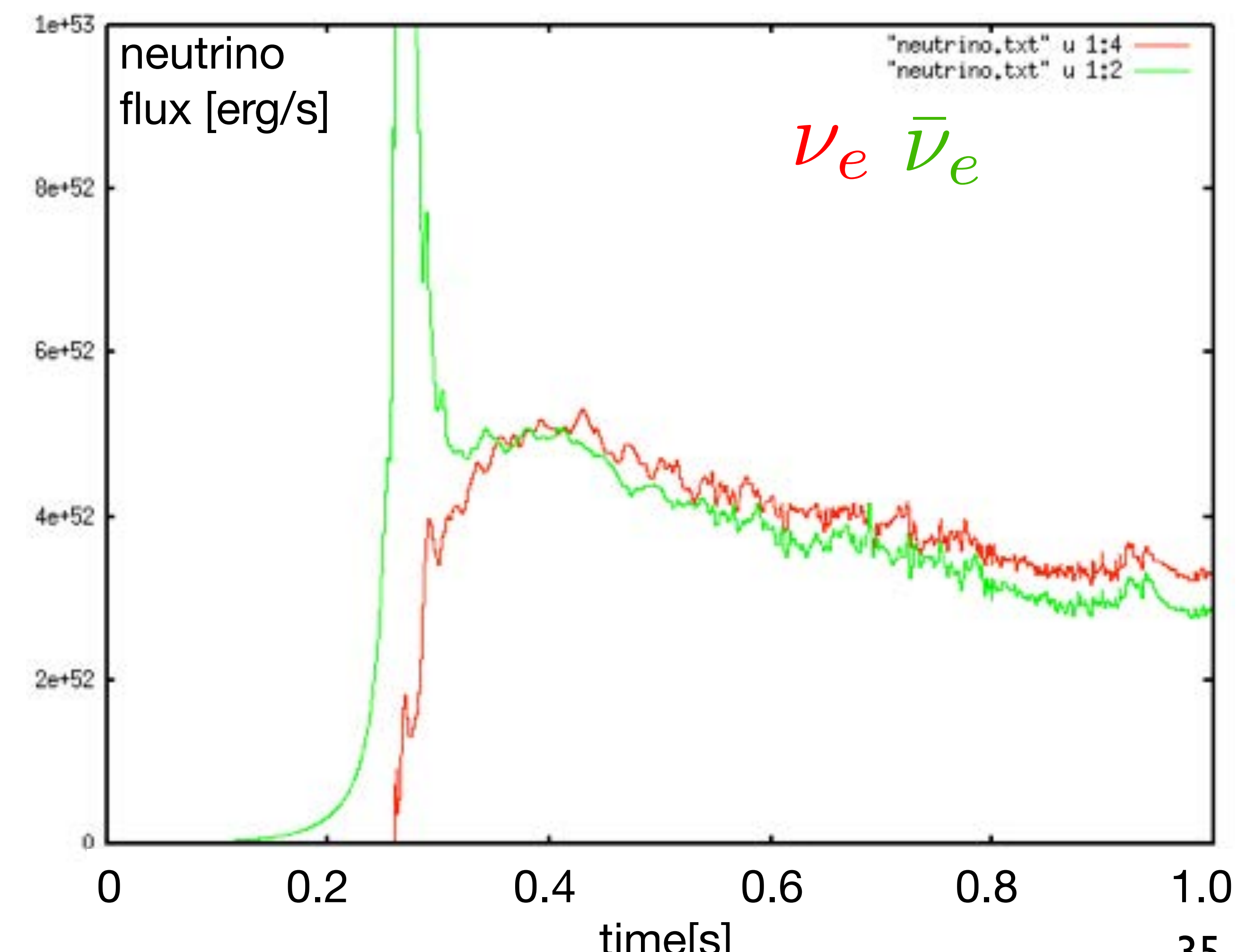
- Time domain astronomy with multi-messanger
- Understand the mechanism from concurrent analysis
  - Inner core information by GW and Neutrino

Simulation of SN (by Y.Suwa)



model S20 (20 Msolar, solar metallicity)





Core rotating

- Submitted to ApJ (arXi
- Focus on **GW observe**
- Supernova detection si

jp.arXiv.org > astro-ph > arXiv:1410.2050

Search or

Astrophysics > High Energy Astrophysical Phenomena

Probing Rotation of Core-collapse Supernova with Concurrent Analysis of Gravitational Waves and Neutrinos

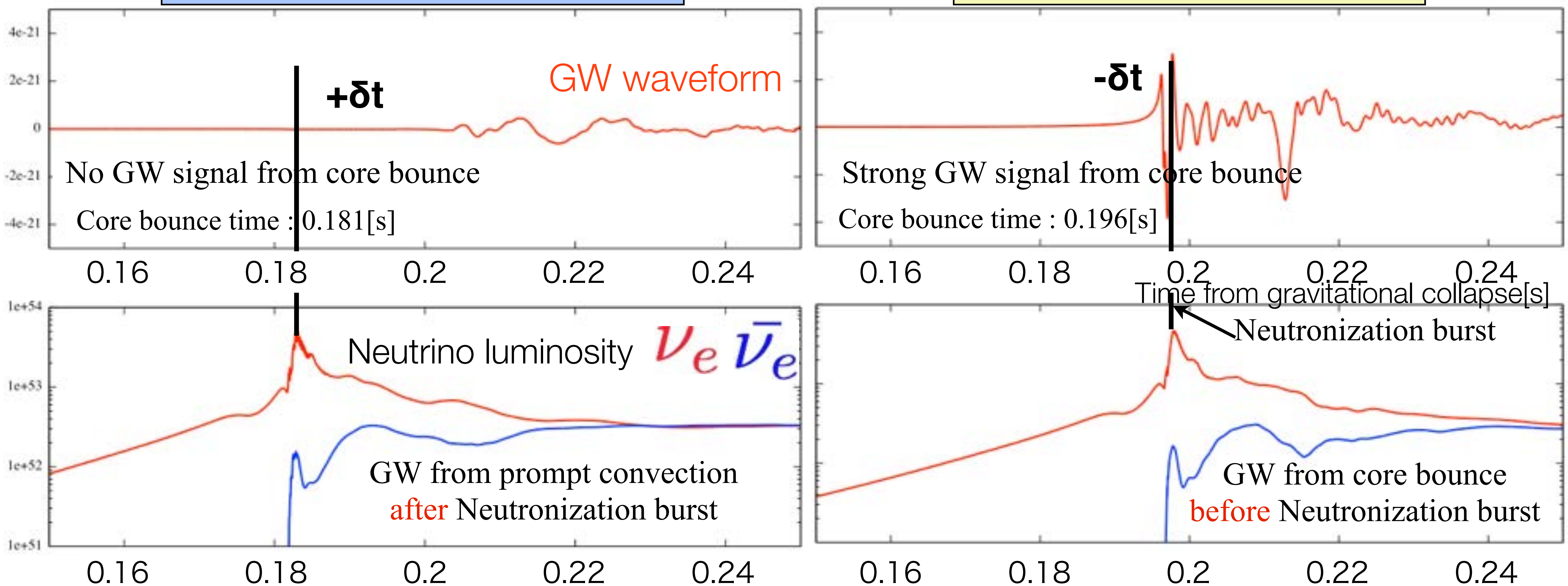
Takaaki Yokozawa, Mitsuhiro Asano, Tsubasa Kayano, Yudai Suwa, Nobuyuki Kanda, Yusuke Koshio, Mark R. Vagins

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

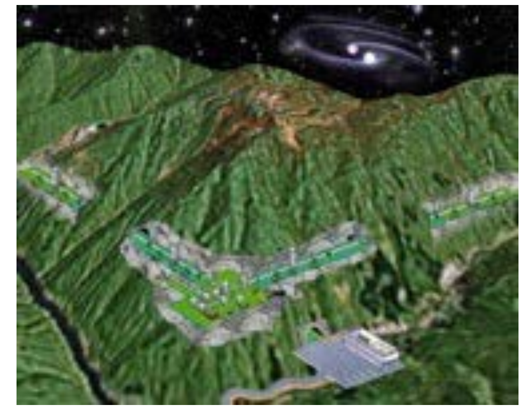
No core rotation case (0[rad/s])

core rotation case(pi[rad/s])



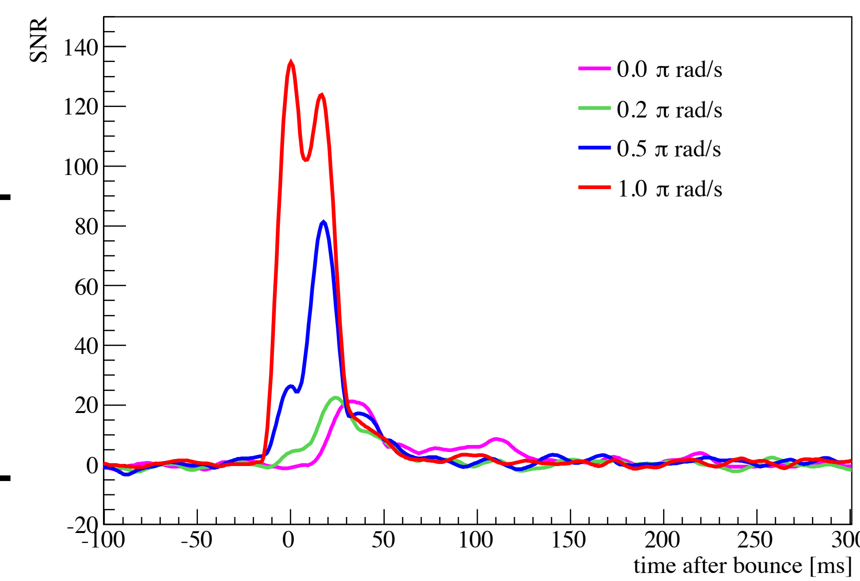
Analysis strategy - Core rotation-

Study with KAGRA and EGADS/SK+Gd
- neutron tagging with Gd(90%)
- test tank for GADZOOKS! project



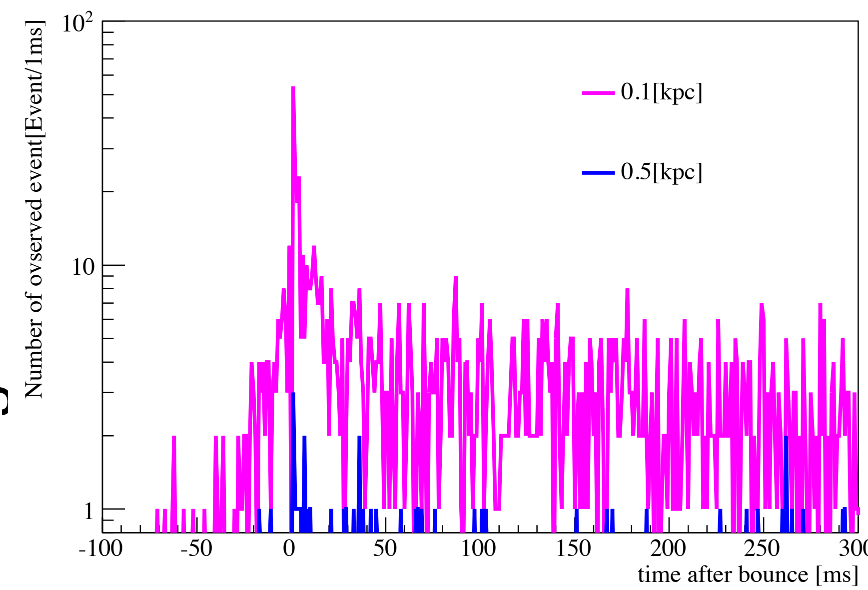
GW analysis
- Excess power filter
- + Short Time Fourier Transform
- Generate signal s(t)=h(t)+n(t)
- Search window which give max power

GW excess power output



Neutrino analysis
- generate signal with Poisson statistics
- search window which give max number of observation electron neutrino

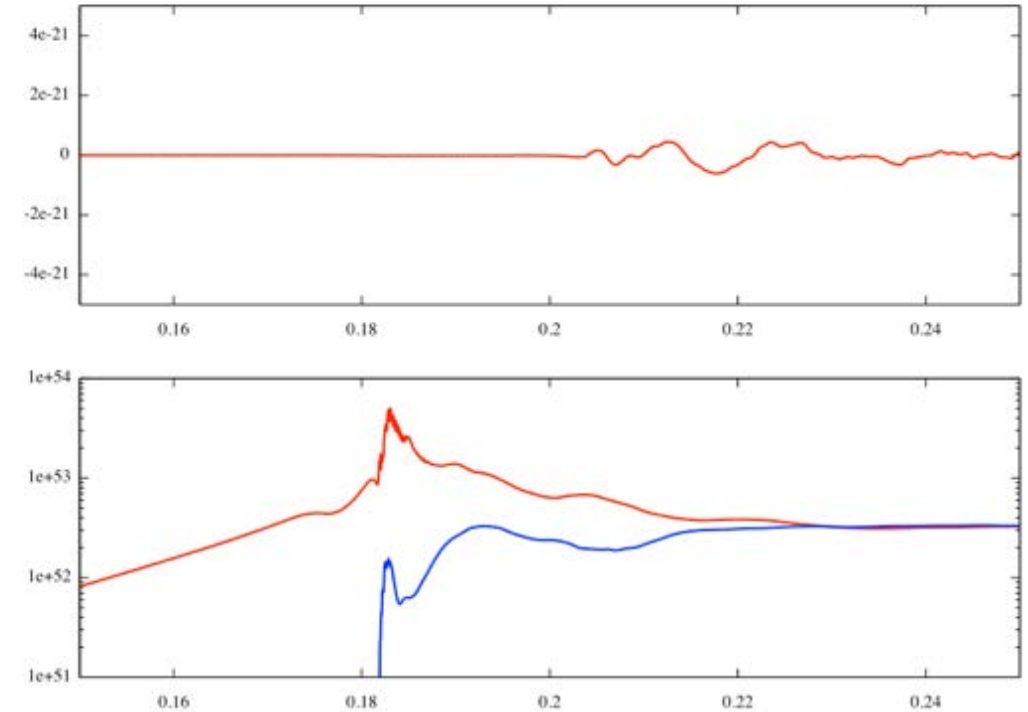
neutrino trigger histogram



result - Core rotation-

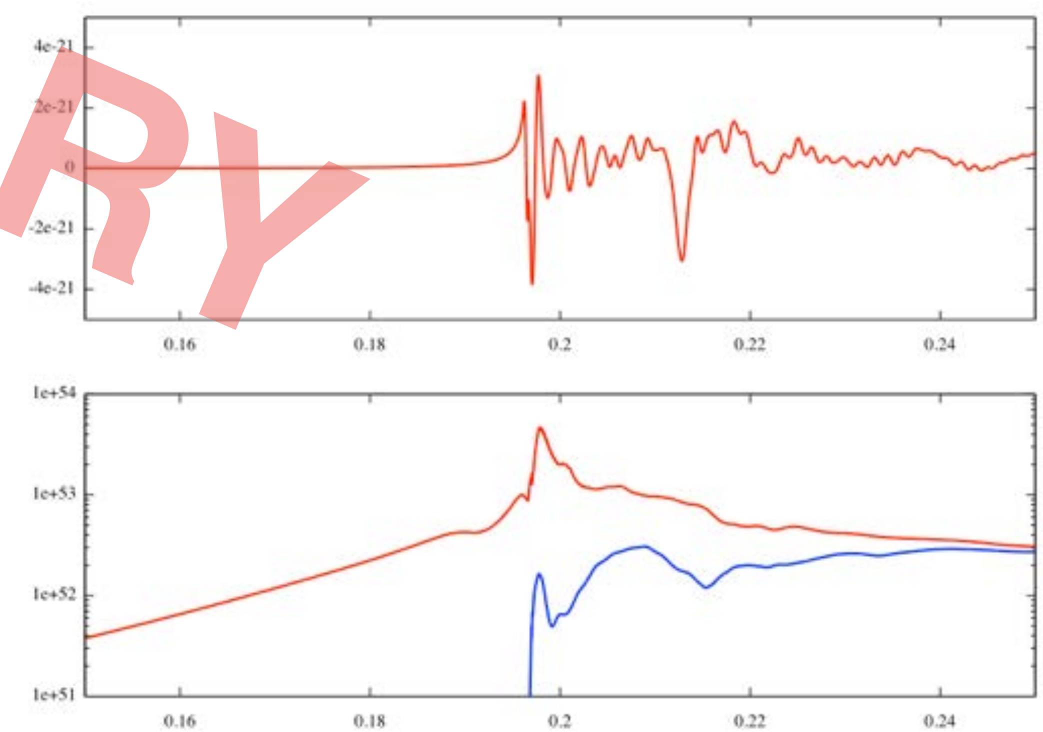
in case of non-rotating progenitor

	KAGRA det. eff.[%]	EGADS det. eff.[%]	SK+Gd det. eff[%]	Evaluate rotation[%]
0.2kpc uniform	76.1	100	--	0
2.0kpc uniform	26.8	1.6	--	8.7
Galactic Center	0	--	97.4	NaN
Galaxy distribution	1.8	--	84.6	1.73



in case of rotating progenitor

	KAGRA det. eff.[%]	EGADS det. eff.[%]	SK+Gd det. eff[%]	Evaluate rotation[%]
0.2kpc uniform	88.6	100	--	98.3
2.0kpc uniform	63.3	1.9	--	91.6
Galactic Center	23.8	--	94.4	72.7
Galaxy distribution	28.9	--	81.6	93.1

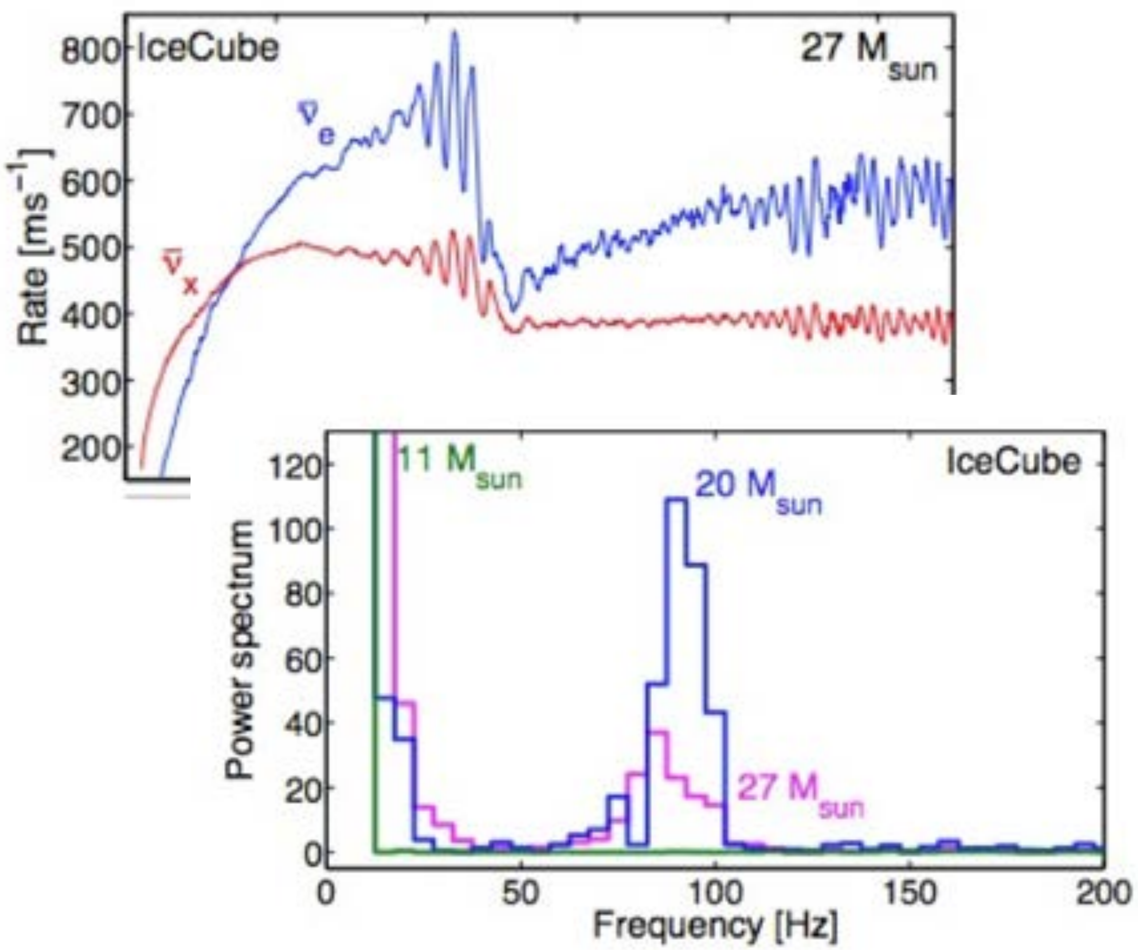


SASI

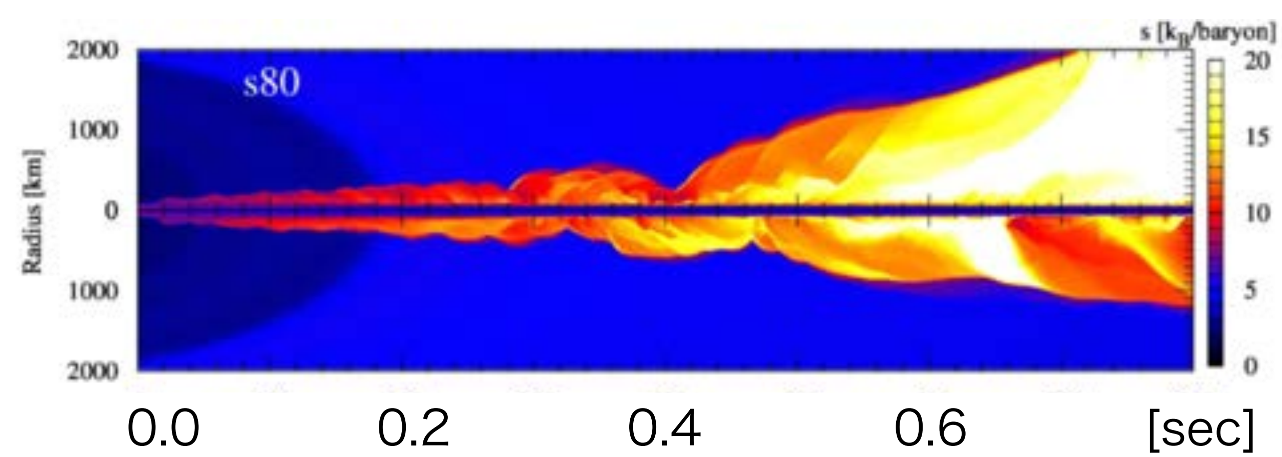
Standing Accretion Shock Instability (SASI)

- neutrino irradiation from PNS make postshock region heating up
- mass-accretion rate fluctuation makes Luminosity modulation(Suwa. 2014)
- Help the mechanism of Supernova explosion, shock wave revival
- Can we detect the characteristics of SASI with exiting detectors?

- Unique point1 : Introducing Time-Frequency analysis to neutrino luminosity
- Unique point2 : Relationship between GW and Neutrino

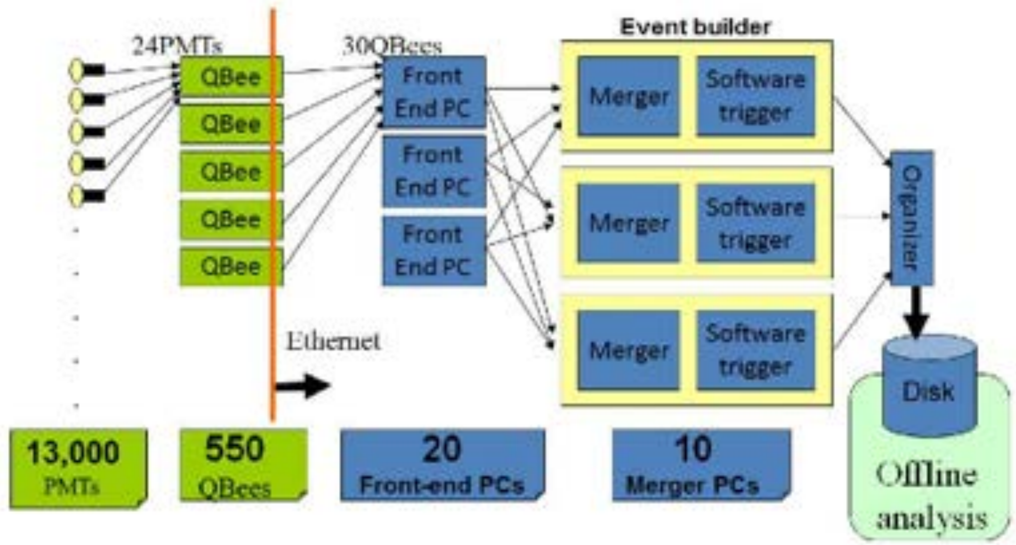


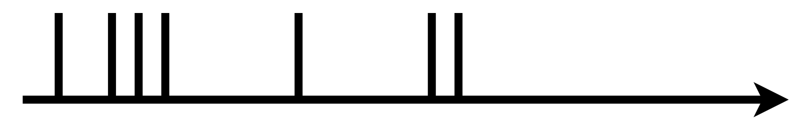
Time-space evolutions of entropy
for north-south pole (80M model)



Numerical simulation of GW and
Neutrino signals (Suwa. 2014)

Reconstruction of neutrino flux ***"time profile"***





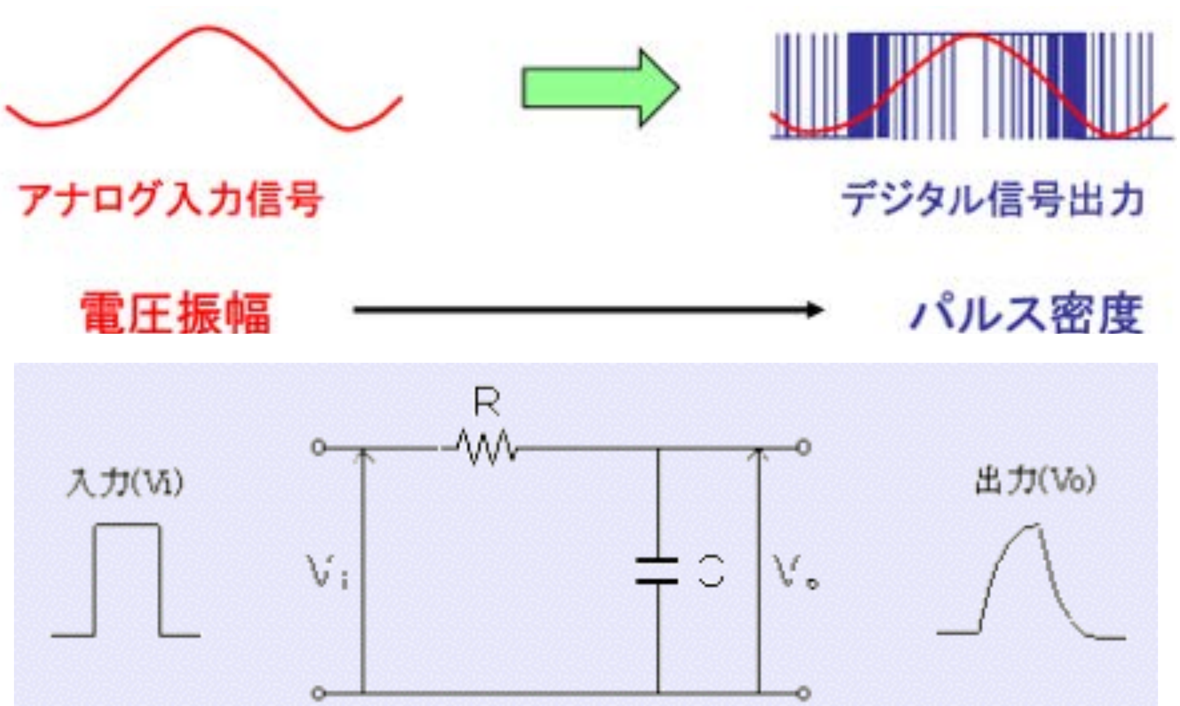
SK trigger information
s(t_i)=0 or 1

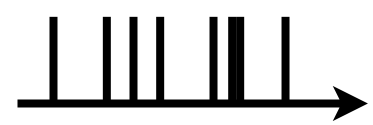
SuperKamiokande detector can save neutrino observe time with high accuracy

Give the signal of 0 or 1 for each time

It will useful to use ΔΣ modulator

http://www.a-r-tec.jp/DSADC2.pdf





SK trigger information s(t_i)=0 or 1

inverse ΔΣ modulator

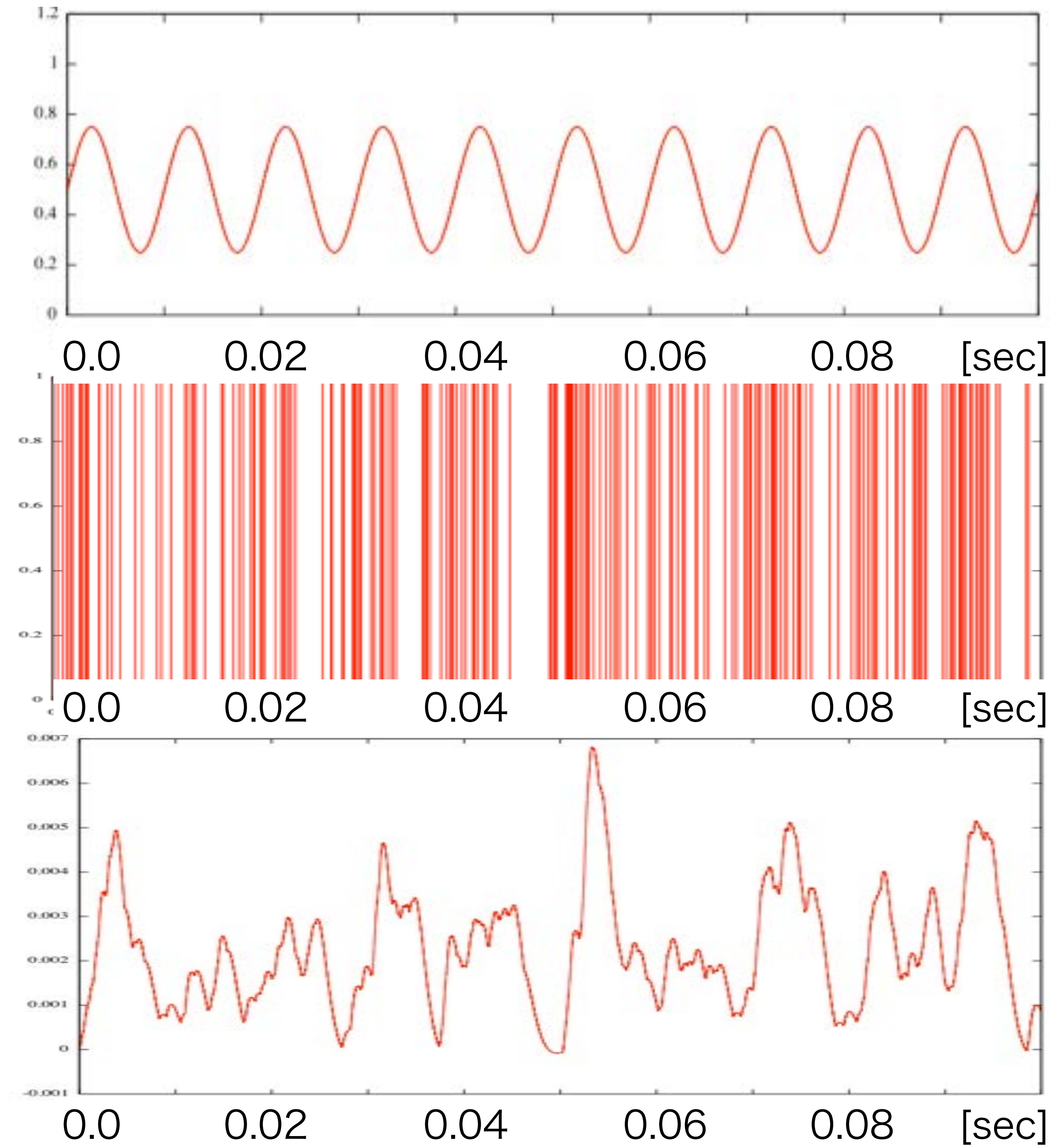
?

Clear modulation? difficult to identify?

- Check the performance of (inverse)ΔΣ modulator

Apply ΔΣ modulator -SASI-

Assume 100Hz modulation with 10 times : 100ms modulation
Number of mean observed neutrino at SuperKamiokande
225[100ms/10kpc/22.5kton] for SASI phase



Signal simulation :

1. Compute # of observed event
   poisson distribution with μ=225
2. With PDF, make trigger event with
   1μs resolution

$$\mathrm{PDF} \propto A \times \sin(2\pi f t) + 0.5$$

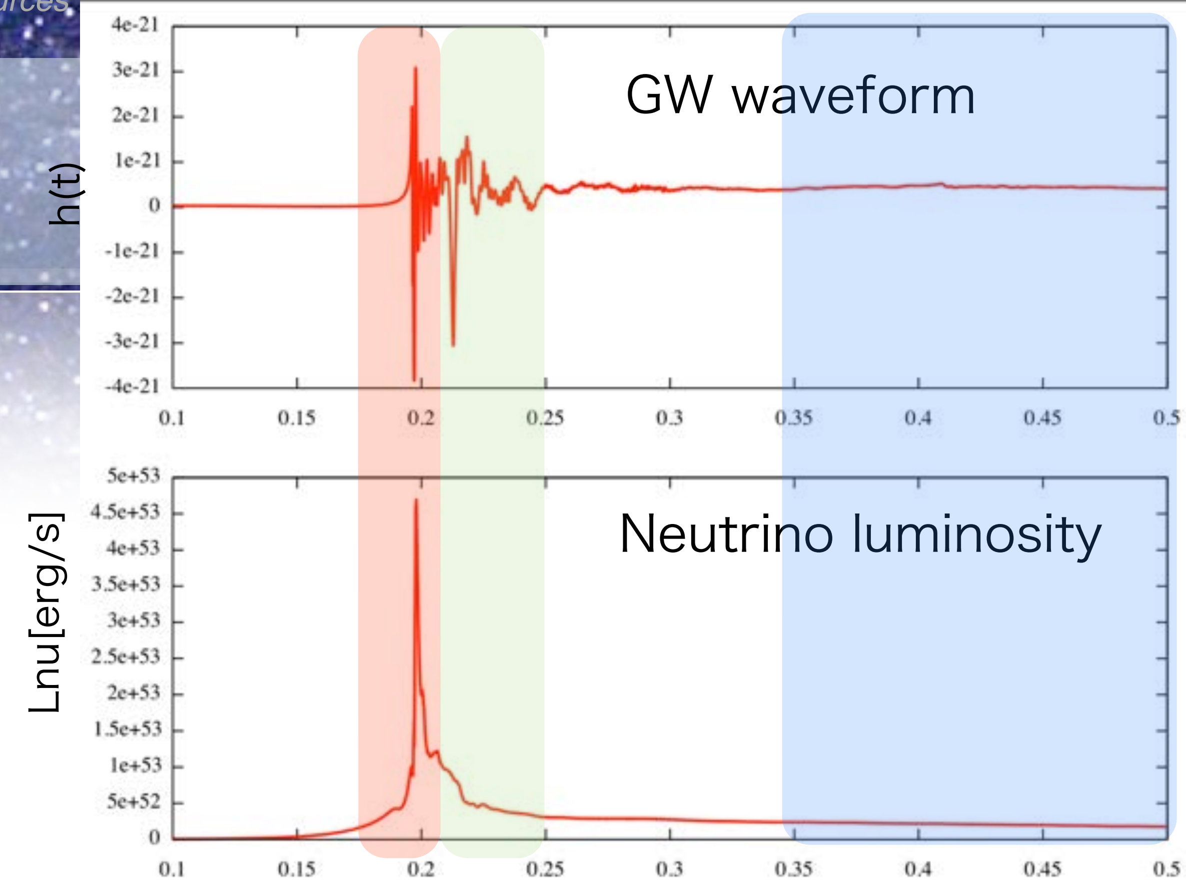
3. Apply inverse ΔΣ modulator(LPF)
4. Apply FFT and extract amplitude, A_{obs}
5. Calculate SNR for 100Hz amplitude

$$\mathrm{SNR} = \frac{A_{obs} - N_m}{N_\sigma}$$

: mean of extracted amplitude for flat PDF

: variance of extracted amplitude for flat PDF

Tagging the epochs of explosion



Time-frequency analysis on both GW and neutrino time series

GW analysis often employs such a representation of waveforms.
A time series h(t) can be converted into

- frequency domain h(f) by Fast Fourier Transform.
- **time-frequency domain :**
  h(t, f) by Sonogram (= time sliced chunk + FFT, in other word as 'Short-FFT'),
  wavelet h(t,f) , but with kernels different with Fourier, etc.

KAGRA

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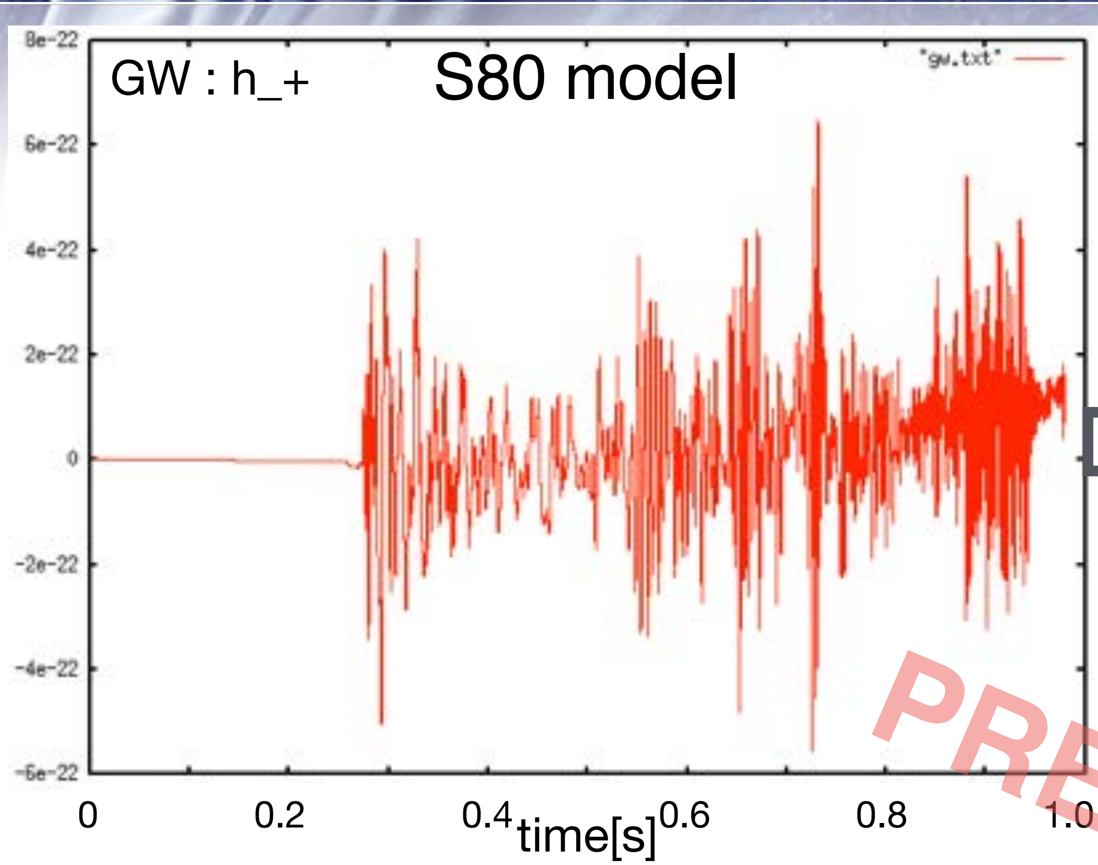
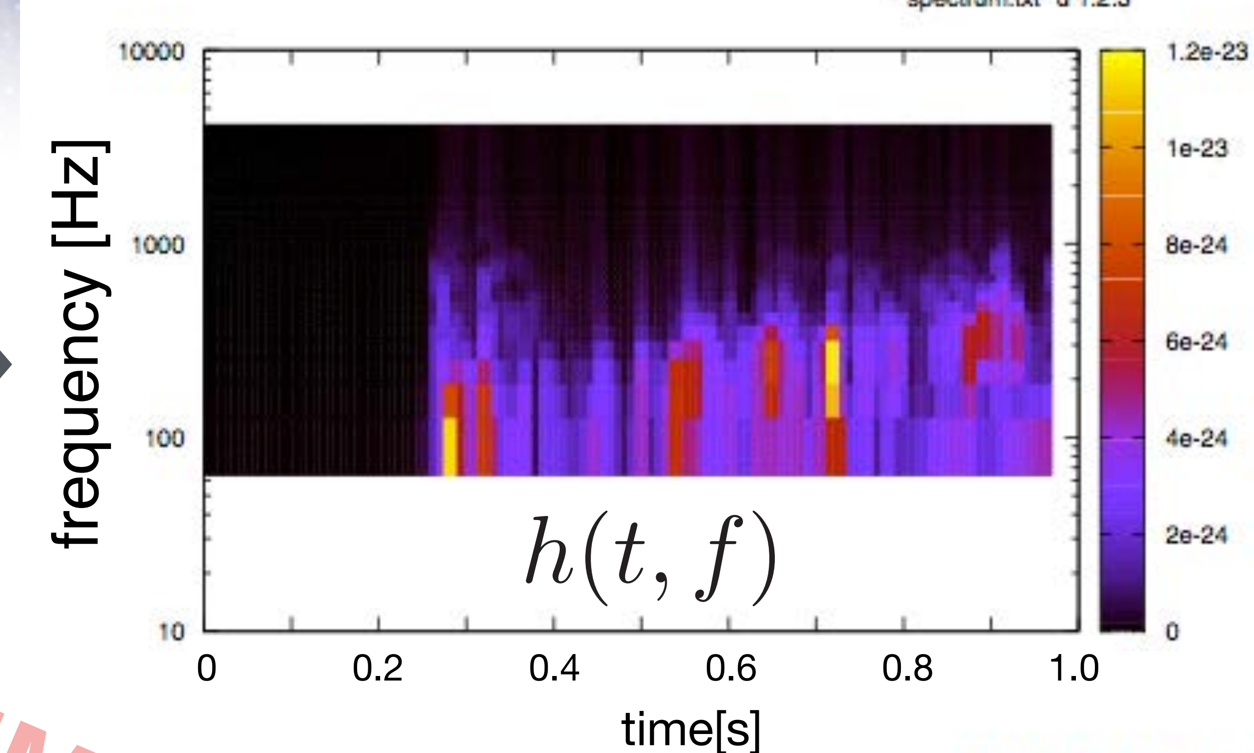
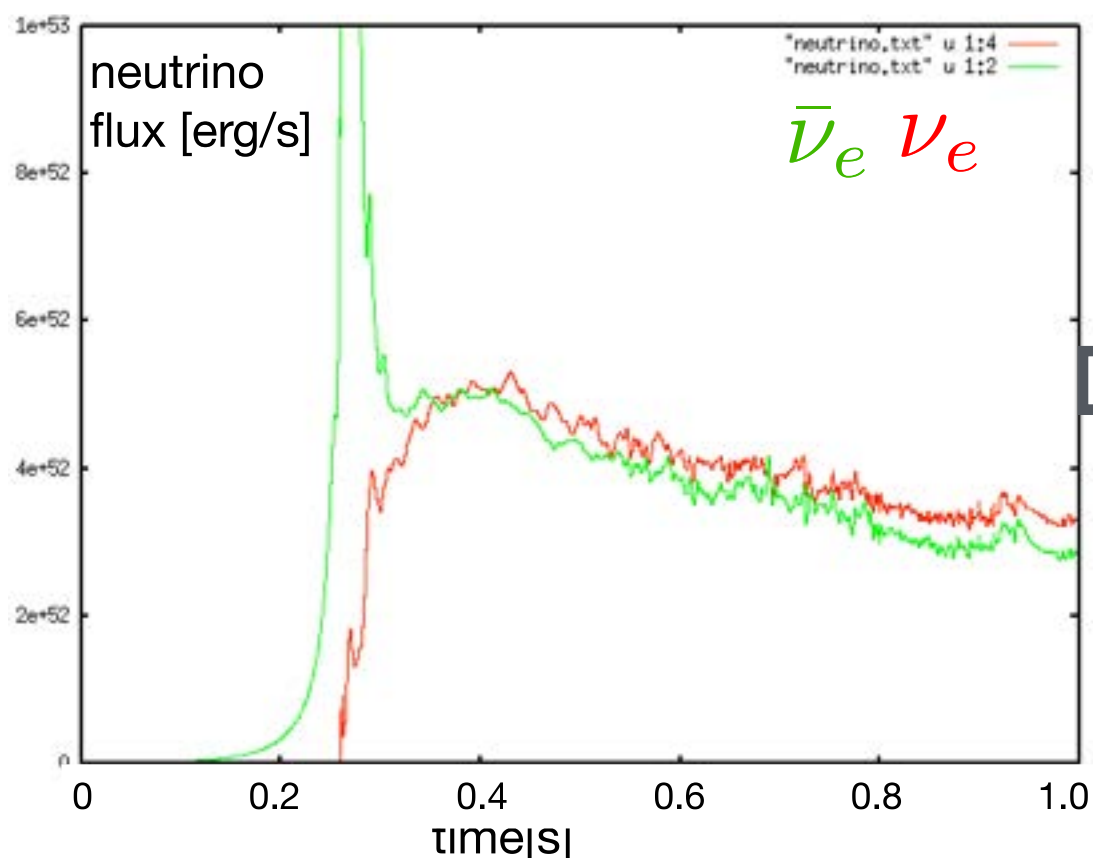
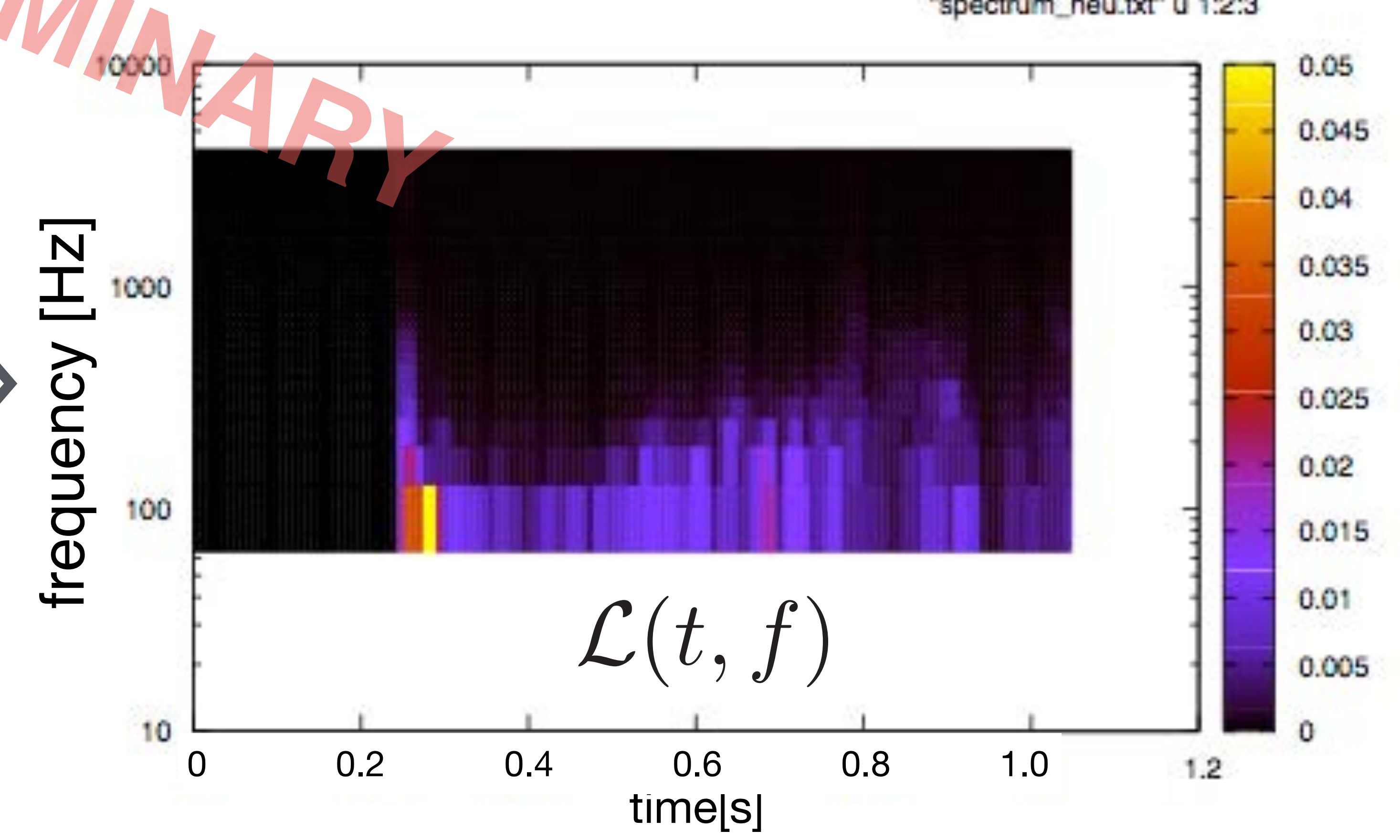
example : SFFT of GW and neutrino

figures by Asano









Is there a chance ?

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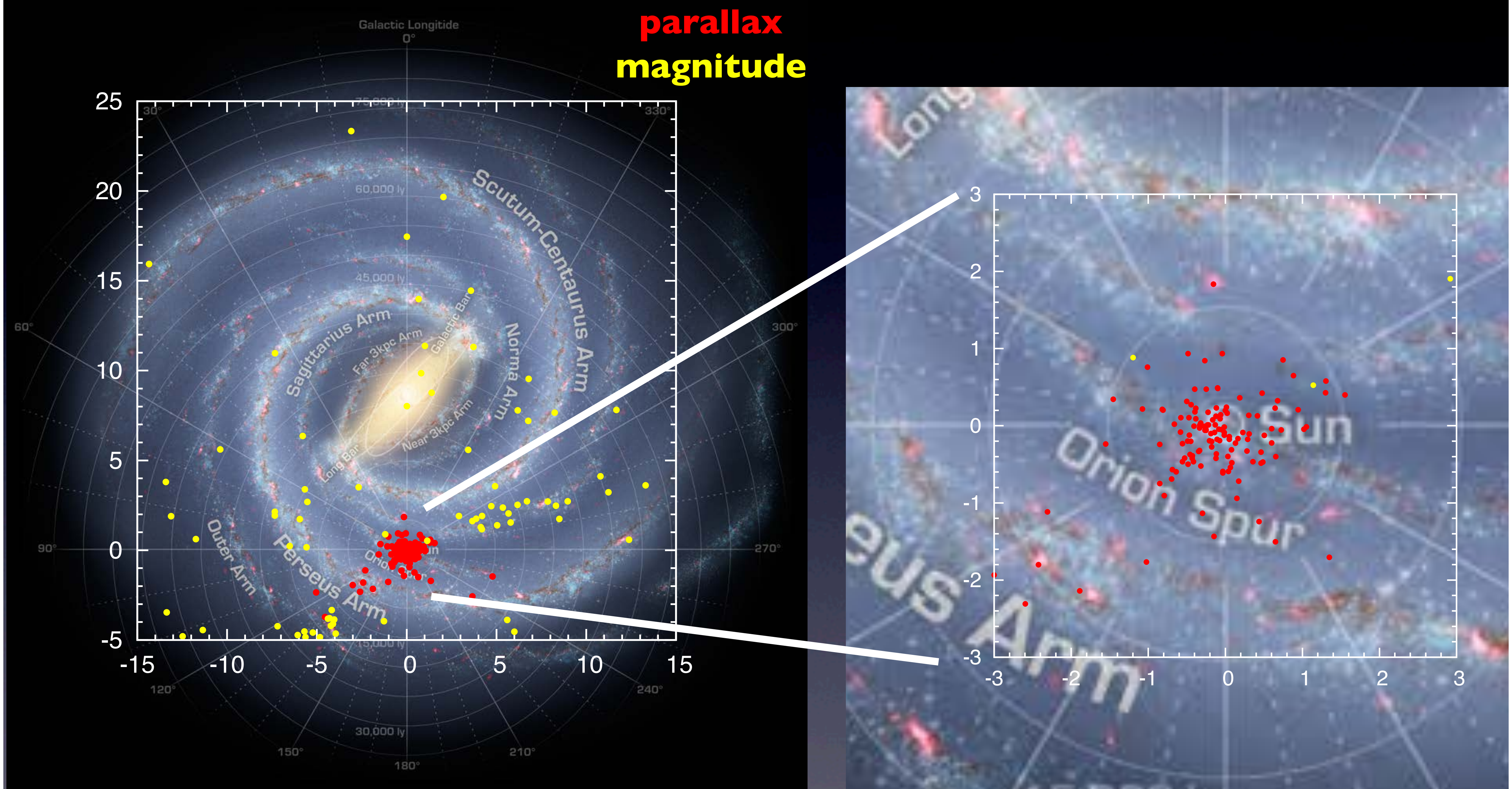
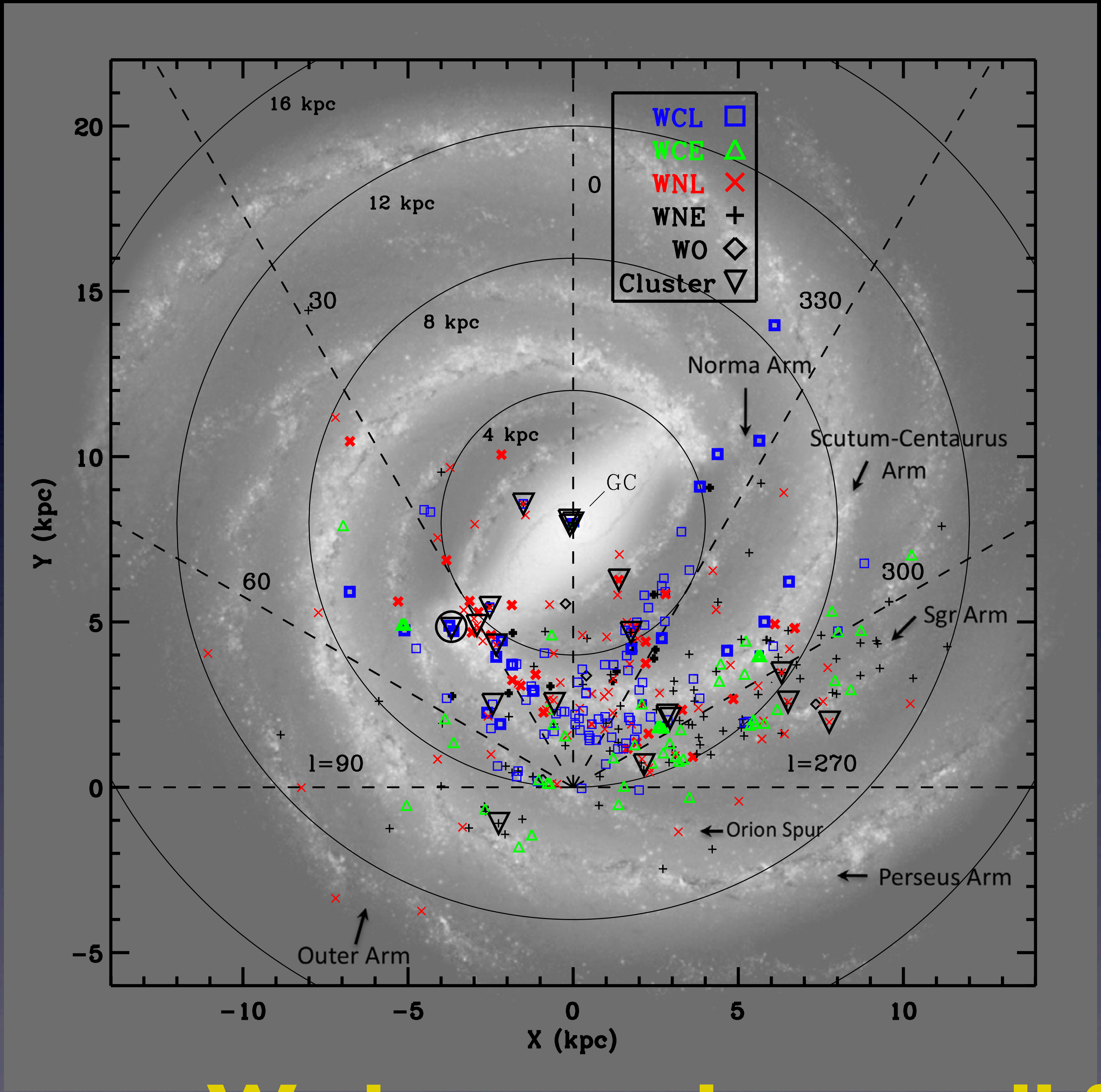
viewgraph by M.Tanaka

How many and where? : (I) RSG



We know only a small fraction!!

How many and where? : (2) WR



WR catalog

van der Hucht 2001, NewAR, 45, 135

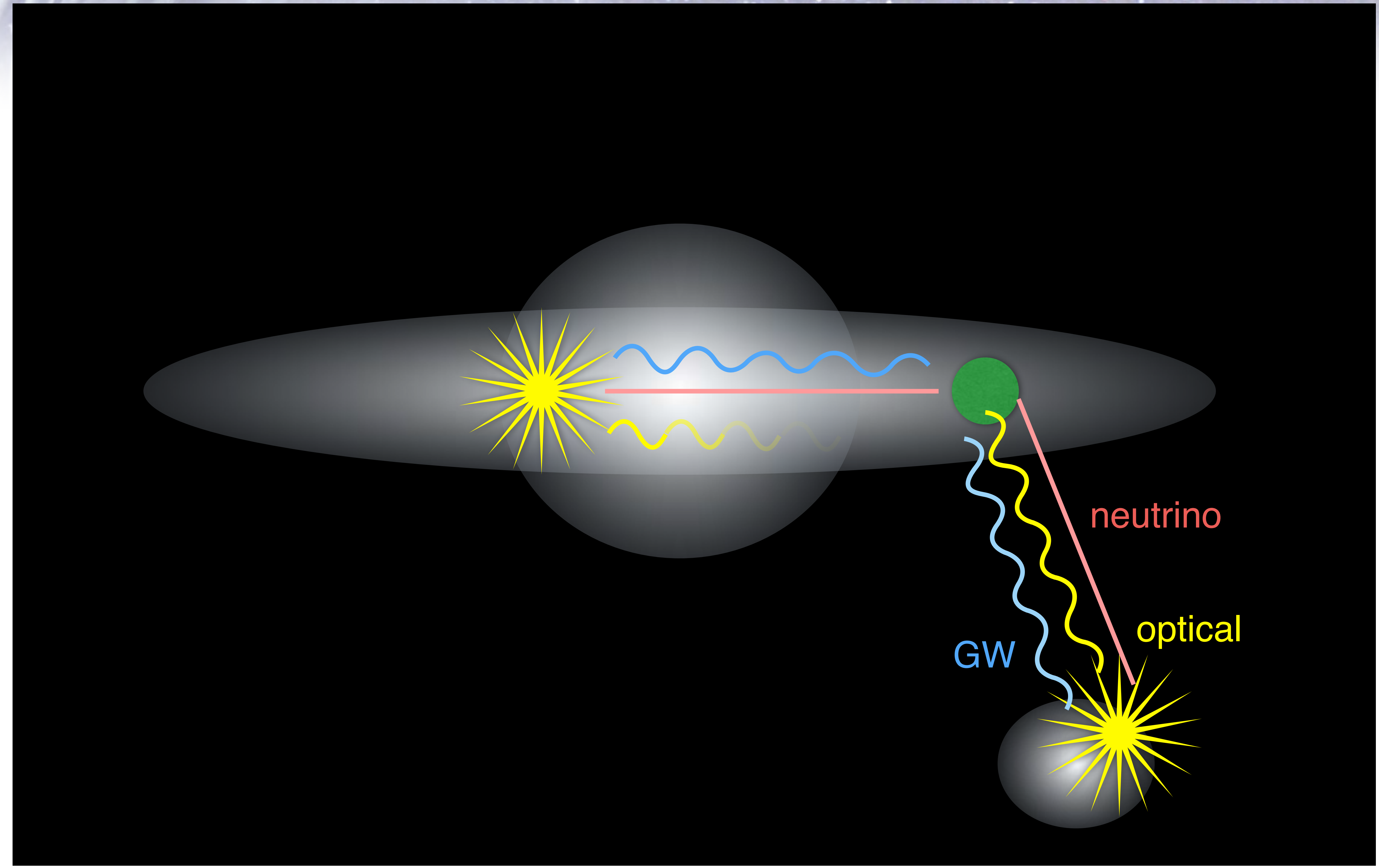
Search in NIR

Mauerhan et al. 2011, AJ, 142, 40

Shara et al. 2012, AJ, 143, 149

We know only a small fraction!!

Our galaxy is opaque for EM (optical thick)



Chance will given only who prepare it !

KAGRA

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Summary and Prospects

MEXT Grant-in-Aid for Scientific Research on Innovative Areas
"New Developments in Astrophysics Through Multi-Messenger Observations of Gravitational Wave Sources"

- We would like to open the window for GW sources.
- Multi-messeanger (mutual follow-ups and/or counterparts) may bring more information.
- LIGO will start it observation soon.
- KAGRA will have 1st test run at Dec. 2015, and cryogenic operation is planned in fiscal year 2017.
- **Neutrino and GW might be a good partner to understand the supernova.**

Appendix : KAGRA status

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KAGRA Collaboration in the world

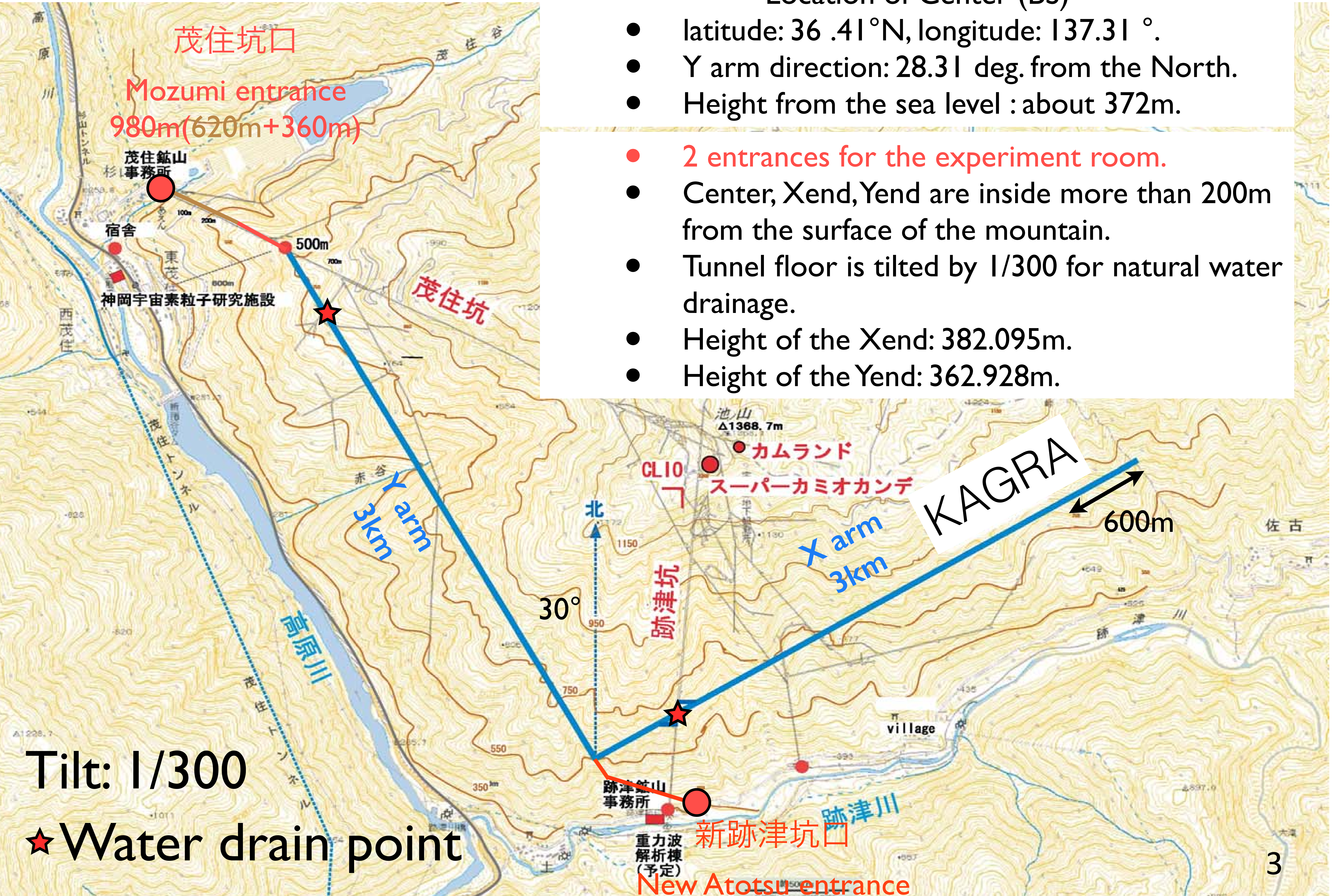
- Research organizations of laboratories and faculties of universities are 41 in Japan and 37 in overseas
- 158 researchers in Japan and 69 in abroad, 227 members in total

viewgraph by K.Kuroda

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.



by T.Uchiyama

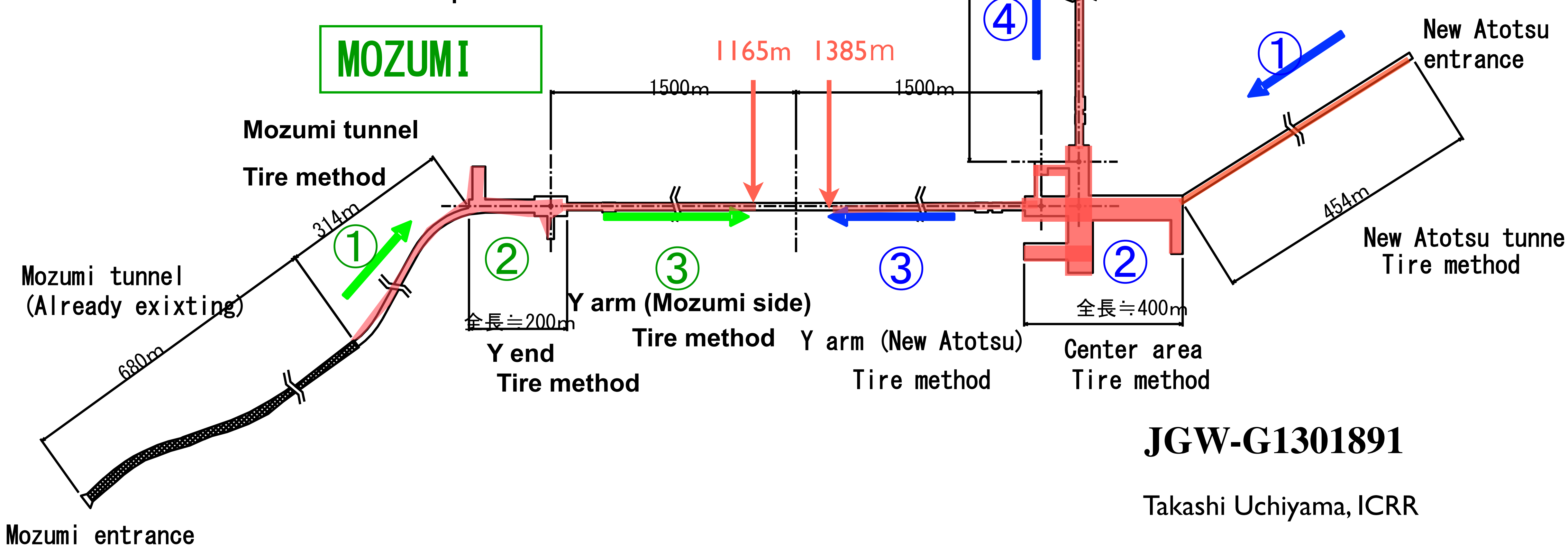
トンネル掘削

KAGRA 科研費 KAKENHI

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

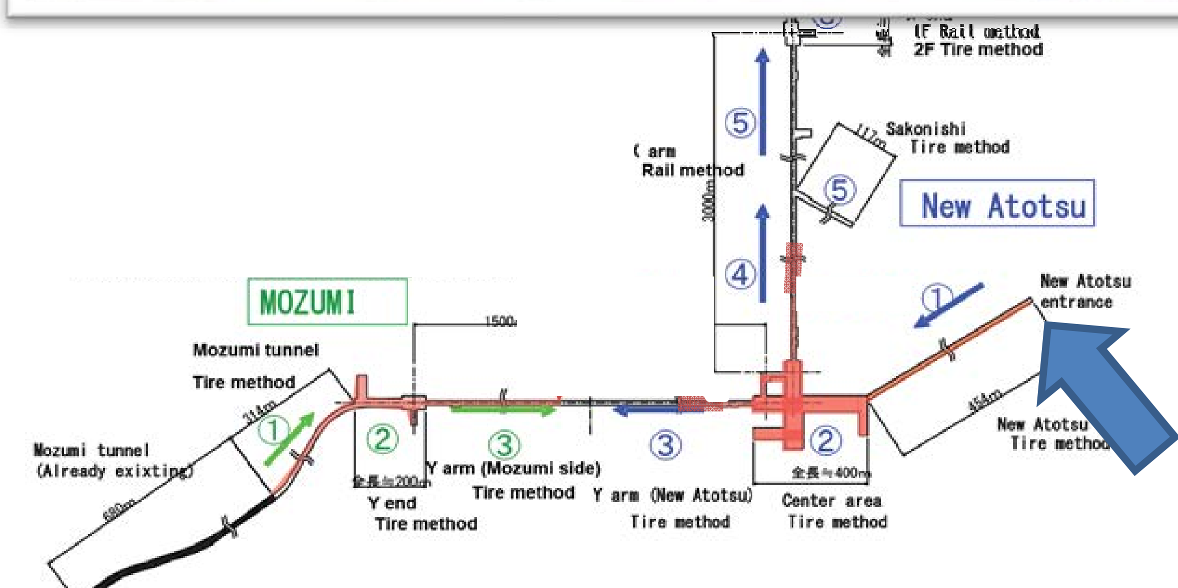
トンネル工事

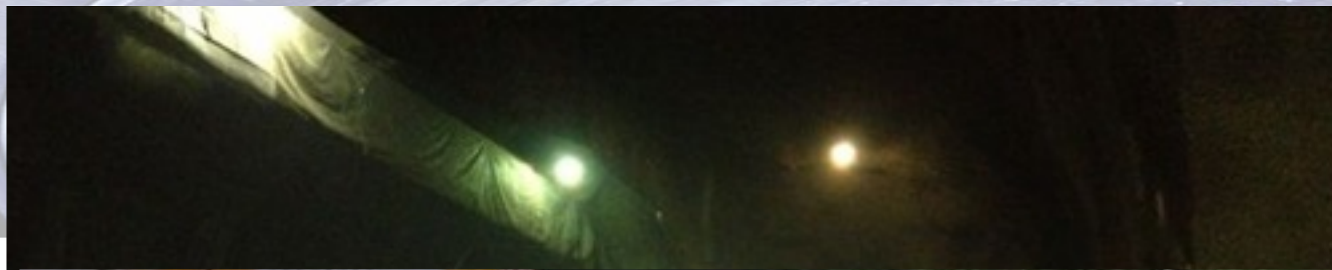
新学術「重力波天体」
viewgraph by T.Kajita

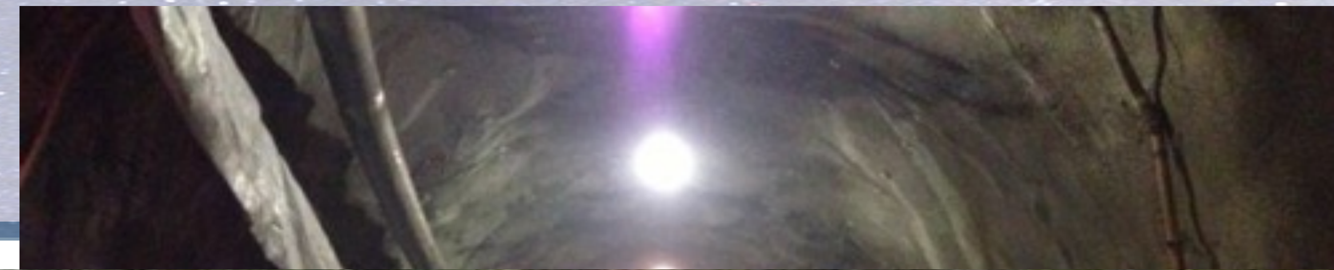
New Atotsu entrance

End of April, 2012

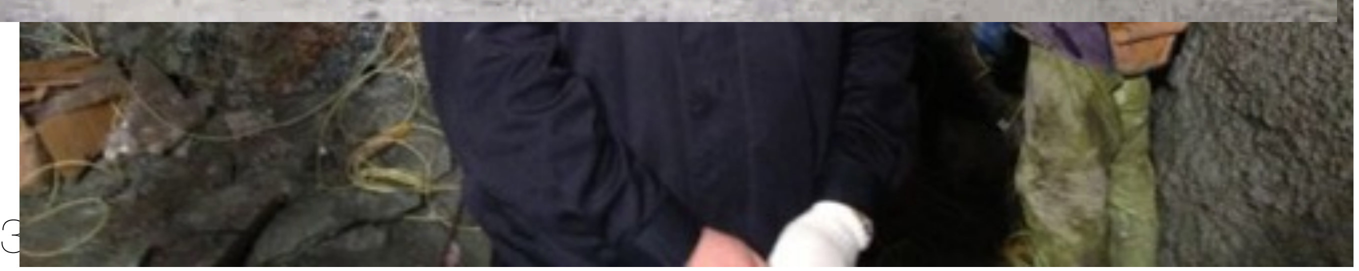
Mid June, 2012



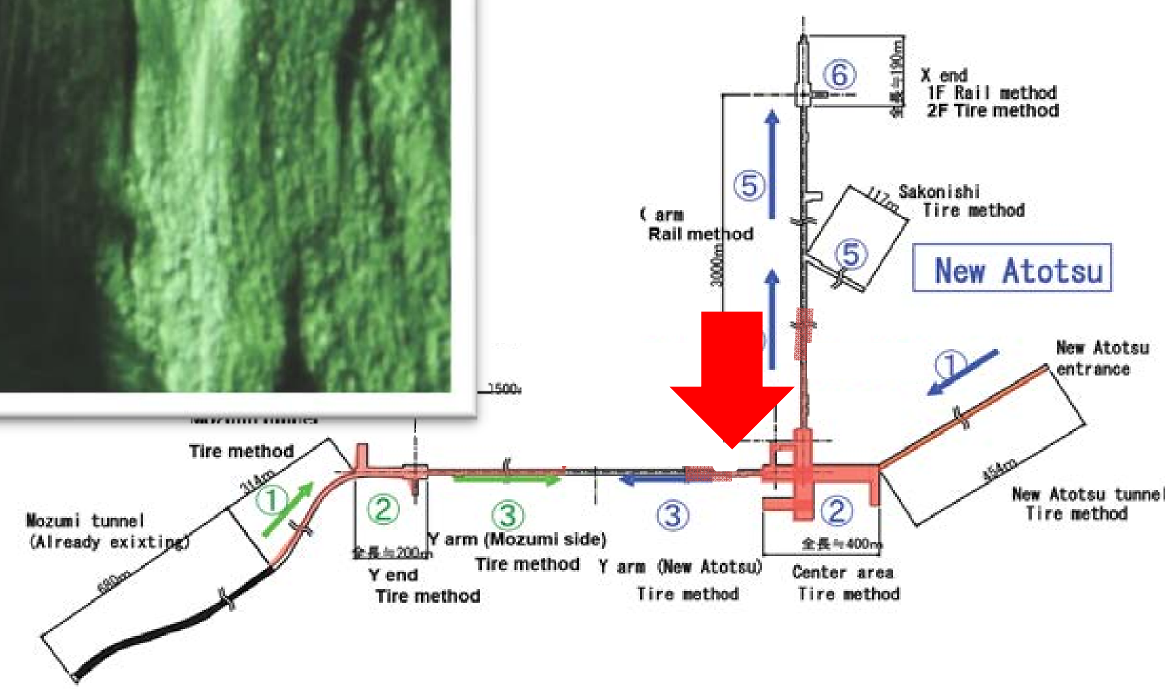





ずり搬出中
ずり出し中
立入り禁止



Y-arm excavation from the Center room

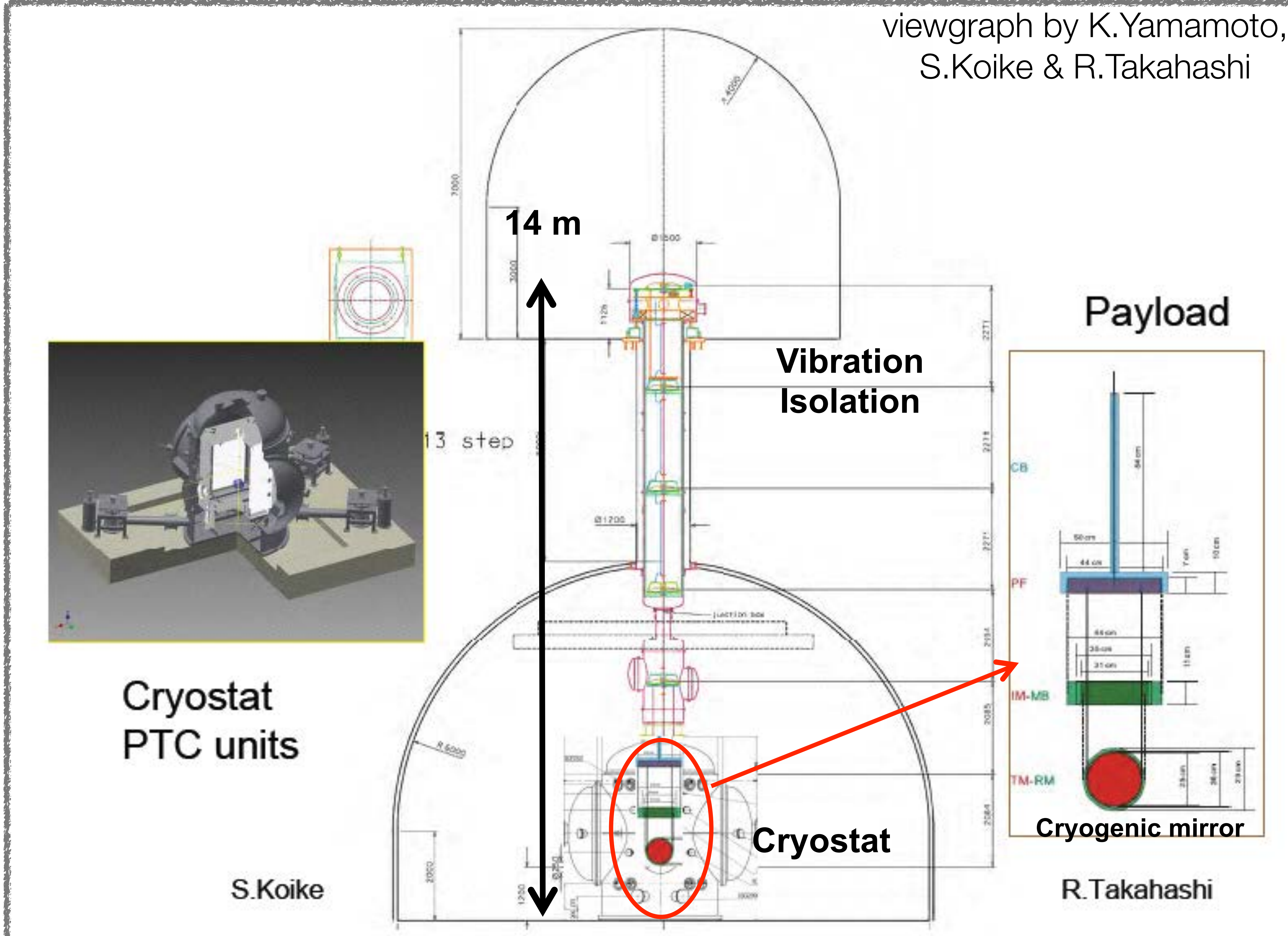


トンネル掘削完成@2014年3月

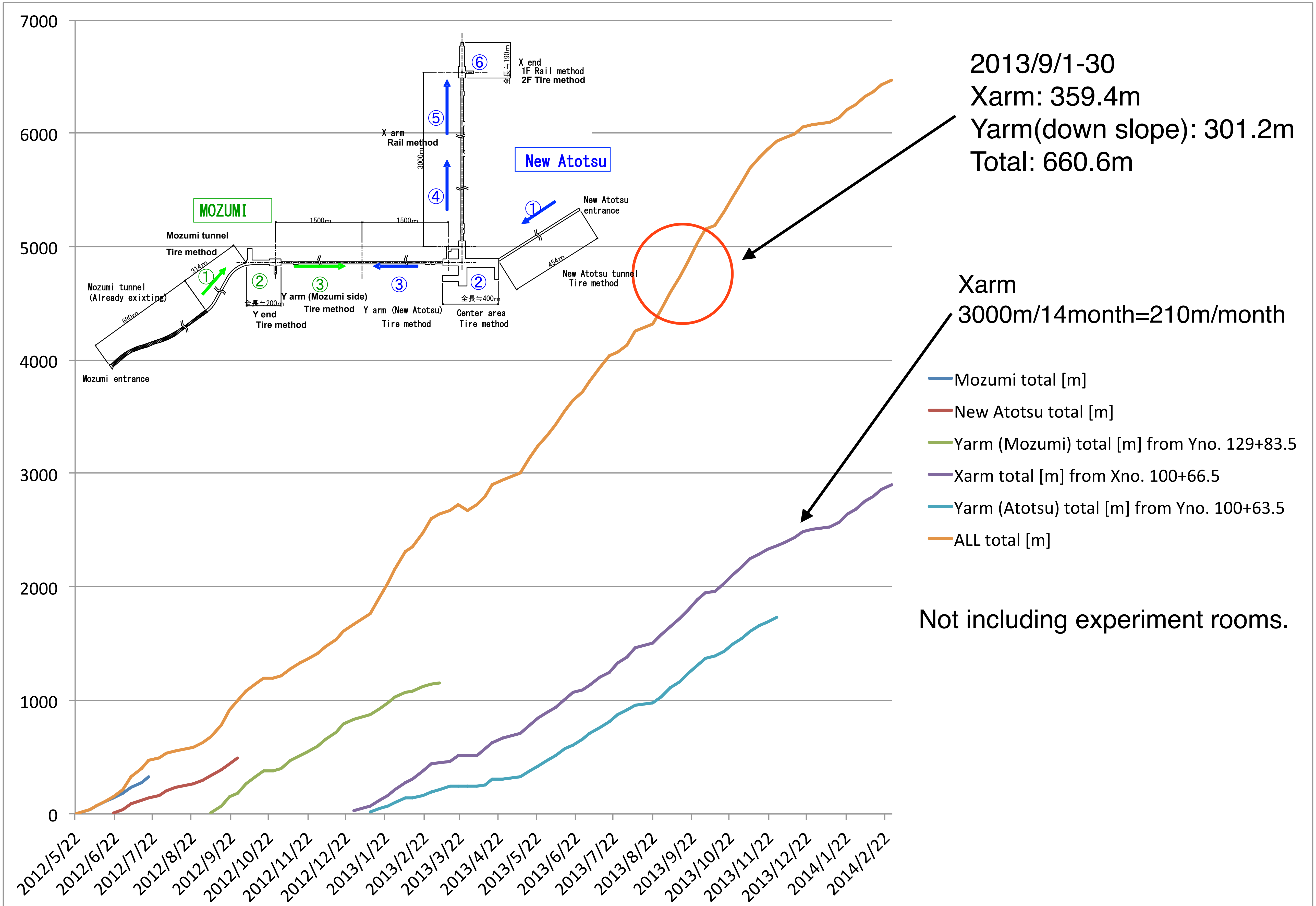
(4th July, 2014)

Vibration isolation and cryostat

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







by T.Uchiyama

Cryostat

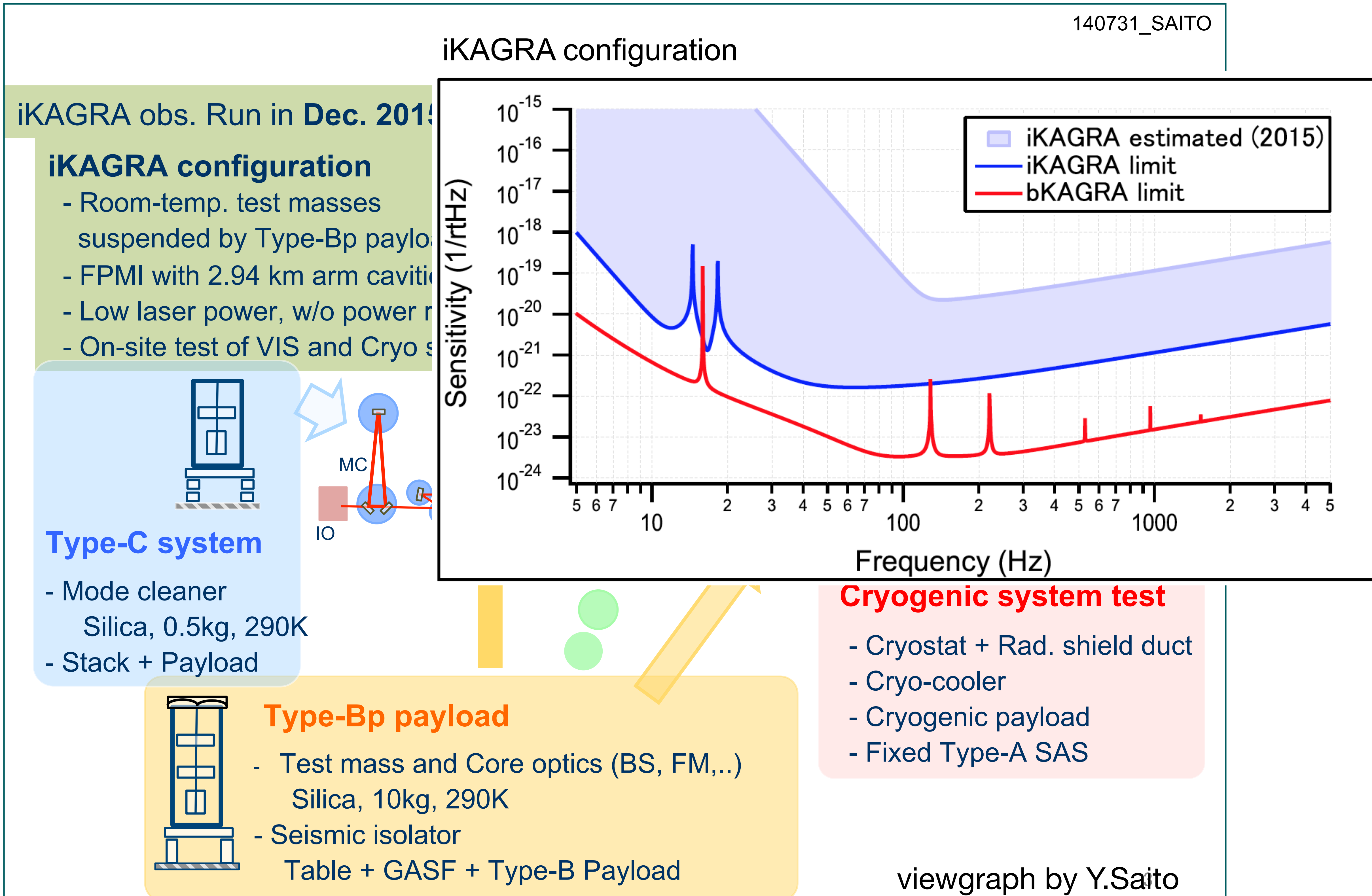
MC chambers and cryostats installation

Transportation of cryostat in Y arm

Installation of MC chambers (center area)

viewgraph by T.Uchiyama

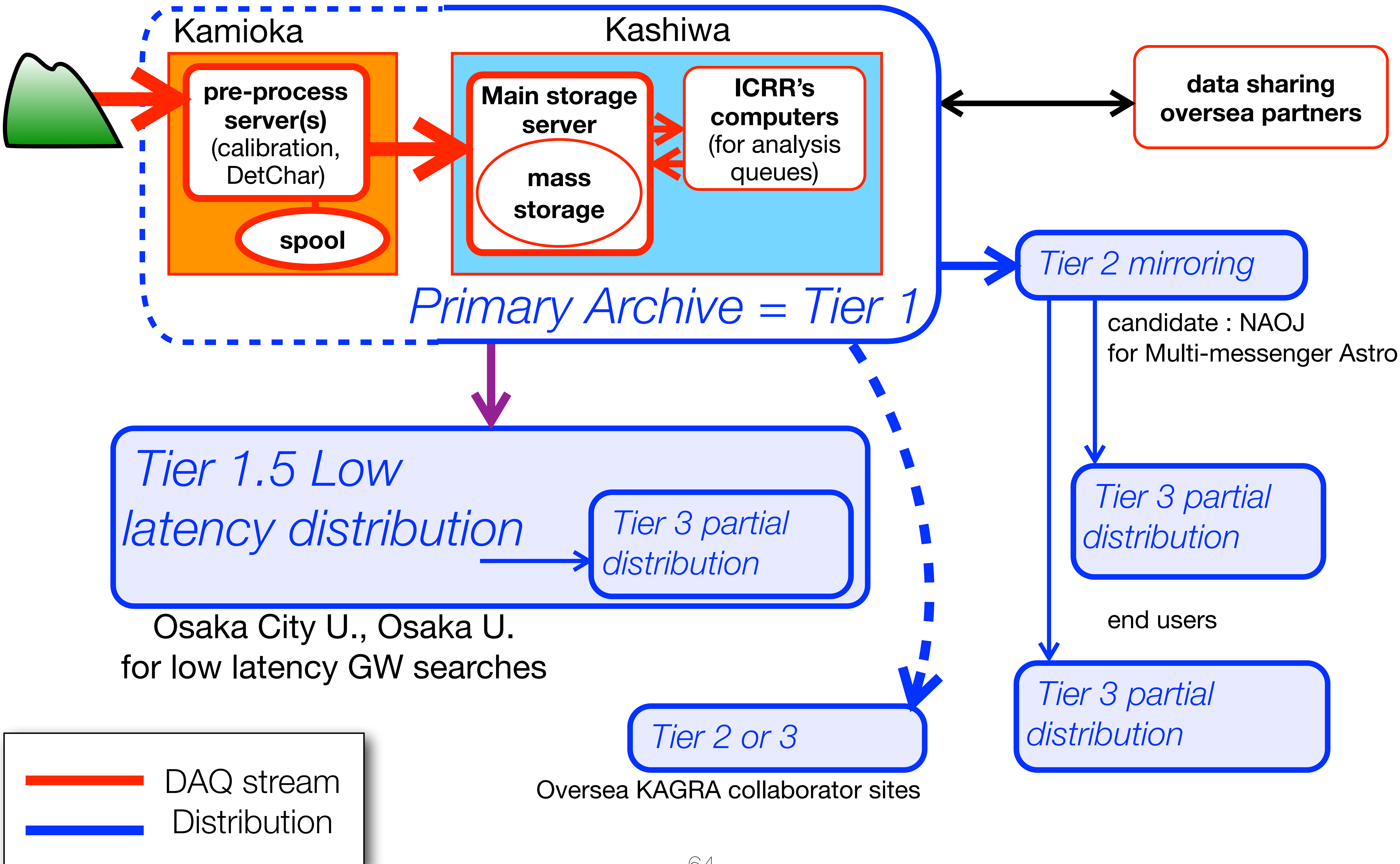
iKAGRA observation will be in December 2015!



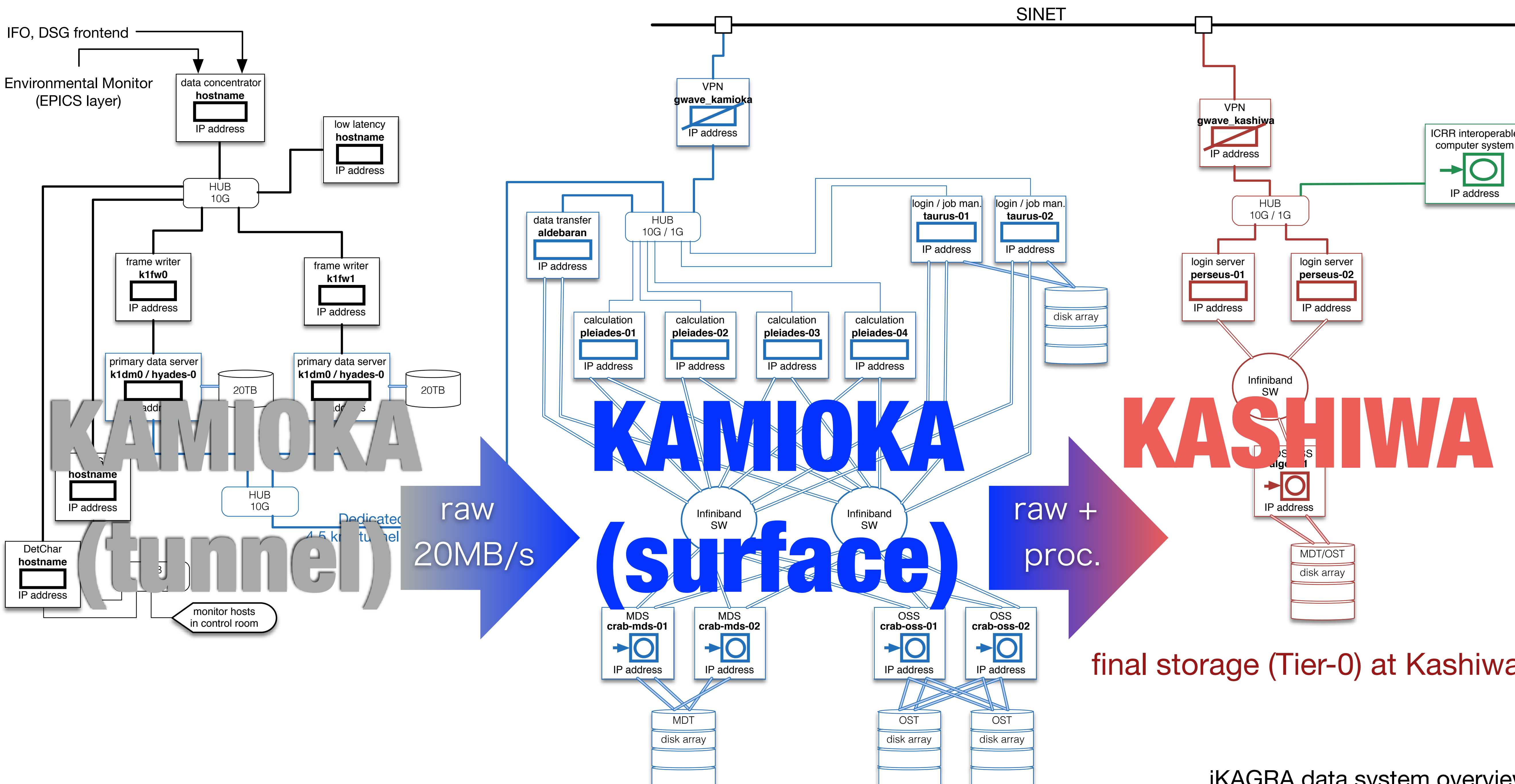
New building (“Analysis build.”)

at Jan.2014

Overview of Data Flow



Overview of data flow



final storage (Tier-0) at Kashiwa

surface building at Kamioka

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

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

Hardware of iKAGRA data system

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@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

@Kashiwa (ICRR building 6th floor)

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

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

200 TiB ‘lustre’ file system

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.

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

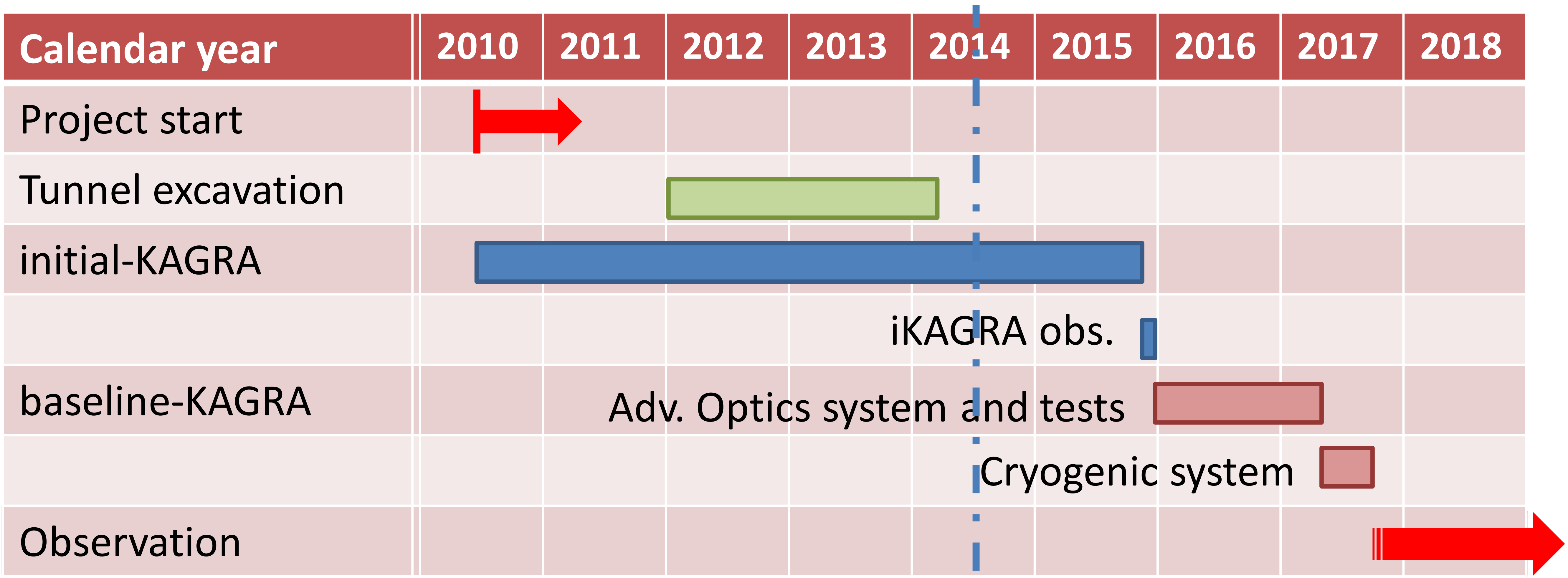
Inje Univ. : Hyung Won Lee
Jeongcho Kim
Seoul Nat. U.: Chunglee Kim

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

About 30 people in the mailing list.

viewgraph by H.Tagoshi, Y.Itoh

Schedule to the observation era



drawn by T.Kajita