

**Promoting Gravitational Wave  
Astronomy with the  
Gravitational Wave Telescope,  
KAGRA**

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Gravitational Wave Science Project, NAOJ**

# 9. Project Organization: KAGRA

Cosmic Ray researchers  
Congress (CRC)

Current plan to push for top priority  
as the most important issue

- Construction
- Operation
- Maintenance
- Upgrade

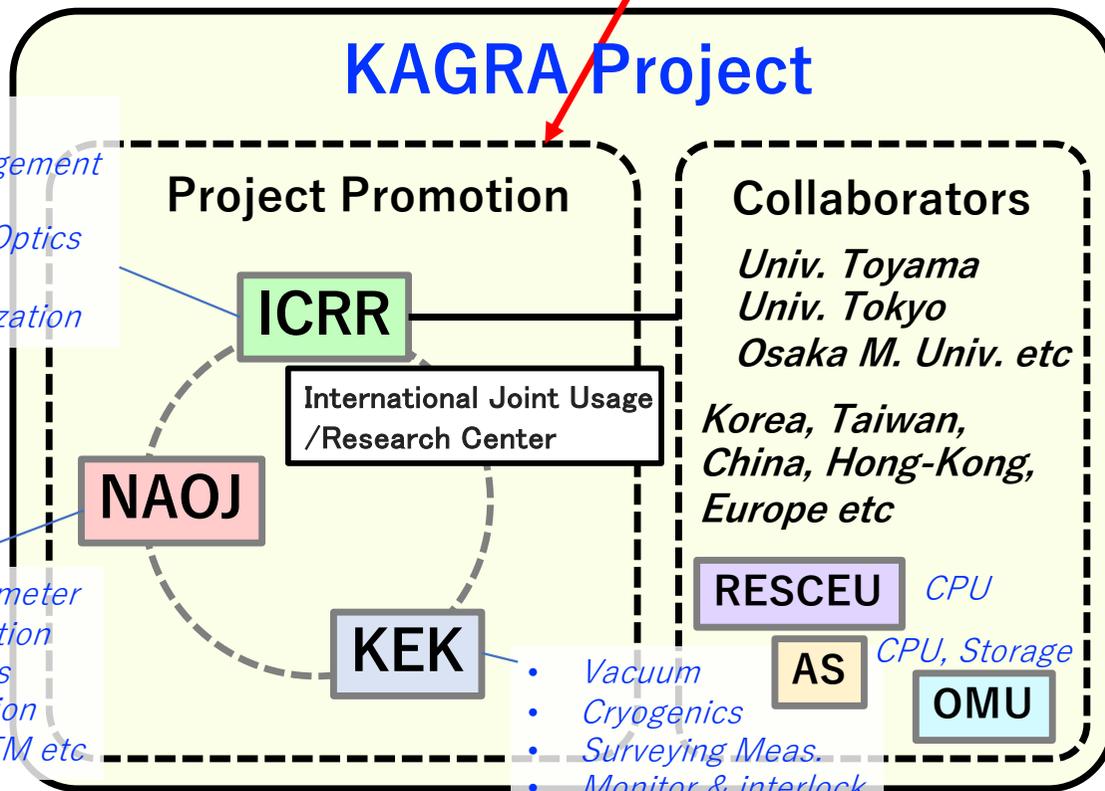
3-parties MoU

Japan Gravitational Wave  
Community (JGWC)

GW observation by KAGRA  
is the top priority

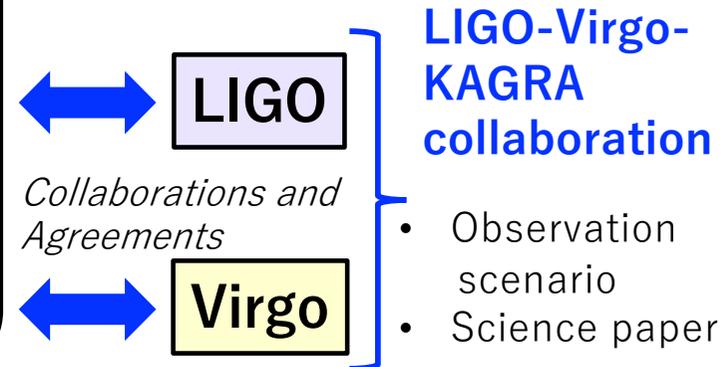
- Facility
- Budget & Management
- Control System
- Input & Output Optics
- Electronics
- Data Characterization

- Main Interferometer
- Vibration Isolation
- Auxiliary Optics
- Mirror Evaluation
- Calibration, PEM etc



Gravitational Wave  
International  
Committee  
(GWIC)

Collaborations and Agreements

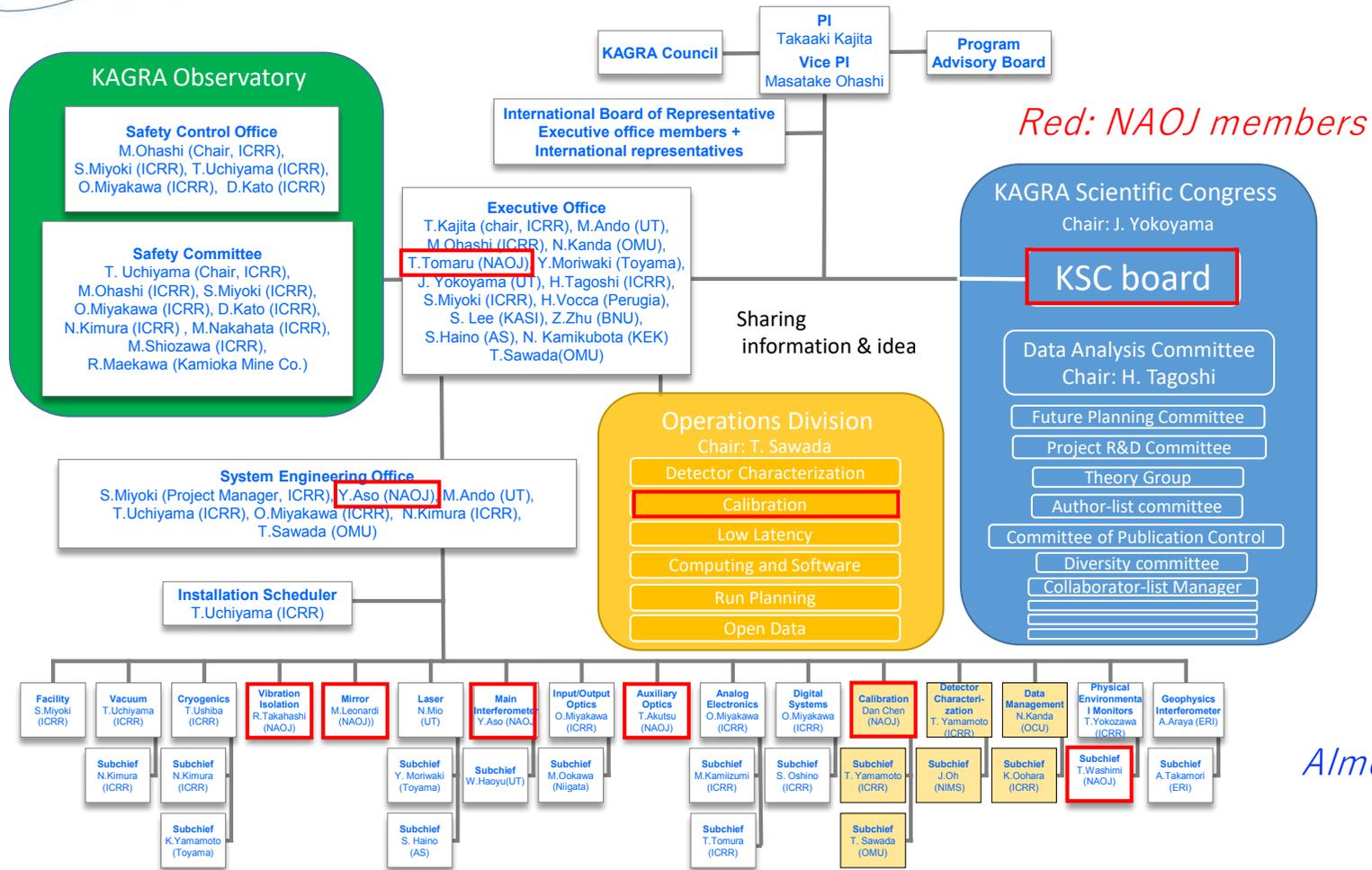


This proposal does **not concern the entire KAGRA project**, but **rather the plan that is being carried out and promoted by** the National Astronomical Observatory of Japan Gravitational Wave Science Project (**NAOJ GWSP**) as one of the sub-host of KAGRA. Therefore, although both the part about KAGRA as a whole and the plan of the NAOJ GWSP will be described, we will try to distinguish between them by clarifying the subject below.



# KAGRA management structure

JGW-M1706715-26



Red: NAOJ members

Almost all Japan

Oct 7, 2022

## 2. Science Goals

### Promoting GW Astronomy

- Understanding the universe based on GW observations
- Study of fundamental physics such as general relativity, cosmology, and particle physics

**KAGRA's science goals = NAOJ-GWSP's science goals**

However, the role of NAOJ-GWSP is to promote GW astronomy [from an astronomical perspective](#), and [advanced technology development](#).

- *Multi-messenger astronomy with EM telescopes*
- *Supernova study with NAOJ-DOS*
- *Advanced technology R&D with NAOJ-ATC*

# Astronomy

## 3. Science Objectives

# Physics

### • **Black-hole Astronomy**

- Stellar mass BH
- Mid mass BH
- Super-massive BH
- Distribution of BH & BH binary
- POP-III, PBH, Dynamical Formation
- BH spectroscopy
- Ringdown

### • **Neutron Star Astronomy**

- Gravitational Collapse & Neutron Star formation
- Neutron star mass, Massive NS ?
- Equation of state of neutron
- Starquake
- Gamma Ray Burst
- Distribution of NS & NS binary

### • **Multi-messenger**

#### **Astronomy**

- Nucleosynthesis of heavy atoms
- Hubble Constant

### • **Cosmology**

- Standard Siren

### • **Supernova**

### • **Pulsar**

### • **Verification of GR**

- Applicable range of GR
- Non-linearity
- Polarization of GW
- Degeneration of masses and inclination angle of binary stars
- GW speed (Mass of graviton)
- Reaction of GW emission
- Quantum Gravity
- GW background (**Cosmology**)
  - Cosmic Inflation
  - Density of binary stars
  - Cosmological parameters
- **Hadron Physics**

# GW Events until O3

## Black-hole Science

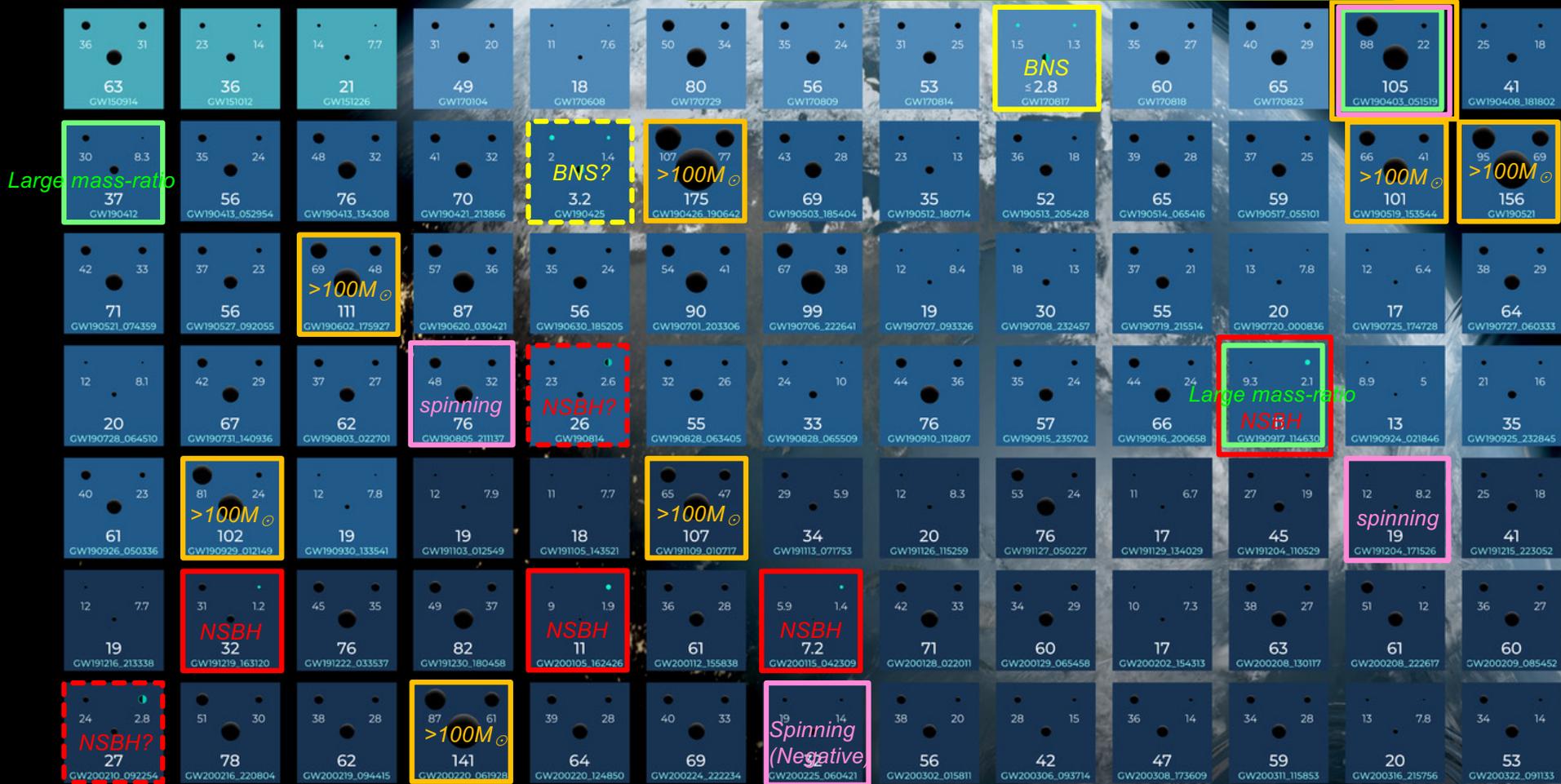
- $>100M_{\odot}$  BH
- $>2M_{\odot}$  Compact Object
- Spin ...

Large mass-ratio  
spinning  
 $>100M_{\odot}$

OBSERVING  
01  
RUN  
2015 - 2016

02  
2016 - 2017

03  
2017 - 2018

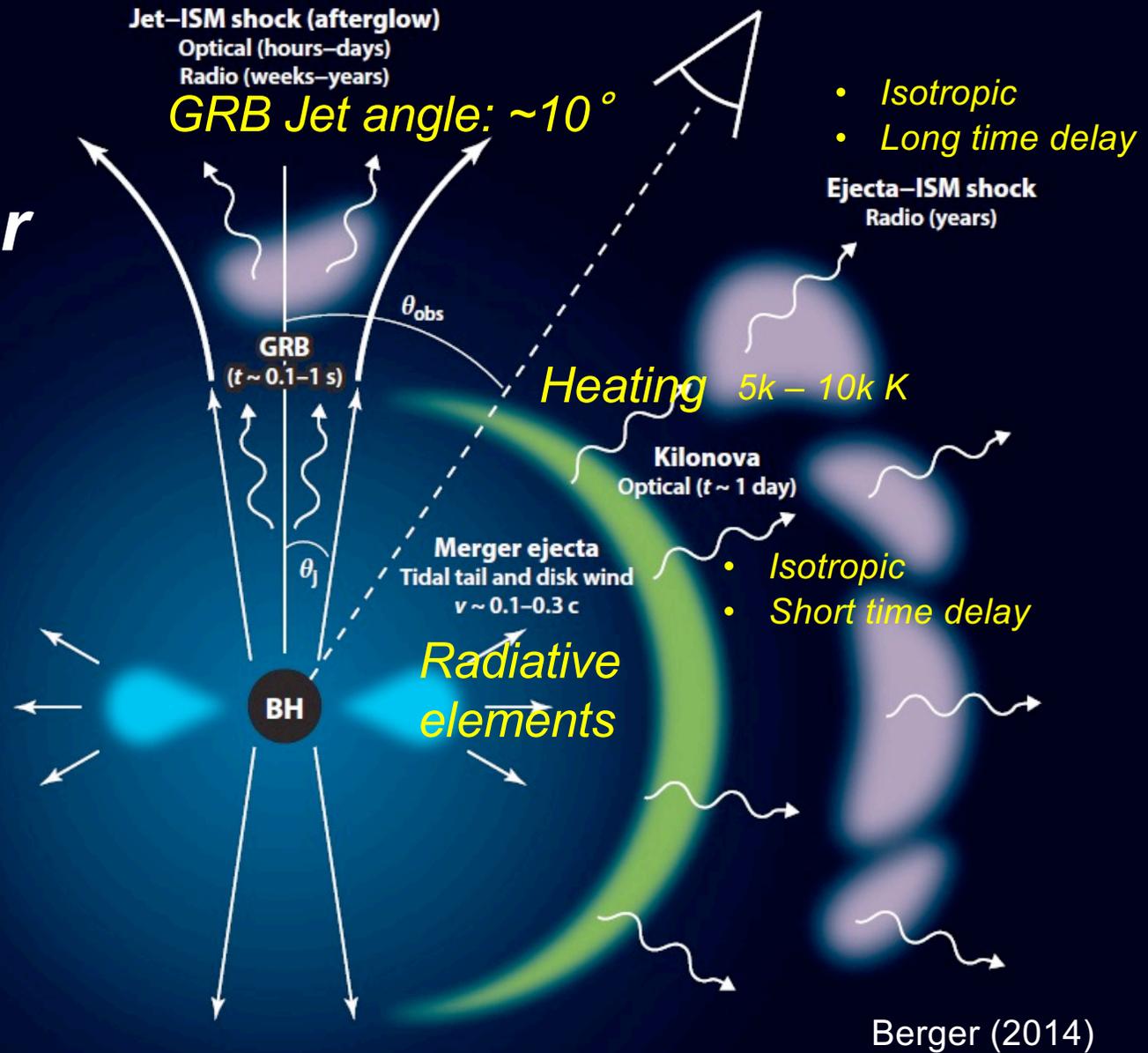
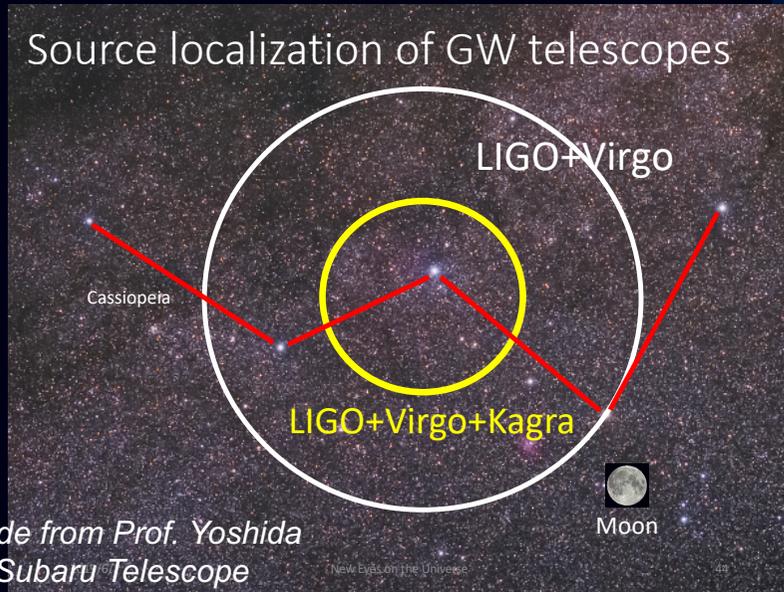


More than 200 events until Dec. 2024

# Binary Neutron Star Merger

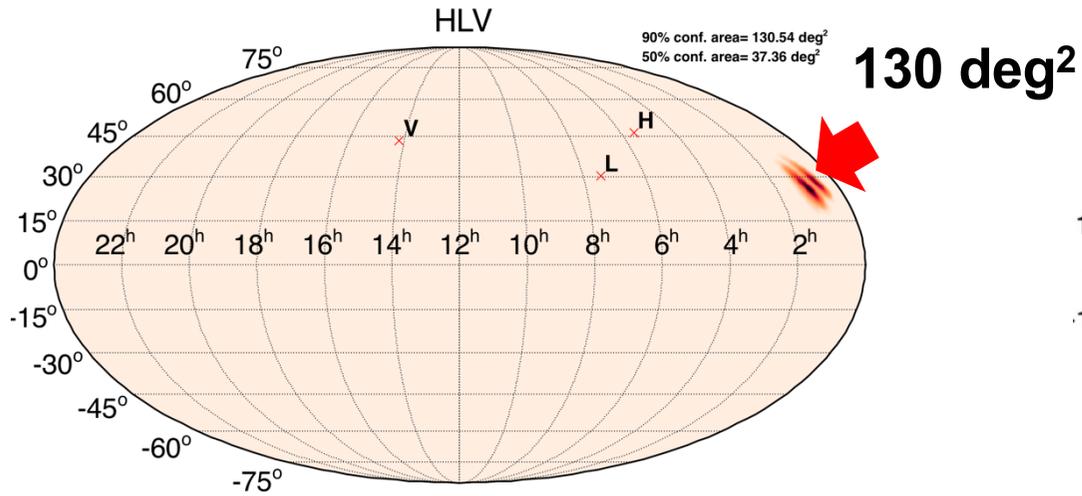
→ **Multi-messenger Astronomy**

Only one follow-up observation was successful.

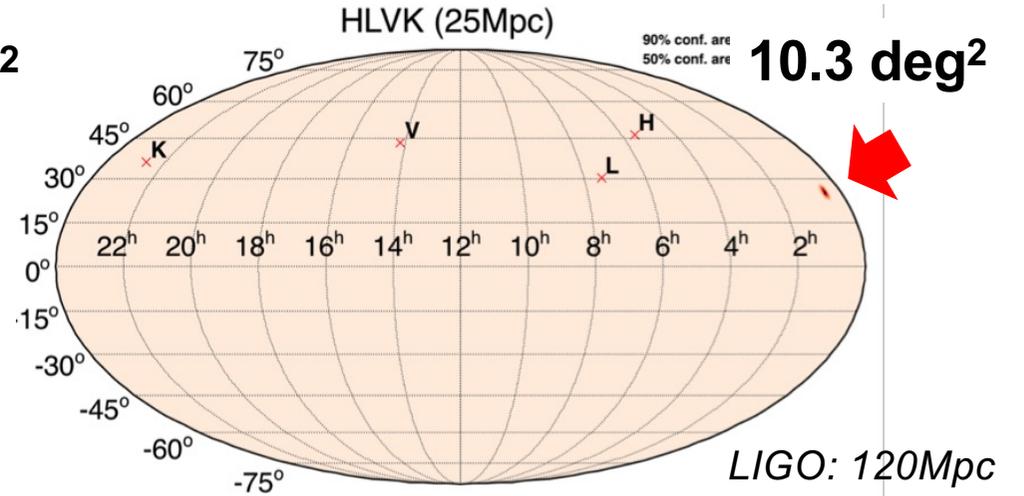


# Expected Localization

## Hanford-Livingston-Virgo



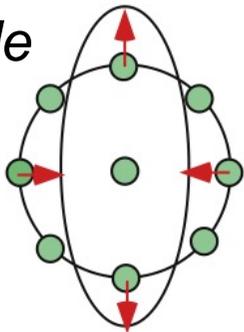
## Hanford-Livingston-Virgo-KAGRA



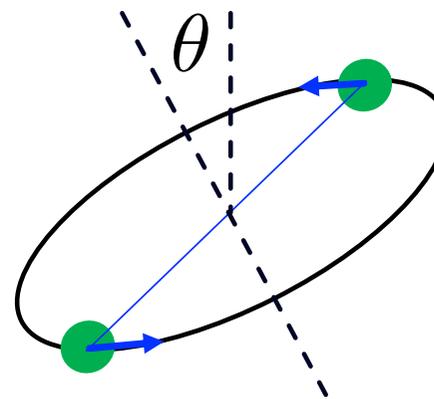
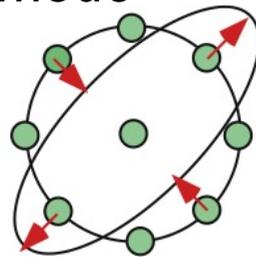
LIGO: 120Mpc  
VIRGO: 60Mpc  
KAGRA: 25Mpc

## GW Polarization

+ mode



x mode

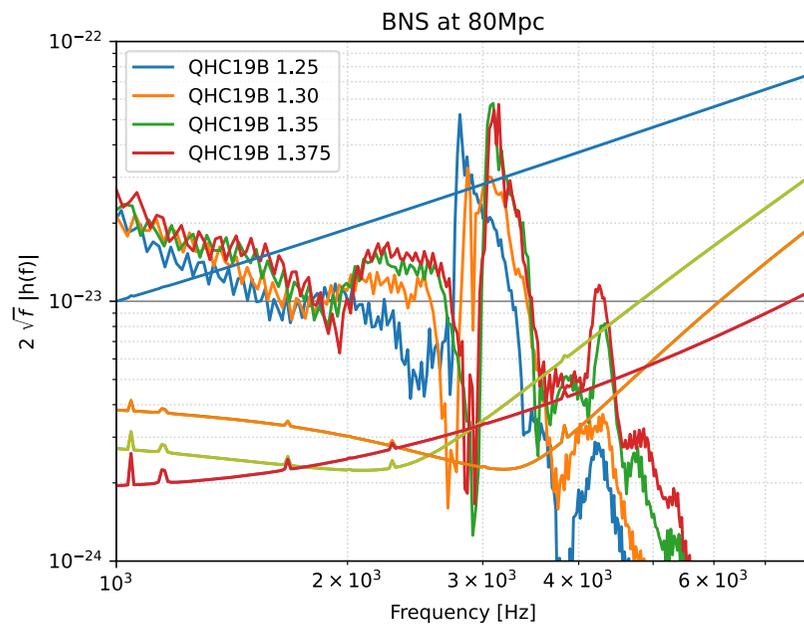


*With more than four telescopes, we can identify GW polarization and can know inclination angle of binary orbit.*

# kHz Band Development: KAGRA-HF (*tentative*)

Post-merger BNS signal

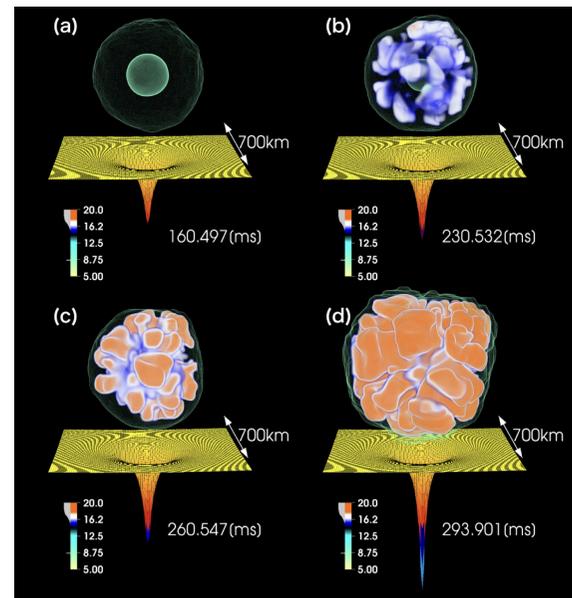
➔ NS EoS



From presentation  
of Tagoshi (ICRR)

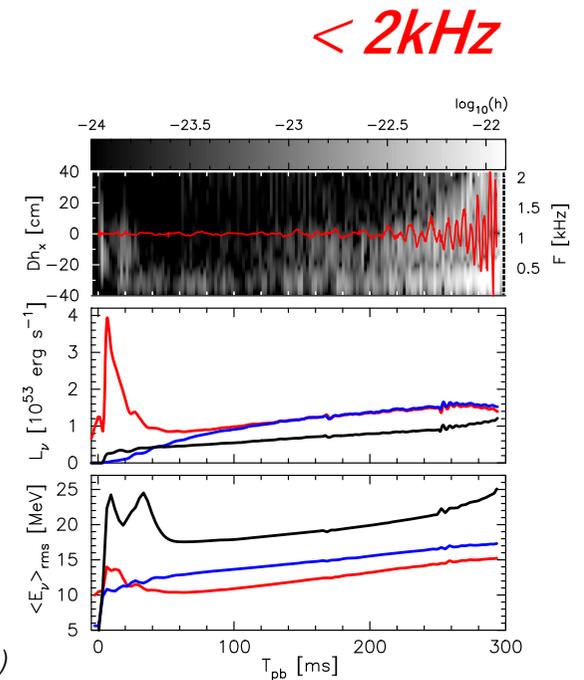
↑  
**~ 3kHz**

Formation of BH by star collapse

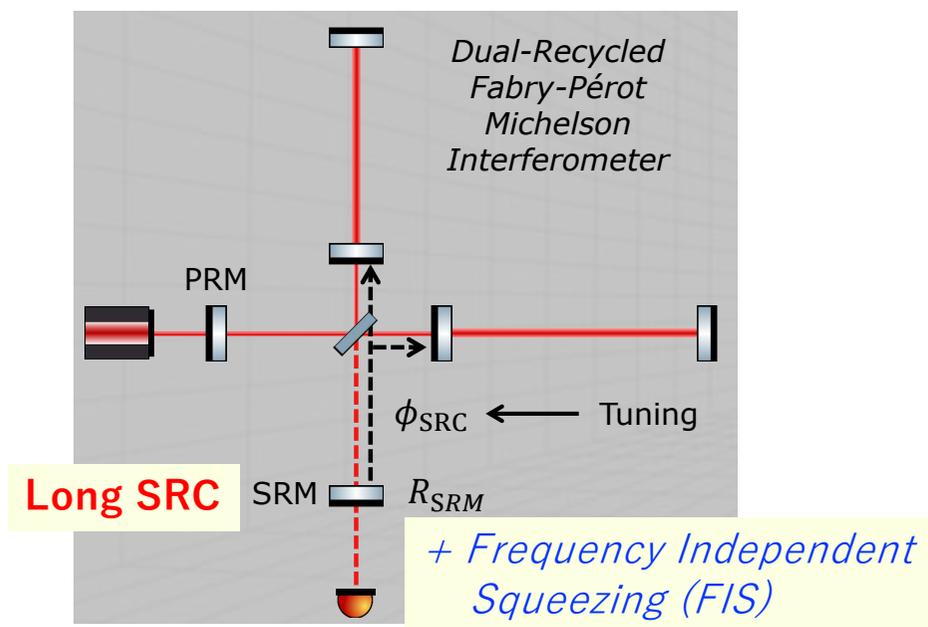


NAOJ & Fukuoka Univ.'s  
study

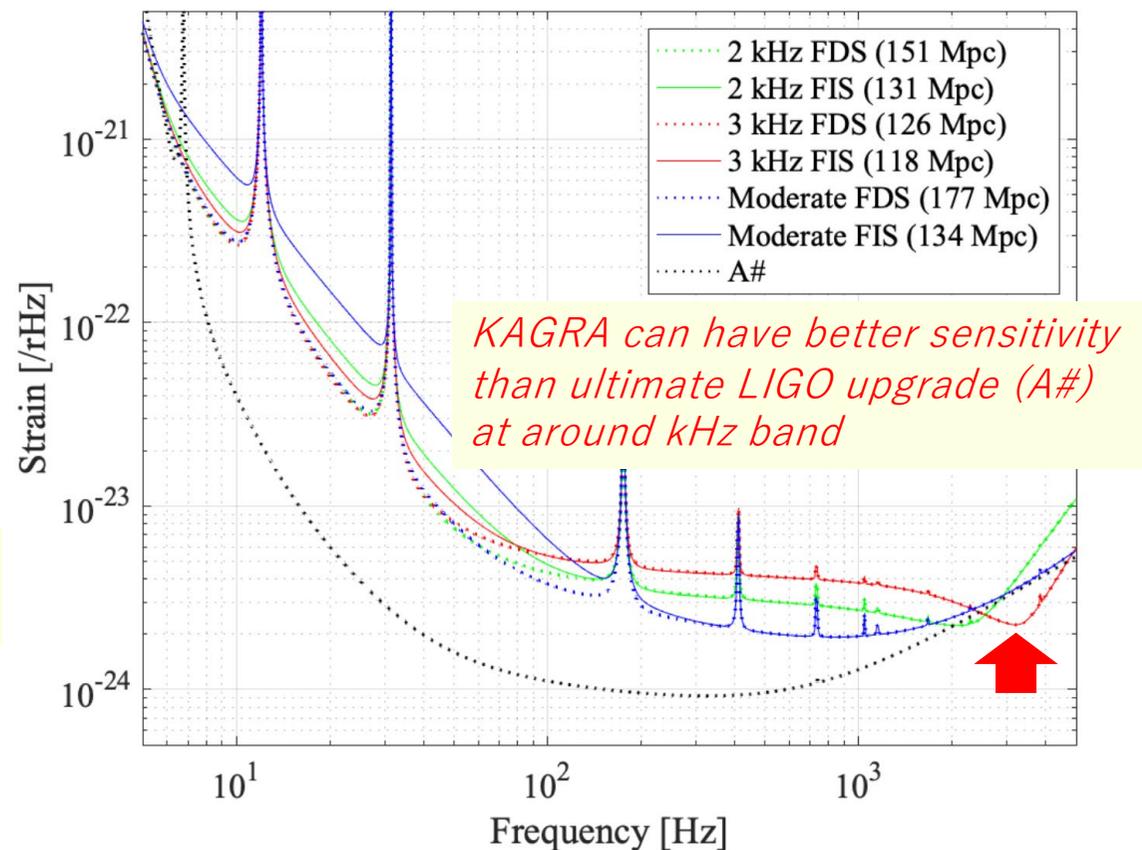
T. Kuroda et al., MNRAS 477, L80-L84 (2018)



# kHz Band Development: KAGRA-HF (*tentative*)



	2 kHz	3 kHz	Mod.
ITM trans.	0.2%	0.4%	0.4%
BS power	750 W	1.5 kW	1.5 kW
Mirror temp.	23.5 K	26 K	26 K
SRM Refl.	99.5%	99.5%	96%



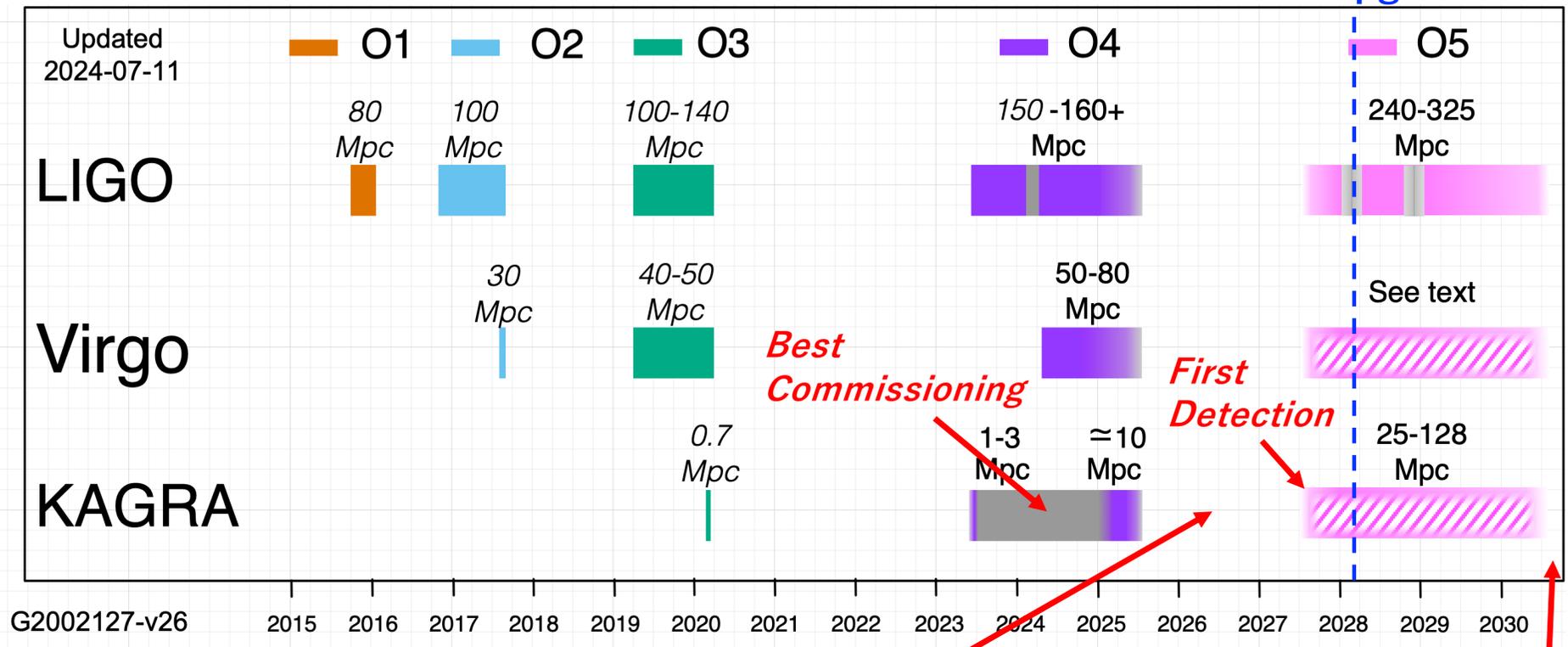
In 60-80Mpc distance, KAGRA-HF can detect postmerger BNS signal with S/N=5

# 4. Science Investigations

NAOJ roadmap & 5th NINS mid-term plan



O5 & upgrade toward O6



*Improvements*

- OMC VIS
- ITMs replacement
- New timing system
- Fiber Q
- DGS upgrade
- Maintenance

*KAGRA-HF upgrade?*

- ITM recoating
- Squeezer

# 4. NAOJ-GWSP's Science Investigations

*KAGRA common investigations*  
*Our unique investigations*

## 4.1 Science Investigations until 2033

Before FY2028 ***Top priority mission for us is successful GW detection by KAGRA***

- Best KAGRA commissioning → ~10Mpc BNS sensitivity → Joining O4
- Hardware improvements → Commissioning → >25Mpc BNS sensitivity  
→ Joining O5 → First GW detection by KAGRA

• *Most of hardware development is only possible on NAOJ*

- KAGRA squeezer development with Taiwan and Korea

- *NAOJ-GWSP is playing a key-role of a practical international development*
- *NAOJ-GWSP has quantum optics technology*

- GRID computing for LVK data and computer-resource sharing

FY2028 – FY2033 ***Detailed plan is not fixed yet, but maybe we have major upgrade before O6***

- KAGRA Squeezer implementation
- KAGRA-HF by Long SRC?
- New data analysis group with 1000 CPU

# 4. NAOJ-GWSP's Science Investigations

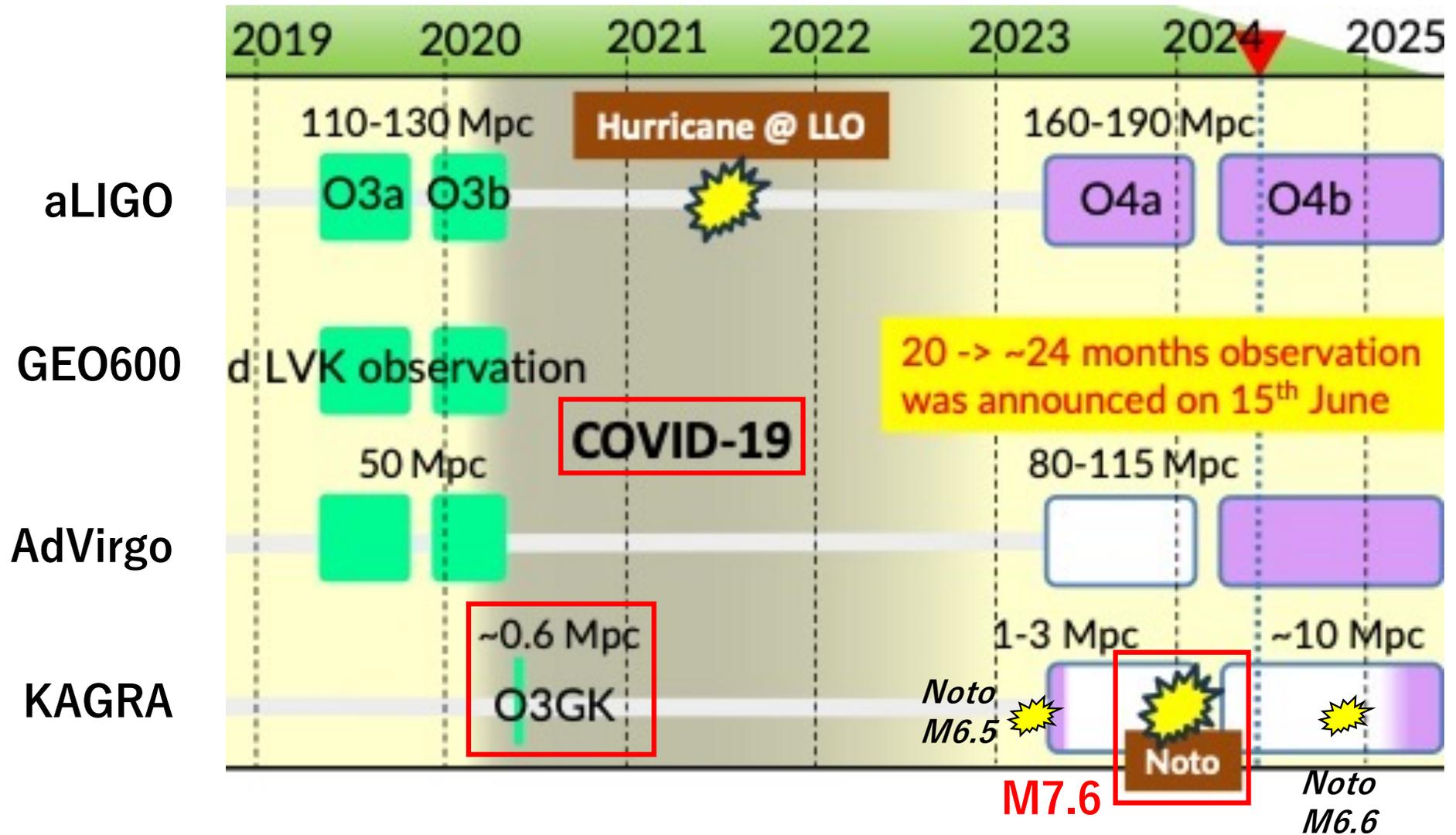
## 4.2 Science Investigations beyond 2034

- KAGRA-HF by Long SRC?
- Data analysis
- New technology development
- Shift to 3G

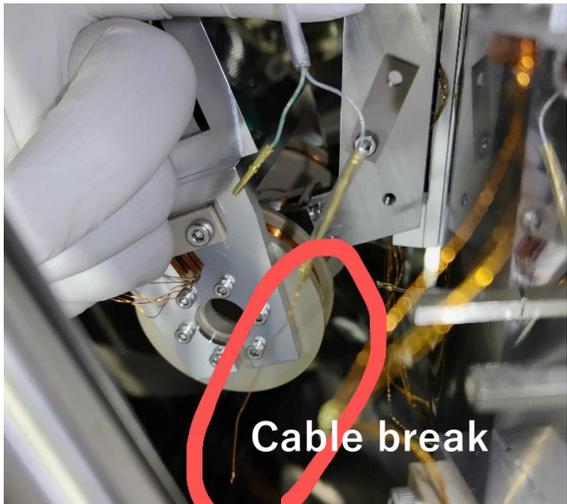
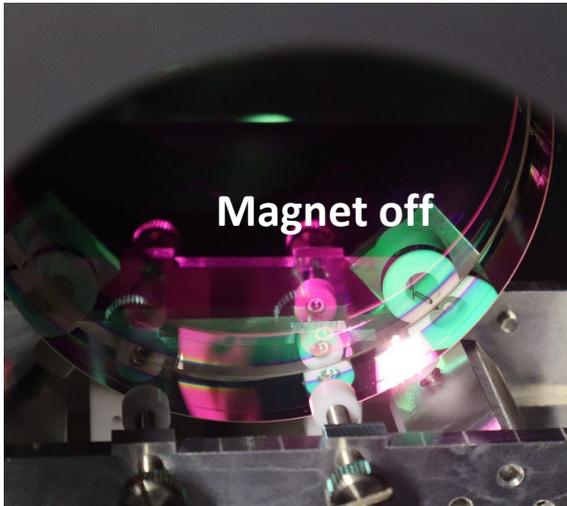
## 4.3 Threshold Science

**GW detection!**

# 7. Current Status

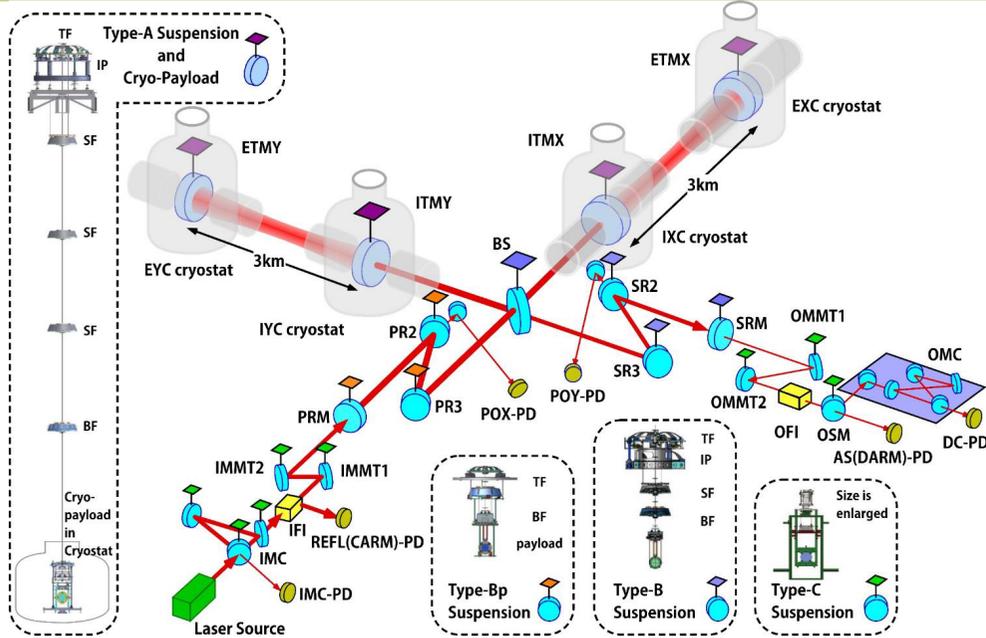


# 7. Current Status



## Mechanical recovery was finished around July 2024

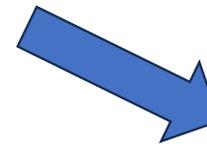
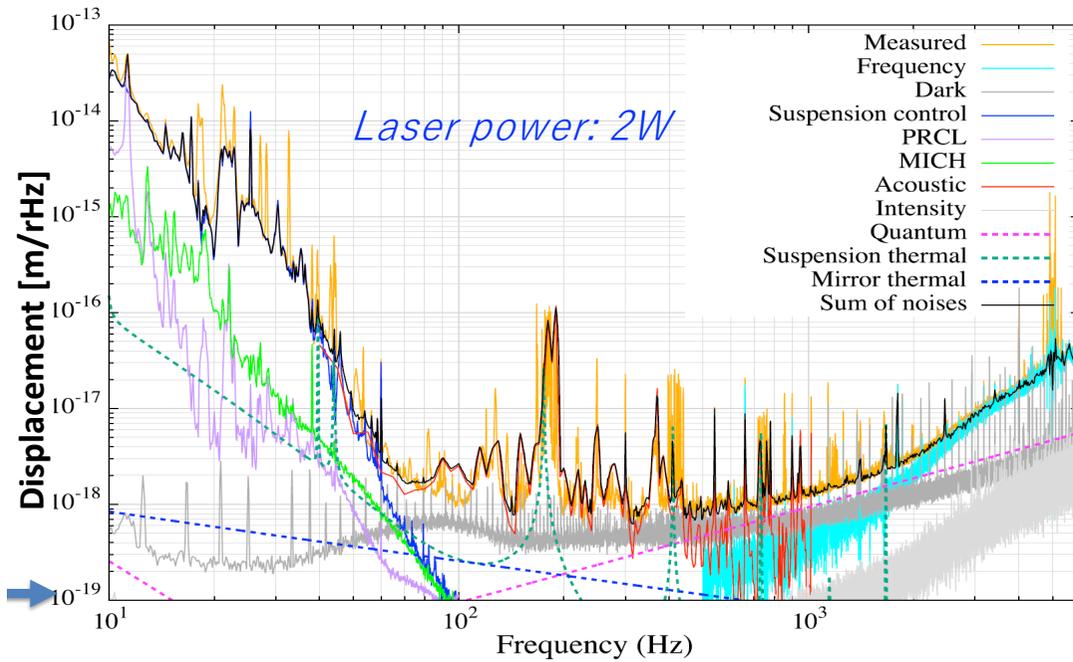
Mirror	Status
MCi	x → o
MCo	x → o
MCE	x → o
IMMT1	o
IMMT2	o
PRM	x → o
PR2	x → o
PR3	x → o
BS	o
SR3	o
SR2	o
SRM	o
OMMT1	o
OMMT2	o
OSM	o
OMC	x → o
ITMX(IXA)	x → o
ITMY(IYA)	o → o
ETMX(EXA)	x → o
ETMY(EYA)	x → o, Small leak
X-arm VAC	Small leak



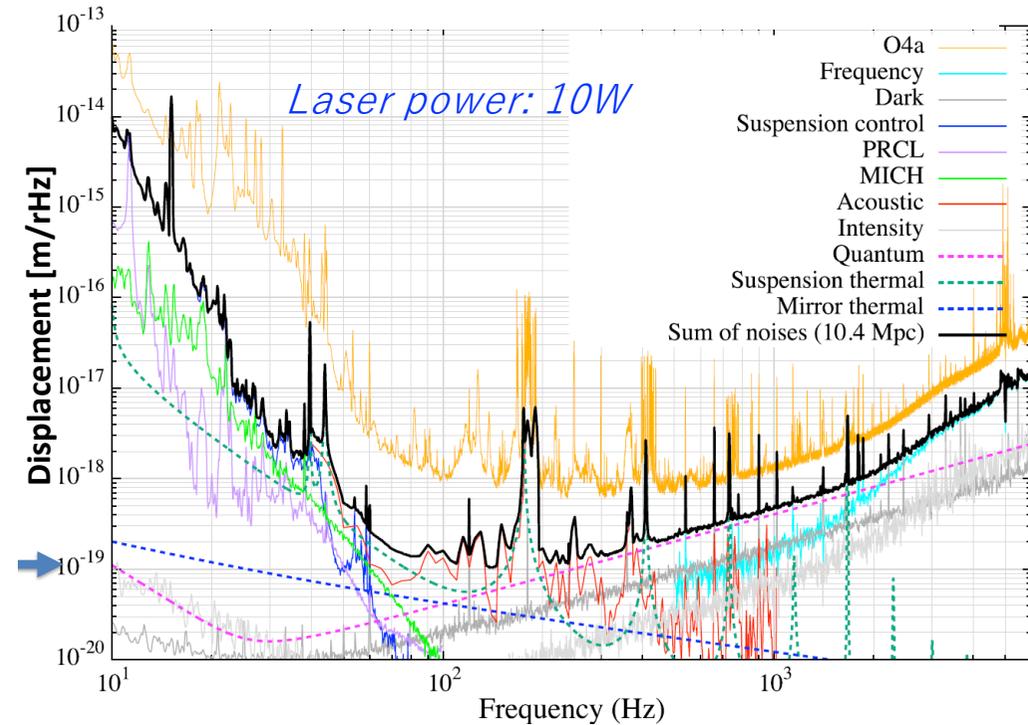
- PRFPMI lock : done @Sep.
- Noise hunting
- Better sensitivity (~2Mpc) than O4a has been achieved.
- Noto Earthquake of M6.6 again @Nov.

# 7. Current Status

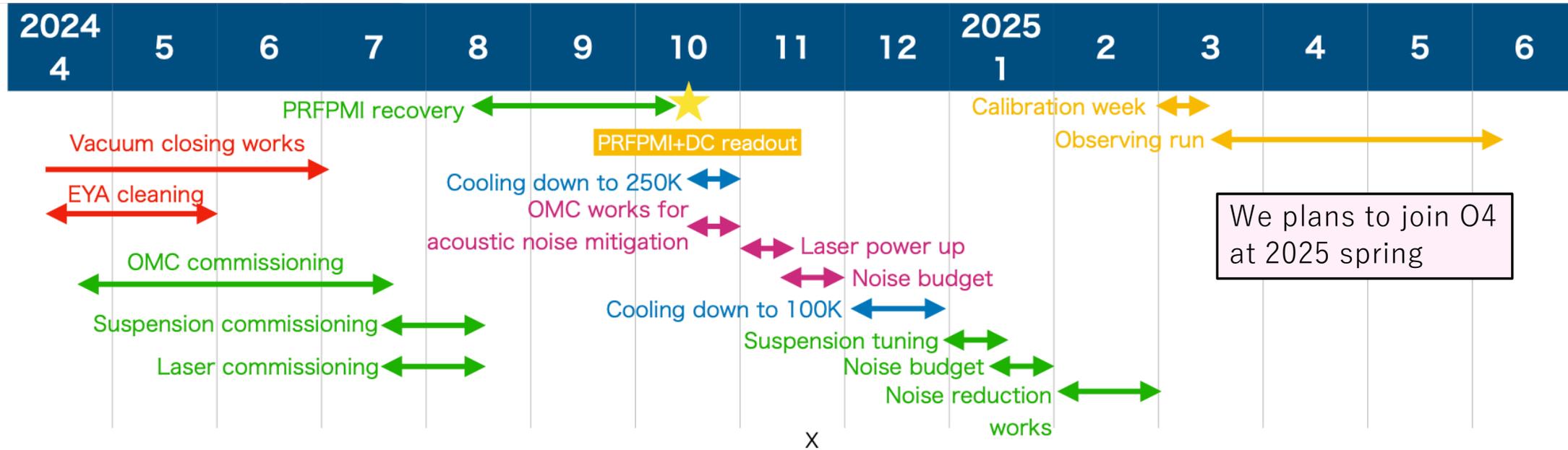
## O4a Sensitivity and Estimated Noise Budget



## Expected Sensitivity and Noise Budget in O4b/c



# 7. Current Status



**Q. A development plan using TAMA300 has also been submitted as a separate LOI, but do you have sufficient budget and human resources to run both in parallel? Wouldn't it be possible to accelerate technological development by concentrating resources on KAGRA?**

In response to the question, "Do we have the budget and human resources to run both TAMA and KAGRA?", the answer is NO.

As explained above, we do not have enough people to operate the KAGRA hardware, which is the responsibility of NAOJ-GWSP.

To add a little more detail, most of the FTE of NAOJ-GWSP staff is used for KAGRA and not for TAMA300. TAMA300 experiments have been and still are funded by Grants-in-Aid for Scientific Research.

Human resources are also dependent on students and domestic and international collaborators.

The reality is that activity has been low in recent years.

In fact, TAMA is extremely important for KAGRA. Of course, research for the future upgrade of KAGAR is being done at TAMA, but more than that, it is important to keep students and domestic and international researchers connected to KAGAR.

For students who develop hardware, there is little room for independent research in KAGRA, which has entered the operational phase, so development at TAMA and ATC seems very attractive.

For this reason, many students enroll thanks to the development research at TAMA and ATC.

Also, since the construction of KAGRA has been carried out only by Japanese researchers, there are overseas collaborators who want to introduce equipment they developed for the upgrade of KAGRA, and TAMA and ATC provide that environment. For example, development of the Squeezer for KAGRA has begun with Taiwan and Korea, centered around NAOJ, and Taiwan and Korea have contributed both financially and human resources. In other words, there is an aspect that KAGRA receives human and financial support thanks to TAMA and others.