EXPO2025, Italian Pavillon
June 26, 2025

Gravitational wave astronomy with KAGRA

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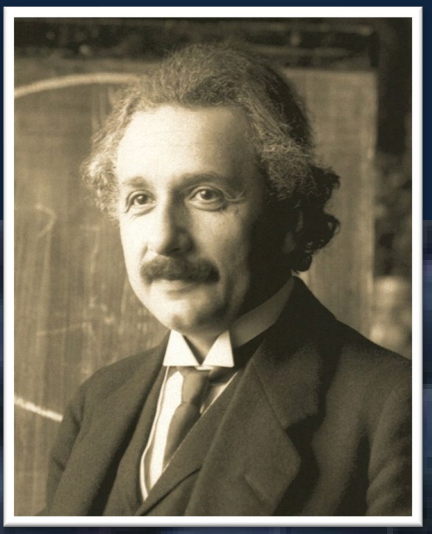
Outline

- *Gravitational waves*
- *KAGRA*
- *KAGRA's contribution to the GW astronomy and future GW detection*
- *Summary*

Gravitational waves

Gravitational waves



A. Einstein
（by F. Schmutzer, Wikipedia）

In 1916, A. Einstein predicted gravitational waves based on his theory of general relativity.

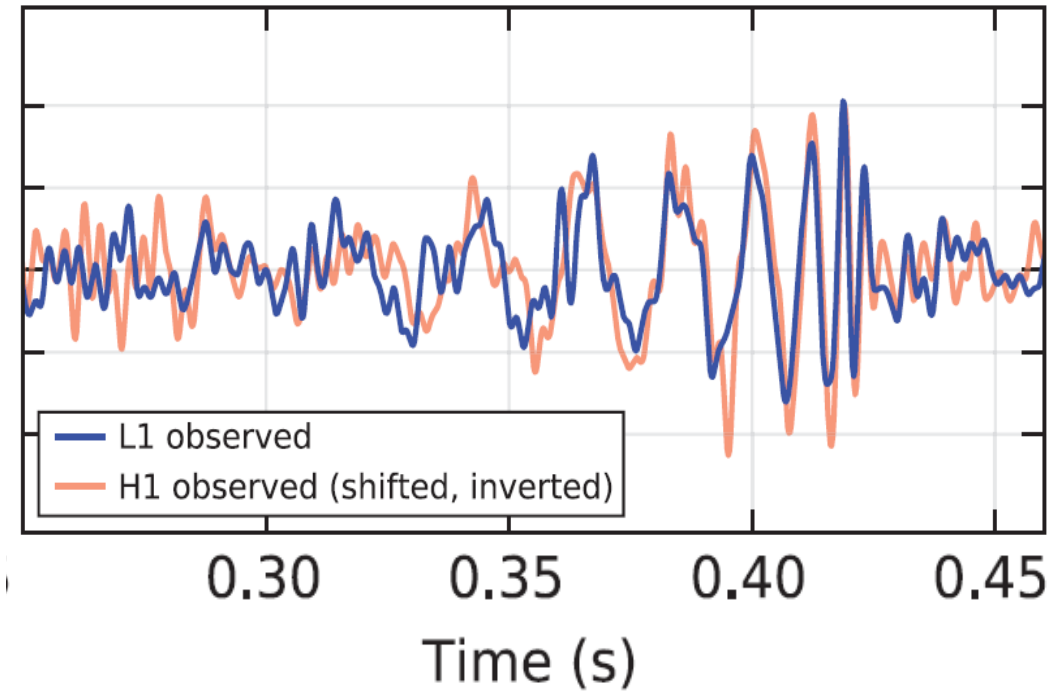
Black hole

Black hole

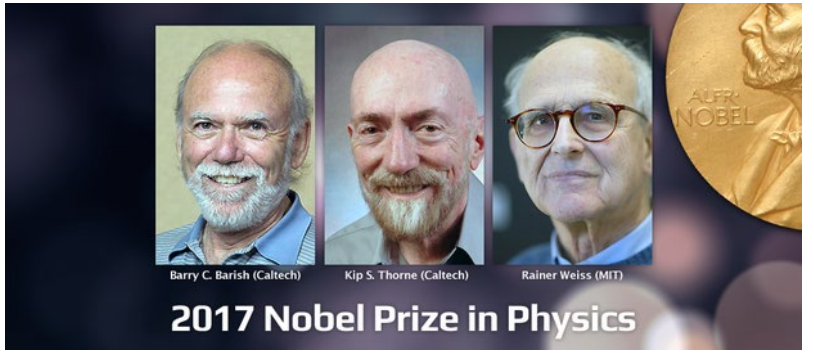
Image of the gravitational wave emission from a binary black hole system.
These back holes merge and a new heavier black hole will be created.

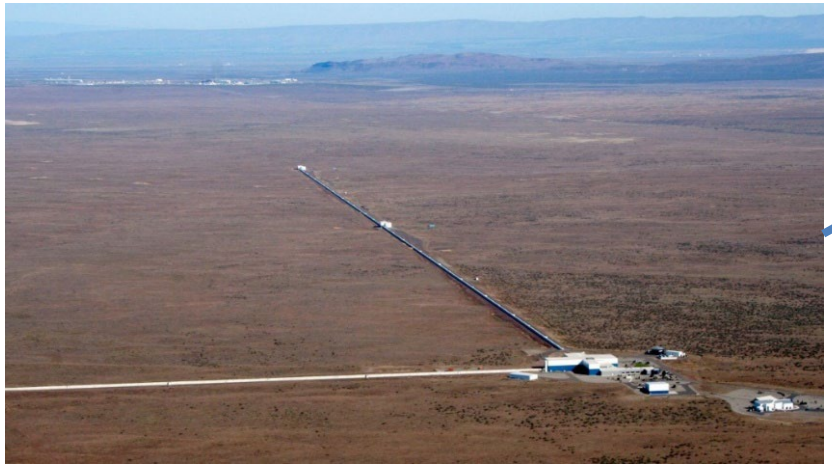
Discovery of gravitational waves

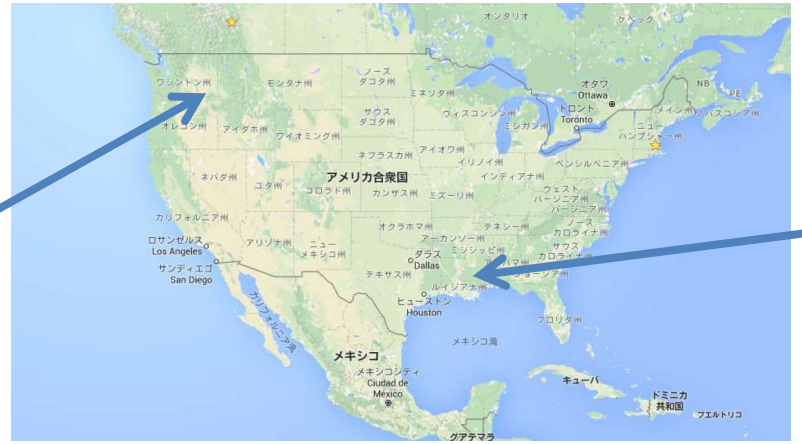
LIGO Scientific Collaboration and Virgo Collaboration, PRL, **116**, 061102 (2016)



- ✓ On Sep. 14, 2015, LIGO observed the signal with the 2 laser interferometers. Data told us that 2 blackholes of 36 M_{Sun} and 29 M_{Sun}, respectively, merged at the distance of 1.3 Billion light-years, newly forming a 62 M_{Sun} blackhole.
- ✓ *Great discovery!*

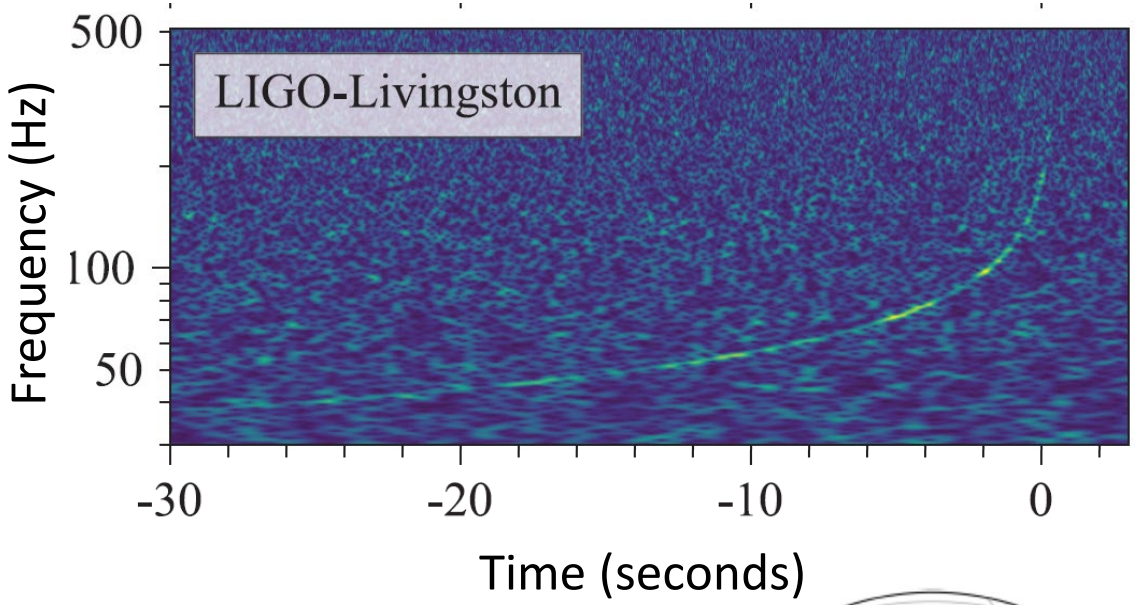


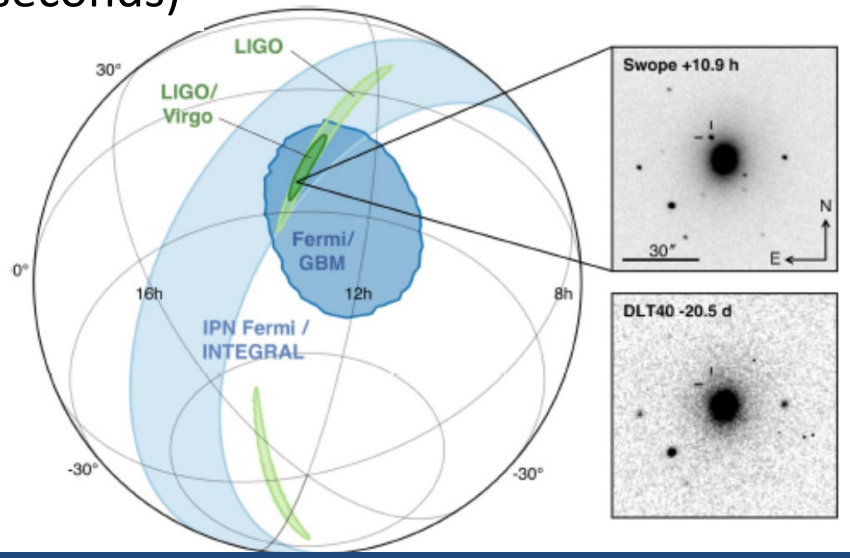




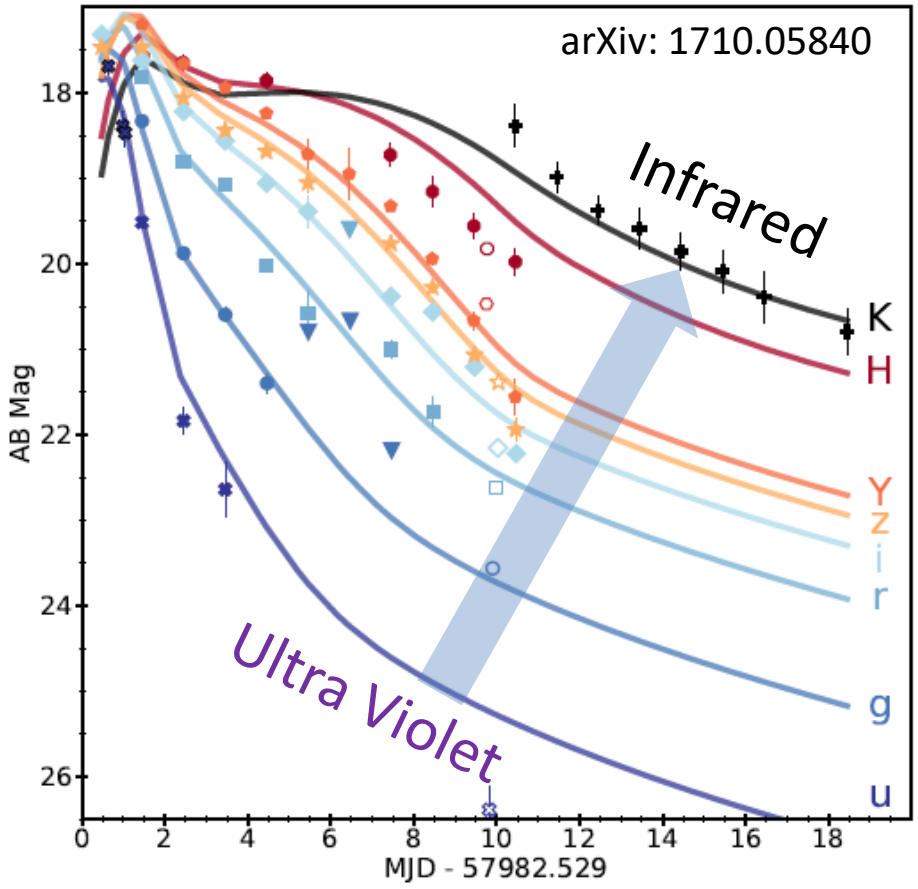
Multi-messenger astronomy with GW

Aug. 17, 2017





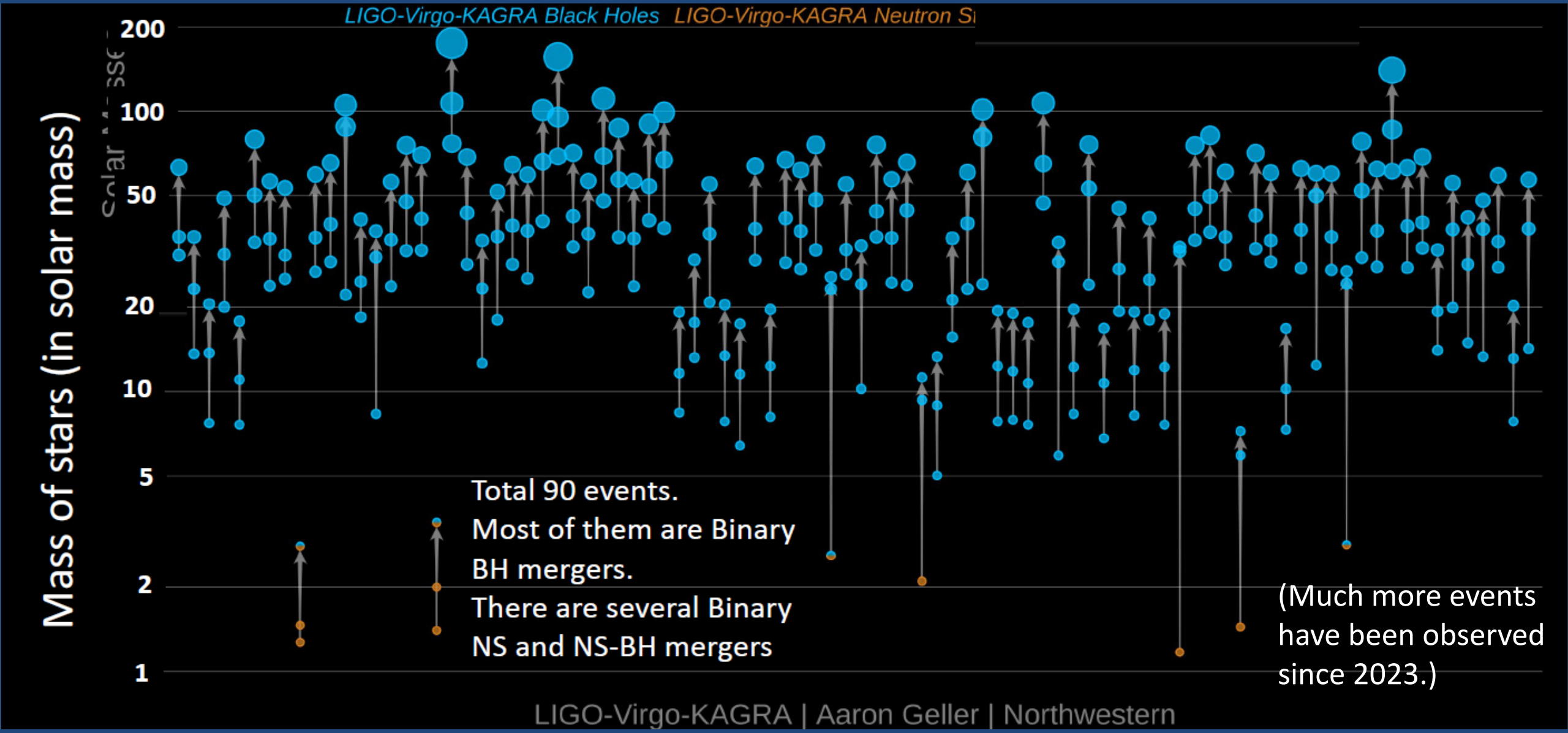
Pointing the BNS merger event by LIGO and Virgo and the discovery of the optical counterpart



Consistent with many heavy metals (such as gold or platinum) generation!

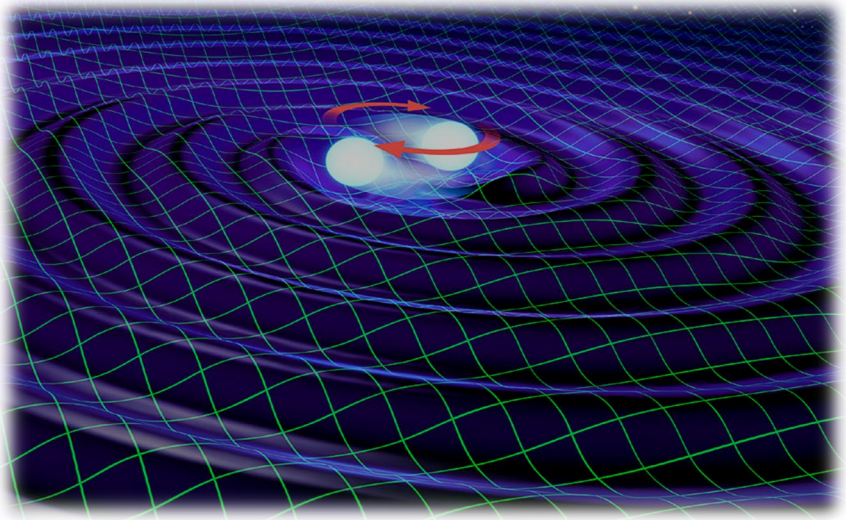
LIGO-Virgo observation summary (before 2023)

https://www.ligo.org/science/Publication-O3bCatalog/images/12_GWTC-3_Stellar_Graveyard_no_EM.png



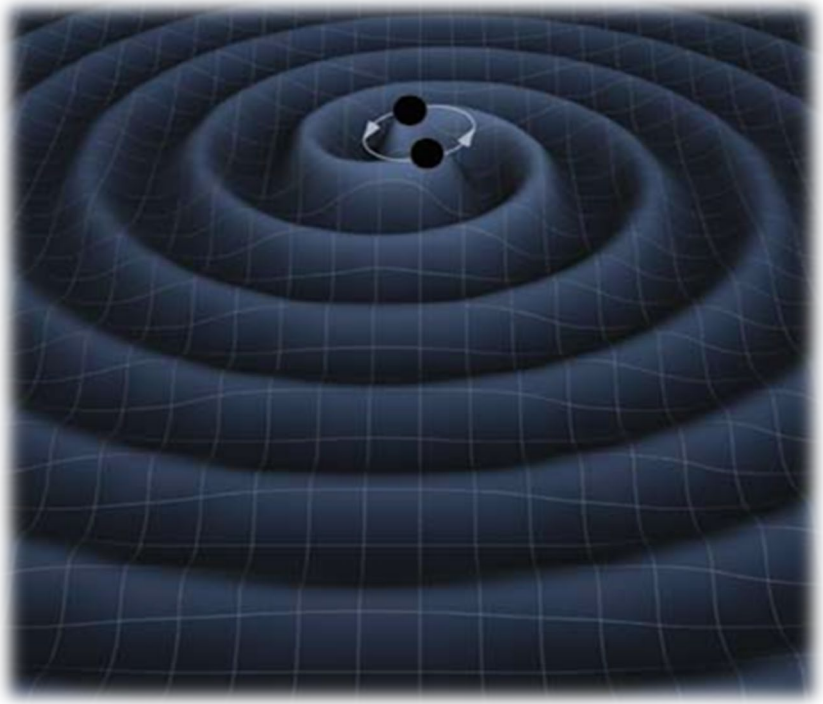
(Much more events have been observed since 2023.)

Science with ground-based GW detectors



Merger of binary neutron stars

- ➔ Origin of the heavy metals in the Universe?
- ➔ What is the inside of neutron stars? (How large is a neutron star?)
- ➔ …



Merger of binary blackholes

- ➔ How the blackholes were created?
- ➔ …

Supernova explosion

- ➔ How the heavy stars finish their life?
- ➔ ….

KAGRA

KAGRA collaboration

9 countries/regions, ~150 authors

(and ~400 collaborators)

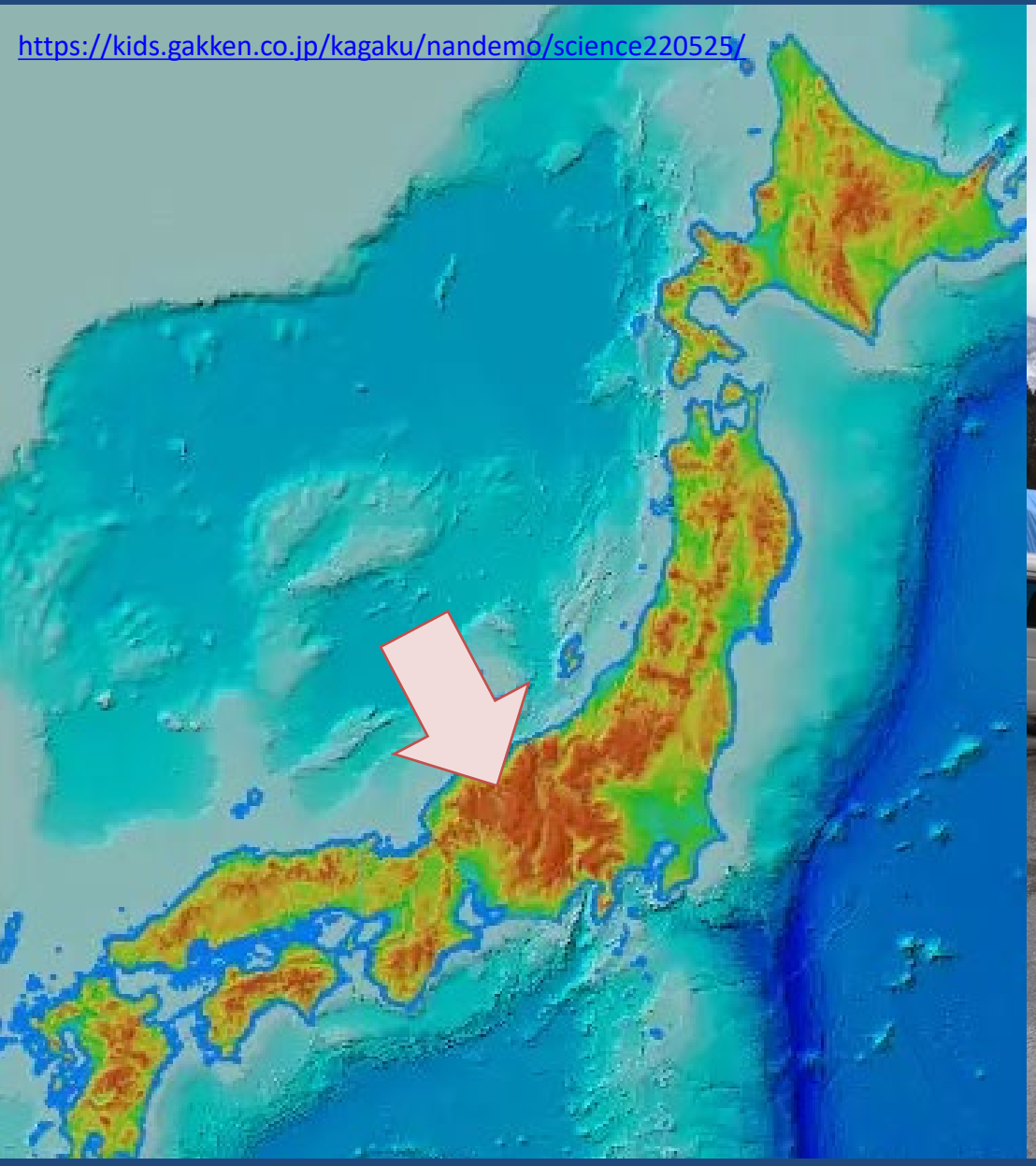
Key features of KAGRA

KAGRA key features:

- ✓ Underground site:
  Smaller seismic noises
- ✓ Cryogenic mirrors:
  Smaller thermal noises

Location of KAGRA

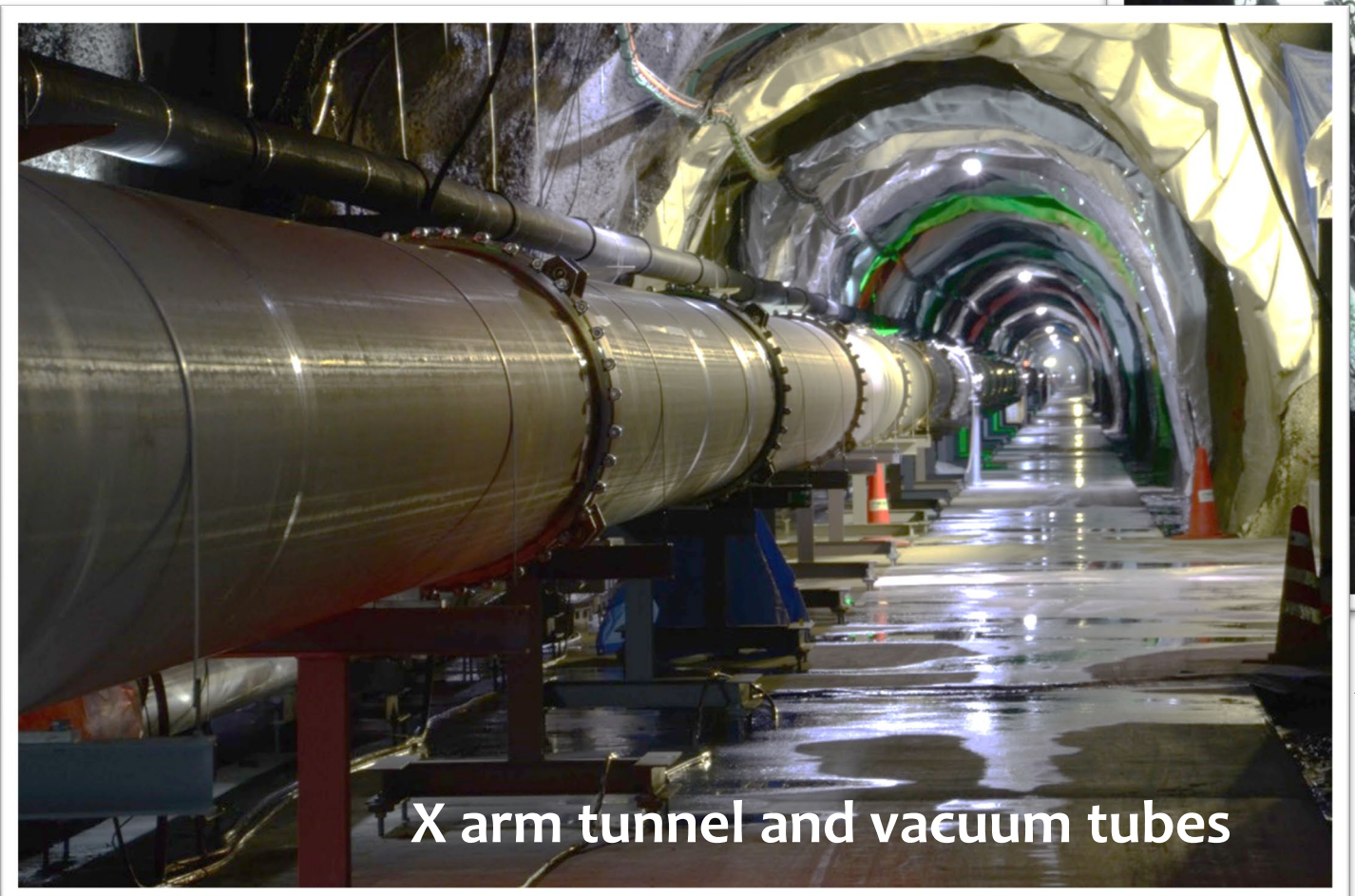
https://kids.gakken.co.jp/kagaku/nandemo/science220525/



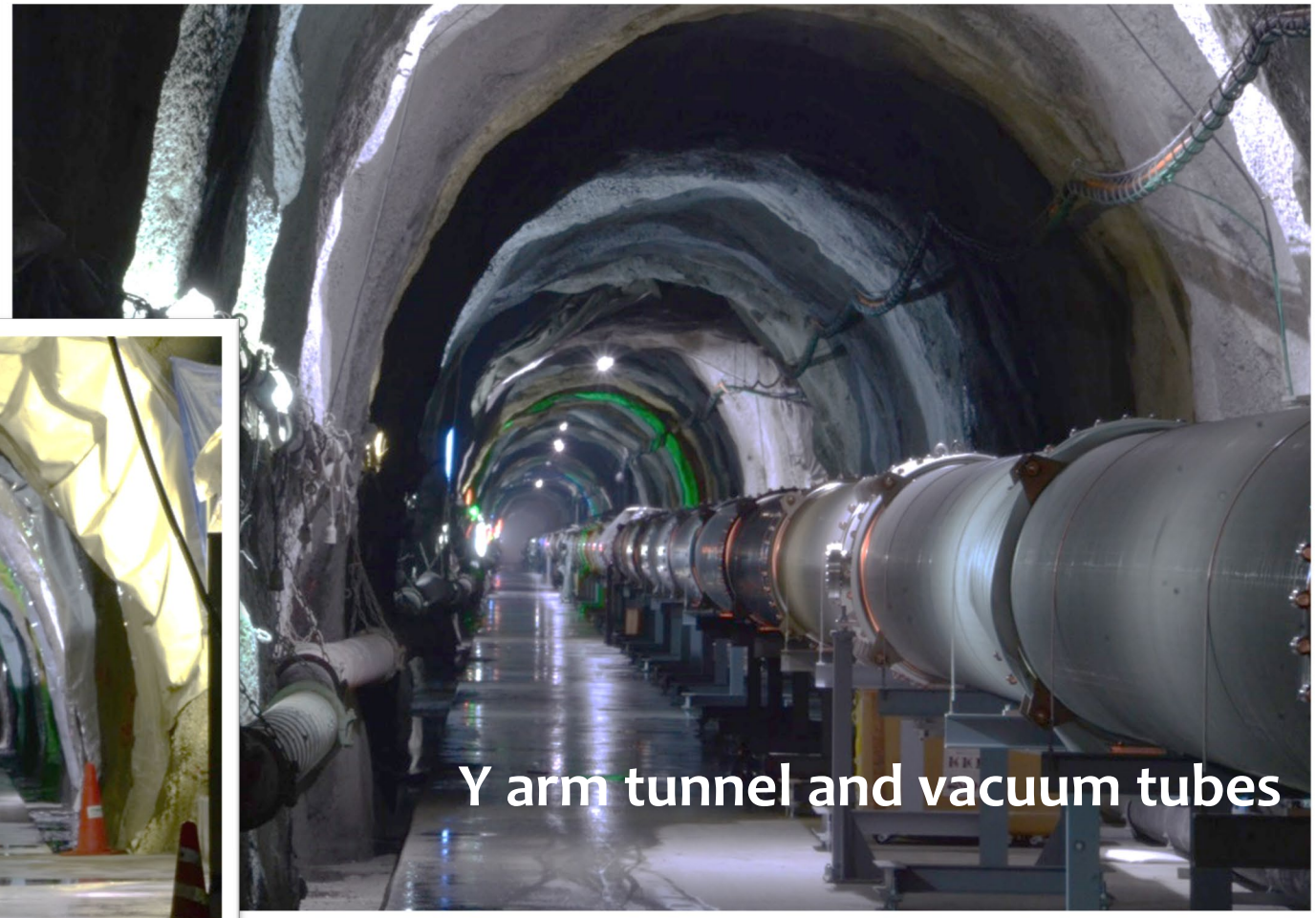
(A slightly old photo during the construction)

3km x 3km arms

KAGRA project was approved in 2010.



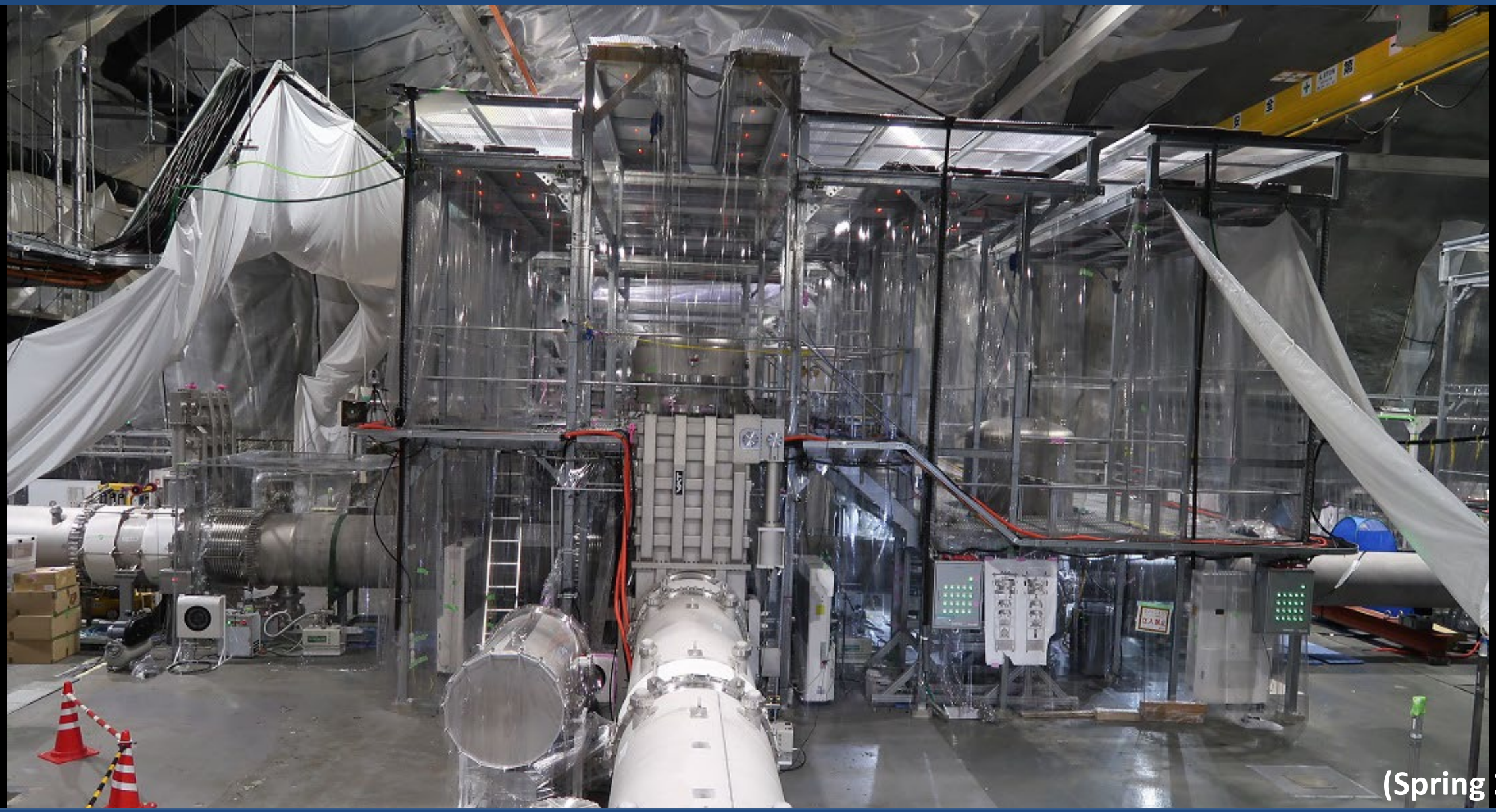
X arm tunnel and vacuum tubes



Y arm tunnel and vacuum tubes

✓ Connection and the leak tests of 3km X 3km beam tubes have been finished in March 2015.

Center area

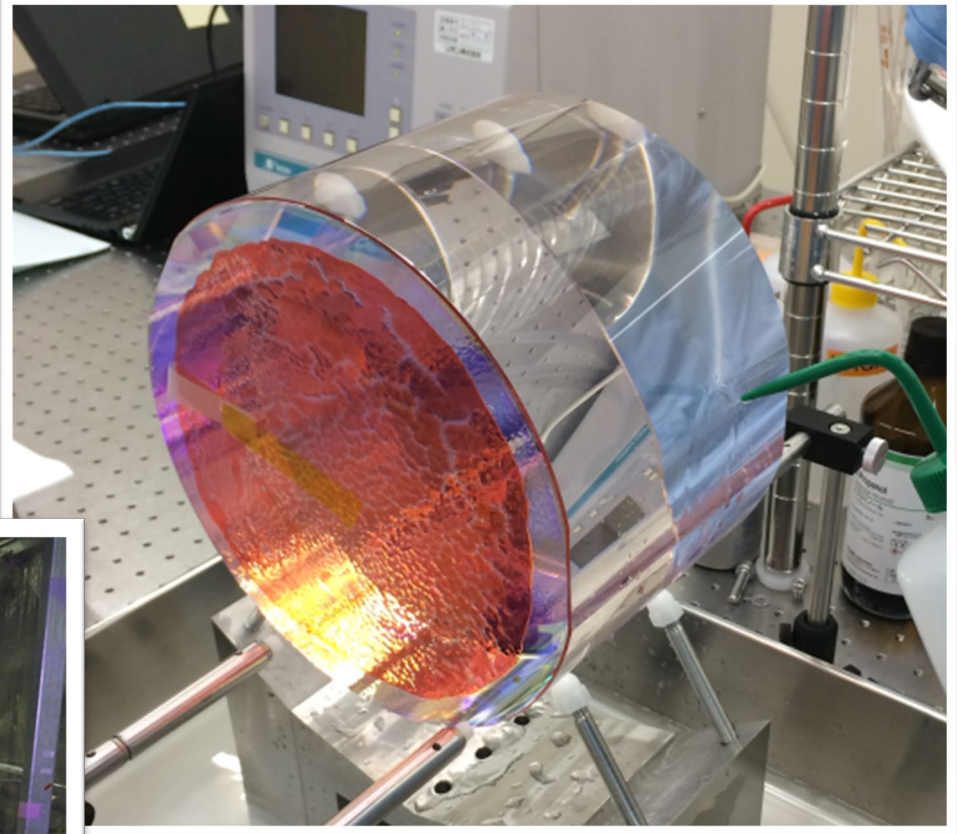


(Spring 2020)

Installation works (until spring 2019)

Installing a mirror

Testing the vibration isolation system



Preparation of cryogenic mirror
（22cm(ϕ), 15cm (t), 23kg）
➔ To the KAGRA site

KAGRA control room at the surface

The interferometer commissioning is carried out at the surface facility.

KAGRA collaboration

KAGRA collaboration meeting
Dec. 2024

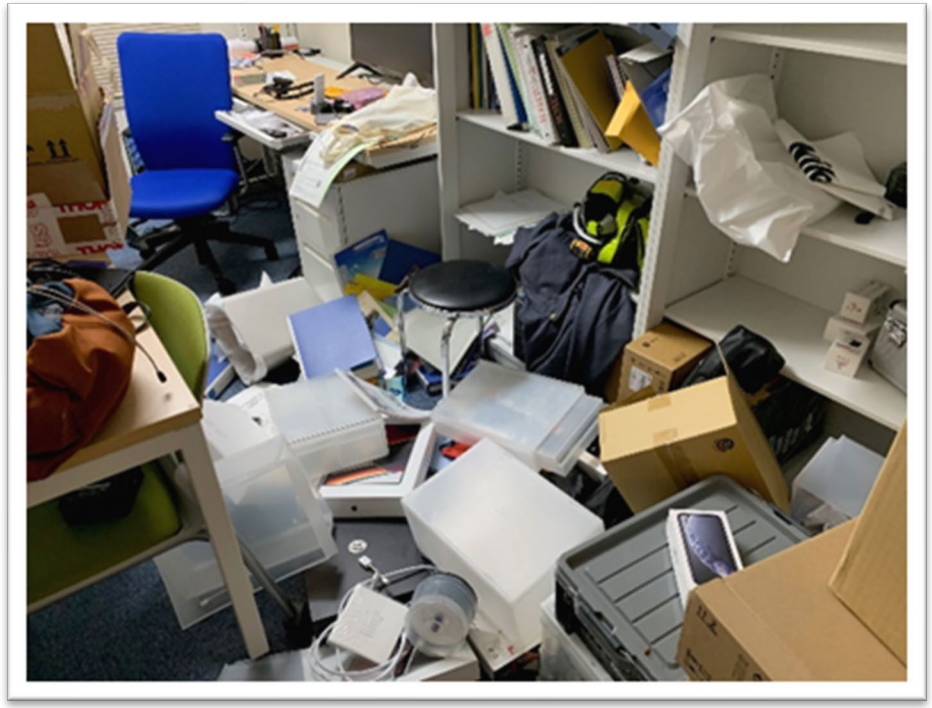
KAGRA is an international collaboration based largely on Asian countries/regions. We work together for the KAGRA project and for the gravitational wave astronomy!

Earthquake on Jan. 1, 2024

A magnitude 7.6 earthquake occurred at 16:10 (JST) on Jan. 1, 2024.

Seismic intensity based on Japanese seismic intensity scale (of 0 to 7)

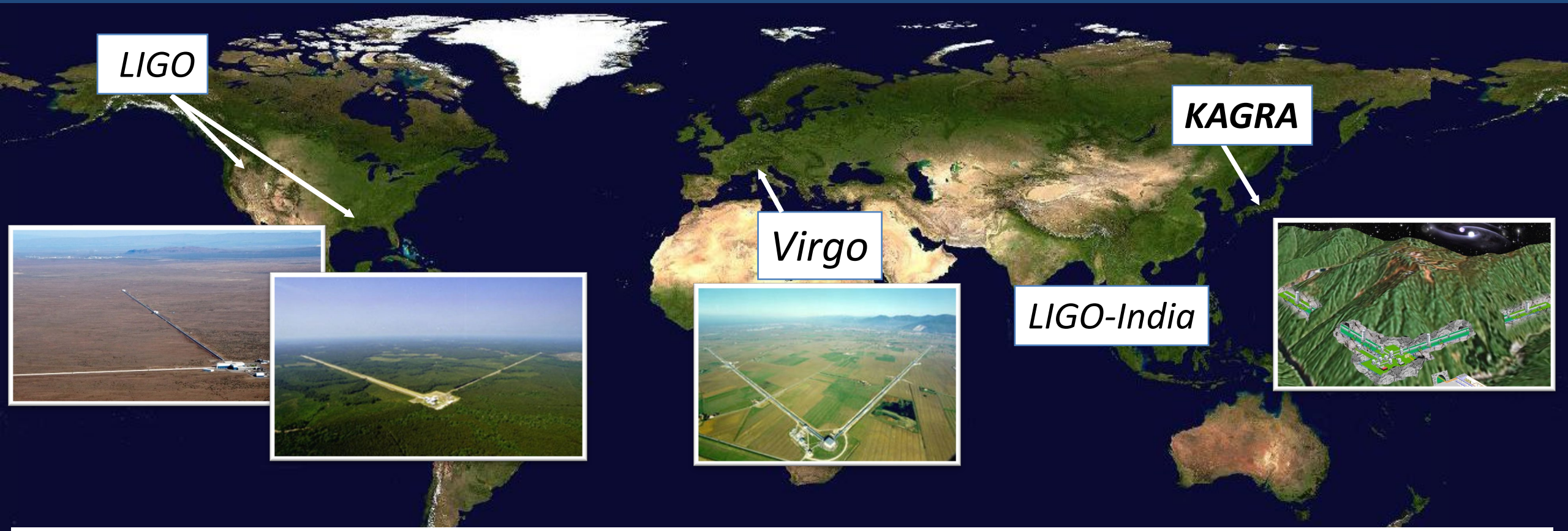
The data indicate that this earthquake was the strongest one in Hida city in the last 100 years.



Inside the KAGRA office building on Jan. 1

- We were fortunate, because we installed the KAGRA laser interferometer in underground. The effect of the earthquake was significantly smaller in underground.
- But there were still many damages in KAGRA.
- We worked hard so that KAGRA can rejoin the observation and contribute to the GW astronomy as soon as possible in 2025. (Best sensitivity so far; ~6.9Mpc for binary neutron star mergers)

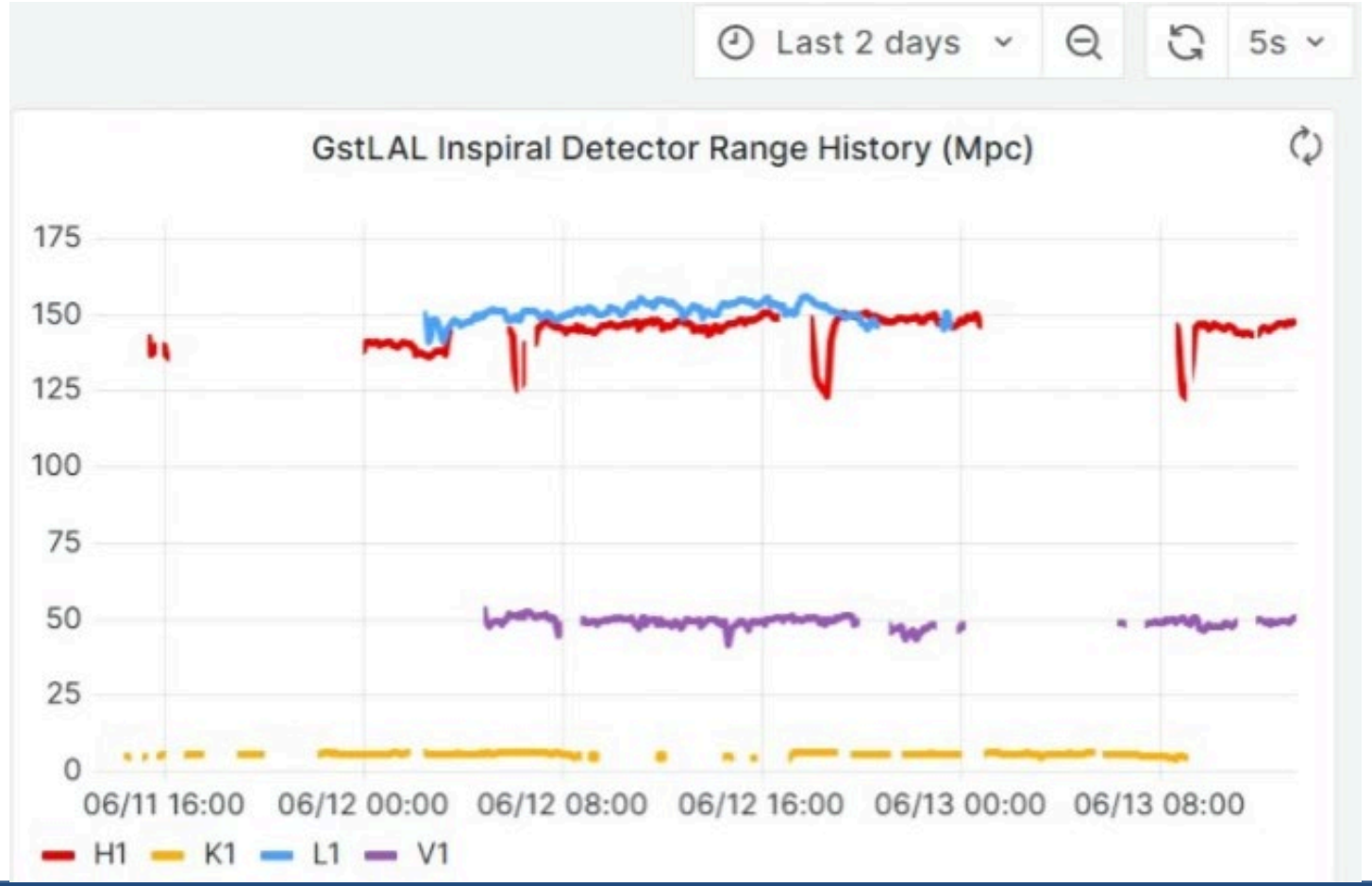
Joining the global GW network



- To determine the location (direction) of the source, we need at least 3 detectors which are located far apart from each other.
- KAGRA joined the network observation with LIGO and Virgo in 2020. We are working together, namely, we observe GWs simultaneously and analyze the data as a team.

LIGO-Virgo-KAGRA Observation resumed

- ✓ LIGO and Virgo stopped the observation for 2 months starting in April 2025.
- ✓ KAGRA decided to join the observation when LIGO and Virgo resumed the observation in June.
- ✓ On June 11 (June 12, 0:00 JST), LIGO-Virgo-KAGRA (LVK) resumed the observation.
- ✓ LVK plans to continue the O4 observation until Nov. 2025.

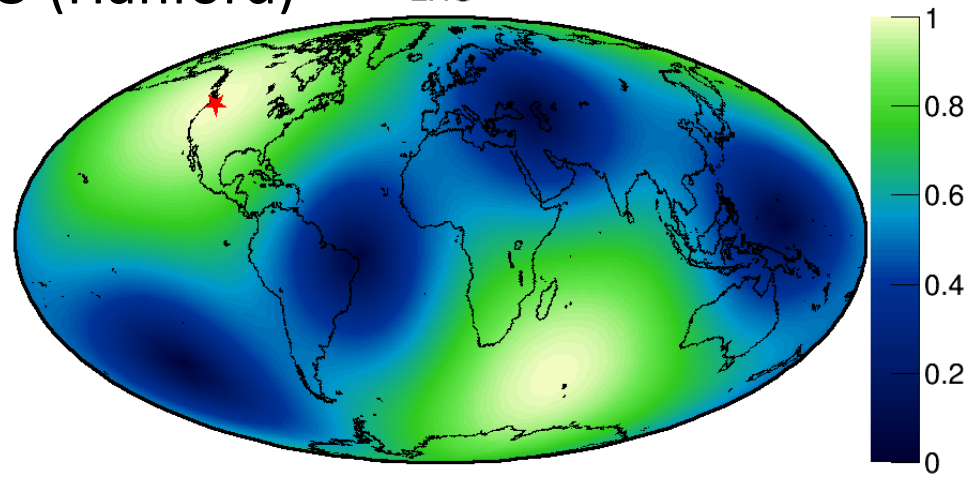


https://online.igwn.org/grafana/public-dashboards/1a0efabe65384a7287abfcc1996e4c4d?orgId=1&refresh=5s&from=now-2d&to=now

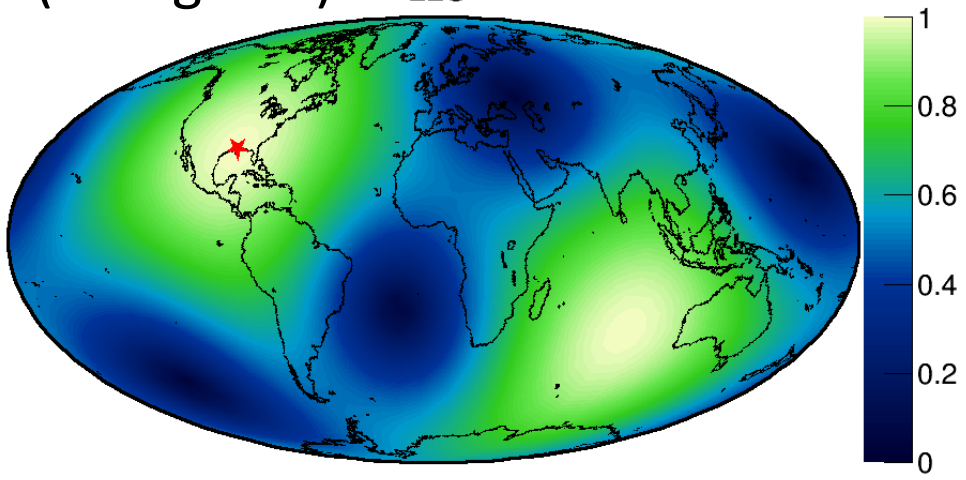
KAGRA's contribution to the GW astronomy and future GW detection

Importance of Global GW Network: Detector antenna patterns

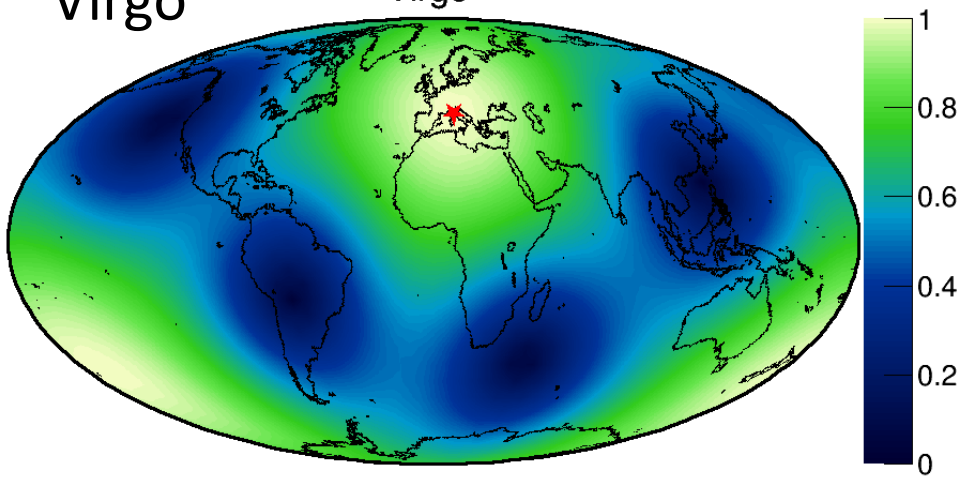
LIGO (Hanford)



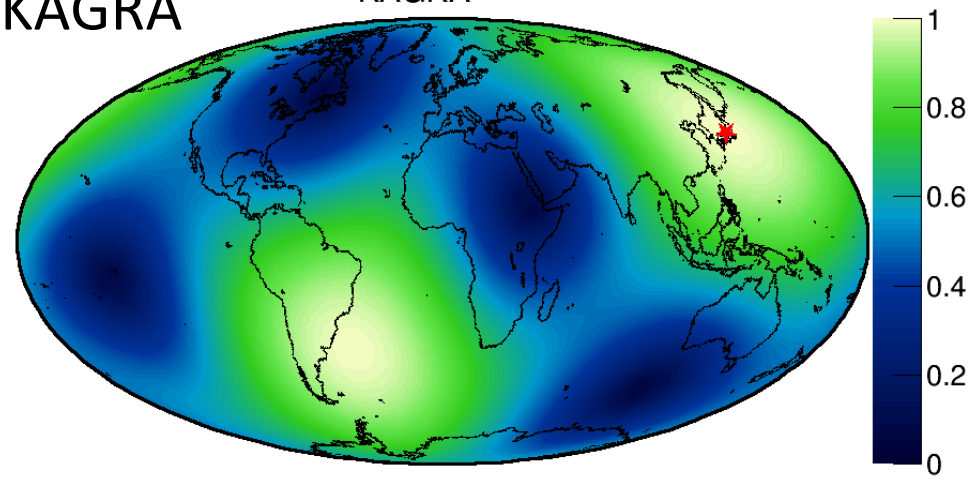
LIGO (Livingston)



Virgo



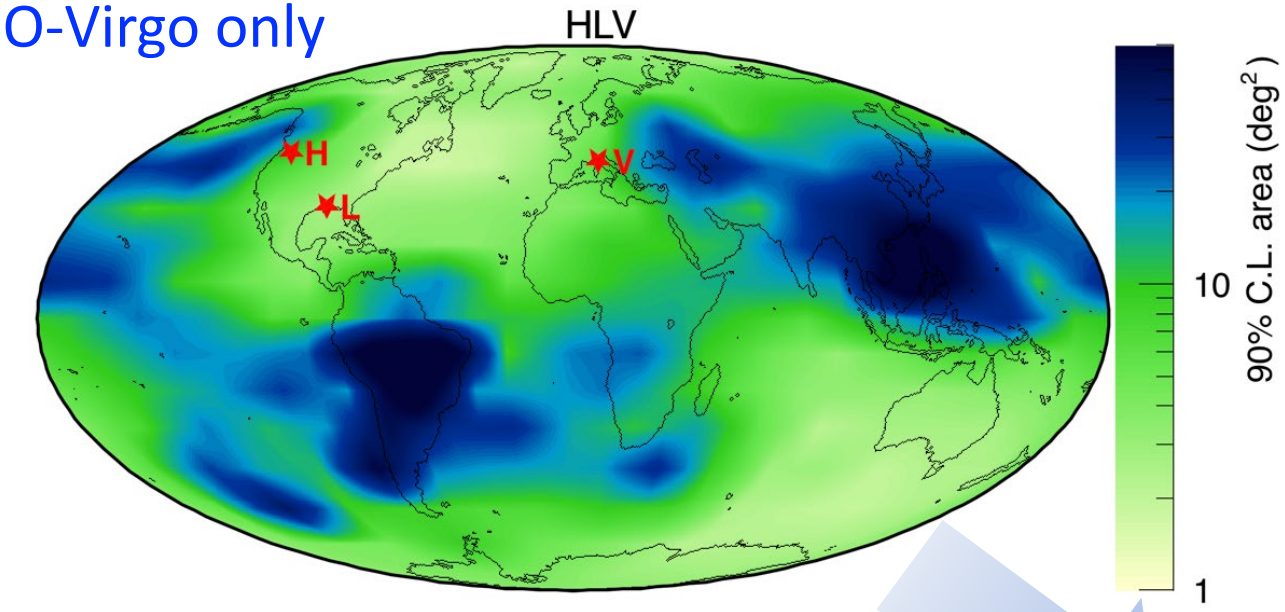
KAGRA



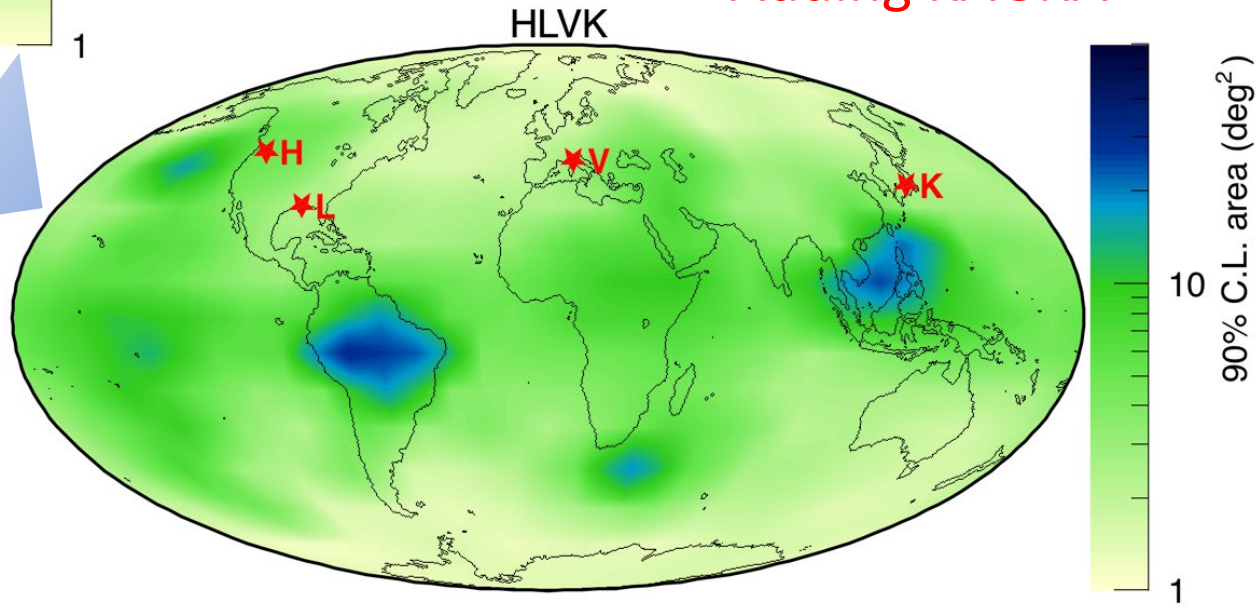
KAGRA is complementary in the sensitive direction to other detectors.

Importance of Global GW Network

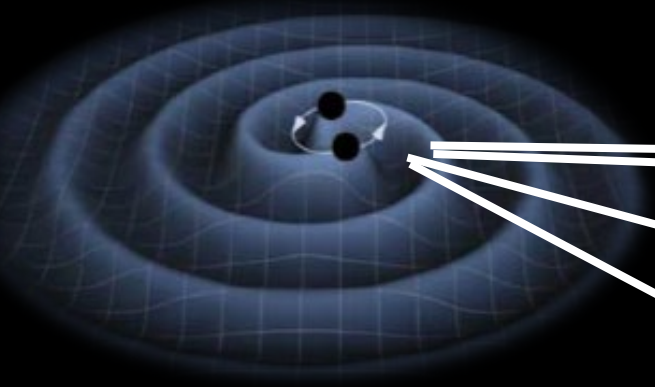
LIGO-Virgo only



Adding KAGRA



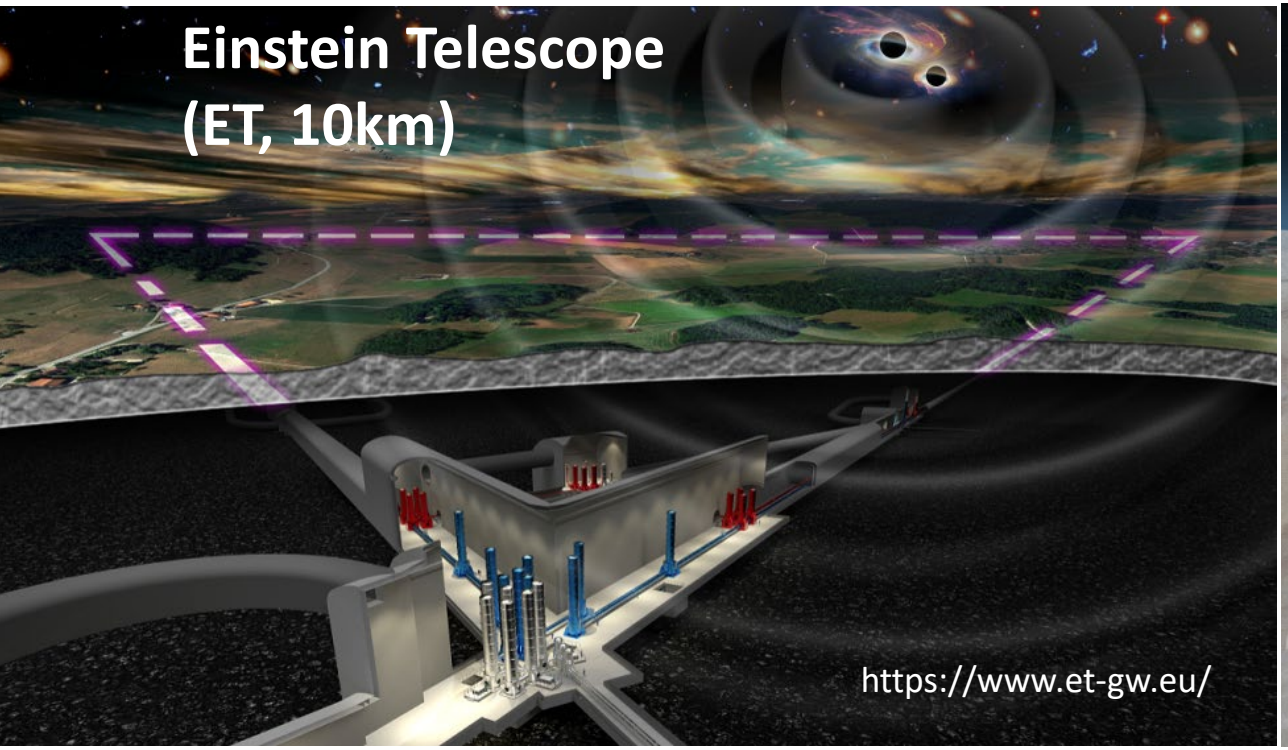
Importance of Global GW Network

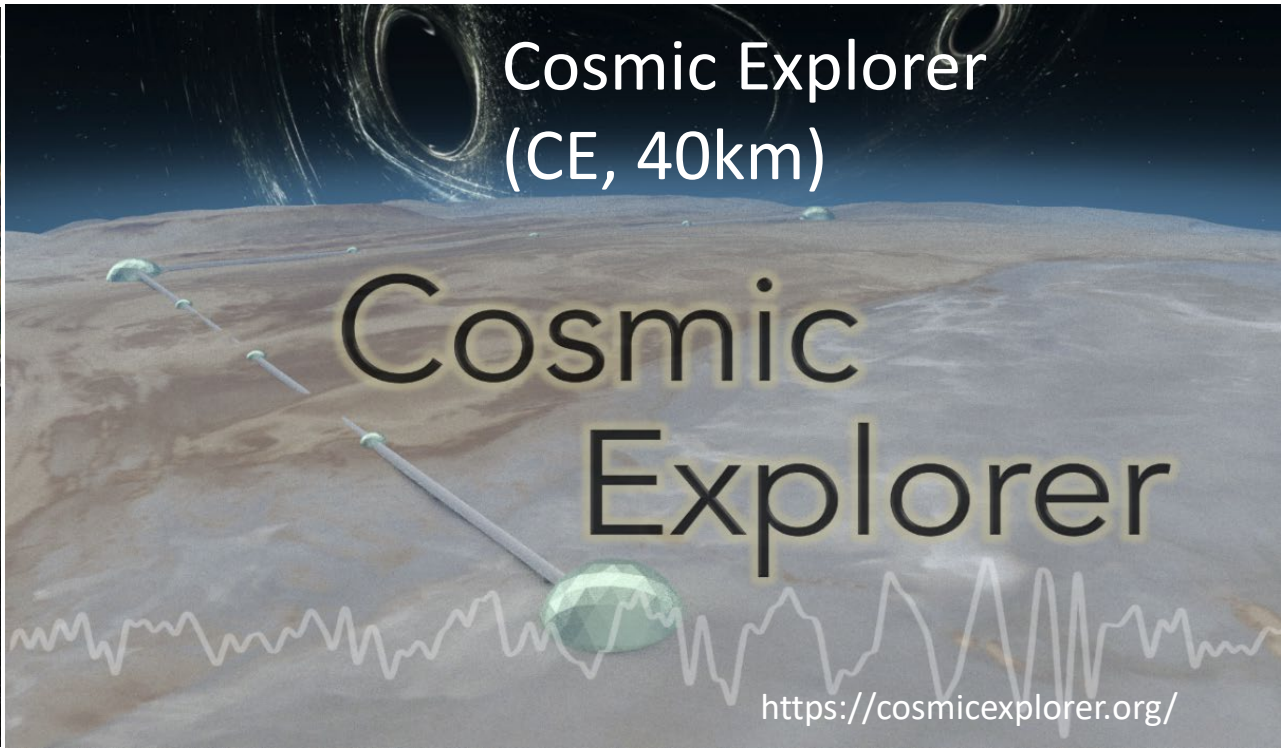


It is very important that there are at least 3 detectors located far from each other to determine the source direction (location) accurately.

➔ KAGRA is important.

Future GW detectors





- ✓ Since the present generation of ground-based GW detectors have been so successful, there have been intense activities to design and propose the next generation detectors (Einstein Telescope (ET) and Cosmic Explorer (CE)).
- ✓ The science with these future GW detectors will be really exciting!

Einstein Telescope – KAGRA Collaboration

- The KAGRA's activities, including the experiences of the underground site and the cryogenic mirrors, could be useful for the future generation of the GW detectors.
- Therefore, KAGRA has been collaborating with the Einstein Telescope project under the ELiTES project. (http://www.et-gw.eu/descriptionelites)
- In Feb. 2019, KAGRA and Einstein Telescope signed an agreement on the 3rd generation detectors.
- On June 21, 2024, a joint research agreement was signed between Italy's INFN and KAGRA on the development of a 3G GW telescope.
- On June 27, 2024, a MEXT statement welcomed the new cooperation in the fields of "gravitational waves" and "storage batteries," based on the MoU on cooperation in science, technology, and research signed between the Italian Ministry of Universities and Research and the Japanese MEXT. (https://www.mext.go.jp/b_menu/activity/detail/2024/20240627_2.html)

KAGRA SEVENTH FRAMEWORK PROGRAMME ELiTES ET EINSTEIN TELESCOPE

盛山大臣がベルニーニ イタリア大学・研究大臣を表敬訪問

Ministry of Japan MEXT made courtesy call the Ministry of Italian Ministry of Universities and Research

6月27日、G7教育大臣会合への出席のためイタリアを訪問していた盛山大臣は、ローマにて、アンナ・マリア・ベルニーニ大学・研究大臣を訪問し、日本とイタリア間の科学技術協力について意見交換を行うとともに、新たな連携強化について合意しました。

盛山大臣は、1988年に締結した日伊科学技術協力協定の下で様々な科学技術交流が行われてきたことや、イタリア大学・研究省と文部科学省の間で昨年署名した科学技術・研究分野での協力に関する覚書に基づき、今回、新たに「重力波」及び「蓄電池」の分野での協力が開始されることを歓迎する旨を伝えました。

ベルニーニ大臣からは、科学技術分野において協力関係が進展することを歓迎するとともに、両国の大学間の協力も更に進展させていきたいと期待等が述べられました。

文部科学省は、引き続きイタリアとの協力関係を促進してまいります。

Summary

- The science of the gravitational wave astronomy will be maximized by the collaboration of the GW detectors. KAGRA has joined O4 in June 2025(!) as a member of the International GW community.
- KAGRA would like to contribute to the global network of gravitational wave detectors and to the science of gravitational wave astronomy as soon as possible.
- KAGRA has still many things to do to improve the sensitivity.
- We hope that KAGRA can contribute to the future generation of the GW detectors, in particular to Einstein Telescope, through KAGRA's key features such as underground and cryogenic mirrors.