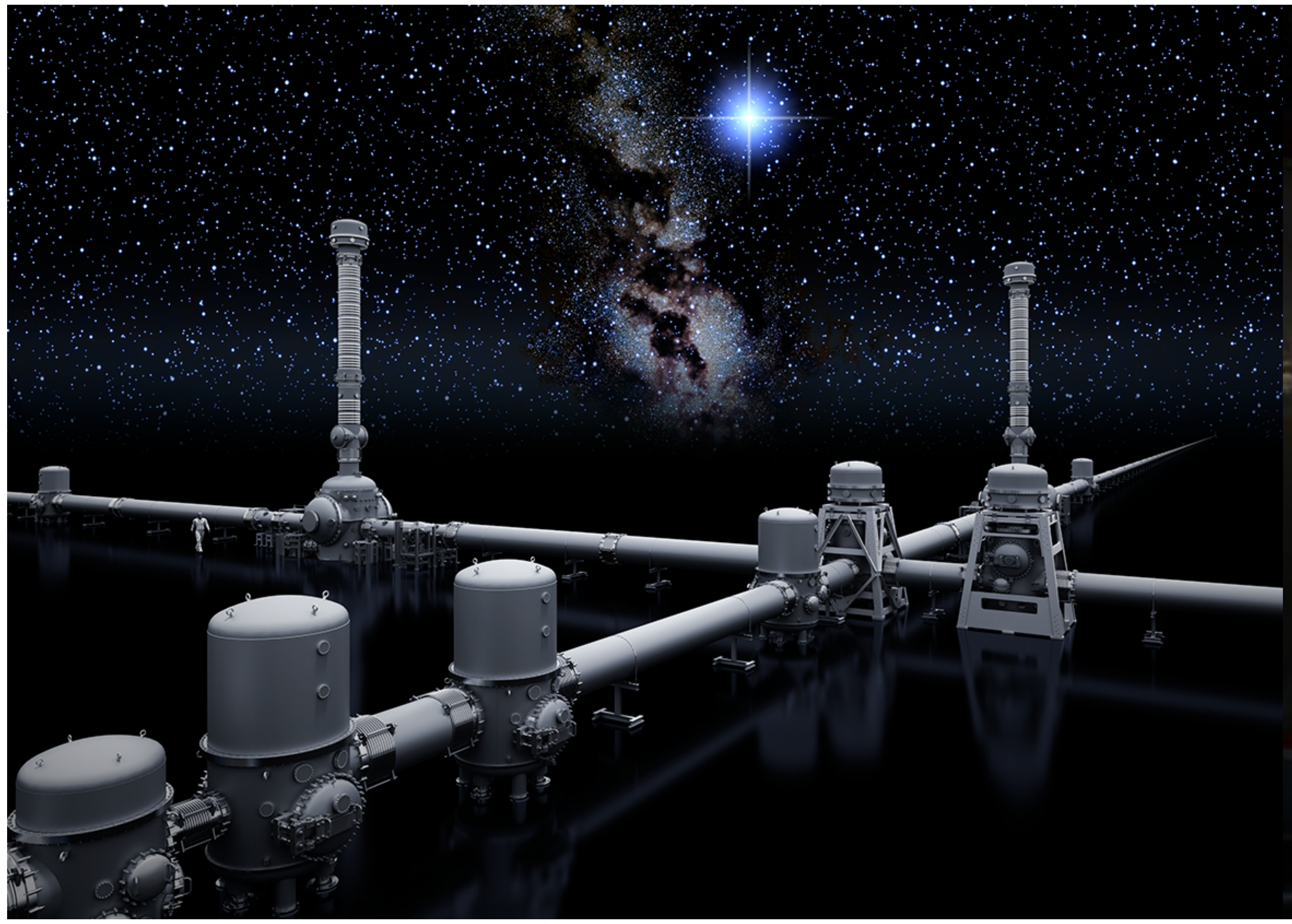
Introduction of KAGRA, Status of KAGRA

◆ Underground and Cryogenic interferometric 3 km gravitational-wave detector at Kamioka, Japan



(c) KAGRA Collaboration / Rey.Hori

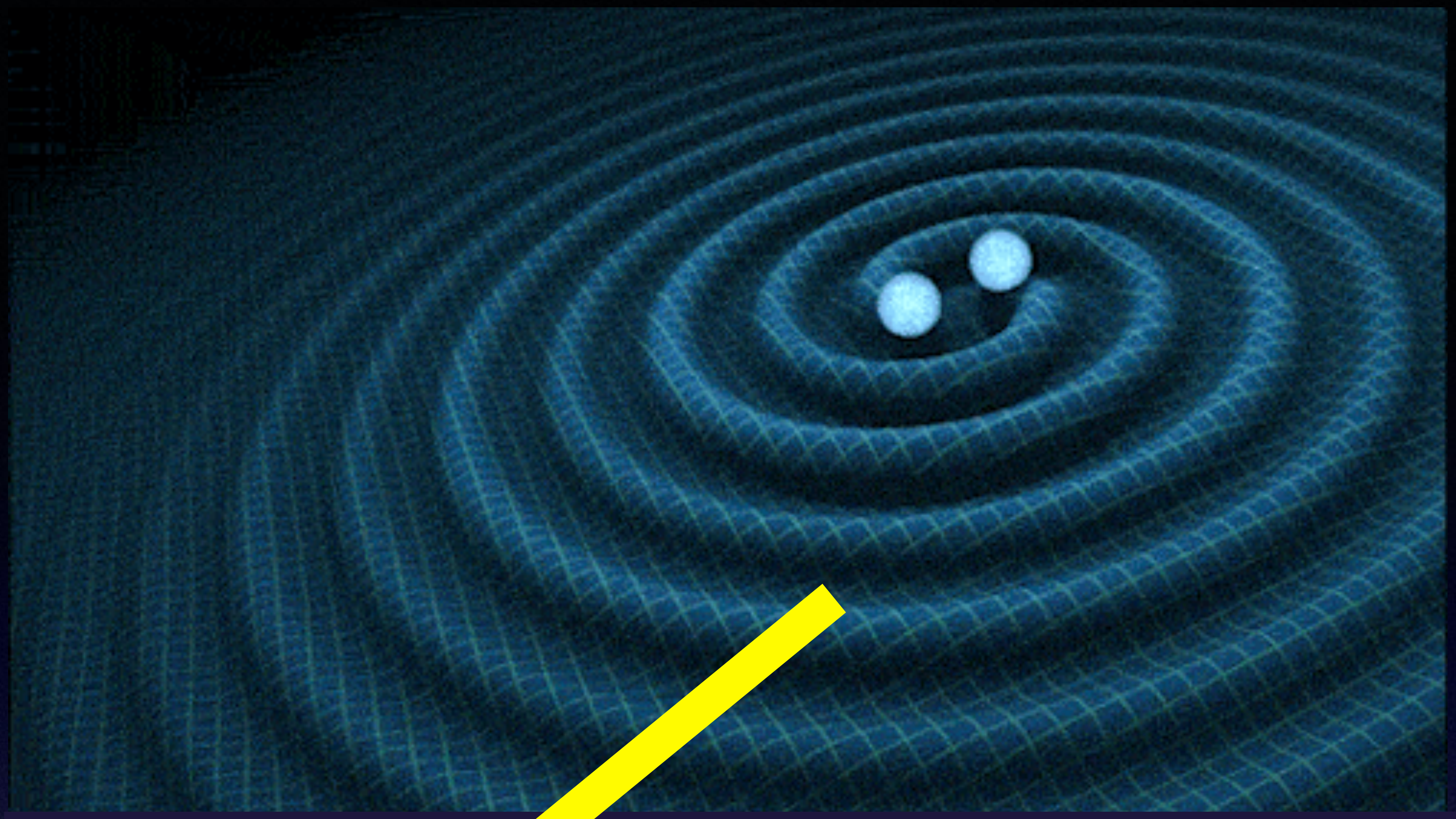
Hisaaki Shinkai (Osaka Inst. Tech.)
真貝寿明（大阪工業大学）

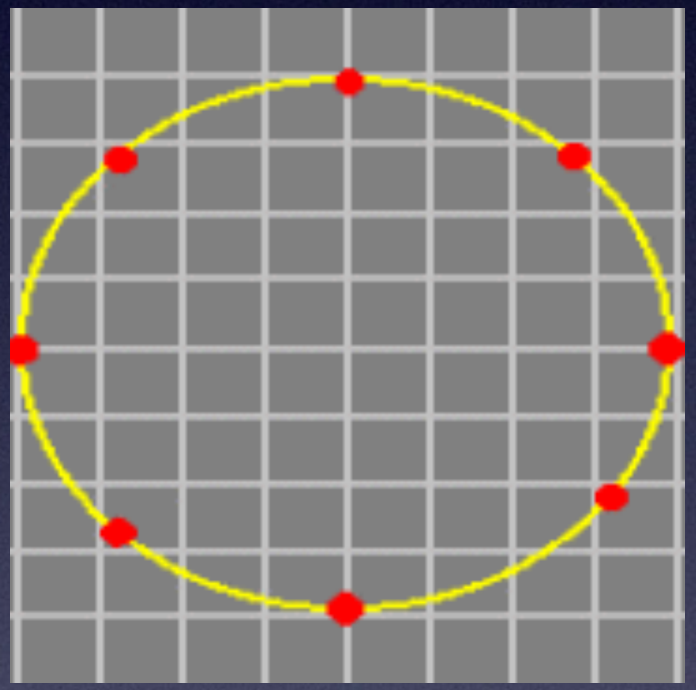
KAGRA Scientific Congress, board chair
on behalf of KAGRA collaboration

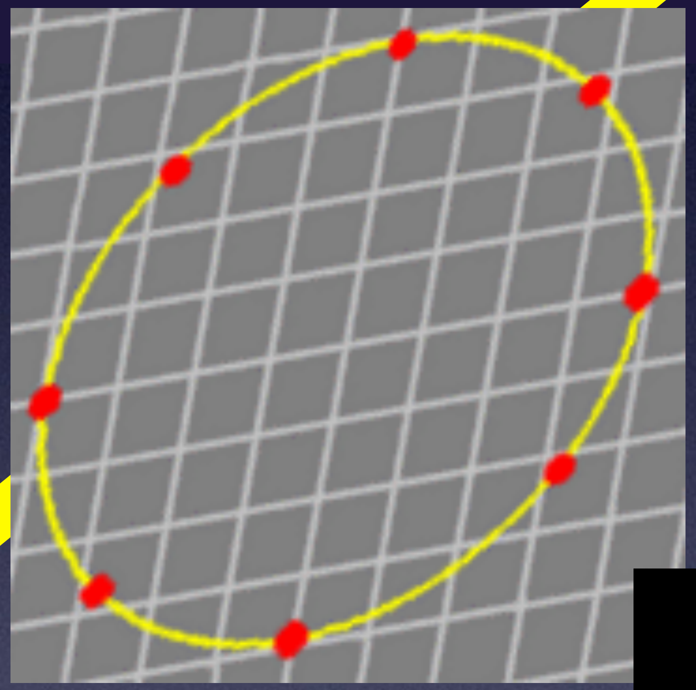
JGW-G2113067

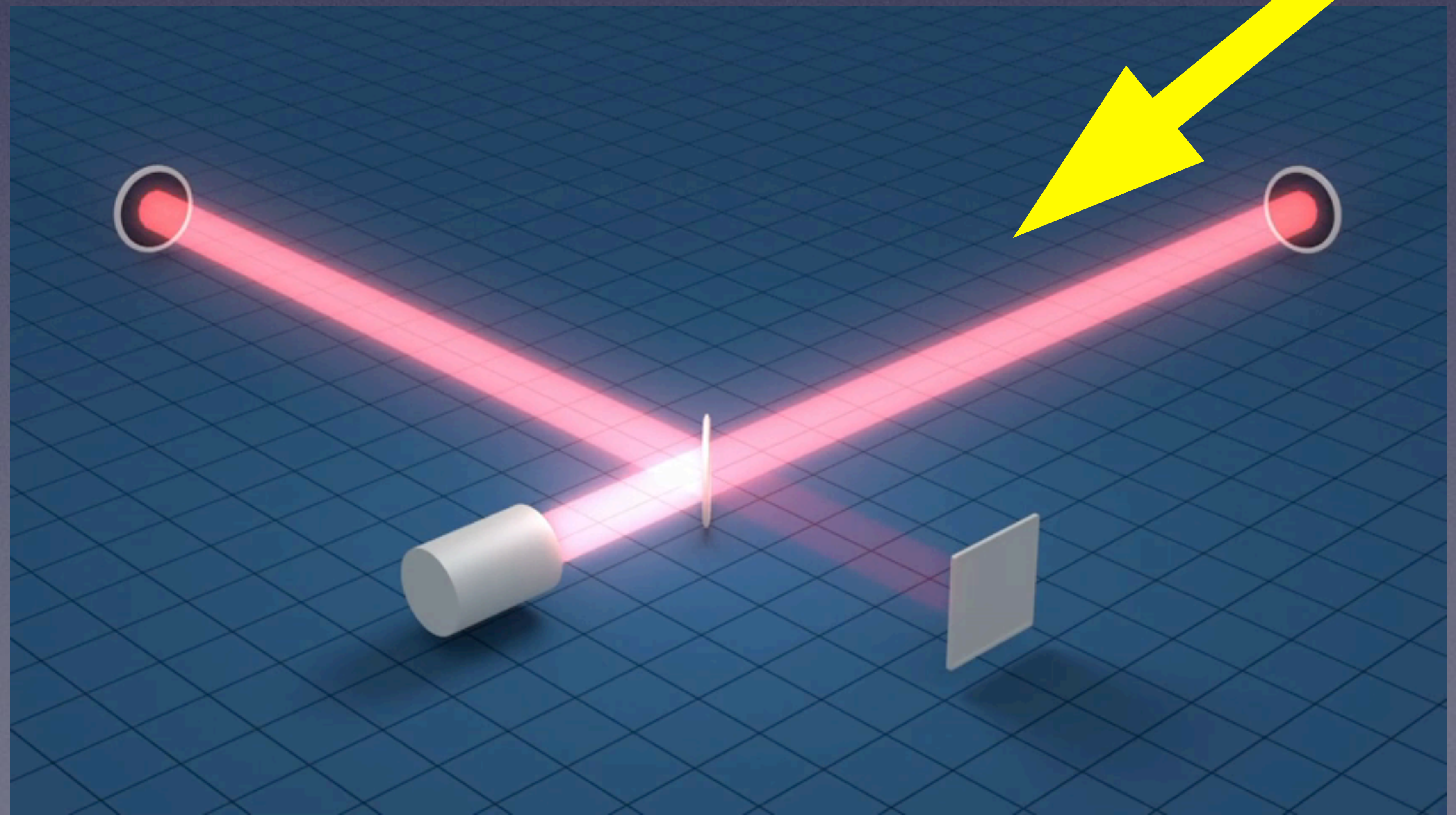
Gravitational Wave

from binary BH-BH, NS-NS, BH-NS

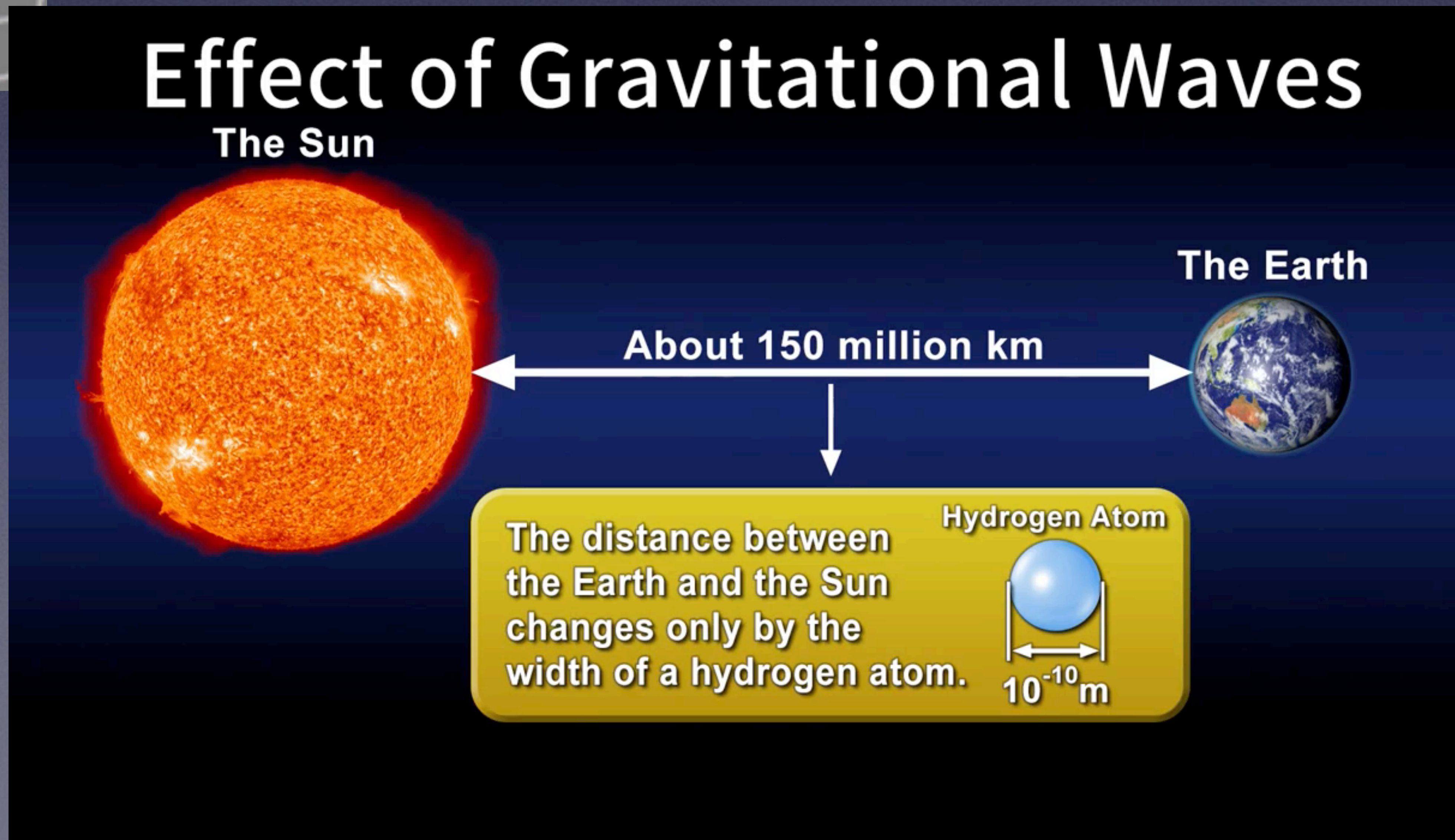




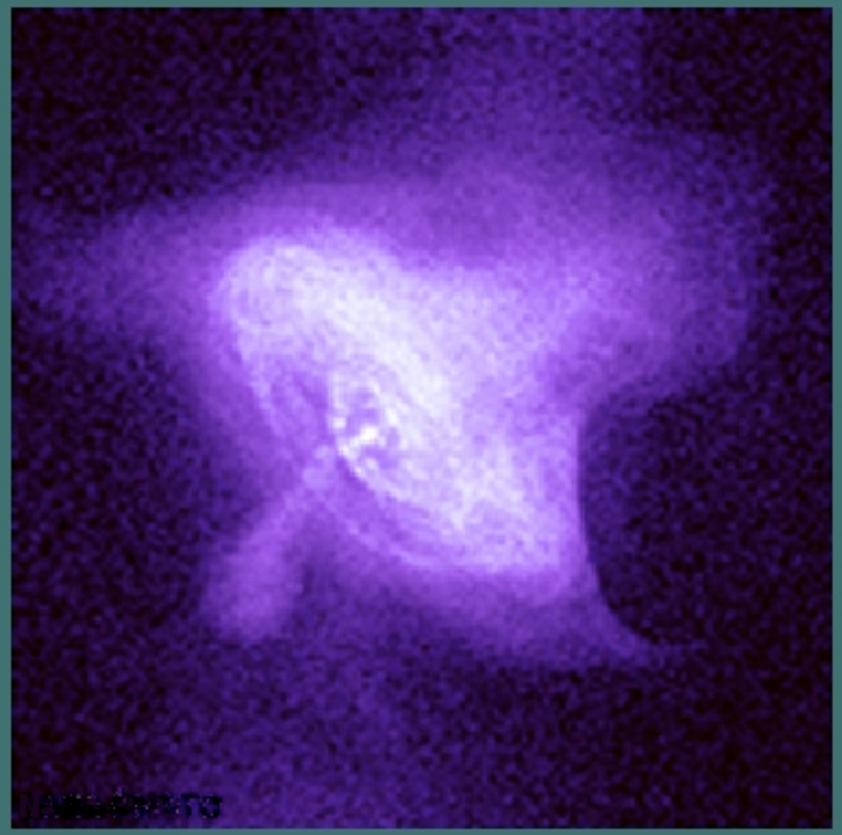
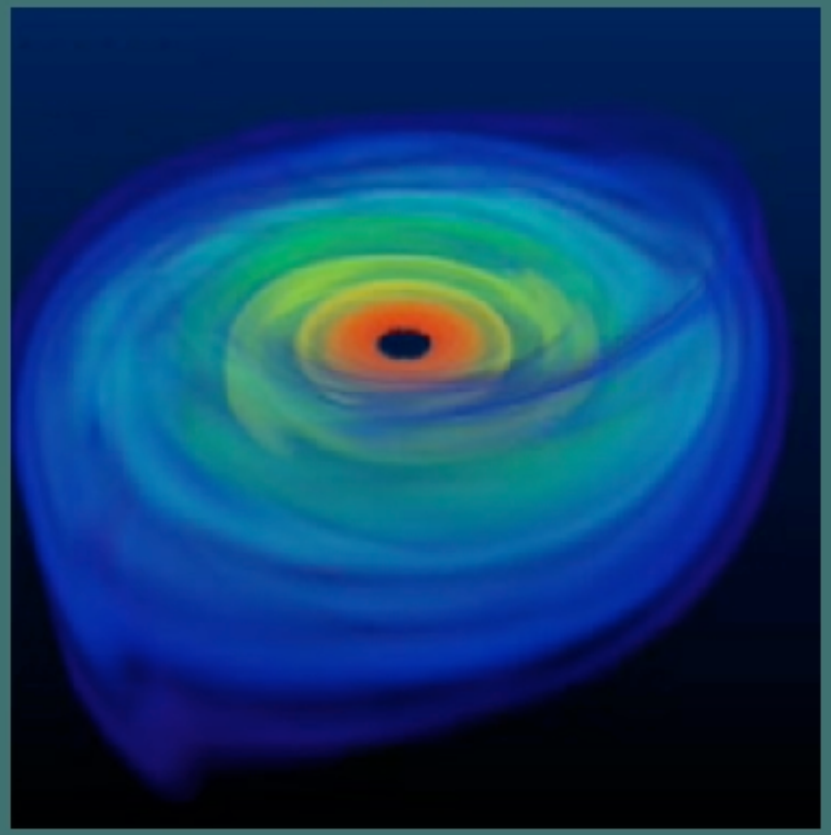




typical amplitude 10^{-22}



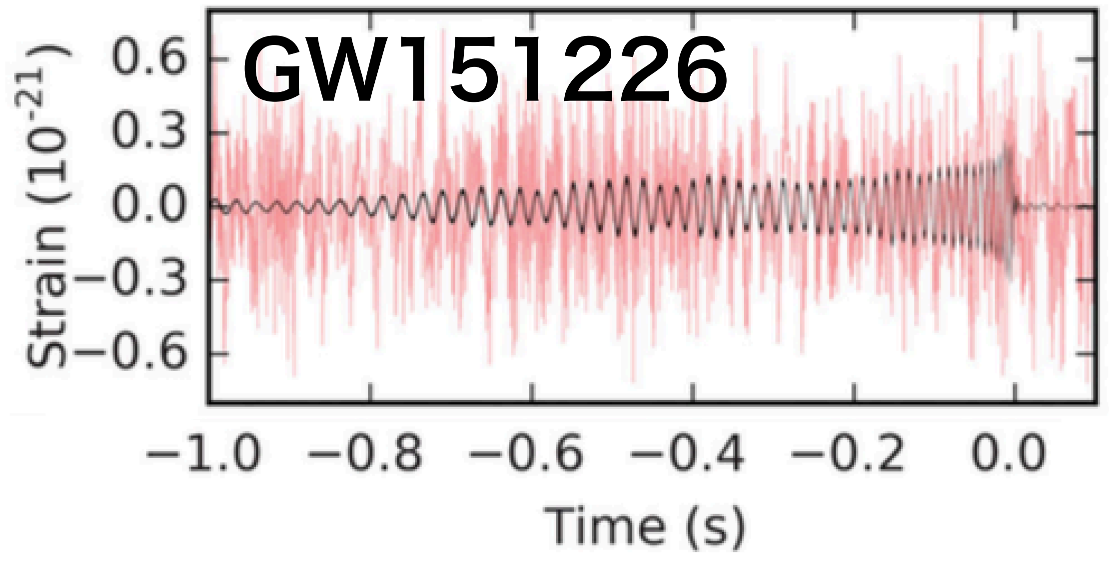
Sources of Gravitational Waves

supernovae	pulsars	black hole	binary neutron stars binary black holes
超新星爆発（写真出典:NASA）	パルサー（写真出典:NASA）	ブラックホール（想像図）	連星中性子星合体（想像図）
			
hard to predict	too small amplitude	too small amplitude	The Target

signal = noise + gw
[dimensionless]

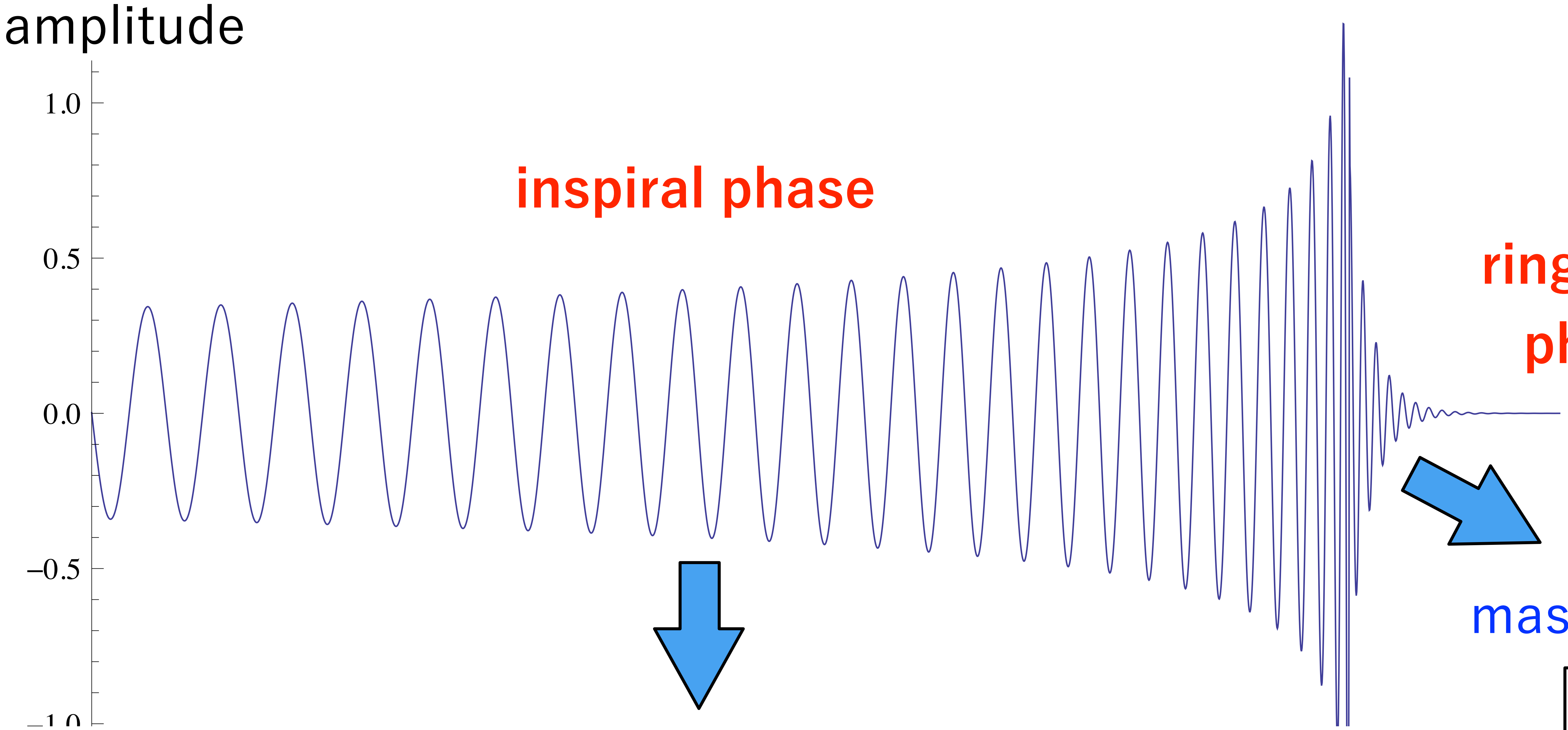
$$s(t) = n(t) + h(t)$$

standard way is to use matched filtering technique
necessary for GW templates in hand



What we can learn from GW (from a binary merger) ?

amplitude



merger phase

inspiral phase

ringdown phase

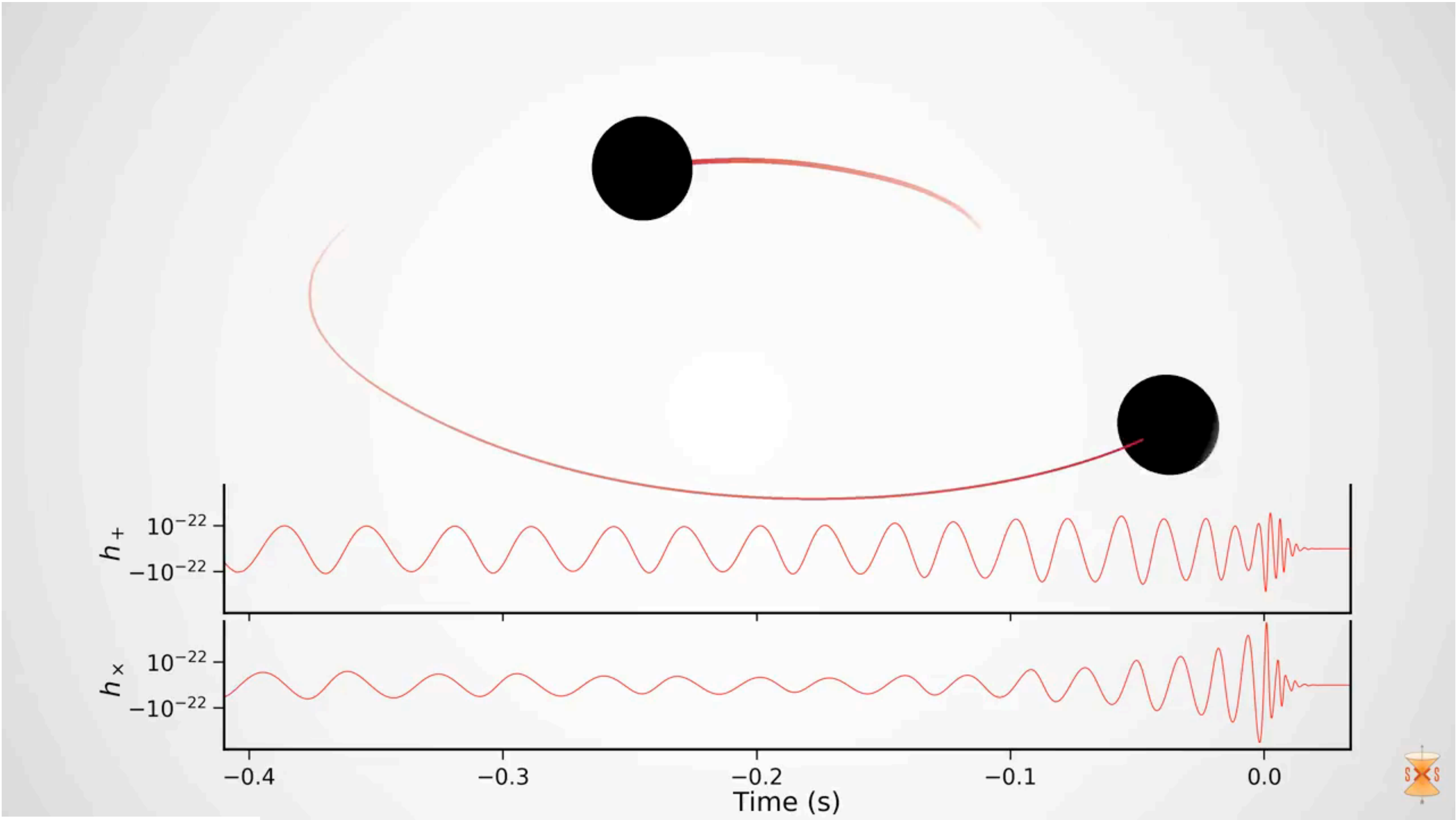
mass, spin

mass, spin, orbital parameters, tidal, distance, polarization

$$(m_1, m_2, \mathbf{s}_1, \mathbf{s}_2, \iota, \mathbf{n}, t_c, \varphi_c, \psi, r)$$

test of GR

unified theory



http://ligo.org/detections/GW170104.php

statistics

nuclear matter EOS

binary formation scenario

galaxy formation scenario

cosmological parameters

Sensitivity requirements for the detectors

LIGO: The Laser Interferometer Gravitational-Wave Observatory

Alex Abramovici, William E. Althouse, Ronald W. P. Drever, Yekta Gürsel, Seiji Kawamura, Frederick J. Raab, David Shoemaker, Lisa Sievers, Robert E. Spero, Kip S. Thorne, Rochus E. Vogt, Rainer Weiss, Stanley E. Whitcomb, Michael E. Zucker

The goal of the Laser Interferometer Gravitational-Wave Observatory (LIGO) Project is to detect and study astrophysical gravitational waves and use data from them for research in physics and astronomy. LIGO will support studies concerning the nature and nonlinear dynamics of gravity, the structures of black holes, and the equation of state of nuclear matter. It will also measure the masses, birth rates, collisions, and distributions of black holes and neutron stars in the universe and probe the cores of supernovae and the very early universe. The technology for LIGO has been developed during the past 20 years. Construction will begin in 1992, and under the present schedule, LIGO's gravitational-wave searches will begin in 1998.

Einstein's general relativity theory describes gravity as due to a curvature of space-time (*1*). When the curvature is weak, it produces the familiar Newtonian gravity that governs the solar system. When the curvature is strong, however, it should behave in a radically different, highly nonlinear way. According to general relativity, the nonlinearity creates black holes (curvature produces curvature without the aid of any matter), governs their structure, and holds them together against disruption (*2*). Inside a black hole, the curvature should nonlinearly amplify itself to produce a space-time singularity (*2*), and near some singularities the nonlinearity should force the curvature to evolve chaotically (*3*). When an object's curvature varies rapidly (for example, because of pulsations, colli-

The authors are the members of the LIGO Science Steering Group. A. Abramovici, W. E. Althouse (Chief Engineer), R. W. P. Drever, S. Kawamura, F. J. Raab, L. Sievers, R. E. Spero, K. S. Thorne, R. E. Vogt (Director), S. E. Whitcomb (Deputy Director), and M. E. Zucker are with the California Institute of Technology, Pasadena, CA 91125. Y. Gürsel is at the Jet Propulsion Laboratory, Pasadena, CA 91109. D. Shoemaker and R. Weiss are at the Massachusetts Institute of Technology, Cambridge, MA 02129.

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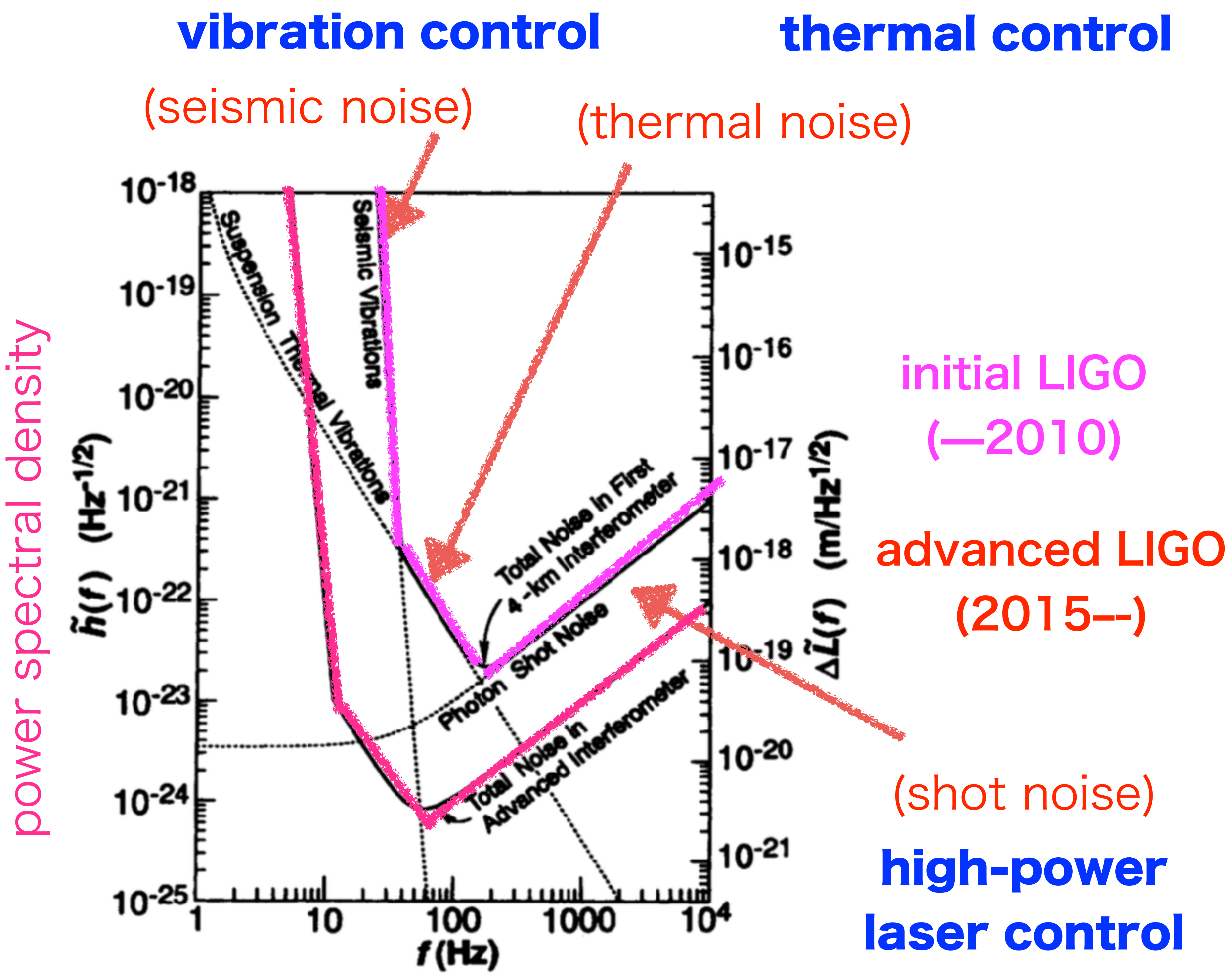


Fig. 7. The expected total noise in each of LIGO's first 4-km interferometers (upper solid curve) and in a more advanced interferometer (lower solid curve). The dashed curves show various contributions to the first interferometer's noise.

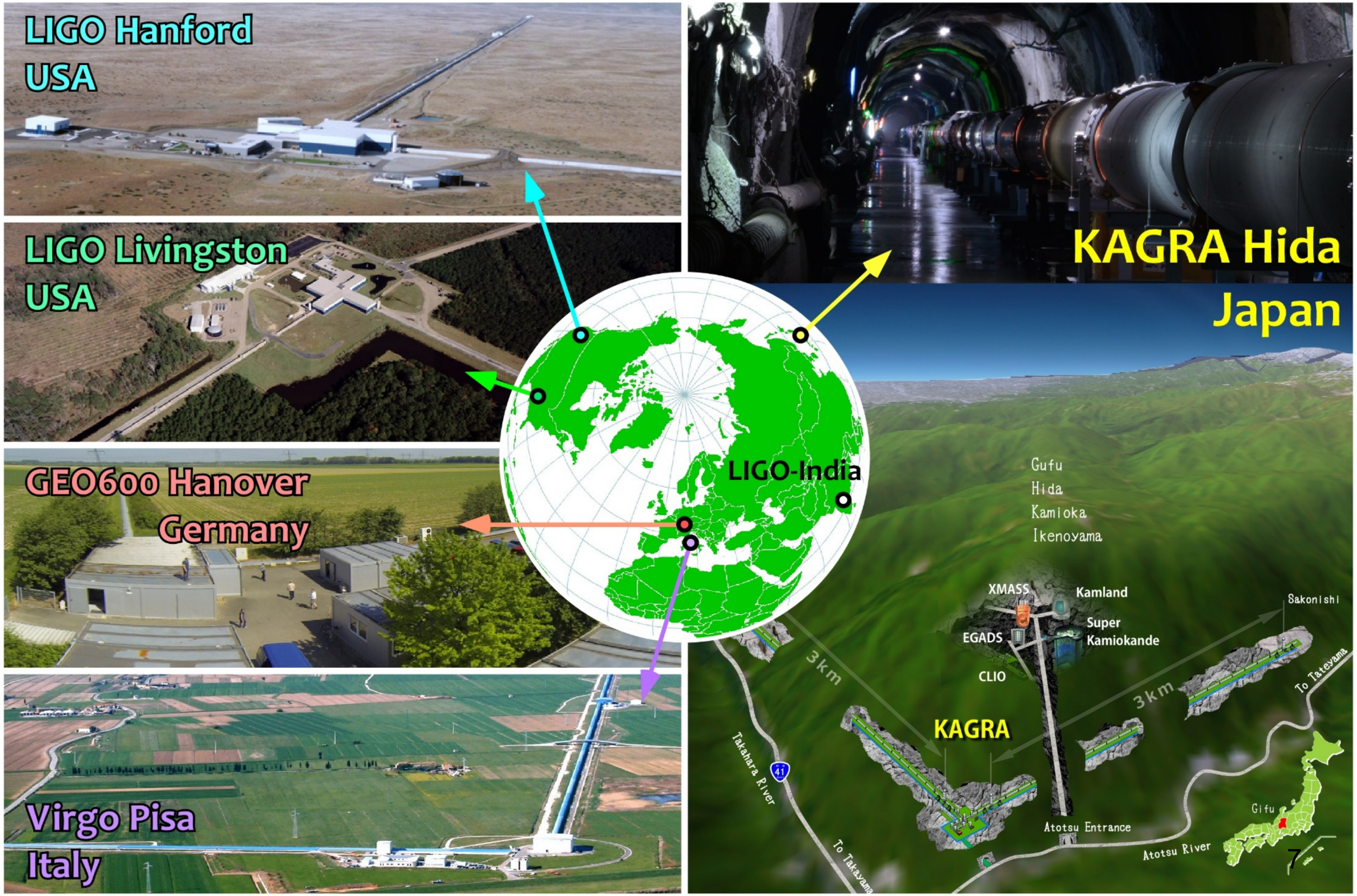
GW International Network

4 km

4 km

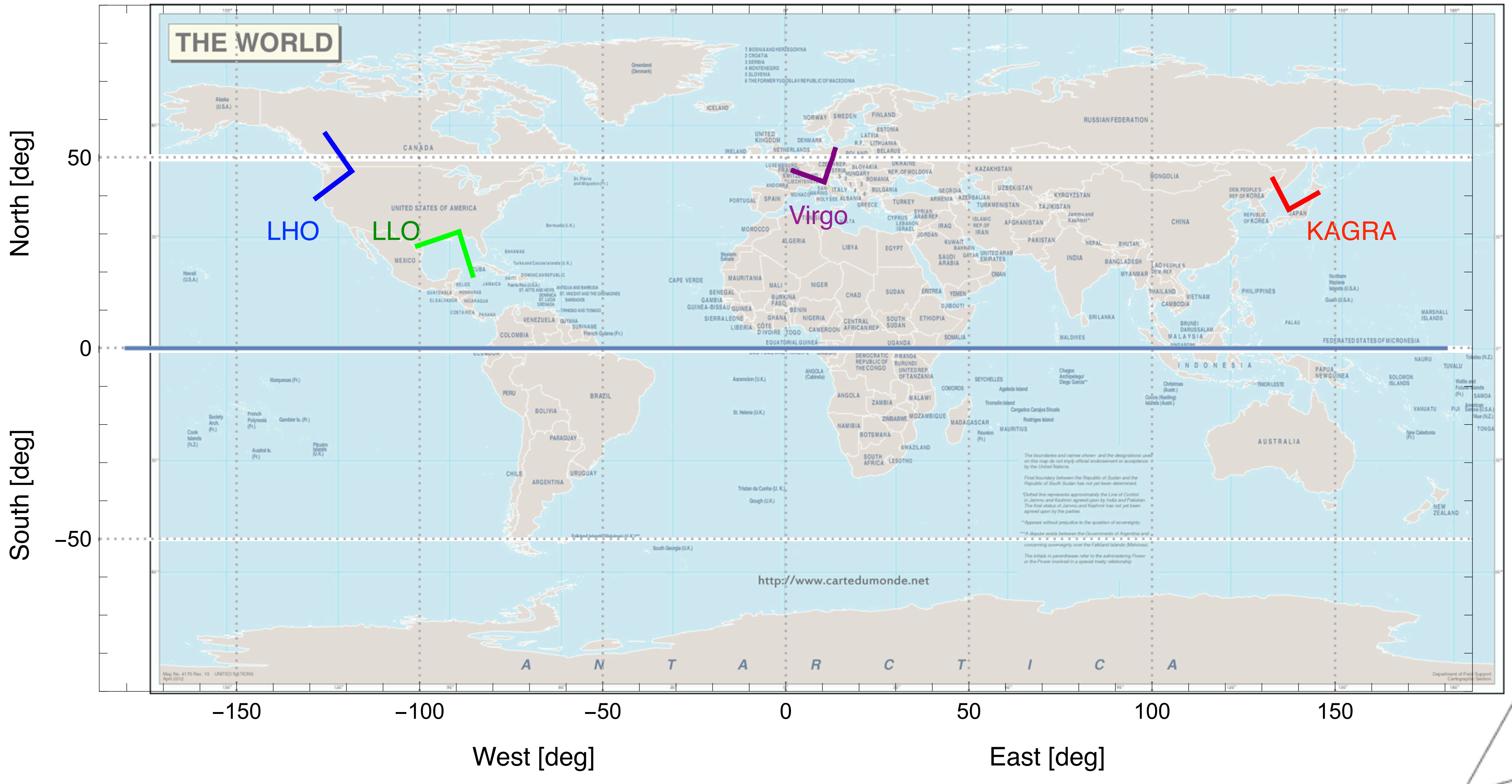
600 m

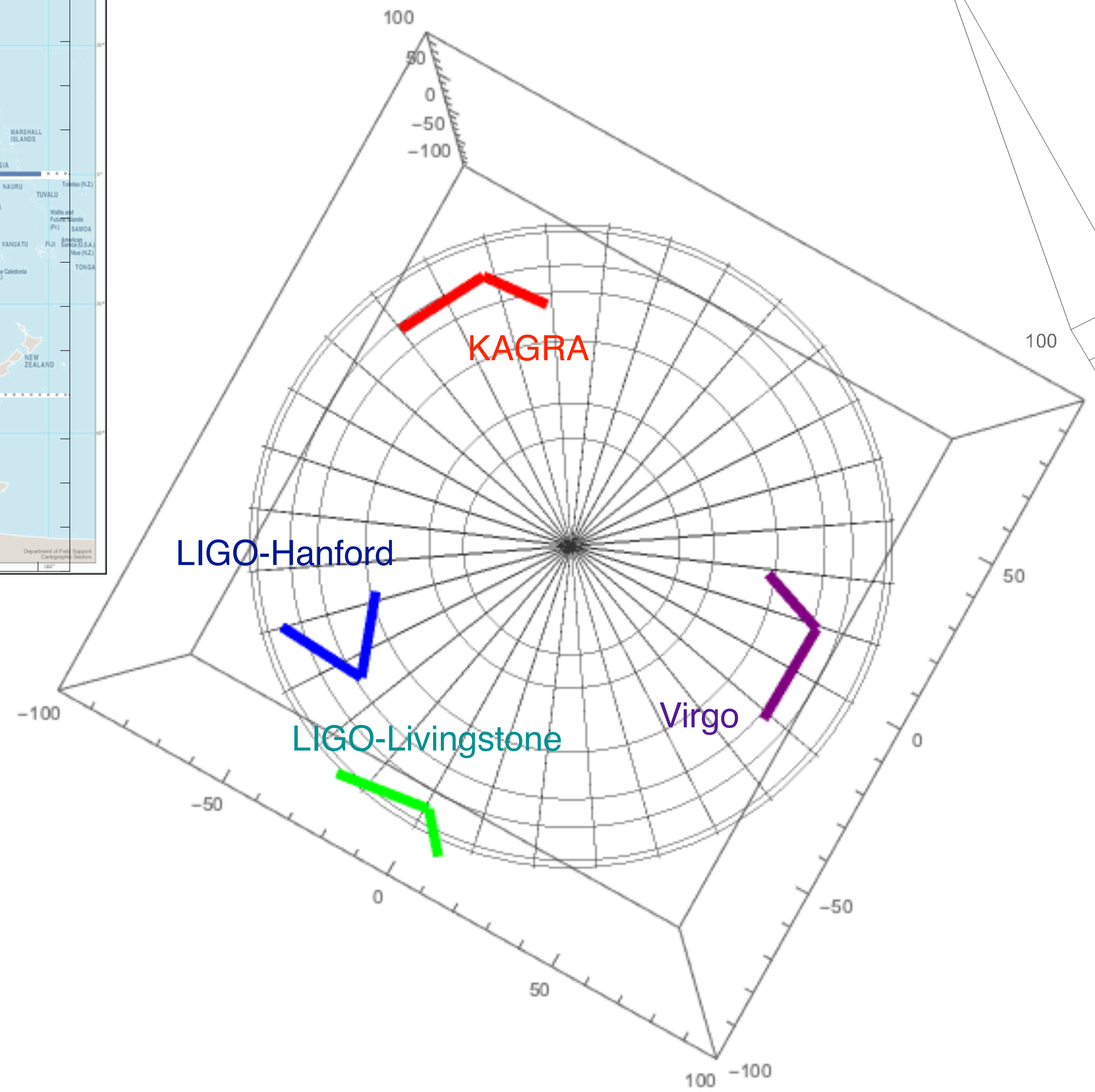
3 km

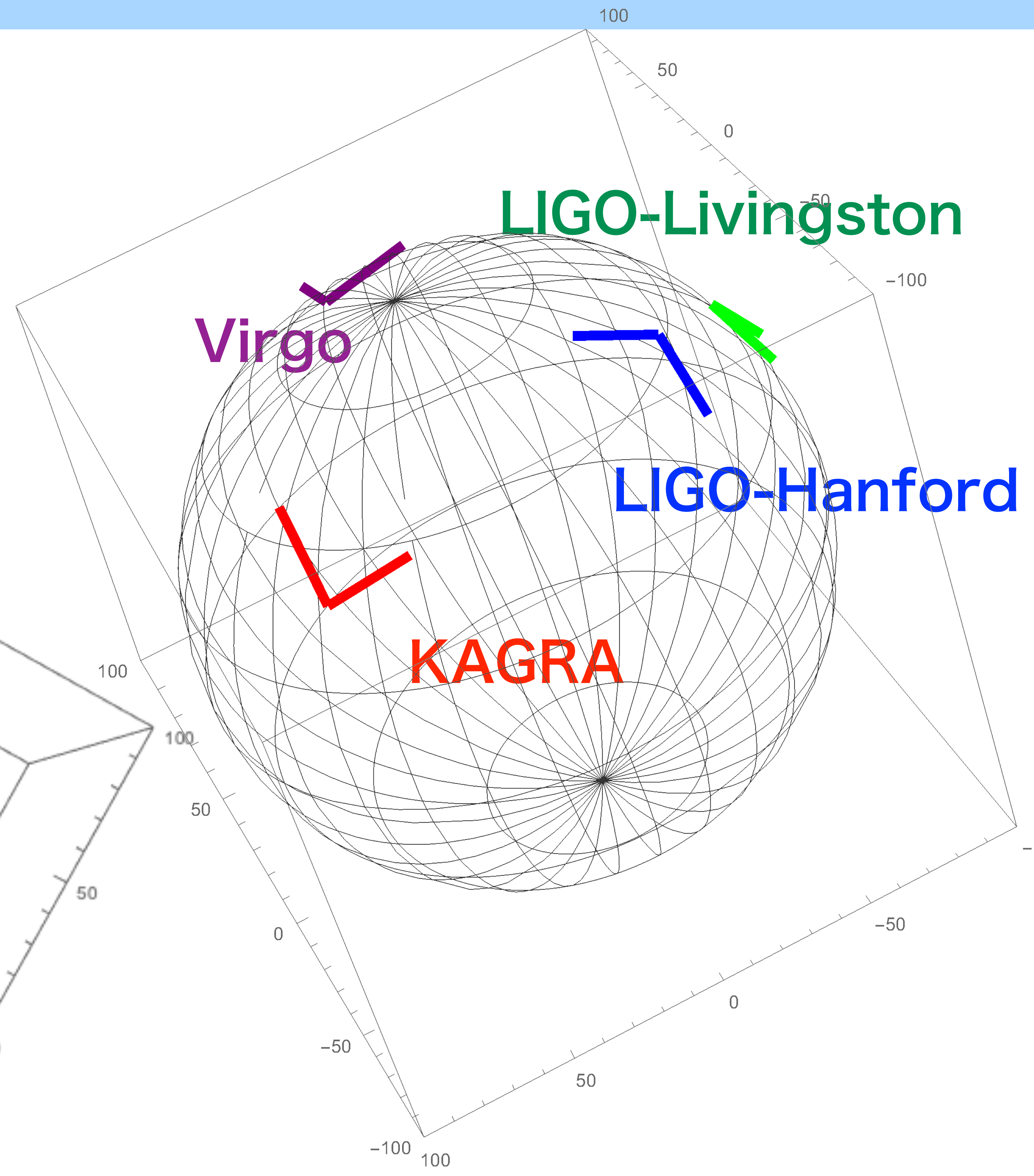


3 km

LIGO, Virgo and KAGRA







more precise GW source localization

more certain GW source parameters

more chances to hunt GW events

more information of GW polarization

more ideas for GW researches

more man power

Table 1 Geometry of LIGO, Virgo & KAGRA detectors.

Detector	arm length	Latitude	Longitude	X-arm	Y-arm
LIGO Hanford (LHO)	4 km	46°27′19″ N	119°24′28″ W	N 36° W	W 36° S
LIGO Livingston (LLO)	4 km	30°33′46″ N	90°46′27″ W	N 18° S	S 18° E
Virgo	3 km	43°37′53″ N	10°30′16″ E	N 19° E	W 19° N
KAGRA	3 km	36°24′36″ N	137°18′36″ E	E 28.3° N	N 28.3° W

Sensitivity Curve

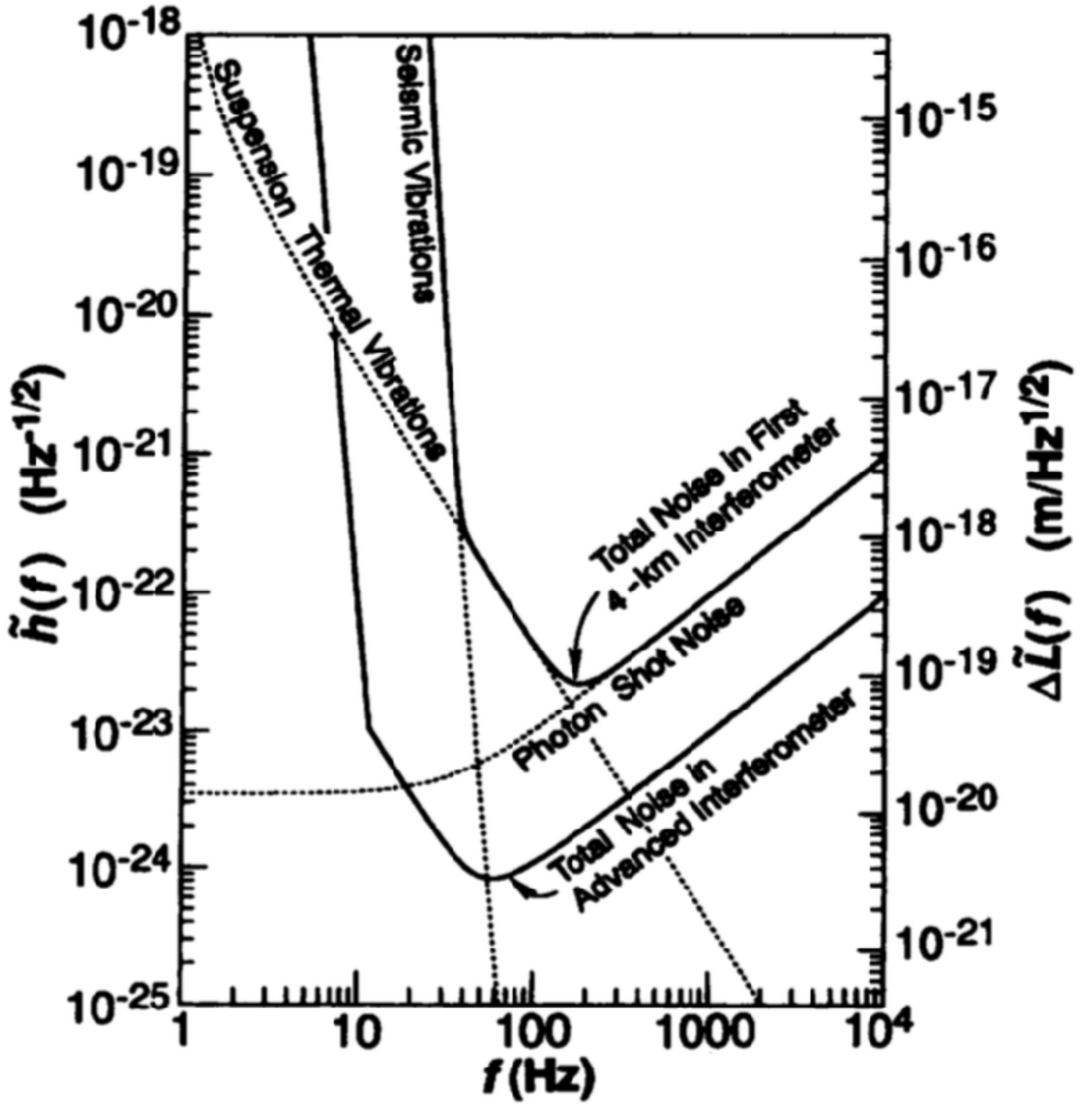


Fig. 7. The expected total noise in each of LIGO's first 4-km interferometers (upper solid curve) and in a more advanced interferometer (lower solid curve). The dashed curves show various contributions to the first interferometer's noise.

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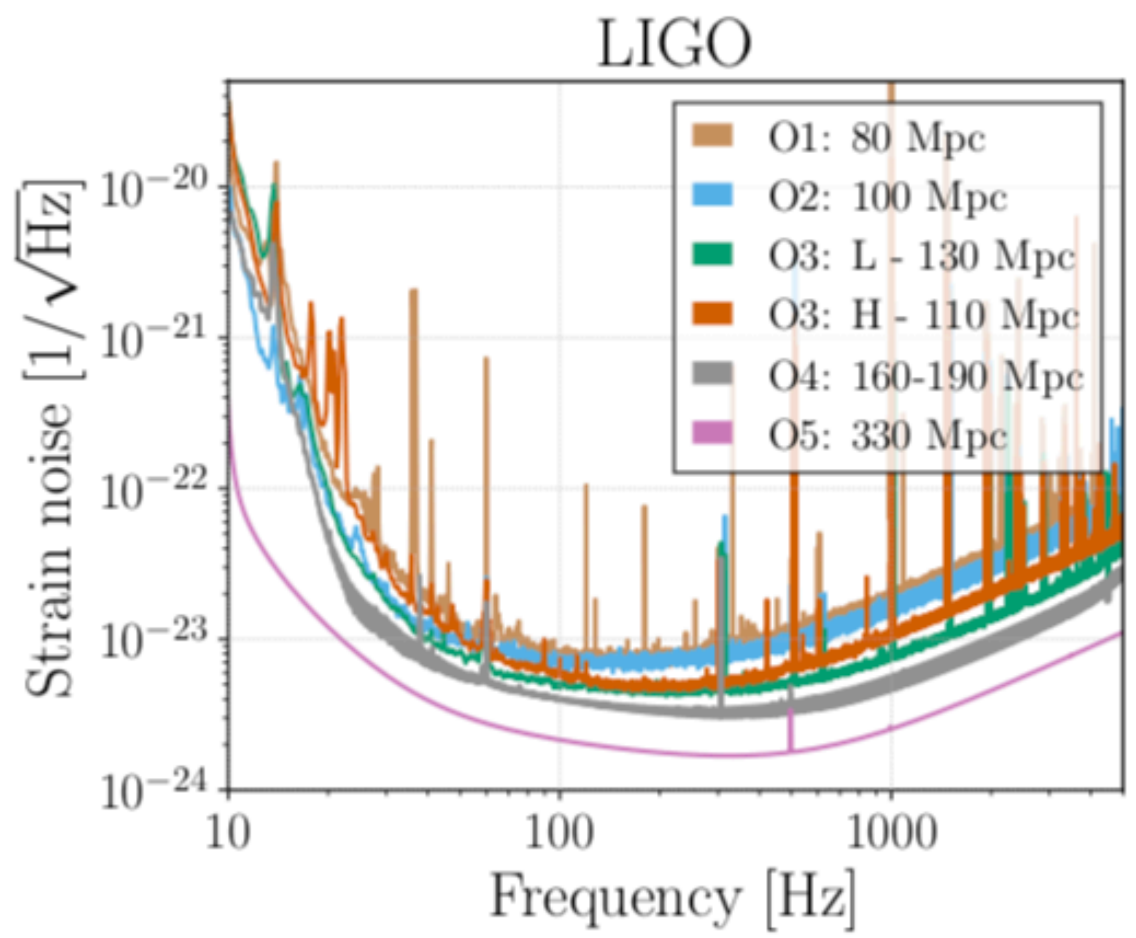
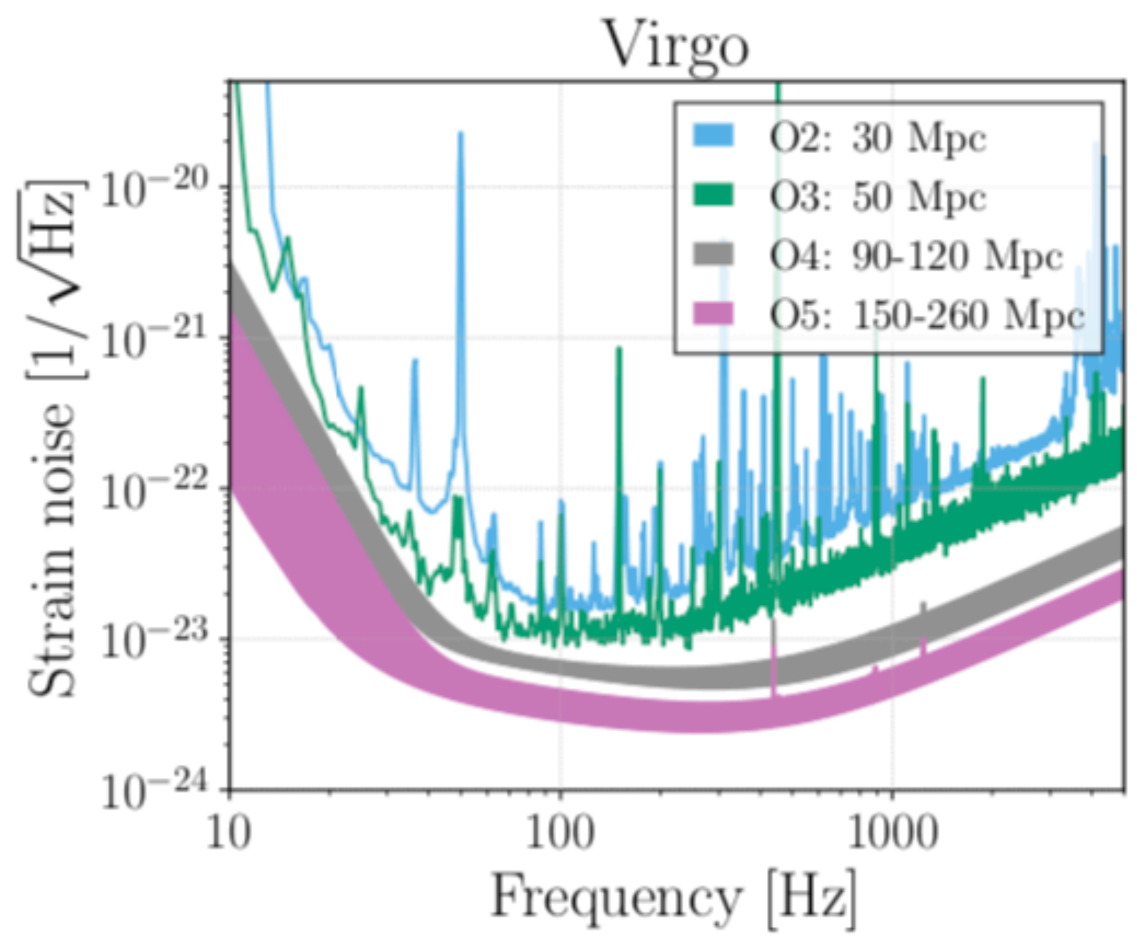
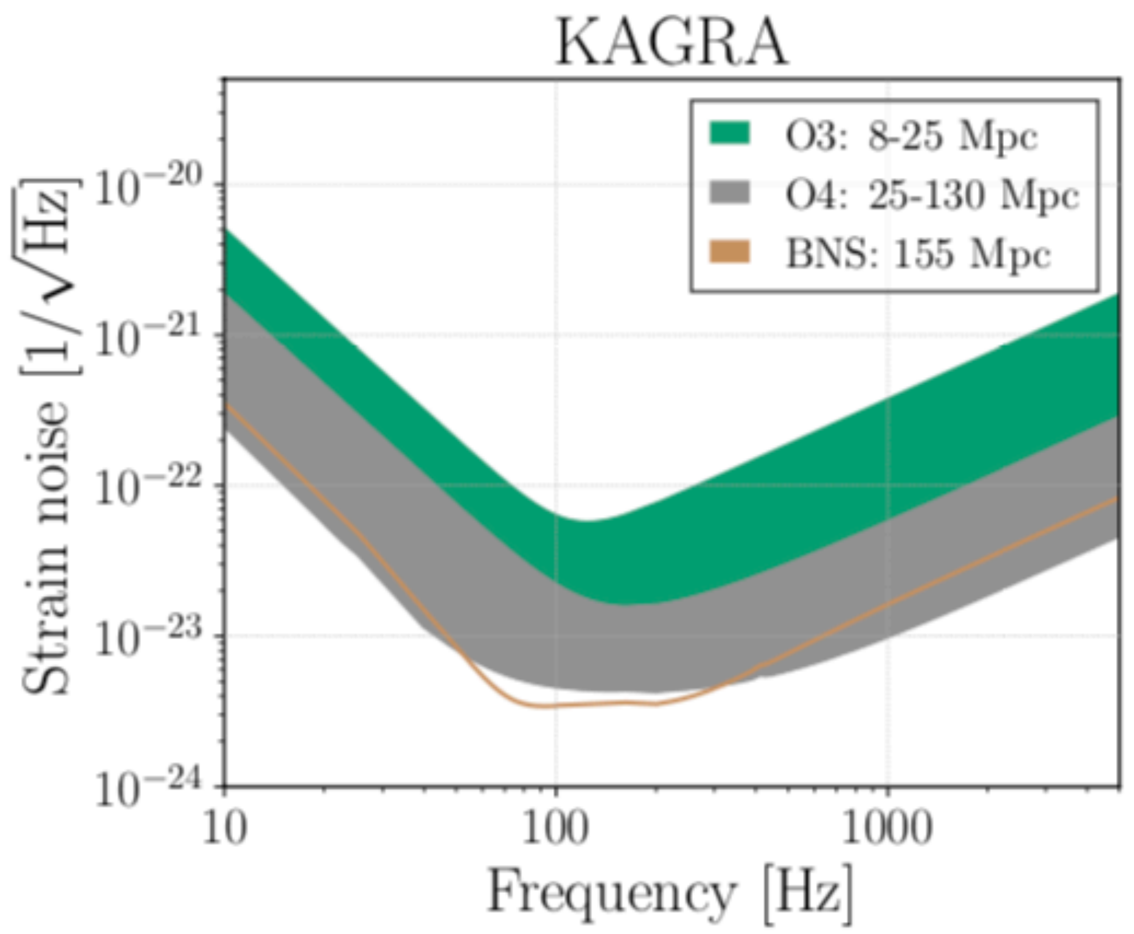






Binary NS range

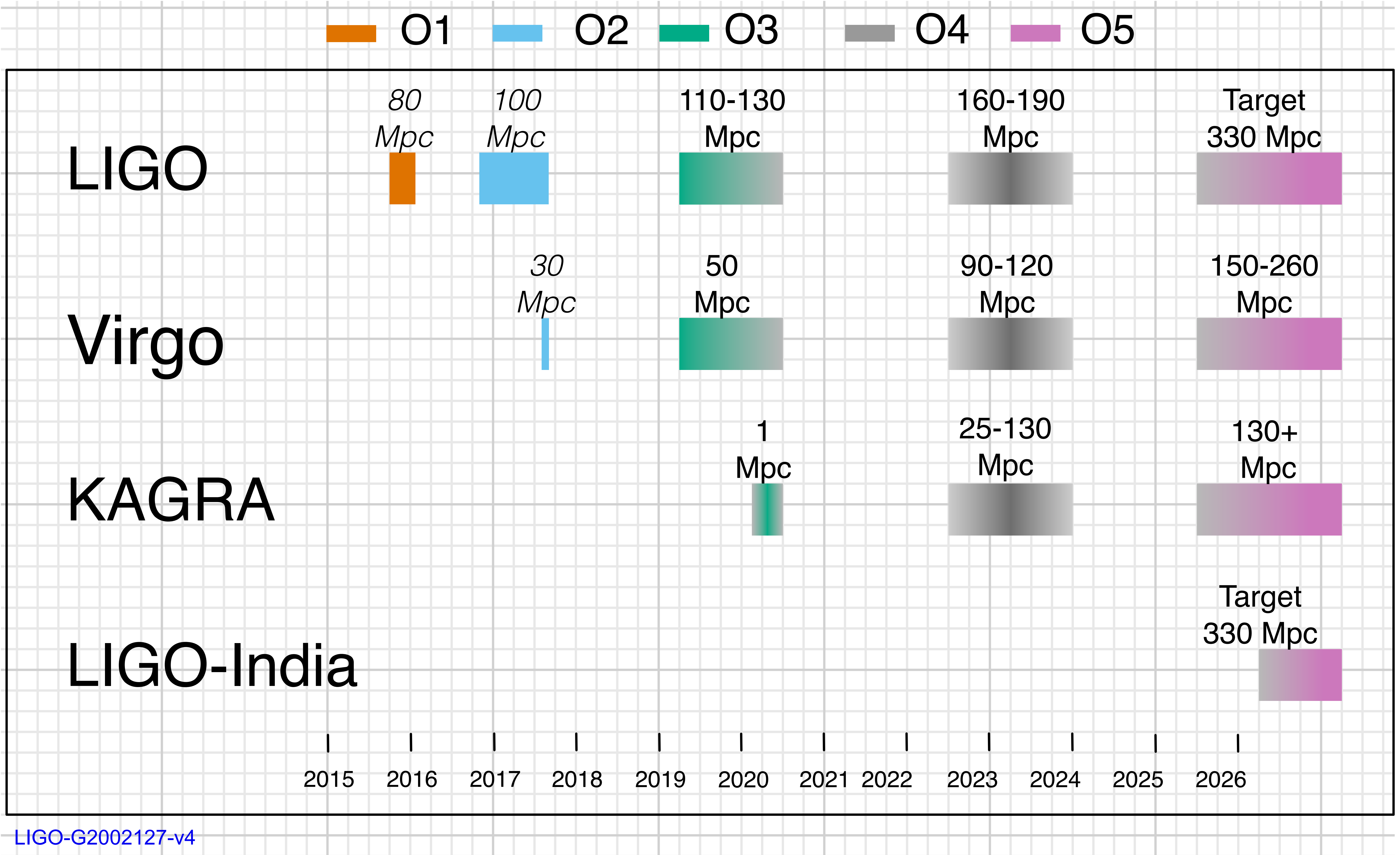
LVK collaboration, Living Rev Relativ (2020) 23:3
https://link.springer.com/article/10.1007/s41114-020-00026-9
[1304.0670ver2020Jan]

Observation Period

Obs. Runs	Advanced LIGO	Advanced Virgo	KAGRA
O1	Sep 12, 2015 to Jan 19, 2016	–	–
O2	Nov 30, 2016 to Aug 25, 2017	Aug 1, 2017 to Aug 25, 2017	–
O3a	Apr 1, 2019 to Sep 30 2019	Apr 1, 2019 to Sep 30, 2019	–
O3b	Nov 1, 2019 to Mar 27 2020	Nov 1, 2019 to Mar 27, 2020	
O3GK	–	–	Apr 7, 2020 to Apr 21, 2020

amplitude of GW $h(t) \propto \frac{1}{r}$ **1/ distance**

if we improve one-order of magnitude of the sensitivity,
then the observational volume of the Universe
become 10^3 times larger.



KAGRA (Kamioka Gravitational-Wave Observatory)

Mozumi
control office.
(15 min)

Toyama City
(60 min)

1000m under the summit of the Mt.

358m above the sea level.

http://gwcenter.icrr.u-tokyo.ac.jp/en/

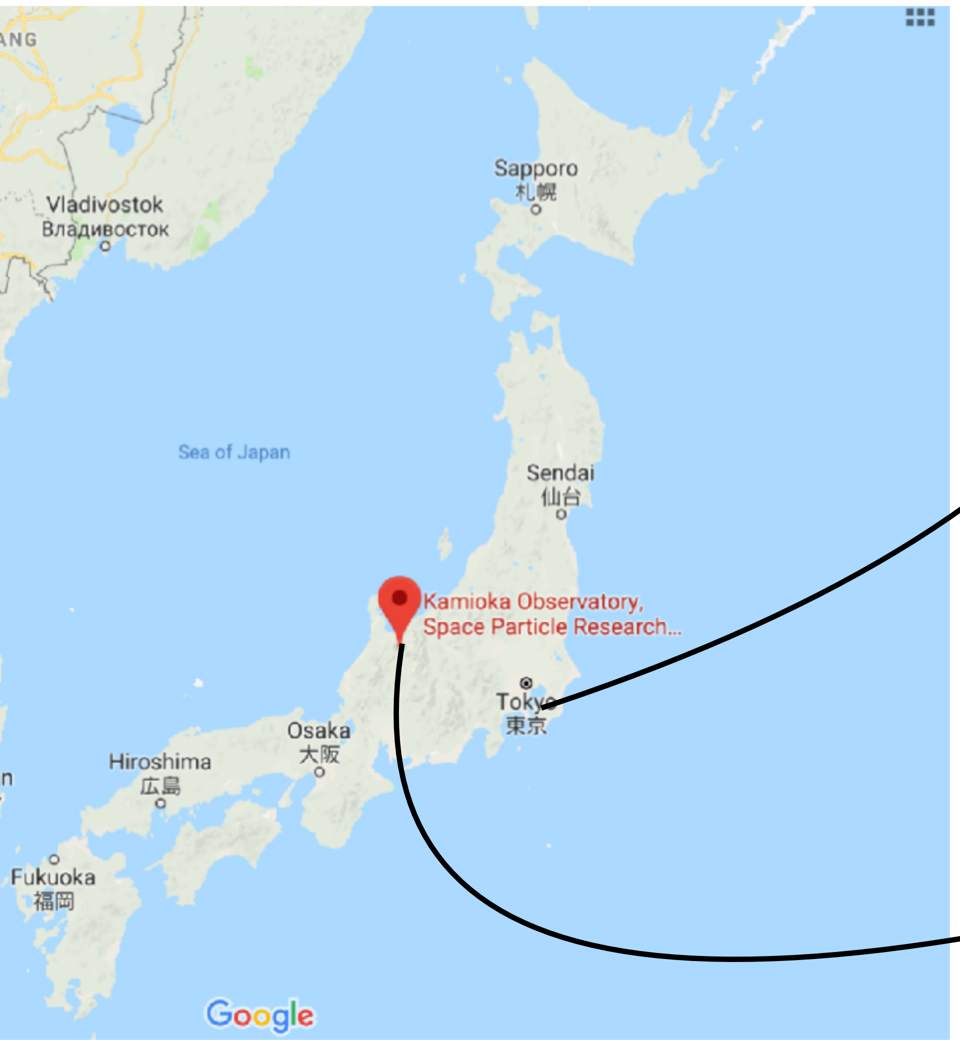
（大型低温重力波望遠鏡）

former name LCGT = large cryogenic gravitational telescope

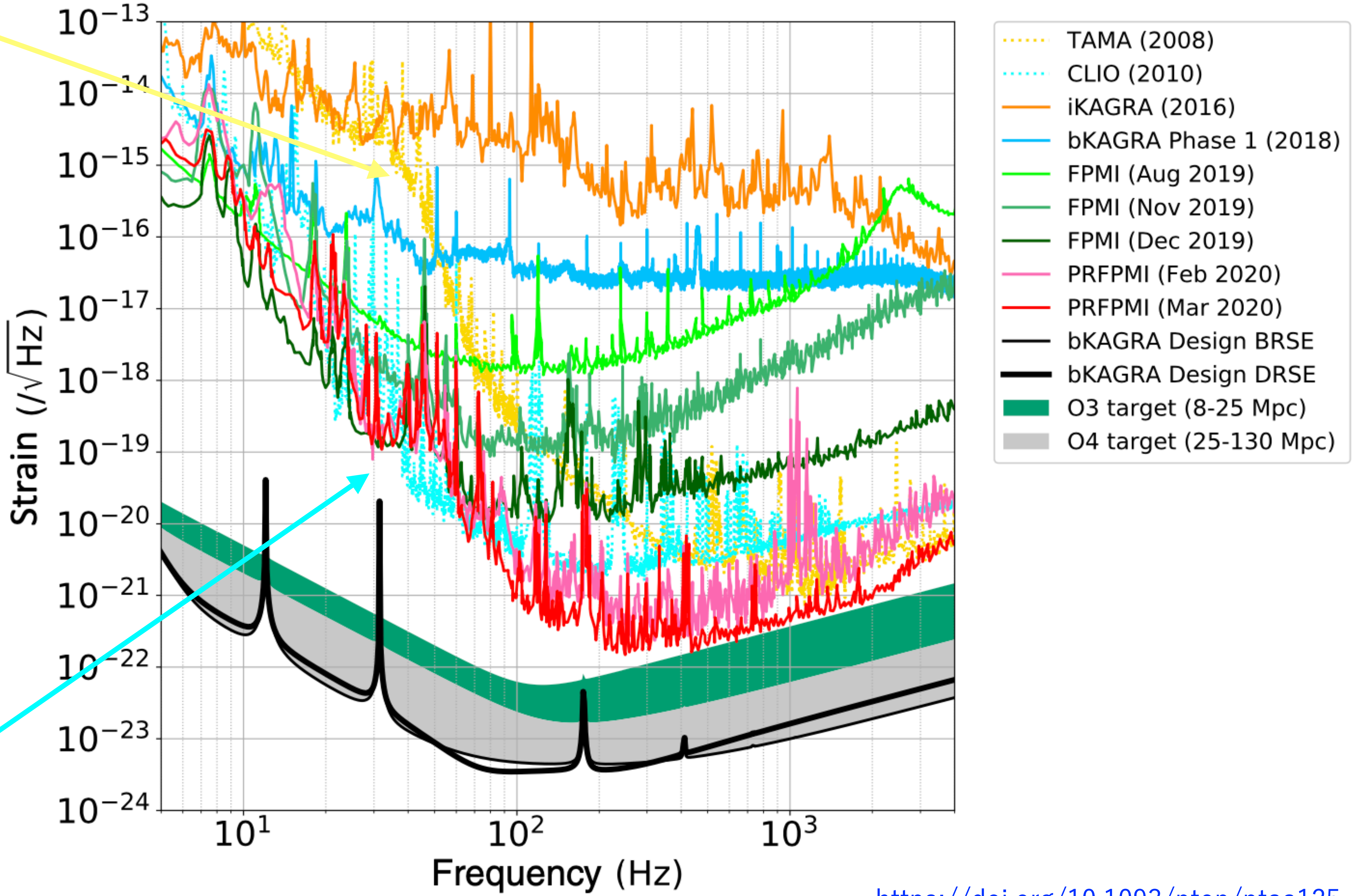
named by public naming contest, 神楽（かぐら）dance music in front of Gods

KAGRA (Kamioka Gravitational-Wave Observatory)

TAMA 300 m (NAOJ, Tokyo area, 2008)



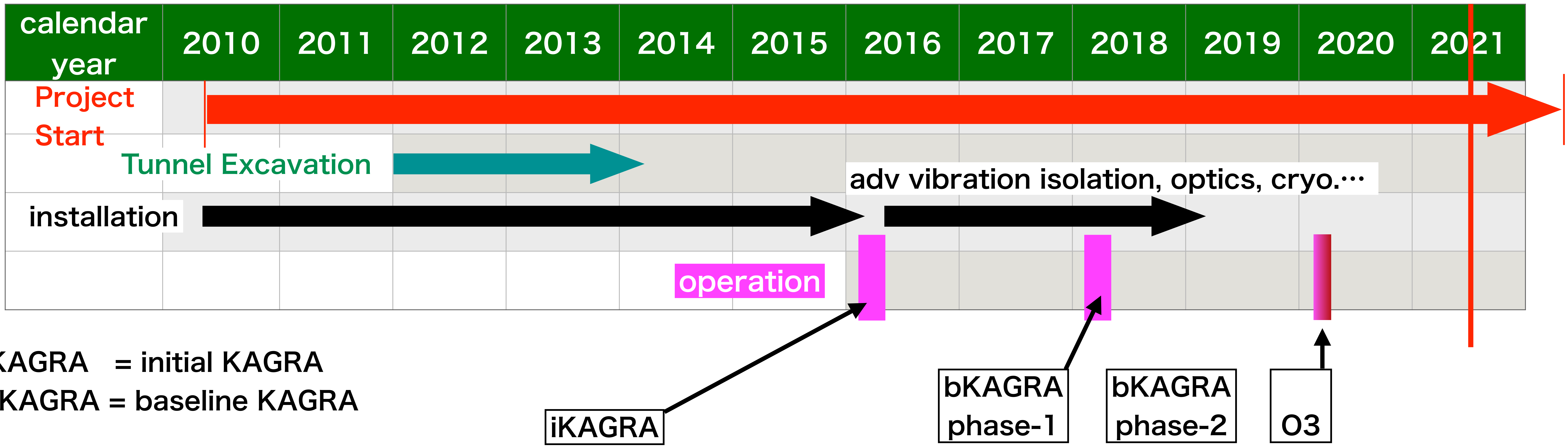
CLIO 20 m (Kamioka, 2010)



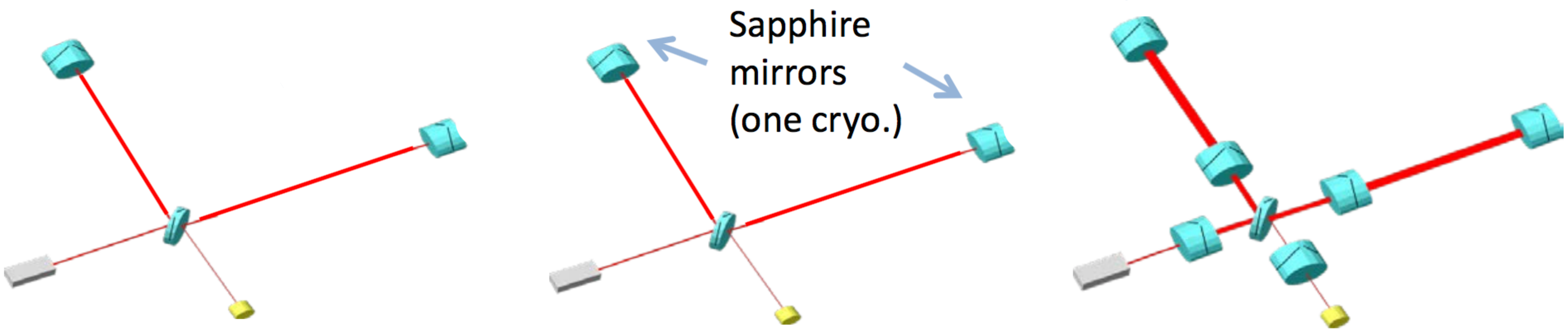
https://doi.org/10.1093/ptep/ptaa125

arXiv: 2005.05574

Brief History of KAGRA



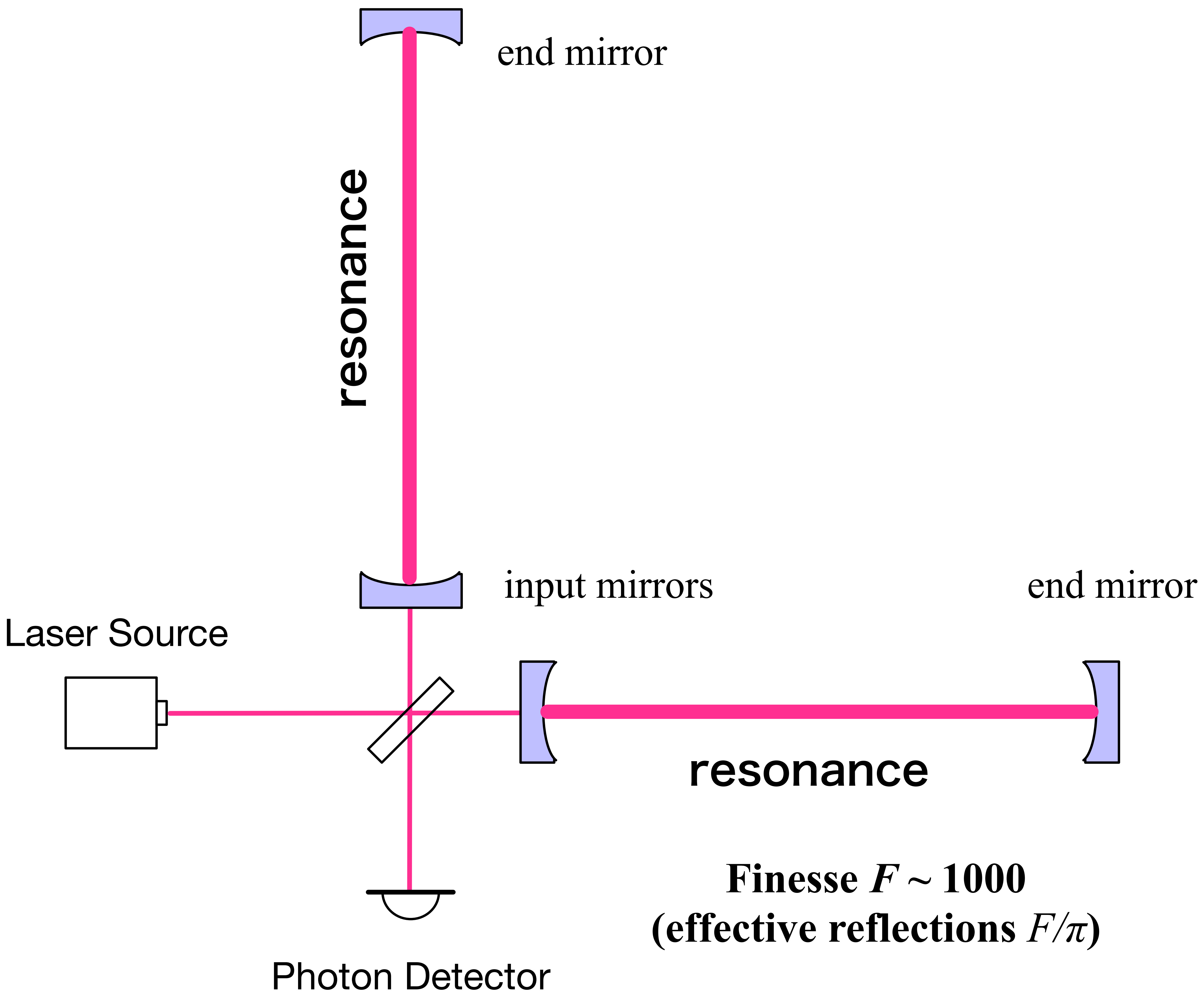
iKAGRA = initial KAGRA
bKAGRA = baseline KAGRA



[arXiv:1712.00148] [arXiv:1901.03569]

Basic Idea of the Interferometer

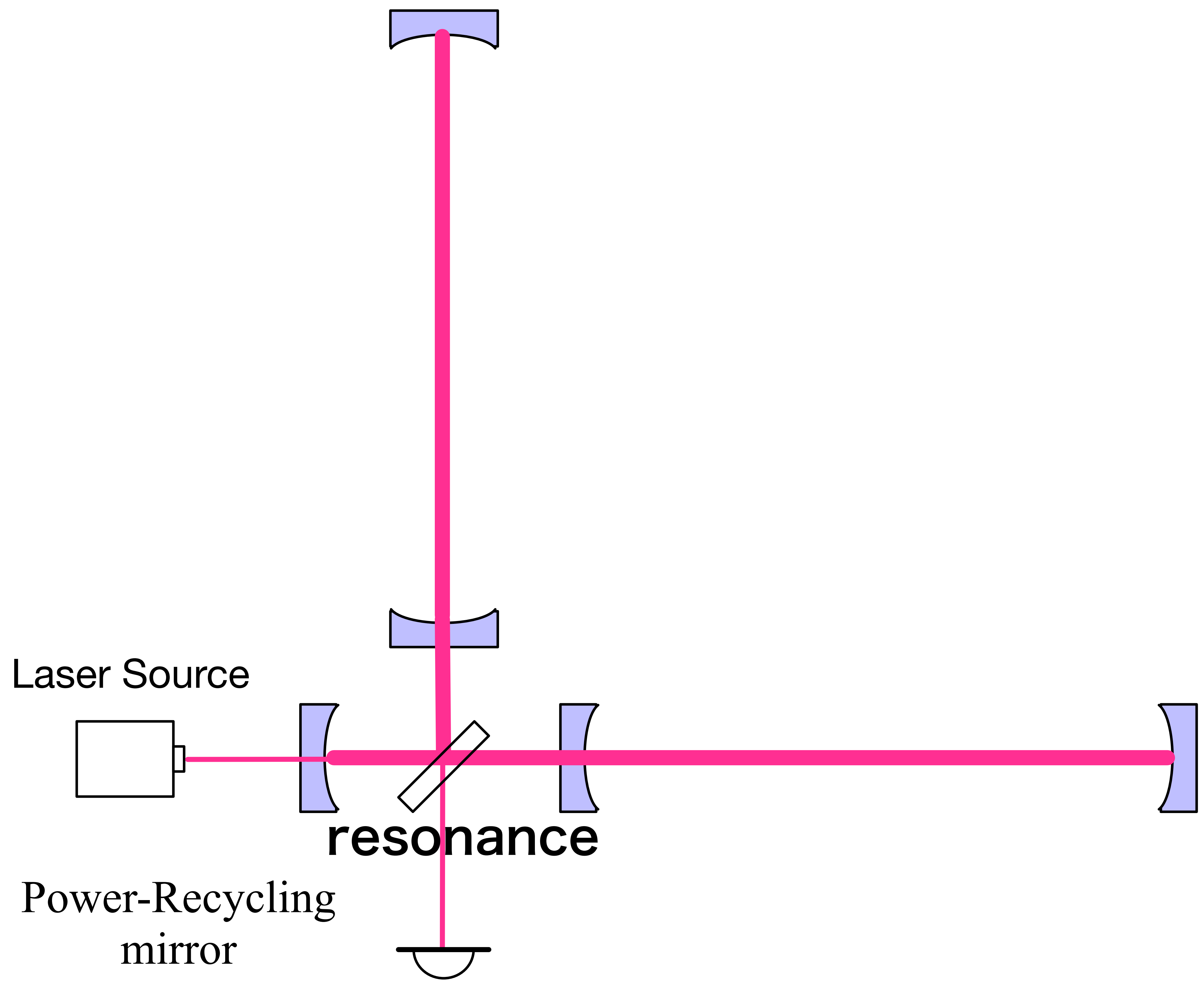
"Fabry-Pérot Michelson" interferometer



Finesse $F \sim 1000$
(effective reflections F/π)

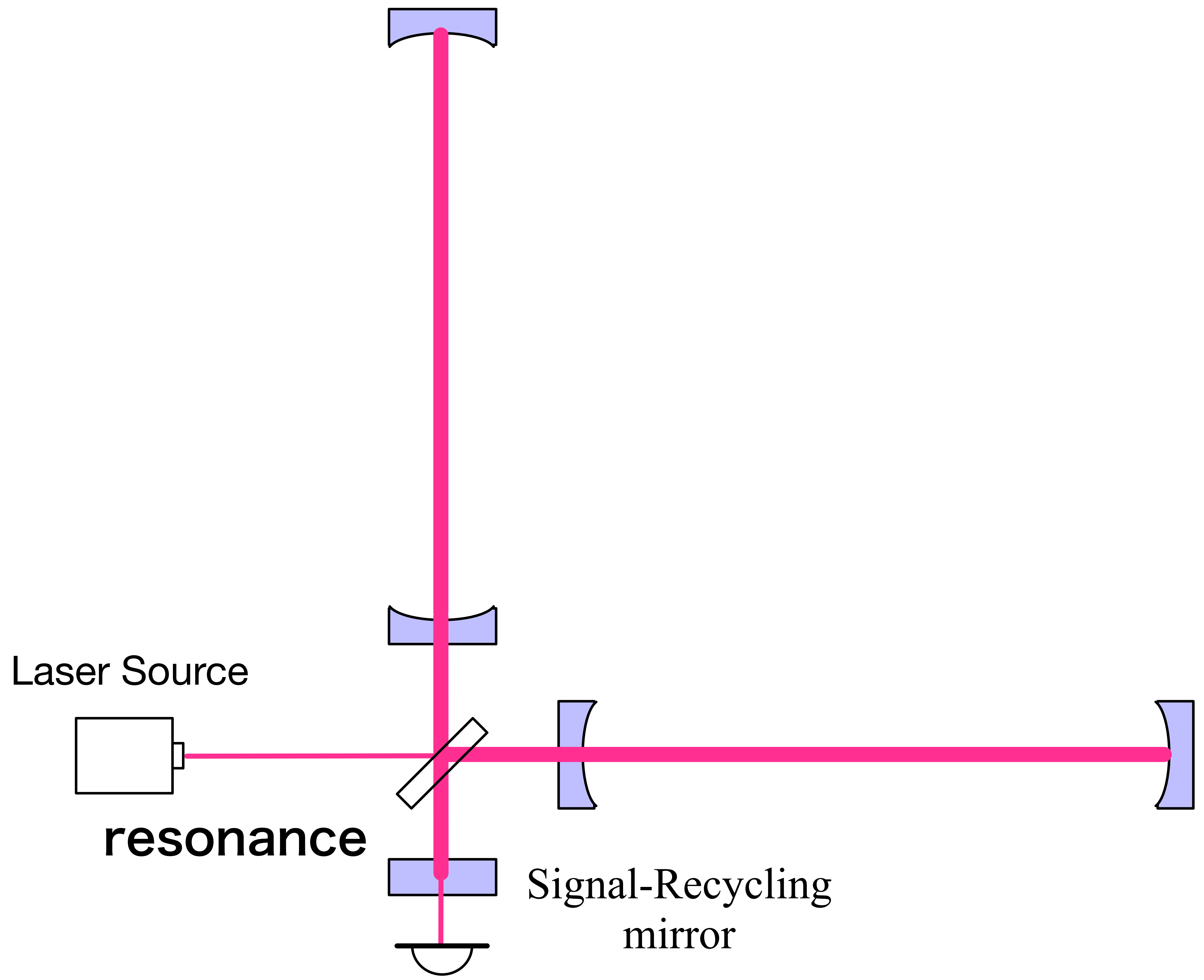
Basic Idea of the Interferometer

Power-Recyled "Fabry-Pérot" interferometer
(TAMA300, initial LIGO, Virgo)



get more effective laser power

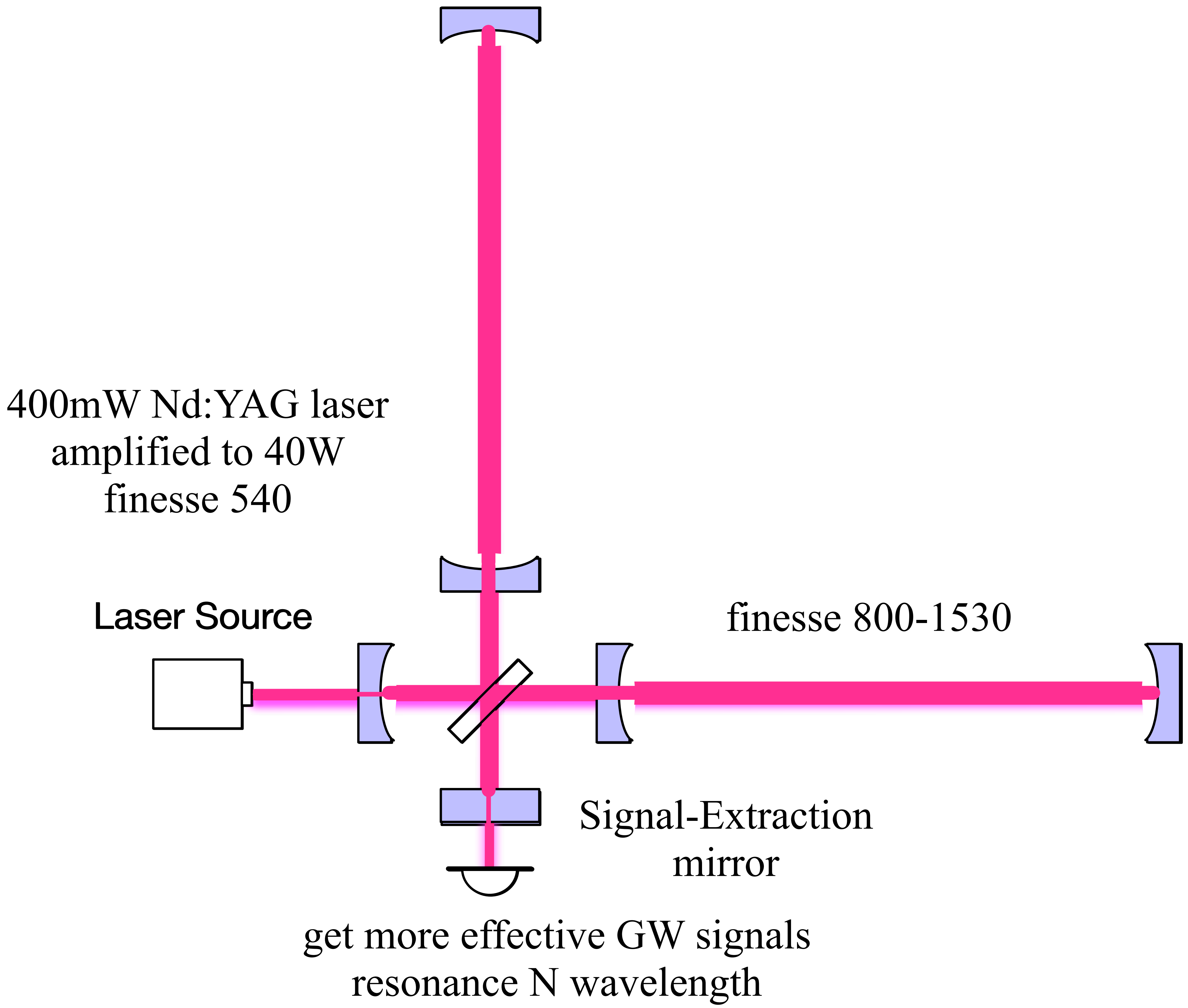
Signal-Recyled "Fabry-Pérot" interferometer
(GEO600)

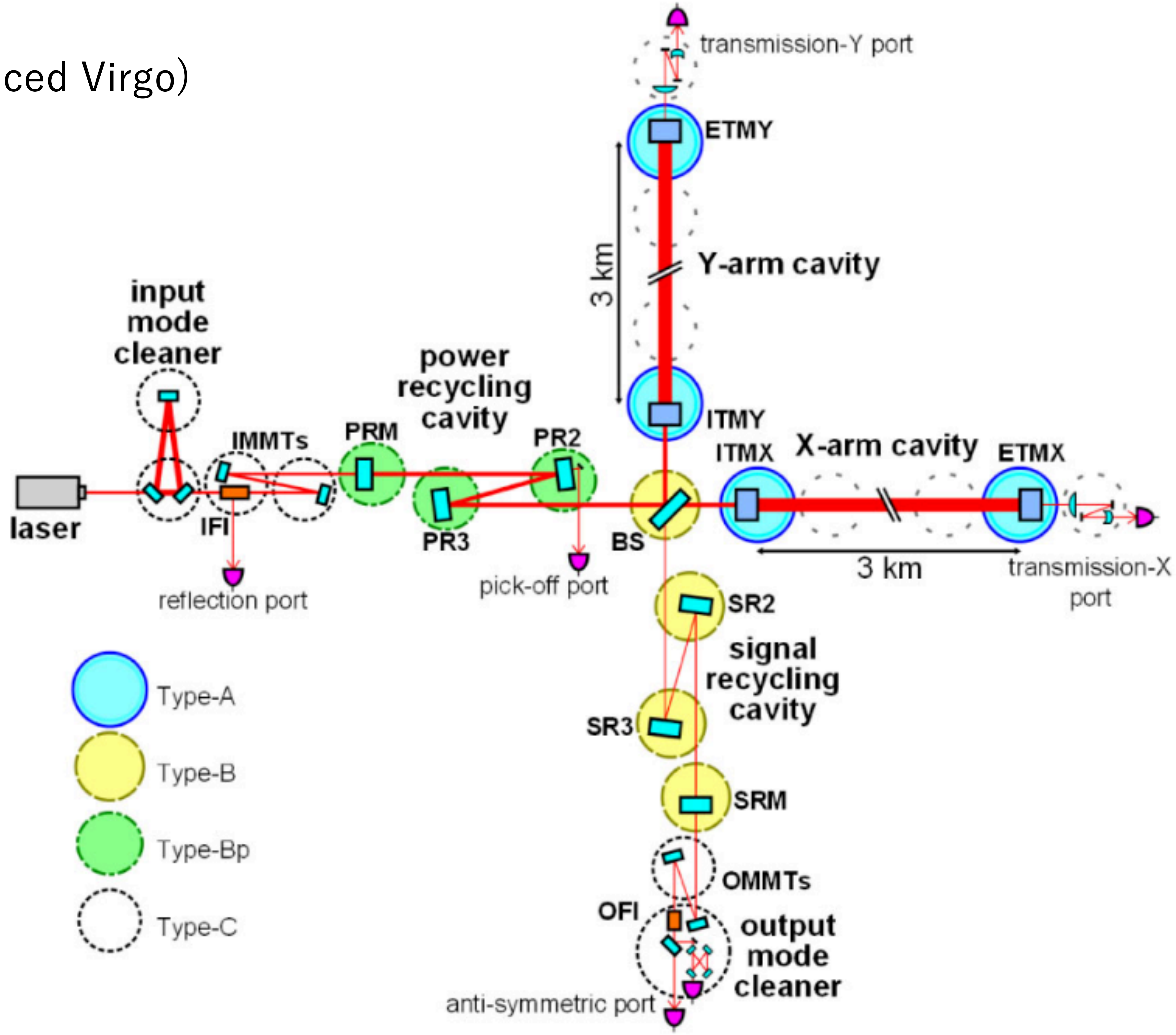


get more effective GW signals
resonance (N+1/2) wavelength between SR & IM

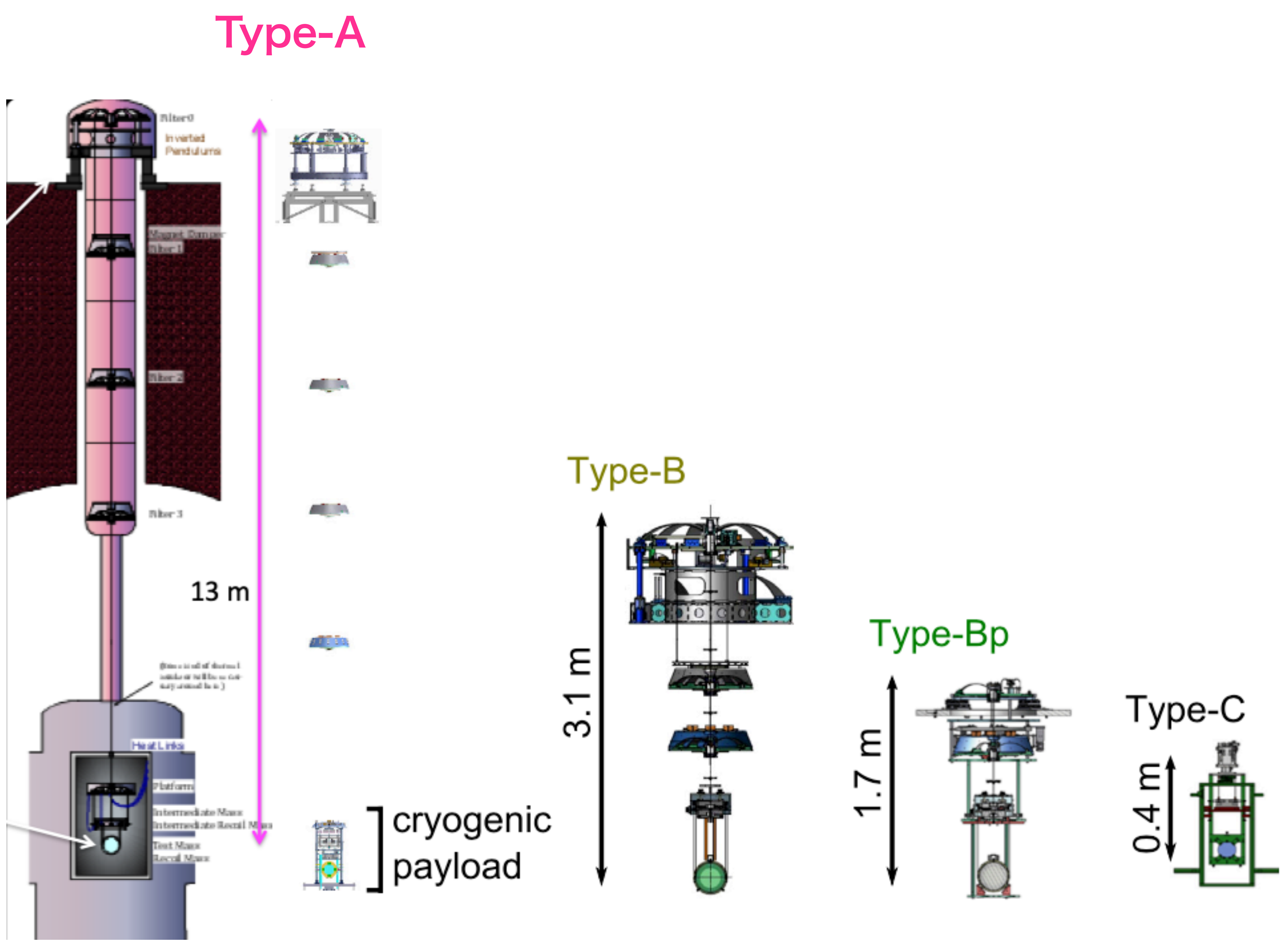
Basic Idea of the Interferometer

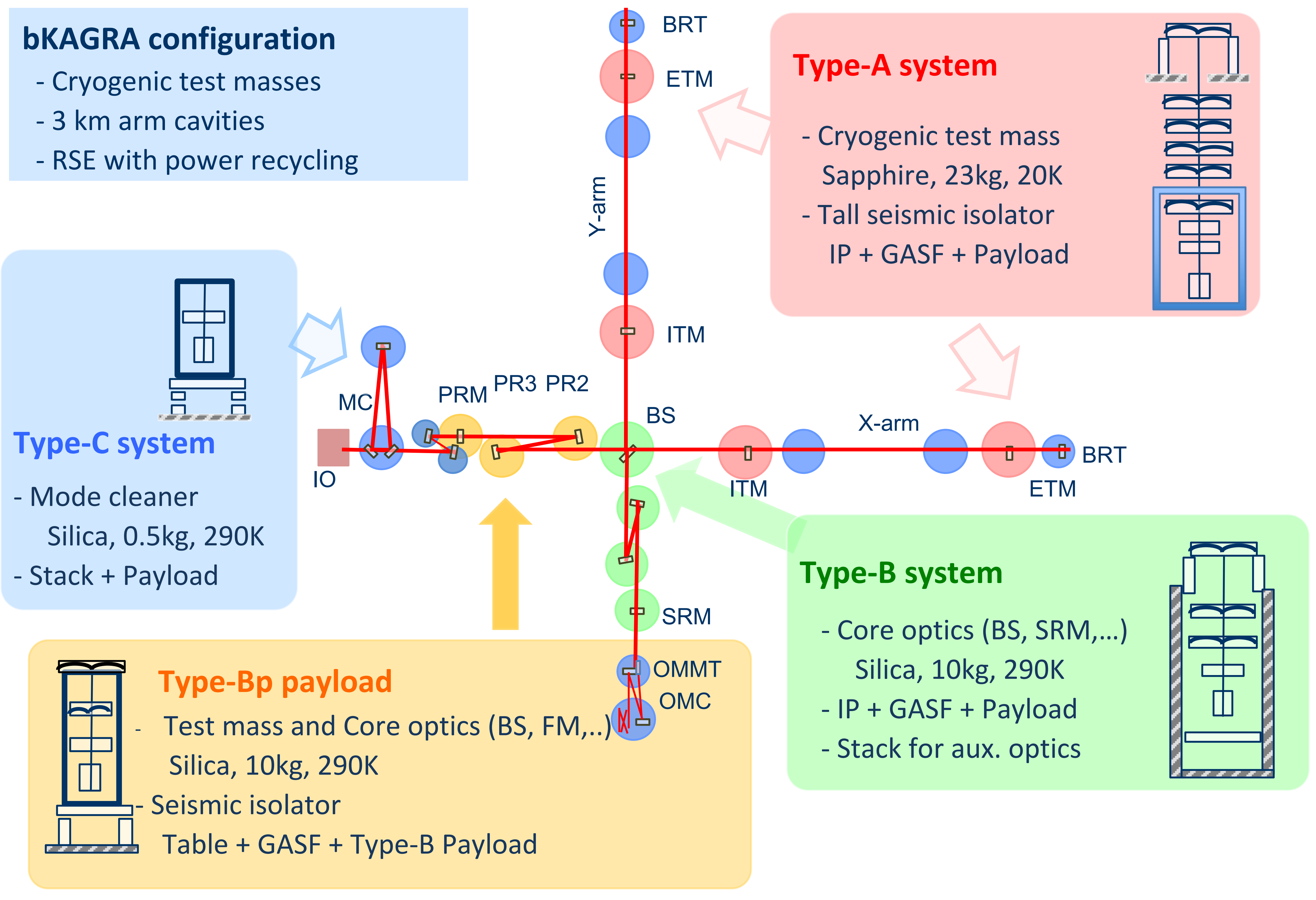
“Resonant Side-band Extraction” interferometer
(KAGRA, Advanced LIGO, Advanced Virgo)





Basic Idea of Suspension System





as the configuration of April 2020 (O3GK)

Class. Quantum Grav. **36** (2019) 165008

Cryogenic System

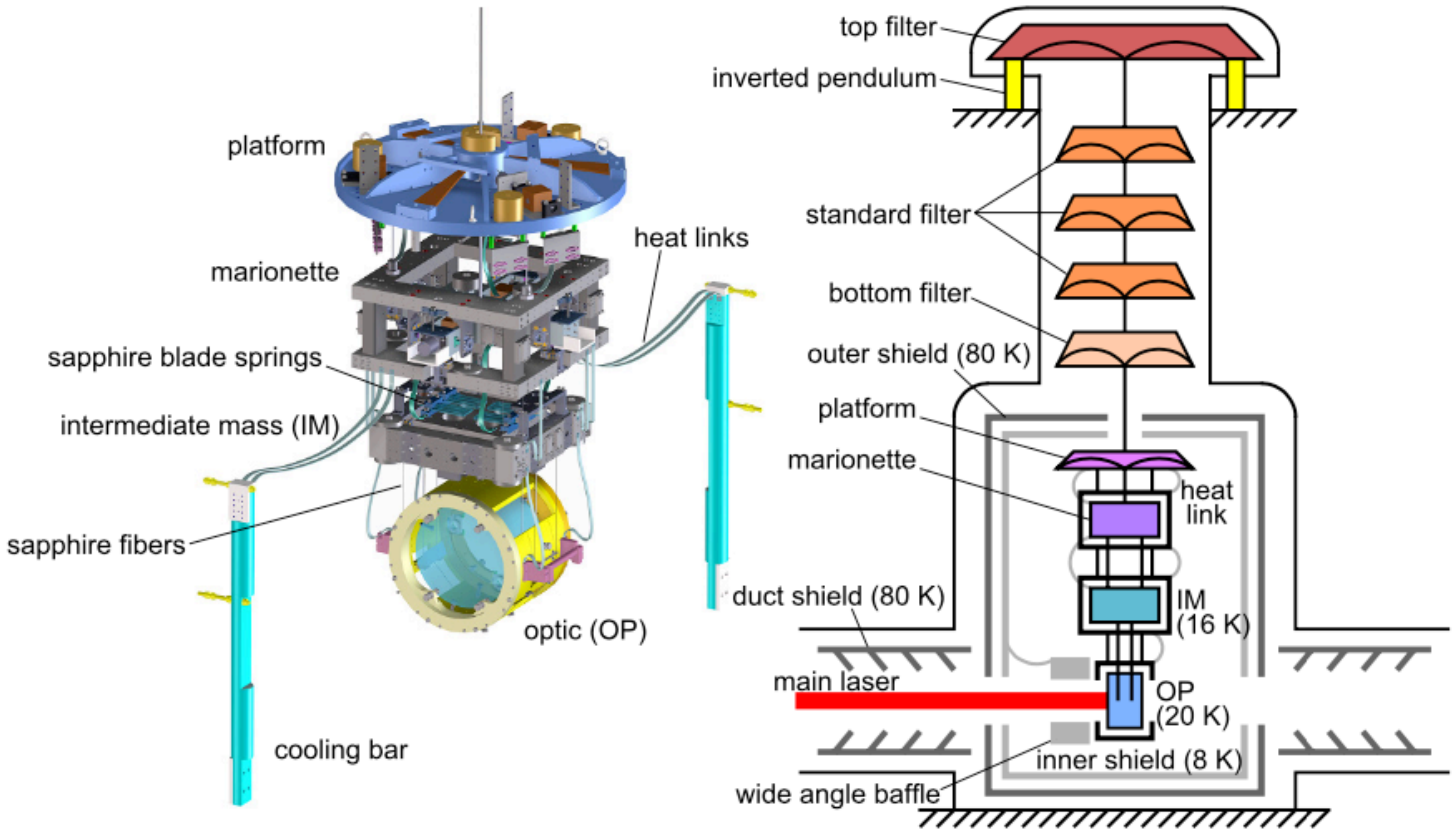
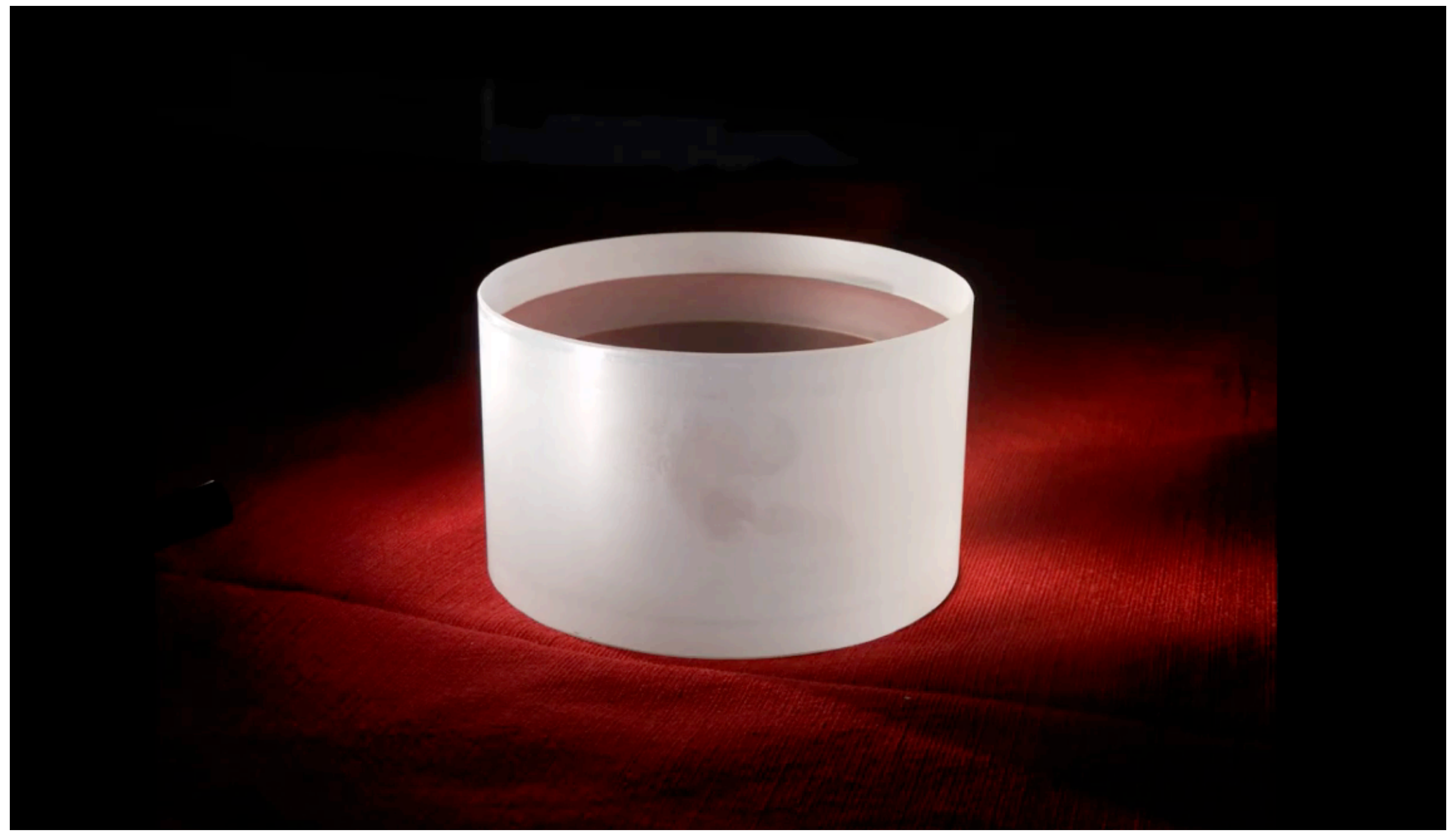


Figure 3. The CAD drawing of the cryogenic payload under Type-A (left) and the schematic of the cryogenic suspension system of sapphire test masses (right). Suspension stages outside of the outer shield are at room temperature.

Class. Quantum Grav. **36** (2019) 165008

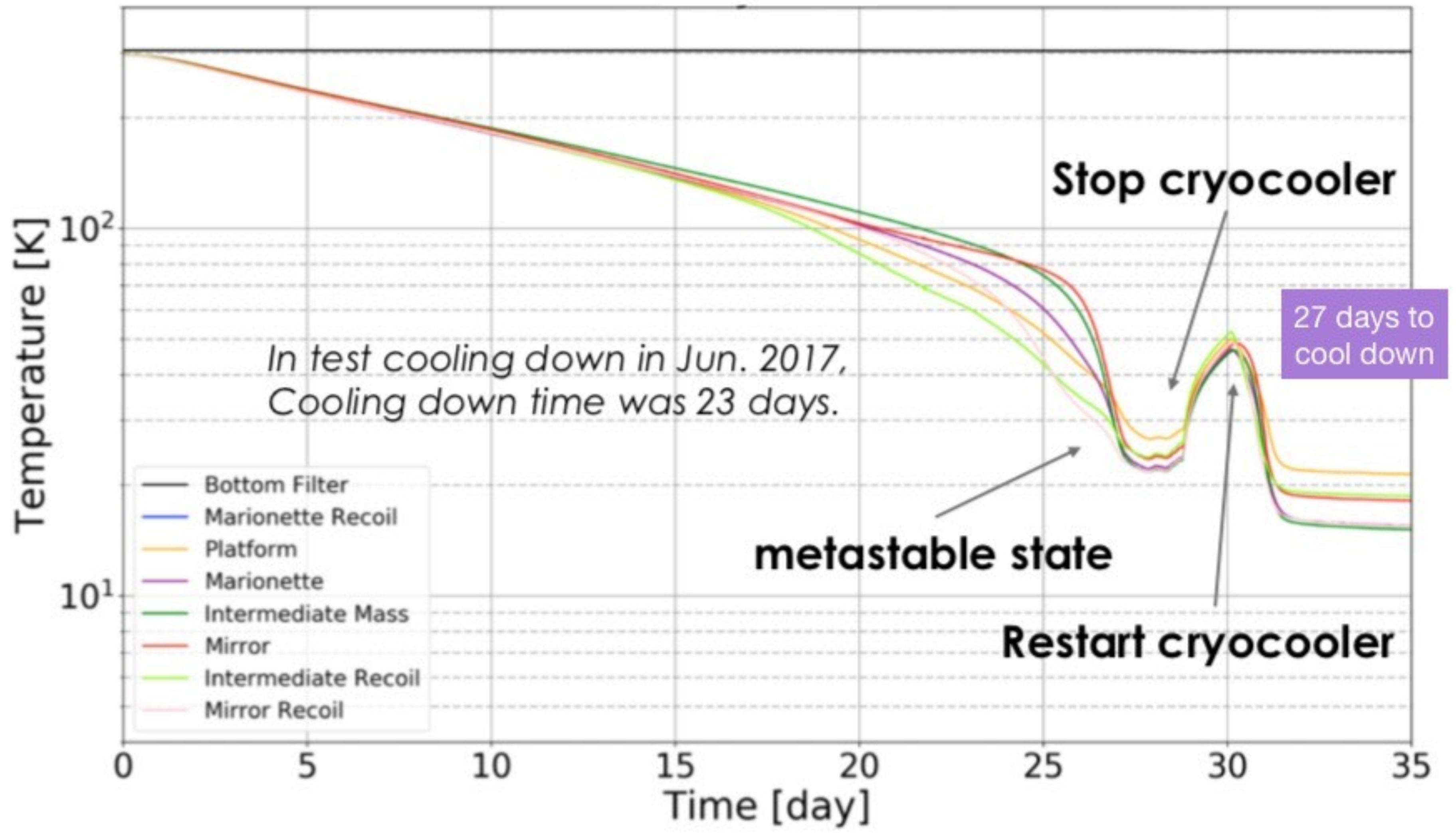
$$\text{Thermal Noise} \propto \sqrt{\frac{4k_BT}{m\omega_0^2\omega Q}}$$

low temperature
large mass



sapphire mirror

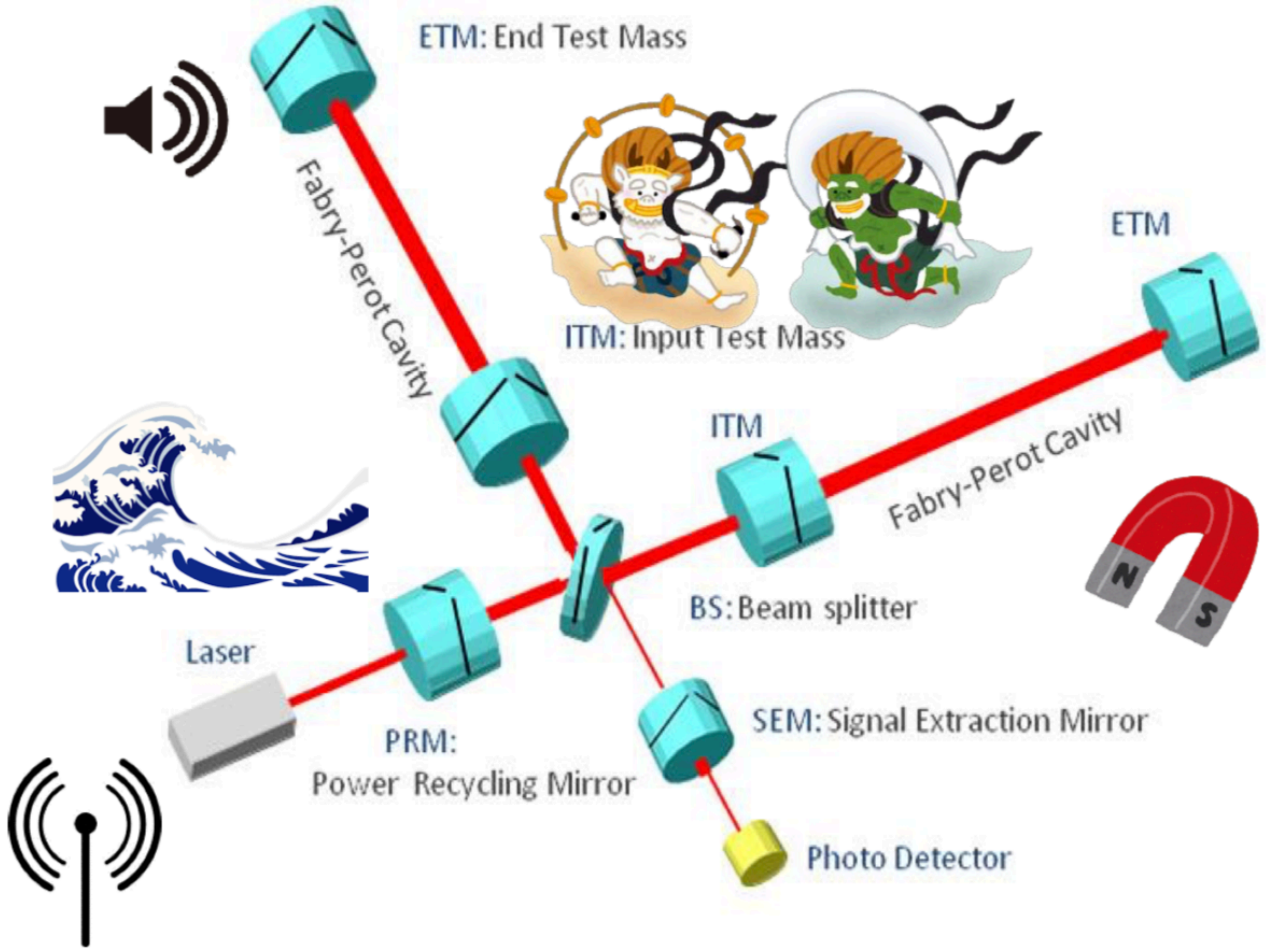
22.8 kg
diameter 22cm
thickness 15cm

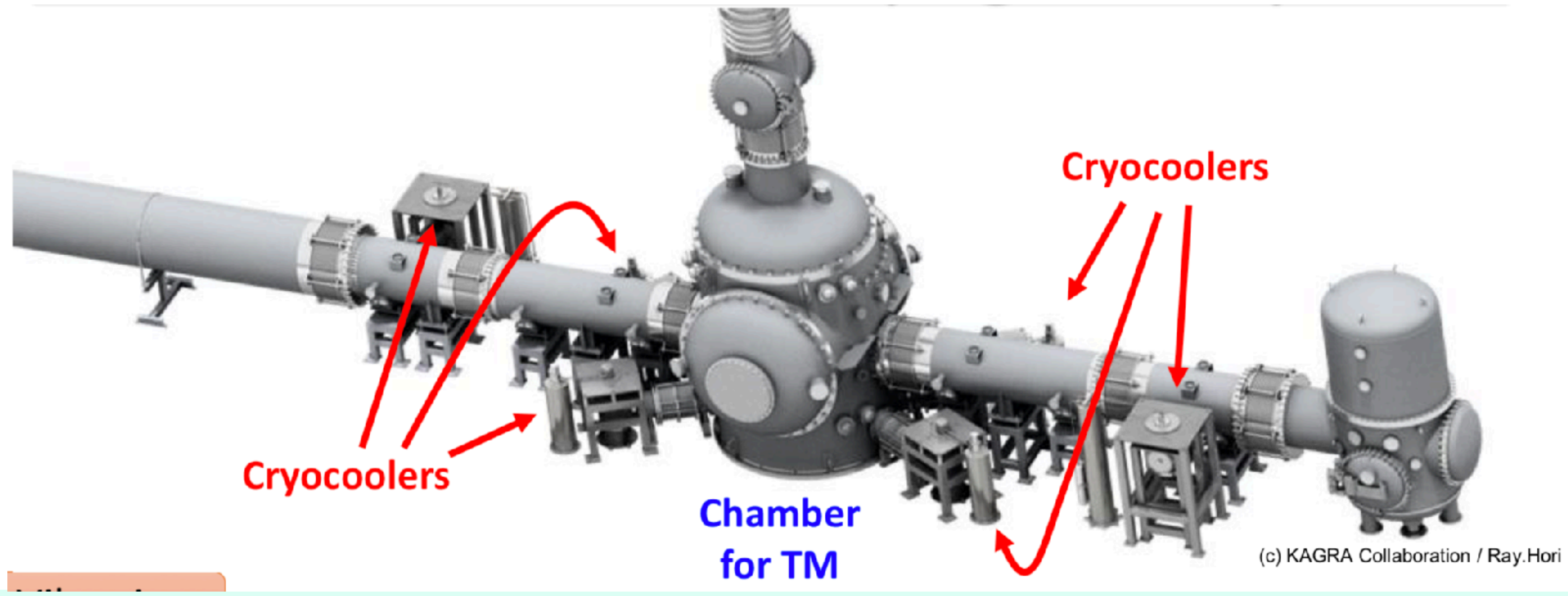


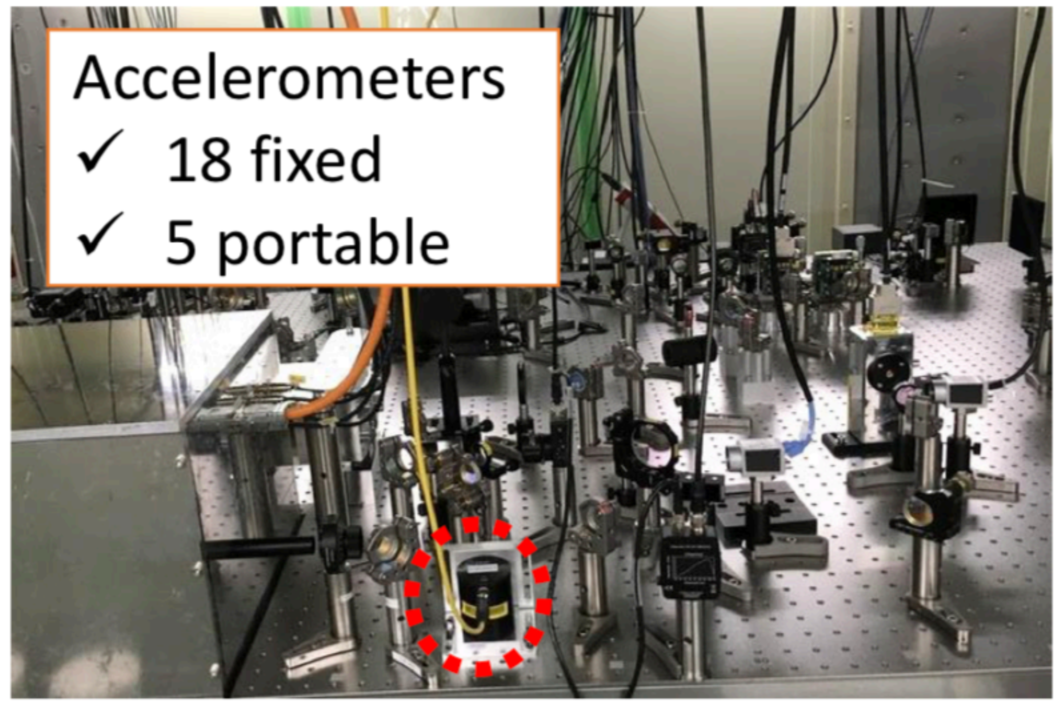
20 K
in 4 weeks

Physical environment monitors

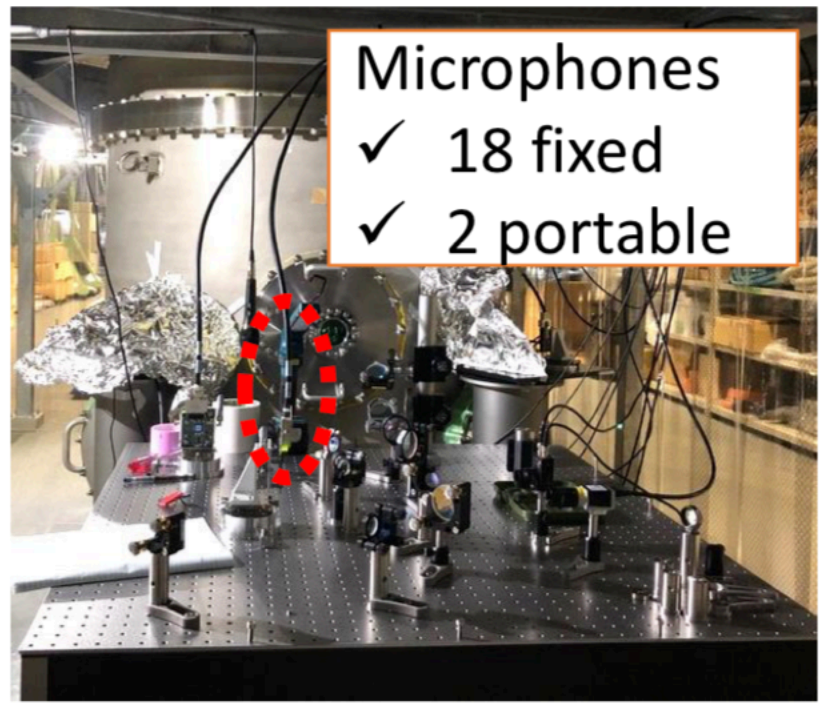
KAGRA







Accelerometers
- ✓ 18 fixed
- ✓ 5 portable



Microphones
- ✓ 18 fixed
- ✓ 2 portable

Magnetometers
- ✓ 2 fixed
- ✓ 3 portable

Seismometers
- ✓ 5 fixed
- ✓ 1 portable

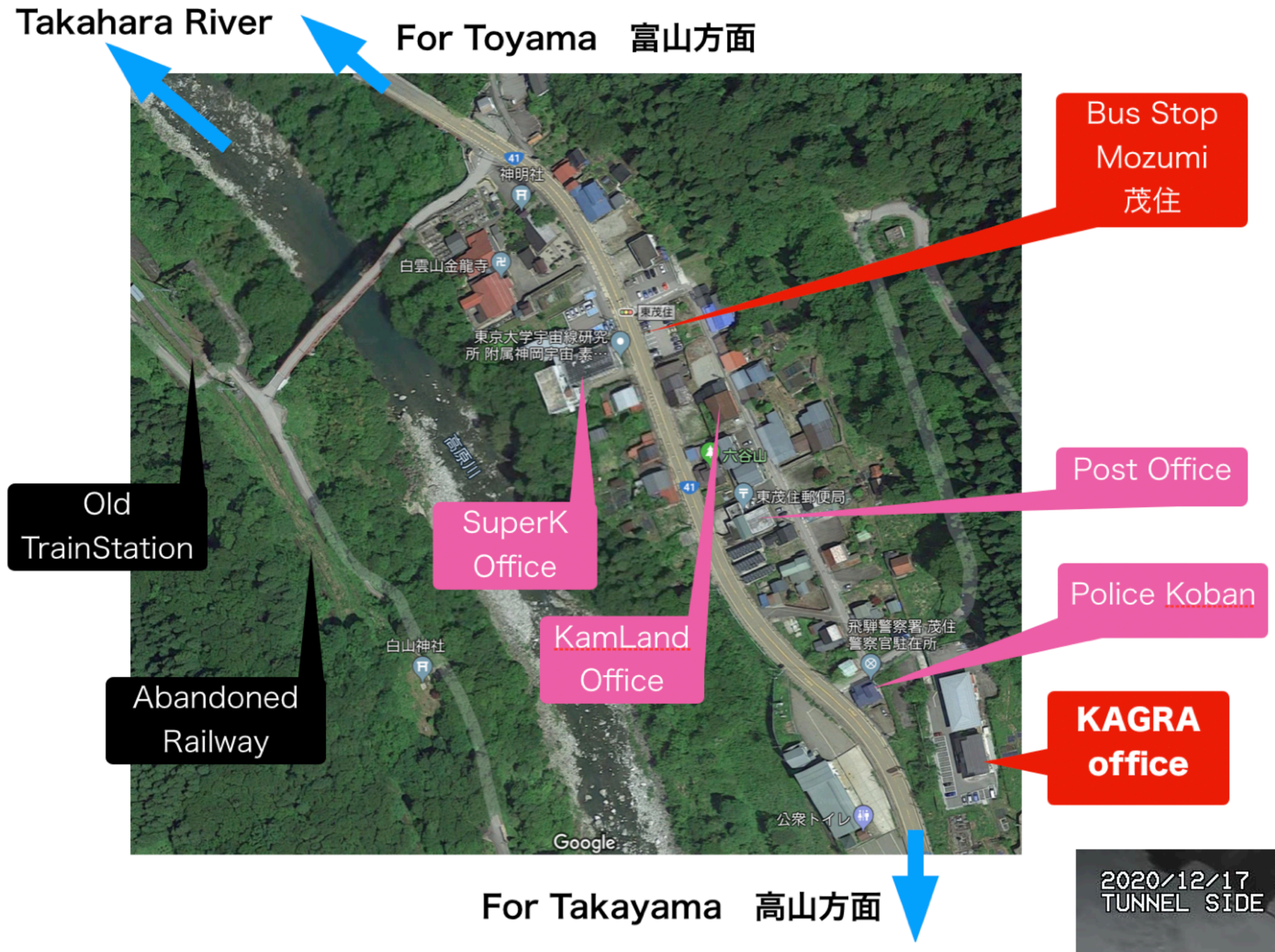
Weather station
- ✓ 1 fixed

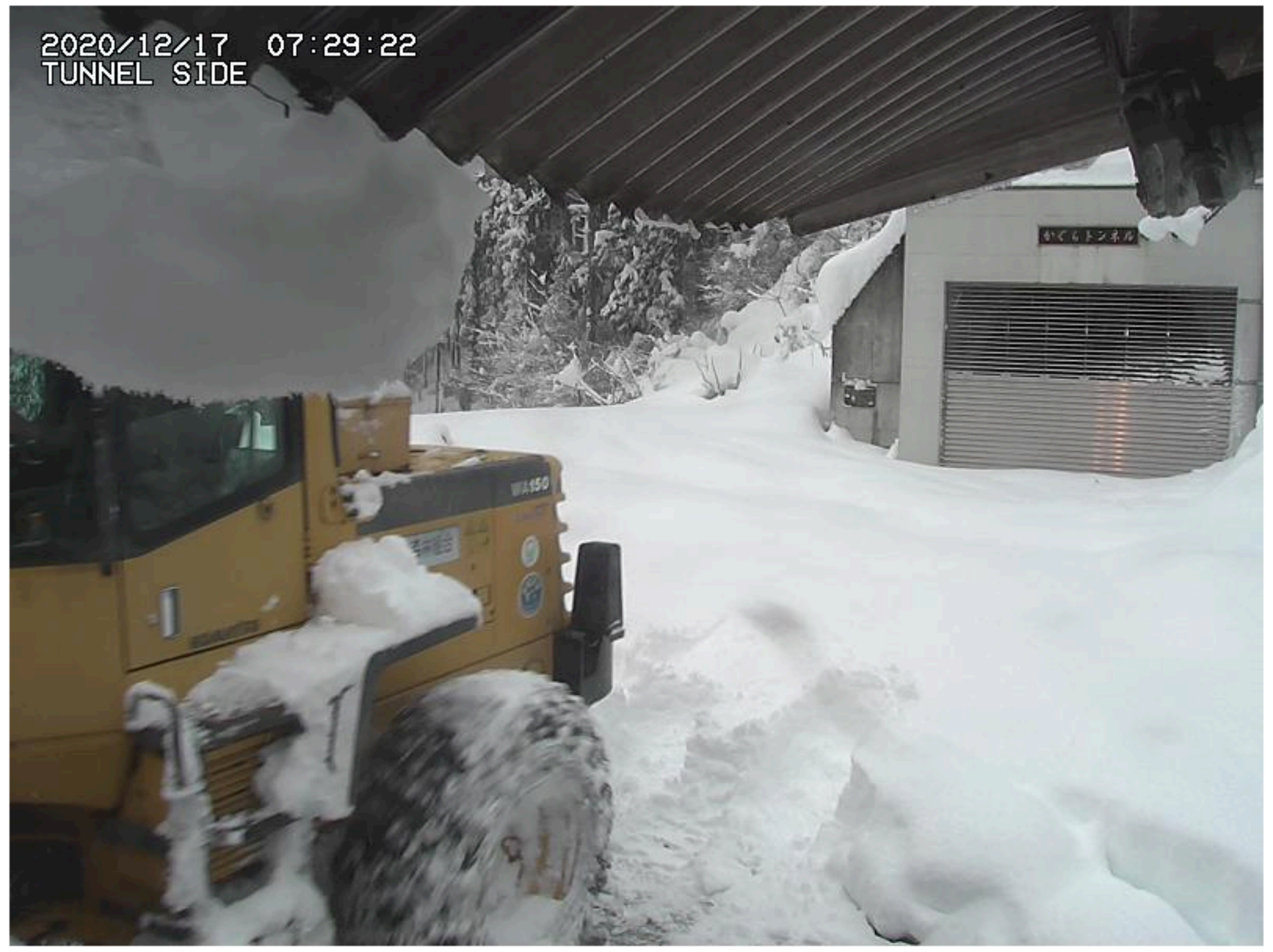
Other sensors :
- ◆ Radio frequency recover (1)
- ◆ DC power monitor (1)
- ◆ Temperature & humidity sensors (69)
- ◆ Vacuum gauges (11)

by T. Washimi

KAGRA (Kamioka Gravitational-Wave Observatory)

KAGRA (Kamioka Gravitational-Wave Observatory)



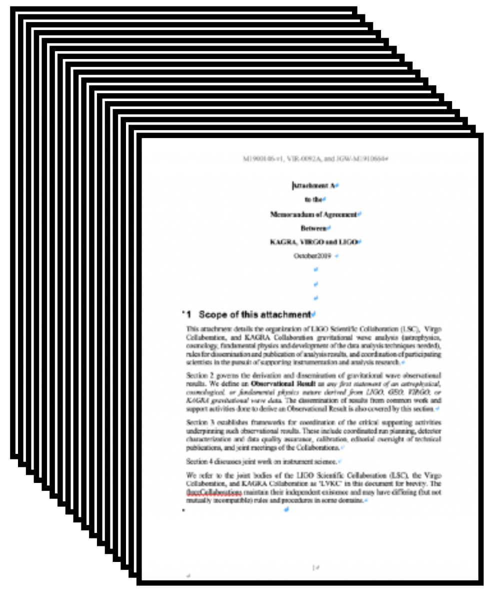


90cm snow in one night, Dec 17 2020

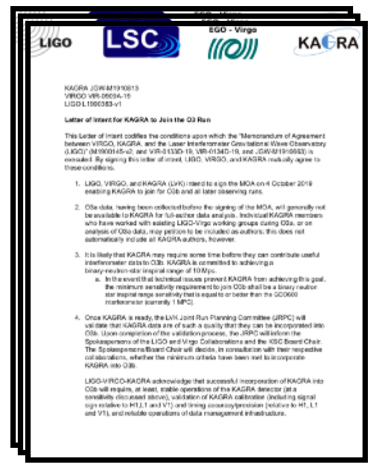
Joint Research MoA signed LIGO-Virgo-KAGRA

October 4, 2019 @ Ceremony of MoA signing

main part (10 pages)
Concept, Definitions, Purposes

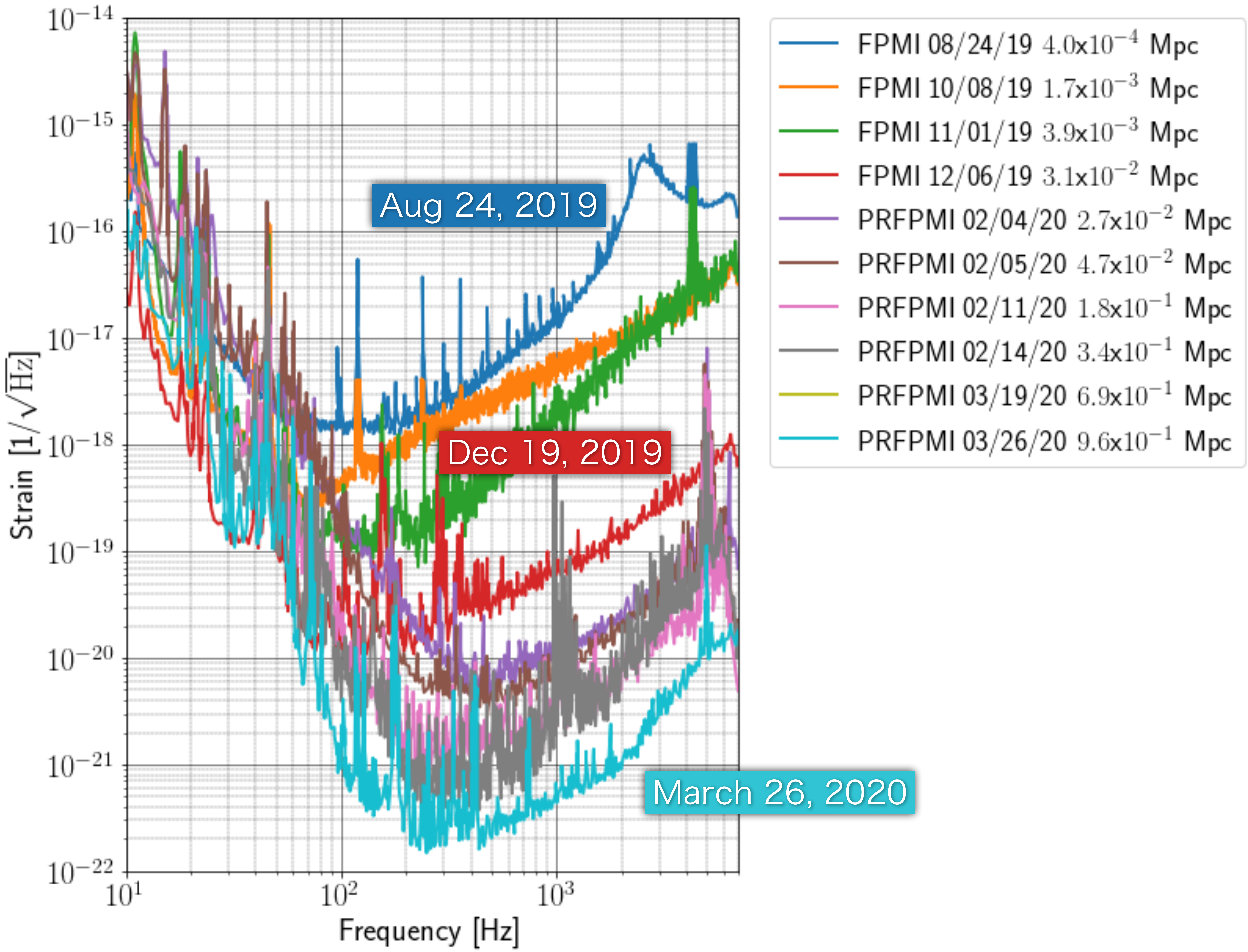


Appendix A (17 pages)
Organizations, Procedures



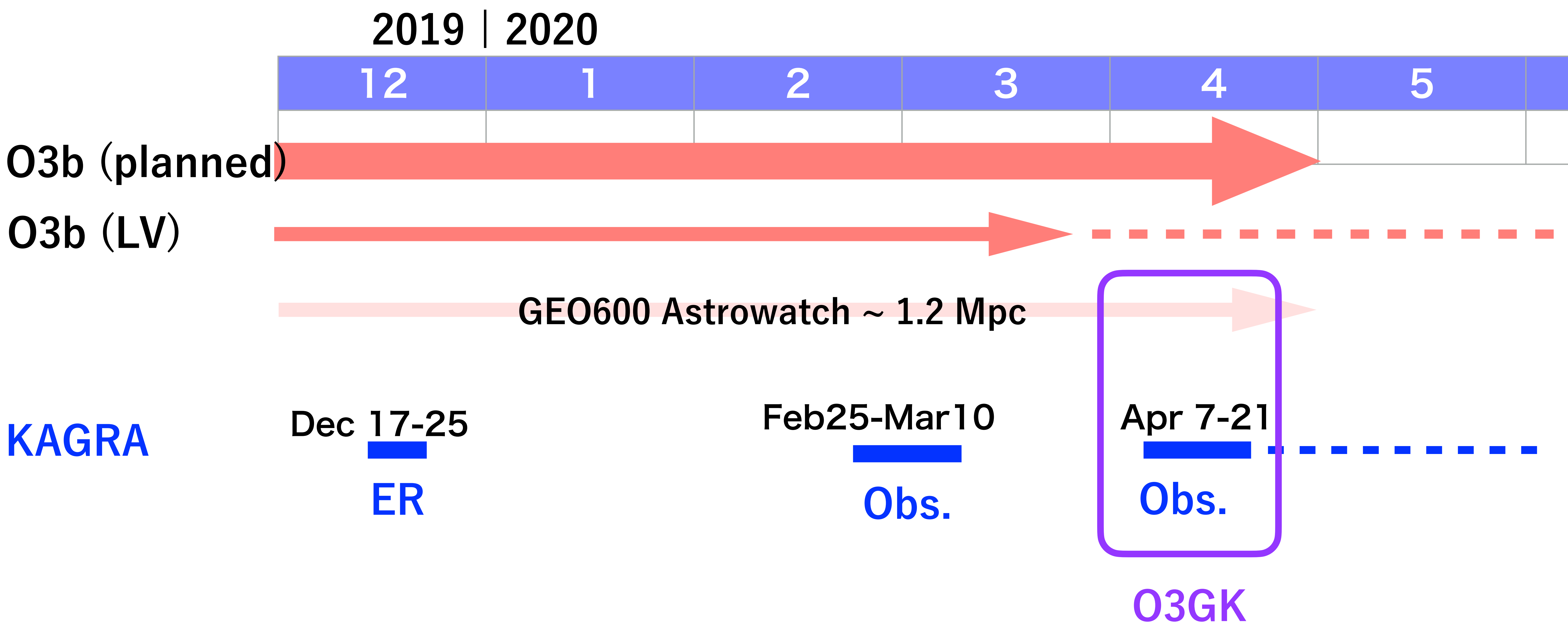
Letter of Intent (3 pages)
KAGRA's Join to O3

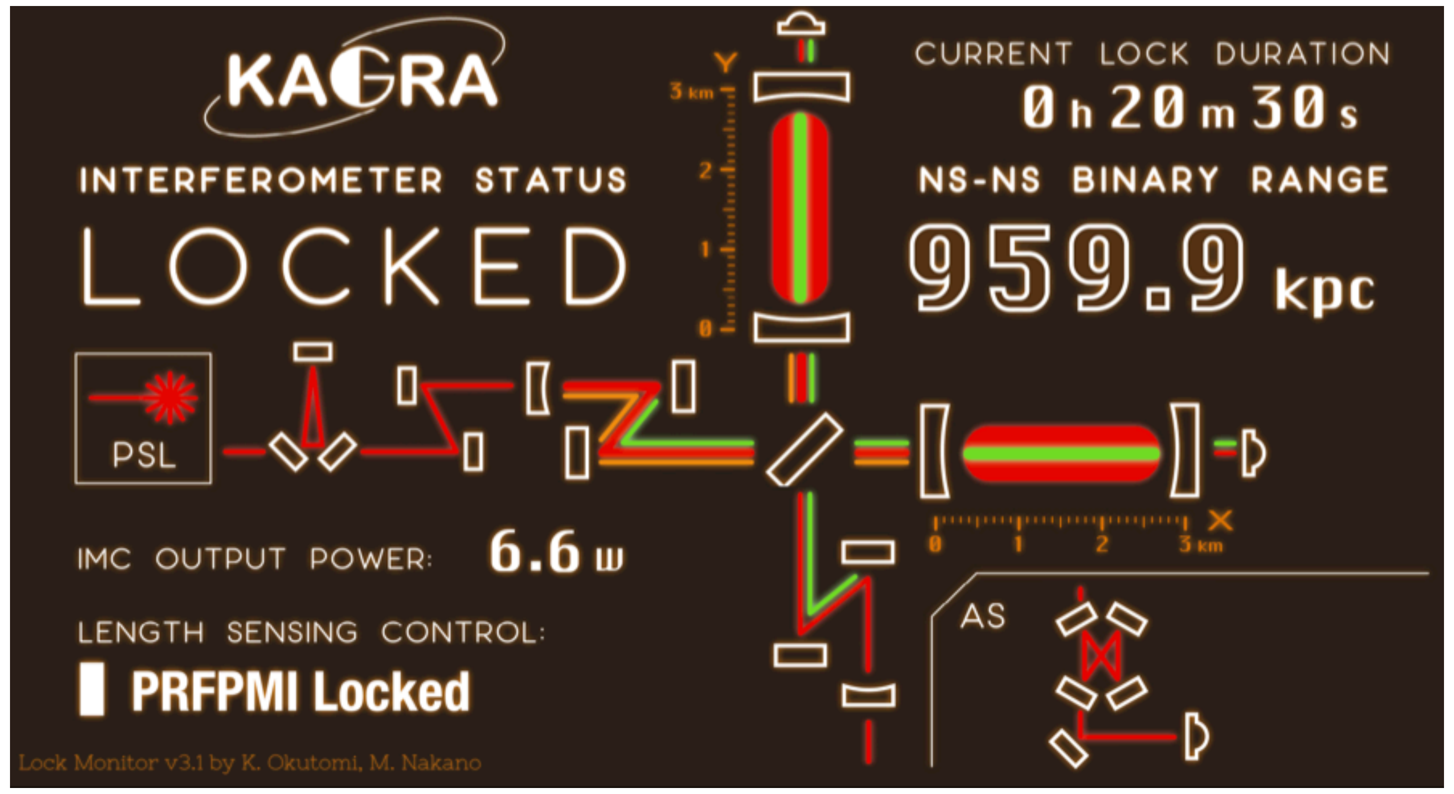
＊ 1 Mpc (BNS) is required to join the observation.



＊ Finally, over 1 Mpc in the end of March 26, 2020.

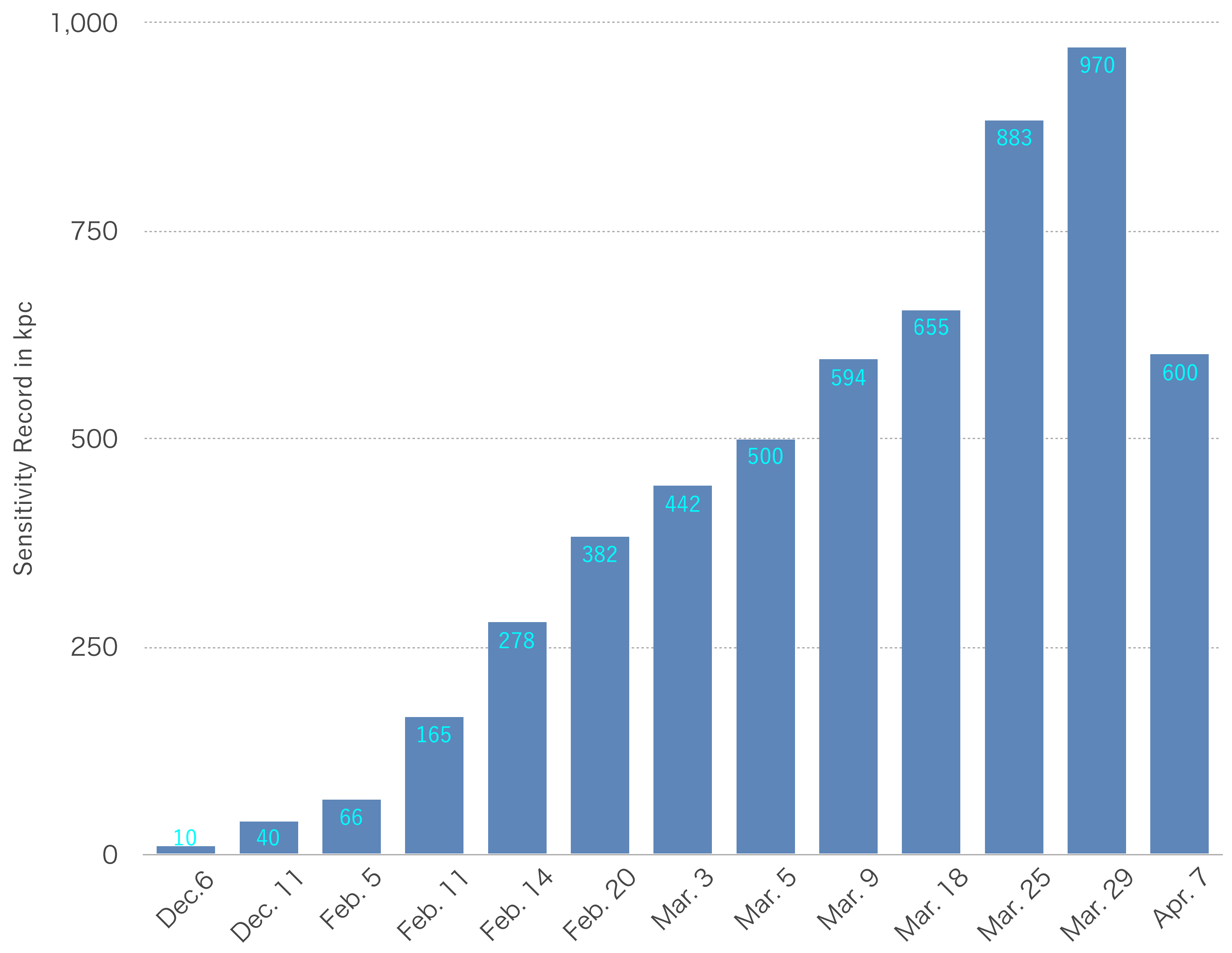
O3b, O3GK, and after that





March 29, 2020

* O3GK observation paper plan (LVK paper)



O3GK（April 7-21, 2020）

KAGRA

Official start and end time

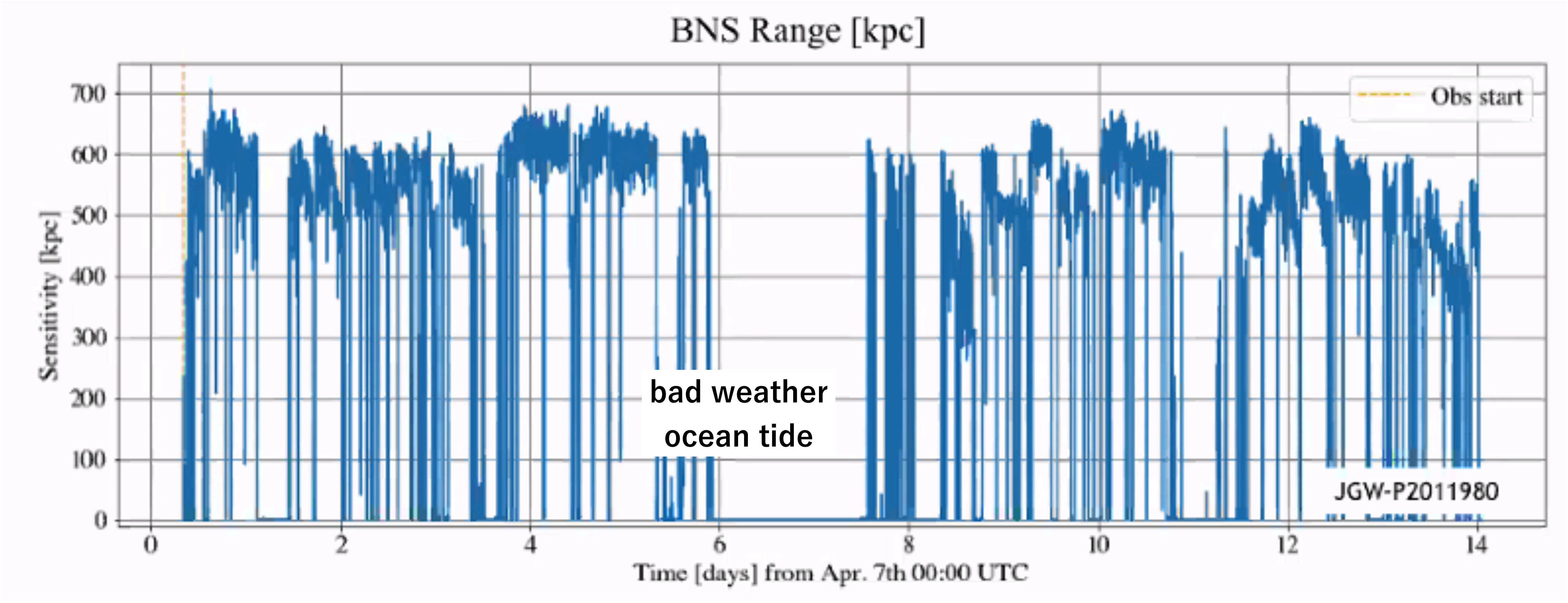
Start : April 7 8:00 2020 UTC, GPS Time : 1270281618

End : April 21 0:00 2020 UTC, GPS Time 1271462418

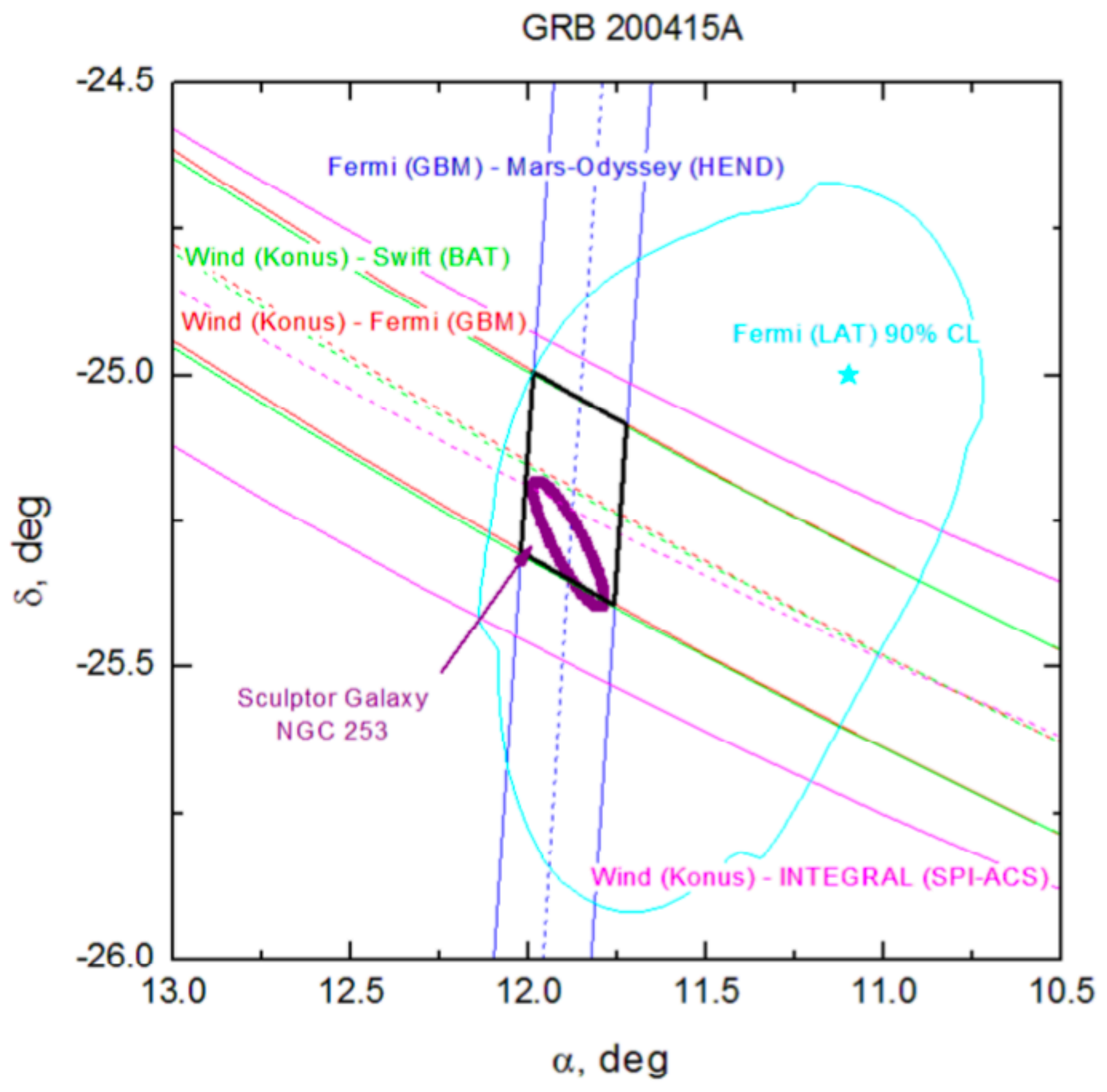
KAGRA Duty Cycle : Locked 69%, Observing 58%

Longest lock 8h05m

Sensitivity : 500-700 kpc



Takahiro Yamamoto, JGW-P2011980



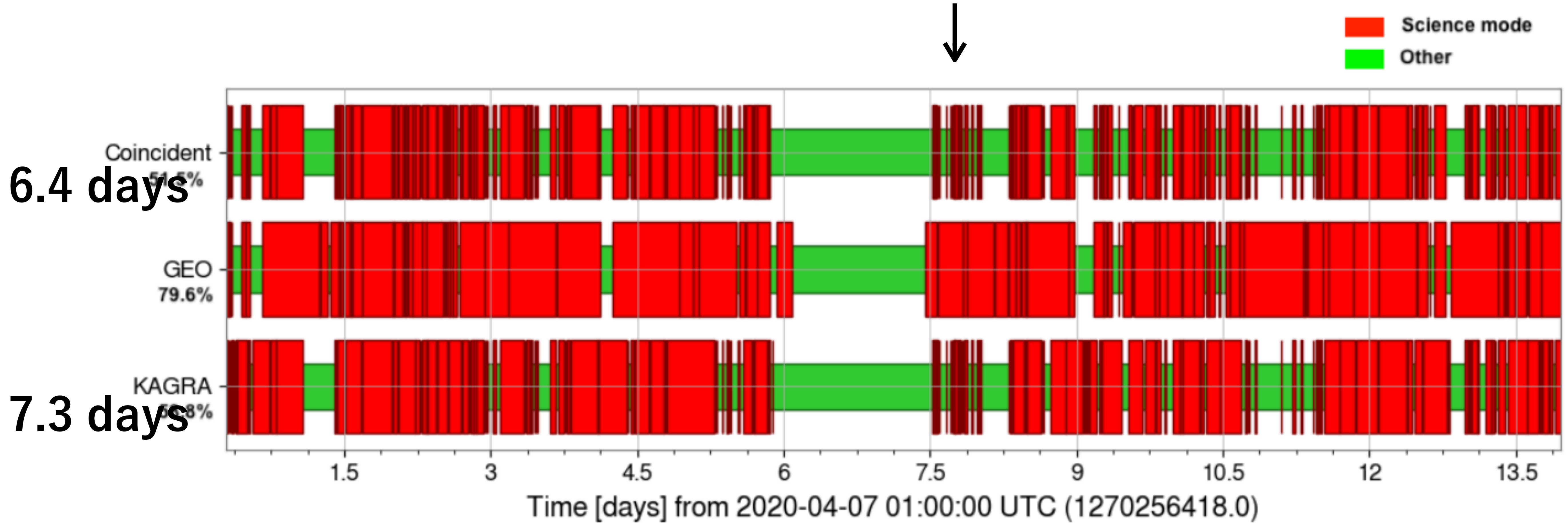
GRB200415A

NGC 235 (Sculptor galaxy)

3.5 Mpc, one of the brightest galaxies

https://gcn.gsfc.nasa.gov/fermi_grbs.html

GRB200415A



Jim Lough, LIGO-G2001554

KAGRA collaboration

Statistics of KAGRA collaboration
(June 30, 2021)

	collaborators	Institutions, Groups
Japan	255	63
Taiwan	69	10
China	52	12
Korea	34	14
Italy	6	4
USA	5	4
Hong Kong	5	1
Australia	2	1
India	1	1
France	1	1
Spain	2	1
Poland	1	1
UK	2	2
Russia	1	1
Germany	1	1
Vietnam	1	1
total	437	117

http://gwwiki.icrr.u-tokyo.ac.jp/JGWwiki/KAGRA

KAGRA collaboration

117groups, 16 countries/regions
430+ active members

Default-author list 2019+2020 has 200 names.

Organize Face-to-Face meeting
2 times (April/August/Dec) / year

F2F Aug. 2020 @ online, Japan

Organize International Workshop
twice / year

KIW8 July 2021 @ Daejeon, Korea

KIW9 May? 2022 @ Beijing China

http://gwwiki.icrr.u-tokyo.ac.jp/JGWwiki/KAGRA

KAGRA collaborators in Korea

Chungnam National University
- David Chung Yue Hui *
- Kwangmin Oh
- Sangin Kim

Ewha Womans University
- Chunglee Kim *
- Chaeyeon Jeon

Hanyang University
- Hyun Kyu Lee

Inje University
- Hyung Won Lee *

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- June Gyu Park *
- Sungho Lee *
- Yunjong Kim
- Jeong-Yeol Han
- Hyeon-Cheol Seong
- Ueejeong Jeong
- Soonkyu Je

Korea Institute of Science and Technology Information (KISTI)
- Sangwook Bae

Korea University
- Tai Hyun Yoon *

Kunsan National University
- Sang Pyo Kim *

Kyungpook National University
- Myeong-Gu Park

Myongji University
- Jaewan Kim *
- Sung-Joon Cho

National Institute for Mathematical Sciences
- John J. Oh *
- Jung Piljong

Pusan National University
- Chang-Hwan Lee *

Sejong University
- Maurice H.P.M. van Putten *

Seoul National University
- Hyung Mok Lee *

Sogang University
- Kyuman Cho

Ulsan National Institute of Science and Technology (UNIST)
- Young-Min Kim
- Lupin Chun-Che Lin *
- Kyujin Kwak *
- Kihyun Jung
- Seungwoo Ha

36 collaborators as of June 30, 2021. * KSC contact person

Organization of KAGRA

Takaakii Kajita
(PI)

Masatake Ohashi
(vice PI)

Shinji Miyoki
(SEO proj. manager)

PI

Executive Office

sharing information & idea

System Engineering Office

Hideyuki Tagoshi
(DAC chair)

KAGRA Scientific Congress (KSC) organization chart

KSC board

* Hisaaki Shinkai
* Shinji Miyoki
* Chunglee Kim
Hideyuki Tagoshi
Tomotada Akutsu

Zhoujian Cao (China)
Hyung-Won Lee (Korea)
Ray-Kuang Lee (Taiwan)
Tatsuki Washimi (PD)
Satoru Takano (Student)

Data Analysis Committee (DAC)

Theory Group

Future Strategy Committee (FSC)

LVK committees

KAGRA committees

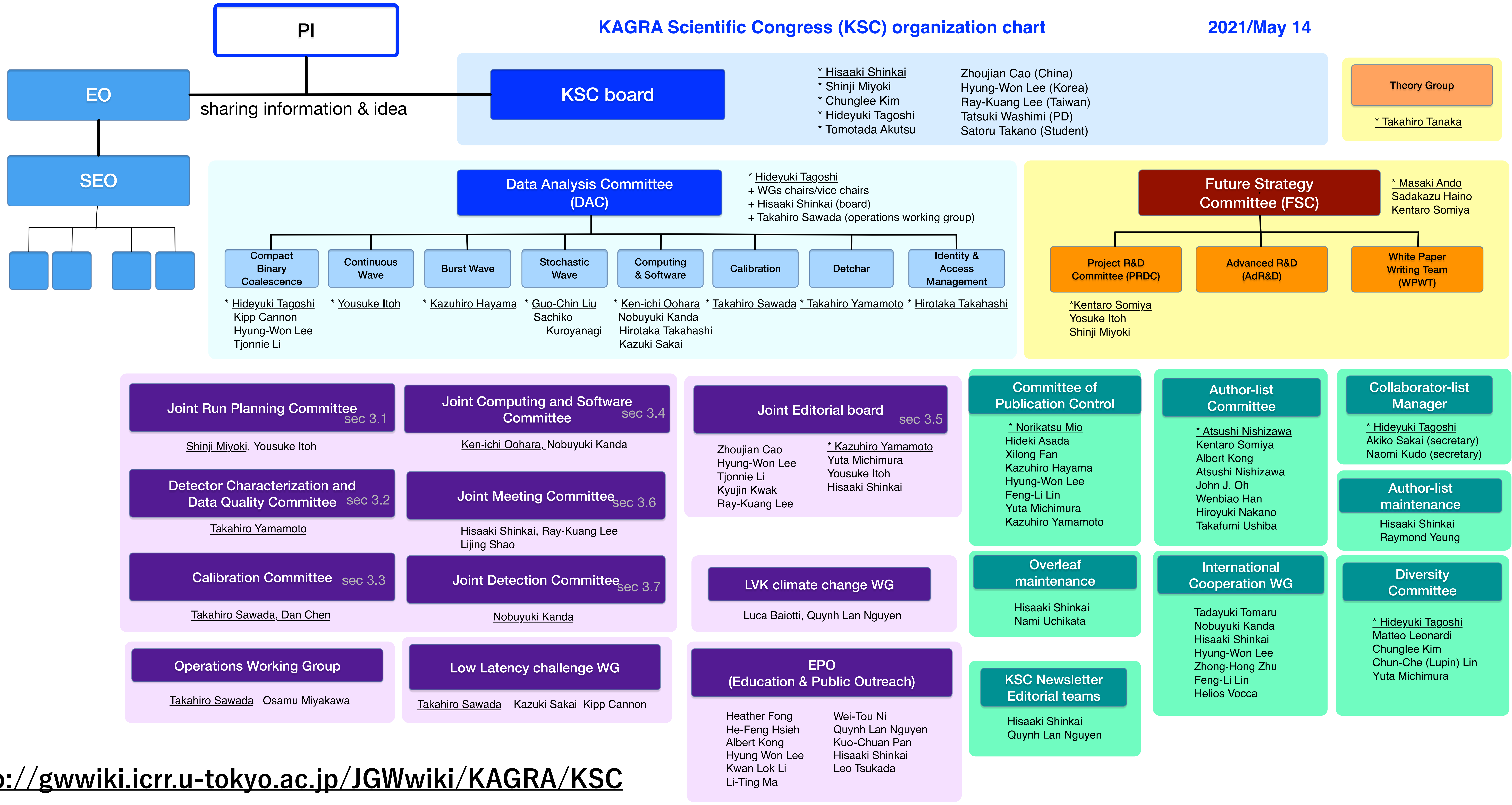
Takahiro Tanaka
(Theory chair)

HS
(KSC chair)

Masaki Ando
(FSC chair)

http://gwwiki.icrr.u-tokyo.ac.jp/JGWwiki/KAGRA/KSC

Organization of KSC（KAGRA Scientific Congress）



http://gwwiki.icrr.u-tokyo.ac.jp/JGWiki/KAGRA/KSC

Science Summary as of LVK-outreach

https://www.ligo.org/science/outreach.php

LSC LIGO Scientific Collaboration

G 言語を選択 ▼

News | Detections | Our science explained | Multimedia | Educational resources | For researchers | About the LSC | LIGO Lab | Observing Plans

Intro to LIGO & Gravitational Waves | Science Summaries | Popular Articles | Frequently Asked Questions | Magazine | Advanced LIGO

SUMMARIES OF LSC SCIENTIFIC PUBLICATIONS

We now feature, for each new research article, a summary written for the general public. Simply click on any of the titles for an online version, or on the '[flyer]' links for a downloadable file in PDF format. Translations into several languages are also available for some of these summaries. Where not noted separately, translations can be accessed through their language acronyms (e.g. 'es' for Spanish, also see details in the sidebar) or from the top of the English online versions.

LATEST DETECTIONS

GW200105 and GW200115 (Jun 29, 2021)
A new source of gravitational waves: neutron star–black hole binaries [flyer]
Also in: Blackfoot [bla] | Catalan [ca] | Chinese (traditional) [zh-Hant] | French [fr] | German [de] | Greek [el] | Italian [it] | Japanese [ja] | Polish [pl] | Portuguese [pt] | Spanish [es]

GWTC-2 (Oct 28, 2020)
Catalog paper summarizing previous and new detections from the O3a observing run:
GWTC-2: An Expanded Catalog Of Gravitational-Wave Detections [flyer]
Also in: Bengali [bn] | Catalan [ca] | Chinese (simplified) [zh-Hans] | Chinese (traditional) [zh-Hant] | French [fr] | German [de] | Greek [el] | Hindi [hi] | Italian [it] | Japanese [ja] | Korean [ko] | Polish [pl] | Spanish [es] .

Companion papers:

- The population properties of compact objects following LIGO/Virgo Run O3a [flyer] | [fr] | [it] | [ja] | [zh-Hant]
- Testing General Relativity with Gravitational Waves from the first half of the LIGO-Virgo 3rd Observing Run [flyer] | [fr] | [de] | [it] | [ja] | [ko] | [pl] | [zh-Hant]
- Searching for hidden gravitational waves produced by gamma-ray burst events in O3a [flyer] | [fr] | [de] | [it] | [ja] | [ko] | [pl] | [zh-Hant]

GW190521 (Sep 2, 2020)
GW190521: The Most Massive Black Hole Collision Observed To Date [flyer]
Also in: Blackfoot [bla] | Catalan [ca] | Chinese (traditional) [zh-Hant] | Dutch [nl] | French [fr] | Galician [gl] | German [de] | Greek [el] | Hindi [hi] | Hungarian [hu] | Italian [it] | Japanese [ja] | Korean [ko] | Marathi [mr] | Polish [pl] | Spanish [es]

GW190814 (Jun 23, 2020)
The Curious Case of GW190814: The Coalescence of a Stellar-Mass Black Hole and a Mystery Compact Object [flyer]
Also in: Blackfoot [bla] | Chinese (traditional) [zh-Hant] | Dutch [nl] | French [fr] | German [de] | Italian [it] | Japanese [ja] | Marathi [mr] | Polish [pl] | Spanish [es]

LOOKING DOWN A DETECTOR ARM

Visitors at LIGO Hanford Observatory gaze down the site's X arm. Half of the 4-kilometer length of the arm is visible in the photo. (Credit: LIGO Laboratory)

TRANSLATIONS: LANGUAGE KEYS

For most summaries, we list the available translations by their ISO 639-1 / ISO 639-2 keys, as listed below. Translations are a volunteer effort and different sets of languages are available for each summary. You can search for the key of your language, in square brackets – for instance [fr] for French – on this page to find all science summaries that have been translated into it.

- [bla]: Blackfoot
- [bn]: Bengali (Bangla / বাংলা)
- [ca]: Catalan (Català)
- [de]: German (Deutsch)
- [el]: Greek (Ellinika / Ελληνικά)
- [es]: Spanish (Español / Castellano)
- [fr]: French (Français)
- [gl]: Galician (Galego)
- [he]: Hebrew (Ivrit / עִבְרִית)
- [hi]: Hindi (मानक हिन्दी)
- [hu]: Hungarian (Magyar)
- [it]: Italian (Italiano)
- [ja]: Japanese (Nihongo / 日本語)

LSC LIGO Scientific Collaboration — VIRGO

GWTC-2: 중력파 검출 확장 목록

이 목록은 2015년 중력파 첫 관측으로 부터 제3차 관측의 전반부인 O3a 종료까지의 중력파 관측을 모두 포함하는 것(GWTC-2, “Gravitational-Wave Transient Catalog 2”) 이다. O3a는 2019년 4월 1일 부터 10월 1일 까지 관측이 진행되었으며 총 39개 중력파를 추가하여 11개 였던 GWTC-1목록에서 GWTC-2 에서는 50개가 되었다. O3a에서 관측된 중력파는 보다 폭 넓은 천문학적 매개변수를 포함하고 있으며 모두 두 블랙홀 병합(BBH), 두 중성자별 병합(BNS), 그리고 중성자별 블랙홀 병합(NSBH)에서 발생한 신호와 일치한다.

놀랍게도 O3a는 이 전에 이루어졌던 두 번의 관측(O1과 O2)에 비하여 3배 더 많은 확정 관측이 이루어졌다.
더구나 비르고는 관측기간 전기간에 두 ...
동작하는 기간은 97%였고 2개의 관측기...
번 째 중성자별 병합 신호와 첫 번 째로 질...
큰 블랭홀 쌍성계의 신호와 같은 특별한...
라이고와 비르고에 이루어진 개선과 이 관...

중력파 관측

O3a기간 동안에 39개의 중력파를 관측할 수...
다양한 검출방법의 결과이다. 최근에 이루어...
개선한 거울 사용, 산란 빛에 대한 처리에 의...
관측 거리 범위의 증가로 이어져 볼 수 있는...
있는 거리의 중간값이, **그림 1**에 보인 것과 같...

LSC LIGO Scientific Collaboration — VIRGO

제3차 관측가동의 전반부 중력파에 의한 일반상대론 검증
(영어원문)

100년 전에 제안된 아인슈타인의 일반상대론은 블랙홀 병합에서 발생한 중력파를 처음 관측하기 전 까지는 이론에 대한 강한 검증은 실험실이나 태양계에서 불가능했기 때문에 이루어지지 않았다. 블랙홀 병합은 일반상대론이 허용하는 매우 강하고 동적인 중력장을 만든다. 블랙홀 병합 관측은 이론의 두 가지 예측 – 중력파의 직접 관측과 병합하는 블랙홀의 존재 – 을
...과 일치하는 지 아니면 비슷하지만 다른 것인가? 파를 생성한
... 되었는가?

...5, GW190412, GW190814, 그리고 GW190521개별 신호에 대하여
...이 검증에 통과되었다! 그러나 이제 새로운 일시적 중력 신호
...존재한다. GWTC-1 신호에 행한 것과 동일한 몇 가지 검증을 그
...도 시도했다.

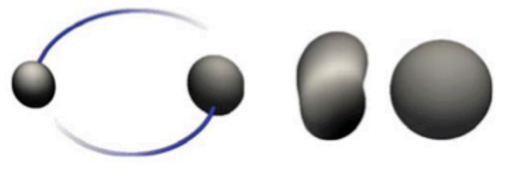


그림 1: 블랙홀 충돌의 세 단계에 대한 도식: 나선운동, 병합, 그리고 감쇄울림을 나타낸다. GW190514 관측논문의 그림.2 에서 가져옴.

...의 검증에서 잘 맞지 않는 것으로 나타났지만 이제는 선택할 수
...는 중력파의 주파수가 기기의 감도가 좋은 범위에 해당하는 가에
...고 이는 낮은 주파수의 중력파 신호로 나타난다. 이러한 신호는
...며 더욱 낮은 주파수가 된다. 그래서 주파수에 따라서 각 신호가

LSC LIGO Scientific Collaboration — VIRGO

GW190521: 관측이래 가장 무거운 블랙홀 충돌

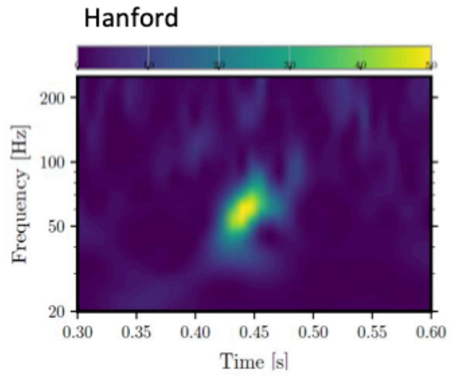
무엇을 관측했나?

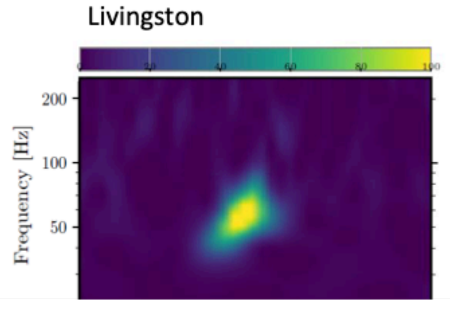
2019년 5월 21일 고등라이고(Advanced LIGO)와 고등비르고(Advanced Virgo) 검출기가 매우 특별한 블랙홀 쌍성으로부터의 중력파를 관측했다. GW190521으로 명명된 이 중력파 신호는 그동안 관측된 다른 블랙홀 충돌에 비해 신호 길이가 짧으며 중력파 신호의 최대값도 더 낮은 주파수에서 관측되었다.

블랙홀 충돌에서 발생한 중력파를 고등라이고와 고등비르고에서 감지할 수 있는 시간은 쌍성계의 총 질량에 반비례한다. GW190521의 경우 이 시간은 약 0.1초로 이는 최초로 발견된 블랙홀 충돌 GW150914의 경우보다 훨씬 짧다. 또한, 블랙홀 쌍성계의 신호가 최대가 되는 주파수도 총 질량에 반비례한다. GW190521의 경우 이 주파수값은 약 60헤르츠로 역시 GW150914보다 훨씬 낮다. 따라서 신호가 감지되었을 때부터(그림 1) 라이고와 비르고가 매우 질량이 큰 블랙홀 쌍성을 발견했다는 것이 분명했다.

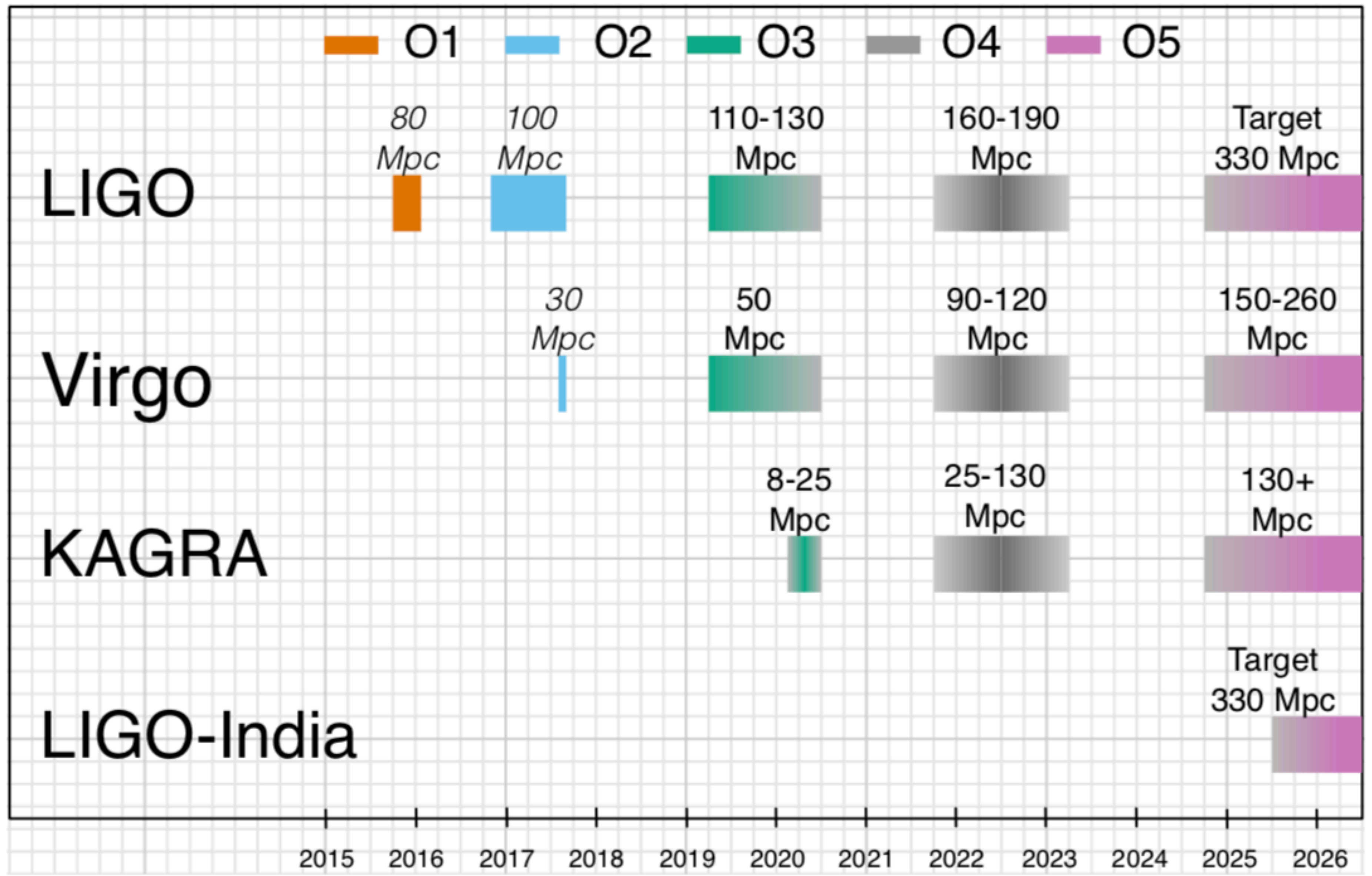
GW190521 중력파로부터 측정된 블랙홀의 질량 값은 그림 2에 나타내었다. 두 블랙홀 중에 큰 질량은 태양질량(기호 $M_\odot$ 으로 표시)의 약 85배이고 작은 것은 66배 정도이다. 이 두 블랙홀의 질량은 그동안 라이고와 비르고에서 관측된 블랙홀 쌍성계의 질량보다 훨씬 크고, 작은 블랙홀의 질량도 그동안 관측된 블랙홀 쌍성계의 합병 후 블랙홀 질량보다 크다(그림 3).

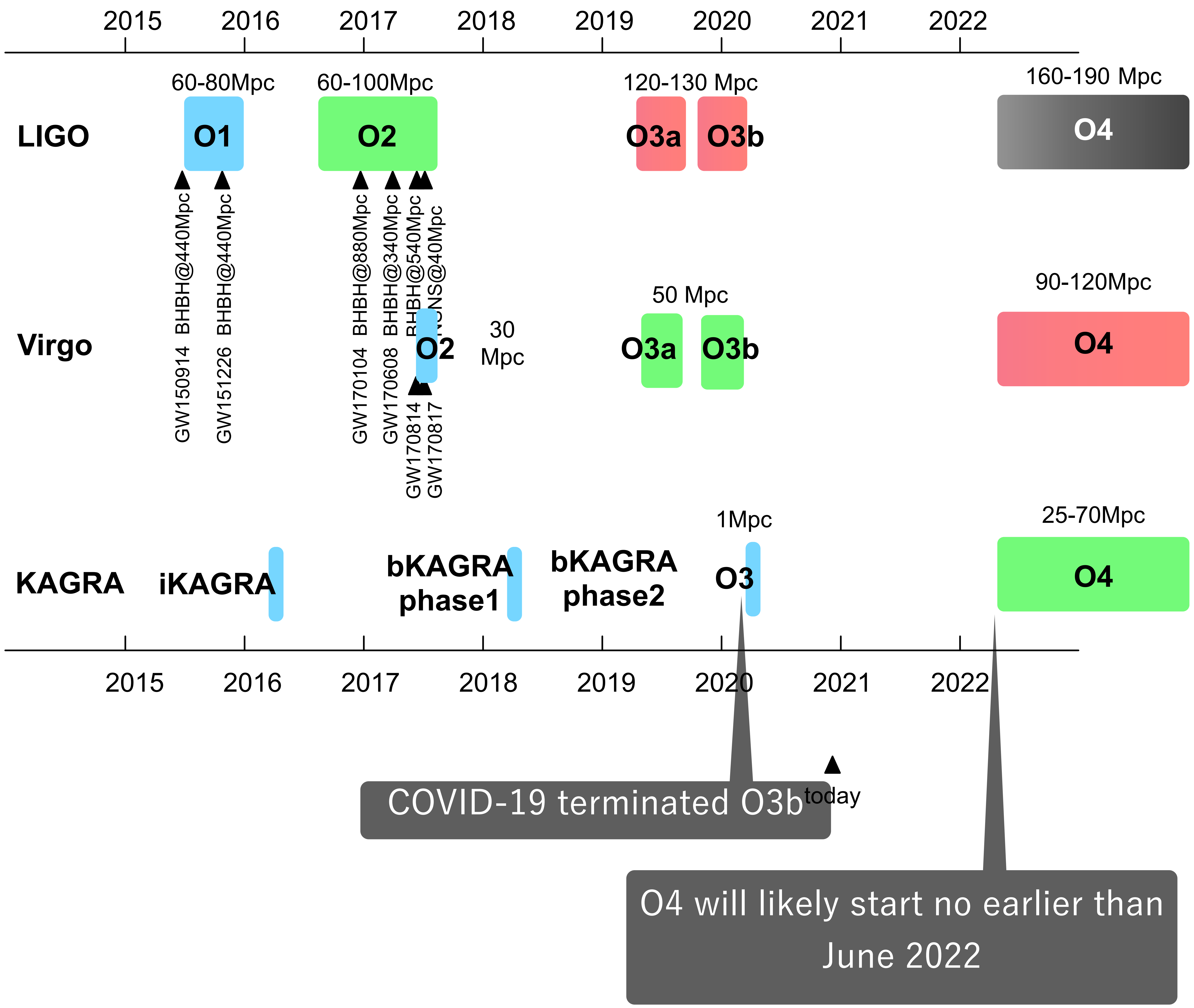
GW190521 블랙홀 쌍성계는 합병후 블랙홀 질량이 약 142 $M_\odot$으로 라이고-비르고에서 관측된 큰 질량의 블랙홀 보다 훨씬 무겁다. 합병 후 질량은 두 블랙홀 질량의 합보다 $8M_\odot$ 만큼 적은 값으로 이 차이에 해당하는 에너지가





Target Sensitivity & Schedule





"Scenario Paper" **[1304.0670ver2020Jan]**

LVK collaboration, Living Rev Relativ (2020) 23:3

https://link.springer.com/article/10.1007/s41114-020-00026-9

Big Project selection in Japan

SciTech Research Selection Comm. (MEXT) : Roadmap 2020 (Sep. 2020)

List for final selection : 15 KAGRA is in the list.

MEXT is accepting public comments.

Final decision was made in the end of September.

physics, astronomy

- ✓ **KAGRA (ICRR)**
- ✓ Subaru (NAOJ)
- ✓ ALMA (NAOJ)
- ✓ Super B-factory (KEK)
- ✓ J-PARC (KEK)
- ✓ LiteBIRD (JAXA)
- ✓ Super-Kamiokande (ICRR)

Grade A: Importance, Community's approval, Core Institutes, Joint research system, Plan's appropriate

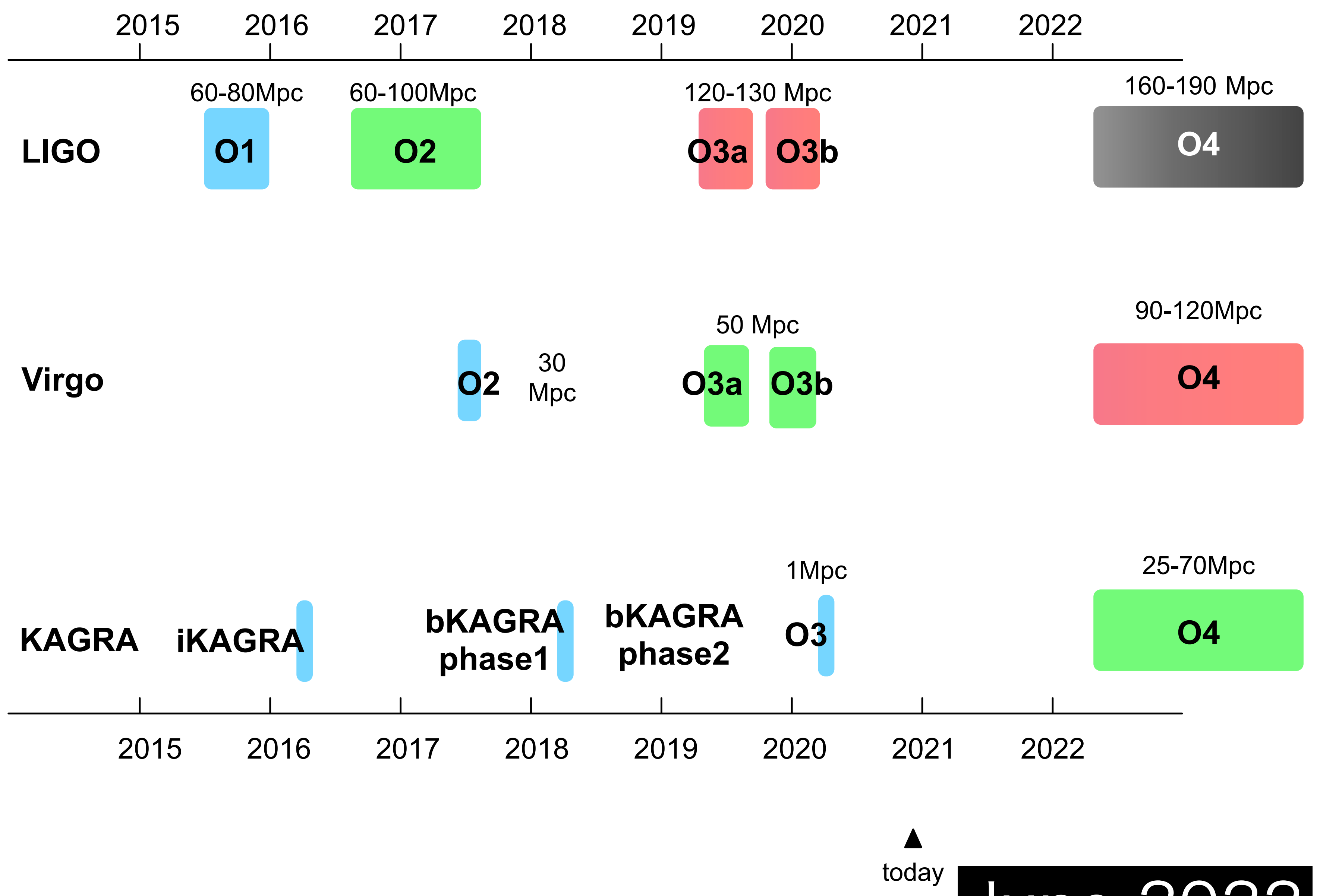
Grade A: Emergency, Strategy, Supports from general

KAGRA project (operation) budget: 2023Apr-2034Mar

Toward O4

KAGRA

* **Target Sensitivity 25 - 130 Mpc**
* Recent estimate: **80 Mpc at most?**
due to heat absorption of sapphire mirrors
by reducing laser noise, low-f noise, then it goes better more.



- ☑ less than 100K
- ☐ dual recycling
  - ☑ lock trials by the end of September
- ☐ suspension noise control for low freq.
  - ☑ one-order reduced in July
- ☐ de-frosting mirrors
- ☐ de-frosting windows for oplev light

x20 sensitivity at mid-freq.

June 2022 O4 ready

commissioning

Summer 2021

repair & installation

October 2020

- Cryo-Payload repairing
- ETMY tower repairing
- install laser beam baffles
- Cryocoolers replacement (CRY)
- Intensity noise reduction system (IOO)

- DGS/AEL upgrade (DGS/AEL)
- Stray light around IOO (AOS)
- Suspension frame modification (AOS, VIS)
- Temperature monitors (VIS)
- and more

Overview of KAGRA: reviews

ACCEPTED MANUSCRIPT

Overview of KAGRA : Detector design and construction history

T Akutsu, M Ando, K Arai, Y Arai, S Araki, A Araya, N Aritomi, Y Aso, S Bae, Y Bae ... Show more

Progress of Theoretical and Experimental Physics, ptaa125,
https://doi.org/10.1093/ptep/ptaa125
Published: 17 August 2020 **Article history** ▾

published PTEP 2020
KAGRA history
https://doi.org/10.1093/ptep/ptaa125
arXiv: 2005.05574

nature astronomy PERSPECTIVE
https://doi.org/10.1038/s41550-018-0658-y

KAGRA: 2.5 generation interferometric gravitational wave detector

KAGRA collaboration

The recent detections of gravitational waves (GWs) reported by the LIGO and Virgo collaborations have made a significant impact on physics and astronomy. A global network of GW detectors will play a key role in uncovering the unknown nature of the sources in coordinated observations with astronomical telescopes and detectors. Here we introduce KAGRA, a new GW detector with two 3 km baseline arms arranged in an 'L' shape. KAGRA's design is similar to the second generations of Advanced LIGO and Advanced Virgo, but it will be operating at cryogenic temperatures with sapphire mirrors. This low-temperature feature is advantageous for improving the sensitivity around 100 Hz and is considered to be an important feature for the third-generation GW detector concept (for example, the Einstein Telescope of Europe or the Cosmic Explorer of the United States). Hence, KAGRA is often called a 2.5-generation GW detector based on laser interferometry. KAGRA's first observation run is scheduled in late 2019, aiming to join the third observation run of the advanced LIGO-Virgo network. When operating along with the existing GW detectors, KAGRA will be helpful in locating GW sources more accurately and determining the source parameters with higher precision, providing information for follow-up observations of GW trigger candidates.

Nature Astronomy 3, 35 (2019)
https://www.nature.com/articles/s41550-018-0658-y

ACCEPTED MANUSCRIPT

Overview of KAGRA: KAGRA science

T Akutsu, M Ando, K Arai, Y Arai, S Araki, A Araya, N Aritomi, H Asada, Y Aso, S Bae ... Show more

Progress of Theoretical and Experimental Physics, ptaa120,
https://doi.org/10.1093/ptep/ptaa120
Published: 12 August 2020 **Article history** ▾

PDF | Split View | Cite | Permissions | Share ▾

published PTEP 2020
KAGRA Science
https://doi.org/10.1093/ptep/ptaa120
arXiv: 2008.02921

Overview of KAGRA: Calibration, detector characterization, physical environmental monitors, and the geophysics interferometer

T Akutsu, M Ando, K Arai, Y Arai, S Araki, A Araya, N Aritomi, H Asada, Y Aso, S Bae ... Show more

Progress of Theoretical and Experimental Physics, Volume 2021, Issue 5, May 2021, 05A102, https://doi.org/10.1093/ptep/ptab018
Published: 22 February 2021 **Article history** ▾

PAPER

Vibration isolation systems for the beam splitter and signal recycling mirrors of the KAGRA gravitational wave detector

T Akutsu[1,2], M Ando[1,3,4], K Arai[5], Y Arai[5], S Araki[6], A Araya[7], N Aritomi[3], H Asada[8], Y Aso[9,10], S Bae[11] + Show full author list

Published 5 March 2021 • © 2021 IOP Publishing Ltd
Classical and Quantum Gravity, Volume 38, Number 6
Citation T Akutsu *et al* 2021 *Class. Quantum Grav.* **38** 065011

https://iopscience.iop.org/article/10.1088/1361-6382/abd922
Class. Quant. Grav. 38 (2020) 065011

published PTEP 2021
KAGRA Calibration, Detector characterization, physical environment monitors
https://doi.org/10.1093/ptep/ptab018
arXiv: 2009.09305

KSC Newsletter : Exchanging Info between collaborators

KAGRA SCIENTIFIC CONGRESS: COLLABORATORS' INFORMATION EXCHANGE 2019/12/01

KSC Newsletter

Issue 6

KAGRA joined International GW Network

Signed up LIGO-Virgo-KAGRA MoA for joint observation

On October 4, 2019, KAGRA held a ceremony to mark the completion of the detector. The ceremony was in the site, and after the play of the music of *kagura* (the traditional Shinto-style ritual music) by local children's musical group, Takaaki Kajita, our PI, pushed a button with U Tokyo Executive Vice President Kohei Miyazono to demonstrate the detector in motion. In the evening of the day, the signing ceremony of a memorandum of agreement (MoA) on a research collaboration between KAGRA, LIGO and Virgo were held.

This MoA makes KAGRA an equal partner of LIGO and Virgo, and once KAGRA satisfied the criteria for joining observation then all the scientific achievements will be presented as LIGO-Virgo-KAGRA collaboration. KAGRA is definitely close to the production phase after the ten-year construction and installation period. 🍏

(Above) Pose for photos after signing a MoA. (from left) EGO vice president Christian Olivetto, Virgo spokesperson Jo van den Brand, KAGRA principal investigator Takaaki Kajita, LIGO Executive Director David Reitze, KSC board chair Hisaaki Shinkai, and KAGRA vice PI Masatake Ohashi. At ANA Crowne Plaza hotel Toyama, October 4, 2019. [Photo courtesy of Hida City]

(Right above) The ceremony at the site. Playing *kagura* music by local shrine musicians. (Right below) Takaaki Kajita and U Tokyo Vice President Kohei Miyazono switched on the green button, and it locked. [Photos courtesy of H. Oobayashi.]

KAGRA SCIENTIFIC CONGRESS: COLLABORATORS' INFORMATION EXCHANGE 2020/APRIL 17

KSC Newsletter

Issue 7

KAGRA entered the observing mode!

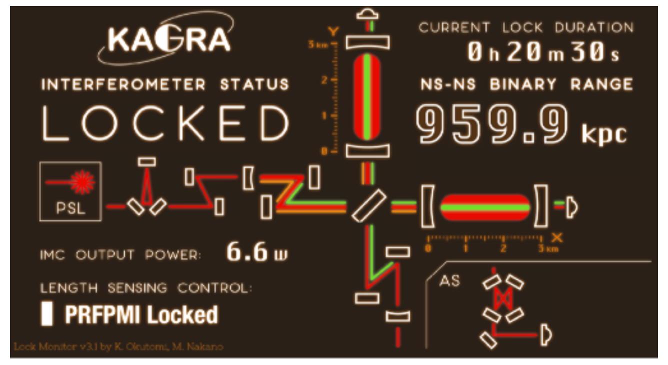
We are operating at Mpc-level finally

After we signed to the memorandum of agreement (MoA) [JGW-M1910663] [JGW-M1910664], with LIGO/Virgo in October, our target has been concentrated to join to Observation 3 (O3) of LIGO/Virgo. The requirements [JGW-M1910813] are to improve the sensitivity of the detector over 1 Mpc in binary neutron-star range, and to clear the readiness checklists of data flows/calibrations/organization. When we first locked the detector on August 23, 2019, the sensitivity was 0.4 kpc. In order to reach our target (10 Mpc), the team so far made great efforts for commissioning and noise-hunting.

The planned date for starting observation was postponed a couple of times. We made engineering run in December, then went back to the commissioning. After the announce of the first lock of the power recycling system on January 26 [klog12639] and OMC readout ready [klog12763], our sensitivity started recording the number as we graphed below.

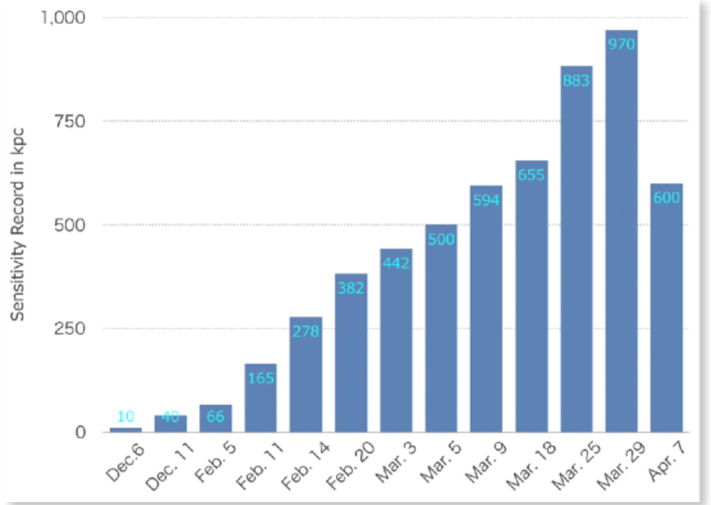
We declare the start of the observation on February 25 with around 300 kpc level. The team decided to go back to commissioning to try again with the signal recycling configuration. We heard we momentally locked with dual recycling, but not enough stability for observation.

Since our time was limited and we decided to go into the observing run from April 7 for two weeks. However, the new virus COVID-19 changed the situation. Both LIGO/Virgo had to stop their detector from March 24. On April 3, KAGRA proposed to make a joint observation with GEO600 in the framework of LVK network, and core members are discussing details with GEO.



The current record of the sensitivity is 970 kpc on March 29, 2020. [klog 13840]

The moment of declaring the start of observation on February 25, 2020. [Photo from KAGRA webpage]



Reported records of the sensitivity in binary neutron-star range (in kpc).

KAGRA SCIENTIFIC CONGRESS: COLLABORATORS' INFORMATION EXCHANGE 2021/MAY 1

KSC Newsletter

Issue 8

Towards New Phase

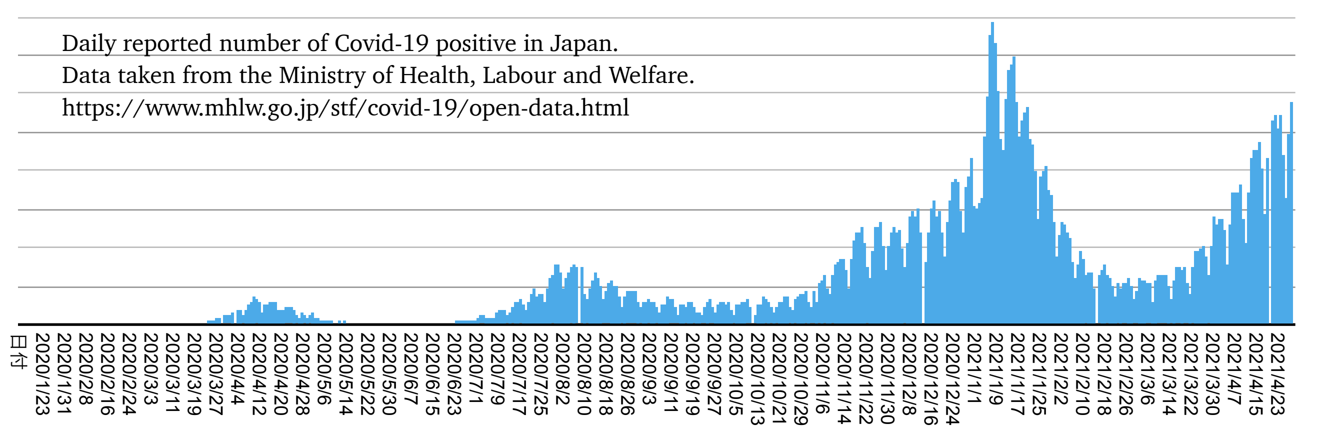
We are still confronting with the war to COVID-19 and its variants. In most regions in the world (except China and Taiwan), we still have to spend our time scared of corona infection, avoiding contact with people as much as possible, having less conversation, and living a life that restrains movement. Academic meetings, workshops, seminars and classes have been made online. All the experiments and installations are under restricted environment. We know criticizing unreliable governments can not solve these problems.

But let's think differently. Epidemics have hit humankind many times in history. Human beings have confronted it and managed to overcome it. Newton had to spent two years returning to the countryside when the city of London was closed due to plague outbreak. At this time, he summarized the calculus method and got the idea of the inverse square law of gravity. Newton himself later recalled in his autobiography that "the last two years have been the pinnacle of his life's imagination." It is a "creative vacation".

From O3a, O3b, O3GK to O4

The third observation period (O3a/b) of LIGO and Virgo was terminated by COVID-19 on March 27, 2020, while KAGRA passed the joining condition of 1 Mpc sensitivity in binary neutron star on March 26 and went into the observing mode in April. KAGRA once decided to make solo observation, but someone noticed that GEO600 in Germany was in operation as Astrowatch with the sensitivity 1.2 Mpc. We therefore organized KAGRA+GEO combinational operation from April 7 to 21, 2020, under the LIGO-Virgo-KAGRA (LVK) collaboration, which was named O3GK later. We were operating KAGRA until summer with the expectation of O3c, but it was the fighting period against the earthquakes in Nagano and Gifu prefectures in Japan. The experiment groups started repairing and installing facilities in September, and are now rushing for O4, which is supposed to start in the summer 2022 (more than a half year delay from the original LVK plan).

Meanwhile, from October 2020, KAGRA's authorship as the LVK-collaboration papers started for O3b data analysis. We established Joint Editorial Board and started assigning our reviewer for each paper, and we are required to check the drafts which come almost every week.



linked from

http://gwwiki.icrr.u-tokyo.ac.jp/JGWwiki/KAGRA/KSC#newsletter

Status of KAGRA: Summary

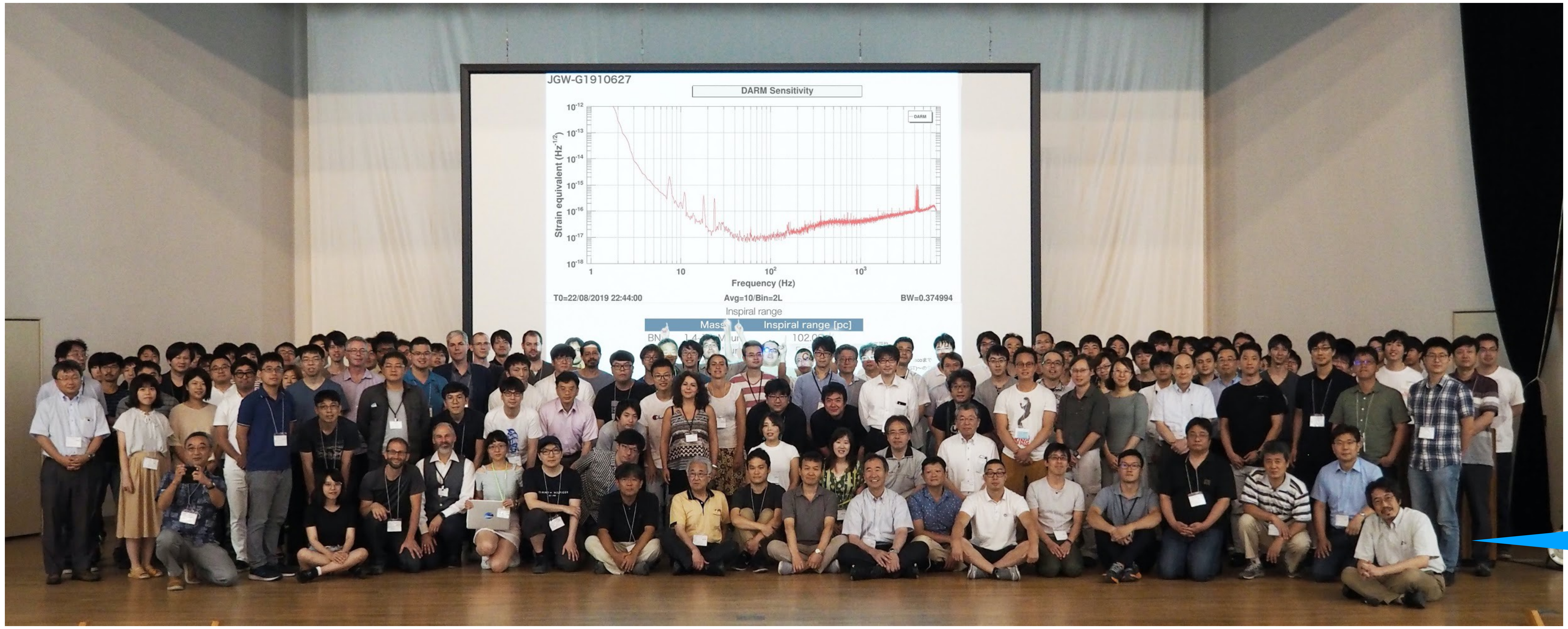
- **Underground and Cryogenic interferometric 3 km gravitational-wave detector at Kamioka, Japan**

LVK ◆ KAGRA is a part of GW international network with LIGO and Virgo.

"O3" ◆ KAGRA joined O3b in the final stage, and O3GK publication plan is ongoing.

"O4" ◆ Repairs and Installations are ongoing.

◆ LVK O4 is planned to start Summer 2022.



If you are planning to join, please contact to your nearest KAGRA collaborators, or consult below FAQ.

http://gwwiki.icrr.u-tokyo.ac.jp/JGWwiki/KAGRA/KSC/FAQ