Status and Perspectives of KAGRA

Soichiro Morisaki on behalf of KAGRA

ICRR/University of Tokyo

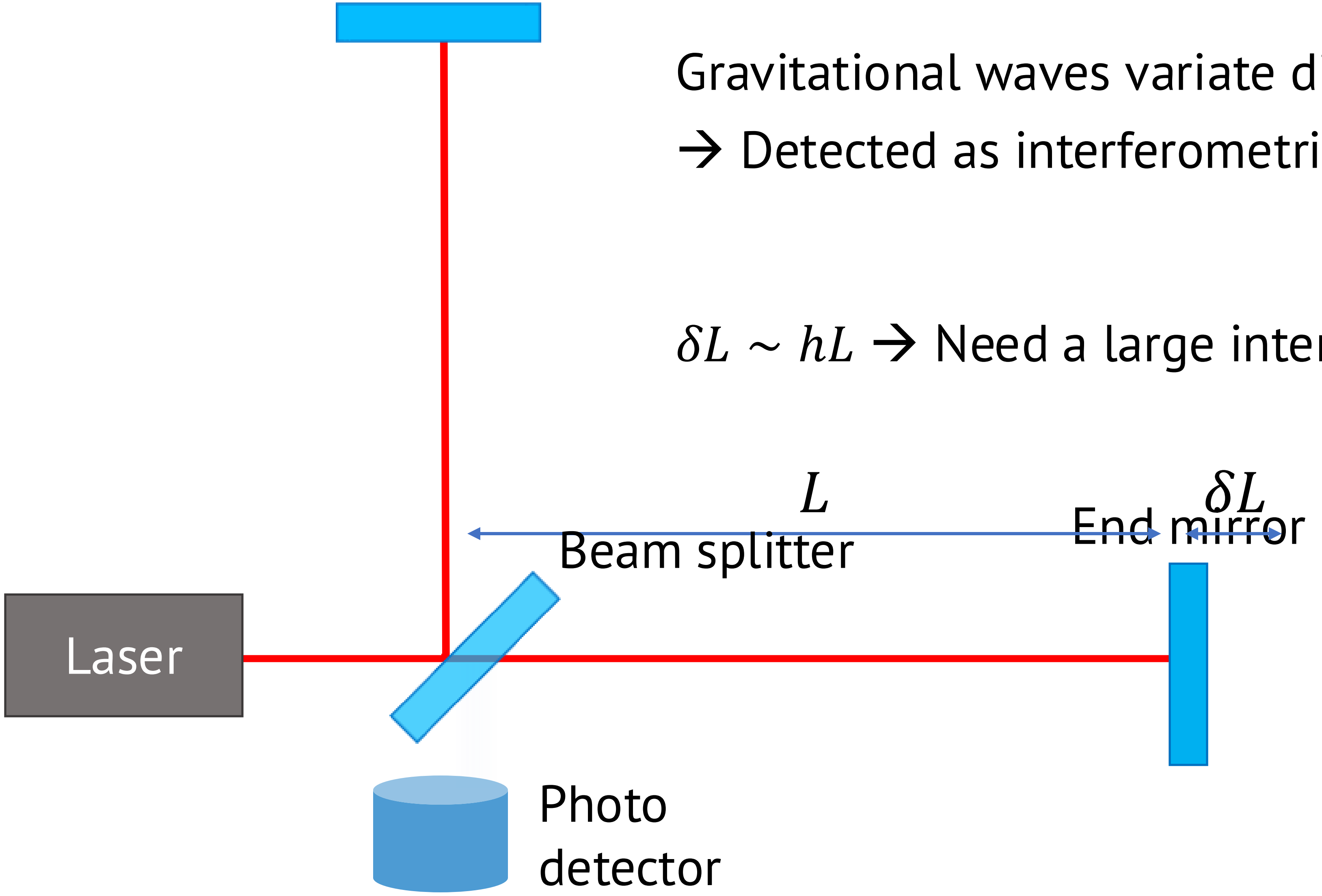
Second International Conference on the Physics of the Two Infinities @ Hongo Campus, Tokyo.

Nov. 21, 2025.

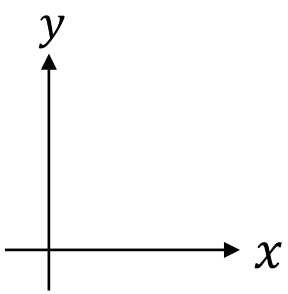
Interferometric Gravitational-Wave Detector

Gravitational waves variate differential arm length.
→ Detected as interferometric patterns.

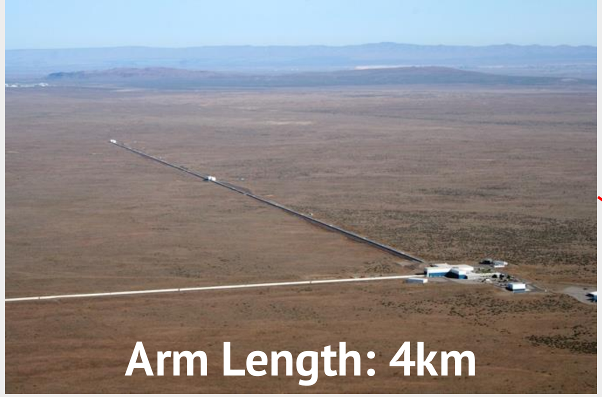
$\delta L \sim hL$ → Need a large interferometer!

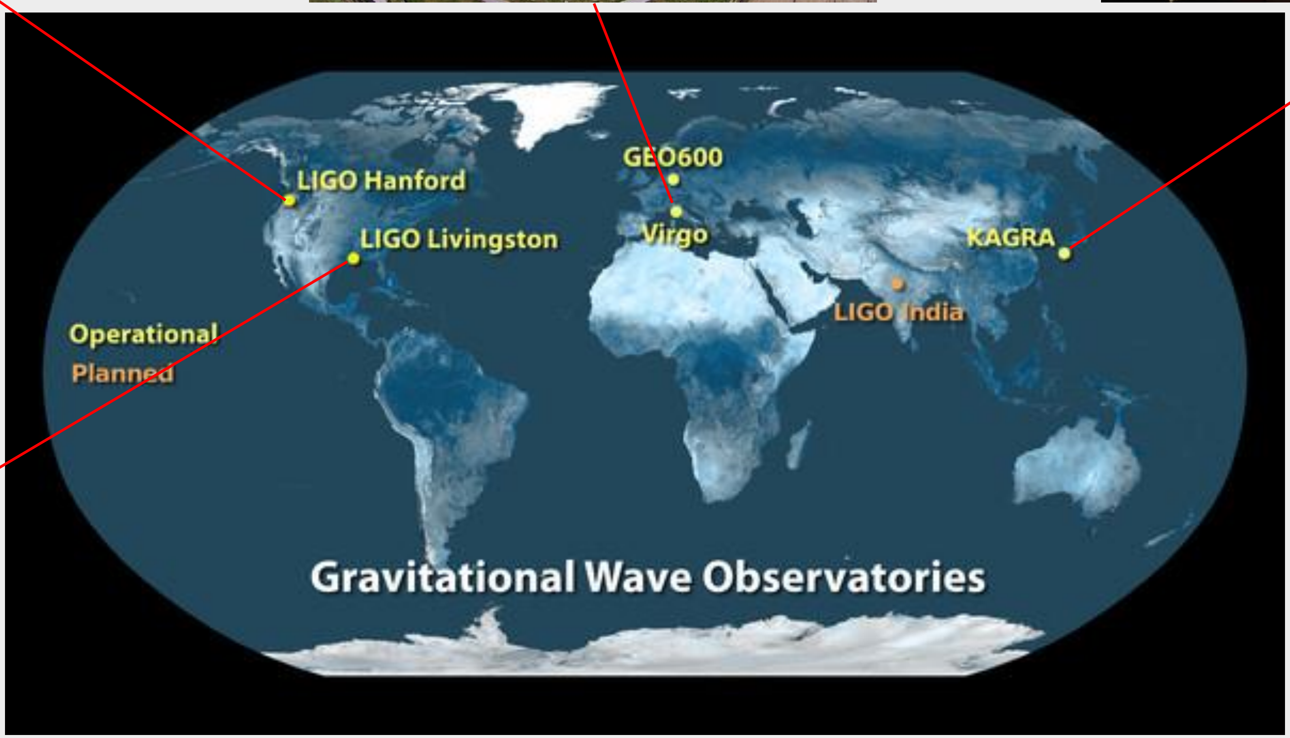


If GWs with plus polarization propagate in the z direction …



Gravitational-Wave Observatories





LIGO-Virgo-KAGRA (LVK) collaboration

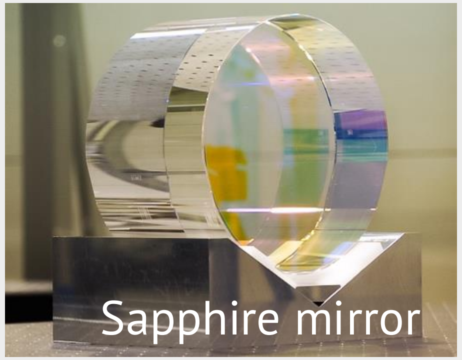
Figure credit: Caltech/MIT/LIGO Lab/ICRR

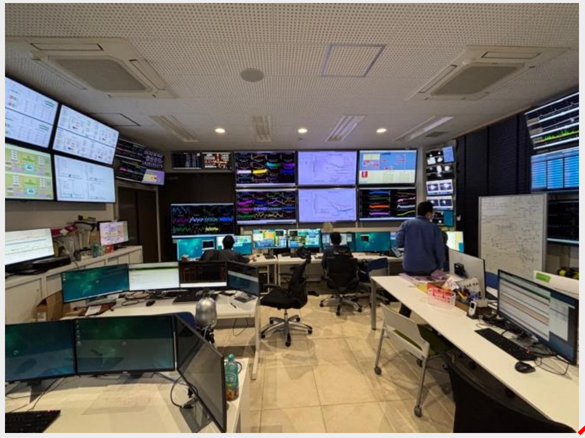
KAGRA

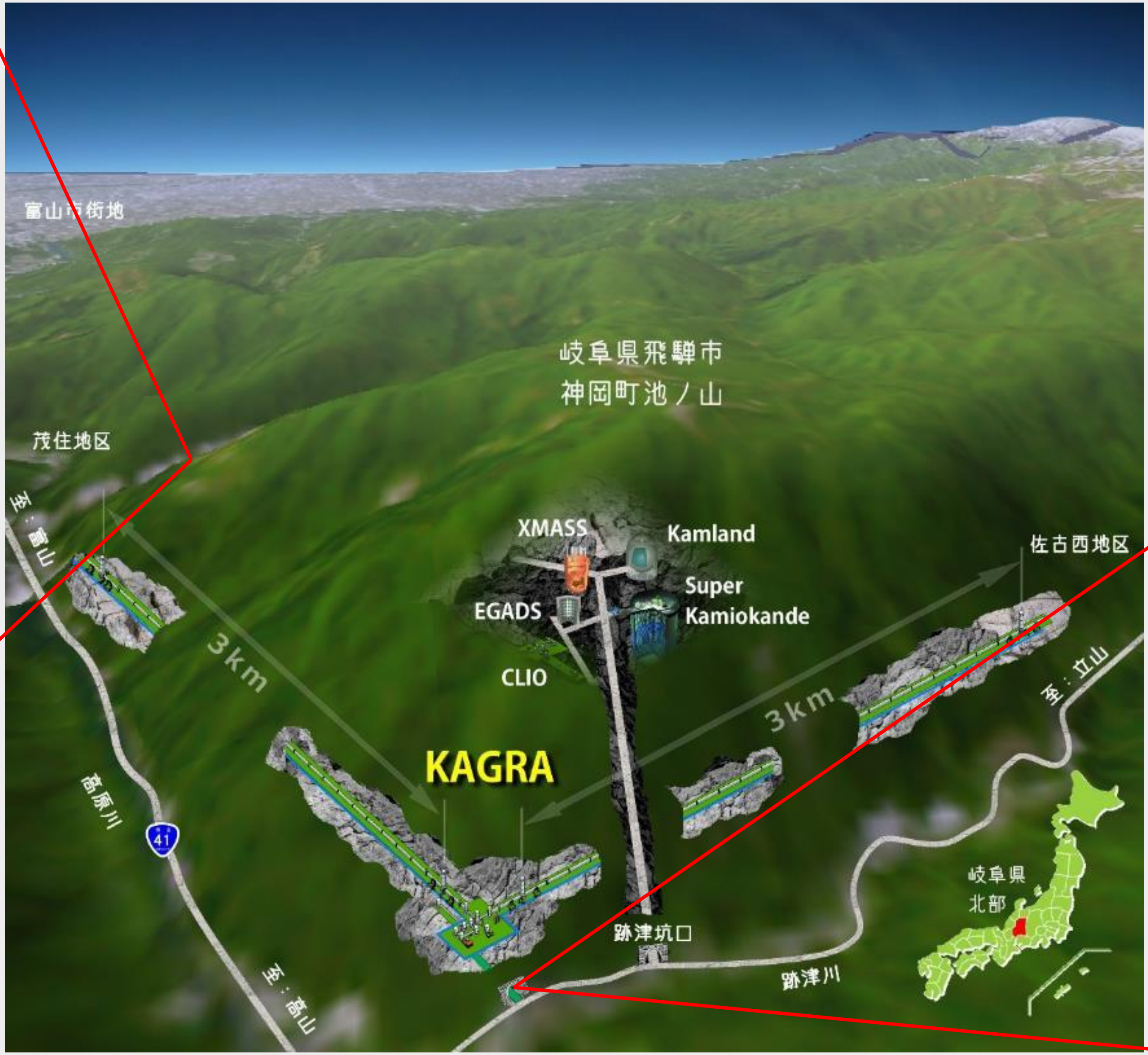
- **Interferometric gravitational-wave (GW) detector** built inside the Kamioka mine in Hida City, Gifu Prefecture.

- Key differences from LIGO/Virgo
  (1) **Underground → Improved stability thanks to low seismic noise**
  (2) **Cryogenic mirrors and suspensions → Reduced thermal noise**


KAGRA's cryostat


Sapphire mirror

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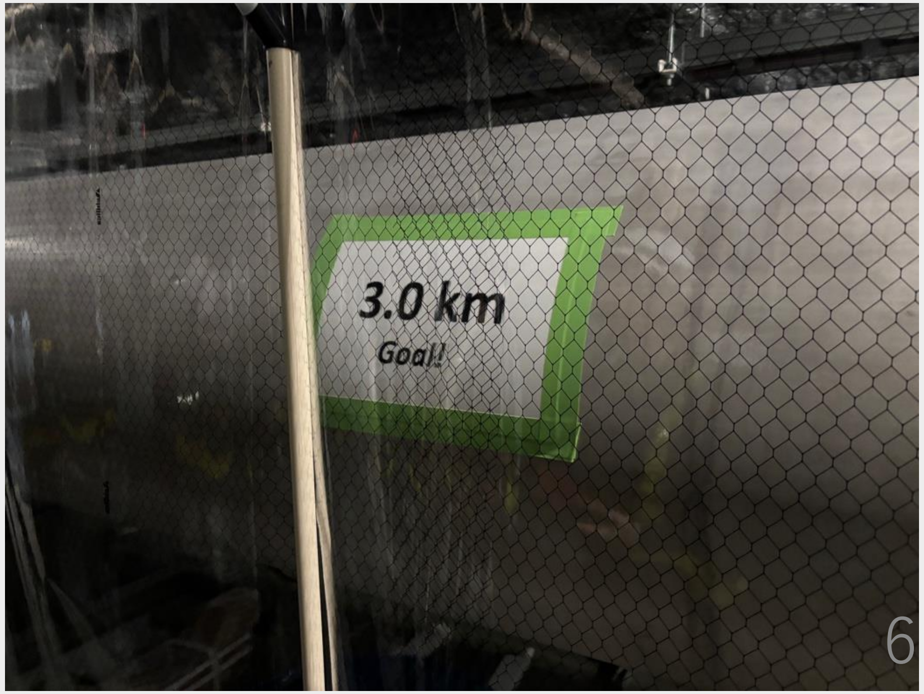
岐阜県飛騨市
神岡町池ノ山
茂住地区
至：富山
XMASS
Kamland
Super
Kamiokande
EGADS
CLIO
3km
佐古西地区
3km
至：立山
KAGRA
高原川
41
跡津坑口
跡津川
岐阜県
北部
至：高山

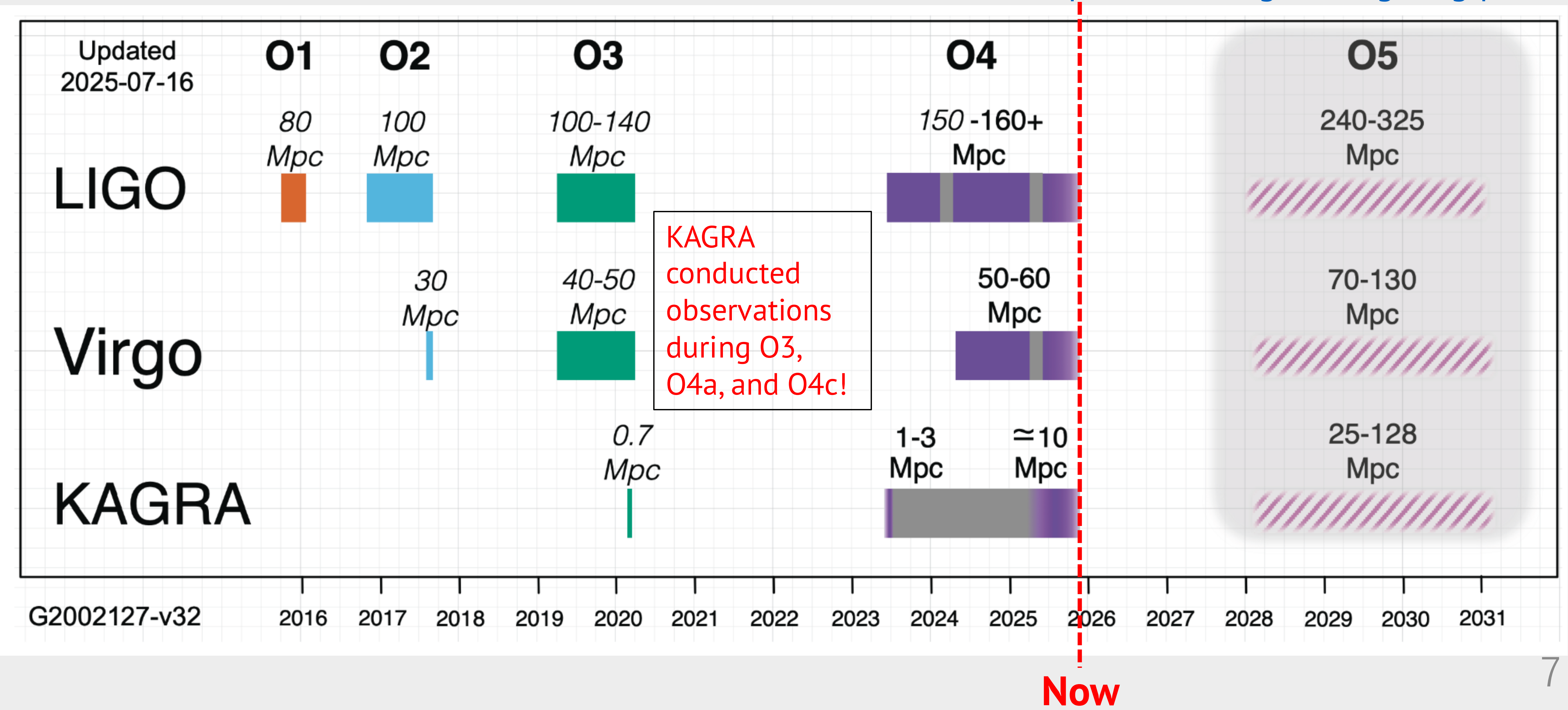

かぐらトンネル



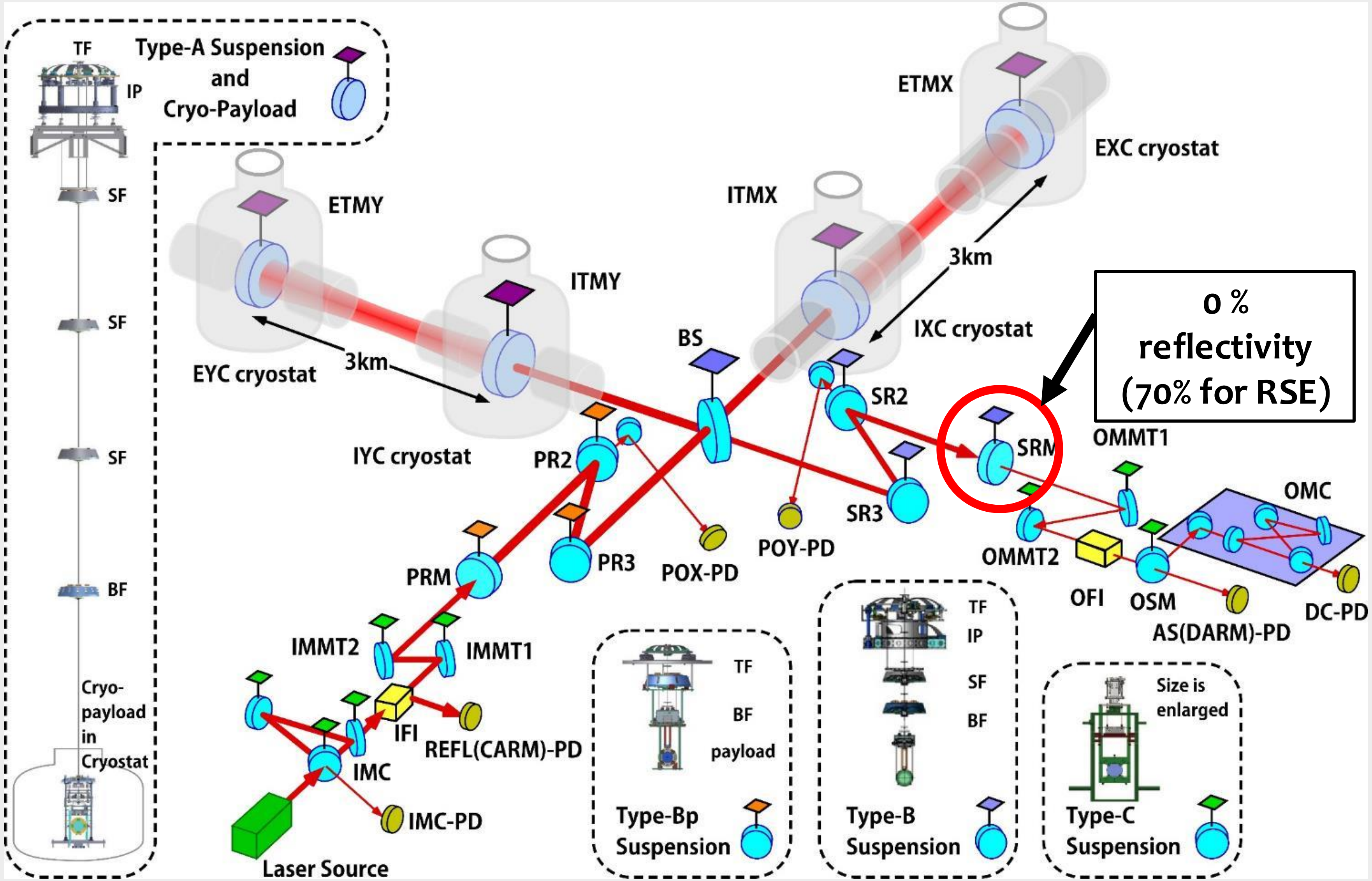
3km arm length, d80cm vacuum ducts

Observing Timeline

Credit: https://observing.docs.ligo.org/plan/



KAGRA Optical Configuration for O4 (PRFPMI)



0 %
reflectivity
(70% for RSE)

KAGRA O4a

- **Period:**
  24th May 08:00 (JST)−21st June 08:00 (JST) in 2023
- **BNS range:** ~ 1.3 Mpc (~ 0.7 Mpc in O3GK)
- **Duty cycle:** ~ 80% (53.2% in O3GK) including weekly maintenance
- Main lock-loss sources are earthquakes.

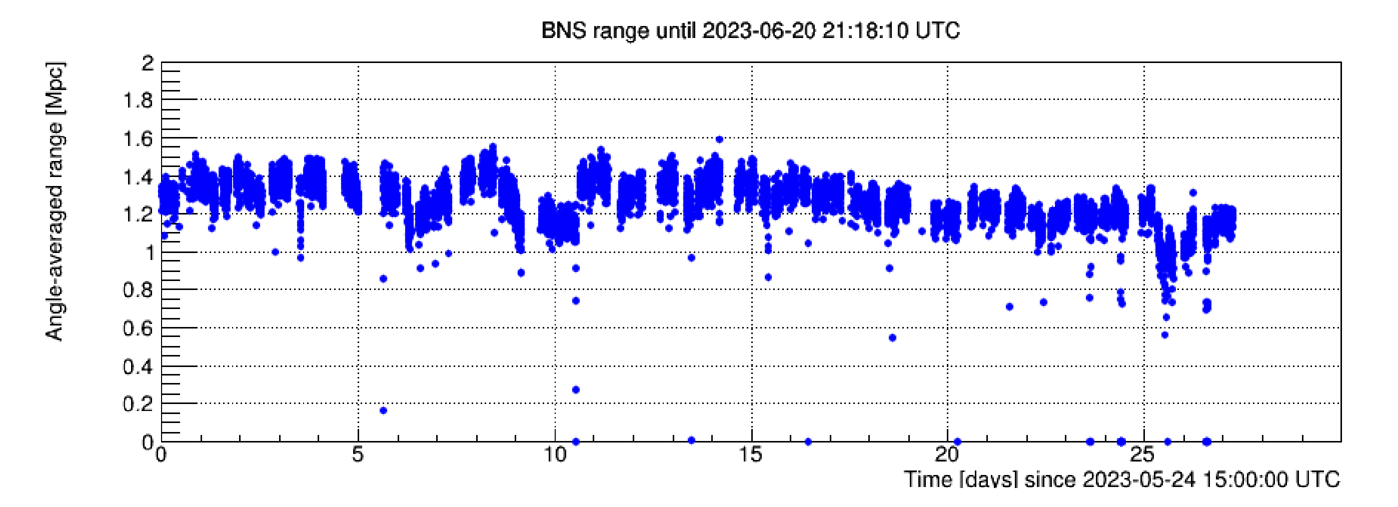
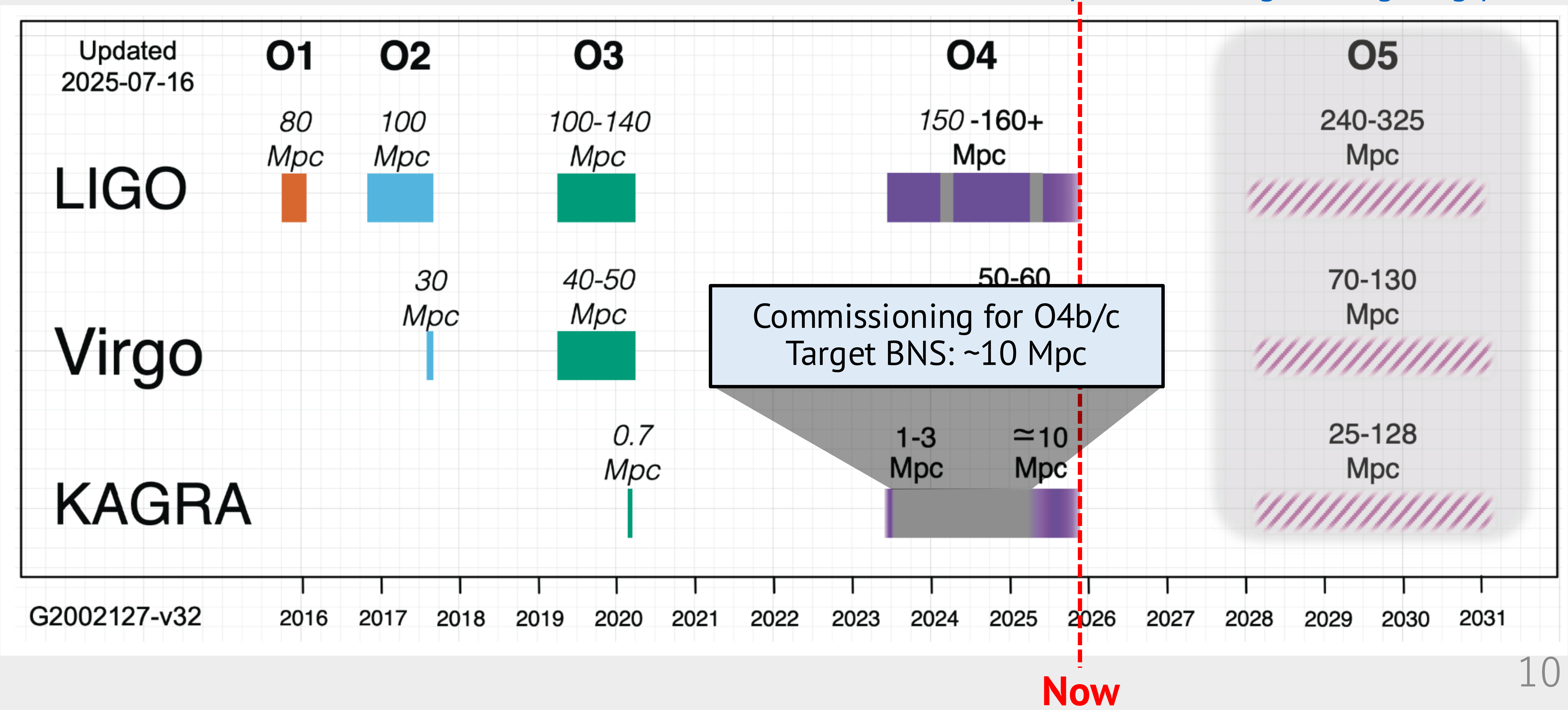


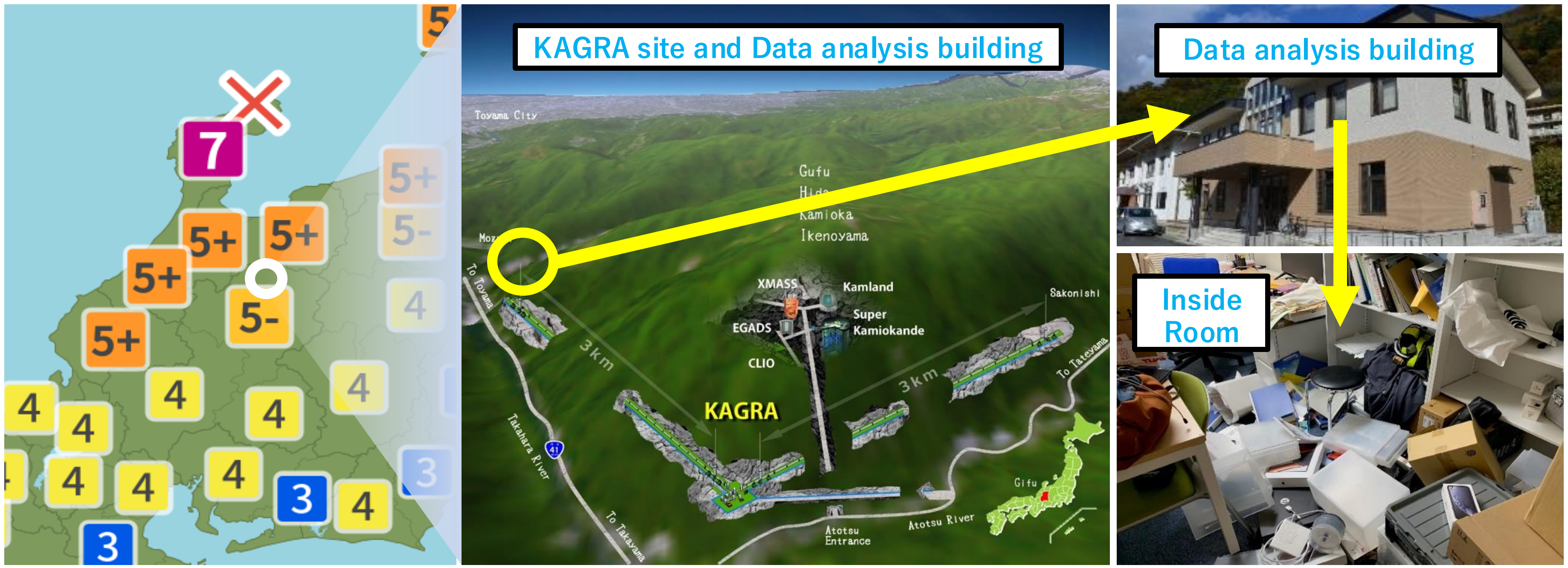
Figure: Binary neutron star (BNS) range of KAGRA during O4a

Observing Timeline

Credit: https://observing.docs.ligo.org/plan/



Noto Earthquakes



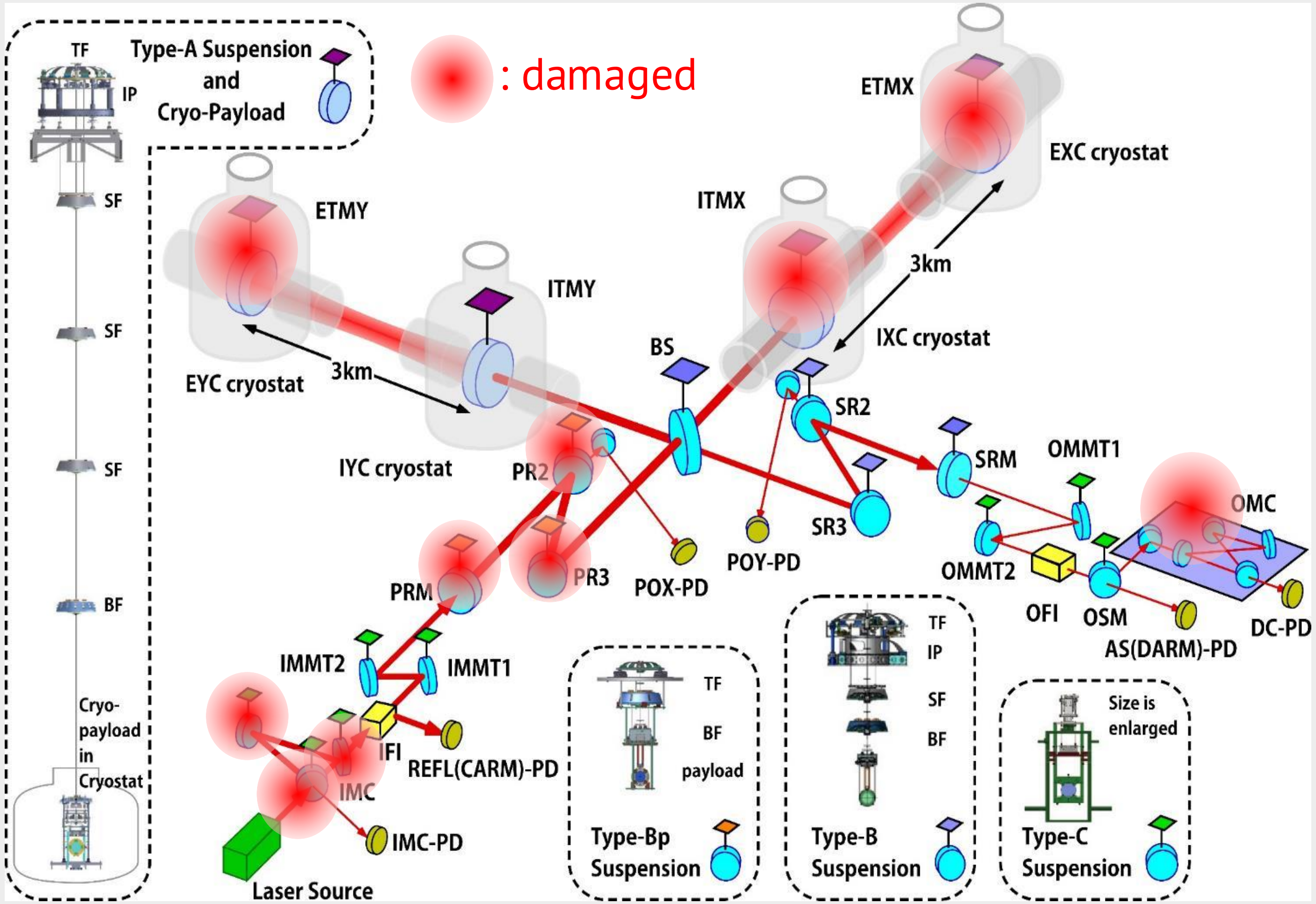
List of Large Earthquakes in the past 100 years

- 1909 Aug 14, M6.8【Anegawa】Lv.3
- 1944 Dec 7, M7.9【Tounankai】Lv.4
- 2011 Feb 17, M5.5【Hida area】Lv.3～4
- 2023 May 5, M6.5【Noto Peninsula】LV.2～3
- 2024 Jan 1, M7.6【Reiwa 6 Noto Peninsula】LV 5- (Red means KAGRA was operated.)

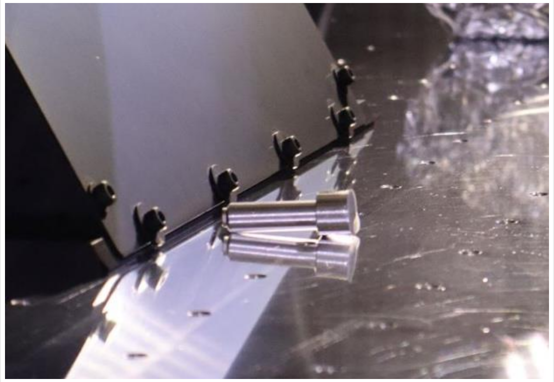
Lv.5- was the largest earthquake at least in the last 100 years.

Noto Earthquakes

10 out of 20 mirror suspensions were damaged ...



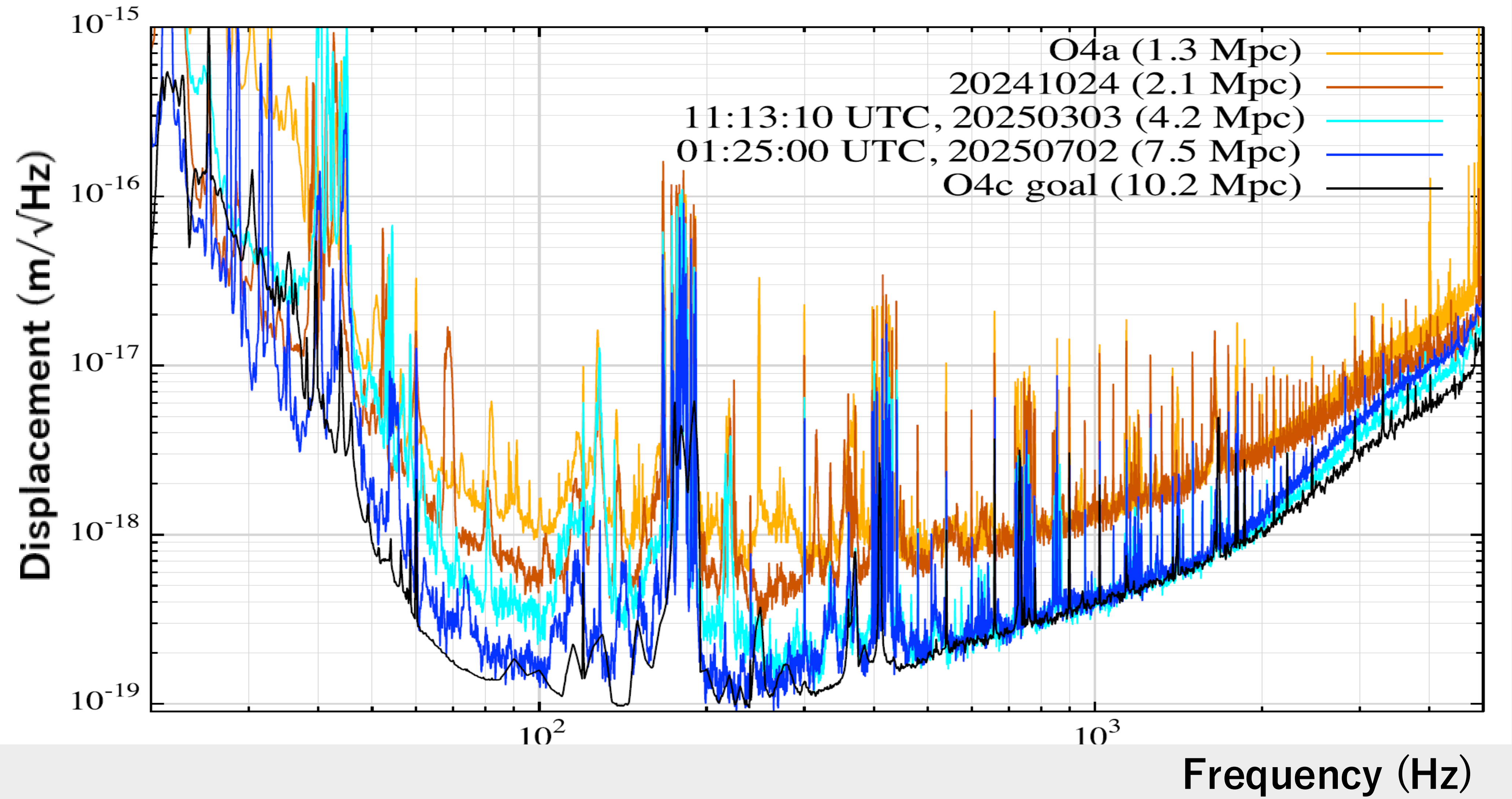
Signal wire cut



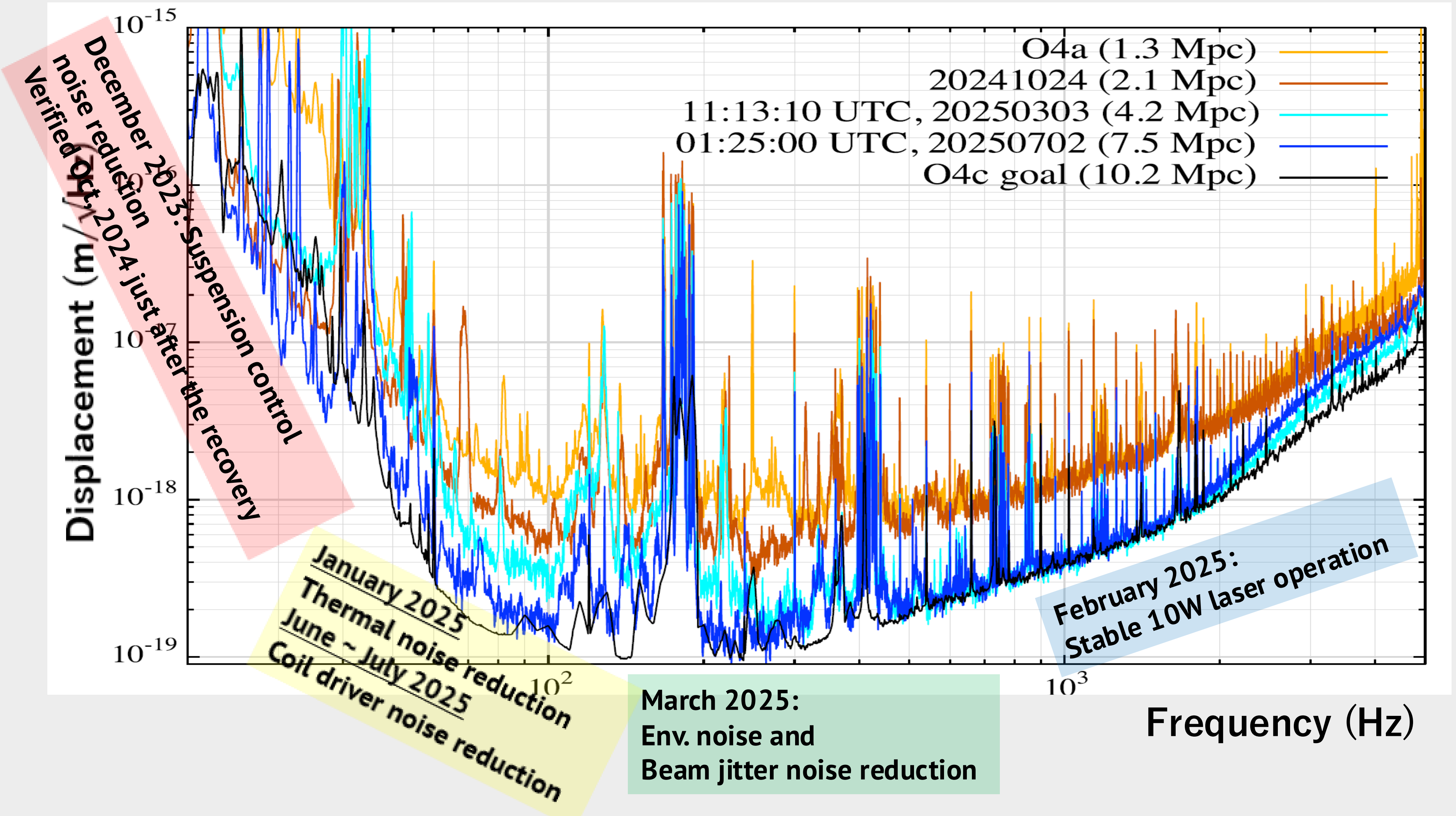
Magnet dropoff

The recovery was completed, and commissioning resumed in July 2024, thanks to the tremendous efforts of the on-site researchers.

Commissioning toward O4c



Commissioning toward O4c



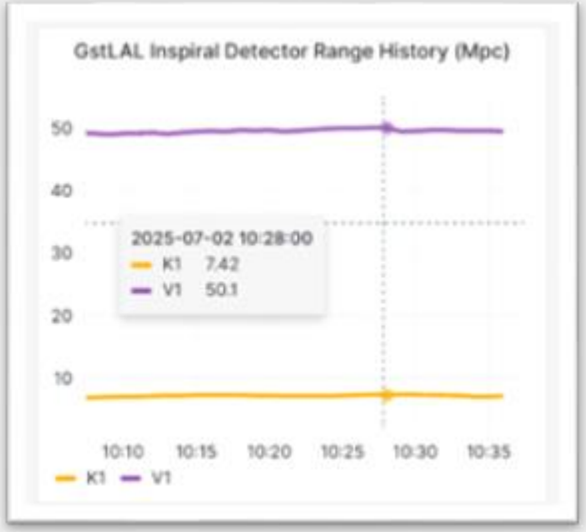
KAGRA O4c

- **Period:** 11th June – 18th November in 2025
- Affected by earthquakes in Tokara Islands (mid July) and Kamchatka Peninsula (July 30 – August)
- Failure of main laser (August 15th –) → Recovered on November 14th

Gravitational Wave Detector Network

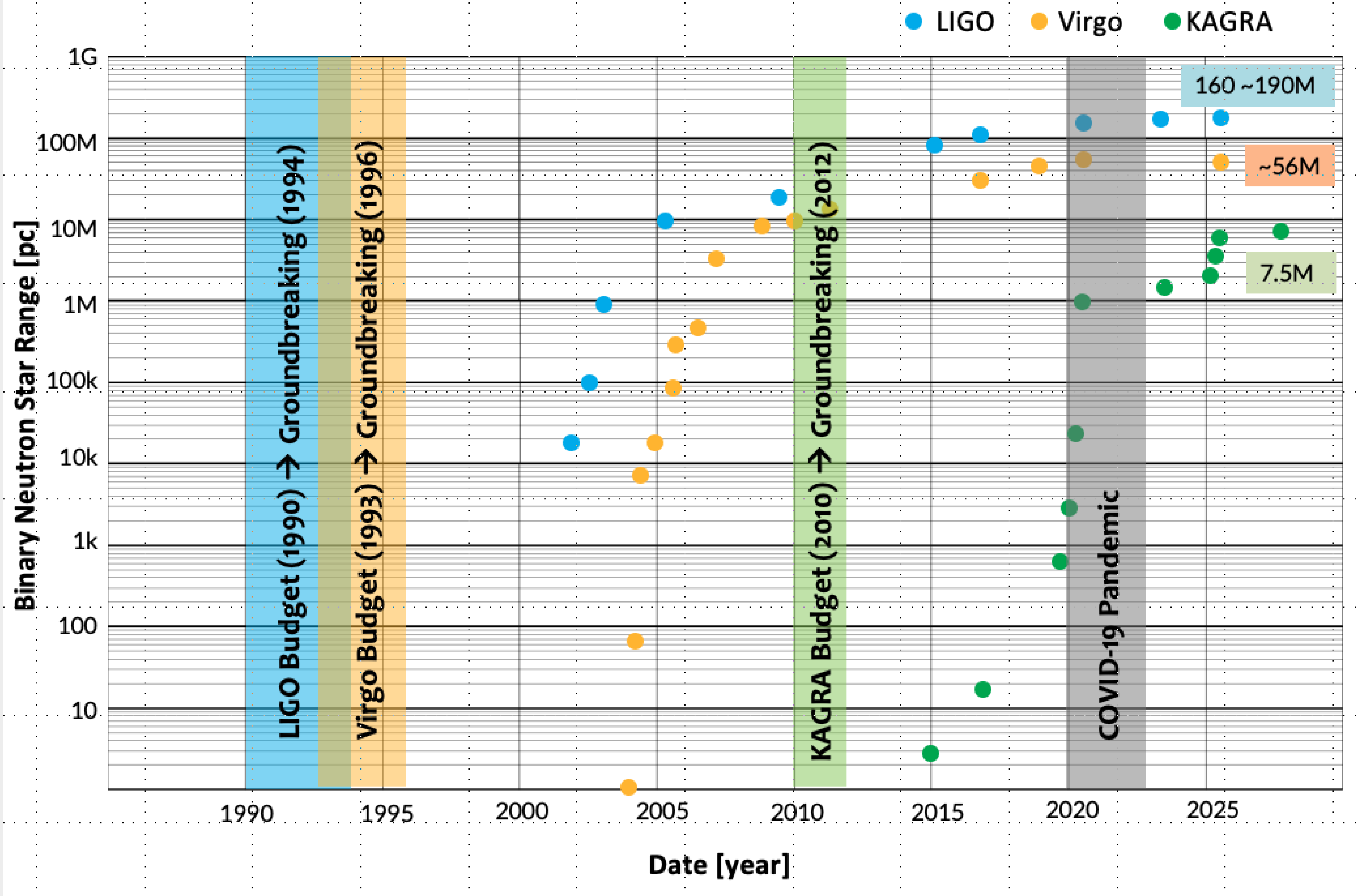
Operational Snapshot as of Jun. 11, 2025 15:16:56 UTC

Detector	Status	Duration [hh:mm]	Latency [s]
GEO600	Observing	00:17	36
LIGO Hanford	Observing	00:19	18
LIGO Livingston	Calib not ready	20:52	62
Virgo	Down	07:43	29
KAGRA	Observing	02:10	37



KAGRA's Best BNS Range ~ 7.5 Mpc

Figure: BNS range of KAGRA on July 2, 2025.



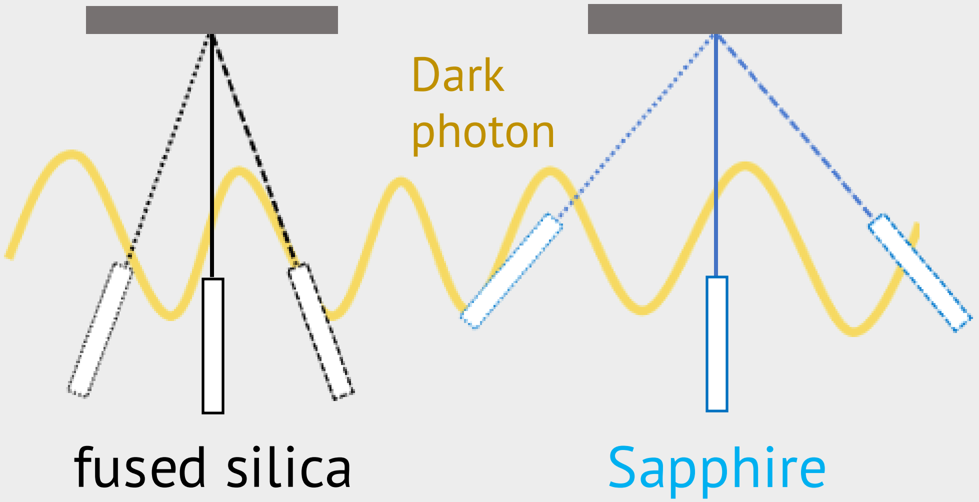
LIGO
Virgo
KAGRA
1G
100M
10M
1M
100k
10k
1k
100
10
Binary Neutron Star Range [pc]
LIGO Budget (1990) → Groundbreaking (1994)
Virgo Budget (1993) → Groundbreaking (1996)
KAGRA Budget (2010) → Groundbreaking (2012)
COVID-19 Pandemic
160 ~190M
~56M
7.5M
1990
1995
2000
2005
2010
2015
2020
2025
Date [year]

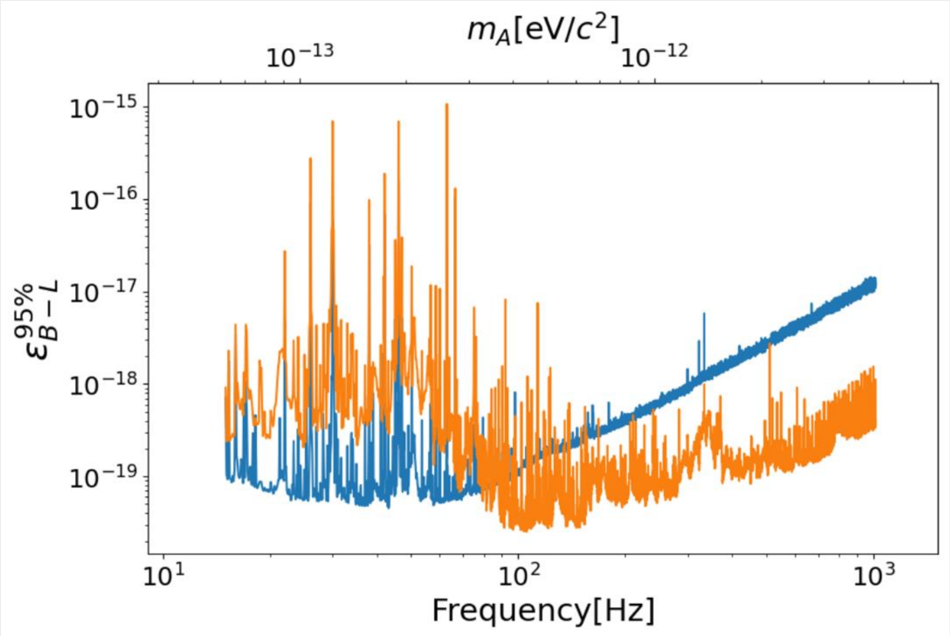
Two Infinities: Gravitational Waves and Dark Matter

- Dark photon exerts *composition-dependent* force on mirrors.

- Length between fused-silica and sapphire mirrors is monitored in KAGRA's auxiliary channels.

Ref: Y. Michimura, T. Fujita, *SM* et al., PRD **102**, 102001 (2020).





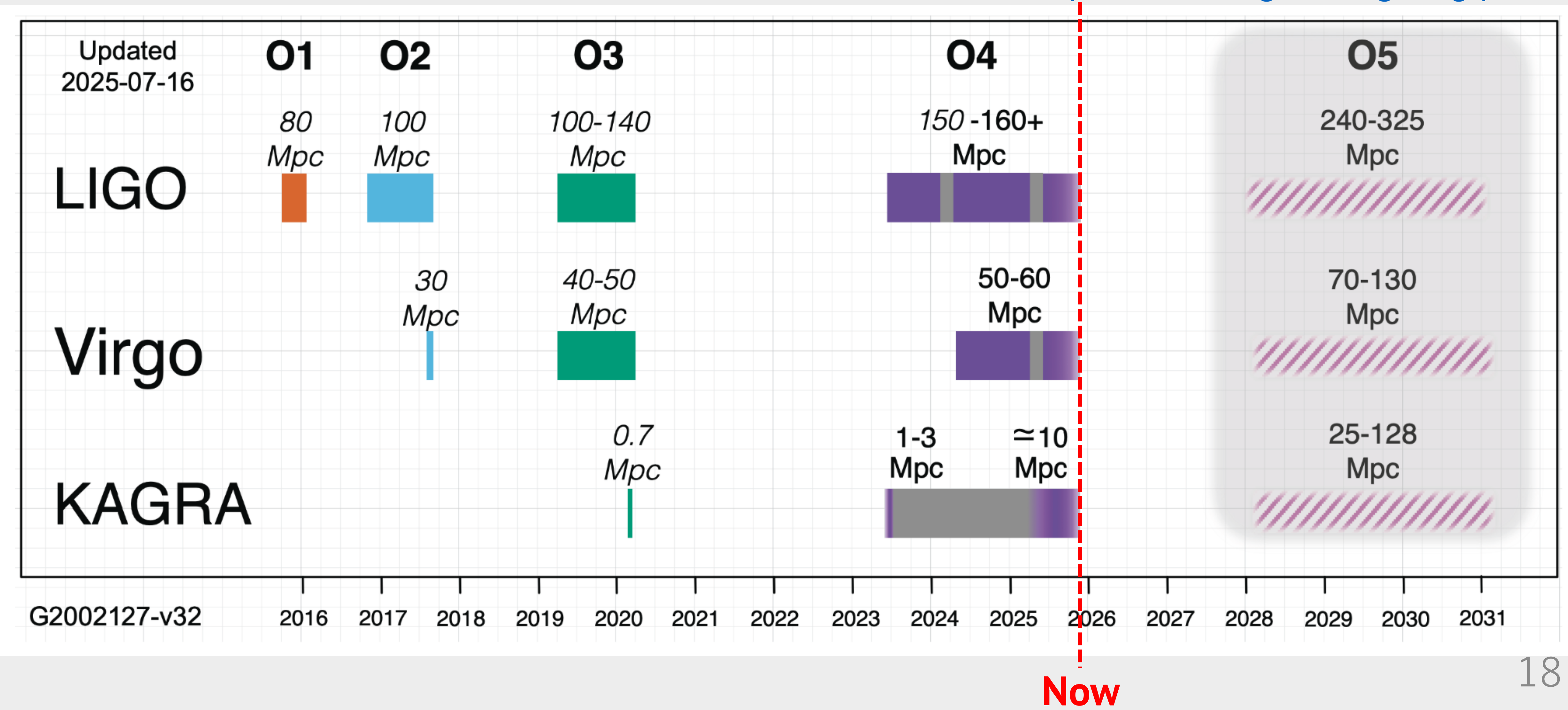
- A search with KAGRA data during O3 was conducted.

- Upper bounds on the dark-photon coupling constant were obtained.

Ref: LIGO-Virgo-KAGRA, PRD **110**, 042001 (2024).

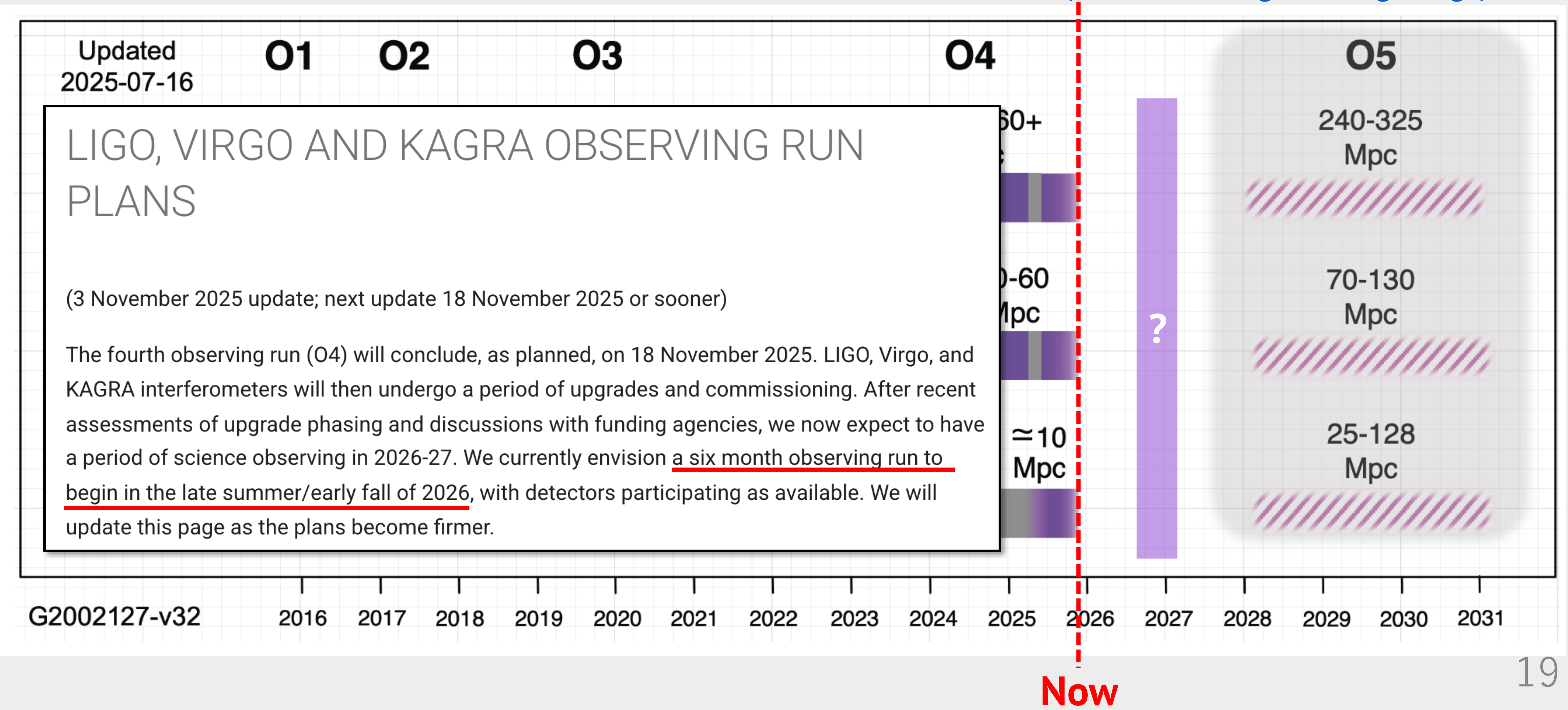
Future Observations

Credit: https://observing.docs.ligo.org/plan/



Future Observations

Credit: https://observing.docs.ligo.org/plan/



LIGO, VIRGO AND KAGRA OBSERVING RUN PLANS

(3 November 2025 update; next update 18 November 2025 or sooner)

The fourth observing run (O4) will conclude, as planned, on 18 November 2025. LIGO, Virgo, and KAGRA interferometers will then undergo a period of upgrades and commissioning. After recent assessments of upgrade phasing and discussions with funding agencies, we now expect to have a period of science observing in 2026-27. We currently envision a six month observing run to begin in the late summer/early fall of 2026, with detectors participating as available. We will update this page as the plans become firmer.

KAGRA beyond O5

[KAGRA collaboration, arXiv: 2508.03392](https://arxiv.org/abs/2508.03392)


arXiv > gr-qc > arXiv:2508.03392

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General Relativity and Quantum Cosmology

[Submitted on 5 Aug 2025]

Decadal upgrade strategy for KAGRA toward post-O5 gravitational-wave astronomy

KAGRA Collaboration: T. Akutsu, M. Ando, M. Aoumi, A. Araya, Y. Aso, L. Baiotti, R. Bajpai, K. Cannon, A. H.-Y. Chen, D. Chen, H. Chen, A. Chiba, C. Chou, M. Eisenmann, K. Endo, T. Fujimori, S. Garg, D. Haba, S. Haino, R. Harada, H. Hayakawa, K. Hayama, S. Fujii, Y. Himemoto, N. Hirata, C. Hirose, H.-F. Hsieh, H.-Y. Hsieh, C. Hsiung, S.-H. Hsu, K. Ide, R. Iden, S. Ikeda, H. Imafuku, R. Ishikawa, Y. Itoh, M. Iwaya, H-B. Jin, K. Jung, T. Kajita, I. Kaku, M. Kamiizumi, N. Kanda, H. Kato, T. Kato, R. Kawamoto, S. Kim, C.Kim, K. Kobayashi, K. Kohri, K. Kokeyama, K. Komori, A. K. H. Kong, T. Koyama, J. Kume, S. Kuroyanagi, S. Kuwahara, K. Kwak, S. Kwon, H. W. Lee, R. Lee, S. Lee, K. L. Li, L. C.-C. Lin, E.-T.-Lin, Y.-C. Lin, G. C. Liu, K. Maeda, M. Meyer-Conde, Y. Michimura, K. Mitsuhashi, O. Miyakawa, S. Miyoki, S. Morisaki, Y. Moriwaki, M. Murakoshi, K. Nakagaki, K. Nakamura, H. Nakano, T. Narikawa, L. Naticchioni, L. Nguyen Quynh, Y. Nishino, A. Nishizawa, K. Obayashi, M. Ohashi, M. Onishi, K. Oohara, S. Oshino, R. Ozaki, M. A. Page, K.-C. Pan, B.-J. Park, J. Park, F. E. Pena Arellano, N. Ruhama, S. Saha, K. Sakai, Y. Sakai et al. (54 additional authors not shown)

The KAGRA Collaboration has investigated a ten-year upgrade strategy for the KAGRA gravitational wave detector, considering a total of 14 upgrade options that vary in mirror mass, quantum noise reduction techniques, and the quality of cryogenic suspensions. We evaluated the scientific potential of these configurations with a focus on key targets such as parameter estimation of compact binary coalescences, binary neutron star post-merger signals, and continuous gravitational waves. Rather than aiming to improve all science cases uniformly, we prioritized those most sensitive to the detector configuration. Technical feasibility was assessed based on required hardware developments, associated R\&D efforts, cost, and risk. Our study finds that a high-frequency upgrade plan that enhances sensitivity over a broad frequency range above ~200 Hz offers the best balance between scientific return and technical feasibility. Such an upgrade would enable sky localization of binary neutron star mergers at 100 Mpc to better than 0.5 deg^2 in a LIGO-Virgo-KAGRA network, and improve the measurement precision of tidal deformability parameter by approximately 10% at median, compared to a network without KAGRA.

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KAGRA beyond O5: Sensitivity Improvements at kHz

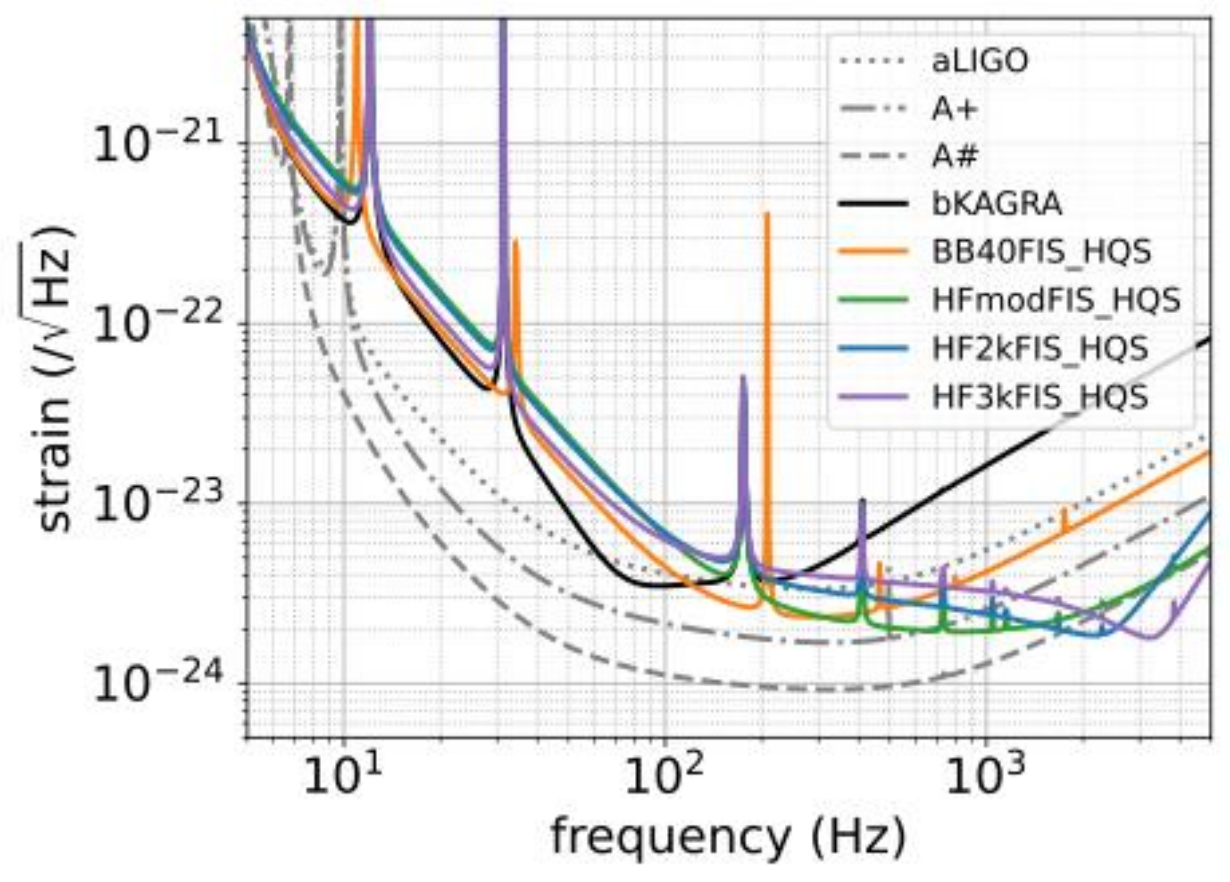

Figure: KAGRA's representative sensitivity options for O6

- **HF** vs **BB**:
  High Frequency vs Broad Band
- **mod/2k/3k**: HF variants optimized for different target frequencies
- **A+** and **A#**: LIGO's design sensitivity for O5 and O6
- **Why HF with KAGRA?**
  – Sapphire's high thermal conductivity mitigates thermal lensing effects, allowing high laser power.

KAGRA beyond O5: Sky Localization

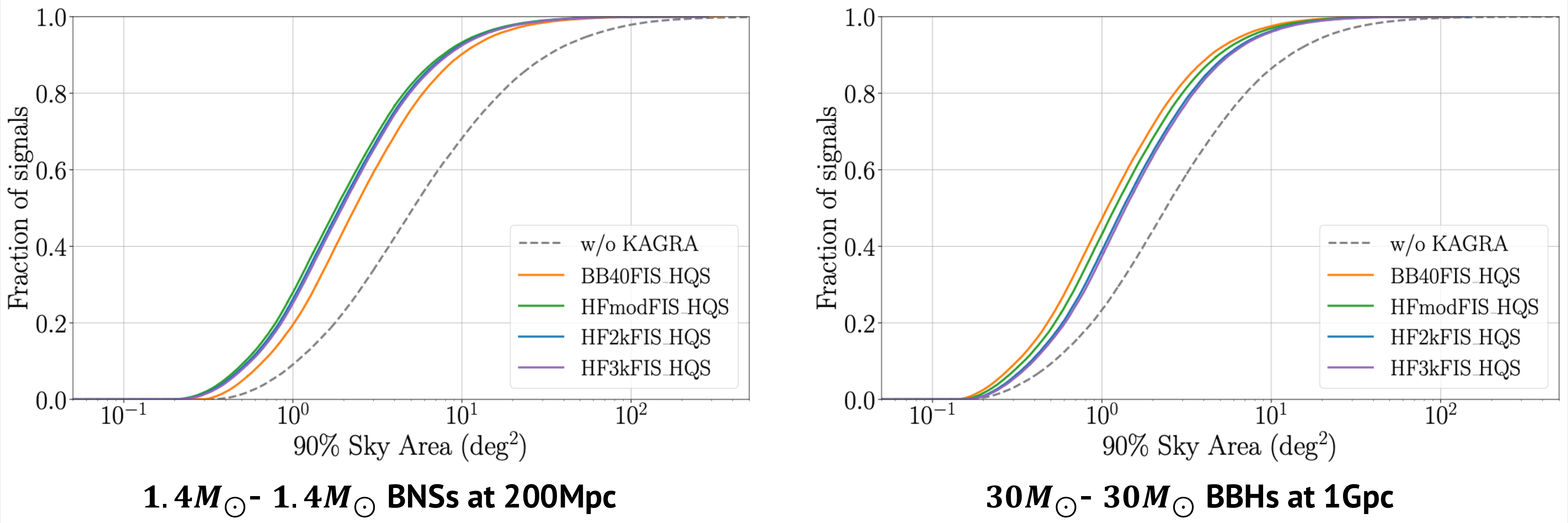

Figure: Cumulative distribution of sky localization errors

Detector network: 2 LIGO detectors (A# sensitivity), Virgo (O5 sensitivity), and KAGRA.

HF options perform better (worse) for BNSs (BBHs) than BB options.

KAGRA beyond O5: Measuring NS's Tidal Effects

Sensitivity improvements at kHz

→ Better measurements of tidal effects

→ Tighter constraints on the NS equation of state (EoS)

Two observable tidal effects

- **Inspiral acceleration** dependent on *NS's tidal deformability Λ.*
- **Post-merger signal** emitted from a rapidly spinning remnant NS.

Data credit: Kyoto group (2020)

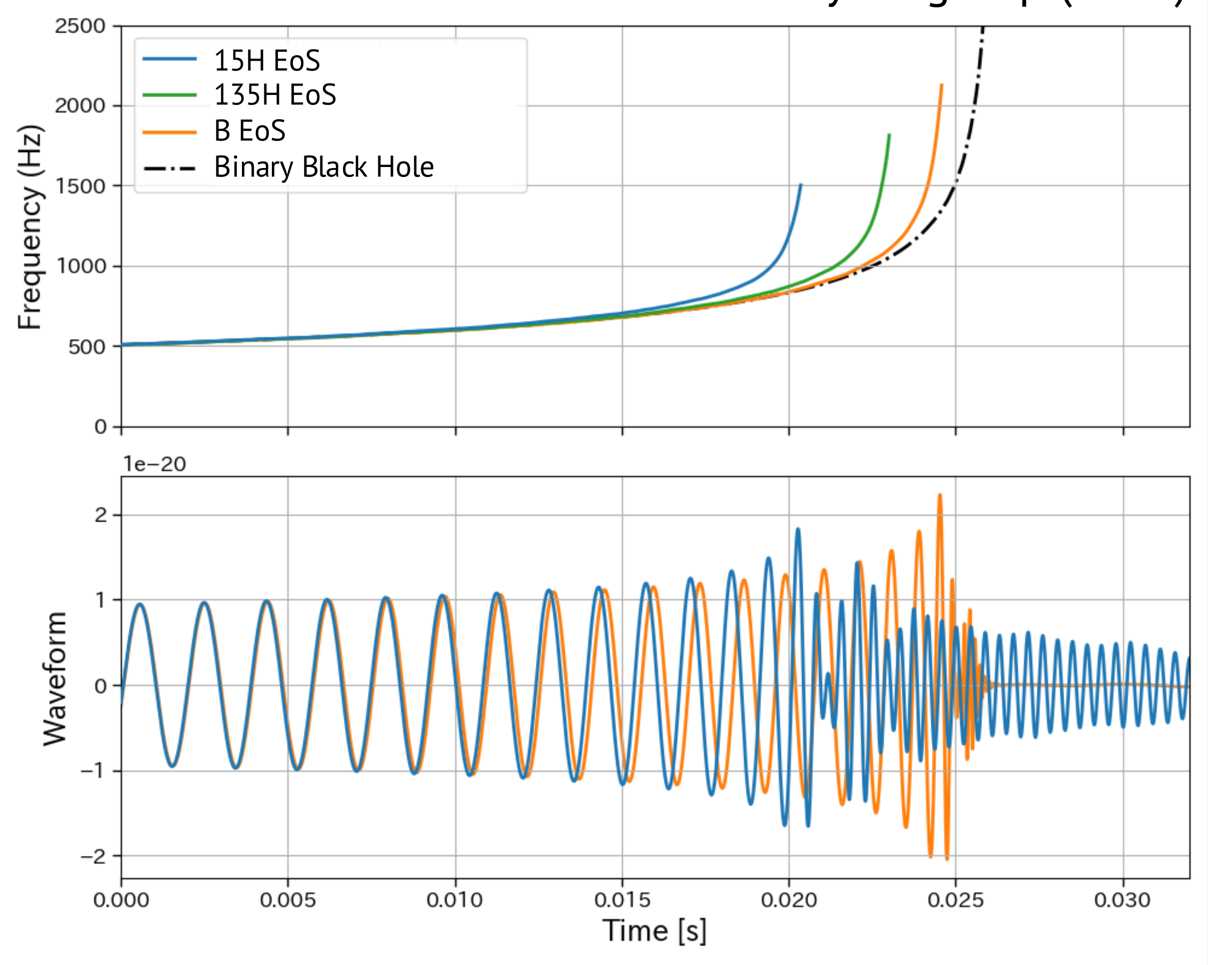

Figure: Frequency evolution and waveform of BNS signals for various equations of state

KAGRA beyond O5: Measuring NS's Tidal Effects

With the HFmod or HF2k configuration, KAGRA can help improve constraints on tidal deformability.

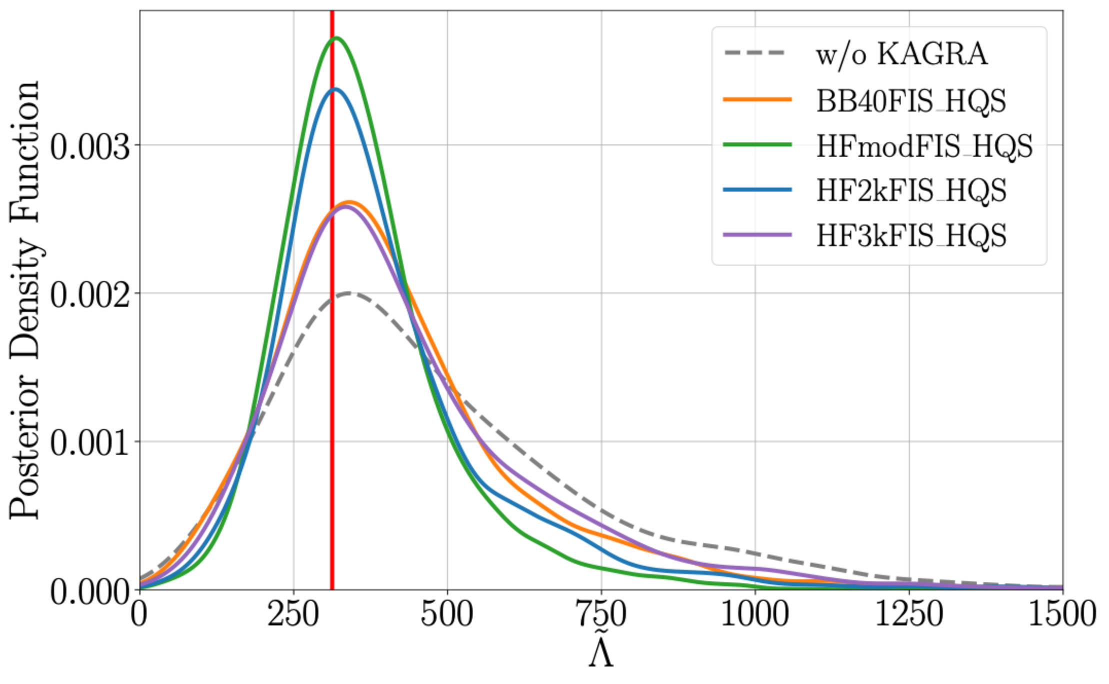

Figure: Mass-weighted tidal deformability $\tilde{\Lambda}$ inferred from a simulated BNS signal

Table: Horizon distances and detection rates of BNS post-merger signal for various KAGRA configurations

PSD	Horizon (Mpc)	Detection Rate (1/year)
A#	60.1−90.7	2×10^{-3}-8×10^{-2}
BB40FIS_HQS	16.7−25.1	4×10^{-5}−2×10^{-3}
HFmodFIS_HQS	55.7−84.2	1×10^{-3}−6×10^{-2}
HF2kFIS_HQS	66.9−104.0	2×10^{-3}−1×10^{-1}
HF3kFIS_HQS	67.3−132.4	2×10^{-3}−2×10^{-1}

The HF2k and HF3k configurations can maximize the detectability of the BNS post-merger signal.

Conclusion

- KAGRA is an interferometric GW detector located in Japan.
  - Built underground to reduce seismic noise
  - Uses cryogenic mirrors and suspensions to reduce thermal noise

- KAGRA participated in O3, O4a, and O4c.
  - Achieved a best BNS range ~7.5 Mpc during O4c.
  - Suffered damage from the Noto earthquakes but has recovered.

- Future plans for KAGRA are under discussion.
  - A part of ~6-month observation run in 2026−2027 is being considered.
  - The target BNS range for O5 is > 25 Mpc to enable the first GW detection.
  - Long-term plans beyond O5 are being explored, including sensitivity improvements around kHz.