From Quarks to Neutron Stars: Insights from kHz gravitational waves (UTokyo, Apr 23-24, 2025)

# KAGRA upgrade in the kHz band for probing neutron star physics

Yuta Michimura
RESCEU, University of Tokyo
michimura@resceu.s.u-tokyo.ac.jp
KAGRA 10yr Task Force,
KAGRA Future Strategy Committee

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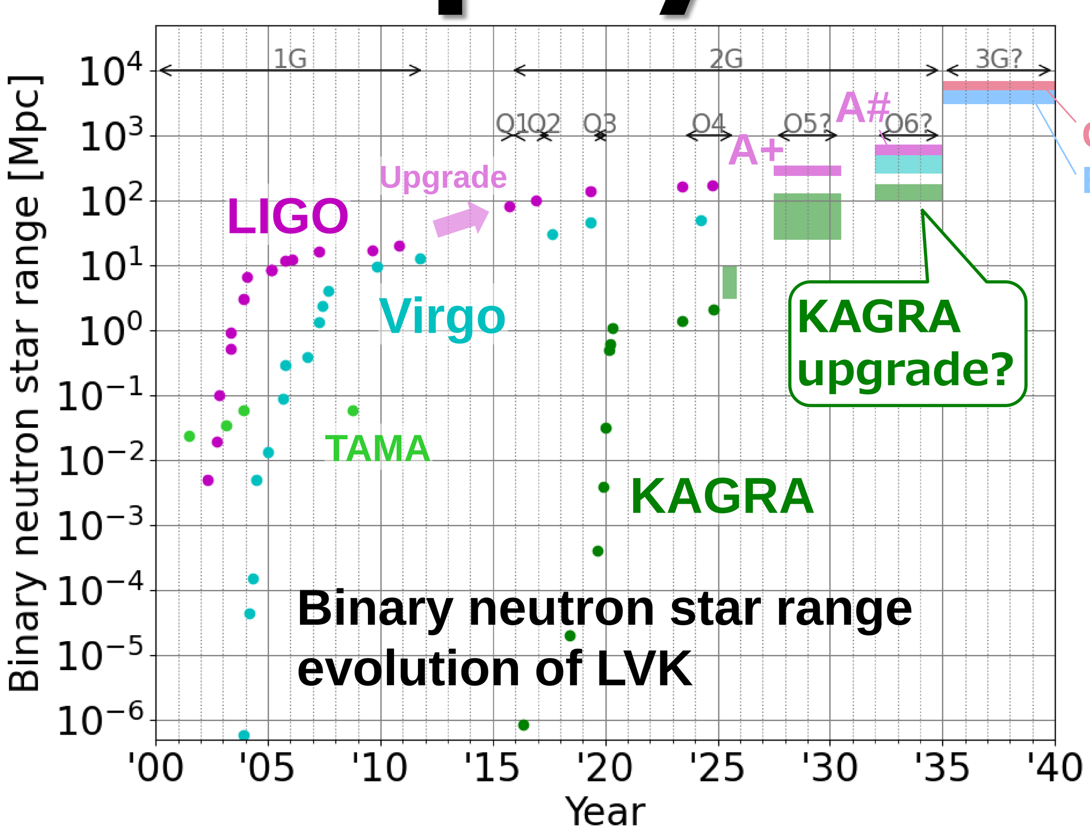
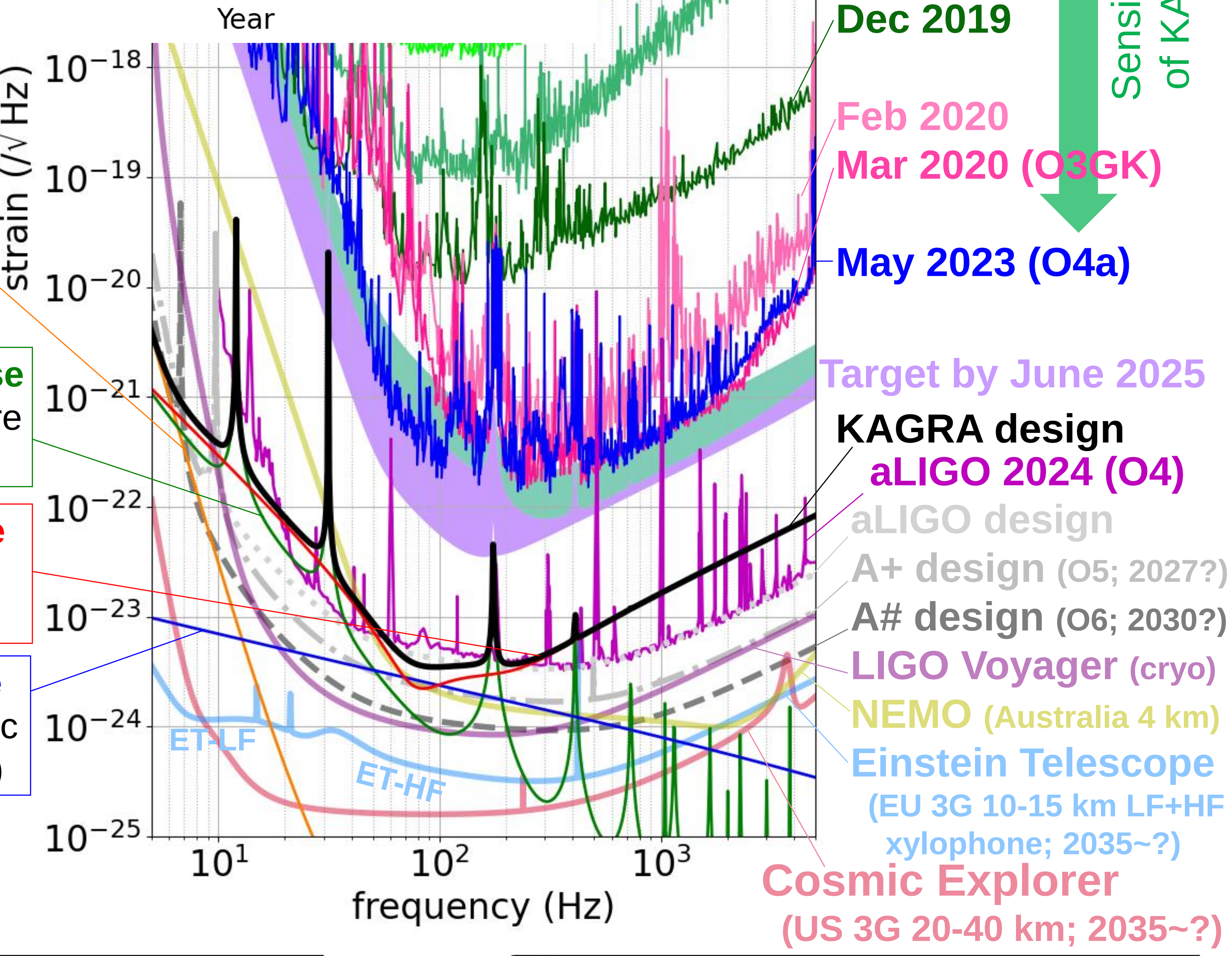
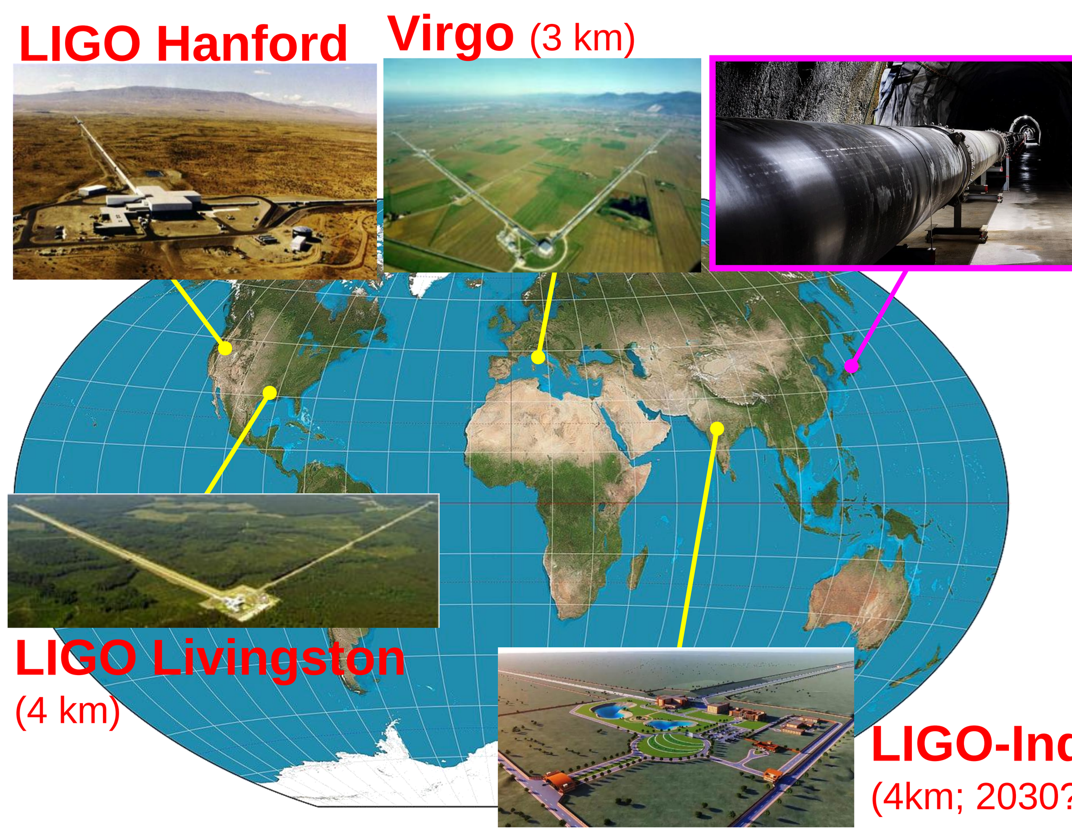
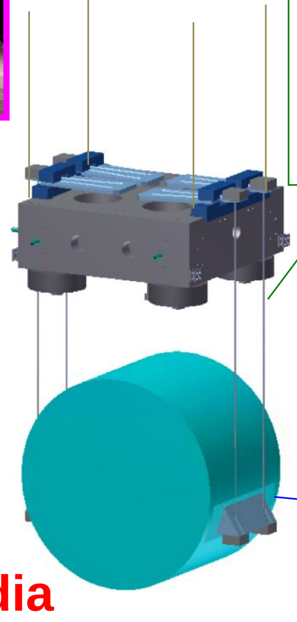
To make multi-messenger observations like GW170817 routine, LIGO and Virgo are planning broadband upgrades, and next-generation projects such as Einstein Telescope and Cosmic Explorer are underway. The world's only cryogenic interferometer, **KAGRA, requires a different upgrade strategy**, as high-frequency sensitivity demands higher laser power, while low-frequency sensitivity requires thin fibers with limited heat extraction capability. After evaluating various upgrade scenarios, we find that **high-frequency option is the most feasible as a first step** towards a broadband upgrade. This upgrade would improve sky localization of binary neutron stars and enable post-merger signal detections.



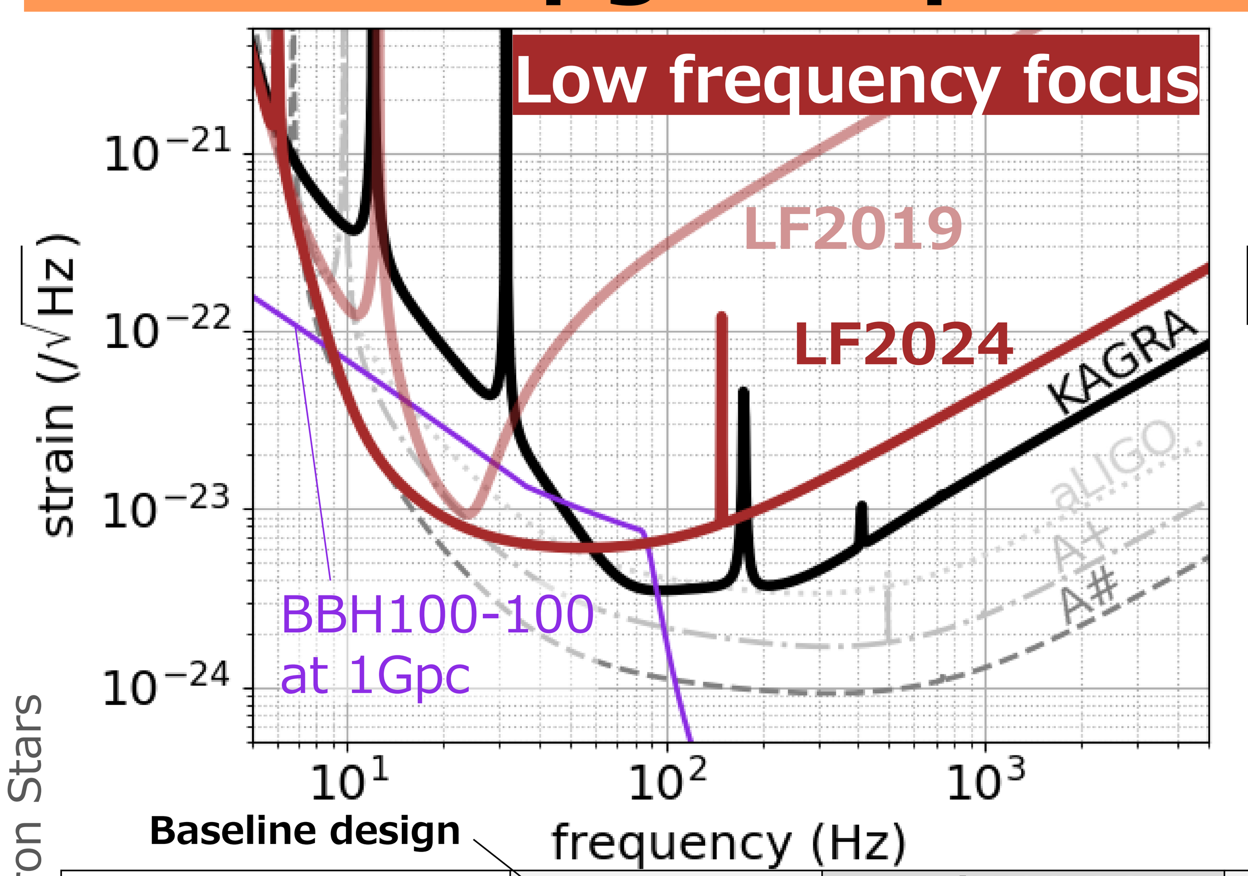



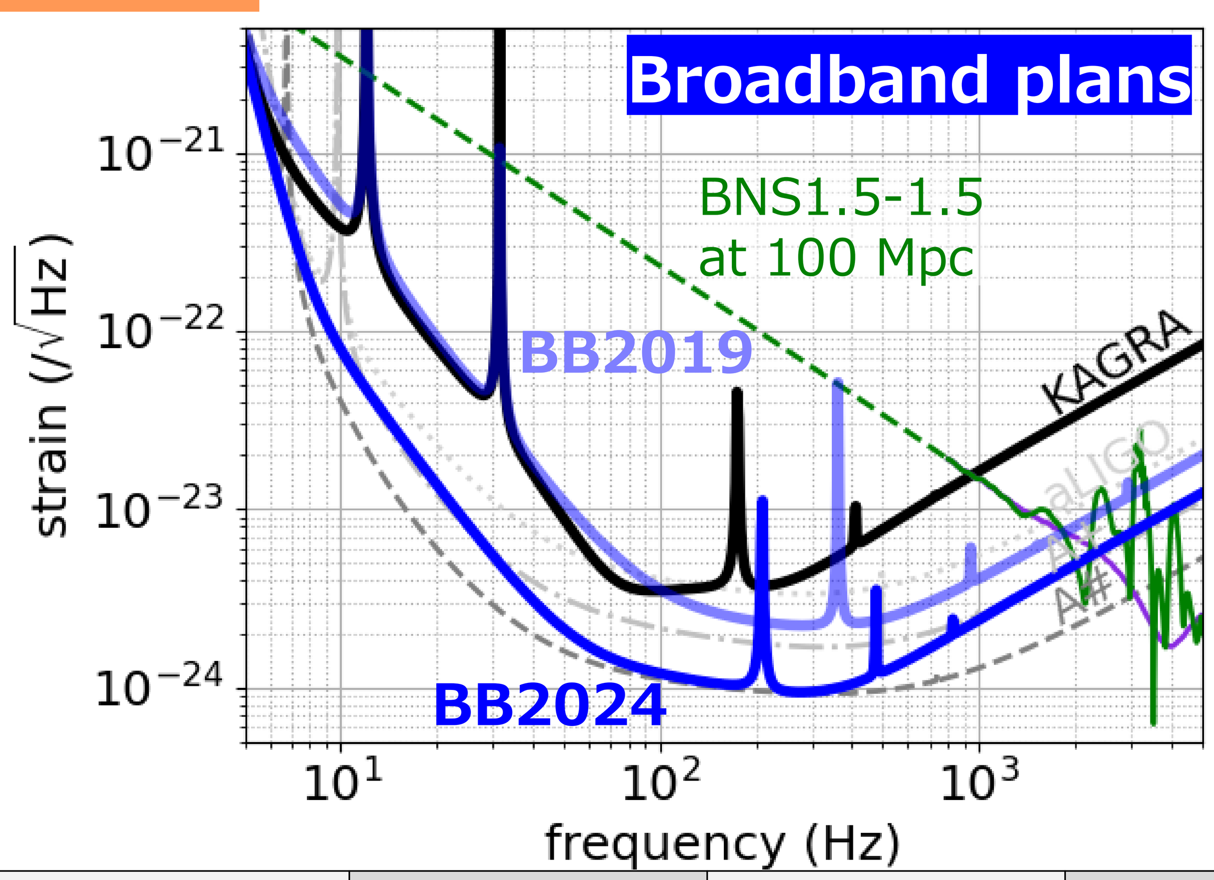

## Design and status of KAGRA

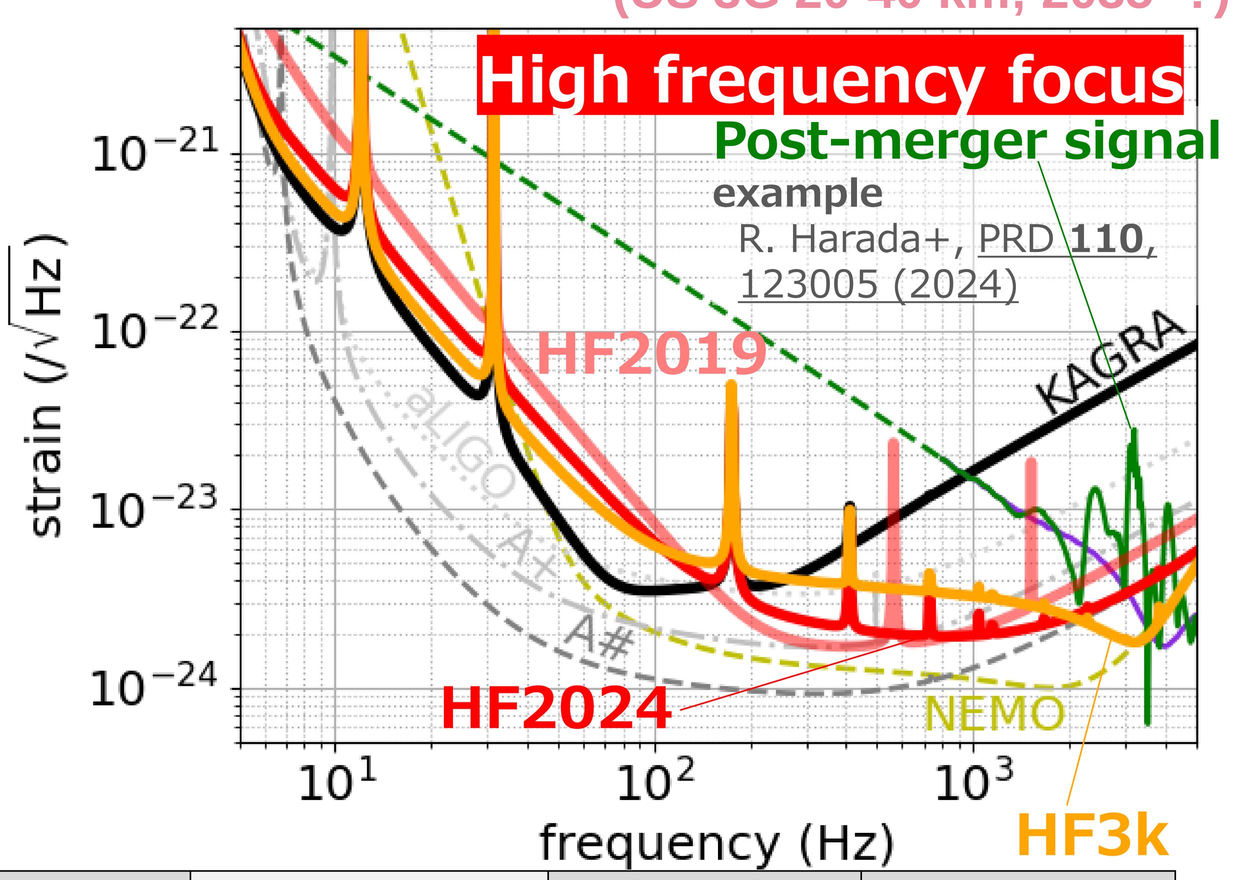


## Possible upgrade plans




Baseline design

Binary Black Holes / Binary Neutron Stars

| | | KAGRA | A# (LIGO O6 upgrade) | LF2019 | LF2024 | BB2019 | BB2024 | HF2019 | HF2024 | HF3k |
|---|---|---|---|---|---|---|---|---|---|---|
| BBH / BNS ranges (SNR>8) | $100M_\odot$ - $100M_\odot$ | 353 Mpc | 4927 Mpc | 2019 Mpc | 3787 Mpc | 306 Mpc | 2154 Mpc | 112 Mpc | 200 Mpc | 277 Mpc |
| | $30M_\odot$ - $30M_\odot$ | 1095 Mpc | 6144 Mpc | 1088 Mpc | 2382 Mpc | 842 Mpc | 4229 Mpc | 270 Mpc | 407 Mpc | 552 Mpc |
| | $1.4M_\odot$ - $1.4M_\odot$ | 153 Mpc | 670 Mpc | 85 Mpc | 196 Mpc | 178 Mpc | 537 Mpc | 155 Mpc | 133 Mpc | 104 Mpc |
| BNS sky localization ※ | | 10.64 deg² (HL-only) → 1.40 deg² (with K) | | 10.28 deg² | 2.65 deg² | 0.77 deg² | 0.42 deg² | 0.57 deg² | 0.61 deg² | 0.93 deg² |
| BNS post-merger signal detection rate (LF & BB plans are less than $10^{-3}$ events/year) Based on merger rate estimate from O3; SNR>5. See H. Tagoshi & S. Morisaki, JGW-P2416311 for details. | | | | | | | | $10^{-5}$-$10^{-3}$ /year | $10^{-3}$-0.06 /year | $10^{-3}$-0.2 /year |
| **Technical challenges** FC = filter cavity SQZ = squeezing SRM = signal recycling mirror | | * Low loss suspension * Sapphire birefringence * 0.35 MW arm power | * 40 kg → 100 kg test mass * 300 m FC, 10 dB SQZ * **1.5 MW arm power** * **1/4 coating thermal** | * Heavier & longer suspensions + for 2024 ver... * **Reducing vertical resonant frequency of blade springs** * 23 kg → 40 kg test mass * **300 m FC w/ 30 ppm loss** * **1/2 absorption** * **Various technical noises at low frequencies** | | * 30 m FC with 30 ppm loss + for 2024 ver... * **Reducing vertical resonant frequency of blade springs** * 23 kg → **100 kg test mass** * 30 m → 85 m FC, 9 dB SQZ * **1.5 MW arm power** * **1/4 coating thermal** * **1/4 absorption** | | * Shorter and thicker sapphire fibers * No FC, 6 dB SQZ * **1.7 MW arm power** * 90.7% SRM | * No FC, 10 dB SQZ * 0.75 MW arm power * **96% SRM** | * **99.5% SRM** |
| | | | | | | | | | * No changes in the suspensions required. Can go to other configurations just by changing the SRM. | |
| **References:** For plans 2019 (~5-year plans), see YM+, PRD **102**, 022008 (2020) For other plans (~10-year plans), see JGW-T2416182 (public document) For various science cases, see KAGRA, PTEP **2021**, 05A103 (2021) | | | | **Which KAGRA upgrade plan do you like?** | | | | | | |

※ Fisher analysis using IMRPhenomD waveform for GW170817-like binary at z=0.03 (127 Mpc) with two A#s and KAGRA. Median of 108 uniformly distributed sets of the source location and the polarization angle is shown.