KAGRA high-frequency upgrade for neutron star physics

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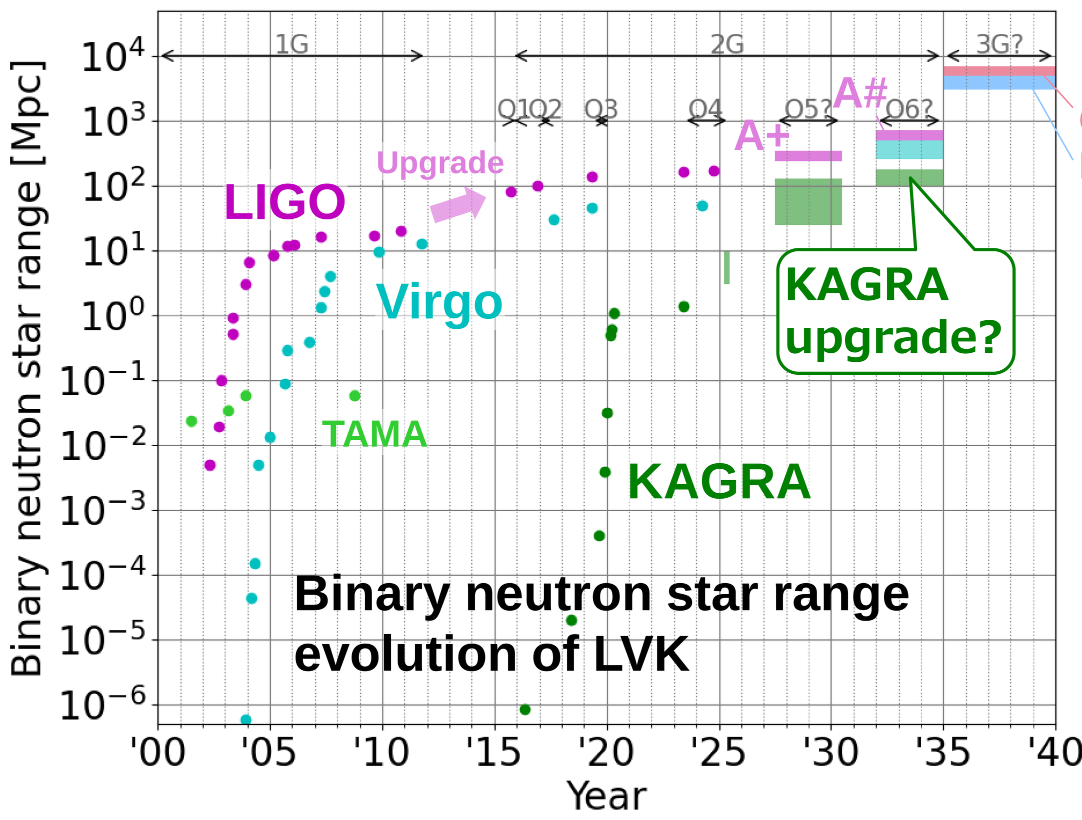
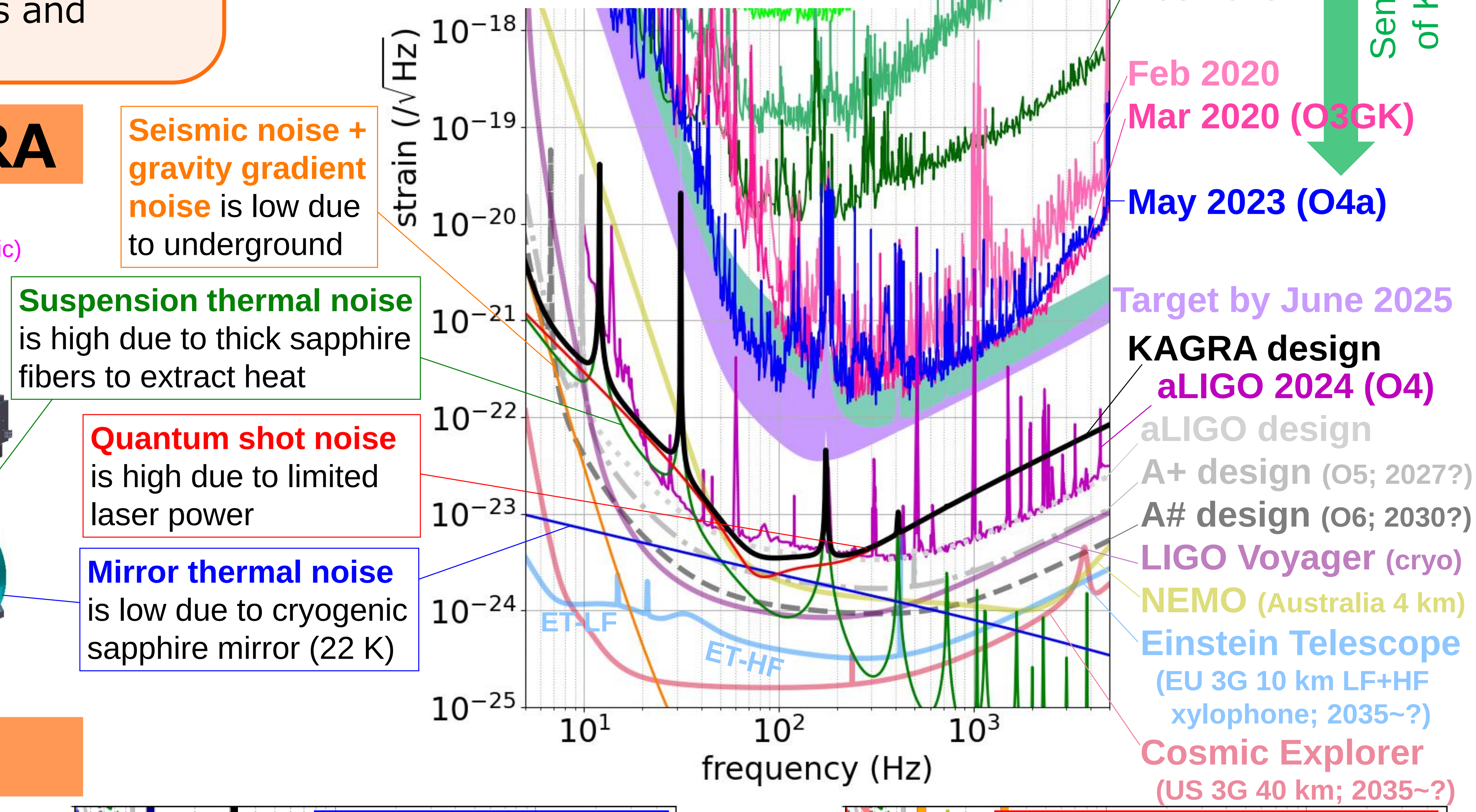
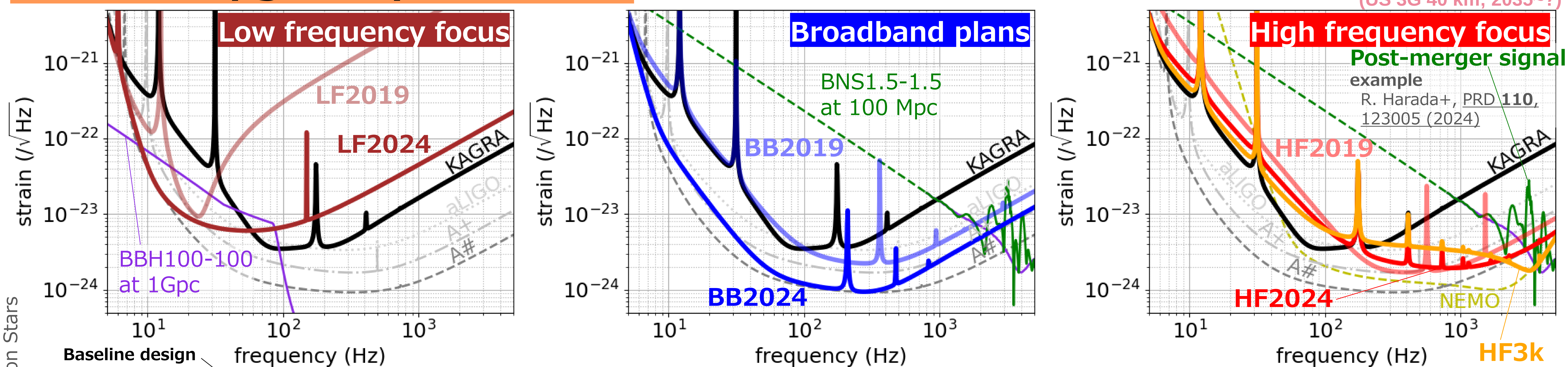
To make multi-messenger observations like GW170817 routine, LIGO and Virgo are planning broadband upgrades, and next-generation projects such as Einstein Telescope and Cosmic Explorer are underway. The world's only cryogenic interferometer, **KAGRA, requires a different upgrade strategy**, as high-frequency 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 deg^2 (HL-only) → 1.40 deg^2 (with K)		10.28 deg^2	2.65 deg^2	0.77 deg^2	0.42 deg^2	0.57 deg^2	0.61 deg^2	0.93 deg^2
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** * No changes in the suspensions required. Can go to other configurations just by changing the SRM.	*** 99.5% 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.