Example sensitivity curves for the KAGRA upgrade

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I. SENSITIVITY DATA IN THE ZIP FILE

In the zip file, there are 5 sensitivity data files for KAGRA:

- bKAGRA.txt: Latest estimated KAGRA sensitivity, DRSE [1]
- KAGRAplusLF.txt: Upgrade plan candidate focused on low frequencies (near term upgrade)
- KAGRAplusHF.txt: Upgrade plan candidate focused on high frequencies (near term upgrade)
- KAGRAplus40kg.txt: Upgrade plan candidate to use heavier mirror to improve mid-frequencies (near term upgrade)
- KAGRAplusFDSQZ.txt: Upgrade plan candidate to inject frequency dependent squeezing (filter cavity) to improve both low and high frequencies (near term upgrade)
- KAGRAplusCombined.txt: Upgrade plan candidate to combine technologies for broadband twofold improvement (longer term upgrade)

For comparison and network calculations, LIGO and Virgo data are also included in the zip file:

- aLIGO.txt: Design sensivity for Advanced LIGO with coating thermal noise update [2]
- Aplus.txt: Design sensitivity for the upgrade of Advanced LIGO, A+ [3]
- AdV.txt: Design sensitivity for Advanced Virgo with recent update to use broadband configuration [4]
- AdVplus.txt: Design sensitivity for the upgrade of Advanced Virgo, phase 2 [4]

The first column in the text file is the frequency in Hz, and the second column is the strain sensitivity in $/\sqrt{\mathrm{Hz}}$. Note that thermal noise peaks in the sensitivities for KAGRA upgrade plans are ommited to generate smooth curves.

II. DETAILS OF THE SENSITIVITY CALCULATION

Details of the sensitivity calculation for KAGRA is described in Ref. [5], and the original MATLAB code for the sensitivity calculation lives in Ref. [1]. Note on the filter cavity calculations live in Ref. [6].

Parameters used for the sensitivity calculations and the sensitivities for bKAGRA and upgrade candidates are summarized in Table I and Fig. 1. Filter cavity parameters are summarized in Table II. Filter cavity length is assumed to be 30 m, considering the space restrictions around signal recycling cavity and OMC chambers for KAGRA.

No coating improvements from bKAGRA design are assumed in the upgrade candidates, but the beam radius at the test masses are proportionally increased with respect to the radius of the test masses, keeping the aspect ratio the same, in 40kg and Combined.

For LF sensitivity, some of the parameters related to suspensions are modified to reduce suspension thermal noise. First, the mass of the intermediate mass is increased from 20.5 kg to 82 kg. Second, the diameter and length of the wire suspending the intermediate mass from the marionette is changed from 0.6 mm dia. 26.1 cm long to 0.2 mm dia. 78.3 cm long. Also, ambient radiation absorbed to the test mass are reduced from 50 mW to 0.3 mW.

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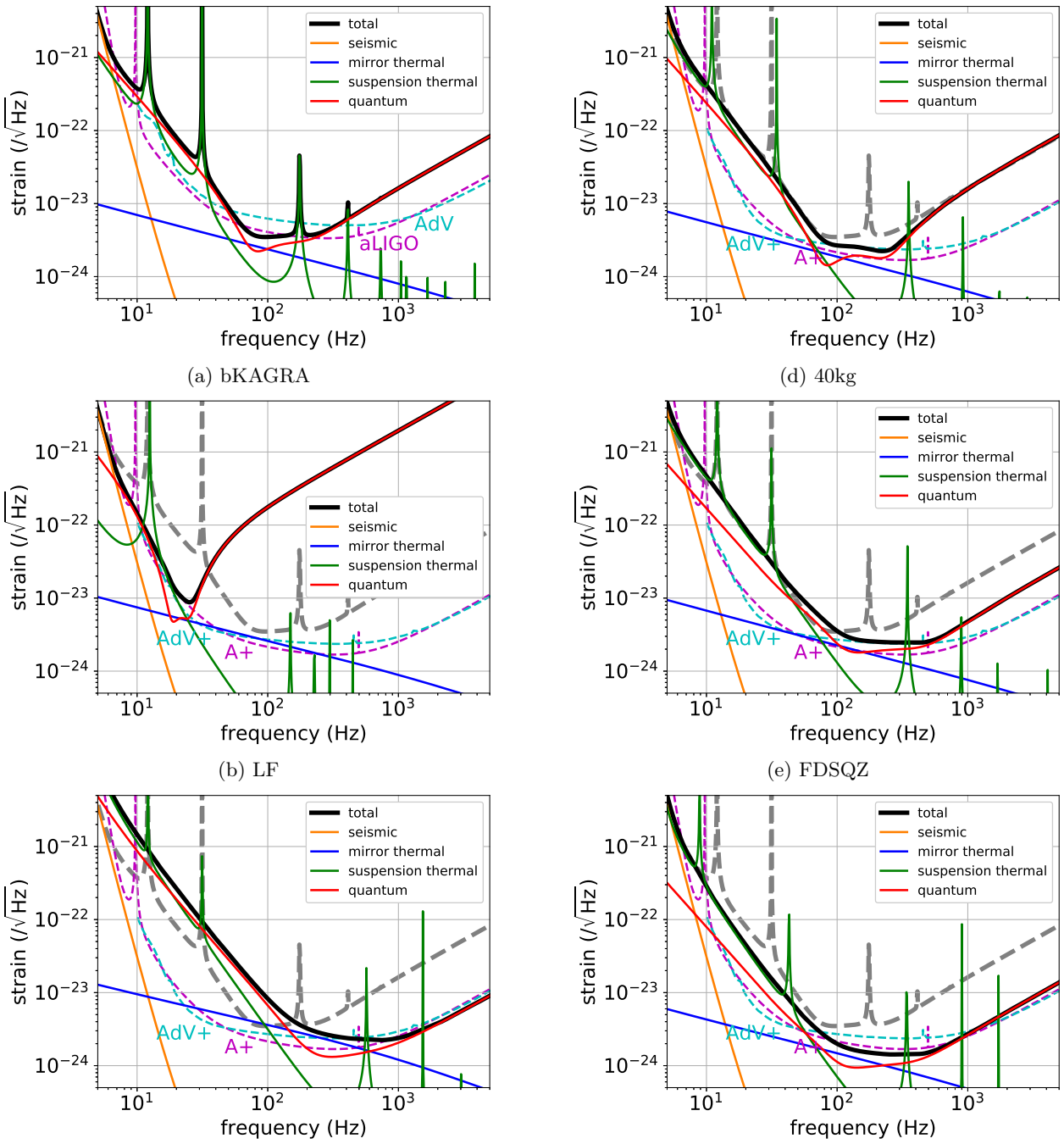
[1] K. Komori, Y. Michimura, and K. Somiya, *Latest estimated sensitivity of KAGRA*, Report No. JGW-T1707038 (2017).
[2] L. Barsotti, S. Gras, M.Evans, and P. Fritschel, *Updated Advanced LIGO sensitivity design curve*, Report No.



(a) bKAGRA (d) 40kg

(b) LF (e) FDSQZ

(c) HF (f) Combined

FIG. 1. Sensitivity curves for bKAGRA and upgrade candidates. Sensitivity curves for Advanced LIGO (aLIGO) and Advanced Virgo (AdV) are also shown for comparison in (a). For other plots, sensitivity curves for their upgrades A+ and AdV+, and bKAGRA are shown for comparison. Note that thermal noise peaks in the sensitivities for KAGRA upgrade plans are ommited to generate smooth curves.

LIGO-T1800044 (2018).
[3] L. Barsotti, L. McCuller, M. Evans, P. Fritschel, *The A+ design curve*, Report No. LIGO-T1800042 (2018).
[4] J. Degallaix (the Virgo Collaboration), *Advanced Virgo+ preliminary studies*, Report No. VIR-0300A-18 (2018).
[5] Y. Michimura, K. Komori, A. Nishizawa, H. Takeda, K. Nagano, Y. Enomoto, K. Hayama, K. Somiya, and M. Ando, Phys. Rev. D 97, 122003 (2018).
[6] Y. Enomoto, *Note on filter cavity part of KAGRA+ sensitivity calculation code*, Report No. JGW-T1808243 (2018).

TABLE I. Interferometer parameter values, inspiral ranges and median of sky localization error for GW17817-like binary for bKAGRA and upgrade candidates. Note that inspiral ranges and sky localization errors for upgrade candidates are calculated with smoothened curves. Details of the inspiral range and sky localization calculations are given in Ref. [5].

		bKAGRA	LF	HF	40kg	FDSQZ	Combined
detuning angle (deg)	$\phi_{\rm det}$	3.5	27.2	0.1	3.5	0.4	0.4
homodyne angle (deg)	ζ	135.1	152.2	95.3	123.7	101.5	100.4
mirror temperature (K)	$T_{\rm m}$	22	24.0	30.0	20.1	20.9	20.1
SRM reflectivity (%)	$R_{\rm SRM}$	84.6	93.1	92.6	92.3	88.4	85.1
fiber length (cm)	$l_{\rm f}$	35.0	100	20.0	25.7	23.5	32.2
fiber diameter (mm)	$d_{\rm f}$	1.6	0.45	2.5	2.3	1.9	3.7
mirror mass (kg)	m	22.8	22.8	22.8	40	22.8	100
input power at BS (W)	I_0	673	5.1	3400	1530	1250	3830
maximum detected squeezing (dB)		0	0	5.5	0	5.3 (FC)	5.3 (FC)
$100M_\odot$-$100M_\odot$ inspiral range (Mpc)		353	**2066**	112	368	336	645
$30M_\odot$-$30M_\odot$ inspiral range (Mpc)		1095	1212	287	1173	836	1629
$1.4M_\odot$-$1.4M_\odot$ inspiral range (Mpc)		**153**	94	122	**201**	**173**	**306**
median sky localization error (deg^2)		0.183	0.486	**0.113**	0.154	0.124	0.095

TABLE II. Filter cavity parameters used for the sensitivity calculation of FDSQZ and Combined sensitivities. Injected squeezing is also 10 dB for HF.

Parameter	Value
filter cavity length	30 m
filter cavity half-bandwidth	$2\pi \times 45$ Hz
filter cavity detuning	$2\pi \times 45$ Hz
filter cavity losses	30 ppm
injection losses	5%
readout losses	5%
injected squeezing	10 dB