Parameters for the latest estimated sensitivity of KAGRA

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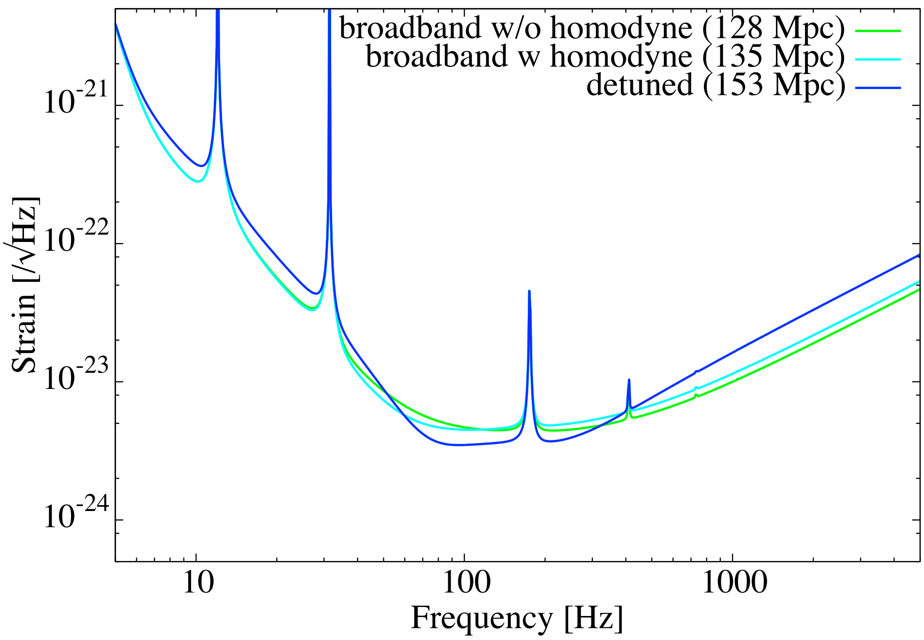

Figure 1: Comparison of KAGRA sensitivity curves with different detune and homodyne phase. These sensitivities are optimized on maximum inspiral range of a binary neutron star merger.

1 Parameters

Item	Parameters
Configuration	VRSE
Baseline length	3 km
Wavelength	1064 nm
Laser power at BS	674 W [i]
Power transmittance of ITM	0.004 [1]
Amplitude reflectivity of SRM	0.92 [1]
Round trip loss of arm	100 ppm [ii]
Power loss at SRM	0.002 [ii]
Power loss at PD	0.1 [ii]
Detune phase	86.5° [iii]
Homodyne Phase (broadband)	119.1° [iii]
Homodyne Phase (detuned)	135.1° [iii]

Table 1: Interferometer parameters reviewed by MIF chief Y. Michimura.

Item	Parameters
Material	Sapphire
Radius	11 cm
Thickness	15 cm
Mass	22.8 kg [iv]
Temperature	22 K [i]
Loss angle	1.0×10^{-8} [2]
Absorption	50 ppm/cm [3]

Table 2: Parameters of the mirror reviewed by MIR chief E. Hirose.

[i] see section2.
[ii] requirement.
[iii] BNS inspiral range optimized.
[iv] reported by E. Hirose, based on CAD drawing, including the mass of the ears.
[v] reported by E. Hirose.
[vi] measured to be 0.35 ppm by LMA.
[vii] reported by A. Hagiwara, based on CAD drawing. Actual mass of IM could vary depending on the masses of the parts.
[viii] requirement. Measured to be 2e-7 with bulk [6], 1e-5 with 20um wire [7].
[ix] reported by K. Yamamoto.
[x] reported by T. Ushiba
[xi] requirement calculated by [9]
[xii] reported by T. Ushiba based on CAD drawing.

Item	Parameters
Material	silica/tantala
Numbers of coating layers	22/40 (ITM/ETM) [v]
Loss angle of silica	3.0×10^{-4} [4, 5]
Loss angle of tantala	5.0×10^{-4} [4, 5]
Beam Radius	3.5 cm [1]
Absorption	0.5 ppm [vi]

Table 3: Parameters of the coating reviewed by MIR chief E. Hirose.

Item	Parameters
IM suspension	
Material	CuBe
Number	4
Length	26.1 cm [vii]
Diameter	0.6 mm [vii]
Loss angle	5×10^{-6} [viii]
IM mass	20.5 kg [vii]
Temperature	16 K [ix]
Blade spring	
Material	Sapphire
Number	4
Horizontal res. freq.	2 kHz [x]
Vertical res. freq.	14.5 Hz (with TM) [8]
Loss angle	7×10^{-7} [xi]
Mass	55 g [xii]
Temperature	16 K [ix]
TM suspension	
Material	Sapphire
Number	4
Length	35 cm [vii]
Diameter	1.6 mm [vii]
Loss angle	2×10^{-7} [9]
Temperature	19 K (average of 16 K and 22 K)
Vertical-Horizontal Coupling	1/200

Table 4: Parameters of the suspension reviewed by CRY group K. yamamoto and T. Tomaru.

2 Process to decide power and mirror temperature

In this section we describe how to set laser power and mirror temperature. Laser power and mirror temperature are in one-to-one correspondence via the mirror absorption. Firstly, the sensitivity of DRSE configuration is optimized with changing homodyne and detune angle, and mirror temperature. The best temperature is 22 K, and then corresponding laser power at BS is calculated to be 674 W to keep the mirror temperature 22 K. In broadband configuration without homodyne detection, the best sensitivity in terms of inspiral range of a binary neutron star merger, 131 Mpc, can be reached at the power of 1250 W and the temperature of 25 K. However, power over 1 kW at BS is too high and 128 Mpc can be realized even at 674 W and 22 K. Therefore, we decided to fix the power and temperature. The relationship between laser power and mirror temperature is derived as follows.

Heat flow of fibers in steady state is the same as energy absorbed by a suspended mass,

$$K_{\mathrm{abs}} = N_f \int_{T_u}^{T_l} \frac{S_f \kappa(T)}{l_f} dT, \tag{1}$$

where K_{abs} is the absorbed energy, N_f is the number of fibers, T_u (T_l) is the temperature of an upper (lower) end, S_f is the area, l_f is the length, and $\kappa(T)$ is the thermal conductivity of the fiber. A marionette of the suspension system is connected to a platform by a thick heat link and the CuBe fibers have high thermal conductivity. Therefore, temperature of the IM, CuBe fibers and the marionette can be cooled down to $T_u = 16$ K. Here we decide that the test mass temperature is $T_l = 22$ K. $\kappa(T)$ is measured by Sascha to be [10]

$$\kappa(T) = 7.98 \times T^{2.2}. \tag{2}$$

Substituting $N_f = 4$, $l_f = 0.35$ m, and $S_f = \pi(1.6 \times 10^{-3}/2)^2$ m^2, total heat flow is calculated as $K_{\mathrm{abs}} = 0.724$ W.

The absorbed energy can be divided to that from sapphire substrate, coating, and radiation from outside,

$$K_{\mathrm{abs}} = 2\beta_{\mathrm{sub}} t_m P_{\mathrm{mich}} + \gamma_{\mathrm{coa}} P_{\mathrm{circ}} + K_{\mathrm{rad}}, \tag{3}$$

where β_{sub} is the absorption rate of the substrate, t_m is the mirror thickness, P_{mich} is the power between BS and ITM, γ_{coa} is the absorption of the coating, P_{circ} is the intra-cavity power of the main arm, and K_{rad} is the radiation energy from outside. β_{sub} is measured to be 30 ppm/cm [3], but that value has a large error and the requirement was 50 ppm/cm. We assumed the absorption rate of 80 ppm/cm before 2016, but here $\beta_{\mathrm{sub}} = 50$ ppm/cm is assumed because it is likely to meet the requirement. $t_m = 15$ cm is designed and $\gamma_{\rm coa} = 0.5$ ppm is assumed. Transmittance of ITM is designed to be $T_{\rm ITM} = 0.004$, so the intra-cavity power is $P_{\rm circ} = 4P_{\rm mich}/T_{\rm ITM} = 10^3 P_{\rm mich}$. Radiation from an opened window for beam is dominant in that from outside and estimated to be $K_{\rm rad} = 50$ mW [11]. With these parameters laser power between BS and ITM can be increased to be $P_{\rm mich} = 337$ W in order to keep the mirror temperature of 22 K. Therefore the maximum laser power at BS is twice than that, $P_{\rm BS} = 674$ W.

References

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