Detectability of CBC GW events with KAGRA at O4

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Motivation

- Toward the 4th observing run of the international GW detectors' network (O4), KAGRA sensitivity is being improved.
- In O4 period, compact binary coalescence (CBC) events are expected to be the main sources of gravitational waves as in previous observing runs.
- In this work, we aim to investigate how many CBC events are observable at the sensitivity of KAGRA in O4 period.

Detector sensitivity in O4

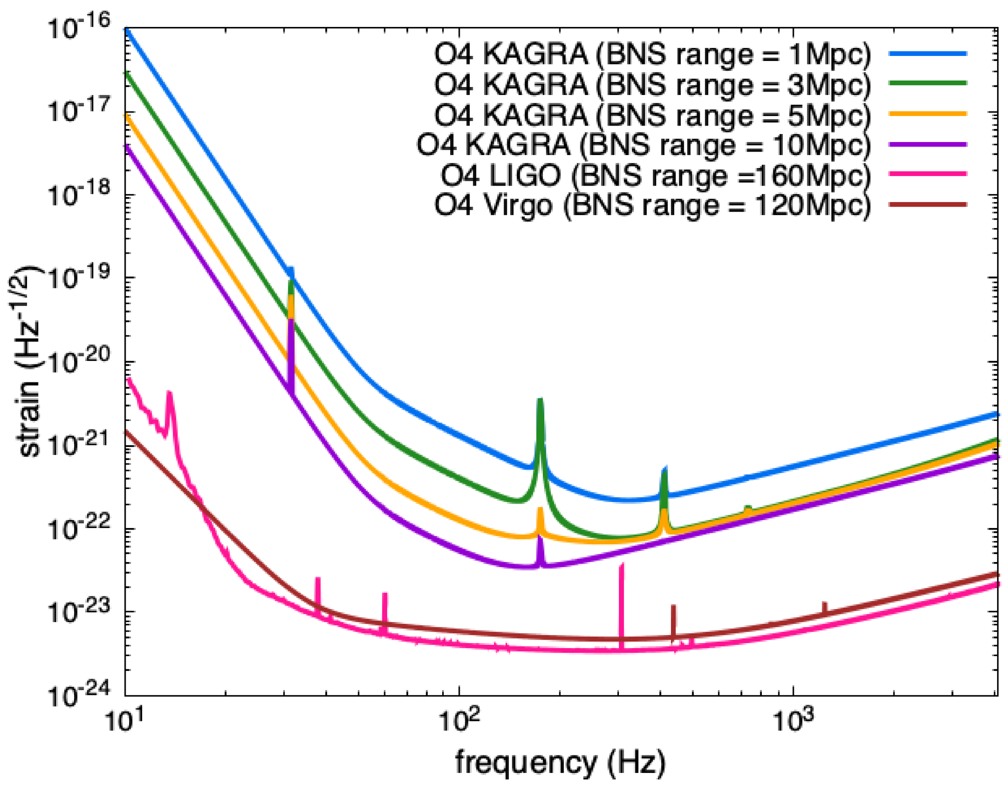

Fig. 1: O4 sensitivity curves[1][2]

We considered 4 different sensitivity curves for O4 KAGRA. All curves are characterized by BNS range, which is the distance at which they are sensitive to binary neutron stars.

Signal-to-noise ratio (SNR)

For a given gravitational waveform h and a detector sensitivity curve S_n, SNR is written as

$$\rho = \left(4\int df \frac{|\tilde{h}(f)|^2}{S_n(f)}\right)^{1/2}.$$

Simulating astrophysical signals

For binary parameters, we generated random samples so that

- Source-frame mass $m_{1,2}$: power-law in $[3, 100]M_\odot$
- Spin magnitude $\chi_{1,2}$: uniform in $[-0.99, 0.99]$
- Luminosity distance D_L : comoving-flat ($D_L \leq 7$Gpc)
- Sky location, binary inclination, polarization : isotropic

Gravitational waveforms were computed at the values of these samples. We then extracted the samples that could be found in LIGO-Virgo network, satisfying the condition that network SNR $\rho_{HLV} = \sqrt{\sum_{\{H,L,V\}} \rho_i^2} \geq 10$. For those chosen samples, we check the SNR values at KAGRA sensitivity.

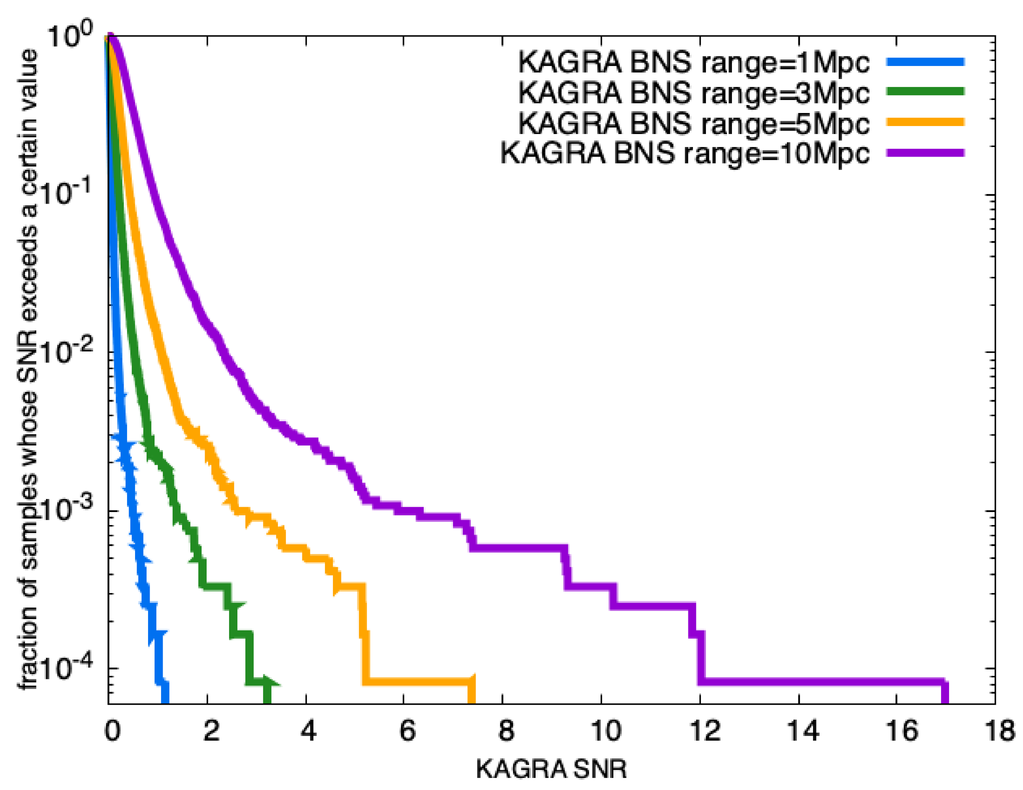

Fig. 2: Fraction of samples whose SNR values exceed a certain threshold at KAGRA. Note that this fraction is relative to the samples that met the above condition.

Rough estimate of detectability

In the last observing run, HLV network detected 34 BBH events over 5 months[3]. Taking into account the improvement of detector sensitivity, we assumed that the number of events that HLV will detect in the 3 months that KAGRA is planned to join in O4 is roughly 37.
We then estimated how many events found in LIGO-Virgo network could also be found in KAGRA.

	SNR>1	SNR>2	SNR>3	SNR>4
BNS range = 1Mpc	6.1×10^{-3}	-	-	-
" 3Mpc	8.0×10^{-2}	1.2×10^{-2}	3.1×10^{-3}	-
" 5Mpc	0.47	9.5×10^{-2}	3.4×10^{-2}	2.1×10^{-2}
" 10Mpc	3.2	0.56	0.18	0.10

Table 1: Rough estimate of the number of detections in O4 KAGRA

Use of previous event data

We did another test using the 91 events observed in previous observing runs[3]. Since the samples of parameter estimations are available, we computed SNR in KAGRA sensitivity at all of the samples for each event.

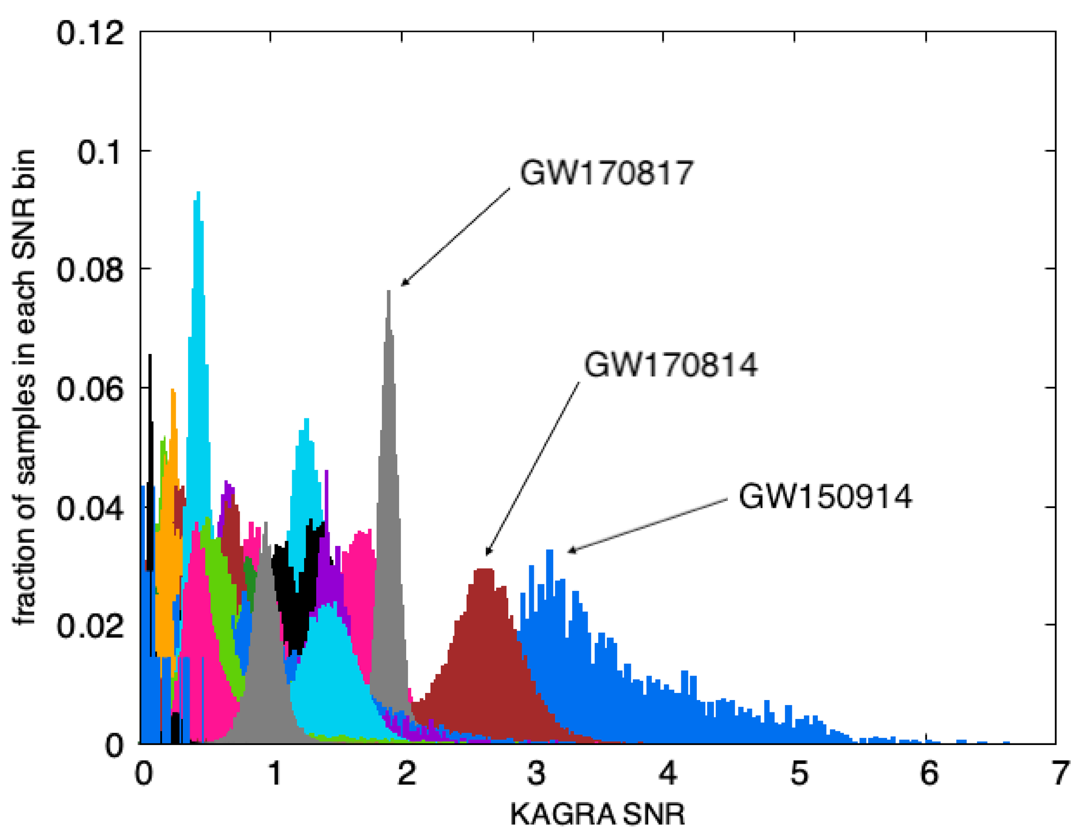

Fig. 3: SNR distributions for parameter estimation samples of 91 GWTC-3 events (KAGRA BNS range=10Mpc). Each mountain corresponds to one event. The hem spread of the distributions reflects the estimation error of parameters.

For each event, we can compute a fraction of samples whose SNR exceeds a certain threshold. Then the sum of those fractions for all events corresponds to an expected total number of detections.

	SNR>1	SNR>2	SNR>3	SNR>4
BNS range = 1Mpc	-	-	-	-
" 3Mpc	0.14	-	-	-
" 5Mpc	2.2	0.16	3.0×10^{-4}	-
" 10Mpc	12	2.5	0.90	0.25

Table 2: Expected number of detections in O4 KAGRA estimated from GWTC-3 event data

Conclusion

- The expectation of detecting events with sufficiently large SNRs in O4 KAGRA is low.
- Fortunate events such as GW150914 may be detected if KAGRA achieves 10Mpc in BNS range.

References

[1] Y. Michimura. KAGRA Document No. JGW-T2113529-v3, 2021.

[2] B. O'Reilly et al. LIGO Document No. T2000012-v2, 2022.

[3] R. Abbott et al. GWTC-3: Compact Binary Coalescences Observed by LIGO and Virgo During the Second Part of the Third Observing Run. arXiv:2111.03606, 2021. (LIGO-Virgo-KAGRA Collaboration).