Advanced LIGO, Advanced Virgo and KAGRA observing run plans

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Abstract

To facilitate proposals by astronomers for observing time we present our current best estimate of the plausible observing scenarios for the Advanced LIGO, Advanced Virgo and KAGRA gravitational-wave detectors over the next several years. We show the sensitivity prospects for the third (O3), fourth (O4) and fifth observing (O5) runs. We present the target strain sensitivities as a function of frequency for Advanced LIGO, Advanced Virgo and KAGRA, including the planned upgrades of the Advanced LIGO and Advanced Virgo detectors, and the achievable range for binary neutron star, neutron star–black hole, binary black hole, and unmodeled signals. We show the planned observing timeline and sensitivity evolution of the detectors. The updated version of the more complete "Prospects for Observing and Localizing Gravitational-Wave Transients with Advanced LIGO and Advanced Virgo"(Abbott et al, 2018) is a work in progress, and will include estimates of the network's ability to localize gravitational-wave transient signals (as sky-localization probability area, distance and volume), and to detect binary neutron star, neutron star–black hole, and binary black hole systems (as number of detections per calendar year of running).

1 Introduction

The fourth updated version of the "Prospects for Observing and Localizing Gravitational-Wave Transients with Advanced LIGO and Advanced Virgo"(Abbott et al, 2018) is currently a work in progress. It will describe the schedule, sensitivity, sky-localization accuracy, and expected number of detections for the gravitational-wave (GW)-detector network. We will discuss the past and future planned sequence of observing runs and the prospects for multi-messenger astronomy. Here, we present the achieved sensitivity curves during O1, O2, and the first two months of observations of O3 for Advanced LIGO (aLIGO) and Advanced Virgo (AdV). We also include KAGRA, which is expected to join the network for the final months of O3. We present the projected sensitivity curves of the four detectors for O4 and O5, including the upgrade of AdV and aLIGO, called AdV+ and aLIGO+. We estimate the sensitivity of the detectors during the next observing runs for binary neutron star (BNS), binary black hole (BBH), neutron star–black hole (NSBH), and unmodeled burst signals. We present the envisioned observing schedule and sensitivity evolution for the next decade. Throughout the summary we assume a flat cosmology with Hubble parameter $H_0 = 67.9\text{kms}^{-1}\text{Mpc}^{-1}$, and density parameters $\Omega_m = 0.3065$ and $\Omega_\Lambda = 0.6935$ (Ade et al, 2016).

2 Summary

2.1 Envisioned Network Sensitivity

As a standard figure of merit for detector sensitivity, we use the range, R, evaluated for compact binary coalescence (CBC) consisting of representative masses. We define V as the orientation-averaged spacetime volume surveyed per unit detector time, assuming a matched-filter detection signal-to-noise ratio (SNR) threshold of 8 in a single detector. The volume V corresponds to the comoving volume with the addition of a $(1+z)$ factor to account for time dilation (redshifted volume V_z in Chen et al, 2017). For a population with a constant comoving source-frame rate density, V multiplied by the rate density gives the detection rate of those sources by the particular detector. The range R is obtained as $(4\pi/3)R^3 = V$.

For unmodeled short-duration ($\lesssim 1$ s) signals or bursts, we evaluate an approximate sensitive luminosity distance determined by the total energy $E_{\rm GW}$ emitted in GWs, the central frequency f_0 of the burst, the detector noise power spectral density $S(f_0)$, and the single-detector SNR threshold $\rho_{\rm det}$ (Sutton, 2013):

$$D \simeq \left(\frac{G}{2\pi^2 c^3} \frac{E_{\rm GW}}{S(f_0) f_0^2 \rho_{\rm det}^2} \right)^{1/2} . \quad (1)$$

This distance is then corrected by the time dilation cosmology factor to obtain the surveyed volume V, and the range R. For further insight into the range, and a discussion of additional quantities such as the median and average distances to sources, see (Chen et al, 2017).

The anticipated strain sensitivity evolution for aLIGO, AdV and KAGRA is shown in Fig. 1. In Table 1 we present values of the range for different detector networks and GW sources. Fig. 1 and Table 1 include upgrading of the existing LIGO and Virgo instruments, which will enable an increase of their range with respect to the Advanced detector design sensitivity. Details on the technological upgrade will be summarized in the in the updated version of Abbott et al (2018).

Commissioning is a complex process which involves both scheduled improvements to the detectors and tackling unexpected new problems. It is not possible for us to make exact predictions for sensitivity as a function of time, and here, we present our best expectations for the sensitivity evolution.

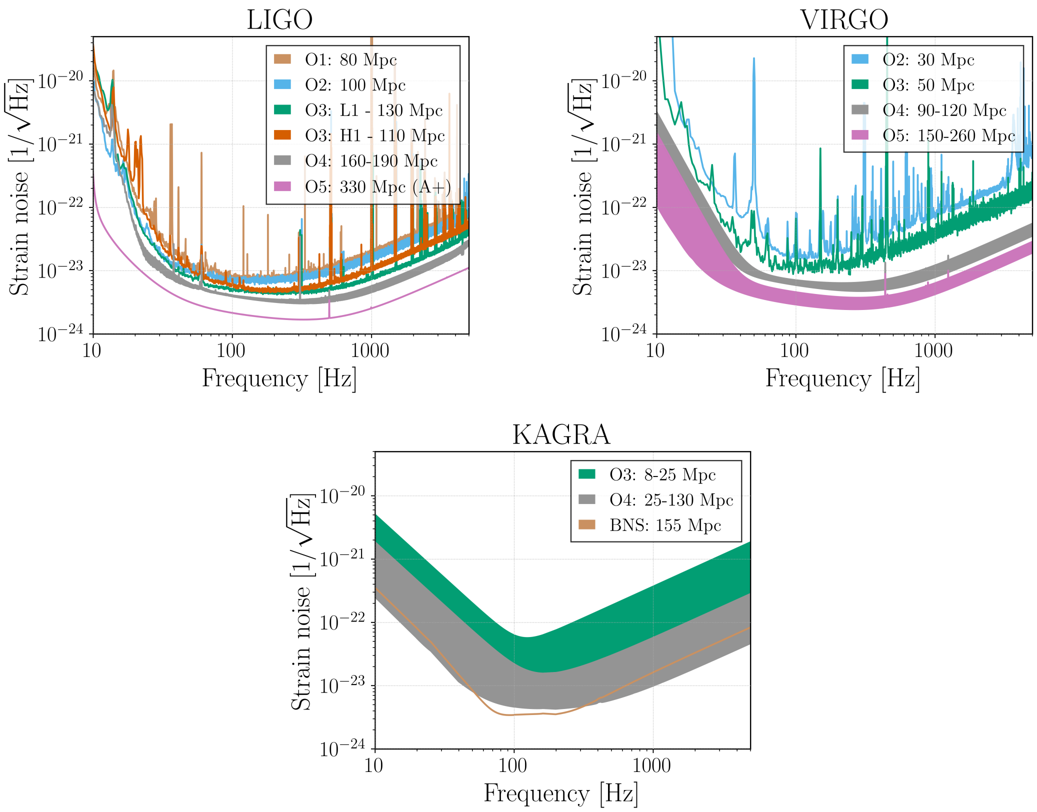

Figure 1: aLIGO (*top left*), AdV (*top right*) and KAGRA (*bottom*) target strain sensitivities as a function of frequency. The quoted range is for a $1.4M_{\odot}$+$1.4M_{\odot}$ BNS merger. The BNS range (in megaparsec) achieved in past observation runs and anticipated for future runs is shown. The O1 LIGO curve is taken from the Hanford detector, the O2 LIGO curve comes from Livingston. In each case these had the better performance for that observing run. The O3 curves for aLIGO and AdV reflect recent performance of the detectors. For some detectors and runs, the anticipated ranges are shown as bands reflecting the uncertainty in the impact of improvements and upgrades to the overall sensitivity. Detailed planning for the post-O3 to O4 period is now in progress and may result in changes to both target sensitivities for O4 and the start date for this run. The KAGRA BNS curve may be realized by detuning the signal recycling cavity to significantly improve the BNS range to 155 Mpc once design sensitivity is reached.

Table 1: Achieved and projected detector sensitivities for a $1.4M_{\odot}$+$1.4M_{\odot}$ BNS system, a $30M_{\odot}$+$30M_{\odot}$ BBH system, a $1.4M_{\odot}$+$10M_{\odot}$ NSBH system, and for an unmodeled burst signal. The quoted ranges for compact binary systems correspond to the orientation-averaged spacetime volumes surveyed per unit detector time. For the burst ranges we assume a standard-candle emission of $E_{\mathrm{GW}} = 10^{-2} M_{\odot} c^2$ in GWs at 140 Hz. Both CBC and burst ranges are obtained using a single-detector SNR threshold of 8. The O1 and O2 numbers are representative of the best ranges for the LIGO detectors: Hanford in O1 and Livingston in O2. The O3 numbers for aLIGO and AdV reflect recent average performance of each of the three detectors. Range intervals are quoted for future observing runs due to uncertainty about the sequence and impact of upgrades.

		O1	O2	O3	O4	O5
BNS Range (Mpc)	aLIGO	80	100	110 – 130	160 – 190	330
	AdV	–	30	50	90 – 120	150 – 260
	KAGRA	–	–	8 – 25	25 – 130	130+
BBH Range (Mpc)	aLIGO	740	910	990 – 1200	1400 – 1600	2500
	AdV	-	270	500	860 – 1100	1300 – 2100
	KAGRA	-	-	80 – 260	260 – 1200	1200+
NSBH Range (Mpc)	aLIGO	140	180	190 – 240	300 – 330	590
	AdV	-	50	90	170 – 220	270 – 480
	KAGRA	-	-	15 – 45	45 – 290	290+
Burst Range (Mpc)	aLIGO	50	60	80 – 90	110 – 120	210
	AdV	-	25	35	65 – 80	100 – 155
	KAGRA	-	-	5 – 25	25 – 95	95+

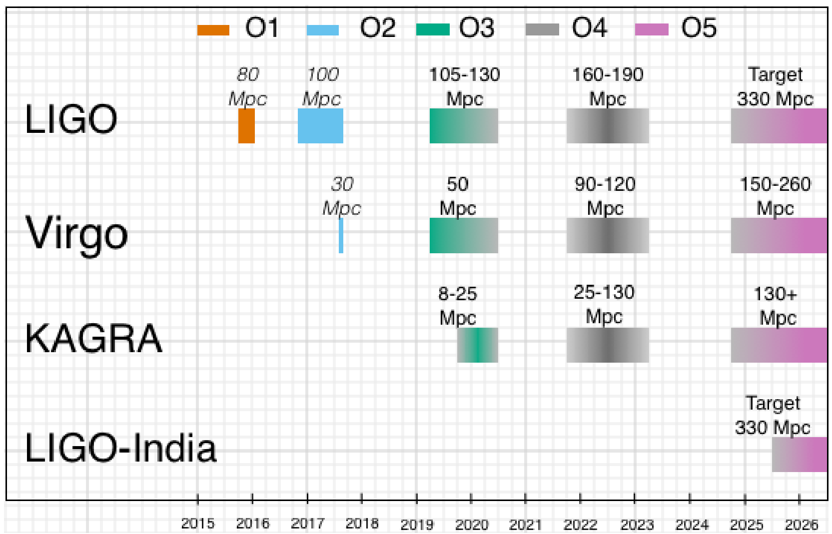

Figure 2: The planned sensitivity evolution and observing runs of the aLIGO, AdV and KAGRA detectors over the coming years. The colored bars show the observing runs, with achieved sensitivities in O1 and in O2, and the expected sensitivities given by the data in Fig. 1 for future runs. There is significant uncertainty in the start and end times of the planned observing runs, especially for those further in the future, and these could move forward or backwards relative to what is shown above. Uncertainty in start or finish dates is represented by shading. We do anticipate that the break between O3 and O4 will last at least 18 months. Any extension of O3 would lead to a corresponding delay in the start of O4. O3 will finish by June 30 2020 at the latest. A commissioning break for the LIGO and Virgo observatories is scheduled to begin October 1, 2019 at 1500 UTC (0800 Pacific Time). The break is planned for one month, and the end date for O3 is now planned to be April 30, 2020. The O4 run is expected to last for one calendar year. We indicate a range of potential sensitivities for aLIGO during O4 depending on which upgrades and improvements are made after O3. The most significant driver of the aLIGO range in O4 is from frequency-dependent squeezing, which may or may not be implemented for this run.

2.2 Envisioned Observing Schedule

The following presents plausible scenarios for the operation of the ground-based GW detector network and their expected BNS ranges over the next decade:

2019 – 2020 (O3): A year-long run (started April 1st, 2019) with the aLIGO detectors currently at 110 – 130 Mpc and AdV at 50 Mpc, joined by KAGRA for the final months at 8 – 25 Mpc. A commissioning break for the LIGO Hanford and Livingston Observatories, and Virgo is scheduled to begin October 1, 2019 at 1500 UTC (0800 Pacific Time). The break is planned for one month. To preserve the 12 month O3 observing period, the end date for O3 is now planned to be April 30, 2020. Possible extensions of the run will be limited so that O3 will end by June 30, 2020 at the latest.

2021/2022 – 2022/2023 (O4): Four-detector network with the two aLIGO instruments at 160 – 190 Mpc; Phase 1 of AdV+ at 90 – 120 Mpc and KAGRA at 25 – 130 Mpc. The projected sensitivities and precise dates of this run are now being actively planned and remain fluid.

2024/2025 – 2026 (O5): O5 will begin with a four-detector network incorporating the A+ upgrade for the aLIGO instruments and the AdV+ Phase 2 upgrade for Virgo. The target range for aLIGO is 330 Mpc and for AdV it is 150 – 260 Mpc. KAGRA will operate at or above its O4 sensitivity of 25 – 130 Mpc.

2025+ : With the addition of an upgraded aLIGO interferometer in India we will have a five-detector network: three aLIGO detectors with a design sensitivity of 330 Mpc, AdV at 150 – 260 Mpc and KAGRA at 130+ Mpc.

This timeline is summarized in Figure 2. Detailed planning for the post-O3 period is in progress and may result in significant changes to both target sensitivities and uncertainty in the start and end times of the planned observing runs, especially for those further in the future. The observational implications of the above detector operation scenarios will be discussed in the update to Abbott et al (2018). Later versions of this document will appear whenever a change in the observing plans is introduced.

References

Abbott BP, et al (2018) Prospects for Observing and Localizing Gravitational-Wave Transients with Advanced LIGO, Advanced Virgo and KAGRA. Living Rev Rel 21(1):3, DOI 10.1007/s41114-018-0012-9,10.1007/lrr-2016-1. arXiv:1304.0670

Ade PAR, et al (2016) Planck 2015 results. XIII. Cosmological parameters. Astron Astrophys 594:A13, DOI 10.1051/0004-6361/201525830. arXiv:1502.01589

Chen HY, Holz DE, Miller J, Evans M, Vitale S, Creighton J (2017) Distance measures in gravitational-wave astrophysics and cosmology. arXiv:1709.08079

Sutton P (2013) A rule of thumb for the detectability of gravitational-wave bursts. arXiv:1304.0210