Astronomy & Astrophysics manuscript no. AA_letter
June 21, 2018

Forecasting Gamma-Ray Bursts with Gravitational-wave Detectors

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June 21, 2018

ABSTRACT

The detection of gravitational waves from the binary neutron star inspiral-merger event GW170817 and the subsequent extended electromagnetic follow-up observations of the resulting kilonova gave us a small taste of multi-messenger astronomy across the spectra of *two* fundamentally different kinds of radiation. The opportunities to conduct such multi-disciplinary study will increase by two orders of magnitude in the 2030s with Einstein Telescope, LIGO's European successor. Due to its extreme sensitivity in the $1-10$ Hz regime, the Einstein Telescope's C configuration (ET-C) will be capable of detecting inspiralling binary neutron star systems out to luminosity distances of 1 Gpc. For inspirals within half of this distance ET-C will accumulate signal-to-noise ratios of $\gtrsim 15$ with more than an hour left to merger. However, the localization of ET alone is rather poor: within $z = 0.1$ we expect to have ~ 5 BNSs to be localized to $\Delta\Omega \lesssim 10\,\mathrm{deg}^2$. On the other hand, a second GW detector with just ten times KAGRA sensitivity at 5 Hz would increase the number of well-localized sources to $O(100)$. Thus it is imperative to have at least one companion detector to ET with significantly improved seismic isolation in the 2030s. Having numerous GW sources localized to $\sim 10\,\mathrm{deg}^2$ opens the possibility of doing detailed follow-up observations of the resulting kilonovae with ATHENA, LSST, BlackGEM ... Here we explore this intriguing possibility... Thus, this letter is an appeal/plea(?) to the astronomy community to have in place ...

Key words. gravitational waves –gamma-ray bursts – kilonovae

1. Introduction

2. Einstein Telescope

Table 1. Horizon distances of ET-B and ET-C assuming $T_{\mathrm{AW}} = 1$ hour. $R(D_H)$ is the BNS merger rate within a volume of D_H^3 obtained by rescaling the rate inferred from Advanced LIGO's O1, O2 observing periods citeGW170817. $\bar{\rho}_F(D_H)$ is the total SNR accumulated due to a BNS inspiralling at D_H [see Eq. ()].

	ET-B	ET-C
D_H	87 Mpc	613 Mpc
$R(D_H)$	$1^{+2}_{-1}\,\mathrm{yr}^{-1}$	$355^{+730}_{-280}\,\mathrm{yr}^{-1}$
$\bar{\rho}_F(D_H)$	420	58

Acknowledgements. SA thanks

Table 2. Forecasting capabilities of Einstein Telescope summarized. ET-B and ET-C refer to the different configurations shown in Fig. . For the advance warning times, we only present the result of the more accurate 3.5PN computation. $\bar{f}_{\rm ET}$ is the threshold frequency at which ET-B/C accumulate SNR of 15 which we take to be our detection criterion. Note that both $T_{\rm AW}$ and $\bar{\rho}_F$ are larger for ET-C due to its improved sensitivity in the $1\,{\rm Hz} \lesssim f \lesssim 30\,{\rm Hz}$ regime compared to ET-B as is clear in Fig. . These results and those of Table. are summarized in Fig.

D (Mpc)	ET-B			ET-C		
	$\bar{f}_{\rm ET}$ (Hz)	$T_{\rm AW}$	$\bar{\rho}_F$	$\bar{f}_{\rm ET}$ (Hz)	$T_{\rm AW}$	$\bar{\rho}_F$
100	≈ 6.72	47.0 minutes	306	≈ 3.27	5.34 hours	365
200	≈ 11.2	11.6 minutes	152	≈ 4.10	2.87 hours	182
400	≈ 18.2	3.00 minutes	75.7	≈ 5.06	1.51 hours	90.5
1000	≈ 41.3	17.2 seconds	29.8	≈ 6.76	35.6 minutes	35.6

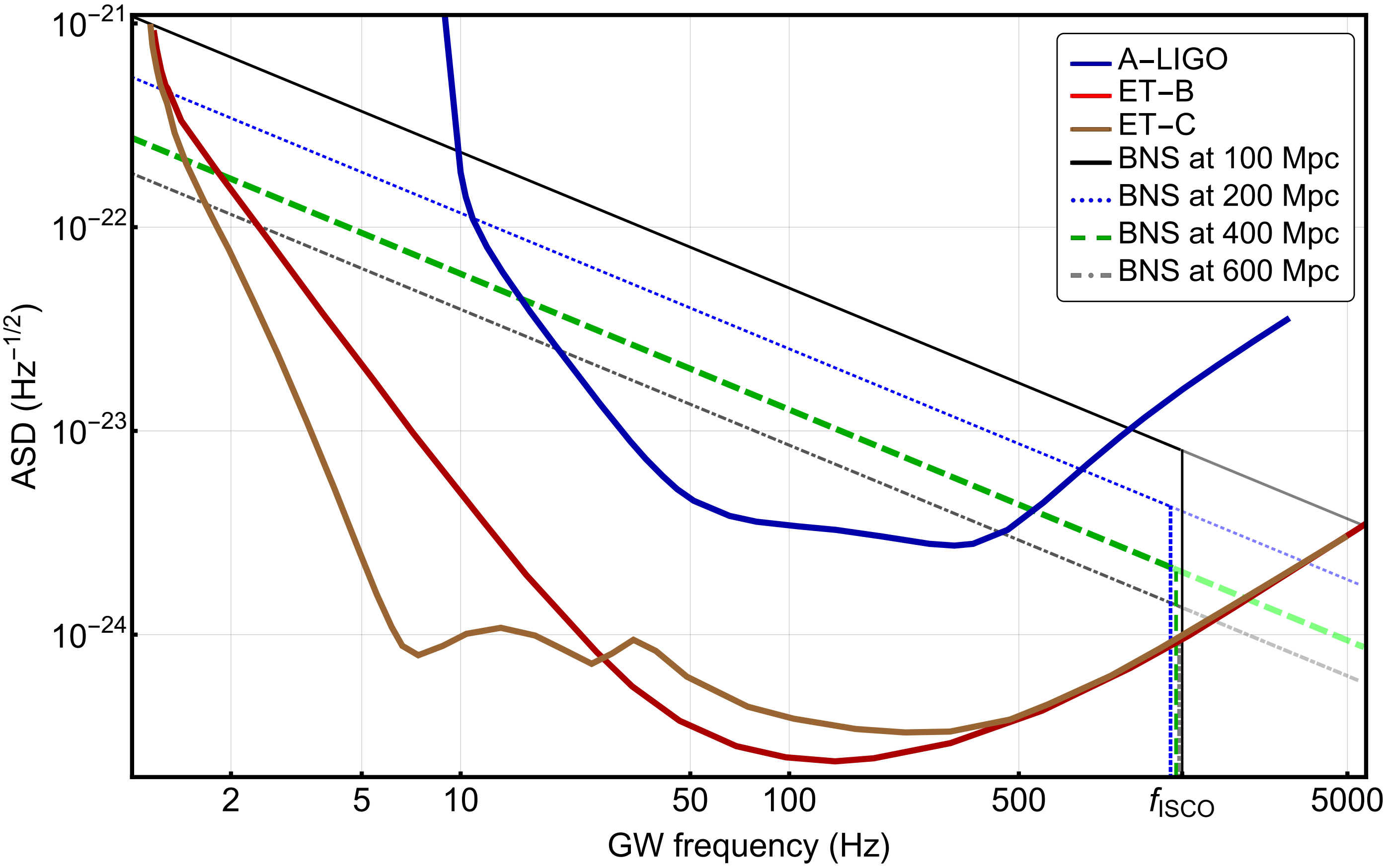

Fig. 1. Typical GW sources that may be harbingers of GRBs in the 2030s: $1.4M_\odot - 1.4M_\odot$ inspiralling BNS systems sweeping across the Einstein Telescope's sensitivity band for both B and C configurations. The solid (black), dotted (blue), dashed (green), and dot-dashed lines (gray) lines are the redshift-corrected RMS-averaged strains, $2\sqrt{f}\tilde{H}_{\rm ET}$, at luminosity distances of $D = 100, 200, 400, 1000$ Mpc, respectively. The vertical lines with correspondingly identical patterns (colors) mark the redshifted ISCO frequencies $(1+z)^{-1} f_{\rm ISCO}$ at which point we terminate each inspiral. As the true ISCO frequency is likely larger than $f_{\rm ISCO}$ citeMarronetti:2003hx, the inspirals would continue to nearly 2 kHz indicated by the faded lines in the plot (drawn to 5 kHz for aesthetic reasons).