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Forecasting Gamma-Ray Bursts with Gravitational-wave Detectors

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ABSTRACT

We explore the intriguing possibility of employing future ground-based gravitational-wave interferometers to detect the inspiral of binary neutron stars sufficiently early to alert electromagnetic observatories so that a gamma-ray burst (GRB) can be observed in its entirety from its very beginning. We quantify the ability to predict a GRB by computing the time a binary neutron star (BNS) system takes to inspiral from its moment of detection to its final merger. We define the moment of detection to be the instant at which the inteferometer network accumulates a signal-to-noise ratio of 15. For our computations, we specifically consider BNS systems at luminosity distances of (i) $D \leq 200\,$Mpc in the three-interferometer Advanced-LIGO-Virgo network of 2020, and (ii) $D \leq 1000\,$Mpc in the Einstein Telescope's B and C configurations. In the case of Advanced LIGO-Virgo we find that we may at best get a few minutes of warning time, thus we expect no forecast of GRBs in the 2020s. On the other hand, Einstein Telescope will provide us with advance warning times of more than five hours for $D \leq 100\,$Mpc. Taking one hour as a benchmark advance warning time, we obtain a corresponding horizon distance of roughly 600 Mpc for the Einstein Telescope C configuration. Using current BNS merger event rates within this volume, we show that Einstein C will forecast $\gtrsim O(10^2)$ GRBs in the 2030s. We reapply our warning-time computation to binary black hole - neutron star inspirals and find that we expect 1 to 3 tidal disruption events to be forecast by the same detector.

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

1. Introduction

2. Einstein Telescope

Table 1. Horizon distances of ET-B and ET-C assuming $T_{\rm AW} = 1\,$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

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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

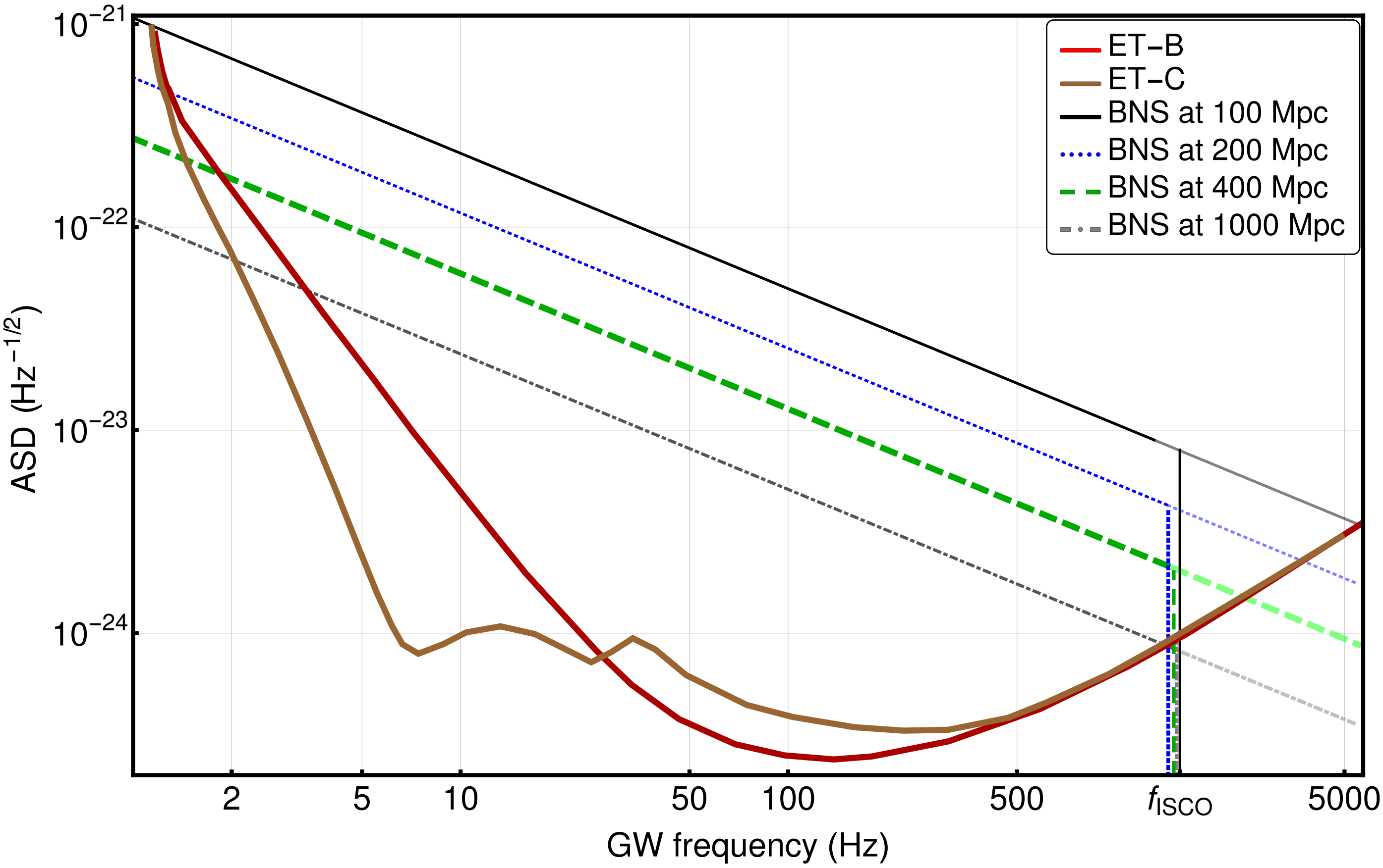

Fig. 1. Typical GW sources that may be harbingers of GRBs in the 2030s: $1.4M_\odot - 1.4M_\odot$ inspiralling BNS systems sweeping across the Einstein Telescope's sensitivity band for both B and C configurations. The solid (black), dotted (blue), dashed (green), and dot-dashed lines (gray) lines are 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).