Effect of metallicity on the gravitational-wave signal from the cosmological population of compact binary coalescences

-The effect of metallicity on the GW stochastic background created by compact binaries is studied
- Stellar evolution of binaries is simulated for three cases: Z_sun, 0.1*Z_sun and the averages of those two
-The GW background is dominated by BH contribution for the frequency range of the terrestrial detectors
-Higher metallicity corresponds to lower amplitude in Ω_gw and the peak shifts to higher frequencies
-All of the models presented here can be detected by ET (and the optimistic models could be detected by LIGO/VIRGO)
-This paper focuses on isolated binaires

Introduction: What has been done before?

It has been shown metallicity is important for the properties of compact binaries

-Formation rate of BH-BH and BH-NS increases with decreasing Z
-With lower Z the typical mass of BH's increase
-Some studies have shown that in very early Universe (with very low Z) binaries might have been formed

Investigation of AGB must take metallicity into account

Simulating a population of compact binaries

For the simulation Startrack binary evolution code was used.

-The output: Masses of the binaries, time delay, eccentricity
-The simulation was run for two metallicities: 0.1Z_sun and Z_sun
-2 million massive binaries were used as an input
-Recent estimates for mass-loss rates
-Updated stellar and binary physics: special attention paid on CE phase

Simulating a population of compact binaries

Lambda coefficent:
-An important parameter to describe the CE phase
-It measures how strongly the donor envelope is bound to the core

$$E_{bind} = -\frac{G M_{\rm don} M_{\rm don,env}}{\lambda R},$$

Simulating a population of compact binaries

Lambda coefficient in this paper is based on the model presented by Xu and Li (2010)
Contrary to previous models it is not constant but depends on:

-The evolutionary stage of the donor
-M_ZAMS of the donor
- Radius of the donor
-Mass of the envelope

Simulating a population of compact binaries

Common envelope phase initiated during Hertzsprung Gap:

-MS stars don’t have a clear core-envelope division
-Similarly HG stars lack a clear entropy jump in the core-envelope structure
Consequence: For these binaries the orbital energy is transferred to the whole star rather than to the envelope -> ejection of envelope is more difficult in this case
For HG stars two models are considered:
-A (optimistic) No suppression in merger rate
-B (pessimistic) Highest suppression possible

-Natal kick velocities are also taken into account

Table 2. Statistical properties of compact binaries used in the simulations of single metallicity populations. For each model we list the average total mass of a binary, the average "chirp mass", and the average frequency at the last stable orbit.

Model	$< M_{tot} >$ [$M_\odot$]	$< M_{chirp} >$ [$M_\odot$]	$< f_{lso} >$ [Hz]
		NSNS	
AZ	2.43	1.05	1809.71
Az	2.51	1.09	1756.74
A	2.45	1.06	1794.74
BZ	2.43	1.05	1811.26
Bz	2.49	1.08	1768.23
B	2.44	1.06	1802.96
		BHNS	
AZ	9.91	3.17	444.89
Az	11.66	3.17	398.82
A	11.17	3.18	412.00
BZ	9.85	3.13	448.39
Bz	12.45	3.21	371.55
B	12.21	3.20	378.43
		BHBH	
AZ	15.56	6.74	283.66
Az	30.31	13.08	188.09
A	28.85	12.45	197.79
BZ	15.60	6.76	282.59
Bz	22.41	9.54	215.14
B	21.78	9.28	221.31

Cosmic coalescence rate

It is assumed that the binary coalescence rate tracks the SFR:

$$\dot{\rho}_c^j(z) = A^j \int \frac{\dot{\rho}_*(z_f)}{1+z_f} P(t_d)\, dt_d,$$

$$t_d = \frac{1}{H_0} \int_z^{z_f} \frac{dz'}{(1+z')E(\Omega, z')}.$$

Cosmic coalescence rate

$$\frac{dR^j}{dz}(z) = \dot{\rho}_c(z)\frac{dV}{dz}(z)\,.$$

$$\frac{dV}{dz}(z) = 4\pi\frac{c}{H_0}\frac{r(z)^2}{E(\Omega,z)}\,, \qquad r(z) = \frac{c}{H_0}\int_0^z \frac{dz'}{E(\Omega,z')}\,,$$

$$E(\Omega,z) = \sqrt{\Omega_\Lambda + \Omega_m(1+z)^3}\,.$$

Cosmic coalescence rate

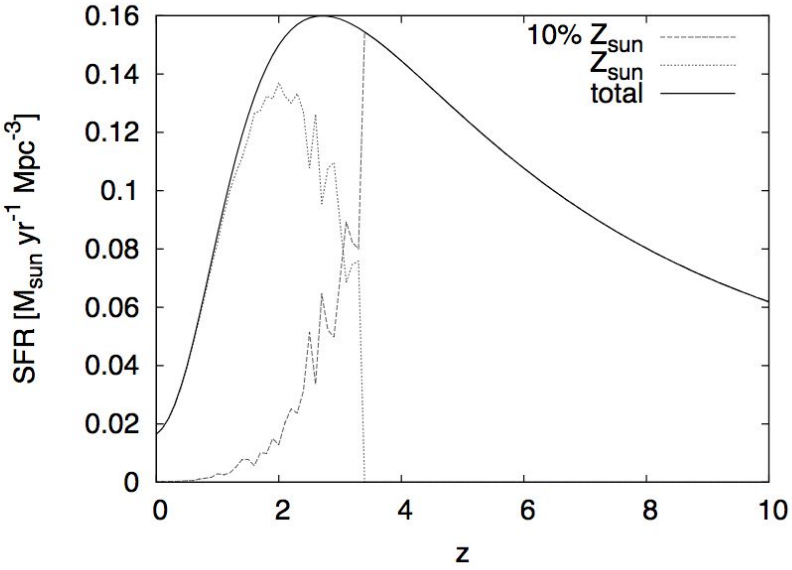
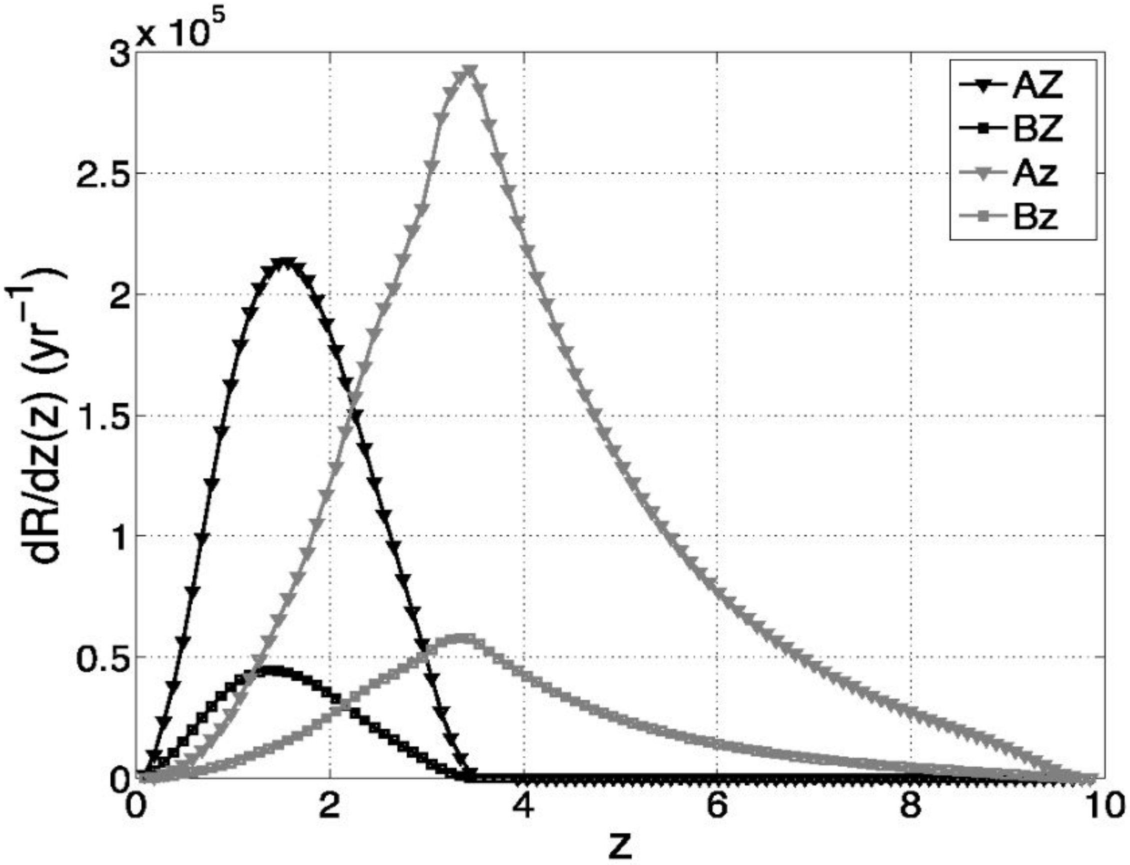


Fig. 1. Star formation rate as a function of redshift. The dashed line corresponds to the low-metallicity environment, the dotted line represents solar metallicity, and the solid line shows total SFR.



x 10^5
dR/dz(z) (yr^-1)
z
AZ
BZ
Az
Bz

Cosmic coalescence rate

Table 3. Total coalescence rate of all compact binaries per year (Col. 2). In the last three columns we show the contribution of each type of compact binaries to the total coalescence rate.

Model	rate [yr^{-1}]	$\mathrm{rate}_{\mathrm{NSNS}}$ [%]	$\mathrm{rate}_{\mathrm{BHNS}}$ [%]	$\mathrm{rate}_{\mathrm{BHBH}}$ [%]
AZ	622 572	71.62	3.70	24.69
Az	1 606 240	10.62	3.56	85.82
A	1 264 605	27.55	3.54	68.91
BZ	154 929	84.78	2.09	13.13
Bz	319 304	10.70	11.50	77.80
B	267 677	34.52	8.31	57.16

GW background

$$\Omega_{gw}(f) = \frac{1}{\rho_c} \frac{d\rho_{gw}}{d \ln f},$$

$$\Omega_{gw}(f) = \frac{1}{\rho_c c} f F(f),$$

GW background

$$F(f) = T^{-1} \sum_{k=1}^{N} \frac{1}{4\pi d_L^2(z^k)} \frac{dE_{gw}}{df}(f, M^k, \mathcal{M}_c^k, z^k),$$

$$F^j(f) \simeq \int_0^{z_{max}} \frac{1}{4\pi d_L^2(z)} \frac{dE_{gw}}{df}(f, \bar{f_{lso}}^j, \bar{\mathcal{M}_c}^j, z) \frac{dR^j}{dz}(z) dz,$$

GW background

$$\frac{dE_{gw}}{df}(f, f_{lso}, \mathcal{M}_c, z) = \frac{(G\pi)^{2/3}(\mathcal{M}_c(1+z))^{5/3}}{3} f^{-1/3},$$

$$\text{for } f < f_{lso}/(1+z),$$

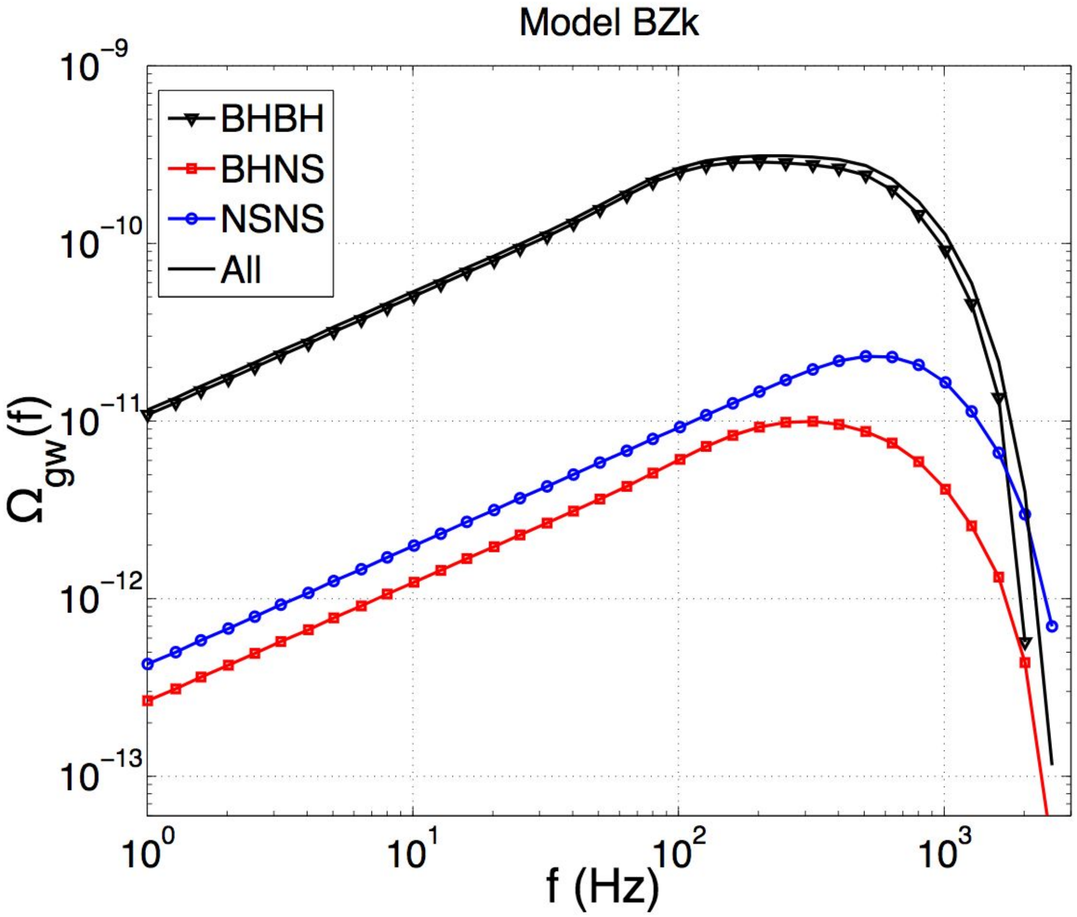
GW background

$$\Omega^j_{gw}(f) \simeq \frac{2\pi^{2/3}G^{5/3}}{9c^3H_0^2}(\bar{\mathcal{M}}_c^j)^{5/3}f^{2/3}$$

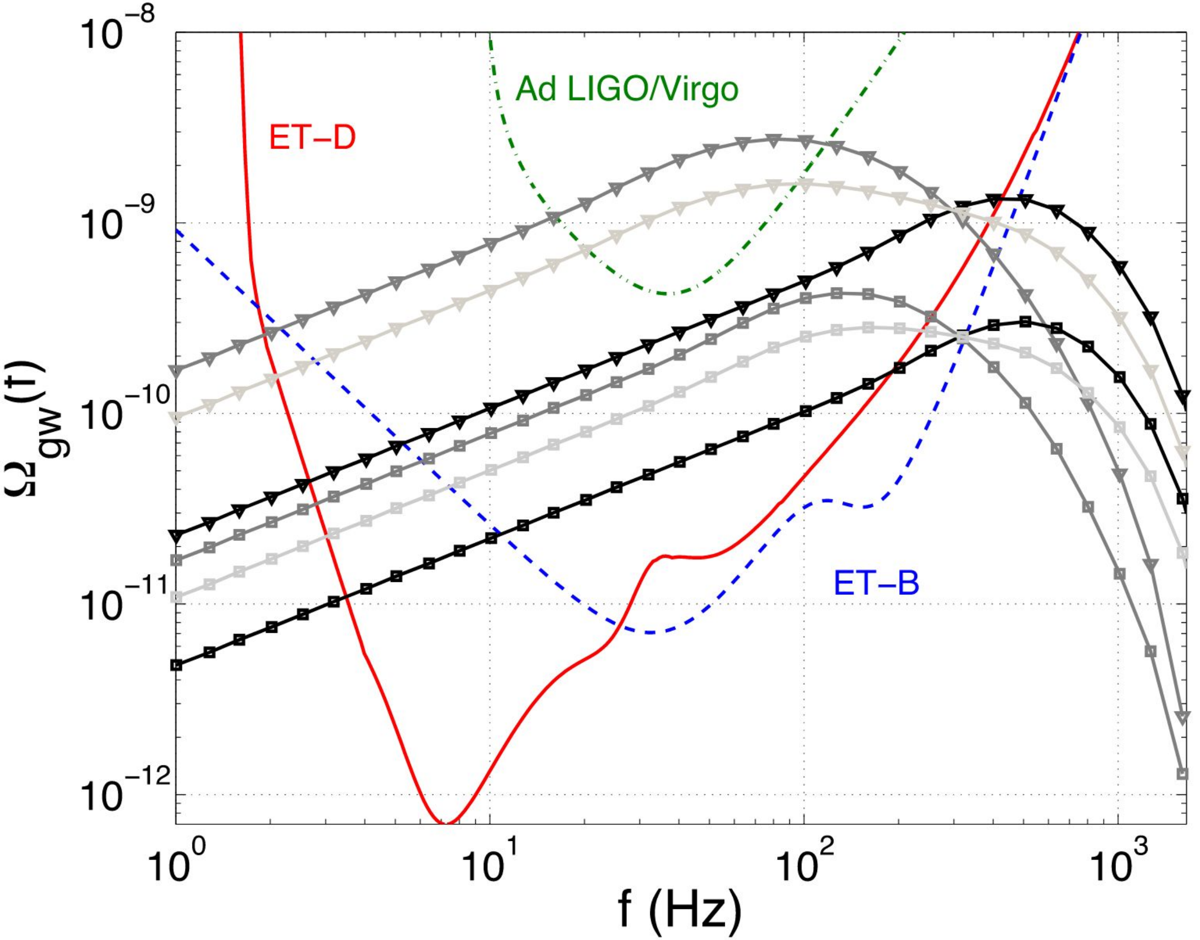
$$\int_0^{z^j_{sup}(f)} \frac{dR^j}{dz}(z)\frac{dz}{r(z)(1+z)^{1/3}}dz,$$

with

$$z^j_{sup}(f) = \begin{cases} z_{max} \text{ if } f < \bar{f_{lso}}^j/(1+z_{max}) \\ (\bar{f_{lso}}^j/f) - 1 \text{ otherwise.} \end{cases}$$



Model BZk
BHBH
BHNS
NSNS
All
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
$\Omega_{gw}(f)$
10^{0}
10^{1}
10^{2}
10^{3}
f (Hz)



Ad LIGO/Virgo
ET−D
ET−B
$\Omega_{gw}(f)$
f (Hz)
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{0}
10^{1}
10^{2}
10^{3}

Results

Model	Adv CC	ET-B	ET-D
AZ	0.925	61.782	116.683
Az	7.138	471.502	854.678
A	4.003	264.726	482.754
BZ	0.192	12.811	24.202
Bz	0.710	47.780	86.195
B	0.444	29.868	54.487

Thank you!