GW Backgound from extragalactic Double Neutron Stars

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Plan

Monte Carlo simulations in the frequency band of:

- Ground-based interferometers:
  last 1000 s before the LSO
- LISA band: low frequency inspiral signal

The GW Stochastic Background

- Two contributions:

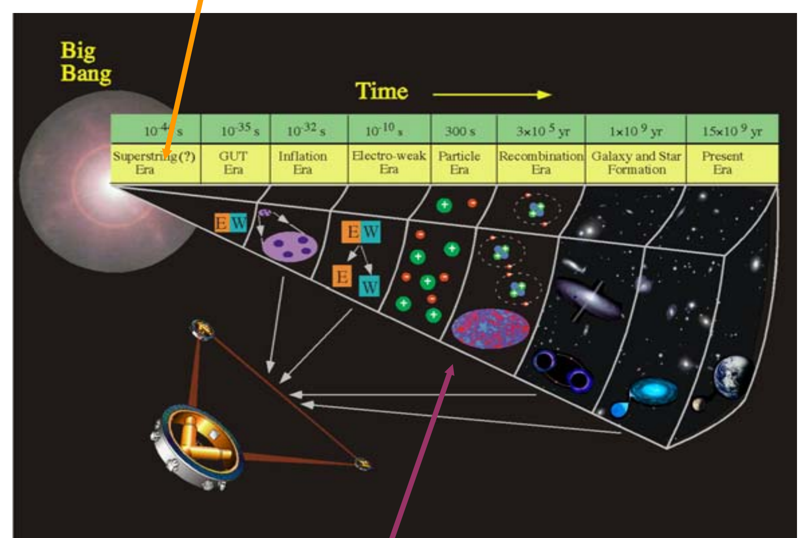
  - **cosmological:** signature of the early Universe
  inflation, cosmic strings, phase transitions…

  - **astrophysical:** superposition of all the sources since the beginning of the stellar activity:
  Compact binairies, supernovae, BH ring down, supermassive BH …

- **characterized by the energy density parameter:**

$$\Omega_{gw}(f) = \frac{d\rho_{gw}(f)}{\rho_c d(\ln f)} = \frac{4\pi^2}{3H_0^2} f^3 S_h(f)$$

10^{-43}s: gravitons decoupled (T = 10^{19} GeV)



300000 yrs: photons decoupled (T = 0.2 eV)

Astrophysical Stochastic Backgrounds

$$\Omega_{gw}(f)=\frac{1}{\rho_{critical}}\frac{\nu_0 F_{\nu_0}}{c^3} \text{ with } F_{\nu_0}=\int_0^{z_{\sup}}\frac{1}{4\pi d_L^2}\frac{dE_{gw}}{d\nu_0}dR(z)$$

$$\text{where } z_{\sup}=\begin{cases}\dfrac{6 \text{ if } \nu_o<\dfrac{\nu_{\sup}}{7}}{\dfrac{\nu_{\sup}}{\nu_o}-1 \text{ otherwise}}\end{cases} \quad (14)$$

To model astrophysical backgrounds one needs to know:

- The cosmological model (H_0, Ω_m , Ω_ν):
737 cosmology: flat Einstein de Sitter Universe with h_0=0.7, Ω_m=0.3, Ω_ν=0.7

- The source rate dR(z)

- The individual energy spectral density $\dfrac{dE_{gw}}{d\nu}$

Last thousands seconds before the last stable orbit:

96% of the energy released, in the range [10-1500 Hz]

Ground-based interferometer frequency band

- **redshift of formation of massive binaries (Coward et al. 2002)**

$$P_f(z_f) = \frac{R_f(z_f)}{\int_0^5 R_f(z_f)dz_f} \text{ with } R_f(z_f) = \lambda_p \frac{R_f^*}{1+z}\frac{dV}{dz}$$

- **redshift of formation of NS/NS**

$$z_b = z_f - \Delta z(\tau_b) \text{ with } \tau_b = 10^8 \text{ yr}$$

- **coalescence time**

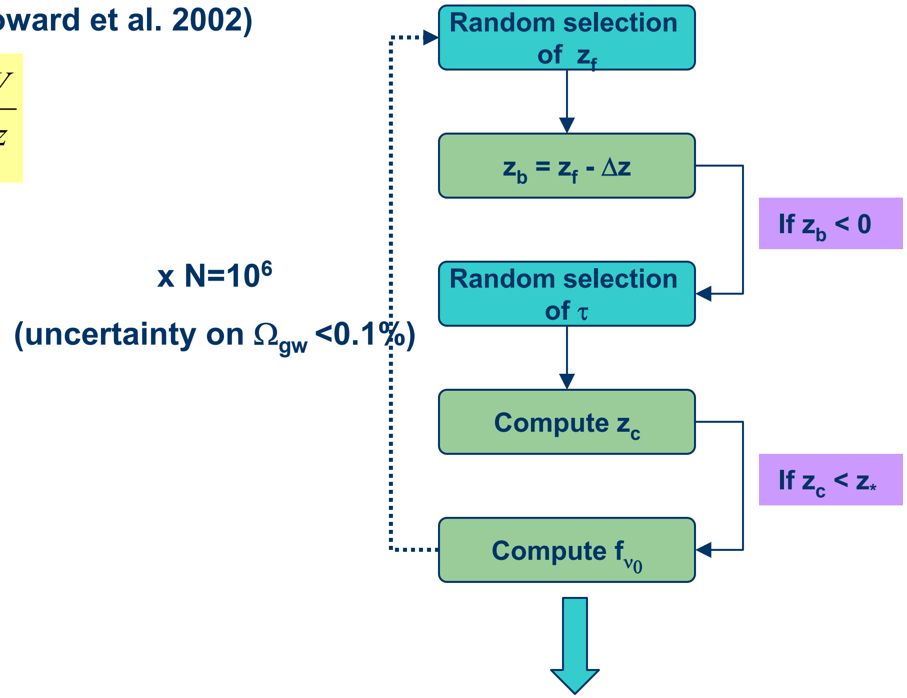
$$P_\tau(\tau) = \frac{0.087}{\tau} \text{ with } \tau \in [2\times10^5; 2\times10^{10} \text{yr}]$$

- **redshift of coalescence**

$$\tau = \frac{1}{H_0}\int_{z_c}^{z_b} \frac{dz}{(1+z)E(z)}$$

- **observed fluence**

$$f_{\nu_o} = \frac{1}{4\pi d_L^2}\frac{dE_{gw}}{d\nu_0} = \frac{K\nu_o^{-1/3}}{4\pi r^2(z_c)(1+z_c)^{4/3}}$$



$$\Omega_{gw}(f) = \frac{\nu_0 F_{\nu_0}}{\rho_c c^3} \text{ with } F_{\nu_0} = \frac{N_{DNS}}{N}\sum_{i=1}^{N} f_{\nu_0}^i$$

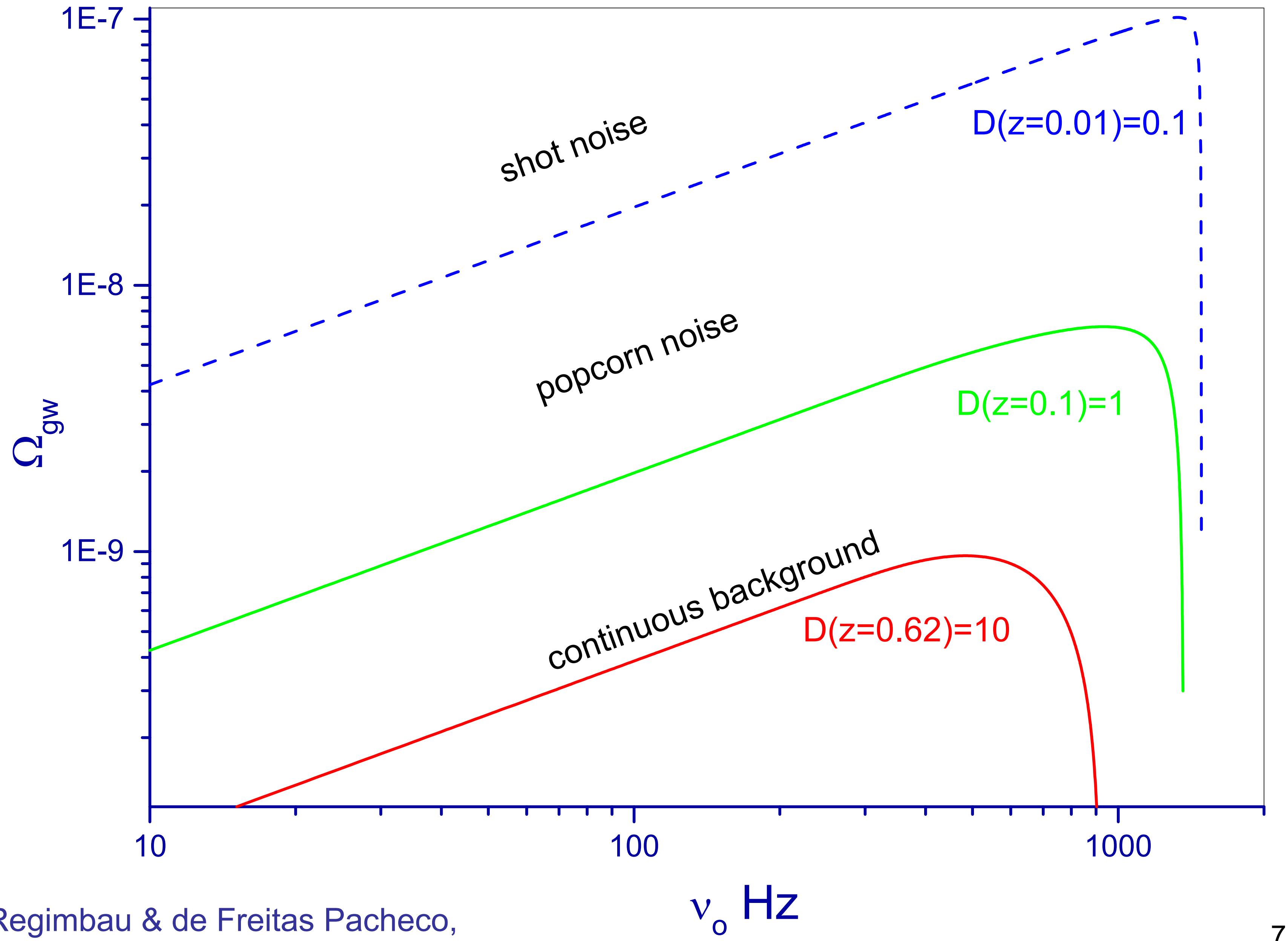
Detection Regimes

The duty cycle characterizes the nature of the background.

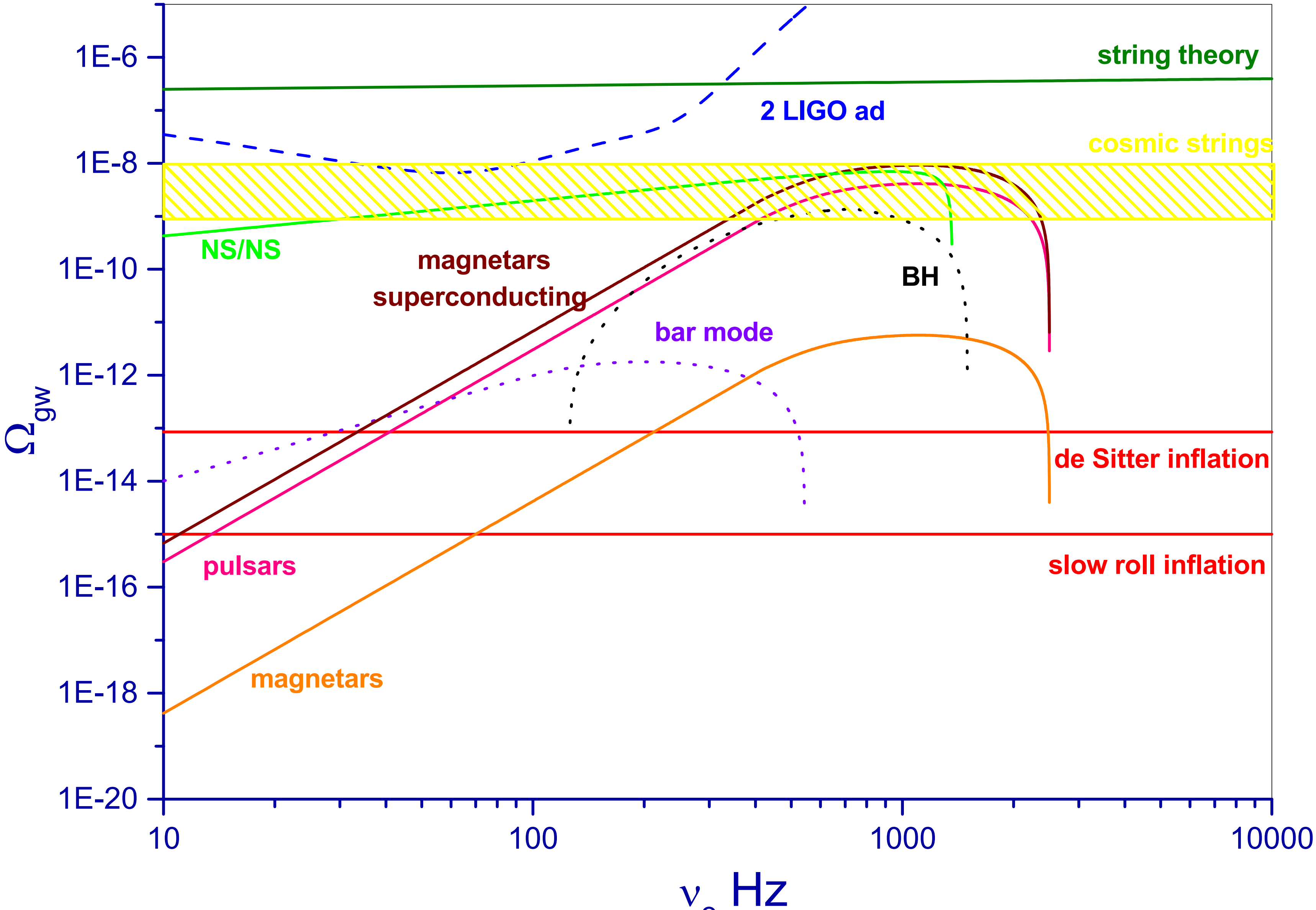
$$D(z) = \int_0^z < \tau > (1+z')R_c(z')dz'$$

$<\tau>$ = 1000 s, which corresponds to 96% of the energy released, between 10-1500 Hz

- **D >1: continuous** (z>0.1, 96%)
  The time interval between successive events is **short** compared to the duration of a single event
- **D <1: shot noise** (z<0.01)
  The time interval between successive events is **long** compared to the duration of a single event
- **D ~1: popcorn** (0.01<z<0.1)
  The time interval between successive events is **of the same order as** the duration of a single event



Regimbau & de Freitas Pacheco,
2005, ApJ, 642, 455



string theory
2 LIGO ad
cosmic strings
NS/NS
magnetars
superconducting
BH
bar mode
de Sitter inflation
pulsars
slow roll inflation
magnetars
1E-6
1E-8
1E-10
1E-12
1E-14
1E-16
1E-18
1E-20
Ω_{gw}
10
100
1000
10000
ν_o Hz

Detection

Because the stochastic background cannot be distinguished from the instrumental noise background, the optimal detection strategy is to correlate the outputs of two (or more) detectors.

hypothesis:

- isotropic, gaussian, stationnary
- signal and noise, detector noises uncorrelated

Cross correlation statistic:

- combine the signal outputs using an optimal filter to optimize the signal to noise ratio

$$Y = \int \tilde{s}_1(f)\tilde{Q}(f)s_2(f)df \quad \text{with} \quad \tilde{Q}(f) \propto \frac{\Gamma(f)S_h(f)}{P_1(f)P_2(f)}$$

Signal to noise ratio:

$$(\frac{S}{N})^2 = 2T\int \frac{\Gamma^2(f)S_h^2(f)}{P_1(f)P_2(f)} = 2T\int \frac{\gamma^2(f)S_{eff}^2(f)}{P_1(f)P_2(f)} \text{ where } S_{eff} = \frac{2}{5}S_h$$

2 colocated/coaligned advanced detectors (LIGO ad): S/N ~0.65
2 colocated/coaligned 3rd generation detectors (EGO):S/N ~10

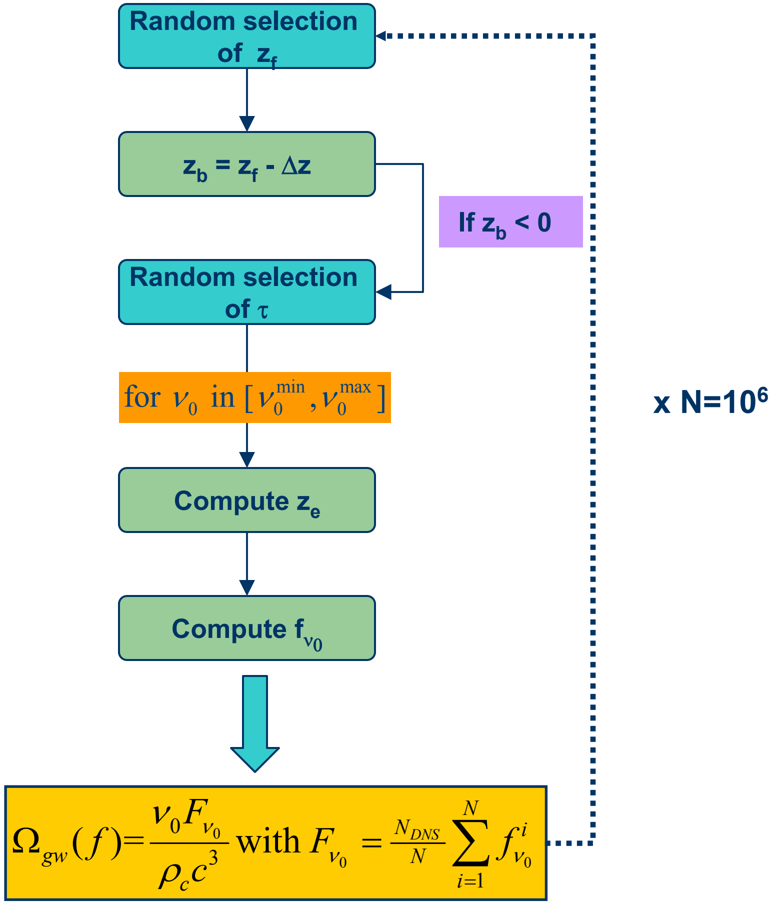
LISA frequency band

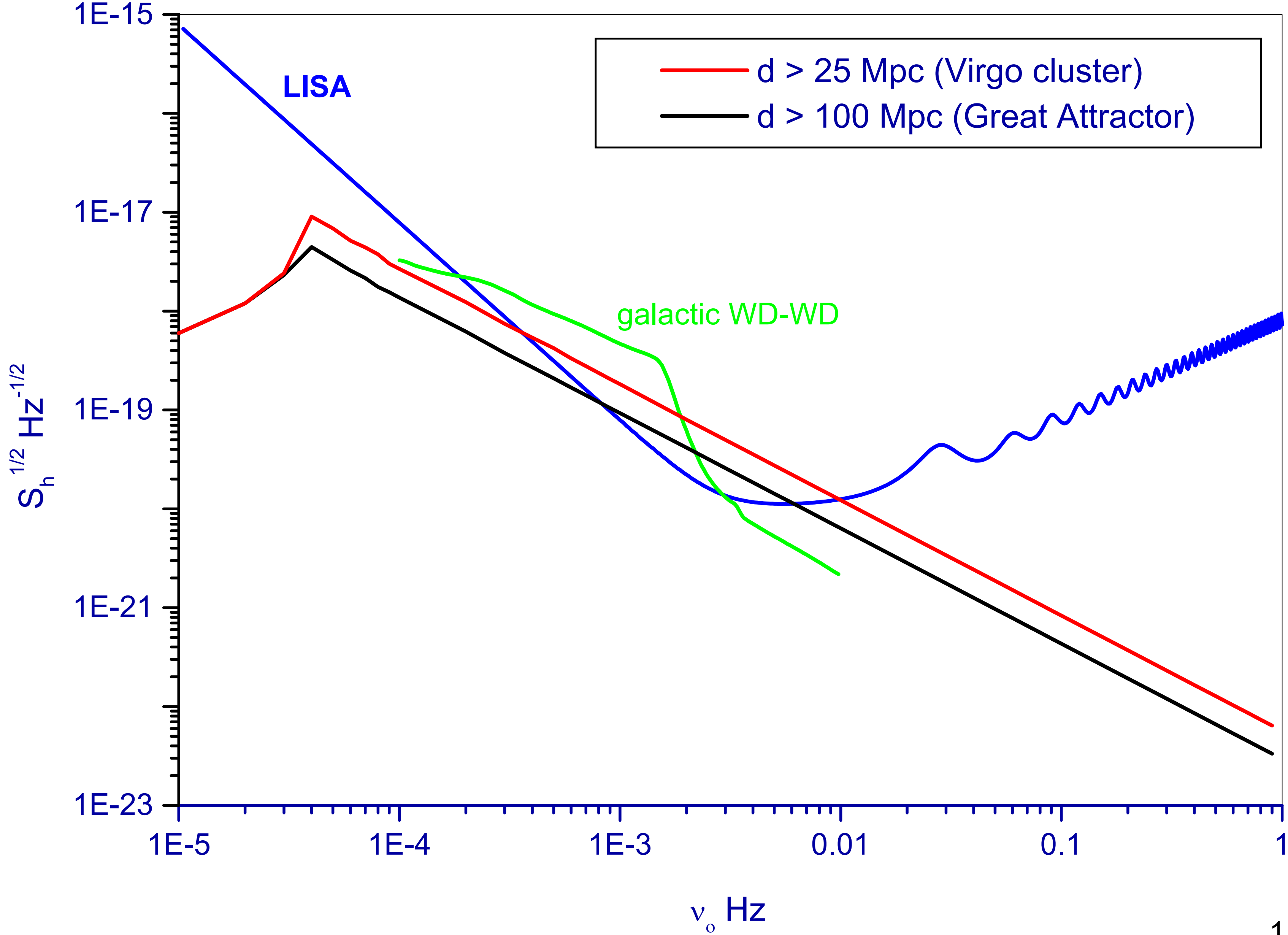
- **redshift of emission**

$$\nu_o = (\nu_{lso}^{-8/3} + K(\tau_c - \tau(z_e, z_b))^{-3/8} / (1 + z_e)$$

- **observed fluence**

$$f_{\nu_o} = \frac{1}{4\pi d_L^2} \frac{dE_{gw}}{d\nu_0} = \frac{K\nu_o^{-1/3}}{4\pi r^2(z_e)(1+z_e)^{4/3}}$$





1E-15
1E-17
1E-19
1E-21
1E-23
$S_h^{1/2}$ $Hz^{-1/2}$
LISA
d > 25 Mpc (Virgo cluster)
d > 100 Mpc (Great Attractor)
galactic WD-WD
1E-5
1E-4
1E-3
0.01
0.1
1
ν_o Hz

Summary

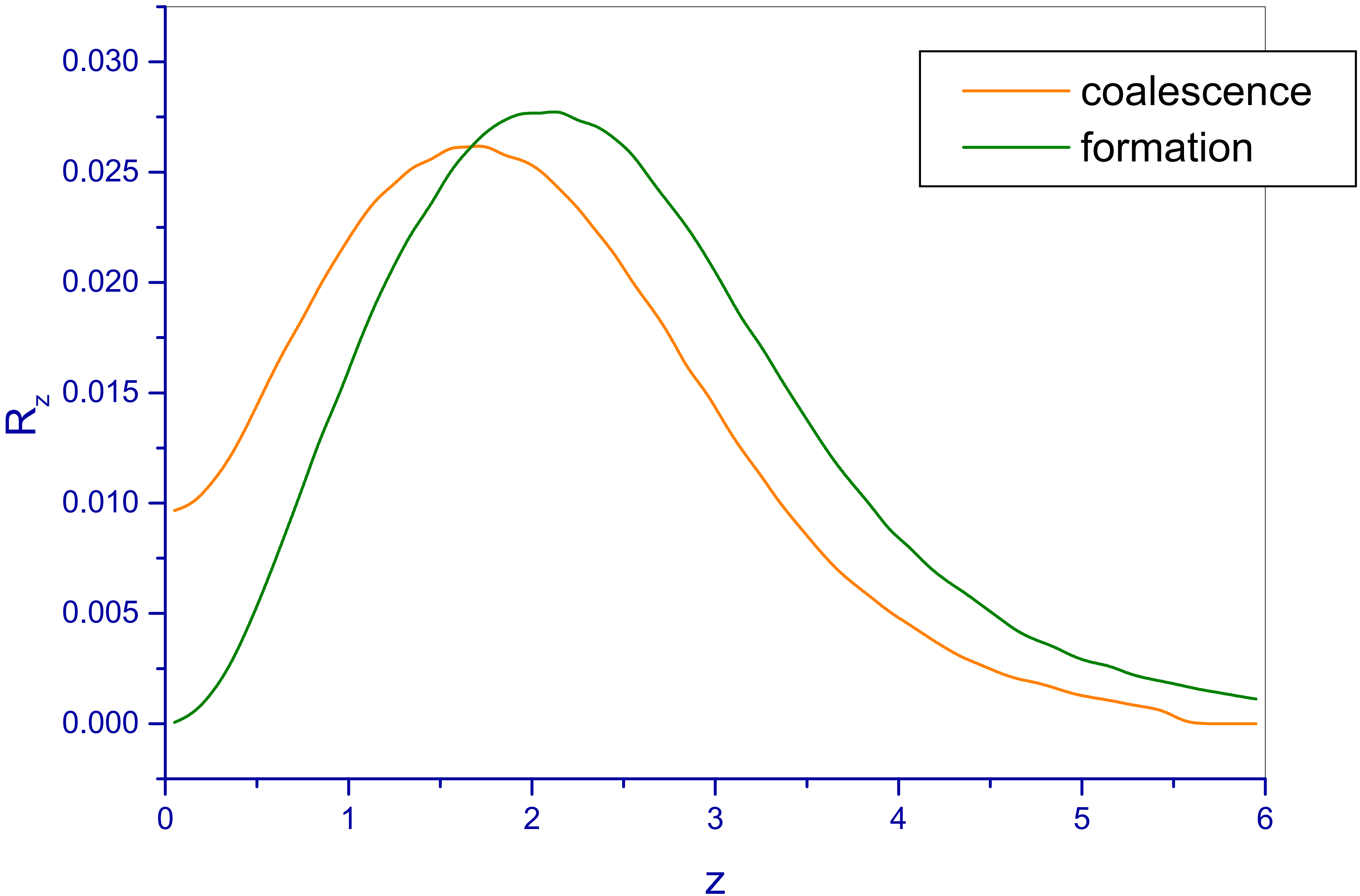
- GBased interferometers (1000s before LSO):

- 3 regimes: resolved ($z<0.01$), popcorn ($0.01<z<0.1$), continuous ($z>0.1$)
- continuous contribution reaches a maximum of $\Omega_{gw} = 7\times10^{-9}$ around 930 Hz
- S/R~0.65 (~10) for second (third) generation of interferometers

- LISA band (low frequency inspiral phase):

- may dominate the LISA instrumental noise between 0.7-6 mHz (or 0.3-10 mHz for the less conservative estimate), and the galactic double white dwarf confusion noise after 2 mHz.
- however, the resulting reduction in the sensitivity should be less than a factor 4 and thus shouldn't affect significantly signal detection.

EXTRA SLIDES


coalescence
formation
0.030
0.025
0.020
0.015
0.010
0.005
0.000
R_z
0
1
2
3
4
5
6
z

LISA frequency band

- **observed frequency range**

$$\nu_o^{\min} = (\nu_{lso}^{-8/3} + K\tau_c)^{-3/8}/(1+z_b) \text{ with } K = \frac{256\pi^{8/3}G^{5/3}}{5c^5}\frac{m_1 m_2}{(m_1+m_2)^{1/3}}$$

$$\nu_o^{\max} = \begin{cases} (\nu_{lso}^{-8/3} + K(\tau_c - \tau(0,z_b))^{-3/8} & /(1+z_c) \text{ if } z_c < 0 \\ \nu_{lso} \text{ if } z_c > 0 \end{cases}$$

- **redshift of emission**

$$\nu_o = (\nu_{lso}^{-8/3} + K(\tau_c - \tau(z_e, z_b))^{-3/8}/(1+z_e)$$

- **observed fluence**

$$f_{\nu_o} = \frac{1}{4\pi d_L^2}\frac{dE_{gw}}{d\nu_0} = \frac{K\nu_o^{-1/3}}{4\pi r^2(z_e)(1+z_e)^{4/3}}$$

- **number of sources present today**

$$N = \int_0^6 N(z)dz \text{ where } \begin{cases} N(z) = \int_z^6 R_f(z')\eta(z')dz' \\ \text{and } \eta(z') = \int_{Max(\tau_{\min};\tau(z,z_b))}^{\tau_{\max}} P(\tau)d\tau \end{cases}$$