Sources of High Frequency Gravitational Waves

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Sources

1) Astrophysical

2) Cosmological

3) Laboratory (?)

4) BSM sources

Astrophysical Sources

Sources	Typical peak frequency	Typical strain	Ref. Talks
NS-NS mergers	~ kHz	$h_c \sim 10^{-23}$	D. Ottaway
|BNS-BBH| mergers	~ kHz	$h_c \sim 10^{-22}$	D. Ottaway
Light PBH mergers $M \sim 10^{-3} - 10^{-1} M_{sun}$	$\sim 10^5 \mathrm{Hz}$	$h_c \sim 10^{-20}$	A. Geraci
Boson stars mergers?	$f \propto C \equiv \frac{M}{R}$	?	
...	...	...	

Cosmological Sources

Sources	Typical peak frequency	Typical strain	Ref. Talks
Axion-inflation			D. Figueroa M. Peloso
Inflation/PBH – 2nd order prehating	Flat or Bump	$h_c \sim 10^{-22}$	D. Figueroa
Chaotic inflation/ preheating	$\sim 10^{10}\mathrm{Hz}$	$h_c \sim 4 \cdot 10^{-24}$	D. Figueroa
Tachyonic Preheating	$\sim 10^{10}\mathrm{Hz}$	$h_c \sim 4 \cdot 10^{-24}$	D. Figueroa
Axion Preheating	$\sim 10^{8}\mathrm{Hz}$	$h_c \sim 4 \cdot 10^{-22}$	D. Figueroa
Oscillons	$\sim 10^{9}\mathrm{Hz}$	$h_c \sim 1 \cdot 10^{-24}$	1803.08047
PBH evaporation $M \sim 10^{13} g$	$\sim M_{PBH}$		
PBH			
...			

Cosmological Sources

Sources	Typical peak frequency	Typical strain	Ref. Talks
1st order Ph. Transition			M. Hindmarsh

Gravitational wave frequencies

- Shear stress at time *t* generate waves with minimum frequency $f \approx 1/t$ (Hubble rate)
- Redshifted to a frequency now: $f_0 = (a(t)/a(t_0))f$
- Redshifted Hubble rates:

Event	Time/s	Temp/GeV	f_0/Hz
QCD transition	10^{-3}	0.1	10^{-8}
EW transition	10^{-11}	100	10^{-5}
?	10^{-25}	10^{9}	100
End of inflation	$\geq 10^{-36}$	$\leq 10^{16}$	$\leq 10^{8}$

- Peak frequencies: $f_{p,0} \simeq 26 (H_n R_*)^{-1} (T_n / 100\,\mathrm{GeV})\,\mu\mathrm{Hz}$
- Typical range: $10^1 \lesssim (H_n R_*)^{-1} \lesssim 10^5$

Cosmological Sources

Sources	Typical peak frequency	Typical strain	Ref. Talks
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High frequency GWs from PTs?

- Peak frequencies: $f_{p.0} \simeq 26 (H_{\rm n} R_*)^{-1} (T_{\rm n}/100\,{\rm GeV})\,\mu{\rm Hz}$
- Typical range: $10^1 \lesssim (H_{\rm n} R_*)^{-1} \lesssim 10^5$
- Highest possible phase transition temperature?
  - Inflation (absence of GWs): $T_{\rm n} \lesssim 10^{15}\,{\rm GeV}$
- Corresponding frequencies: $10^8\,{\rm Hz} \lesssim f_{p,0} \lesssim 10^{12}\,{\rm Hz}$
- Higher frequency means smaller strain 😬

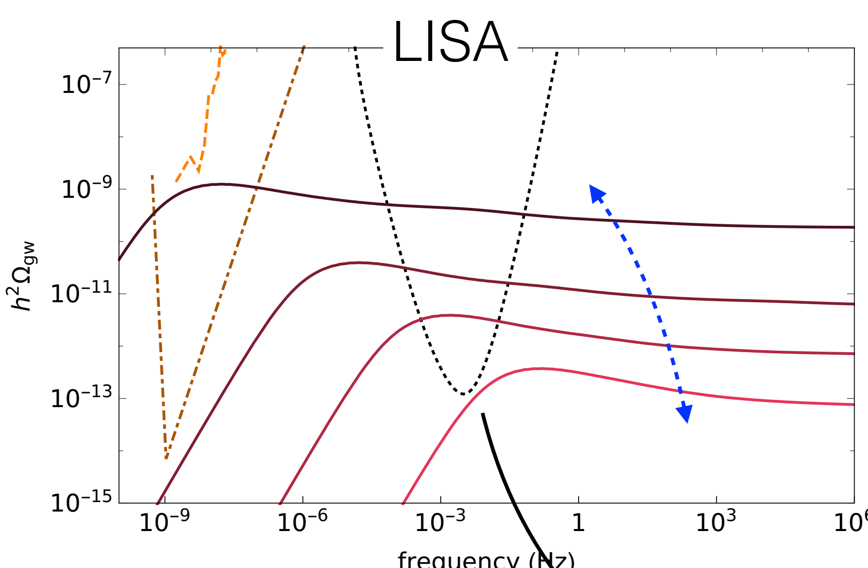
$$h_c \simeq 0.4 \sqrt{\Omega_{\rm gw}} \times 10^{-20}\,(f/100\,{\rm Hz})^{-1}$$

Cosmological Sources

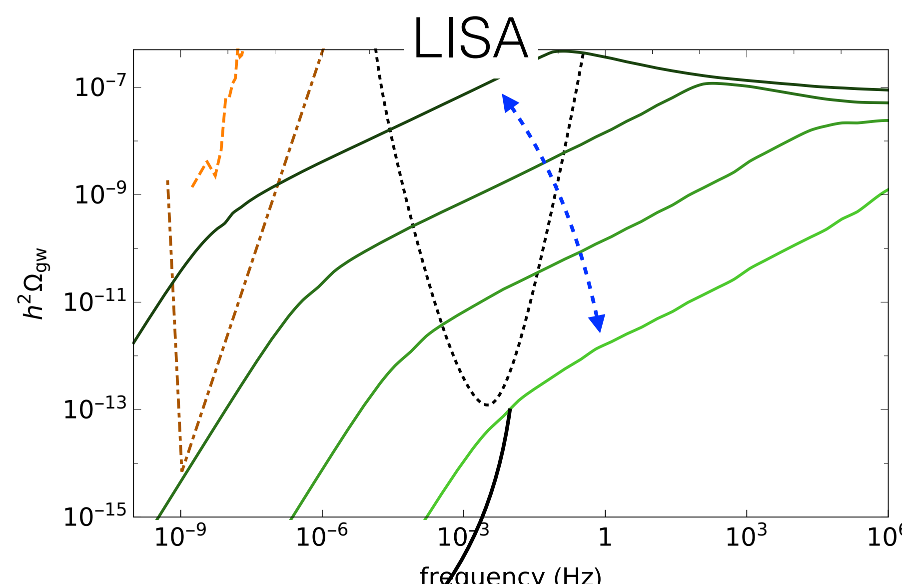
Sources	Typical peak frequency	Typical strain	Ref. Talks
Topological Defects			D. Figueroa

Cosmic strings loops: GW background

Blanco-Pillado, Olum, Shlaer



Lorenz, Ringeval, Sakellariadou



$G\mu \gtrsim 10^{-17}$

Very large parameter space !

LISA paper 1909.00819

BSM Sources

- Astrophysical Sources

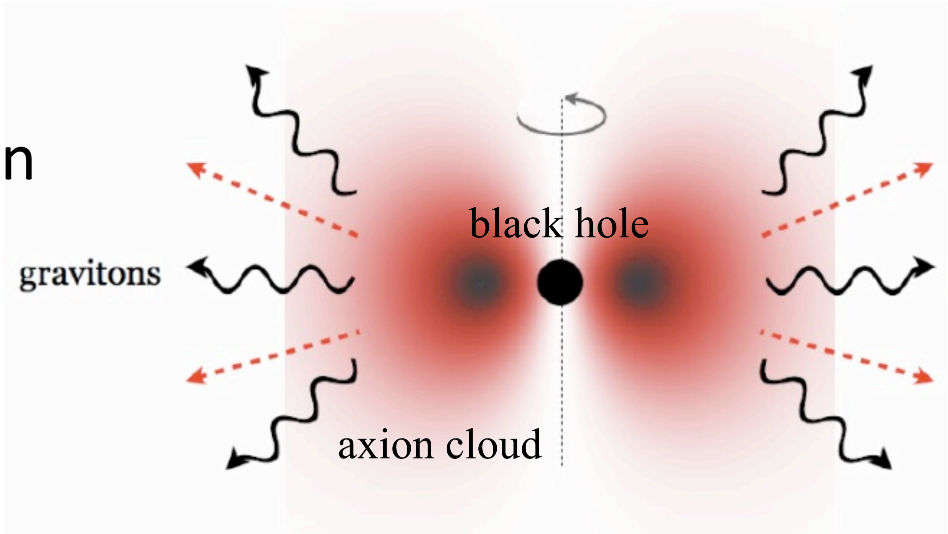
  Inspirals and mergers have higher frequency GW emission for lower masses

  Natural upper bound on GW frequency → M_{sun} mass BH ~ 30 kHz

  Could be lighter Primordial black holes (PBHs) at > 30 kHz

- Beyond standard model physics

  - QCD Axion → Annihilation to gravitons in cloud around Black holes



A. Arvanitaki *et. al*, PRD, 81, 123530 (2010)

A. Arvanitaki *et al.* PRD 83, 044026 (2011)

Black hole superradiance

R. Brustein et. al. Phys. Lett. B, 361, 45 (1995)

- String cosmology
- The unknown?

Ref. Talks **A. Geraci** **S. Sun**

Definitions

(From M. Maggiore review 9909001)

GW energy density

$$\rho_{\rm gw} = \frac{1}{32\pi G}\langle \dot{h}_{ab}\dot{h}^{ab}\rangle\,.$$

For a stochastic background, the spatial average over a few wavelengths is the same as a time average at a given point, which, in Fourier space, is the ensemble average performed using eq. (8). We therefore insert eq. (5) into eq. (13) and use eq. (8). The result is

$$\rho_{\rm gw} = \frac{4}{32\pi G}\int_{f=0}^{f=\infty} d(\log f)\; f(2\pi f)^2 S_h(f)\,, \tag{14}$$

so that

$$\frac{d\rho_{\rm gw}}{d\log f} = \frac{\pi}{2G} f^3 S_h(f)\,. \tag{15}$$

Considering that

$$h_c^2(f) = 2f S_h(f)\,.$$

We have

$$\Omega_{\rm gw}(f) = \frac{2\pi^2}{3H_0^2} f^2 h_c^2(f)\,.$$

$$h_c(f) \simeq 1.263 \times 10^{-18} \left(\frac{1\text{Hz}}{f}\right) \sqrt{h_0^2 \Omega_{\text{gw}}(f)}\,.$$

Actually, $h_c(f)$ is not yet the most useful dimensionless quantity to use for the comparison with experiments. In fact, any experiment involves some form of binning over the frequency. In a total observation time T, the resolution in frequency is $\Delta f = 1/T$, so one does not observe $h_0^2 \Omega_{\text{gw}}(f)$ but rather

$$\int_f^{f+\Delta f} d(\log f)\; h_0^2 \Omega_{\text{gw}}(f) \simeq \frac{\Delta f}{f} h_0^2 \Omega_{\text{gw}}(f)\,, \tag{20}$$

since $h_0^2 \Omega_{\text{gw}}(f) \sim h_c^2(f)$, it is convenient to define

$$h_c(f, \Delta f) = h_c(f) \left(\frac{\Delta f}{f}\right)^{1/2}\,.$$

Using $1/(1\,\text{yr}) \simeq 3.17 \times 10^{-8}$ Hz as a reference value for Δf, and 10^{-6} as a reference value for $h_0^2 \Omega_{\text{gw}}$, eqs. (19) and (21) give

$$h_c(f, \Delta f) \simeq 2.249 \times 10^{-25} \left(\frac{1\text{Hz}}{f}\right)^{3/2} \left(\frac{h_0^2 \Omega_{\text{gw}}(f)}{10^{-6}}\right)^{1/2} \left(\frac{\Delta f}{3.17 \times 10^{-8}\ \text{Hz}}\right)^{1/2}\,, \tag{22}$$