

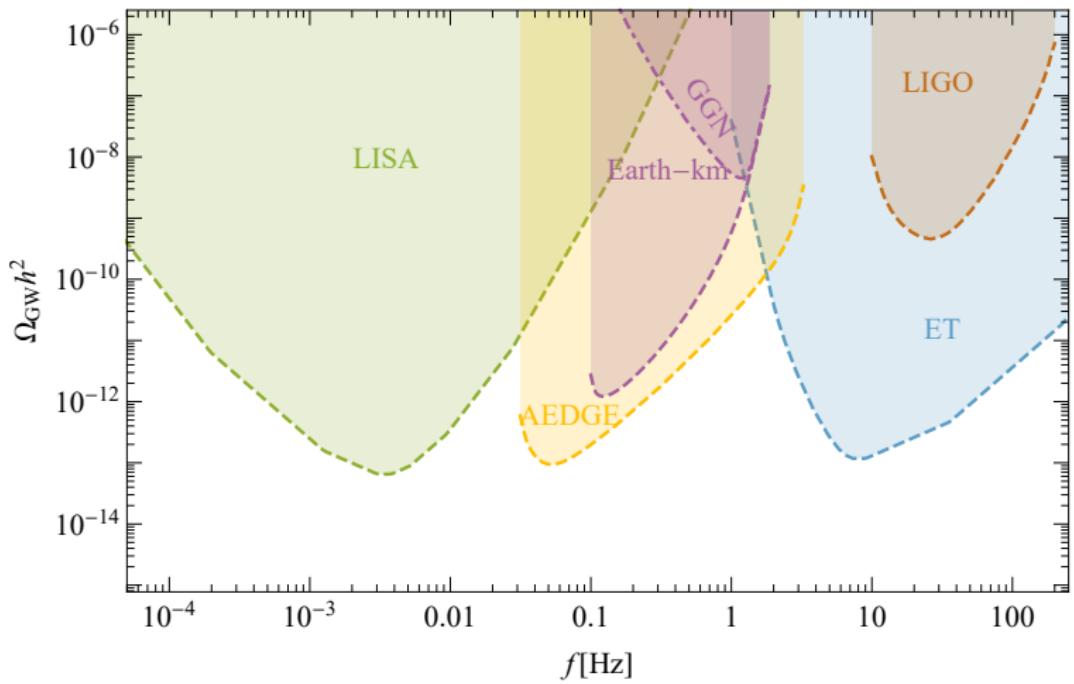
AEDGE: Gravitational Waves

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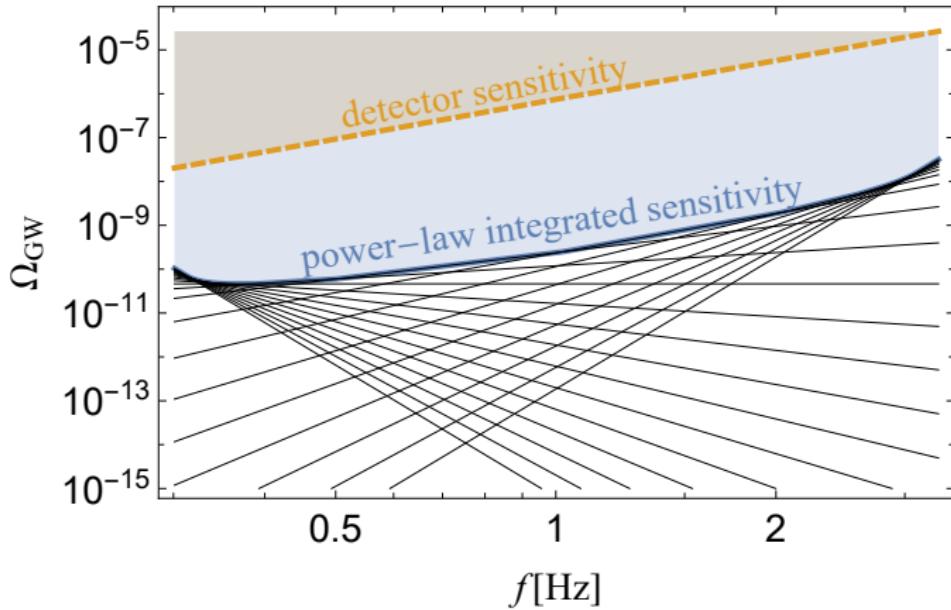
Workshop on Atomic Experiments for Dark Matter and Gravity Exploration,
CERN, 23 July 2019



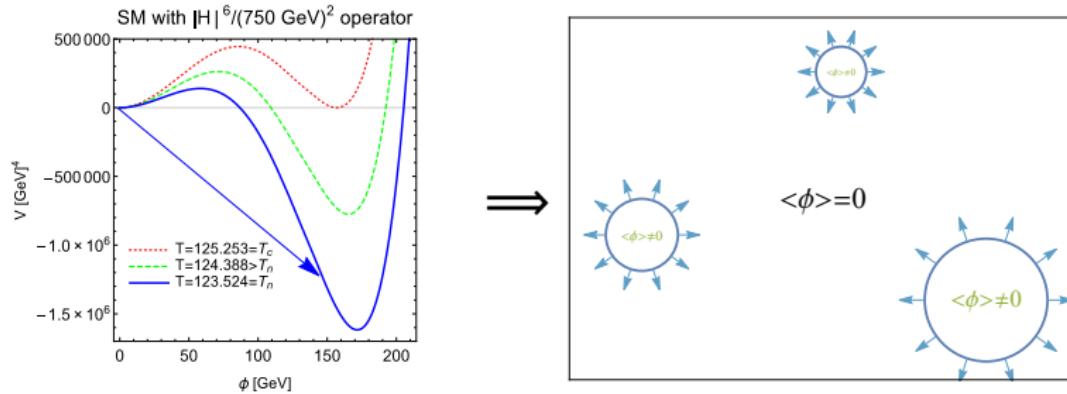


Power-law integrated sensitivity

$$\Omega_{\text{GW}}^{\text{noise}} = \frac{2\pi}{3} \frac{f^3 S_h^2}{H_0^2}, \quad \text{SNR} = \sqrt{\mathcal{T} \int df \left(\frac{\Omega_{\text{GW}}^{\text{signal}}}{\Omega_{\text{GW}}^{\text{noise}}} \right)^2}$$



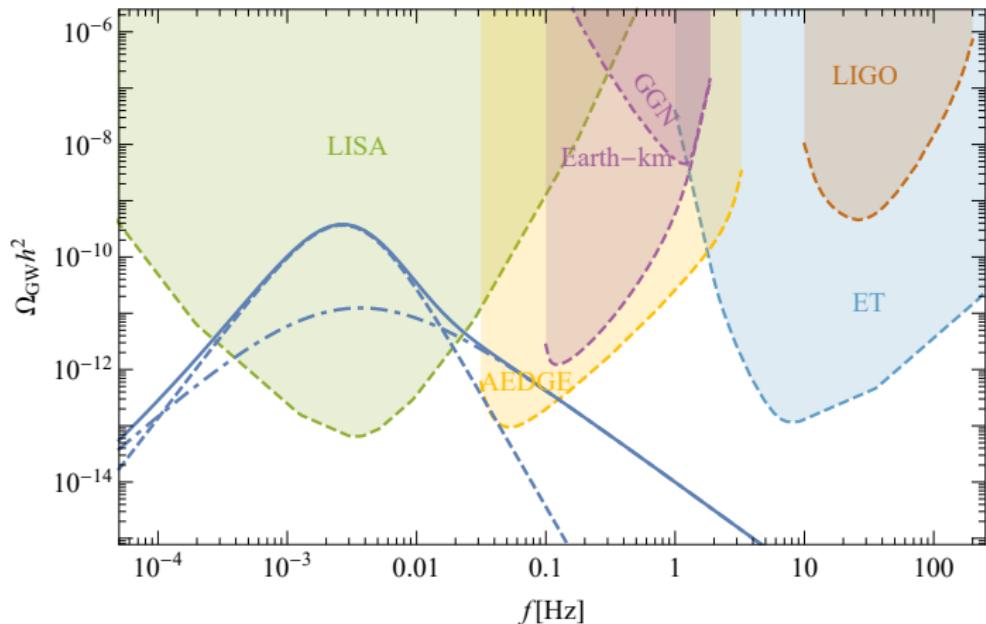
Gravitational waves from a PT



- Signals are produced by three main mechanisms:
 - collisions of bubble walls
Kamionkowski '93, Huber '08, Hindmarsh '18, Ellis '19
 - sound waves
Hindmarsh '13 '15 '17, Ellis '18
 - turbulence
Caprini '09
- The frequency of the signal changes as $f \propto T_{\text{reh}}$

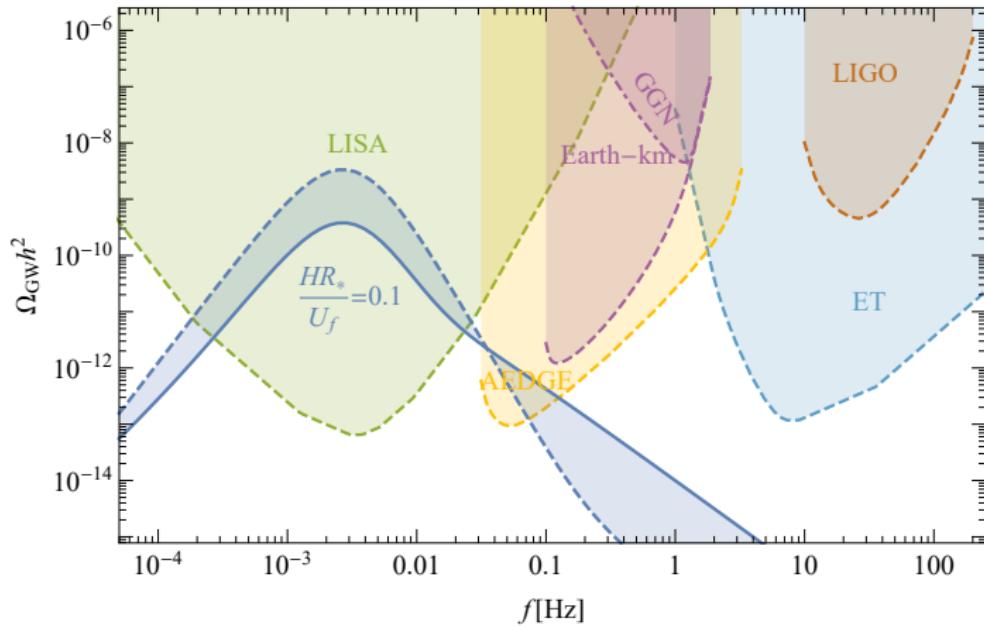
Plasma related sources

$$T_* = 100 \text{ GeV}, \alpha = 1, HR_* = 5 \times 10^{-2}$$



Shortening of the sound wave period

$$T_* = 100 \text{ GeV}, \alpha = 1, HR_* = 5 \cdot 10^{-2}$$

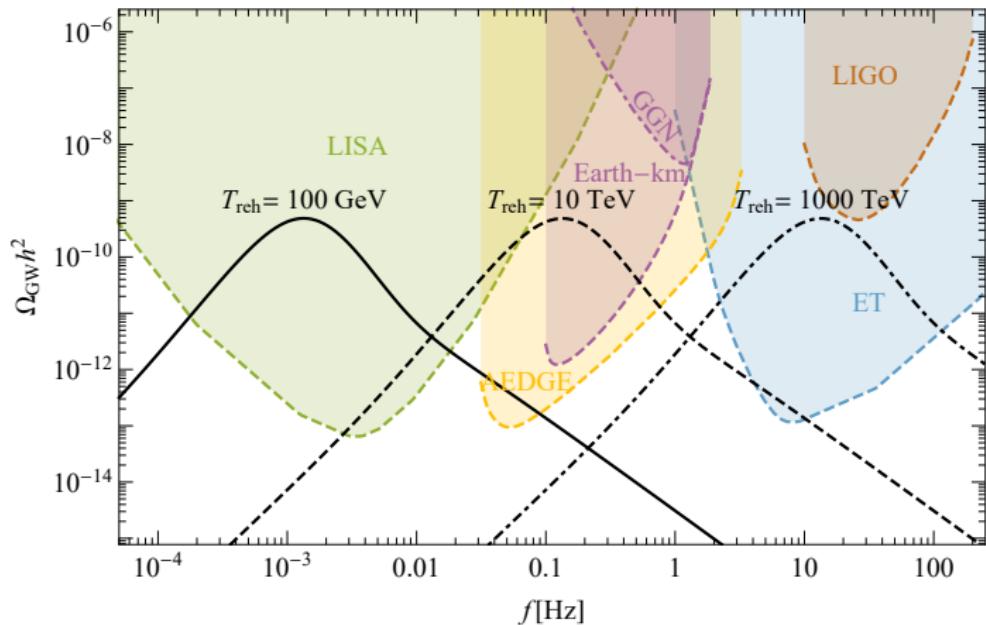


- Root-mean-square four-velocity of the plasma

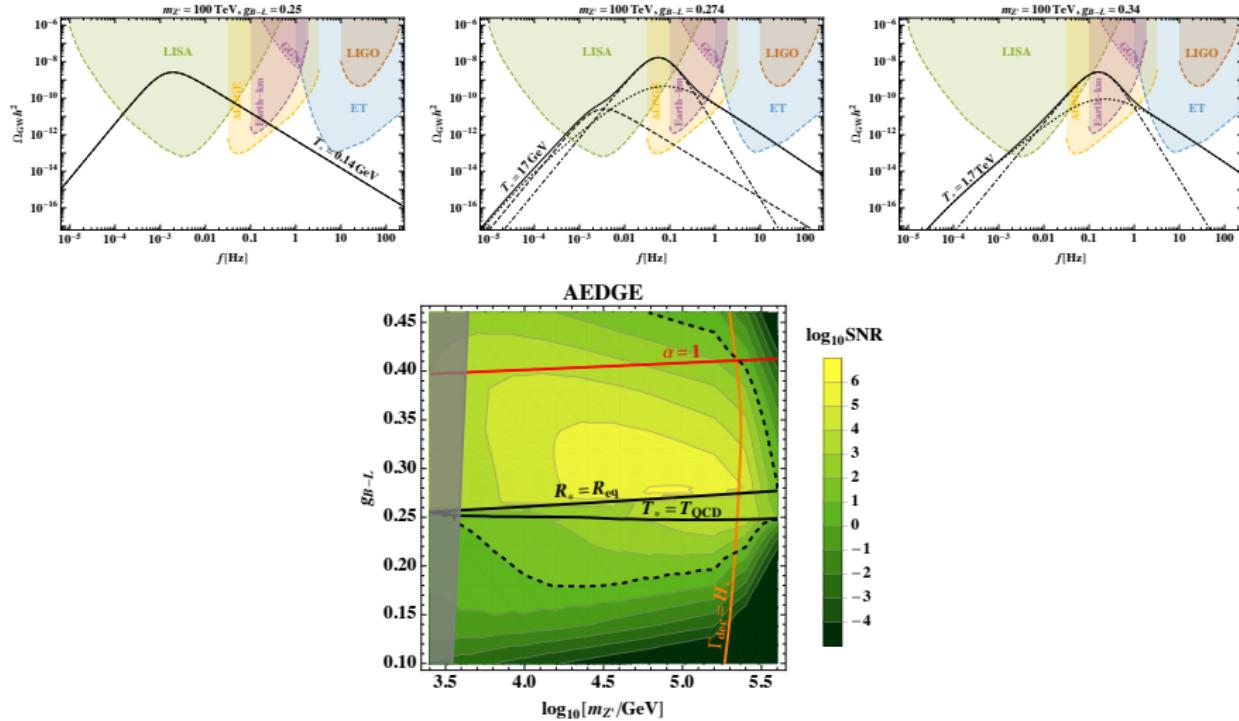
$$\bar{U}_f \approx \sqrt{\frac{3}{4} \frac{\kappa_{\text{sw}} \alpha}{1 + \alpha}} \xrightarrow{v_w \approx 1} \frac{\sqrt{3} \alpha}{2(1 + \alpha) \sqrt{0.73 + 0.083\sqrt{\alpha} + \alpha}}.$$

Frequency to temperature relation

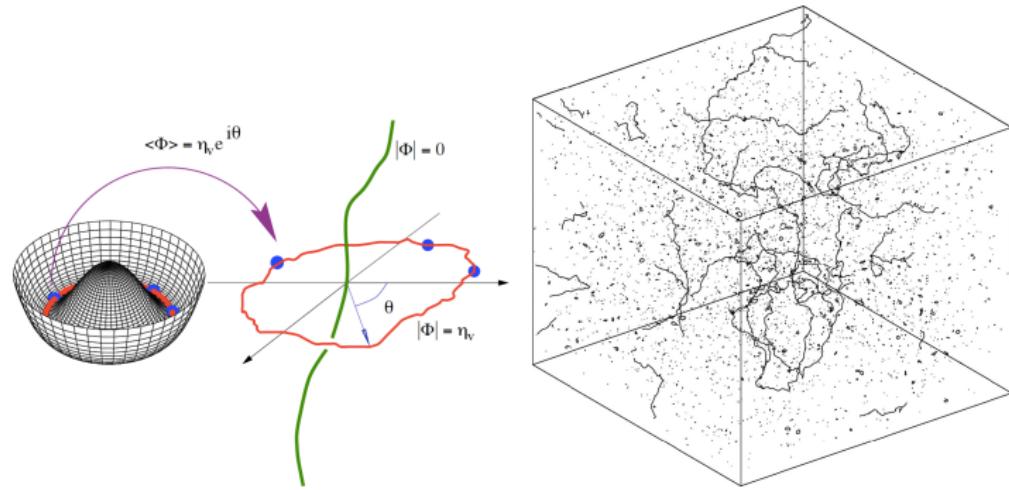
$$\alpha=1/2, HR_*=10^{-1}$$



Supercooling and bubble collision signal



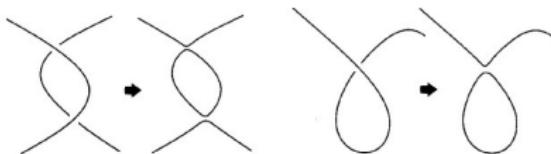
Cosmic Strings



Christophe Ringeval (Adv.Astron. 2010)

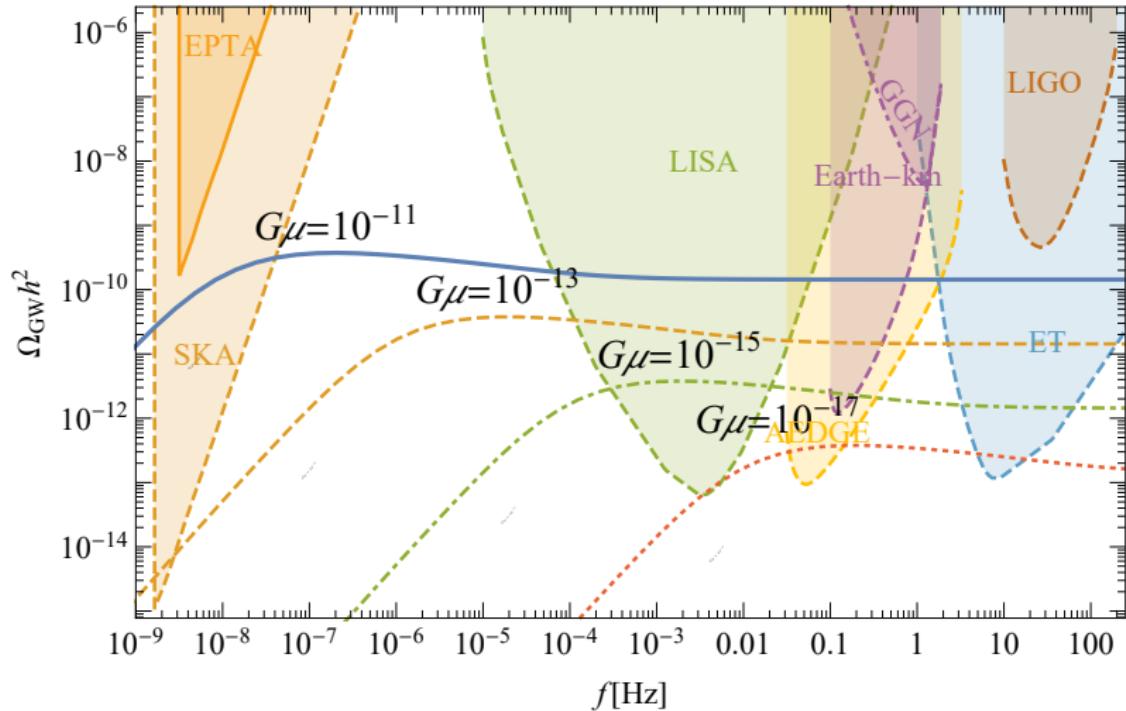
Vilenkin and Shellard '94

- strings intercommute on collision



- Loops decay producing GWs

Cosmic Strings GW signals

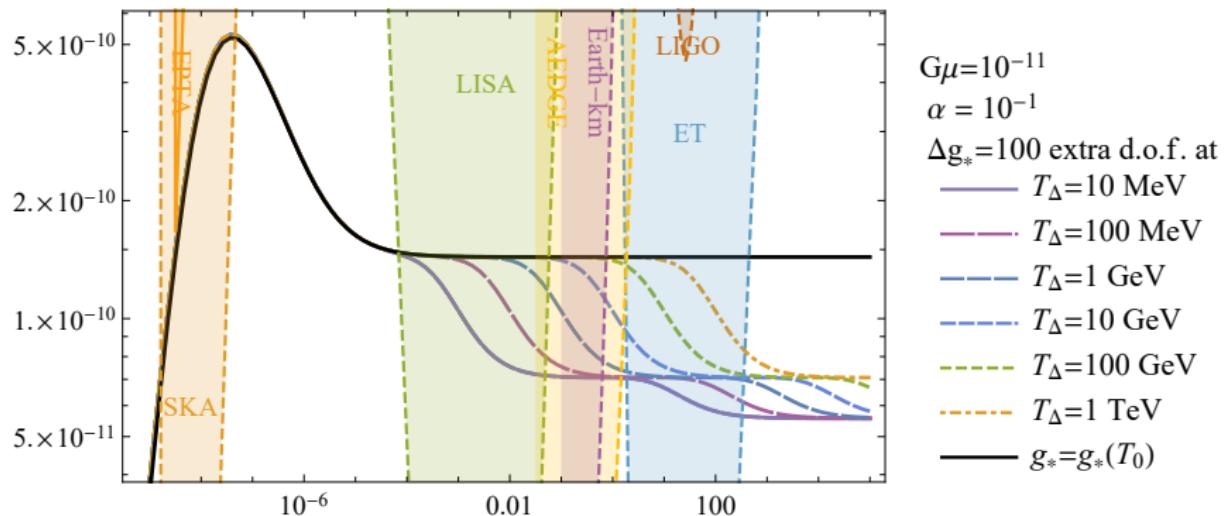


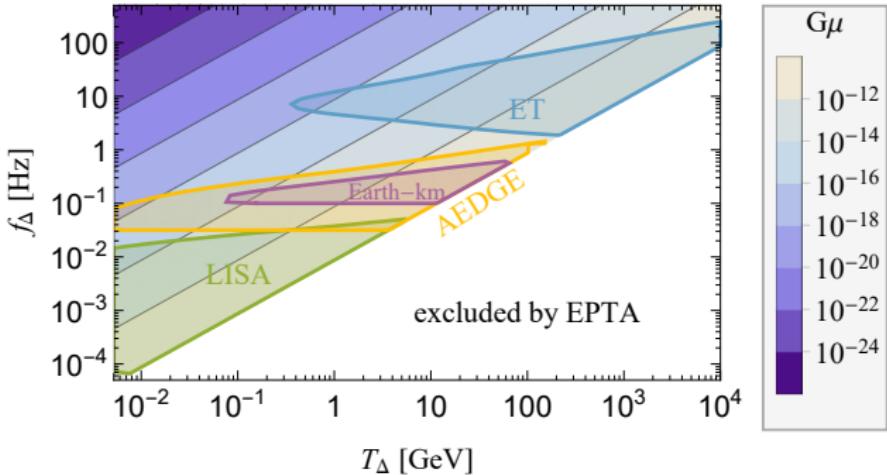
Cosmic Strings GW signal and expansion history

- We add Δg_* new degrees of freedom at T_Δ

$$g_*(T) = \begin{cases} g_*(T_0) & \text{for } T < T_\Delta \\ g_*(T_0) + \Delta g_* & \text{for } T > T_\Delta \end{cases}$$

- An example with $\Delta g_* = 100$





- frequency temperature relation

$$f_{\Delta} = (8.67 \times 10^{-9} \text{ Hz}) \frac{T_{\Delta}/\text{GeV}}{\sqrt{\alpha} G\mu} \left(\frac{g_*(T_{\Delta})}{g_*(T_0)} \right)^{\frac{8}{6}} \left(\frac{g_S(T_0)}{g_S(T_{\Delta})} \right)^{-\frac{7}{6}}$$

Masses in the Stellar Graveyard

in Solar Masses

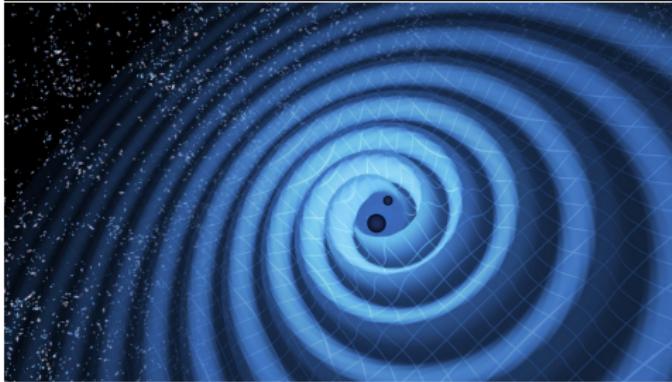
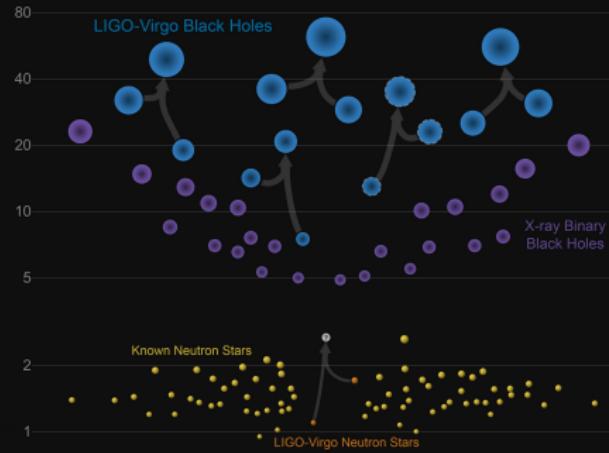
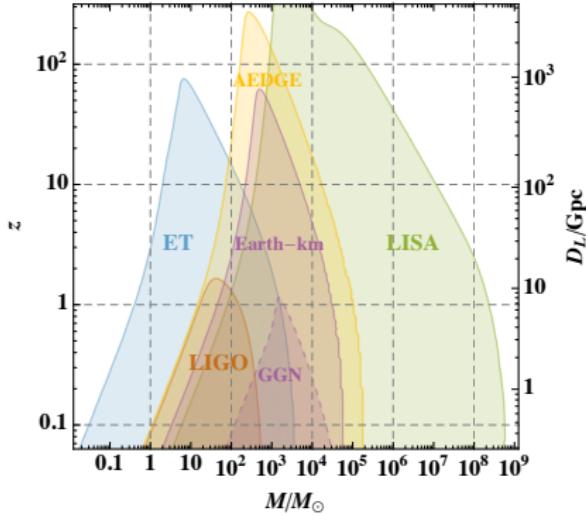
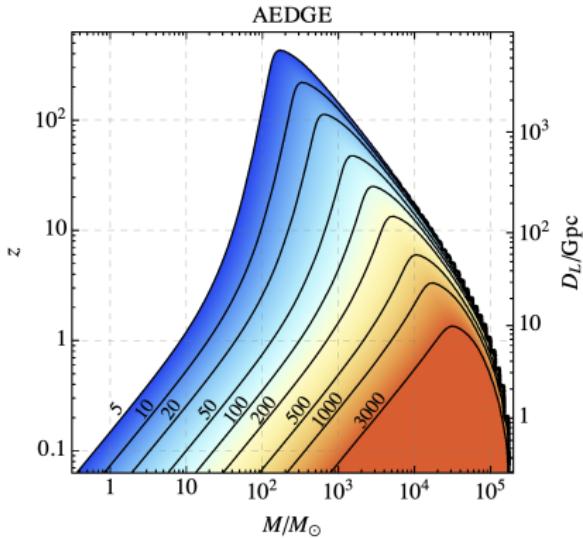
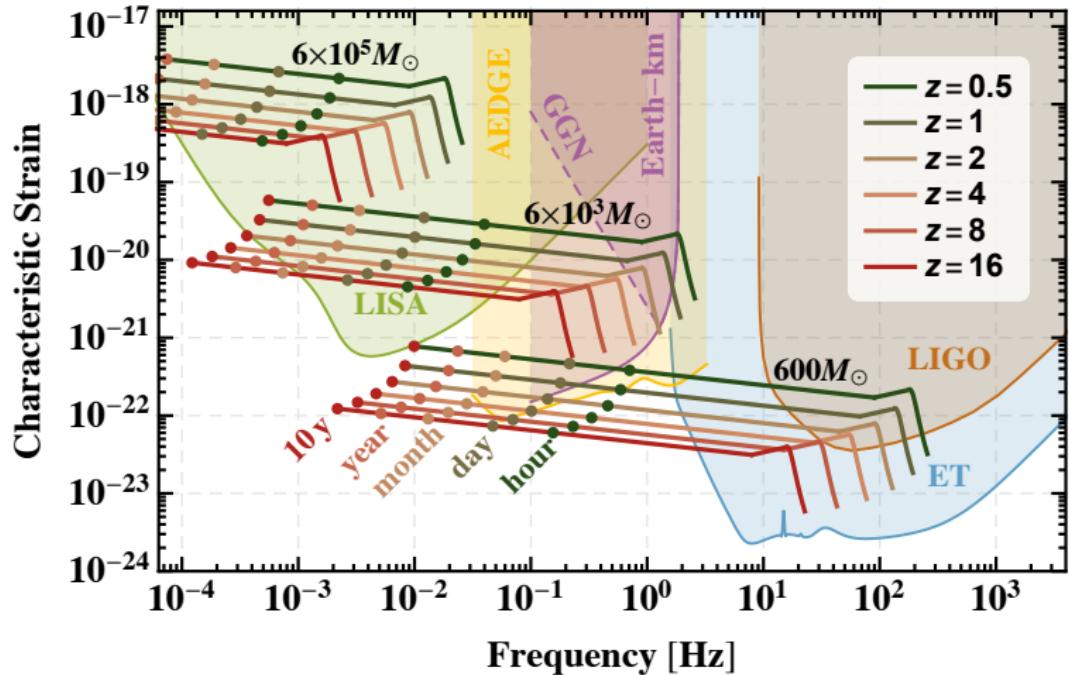


Image credit: LIGO-Virgo/Frank Elavsky/Northwestern University and LIGO/T. Pyle

AEDGE detection capabilities



- $\mathcal{O}(20)$ mergers of $\sim 10^4$ solar-mass BHs are expected per year within $z \sim 3$ observable with $\text{SNR} \gtrsim 1000$
- several hundred mergers of $\sim 10^3$ solar-mass BHs within $z \sim 100$ are expected per year which would be observable with $\text{SNR} \gtrsim 20$



- We indicate time before the merger as a function of frequency

Conclusions

- Wide coverage in frequencies is crucial for probing the evolution of the Universe via GW signals from cosmological sources. This crucially includes the mid frequency band at which AEDGE is aimed.
- Probing the mid frequency band is optimal for probing collisions of black holes with masses between those detected by LIGO and super massive black holes that may be observed by LISA, as well as earlier evolution of LIGO binaries paving the way to multi messenger astronomy.