Sources and Detection Prospects for GHz Gravitational Waves

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MITP workshop *Probing New Physics with Gravitational Waves*

based on [Berlin, Blas, D'Agnolo, Ellis, Harnik, Kahn, **JSE** 21]

03.08.2022

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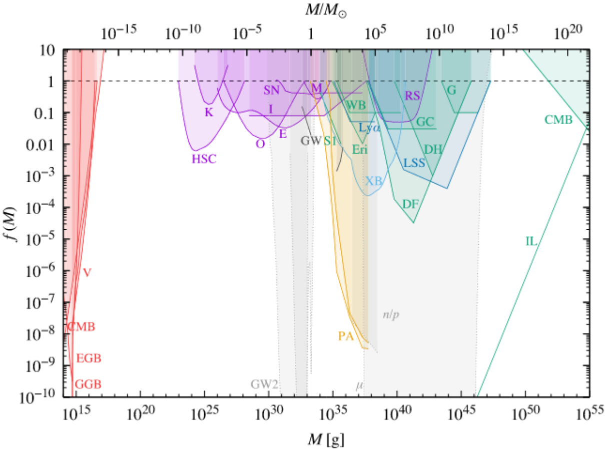
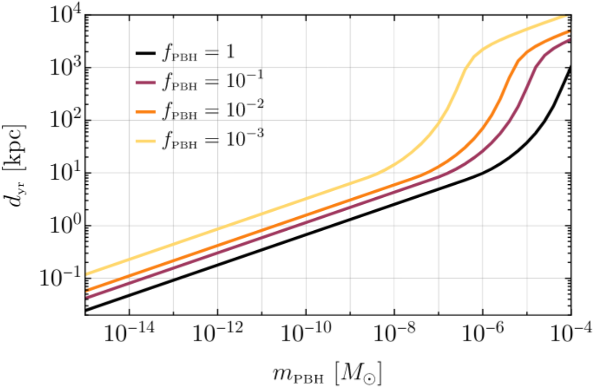
PBHs as dark matter: constraints



[Carr et al. 21]

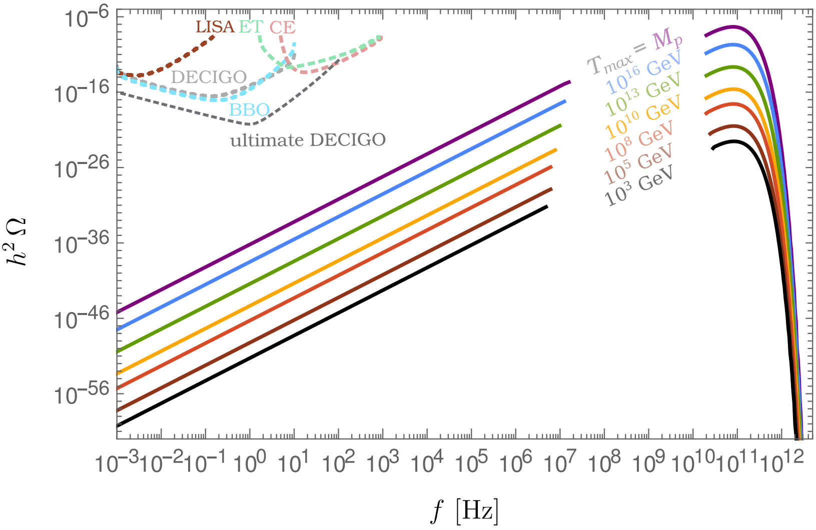
Evaporation (red), lensing (magenta), dynamical effects (green), gravitational waves (black), accretion (light blue), CMB distortions (orange), large-scale structure (dark blue) and background effects (grey).

PBHs merger rate



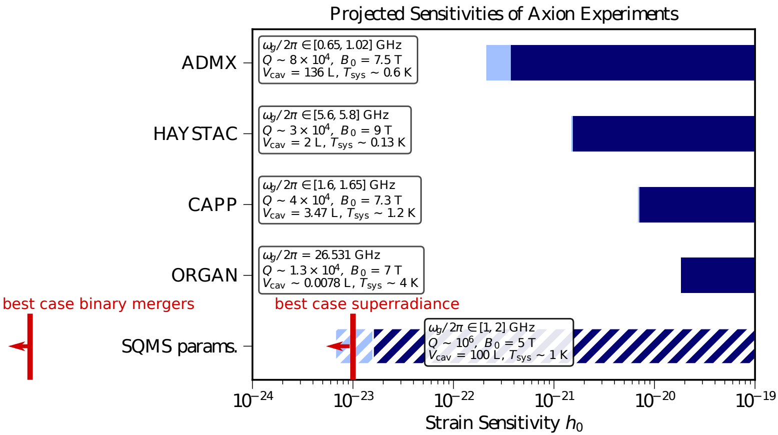
[Franciolini et al. 2205.02153]

CGMB spectrum



[Ringwald, **JSE**, Tamarit 20]

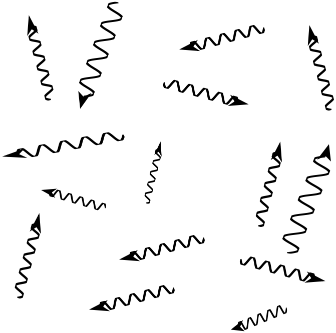
Sensitivity of existing axion experiments



[Berlin, Blas, D'Agnolo, Ellis, Harnik, Kahn, **JSE** 21]

Existing axion experiments only need to reanalyze their data!

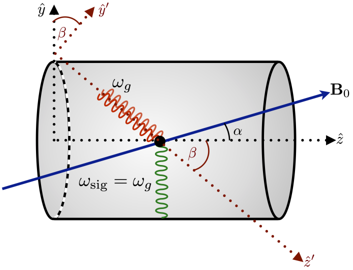
Sensitivity to stochastic GW background



- $\mathrm{SNR} = \frac{S_{\mathrm{sig}}}{S_{\mathrm{noise}}} = \frac{\omega_n Q}{4\pi T} |\eta|^2 B_0^2 V_{\mathrm{cav}} S_h(\omega_g)$
- $\Omega_{\mathrm{GW}}(\omega) = \frac{2}{3} \frac{\omega^3}{H_0^2} S_h(\omega)$

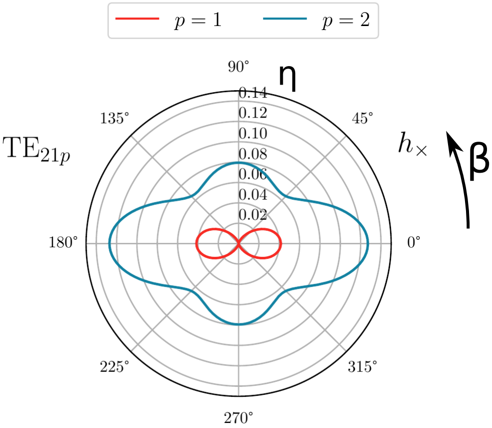
- $\Omega_{\mathrm{GW}} = 8 \times 10^{10} \times \left(\frac{(0.2)^2}{|\eta|^2}\right) \left(\frac{10\,\mathrm{T}}{B_0}\right)^2 \left(\frac{\omega_n}{1\,\mathrm{GHz}}\right)^2 \left(\frac{1\,\mathrm{m}^3}{V_{\mathrm{cav}}}\right) \left(\frac{10^{12}}{Q}\right) \left(\frac{T_{\mathrm{sys}}}{10\,\mathrm{mK}}\right)$
- Cosmologically produced GW backgrounds $\Omega_{\mathrm{GW}} < 10^{-6}$
- Without tricks the detection prospects are not great for stochastic GW backgrounds.

Why the frame matters



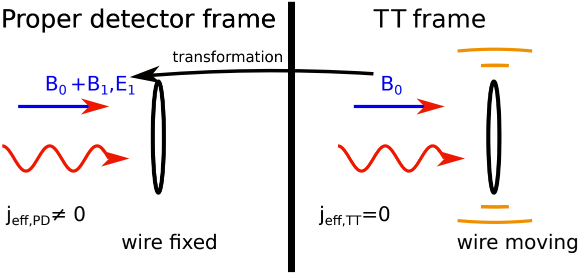
If TT-frame metric is used:
$\alpha = 0, \beta = 0 \Rightarrow \boldsymbol{j}_{\rm eff} = 0 \Rightarrow$ No signal.
But this is wrong!

Proper detector frame result ($\alpha = 0$)



[Berlin, Blas, D'Agnolo, Ellis, Harnik, Kahn, **JSE** 21]

Toy example



$$t_{TT} \simeq t - \tfrac{i}{4}\,\omega_g\,(x^2 - y^2)\,h_+\,e^{i\omega_g t} \;,\quad x_{TT} \simeq x - \tfrac{1}{2}\,x\,(1 - i\omega_g z)\,h_+\,e^{i\omega_g t} \;.$$
$$y_{TT} \simeq y + \tfrac{1}{2}\,y\,(1 - i\omega_g z)\,h_+\,e^{i\omega_g t} \;,\quad z_{TT} \simeq z - \tfrac{i}{4}\,\omega_g\,(x^2 - y^2)\,h_+\,e^{i\omega_g t}$$

- Wire $U_\mu = (1, 0, 0, 0)$
- Signal: E^1 induces current in wire

$$\boldsymbol{E} \simeq \frac{i}{2}\,B_0\,\omega_g\,h_+\,e^{i\omega_g t}\,(y, x, 0),\, J_{\mathrm{sig,PD}} = \sigma\boldsymbol{E}$$

- Wire moves $U_{TT,\mu} \neq (1, 0, 0, 0)$
- Signal: moving wire in static B-field induces current in wire

$$J^i_{\mathrm{sig,TT}} \simeq \frac{i}{2}\,\sigma\,B_0\,\omega_g\,h_+\,e^{i\omega_g t}\,(y, x, 0)$$

Conclusions

- High frequency GWs very well motivated
- Cavities cannot probe PBH inspirals but test best case PBH superradiance scenarios
- Detection of stochastic GW background with cavities is out of reach
- Signal calculation in cavity: Use proper detector frame metric resummed to all orders
- Existing axion experiments only need to reanalyze data to set limits.

Thank you for your attention

Backup