

Gravitational Waves as a Big Bang Thermometer

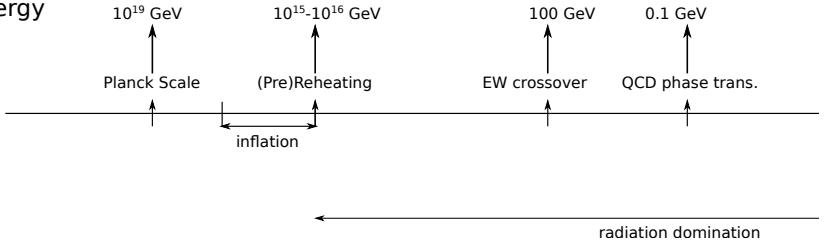
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based on JCAP 03 (2021) 054

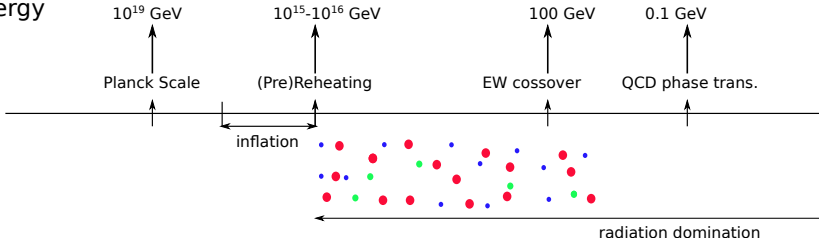
May 19, 2021

Introduction

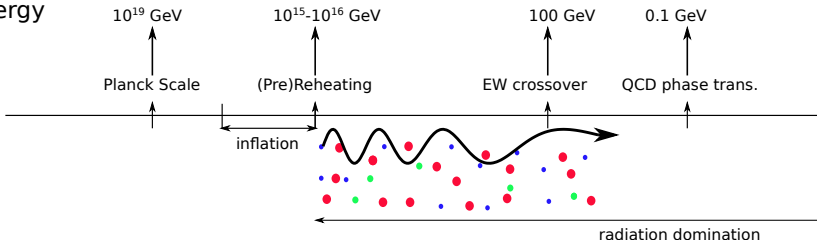
Energy



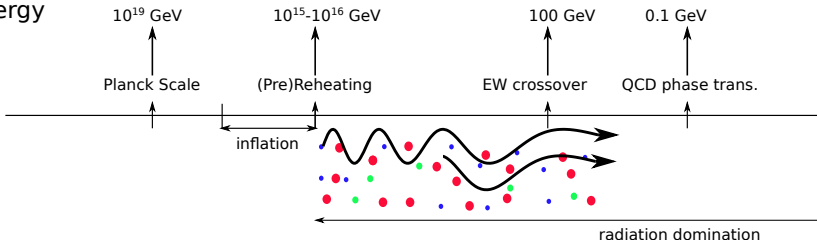
Energy



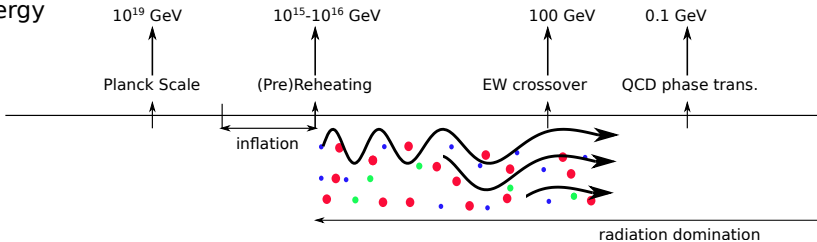
Energy



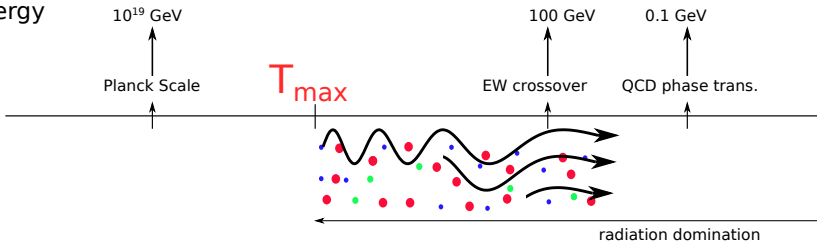
Energy



Energy



Energy



GW production in primordial plasma

GW production in primordial plasma

Energy density of produced GWs from thermal plasma:

$$(\partial_t + 4H)\rho_{\text{CGMB}} = \frac{1}{2M_p^2} \int \frac{d^3k}{(2\pi)^3} \int d^4x e^{ikx} \langle T_{ij}^{TT}(x) T_{ij}^{TT}(0) \rangle =: \frac{4T^4}{M_p^2} \int \frac{d^3k}{(2\pi)^3} \hat{\eta}(T, \frac{k}{T})$$

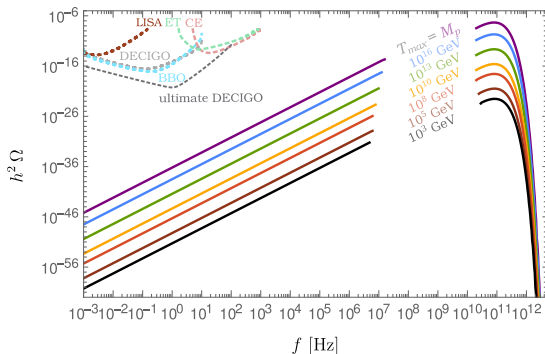
- Computation for SM to leading log accuracy [Ghiglieri, Laine 15] and to full leading order [Ghiglieri, Jackson, Laine, Zhu 20]
- We do the computation for arbitrary theories and specifically for ν MSM, SMASH and MSSM

$$\hat{\eta}\left(T, \frac{k}{T} \equiv \hat{k}\right) \simeq \begin{cases} \frac{\bar{\eta}}{g_1(T)^4 \ln(5/\hat{m}_1)}, & \hat{k} \lesssim \alpha_1^2, \\ \hat{\eta}_{\text{HTL}}(T, \hat{k}) + \sum_{n=1}^{\mathcal{N}_g} g_n(T)^2 N_n \left(\frac{1}{2} T_{n,\text{Ad}} \eta_{gg}(\hat{k}) \right. \\ \left. + \sum_{\hat{i}} T_{n,\hat{i}} \eta_{sg}(\hat{k}) + \frac{1}{2} \sum_{\hat{\alpha}} T_{n,\hat{\alpha}} \eta_{fg}(\hat{k}) \right) & \hat{k} \gtrsim \max\{\hat{m}_n\}. \\ + \frac{1}{4} \sum_{i\alpha\beta} |y_{\alpha\beta}^i(T)|^2 \eta_{sf}(\hat{k}), \end{cases}$$

GW production in primordial plasma

$$\Omega_{\text{CGMB}}(f) \simeq \frac{1440\sqrt{10}}{2\pi^2 M_P} \Omega_\gamma [g_{*s}(\text{fin})]^{1/3} \frac{f^3}{T_0^3} \times$$

$$\times \int_{T_{\text{ewco}}}^{T_{\text{max}}} dT \frac{g_{*c}(T)}{[g_{*s}(T)]^{4/3} [g_{*\rho}(T)]^{1/2}} \hat{\eta} \left(T, 2\pi \left[\frac{g_{*s}(T)}{g_{*s}(\text{fin})} \right]^{1/3} \frac{f}{T_0} \right)$$



GW production in primordial plasma

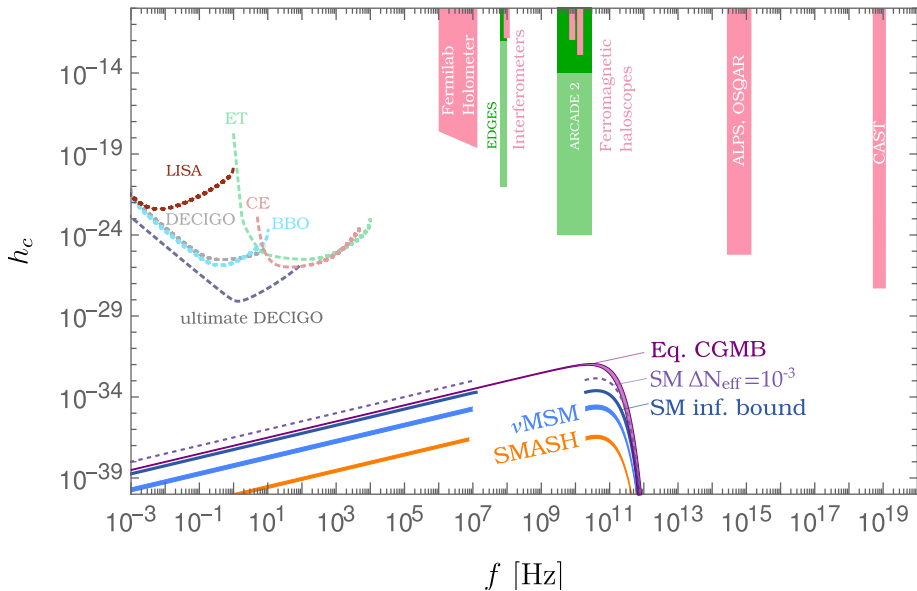
$$\Omega_{CGMB}(f_{\text{peak}}) \approx 2.7 \times 10^{-8} \left(\frac{g_{*s}(T_{\text{max}})}{106.75} \right)^{-11/6} \frac{T_{\text{max}}}{M_p} \times (\text{model dep. factor})$$

$$f_{\text{peak}}(T_{\text{max}}) \approx 79.8 \text{ GHz} \left[\frac{\hat{k}_{\text{peak}}^{\Omega}(T_{\text{max}})}{4.22} \right] \left[\frac{106.75}{g_{*s}(T_{\text{max}})} \right]^{\frac{1}{3}},$$

Cosmic Gravitational Microwave Background (CGMB)

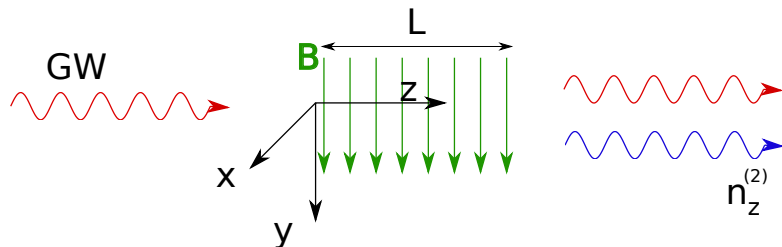
characteristic amplitude:

$$h_c(f) = 1.26 \times 10^{-18} \left[\frac{\text{Hz}}{f} \right] \times \sqrt{h^2 \Omega_{\text{GW}}^{(0)}(f)}.$$



Direct detection of the CGMB

Magnetic conversion

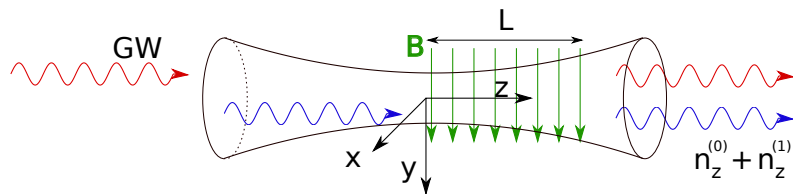


[Gertsenshtein]

Single photon detection:

$$\begin{aligned}
 \left[h_c^{\text{CGMB}} \right]_{\text{sens}}^{\text{SPD}} &\simeq 7.71 \times 10^{-24} \left[\frac{\text{S/N}}{2} \right]^{1/2} \left[\frac{\pi \times 10^7 \text{ s}}{\Delta t} \right]^{1/4} \left(\frac{10^{-4} \text{ eV}}{\Delta \omega} \right)^{1/2} \times \\
 &\times \epsilon^{-1/2} \left[\frac{\Gamma_D}{10^{-3} \text{ Hz}} \right]^{1/4} \left[\frac{\text{T}}{B} \right] \left[\frac{\text{m}}{L} \right] \left[\frac{\text{m}^2}{A} \right]^{1/2} .
 \end{aligned}$$

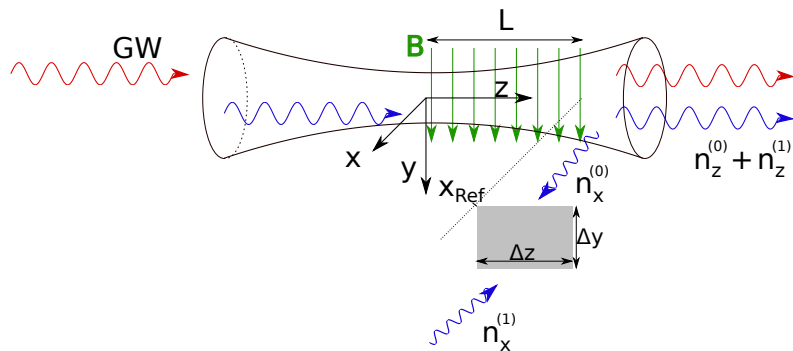
Magnetic conversion with Gaussian beam



[Li et al.]

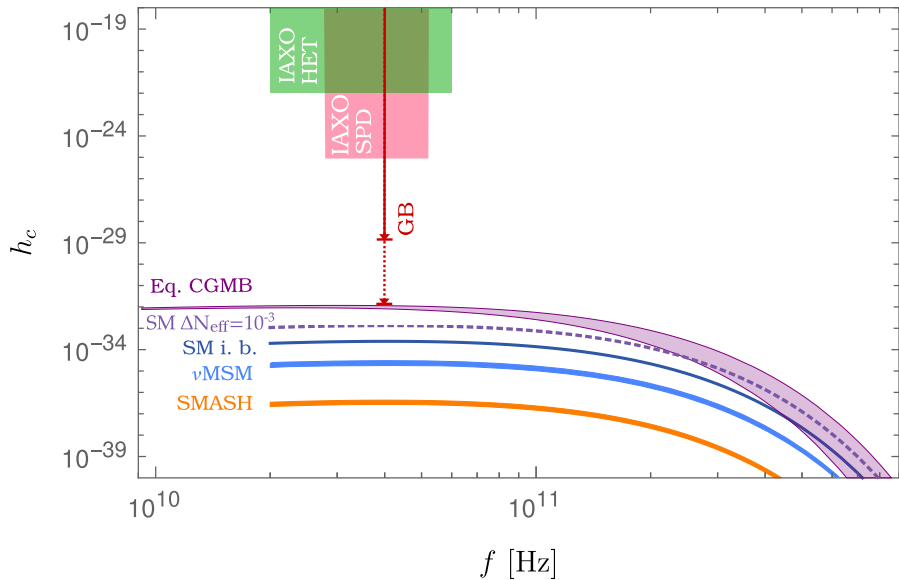
We get first order flux, but... Noise much larger than in inverse Gertsenshtein setup

Magnetic conversion with Gaussian beam



[Li et al.]

$$\begin{aligned}
 [h_c^{\text{CGMB}}]_{\text{sens}}^{\text{GB}} &\simeq 4.02 \times 10^{-29} \eta^{-1} \left[\frac{\text{S/N}}{2} \right] \left[\frac{10^4 \text{ s}}{\Delta t} \right]^{1/2} \left[\frac{10^{-6}}{\frac{\Delta f_0}{f_0}} \right] \left[\frac{10^{-5}}{\mathcal{F}_x^{(1)}(x_{\text{Ref}})} \right] \\
 &\times \epsilon^{-1} \left[\frac{\Gamma_D}{10^{-3} \text{ Hz}} \right]^{1/2} \left[\frac{5 \times 10^5 \text{ V/m}}{E_0} \right] \left[\frac{10 \text{ T}}{B_y^{(0)}} \right] \left[\frac{5 \text{ m}}{L} \right] \left[\frac{0.01 \text{ m}^2}{\Delta y \Delta z} \right]
 \end{aligned}$$



- Guaranteed CGMB peaks in the GHz region
- CGMB scales with maximum temperature: $\Omega_{\text{CGMB}} \sim T_{\text{max}}$
- Probe particle physics models at T_{max} because $f_{\text{peak}} \sim (g_{*s})^{-1/3}$
- Prospect to probe inflation
- Detection possible but challenging
- Synergies to axion search experiments

Thanks for your attention