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Stochastic Gravitational Waves from Modulated Reheating

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Introduction and Setup

We investigate small-scale primordial perturbations sourced by spectator scalar field χ

$$\mathcal{L} = \underbrace{-\frac{1}{2}\nabla^{\mu}\phi\nabla_{\mu}\phi - \Lambda_{\phi}^{4}\left(1 - e^{-\sqrt{2/3}\,\phi/M_{\mathrm{P}}}\right)^{2}}_{\phi\ =\text{Inflaton field}} \underbrace{-\frac{1}{2}\nabla^{\mu}\chi\nabla_{\mu}\chi - \frac{1}{2}\xi R\chi^{2} - \frac{1}{4}\lambda\chi^{4}}_{\chi\ =\ \text{Spectator}} + \underbrace{\mathcal{L}_{\mathrm{dec}}(\phi,\chi,X)} + \ldots$$

Modulated Reheating: a mechanism for generating curvature perturbations

Vector $\quad \mathrm{m}_{A} = \frac{g}{2}\chi \qquad \Gamma^{(A)} = \frac{m_{\phi}^{3}}{4\pi\Lambda_{1}^{2}}\left(1 - \frac{g^{2}\chi^{2}}{m_{\phi}^{2}}\right)^{3/2}$

Fermion $\quad \mathrm{m}_{\psi} = \frac{y_{\psi}}{\sqrt{2}}\chi \qquad \Gamma^{(\psi)} = \frac{m_{\phi}m_{\psi_{I}}^{2}}{2\pi\Lambda_{2}^{2}}\left(1 - \frac{2y_{\psi}^{2}\chi^{2}}{m_{\phi}^{2}}\right)^{1/2}$

← Two scenarios

$$\boldsymbol{\delta\chi(x)} \longrightarrow \boldsymbol{\delta\Gamma(x)} \longrightarrow \boldsymbol{\delta N(x)}$$

Dvali, Gruzinov & Zaldarriaga (2004), Phys. Rev.

Curvature Perturbation

ΔN formalism *Sasaki & Stewart (1996), Prog. Theor. Phys.*

$$\zeta(\mathbf{x}) = N(\phi(\mathbf{x}), \chi(\mathbf{x})) - \langle N(\phi(\mathbf{x}), \chi(\mathbf{x}))\rangle$$

$\langle\chi\rangle = 0$ and $N(\phi, \chi)$ is even in χ → **ζ is non-Gaussian**

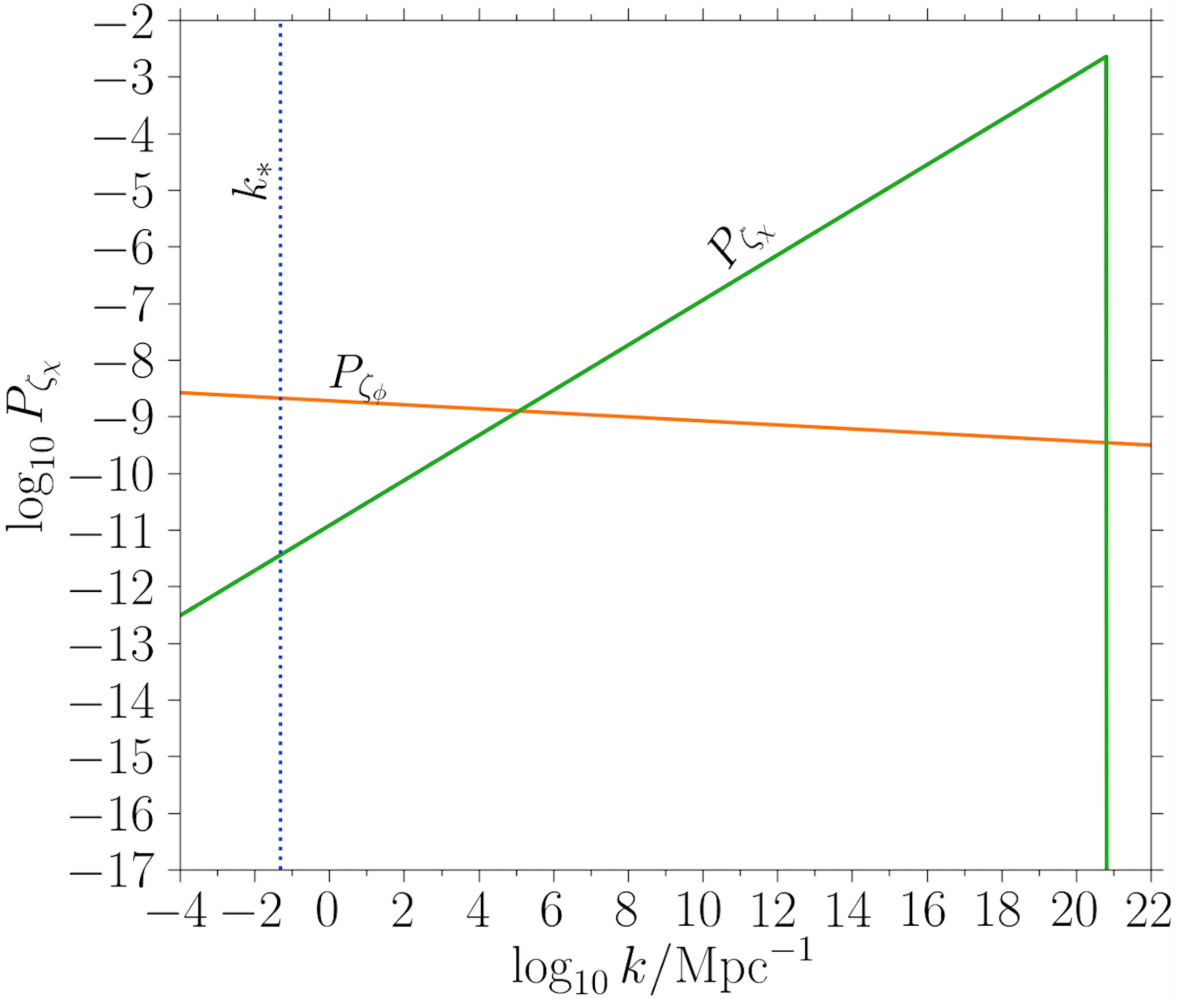
Expanding in $\delta\phi$ and considering $\langle\zeta_\chi\zeta_\phi)\rangle = 0$ $\langle\delta\chi\phi^n\rangle = 0$

$$\mathrm{P}_\zeta = \mathcal{P}_{\zeta\chi} + \mathcal{P}_{\zeta\phi}$$

Appling the **stochastic formalism** and using the **spectral expansion** we obtain:

$$\mathrm{P}_{\zeta\chi} \propto k^{n_s-1} \qquad \mathrm{n}_s - 1 > 0$$

$$\mathrm{P}_{\zeta_\phi}(k) = \frac{M_\mathrm{P}^{-2}}{2\epsilon(t_k)}\left(\frac{H(t_k)}{2\pi}\right)^2$$



Starobinsky & Yokoyama, Phys. Rev. (1994)

Gravitational Wave signals

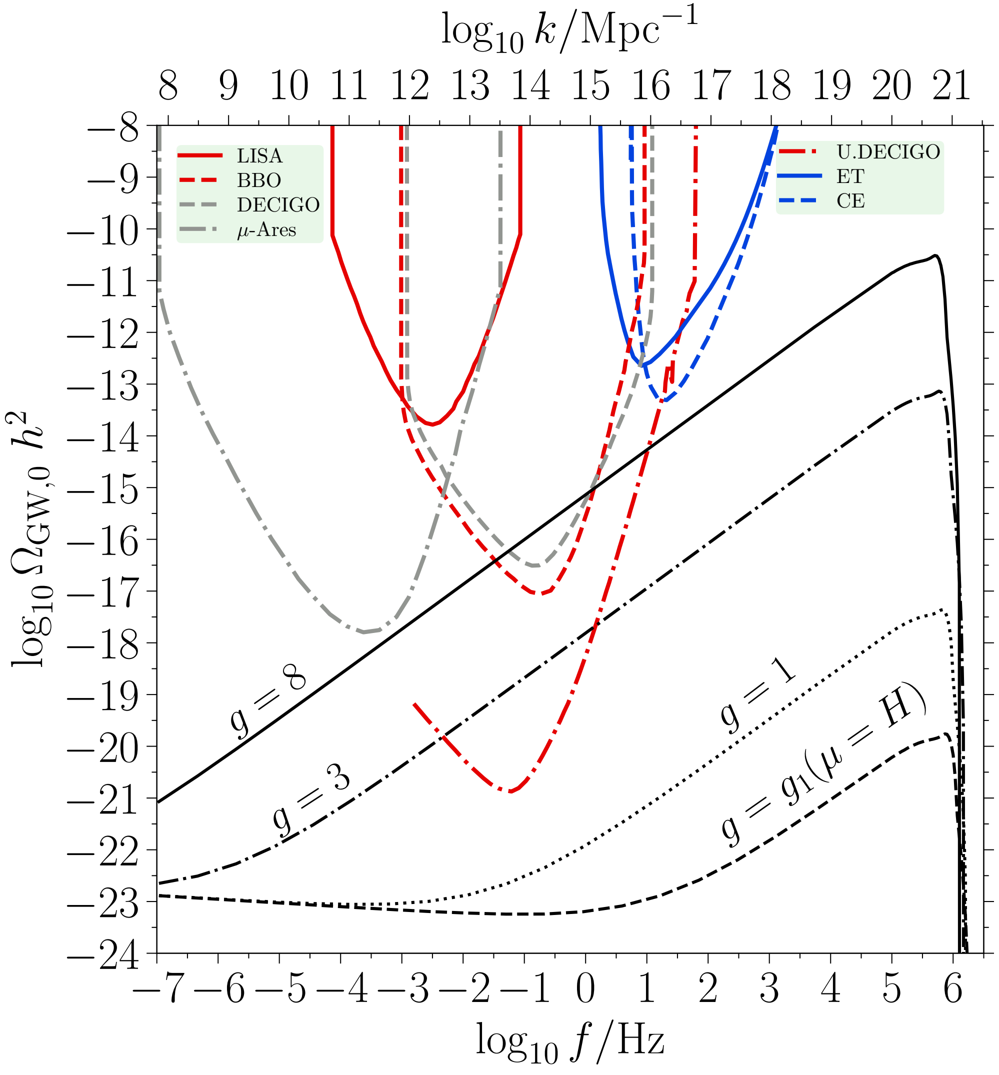
$$h''_\lambda(\tau,k) + \frac{2}{\tau} h'_\lambda(\tau,k) + k^2 h_\lambda(\tau,k) = 4\mathcal{S}_\lambda(\tau,k)$$

$\mathcal{S}_\lambda$ = Source

Contains combination of Φ squared (scalar perturbation)

$$\Phi_{\mathbf{k}}(\tau) = \frac{2}{\left(k\tau/\sqrt{3}\right)^3}\left(\sin\frac{k\tau}{\sqrt{3}} - \frac{k\tau}{\sqrt{3}}\cos\frac{k\tau}{\sqrt{3}}\right)\zeta(k)$$

$$\Omega_{\mathrm{GW}}(\tau,k) = \frac{1}{3H(\tau)^2 M_{\mathrm{P}}^2}\frac{d\rho_{\mathrm{GW}}(\tau)}{d\log k}$$

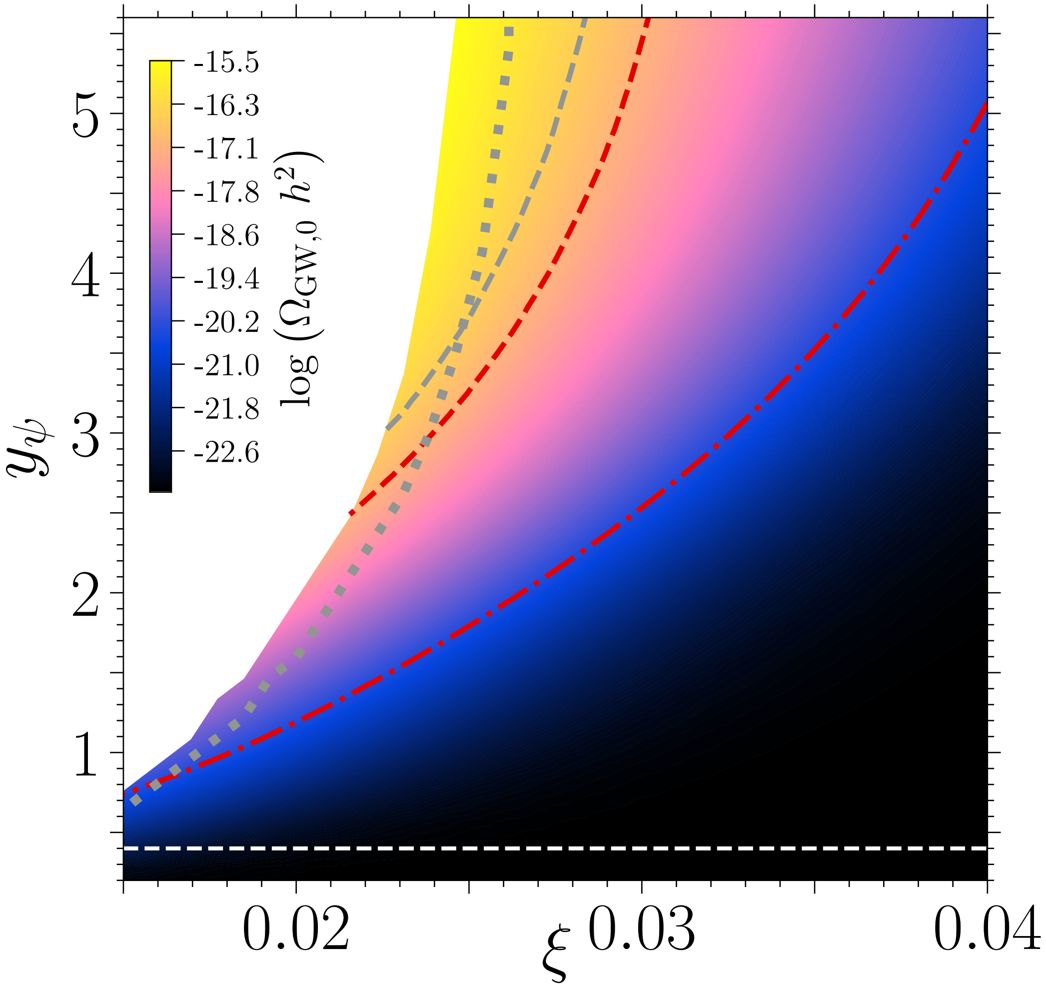


sensitivity curves for signal-to-noise ratio SNR = 1 from: K. Schmitz JHEP 01 (2021), M. Braglia and S. Kuroyanag Phys. Rev. D (2021)

Results

es

Fermion



Vector