ANISOTROPIES in the GWB from Preheating

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0. PREHEATING $\Rightarrow$ GW

1. ANISOTROPIES in the GW from PREHEATING
Reheating: Inflaton decay into other d.o.f.

INFLATION $\rightarrow$ REHEATING $\rightarrow$ BIG BANG THEORY

BIG BANG

INFLATION

REHEATING

STANDARD
BIG BANG
THEORY
BASICs of REHEATING: \( V = V(\phi) + \frac{1}{2} g^2 \phi^2 \chi^2 \)

Inflaton Dynamics After Inflation:

Coherent Oscillations: \( \phi(t) \approx \Phi(t)f(t), \quad f(t + T) = f(t) \)
BASICs of REHEATING: \( V = V(\phi) + \frac{1}{2} g^2 \phi^2 \chi^2 \)

**Preheating**: \( \phi \rightarrow \chi \) (Param. Resonance: Out-of-Eq. & Non-Pert.)

\[
\chi''_k + 3H \chi'_k + \left[ \frac{k^2}{a^2} + g^2 \Phi^2 f^2(t) \right] \chi_k = 0 \quad \Rightarrow \quad \chi_k \sim e^{\mu_k (g^2, ...) t}
\]
BASICs of REHEATING: \( V = V(\phi) + \frac{1}{2}g^2\phi^2\chi^2 \)

Consequences of pREHEATING:
\[
\varphi_k(t) \sim e^{\mu_k t} \leftrightarrow k_i \pm \Delta k_i \Rightarrow \nabla \chi \Rightarrow (\nabla_i \chi \nabla_j \chi) = \Pi_{ij}
\]

\[
h''_{ij} + 3H h'_{ij} + a^{-2} \nabla^2 h_{ij} = 16\pi G \Pi^{TT}_{ij}
\]

GW spectra \((V(\phi) = \frac{\lambda}{4}\phi^4, \frac{g^2}{\lambda} = 120)\)
Anisotropies in the GW amplitude?

If \( m_X^2 < H_*^2 \) \( \Rightarrow \) \( P_X = \frac{H_*^2}{4\pi^2} \) (Scale-Inv Spectrum)

\[
V = \frac{\lambda}{4} \phi^4 + \frac{1}{2} g^2 \phi^2 \chi^2: \quad m_X^2 < H_*^2 \ \Leftrightarrow \ g^2/\lambda \lesssim 2
\]

@ Preheating: \( \chi = \chi_i + \left( \int dk \ e^{-ikx} \chi_k \right) \), \( \frac{\partial \langle |\chi_i|^2 \rangle}{\partial \log k} = P_X \equiv \frac{H_*^2}{4\pi^2} \)

\( (k < H_*) \quad (k > H_*) \)
Anisotropies in the GW amplitude?

\[ \Omega_{GW}(\chi_i(\hat{n})) = c_o + c_1 \cdot \frac{\delta \chi_i}{H*}, \quad \delta \chi_i \equiv \chi_i - \bar{\chi}_i \]

\[ \delta \Omega_{GW} \equiv \left( \Omega_{GW}/\bar{\Omega}_{GW} - 1 \right) = \frac{c_1}{c_o} \cdot \frac{\delta \chi_i}{H*}, \quad \Rightarrow \quad P_{GW} = \frac{c_1^2}{c_o^2} \frac{P_{\chi}}{H^2} = \frac{c_1^2}{4\pi^2 c_o^2} \]

GWB Angular Power Spectrum: \[ l(l + 1)C_l = \frac{\pi}{2} P_{GW} = \frac{1}{8\pi} \frac{c_1^2}{c_o^2} \]
$V = \frac{\lambda}{4} \phi^4 + \frac{1}{2} g^2 \phi^2 \chi^2 \Rightarrow \text{GW spectra \ (} g^2/\lambda = 2 \text{)}$
\[ \left\langle \Omega_{GW}(\chi_i^{(1)})\Omega_{GW}(\chi_i^{(2)}) \right\rangle \equiv \int d\vec{\chi}_i \, P(\chi_i^{(1)}, \chi_i^{(2)}) \Omega_{GW}(\chi_i^{(1)})\Omega_{GW}(\chi_i^{(2)}) \]

\[ P(\chi_i^{(1)}, \chi_i^{(2)}) \propto e^{-\frac{1}{2} \delta \chi_i^T G^{-1} \delta \chi_i}, \quad \left\{ \begin{array}{l} \delta \chi_i^T \equiv (\chi_i^{(1)} - \bar{\chi}_i, \chi_i^{(2)} - \bar{\chi}_i) \\ G_{ab} \equiv \langle (\chi_i^{(a)} - \bar{\chi}_i)(\chi_i^{(b)} - \bar{\chi}_i) \rangle \end{array} \right. \]

\[ \left\langle \Omega_{GW}(\chi_i^{(1)})\Omega_{GW}(\chi_i^{(2)}) \right\rangle \approx \langle \Omega_{GW} \rangle^2 + \langle \delta \chi_i \Omega_{GW} \rangle^2 \frac{G_{12}}{G_{11}^2} + \ldots \]

\[ \Rightarrow \text{Lin. Ansatz :} \quad \left\{ \begin{array}{l} c_0 \equiv \langle \Omega_{GW} \rangle \\ c_1 \equiv \langle \delta \chi_i \Omega_{GW} \rangle \end{array} \right. \quad \Rightarrow \quad l(l + 1)C_l = \frac{\langle \delta \chi_i \Omega_{GW} \rangle^2}{\langle \Omega_{GW} \rangle^2} \frac{H_*^2}{8\pi\sigma_*^4} \]

\[ (\sigma_*^2 = \int_{a_0H_0}^{H_*} \frac{dk}{k} \mathcal{P}_\chi = \frac{H_*^2}{4\pi^2} N_{\text{CMB}}) \]
\begin{align*}
V &= \frac{\lambda}{4} \phi^4 + \frac{1}{2} g^2 \phi^2 \chi^2 \\
\Rightarrow \quad \Omega_{GW}(\chi_i; g^2/\lambda = 2)
\end{align*}
GW Angular power spectrum \( \left( \frac{\lambda}{4} \phi^4 + \frac{g^2}{2} \phi^2 \chi^2 \right) \), \( g^2/\lambda = 2 \)

\[ \sqrt{l(l+1)C_l} = 0.017 \pm 0.008 \]
Conclusions

1. **ANISOTROPIES** expected in the GWB from preheating, when light scalar fields are involved \( (m^2_\chi < H^2_*). \)

2. \( V = \frac{\lambda}{4} \phi^4 + \frac{g^2}{2} \phi^2 \chi^2; \ C^{1/2}_1 \lesssim 1\% \) (but this model is ruled out!)

3. Can we really expect this effect in the GWB from more realistic preheating scenarios? from other GW productions scenarios?

4. What can we learn from it? Computation so far for \( g^2/\lambda = 2. \) \( \Omega_{GW}(E_i, g, \lambda), \) so can we break degeneracies by \( \delta \Omega_{GW}(E_i, g, \lambda)? \)
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