ANISOTROPIES in the GWB from Preheating

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L. Bethke, DGF, A. Rajantie, ArXiv:1304.2657

VIII Iberian Cosmology Meeting, Granada, April 24-26, 2013.

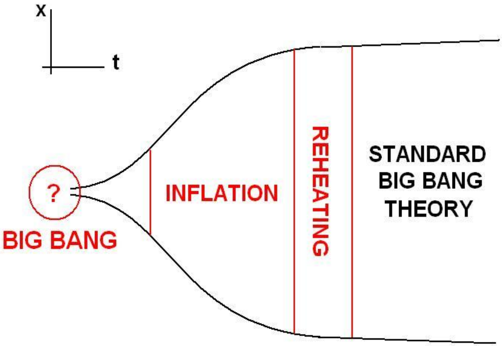
I shall be talking about ...

0. **PREHEATING** $\Rightarrow$ **GW**

1. **ANISOTROPIES in the GW from PREHEATING**

Reheating: Inflaton decay into other d.o.f.

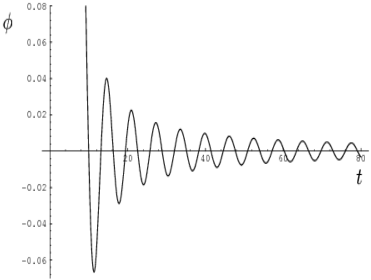
INFLATION $\longrightarrow$ REHEATING $\longrightarrow$ BIG BANG THEORY



BASICs of REHEATING: $V = V(\phi) + \frac{1}{2}g^2\phi^2\chi^2$

Inflaton Dynamics After Inflation:

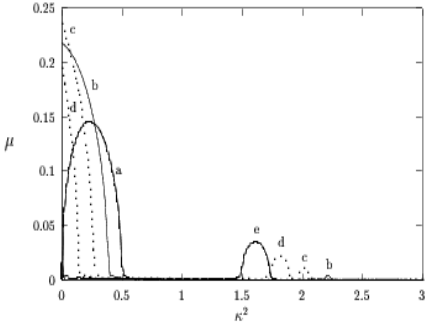
Coherent Oscillations: $\phi(t) \approx \Phi(t) f(t), \quad f(t+T) = f(t)$



BASICs of REHEATING: $V = V(\phi) + \frac{1}{2}g^2\phi^2\chi^2$

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

$$\chi_k'' + 3H\chi_k' + [k^2/a^2 + g^2\Phi^2 f^2(t)]\chi_k = 0 \qquad \Rightarrow \qquad \chi_k \sim e^{\mu_k(g^2,\ldots)t}$$



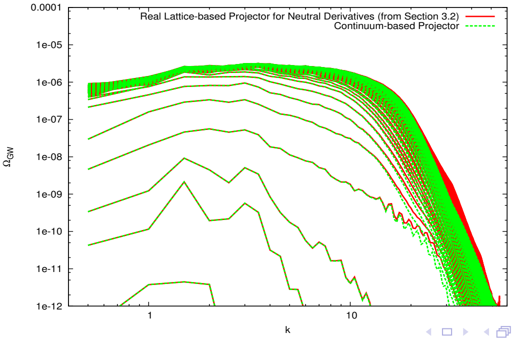
BASICs of REHEATING: $V = V(\phi) + \frac{1}{2}g^2\phi^2\chi^2$

Consequences of pREHEATING:

$$\varphi_k(t) \sim e^{\mu_k t} \leftrightarrow \mathbf{k}_i \pm \Delta\mathbf{k}_i \quad \Rightarrow \quad \vec{\nabla}\chi \quad \Rightarrow \quad (\vec{\nabla}_i\chi\vec{\nabla}_j\chi) = \Pi_{ij}$$

$$h''_{ij} + 3Hh'_{ij} + a^{-2}\nabla^2 h_{ij} = 16\pi G\,\Pi^{TT}_{ij}$$

GW spectra $(V(\phi) = \frac{\lambda}{4}\phi^4,\ g^2/\lambda = 120)$

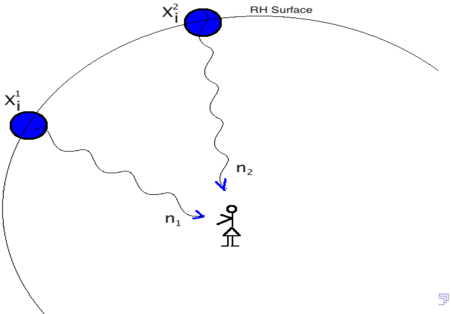


Anisotropies in the GW amplitude?

If $m_\chi^2 < H_*^2 \quad \Rightarrow \quad P_\chi = \frac{H_*^2}{4\pi^2}$ (Scale-Inv Spectrum)

$$V = \frac{\lambda}{4}\phi^4 + \frac{1}{2}g^2\phi^2\chi^2: \qquad m_\chi^2 < H_*^2 \quad \Leftrightarrow \quad g^2/\lambda \lesssim 2$$

@ Preheating: $\chi \;=\; \underset{(k<H_*)}{\chi_i} \;+\; \underset{(k>H_*)}{\left(\int d\mathbf{k}\; e^{-i\mathbf{k}\mathbf{x}}\;\chi_k\right)}$, $\qquad \frac{\partial\langle|\chi_i|^2\rangle}{\partial \log k} = P_\chi \equiv \frac{H_*^2}{4\pi^2}$

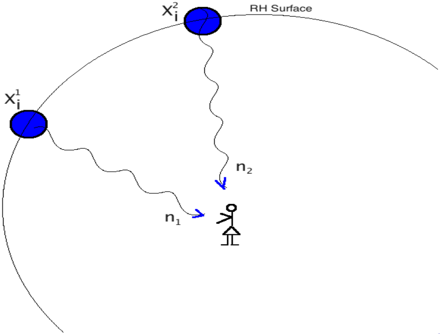


Anisotropies in the GW amplitude?

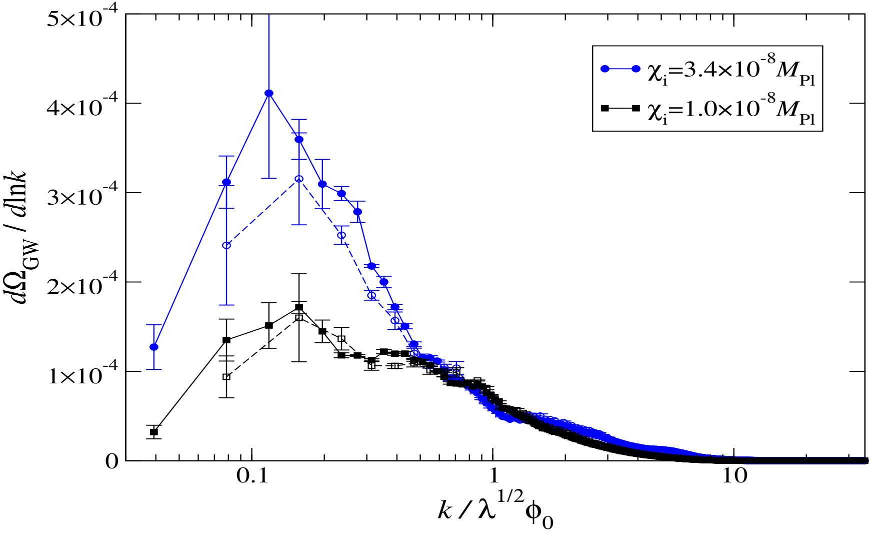
$$\Omega_{\rm GW}(\chi_i(\hat{n})) = c_o + c_1 \cdot \frac{\delta\chi_i}{H_*}, \qquad \delta\chi_i \equiv \chi_i - \bar{\chi}_i$$

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

GWB Angular Power Spectrum: $l(l+1)C_l = \frac{\pi}{2}P_{\rm GW} = \frac{1}{8\pi}\frac{c_1^2}{c_o^2}$



$V = \frac{\lambda}{4}\phi^4 + \frac{1}{2}g^2\phi^2\chi^2 \;\Rightarrow\;$ GW spectra $(g^2/\lambda = 2)$



$\Omega_{\rm GW}$ vs χ_i

$$\left\langle \Omega_{\rm GW}(\chi_i^{(1)})\Omega_{\rm GW}(\chi_i^{(2)}) \right\rangle \equiv \int d\vec{\chi}_i \, P(\chi_i^{(1)}, \chi_i^{(2)}) \, \Omega_{\rm GW}(\chi_i^{(1)})\Omega_{\rm GW}(\chi_i^{(2)})$$

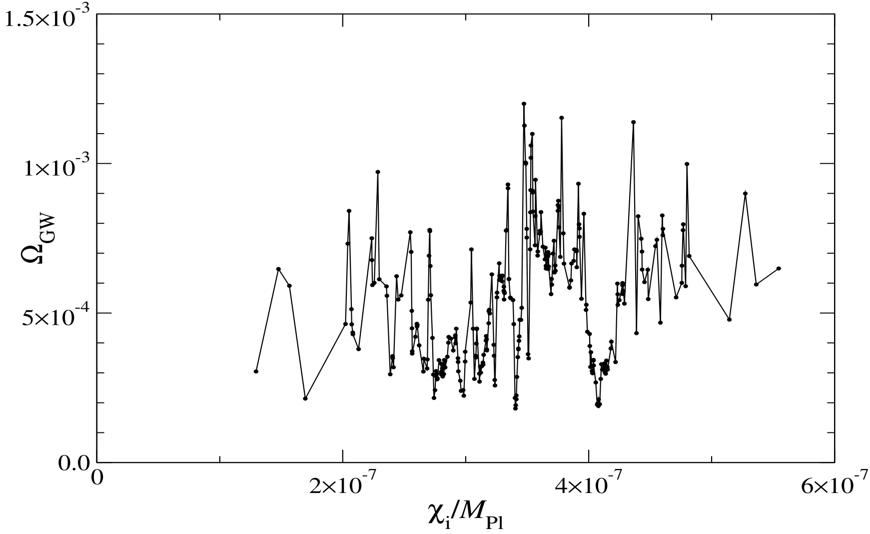
$$P(\chi_i^{(1)}, \chi_i^{(2)}) \propto e^{-\frac{1}{2}\delta\vec{\chi}_i{}^T G^{-1} \delta\vec{\chi}_i}, \quad \left\{ \begin{array}{l} \delta\vec{\chi}_i{}^T \equiv \left(\chi_i^{(1)} - \bar{\chi}_i \, , \, \chi_i^{(2)} - \bar{\chi}_i \right) \\ G_{ab} \equiv \langle \, (\chi_i^{(a)} - \bar{\chi}_i)(\chi_i^{(b)}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

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

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

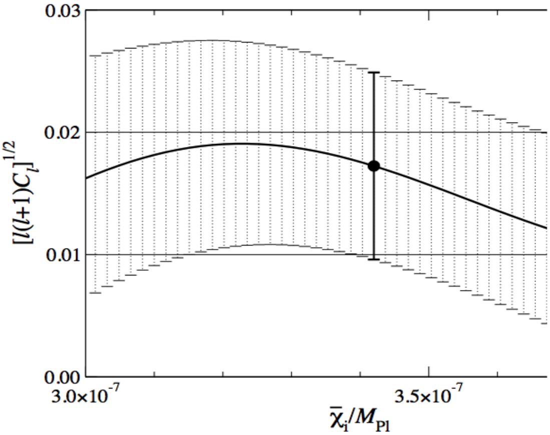
$$\left(\sigma_*^2 = \int_{a_0 H_0}^{H_*} \frac{dk}{k} \mathcal{P}_\chi = \frac{H_*^2}{4\pi^2} N_{\rm CMB} \right)$$

$V = \frac{\lambda}{4}\phi^4 + \frac{1}{2}g^2\phi^2\chi^2 \quad \Rightarrow \quad \Omega_{\rm GW}(\chi_i; g^2/\lambda = 2)$



GW Angular power spectrum $(\frac{\lambda}{4}\phi^4 + \frac{g^2}{2}\phi^2\chi^2)$, $g^2/\lambda = 2$

$$\sqrt{l(l+1)C_l} = 0.017 \pm 0.008$$



Conclusions

1. ANISOTROPIES expected in the GWB from preheating, when light scalar fields are involved ($m_\chi^2 < H_*^2$).
2. $V = \frac{\lambda}{4}\phi^4 + \frac{g^2}{2}\phi^2\chi^2$; $C_l^{1/2} \lesssim 1\%$ (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 $g^2/\lambda = 2$. $\Omega_{\rm GW}(E_i, g, \lambda)$, so can we break degeneracies by $\delta\Omega_{\rm GW}(E_i, g, \lambda)$?

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