Exploring Hidden Regimes during Preheating with Effective Field Theory Methods

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1) How can the inflaton, $\phi$, transfer its energy to other fields at the end of inflation?

The first thing that comes to mind is for the inflaton to perturbatively decay into lighter fields. Being light, such decay products will act like radiation.

When the decay rate wins over the rate of expansion, such decays will lead to radiation domination at the end of inflation.

However, at the end of inflation, it is reasonable to assume that the energy momentum density of the universe continues to be dominated by the inflaton. In this case, for times $m_\phi \ll n$, the background evolves as

$$H_p = H_0 - \frac{3\dot{H}}{8\piG}\sin(2n\phi + \delta)$$

where $\delta = -H_0^2 / 2\dot{H}$ and $n = m_\phi n_0$

which is similar to matter domination. Couplings of the inflaton to other fields can be introduced at the level of perturbations. Assuming a second species of scalar perturbations $\delta \phi$, such a background can set these perturbations into parametric resonance and allow for the exponential growth of certain modes at certain times. The era during which these processes take place on this background is called "Preheating"; and it prepares the initial conditions to increase the efficiency of decaying fields and reheating which will follow [1].

In addition to interactions that lead to particle production, the Effective Field Theory (EFT) methods [2] during Preheating [4] involves three different types of derivative couplings among the inflationary and reheating perturbations [6]. The focus of this poster are these derivative interactions.

3) In Conclusion

- The regimes where one of the species affects the dispersion relation of the other while not appearing as an effective mode itself, are named as "Hidden Regimes" during preheating.
- Previous preheating literature involves examples of only the class of $\beta_2$ couplings, which so far has been noted to be not very efficient for resonant production of small wavelength modes [5].
- At scales below the scale of derivative coupling $R_1$, the reheating modes appear to affect the canonical momenta of the inflaton perturbations, which are the low energy species with a sound speed.
- $\beta_2$ interactions accommodate the reheating modes as the light degrees of freedom with a modified dispersion relation. Indicating that these later type of interactions may be more promising for resonant production in the reheating sector through derivative couplings.
- Derivative couplings of $\beta_3$ and $\beta_4$ imply a sound speed and modified dispersion relations for both of the species even at energies where both modes appear to propagate freely. This suggests that these EFT coefficients address models with additional heavy degrees of freedom.

Denoting $F =\{\xi_{\phi}, \chi_{\phi}\}$, while WKB like solutions to hold:

- In the regime $R_3 \gg \omega \gg m_\phi \gg H_p$
  \[ L^{(3)}_{\phi} = \int d^4 x \left[ -\Delta R_1 \nabla \xi_{\phi} - \frac{1}{2m_\phi} \left( \partial_\phi (R_1 \phi) \right)^2 - \frac{1}{2m_\phi} \left( \partial_\phi \chi_{\phi} \right)^2 - \frac{1}{2m_\phi} R_1^2 \nabla \phi \nabla \phi - \frac{1}{2m_\phi} R_1 \nabla \phi \cdot \nabla \chi_{\phi} \right] \]

  $p_\phi \equiv \frac{\partial L}{\partial \phi} = 0$

  $p_\chi \equiv \frac{\partial L}{\partial \chi_{\phi}} = -R_1 \nabla \phi$

  Dispersion relations:
  - for $k \gg R_1$ \[ \omega \sim k \]
  - for $R_1 \gg k \sim \omega \sim \frac{k^2}{R_1^2}

- In the regime $R_2 \gg \omega \gg m_\phi$, $R_2 \gg H_p$, $p_\phi \ll 1$

  \[ L^{(2)}_{\phi} = \int d^4 x \left[ \frac{1}{2m_\phi} \left( \partial_\phi \xi_{\phi} \right)^2 - \frac{1}{2m_\phi} \left( \partial_\phi \chi_{\phi} \right)^2 - \frac{1}{2m_\phi} R_1^2 \nabla \phi \nabla \phi - \frac{1}{2m_\phi} R_1 \nabla \phi \cdot \nabla \chi_{\phi} \right] \]

  $p_\phi \equiv \frac{\partial L}{\partial \phi} = 0$

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2) EFT Interactions [3,4] in the unitary gauge:

\[ S = S_{\psi} + S_{\chi} + S_{\xi} \]

\[ S_{\psi} = \int d^4 x \sqrt{-g} \left( \frac{1}{2} \bar{\psi} \gamma^\mu \partial_\mu \psi + \bar{\psi} m_\psi \psi + \bar{\psi} \gamma^\mu \gamma^5 \partial_\mu \psi \right) \]

\[ S_{\chi} = \int d^4 x \sqrt{-g} \left( \frac{1}{2} \bar{\chi} \gamma^\mu \partial_\mu \chi + \bar{\chi} m_\chi \chi + \bar{\chi} \gamma^\mu \gamma^5 \partial_\mu \chi \right) \]

\[ S_{\xi} = \int d^4 x \sqrt{-g} \left( \frac{1}{2} \bar{\xi} \gamma^\mu \partial_\mu \xi + \bar{\xi} m_\xi \xi + \bar{\xi} \gamma^\mu \gamma^5 \partial_\mu \xi \right) \]

Performing a time diffeomorphism:

\[ t' = t + \int \omega' = t - \omega \int \omega = t + \omega \int \beta(t) = \beta(t + \omega) \]

[Further conventions: $\xi_{\phi} = \sqrt{\gamma} \chi_{\phi}$, $c_s^2 = 1 - \frac{m_\phi^2}{\lambda}$, $n_\phi = \frac{\lambda}{2\sqrt{m_\phi}}$, $R_1 = \sqrt{\frac{\lambda}{2\sqrt{m_\phi}}}$]