Understanding the reheating dynamics and baryogenesis

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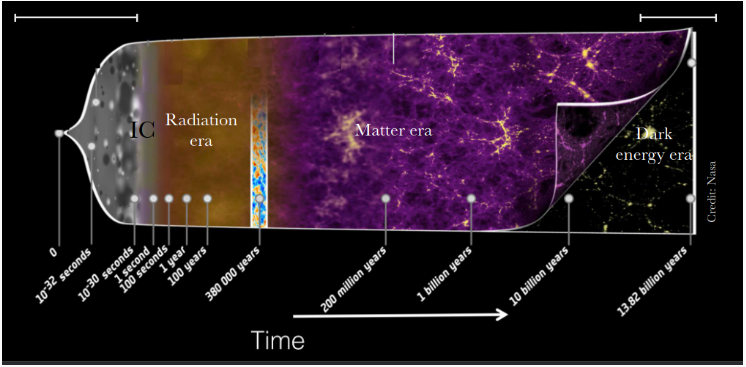
Introduction

- Reheating is a phase between inflation and the radiation era, in which the universe is filled with a hot and dense plasma of elementary particles.



- We will refer to the period when the universe is instantaneously dominated by radiation after inflation as the standard scenario.
- And we will refer to the period when the universe is dominated by matter for prolonged period after inflation as the non-standard scenario.
- We will refer to the reheating temperature T_{RH} as the radiation temperature when the universe starts to be dominated by radiation density.
- During the epoch between the initial time, H_I^{-1}, and the completion of reheating, the maximum temperature of the universe does not scale as $T \propto a^{-1}$ as in the radiation-dominated era. We will refer to the temperature during this period as T_{max}

Model of reheating

We will consider a toy model where the energy is initially dominated by nonrelativistic particles ϕ, which decay into radiation R and reheat the universe, with decay width Γ_ϕ (Giudice et al., 2001):

$$\frac{\mathrm{d}\rho_\phi}{\mathrm{d}t} = -3H\rho_\phi - \Gamma_\phi\rho_\phi$$
$$\frac{\mathrm{d}\rho_R}{\mathrm{d}t} = -4H\rho_R + \Gamma_\phi\rho_\phi$$

we can consider that initially $\rho_\phi(t_0) = \frac{3}{8\pi}M_{pl}^2 H_I^2$, $\rho_R(t_0) = 0$

Standard Scenario

- $\Gamma_\phi \gg H_I$, the decay is "instantaneous" since $\Gamma_\phi^{-1} \ll H_I^{-1}$, in the other words, when the ϕ lifetime is much less than "initial time".

$$\frac{3}{8\pi} M_{pl}^2 H_I^2 = \frac{\pi^2 g_*}{30} T_{RH}^4$$

where g_* is the total number of effective relativistic degrees of freedom. Then, the maximum temperature and the reheating temperature are equal.

$$T_{RH} = T_{max} = \left[\frac{90}{8\pi^3 g_*} M_{pl}^2 H_I^2 \right]^{1/4} .$$

Non-Standard Scenario

• $\Gamma_\phi \ll H_I$: When the Universe's age $t \sim H^{-1}$ matches the lifetime Γ_ϕ^{-1}, we assume all ϕ decay into radiation, making the Universe radiation-dominated.

$$T_{RH} = \left[\frac{2}{3}\sqrt{\frac{45}{4\pi^3 g_*}}\Gamma_\phi M_{pl}\right]^{1/2}$$

The maximum temperature can be estimated when the radiation density curve reaches its maximum value before dilution.

$$T_{max} = \left[\frac{2}{3}\frac{45\Gamma_\phi M_{pl}^2 H_I}{8\pi^{3/2} g_* \sqrt{4\pi^3}}\right]^{1/4}$$

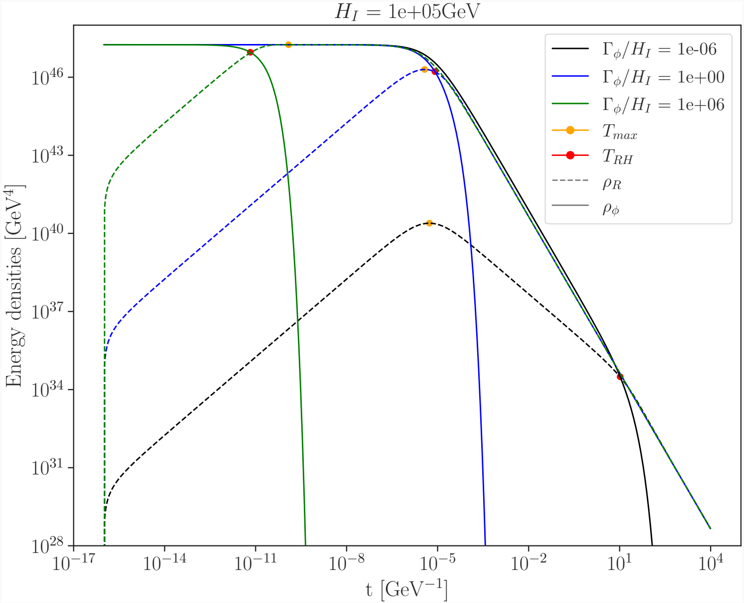


Figure 1: Numerical solution to the system.

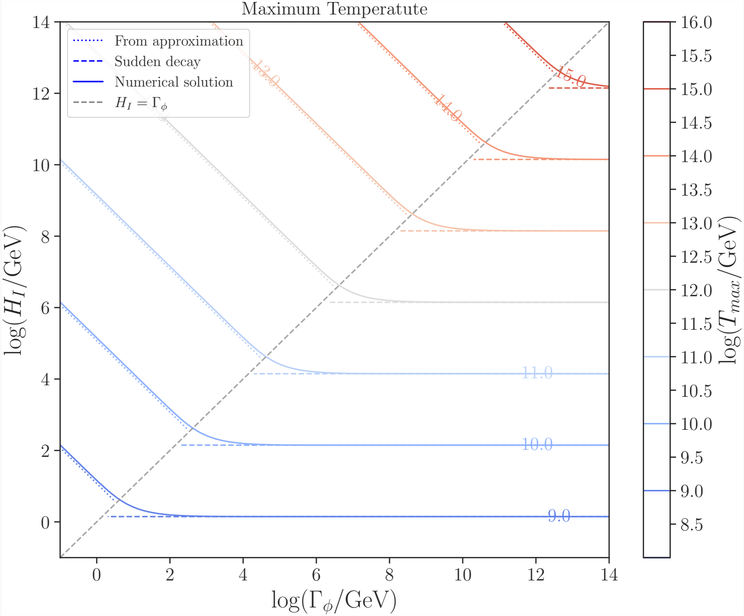


Figure 2: Maximum temperature in terms of H_I and Γ_ϕ

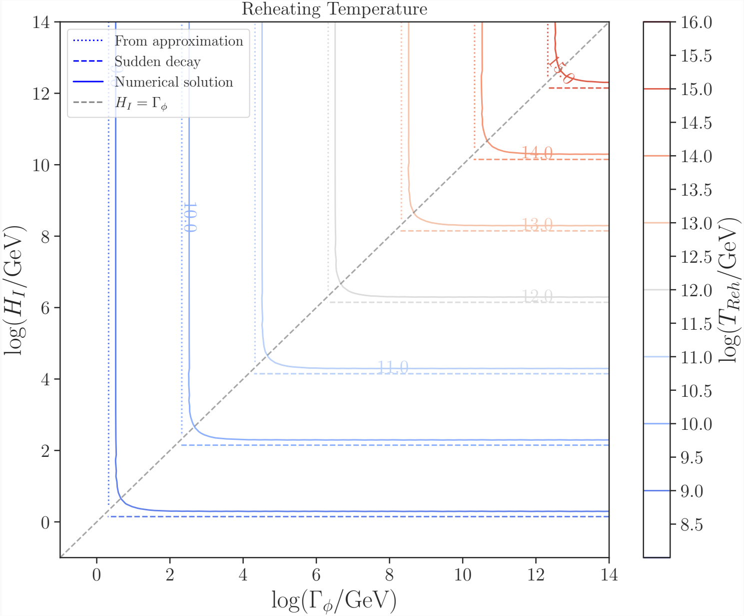


Figure 3: Reheating temperature in terms of H_I and Γ_ϕ

Production of particle X

Assuming a heavy unstable particle X can be produced from the thermal bath R generated by ϕ decay.

$$\frac{\mathrm{d}\rho_\phi}{\mathrm{d}t} = -3H\rho_\phi - \Gamma_\phi\rho_\phi$$
$$\frac{\mathrm{d}\rho_R}{\mathrm{d}t} = -4H\rho_R + \Gamma_\phi\rho_\phi + < E_x > \gamma_x(\frac{n_x}{n_x^{eq}} - 1)$$
$$\frac{\mathrm{d}n_X}{\mathrm{d}t} = -3Hn_X - \gamma_x(\frac{n_X}{n_X^{eq}} - 1)$$

To quantify the production of X particle, we will consider the quantity, its abundance:

$$\frac{Y_X}{g_X} = \frac{n_X}{s}$$

where g_X is the number of degree of freedom of X.

The number of baryons with respect to the number of photons today are measured from the Big Bang Nucleosynthesis (BBN) and Cosmic Microwave Background (CMB), (Cooke et al., 2014), (Planck Collaboration, 2016):

$$\frac{n_{b_0}}{n_{\gamma 0}} = \frac{n_{b_0}}{s_0} \times 7.039 = 6 \times 10^{-10} \Longrightarrow Y_{b_0} = \frac{n_{b_0}}{s_0} = 9 \times 10^{-11}$$

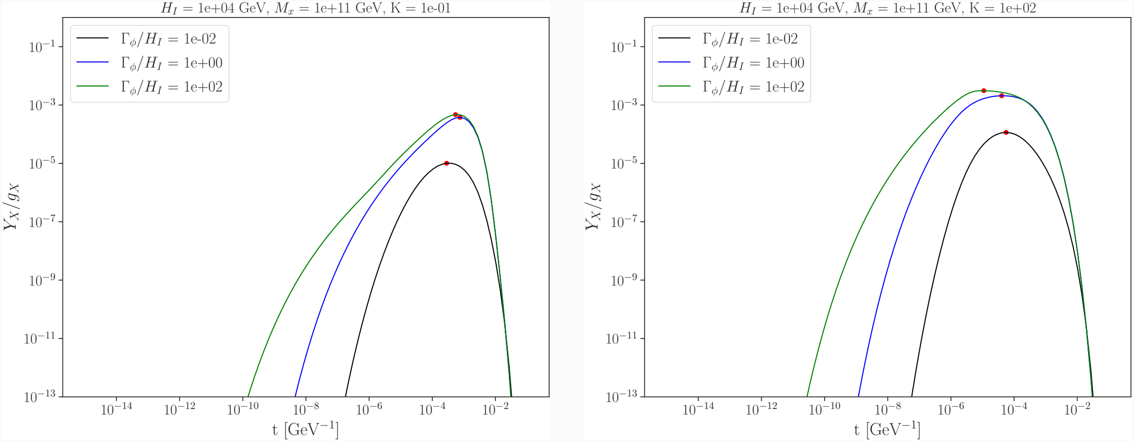


Figure 4: Numerical solution to the system: $M_x = 10^{11}$ GeV and $K = 0.1, 100$.

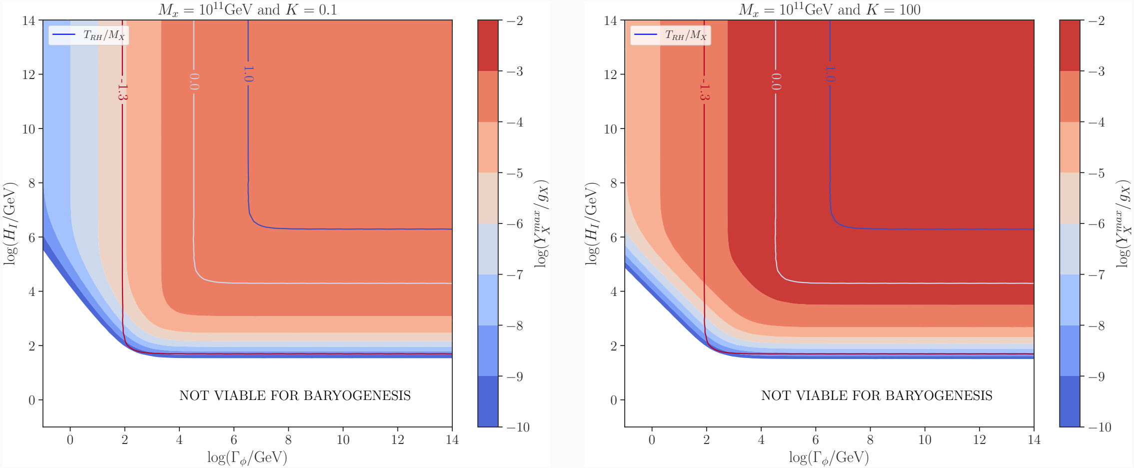


Figure 5: Production of X in terms of H_I and Γ_ϕ: $M_x = 10^{11}$ GeV and $K = 0.1, 100$.

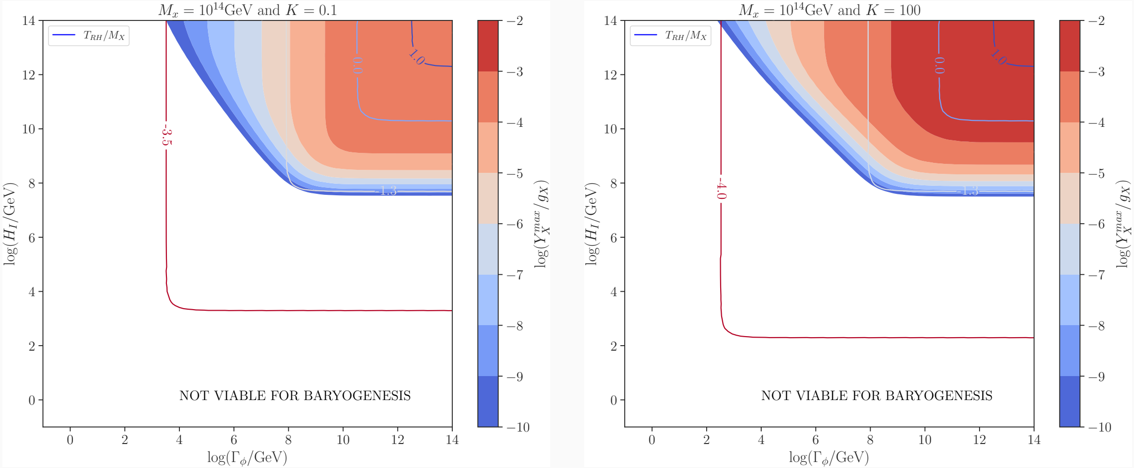


Figure 6: Production of X in terms of H_I and Γ_ϕ: $M_x = 10^{14}$ GeV and $K = 0.1, 100$.

Conclusion and next steps

- Revisited reheating from the decay of a heavy particle ϕ in the early universe.
- Studied the production of a heavy particle X from the thermal bath in this system and showed baryogenesis is not viable for $\dfrac{T_{RH}}{M_X} < 10^{-1.3}$ in the standard regime and for $\dfrac{T_{RH}}{M_X} < 10^{-4}$ in the non-standard regime.
- To complete the work, we would like to study the behavior of an asymmetry density of baryons that are produced by the decay of X, and investigate the efficiency of baryogenesis in this production.


Thank you!