The inflationary trilogy and primordial black hole dark matter

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[arXiv:2407:XXXXX]

Introduction

In the early universe, a scalar field drives inflation

$$H^2 = \frac{V(\phi)}{3M_p^2} \simeq \text{const.} \tag{1}$$

in a slow-regime

$$\epsilon_\phi \equiv \frac{M_p^2}{2}\left(\frac{V_\phi}{V}\right)^2 < 1, \quad \eta_\phi \equiv M_p^2\left|\frac{V_{\phi\phi}}{V}\right| < 1, \tag{2}$$

for $N_e \simeq 50 - 60$ e-folds. But...

- A large number of scalar fields
- Different inflationary mechanisms

Inflationary trilogy

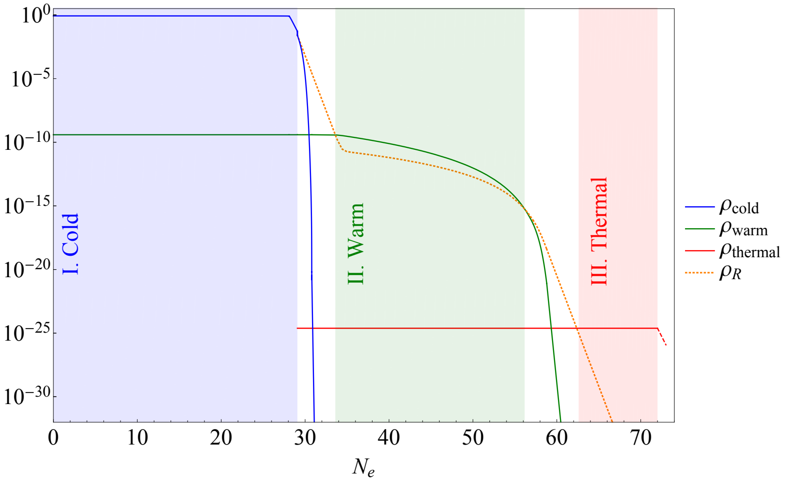


Figure 1: Inflationary dynamics with cold, warm and thermal inflation, in chronological order.

Cold Inflation

During cold inflation,

$$\ddot{\phi} + 3H\dot{\phi} + V_\phi = 0, \tag{3}$$

e.g. supersymmetric hybrid inflation [arXiv:0604198] with potential

$$V = 2\kappa^2|\phi_c|^2|\sigma|^2 + \kappa^2(|\sigma|^2 - M^2) + \Delta V_{1-loop}, \tag{4}$$

results in the spectral index

$$n_s - 1 \simeq \frac{1}{N_c} \quad \text{such that} \quad N_c \simeq 28 \quad \text{e-folds}. \tag{5}$$

While

$$\epsilon_\chi < 3\Omega_\chi^{-1}, \quad \eta_\chi < 3\Omega_\chi^{-1} \tag{6}$$

for $\Omega_\chi \simeq \rho_\chi / 3M_p^2 H^2$.

Warm Inflation

In warm inflation,

$$\ddot{\phi}_w + (3H + \Upsilon)\dot{\phi}_w + V_{\phi_w} = \xi \tag{7}$$

$$\dot{\rho}_R + 4H\rho_r = \Upsilon\dot{\phi}_w^2, \tag{8}$$

e.g. the Warm Little Inflaton model $\Upsilon = C_T T$ with $V = \lambda\phi_w^4$.

[arXiv:1604.08838]

The power spectrum is

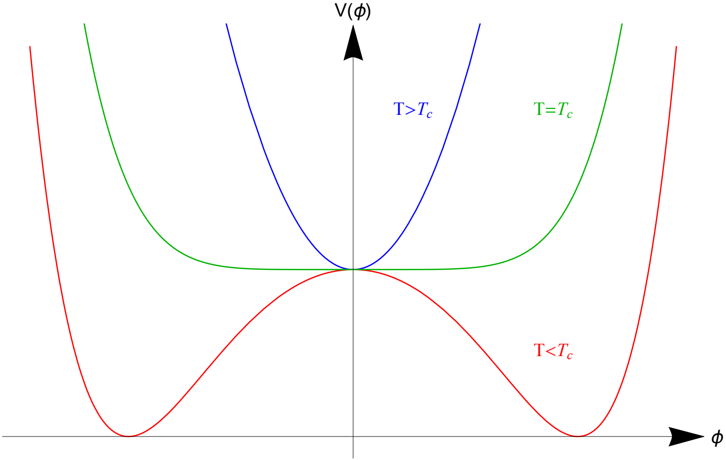
$$\Delta^2_{\mathcal{R}}\Big|_{warm} = \Delta^2_{\mathcal{R}}\Big|_{cold} \times F[Q] \sim 10^{-2} \tag{9}$$

for $C_T \sim 1$ and $Q \equiv \Upsilon/3H \sim 10^4$. We obtain $N_w \sim 20$ e-folds.

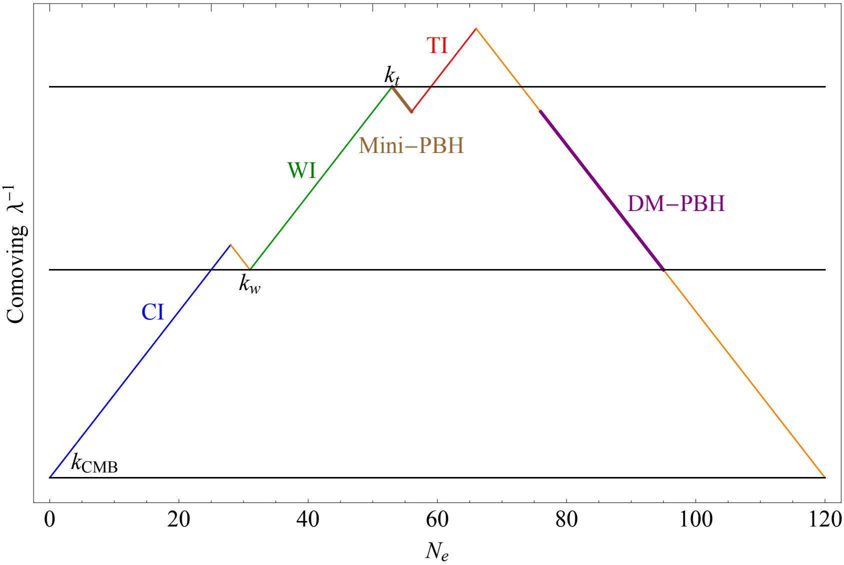
Thermal Inflation

In general, the potential is

$$V_t = V_0 - \frac{m_t^2}{2}\left(1 - \frac{T^2}{T_c^2}\right)\phi_t^2 + ... \tag{10}$$



Scales in Inflationary Trilogy



Primordial Black Holes

As an example:

Inflation: $N_c \simeq 28, \quad N_w \simeq 22, \quad N_t \simeq 10$ e-folds

Radiation: $N_1 \simeq N_2 \simeq 3$ e-folds

which results in the PBH mass spectrum

$$\text{Mini-PBH:} \quad 10^7\, g \lesssim M \lesssim 10^{10}\, g \tag{11}$$

$$\text{DM-PBH:} \quad 10^{19}\, g \lesssim M \lesssim 10^{35}\, g \tag{12}$$

Approximating the power spectrum as Gaussian and using the Press-Schechter formalism we may compute β. Moreover, for the Mini-PBH, we have

$$f \propto \beta \sim e^{-3N_t} \tag{13}$$

Primordial Black Holes

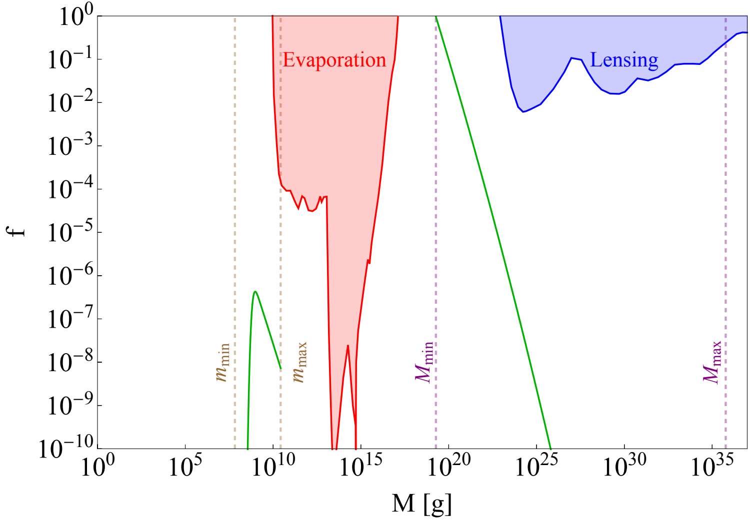


Figure 2: Fraction of dark matter in the form of PBH.

Conclusions

- Inflation can naturally occur in 3 stages:
  Cold → Warm → Thermal
- Warm inflation naturally enhances small-scale power spectrum $\Delta_{\mathcal{R}}^2 \sim 10^{-2}$
- Thermal inflation leads to a distinctive PBH mass spectrum
- PBH in asteroid mass window may account for all dark matter