Non-thermal Production of PNGB Dark Matter and Inflation

HPNP2021

YA-Toma-Yoshioka, JHEP03(2021)130, arXiv:2012.10286[hep-ph]

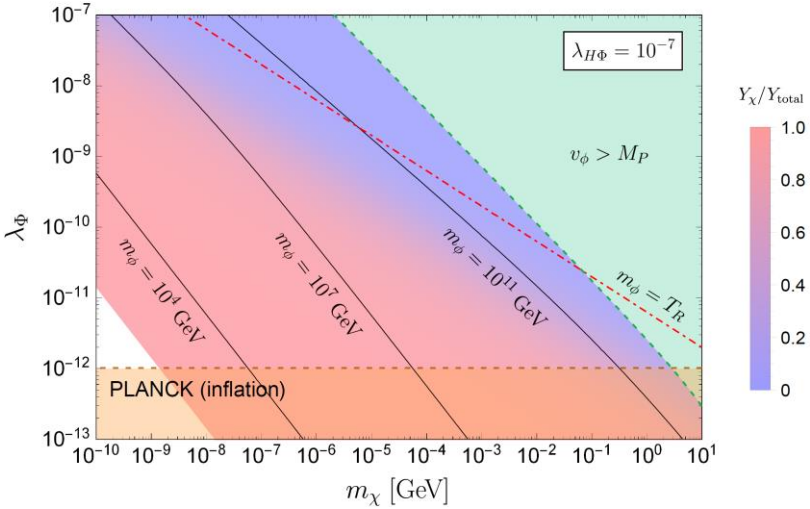
We study the pNGB dark matter relic abundance from the out-of-equilibrium production via feeble Higgs portal coupling and investigate the possibility the radial component plays the role of inflation.
→ The dark matter mass should be less than a few GeV in the wide range of the reheating temperature and the inflaton mass.

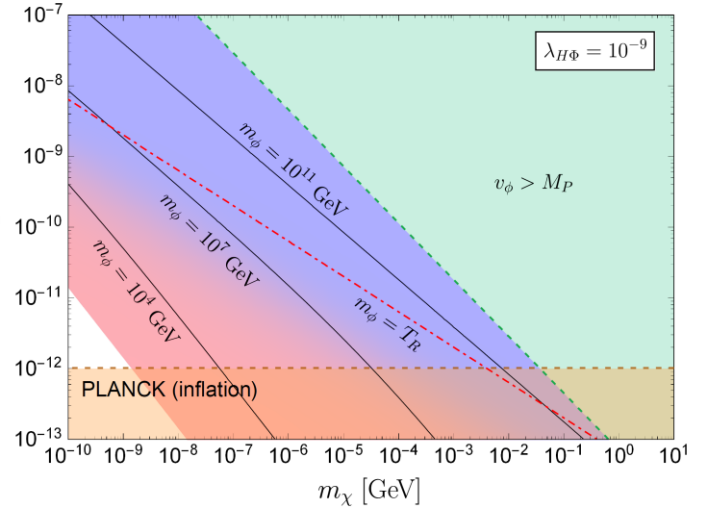
SM + singlet complex scalar w/ softly broken global $U(1)$

$$\mathcal{V}(H,\Phi) = -\mu_H^2|H|^2 + \frac{\lambda_H}{2}|H|^4 - \frac{\mu_\Phi^2}{2}|\Phi|^2 + \frac{\lambda_\Phi}{2}|\Phi|^4 + \lambda_{H\Phi}|H|^2|\Phi|^2 - \frac{m^2}{4}\left(\Phi^2+\overline{\Phi}^2\right)$$

$U(1)$ breaking → (p)NGB → candidate of DM

Nature of (p)NGB ⇒
1. Escaping from the constraints of direct detections (soft pion theorem) [Gross-Levedev-Toma (2017)]
2. Derivative coupling + VEV suppressed coupling Cf. majoron





$$\Phi = \frac{v_\phi + \phi + \mathrm{i}\,\chi}{\sqrt{2}},$$

ϕ : inflaton,

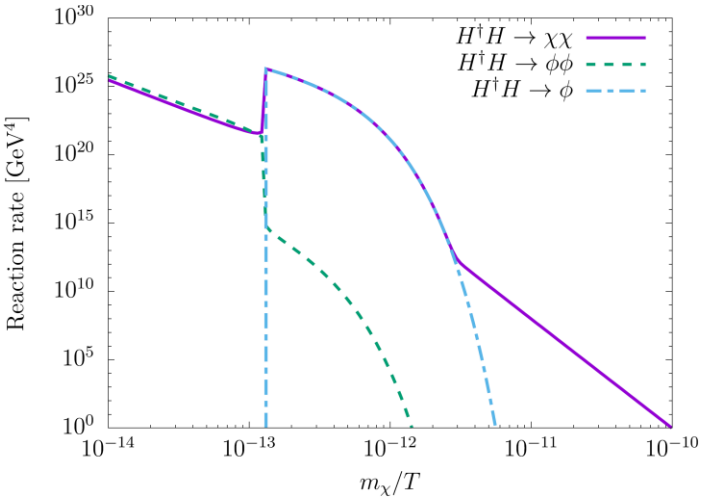
χ : pNGB

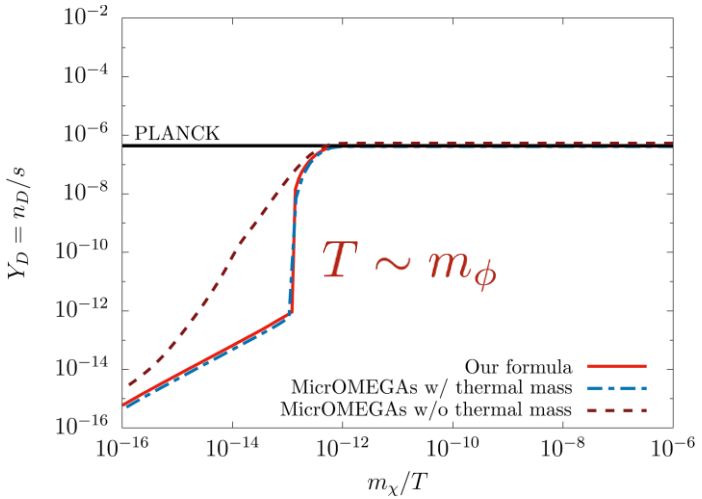
BackUp-1

Non-thermal production of DM

Net dark matter number density $n_D = n_\chi + 2\mathrm{Br}^{\phi\to\chi\chi} n_\phi$

$$\frac{dn_D}{dt} + 3Hn_D = 2\left[\langle\sigma_{H^\dagger H\to\chi\chi}\bar{v}\rangle + 4\mathrm{Br}^{\phi\to\chi\chi}\langle\sigma_{H^\dagger H\to\phi\phi}\bar{v}\rangle + 2\mathrm{Br}^{\phi\to\chi\chi}\langle\sigma_{H^\dagger H\to\phi}\bar{v}\rangle\right](n_H^{\mathrm{eq}})^2$$





$$Y_D^{\mathrm{IR}} \sim \frac{405\sqrt{10}M_P}{(2\pi)^5 g_*^S g_*^{1/2}\lambda_\Phi m_\phi}\frac{\lambda_\Phi^2\lambda_{H\Phi}^2}{\lambda_\Phi^2+\lambda_{H\Phi}^2}\sqrt{1-\frac{4m_h^2}{m_\phi^2}}$$

When the temperature is around mass of ϕ, the DM is mainly produced from the leak of the SM thermal bath.

Cf. UV freeze-in

$$Y_D^{\mathrm{UV}} \sim \frac{135\sqrt{10}\lambda_{H\Phi}^2 M_P T_R^3}{4\pi^8 g_*^S g_*^{1/2} m_\phi^4}$$

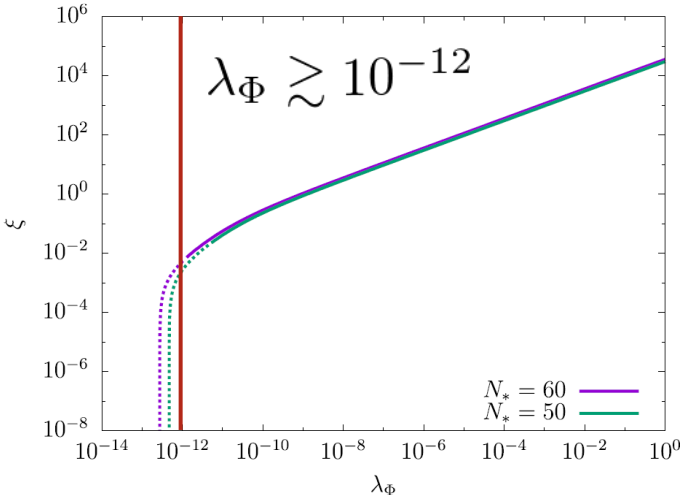
In the UV freeze-in, the DM relic is created at the initial time, temperature being reheating temperature $T = T_R$

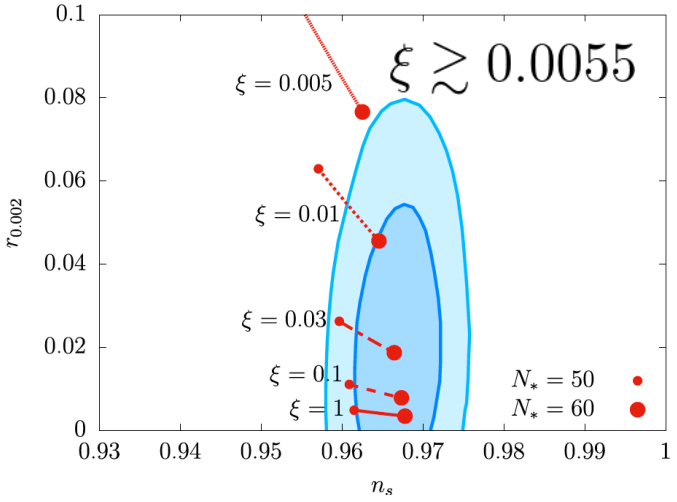
BackUp-2

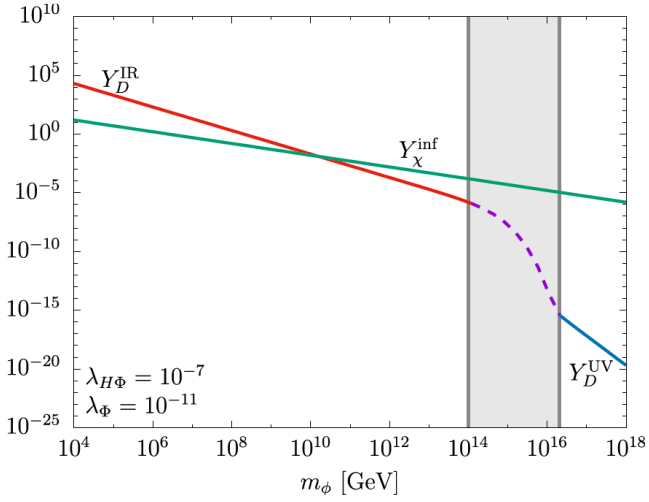
Inflation

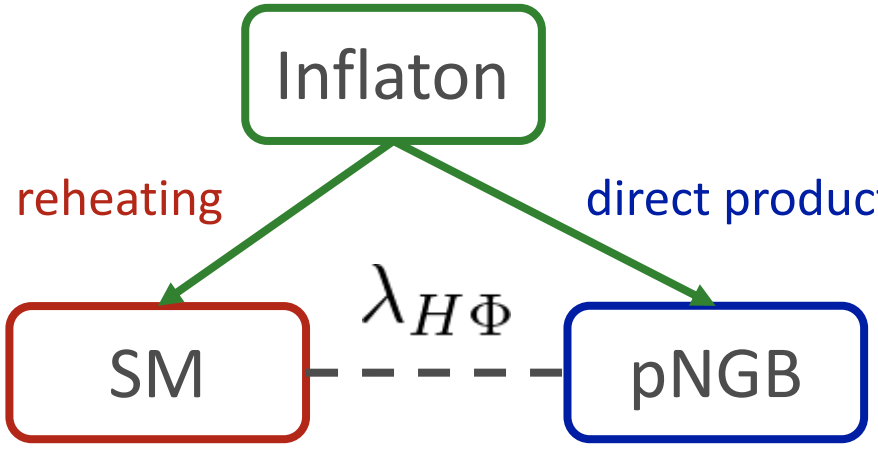
Introduce the non-minimal coupling of Φ to create the flat inflaton potential

$$\frac{\mathcal{L}}{\sqrt{-g}} = -\frac{M_P^2}{2}\mathcal{R} - \xi|\Phi|^2\mathcal{R} + g^{\mu\nu}(\partial_\mu\Phi)^*(\partial_\nu\Phi) - \mathcal{V}(\Phi)$$









Dark matter relic produced by the inflaton decay

$$Y_\chi^{\rm inf} \approx \left(\frac{9\sqrt{10}}{2048\pi^2}\right)^{1/2} \frac{g_*^{3/4}\lambda_\Phi^{3/2}M_P^{1/2}}{g_*^S\lambda_{H\Phi}m_\phi^{1/2}} \left(1-\frac{4m_\chi^2}{m_\phi^2}\right)^{1/2} \times \left(1-\frac{4m_h^2}{m_\phi^2}\right)^{-1/4}$$

Reheating temperature

$$T_R^2 \approx \frac{3\sqrt{10}}{8\pi^2 g_*^{1/2}} \frac{\lambda_{H\Phi}^2}{\lambda_\phi} M_P m_\phi \sqrt{1-\frac{4m_h^2}{m_\phi^2}}$$