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Ultralight Dark Matter

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Summary

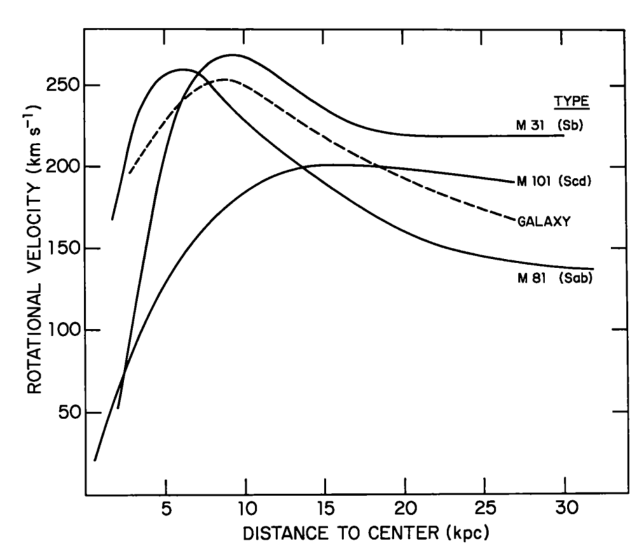

Figure 1: Rotation curves of some galaxies REFERENCIA

Models and recipes

Properties:

- Neutral
- Stable
- Cold
- Weakly interacting

Candidates:

- WIMPs
- FIMPs
- Ultralight scalars
  $m_\theta \sim \mathcal{O}(10^{-10} - 10^{-20})$ eV

Ways to produce:

- Freeze-Out
- Freeze-In
- Cosmic strings
- Domain Walls
- Misalignment mechanism

Section 2

Ultralight Model

Eletroweak theory

Higgs Potential

$$V_0(H) = \mu_H^2 H^\dagger H + \frac{1}{2}\lambda_H (H^\dagger H)^2 \quad (1)$$

Scalar Potential [?]

$$V(H,\phi) = V_0(H) + \mu_\phi^2 \phi^* \phi + \frac{1}{2}\lambda_\phi |\phi^*\phi|^2 + \lambda_{H\phi} H^\dagger H \phi^* \phi \quad (2)$$

Soft breaking potential

$$V(H,\phi) \to V(H,\phi) + \frac{\mu_s^2}{2}\left(\phi^2 + \phi^{*2}\right) \tag{3}$$

The scalar takes the form of

$$\phi = \frac{1}{\sqrt{2}}(\sigma + v_\sigma)e^{i\theta/v_\sigma} \tag{4}$$

The mass of the pNGB reads as

$$m_\theta^2 = -2\mu_s^2 \tag{5}$$

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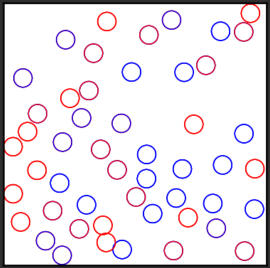
Thermal bath

Interaction rate and Hubble constant:

$$\begin{aligned} \Gamma &> H \quad (\textit{coupled}) \\ \Gamma &< H \quad (\textit{decoupled})\,, \end{aligned} \tag{6}$$



Interaction rate [?]

$$\Gamma = n\langle \sigma v \rangle = \frac{g}{16m^2\pi^2 K_2(m/T)} \int_{4m^2}^{\infty} \sigma(s-4m^2)\sqrt{s}K_1\left(\frac{\sqrt{s}}{T}\right) ds\,. \qquad (7)$$

- $|\overline{M}|^2_{1+2\to 3+4} = |\overline{M}|^2_{3+4\to 1+2} = |\overline{M}|^2$ [?]

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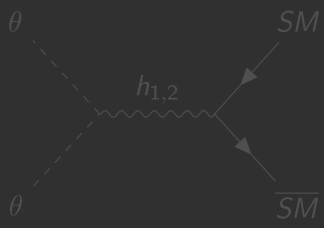
Amplitude

Coupling terms ($\theta + \theta \to SM + \overline{SM}$):

$$\lambda_{\theta\theta h_i} = \frac{m_{h_1}^2}{v_\sigma} U_{2i} \,, \qquad \lambda_{h_i SMSM} = U_{1i} g_{SM} \,. \tag{8}$$

Feynman diagram (s-channel):



- CalcHEP

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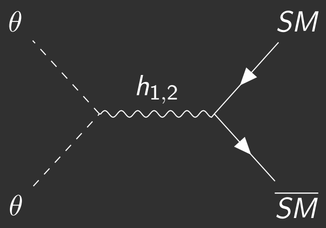

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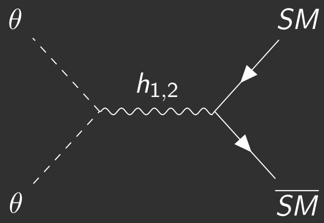

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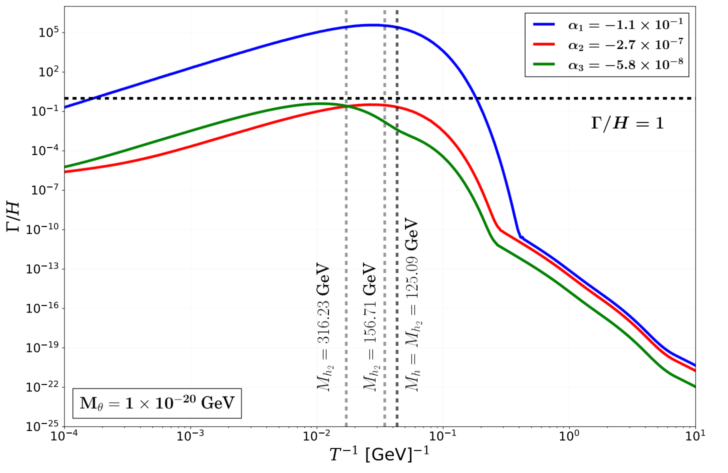

Figure 2: Rate of interaction divided by the Hubble constant assuming $m_h = m_{h_2}$ for $\lambda_H \sim 0.26$, $\lambda_{H\phi} = 2 \times 10^{-8}$ and $\lambda_\phi = 0.1$

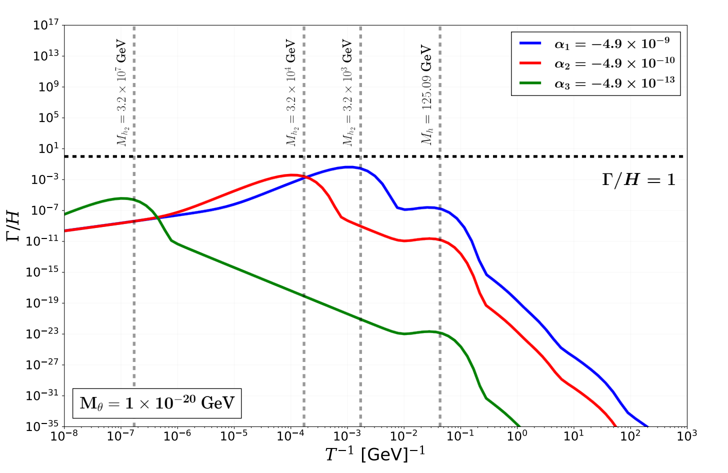

Figure 3: Rate of interaction divided by the Hubble constant assuming $m_h < m_{h_2}$ for $\lambda_H \sim 0.26$, $\lambda_{H\phi} = 2 \times 10^{-8}$ and $\lambda_\phi = 0.1$

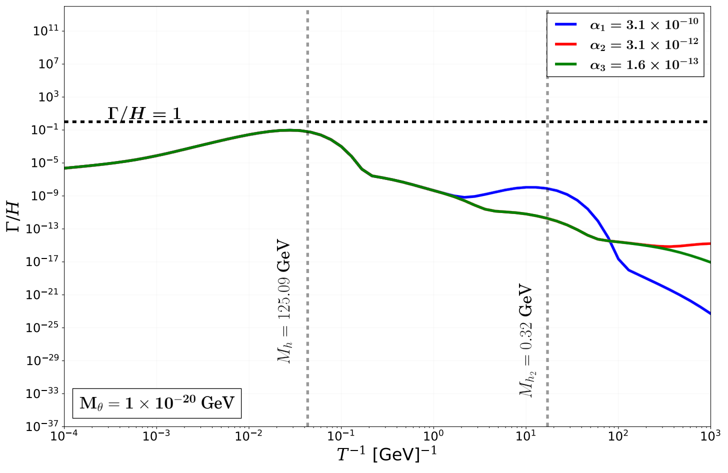

Figure 4: Rate of interaction divided by the Hubble constant assuming $m_h > m_{h_2}$ for $\lambda_H \sim 0.26$, $\lambda_{H\phi} = 2 \times 10^{-8}$ and $\lambda_\phi = 0.1$

Misalignment Mechanism

Aproximation of the soft potential

$$V_{\mathrm{soft}}(\Theta) \simeq \frac{m_\theta^2}{2}\left(\frac{v_\sigma}{2}\right)^2 \Theta^2, \text{ where } \Theta = 2\theta/v_\sigma \tag{9}$$

The energy density is given by

$$\rho_\theta = -T_0^0 = \left(\frac{v_\sigma}{2}\right)^2 \left[\frac{\dot{\Theta}^2}{2} + \frac{m_\theta^2}{2}\Theta^2\right], \tag{10}$$

Continuity equation

$$\dot{\rho} + 3H(\rho + P) = 0 \tag{11}$$

For Matter ($P = 0$):

$$\rho(a) \propto a^{-3} \tag{12}$$

Equation of Motion

$$\ddot{\Theta}^2 + 3H\dot{\Theta} + m_\theta^2\Theta = 0\,. \qquad (13)$$

Radiation era: $a \propto \sqrt{t} \Rightarrow H = 1/t$

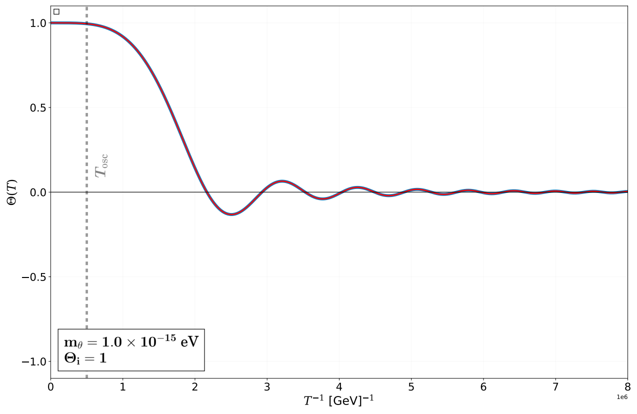

Figure 5: Solution of the equation of motion

Relic Density of pNGB

$$\Omega^0_\theta h^2 = 0.11 \left(\frac{m_\theta}{10^{-14}\text{eV}}\right)^{1/2} \left(\frac{v_\sigma}{\sqrt{50}\times 10^{17}\text{GeV}}\right)^2 \left(\frac{\Theta_{\rm osc}}{10^{-3}}\right)^2 \left(\frac{3.91}{g_{*s}(T_{\rm osc})}\right) \left(\frac{g_*(T_{\rm osc})}{3.36}\right)^{3/4}$$

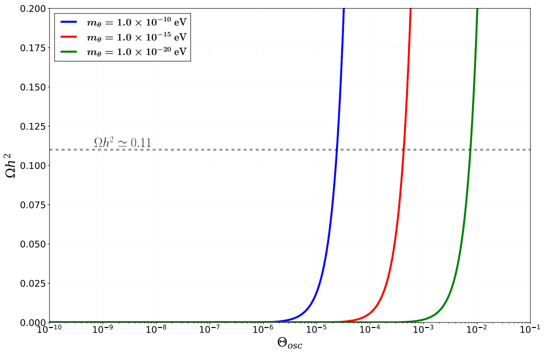

Figure 6: Relic density change with the initial Misalignment angle $\Theta_{\rm osc}$, with $v_\sigma = 3 \times 10^{18}$, for various values of m_θ .

References

Thank you!!!