Inflationary Imprints on Dark Matter

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10th Kosmologietag
7.5.2015

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The Model and Low Energy Particle Phenomenology

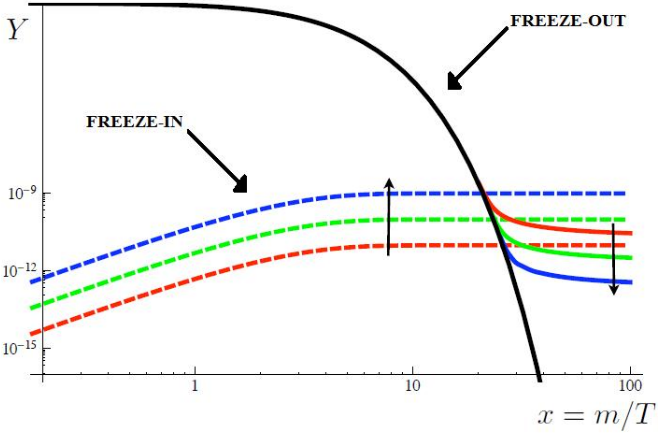
- The scalar sector of the model is specified by the potential

$$V(\Phi, s) = m_{\rm h}^2\Phi^\dagger\Phi + \lambda_{\rm h}(\Phi^\dagger\Phi)^2 + \frac{1}{2}m_{\rm s}^2 s^2 + \frac{\lambda_{\rm s}}{4}s^4 + \frac{\lambda_{\rm sh}}{2}\Phi^\dagger\Phi s^2$$

- Here Φ and s are, respectively, the usual Standard Model Higgs doublet and a real singlet scalar.
- The coupling between Φ and s acts as a portal between the Standard Model and an unknown Dark Sector (the so-called Higgs portal).

Dark Matter Production Mechanisms

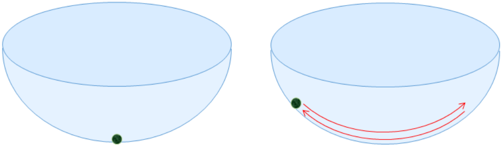
- There are basically two mechanisms for dark matter production: freeze-out and freeze-in[1]



[1] The picture is from Hall et al. (arXiv:0911.1120)

Initial Conditions set by Inflation

- If the scalar fields are light during cosmic inflation, they will typically acquire fluctuations proportional to the inflationary scale, $h, s \simeq H_* \lesssim 10^{14}$ GeV.
- We take these results as inflationary predictions for the initial values of the scalar condensates.



A marble in a bowl.

The Freeze-In

- If the portal coupling takes a value $\lambda_{\rm sh} \lesssim 10^{-7}$, the singlet s never thermalizes $\Rightarrow$ only freeze-in is possible and dark matter is born cold.

- With these values of the coupling, it is possible to slowly produce a sizeable fraction of the observed dark matter abundance via singlet condensate fragmentation already at temperatures above the EW scale.

Condensate fragmentation: an example

- The condensate decays to two singlet particles, $s_0 \to ss$ with an amplitude

$$|\mathcal{M}|_{s_0 \to ss} \sim \int_{-\infty}^{\infty} dt \langle ss | \hat{V}(t) | 0 \rangle,$$

where $\hat{V}(t)$ is the interaction part of the Hamiltonian,

$$\hat{V}(t) = -\lambda_{\rm s} s_0^2(t) \int d^3x \hat{s}\hat{s}.$$

- The corresponding energy dissipation rate is

$$\Gamma_{s_0 \to ss} \simeq 4 \times 10^{-4} \lambda_{\rm s}^{3/2} s_0(t)$$

Boltzmann equation governs the evolution of DM number density

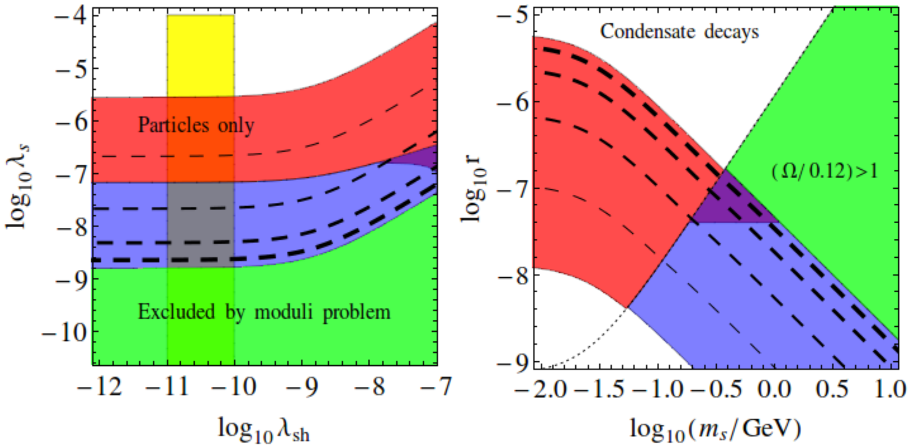
- The singlet number density $n_{\rm s}$ can now be solved from

$$\dot{n}_{\rm s} + 3Hn_{\rm s} = \Gamma_{h\to sh} n_{\rm h} + \left(\Gamma_{s\to ss} - \Gamma_{s\to hh}\right) n_{\rm s} + \Gamma_{s_0\to ss} n_{{\rm s}_0},$$

which is a linearised version (in phase space densities f_i) of the full Boltzmann equation.

- The equation can be solved analytically.

The total Dark Matter yield



- Left panel: $r = 10^{-8}$ (corresponding to $H \simeq 10^{10}$ GeV) and $m_s = 10$ MeV. Right panel: $\lambda_s = 10^{-6}$, $\lambda_{sh} = 10^{-8}$.

Conclusions and Outlook

- Formation and presence of a condensate is a typical consequence in a theory containing scalar fields.
- The inflationary dynamics can affect physics also below the EW scale, and model computations need to be revisited.
- The result constrains also those models in which the frozen-in scalar acts only as a mediator and decays further to the actual Dark Matter particle