Inflationary Imprints on Dark Matter

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From Higgs to Dark Matter
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The Results

- Inflation typically generates specific initial conditions for the hot big bang epoch which can have significant consequences on dark matter production.
- The inflationary dynamics can affect physics also below the EW scale, and model computations need to be revisited.
- Especially the freeze-in production of DM is severely constrained.

The Model

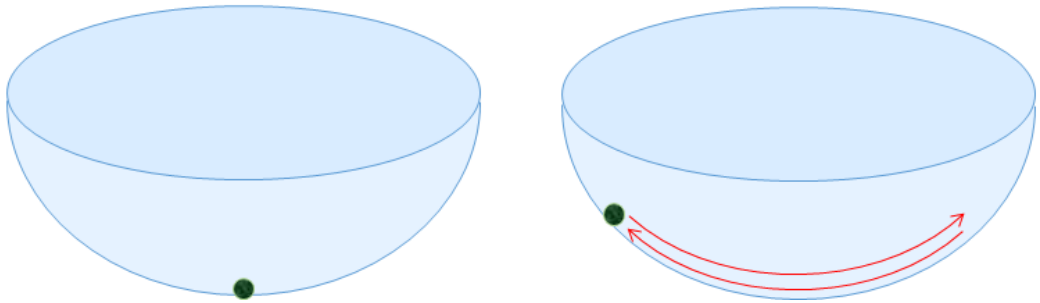
- The scalar sector of the model is specified by the potential

$$V(\Phi, s) = m_h^2 \Phi^\dagger \Phi + \lambda_h (\Phi^\dagger \Phi)^2 + \frac{1}{2} m_s^2 s^2 + \frac{\lambda_s}{4} s^4 + \frac{\lambda_{sh}}{2} \Phi^\dagger \Phi s^2$$

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

Initial Conditions set by Inflation

- If the scalar fields are light during inflation, they will typically acquire fluctuations proportional to the inflationary scale, $h, s \simeq H_* \simeq 10^{14}$ GeV[1].
- We take these results as inflationary predictions for the initial values of the scalar condensates.

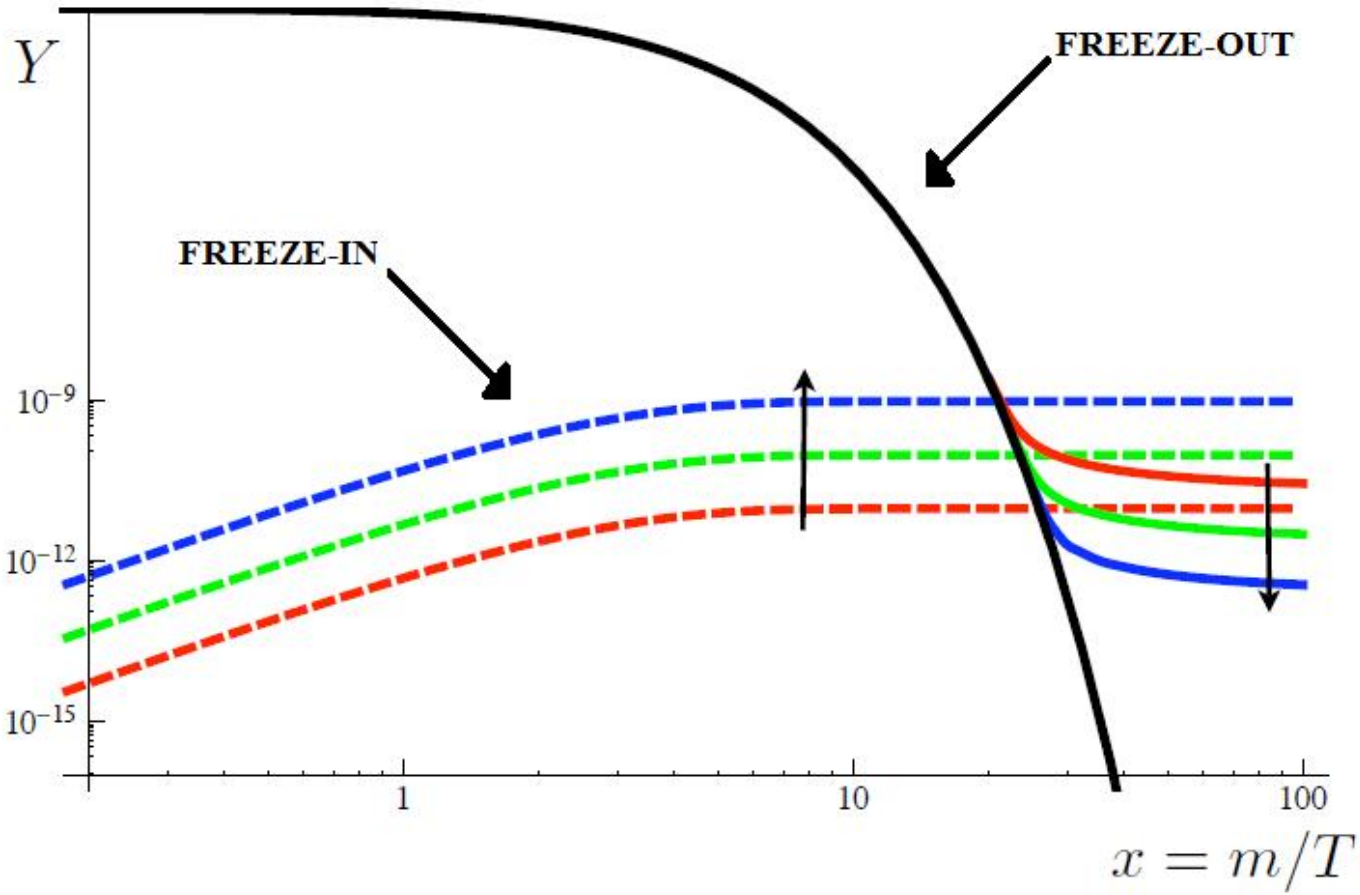


A marble in a bowl.

[1] If the results of BICEP2 were to pass scrutiny.

Dark Matter Production Mechanisms

- There are basically two mechanisms for dark matter production: freeze-out and freeze-in[2]



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

The Freeze-In

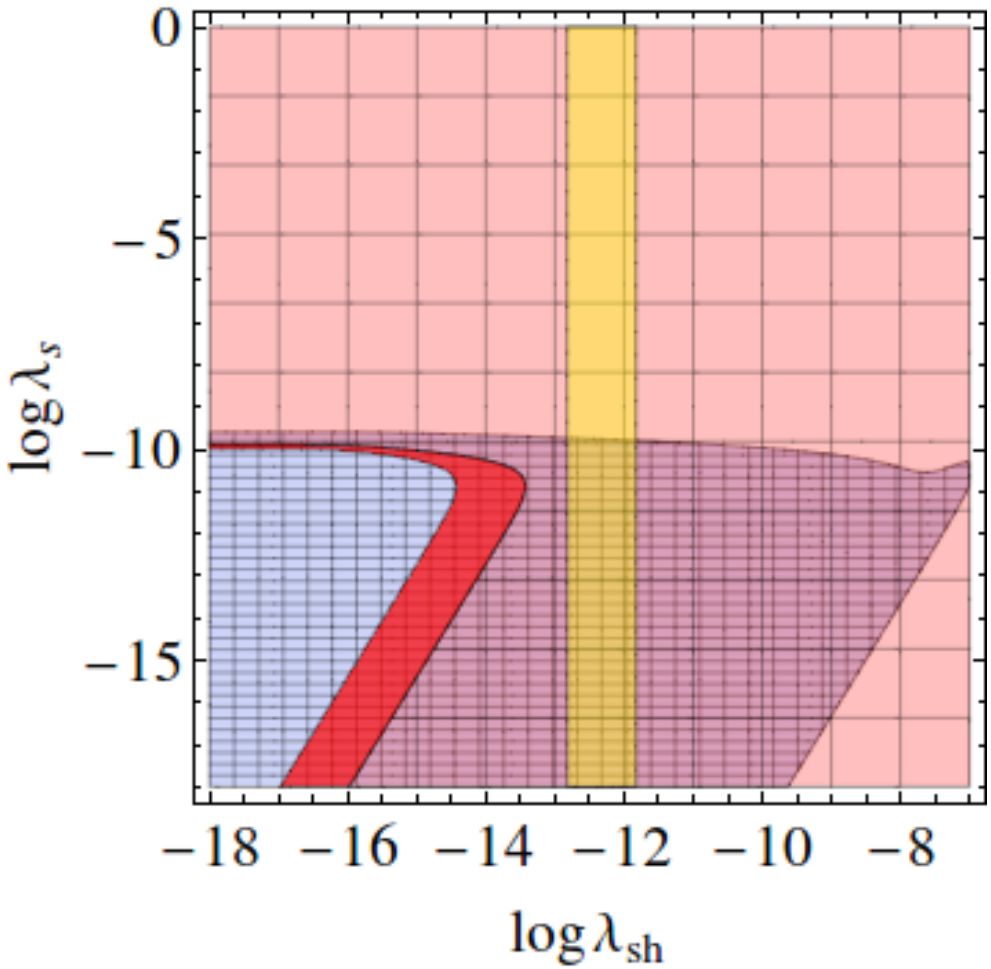
- If the portal coupling takes a value $\lambda_{sh} \lesssim 10^{-7}$, the singlet s never thermalizes $\Rightarrow$ only freeze-in is possible.
- With these values of the coupling, it is possible to slowly produce a sizeable fraction of the observed dark matter abundance via singlet condensate fragmentation already at temperatures above the EW scale.

Fragmentation of the Singlet Condensate

- The total number of produced particles can be calculated by writing the effective Boltzmann equation for n_s

$$
\begin{aligned}
\dot{n}_s + 3Hn_s &= \int dPS_{s_{\rm bg},s,h_1,h_2} |\mathcal{M}|^2_{s_0 h\to sh} f_{s,bg} f_h (1+f_s)(1+f_h) \\
&+ \int dPS_{s_{\rm bg},s_1,s_2,s_3} |\mathcal{M}|^2_{s_0 s\to ss} f_{s,bg} f_s (1+f_s)(1+f_s) \\
&- \int dPS_{s_{\rm bg},s,h_1,h_2} |\mathcal{M}|^2_{s_0 s\to hh} f_{s,bg} f_s (1+f_h)(1+f_h) \\
&+ \Gamma_{s_0\to ss} n_{s,bg}
\end{aligned}
$$

The total DM yield



- In this figure $r = 10^{-6}$ (corresponding to $H \simeq 10^{10}$ GeV) and $m_s = 60$ GeV.

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 portal coupling λ_{sh} has to be super-feeble in order not to produce too much dark matter already at high temperatures.
- Also the self-coupling λ_s plays an important role in determining the correct DM abundance.