Dark Matter Production via the Vev Flip-Flop

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TAE, International Summer School on High Energy Physics, Benasque, 2017

Overview

1. The Vev Flip-Flop
2. Computing the DM Abundance
3. Dark Matter Decay Scenario
4. Vev Induced Mixing

The Vev Flip-Flop

- Add a scalar field S to the SM Lagrangian.
- Coupled via a Higgs Portal coupling

$$-V \supset \mu_H^2 H^\dagger H - \lambda_H (H^\dagger H)^2 + \mu_S^2 S^\dagger S - \lambda_S (S^\dagger S)^2 - \lambda_P (H^\dagger H)(S^\dagger S)$$

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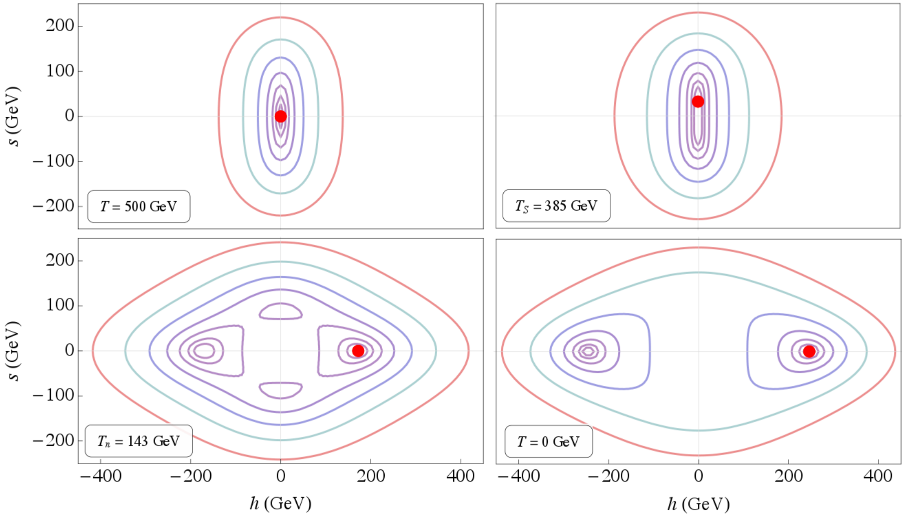
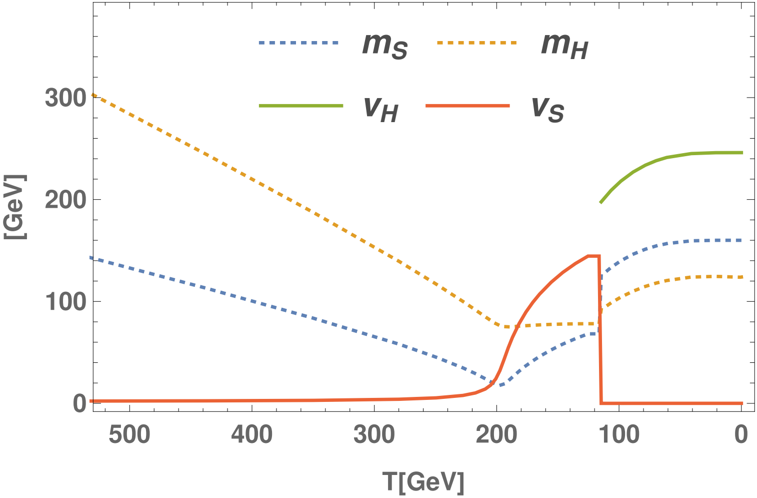
Choose coefficients such that S undergoes two phase-transitions as thermal corrections become subdominant.

The Vev Flip-Flop



The Vev Flip-Flop

- Thermal Evolution tracked with *CosmoTransitions*



Computing the DM Abundance

- Need to track number density through thermal evolution of universe
- Using the output of *CosmoTransitions*
- Solve Boltzmann Equation(s) with temperature dependent masses and vev's
- Via repeated numerical ODE solving for small temperature(time) steps

The Boltzmann Equation

- Describes non-equilibrium dynamics
- Depending on the process, different RHS (Collisionterm)
- e.g DM Annihilation into SM (2-to-2)

$$
\begin{aligned}
\frac{dn_\chi}{dt} + 3Hn_\chi = - \int & d\Pi_{\bar{\chi}} d\Pi_\chi \Pi_{\bar{f}} d\Pi_f \\
& (2\pi)^4 \delta(p_{\bar{\chi}} + p_\chi - p_{\bar{f}} - p_f) \\
& \left[\left| M_{\bar{\chi}\chi \to \bar{f} f} \right|^2 f_{\bar{\chi}} f_\chi (1 \pm f_{\bar{f}})(1 \pm f_f) \right. \\
& \left. - \left| M_{\bar{f} f \to \bar{\chi}\chi} \right|^2 f_{\bar{f}} f_f (1 \pm f_{\bar{\chi}})(1 \pm f_\chi) \right]
\end{aligned}
$$

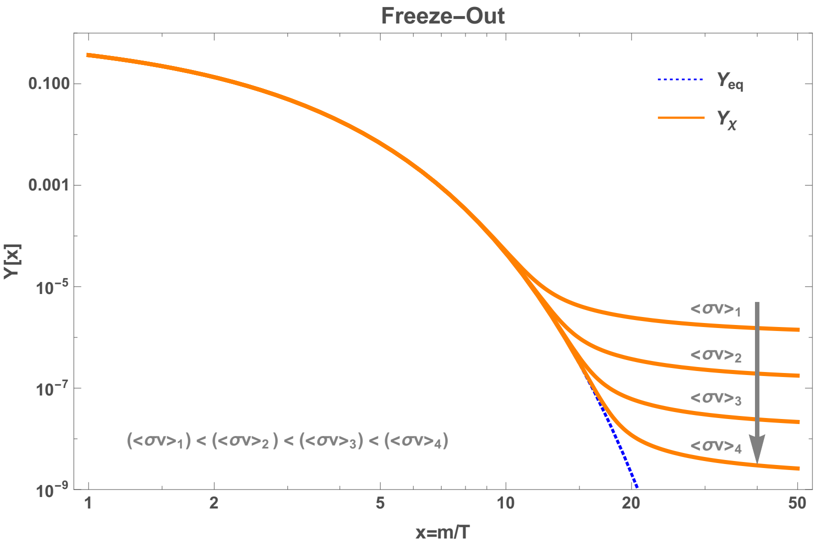
The Boltzmann Equation

Often approximations and simplifications can be made

- $f_{\bar{f}} = f_f$ & $f_{\bar{\chi}} = f_\chi$
- $\left|M_{\bar{f}f\to\bar{\chi}\chi}\right|^2 = \left|M_{\bar{\chi}\chi\to\bar{f}f}\right|^2$
- neglect Pauli-Blocking/Bose-Condensation $(1 \pm f_i) \approx 1$
- depending on mass of particles and temperature $f_i \approx e^{-E_i/T}$ (neglecting chemical potential μ)
- Changing variables from t to $x = {}^m/_T$ and from n to $Y = {}^n/_s$ often convenient

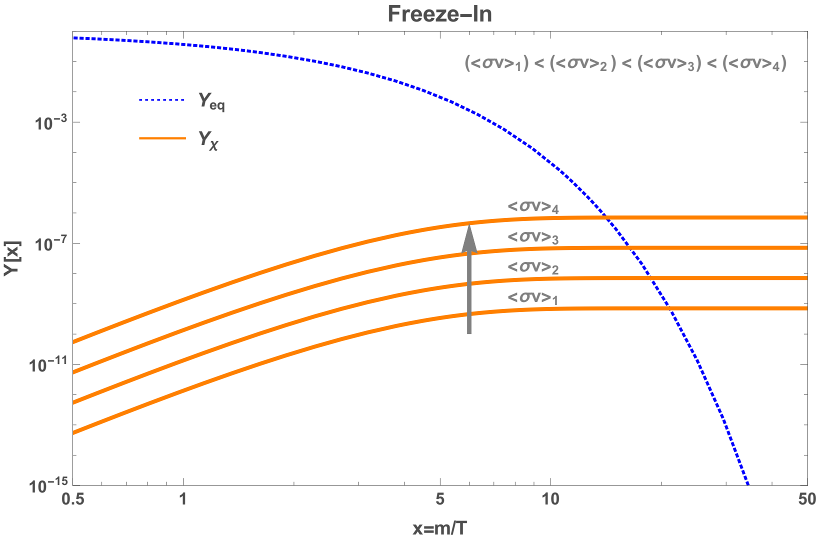
$$\Rightarrow \frac{dY_\chi}{dx} = -\frac{s\left<\sigma v\right>}{Hx^2}\left[Y_\chi^2 - (Y_\chi^{eq})^2\right]$$

Freeze-Out



Freeze–Out
Y_{eq}
Y_χ
$<\sigma v>_1$
$<\sigma v>_2$
$<\sigma v>_3$
$<\sigma v>_4$
$(<\sigma v>_1) < (<\sigma v>_2) < (<\sigma v>_3) < (<\sigma v>_4)$
Y[x]
0.100
0.001
10^{-5}
10^{-7}
10^{-9}
1
2
5
10
20
50
x=m/T

Freeze-In



Freeze–In
(<σv>1) < (<σv>2) < (<σv>3) < (<σv>4)
Yeq
Yχ
<σv>4
<σv>3
<σv>2
<σv>1
10−3
10−7
10−11
10−15
Y[x]
0.5
1
5
10
50
x=m/T

Field	Spin	Mass	$SU(3)_c \times SU(2)_L \times U(1)_Y$	$\mathbb{Z}_3$
χ	$^1/_2$	$\mathcal{O}(1\ \mathrm{TeV})$	$(1,1,0)$	$+120^\circ$
$\Psi^{(\prime)}$	$^1/_2$	$\mathcal{O}(1\ \mathrm{TeV})$	$(1,3,0)$	-120°
S	0	$\mathcal{O}(100\ \mathrm{GeV})$	$(1,3,0)$	$+120^\circ$

$$\mathcal{L}_{\mathsf{Yuk}} = y_\chi^{(\prime)}\, S^\dagger \bar{\chi} \Psi^{(\prime)} + y_\Psi \epsilon^{ijk}\, S^i \overline{\Psi^j} \left(\Psi'^k\right)^c + h.c.$$

Dark Matter Decay Scenario - arXiv:1608.07578

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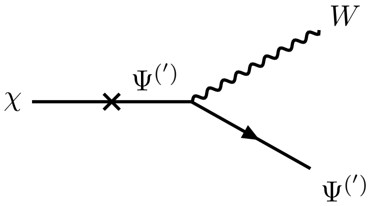
During the $\langle S \rangle \neq 0$ phase χ can mix into $\Psi^{(\prime)}$ and thus decay via:



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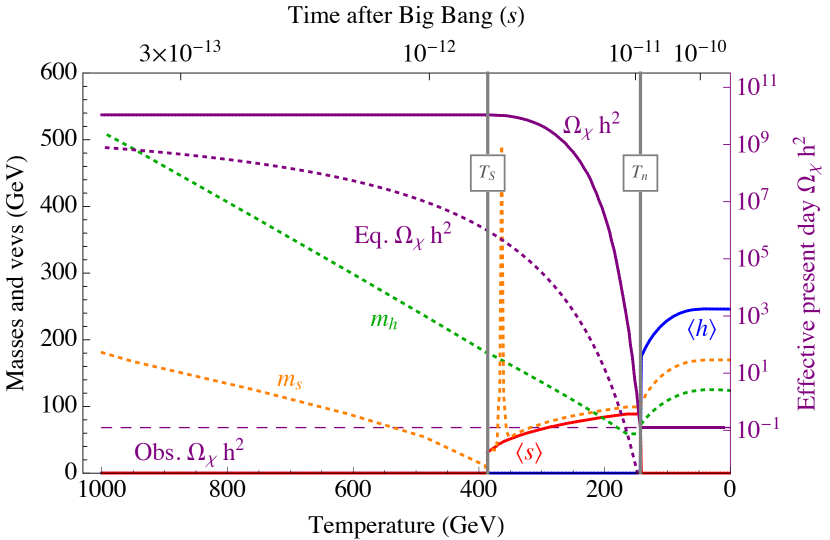

Vev Induced Mixing

Field	Mass	SM	$\mathbb{Z}_2$	$\mathbb{Z}_2'$
χ	$\mathcal{O}\,(100\ \text{GeV})$	$(1,1,0)$	$+1$	-1
ψ	$\mathcal{O}\,(1\ \text{TeV})$	$(1,1,0)$	-1	-1
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$$L_{int} \supset y_\chi S \bar{\chi} \psi + h.c.$$

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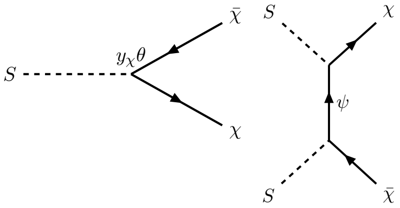

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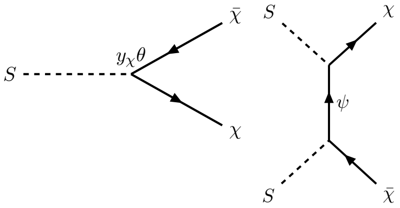

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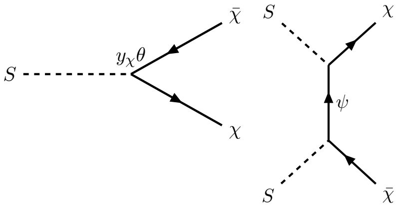

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