Sterile neutrino dark matter in U(1) extensions of the standard model

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Introduction

We consider an extension of the standard model with a $\mathrm{U}(1)_z$ gauge group, called the **superweak model**. This model is aimed to explain the origin of neutrino masses, the stability of the Higgs vacuum, and dark matter.

The particle spectrum of the standard model is extended to include three right-handed sterile neutrinos N_i, a scalar singlet χ, and a neutral gauge boson Z'.

	$\mathrm{SU}(3)_\mathrm{c}$	$\mathrm{SU}(2)_\mathrm{L}$	$\mathrm{U}(1)_Y$	$\mathrm{U}(1)_z$
Q_L	**3**	**2**	1/6	1/6
U_R	**3**	**1**	2/3	7/6
D_R	**3**	**1**	−1/3	−5/6
ℓ_L	**1**	**2**	−1/2	−1/2
N_R	**1**	**1**	0	1/2
e_R	**1**	**1**	−1	−3/2
ϕ	**1**	**2**	1/2	1
χ	**1**	**1**	0	−1

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Dark matter production

The lightest sterile neutrino (N_1) is sufficiently stable, and is a prime candidate for dark matter. In order to track their abundance, we need to solve the Boltzmann equation.

We consider the **freeze-out** mechanism with $\mathcal{O}(\mathrm{MeV})$ scale neutrinos, and the **freeze-in** of light, $\mathcal{O}(\mathrm{keV})$ scale neutrinos.

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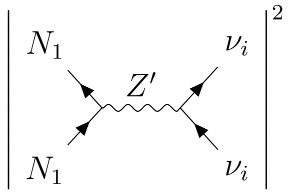
Freeze-out mechanism

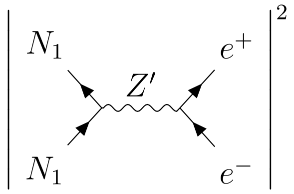
In the freeze-out scenario, annihilations of sterile neutrinos into standard model particles play an important role. The new $\mathrm{U}(1)_z$ gauge boson is assumed to be light,

$$10\ \mathrm{MeV} \lesssim M_{Z'} \lesssim 200\ \mathrm{MeV}\,,$$

and there are only two dominant processes:

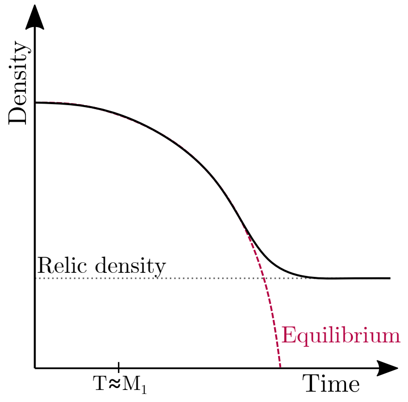


$$\propto g_z^4\,,$$

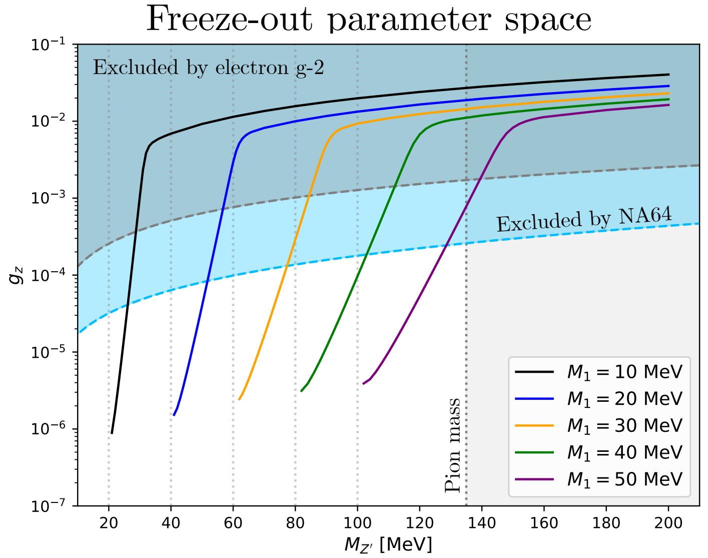


$$\propto g_z^4(4\cos^2\theta_\mathrm{W}-1)^2\,.$$

The sterile neutrinos are in equilibrium at high temperatures ($T \gg M_1$), but the way in which equilibrium was achieved does not matter. Decoupling happens when the above interactions become ineffective as compared to the Hubble rate, usually around $T_\mathrm{dec} \sim M_1$.



The following figure shows the parameter trios (g_z, M_1, and $M_{Z'}$) which correctly reproduce dark matter densities.



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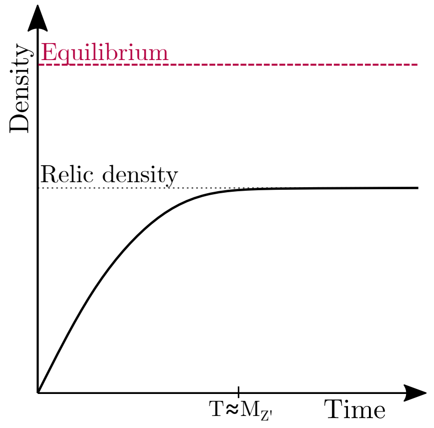
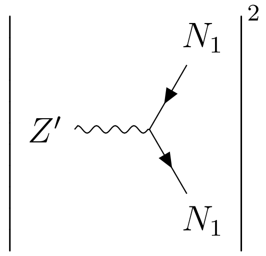
Freeze-in mechanism

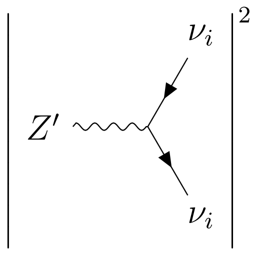
In the freeze-in scenario, the dark sector species are assumed to have (close to) 0 density at very high temperatures. As the Universe cools, dark matter is unable to reach equilibrium densities, due to heavily suppressed production channels. In general, the couplings required for freeze-in are of order $g_z = \mathcal{O}(10^{-10} - 10^{-12})$.

The relevant process to produce N_1 is via the decay of the new gauge boson Z'. Since Z' is also out-of-equilibrium, we also have to consider their production in a coupled set of two Boltzmann equations. Freeze-in ends when all Z' bosons have decayed, around $T \sim M_{Z'}$.

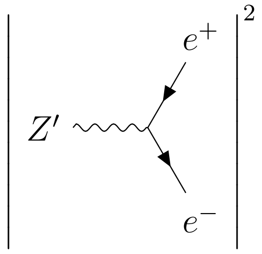




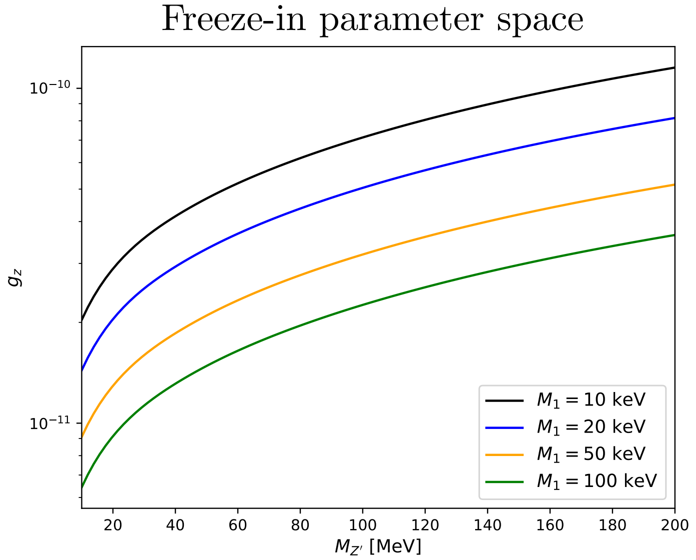
$$\propto g_z^2\,,$$



$$\propto g_z^2\,,$$



$$\propto g_z^2(4\cos^2\theta_\mathrm{W}-1)^2\,.$$



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References

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