Full Phase Space of Sterile Neutrino Dark Matter from a B-L Phase Transition

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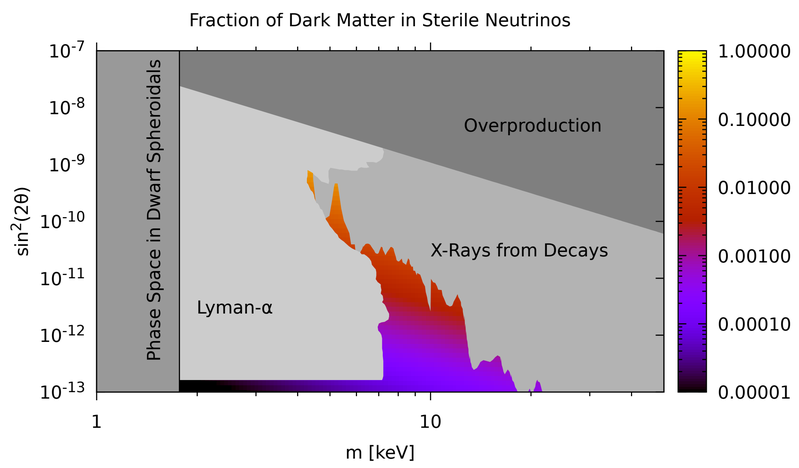
Motivation

Sterile Neutrinos as a Dark Matter Candidate

- Massive lepton without any SM gauge charges
- Well motivated in context of active neutrino masses
- Small couplings, $m > 0$, long-lived $\rightarrow$ Suitable DM candidates
- Basic models almost ruled out for total DM



- Therefore: Study other production mechanisms

$B - L$ Symmetry

- Gauge SM's approximate symmetry of baryon minus lepton number $\rightarrow$ Spontaneous breaking
- Conformal models can solve the hierarchy problem
- Sterile neutrinos needed for anomaly cancellation
- Lagrangian:

$$\begin{aligned} \mathcal{L} &= \mathcal{L}_{SM} + \mathcal{L}_N + V(H,\Phi) \\ \text{mit} \quad \mathcal{L}_N &= \bar{N}^i(iD_\mu\gamma^\mu)N^i - Y_D^{i\alpha}\bar{l_\alpha}\tilde{H}N_i - Y_M^i\Phi\overline{N^{ic}}N^i + h.c., \\ V(H,\Phi) &= \lambda_H|H|^4 + \lambda_{H,\Phi}|H|^2|\Phi|^2 + \lambda_\Phi|\Phi|^4 \\ D_\mu &= \partial_\mu - ig_L W_\mu - ig_Y q_Y B_\mu - ig_{B-L}q_{B-L}X_\mu \end{aligned}$$

Course of Events

Dark Matter from a Supercooled Phase Transition

The Z' Boson opens new production channels for sterile neutrinos. While this gas been studied in standard cosmologies,$B - L$ models allow for interesting phenomenology of phase transitions that could affect the production of sterile neutrinos.

Before Phase Transition

- Electroweak and $B - L$ symmetry are restored
- All particles are massless and in equilibrium
- At critical temperature, thermal barrier prevents Φ from reaching its minimum
- Vacuum domination and potentially large supercooling

At Phase Transition

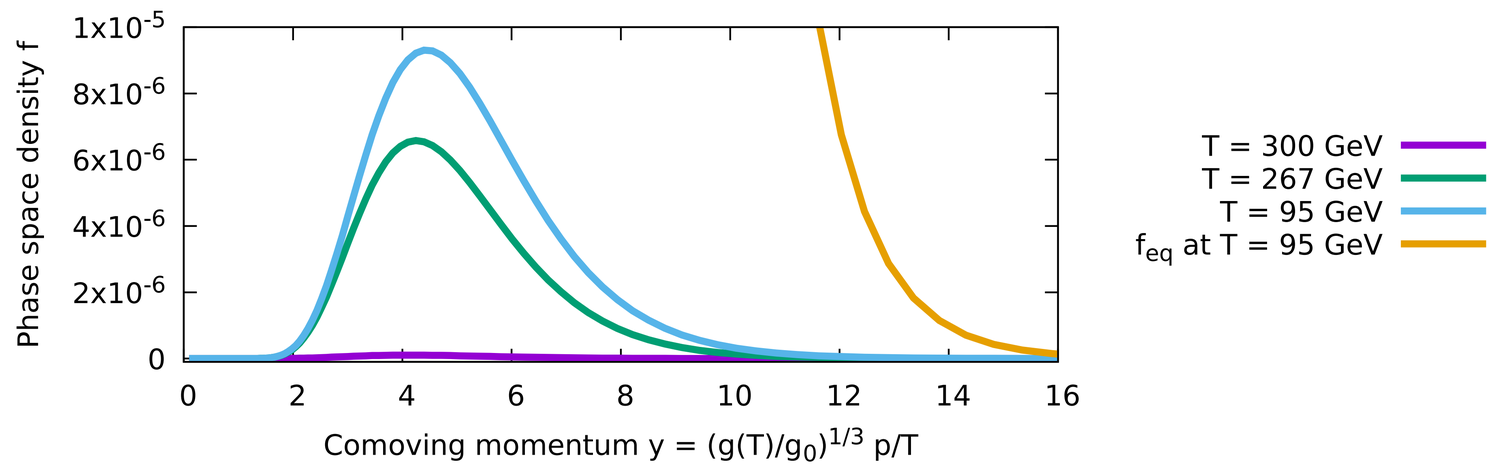
- At QCD scale, quark condensates form
- $< t\bar{t} >$ contributes to Higgs potential and triggers EW phase transition
- Higgs vev affects Φ and pushes it to its true minimum
- Energy is released in the vacuum transition, reheating the universe

After Phase Transition

- Most energy is transferred into SM with restored EW symmetry $\rightarrow$ Standard evolution
- Sterile Neutrino and Z' gain mass from Φ vev
- New neutrino production is suppressed by now large Z' mass

Example of Sterile Neutrino Evolution from Z' Decay

Model parameters:
$g_{B-L} = 10^{-7}$
$m_{Z'} = t\,\text{TeV}$
$m_N = 100\,\text{keV}$



Full Boltzmann Equation

Numerically solve the full Boltzmann equations:

$$\frac{\partial f_N}{\partial t} - Hp\frac{\partial f_N}{\partial p} = \sum C[f_N]$$

with

$$C_{i\leftrightarrow NN}[f_N](p,T) = \frac{1}{16\pi p E_N(p)}\int_{p'_{min}}^{p'_{max}}\frac{p'\mathrm{d}p'}{E_N(p')}\cdot$$
$$|\mathcal{M}|^2(f_N^{eq}(p,T)f_N^{eq}(p',T) - f_N(p,T)f_N(p',T))$$
$$C_{ii\leftrightarrow NN}[f_N](p,T) = \frac{g_i^2}{16E_N(p)(2\pi)^3}\int_0^\infty\frac{p'^2\mathrm{d}p'}{E_N(p')}\int_{-1}^{\cos\alpha_{max}}\mathrm{d}(\cos\alpha)\cdot$$
$$\sqrt{1-\frac{4m_i^2}{s}}|\mathcal{M}|^2(f_N^{eq}(p,T)f_N^{eq}(p',T) - f_N(p,T)f_N(p',T))$$

Next Steps

- Include collision integral for scatterings and consider all relevant processes
- Explore full parameter space
- Study effects of non-thermal spectra on structure formation

References

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