

Sterile neutrino dark matter

Impact of active-neutrino opacities
arXiv:2005.03039

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Two problems of the SM of particle physics:

- neutrino oscillations
- no good DM candidate

Possible solution to both problems: Adding a right-handed neutrino N ,

$$\mathcal{L} = \mathcal{L}_{SM} + \frac{1}{2}\bar{N}(i\not{\partial} - M)N - \sum_{\alpha} \left(\bar{N}\tilde{\varphi}^{\dagger}h_{\alpha}l_{\alpha} + \text{H.c.} \right)$$

How to produce the relic DM abundance?

Sterile neutrino DM production I

Dodelson-Widrow scenario [hep-ph/9303287]

- Early universe: active neutrinos in thermal equilibrium with other SM particles
- keV sterile neutrinos out of equilibrium with no initial abundance
- Due to small couplings h_α a reservoir of sterile neutrinos slowly builds up

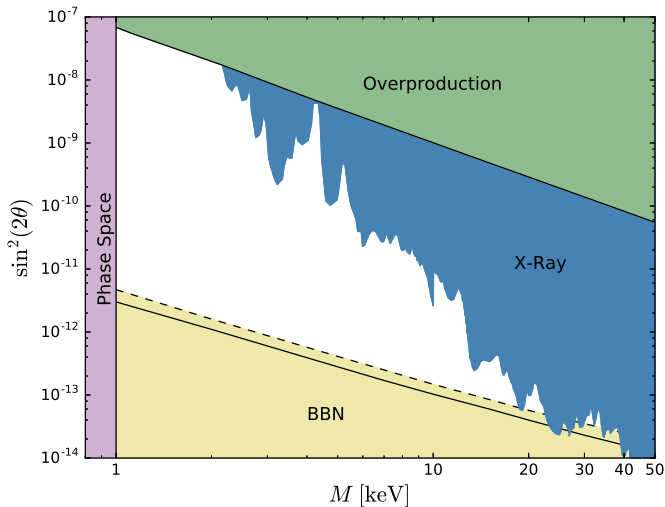
Ruled out by X-ray and Lyman- α observations!

Shi-Fuller scenario [astro-ph/9810076]

- Large primordial lepton asymmetry can lead to resonant production of sterile neutrinos, $n_{L_\alpha} \geq 10^{-6} s$
- smaller mixing angles $\theta_\alpha \equiv \frac{|h_\alpha|v}{\sqrt{2}M}$ and colder spectra possible

Parameter space for 1+1 flavor scenario

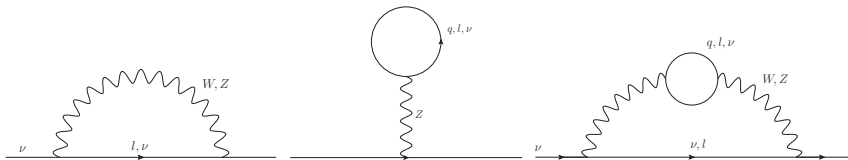
Combined constraints on M and $\sin^2(2\theta) \approx 4 \sum_{\alpha} \theta_{\alpha}^2$ in case of resonant production: see also [0901.0011],[1311.0282],[1609.00667],[1901.01262]



Sterile neutrino DM production II

- Sterile neutrino reaction rate depends on self-energy of active neutrinos:

$$\Sigma_{\alpha}^{\text{ret}}(\pm k, \mu) = \gamma^0 \left(\mp b_{\alpha} + c_{\alpha}(\mu) - \frac{i\Gamma_{\alpha}}{2} \right)$$



- Production mainly takes place around QCD crossover at $T \sim 160\text{MeV}$
→ large hadronic uncertainties in EoS, quark number susceptibilities and **active-neutrino opacity**

Sterile neutrino DM production III

Production governed by set of coupled evolution equations for sterile neutrino PSD f and lepton asymmetry $n_{L\alpha}$.

At leading order in h_α and M/k :

$$D_t f_k = - \sum_{\alpha=e,\mu,\tau} \gamma_\alpha(k, \mu) \left[f_k - f_F(E_k - \mu_{L\alpha}) \right]$$

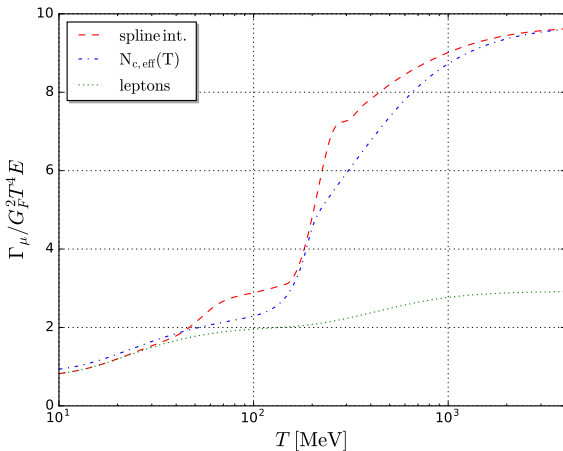
$$D_t n_{L\alpha} = \int_k \gamma_\alpha(k, \mu) \left[f_k - f_F(E_k - \mu_{L\alpha}) \right]$$

with rate coefficients

$$\gamma_\alpha(k, \mu) = \frac{\theta_\alpha^2 M^4 \Gamma_\alpha}{[M^2 + 2E_k(b_\alpha - c_\alpha(\mu))]^2 + (E_k \Gamma_\alpha)^2}$$

Active-neutrino opacities in the QCD epoch

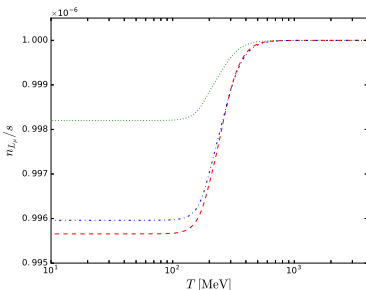
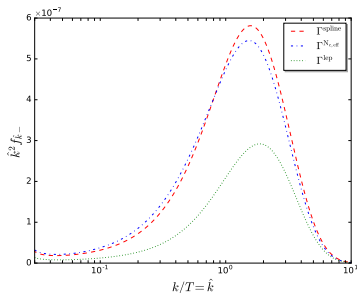
QCD contributions to Γ_α around T_{QCD} difficult to compute, use approximations (see [1507.06655],[hep-ph/0612182])



→ compare their influence on the production

Solutions of the evolution equations

We fix $M = 7.1\text{keV}$ and $\sin^2(2\theta) = 10^{-12}$ and solve the equations for various values of initial lepton asymmetries:



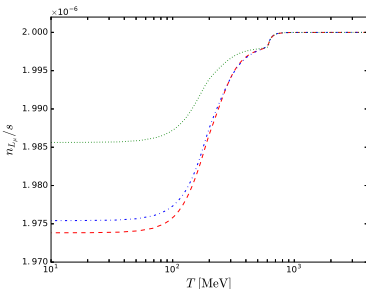
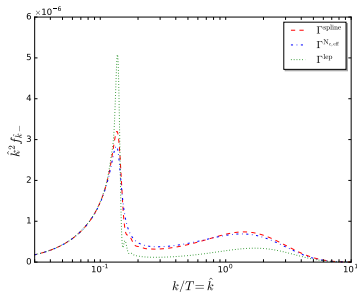
Left: sterile neutrino PSD at $T = 10\text{MeV}$ (end of production)

Right: time evolution of lepton asymmetry

$$(\Omega_s/\Omega_{DM} = 5.7 \cdot 10^{-4})$$

Solutions of the evolution equations

We fix $M = 7.1\text{keV}$ and $\sin^2(2\theta) = 10^{-12}$ and solve the equations for various values of initial lepton asymmetries:



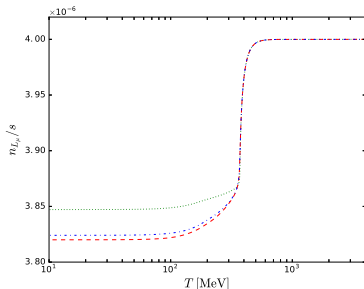
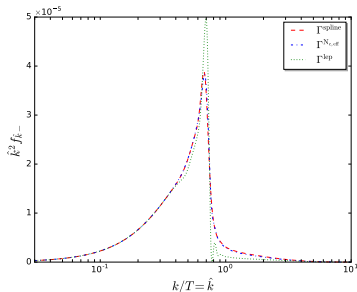
Left: sterile neutrino PSD at $T = 10\text{MeV}$ (end of production)

Right: time evolution of lepton asymmetry

$$(\Omega_s/\Omega_{DM} = 6.6 \cdot 10^{-4})$$

Solutions of the evolution equations

We fix $M = 7.1\text{keV}$ and $\sin^2(2\theta) = 10^{-12}$ and solve the equations for various values of initial lepton asymmetries:



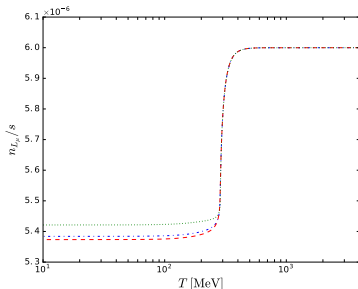
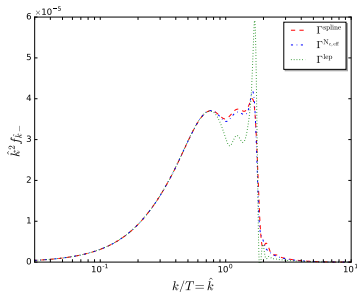
Left: sterile neutrino PSD at $T = 10\text{MeV}$ (end of production)

Right: time evolution of lepton asymmetry

$$(\Omega_s/\Omega_{DM} = 2.9 \cdot 10^{-3})$$

Solutions of the evolution equations

We fix $M = 7.1\text{keV}$ and $\sin^2(2\theta) = 10^{-12}$ and solve the equations for various values of initial lepton asymmetries:



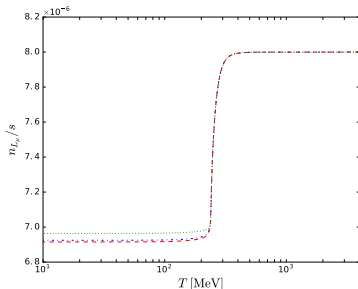
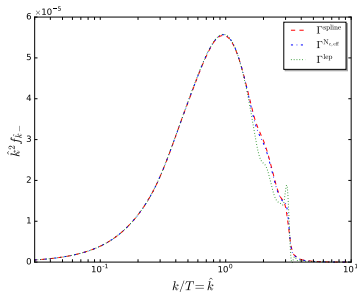
Left: sterile neutrino PSD at $T = 10\text{MeV}$ (end of production)

Right: time evolution of lepton asymmetry

$$(\Omega_s/\Omega_{DM} = 1 \cdot 10^{-2})$$

Solutions of the evolution equations

We fix $M = 7.1\text{keV}$ and $\sin^2(2\theta) = 10^{-12}$ and solve the equations for various values of initial lepton asymmetries:



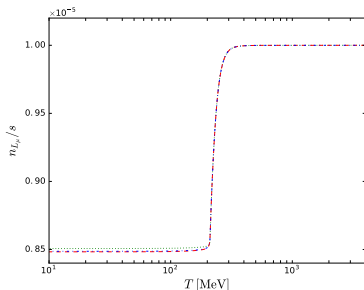
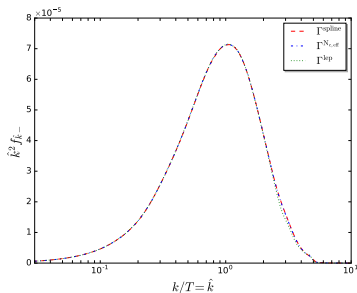
Left: sterile neutrino PSD at $T = 10\text{MeV}$ (end of production)

Right: time evolution of lepton asymmetry

$$(\Omega_s / \Omega_{DM} = 1.8 \cdot 10^{-2})$$

Solutions of the evolution equations

We fix $M = 7.1\text{keV}$ and $\sin^2(2\theta) = 10^{-12}$ and solve the equations for various values of initial lepton asymmetries:



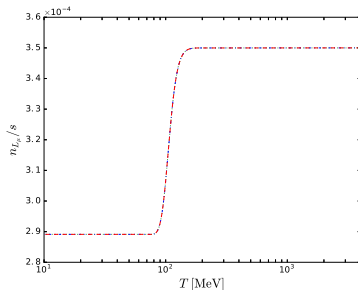
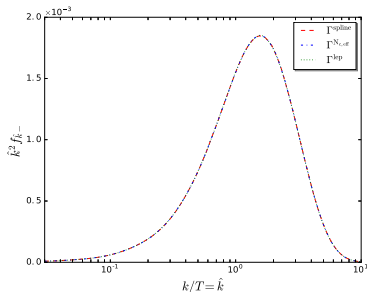
Left: sterile neutrino PSD at $T = 10\text{MeV}$ (end of production)

Right: time evolution of lepton asymmetry

$$(\Omega_s/\Omega_{DM} = 2.5 \cdot 10^{-2})$$

Solutions of the evolution equations

We fix $M = 7.1\text{keV}$ and $\sin^2(2\theta) = 10^{-12}$ and solve the equations for various values of initial lepton asymmetries:



Left: sterile neutrino PSD at $T = 10\text{MeV}$ (end of production)

Right: time evolution of lepton asymmetry

$(\Omega_s/\Omega_{DM} = 1)$
→ Resonant production is blind to the structure of Γ_α

- keV sterile neutrinos make a good DM candidate, given large enough lepton asymmetries
- QCD crossover complicates evolution of sterile neutrino abundance and lepton asymmetry
- For generating relic DM abundance through resonant sterile neutrino production, QCD contributions to active-neutrino opacities not important