

Boosting sterile neutrino dark matter production

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based on JHEP 03 (2024) 032 [arXiv:2307.15565]
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Sterile neutrino dark matter

- ▶ sterile neutrino \rightarrow gauge singlet fermion
- ▶ interacts with SM via mixing with regular neutrinos

interesting since

- ▶ one of the most minimal SM extensions
- ▶ DM candidate since it is naturally dark

with oscillations alone (Dodelson-Widrow mechanism)

- ▶ right amount of DM for $\mathcal{O}(keV)$ masses
- ▶ decays to photon and SM neutrino (X-ray lines)
- ▶ tends to be warm (i.e. affect structure formation)
- ▶ current status: excluded

Self-interacting sterile neutrinos

Minimal setup for a more complex dark sector:

- ▶ add one scalar singlet ϕ
(one new parameter: m_ϕ)
- ▶ ν_s mixing with SM neutrinos remains only connection between DM and SM
- ▶ ϕ interacts with ν_s
(one parameter: Yukawa coupling y)

see also Hansen and SV '17, Fuller and Johns '19, Bringmann et al '22

Production in early Universe

sterile neutrinos are produced by “freeze-in” with some extra hoops
Master equation for production

$$\frac{\partial f_s}{\partial t} - Hp \frac{\partial f_s}{\partial p} = \frac{\Gamma_t}{4} \left(\frac{\omega^2 \sin^2(2\theta)}{\omega^2 \sin^2(2\theta) + \frac{\Gamma_t^2}{4} + [\omega \cos(2\theta) - V_{\text{eff}}]^2} \right) [f_a - f_s] + C_s$$

Diagram illustrating the Master equation for production of sterile neutrinos, with labels for various terms:

- $\frac{\partial f_s}{\partial t}$: Sterile's distribution function
- $Hp \frac{\partial f_s}{\partial p}$: Hubble's rate
- $\frac{\Gamma_t}{4}$: Total rate
- $\omega^2 \sin^2(2\theta)$: Vacuum oscillation frequency $\sim \frac{m_s^2}{2p}$
- $\omega^2 \sin^2(2\theta) + \frac{\Gamma_t^2}{4} + [\omega \cos(2\theta) - V_{\text{eff}}]^2$: Vacuum mixing angle
- V_{eff} : Effective potential
- $[f_a - f_s]$: Active's distribution function
- C_s : Sterile-sterile scattering processes

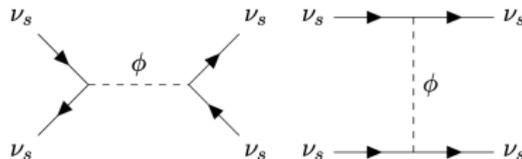
evolution controlled by

- ▶ effective in medium oscillation probabilities, i.e. term in brackets
- ▶ total interaction rate of neutrinos, Γ_t
- ▶ dark sector thermalization rate, C_s

Simple modification ...

... with rich effects in sterile neutrino production

- ▶ large self scattering rate for non-vanishing sterile neutrino population

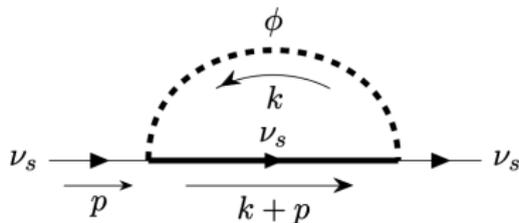


- ▶ heuristic: replace one of the initial states with SM neutrino via mixing

the more sterile there are the more they scatter
 \Rightarrow self-accelerating production rate

... with rich effects in sterile neutrino production

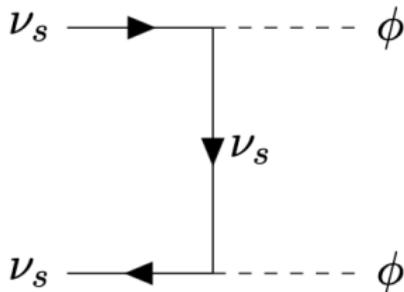
- ▶ new physics contribution to thermal potentials



- ▶ cancelation in denominator of effective oscillation probability for heavy ϕ and large enough y
 \Rightarrow resonant enhancement of the production rate

... with rich effects in sterile neutrino production

- ▶ number changing processes in the sterile neutrino sector

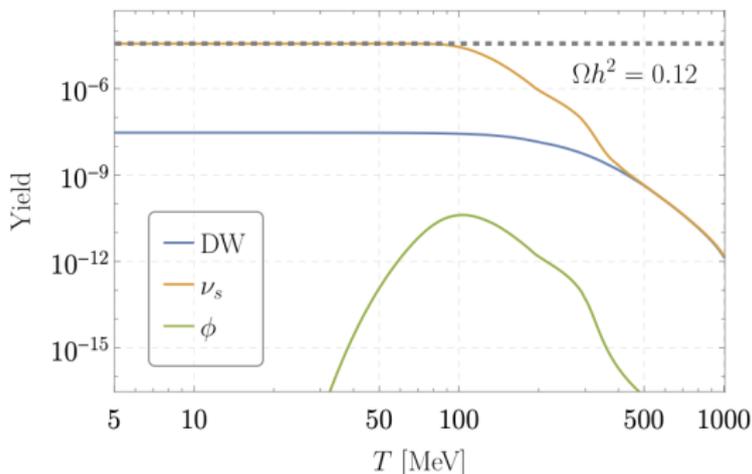


⇒ allows for additional DM production and independent evolution of dark sector temperature

Example DM production

masses: $m_s = 12$ keV, $m_\phi = 1.5$ GeV

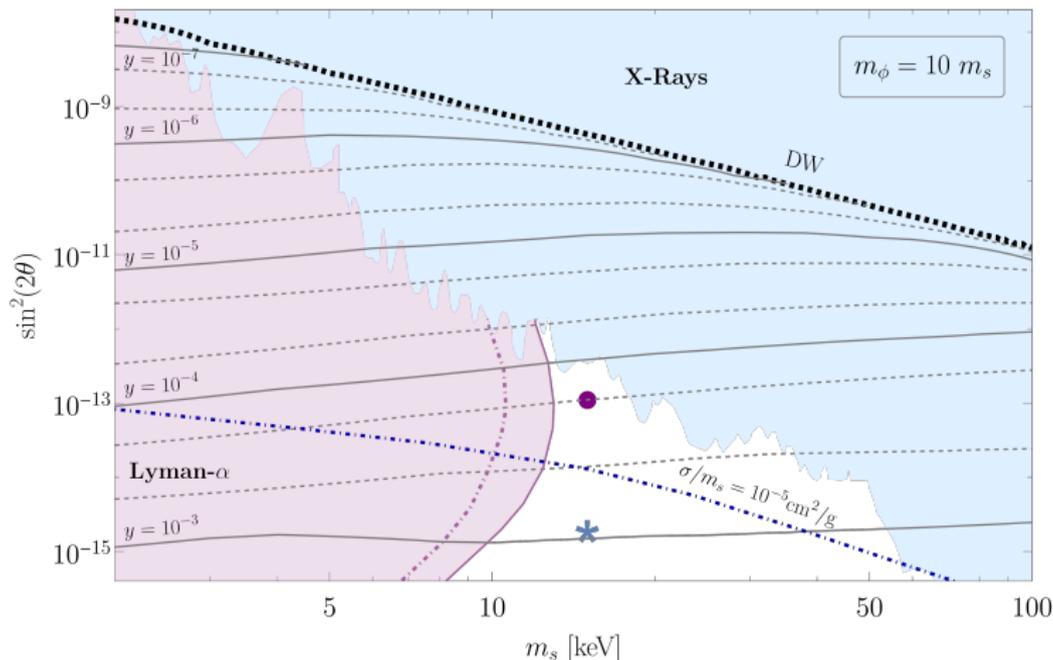
mixing $\sin^2(2\theta) = 5 \times 10^{-13}$ and coupling $y \approx 7 \times 10^{-2}$



- ▶ high T : DW production
- ▶ intermediate T : self-interaction pick up and pull in more stuff
- ▶ low T : production shuts of when ϕ becomes massive

Can this be tested?

Parameter space of sterile neutrino dark matter



constraints from

- ▶ structure formation (Lyman- α forest)
- ▶ X-ray satellites

Conclusions

- ▶ keV sterile neutrinos are an attractive dark matter candidate
- ▶ large enhancement of production from interactions in dark sector
- ▶ impact on phenomenology mixed
 - ▶ X-ray bounds less constraining
 - ▶ structure formation bounds similar or stronger