Sterile Neutrino Dark Matter from Scalar Decay: General Features, Subleties and Related Issues

Based on JCAP 1506 (2015) 011 & 1510.XXXXX
in collaboration with A. Merle and A. Schneider

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- reactor anomalies, gallium anomaly
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- Dark Matter candidate
- Recent excitement about tentative signal ($N \to \nu\gamma$) at $E_\gamma = 3.55\,\mathrm{keV} \Rightarrow M_R = 7.1\,\mathrm{keV}$? (see Bulbul et al., 1402.2301)

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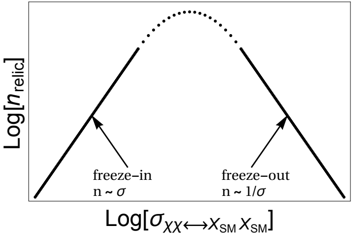

Possible production mechanisms for keV steriles as DM

- Dodelson-Widrow-mechanism (hep-ph/9303287) Production from the plasma via active-sterile-mixing θ; equilibrium never achieved;
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$\Rightarrow$ numerical treatment on the level of distribution functions!

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where

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  $S \to NN$
- Simplification for the time being: $\theta_{\alpha N} = 0$.

Sterile neutrinos from scalar decays – particle physics

The relevant parameters of the setup:

- Yukawa coupling y $\left(-\mathcal{L} \supset \frac{y}{2} S \overline{N^c} N\right)$.
- Higgs portal λ $\left(-\mathcal{L} \supset 2\lambda \left(H^\dagger H\right) S^2\right)$
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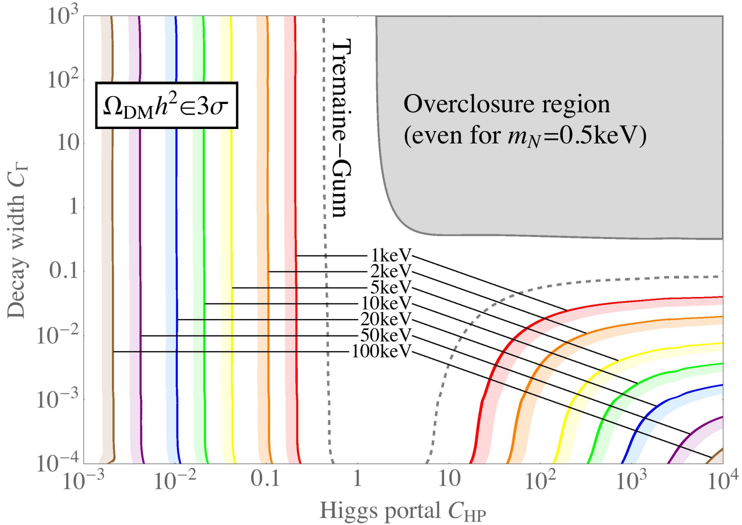
Convenient parametrisation for our analysis:

- $\mathcal{C}_\Gamma \equiv \frac{M_0}{m_S} \frac{y^2}{16\pi} = \frac{M_0}{m_S} \frac{\Gamma}{m_S}$ (effective decay width)
- $\mathcal{C}_{\mathrm{HP}} \equiv \frac{M_0}{m_S} \frac{\lambda^2}{16\pi^3}$ (effective Higgs portal)
- with $M_0 \equiv \left(\frac{45 M_{\mathrm{Pl}}^2}{4\pi^3 g_*}\right)^{1/2}$

Confronting the model with reality – relic abundance



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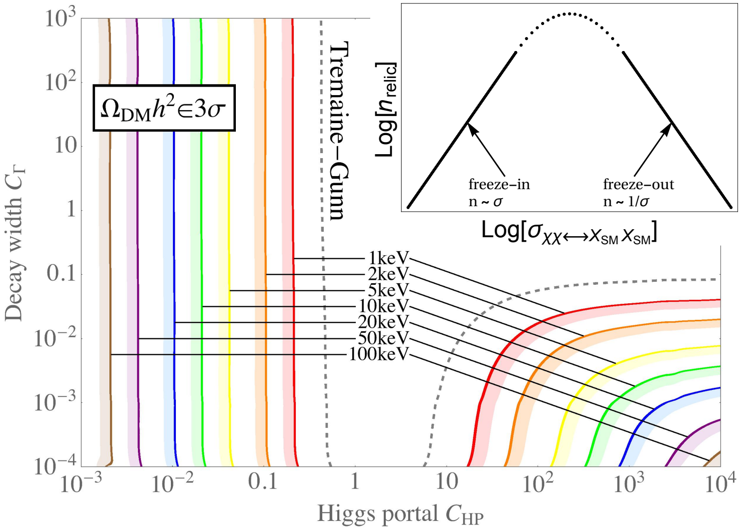

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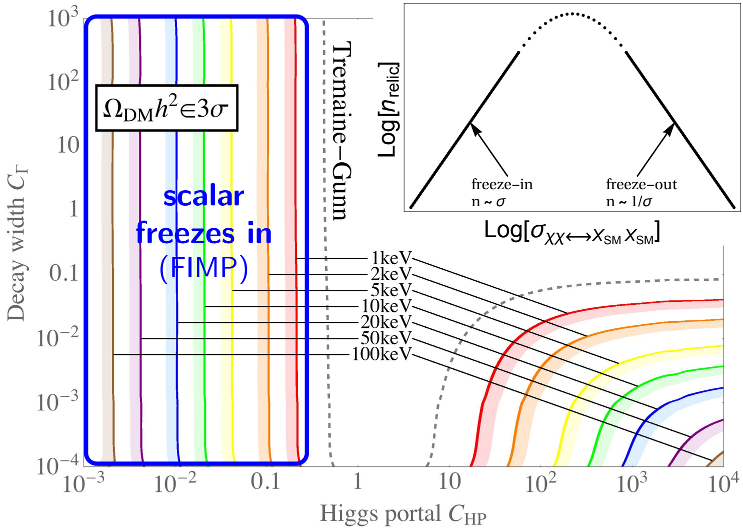

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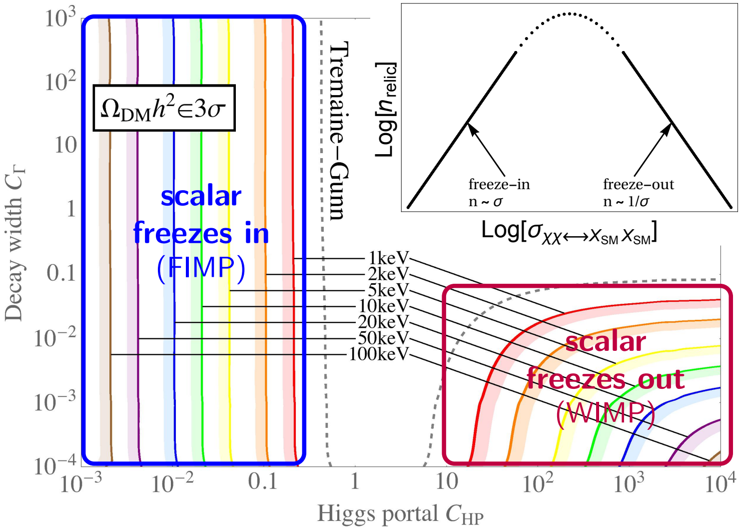
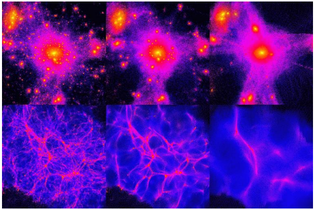


Free-streaming – an estimation for structure formation



http://www.ctac.uzh.ch/gallery/

- $\lambda_{\mathrm{FS}} \equiv \int_{T_{\mathrm{prod}}}^{T_0} \frac{\langle v(T) \rangle}{a(T)} \frac{\mathrm{d}t}{\mathrm{d}T} \mathrm{d}T$
  $\Rightarrow$ estimator for structure formation.

- cold DM: $\lambda_{\mathrm{FS}} \leq 0.01\,\mathrm{Mpc}$
  warm DM: $0.01\,\mathrm{Mpc} < \lambda_{\mathrm{FS}} \leq 0.1\,\mathrm{Mpc}$
  hot DM: $\lambda_{\mathrm{FS}} \geq 0.1\,\mathrm{Mpc}$

- Problem: λ_{FS} captures only average properties of the spectra!
- But: Full large-scale simulations expensive and usually based on thermal spectra

$\Rightarrow$ Use λ_{FS} for the time being, more detailed analyses to come [Merle, Schneider, MT, 1510.XXXXX]

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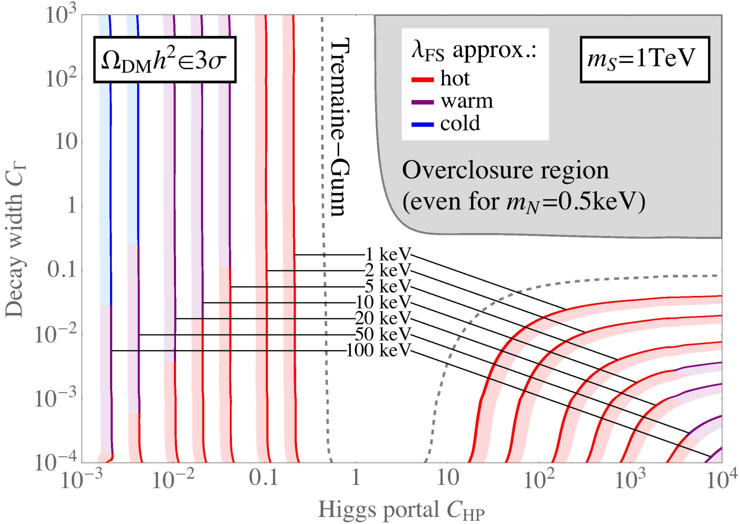

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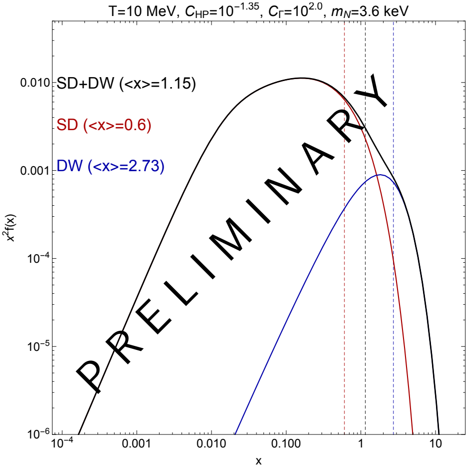

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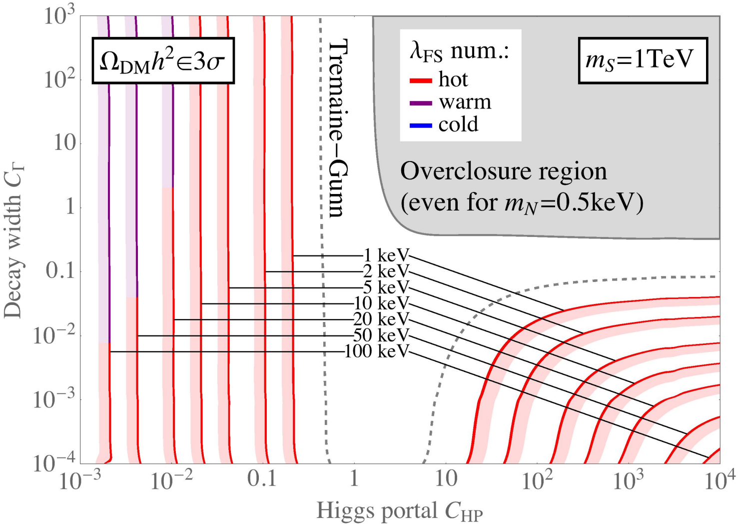
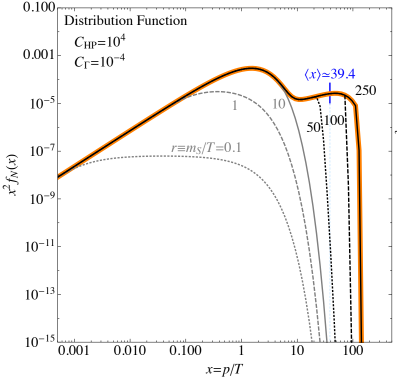
- Implications for structure formation need investigation beyond free-streaming to take into account the full information of the spectrum
  (analysis using transfer functions and other methods to come in $[\mathrm{Merle, Schneider, MT, 1510.XXXXX}]$).
- Smaller scalar masses might alter the spectra further (different kinematics, more production channels for S)
  $\rightarrow$ work in progress.

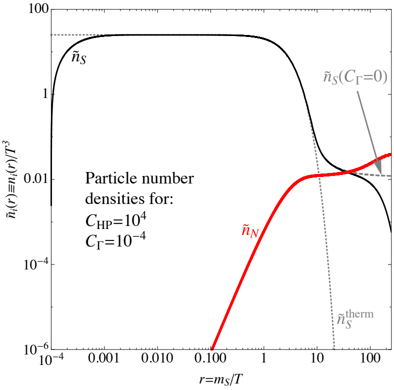
Thank you for your attention!

Backup I – Numerical free-streaming horizon

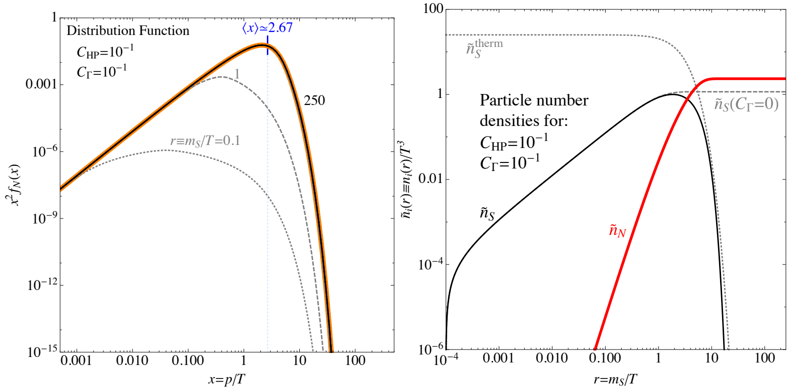


Backup IIa – Evolution of abundances vs. evolution of distribution function

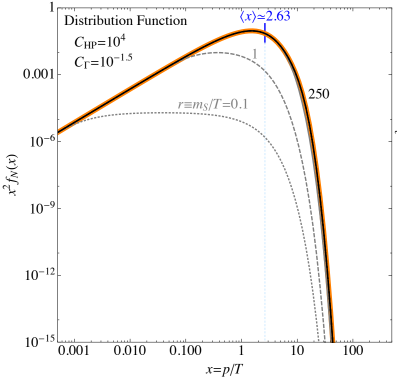


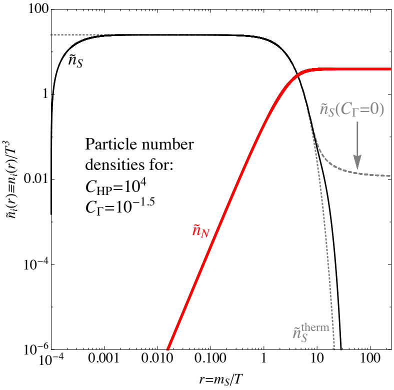


Backup IIb – Evolution of abundances vs. evolution of distribution function

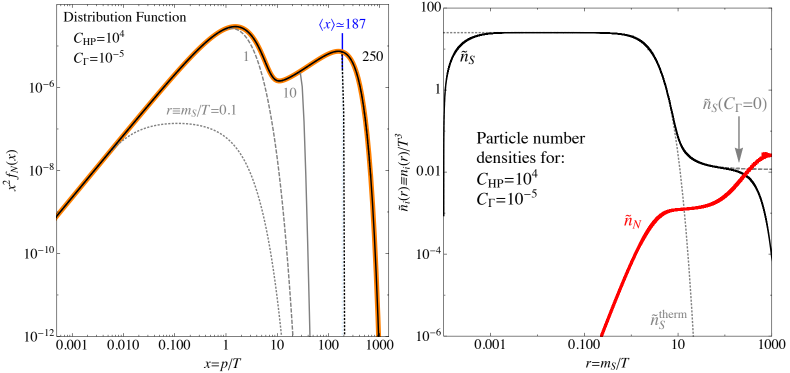


Backup IIc – Evolution of abundances vs. evolution of distribution function

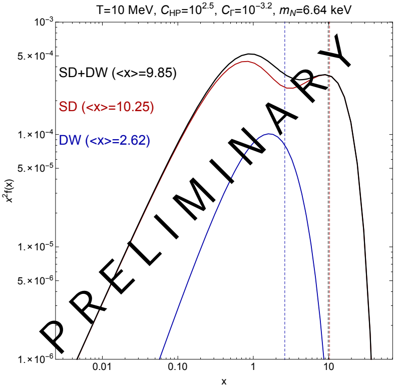


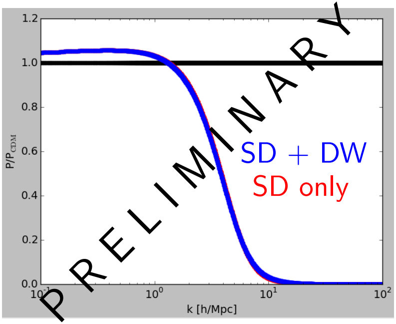


Backup IId – Evolution of abundances vs. evolution of distribution function



Backup III – Effect of DW component on Double Peak





Backup IV – The numerical issues

In general, the Boltzmann equations on the level of distribution functions will be of the form

$$\left(\frac{\partial}{\partial t} - H(t)\, p \frac{\partial}{\partial p}\right) f_i(p,t) = \mathcal{Q}_i(p,t) + \sum_j \mathcal{P}_j(p,t)\, f_j(p,t) + \sum_{j,k} \mathcal{S}_{jk}(p,t)\, f_j(p,t) \int \mathrm{d}^3 p' \mathcal{T}_{jk}(p',t)\, f_k(p',t)$$

$\Rightarrow$ Standard method of discretization $f_i(p,t) \to f_i^{\alpha}(t)$ struggles with the problem of strong coupling: derivative couples neighboring indices α (local information) while integration couples all α (global information).

Backup V – Boltzmann equations and parametrisation

- The dynamics of the species, i.e the momentum distribution functions $f_i\left(p,t\right)$ are described by Boltzmann equations:

$$\hat{L}\left[f\right] = C\left[f\right] \,,$$

$$\text{where } \hat{L} = \frac{\partial}{\partial t} - H\left(t\right) p \frac{\partial}{\partial p} \text{ is the Liouville-operator}$$

- Useful changes of variables:
  - "time" $r = m_S / T$
  - dimensionless momentum $x = p/T$.
- Boltzmann equations in this setup:

$$\frac{\partial f_S\left(r,x\right)}{\partial r} = -\frac{m_S}{r^2}\frac{\mathrm{d}t}{\mathrm{d}T}\left(C^S_{hh\to SS} + C^S_{SS\to hh} + C^S_{S\to NN}\right) \,,$$

$$\frac{\partial f_N\left(r,x\right)}{\partial r} = -\frac{m_S}{r^2}\frac{\mathrm{d}t}{\mathrm{d}T}\; C^N_{S\to NN} \,.$$

$\Rightarrow$ Numerically difficult (i.e. stiff) PIDEs.