

Warm Dark Matter

➤ Cusp vs cores??, missing satellites?

➤ Non-thermal relic

➤ Larger free streaming length: cutoff in $P(k)$ $\lambda_{fs} \sim \sqrt{\frac{\langle p^2 \rangle}{m^2 G \rho}}$

➤ ``Simple'' extensions BSM

Sterile neutrinos: SU(2) singlets

Resonant and non-resonant production mechanisms:

Distribution function.

Sterile neutrinos: a DM candidate

$$\mathcal{L} = \mathcal{L}_{SM} + \frac{1}{2} \partial_\mu \chi \partial^\mu \chi - \frac{M^2}{2} \chi^2 + i \bar{\nu} \partial \nu - \frac{Y}{2} \chi \bar{\nu}^c \nu - \frac{m}{2} \bar{\nu}^c \nu - y_\alpha H^\dagger \bar{L}_\alpha \nu - V(H^\dagger H; \chi) + \text{h.c.}$$

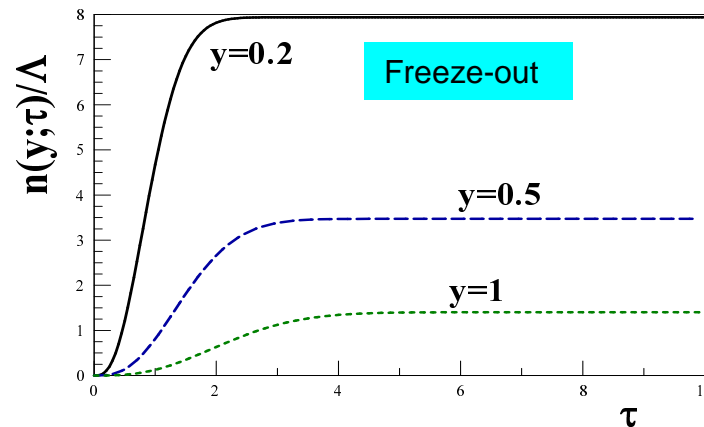
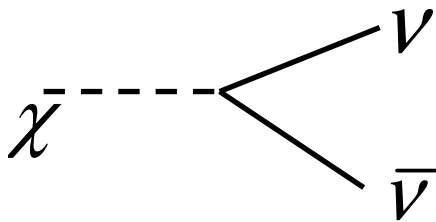
χ = Scalar, gauge singlet

$$M \sim \langle \chi \rangle \sim 100 \text{ GeV} \quad Y \sim 10^{-8}$$

ν = "sterile neutrino" SU(2) singlet

$$m = Y \langle \chi \rangle \sim \text{keV}$$

Production: Scalar decay



$$\Lambda \sim 10^{-2}$$

$$\tau = \frac{M}{T(t)}$$

Frozen distribution

$$f_0(y) = 2\Lambda\sqrt{\pi} \frac{g_{\frac{5}{2}}(y)}{y^{\frac{1}{2}}}$$

↓

$$y = p/T_d$$

Decoupling at ~ 100 GeV

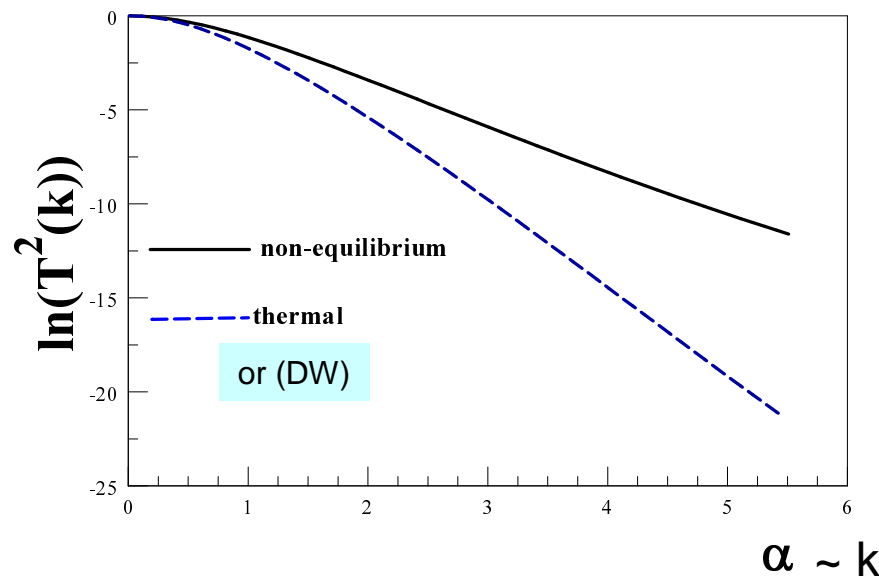
Colder today!!

Strong enhancement of small momentum

Abundance + phase space density constraints:

$$560\text{eV} \lesssim m \lesssim 1330\text{eV}$$

Consistent with model ``beyond SM''



Enhancement of T(K)
at SMALL scales,
from long-range
memory

$$\lambda_{fs} \sim 450\text{kpc}$$

Summary:

1) **Microphysics:** Particle physics model, kinetics of production, decoupling

→ $f(y)$ = decoupled distribution function, $y=p/T_{0,d}$

2) **Constrain** mass, couplings, $T_{0,d}$ **from abundance + phase space density**

$$\underbrace{\frac{100 \text{ eV}}{\mathcal{D}^{\frac{1}{4}}}}_{\text{Lower bound from phase Space density of dSphs}} \leq m \leq 6.5 \text{ eV} \underbrace{\frac{g_d}{g \int_0^\infty y^2 f(y) dy}}_{\text{Upper bound from abundance}} ; \quad \mathcal{D} = \frac{g}{2\pi^2} \frac{\left[\int_0^\infty y^2 f(y) dy \right]^{\frac{5}{2}}}{\left[\int_0^\infty y^4 f(y) dy \right]^{\frac{3}{2}}}$$

Lower bound from phase Space density of dSphs

Upper bound from abundance

Non-Thermal relics that decouple relativistically:

$\mathcal{D} \sim \Lambda \times 10^{-2} \sim 10^{-4} \longrightarrow m \sim \text{keV}$

3) **DM T(k): exact** → **simple + accurate approx:**

arbitrary $f(y)$ +ini. conds.

corrections to fluid+ memory of grav. clustering.

large $f(y)$ at small y =long memory=large $T(k)$ at small scales.