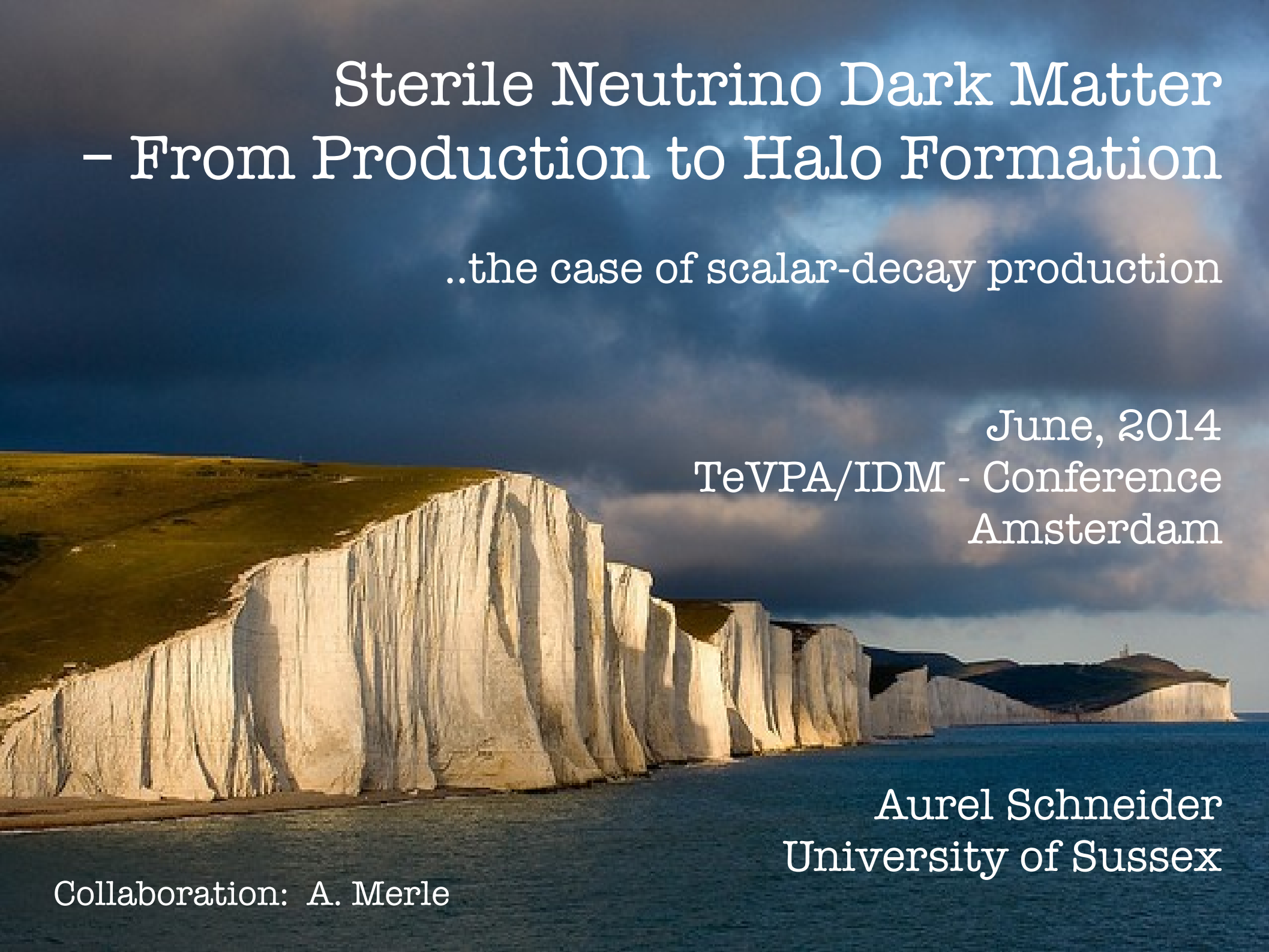
Sterile Neutrino Dark Matter – From Production to Halo Formation

..the case of scalar-decay production



June, 2014
TeVPA/IDM - Conference
Amsterdam

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Collaboration: A. Merle

Sterile Neutrinos: An intriguing DM candidate !

PROS :

- Natural/well-motivated extension of SM.
- Motivated by measured neutrino mixing.
- Potentially measurable (X-ray from decay).
- Interesting Astrophysical effects.

CONS :

- No *a priori* reason to have mass in keV-range
- Straight forward production ruled out.

The Crux: Sterile neutrino production

Production mechanisms:


Thermal freeze-out


Mixing (Dodelson & Widrow 1994)


Resonant Mixing (Shi & Fuller 1999, Laine & Shaposhnikov 2008)


Decay of scalar singlet (Petraki & Kusenko 2008, Merle et al 2013)

Decay Production: Basics

Production : $S \rightarrow 2\,N$

Decay time : $t_d(E \sim C\, m_S)$ $(m_S \sim 100\ \text{GeV},\ C \sim 1)$

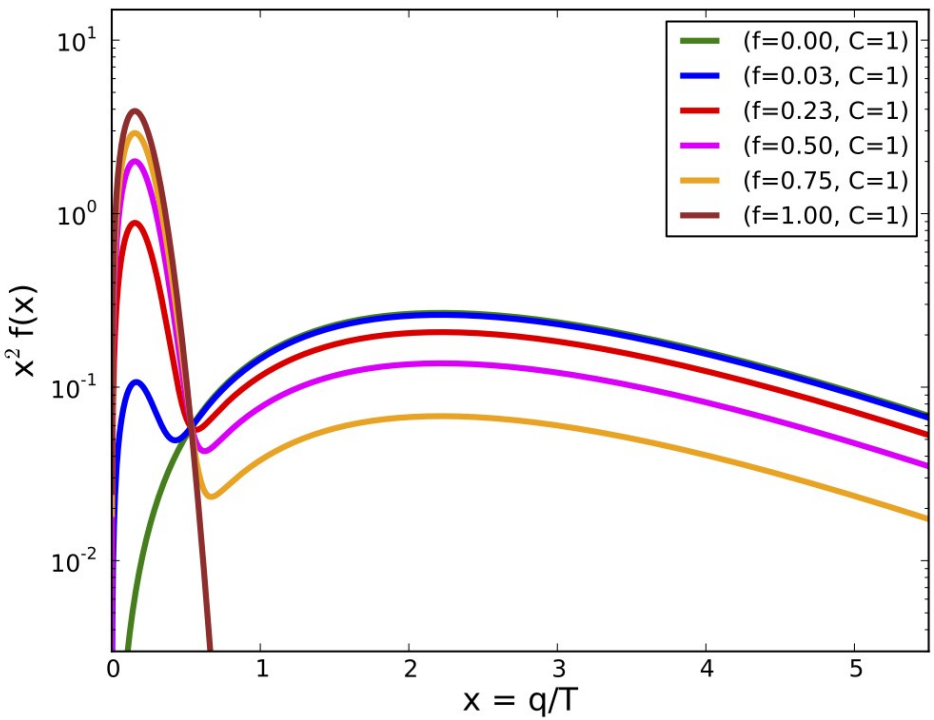
Momentum : $p \sim m_S/2$

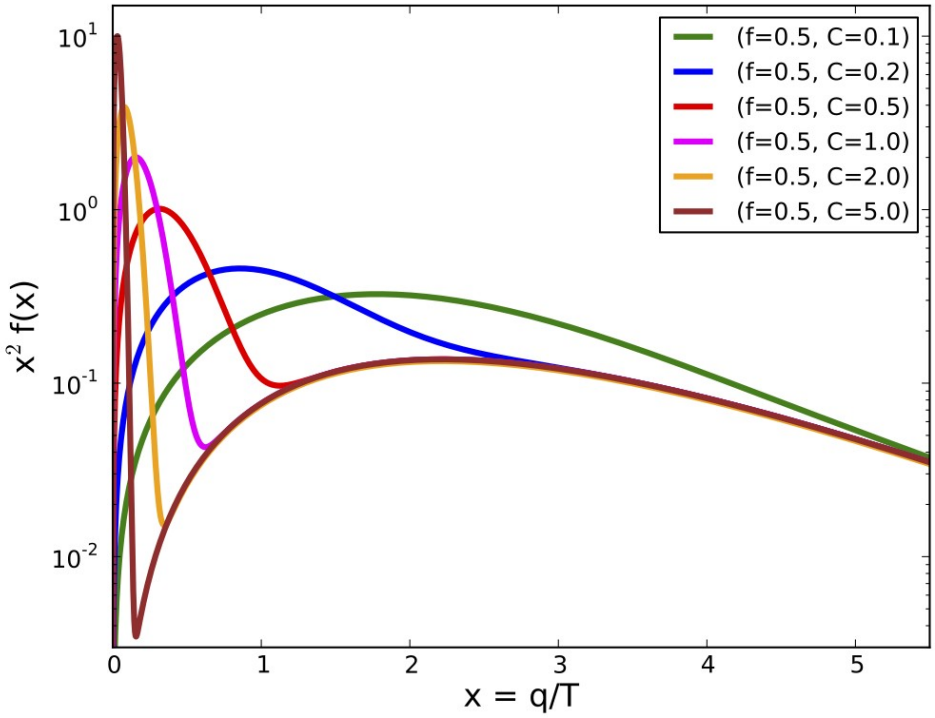
Mixing: possible, not required

Momentum distribution:

$$f(q) = \frac{\beta_{SD}}{q/T_{SD}} e^{-(q/T_{SD})^2} + \frac{\beta_{DW}}{e^{q/T_{DW}} + 1}$$

Decay Production: Momentum Distribution





Momentum distribution:

$$f(q) = \frac{\beta_{SD}}{q/T_{SD}} e^{-(q/T_{SD})^2} + \frac{\beta_{DW}}{e^{q/T_{DW}} + 1}$$

$$\left[f = \frac{\Omega_{SD}}{\Omega_{SD} + \Omega_{DW}} \right]$$

Perturbations: Basics

Fluid approximation (Euler equations):

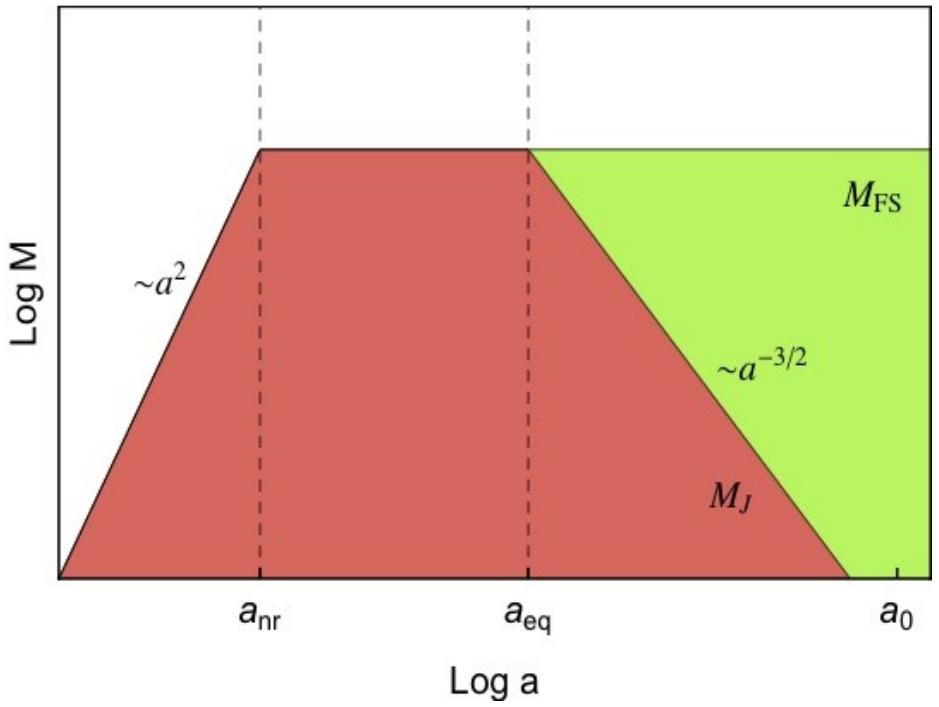
$$\dot{\delta} + \theta - 3\phi = 0,$$
$$\dot{\theta} + H\theta - k^2 c_s^2 \delta - k^2 \psi = 0.$$

$$\Rightarrow \quad \ddot{\delta} + H\dot{\delta} = \left[4\pi G\rho_{\rm b} - k^2 c_s^2\right]\delta,$$

Jeans criterion:

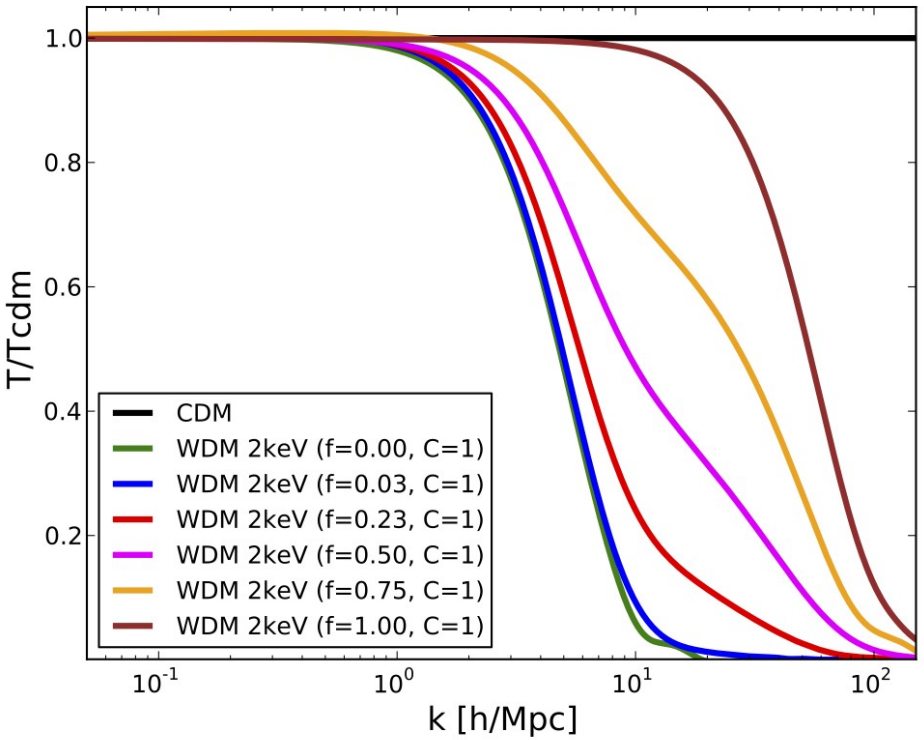
$$\lambda_{\rm J} = \frac{2\pi}{k_{\rm J}} = \sqrt{\frac{\pi c_s^2}{G\rho_{\rm b}}}$$

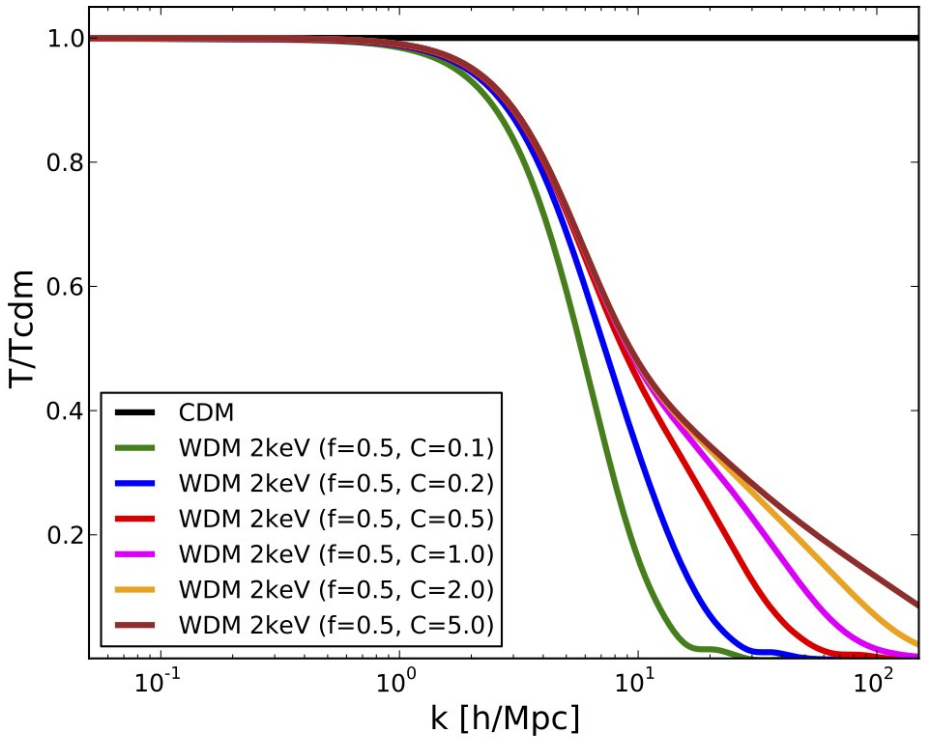
$$c_s^2 \propto (T_{dm}/m)$$



Perturbation: Power Spectra

Full calculation (Boltzmann hierarchy) :





CLASS (Lesgourgues, 2011)

Going Nonlinear : Halo Mass Function

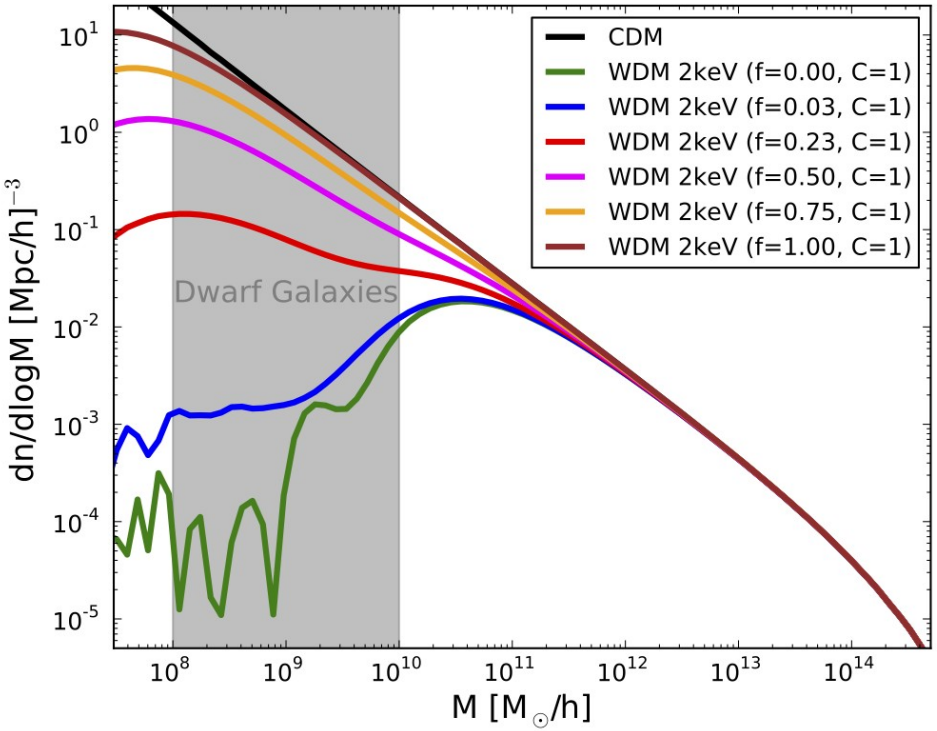
Extended Press-Schechter model:

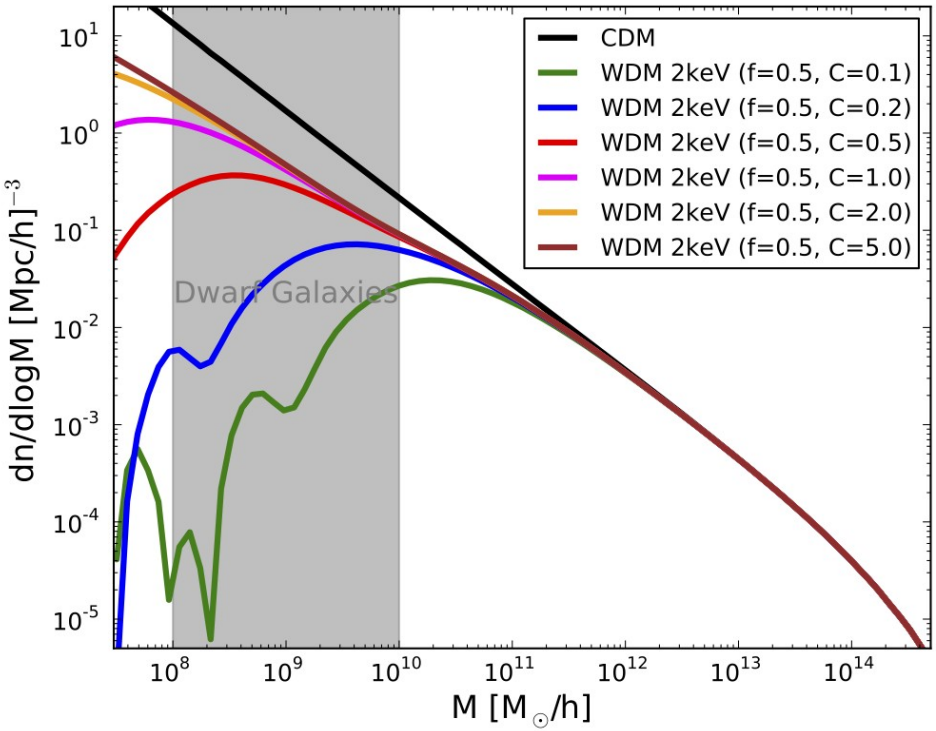
- Good approximation of nonlinear clustering
- Sharp-k filtering required (AS et al 2013)
- No artificial clumping

$$\frac{dn}{d\log M} = \frac{\bar{\rho}}{M} f(\nu) \frac{3}{4\pi^2 \sigma^2(R)} \frac{P_{\rm lin}(1/R)}{R^3} \qquad f(\nu) = A\sqrt{2\nu/\pi}(1+\nu^{-p})\mathrm{e}^{-\nu/2}$$

$$\sigma(R) = \int \frac{d\mathbf{k}^3}{(2\pi)^3} P_{\rm lin}(k)\Theta(1-kR), \qquad M = \frac{4\pi}{3}\bar{\rho}(cR)^3, \quad c = 2.5$$

Going Nonlinear : Halo Mass Function





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Example : The 3.5 keV line (Bulbul et al 2014, Boyarsky et al 2014)

If observed X-ray emission line comes from DM decay:

- Mass: $m = 2\ E = 7$ keV
- Mixing angle: $\sin^2 2\theta \sim 7e\text{-}11$

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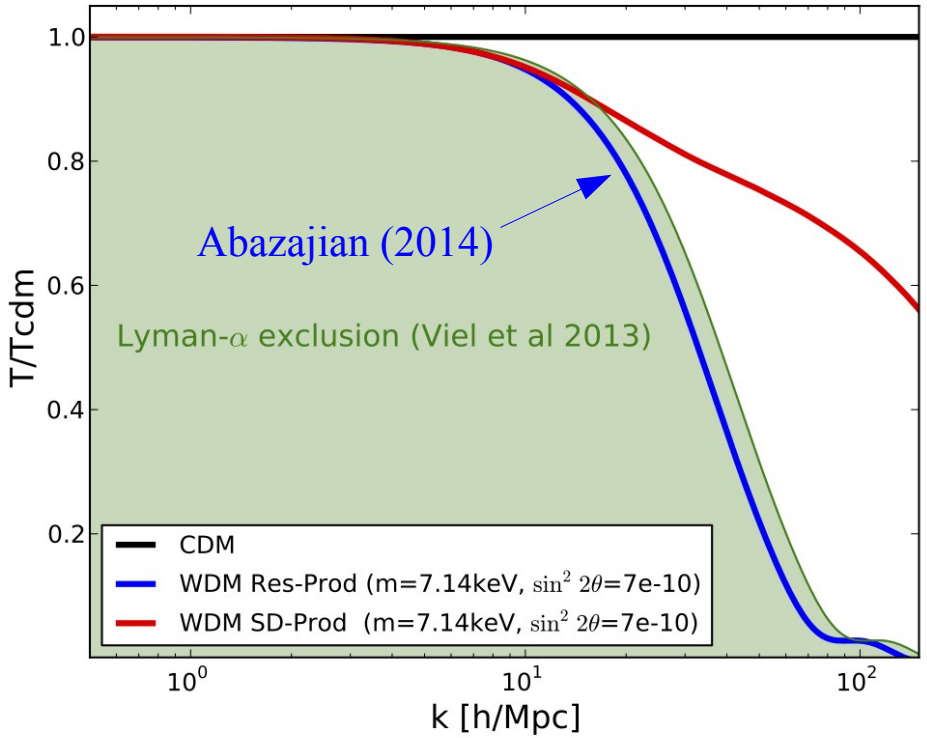

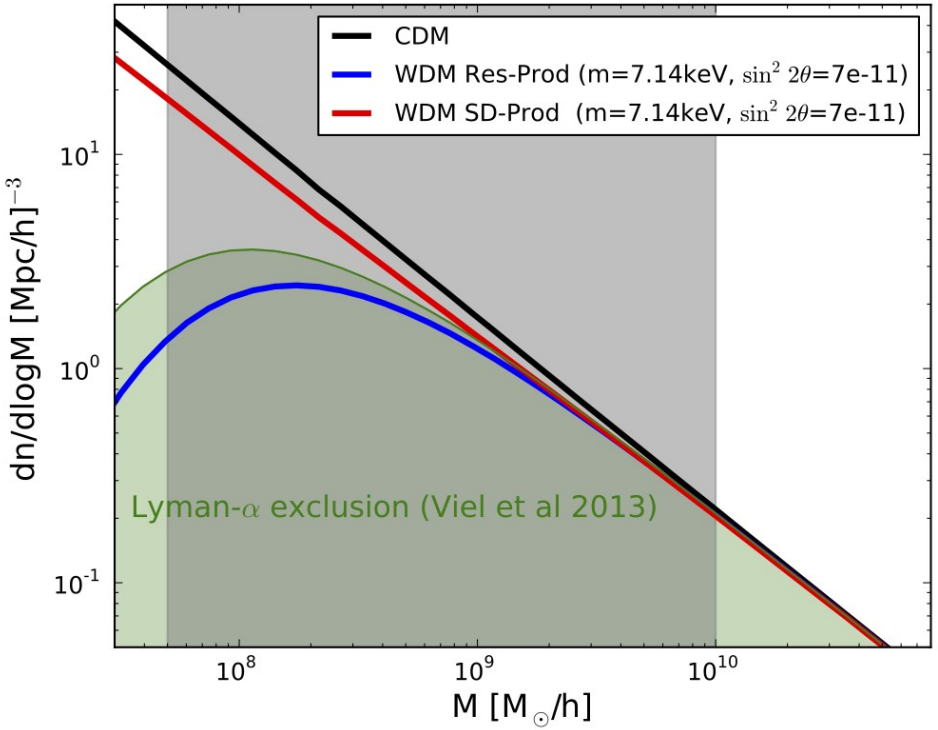

Conclusions:

Sterile neutrino production is very model dependent

Not all production scenarios lead to thermal-like power spectra

(Only scenarios with thermal-like power spectra are thoroughly tested)

3.5keV-line:
SD produced sterile neutrinos agree with Lyman-α constraints

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