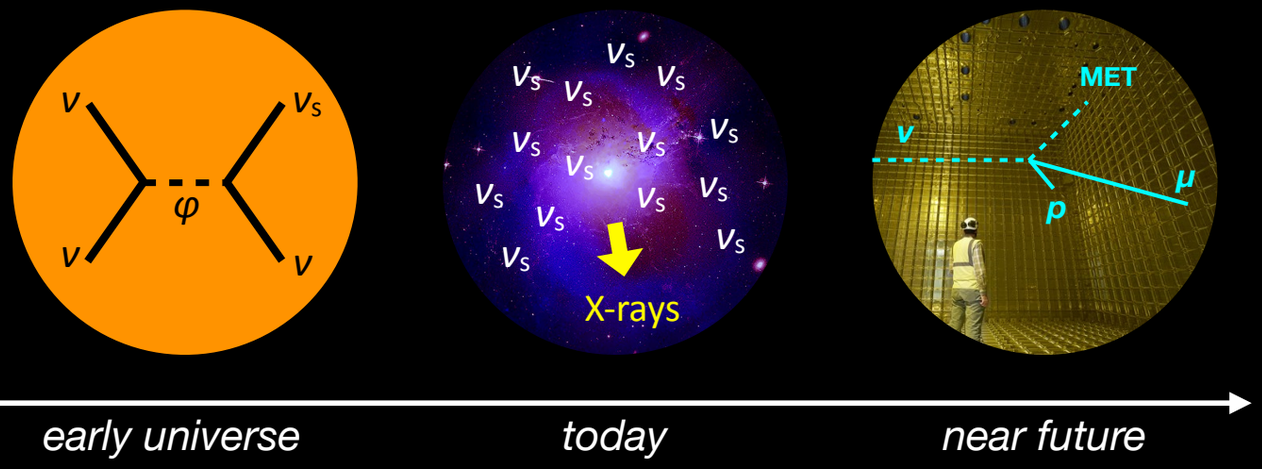

The Dodelson-Widrow Mechanism In the Presence of Self-Interacting Neutrinos

Walter Tangarife

with André de Gouvêa, Manibrata Sen, and Yue Zhang

LOYOLA UNIVERSITY CHICAGO

Preparing people to lead extraordinary lives

PRL 124 (2020) 8, 081802

Can we produce enough sterile neutrino DM in the early universe?

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Motivation

Sterile Neutrino Provides a right partner for the SM neutrino

For a review: Abazajian (2017)

Can give mass to SM neutrinos

Can be used in leptogenesis

Could be the dark matter (DM) particle

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Sterile Neutrino as Dark Matter

Fourth mass eigenstate: $\nu_4 = \nu_s \cos\theta + \nu_a \sin\theta \approx \nu_s$

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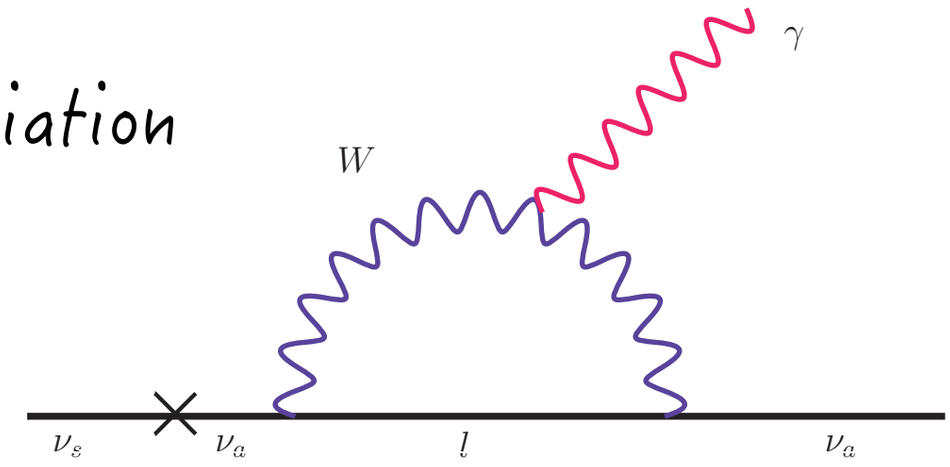
It can be detected through decay into radiation

$$\Gamma \sim 10^{-28} \mathrm{s}^{-1} \left(\frac{\sin^2 2\theta}{7 \times 10^{-11}} \right) \left(\frac{m_s}{7 \text{ keV}} \right)^5$$



e.g. Pal & Wolfenstein (1982),
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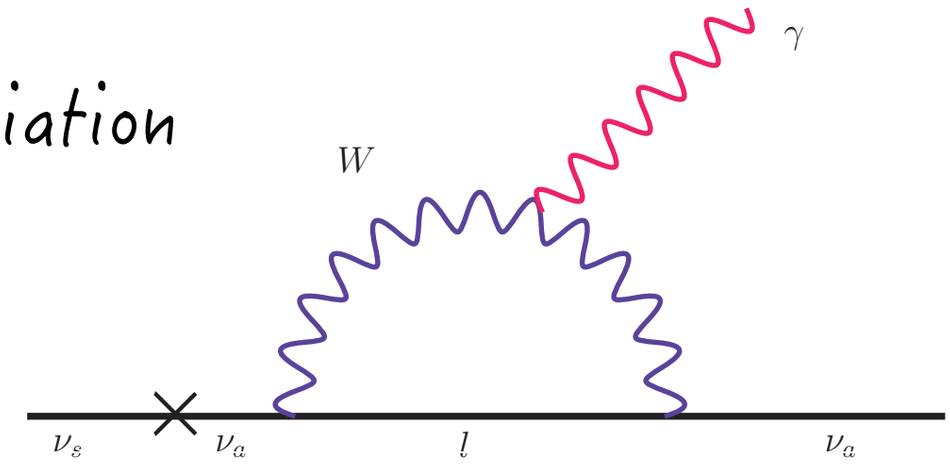

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How to produce it?

Two (among several) proposals:

Dodelson-Widrow (1994)

Shi-Fuller (1999)

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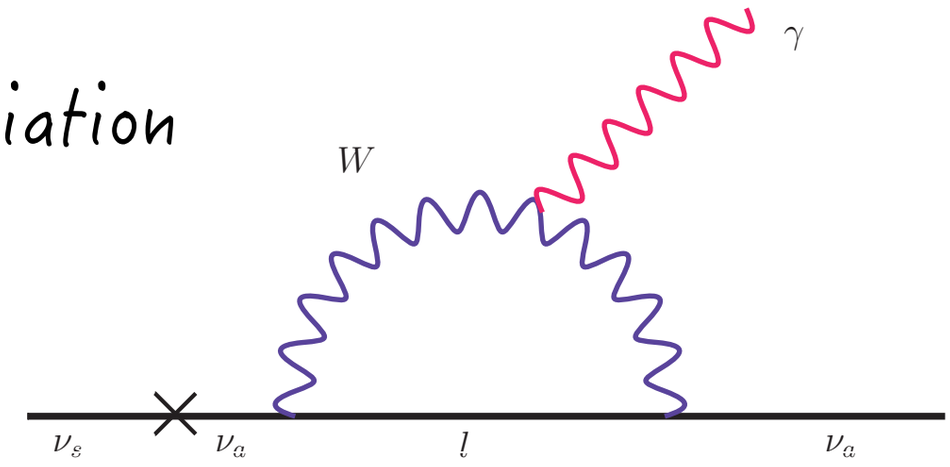

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Dodelson & Widrow (1994)

In the early universe, an active neutrino can oscillate to a sterile neutrino, with probability

$$\sin^2 2\theta_{\rm eff} \simeq \frac{\Delta^2 \sin^2 2\theta}{\Delta^2 \sin^2 2\theta + (\Gamma/2)^2 + (\Delta \cos 2\theta - V_T)^2}$$

$\Delta = m_s^2/2E$

Thermal potential

Quantum Zeno effect (damping)

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Thermal potential

Quantum Zeno effect (damping)

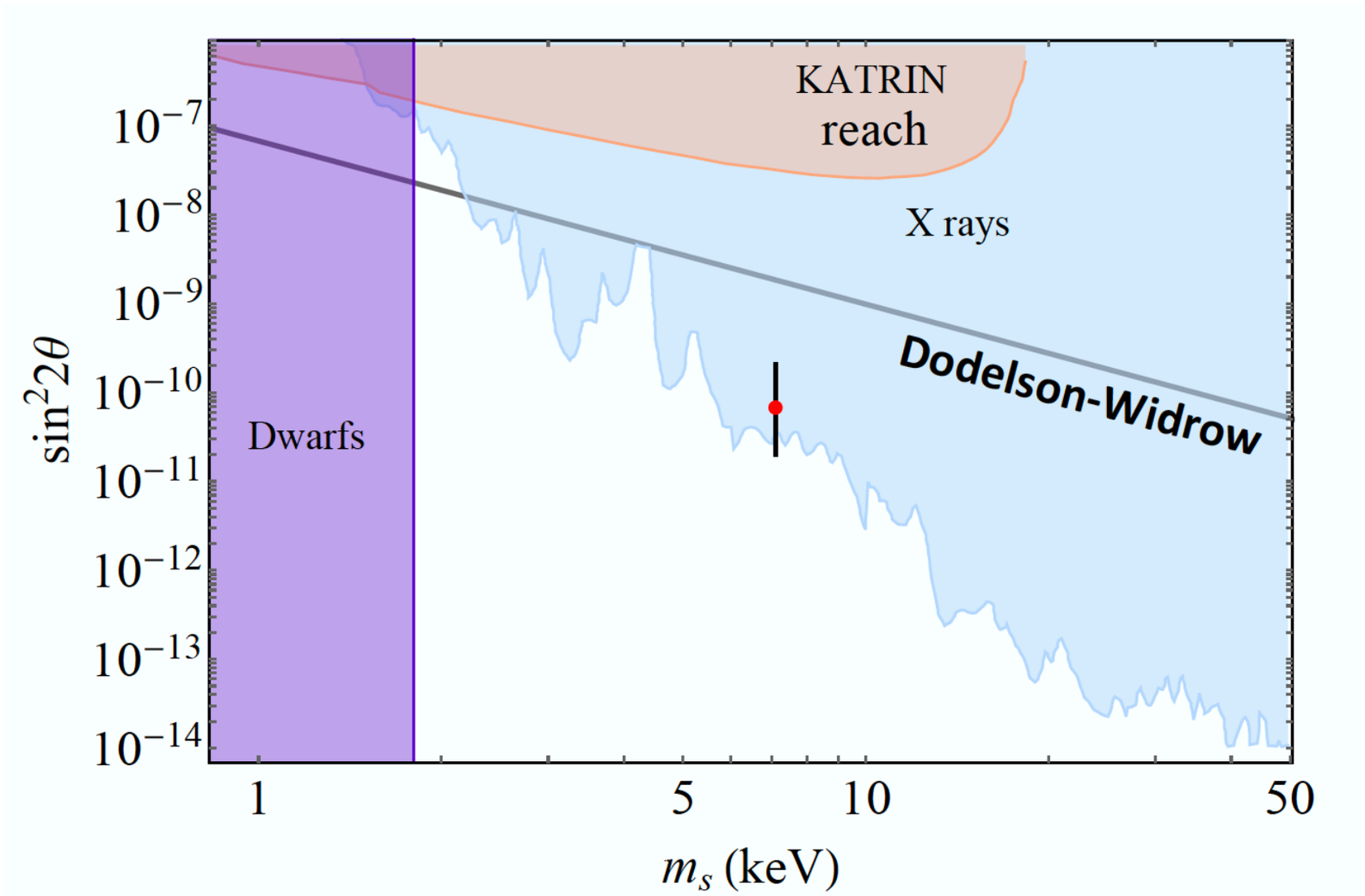
Result: A non-thermal abundance of sterile neutrinos by solving the Boltzmann equation

$$\frac{d\, f_{\nu_4}(x,z)}{d\ln z} = \frac{\Gamma}{4H}\, \sin^2 2\theta_{\rm eff}\, f_\nu(x)$$

$z = \mathrm{MeV}/T$

Dodelson-Widrow Mechanism

Ruled out by X-ray experiments and phase-space considerations



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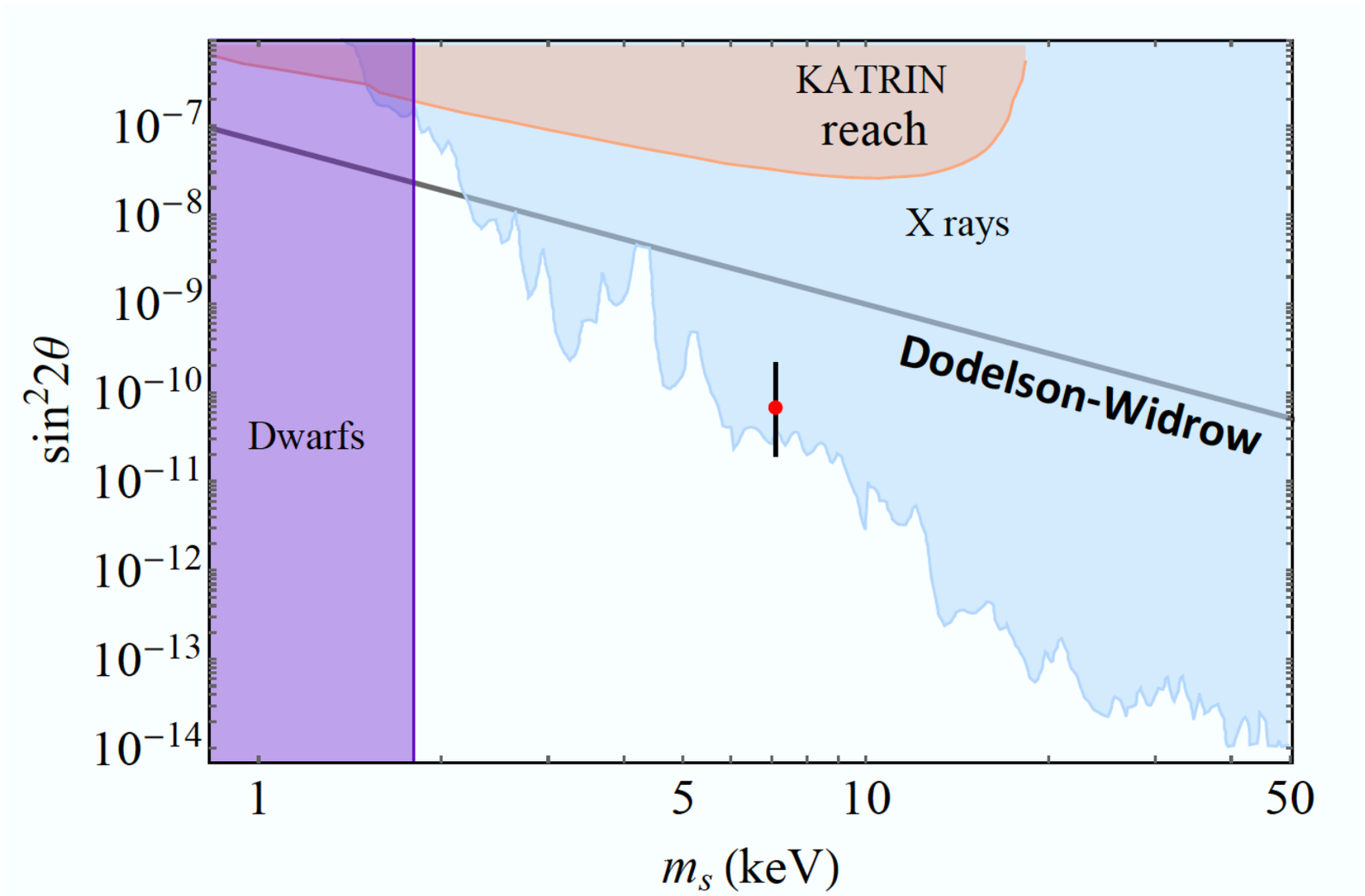
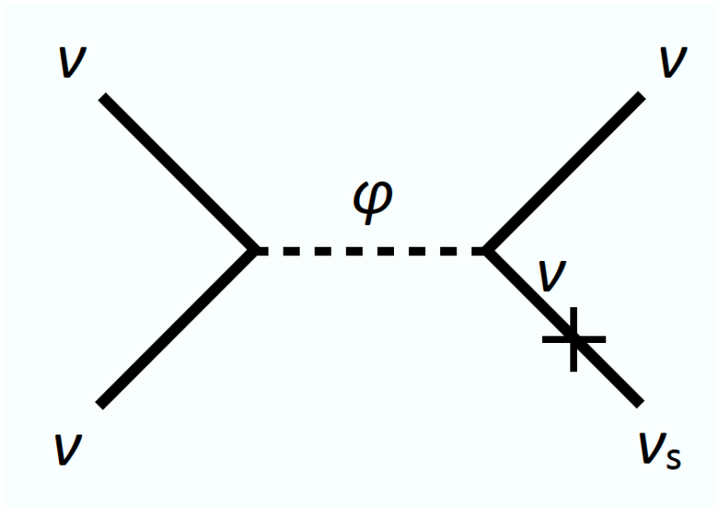


How to generate enough sterile neutrino DM within the allowed region?

Dodelson-Widrow Mechanism + new neutrino self-interactions

De Gouvêa, Sen, Tangarife & Zhang PRL (2020)

$$\mathcal{L} \supset \frac{\lambda_\phi}{2} \nu_a \nu_a \phi + \text{h.c.}$$



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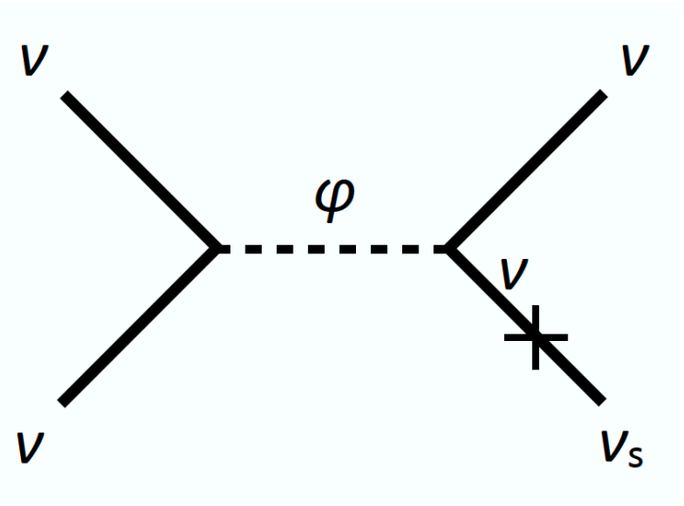


It can enhance the interaction rate while keeping a small mixing angle

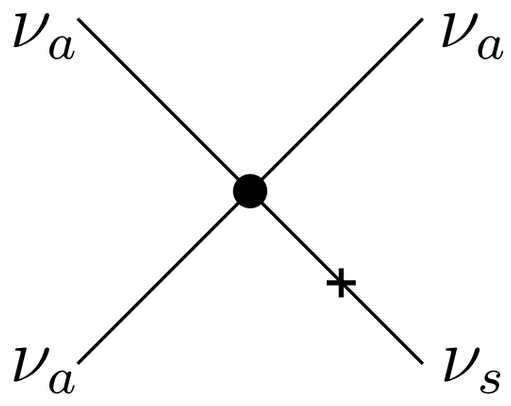
$$\frac{d\, f_{\nu_4}(x,z)}{d \ln z} = \frac{\Gamma}{4H} \sin^2 2\theta_{\text{eff}}\, f_\nu(x)$$

$$\sin^2 2\theta_{\text{eff}} \simeq \frac{\Delta^2 \sin^2 2\theta}{\Delta^2 \sin^2 2\theta + (\Gamma/2)^2 + (\Delta \cos 2\theta - V_T)^2}$$

The new interaction also contributes to the thermal potential V_T

Similar works Koop et al. (2014), Mirizzi et al. (2015), Friedland et al. (2016), Johns et al. (2019), …

Heavy mediator limit: $m_\phi \gg T$



$$\Gamma \sim \frac{\lambda_\phi^4}{m_\phi^4} E T^4 \qquad V_T \sim -\frac{\lambda_\phi^2}{m_\phi^4} E T^4$$

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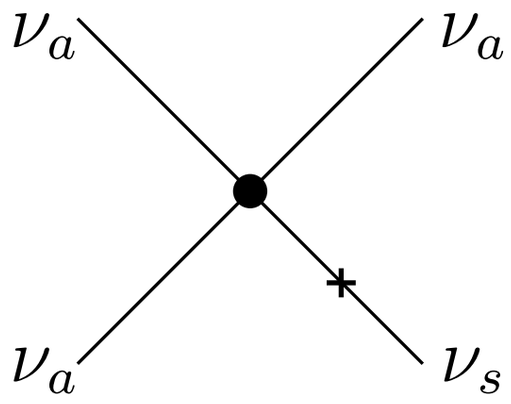

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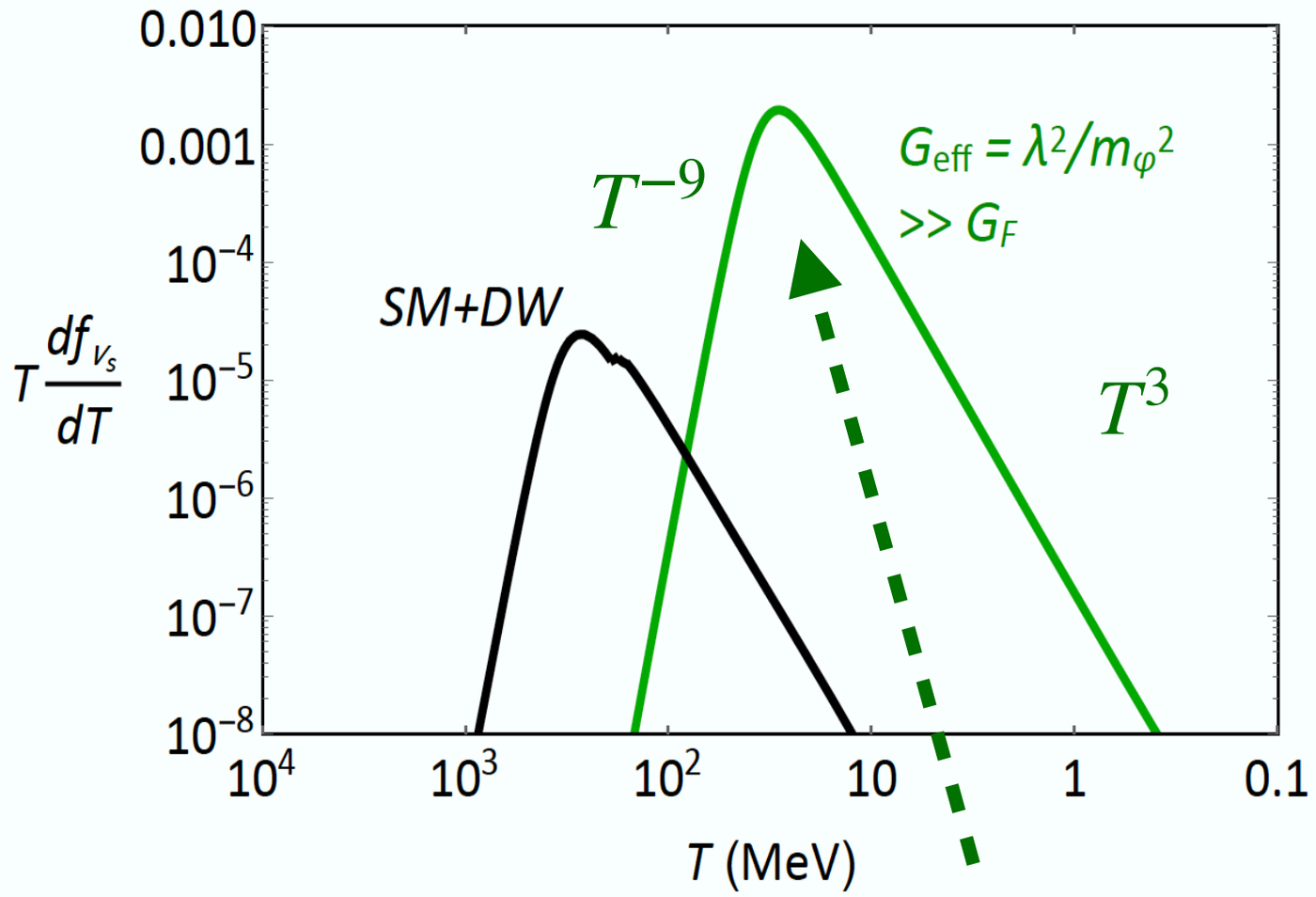
Compare to SM+DW

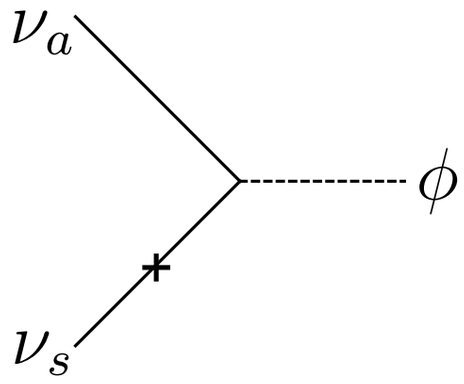


Production peaks at a lower temperature

De Gouvêa, Sen, Tangarife & Zhang PRL (2020)

Light mediator limit: $m_\phi \ll T$

The scalar can be produced on-shell in the plasma



$$\Gamma \sim V_T \sim \frac{\lambda_\phi^2 T^2}{E}$$

A positive thermal potential allows for a resonance in

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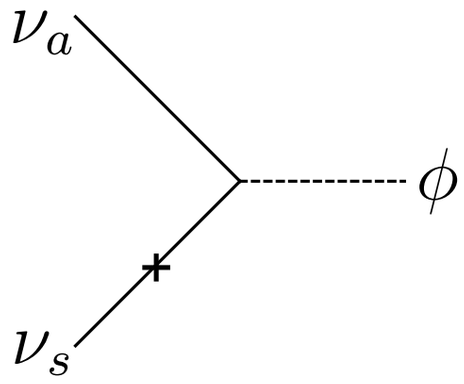

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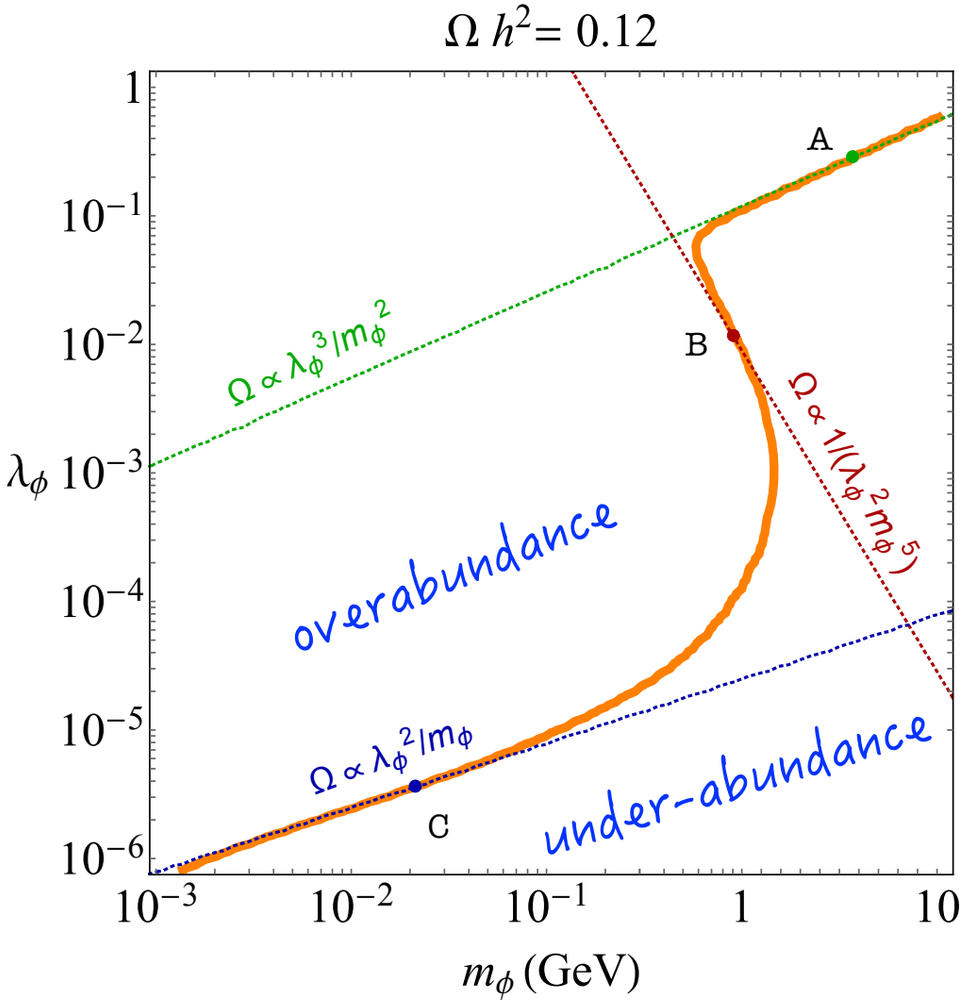
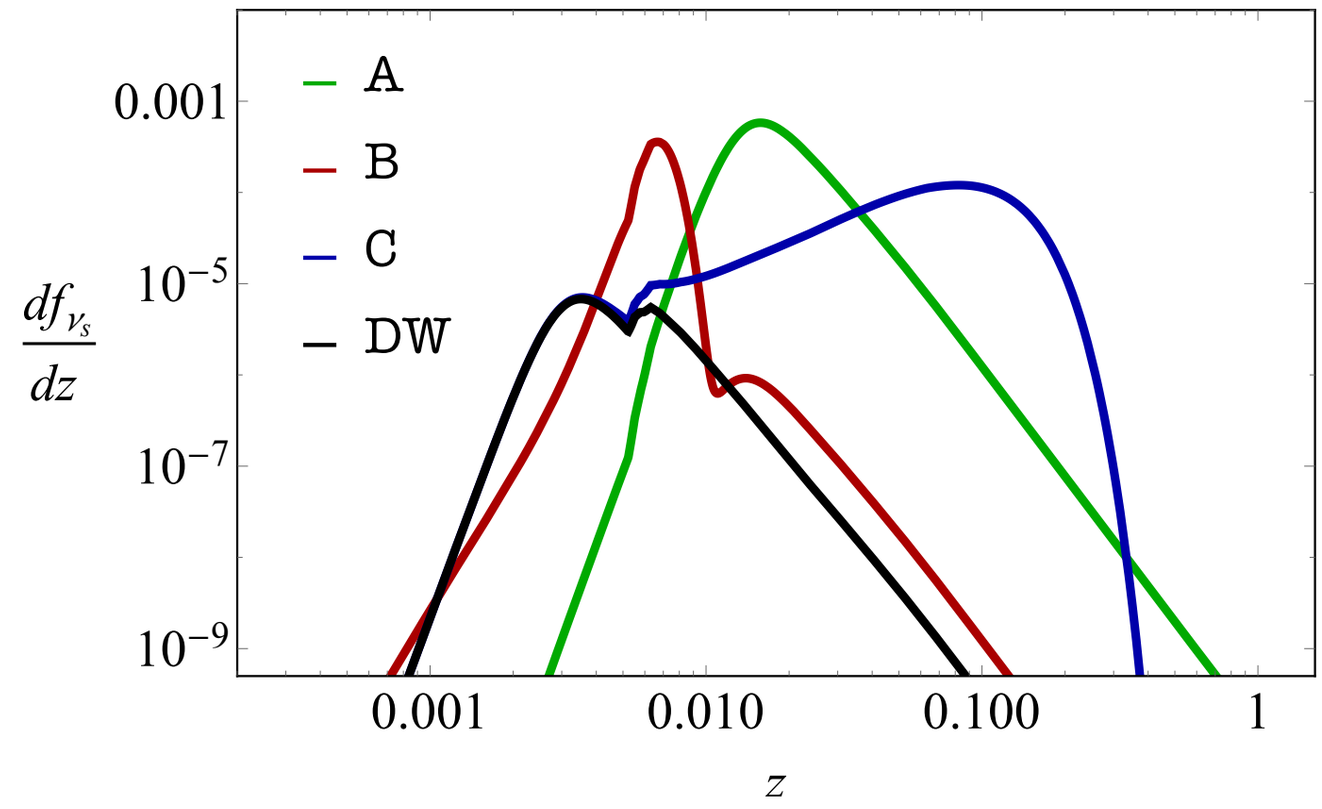
Now let's proceed to integrate the Boltzmann equation

De Gouvêa, Sen, Tangarife & Zhang PRL (2020)

Sterile neutrino relic density



$m_{\nu_s} = 7.1\,\mathrm{keV},\ \ sin^2 2\,\theta = 7 \times 10^{-11}$



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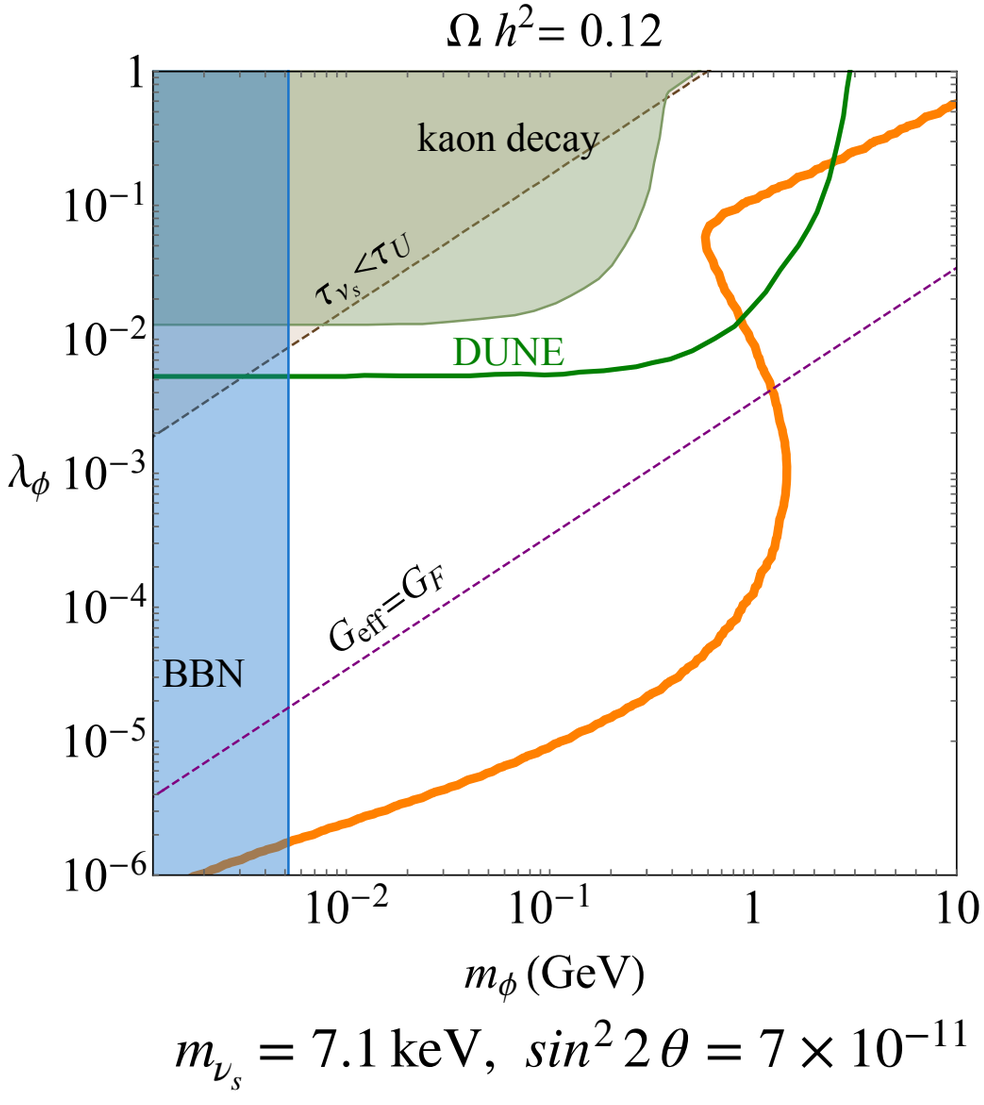
De Gouvêa, Sen, Tangarife & Zhang PRL (2020)

Current and future constraints



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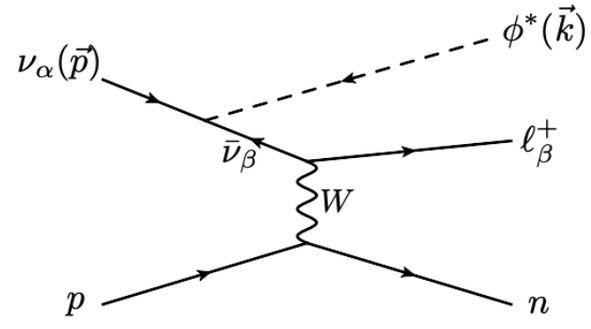
Bounds from $K^- \to \mu^- \nu_\mu \phi,\ \phi \to \nu\nu$

$\text{Br}(K^- \to \mu^- + 3\nu) < 10^{-6}$

BBN bounds on light d.o.f.s

Expected sensitivity of DUNE:
Look for the "wrong-sign muon"

$\nu_\mu N \to \mu^+ N' \phi\,.$



Berryman, de Gouvêa, Kelly & Zhang (2018)
Blinov, Kelly, Krnjaic & McDermott (2019)
Kelly & Zhang (2019)

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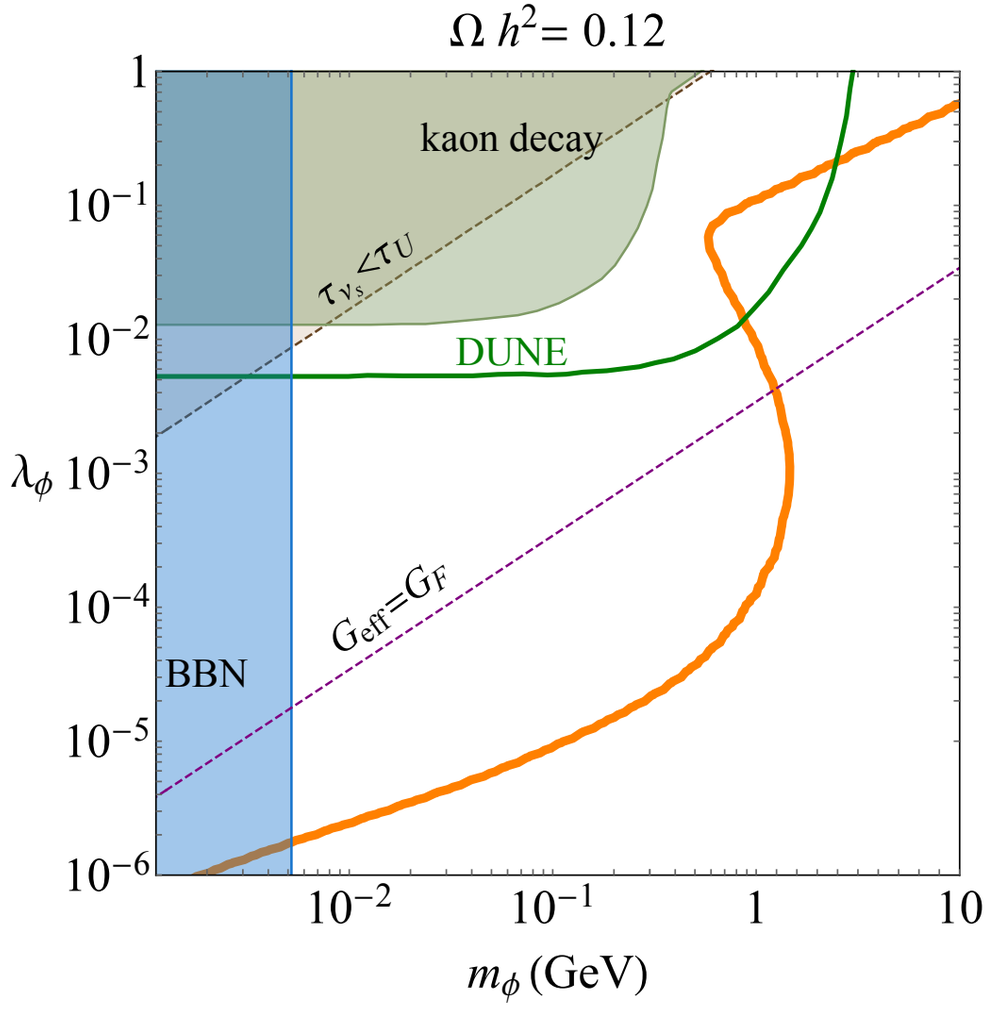

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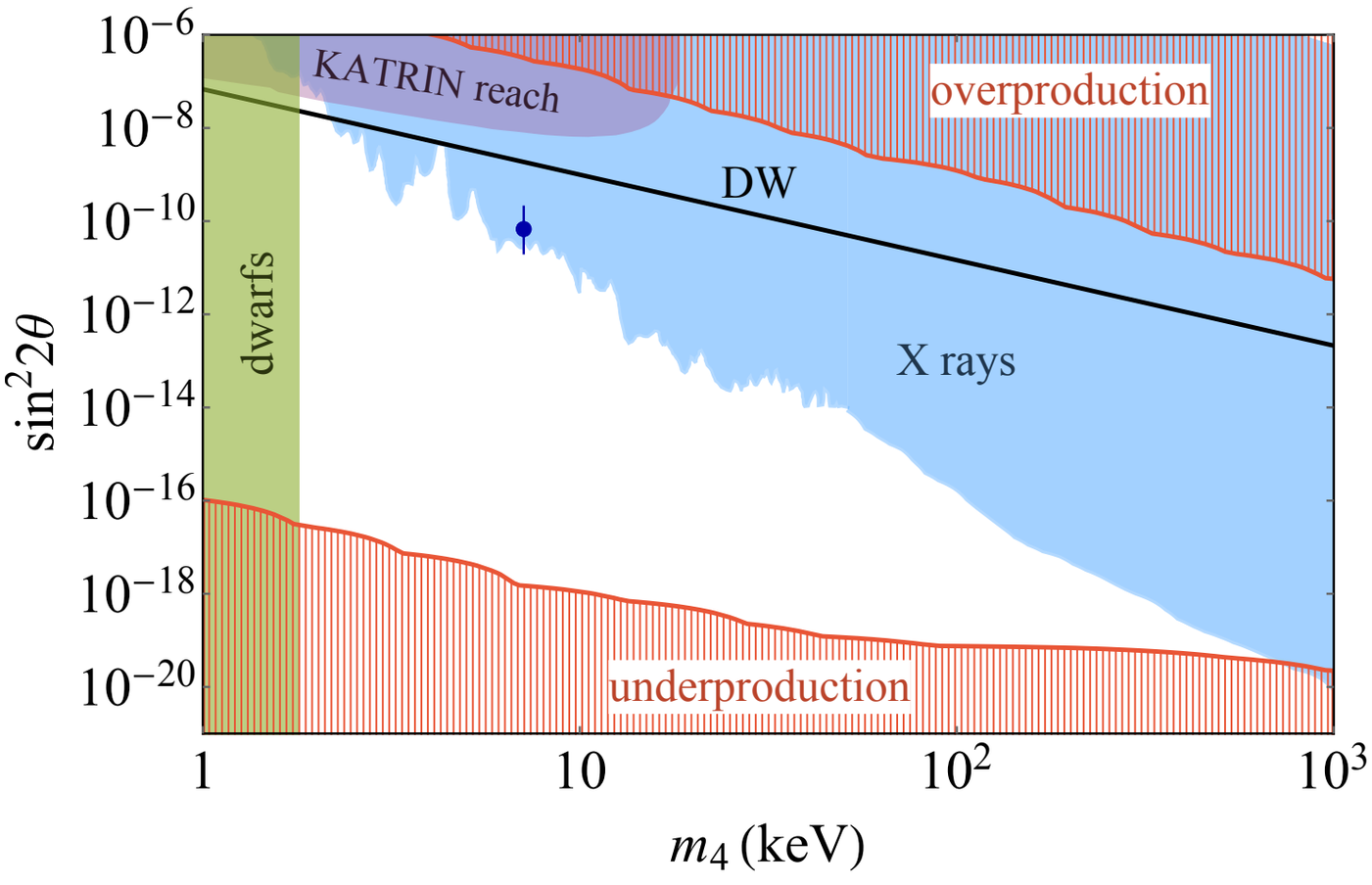

Can we produce enough sterile neutrino DM in the early universe?

Yes! Sterile neutrinos can be produced non-thermally from active-neutrino oscillations.

A new scalar-mediated interaction for the active neutrinos helps alleviate tensions with the Dodelson-Widrow mechanism.

This model can be probed in upcoming neutrinos experiments such as DUNE

We're working on the generalization to vector mediators

Kelly, Sen, Tangarife & Zhang, to appear soon

Thank you!