Tau lepton asymmetry by sterile neutrino emission – Moving beyond one-zone supernova model

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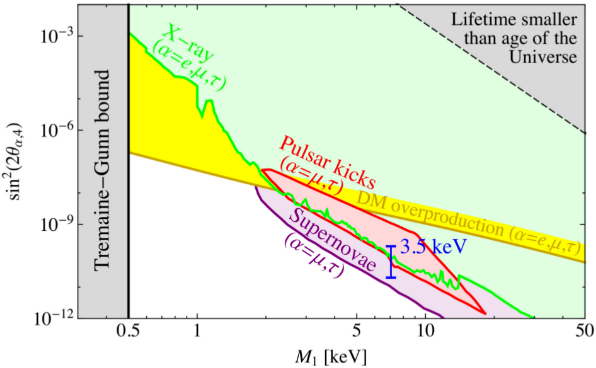
Overview

1. Motivation
2. Sterile neutrino conversions in the stellar core
3. Development of the neutrino lepton asymmetry
4. Conclusions

Motivation

Sterile neutrino as Dark Matter candidate



Favorable regions

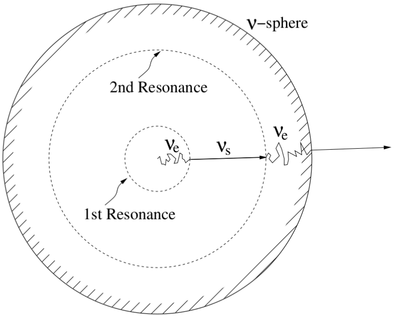
- Pulsar kicks
  (A. Kusenko (2004))
- 3.5 keV line
  (A. Boyarsky et al. (2014))

Constraints

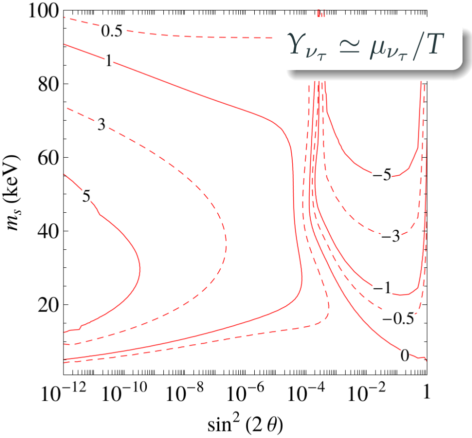
- Supernovae energy bounds (X. Shi & G.Sigl (1994))
- DM overproduction (S. Dodelson, L. M. Widrow (1994), X. Shi, G. M. Fuller (1999))
- Radiative decay (NuSTAR, XMM, Chandra)
- Tremaine-Gunn bound

Sterile Neutrino Dark Matter, A. Merle (2017)

The role of sterile neutrinos in SNe



J. Hidaka and G. M. Fuller (2006)



G. G. Raffelt and S. Zhou (2011)

- Suppression /enhancement of the SN explosion
- Change of the electron or neutrino (ν_e, ν_μ, ν_τ) fractions

H. Nunokawa et al. (1997), M. L. Warren et al. (2016), C. A. Argüelles et al. (2016) ...

Sterile neutrino conversions in the stellar core

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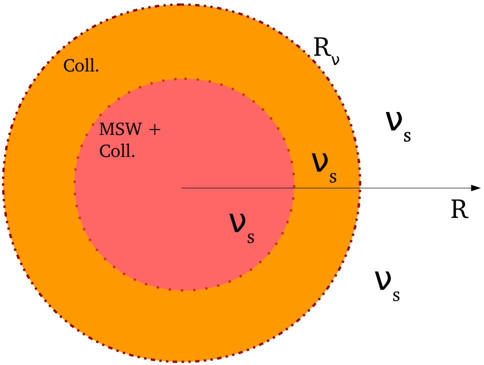


$\nu_\tau - \nu_s$
mixing

1D SN model
Garching group archive

Collisions

$$\Gamma_{\nu_s} = \sin^2 2\theta \, \Gamma_{\nu_\tau}$$

MSW

$$V_{\rm eff} = \sqrt{2} G_F n_B \left[-\frac{1}{2} Y_n + Y_{\nu_e} + Y_{\nu_\mu} + 2 Y_{\nu_\tau} \right]$$

L. Stodolsky (1987), H. Nunokawa et al. (1997), K. Abazajian et al. (2001)

Sterile neutrino conversions in the stellar core

Collisional production

$$\langle P_{\nu_\tau \to \nu_s}(E)\rangle \approx \frac{1}{2}\frac{\sin^2 2\theta}{(\cos 2\theta - 2V_{\mathrm{eff}}E/\Delta m_s^2)^2 + \sin 2\theta^2 + D^2}$$

MSW production

$$P_{\nu_\tau \to \nu_s}(E_{\mathrm{res}}) = 1 - \exp\left(-\frac{\pi^2}{2}\gamma\right)\ ,\gamma = \Delta_{\mathrm{res}}/l_{\mathrm{osc}}$$

$$\Gamma_\nu(E) \simeq n(r)\sigma(E,r)$$

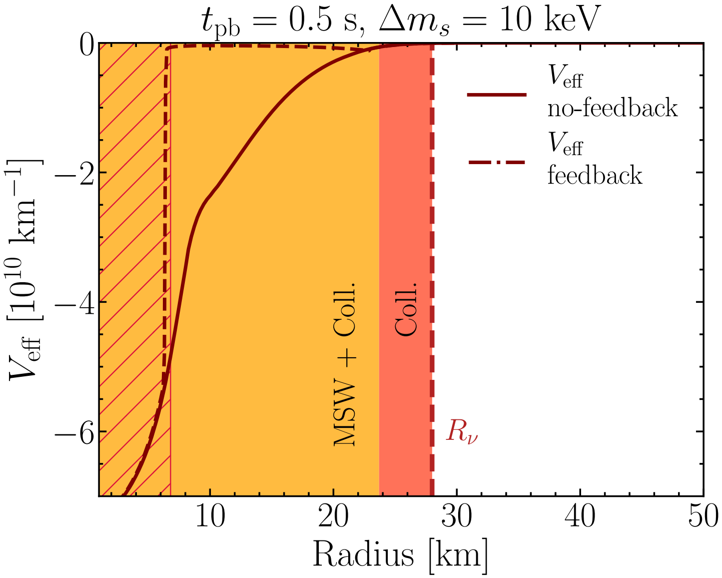
$$D = \frac{E\Gamma_\nu(E)}{\Delta m_s^2}$$

$$\Delta_{\mathrm{res}} = \tan 2\theta \left|\frac{dV/dr}{V}\right|^{-1}$$

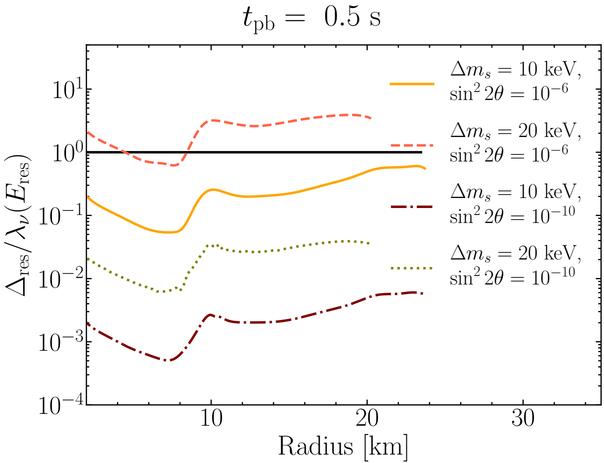
$$l_{\mathrm{osc}}(E_{\mathrm{res}}) = (2\pi E_{\mathrm{res}})/(\Delta m_s^2 \sin 2\theta)$$

C. W. Kim et al. (1987), S. P. Mikheev and A. Yu. Smirnov (2007)

Conversion regions



Will they collide or undergo MSW resonance?

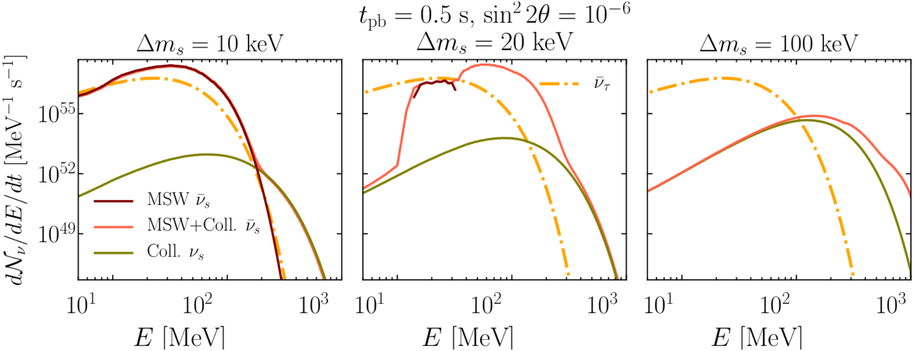


$$\Delta_{\mathrm{res}} = \tan 2\theta \left| \frac{dV/dr}{V} \right|^{-1}$$

$$\Delta_{\mathrm{res}} < \lambda_\nu(E_{\mathrm{res}})\ ?$$

$$\lambda_\nu(E_{\mathrm{res}}) \simeq \frac{1}{n(r)\sigma(E,r)}$$

Sterile neutrino energy distribution



- antineutrinos - collisional and MSW production
- neutrinos - only collisional production
- $\Delta m_s \uparrow$ - collisions are important,

more conversions deep in the core, where λ_ν is small

Development of the neutrino lepton asymmetry

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Only active neutrinos

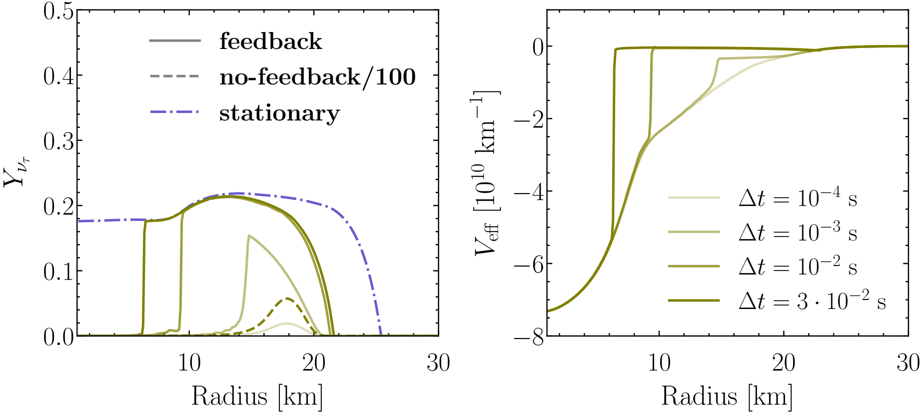
$$Y_{\nu_\tau}(r,t) \equiv 0$$

Active + sterile neutrinos

$$Y_{\nu_\tau}(r,t) = \frac{1}{n_b(r)} \int_0^t dt' \, \frac{d\left(P_{\nu_\tau \to \nu_s} n_{\nu_\tau}(r,t') - P_{\bar{\nu}_\tau \to \bar{\nu}_s} n_{\bar{\nu}_\tau}(r,t')\right)}{dt'}$$

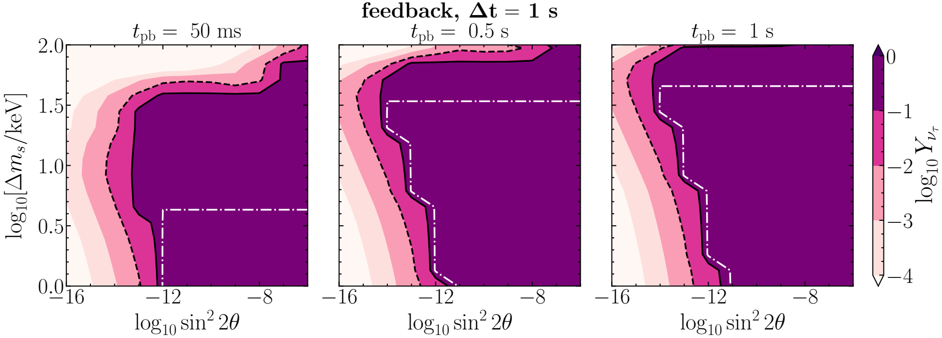
Radial evolution of the asymmetry w and w/o feedback

$$t_{\mathrm{pb}} = 0.5 + \Delta t \text{ s},\ \ \Delta m_s = 10 \text{ keV}, \sin^2 2\theta = 10^{-10}$$



- Feedback inhibits Y_{ν_τ} from unphysical growth.
- Stationary value of Y_{ν_τ} can be reached very quickly.

Contour plot



- Higher mixing angles reach the saturation value faster.
- More massive sterile neutrinos reach smaller saturation values, less energy modes has enhanced conversion probability.

Conclusions

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  - have a major impact on SN physics.
  - Their production leads to the growth of Y_{ν_τ} asymmetry.
- **Feedback is crucial.**
- **Large Y_{ν_τ} asymmetry relevant for SN physics.**
- **SN bounds on the sterile neutrino DM must be updated.**

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Thank you!