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))
- Radiative decay (NuSTAR, XMM, Chandra)
- Tremaine-Gunn bound

Sterile Neutrino Dark Matter, A. Merle (2017)
The role of sterile neutrinos in SNe

- Suppression /enhancement of the SN explosion
- Change of the electron or neutrino ($\nu_e$, $\nu_\mu$, $\nu_\tau$) fractions

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


H. Nunokawa et al. (1997), M. L. Warren et al. (2016), C. A. Argüelles et al. (2016) ...
Sterile neutrino conversions in the stellar core
Sterile neutrino conversions in the stellar core

\[ dr = -i[H, \rho] \]

\[ \frac{4}{12} \]

**Collisions**

\[ \Gamma_{\nu_s} = \sin^2 2\theta \Gamma_{\nu_\tau} \]

**MSW**

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

Collisional production

\[
\langle P_{\nu_\tau \rightarrow \nu_s}(E) \rangle \approx \frac{1}{2} \frac{\sin^2 2\theta}{(\cos 2\theta - 2V_{\text{eff}}E/\Delta m^2_s)^2 + \sin 2\theta^2 + D^2}
\]

MSW production

\[
P_{\nu_\tau \rightarrow \nu_s}(E_{\text{res}}) = 1 - \exp \left( -\frac{\pi^2}{2} \gamma \right), \gamma = \Delta_{\text{res}}/l_{\text{osc}}
\]

\[
\Gamma_\nu(E) \approx n(r)\sigma(E, r)
\]

\[
D = \frac{E\Gamma_\nu(E)}{\Delta m^2_s}
\]

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

\[
l_{\text{osc}}(E_{\text{res}}) = (2\pi E_{\text{res}})/(\Delta m^2_s \sin 2\theta)
\]

Conversion regions

\[ t_{pb} = 0.5 \text{ s}, \ \Delta m_s = 10 \text{ keV} \]

![Graph showing conversion regions with V_{eff} for no-feedback and feedback, R_v, and MSW + Coll regions.](image)
Will they collide or undergo MSW resonance?

\[ \Delta_{\text{res}} = \tan 2\theta \left| \frac{dV}{dr} \right|^{-1} \]

\[ \lambda_{\nu}(E_{\text{res}}) \sim \frac{1}{n(r)\sigma(E,r)} \]

\[ \Delta_{\text{res}} < \lambda_{\nu}(E_{\text{res}}) ? \]
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 $\lambda_\nu$ is small
Development of the neutrino lepton asymmetry
Development of the neutrino lepton asymmetry

Only active neutrinos

\[ Y_{\nu\tau}(r, t) \equiv 0 \]

Active + sterile neutrinos

\[
Y_{\nu\tau}(r, t) = \frac{1}{n_b(r)} \int_0^t dt' \frac{d \left( P_{\nu\tau \rightarrow \nu_s} n_{\nu\tau}(r, t') - P_{\bar{\nu}\tau \rightarrow \bar{\nu}_s} n_{\bar{\nu}\tau}(r, t') \right)}{dt'}
\]
Radial evolution of the asymmetry \( w \) and w/o feedback

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

- Feedback inhibits \( Y_{\nu\tau} \) from unphysical growth.
- Stationary value of \( Y_{\nu\tau} \) can be reached very quickly.
- 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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- Sterile neutrinos with keV mass
  - have a major impact on SN physics.
  - Their production leads to the growth of $Y_{\nu\tau}$ asymmetry.

- Feedback is crucial.

- Large $Y_{\nu\tau}$ asymmetry relevant for SN physics.

- SN bounds on the sterile neutrino DM must be updated.
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Thank you!