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Spin-light of neutrino efficiency in Gamma-Ray Bursts

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Introduction

The spin light of neutrino (*SLν*) [1,2] is a new possible mechanism of electromagnetic radiation emitted by a massive neutrino (with a nonzero magnetic moment) moving in external media. Although this effect is very weak due to smallness of the neutrino magnetic moment [3], it can be of interest for astrophysical environments involving compact relativistic objects because its efficiency is higher, the higher the neutrino energy and background matter density [4]. The most suitable astrophysical site for manifestation of this phenomenon is represented by the Gamma-Ray Bursts (GRBs) where generation of ultra-high energy neutrinos is anticipated and the matter density can reach values of the order of the nuclear. In this work we investigate the principal possibility for the *SLν* to be effectively radiated in connection with the process threshold, competing processes and low production rate.

The *SLν* basics and main properties

$m_\nu \neq 0$ ➡ $\mu_\nu \neq 0!$

- photon is coupled via the magnetic moment [3]

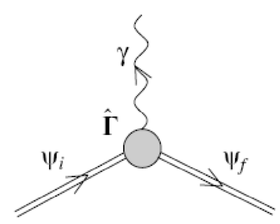
- neutrino state in matter is helicity-dependant [2]

$$\left\{ i\gamma_\mu \partial^\mu - \frac{1}{2}\gamma_\mu(1+\gamma^5) f^\mu - m_\nu \right\} \Psi(x) = 0$$

$E_\nu = \sqrt{(p - s\tilde{n})^2 + m_\nu^2} + \tilde{n}$, s - helicity

matter density parameter for electron

$$\tilde{n}_{\nu_e} = \frac{G_F}{2\sqrt{2}} \left(n_e(1 + 4\sin^2\theta_W) + n_p(1 - 4\sin^2\theta_W) - n_n \right)$$



$$\mathbf{\Gamma} = i\{[\mathbf{\Sigma} \times \mathbf{k}] + i\omega\gamma^5 \mathbf{\Sigma}\}$$

$$s_i = 1 \to s_f = -1$$

The *SLν* photon energy for vacuum photon dispersion:

$$\omega = \frac{2\tilde{n}p\left[(E_\nu - \tilde{n}) - (p + \tilde{n})\cos\theta\right]}{(E_\nu - \tilde{n} - p\cos\theta)^2 - \tilde{n}^2}$$

The rate and power of the *SLν* from relativistic neutrino in dense matter:

$$\Gamma = 4\mu^2\tilde{n}^2 p, \quad I = \frac{4}{3}\mu^2\tilde{n}^2 p^2$$

Considerable fraction of neutrino energy is carried away by the *SLν* photon:

$$\langle\omega\rangle = \frac{1}{3}p \simeq \frac{1}{3}E_\nu$$

For high matter density the *SLν* is completely circular-polarized:

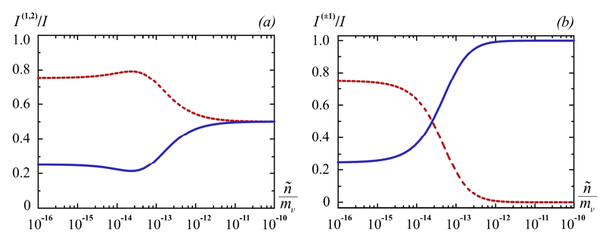


Figure 1. The polarized components of the *SLν* radiation power as functions of the matter density parameter: (a) – linear polarization, $I^{(1)}/I$ – solid line, $I^{(2)}/I$ – dashed line, (b) – circular polarization, $I^{(+)}/I$ – solid line, $I^{(-)}/I$ – dashed line; $p = 10$ TeV, $m_\nu = 1$ eV.

SLν in neutron matter of real astrophysical objects [4]

❑ Plasma effects [5]

- Photon dispersion with plasmon mass in the degenerate electron gas: $\omega = \sqrt{\mathbf{k}^2 + m_\gamma^2}$

$$m_\gamma = \left(\frac{2\alpha}{\pi}\right)^{1/2} \mu_e \simeq 8.87 \times \left(\frac{n_e}{10^{37}\,\mathrm{cm}^{-3}}\right)^{1/3} \mathrm{MeV}$$

- Threshold condition for the *SLν* [10]: $\frac{m_\gamma^2 + 2\,m_\gamma m_\nu}{4\tilde{n}p} < 1$

($Y_e = n_e/n_n$)

- **Neutron matter:** $\tilde{n} = \frac{1}{2\sqrt{2}} G_F n_n \simeq 3.2 \times \left(\frac{n_n}{10^{38}\,\mathrm{cm}^{-3}}\right) \mathrm{eV},$

(antineutrinos act)

$$E > p_{\mathrm{th}} \simeq 28.5 \times \frac{Y_e^{2/3}}{1 - Y_e} \left(\frac{10^{38}\,\mathrm{cm}^{-3}}{n_n}\right)^{1/3} \mathrm{TeV} \quad ➡ \quad E_{\mathrm{th}} \simeq 6.82\ \mathrm{TeV}.$$

$n_n = 10^{38}\mathrm{cm}^{-3}$, $Y_e = 0.1$

- Mean photon energy near the threshold: $\langle\omega\rangle = I/\Gamma \simeq p \simeq E_\nu.$

For most favorable conditions as low density of the charged matter component is needed as possible

❑ W boson production $\bar{\nu}_e + e^- \to W^-$ [4]

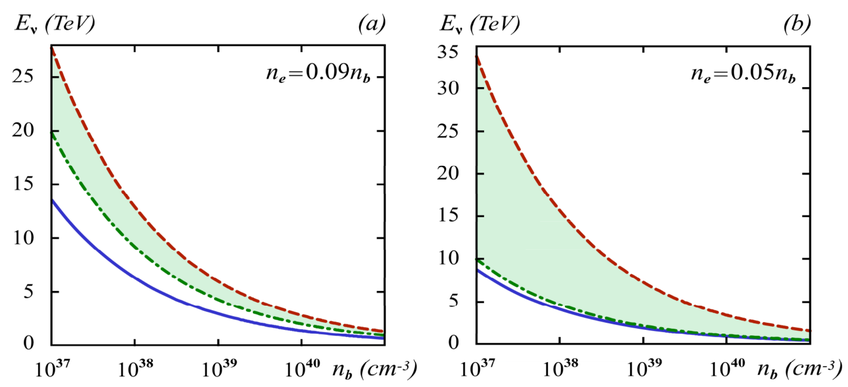


Figure 2. The allowed range of electron antineutrino energies for the *SLν* in the matter of a neutron star depending on the neutron density. Solid line: the *SLν* process threshold without account for the $\bar{\nu}_e e$-scattering; dash-dotted line: the *SLν* process threshold with account for the $\bar{\nu}_e e$-scattering; dashed line: the threshold for the W boson production. (a) $Y_e = 0.09$; (b) $Y_e = 0.05$. The allowed regions are marked in green.

W-boson threshold energy $\varepsilon_W = \frac{m_W^2}{4\mu_e} \simeq 5.77 \times \left(\frac{10^{38}\,\mathrm{cm}^{-3}}{Y_e n_n}\right)^{1/3} \mathrm{TeV}$

- Electron antineutrinos: s-channel interaction with matter through W-boson, importance of the propagator effects ⇒ correction to the effective potential of neutrino motion → antineutrino energy shift up → *SLν* is suppressed at Y_e=0.1, but allowed already for Y_e=0.09

- μ and τ antineutrinos: only t-channel interaction with matter through Z-boson, no propagator effects ⇒ the *SLν* is allowed if neutrino energy is greater than the W-boson threshold ε_W

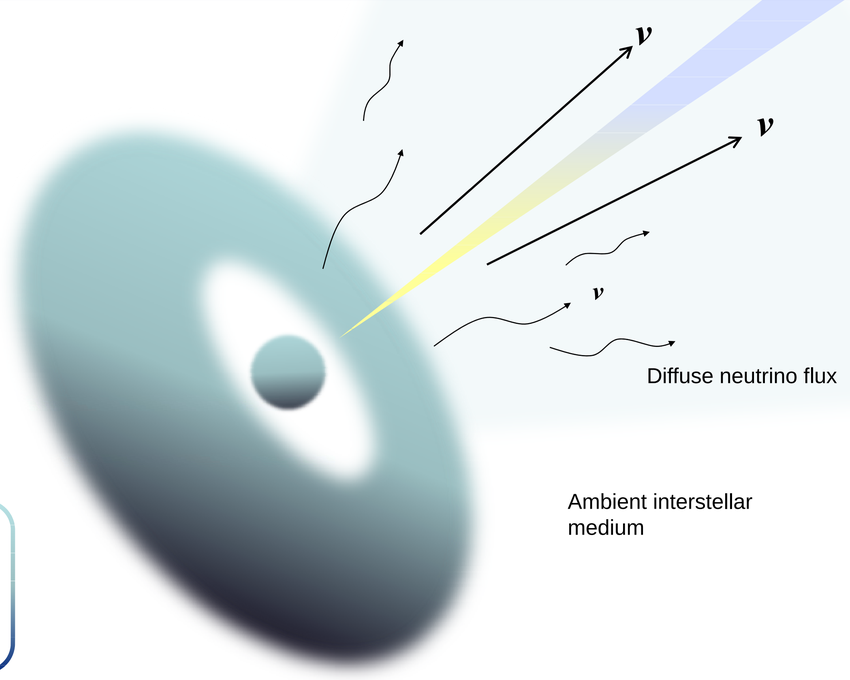
Neutrino lifetime with respect to the *SLν* for most optimistic set of parameters:

$$\tau_{SL\nu} = 10^{-4} - 10^{3}\,s, \quad \text{for} \quad n_b = 10^{41} - 10^{38}\,\mathrm{cm}^{-3}$$

The *SLν* in short Gamma-Ray Bursts (SGRBs)

Factors for best *SLν* generation efficiency

- High neutrino energy and density
- High background neutral matter density
- Low density of the matter charged component
- Low temperature of the charged component
- Considerable extension of the medium



SLν **radiation by ultra high-energy neutrino in the diffuse neutrino wind blown during neutron stars merger**

Matter characteristics[6]:

- neutrinos
  $n_\nu \sim 10^{32}\ \mathrm{cm}^{-3}$
- electrons
  $Y_e = 0.01$
  $T = 0.1\ \mathrm{MeV}$
  $\rho = 5 \times 10^3\ \mathrm{g/cm}^3$

➡ $n_e \simeq 3 \times 10^{25}\ \mathrm{cm}^{-3}$
$m_\gamma \simeq 10^{-3}\ \mathrm{MeV}$
$E_{\mathrm{th}} \simeq 1\ \mathrm{GeV}$

Radiation time

$$\tau_{SL\nu} \simeq 5.4 \times 10^{15} \left(\frac{10^{-11}\mu_B}{\mu}\right)^2 \left(\frac{10^{32}\,\mathrm{cm}^{-3}}{n_{\nu_e}}\right)^2 \left(\frac{1\ \mathrm{PeV}}{E_\nu}\right) \mathrm{s}$$

Neutrino parameters: $\mu \simeq 2.9 \times 10^{-11}\mu_B$, $E_\nu \sim 10^{12} - 10^{18}$ eV

$$\tau_{SL\nu} \simeq 6.4 \times (10^{11} - 10^{17})\ \mathrm{s} = 2 \times (10^4 - 10^{10})\ \text{years}$$

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