Lepton Asymmetry induced by Primordial Magnetic Fields: A Toy Model

David Delepine, Juan Barranco,Roberto Cota
División de Ciencias e Ingenierías
Universidad de Guanajuato
México

Shaaban Khalil

Centre for Theoretical Physics
Zewail City of Science and Technology,
Sheikh Zayed, Giza, Egypt.

arXiv:1205.1250

Outlines

- Spin Flavour Precession (SFP) with Majorana Neutrinos
- Primordial Magnetic Fields
- SFP and Lepton asymmetry
- SFP Effects on Leptogenesis scenario with strong Primordial Magnetic fields
- Conclusion

The Spin Flavour Precession Effect with Majorana Neutrinos

- It is well known that left-handed fermion with magnetic moment could be affected by the Spin Precession effect (SP) which induces in presence of magnetic field a transition from left to right handed fermions or inversely *(see A. Cisneros.Astrophys.Space Sci., 10:87–92, 1971)*.
- For the Majorana neutrinos the magnetic moment matrix is antisymmetric and hermitian $(M^T = -M) \Rightarrow$ SP becomes Spin Flavour Precession (SFP) $(\Delta L = 2)$ *(J.Schechter and J.W.F. Valle, Phys. Rev.D24:1883–1889, 1981)*
- The time evolution of the Majorana neutrinos are described by a Schrödinger equation

$$P(\nu_{eL} \rightarrow \nu^c_{\mu L}; t) = \sin^2 \left(\int_{t_0}^{t} \mu_\nu B_\perp(t')\, dt' \right)$$

Primordial Magnetic Fields (I)

The main constrains on SFP processes are coming from limits an Primordial Magnetic Fields (PMF). If the Universe expands isotropically, magnetic flux conservation implies:

Evolution of the magnetic field

$$B(t) \simeq B(t_i) \left(\frac{a(t_i)}{a(t)} \right)^2 \quad (1)$$

where $a(t)$ is the scale factor, assuming Friedman Robertson Walker dynamics for the universe.

When the Leptogenesis process takes place, the scale factor is given by:

Scale factor

$$a(t) \propto t^{1/2} \quad (2)$$

Primordial Magnetic Fields (II)

Through observations from CMB

- $B < 3 \times 10^{-9} G$ at the present *(see refs. D. Grasso et al., Phys.Rept., 348(2001), K. Ichiki et al.,Phys.Rev., D85:043009, (2012)).*
- $B \sim 10^{9} G$ at Nucleosynthesis time *(see Ref. A.Kandus et al. Phys.Rept.,505 (2011)).*

Primordial Magnetic Field at Leptogenesis Epoch

The bound on magnetic field between electroweak and Right-handed Majorana neutrino scale ($M_1 \simeq 10^{11} GeV$) is:

$10^{27} G \gtrsim$ **Leptogenesis Epoch** $\gtrsim 10^{17} G$

Spin Flavour Precession and Lepton Asymmetry (I)

Clearly, the Spin Flavour Precession is a $\Delta L = 2$ process. This one, should be taken as a new term into the Boltzmann Equations which generate the asymmetry at early universe.

Lepton Number Density N_L

This can be calculated adding all the leptonic minus the antileptonic contributions (in two flavour case).

$$N_L \equiv N_{\nu_1} + N_{\nu_2} - N_{\nu_1^c} - N_{\nu_2^c} \tag{3}$$

Spin Flavour Precession and Lepton Asymmetry (II)

How to construct the term $\dot{N}_L$?

We must follow the next sentence to construct the temporal variation of lepton number density:
The variation of the neutrino (antineutrino) number density is equal to the probability that the antineutrinos (neutrinos) change to neutrinos minus the probability that neutrinos (anti neutrinos) change to anti neutrinos (neutrinos).

$$\begin{aligned} \Delta N_{\nu_i} &= P(\nu_j^c \to \nu_i) N_{\nu_j^c} - P(\nu_i \to \nu_j^c) N_{\nu_i} \\ \Delta N_{\nu_i^c} &= P(\nu_j \to \nu_i^c) N_{\nu_j} - P(\nu_i^c \to \nu_j) N_{\nu_i^c} \end{aligned} \tag{4}$$

Spin Flavour Precession and Lepton Asymmetry (III)

Time-Dependent Lepton Asymmetry

Assuming CP is conserved (*i.e.*, $P(\nu_1 \to \nu_2^c) = P(\nu_1^c \to \nu_2)$) and taking (3) and (4), one gets:

$$\begin{aligned} \Delta N_L &= -2PN_L \\ \frac{dN_L}{dt} &= -2\frac{d}{dt}(PN_L) \end{aligned} \tag{5}$$

where P is the SFP probability.

Spin Flavour Precession and Lepton Asymmetry (IV)

n_f Flavour Case:

If we assume:

- CP is conserved.
- The oscillation between the different flavours are the same.

we can obtain a generalized expression:

$$\frac{dN_L}{dt} = -2(n_f - 1)\frac{d}{dt}(PN_L) \quad (6)$$

This equation represent **a new contribution** for the Lepton Asymmetry **that can affect the Leptogenesis scenario and the lepton asymmetry**.

Spin Flavour Precession and Lepton Asymmetry (V)

It is worth mentioning...

For magnetic fields orders lower than 10^{14} G, using the largest limit on the neutrino magnetic moment 10^{-12} μ_B O.G. Miranda et al. Phys.Rev.Lett.,93(2004)., SFP process will not affect the usual Leptogenesis scenario.

Spin Flavour Precession and Lepton Asymmetry (VI)

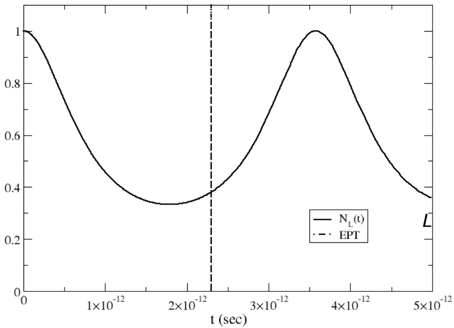

Figure: The continue oscillating line corresponds to $N\ (t)$ assuming an Initial Asymmetry with a constant magnetic field about $(\sim 10^{14}\ G)$. In this case the effect is appreciably after the Electroweak Phase Transition

SFP effects on Leptogenesis (I)

The simplest Leptogenesis Scenario with SFP

- A **strong** magnetic fiel given by (1).
- The existence of Heavy Right-Handed Majorana Neutrino (N_1).
- N_1 decays violating CP and producing a lepton asymmetry.

SFP effects on Leptogenesis (II)

Boltzmann Equations

With this simplest model , the equations of leptogenesis including SFP effect are as follows:

$$\begin{aligned} \frac{dN_{N_1}}{dt} &= -\Gamma_D N_1 \\ \frac{dN_L}{dt} &= \epsilon \Gamma_D N_{N_1} - 2(n_F - 1)\frac{d}{dt}(PN_L) \end{aligned} \quad (7)$$

SFP effects on Leptogenesis (III)

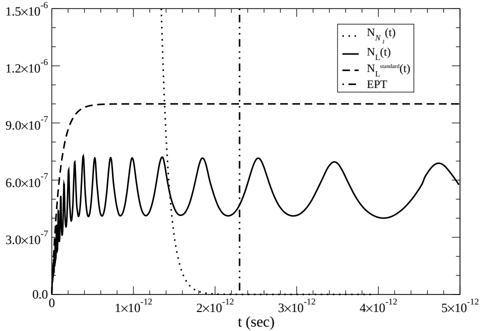

Figure: The continue oscillating line corresponds to η_L including SFP effects. The dash line is η_L as expected from standard leptogenesis scenario.The vertical dotted-dash line represents an approximate value for Electoweak Phase Transition Time (t_{EPT}). For $t > t_{EPT}$, the η_L is not anymore converted into η_B through $B + L$ violating sphalerons. The dotted line show the evolution of the heavy RH majorana neutrino density N_1

Conclusions

We have shown:

- Neutrino SFP $\Delta L = 2$ have a significant impact in Leptogenesis Process due to the fact that the PMF at electroweak scale could be quite strong ($10^{17}\, Gauss$)
- The Lepton Asymmetry is reduced about 50%, at this scale
- Even after this scale, the Lepton Asymmetry keeps changing

Thanks a lot