DETECTION OF CNB II

Stodolsky, L. (1975). Speculations on Detection of the "Neutrino Sea." Physical Review Letters, 34(2), 110–112.

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OUTLINE

- Neutrino Electron Interaction
- Possible Detection Methods
- Summary

NEUTRINO ELECTRON INTERACTION

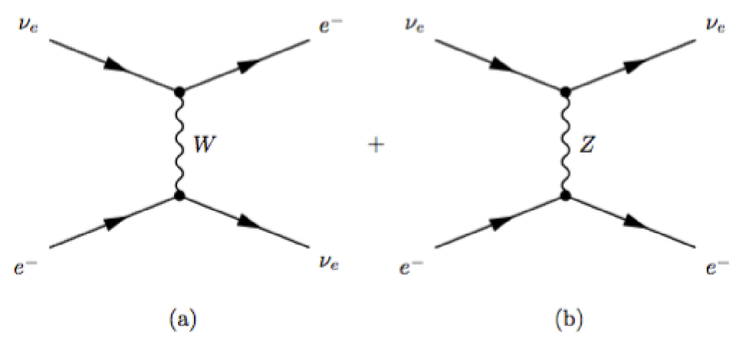

Figure: Neutrino-electron interaction

Effective Lagrangian

$$\mathscr{L}_{\mathrm{eff}} = -\frac{G_F}{\sqrt{2}}\{[\bar{\nu}_e\gamma^\rho(1-\gamma^5)e][\bar{e}\gamma_\rho(1-\gamma^5)\nu_e] + [\bar{\nu}_e\gamma^\rho(1-\gamma^5)\nu_e][\bar{e}\gamma_\rho(g_V^l - g_A^l\gamma^5)e]\}$$

- Red: charged current which exchanges the charge;
- Blue: neutral current

In the context of weak interaction, for a Lagrangian,

$$\mathscr{L}(\Psi_1, \Psi_2, \Psi_3, \Psi_4) = [\bar{\Psi}_1 \gamma^\mu (1 - \gamma^5) \Psi_2][\bar{\Psi}_3 \gamma_\mu (1 - \gamma^5) \Psi_4],$$

exchange the field Ψ_2 and Ψ_4 doesn't change the result.
The Lagrangian is called V-A theory because people define

$$\mathscr{L}^{\mathrm{V}}(\Psi_1, \Psi_2, \Psi_3, \Psi_4) = [\bar{\Psi}_1 \gamma^\mu \Psi_2][\bar{\Psi}_3 \gamma_\mu \Psi_4],$$
$$\mathscr{L}^{\mathrm{A}}(\Psi_1, \Psi_2, \Psi_3, \Psi_4) = [\bar{\Psi}_1 \gamma^\mu \gamma^5 \Psi_2][\bar{\Psi}_3 \gamma_\mu \gamma^5 \Psi_4].$$

Fierz Transformed Lagrangian

$$\mathscr{L}_{\mathrm{eff}} = -\frac{G_F}{\sqrt{2}}\{[\bar{\nu}_e\gamma^\rho(1-\gamma^5)e][\bar{e}\gamma_\rho(1-\gamma^5)\nu_e] + [\bar{\nu}_e\gamma^\rho(1-\gamma^5)\nu_e][\bar{e}\gamma_\rho(g_V^l - g_A^l\gamma^5)e]\}$$

is transformed to

$$\mathscr{L}_{\mathrm{eff}} = -\frac{G_F}{\sqrt{2}}[\bar{\nu}_e\gamma^\rho(1-\gamma^5)\nu_e][\bar{e}\gamma_\rho((1+g_V^l) - (1+g_A^l)\gamma^5)e]$$

What's Good about This New Lagrangian

$$\mathscr{L}_{\mathrm{eff}} = -\frac{G_F}{\sqrt{2}}[\bar{\nu}_e\gamma^\rho(1-\gamma^5)\nu_e][\bar{e}\gamma_\rho((1+g_V^l)-(1+g_A^l)\gamma^5)e]$$

The neutral current only processes $\nu_{\mu,\tau}e^- \to \nu_{\mu,\tau}e^-$ are similar to this

$$\mathscr{L}_{\mathrm{eff},\mu\tau} = -\frac{G_F}{\sqrt{2}}[\bar{\nu}_e\gamma^\rho(1-\gamma^5)\nu_e][\bar{e}\gamma_\rho(g_V^l-g_A^l\gamma^5)e]$$

We calculate the $\nu_e e^- \to \nu_e e^-$ processes only.

Current

Current is

$$\vec{J} = 2\rho\frac{\vec{v}}{\sqrt{1-v^2}},$$

where v is the velocity of electrons with respect to the CNB.

Interaction Energy

The interaction energies for two different helicity states are,

$$\frac{G_F}{\sqrt{2}}\vec{\sigma}\cdot\vec{J} = \pm\sqrt{2}G_F\rho\frac{v}{\sqrt{1-v^2}}.$$

Number Density

$$\rho \propto p_F^3.$$

Energy Split and Frequency

$$\Delta E = 2\sqrt{2} G_F \rho \frac{\vec{v}}{\sqrt{1-v^2}} = 0.6 \times 10^{-24} \left(\frac{p_F}{eV}\right)^3 \frac{v}{\sqrt{1-v^2}} eV$$

What is Fermi Momentum p_F

- β decay: $p_F \leq 60eV$
- cosmological: $p_F \leq 0.75 \times 10^{-2} eV$

Energy Split

Energy split is of the order

$$\Delta E \sim 10^{-19}\text{eV to } 10^{-30}\text{eV}$$

Energy split tells us the frequency.

POSSIBLE DETECTION METHODS

Electron Beams

- Electron Beams with equally $\pm$ helicity states.
- + and - states have different energies = two different frequencies.
- Phase difference between the two states.

How Large is the Phase Difference

$$\phi \sim \Delta E t \sim 2\sqrt{2} G_F \rho z$$
$$\sim 3 \times 10^{-20} \left(\frac{p_F}{eV}\right)^3 \text{rad/cm}$$

For one light year, we gain a phase difference of the order $\left(\frac{p_F}{eV}\right)^3$ rad.

Ferromagnetic Material

- A big chunk of ferromagnetic material (1 ton) contains 10^{27} aligned electrons.
- Torque of order $\left(\frac{p_F}{eV}\right)^3$ eV

Problems

- a small torque
- external B field

Neutrons

The estimation also works for neutral current only processes. He^3 mixed into low temperature He^4 can retain the spin for a long time. Thus we could use the spin dependent interaction of nuclei to detect CNB.

Methods

- Electrons of equally mixing helicity states : a small phase difference
- 1 ton of ferromagnetic material : a small torque
- He^3 nuclei : phase difference similar to electrons

1. Stodolsky, L. (1975). Speculations on Detection of the “Neutrino Sea.” Physical Review Letters, 34(2), 110–112.

BACKUPS

Backups

SR Velocity Transformation

$$u' = \frac{u - v}{\sqrt{1 - v^2}}$$

CURRENT

Current

$$\vec{J} = -\frac{i}{2m}\left(\Phi^*\nabla\Phi - \Phi\nabla\Phi^*\right)$$

Magnetic Moment and B Field

$$\Delta E = -\vec{\mu} \cdot \vec{B}$$