Astrophysical neutrino oscillations accounting for neutrino charge radii

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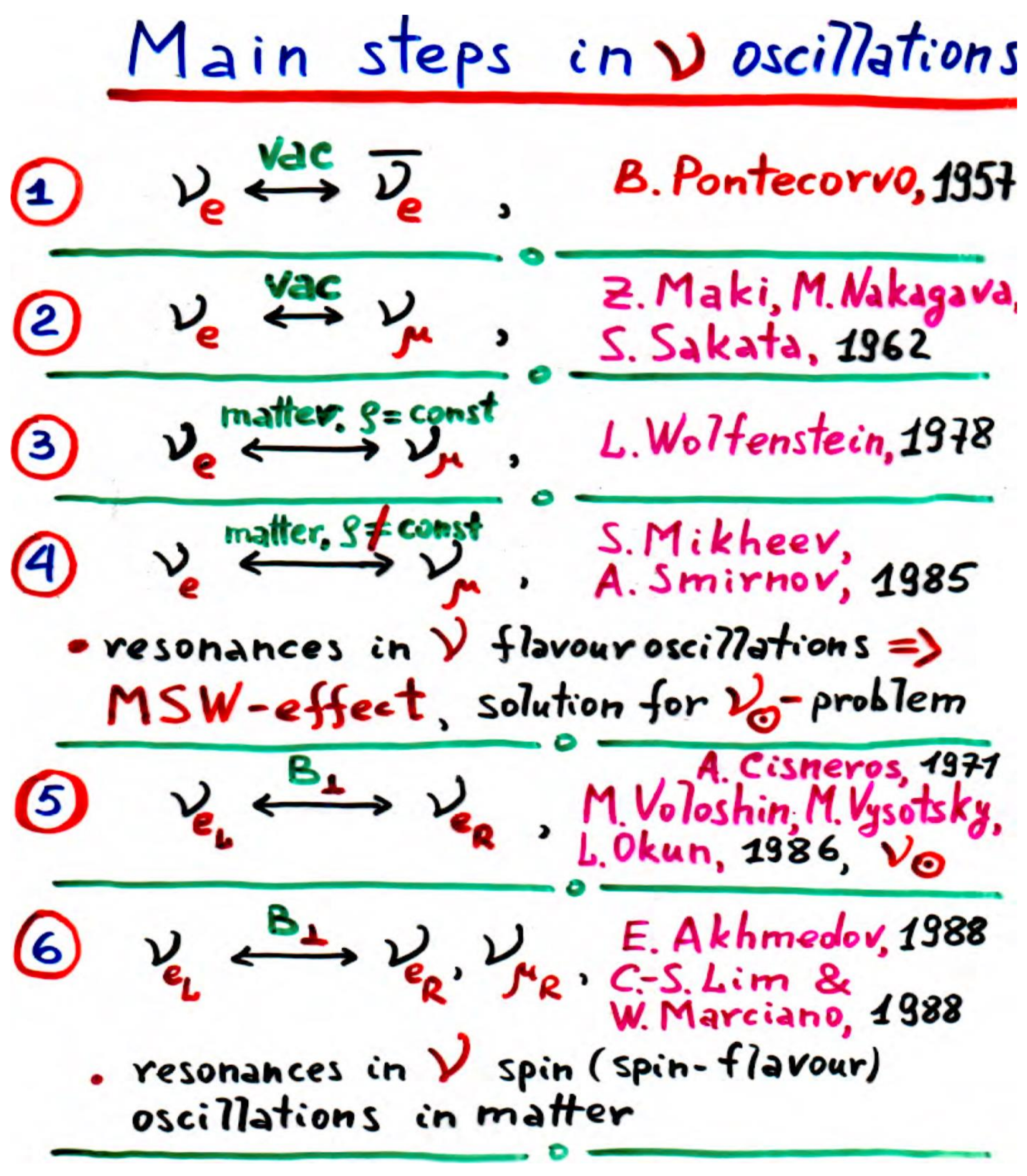

Neutrino oscillations in transversally moving matter

[1] *A.Studenikin*, Phys.Atom.Nucl. 67 (2004) 993

[2] *P.Pustoshny, A.Studenikin*, Phys.Rev. D98 (2018) 113009

It was shown that the nonzero transverse current component or matter polarization leads to neutrino spin and spin flavour oscillations:

- $\nu_e^L \Leftarrow (j_\perp) \Rightarrow \nu_e^R$
- $\nu_e^L \Leftarrow (\mathbf{j}_\perp) \Rightarrow \nu_e^R$
- $\nu_e^L \Leftarrow (j_\perp) \Rightarrow \nu_\mu^R$
- $\nu_e^L \Leftarrow (j_\perp^{NSI}) \Rightarrow \nu_\mu^R$

We present the new possibility of the flavour, spin and spin-flavour oscillations engendered by the interaction of the neutrino charge radii and anapole moment with an external magnetic field

The electromagnetic interactions of a massive neutrino field ν(x) is described by the effective interaction Hamiltonian

C.Giunti, A.Studenikin, "*Neutrino electromagnetic interactions: a window to new physics*", Rev.Mod.Phys. 87 (2015) 531

$$H_{int}(x) = \sum_{k,j} \bar{\nu}_k(x)\Lambda_\mu^{kj}\nu_j(x)A^\mu(x)$$

$$\Lambda_\mu^{fi}(q) = (q^2\gamma_\mu - q_\mu\gamma_\nu q^\nu)\left[\frac{\langle r^2\rangle^{fi}}{6} + f_A^{fi}\gamma_5\right]$$

$$H_{\alpha\alpha'}^{ss'} = u_{s\alpha}^\dagger \left\{[\mathrm{rot}\boldsymbol{B}]_z\left(\frac{\langle r^2\rangle^{\alpha\alpha'}}{6} + f_A^{\alpha\alpha'}\sigma_3\right) + [\mathrm{rot}\boldsymbol{B}]_\perp\left(\gamma_{\alpha\alpha'}^{-1} f_A^{\alpha\alpha'}\sigma_1 - i\tilde{\gamma}_{\alpha\alpha'}^{-1}\frac{\langle r^2\rangle^{\alpha\alpha'}}{6}\sigma_2\right)\right\} u_{s'\alpha'}$$

$$\gamma_{\alpha\beta}^{-1} = \frac{1}{2}\left(\gamma_\alpha^{-1} + \gamma_\beta^{-1}\right) \qquad \gamma_\alpha^{-1} = \frac{m_\alpha}{E_\alpha} \qquad \tilde{\gamma}_{\alpha\beta}^{-1} = \frac{1}{2}\left(\gamma_\alpha^{-1} - \gamma_\beta^{-1}\right)$$

$$P_{\nu_e^L \to \nu_x^L} = \frac{E_{eff}^2}{E_{eff}^2 + \Delta_{eff}^2}\sin^2\left(\frac{\pi x}{L_{eff}}\right)$$

$$E_{eff} = \frac{\Delta m^2 \sin 2\theta}{4E_\nu} + [\mathrm{rot}\mathbf{B}]_z\left[\frac{1}{2}\left(\frac{\langle r^2\rangle^{22} - \langle r^2\rangle^{11}}{6} + f_A^{11} - f_A^{22}\right)\sin 2\theta + \left(\frac{\langle r^2\rangle^{12}}{6} - f_A^{12}\right)\cos 2\theta\right]$$

$$\Delta_{eff} = -\frac{\Delta m^2 \cos 2\theta}{4E_\nu} + [\mathrm{rot}\mathbf{B}]_z\left[\frac{1}{2}\left(\frac{\langle r^2\rangle^{11} - \langle r^2\rangle^{22}}{6} + f_A^{22} - f_A^{11}\right)\cos 2\theta + \left(\frac{\langle r^2\rangle^{12}}{6} - f_A^{12}\right)\sin 2\theta\right]$$

$$L_{eff} = \frac{\pi}{\sqrt{E_{eff}^2 + \Delta_{eff}^2}}$$

$$\langle r_{\nu_e}^2\rangle_{\mathrm{SM}} = -0.83 \times 10^{-32}\ \mathrm{cm}^2$$

$$\mu_\nu \lesssim 10^{-19}\mu_{\mathrm{B}}$$

$$[\mathrm{rot}\mathbf{B}]_z\frac{\langle r^2\rangle^{eff}}{6} \approx 10^{-11}\mathrm{eV}$$

$$\mu B \approx 10^{-15}\mathrm{eV}$$

Y. Suwa, T. Takiwaki, K. Kotake and K. Sato, Publ. Astron. Soc. Jap. 59 (2007), 771-785

Conclusions

- New type of neutrino oscillations (flavour and spin-flavour) engendered by neutrino charge radii and anapole moment interactions with an external magnetic field are proposed and investigated

- In a supernova environment the potential of neutrino interaction with magnetic field through the charge radii and anapole moment could be considerably higher than through the magnetic moment

- New type of oscillations might have important consequences in extreme astrophysical environments such as supernovae, jets and neutron stars