ASTROPHYSICAL LIMITS ON GAUGE INVARIANCE BREAKING IN ELECTRODYNAMICS WITH TORSION

Letter to the Editor

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Abstract. General relativistic electrodynamics in a torsion background can give rise to a situation where the photons can ahve a non-zero rest mass and magnetic moment. Astrophysical limits are used to constrain these parameters.

While considering torsion effects in massive electrodynnamics, one can consider an additional term in the Lagrangian for the torsion-massive-photon interaction like

$$L_I \sim \alpha \, G_\gamma \, R(\Gamma) A_\mu A^\mu \tag{1}$$

where $R(\Gamma)$ is the curvature scalar constructed from the affine collection which includes torsion; α is the fine structure constant and G_γ is the photon-torsion coupling constant. This implies a mass term for the photon (m_γ), which is related to the torsion vector $\mathbf{Q}$, through a relation of the form

$$\left(\frac{m_\gamma c}{\hbar}\right)^2 \approx \lambda Q^2 \tag{2}$$

where λ is the dimensionless torsion-photon coupling constant; Q is related to the average spin density σ of the background (the net spin density being the source for the torsion) as:

$$Q = 4\pi G\sigma / c^3 \tag{3}$$

In De Sabbata *et al.* (1992), Eqs. (2) and (3) were applied to the magnetosphere of a neutron star giving a constraint on λ which is an arbitrary parameter of the theory as:

$$\lambda \, \leq \, 10^{-24}. \tag{4}$$

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This puts the limit on any direct photon-torsion coupling which violates gauge invariance. Again the violation of gauge invariance also implies non-conservation of electric charge in the sense of Lyttleton-Bondi. In the present context this means that the torsion modified Maxwell equations, i.e.,

$$\partial_k F^{ik} = 4\pi J^i + (2\alpha/3\pi)\eta^{iklj} F_{kl} Q_j \tag{5}$$

are not compatible with the current conservation law $\partial_i J^i = 0$. This could imply a net charge carried away by the mediating field. One can use arguments similar to these given in the case of massive neutrinos to put astrophysical limits on the violation of electric charge conservation, i.e., on q/e (e being the electron charge). Following Sivaram (1989) we can write:

$$q/e < (Gm_\gamma^2/e^2)^1/2. \tag{6}$$

Substituting m_γ we have:

$$\frac{q}{e}_\gamma < \frac{G\lambda Q}{e^2}^{1/2} \sim \left(\frac{G\lambda R_H^{-1}/\alpha}{e^2}\right)^2 \sim 10^{-18}. \tag{7}$$

Using Eq. (5) and using for λ Eq. (4) and $Q \sim R_H^{-1}/\alpha$ from De Sabbata *et al.* (1992), R_H being the Hubble radius. This is one ordser of magnitude less than the astrophysical limit $(q/e)_\nu$ for neutrinos and shows that $\lambda \leq 10^{-24}$, is consistent from cosiderations other than neutron stars. Also, in De Sabbata *et al.* (1992), the photon magnetic moment induced by torsion background was estimated as $\mu_g amma \sim 10^{-20}\mu_B$, where $\mu_B = (e\hbar/2m_e c)$ is the Bohr magneton. In the galactic magnetic field, $B_{\rm gal} \sim 10^{-6}$ Gauss, this value of μ_γ implies an energy of $\mu_\gamma B_{\rm gal} \approx 10^{-45}$ ergs. It is interesting that this is consistent with the minimum operationally definable energy, $E_{\rm min}$ in cosmology as given by the uncertainty principle. As shown in Sivaram (1982),

$$E_{\rm min} \approx \hbar H_0 \tag{8}$$

H_0 is the Hubble constant, $H_0 \simeq 10^{-18}$ s^{-1}). So if we insist that μ_γ must be operationally definable, then this gives

$$\mu_\gamma \simeq \frac{\hbar H_0}{B_{\rm gal}} \simeq 10^{-20}\mu_B. \tag{9}$$

For a pair of annihilation γ-ray photons($E \approx 0.5$ MeV), in a neutron star magnetig field (10^{12} Gauss), this implies a fractional energy change of $\Delta E/E \approx 10^{-21}$ (Mossbauer techniques could detect $\Delta E/E \approx 10^{-18}$ at present). A μ_γ of this order could also imply an additional energy loss of $\approx l0^{37}$ ergs in a SN explosion (as about $N_\gamma \approx 10^{63}$ photons are emitted in a tyical SN explosion, so $E_\gamma \approx N_\gamma \mu B \approx 10^{37}$ ergs). However this is only 10^{-14} of the blast energy which is typically $\approx 10^{51}$ ergs in a supernova explosion.

A value of μ_γ, as given by Eq. (9) would also imply a polarisation flip rate (or polarisation oscillation) in the interstellar magnetic field given by $\Gamma \approx \mu_\gamma B/\hbar$ $\approx 10^{18}$ s^{-1}, implying a time scale $\approx 1/H_0 \approx 10^{18}$ s^{-1} for this process. We also remark that a photon rest mass of the order of $E_{\rm min}$ would also be implied by Maxwell equations in a space of constant curvature i.e., the generally covariant equations

$$-A^{\mu;\nu}_{;\nu} + A^{\nu\ ;\mu}_{;\nu} + R^{\mu}_{\alpha}A^{\alpha} = 4\pi J^{\mu}$$

in the Lorentz gauge $A^{\mu}_{;\mu} = 0$ become

$$\Box A^{\mu} + R^{\mu}_{\nu}A^{\nu} = 4\pi J^{\mu}. \tag{10}$$

For a space of constant curvature, i.e., a maximally symmetric space $R^{\mu}_{\nu} = \wedge g^{\mu}_{\nu}$ (and for pure radiation)

$$\Box A^{\mu} + \wedge A^{\mu} = 0. \tag{11}$$

This implies that

$$m_\gamma \approx \frac{\hbar}{c}\sqrt{\wedge}. \tag{12}$$

The limit $\wedge \leq 10^{-57}$ cm^{-2} as implied by the observations, then gives $m_\gamma < \hbar H/c^2$ or $m_\gamma c^2 = 10^{-45}$ erg, consistent with other estimates.

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