Corrections to the photon index of refraction due to the relic neutrinos with magnetic moment

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Index of refraction *n*

K^α - *photon 4-momentum, such that* $K^2 = \omega^2 - k^2$

$$n = \frac{k}{\omega}$$

$$n = \sqrt{\varepsilon(K)\mu(K)}$$

Example: Solar wind

$$n = 1 - \Delta n$$

$$n \simeq 1 - \frac{n_e e^2}{2 m_e \omega^2}$$

$$n_e = 10\ cm^{-3}$$

$\Delta n \sim 10^{-21}$ *for the optical wavelength range*

$$\Pi_{\mu\nu} = \Pi_\perp \mathcal{P}_{\mu\nu} + \Pi_{||} \mathcal{Q}_{\mu\nu}.$$

$$\epsilon(K) = 1 - \frac{\Pi_{||}}{K^2},$$

$$\frac{1}{\mu(K)} = 1 + \frac{K^2 \Pi_\perp - \omega^2 \Pi_{||}}{k^2 K^2}.$$

$$\Pi_\perp(K^2) = K^2$$

$$n \simeq 1 - \frac{\Pi_\perp}{2\omega^2}$$

[3] *Covariant calculations at finite temperature: The relativistic plasma – H. A. Weldon*
[4] *Self-energy corrections to fermions in the presence of a thermal background – E. J. Levinson, D. H. Boal*

Cosmic Neutrino Background (CNB)

- *One the most abundant particles in the Universe*

$$n_\nu = 112 \ \ cm^{-3} \ per \ flavour$$

- *CNB decoupled around BBN*

$$T_{dec} \simeq 2MeV \simeq 2,3 \times 10^7 K$$

- *Nowadays "temperature" of CNB*

$$T_{now} \simeq 1.9K \simeq 1.7 \times 10^{-4} eV$$

- *CNB-spectra*

$$n_F = \frac{1}{1 + e^{\frac{|\vec{p}|}{T}}}$$

  - *remains the same after decoupling up to the redshift of momentum due to the universe expansion*

[1] *Looking for cosmic neutrino background - C. Yanagisawa*
[2] *Massive Fermi Gas in the Expanding Universe - A. Trautner*

Effective coupling of neutrinos with photon and Dirac neutrino magnetic moment

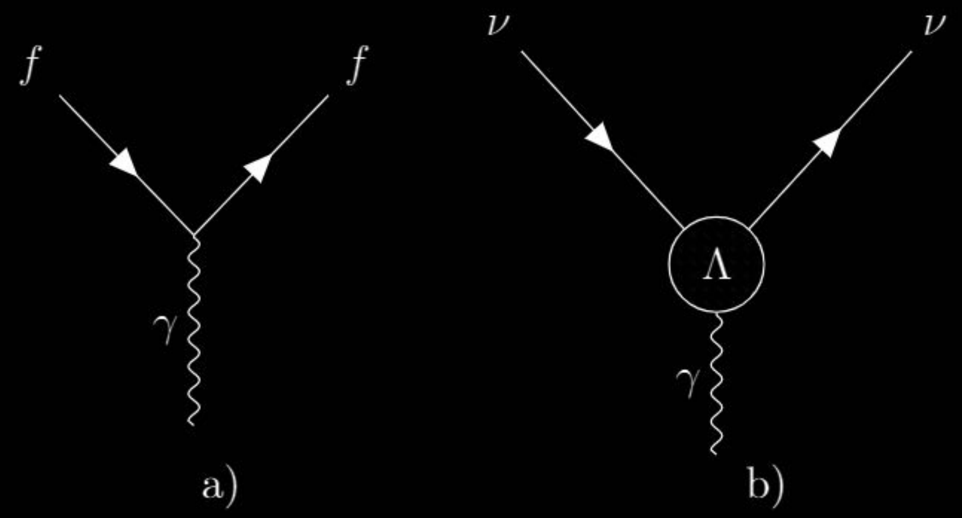
$$\Lambda_\alpha(K) = q_\nu \gamma_\alpha - i\mu_\nu \sigma_{\alpha\beta} K^\beta + \epsilon_\nu \sigma_{\alpha\beta} K^\beta \gamma_5 + a_\nu (K^2 \gamma_\alpha - K_\alpha \hat{K}) \gamma_5$$

$$\mu_{ii}^D = \frac{3eG_F m_i}{8\sqrt{2}\pi^2} \sim 10^{-20} \mu_B$$

- *Standard Model prediction for neutrino magnetic moment*

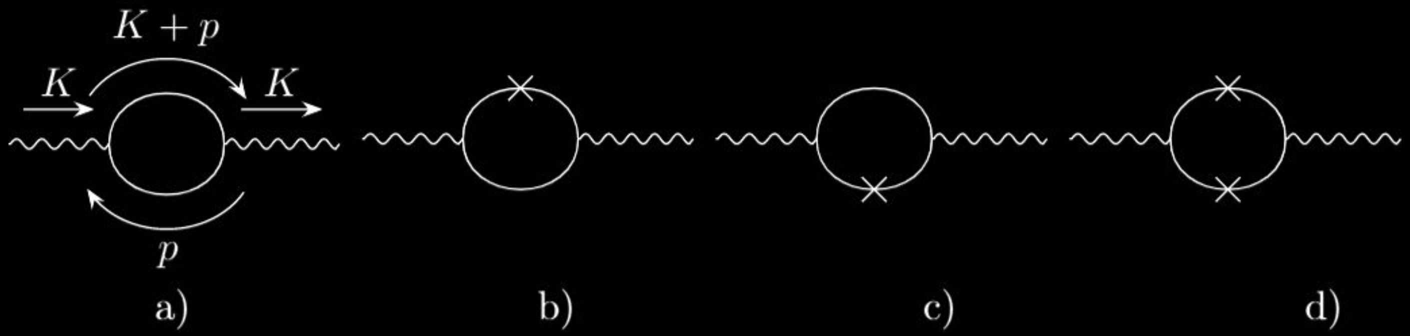
$$\mu_{\bar{\nu}_e} \leq 2.9 \times 10^{-11} \mu_B$$

- *experimental restriction for neutrino magnetic moment*



[3] Electromagnetic Properties of Neutrinos – C. Broggini, C. Giunti, A. Studenikin

Modified propagator of fermion in matter in real time formalism of thermal QFT



$$S(p) = S^{vac}(p) + (\hat{p} + m)\Gamma_F(p,\mu) \qquad S^{vac}(p) = \frac{1}{\hat{p} - m + i\epsilon},$$

$$\Gamma(p) = 2\pi i\delta(p^2 - m^2)\ \theta(p_0) n_F(p,\mu)$$

$$i\Pi_{\mu\nu} = (-1)\int \frac{d^4p}{(2\pi)^4} S(p+K)\Lambda_\mu(K)S(p)\Lambda_\nu(K)$$

The calculation of transverse function for polarization tensor

$$\Pi_\perp = \frac{K^4\mu_\nu^2}{\pi^2}\left(\frac{1}{24} - \frac{6\zeta(3)T^3}{mk^2}\right)$$

$$\Pi_\perp = K^2$$

$$\frac{1}{K^2} = \frac{\mu_\nu^2}{\pi^2}\left(\frac{1}{24} - \frac{6\zeta(3)T^3}{mk^2}\right)$$

$$K^2 \to 0$$

$$\mu_\nu \sim 10^{-19}\mu_B$$

$$m \sim 0.1eV$$

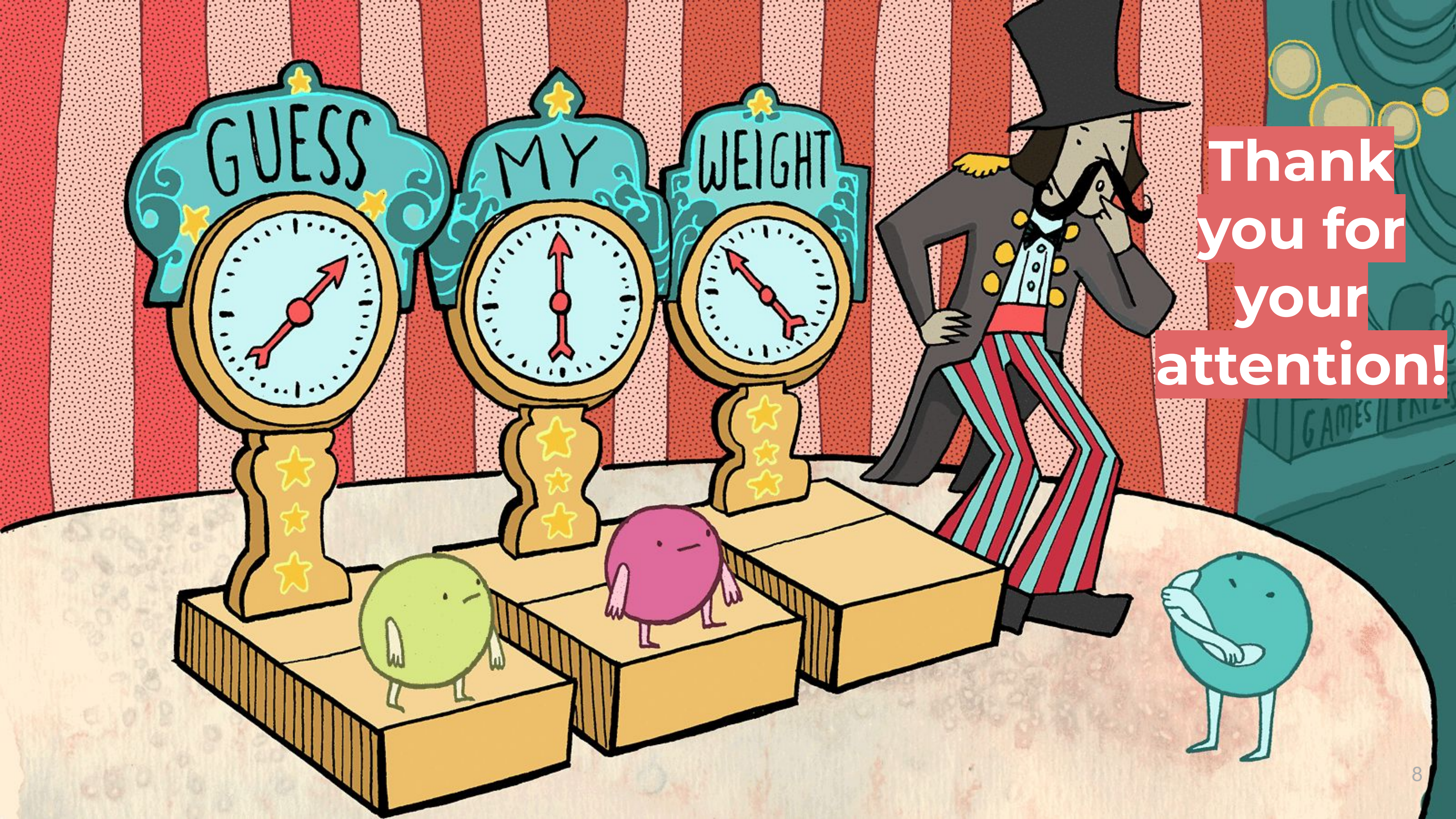
$$T = \frac{1}{\beta} \sim 10^{-4}eV$$

$$\Pi_\perp^{e^- charge} = \frac{e^2}{\pi^2}\left(const - \frac{12\zeta(3)T^3}{m}\right) + \mathcal{O}(K^2)$$

- *For typical values of neutrino magnetic moment given by Standard model or experiments there is no non-trivial solution*
- *No effect to the refractive index from CNB*
- *This is in contrast to electrically charged medium where the effect is present for arbitrarily weak coupling or density*
- $K^2 = 0$ *and* $n = 1$

Conclusion

- *We considered the question of the neutrino magnetic moment impact to the photon propagation in the medium of CNB in the small photon polarization mass regime, which is dictated by the frame of the task*
- *The result for the transverse polarization function tells us that* ***there is no non-trivial solution*** *for the photon polarization mass* ***in physical range*** *of magnetic moment of neutrino, so that there is no effect on phase velocity of light propagating through CNB.*
- *However we do not deny the existence of the critical value of some combination of parameters for other regimes or various other media (characterized by high density, high temperature, high magnetic moment, ...), above which the effect is non-zero, for example in early universe.*



Thank you for your attention!

$$\mathcal{H}_{eff}(x) = j_\mu^{eff}(x) A^\mu(x)$$

$$j^{eff}(x) = \overline{\nu}(x)\Lambda^\mu(x)\nu(x)$$

$$\Lambda(x) = -i\mu_\nu \sigma_{\mu\nu} K^\nu$$

$$\mathcal{P}_{\mu\nu} = \tilde{g}_{\mu\nu} + \frac{K_\mu K_\nu}{k^2}$$

$$\mathcal{Q}_{\mu\nu} = -\frac{1}{K^2 k^2}(k^2 u_\mu + \omega \tilde{K}_\mu)(k^2 u_\nu + \omega \tilde{K}_\nu).$$

$$\Pi_{\mu\nu} = \Pi_{\mu\nu}^{vac} + \Pi_{\mu\nu}^{mat}$$

$$\Pi_\perp^{vac} = \Pi_\parallel^{vac} = K^2 \Pi_0^{vac}$$

$$\mu_\nu^2 = -0.136 \times 10^{12} eV^{-2} \frac{k^2}{K^2}$$

$$\mu_\nu^2 = -1.36843 \frac{m}{T^3} \frac{k^2}{K^2}$$

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