YU ISSN 0015—3206
FZKAAA 14 (2) 69 (1982)

HUBBLE'S LAW AS NEUTRINO-COMPTON EFFECT

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Received 1 September 1981
UDC 539.12

Original scientific paper

We interpret the Hubble's redshift law as the result of photons scattered off of massive neutrinos analogous Compton collision in the universal degenerate neutrino sea, feasibly, with the Einstein static universe; a photon-neutrino *electro-magnetic* interaction (note Bernstein et al.) has been assumed.

1. Introduction: photon-neutrino "electromagnetic" interaction, neutrino mass

It has been noted[1] that there is some indication that a photon should directly interact with a neutrino. We assume (note Bernstein et al.[2]) the simple interaction $e_\nu \gamma_\mu$ (Fig. 1) as it would follow from the principle of minimal electromagnetic coupling with a coupling constant or the neutrino *charge* e_ν (note we take vector coupling; $V - A$ coupling to be considered in the Appendix). This should mean that the reaction[1] $\nu + \bar{\nu} \to \gamma + \gamma$ traces the diagram (Fig. 2) that in the cross channel $\gamma + \nu \to \gamma + \nu$ activates (with one photon suitably reversed in direction and collision considered inelastic) the Compton collision (an analogue) of a photon with a neutrino, which is our immediate concern. We attribute a small non-zero rest mass (we denote it by m_ν or in energy equivalence by $m_\nu c^2$) to a neutrino as suggested by recent experiments[3-7], and treat neutrino as a simple Dirac particle.

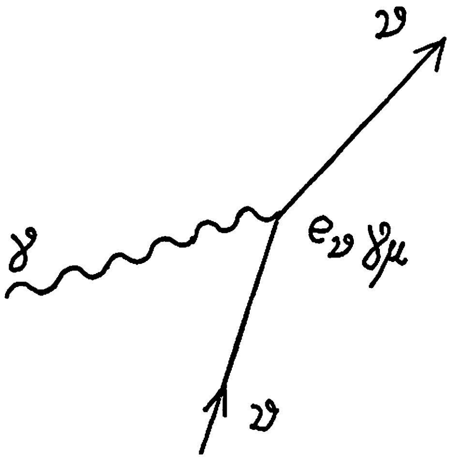

Fig. 1. Photon-neutrino *electromagnetic* interaction.

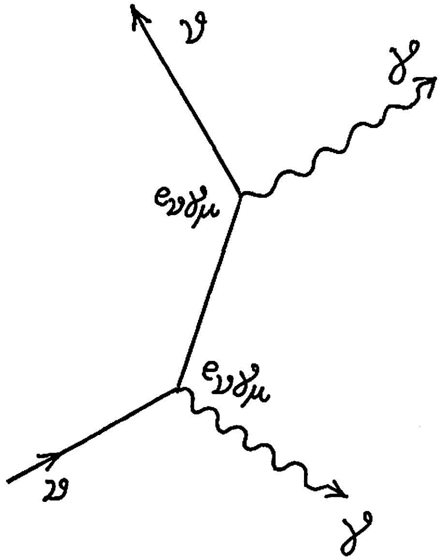

Fig. 2. The reaction[1] $\nu + \bar{\nu} \to \gamma + \gamma$ with the coupling as in Fig. 1. Cross-channel gives the neutrino-Compton collision.

2. *Degenerate neutrino sea, neutrino-Compton collision, Hubble's law*

Now, let us follow a photon as it passes through the degenerate Fermi sea of neutrinos[8,9] and suffers Compton collision with these particles. Each collision should initiate on the average a change in the photon wave-length of order

$$\delta \lambda \sim \frac{h}{m_\nu c}. \tag{1}$$

Again if N represents the neutrino number density, and $\sigma_c(\nu)$ the photon-neutrino Compton collision cross-section, the photon mean free path in the sea is

$$\Lambda = \frac{1}{\sigma_c(\nu) N}, \tag{2}$$

and hence, the number of collisions a photon suffers in travelling the distance $d (\gg \Lambda)$ is given by

$$\frac{d}{\Lambda} = \sigma_c(\nu) N d. \tag{3}$$

$\sigma_c(\nu)$ in the expressions above is obviously represented by the Klein-Nishina formula[10] with the electron charge e and the electron mass m replaced by the neutrino *charge* e_ν and the neutrino mass m_ν, respectively.

Thus, combining (1) and (3), the net change $\Delta\lambda$ in the photon wave-legth in travelling the distance d is

$$\Delta\lambda = \delta\lambda \cdot \left(\frac{d}{\Lambda}\right) = \frac{h}{m_\nu c} \cdot \sigma_c(\nu) N d. \tag{4}$$

Now, for large value of the energy parameter $h\nu/m_\nu c^2$ we have the Compton cross-section $\sigma_c(\nu)$ approximated as [see Eq. (II 42), p. 42, Ref. 10]

$$\sigma_c(\nu) = \frac{3}{8}\sigma_T(\nu) \cdot \frac{1}{a}\left(\ln 2a + \frac{1}{2}\right), \tag{5}$$

where,

$$\sigma_c(\nu) = \frac{8\pi}{3}\left(\frac{e_\nu^2}{m_\nu c^2}\right)^2 \tag{6}$$

(Thompson cross-section for photon-neutrino scattering) and,

$$a = \frac{h\nu}{m_\nu c^2}. \tag{7}$$

We ignore the logarithmic variation due to photon frequency arising through $a = \frac{h\nu}{m_\nu c^2}$ in the term $\left(\ln 2a + \frac{1}{2}\right)$ in (5), and take it as (justified below in sec. 4)

$$\ln 2a + \frac{1}{2} \sim 35. \tag{8}$$

Thus using (5), (8), (7), and then replacing c by c/λ, finally with (6) we get from (4)

$$\frac{\Delta\lambda}{\lambda} = \frac{3}{8}\sigma_T(\nu) \cdot N d \times 35 = \left\{35 N \pi \left(\frac{e_\nu^2}{m_\nu c^2}\right)^2\right\} d, \tag{9}$$

where the quantity within the curly bracket { } is a constant. We note, (9) is the Hubble and Hamason's form ($\Delta\lambda/\lambda \sim d$) of the redshift law (see p. 456 and p. 359, Ref. 11) which runs

$$\frac{\Delta\lambda}{\lambda} = 6.0 \times 10^{-28}\, d, \tag{10}$$

where the distance d is expressed in centimeters.

Should we further identify (9) exactly with the Hubble's formula (10) we get

$$35\, N \pi \left(\frac{e_\nu^2}{m_\nu c^2}\right) = 6.0 \times 10^{-28}. \tag{11}$$

3. Neutrino density, Fermi energy, missing mass

Now, as in the case of an electron, the quantity $e_\nu^2/m_\nu c^2$ in (11) analogously represents the charge radius (r_ν) of a neutrino. Should we therefore take for

$$\left(\frac{e_\nu^2}{m_\nu c^2}\right) \equiv r_\nu^2 \tag{12}$$

the average value $\langle r^2 \rangle_{av} \approx 10^{-32}$ cm^2 (Eq. (17), Ref. 2) as realized by Bernstein et al.[2] from the intermediate boson theory of weak interaction as applied to the photon-neutrino interaction, we get from (11) the neutrino number density $N \sim \sim 5.5 \times 10^2\ \nu/\text{cm}^3$. The corresponding Fermi energy [see Eq. (47), Ref. 8] is $E_F \sim 6.29 \times 10^{-4}$ eV $\left(\text{cf. } \frac{3}{2} k\,T \sim 4 \times 10^{-4}\text{ eV for the 2.7 K microwave heat bath}\right)$. Again the neutrino number density (N) along with the neutrino rest mass $m_\nu c^2 \sim 30$ eV (a reasonable mean of 14 to 46 eV[3]; actually antineutrino) gives for the matter density due to the neutrino sea the value $\varrho \sim 2.9 \times 10^{-29}$ g/cm^3 (cf. the value[12] $\varrho \sim 2 \times 10^{-29}$) which can duly account for the missing mass in the universe.

4. Neutrino "charge", photon mass

On the other hand the relation

$$\left(\frac{e_\nu^2}{m_\nu c^2}\right)^2 = r_\nu^2 = 10^{-32}\ \text{cm}^2 \tag{13}$$

along with $m_\nu c^2 \sim 30$ eV implies $e_\nu \sim 1.4 \times 10^{-4}\, e$, where e is the electron charge.

Above value ($1.4 \times 10^{-4}\, e$) of neutrino *charge* is rather high as compared with the limit estimate (ν_c) by Bernstein et al.[2]. A moderate value $e_\nu \sim 10^{-12} e$ (see electronic neutrinos, Table 1[2]) may however be achieved should we attribute a small non-zero rest mass ($\sim 10^{-15}$ eV; note the experimental limit quoted below) for a photon also: With a photon rest mass (energy equivalent) $m_{ph} c^2 \ll \ll m_\nu c^2$ (neutrino rest mass) we have the reduced mass for the photon-neutrino system that equals the photon mass $m_{ph}c^2$, also the centre of mass reasonably coincide with the neutrino and the reference system (c. m. system) with the neutrino rest frame. Thus it is realized that in the scattering formula we use [Eq. (5); originally Eq. (II 42), Ref.10 in electron rest frame] we should replace the neutrino mass ($m_\nu c^2$) by the photon mass ($m_{ph}c^2$) which is effectively the neutrino mass in the neutrino rest frame for the photon-neutrino scattering process. Thus, for the neutrino charge-radius squared we get [see (13)]

$$\left(\frac{e_\nu^2}{m_\nu c^2}\right)^2 \to \left(\frac{e_\nu^2}{m_{ph} c^2}\right)^2 = 10^{-32}\,\mathrm{cm}^2. \tag{14}$$

This gives the value $e_\nu \sim 0.6 \times 10^{-12}\, e$, moderately in between the electron-neutrino scattering case (ν_e) and the astrophysical limit, Table 1[2] with a photon rest mass $\approx 0.52 \times 10^{-15}$ eV. Following deductions by Adams et al.[13] (on degenerate electron sea) we get the similar photon mass $\sim 0.50 \times 10^{-15}$ eV from consideration of the dispersion relation as a photon propagates through the degenerate Fermi sea of neutrinos and interacts directly with the neutrinos in a similar fashion as in the present investigation. This may be seen as follows: Ours is the neutrino sea much too similar as the degenerate sea of electrons considered by Adams et al.[3]. Thus we use their Eq. (23) e. g. $\omega_0^2 = 4e^2\, p_F^3/(3\pi\, E_F)$, $E_F = (m^2 + p_F)^{1/2}$ with the replacement $e \to e_\nu\, (\sim 0.6 \times 10^{-12}\, e)$ and $m \to m_\nu$ ($m_\nu c^2 \sim 30$ eV) and take for $p_F^2/2m$ (non-relativistic Fermi energy) our estimate $\sim 6.29 \times 10^{-4}$ eV (sec. 3) for the neutrino sea. Remembering that $e^2 = 1/137$ in units ($\hbar = c = 1$) used by Adams et al., we get (note the dispersion relation $\omega^2 = \omega_0^2 + k^2$ due to these authors) the photon rest mass $\hbar\, \omega_0/c^2 = \omega_0 \sim 0.50 \times 10^{-15}$ eV. (Compare the photon masses noted above with the experimental limit[14, 15] 0.6×10^{-15} eV.) It needs no mention that since the early days of L. De Broglie[16] non-zero photon rest-mass has often been stipulated, also various experiments (for Refs. see p. 46[15]) have been performed to obtain an upper limit for it. Recent attempt by Il-Tong Cheon[17] to accommodate a photon rest mass within the framework of the *special theory of relativity* (extended) is again noteworthy.

Further, we have the energy parameter

$$a \equiv \frac{h\nu}{m_\nu c^2} \to \frac{h\nu}{m_{ph} c^2}\,; \quad m_{ph}c^2 \sim 10^{-15}\,\mathrm{eV}. \tag{15}$$

Hence, for the optical photons (1—10 eV) we get $a \sim 10^{15}/10^{16}$, so that the value $\ln 2a + \frac{1}{2} \sim 35$ is reasonable choice in Eq. (8) above (sec. 2).

5. *Conclusions*

Thus, we may interpret the Hubble's redshift law as the result of photons scattered off of massive neutrinos analogous Compton collision in the universal degenerate neutrino sea, eventually/feasibly, in a static Einstein universe. This is opposed to the usual interpretation of the Hubble's redshift as caused (Doppler origin) due to recession of galaxies. It may, however, be mentioned that Einstein was not very happy with the concept of expansion of space (see Appendix IV, pp. 133—134 Ref. 18) — he would rather like a closed and static universe.

At the end we remark, we have so far used the vector coupling with the photon-neutrino interaction, neutrino treated as a Dirac particle. We shall see in the Appendix that similar results should also follow in the $V - A$ theory (two component neutrinos).

Appendix V-A coupling

Let us look at the reduced form of the Compton amplitude on page 126, Ref. 19 (note it is vector coupling γ_μ) e. g.

$$M = \frac{1}{2m}\left[\frac{\hat{\varepsilon}_2\,\hat{q}_1\,\hat{\varepsilon}_1}{\omega_1} + \frac{\hat{\varepsilon}_1\,\hat{q}_2\,\hat{\varepsilon}_2}{\omega_2}\right]. \tag{A1}$$

The corresponding amplitude with the $V - A$ coupling $\gamma_\mu \cdot \frac{1}{2}(1+\gamma_5)$[2] in units $\hbar = c = 1$ and notations as in Refs. 19 and 20

$$\begin{aligned} M' = \frac{1}{4} \times \Bigg\{ &\frac{\hat{\varepsilon}_2\,\hat{\varepsilon}_1}{\omega_1} - \left(\frac{\hat{\varepsilon}_2\,\hat{\varepsilon}_1}{\omega_1} - \frac{\hat{\varepsilon}_2\,\hat{q}_1\,\hat{\varepsilon}_1}{m\,\omega_1}\right)\gamma_5 - \\ &- \frac{\hat{\varepsilon}_1\,\hat{\varepsilon}_2}{\omega_2} + \left(\frac{\hat{\varepsilon}_1\,\hat{\varepsilon}_2}{\omega_2} + \frac{\hat{\varepsilon}_1\,\hat{q}_2\,\hat{\varepsilon}_2}{m\,\omega_2}\right)\gamma_5\Bigg\}. \end{aligned} \tag{A2}$$

Since the photons are in energy region $\omega_1, \omega_2 \sim 1$—$10$ eV (sec. 2), and m should stand for the reduced mass, the photon mass, $m_{ph} \sim 10^{-15}$ eV of the photon-neutrino system (see sec. 4), we have the inequality $\omega_1, \omega_2 \gg m$. Thus (A2) can be approximated as

$$M' \sim \frac{1}{2} \times \frac{1}{2m}\left[\frac{\hat{\varepsilon}_2\,\hat{q}_1\,\hat{\varepsilon}_1}{\omega_1} + \frac{\hat{\varepsilon}_1\,\hat{q}_2\,\hat{\varepsilon}_2}{\omega_2}\right]\gamma_5. \tag{A3}$$

Note (A3) is close to (A1) except for a γ_5 and the factor 1/2, and we obtain after a laborous calculation in $V - A$ theory the total cross-section (σ_T') for unpolarized radiations

$$\begin{aligned} \sigma_T' = \frac{1}{2}\pi r^2 \Bigg[&\left(\frac{m}{\omega_1} + \frac{2m^2}{\omega_1^2} + \frac{2m^3}{\omega_1^3}\right)\log\left(\frac{2\omega_1}{m} + 1\right) + \\ &+ \frac{m}{2\omega_1} - \frac{4m^2}{\omega_1^2} - \frac{m^3}{2\omega_1(2\omega_1 + m)^2}; \quad r = \frac{e^2}{m} \end{aligned} \tag{A4}$$

(cf. the total Compton cross-section σ_T on p. 103, Ref. 20).

Writing $\sigma_{Thom} = \frac{8\pi}{3} r^2$ for the Thompson cross-section and $a = \omega_1/m$ for the energy parameter, we get for large value ($a \gg 1$) of the energy parameter

$$\sigma'_T \sim \frac{1}{2} \cdot \frac{3}{8} \sigma_{Thom} \cdot \frac{1}{a} \left(\ln 2a + \frac{1}{2} \right). \tag{A5}$$

Compare the cross-section (A5) with that in (5), and it is realized that the $V - A$ theory should also give the Hubble's law, other similar results following.

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Originalni znanstveni rad

Hubbleov zakon interpretiran je kao posljedica raspršenja fotona na masivnim neutrinima, analogno Comptonskom raspršenju. Neutrini se nalaze u univerzalnom degeneriranom moru, što je ostvarivo u Einsteinovom statičkom svemiru. Pretpostavljena je foton-neutrino »elektromagnetska« interakcija navedena u radu Bersteina i ostalih.