**Exploration**

# Plausible Further Connection Between Photon Mass and Variation of the Fine Structure Constant

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**Abstract**

In this paper, we explores the plausible further connection between the mass of photon and the observed cosmic variation of the *Fine Structure Constant* (FSC). In an earlier paper, we argued that the observed variation in the FSC may have something to do with the variation of the permittivity of free space $\varepsilon_0$. We reach the same conclusion from a different angle.

**Keywords:** Photon mass, Fine Structure Constant, variation, connection

## 1 Introduction

Further connection is here established between the mass of the Photon and the observed cosmic variation of the *Fine Structure Constant* (FSC) (see *e.g.*, King et al. 2012, Murphy et al. 2009, 2003, 2001, Webb et al. 2011, 2001, 1999). In the reading Nyambuya (2014), a Gauge Invariant, Long Ranged and Long Lived Massive Photon Model [hereafter Massive Photon Model (MP-model)] was put forward while in the reading Nyambuya (2016), the observed variation in the FSC was partially connected to the MP-model, where it was argued that the observed variation in the FSC may have something to do with the variation of the permittivity of free space $\varepsilon_0$.

## 2 Massive Photon Model

In the MP-model of Nyambuya (2016), it is argued that usual Proca-Maxwell massive Photon electrodynamic theory be modified to include a Stückelberg (1938$a$,$b$,$c$) scalar field $\Psi$, so that this modified theory of described by the equation:

$$\partial^\mu F_{\mu\nu} - \kappa^2 A_\mu + \kappa^2 \partial_\mu \Psi = \mu_0 J_\nu. \tag{2.1}$$

where, as usual:

$$F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu, \tag{2.2}$$

is the Maxwellian Electrodynamic (MED) field tensor, $A_\mu$ is the electrodynamic four vector potential, $\partial_\mu$ are the four-partial derivatives and $J_\mu$ is four electrodynamic current density, $\kappa$ is the Photon-mass term and $\mu_0$ is the permeability of free space.

By substituting into equation (2.1) the decomposed MED field tensor $F_{\mu\nu}$ as it is given in equation (2.2), equation (2.1) can be written equivalently as:

$$\Box A_\nu \underbrace{-\partial_\nu \left(\partial^\mu A_\mu\right) - \kappa^2 A_\nu + \kappa \partial_\nu \Psi}_{\textbf{SGC}-\textbf{Terms}} = J_\nu. \tag{2.3}$$

The novelty of the MP-model of Nyambuya (2016) lays in two basics assumptions, *i.e.*:

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1. The first assumption is to do away with the Lorenz (1867) gauge condition, that is the condition:

$$\partial^{\mu} A_{\mu} = 0, \tag{2.4}$$

so that it is no longer holds true wherein this condition is now modified so that it becomes:

$$\partial^{\mu} A_{\mu} = \left( \frac{\mathrm{g}_{\mathrm{s}}^{2} \kappa}{1 + \mathrm{g}_{\mathrm{s}}^{2}} \right) \Psi, \tag{2.5}$$

where ($\mathrm{g}_{\mathrm{s}}^2 \neq 0$) is a dimensionless constant – this constant, $\mathrm{g}_{\mathrm{s}}$, is expected to be a universal fundamental natural constant just as is the case with Planck's constant $\hbar$, Newton's universal constant of gravitation $G$ *etc.* If this constant ($\mathrm{g}_{\mathrm{s}}^2$) is equal to zero, then we are back to the usual Lorenz Lorenz (1867) gauge.

2. The second assumption is to introduce a so-called *Special Gauge Condition* (SGC), and this condition requires that the terms in the *under-brace* in equation (2.3), be set to zero, *i.e.*:

$$\partial_{\nu} \left( \partial^{\mu} A_{\mu} \right) + \kappa^{2} A_{\nu} - \kappa \partial_{\nu} \Psi \equiv 0. \tag{2.6}$$

It is this SGC that allows one to attain the desired theory of massive Photons that are long ranged and long lived. From (2.6), it follows that taking the four divergence of this equation, one will have:

$$\Box \left( \partial^{\mu} A_{\mu} \right) + \kappa^{2} \left( \partial^{\mu} A_{\mu} \right) - \kappa \Box \Psi \equiv 0, \tag{2.7}$$

and further, given (2.5), it follows that the equation resulting from equation (2.7) above, is an equation for the field $\Psi$, *i.e.*:

$$\Box \Psi = \mathrm{g}_{\mathrm{s}}^{2} \kappa^{2} \Psi, \tag{2.8}$$

which is the Klein-Gordon equation (Klein 1926) for the Stückelburg scalar.

Now, when all has been said and done, the resulting equation after the introduction of the SGC, is:

$$\Box A_{\nu} = \mu_{0} J_{\nu}. \tag{2.9}$$

Equation (2.9) is the same as that for a massless Photons in MED theory (Maxwell 1873). In a nuthshell, all the above is the conceptual constitution of the MP-model of Nyambuya (2016). Amongst others, what this model is telling us, is that, the traditional method(s) used to investigate the mass of the Photon by trying to detect this mass *via* the Proca-mass-term $\kappa^2 A_{\mu}$ (see *e.g.*, Hojman & Koch 2013, Tu et al. 2005, Luo et al. 2003, Lakes 1998, Chernikov et al. 1992, Goldhaber & Nieto 2010, Burman 1972, 1973, Goldhaber & Nieto 1971, Williams et al. 1971), this (these) will yield no favourable result on the frontiers of a non-zero mass term because this mass term for the Photon as this terms is concealed deep in the SGC. Other new, ingenious and novel methods to detect the mass of the Photon will, thus have to be devised.

# 3 Photon Mass and Variable FSC Connection

Now, in-order to make further the case of the secular spatial and temporal variability of $\mu_0$ and $\varepsilon_0$, we have to set our eyes onto equation (2.9), first by taking the four divergence of this equation, where in one obtains:

$$\Box \left( \partial^{\alpha} A_{\alpha} \right) = \partial^{\alpha} \left( \mu_{0} J_{\alpha} \right), \tag{3.1}$$

Further, using equation (2.5) to substitute for $\partial^{\alpha} A_{\alpha}$ and expanding the differentials on the right handside of this equation (3.1), we will have:

$$\left( \frac{\mathrm{g}_{\mathrm{s}}^{2} \kappa}{1 + \mathrm{g}_{\mathrm{s}}^{2}} \right) \Box \Psi = \mu_{0} \partial^{\alpha} J_{\alpha} + J_{\alpha} \partial^{\alpha} \mu_{0}. \tag{3.2}$$

The strict and sacrosanct law of conservation of electric current and charge requires that ($\partial^{\alpha} J_{\alpha} \equiv 0$), hence equation (3.2) reduces to:

$$\Box\Psi = \left(\frac{1+\mathrm{g}_{\mathrm{s}}^2}{\mathrm{g}_{\mathrm{s}}^2\kappa}\right) J_\alpha \partial^\alpha \mu_0. \tag{3.3}$$

From (3.3), it is clear that we can not have ($\partial^\alpha \mu_0 = 0$), since:

$$\Box\Psi = \left(\frac{1+\mathrm{g}_{\mathrm{s}}^2}{\mathrm{g}_{\mathrm{s}}^2\kappa}\right) J_\alpha \partial^\alpha \mu_0 = \mathrm{g}_{\mathrm{s}}^2\kappa^2\Psi \neq 0, \tag{3.4}$$

and from this, one obtains:

$$J_\alpha \partial^\alpha \mu_0 = \left(\frac{\mathrm{g}_{\mathrm{s}}^4\kappa^3}{1+\mathrm{g}_{\mathrm{s}}^2}\right)\Psi \neq 0. \tag{3.5}$$

Clearly, we must have:

$$\mu_0 = \mu_0(\boldsymbol{r}, t). \tag{3.6}$$

That is, the permeability of free space must vary spatially and temporally not on local but cosmological scales. Furthermore, since the speed of Light in *vacuo*, $c$, is related to the $\mu_0$ and $\varepsilon_0$ by the equation:

$$c^2 = \frac{1}{\mu_0\varepsilon_0}, \tag{3.7}$$

and with this as given and assuming this speed, $c$, to be a universal and fundamental natural constant throughout the Universe at all times, it follows that:

$$\frac{\Delta\mu_0}{\mu_0} = -\frac{\Delta\varepsilon_0}{\varepsilon_0} = \frac{\Delta\alpha_0}{\alpha_0}. \tag{3.8}$$

# 4 Discussion

We have shown that the MP-model of Nyambuya (2016) requires that evidence for a massive Photon be engrained deep in the secular interstices of the cosmos in the forms of a spatial and temporal variation of two fundamental natural constants $\mu_0$ and $\varepsilon_0$, hence the FSC ($\alpha_0 = e^2/4\pi\varepsilon_0\hbar c$). The variation of the FSC has been observed and this point to the variation of one or more of the four $(e, \varepsilon_0, \hbar, c)$ variables that make up this parameter.

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# References

Burman, R. (1972), 'A Photon Rest Mass and Energy Transport in Cold Plasmas', *Journal of Physics A: General Physics* **5**(11), L128.

Burman, R. (1973), 'A Photon Rest Mass and the Propagation of Longitudinal Electric Waves in Interstellar and Intergalactic Space', *Journal of Physics A: Mathematical, Nuclear and General* **6**(3), 434.

Chernikov, M. A., Gerber, C. J., Ott, H. R. & Gerber, H.-J. (1992), 'Low Temperature Upper Limit of the Photon Mass: Experimental null test of Ampère's Law', *Phys. Rev. Lett.* **68**, 3383–3386.

Goldhaber, A. S. & Nieto, M. M. (1971), 'Terrestrial and Extraterrestrial Limits on The Photon Mass', *Rev. Mod. Phys.* **43**, 277–296.

Goldhaber, A. S. & Nieto, M. M. (2010), 'Photon and Graviton Mass Limits', *Rev. Mod. Phys.* **82**, 939–979.

Hojman, S. A. & Koch, B. (2013), Closing the Window for Massive Photons. (*arXiv:1209.4907v2*).

King, J. A., Webb, J. K., Murphy, M. T., Flambaum, V. V., Caswell, R. F., Bainbridge, M. B., Wilczynska, M. R. & Koch, F. E. (2012), 'Spatial Variation in the Fine Structure Constant – New Results from VLT/UVES', *MNRAS* **422**, 3370–3414.

Klein, O. (1926), 'Quanten-theorie und 5-dimensionale relativitätsheorie', *Z. Phys.* **37**, 895–906.

Lakes, R. (1998), 'Experimental Limits on the Photon Mass and Cosmic Magnetic Vector Potential', *Phys. Rev. Lett.* **80**, 1826–1829.

Lorenz, L. (1867), 'On the Identity of the Vibrations of Light with Electrical Currents', *Philos. Mag.* **34**, 287–301.

Luo, J., Tu, L.-C., Hu, Z.-K. & Luan, E.-J. (2003), 'New Experimental Limit on the Photon Rest Mass with a Rotating Torsion Balance', *Phys. Rev. Lett.* **90**, 081801.

Maxwell, J. C. (1873), *A Treatise on Electricity and Magnetism*, 1 edn, Oxford : Clarendon Press, London. (1892) 3rd edition Reprinted (1952) from Dover Publications (ISBN 0-486-60636-8).

Murphy, M. T., Webb, J. K. & Flambaum, V. V. (2003), 'Further Evidence for a Variable Fine-Structure Constant from Keck/HIRES QSO Absorption Spectra', *MNRAS* **345**(2), 609–638.

Murphy, M. T., Webb, J. K. & Flambaum, V. V. (2009), 'Keck Constraints on a Varying Fine-Structure Constant: Wavelength Calibration Errors', *MEMORIE della Società Astronomica Italiana* **80**, 833–841.

Murphy, M. T., Webb, J. K., Flambaum, V. V., Dzuba, V. A., Churchill, C. W., Prochaska, J. X., Barrow, J. D. & Wolfe, A. M. (2001), 'Possible Evidence for a Variable Fine-Structure Constant from QSO Absorption Lines: Motivations, Analysis and Results', *MNRAS* **327**(4), 1208–1222.

Nyambuya, G. G. (2014), 'Gauge Invariant Massive Long Range and Long Lived Photons', *Journal of Modern Physics* **5**(17), 1902–1909.

Nyambuya, G. G. (2016), 'On the Cosmic Variation of the Fine Structure Constant', *Prespacetime Journal* **7**(12), 1686–1705. Article No. 13, ISBN-10: 1539318826/ISBN-13: 978-1539318828.

Stückelberg, E. C. G. (1938*a*), *Helv. Phys. Acta* **11**, 225.

Stückelberg, E. C. G. (1938*b*), *Helv. Phys. Acta* **11**, 299.

Stückelberg, E. C. G. (1938*c*), *Helv. Phys. Acta* **11**, 312.

Tu, L.-C., Luo, J. & Gillies, T. G. (2005), 'The Mass of the Photon', *Reports on Progress in Physics* **68**(1), 77–130.

Webb, J. K., Flambaum, V. V., Churchill, C. W., Drinkwater, M. J. & Barrow, J. D. (1999), 'Search for time variation of the fine structure constant', *Phys. Rev. Lett.* **82**, 884–887.

Webb, J. K., King, J. A., Murphy, M. T., Flambaum, V. V., Carswell, R. F. & Bainbridge, M. B. (2011), 'Indications of a Spatial Variation of the Fine Structure Constant', *Phys. Rev. Lett.* **107**, 191101.

Webb, J. K., Murphy, M. T., Flambaum, V. V., Dzuba, V. A., Barrow, J. D., Churchill, C. W., Prochaska, J. X. & Wolfe, A. M. (2001), 'Further evidence for cosmological evolution of the fine structure constant', *Phys. Rev. Lett.* **87**, 091301.

Williams, E. R., Faller, J. E. & Hill, H. A. (1971), 'New Experimental Test of Coulomb's Law: A Laboratory Upper Limit on the Photon Rest Mass', *Phys. Rev. Lett.* **26**, 721–724.