Finite photon mass and galactic rotation curves

D.D. Ryutov

LLNL (VSP)

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A. Proca (R) with R. Peierls and S.Tomonaga, 1930s. Courtesy AIP.

L. de Broglie, 1940s. Courtesy AIP.

E. Schroedinger as an artillery officer, WW1. Courtesy http://www.if.ufrj.br/famous/physlist.html

THE BASICS

$$E = \sqrt{m_{ph}^2 c^4 + p^2 c^2}$$

$$E = \hbar\omega, \quad p = \hbar k$$

The photon Compton length

$$\omega = \sqrt{\frac{c^2}{\lambda\!\!\!^{-2}} + k^2 c^2}; \quad \lambda\!\!\!^{-} \equiv \frac{\hbar}{m_{ph} c}$$

Citation: C. Patrignani *et al.* (Particle Data Group), Chin. Phys. C, **40**, 100001 (2016) and 2017 update

γ (photon)

$I(J^{PC}) = 0,1(1^{--})$

γ MASS

Results prior to 2008 are critiqued in GOLDHABER 10. All experimental results published prior to 2005 are summarized in detail by TU 05.

The following conversions are useful: 1 eV = 1.783×10^{-33} g = 1.957×10^{-6} m_e; $\lambda\!\!\!^{-}_C = (1.973 \times 10^{-7}$ m)$\times$(1 eV/m_γ).

VALUE (eV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
<1 $\times 10^{-18}$		[1] RYUTOV	07		MHD of solar wind
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<1.8 \times 10^{-14}$		[2] BONETTI	16		Fast Radio Bursts, FRB 150418
$<1.9 \times 10^{-15}$		[3] RETINO	16		Ampere's Law in solar wind
$<2.3 \times 10^{-9}$	95	[4] EGOROV	14	COSM	Lensed quasar position
		[5] ACCIOLY	10		Anomalous magn. mom.
$<1 \times 10^{-26}$		[6] ADELBERGER	07A		Proca galactic field
no limit feasible		[6] ADELBERGER	07A		γ as Higgs particle

There exists a regular way of describing electromagnetic field for the finite photon mass: the Maxwell-Proca equations (A. Proca, 1930's; L. de Broglie, 1940's-50's)

L.D. Landau, E.M. Lifshitz. "Quantum Theory of Fields," Oxford, Pergamon, 1987

J.D. Jackson. "Classical Electrodynamics," Chichester, Wiley, 1975.

MHD equations become*:

$$\frac{\partial \rho}{\partial t} + \nabla(\rho \mathbf{v}) = 0 \qquad \rho \frac{d\mathbf{v}}{dt} = -\nabla p + \frac{1}{c} \boldsymbol{j} \times \boldsymbol{B}$$

$$\nabla \times \boldsymbol{B} + \frac{\boldsymbol{A}}{\lambda\!\!\!^{-2}} = \frac{4\pi}{c} \boldsymbol{j} \qquad \nabla \times \boldsymbol{A} = \boldsymbol{B}$$

$$\nabla \times \boldsymbol{E} = -\frac{1}{c} \frac{\partial \boldsymbol{B}}{\partial t} \qquad \boldsymbol{j} = \sigma \left(\boldsymbol{E} + \frac{\mathbf{v} \times \boldsymbol{B}}{c} \right)$$

The finite photon mass matters for the scales significantly exceeding the photon Compton length

*) D.D. Ryutov. "The role of finite photon mass in magnetohydrodynamics of space plasmas". PPCF, **39A**, 73, 1997.

- The structure of electromagnetic stresses changes significantly compared to the zero-mass photon: for the scales exceeding the photon Compton length the magnetic pressure changes its sign (pulls the matter into the higher field area)

- This fact has been used to assess the possible effect of electromagnetic stresses on the dynamics of the galactic gas in:

  D.D. Ryutov, D. Budker, V.V. Flambaum. "A hypothetical effect of the Maxwell-Proca electromagnetic stresses on galaxy rotation curves," arXiv: 1708.09514, August 2017

- Random magnetic fields with $B \sim 1$ μG and a scale-length ~ 1 pc (our galaxy) exert a force pulling the interstellar gas towards galactic center; this force affects the "rotation curve" and brings it closer to the observed one.

- This is NOT a dark matter effect; it is purely electrodynamical (the photon mass density is negligible compared to the mass density of the baryonic matter).

- Predicts also a number of subtler effects like the differences in rotation curves for heavy and light stars, vertical field structure, the “halo” stars…