γ $I(J^{PC}) = 0,1(1^{--})$

γ MASS

Results prior to 2008 are critiqued in GOLDHABER 10.

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. • • •					
		[2] ACCIOLY	10		Anomalous mag. mom.
$< 1 \times 10^{-26}$		[3] ADELBERGER	07A		Galactic field existence if Higgs mass
$< 1.4 \times 10^{-7}$		ACCIOLY	04		Dispersion of GHz radio waves by sun
$< 2 \times 10^{-16}$		FULLEKRUG	04		Speed of 5-50 Hz radiation in atmosphere
$< 7 \times 10^{-19}$		[4] LUO	03		Modulation torsion balance
$< 1 \times 10^{-17}$		[5] LAKES	98		Torque on toroid balance
$< 6 \times 10^{-17}$		[6] RYUTOV	97		MHD of solar wind
$< 9 \times 10^{-16}$	90	[7] FISCHBACH	94		Earth magnetic field
$<(4.73\pm0.45) \times 10^{-12}$		[8] CHERNIKOV	92	SQID	Ampere-law null test
$<(9.0 \pm8.1) \times 10^{-10}$		[9] RYAN	85		Coulomb-law null test
$< 3 \times 10^{-27}$		[10] CHIBISOV	76		Galactic magnetic field
$< 6 \times 10^{-16}$	99.7	DAVIS	75		Jupiter magnetic field
$< 7.3 \times 10^{-16}$		HOLLWEG	74		Alfven waves
$< 6 \times 10^{-17}$		[11] FRANKEN	71		Low freq. res. cir.
$< 1 \times 10^{-14}$		WILLIAMS	71	CNTR	Tests Gauss law
$< 2.3 \times 10^{-15}$		GOLDHABER	68		Satellite data
$< 6 \times 10^{-15}$		[11] PATEL	65		Satellite data
$< 6 \times 10^{-15}$		GINTSBURG	64		Satellite data

[1] RYUTOV 07 extends the method of RYUTOV 97 to the radius of Pluto's orbit.

[2] ACCIOLY 10 limits come from possible alterations of anomalous magnetic moment of electron and gravitational deflection of electromagnetic radiation. Reported limits are not "claimed" by the authors and in any case are not competitive.

[3] When trying to measure m one must distinguish between measurements performed on large and small scales. If the photon acquires mass by the Higgs mechanism, the large-scale behavior of the photon might be effectively Maxwellian. If, on the other hand, one postulates the Proca regime for all scales, the very existence of the galactic field implies $m < 10^{-26}$ eV, as correctly calculated by YAMAGUCHI 59 and CHIBISOV 76.

[4] LUO 03 determine a limit on $\mu^2 A < 1.1 \times 10^{-11}$ T m/m^2 (with μ^{-1}=characteristic length for photon mass; A=ambient vector potential) — similar to the LAKES 98 technique. Unlike LAKES 98 who used static, the authors used dynamic torsion balance. Assuming A to be 10^{12} T m, they obtain $\mu < 1.2\times10^{-51}$ g, equivalent to 6.7×10^{-19} eV. The rotating modified Cavendish balance removes dependence on the direction of A. GOLDHABER 03 argue that because plasma current effects are neglected, the LUO 03 limit does not provide the best available limit on $\mu^2 A$ nor a reliable limit at all on μ. The reason is that the A associated with cluster magnetic fields could become arbitrarily small in plasma voids, whose existence would be compatible with present knowledge. LUO 03B reply that fields of distant clusters are not accurately mapped, but assert that a zero A is unlikely given what we know about the magnetic field in our galaxy.

[5] LAKES 98 reports limits on torque on a toroid Cavendish balance, obtaining a limit on $\mu^2 A < 2 \times 10^{-9}$ Tm/m^2 via the Maxwell-Proca equations, where μ^{-1} is the characteristic length associated with the photon mass and A is the ambient vector potential in the Lorentz gauge. Assuming $A \approx 1 \times 10^{12}$ Tm due to cluster fields he obtains $\mu^{-1} > 2 \times 10^{10}$ m, corresponding to $\mu < 1 \times 10^{-17}$ eV. A more conservative limit, using $A \approx (1\ \mu\text{G})\times(600\ \text{pc})$ based on the galactic field, is $\mu^{-1} > 1 \times 10^9$ m or $\mu < 2 \times 10^{-16}$ eV.

[6] RYUTOV 97 uses a magnetohydrodynamics argument concerning survival of the Sun's field to the radius of the Earth's orbit. "To reconcile observations to theory, one has to reduce [the photon mass] by approximately an order of magnitude compared with" DAVIS 75.

[7] FISCHBACH 94 report $< 8 \times 10^{-16}$ with unknown CL. We report Bayesian CL used elsewhere in these Listings and described in the Statistics section.

[8] CHERNIKOV 92 measures the photon mass at 1.24 K, following a theoretical suggestion that electromagnetic gauge invariance might break down at some low critical temperature. See the erratum for a correction, included here, to the published result.

[9] RYAN 85 measures the photon mass at 1.36 K (see the footnote to CHERNIKOV 92).

[10] CHIBISOV 76 depends in critical way on assumptions such as applicability of virial theorem. Some of the arguments given only in unpublished references.

[11] See criticism questioning the validity of these results in GOLDHABER 71, PARK 71 and KROLL 71. See also review GOLDHABER 71B.

γ CHARGE

OKUN 06 has argued that schemes in which all photons are charged are inconsistent. He says that if a neutral photon is also admitted to avoid this problem, then other problems emerge, such as those connected with the emission and absorption of charged photons by charged particles. He concludes that in the absence of a self-consistent phenomenological basis, interpretation of experimental data is at best difficult.

VALUE (e)	*CHARGE*	*DOCUMENT ID*		*TECN*	*COMMENT*
$<1 \times 10^{-46}$	**mixed**	[12] ALTSCHUL	07B	VLBI	Aharonov-Bohm effect
$<1 \times 10^{-35}$	**single**	[13] CAPRINI	05	CMB	Isotropy constraint
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<1 \times 10^{-32}$	single	[12] ALTSCHUL	07B	VLBI	Aharonov-Bohm effect
$<3 \times 10^{-33}$	mixed	[14] KOBYCHEV	05	VLBI	Smear as function of B$\cdot$E$_\gamma$
$<4 \times 10^{-31}$	single	[14] KOBYCHEV	05	VLBI	Deflection as function of B$\cdot$E$_\gamma$
$<8.5 \times 10^{-17}$		[15] SEMERTZIDIS	03		Laser light deflection in B-field
$<3 \times 10^{-28}$	single	[16] SIVARAM	95	CMB	For $\Omega_M = 0.3$, $h^2 = 0.5$
$<5 \times 10^{-30}$		[17] RAFFELT	94	TOF	Pulsar $f_1 - f_2$
$<2 \times 10^{-28}$		[18] COCCONI	92		VLBA radio telescope resolution
$<2 \times 10^{-32}$		COCCONI	88	TOF	Pulsar $f_1 - f_2$ TOF

[12] ALTSCHUL 07B looks for Aharonov-Bohm phase shift in addition to geometric phase shift in radio interference fringes (VSOP mission).

[13] CAPRINI 05 uses isotropy of the cosmic microwave background to place stringent limits on possible charge asymmetry of the Universe. Charge limits are set on the photon, neutrino, and dark matter particles. Valid if charge asymmetries produced by different particles are not anticorrelated.

[14] KOBYCHEV 05 considers a variety of observable effects of photon charge for extragalactic compact radio sources. Best limits if source observed through a foreground cluster of galaxies.

[15] SEMERTZIDIS 03 reports the first laboratory limit on the photon charge in the last 30 years. Straightforward improvements in the apparatus could attain a sensitivity of 10^{-20} e.

[16] SIVARAM 95 requires that CMB photon charge density not overwhelm gravity. Result scales as Ω_M h^2.

[17] RAFFELT 94 notes that COCCONI 88 neglects the fact that the time delay due to dispersion by free electrons in the interstellar medium has the same photon energy dependence as that due to bending of a charged photon in the magnetic field. His limit is based on the assumption that the entire observed dispersion is due to photon charge. It is a factor of 200 less stringent than the COCCONI 88 limit.

[18] See COCCONI 92 for less stringent limits in other frequency ranges. Also see RAFFELT 94 note.

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