Searches for Goldstone Bosons (X^0)

(Including Horizontal Bosons and Majorons.) Limits are for branching ratios.

VALUE	CL%	EVTS	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
			[109] BOBRAKOV 91		Electron quasi-magnetic interaction
$<3.3\times10^{-2}$	95		[110] ALBRECHT 90E	ARG	$\tau\to\mu X^0$. Familon
$<1.8\times10^{-2}$	95		[110] ALBRECHT 90E	ARG	$\tau\to eX^0$. Familon
$<6.4\times10^{-9}$	90		[111] ATIYA 90	CNTR	$K^+\to\pi^+X^0$. Familon
$<1.1\times10^{-9}$	90		[112] BOLTON 88	CBOX	$\mu^+\to e^+\gamma X^0$. Familon
			[113] CHANDA 88	ASTR	Sun, Majoron
			[114] CHOI 88	ASTR	Majoron, SN 1987A
$<5\ \ \times10^{-6}$	90		[115] PICCIOTTO 88	CNTR	$\pi\to e\nu X^0$, Majoron
$<1.3\times10^{-9}$	90		[116] GOLDMAN 87	CNTR	$\mu\to e\gamma X^0$. Familon
$<3\ \ \times10^{-4}$	90		[117] BRYMAN 86B	RVUE	$\mu\to eX^0$. Familon
$<1.\ \ \times10^{-10}$	90	0	[118] EICHLER 86	SPEC	$\mu^+\to e^+X^0$. Familon
$<2.6\times10^{-6}$	90		[119] JODIDIO 86	SPEC	$\mu^+\to e^+X^0$. Familon
			[120] BALTRUSAIT...85	MRK3	$\tau\to\ell X^0$. Familon
			[121] DICUS 83	COSM	ν(hvy) $\to\nu$(light)X^0

[109] BOBRAKOV 91 searched for anomalous magnetic interactions between polarized electrons expected from the exchange of a massless pseudoscalar boson (arion). A limit $x_e^2 < 2\times10^{-4}$ (95%CL) is found for the effective anomalous magneton parametrized as $x_e(G_F/8\pi\sqrt{2})^{1/2}$.

[110] ALBRECHT 90E limits are for B($\tau\to\ell X^0$)/B($\tau\to\ell\nu\overline{\nu}$). Valid for $m_{X^0}<100$ MeV. The limits rise to 7.1% (for μ), 5.0% (for e) for $m_{X^0}=500$ MeV.

[111] ATIYA 90 limit is for $m_{X^0}=0$. The limit B $<1\times10^{-8}$ holds for $m_{X^0}<95$ MeV. For the reduction of the limit due to finite lifetime of X^0, see their Fig. 3.

[112] BOLTON 88 limit corresponds to $F>3.1\times10^9$ GeV, which does not depend on the chirality property of the coupling.

[113] CHANDA 88 find $v_T<10$ MeV for the weak-triplet Higgs vev. in Gelmini-Roncadelli model, and $v_S>5.8\times10^6$ GeV in the singlet Majoron model.

[114] CHOI 88 used the observed neutrino flux from the supernova SN 1987A to exclude the neutrino Majoron Yukawa coupling h in the range $2\times10^{-5}<h<3\times10^{-4}$ for the interaction $L_{\rm int}=\frac{1}{2}ih\overline{\psi}^c_\nu\gamma_5\psi_\nu\phi_X$. For several families of neutrinos, the limit applies for $(\Sigma h_i^4)^{1/4}$.

[115] PICCIOTTO 88 limit applies when $m_{X^0}<55$ MeV and $\tau_{X^0}>2$ns, and it decreases to 4×10^{-7} at $m_{X^0}=125$ MeV, beyond which no limit is obtained.

[116] GOLDMAN 87 limit corresponds to $F>2.9\times10^9$ GeV for the family symmetry breaking scale from the Lagrangian $L_{\rm int}=(1/F)\overline{\psi}_\mu\gamma^\mu(a+b\gamma_5)\psi_e\partial_\mu\phi_{X^0}$ with $a^2+b^2=1$. This is not as sensitive as the limit $F>9.9\times10^9$ GeV derived from the search for $\mu^+\to e^+X^0$ by JODIDIO 86, but does not depend on the chirality property of the coupling.

[117] Limits are for $\Gamma(\mu\to eX^0)/\Gamma(\mu\to e\nu\overline{\nu})$. Valid when $m_{X^0}=$ 0–93.4, 98.1–103.5 MeV.

[118] EICHLER 86 looked for $\mu^+\to e^+X^0$ followed by $X^0\to e^+e^-$. Limits on the branching fraction depend on the mass and and lifetime of X^0. The quoted limits are valid when $\tau_{X^0}\lesssim3.\times10^{-10}$ s if the decays are kinematically allowed.

[119] JODIDIO 86 corresponds to $F>9.9\times10^9$ GeV for the family symmetry breaking scale with the parity-conserving effective Lagrangian $L_{\rm int}=(1/F)\overline{\psi}_\mu\gamma^\mu\psi_e\partial^\mu\phi_{X^0}$.

[120] BALTRUSAITIS 85 search for light Goldstone boson(X^0) of broken U(1). CL = 95% limits are B($\tau\to\mu^+X^0$)/B($\tau\to\mu^+\nu\nu$) <0.125 and B($\tau\to e^+X^0$)/B($\tau\to e^+\nu\nu$) <0.04. Inferred limit for the symmetry breaking scale is m >3000 TeV.

[121] The primordial heavy neutrino must decay into ν and familon, f_A, early so that the red-shifted decay products are below critical density, see their table. In addition, $K\to\pi f_A$ and $\mu\to ef_A$ are unseen. Combining these excludes $m_{{\rm heavy}\nu}$ between 5×10^{-5} and 5×10^{-4} MeV (μ decay) and $m_{{\rm heavy}\nu}$ between 5×10^{-5} and 0.1 MeV (K-decay).

Majoron Searches in Neutrinoless Double β Decay

Limits are for the half-life of neutrinoless $\beta\beta$ decay with a Majoron emission. Previous indications for neutrinoless double beta decay with majoron emission have been superseded. No experiment currently claims any such evidence. For a review, see DOI 88.

VALUE (years)	CL%	DOCUMENT ID	TECN	COMMENT
> 7.2 × 10^{24}	90	[122] BERNATOW... 92	CNTR	^{128}Te
• • • We do not use the following data for averages, fits, limits, etc. • • •				
> 1.7 × 10^{22}	90	BECK 93	CNTR	^{76}Ge
< 7.9 × 10^{20}	68	[123] TANAKA 93	SPEC	^{100}Mo
> 1.9 × 10^{20}	68	BARABASH 89	CNTR	^{136}Xe
> 1.0 × 10^{21}	90	FISHER 89	CNTR	^{76}Ge
> 3.3 × 10^{20}	90	ALSTON-... 88	CNTR	^{100}Mo
(6 ±1) × 10^{20}		AVIGNONE 87	CNTR	^{76}Ge
> 1.4 × 10^{21}	90	CALDWELL 87	CNTR	^{76}Ge
> 4.4 × 10^{20}	90	ELLIOTT 87	SPEC	^{82}Se
> 1.2 × 10^{21}	90	FISHER 87	CNTR	^{76}Ge
		[124] VERGADOS 82	CNTR	

[122] BERNATOWICZ 92 studied double-β decays of ^{128}Te and ^{130}Te, and found the ratio $\tau(^{130}{\rm Te})/\tau(^{128}{\rm Te})=(3.52\pm0.11)\times10^{-4}$ in agreement with relatively stable theoretical predictions. The bound is based on the requirement that Majoron-emitting decay cannot be larger than the observed double-beta rate of ^{128}Te of $(7.7\pm0.4)\times10^{24}$ year. We calculated 90% CL limit as $(7.7–1.28\times0.4{=}7.2)\times10^{24}$.

[123] TANAKA 93 also quote limit 5.3×10^{19} years on two Majoron emission.

[124] VERGADOS 82 sets limit $g_H<4\times10^{-3}$ for (dimensionless) lepton-number violating coupling, g_H, of scalar boson (Majoron) to neutrinos, from analysis of data on double β decay of ^{48}Ca.

INVISIBLE A^0 (AXION) MASS LIMITS FROM ASTROPHYSICS AND COSMOLOGY

Limits on $m(A^0)$ are obtained from the axion coupling to electrons, nucleons, or photons. Quoted limits are often expressed in terms of the axion decay constant f_A which can be defined in terms of the mass or axion-electron coupling by $m(A^0)=3.5\times10^{10}g_{Ae}\cos^{-2}\beta\,{\rm eV}=7.2\times10^7({\rm GeV}/f_A)(N/6)\,{\rm eV}$ [using the conventions detailed in Srednicki [1]; for other conventions take $f_A\to2f_A$ (Bardeen [2]) or $f_A\to4f_A$ (Kaplan [3])] where N is the number of quarks with Peccei-Quinn charge (usually the number of quark flavors) and $\cos^2\beta=v_1^2/(v_1^2+v_2^2)$ is determined by the vacuum expectation values of the two Higgs doublets coupling to up and down quarks (and charged leptons). For the coupling to photons $m(A^0)=6.9\times10^9\,(g_{A\gamma}/{\rm GeV}^{-1})\,{\rm eV}$ and for the coupling to nucleons $m(A^0)=7.7\times10^7g_{AN}/c_{AN}\,{\rm eV}$ where c_{AN} depends on the details of the coupling of axions to nucleons. These couplings are defined by

$$\mathcal{L}_{\rm int}=-\frac{1}{4}g_{A_\gamma}\,\phi_A\,F_{\mu\nu}\,\widetilde{F}^{\mu\nu}=g_{A_\gamma}\,\phi_A\,\mathbf{E}\cdot\mathbf{B}\ ,$$

$$\mathcal{L}_{\rm int}=ig_{Ae}\,\phi_A\,\overline{\psi}_e\,\gamma_5\psi_e\ ,\qquad\text{and}$$

$$\mathcal{L}_{\rm int}=ig_{AN}\,\phi_A\,\overline{\psi}_N\,\gamma_5\,\psi_N\ .$$

The factors in these equations are model dependent, in particular $g_{Ae}=0$ in the KSVZ [4] models. In the comment for each limit below, D indicates that the limit is specific to DFSZ [5] axions, K to KSVZ axions (The limits quoted assume $N=6$ and $v_1=v_2$.)

References

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Invisible A^0 (Axion) MASS LIMITS from Astrophysics and Cosmology

$v_1=v_2$ is usually assumed (v_i = vacuum expectation values). For a review of these limits, see RAFFELT 90C and TURNER 90.

VALUE (eV)	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •			
< 0.01	WANG 92	ASTR	D, white dwarf
< 0.03	WANG 92C	ASTR	D, C-O burning
none 3–8	[125] BERSHADY 91	ASTR	D, K, intergalactic light
<10	[126] KIM 91C	COSM	D, K, mass density of the universe, supersymmetry
	[127] RAFFELT 91B	ASTR	D,K, SN 1987A
< 1 × 10^{-3}	[128] RESSELL 91	ASTR	K, intergalactic light
none 10^{-3}–3	BURROWS 90	ASTR	D,K, SN 1987A
	[129] ENGEL 90	ASTR	D,K, SN 1987A
< 0.02	[130] RAFFELT 90D	ASTR	D, red giant
< 1 × 10^{-3}	[131] BURROWS 89	ASTR	D,K, SN 1987A