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by

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Abstract

I review the theoretical motivations for Majorons and present current experimental constraints on these excitations.

Lepton number is a global symmetry of the minimal standard model. However, it ceases to be a symmetry when one contemplates possible standard model extensions. For instance, introducing an $SU(2) \times U(1)$ singlet ν_R field, one can write a lepton number violating Majorana mass term

$$\mathcal{L}^0 = -\frac{1}{2} M_R \nu_R^T C \nu_R + h.c. \tag{1}$$

Similarly, if one allows effective nonrenormalizable interactions, corresponding to new physics at a high scale Λ, one can write lepton number violating interactions involving ν_L and the Higgs doublet field ϕ:

$$\mathcal{L}^1 = \frac{\phi \vec{\tau} \phi}{\Lambda} \cdot (\nu_e \quad e)_L^T C \vec{\tau} \begin{pmatrix} \nu_e \\ e \end{pmatrix}_L + h.c. \tag{2}$$

The above are explicit L -violating terms. One can imagine, alternatively, that lepton number is an exact symmetry which is, however, spontaneously broken. Although the physical motivation for keeping L an exact Lagrangian symmetry is not clear, the physical consequences of lepton number being a spontaneously broken symmetry are interesting, since then the theory involves a massless Goldstone boson: the Majoron. One can maintain L as a

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symmetry by introducing either singlet or triplet Higgs fields in the theory, with their vacuum expectation values causing the spontaneous breakdown. I discuss these two alternatives below.

CMP Majoron ($I_W = 0$ L-breaking)

A Majorana mass term like (1) can arise from the vacuum expectation value of an $SU(2) \times U(1)$ singlet field σ. If σ carries lepton number -2, then the interaction

$$\mathcal{L}_{CMP} = -\frac{h}{\sqrt{2}} \nu_R^T C \nu_R \sigma + h.c. \tag{3}$$

conserves L, but $\langle \sigma \rangle = \frac{v_s}{\sqrt{2}}$ violates L spontaneously. The right handed neutrino acquires a Majorana mass $M_R = h v_s$ and $Im\sigma$ is a massless Goldstone boson: The CMP Majoron [1]. This excitation, however, is essentially unobservable if $v_s \geq TeV$. Because Goldstone bosons have only derivative couplings, Majoron exchange will only give rise to a spin-spin r^{-3} potential [1]. Furthermore, the effective couplings of the CMP Majorons to matter are tiny, of order $\frac{m_f m_\nu}{v^2}$ - where v is the Fermi scale ($v \simeq 250 GeV$) [1]. The only amusing theoretical consequence of CMP Majorons is that, in models where there is an additional chiral $U(1)_{PQ}$ symmetry, then the Majoron field σ acts essentially as an invisible axion [2].

GR Majorons ($I_W = 1$ L-breaking)

A, perhaps more interesting, spontaneously broken L model has been proposed by Gelmini and Roncadelli [3]. They make the interaction of Eq(2) L invariant and renormalizable by introducing, instead of $\phi\vec{\tau}\phi$, an $SU(2)$ triplet Higgs field $\vec{\Delta}$ which carries L=-2.

$$\mathcal{L}_{GR} = -\frac{g}{\sqrt{2}} (\nu_e \quad e)_L^T C \vec{\tau} \cdot \vec{\Delta} \begin{pmatrix} \nu_e \\ e \end{pmatrix}_L + h.c. \tag{4}$$

Again $\langle \vec{\Delta} \rangle \neq 0$ breaks L. If one writes for the neutral field in $\vec{\Delta}$: $\chi^0 = 1/\sqrt{2}(v_T + \rho + i\chi)$, then the Majorana mass of the neutrinos is $m_\nu = g v_T$ and the field χ is the GR Majoron. Note that in general g could be a matrix in flavor space. However, here I shall consider only the constraints arising from the first generation.

Since L is violated in the GR model, besides the normal two neutrino double beta process [$2\beta(2\nu)$], neutrinoless double beta decay is allowed

$[2\beta(0\nu)]$. In fact, in this model a further double beta process is possible, in which a Majoron is emitted $[2\beta(Majoron)]$. Both the $2\beta(2\nu)$ and $2\beta(Majoron)$ processes give rise to a continuous spectrum for the $e^- e^-$ sum energy, while the $2\beta(0\nu)$ process has a δ-function peak. However, the sum energy spectra for the Majoron process peaks nearer to the end point than that for the $2\beta(2\nu)$ process. The non observation, for the moment, of any $2\beta(0\nu)$ events bounds the electron neutrino Majorana mass and hence the product gv_T. On the other hand, the $2\beta(Majoron)$ process has a rate proportional to g^2 and so one can also experimentally constrain this parameter. [In fact, as Georgi, Glashow and Nussinov have shown [4], the $2\beta(0\nu)$ and $2\beta(Majoron)$ rates are closely related]. Finally, one can get bounds on the triplet expectation value v_T from astrophysics, since Majoron emission cools stars. The cooling rate is proportional to v_T^2, because the coupling of the GR Majorons to fermions occurs only through $\phi - \Delta$ mixing, which is proportional to $\frac{v_T}{v}$.

Current $2\beta(0\nu)$ searches in ^{76}Ge bound $m_\nu = gv_T \leq eV$ [5]. This bound has some nuclear physics uncertainty, of order perhaps of a factor of 2-5 [6]. At present, there is some experimental controversy on whether a signal for the $2\beta(Majoron)$ process has been [7] or has not been seen [8] in ^{76}Ge. However, background subtraction is crucial in both experiments. [For a more detailed discussion, see [6]]. The positive result of Avignone et al [7] corresponds to $g = 8 \times 10^{-4}$, while the bound of the UCSB/LBL experiment [8] imply $g \leq 5 \times 10^{-4}$. A recent compilation of astrophysical bounds for Majorons is contained in [9]. The more conservative bounds, obtained from the sun, give $v_T \leq 5MeV$. I displa in Fig.1 the totality of constraints on GR Majorons. As can be seen, the allowed values for v_T are small and one may wonder why $\frac{v_T}{v} << 1$. Note that if the experiment of Avignone et al. [7] is correct, then $m_\nu \simeq v_T(KeV)eV$. Further double beta experiments in the near future will undoubtedly clarify the GR Majoron controversy. Indeed, as discussed in more detail by Fisher [6], the claim of Avignone et al. [7] appears already to be in difficulty. At any rate, this matter can be settled once and for all with the new Z^0 factories. The decay $Z^0 \to \rho\chi$ - with ρ being the scalar partner of the Majoron, with mass of order $m_\rho \sim v_T$ - contributes an additional width for the Z^0 equivalent to two extra neutrino species [4]. Hence, unless the Z^0 width is about 10% larger than that expected in the standard model, the GR model will be definitely ruled out.

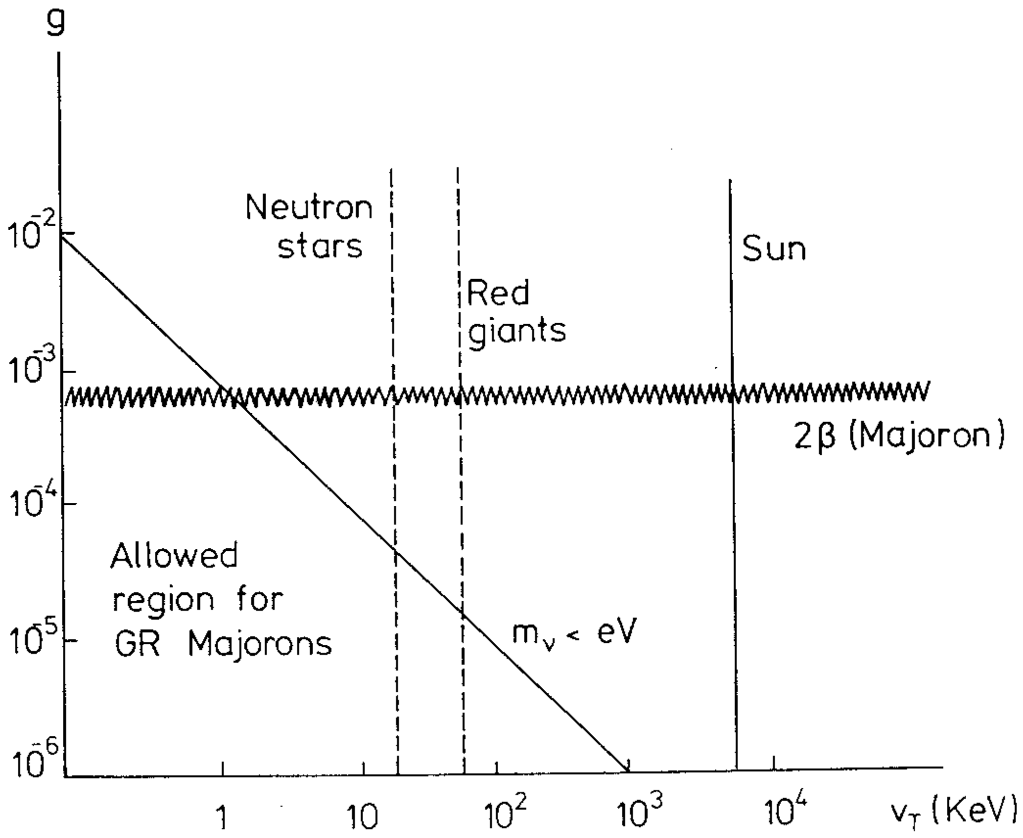

Figure 1: Bounds on GR Majorons

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