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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

*Minirapporteur report at the International Europhysics Conference on High Energy Physics, Uppsala Sweden July 1987 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 display 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.

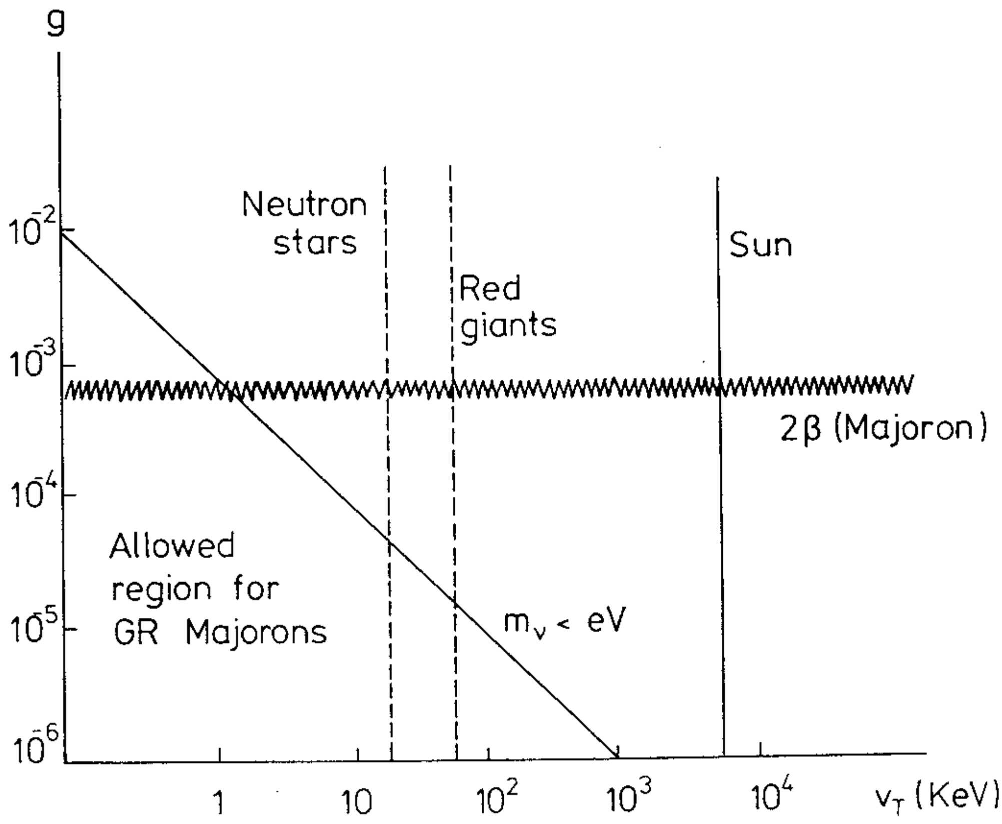

Figure 1: Bounds on GR Majorons

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