Quasi Goldstone fermion as a sterile neutrino

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The existence of sterile neutrinos is hinted by the simultaneous presence of diverse neutrino anomalies. We suggest that the quasi Goldstone fermions (QGF's) arising in supersymmetric theory as a result of spontaneous breaking of global symmetry such as the Peccei-Quinn symmetry or the lepton number symmetry can play the role of the sterile neutrino. The smallness of the mass of QGF's \( m_S \approx 10^{-3} - 10 \) eV can be related to the specific choice of superpotential or Kähler potential (e.g., no-scale kinetic terms for certain superfields). Mixing of QGF’s with neutrinos implies R-parity violation. It can proceed via the coupling of QGF’s with Higgs supermultiplets or directly with a lepton doublet. A model which accounts for the solar and atmospheric anomalies and dark matter is presented. [S0556-2821(96)00217-2]

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I. INTRODUCTION

All the experimentally known fermions transform nontrivially under the gauge group \( SU(3) \times SU(2) \times U(1) \) of the standard model (SM). However there are experimental hints in the neutrino sector which suggest the existence of \( SU(3) \times SU(2) \times U(1) \) singlet fermions mixing appreciably with the known neutrinos. These hints come from (a) the deficits in the solar [1] and atmospheric [2] neutrino fluxes, (b) the possible need for a significant hot component [3] in the dark matter of the Universe, and (c) some indication of \( \bar{\nu}_e - \bar{\nu}_\mu \) oscillations in the laboratory [4]. These hints can be reconciled with each other if there exists a fourth very light \(( \leq 1 \) eV) neutrino mixed with some of the known neutrinos preferably with the electron one. The fourth neutrino is required to be sterile in view of the strong bounds on the number of neutrino flavors coming both from the experiments at the CERN \( e^+e^- \) collider LEP as well as from primordial nucleosynthesis [5].

The existence of a very light sterile neutrino demands theoretical justification since, unlike the active neutrinos, the mass of the sterile state is not protected by the gauge symmetry of the SM and, hence, could be very large. Usually the sterile neutrino is considered on the same footing as the active neutrinos and some \textit{ad hoc} symmetry is introduced to keep this neutrino light. Recently there have been several attempts to construct models for sterile neutrinos which have their origin beyond the usual lepton structure [6–8]. In particular, in Ref. [6] we suggested the possibility that supersymmetry (SUSY) may be responsible for both the existence and the lightness of the sterile fermions.

One could consider three different ways in which supersymmetry can keep sterile states very light: (1) The combination of supersymmetry and the (continuous) \( R \) symmetry present in many supersymmetric models may not allow a mass term for the light sterile state; (2) the spontaneous breakdown of some other global symmetry in supersymmetric theory can lead to massless fermions which form the superpartners of the Goldstone bosons; (3) the spontaneous breakdown of the global supersymmetry itself would give rise to a massless fermion, the Goldstino.

Mechanism (1) and its phenomenological consequences were discussed in Ref. [6]. Mechanism (3) though appealing is not favored phenomenologically in view of the difficulties in building realistic models based on the spontaneously broken global SUSY. We discuss in this paper implications of the mechanism (2) concentrating for definiteness on the simplest case of a global \( U(1)_G \).

The spontaneously broken global symmetries are required for reasons unrelated to the existence of light sterile states. The most interesting examples are the spontaneously broken lepton number symmetry [9] and the Peccei-Quinn (PQ) symmetry imposed [10] to solve the strong \( CP \) problem. PQ symmetry arises naturally in many supersymmetric models. Apart from solving the strong \( CP \) problem, this symmetry can also explain the smallness of the \( \mu \) parameter [11,12]. Phenomenologically consistent breaking of these symmetries generally needs [13] Higgs fields which are singlets of \( SU(3) \times SU(2) \times U(1) \). In the supersymmetric context this automatically generates a massless sterile fermion. While the existence of these quasi Goldstone fermions (QGF’s) is logically independent of neutrino physics, there are good reasons to expect that these fermions will couple to neutrinos. Indeed, in the case of lepton number symmetry the superfield which is mainly responsible for the breakdown of \( U(1)_L \) carries a nontrivial \( U(1)_L \) charge and therefore it can directly couple to leptons if the charge is appropriate. In the case of the PQ symmetry \( U(1)_{PQ} \) this superfield could couple to the Higgs supermultiplet. If theory contains small violation of \( R \) parity then this mixing with Higgs supermultiplet gets

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