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Planck-Scale Effects in a Modified Type-II Seesaw Majoron Model

The Standard Model of particle physics has been highly successful in describing the interactions among the fundamental particles that constitute matter. Despite its achievements, several questions remain unanswered, including the origin of neutrino masses and the nature of dark matter. These open questions motivate ongoing research into models beyond the Standard Model.

Some extensions to the Standard Model include seesaw and Majoron models, both of which offer possible explanations for neutrino masses. The former generates small neutrino masses through heavy mediators, while Majoron models connect their origin to the spontaneous breaking of lepton number.

We study a Majoron model within a type-II seesaw framework modified by Planck-scale effects, extending the Standard Model scalar sector with a $SU(2)$ singlet and triplet. Motivated by the lepton number violation associated with Majorana neutrino masses, the model features spontaneous breaking of global lepton number through nonzero scalar vacuum expectation values. This gives rise to the Majoron, J, which is a massless Nambu–Goldstone boson in the theory. We explore whether the Majoron can serve as a viable dark matter candidate by considering whether explicit breaking induced by nonperturbative gravitational effects can generate a mass for J. To do this, we introduce Planck-suppressed dimension-five operators into the scalar potential; these operators explicitly break lepton number and generate small mass contributions, turning the Majoron into a pseudo-Nambu-Goldstone boson. Our analysis of the parameter space, subject to the relevant constraints, yields Majoron masses in the keV–MeV range.

We scan the parameter space of the extended model to identify regions where the Majoron is sufficiently long-lived to serve as a viable dark matter candidate. Its small tree-level coupling to neutrinos suppresses the corresponding decay rate. We also account for one-loop decays into photons and decays into electron-positron pairs where these decay channels are allowed, identifying regions where the total lifetime satisfies the condition that the Majoron is sufficiently long-lived to serve as a viable dark matter candidate.

Finally, we study Majoron production in the early Universe through the freeze-in mechanism. After imposing several constraints on the parameter space, we find a relic abundance consistent with the observed dark matter density, supporting the Majoron's viability as a dark matter candidate and indicator of neutrino mass mechanism.

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