Fermion mixing in curved spacetime and dark matter

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It is today accepted that neutrinos have a mass and oscillate among three flavors. They are the only known elementary particles to experience field mixing. These peculiarities place neutrinos beyond the standard model of particles. Many of the issues related to neutrino physics, including the origin of their mass, their fundamental nature and the overall number of flavors are still open. It is nevertheless clear that neutrinos play a fundamental role in the universe at all the scales. As they are abundantly produced in nuclear reactions, they carry important informations on astrophysical sources and they represent a valuable resource in multi-messenger astronomy. Relic neutrinos, as probed by experiments like PTOLEMY, may be used to test cosmological theories. Several theories envisage a crucial role of neutrinos during the first phases of the universe in producing the original baryon asymmetry. Furthermore neutrinos may be connected to the dark sector of the universe, contributing to dark matter along with hypothetical particles such as axions, and even to dark energy, for which they can also function as a probe of the underlying model. Due to these reasons, a deep understanding of neutrino physics in gravitational backgrounds is required. The topic has been analyzed primarily in quantum mechanical approaches both in vacuum and in matter. Here we wish to go beyond the quantum mechanical treatment and present a quantum field theoretical approach to fermion mixing in curved space. We limit ourselves to two flavors, but the formalism can be easily generalized to more families. The theory merges the features of mixing with the field quantization on curved space, bringing along several interesting aspects, such as a non-trivial structure of the vacuum. We introduce the flavor fields and pursue their canonical quantization. Then, we derive the transition probabilities for a generic spacetime. We apply the formalism to some specific metrics and compute the corresponding oscillation formulae, showing their departure from their quantum mechanical counterparts. Moreover, we compute the expectation value of the energy-momentum tensor of mixed fermions on the flavor vacuum. We consider spatially flat Friedmann-Lemaître-Robertson-Walker metrics, and we show that the energy-momentum tensor of the flavor vacuum is diagonal and conserved. Therefore, it can be interpreted as the effective energy-momentum tensor of a perfect fluid. In particular, assuming a fixed de Sitter background, the equation of state of the fluid is consistent with that of dust and cold dark matter. Our results establish a new
link between quantum effects and classical fluids, and indicate that the flavor vacuum of mixed fermions may represent a new component of dark matter.