Contribution ID: **1054** Type: **Poster**

Fast Neutrino Flavor Conversion at Late Time

Friday, 31 July 2020 13:45 (3 minutes)

The rate of neutrino oscillations is typically dictated by the vacuum oscillation frequency, ω, and the matter potential, λ. Until the early 2000s, it was believed that this paradigm was sufficient to describe neutrino oscillations inside supernovae, as well. At that time, the outstanding problem of the field appeared to be an understanding of the effect of large and rapid changes in the background matter density. But later it became clear that the issue is more subtle. Owing to the large neutrino density, even free-streaming neutrinos experience significant forward-scattering off other neutrinos. Such scattering leads to a self-interaction potential, $\mu \gg \omega$, that is proportional to the neutrino density, and can dominate over the vacuum term resulting in exciting nonlinear phenomena like rapid and complete neutrino flavor conversion of broadly two types : slow" collective andfast" conversion. Slow" collective effects occur with an intrinsic rate $\sim \sqrt{\omega\mu}$ which are already faster than usual neutrino oscillations and can lead to a variety of new phenomena, e.g., synchronization, bipolar oscillations, spectral swaps, three-flavor effects, multi-angle effects,
decoherence, and linear instabilities, including those that break symmetries of direction, space, and time.Fast" flavor conversions are much more rapid occuring with a frequency $\sim \mu$, and might have a drastic effect of interest to neutrino physics as well as supernova astrophysics.

The flavor evolution of a dense neutrino gas is governed by a large number of coupled nonlinear partial differential equations. These are almost always very difficult to solve. Although the linear stability analysis of such nonlinear flavor conversions has been studied which is useful to ascertain if or when such conversions take place. But it cannot directly answer the question about the impact of such flavor conversions on the observable neutrino fluxes or supernova explosion mechanism. This requires understanding the nature of the system in the full nonlinear regime and is quite nontrivial. Moving towards this direction we study the fast flavor evolution of a non-stationary and inhomogeneous system of dense neutrinos at late times when the system becomes fully nonlinear. We find at late times the polarization vectors associated with the flavor dynamics of such systems become steady in time. Using this steady state approximation we show that the spatial variation of the polarization vectors is given by their precession around a gyrating flavor pendulum with a fixed length, spin, and energy. The polarization vectors, when averaged over space, however, exhibit complete (partial) decoherence for zero (nonzero) lepton asymmetry. For partial decoherence, the non-vanishing range of velocity modes are dictated by conservation of lepton numbers. This kinematic decoherence stems from randomization of the orientations of the transverse components of the polarization vectors.

Secondary track (number)

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Yes

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Session Classification: Neutrino Physics - Posters

Track Classification: 02. Neutrino Physics