Fast Neutrino Flavor Conversion At Late Time

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Background

- High neutrino density inside supernovae allows self-interaction of strength, $\mu >> \lambda$ (matter potential), ω (vacuum scale)
- Such conditions favor fast flavor conversion : *1) Rapid and occurs at a rate* μ *2) Can give rise to complete flavor conversion 3) System gets coupled and also nonlinear*
- Linear stability analysis done in previous literatures helps to understand if or when FFC occurs but fails to study the impact of FFC on the observable neutrino fuxes or explosion mechanism

PhysRevD.84.053013 (2011)

Motivation

- Understanding the nonlinear mechanism of fast conversions both numerically and analytically considering a system of *inhomogeneous and non-stationary dense neutrino gas* with *1 (space) +1 (momentum)+1 (time) phase space dimensionality*

Equations Of Motion

$$\left(\partial_t + v\partial_x\right)\mathbf{P}_v(x,t) = \mu\,\underbrace{\left(\mathbf{M}_0(x,t) - v\mathbf{M}_1(x,t)\right)}_{\mathbf{H}_v} \times \mathbf{P}_v(x,t)$$

$$\mathbf{M}_n = \int_{-1}^{1} L_n(v)\mathbf{P}_v \, dv$$

JCAP 03, 042 (2016

JCAP 02, 019 (2017)

Numerical Strategy

- Discretize in space for every v
- Solve a set of couped nonlinear O.D.E in t
- Method : B.D.F Boundary Condition : Periodic in space
- Solver : Zvode and scipy.fftpack.diff in python

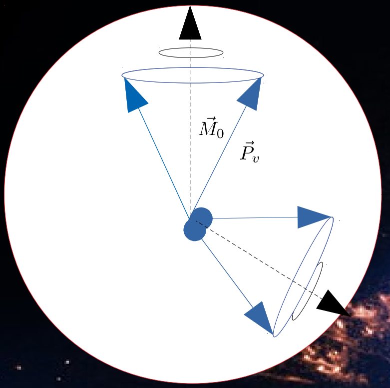
Results

1) Pendulum Motion

- Stationarity in time
- Each P_v shows a precession around M_0 in space
- M_0 shows pendulum motion in space

Phys. Rev.D 74, 105010 (2006)

Phys. Rev. D 101,043009 (2020)

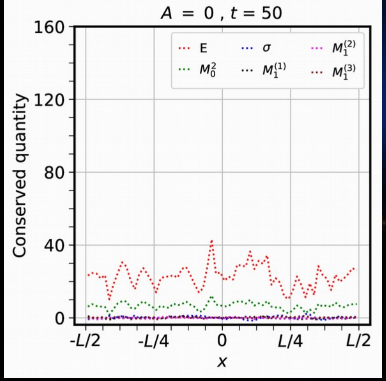


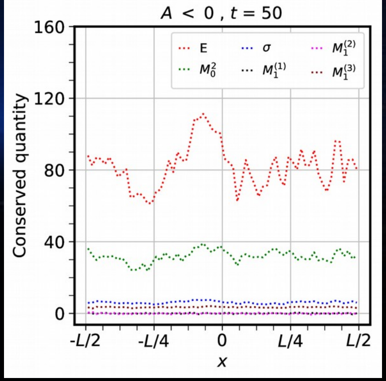
$$\widetilde{\mathbf{P}}_v : \frac{d}{dx}\widetilde{\mathbf{P}}_v(x) = \frac{\widetilde{\mathbf{M}}_0(x)}{v} \times \widetilde{\mathbf{P}}_v(x)$$

$$\widetilde{\mathrm{M}}_0 : \widetilde{\mathrm{M}}_0 \times \frac{d^2}{dx^2}\widetilde{\mathrm{M}}_0 + \sigma\left|\widetilde{\mathrm{M}}_0\right|\frac{d}{dx}\widetilde{\mathrm{M}}_0 = \left|\widetilde{\mathrm{M}}_0\right|^2 \widetilde{\mathrm{B}} \times \widetilde{\mathrm{M}}_0$$

$$E = \widetilde{\mathrm{B}}.\widetilde{\mathrm{M}}_0 + \frac{1}{2}\widetilde{\mathrm{D}}.\widetilde{\mathrm{D}} \qquad \sigma = \widetilde{\mathrm{D}}.\widetilde{\mathrm{M}}_0 \qquad \left|\widetilde{\mathrm{M}}_0\right| = \mathrm{const}$$

$$\widetilde{\mathbf{D}} = \sum_{n=odd} \alpha_n \widetilde{\mathbf{M}}_n,\ \widetilde{\mathbf{B}} = \sum_{n=even} \beta_n \widetilde{\mathbf{M}}_n$$

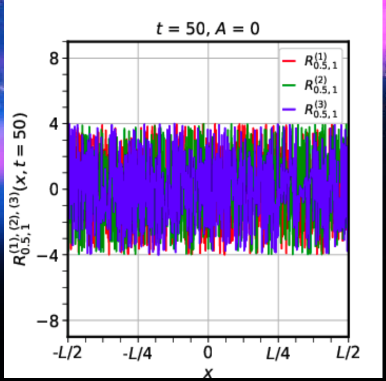


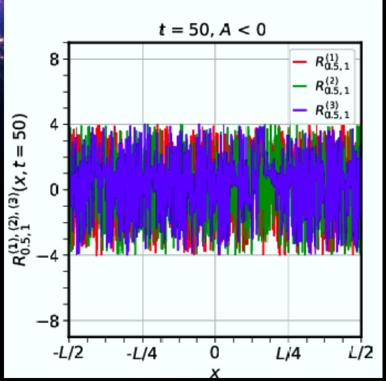


2) Non-separable solution in x & v

- Stationary solution for every P_v is non-separable in x & v for any lepton asymmetry (A)
- This can be checked through the spatial dependence of the quantity,

$$R^i_{v_1,v_2}(x) = \left.\frac{P^i_{v_1}(x)}{P^i_{v_2}(x)}\right|_{t=50} \qquad i = 1, 2, 3$$





Results

3) Phase Randomization

- The phase between the transverse components of P_v gets completely random between $[-\pi, \pi]$ in space independent of any value of v and A at late times.

arXiv: 2005.00459

4) Depolarization in velocity space

- The spatially averaged P_v exhibit complete (or partial) decoherence for zero (or nonzero) lepton asymmetry at late times. Phys. Rev. D 75, 083002 (2007) Phys. Rev. D 76, 125018 (2007)

- For partial decoherence the vanishing range of velocity modes loosely depends on the occurrence of the sign-flip of the z component of the Hamiltonian in corotating frame

- This kinematic decoherence stems from randomization of the transverse components of P_v