8th Supernova Neutrino Workshop (6-7 January 2022)

Collision effects on fast neutrino flavor conversions in astrophysical sites

(arXiv:2109.14011)

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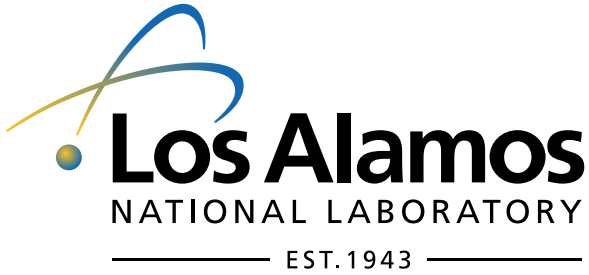
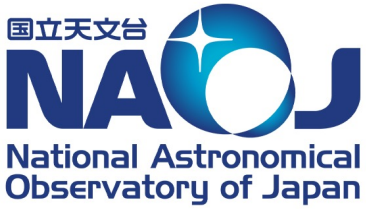
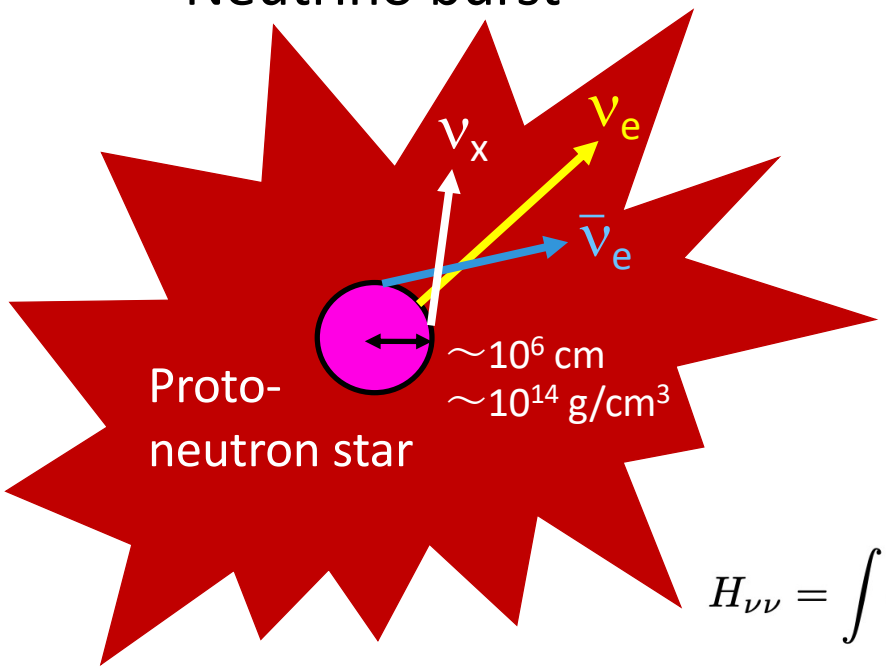


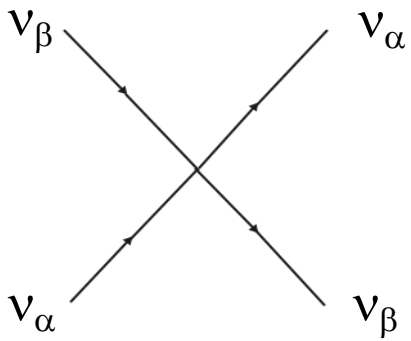


Fast neutrino flavor conversions inside CCSNe

Neutrino burst



Neutrino-neutrino interactions change neutrino spectra



$$H_{\nu\nu} = \int \mathrm{d}\cos\theta' \mathrm{d}\phi' \mathrm{d}E' \, (1 - \cos\theta\cos\theta') \times \{\rho(\cos\theta', \phi', E') - \bar{\rho}(\cos\theta', \phi', E')\}$$

There are two types of oscillation modes:

Slow flavor conversions → $\sim 10^{-6}$ cm^{-1} Duan et al., Ann. Rev. Nucl. Part. Sci. 60:569(2010)

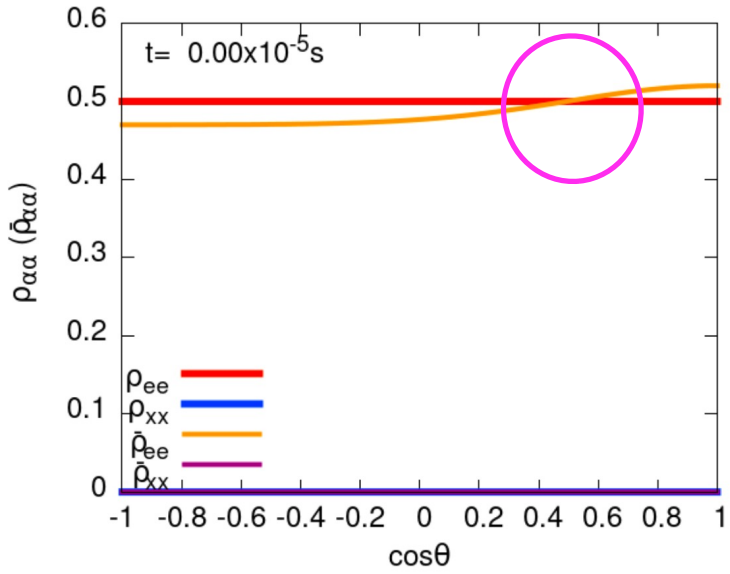
Fast flavor conversions → $\sim$cm^{-1} Tamborra et al., Ann. Rev. Nucl. Part. Sci. 71:165(2021)

Numerical setup

Fast flavor conversions are associated with neutrino angular distributions

The ELN crossing triggers fast flavor conversions

ELN crossing



- Liouville-von Neumann equations

$$\frac{\mathrm{d}}{\mathrm{d}t}\rho = -i[H,\rho] + C[\rho,\bar{\rho}]$$
$$\frac{\mathrm{d}}{\mathrm{d}t}\bar{\rho} = -i[\bar{H},\bar{\rho}] + \bar{C}[\rho,\bar{\rho}]$$

collisions

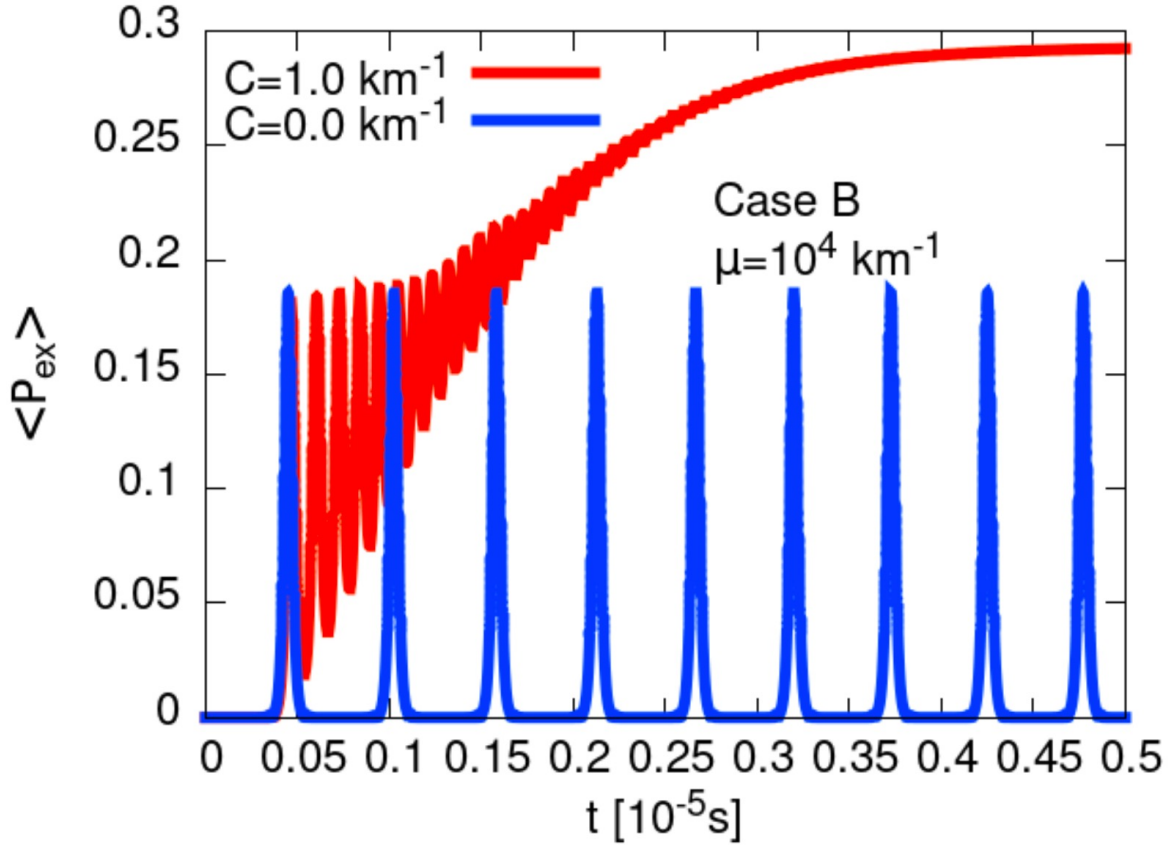
- Spatial homogeneous system

$$\vec{\nabla}\rho = 0$$

- Axial-symmetric neutrino emission and single energy

$$\rho(\cos\theta,\phi,E) \rightarrow \rho(\cos\theta) \qquad E = 50\,\mathrm{MeV}$$

Transition probabilities



Collision terms (scatterings)

$$C[\rho,\bar{\rho}] = -\int_{-1}^{1} \mathrm{d}\cos\theta' C_{\mathrm{loss}}\rho(\cos\theta) + \int_{-1}^{1} \mathrm{d}\cos\theta' C_{\mathrm{gain}}\rho(\cos\theta')$$

$$\bar{C}[\rho,\bar{\rho}] = -\int_{-1}^{1} \mathrm{d}\cos\theta' \bar{C}_{\mathrm{loss}}\bar{\rho}(\cos\theta) + \int_{-1}^{1} \mathrm{d}\cos\theta' \bar{C}_{\mathrm{gain}}\bar{\rho}(\cos\theta')$$

$$C_{\mathrm{loss}} = C_{\mathrm{gain}} = \bar{C}_{\mathrm{loss}} =$$

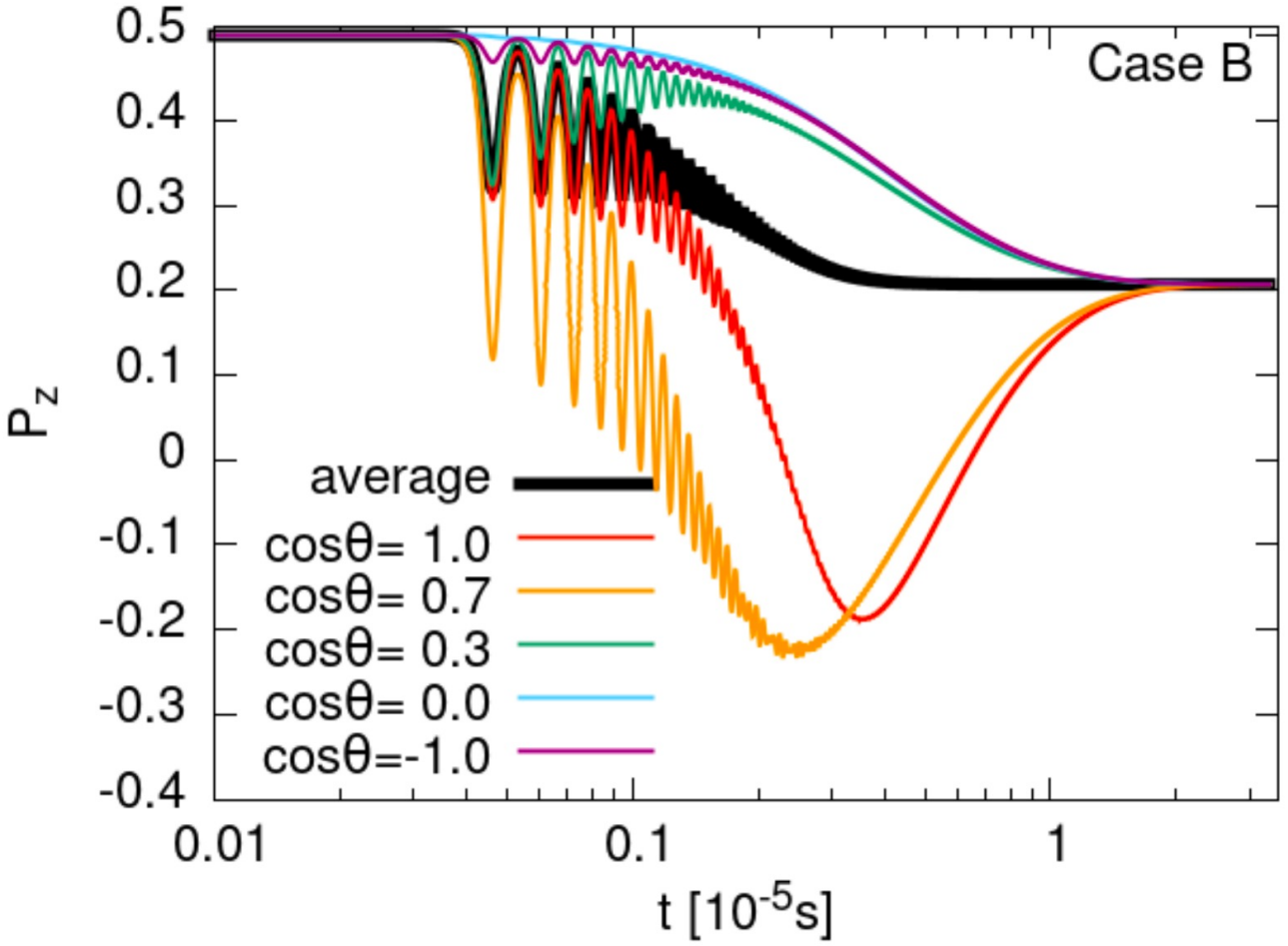
$$\bar{C}_{\mathrm{gain}} = C/2$$

Consistent with results in Shalgar et al., Phys. Rev. D103, 063002 (2021)

The motion of polarization vectors

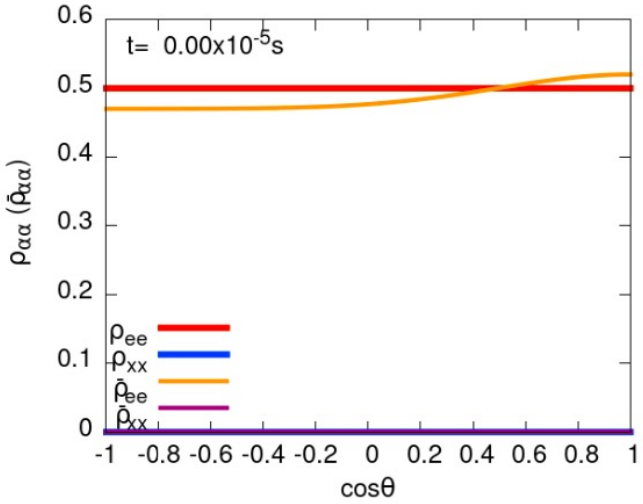
$$\rho = \begin{pmatrix} \rho_{ee} & \rho_{ex} \\ \rho_{xe} & \rho_{xx} \end{pmatrix} = \frac{\mathrm{Tr}\rho}{2} I_{2\times 2} + \frac{P_i \sigma_i}{2}$$

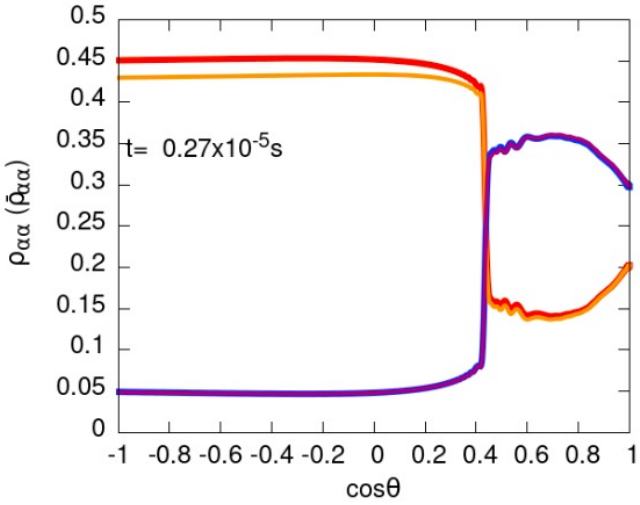
w/ collision (C ≠ 0)

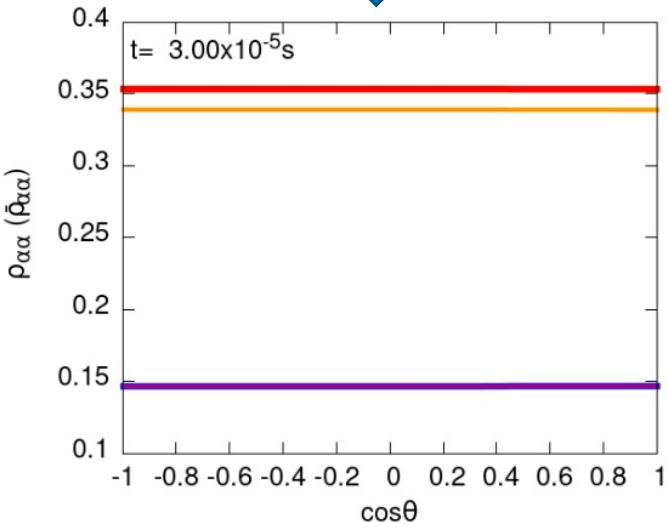


Evolution of neutrino angular distributions

w/ collision (C ≠ 0)







Collision terms enhance flavor conversions

Finally, neutrino spectra become isotropic

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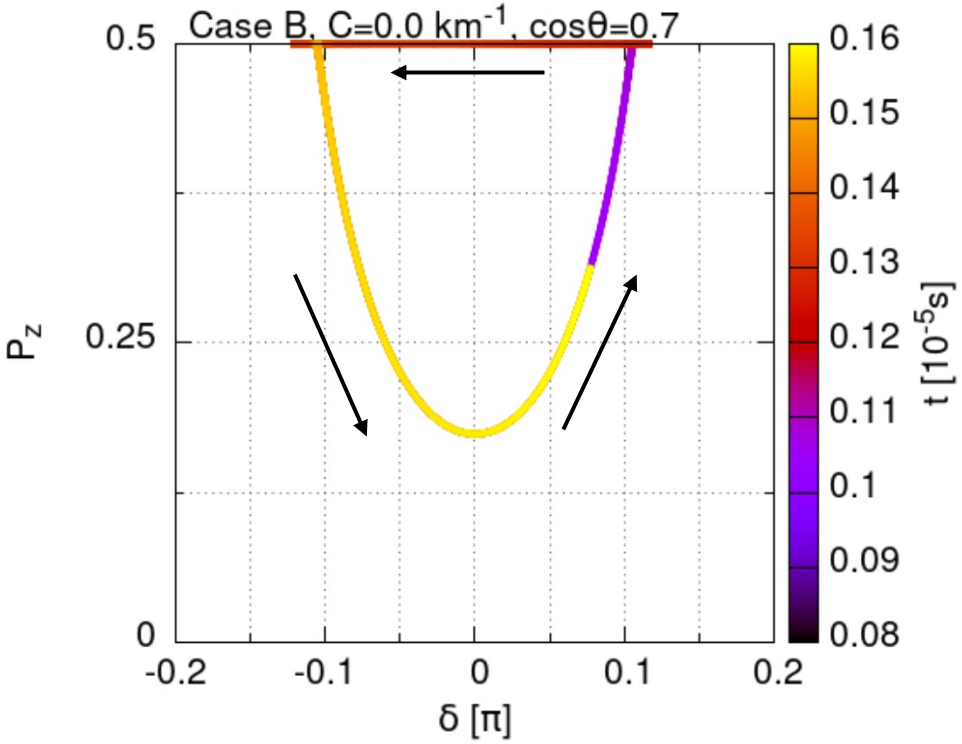
Periodic motion in the case without collision terms

w/o collision (C=0)



$$\frac{\mathrm{d}}{\mathrm{d}t}\mathbf{P} = \mathbf{H} \times \mathbf{P} - \cancel{C\mathbf{P} + C\langle \mathbf{P} \rangle}$$

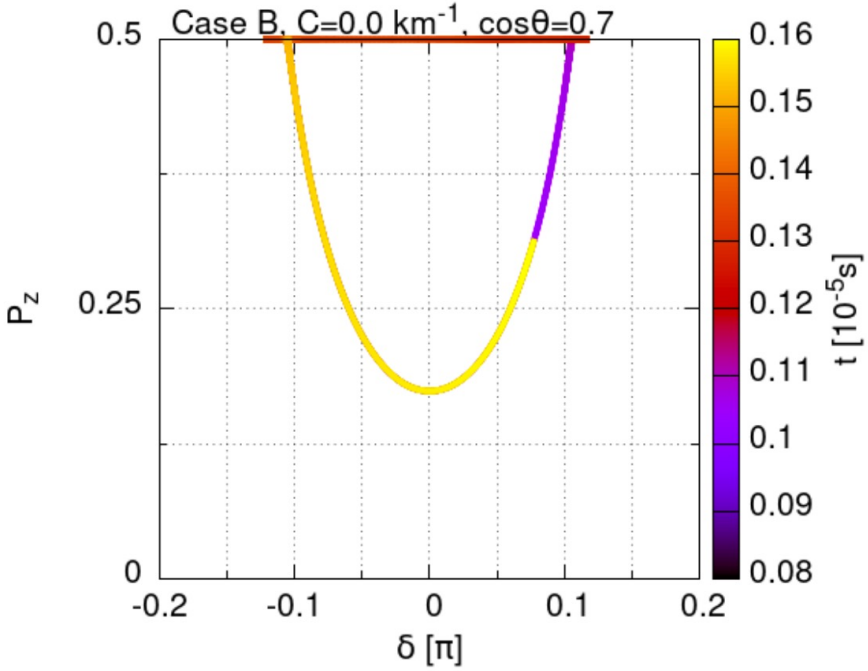
$$\delta = P_\phi - H_\phi$$
$$P_\phi = \tan^{-1}(P_y/P_x)$$
$$H_\phi = \tan^{-1}(H_y/H_x)$$

P ... Polarization Vector

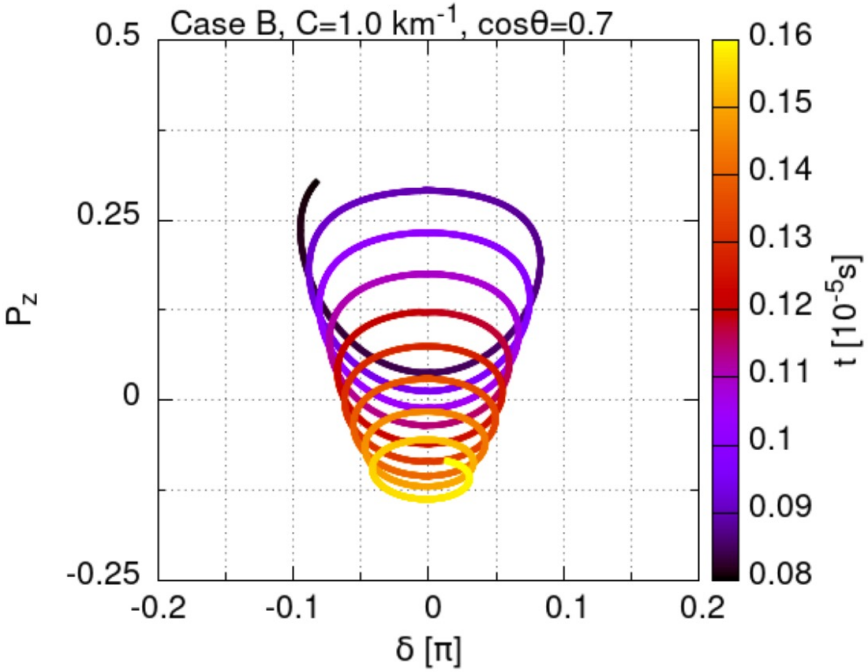
H ... Vector of Hamiltonian

Collision terms break the periodic structure

w/o collision (C=0)



w/ collision (C ≠ 0)



Is the break of periodic structure related to the violation of a conservation law caused by a finite value of C ?

$$\frac{1}{2}\frac{\mathrm{d}}{\mathrm{d}t}|P|^2 = -C|P|^2 + C\mathbf{P}\cdot\langle\mathbf{P}\rangle$$

Summary

- We calculate fast neutrino flavor conversions in homogeneous system assuming axial-symmetric neutrino emission

- We find the enhancement of flavor conversions caused by neutrino scattering collision terms. Our results are well consistent with a previous numerical study

- We confirm that the enhanced neutrino spectra finally become isotropic because of the collision effect

- We suspect that the break of periodic structure of polarization vector is related to the violation of a conservation law of the length of the polarization vector