

Fast flavor conversion of neutrinos

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Why do neutrinos oscillate?

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Two bases for fields:

- massive $\mu(x) = \begin{pmatrix} \mu_1 \\ \mu_2 \end{pmatrix}$ and flavor $\phi(x) = \begin{pmatrix} \phi_e \\ \phi_\tau \end{pmatrix}$
- related via SO(2) mixing matrix $\phi(x) = \hat{U}\mu(x)$
→ propagating dof \neq interacting dof

mixing is environment dependent

oscillation length in vacuum: $L \sim 10\text{km}$

in high neutrino density: $L \sim 1\text{m}$

Equation of Motion

description with Wigner transform

$$\hat{\rho}(\mathbf{x}, \mathbf{k}, t) = \int d^3y e^{-i\mathbf{k}\cdot\mathbf{y}} \phi(\mathbf{x} - \frac{\mathbf{y}}{2}) \phi^\dagger(\mathbf{x} + \frac{\mathbf{y}}{2}) \equiv \begin{pmatrix} D & S \\ S^* & 1-D \end{pmatrix}$$

$$\text{Hamiltonian } \hat{H} = \sqrt{\mathbf{k}^2 + \hat{M}^2} + \sqrt{2} G_F \int \frac{d^3q}{(2\pi)^3} (\hat{\rho} - \hat{\bar{\rho}}) (1 - \cos \theta_{qk})$$

$$\text{Liouville equation } i(\partial_t + \mathbf{v} \cdot \partial_{\mathbf{x}}) \hat{\rho} = [\hat{H}, \hat{\rho}]$$

interpretations: particle transport & wave equation

Two beams

assume: flavor correlation small $S \ll 1$

$$\rightarrow i(\partial_t + \mathbf{v} \cdot \partial_{\mathbf{x}}) S_{\mathbf{v}} = - \int \frac{d\mathbf{v}'}{4\pi} (1 - \cos \theta) G_{\mathbf{v}'} S_{\mathbf{v}'}$$

$G_{\mathbf{v}}$: particle content

simplification: 2 beams in 1 + 1d

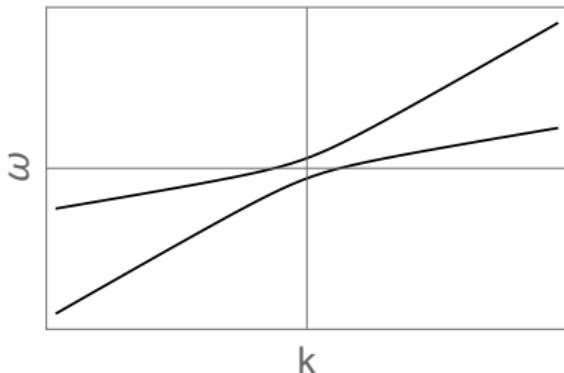
parameters: velocities ($|\uparrow\rangle, |\downarrow\rangle$) & particle content ($\nu, \bar{\nu}$)

look for unstable regions in dispersion relation $\omega(\mathbf{k})$

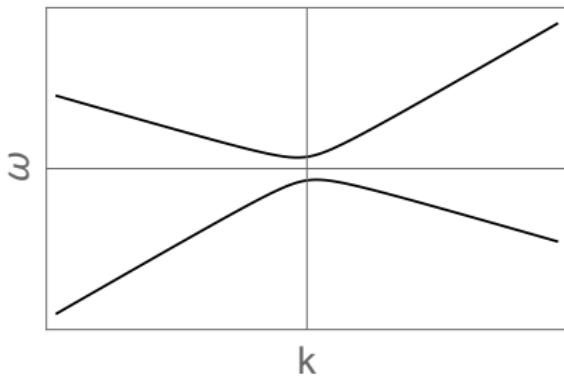
$$\rightarrow \omega \text{ or } \mathbf{k} \text{ complex in } S \sim e^{-i(\omega t - \mathbf{k} \cdot \mathbf{x})}$$

Stable cases

parallel \mathbf{v} , only ν
no excluded regions
 \rightarrow completely stable

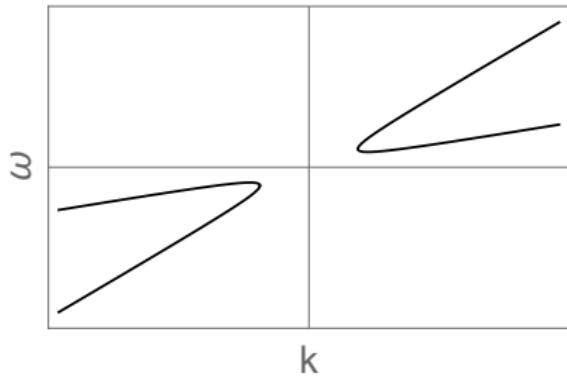


antiparallel \mathbf{v} , only ν
gap in ω
modes with small energy damped

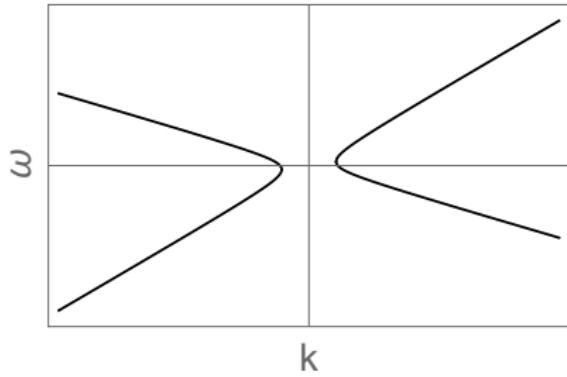


Instable case

parallel \mathbf{v} , ν and $\bar{\nu}$
gaps in ω and \mathbf{k}
convective instability



antiparallel \mathbf{v} , ν and $\bar{\nu}$
gap in \mathbf{k}
absolute instability



Conclusions

- oscillation is a misleading term
- self-interactions can cause complex regions in dispersion relation
- depending on the gaps different instabilities arise

Bibliography

- Izaguirre et al.: "Fast Pairwise Conversion of Supernova Neutrinos: A Dispersion-Relation Approach", arXiv:1610.01612
- Capozzi et al: "Fast flavor conversion of supernova neutrinos: Classifying instabilities via dispersion relations", arXiv:1706.03360
- TS et al.: "Liouville term for neutrinos: Flavor structure and wave interpretation", arXiv:1803.04693