Building a Dissipative Model For Three-Neutrinos Propagation

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Overview

Definitions and properties

Global System

- The global system can be written as $\rho = \rho_\nu \otimes \rho_e$.
- The evolution of the global system is made through the transformation $\rho(0) \to \rho(t) = U\rho_\nu \otimes \rho_e U^\dagger$.
- $U(t) = e^{-iH_G t}$ and $H_G = H_\nu + H_e + H_{int}(\nu, e)$.

Interaction

- The interaction could be obtained from [Burgess and Michaud, 1997]

$$\mathcal{L} = i\bar{\nu}_i\gamma_\mu(\gamma_L g^a_{ij} + \gamma_R h^a_{ij})\nu_j J^\mu_a$$

where J^μ_a is set of operators involving the degree of freedom of the environment.

- To keep as broad as possible: $H_{int}(\nu, e) = \lambda(W \otimes \phi)$.

Definitions and properties

Quantum Evolution

- $\rho_\nu(x) = Tr_e[U\rho_\nu \otimes \rho_e U^\dagger] = \sum_\beta V_\beta \rho_\nu V_\beta^\dagger$, with $\sum_\beta V_\beta V_\beta^\dagger = 1$.
- The quantum evolution equation [Breuer and Petruccione, 2002]:

$$\frac{d\rho_\nu(x)}{dx} = -i[H_\nu, \rho_\nu(x)] - D[\rho_\nu(x)]$$

- Extra term:

$$D[\rho_\nu] = -\frac{1}{2}\sum_{k=1}^{N^2-1}\left(\left[V_k, \rho_\nu V_k^\dagger\right] + \left[V_k \rho_\nu, V_k^\dagger\right]\right)$$

- Solve this equation: $\dot{\rho}_\vartheta \lambda_\vartheta = f_{ijk} H_i \rho_j \lambda_\vartheta \delta_{\vartheta k} - \rho_\nu D_{\vartheta\nu} \lambda_\vartheta$

Definitions and properties

On the General Subsystem of Interest

- Neutrino propagates in vacuum or in matter and the Hamiltonian can always be written as $H_\nu = diag.\{\tilde{E}_1, \tilde{E}_2, \tilde{E}_3\}$.
- The subsystem of interest [Guzzo, Holanda and Oliveira, 2014]:

$$\rho_\nu = |\nu_\alpha\rangle\langle\nu_\alpha|$$

and $\nu_\alpha = \sum_i a_{\alpha i}\tilde{\nu}_i$.

Complete Positivity

Quantum Dissipators

- First step: Energy conservation in subsystem of interest

$$[H_\nu, V_k] = 0 \rightarrow D_{\mu\nu} = diag.\{\Gamma_{12}, \Gamma_{12}, 0, \Gamma_{31}, \Gamma_{31}, \Gamma_{32}, \Gamma_{32}, 0\}$$

- Step 2: Is the energy conserved in subsystem of interest?

$$[H_\nu, V_k] \neq 0 \rightarrow D_{\mu\nu} = diag.\{\Gamma_{12}, \Gamma_{12}, \Gamma_{33}, \Gamma_{31}, \Gamma_{31}, \Gamma_{32}, \Gamma_{32}, \Gamma_{88}\}$$

Constraints on $D_{\mu\nu}$

- $D_{\mu\nu}$ must be positive definite.
- The diagonal elements must be large than the off-diagonal ones.
- All Γ are correlated each other, even in the case of $D_{\mu\nu}$ defined above

Difference between Decoherence and Relaxation effects

The mass state evolved is given by

$$\rho^m(x) = \begin{pmatrix} f_{11}(\theta_{ij}, \Gamma_{33}, \Gamma_{88}|x) & \rho_{12}(0)e^{-(\Gamma_{12}-i\Delta_{12})x} & \rho_{13}(0)e^{-(\Gamma_{13}-i\Delta_{13})x} \\ \rho_{21}(0)e^{-(\Gamma_{12}+i\Delta_{12})x} & f_{22}(\theta_{ij}, \Gamma_{33}, \Gamma_{88}|x) & \rho_{23}(0)e^{-(\Gamma_{23}+i\Delta_{23})x} \\ \rho_{31}(0)e^{-(\Gamma_{13}+i\Delta_{13})x} & \rho_{32}(0)e^{-(\Gamma_{23}-i\Delta_{23})x} & f_{33}(\theta_{ij}, \Gamma_{33}, \Gamma_{88}|x) \end{pmatrix}$$

where $\Delta_{ij} = E_j^2 - E_i^2 \sim \frac{\Delta m_{ij}^2}{2E}$.

- The quantum probabilities $f_{ii}(\theta_{ij}, \Gamma_{33}, \Gamma_{88}|x)$;
- The coherence terms: $\rho_{ij}(0)e^{-(\Gamma_{ij}-i\Delta_{ij})x}$;
- Independent-model for decoherence and relaxation effects.

Solar-Netrino case

Solar neutrinos and Relaxation effect (no decoherence!)

- Solution based on adiabatic limit;
- The coherence terms are averaged out, i. e., $\int_r^R e^{-(\Gamma_{ij}-i\Delta_{ij})x}dx = 0$
- The survival probability (disappearance Probrobabilty $1 - P_{\nu_e\to\nu_e}$)

$$P_{\nu_e\to\nu_e} = A + B\cos(2\tilde{\theta}_{12})\cos(2\theta_{12})$$

where

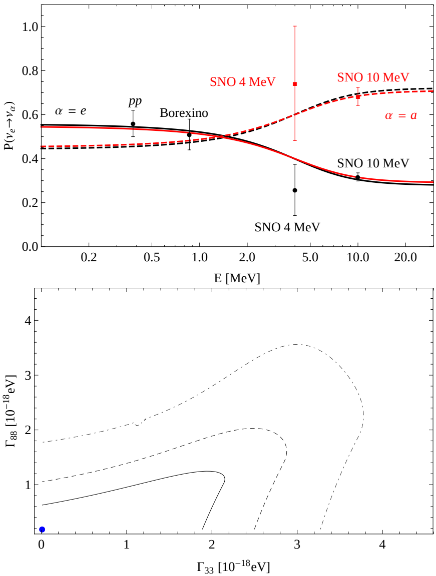
$$A = \frac{1}{2}e^{-\Gamma_{88}x}\cos(\theta_{13})^4 + e^{-\Gamma_{88}x}\sin(\theta_{13})^4 + \frac{1}{3}(1 - e^{-\Gamma_{88}x})$$

and

$$B = \frac{1}{2}e^{-\Gamma_{33}x}\cos(\theta_{13})^4$$

Simple Analysis

- Following the same strategy from [Gouvea at. al., 2015], we perform a simple analysis combining the ^{8}B , ^{7}Be and and low-energy solar neutrinos.
- Our χ^2 has the mass "fixed" on the KamLAND. This simplifies the analisis, but the dissipative effects does not change the Δm^2 [Oliveira at. al., 2016].



Results for the Model and Terrestrial Experiments

- Fot both $\Gamma^{3\sigma}_{relax} \sim 10^{-27}$ GeV,
- The next generation of long baseline experiment:

$$x^{DUNE} = 6.6 \times 10^{21} GeV^{-1} and\ x^{ORCA} = 6.2 \times 10^{22} GeV^{-1}$$

- The relaxation effect with solar constraints:

$$e^{-\Gamma_{rel} x_{lbne}} \cong 1$$

.

- Therefore, the model for terrestrial experiment is reduced to

$$D_{\mu\nu} = diag.\{\Gamma_{12}, \Gamma_{12}, 0, \Gamma_{31}, \Gamma_{31}, \Gamma_{32}, \Gamma_{32}, 0\}$$

Conclusions and Coments

- We changed how the subsystem of interest can be written.
- A quantum dissipator with different effects was introduced following some constraints.
- After the contraints, one independent-model was obtained.
- Solar-neutrinos can put stringent bound only on relaxation effects.
- Only the decoherence effects may be important in the terrestrial experiments case.

References

C. P. Burgess, D. Michaud (1997)
Neutrino Propagation in a Fluctuating Sun
Annals Phys. 256, 1.

H. P. Breuer and F. Petruccione (2002)
The Theory of Open Quantum Systems, Lect. Notes Phys.
Oxford University Press.

M. M. Guzzo, P.C. de Holanda, R. L. N. Oliveira (2014)
Neutrino Propagation in a Fluctuating Sun
arXiv:1408.0823.

Jeffrey M. Berryman, Andre de Gouvea and Daniel Hernandez(2015)
Solar Neutrinos and the Decaying Neutrino Hypothesis
Phys. Rev 91, 053005.

G. B. Gomes, M. M. Guzzo, P. C. de Holanda and R. L. N. Oliveira(2016)
Parameter Limits for Neutrino Oscillation with Decoherence in KamLAND
Submitted to PRD.

Thank you!