SN1987A bounds for gravitationally induced neutrino quantum decoherence in the presence of dark fermions

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Although a complete theory of Quantum Gravity (QG) is still elusive, many phenomena that we would expect to see in such a theory have been proposed in the literature. Within the so-called QG phenomenology, the field of research that I will investigate during my PhD, these phenomena are used to try to identify physical processes that could show first signs of QG in experiments.

In this talk, I will present my first research project that considers a model for gravitationally induced quantum decoherence in neutrino systems. Quantum decoherence describes the loss of coherence in a quantum system. For neutrino systems, there are two types of decoherence: decoherence induced by wave-packet separation and environment-induced decoherence. In a consistent theory of QG, spacetime itself could be subject to quantum fluctuations, often referred to as the *spacetime foam*. This foamy structure of spacetime could provide an environment for propagating neutrinos, thus inducing decoherence.

In order to model such an effect, we describe the propagating neutrinos as an open quantum system, making use of the Lindblad formalism. Within this formalism we require the Hamiltonian of the system and a dissipator describing the environment. As we cannot derive a dissipator from QG, we must find a phenomenological parameterisation based on reasonable assumptions about QG. We assume that QG has the following properties:

1. QG maximally violates global quantum numbers.
2. QG conserves unbroken gauge charges.
3. QG conserves the direction of propagation, spin, and angular momentum.
4. QG conserves the total probability of the system.

Furthermore, we assume the existence of new fermions that share the same quantum numbers as neutrinos under the unbroken standard model (SM) gauge group. Therefore, we expect transitions between the SM neutrinos and the additional dark fermions via quantum gravitational degrees of freedom. The total number of fermions is represented by n_f, so $n_\mathrm{f} = 4$ corresponds to one additional dark fermion compared to the SM case. The simplest dissipator for the QG-induced decoherence fulfilling our assumptions is given by

$$D_{\mathrm{QG}}(\rho) = \sum_{i,j=0}^{n_\mathrm{f}^2-1} \left((\mathcal{D}_{\mathrm{QG}})_{ij} \varrho_j \right) \lambda_i \,, \qquad \text{with} \qquad \mathcal{D}_{\mathrm{QG}} = \mathrm{diag}\left(0, \Gamma, \ldots, \Gamma\right) \,. \tag{1}$$

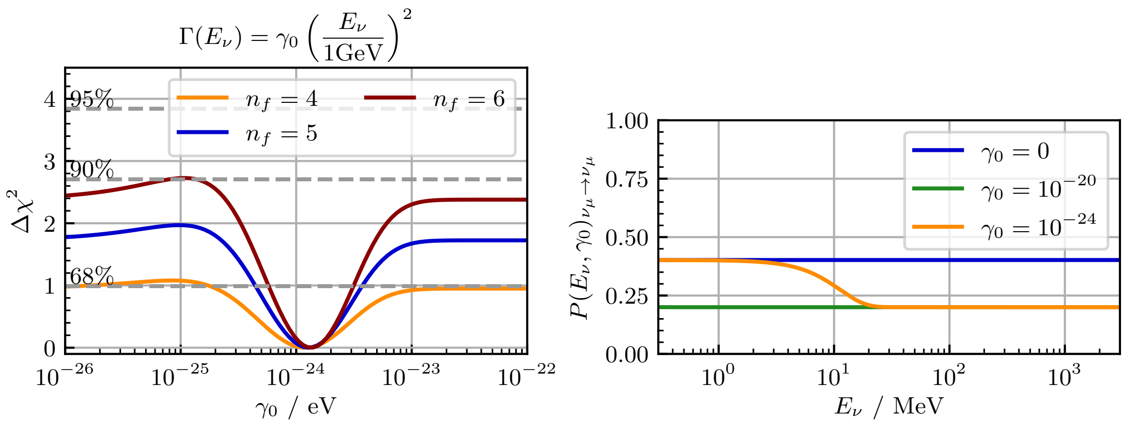

Figure 1: Left: The χ^2 profile of the presented data analysis. Right: The neutrino oscillation probability for $n_\mathrm{f} = 5$ for different values of γ_0.

In this equation, λ_i are the group generators of SU(n_f) plus the matrix λ_0, which is proportional to the identity. Moreover, ϱ_j is the coefficient in front of λ_j when introducing the SU(n_f) representation of the density matrix, i.e. $\rho \equiv \sum_k \varrho_k \lambda_k$. The last piece of the equation is the so-called damping factor Γ, whose exact expression is unknown. Still, we can use the phenomenological parameterisation

$$\Gamma(E) = \gamma_0 \left(\frac{E}{E_0}\right)^n , \tag{2}$$

as it has been done extensively in the literature. With the model being set, we can compute the altered neutrino oscillation probability (OP) by evolving $\rho(0) \to \rho(L)$ using the Lindblad equation. Once we achieved this, the model is fully encoded in $P_{\alpha\beta}(E, L)$.

Now, we can compare the model with data. We have chosen to analyse the supernova data from SN1987A, as measured by the Kamiokande-II, Baksan, and Irvine-Michigan-Brookhaven experiments. Performing a likelihood ratio test revealed the χ^2 profile shown in Figure 1 (left), which indicates a statistically non-significant, yet still interesting, preference for our model. However, this is more a consequence of fitting the neutrino flux to the data than the first sign of QG. In the measured neutrino energy range, the OP is constant for the cases $\gamma_0 << \gamma_0^{\text{min}}$ and $\gamma_0 >> \gamma_0^{\text{min}}$, as indicated in Figure 1 (right). Since we are fitting the detector flux, a constant OP will always result in an equally good fit, regardless of the constant's value, since the nuisance parameters can be adjusted. However, the OP exhibits a non-trivial behaviour for $\gamma_0 \approx \gamma_0^{\text{min}}$, so that the QG parameter has an impact. Therefore, our result can be interpreted as follows: with one additional parameter, we can fit the data better, which is not too surprising.