Two Questions from an Inquiring "Student:"

Do Neutrino Oscillations Conserve Energy?

Could Decoherence Blur Neutrino Oscillations?

http://puhep1.princeton.edu/~mcdonald/examples/neutrino_osc.pdf

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Do Neutrino Oscillations Conserve Energy?

If neutrinos have mass, they have a rest frame.

If a neutrino oscillates and changes its mass in this rest frame, it's mass/energy is not conserved? *If a moving neutrino oscillated with fixed momentum, its energy would change, or if fixed energy, its momentum would change.*

Is this the way neutrino oscillations work?   NO!

Neutrinos are always produced together with some other state X, and if the parent states has definite energy and momentum, then so does the quantum state $|\nu\rangle|X\rangle$.

If the neutrino is produced in a flavor state, it is a quantum sum of mass states,
$|\nu_e\rangle = a_1 |\nu_1\rangle + a_2 |\nu_2\rangle + a_3 |\nu_3\rangle$, and the production involves an entangled state
$|\nu_e\rangle |X\rangle = a_1 |\nu_1 |X_1\rangle \rangle + a_2 |\nu_2\rangle |X_2\rangle + a_3 |\nu_3\rangle |X_3\rangle$

The sum of the energies and momenta of ν_i and X_i equals the initial state energy/momentum, while the different ν_i have different energies and momenta.

The coefficients a_i can change with time (oscillate), but the energy of ν_i does not change with time.

Can Measurement of X Suppress Neutrino Oscillations?

YES.

If X is measured so well that we can distinguish the X_i from one another, then the neutrino must be observed in the corresponding state ν_i.

If the neutrino is observed in a flavor state, the proportions of the 3 possible flavors are just squares of the MNS matrix elements, independent of time/distance.

However, most "observations" of state X do not determine its energy so precisely that the above scenario holds.

Example: In nuclear beta decay, $A \rightarrow A'$ e ν_e, the interaction of A' and e with nearby atoms does not "measure" their energies precisely. Rather, the entanglement of the ν_e with A' and e becomes transferred to the neighbor atoms.

Optical experiments with entangled photons illustrate how measurement of the 2nd photon of a pair can affect the quantum interference of the 1st photon.

X.-S. Ma et al., Quantum erasure with causally disconnected choice, Proc. Nat. Acad. Sci. 110, 1221 (2013)

Decoherence If Wave Packets No Longer Overlap

Since the different ν_i have different energies, they have different velocities, such that their wavepackets no longer overlap at large enough distances, and neutrino oscillation should no longer be possible.

Can this effect ruin a long-baseline neutrino experiment, particularly one like JUNO where it is proposed to observe the ~ 15th oscillation?

NO!

That is, if the neutrinos are observed at some large, fixed distance, and one looks of evidence of oscillation in their energy spectra, then if the detector resolution is good enough to resolve the oscillations, this guarantees that the wavepackets of the different ν_i still overlap (barely).

On the other hand, if the detector energy resolution is poor, and the oscillations can't be resolved in the energy spectrum, the quantum description of this is that the ν_i have "decohered" because their wave packets don't overlap.

Moral: If you want to see neutrino oscillations, you have to observe them with a "good enough" detector.

Neutrinos from sources at different distances are not coherent with one another, which blurs the oscillations when source size $\geq$ oscillation length (as for supernovae).

Dirac: A photon interferes only with itself...