Neutrino Decays: Lifetimes and Decay Modes

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Astrophysical neutrino flavor mix: How many ways can the flavor mix deviate significantly from 1:1:1 ?

1. Initial flux different from canonical: e.g. the damped muon scenario. In this case the flavor mix will be:

   4:7:7

   similarly for the beta beam source, the flavor mix will be:

   5:2:2

   instead of 1:1:1

2. Neutrino Decay:

Do neutrinos decay?

Since δm's ≠ 0, and flavor is not conserved, in general ν's will decay. The only question is whether the lifetimes are short enuf to be interesting and what are the dominant decay modes.

What do we know?

- Radiative decays: $\nu_i \rightarrow \nu_j + \gamma$:

  m.e.: $\Psi_j (C + D\gamma_5)\sigma_{\mu\nu} \Psi_i F_{\mu\nu}$

SM: $1/\tau = (9/16)(\alpha/\pi)G_F^2/\{128\pi^3\}(\delta m_{ij}^2)^3/m_i$
$\Sigma_\alpha m^2_\alpha/m_W^2(U_{i\alpha}U_{j\alpha}^*)^2 \rightarrow \tau_{SM} > 10^{45}$ s

(Petcov, Marciano-Sanda)(1977)

Exptl. Bounds on $\kappa = e/m_i[C + D^2]^{1/2} = \kappa_0\mu_B$

From $\nu_e + e \rightarrow e + \nu'$: $\kappa_0 < 10^{-11}$ (PDG2010), this corresponds to: $\tau > 10^{20}$ s.

Bounds for other flavors somewhat weaker

but still too strong for radiative decay to be

Of practical interest.

Invisible Decays:

- $\nu_i \to \nu_j + \nu + \nu$: Exptl Bounds:

 $F < \varepsilon G_F$, $\varepsilon < O(1)$, from invisible width of Z

Bilenky and Santamaria(1999):If new physics at scales below Z mass, bounds get weaker, Sigurdson et al.

$\tau > 10^{34}$ s

$\nu_{iL} \to \nu_{jL} + \varphi$: $g_{ij}\, \Psi_{jL}\, \gamma_\mu\, \Psi_{jL}\, d_\mu \varphi$

If isospin conserved: invisible decays of charged leptons governed by the same g_{ij}, and bounds on $\mu \to e + \varphi$, and $\tau \to \mu/e + \varphi$ yield bounds such as: $\tau > 10^{24}$ s.

{Jodidio et al. (1986), PDG(1996)}

Conclusion: Only “fast” invisible decays are Majoron type couplings

- $g\, \nu^C_{jR} \nu_{iL}\, X$:
- I(isospin) can be a mixture of 0 and 1(G-R, CMP)
- The final state ν can be mixture of flavor/sterile states………
- Bounds on g from π & K decays
- Barger,Keung,SP(1982),Lessa,Peres(2007), $g^2 < 5.10^{-6}$
- SN energy loss bounds: Farzan(2003): $g < 5.10^{-7}$
- $g^2 < 5.10^{-6}$ corresp. to $\tau > 10^{-8}$ s/eV
- $g < 5.\ 10^{-7}$ corresp. to $\tau > 0.1$ s/ev

Current experimental limits on τ_{i}:

- $\tau_1/m_1 > 10^5$ s/eV SN 1987A
  B. o. E. Careful analysis. Bound can also apply to τ_2/m_2 in principle…

- $\tau_2/m_2 > 10^{-4}$ s/eV (Solar) 10^{-4}-10^{-2}s/eV Beacom-Bell(2003),KamLand(2004) also a better bound for τ_1/m_1 from lower energy events at Borexino
  $\tau_3/m_3 > 3.10^{-11}$s/eV (Atm) 9.10^{-11} s/eV
  Gonzalez-Garcia-Maltoni(2008)

Cosmology: WMAP/PLANCK→free-streaming ν's→
$\tau > 10^{10}$ s/eV at least for one ν…
Hannestad-Raffelt(2005), Bell et al.(2005) , Friedland et al(2007).

(With L/E of TeV/Mpsc or PeV/1000Mpsc, can at most reach τ of 10^3 s/eV)

These bounds depend crucially on free-streaming and whether one or all neutrinos are free-streaming.

When ν_i decays, $U_{\alpha i}{}^2$ gets multiplied by the factor exp(-L/γcτ) and goes to 0 for sufficiently long L. For normal hierarchy, only ν_1 survives,

and the final flavor mix is simply (SP 1981):

$$e:\mu:\tau = |U_{e1}|^2 : |U_{\mu 1}|^2 : |U_{\tau 1}|^2$$

$$\sim 4:1:1$$

or even 10:1:1 with the new best fits…

These flavor mixes are drastically different from canonical 1:1:1 and easily distinguishable.

Beacom et al(2003)

Effects on absolute fluxes in decay scenarios:

- In normal hierarchy, if only ν_1 survives:

  ν_μ flux can go down by as much as a factor of 0.1 from the original flux at the source. .

  ν_e flux is enhanced from the original by a factor of 2.

  Early Universe neutrino count is modified to 3+4/7(this is allowed by PLANCK and BBN)

But if the decay is into a sterile neutrino then (NH)……..

ν_3 and ν_2 simply disappear and only ν_1 survives but at a smaller flux. The final fluxes are then:

ν_e : 2/3 of the original flux

ν_μ : 1/6 of the original flux

Other implications: ν-counting in early universe modified by 3 -> 4+4/7, this isin some conflict with PLANCK + BBN.