Have Massive Cosmological Neutrinos Already Been Detected?

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The possibility is investigated that the decay of massive cosmological neutrinos may have produced a spectral signature which has already been detected in observations of the ultraviolet background radiation. Various implications are discussed including a possible implied neutrino mass of 13.8–14.8 eV. A lower limit is also placed on the lifetime of heavy neutrinos ν_H with respect to the decay $\nu_H \to \nu_L + \gamma$ based on the cosmic uv observations.

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Recently, De Rújula and Glashow suggested that the decay of massive neutrinos originally produced in the big bang could produce potentially observable cosmic fluxes of ultraviolet radiation.[1] In this paper, I attempt to pursue this idea by examining presently available data from optical and ultraviolet astronomical observations and relating these data to the De Rújula–Glashow hypothesis.

I begin by reviewing the De Rújula–Glashow scenario. They consider photons from the decay process of a heavier neutrino ν_H decaying into a lighter neutrino ν_L, i.e.,

$$\nu_H \to \nu_L + \gamma, \tag{1}$$

where ν_H is an "adiabatically cooled" fossil neutrino originally produced in thermal equilibrium in the early big bang, but with a present temperature ~2 K so that the decay takes place with ν_H almost at rest. The photon is then given an energy

$$E_0 = (M_{\nu_H}{}^2 - M_{\nu_L}{}^2)/2M_{\nu_H}. \tag{2}$$

In the case predicted by many theoretical models,[2] $M_{\nu_H} \gg M_{\nu_L}$, Eq. (2) reduces to $E_0 \simeq \frac{1}{2} M_{\nu_H}$. Massive big-bang neutrinos could, in principle, provide the bulk of the mass density of the universe[3] with interesting astrophysical implications.[4,5] Interest in such neutrinos has grown with recent experimental reports of evidence that $M_{\nu_e} \neq 0$ from He endpoint data and neutrino oscillation effects.[6,7]

With neutrino masses M_{ν_H} in the presently astrophysically and experimentally interesting range of ~10 to ~100 eV, E_0 most likely falls in the ultraviolet spectral range. Two types of spectra can then be generated: (i) a line spectrum of narrow Doppler width around E_0 from the decay of ν_H in a galactic halo or local cluster distribution and (ii) a power-law distribution from cosmologically distant neutrinos decaying at all redshifts. I will proceed to compare these hypothesized spectra with present astronomical data.

The fluxes generated are proportional to the decay rate $\Gamma = \tau^{-1}$ for reaction (1) where τ is the neutrino lifetime. De Rújula and Glashow have used recent experimentally determined limits[8] on the rate for the decay $\mu \to e + \gamma$ to argue that $\tau > 10^{16}$ yr for $M_{\nu_H} = 30$ eV and thus $\tau \gg H_0^{-1}$, the age of the universe.

For "local neutrinos," the linewidth is expected to be[1] ~1 Å corresponding to Doppler velocities ~300 km/s. The flux will be

$$I_\lambda = (1/4\pi\tau)\int n_\nu dl \text{ cm}^{-2}\text{ s}^{-1}\text{ sr}^{-1}\text{ Å}^{-1}. \tag{3}$$

For cosmological neutrinos, the flux per eV will be[9]

$$I(E) = \frac{c}{4\pi H_0}\frac{n_0}{\tau}\int dz\,\frac{\delta((1+z)E - E_0)}{(1+z)^{3/2}} = \frac{c}{4\pi H_0}\frac{n_0}{\tau}\frac{E^{1/2}}{E_0{}^{3/2}} \tag{4a}$$

in the case of a closed universe ($\Omega = \rho/\rho_c = 1$) where $\rho_c = 3H_0^2/8\pi G$ is the critical mass density and ρ is the total mass density of the universe, and

$$I(E) = \frac{c}{4\pi H_0}\frac{n_0}{\tau}\int dz\,\frac{\delta((1+z)E - E_0)}{(1+z)} = \frac{c}{4\pi H_0}\frac{n_0}{\tau}\frac{1}{E_0} \tag{4b}$$

in the case of an open universe $[\Omega(E_0 - E)/E_0 \ll 1]$. The density $n_0 \simeq 100$ cm^{-3} is the present volume-averaged density of big-bang neutrinos.

In terms of wavelength spectra, Eqs. (4a) and (4b) become

$$I_\lambda = \frac{cn_0}{4\pi H_0}\frac{1}{\tau}\frac{\lambda_0{}^{3/2}}{\lambda^{5/2}} \simeq 10^{29}\frac{1}{\tau}\frac{\lambda_0{}^{3/2}}{\lambda^{5/2}} \tag{5a}$$

and

$$I_\lambda = 10^{29}\tau^{-1}\lambda_0\lambda^{-2}, \tag{5b}$$

where

$\lambda_0 = hc/E_0$, if we assume $H_0 \simeq 70$ (km/s)/Mpc,

with 1 Mpc = 1 megaparsec.

The advent of space astronomy has made possible recent measurements of cosmic ultraviolet radiation.[10-13] In addition, optical observations[14] have provided new data on the diffuse background light. We now discuss the ν_H decay problems in the context of these measurements.

The uv observations are made at high galactic latitudes. Although it has been pointed out that the flux from a neutrino halo for our galaxy may be higher in the direction of the galactic center, other factors act to make the high-latitude flux more relevant. The observations at low latitudes are complicated by contributions from hot stars and, more importantly, high extinction (~2 magnitude/kpc) from dust in the galactic plane.[15] Also, although the distribution of dark "halo" mass in our galaxy may be highly concentrated, the extent of concentration within 10 kpc of the galactic center is not well determined,[16] having the possibility of a finite core. The size of this core depends on the value of M_{ν_H} and high concentrations within 10 kpc are expected only for M_{ν_H} near the high end of our range of consideration ($M_{\nu_H} \sim 50$ eV).[4] In discussing cluster and cosmological fluxes, of course, the high-latitude measurements are again clearly the most relevant.

The uv observations may be summarized as follows[13]: With use of all numbers in units of photons $\text{cm}^{-2}\ \text{s}^{-1}\ \text{sr}^{-1}\ \text{Å}^{-1}$, the diffuse, high-latitude, far-ultraviolet spectrum appears to be flat between 1300 and 1525 Å with an intensity of 263 ± 40 units. In the range between 1680 and 1800 Å the mean flux level increases to ~600 units.[13,17] The big question here is how much of the flux is from such things as scattered starlight, airglow, and the integrated light of distant galaxies. It has been argued that backscattering of starlight is negligible,[18] and that the increase near 1700 Å is *not* due to integrated light from distant galaxies[13] but may be due to airglow.[11] Finally, we mention the diffuse high-latitude optical flux of ~1300 units at a wavelength of 5115 Å.[14]

Let us first consider the present measurements to be upper limits on the cosmological continuum flux from cosmological ν_H decay [Eqs. (5a) and (5b)] and use these limits to place lower limits on the lifetime τ for ν_H decay (assuming, of course, that massive neutrinos exist and decay).

Since the continuum flux drops off like $\lambda^{-5/2}$ (or λ^{-2} for an open universe), the most restrictive limits lie at the shortest wavelengths. I note that since[13]

$$I(1250\ \text{Å}) \lesssim 200\ \text{cm}^{-2}\ \text{s}^{-1}\ \text{sr}^{-1}\ \text{Å}^{-1}, \tag{6}$$

if one assumes that $250 \lesssim \lambda_0 \lesssim 1250$ Å ($10\ \text{eV} \lesssim E_0 \lesssim 50$ eV, $M_{\nu_H} \gtrsim 20$ eV), then from equations (5a) and (5b),

$$\tau > 4\times 10^{22}\ \text{s} \equiv \tau_{\min}. \tag{7}$$

For $M_{\nu_H} = 30$ eV and $E_0 = 15$ eV, I find $\tau \gtrsim 2.2 \times 10^{23}$ s. This value is comparable to the experimentally derived lower limit given by De Rújula and Glashow[1] and is consistent with their theoretical estimates.

Let us now consider the alternative and much more interesting possibility that the increase near 1700 Å is due to a De Rújula–Glashow line from the decay of galactic halo neutrinos. In other words, let us entertain the possibility that the decay of ν_H's has already been detected! The flux from a "loose" galactic halo of core radius $r_c \sim 10$ kpc corresponding to $M_{\nu_H} \sim 25$ eV (see Ref. 4) follows from Eq. (3) to be

$$I_{\text{halo}}(1700\ \text{Å}) \simeq 10^{29}\tau^{-1}\ \text{cm}^{-2}\ \text{s}^{-1}\ \text{sr}^{-1}\ \text{Å}^{-1} \tag{8}$$

with use of the local halo density given in Ref. 16. A tighter halo ($M_{\nu_H} > 25$ eV) would give a lower high-latitude flux. Thus the observed feature may be due to a line ~1 Å wide somewhere between 1680 and 1800 Å if the neutrino lifetime against photon decay $\tau \sim 10^{17}$ yr. This lifetime is much larger than the age of the universe but is orders of magnitude smaller than the model estimates given in Ref. 1. There is, of course, no inconsistency with the continuum background observations.

If one carries this interpretation further, for $1680\ \text{Å} \leq \lambda_0 \leq 1800$ Å and $6.9\ \text{eV} \leq E_0 \leq 7.4$ eV, from Eq. (2) it follows that

$$M_{\nu_H} \simeq 2E_0, \text{ or } 13.8\ \text{eV} \leq M_{\nu_H} \leq 14.8\ \text{eV} \tag{9}$$

for $M_{\nu_H} \gg M_{\nu_L}$, consistent with Ref. 6.[18] In the extreme case $M_{\nu_H} = 50$ eV, we would conclude that there exists another neutrino of mass $M_{\nu_L} \simeq 42$ eV. In this latter case, however, such high masses would not yield the observed increase in mass-to-light ratio with astronomical scale.[19] In this regard, it should be noted that detailed calculations attempting to account for the distribution of missing mass in the universe suggest a neutrino mass consistent with that given in Eq. (9).[20]

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