DO MASSIVE NEUTRINOS IONIZE INTERGALACTIC HI ?

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Abstract. The radiative decay of massive relic 30eV neutrinos could explain several observational puzzles including the missing dark matter in the universe and the anomalous degree of ionization of interstellar matter in the Galaxy. We note that various non-standard particle physics models with extended scalar sector or minimal supersymmetry have sufficient freedom to accommodate such neutrinos. We discuss observational constraints in the immediate Solar neighborhood, in nearby regions of low interstellar absorption, in the Galactic halo, in clusters of galaxies, and in extragalactic space. Although some observations have been interpreted as ruling out this picture, we note that this is true only for models in which extreme concentrations of neutrinos occur in clusters of galaxies. An instrument is under development to measure the cosmic diffuse EUV background in the local Solar neighborhood, for flight on the Spanish Minisat satellite platform. This instrument will have the capability of providing a definitive test of the radiative neutrino decay hypothesis.

1. Introduction

A relic neutrino ν could decay radiatively into a lighter neutrino ν' and a photon if it has a nonvanishing mass m_ν and an electromagnetic coupling.

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The decay photons would be monochromatic, with energy

$$E_\gamma = \frac{m_\nu^2 - m_{\nu'}^2}{2m_\nu} \approx \frac{1}{2}m_\nu \ .$$

The wavelength λ of a photon radiated by a relic dark matter neutrino in the mass range of 10–30 eV would be in the far ultraviolet (FUV) or the extreme ultraviolet (EUV) bands. Recall that the dividing line between FUV and EUV is the hydrogen ionizing Lyman limit at energy $E_\gamma = 13.6$ eV corresponding to the wavelength $\lambda = 91.1$ nm.

The hypothesis of a radiatively decaying relic neutrino is attractive in that it establishes a plausible identity for dark matter manifested in the large scale motions of galaxies and clusters and for the high degree of ionization of intergalactic gas as evidenced by the Gunn-Peterson effect [1]. If these neutrinos have an appropriate mean life of about 10^{24} s, the photons produced can furnish the ionizing energy needed to maintain the high ionization state of intergalactic hydrogen [2, 3, 4]. Moreover, Sciama has shown [5] that the decay radiation is capable of explaining the anomalously high degree of hydrogen ionization within our Milky Way Galaxy if the radiatively decaying neutrino has a mass and mean life in the narrow window $m_\nu = (29.21 \pm 0.15)$eV, $t_\nu = (2 \pm 1) \cdot 10^{23}$s, provided that the neutrinos can coalesce within galaxies. This massive neutrino could be the τ or μ neutrino because their masses are only bound to ≤ 31 MeV and ≤ 0.22 MeV, respectively [6].

2. Non-standard interactions

While physical theories admitting massive neutrinos can easily be formulated, the electromagnetic coupling of these neutral particles requires more elaboration. In the minimal standard model of electroweak interactions the neutrinos are massless and left-handed (negative helicity states, spin and momentum vectors antiparallel). Enlarging the model to include also right-handed states, all neutrinos would be naturally massive four-component Dirac particles like the electrons, but there would be no explanation for the smallness of their mass. Radiative decay is then possible, but only in second-order processes where the rate depends on the small external neutrino mass. This makes the decay extremely slow, yielding a mean lifetime six orders of magnitude larger than that required by Sciama. Also, the standard model predicts a magnetic transition moment of only $3 \cdot 10^{-19}\mu_B(m_\nu/\mathrm{eV})$ for a massive Dirac neutrino, whereas the required moment is 0.5–$1 \cdot 10^{-14}\mu_B$.

One can obtain a larger electromagnetic coupling by introducing new non-standard interactions allowing the chirality flip to occur due to the mass of the virtual fermion present in the second order radiative loop correction.

The minimal scenarios involve one new charged scalar boson coupling to neutrinos and charged leptons [8, 9], and generating a magnetic moment up to $10^{-11}\mu_B$. The simplest scenario generating consistently both the appropriate mass matrix and the required electromagnetic coupling is then a hybrid model, involving both the Zee model [10] and the see-saw mechanism. Other alternative remedies are new exotic fermions, a more complicated radiative scenario involving two loop diagrams or supersymmetric models. Suffice it to say that models can be constructed [11] to realize the Sciama parameters.

All these models can have other observable consequences for low energy phenomenology. In the mass matrix the neutrino flavors naturally mix, as will be tested in on-going or planned experiments. Actually, present experiments already constrain the parameters of the simplest scenarios to being marginally allowed. Also, the resulting Majorana masses imply neutrinoless double-beta decay close to present search limits. Of course, all these models have variants, so that a negative result would only imply that the simplest versions are ruled out.

3. Observations

The confrontation of models of decaying neutrino populations with observations demands a careful treatment of combined attenuation and emission [11]. The absorption cross section of neutral hydrogen becomes enormously smaller for wavelengths greater than the Lyman edge and the highest terms of the Lyman series lines 91.1–91.5 nm.

Because of the very different distance scales involved, the observations divide into two kinds: EUV ($\lambda < 91$ nm) observations that constrain the emissivity from neutrinos within our Galaxy, and FUV ($\lambda > 91$ nm) observations that constrain extragalactic emissivity at redshifts ≥ 0.1.

3.1. EXTREME ULTRAVIOLET OBSERVATIONS

• *Component 1:* Emission from material in the local Solar neighborhood, assuming a uniformly intermixed emitter and absorber of density 0.1 cm^{-3}, predicts a local diffuse EUV line intensity of 60 photons cm^{-2} s^{-1} sr^{-1}.

• *Component 2:* The hot interstellar medium provides no absorption for 80 nm photons. Attenuation would only occur in localized wisps of cooler matter containing neutral or partly ionized atoms. Thus corridors of high EUV transmission define long lines of sight along which neutrino decay emissivity could integrate to significant values. The predicted flux in the direction of the hot ISM corridors is 300 photons cm^{-2} s^{-1} sr^{-1} which is considerably greater than the flux in the case of the local medium alone, in spite of attenuation by the local solar-neighborhood cloud, because of the 100 times greater mean free path in the hot ISM corridors.

• *Component 3:* A Galactic halo of massive decaying neutrinos has a decay luminosity which is not self-absorbed but radiated efficiently into intergalactic space. Unfortunately, the Galactic hydrogen column density constitutes an optical depth which eliminates the possibility of directly observing decay photons in the 80–91 nm band. Thus, regardless of the extent of the halo of the Galaxy, no direct observational limit on the halo neutrino decay luminosity can be set by EUV observations.

• *Component 4:* An 80–91 nm emission process from galaxies and clusters of galaxies at $z < 0.1$ is again unobservable by direct EUV photometry owing to our Galactic hydrogen, even in the most favorable scenario of the source neutrino halo of the cluster being fully exterior to the hydrogen content of its member galaxies.

The most sensitive upper limits that have been placed on diffuse EUV line emission in the 80–90 nm band are those from the Voyager UVS [12] (re-evaluated): 6000 photons $\text{cm}^{-2}\ \text{s}^{-1}\ \text{sr}^{-1}$.

3.2. FAR ULTRAVIOLET OBSERVATIONS

• *Component 5:* A uniform extragalactic emission from decaying neutrino populations beyond $z = 0.1$ benefit from the transparency of the ISM at wavelengths longer than the Lyman edge. Consequently, a diffuse decay emission line is extended into a diffuse continuum. The flux would appear spatially uniform, spectrally smooth, steadily rising toward shorter wavelengths. One can show that the flux intensity at 140 nm should be 4000 photons $\text{cm}^{-2}\ \text{s}^{-1}\ \text{sr}^{-1}\ \text{nm}^{-1}$. Detecting such an emission source is a considerable challenge.

An observational upper limit to diffuse extragalactic light is at the level of 3600 photons $\text{cm}^{-2}\ \text{s}^{-1}\ \text{sr}^{-1}\ \text{nm}^{-1}$ [13], marginally consistent with the expected flux. The most sensitive available FUV diffuse spectroscopy detected no positive extragalactic flux and yielded an upper limit of 2800 photons $\text{cm}^{-2}\ \text{s}^{-1}\ \text{sr}^{-1}\ \text{nm}^{-1}$ at 140 nm [14].

• *Component 6:* The amount of non-uniform extragalactic emission at $z >$ 0.1 depends on the degree of clumping. A rich cluster of galaxies with mass $10^{15}\ M_{\odot}$ at redshift $z = 0.2$ would be expected to yield an observable flux of intensity 2 photons $\text{cm}^{-2}\ \text{s}^{-1}$ at an observed wavelength $\lambda = \lambda_e(1 + z)$.

Observations of the rich cluster Abell 665 at $z = 0.181$ with the HUT instrument revealed no emission at a local wavelength of 99 nm. This set a mean life limit for cluster-binding neutrinos of $\geq 3 \times 10^{24}$ s, assuming that all the dark matter is neutrinos. Observations of IUE spectra of the cluster of galaxies surrounding the quasar 3C263 at $z = 0.646$ also revealed no emission line, setting a limit of $\geq 2 \times 10^{23}$ s if the neutrinos dominate the cluster mass. Both the IUE and the HUT workers point out that these limits are weakened if absorbing material intervenes. Neutral hydrogen absorbs 15 eV photons strongly, and dust absorbs hydrogen recombination radiation. Consequently the presence of small amounts of neutral gas and dust could destroy the emission signature. Thus the IUE and HUT observations rule out only models in which extreme concentrations occur in clusters of galaxies.

4. Conclusions

Theoretically, there exist many possibilities for massive neutrinos with non-standard interactions [11] which could fit the Sciama scenario [3, 5]. Observationally, the search for photons from decaying neutrinos divides into two parts: neutrinos local to our own Galaxy, whose decay photons appear in the EUV band, and neutrinos at cosmologically significant distances, whose photons appear in the FUV band. Neither population has been detected, but existing data rule out only highly clumped neutrino populations [11]. We conclude that 30 eV neutrinos can be responsible for most of the mass density of the universe, but large galaxies and clusters are bound by dark baryons. This reduces the total number of decaying neutrinos in clusters, and partially attenuates their decay radiation. An instrument to measure the diffuse EUV background, including the neutrino decay line predicted by Sciama, will be flown in the near future on the Spanish Minisat satellite.

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