Interactions of UHE Cosmic Ray Neutrinos with the Cosmological Neutrino Background

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Abstract

Apart from the cosmic microwave radiation background, the standard cosmology predicts a thermal neutrino background with a temperature around 2oK. Methods suggested to detect such a background, include anomalous forces exerted in sensitive devices, rotation of a polarised laser beam, etc. These are briefly reviewed. If the cosmic ray neutrino spectrum extends to the highest conceivable energies, one would expect interactions of these neutrinos with the background thermal neutrionos. Charged Lepton pair production arising in such interactions can cause dips in the UHE neutrino spectrum. Moreover one would expect resonant interactions at the W and Z masses and also at other energies if there are extra bosons beyond the standard electroweak model. The probabilities for the interactions of UHE cosmic ray neutrinos with the Dark Matter neutrino galactic halos are calculated taking all the above processes into account. The dips in the UHE neutrino spectrum due to such interactions (which are potentially observable in DUMAND or AMANDA etc.) is estimated. Other consequences are explored.

Introduction

The standard big bang cosmological model predicts an isotropic background of relic neutrinos comparable in number density to the background microwave photons i.e. about 100 cm^{-3} ($\nu + \vec{\nu}$ for each of the three species. The energy would have a red-shifted Fermi distribution with a current mean momentum of 5×10^{-4} eV and a flux $\sim 10^{12} cm^{-2} s^{-1}$. However, if one of the ν/s has a mass $m_\nu \sim$ 20-50 eV, they could be clustered in galactic halos constituting the bulk of galactic dark matter with a flux $\sim 10^{15} cm^{-2} s^{-1}$. This relic neutrino background appears undetectable at present mainly as the low neutrino energy ($\sim 10^{-5}$ eV) results in a very low energy transfer to any conceivable detector. Morever the low energy again gives a low interaction cross-section with low event rates. For instance consider as target the free electrons in a metallic foil. The typical recoil energy from collision with a galactic clustered relic neutrino is $\sim 10^{-9}$ eV (potentials < one nano volt can be detected). However, the expected event rate (for a 30 eV neutrino) is < 1 per day per kilotonne. The accompanying bremsstrahlung photon production from the interaction of relic neutrinos with conduction electrons in a multilayer metallic target is $< 10^{-3}$ day^{-1} K tonne^{-1}. Moreover these photons would have too low an energy ($< 10^{-5} eV$). Instead of single electron scattering one can consider using coherent interactions[1] with electrons (say a superconducting circuit) to produce a tiny current. Consider a one m^3 target of $\sim 10^6$ superconducting layers each of 10m × 1m connected to a SQID. When oriented parallel to galactic motion the coherent neutrino neutral current interaction is equivalent ,to an electric field $\sim 10^{-36} V cm^{-1}$ giving after 10 days a linear rise in current of only one atto ampere (10^{-18} amp). One can also look for forces due to background neutrino induced potentials eg. of Van-der-Waals type of 1/r^6 forces due to two-neutrino exchange[2]. The average distance between two neutrinos is $\sim$ 0.1 cm (α 1/T) in the background. At this distance this force between two objects (plates) is a billionth of the gravitational forces. One can also look for drag acceleration of objects in the neutrino background[3].

Again for a degenerate neutrino dark matter background a laser beam propagating through it would have its plane of polarisation rotated by $\phi \sim G_F^2 m_\nu^2 K_F^3$. For $M_\nu \sim 10eV$, $K_F \sim 10^{-3}$ eV, this gives $\sim 10^{-11}$ rad. over solar system dimensions

2. Cut-off in the UHE CR Neutrino Spectrum

If the CR neutrino spectrum extends to the highest conceivable energies (> 10^{20} or 10^{21} eV) one would expect interactions of these neutrinos with the background thermal neutrinos. We would then have a counterpart of the well known GKZ cutoff for CR protons interacting with the CMBR.

Thus one could have processes like:

$$\nu_{CR} + \vec{\nu}_b \rightarrow l^+ + l^-(l = e, \nu, \tau) \;\; etc.$$

For $M_\nu = 0$, this would be similar to the degradation of CR gamma radiation by CMBR.

We would have: (taking redshift factor Z)

$$\frac{E_{\nu_{CR}}}{\gamma} = \gamma \, E_{\nu b}(1 + Z) = 2m_l \, c^2$$

For z = 0, $E_{\nu b} = 5 \times 10^{-4} eV$, this gives a cut-off $E_{\nu_{CR}} = 2 \times 10^{15} eV$ (for l = e), $8 \times 10^{19} eV$ (for l = μ) and $2 \times 10^{22} eV$ (for l = τ). These energies scale with redshift as $(1 + Z)^{-2}$. However, electroweak theory predicts a sharp enhancement in the cross-section at the Z° mass (cms energy) this coresponding to a resonance neutrino energy of $E_{res} \approx M_z^2/2m_\nu \approx 4 \times 10^8$ TeV/m$_\nu$(10eV). At $\sqrt{s} \sim 91$ GeV, the Z° mass, the cross-section for $\nu_{CR}\bar{\nu}_b$ annihilation in all channels, peaks at $5 \times 10^{-31} cm^2$ and drops down to $10^{-34} cm^2$ at $\sqrt{s} = 150$ GeV. The peak corresponds to a $E_{\nu_{CR}}$ cut off of 5×10^8 TeV for $M_\nu \approx 10eV$. This is in the range of the 'falling brick' event. At Z=10, the cut off energy drops to to $\sim 3 \times 10^6$ TeV. This can cause strong absorption of $\nu's$ with E near this energy if DM $\nu's$ are clustered in galactic halos with a density distribution $\rho_h(r) = \rho_o/(1 + (r/r_c)^2)$. The corresponding halo DM neutrino number density is $n_{\nu_0} \approx 10^9 cm^{-3}$, a 10^6 enhancement over the thermal background. With a reconant C.S of $\sim 10^{-32} cm^2$, this implies an absorption mean free path (mfp) $\sim$ 30 KPC, i.e. comparable in size to the galactic halo Thus in principle future experiments should be able to discern such **dips** in the UHE CR ν spectrum.

Absorption In Halos

If a source produced UHE $\nu's$ at redshift Z with energy $E_Z = (1 + Z)E_o$, ν absoprtion by the DM ν background is also sizeable. For eg., if the UHE ν CR's are produced at Z=5, the neutrinos with present energy $E_o \approx 10^{20}$ eV, would have bneen almost **completely absorbed**. The effect is larger for larger Z. This is of significance in analysing the higher energy CR's in future arrays for UHE ν events and possible source location. For a typical beamed AGN source, UHE $\nu's$ will cross a DM column density $\approx n_\nu r_c \approx 10^{30} cm^{-2}$ for above parameters. The probability for absorption is $\sim exp(-M_\nu r_c \sigma \rho(E_o))$ which approaches one for an energy of $\sim 5 \times 10^{20} eV$! It is ~ 0.6 for $3 \times 10^{20} eV$, UHE ν energy. Again if there are extra bosons beyond the SM, there will further resonant absorptions at different UHE energies. For a 250 GeV boson or for a TeV boson (like in supersymmetric models) the corresponding, cut offs are at 6×10^9 TeV and $\sim 2 \times 10^{11}$ TeV respectively at Z=0. The absorption probabilities of such UHE $\nu's$ in galactic halos are similar to that given earlier[5]. It may be noted that these probabilities are much higher than the annihilation channel for the $\nu's$ with mangetic moments directly into high energy gammas. This can be estimated as $\sim 10^{-30}$ (even for a $10^{-10}\mu_B$) for a 10 KPC halo radius with a magnetic field of $10\mu G$.

After completing this work in detail, we came across a paper of E.Roulet in June 15 1994 issue of PRD, which comes to similar conclusions.

References

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