MASSIVE NEUTRINOS AND ULTRAVIOLET ASTRONOMY

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ABSTRACT

Massive neutrinos (or photinos) dominating galactic halos may decay into less massive particles by emitting ultraviolet photons. The lifetime for this process can be calculated from particle physics in a model-dependent way. The observed ultraviolet background constrains this lifetime to exceed about 10^{24} seconds. If the photon energy exceeds 13.6 ev, the existence of HI structures from the galactic plane imposes a similar constraint. The existence of Si IV and C IV in the halos of our own and other galaxies could be due to $\sim$ 50 ev photons emitted by neutrinos or photinos of rest-mass $\sim$ 100 ev if their lifetime $\sim 10^{27}$ seconds. This lifetime could be in agreement with the theoretical value for 100 ev particles.

INTRODUCTION

The idea that massive neutrinos might be unstable was suggested by Tennakone and Pakvase (1971) and by Bahcall, Cabibbo and Yahill (1972). The production of photons in such a decay process was considered by Pakvase and Tennakone (1972). The crucial idea that if massive neutrinos dominate galactic halos such photons would lie in the ultraviolet and might be detectable was introduced by de Rujula and Glashow (1980). Their calculations of the decay rate have since been improved by Pal and Wolfenstein (1982), who give references to earlier work.

An alternative possibility is that massive <u>photinos</u> play some or all of the astronomical roles which have been attributed to massive neutrinos. These photinos are spin 1/2 partners of photons in super-symmetric theories, in which bosons and fermions can be transformed into one another, and can belong to the same (super) multiplet (for a review, see Fayet and Ferrara 1977). Their role in cosmology, and in particular their decay into photons, has been considered by Cabibbo, Farrar and Maiani (1982).

Observations of the ultraviolet background can be used to place a lower limit on the radiative lifetime τ of a decaying particle of rest-mass lying in the range of 20 to 100 electron volts, which is assumed to dominate a) the universe, b) clusters of galaxies, and c) the halo of our Galaxy.

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If the photon energy exceeds 13.6 ev, the ionization of hydrogen becomes possible, and the existence of neutral hydrogen structures away from the galactic plane (in the plane absorption of such photons would dominate) can also be used to derive a lower limit on τ.

Finally, various observed or inferred ionization stages of hydrogen and helium in the intergalactic medium, and of silicon and carbon in galactic halos, including our own, if attributed to photons from decaying neutrinos or photinos, would lead to a mass ($\sim$ 100 ev) and a radiative lifetime ($\sim 10^{27}$ secs) for these particles which would be acceptable both cosmologically and in terms of elementary particle physics. These ideas could be tested by searching for a narrow line at $\sim$ 50 ev in the radiation background of the galaxy.

ELEMENTARY PARTICLE ASPECTS

The decays envisaged are $\nu_1 \to \gamma + \nu_2$, where ν_2 is a neutrino of lower mass m_2 than ν_1, and $\bar{\gamma} \to \gamma + \bar{g}$, where $\bar{\gamma}$ is a photino and $\bar{g}$ is goldstino (the spin 1/2 partner of the Goldstone boson whose existence results from the spontaneous breaking of supersymmetry).

If the parent particle is at rest relative to the observer, then conservation of energy and momentum in the decay process results in a photon energy E_γ given by:

$$E_\gamma = \frac{m_1^2 - m_2^2}{2m_1} .$$

If $m_2 << m_1$ we can simplify this to:

$$E_\gamma \sim \frac{1}{2} m_1 .$$

Thus, if m_1 lies in the range 20 to 100 ev, which is relevant both for cosmology (Cowsik and McClelland 1972) and for the domination of galaxy clusters and individual galaxiès (Tremaine and Gunn 1979), we would have:

$$E_\gamma \sim 10 - 50 \text{ ev} ,$$

(unless $m_2 \approx m_1$), so that the decay photons would lie in the ultraviolet.

The lifetime for neutrino decay depends critically on whether a cancellation process called GIM suppression is operating (GIM = Glashow, Iliopoulos, Maiani). If one assumes that there are only the three standard neutrino flavors (e-type, μ-type and τ-type), then GIM suppression would occur and theoretical values of τ would range from:

$$\frac{10^{36}}{\sin^2 2\beta_1} \left(\frac{30 \text{ ev}}{m_1}\right)^5 \text{ sec}$$

to ten times this quantity (Pal and Wolfenstein 1981). Here β_1 is the mixing angle between ν_1 and ν_2 (which also influences their oscillation rate).

This theoretical lifetime turns out to be too long to be of astronomical interest for the foreseeable future, but various mechanisms exist for eliminating the GIM mechanism. These have been discussed by de Rujula and Gashow and by Pal and Wolfenstein. Examples are introducing a fourth generation with a much heavier charged lepton (analogous to e, μ, and τ) or a fourth neutrino without an associated charged lepton. In the latter case, Pal and Wolfenstein obtain for $m_1 >> m_2$:

$$\tau \sim \frac{6 \times 10^{29}}{\sin^2 2\beta_2} \left(\frac{30 \text{ ev}}{m_1}\right)^5 \text{ sec},$$

where β_2 is the mixing angle between ν_1 and the fourth neutrino. The resulting decrease in τ would bring it into the realm of astronomical interest if $\sin^2 2\beta_2$ is not much less than unity, as we shall see.

The photino lifetime has been calculated by Cabibbo, Farrar and Maiana (1982). They obtain:

$$\tau \sim 6.8 \times 10^{22} \left[\frac{d}{(100 \text{ Gev})^2}\right]^2 \left(\frac{30 \text{ ev}}{m_{\tilde{\gamma}}}\right)^5 \text{ sec},$$

where d is a parameter associated with the breaking of supersymmetry (roughly speaking, this breaking occurs at an energy $\sim d^{1/2}$). There is no question of GIM suppression here, but the value of d is unknown. Some particle physicists consider that it is likely to exceed the weak interaction value of 10^5 Gev^2. For the lower part of this range ($d \leq 3 \times 10^7$ Gev^2), the resulting decay rate would be faster than even the enhanced neutrino rate, and again could be astronomically relevant.

Finally, we note that values of τ which would arise if leptons and quarks are composite have been considered by Stecker and Brown (1982).

ASTRONOMICAL LOWER LIMITS ON τ

We note first the coincidence that the photon flux at the Earth coming from the proposed galactic neutrinos has the same order of magnitude as that coming from cosmological neutrinos (ignoring absorption effects for the moment). This follows from the fact that the proposed galactic enhancement in the neutrino concentration over its cosmological value is of the same order ($\sim 10^5$) as the ratio of the radius of the universe ($\sim$ 3000 Mpc) to the scale-height of the galactic halo ($\sim$ 30 kpc). The main difference is that the galactic flux is nearly monochromatic (since the velocity-dispersion of the galactic neutrinos $\sim$ 200 km/sec << c), whereas the cosmological flux would be drawn out into a continuous spectrum by the differential redshift associated with the expansion of the universe.

In fact, this spectrum would have the form:

$$\underset{(\lambda \geq \lambda_0)}{I_\lambda} = \frac{c n_\nu(z=0)\ \lambda_0^{3/2}}{H_o\ 4\pi\tau\ \lambda^{5/2}} \left[1 + (2q_o - 1)\left(1 - \frac{\lambda_0}{\lambda}\right)\right]^{-1/2},$$

where λ_0 is the rest wavelength of the decay photon, λ the observed

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wavelength, τ the neutrino lifetime and q_0 the deceleration parameter. Any absorption effects would have to be added to this relation. (There is a numerical error $\sim 10^4$ in equation [7c] of de Rujula and Glashow [1980] which has been corrected by Kimble, Bowyer and Jakobsen [1981]).

It has been pointed out by Stecker (1980) and Kimble, Bowyer and Jakobsen (1981) that one can use this spectrum to obtain lower limits on τ from the observed ultraviolet background even if λ_0 corresponds to a wavelength at which the galaxy is opaque. Since the observed background is probably due to other sources, it has been used to limit τ rather than to determine it. From an observed background $\sim$ 200 to 300 photons cm^{-2} sec^{-1} ster^{-1} A^{-1}, they deduce that:

$$\tau > 10^{22} - 10^{23} \text{ sec}; \quad 10 \text{ ev} < \frac{hc}{\lambda_0} < 50 \text{ ev}$$

if the intergalactic medium is transparent out to the largest redshifts involved ($z \sim 6$). We return to the question of this transparency later.

Stecker also discussed the possibility that a reported increase in the background at 1700 Å might represent a photon flux from galactic neutrinos and he suggested that $\tau \sim 3 \times 10^{24}$ sec. According to Kimble, Bowyer and Jakobsen, this increase has not been confirmed and is best treated as an upper limit to the actual intensity.

These authors also derived a lower limit on τ for galactic neutrinos, from the general observed background in the 30 to 50 ev range (which corresponds to the mass range in which neutrinos of cosmological origin could dominate the Galaxy). Their limit depends on the uncertain opacity of the Galaxy at these photon energies, and on the photon energy itself, but lies in the range:

$$\tau > 10^{20} - 10^{22} \text{ sec}; \quad 30 \text{ ev} < E_\gamma < 50 \text{ ev} .$$

More stringent limits have been derived by Shipman and Cowsik (1981) and Henry and Feldman (1981) from optical and ultraviolet observations of the Virgo and Coma clusters of galaxies. If these clusters are dominated by neutrinos of appropriate mass, the derived limits are:

$$\tau > 10^{23} - 10^{25} \text{ sec}; \quad 1 \text{ ev} < E_\gamma < 10 \text{ ev} .$$

Shipman and Cowsik consider that with existing or proposed instruments one could improve these limits up to the range 10^{26} to 10^{27} sec.

All these limits are derived from direct observations of photon fluxes. One can also use arguments derived from the ionizing effects of photons, as pointed out by Melott and Sciama (1981). These differ from the previous arguments in that they can lead to limits on (or perhaps evaluations of) photon fluxes at positions distant from the galactic plane, where the effects of absorption by neutral hydrogen or dust will be different (and in general less). For example, Melott and Sciama (1981 demanded that these photon fluxes should not completely ionize the High Velocity Clouds. These clouds are neutral hydrogen features observed at 21 cm to be predominantly approaching us with velocities of a few hundred kilometers per second. Various arguments suggest that some clouds lie at least a kiloparsec above the galactic plane, while a recent estimate puts them at tens of kiloparsecs away. In fact, the limits obtained for τ are valid so long as the clouds lie within the Local Group of galaxies, but not within the galactic plane. One finds in this way that:

$$\tau > 10^{24} \text{ sec}; \quad E_\gamma > 13.6 \text{ ev} .$$

These astronomical lower limits on τ are several orders of magnitude less than the expected theoretical values, except for photinos with a small value of d. The next step should therefore be to search for more sensitive ionization processes which would lead either to an actual effect being identified, or at least to a much more stringent limit on τ in the relevant photon energy range. Some possible ionization processes will be considered in the next section.

POSSIBLE IONIZATION PROCESSES

We consider first the intergalactic medium, which is generally believed to be highly ionized in H I and He I (this is inferred from the absence of absorption troughs in quasar spectra (Gunn and Peterson 1965; Green *et al.* 1980; Wampler *et al.* 1973; Ulrich *et al.* 1980). The ionization source is unknown. Perhaps the most plausible possibility is ultraviolet radiation from quasars (Sherman 1981).

The ionization of intergalactic H I by photons from decaying cosmological neutrinos was suggested by Raphaeli and Szalay (1981) and by Sciama (1981a). The first authors took $\tau < 10^{25}$ sec, which would lead to ionization at relatively early cosmic epochs, but is in disagreement with most of the particle physics expectations. Sciama took $\tau \sim 10^{27}$ sec, which may avoid this disagreement, but would lead to ionization of H I only after a cosmic epoch corresponding to a redshift ~ 4 and only for a low density intergalactic medium. He also pointed out that if He I is ionized in this way, one would need $m_\nu >> 50$ ev in order that the decay photons be energetic enough. On the other hand, if appreciable quantities of He II are present in the IGM (which might be testable by observations with IUE [Gondhalekar 1981] or Space Telescope) one might be able to infer that $m_\nu \lesssim 110$ ev.

Another possible ionization process involves Si IV and C IV in galactic halos. The presence of these high ionization stages is known for the Milky Way halo from the IUE observations (*e.g.*, Savage and de Boer 1979, 1981; Bromage, Gabriel and Sciama 1980; Ulrich *et al.* 1980; Pettini and West 1982). Their presence in other galactic halos would follow from the now widely-held view that many of the absorption line systems in quasar spectra arise in intervening galactic halos (Weymann, Carswell and Smith 1981; Young, Sargent and Boksenberg 1982).

The ionization involved could be collisional in origin ($T \sim 10^5$°K) or due to photons from hot stars, hot gas, or the integrated ultraviolet radiation from quasars, etc. The recent observations of Pettini and West (1982) which suggest that in our Galaxy N(C IV)/N(Si IV) = 4.5 ± 1.5 throughout the region between 1 and 3 kpc from the galactic plane, put in doubt both the collisional explanation (which would require an abnormally constant temperature throughout this region [but see

Hartquist 1982]), and the hot stars (whose radiation would be too soft to give the observed C IV/Si IV ratio).

The other conventional explanations are numerically reasonable, but may be ineffective because of absorption of H I, He I and He II near the plane of the Galaxy, in the outer regions of the halo, in intergalactic space, and in quasars. Accordingly, it is of interest to examine the possibility that the ionization is due to photons from decaying neutrinos (Sciama and Melott 1982) or photinos (Sciama 1982b,c) which are assumed to dominate galactic halos. Such particles would then exist close to any observed Si IV and C IV, and this might overcome the absorption problem. Evidence against this ionization hypothesis has been adduced by Feldman, Brune and Henry (1981), who observed an emission line component of the background radiation field at high galactic latitudes. They attributed this to hot gas in the halo, which they also related to the observed Si IV and C IV. However, their observed emission lines could have been produced in warm gas close to the galactic plane (Deharveng, Joubert and Berge 1982). This seems the likely explanation in view of the results of Pettini and West on the constancy of the C IV/Si IV ratio noted above.

The photon energy required to produce C IV (47.9 ev) would imply that the parent particle has a mass $\sim$ 100 ev, and the abundance of C IV then implies that $\tau \sim 10^{27}$ sec. These results are cosmologically reasonable, are compatible with some of the particle physics estimates of τ and are comparable to the values required by the IGM ionization hypothesis. However, if we demand that the universe has the critical density (Guth 1982), its age would be rather low ($\sim 7 \times 10^9$ years) for neutrinos, and photinos might be a better choice. The reason is that for photinos we could tentatively take $d \sim 5 \times 10^7$ Gev^2. They would then decouple earlier in the big bang than do neutrinos ($T_d \sim 200$ Mev instead of 1 Mev) (Sciama 1982c) and so would have a lower cosmological number density by a factor ~ 4 (since muons and pions annihilating after photinos decouple would feed the 3°K background but not the photinos). A critical density in photinos would then correspond to a higher age for the universe ($\sim 13 \times 10^9$ years) which would be more compatible with other estimates of this quantity. Moreover, with this value of d and $m_{\tilde{\gamma}} \approx 100$ ev, $\tau_{\tilde{\gamma}}$ would be close the value $\sim 10^{27}$ sec required by our ionization hypothesis. Finally, we note that this suppression of the photino abundance would just be compatible with primordial nucleosynthesis, which appears to permit three "neutrino" types but not four so long as they were relativistic at the time of nucleosynthesis (Schramm 1982).

These ideas could be tested by searching for a narrow line ($\Delta\lambda/\lambda < 10^{-3}$) in the galactic background at ~ 50 ev with a flux $\sim 10^3$ photons cm^{-2} sec^{-1}. It is hoped that such a measurement can be carried out in the near future.

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Discussion

Stecker: It should be pointed out that some recent analyses based on observations of He in less evolved galaxies give a very low primordial He abundance ($\sim$ 21.6%) as compared with the prediction of the standard model with $N_\nu \gtrsim 3$ ($\gtrsim$ 25%). This has important complications for all arguments trying to limit N_ν, since they may be basically self-contradictory (Stecker, 1980, Phys. Rev. Lett., 44, 1237; 46, 517; Rana, 1982, Phys. Rev. Lett., 48, 209; Rayo et al., 1982, Ap. J., 255, 1).

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Sciama: A recent critical analysis of the data on helium abundances by Pagel at the Royal Society meeting on cosmology yields a preferred value of 0.25. This is partly based on the recent work of Kunth and Sargent, shown on a poster at this meeting. This value, together with an estimate of n_b/n_γ of 3×10^{-10}, would lead to an allowed number of effective neutrino types lying between 3 and 4. This result would be important if correct, as it would require photinos to be suppressed (unless the tau neutrino is more massive than 1 Mev, so that it was nonrelativistic when neutrons froze out).