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Updated parameters for the decaying neutrino theory and EURD observations of the diffuse UV background

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Abstract. Various recent observational developments are here used to make a more critical analysis of the parameter space of the decaying neutrino theory for the ionisation of the interstellar medium. These developments involve phenomena inside our Galaxy, outside the Galaxy but at essentially zero red shift, and at large red shifts. This new analysis leads to a viable theory with a decay lifetime of $2{\pm}1 \times 10^{23}$ sec, a decay photon energy of $13.7{\pm}0.1$ eV, and a mass for the decaying neutrino of $27.4{\pm}0.2$ eV.

These parameters, when combined with some known astronomical quantities, lead to predictions for the intensity, the wavelength and the width of the decay line produced by neutrinos lying within one optical depth of the sun $(\sim\frac{1}{2}\,\mathrm{pc})$. One finds an intensity in the line of 350^{+350}_{-117} photons cm^{-2} sec $^{-1}$, a wavelength of 905 ± 7Å, and a width ~ 1Å. These predictions are relevant for the observations about to be made by the EURD ultra-violet detector which is currently in Earth orbit on board the Spanish MINISAT 01 satellite.

Key words: elementary particles – quasars: absorption lines – cosmology: dark matter – cosmology: diffuse radiation

1. Introduction

A variety of recent observational developments, including Hipparcos data and the probable discovery of the HeII Gunn-Peterson effect (Zheng et al 1998), make it desirable to update the parameters of the decaying neutrino theory for the ionisation of hydrogen in warm opaque regions of the interstellar medium (Sciama 1990a, 1995, 1997a). In particular we need to prepare for the forthcoming observations of the extraterrestrial diffuse background at wavelengths below 912Å to be made by the EURD detector (Bowyer et al 1995, Morales et al 1997, Bowyer, Edelstein & Lampton 1997) on board the Spanish MINISAT 01 satellite. This satellite was successfully launched on April 21 1997, and at the time of writing the detector is working well. One of its tasks is to search for a decay line emitted by neutrinos within half a parsec of the sun.

The decaying neutrino theory makes a number of specific predictions for a variety of phenomena within individual galaxies,in intergalactic space at red shifts in the range 0 to 5, and in the early universe at red shifts between 5 and 1000. Two recent successes may be noted here. The first is the observational verification of its prediction that the density of free electrons in the interiors of warm opaque interstellar clouds near the sun should be (a) substantial (~ 0.05 cm^{-3}) and (b) the same in each cloud (Spitzer & Fitzpatrick 1993, Sciama 1997a).

The second success concerns its rather precise predictions (Sciama 1997b) that the Hubble constant should be 55 ± 0.5 km sec^{-1} Mpc^{-1} and that the age of the universe should be 12 ± 0.1 Gyr. While the actual values of these quantities remain controversial, it is noticeable that there has been a general tendency recently for the higher estimates of both these quantities to be significantly reduced. Moreover a number of these recent estimates are in good agreement with our predictions, although the observational uncertainties are still in the range 10 to 20 %, rather than our uncertainty of 1% .

The decaying neutrino theory is based on three parameters, namely, the rest mass m_ν of the decaying neutrino, its radiative lifetime τ, and the monochromatic energy E_γ of the decay photon in the rest frame of its parent neutrino. For simplicity we follow popular (but unproved) particle physics models (such as the see–saw model (Yanagida 1978, Gell-Mann, Ramond & Slansky 1979)) in which the secondary neutrino in the decay has a much smaller mass than m_ν. In that case $E_\gamma = \frac{1}{2}\,m_\nu$, and there are only two parameters to be determined, namely, τ and E_γ.

In Sect. 2 τ is determined from the observed ionisation in the interstellar medium and from observational limits on the diffuse extragalactic background at 1500Å. Its value is found to be 2 ± 1x10^{23} sec. In Sect. 3 E_γ is determined from upper limits on the extragalactic hydrogen–ionising background at various redshifts to be 13.7 ± 0.1eV. Finally Sect. 4 discusses the implications of these results for the forthcoming observations by EURD. In particular, with the help of additional astronomical parameters, estimates are given for the intensity, the wavelength, and the width of the decay line postulated to be emitted by neutrinos in the vicinity $(\sim \frac{1}{2}\,\mathrm{pc})$ of the sun.

2. The decay lifetime τ

2.1. The ionisation of the interstellar medium

An upper limit on τ will now be derived from recent estimates of the maximum permitted density of dark matter near the sun and of the free electron density n_e which is here being attributed to the ionisation of hydrogen by decay photons.

In Sect. 2.2 a lower limit on τ will be determined from recent observational upper limits on the extragalactic diffuse background at 1500 Å, which impose an upper limit on the flux of red shifted decay photons emitted by the cosmological distribution of neutrinos.

Our derived upper and lower limits on τ are only just consistent with one another, and so lead to a highly constrained value for this quantity.

To derive the upper limit on τ consider a region near the sun whose atomic hydrogen density makes it opaque to ionising decay photons. In ionisation equilibrium one would have

$$\frac{n_\nu}{\tau} = \alpha\, n_e^2, \qquad (1)$$

where n_ν is the local number density of neutrinos and α is the recombination coefficient (excluding recombinations directly to the ground state). The value of n_e which the theory attributes to ionisation by decay photons has been recently rediscussed by Sciama (1997a). Using observations of dispersion measures for nearby pulsars with known radio parallaxes (Gwinn et al 1986, Bailes et al 1990), and HST observations of the absorption spectrum of the halo star HD93521 (Spitzer & Fitzpatrick 1993) (which are somewhat less straightforward to interpret), the result obtained was $n_e = 0.05 \pm 0.01 \mathrm{cm}^{-3}$ (Reynolds 1990, Sciama 1990 b, 1997a).

The value of α depends on the temperature T of the gas. For the relevant regions of the interstellar medium with the better determined values of n_e one has $T < 2\mathrm{x}10^4\, K$ (Reynolds 1985). Hence $\alpha > 1.3 \times 10^{-13} \mathrm{cm}^3\, \mathrm{sec}^{-1}$ (Ferland et al 1992).

Finally, to derive an upper limit on τ an upper limit on the number density n_ν must be established. This can be obtained from an upper limit on the local mass density of neutrinos ρ_ν, since earlier discussions of the decaying neutrino theory have already provided a sufficiently accurate value for m_ν, namely $\sim$ 28eV (Sciama 1990 a, 1995). An upper limit on ρ_ν near the sun was recently derived by Sciama (1997 b) in connexion with values for the largest permitted flattening of the neutrino halo and for the rotational velocity of the Galaxy at the sun's position. By taking into account various estimates for column densities of material near the sun an upper limit for ρ_ν of 0.03 $M_\odot \mathrm{pc}^{-3}$ was obtained. This upper limit would be associated with the largest permitted flattening of the dark halo (Dehnen & Binney 1997), corresponding to an axial ratio of 0.2 (shape E8). It is reassuring that some other galaxies do seem to exhibit a similar flattening (Sackett et al 1994, Olling 1996, Becquaert & Combes 1997).

The local mass density ρ_ν can also be determined by comparing dynamical estimates of the total density ρ_o near the sun (the Oort limit) with the densities of known stars and gas. The value of ρ_o has been controversial; an estimate will be used here which is based on recent Hipparcos observations of F stars, and so may lead to a more reliable result. This result is $\rho_o = 0.11 \pm 0.01 M_\odot$ pc^{-3} (Pham 1996, 1997). However, a lower value for ρ_o has recently been obtained from Hipparcos data by Crézé et al (1998), namely $0.076 \pm 0.015 M_\odot$ pc^{-3}. This result seems rather low when compared to the density of known matter (see below) and the disagreement remains to be clarified. Here we provisionally adopt Pham's value.

The contribution of known stars and gas to ρ_o is itself somewhat uncertain. Often quoted values for each are $0.04 M_\odot$ pc^{-3} (e.g. Bienaymé, Robin & Crézé 1987, Crézé et al 1998). The stellar contribution may have to be increased to allow for the existence of faint stars, but the HST deep survey suggests that this additional contribution may be small (e.g. Gould et al 1996). If this is correct, one again obtains an upper limit for ρ_ν of $0.03 M_\odot$ pc^{-3}. This upper limit was previously derived by Bienaymé et al (1987). If now $m_\nu = 27.4\, \mathrm{eV}$, as derived in Sect. 2.2, there follows an upper limit for n_ν near the sun of $4.16 \times 10^7 \mathrm{cm}^{-3}$.

Our limits on the values of n_ν, α and $n_e (\geq 0.04 \mathrm{cm}^{-3})$ now lead, in conjunction with (1), to the conclusion that

$$\tau \leq 2 \times 10^{23}\ \mathrm{sec}. \qquad (2)$$

This result can be shown to be compatible with our interpretation of Reynolds' (1984) global Hα data for the Galaxy (Sciama 1997b).

2.2. The extragalactic background at 1500 Å

Some of the earliest lower limits on τ (for a decaying neutrino not then related to the ionisation of the interstellar medium) were based on observational estimates of the cosmic background in the far ultra-violet, which was compared with the red shifted decay flux produced by the cosmological distribution of neutrinos (Stecker 1980, Kimble, Bowyer & Jakobsen 1981). Estimates of this background are still controversial (compare Bowyer 1991 with Henry 1991). Recent contributions to the discussion have been made by Henry & Murthy (1993), Witt & Petersohn (1994) and Witt, Friedmann & Sasseen (1997). We adopt from their discussions an upper limit of about 300 photons cm^{-2} sec^{-1} ster^{-1}Å^{-1} (continuum units or CU) at 1500Å. From this value one must subtract the contribution due to galaxies, which has been evaluated by Armand, Milliard and Deharveng (1994) as about $40 - 130\, CU$, leaving an upper limit of about $200\, CU$ available for the decay flux.

Theoretical aspects of this flux have been re-discussed by Sciama (1991), Overduin, Wesson & Bowyer (1993), Dodelson & Jubas (1994) and most recently by Overduin & Wesson (1997). These calculations show that a decay flux of $200\, CU$ at 1500 Å corresponds to a lifetime τ of 2×10^{23} sec. Hence

$$\tau \geq 2 \times 10^{23}\ \mathrm{sec}. \qquad (3)$$

Our overall conclusion from this discussion is that, if the decaying neutrino theory for the ionisation of the interstellar medium is correct, the decay lifetime τ is determined as

$$\tau \sim 2 \times 10^{23} \text{ sec.} \tag{4}$$

The uncertainty in this estimate is difficult to pin down. A reasonable guess would be 50% at most. Hence we adopt

$$\tau = 2 \pm 1 \times 10^{23} \text{ sec.} \tag{5}$$

We note, however, that if the Crézé et al (1998) value for ρ_o is correct no solution for τ is possible, and the decaying neutrino theory would be ruled out.

3. The photon energy E_γ

3.1. The H_α flux from intergalactic HI clouds

Existing attempts to observe H_α radiation from opaque intergalactic HI clouds lead to an upper limit on the hydrogen–ionising photon flux F incident on the clouds arising from the cosmological distribution of neutrinos. This upper limit on F then leads to an upper limit on E_γ because of the role of the red shift in reducing the energy of a decay photon to below 13.6 eV. Write

$$E_\gamma = 13.6 + \epsilon \text{ eV.} \tag{6}$$

Then, if $\frac{\epsilon}{13.6} \ll 1$, F at zero red shift $F(0)$ is given by

$$F(0) = \frac{n_\nu(0)}{\tau} \frac{c}{H_o} \frac{\epsilon}{13.6}, \tag{7}$$

where $n_\nu(0)$ is the standard cosmological number density of neutrinos at $z = 0$, (namely $3/11$ of the number density of photons in the cosmic microwave background), c is the velocity of light, and H_o is the present value of the Hubble constant. In the decaying neutrino theory $H_o = 55 \pm 0.5$ km sec^{-1}Mpc^{-1} (Sciama 1997c).

The H_α upper limit observations of Vogel et al (1995) and of Donahue, Aldering & Stocke (1995) imply that $F(0) \leq 10^5$ photons cm^{-2} sec^{-1}. Since $n_\nu(0) = 112.6 \pm 0.5\,\text{cm}^{-3}$ (Sciama 1997c) it follows that

$$\frac{\epsilon}{\tau} \leq 7 \times 10^{-25} \text{ eV sec}^{-1}. \tag{8}$$

Combining this inequality with our previous value for τ, one obtains

$$\epsilon \leq 0.2 \text{ eV}, \tag{9}$$

so that indeed $\frac{\epsilon}{13.6} \ll 1$. It follows that

$$E_\gamma \leq 13.8 \text{ eV.} \tag{10}$$

We need not be too surprised that E_γ is required to be so close to the ionisation potential of hydrogen, since cosmological considerations alone had previously suggested that $m_\nu \sim 28$ev, so that $\frac{1}{2} m_\nu \sim 14$ eV, which is within 3% of 13.6 eV.

The upper limit on $F(0)$ is based on the assumption that the intergalactic clouds are so opaque that essentially every incident ionising photon actually produces a free electron which then recombines with a proton. However, the clouds concerned may contain holes in their HI distribution which would then permit a larger ionising flux to be compatible with the observed upper limits on the $H\alpha$ flux (Bland-Hawthorn 1996). The covering factor of the clouds concerned is in fact unknown. It is therefore desirable to establish an independent upper limit on $F(0)$. Such a limit can be obtained from constraints on the hydrogen-ionising flux at red shifts in the range 2 to 4.5. These constraints can be obtained in two independent ways: (i) from the proximity effect in Lyman α clouds at these red shifts (Bajtlik, Duncan & Ostriker 1988) and (ii) from the recently observed absorption by He II at 304 Å in the spectra of high red shift QSOs.

3.2. The proximity effect in Lyman α clouds

The proximity effect is the reduction in the number of Lyman α clouds near a QSO (Murdoch et al 1986). This effect can be used to derive an upper limit on the ionising decay flux F(z) at a red shift z in the range 2 to 4.5. The relation $F(z) = (1+z)^{\frac{3}{2}} F(0)$ (Sciama 1990a) then leads to an upper limit on $F(0)$. Absorption of decay photons by intergalactic clouds does not have to be taken into account in deriving this relation even at $z \sim 2$ or greater, where in principle the absorption would be much larger than at $z \sim 0$ (eg. Haardt & Madau 1996), because with our small value for ϵ the red shift reduces the energy of a decay photon to below 13.6 eV in a shorter distance than the absorption mean free path even at large z.

The proximity effect was first used by Bajtlik, Duncan & Ostriker (1988) to derive the background ionisation rate Γ per H atom for $1.7 < z < 3.8$ by attributing this effect to the additional and known direct ionising influence of the QSO on nearby clouds. They obtained $\Gamma \sim 3 \times 10^{-12}\,\text{sec}^{-1}$, with an uncertainty of a factor 3 either way. They also found that, within their uncertainty, Γ did not vary significantly with z. Of the many later attempts to determine Γ and its possible variation with z, the most recent are due to Giallongo et al (1996), Lu et al (1996), Savaglio et al (1997) and Cooke, Epsey & Carswell (1997). Despite the considerable remaining uncertainties there is a consensus that $\Gamma \sim 2 \times 10^{-12}\,\text{sec}^{-1}$, with no significant z variation out to $z = 4.5$.

There has been much discussion in the literature as to whether the population of QSOs alone can provide a sufficient ionising flux to account for Γ. According to Haardt & Madau (1996) $\Gamma_{\text{QSO}} \sim 10^{-12}\,\text{sec}^{-1}$ at $z \sim 2$, but only $2 \times 10^{-13}\,\text{sec}^{-1}$at z ~ 4.5. The discrepancy of a factor ~ 10 at $z \sim 4.5$ appears to be significant, even if the one at $z \sim 2$ lies within the uncertainties.

All the estimates of Γ from the proximity effect which have so far been made have been based on the simple assumption that the influence of the QSO on the nearby clouds is entirely due to the additional direct ionisation which it produces. However, as Miralda-Escudé & Rees (1994) (MR) pointed out, one should also allow for the additional heat input due to the radiation from the QSO. The resulting expansion of the clouds reduces their electron density, and the increase of temperature reduces the recombination coefficient, so that the recombination rate of the clouds is reduced. The net additional ionisation produced by the QSO is thus increased, and so the implied value of the background ionisation rate is also increased. MR further pointed out that, since the main contribution to the additional heating comes from the ionisation of He II in the clouds, the effect is larger where the QSO (but not the general UV background) is capable of ionising He II. This remark has become particularly pertinent now, because it seems that ionisation breakthrough for He II in the intergalactic medium may not have occurred until $z \sim 3$ (Songaila & Cowie 1996, Hogan et al 1997, Reimers et al 1997, Boksenberg 1998, Songaila 1998), a situation which was theoretically anticipated by MR and by Madau & Meiksin (1994).

While the numerical value of the MR effect is model dependent (preliminary attempts to estimate it having been made by MR themselves) it is clear that it has two consequences for our discussion. It leads to an increase in the (small) discrepancy between Γ and $\Gamma_{\rm QSO}$ at $z \sim 2$, and to an increase of Γ with z, in contrast to the rapid decrease in $\Gamma_{\rm QSO}$.

It has often been suggested that any discrepancy between Γ and $\Gamma_{\rm QSO}$ could be resolved by appealing to ionising radiation emitted by hot stars in galaxies (eg. Miralda-Escudé and Ostriker 1990). Recent discussions of this possibility have been given by Giroux & Shapiro (1996) and by Madau & Shull (1996). Metal-enrichment arguments imply that if $\sim 25\%$ of the Lyman continuum photons emitted by hot stars escape from their parent galaxies, then these photons would be responsible for an ionisation rate $\sim 10^{-12}\,{\rm sec}^{-1}$ per H atom at $z \sim 3$. The actual escape fraction is not known at high z, but at $z \sim 0$ it is less than 1% (Deharveng et al 1997). This strong constraint was deduced by relating the H_α luminosity density of star-forming galaxies in the local universe (Gallego et al 1995) to the H_α observations of Vogel et al (1995) and Donahue et al (1995) which, as already mentioned, lead to an upper limit on the hydrogen-ionising flux at $z \sim 0$. Although the escape fraction is not known at high z, there exists evidence for considerable dust extinction in galaxies at these redshifts (Meurer 1997, Cimatti et al 1997). Absorption by atomic hydrogen in these galaxies may also be important.

This argument has recently been much strengthened by the observations of Spinrad et al (1998) which failed to detect any Lyman continuum radiation escaping from $z > 3$ Lyman-limit galaxies. According to these authors it is implausible that ionising radiation from young galaxies can replace QSO ionisation at $z > 4$.

Another much-discussed possibility is that radiation from stars at red shifts much greater than 5 (the so-called Population III stars) might make an appreciable contribution to Γ and be responsible for the reionisation of the universe at $z > 5$. Recent discussions of this possibility have been given by Haiman & Loeb (1997), Gnedin & Ostriker (1997) and Gnedin (1998). An important aspect of this proposal concerns the level of metallicity which would result from the required stellar activity. It is not clear whether this level agrees with observation, especially in view of the low metallicity recently derived by Songaila (1997) for the Lyman α clouds. We cannot go into this intricate question here,and since we are seeking an upper limit on the intergalactic flux of decay photons, it will now be assumed that most of the missing ionising photons at $z \sim 2$ to 4.5 are produced by the cosmological distribution of decaying neutrinos and not by hot stars.

This assumption would enable us to understand why the usual interpretation of the proximity effect leads to a value of Γ which is approximately independent of z. If, at $z \sim 2$, Γ_ν is of the same general order as $\Gamma_{\rm QSO}$ then, as z increases, Γ_ν would increase as $(1+z)^{\frac{3}{2}}$ while $\Gamma_{\rm QSO}$ decreases, leaving Γ approximately constant.

It would seem that a rough upper limit for Γ_ν can be derived by setting $\Gamma_\nu \sim 2\,\Gamma_{\rm QSO}$ at $z = 2$. Then, since at this red shift $\Gamma_{\rm QSO} \sim 10^{-12}\,{\rm sec}^{-1}$ according to Haardt & Madau (1996), Γ_ν would $\sim 2\times10^{-12}\,{\rm sec}^{-1}$ and $\Gamma \sim 3\times10^{-12}\,{\rm sec}^{-1}$. This excess of Γ over the proximity effect value of $\sim 2\times10^{-12}\,{\rm sec}^{-1}$ could be attributed to the MR effect. Indeed, since in this picture Γ_ν is the dominant contributor to Γ, the spectrum of the QSO would differ appreciably from that of the background, and the MR effect would then be greater than in the pure QSO case (Rees 1990, Sciama 1995). Finally, it should be noted that, with our adopted values, Γ would increase by a factor 1.7 between $z = 2$ and $z = 4.5$. This increase could be consistent with the dependence of the MR effect on z.

Our upper limit on Γ_ν at $z = 2$ implies an upper limit on Γ_ν at $z = 0$ of $4\times10^{-13}\,{\rm sec}^{-1}$. Since the decay photons have an energy close to the Lyman limit this ionisation rate converts to a photon flux by using the photoionisation cross-section at this limit, which is $6\times10^{-18}\,{\rm cm}^2$. Hence one obtains $F(0) \leq 7\times10^4{\rm cm}^{-2}{\rm sec}^{-1}$, which is not essentially different from the upper limit $\sim 10^5{\rm cm}^{-2}{\rm sec}^{-1}$ derived by Vogel et al (1995) and by Donahue, Aldering & Stocke (1995), the precise value of which in fact depends on the uncertain shapes of the intergalactic clouds which they observed.

3.3. HeII absorption at $z \sim 3$

We now show that the recently derived Gunn-Peterson optical depth in HeII at $z \sim 3$, $\tau_{\rm GP,HeII}$ (Zheng et al 1998), in conjunction with the known upper limit on $\tau_{\rm GP,HI}$, leads to a lower limit on Γ at $z \sim 3$. It turns out that this lower limit is close to the upper limit estimated in Sec. 3.2.

There now exist a number of observations of HeII absorption at $z \sim 2$ to 3 in the spectra of QSOs (Jakobsen et al 1994, Tytler et al 1995, Jakobsen 1996, Davidsen, Kriss & Zheng 1996, Hogan, Anderson & Rogers 1997, Reimers et al 1997). There has been considerable discussion in these and other papers (Madau & Meiksin 1994, Fardal, Giroux & Shull 1998) as to whether this absorption is entirely due to the HeII in Lyman α clouds,or whether part of it must be attributed to the Gunn-Peterson effect arising in an essentially diffuse intergalactic medium. We here follow the calculations of Zheng, Davidsen & Kriss (1998), which lead to a definite value of $\tau_{\rm GP,HeII} = 1$ for this effect at $z = 3$. This would imply that $n_{\rm HeII}(3) = 4 \times 10^{-10}$ $\rm cm^{-3}$. To see whether this result is reasonable we derive from it the implied value of the total diffuse intergalactic gas density $n(3)$ at $z = 3$, using estimates for the HeII-ionising flux due to QSO radiation filtered through the absorbing medium of Lyman α clouds and Lyman limit systems (Haardt & Madau 1996, Fardal, Giroux & Shull 1998), and the value 0.08 for the He/H number ratio. Using $\Gamma_{\rm HeII} = 6 \times 10^{-15}$ $\rm sec^{-1}$ one obtains $n(3) = 4.7 \times 10^{-6}$ $\rm cm^{-3}$. Comparing this with the higher of the two competing values for the total baryon density $n_b(3)$, based on measurements of the deuterium abundance and the theory of big bang nucleosynthesis (Schramm & Turner 1998), one finds that $n(3)/n_b(3) = 0.36$.

This result is compatible with the somewhat model-dependent estimate of $\Omega_{\rm Ly\alpha}(3)$ made by Giallongo, Fontana & Madau (1997). These authors found that at $z \sim 3$ about half of n_b could be attributed to gas in Lyα clouds, leaving about half for the IGM (since the contribution from galaxies can here be neglected (Persic & Salucci 1992)). Given the uncertainties, this fraction of 1/2 is compatible with our derived value of 0.36.

The next step is to use the 1σ upper limit of 0.04 for $\tau_{\rm GP,HI}(3)$ (Giallongo, Cristiani & Trevese 1992). Since

$$\frac{\tau_{\rm GP,HeII}}{\tau_{\rm GP,HeI}} = 0.1\,\frac{\Gamma_{\rm HI}}{\Gamma_{\rm HeII}} \tag{11}$$

it follows that

$$\Gamma_{\rm HI} \geq 250\,\Gamma_{\rm HeII}, \tag{12}$$

so that $\Gamma_{\rm HI} \geq 1.5 \times 10^{-12}\ \rm sec^{-1}$. This lower limit is compatible with the upper limit for $\Gamma_{\rm HI}$ ($\sim 3 \times 10^{-12}$ $\rm sec^{-1}$) proposed in Sec. 3.2.

This comparison is not strictly self-consistent because, by choosing a value of $\Gamma_{\rm HI}$ greater than that due to QSOs, a disturbance has been introduced into the calculation of the opacity of the universe,since the ionisation state of the absorbers would be affected. This disturbance would be reduced if in fact $\Gamma_{\rm HeII}$ from QSOs had to be increased by a factor of the same order as the ratio $\Gamma_{\rm HI}/\Gamma_{\rm QSO} \sim 3$, since then $\Gamma_{\rm HI}/\Gamma_{\rm HeII}$ would not be much altered.

An increase in the HeII - ionising power of QSOs over that arising from the usual power-law spectrum has already been proposed by Sciama (1994), who needed to ensure that an increase in $\Gamma_{\rm HI}$ due to decay photons would not drive the universe to become completely opaque at the HeII edge. This proposal was based on existing observational hints that many QSOs possess a soft x-ray excess in their spectra. This excess was attributed to a Guilbert-Rees (1988) thermal bump with $T \sim 50$ eV, resulting from the reprocessing of harder x-rays from the central regions of QSOs by optically thick cold material. Since 1994 further observational evidence has accumulated for the prevalence of a soft x-ray excess in the spectra of QSOs. This evidence has been reviewed by Gondhalekar, Rouillon-Foley & Kellett (1996). It is also noteworthy that a 50 eV bump would fit nicely in the gap (due to galactic absorption) in the composite spectrum shown in fig.6 of Laor et al (1997). On the theoretical side it has been found recently that a slim accretion disk around a black hole at the centre of a QSO would produce a soft x-ray excess without any Guilbert-Rees reprocessing (Shimura & Takahara 1995, Szuszkiewicz 1996, Szuszkiewicz, Malkan & Abramowicz 1996).

These arguments have recently been strengthened by the considerations of Korista, Ferland & Baldwin (1997) who pointed out that a QSO emission spectrum without a bump at 50 ev would not account (via excitation effects) for the observed strengths of the HeII emission lines in QSO spectra. These authors suggested that either the QSOs have a suitably complicated geometry, or that their emission spectrum contains a significant bump in the vicinity of the HeII ionisation edge at 54.4 ev.

A rough estimate for the resulting increase in $\Gamma_{\rm HeII}$ led to a factor ~ 3.6 (Sciama 1994). If the actual factor were closer to 2 the absorption analysis would still not be much changed, while the lower limit on $\Gamma_{\rm HI}$ would be increased to 3×10^{-12} $\rm sec^{-1}$ which is the same as our proposed approximate upper limit. A self-consistent solution is thus possible. For this solution one would have $n(3)/n_b(3) = 0.5$, which is in good agreement with the estimate implied by the calculations of Giallongo, Fontana & Madau (1997).

Our proposed introduction of an appreciable flux of decay photons at high z also has implications for the abundance of HeI at these red shifts. It was argued by Miralda-Escudé & Ostriker (1992) and by Reimers et al (1993) that the low values of $N_{\rm HeI}$ observed in Lyman limit systems and Lyman α clouds are incompatible with the decaying neutrino theory. However, Sciama (1994) showed that if QSOs possess a soft x-ray bump in their spectra, the resulting high ionisation of HeII in the various cloud systems would sufficiently lower their abundance of HeI. A further reduction in $N_{\rm HeI}$ could arise from hot stars in galaxies, since the escape fraction of HeI-ionising photons would be expected to exceed that of HI-ionising photons. Accordingly the existence of an appreciable flux of decay photons at high z is not incompatible with the observed values and upper limits on $N_{\rm HeI}$.

Our conclusion from all these considerations is that it is unlikely that F(0) can be increased by a substantial factor, say ~ 2, over the upper limit derived from the $H\alpha$ measurements of intergalactic clouds, by appealing to a small HI covering factor in these clouds. Accordingly the constraint $E_\gamma \leq 13.8$ eV still holds good, so that

$$E_\gamma = 13.7 \pm 0.1\,{\rm eV} \tag{13}$$

$$m_\nu = 27.4 \pm 0.2\,{\rm eV}, \tag{14}$$

and, from Sect. 2

$$\tau = 2 \pm 1 \times 10^{23}\,{\rm sec}. \tag{15}$$

These are our updated parameters for the decaying neutrino theory. It should be noted that these parameters lead to precise values for the Hubble constant H_0 $(55 \pm 0.5\,{\rm km\,sec^{-1}Mpc^{-1}})$ and the age of the universe $(12 \pm 0.1$ Gyr) (Sciama 1997c), if the cosmological constant is zero.

4. Predictions for the EURD observations

We now predict the intensity, the wavelength and the width of the decay line due to neutrinos near the sun. The uncertainties which will be quoted are not formal errors but represent reasonable ranges for the values of these parameters. An attempt to detect this line is currently being made by the EURD detector (Bowyer et al 1995, Morales et al 1997, Bowyer, Edelstein & Lampton 1997) which is on board the orbiting Spanish satellite MINISAT 01.

To determine the intensity of the line one must know the opacity of the medium surrounding the sun for photons just beyond the Lyman limit. In fact the sun is known to be immersed in a partially neutral hydrogen cloud, which is the central part of what is called the Local Interstellar Medium (Cox & Reynolds 1987). The best determinations of the volume density n_{HI} of HI near the sun have been derived from HST observations of the Lyman α absorption line in the spectra of Procyon $(l = 214°, b = 13°, d = 3.5\text{pc})$ (Linsky et al 1995) and of ϵ Ind $(l = 336°, b = -48°, d = 3.46\text{pc})$ (Wood, Alexander & Linsky 1996). They obtained for the lines of sight to these two stars $n_{\rm HI} = 0.1065 \pm 0.0028$ cm^{-3} and 0.094 ± 0.022 cm^{-3} respectively. The two stars lie in rather different directions, so it is comforting that they lead to the same value of $n_{\rm HI}$, namely 0.1 cm^{-3}. The corresponding mean free path l for a photon at the Lyman limit $\sim \frac{1}{2}$ pc, which is substantially less than the distances to the two stars. Accordingly the flux in the line at the sun, which is $\frac{n_\nu l}{\tau}$, will be 350^{+350}_{-117} cm^{-2} sec^{-1}, since $n_\nu = 4.16 \times 10^7$ cm^{-3} and $\tau = 2 \pm 1 \times 10^{23}$ sec.

The wavelength λ of the line for our updated value of E_γ is

$$\lambda = 905 \pm 7\text{Å}. \qquad (16)$$

The error quoted is the uncertainty in the central wavelength, not the linewidth, which, as we shall see, is about 1Å. Unfortunately our predicted wavelength falls right inside the position of a much stronger nightglow emission feature which stretches from about 900Å to 911Å, and is due to the recombination of OII in the Earth's outer atmosphere (Chakrabarti 1984, Chakrabarti, Kimble & Bowyer 1984). This emission feature was detected by the EUV spectrometer on board the STP78-1 satellite which was launched in 1979. The minimum intensity of the detected feature is 15 Rayleighs, which is $\sim 5 \times 10^4$ times greater than our predicted flux for the decay line. Nevertheless it may be possible to observe this line if sufficient data are available (Bowyer 1997).

Finally we consider the expected width of the decay line. This width is due to the velocity dispersion v of the neutrinos producing the line. For a simple isotropic isothermal sphere model of the neutrino halo of our Galaxy one would have $v = \sqrt{\frac{3}{2}} v_{rot}$, where the asymptotic rotation velocity v_{rot} of the Galaxy can be taken to be about 220 km. sec^{-1} (Binney & Tremaine 1987). Thus $v \sim 270$ km. sec^{-1} and so $\Delta\lambda < 1$Å, which is much less than the wavelength resolution of EURD. However, recently Cowsik, Ratnam & Bhattacharjee (1996) have claimed to have constructed a self-consistent model of the dark matter halo of our Galaxy which requires v to lie between 600 and 900 km. sec^{-1}. This claim has been challenged by Evans (1997), Gates, Kamionkowski & Turner (1997) and Bienaymé & Pichon (1997), and Cowsik et al (1997) have replied to the first two criticisms.

We do not wish to enter into this controversy here, and merely note that, if the decay line could be detected and its width measured, one would be able to deduce directly the velocity dispersion of the neutrinos. In this connexion it should be noted that in our strongly flattened model for the neutrino halo (Sciama 1997b), referred to in Sect. 2, the velocity dispersion, and so the linewidth, would depend strongly on direction. One could imagine measuring this anisotropic effect in a future mission with adequate wavelength resolution, if the decay line could be disentangled from the OI emission feature. In addition, if the neutrino halo itself has little or no rotation, one might be able to observe the Doppler effect associated with the sun's rotation in the Galaxy, which would shift the central wavelength of the line by nearly ∓ 1Å in directions parallel and antiparallel to the sun's motion.

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