DIFFUSE COSMIC X-RAYS FROM NON-THERMAL INTERGALACTIC BREMSSTRAHLUNG

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Abstract. The diffuse X-ray background between 1 keV and 1 MeV is interpreted as non-thermal bremsstrahlung in the intergalactic medium. The observed break in the X-ray spectrum at ~ 40 keV yields the heat input to the intergalactic medium, the break being produced by ionization losses of sub-cosmic rays. Proton bremsstrahlung is found not to yield as satisfactory an agreement with observations as electron bremsstrahlung: excessive heating tends to occur. Two alternative models of cosmic ray injection are discussed, one involving continuous injection by evolving sources out to a redshift of about 3, and the other model involving injection by a burst of cosmic rays at a redshift of order 10. The energy density of intergalactic electrons required to produce the observed X-rays is $\sim 10^{-4}$ eV/cm^3. Assuming a high density ($\sim 10^{-5}$ cm^{-3}) intergalactic medium, the energy requirement for cosmic ray injection by normal galaxies is $\sim 10^{58-59}$ ergs/galaxy in sub-cosmic rays. The temperature evolution of the intergalactic medium is discussed, and we find that a similar energy input is also required to explain the observed high degree of ionization (if 3C9 is at a cosmological distance).

1. Introduction

The diffuse X-ray background between 1 keV and 1 MeV has been measured by many different experimenters over the past 5 years. Paying particular attention to the most recent results presented at this Symposium, we note two significant conclusions that may be drawn from the data. Out of the galactic plane, the diffuse background appears to be remarkably isotropic. Also, there appears to be a change in slope, between 20 and 60 keV.

The isotropy of the X-ray background has been an important feature of earlier attempts at interpretation. These have generally assumed a metagalactic origin, and may be divided into either discrete source models or models involving X-ray production in the intergalactic medium. It was soon apparent that normal galaxies, if assumed to have X-ray luminosities comparable to that of our own galaxy, would be inadequate to account for the diffuse background (Oda, 1965), and evolving discrete source models were proposed (Bergamini *et al.*, 1967, subsequently denoted by BLS; Silk, 1968). One of the less appealing aspects of these models is that, in order to enhance the X-ray background at the cost of the radio background one has to appeal in essence to a new class of X-ray sources, emitting at redshifts exceeding those attainable by radio sources. A somewhat different approach involves inverse Compton scattering of 3K black-body radiation in the intergalactic medium (Felten and Morrison, 1966), and is essentially independent of evolutionary assumptions (Brecher and Morrison, 1967).

However, realization of the break in the X-ray spectrum at $\varepsilon_b \sim 40$ keV has prompted reconsideration of these models. In particular, the discrete source models are found to impose stringent requirements on source evolution (Silk, 1969; Felten and Rees, 1969). For example, in the BLS interpretation, ε_b has a strong z-dependence: with the

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radio source model suggested by Rees and Setti (1968) one requires $\varepsilon_b \alpha (1+z_*)^{-11}$, where z_* is the limiting redshift at which evolutionary effects are important. Now z_* is found to be ~ 4 from studies of radio source counts, and in a Friedmann cosmology there is no reason to expect a sharp cut-off in source distribution with z. Only in somewhat esoteric circumstances, such as occur, for example in the Lemaître cosmology, could one hope to reconcile the BLS model with observation.

Intergalactic inverse Compton radiation produces a break at ε_b provided that the metagalactic relativistic electron spectrum has a corresponding break at $\gamma_b \simeq (\varepsilon_b/\langle\varepsilon\rangle)^{1/2}$, where $\langle\varepsilon\rangle \simeq 3.6kT$ and $T=2.7\,\mathrm{K}$. Brecher and Morrison (1969) have recently suggested that this requirement may in fact be met by electrons injected from normal galaxies. However, an intrinsic break in the electron source spectrum at $\sim\gamma_b$ is hypothesized by these authors without proposing any physical mechanism which would somehow constrain γ_b to be similar for all normal galaxies.

Clearly, none of these interpretations can be regarded as accounting in a satisfactory manner for the diffuse X-ray spectrum. We wish to discuss in the present contribution a mechanism which provides a natural (i.e. model-independent) explanation of the 40 keV break. Non-thermal bremsstrahlung in the intergalactic medium by a power-law spectrum of fast electrons (or protons) will produce a power-law photon spectrum with the same differential energy spectral index (for non-relativistic particles). The stopping of the cosmic rays in the intergalactic medium by ionization losses produces a break in their spectrum, and this is reflected by a corresponding curvature in the X-ray bremsstrahlung spectrum. We show below that the spectral region at which this effects occurs depends on the density of the intergalactic medium n_0 and only very weakly, if at all, on z_*. There is essentially no dependence on the properties of individual sources, although the mode of cosmic ray injection enters as a parameter which is determined by the X-ray spectrum at $\varepsilon < \varepsilon_b$. A consequence of this model is that one may also account for the thermal properties of the intergalactic medium. Indeed, the heat input to the intergalactic medium is essentially determined by our interpretation of ε_b.

2. Relaxation of Cosmic Ray Spectra

We first discuss how one may study the relaxation of a cosmic-ray spectrum, subject to losses by adiabatic expansion of the metagalaxy and coulomb losses in the intergalactic medium. The relaxation of a cosmic-ray flux $J(E)$ $(\mathrm{cm}^2-\mathrm{sec}-\mathrm{st}-\mathrm{keV})^{-1}$ is described by a Fokker-Planck equation for a spatially uniform system of the form (cf. Kardashev, 1962)

$$\frac{\partial}{\partial t}\left\{\frac{J(E,z)}{(1+z)^3\,V(E)}\right\} + \frac{\partial}{\partial E}\left\{\frac{b(E,z)\,J(E,z)}{(1+z)^3\,V(E)}\right\} = \frac{S(E,z)}{V(E)}\,. \tag{1}$$

Here $V(E)$ is the velocity of a cosmic ray, $b(E,z)$ is an energy loss term, and $S(E,z)$ is the source function, for which we shall consider two models. For case A, we take

$$S_{\mathrm{A}}(E,z) = J(E,z)\,\delta(z-z_*)\,.$$

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This describes an initial burst of cosmic rays, at redshift z_*. For case B we write

$$S_B(E, z) = q(z)\, E^{-\gamma},$$

where we now consider the effects of continuous injection of cosmic rays. Possible evolutionary effects are contained in the z-dependence of $q(z)$. Cases A and B, in an appropriate linear combination, may be taken to represent a realistic model for cosmic ray injection.

In order to solve (1), it is necessary to specify the energy loss term $b(E, z)$. Consider first the relaxation of a non-relativistic electron spectrum, for which $b(E, z)$ takes the form

$$b(E, z) \equiv \frac{\mathrm{d}E}{\mathrm{d}t} = -\frac{2E}{t(z)} - \frac{E_{cr}^{3/2}}{E^{1/2}} \frac{(1+z)^3}{t_0}. \tag{2}$$

The first term on the right-hand side represents the effect of adiabatic expansion and the second term describes Coulomb losses. In deriving the second term we have made use of the energy loss formula for a fast non-relativistic electron in ionized hydrogen with electron density $n_0(1+z)^3$ cm^{-3}, namely (Montgomery and Tidman, 1964)

$$\frac{\mathrm{d}E}{\mathrm{d}t} = -\xi \frac{n_0 (1+z)^3}{\sqrt{E_{\mathrm{keV}}}} \text{ keV sec}^{-1}, \tag{3}$$

where

$$\xi = 7.35 \times 10^{-10} \ln(24\pi\eta_0 L_D^3),$$

and we shall neglect the slight variation of the logarithmic factor. After a time t_0 electrons below a critical energy $E_{cr}(z) = (1+z)^2 \times (\xi n_0 t_0)^{2/3}$ are substantially depleted. If t_0 is identified with the characteristic time-scale for energy loss by adiabatic expansion, we have $t_0 = H_0^{-1}\, \alpha(1+z)^{-\alpha}$, where $H_0^{-1} = 4 \times 10^{17}$ sec (Sandage, 1968). We consider two cosmological models, defined by $\alpha = 1.5$ (an Einstein-de Sitter cosmological model in which $q_0 = \frac{1}{2}$ and $n_0 \simeq 10^{-5}$ cm^{-3}), and $\alpha = 1$ (a low density-universe with $q_0 = 0.02$ and $n_0 \simeq 10^{-7}$ cm^{-3}). Hence we may write $E_{cr}(z) = (1+z)^{2-2\alpha/3}\, E_{cr}$ where $E_{cr} = (\xi n_0 H_0^{-1})^{2/3}$. Numerically we obtain $E_{cr} \simeq 1$ MeV with $n_0 = 10^{-5}$ and $E_{cr} \simeq 50$ keV with $n_0 = 10^{-7}$. The corresponding values of E_{cr} for a cosmic ray proton spectrum are larger by a factor $\sim (m_p/m_e)^{1/3}$.

We have derived analytic solutions for $J(E, z)$ in a few cases of interest, both for the burst and continuous injection source functions. For the burst source function $S_A(E, z) = K(z)\, E^{-\gamma}\, \delta(z - z_*)$, we find that the power law shape is preserved above $E_{cr}(z)$. In this region, ionization losses are negligible compared with the adiabatic expansion losses. For $E \ll E_{cr}(z)$, the spectrum relaxes to $J(E)\, \alpha E$, and the complete solution is

$$J(E, z) = KE^{-\gamma} \left(\frac{1+z}{1+z_*}\right)^{2(\gamma+1)} \times \left[1 + \frac{3}{2}\left(\frac{E_{cr}}{E}\right)^{3/2} \frac{(1+z)^{3-\alpha}}{\alpha} \left\{1 - \left(\frac{1+z}{1+z_*}\right)^{\alpha}\right\}\right]^{-2(\gamma+1)/3}.$$

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With the continuous injection source function S_B, the power-law spectrum is also maintained for $E \gg E_{cr}(z)$. However, for $E \ll E_{cr}(z)$, we find that $J(E, z) \propto E^{-(\gamma - 3/2)}$. Exact solutions have been found in analytic form only for an evolutionary function $q(z) = q_0 (1+z)^m$, for specific values of γ or m. Here it will suffice to give the asymptotic solutions, valid for arbitrary m. For $E \ll E_{cr}(z)$

$$J(E, z) \simeq \frac{q_0 t_0}{(\gamma - 1)\,\alpha} \frac{(1+z)^{2\gamma}}{(1+z_*)^{2(\gamma-1)-m}} \left(\frac{E}{E_{cr}}\right)^{3/2} E^{-\gamma} \times \left[1 - \left\{1 + \frac{3}{2}\frac{(1+z)^{3-\alpha}}{\alpha}\left(\frac{E_{cr}}{E}\right)^{3/2}\left(1 - \left(\frac{1+z}{1+z_*}\right)^{\alpha}\right)\right\}^{-2(\gamma-1)/3}\right] \tag{5}$$

and for $E \gg E_{cr}(z)$,

$$J(E, z) \simeq \frac{t_0 q_0 (5 - 2\alpha)/3}{\alpha + 2\gamma - m - 2} (1+z)^{m+3-\alpha} E^{-\gamma}. \tag{6}$$

The flattening by $\frac{3}{2}$ power of energy is due to the fact that the stopping time $t_0 E^{3/2}$ determines the equilibrium spectrum, to a first approximation. In order to take proper account of relativistic effects, especially for the $n_0 = 10^{-5}$ cm^{-3} model, it is necessary to seek exact numerical solutions of (1). Further details of these solutions will be given elsewhere (Arons *et al.*, 1970). One may then include additional energy losses, such as inverse Compton losses for relativistic electrons. However, we shall here restrict ourselves to a qualitative discussion based on the asymptotic relaxation spectra.

3. Cosmic Ray Electron Bremsstrahlung

A noteworthy feature of cosmic-ray bremsstrahlung as a mechanism for producing diffuse X-rays is that the cosmological expansion predicts a significant enhancement at earlier epochs. At the present epoch, non-thermal bremsstrahlung is an extremely inefficient process, and we find that unrealistically high fluxes of metagalactic cosmic rays would be required to explain the X-ray background. The effects of cosmology are apparent from the expression for the X-ray flux (Silk and McCray, 1969)

$$I(\varepsilon) = cH_0^{-1} n_0 \int_0^{z_*} j\{\varepsilon(1+z), z\} \frac{dz}{(1+z)^{\alpha+1}} \text{ keV} \times (\text{cm}^2\text{-sec-st-keV})^{-1} \tag{7}$$

where the bremsstrahlung emissivity is given by

$$j(\varepsilon, z) = \int_\varepsilon^\infty \chi(\varepsilon, E)\, J(E, z)\, dE \quad \text{keV}\,(\text{sec-st-keV})^{-1}. \tag{8}$$

Here, $\chi(E, \varepsilon) = 2\pi\alpha\sigma_T \beta^{-2}\, G(E, \varepsilon)/\sqrt{3}$ and $G(E, \varepsilon)$ is the Gaunt factor (Bekefi, 1966). A power-law spectrum of non-relativistic cosmic-ray electrons $J(E) = KE^{-\gamma}$ gives rise to an X-ray flux $I(\varepsilon)$, which is a power law with the same exponent γ. The slope of

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the X-ray spectrum resulting from bremsstrahlung of relativistic particles is $\gamma - 1$. It then follows that photons of energy $\varepsilon > \varepsilon_{cr} \equiv E_{cr}(z)/(1+z)$ originate from that part of the electron spectrum not affected by stopping. Note that ε_{cr} has only a weak dependence on redshift, varying at most as $(1+z)^{1/3}$ if $n_0 = 10^{-7}\ \text{cm}^{-3}$.

The effects of cosmology on the cosmic-ray requirements of this model are best seen by considering the energy range where stopping is unimportant. We may then obtain an analytic expression for the X-ray flux (negelecting the energy dependence of the Gaunt factor)

$$I(\varepsilon) = I_0(\varepsilon) f(z_*),$$

where $I_0(\varepsilon) = cH_0^{-1} j(\varepsilon)$. Approximate expressions for $f(z_*)$ are, in model A,

$$f(z_*) = [(1 + z_*)^{\gamma + 2 - \alpha} - 1]/(\gamma + 2 - \alpha) \tag{9}$$

and in model B,

$$f(z_*) = [(1 + z_*)^{m + 3 - \alpha - \gamma} - 1]/(m + 3 - \alpha - \gamma). \tag{10}$$

The required electron flux is reduced at the present epoch from that required if the effects of cosmology were negligible (i.e. $0 < z_* \ll 1$) by $\sim [f(z_*)]^{-1}$.

For $\varepsilon > \varepsilon_{cr}$, stopping is unimportant, and the X-ray energy spectral index is γ. At photon energies $\varepsilon < \varepsilon_{cr}$, however, stopping is significant, and the burst model produces an essentially flat X-ray spectrum ($\gamma \simeq 0$). The continous injection model gives an X-ray spectrum of slope $\sim (\gamma - \frac{3}{2})$, for $\gamma > 2.5$, below ε_{cr}. These remarks are not exact, because relativistic bremsstrahlung is one power flatter than non-relativistic bremsstrahlung, for the same electron spectrum. Hence relativistic effects, especially in the high-density model, will modify the spectra.

In the burst model, the observations are best fitted with a low-density intergalactic medium ($n_0 = 10^{-7}$). With $z_* = 10$, we require a metagalactic electron density of $\sim 10^{-4}\ \text{eV/cm}^3$. The injected electron spectral index is 2.5, and above 100 keV, the X-ray slope is approximately 1.5 (Silk and McCray, 1969). Alternatively, we might consider the continuous injection model. This would enable us to utilize a high density intergalactic medium ($n_0 = 10^{-5}$). With burst injection, the X-ray spectrum would flatten below ε_{cr}, and with ε_{cr} ~ 1 MeV, too flat a spectrum would result. However, by continuous injection of an electron spectrum with $\gamma \simeq 2$, the X-ray spectrum is steepened sufficiently at low energies to fit the observations, which indicate a slope of ~ 0.5 below 40 keV.

4. Cosmic Ray Proton Bremsstrahlung

We have hitherto been concerned mainly with bremsstrahlung by cosmic-ray electrons. However, much of our discussion is valid for the analogous case of inner-bremsstrahlung by cosmic-ray protons, originally suggested as a possible mechanism by Hayakawa and Matsuoka (1964). Identification of ε_b as due to the stopping of fast protons in the intergalactic medium would then be an alternative possibility. In this section, we explore the feasibility of this suggestion.

The cross-section for bremsstrahlung by fast protons is reduced by m_e/m_p relative to that for electrons, for non-relativistic particles of the same energy (the centre of momentum of the proton-electron collision being approximately that of the fast proton). Thus an electron of energy E and a proton of energy $E(m_p/m_e)$ produce a similar bremsstrahlung spectral intensity. Hence with burst injection, we require the proton spectrum to break at ~ 30 MeV in order to produce ε_b at ~ 15 keV. Since $E_{cr}^{\text{proton}} \sim (m_p/m_e)^{1/3} E_{cr}$ we see that a high density intergalactic medium may just allow this, although if n_0 were less than 2.10^{-5} the X-ray spectrum would remain steep at too low an energy. Continuous injection does not modify this requirement on n_0. Moreover, the proton spectral index must be ~ 1.2 at injection to produce the required X-ray slope above the break.

5. Heating of the Intergalactic Medium

The lack of Ly α absorption in 3C9 offers compelling evidence, provided we accept that this quasar is at a cosmological distance, that the intergalactic medium is highly ionized. Sciama (1964) realized that ionization losses by sub-cosmic rays would be an important heat source for the intergalactic medium, and a detailed discussion was subsequently given by Ginzburg and Ozernoi (1966). In an analogous manner we now estimate the heating due to the cosmic-ray flux $J(E, z)$ derived earlier.

In our interpretation of the X-ray background the heat input to the intergalactic medium is essentially an observable quantity, determined by ε_b. The energy transferred by sub-cosmic rays to the intergalactic medium is comparable to that remaining in the relaxed spectrum, which is itself of order

$$W(E_{cr}, z) \simeq 4\pi \int_{E_{cr}(z)} EJ(E, z) \frac{\mathrm{d}E}{V(E)}. \tag{11}$$

The rate of heat input is $L = W(E_{cr}, z)/t(z)$. Denoting by L_0 the value of L at $z=0$, we find that $L = L_0(1+z)^{5+p}$, where $p = 2\alpha\gamma/3$ in the burst model, and $p = m + 1 + 2\alpha\gamma/3 - \alpha - 2\gamma$ in the continuous injection model. One would have guessed $p=0$ without carrying out the calculation, since the energy density of subcosmic rays varies as $(1+z)^5$. The difference is due to the fact that we are taking proper account of the effect of ionization losses on the injected spectrum of cosmic rays. Values of W_0 ($\equiv L_0 t_0$, the energy density of cosmic rays at $z=0$) are given in Table I for cosmic ray electrons, with $n_0 = 10^{-5}$ and 10^{-7}, and $z_* = 3$ and 10. Similar results for protons are given in Table II.

Following Ginzburg and Ozernoi (1966), we have solved the energy equation for the kinetic temperature $T(z)$ as a function of epoch. We find (if $p \neq \alpha$)

$$\frac{T(z)}{(1+z)^2} = T_* + T_1 \frac{\alpha}{\alpha - p} \left[(1+z)^{-(\alpha - p)} - (1 + z_*)^{-(\alpha - p)}\right], \tag{12}$$

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TABLE I

Parameters for electron bremsstrahlung
Injected electron spectral index $\gamma = 2.5$

	continuous injection ($m = 3$)		burst	
n_0 (cm^{-3})	10^{-5}		10^{-7}	
E_{cr} (keV)	1300		60	
z_*	3	10	3	10
W_0 (eV/cm^3)	10^{-4}	10^{-5}	10^{-2}	10^{-4}
T_1 (K)	10^5	10^4	10^9	10^7
P_{inj} (ergs/galaxy)	10^{59}	$10^{58.5}$	$10^{62.5}$	10^{62}

TABLE II

Parameters for proton bremsstrahlung.
Injected proton spectral index $\gamma = 1.2$
$n_0 = 2.10^{-5}$ cm^{-3}, $E_{cr} = 30$ MeV

	continuous injection ($m = 3$)			burst	
z_*	10	30	100	10	30
W_0 (eV/cm^3)	10^{-2}	10^{-3}	10^{-4}	10^{-3}	$10^{-4.5}$
T_1 (K)	5.10^6	5.10^5	5.10^4	5.10^5	10^4
P_{inj} (ergs/galaxy)	$10^{61.5}$	10^{61}	$10^{60.5}$	10^{63}	$10^{62.5}$

where $T_1 = L_0 t_0 / n_0 k$. Numerical values for T_1 are given in Table I. This expression indicates that cosmic-ray heating allows T to decrease less rapidly with z than in adiabatic expansion. A steeper cosmic-ray spectrum would produce more heating at $z \sim z_*$, but the temperature decrease with z would rapidly tend towards its adiabatic dependence on z, if $p > \alpha$. The effect of enhanced evolution (increasing m) is similar in the case of continuous injection of cosmic rays. However, for $m \simeq 3$, as suggested by the radio source counts (Longair, 1966) and $\gamma = 2.5$, we find $p < \alpha$, and the temperature satisfies

$$T(z) \simeq T_1 (1 + z)^{2 + p - \alpha} \tag{8}$$

for $z \ll z_*$. Quasar observations (Schmidt, 1968) indicate a somewhat larger value for m, of about 5. Consequently if $p > \alpha$, we have

$$T(z) \simeq T_1 (1 + z)^2 (1 + z_*)^{p - \alpha}. \tag{9}$$

Now observations of diffuse soft X-rays (< 1 keV) enable limits to be set on the thermal emission from the intergalactic medium. In fact recent observational data set the limit (Bunner *et al.*, 1969) $T(0) \lesssim 10^6$ K. (If the measured flux is interpreted as thermal bremsstrahlung of the intergalactic medium, then $n_0 \simeq 2 \times 10^{-6}$ cm^{-3}; however, possible contributions from local sources have not yet been eliminated). Hence a constraint on possible injection models is $T_1 \lesssim 10^6$ K, in the high density model. This imposes severe limitations on the proton bremsstrahlung mechanism. From Table II it appears that one has to take $z_* \gtrsim 30$ to avoid excessive thermal bremsstrahlung by over-heating the intergalactic medium. Electron bremsstrahlung, however, enables one to choose $z_* \sim 3$ in the case of continuous injection (see Table I). On the other hand, with a low density intergalactic medium and burst injection, we require $z_* \gtrsim 10$, otherwise a power-law spectrum would not be produced below 100 keV.

6. Conclusion

Various properties of the non-thermal bremsstrahlung interpretation of diffuse X-rays are summarised in Tables I and II. Choice of n_0 determines E_{cr}, and the required present energy density of intergalactic cosmic rays W_0 is determined once z_* is chosen. The temperature $T_1 = W_0/n_0k$ is related by (8) or (9) to the present kinetic temperature of the intergalactic medium. We have also estimated the energy requirements at injection, defining the energy requirement per galaxy to be $P_{inj} = W(z_*)/n_g(z_*)$. $n_g(z) = n_g(0)\,(1+z)^3$, and $n_g(0) \simeq 2\times 10^{-75}$ cm^{-3} is the observed number density of normal galaxies.

It is apparent that P_{inj} is only slightly reduced by appealing to large values of z_*. If we regard it as desirable to minimize the energy requirements, then the most favourable model involves continuous cosmic-ray electron injection in a high density universe. An ionized intergalactic medium is maintained by heating by supra-thermal electrons for $3 \lesssim z_* \lesssim 10$, and between 10^{59} and $10^{58.5}$ ergs/galaxy are required at z_* in 10 or 100 MeV electrons.

The situation does not change significantly even if the injected energy is in the form of subcosmic ray protons. This is because the subcosmic rays lose energy by production of plasma waves which are extremely efficient at accelerating thermal electrons in the Maxwellian tail (cf. Pikel'ner and Tsytovich, 1969). These electrons are then stopped by interacting with the thermal plasma. Hence with injection into the IGM at z_* of 10^{59} ergs/galaxy in 100 MeV protons, one still has almost as much energy present in fast electrons. Pikel'ner and Tsytovich show that the electron spectrum has a power-law behaviour, cutting off above m_ec^2. Hence proton inner-bremsstrahlung in the IGM would necessarily imply far more X-radiation via electron bremsstrahlung from electrons produced in this manner for protons of energy $\sim E_{cr}^{proton}$. For the two mechanisms to give equal contributions, the proton energy must exceed $\sim 10\ E_{cr}^{proton}$. One can therefore only hope to account for the break at ε_b by the stopping of suprathermal protons if the X-radiation is predominantly electron bremsstrahlung.

It is of interest to note that a recent interpretation of diffuse galactic γ-rays by electron bremsstrahlung requires that our galaxy contains ~ 1eV/cm^3 in 10 MeV electrons, or about $10^{58.5}$ ergs averaged over 10^{10} years (Rees and Silk, 1969). Uncertainty in solar modulation allows one to assume a low-energy electron flux of this magnitude. If this suggestion is correct, then ionization losses by these electrons are an important heat source for interstellar H I regions. The possible excess γ-ray flux over the extrapolated X-ray background at ~ 1 MeV reported at this Symposium by Vette *et al.* may be attributed in a bremsstrahlung interpretation to the transition from nonrelativistic to relativistic electron energies, where the photon spectrum flattens by one power. This explanation requires an injection spectral index of about 1.5. At electron energies above a few MeV, inverse Compton losses become important. Provided that in this energy range, the injected electron spectrum has a spectral index no flatter than 2.5, the inverse Compton radiation at keV energies produced by ultrarelativistic electrons interacting with microwave photons will be an order of magnitude lower in intensity than the bremsstrahlung X-rays. Proton inner-bremsstrahlung seems to be less plausible than electron bremsstrahlung as a mechanism for the X-ray background because z_* must exceed ~ 30. Improved spectral measurements of the diffuse component should enable us to choose between different injection models, since the degree of flattening below ε_b is a direct measure of continuous injection of cosmic rays.

Measurement of small-scale fluctuations in the diffuse X-ray background would also provide a means of distinguishing between different theories. Electrons with energy $E \ll E_{cr}$ do not travel far from their sources, and the stopping distance increased with increasing electron energy. Consequently, with a diffuse bremsstrahlung origin of the X-ray background, fluctuations in the background should be present at $\varepsilon \ll \varepsilon_b$, and their amplitude should *decrease* with increasing photon energy. However if the diffuse X-rays are produced by inverse Compton scattering of microwave photons by ultrarelativistic electrons in the IGM, background fluctuations should *increase* with increasing photon energy (since the more energetic an electron, the shorter its mean free path against inverse Compton losses). If the diffuse X-rays are produced by discrete sources, there seems to be no reason to expect any correlation between fluctuation scales and photon energy observed.

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