The e^+-e^- Annihilation Line and The Cosmic X-Ray Background

Demosthenes Kazanas and Richard A. Shafer
NASA/Goddard Space Flight Center, Code 665, Greenbelt,
MD. 20771 and University of Maryland

Abstract

The possibility that the processes responsible for the Cosmic X-ray Background (CXB) would also produce an e^--e^+ annihilation feature is examined. Under the assumption that these processes are thermal, the absence of a strong e^--e^+ annihilation feature places constraints on the compactness (L/R ratio) of these sources. Observations favor sources of small compactness ratio.

1. INTRODUCTION

The fact that the X-ray sky is dominated by an isotropic component (the so called Cosmic X-ray Background, hereafter CXB) had been established by the earliest X-ray astronomy observations (Giacconi et al 1962). The subsequent sattelite X-ray observations, especially by the A-2 and A-4 experiments on HEAO 1 (Marshall et al. 1980), allowed the detailed spectral determination of CXB. The observed spectrum in the region 5-150 KeV, along with the higher energy data is shown in fig 1. Marshall et al. (1980) find a remarkably good fit of this spectrum to that expected from thermal bremsstrahlung from

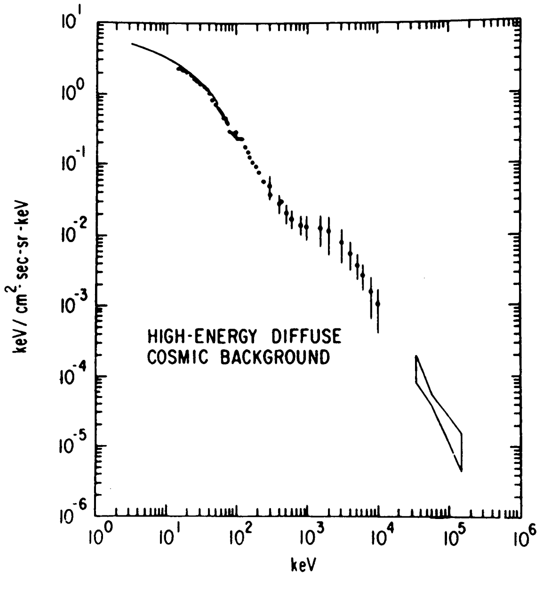

Fig. 1 - The diffuse X and gamma-ray background. (From Ramaty and Lingenfelter 1982).

G. O. Abell and G. Chincarini (eds.), Early Evolution of the Universe and Its Present Structure, 19–22.

https://doi.org/10.1017/S0074180900038511 Published online by Cambridge University Press

an optically thin plasma of temperature 40 ± 5 keV. Interestingly enough, no studied population of sources is known to have a thermal spectrum with the required properties. One can of course contrive to combine sources with a variety of spectra emitting over a range of red shifts to produce the observed total background spectrum, even if the individual spectra are different than that of CXB (DeZotti 1982). The shape of of the spectrum however clearly suggests a thermal distribution of rather specific temperature and it would be more "natural" if the CXB could be explained as such. A thin thermal bremsstrahlung from a heated intergalactic medium will provide such a spectrum (Cowsik and Kobetich 1972; Field and Perrenod 1975).

However, the energy required to heat a diffuse uniform medium to such a temperature is quite large. Clumping of the medium however may provide a solution to the problem since it would reduce the input energy requirements. Taken to its extremes, the thin thermal bremsstrahlung clumps might be reduced to a size comparable to galaxies, or smaller, becoming equivalent to the known "compact" sources of x-rays.

For either the heated intergalactic medium or the "compact source" models for the CXB, the bulk of the emission originates at redshifts $\gtrsim$ 2-3 (or maybe even larger) so that the corresponding source temperature would be kT$\gtrsim$ 100-200 keV. For these temperatures a sufficiently compact source would thermally produce electron-positron pairs from the tails of the photon and particle distributions. Under certain conditions the positron abundance would be sufficient to produce an observable e^+-e^- annihilation feature in the CXB.

2. THE POSITRON ABUNDANCE

In a thermal plasma of temperature kT$\gtrsim$ 100 KeV it is possible to produce positrons at significant abundances by ee, eγ or $\gamma\gamma$ collisions since a non-negligible fraction of the particles and photons at the tails of the distributions fulfills the pair production threshold condition. Their steady state abundance is determined by the balance between pair production and annihilation reactions (Lightman 1982).

In the cases of interest for the CXB the dominant production is due to $\gamma\gamma$ reactions so the ee, eγ will not be currently considered. The approximate expressions for the relevant rates then are:

$$R_{\gamma\gamma} \simeq \frac{3}{8}\sigma_\tau c n_\gamma^2 \phi^3 e^{-2\phi} \text{ (Weaver 1976)}$$
$$R_{+-} \simeq \frac{3}{16}\sigma_\tau \langle v\rangle n_+ n_- \qquad (1)$$

https://doi.org/10.1017/S0074180900038511 Published online by Cambridge University Press

where η_+, η_-, η_γ are the positron, electron and photon number densities, σ_T the Thomson cross section, $<v> \simeq (2kT/m_e)^{1/2}$ the mean electron velocity, and $\phi = m_e c^2/kT$. The balance equation $R_{\gamma\gamma} = R_{+-}$ then gives:

$$(e^{-2\phi}\phi^3 (\frac{\eta_\gamma}{\eta_+ + \eta_-}))^2 = 1/2 \frac{1}{\phi^{1/2}} \frac{\eta_+\eta_-}{(\eta_+ + \eta_-)^2} \qquad (2)$$

If $m = M/M_\odot$ is the mass of the typical source in solar masses, then its luminosity L and radius R can be expressed in terms of the solar mass Eddington luminosity ($\simeq 1.3 \times 10^{38}$ erg s^{-1}) and Schwarzschild radius ($\simeq 3 \times 10^5$ cm) as $L = 1.3 \times 10^{38}$ mF erg s^{-1} and $R = 3 \times 10^5$ m/f cm where F, f are numerical factors between zero and one ($0 < F,f \lesssim 1$). Then

$$\eta_\gamma/(\eta_+ + \eta_-) \simeq Ff\ 1.2 \times 10^4/(1 + Z)\ T_{40}(1 + \tau)\ \tau \qquad (3)$$

Where τ is the optical depth of the sources and T_{40} the observed CXB temperature in units of 40 keV. The balance equation then reads:

$$e^{-\phi}\ \phi^{7/4} \frac{F,f\ 1.7 \times 10^4}{(1 + Z)\ T_{40}(\tau + 1)\tau} = \frac{\lambda^{1/2}}{1 + \lambda} \qquad (4)$$

where $\lambda = \eta_+/\eta_-$ is the positron abundance at the sources.

3. COMPARISON TO OBSERVATION

Eq (4) provides an estimate of the positron abundance λ and can be directly related to observation since no obvious annihilation feature is observed in the CXB. The corresponding condition is that the annihilation spectral luminosity (Ramaty and Meszaros 1981) be smaller than that of thermal bremsstrahlung. The latter condition gives

$$\frac{\lambda^{1/2}}{1+\lambda} \lesssim 6\ 10^{-2}\ e^{-\phi/2} [(1+Z)\ T_{40}]^{1/4} \qquad (5)$$

Elimination of λ between (4) and (5) and taking into account that $\phi \simeq 12.8/(1+Z)T_{40}$ gives

$$Ff \lesssim 4.10^{-8} \exp[6.4/(1+Z)T_{40}]\ [(1+Z)\ T_{40}]^3\ (\tau+1)\ \tau \qquad (6)$$

Eq (6) is independent of the mass of the sources and determines (as a function of the redshift z at which the CXB was produced) their L/R ratio so it is compatible with the absence of a prominent annihilation feature in the CXB. The optical depth τ of the sources is of course unknown, however it is constrainted to be $\tau \lesssim 3$ otherwise the corresponding Comptonization Wien peak should be apparent in the spectrum (Lightman and Band 1981). For compact sources ($f \simeq 0.1 - 0.01$) eq (6) constraints the sources to emit at a small fraction of their Eddington luminosity ($10^{-3} - 10^{-2}$), even for $\tau=3$ and Z=0, an important constraint in understanding the nature of the sources of CXB.

4. REFERENCES

Cowsik, R. and Kobetich, E. J., 1972, Ap. J., 177, 585.
Dezotti, G., 1982, Astron. and Astrophys.
Field, G. B. and Perrenod, S., 1977, Ap. J., 215, 717.
Giacconi, R., Gursky, J., Paolini, F. and Rossi, B., 1962, Phys. Rev. Lett., 9, 439.
Lightman, A. D. and Band, D. L., 1981, Ap. J., 251, 715.
Lightman, A. D., 1982, Ap. J., 253, 842.
Marshall, F., Boldt, E., Holt, S., Miller, R., Mushotzky, R., Rose, L. A., Rothchild, R. and Serlemitsos, P., 1980, Ap. J., 235, 377.
Ramaty, R. and Meszaros, P., 1981, Ap. J., 250, 384.
Ramaty, R. and Lingenfelter, R. E., 1982, Annual Reviews of Nuclear and Particle Science.
Weaver, T. A., 1976, Phys. Rev. A, 13, 1536.

DISCUSSION

G. Burbidge: How did you choose the epoch at which the sources generated the original photons?

Kazanas: The epoch is not chosen. The constraints on the L/R (Ff here) ratio of the sources are given as a function of the redshift z. So once a redshift is chosen, the absence of the line limits the ratio L/R.

https://doi.org/10.1017/S0074180900038511 Published online by Cambridge University Press