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ACTIVE GALACTIC NUCLEI AND THE GAMMA-RAY COSMIC DIFFUSE BACKGROUND

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ABSTRACT

Number-flux relations at γ-ray energies (0.3–20 MeV) for active galactic nuclei have been computed, starting from their X-ray luminosity function and making different assumptions on the spectral shape and cosmological evolution of these sources. The resulting contribution to the cosmic diffuse emission has then been compared to the measured intensity and spectrum of the extragalactic background, in order to derive quantitative constraints on the population properties of active galactic nuclei. Upper limits on the γ-ray luminosity evolution have thus been derived as a function of the assumed spectral properties. These constraints are discussed in the context of the capabilities of the future γ-ray astronomy missions *SIGMA* and *GRO*, whose expected results in this field have been quantitatively estimated.

Subject headings: cosmic background radiation — galaxies: nuclei — gamma rays: general

I. INTRODUCTION

A few extragalactic sources of different kinds have been observed at energies greater than a few hundred keV with balloon and satellite experiments. These sources include two objects which, at various wavelengths, are among the brightest members of their respective classes: the Seyfert galaxy NGC 4151 (Perotti *et al.* 1979, 1981), and the quasar 3C 273 (Swanenburg *et al.* 1978). These observations suggest the possibility that a large number of Seyfert galaxies and quasars emit a considerable fraction of their total luminosity in the γ-ray domain. Further support of this hypothesis comes from the existence of the isotropic background of diffuse radiation extending to energies greater than 100 MeV. In fact, although several mechanisms based on truly diffuse processes have been proposed to explain the cosmic diffuse background (Brown and Stecker 1979; Olive and Silk 1985; Daly 1988), it could also be formed by the integrated emission from many faint, unresolved point sources. Models for the cosmic diffuse background (CDB), based on the contribution from unresolved extragalactic sources, have also been stimulated by the similarity between the CDB spectrum in the MeV region and that of the active galaxies detected at these energies (see, e.g., Bassani and Dean 1983).

Several authors have estimated the expected contribution to the γ-ray background from different classes of extragalactic sources. Due to the scarcity of high-energy data on such sources, most of the earlier works were based on number densities at radio or optical wavelengths, plus some assumptions on the average ratio of γ-ray to radio or optical luminosity (Strong, Wolfendale, and Worral 1976; Bignami, Lichti, and Paul 1978; Lichti, Bignami, and Paul 1978). Although these results were quite dependent on the assumptions made, it was recognized that Seyfert galaxies could account for a large fraction or even the totality of the CDB in the MeV region. The significance of the point source contribution to the γ-ray CDB was later consolidated by the detection of many active galaxies in the 2–10 keV band, and by the measurement of their relatively flat spectra (power-law energy index $\sim$0.6–0.7) extending to hard X-ray energies (Rothschild *et al.* 1983; Bassani and Dean 1984; Yu 1987).

The aim of this paper is to derive some quantitative constraints on the cosmological evolution, spectral shape, and luminosity function of active galaxies at γ-ray energies, in the framework of models for the CDB based on unresolved point sources. We will assume that the CDB at energies greater than $\sim$500 keV is due to the integrated γ-ray emission from Seyfert galaxies and quasars (henceforth called active galactic nuclei [AGNs]). Some general considerations of this problem have already been made by several authors: for example, that the X-ray spectra of AGNs must become steeper in the γ-ray range, that only a fraction of the X-ray Seyfert galaxies can be γ-ray sources (invoking e.g., variability, different beamings, or evolutionary effects), that luminosity or density evolution of γ-ray AGNs must be very limited or null, etc. (Schönfelder 1978; Bassani and Dean 1984; Bignami, Lichti, and Paul 1978). We present here a more quantitative analysis, based on the observed luminosity function for X-ray selected AGNs and on reasonable assumptions for some of their population properties, such as spectral shape and evolution. This work represents a step further, which is particularly needed in view of the expected new data from the forthcoming γ-ray missions *SIGMA* and *GRO*. In the next section, it is explained how the γ-ray number flux relations have been derived from the X-ray luminosity function of AGNs. In § III, the constraints deriving from the CDB on the spectra and evolution of AGNs are described. These results are discussed in § IV, where they are also used to predict the number of AGNs detectable by the future γ-ray instruments, under different assumptions.

II. METHOD AND COSMOLOGICAL MODEL

a) *Spectra of AGNs*

We describe the broad-band energy spectra of AGNs using the parameter $\alpha_{x\gamma}$ defined as follows:

$$\alpha_{x\gamma} = -\frac{\log (L_\gamma/L_x)}{\log (E_\gamma/E_x)}, \tag{1}$$

where L_γ and L_x are the monochromatic luminosities at energies E_γ and E_x, respectively. This parameter, similar to the more commonly used α_{ox} (Tananbaum *et al.* 1979), represents the energy index of an ideal power-law spectrum connecting the *X*- and γ-ray bands. The available information on the value of $\alpha_{x\gamma}$ for AGNs is very limited, and moreover, it is affected by a selection bias favoring γ-ray bright objects. We have therefore assumed that AGNs have values of $\alpha_{x\gamma}$ characterized by a distribution $P(\alpha_{x\gamma})$ with average $\langle\alpha\rangle$ and full width at half-maximum $\alpha_{\rm FWHM}$, and we have carried out our computations for different values of these two parameters. For the sake of simplicity, and in order to avoid unrealistic effects due to the extended tails of, e.g., Gaussian distributions, we have used a triangular distribution given by:

$$P(\alpha_{x\gamma}) = \begin{cases} \dfrac{1}{\alpha_{\rm FWHM}} - \dfrac{|\alpha_{x\gamma} - \langle\alpha\rangle|}{\alpha^2_{\rm FWHM}} \\ \qquad \text{if } \langle\alpha\rangle - \alpha_{\rm FWHM} \leqslant \alpha_{x\gamma} \leqslant \langle\alpha\rangle + \alpha_{\rm FWHM}\,, \\ 0 \qquad \text{otherwise.} \end{cases} \tag{2}$$

The following hypotheses have been made on the spectral shape of AGNs in the γ-ray energy range of interest (see Fig. 1): (i) between 300 keV and a few MeV, the AGNs have power-law spectra with energy index equal to $\alpha_{x\gamma}$. Thus, the sources can have different spectral slopes, according to the distribution function $P(\alpha_{x\gamma})$. Note that this assumption does not necessarily imply that the spectra continue as single power laws down to the reference energy E_x. (ii) At higher energies, all the AGNs have the same power-law spectrum with a greater energy index, α_b. We indicate with E_b the energy at which the spectral break occurs ($E_b \sim$ 5–15 MeV). This spectral steepening is required to avoid exceeding the high-energy CDB, and it has also been observationally confirmed by the *SAS 2* upper limits on the high-energy (>35 MeV) emission from AGNs (Bignami *et al.* 1979).

b) *The Gamma-Ray Luminosity Function and Evolution of AGNs*

Starting from an X-ray luminosity function $\Phi_x(L_x)$, defined between $L_{x_{\rm min}}$ and $L_{x_{\rm max}}$, the luminosity function $\Phi_\gamma(L_\gamma)$ at energy E_γ is obtained from the relation:

$$\Phi_\gamma(L_\gamma) = \int_{L_{x\,\rm min}}^{L_{x\,\rm max}} \Phi_x(L_x) P(L_x \,|\, L_\gamma)\, dL_x\,, \tag{3}$$

where $P(L_x \,|\, L_\gamma)$ is the probability that a source with X-ray luminosity in the interval $(L_x, L_x + dL_x)$ has a luminosity at E_γ equal to L_γ. $P(L_x \,|\, L_\gamma)$ is derived from the assumed distribution $P(\alpha_{x\gamma})$; it can be easily seen from equations (1) and (2) that it is a triangular function of log (L_γ).

The luminosity function at redshift $z = 0$ is indicated by $\Phi_\gamma(L_\gamma)$ and is defined between $L_{\gamma_{\rm min}}$ and $L_{\gamma_{\rm max}}$ given by:

$$\log(L_{\gamma_{\rm min}}) = \log(L_{x_{\rm min}}) - (\langle\alpha\rangle + \alpha_{\rm FWHM}) \log(E_\gamma/E_x)\,, \tag{4a}$$

$$\log(L_{\gamma_{\rm max}}) = \log(L_{x_{\rm max}}) - (\langle\alpha\rangle - \alpha_{\rm FWHM}) \log(E_\gamma/E_x)\,. \tag{4b}$$

There is strong evidence indicating a cosmological evolution of AGNs at radio, optical, and X-ray wavelengths (see, e.g., Schmidt and Green 1986; Marshall *et al.* 1983). To allow the possibility of evolution also at γ-ray energies, and to eventually derive some information on its amount, we have introduced a model of exponential luminosity evolution to compute the luminosity functions at redshift z, $\Phi_\gamma(L_\gamma, z)$. In this model, the cosmological evolution of the γ-ray luminosity is governed by the evolution parameter C_γ, through the relation:

$$L_\gamma(z) = L_\gamma \exp[C_\gamma \tau(z)]\,, \tag{5}$$

where $\tau(z)$ is the look-back time.

c) *Gamma-Ray Number-Flux Relations (log N − log S)*

The γ-ray luminosity function can be numerically integrated to derive the integral number-flux relation, $N(S_\gamma)$, giving the number of AGNs per steradian with γ-ray flux greater than S_γ:

$$N(>S_\gamma) = \frac{1}{4\pi} \int_0^{z_{\rm max}} \frac{dV}{dz}\, dz \int_{L_1}^{L_2} \Phi_\gamma(L_\gamma, z) dL_\gamma\,, \tag{6}$$

where

$$\frac{dV}{dz} = \frac{4\pi c}{H_0}\, d_L^2(z) \frac{1}{(1+z)^3\sqrt{1+2q_0 z}}\,, \tag{7}$$

$$L_1 = \max\{L_{\gamma_{\rm min}} \exp[C_\gamma \tau(z)],\, L_*(S_\gamma, z)\}\,, \tag{8a}$$

and

$$L_2 = L_{\gamma_{\rm max}} \exp[C_\gamma \tau(z)]\,. \tag{8b}$$

$L_*(S_\gamma, z)$ is the minimum luminosity that a source at redshift z must have in order to be detected with a flux greater than S_γ, and it is given by the relation:

$$L_*(S_\gamma, z) = 4\pi\, d_L^2(z) S_\gamma K(z, \alpha_{x\gamma}, \alpha_b, E_b)\,, \tag{9}$$

where $K(z, \alpha_{x\gamma}, \alpha_b, E_b)$ is the K-correction relating the energies of the emitted and observed photons. We have indicated with d_L the luminosity distance, in the context of a Friedman universe with Hubble constant H_0 and deceleration parameter q_0. In all the computations, a value of 50 km s^{-1} Mpc^{-1} has been assumed for H_0.

d) *The Contribution of AGNs to the Gamma-Ray CDB and CDB Fluctuations*

The contribution of AGNs to the CDB is computed from the differential γ-ray number-flux relation, $N(S_\gamma)$:

$$I_{\rm AGN}(E_\gamma)(\text{ergs cm}^{-2}\ \text{s}^{-1}\ \text{sr}^{-1}\ \text{Hz}^{-1}) = \int S_\gamma N(S_\gamma) dS_\gamma\,. \tag{10}$$

If the AGNs have a random angular distribution, the statistical fluctuations on their contribution to the CDB, measured over a solid angle Ω, are given by

$$\delta I^2_{\rm AGN}(E_\gamma) = \Omega \int S_\gamma^2 N(S_\gamma) dS_\gamma\,. \tag{11}$$

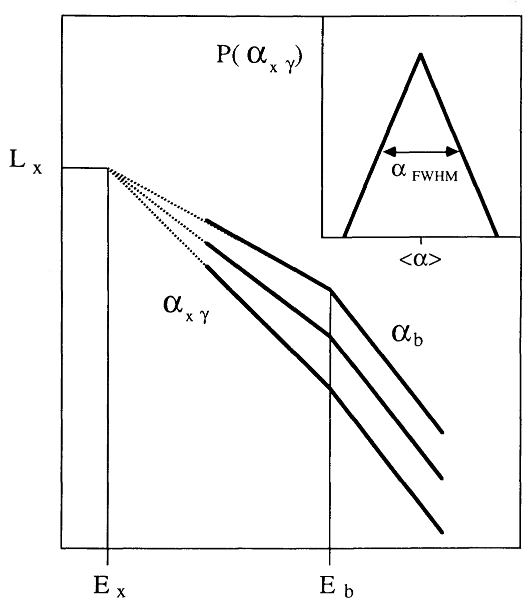

FIG. 1.—Assumed spectral shape of active galactic nuclei and distribution of the $\alpha_{x\gamma}$ parameter (inset).

III. RESULTS

For different choices of the parameters describing the population characteristics of the AGNs, we have computed $I_{AGN}(E_\gamma)$ and have compared it to the measured spectrum of the CDB in the 300 keV–10 MeV energy range, as reported by Trombka *et al.* (1977).

The total number of variables affecting the results is quite large. The spectra of the sources are described by four parameters ($\langle\alpha\rangle$, α_{FWHM}, α_b, E_b); six more are required to define an X-ray luminosity function like the one discussed below. Finally, we have the evolution parameter C_γ, z_{max}, H_0, and q_0, for a total of 14 parameters. This obviously implies that it is not possible to uniquely determine all of them with the scarcity of data presently available. On the other hand, it is interesting to derive limits on some of them as a function of different reasonable assumptions on the values of the remaining parameters.

We have used the X-ray luminosity function of the AGNs at 2 keV derived from the *Einstein Observatory* Medium Sensitivity Survey (Gioia *et al.* 1984). This luminosity function has been computed from a sample of 56 X-ray selected quasars and Seyfert galaxies serendipitously discovered in the energy range 0.3–3.5 keV. From Figure 4 of Maccacaro, Gioia and Stocke (1984), we have derived the following expression for the luminosity function at redshift $z = 0$:

$$\Phi_x(L_x) = 6 \times 10^{-33}(L_x/L_{x_{break}})^{-2.1} \quad \text{for } L_{x_{min}} < L_x < L_{x_{break}} ,$$

$$\Phi_x(L_x) = 6 \times 10^{-33}(L_x/L_{x_{break}})^{-3.6} \quad \text{for } L_{x_{break}} < L_x < L_{x_{max}} .$$

Φ_x is in units of sources Mpc^{-3} (ergs s^{-1} Hz^{-1})$^{-1}$, L_x is the 2 keV monochromatic luminosity, $L_{x_{min}} = 8 \times 10^{23}$ ergs s^{-1} Hz^{-1}, $L_{x_{break}} = 5 \times 10^{25}$ ergs s^{-1} Hz^{-1}, and $L_{x_{max}} = 2 \times 10^{27}$ ergs s^{-1} Hz^{-1}.

Considering that our main results are not very dependent on the exact choice of α_b (the spectral shape of the AGNs after the break energy E_b), we have kept this parameter fixed to the single value $\alpha_b = 2$, a good approximation to the slope of the high-energy γ-ray background.

For what concerns z_{max} and the deceleration parameter q_0, we restricted our choice to four representative couples of values: $z_{max} = 3.5$ and $q_0 = 0$ (referred to as model A in the following), $z_{max} = 3.5$ and $q_0 = 0.5$ (model B), $z_{max} = 1$ and $q_0 = 0$ (model C), $z_{max} = 1$ and $q_0 = 0.5$ (model D).

a) Models Without Evolution

We consider first the simple case in which all the AGNs have the same value of $\alpha_{x\gamma}$ (i.e., eq. [2] reduces to a delta function). A good agreement with the measured CDB data is obtained with $\langle\alpha\rangle = 0.5$ and $E_b = 5$ MeV. This is shown in Figure 2, where the expected diffuse background resulting from models A and D are compared to the experimental points of Trombka *et al.* (1977). Models B and C lead to values of $I_{AGN}(E_\gamma)$ which lie between the two former curves, and, for clarity, they have not been reported in the figure. Values of $\langle\alpha\rangle$ smaller than 0.5 are excluded, because they would produce an emissivity greater than the observed background. Larger values of $\langle\alpha\rangle$ are compatible with the data but require an extra contribution from some different mechanism to account for the CDB in the few MeV region. In this case, the value of E_b can be greater than 5 MeV. For example, for model A with $\langle\alpha\rangle = 0.7$, the upper limit on E_b is at ~ 15 MeV (see the dashed line of Figure 2).

Of course, these results are somewhat dependent on the X-ray luminosity function we have used, and, in particular, on

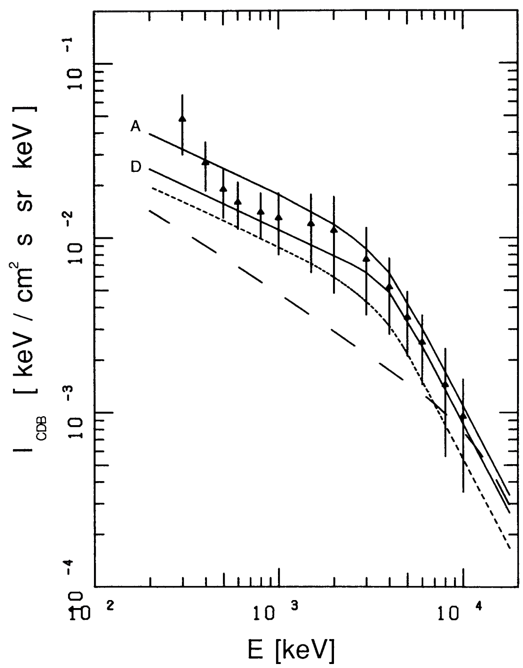

FIG. 2.—Computed contribution from active galactic nuclei to the γ-ray diffuse background, in the case without γ-ray luminosity evolution. The two solid lines refer to models A and D with $\langle\alpha\rangle = 0.5$, $\alpha_{FWHM} = 0$, and $E_b = 5$ MeV. The dashed curve is for model A with $\langle\alpha\rangle = 0.7$, $\alpha_{FWHM} = 0$, and $E_b = 15$ MeV. The dotted line refers to the same parameters as the solid curve A, but with a flatter luminosity function for low-luminosity AGNs (see text). The observed intensity of the cosmic diffuse background between 0.3 and 10 MeV is shown for comparison (Trombka *et al.* 1977).

its shape and extension at low X-ray luminosities. In fact, changing $L_{x_{max}}$ by one order of magnitude in both directions or the power-law index after $L_{x_{break}}$ from -4 to -3 does not substantially affect the position of the curves in Figure 2. On the other hand, by taking a flatter luminosity function for dim X-ray AGNs, one can reduce their contribution to the CDB. For example a slope of -0.7 before $L_{x_{break}} = 10^{25}$ ergs s^{-1} Hz^{-1} is still compatible with the uncertainties in the luminosity function of Maccacaro, Gioia, and Stocke (1984), and, for model A with $\langle\alpha\rangle = 0.5$ and $E_b = 5$ MeV, would produce the CDB contribution showed by the dotted line in Figure 2. A similar reduction in the emissivity of the AGNs, obtained by changing only the lower bound of our "baseline" X-ray luminosity function, would require us to move $L_{x_{min}}$ up to 5×10^{24} ergs s^{-1} Hz^{-1}, in clear contrast with the observed space density of dim X-ray AGNs. Conversely, the limit posed by the diffuse X-ray background implies that a reduction of $L_{x_{min}}$ must necessarily be accompanied by a further flattening of the luminosity function (see, e.g., Boldt 1989), and in this case the volume emissivity of the AGNs is not very dependent on $L_{x_{min}}$. In conclusion, the uncertainties deriving from the X-ray luminosity function, as well as those due to different values of z_{max} or q_0, are of the same order of the error bars of the experimental points in Figure 2. Therefore, in the following, we will concentrate mainly on the much more important effects due to the distribution of $\alpha_{x\gamma}$ and to the γ-ray luminosity evolution.

Let us now consider the case in which the AGNs have different spectral slopes, i.e., the distribution $P(\alpha_{x\gamma})$ has a dispersion given by $\alpha_{FWHM} \neq 0$. In this case, for a fixed value of the average index $\langle\alpha\rangle$, the CDB contribution increases with α_{FWHM}, and the increase is larger at higher energy. This excludes the possibility of $\alpha_{FWHM} > 0$ for $\langle\alpha\rangle = 0.5$. The correct intensity and slope (~ 0.5) to fit the CDB data in the 0.5–3 MeV region is obtained for increasingly wider distributions, as the average $x - \gamma$ slope becomes steeper. For example, for $\langle\alpha\rangle = 0.6$, 0.8, and 1.0, the required values of α_{FWHM} are, respectively, 0.5, 0.9, and 1.1. A break in the spectra of the AGNs is required in any case above a few MeV, but unfortunately the data do not allow us to pose significant constraints on the exact value of E_b.

b) Models With Evolution

We have performed a similar analysis for the models with γ-ray luminosity evolution, and the derived results are summarized in Figure 3 for three representative values of the evolution parameter ($C_\gamma = 1$, $C_\gamma = 3$, and $C_\gamma = 5$). The plotted curves indicate the ($\langle\alpha\rangle$, α_{FWHM}) pairs which produce the correct intensity and slope of the CDB at energies below the steepening around a few MeV. For a given C_γ, values of $\langle\alpha\rangle$ and α_{FWHM} on the left of the corresponding curve are excluded, because they would yield a contribution from AGNs exceeding the measured CDB, while values on the other side of the curve, leading to a CDB contribution smaller than 100%, are compatible with the data. Again, a break in the spectrum is required in any case to avoid exceeding the CDB at energies greater than a few MeV. For example, in the case of the models lying exactly on the curves of Figure 3, the spectral break occurs at $E_b \sim 5$–10 MeV.

From a comparison between Figures 3*a* and 3*b*, one can note that, as expected, in the models with $z_{max} = 1$, flatter spectra are allowed than in those with $z_{max} = 3.5$ (this is equivalent to the effect of a negative number density evolution of γ-ray AGNs). Also visible in Figure 3 is the influence of the deceleration parameter on the CDB contribution from unresolved point sources at cosmological distances. This stems from the combination of two opposite effects: the reduction in the emissivity of AGNs deriving from the geometrical properties of the comoving volume element, and the faster evolution due to the implicit dependence of the γ-ray luminosity on q_0 (see eq. [5]). The second process, which increases the CDB contribution from AGNs in the models with $q_0 = 0.5$, dominates when C_γ is greater than ~ 3; this effect is more evident in the models with $z_{max} = 1$, as can be seen from the relative distance between the curves $C_\gamma = 5$ in Figures 3*a* and 3*b*. Conversely, for small values of the evolution parameter, the first process dominates, thus allowing the existence of AGNs with slightly flatter spectra in the models with $q_0 = 0.5$ (see curves for $C_\gamma = 1$).

IV. DISCUSSION

The results we obtained in the case without evolution and adopting a "universal" spectrum for AGNs, i.e. $\alpha_{FWHM} = 0$, can be compared to those derived by Rothschild *et al.* (1983) under the same hypothesis, but using the X-ray luminosity function of the AGNs determined with the *HEAO* A-2 instrument (Piccinotti *et al.* 1982). These authors have assumed that the average 2–165 keV spectrum measured for 12 AGNs, a power-law with energy slope $\alpha = 0.62$, is representative of the spectra of all AGNs and that it extends without breaks up to ~ 5 MeV. They have shown that the CDB in the 0.3–5 MeV region can be reproduced by adopting $z_{max} = 1$, $q_0 = 0$, and a flattening in the Piccinotti *et al.* luminosity function for $L_{x_{break}} \leqslant 10^{25}$ ergs s^{-1} Hz^{-1}. This is in very good agreement with our result for model C (see Fig. 2). The small difference ($\Delta\alpha \sim 0.1$) is due to the slightly different volume emissivities deriving from the two X-ray luminosity functions. This example, and the discussion in § III*a*, show that our main results are not substantially dependent on the present uncertainties in the X-ray luminosity function of the AGNs, which affect the value of $I_{AGN}(E_\gamma)$ much less than other interesting parameters, such as $\langle\alpha\rangle$, α_{FWHM}, and C_γ.

If the γ-ray luminosity of AGNs does not evolve, our results indicate that quite large values of $\alpha_{x\gamma}$ (i.e., relatively flat γ-ray spectra) are required for a substantial fraction of AGNs in order to account for 100% of the observed CDB. For example, assuming that $\langle\alpha\rangle = 0.7$, equal to the "canonical" spectral slope in the hard X-ray band (Mushotzky 1982; Petre *et al.* 1984; Turner and Pounds 1989), the required $P(\alpha_{x\gamma})$ distribution has $\alpha_{FWHM} = 0.7$, implying that 25% of the sources have spectra flatter than 0.5. Larger values of $\langle\alpha\rangle$ lead to very wide $P(\alpha_{x\gamma})$ distributions, implying also the existence of some AGNs with "inverted" X-/γ-ray spectra. Although this cannot be excluded by the present data, we think that more likely models (also in view of the observed evolution of AGNs at X-ray energy; Maccacaro, Gioia, and Stocke 1984) are those with γ-ray evolution. These require, in fact, steeper average X-/γ-ray spectra and generally narrower $P(\alpha_{x\gamma})$ distributions (see Fig. 3). The intrinsic dispersion of the spectral slope distribution of AGNs has been measured in the hard X-ray band by Rothschild *et al.* (1983), who derived an upper limit for the rms of a Gaussian distribution of 0.15. If we assume that the distribu-

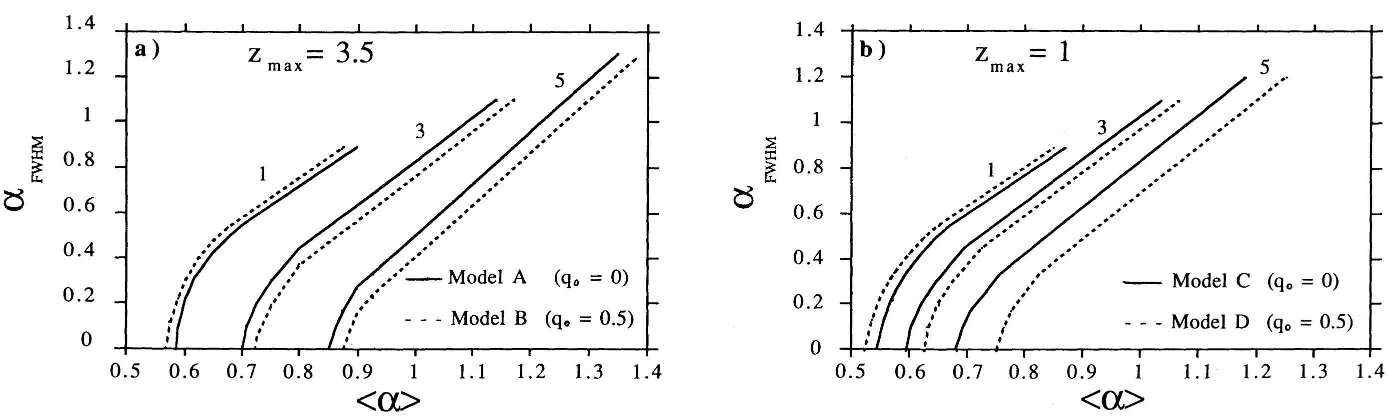

FIG. 3.—Empirical relations between $\langle\alpha\rangle$ and α_{FWHM} required to fit the cosmic diffuse background in the energy range from a few hundred keV to a few MeV. The results for three different values of the evolution parameter C_γ, listed next to each curve, are shown.

tion $P(\alpha_{x\gamma})$ has the same rms (corresponding to $\alpha_{\rm FWHM} = 0.37$) and that $\langle\alpha\rangle = 0.7$, then a moderate luminosity evolution is required to account for the observed CDB ($C_\gamma \sim 2$ if $z_{\rm max} = 3.5$, or $C_\gamma \sim 3$ if $z_{\rm max} = 1$). The comparison of these values of C_γ with those of the similar parameters in soft X-rays, ~ 5, (Maccacaro, Gioia, and Stocke 1984) and in the optical, ~ 7, (Marshall *et al.* 1983) would support a scenario in which the amount of luminosity evolution decreases with energy.

In conclusion, if our assumptions are valid, the cosmological evolution of AGNs at γ-ray energy cannot be ruled out by the CDB data, provided that a spectral break at energies of a few MeV exists. This is in contrast to previous reports, based on the assumption that the characteristics of the few extragalactic objects detected at high energy were representative of the properties of the whole AGNs population.

The γ-ray $\log N - \log S$ we have computed to estimate the CDB contribution from AGNs can also be used to make some predictions on the results expected from the γ-ray missions planned for the future. We shall briefly discuss here the case of the *SIGMA* instrument on the Franco-Soviet mission *GRANAT*, due to launch in 1989 December, and of the *GRO*, which is scheduled to launch in 1990.

The *SIGMA* telescope is a hard X-ray/soft γ-ray imaging instrument, using a coded aperture mask and a position sensitive Anger camera (Rivière, Paul, and Mandrou 1984). It will obtain images of the sky in the 30 keV–2 MeV energy range, with a very good angular resolution ($\sim 1'$–$2'$) and a fully coded field of view of $4° \times 4°$. The NASA *GRO* will carry four distinct γ-ray instruments with specific objectives in different energy bands (see, e.g., Kniffen 1989). We consider here the case of the Imaging Compton Telescope (COMPTEL), which will provide 1–30 MeV images with angular resolution of a few degrees over a very wide (~ 1 sr) field of view. This instrument is particularly interesting in the present context because, during the first year of the *GRO* mission, it will perform a complete sky survey in a virtually unexplored spectral region. The sensitivity of these instruments, although much better with respect to the present limit, is still such that only the very bright end of the $\log N - \log S$ curves for γ-ray AGNs will be sampled. This means that, as far as the number of detectable sources is concerned, the models A, B, C, and D are equivalent. Different values of q_0 and $z_{\rm max}$ begin to significantly affect the corresponding $\log N - \log S$ relations only at fluxes three to four orders of magnitude below the sensitivity threshold for the next generation of γ-ray instruments.

The expected numbers of AGNs in the whole sky, with fluxes above the detection thresholds of *SIGMA* and COMPTEL are reported in Table 1, for different values of $\langle\alpha\rangle$, $\alpha_{\rm FWHM}$, E_b, and C_γ. It can be seen that, if AGNs do indeed account for a large fraction of the γ-ray CDB, a significant number of them will be detected in the COMPTEL sky survey and also (especially at low energies) in *SIGMA* observations. These detections will allow for the first time to obtain direct data on the spectral parameters used in our models, and then, also with the help of Figure 3, to derive useful information on the evolution of AGNs at γ-ray energies and on their contribution to the CDB.

The relation between AGNs and γ-ray background could also be investigated by the future instruments through the study of the CDB anisotropies on small angular scale. In fact, if an apparently diffuse emission is a result of the sum of unresolved sources, spatial fluctuations on its intensity are expected, due to the statistical fluctuations on the number of sources contributing in the different directions. The study of such fluctuations is a well-established technique, first used in radio astronomy and later also successfully applied at X-ray energies. The extension of this technique to the γ-ray range will be, however, a very difficult task, due to several effects, both instrumental (artifacts in coded aperture telescopes, disuniformities in detector sensitivity, etc.), and of intrinsic origin (low signal, presence of a structured contribution from the foreground galactic emission, etc.). Using our derived $\log N - \log S$ curves, we have computed the fluctuations expected if the contribution of AGNs accounts for the totality of the CDB (Bignami and Mereghetti 1989). These fluctuations, on an angular scale of ~ 30 deg^2, are of the order of 10%–20%. According to Kanbach *et al.* (1988), the EGRET instrument on *GRO* should be able to measure the CDB on this angular scale with an accuracy of 20% in a deep exposure at high galactic latitude. It is thus possible that, although marginally, CDB fluctuations can be detected for the first time at γ-ray energies.

TABLE 1

EXPECTED NUMBER OF AGNS DETECTABLE BY THE *SIGMA* AND COMPTEL GAMMA-RAY TELESCOPES

A. *SIGMA*

$\langle\alpha\rangle$	$\alpha_{\rm FWHM}$	Number of Sources $C_\gamma = 0$	$C_\gamma = 3$	$C_\gamma = 5$
		30–300 keV[a]		
0.5	0.0	157	...	...
0.7	0.0	49	61	...
	0.6	119	...	...
1.0	0.0	9	97	106
	0.8	39	53	60
		0.1–2 MeV[b]		
0.5	0.0	13	...	...
0.7	0.0	1	3	...
	0.6	13	...	...
1.0	0.0	0	7	8
	0.8	5	4	4

B. COMPTEL 1–30 MeV[c]

$\langle\alpha\rangle$	$\alpha_{\rm FWHM}$	E_b (MeV)	Number of Sources $C_\gamma = 0$	$C_\gamma = 3$	$C_\gamma = 5$
0.5	0.0	5	87	...	...
0.7	0.0	15	8	9	...
	0.6	5	138	...	...
1.0	0.0	15	0	0	0
	0.8	5	29	38	44

[a] Assumed sensitivity: 2×10^{-4} photons cm^{-2} s^{-1}, corresponding to $\sim 5 \times 10^{-31}$ ergs cm^{-2} s^{-1} Hz^{-1} at 100 keV.

[b] Assumed sensitivity: 8×10^{-4} photons cm^{-2} s^{-1}, corresponding to $\sim 10^{-30}$ ergs cm^{-2} s^{-1} Hz^{-1} at 500 keV.

[c] Assumed sensitivity: 5×10^{-5} photons cm^{-2} s^{-1}, corresponding to $\sim 10^{-31}$ ergs cm^{-2} s^{-1} Hz^{-1} at 5 MeV.

V. SUMMARY

The direct knowledge of the γ-ray properties of AGNs is, so far, limited to the observations of only a few objects, whose energy output peaks in the MeV region. If one assumes that γ-ray emission is a common property of all the Seyfert galaxies and quasars detected in the soft X-ray range (0.3–3.5 keV), the observed spectrum and intensity of the γ-ray diffuse background above ~ 300 keV can be well explained by the integrated emission from these sources. Accepting this scenario, it is then possible to use the information contained in the CDB to derive some indirect data on the average properties of the contributing sources.

Following this approach, we have computed upper limits on the γ-ray luminosity evolution of AGNs as a function of their average spectra, also taking into account the important effect due to the width of the spectral index distribution. Unfortunately, the constraints we have derived are not, for the moment, complemented by observational data which would help to discriminate among the possible combinations of parameters allowed by the data. In any case, the theoretical models to explain high-energy emission from active galaxies must predict source spectra and cosmological evolution satisfying the limits summarized in Figure 3 in order to be compatible with the observations.

The model used for the present computations is, of course, very simplified. One could introduce several effects in order to make it more realistic or to investigate different possibilities. These include, for example, different evolutionary laws, dependence on energy and/or luminosity of the evolution parameter, distributions instead of single values of parameters such as, e.g. E_b and α_b. However, the quantity and quality of the data now available severely limit the amount of information obtainable using such complicated models. We have therefore tried to keep the free parameters of our model within a reasonable number.

A substantial development in the field of extragalactic γ-ray astronomy is expected in the near future, with the launch of the *GRANAT* and *GRO* satellites. We have made quantitative predictions of the results expected from these missions, showing that several AGNs should be detected, if they contribute significantly to the γ-ray diffuse background. If this is the case, the presently lacking data on their broad-band spectral shape distribution will be directly obtained, and, possibly, a luminosity function for AGNs could be determined for the first time at γ-ray energies.

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