THE CONTRIBUTION OF ACTIVE GALAXIES TO THE FAR–INFRARED AND SUBMILLIMETER BACKGROUND

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We present a simple model, developed to estimate the contribution of Active Galactic Nuclei to the far–infrared background, closely linked to the AGN synthesis model for the X–ray background. According to our calculation the AGN contribution is never dominant, ranging from a few to 15 percent between 100 and 850 µm.

1 Introduction

Deep X–ray surveys carried out with Chandra and XMM–Newton have resolved into discrete sources a large fraction (more than 75%) of the hard 2–10 keV X–ray background (XRB) (Mushotzky et al. 2000, Giacconi et al. 2001, Hasinger et al. 2001). Most of the so far optically identified objects are Active Galactic Nuclei (AGN) and a sizeable fraction of them shows indication of nuclear obscuration, in relatively good agreement with the expectation of AGN synthesis models of the XRB (Setti & Woltjer 1989, Madau, Ghisellini & Fabian 1994, Comastri et al. 1995, Gilli et al. 2001).

The nuclear radiation of the obscured AGN responsible for the majority of the XRB spectral intensity must be re–irradiated by dust in the far–Infrared (FIR) and submillimeter (submm) bands. It is thus likely that absorbed AGN provide a significant contribution to the Cosmic Far Infrared Background (CFIRB) recently measured by COBE between 100 and 2000 µm (Puget et al. 1996, Fixsen et al. 1998, Hughes et al. 1998, Lagache et al. 2000) and to the 850 µm SCUBA source counts (Smail, Ivison & Blain 1997).

In order to quantitatively estimate the contribution of X–ray (obscured) sources to the CFIRB, a simple synthesis model has been developed. Our strategy is to link the FIR and X–ray spectral properties of a representative sample of AGN and then evaluate their contribution to the CFIRB adopting the same assumptions used by Comastri et al. (1995) to fit the XRB. More specifically, since a key parameter in this model is the distribution of objects as a function of their X–ray column density ($N_H$), in the range $10^{21} – 10^{25}$ cm$^{-2}$, the CFIRB model has been computed keeping the absorption distribution which provides the best fit to the XRB observational constraints and looking for correlations between the FIR and X–ray properties for each class of $N_H$. 
2 The model

The intensity of diffuse emission due to discrete sources at an observed frequency \( \nu_0 \) can be written as:

\[
I(\nu_0) = \frac{c}{4\pi H_0} \int_{0}^{z_{\text{max}}} \int_{L_{\text{min}}}^{L_{\text{max}}} \frac{dV}{dz} L(\nu_0) g(\nu) dL dz
\]

where \( g(\nu = \nu_0(1 + z)) \) is the source spectral shape and \( \rho(L, z) \) describes the luminosity function and its evolution with the redshift.

The FIR spectrum is modelled with a single-temperature, optically-thin greybody curve \( (g(\nu) \propto \nu^\beta \), where \( B(\nu) \) is the Planck function), which is appropriate to describe thermal re-radiation of primary emission from dust. Fiducial values for the dust temperature \( T \) and the emissivity index \( \beta \) were derived by fitting the FIR (longward of 60 \( \mu \)m) and 850 \( \mu \)m literature data of a large sample of about 100 nearby, hard X-ray selected AGN, almost equally populating the four classes of absorption column density used in the XRB model (centered at \( \log N_H = 21.5, 22.5, 23.5, 24.5 \)). The results indicate a narrow range in the best-fit values for both the dust temperature \( (T=30–50 \text{ K}) \) and the emissivity index \( \beta \ (1–2) \); moreover these values are independent from X-ray absorption and luminosity. The median values \( (T=40 \text{ K}, \beta=1.3) \) are considered to be representative of the average infrared spectrum used in the model calculation.

The spectral templates at FIR and submm wavelengths have been normalized to the X-ray model spectra looking for correlations between the monochromatic luminosities at 30 keV and 100 \( \mu \)m for each class of \( N_H \). We note that at 30 keV the source luminosity is not affected by absorption. The choice of this energy assures an unbiased estimate of the intrinsic nuclear emission.

It is then possible to integrate eq. (1) using the luminosity function, redshift evolution and absorption distribution adopted in the XRB synthesis model and then calculate the AGN contribution to the CFIRB. The adopted values for the Hubble constant and the cosmological deceleration parameter are \( H_0 = 50 \text{ Km s}^{-1}\text{Mpc}^{-1} \) and \( q_0 = 0 \).

3 Results

The model predictions are reported in Fig. 1, along with a compilation of recent measurements of the Extragalactic Background from FIR to X-rays.

It is clear, from a visual inspection of the figure, that the sources making most of the XRB do not significantly contribute to the CFIRB (thick solid lines in Fig. 1).

In order to test the sensitivity of the results to the model parameters, we have run a number of different models by modifying the input parameters (dust temperature, slope and normalization of the \( L_{IR} - L_X \) correlation) within 1\( \sigma \) from their best fit values.

The results suggest that the AGN contribution is never dominant, being always in the range 3-15% when compared to the 850 \( \mu \)m energy density \( (\nu I_\nu = 0.5 \text{ nW m}^{-2}\text{sr}^{-1}, \text{Fixsen et al.} 1998) \), and of the order of a few percent in the 100-200 \( \mu \)m range (dashed region in Fig. 2). According to unified models for Active Galaxies, obscured AGN are characterized by a large amount of dust and gas able to reprocess the primary radiation. It is not surprising that the most important AGN contribution to the CFIRB is due to Compton–thick sources, with \( N_H \) in excess of \( 10^{24} \text{ cm}^{-2} \) (dotted line in Fig. 1). On the other hand, the bulk of the XRB is accounted for by Compton–thin AGN \( (N_H < 10^{24} \text{ cm}^{-2}, \text{dashed line in Fig. 1}) \).
Figure 1: The model predicted AGN contribution at FIR and X-ray wavelengths (solid thick line). The dashed line represents the contribution of Compton–thin sources, while the dotted line that of Compton–thick objects. Data points are from a compilation of measurements of the Extragalactic Background intensity from Fixsen et al. 1998 (submm data and best–fit curve — green point and black curve), Lagache et al. 2000 (FIR data — red points), Dwek & Arendt 1998 (DIRBE Mid–IR data — yellow points), Pozzetti et al. 1998 (optical and Near–IR data — blue points) and Marshall et al. 1980 (X–ray data — cyan points).

4 Discussion

The AGN contribution to the CFIRB has been calculated by Almaini, Lawrence & Boyle (1999) and Gunn & Shanks (1999), following a similar approach, but with different assumptions concerning the broad–band AGN spectral energy distribution and their cosmic evolution. A good agreement is found between our results and their estimate (see Fig. 2): the predicted AGN contribution at 850 µm is in the range 3-20% for all the models.

Our results are also consistent with the observed (anti)–correlation between X–ray and FIR/submm sources content at limiting fluxes where a large fraction of the backgrounds in the two bands is resolved (Fabian et al. 2000, Hornschmeier et al. 2000, Barger et al. 2001). Recent observational results are also reviewed by Lawrence (2001) and Hauser & Dwek (2001): they both stress that AGN contribute at most only 10 – 20% to the CFIRB. An even more tight constraint (< 7%) has been obtained by Severgnini et al. (2000).
As already pointed out in previous works, we note that our results should be considered as lower limits of the AGN contribution to the CFIRB.

Indeed our approach is biased toward X–ray bright AGN; as a consequence, the observational $L_X–L_{IR}$ relation obtained from an X–ray selected sample favours a low IR/X ratio. A possible important contribution from FIR bright, X–ray weak sources might have been underestimated or not be accounted at all.

Moreover, according to our calculations, the most important contribution to the CFIRB comes from heavily obscured sources ($N_H > 10^{24} \text{ cm}^{-2}$). The relative number of Compton–thick AGN is only poorly constrained by XRB synthesis model which are not sensitive to their precise numerical fraction. It is thus possible to accommodate a larger number of Compton–thick AGN without exceeding the XRB observational constraints and, at the same time, to increase the contribution to the CFIRB. Recent observational evidences do indeed indicate that the fraction of obscured objects in the local universe is higher than previously thought (Risaliti et al. 1999). Finally, as already recognized by Almaini, Lawrence & Boyle (1999) the contribution to the
CFIRB is strongly dependent from the AGN evolution at high redshift, adding further uncertainties to the model predictions.

A more detailed analysis of the parameter space, including an extension of model predictions to Mid–IR wavelengths, is the subject of a paper in preparation (Brusa, Comastri & Vignali 2001).

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