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A LIMIT TO THE X-RAY LUMINOSITY OF NEARBY NORMAL GALAXIES

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The origin of the extragalactic diffuse X-ray background is not yet well understood. It is isotropic to the extent that a Galactic origin can be excluded. Indeed, even a halo of radius as large as 12 kpc could provide no more than 3% of the flux (ref. 1). The spectrum between 3 and 50 keV fits a 40 keV thermal bremsstrahlung form which is suggestive of emission from a hot intergalactic medium (ref. 2). This or some other truly diffuse mechanism may be responsible. If, however, discrete sources play a major role, we require either strong evolution of an already recognized X-ray emitting class, such as quasars, or a hitherto elusive population of low luminosity emitter. In the following we address the latter.

Without invoking evolution, the largest background contributions are thought to derive from Seyfert galaxies and clusters of galaxies. Based on estimated local densities, the total background can not be accounted for (refs. 2 and 3). Consistency with fluctuation measurements of the diffuse background is only achieved if members of the additional non-evolved class of source, which would be required to complete the background, are sufficiently numerous and hence of low luminosity. Compatibility requires a volume density $\gtrsim$ (8 x $10^{-3}$ $h^3$) Mpc$^{-3}$ (ref. 3), where h is the present Hubble constant in units of 100 km s$^{-1}$ Mpc$^{-1}$. The diffuse background between 2 and 10 keV has an emissivity $\sim$ (4.7 x $10^{39}$h) erg s$^{-1}$ Mpc$^{-3}$, which places an upper limit of $\sim$ (6 x $10^{41}/h^2$) erg s$^{-1}$ on the source luminosity. (We quote luminosities between 2 and 10 keV to ease comparison with other work. However, the source and diffuse background data used here are both from the HEAO-A2 experiment and comparison will be made over the entire energy range for which we have response, i.e. 2-60 keV; with highest efficiency 3-20 keV).

Such weak extragalactic sources do not present a high detection probability for non-imaging proportional counter experiments. The requirements for source detection with the A2 detectors on the HEAO 1 spacecraft are discussed in ref. 4. There is dependence on ecliptic latitude and consequent exposure but a $5\sigma$ detection threshold is $\sim 2 \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$ (2 - 10 keV) requiring, for example, a $10^{40}$ erg s$^{-1}$ emitter to be within $\sim$ 2 Mpc. To date the only catalogued galaxies < $10^{42}$ erg s$^{-1}$ are SMC, LMC, M31, Cen A and M82. Of these the latter two are radio galaxies but are, probably, atypical of their class in general. The others are classed as normal galaxies and their X-ray luminosity is compatible with that of our Galaxy, estimated, from the summed emissivity of known sources, to be $\sim 2 \times 10^{39}$ erg s$^{-1}$. Taking M31 and the Galaxy as standards, normal galaxies are estimated to contribute only a few percent of the diffuse background (see refs. 3,5-6). However, as the most numerous extragalactic objects they merit further examination in the search for a class of low luminosity X-ray source.

In this work we report results of a test of the hypothesis that normal galaxies are on average more luminous than our Galaxy and M31 and therefore form a candidate class of numerous low luminosity emitters which may fulfill requirements for contributing substantially to the diffuse background. The imaging experiments on the Einstein Observatory will measure at energies below $\sim$ 4 keV where low energy absorption and soft sources will limit comparison with the 2-60 keV background. As noted above, the comparison between source and background fluxes are made over the HEAO-A2 experiment energy range. But, where 2-10 keV source luminosities are given, a constant multiplicative factor suitable for a 9 keV thermal bremsstrahlung spectrum has been used.

Data from the A2 detectors on the HEAO 1 spacecraft (ref. 7) were investigated for emission from positions coincident with normal galaxies selected from the Second Reference Catalogue of Bright Galaxies (ref. 8). Selection required a velocity less than 1100 km $s^{-1}$ (i.e. D < 20 Mpc for $H_0 = 55$ km $s^{-1}$ $Mpc^{-1}$). Positions contaminated by catalogued X-ray sources were excluded. Since only data from the $1\frac{1}{2}^{o} \times 3^{o}$ field of view detectors were used, a source free region $3^{o}$ each side of the galaxy along the scan direction and $5^{o}$ in the perpendicular direction was demanded. Where galaxies were clustered the closest member was selected. 76 galaxies satisfied requirements. A $25^{o}$ field of scan angle about the galaxy position, accumulated over $\sim$ 4 days about the one of maximum exposure, was fit with a fixed source at the galaxy position and as many other sources as necessary to fit the remainder of the field. Negative values for the source count rate were allowed. After correcting for effective exposure for each fixed source a count rate distribution was found. This was consistent, to within $1\sigma$ errors, with zero. This result implies that we can only determine upper limits to the average luminosity for various model luminosity distributions.

The simplest model which can be examined is one in which all galaxies are assumed to have a standard luminosity, $Lh^2$. Then the probability of observing the ith member of the 76 galaxies with its measured luminosity, $L_i h^2$, and associated standard deviation, $\sigma_i$, is $P_{si}(Lh^2) = (\sigma_i(2\pi)^{\frac{1}{2}})^{-1} \exp(-z_i^2/2)$, where $z_i = (L_i - L)h^2/\sigma_i$. Hence the liklihood function for the measured luminosities of the complete sample is $P_s(Lh^2) \propto \exp(-(\Sigma_i(z_i^2/2)))$. The values for $\sigma_i$ were calculated from the standard deviation of the count rate distribution for the selected galaxies after this value had been confirmed to be consistent with values derived using random sample positions on the sky. The function $P_S(Lh^2)$ is of a Gaussian form. The values of $Lh^2$ bounding 70% and 90% of the area are $1.5 \times 10^{38}$ erg $s^{-1}$ and $2.7 \times 10^{38}$ erg $s^{-1}$ respectively, which are the upper limits to the standard normal galaxy luminosity at these respective confidence levels. Even for a value of $H_0$ of 50 km $s^{-1}$ $Mpc^{-1}$ the results show that the average X-ray luminosity of normal galaxies is $\lesssim 10^{39}$ erg $s^{-1}$. This is a little lower than the X-ray luminosity of our Galaxy. However, we note that the average optical luminosity of the chosen galaxies in the B system is $(2 \times 10^9/h^2)$ $L_\odot$ and the appropriate value for our Galaxy with which this should be compared is $11 \times 10^9$ $L_\odot$ (the mean orientation value estimated from the Galactic pole value given in ref. 9).

More realistically, the luminosity function of the galaxies can be assumed to be an exponential, i.e. $F(L,L_0) = (L_0h^2)^{-1} \exp(-L/L_0h^2)$. The probability of observing the ith member of the 76 galaxies with its measured luminosity is now $P_i(L_0h^2) = \int F(L,L_0)\, P_{si}(Lh^2)dL$. The product over all values of i gives the liklihood function for the complete sample. As shown in Fig. 1, it is approximately exponential. The 70% and 90% upper limits to $L_0h^2$ are now $1.8 \times 10^{38}$ erg $s^{-1}$ and $3.4 \times 10^{38}$ erg $s^{-1}$, in reasonable agreement with the simple model.

The method generates a strong distance-dependent weighting factor. Because the answer is dominated by the closest 10 galaxies, selection effects may be important. To investigate this we divide the galaxies by distance into 3 bands. The number of galaxies per band increases with distance so that the three calculated luminosity upper limits are roughly equal. We find that they are $\sim$ 3 times those quoted above. Thus we conclude that, to within a factor of 3, the 76 galaxies form a homogeneous class of which the closest 10 are not particularly anomalous. This is further confirmed in that the mean count rate for these 10 is within 1$\sigma$ of the mean of the total sample.

Based on these results, we can make an h-independent comparison of the emissivity of galaxies with that of the diffuse background. The density of normal galaxies is calculated to be $\simeq(0.13\ h^3)\ \mathrm{Mpc}^{-3}$. This uses a likely maximum value for the optical luminosity density of galaxies of $(2.6 \times 10^8 h)\ L_{\odot}\ \mathrm{Mpc}^{-3}$ (see critical review by Felten; Ref.10) and the average luminosity for our sample as given above.
For the detector fields of view we are using (defined as R15 in ref. 4) and applying the 90% upper limit criterion for the exponential luminosity distribution model, we find an emissivity of $< (2.7 \times 10^{45} h)$ ct $\mathrm{s}^{-1}\ \mathrm{Mpc}^{-3}$. This is to be compared with the diffuse background emissivity of $\sim (3 \times 10^{47} h)$ ct $\mathrm{s}^{-1}\ \mathrm{Mpc}^{-3}$. Thus normal galaxies contribute $\lesssim$ 1%

Van Paradijs (ref. 6) has calculated the normal galaxy contribution to the X-ray background by modelling the X-ray luminosities of galaxy constituents. He estimates 0.5 - 2.8% (2-10 keV) for no evolution, but investigates several ways in which this value may be increased. While we can not address those involving evolution, our calculations indicate that further non-evolutionary effects are not important.

In summary, by using a sample of objects we have investigated emission at luminosities lower than those for which we can study individual discrete sources and have shown that normal galaxies do not appear to provide the numerous low luminosity X-ray sources which could make up the 2-60 keV diffuse background. Indeed, upper limits suggest luminosities comparable with, or a little less than, that of the Galaxy. This is consistent with the fact that the average optical luminosity of the sample galaxies within $\sim$ 20 Mpc is slightly lower than that of the Galaxy. An upper limit of $\sim$ 1% of the diffuse background from such sources is derived.

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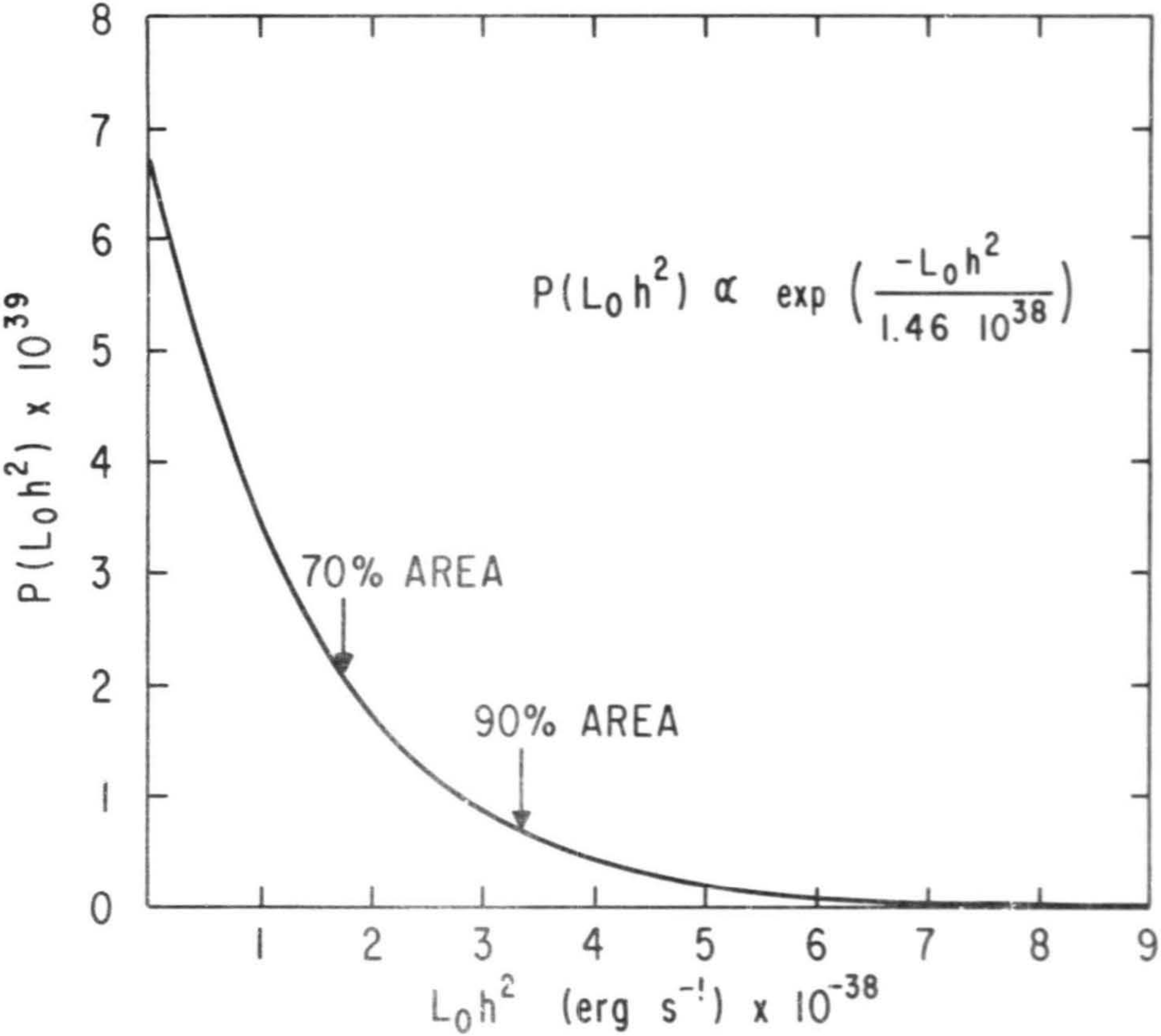
FIGURE CAPTIONS

Figure 1 - The $L_0h^2$ probability function resulting from the application of a luminosity function $F(L,L_0) = (1/L_0h^2) \exp(-L/L_0h^2)$ to the sample of 76 normal galaxies. The result fits the indicated exponential function. The values of $L_0h^2$ bounding 70% and 90% of the area are shown, i.e. the upper limits to $L_0h^2$ at these respective confidence levels.


P(L₀h²) x 10^39
L₀h² (erg s^-1) x 10^-38
P(L₀h²) α exp(-L₀h² / 1.46 10^38)
70% AREA
90% AREA
0
1
2
3
4
5
6
7
8
9