Limits on the X-ray emission from several hyperluminous IRAS galaxies

R. J. Wilman,¹ A. C. Fabian,¹ R. M. Cutri,² C. S. Crawford¹ and W. N. Brandt³

¹Institute of Astronomy, Madingley Road, Cambridge CB3 0HA
²IPAC, Caltech, MS 100-22, Pasadena, CA 91125, USA
³Department of Astronomy & Astrophysics, Pennsylvania State University, 525 Davey Lab, University Park, PA 16802, USA

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ABSTRACT

We report long, pointed ROSAT HRI observations of the hyperluminous galaxies IRAS F00235+1024, F12514+1027, F14481+4454 and F14537+1950. Two of them are optically classified as Seyfert-like. No X-ray sources are detected at the positions of any of the objects, with a mean upper limit \( L_X \mid L_{\text{Bol}} \approx 2.3 \times 10^{-4} \). This indicates that any active nuclei are either atypically weak at X-ray wavelengths or obscured by column densities \( N_H > 10^{23} \text{ cm}^{-2} \). They differ markedly from ‘ordinary’ Seyfert 2 galaxies, bearing a closer resemblance in the soft X-ray band to composite Seyfert 2 galaxies or to some types of starburst.


1 INTRODUCTION

With bolometric luminosities in excess of \( 10^{13} L_\odot \) emitted mostly in the mid- to far-infrared, hyperluminous IRAS galaxies are among the most luminous objects in the Universe. The origin of the high luminosity, however, remains uncertain, with massive starbursts and buried active nuclei having both been implicated as radiation sources capable of powering thermal reradiation by dust grains (see e.g. Rowan-Robinson et al. 1993; Sanders & Mirabel 1996). Morphologically, many of these galaxies display the signatures of the long-sought class of type 2 quasars: Seyfert 2 galaxies, exhibiting at least the presence of an active nucleus. The third object, IRAS F14481+4454, has optical spectra similar to Seyfert 2 galaxies, indicating at least the presence of an active nucleus. The third object, IRAS F14537+1950, exhibits starburst characteristics in its optical spectrum. The fourth object in our sample, IRAS F00235+1024, was discovered by McMahon et al. (in preparation) during a systematic search for ultraluminous IRAS galaxies with the

that the emission is actually dominated by a cooling flow (Fabian & Crawford 1995), consistent with the observation that the object appears to reside at the core of a rich cluster of galaxies (Kleinmann et al. 1988). The hyperluminous galaxy IRAS F20460+1925 and the ultraluminous galaxy IRAS F23060+0505 are X-ray-detected (Ogasaka et al. 1997 and Brandt et al. 1997, respectively) behind intrinsic column densities of \( \sim 10^{22} \text{ cm}^{-2} \). The hyperluminous galaxy IRAS F10214+4724 was only marginally detected in X-rays [Lawrence et al. 1993; its luminosity is now known to be greatly enhanced by gravitational lensing (Eisenhardt et al. 1996)]. A 20-ks HRI observation of IRAS F15307+3252 (Fabian et al. 1996, hereafter F96) failed to detect any X-ray source at an upper limit of \( \sim 4 \times 10^{38} \text{ erg s}^{-1} \), representing less than \( 2 \times 10^{-4} \) of the bolometric luminosity and indicating that the emission is actually dominated by a cooling flow (Fabian & Crawford 1995), consistent with the observation that the object appears to reside at the core of a rich cluster of galaxies (Kleinmann et al. 1988). The hyperluminous galaxy IRAS F20460+1925 and the ultraluminous galaxy IRAS F23060+0505 are X-ray-detected (Ogasaka et al. 1997 and Brandt et al. 1997, respectively) behind intrinsic column densities of \( \sim 10^{22} \text{ cm}^{-2} \). The hyperluminous galaxy IRAS F10214+4724 was only marginally detected in X-rays [Lawrence et al. 1993; its luminosity is now known to be greatly enhanced by gravitational lensing (Eisenhardt et al. 1996)].
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level using the Bayesian method of Kraft, Burrows & Nousek (1991). upper limits on the count rates (calculated at the 90 per cent confidence sources are detected at the optical positions of the objects. Upper
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IRAS F00235+1024, F12514+1027, F14481+4454 and
2 ROSAT HRI OBSERVATIONS
IRAS F00235+1024, F12514+1027, F14481+4454 and
and F14537+1950 were observed with the ROSAT (Trümper 1983)
HRI (David et al. 1995) between the dates given in Table 1. No sources are detected at the optical positions of the objects. Upper
limits on the count rates (calculated at the 90 per cent confidence level using the Bayesian method of Kraft, Burrows & Nousek 1991) are shown in Table 1. Also shown are upper limits on the unab-
sorbed flux, $3$, and luminosity, $L_X$, for each object in the intrinsic 0.1–2.4 keV band, assuming a power-law continuum of photon index 2. For comparison with a sample of starburst galaxies in Section 3.2, a thermal bremsstrahlung source spectrum with $kT = 1$ keV was used to calculate $L_X$, the luminosity in the intrinsic 0.5–2.0 keV band. Allowance was made for photoelectric absorption by the Galaxy (with column densities $N_H$ shown in the table), and a cosmology of $H_0 = 50$ km s$^{-1}$ Mpc$^{-1}$ and $q_0 = 0.5$ has been adopted throughout.

3 DISCUSSION
3.1 On active nuclei
From the table, we see that the upper limits on the ratio $L_X/L_{bol}$ are quite similar for all of the objects, with a mean of $\approx 2.3 \times 10^{-4}$. If we adopt in the first instance the assumption that the sources are powered by active nuclei, we can use this figure to make a number of inferences about their properties. A similar discussion was given in F96 for the case of IRAS F15307+3252 which was observed to have $L_X/L_{bol} < 2 \times 10^{-4}$ (a 3σ upper limit). We show, in Fig. 1, $L_X/L_{bol}$ plotted against $L_{bol}$ for these sources and some representa-
tive AGN and starbursts. Denoted by the arrows in this figure are the upper and lower ends of the range of values of $L_X/L_{IR}$ for the sample of Seyfert 2 galaxies in Green, Anderson & Ward (1992). The latter authors provide Einstein Imaging Proportional Counter (IPC) (0.5–
4.5 keV) X-ray luminosities corrected for Galactic absorption which we convert to (0.1–2.4 keV) luminosities ($L_X$). Luminosities in the 8–1000 μm band ($L_{IR}$) were calculated from the IRAS photometric data in Bonatto & Pastoriza (1997) according to the prescription of Perault (1987). In our sample we include only those

<table>
<thead>
<tr>
<th>IRAS</th>
<th>F00235+1024</th>
<th>F12514+1027</th>
<th>F14481+4454</th>
<th>F14537+1950</th>
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</thead>
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<tr>
<td>$z$</td>
<td>0.57$^a$</td>
<td>0.30$^f$</td>
<td>0.66$^i$</td>
<td>0.64$^f$</td>
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<tr>
<td>optical classification:</td>
<td>starburst</td>
<td>Seyfert 2</td>
<td>Seyfert 2</td>
<td>starburst</td>
</tr>
<tr>
<td>Galactic column density $N_H$: $10^{20}$ cm$^{-2}$</td>
<td>5.1</td>
<td>1.73</td>
<td>1.72</td>
<td>2.81</td>
</tr>
<tr>
<td>exposure time: $s$</td>
<td>60365</td>
<td>20398</td>
<td>26883</td>
<td>17970</td>
</tr>
<tr>
<td>count rate: $10^{-8}$ count s$^{-1}$</td>
<td>$&lt; 0.70$</td>
<td>$&lt; 2.40$</td>
<td>$&lt; 1.72$</td>
<td>$&lt; 1.99$</td>
</tr>
<tr>
<td>$3$: $10^{-14}$ erg cm$^{-2}$ s$^{-1}$</td>
<td>$&lt; 0.50$</td>
<td>$&lt; 1.21$</td>
<td>$&lt; 0.87$</td>
<td>$&lt; 1.17$</td>
</tr>
<tr>
<td>$L_X$: $10^{43}$ erg s$^{-1}$</td>
<td>$&lt; 0.87$</td>
<td>$&lt; 0.54$</td>
<td>$&lt; 2.07$</td>
<td>$&lt; 2.61$</td>
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<tr>
<td>$L_{bol}$: $10^{43}$ L$\odot$</td>
<td>1.5$^a$</td>
<td>1.0$^{f}$</td>
<td>2.0$^i$</td>
<td>2.0$^f$</td>
</tr>
<tr>
<td>$L_X/L_{bol}$</td>
<td>$&lt; 1.5 \times 10^{-4}$</td>
<td>$&lt; 1.4 \times 10^{-4}$</td>
<td>$&lt; 2.7 \times 10^{-4}$</td>
<td>$&lt; 3.4 \times 10^{-4}$</td>
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<tr>
<td>$\Delta N_H$: $10^{23}$ cm$^{-2}$</td>
<td>1.8</td>
<td>1.0</td>
<td>1.5</td>
<td>1.5</td>
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<td>$A_V$: mag</td>
<td>120</td>
<td>67</td>
<td>100</td>
<td>100</td>
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<tr>
<td>$L_X/L_{bol}$</td>
<td>$&lt; 8.96 \times 10^{-5}$</td>
<td>$&lt; 7.81 \times 10^{-5}$</td>
<td>$&lt; 2.09 \times 10^{-4}$</td>
<td>$&lt; 2.41 \times 10^{-4}$</td>
</tr>
</tbody>
</table>

† From Cutri et al. (in preparation); ‡ from McMahon et al. (in preparation).
* Using the $N_H(E(B–V))$ conversion of Bohlin, Savage & Drake (1978), with a dust/gas ratio equal to that of the Galaxy.

![Figure 1](https://academic.oup.com/mnras/article-abstract/300/1/L7-10/1130793/300)
Seyfert 2 galaxies that were detected in all four IRAS bands and with the Einstein IPC. We note that for Seyfert 2 galaxies $L_B$ may differ substantially from $L_{Bol}$, but we have insufficient information upon which to base a computation of the latter quantity. Nevertheless, since $L_{IR} \approx L_{Bol}$ for the hyperluminous galaxies, the comparison is still a useful one. The large extent of the range for the Seyfert 2 galaxies is, we believe, a consequence of the heterogeneous nature of the sample, comprising composite objects with active nuclei and starbursts, as well as ‘ordinary’ Seyfert 2 galaxies without the latter component. (We are not aware of any study that compares the values of $L_X/L_{Bol}$ for the known Seyfert 2 sub-populations.)

If being observed directly, it follows that the active nuclei are emitting less than 0.02 per cent of their power at soft X-ray wavelengths, which is substantially below the figure of 5 per cent for a typical quasar (F96). Assuming that any active nuclei are intrinsically typical, the existence of material with absorbent or scattering properties is thus inferred. In the former case, i.e. if nuclei are being observed in direct light, quantities of material capable of depressing the soft X-ray fluxes by minimum factors of between $=150$ (for IRAS F14537+1950) and $=360$ (for IRAS F12514+1027) are required. A proper treatment of redshifted absorption using XSPEC (assuming an intrinsic power-law continuum with a photon index of 2) demonstrated that this can be effected by intrinsic column densities $\Delta N_H > 10^{23} \text{cm}^{-2}$ (the inferred $\Delta N_H$ for each object, along with the corresponding value of the visual extinction $A_V$, is shown in the table). This is very much less than the $\Delta N_H \sim 1.5 \times 10^{24} \text{cm}^{-2}$ at which the sources would become optically thick to Compton scattering.

Alternatively, if the intrinsic column densities are large enough to block all of the direct light, the results imply that on average less than 0.5 per cent of the soft X-ray flux is scattered into our line of sight (assuming a typical intrinsic value of 5 per cent for $L_X/L_{Bol}$; if the spread in the latter quantity is incorporated – see Fig. 1 – the scattering fraction can be as high as $\sim 3$ per cent). This is surprisingly small [cf. the $=10$ per cent scattering fraction inferred in the optical for IRAS F15307+3252 by Hines et al. (1995)] and implies that any optical scattering medium is composed of dust (which does not scatter X-rays through large angles), not electrons. The hyperluminous galaxies are in this way different from nearby, lower luminosity Seyfert 2 galaxies such as NGC 1068 where electron scattering plays an important role. Note too from Fig. 1 that they have a significantly lower value of $L_X/L_{Bol}$ than that of NGC 1068, which is itself low for a (non-composite) Seyfert galaxy (see e.g. Awaki, Ueno & Koyama 1997). This is perhaps an indication that even any scattered soft X-ray emission in our objects is absorbed.

It could instead be that intrinsically typical active nuclei are present but that they account for less than 5 per cent of the total bolometric flux from the objects (assuming a scattering fraction of 10 per cent). They may therefore be high-luminosity counterparts to composite starburst/Seyfert 2 galaxies, which, according to Ueno et al. (1997), fall toward the lower end of the Seyfert 2 range in Fig. 1, near the region occupied by our upper limits. Based upon the appearance of the optical spectrum, however, F96 provide reasons for believing this scenario to be unlikely for IRAS F15307+3252.

Indeed, given the large amounts of gas expected to be driven to the nucleus of the galaxy during a merger, and discoveries at low redshift that most galaxies have central black holes (Magorrian et al. 1998), it would be surprising if there were no luminous AGN in the objects observed. The Eddington limit does, however, provide a restriction on the AGN luminosity component, and requires a central mass exceeding $3-6 \times 10^8 M_\odot$ in order that the AGN component dominates a bolometric luminosity of $L_{bol} = 1-2 \times 10^{43} L_\odot$. If the merging galaxies had black holes with masses ranging between that of our Galaxy ($2.6 \times 10^6 M_\odot$; Eckart & Genzel 1997) and M31 ($6 \times 10^7 M_\odot$; Magorrian et al. 1998), they could not then power the hyperluminous IRAS galaxies at the observed rate. In other words, a merger between our Galaxy and M31 could not produce a hyperluminous AGN. (The Salpeter black hole growth time-scale exceeds the likely age of any merger.) A hyperluminous AGN requires a supermassive black hole in the first place.

3.2 On starbursts

IRAS F00235+1024 and F14537+1950 are classified as starbursts on the basis of optical spectra (McMahon et al. in preparation and Cutri et al. in preparation, respectively). In order to assess the implications of the present soft X-ray data for a starburst interpretation for these objects, we compare our upper limits on the quantity $L_X/L_{Bol}$ with the range of values given by Kii et al. (1997) for a sample of starburst galaxies. Our definition of $L_X$ is motivated by the latter authors’ use of the soft X-ray ASCA band of 0.5–2.0 keV and by the fact that the spectra of starburst galaxies are best described by thermal models. Kii et al. report that $L_X/L_{Bol}$ is of the order of $10^{-5}$ for starburst galaxies, ranging from $3.2 \times 10^{-5}$ for Arp 220 [an ultraluminous starburst galaxy the ASCA spectrum of which is analysed by Iwasawa & Fabian (in preparation)] to $3.2 \times 10^{-4}$ for M82. It can be seen from Table 1 that the 90 per cent upper limits for the objects in our sample fall within this range and are thus not wholly inconsistent with a starburst origin for the soft X-ray emission. Our data suggest that, if starbursts do exist in these objects, they are more likely to resemble that in Arp 220 than that in M82.

4 CONCLUSIONS

We have reported the non-detection at soft X-ray wavelengths of four hyperluminous galaxies. This result extends to a larger sample that found by F96 for IRAS F15307+3252, thus enabling constraints to be placed upon the properties of some of the most luminous objects in the Universe.

Two of the objects show evidence for an active nucleus in their optical spectra. These AGN must be either anomalously weak at X-ray wavelengths or obscured by column densities $N_H > 10^{23} \text{cm}^{-2}$. Any optical scattering medium must be composed of dust, not electrons. The upper limits fall near the lower end of the range for a sample of Seyfert 2 galaxies, close to the region where objects of the latter type are thought to be of a composite nature (possessing starburst and active nucleus components).

By comparison with ASCA observations of the soft X-ray fluxes from a sample of local starburst galaxies, we find that our ROSAT observations are not inconsistent with the presence of starbursts in our objects. For IRAS F00235+1024 and F14537+1950, this is at least in line with expectations based upon the appearance of their optical spectra.

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REFERENCES


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