1989ApJ...344..125P

THE ASTROPHYSICAL JOURNAL, 344:125–134, 1989 September 1
© 1989. The American Astronomical Society. All rights reserved. Printed in U.S.A.

CONTRIBUTIONS OF LOW-LUMINOSITY SOURCES TO THE X-RAY BACKGROUND

M. PERSIC,[1,2,3] G. DE ZOTTI,[4] L. DANESE,[5] G. G. C. PALUMBO,[1,3,6,7] A. FRANCESCHINI,[5]
E. A. BOLDT,[1] AND F. E. MARSHALL[1]
Received 1987 October 12; accepted 1989 February 22

ABSTRACT

We have exploited the *HEAO 1* A-2 data base to determine hard X-ray fluxes, or upper limits, for complete optically selected samples of active and normal galaxies, in order to estimate or to constrain their local X-ray luminosity functions. We find that the luminosity function of Seyfert nuclei must flatten down drastically shortly below the observational limit of Piccinotti *et al.*; little can be added by dwarf active nuclei hidden in otherwise normal galaxies. We also analyze the possible contribution to the X-ray background from galaxies with strong star formation activity, in the light of the possibility of a substantial cosmological evolution suggested by recent radio and *IRAS* data.

Subject headings: galaxies: nuclei — galaxies: Seyfert — galaxies: stellar content — galaxies: X-rays — X-rays: sources

I. INTRODUCTION

Although it is acknowledged that much of the extragalactic X-ray background (XRB) may not be ascribed to currently known classes of discrete sources (Leiter and Boldt 1982; Giacconi and Zamorani 1987; Guilbert and Fabian 1986), quantitative estimates of the actual XRB contributions of such populations are still very uncertain.

A closer look at existing data, however, allows us to narrow down considerably the range of viable possibilities. We will deal primarily with data from the *HEAO 1* A-2 experiment with $1^\circ.5 \times 3^\circ$ field of view (Rothschild *et al.* 1979); these are the R15 rates as defined by Marshall *et al.* (1979).

A particularly debated issue is the role of low-luminosity active galactic nuclei (AGNs). In § II, by investigating the hard X-ray emission of Seyfert galaxies in Huchra and Burg's (1989) sample, we derive strong constraints on the extension of their luminosity function below the limit of the direct determination by Piccinotti *et al.* (1982). By determining the distribution of X-ray count rates for a sample of disk galaxies with nuclear emission lines and comparing it with their distribution of Hα fluxes, we set, in § III, limits on space densities of dwarf AGNs hidden in " normal " galaxies (Elvis, Soltan, and Keel 1984).

The growing circumstantial evidence, further substantiated by our analysis, that canonical AGNs are unlikely to explain the XRB, may hint at a new population (Boldt and Leiter 1981) or to a known class whose X-ray properties have not yet been fully recognized. In § IV we analyze the possible contribution to the XRB of starburst galaxies (Bookbinder *et al.* 1980; Weedman 1987; De Zotti 1987), for which a strong cosmological evolution is expected on simple physical grounds and is indeed strongly suggested, at least at radio wavelengths, by the recent ultradeep VLA surveys (Danese *et al.* 1987). In § V we deal with ultraluminous infrared galaxies. In § VI we discuss elliptical and S0 galaxies hosting compact nuclear radio sources, for which a substantial cosmological evolution is also indicated by radio data, as well as "normal" galaxies. Our results are summarized and discussed in § VII.

We will make reference to the XRB intensity in either the 2–10 keV band or at 2 keV. Both have been obtained from the spectral fit determined by Marshall *et al.* (1980) using a 40 keV thermal bremsstrahlung model. We find $I(2\ \text{keV}) = 4.0 \times 10^{-26}$ ergs cm^{-2} s^{-1} sr^{-1} Hz^{-1}, $I(2\text{–}10\ \text{keV}) = 5.3 \times 10^{-8}$ ergs cm^{-2} s^{-1} sr^{-1}. An average conversion factor value of 2.17×10^{-11} ergs cm^{-2} s^{-1} in the 2–10 keV band per R15 count s^{-1} (appropriate to a power-law spectrum with energy index 0.65; see Piccinotti *et al.* 1982) was assumed for *all* classes of sources. The same spectral index was adopted to convert 2–10 keV fluxes into flux densities at 2 keV.

A Hubble constant $H_0 = 50$ km s^{-1} Mpc^{-1} and $q_0 = \frac{1}{2}$ are used throughout this paper.

II. SEYFERT NUCLEI

Contrary to earlier expectations (Setti and Woltjer 1979; Tananbaum *et al.* 1979; see, however, Cavaliere *et al.* 1981*a*, *b*; Kembhavi and Fabian 1982), the most recent estimates of the contribution to the XRB of high-luminosity quasars ($M_B < -23$) now converge in indicating quite modest values ($<20\%$ at 2 keV), both in the case of luminosity evolution (Cavaliere, Giallongo, and Vagnetti 1985; Danese *et al.* 1986) and of (luminosity-dependent) density evolution (Schmidt and Green 1986) models.

The role of low-luminosity AGNs is much more difficult to assess. The hard X-ray surveys were not sensitive enough to allow a determination of their local luminosity function below 10^{42} ergs s^{-1} (Piccinotti *et al.* 1982), and the interpretation of the *Einstein* medium-sensitivity and deep survey data (Gioia *et al.* 1984; Griffiths *et al.* 1983; Murray 1987) is complicated by the variety of soft X-ray spectra of these objects which may exhibit either strong photoelectric absorption (Lawrence and Elvis 1982; Reichert *et al.* 1985), or soft excesses (Wilkes and Elvis 1986). Optical surveys also miss an important fraction of them, mainly because of contamination from the surrounding galaxy.

Nevertheless, useful constraints on the extension of the Piccinotti *et al.* luminosity function may be derived exploiting the CfA sample of 48 Seyfert galaxies (Huchra and Burg 1989), as

[1] Laboratory for High Energy Astrophysics, Goddard Space Flight Center.
[2] Osservatorio Astronomico, Trieste, Italy.
[3] NRC/NAS Resident Research Associate.
[4] Osservatorio Astronomico, Padova, Italy.
[5] Dipartimento di Astronomia, Padova, Italy.
[6] Dipartimento di Astronomia, Bologna, Italy.
[7] Istituto Tecnologie e Studio Radiazioni Extraterrestri (I.Te.S.R.E.) Consiglio Nazionale delle Ricerche (CNR), Bologna, Italy.

© American Astronomical Society • Provided by the NASA Astrophysics Data System

listed by Edelson (1987). The relevant data are summarized in Table 1, where we have sorted the type 1 Seyfert galaxies first, and then the type 2 Seyferts. Note that Mrk 334 and NGC 3227 are actually of type 1 (see Veron-Cetty and Veron 1987, and references therein) rather than of type 2, as quoted in Edelson (1987).

a) *Optical Luminosity Function*

A straightforward application of standard techniques (see, e.g., Felten 1977) to the CfA sample yields a local optical luminosity function essentially flat for $M_{Zw} \geq -21$ (see Fig. 1); as discussed by Piccinotti *et al.* (1982), this would suggest a corresponding leveling of the X-ray luminosity function for $L_x \leq 2 \times 10^{42}$ ergs s^{-1}.

On the other hand, the V/V_{max} test may suggest (see Fig. 2) an increasing incompleteness for $M_{Zw} \geq -21$, which is not surprising given the difficulty in recognizing Seyfert properties when the nuclear emission is weak. Although the evidence is not very strong ($\langle V/V_{max} \rangle$ is $\leq 2.1\ \sigma$ below 0.5 for each of the three low-luminosity bins; combining them, we find

TABLE 1

X-Ray Data for CfA Seyfert Galaxies

							log L_x (2–10 keV)				
R.A.	Decl.	Names	Type	z	R15	Error	A-2	A-1	MPC	IPC/HRI	References
$00^h00^m35^s.5$	21°40′53″	Mrk 334	1	0.0220	<0.86	0.29	<43.59	...	...	...	
00 03 45.1	19 55 27	Mrk 335	1	0.0259	<0.86	0.29	<43.73	43.59	43.46	43.89	1
00 48 53.0	29 07 46	UGC 524	1	0.0359	<0.85	0.28	<44.01	44.00[a]	...	...	
00 50 57.8	12 25 19	I Zw 1	1	0.0604	<0.82	0.27	<44.44	...	...	44.26	2
01 52 44.0	06 22 36	UGC 1395	1	0.0174	<0.90	0.30	<43.41	...	...	...	
02 12 00.5	−00 59 57	Mrk 590	1	0.0263	1.23	0.29	43.90	43.58	43.51	43.90	2
09 57 14.4	13 17 02	Mrk 1243	1	0.0353	0.89	0.30	<44.01	...	...	...	
10 20 48.0	20 06 00	NGC 3227	1	0.0038	1.42	0.28	42.28	42.41	42.02[b]	...	
11 03 23.0	72 50 24	NGC 3516	1	0.0085	1.09	0.24	42.87	...	43.16[b]	42.30	3
11 37 04.7	32 11 13	Mrk 744	1	0.0091	<0.86	0.29	<42.82	...	...	...	
12 00 36.0	44 48 00	NGC 4051	1	0.0022	<0.90	0.30	<41.61	41.46	41.46	41.49	4
12 08 00.0	39 41 00	NGC 4151	1	0.0030	7.81	0.30	42.82	42.17	42.95[b]	41.52	5
12 14 37.0	07 28 06	NGC 4235	1	0.0077	<0.91	0.30	<42.70	...	<42.14	41.99	6
12 15 55.5	30 05 27	Mrk 766	1	0.0128	<1.01	0.36	<43.22	...	42.72	42.34	2
12 19 31.8	75 35 10	Mrk 205	1	0.0714	<0.71	0.24	<44.53	44.51	44.26	44.45	7
12 54 05.0	57 08 37	Mrk 231	1	0.0410	<0.75	0.25	<44.07	...	...	<42.28	6
13 11 12.0	36 51 00	NGC 5033	1	0.0030	<0.80	0.27	<41.83	42.09[c]	...	41.20	8
13 29 54.0	11 22 00	Mrk 789	1	0.0320	<0.86	0.29	<43.92	...	...	...	
13 39 55.0	35 54 30	NGC 5273	1	0.0036	<0.78	0.26	<41.98	...	...	...	
13 51 51.9	69 33 13	Mrk 279	1	0.0304	1.03	0.24	43.95	44.06	43.87[b]	44.08	9
14 15 42.0	25 22 00	NGC 5548	1	0.0166	2.87	0.28	43.87	43.86	43.68	43.40	5
14 34 58.0	59 00 40	Mrk 817	1	0.0314	<0.78	0.26	<43.86	...	...	...	
15 01 36.4	10 37 59	Mrk 841	1	0.0364	<0.85	0.28	<44.02	...	43.92[b]	44.32	6
15 28 51.0	07 37 38	NGC 5940	1	0.0339	1.26	0.35	44.13	...	...	...	
16 14 40.0	35 49 49	NGC 6104	1	0.0280	<0.75	0.25	<43.74	...	...	...	
22 37 47.0	07 47 33	UGC 12138	1	0.0250	<0.86	0.28	<43.70	...	...	...	
23 00 44.0	08 36 18	NGC 7469	1	0.0160	1.68	0.30	43.60	43.71	43.60[b]	...	
23 16 22.7	00 01 48	Mrk 530	1	0.0290	<1.54	0.52	<44.08	...	<43.57	43.28	10
01 22 42.7	31 52 35	Mrk 993	2	0.0154	<0.81	0.27	<43.26	...	...	...	
01 41 22.7	02 05 54	Mrk 573	2	0.0173	<0.81	0.27	<43.36	...	...	41.83	11
02 40 07.0	−00 13 30	NGC 1068	2	0.0037	<0.86	0.29	<42.04	41.96	<41.68	41.86	12
02 52 39.8	−00 23 07	NGC 1144	2	0.0288	<0.81	0.27	<43.80	...	...	...	
09 58 34.9	55 55 16	NGC 3079	2	0.0037	<0.75	0.25	<41.98	...	...	40.50	13
10 42 15.2	06 51 35	NGC 3362	2	0.0227	<0.82	0.27	<43.60	...	...	...	
10 58 42.4	45 55 22	UGC 6100	2	0.0292	<0.75	0.25	<43.79	...	...	...	
11 53 53.0	55 24 18	NGC 3982	2	0.0037	<0.76	0.25	<41.99	...	...	...	
12 23 15.0	12 56 18	NGC 4388	2	0.0086	Confused			...	...	40.35	14
13 35 28.5	39 24 31	UGC 8621	2	0.0201	<0.79	0.26	<43.48	...	...	...	
13 35 44.3	04 47 47	NGC 5252	2	0.0231	<0.84	0.28	<43.63	...	...	...	
13 36 14.7	48 31 48	Mrk 266A	2	0.0275	<0.73	0.24	<43.71	...	...	...	
13 39 40.7	67 55 33	Mrk 270	2	0.0090	<0.69	0.23	<42.72	...	...	40.92	2
13 45 04.4	34 23 57	Mrk 461	2	0.0163	<0.77	0.26	<43.28	...	...	...	
14 15 42.	26 39	IC 4397	2	0.0147	<0.79	0.26	<43.20	...	...	...	
14 31 22.5	05 40 38	NGC 5674	2	0.0248	<0.77	0.26	<43.65	...	...	...	
14 35 20.6	36 47 13	Mrk 686	2	0.0122	<0.76	0.25	<43.02	...	...	...	
15 24 18.9	41 50 41	NGC 5929	2	0.0083	<0.73	0.24	<42.67	...	...	...	
23 25 24.8	08 30 17	Mrk 533	2	0.0289	<0.83	0.28	<43.81	...	...	...	
23 26 30.7	03 15 28	NGC 7682	2	0.0170	<0.84	0.28	<43.35	...	...	...	

Note.—L_x in ergs s^{-1}.

[a] If UGC 524 is the identification of 1H0043+294.

[b] Average luminosity.

[c] If NGC 5033 is the identification of 1H1313+363.

References.—(for IPC/HRI luminosities): (1) Wu, Boggess, and Gull 1983. (2) Kriss, Canizares, and Ricker 1980. (3) Ku, quoted by Kriss 1985. (4) F. E. Marshall, quoted by Lawrence and Elvis 1982. (5) Lawrence and Elvis 1982. (6) Kriss 1982. (7) Zamorani *et al.* 1981. (8) Halpern and Steiner 1983. (9) Kriss 1984. (10) Kriss 1985. (11) Ulvestad and Wilson 1983. (12) Ku, quoted by Lawrence and Elvis 1982. (13) Fabbiano, Feigelson, and Zamorani 1982. (14) Forman *et al.* 1979.

© American Astronomical Society • Provided by the NASA Astrophysics Data System

1989ApJ...344..125P

1989ApJ...344..125P

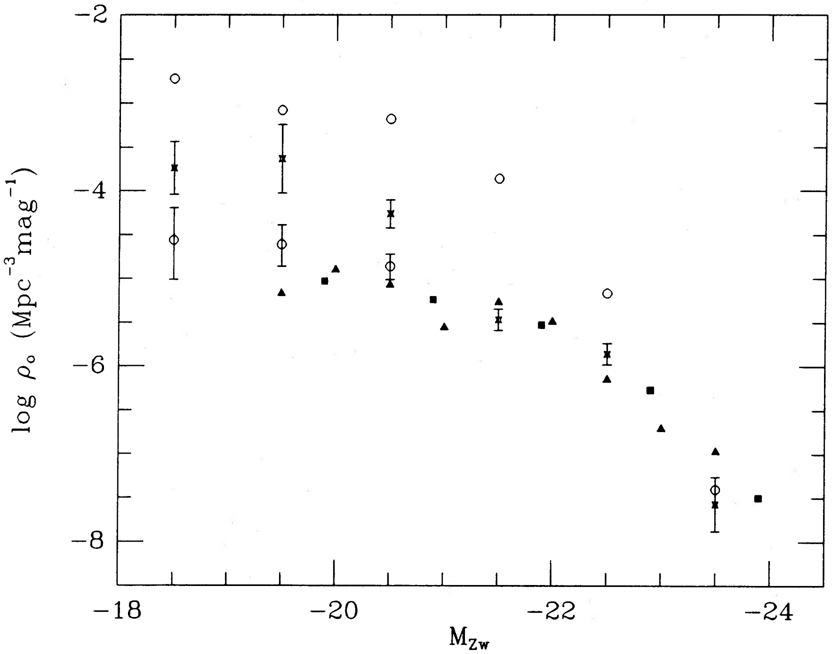

FIG. 1.—Optical luminosity function of Seyfert galaxies. Data points with error bars show the present results, both with and without corrections for the possible incompleteness at $M_{Zw} > -21$. Estimates by Huchra (1977; *filled triangles*) and by Terebizh (1980; *filled squares*) are also shown for comparison, omitting the error bars. Open circles represent the local luminosity function of normal spiral and irregular galaxies.

$\langle V/V_{max} \rangle = 0.30 \pm 0.065$, about 3 σ below the expected value for a uniform distribution), it is interesting to explore this possibility further, in view of its implications for the optical and X-ray luminosity functions. Then, assuming that the suggested incompleteness is real, tentative corrections may be estimated as follows.

There are five objects in the absolute magnitude bin $-20 \leq M_{Zw} < -19$, with $m_{Zw} = 11.75$, 11.20, 11.50, 14.30, 14.0. The first three of them would form a complete sample (i.e., they would yield a $\langle V/V_{max} \rangle$ consistent with 0.5) for a limiting magnitude in the range $12.1 \leq m_{lim} \leq 12.3$. The corresponding density is $(\frac{3}{5})$ dex $[0.6(14.5 - m_{lim})]\rho_{in}$, where $\rho_{in} \simeq (2.4 \pm 1.1) \times 10^{-5}$ Mpc^{-3} mag^{-1} is the space density not corrected for incompleteness. Alternatively, following Huchra and Sargent (1973), we may estimate the correction factor by repeatedly applying the V/V_{max} test, successively increasing the assumed limiting magnitude (we used steps of 0.1 mag) and adding, at the limiting magnitude, the integer number of objects needed to make V/V_{max} consistent with 0.5, within $\pm(12N)^{-1/2}$. The minimum correction we find is a factor of 5.4. The estimated

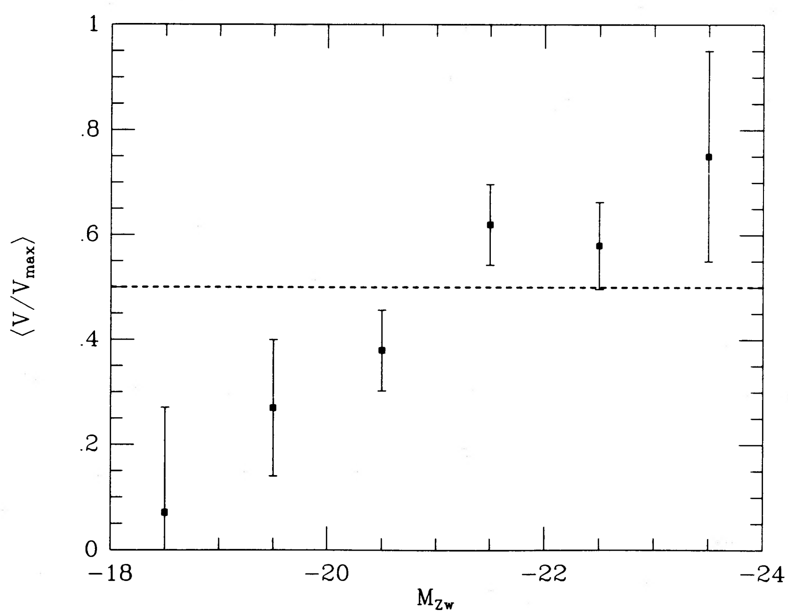

FIG. 2.—V/V_{max} test for CfA Seyfert galaxies

© American Astronomical Society • Provided by the NASA Astrophysics Data System

1989ApJ...344..125P

space density then ranges from 1.3×10^{-4} to 4×10^{-4} Mpc^{-3} mag^{-1}; we adopt the geometric mean of the extremes with an error of a factor of 1.75.

The only two objects in the bin $-19 \leq M_{Zw} < -18$ (m_{Zw} = 12.9 and 12.7) form a complete sample for $12.9 \leq m_{lim} \leq 13.4$. The corresponding correction factor for incompleteness is in the 4.5–9. Again we adopt the geometric mean of the extremes with an error of a factor of 2.

Finally, we have used Huchra and Sargent's (1973) method to correct for incompleteness in the bin $-21 \leq M_{Zw} < -20$. No corrections have been applied for $M_{Zw} < -21$.

Our estimates of the optical luminosity function of Seyfert galaxies, ρ_0, are listed in Table 2 and are compared with previous results, based on Markarian's survey, in Figure 1. Good agreement is found at high luminosities ($M_{Zw} < -21$). Space densities of fainter objects might be substantially higher than previously estimated if the suggested incompleteness of the CfA sample is real; in this case, the total space density of Seyfert galaxies brighter than $M_{Zw} \simeq -18$ is $\simeq 4.8 \times 10^{-4}$ Mpc^{-3}.

b) X-Ray Luminosity Function

First and second scan data from the A-2 1°.5 × 3° field of view detectors on *HEAO 1* were investigated for emissions from all galaxies in the sample. The count rate for each source has been determined by fitting a 25° field of scan angle, centered on the galaxy position, with a fixed central source and as many other sources as necessary to obtain a χ^2 per degree of freedom close to unity. Both positive and negative counting rates were allowed for each source. The measurement errors (σ_m) on the intensities of central sources correspond to $\Delta\chi^2 = 1$ and were obtained by a detailed analysis of χ^2 versus intensity. In this way it was generally possible to derive reliable upper limits also for target positions contaminated by nearby bright sources. The only exception is NGC 4388, which is masked by the Virgo cluster emission.

The threshold for source detection was set to $3(\sigma_m^2 + \sigma_i^2)^{1/2}$. The rms confusion noise, σ_i, has been estimated from the distribution of fluxes for 939 independent blank sky directions, separated by 3° in ecliptic latitude and by 6° in ecliptic longitude and selected according to the following criteria: (i) ecliptic latitude in the range $-60° \leq \beta \leq +60°$; (ii) high galactic latitude ($|b| \geq 20°$); (iii) well resolved by the *HEAO 1* A-2 detectors from known bright X-ray sources (i.e., ≥6° away from each of them). After having allowed for the contribution of statistical errors to the observed variance, we find $\sigma_i \simeq 0.22$ counts s^{-1}, in very good agreement with the result ($\sigma_i \simeq 0.21$) obtained by Shafer (1983), based on a similar, yet significantly smaller, sample (437 random fields).

In Table 1 (cols. [6] and [7]) we list, for sources detected above the threshold in at least one scan or in the combination of the two scans, the *average* counting rate and the 1 σ total error, equal to the quadratic sum of the measurement and confusion errors; for the other sources we give an upper limit equal to the detection threshold. Column (8) gives the corresponding A-2 luminosities (or upper limits) obtained assuming a conversion factor 1 count s^{-1} = 2.17×10^{-11} ergs cm^{-2} s^{-1} (2–10 keV), appropriate to an energy index of 0.65 (Piccinotti *et al.* 1982), $H_0 = 50$, and redshift distances.

Columns (9), (10), and (11) list 2–10 keV luminosities based, respectively, on A-1 (Wood *et al.* 1984; 10^{-3} A-1 counts cm^{-2} s^{-1} = 4.78×10^{-12} ergs cm^{-2} s^{-1}), MPC (Halpern 1982), and IPC or HRI data (collected from references in col. [12]).

On the whole, 14 sources have measured hard (A-2, A-1, or MPC) X-ray fluxes. We may add to those I Zw 1, whose soft X-ray luminosity is larger than 10^{44} ergs s^{-1} and is, therefore, unlikely to be badly affected by photoelectric absorption (Lawrence and Elvis 1982; Petre *et al.* 1984). We have adopted A-2 fluxes whenever possible; otherwise, we have preferred A-1 to MPC data since they were accumulated concurrently with A-2. The tightest upper limit has been used for undetected sources.

Survival analysis techniques (Schmitt 1985; Feigelson and Nelson 1985) have been applied to exploit fully the available information, including the upper limits. The Kaplan-Meier estimator has been used to derive the cumulative distribution of X-ray sources within each optical magnitude bin (ΔM_{Zw} = 1). The bivariate luminosity function has then been estimated as the fractional number of sources in each X-ray luminosity interval multiplied by the optical space densities listed in Table 2. After having corrected for the effect of binning, we obtain the space densities for $L_x \geq 42.6$ shown in Figure 3 (see the Appendix of Franceschini *et al.* 1988*a* for further details on the adopted procedure). The adopted errors on the bivariate luminosity function are the quadratic sum of the variances of the Kaplan-Meier estimator at the boundaries of the bin (i.e., the unknown covariance term is neglected); hence, they are likely to be underestimated. Such underestimate may amount to a substantial factor for log $L_x = 43.4$ because of the very unfavorable ratio of detections to upper limits in the corresponding X-ray luminosity interval.

On the whole, the present results are in satisfactory agreement with the luminosity function of Piccinotti *et al.*, updated by Danese *et al.* (1986).

Estimates of space densities below 10^{42} ergs s^{-1} critically depend on the chosen distribution of upper limits among the luminosity bins. Shown in Figure 3 are the conservative upper bounds obtained by assigning to the luminosity bin under consideration *all* X-ray undetected sources whose corresponding luminosity upper limit is larger than the lower boundary of the bin, and adopting the upper bounds to the optical space densities. A drastic flattening of the X-ray luminosity function of Seyfert galaxies brighter than $M_{Zw} = -18$ is unambiguously required by the data, even in the presence of the strong correction for incompleteness discussed above.

III. DWARF ACTIVE GALACTIC NUCLEI

It is clear from Figure 2 that a significant fraction of otherwise normal galaxies host a Seyfert nucleus detectable through a moderately sensitive spectroscopic survey. The faint end of

TABLE 2

OPTICAL LUMINOSITY FUNCTION OF SEYFERT GALAXIES

	log ρ_0 (Mpc^{-3} mag^{-1})	
M_{Zw}	Corrected	Uncorrected
−18.5	−3.74 ± 0.30	−4.56 (+0.37, −0.45)
−19.5	−3.63 ± 0.39	−4.61 (+0.22, −0.25)
−20.5	−4.26 ± 0.16	−4.86 (+0.14, −0.15)
−21.5	−5.47 (+0.13, −0.14)	−5.47 (+0.13, −0.14)
−22.5	−5.86 ± 0.13	−5.86 ± 0.13
−23.5	−7.57 (+0.37, −0.45)	−7.57 (+0.37, −0.45)

NOTE.—Cols. (2) and (3) give log ρ_0 with and without the correction for a possible incompleteness for $M_{Zw} > -21$. In the latter case the errors correspond to the 1 σ, two-tailed limits based on Poisson statistics (Gehrels 1986) (H_0 = 50 km s^{-1} Mpc^{-1}).

© American Astronomical Society • Provided by the NASA Astrophysics Data System

1989ApJ...344..125P

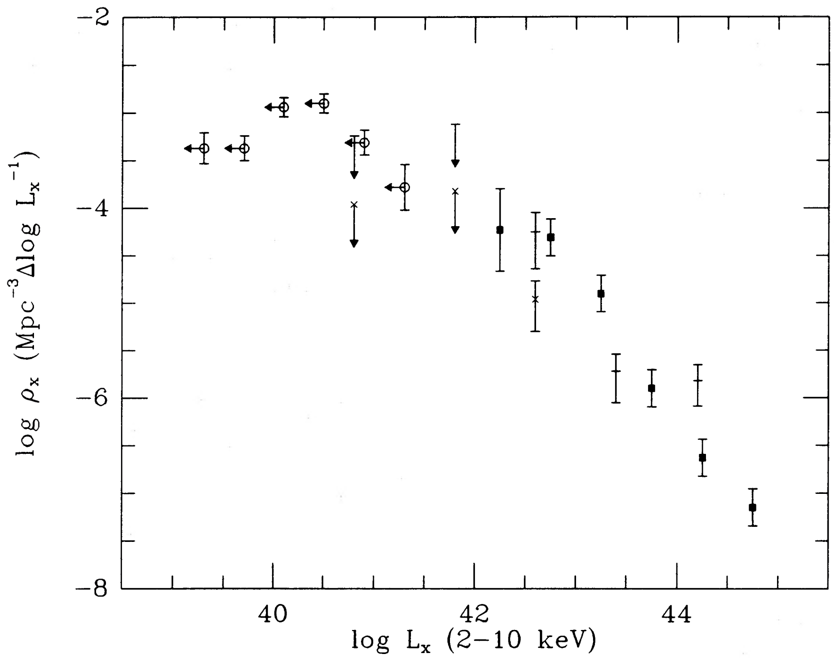

FIG. 3.—X-ray luminosity function of AGNs. Filled triangles and crosses show the space densities of Seyfert galaxies with $M_{\rm Zw} < -18$, derived from the CfA sample, with and without the correction for the possible incompleteness for $M_{\rm Zw} > -21$, respectively; downward pointing arrows represent, for the same two cases, the conservative upper limits derived as described in the text. Also shown, for comparison, is the local luminosity function of X-ray–selected AGNs (Piccinotti *et al.* 1982; *filled squares*). Arrows pointing to the left show the limits on the space densities of dwarf AGNs hidden in normal bright galaxies (§ III).

the luminosity function of AGNs is likely to be even more populated if we take into account dwarf Seyfert nuclei.

Following Keel's (1983) discovery that essentially all bright ($M_{\rm Zw} < -19$) spiral galaxies show nuclear emission lines (see, however, Rubin and Ford 1986), Elvis, Soltan, and Keel (1984) argued that these are probably indicative of photoionization by a nonstellar continuum similar to those in AGNs. On this assumption, they exploited the proportionality between Hα and X-ray emissions, observationally established for Seyfert 1 galaxies, to estimate the X-ray luminosity function. Adopting an average ratio $\langle L_x/L_{\rm H\alpha}\rangle = 40 \pm 9$, derived from a sample of mostly type 1 Seyferts, they concluded that the contribution to the XRB of AGNs with $L_x \leq 10^{42.5}$ ergs s^{-1} is substantial, even without cosmological evolution.

To check this result we have investigated the X-ray emission of galaxies whose nuclei have been observed spectrophotometrically by Keel (1983) and Stauffer (1982), generally with an aperture of ~8", and were found to have Hα fluxes $\geq 10^{-13}$ ergs cm^{-2} s^{-1}. Keel's data were used for objects in common. Well-known Seyfert galaxies (NGC 1068, 3227, 4051, 4151, 4258, 4941, 5005, 5033) were excluded.

The X-ray properties of these galaxies were investigated using a method similar to that described by Worrall, Marshall, and Boldt (1979) and Worrall and Marshall (1984). It consists essentially in comparing the distribution of counting rates (negative rates allowed) from positions coincident with the sources under study with that found for control fields (Fig. 4*a*).

After having excluded those objects whose observed fluxes may be contaminated by known bright X-ray sources, we are left with 34 objects. The histogram of the observed counting rates is shown in Figure 4*b*; their cumulative distribution is plotted against that of control fields in Figure 5 (panel 1).

The sample value of the Kolmogorov-Smirnov statistic, $Z = 0.588$, is fully consistent with the fields containing the galaxies in the sample being drawn from the same parent population as the control fields (the probability of exceeding Z under the hypothesis of equality is $p(>Z) = 0.50$; one-sided alternative). The difference between the mean count rates for galaxies and for control fields is 0.02 ± 0.06 counts s^{-1}. The mean Hα flux of the sample is 4.0×10^{-13} ergs cm^{-2} s^{-1}; for 1 count s^{-1} = 2.17×10^{-11} ergs s^{-1} (2–10 keV), we get $\langle F_x\rangle/\langle F_{\rm H\alpha}\rangle < 4$ (1 σ limit).

On the other hand, $\langle F_x\rangle/\langle F_{\rm H\alpha}\rangle$ is, in general, different from $\langle L_x/L_{\rm H\alpha}\rangle \simeq \langle F_x/F_{\rm H\alpha}\rangle$, which is the quantity of interest to estimate contributions to the XRB. To derive constraints on $\langle F_x/F_{\rm H\alpha}\rangle$ we have resorted to numerical simulations.

The IMSL routine GGVCR has been used to extract from the observed distribution of count rates for control fields 10^3 random samples of size equal to that of the sample being analyzed. The count rate for each field in a given simulation represents the "noise"; to the latter we add the "signal," i.e., the count rate expected from the associated source on the basis of its observed Hα flux and of an assumed $\langle F_x/F_{\rm H\alpha}\rangle$. Next we compute the average of the 10^3 simulated distributions of count rates and use the Kolmogorov-Smirnov test to compare it with the observed distribution. From the variations of the statistic Z as a function of $\langle F_x/F_{\rm H\alpha}\rangle$ we finally determine the allowed range for the latter quantity at a given confidence level.

For the present sample, taking 1 count s^{-1} = 2.17×10^{-11} ergs s^{-1} (2–10 keV), we find $\langle F_x/F_{\rm H\alpha}\rangle < 5$ (1 σ limit).

The data are consistent with the ratio of X-ray to Hα fluxes being independent of luminosity. The results of the division of our sample by Hα luminosity into two equally populated parts are given in Table 3. Our results rule out the Elvis *et al.* hypothesis that all bright galaxies with nuclear emission lines have X-ray to Hα luminosity ratios equal to those of Seyferts. The possibility of $\langle F_x/F_{\rm H\alpha}\rangle = 30$ (close to the lower bound of

© American Astronomical Society • Provided by the NASA Astrophysics Data System

1989ApJ...344..125P

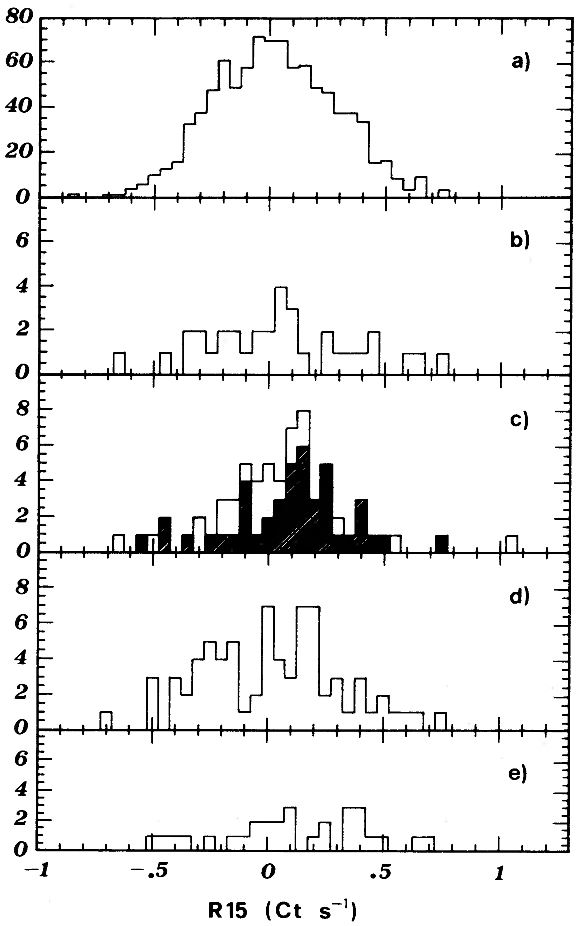

FIG. 4.—Distributions of count rates for (*a*) control fields; (*b*) bright galaxies with nuclear emission lines; (*c*) starburst/interacting galaxies (shaded area corresponds to intermediate + high luminosity objects); (*d*) Markarian starburst nuclei (Balzano's sample); (*e*) normal galaxies with $B_T^{0,1} < 10$.

the range found for Seyferts) is ruled out at a significance level $\simeq 3 \times 10^{-7}$ (see also Fig. 6).

Keel's (1983) measurements of Hα fluxes for a complete sample of galaxies of types later than S0/a allow us to derive the fractional bivariate (M_B, $L_{H\alpha}$) function for galaxies brighter than $M_{Zw} = -19$. Combining with the optical luminosity function for spiral and irregular galaxies constructed by Franceschini *et al.* (1988*a*), allowing for the mean photometric shift $\langle B_T - m_{Zw} \rangle = -0.243$ (Fasano 1985), we obtain the Hα-luminosity function listed in Table 4. For $\langle L_x/L_{H\alpha} \rangle < 5$ (independently of luminosity) the latter yields the limits on the X-ray luminosity function of dwarf AGNs shown in Figure 3.

TABLE 3

SAMPLE PARTITIONED BY Hα LUMINOSITY

Low-Luminosity Group	High-Luminosity Group
Median log $L_{H\alpha} = 39.725$	Median log $L_{H\alpha} = 40.803$
$\langle F_x \rangle = 0.04 \pm 0.07$	$\langle F_x \rangle = 0.006 \pm 0.09$
$\langle F_{H\alpha} \rangle = 2.9 \times 10^{-13}$	$\langle F_{H\alpha} \rangle = 5.1 \times 10^{-13}$
$\langle F_x \rangle / \langle F_{H\alpha} \rangle \leq 8$ (1 σ)	$\langle F_x \rangle / \langle F_{H\alpha} \rangle \leq 4$ (1 σ)
$\langle F_x / F_{H\alpha} \rangle \leq 9.5$ (1 σ)	$\langle F_x / F_{H\alpha} \rangle \leq 4$ (1 σ)

NOTE.—Luminosities in ergs s^{-1}, X-ray fluxes in counts s^{-1}. Hα fluxes in ergs cm^{-2} s^{-1}.

TABLE 4

Hα LUMINOSITY FUNCTION OF NUCLEI OF SPIRAL GALAXIES

log $L_{H\alpha}$ (ergs s^{-1})	log $\rho_{H\alpha}$ (Mpc^{-3} Δ log L^{-1})
38.6	-3.37 ± 0.16
39.0	-3.37 ± 0.13
39.4	-2.94 ± 0.10
39.8	-2.90 ± 0.10
40.2	-3.31 ± 0.13
40.6	-3.78 ± 0.24

The above results apply to Seyfert nuclei hosted by bright galaxies ($M_{Zw} \leq -19$); on the other hand, Worrall, Marshall, and Boldt (1979) have shown that low-luminosity normal galaxies (without evolution) contribute $\leq 1\%$ of the XRB (>2 keV). Furthermore, the soft X-ray spectrum observed for the low-luminosity Seyfert nucleus of M81 suggests that such sources make their principal contribution to the XRB at less than 2 keV (Fabbiano 1988*a*).

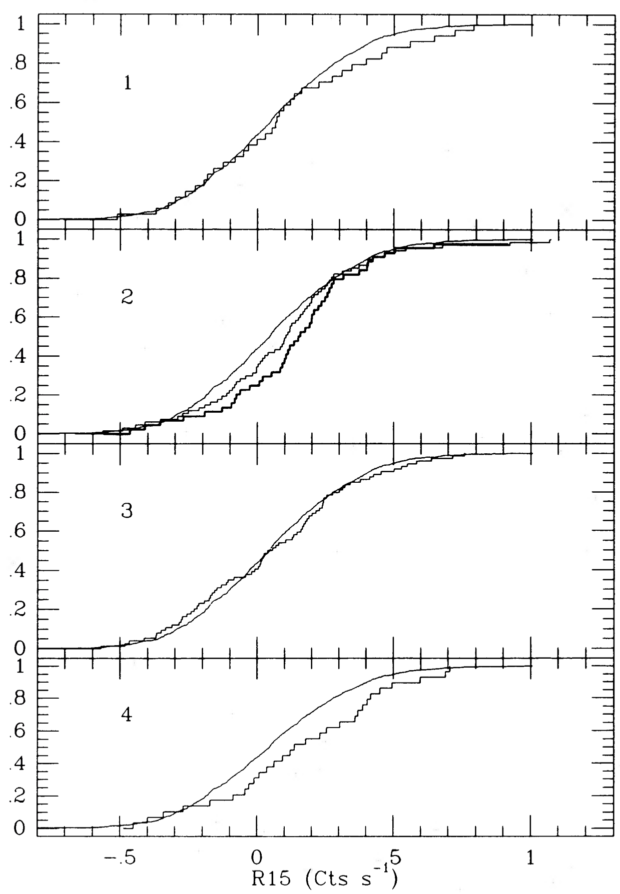

FIG. 5.—Comparison of the cumulative distributions of counting rates for the various samples with that for control fields. *Panel 1*: bright galaxies with nuclear emission lines. *Panel 2*: starburst/interacting galaxies, whole sample and intermediate + high luminosity objects only (*heavy lower line*). *Panel 3*: Markarian starburst nuclei (Balzano's sample). *Panel 4*: normal galaxies. In each panel the smoother line gives the cumulative distribution for control fields.

© American Astronomical Society • Provided by the NASA Astrophysics Data System

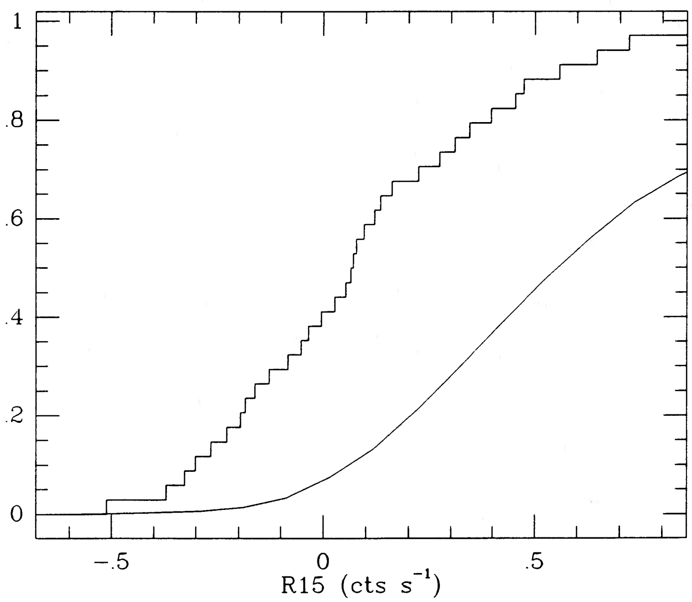

FIG. 6.—Comparison of the observed cumulative distribution of counting rates for bright galaxies with nuclear emission lines with the expected distribution for $\langle L_x/L_{H\alpha} \rangle = 40$.

IV. STARBURST/INTERACTING GALAXIES

A most exciting outcome of deep radio surveys with the VLA carried out in the last few years at 1.4 and 5 GHz (Windhorst, van Heerde, and Katgert 1984; Fomalont *et al.* 1984; Condon and Mitchell 1984) was the discovery of a significant resteepening of the source counts below a few millijanskys. Ultradeep CCD imaging, multicolor photometry, and spectroscopy of millijansky and submillijansky sources (Windhorst, Dressler, and Koo 1987; Kron, Koo, and Windhorst 1985; Donnelly, Partridge, and Windhorst 1987) converge in suggesting that the submillijansky counts are probably dominated by a population of blue radio galaxies with properties consistent with those of starburst galaxies (Windhorst 1984; Windhorst *et al.* 1985).

Danese *et al.* (1987) have shown that starburst galaxies can indeed account in detail for all the available data if they undergo a strong cosmological evolution. As pointed out independently by Weedman (1987) and De Zotti (1987), evolving starburst galaxies might play an important role in explaining the XRB.

Fabbiano, Feigelson, and Zamorani (1982) found a strong correlation between X-ray and radio fluxes for a sample of 33 galaxies whose optical properties are suggestive of starburst activity and derived a relationship between the monochromatic luminosities at 2 keV and at 1.4 GHz. Using this relationship and their models for evolution in the radio band, Danese *et al.* (1987) estimated a contribution to the XRB at 2 keV in the range 5%–11%. On the other hand, the results by Fabbiano *et al.* not only rely on soft X-ray data but also, as emphasized by the authors themselves, were derived using a sample which does not correspond to a well-defined selection criterion, and may, therefore, be not fully representative.

To get a deeper insight into this problem we have constructed a sample comprising all starburst/interacting (S/I) galaxies brighter than $m_{Zw} = 13.5$ in the Uppsala General Catalogue (Nilson 1973), excluding a strip ($|b| < 30°$) around the galactic plane. Following Danese *et al.* (1987), we have included among S/I galaxies non-Seyfert Markarians, Zwicky blue compacts, and galaxies classified by Nilson (1973) as peculiars, distorted, interacting, or in close multiple systems. After dropping directions not well resolved by A-2 detectors from known bright sources, we are left with 67 objects.

The Kolmogorov-Smirnov test shows that the distribution of count rates for this sample (Fig. 4*c* and Fig. 5, panel 2) is not significantly different from that for control fields ($Z = 1.05$; $p[>Z$; one-sided$] = 0.11$). The mean count rate exceeds that of control fields by $\Delta R15 = 0.034 \pm 0.037$ counts s^{-1}.

However, if we subdivide the sample by optical luminosity into three equally populated parts (leaving aside UGC 11466, for which no redshift is available), we find that the counting rates for high- and intermediate-luminosity sources tend to be systematically larger than those of control fields. In detail, for high-luminosity galaxies ($-21.2 \geq M_B > -23.2$) the Kolmogorov-Smirnov test yields $Z = 1.14$ [$p(>Z$; one-sided) $= 0.074$], and we get $\Delta R15 = 0.084 \pm 0.065$; for intermediate luminosities ($-19.8 \geq M_B > -21.2$), we find $Z = 1.17$ [$p(>Z$; one-sided) $= 0.063$], $\Delta R15 = 0.057 \pm 0.046$; for low luminosities ($-16.1 > M_B > 19.8$), $Z = 0.87$ [$p(>Z$; one-sided) $= 0.22$], $\Delta R15 = -0.04 \pm 0.075$. The distribution of counting rates for intermediate and high luminosities, taken together, differs from that of control fields at the 5.5×10^{-3} significance level ($Z = 1.61$), and we have $\Delta R15 = 0.071 \pm 0.040$.

The monochromatic fluxes at 0.44 μm, f_B have been derived using Johnson's (1966) calibration ($f_B = 4.44 \times 10^{-20} 10^{-0.4B}$ ergs cm^{-2} s^{-1} Hz^{-1}) after having transformed Zwicky magnitudes into B magnitudes with the mean relation $B_T = m_{Zw} - 0.243$ (Fasano 1985).

Constraints on $\langle f_x(2 \text{ keV})/f_B \rangle$ obtained by means of numerical simulations (see § III) are given in Table 5. For comparison, the relation between f_x and f_B derived by Fabbiano, Feigelson, and Zamorani (1982), yields, for $f_B = 50$ mJy, $\langle f_x/f_B \rangle = 6.8\ (+3.2, -2.2) \times 10^{-7}$.

Thus, the A-2 data do not allow to estimate reliably the mean X-ray to optical luminosity ratio for S/I galaxies. Still, they suggest that such ratio might be increasing with optical luminosity, rather than decreasing as implied by the relationship derived by Fabbiano, Feigelson, and Zamorani (1982); note, however, that, at high l_B, their data tend to lie above their straight line relation (see their Fig. 3*b*).

TABLE 5

CONSTRAINTS ON $\langle f_x(2 \text{ keV})/f_B \rangle$

Sample	$\langle f_B \rangle$ (mJy)	$\langle f_x(2 \text{ keV}) \rangle / \langle f_B \rangle$	$\langle f_x(2 \text{ keV})/f_B \rangle$
Whole sample	52.0	$<3 \times 10^{-6}$	$<3.7 \times 10^{-6}$
High luminosities	39.8	$(4.6 \pm 3.5)\ 10^{-6}$	$(6.1 \pm 4.5)\ 10^{-6}$
Intermediate luminosities	81.5	$(1.5 \pm 1.2)\ 10^{-6}$	$2.3\ (+2.5, -1.3)\ 10^{-6}$
Low luminosities	36.3	$<2 \times 10^{-6}$	$<9 \times 10^{-7}$
High + intermediate luminosities	58.9	$(2.6 \pm 1.5)\ 10^{-6}$	$(4.3 \pm 1.3)\ 10^{-6}$

© American Astronomical Society • Provided by the NASA Astrophysics Data System

1989ApJ...344..125P

1989ApJ...344..125P

No correlation between X-ray and radio emissions is discernible in our data.

We have also analyzed the A-2 count rates in the direction of Markarian starburst nuclei in Balzano's (1983) sample. We have 74 such objects lying in fields not contaminated by known bright sources. No significant difference with the distribution of counting rates for control fields is found neither for the full sample nor subdividing it into three almost equally populated luminosity bins. For the sample as a whole we find $Z = 0.64$, $p(>Z) = 0.02$, $\Delta R15 = -0.005 \pm 0.036$ counts s^{-1}, $\langle F_x \rangle / \langle F_{H\alpha} \rangle < 2.2$ ($\langle F_{H\alpha} \rangle = 3.0 \times 10^{-13}$ ergs cm^{-2} s^{-1}), $\langle F_x/F_{H\alpha} \rangle < 2.5$.

Combining the limit on $\langle L_x/L_{H\alpha} \rangle \simeq \langle F_x/F_{H\alpha} \rangle$ with the Hα luminosity function derived by Balzano (1983), we can derive constraints on the contribution of starburst nuclei to the local X-ray luminosity function. It is easily seen that such contributions might still be important, or even dominant, below $L_x = 10^{42}$ ergs s^{-1}.

V. ULTRALUMINOUS INFRARED GALAXIES

The *IRAS* discovery of a substantial number of galaxies with far-IR luminosities exceeding 10^{12} $L_\odot$, i.e. emitting a power comparable to that of optically selected QSOs, has raised the problem of their energy source. Extreme star-formation activity, possibly triggered by strong interactions or merging, and/or an active nucleus may provide the observed luminosity (Harwit *et al.* 1987; Soifer *et al.* 1987*a*; Sanders *et al.* 1988). Although there seems to be evidence that, at least in some galaxies, the two components coexist in various intensity ratios, it is still far from clear whether or not there exists a definite relationship between them.

By searching for hard X-ray emission from these objects one may hope to find some direct evidence for nonthermal emission from an active nucleus. To this end, Rieke (1988) has exploited the *HEAO 1* A-1 data base.

We have searched in the usual way for emission from galaxies of this class in the A-2 data. Our sample comprises all galaxies with $L_{FIR} > 10^{12}$ $L_\odot$ ($H_0 = 50$) in the complete sample of Soifer *et al.* (1987*b*), the galaxies with $L(60\ \mu m) > 10^{12}$ $L_\odot$ listed by Lawrence *et al.* (1986) and IRAS 23060+0505 (Hill *et al.* 1987). After the usual rejection of objects not well resolved from bright X-ray sources, we are left with 23 galaxies. The distribution of their counting rates turns out to be not significantly different from that for control fields. For the full sample we find: $Z = 0.51$, $p(>Z) = 0.60$, $\Delta R15 = 0.014 \pm 0.061$ counts s^{-1}, $\langle f_x \rangle / \langle f_{60\ \mu m} \rangle < 9.8 \times 10^{-9}$ ($\langle f_{60\ \mu m} \rangle = 16.7$ Jy), $\langle f_x/f_{60\ \mu m} \rangle < 2.7 \times 10^{-8}$.

Confining ourselves to the 15 galaxies taken from the complete sample of Soifer *et al.* (1987*b*), we find $Z = 0.64$, $p(>Z) = 0.44$, $\Delta R15 = 0.003 \pm 0.073$ counts s^{-1}, $\langle f_x \rangle / \langle f_{60\ \mu m} \rangle < 6.6 \times 10^{-9}$ ($\langle f_{60\ \mu m} \rangle = 24.9$ Jy), $\langle f_x/f_{60\ \mu m} \rangle < 1.1 \times 10^{-8}$ (1 σ limit). Assuming that the bolometric luminosities of these galaxies are not significantly larger than their far-IR luminosities, and adopting for the latter the estimates of Soifer *et al.* (1987*b*), we find an upper limit to their average X-ray to bolometric luminosity ratio: $\langle L(2\text{–}10\ \text{keV})/L_{bol} \rangle \leq 1.8 \times 10^{-3}$. For comparison, Padovani and Rafanelli (1988) find, both for Seyfert 1 nuclei and for QSOs, $\langle L(2\text{–}10\ \text{keV})/L_{bol} \rangle \simeq 3 \times 10^{-2}$, with a dispersion of a factor $\simeq 2$. We thus confirm Rieke's (1988) conclusion that the hard X-ray luminosities of ultraluminous infrared galaxies appear to be substantially lower, in comparison to their bolometric luminosities, than would be expected if their main energy source is a dust embedded active nucleus.

On the other hand, the above upper limits on $\langle f_x/f_{60\ \mu m} \rangle$ are still compatible with the possibility that actively star-forming galaxies make up a substantial fraction of the XRB. According to Weedman (1987), $\langle f_x/f_{60\ \mu m} \rangle \simeq 3.7 \times 10^{-9}$ would entail a contribution to the background of 13%, without evolution.

VI. OTHER CLASSES OF SOURCES

a) Galaxies Hosting Compact Nuclear Radio Sources

Combining the samples of Jenkins (1982) and Sadler (1984), we have put together 16 galaxies with "flat" radio spectrum, indicative of compact nuclear sources, in "clean" areas. Their mean X-ray count rate is $\Delta R15 = -0.008 \pm 0.082$ counts s^{-1}, while their mean flux density at 2.7 GHz is 389 mJy, whence $\langle f_x(2\ \text{keV}) \rangle / \langle f(2.7\ \text{GHz}) \rangle < 4.2 \times 10^{-7}$ (1 σ); numerical simulations yield $\langle f_x(2\ \text{keV})/f(2.7\ \text{GHz}) \rangle < 6 \times 10^{-7}$. It follows that the contribution of these objects to the XRB cannot exceed a few percent even in the presence of the strongest evolution consistent with radio data. A similar conclusion follows using the *Einstein Observatory* results of Dressel and Wilson (1985).

b) Normal Galaxies

The very deep optical counts by Tyson and Seitzer (1986) allow to estimate the contribution to the XRB of normal galaxies, on the assumption of a constant X-ray to optical luminosity ratio (Giacconi and Zamorani 1987). We have looked in the usual way at the galaxies in the RSA catalog (Sandage and Tammann 1981) with $B_T^{0,i} < 10$ and $|b| > 30°$ excluding M31, M32 and the Magellanic Clouds as well as those not well resolved from bright X-ray sources. For the 29 galaxies in the final sample we find that the distribution of count rates differs from that for control fields at 10% significance level ($Z = 1.07$), $\Delta R15 = 0.084 \pm 0.059$ counts s^{-1}, $\langle f_x \rangle / \langle f_B \rangle = (0.82 \pm 0.58) \times 10^{-7}$ ($\langle f_B \rangle = 2.21$ 10^3 mJy), $\langle f_x/f_B \rangle < 3.1 \times 10^{-7}$. For comparison, Giacconi and Zamorani (1987) find $\langle f_x/f_B \rangle = 1.5 \times 10^{-7}$ for the spiral galaxies studied by Fabbiano and Trinchieri (1985). Indeed, we have only two early-type galaxies in our sample, not only because spirals are the dominant component in the field, but also because E and S0 galaxies are mostly in clusters and their X-ray emission cannot be resolved from that of the intergalactic gas. Note, however, that for the majority of early-type galaxies, most, if not all, of the X-ray luminosity is likely due to gas at $kT \leq 2$ keV (Trinchieri and Fabbiano 1985), which does not contribute to the XRB measured by Marshall *et al.* (1980). We may then conclude that, if the X-ray to optical luminosity ratio does not evolve, the contribution of normal galaxies to the XRB is $\leq 10\%$ at 2 keV.

VII. DISCUSSION AND CONCLUSIONS

Canonical active galactic nuclei constitute the dominant population of extragalactic sources in the Einstein medium sensitivity survey (Gioia *et al.* 1984) and in the identified portion of the deep surveys (Griffiths *et al.* 1983; Murray 1987). Yet circumstantial evidence is accumulating which suggests (although does not prove) that they cannot be the dominant constituents of the XRB.

The fast convergence of the optical counts of bright QSOs (Koo, Kron, and Cudworth 1986; Marano, Zamorani, and Zitelli 1986), together with their relatively low X-ray to optical luminosity ratio (Avni and Tananbaum 1986), point to a con-

© American Astronomical Society • Provided by the NASA Astrophysics Data System

1989ApJ...344..125P

tribution smaller (possibly by a substantial factor) than 20% at 2 keV.

The present study shows that the X-ray luminosity function flattens so drastically below log $L_x \simeq 42$ that no more than $\approx 10\%$ to 15% of the 2–10 keV XRB can be produced by dwarf Seyfert nuclei, without evolution.

On the other hand, the evolution properties of Seyfert nuclei are still poorly understood, and the estimates of their contribution to the XRB correspondingly very uncertain.

A useful working hypothesis, supported by recent analyses of optical data (Danese, De Zotti, and Franceschini 1986; Green 1986), is that of an evolution in luminosity. In this framework, a lower limit to the luminosity of evolving objects at $L_s \approx 10^{43}$ ergs s^{-1} is expected on simple physical grounds (Cavaliere, Giallongo, and Vagnetti 1985) and may be already called for by preliminary estimates of the quasar luminosity functions at high redshifts (Koo 1986). It is interesting that, for $L_s \geq 10^{43}$ ergs s^{-1}, the resulting total contribution to the 2–10 keV XRB from AGNs turns out to be $\leq 30\%$ (for a density parameter $\Omega = 1$ and an X-ray energy index $\alpha_x = 0.7$; see Danese *et al.* 1986).

An alternative model, applying the concept of luminosity-dependent density evolution, leads to an estimated contribution from AGNs of $\leq 30\%$ (2–10 keV) for $\alpha_x \geq 0.7$ (Schmidt and Green 1986). The most recent studies, based on different evolution models, thus converge in yielding estimates consistent with the constraint inferred by De Zotti *et al.* (1982) from a study of the XRB spectrum.

The role of evolving starburst galaxies as to the XRB is still an open problem. The present analysis does not confirm the conclusion by Fabbiano, Feigelson, and Zamorani (1982) that the mean X-ray to optical luminosity ratio for these sources takes on, at high optical luminosities, values comparable to those found for normal galaxies. In the framework of the luminosity evolution models which account for all the available data on the statistics of deep radio sources (Danese *et al.* 1987) as well as of *IRAS* sources (Franceschini *et al.* 1988*b*), the results by Fabbiano *et al.* would entail a contribution to the XRB at 2 keV in the range 5%–11%.

On the other hand, the hard X-ray data on the statistically well defined sample of starburst/interacting galaxies discussed in § IV, albeit not sensitive enough to allow a reliable definition of the mean X-ray to optical luminosity ratio, suggests that the latter is not decreasing, but may be rather increasing, with optical luminosity, and are consistent with a mean value substantially higher than that implied by the results of Fabiano, Feigelson, and Zamorani.

As discussed by Bookbinder *et al.* (1980), actively star-forming galaxies might make a substantial contribution to the XRB both by bremsstrahlung emission during a hot wind phase powered by supernovae, and by hard X-ray binaries which may be overabundant in metal-poor systems. In addition, galaxy interactions might trigger nuclear activity. On the other hand, based on *HEAO 2* (*Einstein Observatory*) spectral observations of the nearby starburst galaxies NGC 253 and M82, Fabbiano (1988*b*) concludes that the X-radiation from this population could well be significantly softer than the XRB. It will be important to ascertain whether the X-ray spectra of these relatively low-luminosity sources are really typical for their class.

We wish to thank J. Swank for her constant help, R. Mushotzky for useful discussions, and Y. Rephaeli for having stimulated us to investigate the ultraluminous infrared galaxies. L. D. and G. D. Z. are grateful to S. Holt and to the GSFC X-ray astronomy group for their warm hospitality. Comments of the referee helped in substantially improving the presentation of our results. The work of the Italian group was supported in part by MPI and CNR (through GNA and PSN).

REFERENCES

Avni, Y., and Tananbaum, H. 1986, *Ap. J.*, **305**, 83.
Balzano, V. A. 1983, *Ap. J.*, **268**, 602.
Boldt, E., and Leiter, D. 1981, *Nature*, **290**, 483.
Bookbinder, J., Cowie, L. L., Krolik, J. H., Ostriker, J. P., and Rees, M. J. 1980, *Ap. J.*, **237**, 647.
Cavaliere, A., Danese, L., De Zotti, G., and Franceschini, A. 1981*a*, *Astr. Ap.*, **97**, 269.
———. 1981*b*, *Space Sci. Rev.*, **30**, 101.
Cavaliere, A., Giallongo, E., and Vagnetti, F. 1985, *Ap. J.*, **296**, 402.
Condon, J. J., and Mitchell, K. J. 1984, *A.J.*, **89**, 610.
Danese, L., De Zotti, G., Fasano, G., and Franceschini, A. 1986, *Astr. Ap.*, **161**, 1.
Danese, L., De Zotti, G., and Franceschini, A. 1986, in *Structure and Evolution of Active Galactic Nuclei*, ed. G. Giuricin, F. Mardirossian, M. Mezzetti, and M. Ramella (Dordrecht: Reidel), p. 537.
Danese, L., De Zotti, G., Franceschini, A., and Toffolatti, L. 1987, *Ap. J. (Letters)*, **318**, L15.
De Zotti, G. 1987, in *Proc. 7th Italian Conf. General Relativity and Gravitational Physics*, ed. U. Bruzzo, R. Cianci, and E. Massa (Singapore: World Scientific), p. 331.
De Zotti, G., Boldt, E. A., Cavaliere, A., Danese, L., Franceschini, A., Marshall, F. E., Swank, H. J., and Szymkowiak, A. E. 1982, *Ap. J.*, **253**, 47.
Donnelly, R. H., Partridge, R. B., and Windhorst, R. A. 1987, *Ap. J.*, **321**, 94.
Dressel, L. L., and Wilson, A. S. 1985, *Ap. J.*, **291**, 668.
Edelson, R. A. 1987, *Ap. J.*, **313**, 651.
Elvis, M., Soltan, A., and Keel, W. C. 1984, *Ap. J.*, **283**, 479.
Fabbiano, G. 1988*a*, *Ap. J.*, **325**, 544.
———. 1988*b*, *Ap. J.*, **330**, 672.
Fabbiano, G., Feigelson, E., and Zamorani, G. 1982, *Ap. J.*, **256**, 397.
Fabbiano, G., and Trinchieri, G. 1985, *Ap. J.*, **296**, 430.
Fasano, G. 1985, *Astr. Ap. Suppl.*, **60**, 285.
Feigelson, E. D., and Nelson, P. I. 1985, *Ap. J.*, **293**, 192.
Felten, J. E. 1977, *A.J.*, **82**, 861.
Fomalont, E. B., Kellermann, K. I., Wall, J. V., and Weistrop, D. 1984, *Science*, **225**, 23.
Forman, W., Schwarz, J., Jones, C., Liller, W., and Fabian, A. C. 1979, *Ap. J. (Letters)*, **234**, L27.
Franceschini, A., Danese, L., De Zotti, G., and Toffolatti, L. 1988*a*, *M.N.R.A.S.*, **233**, 157.
Franceschini, A., De Zotti, G., Danese, L., and Xu, C. 1988*b*, *M.N.R.A.S.*, **233**, 175.
Gehrels, N. 1986, *Ap. J.*, **303**, 336.
Giacconi, R., and Zamorani, G. 1987, *Ap. J.*, **312**, 503.
Gioia, I. M., Maccacaro, T., Schild, R., Stocke, J. L., Liebert, J. W., Danziger, I. J., Kunth, D., and Lub, J. 1984, *Ap. J.*, **283**, 495.
Green, R. 1986, in *IAU Symposium 119*, *Quasars*, ed. G. Swarup and V. K. Kapahi (Dordrecht: Reidel), p. 429.
Griffiths, R. E., *et al.* 1983, *Ap. J.*, **269**, 375.
Guilbert, P., and Fabian, A. 1986, *M.N.R.A.S.*, **220**, 439.
Halpern, J. P. 1982, Ph.D. thesis, Harvard University.
Halpern, J. P., and Steiner, J. E. 1983, *Ap. J. (Letters)*, **269**, L37.
Harwit, M., Houck, J. R., Soifer, B. T., and Palumbo, G. G. C. 1987, *Ap. J.*, **315**, 28.
Hill, G. J., Wynn-Williams, C. G., and Becklin, E. E. 1987, *Ap. J. (Letters)*, **316**, L14.
Huchra, J. P. 1977, *Ap. J. Suppl.*, **35**, 171.
Huchra, J. P., and Burg, R. 1989, in preparation.
Huchra, J. P., and Sargent, W. L. W. 1973, *Ap. J.*, **186**, 433.
Jenkins, C. R. 1982, *M.N.R.A.S.*, **200**, 705.
Johnson, H. L. 1966, *Ann. Rev. Astr. Ap.*, **4**, 193.
Keel, W. C. 1983, *Ap. J. Suppl.*, **52**, 229.
Kembhavi, A. K., and Fabian, A. C. 1982, *M.N.R.A.S.*, **198**, 921.
Koo, D. C. 1986, in *Structure and Evolution of Active Galactic Nuclei*, ed. G. Giuricin, F. Mardirossian, M. Mezzetti, and M. Ramella (Dordrecht: Reidel), p. 317.
Koo, D. C., Kron, R. G., and Cudworth, K. M. 1986, *Pub. A.S.P.*, **98**, 285.
Kriss, G. A. 1982, Ph.D. thesis, Massachusetts Institute of Technology.
———. 1984, *Ap. J.*, **277**, 495.
———. 1985, *A.J.*, **90**, 1.
Kriss, G. A., Canizares, C. R., and Ricker, G. R. 1980, *Ap. J.*, **242**, 492.

© American Astronomical Society • Provided by the NASA Astrophysics Data System

1989ApJ...344..125P

Kron, R. G., Koo, D. C., and Windhorst, R. A. 1985, *Astr. Ap.*, **146**, 38.
Lawrence, A., and Elvis, M. 1982, *Ap. J.*, **256**, 410.
Lawrence, A., Walker, D., Rowan-Robinson, M., Leech, K. J., and Penston, M. V. 1986, *M.N.R.A.S.*, **219**, 687.
Leiter, D., and Boldt, E. 1982, *Ap. J.*, **269**, 1.
Marano, B., Zamorani, G., and Zitelli, V. 1986, in *Structure and Evolution of Active Galactic Nuclei*, ed. G. Giuricin, F. Mardirossian, M. Mezzetti, and M. Ramella (Dordrecht: Reidel), p. 339.
Marshall, F. E., Boldt, E. A., Holt, S. S., Miller, R. B., Mushotzky, R. F., Rose, L. A., Rothschild, R. E., and Serlemitsos, P. J. 1980, *Ap. J.*, **235**, 4.
Marshall, F. E., Boldt, E. A., Holt, S. S., Mushotzky, R. F., Pravdo, S. H., Rothschild, R. E., and Serlemitsos, P. J. 1979, *Ap. J. Suppl.*, **40**, 657.
Murray, S. S. 1987, unpublished.
Nilson, P. 1973, *Uppsala General Catalogue of Galaxies* (Uppsala: Uppsala Astronomical Observatory).
Padovani, P., and Rafanelli, P. 1988, *Astr. Ap.*, **205**, 53.
Petre, R., Mushotzky, R. F., Krolik, J. H., and Holt, S. S. 1984, *Ap. J.*, **280**, 499.
Piccinotti, G., Mushotzky, R. F., Boldt, E. A., Holt, S. S., Marshall, F. E., Serlemitsos, P. J., and Shafer, R. A. 1982, *Ap. J.*, **253**, 485.
Reichert, G., Mushotzky, R. F., Petre, R., and Holt, S. S. 1985, *Ap. J.*, **296**, 69.
Rieke, G. H. 1988, *Ap. J. (Letters)*, **331**, L5.
Rothschild, R., *et al.* 1979, *Space Sci. Instr.*, **4**, 269.
Rubin, V. C., and Ford, W. K. 1986, *Ap. J. (Letters)*, **305**, L35.
Sadler, E. M. 1984, *A.J.*, **89**, 53.
Sandage, A., and Tammann, G. A. 1981, *A Revised Shapley-Ames Catalog of Bright Galaxies* (Washington, DC: Carnegie Institution of Washington).
Sanders, D. B., Soifer, B. T., Elias, J. H., Madore, B. F., Matthews, K., Neugebauer, G., and Scoville, N. Z. 1988, *Ap. J.*, **325**, 74.
Schmidt, M., and Green, R. F. 1986, *Ap. J.*, **305**, 68.
Schmitt, J. H. M. M. 1985, *Ap. J.*, **293**, 178.
Setti, G., and Woltjer, L. 1979, *Astr. Ap.*, **76**, L1.
Shafer, R. A. 1983, Ph.D. thesis, University of Maryland.
Soifer, B. T., Houck, J. R., and Neugebauer, G. 1987*a*, *Ann. Rev. Astr. Ap.*, **25**, 187.
Soifer, B. T., Sanders, D. B., Madore, B. F., Neugebauer, G., Danielson, G. E., Elias, J. H., Lonsdale, C. J., and Rice, W. L. 1987*b*, *Ap. J.*, **320**, 238.
Stauffer, J. R. 1982, *Ap. J. Suppl.*, **50**, 517.
Tananbaum, H. 1979, *Ap. J. (Letters)*, **234**, L9.
Terebizh, V. Yu. 1980, *Astrophysics*, **16**, 36.
Trinchieri, G., and Fabbiano, G. 1985, *Ap. J.*, **296**, 447.
Tyson, J. A., and Seitzer, P. 1986, *Bull. AAS*, **18**, 1047.
Ulvestad, J. S., and Wilson, A. S. 1983, *A.J.*, **88**, 253.
Veron-Cetty, M.-P., and Veron, P. 1987, ESO Sci. Rept., No. 5.
Weedman, D. W. 1987, in *Proc. Conf. Star Formation in Galaxies*, ed. C. J. Lonsdale Persson (NASA Conf. Publ. 2466), p. 351.
Wilkes, B. J., and Elvis, M. 1986, *Bull. AAS*, **18**, 925.
Windhorst, R. A. 1984, Ph.D. thesis University of Leiden.
Windhorst, R. A., Dressler, A., and Koo, D. C. 1987, in *IAU Symposium 124, Observational Cosmology*, ed. A. Hewitt, G. Burbidge, and L. Z. Fang (Dordrecht: Reidel), p. 573.
Windhorst, R. A., Miley, G. K., Owen, F. N., Kron, R. G., and Koo, D. C. 1985, *Ap. J.*, **289**, 494.
Windhorst, R. A., van Heerde, G. M., and Katgert, P. 1984, *Astr. Ap. Suppl.*, **58**, 1.
Wood, K. S., *et al.* 1984, *Ap. J. Suppl.*, **56**, 507.
Worrall, D. M., and Marshall, F. E. 1984, *Ap. J.*, **276**, 434.
Worrall, D. M., Marshall, F. E., and Boldt, E. A. 1979, *Nature*, **281**, 127.
Wu, C.-C., Boggess, A., and Gull, T. R. 1983, *Ap. J.*, **266**, 28.
Zamorani, G., *et al.* 1981, *Ap. J.*, **245**, 357.

E. A. BOLDT and F. E. MARSHALL: Code 666, Laboratory for High Energy Astrophysics, NASA/Goddard Space Flight Center, Greenbelt, Maryland 20771, USA

L. DANESE and A. FRANCESCHINI: Dipartimento di Astronomia, Vicolo dell'Osservatorio 5, I-35122 Padova, Italy

G. DE ZOTTI: Osservatorio Astronomico, Vicolo dell'Osservatorio 5, I-35122 Padova, Italy

G. G. C. PALUMBO: Dipartimento di Astronomia, C. P. 596, I-40100 Bologna, Italy

M. PERSIC: Osservatorio Astronomico, Via G. B. Tiepolo 11, I-34131 Trieste, Italy

© American Astronomical Society • Provided by the NASA Astrophysics Data System