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A NEAR-INFRARED STUDY OF A HOMOGENEOUS SAMPLE OF OPTICALLY SELECTED ACTIVE GALACTIC NUCLEI. II. ANALYSIS OF THE RESULTS AND INTERPRETATION

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ABSTRACT

New imaging and photometric IR data have been used to discuss the properties of nuclei and hosting galaxies of a well-defined and large sample of optically selected Seyfert 1 galaxies. The *K*-band luminosity distribution of galaxies hosting the active nuclei has been derived, and the comparison with the local luminosity function of the spirals confirms that the probability of a spiral galaxy hosting bright AGNs increases with the luminosity. On average, the colors of the galaxies are slightly redder than those of spirals, suggesting that hosting galaxies usually have moderately enhanced star formation rates. The analysis of the correlation of the *K* band with *IRAS* fluxes demonstrates that the nuclei largely dominate the 12 μm emission, whereas the galaxies are the major contributors at $\lambda \geq 60$ μm. It is also shown that galaxies with spectral index between 12 and 60 μm flatter than -1.5 are likely hosting an active nucleus. The IR spectral data of the nuclei as well as the correlation of the X-ray with IR emissions are briefly discussed. The conclusion is that the IR emission of the nuclei is probably dominated at $\lambda \geq 2.2$ μm by thermal dust radiation.

Subject headings: dust, extinction — galaxies: nuclei — galaxies: photometry — galaxies: Seyfert

1. INTRODUCTION

In the last decade the general improvement of the astronomical detectors both in sensitivity as well as in spatial resolution has allowed reliable spectral energy distributions (SED) of AGNs over a wide range of frequencies to be obtained (see, e.g., Edelson & Malkan 1986; Ward et al. 1987; Carleton et al. 1987; Neugebauer et al. 1987), casting light on the fact that other emission mechanisms operate in addition to nonthermal processes.

Evidences of a generalized presence of a blue bump possibly due to an accretion disk have accumulated (see, e.g., Band & Malkan 1989; Osterbrock 1991 and references therein). Many recent observations suggest that absorption and reradiation by material around the nuclei are relevant processes in shaping the AGN spectra. The spectra obtained in the X-ray band with *EXOSAT* and *Ginga* point toward the existence of a reflected component due to the presence of cold and/or warm matter. The column density of such material may be very high ($N_H \geq 10^{24}$ cm^{-2}) as suggested by a possible high-energy bump found in several observed spectra (Piro, Yamauchi, & Matsuoka 1990; Inoue 1989). Several authors (see, e.g., Pounds et al. 1990; Sanders et al. 1989) envisaged that the presence of a torus or a warped disk around the central engine can explain many observed spectral properties with a unified picture of the AGN phenomenon.

Presence of obscuring material around the nuclei has been discussed by many authors on the basis both of the continuum emission (Rieke 1978; Lawrence & Elvis 1982; Cheng, Danese, & De Zotti 1983; Lawrence et al. 1985; Ward et al. 1987) and of the emission-line ratios and polarization (Wampler 1971; De Zotti & Gaskell 1985; Miller & Antonucci 1985; Ward et al. 1987; Dahari & De Robertis 1988; Berriman 1989).

In this framework the dust reradiation is expected to play a relevant role in the IR region of the AGN spectra. Actually Neugebauer et al. (1979) called attention to the fact that some objects show a radiation excess at 3.5 μm. Edelson & Malkan (1987) and Edelson, Malkan, & Rieke (1987) noted the presence of a bump around 5 μm in several AGNs. Barvainis (1987) substantiated previous hints of many authors in a model which naturally explains the bump in the near-IR with the reradiation by dust heated to the evaporation temperature by primary optical and ultraviolet continuum emissions. Recently Sanders et al. (1989) presented the observations of the continuum of 109 bright QSOs of the Palomar-Green survey in the frequency range from $\nu \sim 10^{10}$ to $\nu \sim 10^{18}$ Hz. They noticed that the shapes of the spectral energy distributions (SEDs) are quite similar and, in particular, that an IR bump and a minimum at around 1 μm are usually present. They concluded that dust heated to the sublimination temperature can account for the observed spectra and suggested that the absorbing material is distributed in a warped disk. In the same framework, detailed spectral fits from 0.3 to 100 μm have been done by Barvainis (1990). On the other hand, Band & Malkan (1989) fitted spectral observations from X-ray to *IRAS* bands of 12 AGNs with a nonthermal source plus an accretion disk. However, they argued that their fits leave room for a further component in the near-IR bands. Indeed, in the Seyfert galaxies and even in QSOs, the contributions by the host galaxy in the infrared bands are not at all negligible.

Therefore we decided to investigate the IR properties of a well-defined sample of faint active galactic nuclei harbored in Seyfert 1 galaxies. With the UK Infrared Telescope (UKIRT) using both photoelectric photometer and imaging camera, we observed almost all the objects of the homogeneous sample used to derive the optical luminosity function of low-luminosity AGNs (Cheng et al. 1985). In another paper (Zitelli et al. 1992, hereafter Paper I) we have reported the observations and we have also presented a method for a reliable

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separation of the emission of the nuclei and of the galaxies using the K-band images. The computed magnitudes have typical errors of 0.2 and 0.3 for nuclei and galaxies respectively. We have also obtained optical CCD frames of the same objects; the results will be reported in a subsequent paper. Observations in other bands, from X-ray to radio, are largely available for the sample objects and the SEDs will be discussed elsewhere.

We present the observational data in § 2, in § 3, the results are discussed, and the conclusions are summarized in § 4.

2. DATA

We concentrated our observations on the optically selected sample of Seyfert 1 and 1.5 galaxies defined by Cheng et al. (1985), when deriving the optical luminosity function of low-luminosity AGNs. The sample, limited to $U \leq 16.3$, $M_u \leq -18.5$, and $z \leq 0.08$, comprises 56 objects and has been shown to be *homogeneous* in the sense that there is no significant correlation of the apparent magnitudes with the absolute magnitudes, or with the ratios of the fluxes of the nuclei to those of the underlying galaxies. High-resolution K-band images with a scale of 0".62 pixel^{-1} have been obtained in 1988 January and July with the IRCAM system for 41 objects randomly chosen out of the sample. The intensity profiles computed from the two-dimensional images are reported in Paper I.

To disentangle the nuclear from the galactic fluxes, we have modeled the profiles of the host galaxies as the sum of two components: a bulge following the $r^{1/4}$ law and an exponential disk. The model of Seyfert galaxy is fully described by five parameters: the total flux of the nucleus F_n, the effective radius r_e which encloses half of the total light of the bulge, the surface brightness I_e at r_e, and the two parameters modeling the disk, namely the scale length r_D and the central surface brightness I_D. For each object, the fitting profile has been calculated taking into account the effect of the galaxy inclination and of the seeing on both the galaxy and the nucleus. The best-fit parameters obtained by χ^2 minimization have been reported in Paper I. In columns (2), and (10) of Table 1A and (2) and (8) of Table 1B we present the derived K-band magnitudes of nuclei and host galaxies, respectively.

We have observed 27 objects from the same sample using the photometers UKT9 in two nights in April and UKT6 in two nights in 1987 August in the J, H, K, L bands with 5" and 7".8 apertures. The data have been reported in Paper I, where the photometric data have been used to get estimates of the nuclear magnitudes to be compared to those derived from K-band frames. In the following we will use the photometric data to derive the J, H band fluxes for the nuclei and the host galaxies, starting from the K-band frames. The uncertainties in the L-band data are too large to permit reliable separation of nuclear from galactic fluxes.

The nuclear magnitudes K_n with their errors δK_n and the *total* galactic magnitudes K_g with their errors δK_g reported in Tables 1A and 1B have been taken from Paper I. For the 15 galaxies listed in Table 1A, in addition to K-band frames, we have JHK photometry with two apertures. These data can be combined to estimate the colors of the nuclei and of the surrounding galaxies. Assuming that the colors of the latter are aperture-independent (cf. Griersmith, Hyland, & Jones 1982) and that the seeing is essentially the same both for K-band frames and for aperture photometry, we can write for, e.g., $(J-K)$ colors:

$$(J-K)_n = -2.5 \log \left\{ \frac{[a_K(r_1)+1]10^{-0.4c(r_1)} - [a_K(r_2)+1]10^{-0.4c(r_2)}}{a_K(r_1)-a_K(r_2)} \right\}, \quad (1)$$

$$(J-K)_g = -2.5 \log \{[a_K(r_2)+1]10^{-0.4c(r_2)} - a_K(r_2)10^{-0.4(J-K)_n}\}, \quad (2)$$

where $a_K(r) = F_n f_n(r)/F_g f_g(r)$ is the ratio of the nuclear to galactic flux within the aperture r and can be derived from the analysis of K-band frames, and the color $c(r)$ is obtained from aperture photometry. Analogous relationships hold for the $(H-K)$ and $(K-L)$ colors. It is not straightforward to evaluate the uncertainties on nuclear fluxes derived using equation (1).

A direct check of the validity of the method is possible in the case of Mrk 704, for which we have also obtained a J frame with IRCAM. The analysis of the frame has given $J_n = 13.36$ to be compared with $J_n = 13.45$ obtained using equation (1).

A very interesting comparison is possible with the results obtained by Koitilainen et al. (1992a, b), who have analyzed with a technique quite similar to ours their IR images of hard X-ray–selected AGNs. In particular we have one object in Table 1A, Mrk 509, in common with them. The results are in

TABLE 1A

NUCLEAR AND GALACTIC MAGNITUDES OF OBJECTS FOR WHICH WE HAVE K-BAND FRAMES AND JHK PHOTOMETRY WITHIN TWO APERTURES

Name (1)	K_n (2)	δK_n (3)	J_n (4)	J_n(tp) (5)	H_n (6)	H_n(tp) (7)	$\frac{N}{G}$ (5") (8)	$\frac{N}{G}$ (7".8) (9)	K_g (10)	δK_g (11)	$(J-K)_g$ (12)	$(J-K)_a$ (13)	$(H-K)_g$ (14)	$(H-K)_a$ (15)
0048+29	12.15	0.27	14.26	13.67	12.87	12.57	1.50	1.05	11.50	0.24	0.77	0.67	0.32	0.27
2237+07	11.83	0.23	14.76	14.30	12.82	12.65	2.24	1.43	11.30	0.24	0.58	0.36	0.20	0.10
II Zw 1	13.77	0.32	16.50	16.50	15.58	15.57	0.58	0.36	11.85	0.20	1.20	1.15	0.42	0.37
II Zw 136	11.49	0.23	13.72	13.86	12.79	12.94	4.41	3.08	12.19	0.42	1.74	1.85	0.69	0.82
Mrk 9	11.03	0.21	13.20	13.14	12.22	12.16	7.11	3.73	11.38	0.33	1.77	1.38	0.89	0.57
Mrk 110	12.33	0.24	...	...	...	...	...	...	...	...	...	...	...	...
Mrk 290	12.06	0.29	13.39	13.49	12.70	12.80	2.36	1.79	11.66	0.37	2.07	1.87	1.29	1.12
Mrk 304	12.00	0.24	14.01	13.88	13.21	13.08	2.63	1.98	12.11	0.31	1.23	1.35	0.43	0.55
Mrk 382	13.16	0.29	...	...	...	...	...	...	12.89	0.28	...	...	...	...
Mrk 506	12.55	0.28	15.11	14.71	13.76	13.51	1.46	0.97	10.82	0.42	0.96	0.90	0.30	0.25
Mrk 509	10.50	0.23	12.70	12.39	11.57	11.37	3.40	2.49	9.79	0.47	1.12	0.99	0.64	0.56
Mrk 530	11.99	0.34	14.80	13.68	13.38	12.64	0.59	0.39	10.20	0.18	1.25	1.25	0.48	0.48
Mrk 704	11.07	0.23	13.44	13.80	12.67	13.08	5.20	3.16	11.49	0.36	1.12	1.28	0.14	0.31
Mrk 739	11.80	0.24	...	...	13.30	...	2.09	1.08	10.64	0.23	1.03	0.88	0.47	0.37
Mrk 975	11.64	0.27	14.54	14.55	12.84	12.91	2.96	2.05	11.46	0.30	1.02	1.17	0.55	0.63

TABLE 1B

NUCLEAR AND GALACTIC MAGNITUDES OF OBJECTS FOR WHICH WE HAVE K-BAND FRAMES AND SINGLE-APERTURE PHOTOMETRY

Name (1)	K_n (2)	δK_n (3)	J_n (4)	H_n (5)	Aperture (6)	N/G[a] (7)	K_g (8)	δK_g (9)	References (10)
I Zw 1	10.20	0.22	13.13	11.60	8″5	3.40	11.02	0.45	1
Mrk 79	11.19	0.23	13.57	12.34	8	1.87	10.57	0.37	2, 3
Mrk 335	10.04	0.30	12.87	11.42	6	3.40	11.02	0.60	4
Mrk 352	12.42	0.29	13.82	13.11	8.5	1.26	11.77	0.24	1, 5
Mrk 359	12.35	0.24	14.26	13.07	8	0.47	10.74	0.18	6
Mrk 374	12.30	0.23	13.87	13.11	5	2.47	11.48	0.22	7
Mrk 376	11.07	0.24	13.81	12.63	5	3.70	11.58	0.42	7
Mrk 464	13.35	0.27	14.96	14.29	5	1.38	...	...	7
Mrk 478	11.28	0.23	13.70	12.63	5	3.37	11.88	0.42	7
Mrk 486	11.39	0.23	13.64	12.74	5	3.94	...	...	8, 9
Mrk 493	12.69	0.27	14.66	14.20	8.5	0.63	11.36	0.23	10
Mrk 504	14.27	0.68	16.65	15.20	8.5	0.21	11.86	0.23	1, 11
Mrk 584	14.71	0.74	...	...	7.8	0.16	11.94	0.17	7
Mrk 618	11.54	0.22	13.79	12.68	7	4.37	11.34	0.33	8
Mrk 634	13.24	0.31	15.41	14.15	5	1.74	12.60	0.24	7
Mrk 705	11.58	0.22	13.30	12.40	5	2.94	...	...	7
Mrk 734	11.98	0.22	13.76	12.95	10	2.07	12.36	0.35	10
Mrk 766	11.30	0.28	13.75	12.89	8.5	1.01	...	...	1, 10
Mrk 771	12.74	0.32	...	...	10	0.42	11.42	0.20	8, 12
Mrk 783	14.06	0.41	15.62	14.89	7.8	1.21	...	...	7
Mrk 817	11.21	0.32	...	...	10	0.72	10.31	0.22	10
Mrk 841	11.59	0.23	13.85	12.98	5	1.87	11.03	0.27	7, 10
Mrk 845	13.51	0.41	14.97	14.08	5	0.52	11.34	0.20	7, 10
Mrk 871	12.50	0.25	14.96	...	8.5	0.38	10.70	0.18	10
NGC 5548	10.64	0.23	12.63	11.65	7.9	1.49	10.19	0.24	1, 13
NGC 5940	12.53	0.23	14.63	13.64	5	1.47	...	...	7

[a] The ratio is computed within the aperture in col. (6).

REFERENCES.—(1) Balzano & Weedman 1981; (2) McAlary et al. 1979; (3) Ward et al. 1987; (4) Rudy et al. 1982a; (5) Stein & Weedman 1976; (6) Lawrence et al. 1985; (7) our data; (8) Ward et al. 1982; (9) Neugebauer et al. 1985; (10) Rudy et al. 1982b; (11) Rieke 1978; (12) Worrall et al. 1984; (13) McAlary et al. 1983.

very good agreement for the K and J bands, while our estimate of the H band magnitude is 0.16 mag brighter.

The statistical comparison of nuclear colors of the objects listed in Table 1A with those of the objects observed by Koitilainen et al. (1992b) shows that their distributions are very similar, with almost identical median values $(J-K)_n \simeq 2.3$ and $(H-K)_n \simeq 1.2$.

For 12 objects we have reported in Table 1A the J_n(tp) and H_n(tp) nuclear magnitudes (in cols. [5] and [7] respectively), computed assuming a template profile for the hosting galaxies (see Paper I). The results obtained using equation (1) are in decent agreement ($\Delta J_{max} \simeq 0.6$ and $\Delta H_{max} \simeq 0.4$) except in the case of Mrk 530 ($\Delta J \simeq 0.9$ and $\Delta H \simeq 0.7$). It is likely that the uncertainties of the J and H fluxes are larger than the uncertainties in K fluxes by no more than 50%. Of course the uncertainties on nuclear fluxes increase with decreasing ratio of the nuclear to the galactic contributions presented in columns (8) and (9) of Table 1A.

Using equation (2) we have also computed the colors $(J-K)_g$ and $(H-K)_g$ of the underlying galaxies. The results have been reported in columns (12) and (14) of Table 1A. For comparison we have also reported the colors of the rings between the two angular radii of 2″5 and 3″9 (obtained by subtracting out the observed flux within the 5″ aperture from that measured within 7″8), which, at the median redshift of the sample ($z \simeq 0.035$), correspond to $r \simeq 2.5$ kpc and $r \simeq 4$ kpc, respectively. It is apparent that the agreement is good, because the largest discrepancy is 0.3 mag, and the color distributions are quite similar. The median values are $(J-K)_g \simeq 1.13$ and $(H-K)_g \simeq 0.45$. Neugebauer et al. (1985) have measured the IR colors of the rings between the two angular radii of 2″5 and 5″ of 10 QSOs. Their results have median values $(J-K)_g \simeq 1.13$ and $(H-K)_g \simeq 0.48$, in good agreement with our findings.

These values are redder than observed in normal early-type spirals ($\langle J-K \rangle \simeq 1.0$, $\langle H-K \rangle \simeq 0.25$; Griersmith et al. 1982; Devereux, Becklin, & Scoville 1987).

Using Spearman rank correlation coefficient and Kendall's coefficient of concordance W, we have tested that there is no correlation of the galactic with nuclear colors. Moreover, there is no significant correlation of these colors with the ratios of the nuclear to the galactic flux. The only relevant correlation is between these ratios and the *observed* colors, as is expected.

In the case of Mrk 110, no reliable estimate of the integral galactic magnitude has been obtained (see Paper I). Moreover, the observed IR colors of Mrk 110 and Mrk 382 within the 7″8 aperture are redder than those in the 5″ aperture. This would imply the implausible circumstance that the hosting galaxies are much redder than the nuclei. Therefore the J and H magnitudes derived using equation (2) would have been unreliable and have not been reported.

The median colors of the underlying galaxies [$(J-K)_g \simeq 1.13$, $(H-K)_g \simeq 0.45$] have been used to derive J- and H-band nuclear magnitudes, through equation (2) when only single-aperture photometry (in addition to K-band images) was available. This is the case of objects listed in Table 1B. In a few cases, no solution has been obtained for J and/or H magnitudes. Of course, the uncertainties in the fluxes derived in this way are larger than those derived from the K-band frames and the evaluation of the errors is not easy. It is clear that the uncertainties are smaller when the underlying galaxy gives only a small contribution of the observed flux. Actually all the objects lacking estimates of nuclear magnitudes in Table 1B have nuclear to the galactic flux ratios $N/G < 1$ (see col. [7]). Moreover the J and H magnitudes of objects with small N/G ratios are quite sensitive to the assumed galactic colors. On the contrary, the results of objects with $N/G > 1$ are quite independent of galaxy colors.

Among the objects in Table 1B, NGC 5548 is the only one observed also by Koitilainen et al. (1992b). The difference between our results and theirs is very small in the K band (0.04 mag), but increases to 0.34 mag in J and reaches 0.45 magnitudes in the H band.

The distributions of nuclear colors of objects listed in Tables 1A and 1B are consistent with both groups having been drawn from the same parent population.

The nuclear colors of all objects listed in Table 1A and 1B have been compared with the colors of the sample of Koitilainen et al. (1992b). The results of the statistical tests show that they have very similar distributions.

Note that no K-corrections have been applied, so that the results refer to the observer's frame. On the other hand, owing to the relatively low redshifts of the galaxies, such corrections are bound to be small.

3. DISCUSSION

3.1. *Characteristics of the Host Galaxies*

As mentioned above, we have described the light distribution of the underlying galaxies as the superposition of bulge and disk. Using the best-fit parameters, we found that both bulge and disk give in general appreciable contributions to the total K-band galactic emission (see Paper I). This fact confirms the claim that the large majority of the Seyfert nuclei reside in early-type spirals or S0 galaxies (Adams 1977; Simkin, Su, & Schwartz 1980; Yee 1983; MacKenty 1990).

We have obtained a reliable determination of the total absolute magnitude for 34 objects. In Figure 1 we present the K-band luminosity distribution of host galaxies in our sample. The median value is $M_{Kg} = -25.6$. This value falls in the exponentially decreasing tail of the K-band local luminosity function of spiral galaxies computed by Franceschini et al. (1991). This outcome confirms the results obtained by Neugebauer et al. (1985) in the near-IR. It is also in keeping with the results found by authors who have investigated the *optical* luminosity distribution function of galaxies hosting AGNs for optically selected samples (Yee 1983; Malkan 1984a; MacKenty 1990), and for an X-ray–selected sample (Kruper & Canizares 1989). Similar investigations have also been performed on galaxies harboring radio-quiet and radio-loud QSOs (Hutchings, Crampton & Campbell 1984; Gehren et al. 1984; Smith et al. 1986; Véron-Cetty & Woltjer 1990).

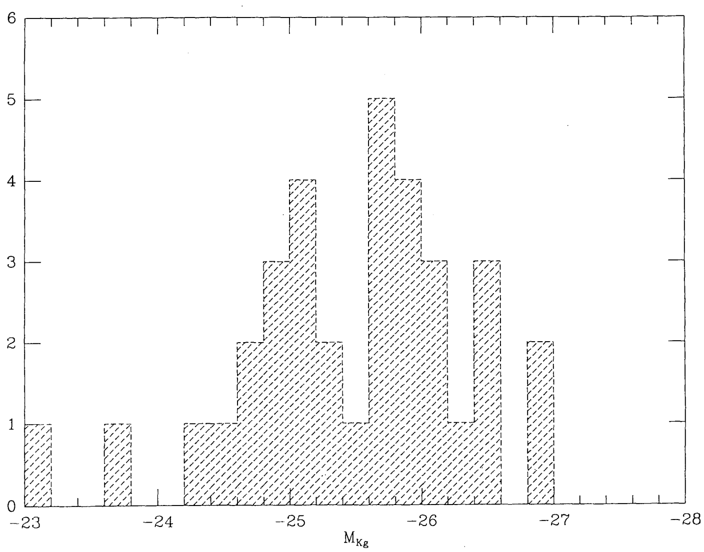

FIG. 1.—Distribution of the total K-band absolute magnitudes of the host galaxies.

Nine of these 34 objects are PG QSOs (Schmidt & Green 1983); for them we find a median $M_{Kg} = -25.7$. For the remaining 25 objects ("Seyferts"), we get a median $M_{Kg} = -25.5$.

Assuming that the colors of galaxies hosting an active nucleus are similar to those of normal early-type spirals ($B-K = 4.15$, $V-K = 3.2$; Griersmith et al. 1982), the M_{Kg} corresponds to $M_{Bg} = -21.55$ and to $M_{Vg} = -22.5$ in the case of galaxies hosting PG QSOs; to $M_{Bg} = -21.35$ and to $M_{Vg} = -22.30$ for "Seyferts."

In Figure 2 we have plotted the monochromatic luminosities at 2.2 μm of the host galaxies against those of the nuclei; there is a clear correlation, significant at the 99.9% confidence level, that might at least partly be accounted for by selection effects. In particular, bright galaxies with low-luminosity nuclei, which would populate the upper left-hand corner, are likely to be underrepresented in our sample of UV excess objects. On the other hand, the correlation is still significant if we confine ourselves to bright nuclei. Using the K-band local luminosity function of spiral galaxies (Franceschini et al. 1991), we find that the fraction of such galaxies hosting a nucleus brighter than $M_{Kn} = -25$ (corresponding to $M_{Bn} \approx -22.5$) strongly decreases with galactic luminosity: it is $\simeq 3 \times 10^{-3}$ for $-27 < M_{Kg} < -26$, it falls to $P \simeq 3 \times 10^{-4}$ for $-26 < M_{Kg} < -25$, and it becomes very small for galaxies fainter than $M_{Kg} = -25$.

It thus appears that bright AGNs tend to live in bright galaxies, whereas low-luminosity nuclei may reside in galaxies of any luminosity.

As mentioned above, on average the $J-K$ and $H-K$ colors of galaxies in our sample are slightly redder than those of normal galaxies. On the other hand, they turn out to be slightly bluer than those of starbursting and H II galaxies: based on the samples of such galaxies observed by Lawrence et al. (1985) and Glass & Moorwood (1985) we find $\langle J-K \rangle = 1.25$ and $\langle H-K \rangle = 0.5$. Similar results have been derived by Joseph et al. (1984) for a sample of interacting galaxies.

It is also interesting to note that the average values of $(J-H)_g$ and $(H-K)_g$ of the host galaxies are close to the values measured along the major axis of NGC 253 at distance of 1–3 kpc by Scoville et al. (1985), who argued that the colors are probably due to reradiation by hot dust associated with star forming regions. They are also compatible with the observed distribution of colors across the center of M82 (Telesco et al. 1991).

In conclusion our data are consistent with the suggestion that nuclear activity in galaxies is often associated with moderate starbursting activity in central regions.

The possible correlation of the nuclear with starburst activity is a matter of debate (see, e.g., Heckman 1987; Terlevich & Melnick 1987; Scoville 1988). On the other hand evidences of circumnuclear starbursting activity in AGNs have accumu-

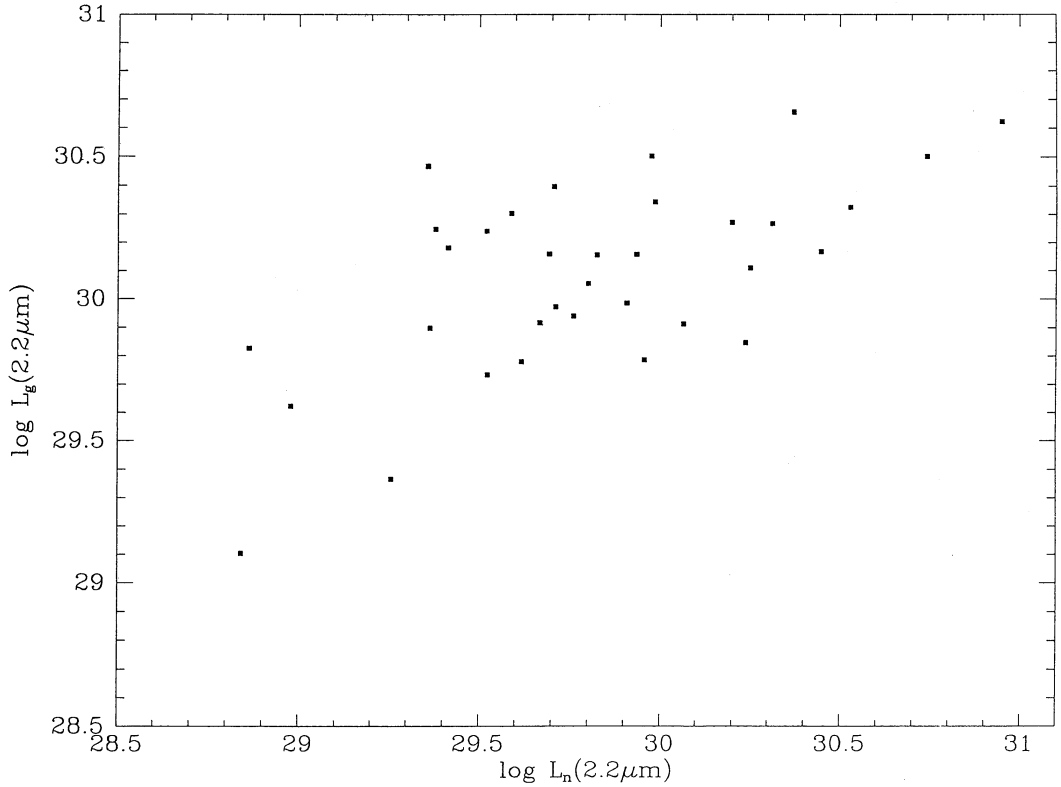

FIG. 2.— Galactic vs. nuclear luminosities (ergs s^{-1} Hz^{-1}) at 2.2 μm

lated. For instance, recent high-resolution optical and radio observations of NGC 7469 support the presence of a starbursting region confined within 1 kpc (Wilson et al. 1991).

Moreover, observations of CO emission in Seyfert galaxies detected molecular gas in the circumnuclear regions that could fuel both the nuclear activity as well as a moderate star-forming activity. Heckman et al. (1989) have shown that Seyfert galaxies of both types exhibit a well-defined correlation between the CO and far-infrared luminosity, as normal and starburst galaxies do. They also pointed out that Seyfert 1 galaxies look relatively normal in the overall abundance of CO. Meixner et al. (1990) observed three nearby Seyfert 1 galaxies at high resolution and found that a large portion of their CO emissions comes from regions within a few kpc of the nucleus. Taniguchi et al. (1990) found that there is no significant difference in circumnuclear molecular gas densities between Seyferts and starburst nuclei.

3.2. *The Emission at IRAS Wavelengths*

Using the IR luminosities of the nuclei and underlying galaxies, we can explore the problem of the respective contributions also in the far-IR. More than half of the objects we observed in IR have been detected by *IRAS*, and for the others reliable upper limits are often available.

Ground observations at 10 μm with small apertures ($\leq 5''$) compared to *IRAS* 12 μm data have been used by many authors to illustrate the relative importance of the nuclear and galactic emissions (Edelson et al. 1987; Neugebauer et al. 1987; McAlary & Rieke 1988; Roche et al. 1991). Following Edelson et al. (1987), we can define the "compactness parameter" R as the ground-based to *IRAS* flux at 12 μm for 14 objects of our sample. The minimum value of R is 0.53 (it refers to Mrk 530 which has a nucleus particularly faint with respect to the galaxy) and the median is 0.8. This results is indicative of the predominance of the nuclear emission at 12 μm. However, spiral galaxies are known to be strong emitters in the far-IR, and this circumstance could reverse the relative importance of the nuclear to the galactic contribution with increasing wavelength.

In Figures 3, 4, 5, and 6, we have reported the luminosities (and upper limits) in the *IRAS* bands against the nuclear and the galactic luminosities at 2.2 μm. It is apparent that the correlation between the 2.2 μm nuclear and *IRAS* luminosities tends to weaken with increasing wavelength, whereas the opposite holds for the galactic luminosities L_g(2.2 μm). Of course in analyzing the correlations it should be kept in mind that nuclear and galactic luminosities are correlated (see above).

We have investigated the correlations using various statistics: Kendall's coefficient of concordance W, Kendall's rank correlation coefficient τ, Kendall's rank partial correlation coefficient $\tau_{xy;z}$, Spearman partial rank correlation coefficient (Macklin 1982) and the usual correlation coefficient. In particular we used a generalized version of Kendall's rank correlation and the usual correlation coefficient statistics which takes into account also the upper limits (see Schmitt 1985; Isobe, Feigelson, & Nelson 1986). In Table 2 we have reported the results.

All the tests indicate that the strongest correlation is between the nuclear luminosities L_n(2.2 μm) and 12 μm luminosities L(12 μm). For example, the probability of reproducing the correlation by chance is $P_k \leq 10^{-5}$ both for W and τ statistics, and the correlation coefficient is high ($r = 0.8$). The analysis with the partial correlation coefficient confirms that

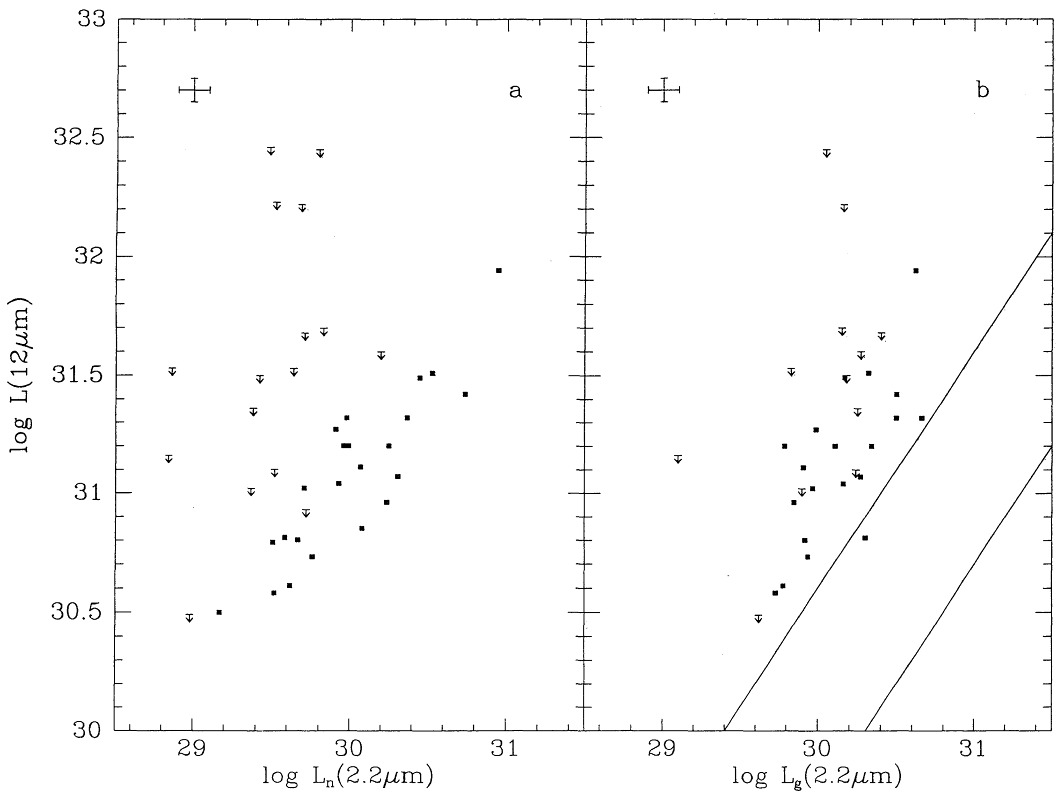

FIG. 3.—*IRAS* 12 μm luminosities (ergs s^{-1} Hz^{-1}) vs. nuclear (*a*) or galactic (*b*) luminosities (ergs s^{-1} Hz^{-1}) at 2.2 μm. The upper and lower lines bound the range of galaxian contributions inferred from the distribution of 2.2 μm to 12 μm luminosity ratios for a sample of normal spiral galaxies (see text). The typical error bars of the data along the two axes are also shown (*upper left-hand corner*).

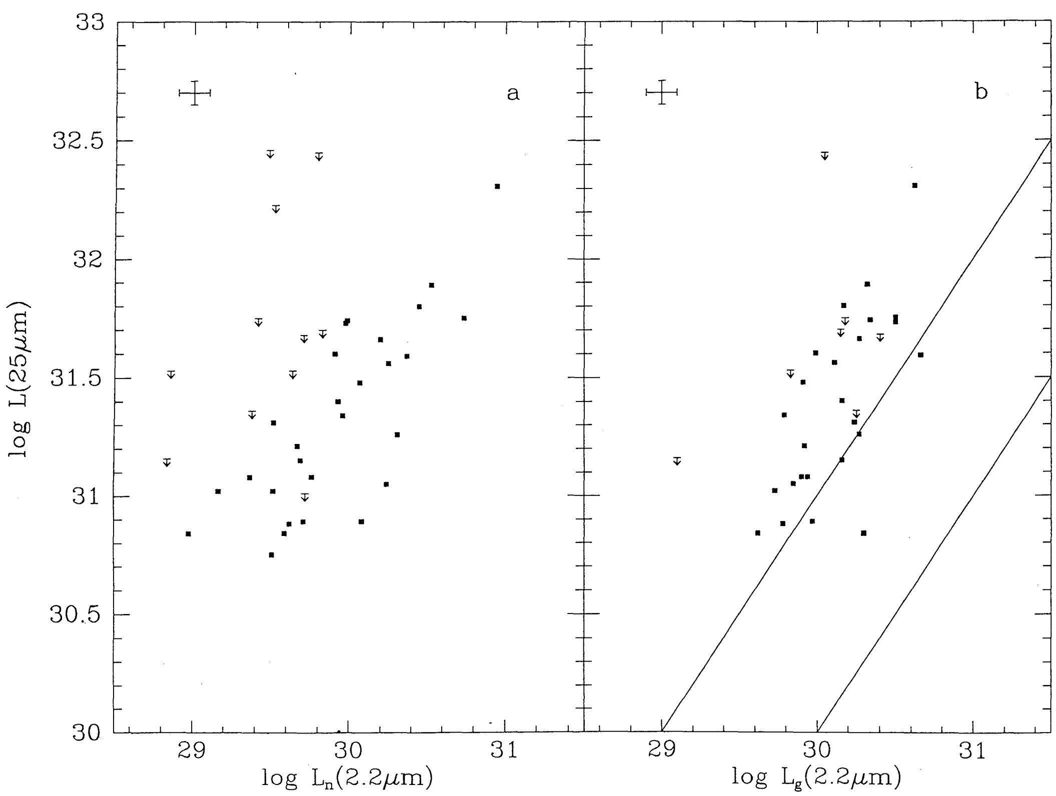

FIG. 4.—Same as Fig. 6 but for 25 μm luminosities

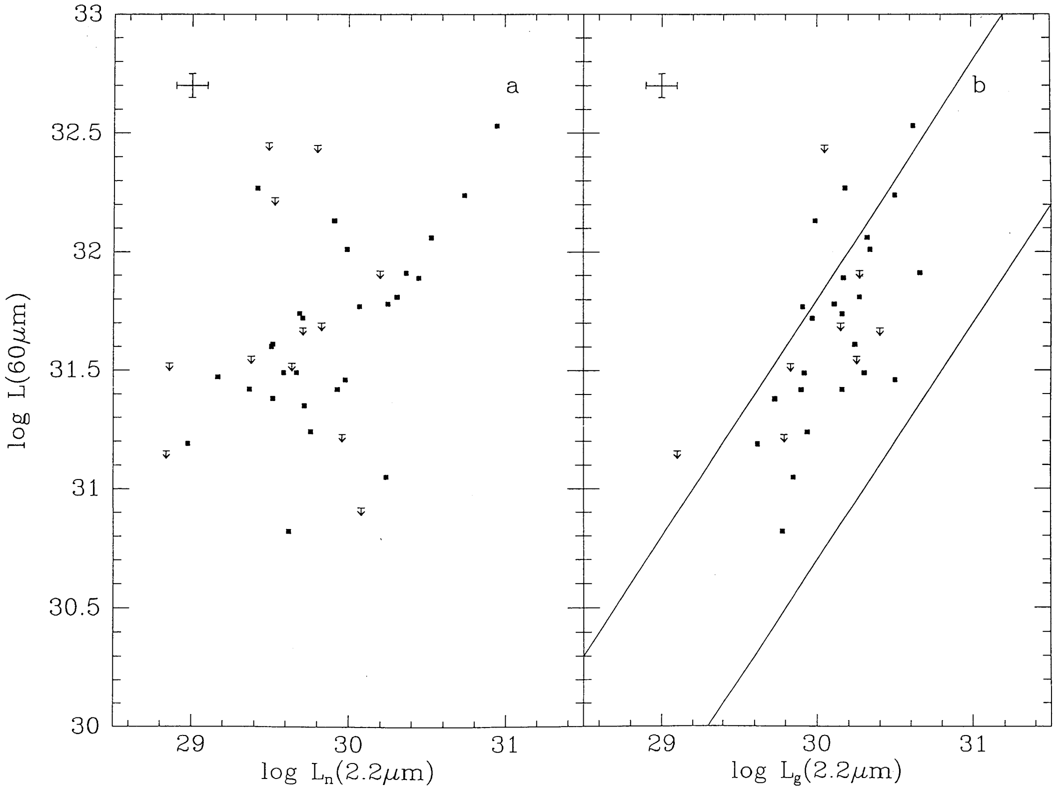

FIG. 5.—Same as in Fig. 6 but for 60 μm luminosities

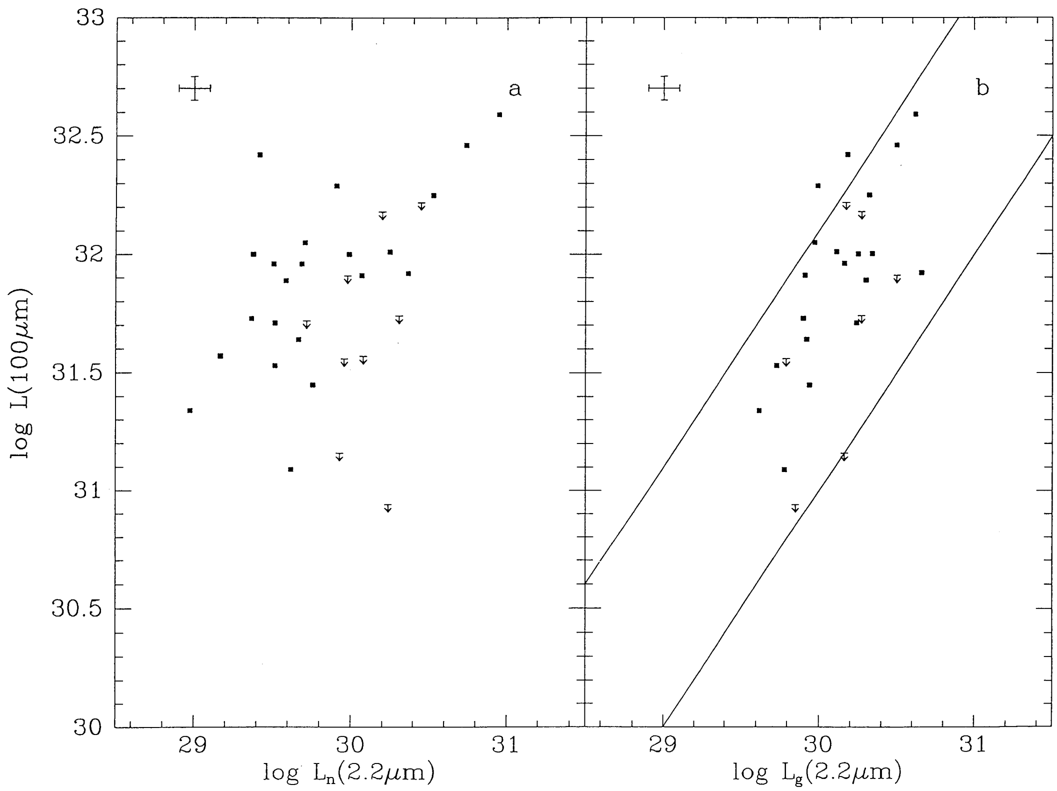

FIG. 6.—Same as in Fig. 6 but for 100 μm luminosities

TABLE 2

2.2 MICRON–*IRAS* CORRELATIONS

Values Correlated	Detections and Limits P_k	Detections and Limits r	Detections Only τ	Detections Only $\tau_{xy;z}$	Detections Only $P_{xy;z}$
$L_{2.2,n}$–L_{12}	8×10^{-6}	0.82	0.66	0.53	5.6×10^{-4}
$L_{2.2,g}$–L_{12}	8×10^{-4}	0.63	0.57	0.39	1.1×10^{-2}
$L_{2.2,n}$–L_{25}	7×10^{-6}	0.80	0.61	0.48	7.4×10^{-4}
$L_{2.2,g}$–L_{25}	3×10^{-4}	0.67	0.52	0.34	2.7×10^{-2}
$L_{2.2,n}$–L_{60}	4×10^{-3}	0.46	0.47	0.32	0.18
$L_{2.2,g}$–L_{60}	4×10^{-4}	0.71	0.51	0.37	1.4×10^{-2}
$L_{2.2,n}$–L_{100}	0.25	0.27	0.42	0.27	0.22
$L_{2.2,g}$–L_{100}	7×10^{-3}	0.40	0.50	0.39	2.1×10^{-2}

the correlation between $L_n(2.2\ \mu\text{m})$ and $L(12\ \mu\text{m})$ is relatively independent of the galactic K luminosities: keeping $L_g(2.2\ \mu\text{m})$ constant the correlation coefficient changes from 0.66 to 0.53 and the probability (computed using the Spearman partial rank correlation coefficient) that the correlation entirely arises from the $L_n(2.2\ \mu\text{m})$–$L_g(2.2\ \mu\text{m})$ and $L_g(2.2\ \mu\text{m})$–$L(12\ \mu\text{m})$ ones separately is $P_{xy;z} \simeq 5.6 \times 10^{-4}$. The correlation between $L_g(2.2\ \mu\text{m})$ and $L(12\ \mu\text{m})$ is a little less significant ($\tau = 0.57$ and $r = 0.63$) and decreases substantially ($\tau = 0.39$) at constant $L_n(2.2\ \mu\text{m})$. The above results are in keeping with the large compactness ratios R we have found. The statistical predominance of the nuclear emission is confirmed even at 25 μm, whereas at 60 μm a clear change occurs. The correlation coefficient between $L_n(2.2\ \mu\text{m})$ and $L(60\ \mu\text{m})$ is $\tau = 0.47$, smaller than that between $L_g(2.2\ \mu\text{m})$ and $L(60\ \mu\text{m})$ ($\tau = 0.51$). Moreover, the partial correlation coefficient between $L_n(2.2\ \mu\text{m})$ and $L(60\ \mu\text{m})$, at constant $L_g(2.2\ \mu\text{m})$, is only $\tau = 0.32$. The probability that the correlation between $L_n(2.2\ \mu\text{m})$ and $L(60\ \mu\text{m})$ entirely arises from the $L_n(2.2\ \mu\text{m})$–$L_g(2.2\ \mu\text{m})$ and $L_g(2.2\ \mu\text{m})$–$L(60\ \mu\text{m})$ ones separately is $P_{xy;z} \simeq 0.18$, whereas in the case of $L_g(2.2\ \mu\text{m})$ and $L(60\ \mu\text{m})$, the probability of a completely induced correlation drops to $P_{xy;z} \simeq 1.3 \times 10^{-2}$. The trend of an increasing statistical relevance of the galactic contribution to the far-IR emission with increasing wavelengths is confirmed by the 100 μm data. In this case the correlation coefficient of $L(100\ \mu\text{m})$ with $L_g(2.2\ \mu\text{m})$ is $r = 0.40$, but is only $r = 0.27$ in the case of $L(100\ \mu\text{m})$ versus $L_n(2.2\ \mu\text{m})$.

We conclude that the nuclear contribution to the far-IR emission of Seyfert galaxies is definitely decreasing with increasing wavelength. As a further test of this conclusion, we have examined the distribution of the ratios of the *IRAS* to the K-band luminosities for a sample of normal early-type spirals From a sample of normal spiral galaxies collected by Devereux (1987, 1989), we chose the objects observed in the K band with apertures large enough to allow a reliable determination of their total luminosities. The ratios $L(12\ \mu\text{m})/L(2.2\ \mu\text{m})$ range from 0.5 to 4.5 with a median $r_{12-2.2} \simeq 2$; the $L(25\ \mu\text{m})/L(2.2\ \mu\text{m})$ ratios vary from 1 to 10 with a median value $r_{25-2.2} \simeq 4$; at 60 μm the ratios fall between 5 to 65 and the median value is $r_{60-2.2} \simeq 22$; finally, the ratios $L(100\ \mu\text{m})/L(2.2\ \mu\text{m})$ are in the interval 10–120 with a median value $r_{100-2.2} \simeq 50$. For sake of comparison, we notice that a small subsample of *IRAS* selected luminous bright galaxies observed by Carico et al. (1988, 1990) have $100 \leq r_{60-2.2} \leq 700$. Using these results we have reported in Figures 3, 4, 5. and 6, the maximum and minimum possible contribution (*upper and lower lines*) of the host galaxies to the total luminosities. While the observed luminosities at 12 and 25 μm are mostly above the maximum, at 60 and 100 μm they are well within the possible contributions of the host galaxies.

Rodriguez Espinosa, Rudy, & Jones (1986, 1987) pointed out that the spectral indices between 60 and 100 μm, α_{60-100}, ($f_\nu \propto \nu^\alpha$) of Seyfert and starburst galaxies are quite similar. We confirm their result for our sample of Seyferts, which has a α_{60-100} distribution similar to that of the starburst galaxies of the optically selected sample investigated by Sekiguchi (1987). However, their claim that 75% of the Seyfert galaxies in their sample have *massive* starburst episodes is based on a rather arbitrary choice for the lower limit of the luminosities of the starburst galaxies ($L_{\text{fir}} > 10^{44}$ ergs s^{-1}). Actually, as we have shown above, the galaxies hosting AGNs are usually brighter than L_* (the typical luminosity where the luminosity function is falling exponentially), and the 60 and 100 μm emissions of the Seyferts are compatible with the emission from the host galaxies, with ratios between the IR (stellar) and the far-IR (dust) luminosities typical of normal or moderate starburst galaxies.

In conclusion, there is statistical evidence that in Seyfert 1 galaxies the nuclear emission largely dominates at 12 μm and is still important at 25 μm, while longward of 60 μm the emission from the host galaxies is overwhelming. This result is also in keeping with the fact that in a 12 μm flux-limited sample, the percentage of galaxies harboring active nuclei can be higher than 20% (Spinoglio & Malkan 1989).

A similar conclusion has been drawn by Berriman (1989) on the basis of the correlation of the polarization with the luminosities at 12 and 25 μm.

If the observed IR and mid-IR spectrum is ascribed to synchrotron emission, as suggested by Band & Malkan (1989), a consequence of the galaxy dominance at 60 μm is that the turnover in the synchrotron self-absorbed power law must occur at shorter wavelengths. At longer wavelengths, the spectrum of Seyfert 1 is likely to be dominated by the cold dust emission in the host galaxies, in agreement with the steep fall-off of the spectrum of Seyfert 1 galaxies and QSOs in the submillimeter region observed by several authors (Engargiola et al. 1988; Chini, Kreysa, & Biermann 1988; Edelson et al. 1988; Lawrence et al. 1991).

As expected from the above discussion, the Seyfert 1 galaxies of our sample exhibit a slope α_{12-60} definitely flatter than those of normal and starburst galaxies. The flatness of the IR spectra of AGNs has been noticed by many authors (e.g., Miley, Neugebauer, & Soifer 1985; Edelson 1986; Edelson et al. 1987). In particular, Edelson (1986) showed that the spectral indices α_{12-60} of AGNs are much flatter than those of normal galaxies.

As it is apparent from Figure 7, the distributions of α_{12-60} for our sample and for an optically selected sample of normal spiral galaxies detected at 12 μm are quite different with a negligible probability $P(F1 = F2) \leq 4 \times 10^{-5}$ that they have been drawn from the same parent population (here and in the following we will use the Gehan's test and the Peto-Prentice generalized Wilcoxon statistic in comparing distributions).

For starburst galaxies Xu & De Zotti (1989) found an average $\alpha_{12-60} \simeq -1.9$, while the median value of our Seyfert galaxies is -0.9 (for both classes we used in the statistics only objects detected at both wavelengths).

On the other hand, the distribution of the slopes α_{12-60} for

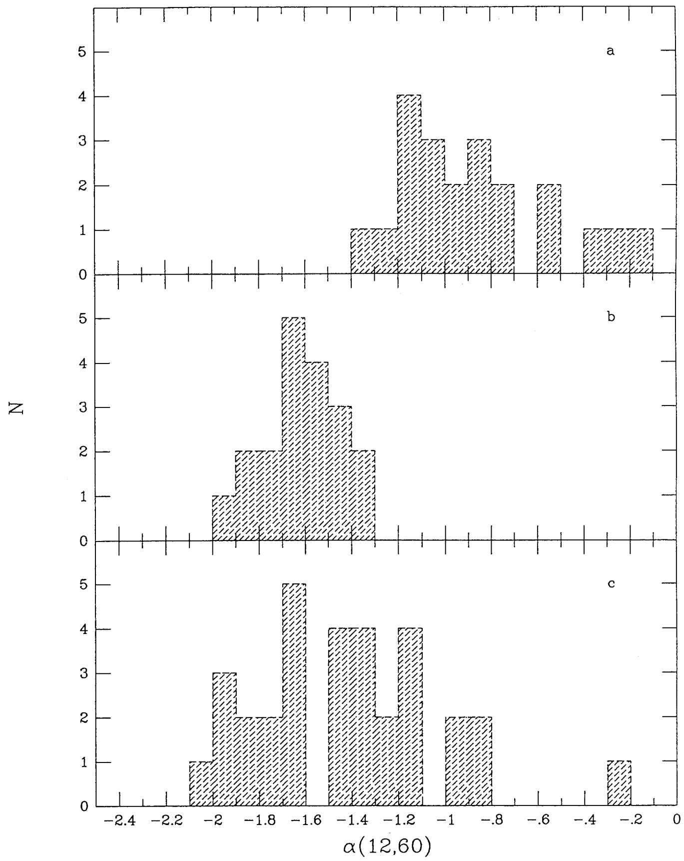

FIG. 7.—Distributions of the α_{12-60} slopes. (*a*): Type 1 Seyferts in our sample; (*b*): normal optically selected spirals; (*c*): type 2 Seyferts selected at 12 μm (Spinoglio & Malkan 1989).

the Seyfert 1 galaxies in the CfA sample looks very similar to that of our Seyferts [$P(F1 = F2) \simeq 0.15$], as might be expected on the basis of the fact that about half of the objects are common to the two samples. However, in the CfA sample, there are five objects out of 19 with $\alpha_{12-60} < -1.5$, the minimum value for our sample; three objects, NGC 2992, NGC 3227, and NGC 5033, have very low total luminosities ($M_B > -19.4$), and two others, Mrk 231 and NGC 7469, have large starbursts (Aitken, Roche, & Phillips 1981; Cutri et al. 1984; Wilson et al. 1991).

The *IRAS* data on the hard X-ray–selected AGN sample of Piccinotti et al. (1982) again confirms that the AGNs have α_{12-60} slopes flatter than normal and starburst galaxies; the statistical tests on this distribution in comparison to ours give $P(F1 = F2) \simeq 0.20$.

It is worth noticing that the Seyfert 1 galaxies selected on the basis of their 12 μm emission by Spinoglio & Malkan (1989) show a distribution of α_{12-60} quite similar to those of our optically selected sample [$P(F1 = F2) \sim 0.2$].

Seyfert 2 galaxies in the CfA sample (Edelson et al. 1987) and those selected at 12 μm (Spinoglio & Malkan 1989) exhibit distributions much broader than those of Seyfert 1 samples (the probability that they are drawn for the same parent distribution is only $P \sim 2 \times 10^{-3}$), probably because of a larger variety of luminosity ratios among different emission mechanisms. However in this context it is quite interesting to note that NGC 1068 has a slope $\alpha_{12-60} \simeq -1$, close to the average value of our sample.

In a sample of optically selected nonactive spiral galaxies the objects with $\alpha_{12-60} \geq -1.5$ are only 15% of the total number; the percentage reaches 20% if the primary selection is done at 12 μm. Contrariwise, less than 15% of Seyfert 1 galaxies have $\alpha_{12-60} \leq -1.5$, independently of the primary selection (optical or mid-IR); these objects usually possess faint nuclei or exhibit large starbursts. No nonactive spiral galaxy has a slope flatter than -1.1, while more than 50% of the Seyfert 1 galaxies do. Therefore we can conclude that extragalactic objects with $\alpha_{12-60} > -1.5$ are good AGN candidates.

3.3. *Near-IR and Mid-IR Colors of the Nuclei*

The distributions of the $(J-K)_n$ and $(H-K)_n$ colors of the nuclei of our sample are presented in Figures 8, and 9*a*. The average values, $\langle J-K\rangle = 2.25 \pm 0.1$ (rms), $\langle H-K\rangle = 1.19 \pm 0.06$ for our sample are quite close to the median values, but it is evident that there is a considerable spread. For sake of comparison we have reported in Figures 8, and 9*b* the IR colors of the nuclei of an X-ray–selected sample of Seyfert galaxies (Koitilainen et al. 1992b). The distributions of $(J-K)$ and $(H-K)$ colors are very similar; as an example, for $(J-K)_n$ colors the statistical tests give $P(F1 = F2) \simeq 0.7$. Moreover the slopes between the 2.2, 12, and 25 μm of the two samples are compatible.

Many nuclei in the sample exhibit curved IR spectra, with an excess at 3–5 μm already noted by several authors (see, e.g., Neugebauer et al. 1979). A detailed analysis of the spectra of the nuclei from the X-ray to the radio band will be presented

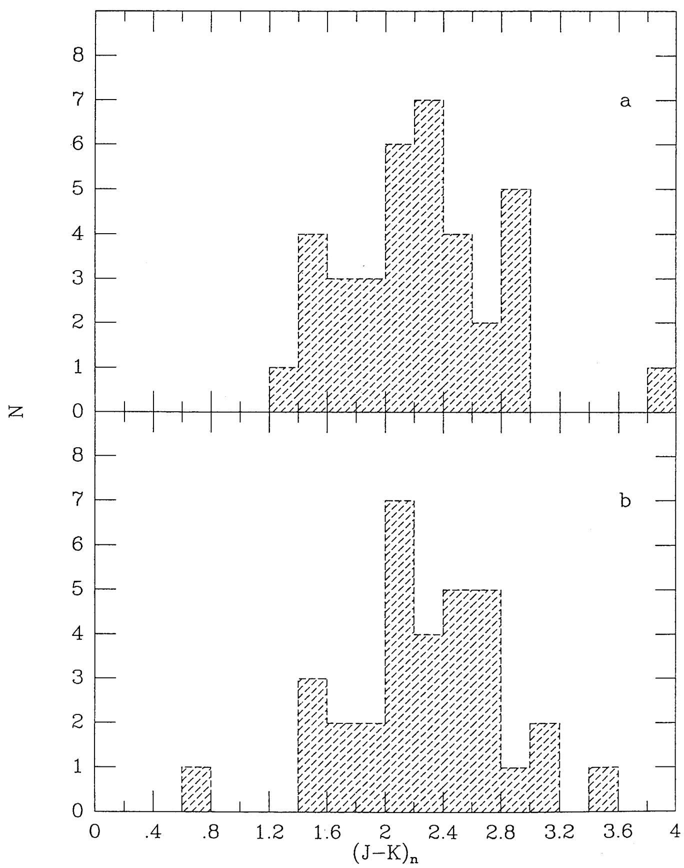

FIG. 8.—Distribution of nuclear $(J-K)$ colors. (*a*): Our sample; (*b*): hard X-ray–selected sample (Koitilainen et al. 1991b).

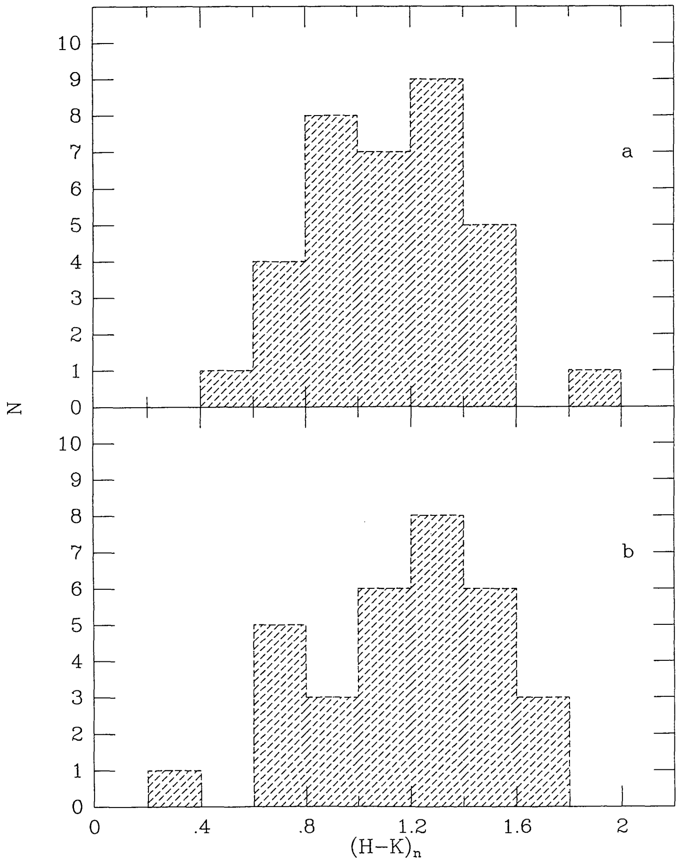

FIG. 9.—Same as Fig. 8 but for $(H-K)$

elsewhere. However, our optical and IR data confirm the claim by Sanders et al. (1989) that a minimum in νf_ν around 1 μm is a common feature in AGN spectra. This minimum suggests that the emission mechanism dominating the optical part of the spectrum fades at longer wavelengths, where a different process is emerging.

If we take into account the emission by the host galaxies at $\lambda \geq 60$ μm (see § 3.2), the nuclear spectra are remarkably curved. Synchrotron models have many drawbacks in fitting this kind of spectra, because they require high magnetic fields (larger than 100 G), small sizes of the emitting regions (smaller than several light-days) and large ratios of the photon–to–magnetic energy density (see Band & Malkan 1989; Lawrence et al. 1991). On the other hand, dust emission models naturally reproduce the raising in the near-IR (dust grains sublimate at 1000–1500 K) and the fall-off at $\lambda \geq 60$ μm (Barvainis 1987, 1990; Sanders et al. 1989).

In this context it is also worth noticing that the slopes between the 2.2, 12, and 25 μm are flatter for the brightest objects. Sanders et al. (1989) already noticed a flattening of the spectra of their PG QSOs with the lowest luminosities ($L_{\rm bol} < 10^{12}$ $L_\odot$). However, they interpreted this effect as due to the contribution of the host galaxies in the near-infrared, while in our case we have already subtracted the galactic contributions.

3.4. *The Relation of the IR to the X-ray Nuclear Luminosity*

The correlation between near IR and X-ray luminosities of AGNs has been explored by many authors (e.g., Glass 1979; Malkan 1984b; Wilkes & Elvis 1987; Carleton et al. 1987; McAlary & Rieke 1988; Kriss 1988; Mushotzky & Wandel 1989; Sanders et al. 1989), to probe the relevance of the nonthermal emission in the IR band. So far, no definite conclusion has been reached.

Although the objects of our sample detected in X-rays span only two decades in flux or in luminosity both at 2.2 μm and at 2 keV (Figs. 10*a*, *b*), a positive correlation is discernible. Kendall's rank test gives a probability of 0.03 that the correlation of the fluxes is spurious. As for the luminosities the probability of a spurious correlation falls to $P \leq 0.003$. The classical correlation coefficient is also significant ($r = 0.58$), and the fit suggests that the correlation is not linear: $L_{2\ \rm keV} \propto L_{2.2}^{0.63\pm0.17}$. The result is in reasonable agreement with that found by Kriss (1988), who explored the correlation of the 2 keV luminosity with the luminosity at 1 μm for a sample of 88 AGNs and radio-quiet QSOs. Indeed, using the 1.26 μm monochromatic luminosities we found $L_{2\ \rm keV} \propto L_{1.26}^{0.75\pm0.20}$ quite close to Kriss's result ($L_{2\ \rm keV} \propto L_{1\ \mu\rm m}^{0.73}$). A closer to linear correlation has been found by Mushotzky & Wandel (1989) between the X-ray and 0.75 μm rest frame luminosities ($L_x \propto L_{0.75}^{0.85}$). On the contrary, Sanders et al. (1989) claimed that there is no evidence of any correlation between the 2 keV and the 3.5 μm fluxes of PG QSOs, and argued that objects covering a narrow range of fluxes occupy a strip in luminosity-luminosity plots, thus mimicking a correlation.

All these authors have used *Einstein Observatory* X-ray data.

Hard X-ray data were used by McAlary & Rieke (1988) who concluded that the emission at 6 keV of their *hard X-ray–*

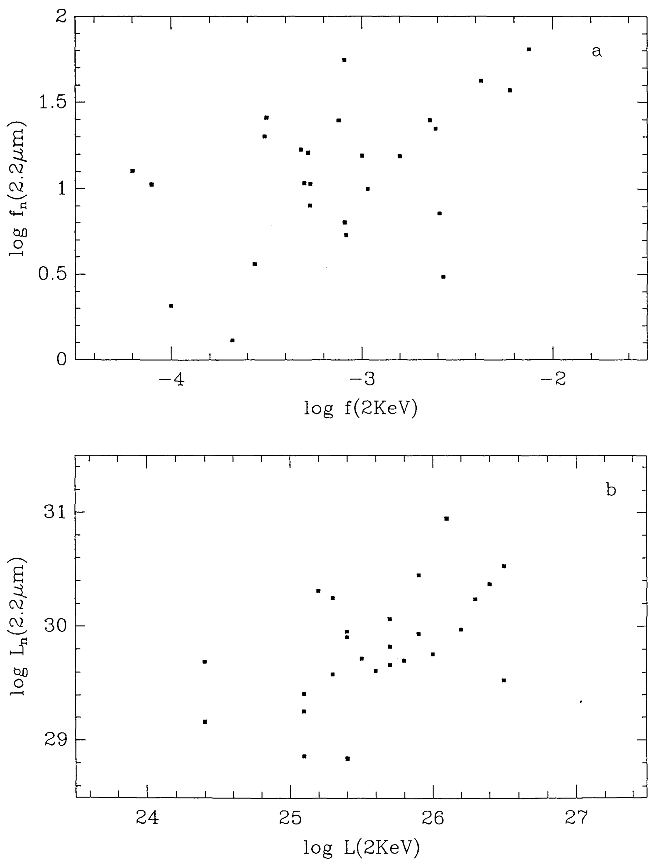

FIG. 10.—(*a*) Nuclear fluxes (mJy) at 2.2 μm vs. fluxes at 2 keV. (*b*) Same as in (*a*) but in terms of luminosities (ergs s^{-1} Hz^{-1}).

selected sample of Seyfert 1 galaxies does not show any significant correlation with the emission at 3.5 μm. On the other hand, Carleton et al. (1987), using a similar sample, found a strict correlation between the hard X-ray and the infrared *baseline* luminosity; they exploited this correlation to derive a rough estimate of the possible nonthermal IR component.

Our statistical analysis suggests that the correlation between X-ray and IR emission is significant at $\lambda = 2.2$ μm and increases both in significance and in linearity with decreasing IR wavelength. These facts are not in contrast with an IR continuum dominated by thermal dust reradiation. Actually many models predict a tight connection between X-ray and UV-optical emissions of AGNs: X-ray photons can be produced by Compton upscattering of UV-optical photons by high-energy electrons, or, alternatively, X-ray primary photons may be reprocessed into UV-optical photons (see, e.g., Collin-Souffrin 1991). On the other hand, thermal dust emission is directly powered by the UV emission of the nucleus. Therefore, it is not surprising that a significant correlation between the IR and X-ray emissions exists. Of course, this argument also implies that the variability in the three bands are related (see below).

A further interesting fact is that an important fraction of the total luminosity of the nuclei is emitted in the near- and mid-IR: for the majority of our objects the IR (1.2–25 μm) luminosity is more than 3 times their X-ray luminosity (2–10 keV) and can reach 30%–40% of the bolometric luminosity. Therefore, any model which attributes the IR emission to dust must solve the problem of producing such huge amount of light at shorter wavelengths and enough dust to absorb it.

4. CONCLUSIONS

We have analyzed new IR data on 41 Seyfert 1 galaxies of the 56 comprised by the *homogeneous* optically selected sample defined by Cheng et al. (1985).

Almost all the galaxies exhibit detectable bulge and disk components, confirming that AGNs are preferentially located in early-type spirals. The average luminosity of the host galaxies falls in the high-luminosity tail of the *K*-band luminosity function of the spiral galaxies. The probability that a spiral galaxy hosts a bright AGN increases with its luminosity. The average colors of the hosts are close to the colors of moderately starbursting galaxies.

The galaxian 2.2 μm luminosities correlate with 60 and 100 μm luminosities, whereas the 12 and 25 μm luminosities show a tighter correlation with the nuclear luminosities. This fact statistically demonstrates the predominance of the disk emission longward of 25 μm. As a consequence, any synchrotron emission must fall off at these wavelengths. The total 60 and 100 μm luminosities can be easily accounted for if the host galaxies have $L(60\ \mu\mathrm{m})/L(2.2\ \mu\mathrm{m})$ and $L(100\ \mu\mathrm{m})/L(2.2\ \mu\mathrm{m})$ ratios similar to those of galaxies with normal or moderately enhanced star formation rates.

The curved IR spectra of the nuclei are more easily modeled by dust emission rather than by synchrotron. Moreover synchrotron emission would imply variability on time scales of order of several light-days, whereas at *IRAS* wavelengths radio-quiet QSOs and AGNs show no evidence of variability (Edelson & Malkan 1987) at least on time scales of up to few months.

We also substantiated the suggestion that the slope α_{12-60} can be used to efficiently select AGN candidates. In particular only 15% of Seyfert 1 galaxies in our sample (either hosting a weak nucleus or undergoing a violent starburst) have $\alpha_{12-60} < -1.5$, whereas 85% of the normal galaxies do.

Our data confirm that there is correlation between the IR (*K* band) and the X-ray (2 keV) emissions. We have also found that the correlation strengthens with decreasing IR wavelength. We argued that this is not in contrast with dust emission dominating the IR. Actually almost all the models of AGN continua predict a strict correlation between the UV-optical and X-ray luminosities; the correlation between X-ray and IR can be induced by the fact that dust is heated by UV-optical radiation. The studies on the variability of Fairall 9 (Clavel, Wamsteker, & Glass 1989) support the dust emission model. While the optical and the *J* fluxes varied in the same sense and almost in phase with the UV continuum, the *K* and *L* emissions show a delay of about 400 days.

Our data support a picture in which the nuclear emission of optically selected AGNs in the IR is the sum of two components. The first one is the fading part of the UV-optical emission. At $\lambda \geq 3$ μm it is overwhelmed by the emission of the *circumnuclear* dust, which is important up to $\lambda \simeq 60$ μm, where the galactic disk contributions start to dominate the total emission.

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REFERENCES

Adams, T. F. 1977, ApJS, 33, 19
Aitken, D., Roche, R. J., & Phillips, M. M. 1981, MNRAS, 196, 101P
Allen, D. A. 1976, ApJ, 207, 367
Balzano, V., & Weedman, W. D. 1981, ApJ, 243, 765
Band, D. L., & Malkan, M. A. 1989, ApJ, , 345, 122
Barvainis, R. 1987, ApJ, 320, 537
———. 1990, ApJ, 353, 419
Berriman, G. 1989, ApJ, 345, 713
Carico, D. P., Sanders, D. B., Soifer, B. T., Elias, J. H., Matthews, K., & Neugebauer, G. 1988, AJ, 95, 356
Carico, D. P., Sanders, D. B., Soifer, B. T., Matthews, K., & Neugebauer, G. 1990, AJ, 100, 70
Carleton, N. P., Elvis, M., Fabbiano, G., Willner, S. P., Lawrence, A., & Ward, M. 1987, ApJ, 318, 595
Cheng, F. Z., Danese, L., & De Zotti, G. 1983, MNRAS, 204, 13P
Cheng, F. Z., Danese, L., De Zotti, G., & Franceschini, A. 1985, MNRAS, 212, 857
Chini, R., Kreysa, E., & Biermann, P. L. 1989, A&A, 219, 87
Clavel, J., Wamsteker, W., & Glass, I. S. 1989, ApJ, 337, 236
Collin-Souffrin, S. 1991, A&A, 243, 344
Cutri, R. M., Rudy, R. J., Rieke, G. H., Tokunaga, A. T., & Willner, S. P. 1984, ApJ, 280, 521
Dahari, O., & De Robertis, M. M. 1988, ApJS, 67, 249
De Zotti, G., & Gaskell, C. M. 1985, A&A, 147, 1
Devereux, N. A. 1987, ApJ, 323, 91
———.1989, ApJ, 346, 91
Devereux, N. A., Becklin, E. E., & Scoville, N. 1987, ApJ, 312, 529
Edelson, R. A. 1986, ApJ, 309, L69
Edelson, R. A., Gear, W. K. P., Malkan, M. A., & Robson, E. I. 1988, Nature, 336, 749
Edelson, R. A., & Malkan, M. A. 1986, ApJ, 308, 59
———. 1987, ApJ, 323, 516
Edelson, R. A., Malkan, M. A., & Rieke, G. H. 1987, ApJ, 321, 233
Engargiola, G., Harper, D. A., Elvis, M., & Willner, S. P. 1988, ApJ, 332, L19
Franceschini, A., Toffolatti, L., Mazzei, P., Danese, L., & De Zotti, G. 1991, A&AS, 89, 285
Gehren, T., Fried, J., Wehinger, P. A., & Wyckoff, S. 1984, ApJ, 278, 11
Glass, I. S. 1973, MNRAS, 164, 155
———. 1979, MNRAS, 186, 29P
Glass, I. S., & Moorwood, A. F. M. 1985, MNRAS, 211, 461

Griersmith, D., Hyland, A. R., & Jones, T. J. 1982, AJ, 87, 1106
Heckman, T. M. 1987, in Starbursts and Galaxy Evolution, ed. T. X. Thuan, T. Montmerle, & T. T. Van (Paris: Editions Frontières), 381
Heckman, T. M., Blitz, L., Wilson, A. S., Armus L., & Miley, G. K. 1989, ApJ, 342, 735
Hutchings, J. B., Crampton, D., & Campbell, B. 1984, ApJ, 280, 41
Inoue, H. 1989, in X-ray Astronomy (Proc. 23rd ESLAB Symp.), ed. J. Hunt & B. Battrick (ESA SP-296) (Paris: ESA), 783
Isobe, T., Feigelson, E. D., & Nelson, P. I. 1986, ApJ, 306, 490
Joseph, R. D., Meikle, W. P. S., Robertson, N. A., & Wright, G. S. 1984, MNRAS, 209, 111
Koitilainen, J. K., Ward, M. J., Boisson, C., DePoy, D. L., Bryant, L. R., & Smith, M. G. 1992a, MNRAS, 256, 125
Koitilainen, J. K., Ward, M. J., Boisson, C., DePoy, D. L., & Smith, M. G. 1992b, MNRAS, 256, 143
Kriss, G. A. 1988, ApJ, 324, 809
Kruper, J. S., & Canizares, C. R. 1989, ApJ, 343, 66
Lawrence, A., Elvis M. 1982, ApJ, 256, 410
Lawrence, A., Ward, M., Elvis, M., Fabbiano, G., Willner, S. P., Carleton, N. P., & Longmore, A. 1985, ApJ, 291, 117
Lawrence, A., Rowan-Robinson, M., Efstathiou, A., Ward, M. J., Elvis, M., Smith, M. G., Duncan, W. D., & Robson, I. E. 1991, MNRAS, 248, 91
MacKenty, J. W. 1990, ApJS, 72, 231
Macklin, J. T. 1982, MNRAS, 199, 1119
Malkan, M. A. 1984a, ApJ, 287, 555
———. 1984b, in X-Ray and UV Emission from Active Galactic Nuclei, ed. W. Brinkmann & J. Trümper (Munich: MPI fur Extraterresriche Physik), 121
McAlary, C. W., McLaren, R. A., & Crabtree, D. R. 1979, ApJ, 234, 471
McAlary, C. W., McLaren, R. A., McGonegal, R. J., & Maza, J. 1983, ApJS, 52, 341
McAlary, C. W., & Rieke, G. H. 1988, ApJ, 333, 1
Meixner, M., Puchalsky, R., Blitz, L., Wright, M., & Heckman, T. 1990, ApJ, 354, 158
Miley, G. K., Neugebauer, G., & Soifer, B. T. 1985, ApJ, 293, L11
Miller, J. S., & Antonucci, R. R. J. 1985, ApJ, 297, 621
Mushotzky, R. F., & Wandel, A. 1989, ApJ, 339, 674
Neugebauer, G., Green, R. F., Matthews, K., Schmidt, M., Soifer, B. T., & Bennett, J. 1987, ApJS, 63, 615
Neugebauer, G., Matthews, K., Soifer, B. T., & Elias, J. H. 1985, ApJ, 298, 275
Neugebauer, G., Oke, J., Becklin, E., & Matthews, K. 1979, ApJ, 230, 79
Osterbrock, D. E. 1991, Rep. Progr. Phys., 54, 579
Piccinotti, G., Mushotzky, R. F., Boldt, E. A., Holt, S. S., Marshall, F. E., Serlemitsos, P. J., & Shafer, R. A. 1982, ApJ, 253, 485
Piro, L., Yamauchi, M., & Matsuoka, M. 1990, ApJ, 360, L35
Pounds, K. A., Nandra, K., Stewart, G. C., George, I. M., & Fabian, A. C. 1990, Nature, 344, 132
Rieke, G. H. 1978, ApJ, 226, 550
Roche, P. F., Aitken, D. K., Smith, C. G., & Ward, M. J. 1991, MNRAS, 248, 606
Rodriguez Espinosa, J. M., Rudy, R. J., & Jones, B. 1986, ApJ, 309, 76
———. 1987, ApJ, 312, 555
Rudy, R. J., Le Van, P. D., Puetter, R. C., Smith, H. E., Willner, S. P., & Tokunaga, A. T. 1982a, ApJ, 257, 570
Rudy, R. J., LeVan, P. D., & Rodriguez-Espinosa, J. M. 1982b, AJ, 87, 598
Sanders, D. B., Phinney, E. S., Neugebauer, G., Soifer, B. T., & Matthews, K. 1989, ApJ, 347, 29
Schmidt, M., & Green, R. F. 1983, ApJ, 269, 352
Schmitt, J. H. M. M. 1985, ApJ, 293, 178
Scoville, N. 1988, in Galactic and Extragalactic Star Formation, ed. R. E. Pudritz & M. Fich (Dordrecht: Kluwer), 541
———. 1990, in Submillimetre Astronomy, ed. G. D. Watt & A. S. Webster (Dordrecht: Kluwer), 197
Scoville, N. Z., Soifer, B. T., Neugebauer, G., Young, J. S., Matthews, K., & Yerka, J. 1985, ApJ, 289, 129
Sekiguchi, K. 1987, ApJ, 316, 145
Simkin, S. M., Su, H. J., & Schwarz, M. P. 1980, ApJ, 237, 404
Smith, E. P., Heckman, T. M., Bothun, G. D., Romanishin, W., & Balick, B. 1986, ApJ, 306, 64
Spinoglio, L., & Malkan, M. A. 1989, ApJ, 342, 83
Stein, W. A., & Weedman, D. W. 1976, ApJ, 205, 44
Taniguchi, Y., Kameya, O., Nakai, N., & Kawara, K. 1990, ApJ, 358, 132
Telesco, C. M., Campins, H., Joy, M., Dietz, K., & Decher, R. 1991, ApJ, 369, 135
Terlevich, R., & Melnick, J. 1987, in Starbursts and Galaxy Evolution, ed. T. X. Thaun, T. Montmerle, & T. T. Van (Paris: Editions Frontières), 393
Véron-Cetty, M. P., & Woltjer, L. 1990, A&A, 236, 69
Wampler, E. J. 1971, ApJ, 164, 1
Ward, M., Allen, D. A., Wilson, A. S., Smith, M. G., & Wright, A. E. 1982, MNRAS, 199, 953
Ward, M., Elvis, M., Fabbiano, G., Carleton, N. P., Willner, S. P., & Lawrence A. 1987, ApJ, 315, 74
Wilkes, B. J., & Elvis, M. 1987, ApJ, 323, 243
Worrall, D. M., Puschell, J. J., Bruhweiler, F. C., Miller, H. R., Aller, M. F., & Aller, H. D. 1984, PASP, 96, 699
Wilson, A. S., Helfer, T. T., Haniff, C. A., & Ward, M. J. 1991, ApJ, 381, 79
Xu, C., & De Zotti, G. 1989, A&A, 225, 12
Yee, H. K. C. 1983, ApJ, 272, 473
Zitelli, V., Granato, G. L., Mandolesi, N., Wade, R., & Danese, L. 1992, ApJS, in press (Paper I)