Astron. Astrophys. 206, 227–236 (1988)

ASTRONOMY AND ASTROPHYSICS

The link between IRAS spectra and near-infrared emission features in external galaxies

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Received April 13, 1987; accepted April 20, 1988

Summary. The relationship in external galaxies between the presence of the near-infrared (NIR) emission features attributed to polycyclic aromatic hydrocarbon (PAH) molecules, and the far-infrared (FIR) properties as observed by IRAS, is investigated. Using the sample of galaxies spectroscopically studied in the infrared by Aitken and Roche, we find that whenever the NIR features are absent in a galaxy, the FIR spectrum displays an enhancement at shorter wavelengths (12 and 25 μm) relative to normal galaxies. This enhancement is always associated with a strong activity in the galactic nucleus. Some Seyfert galaxies do not exhibit such an infrared signature and therefore, they are probably energetically dominated by star formation processes. Finally, the importance of hard UV photons and of the hot medium in the narrow line region of active nuclei is emphasized in relation to the survival of the PAH molecules. In this frame, the absence of PAHs in the galactic centre could be taken as evidence for the presence of an active nucleus.

Key words: galaxies: general, nuclei of, Seyfert – infrared radiation – X-rays: general

1. Introduction

We present in this article a discussion of the relations between the presence of dust related near-infrared (NIR) features in galaxies and their global infrared spectra. These emission features which appear at 3.3, 6.2, 7.7, 8.6, and 11.3 μm are always seen together in various kinds of galactic objects like reflection nebulae (e.g. NGC 2023, NGC 7023: Sellgren et al., 1985), planetary nebulae (e.g. NGC 7027, Gillett et al., 1973; Aitken and Roche, 1983), H II regions (e.g. the Orion nebulae, Sellgren, 1981). The association of these features with the Polycyclic Aromatic Hydrocarbon (PAH) molecules is tentatively adopted here (Léger and Puget, 1984; Puget et al., 1985; Allamandola et al., 1985; see a recent review by Léger and d'Hendecourt, 1986), although most of the results of Sect. 3 are independent of that assumption.

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These features have also been observed in external galaxies, the first examples being M82 and NGC 253 (Gillett et al., 1975). Aitken, Roche and their collaborators (hereafter called AR) have observed a set of 33 bright nuclei of galaxies (called the AR sample) in the infrared spectral window from 8 to 13 μm (ARa: Aitken et al., 1981; ARb: Aitken et al., 1982; AR1: Phillips et al., 1984; AR2: Roche et al., 1984; AR3: Roche et al., 1983; AR4: Aitken and Roche, 1985; AR5: Roche and Aitken, 1985a). From those spectra, the galaxies can be clearly divided into two general classes. The first class contains objects with detected NIR features at 8.6 and 11.3 μm (the 7.7 μm feature shoulder is also detected), which we call hereafter the *P galaxies* (P for PAHs). The second class contains objects with featureless spectra, called *NP*, and they always contain an active galactic nucleus, as deduced from optical studies.

We further investigate this dichotomy, first discovered by AR, in relation to the large database provided by the Infrared Astronomical Satellite (IRAS), the AR galaxies being generally detected at all four IRAS wavelength bands (12, 25, 60, 100 μm). In Sect. 2, we describe the AR sample of galaxies and a more complete sample of known P or NP type galaxies. We show in Sect. 3 how the dichotomy between P and NP galaxies translates into their IRAS properties and discuss in Sect. 4 some examples and cautions regarding the use of the analysis in Sect. 3. In Sect. 5, a two-component galaxy model is suggested which agrees with the previous results. In Sect. 6, we propose some possible physical explanations for the absence of the PAHs in active galactic nuclei (AGN). The galactic centre is analysed in the final Sect. 7.

2. The samples

The AR sample of galaxies contains mainly infrared-active galaxies, Seyferts and a few quasars. The references are summarized in Table 1. Their selection criterion was to observe the infrared brightest galaxies regardless of whether they were starburst or Seÿfert-like (AR2). Table 1 also lists the activity type of each galaxy and the radius R (typically a few hundreds parsecs) of the nuclear region covered by the AR NIR beam (assuming $H_0 = 75\ \mathrm{km\,s^{-1}\,Mpc^{-1}}$) which is relevant to the discussion in Sects. 5 and 6. The AR sample has the advantage of being a set of objects observed in a homogeneous way. In particular, the spectroscopy has been made with a beam centered on the optically brightest point of each galaxy (AR2).

Table 1. AR galaxy sample

No.	Name	Other name	IRAS Name	Type	v (km s^{-1})	F_1 (Jy)	F_2 (Jy)	F_3 (Jy)	F_4 (Jy)	AR	Radius (pc)	PAH type	F_1/F_4	F_2/F_4	F_3/F_4	log L_X (erg s^{-1})
1	N253	E474-G29	00450−2533	L	259	20.52	117.10	758.6	1045.	5	60	P	0.020	0.11	0.73	—
2	N262	MK348	00461+3141	S2	4399	0.34	0.79	1.43	1.75	2	840	NP	0.195	0. 44	0.81	41.23
3	U545	IZW1	00509+1225	S1	18450	0.54	1.26	2.13	2.43	2	2800	NP	0.223	0.52	0.88	43.86
4	N1068	ARP37	02401−0013	S2	1134	38.30	86.83	185.6	238.7	2	170	NP	0.161	0.36	0.78	41.51
5	N1275	3C84	03164+4119	BL	5361	1.03	3.63	7.10	7.76	a	820	NP	0.133	0.47	0.91	43.72
6	N1365	U2669	03317−3618	S1	1502	3.23	11.13	77.75	139.9	2	220	NP	0.023	0.08	0.56	40.89
7	I342	U2847	03419+6756	G	228	3.80	18.76	85.15	126.0	5	60	P	0.030	0.15	0.68	39.85
8	3C120	U3087	04305+0514	S1	9927	0.38	0.71	1.30	2.56	2	1500	NP	0.149	0.28	0.51	43.86
9	N1614	ARP186	04315−0840	G	4643	1.39	7.59	33.19	31.61	a	710	P	0.044	0.24	1.05	—
10	N1808	E305-G8	05059−3734	S	769	4.14	15.94	96.69	134.9	1	100	P	0.031	0.12	0.72	—
11	N2110		05497−0728	S2	2100	0.39	0.89	4.39	6.08	2	320	NP	0.064	0.15	0.72	42.68
12	U3374	M8-11-11	05511+4625	S1	6000	0.63	1.99	2.76	4.32	4	830	NP	0.147	0.46	0.64	43.51
13	HE2–10	E495-G21	08341−2614	G	750	1.10	6.55	23.78	35.68	1	140	P	0.043	0.26	0.93	—
14	N2992	ARP245	09432−1405	S1	1864	0.60	1.38	6.76	13.98	4	260	P	0.043	0.10	0.48	42.95
15	M5-23-16	E434-G40	not covered	S2	2400	—	—	—	—	4	330	NP	—	—	—	43.23
16	N4051	U7030	12005+4448	S1	762	0.78	1.42	8.16	20.35	4	100	NP	0.038	0.07	0.40	41.15
17	N4151		not covered	S1	1002	—	—	—	—	4	140	NP	—	—	—	42.60
18	3C273		12265+0219	S1	47400	0.54	0.93	2.18	2.80	2	7900	NP	0.194	0.33	0.78	45.76
19	N4736	M94	12485+4123	L	329	2.79	3.50	55.70	103.8	5	50	NP	0.027	0.03	0.54	—
20	MK231	U8058	12540+5708	S1	12600	1.82	8.56	33.26	30.0	3	1800	NP	0.061	0.29	1.11	—
21	N5195		13278+4731	G	658	0.87	1.57	9.87	—	5	90	P	—	—	—	39.32
22	N5236	M83	13341−2936	G	337	4.72	19.61	103.2	212.1	5	50	P	0.022	0.09	0.49	40.20
23	N5253	E445-G4	13370−3123	G	210	2.59	12.21	30.91	29.04	b	210	NP	0.089	0.42	1.06	—
24	I4329A	E445-G50	13464−3003	S1	4640	1.06	2.27	2.01	1.56	2	680	NP	0.684	1.46	1.29	43.41
25	N5506	MK1376	14106−0258	S2	1690	1.30	3.66	8.67	9.40	2	280	NP	0.139	0.39	0.92	42.51
26	3C345		16413+3954A	Q	178200	0.14	0.34	0.77	1.28	4	25000	NP	0.109	0.27	0.60	45.57
27	N6946		20338+5958	G	338	2.17	6.56	52.07	126.37	1	60	P	0.017	0.05	0.41	39.99
28	MK509		20414−1054	S1	10500	0.35	0.75	1.40	1.37	2	2000	NP	0.259	0.55	1.02	43.93
29	N7469	ARP298	23007+0836	S1	5102	1.30	5.50	26.67	34.40	a	780	P	0.038	0.16	0.78	43.41
30	N7552	E291-G12	23134−4251	G	1636	2.99	12.01	72.52	99.46	1	240	P	0.030	0.12	0.73	40.65
31	N7582	E291-G16	23156−4238	S2	1427	1.36	6.37	47.63	71.49	2	210	P	0.019	0.09	0.67	41.78
32	N7674	MK533	23254+0830	S2	9047	0.72	1.93	5.47	8.19	4	1300	NP	0.088	0.24	0.67	—
33	N7714	MK538	23336+0152	G	2980	0.5	2.81	11.07	10.92	1	570	P	0.046	0.26	1.01	—

Notes:

1) N = NGC, U = UGÇ, MK = Markarian, M = Messier or MCG, E = ESO.

2) The type of each galaxy comes from Véron-Cetty and Véron (1985): G = non active galactic nucleus or H II nucleus, L = liner, S = Seyfert, BL = BL Lac, Q = quasar.

3) F_1, F_2, F_3 and F_4 are the IRAS observed flux densities in Jansky respectively at 12, 25, 60 and 100 μm (without any color correction) as given in the Cataloged Galaxies and Quasars Observed in the IRAS Survey (1985) (MCG5-23-16 and NGC4151 have not been covered by IRAS).

* IRAS pointed observations (Bregman et al., 1986, quoted by Neugebauer et al., 1986).

4) The PAH type of each galaxy comes from the presence (P) or not (NP) of the 8.6 and 11.3 μm emission features, according to AR observations, referred to by: (a) Aitken et al. (1981), (b) Aitken et al. (1982), (1) Phillips et al. (1984), (2) Roche et al. (1984), (3) Roche et al. (1983), (4) Aitken and Roche (1985), (5) Roche and Aitken (1985). The only ambiguous case is N2992 which shows only weakly the 11.3 μm feature.

5) The radius refers to the projected beam (divided by 2) of the AR observations at the distance of the galaxy obtained with the RC2 catalog (de Vaucouleurs et al., 1976) or the Véron-Cetty and Véron (1986) catalog or Allen et al. (1976) for He2-10, with $H_0 = 75$ km/s/Mpc.

6) The X-ray luminosity L_X (between 0.5 and 4.5 keV: Lawrence and Elvis, 1982; Palumbo, private communication), when available, has been corrected for galactic absorption.

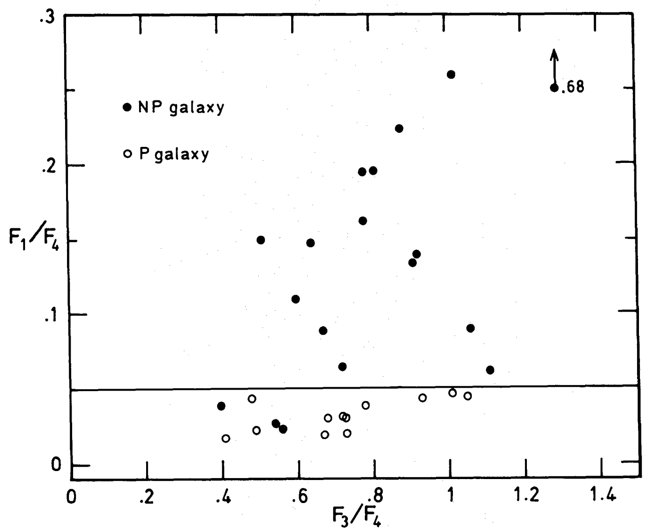

Fig. 1. Colour-colour diagram of the AR sample of galaxies. The 12 to 100 μm flux ratio is plotted against the 60 to 100 μm flux ratio for each individual galaxy. The full circles correspond to NP galaxies i.e. with a featureless continuum between 8 and 13 μm. The empty circles to P galaxies i.e. showing the emission features at 8.6 and 11.3 μm, characteristic of PAHs. The dashed line represents a constant ratio of 12 to 100 μm fluxes equal to 0.05. All the P galaxies are below this line (criterion 1)

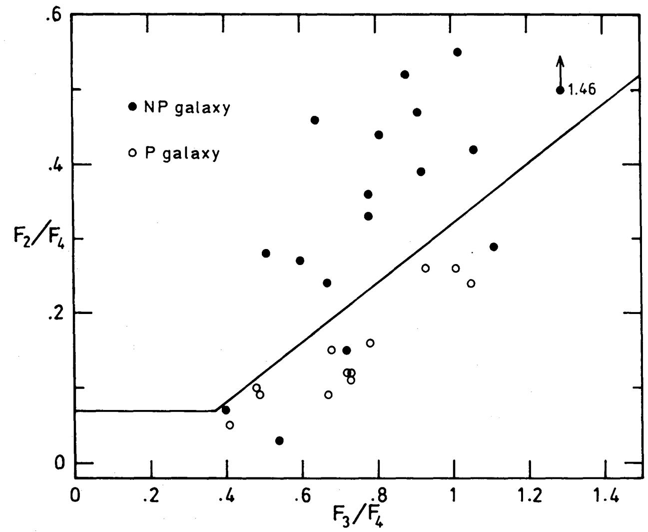

Fig. 2. Colour-colour diagram of the 25 to 100 μm flux ratio vs. 60 to 100 μm flux ratio. Same conventions as Fig. 1. The dashed line is the upper limit for the domain where all the P galaxies (criterion 2) lie

The IRAS data for these galaxies have been taken from the Cataloged Galaxies and Quasars Observed in the IRAS Survey (1985), a subset of the IRAS Point Source Catalog which includes known extragalactic objects. Almost all galaxies (29 out of 33) are detected in the four bands. In the few cases where more than one IRAS point-source is associated with a galaxy, the closest to the centre of the galaxy has been taken. Because the IRAS point-like character of the sources is generally good and their nucleus is quite bright relative to their disk component, the four IRAS flux densities F_1, F_2, F_3, F_4, at 12, 25, 60, 100 μm, respectively, can be considered as total fluxes. These are given in Table 1 together with the type P or NP defined by the presence or absence of the PAH features in each of them. Although the equivalent widths of the NIR features vary from one galaxy to another, the division into P or NP is quite easily made (except for the galaxy NGC 2992, AR4).

In order to test the conclusions drawn from the AR sample, we gathered from the literature an additional sample consisting of all the galaxies (distinct from the AR ones) which have been spectroscopically studied in the region around the 3.3 μm PAH feature. This feature is always associated, in galactic objects, with the NIR features observed by AR at 8.6 and 11.3 μm, so that we will assume the same is true for extragalactic objects. In particular, the Moorwood (1986) sample is included which adds thirteen more galaxies. Table 2 lists the basic information on this additional sample. This sample suffers more from heterogeneity than does the AR one. The spectroscopy at 3.3 μm sometimes yields contradictory results. Some of these discrepancies may be attributed to 1) Variations in the limiting equivalent width of the feature for the non-detections, 2) Use of different beam widths which can give insights into the distribution of dust emission in a galaxy (see Sect. 4), 3) Pointing differences between the various observations of each galaxy (exact positions of each observation would have been most useful), 4) Problems with atmospheric emission occurring at 3.3 μm which can lead to spurious detections (see the discussion in Moorwood and Salinari, 1981), or 5) Variability of the sources, but this is unlikely in view of the general extension of dust ($R \gg 1$ light-year). For example, different results are obtained in NGC 4151 (Cutri and Rudy, 1981; Lee et al., 1982; see AR4 also) and in IC 4329A (Moorwood and Salinari, 1981; Moorwood, 1986). For NGC 1365, NGC 5253 and NGC 5506, Moorwood and Salinari (1981) and/or Moorwood (1986) observe the 3.3 μm feature (with 2 to 3σ detections), but Aitken et al. (1982: ARb) and Roche et al. (1984: AR2) do not detect the 8.6 nor the 11.3 μm features. Some of these cases will be discussed later.

3. Data analysis

We have normalized the three upper frequency bands (F_1, F_2, F_3) to the 100 μm flux (F_4) (not colour corrected). Though this choice is not fundamental, it allows us to emphasize the different properties of the galaxies relative to their infrared colours, rather than their absolute luminosities. The infrared colours are defined as ratios of luminosities in the different broad wavelength bands, they are therefore proportional to the IRAS flux density ratios. In particular, previous studies (de Grijp et al., 1985; Miley et al., 1985) have shown that the spectra of strong Seyfert galaxies are generally flatter than those of starburst or normal galaxies which are dominated by dust emission. These studies used only the three longest wavelength IRAS bands. However, the F_1/F_4 ratio seems to be the most appropriate IRAS quantity to compare with the spectral information of the AR sample obtained near 12 μm. Also, this ratio uses the maximum range of frequencies available with IRAS so that it can better indicate any deviation from the power-law spectrum expected in strong nuclear sources (see for instance the discussion by Dennefeld and Véron-Cetty, 1986). A drawback of this method is obviously its limitation to galaxies detected in at least the two extreme IRAS bands.

Figures 1 and 2 show colour-colour diagrams of the AR galaxies, according to the presence (open circles) or absence (full circles) of the PAH features at 8.6 and 11.3 μm. We see that, in

Table 2. Additional galaxy sample

No.	Name	Other name	IRAS Name	Type	v ($km\,s^{-1}$)	F_1 (Jy)	F_2 (Jy)	F_3 (Jy)	F_4 (Jy)	AR	Radius (pc)	PAH	F_1/F_4	F_2/F_4	F_3/F_4	log L_X ($erg\,s^{-1}$)
1	N424	TOL0109-38	01091−3820	S2	3300	1.09	1.77	1.83	1.95	4	800	NP	0.559	0.91	0.94	—
2	N1386	E358-G35	03348−3609	S2	645	0.50	1.45	5.82	9.54	4	160	NP	0.052	0.15	0.61	—
3	N1672	E118-G43	04449−5920	S	1200	1.48	4.06	34.47	68.25	4	290	+NP	0.022	0.06	0.51	—
4	N1667		04461−0624	S2	4504	0.40	0.67	5.77	14.21	4	1100	+NP	0.028	0.05	0.41	—
5	N2903		09293+2143	G	467	0.86	2.33	27.93	102.64	1	130	P	0.008	0.02	0.27	—
6	N3034	M82	09517+6954	G	388	53.21	273.98	1167.8	1145.1	6	380	P	0.046	0.24	1.02	41.00
7	N3256		10257−4338	G	2595	3.23	15.50	94.21	120.30	4	630	P	0.027	0.13	0.78	—
8	N3281	E375-G55	10295−3435	S2	3300	0.88	2.58	6.66	7.40	4	800	+NP	0.119	0.35	0.90	42.72
9	N3783	E378-G14	11365−3727	S1	2700	0.80	2.45	3.33	4.93	4	650	NP	0.162	0.50	0.68	42.74
10	N4945	E219-G24	13025−4911	S	356	3.65	14.32	388.05	684.01	3,4	120	P	0.005	0.02	0.57	—
11	N5128	Cen A	13225−4245	G	508	11.20	15.07	171.12	335.73	7	200	NP	0.033	0.05	0.51	41.62
12	Circinus	E97-G13	14092−6506	G	176	18.86	68.44	248.64	313.61	3,4	60	P	0.060	0.22	0.79	—
13	N5757		14449−1852	G	2600	<0.48	0.99	6.07	12.72	4	840	P	0.038	0.08	0.48	—
14	IC4553	ARP220	15327+2340	S2	5541	0.48	8.15	103.68	116.25	5	1500	P	0.004	0.07	0.89	—
15	N6240	U10592	16504+0228	L	7116	0.57	3.52	23.21	25.88	5	1700	P	0.022	0.14	0.90	—
16	PKS2048-57		20481−5715	S2	3300	1.17	3.87	5.89	4.26	4	800	+NP	0.275	0.91	1.38	—
17	N7172		21591−3206	S2	2698	0.46	0.78	5.85	12.41	4	650	P	0.037	0.06	0.47	42.61
18	N7213	E288-G44	22061−4724	S1	1800	0.64	0.75	2.54	8.28	4	440	NP	0.077	0.09	0.31	42.08

Notes:
Same remarks as in Table 1 and
1) The 3.3 μm feature observations are referred to by the corresponding following numbers: (1) Lebofsky and Rieke (1979); (2) Lee et al. (1982); (3) Moorwood and Glass (1984); (4) Moorwood (1986); (5) Rieke et al. (1985); (6) Willner et al. (1977); (7) Grasdalen and Joyce (1976).
2) The PAH column refers to the presence (P) or not (NP) of the 3.3 μm PAH feature. NGC2903 is tentatively P because of a significative bump in the broad band observations of Lebofsky and Rieke (1979).
+ indicates that the observation does not rule out the presence of the 3.3 μm feature at the normal equivalent width.

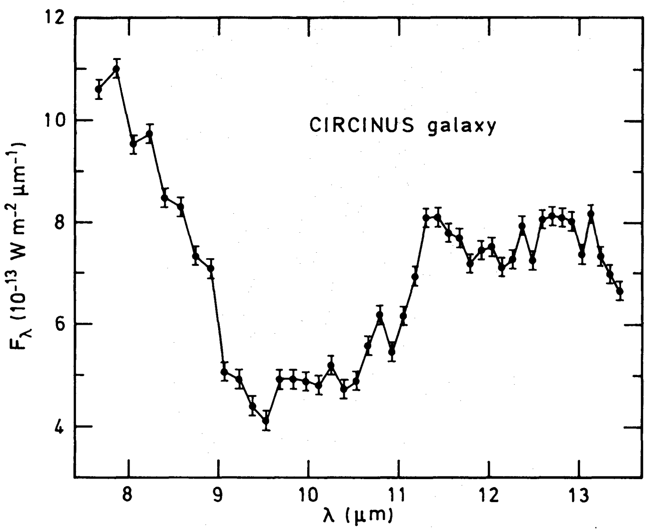

Fig. 3. The infrared spectrum of the Circinus galaxy between 8 and 13 μm, as measured by the Low Resolution Spectrometer of the IRAS mission (*IRAS Explanatory Supplement*, 1985, spectrum number 30982, short wavelength part), with a beam diameter of about 15 arcseconds. The peak at 11.3 μm is likely to be a PAH feature although the always associated (but weaker) 8.6 μm feature does not show up, probably due to a noisy baseline

both diagrams, there are striking qualitative differences between the two types of galaxies. In Fig. 1, the P galaxies show no correlation between the F_1/F_4 and the F_3/F_4 colours. *The P galaxies appear always to satisfy*:

$$F_1/F_4 \leq 0.05. \quad (1)$$

On the contrary, most (74%) of the NP galaxies emit relatively more energy at 12 μm than the upper limit (1) of the P galaxies.

The distinction is qualitatively the same in Fig. 2. However, one must take into account the positive correlation between F_2/F_4 and F_3/F_4, which holds for P galaxies. The P galaxies *always* satisfy the empirical inequality approximately given by:

$$F_2/F_4 \leq 0.4\ (F_3/F_4 - 0.38) + 0.07 \quad \text{for } F_3/F_4 \geq 0.38, \quad (2a)$$

and

$$F_2/F_4 \leq 0.07 \quad \text{for } F_3/F_4 \leq 0.38. \quad (2b)$$

The limit of 0.07 is chosen because expression (2a) yields negative results at low 60/100 μm flux ratios. It corresponds to the largest value of F_2/F_4 in cirrus clouds of the Galaxy (Boulanger and Pérault, 1987). As can be seen in Table 1, *the galaxies which do not satisfy* one and generally two of *the criteria* (1) *and* (2) *always contain an AGN* (as deduced from optical spectra) *and never show any PAH features*. The only exception to this rule is the NP galaxy NGC 5253 for which the optical data do not show evidence for an AGN. But ARb have shown from the study of the [S IV] NIR line in this object that a very obscured ($A_V > 8$) region is present in the centre. Our present analysis thus suggests strongly that an AGN is hidden inside NGC 5253.

The criterion (2) is slightly different from the one used by de Grijp et al. (1985), in the sense that criterion (2) eliminates more non-Seyfert galaxies than the latter one ($F_2/F_3 \leq 0.33$) does. In Fig. 2, we see clearly that most of the NP galaxies lie above this line.

From the analysis of the Cataloged Galaxies and Quasars Observed in the IRAS Survey (1985), 152 galaxies do not satisfy criterion (1), but only 42 of them (i.e. 28%) are contained in the Véron-Cetty and Véron (1985) catalog of Seyferts and quasars (see Sect. 5). The 110 others are therefore potential AGN candidates.

However, it should be stressed that criteria (1) and (2) being defined using a limited sample of galaxies, are still approximate and could be improved in the future. This may partly explain some peculiar cases discussed in the next section.

4. Some remarks, peculiar cases and cautions

Using the additional sample in Table 2, we verify, by comparing columns 13 and 14, that criterion (1) is satisfied by all the P galaxies (i.e. with the 3.3 μm feature present) except the CIRCINUS galaxy (A1409-65), which therefore deserves a comment. This galaxy definitely shows the PAH features near its nucleus (Moorwood and Glass, 1984) and globally (Fig. 3 shows its IRAS Low Resolution Spectrum, number 30982; see also IRAS Team, 1986). Nevertheless, the CIRCINUS galaxy has a ratio F_1/F_4 equal to 0.060. The uncertainty in this ratio, as given by the IRAS catalog, is about $0.008 = 1\sigma$ which leaves some margin for consistency with criterion (1); on the other hand criterion (2) is satisfied. An alternative explanation could be that the very nucleus of the CIRCINUS galaxy does not show the NIR features, but that they start to appear further out, as may be indicated by the small equivalent width of the 3.3 μm feature (see the detailed discussion of this galaxy by Moorwood and Glass, 1984).

In our samples, there are four NP galaxies (out of a total of 52 objects): NGC 1365, 4051, 4736, and 5128 which, unlike the majority of NP galaxies, do satisfy criterion (1). They perhaps represent some intermediate state between P and NP-type activities. Their nuclei are devoid of the NIR features, but their global infrared properties are typical of normal galaxies (criteria (1) and (2)). We note also that their far IR colour is rather cold (F_3/F_4 is less than 0.6). We shall briefly discuss these galaxies;

1) The galaxy NGC 1365, a weak Seyfert 1, may be a prototype of this category. The AR2 observations imply that within 220 pc of the centre of the galaxy, the PAH features are absent. However, the features are probably present outside this central region, as suggested by AR (unpublished observations quoted in AR4) and Moorwood (1986) with a 2σ detection of the 3.3 μm feature with a small equivalent width within a radius of 370 pc. Furthermore the nuclear flux at 12 μm, as deduced from AR2 observations, represents only 12 percent of the IRAS flux.

2) Similar remarks apply to the galaxy NGC 4736, classified as an ex-Seyfert (see the discussion by AR5). This galaxy shows no NIR features in its very nucleus (50 pc). However, we deduce from the AR5 ground-based observations that the nuclear region contributes less than ten percent to the IRAS 12 μm flux and is therefore not dominant in the global properties. We therefore suspect that, because the IR colours of NGC 4736 satisfy the criteria (1) and (2), the NIR features should be apparent in large beam observations.

3) As for NGC 4051, more observations with larger beams are needed. The nuclear flux represents half of the IRAS flux at 12 μm.

4) The nucleus of Centaurus A (NGC 5128: Kunkel and Bradt, 1971 and Wade et al., 1971) contains no PAHs out to

200 pc, but the colours of this galaxy, as a whole, are typical of a P galaxy. Indeed, Telesco (1978) has shown that the emission at 10 μm extends out to a few kiloparsecs. We therefore expect once again that the PAH features will be present outside of the nucleus. Recently, Marsten and Dickens (1987) have shown, from a spatial analysis of IRAS data, that there is a 12 to 100 μm ratio excess which is localized in the centre of Centaurus A, thus supporting our hypothesis. Joy et al. (1988) also find the galaxy dominated by star formation regions.

Two NP-type galaxies do not satisfy (1) but do satisfy (2): MKN 231 and NGC 2110. As explained in Sect. 1, criterion (1) seems more powerful than criterion (2) in selecting NP galaxies because it encompasses a wider wavelength range. Indeed, we have verified in the Cataloged Galaxies and Quasars Observed in the IRAS Survey (1985) that all but three galaxies, detected in the four wavelength bands and which do not satisfy (2), do not satisfy (1) either. On the contrary, 44 galaxies, like MKN 231 and NGC 2110, show evidence of an NP spectrum only at 12 μm, that is, they do not satisfy (1), but satisfy (2). Contamination by galactic field stars is more likely at 12 than at 25 μm, but should not be a major problem.

There is a correlation between the type of Seyfert galaxy and the presence or not of the NIR features. More Seyfert 2 are P galaxies than Seyfert 1 (see Moorwood, 1986), as expected because the contribution of the central power law source is more dominant in Seyfert 1's than in 2's. But counterexamples exist; for example, the typical Seyfert 2 NGC 1068 is NP and the Seyfert 1 NGC 7469 is P. However, the spatial study of the 3.3 μm in this galaxy by Cutri et al. (1984) reveals that the emission does not come from the very nucleus but rather from the region surrounding it. The strength of the Seyfert activity as measured by the X-ray luminosity (last column of Table 1 and 2) can be also related to the presence of the features. The weak Seyferts (whatever type 1 or 2) tend to be P galaxies. Figure 4 shows the relationship between the X-ray luminosity and the 12 μm luminosity. The NP galaxies are generally more luminous than the P galaxies, but some overlap between the two types is also present.

Finally, three cautions should be mentioned when using the criteria (1) and (2). The first caution is related to the galaxy's angular size. The point-source catalog cannot be used to compute the central colours of large (more than few arcminutes) galaxies, because the beam size increases with the wavelength. Because of this beam effect, galaxies which do not satisfy criteria (1) and/or (2) in the point-source catalog would not a fortiori satisfy them if we could use total fluxes.

The second caution applies to the 12 μm fluxes quoted in the first IRAS catalog. They were generally overestimated at the low flux end because only detected signals were averaged together to compute the final flux, while significant upper limits were omitted. However, a comparison of the first IRAS fluxes for galaxies in the additional sample with those in the second version of the IRAS point source catalog shows that the correction is less than a few percent.

The third remark concerns the extinction in the IR which can significantly affect some IR colours of galaxies (Joy and Harvey, 1987; Boissé and Désert, in preparation). An example of such an effect is given by the galaxy NGC 4418 (IRAS 12243-0036) studied in the NIR by Roche et al. (1986). The ratio F_1/F_4 has a value of 0.028 consistent with criterion (1). However, the NIR spectroscopy shows no PAH features, but a deep silicate-like absorption feature implying an optical depth of $\tau(9.7\ \mu\mathrm{m})=6.8$.

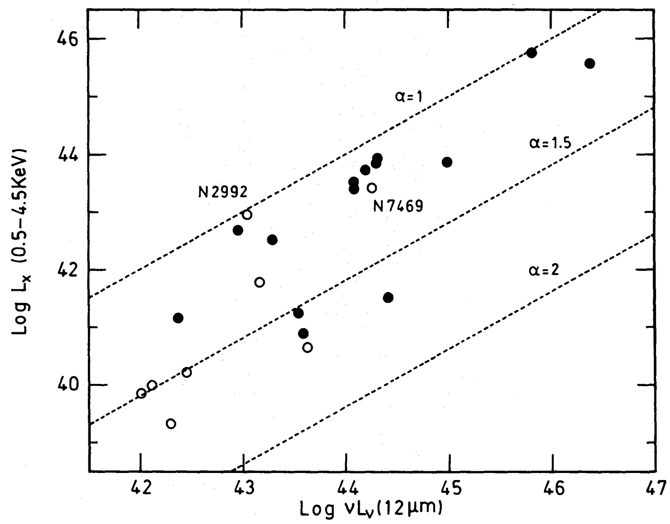

Fig. 4. The relation between the X-ray luminosity (0.5–4.5 keV) of a subset of AR galaxies (Palumbo, private communication, Lawrence and Elvis, 1982) and their 12 μm luminosity (not colour corrected). Same conventions as in Fig. 1. Examples of the index α of the power-law that would connect the near-infrared to the X-ray spectra ($L_\nu \propto \nu^{-\alpha}$) are shown in dashed lines. The P galaxies generally have lower X-ray *and* NIR luminosities than the NP galaxies. However, overlap between the two categories is present

Correcting for this extinction gives a ratio $F_1/F_4 \geq 0.8$ (using an effective depth of 3.4 in the 12 μm band), which is quite consistent with the conclusions of Sect. 3. Incidentally, the case of ARP 220 (Table 2) could be considered in the same way (see also the recent observations by Aitken and Roche, 1987).

5. The infrared energy sources in a galaxy

We have seen that for a limited sample of objects the distinction between P and NP galaxies (i.e. containing or not PAHs in their centre) is reflected in their overall infrared properties. We suggest that this distinction should hold generally. More precisely, the galaxies which do not satisfy the criteria (1) or/and (2) should always have nuclear activity which makes the NIR features disappear. In other words, a nuclear property (the absence of NIR features) is reflected in an overall property of a galaxy (the global ratio F_1/F_4). Thus, it appears that a large fraction of the infrared emission coming from a galaxy which does not satisfy (1) and (2) is highly concentrated in the nucleus. On the other hand, it has been shown that in typical P galaxies like M 82 (Jones and Rodriguez-Espinosa, 1984) and in NGC 253 (AR5, 1985 and references therein), the PAH features are instead emitted from an extended region (at least a kiloparsec). From the discussion of particular cases in Sects. 2 and 4, especially with regard to beam size effects, this seems to be true also when the PAHs are observed in a galaxy containing an AGN (Cutri et al., 1984).

Thus, we suggest the following scheme to explain the sources of infrared energy in a galaxy, being the simplest one consistent with the present data. The two primary sources of infrared energy in a galaxy are 1) star-forming regions (and also old stars) and 2) an active galactic nucleus.

1) The star-forming regions are extended, contain PAHs, and emit a steep infrared spectrum as measured by the ratio F_1/F_4,

Table 3. Known Seyfert galaxies (Véron-Cetty and Véron 1985) detected by IRAS at 12 and 100 μm. Only Seyferts with well-defined types (1 or 2) have been included

IRAS name	Other name	Type	F_1/F_4
00400+4059	M 31	S2	0.080
00461+3141	MK 348	S2	0.194
00509+1225	I ZW 1	S1	0.222
01091−3820	TOL 0109–38	S2	0.559
02252+3105	MK 1040	S1	0.140
02401−0013	NGC 1068	S2	0.160
02441−3029	NGC 1097	S2	0.022
02526−0023	NGC 1144	S2	0.029
02568+3637	MK 1066	S2	0.039
03059−2309	NGC 1229	S2	0.151
03117+4151	MK 1073	S2	0.041
03317−3618	NGC 1365	S1	0.023
03348−3609	NGC 1386	S2	0.052
04189−5503	NGC 1566	S1	0.014
04305+0514	3C 120	S1	0.148
04339−1028	MK 618	S1	0.095
04461−0624	NGC 1667	S2	0.028
05497−0728	NGC 2110	S2	0.064
05511+4625	MCG 8.11.11	S1	0.146
06097+7103	MK 3	S2	0.209
06456+6054	MK 620	S2	0.046
07388+4955	MK 79	S1	0.148
08014+0515	MK 1210	S2	0.389
09432−1405	NGC 2992	S1	0.043
09497−0122	MK 1239	S1	0.623
09514+6918	NGC 3031	S1	0.027
10207+2007	NGC 3227	S1	0.040
10295−3435	NGC 3281	S2	0.119
11033+7250	NGC 3516	S1	0.221
11365−3727	NGC 3783	S1	0.162
11538+5524	NGC 3982	S2	0.032
12005+4448	NGC 4051	S1	0.038
12159+3005	MK 766	S1	0.101
12232+1256	NGC 4388	S2	0.058
12265+0219	3C 273.0	S1	0.193
12329−3938	NGC 4507	S2	0.085
12370−0504	NGC 4593	S1	0.064
12381−3628	TOL1238–364	S2	0.061
12540+5708	MK 231	S1	0.061
13111+3651	NGC 5033	S1	0.018
13229−2934	NGC 5135	S2	0.023
13277+4727	NGC 5194	S2	0.011
13464−3003	IC 4329A	S1	0.684
13510+3344	NGC 5347	S2	0.131
13536+1836	MK 463	S2	0.335
14106−0258	NGC 5506	S2	0.138
14156+2522	NGC 5548	S1	0.229
14349+5900	MK 817	S1	0.183
14454−4343	ESO273–IG04	S2	0.102
15243+4150	NGC 5929	S2	0.030
16484−5908	NGC 6221	S2	0.018
17123−6245	NGC 6300	S2	0.019
18333−6528	ESO103–G35	S1	0.397
18401−6225	F 51	S1	0.171
19399−1026	NGC 6814	S1	0.021
20148−4457	NGC 6890	S2	0.054
20414−1054	MK 509	S1	0.255
20481−5715	PKS 2048–57	S2	0.275
21453−3511	IC 5135	S2	0.025
21591−3206	NGC 7172	S2	0.037
22061−4724	NGC 7213	S1	0.077
23007+0836	NGC 7469	S1	0.038
23069−4341	NGC 7496	S2	0.022
23128−5919	ESO148−IG02	S2	0.030
23156−4238	NGC 7582	S2	0.019
23161−4230	NGC 7590	S2	0.030
23254+0830	NGC 7674	S2	0.088

which is less than 0.05 (criterion 1). This ratio can be understood as measuring roughly the abundance of PAHs relative to large grains.

2) The AGN is concentrated, does not emit PAH features, and has a flatter emitted spectrum. The radiation mechanism is not yet understood. If it is reradiation by dust, this dust produces no 220 nm absorption dip (see e.g. the case of NGC 1068, Neugebauer et al., 1980), and no silicate-type features in emission at 9.7 μm, so that it is very different from the Milky Way dust, and we must understand the reason why the high frequency flux in the IR spectrum is larger than 0.05 times the low frequency one (criterion 1), i.e. the proportion of hot dust is always large compared with the cold dust. The hot dust can evidently not be associated with PAHs because these are absent (no NIR emission features in this case). More likely, the radiation seen could be the non-thermal power law itself, as seems to be the case for some quasars (Neugebauer et al., 1986). These two components have also been distinguished in optical studies of emission lines e.g. by Wilson (1986). Finally, we wish to stress the following points:

a) The infrared spectrum of a galaxy containing an AGN, as deduced from optical studies, is not necessarily dominated by this AGN component. Indeed, among the Seyfert galaxies (of type 1 and 2 respectively) in the Véron-Cetty and Véron (1985) catalog, listed in Table 3 and detected by IRAS at 12 and 100 μm, 27 (9 and 18 respectively) satisfy criterion (1), whereas 40 (20 and 20) do not.

b) It is not yet known how the radius r_P at which the PAH features start to appear outside an AGN varies from galaxy to galaxy. This radius is less than 210 pc in NGC 7582 and less than 320 pc in NGC 7469 (Cutri et al., 1984). On the other hand, it satisfies 220 pc $< r_P <$ 370 pc in NGC 1365, and $r_P >$ 50 pc in NGC 4736. The CIRCINUS galaxy is at odds with these values (if it really contains an AGN), because $r_P <$ 60 pc. We discuss in Sect. 6 a possible scenario to explain the absence of PAHs features around an AGN. Clearly, more PAH observations are needed, with special emphasis on mapping their spatial extent.

c) The new Seyfert galaxies discovered on the basis of their IR properties (e.g. de Grijp et al., 1985) or to be discovered, number about 110 among galaxies with 4 detected IRAS fluxes, according to Sect. 3. These do not constitute a new type of AGN. The spectral distribution of the far infrared flux is a criterion which complements optical studies in searching for new AGNs (e.g. Dennefeld and Véron-Cetty, 1986), and could especially help to reveal the obscured cases.

d) High-resolution mapping of the ratio of NIR to FIR luminosities in galaxies by future infrared satellites will certainly help us to understand the spatial distribution of the different infrared components.

6. The survival of PAH molecules in an active galactic nucleus

Although the conclusions of section 5 need to be confirmed by more data – some observations are under way – they also require specific theoretical explanations for the absence of the PAH features in the AGNs. We discuss in the context of the PAH hypothesis the consequences of the particularly harsh conditions that prevail within a few hundred parsecs of an idealized AGN, which typically corresponds to the narrow line emitting region (NLR).

6.1. Could the PAH features be hidden by a strong continuum?

Because the NLR emitting clouds have a small filling factor, we are mainly concerned with the power emitted by the intercloud medium (ICM) which is assumed to have a density of about $n_p = n_e = 10^2\ \mathrm{cm}^{-3}$ (we come back to the NLR clouds at the end of Sect. 6). The emission of PAHs (both the features and the continuum) is computed using the model of Puget et al. (1985) (see also Désert, 1986), assuming that they are illuminated only by the central source. The luminosity per hydrogen atom is given in terms of the distance r to the nuclear source of luminosity L_n (per logarithmic band, assuming a power-law spectrum $L_\nu \propto \nu^{-1}$) and the abundance A in mass of the PAHs:

$$L_{\mathrm{pah}}/N_{\mathrm{H}} = 7.8\ 10^{-26}\ (L_{\mathrm{n}}/10^9 L_\odot)\ (r/\mathrm{pc})^{-2}\ (A/3\ 10^{-4}) \times \mathrm{W/H\text{-}atom}. \quad (3)$$

An abundance in mass of $A = 3\ 10^{-4}$ is required for the general interstellar medium to explain the 12 μm brightness of cirrus clouds (Boulanger and Pérault, 1987). Assuming a spherical geometry, we can integrate Eq. (3) out to the equivalent radius r of the AR observations or the NLR to obtain the total luminosity of the PAH molecules (similar results are obtained by putting all the ICM mass at the same distance from the nucleus):

$$L_{\mathrm{pah}} = 7.5\ 10^8 (r/100\ \mathrm{pc})\ (n_{\mathrm{p}}/10^2\ \mathrm{cm}^{-3})\ (L_{\mathrm{n}}/10^9 L_\odot) \times (A/3\ 10^{-4})\ L_\odot. \quad (4)$$

Converting this luminosity into a flux density gives, after proper normalization:

$$\nu F_{\nu\mathrm{pah}} = 7.8\ 10^{-15}\ (\nu F_\nu(59\ \mathrm{nm})/10^{-14}\mathrm{Wm}^{-2})\ (r/100\ \mathrm{pc}) \times (n_{\mathrm{p}}/10^2\ \mathrm{cm}^{-3})\ (A/3\ 10^{-4})\ \mathrm{Wm}^{-2}, \quad (5)$$

where the UV nuclear flux has been normalized at 59 nm, which corresponds to the second ionization potential energy (21 eV) and is therefore a natural cutoff for the absorption of PAHs (see below). A density of 100 cm^{-3} is typical of the intercloud medium in the NLR (Krolik and Vrtilek, 1984). The mean NIR flux due to the reradiation of the nuclear continuum by the PAHs, if they were within 100 pc of the nucleus, should be detectable for the high UV flux galaxies, since a significant fraction of the nucleus light is absorbed by PAHs. For example, NGC 1068 which emits more than $2\ 10^{-13}\ \mathrm{Wm}^{-2}$ in the UV (Neugebauer et al., 1980) should produce about the same energy in the NIR features. The non-detection of these features at the level $5\ 10^{-14}\ \mathrm{Wm}^{-2}$ implies an underabundance of the PAHs by a factor 4 at least. Thus the strong featureless continuum emitted by an AGN in the NIR cannot hide the PAH features if the PAH abundance is typical of cirrus clouds. If the PAHs have been transported with the interstellar medium flow towards the nucleus, the absence of the features truly indicates the destruction of the PAHs in the central 100 pc of an AGN rather than a problem of signal-to-noise ratio in NIR observations.

6.2. How are the PAHs destroyed in the central 100 pc of an AGN?

The PAHs can be destroyed either by the hard photons (X-ray or UV) coming from the nucleus or by the hot intercloud medium (10^6K). We analyse first the former case, previously suggested by AR (see the thorough discussion in AR4) in the context of the PAH hypothesis. The UV region of the AGN continuum will be as important as the X-ray region for the following reason. An X-ray photon of energy larger than the second ionization potential (about 21 eV) of the PAH will simply hit and eject an electron from the PAH. The internal energy of the PAH cannot therefore rise by more than 21 eV when absorbing an X-ray photon. Because the UV photon flux is larger than the X-ray flux, it means that the UV component of the AGN is a more powerful destructive agent. This UV (power-law and bump) component is characteristic of the AGNs (e.g. Malkan and Sargent, 1982; Penston, 1983; Gondhalekar et al., 1986). The destruction rate of PAHs can be computed as a function of the number N_c of carbon atoms in the PAH molecule at a given distance r from an AGN of luminosity L_{UV} (Léger et al., 1988). Assuming that the metallic abundances are similar to those in the solar neighborhood (in order to evaluate the reconstruction timescale of PAHs), we obtain that the minimum number N_c a PAH must contain to survive is approximately given by:

$$N_1 = 70.8 + 8.0 \log_{10}(L_{\mathrm{UV}}/r^2), \quad (6)$$

where L_{UV} is in units of $10^8\ L_\odot$ and r is in pc. But closer to the AGN (at about 100 pc) the PAHs do not have enough time to cool down completely before the arrival of another photon. Therefore, including the multiphoton processes (Désert et al., 1986) this gives:

$$N_2 = 89.8 + 17.0 \log_{10}(L_{\mathrm{UV}}/r^2), \quad (7)$$

so that the true lower limit N_c for the surviving species is the maximum of N_1 and N_2 and is shown in Fig. 5. [These preliminary calculations include the cooling of PAHs by fluorescence in an approximate manner only, but the final results do not change by more than few units in N_1 and N_2.] Outside 100 pc, PAHs with more than 50 carbons (which is the mean size found in our Galaxy: Puget et al., 1985) can survive the flux of UV photons. The destruction of PAHs is efficient inside a sphere of 10 pc around the AGN (of $10^9\ L_\odot$) even for heavy species of 100 carbons. But the problem remains to account for the absence of PAHs within the few *hundred* parsecs of the nucleus. Ryter et al. (1987) have noticed that in the Galaxy the PAHs are destroyed when the energy density of the radiation field is larger than

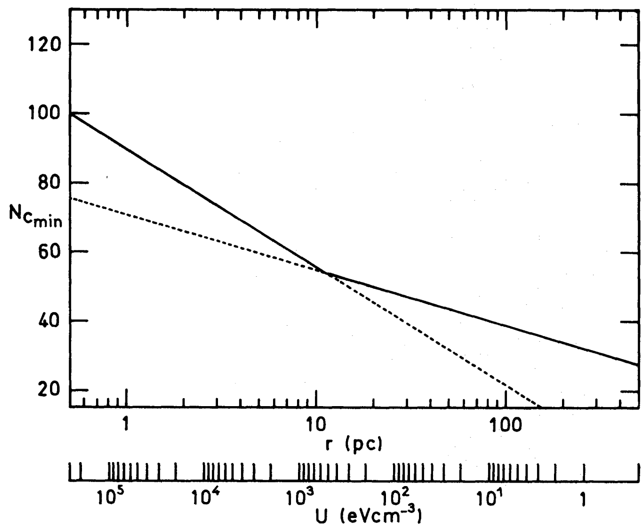

Fig. 5. The minimum number N_{Cmin} of carbons a PAH must contain in order to survive photothermodissociation (Léger et al., 1988) at a given distance r from an AGN (luminosity $L_{\mathrm{UV}}=10^8\,L_\odot$). At large distance the monophoton absorption process dominates the destruction of PAHs. Closer to the AGN, multiphoton processes become important, in which more than one photon are absorbed before the molecule cools down. At energy density U (lower horizontal scale) larger than $100\,\mathrm{eV\,cm^{-3}}$, the PAHs of sizes larger than 50 begin to be destroyed

$100\,\mathrm{eV\,cm^{-3}}$. If similar PAH destruction phenomena occur in H II regions and around AGNs, then PAHs are destroyed inside a radius of about 30 pc around the AGN (Fig. 5) for a luminosity of $10^8 L_\odot$, and much further out for more luminous AGNs.

If the PAHs are inside the hot intercloud medium, they can be destroyed by the sputtering by electrons and ions. Adopting the geometrical cross-section of PAHs for the capture of particles of mass m_i yields a rate of interaction of:

$$R_i = 2.1\ 10^{-5}\ (N_c/50)\ (n_i/10^2\,\mathrm{cm}^{-3})\ (T/10^6\mathrm{K})^{1/2}\ (m_i/m_p)\ \mathrm{s}^{-1}, \quad (8)$$

where m_p is the proton mass and n_i is the density of particles. Because the collisions are so energetic ($kT \sim 90$ eV), they result in the loss of an atom by the PAH molecule. Thus, PAHs cannot survive more than a month in the intercloud medium due to the erosion by the fast particles — the reconstruction time is typically a thousand years.

Nevertheless, the possibility remains that the PAHs can survive in the denser clouds of the NLR where the temperature is lower ($2\,10^4$K, Krolik and Vrtilek, 1984) but shielding from the central heating source may prevent their detection.

7. Conclusion and consequences for the galactic centre

The IRAS data provide valuable insights into the energetic processes in galaxies, especially in their centres, where we can, partially at least, disentangle star-forming and non-thermal activities. In the available sample of 52 galaxies, the absence of the NIR PAH feature is always linked to a non-thermal nuclear activity. All the galaxies which show an excess emission at short wavelengths (12 and 25 μm) from the criteria (1) and/or (2) contain an AGN, with strong nuclear activity dominating the IR spectrum, and hence the whole energy output of the galaxy. Possible explanations for the absence of PAHs in the centre of these galaxies involve some processing by the hard UV photons emitted by the nucleus or by the fast particles in the intercloud medium of the NLR.

We may thus argue that in our galactic centre the absence of PAHs (Willner and Pipher, 1982; Roche and Aitken, 1985b) is a strong indication (amongst others) for an active nucleus. The four pixels ($2' \times 2'$ per pixel) in the IRAS Sky flux plate (HCON 1 and 2, IRAS Explanatory Supplement, 1985) corresponding to the very centre of our galaxy have average brightnesses of 6.5 10^8, 3.8 10^9, 1.25 10^{10}, and 1.63 10^{10} $\mathrm{Jy\,sr^{-1}}$, at 12, 25, 60 and 100 μm, respectively, after a linear background has been removed. Normalizing by the 100 μm flux, the following three colours are obtained:

$$F_1/F_4 = 0.04,\ F_2/F_4 = 0.23 \text{ and } F_3/F_4 = 0.77.$$

By taking into account the extinction along the line of sight one sees that these colours (corrected by at least a factor of 2 of optical depth at 12 and 25 μm) do not satisfy the criteria (1) and (2). This is consistent with our previous analysis and with the existence of a small AGN ($L_{\mathrm{IR}} \simeq 2$–4 $10^6\,L_\odot$ at 8 kpc) at the galactic centre.

Acknowledgements. We wish to thank Drs. S. Collin, E. Dwek, M.G. Hauser, J.L. Masnou, J.L. Puget, J. Vrtilek for valuable discussions and an anonymous referee for several helpful comments on the manuscript. This work was done while one of us (F.X.D.) held a National Research Council Research Associateship at the Infrared Astrophysics Branch of NASA Goddard Space Flight Center.

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