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Warm IRAS sources from the point source catalog. IV. Extended optical line emission

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Abstract. — We present a list of objects** observed to have extended line emission in our spectroscopic survey of infrared-warm AGN. Slit spectroscopic data were obtained for 225 galaxies identified with objects in our compendium of warm sources from the IRAS Point Source Catalog. Of these, 44 have spatially–resolved emission–line regions along the (arbitrarily placed) slit direction. Measured (projected) linear sizes of the ionized gas regions extend to >10 kpc. In the case of the IRAS Seyfert galaxies the spatially extended line emission appears to have a lower ionization state than the nuclear emission. This contrasts with the warm IRAS starburst galaxies for which there is no significant difference between the ionization states of the nuclear and extended emission. For the starburst galaxies, there is a relation between the extent of star formation as seen at Hα and the far-IR colors, with more compact bursts having "warmer" colors.

Key words: galaxies: active — galaxies: Seyfert — infrared: galaxies — galaxies: ISM

1. Introduction

This is one of several papers describing an investigation of the properties of warm IRAS sources. First, we showed that IRAS galaxies which have a relatively warm IRAS spectrum have a large chance of exhibiting Seyfert activity (de Grijp et al. 1985). Then, in order to use this technique to find new Seyferts, we compiled a catalogue of all high-latitude sources in the IRAS Point Source Catalog (PSC) having warm AGN-like mid-IR colours: $-1.5 < \alpha_{25\mu,60\mu} < 0$ (de Grijp et al. 1987, hereafter Paper I). We next carried out spectroscopy of 358 extragalactic objects from the total of 563 sources listed in Paper I and presented the results in de Grijp et al. (1991) (hereafter Paper II), including classification of our objects according to their spectroscopic type. In the spectroscopically-observed sample, 80 sources had Seyfert 1 spectra, 141 had Seyfert 2 spectra and 133 had H II- type spectra. We also used the redshift and spectroscopic data to discuss the completeness and IR luminosity function for each type of object. More than 40 of our objects have luminosities in the 60μ band greater than $10^{11} L_\odot$. Correlations between the (spatially-integrated) emission line properties and the infrared properties were considered in Keel et al. (1993) (hereafter Paper III).

Of the 358 objects in the spectroscopic survey, 225 were observed with slit spectroscopy, as well as 34 galaxies that were not in the catalogue of Paper I, and that do not meet the IRAS colour criterion. This gives a total number of 259 sources observed with slit spectroscopy. Although in general only one position angle was available (usually PA≈90°), these data contain useful information about spatial extensions in the line emission. Here (Paper IV) we present a list of the survey objects for which such line extensions were seen and consider possible differences in the line emission properties between the nuclear and extranuclear emission.

2. The survey

For details of the sample definition, spectroscopic observations and reductions readers are referred to Papers II and III. We shall be concerned here only with additional information relevant to the two-dimensional slit spectra. To estimate the sky level for subtraction, the levels on the two sides of the object were interpolated. The relative spectrophotometric accuracy is about 10%.

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** Tables 1 and 2 are available in electronic form via an anonymous ftp copy at the CDS (ftp 130.79.128.5)

To determine whether an object is spatially resolved, the point source response was measured regularly each night using a star. The spectra were then inspected using the IVAS two-dimensional imaging monitor at Leiden. The emission-line profiles through the slit were compared to the point source response and categorized into the following 3 classes (over a total number of 259 sources, of which 225 in the catalogue): Unresolved (169, resp. 141), Possibly Resolved (45, resp. 40) and Definetely Resolved (extended) line-emission (45, resp. 44). Generally, the class of possibly extended objects is populated with objects for which the data are noisy and difficult to interpret.

We re-evaluated the spectroscopic classifications of the galaxies with clearly resolved line emission, since extranuclear line emission might lead to a misclassification from slit-integrated spectra. The following changes may be noted with regard to the classifications given in Paper II:

1) Number 70 (IRAS 0302-729) has a Seyfert nucleus (rather than LINER)
2) Number 99 (IRAS 0338-712) has redshift 0.0483 (instead of 0.0475)
3) Number 342 (IRAS 1411+078) has a starburst, rather than LINER, nucleus
4) Number 430 (IRAS 1657+290) has a Seyfert 2 (instead of starburst) nucleus

3. Results on spatial extension[2]

In Table 1 the unresolved objects are tabulated. The columns are:

1) Running number as introduced in the catalogue of Paper I. If the number is absent, the source does not appear in the catalogue.
2) IRAS name
3) Slit position angle (degrees)

Table 2 lists the objects that were found to be extended or possibly extended. From left to right the columns are:

1) Running number, see Table 1
2) IRAS Name
3) Alternative Name
4) Redshift
5) AGN spectral type
6) Observing night number, see Paper II
7) Slit position angle (degrees)
8) Angular size of line-emission (arcsec)
9) Linear projected size (kpc), $H_0 = 75$ km s^{-1} Mpc^{-1}
10) Notes, as follows:

1. Possibly extended. Stated size is uncertain.

2. **IRAS 0032-617SW**. This galaxy has a long tidal arm. The line profile along the slit has two peaks of emission, but the continuum profile has a single maximum. The line-emitting regions are $\sim 4''$ apart and H II-type.

3. **IRAS 0033-819**. A ring-shaped galaxy with two brightness enhancements, $11''$ apart, both strong line emitters.

4. **IRAS 0141+020 (Markarian 573)**. The Seyfert-like emission extends out to $3.4''$ on either side of the nucleus, including relatively strong [O I]. This emission has been examined by Afanasiev & Sil'chenko (1991) and by Tsvetanov & Walsh (1992) from kinematic and ionization standpoints.

5. **IRAS 0146-615**. This galaxy has a long tidal arm. Along the slit, two peaks of emission are seen, both in line and continuum. The peaks are $8''$ apart and both are H II-type.

6. **IRAS 0225-103 (Markarian 1039)**. This galaxy hosts two H II-type nuclei, $24''$ apart.

7. **IRAS 0229-368 (IC 1816)**. The Seyfert-like spectrum extends as far as $3.4''$ east of the nucleus, including relatively strong [O I]. The nuclear [O III] lines are spectrally resolved, FWHM $\approx$ 900 km/s, whereas the extended line-emission is narrower, FWHM $<$ 500 km/s.

8. **IRAS 0240-002 (NGC 1068)**. The nuclear emission lines have a width of FWHM $\sim$ 1200 km/s, whereas the extranulcear emission is unresolved spectrally, FWHM $<$ 200 km/s.

9. **IRAS 0302-729**. The nuclear emission lines are spectrally resolved, with FWHM $\approx$ 1300 km/s, the extended emission lines are unresolved, FWHM $<$ 500 km/s.

10. **IRAS 0310-515**. This galaxy has a long tidal arm. The brightness profile along the slit shows two peaks of emission, $7.4''$ apart. Both have Seyfert spectra.

11. **IRAS 1703+606**. An interacting pair, with a Seyfert and a starburst galaxy $6.5''$ apart, at almost the same redshift.

12. **IRAS 1855+716**. An interacting pair, two starburst galaxies $6.7''$ apart, almost same redshift. The line-emission (especially [O II]λ3727) forms a bridge between them.

13. **IRAS 1908-539**. This galaxy has a highly irregular morphology. The emission line- and continuum-profiles along the slit show double structure, two peaks separated by $20''$. One has a Seyfert spectrum and the other is H II-type.

14. **IRAS 2048-572 (PKS 2048-57)**. This object has a Seyfert-like spectrum extending by at least $4''$ on either side of the nucleus, including relatively strong [O I]. There is a large velocity gradient, the emission lines $3''$ east and west of the nucleus being shifted by 230 km/s red- and bluewards respectively, relative to the nucleus.

15. **IRAS 2117-492**. An interacting pair of starburst galaxies $41''$ apart, at almost the same redshift. The line emission in the eastern galaxy is extended by at least $24''$.

[2] Tables 1 and 2 are available in electronic form via an anonymous ftp copy at the CDS.

4. Discussion and conclusion

4.1. *The line ratios*

Line ratios are a powerful tool in studying the ionization mechanism (Baldwin et al. 1981). The ratios of [O III]λ5007/Hβ, [N II]λ6583/Hα, [S II]$\lambda\lambda$6716,6731/Hα and [O I]λ6300/Hα are among the most effective diagnostics (Veilleux & Osterbrock 1987). We determined the line ratios in the nuclei and in the outer regions, but [O I] was generally too weak in the outer regions to be detected. The difference of the logarithms of the line ratios in the outer regions and the logarithms of the ratios in the nuclei is plotted in Figs. 1 and 2. A single galaxy can be represented by several points. The Seyfert 1 galaxies are omitted because it is not meaningful to compare the fluxes in the broad and narrow lines.

Figure 1 shows that the degree of ionization [O III]/Hβ is strikingly lower in the extended regions than in the nuclei of Seyfert 2 galaxies. There is also marginal evidence from Figs. 1 and 2 that the [N II]/Hα ratio in the extended regions is lower than the nuclear value, in both Seyfert 2 and H II-type galaxies, but this needs to be confirmed on a larger sample.

The data on starburst (H II-type nucleus) galaxies are consistent with photoionization by locally embedded hot stars, both in the nucleus and in the extended regions, although the variety in ionization in a single galaxy (scatter around the origin in Fig. 2) is large.

The Seyfert data are consistent with at least two different ionization mechanisms in the outer regions. One is photoionization by local hot stars, the other is photoionization by the distant nucleus. The lower ionization outside the nucleus is explained by the softer ionizing source in the first case, and by a decrease of the ionization parameter with distance from the nucleus in the other (Veilleux et al. 1987). Yet there are three Seyfert 2 galaxies with extended line ratios typical of a Seyfert 2 spectrum, including even relatively strong [O I]. These galaxies are numbered 33, 52 and 512 (see Table 2). These objects suggest either a rapid decrease in density with distance from the core (steeper than $n_e \propto r^{-2}$) or anisotropic ionizing radiation, as often discussed for the very extended NLRs in some Seyfert and radio galaxies.

4.2. *The line widths*

Most of the spatially–extended sources were found during the observing sessions for which the spectral resolution was lowest: FWHM=12 Å. This corresponds to 500 km/sec at Hα, or to higher velocities at shorter wavelengths. This is a typical value of the Seyfert 2 line width, so we do not expect many to be resolved. Still, we find three Seyfert 2 galaxies where the nuclear emission lines are broader (resolved) than the extended emission lines (unresolved). They are numbered 52, 57 and 70 (see Table 2).

4.3. *The IRAS colours and starbursts*

An interesting question is whether there is a difference in dust properties between compact nuclear starbursts and those for which a substantial amount of the star formation occurs within the galaxy disks. One method of investigating this question is to compare the $60\mu/100\mu$ flux ratios (measure of the dust temperature), for the IRAS galaxies having extended line emission with those that do not. The median 60/100 flux ratio for the 43 compact starbust galaxies is 0.78 ± 0.05, whereas for the 11 starburst galaxies with sizes > 10 kpc, the median ratio is 0.59 ± 0.07. These differ at more than the 95% significance level, implying that the dust in the compact starbursts is systematically warmer. This might be expected, since the energy density in a starburst of given luminosity is a strong function of its volume.

4.4. *Conclusions*

In $\sim$ 20% of the galaxies hosting Seyfert and H II-type (starburst) nuclei, spatially extended line-emission was detected. Since we have spatial information in one direction only, it is likely that a majority of the galaxies have extended line-emission at the levels observed. The projected linear sizes measured extend to >10 kpc. For the Seyfert 2 galaxies the ionization is higher in the nucleus than in the extended emission.

Additional observations of objects in our sample are desirable. In contrast to most other samples of active galaxies, infrared samples are selected on the basis of a property that is nominally unbiassed within the context of orientation-based unification scenarios. The present work was restricted by the one dimensional nature of the initial slit spectra. The tables provide finding lists for the important narrow-band and broad-band followup that will be needed to investigate further the effects pointed out here.

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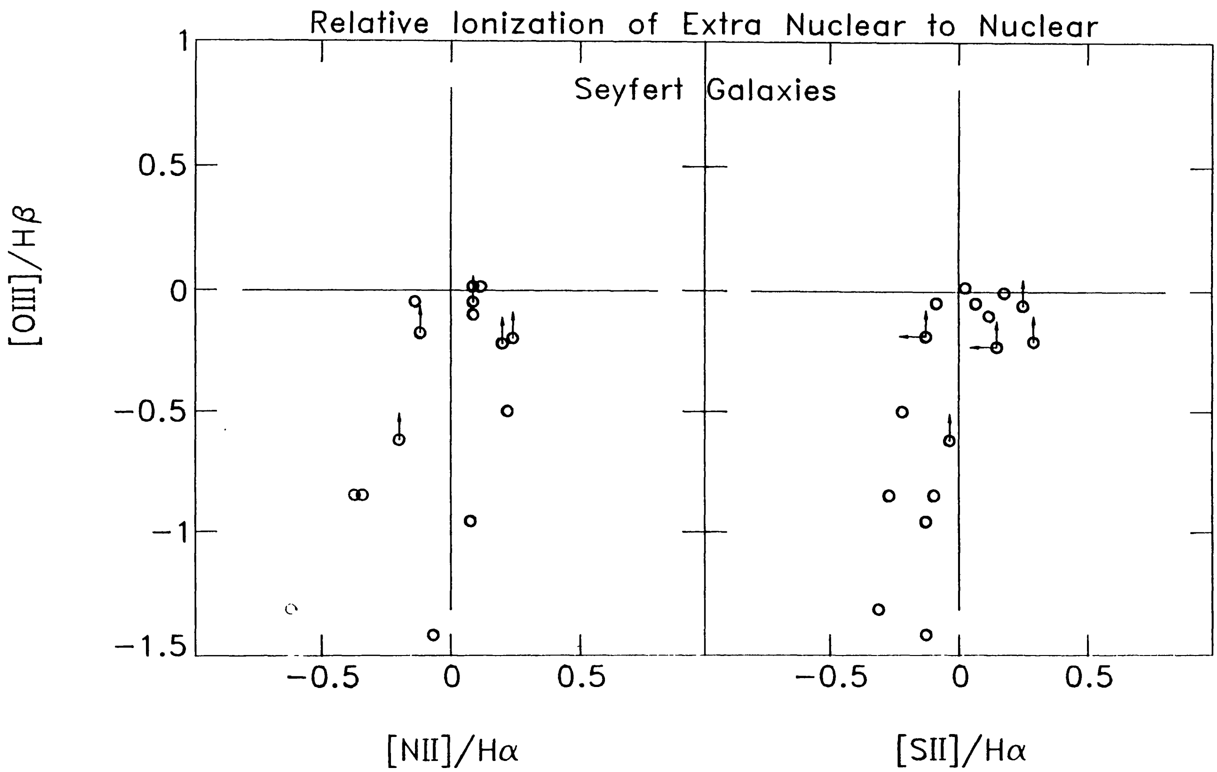

Fig. 1. The difference of the logarithms of the line ratios in the extended regions and the logarithms of the ratios in the nuclei for Seyfert 2 galaxies. Objects for which the ionization state of the extended emission is lower than that of the nuclear emission fall in the bottom ([O III]/Hβ) left ([N II]/Hα) corner of the diagram

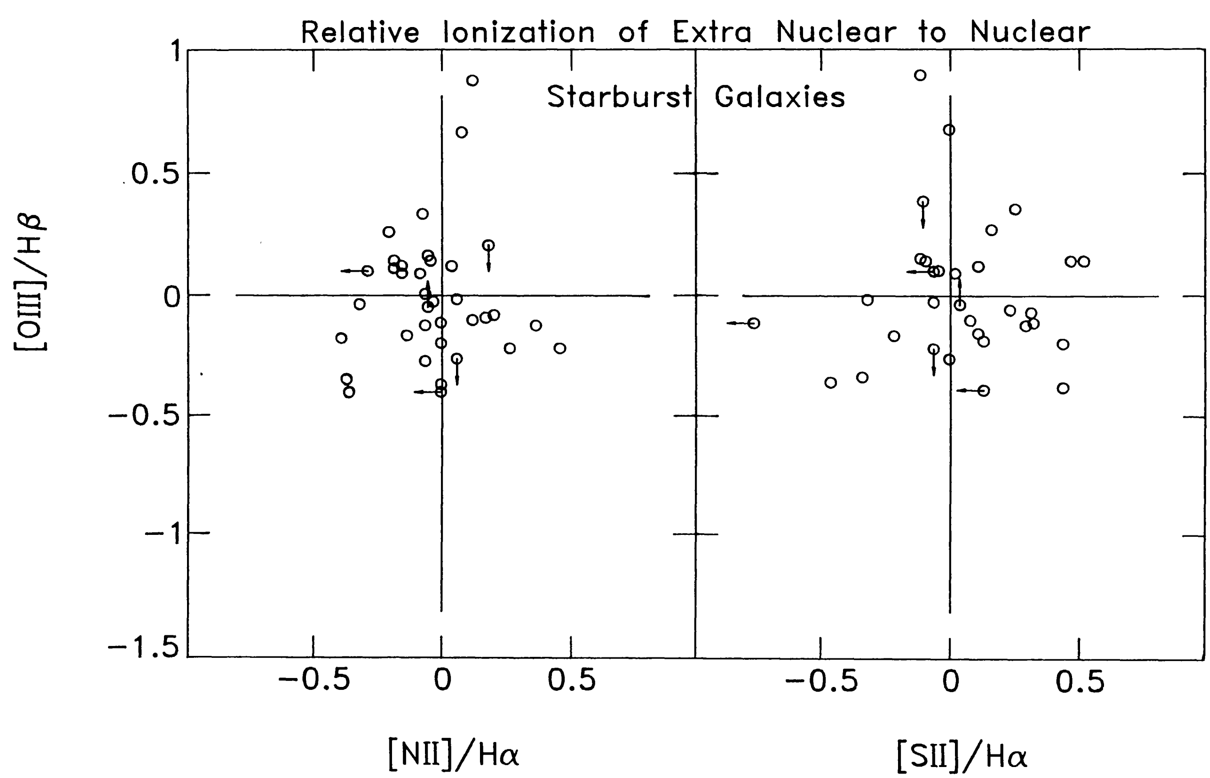

Fig. 2. Plot of similar quantities as in Fig. 1, for starburst galaxies

Table 1. Galaxies with unresolved line-emission

Num	IRAS name	Slit PA (degrees)	Num	IRAS name	Slit PA (degrees)	Num	IRAS name	Slit PA (degrees)	Num	IRAS name	Slit PA (degrees)
2	0002-084A	212	141	0438-086	291	390	1557+351	90	510	2045+002E	95
3	0006+215	90	184	0531-124	291	391	1559+832	0	511	2045-529	90
9	0032-003	6	196	0609+710	352	402	1612-078	90	517	2116-206	89
14	0038+235W	102	201	0625+637	291	403	1615+141	194	521	2129+099	89
	0042+325	90	203	0628+637	70		1633+310	90	524	2136-270	90
16	0046+316	90	208	0641+636W	70	417	1636+856	90		2142+153	90
18	0050+124	6,90	215	0710+457	337		1638+465MID	111	528	2201+033	90
19	0052-709	90	216	0712+879NW	337		1641+398	90		2204+256	88
20	0059-199MID	79	218	0731+621	337	426	1645+391NW	129	529	2205-519W	96
22	0105+331	283	270	1040+706	90	429	1649+220N	190	530	2206-474	90
23	0107-038	90	271	1045+503	90	432	1700+518	90	531	2211-393	90
	0109-019	90	278	1103+728	90	433	1702+457S	180	536	2230-649	90
	0111+130	90	283	1129+532(1)	72	434	1704+673	0		2235-128E	79
25	0111+849	102,90	285	1133+572	90		1712+393	194	539	2239+200SW	40
26	0113+328	283	306	1246+421	90	442	1721+365SW	60	540	2240+294	240
27	0124+189	90	315	1314+451E	81	445	1729+596	180	541	2240-186W	97
28	0134-094W	268	320	1324+268W	90	449	1734+493W	110	542	2241-608	90
31	0137-225	90		1331+424	90	450	1737+562S	90,190	543	2245-669	90
34	0142-420	90	327	1344+351	90	453	1743+579S	168	548	2302+120	291
35	0145+413S	15	329	1351+337	90	456	1750+507	190	550	2306+050	90
39	0157+001	90	331	1351+640	140		1754+437	90	551	2309-733	90
40	0202-605	91	332	1351+695	90	460	1759+423	194		2314-443NW	145
41	0204-554	91		1353+790	90	462	1801+414NE	64,247		2316+056	90
42	0207-104	268	334	1357+562	90		1807+591	90		2317+329	90
47	0225+310	268	336	1402+436	168	464	1807+698	0		2320+244W	90
53	0230+002	20	338	1404+286W	90	467	1821+643	0		2331+297	90
55	0236-310	88	340	1408+137	157	468	1825+717	0	556	2339-044	212
56	0238-084	90	347	1426+573		470	1829+412N	186		2340+272	90
63	0253+021	79	350	1434+590	90		1832+472	110	557	2344+153	64
68	0301-012	261	351	1435+386	125		1835+490E	90	559	2353+299	90
75	0310-029	20		1437+537SW	45	474	1840+773E	260	560	2354+192	212
78	0312+013	79		1437+537NE	45	476	1850-782	90	561	2357+397W	72
80	0320-518	93		1440+356	90	478	1900-672	90	562	2358+182	90
83	0322-032	79	356	1447+425	90	480	1908-609gal	90	563	2358-012	6
84	0323-580	90	357	1454+491	241	481	1910+846	194			
90	0327-434W	69	361	1506+283	90	482	1911-498	90			
92	0330-623	91	366	1517+522NW	90	484	1916-587	90			
95	0334-210	90		1518+657NE		489	1925-727	1			
96	0335+010S	30	373	1529+242S	194	490	1926-425E	88			
98	0336-167	291	375	1530+302	90	491	1926-436E	60			
105	0351-174S	352	377	1536+736	90	495	1958-183	274			
	0351-174N	352		1537+251NE	233	496	2002-204NW2	91			
108	0357-615	88	379	1541+286	233	498	2008-291N	353			
118	0420-014	291	380	1543+272	233	506	2032-503E	68			
129	0428-097B	79	381	1544+060	117	508	2038-383	89			

Table 2. Galaxies with extended and possibly extended line-emission

Num	IRAS name	Alternative name	z	AGN type	Obser night	Slit PA (degrees)	Size (")	Size (kpc)	Notes
4	0016-073		0.0178	Seyf2	21	291	11.3	3.9	
5	0019-625		0.0321	HII	18	90	10.3	6.3	
7	0026-102E		0.0496	HII	20	283	9.7	9.1	1
10	0032-617SW		0.0286	HII	18	56	9.1	5.0	2
11	0033-819		0.1271	Seyf2	18	92	18.2	42	3
21	0102-643	79- G 16	0.0198	HII	19	91	11.4	4.3	1
33	0141+020	Mrk 573	0.0172	Seyf2	18	90	22.8	7.5	4
36	0146-615	114-IG 9	0.0421	HIIx2	19	111	17.1	14	5
37	0147-076		0.0177	Seyf2	18	90	8.0	2.7	1
44	0210-505	197- G 29	0.0212	HII	19	91	8.0	3.2	1
	0219+025		0.0274	HII	23		14.6	7.6	1
46	0225-103	Mrk 1039	0.0068	HIIx2	20	261	32.4	4.3	6
52	0229-368	IC 1816	0.0168	Seyf2	19	90	27.4	8.8	7
54	0232-090	NGC 985	0.0431	Seyf1	18	90	31.9	26	
57	0240-002	NGC 1068	0.0026	Seyf2	23	79	>40.5	> 2.0	8
67	0258-116	M-02-08-039	0.0296	Seyf2	21	20	19.4	11	
69	0302-472	247- G? 16	0.0305	HII	19	91	9.1	5.3	1
70	0302-729		0.0431	Seyf2	18	90	13.7	11	9
72	0305-231	NGC 1229	0.0355	Seyf2	18	90	28.5	19	
76	0310-515	199-IG 23	0.0778	Seyf2x2	19	122	17.1	25	10
94	0333-564		0.0785	Seyf2	19	153	14.8	22	
99	0338-712	54-IG 15	0.0483	HII	19	88	14.8	14	
209	0645+744	Mrk 6	0.0184	Seyf1	23	337	16.2	5.7	1
251	0911+679	Mrk 103	0.0308	HII	14	90	4.4	2.6	1
255	0930+682		0.0703	Seyf2	14	90	4.4	5.8	1
258	0945+594	M+10-14-039	0.0072	HII	15	90	14.1	2.0	
259	0945+507E	Mrk 124	0.0563	Seyf1	15	90	4.4	4.7	1
262	1020+331N		0.1256	?	16	180	4.4	10	1
263	1021+675	ZG 1021+67	0.0386	Seyf2	14	90	3.7	2.7	1
266	1028+290	NGC 3265	0.0041	HII	13	90	8.9	0.7	1
267	1030+602	Mrk 34	0.0505	Seyf2	14	90	7.4	7.1	1
268	1033+636		0.0377	HII	14	90	5.9	4.2	1
284	1131+216	M+04-27-064	0.0214	HII	13	90	29.6	12	
292	1215+300	Mrk 766	0.0123	Seyf1	13	90	6.7	1.6	1
298	1231+779SE	ZG 1231+77	0.0277	HII	14	140	14.8	7.8	
308	1247+437		0.0622	HII	16	157	14.8	17	
	1327+322		0.0246	HII	5	90	6.5	3.1	1
339	1407+266		0.0597	HII	6	90	9.7	11	1
342	1411+078	U09102	0.0235	HII	13	125	29.6	13	
344	1415+253	NGC 5548	0.0169	Seyf1	15		7.4	2.4	1
346	1426+274	Mrk 682	0.0143	HII	13	125	8.9	2.4	
353	1442+590	M+10-21-028	0.0388	HII	14	90	11.1	8.2	
354	1443+272		0.0294	Seyf2	13	125	5.9	3.3	1
360	1506+661	M+11-18-027	0.0286	HII	14	90	9.6	5.3	
365	1514+601		0.0447	HII	15	90	5.2	4.4	

Table 2. continued

Num	IRAS name	Alternative name	z	AGN type	Obser night	Slit PA (degrees)	Size (")	Size (kpc)	Notes
367	1518+085	ZG 1518+08	0.0306	Seyf2	13	125	6.7	3.9	1
368	1518+657SW	M+11-19-006	0.0444	Seyf2	13		5.9	5.0	1
369	1519+393	U09826	0.0292	Seyf1	13	125	14.1	7.8	
370	1521+087	ZG 1521+08	0.0364	Seyf2	16	117	7.4	5.1	1
376	1531+580S	Mrk 289	0.0391	HII	15	180	9.6	7.2	1
378	1537+251SW	Mrk 860	0.0228	Seyf2	15	233	6.7	2.9	1
388	1556+269	Mrk 492	0.0136	HII	13	194	5.9	1.6	1
392	1559+021	3C 327.0	0.1034	Seyf2	16	117	5.2	9.9	1
393	1600+264N	Mrk 867	0.0724	Seyf1	15	183	6.7	9.0	1
396	1603+632		0.0558	HII	14	0	5.9	6.2	
398	1606+124	Mrk 871	0.0323	Seyf1	16	117	4.4	2.7	1
408	1626+518	Mrk 1498	0.0547	Seyf1	14	0	4.4	4.6	1
409	1628+394W		0.0297	Seyf2	15	255	8.9	5.0	1
415	1634+441	M+07-34-117	0.0350	HII	15	255	18.5	12	
	1638+465C E		0.0585	Seyf2	6	111	8.1	8.9	1
421	1641+156NW		0.0662	HII	16	118	3.7	4.6	1
	1641+398		0.029	Seyf1	15	90	5.2	2.9	1
430	1657+290	U10639	0.0322	Seyf2	15	270	17.0	11	
	1703+606		0.0971	Seyf2+HII	4	332	11.3	20	11
438	1712+395	ZG 1712+39	0.0362	Seyf2	22	75	9.7	6.7	1
441	1716+302NE		0.0140	HII	15	241	14.8	4.0	
444	1727+575E	ZG 1727+57	0.0282	HII	14	75	11.8	6.4	
447	1733+208B	M+03-45-003	0.0240	Seyf2	13	90	5.9	2.7	1
457	1752+189		0.0395	Seyf2	15	241	8.9	6.7	
469	1825+412SW		0.0833	HII	16	223	8.9	14	1
475	1846+721	ZG 1846+72	0.0461	Seyf2	14	0	5.2	4.5	
477	1855+716		0.0923	HIIx2	14	175	11.1	19	12
479	1908-539	184-IG 32	0.0230	Seyf2+HII	18	166	45.6	20	13
485	1918-578 core		0.0587	Seyf2	18	90	8.0	8.8	1
486	1918-558	NGC 6780	0.0120	HII	18	90	62.7	15	
488	1924-416E	338-IG 4	0.0094	HII	19	66	13.7	2.5	
492	1944-464		0.0196	HII	18	90	16.0	6.0	
502	2020-565NW		0.0596	Seyf2	19	141	8.0	8.9	1
512	2048-572	PKS 2048-57	0.0113	Seyf2	19	89	22.8	5.0	14
513	2055-521	235-IG 26	0.0513	Seyf2	18	90	11.4	11	1
518	2117-492		0.0541	HIIx2	19	95	45.6	47	15
527	2154-348gal	404- G 12	0.0088	HII	19	67	34.2	5.8	1
	2201-002		0.0326	HII	6	90	11.3	7.1	1
532	2217-490	238- G 2	0.0306	HII	18	37	39.9	23	
535	2226-659	109- G 6	0.0106	HII	19	91	10.3	2.1	1
538	2237+077E gal		0.0246	Seyf1	19	90	16.0	7.5	
547	2301+223	Mrk 315	0.0385	Seyf1	18	90	14.8	11	
549	2302-000	U12348	0.0253	Seyf2	6	90	9.7	4.7	
552	2311-578E		0.0348	HII	19	90	17.1	11	
554	2314-443SE		0.0480	HII	18	145	6.8	6.2	1