1985ApJS...57..643D

THE ASTROPHYSICAL JOURNAL SUPPLEMENT SERIES, 57:643–664, 1985 April
© 1985. The American Astronomical Society. All rights reserved. Printed in U.S.A.

THE NUCLEAR ACTIVITY OF INTERACTING GALAXIES[1]

OVED DAHARI
Lick Observatory, Board of Studies in Astronomy and Astrophysics, University of California, Santa Cruz
Received 1984 July 31; accepted 1984 September 21

ABSTRACT

A search for active galactic nuclei among interacting galaxies is reported. A sample of 167 systems of interacting and asymmetric galaxies was observed spectrophotometrically in the spectral range 4700–7100 Å. The results are compared with a sample of isolated galaxies. It is found that (*a*) there are no Seyfert nuclei in elliptical or dwarf irregular galaxies of the sample; (*b*) there is an excess of Seyfert nuclei among interacting spirals, but it is only at the 90% confidence level; (*c*) this excess becomes statistically significant (98%) when only *strongly* interacting spirals are included (four new Seyfert nuclei are presented); (*d*) in the subgroup of galaxies with extreme tidal distortions, no Seyfert nuclei were found.

Subject headings: galaxies: clustering — galaxies: nuclei — galaxies: Seyfert

I. INTRODUCTION

The influence of gravitational perturbations on spiral galaxies has been of considerable interest in the last two decades. These systems are interesting from many points of view: for example, interaction dynamics, the question of galactic merging and cannibalism, the extent of induced star formation in the disk and/or the nucleus, and the question of the influence on nonstellar activity in the nucleus (which is the subject of this study).

The morphologies and velocity fields of interacting systems have been studied by optical observations (Rubin, Ford, and D'Odorico 1970; Chincarini and Heckathorn 1973; Barbieri *et al.* 1979; Bergvall 1981; Arkhipova *et al.* 1981; Blackman 1982), by radio observations (Condon *et al.* 1982; Sulentic and Arp 1983), and by theoretical *N*-body simulations (Toomre and Toomre 1972; Spiegel and Theys 1976; Miller and Smith 1980; Negroponte and White 1983). Recent studies of the nuclei of interacting galaxies have been concerned with the frequency and magnitude of star formation (i.e., H II regions) as evidence for the gravitationally induced flow of gas into the nucleus. Studies in the radio (Hummel 1980, 1981; Gallagher, Knapp, and Faber 1981; Toomasyan 1982; Davis and Seaquist 1983) and in the visual (Larson and Tinsley 1978; Tifft 1982; Gehrz, Sramek, and Weedman 1983; Kennicutt and Keel 1984; Keel *et al.* 1984) have shown that radio emission and optical emission-line activity *are* enhanced in the nuclei of these systems, and some evidence for radial flow of gas has also been found.

The nonstellar nuclear activity in interacting galactic systems is of special interest, since it is related to the question of matter supply to active galactic nuclei (AGNs). It has been shown that many Seyfert galaxies have companions (Adams 1977), and that this excess is statistically significant when compared with field galaxies (Dahari 1984). (Hereafter the term *statistically significant* is used when the level of confidence is above 95%.) Many QSOs have companions as well (Stockton 1982; Heckman *et al.* 1984; Hutchings *et al.* 1984), and the Seyfert galaxy population has excesses of bars and of morphological peculiarities (Adams 1977; Simkin, Su, and Schwarz 1980). Accordingly, we would like to find out whether there is an excess of Seyfert nuclei among interacting or asymmetric systems as well. Kennicutt and Keel (1984) and Keel *et al.* (1984) reported recently on an excess of AGNs among close pairs of galaxies, although their result was not statistically significant because of the small sample. In this paper we report on a spectral survey of a large sample of interacting galaxies, and compare the frequency of Seyfert nuclei in that sample with the corresponding frequency in a sample of isolated galaxies.

In the next section we describe the sample selection, and in § III we describe the observations and data reduction. In § IV we define a classification scheme for interaction strength and for the nuclear activity level, and in § V we examine the relation between these parameters according to the survey results. In § VI we present more detailed spectra of the newly discovered Seyfert galaxies.

The large number of new spectral data presented in this paper will be used elsewhere for further analysis of the emission from these nuclei, in addition to Seyfert activity (which is the subject of the present paper).

II. SAMPLE SELECTION

The term *interaction* usually refers to two (or more) galaxies close to each other. However, many isolated spiral galaxies seem to have various degrees of asymmetry and distortion (Arp 1966; Vorontsov-Vel'yaminov 1977). This could result from one or more of the following reasons: (i) The system is observed in a late epoch, after the companion has moved away to a distance at which it is no longer considered a companion. (ii) The companion is behind the apparently single galaxy. (Statistically we would expect to find only a small number of systems in that situation.) (iii) The compan-

[1] *Lick Observatory Bulletin*, No. **996**.

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

1985ApJS...57..643D

ions have already merged (sometimes seen as a double-nucleus galaxy). (iv) The spiral galaxy is subject to an asymmetric gravitational potential of the (hypothetical) nonluminous matter. In fact, the ranges of distortions in double and single systems seem to be comparable.

In any case, for our purpose the reason for the distortion is not as important as the distortion itself. We are interested in tidal effects under the assumption that radial flows of matter in the galactic disk are caused by them (Gallagher, Knapp, and Faber 1981). The potential well of a distorted galaxy must be asymmetric. Hence we expect to find comparable amounts of radial motion (toward or away from the nucleus) in spirals with similar amounts of distortion, whether or not they have close companions. Therefore, we would like to base our selection criterion on morphology, rather than solely on the presence of a companion. Accordingly, a sample including only pairs of galaxies (such as one of the samples of Kennicutt and Keel 1984) is not sufficient for our purpose. While many pairs show clear signs of interaction, many others do not, and they may well be optical pairs or pairs with large spatial separations which therefore do not have strong tidal effects.

We used the catalogs of Vorontsov-Vel'yaminov (1959, 1977; hereafter VVI and VVII, respectively) for our sample selection. Although both catalogs are titled *Atlas and Catalogue of Interacting Galaxies*, they include many single systems with various degrees of asymmetry. Especially in VVII, Vorontsov-Vel'yaminov was trying to illustrate the concept of "fragmentation," and therefore, he included many M51-type systems (having a small companion connected to an extended arm), "nests," and multiple-nuclei systems. Hence the range of tidal strengths and effects in the two catalogs is large. Many of the VV systems are also included in Arp's *Atlas of Peculiar Galaxies* (1966), which provides excellent photographs for detailed morphological studies.

The VVI catalog included a brief description of each system. In VVII, some systems were discussed thoroughly, with many references to previous studies, while for other systems only small photographs were provided. Hence in the notes to Table 5 (see § IV) we provide additional descriptions, referring especially to the nature of the tidal effects. For further references and descriptions of individual systems, see Arp (1966) and de Vaucouleurs, de Vaucouleurs, and Corwin (1976, hereafter RCBGII).

The VV catalogs include some 850 systems. The catalogs are not complete in any statistical sense but rather were selected to represent various observed phenomena of tidal interaction (see introduction to VVII). The selection criteria of Vorontsov-Vel'yaminov were not based on the spectra of the systems, so we expect no selection effect on the spectral distribution, unless the AGN activity *does* depend on some special kind of morphological type or peculiarity. We chose a subset of the VV objects which could be observed with the 1 m Anna Nickel telescope at Lick Observatory. The declination limits of the telescope are $-30° < \delta < +65°$. At the moderate dispersion of the ITS spectrograph (~ 10 Å, see next section), exposures of about 30 minutes were required to achieve a signal-to-noise (S/N) ratio of 10 for $m \approx 14$. Hence we further limited our sample to $m < 14.5$. The magnitudes quoted in the VV catalogs are uncertain in many cases. Therefore, we used the values from the UGC (Nilson 1973), which are more accurate. For many (southern) VVs there are no entries in the UGC, and therefore, a few systems with very faint surface brightnesses are still included in our sample.

Setting a limiting magnitude might introduce a bias towards preferentially including galaxies with bright nuclei. However, only bright Seyfert 1 galaxies have nuclei which are comparable in brightness to the underlying galaxies (Hutchings *et al.* 1982; Yee 1983). The magnitudes in the VV and UGC catalogs refer to the total galaxy, so we do not feel that this bias is strong. The effect will be checked *a posteriori* by comparing the magnitude and redshift distributions of the interacting VV Seyferts with the rest of the sample (see § V).

In Table 1 we list 206 VV systems which comply with the declination and brightness limits. Those VVs for which the photographs given in the catalogs could not be matched with any galaxy near the given positions are not included in the table. These systems are VV 87, 118, 128, 151, 254, 527, 635, and 645. Apparently the positions quoted for these galaxies are erroneous. The positions of the VVII galaxies were given only by their MCG numbers (Vorontsov-Vel'yaminov and Krasnogorskaya 1962; Vorontsov-Vel'yaminov and Arkhipova 1963, 1964, 1968, 1974), so we list here the equatorial coordinates (1950) of all the VVs in our sample. In Table 1 the sample is sorted by right ascension, and cross-reference numbers are given from the Messier, IC, NGC, UGC, and Arp catalogs, as well as the Karachentsev (1972) number from his list of binary galaxies. (The objects are sorted by VV numbers, with main secondary name, in Table 5.)

III. OBSERVATIONS AND DATA REDUCTION

The most productive way to discover new Seyfert galaxies has been the use of objective prisms with blue-sensitive photographic plates. The 15 lists (and supplements) of nonstellar objects with ultraviolet excess published by Markarian and collaborators (Markarian, Lipovetskii, and Stephayan 1981, and references therein) provide the majority of the Seyfert galaxies known. However, these surveys are not complete. The Seyfert and AGN activity can occur at relatively low intensity (see, e.g., Fig. 2), with the ultraviolet nonthermal continuum weak compared with the stellar continuum. Wasilewski (1983) conducted an emission-line survey in areas previously covered by Markarian *et al.* and found a substantial number of additional Seyferts not listed by them. Most of Wasilewski's newly discovered Seyferts were type 2, as expected, since they have relatively weak ultraviolet excesses.

Wasilewski used objective-prism spectroscopy, but with higher resolution than Markarian, and plates sensitive to the [O III] green lines. However, the presence of strong [O III] emission lines is not sufficient to distinguish between highly ionized H II regions and Seyfert 2 galaxies, at least if the spectral resolution is lower than ~ 10 Å. As will be discussed in the next section, spectra of some highly ionized H II regions (galactic and extragalactic) have the ratio [O III] $\lambda 5007/H\beta > 3$, which is one of the criteria for the definition of type 2 Seyferts (Shuder and Osterbrock 1981). Additionally, some nuclei are heavily reddened. While the red part of the spectrum looks much like a Seyfert 2, the [O III] lines are very

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

TABLE 1

THE VORONTSOV-VEL'YAMINOV SAMPLE

RA hr	RA mn (1950)	Dec deg	Dec mn	VV	NGC	UGC	Other Name
0	1.2	21	40	806			M334.
0	4.3	-13	41	272	7828/9		A144.
0	6.2	15	32	80	14	75	
0	8.8	-12	22	850	34		M934.
0	14.9	-6	39	721			
0	16.3	-10	38	352			A256.
0	30.0	-10	27	661			
0	33.8	-10	10	548			
0	35.3	-20	14	791	175		
0	44.3	32	23	441			K17.
0	44.8	-15	43	728	244		
0	45.4	-20	41	518			
0	48.5	-7	21	81	274		A140.
0	58.4	-9	27	361	341		M968.A59.
1	0.7	-7	16	486	356		
1	4.3	32	9	193	383	689	A331.3C31.
1	12.0	-17	4	779			I1670
1	13.8	30	46	430	452	820	K28.
1	18.1	-17	39	781			
1	20.9	33	0	207	507	938	A229.
1	21.9	33	10	36	517	960	
1	22.0	3	32	231	520	966	A157.K31.
1	22.8	33	54	783	523	797	A266.
1	44.7	27	5	338	672	1225	
1	46.1	10	16	53		1266	I162.A228.
1	54.1	5	23	175	741	1413	III-ZW-38.4C05.
1	54.6	32	58	189	750/1	1430/1	A166.K46.
1	57.4	-8	6	733			
2	0.7	37	53	428	797	1541	II-ZW-170.
2	1.2	14	37	309		1556	I196.K53.A290.
2	16.3	5	27	362		1775	A10.
2	18.5	39	11	323		1810/3	K64.A273.
2	25.5	19	22	238	935	1937/6	K68.
2	25.9	-11	3	217	942/3		A309.
2	32.1	-9	0	285	985		M1048.
2	39.3	-10	9	423			
2	53.7	-10	8	482	1140		
2	54.5	0	-7	331	1143/4	2388/9	K83.A118.
2	58.5	25	8	531	1156	2455	
3	5.8	-23	10	337			I1892.A332.
3	8.8	-9	6	334	1241		A304.
3	27.8	-22	26	23	1347		A39.
3	28.3	-17	53	690	1345		
3	40.5	-28	1	610			
4	59.2	-4	20	565	1741		
6	4.2	-15	38	545			
6	38.0	-27	9	134			
6	45.3	-26	41	178	2293		
7	20.8	33	32	528		3829	M1199.K26.
7	43.5	39	9	117	2444/5	4016/7	A143.
8	5.3	57	55	632	2521	4235	
8	8.2	25	21	9	2536	4264	A82.
8	11.2	46	5	138	2537	4274	A6.M86.
8	15.2	-27	19	475	2559		
8	37.5	25	51	79	2623	4509	A243.
9	1.2	22	11	481	2738	4752	
9	2.4	18	39	612	2744/9	4757	
9	3.7	25	39	541	2750	4769	
9	12.5	53	2	124		4879	
9	14.3	42	11	50	2798/9	4905/9	K195.A283.
9	35.1	3	48	316	2936/7	5130/1	A142.
9	36.5	32	36	83		5146	K209.
9	40.3	9	42	547		5189	
9	40.8	-5	2	52			A253.
9	47.1	0	51	620	3018/23	5269/5	K216.
9	56.2	47	57	618		5354	
9	57.0	-28	22	592			
10	0.3	40	58	119	3104	5414	A264.
10	6.3	-2	17	620		5469	I593.
10	12.8	-28	37	796	3175		
10	14.7	-3	15	97			I600.
10	15.4	22	5	307	3190/87	5559/5	A316.
10	20.8	20	7	209	3227/6	5620/17	A84.
10	23.1	-1	58	354		5641	I609.
10	24.3	17	17	95	3239	5637	
10	29.0	7	7	396			
10	35.7	53	46	406	3310	5786	A217.
10	40.3	13	43	112		5832	
10	42.0	7	1	529	3356	5852	
10	44.7	26	47	727		5884	
10	47.2	33	16	246	3395/6	5931/5	A270.
10	49.7	36	53	11	3432	5986	A206.
10	51.5	57	16	14	3445	6021	A24.K256.
11	2.7	5	3	75	3509	6134	A335.K265.
11	15.7	32	17	686			
11	17.4	13	17	308	3627	6346	Me66.A317.
11	18.0	2	48	795		6345	
11	18.3	53	28	363	3631	6360	A27.
11	20.8	54	7	22	3656	6403	K282.
11	23.3	3	28	251	3664	6419	K283.A5.

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

TABLE 1—*Continued*

RA hr	RA mn (1950)	Dec deg	Dec mn	VV	NGC	UGC	Other Name
11	25.9	58	49	118	3690	6472	A296.M171.
11	32.3	55	7	459	3733	6554	
11	37.1	32	13	228	3788/6	6623/1	A294.M744.
11	37.7	15	36	350	3800	6634	A83.
11	38.2	22	44	300	3808	6643	A87.
11	39.4	-6	13	544			
11	41.5	-16	32	477	3836		
11	41.6	55	18	320	3846	6706	
11	45.7	56	15	455	3888	6765	M188.
11	47.7	25	10	367	3920	6803	
11	48.5	56	21	31	3921	6823	M430.A224.
11	50.7	-4	8	457			
11	53.6	-19	37	8	3981		A289.
11	54.8	32	37	523	3991	6933	Haro5.
11	55.2	32	35	249	3995/4	6944	A313.
11	55.5	28	10	230	4004	6950	M432.
11	55.6	36	40	126		6945	
11	55.8	27	48	424	4017		A305.
11	56.1	25	19	216	4015	6965	A138.K314.
11	57.7	-18	59	66	4027		A22.
11	59.3	-18	35	245	4038/9		A244."The Antennae"
12	0.5	18	19	384	4048	7023	
12	1.5	20	30	179	4065	7050	
12	3.1	50	48	357	4088	7081	A18.
12	11.2	36	54	104	4190	7232	
12	11.7	54	48	261	4194	7241	A160.M201.
12	12.7	6	5	520	4197	7247	
12	15.7	6	56	431		7333	I3115.
12	16.5	47	35	448	4258	7353	Me106.
12	25.3	13	17	188	4438	7574	A120.
12	28.3	41	55	30	4490	7651	A269.
12	29.1	4	12	76	4496	7668	K343.
12	30.2	14	20	563		7695	I3476.
12	34.0	19	36	571	4561	7768	K346.I3569.
12	34.1	11	31	219	4568/7	7776/7	
12	39.2	41	25	73	4618	7853	A23.
12	41.1	11	49	206	4649/7	7898/6	A116.K353.Me60.
12	41.3	16	42	56	4651	7901	A189.
12	41.8	55	11	708		7905	M221.
12	43.7	31	0	224	4676	7938/9	I819.K355.A242.
12	49.7	-15	11	434			
12	51.2	4	44	366	4765	8018	
12	52.5	2	55	313	4809/10	8034	K358.A277.
12	53.5	-12	27	201	4782/3		
12	56.6	35	8	797	4861	8098	

RA hr	RA mn (1950)	Dec deg	Dec mn	VV	NGC	UGC	Other Name
13	0.3	29	27	609	4922	8135	K363.
13	9.0	29	12	460	5000	8241	
13	13.7	62	18	250		8335	A238.K369.
13	22.8	-19	31	485			
13	27.8	47	27	1	5194	8493	A85.Me51.
13	30.8	62	57	33	5216/8	8528/9	A104.
13	33.0	51	51	828	5238	8565	
13	37.4	1	5	55	5258/7	8645/1	A240.
13	39.8	55	55	19	5278/9	8677/8	A239.M271.
13	46.6	-6	58	135	5306		
13	56.5	37	39	48	5395/4	8900/898	A84.I-ZW-77.
13	58.8	41	13	256	5410	8931	K406.
13	59.5	34	4	120	5421	8941	A111.M665.
14	0.8	-5	49	21	5427/6		A271.
14	1.4	54	35	344	5457	8981	Me101.A26.
14	14.9	36	48	210	5545/4	9142/3	A199.
14	21.7	-16	30	530	5595		
14	21.8	-16	31	446	5597		
14	22.0	35	5	77	5614/3	9226	A178.
14	24.8	5	1	408	5619	9255	
14	30.0	8	18	412	5665	9352	A49.
14	42.3	-13	44	98	5745		
14	44.7	51	47	713			
14	48.3	-10	2	140			A261.
14	48.2	-20	15	130			
14	49.3	35	46	324		9562/0	K438.
14	52.3	-19	28	137			
15	24.4	41	51	823	5929/30	9851/2	A90.
15	25.3	40	45	427		9858	
15	32.2	15	21	244	5953/4	9903/4	A91.
15	33.3	23	40	540		9913	I4553.A220.K470.
15	44.2	18	3	16	5996	10033	K472.A72.
16	3.1	20	42	86	6052	10182	M297.A209.
16	5.2	30	14	624		10205	
16	10.4	52	35	626	6090	10267	M496.
16	28.3	39	37	364	6166	10409	
16	32.3	29	4	625		10445	
17	8.2	63	43	726		10731	K505.
17	12.8	59	23	89		10770	A32.K506.
17	26.6	58	35	101		10869	I1259.K517.A310.
17	45.1	30	44	426		10976/7	K524.
18	9.3	14	5	537	6570	11137	
20	31.0	-2	12	621	6926	11588	
20	57.3	-2	3	668		11658/7	K551.
21	5.0	-25	40	764	7018		

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

TABLE 1—*Continued*

RA hr	RA mn	Dec (1950) deg	Dec mn	VV	NGC	UGC	Other Name
21	41.3	-25	35	800	7115		
22	6.5	-28	5	700	7214		
22	14.2	-21	30	494			
22	17.2	29	9	242	7253	11984/5	A278.K5.
22	25.9	-25	7	74	7285		A93.
22	28.5	-17	50	372	7301		
22	31.2	-27	30	832	7306		
22	33.8	33	43	288	7319/8	12102	Stephan Quintet.A319.
22	49.1	-5	50	68	7393		A15.
22	54.5	-9	13	488			
22	55.5	-4	2	295			A314.
22	55.6	25	53	84	7436/3	12269	
23	17.9	16	57	280	7625	12529	A212.III-ZW-102.
23	22.5	-19	21	669	7656		
23	25.4	8	30	343	7674/5	12608	A182.M533.
23	25.9	22	7	359	7678	12614	A28.
23	26.7	23	27	619	7673		M325.
23	27.8	3	22	329	7679	12618	M534.A216.
23	33.5	7	2	470		12688	
23	33.7	1	53	51	7714/5	12699/700	K587.M538.A284.
23	37.3	-12	34	67	7727		A222.
23	39.8	-4	30	480			
23	44.4	29	12	5	7752/3	12780	
23	46.2	3	53	407	7757		A68.
23	47.7	0	-24	208	7783	12837	A323.K595.
23	58.9	31	10	226	7806	12911	K602.A112.

NOTE.—A, Arp 1966. I, IC number. K, Karachentsev 1972. M, Markarian number. Me, Messier number.

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

1985ApJS...57..643D

weak and Hβ is totally absent. (Such galaxies were probably overlooked by Wasilewski.) Furthermore, a few Seyferts have relatively weak [O III] and only narrow Hβ emission lines, but weak, broad Hα is evident (Shuder 1980; Stauffer 1982a; Osterbrock and Dahari 1983). Hence the inclusion of the Hα–[N II] blend is crucial for correct spectral classification (see also Kinman 1985).

Consequently, we need spectra which cover the Hα–Hβ spectral region. Inclusion of [O II] λ3727 would be beneficial but is not crucial. (We could either expand the spectral coverage at the expense of lower resolution or take an additional blue scan for every object. The first possibility is not available on the 1 m spectrograph, while the second possibility would have doubled the telescope time needed.)

The image-tube scanner (ITS) spectrophotometer (Robinson and Wampler 1972; Miller, Robinson, and Wampler 1976; Miller, Robinson, and Schmidt 1980) on the 1 m was used for most of the observations. An entrance aperture 8$''$.1 in diameter (projected on the sky) was used, as a compromise between having either more light or a better spectral resolution. The "red" ITS systems has a good response in the range 4000–8500 Å. The grating with 600 lines mm^{-1} provided a spectral range of 2400 Å with a resolution of $\sim$10 Å. It was centered at $\sim$5700 Å so that both the Hα and the Hβ spectral regions were covered.

The main observing aim was to detect emission lines, since these are the principal indicators of nuclear activity and are straightforward to detect. Since the ITS system allows the observer to examine the data as they accumulate, the exposure was terminated after 8–16 minutes if no emission lines were seen. The upper limit on the equivalent width of the undetected emission lines is less than 10 Å in most cases (see Table 2). The S/N in some cases was not good enough to detect absorption lines for redshift determination. However, for many systems the redshift is available from other sources (see Table 2). In cases where emission lines *were* detected, the exposure was lengthened until the S/N was sufficiently high to decide whether or not the spectrum is Seyfert-like. If an exposure of $\sim$1 hr was not sufficient, the object was later observed with the 3 m Shane telescope (if possible). The 3 m ITS system is similar to the one on the 1 m, and the same spectral setup was used. In cases of "marginal" Seyfert-like spectra, a 1200 lines mm^{-1} grating was used on the 3 m, if time permitted, to get better information on the line widths.

A few systems were observed with the ITS system on the 1.5 m reflector of the University of California, San Diego, and the University of Minnesota at Mount Lemmon (Arizona). The ITS system at the 1.5 m is again similar to the Lick ITSs, except that the grating of 600 lines mm^{-1} at the 1.5 m gives a spectral coverage of 3400 Å (with resolution of $\sim$13 Å), and the round entrance aperture used was 6$''$.5 in diameter (projected on the sky).

The standard Lick ITS data reduction package was used to reduce the ITS data from the three telescopes. Adjustments had to be made for the 1.5 m data, since the Mount Lemmon latitude and altitude are different. Also, the software was modified to use different dead-time correction for the 1.5 m data (usually an insignificant correction for faint objects). Lick's standard PDP-8I software was used to measure line intensities and equivalent widths. The uncertainties in the spectral information obtained by the ITS systems are the following: 10% in the line ratios and in the equivalent widths, 50% in the flux calibration (0.3 in the logarithm), and 0.0002 in the redshift measurement (on the average, depending on the number of spectral lines available). For the deconvolution of blends (like the Hα–[N II] blend) a separate Gaussian fitting FORTRAN program was used on the Lick VAX computer. The program fits up to four independent Gaussians to a blend by a least-squares method taken from Bevington (1969). This program was written by R. W. Goodrich and the author.

Toward the end of the observing program, a few VV systems were observed with the 3 m CCD spectrophotometer by Drs. D. E. Osterbrock, M. M. DeRobertis, and the author during routine observing runs of Seyfert galaxies and related objects. The CCD spectrograph and the reduction systems were developed and described by Lauer *et al.* (1984). Data-acquisition programs were also written by R. Kibrick and D. Terndrup, and data-reduction programs were supplemented by M. M. DeRobertis, R. W. Goodrich, and the author. A long slit 2$''$ wide was used, and the data were summed over 10–12 pixel rows, so that the resulting aperture was $2'' \times 8''$ projected on the sky. The grism used had 420 lines mm^{-1}, which provides spectral coverage of $\sim$2500 Å, with a resolution of $\sim$13 Å. Sky subtraction was done by summing the sky spectra on both sides of the object's spectrum, up to some 60$''$ away. The flux calibration was carried out by observing the same standard stars (Stone 1974, 1977) used for the ITS calibration (see, for example, the spectrum of VV 334 in Fig. 2).

As mentioned in § II, one of the criteria used to define the sample was the magnitude limit of $m < 14.5$. However, the magnitudes given in VVI and VVII were not accurate, and a few galaxies were found to be very faint. Some galaxies could not be seen on the TV monitor, while other galaxies with $m = 14.4$ (as given in UGC) were clearly seen. Hence we exclude from the sample those galaxies that were too faint for the TV monitors of the 1.5 m and 3 m telescopes: VV 29, 252, 431 (foreground star superposed), 494 (probably irregular), 785, and 525. These galaxies are not listed in Table 2 or Table 5. The galaxies that were too faint on the 1 m TV monitor are not listed in Table 2 but are listed in Table 5 (with nuclear emission type = 7, see § IV*b*). These galaxies might be brighter then $m = 14.5$ and hence should be included, while the absence of a nucleus clearly indicates their non-Seyfert nature. The galaxies VV 620 and VV 733 were not observed, because of misidentification. That error was not caused by any morphological or spectral information. Since the VV sample is not complete statistically, we exclude these two systems from the sample as well.

For many (mostly bright) VVs, spectra were previously obtained by Keel (1983), Keel *et al.* (1984), or Stauffer (1982*b*), who used the same instruments with the same spectral setups. Hence we include their results in our study. Note that Keel (1983) and Keel *et al.* (1984) corrected the intensities of the Balmer emission lines for the absorption in the spectrum of the underlying galaxy. We could not follow the same procedure since the VV galaxies are fainter (on the average), and therefore the continuum in most of our spectra is too noisy for

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

1985ApJS...57..643D

TABLE 2

SPECTRAL INFORMATION FOR THE VORONTSOV-VEL'YAMINOV NUCLEI

VV (1)	z (2)	Ref. (z) (3)	Flux Hα (4)	E.W. Hα (5)	6583 ---- Hα (6)	SII --- Hα (7)	5007 ---- Hβ (8)	Hα -- Hβ (9)	6300 ---- Hα (10)	Ref. (e.l.) (11)	Apr. (12)
1 N	0.0018	6	-12.7	11	3.8	0.58	1.7	3.9	0.33	6	e
1 S	0.0022	6	-12.96	3	0.63	0.42		>10	<0.13	6	e
5 NE	0.0171	2	<-13.5	<6							a
5 SW	0.0173	2	-13.35	130	0.27	0.33	0.47	13			a
8	0.0055		-13.38	15	0.3	>0.3		>4			b
9	0.0132	6	-13.53	23	0.31	0.45		>3		6	c
11	0.0021	8	-13.01		0.23	0.46				8	
14	0.0068	2	-13.88	18	0.26	0.80	>1	>3			b
16	0.0107	2	-12.64		0.40	0.20	0.36	6.6	<0.05		c
19 W	0.0257	6	-14.02	15	1.2	0.49	1.4	6.3	1.35	6	e
19 E	0.0261	6	-13.66	18	0.85		1.7			6	e
21 S	0.0085	6	-13.44	13	1.6	0.51	8.1		0.29	6	e
21 N	0.0079	6	-14.02	5						6	e
22	0.0097	9	no emission							9	
31	0.0199	8	-13.42		1.6	1.1				8	
33 N	0.0095	2	<-13.70	<2							a
33 S	0.0098	2	<-13.60	<3							a
36	0.0140		<-14.15	<2							a
48 NW	0.0116	6	-12.65	56	0.53	0.28	0.44			6	e
48 SE	0.0121	6	-14.42	2	0.8					6	e
50 E	0.0062		-13.42	48	0.29	0.46		>5			a
50 W	0.0054		-12.24	90	0.47	0.22	0.30	8.2	0.03		a
51 W	0.0093		-11.77	130	0.16	0.36	1.69	4.8	0.02		d
51 E	0.0080	9	possible weak H-alpha.							9	
52 W	0.0057		-13.59	53	<0.1	<0.1	6.5	6.0			b
53	0.0178	2	-13.9	2	<0.5						d
55 E	0.0226	6	-13.59	19	0.34	<0.3				6	e
55 W	0.0220	6	-13.67	24	0.41	0.07				6	e
56	0.0026	6	<-14.50		>1					6	e
66	0.0054		-13.13	25	0.34	0.38		>10			b
67	0.0060	5	<-13.80		>1					5	f
68	0.0120		-13.89		0.66	0.56		>6			c
73	0.0019	6	-13.30	58	0.21	0.27	1.5	3.1		6	e
74 E	0.0140		-14.33	4	1.5	<0.5		>3			c
74 W	0.0151		<-14.00	<1							c
75	0.0254	2	no emission.							9	
76 S	0.0148		-13.22	51	0.38	0.29	<0.4	8.3			b
76 N	0.0059	2	<-14.0	<2							b
77 S	0.0129	6	-13.62	2	1.0					6	e
77 N	0.0132	6	-13.93	10	0.64					6	e
79	0.0180		-13.73	19	1.0	0.45	>2	>5			d
81 NW	0.0062		<-13.40	<6							a
83 E	0.0226		no emission.							9	
84 SW	0.0248		-14.61		1.9	1.4	>2	>3			c
84 C	0.0244		<-14.7	<2							c
84 W	0.0271		<-14.7	<2							c
86	0.0156	6	-12.75	72	0.19	0.29	0.61	3.5		6	e
101	0.0270		no emission	(both)						9	
117 S	0.0133		<-14.70								e
117 N	0.0128	6	-13.14	62	0.50	0.25		6.1		6	e
120 A	0.0260	6	-13.44	17	0.83	0.23	1.0	>4		6	e
120 B	0.0258	6	-14.52	1	1.0					6	e
126 S	0.0347	1	-13.04	180	0.44	0.28	1.3	8.3			b
126 NW	0.041		-14.5		<0.2						b
130	0.0108		-14.04	17	<0.3						b
135	0.0241		<-14.5								b
135 N	0.0240		-14.03	19	0.4	<0.3		>3			b
137	0.0113		-13.71	31	0.47	0.45	<1	3.5			b
140	0.0061		-13.36	99	0.14	0.25	3.3	6.5			b
175	0.0185	2	<-13.5	<5							a
175 E	same?		<-13.5	<5							a
178 SE	0.0063		<-13.4	<3							a
178 NW	same?		<-13.6	<7							a
188	0.0030	3	-12.96	67	1.7	1.6	3.5	18	0.24		b
189	0.0176		no emission	(both nuclei).						9	
193 N	0.0169	2	-14.6	3	2	<0.5					d
193 S	0.0172		<-14.0	<3							d
201 N	0.0132		<-13.7	<3							b
201 S	0.0150		<-13.7	<2							b
206 SE	0.0036	2	<-14.0	<3							b
206 NW	0.0029		-13.60	11	0.35	0.19		>5			b
207 N	0.0184		-14.25	2	<0.5			>2			d
207 S	0.0165		<-13.8	<2							d
208	0.0261	9	no emission	(both).						9	
209 SE	0.0033	2	-12.52	Sey 1.5.						17	
209 NW	0.0042	2			1.6					17	
210 N	0.0102	2	-14.00	9	1.0	<0.5				6	e
210 S	0.0101	2	-14.57	2	0.8					6	e
216 S	0.0144	9	<-14.3	<2							d
216 N	0.0157	9	weak H-alpha.							9	
217 S			<-13.5	<7	(both)						a
219 N	0.0074	6	-13.67		0.71					6	e
219 S	0.0075	6	-13.29	18	0.39	<0.3		>3		6	e
224	0.0217	10	no emission	(both).						9	
226	0.0161	9	no emission	(both).						9	
228 NE	0.0078	6	<-14.40	<2						6	e
228 SW	0.0090	2	-11.92	Seyfert 2.						16	
230	0.0114	2	-13.12	82	0.15	0.27	1.0	8.1			b
231 NW	0.0072	2	-13.57	9	1.1	<0.5		>2			a
238 N	0.0136	2	<-14.5	<3							d

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

TABLE 2—*Continued*

VV (1)	z (2)	Ref. (z) (3)	Flux Hα (4)	E.W. Hα (5)	6583 ---- Hα (6)	SII --- Hα (7)	5007 ---- Hβ (8)	Hα -- Hβ (9)	6300 ---- Hα (10)	Ref. (e.l.) (11)	Apr. (12)
238 S	0.0143	2	-13.52	48	0.34	0.24	<1	11			d
242	0.0167	9	both H-II regions.							9	
244 SE	0.0067	2	-12.74	24	1.24	0.40	3.04	6.7	0.10	6	e
244 NW	0.0066	2	-12.92	100	0.36	0.19	0.24	6.7		6	e
245 W	0.0049	6	-12.76	91	0.35	0.18	0.29	7.2		6	e
245 E	0.0048	6	-12.70	91	0.35	0.42	1.1	7.6	0.08	6	e
246 W	0.0055	6	-12.65	99	0.21	0.12	1.7	2.3		6	e
246 E	0.0053	6	-13.13	63	0.19	0.4	1.6	4.4		6	e
249 E	0.0113	6	-12.76	97	0.24	0.23	1.0	3.7		6	e
249 W	0.0105	6	-13.28	18	0.89	0.69	0.56	4.2	0.19	6	e
250 E	0.0306		-12.38	290	0.29	0.24	1.1	8.9			a
250 W	0.0310		-13.8	5	0.3	<0.3					a
251	0.0046	2			<<1		<1			9	
256 N	0.0125	2	-13.67	62	<0.1	0.50	5.4	7.9			b
256 S	0.0121		-13.76	11	<0.2						b
261	0.0082		-11.79	210	0.26	0.26	1.1	6.7			a
272 SE	0.0189	18	<-13.4	<10							a
280	0.0063	8	-12.47	35	0.31	0.25				8	
285	0.0432		-11.98	Seyfert 1.						21	
288 a	0.0223	19	-13.35	Seyfert 2.						14	
288 c	0.0190	24		H II region						24	
288 e	0.0223	24		H II region						24	
295 SE	0.0120		-13.25	240	0.19	0.22	1.9	4.1	0.03		c
295 NW	0.0119		-13.65	62	0.50	0.40		>3			c
300 S	0.0234	6	-14.17	11	0.97	<0.5				6	e
300 N	0.0240	6	-13.28	46	0.38	0.08	0.67	8.3		6	e
307 S	0.0043	8	-13.31	2	0.2	<0.1				8	
307 N	0.0053	23	H-II region.							23	
308	0.0022		-13.45	1	3.0	1.6				8	
309 N	0.0121	2	<-13.6	<6							a
309 S	0.0122	2	<-13.4	<9							a
316 S	0.0246	11	-14.22		1.0					25	e
316 N			-14.60		1.0					25	e
320	0.0047	2	-14.13	20	<0.4	0.43		>2			b
323 NW	0.0255		-14.42	3	0.70	<0.3		>4			d
323 SE	0.0255	4	-13.62	48	0.67	0.22	1.0	9.4			d
324 NW	0.0039		-12.79	200	0.06	0.10	4.5	4.8			c
329	0.0171	2	-12.27	91	0.45	0.31	1.3	6.6	0.02		a
331 SE	0.0288	2	-13.53	Seyfert 2.						14	
331 NW	0.0282	2		no emission						9	
334	0.0134		-13.52	13	1.2	0.42	>10	>30	0.04		d
343	0.0289		-12.44	Seyfert 2.						22	
344	0.0012	8	-13.15	26	0.36	0.27	<0.2	4.4	<0.01	7	g
350	0.0117	6	-13.58	14	0.69	0.33		>3		6	e
352 S	0.0271		-12.72	190	0.25	0.29	0.51	4.6			d
354	0.0420?		-14.04	5	<1	(H-alpha?)					a
357	0.0026		-13.52	21	0.36	0.17		>10			b
359	0.0114		-13.08	30	0.53	0.15		>6			a
361	0.0149		-13.48	6	0.50			>3			d
362	0.0303	2	-14.29	4	1.21	<0.5		>3			c
364	0.0309		<-13.7	<3	(both nuclei)						a
366	0.0021		-12.61	79	0.14	0.24	3.6	4.4	0.03		b,c
367	0.0120	2	-13.70	13	<0.5						a
372	0.0240		-13.52	26	<0.3						a
384	0.0162		-13.02	70	0.40	0.31	0.5	6.9			a
396	0.0527		-13.82	56	0.28	<0.3	3.1	5.9			b
406	0.0036	8	-12.39	50	0.43	0.30	1.1	8.6	<0.02	7	g
407	0.0105	13	-13.60	22	<0.8						a
408	0.0275		<-13.90	<4							b
412	0.0073		-12.98	67	0.43	0.33	<0.2	5.2			b
424	0.0100		-13.42	45	0.18	0.28	<0.4	12			d
426 W	0.0152		-13.18	47	0.39	<0.3					a
428	0.0195	11	<-14.1		<2						a
430	0.0171	2	-13.77	4	1.4	1.1	>1.2	>5			b
434	0.0161		-13.98	28	0.44	<0.4					b
446	0.0085		-12.42	160	0.44	0.20	0.30	4.7			a
448	0.0018	8	-12.66	11	0.84	0.71	4.2	9.1	0.05	7	g
455	0.0079		-12.15	18	0.31	0.21		>15			b
457	0.0050		-13.75	75	<0.1	0.25	6.9	5.7			b
459	0.0040	12	<-14.40	<8							b
460	0.0180		-13.60	12	<0.5						a
470 W	0.0175		-13.55	38	0.34	<0.3		>4			a
475	0.0052		-12.74	70	0.38	0.15		>5			a
477	0.0122		-12.81	150	0.32	0.30	0.87	5.5			b
480	0.0188		-12.82	48	0.37	<0.3	>1	5.3			a
481	0.0103		-13.26	57	0.41	0.50		>4			a
482	0.0048		-12.03	140	0.09	0.17	8.3	3.7			a
485	0.0173		-13.37	30	0.47	<0.2	<1.5	16			b
486	0.0197		-13.65	7	0.39	<0.3					a
488			<-13.80	<5							a
518 N	0.0206		-13.13	30	0.17	<0.2		>5			a
518 S	0.0210		-13.48	56	<0.5			2.0?			a
520	0.0069	2	-13.65	29	0.29	0.40		>3			b
523	0.0110	6	-12.56	235	0.10	0.23	2.8	3.1	0.02	6	e
528	0.0130		-12.12	120	0.48	0.26	0.40	4.0			a
529	0.0206	2	-13.29	28	0.42	0.29	<0.5	14			b
530	0.0087		-13.13	40	0.42	0.36	<1	11			b
537	0.0068		-14.00	6	2.0	<0.7					a
540	0.0183		weak H-alpha.							9	
541	0.0082		-12.67	58	0.48	0.22	0.37	5.3			a

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

1985ApJS...57..643D

TABLE 2—*Continued*

VV (1)	z (2)	Ref. (z) (3)	Flux Hα (4)	E.W. Hα (5)	6583 / Hα (6)	SII / Hα (7)	5007 / Hβ (8)	Hα / Hβ (9)	6300 / Hα (10)	Ref. (e.l.) (11)	Apr. (12)
545			<-13.60	<1							a
547 NW	0.0104	2	-13.11	110	0.07	<0.1	4.1	4.3			a
547 SE	0.0104		-12.71	460	0.04	0.10	5.8	3.8			a
563	0.0030	3	-13.39	58	0.18	<0.2	<1	4.8			a
565 NE	0.0132		-12.14		0.13	0.16	2.6	3.4	0.01		c
592			<-13.80	<8							a
609	0.0238	2	-13.07	Seyfert 2.						14	
610	0.0133		-13.30	40	<0.6						a
612	0.0113		-12.96	90	0.26	<0.2	1.2	3.5			a,d
619	0.0113	2	-12.53		0.19	0.23	2.0	4.3			a
626 SW	0.0293		-12.78		0.44	0.31	1.1	5.8			a
626 NE	0.0291		-12.12		0.45	0.20	0.47	6.0			a
668 S	0.0201	9	H II region							9	
668 N	0.0201	9	5007>>H-beta ; 6583 = H-alpha							9	
669	0.0256?		<-13.70	<6							a
686	0.0417		-14.18	33	0.55	<0.4		>2.5			b
690	0.0051		-13.03	38	0.16	0.44	2.0	5.0			b
700	0.0226		-12.28	Seyfert 1 (see Table 10)							c
708 S	0.0164		-12.66		0.22	0.33	2.3	5.8			a
713	0.0291		-13.60	15	0.98	<0.2		>5			b
721			<-13.8	<10							a
727	0.0210	2	-13.40	46	0.35	0.25	<0.5	7.2			b
764			<-13.6	<11	(both galaxies)						a
779			<-13.5	<10	(both galaxies)						a
781 S	0.0199		-12.81	200	0.37	0.29	<0.5	3.7			a
783 E	0.0157		-13.81	6	<1						a
783 W	0.0167		-13.27	20	0.35	<0.2		>5			a
791	0.0115		<-14.32	<3						7	
796	0.0037	15	no emission.							20	
800 SW			<-13.60	<8	star?						a
806	0.0220		-12.46	Seyfert 1.8 (see Table 10)							c
823 S	0.0091	6	-12.77	58	0.64	0.29	0.43	10.9	0.05	6	e
823 N	0.0085	2	-12.87	51	0.68	0.59	4.1	5.9	0.28	6	e
832			<-13.70	<5							a
850	0.0191		-13.12	Seyfert 2 (see Table 10)							c

REFERENCES.—(1) Afanasiev *et al.* 1980. (2) Huchra *et al.* 1983. (3) In Virgo. (4) Karachentsev 1980. (5) Keel 1983. (6) Keel *et al.* 1984. (7) Heckman, Balick, and Crane 1980. (8) Stauffer 1982*b*. (9) Tifft 1982. (10) Arp 1966. (11) Rood 1982. (12) Fisher and Tully 1981. (13) Sargent 1970. (14) Huchra, Wyatt, and Davis 1982. (15) Sandage and Tammann 1981. (16) Goodrich and Osterbrock 1983. (17) Rubin and Ford 1968. (18) RCBGII. (19) Arp 1973*b*. (20) Sandage 1978. (21) Weedman 1977. (22) Osterbrock and Dahari 1983. (23) de Vaucouleurs and de Vaucouleurs 1967. (24) Arp 1973*a*. (25) Keel, private communication.

APERTURE.—a, 8″.1 in diameter (1 m). b, 6″.5 in diameter (1.5 m). c, 2″.7×4″.0 (3 m ITS). d, 2″.0×8″.0 (3 m CCD). e, 6″.5 in diameter (1 m). f, 4″.7 in diameter (1.5 m). g, 6″.0 in diameter (2.5 m at Mount Wilson).

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

1985ApJS...57..643D

adequate spectral classification. While the correction for the equivalent width of Hα is in the order of 2 Å, it can be as large as 10 Å for Hβ (Keel 1983). Many systems from Karachentsev (1972, see Table 1) were observed by Tifft (1982). While Tifft did not publish line ratios or intensities, he described the spectra in words. At least one galaxy was included in his sample which was later classified as a Seyfert (NGC 1144, Huchra, Wyatt, and Davis 1982), but Tifft only mentioned the presence of emission lines. Therefore we used his data for our purposes only in cases where he reported on either the presence of a very weak Hα or when he detected no emission lines. As for other published sources of spectral information (i.e., Page 1970; Sargent 1970; Sandage 1978), most of them did not include Hα and hence could not be used.

Table 2 summarizes the spectral information available from our observations and other sources. In this table we do not include VVs of morphological type Im and later (see next section). Heliocentric redshifts are given in column (2), and references to their sources in column (3). If no reference is given, the redshift was measured in the present study. In column (4), logarithms of the observed fluxes in Hα (above Earth's atmosphere) are given in units of ergs s^{-1} cm^{-2}, and in column (5) the Hα equivalent widths in angstroms are listed. When the emission-line data are taken from other sources, the references are given in column (11). In column (12) we list the telescope and aperture used, as given in the notes. In Table 2, blanks are left if data are not available, or if the emission line is not detected above the noise in the continuum (see upper limits). Note that Tifft (1982) and Stauffer (1982*b*) did not specify the aperture used for the observations of individual objects.

IV. MORPHOLOGICAL AND SPECTRAL CLASSIFICATION

a) *Morphological Classification*

The VV catalogs include systems of vastly different shapes and sizes. They can be categorized in many ways. One classification scheme was adopted in VVII, where the galaxies are grouped to demonstrate the various effects or stages of "fragmentation." For the present study, however, we are concerned with interaction or tidal effects on the main body of the galaxy. From that point of view, the VV catalogs provide an almost uniform distribution of the degree of distortion. While some objects are almost perfectly symmetric, others are strongly distorted, or even totally disordered. Hence we feel that the general class of "interacting galaxies" can be further divided into subgroups of various interaction strengths. Similarly to the correlation between the parameter Q (Dahari 1984) and nuclear activity, we would like to see whether Seyfert nuclei appear preferentially in a specific interaction group, or whether the level of activity (see below) is correlated with the interaction strength.

The number of subclasses in any classification scheme is dictated by the span of the variables considered and by the degree of confidence at which each object of the sample can be classified. It is clear that single, symmetric spiral galaxies are less interacting than distorted members of close pairs, but it might be difficult to subclassify the many different kinds of asymmetric spirals, for example. After examining the photographs of the VVs of Table 1, we decided to divide the systems into six groups. We define the dimensionless "interaction class" (IAC) as an integer, which grows with the interaction *effect* on the galaxies, as seen projected on the sky. IAC = 1 (group 1) is assigned to isolated symmetric galaxies, and IAC = 6 (group 6) is assigned to severely disordered spirals or overlapping systems.

The IAC is determined by the degree of asymmetry of the galaxy, by the distance and size of a companion, and by the presence of connecting arms between the pair members. The presence of a nearby companion (with a comparable redshift) almost certainly imposes a significant tidal force on the galaxy. It is not certain whether radial flows are present when a galaxy is still symmetric despite the presence of a close companion, but we consider that the IAC should be larger for galaxies that have companions (in addition to the IAC based on their degree of asymmetry). In a few cases where a large redshift difference between pair members was found, the system was treated as two single galaxies or was not included in the sample (see below). The presence of tidal effects in pairs is evident not only by distortion of pair members, but also by "bridges," or faint connections, between them. In Tables 3 and 4 we describe the IAC classification of single- and double-galaxy systems, respectively. Representative examples illustrated by Arp (1966), with corresponding VV numbers in parentheses, are given in both tables. For most pairs, only Table 4 was used. For those pair members that were symmetric or very distorted, the IAC was decreased or increased by one subclass, respectively. Single galaxies with ring structures (i.e., ring galaxies, and not the more common galaxies with internal rings) were given larger IAC values. These galaxies are believed to be results of face-on collisions between spiral galaxies (Spiegel and Theys 1976).

The IAC classification was made without knowledge of the nature of the nuclear emission-line spectra, so that no bias was introduced into the Seyfert distribution among the IAC groups. The IAC values are listed in Table 5, column (3). In all but a few cases, the uncertainty in IAC classification was small, not larger than one subclass. By comparing the IAC values in Table 5 and the photographs in the VV catalogs (or the Arp catalog), one can examine the validity and uncertainty of the classification.

Since no Seyfert nucleus is known to be in a dwarf irregular, we had to distinguish between LMC-like irregulars and strongly disordered spirals (which have very complex struc-

TABLE 3

THE INTERACTION CLASS (IAC) OF SINGLE GALAXIES

IAC	Description	Example Arp (VV)
1	symmetric	27 (363)
2	slightly asymmetric, diffuse extensions	26 (344)
3	asymmetric, extended arm	222 (67)
4	distorted, out of shape	224 (31)
5	strongly disordered	220 (540)
6	aftermath	157 (231)

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

1985ApJS...57..643D

TABLE 4

THE INTERACTION CLASS (IAC) FOR PAIRS

	COMPANION SIZE					
	SAME		~1/2		SMALL	
SEPARATION	IAC	Arp (VV)	IAC	Arp (VV)	IAC	Arp (VV)
Large, no contact.......	3	305 (424)	2	23 (73)	1	...
Large, connected.......	4	314 (295)	3	304 (334)	2	24 (14)
Small, no contact.......	4	271 (21)	4	112 (226)	3	290 (309)
Small, connected.......	5	283 (50)	4	85 (1)	4	82 (9)
Overlap.................	6	166 (189)	5	309 (217)	4	239 (19)

tures in some cases). The origin and evolution of dwarf irregulars is not well understood, and it is not at all clear whether their irregular morphology is caused by tidal forces. These galaxies show no evidence of spiral arms, have very small sizes (based on the redshifts), and no symmetry. Most of the dwarf irregulars have low surface brightness, do not have a nucleus, and some have many H II regions. The morphologies of the following VVs agree with the above definition, and they are therefore not included in Tables 2 and 5: VV 30, 80, 89, 95, 97, 98, 104, 112, 119, 124, 134, 138, 313, 338, 531, 544, 545, 571, 618, 625, 726, 728, 795, 797, and 828. All these galaxies were observed by the author or by one of the following: Stauffer (1982*b*), Tifft (1982), Keel (1983), or Huchra *et al.* (1983). None of these galaxies have a Seyfert or a Seyfert-like nucleus. In a few cases the distinction between irregulars and disordered spirals was very uncertain and requires further study. These cases are marked with the letter I in Table 5, column (5).

Since this study concerns only galaxies undergoing tidal interaction, we decided to exclude galaxies with IAC = 1 as well: namely, single galaxies with symmetric morphology or symmetric members of *optical* pairs. These were not included in Tables 2 and 5, and are listed below:

VV 179, two ellipticals with $c\Delta z = 962$ km s^{-1} (Huchra *et al.* 1983);
VV 337, single elliptical galaxy;
VV 363, symmetric spiral;
VV 423, very faint, not interacting;
VV 427, symmetric spiral;
VV 441, symmetric spiral;
VV 624, symmetric Sa galaxy.

Should small companion galaxies be considered candidates for Seyfert activity? Although the luminosity function of Seyfert galaxies extends to low luminosities (Meurs 1982), we exclude dwarf companions from the sample for the following reasons: (i) in most cases the morphological classification is difficult, and (ii) in nearby galaxies in which classification is more precise, most dwarf companions are elliptical or irregular. Hence in pairs where the ratio of the semimajor axes is less than 0.5, only the larger galaxy of the pair is considered. In other cases both galaxies are included separately (see Table 5).

In Table 5, column (5), we divide the galaxies into three groups: spirals (S), ellipticals (E), and suspected irregulars (I). The letter C is added when the system is located in a dense cluster (within about one core radius). In column (4) we note whether or not systems with single entries in the table have (small) companions. In column (9), we list the classification from the RCBGII, and in the notes a brief description of each system is given (addressing especially the signs of interaction).

b) Spectral Classification

The main aim of this study is to find the frequency of Seyfert galaxies among interacting systems. However, the Seyfert phenomena appears to be at the upper end of a continuous range of emission-line activity (Keel 1982; Stauffer 1982*a*; Phillips, Charles, and Baldwin 1983). Although it is believed that the energy sources of nuclei along that sequence are not all the same (Seyferts vs. H II regions), the nature of Liners (low-ionization nuclear emission-line regions) (Heckman 1980) is still controversial (Ferland and Netzer 1983; Halpern and Steiner 1983). The difference between the various classes is based on line widths and line ratios (see Heckman 1980; Baldwin, Phillips, and Terlevich 1981, hereafter BPT; Shuder and Osterbrock 1981). The upper limit that can be set to the full width at half-maximum (FWHM) of the emission lines in our spectra was too high to distinguish between type 2 Seyferts and H II regions. Hence we have to base our classification on emission-line ratios only (except for very broad Balmer lines), in the region $\lambda\lambda$4700–7100.

By definition, Seyfert galaxies show emission lines from ions having a wide range of ionization potential. Among others, strong emission lines of low-ionization ions like [O I] and [N II] appear along with relatively strong lines of [O III] and He II. While in Liners the high-ionization lines are weak (or absent), in H II regions the low-ionization lines are weak or absent. Hence the ratios [O III] λ5007/Hβ, [O I] λ6300/Hα, and [N II] λ6583/Hα can be used to distinguish between the three groups, while defining as "intermediate" those spectra which have intermediate line ratios.

We define a qualitative variable that describes the emission activity in the nucleus, the nuclear emission type (NET), in Table 6. (The line ratio criteria are similar to Fig. 5 of BPT.) As evident from Table 2, in many cases only upper limits for [O III] λ5007 and/or Hβ are available, mostly because of very strong interstellar extinction and/or strong stellar Hβ absorption (see Hα/Hβ ratios). In these cases, when [N II] λ6583/H$\alpha > 0.5$, the distinction between Liners and type 2

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

TABLE 5

MORPHOLOGICAL AND SPECTRAL TYPES OF THE VORONTSOV-VEL'YAMINOV GALAXIES

VV (1)	Name (2)	IAC (3)	Comp. (4)	Rem. (5)	L(Hα) (6)	UL (7)	NET (8)	Hubble Type (9)
1	N5194	4	Y	S	39.09		3.0	SA(s)bc Pec
5	N7752	3	Y	S	41.47		6.0	SAB(rs)bc
8	N3981	2	N	S	39.62		5.0	SA(rs)bc
9	N2536	4	Y	S	40.24		3.5	SB(rs)c Pec
11	N3432	2	Y	S	39.30		3.5	SB(s)m
14	N3445	2	Y	S	39.19		5.0	SAB(s)m
16	N5996	3	Y	S	40.83		3.5	
19	N5278	4		S	40.50		2.0	SA(s)b(?)Pec
19	N5279	5		S	40.14		3.0	SB(s)a Pec
21	N5427	4		S	39.79		2.0	SA(s)c Pec
21	N5426	4		S	39.37		5.0	SA(s)c Pec
22	N3656	3	N	I			6.0	Pec I0(?)
23	N1347	3	Y	S			7.0	
31	N3921	4	N	SC	40.52		3.0	
33	N5216	5		E	39.70	UL	6.0	E0 Pec
33	N5218	4	Y	S	39.60	UL	6.0	SB(s)b(?)Pec
36	N0517	3	Y	EC	39.59	UL	6.0	
48	N5395	4		S	39.06		3.0	SB(s)b Pec
48	N5394	4		S	37.29		4.5	SA(s)b Pec
50	N2798	5		S	39.66		4.5	SB(s)a Pec
50	N2799	5		S	38.48		3.5	SB(s)m(?)
51	N7714	4		S	41.34		4.0	SB(s)b(?)Pec
51	N7715	4		I			5.0	Im Pec
52	A0253	5	Y	S	39.49		4.0	SB(s)dm(?)
53	I0162	2	Y	E	40.02		5.5	
55	N5258	5		S	40.38		3.5	SA(s)b(?)Pec
55	N5257	5		S	40.31		5.0	SAB(s)b Pec
56	N4651	2	N	S	37.93	UL	6.0	SA(rs)c
66	N4027	3	Y	I	39.85		5.0	SB(s)dm
67	N7727	3	N	S	38.65	UL	3.0	SAB(s)a Pec
68	N7393	3	N	S	39.47		3.0	SB(rs)c Pec
73	N4618	2	Y	S	38.92		3.5	SB(rs)m
74	N7285	6		S	39.18		5.0	
74	West	6		S	39.51	UL	6.0	
75	N3509	3	N	S			6.0	SA(s)bc Pec
76	N4496	4	Y	I	40.48		6.0	SB(rs)m
77	N5614	3	Y	S	39.65		5.0	SA(r)ab Pec
79	N2623	6	N	S	40.26		3.0	Pec
81	SW	6		S			7.0	SAB0(r) Pec
81	N0274	5		E	39.31	UL	6.0	
83	U5146	6	N	S	39.05	UL	6.0	
84	N7436	5		S	39.63		2.5	
84	NE	5		E	39.56	UL	6.0	
86	N6052	3	N	I	41.03		3.5	Sc
101	I1259	6		E			6.0	S0 Pec(?)

VV (1)	Name (2)	IAC (3)	Comp. (4)	Rem. (5)	L(Hα) (6)	UL (7)	NET (8)	Hubble Type (9)
101	South	6		E			6.0	
117	N2444	6		I	39.10	UL	3.5	Ring A
117	N2445	5		S	37.54	UL	6.0	Ring B
120	N5421	6		S	40.76		3.0	
120	b	6		E	39.68		6.0	
126	U6945	4	Y	S	41.38		5.0	
130		3	N	S	39.50		5.0	
135	N5306	4	Y	E	40.06		6.0	
137		3	N	I	39.86		3.0	
140	A0261	4	Y	I	39.66		4.0	
175	N0741	4	Y	E	40.29	UL	6.0	E0
178	N2293	4		E	40.15	UL	6.0	
178	NW	5		E	39.95	UL	6.0	
188	N4438	4	Y	S	38.51		2.5	SA(s)0/a Pec(?)
189	N0750	6		E			6.0	E pec
189	N0751	6		E			6.0	E pec
193	N0383	2	Y	EC	39.99	UL	5.0	SA0(?)
201	N4782	5		E	39.89	UL	6.0	E0 Pec
201	N4783	5		E	39.89	UL	6.0	E0 Pec
206	N4649	3		SC	38.89		4.5	SAB(rs)c
206	N4647	3		EC	40.14	UL	6.0	E2
207	N0507	3	Y	SC	40.54		6.0	SA0(r)
208	N7783	4		S			6.0	S0(?)
208	b	4		E			6.0	
209	N3227	5		S	41.07		1.5	SAB(s)a Pec
209	N3226	4		E			3.0	E2(?)Pec
210	N5545	6		S	39.42		3.5	SA(s)bc(?)
210	N5544	6		S	38.85		5.0	(R)SB(rs)0/a
216	N4015	5		S	39.41	UL	5.0	
216	South	4		E			6.0	
217	N0942	5		S	39.62	UL	7.0	S0(?)Pec
217	N0943	5		E	39.62	UL	6.0	I0(?)Pec
219	N4568	6		SC	39.87		3.5	SA(rs)bc
219	N4567	6		SC	39.49		4.5	SA(rs)bc
224	N4676	5		S			6.0	
224		5		S			6.0	
226	N7806	4	Y	S			6.0	SA(rs)bc(?)Pec
228	N3786	5		S	38.79	UL	2.0	SAB(rs)ab Pec
228	N3788	5		S	41.19		6.0	SAB(rs)a Pec
230	N4004	5	N	S	40.37		3.5	Pec
231	N0520	6	N	S	39.30		3.5	Pec
238	N0935	5		S	40.74		4.5	
238	North	5		S	39.76	UL	6.0	
242	N7253	5		I			4.0	
242	SE	4		S			4.0	

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

TABLE 5—*Continued*

VV (1)	Name (2)	IAC (3)	Comp. (4)	Rem. (5)	L (Hα) (6)	UL (7)	NET (8)	Hubble Type (9)
244	N5953	5		S	40.34		2.0	SAa(?)Pec
244	N5954	5		S	40.16		3.5	SAB(rs)cd(?)Pec
245	N4038	6		S	39.76		4.0	SB(s)m Pec
245	N4039	6		S	39.70		3.5	Pec
246	N3395	4		S	39.90		3.5	SAB(rs)cd Pec(?)
246	N3396	4		I	39.42		3.5	IBm Pec
249	N3994	3	Y	S	40.72		4.0	SA(r)c Pec(?)
250	A0238	5		S	41.92		4.0	
250	West	5		S	41.34		4.5	
251	N3664	3	N	I			4.0	SB(s)m Pec
256	N5410	4	Y	S	39.88		5.0	
261	N4194	4	N	I	41.42		3.5	IBm Pec
272	N7828	4	Y	I	39.45	UL	7.0	Ring A+B
280	N7625	2	N	S	40.37		4.5	
285	N0985	4	N	S	42.59		1.0	Ring
288	N7319	4		S	40.61		2.0	
288	N7318	5		S			4.0	
288	West	5		S			4.0	
295	A0314	4		S	40.11		3.5	(R')SA(s)bc(?)
295	NW	4		S	39.71		4.5	
300	N3808	5		S	39.91		3.0	SAB(rs)c(?)Pec
300	North	5		S	40.80		4.5	IO(?)Pec
307	N3190	3		S	39.45		5.0	SA(s)a Pec
307	N3187	4		S			4.0	SA(s)c Pec
308	N3627	3	N	S	38.90		3.0	SAB(s)b
309	I0196	3	Y	S	40.08	UL	6.0	
316	N2936	5		S	40.01		5.0	Ring A
316	N2937	4		E	39.58		5.0	Ring B
320	N3846	3	N	I	38.66		4.5	SAc(?)
323	U1810	3		S	41.44		3.0	SA(s)b Pec
323	NW	4		S	40.64		5.0	SB(s)a Pec
324	U9562	3		S	39.83		4.0	
324	SE	3		S			7.0	Pec
329	N7679	3	N	S	41.42		3.5	SBO Pec(?)
331	N1144	5		S	40.73		2.0	Ring A
331	N1143	4		E			6.0	Ring B
334	N1241	3	Y	S	39.98		2.0	SB(rs)b
343	N7674	3	Y	S	41.81		2.0	SA(r)bc Pec
344	N5457	2	N	S	39.04		4.5	SAB(rs)cd
350	N3800	4	Y	S	39.93		3.0	SAB(rs)b(?)Pec
352	A0256	4		S	41.41		4.0	
352	North	5		S			7.0	
354	I0609	3	Y	S	40.62		5.0	
357	N4088	3	N	S	38.88		4.5	SAB(rs)bc
359	N7678	2	N	S	40.37		3.5	SAB(rs)c
361	N0341	3	Y	S	40.10		4.5	
362	U1775	4	Y	S	39.96		5.0	
364	N6166	5	Y	E	40.68	UL	6.0	E2 Pec
366	N4765	2	N	S	39.67		4.0	SO(?)
367	N3920	2	N	E	39.84		5.0	
372	N7301	3	N	S	40.50		5.0	
384	N4048	2	Y	E	40.76		4.5	
396		4	Y	S	40.97		4.0	
406	N3310	2	N	S	40.40		3.5	SAB(r)bc Pec
407	N7756	2	Y	S	39.64		5.0	SA(rs)c
408	N5619	2	N	S	40.31	UL	6.0	SAB(rs)b
412	N5665	2	N	S	40.12		3.5	SAB(rs)c Pec
424	N4017	3	N	S	40.36		4.5	
426	NW	4		S	40.70		5.0	
426	SE	4		S			7.0	
428	N0797	3	Y	S	40.00	UL	6.0	
430	N0452	2	N	S	40.08		2.5	
434		3	N	S	39.84		5.0	
446		3	N	S	41.88		4.0	SAB(s)cd
448	N4258	2	N	S	39.32		2.0	SAB(s)bc
455	N3888	3	N	S	41.03		4.5	SAB(rs)c
457		3	Y	S	39.11		4.0	
459	N3733	3	N	S	38.28	UL	6.0	SAB(s)c(?)
460	N5000	3	Y	S	40.26	UL	5.0	SB(rs)bc
470		4	Y	S	40.18		5.0	
475	N2559	3	N	S	42.16		4.5	
477	N3836	3	N	S	40.81		3.5	
480		2	N	S	40.97		4.5	
481	N2738	3	N	S	40.25		4.5	
482	N1140	3	N	I	40.48		4.0	Im
485		3	N	S	40.53		4.5	
486	N0356	3	N	S	40.19		5.0	
488		4	Y	S			6.0	
518	South	3		S	40.75		5.0	SB(s)c PeC(?)
518	North	3		S	40.50		5.0	
520	N4197	2	N	S	39.45		5.0	Scd
523	N3991	3	N	I	40.90		4.0	Im Pec
528	M1199	4	N	S	41.77		3.5	
529	N3356	3	N	S	40.69		3.5	
530	N5595	3	N	S	40.89		3.5	SAB(rs)c
537	N6570	3	N	S	39.43		5.0	SB(rs)m(?)
540	I4553	5	N	I			5.0	
541	N2750	3	N	S	40.65		3.5	SABc
547	U5189	4	N	I	40.79		4.0	
548		3	N	S			7.0	

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

1985ApJS...57..643D

TABLE 5—*Continued*

VV (1)	Name (2)	IAC (3)	Comp. (4)	Rem. (5)	L(H) (6)	UL (7)	NET (8)	Hubble Type (9)
563	I3476	4	N	IC	34.93		5.0	IB(s)m(?)
565	N1741	5		S	41.61		4.0	SB(s)m(?)
565	SW	4		S			7.0	SB(s)m Pec
592		3	N	I			6.0	
609	N4922	5	N	S	41.02		2.0	IO Pec
610		3	N	S	40.20		5.0	
612	N2744	4	Y	S	40.63		4.5	SB(s)ab(?)Pec+E3
619	N7677	6	N	S	40.90		4.5	(R')SAc(?)
621	N6926	3	N	S			7.0	SB(s)c Pec
626	N6090	6		S	42.20		3.5	
626	SW	6		S	41.54		3.5	
661		4	N	I			7.0	
668	North	4		S			3.0	
668	South	4		S			4.0	
669	N7656	4	N	I	40.38	UL	6.0	
686		3	N	S	40.40		5.0	
690	N1345	2	N	S	39.56		4.0	S Pec
700	N7214	4	Y	S	41.68		1.0	SAB(rs)c Pec
708	M0221	5		S	41.11		4.0	Pec
708	North	4		S			7.0	
713		3	N	S	40.66		3.0	
721		3	N	S			7.0	
727	U5884	3	N	S	40.59		4.5	
764	N7018	6		EC			6.0	
764	N7017	6		EC			7.0	
779	I1670	5		S			6.0	
779	West	5		S			7.0	
781	South	5		S	41.04		3.5	
781	North	5		S			7.0	
783	N0523	4	N	S	40.64		5.0	Pec
791	N0175	3	N	S	39.00	UL	6.0	SB(r)ab
796	N3175	2	N	S			6.0	SAB(s)a(?)
800	N7115	3	N	S			7.0	
806	M0334	4	N	S	41.59		1.5	Pec.
823	N5929	5		S	40.31		2.0	Sab(?)Pec
823	N5930	5		S	40.41		3.5	SAB(rs)b Pec
832	N7306	2	N	S			6.0	
850	N0034	3	N	S	40.69		2.0	

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

1985ApJS...57..643D

NOTES TO TABLE 5 (BY VV NUMBER)

(For additional descriptions and references see VVII and Arp 1966.)

5. Spiral with a small companion. The spiral appears to have a double nucleus, one of which might be a foreground star. See also Arp 1969, Bertola and D'Odorico 1973.
8. Spiral with a faint extended arm. The nucleus is $\sim 8''$ in diameter.
9. Spiral with a small companion on an extended arm (Arp 1969).
11. Edge-on asymmetric spiral with a faint extension out of plane.
14. Spiral (irregular?) with a small companion on an extended arm. Nucleus is $\sim 10''$ in diameter.
19. Two interacting spirals of comparable size (east is NGC 5278). See Bergvall 1981.
22. Elliptical with a faint extension to south (dust lane?).
23. Faint spiral with a small companion. No bright nucleus.
31. Distorted spiral (aftermath?), in a cluster.
33. Distorted spiral with an S0 companion, well separated but with a connecting arm. North (spiral) is NGC 5218, which has no bright nucleus.
36. Elliptical with a very small companion. Nucleus is elongated to $\sim 6'' \times 15''$.
48. Asymmetric spiral with a spiral companion having two open arms, one of which is connected to the asymmetric spiral (Arp 1969).
50. Two distorted, interacting spirals. West has a blue continuum (de Vaucouleurs 1979).
51. Two interacting spirals (west is distorted). For a good spectrum, see French 1980.
52. Two edge-on spirals in a plane (contact). East is very faint.
56. Spiral with a very faint extended (straight) spiral arm.
66. Asymmetric sprial (irregular?) with a small, separated companion.
68. Slightly asymmetric spiral with a fuzzy nucleus.
73. Asymmetric spiral with a separated, small companion.
74. Spiral strongly interacting with an S0 companion.
75. Asymmetric spiral with loose arms. But see VVII.
76. Spiral/irregular with a nearby small companion, which differs in radial velocity by 2700 km s^{-1} (optical pair?).
77. Asymmetric spiral with extended arm and a small, separated companion (NGC 5615).
79. Very distorted spiral—aftermath? Nucleus is approximately $10''$ in diameter. See VVII.
81. Interacting close pair; one is elliptical.
83. Patchy spiral overlapping with an Sa galaxy.
84. Elliptical with an extension to the west (edge-on spiral?) and a spiral companion. In a small group.
86. Irregular(?) galaxy with many H II regions. Interacting?
120. Distorted spiral with an overlapping elliptical.
126. Distorted spiral, connected to a small companion. See Meltov 1980.
135. Elliptical with a small companion. The nucleus might have a jet to the northwest ($10''$ in diameter).
137. Faint amorphous spiral with a very faint nucleus. Stellar object east of nucleus is probably a foreground star.
140. Irregular (spiral?) with a faint companion, embedded in a faint envelope. See VVII.
188. Strongly distorted spiral with a small S0 companion.
193. Elliptical overlapping a small companion (brightest in a loose chain).
201. Two overlapping ellipticals. North (NGC 4782) has a nucleus approximately $5''$ in diameter.
206. Symmetric spiral with a giant elliptical companion (in Virgo).
208. Two flat S0's in a row (bridge).
217. S0 with a dust lane, with a nearby elliptical.
219. Two overlapping spirals, not distorted (in Virgo).
224. Two strongly interacting spirals (both distorted, tails).
226. Distorted spirals with an S0 companion.
230. Strongly distorted spiral (aftermath?).
231. Strongly distorted spiral, edge-on (aftermath?).
238. Two interacting spirals, North has no nucleus. South (smaller) has a small nucleus.
242. Irregular(?), very faint, no nucleus.
244. Distorted spiral in contact with an S0. See Jenkins 1984.
245. See Toomre and Toomre (1972).
246. Two spirals in contact, many H II regions. North is irregular? See VVII.
249. Distorted spiral with a small, separated companion.
251. Distorted spiral (irregular?). Anemic, with a few H II regions.
256. Distorted spiral with a small separated companion. See Bergvall 1981.
272. Distorted spiral (irregular?) with a small elliptical companion. See Freeman and de Vaucouleurs 1974.
280. Spiral with asymmetric dust lanes.
285. Very asymmetric spiral, a ring with nucleus on its arm.
288. Stephan's Quintet. I did not include NGC 7317 (separated, small elliptical) or NGC 7320 (foreground galaxy). However, see Arp 1973*a*.
295. Two separated spirals with faint tails and a connecting arm.
307. Edge-on spiral with a smaller spiral (not connected). Interacting?
316. Very distorted spiral "around" an elliptical.
320. Spiral (irregular?) with a diffuse envelope.
323. Two distorted spirals. In contact?
324. Two small Sa galaxies, far apart but showing signs of interaction.
329. Distorted spiral (another SB galaxy located $4'$ east). See Grayzeck 1983.
334. Slightly asymmetric spiral with a small companion.
352. Two very distorted spirals, in contact(?). North is very faint, with no visible nucleus.
354. Asymmetric spiral with a very small, separated companion. Nucleus is $\sim 3''$ in diameter.
357. Distorted spiral with many H II regions (irregular?). Elongated nucleus, $\sim 8'' \times 15''$.
361. Barred spiral with a very small companion at tip of arm. Has stellar nucleus.
362. Ring galaxy; nucleus is off-center; asymmetric faint outer arms.
364. Double-nucleus (about $10''$ apart) elliptical.

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

1985ApJS...57..643D

NOTES TO TABLE 5—*Continued*

366. Looks like a dwarf elliptical with a very faint extension to the southeast. Nucleus is ~ 8″ in diameter.
367. Small elliptical with a small extension to the north. Nucleus is ~ 6″ in diameter.
384. Elliptical(?) with extension toward stellar companion. Nucleus is ~10″ in diameter.
396. Very faint galaxy (~15″ in diameter) with two faint stellar companions(?).
406. Asymmetric spiral with many H II regions.
407. Asymmetric spiral, with one arm extending to a very small companion (H II region?).
408. Slightly asymmetric spiral. Nucleus is ~10″ in diameter.
412. Asymmetric spiral. Nucleus is ~ 4″ in diameter.
424. Asymmetric barred spiral (= Arp 305 south).
426. Asymmetric spiral (no nucleus) with a faint edge-on spiral in contact.
448. Asymmetric spiral. See van der Kruit, Oort, and Mathewson 1972.
457. Faint, asymmetric spiral (almost edge-on), may have a very small companion out of plane.
459. Slightly asymmetric spiral, no nucleus.
460. Asymmetric spiral with an extended arm pointing at a small companion.
470. Spiral in an "arc" shape, having a second bulge on one side. See Korovyakovskaya 1983.
475. Asymmetric spiral with no nucleus.
477. Distorted spiral with an elongated nucleus (12″×4″).
480. Slightly asymmetric spiral, no nucleus.
481. Slightly asymmetric spiral with a stellar object on one arm (no nucleus).
482. Spiral with one extension. Nucleus is ~10″ in diameter (elongated).
486. Asymmetric spiral. Nucleus is ~ 5″ in diameter.
488. Edge-on spiral with a small companion out of plane.
523. Elongated spiral (banana shape). See VVII and Korovyakovskaya 1983.
528. Asymmetric spiral with a straight arm to the northeast.
529. Asymmetric spiral. Nucleus is ~12″ in diameter.
530. Asymmetric spiral. Southeast is VV 446, but no evidence for contact.
540. Very irregular spiral.
541. Asymmetric spiral with a stellar nucleus.
545. Irregular? West nucleus is a foreground star.
547. Very faint spiral(?) with a stellar nucleus and a bright extended arm to the northwest.
548. Distorted spiral (very faint, no nucleus).
563. Spiral (irregular?) with an extension but no nucleus.
565. Two interacting spirals, or one spiral with a distorted arm which looks like another galaxy.
592. Spiral (irregular?) with an extension.
609. Strongly distorted spiral (aftermath?).
610. Asymmetric spiral with extension (faint, no nucleus).
612. Very asymmetric spiral with a faint connected companion(?).
619. Bright, double-nucleus spiral (south nucleus might be a foreground star).
621. Distorted spiral. Small elliptical located 4′ east (not connected).
626. Double-nucleus spiral with tail. See Bergvall 1981.
661. Blue distorted spiral, very faint, no nucleus.
669. Looks like an elliptical with faint extensions to the northeast and northwest.
690. Slightly asymmetric spiral(?) with small extension.
708. Two small distorted spirals(?) in contact.
713. Asymmetric spiral, nucleus ~ 6″ in diameter.
727. Asymmetric spiral, nucleus ~10″ in diameter.
764. Two ellipticals? In cluster.
779. Two edge-on spirals (interacting?), one pointing at nucleus of the other.
781. Two slightly distorted, interacting spirals (north is faint).
783. Peculiar spiral, with two nuclei on sides (east-west). Chincarini and Heckathorn 1973 claim that the west nucleus is a foreground star, but our measured redshift is similar to that of the east one.
800. Asymmetric spiral ("comet") with no nucleus. Southwest tip might be a foreground star (no emission lines).
806. Ring galaxy; nucleus is off-center.
832. Slightly asymmetric spiral with faint extension (faint, no nucleus).
850. Asymmetric spiral with a faint "jet" to the northeast.

For additional information on VV 249, 523, 565, 609, 612, 621, and 713, see Barbieri *et al.* 1979.

Seyferts was not certain, and when [N II] λ6583/Hα < 0.5, the NET was 4, 4.5, or 5 according to the equivalent width of Hα. The class NET = 3.5 includes cases of intermediate line ratios, or cases where [N II] λ6583 ≈ Hα, but both emission lines have small equivalent widths and are the only lines detected. For most of the Seyfert galaxies in the sample, detailed studies of the spectra have already been published (see references in Table 5). For those Seyferts or suspected Seyferts for which spectral data are not available from other sources, we obtained further observations of high S/N and higher resolution with the 3 m telescope (see § VI). Thus their classification as Seyferts is based on additional information, such as weak high-ionization emission lines, line widths, and the existence of weak, broad components to the Balmer lines.

In Table 5 we list the NET according to the data of Table 2. We also list the logarithm of the luminosity in Hα (in ergs s^{-1}), as calculated from the observed flux and redshift. To get the distance, we used $H_0 = 75$ km s^{-1} Mpc^{-1} and corrected the redshift for the solar motion relative to the background 3 K blackbody radiation (360 km s^{-1} toward

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

1985ApJS...57..643D

TABLE 6

THE DEFINITION OF THE NUCLEAR EMISSION TYPE (NET)

NET	Name	λ5007/Hβ	λ6583/Hα	λ6300/Hα
1......	Seyfert 1 (very broad Balmer lines)			
1.5 ...	Seyfert 1.5–1.9[a]			
2......	Seyfert 2	> 3	> 0.5	> 0.1
2.5 ...	marginal Seyfert	~ 3	~ 0.5	> 0.1
3......	Liner	< 3	> 0.5	> 0.1
4......	H II region	> 3	< 0.4	< 0.1
5......	weak Hα			
6......	no emission [EW(Hα) < 10]			
7......	no emission: noisy or not observed when no nucleus is seen			

[a] See Osterbrock and Dahari 1983.

R.A. $=11^{\mathrm{h}}.2$ and $\delta=+19°$, Gorenstein and Smoot 1981). We also corrected the observed Hα flux for reddening in the Galaxy. In cases where only upper limits to the flux in Hα are available, the letters UL appear in column (7).

V. RESULTS

We compare the distributions of redshifts and apparent magnitudes of the VV Seyferts with those of the non-Seyfert VVs. Table 7 lists the averages and standard deviations of redshifts and magnitudes for the two samples. In Table 7, the magnitudes are taken from the UGC and the VV catalog, and the redshifts from Table 2 (redshifts were not available for all systems). Note that for multiple galaxy systems, only one entry was included in the statistical calculations of Table 7, and that the "Seyferts" include the marginal cases (NET = 2.5). In cases where the Seyfert is in a multiple-galaxy system (Table 5), the redshift and magnitude are included in both samples.

The median statistical test (Siegel 1956) is used to find whether the mean redshift or mean magnitude of the Seyferts is statistically different from the non-Seyfert VVs. Since the sum of the number of galaxies in the samples is larger than 40, the χ^2 (corrected for continuity) is used. The results are $\chi^2=0.28$ and $\chi^2=0.89$ for the redshift and magnitude distributions, respectively. Hence the means of the redshifts and magnitudes of the two samples are *not* statistically different. The Seyferts are intrinsically brighter, on the average, by ~ 0.5 mag, but their mean is brighter than the sample limit of $m \leq 14.5$. Therefore, we conclude that no bias that favors galaxies with Seyfert nuclei was introduced by the magnitude limit of the VV sample.

TABLE 7

AVERAGES OF REDSHIFTS AND APPARENT MAGNITUDES FOR SEYFERT AND NON-SEYFERT VV GALAXIES

Parameter	non-Seyferts	Seyferts
$\langle z \rangle$................	0.0143	0.0174
σ	0.0093	0.0112
Number...........	158	19
$\langle m \rangle$	13.3	13.0
σ	1.05	1.34
Number...........	171	19

TABLE 8

SUMMARY OF THE MORPHOLOGIES IN TABLE 5

Total number of interacting galaxies ...	218
Seyferts (NET = 1–2.5)	19
Ellipticals................................	29
Suspected irregulars	22
Spirals in clusters	5
Suspected irregulars in clusters	1
Pairs (of comparable size)	51
Pairs of spirals (of comparable size)	29
Spirals (outside clusters).................	162
Number of spirals with IAC > 3	91
Seyfert spirals with IAC > 3	14
Pairs of spirals with IAC > 3...........	26

In Table 8 we summarize the morphologies of Table 5, and in Table 9 we list the frequencies of NET versus IAC. We find that Seyfert nuclei occur in 9% of the total sample. However, none of the Seyfert nuclei (i.e., types 1–2.5) are located in an elliptical or suspected irregular galaxy, or in a dense cluster. This result agrees well with the Hubble-type distribution of Seyfert galaxies (Weedman 1977; Adams 1977; Simkin, Su, and Schwartz 1980). A few ellipticals are known to have active nuclei, but they are usually giant radio galaxies, which constitute a separate AGN subgroup. That group differs from Seyferts in characteristics other than morphology (see review by Osterbrock 1984). Since the Hubble-type distribution of Seyfert galaxies is concentrated within types S0–Sc, we should examine the frequency of Seyfert nuclei among VV *spirals*. If we exclude the ellipticals, suspected irregulars, and cluster galaxies from Table 5, we are left with 162 spirals, of which 19 (12%) are Seyferts (see Table 10, which is similar to Table 9 but includes only spirals). This result explains why a pair of spirals in which both components are Seyferts was not found: The probability of finding such a pair, on the assumption that the probabilities are independent, is only 0.014. Hence we would need about 70 pairs (outside clusters) in our sample, with both components spirals of comparable size, in order to find on the average one double-Seyfert pair. However, only 30 such pairs are available in our sample.

We now compare the above results with the frequency of Seyferts among *isolated* field spiral galaxies. We do not know of a previous spectral survey of such a sample. However, we

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

1985ApJS...57..643D

TABLE 9

IAC VERSUS NET (TOTAL SAMPLE)

NET	IAC 2	3	4	5	6	TOTAL	AVERAGE
1.0	0	0	2	0	0	2	4.0
1.5	0	0	1	1	0	2	4.5
2.0	1	3	3	5	0	12	4.0
2.5	1	0	1	1	0	3	3.7
3.0	0	6	6	2	2	16	4.0
3.5	5	7	6	6	7	31	4.1
4.0	2	7	8	7	1	25	3.9
4.5	4	10	3	4	2	23	3.6
5.0	6	14	11	4	2	37	3.5
5.5	1	0	0	0	0	1	2.0
6.0	4	11	12	13	9	49	4.2
6.5	0	0	0	0	0	0	0.0
7.0	0	6	5	5	1	17	4.1
Total	24	64	58	48	24	218	
Average	4.5	4.7	4.5	4.6	4.8		

TABLE 10

IAC VERSUS NET (ONLY SPIRALS)

NET	IAC 2	3	4	5	6	TOTAL	AVERAGE
1.0	0	0	2	0	0	2	4.0
1.5	0	0	1	1	0	2	4.5
2.0	1	3	3	5	0	12	4.0
2.5	1	0	1	1	0	3	3.7
3.0	0	5	4	2	2	13	4.1
3.5	5	6	4	6	5	26	4.0
4.0	2	4	6	6	1	19	4.0
4.5	3	8	3	4	1	19	3.6
5.0	4	13	8	3	2	30	3.5
5.5	0	0	0	0	0	0	0.0
6.0	4	6	4	6	3	23	3.9
6.5	0	0	0	0	0	0	0.0
7.0	0	6	3	4	0	13	3.8
Total	20	51	39	38	14	162	
Average	4.4	4.6	4.1	4.3	4.3		

can use the surveys of Keel (1983) and of Stauffer (1982*b*), who used the same instruments and hence had similar detection efficiencies regarding Seyfert emission. Keel observed a complete sample of *bright* spiral galaxies, while Stauffer observed a sample of *field* spirals. By classifying their galaxies according to the IAC (see § IV*a*), we can eliminate the interacting galaxies in their sample and obtain a sample of noninteracting, well-studied galaxies. Out of 205 galaxies in the combined sample, five galaxies are irregular, one is an elliptical (NGC 5363), one is in a dense cluster (NGC 4388), and seven are edge-on spirals (in which the nuclei are probably obscured). Of the remaining galaxies, only 65 have IAC $=1$. Hence most isolated galaxies are not perfectly symmetric but rather have a small degree of asymmetry. Consequently, in order to have a sample large enough, we exclude only the 19 galaxies that have IAC > 3. Therefore, the Keel-Stauffer sample of noninteracting field spirals includes 172 galaxies.

The comparison of the two samples is sensitive to the Seyfert definition since different authors use different criteria. Therefore, we need to apply the same spectral classification to the Keel-Stauffer sample as we applied to the VV spirals (§ IV*b*). Stauffer (1982*a*) published detailed spectral information for galaxies for his survey which have "non-stellar emission nuclei" according to him. Using Table 6 of this paper and the line widths given by Stauffer, we classify these nuclei as follows:

Seyfert 1.8–2:	NGC 3079, 4258, 4438, 4941, 5005, 5033, 5273.
NET = 2.5:	NGC 4388, 4450, 4579, 7314, 7743.
Liners:	NGC 3312, 3921, 4303, 4419, 4569, 5194, 5899, 7217.
Others (emission-line galaxies):	NGC 404, 3185, 4501, 4826.

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

1985ApJS...57..643D

TABLE 11

THE FREQUENCY OF SEYFERT NUCLEI AMONG ISOLATED AND INTERACTING GALAXIES

Sample	Total	Seyfert	%	NET = 2.5
Keel-Stauffer (isolated)	172	8	4.6	4
VV spirals (total)	162	16	10.0	3
VV spirals with no companion	58	5	8.6	1
VV spirals with IAC > 3	91	12	13.2	2

Few of the galaxies above are included in Keel's sample, in which no additional nuclei with NET = 2.5 were found (Keel's survey included four previously known Seyferts and NGC 4941).

A comparison between the VV and Keel-Stauffer samples is given in Table 11. In order to test the results, we use the χ^2 statistical test (Siegel 1956), classifying the Seyfert/Liner cases (NET = 2.5) as "undecided." The χ^2 test of the *total* number of VV spirals against the Keel-Stauffer sample gives only 90% confidence for their difference. However, if we use only VV spirals with IAC > 3, we get 98% confidence that the samples are statistically different. The use of the latter sample is more appropriate, since the VV and Keel-Stauffer samples overlap at IAC = 2–3. Note that the IAC classification is uncertain, and the number of VV Seyferts is small. Out of six VV spiral Seyferts with IAC = 4, we estimate that up to two could have been classified as IAC = 3. In that case the confidence level in the χ^2 test would have been decreased from 98% to 93%. We find from Table 11 that VV spirals without companions have an excess of Seyfert nuclei as well. Three Seyferts of the five in that category are ring galaxies (see Table 12). Therefore, single distorted galaxies are as important in this study as interacting pairs.

In Table 12 we summarize the morphologies of the VV Seyferts and of the nuclei with NET = 2.5. It is evident that the frequency of Seyfert nuclei is not statistically enhanced among the spiral pairs of our sample (4 out of 60 galaxies, or about 7%). That results was also obtained by Keel *et al.* (1984). Consequently the excess of Seyfert activity is more prominent when other kinds of tidally affected galaxies and/or only *close* pairs are included.

The distribution of the Seyferts along the IAC sequence is interesting, despite the uncertainty in the classification. About 18% of the spirals with IAC = 4–5 are Seyferts; these spirals make up 74% of the Seyferts in the sample. None of the Seyferts have IAC = 6. Statistically, we would expect to find two Seyferts out of 14 spirals in the last category (using the assumption of uniform distribution among the groups IAC = 4–6). Thus, evidently, if the interaction is very strong and the gravitational field is totally distorted, the nucleus is not active. This result was also reported by Keel *et al.* (1984), who found no Seyferts in the extreme cases of Arp (1966) interacting galaxies. However, note that Seyfert nuclei *are* found in double-nucleus galaxies (Petrosyan, Saakyan, and Kachikyan 1979; Kollatschny and Fricke 1984), in which the nuclei probably suffer very strong mutual tidal forces. Morphologically, these galaxies should be classified as interacting with IAC = 6 (unless the other "nucleus" is actually a foreground star).

TABLE 12

THE NATURE OF THE INTERACTION OF VV SEYFERTS

Interaction	NET = 1–2	NET = 2.5
Spiral companion	4	1
Elliptical companion	4	
Small companion	3	1
Ring galaxy	2	
Slightly distorted	3	1

In summary, the 91 strongly interacting VV spirals have about *three* times more Seyfert nuclei than the sample of isolated field spirals. Interestingly, in the group of VVs with IAC = 2–3 (Table 10), out of 71 spirals, four are Seyferts (6%), which is comparable to the percentage of Seyferts in the isolated galaxies sample (Table 11).

Further analysis of Table 10 shows that there is no clear correlation between IAC and NET in the interacting spirals. The correlation coefficient of Table 10 is $\gamma = -0.078$ (for the data in Table 9 we have $\gamma = 0.022$). The lack of correlation is also apparent from the averages of the individual NETs and IACs given in the bottom rows and last columns of the tables, respectively. The absence of correlation could indicate one (or more) of the following: (*a*) The IAC classification as presented is not a physical sequence of increasing tidal effects. (*b*) The NET does not adequately represent the nuclear activity, and other indicators such as luminosity in Hα or in 10μm need to be examined. (*c*) The influence of the interaction on the nuclear activity is only a trigger mechanism. We tend to favor the last possibility, but it is hoped that future work will enable distinctions to be made between them, or perhaps future work will provide a larger data base for further analysis.

VI. NEW SEYFERT NUCLEI

Four new Seyfert galaxies were discovered in the present survey (Dahari 1983). These Seyferts were subsequently observed with the 3 m Shane telescope in order to get better S/N ratios and higher spectral resolution. The galaxy VV 731 (NGC 7592) is not included in the VV sample (Table 1) since it has $m = 14.5$. That limit was inclusive at an early phase of the observing program but later became exclusive when the VVI galaxies were included. VV 731 NW was observed by Arkhipova *et al.* (1981). They found a broad component of Hα (width > 1000 km s^{-1}), which is not seen in our spectrum (Fig. 1).

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

1985ApJS...57..643D

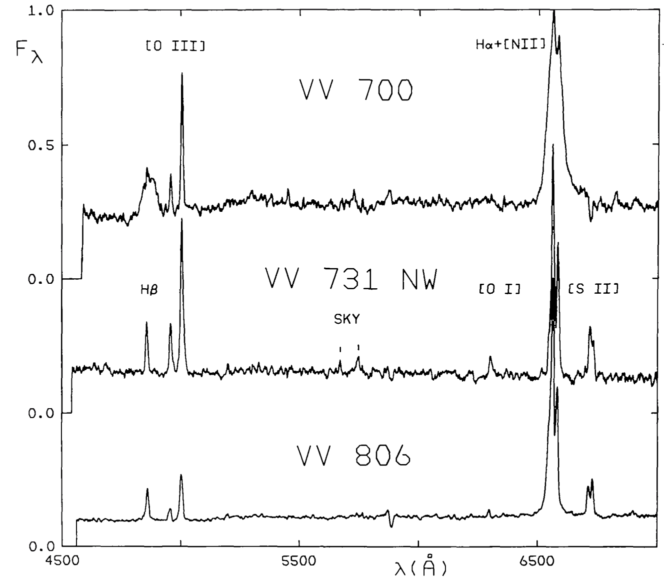

FIG. 1

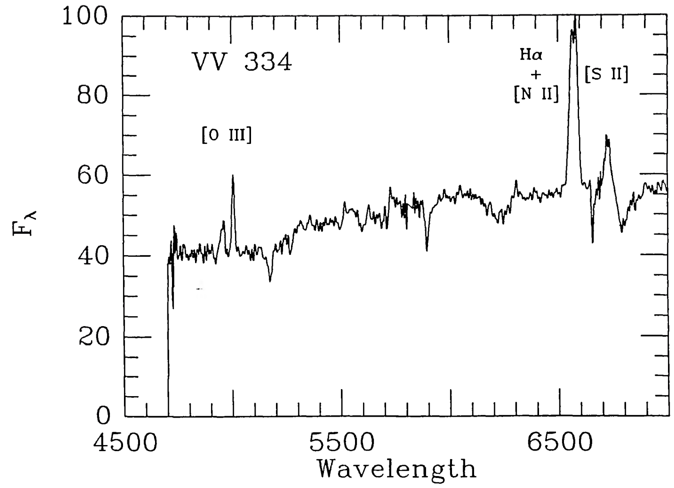

FIG. 2

FIG. 1.—Three Shane 3 m ITS spectra of new Seyfert galaxies plotted in units of relative flux per unit wavelength interval (normalized to the peak of Hα) vs. wavelength in the rest system of the galaxies. In the spectrum of VV 700, the atmospheric band at λ6877 (de-redshifted here to λ6725) is not properly subtracted out by the reduction program, and hence the [S II] emission-line strengths are not available. In the spectrum of VV 731 NW, two sky lines were not fully subtracted and are marked. Note the weak, broad components of Hα and Hβ in the spectrum of VV 806.

FIG. 2.—Shane 3 m CCD spectrum of VV 334 (NGC 1241), with scales as in Fig. 1. This is a Seyfert 2 galaxy with Hβ very weak or lost in the integrated stellar absorption line. The resolution in this scan is ~13 Å.

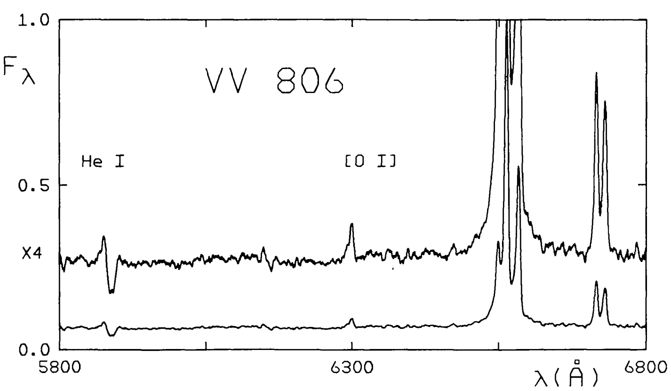

FIG. 3.—A high-resolution (~5 Å) scan of VV 806 (Mrk 334), taken with the Shane 3 m ITS. Scales as in Fig. 1. The upper spectrum is a vertical expansion (×4), in which the broad component of Hα is clearly seen.

The red spectra of the four new Seyferts are illustrated in Figures 1–3. The plots are good examples of Seyferts of type 1 (VV 700), type 1.8 (VV 806), type 2 (VV 334), and NET = 2.5 (VV 731 NW). The galaxy VV 334 has relatively weak [O I] λ6300 emission (Fig. 2 and Table 13). Therefore, its classification as Seyfert 2 is somewhat doubtful. Spectra with better S/N ratio, higher resolution, and in the blue spectral region are needed for better classification.

The line intensities, widths, and equivalent widths are listed in Table 13. In this table we also list the data for four other VV Seyferts for which no similar data have been published previously. The galaxy VV 850 (NGC 34, Mrk 938) was classified by Osterbrock and Dahari (1983) as an emission-line galaxy. However, by reexamining the spectral information (Table 13), I reclassify it here as a Seyfert 2. In Table 13, the line intensities are given as 100 times their ratio to Hα (narrow + broad), and the redshift is heliocentric.

The line widths of [O III] λ5007 and of broad Hα were measured by least squares fits of Gaussian profiles (see also § III*c*). The fits were not perfect for the broad Hα components, but their FWHMs were very close to the actual profiles. Gaussians were similarly fitted to the instrumental profiles, which had approximately the same wavelengths (taken from the comparison-lamp scans). The widths of the intrinsic emission lines were then computed as the square roots of the differences between the squares of the widths of the emission and comparison lines.

VII. SUMMARY

In this paper we reported on the emission-line survey of a sample of interacting galaxies. By classifying the galaxies by their morphologies and by their spectra, we examined the frequency and distribution of Seyfert nuclei in the total sample and within the morphological subclasses.

Comparing the sample of interacting spirals with a sample of isolated field spiral galaxies, it was found that there is an excess of Seyferts among the interacting sample. When only *strongly* interacting spirals were considered, this excess was statistically significant. Considering the results of Dahari (1984), who found that Seyfert galaxies have physical compan-

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

1985ApJS...57..643D

TABLE 13

NEW SEYFERT (VV) GALAXIES

Parameter	VV 228 (NGC 7319)	VV 331 (NGC 1144)	VV 334 (NGC 1241)	VV 609 (NGC 4922)	VV 700 (NGC 7214)	VV 806 (Mrk 334)	VV 850 (NGC 34)	VV 731 NW (NGC 7592)	Uncertainty
Seyfert type	2	2	2	2	1	1.8	2	2	...
Date of observation (mo/day/yr)	5/27/84	2/4/84	11/28/83	2/4/84	8/14/83	9/12/83	8/22/81	9/11/83	...
Instrument	3 m ITS	3 m ITS	3 m CCD	1.5 m ITS	3 m ITS	3 m ITS	3 m ITS	3 m ITS	...
High resolution	no	yes	no	no	no	yes	no	no	...
λ4861	18	9	<1	10	20	9.4	3[a]	23	20%
λ5007	175	146	33	37	12	14	12	89	10%
λ5200	5	...	...	...	...	...	5	2	
λ5875	...	...	...	...	2	...	...	...	20%
λ6300	19	6	4	6	...	1.5	10	12	
λ6562 narrow	100	100	100	100	...	46	100	100	
λ6562 broad	...	...	...	...	100	54	...	...	
λ6584	122	128	117	67	2.5	36	125	66	20%
λ6717+6730	94	45	42	44	...	16	40	32	10%
λ4861 E.W. (Å)	19	1.5	<1	15	42	18	1	16	
λ6562 (nar.+br) E.W. (Å)	65	10	13	94	150	190	27	77	10%
FWHM λ6562 br. (km s^{-1})	...	...	...	...	3200	2060	...	...	
FWHM λ6562 nar. (km s^{-1})	380	450	< 400	< 400	...	220	400	320	100 km s^{-1}
FWHM λ5007 (km s^{-1})	410	< 400	< 400	480	250	< 250	330	590	
Log flux λ6562 (nar.+br.) (ergs s^{-1} cm^{-2})	−13.35	−13.53	−13.52	−13.07	−12.28	−12.46	−13.12	−13.32	0.17
z (heliocentric)	0.0223	0.0288	0.0134	0.0238	0.0226	0.0220	0.0191	0.0224	0.0003

[a] The intensity of Hβ of VV 850 is only an estimate, made by assuming a symmetric Balmer-absorption profile.

ions about 4 times more frequently than the general population of field galaxies, we find that the Seyfert activity and the existence of external tidal forces *are interrelated*.

Seyfert nuclei were *not* found, however, in the group of extremely disordered spirals (like NGC 4038/9). That result agrees with Keel *et al.* (1984), who examined samples of pairs and of Arp galaxies. Evidently, the connection between the Seyfert activity and the external tidal forces is not a one-to-one relation (Dahari 1984). In addition to the absence of Seyfert nuclei among strongly interacting spirals, many Seyfert nuclei seem to be in isolated and morphologically symmetric galaxies.

Seyfert nuclei were not found in interacting ellipticals, nor in LMC-like irregulars. This result agrees with previous knowledge of their Hubble-type distribution.

The spectral data presented in Table 2 provides information for further studies, which will be presented elsewhere.

I would like to thank Drs. M. M. DeRobertis, W. C. Keel, and H. Netzer for useful discussions, L. Kay for helping with the observations on Mount Lemmon, and the technical staff of Lick Observatory for their assistance. I would like especially to thank Dr. W. C. Keel for providing his Mount Lemmon data ahead of publication. I am deeply grateful to Dr. D. E. Osterbrock for his advice and support, and for generously making available observing time at the 3 m telescope. This work was supported in part by NSF grant AST 83-11585. The 1.5 m telescope at Mount Lemmon is supported by an NSF grant, as was the VAX computer at Lick Observatory during the early part of this study.

REFERENCES

Adams, T. F. 1977, *Ap. J. Suppl.*, **33**, 19.
Afanasiev, V. L., Karachentsev, V. P., Arkhipova, V. A., Dostal, V. A. and Metlov, V. G. 1980, *Astr. Ap.*, **91**, 302.
Arkhipova, V. P., Afanas'ev, V. L., Dostal, V. A., Zasov, A. V., Karachentsev, I. D., Noskova, R. I., and Savel'eva, M. V. 1981, *Soviet Astr.*, **25**, 277.
Arp, H. 1966, *Atlas of Peculiar Galaxies* (Pasadena: California Institute of Technology).
______. 1969, *Astr. Ap.*, **3**, 418.
______. 1973*a*, *Ap. J.*, **183**, 411.
______. 1973*b*, *Ap. J.*, **185**, 797.
Baldwin, J., Phillips, M. M., and Terlevich, R. 1981, *Pub. A.S.P.*, **93**, (BPT).
Barbieri, C., Casini, C., Heidmann, J., Di Serego, S., and Zambon, M. 1979, *Astr. Ap. Suppl.*, **37**, 559.
Bergvall, N. 1981, *Astr. Ap.*, **97**, 302.
Bertola, F., and D'Odorico, S. 1973, *Ap. Letters*, **13**, 161.
Bevington, P. R. 1969, *Data Reduction and Error Analysis for the Physical Sciences* (New York: McGraw-Hill).
Blackman, C. P. 1982, *M.N.R.A.S.*, **200**, 407.
Chincarini, G., and Heckathorn, H. M. 1973, *Pub. A.S.P.*, **85**, 568.
Condon, J. J., Condon, M. A., Gisler, G., and Puschell, J. J. 1982, *Ap. J.*, **252**, 102.
Dahari, O. 1983, *Bull. AAS*, **15**, 987.
______. 1984, *A.J.*, **89**, 966.
Davis, L. E., and Seaquist, E. R. 1983, *Ap. J. Suppl.*, **53**, 269.
de Vaucouleurs, A., and de Vaucouleurs, G. 1967, *A.J.*, **72**, 730.
de Vaucouleurs, G. 1979, *A.J.*, **84**, 1811.

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

1985ApJS...57..643D

de Vaucouleurs, G., de Vaucouleurs, A., and Corwin, H. G. 1976, *Second Reference Catalogue of Bright Galaxies* (Austin: University of Texas) (RCBGII).
Ferland, G. J., and Netzer, H. 1983, *Ap. J.*, **264**, 105.
Fisher, J.R., and Tully, R. B. 1981, *Ap. J. Suppl.*, **47**, 139.
Freeman, K. C., and de Vaucouleurs, G. 1974, *Ap. J.*, **194**, 569.
French, H. B. 1980, *Ap. J.*, **240**, 41.
Gallagher, J. S., Knapp, G. R., and Faber, S. M. 1981, *A.J.*, **86**, 1781.
Gehrz, R. D., Sramek, R. A., and Weedman, D. W. 1983, *Ap. J.*, **267**, 551.
Goodrich, R. W., and Osterbrock, D. E. 1983, *Ap. J.*, **269**, 416.
Gorenstein, M. W., and Smoot, G. F. 1981, *Ap. J.*, **244**, 361.
Grayzeck, E. J. 1983, in *IAU Symposium 100, Internal Kinematics and Dynamics of Galaxies*, ed. E. Athanassoula (Dordrecht: Reidel), p. 97.
Halpern, J. P., and Steiner, J. E. 1983, *Ap. J. (Letters)*, **269**, L37.
Heckman, T. M. 1980, *Astr. Ap.*, **87**, 152.
Heckman, T. M., Balick, B., and Crane, P. C. 1980, *Astr. Ap. Suppl.*, **40**, 295.
Heckman, T. M., Bothun, G. D., Balick, B., and Smith, E. P. 1984, *A.J.*, **89**, 958.
Huchra, J. P., Davis, M., Latham, D., and Tonry, J. 1983, *Ap. J. Suppl.*, **52**, 89.
Huchra, J. P., Wyatt, W. F. and Davis, M. 1982, *A.J.*, **87**, 1628.
Hummel, E. 1980, *Astr. Ap.*, **89**, L1.
______. 1981, *Astr. Ap.*, **96**, 111.
Hutchings, J. B., Crampton, D., Campbell, B., Dundan, D., and Glendenning, B. 1984, *Ap. J. Suppl.*, **55**, 319.
Hutchings, J. B., Crampton, D., Campbell, B., Gower, A. C., and Morris, S. C. 1982, *Ap. J.*, **266**, 48.
Jenkins, C. R. 1984, *Ap. J.*, **277**, 501.
Karachentsev, I. 1972, *Soob. Ap. Obs. Zelentchuk*, No. 7.
______. 1980, *Ap. J. Suppl.*, **44**, 137.
Keel, W. C. 1982, Ph.D. thesis, University of California at Santa Cruz.
______. 1983, *Ap. J. Suppl.*, **52**, 229.
Keel, W. C., Kennicutt, R. C., Jr., Hummel, E., and van der Hulst, J. M. 1984, preprint.
Kennicutt, R. C., Jr., and Keel, W. C. 1984, *Ap. J. (Letters)*, **279**, L5.
Kinman, T. D. 1985, in *IAU Colloquium 78, Astronomy with Schmidt-type Telescopes*, ed. M. Capaccioli (Dordrecht: Reidel), in press.
Kollatschny, W., and Fricke, K. J. 1984, *Astr. Ap.*, **135**, 171.
Korovyakovskaya, A. A. 1983, *Astrophysics*, **19**, 419.
Larson, R. B., and Tinsley, B. M. 1978, *Ap. J.*, **219**, 46.
Lauer, T. R., Miller, J. S., Osborne, C. S., Robinson, L. B., and Stover, R. J. 1984, in *Instrumentation in Astronomy V (Proc. Photo-Opt. Instrum. Eng.*, Vol. **445**).
Markarian, B. E., Lipovetskii, V. A., and Stephayan, D. A. 1981, *Astrophysics*, **17**, 321.
Meltov, V. G. 1980, Soviet *Astr. Letters*, **6**, 10.
Meurs, E. J. A. 1982, Ph.D. thesis, Leiden Observatory.
Miller, J. S., Robinson, L. B., and Schmidt, G. 1980, *Publ. A.S.P.*, **92**, 702.
Miller, J. S., Robinson, L. B., and Wampler, E. J. 1976, *Advances in Electronics and Electron Physics*, Vol. **40B** (New York: Academic Press), p. 1018.
Miller, R. H., and Smith, B. F. 1980, *Ap. J.*, **235**, 421.
Negroponte, J., and White, S. D. M. 1983, *M.N.R.A.S.*, **205**, 1009.
Nilson, P. 1973, *Uppsala General Catalogue of Galaxies* (Uppsala: Uppsala Offset Center).
Osterbrock, D. E. 1984, *Quart. J.R.A.S.*, **25**, 1.
Osterbrock, D. E., and Dahari, O. 1983, *Ap. J.*, **273**, 478.
Page, T. 1970, *Ap. J.*, **159**, 791.
Petrosyan, A. R., Saakyan, K. A., and Kachikyan, E. E. 1979, *Astrophysics*, **15**, 250.
Phillips, M. M., Charles, P. A., and Baldwin, J. A. 1983, *Ap. J.*, **266**, 485.
Robinson, L. B., and Wampler, E. J. 1972, *Pub. A.S.P.*, **84**, 161.
Rood, H. J. 1982, *Ap. J. Suppl.*, **49**, 111.
Rubin, V. C., and Ford, W. K. Jr. 1968, *Ap. J.*, **154**, 431.
Rubin, V. C., and Ford, W. K. Jr., and D'Odorico, S. 1970, *Ap. J.*, **160**, 801.
Sandage, A. 1978, *A.J.*, **83**, 904.
Sandage, A., and Tammann, G. A. 1981, *A Revised Shapley-Ames Catalog of Bright Galaxies* (Washington: Carnegie Institution of Washington).
Sargent, W. L. W. 1970, *Ap. J.*, **160**, 405.
Shuder, J. M. 1980, *Ap. J.*, **240**, 32.
Shuder, J. M., and Osterbrock, D. E. 1981, *Ap. J.*, **250**, 55.
Siegel, S. 1956, *Nonparametric Statistics* (New York: McGraw-Hill).
Simkin, S. M., Su, H. J., and Schwarz, M. P. 1980, *Ap. J.*, **237**, 404.
Spiegel, J. C., and Theys, E. A. 1976, *Ap. J.*, **208**, 650.
Stauffer, J. R. 1982*a*, *Ap. J.*, **262**, 66.
______. 1982*b*, *Ap. J. Suppl.*, **50**, 517.
Stockton, A. 1982, *Ap. J.*, **257**, 33.
Stone, R. 1974, *Ap. J.*, **193**, 135.
______. 1977, *Ap. J.*, **218**, 767.
Sulentic, J. W., and Arp, H. 1983, *A.J.*, **88**, 489.
Tifft, W. G. 1982, *Ap. J. Suppl.*, **50**, 319.
Toomasyan, G. M. 1982, *Astrophysics*, **18**, 139.
Toomre, A., and Toomre, J. 1972, *Ap. J.*, **178**, 623.
van der Kruit, P. C., Oort, J. H., and Mathewson, D. S. 1972, *Astr. Ap.*, **21**, 169.
Vorontsov-Vel'yaminov, B. 1959, *Atlas and Catalogue of Interacting Galaxies*, Part 1 (Moscow: Moscow State University) (VVI).
______. 1977, *Astr. Ap. Suppl.*, **28**, 1 (VVII).
Vorontsov-Vel'yaminov, B., and Arkhipova, V. 1964, *Morphological Catalogue of Galaxies*, Part 2 (Moscow).
______. 1963, *Morphological Catalogue of Galaxies*, Part 3 (*Trudy Gos. Astr. Inst. Shternberga*, Vol. **33**).
______. 1968, *Morphological Catalogue of Galaxies*, Part 4 (*Trudy Gos. Astr. Inst. Shternberga*, Vol. **38**).
______. 1974, *Morphological Catalogue of Galaxies*, Part 5 (Moscow: Moscow State University).
Vorontsov-Vel'yaminov, B., and Krasnogorskaya, A. A. 1962, *Morphological Catalogue of Galaxies*, Part 1 (*Trudy Gos. Astr. Inst. Shternberga*, Vol. **32**).
Wasilewski, A. J. 1983, *Ap. J.*, **272**, 68.
Weedman, D. W. 1977, *Ann. Rev. Astr. Ap.*, **15**, 69.
Yee, H. K. C. 1983, *Ap. J.*, **272**, 473.

OVED DAHARI: Nuclear Physics Department, Weizmann Institute of Science, Rehovot 76100, Israel

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