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THE RELATIVE NUMBER OF SEYFERT 2 GALAXIES. I. SPECTRA OF EMISSION-LINE GALAXIES IN THE WASILEWSKI FIELD

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ABSTRACT

Slit spectra were obtained of all the Seyfert galaxy candidates and many other emission-line galaxies discovered (or recovered) by Wasilewski in his objective-prism survey centered on the region of the north Galactic pole. Redshifts and relative emission-line fluxes were measured for these galaxies, and all of their spectra were classified. Among the Wasilewski candidates, Was 26 is a Seyfert 1, Was 45 is a Seyfert 1.9, and Was 2 and Was 31 are Seyfert 2 galaxies. The other Seyfert 2 candidates he identified are actually H II region galaxies. Including previously known Seyfert galaxies in this region, it is confirmed that the relative number of Seyfert 2 galaxies, down to a given apparent magnitude, is large. Per unit volume of space, the relative numbers of Seyfert (1 + 1.5) to Seyfert (1.8 + 1.9) to Seyfert 2 are approximately 0.1/0.1/0.8. If the same galaxies were to evolve through all these stages, they would spend most of their AGN lifetimes as Seyfert 2s. If all Seyfert nuclei were similar objects with central broad-line regions hidden by obscuring disks to various extents, the disks would be thick and the line broadening due to any presumed rotational or radial velocity field in the plane of the disk would be greatly reduced by projection effects.

Subject headings: galaxies: redshifts — galaxies: Seyfert — luminosity function

I. INTRODUCTION

The local luminosity function of Seyfert galaxies, particularly for Seyfert 1 and Seyfert 2 galaxies separately, is very important for understanding the nature of these objects. Every physical picture of Seyfert galaxies—for instance, that most Seyfert 2s are actually objects containing a Seyfert 1 nucleus, but seen in a direction from which the broad permitted lines are effectively hidden (Antonucci and Miller 1985), or that essentially all Seyfert 2s are similar to Seyfert 1s but seen in different projections (Krolik and Begelman 1986)—implies a prediction as to the relative observed numbers of Seyfert 1 and 2 nuclei. Likewise, any evolutionary picture that considers Seyfert 1 galaxies as the low-luminosity active galactic nuclei (AGNs) to which quasi-stellar objects (QSOs) evolve, predicts or is based upon the luminosity functions of those types of objects (Schmidt and Green 1983; Weedman 1986), and may contain a further prediction as to the luminosity function of Seyfert 2s as well.

Seyfert galaxy spectra cover a wide range of emission-line strengths and widths. In addition to the two simple types 1 and 2, it is possible to define an intermediate type, Seyfert 1.5, in which both broad and narrow components of the Hα and Hβ emission lines are easily apparent on fairly good signal-to-noise ratio spectra (Osterbrock 1977). In fact, a wide range of relative strengths of the broad and narrow components exists in nature (Osterbrock and Koski 1976). Although essentially every Seyfert 1 contains at least weakly visible narrow components of Hα and Hβ emission, it is nonetheless quite simple to make a fairly clearcut separation into Seyfert 1, 1.5, and 2 galaxies (Cohen 1983; Osterbrock 1984).

In addition, very weak broad wings of Hα and/or Hβ emission can be detected in some Seyfert galaxies. These are often galaxies that have previously been classified as Seyfert 2 on the basis of spectra with lower signal-to-noise ratios. We have called these objects Seyferts 1.8 galaxies if broad components of both Hα and Hβ can be detected by visual inspection of our scans, and Seyfert 1.9 galaxies if only a broad Hα component can be seen (Osterbrock 1981). This classification scheme has been described in somewhat greater detail in a review by Osterbrock (1984).

Our ideal then would be to obtain luminosity functions for Seyfert 1, 1.5, 1.8, 1.9, and 2 galaxies, down to relatively faint absolute magnitude limits. It is an ambitious program. An approximation to it, which we present here as a first step in a limited observing program, is to determine the relative numbers of the various types of Seyfert galaxies in one well-defined area of the sky.

Most of the Seyfert galaxies known at present were originally identified as candidates in the Markarian objective-prism survey (see Markarian, Lipovetsky, and Stepanian 1981, and the earlier papers in the series referenced there) and then classified on the basis of slit spectra. The Markarian survey selected galaxies with strong ultraviolet continua. As a result, though it seems fairly complete for Seyfert 1 galaxies, many Seyfert 2s were not discovered, as was pointed out by Rieke (1978). This has become increasingly apparent from surveys based on other criteria than the ultraviolet continuum. Meurs and Wilson (1984) obtained what is still probably the best published luminosity function for Seyfert galaxies, essentially from a list of then known Markarian Seyferts. Down to apparent magnitude $B \approx 15.5$, about 65% of these were classified Seyfert 1, and about 35%, Seyfert 2. However, Phillips, Charles, and Baldwin (1983) obtained individual slit spectra of galaxies selected because they had previously been reported to have "high-excitation" (or high-ionization) emission-line spectra, rather than on the basis of ultraviolet continuum. They found many Seyfert 2s among these galaxies and estimated the relative number of Seyfert 1s to 2s down to a given apparent magnitude to be 1:2, rather than 2:1. Also, Huchra, Wyatt and Davis (1982), from slit spectra taken in the CfA redshift survey (which is intended to include *all* galaxies down

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to $B = 14.5$ over a large area of the sky) found the ratio of numbers of observed Seyfert 1s to Seyfert 2s to be considerably smaller than earlier assumed, but did not state a quantitative value. Also, Miley, Neugebauer, and Soifer (1985) developed criteria for identifying Seyfert candidates by their *IRAS* colors, and a fair fraction of these candidates have turned out in fact to be previously unknown Seyfert 2s (Carter 1984; de Grijp *et al.* 1985; Osterbrock and De Robertis 1985).

As a smaller area which can be studied to a fainter apparent magnitude limit than the CfA survey, we selected the area at the north Galactic pole cap surveyed by Wasilewski (1983) for emission-line galaxies. He used the Burrell Case Schmidt telescope with an objective prism giving "moderate" dispersion (400 Å mm^{-1} at Hβ), and selected galaxies strictly on the basis of the presence of emission lines in their spectra. In this area he identified 96 new emission-line galaxies, and from among them listed eight new Seyfert galaxy candidates: one a Seyfert 1 and seven (according to his classification) Seyfert 2s. This again would indicate a significantly larger relative number of Seyfert 2 galaxies, as Wasilewski stated.

The Wasilewski area is an excellent one for study of the Seyfert galaxy luminosity function. It has been surveyed not only by Wasilewski and by Markarian, Lipovetsky, and Stepanian (1981), but by several other authors using various techniques. Part of it has already been included in the Sanduleak and Pesch (1987, and earlier papers in the series listed there) low-dispersion Case survey, and all of it will be included in time. Hence we began our study of this area by obtaining spectra of all the Wasilewski Seyfert candidates, plus many additional emission-line galaxies chosen from his lists in an effort to include even unlikely Seyfert candidates. The results measured from these spectra, and the preliminary conclusions from them, are reported in the present paper. Some of them were previously given in brief abstract form (Osterbrock 1985*a*; Shaw and Osterbrock 1986). A second paper (Shaw 1988) will contain spectral data on Seyfert candidates in this same field selected from other surveys, particularly the *IRAS* survey, plus measured magnitudes and the derived luminosity functions.

II. OBSERVATIONS

Our observations span a 4 yr period from 1981 through 1985. We observed several of the galaxies in the Wasilewski (1983) field with the dual-beam image dissector scanner (IDS) (Robinson and Wampler 1972; Miller, Robinson, and Wampler 1976; Miller, Robinson, and Schmidt 1980) attached to the Cassegrain focus of the Shane 3 m telescope of Lick Observatory. We observed the remainder of the galaxies with the transmission grating (grism) spectrograph on the same telescope using a TI 500 × 500 CCD detector, and later with a TI 800 × 800 (Lauer *et al.* 1984). Spectra were obtained of all of Wasilewski's Seyfert candidates, as well as an approximately equal number of the new emission-line galaxies discovered by Wasilewski (1983) but not listed as Seyfert candidates. We tried to select those that, from his published description of their objective-prism spectra, might conceivably be Seyferts. In addition to the new emission-line galaxies, Wasilewski (1983) recovered 36 previously known emission-line galaxies in the area he studied. They are not individually named in his published paper, but are listed in a table in his thesis, a copy of which he very kindly sent us. Most of these previously known emission-line galaxies had been classified earlier by other authors, but we obtained spectra of those that had not been, as well as of some that were in doubt. Also, we had taken spectra of some of these previously known emission-line galaxies before Wasilewski's (1983) paper was published.

The observing log for our spectra is presented in Table 1. Listed are, in order, the galaxy name, the UT date of the observation, the detector, the dispersion used, and the exposure time in minutes. (Note that some of these exposures were taken through clouds.) The IDS scans were normally taken with a 600 line mm^{-1} grating ("N" in the table) which spanned about 2500 Å with 10 Å resolution, although some scans were obtained with a 1200 line mm^{-1} grating ("H") which gave half the wavelength coverage and 5 Å resolution. The CCD spectra were normally obtained with a 420 line mm^{-1} grism ("L") which gave about 3500 Å coverage at 12 Å resolution. Some

TABLE 1

LOG OF OBSERVATIONS

Galaxy	Date Observed	Detector	Dispersion	Exposure (minutes)
Was 2	1983 Nov 29	CCD	M	20
	1983 Nov 29	CCD	L	20
Was 5	1985 Feb 16	CCD	L	40
Was 6	1985 Feb 16	CCD	L	30
	1985 Feb 17	CCD	M	75
Was 11	1985 Feb 16	CCD	L	20
Was 15	1985 Feb 16	CCD	L	30
Was 26	1983 Nov 29	CCD	M	20
	1983 Nov 29	CCD	L	20
Was 31	1984 Jan 4	CCD	L	20
	1984 Jan 5	CCD	E	45
	1984 Feb 6	CCD	M	30
Was 32	1984 Jan 4	CCD	L	20
	1984 Jan 5	CCD	E	45
Was 45	1984 Jan 4	CCD	L	20
	1984 Jan 5	CCD	E	45
	1984 Mar 30	CCD	M	45
Was 45 NE[a]	1984 Mar 30	CCD	L	30
Was 66	1984 Jan 4	CCD	L	20
	1984 Jan 5	CCD	E	40
	1984 Feb 6	CCD	M	30
	1984 May 25	IDS	H	16
	1984 May 25	IDS	H	16
Was 69	1984 Mar 29	CCD	L	45
	1984 Mar 30	CCD	M	45
Was 80	1984 May 26	IDS	N	32
Was 87	1984 Jan 4	CCD	L	20
Was 88	1984 May 27	IDS	N	32
Was 89	1984 Mar 29	CCD	L	45
	1984 May 1	CCD	M	15
Was 96	1984 Jan 4	CCD	L	30
	1984 Jan 5	CCD	E	40
	1984 Feb 6	CCD	M	30
Was 96 SE[b]	1984 Feb 6	CCD	M	30
Haro 4	1984 Feb 6	CCD	L	25
	1984 Mar 30	CCD	M	30
Haro 5	1984 Feb 6	CCD	L	15
Haro 22	1984 Mar 9	IDS	N	32
Haro 25	1984 Feb 5	CCD	L	15
	1984 Feb 6	CCD	M	25
Mrk 67	1984 Mar 8	IDS	N	32
Mrk 403	1981 May 13	IDS	N	16
Mrk 417	1984 May 25	IDS	N	32
Mrk 432	1984 Dec 31	CCD	L	35
Mrk 717	1984 Mar 8	IDS	N	32
Mrk 724	1984 Feb 6	CCD	L	30

[a] Was 45 NE: one of the two "nearby companions" mentioned by Wasilewski 1983. It is ~60″ distance from Was 45, in PA ~30°, and is itself apparently a close double or a distorted galaxy.

[b] Was 96 SE: the "southern component" mentioned by Wasilewski 1983. It is ~10″ distant in PA ~130° from the fainter Was 96.

CCD spectra were obtained with a 600 line mm^{-1} grism ("M") which gave about 2000 Å coverage at 6 Å resolution, or with a 300 line mm^{-1} echelle-grism (or "echism") ("E") which gave about 1000 Å coverage at 2.5 Å resolution. The wavelength range was somewhat less with the smaller chip.

Osterbrock (1981) details the reduction procedure for the IDS observations. The CCD spectra were extracted from flat-field–corrected CCD images by summing counts along the spatial direction and subtracting the night sky at each channel. The night sky spectrum was determined by averaging several sky columns which were spatially near and centered on the columns containing the target spectrum. The details of the instrumental setup, of the grisms used, and of the data reduction procedure are given by Osterbrock and De Robertis (1985). The CCD spectra were interpolated to a linear wavelength scale, although the interpolation routine now in use is superior to that used for earlier Lick spectra in that it eliminates the "ringing" formerly introduced near narrow, strong emission lines. The spectra were calibrated approximately on an absolute flux scale with the aid of mean atmospheric extinction coefficients for Mount Hamilton, and observations of standard stars (Stone 1977) observed on the same night.

The fluxes in selected emission lines, used in the classification of narrow emission-line galaxies, were measured from these spectra. The flux in each line was determined with the aid of standard Lick Observatory spectrum-analysis software, which finds the best-fit Gaussian + continuum background functions for up to four emission and/or absorption lines at once. A fit to a spectral line consists of the line center, its height above (or below) the continuum, and its width; the area of the Gaussian gives the total flux in that line. A fit to the continuum consists of a quadratic fit to all those points not included in the emission-line fit(s). The program determines continuum-subtracted line fluxes very consistently, but it is particularly useful for deconvolving closely-spaced lines, such as Hα, [N II] λλ6548, 6583. For near-blends the program can constrain the widths of the lines to be equal, which is a good approximation especially for emission-line galaxies with near-instrumental profiles. For the Hα + [N II] blend the program can constrain the width, separation, and relative strength of the forbidden lines independently of the fit to Hα. We integrated directly the flux (above an eye-estimate of the continuum) in those emission lines that were extremely weak, or blended, and/or non-Gaussian in shape.

The fluxes in various emission lines, relative to $F(\mathrm{H}\alpha) + F([\mathrm{N\,II}]) = 100$, are presented in Table 2. This normalization was chosen to give the line fluxes from all galaxy spectra on the same scale, even though they did not all include

TABLE 2

RELATIVE EMISSION LINE FLUXES

Object	Hβ 4861	[O III] 4959	[O III] 5007	[O I] 6300	[N II] 6548	Hα 6563	[N II] 6583	[S II] 6716	Sum[a]	[S II] 6731
Was 2	8.0:	36.8	104.7	7.4	15.1	40.4	44.5	18.2		17.9
Was 5	35.7	66.9	196.9	1.5	0.4:	98.3	1.3:	3.4		2.4
Was 6	27.7	43.6	130.3	1.1	1.8	92.8	5.4	5.9		4.9
Was 11	6.1:	...	≤1.5:	2.4	10.5	58.5	31.0	10.2		9.0
Was 31	8.4	69.8	196.4	4.5	14.4	43.9	41.7		16.0	
Was 32[b]	31.0	46.7	139.1	1.8	2.0	92.1	5.9	7.0		5.5
Was 45[c]	6.0	21.9	65.1	4.8	15.6	42.8	41.6	10.2		11.0
Was 45 NE	2.9:	...	1.3:	...	7.0:	57.9	35.1		13.2:	
Was 66	24.1	32.4	98.7	1.8	3.2	87.4	9.3	8.0		5.9
Was 69	33.3	62.4	181.4	1.0	0.9:	96.5	2.6	5.1		3.7
Was 80	...	...	...	...	...[d]	100.0[d]	...[d]		36.9	
Was 87	18.8	8.7	22.0	2.3:	5.4	78.9	15.8		23.3	
Was 88	1.6:	...	1.1:	...	12.2	51.9	35.9	10.7		7.4
Was 89	22.0	23.6	68.4	2.1	3.7	84.8	11.6	15.8		9.3
Was 96	34.5	63.0	191.2	1.2	[0.8]	96.8	2.4	3.3		2.1
Was 96 SE	100.0[e]	163.2[e]	485.6[e]	...	...	...	...	...		...
Akn 347[f]	6.3	33.7	102.0	3.9	16.3	37.8	45.9	11.2		11.2
Haro 4	34.5	53.8	158.0	0.8	0.4	98.5	1.1	4.5		3.3
Haro 5	26.8	24.8	74.9	1.6	[3.4]	86.4	10.3		18.0	
Haro 22	20.0	43.4	137.9	1.7:	1.7:	93.3	5.0	8.5		5.8
Haro 25	19.1	17.9	2.9	1.7	3.8	85.0	11.2	7.1		6.1
Mrk 67	17.9	53.8	180.6	0.8:	0.8	97.0	2.2	4.5		2.9
Mrk 403	8.8	37.6	121.5	4.0	14.0	44.6	41.4	9.7		8.1
Mrk 417	9.0	50.7	165.4	13.8:	12.2	51.8	36.0	14.7		16.9
Mrk 432	15.2	6.8	17.9	3.4	6.2	75.6	18.2		25.1	
Mrk 717	9.0	2.1	7.3	1.5	9.2	63.7	27.1	8.3		6.9
Mrk 724	33.7	57.3	167.1	<0.8	0.0:	93.1	6.9:		7.0	
Mrk 744[g]	16.0	51.3	140.0	18.7	15.3	35.0	49.7	38.3		38.3
Mrk 1388[h]	15.2	57.2	169.2	7.9	8.2	68.9	22.9	5.3		4.7

[a] See text for explanation.

[b] Was 32 = Mrk 1459.

[c] Seyfert 1.9 galaxy. Fluxes are from the narrow-line component only.

[d] Individual line fluxes cannot be deconvolved; Hα, and [N II] λλ6548, 6583 all present but badly blended against strong galaxy absorption-line spectrum.

[e] No overlapping red spectrum available: Fluxes normalized to $F(\mathrm{H}\beta) = 100$.

[f] Fluxes from Shuder and Osterbrock 1981.

[g] Mrk 744 = NGC 3786, Seyfert 1.8 galaxy. Fluxes from Goodrich and Osterbrock 1983 for narrow-line components only.

[h] Fluxes from Osterbrock 1985*b*.

Hβ or [O III] λ5007. In addition, the lower-resolution scans often did not permit a deconvolution of Hα from [N II], leaving the sum $F(\mathrm{H}\alpha) + F([\mathrm{N\ II}])$ as the best choice. The observed galaxies are listed in the first column of the table. The emitting ions and wavelengths are listed at the top of the succeeding columns. The measured relative flux $F(\lambda)$ is listed for each measured line for each galaxy. Separate fluxes for Hα and the two [N II] lines are listed for all galaxies in which these lines could be separated. If [S II] $\lambda\lambda$6716, 6731 could not be deblended, the total relative flux in this blend is listed as "Sum" between the individual [S II] lines.

The wavelengths of the isolated, symmetric lines were measured for the galaxies using the line centers as determined from the Gaussian fits. The velocities determined from these measured wavelengths were converted to heliocentric redshifts, and are listed in the first column of Table 3. Most are average values determined from several lines each from several spectra. An independent check is possible from the eight Markarian galaxies (including Haro 4 = Mrk 36) measured for radial velocity by us and also included in a preprint of the *First Byurakan Spectral Survey* (FBSS) *Catalogue of Galaxies with UV-Continuum* (Markarian *et al.* 1987) kindly communicated to us by V. Lipovetsky and J. Stepanian. When its redshifts are converted to heliocentric values for comparison with ours, the mean difference is z (this paper) − z(FBSS) = +0.00009 ± 0.0002. The sample error is ±0.0005. The random error in the FBSS redshifts, from a previous comparison, is about ±0.0002 or ±0.0003. Hence the typical error of a redshift measured in the present paper is about ±0.0004, as judged from this small sample.

TABLE 3

REDSHIFTS AND EXTINCTIONS

Object	z	c
Was 2	0.0345	0.29[a]
Was 5	0.0038	0.00
Was 6	0.0179	0.22
Was 11	0.0183	1.58:
Was 15	0.0530	...
Was 16	0.0200	...
Was 26	0.0641	...
Was 31	0.0313	0.79
Was 32	0.0268	0.00
Was 45 nar.	0.0252	1.11[a]
Was 45 NE	0.0236	2.5:
Was 66	0.0379	0.26
Was 69	0.0148	0.02
Was 80	0.0281	...
Was 87	0.0277	0.50
Was 88	0.0263	0.42[b]
Was 89	0.0324	0.30
Was 96	0.0333	0.00
Was 96 SE	0.0344	0.00[c]
Akn 347	0.0229[d]	0.85
Haro 4	0.0028	0.00
Haro 5	0.0118	0.20
Haro 22	0.0046	0.64
Haro 25	0.0262	0.51
Mrk 67	0.0029	0.83
Mrk 403	0.0243	0.63[a]
Mrk 417	0.0326	0.81[a]
Mrk 432	0.0109	0.72
Mrk 717	0.0210	1.17
Mrk 724	0.0046	0.00
Mrk 744	0.0090[e]	0.00[a]
Mrk 1388	0.0213[f]	0.49[a]

[a] Assuming unreddened $F(\mathrm{H}\alpha)/F(\mathrm{H}\beta)$ ratio is 3.1. See text.

[b] Interstellar reddening indeterminate: Adopted mean $c = 0.42$.

[c] Adopted reddening from Was 96. See text.

[d] From Shuder and Osterbrock 1981.

[e] From Osterbrock and Dahari 1983.

[f] From Osterbrock 1985*b*.

Wasilewski (1983) also measured redshifts from slit spectra of many of the "new" emission-line galaxies he discovered. Nine were measured both by him and by us. Converting his published results to heliocentric redshifts for comparison with ours, the mean difference is z (this paper) − z (Wasilewski) = +0.00074 ± 0.0002. The sample error is ±0.0005. Hence the random error in Wasilewski's redshifts is only about ±0.0002, but there is a zero-point difference between his redshifts and both ours and the FBSS of almost +0.0007.

In one of the galaxies, Was 15, no emission lines could be seen on our spectra, and for another, Was 16, only one very weak emission line, Hα. For these two objects the redshifts were measured from the absorption lines Hβ, Mg Ib, and Na I D, with the results listed in Table 3. No emission-line fluxes were measured for these two galaxies.

III. EMISSION LINE WIDTHS

The full widths at half-maximum (FWHMs) were measured for the stronger emission lines for which medium, high, or echism dispersion spectra were available. The measurements were made in the way described in previous papers (e.g., Osterbrock and De Robertis 1985). Lines in both the comparison and galaxy spectra were fitted by Gaussians. The FWHMs of the comparison lines were plotted as a function of wavelength and interpolated to the position of each emission line measured in the galaxy, to determine the instrumental FWHM. This is particularly important for the CCD spectra, on which the resolution varies significantly along the chip, mostly as a result of changes in focus. The measured galaxy FWHM was then assumed to be the quadrature sum of the intrinsic and instrumental FWHMs. The resulting intrinsic FWHMs, expressed in velocity units and rounded off to the nearest 50 km s^{-1}, which is the approximate probable error as judged from internal consistency, are listed in Table 4. The [S II] FWHMs are average values for $\lambda\lambda$6716, 6731, while many of the [N II] FWHMs refer to λ6583 alone, in the objects on which λ6548 was too weak to give a good determination also.

In a very few cases the measured FWHM in the galaxy spectrum was less than the instrumental FWHM. These are objects with narrow lines, and with small, almost stellar appearing nuclei, observed in good seeing, so that their images are sharper than that of the uniformly illuminated slit. For these objects, as well as those with measured FWHMs only slightly larger than the instrumental width, an upper limit alone is given in Table 4.

IV. ACTIVITY CLASSIFICATION

The principal aim of this paper is to examine a uniformly selected set of galaxies whose nuclear activity is classified by well-defined criteria. First, the single Seyfert 1 among the "new" emission-line galaxies, Was 26, was classified on the basis of its broad H I emission lines, as shown in Figure 1. Also, both [Fe VII] λ6087 and [Fe X] λ6375 may be seen in its spectrum, each with strength ~0.2 that of [O I] λ6300. Thus our spectra of this galaxy confirm its original classification by

TABLE 4

EMISSION LINE WIDTHS

Line	FWHM (km s^{-1})
Was 2	
Hα	400
[N II]	400
[S II]	500
Was 6	
Hα	≤200
[N II]	≤200
[S II]	≤200
Was 26	
[S II]	350
Was 31	
Hα	550
[N II]	500
Was 32	
Hα	250
[N II]	250
[S II]	250
Was 45	
Hα	350
[N II]	350
[S II]	350
Was 66	
Hβ	≤250
Hα	200
[O III]	≤250
[N II]	200
[S II]	200
Was 69	
Hα	≤250
[N II]	≤250
[S II]	≤250
Was 89	
Hα	≤250
[N II]	≤250
[S II]	300
Was 96	
Hα	200
Haro 4	
Hα	≤300
[S II]	≤300
Haro 25	
Hα	≤350
[N II]	≤350
[S II]	≤350

Wasilewski (1983). It is not included in Table 2. Was 45 has a weak, broad Hα emission component, as shown in Figure 2, and is therefore a Seyfert 1.9 galaxy in our classification system. Also, Mrk 744 is a previously classified Seyfert 1.8 galaxy with weak broad Hα and Hβ emission (Goodrich and Osterbrock 1983). Their *narrow* emission lines alone were measured and are included in Table 2.

For the purely narrow emission-line galaxies, we follow the quantitative method originated by Baldwin, Phillips, and Terlevich (1981), and adopt the specific spectral criteria recommended by Veilleux and Osterbrock (1987). They used the strengths of emission lines of [O III], [O I], [N II], and [S II], relative to nearby Balmer lines, as diagnostics of nuclear activity. They define an active galactic nucleus as one in which the observed gas is photoionized by a hard spectrum similar to a power-law continuum. All QSOs, Seyferts, and LINERs are included in this category, as can be recognized from the broad range of ionization evident in their spectra. Galactic nuclei that are not AGNs are those in which the gas is photoionized by hot OB stars. All starburst and giant H II–region galaxies are included among these objects, which we shall refer to collectively as H II region galaxies in the rest of this paper.

The diagnostic line flux ratios were corrected for interstellar reddening using the relation $I(\lambda) = F(\lambda)10^{cf_\lambda}$, where f_λ is the Whitford (1958) reddening function, as normalized and tabulated by Kaler (1976). The amount of correction was derived from the Balmer decrement. Following the procedure of Veilleux and Osterbrock (1987), the intrinsic Hα/Hβ ratio for AGNs was taken to be 3.10, owing to the contribution by collisional excitation of H^0, while it was taken to have the recombination value, 2.85, for H II region galaxies. The activity

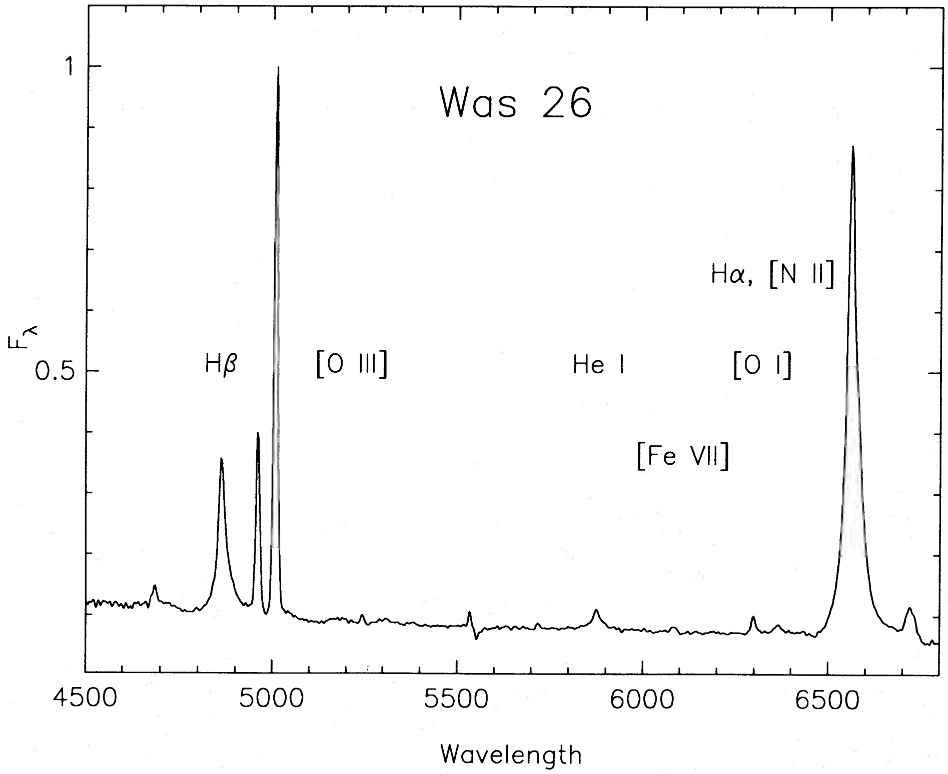

FIG. 1.—Spectral scan of Was 26 λλ4500–7000, in rest system of object. Relative flux F_λ in flux units per unit wavelength interval vs. wavelength in Å.

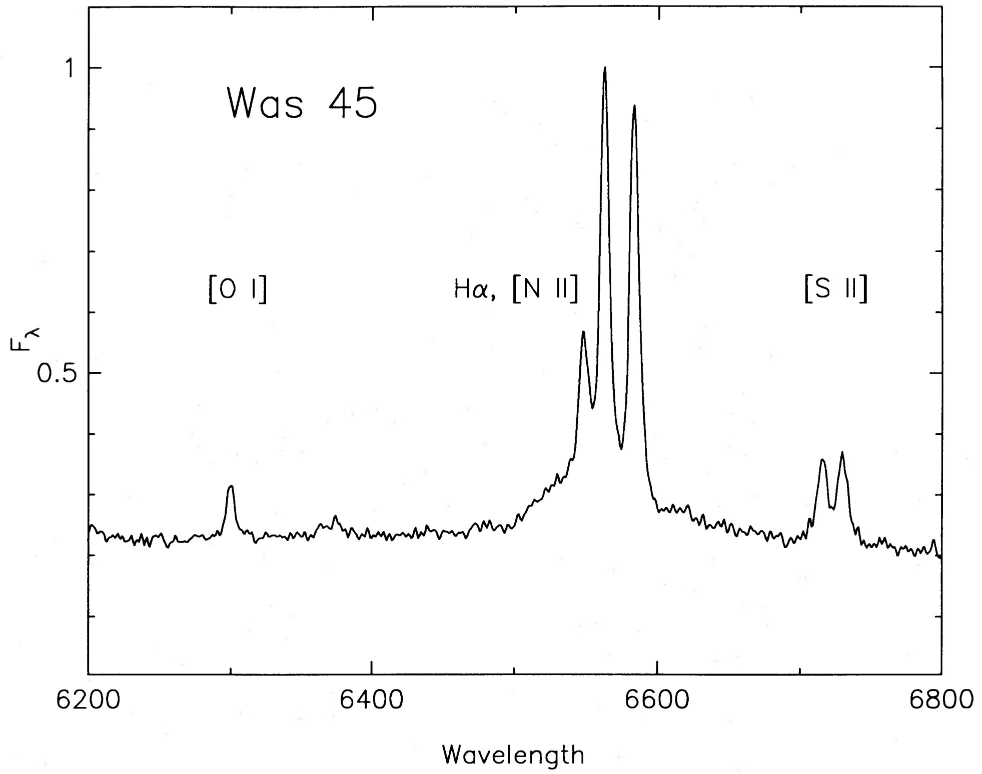

FIG. 2.—Spectral scan of Was 45 λλ6200–6800, showing weak broad Hα emission component. Axes as in Fig. 1.

TABLE 5

EMISSION-LINE DIAGNOSTIC RATIOS

	$\log \frac{F(5007)}{F(H\beta)}$		$\log \frac{F(6300)}{F(H\alpha)}$		$\log \frac{F(6583)}{F(H\alpha)}$		$\log \frac{F[S\ II]}{F(H\alpha)}$		
GALAXY	Observed	Corrected	Observed	Corrected	Observed	Corrected	Observed	Corrected	ACTIVITY CLASS
Was 2	1.12	1.11	−0.74	−0.72	0.04	0.04	−0.05	−0.06	Sey 2
Was 5	0.74	0.74	−1.83	−1.83	−1.89	−1.89	−1.22	−1.22	H II
Was 6	0.67	0.67	−1.91	−1.90	−1.24	−1.24	−0.93	−0.94	H II
Was 11	−0.61:	−0.67:	−1.39	−1.32	−0.28	−0.28	−0.48	−0.51	H II
Was 31	1.37	1.34	−0.99	−0.95	−0.02	−0.02	−0.44	−0.45	Sey 2
Was 32	0.65	0.65	−1.72	−1.72	−1.20	−1.20	−0.87	−0.87	H II
Was 45	1.04	1.02	−0.95	−1.03	−0.04	−0.04	−0.31	−0.62	Sey 1.9
Was 45 NE	−0.34:	−0.34:	...	...	−0.22	−0.22	−0.70:	−0.70:	H II
Was 66	0.61	0.60	−1.70	−1.68	−0.97	−0.97	−0.80	−0.80	H II
Was 69	0.74	0.74	−1.98	−1.98	−1.56	−1.56	−1.04	−1.04	H II
Was 87	0.07	0.06	−1.54:	−1.52:	−0.70	−0.70	−0.53	−0.54	H II
Was 88	−0.18:	−0.19:	...	...	−0.16	−0.16	−0.46	−0.47	H II
Was 89	0.49	0.49	−1.61	−1.59	−0.87	−0.87	−0.53	−0.53	H II
Was 96	0.73	0.73	−1.90	−1.90	−1.60	−1.60	−1.26	−1.26	H II
Was 96 SE	0.69	0.69	...	...	...	...	...	...	H II
Akn 347	1.21	1.18	−0.99	−0.95	−0.09	−0.09	−0.23	−0.24	Sey 2
Haro 4	0.66	0.66	−2.11	−2.11	−1.94	−1.94	−1.10	−1.10	H II
Haro 5	0.45	0.44	−1.73	−1.72	−0.92	−0.92	−0.68	−0.68	H II
Haro 22	0.84	0.82	−1.74	−1.72	−1.27	−1.27	−0.81	−0.83	H II
Haro 25	0.44	0.42	−1.70	−1.68	−0.88	−0.88	−0.81	−0.82	H II
Mrk 67	1.00	0.97	−2.10:	−2.06:	−1.64	−1.64	−1.12	−1.13	H II
Mrk 403	1.14	1.12	−1.04	−1.01	−0.03	−0.03	−0.40	−0.41	Sey 2
Mrk 417	1.27	1.24	−0.57:	−0.54:	−0.16	−0.16	−0.21	−0.23	Sey 2
Mrk 432	0.07	0.05	−1.35	−1.32	−0.62	−0.62	−0.48	−0.49	H II
Mrk 717	−0.09	−0.13	−1.63	−1.58	−0.37	−0.37	−0.62	−0.65	H II
Mrk 724	0.69	0.69	< −2.09	< −2.09	−1.13:	−1.13:	−1.13	−1.13	H II
Mrk 744	0.95	0.95	−0.29	−0.29	0.17	0.17	0.34	0.34	Sey 1.8
Mrk 1388	1.05	1.03	−0.94	−0.92	−0.48	−0.48	−0.84	−0.85	Sey 2

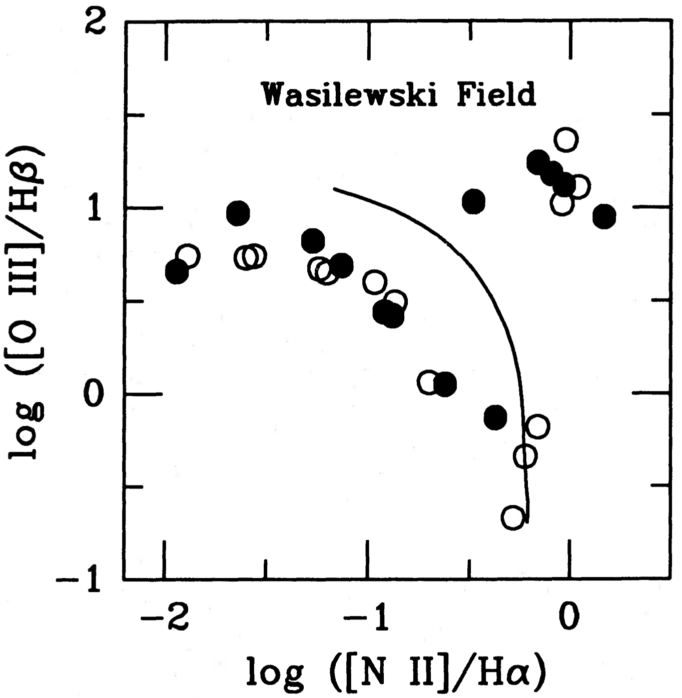

FIG. 3

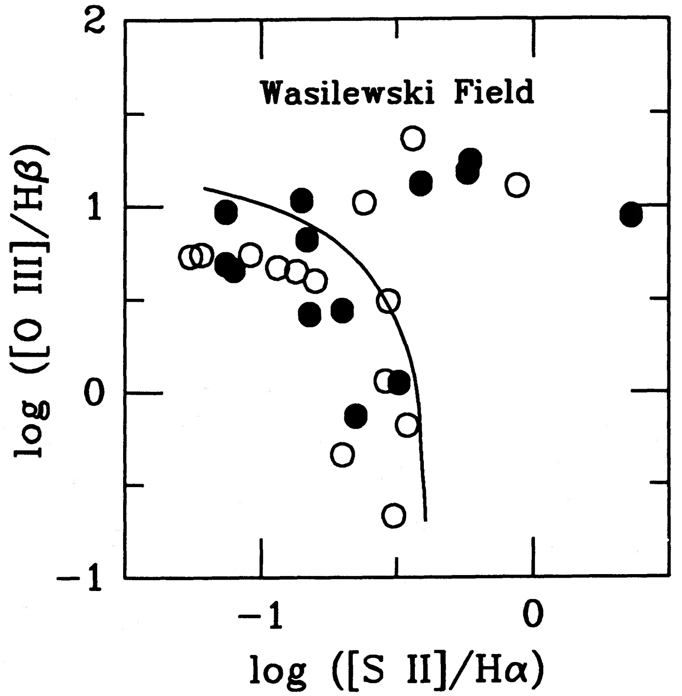

FIG. 4

FIG. 3.—Reddening-corrected [N II] λ6583/Hα vs. [O III] λ5007/Hβ for emission-line galaxies. Solid curve is from Veilleux and Osterbrock (1987) and divides the active from the nonactive galactic nuclei (see text). Solid symbols denote previously known emission-line galaxies; open symbols denote emission-line galaxies discovered by Wasilewski (1983).

FIG. 4.—Reddening-corrected [S II] ($\lambda\lambda$6716 + 6731)/Hα vs. [O III] λ5007/Hβ. Symbols and curves as in Fig. 3.

class is not always obvious *a priori*, but the difference in the reddening correction is very small, and the correct intrinsic Balmer decrement can be substituted ex post facto. The derived extinction constant, c (the logarithmic extinction at Hβ, so that $c = 1.54E_{B-V}$), is listed for each galaxy in the third column of Table 3. For Was 88, for which Hα/Hβ could not be measured, we adopted an extinction constant $c = 0.42$, the mean of the average ($c = 0.43$) and median ($c = 0.40$) values of reddening for the galaxies in this sample, omitting the two poorly determined values marked with a semicolon. For Was 96 SE we adopted $c = 0.00$, the value found for the very nearby Was 96.

Table 5 lists the logarithms of the corrected values of four line ratios recommended by Veilleux and Osterbrock (1987): I([O III] λ5007)/I(Hβ), I([O I] λ6300)/I(Hα), I([N II] λ6583)/I(Hα), and I([S II] λ6716 + λ6731)/I(Hα). For each galaxy both the observed ratio and next to it the same ratio corrected for reddening are listed. The reddening-corrected ratios for [N II], [S II], and [O I] are plotted against the corrected ratio for [O III] in Figures 3, 4, and 5 respectively. In these plots, the emission-line galaxies (*open circles*) discovered by Wasilewski (1983), are distinguished from the previously known emission-line galaxies (*filled circles*). The plotted curves, adopted by Veilleux and Osterbrock (1987), separate the AGNs (*upper right*) from the H II region galaxies (*lower left*). Thus the positions of a galaxy's measured line ratios in these three diagnostic diagrams determine whether or not it is an AGN. The same eight galaxies are classified as AGNs by all three diagrams.

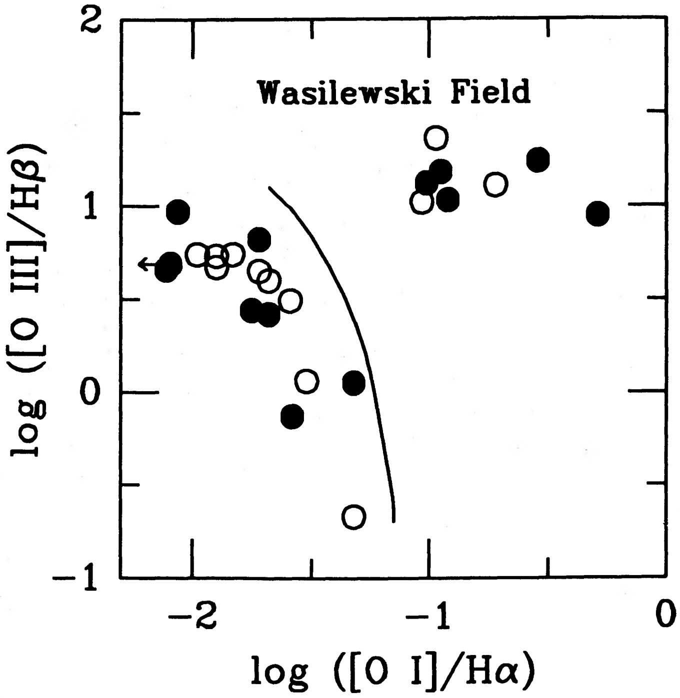

FIG. 5.—Reddening-corrected [O I] λ6300/Hα vs. [O III] λ5007/Hβ. Symbols and curves as in Fig. 3.

Two of them are the narrow-line components of Mrk 744, the Seyfert 1.8 galaxy, and Was 45, the Seyfert 1.9 galaxy discussed above. The other six are all Seyfert 2 galaxies, as identified in Table 5.

With two exceptions all the other galaxies listed in Table 5 are classified as H II region galaxies from the diagnostic diagrams of Figures 3, 4, and 5. In particular, of the seven Seyfert 2 candidates found by Wasilewski (1983), one (Was 45) is a Seyfert 1.9, two (Was 2 and 31) are Seyfert 2s, and four (Was 32, 66, 87, and 96) are actually H II region galaxies. This discrepancy is not surprising, for Wasilewski used a single criterion for identifying Seyfert 2 candidates, $F([\text{O III}]\ \lambda 5007)/F(\text{H}\beta) \geq 3$, as recommended earlier by Shuder and Osterbrock (1981), but now known to be incorrect (Osterbrock and Dahari 1983; Veilleux and Osterbrock 1987). Two of the galaxies in Table 5 cannot be plotted in Figures 3, 4, or 5, because either Hα or Hβ was not measured in their spectra. For one, Was 96 SE, our spectrum covers the range $\lambda\lambda$4600–6150, equivalent to $\lambda\lambda$4450–5950 in the rest system of the object. In addition to Hβ and [O III], only a weak He I λ5876 emission line can be seen. There is no trace of He II λ4686 nor [N I] λ5199. From the noise in the spectrum, an upper limit to the strength of either of these lines is about 0.05 the strength of Hβ, or 0.01 the strength of [O III] λ5007. Thus Was 96 SE is definitely not an AGN (Osterbrock and Dahari 1983; Veilleux and Osterbrock 1987), but rather is an H II region galaxy. It is brighter in the continuum than Was 96 itself and has slightly lower ionization than it; the two are separated by about 10″ ≈ 6500 pc (taking $H_0 = 75$ km s^{-1}). They may form a pair of interacting galaxies, as Wasilewski (1983) described them, or Was 96 SE may be the nucleus of a galaxy and Was 96 an outlying highly luminous H II region in it. The pair is similar in many ways to Mrk 490 (De Robertis and Osterbrock 1986).

The other object for which our data are incomplete is Was 80. Its emission lines are relatively weak with respect to its integrated stellar spectrum, which has strong deep absorption lines. Emission lines of Hα, [N II], and [S II] are definitely present, but only poorly measured because of the effects of the absorption lines superposed on the emission lines and on the location of the continuum; [O III] λ5007 is probably, but not certainly present; and Hβ, if present, is nearly lost in a very strong integrated stellar absorption line. Possibly Was 80 is a LINER, but a much longer-exposure spectrum would be necessary to classify this galaxy with certainty.

There are other previously known AGNs in the Wasilewski field, which were not studied in the present paper and which therefore are not included in Table 5. To find any such objects, Wasilewski's (1982) list of previously known emission-line galaxies was compared with our own spectral classifications, as well as with the catalogs of Huchra (1983), Véron-Cetty and Véron (1985), and Kaneko (1986). All Seyfert galaxies or LINERs found in this way are listed in Table 6 with their published classifications. Preference is given to Lick classifications, if available, for the sake of uniformity.

Combining Tables 5 and 6, and including Was 26, described in the text above, there are four known Seyfert 1 or 1.5 galaxies in the Wasilewski field, two known Seyfert 1.8 or 1.9 galaxies, and nine known Seyfert 2 galaxies. In addition, one possible and three definite LINERs are listed, but they are probably very incomplete. Two of them are elliptical galaxies; these LINERs may perhaps be objects of a different physical type. They are not included in the remainder of this discussion.

The emission-line widths listed in Table 4 include four galaxies with FWHMs greater than 300 km s^{-1}. These are Was 26, a Seyfert 1; Was 45, a Seyfert 1.9; and Was 2 and Was 31, Seyfert 2s. On the other hand seven other galaxies have intrinsic FWHMs less than or equal to 300 km s^{-1}. They are thus all in accord with the general tendency (which is not an absolute rule) for a separation between Seyfert and H II region galaxies at about that value of the FWHM (e.g., Shuder and Osterbrock 1981; Phillips, Charles, and Baldwin 1983; Whittle 1985).

TABLE 6

OTHER ACTIVE GALAXIES

Galaxy	Type	Reference
Mrk 268	Sey 2	1, 2
Mrk 670	Sey 2	3
Mrk 739[a]	Sey 1[b]	2, 4
Mrk 766[c]	Sey 1.5	5
NGC 3994	LINER	6
NGC 4278	LINER	2
NGC 4283	LINER	2
NGC 4922	Sey 2	2, 7
NGC 5548	Sey 1.5	8, 9

[a] Mrk 739 = NGC 3758.

[b] Main component; companions is H II.

[c] Mrk 766 = NGC 4253.

REFERENCES.—(1) Koski 1978; (2) Huchra, Wyatt, and Davis 1982; (3) Markarian *et al.* 1985; (4) Dahari 1985*b*; (5) Osterbrock and Pogge 1985; (6) Keel *et al.* 1985; (7) Dahari 1985*a*; (8) Osterbrock 1977; (9) Cohen 1983.

V. DISCUSSION AND CONCLUSIONS

The numbers of Seyfert galaxies of the various types are listed in the second column of Table 7. The numbers in some of the subclassifications are small, and we must combine them in some way for discussion. If we consider all of them which have any visible broad Hα emission component in their spectra as forming one group, the relative proportion of Seyfert (1 + 1.5 + 1.8 + 1.9) to Seyfert 2 is 6/9 = 0.67. If, on the other hand, we include the Seyfert 1.8 and 1.9 galaxies with Seyfert 2s, with which they would probably be classified on spectra of poorer signal-to-noise ratio, the relative proportion of Seyfert (1 + 1.5) to Seyfert (1.8 + 1.9 + 2) is 4/11 = 0.36. These ratios are similar to the ratio of numbers of Seyfert 1 to Seyfert 2 ≈ 1/2 = 0.5 found by Phillips, Charles, and Baldwin (1983), but significantly smaller than the ratios found in other earlier studies, including the Markarian sample used by Meurs and Wilson (1984). The reason, as noted in the introduction, is that many Seyfert 2 galaxies are difficult to recognize except on high-quality slit spectra. No doubt there are still undetected

TABLE 7

RELATIVE NUMBERS OF SEYFERT GALAXIES IN WASILEWSKI FIELD

Seyfert	Observed	Relative Volume	Number per Unit Volume of Space
1	2	2.82	2.0
1.5	2	2.82	2.0
1.8	1	1.68	1.7
1.9	1	1.68	1.7
2	9	1.00	25.4

Seyfert 2 galaxies in the Wasilewski field, brighter than the approximate limit of his survey, and the true proportions of Seyfert 1s are even smaller than found here.

Tables 5 and 6, and the numbers in the "observed" column of Table 7, refer to a survey that is reasonably complete to apparent magnitude $B \approx 15.7$ (Wasilewski 1983). On the average, however, Seyfert 1 and 1.5 galaxies are more luminous than Seyfert 2 galaxies, so a further analysis is necessary to find the relative numbers per unit volume of space. Such a study, including better measured apparent magnitudes and a discussion of completeness of other surveys of the Wasilewski field is planned (Shaw 1988). For the present paper we simply use available data on the relative volume of space surveyed to form a preliminary estimate.

According to the Seyfert galaxy luminosity function of Meurs and Wilson (1984), both classes cover a wide range of absolute magnitudes, but the maximum of the Seyfert 1 luminosity function is at absolute magnitude $M_B = -21.5$, and of the Seyfert 2 luminosity function, at $M_B = -20.7$, for a difference of $\Delta M_B = 0.8$. If we take these same values as referring to the typical Seyfert galaxies in the Wasilewski field, the volume surveyed for Seyfert 2s is $10^{0.6\Delta M_B} = 3.02$ times smaller than the volume surveyed for Seyfert 1s. This ratio is probably not exact, for the Meurs and Wilson (1984) luminosity function is based on Markarian Seyfert galaxies, among which the Seyfert 2 are known to be incomplete, so their mean absolute magnitude may be biased. Another estimate may be derived from the complete sample of Seyfert galaxies studied by Edelson (1987). He gives the redshifts and classifications (Seyfert 1 or 2) for all his objects; from them the distribution in redshift z of each type of Seyfert galaxy in his sample may be derived. The ratio of mean redshifts of the two types is $\langle z(\text{Sey 1})\rangle / \langle z(\text{Sey 2})\rangle = 1.32$; likewise the ratio of median redshifts is $z_{1/2}(\text{Sey 1})/z_{1/2}(\text{Sey 2}) = 1.44$. Taking the mean of these two values gives, for his sample $\Delta M_B = 0.70$ or a ratio of volumes 2.63. These two determinations are in reasonably good agreement, and we adopt for our preliminary study their average, 2.82. We take this to apply to both Seyfert 1 and Seyfert 1.5 galaxies, which are lumped together as Seyfert 1 in the statistical discussions of both Meurs and Wilson (1984) and Edelson (1987). The numbers of Seyfert 1.8 and 1.9 galaxies are too small for similar statistics, so we adopt an intermediate mean absolute magnitude and relative volume of space surveyed for them in the Wasilewski field. These relative volumes of space are listed in Table 7. From them the relative numbers per unit volume of space listed in the last column of Table 7 are derived. Summing these figures leads to relative numbers per unit volume of space (here and now) of Seyfert $(1 + 1.5 + 1.8 + 1.9)$/Seyfert $2 = 0.29$, or Seyfert $(1 + 1.5)$/Seyfert $(1.8 + 1.9 + 2) = 0.14$. A third way of presenting the result is that the relative numbers of Seyfert $(1 + 1.5)$/Seyfert $(1.8 + 1.9)$/Seyfert $2 = 0.12/0.10/0.78$, with of course a substantial uncertainty in each number. These numbers are the final result of our present preliminary study. They will be improved and extended by inclusion of further surveys of the Wasilewski field, but it is clear that any complete physical picture or evolutionary theory of AGNs must predict a relatively large number of Seyfert 2 galaxies.

Two very simple illustrations may be given, based on physical ideas put forward by various authors and reviewed recently, for instance, by Lawrence (1987). One is that AGNs evolve in time through a Seyfert 1 or 1.5 stage, then become Seyfert 1.8 or 1.9 objects, then Seyfert 2s, or alternatively evolve the other way, or perhaps back and forth many times through these stages. On this picture the relative time spent in each stage would be just in the ratio 0.12/0.10/0.78 (or, with more statistical certainty, 0.1/0.1/0.8) stated above.

If on the other hand we hypothesize that all Seyfert AGNs are more or less identical objects seen in different orientations, each containing a luminous nucleus and broad-line region (BLR) surrounded by an optically thick obscuring torus or cylinder, then these numbers contain information on the projected area of the torus. On this picture the Seyfert 1s and 1.5s are the objects seen nearly pole on, with inclination θ between the axis of the torus and the line of sight in the range $0 < \theta < \theta_1$, where for instance for a point BLR at the center of a torus with radius r and height h_1, $\theta_1 = \cot^{-1} h_1/2r$. Seyfert 2s on this picture are similar objects seen nearly edge on, with $\theta_2 < \theta < \pi/2$, with $\theta_2 = \cot^{-1} h_2/2r$. If we interpret θ_1 as defining the angle at which the central BLR is completely unobscured, and θ_2 the angle at which it is completely obscured, then the range $\theta_1 < \theta < \theta_2$ (or $h_1 < h < h_2$) of partial obscuration would presumably correspond to Seyfert 1.8 and 1.9 objects. Some Seyferts are known to change their sub-type, e.g., NGC 4151 from 1.5 to 1.9 (Cohen and Antonucci 1983; Penston and Perez 1984). Such temporal behavior is quite consistent with the concept of a partly obscured BLR with "fuzzy" or ill-defined edges. For a random distribution of orientations with respect to the line of sight, it is easy to derive from the numbers above $\theta_1 = 29°$, $\theta_2 = 39°$, or $h_1/r = 3.7$, $h_2/r = 2.4$, a rather thick disk. With such a picture, in Seyfert 1 galaxies with $\theta < \theta_1 = 29°$, any component of velocity in the plane perpendicular to the axis, a rotational component for instance, would have only a small component in the line of sight. Thus the observed broad-line widths, on this picture, would have to be attributed to radial or polar outflow, or else the rotational velocities would have to be several times larger than velocities calculated directly from the line widths.

Both these pictures are doubtless greatly oversimplified, but they illustrate the types of conclusions that can be drawn from the relative numbers of the different types of Seyfert galaxies on the basis of specified assumptions.

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