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THE SPECTRA OF NARROW-LINE SEYFERT 1 GALAXIES[1]

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ABSTRACT

Measurements are presented of a group of active galactic nuclei with all the properties of Seyfert 1 or 1.5 galaxies, but with unusually narrow H I lines. They include Mrk 42, 359, and 1239 (previously studied by other authors) as well as Mrk 493, 766, 783, and 1126. One other somewhat similar object, Mrk 1388, is also included in the discussion; measurements of its spectrum have been published elsewhere. For these objects, narrow-line widths, relative intensities of the emission lines, etc., are all similar to those in other Seyfert 1 galaxies. Some, in particular Mrk 493 and Mrk 42, have relatively strong Fe II emission; in others, especially Mrk 359, 783, and 1126, it is quite weak.

As a group, these narrow-line Seyfert 1 galaxies have approximately normal luminosities. Their Hβ emission-line equivalent widths are, on the average, somewhat smaller than in typical Seyfert 1's. Overall, these narrow-line Seyfert 1 galaxies show a wide variety of deviations from the properties of typical Seyfert 1 objects. They clearly demonstrate that the Seyfert phenomenon is not a simple one-parameter effect.

Subject headings: galaxies: nuclei — galaxies: Seyfert

I. INTRODUCTION

Seyfert galaxies are defined as galaxies with bright, starlike nuclei that have relatively broad emission lines covering a wide range of ionization. They are generally divided into two types according to the standard spectral classification scheme of Khachikian and Weedman (1974). A Seyfert 1 galaxy is one in whose spectrum the H I Balmer lines are broader than the forbidden lines, while a Seyfert 2 is one in which the H I and forbidden lines are approximately the same width. Typical full widths at half-maximum (FWHM) of the forbidden lines in both classes of Seyfert galaxies are in the range of 300–800 km s^{-1}, while the H I lines in Seyfert 1's are usually much broader, lying in the range of 1000–6000 km s^{-1} (cf. Osterbrock 1984).

Davidson and Kinman (1978) have called attention to Mrk 359 as a "possibly important" Seyfert galaxy. It has H I and forbidden lines with similar widths with FWHM $\approx$ 300 km s^{-1} (the H I emission lines are only slightly broader) in its spectrum, which makes it similar to a Seyfert 2 galaxy at the lower end of the line-width distribution (Shuder and Osterbrock 1981). In addition, it has a strong featureless continuum and strong high-ionization lines like [Fe VII] $\lambda\lambda$5721, 6087 and [Fe X] λ6375. These are properties common in Seyfert 1 galaxies (Cohen 1983; Osterbrock 1984), but quite rare in the Seyfert 2 class (Koski 1978; Cohen and Osterbrock 1981). Thus Mrk 359 appears to have a mixture of properties from both classes. Its spectrum, however, is not typical of so-called "Seyfert 1.5" galaxies (Osterbrock 1977; Cohen 1983), which are defined by their composite broad plus narrow H I line profiles. Thus Mrk 359 appears to represent a rarer type of Seyfert galaxy that might be called a "narrow-line Seyfert 1" (Osterbrock and Dahari 1983).

Another somewhat similar Seyfert galaxy is Mrk 42. As both Koski (1978) and Phillips (1978) emphasized, it has many of the properties of a Seyfert 1 galaxy, including strong Fe II emission lines, but all the line widths are characteristic of a Seyfert 2. Mrk 42 has weaker [Fe VII] and [Fe X] emission than Mrk 359, but these high-ionization lines are definitely present.

Several other narrow-line Seyfert 1 galaxies are known to us; we give new measurements for Mrk 42 and Mrk 359 in the present paper, plus measurements of Mrk 493, 766 (= NGC 4253), 783, 1126 (= NGC 7450), and 1239. Several of these galaxies were mentioned in remarks in Table 1 of Osterbrock and Dahari (1983). An eighth, Mrk 1388, was discovered by Osterbrock (1985) during a study of emission-line galaxies in the Wasilewski (1983) field and is described in a separate paper but is included in the discussion here. The only other narrow-line Seyfert 1 galaxies that we know but have not included here are Akn 564 (Osterbrock and Shuder 1982), Mrk 684 (see note added in manuscript), and Mrk 1044 (Osterbrock and Dahari 1983). Mrk 1239 was previously studied by Rafanelli and Bonoli (1984).

II. OBSERVATIONS

Spectral data on the seven program galaxies were obtained with the image tube image dissector scanner (IDS) developed by Robinson and Wampler (1972) and the Cassegrain spectrograph and peripherals developed to match it by Miller, Robinson, and Wampler (1976), on the 3 m Shane telescope of Lick Observatory. These spectral scans were taken since 1975, many of them in connection with other programs. Gratings of 600 lines mm^{-1} ("normal dispersion") and 1200 lines mm^{-1} ("high dispersion") were used, giving resolutions of approximately 10 Å and 5 Å respectively and spectral coverages of approximately 2550 Å and 1275 Å respectively. For Mrk 1126, one scan was obtained with the 1.5 m telescope at the Mount Lemmon Observing Facility, operated by the University of California, San Diego, and the University of Minnesota. The IDS system there is almost identical with that at Lick Observatory, but the spectrograph is different. A grating of 1200 lines mm^{-1} was used, giving a resolution of approximately 7.5 Å and spectral coverage of approximately 1700 Å. The spectra of the seven galaxies measured in this investigation are listed in Table 1, in which λ_0 gives the low wavelength at which the spectral scan begins, N and H stand for normal or high dispersion as defined above. The label HL stands for the Mount Lemmon "high-dispersion" scan.

[1] Lick Observatory Bulletin No. 1010.

TABLE 1

JOURNAL OF OBSERVATIONS

Object	z	Date	λ_0	Dispersion	Exposure (minutes)
Mrk 42	0.0245 ± 0.0001	1975 Feb 15/16	5421	N	32
		1976 May 5/6	3446	N	48
		1976 May 5/6	4893	N	48
		1977 Jan 17/18	6496	N	48
		1977 Feb 24/25	3684	H	64
Mrk 359	0.0169 ± 0.0001	1978 July 31/Aug 1	3260	N	32
		1978 July 31/Aug 1	4825	N	32
		1978 Nov 5/6	5801	H	48
		1978 Nov 6/7	5919	N	64
		1978 Nov 6/7	5224	H	64
		1979 Sept 14/15	4473	H	64
		1979 Dec 11/12	2924	N	48
		1981 July 26/27	3411	N	32
		1981 July 26/27	4384	N	32
		1983 Aug 13/14	3243	H	64
Mrk 493	0.0315 ± 0.0001	1978 July 4/5	3350	N	32
		1978 July 4/5	4689	N	32
		1978 July 5/6	2940	N	48
		1978 July 30/31	3778	H	48
		1978 July 30/31	4849	H	48
		1978 July 30/31	5816	H	48
		1980 Mar 28/29	4258	H	48
Mrk 766 .... (= NGC 4235)	0.0127 ± 0.0001	1978 Dec 23/24	4692	N	16
		1979 May 30/31	3456	N	16
		1979 May 30/31	4753	N	16
		1979 Dec 11/12	2924	N	32
Mrk 783	0.0669 ± 0.001	1979 May 30/31	3454	N	32
		1979 May 30/31	4752	N	32
Mrk 1126 .... (= NGC 7450)	0.0101 ± 0.0001	1979 Nov 20/21	3386	N	32
		1979 Nov 20/21	4681	N	32
		1979 Dec 10/11	5617	N	64
		1979 Dec 11/12	2922	N	48
		1981 Aug 22/23	3415	N	32
		1981 Aug 22/23	4644	N	32
		1982 Sept 19/20	5558	HL	80
		1983 Aug 16/17	4525	H	64
Mrk 1239	0.0195 ± 0.0001	1982 Feb 22/23	3406	N	32
		1982 Feb 22/23	4638	N	48

All the spectral scans were calibrated into wavelength units using emission lines of He, Ne, Hg, and Cd from standard comparison lamps to give the scale and local dispersion and sky lines of [O I], Na I, and Hg I, recorded simultaneously with the galaxy spectra, to give the zero point for each scan. This procedure has been used at Lick Observatory for the past several years to eliminate the small wavelength shifts, dependent on telescope position, that might otherwise arise, apparently as a result of flexure in the sweep coils of the image dissector. The scans were all calibrated into relative energy units using measurements of standard stars (from the lists of Stone 1974, 1977) taken on the same nights as the galaxy scans with the same observational setups. The data reduction was carried out using regular Lick Observatory computer programs, which include a standard atmospheric-extinction correction and removal of atmospheric absorption bands in the red and near-infrared spectral regions by comparison with the standard-star measurements.

As a sample of the data, the spectrum of Mrk 1126 is plotted in Figure 1. It is shown in the rest system of the emitting galaxy, using the redshift tabulated in Table 1. These heliocentric redshifts were measured from the strong forbidden lines ([O III] and [Fe VII] where observed). The short-wavelength limits of the spectra are close to the limit set by atmospheric extinction, and the long-wavelength limits are close to the limit set by the decreasing sensitivity of the image tube in the scanner.

III. DATA REDUCTION

a) Line Intensities

For each of the scans listed in Table 1, we made measurements of the total intensities of the emission lines relative to Hβ λ4861 (entire profile; broad + narrow components). For the measurement of unblended lines, standard Lick Observatory interactive reduction programs were used. For each line, the local continuum can be drawn on a graphics display, and the relative energy flux in the line, *F*(line), and its wavelength can be measured. The greatest source of uncertainty, especially in the case of weak lines, is the subjective specification of the local continuum under each line.

For measuring blended lines, particularly Hγ and [O III] λ4363, Hα and [N II] $\lambda\lambda$6548, 6583, and [S II] $\lambda\lambda$6716, 6731, a more complicated technique was used to obtain the relative intensities. First, the total relative intensity of the blend was

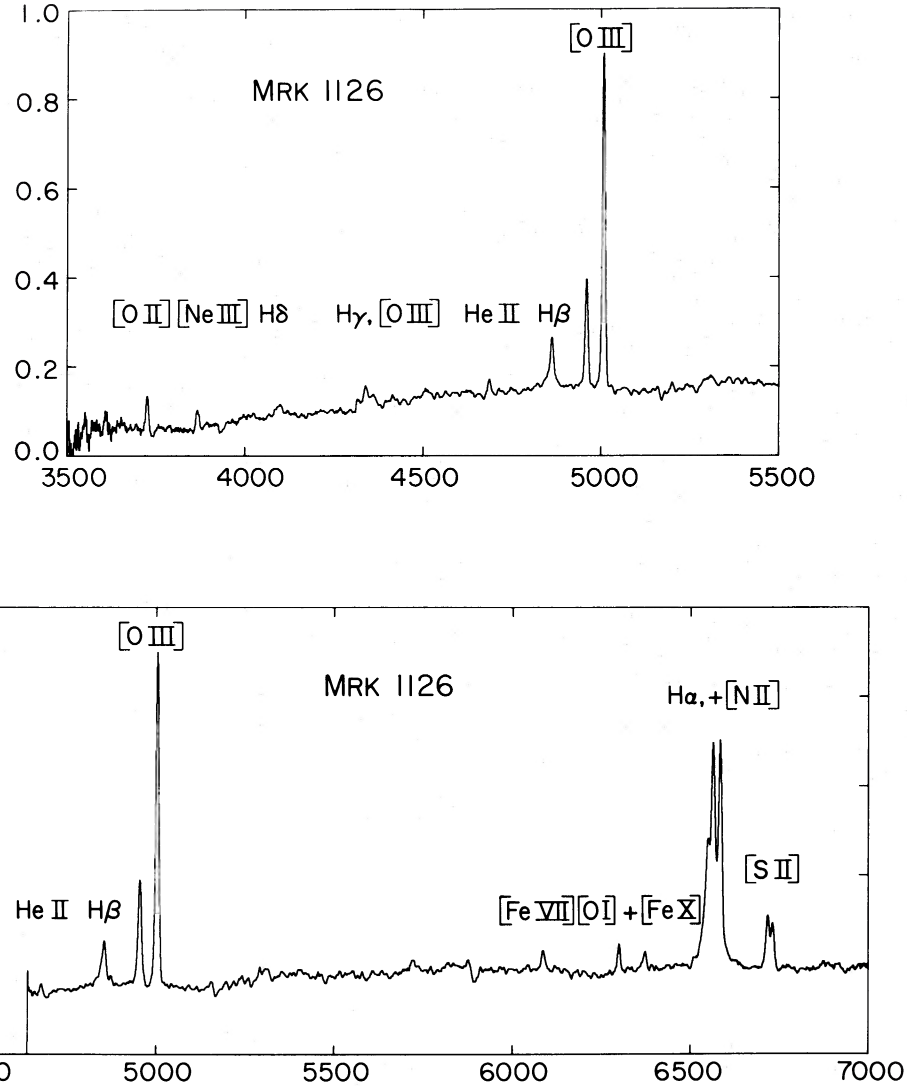

FIG. 1.—Spectral scans of Mrk 1126. (*top*) 3500–5500 Å, (*bottom*) 4750–7000 Å, both in the rest system of the object. *Vertical scale*, relative energy flux in flux units per unit wavelength interval; *horizontal scale*, wavelength in angstroms.

measured using the same technique as for unblended emission lines. Then the relative contribution of each component of the blend to the total intensity was determined by "deblending" the lines with one of two techniques.

For blends of narrow lines in which the profiles are very nearly Gaussian (e.g., the [S II] λλ6716, 6731 blend), the program GAUSS (Dahari 1985) was used. It fits Gaussian profiles to the blended features using a least-squares technique. For each assumed component of a blended feature, a "first guess" of the height, width, and wavelength of that component was specified interactively on a plot of the feature. The program then used a least-squares method to vary these parameters to give the best fit possible. While it is true that the line profiles are not explicitly Gaussian, the fits obtained were of sufficient precision that the uncertainty due to the choice of the underlying continuum was still the dominant source of error.

For line blends in which one of the components had broad wings (e.g., Hα in the blend with [N II] λλ6548, 6583), the Gaussian fitting technique was inappropriate, as the wings are clearly not Gaussian. In these cases, deblends were performed with a special program called DEBLEND (Phillips 1978) that allows the composite feature to be synthesized by blending assumed lines with profiles taken from unblended lines of the same object, usually Hβ for Hα and [O III] λ5007 for [N II], taken at the same dispersion. The fluxes, widths, and wavelengths of the assumed lines can be systematically varied to give the best fit of the artificial blend constructed in this way to the actual observed feature.

Two of the galaxies, Mrk 42 and 493, have very strong complexes of permitted Fe II emission lines. They are shown well in the scan of Mrk 42 in Figure 2. The individual Fe II lines are identified in the three high-dispersion sections of the spectrum of Mrk 493 in Figure 3. The relative intensities of the individual Fe II lines in this object and in Mrk 42 are similar to those in I Zw 1 (Phillips 1976, 1978). Mrk 766 and 1239 also have fairly strong Fe II emission, but not as strong as in Mrk 42 and 493. In measuring intensities, no attempt was made to deblend the Fe II lines, but rather the relative total intensities of the multiplet groups at λ4750 and λλ5190, 5320 were measured. Individual line intensities are given for Fe II λ4924 and Fe II λ5018, which lie outside the main complexes. The latter was deblended from [O III] λ5007. No Fe II was observed in Mrk 359, 783, or 1126, but quantitative upper limits were measured.

The final list of measured relative intensities is collected in Table 2. Note that all wavelengths given are laboratory wavelengths of the lines, not observed wavelengths. Those relative intensities marked with a colon indicate approximate measurements of weak or badly blended lines, and are only accurate to within a factor of 2. Ellipsis dots indicate those lines not observed in the spectra, and a blank entry indicates that available spectra did not cover that wavelength region.

Apparent variation of [Fe X] λ6375 was noted between the two scans of Mrk 766 taken five months apart; we intend to return to this observation in a later paper.

Our spectra were taken primarily for measuring relative emission-line intensities. Wavelength resolution, exposure time, and number of objects observed were maximized at the expense of a highly accurate absolute-flux calibration. The latter requires using a large slit, measuring standard objects many times during the night, and ceasing data collection at the first sign of any thin clouds. The absolute Hβ fluxes, listed in Table 3, are estimated to have probable errors of ±20% as judged from the 10% internal consistency of measurements of those galaxies for which there are several scans on different nights, with an additional allowance for possible systematic effects. The equivalent widths, which are of course independent of seeing, clouds, absolute calibration, etc., are also listed in Table 3. Their probable errors are about ±10%.

b) *Line Widths*

In addition to relative intensities of the emission lines, line widths (FWHM) were also measured for the emission lines. Two different techniques were used, and both gave quantitatively the same result. The first technique used RETICENT, a one-dimensional spectrophotometric command program (Pritchet and Mochnacki 1982). A local continuum was fitted to the line and subtracted. The program then determined the line peak and from that specified the width at half the determined peak intensity of the line. This method is useful in that it makes no assumptions about the shape of the line profile (e.g., it does not assume a Gaussian profile). However, it cannot be used to determine the widths of lines that are badly blended. Widths obtained in this way from the high-dispersion scans have an uncertainty of ±50 km s^{-1}, and from the normal-dispersion scans, about twice this large. In most of these galaxies Hα is too strongly blended with [N II] λλ6716, 6731 to be measured in this way. In these cases the less accurate method of scaling up the Hβ width to best fit Hα in the DEBLEND program was used. The second technique was to use GAUSS to measure the widths of blended lines. This

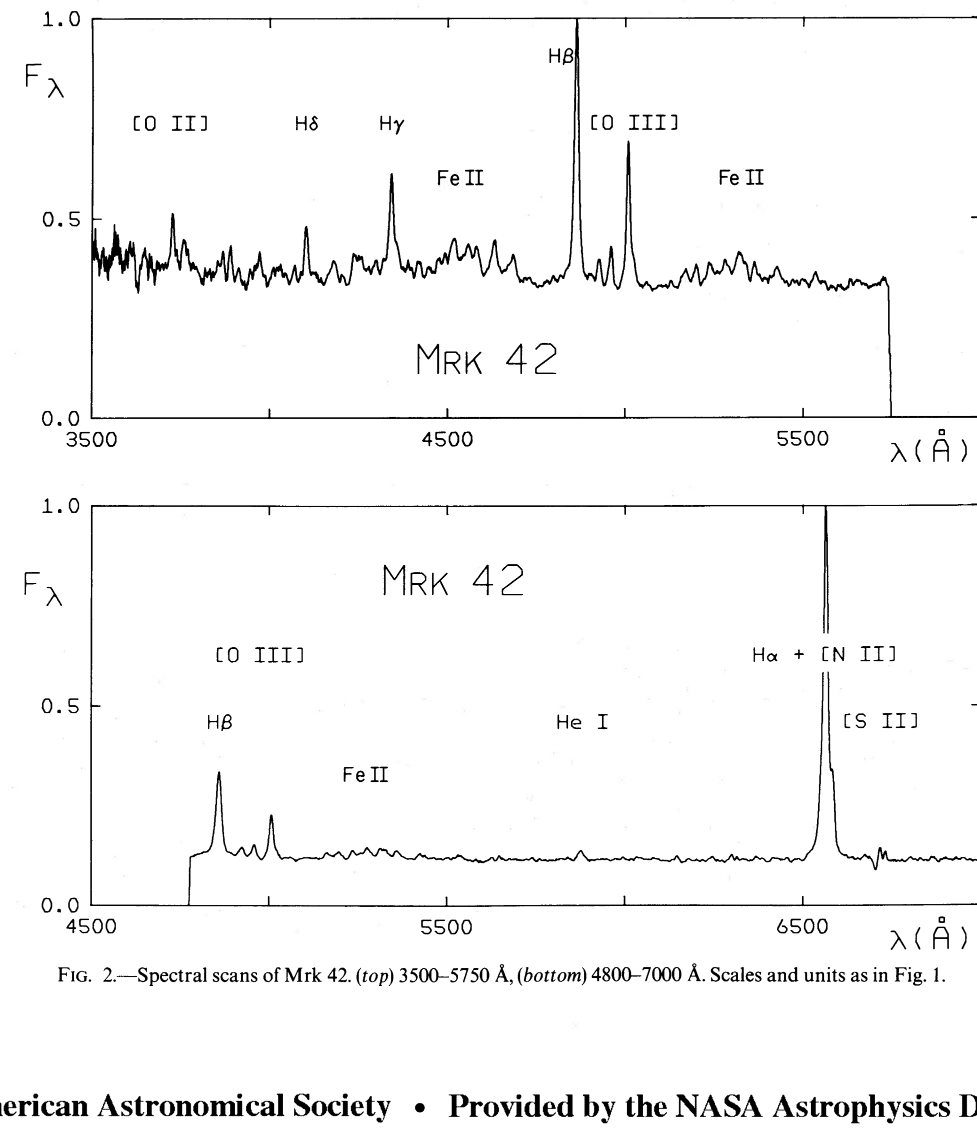

FIG. 2.—Spectral scans of Mrk 42. (*top*) 3500–5750 Å, (*bottom*) 4800–7000 Å. Scales and units as in Fig. 1.

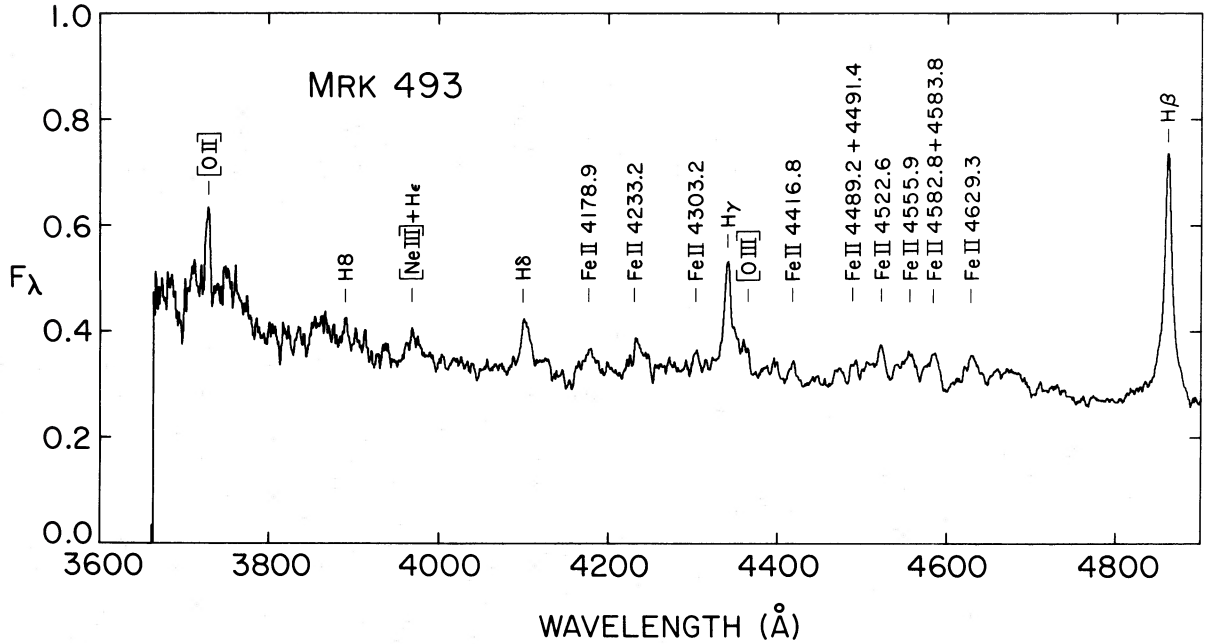

FIG. 3a

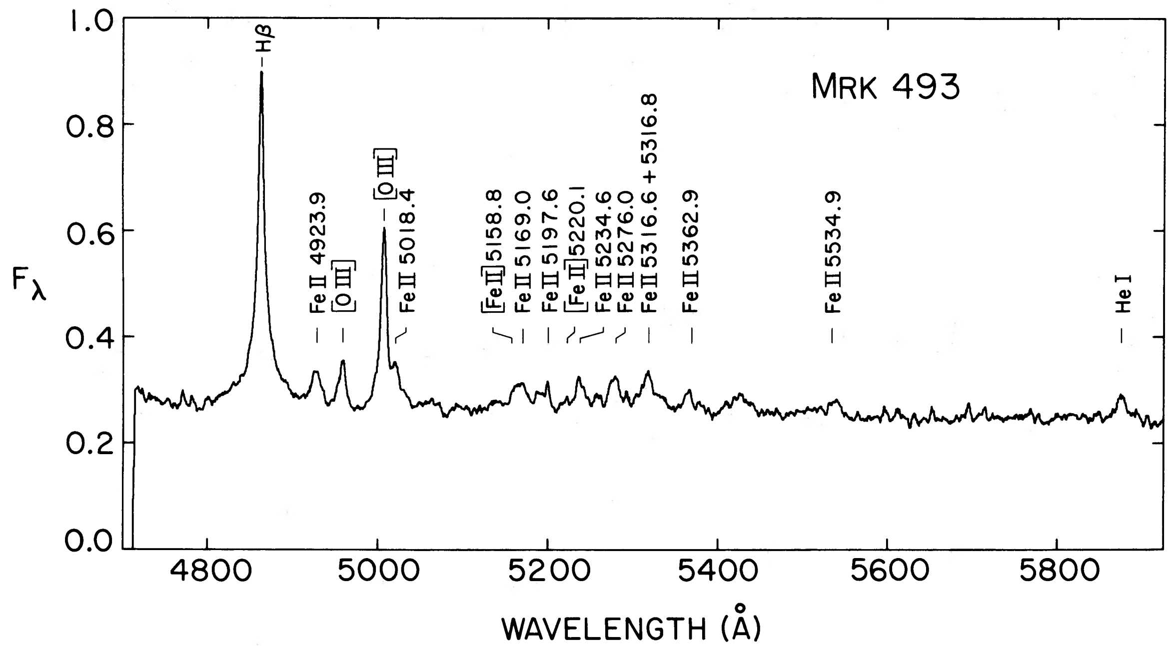

FIG. 3b

FIG. 3.—High-dispersion spectral scans of Mrk 493. (*a*) 3700–4900 Å, (*b*) 4700–5900 Å, (*c*) 5700–6800 Å. Scales and units as in Fig. 1.

program was discussed in the previous subsection on line intensities. GAUSS was also used to measure the width of individual lines, and the results were the same (to within ± 30 km s^{-1}) as those obtained with RETICENT.

The observed width obtained by either of these methods is the actual width convolved with the instrumental width of the scanner. In order to correct for the instrumental width and obtain the "true" width, we assumed that the true and instrumental profiles were Gaussians and that the observed width is therefore the quadrature sum of the true and instrumental widths. As has been stated before, there is no known physical reason to believe that the line profiles are explicitly Gaussian. The observed profiles clearly depart from Gaussians, particularly in the lowest 25% of each line, where they have more area in the wings, with respect to the core, than a true Gaussian. This property is shared by the deconvolved profiles in Mrk 359 and 1126 (De Robertis and Osterbrock 1984). However, the narrow lines are sufficiently close to Gaussians so that this simplifying assumption is reasonably justified. Since specifying the continuum is perforce a rather subjective process, it is the

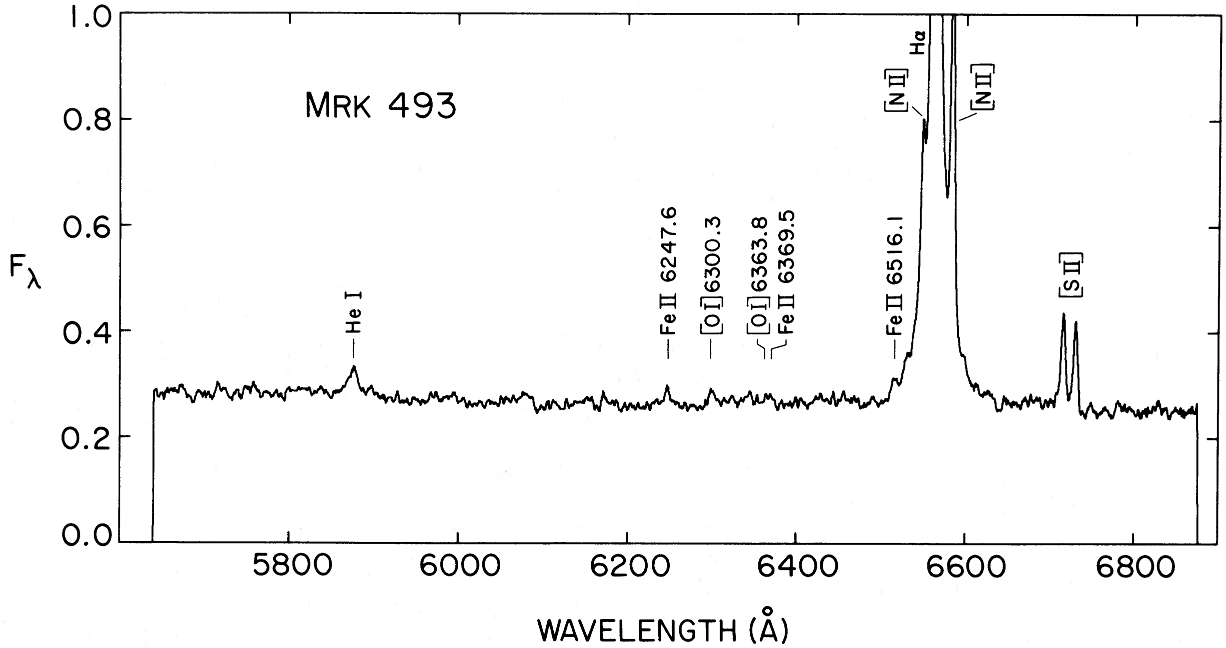

FIG. 3*c*

TABLE 2

OBSERVED RELATIVE EMISSION-LINE INTENSITIES IN NARROW-LINE SEYFERT 1 GALAXIES

		F/F(Hβ)						
WAVELENGTH (Å)	ION	Mrk 42	Mrk 359	Mrk 493	Mrk 766	Mrk 783	Mrk 1126	Mrk 1239
3345.........	[Ne v]	...	0.12	0.027:	0.092		0.15	
3426.........	[Ne v]	...	0.32	0.062	0.18	0.075:	0.47	
3727.........	[O ii]	0.11	0.24	0.14	0.20	0.76	0.55	0.21
3760.........	[Fe vii]	0.070	0.26	0.033:	0.033	...	0.080	0.16
3869.........	[Ne iii]	0.051:	0.21	0.16:	0.21	0.24	0.26	0.20
3967.........	[Ne iii]	0.075:	0.076	0.12	0.072	0.091	...	0.12
4102.........	Hδ	0.14	0.14	0.20	0.15	0.12	0.20	0.16
4340.........	Hγ	0.36	0.36	0.44	0.27	0.26	0.50	0.31
4363.........	[O iii]	0.052	0.26	0.18	0.059	0.23	0.50	0.17
4570.........	Fe ii	0.92	$\leq$0.085	1.31	0.52	$\leq$0.11	$\leq$0.010	0.64
4686.........	He ii	0.11	0.19	0.24	0.12	0.067:	0.20	0.16
4861.........	Hβ	1.00	1.00	1.00	1.00	1.00	1.00	1.00
4924.........	Fe ii	0.083	...	0.076	...	...	...	0.040:
4959.........	[O iii]	0.13	1.07	0.087	0.91	0.86	1.44	0.48
5007.........	[O iii]	0.37	3.16	0.25	3.74	2.57	4.30	1.40
5018.........	Fe ii	0.15	...	0.14	...	...	...	...
5190} 5320}.........	Fe ii	0.79	$\leq$0.075	0.84	0.41	$\leq$0.075	$\leq$0.010	0.43
5721.........	[Fe vii]	...	0.19	...	0.038	...	0.16	0.045
5876.........	He i	0.12	0.15	0.11	0.14	0.14	0.55:	0.057
6087.........	[Fe vii]	0.022:	0.25	...	0.57	0.031:	0.29	0.10
6300.........	[O i]	0.058	0.11	...	0.090	0.15	0.34	0.029
6364.........	[O i]	0.019:	0.036	...	0.030	0.051	0.11	0.010
6375.........	[Fe x]	0.031:	0.19	...	0.027[a]	...	0.15	0.043
6548.........	[N ii]	0.23	0.23	0.17	0.27	0.13	0.84	
6563.........	Hα	4.01	5.69	3.97	4.51	4.76	6.64	4.54
6583.........	[N ii]	0.67	0.67	0.51	0.81	0.38	2.50	
6716.........	[S ii]	0.076	0.22	0.11	0.12	0.20	0.72	0.044
6731.........	[S ii]	0.052	0.19	0.096	0.14	0.18	0.67	0.037
7065.........	He ii	0.074	0.048:		0.11		...	
7325.........	[O ii]	0.015:	0.054:				...	
7892.........	[Fe xi]	...	0.14				...	

[a] Variable, see text.

TABLE 3

FLUXES AND Hβ EMISSION EQUIVALENT WIDTHS

Galaxy	F(Hβ) (ergs cm^{-2} s^{-1})	W_0(Hβ) (Å)
Mrk 42	2.6×10^{-14}	25
Mrk 359	3.3×10^{-14}	16
Mrk 493	4.2×10^{-14}	29
Mrk 766	1.8×10^{-13}	43
Mrk 783	5.7×10^{-14}	45
Mrk 1126	1.7×10^{-14}	10.5
Mrk 1239	1.6×10^{-13}	57

main source of uncertainty in all these measurements, and any uncertainty which is introduced by assuming that the narrow line profiles are Gaussian when in fact they may not be is small in comparison. For the broader, distinctly non-Gaussian H I and He I profiles, the approximation is not a good one, but is better than no instrumental correction at all.

To determine the instrumental width, comparison-lamp spectra taken with each of the scans were used. The FWHMs of a number of comparison lines were measured and the results plotted as a function of wavelength. To these data a parabola was fitted using a least-squares technique. The image-dissector focus varies along the spectral range, causing the comparison-line profiles to be slightly, and in some scans significantly, broader toward the ends. The curve thus fitted was used as the instrumental FWHM and quadrature-subtracted from the observed narrow emission line profile FWHMs. The resultant corrected line widths are listed in Tables 4 and 5 in velocity units. Except where specified, all measurements from the high-dispersion scans have a mean uncertainty of ± 50 km s^{-1}, and for the normal-dispersion scans, ± 100 km s^{-1}.

For two of these narrow-line Seyfert 1 galaxies, Mrk 359 and 1126, FWHMs measured (on very largely the same spectral scans) by the more nearly accurate but more time-consuming deconvolution method are also available from an earlier paper (De Robertis and Osterbrock 1984). Therefore, for comparison purposes, the quadrature subtraction results of the present paper for these two galaxies are listed in Table 4, along with the deconvolution results of the earlier paper. It can be seen that there is generally reasonable agreement between the two independent sets of measurements, but that there is a definite systematic difference. It is in the sense that the quadrature subtraction method gives FWHMs that are somewhat too small. Numerically, the average differences are FWHM(quadrature sum) − FWHM(deconvolution) = -50 km s^{-1} for twelve high-dispersion profiles of Mrk 359, -30 km s^{-1} for four high-dispersion profiles of Mrk 1126, and -60 km s^{-1} for nine normal-dispersion scans of Mrk 1126. Numerical experiments with non-Gaussian profiles of the general type observed in Seyfert galaxies confirm that a difference in this sense is expected. Hence all the FWHMs measured by the quadrature subtraction method in the present paper should be corrected, as a first approximation, by $+40$ km s^{-1} if measured on a high-dispersion scan (the average of the Mrk 359 and 1126 results), or $+60$ km s^{-1} if measured on a normal-dispersion scan.

The measured FWHMs of the other five galaxies are listed in Table 5. They are given directly as measured by the quadrature subtraction technique and should be corrected by the numbers given above to be put on the same basis as the more nearly accurate deconvolution measurements.

TABLE 4

INTRINSIC FWHMs OF EMISSION LINES IN MRK 359 AND MRK 1126

		FWHM (km s^{-1})					
		Mrk 359			Mrk 1126		
WAVELENGTH (Å)	ION	This Paper[a]	Earlier Paper[b]	Dispersion	This Paper[a]	Earlier Paper[b]	Dispersion
3426.........	[Ne V]	330	370	H	280	320	N
3727.........	[O II]	510	470	H	280	470	N
3760.........	[Fe VII]	580	...	H	420	...	N
3869.........	[Ne III]	240	270	H	350	340	N
4102.........	Hδ	440	...	H	...	...	N
4340.........	Hγ	710	...	H	850	...	N
4363.........	[O III]	490	590	H	790	920	N
4686.........	He II	270	350	H	460	390	N
4861.........	Hβ	400	...	H	330	...	H
4959.........	[O III]	150	210	H	210	210	H
5007.........	[O III]	150	190	H	200	210	H
5721.........	[Fe VII]	230	320	H	530	410	N
5876.........	He I	880	...	H	...[c]	...	...
6087.........	[Fe VII]	290	310	H	410	520	N
6300.........	[O I]	220	260	H	170	370	N
6364.........	[O I]	220	...	H	...	...	...
6375.........	[Fe X]	380	...	H	340	380	N
6563.........	Hα	420	...	H	350	...	H
6716.........	[S II]	190	260	H	190	320	H
6731.........	[S II]	170	260	H	170	290	H
7892.........	[Fe XI]	380	370	N	...	...	...

[a] Quadrature subtraction method.
[b] Deconvolution method (DeRobertis and Osterbrock 1984).
[c] Galaxy Na I absorption line coincident.

TABLE 5

INTRINSIC FWHMs OF EMISSION LINES IN NARROW-LINE SEYFERT 1 GALAXIES

		FWHM (km s^{-1})				
WAVELENGTH (Å)	ION	Mrk 42	Mrk 493	Mrk 766	Mrk 783	Mrk 1239
3426.........	[Ne V]	...	...	420	...	...
3727.........	[O II]	360	370	420	580	830
3760.........	[Fe VII]	...	...	380	...	1230
3869.........	[Ne III]	...	...	490	500	960
4102.........	Hδ	450	380	730	590	910
4340.........	Hγ	660	540	780	500	910
4363.........	[O III]	510	570	410	980	650
4686.........	He II	...[a]	...[a]	870	740	...[a]
4861.........	Hβ	670	410	850	770	910
4924.........	Fe II	390	780	...	...	...
4959.........	[O III]	440	580	360	470	730
5007.........	[O III]	450	480	360	450	710
5018.........	Fe II	360	840	...	...	...
5721.........	[Fe VII]	...	...	540	...	770
5876.........	He I	880	700	800	680	670
6087.........	[Fe VII]	420	...	620	...	1100
6300.........	[O I]	...	240	310	510	620
6364.........	[O I]	...	...		500	...
6375.........	[Fe X]	...	...		...	760
6563.........	Hα	570	350	900	790	920
6716.........	[S II]	190	200	240	360	420
6731.........	[S II]	170	180	260	330	420

[a] Strongly blended with Fe II λ4570 complex.

IV. DISCUSSION

From the relative intensities listed in Table 2, Mrk 42, 493, and 1239 are the three objects in this paper that are the most securely Seyfert 1 galaxies. They all have intensity ratios [O III] λ5007/Hβ below the lower limit 3 of Seyfert 2 galaxies (Shuder and Osterbrock 1981), and well into the range covered by Seyfert 1's (Osterbrock 1977). In particular, Mrk 493 is quite similar to I Zw 1, the Seyfert 1 galaxy with extremely strong Fe II emission and weak forbidden lines (Sargent 1968; Phillips 1976), except that Mrk 493 has even narrower lines. Mrk 1239 does not have measurable [N II] λλ6548, 6583, as Rafanelli and Bonoli (1984) have pointed out. Though this is uncommon, it is by no means unique; Mrk 124, Mrk 478, and I Zw 1 are three Seyfert 1 galaxies with only slightly broader Hα emission in which the [N II] lines cannot be seen, presumably because they are blended with Hα (Osterbrock 1977). The same is no doubt true of Mrk 1239.

Mrk 783 has [O III] λ5007/Hβ = 2.6, larger than typical Seyfert 1's, but similar to the Seyfert 1.5 galaxies MCG 8-11-11, in which this ratio is 2.2, and Mrk 6, in which it is 4.0 (Cohen 1983). Indeed, the Hβ emission-line profile in Mrk 783 can be understood as a Seyfert 1.5 profile with a relatively narrow broad component, as discussed below. The Fe II emission lines are too weak to be detected in Mrk 783, but this property is shared by a certain fraction of Seyfert 1's and by Mrk 6 in particular. Mrk 766 and Mrk 1126, with [O III] λ5007/Hβ = 4.3 and 3.7 respectively, are two other Seyfert 1.5's with relatively narrow broad components of Hβ.

On the other hand, from the line intensities in Table 2, Mrk 359 has [O III] λ5007/Hβ = 3.2, barely large enough for it to be classified as a Seyfert 2 galaxy (Shuder and Osterbrock 1981). Mrk 1388, with [O III] λ5007/Hβ = 11.1, has a much more typical Seyfert 2 ratio (Osterbrock 1985). Both these objects have only very weak, if any, Fe II emission, as in typical Seyfert 2's. But they differ from typical Seyfert 2's in their strong high-ionization emission lines, particularly [Fe VII] λλ5721, 6087 and [Fe X] λ6375. Mrk 1388 has these lines stronger with respect to [O III] λ5007 than any other Seyfert 2 known to us, and Mrk 359 has them stronger than average Seyfert 2 galaxies by a factor of ~10 (Koski 1978; Cohen and Osterbrock 1981).

Turning to line widths, the H I emission line widths are definitely broader than the well-determined forbidden-line widths in Mrk 42, 359, 766, 783, 1126, and 1239. As stated above, the relative line intensities in Mrk 766, Mrk 783, and Mrk 1126 are consistent with their being classified as Seyfert 1.5 galaxies. The spectral scan of Mrk 783 is plotted in Figure 4, and it can be seen that this profile can certainly be regarded as composite, although there is not a well-defined break between the narrow and broad components in its Hβ profile. In order to analyze it quantitatively, we may assign the narrow-line Hβ component a strength given by the mean of $H\beta_n$/([O III] λ5007) = 1/10, and $H\beta_n$/([O III] λ4959) = 1/3 a very good average value (Cohen 1983). Subtracting this narrow line from the total Hβ profile leaves a weak but quite well defined broad component in the spectrum of Mrk 783, as well as in the spectra of the other two galaxies, which were treated in the same way. The measured FWHMs of these residual broad components were measured by the techniques described in § III*b* and are listed in Table 6. These values have fairly large uncertainties, but are clearly near the lower limit of the range of typical Seyfert 1 galaxies (Osterbrock 1977). The full widths at zero intensity (FW0I) are also given in the table. Though they are poorly determined, they are definitely lower than in typical Seyfert 1's.

In all these galaxies the He I and He II lines have either the same or slightly greater FWHMs than the H I lines, as in typical Seyfert 1 galaxies. In Mrk 1388 the H I line widths are essentially the same as the well-determined forbidden-line widths (Osterbrock 1985). In this respect it again has the properties of a Seyfert 2 galaxy. The measurements suggest that in Mrk 493 the FWHM of Hβ is narrower than the FWHMs of Fe II λλ4924, 5018, or of [O III] λλ4959, 5007, which makes it a unique case.

Though the range in FWHMs of the forbidden lines in most of these objects is small, in Mrk 1239 they exhibit the typical increase with increasing ionization potential characteristic of Seyfert 1's (Wilson 1979; Osterbrock 1981). In nearly all of them the [S II] lines are significantly narrower than [O I], and in Mrk 783 and Mrk 1126 [O III] λ4363 is significantly wider than λλ4959, 5007. This indicates that the secondary correlation of line width with critical density that is present in many (but not all) Seyfert 1 spectra (Pelat, Alloin, and Fosbury 1981; DeRobertis and Osterbrock 1984) also occurs in some of these objects.

Little can be said about the morphological characteristics of these galaxies, since even the nearest have redshifts $z \gtrsim 0.01$.

TABLE 6

INTRINSIC FWHMs OF BROAD COMPONENT OF Hβ IN SEYFERT 1.5 GALAXIES (km s^{-1})

Galaxy	FWHM (observed)	FWHM (corrected)	FW0I (observed)
Mrk 766..........	2450	2400	7000
Mrk 783..........	2000	1900	6500
Mrk 1126.........	2600	2500	4500

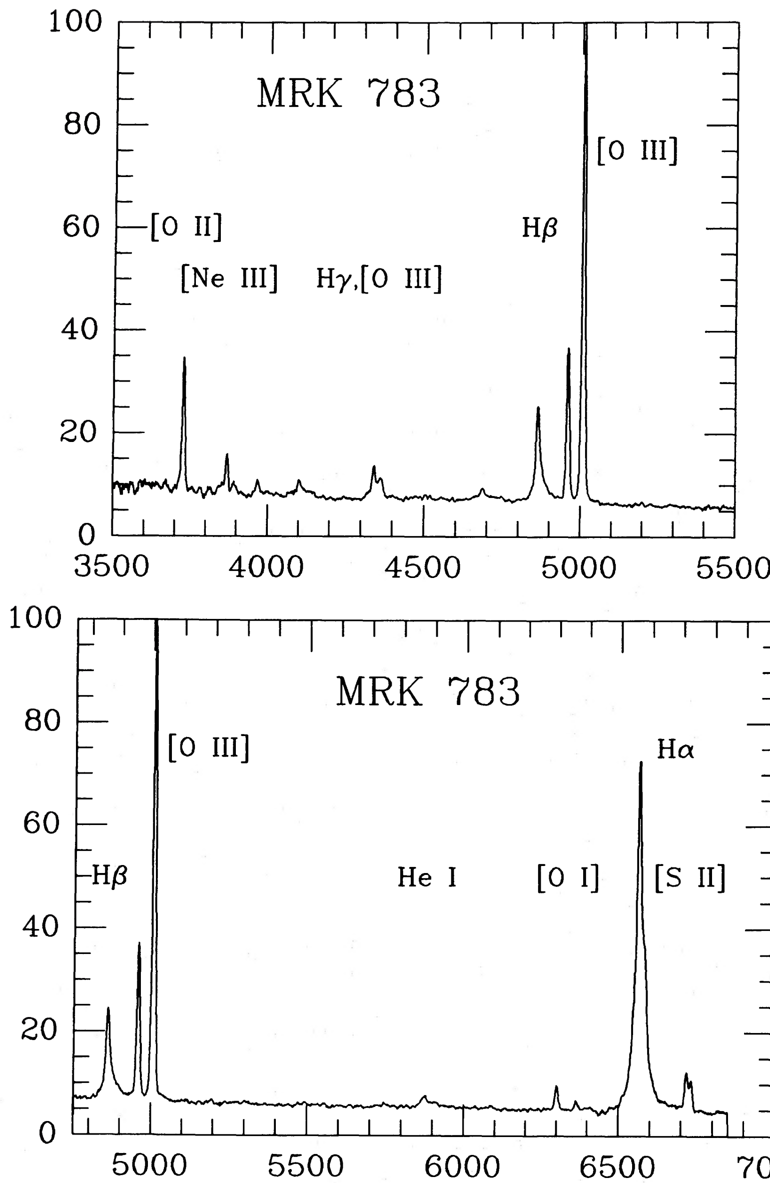

FIG. 4.—Spectral scans of Mrk 783. (*top*) 3500–5500 Å, (*bottom*) 4750–7000 Å. Scales and units as in Fig. 1.

However the apparent axial ratios of all except Mrk 783 (which has the largest redshift and only a small, almost stellar image) can be approximately measured on the Palomar Observatory–National Geographic Society Sky Survey plates. Mrk 42, 359, 493, and 766 were measured by Keel (1980); we have measured Mrk 766 as a check (and found almost the identical result) and have also measured Mrk 1126, 1239, and 1388. The results are listed in Table 7. For these seven galaxies the average $b/a = 0.65 \pm 0.11$ (dispersion); this is essentially the same as the mean result for all Seyfert galaxies, $b/a = 0.62$, or all the "near" Seyfert 1's, $b/a = 0.60$ (Keel 1980). The narrow-line Seyfert 1 galaxies are not, as a group, seen in a peculiar orientation.

Finally, we may discuss the absolute magnitudes of these galaxies. Four of them are included in the luminosity-function discussion of Meurs and Wilson (1984). Of these, one, Mrk 783,

TABLE 7

AXIAL RATIOS AND ABSOLUTE MAGNITUDES

	b/a			
Galaxy	Keel (1980)	This Paper	m_p (Zwicky)	M_p
Mrk 42	0.52	...	15.2	−20.6
Mrk 359	0.68	...	13.8	−21.2
Mrk 493	0.83	...	14.9	−21.5
Mrk 766	0.74[a]	0.71[a]	13.7	−21.5
Mrk 783	...	b	...	...
Mrk 1126	...	0.50	...	...
Mrk 1239	...	0.63	...	...
Mrk 1388	...	0.65	15.7	−19.8

[a] Adopt mean $b/a = 0.72$.
[b] Image nearly stellar.

has only an estimated apparent magnitude of significantly lower accuracy than the other three. It is omitted from the present discussion; the other three are listed in Table 7. Two other galaxies discussed in the present paper, Mrk 766 and Mrk 1388, also have magnitudes in the Zwicky catalog, the source used by Meurs and Wilson (1984). These two are also included in Table 7. (Note the absolute magnitudes are computed on the basis of $H_0 = 50$ km s^{-1} Mpc^{-1}, the value those authors used.) For these five the mean absolute magnitude is $M_{pg} = -20.8 \pm 0.6$ (dispersion). If Mrk 1388, the object with strong Seyfert 2 characteristics, is omitted, the mean for the other four "narrow-line Seyfert 1" galaxies is $M_{pg} = -21.1 \pm 0.3$. The number of objects is too small for any real statistical discussion. However, these mean values do not disagree with the results found for normal Seyfert galaxies by Meurs and Wilson (1984), that the Seyfert 1 galaxies have a broad distribution in luminosity with a weak maximum near $M_{pg} = -21$, and the Seyfert 2's a similar distribution with weak maximum near $M_{pg} = -20$.

V. INTERPRETATION

All galaxies discussed in this paper have some of the properties of Seyfert 1 galaxies but have relatively narrow H I emission lines. In all of them except Mrk 493 and Mrk 1388 the H I, He I, and He II lines have somewhat greater FWHMs than the forbidden lines. Thus in these six objects, as in ordinary Seyfert 1 galaxies, there is a dense broad-line region in which the internal velocities are on the average larger than in the less dense narrow-line region in which the forbidden lines are emitted. However, in these objects the broad-line widths are much smaller than in typical Seyfert 1 galaxies. Thus the range of values or dispersion in the component of velocity along the line of sight is much smaller in these objects than in typical Seyfert 1 galaxies. This could result either from a lower internal velocity dispersion or from a peculiar aspect effect. For instance, if the velocities in the broad-line regions in Seyfert 1 galaxies were largely confined to a plane, the narrow-line Seyfert 1 galaxies could perhaps be understood as cases in which the line of sight is nearly perpendicular to this plane. However, since the narrow-line Seyfert 1's are not preferentially seen face on, this picture would imply that the axes of the broad-line regions are randomly oriented with respect to the axes of the patent galaxies (Tohline and Osterbrock 1982).

Three of the galaxies, Mrk 42, 359, and 1239, can be understood as Seyfert 1 galaxies of this type. Three others, Mrk 766, 783, and 1126 can be understood as Seyfert 1.5 galaxies, in which the narrow components of the H I lines are relatively strong, but the broad components have widths near the lower limit of typical Seyfert 1 galaxies.

The relative strengths of the emission lines in these objects are similar to those in typical Seyfert 1 and 1.5 galaxies. The narrow lines (forbidden and narrow components of H I lines) have widths quite similar to those in typical Seyfert 1 and 1.5 galaxies. In some of them the FWHMs are correlated with ionization potential, and in two of them with critical density, as in many typical Seyfert 1 galaxies. The narrow-line regions are more nearly similar to those in Seyfert 1's than are the broad-line regions. This suggests that, though the broad- and narrow-line regions are continuous, there is a gradual change in the velocity field from one of these regions to the other, and that these "narrow-line Seyfert 1" galaxies differ from the normal Seyfert 1's in having lower velocities in the broad-line region, or perhaps in having less gas in what would otherwise be the broad-line region. For instance, the velocity field in a typical broad-line region might have a strong rotational component, perhaps connected with an accretion disk, while the velocity field in the narrow-line region might have a strong radial component, connected with a radiation pressure–driven wind. On this picture the narrow-line Seyfert 1 galaxies might be objects in which there is less dense gas associated with the most rapidly rotating parts of the accretion disk.

The Hβ emission-line equivalent widths listed in Table 3 are on the average significantly smaller than in typical Seyfert 1 galaxies. The average for the seven narrow-line Seyfert 1 galaxies of Table 3 is $W_0(\mathrm{H}\beta) = 32 \pm 16$ Å (dispersion), while for the 36 "ordinary" Seyfert 1 galaxies studied by Osterbrock (1977), $W_0(\mathrm{H}\beta) = 88 \pm 37$ Å. This difference is in part a result of the fact that several of the narrow-line Seyfert 1's have fairly strong integrated stellar absorption-line continua in their spectra, which dilute the intrinsic active galactic nucleus featureless continua and thus weaken the emission-line Hβ equivalent widths. However, simple inspection of the spectra shows this cannot account for the entire factor of 2.8 difference between the two groups. The narrow-line Seyfert 1 galaxies, as a group, are an extreme example of the tendency for the Hβ equivalent widths to be larger in the objects with the largest Hβ line widths (Osterbrock 1977). It indicates a close connection between the energy-input mechanism to the ionized gas and the total internal velocity range. Since other evidence points to photoionization as the dominant energy-input mechanism, this correlation suggests that the Seyfert 1 galaxies with larger internal velocity ranges also have larger covering factors, so that the dense gas in their nuclei absorbs a larger fraction of the ionizing photons. Various possibilities, including a thicker disk, or a less extended ionizing source in the "external illumination" disk model (Shields 1978), can be imagined.

Mrk 1388, on the other hand, has no sign of a broad-line region. Yet it has a very strong featureless continuum and extremely high ionization (Osterbrock 1958). Narrow H I lines are the distinguishing property of a Seyfert 2 galaxy, but Mrk 1388 has much higher ionization than any other one known. Its Hβ equivalent width is $W_0(\mathrm{H}\beta) = 31$ Å, similar to the average of the six narrow-line Seyfert 1 and 1.5 galaxies discussed above. Evidently it is an outstanding exception to the generally strong correlation between strong featureless continuum, broad H I lines, and relatively high ionization shared by many Seyfert 1 galaxies.

Both Mrk 42 and Mrk 493 have relatively strong Fe II lines, most likely indicating large amounts of gas in regions in which H is only partly ionized to H^+, but in which Fe^0 (with ionization potential 7.9 eV) is chiefly ionized to Fe^+ and emits Fe II line radiation (see Netzer and Wills 1983). In Mrk 42 the Fe II lines were measured to be somewhat narrower than the H I lines. This is qualitatively consistent with the earlier result of Phillips (1978), who found that in several Seyfert 1 galaxies the Fe II lines have FWHMs either approximately the same as the H I lines or slightly smaller. Such a correlation fits in with the general decrease of line width with ionization potential in the broad-line region exhibited by He II, He I, and H I (Osterbrock 1977).

Mrk 493, on the other hand, is quite anomalous in having the Fe II lines wider than the H I lines. These lines are not strong, as Figure 3 shows, and Fe II λ5018 is blended with [O III] λ5007, but we believe the measured difference is significant. If it is, it probably indicates that the H I lines, especially

Hα and Hβ, have a fairly strong narrow component not shared by Fe II, as Phillips (1978) found in NGC 7469. The narrow-line Seyfert 1 galaxies certainly have a wide variety of relative strengths of Fe II (indicating wide variety in relative amounts of partly ionized dense gas), just as the normal Seyfert 1's do.

Overall, these narrow-line Seyfert 1 galaxies show a wide variety of deviations from the typical properties of Seyfert 1 galaxies. They clearly demonstrate that the Seyfert phenomenon is not a simple one-parameter effect. Though line width, featureless continuum strength, and level of ionization tend to be correlated, there are large deviations from the mean correlations. Physically, several parameters must be involved in the phenomenon and must be included in any correct model.

Note added in manuscript 1985 May 21.—Mrk 684 has been described by Schmidt and Green (1983) as the most luminous nucleus encountered in their Bright Quasar Survey that has "narrow emission lines, such as those observed in Seyfert 2 galaxies." In fact, however, a recent Lick high signal-to-noise ratio CCD spectral observation shows it has a narrow-line Seyfert 1 type spectrum with strong Fe II emission and weak or nonexistent forbidden lines. Its spectrum is very similar to that of Mrk 42, but with intrinsic FWHMs ≈ 1400 km s^{-1} estimated for Hα and Hβ from this one low-resolution scan.

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