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OUTFLOW OF GAS IN THE SEYFERT 1 GALAXY MARKARIAN 509

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ABSTRACT

The nucleus of the luminous Seyfert 1 galaxy Mrk 509 ($z = 0.0345$) is surrounded by two distinct systems of ionized gas. One is a rotating disk of low ionization ([O III] $\lambda 5007/H\beta \sim 2$) and is almost certainly photoionized by hot stars. This gas resembles that commonly observed in the disks of spiral galaxies, although Mrk 509 looks more like a featureless elliptical or S0 galaxy on direct photographs, with a luminosity profile which falls off linearly as $r^{1/4}$. The second component is an extensive system of high-ionization gas ([O III] $\lambda 5007/H\beta \gtrsim 5$) which is very probably photoionized by the Seyfert nucleus. All of the high-ionization gas is observed at radial velocities which are lower than the systemic velocity of the low-ionization disk.

Echelle profiles of the nuclear [O III] emission lines are flat-topped, suggesting an expanding shell. International Ultraviolet Explorer observations by York *et al.* show a low-velocity, high-ionization absorption-line system which fits well as being the near edge of this shell. The negative velocities of the extended high-ionization gas also point to general outflow. The corresponding positive-velocity component may be hidden by the disk of hot stars and gas (and dust?) which produces the low-ionization emission-line system. We discuss the relationship of this galaxy-wide outflow in Mrk 509 with the available data for other Seyfert galaxies.

Subject headings: galaxies: individual — galaxies: internal motions — galaxies: Seyfert

I. INTRODUCTION

Markarian 509 ($z = 0.0345$) is classified as a Seyfert 1 galaxy, but it has a high luminosity and compact morphology more like a QSO (Kopylov *et al.* 1974; Bradt 1980). The optical spectrum of the nucleus has been studied in detail by Allen (1976), Osterbrock (1977), and Atwood, Baldwin, and Carswell (1982). In addition, Mrk 509 has been detected as a strong source of infrared radiation (Stein and Weedman 1976; Allen 1976) and X-rays (Elvis *et al.* 1978; Mushotzky *et al.* 1980; Dil *et al.* 1981).

Adams (1977) obtained several image-tube photographs of Mrk 509 which showed a nucleus with diffraction spikes embedded in a faint and apparently structureless nebulosity some 15″ in extent. Considering the QSO-like properties of the nucleus, the exact nature of this nebulosity is of considerable interest. The relative proximity of Mrk 509 compared with other Seyfert 1/QSO transition objects makes it a particularly good candidate for spatially resolved observations. We therefore have carried out an extensive series of optical observations designed both to investigate the morphology of the underlying galaxy and to look for evidence of extended ionized gas.

Our study combines several types of observations. Both direct photography and low-resolution (20 Å) spectrophotometry were employed to investigate the structure and morphology of the stellar component. The low-resolution spectra also served to locate extended regions of ionized gas which were then mapped in more detail at higher wavelength resolution (1.5 Å). Finally, the profiles of the emission lines arising in the bright nucleus were studied using very high resolution (0.53 Å) echelle data.

II. DIRECT PHOTOGRAPHY

A 60 minute direct plate showing the stellar component of Mrk 509 was kindly obtained for us on 1979 November 22 (UT) by F. Schweizer, at the prime focus of the Cerro Tololo Inter-American Observatory (CTIO) 4 m telescope. A IIa-D emulsion, baked in forming gas, was exposed through an OG570 filter. The effective

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bandwidth of 5700–6500 Å for this combination does not include any strong emission lines in the rest system of Mrk 509 (see § III).

A contrast-enhanced print made from the 4 m plate is reproduced in Figure 1. The seeing as measured from stellar images was approximately 2$''$.5 (FWHM). Although this exposure is considerably deeper than that illustrated by Adams (1977), there are still no distinct structures such as spiral arms to be seen. Rather, the nebulosity is amorphous and slightly elliptical in shape, with the major axis lying at a position angle of $70° \pm 5°$. This is suggestive of an elliptical galaxy, or perhaps a lenticular with a large bulge component. This plate shows no close companions to Mrk 509 nor evidence for an associated galaxy cluster or group.

The luminosity profile of the nebulosity was measured off this plate using the Anglo-Australian Observatory (AAO) PDS microdensitometer. The scanning pixel size of 25 μm^2 corresponded to 0.46 $arcsec^2$ on the sky. Reduction programs generously made available to us by D. Carter of the AAO were used to first put the raw data onto a linear intensity scale, using a characteristic curve derived from sensitometry spots on the original plate and from an accompanying sensitometry plate taken as a backup (and developed in the same manner as the original). A two-dimensional polynomial fit was then made to the observed plate background and used to correct the data on a pixel-by-pixel basis. Next, simulated raster scans were made at various position angles through the background-corrected, intensity-calibrated data. Similar scans were made of four stars whose brightness was comparable to that of the starlike nuclear source in Mrk 509. The averaged profile of the images of these stars was then fitted to the nucleus of Mrk 509 and subtracted to produce the final brightness profiles of the nebulosity. This last step significantly alters only the innermost few points of the derived profiles.

Simulated raster scans made at a position angle of 90°, to the east and west of the nucleus, with an "aperture" of 0$''$.9 × 1$''$.9 (long dimension in direction of raster scan) are illustrated in Figure 2. Although the scatter is large beyond about a 7$''$ radius, there is a definite linear trend as a function of $r^{1/4}$ out to a radius of 15$''$ (10 kpc for $H_0 = 75$ km s^{-1} Mpc^{-1}), covering a total brightness range of 4 mag. This well-known radial dependence again points to a morphological classification of E or possibly S0 for the underlying galaxy (de Vaucouleurs 1948, 1953).

Stein and Weedman (1976) measured $V = 13.12$ for Mrk 509 through a large (17$''$) aperture. For $H_0 = 75$ km s^{-1} Mpc^{-1} and $q_0 = 1$, this corresponds to an absolute magnitude $M_v = -22.6$. For the same cosmological parameters, a first-ranked cluster elliptical galaxy has $M_v = -22.4$ (Sandage 1972). But optical spectra (see § III) show that only a small ($\lesssim 20\%$) percentage of the total continuum emission is likely to be of stellar origin. Thus the absolute magnitude of the underlying galaxy must be at least 2 mag fainter than a first-ranked cluster elliptical galaxy. This value is consistent with the absolute magnitude limits found by Miller (1981) in an unsuccessful search for underlying galaxy components in higher redshift, low-luminosity QSOs. In fact, the total absolute visual magnitude of Mrk 509 is brighter than seven of the nine low-luminosity QSOs studied by Miller, and if Mrk 509 were placed at the distances of those QSOs, it would be morphologically and spectroscopically indistinguishable from them.

III. SPECTROSCOPY

a) *Observations*

Low-resolution (20 Å) spectrophotometry of the nucleus and surrounding nebulosity of Mrk 509 was carried out in 1980 on the nights of July 14, August 5, and August 6 (UT) using a SIT-vidicon detector (Atwood *et al.* 1979) on the Cassegrain spectrograph of the CTIO 4 m telescope. All three nights were photometric with seeing of approximately 2$''$ (FWHM). As detailed in Table 1, on the two nights in August three different series of long-slit observations were acquired using a narrow (1$''$.5) slit at position angles of either 0° or 90°. Spectra were extracted from these observations to produce a systematic grid of points covering the entire galaxy. Short exposures of the nucleus were also made on the two August nights with a wide (6$''$.7) slit to measure accurate absolute emission-line and continuum fluxes for the nucleus. All of these data were calibrated by means of wide-slit observations made the same nights of five or more standard stars from the lists of Oke (1974), Stone (1977), and Stone and Baldwin (1983). Mean residuals of approximately 5% were achieved in the final flux calibrations.

As part of another study, several 35 Å resolution SIT-vidicon spectra of the nucleus of Mrk 509 were obtained on the CTIO 4 m telescope two years earlier, on 1978 August 8 and 9 (UT). A 10$''$ slit was employed in seeing estimated at 4$''$ (FWHM). The data were reduced and calibrated from observations of three standard stars in a manner identical to that for the 1980 data.

With the goal of obtaining a two-dimensional velocity map, we observed the extended ionized gas in Mrk 509 at high dispersion on several occasions with both the CTIO 4 m and AAO 3.9 m telescopes. The most extensive observations were made on the nights of 1980 September 3, 4, and 6 (UT) with the SIT-vidicon on the Cassegrain spectrograph of the CTIO 4 m. In a manner similar to that employed for the low-dispersion spectra, a series of long-slit spectra were taken at position angles of either 0° or 90° to produce a grid covering the entire

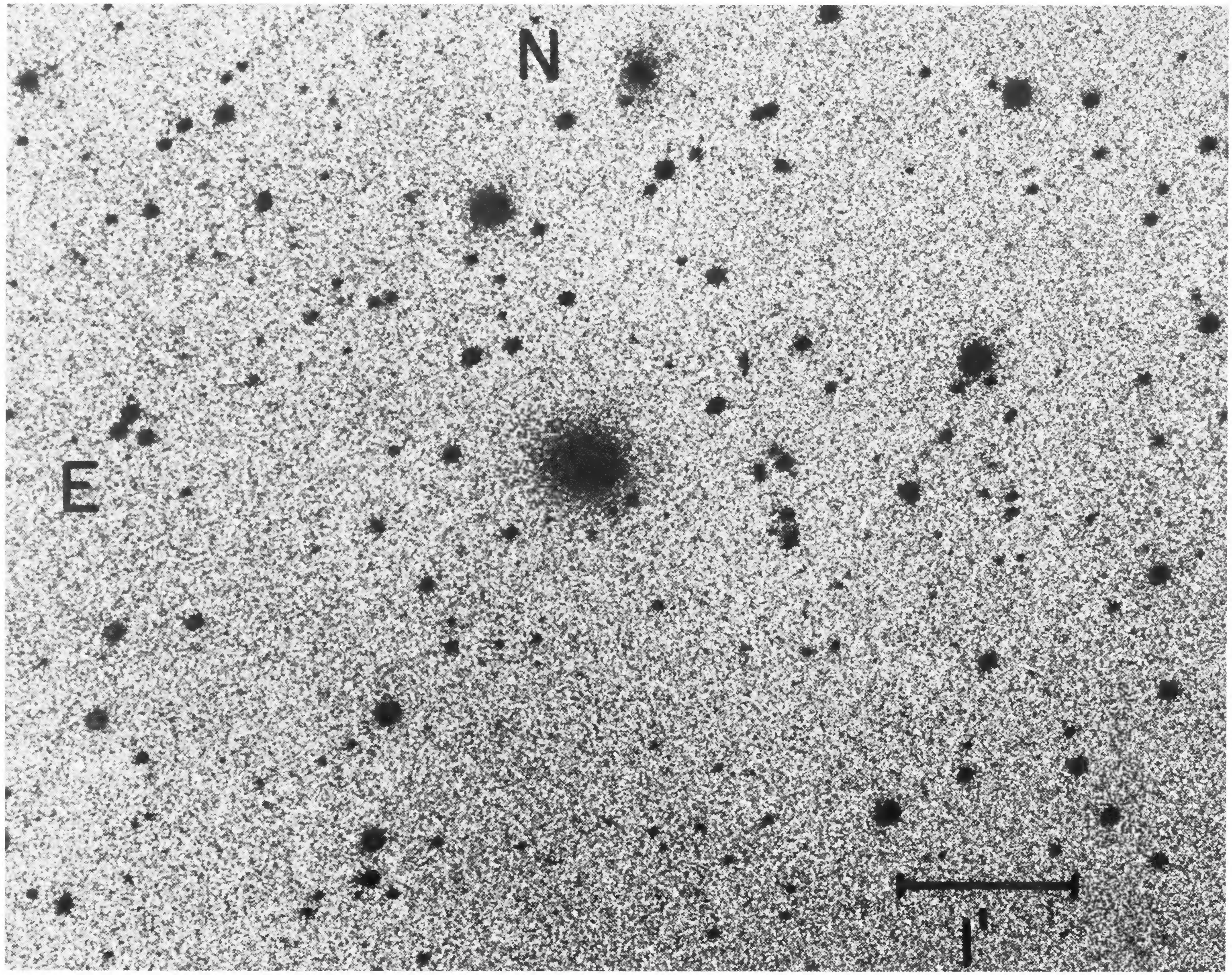

FIG. 1.—Direct 4 m plate of Mrk 509, using IIa-D emulsion with OG570 filter (5700–6500 Å bandpass)

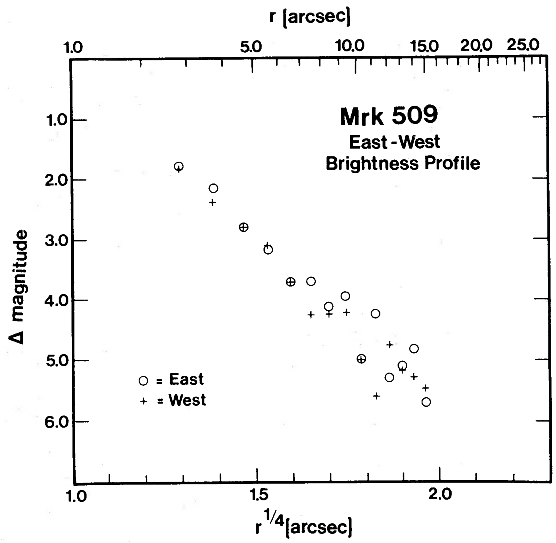

FIG. 2.—Brightness profiles of Mrk 509 measured from the 4 m plate shown in Fig. 1. The point source at the nucleus has been subtracted.

galaxy. The slit was 1″.5 wide, and the grid spacing 2″.5. A total wavelength range of 4355–5594 Å was covered at a resolution of 2.5 Å (FWHM). A complete log of the positions covered is given in Table 1.

Less extensive, but higher wavelength resolution, long-slit observations were obtained on the nights of 1980 June 7 and 1981 August 22 (UT) with the image photon counting system (IPCS) (Boksenberg and Burgess 1973) on the Royal Greenwich Observatory Cassegrain spectrograph of the 3.9 m Anglo-Australian telescope (AAT). The 25 cm camera was employed for both sets of observations. Slightly different slit widths were used on the two nights, yielding wavelength resolutions of 1.3 Å and 1.1 Å, respectively. Further details of these observations are to be found in Table 1.

Finally, very high resolution (0.56 Å at 5000 Å) spectra of the nucleus of Mrk 509 were obtained at CTIO in 1981 April, 1982 August, and 1982 October with the SIT-vidicon attached to the Cassegrain echelle spectrograph of the 4 m telescope. The 1981 spectrum was reported in detail by Atwood, Baldwin, and Carswell (1982), where a full description of the instrument configuration is given. The 1982 spectra were taken to improve the signal-to-noise ratio of the weaker narrow emission lines.

b) *The Spectrum of the Nucleus*

The nuclear spectrum of Mrk 509 has been investigated in detail by Allen (1976), Osterbrock (1977), and most recently by Atwood, Baldwin, and Carswell (1982). These studies found broad permitted lines of hydrogen and helium, and a high-excitation narrow-line system including [O I], [O II], [O III], [Ne III], [N II], and [S II] forbidden lines, in keeping with the galaxy's Seyfert 1 classification. Atwood *et al.* also pointed out the curious flat-topped shape of the [O III] λλ4959, 5007 lines and suggested a possible difference between the profiles of the [O III] and [S II] lines.

The improved echelle data now have sufficient signal-to-noise ratio to definitely show that the low-ionization lines ([O I] λ6300, [S II] λλ6717, 6731) are slightly narrower than [O III] λλ4959, 5007 (Fig. 3). The [Ne III] λ3869 line has the same flat-topped profile as the [O III] lines, while the data for [O II] λ3727 are too noisy to tell. In addition, the improved data appear to show narrow components on top of Hα, Hβ, Hγ, and Hδ, all having the same flat-topped profile as the [O III] lines (Fig. 4). The weak, narrow spike on top of Hβ previously reported by Atwood *et al.* now appears to be a noise feature; the much stronger and broader Hβ narrow-line component reported here has subsequently been detected in two independent echelle spectra. The intensities of [S II] λ4076 and [N II] λ6584, and an upper limit for [O III] λ4363, were obtained by fitting combinations of the λ5007 and Hβ profiles to the blends around Hα, Hγ, and Hδ.

The low-resolution spectra of the nucleus add [Ne V] λλ3346, 3426 to the previously detected narrow lines (see Fig. 5). Line intensities measured from our new spectra are listed in Table 2. The relative intensities of the narrow lines point to photoionization by the Seyfert nucleus (cf. Baldwin, Phillips, and Terlevich 1981). The λ5007/Hβ intensity ratio (7:1) is rather lower than is typically found for Seyfert 2 galaxies, but this could be due either to different physical conditions in this Seyfert 1 galaxy or to a mixture of Hβ emission from the gas components producing the differing high- and low-ionization profiles. In any case, the presence of the [Ne V] lines is a good indication of some excitation process other than photoionization by stars.

We adopt as the systemic velocity for Mrk 509 the "line center" measured from the nuclear λ5007 emission line. This is the wavelength about which a reflection of the line profile gives a best fit of the red and blue wings near the half-power point. The corresponding heliocentric velocity is 10,365 km s^{-1}. This is marked on Figure 3, along with some other velocities which will be discussed in § IV.

c) *Nuclear Variability*

Optical continuum variability in Mrk 509 over the period of a year in 1974–1975 has been claimed by Magnitskaya and Saakyan (1976). In comparing our low-resolution data from 1978 with that taken in 1980, a 30% decrease in the continuum level is also apparent. This difference is several times greater than the mean residuals of the individual flux calibrations and, hence,

TABLE 1

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Date (U.T.)	Telescope/Detector	Slit Width (arcsec)	Slit Length (arcsec)	Slit P.A. (degrees)	Slit Center Position	Wavelength Resolution (Å)	Wavelength Range (Å)
1978 Aug 8	CTIO 4m/SIT Vidicon	10	50	90	Nucleus	35	3400-6100
1978 Aug 9	" "	10	50	90	Nucleus	35	4550-7400
1980 July 14	" "	2	100	90	Nucleus	20	4670-7830
"	" "	"	"	"	5" N of Nucleus	"	"
"	" "	"	"	"	10" N of Nucleus	"	"
"	" "	"	"	"	5" S of Nucleus	"	"
"	" "	"	"	"	10" S of Nucleus	"	"
1980 Aug 5	" "	6.7	100	90	Nucleus	30	3400-6600
"	" "	1.5	"	"	"	20	"
"	" "	"	"	"	5" N of Nucleus	"	"
"	" "	"	"	"	5" S of Nucleus	"	"
1980 Aug 6	" "	6.7	100	90	Nucleus	30	3650-6900
"	" "	1.5	"	"	"	20	"
"	" "	"	"	"	5" N of Nucleus	"	"
"	" "	"	"	"	5" S of Nucleus	"	"
"	" "	"	"	0	Nucleus	"	"
"	" "	"	"	"	2″.5 E of Nucleus	"	"
"	" "	"	"	"	5" E of Nucleus	"	"
"	" "	"	"	"	5" W of Nucleus	"	"
"	" "	"	"	60	5" SE of Nucleus	"	"
1980 Sept 3	" "	1.5	50	90	Nucleus	2.5	4355-5594
"	" "	"	"	"	2.5" N of Nucleus	"	"
"	" "	"	"	"	5" N of Nucleus	"	"
1980 Sept 4	" "	1.5	50	90	Nucleus	2.5	4355-5594
"	" "	"	"	"	2″.5 S of Nucleus	"	"
"	" "	"	"	"	5" S of Nucleus	"	"
"	" "	"	"	0	Nucleus	"	"
"	" "	"	"	"	2″.5 E of Nucleus	"	"
1980 Sept 6	" "	1.5	50	0	Nucleus	2.5	4355-5594
"	" "	"	"	"	5" E of Nucleus	"	"
"	" "	"	"	"	2″.5 W of Nucleus	"	"
"	" "	"	"	"	5" W of Nucleus	"	"
1980 June 7	AAT 3.9m/IPCS	1.9	140	0	Nucleus	1.3	4440-5410
"	" "	"	"	"	2″.5 E of Nucleus	"	"
"	" "	"	"	"	2″.5 E of Nucleus	1.3	6070-7080
1981 Aug 22	" "	0.9	225	0	Nucleus	1.1	4785-5500
"	" "	"	"	"	2″.5 E of Nucleus	"	"
"	" "	"	"	"	2″.5 W of Nucleus	"	"
1982 July 7	CTIO 4m/SIT + Echelle	2	16	90	Nucleus	0.5	4350-8500
1982 Oct 27	" "	"	"	"	"	"	3850-7700
1982 Oct 29	" "	"	"	"	"	"	"

is almost certainly real. Corroboration comes from the independent observations of Peterson *et al.* (1982), who noted a nearly 100% increase in the equivalent width of the [O III] λλ4959, 5007 lines in their spectrum obtained on 1980 May 19 (UT) as compared with Osterbrock's (1977) measurements of spectra taken ca. 1974–1976 (Osterbrock and Koski 1976). Peterson *et al.* interpret this change as being due almost entirely to a drop in the continuum level between 1976 and 1980, since the time scale for change in the [O III] lines should be considerably longer. Further support is provided by the low-resolution observations published by de Bruyn and Sargent (1978). These authors carried out spectrophotometry of Mrk 509 through a 10″ aperture on 1977 June 21, and these data are in excellent agreement with our own observations made in 1978.

Since the low in 1980, Mrk 509 has apparently recovered to its 1977–1978 level. This is demonstrated by a recent (1982 October 30) spectrophotometric measurement made through a 20″ aperture by R. P. S. Stone with a single-channel scanner on the CTIO 1.5 m telescope. A flux of 1.55×10^{-24} ergs cm^{-2} s^{-1} Hz^{-1} was measured through a 40 Å bandpass centered at 6436 Å on this occasion. This value agrees well with the 1978 SIT-vidicon data and the 1977 spectrophotometry of de Bruyn and Sargent (1978).

On the basis of equivalent width measurements, Peterson *et al.* (1982) argued that a decrease in the Hβ

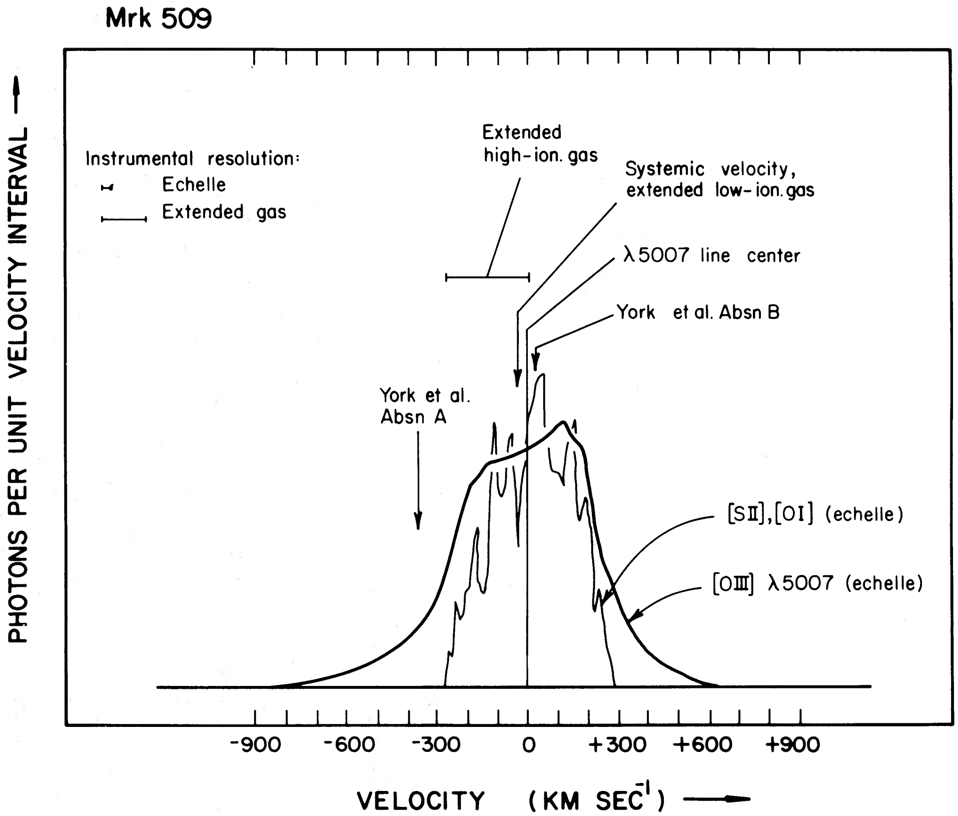

FIG. 3.—Emission-line profiles measured for the nucleus. Several other relevant velocity systems (see § IV) are also marked.

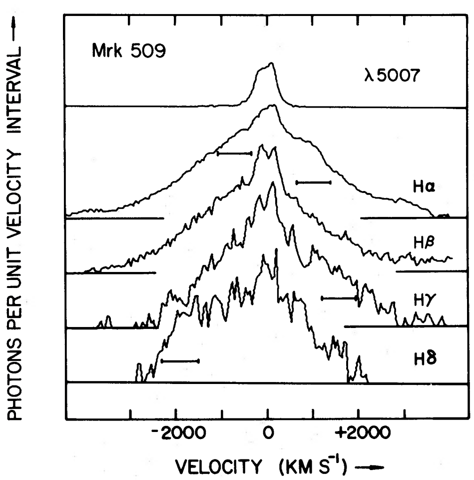

FIG. 4.—Profiles of the Balmer emission lines from the nucleus, compared with that of [O III] λ5007. The horizontal bars under the Hα, Hγ, and Hδ profiles mark the positions of [N II] λλ6548, 6584, [O III] λ4363, and [S II] λ4076, respectively.

flux accompanied the decrease in continuum luminosity. Such comparisons involving the broad lines in type 1 Seyfert galaxies and/or QSOs are notoriously difficult owing to the problems of determining the proper continuum and defining the extent of the emission in the line wings. However, plotting the 1978 spectra on top of the 1980 spectra (Fig. 6) after multiplying the latter by 1.4 to compensate for the drop in continuum luminosity shows that the higher order Balmer lines (Hγ and Hδ) in the two spectra agree very closely in equivalent width. The Hα and Hβ lines, on the other hand, definitely had greater equivalent widths in 1980 than in 1978. We therefore conclude that while the Hγ and Hδ intensities changed in step with the continuum variations, those of Hα and Hβ did not. In fact, the Hα intensity stayed virtually constant. Such a steepening of the Balmer decrement in response to a drop in the continuum luminosity is consistent with the few well-documented variations detected in other Seyfert 1 galaxies (see Antonucci and Cohen 1983, and references therein) and is at least qualitatively similar to the predictions of recent optically thick photoionization models (cf. Kwan and Krolik 1981). Figure 6 also shows that the [O III] λλ 4959, 5007 intensities remained constant, as expected.

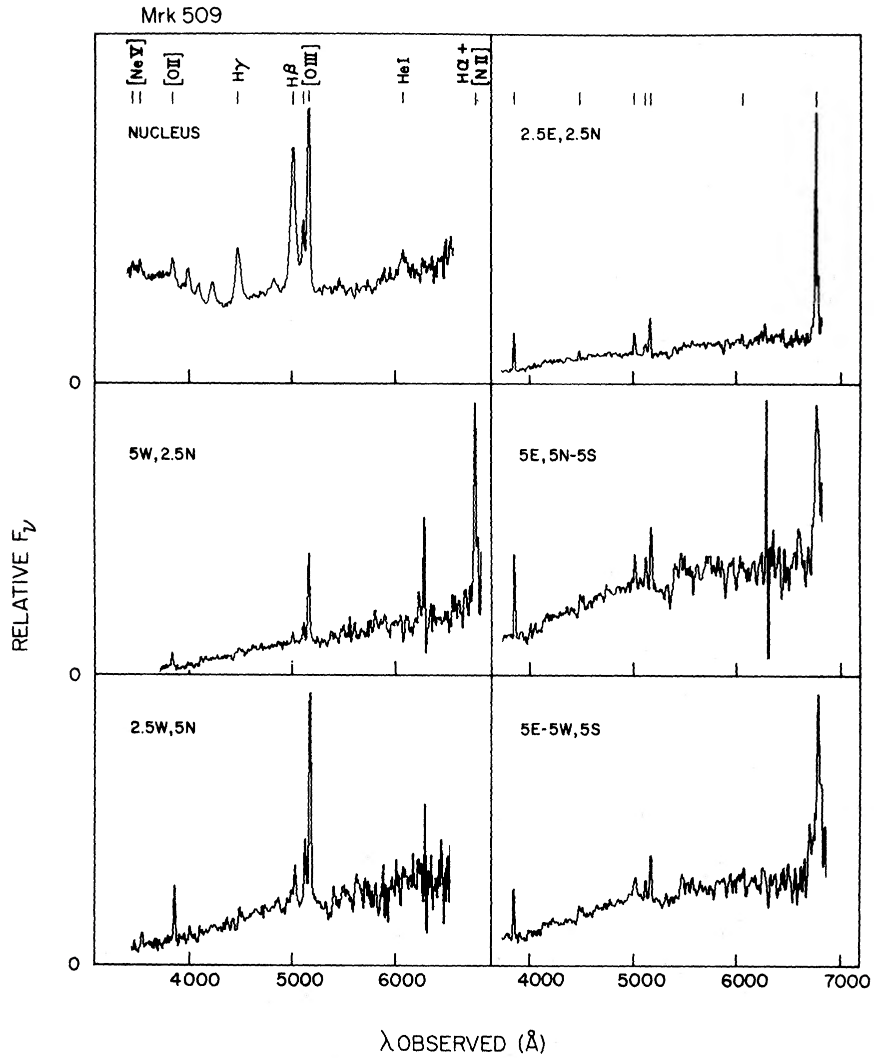

FIG. 5.—Low-resolution spectra at several points in Mrk 509. Positions are given in arcsec relative to the nucleus. The center-right and bottom-right spectra are summed along strips as indicated, in order to increase the signal-to-noise ratio.

d) Two Components of Extended Ionized Gas

The low-dispersion spectra of the off-nuclear regions of Mrk 509 show narrow emission lines concentrated in an area approximately 10″ (6.6 kpc) in diameter, centered on the nucleus. The absence of broad permitted lines rules out any possibility that this is scattered light from the nucleus. Spectra of the nucleus and five different off-nuclear positions are shown in Figure 5. These illustrate that a large range in excitation is present in the extended ionized gas.

The regions of highest ionization show an emission-line spectrum which is very similar to that observed in the ionized gas surrounding the nuclei of two other other Seyfert 1/QSO transition objects, 3C 120 (Balick and Heckman 1979; Baldwin *et al.* 1980) and MR 2251-178 (Bergeron *et al.* 1983). However, Mrk 509 also has regions of much lower ionization. These have no counterpart in 3C 120 or MR 2251-178, which show only very high excitation gas.

The higher dispersion spectra show that these two ionization components are also kinematically distinct. This is illustrated in Figure 7, which shows a subset of the SIT-vidicon spectra. The resolution into two components with very different [O III] λ5007/Hβ intensity ratios is most obvious in the southwest quadrant, but it is detectable over a much larger area. Although both components of ionized gas are projected over more or less the same area, the high-resolution spectra reveal a few positions where one component dominates over the other. For example, one of the locations showing the "purest" high-ionization component spectrum is 5″ west

TABLE 2

RELATIVE EMISSION-LINE INTENSITIES OF THE NUCLEAR NARROW-LINE COMPONENT

Emission Line	Relative Intensity
[Ne v] λ3426	0.6
[O II] λ3727	1.4
[Ne III] λ3869	1.0
[S II] λ4076	0.16±0.09
Hδ λ4101	0.15±0.08
Hγ λ4340	0.41±0.12
[O III] λ4363...........	< 0.3
Hβ λ4861	1.0
[O III] λ4959...........	2.8
[O III] λ5007...........	7.4
[O I] λ6300	0.2
Hα λ6563	2.8±0.8
[N II] λ6584	1.7±0.6
[S II] λ6717	0.26
[S II] λ6731	0.33

and 2″.5 north (abbreviated 5W, 2.5N) of the nucleus, while one of the least contaminated regions of low-ionization component emission is found 2″.5 east and 2″.5 north (2.5E, 2.5N) of the nucleus (see Fig. 5). Approximate relative line intensities measured from both of these spectra are given in Table 3. We caution, however, that although the emission from these regions is dominated by one or the other component, neither is entirely pure (cf. Fig. 5).

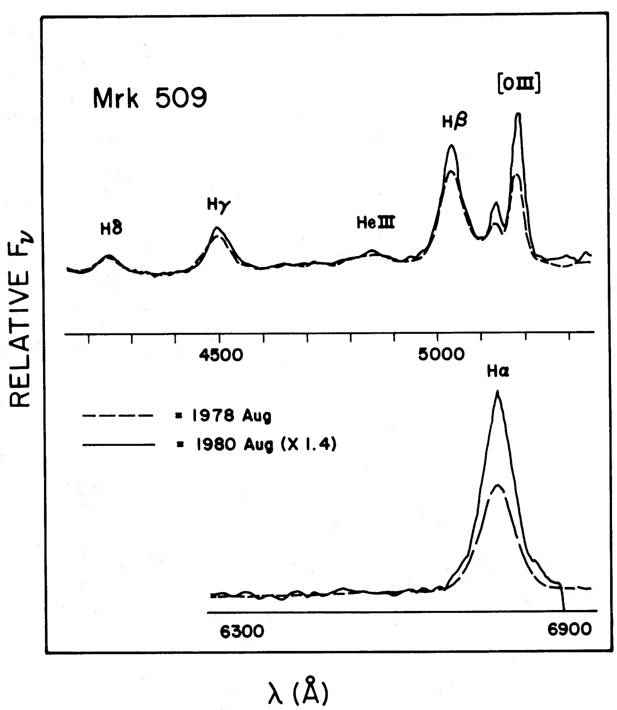

FIG. 6.—Comparison of emission-line equivalent widths at two different epochs.

e) Radial Velocity Map

Two-dimensional radial velocity maps of both the low- and high-ionization components of extended gas were derived from the combined SIT-vidicon and IPCS high-dispersion spectra. These are shown in Figure 8, projected onto a contour map derived from the CTIO 4 m plate described in § II. Each number represents the mean of several measurements. A constant heliocentric value of 10,365 km s^{-1} was subtracted from each mean measurement to produce the numbers given in the figure. The accuracy of the final values is estimated to be ±30 km s^{-1}, except for those in parentheses, which are of lower precision. All velocities were calculated using the formula $v = cz$; a proper relativistic correction would decrease these values by 180 km s^{-1}.

As the left-hand side of Figure 8 shows, the low-ionization component of extended gas seems to be undergoing well-ordered, disklike rotation about an axis at a position angle of approximately 135°. The velocity gradient is relatively steep near the nucleus (~50 km s^{-1} $arcsec^{-1}$) but would seem to have nearly flattened out at a radius of 7″ (5 kpc). The spatial extent is too limited to say much more. The systemic velocity of this rotating structure is calculated to be approximately 10,330 km s^{-1}, in good agreement with the [O III] λ5007 line center velocity at 10,365 km s^{-1}.

The high-ionization component in Mrk 509 shows completely different kinematics. There seems to be little, if any, organized rotation. The outstanding feature is the nearly complete absence of positive velocities—i.e., velocities greater than the systemic velocity of the low-ionization disk. This will be discussed further in § IV.

f) Stellar Content of the Underlying Galaxy

The continuum radiation from the surrounding nebulosity shows a rich variety of absorption lines which can only be due to an underlying galaxy—a point which was tacitly assumed in § II. But here again there are considerable variations from place to place. This can be seen in Figure 5, and to better advantage in Figure 9, where the spectra observed at 2.5E, 2.5N and 5W, 5N-5S are reproduced at larger scale. The spectra differ considerably both in their continuum slopes and in which absorption features are visible. At the position 2.5E, 2.5N, the strongest lines are the H I Balmer series (including the Balmer jump), Ca II H and K, and Mg I *b* λ5175. At 5W, 5N-5S, the Ca II lines, G band, Mg I *b*, and Na I D lines dominate.

The continuous spectrum observed at 2.5E, 2.5N is most readily understood in terms of a composite stellar population, dominated in the blue by young early-type stars. Such a spectrum is commonly observed in the

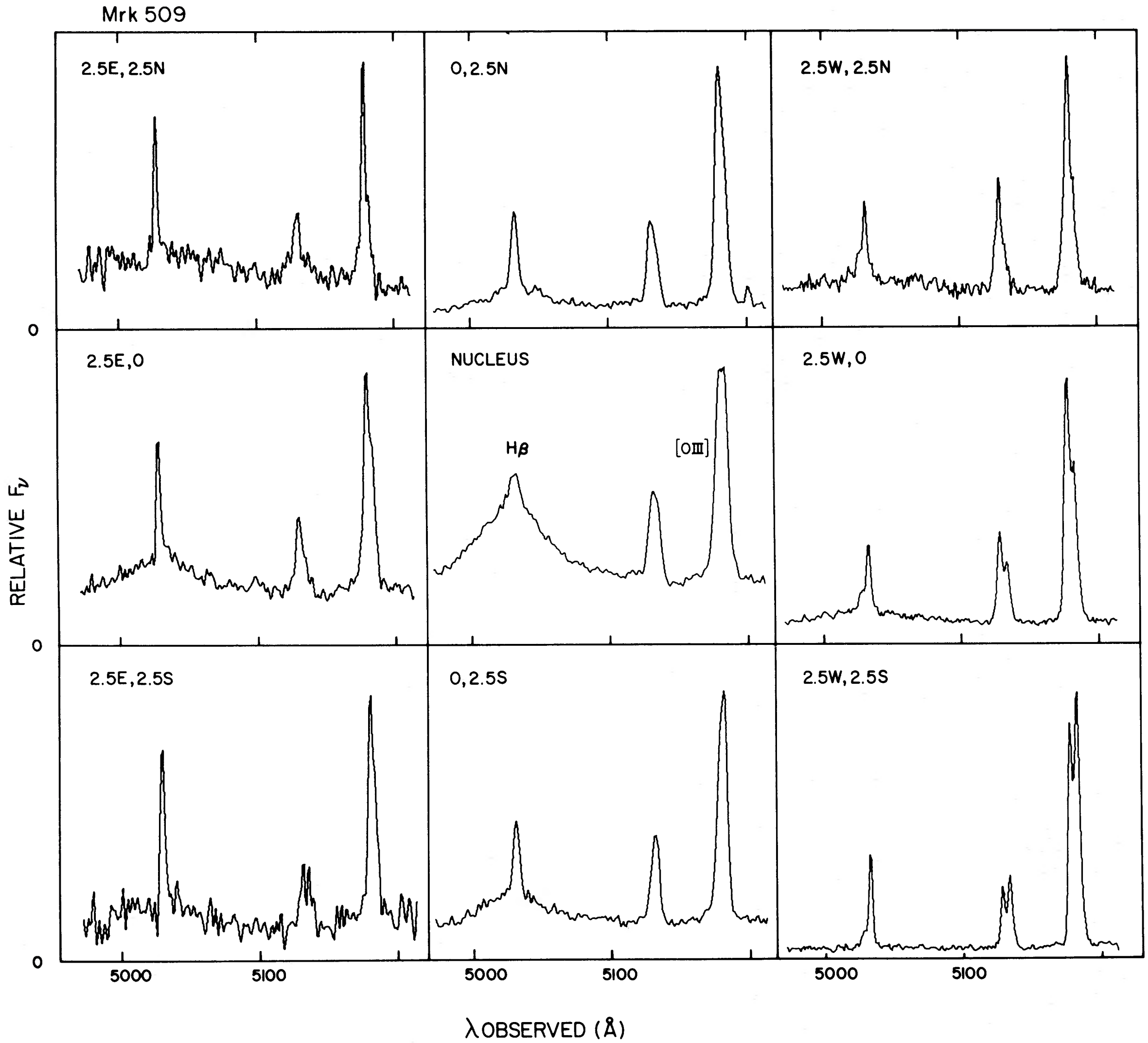

FIG. 7.—Grid of high-resolution spectra, showing the individual high- and low-ionization components

nuclear regions of late-type spiral galaxies (e.g., cf. the spectrum of the SBbc[s] I–II galaxy NGC 7552 illustrated in Fig. 1 of Ward *et al.* 1980). This spectrum is also very similar to that detected recently by Boroson and Oke (1982) in the faint nebulosity north of the luminous QSO 3C 48. In contrast, the continuous spectrum recorded at 5W, 5N-5S is that of a largely late-type stellar population such as is found in E and S0 galaxies (cf. Fig. 1 of Miller 1981) or in the bulges of early-type spiral galaxies.

The low-resolution SIT-vidicon spectra also reveal a strong correlation between the continuum properties at a given off-nuclear position and the ionization of the extended gas at that point. This is clearly illustrated in Figure 5, which shows that in the regions of bluest continuum, the low-ionization component is predominant.

IV. DISCUSSION

a) *The Nature of the Low-Ionization Disk*

The regions of strongest emission in the low-ionization component of extended gas are the same areas where a substantial hot stellar component is detected in the low-resolution data. The [O III] $\lambda 5007/\mathrm{H}\beta$ ratio in this component ranges from 0.5 to 2.0, while the IPCS spectra yield a mean [N II] $\lambda 6584/\mathrm{H}\alpha$ ratio of 0.3. These are typical values for Galactic H II regions (see Baldwin, Phillips, and Terlevich 1981). The same is true

TABLE 3

RELATIVE EMISSION-LINE INTENSITIES IN THE EXTENDED IONIZED GAS

Emission Line	Low-Ionization Component 2.5E, 2.5N	High-Ionization Component 5W, 2.5N
[O II] λ3727	2.4	2.4[a]
Hβ	1.0	1.0[a]
[O III] λ4959 ...	0.6[b]	2.0
[O III] λ5007 ...	1.6[b]	8.8
[O I] λ6300	≤ 0.2	≤ 0.4
Hα	4.8	9.2:[a]
[N II] λ6584	1.6:	4.6:
[S II] λ6716 } [S II] λ6731 }	0.7:	...

[a] Lines which may be significantly contaminated owing to the contribution of the *low-ionization* component at this same position.

[b] Lines which may be significantly contaminated owing to the contribution of the *high-ionization* component at this same position.

for the [O II] λ3727/[O III] λ5007 and [O I] λ6300/Hα intensity ratios observed at the position 2.5E, 2.5N (see Table 3), where the low-ionization component is seen to dominate. Hence, there is little doubt that this gas is photoionized by the ultraviolet radiation of young hot stars.

We have also seen that this low-ionization gas rotates in an orderly disklike fashion. The existence of a disk along with the absence of spiral arm structures suggests that Mrk 509 may be an S0 galaxy. As discussed in § II, the luminosity profile of the stellar component is probably consistent with this hypothesis, although a stellar disk is not actually visible in direct photographs. However, the disks of S0 galaxies only rarely show such large amounts of ionized gas and young stars. Also, there is a suggestion that the position angles of the isophotal minor axis and the projected rotation axis of the disk differ by ~ 25°. There is therefore some doubt that Mrk 509 is a true S0.

We reject as highly unlikely the possibility that the low-ionization disk is actually a neighboring small spiral or irregular galaxy seen projected onto Mrk 509. The close agreement between the systemic velocities of the disk and the Seyfert nucleus and the symmetry of the disk around the position of the Seyfert nucleus argue strongly that the two are in the same galaxy.

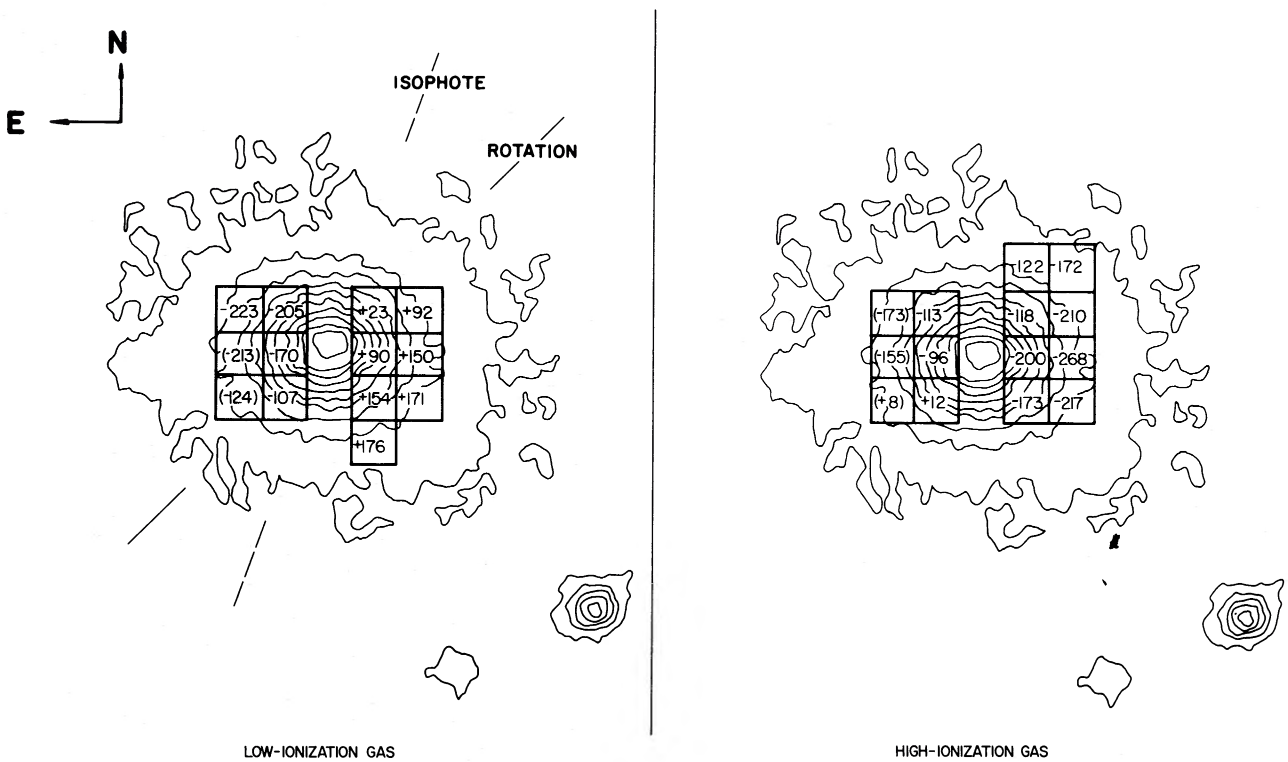

FIG. 8.—Velocity maps of the two ionization components in Mrk 509, superposed on an isophotal contour map measured from the plate shown in Fig. 1.

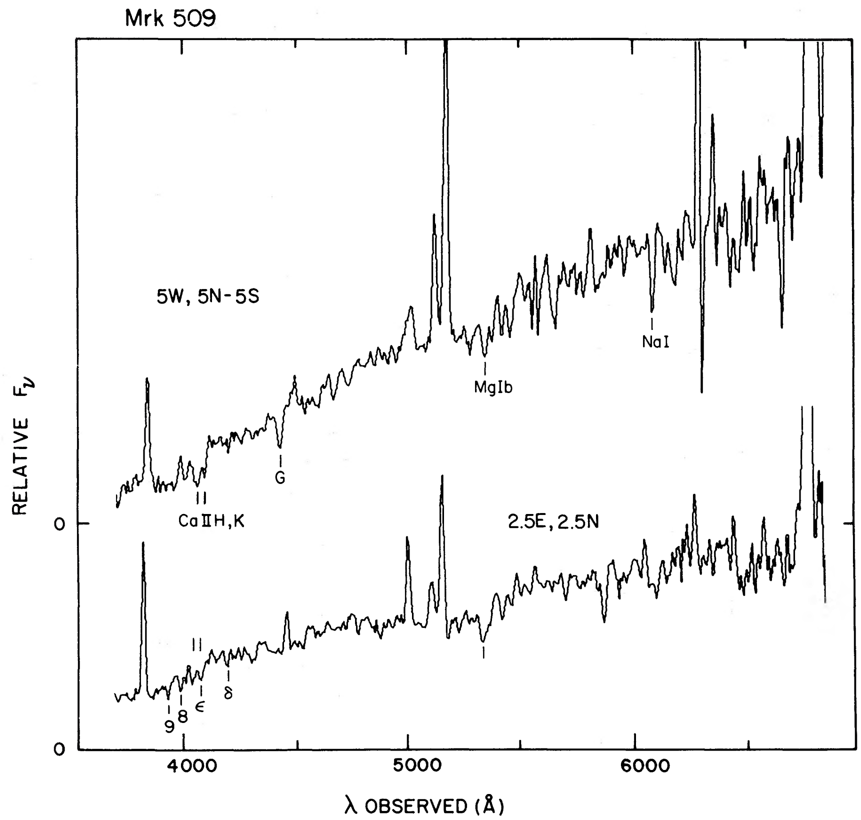

FIG. 9.—Spectra of the underlying stellar continuum at two points in the nebula

b) *The Expanding High-Ionization Gas*

The high-ionization component of extended gas also appears to be photoionized, but in this case by the nonthermal radiation emitted by the nucleus. The evidence for this is twofold. First, this gas shows emission lines arising from at least two ions with extremely high ionization potentials—He^+ and Ne^{+4}. The He II λ4686 line is clearly present in the SIT-vidicon and IPCS spectra of the southwest quadrant emission at a radial velocity consistent with the large λ5007/Hβ component. The [Ne V] λ3426 line is observed in the low-dispersion spectra of the 5W, 2.5N position (see Fig. 5), which the high-dispersion data confirm as dominated by the large λ5007/Hβ component. Such ionization is never attained in Galactic H II regions but is common in the nuclei of Seyfert galaxies and QSOs and in the extended gas often surrounding them (e.g., see Ulrich and Péquignot 1980; Bergeron *et al.* 1983). Second, the relative intensities of the other stronger emission lines associated with the high-ionization component are inconsistent with stellar photoionization, but they are indistinguishable from those found in the narrow-line spectra of Seyfert galaxies and QSOs. This can be seen by comparing the relative intensities given in Table 3 with the intensity ratio diagrams of Baldwin, Phillips, and Terlevich (1981).

The fact that all of this extended, high-ionization gas is seen coming toward us, relative to the nucleus, strongly implies outflow. We could be seeing either a broad front coming only out the near side of the galaxy, or the near side of a more symmetrical expansion in which the corresponding gas moving away from us is obscured by dust in the low-ionization gas disk or in some other part of the galaxy. There is a parallel to this latter interpretation in at least one other active galaxy, NGC 1365, where only small segments of the far side of an outward-expanding gas component can be glimpsed through the dust in the plane of the parent galaxy (Phillips *et al.* 1983).

There is additional evidence for an expanding shell from the spectroscopy of the nucleus of Mrk 509. The nuclear [O III] λ5007 profile found from our echelle data is shown in Figure 3. Although there are enough extra frills to make the argument ambiguous, the λ5007 line is basically flat-topped with steeply descending wings, the profile expected for an expanding shell with perhaps some minor added effects due to a velocity dispersion or non-instantaneous ejection. This interpretation is considerably strengthened by recent *International Ultra-*

violet Explorer (*IUE*) spectra taken by York *et al.* (1983). These show two absorption systems both in Lyα and C IV λ1550. One system is essentially at the velocity of the blueward edge of the central part of the λ5007 profile, while the other is at a velocity which within the errors is equal to both the "line center" velocity of the forbidden lines of the nucleus and the systemic velocity of the low-ionization disk. These are interpreted to be, respectively, the near side of the expanding shell and the gas in the low-ionization disk (but the latter now ionized through C^{+3} because of its proximity to the nucleus).

The radial velocity situation is summarized in Figure 3, where it can also be seen that the radial velocity range covered by the extended high-ionization gas is about the same as the blueward half of the nuclear λ5007 profile, but that in the latter there is an additional blueward extension out to about -800 km s^{-1}. This asymmetrical blueward tail is seen in the spectra of many, but by no means all, Seyfert 1 nuclei. In the case of Mrk 509 it is tempting to associate it with the general pattern of extended high-ionization gas, on the grounds that both components show only a negative velocity relative to the nucleus and that by far the most negative velocity is seen in the line of sight to the nucleus. Although speculative, this is again highly consistent with outward expansion from the nucleus, either as part of a continuing ejection process or because this material was at the extreme end of the velocity distribution of a single explosive event which also produced the expanding shell which emits the core of the nuclear λ5007 line.

c) Relationship to Other Seyfert Galaxies and QSOs

An underlying aim of the continued study of active galaxies is to find common denominators which might delineate the basic energy production mechanism. Extended high-excitation gas has been detected in a growing number of active galaxies. In most of the well-studied cases, the data equally admit two alternate interpretations: the gas could be in a disk rotating about an axis skewed to the main rotation axis of the galaxy, or it could be in some sort of incomplete expanding shell or cone. Good examples include 3C 120 (Baldwin *et al.* 1980), NGC 1365 (Phillips *et al.* 1983), and NGC 5728 (Rubin 1980). The skewed (or possibly warped) rotating-disk interpretation is often made in the context of an accretion process, with the energy output of the active nucleus being derived from the gravitational potential energy of a captured galaxy or intergalactic gas cloud (e.g., see Danziger, Goss, and Wellington 1981, and references therein).

The case of Mrk 509 is particularly interesting in this respect, since for the high-excitation component of extended gas (and perhaps for the nuclear narrow-line region as well) the seemingly unavoidable interpretation is that of outflow. This, in turn, implies that outflow from the nucleus spreading throughout a large solid angle is likely to be a common phenomenon in active galaxies. In this picture, Mrk 509 can be viewed as a case where the axis of the outflow is coming more or less directly at us, and if Mrk 509 were viewed from some other angle, the distinction between outflow and a skewed disk would again be uncertain.

But Mrk 509 may be the "complete" active galaxy, in the sense that in addition to this high-ionization outflow, the low-ionization gas represents a possible case of accretion. The rotating disk of low-ionization gas, dust, and stars in Mrk 509 is anomalous for the morphology of the underlying galaxy. This is very reminiscent of the situation in the nearby giant elliptical radio galaxy NGC 5128 (Cen A). The latter has been studied in great detail in recent years (e.g., see Graham 1979; Dufour *et al.* 1979; Phillips 1981; Möllenhoff 1981; Marcelin *et al.* 1982). Although some controversy exists, it seems most likely that the disk component in NGC 5128 developed from the merger of a gas cloud or small galaxy with a giant elliptical galaxy (e.g., see Graham 1979). Significantly, there is also a high-excitation component of gas in NGC 5128, far out of the plane of the disk and approximately along the disk's axis of rotation, which may be moving systematically away from the nucleus (e.g., see Graham and Price 1981). Further examples of active galaxies with rotating disks which may be morphologically similar are IC 5063 (Caldwell and Phillips 1981; Danziger, Goss, and Wellington 1981) and MR 2251-178 (Bergeron *et al.* 1983). Similarly, Caldwell (1982) has argued that other elliptical galaxies with large amounts of ionized gas and dust have acquired the material from outside.

In Mrk 509, an extragalactic origin of the low-ionization disk would explain the possible misalignment of the rotation axis. Although the emission-line intensities of the low-ionization gas in Mrk 509 (see Table 3) do not imply unusually low abundances of the heavy elements, and thus rule out a completely primordial gas cloud, the swallowing up of a preexisting galaxy or the triggering of waves of star formation by the accretion process are still possibilities. We note that in none of these active galaxies with extended ionized gas is there evidence for primordial gas, not even in MR 2251-178, where the gas has been detected out to 150 kpc from the ionizing QSO.

V. SUMMARY

Our main conclusions are as follows:

1. On direct photographic plates, the luminous Seyfert 1 galaxy Mrk 509 has the general appearance and radial luminosity profile of an E or S0 galaxy.

2. Nevertheless, spectra of its outer parts show a far-flung double emission-line system, with low- and high-ionization components.

3. The low-ionization component is a rotating disk with the same systemic velocity as the Seyfert nucleus.

The gas is photoionized by hot stars. There is some evidence that this disk's axis of rotation is not aligned with the minor axis of the underlying stellar population.

4. Superposed on this is an outflowing system of high-ionization gas, covering much of the galaxy. We only see gas which is coming toward us relative to the nucleus. A corresponding component on the far side of Mrk 509 may be hidden behind the low-ionization disk. The high-ionization gas appears to be photoionized by the Seyfert nucleus.

5. On a much smaller scale, spectra of the nucleus show what is probably an expanding shell of high-excitation gas.

6. Mrk 509 is the clearest-cut example to date of the outflow of optically emitting gas over a very large volume of an active galaxy. However, the presence of the low-ionization disk and its possible misalignment with respect to the rest of the galaxy suggest that an accretion process may be going on at the same time.

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