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ON THE POSSIBLE IMPORTANCE OF MARKARIAN 359

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ABSTRACT

Markarian 359 has a compact nucleus whose permitted emission lines are slightly wider than its forbidden lines, but much narrower than the permitted lines in a "Seyfert class 1" nucleus. Its line spectrum resembles that of a "Seyfert 1" galaxy in which the permitted lines are greatly reduced. This unusual object merits further observations; some suggestions are given.

Subject headings: galaxies: individual — galaxies: nuclei — galaxies: Seyfert

I. INTRODUCTION

Broad permitted lines, whose widths may correspond to velocity dispersions of thousands of km s^{-1}, appear in the spectra of many active galactic nuclei; forbidden lines in the same spectra are much narrower (see Weedman 1977, and references therein). It is thought that the broad lines originate in gaseous regions which are too dense to emit noticeable forbidden lines, and which really have large velocity dispersions, perhaps due to random motions, rotation, expansion, or infall of material. It is also suspected that nonthermal continua, usually of the power-law type, are found in the same objects, and many theories have been invented to explain the energy fluxes involved; velocity dispersions of thousands of km s^{-1} occur quite naturally in most theories (e.g., those involving supernovae or black holes). In this context, the fourteenth-magnitude galaxy Markarian 359 has an extremely interesting, peculiar central feature: dense permitted-line gas, possibly associated with a nonthermal energy source, wherein the apparent velocity dispersion is only a few *hundred* km s^{-1}. Narrower forbidden lines, representing a wide range of qualitative "excitation levels," are also present.

II. GENERAL CHARACTERISTICS OF MARKARIAN 359

Markarian 359 (MCG-3-4-41) is described as a "face-on" galaxy in the morphological catalog of galaxies (Vorontsov-Vel'yaminov, Krasnogorskaya, and Arkhipova 1964). Markarian and Libovetsky (1971) noticed its emission lines and moderately strong ultraviolet continuum, while Arakelian, Dibai, and Yesipov (1972) described it as a "spheroidal object with a corona" and mentioned strong Hα, [N II], and [S II] emission. De Vaucouleurs, de Vaucouleurs, and Corwin (1976) give it a heliocentric radial velocity of 5070 km s^{-1}. Huchra (1977) has given photometric data and described the object as a ringed galaxy of type SB0.

New photometric data are listed in Table 1. Each entry refers to a circular region, centered on the nucleus of Markarian 359, with an angular diameter specified in the first column of the table. No corrections for interstellar extinction have been applied (the galactic latitude is −43°). The magnitudes labeled "1.3 m" were obtained with the Kitt Peak 1.3 m telescope, on 1978 February 18 (UT); magnitudes labeled "IIDS" were estimated from digital spectra described later in this paper, obtained in 1977 December and 1978 January, and are of lower precision. The annular region with inner diameter 12″ and outer diameter 23″ has a light distribution and colors ($B - V \approx +0.8$, $U - B \approx +0.3$) like those of a normal Sab galaxy. The colors within a 14″ diameter aperture place the object near a boundary which (according to Weedman 1973) divides bright-nucleus and diffuse galaxies from Seyfert galaxies.

III. EMISSION LINE INTENSITIES

It is the emission lines that make Markarian 359 remarkable. Using the Kitt Peak 2.1 m telescope and

TABLE 1
Photometry of Markarian 359*

Aperture Diameter	V	$B - V$	$U - B$	Source
6″.1........	15.1:	+0.5:	−0.2:	IIDS
11″.7........	14.22	+0.67	−0.21	1.3 m
14″.0........	14.09	+0.67	−0.16	1.3 m
17″.7........	13.96	+0.70	−0.14	1.3 m
23″.4........	13.84	+0.70	−0.10	1.3 m
41″.........	13.68	+0.67	−0.08	Huchra 1977

* Uncorrected for interstellar extinction.

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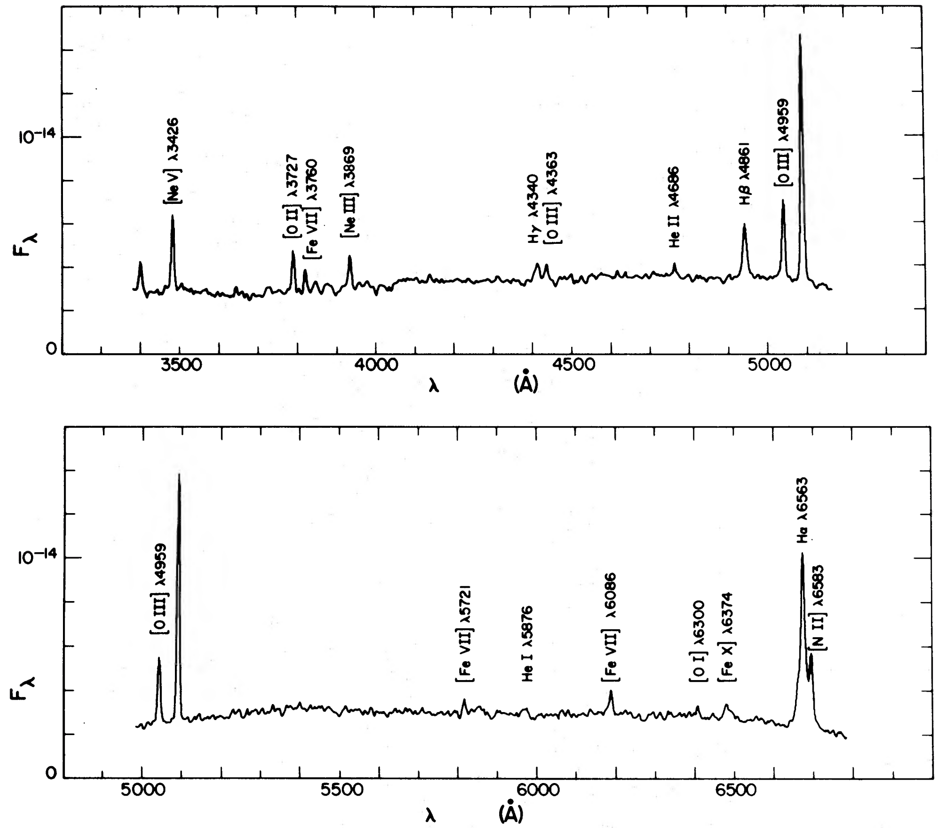

FIG. 1.—The apparent spectrum of a 6".1 diameter region at the center of Markarian 359, in 1977 December. F_λ (in ergs cm^{-2} s^{-1} Å^{-1}) is plotted versus λ (in Å); sky has been subtracted, but no correction for interstellar extinction has been attempted. Each end of the red spectrum is shown noticeably below the true flux values because of a minor error in the calibration reduction program; appropriate corrections for this have been made in Tables 1 and 2.

intensified image dissector-scanner (IIDS), we have obtained sky-subtracted digital spectra of a 6".1 diameter region at the center of the galaxy. On 1977 December 14, we obtained data covering the wavelength range 3400–5200 Å, with an integration time of about 20 minutes; the following night, we obtained data in the range 5000–6800 Å, with a similar integration time. On 1978 January 13, an additional 8 minute blue spectrum was obtained. Absolute fluxes were calibrated in the usual way with the standard routines provided with the Kitt Peak interactive picture processing system. It seemed appropriate to smooth the data slightly; the final spectral resolution (FWHM) is somewhat better than 10 Å.

Tracings of the December spectra are shown in Figure 1 (the January spectrum showed no significant change). The observed relative intensities of some emission lines are listed in Table 2, where unit intensity corresponds to an energy flux of 3.5×10^{-14} ergs cm^{-2} s^{-1} incident above the Earth's atmosphere. If Markarian 359 is compared with Seyfert galaxies, its [O III]/Hβ and [N II]/Hα intensity ratios are intermediate between Seyferts of class 1 (which have broad permitted lines and small [O III]/Hβ intensity ratios) and class 2 (which have only narrow lines and large [O III]/Hβ ratios); see Adams and Weedman (1975), Osterbrock (1977), Koski (1978), and Phillips (1978). However, the relative forbidden line intensities are more like those in a Seyfert 1 spectrum; the high-excitation [Ne V], [Fe VII], and [Fe X] lines are much brighter, relative to [O III] λ5007, than in a Seyfert 2 spectrum. The equivalent width of the Hβ line is about 10 Å, which is much smaller than in a typical Seyfert 1 spectrum; because of the relatively large [O III]/Hβ ratio, this means that the forbidden lines' equivalent widths resemble those in a Seyfert 1 spectrum. Thus, *the line intensities listed in Table 2 are like those which would result if the broad permitted lines were largely removed from the spectrum of a Seyfert nucleus of class 1.* (Relative to the total amount of line emission, the high-excitation [Ne V], [Fe VII], and [Fe X] lines are therefore quite prominent.) Although it may be present, Fe II emission is not obvious in our spectra; this seems consistent with the idea that Fe II emission in Seyfert 1 nuclei is correlated with the broad Balmer lines (Phillips 1978).

It is suspected that Seyfert 1 nuclei are the sites of nonthermal processes which result in power-law continua (see Weedman 1977, and references therein); and it is well known that wide ranges of ion species

TABLE 2

RELATIVE LINE INTENSITIES IN THE SPECTRUM OF THE CENTER OF MARKARIAN 359*

Line	Relative Intensity
[Ne v] λ3346	0.45 ± 0.10
[Ne v] λ3426	0.97 ± 0.12
[Fe VII] λ3587(?)	0.07 ± 0.04
[Fe VI] λ3664 (?)	0.12 ± 0.06
[O II] λλ3726, 3729	0.45 ± 0.07
[Fe VII] λ3760 ([Fe V] λ3756?)	0.21 ± 0.05
[Ne III] λ3869	0.41 ± 0.06
[S II] λλ4068, 4076 ([Fe V] λ4071?)	0.07 ± 0.03
(?) λ4238	0.07 ± 0.03
Hγ λ4340	0.26 ± 0.06
[O III] λ4363	0.21 ± 0.05
He II λ4686	0.17 ± 0.05
Hβ λ4861	1.00
[O III] λ4959	1.06 ± 0.12
[O III] λ5007	3.24 ± 0.25
[Fe VII] λ5721	0.16 ± 0.04
He I λ5876	0.14 ± 0.05
[Fe VII], [Ca V] λ6086	0.38 ± 0.08
[O I] λ6300 (?)	0.12 ± 0.06
[Fe X] λ6374	0.38 ± 0.09
Hα λ6563	4.60 ± 0.45
[N II] λλ6548, 6583	2.20 ± 0.34

* No interstellar reddening corrections have been applied.

(e.g., N II, O III, Ne V, and Fe X) can simultaneously be present in a gaseous configuration which is photoionized by a power-law ultraviolet and X-ray continuum. Semiquantitatively, but without referring to detailed photoionization models, we suspect that the intensities listed in Table 2 are consistent with such photoionization. A spectral index $s \approx 1.5$ ($F_\nu \sim \nu^{-s}$) would probably be consistent with the observed Hβ, He II, and high-ionization forbidden line intensities. However, absorption lines are also present, showing that much of the observed continuum is stellar. (H11 λ3770, H10 λ3797, Hη λ3835, Ca II λ3933, Ca II and Hε λ3970, the G-band, and probably lines near λ4385 and/or λ4465 are present in absorption, all with the expected redshift.) A nonthermal continuum might be demonstrated by either strong or variable polarization.

The hydrogen, helium, and [O III] lines can be used to derive various constraints on the interstellar extinction, temperatures and densities in the emitting regions, and the helium/hydrogen and oxygen/hydrogen abundance ratios. In order to save space, these will not be discussed here; the results are not strikingly different from the cases of typical Seyfert 1 and other active galactic nuclei.

IV. EMISSION LINE WIDTHS

Figure 2 shows the Hβ and [O III] λ4959 lines in our 1977 December and 1978 January spectra; *Hβ is broader than the* [O III] *line, but not nearly as wide as the broad permitted component in a typical Seyfert 1 spectrum.* There can be no reasonable doubt about the reality of the effect, for the following reasons:

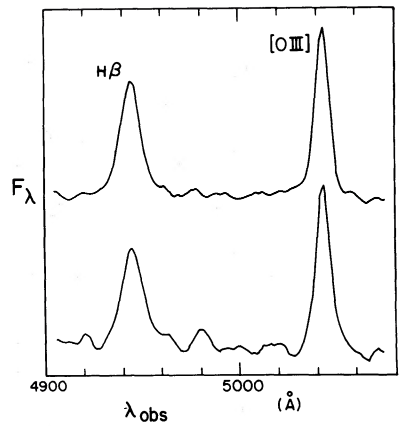

FIG. 2.—Tracings of our IIDS data on the Hβ and [O III] λ4959 lines, obtained in 1977 December (*upper*) and 1978 January (*lower*). The upper tracing represents an integration time about 2.5 times as long as the lower tracing, hence the difference in noise levels.

(1) the two independent spectra shown in Figure 2 have practically identical line profiles; (2) the [O III] λ5007 line, not shown in Figure 2, has practically the same profile as [O III] λ4959 in each spectrum, thus suggesting that the instrumental line widths do not vary significantly in the crucial wavelength region; (3) the other forbidden lines (except perhaps [Fe X] λ6374) do not show significant deviations from the [O III] width; and (4) Hγ is slightly wider than [O III] λ4363. Furthermore, Hα is probably wider than [N II] λ6583, although these lines are not well resolved. There are several conceivable explanations for such differences in line widths, but here we shall adopt the most conventional one: there is a component of gas which is too dense to emit much forbidden-line radiation, and which has a larger velocity dispersion than the lower-density gas where the forbidden lines originate.

In Figure 2, the apparent width of Hβ is 12.0 ± 0.7 Å—slightly less in the 1977 December data, slightly more in the 1978 January data. (Like other widths mentioned below, this is the FWHM [full width at half-maximum].) The width of [O III] λ4959 or λ5007 is 8.8 ± 0.4 Å. The instrumental width is uncertain (partly because it depends upon the angular size of the emitting region), but is between 6 and 9 Å. If the relevant profile shapes resemble $\exp(-x^q)$, with $1.5 \leq q \leq 2.0$ ($q = 1.6$ is in fact a good fit to the profiles in Fig. 2), then we can roughly estimate the intrinsic line widths, expressed as velocity widths (FWHM). Thus, the intrinsic width of [O III] is less than 450 km s^{-1} (probably less than 350 km s^{-1}), while the intrinsic width of Hβ is between 300 and 750 km s^{-1}; the major likely errors are correlated so that, in any case, Hβ is wider than [O III]. The most probable Hβ width is in the range 520 ± 100 km s^{-1}. By comparison, among the Hβ widths listed by Osterbrock (1977) for 36 Seyfert 1-like objects, the smallest is roughly 900 km s^{-1} and the median is about 2400 km s^{-1} (FWHM, crudely corrected for instrumental profile). In the spectra described by Osterbrock, the bases or wings of the Balmer lines have widths of the order of 10,000 km s^{-1}; if such wings are present in the spectrum of Markarian 359, Figure 2 shows that they must be quite faint.

V. DISCUSSION

If there were no perceptible differences between the widths of permitted and forbidden lines in the spectrum of Markarian 359, then this object would be only mildly interesting. But since there are differences in line widths, indicating that more than one component of gas is present, it is surprising that the permitted-line component has such a *small* apparent velocity dispersion; the implied kinetic energy per unit mass may be one or two orders of magnitude less than in some of the broad-line gas associated with quasars and class 1 Seyfert nuclei.

Conceivably, this may be only an illusion, the result of viewing faster rotational motion from a perpendicular direction. Netzer (1977) has remarked that gravitational and transverse Doppler redshifts can be quite noticeable in such a case. The approximate combined effect would be

$$\frac{\Delta\lambda}{\lambda} \approx 3v_{\perp}^2/2c^2 ,$$

where $v_{\perp}$ is a characteristic rotational speed. In our spectra, measured by comparison with the [O III] lines, Hβ seems to be shifted by about $\Delta\lambda = +0.8 \pm 0.6$ Å, which suggests that $v_{\perp}$ might be of the order of 3000 km s^{-1} but cannot be as large as 6000 km s^{-1}. While this result is not precise enough to be very interesting, it does indicate that better wavelength measurements and line profiles—which should not be difficult to obtain with appropriate equipment—may be revealing.

However, we must emphasize that the idea of rotation seen from an axial direction is not enough to explain the spectral peculiarities of Markarian 359. As stated in § III, the permitted lines are significantly less intense than in a normal Seyfert 1 spectrum, and there is no obvious reason why this should be a result of viewing a dense rotating configuration face-on. Our data should not be taken as evidence for rotational motions in an active galactic nucleus, although Markarian 359 may be a good place to seek such evidence.

The possibilities are various, and the primary purpose of this paper is to draw attention to this object as a potentially important subject of future investigation. The spectrum should be reobserved occasionally, because broader permitted lines may eventually appear (time scales for variation in active nuclei can be of the order of several years or less, and we may have observed this object at an unusual time). Perhaps more importantly, the Hβ, [O III], Hα, and [N II] lines should be observed with improved spectral resolution, in order to investigate the line profiles as well as the possible extra redshift of permitted lines suggested by Netzer (1977). Finally, it is possible that other objects, classified as having "narrow-line" spectra from low-resolution spectra, may also prove to have permitted lines and forbidden lines with inconspicuously different widths—a casual glance at tracings like those in Figure 1 would not necessarily reveal the differences in line widths, even in the case of Markarian 359; other cases may be more subtle.

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