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A SPECTROSCOPIC STUDY OF LUMINOUS GALACTIC NUCLEI*

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Spectroscopic observations of a sample of galactic nuclei from the lists of Markarian and Seyfert are presented in order to consider the nature of the nuclei with broad emission lines. It is found from photographic spectrophotometry and emission line profiles that such galaxies can be consistently classified into two classes: objects like NGC 5548 that are found to have small, dense nuclei containing low velocity gas and objects like NGC 1068 with larger nuclei containing gas of lower density but higher velocity. The observational data favors broadening by electron scattering for the Balmer lines in the first class, and the absolute luminosity in H_β is generally greater in the first class than in the second. From the extreme spectroscopic and morphological similarity of all galaxies in the second class, it is concluded that the outflow of gas from the nucleus has affected the structure of the entire galaxy.

1. *Introduction.* Many of the 300 galaxies with strong ultraviolet continua detected by Markarian [1] with objective prism spectroscopy have now been observed at higher dispersions using slit spectrographs [2—7]. The brightest of these galaxies have nuclei with emission line spectra and absolute luminosities (based on their redshifts) resembling the nuclei of the classical Seyfert galaxies and the fainter quasi-stellar sources. Because Markarian's search was carried to a defined magnitude limit without regard for galaxy type, his lists provide an important statistical sample of galaxies with such excited nuclei. The first Markarian list contained 70 objects from 650 square degrees of the sky. All 70 objects have now been observed sufficiently

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to detect those galaxies having small, bright nuclei in which emission lines arise. Of these 70 objects, seven (numbers 1, 3, 6, 9, 10, 34, 42) are galaxies with broad and strong emission lines in their nuclei [3]. Broad emission lines are also found in 50 and 69 [4] and 40 (VV144, see [8]), although these are fainter, more compact or peculiar objects having no obvious surrounding galaxy. In addition, object 64 had been classified as a QSO by Braccesi et al [9]. In the present paper we consider in detail the seven galaxies with broad and strong nuclear emission lines in order to study the energetic phenomena in these nuclei. Object number 52 is also considered for comparison since it is an excellent example of a bright galactic nucleus with strong but narrow emission lines. Less complete observations of other excited nuclei from the lists of Seyfert [10] and Markarian [1] are also presented to supplement the results on the eight primary objects.

The present study is not an attempt to reproduce detailed analyses of individual objects such as were previously carried through for NGC 1068 [11] and NGC 4151 [12]. Both of these studies showed that the interior of a Seyfert nucleus is an extremely complex, inhomogeneous region. In hopes of gaining some insight on the overall properties of such regions, we restrict ourselves to a presentation of the obvious differences found to exist among various nuclei and the galaxies in which they occur. None of the objects discussed are QSO's, although the nuclei of some appear stellar, and we will assume that the relative distances of the objects are proportional to their redshifts, which range in z from 0.0072 to 0.0507.

2. *Observations and Results.* The first purpose of the present study was to provide reasonably accurate measures of the relative intensities of the brighter emission lines arising in the nuclei. It was also desirable to have an estimate of the absolute intensities of these lines. Our primary set of observations is therefore a series of spectra of 8 Markarian galaxies obtained under as nearly similar observing conditions as possible. The 8 objects are numbers 9, 10 and 42 (class 1 as defined below in section 3), numbers 1, 3, 6 and 34 (class 2), and number 52 (class 3). These observations were made at 220 $A\ mm^{-1}$ with an image tube spectrograph at the $f/18$ cassegrain focus of the 107-inch reflector at McDonald Observatory. All spectra were trailed to a width of 0.4 mm on the plate and all cover the wavelength interval λ3500 to λ7000. Exposure times were short, averaging about 15 minutes, so several spectra of different exposure times were obtained for most objects. We have five such spectra for Markarian 3; four each for 9, 1 and 6;

three for 34 and 52; two for 10 and only one for number 42. Virtually all of these spectrograms together with the calibration spectra discussed below were obtained on the same night (1970 January 12) on only two plates, since the spectrograph has a large, movable plateholder. The plates were developed simultaneously with a plate exposed in a spot sensitometer through a filter that approximates the color of the image tube phosphor. Five spectra of the planetary nebula IC 418 were included with exposure times differing by a factor of two between successive exposures. These spectra were used to determine the spectrograph response as a function of wavelength and to check the density-intensity calibration as discussed below. In addition three spectra were obtained (on one of the plates with the Markarian objects) of the Seyfert galaxy NGC 4151 since the absolute intensities for emission lines in this galaxy are known [12]. The NGC 4151 observations were also used to verify the derived spectral response of the spectrograph. Results of the spectrophotometry are given in Table 2.

For studying emission line profiles, spectra near λ 5000 for the objects listed in Table 1 were obtained at a dispersion of 28 A mm^{-1} with the cassegrain image tube spectrograph on the 82-inch telescope at McDonald Observatory. Objects number 9, 10 and 42 were observed for this purpose at 85 A mm^{-1} with the cassegrain image tube spectrograph on the 200-inch telescope of the Hale Observatories. Four spectra used to determine electron densities in NGC 1068 were observed at 28 A mm^{-1} using an image tube spectrograph on the 36-inch telescope at McDonald. The direct photographs of Markarian 3 and 6 discussed below were obtained with the $f/4.5$ reducing camera at the cassegrain focus of the 82-inch, and 200-inch prime focus photographs for Markarian 1, 9 and 10 which were published in an earlier paper are also described below for comparison to 3 and 6.

All spectra were traced with the Zeiss microphotometer at the Byurakan Observatory. This microphotometer has been modified to trace in intensity by dividing the density-intensity characteristic curve into linear portions. The accuracy of the final intensity measures was checked by noting the measured intensity to exposure time ratio of several emission lines from the succesive IC 418 exposures. It was found that the measured intensity increased linearly with exposure time over the density interval used in the reductions to within a maximum error of $\pm 10\%$. This accuracy is not expected for the relative emission line intensities measured for the galactic nuclei since these lines are often broad, sometimes faint, and superimposed on a strong continuum. From the consistency of measures made from different spectra as well as the known reliability of the density-intensity calibration, we feel that the uncertainty in the relative intensities and equivalent widths

Table 1

PROFILE WIDTHS

Object (Mark. No.)	[O III] width** (*km sec*$^{-1}$)	Hβ width** (*km sec*$^{-1}$)	*z*	Nucleus*
79	440	3100	0.0218	s
133	—	120	0.0069	ns
169	210	110	0.0041	ns?, d?
171+	160	120	0.0100	d
180‡	—	—	—	s
195	220	170	0.0050	ns
215	220	220	0.0197	d
220+	150	160	0.0164	d
247+	190	120	0.0323	d?, ss?
267‡	—	—	—	d
279§	790	—	0.0302	ss
281+	—	—	—	d
290	410	>1600	0.0301	s
292‡	—	—	—	d
296‡	—	—	—	d
297+	190	250	0.0159	d
298	350	380	0.0341	ss?, d?
300‡	—	—	—	d
NGC 5548	510	5750	0.0166	s

* Visual description through 82-inch telescope; ns, nucleus definitely appears non-stellar; ss, semi-stellar nucleus; s, stellar nucleus; d, diffuse object with no obvious bright nucleus.

‡ Extended, tilted or structured emission lines.

\+ No emission features strong enough to be measured reliably.

§ Hβ line very broad and faint; λ 5007 line asymmetric.

** Listed widths are full widths at half maximum intensity.

in Table 2 is less than ± 30 %. Lines considered too faint to be measured with this reliability were not included in the table. This error estimate also includes an estimate of the uncertainty in the spectral response of the spectrograph although such uncertainty is difficult to

Table 2

LINE INTENSITIES AND EQUIVALENT WIDTHS

Line Intensities

Ion	Line (λ)	Markarian Number								NGC	
		1	3	6‡	34	9	10	42	52	4151*	1068+
[S II]	6717 +6731	3.30	6.11	0.62	2.85	—	—	—	1.29	0.52	2.1
[N II] H_α [N II]	6583 +6562 +6548	11.8	17.9	9.33	9.85	4.61	5.20	5.66	9.41	3.66	21.9
[O III]	5007 +4959	11.4	15.5	2.53	15.0	0.58	0.83	0.32	0.91	2.84	21.4
H_β	4861	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
He II	4686	—	0.25	—	—	—	0.19	—	—	0.25	0.34
[O III] H_γ	4363 +4340	0.68	0.89	—	0.77	0.54	0.57	0.48	0.48	0.40	0.43
[Ne III]	3869	1.08	1.34	0.16	1.57	—	0.17	—	—	0.29	0.78
[O II]	3726 +3729	1.87	2.98	0.37	3.54	—	0.24	—	1.95	0.51	0.93
absolute H_β 10^{40} *ergs sec*$^{-1}$		2.1	5.8	18.6	14.2	72.5	36.2	2.8	1.1	13.2	3.3

Equivalent Widths (A)

Ion	Line (λ)	1	3	6‡	34	9	10	42	52
[S II]	6717 +6731	50	92	16	44	—	—	—	33
[N II] H_α [N II]	6583 +6562 +6548	177	425	236	128	177	240	112	190
[O III]	5007 +4959	217	840	135	276	35	56	7	20
H_β	4861	17	36	43	21	159	61	21	19
He II	4686	—	8	—	—	—	10	—	—
[O III] H_γ	4363 +4340	11	41	—	15	23	27	8	8
[Ne III]	3869	24	88	7	37	—	8	—	—
[O II]	3726 +3729	41	--	15	78	—	11	—	31

* Oke and Sargent [12].

\+ Osterbrock and Parker [11].

‡ Line intensities on 1970 January 12, but new hydrogen line emission had by then appeared in this object [13].

measure. It is therefore possible that further systematic color errors may be present, but such errors would be nearly the same for all objects observed and would not affect our discussion or conclusions about the nature of these objects.

It is more difficult to evaluate the reliability of the absolute intensity estimates. We attempted to measure the intensities of emission lines in the nuclei relative to the intensities of the lines in NGC 4151. To do so it is necessary to assume that all objects have the same apparent size on the spectrograph slit, that atmospheric extinction does not change during the observations, and that there is no reciprocity failure for the measured intensities on the spectrograms. The last assumption is valid since, for the density range used in the reductions, the measured intensities of emission lines from the observations of different exposure times increase linearly with exposure time. All observations used to estimate the intensities relative to NGC 4151 were made on the same night and were developed together. On this night stellar images were larger than 2″ compared to a slit width of 1.″5 so that seeing was the only contribution to the apparent angular size for the class 1 objects in which the nuclei always appear stellar. The class 2 nuclei can be visually resolved when seeing is as good as 1″ so a small systematic underestimate of the intensity of these nuclei may be present in our results. All observations were corrected for extinction at the wavelengths of the lines measured using the mean extinction curve for McDonald Observatory. Uncertainties in the absolute extinction correction are not significant for the relative corrections among the galaxies observed since no galaxy was observed at an air mass greater than 1.4.

The results in Table 2 give the absolute intensity in H_β emission for the nuclei observed. These intensities are scaled to the absolute line intensities in NGC 4151 by assuming that the relative distances are proportional to the redshifts. The absolute intensities in NGC 4151 originally given by Oke and Sargent were based on a Hubble constant of 100 $km\ sec^{-1}\ Mpc^{-1}$, but in Table 2 the results are rescaled to an H of 75 $km\ sec^{-1}\ Mpc^{-1}$. No corrections are made for interstellar absorption since there is no estimate of the reddening within the nuclei themselves. The intensities given were derived only by comparison with the forbidden lines in NGC 4151 because there is uncertainty as to the actual extent of the Balmer line wings. For the same reason the H_β intensities for Markarian 9, 10 and 42 may be somewhat underestimated. Regardless of the precautions taken in deriving these results, a high accuracy is not claimed, and any values could readily be wrong by a factor of 2 due to observational errors. These results are no substitute for accurate photoelectric spectrophotometry, but they are useful for the present discussion because they illustrate the approximate differences and similarities among the observed objects.

In Table 1 are given line widths, redshifts and visual descriptions for those objects observed at 28 A mm^{-1}. These line widths were measured by microphotometry and have been corrected for the instrumental resolution determined from profiles of comparison lines on the spectra.

Except for the observations of NGC 5548 and Markarian 79, these spectrograms were untrailed in order to reveal any spatial structure in the emission lines from non-stellar objects. For the stellar nuclei, the spectra were therefore widened only by seeing. These spectra were wide enough for microphotometry, however, since the scale on the spectrograms is 23.7 mm^{-1} perpendicular to the dispersion. In Figures 1 and 2 are shown [O III] and H_β line profiles for five objects derived from observations at 28 A mm^{-1} and 85 A mm^{-1}. The profiles for NGC 5548 (Figure 1) were derived from three 28 A mm^{-1} spectra widened to 0.4 mm. Those for Markarian 79 (Figure 2) were found from two 28 A mm^{-1} spectra widened to 0.1 mm. The profiles for Markarian 9, 10 and 42 were each derived from only one 85 A mm^{-1} spectrogram, widened to 0.5 mm.

3. *Discussion.*

a) *Classification of the Nuclei.* As previously discussed [3, 14] galaxies with strong emission lines in their nuclei can be spectroscopically classified on the basis of their line profiles alone into three groups. The class 1 objects resemble the Seyfert galaxies NGC 4151 and 5548, having extremely broad hydrogen lines and much narrower forbidden lines. (As shown below, NGC 5548 is more representative of this class since the broad wings of the hydrogen lines are much stronger relative to the central core than in NGC 4151). Class 2 includes objects like NGC 1068 in which both the hydrogen lines and forbidden lines are broad, asymmetric and generally of comparable width. Class 3 galaxies are like Markarian 52 (NGC 4385) with strong but very narrow hydrogen and forbidden lines. Even though this classification was originally based only on line profiles, another correlation is now obvious from the spectroscopic data in Table 2. The class 2 objects (1, 3, 6, 34) all have extremely intense forbidden lines. The [O III] $\lambda\lambda$ 5007, 4959 doublet, for example, is always much stronger then H_β. In the class 1 objects 9, 10 and 42 all forbidden lines are weak compared to the hydrogen lines (Table 2). The relative intensity of [O III] compared to H_β is also much less in the intensity tracings of the class 1 objects NGC 5548 and Markarian 79 (Figure 1 and 2) than in the class 2 objects. The implications of these difference between classes 1 and 2 are discussed later in the paper.

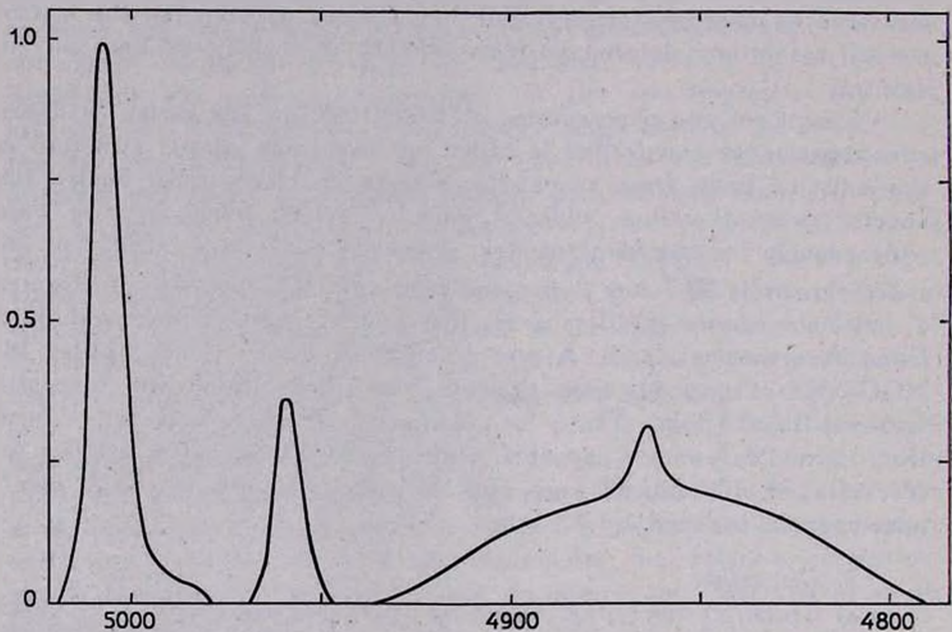

Fig. 1. $\lambda\lambda$ 5007 4959 and H_β emission line profiles for NGC 5548 from 28 A *mm*$^{-1}$ spectra.

Even without reference to the spectra of their nuclei, the class 2 galaxies morphologically form a consistent group. On our large scale direct photographs of Markarian 1, 3 and 6 as well as on Palomar Sky Survey prints, these class 2 objects appear extremely similar. The bright, resolved nucleus seen visually is contained within a small centrar disk having a reasonably defined border, surrounded by a fainter outel envelope. There is no definite indication of spiral structure. The diameter of the central disk for an H of 75 *km sec*$^{-1}$ *mpc*$^{-1}$ is 1500 *pc*, 1400 *pc*, and 1900 *pc* for Markarian 1, 3 and 6 respectively. The fainter envelopes in the same three objects are measured on the original plates to be 7000 pc by 4100 *pc*, 8600 *pc* by 4300 *pc*, and 9700 *pc* by 5600 *pc*. In Markarian 1 a second even fainter but well defined envelope of 11000 *pc* by 7800 *pc* is also visible on the 200-inch plate. These descriptions of class 2 objects are strikingly similar to that of NGC 1068 [15] where a bright inner arm system about 2800 *pc* by 1700 *pc* surrounds the nucleus, and the fainter surrounding envelope has a diameter of 7000 *pc*. Hodge's [16] isophotometric measures indicate that an outer, very faint ring of 13000 *pc* by 10000 *pc* surrounds

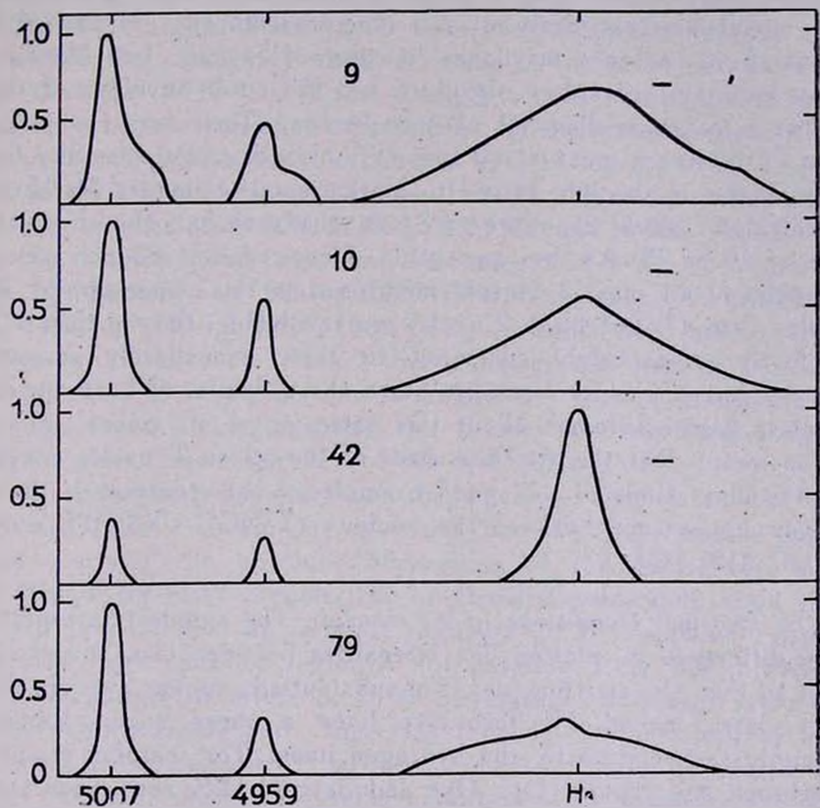

Fig. 2. λλ 5007, 4959 and Hβ emission line profiles for Markarian 9, 10, 42 and 79. Full widths at half maximum intensity of instrumental profiles are shown by error bars.

this envelope. Sandage noted the large discontinuity in surface brightness between the inner set of arms and the surrounding envelope and called NGC 1068 the type example of such galaxies. NGC 1068 is classed as an Sb galaxy, and the resolution into spiral arms is indistinct, especially in the outer envelope. Such an object at the distance of Markarian 1, 3 or 6 would not have detectable spiral structure. Object 34 is so distant ($z_i' = 0.0507$) that it cannot be accurately studied morphologically although its image on Sky Survey prints is consistent with what would be expected from any other class 2 object removed to the same distance.

In contrast, the galaxies classified spectroscopically as class 1 do not have a consistent morphological appearance. For example, the photographs in Khachikian [17] illustrate the extreme morphological difference between the class 1 galaxies Markarian 9 and 10 even though their nuclei are extremely similar spectroscopically. Markarian 10 is a giant spiral having a maximum diameter of 54 *kpc*, but Markarian 9 has no indication of spiral structure and the outer envelope of the galaxy has a maximum diameter of only 14 *kpc*. The class 1 object Markarian 79 is also a giant spiral (possibly barred) on Palomar Sky Survey prints similar in absolute size to Markarian 10 whereas Markarian 42 has only faint spiral structure and less than one half the absolute diameter of 10 or 79. At the cassegrain focus of the 82-inch telescope the nuclei of all class 1 objects mentioned in this paper appear stellar (smaller than 1″) but class 2 nuclei are resolvable (larger than 1″) and are clearly not as bright compared to their immediately surrounding galaxy as are the class 1 nuclei. Since the redshifts of both the class 1 and class 2 objects cover about the same range of values, this comparison means that the absolute sizes of the class 2 nuclei are larger than the class 1 nuclei. A good example of this contrast is the difference in appearance between the nucleus of NGC 1068 [18] and that of NGC 4151 [12].

b) *Physical Conditions in the Nuclei.* The simplest interpretation of the difference in relative line intensities between class 1 and class 2 nuclei is that the emitting gas is of substantially higher average density in the class 1 nuclei. The forbidden lines in these nuclei would then be suppressed relative to the hydrogen lines. The careful studies by Osterbrock and Parker [11], Oke and Sargent [12], and Anderson [19] have shown that the density within a Seyfert galaxy nucleus cannot be uniquely defined. There is substantial evidence of stratification and clumping so that different ions concentrate in regions with different densities. A further difficulty in the observational analysis is the presence of reddening in the nuclei which Wampler [20] has shown can be significant. Because of the difficulty in measuring this reddening, densities cannot be confidently obtained from such ratios as [S II] λ 4068 + λ 4076 to [S II] λ 6717 + λ 6731 [19]. The brightest line pairs that can provide a reliable measure of density are the close doublets [O II] $\lambda\lambda$ 3726, 3729 and [S II] $\lambda\lambda$ 6717, 6731. The low dispersion of most observations combined with the large intrinsic widths of the lines usually prevents measurement of these ratios. This is the case for our present observations of the Markarian objects. But for the class 1 and class 2 examples NGC 4151 and NGC 1068 the nuclei are bright enough that 28 A mm^{-1} observations have been made from which the [S II] λ 6717 to λ 6731 ratio can be measured. As previously reported [21], this ratio in NGC 4151 is 0.82 (from three spectra). In NGC 1068 the λ 6717 and λ 6731 lines are sufficiently blended by the line widths that an exact ratio measure is difficult, but there is no doubt that the λ 6717 line is the stronger on the four available spectra. Three spectra are somewhat overexposed for accurate microphotometry, but the fourth gives a reliable measure of 1.11 for the λ 6717 to λ 6731 ratio. Using the temperatures derived for the regions in which the forbidden lines arise of 20 000° in NGC 4151 [12] and 10 000° in NGC 1068 [11], the electron densities can be calculated from the tabulations given by Saraph and Seaton [22]. The results for N_e are 3500 for NGC 4151 and 800 for NGC 1068. This certainly does not prove that the average density in class 1 nuclei is greater than in class 2. It does indicate, however, that in a region of similar ionization (i. e. where sulfur is singly ionized) the density in one class 2 nucleus is significantly less than in one class 1 nucleus.

An approximate measure of the average density in the region where hydrogen emission arises could be obtained from the absolute H_β luminosity if the absolute dimensions of the nuclei were known. Even though the class 2 nuclei can be visually resolved in good seeing, they are so small that an accurate measure of the apparent diameter of the hydrogen emission region is not possible from our present observations. Careful interference filter photographs at a large scale might enable such a measurement. The class 1 nuclei, however, appear stellar even with seeing disks of 1″ so measurements of their diameters would not be possible in typical seeing conditions. We therefore are unable to measure the gas density in the regions where only hydrogen emission arises. But the weakness of all forbidden lines in class 1 nuclei is evidence that much of the hydrogen emission comes from regions of high density ($N_e > 10^5\ cm^{-3}$). The invariable presence of extremely broad hydrogen lines in these same nuclei is circumstantial evidence favoring the suggestion that the hydrogen lines are broadened by electron scattering [23] in regions of even higher density ($N_e > 10^8\ cm^{-3}$). The extreme symmetry of the broad hydrogen lines in the class 1 nuclei (Figures 1 and 2) compared to the profile asymmetries in all the class 2 galaxies [14] certainly implies that the broadening mechanism is not the same in the two classes of nuclei. The broad, invariably asymmetric emission lines in the class 2 nuclei are presumably broadened only by mass motions. It seems improbable that rapid mass motions would generally produce asymmetric lines in class 2 nuclei while even faster motions produced symmetric hydrogen lines in class 1 nuclei. The profiles in Figure 1 for NGC 5548 are representative of those in Figure 2 for Markarian 9, 10, 42 and 79. In none of the H_β profiles is there a positive indication of any line asymmetry although a slight irregularity present in the tracing of Markarian 9 is shown since this irregularity is larger than the resolution. (Even though the profiles are intensity tracings, no correction has been applied for the instrumental sensitivity which rapidly decreases near 5000 A on the three spectra of 9, 10 and 42. Therefore the $\lambda 5007/\lambda 4959$ ratio does not have the true value of three). The arguments favoring broadening by electron scattering are not meant to imply, however, that there cannot be objects in which more rapid mass motions are seen in the hydrogen lines than in the forbidden lines. A few objects—Markarian 6 [13], NGC 3227 [24], 3C 227 and 3C 390.3 [25] — have asymmetrical, structured hydrogen lines which are broader than the forbidden lines, and the structure in the hydrogen lines indicates that mass motions must be present.

The H_β profiles in Figure 1 and 2 also show why NGC 5548 better represents a typical class 1 profile than NGC 4151. None of the five profiles illustrated has the very narrow, intense H_β core superimposed on very broad, faint wings as found in NGC 4151 [12], and only a weak core is present in NGC 5548. NGC 4151 is also anomalous in having a higher $\lambda 5007 + \lambda 4959$ to H_β ratio than any other class 1 object considered in this paper. From NGC 4151 and the five profiles in Figures 1 and 2, there appears to be a correlation between the relative [O III] to H_β intensity and the strength of the H_β core relative to the wings. The relative [O III] intensity becomes greater as the H_β core becomes stronger compared to the wings which supports the suggestion by Oke and Sargent [12] that the Balmer line cores and the forbidden lines in NGC 4151 arise in the same region whereas the Balmer line wings arise from electron scattering in a much denser region.

It can therefore be concluded from the observational data that there is significant empirical evidence that the broad Balmer line wings in class 1 nuclei arise due to electron scattering. It can then be qualitatively argued that the mass motions revealed in the forbidden lines of objects like NGC 4151 do not produce collisional ionization since motions of similar magnitude do not produce strong emission lines in the nuclei of the galaxies M 51 and NGC 4569 [14]. As verified by the line widths in Table 1 for the class 1 nuclei NGC 5548 and Markarian 79 and 290, as well as the profiles of Markarian 9, 10 and 42, the forbidden line widths in these class 1 nuclei are no more than twice the widths in M 51 and about the same as in NGC 4569. There is another simple argument that the emission lines in the class 1 nuclei arise because of radiative ionization. This is the fact that all Markarian objects were detected because they had a strong continuum in the visible ultraviolet and not because they had emission lines. The fact that so many of these objects were subsequently found to have strong emission lines implies that the continuum may be the visible tail of a strong far ultraviolet radiation source which ionizes the nuclear gas. The equivalent widths of H_β in Table 2 are small and reasonably uniform, ranging between 15 A and 60 A. As Searle and Sargent [26] pointed out, such small equivalent widths cannot arise if both line and continuum emission both arise from hydrogen recombination. They concluded that such equivalent widths are evidence that the gas is ionized by non-thermal radiation and that the visible continuum is part of the non-thermal continuum. This argument cannot be quantitatively applied to our data, however, since we have no measure of how much of the observed continuum is due to stars in the nuclei.

In the class 2 nuclei, the much more rapid mass motions may still be sufficient to produce strong collisional ionization [11]. These authors also showed that fast protons can excite the 2s level of neutral hydrogen which then decays by two photon emission and produces a visible ultraviolet continuum. So even the appearance of an unusually blue continuum is not proof that the ionization of the class 2 nuclei is due to radiation alone. If it is assumed, however, that all class 2 nuclei have comparable temperatures and densities, the data in Table 2 indicate that the ionizing source must at least be similar in objects 1, 3, 6 and 34. This is because the relative intensities among the forbidden lines of different ions are similar, implying similar relative ion abundances.

Regardless of what is responsible for the ionization in the nuclei, the only measure available of the amount of ionizing energy is the strength of the Balmer lines, because the forbidden lines have such a complex dependence on temperature, density, and ion abundances. An interesting result of Table 2 is the wide range of absolute intensities in the H_β line. There is no invariable relation between the classification of a nucleus and the H_β intensity, implying that the ionizing sources can vary in energy over a wide range, but the H_β lines in the most luminous class 1 objects are definitely stronger than in the most luminous class 2 objects. Although NGC 5548 and Markarian 79 were not included in the spectrophotometric observations, our impression from the 28 A mm^{-1} spectra of these objects is that the absolute H_β luminosities derived from their redshifts should be comparable to those of Markarian 9 and 10. It is perhaps significant that the faintest class 1 galaxy, Markarian 42, has the narrowest H_β line for a class 1 object, implying a possible connection between the density and temperature of the electron scattering region and the amount of ionizing radiation. Also of particular interest is the fact that the galaxy Markarian 52 whose emission lines are all extremely narrow has an H_β flux only two or three times less than in the broad line objects 1 and 42. The relative intensities of the forbidden lines in Markarian 52 (strong [O II], [S II], and [N II] but weak [O III] and [Ne III]) indicate an object of different excitation class than all other objects in Table 2. The narrow line widths and relative line intensities are what would be expected if the nucleus is simply a collection of low excitation H II regions. It is surprising, however, that the strength of the ionizing source approaches that in the energetic class 1 or class 2 galaxies. For comparison the H_α flux from the nucleus of M 51 is only 17×10^{37} *ergs sec*$^{-1}$ [27]. Even if there were no reddening in this nucleus, the H_β flux would not exceed 6×10^{37} *ergs sec*$^{-1}$, about 200 times less than in Markarian 52. From Table 2 the lower limit to the H_β flux for the class 1 and class 2 nuclei is comparable and is about 10^{40} *ergs sec*$^{-1}$.

c) *Evolution of the Nuclei.* From the extreme spectroscopic and morphological similarity of all class 2 objects discussed above, it is reasonable to consider these galaxies as a related group. The similar appearances of class 2 galaxies are a strong indication that there is a connection between the events in a class 2 nucleus and the nature of the entire surrounding galaxy. The question is then whether the events in the nucleus arise because of some peculiarity in the galaxy or whether the appearance of the galaxy has been determined by the activity of the nucleus. Hodge [16] noted the peculiar morphological features of NGC 1068 and suggested that nuclear ejections may have affected the structure of the entire galaxy. Walker [18] found the inner arm system of NGC 1068 to be expanding, and suggested that events in the nucleus had affected the galaxy out to a radius of about 25″ (1700 *pc*, the outermost extent of the inner arm system) since non-circular motions existed up to that radius. This analysis implied that matter is flowing out of class 2 nuclei so we may conclude that the events in the nuclei of class 2 galaxies can affect the surrounding galaxy. If this mass outflow is to affect the appearance of the outer parts of the galaxy, large amounts of gas must flow from the nuclei for a long time. From the forbidden line profiles of these objects [14], the most probable velocities of gas motions are typically somewhat less than 1000 $km\ sec^{-1}$. Taking an average galactic radius of 4000 *pc* and assuming that the gas does not decelerate as it leaves the nucleus, we find as a minimum estimate that the gas flow has continued for at least 4×10^6 years. This is similar to the previous suggestion by Walker [18] that there was at least one previous outburst about 3×10^6 years ago in NGC 1068. If a continuous flow of matter out of a class 2 nucleus occurs, either the mass of the nucleus does not remain constant or new gas must continually appear in the nucleus. The analysis of a recent eruption in Markarian 6 that occurred on a time scale of a year and produced new Balmer emission lines [13] shows that recurring outbursts can indeed occur frequently in the class 2 nuclei. Even though newly ionized gas appeared in this event, it is not known where or in what condition was the gas before its ionization. What the end product of such eruptions and gas flow from the nucleus of a class 2 galaxy will be is uncertain, but it seems evident that these events could alter the surrounding galaxy. We are thus faced with an intriguing group of galaxies that look as if they may actually have grown out of their nuclei. Data on the total mass in the nuclei and the rate of mass transfer from the nucleus to the rest of the galaxy is necessary, however, before this suspicion can be verified.

For the class 1 galaxies the nuclei spectroscopically appear very similar, but the lack of any consistent similarity among the appearances of the galaxies themselves means that the events in the nuclei cannot readily be related to the nature of the galaxies. A further question is whether there is any relation between the class 1 and class 2 galaxies. It has generally been assumed in studies of the Seyfert galaxies and related objects that the ultimate energy source in all such objects is the same basic, though unknown, phenomenon. If this is so, the class 1 and class 2 galaxies should differ only if they are seen at different stages of development. If we accept the assumption that the energetic events in all nuclei begin and evolve in the same way, it follows empirically that the class 1 phase must precede class 2. The gas in a small, high density class 1 nucleus need only gain kinetic energy in order to expand and produce a larger, lower density nucleus containing high velocity gas—just what is found in a class 2 nucleus. But such evolution is not consistent with the morphological appearances of the surrounding galaxies. If class 1 nuclei evolve to class 2, some class 2 nuclei should appear within giant spiral galaxies like the class 1 objects Markarian 10 and 79, but this has not yet been observed. The possibility of evolution from class 1 to class 2 must therefore be considered as only a suggestion based on the assumption that similar original conditions are required for all energetic nuclear activity. In order to prove and trace the actual evolution of events in a galactic nucleus, it is necessary to find objects which are clear examples of a transition between class 1 and 2. Within our high dispersion data, there is presently only one 28 A mm^{-1} spectrum of a nucleus which resembles spectroscopically the expected appearance of such a transition object. This is Markarian 279, which has broad and asymmetric [O III] lines but an extremely broad and shallow H_β line. These line profiles are what would be expected from a class 1 nucleus that had just begun to expand to class 2, but this galaxy already morphologically resembles the class 2 objects on Sky Survey prints. Further study of such possible transition objects will be necessary to decide whether the class 1 and class 2 galaxies are related phenomena.

4. *Summary* By spectroscopic observations of a sample of excited galactic nuclei, it is concluded that galaxies with extremely luminous nuclei and broad emission lines (often called Seyfert galaxies) can be consistently separated into two types. Class 1 contains objects like NGC 4151 and NGC 5548 and is characterized by small nuclei containing gas of high density and slow internal motions which is probably ionized by some radiative source. Galaxies in class 1 are not morphologically the same; some are giant late type spirals while others show no indication of spiral structure. The class 2 galaxies are objects like NGC 1068 which have large nuclei with gas of lower density and faster motions than in class 1. The ionizing source may be radiative or collisional but seems to be typically less intense than in class 1 nuclei. The class 2 objects are remarkably similar morphologically having an inner bright disk of diameter about 1500 *pc* surrounded by a fainter envelope of diameter about 8000 *pc*. Because of the proximity of NGC 1068, these two regions can be weakly resolved into spiral arms in this galaxy but not in other members of this class. One object is considered which represents a third class of bright nuclei having strong but narrow emission lines. In this nucleus the ionizing source seems comparable in strength to that in the fainter class 1 or class 2 nuclei, but it is presently not possible to conclude what relation, if any, these class 3 nuclei have to class 1 and 2.

Because the class 2 galaxies show rapid nuclear mass motions and common morphological properties, it is suggested that the present appearance of these galaxies has been affected by events arising in the nuclei. In order for the class 2 galaxies to be affected by the gas outflow from their nuclei, this flow must have continued for a period greater than 4×10^{8} years and must have involved a mass comparable to the presently visible mass of the galaxy. Such a picture therefore requires that substantial amounts of gas transit through the nuclei of such galaxies from some as yet unknown source. There is no clear evidence that the class 1 and class 2 nuclei are related. But if all energetic events in galactic nuclei arise and evolve in the same fashion, the class 1 nuclei would be the logical precursors to class 2. A small, high density galactic nucleus would appear as class 1 but could change to class 2 if the gas absorbed kinetic energy and the nucleus expanded. Such evolution cannot be proven until examples of the expected transition phases have been studied.

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СПЕКТРАЛЬНОЕ ИССЛЕДОВАНИЕ ЯРКИХ ГАЛАКТИЧЕСКИХ ЯДЕР

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Выполнено спектрофотометрическое исследование ядер некоторых галактик из списков Маркаряна и Сейферта, имеющих широкие эмиссионные линии с целью выяснения природы их ядер. Показано,

что такие галактики могут быть разделены на два класса: галактики, типа NGC 5548, имеющие маленькое и плотное ядро и содержащие газ с малыми внутренними скоростями, и объекты типа NGC 1068, имеющие большие ядра и содержащие в себе газ малой плотности, но имеющие большие внутренние скорости. Наблюдательные данные говорят в пользу того, что расширение эмиссионных линий Бальмера в первом классе галактик вызвано электронным рассеянием. Абсолютная яркость галактик первого класса в линии H_β больше, чем у второго класса. Из подобия спектроскопических и морфологических характеристик галактик второго класса делается заключение, что вытекание газа из их ядер обусловлено их внутренней структурой.

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