NUCLEAR EMISSION IN SPIRAL NEBULAE*

CARL K. SEYFERT†

ABSTRACT

Spectrograms of dispersion 37–200 A/mm have been obtained of six extragalactic nebulae with high-excitation nuclear emission lines superposed on a normal G-type spectrum. All the stronger emission lines from λ 3727 to λ 6731 found in planetaries like NGC 7027 appear in the spectra of the two brightest spirals observed, NGC 1068 and NGC 4151.

Apparent relative intensities of the emission lines in the six spirals were reduced to true relative intensities. Color temperatures of the continua of each spiral were determined for this purpose.

The observed relative intensities of the emission lines exhibit large variations from nebula to nebula. Profiles of the emission lines show that all the lines are broadened, presumably by Doppler motion, by amounts varying up to 8500 km/sec for the total width of the hydrogen lines in NGC 3516 and NGC 7469. The hydrogen lines in NGC 4151 have relatively narrow cores with wide wings, 7500 km/sec in total breadth. Similar wings are found for the Balmer lines in NGC 7469. The lines of the other ions show no evidence of wide wings. Some of the lines exhibit strong asymmetries, usually in the sense that the violet side of the line is stronger than the red.

In NGC 7469 the absorption K line of *Ca* II is shallow and 50 A wide, at least twice as wide as in normal spirals.

Absorption minima are found in six of the stronger emission lines in NGC 1068, in one line in NGC 4151, and one in NGC 7469. Evidence from measures of wave length and equivalent widths suggests that these absorption minima arise from the G-type spectra on which the emissions are superposed.

The maximum width of the Balmer emission lines seems to increase with the absolute magnitude of the nucleus and with the ratio of the light in the nucleus to the total light of the nebula. The emission lines in the brightest diffuse nebulae in other extragalactic objects do not appear to have wide emission lines similar to those found in the nuclei of emission spirals.

Many of the spectra of extragalactic nebulae obtained at the Mount Wilson and Lick observatories show one or more emission lines in addition to the usual absorption spectra. In particular, N. U. Mayall[1] finds that 50 per cent of his spectra of spirals show the [*O* II] doublet λ 3727 in emission either in the nuclear region or in the arms. However, only a very small proportion of extragalactic nebulae show spectra having many high-excitation emission lines localized in the nuclei. These emission features are similar to those found in planetary nebulae and are superposed on the characteristic solar-type absorption spectra. Twelve nebulae[2] are now known which probably belong to this unusual class of objects. Most of them are intermediate-type spirals with ill-defined amorphous arms, their most consistent characteristic being an exceedingly luminous stellar or semistellar nucleus which contains a relatively large percentage of the total light of the system. Plate I shows a photograph of NGC 4151, a typical example of this type of nebula.

Probably the earliest spectrographic observation of a member of this unusual class of objects was that of NGC 1068 by E. A. Fath,[3] in which he found five emission and two absorption lines. In 1917, V. M. Slipher[4] found hydrogen lines and the nebular lines N1 and N2 bright in the nucleus of NGC 5236. Shortly afterwards, Slipher[5] made the discovery that the emission lines in NGC 1068 were not monochromatic images of the slit but were small "discs." These findings were confirmed by Campbell and Moore,[6]

* *Contributions from the Mount Wilson Observatory, Carnegie Institution of Washington*, No. 671.

† Fellow of the National Research Council.

[1] *Lick Obs. Bull.*, **19**, 33, 1939.

[2] NGC 1068, 1275, 2782, 3077, 3227, 3516, 4051, 4151, 4258, 5548, 6814, and 7469.

[3] *Lick Obs. Bull.*, **5**, 71, 1908.

[4] *Pop. Astr.*, **25**, 36, 1917; *Proc. Amer. Phil. Soc.*, **56**, 403, 1917.

[5] *Lowell Obs. Bull.*, **3**, 59, 1917.

[6] *Lick Obs. Pub.*, **13**, 88, 1918.

who stated that the bright bands in NGC 1068 were "fully 30 Angstroms wide." Campbell and Moore[7] also found in NGC 4151 emission lines several angstroms wide. E. P. Hubble[8] refers to planetary-type emission in the nucleus of NGC 4051 (as well as NGC 1068 and NGC 4151) in a paper published in 1926. Detailed descriptions of the typical emission spirals NGC 1275 and NGC 4151 were published by M. L. Humason[9] and N. U. Mayall,[10] respectively. In addition, a private communication from Dr. Mayall indicates that NGC 3516 and NGC 7469 show broad bands of hydrogen in emission and hence belong in the group under consideration.

I. THE OBSERVATIONAL MATERIAL

The present investigation is an intensive study of six of the brightest extragalactic nebulae showing emission bands in their nuclei (Table 1). Of these six, special emphasis was placed on the three having the brightest nuclei, NGC 1068, 3516, and 4151, because

TABLE 1*

EMISSION SPIRALS OBSERVED

NGC	1950		Type	m_{total}	$m_{\text{nucl.}}$	Spect.	Modulus	No. of Plates
	R.A.	Dec.						
1068	$2^h40.1$	$-0°14$	Sb	10.0	13.0	G3	26^m0	17
1275	3 15.6	+41 18	E:	13.0	15.5	G3	30.0	4
3516	11 3.4	+72 50	Sa	12.2	13.7	G2:	28.5	6
4051	12 0.6	+44 48	Sb	11.7	14.0	G2	26.0	4
4151	12 8.0	+39 41	Sb	11.2	12.0	G2	26.0	12
7469	23 0.7	+ 8 36	Sa	13.0	14.3:	G0:	29.8	2

* The total apparent photographic magnitudes are from the *Shapley-Ames Catalogue of External Galaxies* (*Harv. Ann.*, **88**, 43, 1932). The apparent magnitudes (photographic) of the nuclei were estimated from short-exposure plates, taken in series with selected areas. The distance moduli are new determinations derived from magnitudes of resolved stars in the arms (NGC 1068), radial velocity (NGC 1068, 3516, 7469), or from association with recognized clusters or groups (NGC 1275, 4051, 4151). The plates used for determinations of nuclear magnitudes and most of the data for computing the distance moduli were supplied by E. P. Hubble. The spectral types were determined by M. L. Humason.

it was possible to observe them with higher dispersion than could be used on the fainter objects.

The observations were obtained mainly at the Cassegrain focus of the 60-inch reflector using (1) the one-prism spectrograph and cameras of 3.5, 6, 9, 10, and 18 inches in focal length, and (2) the two-prism nebular spectrograph "VIA" with a 3-inch camera. In addition, a few plates were obtained with a grating spectrograph and Schmidt camera and with the "VIC" Cassegrain two-prism spectrograph and 10-inch camera at the 100-inch reflector. Table 2 lists the dispersions with the various combinations.

Spectral calibration strips for determining relative intensities at each wave length were placed beside the nebular spectrum on the same photographic plate during the course of the nebular exposure. These standardization exposures were never shorter than 5 minutes and were usually 30 minutes in length, or 13 per cent as long as the average nebular exposure. For a few plates the ratio of standard to nebular exposure was as low as 1 or 2 per cent. Examination showed that the photometric results obtained from these plates were not systematically different from plates with much larger ratios.

[7] *Lick Obs. Bull.*, **13**, 122, 1918.

[8] *Mt. W. Contr.*, No. 324; *Ap. J.*, **64**, 328, 1926.

[9] *Pub. A.S.P.*, **44**, 267, 1932.

[10] *Pub. A.S.P.*, **46**, 134, 1934.

Hence we believe that the relatively short standardization exposures do not introduce any serious errors.

The chief photographic plates used were Cramer Hi-Speed, Eastman 103-O, and Eastman 103-F. To increase their sensitivity, the two blue-sensitive emulsions (Hi-Speed and 103-O) were as a rule baked for three days at 50° C., and the red-sensitive 103-F plates were bathed in a 4 per cent ammonia solution for one minute.

II. IDENTIFICATION OF LINES

Table 3 lists the lines identified with certainty in any or all of the six nebulae under investigation. The intensities given are relative to $H\beta$ assumed equal to 100. The method of obtaining the intensities is described in a later paragraph.

TABLE 2

SPECTROGRAPH-CAMERA COMBINATIONS EMPLOYED

Spectrograph	Camera Focal Length	Dispersion at $H\gamma$	Telescope	
One-prism	3.5 inches	195 A/mm	60-inch	Cassegrain
One-prism	6	122	60	Cassegrain
One-prism	9	78	60	Cassegrain
One-prism	10	71	60	Cassegrain
One-prism	18	36	60	Cassegrain
Two-prism "VIA"	3	200	60	Cassegrain
Grating	1.3	400	60	Cassegrain
Two-prism "VIC"	10	66	100	Cassegrain

All the lines identified, with the exception of those of hydrogen and helium, arise from forbidden transitions. The identification of the lines in Table 3 is complete with the single exception of λ 5670.5, which was measured on two plates of NGC 4151. For purposes of comparison, the relative intensities determined by A. B. Wyse[11] for the emission lines in the planetary nebula NGC 7027 are given in Table 3.

The chief features of the spectra which appear in absorption are the cyanogen band (effective wave length, λ 3873); H and K lines of *Ca* II (λ 3934 and λ 3969); the G band, composed chiefly of *CH* (measured position, λ 4303); and the D lines of *Na* (λ 5890 and λ 5896). Since the absorption lines are usually ill-defined and sometimes absent altogether, the spectral types in Table 1 may be subject to fairly large uncertainties.

III. RELATIVE INTENSITIES OF THE EMISSION LINES

The conventional method of obtaining the true relative intensity of a wide emission line is to measure the intensity (corrected for the background) at each wave length in the line relative to the intensity at the corresponding wave length in a comparison star of known color temperature. These values are multiplied by the relative intensity of a black body[12] of temperature equal to that of the comparison star and summed over all wave lengths in the line. The ratio of such summations for two different emission lines, corrected for differential extinction, gives the ratio of relative intensities of the lines freed of instrumental and atmospheric absorption, i.e., the true relative intensities.

The method described above has been used for determining true relative intensities for the six objects under investigation. However, the continuum of each spiral was used

[11] *Ap. J.*, **95**, 356, 1942.

[12] The black-body intensities may be calculated from Table VII in Jahnke and Emde, *Tables of Functions*, p. 46 (Leipzig, 1933).

instead of stars for comparison standards. Not only does this make it possible to use all the plates on which this continuum appears, but it eliminates uncertainties due to differential extinction, exposure time, changes during exposure of plate-sensitivity and sky conditions.

TABLE 3

INTENSITIES OF EMISSION LINES IN SIX EXTRAGALACTIC NEBULAE

ATOM	λ	NGC 1068	NGC 1275	NGC 3516	NGC 4051	NGC 4151 Core	NGC 4151 Wing	NGC 4151 Core+Wing	NGC 7469 Core	NGC 7469 Core+Wing	NGC 7027*
[*O* II]	3726.2	80:	140:	......	......	100:	......	25:	48:	15:	8
[*O* II]	3729.7										4
[*Ne* III]	3869	65:†	35:	......	P	65:	......	15:	......	......	40
H ζ	3889.1	5:	......	......	......	......	......	......	......	......	7
[*Ne* III]	3968	25:†	20:	......	......	25:	......	5:	......	......	15
H ε	3970.1										8
[*S* II]	4068.5	20	50	......	......	25	......	5	......	......	5
[*S* II]	4076.5										2
H δ	4101.8	20	10:	25	......	20	20	20	......	35:	12
H γ	4340.5	40	50	40‡	40	35	30	35	......	60:‡	20
[*O* III]	4363.2	35	40	......	20	75	......	18	......	......	10
C IV[*Fe* III]	4658.6	......	......	......	......	5	......	1	......	......	0.9
He II	4685.8	40	......	......	25	25	......	5	......	......	40
[*A* IV]	4711.4	......	......	......	......	10	......	2	......	......	3
[*A* IV]	4740.3	......	......	......	......	10	......	2	......	......	7
H β	4861.3	100§	100	100	100	100	100	100	100	100	100
[*O* III]	4959.5	400§	80	15	55	375	......	90	125	35	430
[*O* III]	5007.6	1200§	270	40	190	1150	......	275	300	80	1190
[*Fe* VII]	5158.3	5	......	......	......	P‖	......	P	......	......	2
[*N* I]	5199.2	25	......	......	......	15	......	5	......	......	3
[*Fe* VII]	5276.1	5:	......	......	......	P:	......	P:	......	......	1.5±
	5670.5	......	......	......	......	P	......	P	......	......	......
[*Fe* VII]	5720.9	10	......	......	......	20	......	5	......	......	4
[*N* II]	5755.0	10	......	......	......	......	......	......	......	......	20
He I	5875.6	15:	......	......	......	30	......	5	......	......	35
[*Fe* VII] [*Ca* V]	6085.7	30	......	......	......	35	......	10	......	......	5
[*O* I]	6300.2	85	100	......	30	150	......	35	......	......	40
[*S* III]	6310.2										15
[*O* I]	6363.9	30	40	......	20	50	......	10	......	......	20
[*N* II]	6548.4				25:	100		25	......	......	90
H α	6562.8	1000¶	700	600	600	400	375	400	......	......	420
[*N* II]	6583.9				50:	200		50	......	......	190
[*S* II]	6717.3	140	210	......	40:	180	......	40	......	......	8
[*S* II]	6731.5										15

* The intensities in the planetary nebula NGC 7027 (included for comparison) are from the paper by A. B. Wyse, *Ap. J.*, **95**, 356, 1942.

† The measures of λ 3869 and λ 3968 in NGC 1068 are probably affected by the strong absorptions in the underlying G-type spectrum. The true values are probably somewhat greater (see pp. 37, 38).

‡ The G band in the underlying continuum affects the measures of $H\gamma$ in NGC 3516 and NGC 7469 (wing). The true values are probably somewhat larger.

§ The effect of the narrow central minima in λλ 4861, 4959, and 5007 on the measures is negligibly small.

‖ P indicates the presence of a line which is too weak to measure.

¶ The sum of the [*N* II] intensities (λ 6548 and λ 6583) approximately equals that of $H\alpha$ in NGC 1068.

The method necessitates ascertaining the color temperature of the continuum of each nebula. For this purpose a special series of red-sensitive plates (103-F) was taken with the small-scale VIA spectrograph and 3-inch camera. Suitable bright comparison stars of well-determined color gradient[13] were taken at the beginning and end of the nebular exposures. The stellar exposures were lengthened to 10 or 15 minutes by interposing several thicknesses of copper mesh about 8 inches in front of the slit. The nebular exposures ranged from 40 to 110 minutes. A slit approximately 6 inches wide was used, and both nebular and stellar spectra were widened by trailing along the slit. Differential extinction corrections were computed from Table 767 of the *Smithsonian Physical Tables* (8th ed.) by F. E. Fowle. The gradient of the nebular continuum relative to the standard stars was found to be closely linear from λ 4000 to λ 6700, and the black-body temperature corresponding to this gradient was determined.[14]

Mean color temperatures were found in this way for the continua of NGC 1068, 3516, and 4151. The temperatures of NGC 1275, 4051, and 7469 were deduced by means of photometric comparisons with spectrograms of NGC 1068, 3516, and 4151 obtained on plates of the same type with similar development but taken one or more months apart. The adopted values of the temperatures of the continua are in Table 4.

TABLE 4

COLOR TEMPERATURES OF CONTINUA OF 6 EMISSION SPIRALS

NGC	*T*	NGC	*T*
1068	5250°	4051	5250:
1275	5250:	4151	4750
3516	5250	7469	8000:

The investigations of Stebbins and Whitford[15] indicate that the continua of nebulae deviate from black-body radiation, particularly in the ultraviolet and infrared. I am very grateful to Dr. Stebbins, who, at my request, kindly measured photoelectrically the spectral radiation of NGC 1068 at the following mean wave lengths: λλ 3510, 4220, 4880, 5700, 7190, and 10300. He finds that the intensity distribution from λ 3510 to λ 10300 is nearly identical with that of the nonemission spiral NGC 4826 (same nebular type and spectrum as NGC 1068). From λ 4220 to λ 7190 the intensity distribution corresponds closely to that of a black body of temperature 4800°. From λ 3510 to λ 4220, Stebbins' measures indicate a temperature of 5600°. Considering the relatively low accuracy of my measures and the fact that the emission lines affect the photoelectric measures somewhat,[16] the agreement with the mean value (5250°) used in this paper for NGC 1068 is considered satisfactory. Furthermore, even though the nebular spectral radiation deviates from that corresponding to the color temperatures adopted, the effect of such deviations or errors on the relative intensities is comparatively small. For example, an error of 500° in the color temperature of the continuum of NGC 1068 introduces an error at λ 6720 of 14 per cent and at λ 3727 of only 9 per cent relative to the intensity of $H\beta$. The uncertainty is, of course, correspondingly less for lines less widely separated.

The final true relative intensities are given in Table 3. The estimated uncertainty is of the order of 10 per cent, though it may exceed this value for NGC 7469 for which the measures are from a single plate. In view of the ultraviolet excess mentioned above, the intensities given for lines less than λ 4000 may be somewhat too small and have been marked with a colon.

[13] Chosen from the Greenwich list (*M.N.*, **100**, 189, 1939). The comparison stars were 13 Eri for NGC 1068, 21 LMi; and χ Her for NGC 3516 and NGC 4151, and ρ_1 and ρ_2 Lyr for NGC 3516.

[14] The Greenwich relative gradients must be reduced to absolute gradients by adding a correction for the Greenwich zero point. The value adopted is 1.10 in accordance with *M.N.*, **100**, 189, 1939.

[15] *Pub. Amer. Astr., Soc.*, **10**, 239, 1942.

[16] A rough calculation indicated that the effect of the emission lines in NGC 1068 would probably not be large but would tend to make the observed photoelectric color temperature too small.

NGC 1068.—Thirteen per cent of the total light of the nucleus in the photographic region is in the emission lines. The intensities of the lines are similar to those in the planetary nebula NGC 7027 except that the [*O* II], [*S* II], [*N* I], and [*Fe* VII] lines are considerably stronger in NGC 1068. The line λ 6086 [*Fe* VII] is unusually strong, although [*Ca* V] probably contributes to its strength. The corresponding [*Ca* V] line at λ 5308 is, however, absent or very weak. On the other hand, λ 5276 of [*Fe* VII] is possibly weakened by the superposed absorption λλ 5262–76 of *Ca, Fe,* and other metals. This blend would also probably obscure λ 5270 of [*Fe* III] if it were present. Further evidence regarding absorptions superposed on emissions will be discussed later (p. 37). The absence of λ 5270 of [*Fe* III] and of the lines λλ 5802 and 5812 of *C* IV makes it impossible to determine with certainty whether [*Fe* III] or *C* IV is responsible for the line λ 4658.6.

NGC 1275.—The intensities resemble those in NGC 1068 except that the [*O* II] and [*S* II] lines are stronger and N1 and N2 [*O* III] considerably weaker while λ 4686 *He* II is absent altogether.

NGC 3516.—The emission spectrum consists practically of nothing but hydrogen. The only other lines visible are extremely weak N1 and N2; λ 3727 [*O* II] is absent. Only 5 per cent of the total photographic light of the nucleus is in the emission lines. The K line of (*Ca* II) is visible in absorption, and the G band (λ 4303) is present at the edge of $H\gamma$ (λ 4340).

NGC 4051.—N1 and N2 are relatively weak. The plates are not sufficiently strong in the violet to establish the existence of λ 3727 [*O* II].

NGC 4151.—The intensities of the cores of the lines are very similar to those in NGC 1068 except that the [*O* I] lines are considerably stronger in NGC 4151. The Balmer decrement of the core of the lines is the same as that of the wings. The hydrogen wings contribute 8 per cent of the total photographic light of the nucleus, the rest of the emissions 14 per cent.

NGC 7469.—N1 and N2 are weaker than in NGC 1068 and NGC 4151. The Balmer decrement seems to be normal for the cores of the lines, but that for the wings appears to be extremely slow. The G band and the K line of *Ca* II are visible, despite the relatively high color temperature (8000°).

IV. PROFILES OF THE EMISSION LINES

All spectrograms of suitable dispersion were analyzed with the microphotometer for the purpose of measuring profiles of the emission lines. No attempt was made to allow for the instrumental profile, since only those spectrograms were used for which the instrumental widening was a negligible fraction of the width of the emission lines. The profiles of the hydrogen lines are similar when expressed in kilometers per second rather than angstroms. In Figure 1 are microphotometer tracings of $H\beta$, N2 and N1 showing the main types of emission lines observed. Figures 2–4 are the mean profiles obtained from the measures. Most of the lines in NGC 1068 were sufficiently symmetrical to warrant combining the two halves of the line. Table 5 lists, for the lines measured in each object, the total widths in kilometers per second derived from the mean measured profile.

NGC 1068.—The line widths range from 2400 km/sec for λ 4686 (*He* II) to 3600 km/sec for the hydrogen lines and the [*S* II] doublet λ 6717, λ 6731. The profiles of the lines of NGC 1068 fall into two main groups; lines with rounded maxima which are relatively wide in the range from 0.25 to 0.50 of the central intensity (λλ 3727 [*O* II],[17] 4363 [*O* III], 6086 [*Fe* VII],[17] 6300 and 6364 [*O* I], and 6717, 6731 [*S* II][18] and lines with sharp maxima

[17] The profile of λ 3727 is uncertain, owing to the presence of the strong absorption features at λ 3720 and λ 3736. The profile of λ 6086 is uncertain, owing to the possibility that λ 6073 (unknown origin) and λ 6102 [*K* IV] may be present.

[18] The lines λ 4069 and λ 4076 probably belong in the group, but because of blending, the profile is too uncertain to be included.

which are relatively narrow in the range from 0.25 to 0.50 of the central intensities (λλ 3869, 3968 [*Ne* III], 4686 *He* II, and 4959 and 5007 [*O* III]). The profile of the hydrogen lines seems to belong between the two groups.

The question whether the absorption lines are also widened in NGC 1068 is not readily answered, because the prominent absorption lines visible (*CN;* K (*Ca* II); G and D) are either intrinsically very wide or composite. Measures from microphotometer tracings,

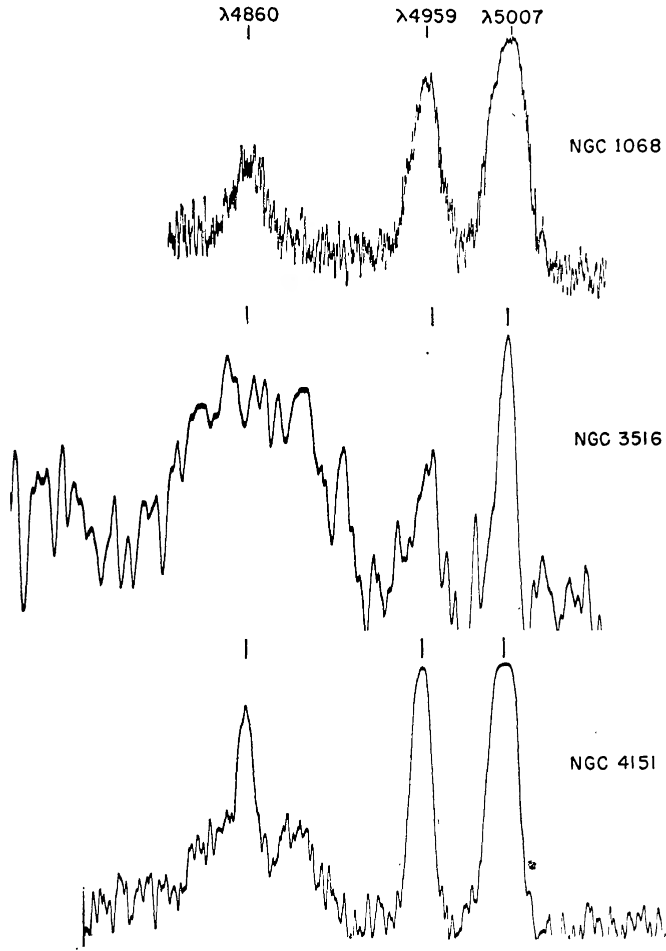


FIG. 1.—Microphotometer tracings of the emission lines λλ 4860 ($H\beta$), 4959 and 5007 [*O* III] in the nebulae NGC 1068, 3516, and 4151.

however, show that the K line in NGC 1068 is not significantly wider than the corresponding line in M 32 and has about the same width as in a star of type dG5.

NGC 1275.—Owing to the faintness of this object, only the line N1 has a well-determined profile. Not only is it the broadest N1 line measured, among the six nebulae investigated, but it shows the largest amount of asymmetry. The blue part of the line is 60 per cent wider than the red part at $I = 0.25\ I_{\max}$ (Fig. 4). Comparisons of the widths of the other emission lines from smaller-scale spectra indicate that the lines in NGC 1275 are probably somewhat wider than the corresponding lines in NGC 1068. In particular, the [*Ne* III] lines are unusually wide in NGC 1275.

NGC 3516.—Only the hydrogen and N1 and N2 lines are present in emission. N1 and N2 are weak and much narrower (1400 km/sec wide) than the corresponding lines in NGC 1068 and NGC 1275. The hydrogen lines, however, are great shallow bands 8500 km/sec wide, the widest found among the objects studied. The lines are all fairly symmetrical (Fig. 4).

NGC 4051.—The N1 and N2 lines are relatively narrow (1200 km/sec), and the hydrogen lines are peaked and wide (3600 km/sec). The N1, N2, and hydrogen lines appear

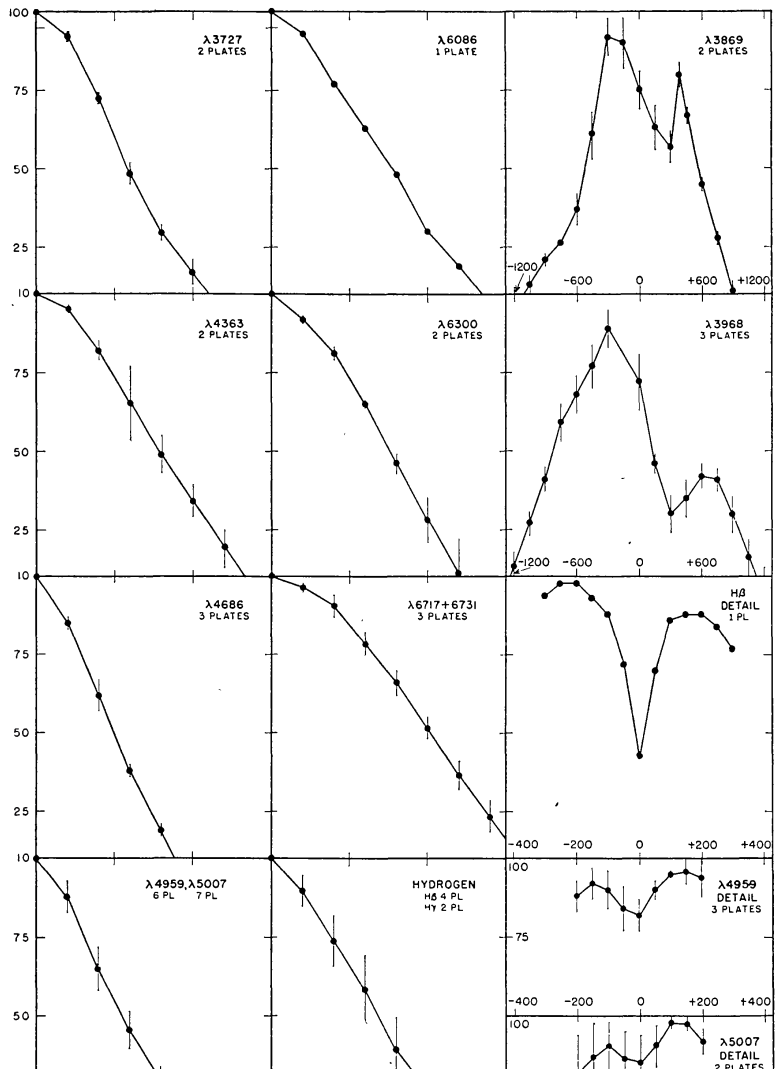


FIG. 2.—Profiles of emission lines in NGC 1068. Ordinates are intensities, abscissae distances from the center of each line in km/sec. The vertical lines indicate the average deviation of the individual observations from the plotted means. For symmetrical lines the two halves of each profile have been combined.

symmetrical within the accuracy of the measures. Small-scale spectrograms indicate that the remaining lines are probably similar in width to those in NGC 1068.

NGC 4151.—The hydrogen lines are markedly different from the other lines in that each hydrogen line has very broad wings (7500 km/sec wide) extending outward from the relatively narrow core. The discontinuity between the core and the wing is so sharp that the Balmer lines appear to be composite, with sharp cores centrally superposed on broad emission bands. All the forbidden lines, as well as λ 4686 and the cores of the hydrogen lines, are similar in shape and relatively narrow (<1800 km/sec).

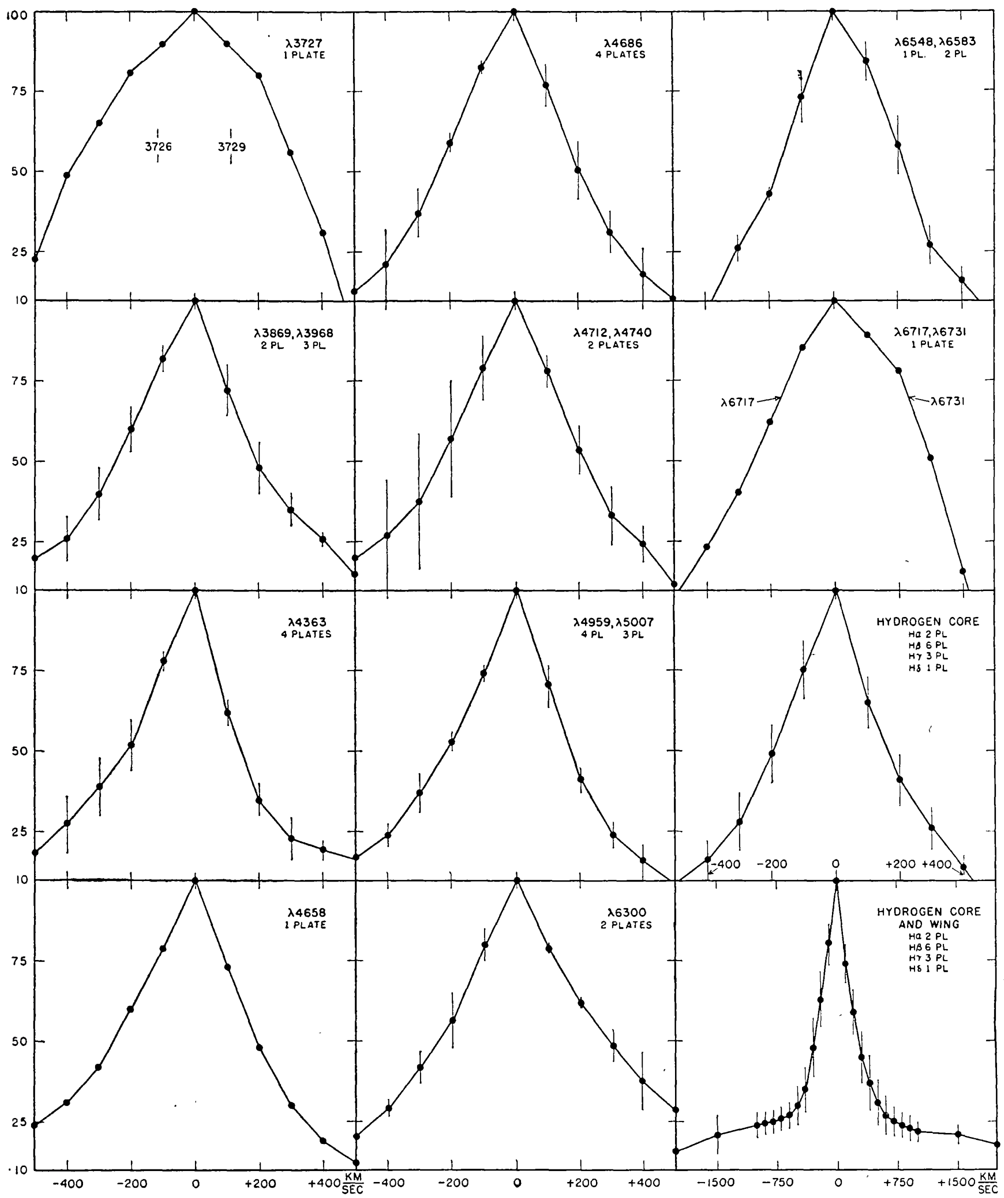
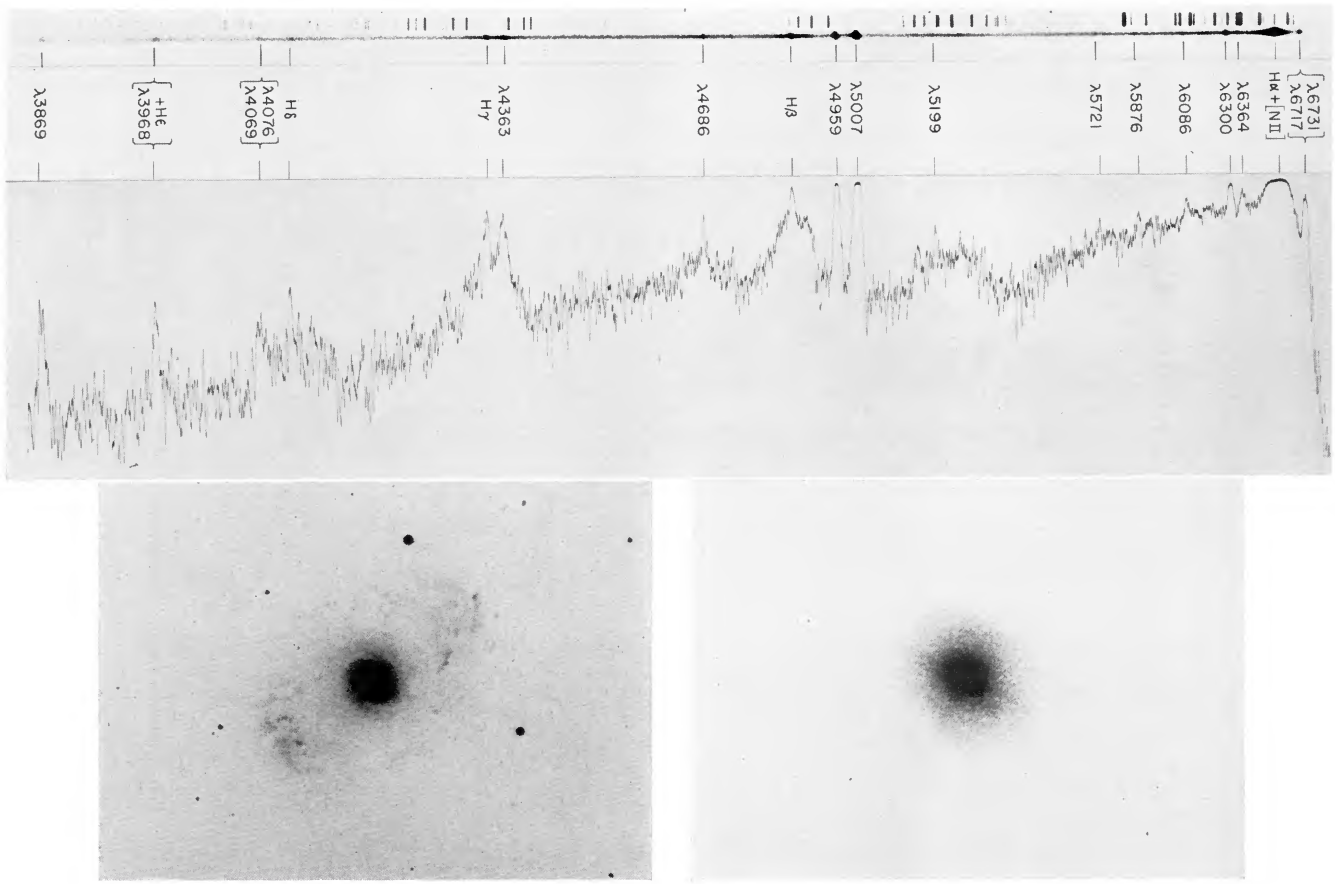


FIG. 3.—Profiles of emission lines in NGC 4151. Ordinates are intensities, abscissae distances from the center of each line in km/sec. The vertical lines indicate the average deviation of the individual observations from the plotted means. The scale of the abscissae for the profile of hydrogen core and wing (*lower right corner*) is widely different from that of the other profiles.

Most of the lines in NGC 4151 are asymmetrical in the sense that the blue part of the line is, on the average, 16 per cent wider than the red part at the point where the intensity drops to 0.25 of the central intensity. The profile of λ 6300, the only outstanding exception, is undoubtedly distorted by the presence of λ 6310 on the red side of λ 6300.

PLATE I



NGC 4151

Spectrum, microphotometer tracing, and direct photographs. The spectrum is an enlargement from a 325^{m} exposure taken with the one-prism Cassegrain spectrograph and 10-inch camera at the 60-inch reflector. The photographs (enlargements from a plate taken with the 100-inch reflector) show the weak, amorphous arms on the left and the semistellar nucleus on the right.

NGC 7469.—The spectrum is similar to that of NGC 4151 in that the N1 and N2 lines are relatively narrow (<1400 km/sec), and the hydrogen lines have cores and very wide wings. However, both cores and wings seem wider than those in NGC 4151 and the wings more intense. Absorption K (*Ca* II) is extremely shallow and at least 50 A wide, twice as wide as in the other nebulae. The large apparent asymmetry for $H\beta$ in NGC 7469 may not be real, since the profile is determined from only one blue-sensitive plate. The rapidly changing background over the great width of the $H\beta$ line (8500 km/sec) makes the profile somewhat uncertain.

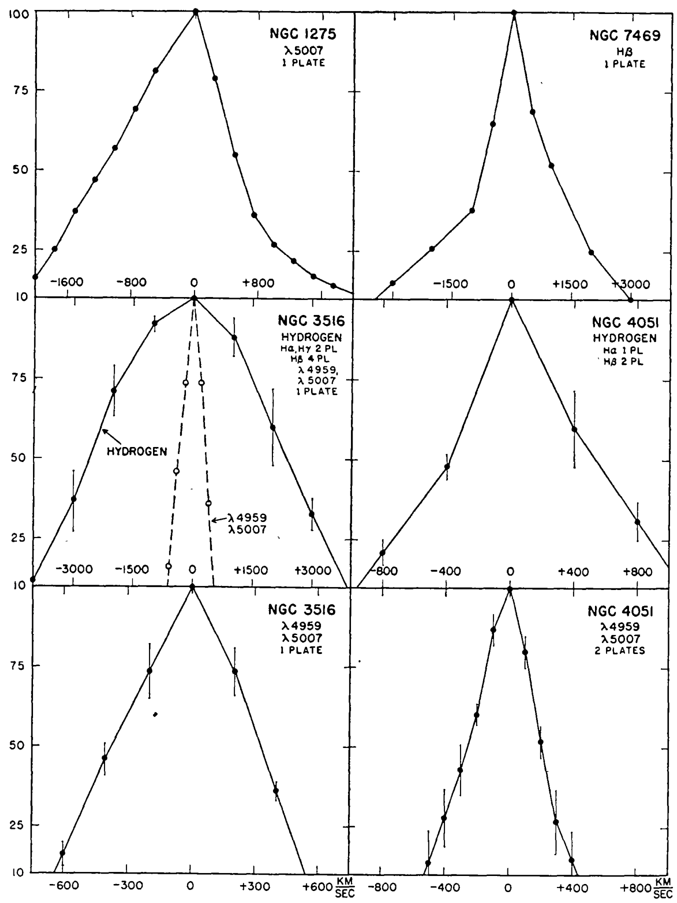


FIG. 4.—Profiles of emission lines in NGC 1275, 3516, 7469, and 4051. Ordinates are intensities, abscissae distances from line center in km/sec. The vertical lines indicate the average deviation of the individual observations from the plotted means.

V. MINIMA IN EMISSION LINES

An unusual feature of six of the strongest lines in NGC 1068 and one line each in NGC 4151 and NGC 7469 is the presence of minima in the emission lines (see Fig. 2). A tentative explanation of these apparent reversals is that the broad emission lines are superposed on a G-type spectrum which contains strong absorption lines at or near the position of the emission lines. Table 6 lists the emission lines in which the minima appear, the observed wave lengths of the minima, the suggested identifications, and the equivalent widths of the minima as measured in the nebular spectrum. Measures of the equivalent widths of the corresponding lines in the sun are included in the table for comparison. The measured wave lengths and equivalent widths agree with the corresponding solar

TABLE 5

TOTAL WIDTHS OF EMISSION LINES (IN KM/SEC)

λ	NGC 1068	NGC 1275	NGC 3516	NGC 4051	NGC 4151	NGC 7469
3727	2600	...	...	...	1050	...
3869, 3968	2500:	>4000	...	...	1700	...
4363	2800	...	...	...	1800	...
4659	...	...	...	...	1250	...
4686	2400	...	...	...	1300	...
4711, 4740	...	...	...	...	1150	...
4959, 5007	3000	4500	1400	1200	1300	<1400
6086	3000*	...	...	...	...	...
6300	2700	...	...	...	1800†	...
6548, 6563	...	...	...	...	950	...
6717, 6731	3600‡	...	...	...	1000:, 900:	...
H lines	3600	≥ 4500	8500	3600	7500	8500
H (core of line)	...	...	...	...	1100	2500:

* The true width of the line λ 6086 in NGC 1068 may be considerably smaller than that indicated, owing to the possible presence of λ 6073 (unknown origin) and λ 6102 [*K* IV].

† In NGC 4151, since λ 6310 influences the profile, the true width of λ 6300 is probably considerably smaller than that indicated.

‡ The fact that the two lines are blended in NGC 1068 contributes only a negligible amount to the width of the line.

TABLE 6

SUGGESTED IDENTIFICATIONS OF ABSORPTION MINIMA IN EMISSION LINES

NGC	Emission Line	Observed λ of Abs. Min.*	Suggested Identification of Abs. Min.	E. W. Nebula	E. W.† Sun
	λ	λ	λ		
1068	3869	3873 $\pm$	3872 (*CN*)	3.6 A	4.0: A
1068	3968	3972 $\pm$	3968.5 (*Ca* II), 3970.1 (*H*ε)	2.0	10
7469	4340.5	4300 $\pm$	4303 (*CH G* band)	2.0	3.5
1068	4340.5	4340 $\pm$	4340.5 (*H*γ)	1.0	2.3
1068	4861.3	4862.0	4861.3 (*H*β)	2.0	2.9
4151	4861.3	4873	4870.8 (*Cr*, *Ni*), 4871.3 (*Fe*), 4872.1 (*Fe*)	1.8	0.6
1068	4959.5	4958.1	4957.3 (*Fe*), 4957.6 (*Fe*)	0.6	0.8
1068	5007.6	5007.3	5005.7 (*Fe*), 5006.1 (*Fe*), 5007.2 (*Ti*), 5007.3 (*Fe*)	1.3	0.6

* The wave length of each absorption minimum is measured on the tracings relative to the emission line.

† Determined from the *Photometric Atlas of the Solar Spectrum* by Minnaert, Mulders, and Houtgast (Amsterdam, 1940).

values within the accuracy of the measures except for the *H* (*Ca* II) and $H\epsilon$ absorption in the λ 3968 [*Ne* III] emission. The large discrepancy in this case between the observed and expected equivalent widths of the minimum is probably due to the great intrinsic width of the *H* line. The small systematic difference of approximately one angstrom between the observed and expected wave lengths may or may not be significant.

VI. DISCUSSION

Ten of the twelve extragalactic nebulae known to exhibit high-excitation nuclear emission are spirals of either early or intermediate type (i.e., Sa or Sb). The remaining two, NGC 1275 and NGC 3077, are objects which could be classified as either peculiar elliptical or irregular nebulae. The average absolute magnitude of the twelve emission spirals (−15.8) is somewhat brighter than the average nonemission spiral. All emission spirals have nuclei of high luminosity, which on direct photographs are scarcely distinguishable from stars—a fact first noted by Humason in his paper on NGC 1275.

The widths of the emission bands are probably correlated with the physical properties of the nucleus. The data in Table 7 suggest that the maximum width of the hydrogen

TABLE 7*

RELATION BETWEEN MAXIMUM WIDTHS OF BALMER LINES AND THE PHYSICAL PROPERTIES OF NUCLEI

NGC	Max. Width of H Lines (in Km/Sec)	Abs. Mag. of Nucleus	Percentage of Total Light in Nucleus
4051	3600	−12.0	12
1068	3600	−13.0	6
1275	>4500	−15.0	10
4151	7500	−14.0	48
3516	8500	−14.8	25
7469	8500	−15.5	30:

* The maximum widths of the hydrogen lines are from Table 5. The absolute magnitude and the percentage of the total light in the nucleus are derived from the data in Table 1. The absolute magnitude of NGC 1275 is calculated on the assumption of $0^{m}5$ photographic interstellar absorption, a value suggested by the low galactic latitude and counts of faint nebulae in the vicinity of NGC 1275.

emission lines increases with absolute magnitude and with the ratio of light in the nucleus to the total light of the nebula. No definite correlation seems to exist between the line widths and color temperatures or spectral type of the nucleus, and the number of nebulae investigated is too small to indicate any certain correlations of widths of the emission lines with emission-line intensity ratios.

Since some of the brightest emission knots in the periphery of other extragalactic nebulae have total absolute magnitudes comparable with those of the emission nuclei, the question arises whether such emission knots show spectra with wide lines. Spectra of NGC 5471 (abs. mag. −9) and NGC 604 (abs. mag. −10), the brightest emission nebulae in the spirals M 101 and M 33, revealed no evidence of widening of the lines. At the writer's request, Dr. Mayall kindly examined the available Lick Observatory spectra of the giant emission nebula 30 Doradus (abs. mag. −14) in the Large Magellanic Cloud. He reports that the emission lines on the existing plates show no conspicuous evidences of broadening. Mayall also states that the very bright knot in NGC 2366 reveals no large line width. Evidently there is no close connection between the giant diffuse nebulae and the nuclei of spirals showing nebular emission lines.

Further discussion of the data will be presented in a contribution being prepared jointly by Dr. R. L. Minkowski and the present author.

It is a pleasure to express my sincere gratitude to the National Research Council for the Fellowship which made this investigation possible and to Dr. W. S. Adams, director of the Mount Wilson Observatory, for allowing me full use of the facilities of the observatory. I am greatly indebted to Dr. E. P. Hubble for his continued guidance in this investigation, and I want to thank both Dr. Hubble and Mr. M. L. Humason for generously placing their observational material at my disposal. The helpful advice of Dr. R. L. Minkowski and all the other members of the Mount Wilson Observatory staff is heartily acknowledged.

Carnegie Institution of Washington
Mount Wilson Observatory
October 1942