SPECTROPHOTOMETRY OF H II REGIONS AND THE NUCLEUS OF NGC 1566

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ABSTRACT

Spectrophotometric observations of the nucleus and nine H II regions in the spiral arms of the Sbc galaxy NGC 1566 are presented. The emission-line spectra of the H II regions are strikingly uniform and characterized by a relatively low level of ionization. Most of the line intensities do not show radial gradients. In particular, the [N II]/Hα measurements are remarkably constant over the range of galactocentric distance observed. The [N II]/[O II] ratio appears to increase toward the nucleus, and the [O III]/Hβ ratio may decrease in the same direction. A possible explanation for this behavior is that the oxygen abundance increases slightly and the electron temperature decreases toward the nucleus. Our measurements appear to support the suggestion that the H II regions in earlier-type spiral galaxies are generally characterized by low ionization and an absence of strong abundance gradients.

Although NGC 1566 is classified as a Seyfert 1 galaxy, the emission-line spectrum of the nucleus is relatively weak. The Hβ luminosity is only a factor of 10 greater than that of the brightest of the outer-arm H II regions, and the ionization of the nuclear gas is not unlike that observed for certain galactic and extragalactic H II regions with essentially solar abundances. Our spectra appear to confirm the presence of the weak, broad emission wings at Hα which have been reported by other observers. However, aside from this broad emission, the nuclear spectrum of NGC 1566 resembles more that of a giant H II region than that of a Seyfert galaxy.

Subject headings: galaxies: individual — galaxies: nuclei — galaxies: Seyfert — nebulae: general — spectrophotometry

I. INTRODUCTION

Recent spectrophotometry of H II regions has established the existence of abundance gradients across the disks of some late-type spiral galaxies (Searle 1971; Smith 1975; Peimbert, Torres-Peimbert, and Rayo 1978; Hawley 1978). An extension of this type of investigation to spiral galaxies of earlier type is desirable to test the suggestion that abundance gradients are more prominent in later-type spirals (Searle 1971; Smith 1975) and that the [O III]/Hβ ratio correlates with the strength of the shock produced by the spiral density wave (Jensen, Strom, and Strom 1976).

We present in this paper the results of an investigation of H II regions in the southern Sbc galaxy NGC 1566. Well-defined spiral arms extend to the north and south of the nucleus, and many H II regions are visible on Hα plates. These features make NGC 1566 ideally suited for studying the relationship between chemical abundances and the amount of compression in the material caused by the spiral pattern.

NGC 1566 has also received much attention in the past because of its classification as a Seyfert 1 galaxy. This classification was first made by de Vaucouleurs and de Vaucouleurs (1961) on the basis of broad Hγ, Hβ, and [O III] λ5007 nuclear emission. Shobbrook (1966) also reported the presence of broad emission lines and measured the full width at half-intensity of Hβ to be 2000 km s⁻¹. Variations in the relative strengths of the nuclear emission lines were claimed by Pastoriza and Gerola (1970), who compared their photographic spectra with the spectra of de Vaucouleurs and de Vaucouleurs (1961) and Shobbrook (1966). A combined photometric and spectroscopic study of NGC 1566 was made by Smith, Weedman, and Spinrad (1972). These authors reported the Balmer lines to have narrow cores with the same widths as the forbidden lines (~300 km s⁻¹), but with weak, broad wings (~2000 km s⁻¹). Thus NGC 1566 was classified as a Seyfert 1 galaxy. The broad, faint Balmer-wing emission was confirmed by Osmer, Smith, and Weedman (1974), who estimated the width to be as large as 5000 km s⁻¹.

In NGC 1566 we are given the opportunity of comparing the physical conditions in the H II regions in the disk of a Seyfert galaxy with those of the gas

1 Cerro Tololo Inter-American Observatory is supported by the National Science Foundation under contract AST 74-04128.
in the nucleus. The observations of the nucleus are presented in § IV. A discussion of the observations of the H II regions in the spiral arms is given in § III. Evidence for abundance gradients is considered and compared to the results of similar studies of H II regions in other spiral galaxies.

II. OBSERVATIONS

The two spiral arms in NGC 1566 are both studded with bright H II regions. Nine of these were selected for observation from an Hα plate taken at the prime focus of the CTIO 4 m telescope by Dr. P. Osmer (reproduced in Fig. 1, which also shows the numbering system used for the H II regions). Spectrophotometry of regions I–VII was obtained on the nights of 1977 December 30 and 31 (UT) with the SIT–vidicon spectrometer (Osmer and Smith 1976; Atwood et al. 1979) and the Ritchey-Chrétien spectograph on the CTIO 4 m reflector. The wavelength ranges λλ3500–5100 and λλ5600–7100 were observed at a spectral resolution of approximately 10 Å. At this resolution, Hα and [N II] λλ6548, 6583 are not seriously blended and can be individually measured. However, because the spectra do not overlap, it was necessary to obtain low-resolution (~20 Å) spectra in the wavelength region λλ4600–7100. These were taken on 1978 April 11 and 1978 November 7 through a slit which was 5″ wide, as opposed to 3″ for the December observations. Regions VIII and IX were also observed at low dispersion, but higher-resolution data were not obtained because of the faintness of these H II regions. All spectra were reduced to energy units via observations of standard stars calibrated by Oke (1974) and Stone (1974, 1977).

Observations of the nucleus of NGC 1566 were obtained with the SIT–vidicon and spectrograph on the 1.5 m telescope on four successive nights in 1977 November. Spectrophotometric observations at 20 Å resolution were made which covered the wavelength range λλ5200–7100. In addition, a higher-resolution (~10 Å) spectrum was obtained in the wavelength range λλ3700–5200. A slit width of 6″9 was used in all of these observations, and scan lines covering a spatial extent of ~25″ along the slit, centered on the nucleus, were summed together to produce the individual spectra. Finally, a high-dispersion (~5 Å) spectrum was obtained with the SIT–vidicon on the 4 m telescope the night of 1978 August 10. This observation was made with a 5″ slit, covering 750 Å centered on Hα.

The prominence of absorption lines from the galaxian continuum in the nuclear spectrum of NGC 1566 made the measurement of emission-line intensities particularly difficult. Although the situation was most serious for the H I Balmer lines, other lines such as [O II] λλ3727 and [O III] λλ4959, 5007 were also somewhat affected. To attempt to minimize this problem, use was made of the two-dimensional nature of the SIT–vidicon data. The spectra were exposed, untrailed, using a long slit, so that data were simultaneously recorded for both the nucleus and the galactic disk region surrounding it. In the reduction process, data were extracted off the nucleus, both the east and west, and were summed together to form an average spectrum of the disk region. This galactic disk spectrum was then multiplied by a constant and subtracted from the nuclear scan in an attempt to remove the absorption features. A similar technique was utilized by Koski and Osterbrock (1976), Costero and Osterbrock (1977), and Koski (1978) to study other emission-line galaxies, although in none of these cases was the absorption-line spectrum of the same galaxy used to study the emission lines observed in its nucleus. One problem encountered with this procedure in NGC 1566 was the presence of weak Hα + [N II] λλ6548, 6583 emission in the galactic disk region. This emission was artificially removed before subtracting the disk spectrum from the nuclear spectrum, but an uncertainty has necessarily been introduced into the final measurement of the nuclear Hα + [N II] emission. Nevertheless, in general, this method should result in more reliable emission-line flux measurements since, to first order, the effects of underlying absorption lines have been removed.

III. THE H II REGION DATA

a) Line Intensities and Reddening

The blue and red 10 Å resolution observations of H II region VI in NGC 1566 are displayed in Figure 2. The data are plotted on a relative linear F K scale versus rest wavelength and are representative of the average quality of the spectra obtained in this study. Emission-line intensities for each H II region were measured from the 10 Å resolution data and were normalized to Hβ by adopting the Hα + [N II]Hβ ratio from the low-dispersion (20 Å resolution) spectra.

The corrections for reddening were computed by assuming that the intrinsic Balmer decrement results from pure case B recombination (Brocklehurst 1971) and taking the Whitford reddening curve as formulated by Miller and Mathews (1972). For H II regions I–VI, the values of Aν show no trend with galactocentric distance and cluster around a value of Aν = 2.0 ± 0.3. For region VII, however, the Hα/Hβ ratio was measured to be 2.80, implying little or no extinction. A check on the reddening may be made by comparing the Hγ/Hβ ratio with its theoretical recombination value. We find that to within the estimated uncertainties of 10–20%, the observed Hγ/Hβ values in each of the seven H II regions are consistent with recombination plus the amount of reddening deduced from Hα/Hβ. We estimate that the errors associated with the other line fluxes (corrected for reddening and normalized to Hβ) are ~10% for I(λ) > 0.80, ~20% for 0.80 ≥ I(λ) ≥ 0.20, and 50% for I(λ) < 0.20.

b) Radial Dependence of Line Intensity Ratios

To illustrate whatever radial dependence may be present, we have plotted in Figure 3 several important
Fig. 1.—Hα plate of NGC 1566 taken by P. Osmer at the prime focus of the CTIO 4 m telescope. The H II regions observed are numbered I to IX in order of decreasing distance from the nucleus.
emission-line ratios versus galactocentric distance. Since the inclination and line of nodes of NGC 1566 are not well known, projection effects, which are presumably small, have been neglected. A distance of 23.6 Mpc was assumed, based on the corrected radial velocity of 1178 km s\(^{-1}\) (de Vaucouleurs, de Vaucouleurs, and Corwin 1976) and a Hubble constant of 50 km s\(^{-1}\) Mpc\(^{-1}\). The estimated uncertainty of each value has also been indicated.

As shown in Figure 3, the ratio \([\text{N II}] \lambda 6548 + \lambda 6583/\text{He}\) is remarkably constant at \(\log I([\text{N II}])/I(\text{He}) = -0.32 \pm 0.04\). Moreover, two long-slit spectrograms obtained across NGC 1566 by Dr. F. Schweizer in the wavelength region around \(\text{He} + [\text{N II}]\), and inspected by us, confirm that outside the nucleus the \([\text{N II}]/\text{H}\alpha\) ratio is very constant. Thus, while we have data for only seven places in NGC 1566, they are evidently representative of the emission regions throughout the disk, at least in terms of \([\text{N II}]/\text{H}\alpha\).

Significantly, this ratio has been observed to show order-of-magnitude variations from place to place in certain other spiral galaxies (Searle 1971; Smith 1975). The ratio \([\text{N II}] \lambda 6548 + \lambda 6583/[\text{S II}] \lambda 6716 + \lambda 6731\) also shows no dependence on position, although the scatter is somewhat larger. Likewise, the \(\log [\text{O II}] \lambda 3727/[\text{O III}] \lambda 4959 + \lambda 5007\) ratio is apparently constant at a value of \(\sim 1.0\). The \(\text{He} 1 \lambda 5876/\text{H}\beta\) values show considerable scatter, which is undoubtedly a reflection of the difficulty in accurately measuring such a weak line. However, within the errors there is no clear trend in the data, and we conclude that there is no strong evidence of an ionized helium gradient in NGC 1566.

The intensity ratio \([\text{N II}] \lambda 6548 + \lambda 6583/[\text{O II}]\)
\( \lambda 3727 \) does appear to show a dependence on radial distance, although the amplitude of the gradient rests strongly on the measurement for region VII. However, even if this data point is disregarded, the measurements for regions I–VI are suggestive of a gradient, and on this basis we believe that the radial dependence of the \([\text{N} \text{ ii}] / [\text{O} \text{ ii}]\) ratio in NGC 1566 is reasonably well established.

The other line ratio in NGC 1566 which may show a trend with galactocentric distance is \([\text{O} \text{ iii}] \lambda 4959 + \lambda 5007 / \text{H} \beta \). Again, the evidence depends strongly on region VII, where the \([\text{O} \text{ iii}] / \text{H} \beta \) ratio is clearly much smaller. To further investigate the possibility of an \([\text{O} \text{ iii}] / \text{H} \beta \) gradient, we obtained low-dispersion observations of \( \text{H} \text{ ii} \) region VIII, which is approximately \( 7^\circ \) northeast of region VII (see Fig. 1), and the fainter \( \text{H} \text{ ii} \) region IX, which is approximately \( 5^\circ \) north of region VIII. In neither of these regions was \([\text{O} \text{ iii}] \) emission detected, from which we have estimated upper limits to \([\text{O} \text{ iii}] / \text{H} \beta \) of 0.10 and 0.12, respectively. Thus the small \([\text{O} \text{ iii}] / \text{H} \beta \) ratio observed in region VII is apparently representative of the other \( \text{H} \text{ ii} \) regions in the same vicinity of NGC 1566, and the existence of an \([\text{O} \text{ iii}] / \text{H} \beta \) gradient seems more likely.

We conclude that most of the line intensity ratios in the \( \text{H} \text{ ii} \) regions of NGC 1566 do not show radial variations. However, our data do indicate an increase of the \([\text{N} \text{ ii}] / [\text{O} \text{ ii}]\) ratio toward the nucleus and a possible decrease in \([\text{O} \text{ iii}] / \text{H} \beta \). The most likely explanation for these observations is that the oxygen abundance increases slightly and the electron temperature decreases toward the nucleus. Oxygen is the dominant coolant, so, as the oxygen abundance increases, the electron temperature decreases. Because the nebular lines are collisionally excited, the lower electron temperature results in less \([\text{O} \text{ iii}] \) emission. The observed constancy of the \([\text{N} \text{ ii}] / \text{H} \alpha \) ratio makes the presence of a nitrogen gradient unlikely. If the nitrogen abundance is constant but the oxygen abundance increases toward the nucleus (so \( \text{N}/\text{O} \) decreases), \([\text{N} \text{ ii}] / [\text{O} \text{ ii}]\) could still increase because of its electron temperature dependence. The \([\text{N} \text{ ii}] / \text{H} \alpha \) ratio is also a function of electron temperature. However, a systematically softer ionizing radiation toward the nucleus could offset the effect of an electron temperature gradient. Model calculations support this scenario for \( \text{H} \text{ ii} \) regions in M83 (Dufour, Talbot, and Jensen 1980). However, care must be taken in interpreting the decreasing \([\text{O} \text{ iii}] / \text{H} \beta \) ratio. Because of the influence of factors besides abundance on \([\text{O} \text{ iii}] / \text{H} \beta \), it would be premature to attribute the low observed values of this ratio in \( \text{H} \text{ ii} \) regions VII, VIII, and IX to an overall oxygen overabundance closer to the nucleus.

d) Comparison with Other Galaxies

The \( \text{H} \text{ ii} \) regions in NGC 1566 are, on the average, of much lower excitation than the \( \text{H} \text{ ii} \) regions of the two most-studied spiral galaxies to date, M33 and M101. For example, in M101, where a large range in the level of ionization is observed, the \( \text{H} \text{ ii} \) region with the lowest excitation, Searle 5, is the one most similar spectroscopically to the \( \text{H} \text{ ii} \) regions investigated in this paper (see Hawley 1978). Instead, the ionization of the \( \text{H} \text{ ii} \) regions in NGC 1566 is much more like that observed in two other galaxies, M51 (Smith 1975) and M83 (Dufour, Talbot, and Jensen 1978).

Like NGC 1566, M51 and M83 also do not show evidence of large abundance gradients. The only line intensity ratios in M51 which display a radial dependence are \([\text{N} \text{ ii}] / [\text{O} \text{ ii}]\) and \([\text{O} \text{ iii}] / \text{H} \beta \), while in M83 there are no obvious gradients. In M33 and M101, on the other hand, gradients in several line intensity ratios are quite pronounced. Specifically, radial variations in \([\text{O} \text{ ii}] / [\text{O} \text{ iii}]\), \([\text{N} \text{ ii}] / \text{H} \alpha \), and \([\text{N} \text{ ii}] / [\text{S} \text{ ii}]\), as well as in \([\text{O} \text{ iii}] / \text{H} \beta \) and \([\text{N} \text{ ii}] / [\text{O} \text{ ii}]\), have been observed in (Peimbert and Costero 1969; Smith 1975; Hawley and Miller 1977). Unfortunately, we have no direct measure of the electron temperature, on which the computed abundances critically depend. We will proceed on the assumption that \( T_e = 10,000 \text{ K} \) and discuss the sensitivity of the results to the assumed \( T_e \).

The ionized helium abundance deduced from the strength of \( \lambda 5876 \) is \( N(\text{He}^+) / N(\text{H}^+) \approx 0.13 \). In this case, the electron temperature uncertainty is not so important as errors in the line flux, since the \( \text{He}/\text{H} \) abundance is determined from ratios of recombination coefficients which have similar temperature dependences. Considering the large uncertainties in our measurements of \( \lambda 5876 \) and our lack of knowledge of the amount of neutral helium present in the \( \text{H}^+ \) zone, we conclude only that the total helium abundance is \( 0.10 \pm 0.05 \), and therefore roughly solar.

The calculated relative abundances of oxygen and nitrogen are \( \text{O}/\text{H} \approx 1 \times 10^{-4} \) and \( \text{N}/\text{H} \approx 2 \times 10^{-5} \). However, a more informative ratio is \( \text{N}/\text{O} \), which is less temperature sensitive than either \( \text{O}/\text{H} \) or \( \text{N}/\text{H} \). We find \( \text{N}/\text{O} \approx 0.2 \), as compared with the average value for galactic \( \text{H} \text{ ii} \) regions of 0.10 (Hawley 1978). We feel that a safe statement is that neither oxygen nor nitrogen is overabundant by a large amount (say, an order of magnitude), and, given the present evidence, it is plausible that both oxygen and nitrogen have normal abundances.

Finally, we calculate the ionized sulfur abundance to be \( \text{S}^+ / \text{H}^+ \approx 1 \times 10^{-6} \), which is typical of the value in galactic \( \text{H} \text{ ii} \) regions (Hawley 1978). The total abundance is particularly uncertain because the sulfur ionization distribution is unknown. However, from the similarity of the general level of ionization of the \( \text{H} \text{ ii} \) regions in NGC 1566 to some galactic \( \text{H} \text{ ii} \) regions with \( \text{S}^+ / \text{H}^+ \approx 1 \times 10^{-6} \), we infer that the total sulfur abundance is probably normal as well.

c) Abundances

By adopting line intensities characteristic of the average \( \text{H} \text{ ii} \) region from our sample, we can estimate abundances in the interstellar medium in NGC 1566. We use standard abundance determination techniques
Fig. 4.—The summed data of two low-resolution SIT-vidicon spectra of the nucleus of NGC 1566 are displayed on an observed $F$$_{\lambda}$ scale versus observed wavelength. Incomplete cancellation of the [O i] $\lambda$5577 night-sky emission is marked “N.S.”

IV. THE NUCLEAR SPECTRUM

The sum of the low-resolution SIT-vidicon spectra of the nucleus of NGC 1566 is displayed in Figure 4 on a linear observed $F$$_{\lambda}$ scale versus observed wavelength. This spectrum represents 11 minutes of observation in the blue and 17 minutes in the red. The data show the nuclear emission lines of NGC 1566 to be very weak in comparison with other Seyfert galaxies, a fact that was originally pointed out by Osmer, Smith, and Weedman (1974, hereafter OSW). The strongest emission lines present are [O iii] $\lambda$5007, 5007; H$\beta$ + [N ii] $\lambda\lambda$6548, 6583; and [S ii] $\lambda\lambda$6716, 6731. The continuum is dominated by stellar absorption lines such as Ca ii H and K, the G band, Mg i b, and Na i D, and resembles the continua observed in the nuclei of certain giant elliptical galaxies (Schild and Oke 1971; Whitford 1971). The continuum slope agrees well with the measurements of OSW, although there is a zero-point difference in the absolute scale of approximately 0.25 mag which is probably accounted for by different effective aperture sizes.

A portion of a higher-dispersion (~5 Å resolution) spectrum of the nucleus in the wavelength region of H$\alpha$ is shown in Figure 5. These data were obtained to check the reports of broad, low-contrast Balmer-wing emission which have led to the classification of NGC 1566 as a Seyfert 1 galaxy. Indeed, measurement...
of this spectrum yields a full width at zero intensity of the Hα + [N ii] blend of approximately 5000 km s\(^{-1}\), which is the same as the value given by OSW. With these data alone, it is difficult to say how much of this width is due solely to Hα. However, judging from the lack of similar wings on the [S ii] \(\lambda 6716, 6731\), that weak, broad Hα emission is likely present.

Relative emission-line fluxes which we have measured from our data in the manner described in § II are listed in Table 1. The errors in these values are probably of the order of 20\%, except for those measurements followed by a colon, which may be in error by as much as a factor of 2. Also given for reference in Table 1 are the measurements of OSW and Martin (1974). We believe that the differences between these values do not provide evidence of variability, but rather reflect the difficulty in accurately measuring such a weak emission-line spectrum.

High-ionization lines often seen in the spectra of both Seyfert 1 and Seyfert 2 galaxies, such as [Ne v] \(\lambda 3426\) and He ii \(\lambda 4686\), were not detected in the nuclear spectrum of NGC 1566. In fact, the ionization is strikingly similar to that observed in some galactic and extragalactic H ii regions. This is shown in Table 2, where the line intensities of the nucleus of NGC 1566 are compared with those of the galactic H ii region IC 410 (Hawley 1978), three giant H ii regions in M101 (Smith 1975), and the 30 Doradus H ii region in the Large Magellanic Cloud (Peimbert and Torres-Peimbert 1974). The values for NGC 1566 have been corrected for an extinction of \(A_v = 1.07\), based on the observed Hα/\(\beta\) ratio. The assumption that the observed Balmer decrement is a result of reddening may be incorrect, particularly in light of the evidence of weak, broad emission at Hα. However, the conclusion that the ionization of the nuclear spectrum of this galaxy is similar to that of certain H ii regions is unchanged.

As previously shown by OSW, the absolute luminosity of the nuclear emission is very small for a Seyfert galaxy. We measure an observed flux in H\(\beta\) of \(9.3 \times 10^{-14}\) ergs cm\(^{-2}\) s\(^{-1}\), which implies an absolute luminosity of \(6.3 \times 10^{39}\) ergs s\(^{-1}\) for \(H_0 = 50\) km s\(^{-1}\) Mpc\(^{-1}\). This is smaller than all of the Seyfert 1 galaxy H\(\beta\) luminosities given by Weedman (1976) except that of NGC 4051, which is essentially the same. Interestingly, the H\(\beta\) luminosity we measure in the nucleus of NGC 1566 is only a factor of 10 greater than the value for the brightest of the outer-arm H ii regions we observed and is only 2 times larger than the integrated H\(\beta\) luminosity of 30 Dor (Sargent and Searle 1970).

In summary, the nuclear spectrum of NGC 1566 shows few of the characteristics of a "normal" Seyfert 1 galaxy. Our observations suggest that the emission-line spectrum of the nucleus can reasonably be interpreted as arising from radiative excitation by hot stars rather than photoionization by a nonthermal continuum, as appears necessary in other objects classified as Seyfert galaxies (e.g., Osterbrock 1977; Koski 1978). We consider the evidence for variability of the nuclear emission lines to be very weak. In particular, the uncalibrated spectra presented by Pastoriza and Gerola (1970) show no obvious change in the equivalent widths of the H\(\beta\) and [O iii] \(\lambda 4959, 5007\) emission lines. A comparison of all available broad-band photometry data also reveals little evidence for variability of the nucleus (C. J. Peterson, private communication). Clearly, the relative faintness of the nucleus of NGC 1566 with respect to the surrounding galactic disk makes such measurements particularly sensitive to the placement of the diaphragm or slit, and to guiding errors. In short, were

### Table 1

**Observed Line Intensities for the Nucleus of NGC 1566**

<table>
<thead>
<tr>
<th>Line</th>
<th>(\lambda) (Å)</th>
<th>This Paper</th>
<th>OSW</th>
<th>Martin 1974</th>
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<tr>
<td>[O ii]....</td>
<td>3727</td>
<td>0.98</td>
<td>0.47</td>
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<tr>
<td>H(\beta)</td>
<td>4861</td>
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<td>1.00</td>
<td>1.00</td>
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<td>3.75</td>
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<td>2.60</td>
</tr>
<tr>
<td>[O i].....</td>
<td>6300</td>
<td>0.40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H(\alpha)</td>
<td>6563</td>
<td>4.26</td>
<td>4.18</td>
<td>4.70</td>
</tr>
<tr>
<td>[N ii]...</td>
<td>6548, 6583</td>
<td>2.14</td>
<td>1.33</td>
<td>1.20</td>
</tr>
<tr>
<td>[S ii]...</td>
<td>6716, 6731</td>
<td>1.03</td>
<td></td>
<td>0.25</td>
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### Table 2

**Comparison of Reddening-corrected Intensities for the Nucleus of NGC 1566**

<table>
<thead>
<tr>
<th>Line</th>
<th>(\lambda) (Å)</th>
<th>NGC 1566 IC 410(^a)</th>
<th>M101(^b)</th>
<th>NGC 5461 Smith No. 3</th>
<th>Smith No. 5</th>
<th>30 Dor IV(^c)</th>
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<td>3727</td>
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<td>1.92</td>
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<td>[Ne iii]..</td>
<td>3868</td>
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<td>1.00</td>
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<td>4.57</td>
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<td>5876</td>
<td>...</td>
<td>...</td>
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<td>0.14</td>
<td>...</td>
</tr>
<tr>
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<td>0.27</td>
<td>0.22</td>
<td>0.10</td>
<td>0.72</td>
</tr>
</tbody>
</table>

\(^a\) Hawley 1978.

\(^b\) Smith 1975.

\(^c\) Peimbert and Torres-Peimbert 1974.
it not for the weak, broad Hα emission which our observations apparently confirm and the reported presence of a stellar nucleus (Garrison and Walborn 1974), classification of NGC 1566 as a Seyfert galaxy would not be indicated.

V. CONCLUSIONS

We have shown in this paper that with the exception of \([\text{N} \text{II}]/[\text{O} \text{II}]\) and \([\text{O} \text{III}]/\text{H}β\) there is little evidence for radial gradients in line intensity ratios of the H II regions in NGC 1566. In fact, if the data for regions VII, VIII, and IX are ignored, the emission-line spectra of the H II regions are strikingly uniform. Thus the usage of the term “gradient” may be misleading. The \([\text{N} \text{II}]/[\text{O} \text{II}]\) ratio in region VII is clearly much greater than in the outer H II regions, and the \([\text{O} \text{III}]/\text{H}β\) ratios in regions VII, VIII, and IX are also definitely smaller than the average value for the outer regions. As we have pointed out, these observations could be explained by a general increase in the oxygen abundance toward the nucleus. However, regions VII, VIII, and IX lie very close to one another in the galaxy, and we feel that to make such a conclusion on the basis of the anomalous \([\text{O} \text{II}]/[\text{N} \text{II}]\) and \([\text{O} \text{III}]/\text{H}β\) line strengths in these H II regions alone would be improper. It would be highly desirable to observe other H II regions near the nucleus, as well as ones at galactocentric distances between regions VI and VII, to determine if true “gradients” in the \([\text{O} \text{III}]/[\text{N} \text{II}]\) and \([\text{O} \text{III}]/\text{H}β\) ratios exist in NGC 1566. Unfortunately, the H II regions which satisfy these requirements are faint, and to obtain the necessary observations would be difficult.

Both the low excitation of the H II regions in NGC 1566 and the lack of evidence for strong abundance gradients are consistent with the suggestion by Searle (1971) and Smith (1975) that such characteristics are correlated with morphological type. The morphological classification of NGC 1566 is Sbc (de Vaucouleurs, de Vaucouleurs, and Corwin 1976), and, as previously noted, the range in \([\text{O} \text{III}]/[\text{N} \text{II}]\) and the low level of ionization of the H II regions we have observed are most similar to those of another Sbc galaxy, M51. Smith (1975) has suggested that the H II regions in earlier-type galaxies show a lower level of ionization because of softening of the radiation field by dust, and indeed the reddening values we have measured for the H II regions in NGC 1566 are (except for region VII) substantially greater than the values observed in the Scd galaxies M33 and M101. The same explanation has also been given by Dufour, Talbot, and Jensen (1978) for the low ionization of the H II regions in the Sc galaxy M83. Alternatively, Jensen, Strom, and Strom (1976) have suggested that the difference in the mean level of ionization of the H II regions between early- and late-type galaxies reflects a difference in the average value of \(\Omega - \Omega_p\) (i.e., the frequency at which the spiral density wave moves through the interstellar medium) among the morphological classes. An accurate rotation curve for NGC 1566 both at optical wavelengths and at 21 cm would be particularly useful in further testing the latter theory.

Abundances in the H II regions of the disk of NGC 1566 are roughly solar. It is interesting to speculate on the composition of the gas in the nucleus. We have shown that the ionization of the nuclear spectrum is not typical of other Seyfert galaxies, but rather is similar to certain galactic and extragalactic H II regions. Analyses of the spectra of the four particular H II regions with which we have made comparison (see Table 2) yield abundances within a factor of 2 of the solar values. Thus it does not seem unreasonable to infer that the composition of the gas in the nucleus of NGC 1566 is also close to solar.

Our observations serve to emphasize the extreme weakness of the Seyfert characteristics of NGC 1566. The contrast is striking between the nuclear spectrum of this galaxy and the broad lines, strong featureless continua, and quasar-like luminosities which distinguish objects at the other extreme of the Seyfert 1 class, such as the recently discovered ESO 141-G55 (Ward et al. 1978). Direct plates of the latter object show it to be a moderately early-type spiral galaxy which at least superficially resembles NGC 1566. One wonders if perhaps these two galaxies represent different evolutionary stages of the same phenomenon or if they represent merely the different extremes of activity which can occur in the nuclei of spiral galaxies. Regardless of such speculation, however, it is clear that the range in properties of Seyfert 1 galaxy nuclei is very great.

REFERENCES


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