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STAR FORMATION IN BLUE GALAXIES. I. ULTRAVIOLET, OPTICAL, AND INFRARED OBSERVATIONS OF NGC 4214 AND NGC 4670[1]

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ABSTRACT

We have observed NGC 4214 and NGC 4670 between 1150 Å and 1950 Å with the *IUE* satellite and have obtained new infrared and optical broad-band photometry. The spectra of both galaxies are dominated by O stars, and, in the spectrum of NGC 4214, the C IV λ1550 line exhibits a P Cygni profile indicative of hot stars with large mass-loss rates. Although the optical spectra of both galaxies are dominated by strong narrow emission lines, *no* strong emission lines are seen in the UV (the observed Lyα flux is dominated by geocoronal emission). Both galaxies contain giant H II region complexes in which the energy (in particular, the Hβ luminosity and the ultraviolet continuum) is provided by several hundred O stars. The comparison of the observed UVOIR energy distributions with evolutionary population models indicate that the regions observed consist of young "bursts" of star formation superposed on an underlying old population. The initial mass function for this epoch of star formation is constrained to be similar in slope to or flatter than the Salpeter function.

Subject headings: galaxies: individual — galaxies: stellar content — luminosity function — stars: formation — ultraviolet: spectra

I. INTRODUCTION

Blue irregular galaxies provide the ideal site for the study of the integrated stellar populations in regions with high star formation rates. These regions are of interest for studies of galaxy evolution, the slope of the initial mass function for high-mass stars, and the expected spectra of "young" galaxies at high redshifts.

Traditionally, star formation rates in late type galaxies have been studied by comparison of optical broad-band colors to theoretical evolutionary models (Searle, Sargent, and Bagnuolo 1973; Huchra 1977). The interpretation of optical colors with such models is complicated by the folding together of the current star formation rate with the entire integrated star formation history. Furthermore, the dominant young stars radiate primarily at ultraviolet wavelengths and any underlying old population of low mass giants radiates primarily in the infrared.

There are several additional measurements which can improve the determination of the stellar population. Metal abundances are required to define the input stellar evolutionary tracks (Chiosi, Nasi, and Sreenivasan 1978; Brunish and Truran 1982) which determine the mix of blue and red supergiants. Infrared measurements are necessary to determine the population of both the underlying old stars (K and M giants, if any) and the red supergiants. Ultraviolet observations are necessary to measure the population of O and B stars directly.

Here we report *IUE* and infrared observations of the very blue Magellanic irregular galaxies NGC 4214 and NGC 4670 (also known as Haro 9 or Arp 163). NGC 4214 is at a distance of ~6.4 Mpc (Sandage and Tammann 1974, 1982), and NGC 4670, probably a member of de Vaucouleurs's (1975) Coma I cloud, is at ~12.1 Mpc (Aaronson *et al.* 1982), NGC 4214 is resolved optically into stars as well as H II regions and associations (Sandage and Tammann 1974), whereas NGC 4670 is a lenticular galaxy with several associated condensations (Arp 1966). Although NGC 4670 was originally classified as S0, detailed observations have shown it to be much more similar to Im galaxies (Sakka, Oka, and Wakamatsu 1973). In spite of the morphological differences, the energy distributions of these two galaxies from the radio to the ultraviolet are almost identical. The optical spectra are dominated by a blue continuum and narrow (FWHM less than 300 km s^{-1}) emission lines. The ionization state of these spectra resembles that of galactic H II regions. Both galaxies are metal deficient with $[N/H] \approx -1.0$ and $[O/H] \approx -0.3$ (Alloin *et al.* 1979; Hunter, Gallagher, and Rautenkranz 1982). High-dispersion echelle spectra and video camera images of the H II regions in NGC 4214 and NGC 4670 further underscore the similarity of the star-forming regions in these objects (Hunter 1982).

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II. OBSERVATIONS

a) *Optical and Infrared Observations*

Small aperture *UBVR* photometry of NGC 4670 was obtained by two of us (J. H. and M. A.) on the Palomar 60 inch and the Mount Wilson Hooker telescopes. *UBV* measurements for NGC 4214 and NGC 4670, including some from Neff (1970), are also listed by de Vaucouleurs (1961). Broad-band *JHK* photometry for NGC 4670 was obtained by M. A. and J. H. on the KPNO No. 1 90 cm telescope and by S. Willner on the MMT. Infrared data for NGC 4214 come from Aaronson (1977). The collected photometry for these galaxies is listed in Table 1. The IR colors of both galaxies are similar to those of other Magellanic irregular galaxies. Optical spectra of both galaxies were obtained using both the IRS on the KPNO No. 1 90 cm telescope and the Digital Spectrograph at the Mount Hopkins Observatory 60 inch. The MHO spectra were obtained with a 3″ by 12″ slit aligned EW and cover the range 4400 Å to 7000 Å at a resolution of ~6 Å. In both cases the central brightest blob was observed. Line ratios are listed in Table 2.

b) *Ultraviolet Observations*

Ultraviolet observations of these galaxies were obtained with the SWP camera of the *International Ultraviolet Explorer* (*IUE*) in the low-dispersion mode on 1981 March 19. One exposure of 180 minutes was obtained for each object after carefully offsetting from a bright reference star to the optical center of the galaxy measured accurately with the two-axis Grant engine at KPNO.

Figure 1 shows the spectra of the two galaxies. Figure 1*c* is a smoothed, summed spectrum which demonstrates the reality and reproducibility of the indicated features. The continuum flux increases toward shorter wavelengths, and there are a number of prominent absorption lines characteristic of hot stars. There is P Cygni emission in the C IV line in NGC 4214; the C IV absorption appears to be broader than the spectral resolution and is consistent with the broadening by the expansion of strong winds typically seen in O stars. For both galaxies the FWHM of the C IV line is 12 Å, corresponding to a velocity width of 2000 km s^{-1}. It should be noted that the spatial extent of these galaxies contributes to the width of the spectral features as seen in the 10″ × 20″ aperture of *IUE*. The Lyα line cannot be seen because of the strong geocoronal emission line and because of the possibility of absorption by interstellar components. There are no other strong emission lines in the ultraviolet.

The spectrum of NGC 4214 is resolved into two

TABLE 1

BROAD-BAND PPHOTOMETRY

A. OPTICAL PHOTOMETRY

Aperture (1)	V (2)	$B-V$ (3)	$U-B$ (4)	$V-R$ (5)	Date/Telescope[a] (6)
			NGC 4670		
24″........................	13.20	0.38	−0.54	0.57	1978 Apr 10, MW 100
38″........................	12.96	0.38	−0.50	0.61	1978 Apr 10, MW 100
41″........................	12.98	0.38	−0.49	0.55	1976 Mar 29, P60
57″........................	12.83	0.39	−0.47	0.55	1976 Mar 29, P60
106″........................	12.72	0.43	−0.40	...	DV 1961
138″........................	12.78	0.36	−0.56	...	DV 1961
			NGC 4214		
23″........................	13.24	0.33	−0.39	...	DV 1961
90″........................	11.54	0.38	−0.33	...	N 1970
138″........................	10.71	0.43	−0.34	...	DV 1961

B. INFRARED PHOTOMETRY

Aperture (1)	J (2)	H (3)	K (4)	$J-H$ (5)	$H-K$ (6)	Date/Telescope[a] (7)
			NGC 4670			
9″	12.99	12.42	12.15	0.57	0.27	1982 Apr 8, MMT
27″........................	11.84	11.21	11.02	0.63	0.19	1978 Feb 9, K36
55″........................	11.46	10.81	10.56	0.65	0.26	1978 Feb 9, K36
			NGC 4214			
41″........................	10.92	10.35	10.18	0.57	0.17	A 1977

[a] A = Aaronson; DV = de Vaucouleurs; N = Neff. MW 100 = Mount Wilson 100 inch. P60 = Palomar 60 inch. MMT = Multipole Mirror telescope. K36 = Kitt Peak 36 inch.

TABLE 2

GALAXY PROPERTIES

Parameter	NGC 4214 $12^{\rm h}13^{\rm m}08\overset{\rm s}{.}4$, $+36°36'30''$	NGC 4670 $12^{\rm h}42^{\rm m}49\overset{\rm s}{.}9$, $27°23'56''$
V_r (km s^{-1})	300 ± 31[a]	1051 ± 29[a]
Type	IX9 III–IV[b]	SB0 P[b]
D(Mpc)	6.4	12.1
B_T	10.20	13.05
M_B	−18.8	−16.9
M_H/L_B	0.30[c]	0.33[d]
log f (ergs s^{-1} $\mathrm{Å}^{-1}$ cm^{-2}) in 20″ aperture:		
1400 Å	−12.81[e]	−13.10[e]
1700 Å	−12.95[e]	−13.22[e]
3600 Å	−13.71[f]	−13.61[e]
4400 Å	−13.65[f]	−13.61[e]
5500 Å	−13.84[f]	−13.78[e]
6700 Å	...	−13.84
1.25 μm	−14.33[e]	−14.34[e]
1.65 μm	−14.54[e]	−14.52[e]
2.2 μm	−14.92[e]	−14.89[e]
log Hβ	−12.1[f]	−12.4[f]
$U-B$	−0.39	−0.54
$B-V$	0.33	0.38
$V-K$	2.18	2.10
5007/Hβ	2.6[e]	2.6[e]
6584/Hα	0.09[e]	0.09[e]
[O/H]	−0.26[g]	−0.22[h]
[N/H]	...	−0.89[h]
Radio flux (mJy):		
1415 MHz	30[i]	11[j]
2380 MHz	36[k]	15[k]

[a] Huchra *et al.* 1983.
[b] de Vaucouleurs *et al.* 1976.
[c] Allsop 1979.
[d] Heckman *et al.* 1978.
[e] This paper.
[f] Hunter and Gallagher 1982.
[g] Hunter *et al.* 1982.
[h] Alloin *et al.* 1979.
[i] Hummel 1981.
[j] van der Kruit 1971.
[k] Dressel and Condon 1978.

spatial components by *IUE*. Cross sections of the spectra perpendicular to the dispersion at 1550 Å and at 1850 Å are shown in Figure 2. Spectra of the two components are shown in Figure 3. From intensity cross sections taken every 100 Å, we find that the intensity maxima are separated by ~8″ and their intensity ratio is ~3. The integrated fluxes from the two components also differ by about a factor of 3, and the fainter component appears to be redder than the brighter one. The *IUE* large-aperture orientation is 81° ± 2° (0° points north, and 90° east). Therefore, the faint component is to the east of the brighter component. Figure 4 is a *B* band video camera map of the central region of NGC 4214 which shows that there is a knot (B) of emission 5″ ± 1″ to the east of the brightest knot (A). An Hα map is also given by Hunter (1982). At Hα the peak-to-peak flux ratio of these components determined from video camera measurements is ~2; the flux ratio from KPNO echelle measurements is about 3 (Hunter 1982). The separation and intensity ratios in the optical and UV are consistent. In the *B* map, the next condensation to the east lies outside the *IUE* aperture, and to the west there is a faint blob 7″–8″ from the central knot, probably responsible for the extended UV emission in that direction. NGC 4670 is optically extended but unresolved in the UV. The slit orientation is 99° ± 2°, and the two brightest H II regions (regions 1 and 2 in Hunter 1982) are within the aperture.

Table 2 contains a summary of the observed properties of the two galaxies including radio data from other sources. The optical and IR fluxes have been normalized to a 20″ circular aperture using the smallest aperture broad-band photometry and standard growth curves (de Vaucouleurs, de Vaucouleurs, and Corwin 1976). The ultraviolet fluxes are observed in the 10″ by 20″ oval aperture of *IUE*. For comparison with the 20″ optical data, we have made an approximate correction upward by 30% for NGC 4214 and 10% for NGC 4670. Note that for objects of constant surface brightness (or large core radii in the case of a Hubble profile) the

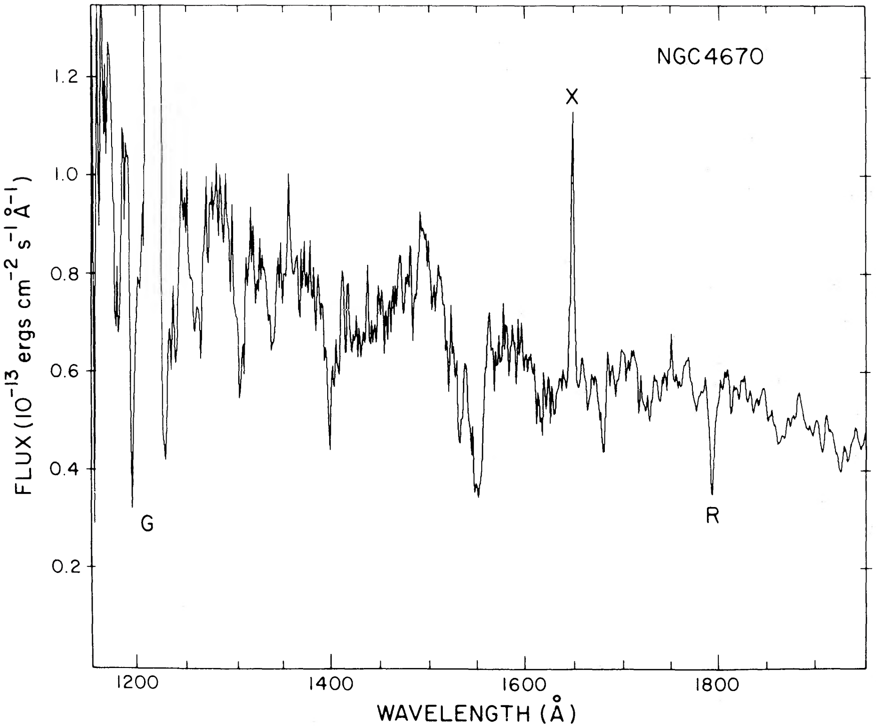

FIG. 1*a*

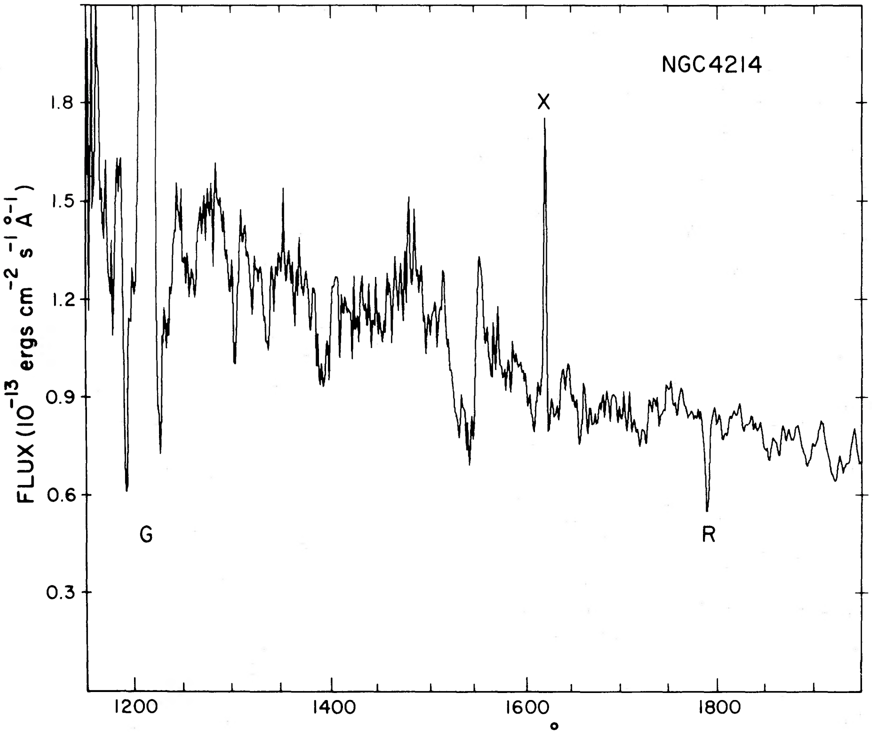

FIG. 1*b*

FIG. 1.—*IUE* SWP spectra of (*a*) NGC 4670, (*b*) NGC 4214, and (*c*) the smoothed sum of the above two spectra with features identified. The symbols X, R, and G denote hits, reseaux, and the geocoronal Lyα line, respectively. The ×'s in Fig. 1*c* mark the region where we have removed the geocoronal feature.

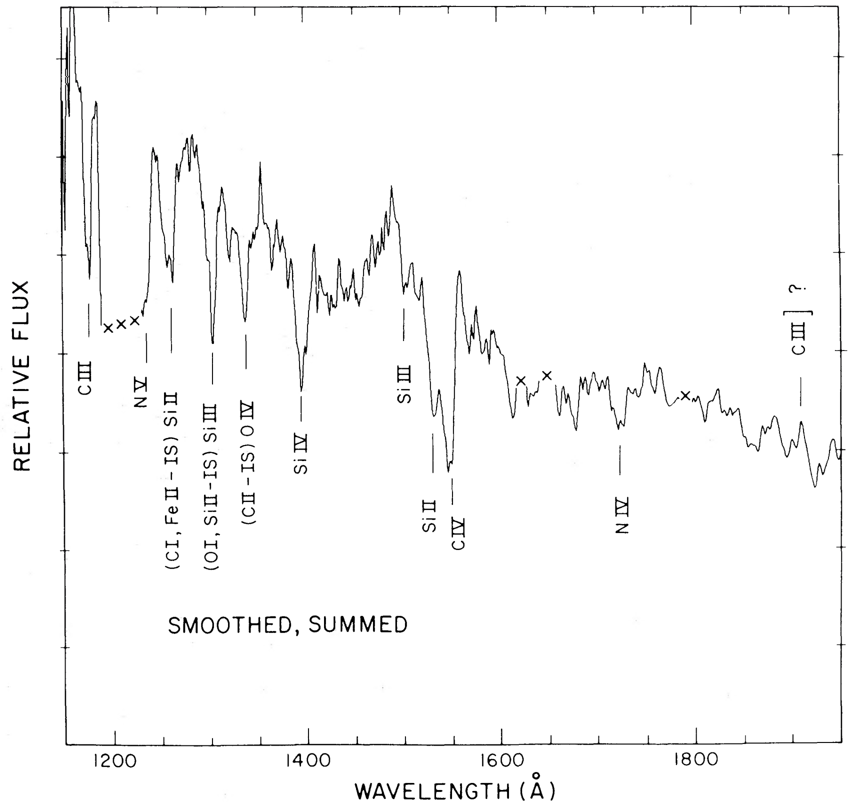

FIG. 1*c*

correction from a 10″ × 20″ oval to a 20″ circle is 50%, while for objects with very small core radii the correction is less than 10%. Note also that the accuracy of the *IUE* flux based on calibration error and measured signal-to-noise is only ~10%. The problem of matching apertures is thus not severe, but should be kept in mind. In Figure 5 we show the UVOIR energy distributions with all the data scaled to a 20″ circular aperture. For NGC 4670, the radio beam size is larger than the optical size of the galaxy. For NGC 4214 the radio beam sizes are 2′.7 at 2380 MHz and 7′.8 at 1415 MHz.

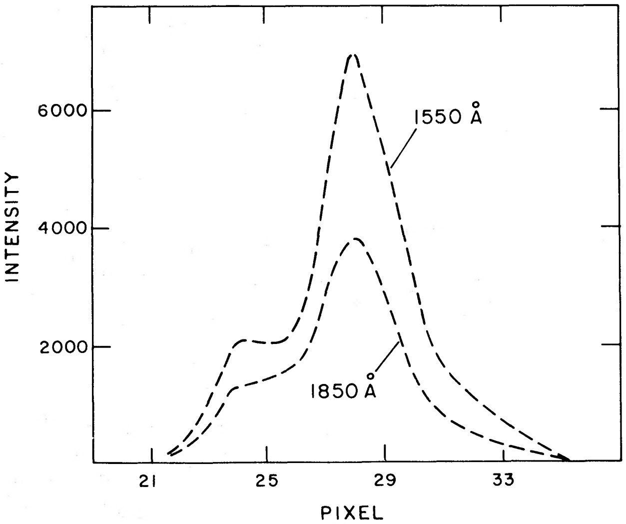

FIG. 2.—The spatial cross section along the 20″ *IUE* aperture of the spectrum of NGC 4214. Two condensations, H II regions/OB associations, are visible.

III. STELLAR CONTENT

a) *The Ultraviolet Spectrum*

The ultraviolet energy distribution produced by a collection of young stars depends both on the mix of stellar types *and* on the effects of any internal or intervening interstellar dust (e.g., Koornneef 1978; Vangioni-Flam *et al.* 1980; Lequeux *et al.* 1981; Koornneef and Code 1981). The stellar content of these young regions can be obtained, however, from the strengths of stellar atomic absorption features which are unaffected by dust.

The UV spectra of both galaxies (Figs. 1*a*–1*c*) are dominated by O stars. Comparison with the *IUE* Spectral Atlas (Wu *et al.* 1981) shows that these must be dwarfs earlier than O7, or supergiants earlier than B0.5, in order to match the P Cygni profile in C IV and the C III absorption line at 1179 Å as well as the pattern of line blanketing in the region 1400 Å–1600 Å. The *IUE* atlas was obtained at the same resolution as the galaxy spectra and is thus the best vehicle for

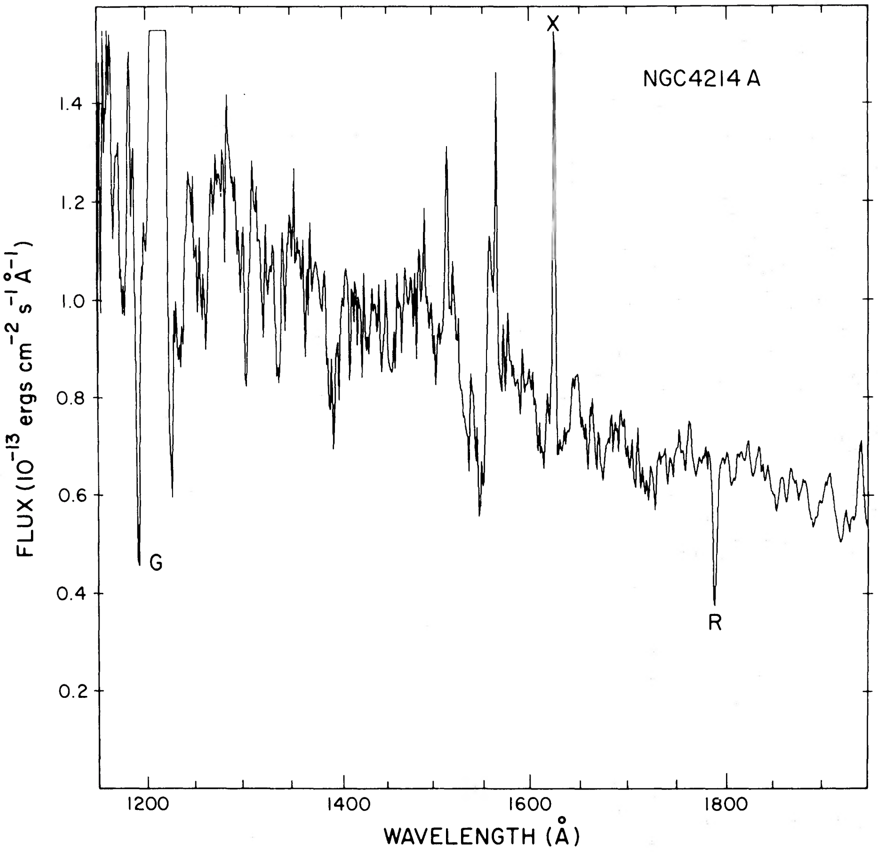

FIG. 3*a*

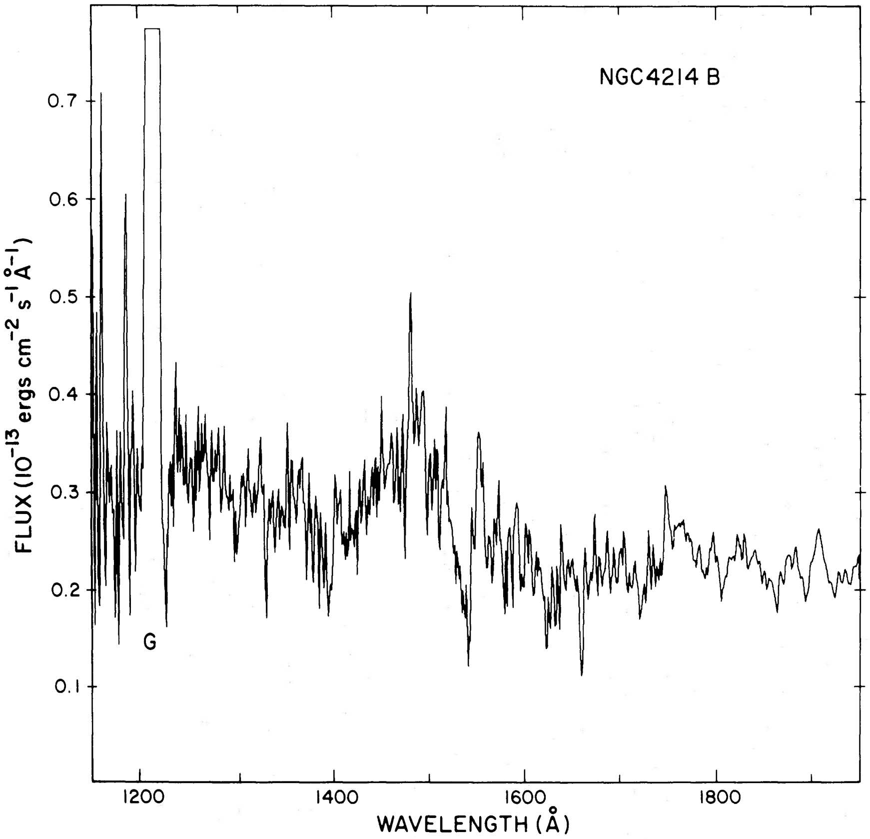

FIG. 3*b*

FIG. 3.—The ultraviolet spectrum of (*a*) the brightest of the two condensations, (*b*) the spectrum of the fainter condensation.

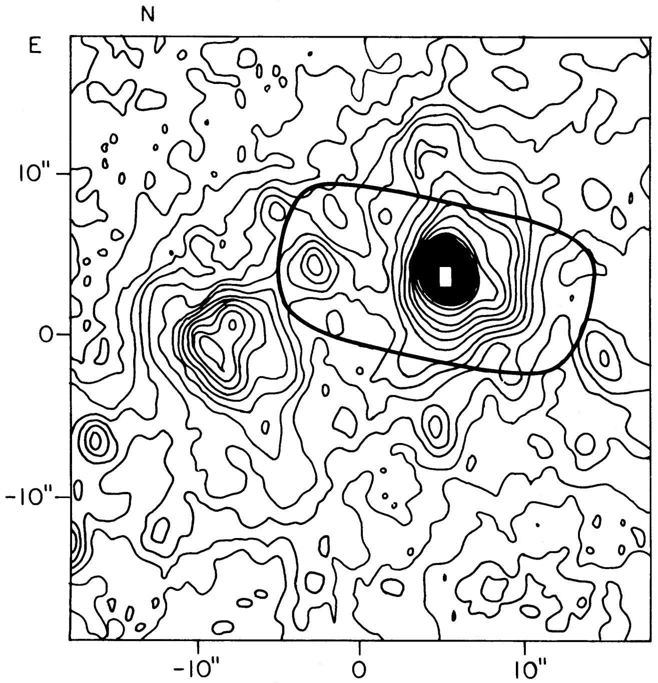

FIG. 4.—The *B* band map of the central 36" × 36" region of NGC 4214. The contours are logarithmic with interval 0.2 mag. The highest and lowest contours are 17.7 and 21.5 mag arcsec^{-2}, respectively. North is at the top, and east is to the left. The *IUE* aperture is shown as an oval; component A is to the west and B is to the east.

comparison. Note, however, that spectra of OB stars in intermediate-metallicity environments may differ systematically from those of the Galactic standard stars (Hutchings 1980; Prévot *et al.* 1980).

The depth of the C IV line relative to the continuum indicates that early O stars contribute on the order of 50% of the flux at 1500 Å. The required number of O5 or equivalent stars necessary to produce 50% of the flux in the observed region is ~2000 for NGC 4670 and ~500 for NGC 4214. These values are consistent with the estimates of Hunter (1982) based on Hα photometry.

Are these hot stars Wolf-Rayet stars? Conti and Massey (1981) have found that as many as 50% of the optically brightest stars in giant H II regions are massive Wolf-Rayet stars. In NGC 604, for example, 50 W-R stars are known from optical data (D'Odorico and Rosa 1981). These stars are distributed throughout the H II region. In the UV, the signature of such stars is strong P Cygni profiles in such lines as C IV 1549 Å, Si IV 1399 Å, N V 1240 Å, and N IV 1719 Å (D'Odorico and Rosa 1981; D'Odorico, Patriarchi, and Perinotto 1980). We see only weak P Cygni profiles in our spectra, and we conclude that normal O stars dominate the emission in NGC 4214 and NGC 4670

Stars with effective temperatures of 30,000 K < T_e < 35,000 K and initial masses near 20 $M_\odot$ are the most probable contributors to the mid-UV light detected by the *IUE*. This conclusion is in agreement with the expection that a region having a sufficiently high star

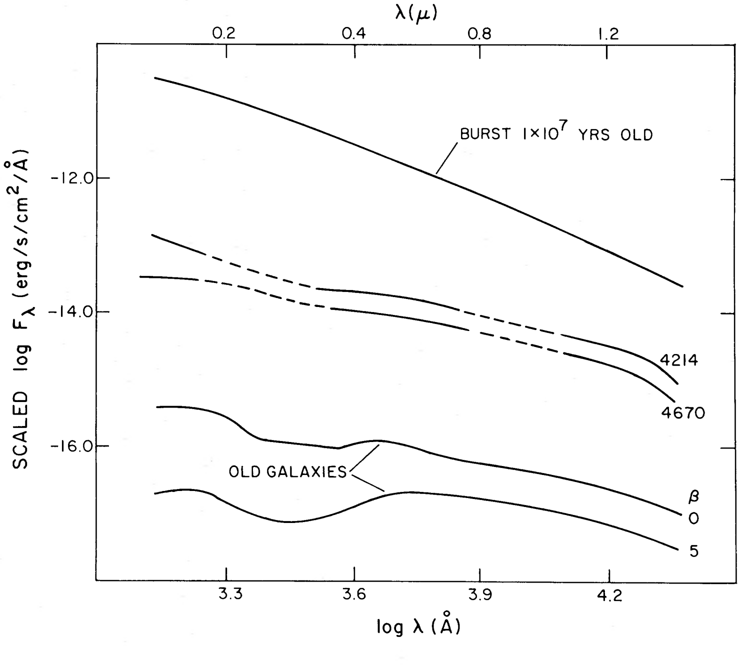

FIG. 5.—The UVOIR energy distributions of NGC 4214 and NGC 4670 with models superposed for comparison. The "burst" model is for a 10^7 year old galaxy; its form at this age is *independent* of the IMF—the most massive stars dominate at all wavelengths. The "old" models are for galaxies with a Salpeter (slope 2.35) IMF, age 10^{10} years, and whose star formation rates were either constant ($\beta = 0$) or *e*-folded 5 times over its age ($\beta = 5$). The dashed lines indicate regions without observations.

formation rate will maintain a well-populated upper main sequence on which stars are distributed following a near normal initial mass function (IMF); i.e., $N(M)$, the number of stars with mass M, is given by $dN(M)/dM = M^{-x}$, with $x \approx 2$ (Israel and Koornneef 1979; Lequeux *et al.* 1981). If the IMF were flat or if the stellar distribution contained anomalous supermassive stars, then the composite spectral type would be pushed well into the early O star regime (see Lequeux *et al.* 1981), contrary to the observed strengths of C III and Si IV in our spectra.

b) The Integrated UVOIR Energy Distribution

One might expect that reflection and extinction have to be taken into account in attempts to determine the stellar population in regions with high rates of star formation. The total flux and energy distribution of the stellar plus nebular combination is sensitive to both the spatial structure of the H II region and the unknown wavelength dependence of the grain scattering phase functions (Witt and Lillie 1978; Bohlin *et al.* 1980). However, it is clear from the spectra that the regions we observe have relatively little extinction. Comparison with *IUE* spectra of O stars with known reddening limits the extinction to significantly less than $A_V = 1$ mag. Furthermore, the Balmer decrements in NGC 4214 and NGC 4670 are both approximately 3—i.e., normal for Case B with no reddening. The ratios of Hβ to UV flux are as expected for a population which is only slightly reddened. In general, observations of both the H I column densities and the Balmer decrements in irregular galaxies and extragalactic H II regions (Huchra 1977) indicate low ($A_V < 1$) internal extinction.

Simple evolutionary models similar to those in Huchra (1977) or Larson and Tinsley (1978) have been used to model expected broad-band UVOIR energy distributions for populations with a variety of parameters. These models have UV and IR fluxes computed from UV stellar observations by the TD-1 satellite (Jamar *et al.* 1976) and revised IR stellar colors compiled by two of us (M. A. and J. P. H.). A detailed description of the model algorithm is given in Huchra (1977). The major descriptive parameters for the models are IMF, age, and time dependence of the star formation rate (SFR). Secondary parameters are the upper mass limit of the IMF and two parameters that we cannot model presently: metallicity and internal extinction. Extinction appears to be unimportant for the systems discussed here, in fact, the models *rule out* any significant extinction in the galaxies. The most extreme models (youngest models with flattest IMFs) allow less than 0.6 mag of visual extinction in these galaxies if the reddening law is normal (Allen 1973). For the extragalactic H II regions, it is hard to make composite population models as blue as the observed continuum if there is *any* reddening at all. Metallicity effects can only be modeled when we have both evolutionary tracks and model atmosphere or observational calibrations of the fluxes and colors for low-metallicity stars.

We find, as might be expected, that models with a variety of parameters can fit the observed energy distributions. We can rule out models with a continuous-decreasing SFR and even models with constant SFR: they do not produce enough blue stars. The simplest models that provide reasonable fits to the 1400 Å $-V$, $U-B$, and $V-K$ colors have $\sim 5\%$ of their mass in a recent ($1 \times 10^8 > t > 2 \times 10^7$ years) burst of star formation superposed on an older population which has experienced a roughly constant SFR in the past. The mass fraction depends on the assumed IMF of the burst. NGC 4670 has a slightly more "well developed" (i.e., older and redder) underlying population than NGC 4214. This might be expected from the relative masses of the two galaxies and their relative morphology—NGC 4670 is larger and more regular in appearance.

We are unable to place stringent limits on the IMF. From the observed equivalent width of Hβ, we know that the slope of the IMF must be Salpeter (2.35) or flatter. Except for this limit, it is possible to trade off between IMF, age, and the fraction of mass in the burst to fit the observations.

IV. DISCUSSION

a) Comparison with Other Young Stellar Systems

Table 3 summarizes ultraviolet properties of several luminous H II regions and their associated OB stellar complexes. These giant star-forming systems all reside within larger galaxies and are similar to superassociations which are found in many late type galaxies (Wray and de Vaucouleurs 1980), but are distinct from the isolated "extragalactic H II region" galaxies like Mrk 36, I Zw 18, and II Zw 70 (Sargent and Searle 1970; Huchra *et al.* 1982). Because the ultraviolet extinction within a galaxy, and to a lesser degree the distribution of stellar temperatures for massive stars (Brunish and Truran 1982), are likely to depend on metallicity, we have chosen comparison objects which, like NGC 4214 and NGC 4670, lie in the intermediate gas metallicity range defined by the Magellanic Clouds (Hunter, Gallagher, and Rautenkrantz 1982). In fact, both the lines and continuum shape of the *IUE* spectra of NGC 4214 and NGC 4670 are very similar to those of NGC 604 and NGC 5471, giant H II regions in M33 and M101 respectively (Rosa 1980), and the clumpy irregular galaxies described by Benvenuti, Casini, and Heidmann (1979, 1982). They differ from those of the extragalactic H II regions—Mrk 36 (Huchra *et al.* 1982), II Zw 70 (Huchra *et al.* 1983), Mrk 116 (Wu, Huchra, and Geller 1983)—the UV spectra of this class of objects rise more steeply at short wavelengths and show only very weak, if any, absorption features, and their optical spectra imply metallicities much lower than in the Small Magellanic Cloud (French 1980).

Extinction does not appear to present a problem for the interpretation of the NGC 4214 and NGC 4670 data. The UV fluxes, combined with the approximate spectral type shown in the *IUE* data, are consistent with the number of ionizing photons required by the Hβ fluxes. Therefore, the NGC 4214 and NGC 4670 data provide

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TABLE 3

Comparative Ultraviolet Properties of Hot Stellar Systems

Object (1)	F (1400) (2)	C (3)	$F(\mathrm{H}\beta)$ (4)	$F(\mathrm{H}\beta)/F(1400)*1$ Å (5)
NGC 604	2.0(−13)^{a}	−0.3	5.0(−13)^{e}	2.5
30 Dor	1.5(−11):^{b}	...	~5.0(−10)^{c,f}	33
NGC 2363	5.5(−14)^{c}	−0.1	1.9(−12)^{c}	35
NGC 4214	1.2(−13)^{d}	−0.35	4.6(−13)^{d}	3.8
NGC 4449	2.5(−14)^{c}	−0.1	...	...
NGC 4670	7.2(−14)^{d}	−0.30	5.0(−13)^{d}	7
NGC 5471	6.0(−14)^{a}	−0.4	6.0(−13)^{g}	10

Col. (1), Object: NGC 604 is a supergiant H II region in M33, 30 Doradus gives core region properties. N2363 = Mrk 71, supergiant H II region in Irr galaxy NGC 2366. H II region in NGC 4449 (Irr galaxy discussed by Lequeux *et al.* 1981. NGC 5471, supergiant H II region in M101.

Col. (2), Estimated UV flux; notes are referred to by number in each column.

Col. (3), C refers to F magnitude difference between 1400 Å and 1700 Å.

Col. (4), Observed $F(\mathrm{H}\beta)$ scaled approximately to the *IUE* aperture size (*ANS* measurement for 30 Dor).

Col. (5), Hβ flux to UV flux ratio; neither flux is corrected for internal reddening.

[a] From Rosa 1981 10″ × 20″ aperture *IUE* observations.

[b] Estimated from 1500 *ANS* observations given by Israel and Koornneef 1979.

[c] Lequeux *et al.* 1981.

[d] This paper; see Tables 1 and 2.

[e] Flux extrapolated from 14″ aperture observations of Hawley and Grandi 1977.

[f] Strauss, Braz, and Ducati 1979.

[g] Scaled from 20″ aperture of Searle 1971.

reasonable standards for the interpretation of other giant H II regions.

The H II regions in NGC 2363 and the 30 Dor core region exhibit much less UV flux relative to recombination radiation than characterize NGC 4214 and NGC 4670, but extinction plays a more important role in the former objects. Approximately 3 mag of extinction at 1400 Å would bring the UV/Hβ ratio in 30 Dor into agreement with other regions, assuming similar spectral types of the exciting stars. The required UV extinction implies $E_{B-V} \approx 0.4$ mag with a standard reddening law, which appears quite reasonable from optical and UV studies of the 30 Dor core (cf. Cassinelli, Mathis, and Savage 1981).

b) *30 Doradus*

Optical studies of the 30 Dor region have not been able to identify enough individual hot stars to account for the photoionization of the region (cf. Feitzinger *et al.* 1980). This problem led Cassinelli, Mathis, and Savage (1981) to suggest that the early-type object R136a near the center of the nebula might account for all of the ionizing flux if it were superluminous (and thus supermassive). This solution requires adoption of ~4 mag of extinction at 1400 Å in the line of sight to the central region.

The spectra of our H II regions in other galaxies are dominated by O star features, not the high-temperature Wolf-Rayet features characteristic of R136a: they do not require the existence of supermassive stars. In fact, R136a does *not* dominate the UV spectrum of the 30 Dor core; it accounts for only ~10% of the UV flux (Table 3) derived from the flux at 1550 Å in the *ANS* 2′.5 × 2′.5 aperture (Israel and Koornneef 1979). Long-slit observations of 30 Dor by Koornneef and Mathis (1981) show strong O star features clearly out to 20″. These features are still apparent at 50″. These observations raise a question: If one is willing to assume that the UV extinction to R136a is 4 mag, why not apply a similar extinction to the rest of the stars in the immediate vicinity? In fact, Koornneef and Code (1981) observe high extinction away from the central source. If 30 Dor were observed in a large aperture or placed at the distance of our galaxies, it would probably look just like them. The results presented in Table 3 suggest that the photoionization could then be explained by many O stars of modest luminosity.

Cassinelli *et al.* argue that it is unlikely that ~30–100 O stars can reside in a 0.1 pc diameter volume; therefore, the central ionizing object must be a single star. However, there is no need to place the ionizing source in such a small volume. The highest resolution radio data on 30 Dor indicate that the radio flux of ~12 Jy, corresponding to 3×10^{51} recombinations s^{-1}, arises from a ~5.1 arcmin^2 area (Mills, Turtle, and Watkinson 1978), corresponding to a linear diameter ~30 pc.

Few hot stars have been identified in the 30 Dor core. However, it may be difficult to identify individual high-temperature stars in regions of high extinction and dense nebulosity. In a recent report, Melnick (1978) managed to double the number of known W-R stars in the 30 Dor core. These objects are all within 2′ of the center and have $m_v \approx 12.5$–14. Melnick suggests that there is substantial incompleteness in the surveys of W-R stars in dense star-forming regions in the LMC (let alone O stars!).

Ebbets and Conti (1982) favor the supermassive star hypothesis for R136a on the basis of a detailed study of the optical spectrum. However, they note that the possibility of a dense cluster of luminous early-type stars cannot be ruled out. In either case, it is not clear that R136a alone must account for the ionization of the gas in the 30 Dor core. Our observations of slightly reddened H II regions in galaxies show that it is possible to have extended distributions of hundreds to thousands of O stars with very early average spectral type contained in regions a few hundred parsecs in size. The lesson suggested by the observations of H II regions in other galaxies is that the extended distribution of stars and gas must be taken into account in any attempt to understand the source of ionization in 30 Dor.

V. CONCLUSIONS

The ultraviolet spectra of giant H II complexes in galaxies of widely differing morphologies are remarkably similar in their general properties. NGC 4214 is a chaotic looking Magellanic irregular, while NGC 4670 is more amorphous and centrally concentrated. Yet the spectra of the regions observed in these two galaxies differ only in minor details. Furthermore, both spectra are very similar in both continuum and absorption features to those obtained for NGC 604 and NGC 5471, giant H II regions in the spirals M33 and M101, respectively (Rosa 1980). Early type O stars produce $\sim 50\%$ of the UV light: for an O5 average type, there are 2000 hot stars in the region observed in NGC 4670 and 500 in NGC 4214. The stellar content of these regions is consistent with a solar-neighborhood IMF. The optical data indicate little internal extinction.

P Cygni profiles of the C IV feature in these and other H II regions in galaxies indicate mass loss from the hot stars. Our observations of extragalactic star forming regions suggest an alternative explanation to a single, supermassive star in 30 Dor: many hundreds of O stars can and do form in small regions.

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REFERENCES

Aaronson, M. 1977, Ph.D. thesis, Harvard University.
Aaronson, M., *et al.* 1982, *Ap. J. Suppl.*, **50**, 241.
Allen, C. W. 1973, *Astrophysical Quantities* (London: Athlone Press).
Alloin, D., Collin-Souffrin, S., Joly, M., and Vigroux, L. 1979, *Astr. Ap.*, **78**, 200.
Allsopp, N. 1979, *M.N.R.A.S.*, **188**, 765.
Arp, H. 1966, *Ap. J. Suppl.*, **14**, 1.
Benvenuti, P., Casini, C., and Heidmann, J. 1979, *Nature*, **282**, 272.
———. 1982, *M.N.R.A.S.*, **198**, 825.
Bohlin, R. C., Hill, J. K., Stecher, T. P., and Will, A. N. 1980, *Ap. J.*, **239**, 137.
Brunish, W., and Truran, J. 1982, preprint.
Cassinelli, J., Mathis, J., and Savage, B. 1981, *Science*, **212**, 1497.
Chiosi, C., Nasi, E., and Sreenivasan, S. 1978, *Astr. Ap.*, **63**, 103.
Conti, P., and Massey, P. 1981, *Ap. J.*, **249**, 471.
de Vaucouleurs, G. 1961, *Ap. J. Suppl.*, **5**, 233.
———. 1975, in *Galaxies and the Universe*, ed. A. Sandage, M. Sandage, and J. Kristian (Chicago: University of Chicago Press), p. 557.
de Vaucouleurs, G., de Vaucouleurs, A., and Corwin, H. 1976, *Second Reference Catalog of Bright Galaxies* (Austin: University of Texas Press).
D'Odorico, S., and Rosa, M. 1981, preprint.
D'Odorico, S., Patriarchi, P., and Perinotto, M. 1980, Proceedings of the ESO/ESA Workshop on Dwarf Galaxies, ed. M. Tarenghi and K. Kjar, p. 103.
Dressel, L. and Condon, J. 1978, *Ap. J. Suppl.*, **36**, 53.
Ebbets, D., and Conti, P. 1982, *Ap. J.*, **263**, 108.
Feitzinger, J., Schlosser, W., Schmidt-Kaler, Th., and Winkler, Chr. 1980, *Astr. Ap.*, **84**, 50.
French, H. 1980, *Ap. J.*, **240**, 41.
Hawley, S., and Grandi, S. 1977, *Ap. J.*, **217**, 420.
Heckman, T., Balick, B., and Sullivan, W. 1978, *Ap. J.*, **224**, 745.
Huchra, J. 1977, *Ap. J.*, **217**, 928.
Huchra, J., Davis, M., Latham, D., and Tonry, J. 1983, *Ap. J. Suppl.*, **52**, 89.
Huchra, J., Geller, M., Gallagher, J., and Hunter, D. 1982, in *Advances in Ultraviolet Astronomy: Four Years of IUE Research*, ed. Y. Kondo (NASA: in press).
Huchra, J., Hartmann, L., Geller, M., Gallagher, J., and Hunter, D. 1983, in preparation.
Hummel, E. 1981, Ph.D. thesis, Leiden.
Hunter, D. 1982, *Ap. J.*, **260**, 81.
Hunter, D., and Gallagher, J. 1982, in press.
Hunter, D., Gallagher, J., and Rautenkranz, D. 1982, *Ap. J. Suppl.*, **49**, 53.
Hutchings, J. 1980, *Ap. J.*, **237**, 285.
Israel, F., and Koornneef, J. 1979, *Ap. J.*, **230**, 390.
Jamar, C., Macau-Hercot, D., Monfils, A., Thompson, G. I., Houziaux, L., and Wilson, R. 1976, *Ultraviolet Bright-Star Spectrophotometric Catalog* (Paris: ESA SR-27).
Koornneef, J. 1978, *Astr. Ap.*, **64**, 179.
Koornneef, J., and Code, A. 1981, *Ap. J.*, **247**, 860.
Koornneef, J., and Mathis, J. 1981, *Ap. J.*, **245**, 49.
Larson, R. and Tinsley, B. 1978, *Ap. J.*, **219**, 46.
Lequeux, J., Maucherast-Joubert, M., Deharveng, J., and Kunth, E. 1981, *Astr. Ap.*, **103**, 305.
Melnick, J. 1978, *Astr. Ap. Suppl.*, **34**, 383.
Mills, B., Turtle, A. and Watkinson, A. 1978, *M.N.R.A.S.*, **185**, 263.
Neff, J. 1970, *M.N.R.A.S.*, **149**, 45.
Prévot, L., *et al.* 1980, *Astr. Ap.*, **90**, L13.
Rosa, M. 1980, *Astr. Ap.*, **85**, L21.
Sakka, K., Oka, S., and Wakamatsu, K. 1973, *Pub. Astr. Soc., Japan*, **25**, 317.
Sandage, A., and Tammann, G. 1974, *Ap. J.*, **194**, 559.
———. 1982, *Ap. J.*, **256**, 339.
Sargent, W., and Searle, L. 1970, *Ap. J.* (*Letters*), **162**, L155.
Searle, L. 1971, *Ap. J.*, **168**, 327.
Searle, L., Sargent, W., and Bagnuolo, W. 1973, *Ap. J.*, **179**, 427.
Strauss, F., Biaz, M., and Ducati, J. 1979, *Astr. Ap.*, **74**, 280.
Van der Kruit, P. 1971, *Astr. Ap.*, **15**, 110.

Vangioni-Flam, E., Lequeux, J., Maucherat-Joubert, M., and Rocca-Volmerange, B. 1980, *Astr. Ap.*, **90**, 73.

Wray, J., and de Vaucouleurs, G. 1980, *A.J.*, **85**, 1.

Witt, A. N., and Lillie, C. F. 1978, *Ap. J.*, **222**, 909.

Wu, C.-.C., Boggess, A., Holm, A., Schiffer, F., III, and Turnrose, B. 1981, *IUE Ultraviolet Spectral Atlas*, preliminary ed. (Greenbelt: Goddard Space Flight Center).

Wu, C.-C., Huchra, J., and Geller, M. 1983, in preparation.

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