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MULTIAPERTURE PHOTOMETRY OF ISOLATED GALAXIES

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ABSTRACT

Multiaperature U, B, V photometry of isolated galaxies by Huchra and Thuan shows a behavior different from normal field galaxies in that the inner regions of the isolated galaxies appear to have excess blueness similar to galaxies with active nuclei. The implication of this finding is that gas, which does not escape from isolated galaxies sinks into the nucleus and gives rise to nonstellar radiation.

Subject headings: galaxies: photometry — galaxies: stellar content — galaxies: structure

I. INTRODUCTION

Lately an increasing number of papers dealing with the differences between "cluster population" and "field population" of galaxies have been published. The definitions of both these populations are somewhat ambiguous; studies of the space distribution of galaxies have shown that all galaxies appear to be clustered on scales of up to 10 Mpc (Peebles 1974), and that there is no obviously identifiable and smoothly distributed component. Shane (1975) said that "it is well known that galaxies are not distributed in space with statistical uniformity unless on a very large scale. Double and multiple galaxies, groups of a few tens, and clusters with hundreds of members are commonplace. There may be no important background of field galaxies." This is probably why the class of field galaxies is usually defined, by default, to be those galaxies which do not reside in the "cores" of rich clusters or in the recognizable envelope of a rich cluster and which do not belong to any of the numerous sparse groups of galaxies. As an example, van den Bergh (1962) considered an object to be an isolated field galaxy if "it appeared to have no more than two (nondwarf) companions."

It is of interest to compare field to cluster galaxies. Van den Bergh (1976) was the first to notice the "anemic" appearance of cluster spirals compared to field spirals. Krumm and Salpeter (1979*a*, *b*) have shown that S0 galaxies inside the Virgo cluster have less hydrogen (on the average) than similar galaxies outside the cluster. Chamaraux, Balkowski, and Gerard (1980) have compared the amounts of H I in cluster spirals and the field and concluded that the cluster spirals are deficient in H I relative to the field spirals. The paucity of gas in a galaxy reduces the rate of the star formation, and hence we expect that over a long time scale a change in the stellar population will develop. Galaxies which lose their gas will contain mainly old stars while galaxies that maintain their gas, or manage to accrete gas, have star formation going on, young stars, etc. The above evidence, as well as along other lines (statistics of galaxies, X-ray emission from cluster gas, the existance of Fe in the cluster gas, etc.) have led to the floating speculation that galaxies in dense regions (like clusters of galaxies) do not evolve as close systems. The galaxies may be affected by the interaction with the intracluster gas (Gisler 1976; Lea and DeYoung 1976; Livio, Regev, and Shaviv 1978, 1980) giving rise to ablation of gas in some cases and accretion in others (Shaviv and Salpeter 1981). If the density of galaxies is high over a long period of time, interaction between galaxies can also affect the internal structure of galaxies.

The purpose of this work is to look for changes in the stellar population or other properties in galaxies found in low density regions. A crucial point is clearly the selection procedure of the measured galaxies. A number of catalogs of field galaxies have been published recently. Turner and Gott (1975) selected a sample of field galaxies from the Shapley-Ames catalog, while other groups (e.g., Kirshner, Oemler, and Schechter 1978) produced their own survey. Huchra and Thuan (1977, hereafter HT) published a list of what they defined as "truly isolated" galaxies. The galaxies were selected from the sample of Turner and Gott (1975) on the basis of the following criteria: (a) the galaxy has no companion

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brighter than 15.7 mag within a 45′ radius, and (*b*) the galaxy does not belong to any de Vaucouleurs (1975) group. The first criterion is essentially a condition on the density of massive (bright) galaxies of whatever class at the location of the examined object. The HT sample contains only 12 galaxies out of the 1088 that are listed in the Zwicky catalog. It is evident that these galaxies represent an approximation to an "isolated" galaxy. The term "isolated" is evidently a relative term that expresses the extent to which the effects of neighboring galaxies can be ignored *today*.

We present in this paper multiaperture U, B, V photometry for all the HT galaxies. In § II we summarize the information previously available on the galaxies and describe our observational technique; in § III we present the photometry and show, in 12 subsections, the multiaperture results. Finally § IV compares the results with data on other galaxies and discusses some possible conclusions.

II. OBSERVATIONS

a) *The Sample*

The previously available information on our sample is summarized in Table 1. There we give, besides two identifications for each galaxy and its equatorial coordinates, different morphological descriptions, size, integral magnitude and colors, and the radial velocity. Note that the faintest galaxy in the sample has a magnitude of 14.0 (Z0902+36), and the condition is that no galaxy brighter than 15.7 mag is close by. The 15.7 mag condition is actually determined by the available catalogs. However, the difference of 1.7 mag is probably sufficient to rule out the possibility that the HT galaxies are just the brightest galaxies in otherwise faint groups of galaxies. Some additional information for individual objects may be found in the remarks to the table. We added, for the sake of completeness, the description given by Sulentic and Tifft in the *Revised New General Catalogue* (1977).

We note that most, if not all, of the objects in the HT sample of isolated galaxies are spirals. This fact agrees with the findings of Dressler (1980) and many previous observers (see references in the above work) that the galaxy population of the low density fields consists mainly of spirals while ellipticals and S0's are generally found in dense regions. Note also that the basic criterion for selection of these galaxies is their location in a low density region.

b) *Photometry*

The multiaperture photometry was carried out with the two-star photometer on the 40 inch (1 m) reflector of the Wise Observatory. The photometer has been described previously (Nather and Warner 1971; Vidal, Brosch, and Livio 1978). We have used the instrument as a one-star photometer, by observing the objects with the main photomultiplier (RCA 8850) and standard U, B, V filters. The second channel was set to observe a nearby star in the B band, to monitor possible atmospheric changes. The diaphragms used range from 0.5 mm to 4.0 mm in diameter, corresponding, at the f/13.5 focus, to 7″–58″.

The observational procedure was as follows: The galaxy was centered visually in the smallest aperture of the main channel, and a suitable star was chosen to monitor the sky transparency in the second channel. The measurement proceeded through the standard U, B, V filters until the desired number of counts was accumulated. Normally, the total integration time was chosen such that the quantity σ, defined by

$$\sigma = \frac{(N_g)^{1/2} + (N_s)^{1/2}}{N_g - N_s} \quad (1)$$

(where N_g is the number of counts obtained from the galaxy and the sky and N_s is the number obtained from the sky only), was less than 0.01. The measurement proceeded through all the apertures, and then a nearby sky region was observed with the largest aperture and the U, B, V filters. Here again, enough counts were accumulated to ensure a statistical error of less than 1%.

The observations took place between 1978 and 1980, and most galaxies have been measured at least twice. We have also observed photometric standards from Landolt (1973) and two galaxies whose multiaperture photometry has been performed by other observers. The extinction and transformation obtained each night through observations of standard stars, indicate an error in magnitude and colors of $\sigma_V \sim 0.02$ mag, $\sigma_{B-V} \sim 0.02$ mag, and $\sigma_{U-B} \sim 0.03$ mag. This is smaller than the day-to-day differences, caused presumably by difficulties in centering. We have averaged the magnitudes and colors measured for each object and through each aperture on different dates, weighing the values according to the representative errors in that day transformation. The adopted magnitudes and colors for the different apertures used are listed in Table 2.

c) *Photography*

In order to perform a uniform morphological classification of the HT sample galaxies, we have obtained electronographic exposures of all these objects. We used the McMullan 40 mm diameter camera at the f/7 focus of the 40 inch reflector. The camera has an S20 cathode and has been described previously (McMullan, Powell, and Curtiss 1972). All the plates were of G5 emulsion and have been exposed uniformly for 20 minutes through a RG610 filter. This cathode-filter combination corresponds to the standard R color.

TABLE 1

THE LIST OF GALAXIES OBSERVED

Galaxy ID[a]	1950 Equatorial Coordinates	Morphological Description[b]	de Vaucouleurs T Type[c]	Major Axis Dimension[c] log D_{25}	Integrated Magnitude[c] m_c	Integrated $(B-V)_0$[c]	Integrated $(V-B)_0$[c]	Estimated Total Magnitude[d]	Corrected Radial Velocity
N2684, 04662	8^h51^m3, 49° 20′	..., S(pec)	...	...	...	...	...	13.4	3372
N2712, 04708	8 56.2, 45 06	SBR, SBb	3	1.46	12.57	0.68	0.09	12.3	1849
Z0902+36, 04767 ...	9 02.6, 36 32	..., SO	...	...	...	...	...	14.0	...
N3622, 06339	11 17.2, 67 31	..., S?	...	...	...	...	...	13.7	...
N3682, 06459	11 24.7, 66 52	SAS, SO-a	0	1.31	...	...	...	13.4	...
N4566, 07769	12 33.6, 54 30	S, S	...	1.18	...	...	...	13.9	5398
N5301, 08711	13 44.4, 46 22	SAS, Sc	3	1.64	12.66	...	...	13.0	1673
N5448, 08969	14 01, 49 25	RSXR, SBb	1	1.62	12.12	...	...	12.7	2103
N5832, 09649	14 57.6, 71 53	SB, Sbc?	3	1.60	...	...	...	13.3	621
N5987, 09971	15 38.8, 58 15	S, Sb	3	1.67	...	...	...	13.3	...
Z1549+47, 10070 ...	15 49.7, 47 23	..., S	...	...	...	...	...	13.6	...
N6012, 10083	15 51.9, 14 44	SB, SBa	2	1.36	...	...	...	13.1	2081

[a] First number, NGC number or Zwicky identifier, second number, UGC number.
[b] First entry according to RC1 or RC2; second entry from UGC.
[c] From RC2.
[d] From UGC.

REMARKS.—*N2684.*—UGC: group of S galaxies p; vB center region, asymmetric disk. RNGC: round, bright toward center, high surface brightness, several companions. *N2712.*—RC1: vsBN; smooth narrow bar 0′55×0′03. (r): 1′0×0′55; Several knotty branching arms. RNGC: elongated, bright toward center, bar suspected. *Z0902+36.*—Dressel and Condon 1978: Radio 2380 MHz 5±3 mJy. *N3622.*—RNGC: Brighter toward center, slightly elongated, high surface brightness. *N3682.*—RC1: Classification doubtful dimension for B part only. RNGC: almost edge-on system, brighter toward center, equatorial dark lanes. *N4566.*—RC2: in Haro 32 (A1241+55 A, B) group. RNGC: spiral, round, brighter toward center, stellar nucleus. *N5301.*—RC1: B bulge partially observed by dark lane; vSH or no def. N.; two main arms with strong dark lane. Bottinelli *et al.* (1970): Radio $M_{H I}=3.5$ 10^9 M_0. RNGC: elongated, diffuse, little brighter toward center, dark lanes. *N5448.*—RC1: s v BN with dark matter on one side, F bar, F(r): 1′6×0′5, 2 F arms form pseudo (R): 3′3×1′4. RNGC: spiral, much inclined, elongated, bright ring nucleus. *N5832.*—RC1: no BN, F bar, F asymmetric spiral structure, classification uncertain possibly SB(s) m? RC2: QSO 3C 309.1 ($Z=0.904$) at 6′1. UGC: Singular luminosity, unusual object; bar and spiral pattern visible on blue PA map only, nuclear region appears too B for class Sc. RNGC: stellar, little brighter toward center, diffuse. *N5987.*—RC2: $m_p=12$ in MCG I (1962), $m_p=13.3$ in CGCG IV (1968). RNGC: almost edge-on system, brighter toward center, equatorial dark lane. *N6012.*—Dressel and Condon 1978: radio 2380 MHz 12±5 mJy. RNGC: Bars spiral, diffuse oval, small brightness toward center, knotty.

TABLE 2

RESULTS OF *UBV* PHOTOMETRY FOR GALAXIES IN TABLE 1

Galaxy Identification	Aperture Size (arcsec)	Number of Times Observed	*V* magnitude	$B-V$	$U-B$
N2684	22	2	14.05	0.88	−0.36
	29	2	13.79	0.80	−0.30
	58	2	13.31	0.62	−0.03
N2712	15	2	14.42	0.96	0.18
	22	2	13.85	0.94	0.21
	29	2	13.56	0.87	0.23
	58	2	12.73	0.77	0.26
Z0902+36	22	2	13.70	1.18	0.03
	29	2	13.55	1.18	0.15
	58	2	13.33	1.04	0.58
N3622	22	2	13.86	0.59	−0.39
	29	2	13.65	0.57	−0.31
	58	2	13.32	0.47	−0.15
N3682	7	1	14.57	0.72	−0.14
	15	1	13.55	0.73	−0.02
	29	1	13.00	0.75	0.04
	58	1	12.60	0.77	0.15
N4566	22	2	13.83	1.13	−0.19
	29	2	13.67	1.04	0.02
	58	2	13.41	0.80	0.08
N5301	7	2	15.96	0.86	−0.52
	15	2	14.64	0.96	−0.04
	29	2	13.77	0.80	0.11
	58	2	13.00	0.71	0.20
N5448	7	2	15.20	1.20	−0.16
	15	2	14.19	1.06	0.14
	29	2	13.26	0.99	0.38
	58	2	12.57	0.87	0.40
N5832	15	1	15.26	1.02	−0.36
	29	1	14.24	0.77	−0.01
	58	1	13.26	0.65	0.21
N5987	7	2	14.46	1.20	0.15
	11	1	13.73	0.78	0.28
	15	2	13.70	1.11	0.44
	22	1	13.28	1.10	0.52
	29	3	13.02	1.07	0.49
	58	3	12.50	1.00	0.54
Z1549+47	7	3	15.07	1.11	−0.10
	11	1	14.62	1.00	−0.07
	15	3	14.20	0.95	0.16
	22	2	13.77	0.91	0.22
	29	3	13.53	0.87	0.21
	58	3	13.26	0.80	0.27
N6012	7	1	15.37	1.41	−0.58
	15	2	14.63	1.03	0.12
	22	1	14.04	0.96	0.25
	29	2	13.68	0.88	0.20
	58	2	12.91	0.77	0.22

III. RESULTS

We have reclassified the HT galaxies on the basis of our electronographs. Because of their better scale (29″ mm^{-1}) and finer grain, many more pixels are available for classification than used in the UGC (Nilson 1973).

In most cases our morphological types coincide with the UGC classification, differing by at most one subclass, with the exception of NGC 2684. The Hubble type assigned in the classification was translated into the de Vaucouleurs revised system according to the precepts given by de Vaucouleurs, de Vaucouleurs, and Corwin (1976, hereafter RC2). The allotted *T* types differ by about 1.1 from those in RC2 for the seven common objects.

As galaxian colors and magnitudes are a function of the measuring aperture, it is customary to define a standard diameter to which the measuring apertures are

TABLE 3

COEFFICIENTS FOR UGC→RC1 TRANSFORMATION

Range of T	A'	B'
$T<0$..........	0.218–0.023(5−T)	0.871
$0\leq T\leq 4$	0.099–0.023(5−T)	0.911
$T\geq 5$..........	0.099	0.911

normalized. We have chosen to use the major diameters measured on blue Palomar Sky Survey prints, D_{ss}, as appear in the UGC. These diameters were translated to those in the Reference Catalog (de Vaucouleurs and de Vaucouleurs 1964, hereafter RC1) using the correction formulae derived from RC2 for the transformations UGC→RC2 and RC1→RC2. These depend on the assigned T type, and have the form:

$$\log D_{\mathrm{RC}}(0)=A'(T)+B'(T)\log D_{\mathrm{UGC}} +0.4\log(d/D)_{\mathrm{UGC}}, \quad (2)$$

which includes the correction to face-on orientation (de Vaucouleurs 1961). Here d and D are respectively the blue minor and major axes from UGC. The coefficients $A'(T)$ and $B'(T)$ appear in Table 3.

For all our objects we used the T type derived from the deduced morphological type, and calculated the face-on diameter $D_{\mathrm{RC}}(0)$. Five galaxies of the sample have diameters given in RC1. We have compared our values with those in the catalog and found:

$$\langle D_{\mathrm{RC}}(0)-D_{\mathrm{RC1}}(0)\rangle = 0\!'.19\pm 0\!'.45. \quad (3)$$

Thus we used finally

$$D_{\mathrm{RC1}}(0)=D_{\mathrm{RC}}(0)-0\!'.19, \quad (4)$$

where $D_{\mathrm{RC}}(0)$ is the value derived in (2). These values of $D_{\mathrm{RC1}}(0)$ were used to normalize the measuring apertures.

The galactic latitude of the HT galaxies ranges from 40° to 68°, and their colors and magnitudes are slightly affected by galactic reddening. To correct for this and obtain absolute colors, we have used the standard Whitford (1958) law with the galactic extinction law of Burstein and Heiles (1978).

Table 4 presents the photometry. Besides the identifying name of the galaxy, we show the size of the aperture through which the object has been measured, the normalized aperture $A/D_{\mathrm{RC1}}(0)$, the magnitude and colors found (corrected for galactic extinction), and the Hubble morphological type from our reclassification.

In 12 subsections we present plots of $B-V$ and $U-B$ versus normalized apertures (Figs. 1*a*–1*l*) and our remarks on the individual objects. We have not corrected the photometry for internal absorption within the objects, because this correction could be different for the HT galaxies than, for example, for the ones studied by the Vaucouleurs in RC2. Note however, that the color-aperture relations are taken from de Vaucouleurs (1961) where the colors are indeed corrected for internal absorption. This should be kept in mind when comparing the standard color-aperture curves to our data, although its effect is not significant; for the object with the highest inclination the resultant color excesses are $E(B-V)\approx 0.10$, $E(U-B)\approx 0.08$ independent of the measuring aperture. Also, all objects were found to have a blue excess. A correction for internal reddening may only increase this effect. We proceed now to the description of each object.

1. *NGC 2684* (Fig. 1*a*).—This galaxy lies near the center of a rather compact cluster of galaxies. Huchra and Thuan (1977) assume that the cluster is in the background of the galaxy, but no radial velocity data are available to substantiate this claim. The position of NGC 2684 is rather close to the apparent center of the cluster; four other galaxies are nearby and seem brighter than the other cluster galaxies. It is obvious that a possible connection between NGC 2684 and the surrounding cluster should be looked for. We could not obtain radial velocities for the cluster galaxies, but this should be one of the first things to be checked.

NGC 2684 has been classified by us as Irr II, whereas the UGC assigned a type S_{pec}. Its appearance on electronographic plates does not resemble a spiral shape at all. The central region is indeed very bright, but the outer parts do not have equal surface brightness and seem mottled.

The multiaperture photometry is presented in Figure 1*a*. The color-aperture relation for the outermost point corresponds to Sbc or Sc, and not to the type assigned by us.

2. *NGC 2712* (Fig. 1*b*).—This large spiral is the only one in the HT sample with previously published color information. Pettit (1954) measured the object through a 2\'.27 diameter aperture with the 60 inch (1.5 m) telescope on Mount Wilson. His results, transformed into standard B, V colors according to RC2, are $V=12.14$, $B-V=0.72$.

Bigay and Dumont (1954) used the 1.2 m telescope of the Haute Provence Observatory to measure this object through apertures of diameter 2\'4 and 3\'.35. Their results, again transformed into B and V according to RC2 precepts are respectively: $V=12.05$; $B-V=0.69$ (2\'4) and $V=12.25$; $B-V=0.67$ (3\'.35). De Vaucouleurs, de Vaucouleurs, and Corwin (1978) have also performed multiaperture photometry of NGC 2712. Their results (not shown in Fig. 1*b*) compare quite well with our data, except for the $U-B$ through their smallest aperture.

The color-aperture results are presented in Figure 1*b*. Although our values of $B-V$ refer to regions inner to

TABLE 4

CORRECTED *UBV* PHOTOMETRY FOR GALAXIES IN TABLE 1

Galaxy Identification	Aperture Size A (arcsec)	Normalized Aperture $A/D_{RC1}(0)$	V magnitude[a]	$B-V$[a]	$U-B$[a]	Morphological Classification[b]
N2684............	22	0.74	13.99	0.86	−0.37	Irr II
	29	0.98	13.73	0.78	−0.31	
	58	1.96	13.25	0.60	−0.04	
N2712............	15	0.15	14.33	0.93	0.16	SBa
	22	0.21	13.76	0.91	0.19	
	29	0.28	13.47	0.84	0.21	
	58	0.55	12.64	0.74	0.24	
Z0902+36	22	0.49	13.54	1.15	0.00	E–S0?
	29	0.64	13.39	1.15	0.12	
	58	1.31	13.24	1.01	0.56	
N3622............	22	0.68	13.86	0.59	−0.39	Sa?
	29	0.90	13.65	0.57	−0.31	
	58	1.82	13.32	0.47	−0.15	
N3682............	7	0.10	14.57	0.72	−0.14	Sa?
	15	0.17	13.55	0.73	−0.02	
	29	0.36	13.00	0.75	0.04	
	58	0.72	12.60	0.77	0.15	
N4566............	22	0.53	13.82	1.13	−0.19	Sa–b
	29	0.71	13.66	1.04	0.02	
	58	1.41	13.40	0.80	0.08	
N5301............	7	0.08	15.95	0.86	−0.52	Sb–c
	15	0.14	14.64	0.96	−0.04	
	29	0.28	13.77	0.80	0.11	
	58	0.58	13.00	0.71	0.20	
N5448............	7	0.03	15.19	1.20	−0.16	SBa–b
	15	0.05	14.18	1.06	0.14	
	29	0.10	13.25	0.99	0.38	
	58	0.20	12.56	0.87	0.40	
N5832............	15	0.05	15.22	1.01	−0.37	Sc–SBc?
	29	0.09	14.20	0.76	−0.02	
	58	0.18	13.22	0.64	0.20	
N5987............	7	0.04	14.46	1.20	0.15	Sb
	11	0.05	13.73	0.78	0.28	
	15	0.07	13.70	1.11	0.44	
	22	0.11	13.28	1.10	0.52	
	29	0.16	13.02	1.07	0.49	
	58	0.31	12.50	1.00	0.54	
Z1549+47	7	0.18	15.03	1.10	−0.11	Sa–b?
	11	0.27	14.58	0.99	−0.08	
	15	0.36	14.16	0.94	0.15	
	22	0.52	13.73	0.90	0.21	
	29	0.70	13.49	0.86	0.20	
	58	1.41	13.22	0.79	0.26	
N6012............	7	0.08	15.27	1.38	−0.60	SBb
	15	0.16	14.53	1.00	0.10	
	22	0.25	13.94	0.93	0.23	
	29	0.34	13.58	0.85	0.18	
	58	0.67	12.81	0.74	0.20	

[a] Corrected for galactic extinction.
[b] Electronographic plates.

those measured by Pettit and by Bigay and Dumont, they connect smoothly with the previous values, and indicate, for the outermost point, a morphological class of Sbc and not, as proposed here, SBa.

3. *Z0902+36* (Fig. 1*c*).—This object belongs to one of the early Hubble classes, either S0 or E. This assignment is confirmed by the last point of the color-aperture diagrams. On the PSS prints, at least four very faint galaxies can be discerned within a 6′ radius around the object.

4. *NGC 3622* (Fig. 1*d*).—We have assigned it a morphological type Sa? while the UGC classified it as S?. The outermost point on Figure 1*d* points toward a Sm, Im, or possibly Sc.

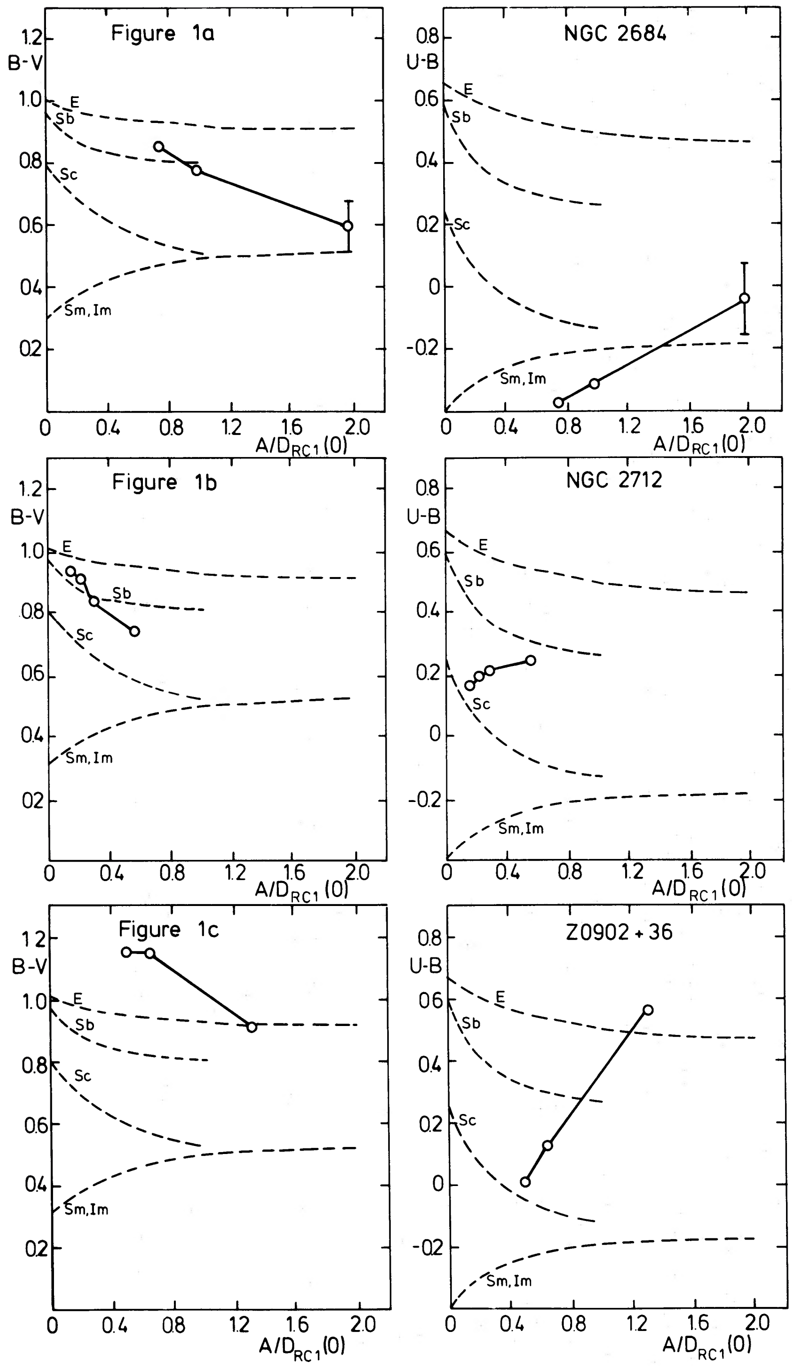

FIG. 1.—Color-aperture relations for isolated galaxies. De Vaucouleurs normal color-aperture relations are represented by broken lines, experimental points by circles joined by a full line. Representative errors have been marked on the outermost point of 1*a*.

5. *NGC 3682* (Fig. 1*e*).—We have classified the galaxy as Sa? while the UGC assigns a type S0-a and RC2 gives SAS. The final point in the color-aperture plots indicates a morphological class of Sb or Sbc.

6. *NGC 4566* (Fig. 1*f*).—If the morphological type is based on the outer most point there, it should be a Sb or Sbc while we assigned it a Sa-b (R). The galaxy is classified in the UGC as an S type.

7. *NGC 5301* (Fig. 1*g*).—This high inclination ($i = 77°$, RC2) object was classified here as Sb-c while RC2 assigns SAS and UGC assigns Sc. The last point on the color-aperture plots (Fig. 1*g*) points toward an Sbc type.

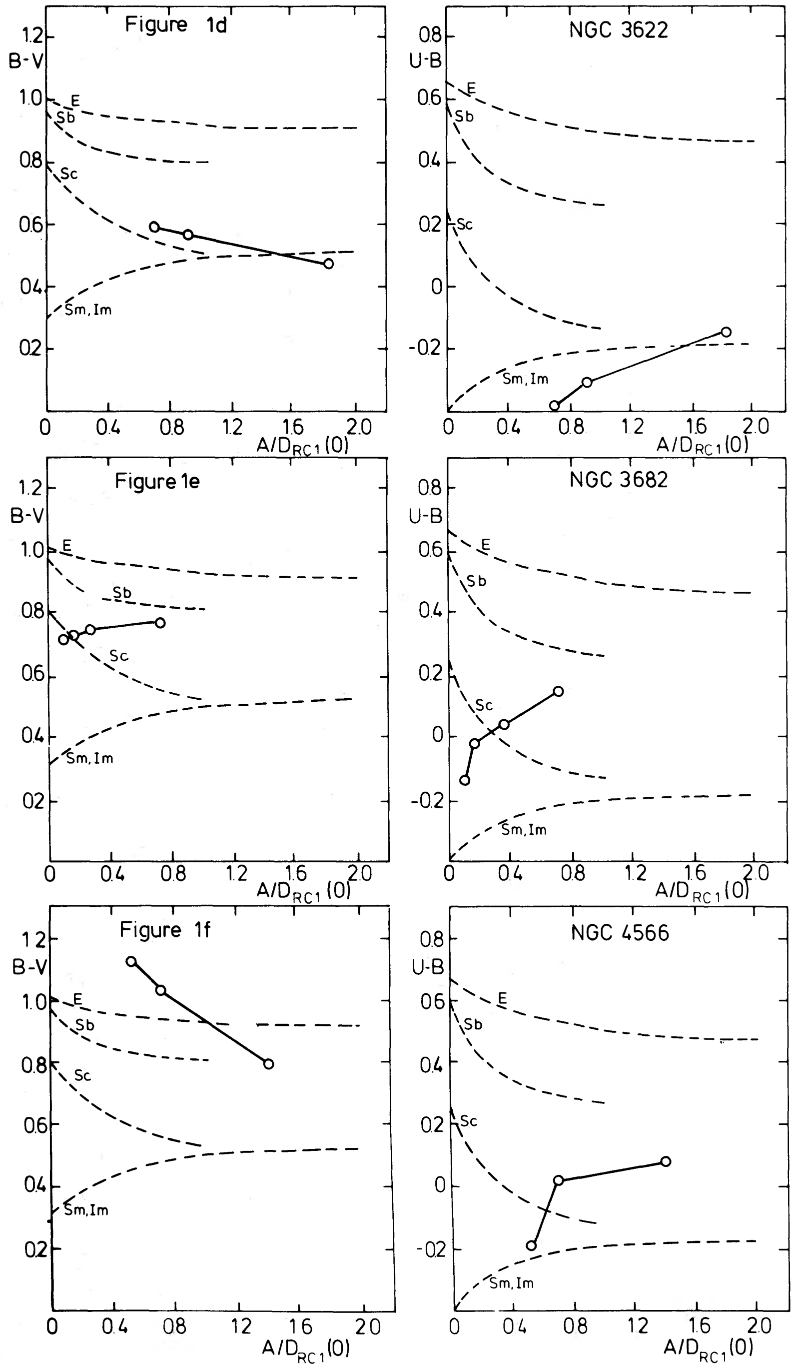

FIG. 1—*Continued*

A dark lane appears on our electronograph (see also remark to Table 1) and possibly is responsible for the apparent reddening of the second point on the $(B-V)$ versus $A/D_{RC1}(0)$ plot relative to the three other points.

8. *NGC 5448* (Fig. 1*h*).—The last point (largest aperture) sits well within the Sb morphological class, in agreement with our assignment and also that in the UGC. The faint bar and the outer pseudo-ring (see remark in Table 1) are easily visible on our electronograph.

9. *NGC 5832* (Fig. 1*i*).—Our electronographs show this object only as a diffuse patch. There, as also on

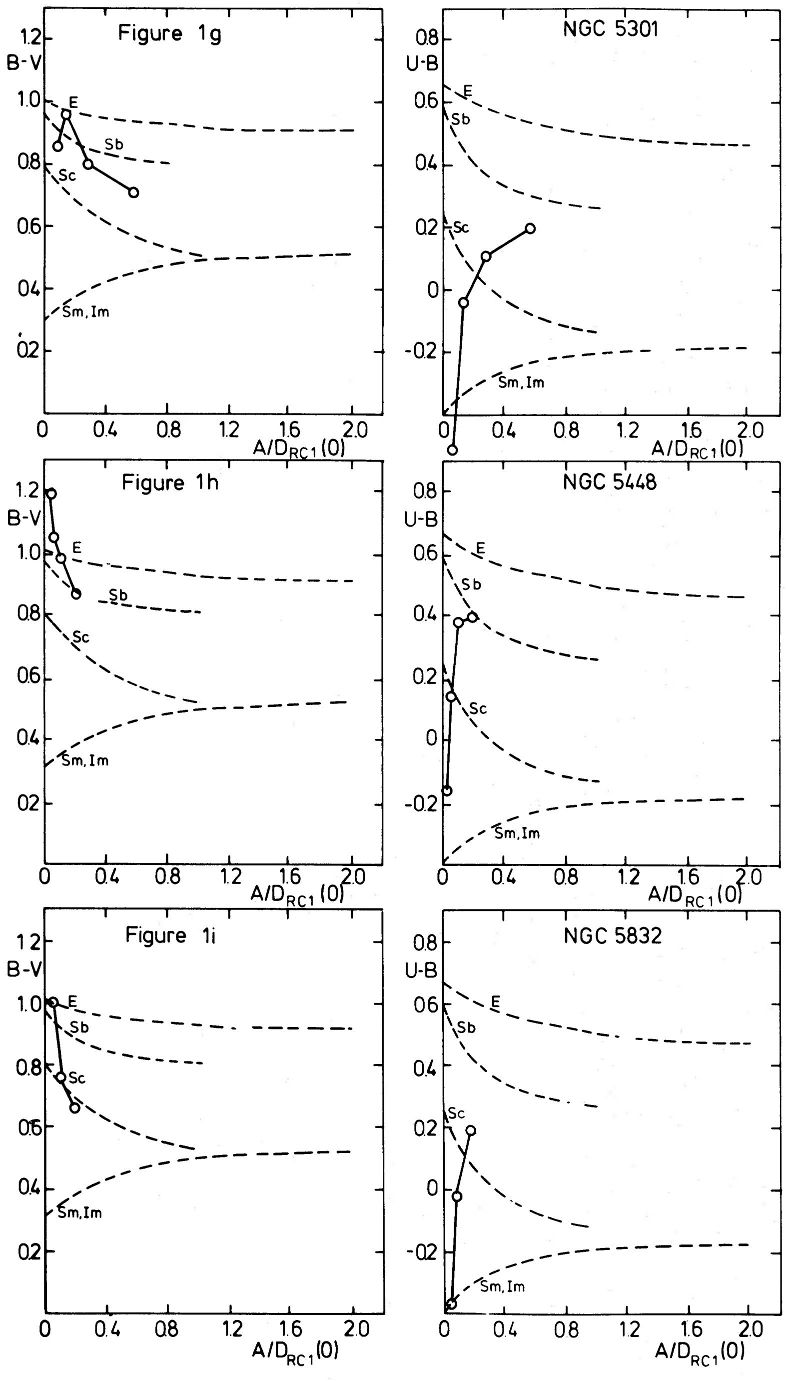

FIG. 1—*Continued*

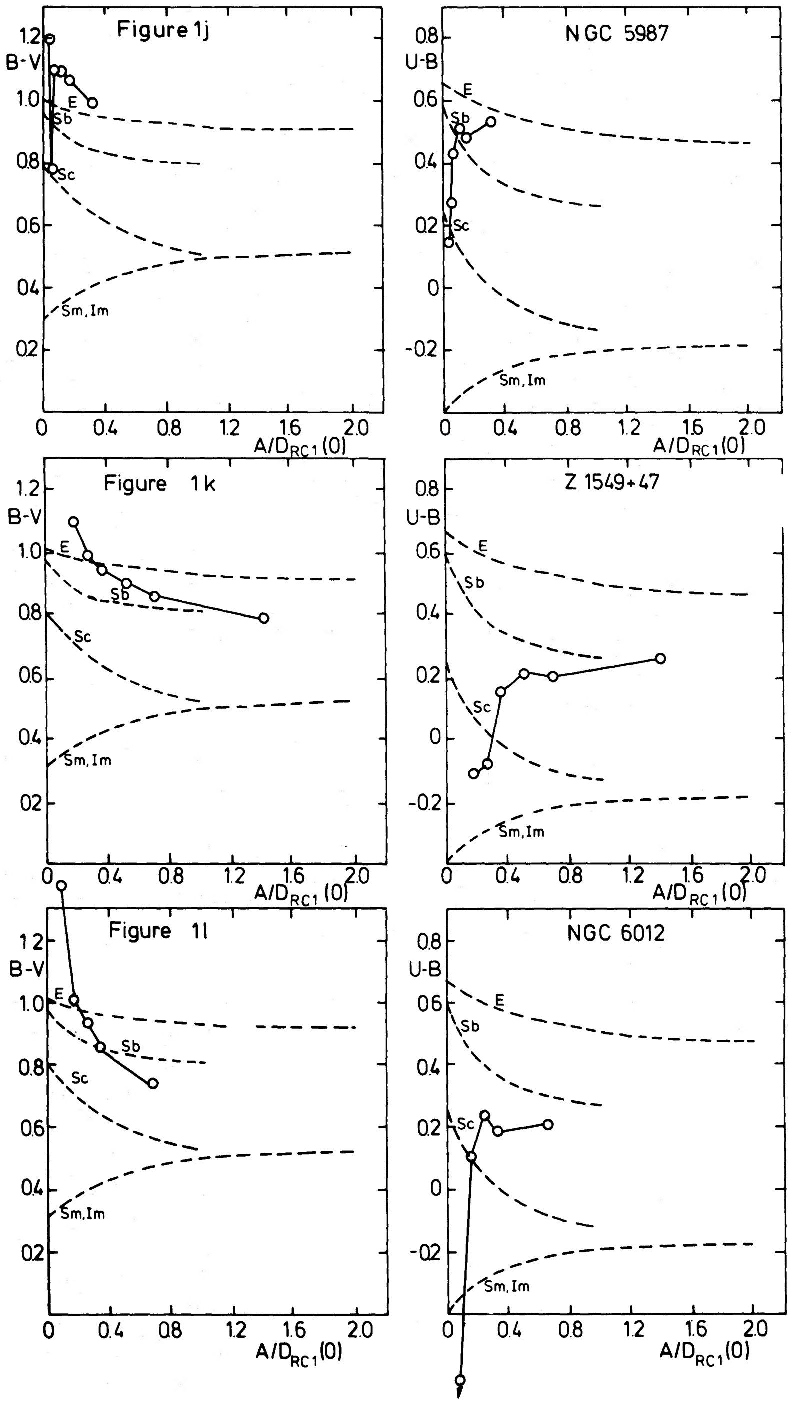

FIG. 1—*Continued*

PSS, a stellar object appears about 30″ from the center of the image. The object has been identified as a foreground star by Burbidge *et al.* (1971). The closeness of the star to the center of the image causes an increase of the surface brightness at that point, which has probably been taken to represent the nucleus of the galaxy. It is highly probable that the telescope has been pointed toward that point and that the foreground star has been included within all our measuring apertures.

Could the existence of this foreground object so close to the center of the galaxy induce the UGC and the RNGC to remark on the brightness of the nuclear regions (see remark in Table 1)?

Note the Burke (1978) lists this object as a candidate for a QSO-galaxy pair. The QSO 3C 309.2 is 6′.2 away.

The color-aperture relations found here are depicted in Figure 1*i*. These, mainly the outermost point, imply a morphological class Sbc or Sc, confirming the UGC and our assignment.

10. *NGC 5987* (Fig. 1*j*).—This large spiral was classified by the UGC and by us as Sb. The color-aperture relations shown in Figure 1*j* have their outermost point on the E-S0 plots. On the other hand, our electronographs show a bright, enlarged central bulge, whose color distribution was probably measured. The apparent blueing of the second point on the $B-V$ versus $A/D_{RC1}(0)$ plot relative to the other points could possibly indicate an emission region near the galaxy center.

11. *Z1549+47* (Fig. 1*k*).—The color-aperture relations found for this object imply a morphological type Sb. We have assigned it Sa-b? and thus find our estimate confirmed when referred to the outer regions.

12. *NGC 6012* (Fig. 1*l*).—Our color-aperture measurements indicate a morphological type Sb or Sbc. We have assigned it SBb while the UGC classified it SBa, with a subsequent de Vaucouleurs type SB(rs)ab:. The bar is prominent on our electronographs, having a visible condensation on the northern end.

In order to confirm our multiaperture results we have observed two objects that have been measured by other observers. We have chosen for this purpose M87 = NGC 4486 whose extensive multiaperture results appear in de Vaucouleurs (1961) and NGC 4881 which has been measured by Strom and Strom (1978). In Figure 2 we compare our results with those obtained by other observers. The measurements reported here are depicted as open squares while those of the other observers are represented by open circles. The representative experimental error is shown by error bars on our outermost points. This error was obtained by comparing measurements of the isolated galaxies performed on different dates.

We find that our points reproduce rather well the published measurements, the difference being in most cases less than 0.05 mag. The same is true for the measurements of NGC 2712 in common with de Vaucouleurs, de Vaucouleurs, and Corwin (1978). Note that their smallest aperture measurement of this object could be problematic (Corwin, private communication).

IV. DISCUSSION

We have presented a series of multiaperture color measurements of a sample of "isolated" galaxies selected according to some *a priori* set of criteria. Assuming no substantial error in our aperture normalization we remark that half of our measuring points are within $A \leq 0.25\ D_{RC1}(0)$, while only 15% of the points represent regions with $A \geq 0.9\ D_{RC1}(0)$. Hence our data refer mainly to the inner regions of the sample galaxies.

We find the following results:

a) All HT galaxies show a tendency of $U-B$ to redden with increasing aperture. Only Sm and Im galaxies show the same $U-B$ versus A behavior (namely $U-B$ increases with A) while all other galaxies show opposite behavior (namely $U-B$ decreases with A).

Very often we find (cf. Figs. 1*a*, 1*c*, 1*g*, 1*h*, 1*i*, and 1*j*) that the $U-B$ versus A slope is much larger than the corresponding one in Sm or Im galaxies. Even if we

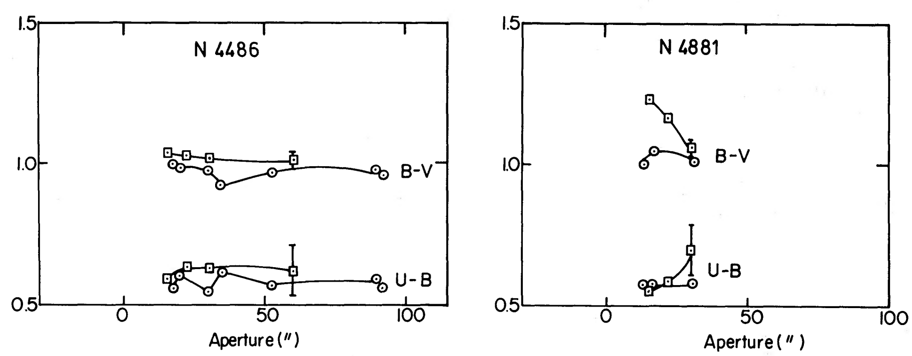

FIG. 2.—Comparison of our photometry with others; color-aperture relations for two selected objects. Representative errors have been marked on the outermost point. Our points are represented by open squares. Data derived by other observers are represented by open circles.

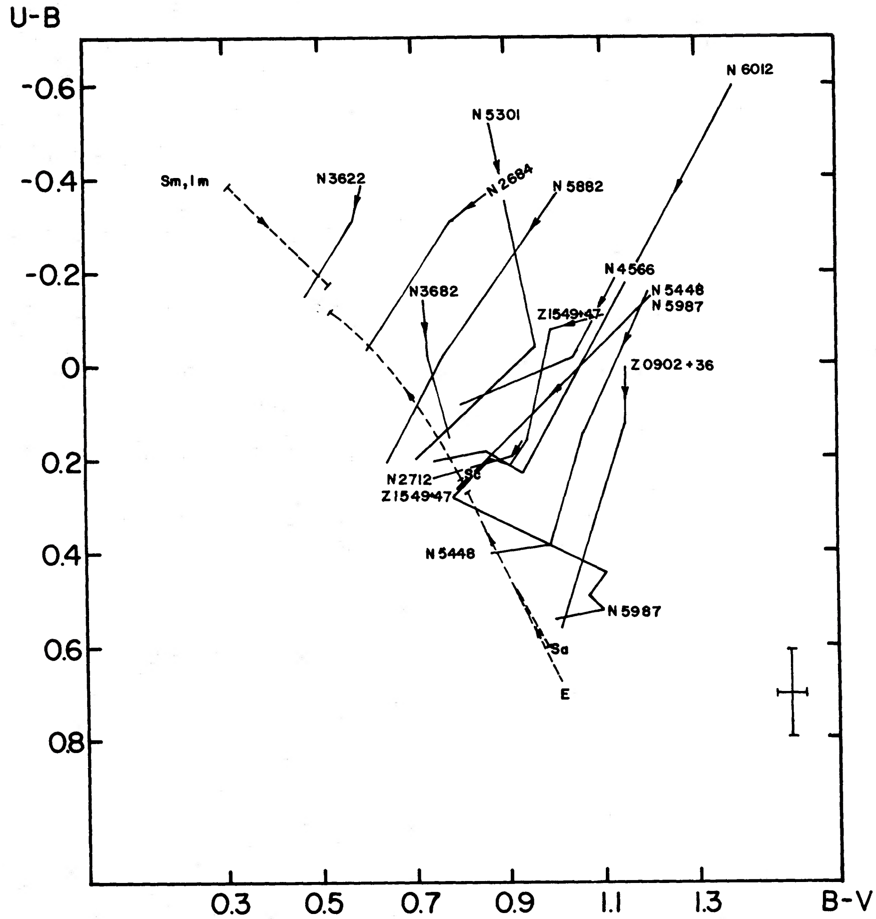

FIG. 3.—Color-color diagram for isolated galaxies. A cross depicts the representative errors of measurement.

had a large calibration error in $A/D_{RC1}(0)$, the large slopes in the HT sample would prevail. Hence we conclude that the nucleus of the HT galaxies is significantly bluer than the nuclei of Sm or Im galaxies. Incidentally, all the galaxies of the HT sample were noted by the Revised New General Catalog to be brighter toward the center.

b) The behavior of $B-V$ as a function of $A/D_{RC1}(0)$ of HT galaxies resembles that of E and S type galaxies, but is opposite to that exhibited by Sm and Im galaxies. We find again larger gradients than are usually found in "normal" spirals.

c) The large color gradients prevent a unique galaxy classification which is based solely on absolute colors.

d) We give in Figure 3 the corresponding color-color diagram as a function of A in the galaxy. The direction of increasing A is marked by an arrow on the line joining all the measurements (with different aperture) of the same galaxy. The broken line is the color-color plot for the various morphological classes using data from de Vaucouleurs (1961). (The arrow on the broken line points toward increasing $A/D_{RC1}(0)$.) We find that the nuclei of the HT galaxies resemble galaxies with active nuclei in the sense that (*a*) the colors are above the blackbody curve and (*b*) $U-B$ is greater than -0.6 and $B-V$ is greater than 0.5 (cf. Sandage 1967). These conclusions are independent of the face-on diameter used.

Broad-band colors of galaxies have been recently studied by Larson and Tinsley (1978) with the purpose of determining the stellar population, stellar formation in bursts etc. Larson and Tinsley explain the color difference between Arp interacting objects (Arp 1966) and Hubble galaxies (Sandage 1961) by invoking a more recent burst for the former, possibly induced by tidal interaction. Bursts of star formation move the galaxy perpendicularly to the galaxies' normal trajectory in the color-color diagram. Thus they claim that the blueness of at least those Arp objects they studied is due to a young blue population. It is clear from our results that this explanation cannot explain the blueness of the nuclei of the HT galaxies. Furthermore, McClure, Cowley, and Crampton (1980) have studied the nuclei of normal spiral galaxies spectroscopically and have shown that at least in the nucleus, the major contribution to ultraviolet light is from old horizontal branch stars and not from young main-sequence stars. These objects represent, according to them, the most metal-poor tail of the stellar population therein. This explanation also does not explain the blueness of the nuclei of the HT galaxies. No metal-poor star, or mixture of stars, can carry the colors to beyond the blackbody curve. We are therefore led to the conclusion that a major contribution to the radiation in the deep nuclei of the HT galaxies is nonstellar. If this conclusion is correct, then the stellar content of their nuclei can be determined only by spectroscopic methods as was done by McClure, Cowley, and Crampton (1980).

Any nuclear activity demands the existence of gas. Since these galaxies are isolated, they are expected not to be affected by other galaxies or by extragalactic gas. The massive halo of field galaxies may provide a more accentuated gravitational potential which would force any gas released in the galaxy or accreted from intergalactic space to sink to the central regions (Dekel, Lecar, and Shaham 1980). This gas could subsequently be the source for the observed nonstellar radiation by any one of the known processes (cf. Burbidge 1978). Obviously, since the galaxies are isolated, their internal gas would not be swept away by the interaction with other galaxies or ram pressure effect of intracluster gas (Gunn and Gott 1972).

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