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IUE OBSERVATIONS OF TWO ELLIPTICAL GALAXIES: NGC 3379 AND NGC 4472

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ABSTRACT

Ultraviolet spectroscopic observations of the elliptical galaxies NGC 3379 and NGC 4472 made with the *IUE* show that the flux F_λ decreases rapidly below 3200 Å and then increases again further in the ultraviolet. The hot UV radiation can be represented by a blackbody at 30,000 K and is probably produced by hot horizontal-branch stars, although main-sequence OB stars cannot be ruled out. The whole UV and visual energy distributions of the three galaxies, NGC 3379, NGC 4472, and M31 are very similar; the hot UV radiation is abnormally faint in M32 but very bright in M87. This hot UV radiation is extended in the same way as the visual radiation and is therefore a part of the overall stellar population seen in the 10″ × 20″ *IUE* aperture. Several broad spectral features are seen in the 2600–3200 Å spectral range which are also seen in solar-like stars. These features can be used for redshift determinations, although the flux is very low in this spectral range compared with that at the H and K lines of Ca II. A comparison of the UV fluxes discussed in this paper with those measured in large-redshift normal galaxies shows substantial agreement, although allowance must be made for the line-strength differences found between integrated galaxy spectra and nuclear-region spectra. The UV spectral energy distributions of NGC 3379, NGC 4472, and M31 are very similar to that of the globular cluster NGC 6624. The hot UV radiation source is not seen as individual stars in the cluster color-magnitude diagram because the whole cluster need contain only a few such stars.

Subject headings: galaxies: individual — spectrophotometry — ultraviolet: spectra

I. INTRODUCTION

The first ultraviolet observations of galaxies were made with *OAO 2* using broad-band filters (Code, Welch, and Page 1972). Although the spectral resolution was minimal, the observations showed that in addition to the cool stars seen in the visual spectral range, a new component appeared in the far-ultraviolet which was thought to be due to hot horizontal-branch or perhaps young OB stars (Code and Welch 1979). The interpretation as hot horizontal-branch stars was based partly on the similar spectral behavior of globular clusters (Welch and Code 1972; Code and Welch 1979).

The *International Ultraviolet Explorer* (*IUE*) (Boggess *et al.* 1978) represents the first opportunity to observe galaxies down to 1200 Å with enough resolution to see strong spectral features and to obtain in detail the overall spectral energy distribution. Observations have already been reported for the two nearby galaxies, M31 and M32 (Johnson 1979), for the peculiar elliptical M87 (Bertola *et al.* 1980), and NGC 4472 (Nørgaard-Nielsen and Kjaergaard 1980). In this paper we report observations of two normal elliptical galaxies, NGC 3379 and NGC 4472.

NGC 3379 is the nearest giant elliptical galaxy, probably a member of the M96 (NGC 3368) group (de Vaucouleurs 1975). According to de Vaucouleurs and Capaccioli (1979), its distance is 8.0 Mpc, the redshift is $cz_0 = 885$ Km s^{-1}, and the total magnitude is $B = 10.22$. This object was studied, along with M87, by Sargent *et al.* (1978). The galaxy is almost perfectly circular near the center ($r < 0'.1$), then becomes an E1. In spite of the absence of any morphological pecularity, recent studies have shown that the nuclear region has photometric and dynamical properties which are similar to those of the well-known peculiar elliptical M87. A light excess in the center has recently been found by de Vaucouleurs and Capaccioli (1979) and a steep gradient of the velocity dispersion by Davies (1980) and Bertola, Capaccioli, and Rose (1980).

NGC 4472 is a well-known E2 galaxy and one of the brightest members of the Virgo cluster. According to de Vaucouleurs, de Vaucouleurs, and Corwin (1976), the redshift cz_0 is 914 km s^{-1}, and the total blue magnitude is 9.31. This galaxy does not appear to possess those peculiarities which are present in its close neighbor M87.

II. OBSERVATIONS

The *IUE* observations consist of two short-wavelength spectra (SWP) covering the range from 1200 to 2000 Å and two long-wavelength spectra (LWR) covering the range from 2000 to 3200 Å for each of the two objects. The exposure number, exposure time, and date of observation are given in Table 1. Wavelength calibration, spatial rectification, and conversion to intensities were carried out using the standard subroutines available at the *IUE* observatories. Observed fluxes were derived by summing all intensity seen in the large 10″×20″ aperture used for the exposures and subtracting the background by summing pixels on either side of the observed spectrum. Reseau marks and ion spots in the background measurements were avoided, but if they occurred in the actual spectrum they are included but noted where possible. The resulting *IUE* flux numbers were converted to absolute fluxes f_λ (ergs cm^{-2} s^{-1} Å^{-1}) using the calibrations of Bohlin and Snijders (1978). They are thought to be accurate to 5–10%.

The results for NGC 3379 and NGC 4472 are given in Table 2 and plotted in the upper part of Figure 1. Above 2400 Å, seven adjacent spectral pixels are averaged together, as are the two individual spectra. Each plotted point represents approximately 30 Å. Below 2400 Å, 21 pixels are averaged together to represent 56 Å below 2000 Å and 93 Å above. Standard deviations are based on the assumption that all measurements within a band are measurements of the same quantity. Below 2400 Å the errors are largely due to the very small signal.

Above 3200 Å, the fluxes are derived from observations made with the multichannel spectrometer on the Palomar 5.08 m Hale telescope. Bandpasses were 40 Å below 5800 Å and 80 Å above. The fluxes are those for a 14″ diameter aperture which has almost the same effective area as the *IUE* 10″×20″aperture. The fluxes are based, within 2%, on the adopted absolute fluxes for α Lyrae given by Hayes and Latham (1975). They are plotted in the upper part of Figure 1. The lack of any significant discontinuity between the multichannel and *IUE* fluxes at 3200 Å suggests that the absolute calibrations are approximately correct; the visual fluxes at 5200 Å should be accurate to about 3%.

For comparison purposes data similar to that given above have been reconstructed using the *IUE* observations of M31 and M32 by Johnson (1979). The points in his Table 1 are used below 2500 Å, while 25 Å

TABLE 1

LIST OF *IUE* OBSERVATIONS

Observation Number	Exposure (m)	Date
NGC 3379		
LWR 2960	425	1978 Nov. 17
LWR 4948	395	1979 Jul. 05
SWP 5690	480	1979 Jul. 02
SWP 5708	550	1979 Jul. 11
NGC 4472		
LWR 6877	360	1980 Feb. 08
LWR 6912	330	1980 Feb. 12
SWP 7913	340	1980 Feb. 10
SWP 7949	320	1980 Feb. 14

TABLE 2

FLUXES (in units of ergs cm^{-2} s^{-1} Å^{-1})

	NCG 3379		NCG 4472	
λ	log f_λ	s.d.	log f_λ	s.d.
1264	−14.35	0.05	−14.13	0.04
1320	−14.65	0.05	−14.32	0.03
1376	−14.38	0.07	−14.31	0.04
1431	−14.69	0.08	−14.47	0.05
1487	−14.66	0.08	−14.42	0.06
1543	−14.86	0.13	−14.67	0.11
1599	−14.93	0.11	−14.70	0.09
1655	−14.88	0.12	−14.54	0.09
1710	−14.88	0.09	−14.45	0.06
1755	−14.65	0.04	−14.24	0.10
1822	−14.93	0.04	−14.65	0.05
1878	−14.99	0.04	−14.50	0.08
1934	−14.98	0.06	−14.54	0.11
2042	−14.72	0.07	−14.82	0.17
2135	−14.66	0.08	−14.74	0.17
2228	−14.60	0.07	−14.42	0.08
2322	−14.68	0.04	−14.43	0.06
2415	−14.78	0.10	−14.61	0.08
2445	−14.54	0.04	−14.40	0.10
2476	−14.73	0.04	−14.59	0.10
2508	−14.80	0.04	−14.62	0.10
2538	−14.75	0.04	−14.63	0.10
2601	−14.55	0.02	−14.48	0.05
2631	−14.49	0.02	−14.42	0.04
2663	−14.36	0.02	−14.31	0.03
2694	−14.36	0.02	−14.30	0.03
2724	−14.39	0.02	−14.33	0.03
2756	−14.46	0.02	−14.40	0.03
2786	−14.40	0.02	−14.40	0.03
2818	−14.47	0.02	−14.38	0.03
2849	−14.42	0.02	−14.42	0.03
2879	−14.29	0.02	−14.32	0.03
2911	−14.08	0.02	−14.12	0.03
2942	−14.08	0.03	−14.04	0.03
2972	−14.07	0.06	−14.07	0.03
3004	−14.14	0.05	−14.16	0.03
3035	−14.10	0.03	−14.17	0.03
3066	−14.02	0.02	−14.08	0.03
3092	−13.98	0.05	−13.95	0.03
3124	−13.94	0.07	−13.92	0.03
3153	−14.00	0.02	−13.88	0.03
3194	−13.98	0.11	−13.98	0.03
3226	−13.89	0.02	−13.84	0.07

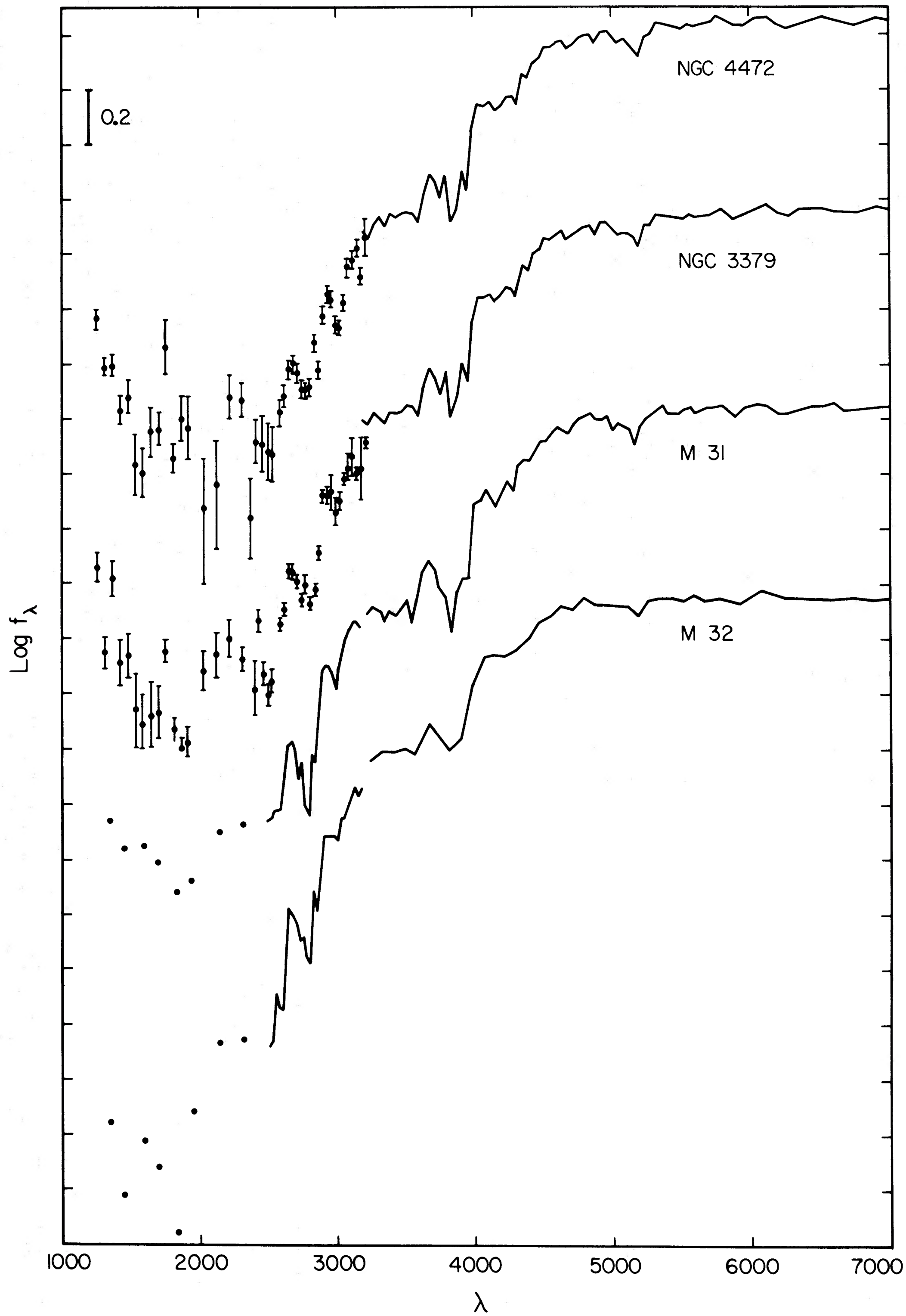

FIG. 1.—Absolute spectral energy distributions in terms of log f_λ (ergs cm^{-2} s^{-1} Å^{-1}) for the nuclear regions of several galaxies. Below 3200 Å the data are from the *IUE* with the M31 and M32 data from Johnson (1979). Standard deviation bars are shown for the data of this paper. Above 3200 Å the data are from the multichannel spectrometer on the Palomar Hale telescope adjusted where necessary to correspond to the *IUE* aperture used. The data for each object are displaced vertically by arbitrary amounts.

averages, based on his Figures 1 and 2, are used above 2500 Å. The visual data again are multichannel observations measured with a 10″ diameter aperture by Oke and Schwarzschild (1975). To correct to an aperture of 14″, a scale factor of 1.66 has been used which is based on the surface brightness analysis of M31 by Light, Danielson, and Schwarzschild (1974). The results are shown in the lower part of Figure 1. Finally the data already obtained for M87 (Bertola *et al.* 1980) are also available. They are of lower accuracy than the data in Figure 1, since they are based on one spectrum of each region only.

III. THE UV LUMINOSITY PROFILE

In the same way as was done for M87 (Bertola *et al.* 1980), the UV spectra of NGC 3379 were analyzed perpendicular to the dispersion, in order to obtain the luminosity profile of the galaxy. Results for the short- and long-wavelength ranges are shown in Figure 2, where the full line is the *B* luminosity profile from de Vaucouleurs and Capaccioli (1979) convolved to *IUE* resolution. After allowing for the low signal-to-noise ratio in the short-wavelength range, it is evident that there is a good agreement between the UV and *B* profiles. Therefore, as in the case of M87, the contributors to the UV light distribution must be of the same nature as those providing the visual light. In other words, the spectral behavior in the UV is not due to a pointlike source. Similar computations were not carried out for NGC 4472, but direct inspection of the spectral images shows that the far-UV light is extended.

IV. DISCUSSION OF THE SPECTRA

An intercomparison of the energy distributions of the four objects shown in Figure 1 and M87 yields the following points.

1. Between 2500 and 7000 Å (and also out to 10,000 Å, although the data are now shown), NGC 3379, NGC 4472, and M31 have essentially identical energy distributions. Since NGC 3379 and NGC 4472 are near the galactic pole and presumably not reddened, this implies either that the nucleus of M31 is not reddened significantly, or, if it is, then M31 is just enough bluer than the other galaxies to compensate for the reddening.

2. If M32 is matched to the above objects to the red of 5000 Å, then they again agree with each other between 2500 and 2600 Å. From 2600 to 4000 Å, however, M32 is as much as 0.2 in log f_λ brighter than the other objects. This difference has usually been attributed to less metallic line blanketing in M32 than in M31, and the UV observations are in conformity with this view.

3. The energy distributions of M87 and NGC 3379 or NGC 4472 agree very well from 3800 Å out to 10,000 Å. From 3800 Å down to 2500 Å, M87 becomes progressively brighter until it is 0.2 to 0.3 brighter in log f_λ at 2500 Å than NGC 3379. This behavior is very different from that in M32 and cannot be attributed to line-blanketing effects because the blanketing is comparable in the two objects from 3800 to 4500 Å.

4. In the spectral range below 2500 Å, the data are very noisy as a result of the small signal levels, but the

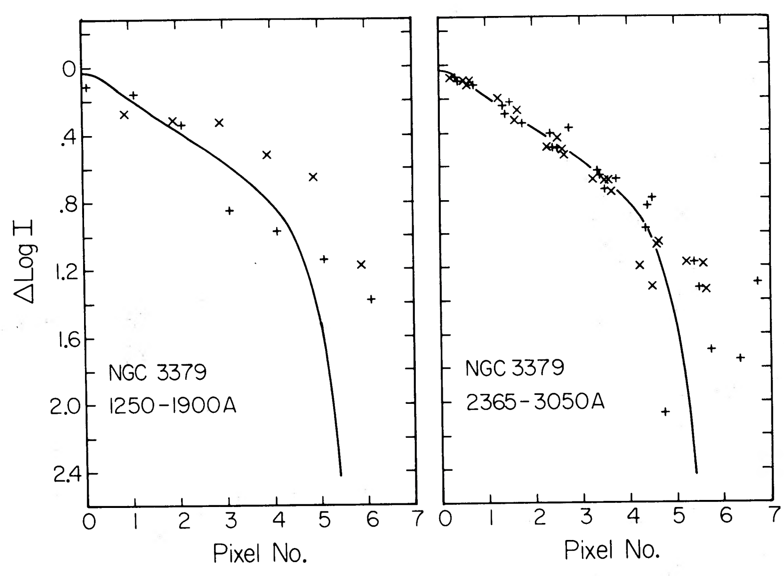

FIG. 2.—The light distribution per unit surface area perpendicular to the dispersion as a function of angular distance in pixel units (one pixel is 2″). The different symbols plotted represent opposite sides of the galaxy. The points plotted in the left diagram, from short-wavelength camera data, correspond to 1250–1900 Å. The points in the right diagram, from the long-wavelength camera, correspond to 2365–3050 Å. The solid curve is the blue *B* light profile (de Vaucouleurs and Capaccioli 1979) convolved to the *IUE* spatial resolution.

TABLE 3

RELATIVE BRIGHTNESS OF THE FAR-UV COMPONENT

Object	$\overline{\log f_\lambda^a}$ (3300–3600 Å)	$\overline{\log f_\lambda^a}$ (1260–1720 Å)	$\overline{\Delta \log f_\lambda^a}$	UV Component (fraction of total light at 3400 Å)
NGC 3379 . . .	−13.78	−14.70	+0.92	0.025
NGC 4472 . . .	−13.76	−14.46	+0.70	0.033
NGC 4486 . . .	−13.86	−14.19	+0.33	0.066
M31	−13.40	−14.24	+0.84	0.016
M32	−13.11	−14.58	+1.47	0.004

[a]Units of ergs cm^{-2} s^{-1} $Å^{-1}$.

overall flux levels are fairly well determined. In all five objects there is a sudden increase in f_λ below 1900–2400 Å similar to that found by *OAO 2* (Code, Welch, and Page 1972) and by *IUE* for M87 (Bertola *et al.* 1980) and corresponds very roughly to the addition of a blackbody or model-atmosphere source at 30,000 K. The level of this turnup varies in different galaxies, being relatively similar in NGC 3379, NGC 4472, and M31, very high in M87, and abnormally low in M32. Preliminary data on NGC 4649 (Bertola, Oke, and Capaccioli 1980) show that it is similar to M87. A measure of the level of this hot UV source is to determine $\overline{\log f_\lambda}$ (3300–3600 Å)–$\overline{\log f_\lambda}$ (1260–1720 Å). These are given in Table 3.

5. The contribution of this hot UV source to the total flux above 3000 Å is probably very small. Assuming a 30,000 K blackbody for the source, then at 3400 Å the contributions to the observed flux are shown in the last line of Table 3. Even in M87, this contribution is only 7%.

6. Between 2600 and 3200 Å the *IUE* spectra of NGC 3379 and NGC 4472 are of sufficient quality that they can be looked at in some detail. Since the spectra of these objects are very similar, they have been averaged and smoothed with a running mean of three adjacent pixels corresponding to 13 Å. The results are shown in Figure 3. Standard deviation bars are shown for a few points and are representative of all the points near them. A comparison with spectra of M31 and M32 (Johnson 1979) indicates that the same features are present with approximately the same contrast.

Morton *et al.* (1977) have studied spectra of α Aql (A7 IV–V), α CMi (F5 IV–V), and the Sun (G2 V) in this spectral range to see what one would expect to see in low-resolution galaxy spectra. A comparison shows the same general features in the stars and the galaxies, with the solar spectrum providing a much better match than the other hotter stars. At low spectral resolution, Morton *et al.* (1977) identify four absorption features and two discontinuities which could be seen. These are shown, suitably redshifted, in Figure 2, and they are all present in the galaxy spectra. Most prominent are the discontinuity which begins at 2900 Å, the absorption feature at 2862 Å mainly due to Mg I λ2852, and the absorption line at 2807 Å mainly due to the Mg II resonance lines at 2795 and 2802 Å. The broad galaxy feature between 3000 and 3040 Å is a combination of several lines seen in the solar spectrum. The fact that the galaxy spectra match the solar spectrum very much better than the spectra of the earlier-type stars, and particularly the presence of the 2727 Å line and the 2900 Å discontinuity indicates that most of the light in

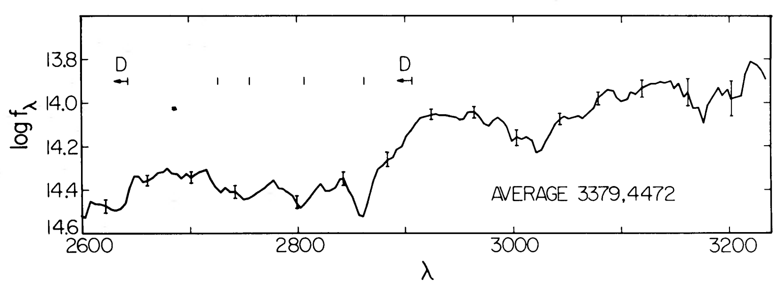

FIG. 3.—The average $\log f_\lambda$ for NGC 3379 and NGC 4472. A three-point running mean has been used to smooth the data. Standard deviations are shown for a few representative points. The four vertical marks indicate the redshifted locations of strong features in the solar spectrum, while *D* denotes discontinuities in the solar spectrum.

this spectral range is still coming from cool stars. The contribution from hotter spectral types must be small.

V. COMPARISONS WITH LARGE-REDSHIFT GALAXIES

The fluxes shown in Figure 1 are accurate down to about 2500 Å. They can therefore be compared with fluxes measured from Earth for galaxies with redshifts greater than 0.30. Such fluxes are available for a substantial sample of brightest cluster member galaxies (Gunn and Oke 1975, 1980). This range now includes galaxies with redshifts larger than 0.5 so that ground-based fluxes down to 2200 Å are in principle available. These galaxies, however, are very faint, and the UV data are of poor quality. Instead, we have selected all the galaxies with reliable data which have redshifts between 0.30 and 0.45; the fluxes have been averaged, after shifting to the rest frame. The results are shown in Figure 4 along with the average of NGC 3379 and NGC 4472. It should be noted that the spectral resolution for the larger-redshift galaxies is substantially less than that for the nearby ones.

Several points should be made about Figure 4. As expected (Gunn and Oke 1975), above 4000 Å the energy distributions are very similar. There is some indication that the line absorption in the λ4150, λ4300, and λ5200 regions is greater in the nuclei of the two nearby galaxies than in the distant galaxies where the entire galaxy is included in the observation. Between 3100 and 4000 Å, the cluster galaxy fluxes are systematically brighter than those of the nearby galaxy nuclei by about 0.1 in $\log f_\lambda$. Below 3000 Å, the difference is even larger. The difference between the two energy distributions is just that expected when one compares the integrated light of a total galaxy with the light from the nucleus region and is caused by the relatively stronger absorption lines in the nucleus. This effect, of just about the size shown in Figure 4, is seen clearly in M31 (Oke and Schwarzschild 1975) and in elliptical galaxies (de Vaucouleurs 1961; Schild and Oke 1971; Whitford 1971; de Vaucouleurs, de Vaucouleurs, and Corwin 1976). The fluxes shown in Figure 4 for the faint cluster galaxies agree well with fluxes for first-rank elliptical galaxies in clusters with redshifts between 0.10 and 0.20, where again the whole galaxy is observed (Yee and Oke 1978). Thus the difference in Figure 4 is not an age effect.

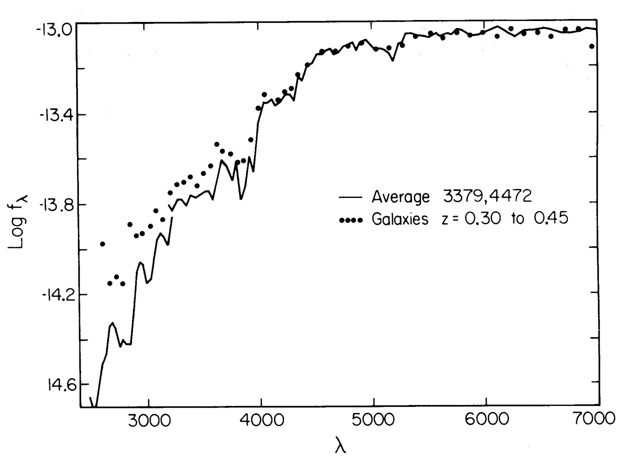

FIG. 4.—The average energy distribution of NGC 3379 and NGC 4472 (*solid curve*) compared with the average of first-rank cluster galaxies with redshifts between 0.30 and 0.45. The difference is a consequence of comparing spectra of nuclear regions and whole galaxies.

The rapid drop in flux below 2900 Å which is seen in the nearby galaxies (see also § IV) is also present to a somewhat smaller extent in the large-redshift sample. This drop can be used in the same way as the H and K lines drop to measure redshifts in distant galaxies; the flux, however, is a factor of 3 less than at the H and K lines.

It should be noted that the energy distribution for M87 is in excellent agreement with that shown for the distant clusters over the whole range from 2600 to 2000 Å, except in the neighborhood of the H and K lines, where M87 shows more absorption. It is not clear whether this is significant or purely fortuitous.

VI. COMPARISON WITH GLOBULAR CLUSTERS

Several globular clusters have been observed with the *IUE* (Duprée *et al.* 1979), and it is possible to compare their spectra with those of the galaxies observed. The energy distributions for the metal-deficient clusters, M15, M92, and NGC 1851, are much flatter than those of the galaxies. These objects do not show a turnup in the far-UV, and Duprée *et al.* (1979) suggest that the UV light can be accounted for by stars corresponding to a spectral type near B7. Their spectrum of the central region of the relatively metal-rich cluster NGC 6624 is very similar, even in detail, to that of NGC 3379 and NGC 4472 in the 1300–3200 Å region. This cluster shows the hot UV component, and the spectral features shown in Figures 1 and 3 are also present with comparable strengths in the cluster spectrum.

The metal abundance of NGC 6624 is given by Zinn (1980) as $[m/H] = -0.23$. The color-magnitude diagram (Liller and Carney 1978), as expected for metal-rich clusters, has only a red horizontal branch and no very blue stars. This is not in conflict with the hot UV flux, since if the V magnitude of the hot stars is 2 mag fainter than the red giants, then one needs only about one blue star for every 300 giants. Therefore, the fact that blue stars are not found in NGC 6624 is not surprising. Even in the whole cluster there are at most a few such stars, and these presumably are mainly in the crowded regions where photometry is avoided.

VII. SUMMARY

IUE observations of the nuclei of the elliptical galaxies NGC 3379 and NGC 4472 show that the flux drops rapidly with decreasing wavelength until a wavelength of about 2300 Å is reached, below which the flux increases rapidly again. This hot UV component of the radiation can be fitted approximately by a blackbody at 30,000 K. The spectra of NGC 3379, NGC 4472, and M31 are very similar from 1260–8000 Å. The hot UV component is abnormally weak in M32 and abnormally strong in M87. The UV spectrum from 1300 to 3200 Å of the metal-rich globular cluster NGC 6624 (Duprée *et al*. 1979) is very similar to those of NGC 3379, NGC 4472, and M31, and also shows evidence for hot blue stars. The color-magnitude diagram of NGC 6624 does not show any such stars, but this is presumably because only a very few hot blue stars are needed in the whole cluster to account for the observed flux.

This hot UV source appears to contribute very little radiation above 3000 Å. It is of interest to speculate that if this source were to become an order of magnitude brighter relative to the cool stars because of star formation or evolutionary effects, the energy distributions would be similar to those found for the very faint blue galaxies which have been found. This component would very much decrease the strength of the H and K lines of Ca II making redshift determinations difficult.

When allowance is made for the difference between the spectrum of the nuclear region of a galaxy and the whole galaxy, it is found that the spectra of NGC 3379 and NGC 4472 are similar to those of faint large-redshift galaxies. The spectral features from 2600 to 3200 Å are similar to those seen in the solar spectrum, indicating that the light is predominantly from cool stars. A substantial drop in intensity at 2900 Å can be used for measuring redshifts in large-redshift objects.

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