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ULTRAVIOLET SPECTROPHOTOMETRY OF THREE LINERs[1]

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ABSTRACT

Three galaxies known to be LINERs were observed spectroscopically in the ultraviolet in an attempt to detect the presumed nonthermal continuum source thought to be the source of photoionization in the nuclei. NGC 4501 was found to be too faint for study with the *IUE* spectrographs, while NGC 5005 had an extended ultraviolet light profile. Comparison with the optical light profile of NGC 5005 indicates that the ultraviolet source is distributed spatially in the same manner as the optical starlight, probably indicating that the ultraviolet excess is due to a component of hot stars in the nucleus. These stars contribute detectable absorption features longward of 2500 Å; together with optical data, the *IUE* spectra suggest a burst of star formation $\sim 10^9$ yr ago, with a lower rate continuing to produce a few OB stars. In NGC 4579 we find a point source contributing most of the ultraviolet excess, much different than the optical light distribution. Furthermore, the ultraviolet to X-ray spectral index in NGC 4579 is $\alpha = 1.4$, compatible with the UV to X-ray indices found for samples of Seyfert galaxies. This provides compelling evidence for the detection of the photoionizing continuum in NGC 4579 and draws the research fields of normal galaxies and active galactic nuclei closer together. The emission-line spectrum of NGC 4579 is compared with calculations from a photoionization code, CLOUDY, and several shock models. The photoionization code is found to give superior results, adding to the increasing weight of evidence that the LINER phenomenon is essentially a scaled-down version of the Seyfert phenomenon.

Subject headings: galaxies: nuclei — ultraviolet: spectra

I. INTRODUCTION

Surveys of spiral galaxies by Heckman (1980), Stauffer (1982), and Keel (1983*a*, *b*) showed that the nuclei of most spirals exhibit some degree of emission. While much of this emission could be ascribed to H II regions, many of the survey galaxies showed emission spectra characterized by low ionization and by large [N II]/Hα line ratios. Heckman coined the name "LINERs," an acronym for "low-ionization nuclear emission regions," for these galaxies. The source of the excitation of LINERs was thought to be either shock heating, as occurs in supernova remnants, or photoionization by a power-law continuum, as occurs on a more powerful scale in Seyfert galaxies and QSOs. The spiral galaxy NGC 1052 was extensively studied by Koski and Osterbrock (1976) and by Fosbury *et al.* (1978). Both of these papers compared observed emission-line intensity ratios with those predicted by both shock and photoionization models, concluding that NGC 1052 was most likely shock-heated. The shock heating of LINERs gained more acceptance with the work of Baldwin, Phillips, and Terlevich (1981). The main obstacle upon which the photoionization models stumbled was the high ratio of [O III] λ4363/λ5007, which indicated gas temperatures of 30,000 K, while the other lines in the spectrum indicated 10,000–15,000 K. Keel and Miller (1983) showed that much of the problem lay with improper subtraction of the underlying stellar continuum, which tended to increase the measured strength of [O III] λ4363. Subsequent improvements in photoionization models have more or less removed the [O III] problem (see, e.g., Halpern and Steiner 1983; Ferland and Netzer 1983). Keel and Miller (1983) argued that the improved photoionization models gave as good a fit to the NGC 1052 data as did the shock models. Subsequent work on many other LINERs seems to draw support for the photoionization mechanism, especially the X-ray work by Halpern and Steiner (1983) and the very recent analyses by Fillippenko and Halpern (1984) and Miller (1985). The detailed Hα line profile work by Fillippenko and Sargent (1985) indicated that many LINERs display broad wings on Hα, again in analogy with active galactic nuclei. The X-ray observations are also especially important because they may provide an estimate of the flux level of the nonthermal ionizing source, which can then be compared to the model calculations.

In this context the ultraviolet part of the spectrum may be equally important, because here the continuum flux from the stars in the galaxy is very low but the nonthermal continuum may be strong enough to detect. Halpern and Steiner (1983), however, caution that the ionizing sources in LINERs may have covering factors approaching unity and hence may not be detectable in the ultraviolet. Another attractive feature of the ultraviolet part of the spectrum is that it includes several lines which may be diagnostic of photoionization versus shock heating, including the C IV λ1550, He II λ1640, and C II λ2326 lines. In this paper we have selected three LINERs from the sample of Keel (1983*a*, *b*) to observe using the *International Ultraviolet Explorer* (*IUE*), in an attempt to directly detect the ionizing continuum in the ultraviolet. In NGC 5005 we find that the nucleus contains enough hot stars to make detection of a nonthermal continuum ambiguous at best. In NGC 4579,

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however, we have detected a continuum source with approximately the correct flux level and appearing stellar with the *IUE* telescope. NGC 4501 was too faint in the ultraviolet to obtain a spectrum of it with the *IUE*.

II. OBSERVATIONS

The galaxies in this study were selected to be bright, nearby systems, so that the *IUE* aperture would include as little contaminating starlight from the bulge as possible, and so that the *IUE* fine-error sensor (FES) could verify that the spacecraft was pointing at the nucleus. They have emission lines among the strongest of known LINERs, implying relatively high levels of nuclear activity and thus the greatest chance of detecting emission lines or continuum excesses in the ultraviolet. All three are at high galactic latitudes, minimizing possible reddening within our own galaxy. Early Hubble types (Sa–Sb) were chosen to reduce the chances of having regions of recent star formation within the *IUE* aperture, as such regions are very bright in the UV and would reduce the contrast of the features sought. This is especially important in view of the poorly understood ultraviolet properties of even normal old stellar populations. Finally, Hα images for all three galaxies are available (Keel 1983*c*) so that the lack of nearby H II regions can be confirmed and aperture effects in comparing *IUE* to optical emission-line data can be evaluated; these latter effects proved to be small, since the optical emission is strongly concentrated to the nucleus in each case.

The *International Ultraviolet Explorer* (*IUE*) was used in the low-resolution, large-aperture mode to observe the three galaxies NGC 4501, 4579, and 5005. Table 1 presents the details of the *IUE* exposures, including camera and image number, exposure time, and orientation of the long axis of the spectrograph aperture. The large aperture, 10″ × 20″, provides some important spatial information about the extent of the UV light from the galaxies perpendicular to the dispersion. The resolution of the two cameras is slightly different, being about 6 Å with the short-wavelength prime (SWP) camera and 9 Å with the long-wavelength (LWP) camera. The two-dimensional image was processed by standard *IUE* methods to correct for nonlinear camera response and geometric distortion in the field. This two-dimensional image was then reduced further using a custom package designed at Lick Observatory by R. W. G. and G. H. Herbig. The reduction to the form of a spectrum involves using a two-dimensional median filter to remove cosmic-ray hits and hot pixels in the background of the image, and then allows either the summation of rows which contain the spectrum or the fitting of a point-spread function (PSF) perpendicular to the dispersion at each wavelength. The standard conversions from *IUE* flux numbers (FN) to absolute flux units (Bohlin and Holm 1980; Blades and Cassatella 1983) were then applied to the spectra. The PSF-fitting technique gives somewhat better signal-to-noise ratio than the order-summation technique, but it was used only on essentially point sources (specifically, images SWP 22281 and SWP 21640). A slightly more detailed account of the technique may be found in Goodrich and Dahari (1985). Because the full-resolution spectra of our three target galaxies are fairly noisy, we have chosen to display them by averaging them into 20 Å wide bins.

A feature added to the reduction package for this project was a profile calculation, which allowed the two-dimensional image to be collapsed parallel to the direction of dispersion, hence providing the distribution of the light perpendicular to the dispersion. To compare with these observed ultraviolet light distributions *V* band images of the three galaxies were obtained with a 576 × 386 GEC CCD on the 1 m Nickel telescope at Lick Observatory in moderate (∼2″) seeing. The GEC device has a scale of 0″.26 per pixel in this mode, and the seeing was comparable to the resolution of the *IUE* spectrographs. The data reduction package VISTA was used to rotate these images into the orientations which the *IUE* spectrograph apertures were in during the *IUE* exposures and then to create a 10″ × 20″ "software aperture" and hence determine the optical light profile. The optical light profile is assumed to represent the distribution of the "normal" population of stars which contribute the optical continuum of the nucleus.

We further complement these data through ground-based spectra overlapping the *IUE* range in spectral coverage, extending from 3150 to 4500 Å. These latter spectra were obtained with the intensified image-dissector scanner (IIDS) at the KPNO 2.1 m telescope, using an aperture of 6″.1 diameter. Several nuclei were observed, including NGC 5005 from the *IUE* sample; a blue excess was also detected in M87, as described below. There are two types of aperture effects encountered when trying to compare the *IUE* and the ground-based spectra, because the emission-line region may have a different spatial extent than the region forming the optical continuum. The aperture effect of the former is small; the Hα images of Keel (1983*c*) show that the emission region is smaller than either the *IUE* aperture or the KPNO aperture. The aperture effect in the continuum is also small, about 20%, because the concentration of the starlight towards the center of the nucleus is great. Special attention was given to measuring and removing atmospheric extinction in the KPNO observations, since it exceeds 1.5 mag per airmass at 3200 Å and is a very steep function of wavelength. Standard stars were observed over a wide range in airmass, and an extinction curve derived from these observations; this proved to be indistinguishable from the mean curve usually adopted for Kitt Peak. Atmospheric dispersion was compensated for by offsetting the telescope from the position of the nucleus on the acquisition TV (which has an effective wavelength of 6000 Å) to that of the image at 3500 Å.

TABLE 1

OBSERVATIONS

Galaxy	Camera	Image	Exposure (minutes)	Aperture p.a. (degrees)
NGC 4501.........	SWP	21640	180	14
NGC 5005.........	SWP	22272	405	147
	LWP	2332	160	27
NGC 4579.........	SWP	22281	330	168
	LWP	5338	180	172

III. NGC 4501

The Virgo galaxy NGC 4501 was chosen for this project on the basis of a large [N II] λ6584/Hα emission line flux ratio, as well as strong [O III] λ5007 emission. It has also been observed with the *Einstein X-ray Observatory*. NGC 4501 is also interesting because for a LINER it has a relatively large ratio of [O III] λ5007/Hβ (∼4), similar to the ratios found in Seyfert 2 galaxies. The moderate-resolution optical spectra of Filippenko and Sargent (1985) show that the Hα, [N II] λλ6548, 6583, and [S II] λλ6717, 6731 emission lines are all relatively narrow (for their sample of "interesting" objects). Our 180 minute exposure with the SWP camera of *IUE* did not show any clear evidence of the galaxy's spectrum, indicating that the mean flux in the SWP region of the ultraviolet was below 2×10^{-15} ergs cm^{-2} s^{-1} $Å^{-1}$. However, when the two-dimensional *IUE* spectrum is collapsed parallel to the dispersion, the resulting profile shows an excess in the center of the aperture. As NGC 4501 was bright enough for the *IUE* FES camera to detect and point to, we may be confident that the galaxy was well centered in the *IUE* spectrograph aperture and hence is responsible for this excess emission. In the region 1300–1900 Å, the excess in *IUE* flux numbers (FN) is 257. The inverse sensitivity curve used to convert FN to absolute flux units varies by only a factor of 2 in this wavelength region, with an average close to 2.75×10^{-14} ergs cm^{-2} $Å^{-1}$ FN^{-1}, yielding a mean flux in the SWP of 7×10^{-16} ergs cm^{-2} s^{-1} $Å^{-1}$ with an uncertainty of perhaps 20%. This value is consistent with the detection of the "normal" stellar component of the optical spectrum of NGC 4501, but unfortunately little else can be gleaned from this broad-band "ultraviolet photometry." Keel's (1983*b*) stellar population synthesis of NGC 4501 gave some indications that NGC 4501 may suffer from a small amount of reddening, and even a reddening as small as $E_{B-V} = 0.06$ could hide a photoionizing continuum near 1600 Å.

IV. NGC 5005

Filippenko and Sargent (1985) found fairly broad emission lines in this object, but they attributed much of the velocity width to a very steep rotation curve in the nucleus. Excess ultraviolet flux, above the level expected from a normal stellar population synthesis of the optical spectrum, was detected; the *IUE* spectra, binned into 20 Å intervals, are shown in Figure 1. In the LWP camera the spectrum of NGC 5005 is clearly extended, indicating that it arises from a region which has been resolved by the *IUE* spectrograph (which has a scale of 70 pc per pixel for NGC 5005). Absorption lines characteristic of the underlying stellar population are quite evident in the LWP spectrum. Figure 2 shows the profiles of the light distribution perpendicular to the dispersion for the SWP and LWP cameras, as well as the optical light distribution measured from the 1 m CCD image at the appropriate position angles. (Also shown is a Gaussian representing the *IUE* point-spread function.) The solid circles, representing the LWP profile, are consistent with the optical profile out to 4″–5″ on either side of the nucleus. The SWP profile is somewhat noisier, but it is also fairly consistent with the optical profile on the right-hand side of the light distribution. On the left-hand side the SWP profile falls off much more rapidly than the optical profile. (This fall-off is due to the encroachment of a dust lane into the aperture, as clearly seen on the 1 m CCD images. Hence this side of the profile is more highly reddened than the rest of the starlight.) Neither of the *IUE* profiles is fitted well by the point-spread function.

We interpret the UV excess in NGC 5005 as being due to hot stars in the nucleus of the galaxy. The ultraviolet profiles indicate that the distribution of the hot stars is similar to the distribution of the stars which contribute most of the optical light. An approximate characterization of the stellar population is possible after combining the *IUE* and IIDS data. A composite spectrum is shown in Figure 3, where the IIDS data have been scaled by a factor of 1.2 to match the *IUE* spectrum in the region of overlap. The intensity profiles in both the optical and the UV indicate that the population does not change strongly between the areas sampled by the two apertures, and in any case the *IUE* spectrum is dominated by the inner few arc seconds. Significant spectral features in the composite spectrum include Ca II H and K lines and their Mg II analogs at 2800 Å, the spectral breaks near each of these doublets, Mg I just blueward of Mg II, a "hump" near 2650 Å, and

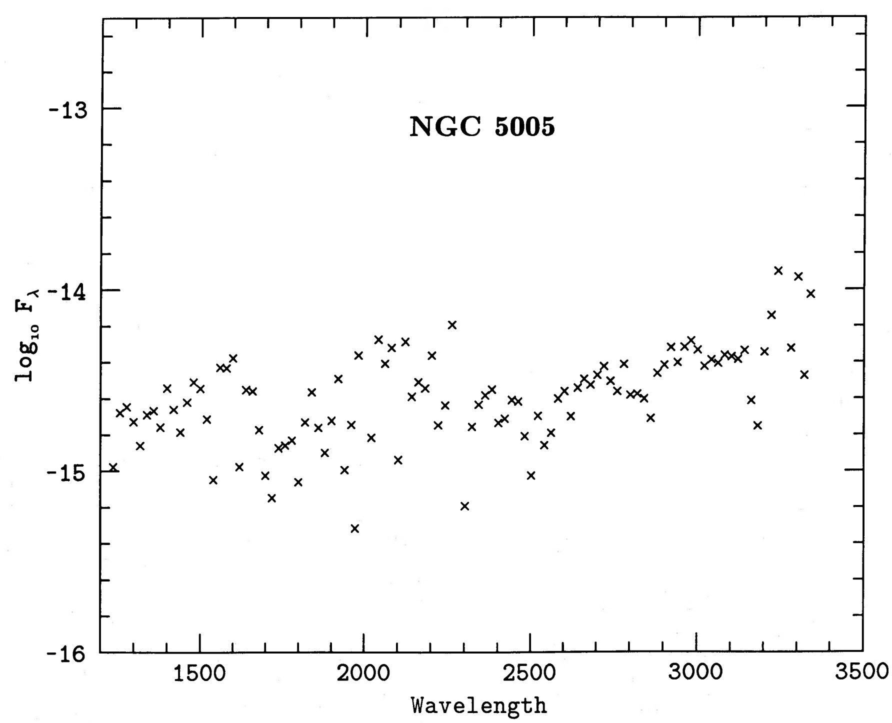

FIG. 1.—The *IUE* spectrum of NGC 5005, averaged in 20 Å bins

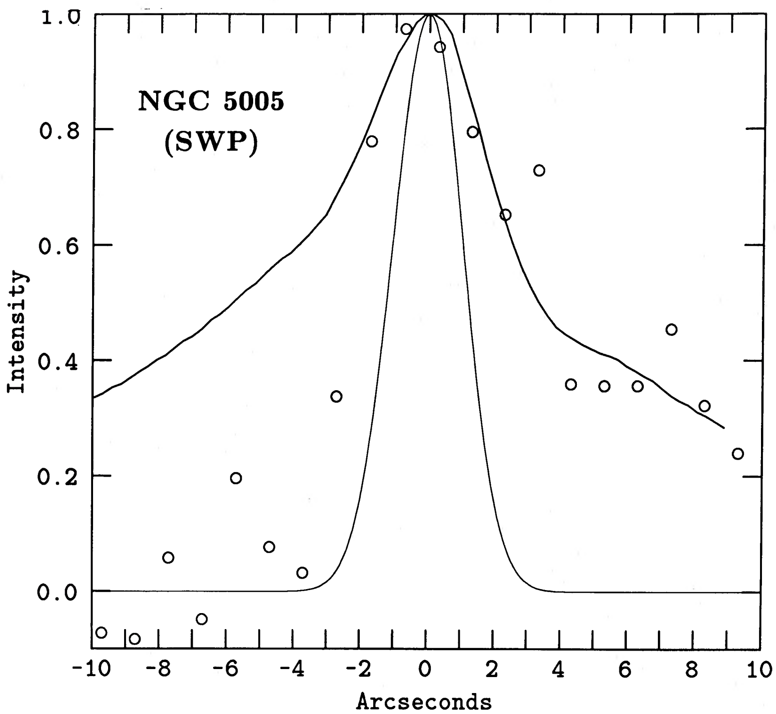

FIG. 2*a*

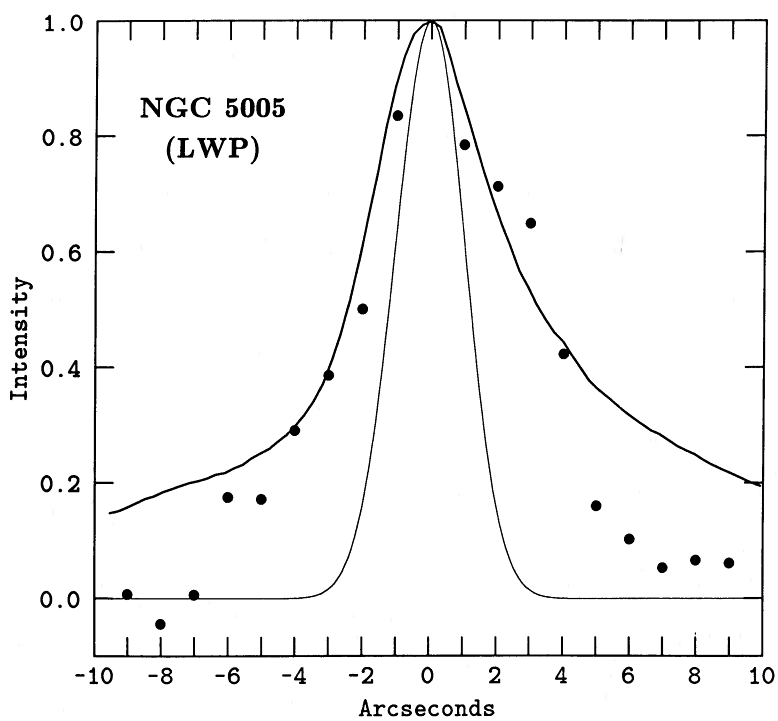

FIG. 2*b*

FIG. 2.—(*a*) The profile of NGC 5005 perpendicular to the direction of dispersion of the SWP spectrograph. The heavy solid line is the optical profile from the CCD image, at the same position angle. The open circles are the SWP profile. The light solid line is the shape of the *IUE* point-spread function. (*b*) Same as Fig. 2*a*, for the LWP image. The filled circles are the LWP profile.

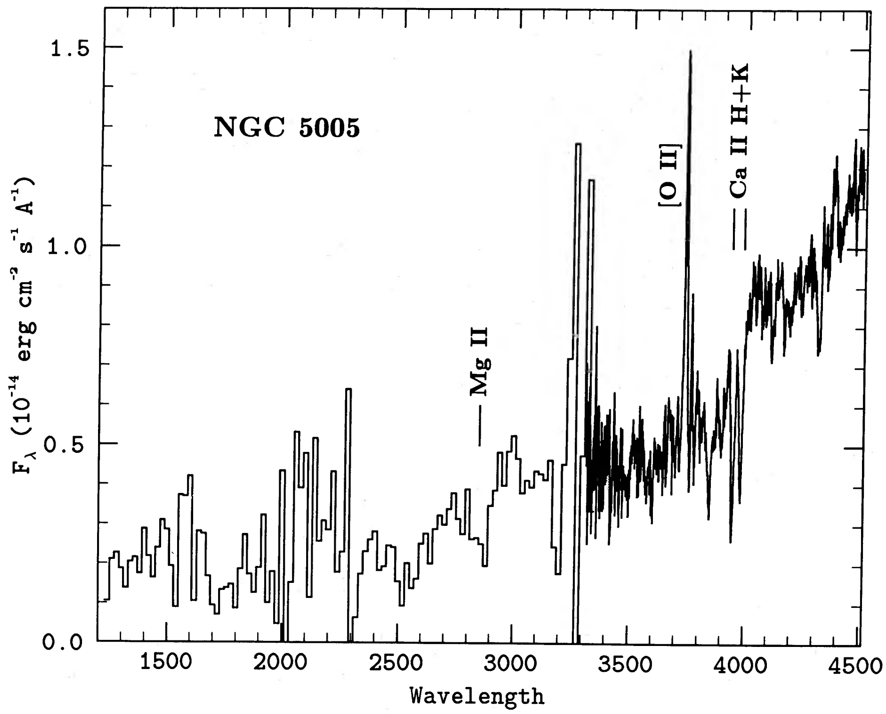

FIG. 3.—Composite UV-optical spectrum of NGC 5005, plotted in linear flux units. Selected stellar absorption features are marked.

absorption at 2530 Å. These features may be interpreted in terms of an effective spectral type for each, using data from Hamilton (1985) for the Ca II break and from Wu *et al.* (1983) for the UV features. The results so obtained are remarkably concordant, indicating that A5–F0 stars dominate the light from 2500 to 4000 Å. The continuum requires an additional component shortward of this, reflecting some combination of hotter (presumably younger) stars and a possible weak non-thermal source like that found in NGC 4579 (§ V).

The star-forming history of the inner region of NGC 5005 has obviously been rather eventful. The blue and ultraviolet light is dominated by a population characterized by F star features, which suggests a star formation burst of age near 10^9 yr; in such cases, the main-sequence turnoff dominates the blue light. As expected, a later population dominates to the red (from the synthesis of Keel 1983*b*). Some yet hotter stars must contribute to the continuum below 2000 Å; approximately 700 B0 stars, or concomitantly fewer earlier type stars, would produce the observed flux. This sort of calculation is of course very crude, since the stars referred to naturally produce a wider range of radiation than this, but the data do not warrant a sophisticated analysis.

The inferred rate of star formation within the *IUE* aperture, with a typical dimension of 400 pc, is 0.0003 $M_\odot$ yr^{-1} of OB stars, or 0.005 $M_\odot$ yr^{-1} total mass for a Salpeter initial mass function. This is not extreme for such a volume and density of stars of all types; the contrast with NGC 4501 and NGC 4579 perhaps serves to emphasize just how quiescent the nuclei of the latter are with respect to recent star formation.

Since the recent star formation and nuclear emission lines of NGC 5005 indicate that substantial gas is present in its nuclear region, it is interesting to note the apparent lack of significant reddening in the UV spectrum. The continuum shape of the starlight is consistent with its spectral features, indicating little reddening, and no evidence of absorption at the location of the λ2175 feature characteristic of galactic grains is found.

V. NGC 4579

The Hα emission line of NGC 4579 was found by Stauffer (1982) to be broad, an observation confirmed by Keel (1983*a*) and recently by Filippenko and Sargent (1985). The latter analysis, done at $\sim$2.5 Å resolution, indicated that the broad wings had full widths at zero intensity (FWZI) of 5700 km s^{-1}. NGC 4579 has also been detected by both the IPC and the HRI instruments aboard the *Einstein Observatory* (Long and van Speybroeck 1984). The IPC observations showed a flux of 9.28×10^{-13} ergs cm^{-2} s^{-1} in the 0.5–4.5 keV energy range, and the HRI observation confirmed that the source was unresolved. Figure 4 shows the *IUE* spectra of NGC 4579, again binned into 20 Å intervals. There are two possible features of interest in the SWP wavelength region, one near the position of C IV λ1550 and the other near the position of He II λ1640. Inspection of the two-dimensional version of the *IUE* spectrum shows that the feature at 1550 Å is slightly displaced relative to the continuum and does not look like a spectral feature but more like a diffuse "flare" in the *IUE* camera. These "flare" features are not uncommon, but it seems particularly ill-fated that in this instance one has fallen on top of the important C IV line, preventing us from detecting a faint line if it were there. Hence we can only give a very rough upper limit to the flux of C IV λ1550. The feature at 1640 Å, on the other hand, is centered on the continuum and has the appearance of a genuine line. We are confident that this is indeed the He II λ1640 line and determine a flux for it. This measurement, together with 3 σ upper limits determined for a number of important diagnostic lines which we did not detect in our spectra, are given in Table 2. (The upper limits were calculated from the observed point-to-point noise in the spectrum and assuming a line width of 6 Å in the SWP and 9 Å in the LWP.)

TABLE 2

NUCLEAR EMISSION SPECTRUM OF NGC 4579

Observation/ Model	C II λ1335	C IV λ1550	He II λ1640	C III] λ1909	C II λ2326	[O II] λ3727	[O I] λ6300	Hα λ6563	[N II] λ6584	[S II] λλ6716, 6731
Observed	<0.21	<0.82	0.59	<0.21	<0.22	1.42	0.70	1.52	4.40	2.13
Model 1	0.03	0.00	0.32	0.24	0.40	1.86	0.30	0.81	0.53	0.59
Model 2	0.04	0.00	0.31	0.07	0.33	2.21	0.43	0.75	0.96	0.94
Model 3	0.21	0.00	0.57	0.20	0.16	2.37	0.60	1.49	2.04	2.01
Model 4	0.07	0.00	0.52	0.16	0.66	4.49	0.90	1.46	2.02	2.18
Model D	1.01	0.03	0.01	0.27	2.14	6.13	0.22	2.15	1.32	1.78
Model E	0.44	0.78	0.08	0.75	0.88	1.88	0.22	0.83	0.60	1.09
Model F	0.31	1.56	0.16	0.56	0.67	1.59	0.35	0.64	0.62	1.23
Model G	0.17	1.57	0.16	0.37	0.43	1.56	0.33	0.54	0.54	1.10
Model H	0.41	0.77	0.08	0.68	0.86	1.28	0.39	0.75	0.65	1.13
Model I	0.45	0.42	0.05	0.73	0.85	1.80	0.09	0.92	0.59	0.70
Model J	0.48	0.58	0.18	0.65	1.01	2.32	0.46	1.38	0.61	2.13

Also included in Table 2 are the optical line measurements of Keel (1983*a*) for a number of emission lines. All of these lines are given in the form of a ratio with the flux of [O III] λ5007. Keel gives a value of $(85 \pm 7) \times 10^{-15}$ ergs cm^{-2} s^{-1} for the absolute flux of the λ5007 line. From Hα images of NGC 4579 it appears that aperture effects in matching the *IUE* fluxes with the optical line fluxes are <20%.

In the lower half of Table 2 are the calculations of a number of models: shock models taken from Shull and McKee (1979), and photoionization models calculated from Ferland and Netzer's CLOUDY photoionization code (Ferland and Netzer 1983). Filippenko (1985) has demonstrated that there are different density regimes in the emission line regions of LINERs, so that the use of one-zone models must be considered a simplifying assumption. With this caveat in mind we compare the emission-line spectrum of NGC 4579 with the various models. The shock models are designated by their labels in Shull and McKee (1979); for all models except model H the preshock hydrogen number density is 10 cm^{-3}. The shock velocities of models D through G are 80, 90, 100, 110, and 130 km s^{-1} respectively. Models H, I and J have shock velocities of 100 km s^{-1}, with model H having a preshock number density of 100 cm^{-3}, model I having a 10 μG magnetic field, and model J having a subsolar metal abundance. The photoionization models in Table 2 were run specifically for this paper and are parameterized by the ionization parameter U and the metal abundance. All four photoionization models have an ionizing spectrum in the form of a power-law of index $\alpha = 1.4$, and a

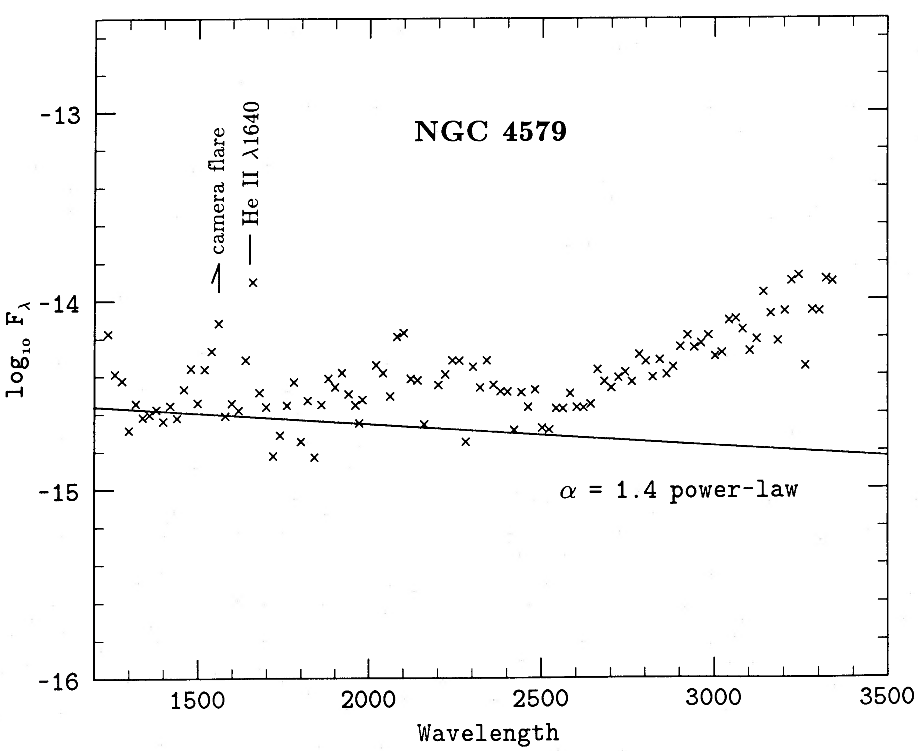

FIG. 4.—The *IUE* spectrum of NGC 4579, averaged in 20 Å bins. The line is a power law of spectral index 1.4 extrapolated from the X-ray detection to the ultraviolet. The camera flare and the He II λ1640 emission line mentioned in the text are both marked.

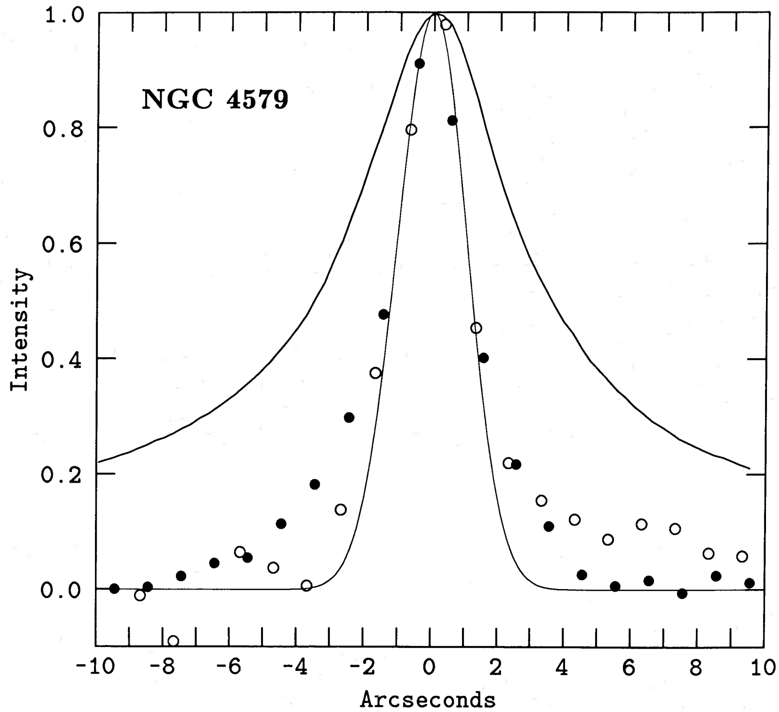

FIG. 5.—The profile of NGC 4579 perpendicular to the direction of dispersion of the *IUE* spectrographs. The heavy line is the optical profile, the open circles are the SWP profile, the filled circles are the LWP profile, and the light line is the *IUE* point-spread function.

cloud density of 1000 cm^{-3}. Models 1–3 have ionization parameters log $U = -3.5$, while model 4 has log $U = -3.7$. Models 2 and 4 have solar metal abundances, while model 1 has one-third of the solar metal abundances, and model 3 has 3 times the solar metal abundances. The outstanding problem of both types of models seems to be the failure to predict the large [N II] flux observed in NGC 4579. Model 3 comes the closest, but still is a factor of 2 too low. The broad component of Hα may be contaminating the flux measurement of [N II] λ6584 in Keel's (1983*a*) analysis by as much as 30%, but it cannot explain a factor of 2 discrepancy. The large [N II] flux may indicate that the nitrogen abundance in this galaxy's nucleus is a factor of 2 or more above the solar abundance. (Note that model 3 has elevated all of the metals by a factor of 3, and hence it is not really testing the hypothesis of an elevated N abundance and otherwise normal metals.) Of the shock models, none seems to give a particularly good fit to the observed line ratios and the upper limits of lines in the ultraviolet. In particular they predict that He II λ1640 should be undetectable, and that C III] λ1909, C II λ2326, and C II λ1335 should all be visible. They also predict that [O I] λ6300 should be weaker than is observed, and they have difficulty reproducing the [S II] line flux. Model J predicts [S II] correctly, but predicts a C II λ2326 flux 5 times higher than our upper limit. The photoionization models, on the other hand, fare somewhat better, predicting a He II flux close to that observed. Model 3, with log $U = -3.5$ and a high metal abundance, seems to fit the emission-line spectrum the best, although it predicts an [O II] λ3727 line which is larger than observed. This model has metal abundances which are 3 times as large as the solar metal abundances, perhaps indicating that the gas in the nuclei of LINERs is metal-rich. Note that Mg II λ2800 is not included in this table. There are three reasons for this. First, the Mg II line was not included in the tables of the Shull and McKee shock models. Second, because there is substantial contribution from starlight at 2800 Å, the Mg II emission line is swallowed in the Mg II absorption from the stars. Last, interstellar Mg II absorption may be significant, although the apparent lack of reddening toward the nucleus indicates that there is little dust along the line of sight. The overall impression one gets from the models is that the photoionization models provide a better fit to the emission line spectrum than do the shock models. This tends to confirm the growing body of evidence that LINERs are photoionized and not shock-heated.

The optical and ultraviolet profiles of NGC 4579 are shown in Figure 5, again compared to the *IUE* point-spread function. The optical distribution was measured at position angle 170° and may be compared to both the SWP profile taken at 168° and the LWP profile taken at 172°. In contrast with the situation discussed above in conjunction with NGC 5005, the optical light profile of NGC 4579 is much broader than the ultraviolet profiles. The cores of both the LWP and SWP profiles are fairly well fitted by the *IUE* point-spread function, but the wings of the LWP profile are higher, indicating an extended source. This effect is also clearly visible in the photowrite of this image. The SWP profile also appears to have somewhat broader wings, at least on the right-hand side of the figure. However, this side is contaminated by some camera artifacts, including the flare that affects the C IV λ1550 line. There is no evidence from the photowrite that the spectrum is extended perpendicular to the dispersion. The *IUE* point-spread function is a fairly good fit to the profile's left wing. We interpret these data as indicating that a UV-bright point source is being detected in the *IUE* spectra, with an extended stellar component contributing broad wings to the profile in the LWP spectrum. The most interesting prospect is that we are actually observing the photoionizing continuum of the LINER in the ultraviolet.

We may check this last proposal by looking at the X-ray flux from *Einstein* and comparing it to the flux we have observed with *IUE*. A recent analysis of Seyfert 2 galaxies and narrow-line radio galaxies (Ferland and Osterbrock 1986) indicates that the photoionizing continuum may be represented by a power-law of the form $f_\nu \propto \nu^{-\alpha}$, where the spectral index α is close to 1.4. If we take the observed *Einstein* IPC flux and connect it to the SWP flux of NGC 4579, we find a UV to X-ray spectral index of 1.4 ± 0.1, in excellent agreement with the analysis for Seyfert 2 galaxies. Figure 4 shows the level of the $\alpha = 1.4$ power law as extrapolated into the ultraviolet from the X-ray detection. Hence both the X-ray and the ultraviolet flux levels are consistent with the assumption that they are both part of the photoionizing continuum of the LINER, and that they have the same power-law slope as that generally found in Seyferts. This observation indicates that the covering factor along our line of sight to NGC 4579 is not so large as to preclude observation of the photoionizing continuum, as Halpern and Steiner (1983) warned.

The strength of the observed continuum may be compared to the strength of the emission lines and checked for consistency. As Searle and Sargent (1968) pointed out the equivalent width of Hβ may be calculated as a function of the continuum shape. Ferland and Netzer (1983) give a simple formula for the equivalent width of Hβ for a power law of slope α and a covering factor of 1,

$$W_\lambda(\mathrm{H}\beta) = \frac{560}{\alpha}\left(\frac{3}{16}\right)^\alpha \text{Å},$$

which, for $\alpha = 1.4$, yields $W_\lambda(\mathrm{H}\beta) = 38.4$ Å. Keel (1983*a*) did not obtain an accurate measurement of Hβ for NGC 4579, but we may use his Hα flux to estimate the equivalent width of Hβ (with respect to the *photoionizing* continuum, of course, not the stellar continuum). Using the mean Balmer decrement of 2.8 for LINERs given by Ferland and Netzer (1983) and taking for the continuum at Hβ the extrapolated $\alpha = 1.4$ power law displayed in Figure 4, we calculate $W_\lambda(\mathrm{H}\beta) = 38.9$ Å, in excellent agreement with the predicted value. This indicates that the covering factor in NGC 4579 is indeed close to unity. It remains to be seen, however, whether the covering factor of LINERs in general is high or low.

The power-law form of the continuum here, and the detection of He II λ1640 at the level predicted by extrapolating this continuum, suggest that the ionizing spectrum in NGC 4579 is very close to this shape over the entire relevant frequency range. NGC 4579 does not show the discordant lack of He II which led Péquignot (1984) to infer the presence of a hot blackbody contribution to the ionizing spectrum in NGC 1052, in order to yield strong enough lines of hydrogen and low-ionization species of heavy elements without violating the observed limits to He II λ4686.

Previous ultraviolet observations of LINERs have been largely confined to elliptical galaxies and have been inconclusive as regards a nonstellar continuum. Fosbury *et al.* (1981) found no evidence of such a continuum in NGC 1052, although a longer exposure by Snijders (reported by Diaz, Pagel, and Terlevich 1985) shows some evidence for a power-law–like continuum. The ultraviolet spectrum of M87 shows a very blue component shortward of 2200 Å (Bertola *et al.* 1980), but this component is spatially extended and may be understood in terms of residual star formation (Gunn, Stryker, and Tinsley 1981); as in the case of NGC 5005 a small hot stellar population can mask the nonstellar contribution sought, given the limits of present ultraviolet equipment. Some excess blue continuum is detectable in the optical (3200–4000 Å) at the nucleus of M87 itself, with approximately the level predicted from the emission lines and photometric properties of the nucleus (W. C. Keel, unpublished data as described in § II). Our observations of NGC 4579 are most comparable to published data on M81. Bruzual, Peimbert, and Torres-Peimbert (1982) found an upper limit to the UV continuum from a power-law source consistent, within the uncertainties, with photoionization powering the emission-line region. This result was partly based on the nuclear X-ray flux of M81, as they did not directly detect the UV continuum.

We must say here that the evidence presented is not conclusive evidence that we have detected for the first time in the ultraviolet the photoionizing continuum of a LINER, but it is fairly compelling. The other alternative is that we are detecting a hot stellar component in the nucleus of NGC 4579, which is unresolved at the 2″ level. The difficulty of obtaining good SWP spectra of the nuclei of galaxies such as NGC 4579 makes this proposal hard to test, as the best way to identify a stellar component to the flux is by detecting the absorption lines presumably found in the spectrum. An analysis of this sort may have to await the orbiting of a larger ultraviolet telescope. However, the combined evidences of the match of the emission spectrum with the photoionization models, the unresolved nature of the SWP ultraviolet excess, and the agreement of the UV to X-ray spectral index with that found in Seyferts adds substantial weight to the argument that LINERs harbor "mini-Seyferts" in their nuclei.

In this paper we report the possible detection of a photoionizing, power-law continuum in only one of three LINERs studied. This apparent "failure" rate of 67% should not be taken too seriously, however, because of the inherent difficulties involved in the study. As mentioned in § III the existence of a small amount of reddening in NGC 4501 would be enough to place any photoionizing continuum below the *IUE* limit of detectability. The small reddening needed would be very hard to detect from the optical spectrum. Similarly, undetected reddening in NGC 5005 may help to explain the failure to detect a photoionizing continuum in this nucleus, although the continuum is even further masked here by the presence of young stars contributing to the ultraviolet flux. Obviously more sensitive instrumentation is needed to define and properly observe a complete sample of LINERs in the ultraviolet.

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