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FAR-ULTRAVIOLET AND OPTICAL SPECTROPHOTOMETRY OF X-RAY SELECTED SEYFERT GALAXIES[1]

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ABSTRACT

We have performed near-simultaneous far-ultraviolet and optical spectrophotometry of five X-ray selected Seyfert galaxies (previously unobserved by the *International Ultraviolet Explorer*) to further test the models for excitation of the emission lines by X-ray and ultraviolet continuum photoionization. Indications of variability in these sources over the 2 week interval between our visible and *IUE* observations stresses the importance of simultaneous observations in the study of correlations between emissions in different wavelength bands. The X-ray to optical continuum spectra and most emission-line properties of the nuclei of these Seyfert I galaxies appear very similar to those of previous samples of Seyfert I nuclei, but the observed ratio Lyα/Hβ in our sample averages 22, which is significantly higher than that observed in previous samples. In our limited sample there also appears a positive correlation between the width of the lines and the ratio Lyα/Hβ. We have additionally observed an increasing ratio Lyα/Hβ toward the high-velocity wings of the H lines in the spectrum of at least one of the Seyfert I nuclei. If this correlation proves to hold for Seyfert I galaxies in general, this will imply that Seyfert galaxies with the most high-velocity gas exhibit the highest Lyα/Hβ ratios at all velocities in the line profiles, and that in some cases the ratio Lyα/Hβ may be highest for the highest velocity material in the broad-line clouds. Since the explanation for the previously observed anomalously low ratio Lyα/Hβ ≈ 5 from Seyfert 1 galaxies has been the "trapping" of Lyα photons by a high optical depth of H, possibly coupled with some additional extinction by dust or variation in electron density, it may be that the broad-lined objects that we have observed are least affected by this phenomenon and therefore have ratios Lyα/Hβ much closer to those predicted by the early photoionization calculations.

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

I. INTRODUCTION

Much theoretical and observational work has been reported in recent years regarding the production of the prominent emission lines observed in the spectra of active galactic nuclei (AGNs). The modeling of the excitation of these lines has concentrated on the effects of photoionization by X-ray and ultraviolet (UV) continuum emission emanating from a compact central source on a surrounding quasi spherically symmetric distribution of clouds. The physical conditions and dynamics of these clouds then determine the strengths, ratios, and the shapes of the observed broad resonant emission lines. Fairly extensive observational data bases now exist for the brighter Seyfert galaxies and low-redshift QSOs from the X-ray to the IR bands, and these have permitted studies to be performed of correlations between various continuum and line emission properties, which in turn test the predictions of the photoionization models.

Correlation studies of known Seyferts by Kriss, Canizares, and Ricker (1980) and of X-ray selected AGNs by Reichert *et al.* (1982) have shown that the optical continuum, emission-line, and X-ray luminosities are all strongly correlated. More recently Kriss (1984, 1985) has specifically addressed the correlations between X-ray luminosity and emission-line properties predicted by the models for X-ray heating of the broad-line regions (BLR) (cf. Kwan and Krolik 1981; Ferland and Mushotzky 1982). However, Kriss found little, if any, evidence for the predicted correlations and therefore support for X-ray heating in the BLR.

An outstanding problem with the photoionization models is explaining the observed ratio Lyα/Hβ from the BLR of Seyfert I's and QSOs. Baldwin (1977) showed that the ratio of integrated fluxes Lyα/Hβ is observed to be ~ 3 for low-redshift QSOs and Wu, Boggess, and Gull (1983) have shown that it is ~ 5 for Seyfert I's, whereas ratios ~ 30 were predicted by the early photoionization models (see Davidson and Netzer 1979 for a review). This discrepancy can be explained by a combination of extinction by dust and high optical depths of H in the BLR, which will act to trap the Lyα photons by the very large resonant scattering cross section. Near-simultaneous observations of Paα, Hα, Hβ, and Lyα line emission from a sample of Seyfert nuclei by Lacy *et al.* (1982) indicate that extinction by dust alone within the BLR clouds cannot explain the observed line ratios from the UV to the IR. The effects of dust should also be seen very clearly in the extinction of the UV continuum (see Neugebauer *et al.* 1979), whereas the continuum spectra of Seyfert I nuclei tend to have very similar spectral slopes from object to object (Mushotzky *et al.* 1980; Wu, Boggess, and Gull 1983).

International Ultraviolet Explorer (*IUE*) spectra of 20

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known Seyferts (giving continuum measurements down to ~1200 Å) have been presented by Wu, Boggess, and Gull (1983). From the sources they observed which had also been detected in X-rays, they found that an extrapolation of the infrared (IR)–optical–far-ultraviolet (FUV) continuum to X-ray wavelengths would greatly overestimate the ionizing flux shortward of the Lyman limit at 912 Å, and they concluded that there is a spectral break downward somewhere in the extreme ultraviolet (EUV) range. They also found strong correlations between the FUV emission line strengths and both the 1450 Å continuum flux and the 2–10 keV X-ray luminosity, giving strong support to the models of the production of line emission by photoionization. It should be noted that the shape of the ionizing continuum $\lambda < 912$ Å is an important input to the photoionization models but is generally unobservable, so that the continuum emission observed at somewhat longer wavelengths is often used to indicate the corresponding level of EUV continuum.

Unfortunately, relatively few of the known X-ray AGNs are sufficiently bright to be observed with a moderately high signal-to-noise ratio by the *IUE* (for a typical Seyfert I spectrum, this sets a limit around $m_v = 17$). Since a further constraint is imposed by the desire to obtain good measurements of the FUV line strengths (at least Lyα and C IV), there is an additional incentive to concentrate on the broad-lined QSOs and Seyfert I's. We have therefore chosen the five optically brightest X-ray selected AGNs (consisting of four Seyfert I's and one Seyfert II) from the sample presented by Reichert *et al.* (1982) to observe with near-simultaneity in the optical and FUV. With these new observations and through comparison with existing samples, we can then test the models for excitation of the emission-line clouds by X-ray and EUV radiation.

II. OBSERVATIONS

IUE observations of all five sources (see Table 1) were performed over 1983 May 25–29 covering three US1, one US2, and one European shift. All sources were too faint visually to be detected by the FES camera (see Boggess *et al.* 1978 for a description of the *IUE Observatory* operations), and were therefore acquired by blind offset from nearby SAO stars with the Seyfert centered in the large entrance aperture. Astrometry of the positions of the Seyfert galaxies and nearby field stars was performed using archived Lick Observatory Astrograph plates with positions determined in each case by a fit to the coordinates of six to eight nearby SAO stars. Consistency checks of the positions of brighter stars ($m_v \approx 10$–13) close to the AGNs and visible to the FES indicated that our blind offset positions and technique were accurate in all cases to better than 2″, and we therefore conclude that the *IUE* spectra are of photometric quality. Good exposure level SWP spectra were obtained for all four Seyfert I nuclei; however, the one Seyfert II nucleus was relatively much fainter in the FUV than the other sources and was underexposed even after a 365 minute integration, revealing just the H Lyα emission line and a weak continuum. The LWR spectra of these sources were regarded as a second priority in our *IUE* observations, since the LWR continuum level can be roughly interpolated between the visible and SWP bands and the most prominent FUV emission lines appear in the SWP range for these low-redshift sources. Limited observing time restricted us to obtaining LWR spectra of two of the Seyfert I nuclei, and we note that an additional well-exposed LWR spectrum (LWR 11477) of E1613+65 exists in the *IUE* archives. This archived LWR image was obtained nearly 2 yr before our SWP spectrum, however, and shows a continuum level which is about one-half that required to match either our SWP or optical spectra.

A comparison of the FUV and visible continuum fluxes from E1613+65 (see Table 2) further indicates that this object had brightened considerably after the Lick and before the *IUE* observations. If we assume that E1613+65 has an intrinsic spectral slope $F_{uv}/F_{vis} = 0.61$ (which is the average value observed from the other Seyfert I's in our sample) then a brightening by a factor ×3.0 over the 2 week interval is indicated. E1613+65 therefore appears to be an optically violently variable AGN, and in Table 2 we have listed extreme values for several parameters, assuming both no variation and a ×3 brightening of all continuum fluxes. Light travel time effects in the broad-line clouds should prevent the emission lines from brightening nearly as quickly as the continuum, and we have arbitrarily split the difference and assumed that the UV lines brightened by only ×1.5 over the same interval (the conclusions that we will draw about the line strength ratios later in this paper hold up for any value in this range of variability). Finally, E1613+65 shows great promise as a candidate for studying the response of the emission-line clouds to a sudden and dramatic change in the ionizing continuum flux. Ulrich *et al.* (1984) have reported such observations of NGC 4151, and they have observed the lines to brighten relatively uniformly

TABLE 1
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Source	Classification	α^a(1950)	δ^a(1950)	Date(s) of Lick Spectra[b] (m/d/y)	Date(s) of *IUE* Spectra (m/d/y)
E0849+08	Seyfert I	$08^h49^m34\overset{s}{.}3$	+8° 4′59″	1/23/80(IDS)	5/28/83(SWP) 5/29/83(LWR)
E1426+01 (Mrk 1383)	Seyfert I	14 26 33.7	+1 30 28	5/11/83(CCD)	5/28/83(SWP) 5/28/83(LWR)
E1530−08	Seyfert II	15 30 38.9	−8 31 58	5/13/83(CCD)	5/26/83(SWP)
E1556+27	Seyfert I	15 56 25.4	+27 25 46	5/12/83(CCD) 1/23/80(IDS)	5/26/83(SWP)
E1613+65 (Mrk 876)	Seyfert I	16 13 36.2	+65 50 34	5/12/83(CCD)	5/29/83(SWP)

[a] Coordinates accurate to better than 2″.
[b] Taken with the 120 inch telescope.

TABLE 2

OBSERVED CONTINUUM AND EMISSION-LINE FLUXES FROM X-RAY ACTIVE GALACTIC NUCLEI[a]

	SOURCE				
LINE/PARAMETER	E0849+08	E1426+01	E1530−08	E1556+27	E1613+65
Hα	3.4×10^{-13} [263]	9.9×10^{-13} [360]	5.0×10^{-13} [469]	2.2×10^{-13} [450]	2.1×10^{-13} [408]
Hβ	1.0×10^{-13} [73]	2.3×10^{-13} [57]	3.5×10^{-14} [47]	4.7×10^{-14} [73]	3.7×10^{-14} [64]
[O III]	1.0×10^{-13} [76]	1.1×10^{-13} [31]	3.2×10^{-13} [411]	2.0×10^{-14} [33]	3.8×10^{-14} [73]
Lyα	1.3×10^{-12} [87]	5.1×10^{-12} [129]	1.9×10^{-13} [57]	1.0×10^{-12} [303]	1.8×10^{-12} [142]
C IV	5.7×10^{-13} [56]	1.9×10^{-12} [58]	2.4×10^{-14} [12]	6.6×10^{-13} [193]	7.6×10^{-13} [59]
[C III]	...	3.3×10^{-13} [15]	...	...	...
Mg II	9.6×10^{-14} [18]	4.3×10^{-13} [25]	...	...	...
F_{vis} (6000 Å)[b]	1.3	3.1	1.1	0.51	0.54
F_{uv} (1450 Å)[b]	0.81	2.3	0.08	0.25	1.0
$L_x/F_\nu(1450)$[c]	1.2×10^{15} Hz	...	5×10^{14}	1.6×10^{15}	4.3×10^{14} (1.3×10^{15})[d]
F_{radio}[b]	0.13	≤0.08	≤0.08	≤0.08	...
Hα FWZI (km s^{-1})	7900	17700	5900	11500	14800
Lyα FWZI (km s^{-1})	9300	23500	5300	16300	15700
Lyα/Hβ	13	22	5.4	21	49 (33)[d]
Hα/Hβ	3.4	4.3	14	4.7	5.7
F_u/F_{vis}	0.62	0.74	0.07	0.49	1.85 (.61)[d]

[a] Line fluxes: ergs cm^{-2} s^{-1}: [equivalent widths: Å].
[b] Continuum fluxes: (ergs cm^{-2} s^{-1} Hz^{-1}) $\times 10^{-26}$.
[c] From Reichert *et al.* 1982.
[d] Corrected for $\times$ 3 (continuum) and $\times$ 1.5 (line) brightenings at the time of *IUE* observations (see text).

over the line profile (following a time delay after the continuum brightening) as would be expected for chaotic motions within the clouds.

Visual spectra were obtained with the 120 inch (3 m) Shane Telescope at Lick Observatory, employing an objective grism CCD spectrograph over the nights of 1983 May 11–13 (roughly 2 weeks before the *IUE* observations). Two different grisms gave spectral resolutions of ~6 Å and ~20 Å. The CCD spectra were obtained in a long-slit mode with an aperture 10″ wide in the dispersion direction and 20″ wide perpendicular to dispersion to match the *IUE* aperture size. Observations of the same standard stars each night (Stone 1977) indicate that the photometry was 10% or better. The one source which was not observed during this run (E0849+08) had been observed on the Lick 120 inch telescope with an IDS detector at 10 Å resolution on 1980 January 23. It is possible that E0849+08 also varied over the 3 yr interval between the optical and FUV observations, but we note that the *IUE* and Lick continuum flux levels appear to match well over ~3000–4000 Å suggesting comparable emission strength at the times of the two observations. The *IUE* and Lick spectra of all five AGNs are plotted together in Figure 1 on the same flux scales to show the prominent emission lines and the continuum shape over the range from 1200 to ~8000 Å. We note that a different observation of E1426+01 over the same period as our own observations by Kriss (1985) found an Hα/Hβ ratio of 2.77, as opposed to our measurement of Hα/Hβ = 4.3, stressing the importance of simultaneous observations in comparing different line strengths. In the interests of characterizing the spectral properties of these sources as completely as possible, we have further observed four of the sources with the 100 m Bonn radio telescope on 1982 December 18 at a wavelength of 2.8 cm. Only one of the sources was detected, and at a flux level just greater than three times the RMS noise level (see Table 2).

III. SPECTRAL ANALYSIS

a) Line and Continuum Properties

We have listed in Table 2 the derived continuum levels in the visible, FUV, and soft X-ray bands, the fluxes and equivalent widths (at zero redshift) of the major emission lines, and the line widths and ratios of several selected features. The strengths of all lines were measured with respect to continuum levels determined by polynomial fits to the data in 50–100 Å bands on either side of the line and clearly resolved from the line wings and other features. The 1450 Å continuum flux was extrapolated from the red continuum side of Lyα due to camera noise over the range 1500–1600 Å on the *IUE* detector. The full width at zero intensity (FWZI) of the emission lines have been measured by extending the slope of each line profile

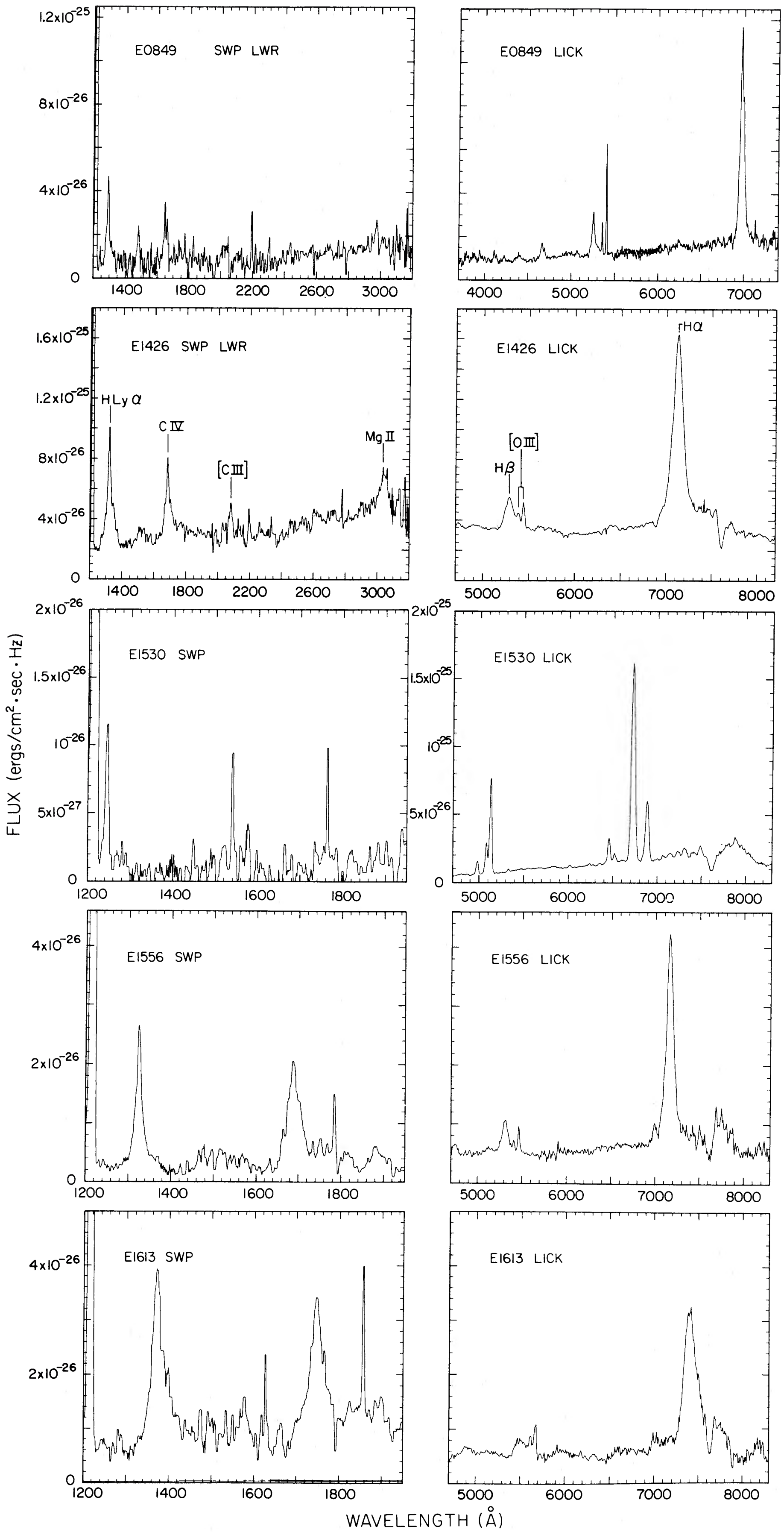

FIG. 1.—*IUE* and Lick 120 inch telescope optical spectra of the five X-ray selected AGNs. All sources have the FUV and optical spectra plotted on the same flux scale except E1530−08, which has the FUV scale expanded by an order of magnitude compared to the optical scale. The visible and FUV spectra were acquired roughly 2 weeks apart.

at 10% of full intensity through the zero level. It should be noted that in our sample the one Seyfert II nucleus (E1530−08) stands out in several respects from the other sources. It has a lower X-ray flux by at least an order of magnitude, appears far redder when comparing the FUV and visible continua, and has quite different line ratios with a steep Balmer decrement and weak Lyα. We therefore confine the following discussion of the properties of Seyfert galaxies as a class to the observations of Seyfert I nuclei.

The first test performed in looking for distinguishing characteristics of the X-ray AGNs has been to compare them with the larger sample of known Seyfert nuclei presented by Wu, Boggess, and Gull (1983). These authors have given a thorough analysis and discussion of the strong support for heating by continuum photoionization as shown by the correlations between the line fluxes and 1450 Å continuum flux. We have analyzed our source parameters from Table 2 in a similar manner and found a significant discrepancy with one of the correlations derived by Wu, Boggess, and Gull (1983). Our X-ray selected Seyfert I nuclei have ratios Lyα/Hβ which average 22 ± 7 (when the value for E1613+65 is corrected for a $\times 1.5$ Lyα increase), which is much closer to the early model predictions than the value Lyα/Hβ ≈ 5 from the sample of Wu, Boggess, and Gull (1983). Our sources have visible line ratios Hα/Hβ quite similar to the previously reported objects, however, which argues against the presence of simple extinction by dust and complicates the interpretation of the difference between our sample and the previously reported objects. In addition to the correlations tested by Wu, Boggess, and Gull (1983), we have looked for but found no apparent correlation between the ratio Lyα/Hβ and the ratio of continuum fluxes $F_{\rm uv}/F_{\rm vis}$, which might be expected to correlate with both the relative strength of the $\lambda < 912$ Å ionizing continuum flux and the effects of extinction by dust in the BLR clouds. We have further tested for the effects of extinction by dust by correcting the LWR spectra of E0849+08, E1426+01, and E1613+65 for varying amounts of reddening using the average galactic extinction curve of Savage and Mathis (1979). Judging mainly by the lack of a 2175 Å absorption feature in any of these spectra, we have been able to set upper limits of $E(B-V) \lesssim 0.1$ for these sources. It is not clear, however, that extragalactic dust would exhibit the same 2175 Å features as galactic dust or that the continuum emission in a Seyfert galaxy would be subject to the same degree of reddening as line emission from the BLR clouds.

We find a positive correlation in our sample between the ratio Lyα/Hβ and the full width at zero intensity (FWZI) of the H lines. This correlation suggests that either Seyfert galaxies with more high-velocity gas tend to exhibit higher Lyα/Hβ ratios across the line profile and/or that Lyα emission is enhanced with respect to Hβ with increasing velocity in the wings of these lines (i.e., the highest velocity material in the line-emitting clouds, see also § III*b*).

Since our sample of Seyfert galaxies was primarily selected on the basis of the X-ray emission and secondarily selected on the basis of optical flux, we anticipated finding some correlation between the X-ray flux and any observed FUV or visual peculiarities of these objects. The ratio L_x/F_v (1450) is given in Table 2 for comparison with the same quantity given for 15 non–X-ray selected Seyfert galaxies by Wu, Boggess, and Gull (1983), who found an average value 1.6×10^{15} Hz. The average value for our Seyfert I nuclei is 1.4×10^{15} Hz which is in close agreement with the value for non–X-ray selected objects. From the observed values of $F_{\rm uv}/F_{\rm vis}$ and L_x/F_v (1450), we conclude that the continuum spectra of Seyfert I nuclei are very similar from object to object (similar conclusions have been reached by Wu, Boggess, and Gull 1983, Reichert *et al.* 1982, and Mushotzky *et al.* 1980). This in turn suggests that the relatively large differences in Lyα/Hβ observed from different samples of objects is determined not so much by the ionizing continuum emanating from the central object as it is determined by the distribution, quantity, and composition of the line-emitting clouds (see § IV).

b) *Emission-Line Profiles*

Stratification of the physical conditions in the broad line-emitting clouds or simply optical depth effects may in principle be observed through the measurement of varying line ratios at different velocities in the line profiles. Shuder (1982) has reported a general increase in the ratio Hβ/Hα toward the high-velocity wings of these lines in the spectra of Seyfert I nuclei. He proposed that the physical conditions of either electron density N_e, ionization parameter U (cf. Ferland and Mushotzky 1982), or Lyα optical depth $\tau_{\rm Ly\alpha}$ increase with increasing velocity in the BLR clouds. The interpretation of these effects also depends on the assumed velocity field of the BLR clouds, i.e., whether the clouds are subject to infall, chaotic motions, rotation about the compact object, etc. For example, the ionization parameter would be expected to increase toward the wings of the lines if the BLR clouds have the gravitational infall geometry modeled by Capriotti, Flotz, and Byard (1981) in which the highest velocity material is closest to the central source of ionizing continuum. There is presently considerable uncertainty about the nature of the velocity field in Seyfert I galaxies as a class, but observations of the ratios of UV to visible lines across the line profiles may provide additional information about the relative contributions of N_e, U, and $\tau_{\rm Ly\alpha}$ even without a prior knowledge of the velocity field.

We have therefore compared the profiles of the UV and visible emission lines from the Seyfert I nuclei to look for velocity effects in the line profiles. We have concentrated mainly on the Lyα, C IV, and Hα lines since these are the brightest lines (and give a correspondingly high signal-to-noise ratio when comparing their profiles), and they are also relatively uncontaminated by other nearby lines. The spectral resolution of 6–7 Å in the *IUE* spectra and ~20 Å in the CCD spectra give comparable velocity resolutions, and only the 10 Å visible IDS spectrum of E0849+08 has been smoothed with a running mean filter to match the *IUE* velocity resolution. Comparisons of the visible and UV line profiles are limited predominantly by the noise in the *IUE* spectra (see Fig. 1) and the fact that the redshifted Hα line in several cases overlaps partially with the atmospheric absorption bands ~6900 Å and ~7600 Å. Limited 120 inch telescope observing time prevented us from obtaining comparison star spectra at similar times and air masses to accurately correct for these atmospheric absorptions, and we present the optical spectra in Figures 1 and 2 in uncorrected form.

Reasonably high-quality comparisons between the Hα and Lyα line profiles extending into the wings of the lines were obtained for E1426+01, E1556+27, and E1613+65. The suggestion of structure in the wings of the Lyα line in image SWP 20076 of E1426+01 prompted us to take an additional long exposure of that source, and Figure 2 (*top*) illustrates the well-defined structure in both the Lyα and C IV lines that appeared when the signal-to-noise ratio was significantly higher. An

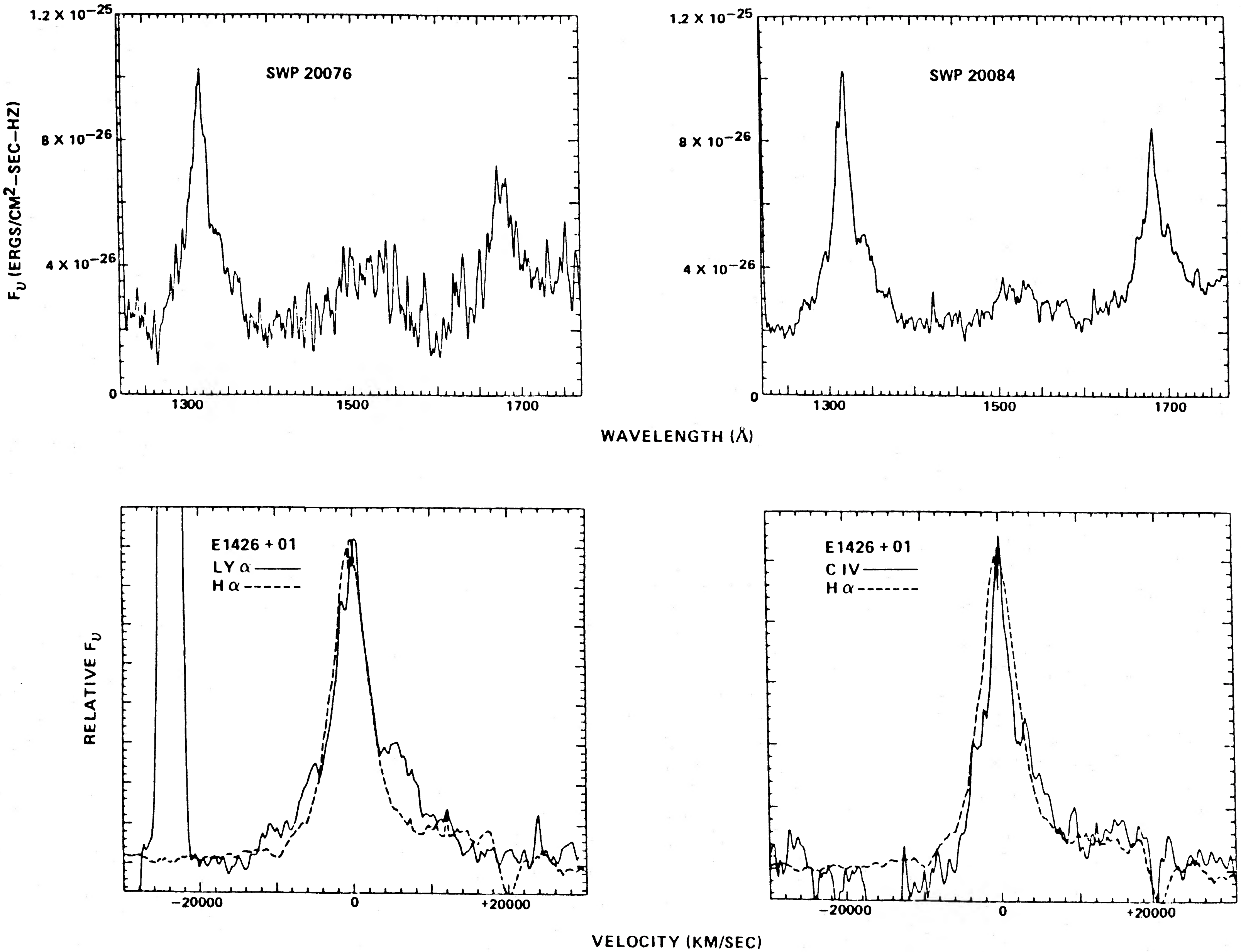

FIG. 2.—(*top*) *IUE* spectra of E1426+01, showing the structure in the wings of the Lyα and C IV lines which appears clearly in the longer exposure. The structure from 1450 to 1600 Å is believed to be noise in the SWP detector. (*bottom*) Lyα and C IV line profiles from E1426+01 overplotted on the Hα line. The absorption features at −10,000 and +20,000 km s^{-1} in the Hα data are atmospheric features, and there may be N V emission at +5900 km s^{-1} in the Lyα data. The feature at −22,000 km s^{-1} in the Lyα plot is sky background Lyα emission at zero redshift.

overlapping N V line ($\lambda_0 = 1240$) appears at 1342 Å unresolved from the Lyα wing, and the range from ∼1330 to 1350 Å must be overlooked in the comparison with the Hα line profile (Fig. 2, *bottom*). An additional feature at -5900 km s^{-1} is consistent with Si II λ_o 1192, which appears with a similar strength in the spectrum of PKS 2135−14 (Bergeron and Kunth 1983). We also detect [N IV] at -1250 km s^{-1} from C IV, which is of comparable strength to the broad wings of Lyα. It is apparent from the data in Figure 2, however, that there is a multiple component structure to the Lyα and C IV lines, and a single smooth component to the Hα line. From Figure 2 (*bottom*) it can be seen that the central component of the Lyα line overlaps with the Hα line, whereas the ratio Lyα/Hβ is relatively higher in the wings of these lines (Δv = 8,000–12,000 km s^{-1}). The two "shoulders" in both the red and blue wings of the Lyα line are well resolved above the noise level in SWP 20084 and suggest that there is some stratification in the velocity field of the BLR clouds in E1426+01. The central component of the C IV line appears significantly narrower than the Hα line, however, while the line wings of C IV overlap much more closely with the line wings of Hα. A similar stratification has been observed in the C IV line from NGC 4151 by Ulrich *et al.* (1984) by means of time-resolved spectra, in which the high-velocity emission varied much more dramatically than the central component. These authors also detected multiple resolved components to the C IV line. There is also an indication in the E1556+27 spectra of a broad, weak base component in the Lyα line which may be less pronounced in the Hα line, although the quality of these spectra is not as high as those of E1426+01. Finally, the Lyα and Hα lines appear to overlap throughout the line profiles in E0849+08 and E1613+65. We wish to point out, however, that higher signal-to-noise ratio FUV spectra of these objects may reveal additional structure in the wings of the Lyα and C IV lines, as was the case with E1426+01 in the present set of observations.

IV. DISCUSSION

There are several features of our limited set of Seyfert galaxy spectra which argue against our having chosen a random selection of sources from the sample of Reichert *et al.* (1982), most notably the unusually high ratio of integrated fluxes Lyα/Hβ in the four Seyfert I spectra. The five sources chosen for *IUE* observations were selected mainly on the basis of m_v (due to the limited sensitivity of the *IUE*), but in addition, in the case of sources of comparable m_v the source with the more "prominent" visible emission lines was chosen from the desire to obtain high-quality spectra of the FUV lines. The combination of these two biases produced a set of low-redshift Seyfert galaxies and also those that have the broadest Hβ lines. The average Hβ FWZI of the Seyfert I galaxies reported here is 15,000 km s^{-1}, compared with an average value of 7600 km s^{-1} for the whole X-ray selected sample of AGNs of Reichert *et al.* (1982). Although four sources constitute too small a sample for a detailed statistical analysis, the existence within this data set of a correlation between Lyα/Hβ and the full width of the H lines, coupled with the knowledge that existing larger samples of sources have, on the average, lower Lyα/Hβ values by a factor of 4 and narrower H lines by roughly a factor of 2, lends considerable support to this correlation. Comparisons between the Lyα and Hα line profile in these sources further indicate that while part of this effect may be due to an increasing Lyα/Hβ ratio in the wings of these lines, as observed in E1426+01, there must also be a generally higher ratio Lyα/Hβ throughout the line profiles to explain the difference between our average value Lyα/Hβ = 22 and averages of roughly 5 from previous samples. Finally, from our data and the larger sample of Wu, Boggess, and Gull (1983), it is known that while the individual line strengths correlate well with continuum luminosity, the ratio Lyα/Hβ does not appear to correlate with either continuum luminosity or slope.

The next logical question is whether the correlation between Lyα/Hβ and FWZI applies to Seyfert I galaxies in general. Particularly in view of the small sample reported here, we have consulted the literature to see if the correlation holds for a larger sample. Unfortunately earlier comparisons between the FUV and optical spectra have consisted almost exclusively of comparisons between nonsimultaneous observations, with a few exceptions such as Kriss (1985). For example, large compilations by Kinney *et al.* (1985) and Wu, Boggess, and Gull (1983), while quite valuable within the *IUE* band, depend on other compilations such as that of Steiner (1981) for optical spectra covering observations from the early 1970s to the present. In view of our own experience with two of our five program objects apparently varying over a 2 week interval, we regard observations separated by years without additional information about the source as being too uncertain to test this correlation. We note that earlier derived ratios of Lyα/Hβ have also been based on nonsimultaneous observations, but variability of the different line strengths should introduce scatter in the measured Lyα/Hβ rather than a systematic bias, whereas any correlation between Lyα/Hβ and FWZI would be degraded by variability. The possibility also exists that this correlation may be limited to one of the subclasses of Seyfert galaxies discussed by Steiner (1981).

As discussed earlier in this paper, previous explanations for the observed anomalously low ratio Lyα/Hβ have invoked a combination of a high Lyα optical depth in the BLR clouds with a possible component of reddening by dust also in the BLR clouds. The observed effect of a varying Lyα/Hβ ratio over the line profile may additionally indicate changing conditions of electron density *Ne* and/or photoionization parameter U_1 as discussed by Shuder (1982), although *Ne* may, and U_1 certainly will, be highest near the continuum-emitting central object. These explanations therefore require a velocity distribution of the BLR clouds in which the highest velocity material is at the smallest radial distance (e.g., gravitational infall or rotational motions). The lack of a correlation between Lyα/Hβ and the continuum luminosity, however, suggests that the strength of the photoionization alone does not determine the line-integrated value of Lyα/Hβ. Observations of Lyman, Balmer, and Paschen series lines from the same objects indicate that high densities are only a partial contributor to the observed line ratios. A more promising explanation for the Lyα/Hβ correlation with line width appears to be the decrease in Lyα optical depth at any given point in the line profile which could accompany an increase in the velocity dispersion of the BLR clouds. Independently of the velocity field of the BLR clouds, those objects with smaller (i.e., less optically thick) and higher velocity clouds would exhibit higher Lyα/Hβ ratios across the line profiles, bringing the line-integrated ratio Lyα/Hβ up closer to the originally predicted values. The determination of the slope and the scatter in this correlation through analysis of a larger sample of line profiles will permit a more detailed modeling of these effects.

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