HYDROGEN LINE RATIOS IN SEYFERT GALAXIES AND LOW REDSHIFT QUASARS

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ABSTRACT

New observations of the Lyα/Hα ratio in a set of X-ray selected active galactic nuclei and an archival study of International Ultraviolet Explorer (IUE) observations of Lyα in low redshift quasars and Seyfert galaxies have been used to form a large sample (49 objects) for studying the influence of soft X-rays on the enhancement of Balmer emission in the broad line region. In common models of broad line clouds, the Balmer lines are formed deep in the interior, largely by collisional excitation. Heating within the clouds is provided by soft X-ray radiation, while Lyα is formed mainly by recombination after photoionization. The ratio Lyα/Hα is expected to depend weakly on the ratio of ionizing ultraviolet luminosity to X-ray luminosity (L_{uv}/L_x). If the Lyα luminosity is used as a measure of L_{uv}, a weak dependence of Lyα/Hα on the X-ray luminosity is found (valid at the 94% confidence level), similar to previous results. Future defintive studies depend more critically on contemporaneous observations and better internal reddening estimates rather than a larger sample size.

I. INTRODUCTION

The low ratio of Lyman α to Hα in the broad lines of quasars and Seyfert galaxies relative to the Case B recombination theory value is most frequently explained as an enhancement of the Balmer radiation in a cool, dense zone of the broad line region clouds (Weisheit, Shields, and Tarter 1981; Kwan and Krolik 1981). In this zone Lyα is trapped by resonant scattering at large optical depths. The Lyα trapping maintains a large fraction of the hydrogen in excited states, and collisional excitation becomes an important contributor to the generation of the Balmer lines. X-rays provide the heating at the large optical depths of the cool, dense zone, and the models of Kwan and Krolik (1981) predict weak correlations between the Lyα/Hα ratio and the ratio of ionizing ultraviolet luminosity to the soft X-ray luminosity.

The basic reason for such an expected correlation is that Lyα is predominately recombination radiation formed after photoionization by the ionizing UV while the Balmer radiation is produced by collisional excitation in the cool, dense zone which is heated by the soft X-rays. In a previous observational study of this problem Kriss (1984) found only weak evidence that the excess Balmer radiation is due to heating by soft X-rays. For a sample of 30 AGN with Lyα/Hα line ratios and soft X-ray measurements, a joint dependence of the Hα luminosity on the Lyα luminosity and the X-ray luminosity was significant at the 94% confidence level.

Since not all of the objects in the sample had simultaneous measurements of Lyα, Hα, and the X-ray luminosity, and since only reddening in our own galaxy was corrected for, any correlation may have been weakened by scatter introduced by variability or reddening internal to the AGN. An increased sample size can minimize the influence of scatter external to the correlation. This paper examines a larger sample of active galactic nuclei (AGN) that has been bolstered by new optical and UV observations and an examination of the IUE archives for additional observations of Lyα in low redshift AGN. The new observations include objects with more extreme values in their X-ray to optical luminosity ratios to probe the range covered by the correlation. Three bright X-ray selected AGN (1E1059+730, 1E1352+182, and 1E1426+015) were chosen for their high X-ray to optical luminosity ratios, and the Seyfert 1 galaxy Mrk 142 was chosen for its low X-ray to optical luminosity ratio. The three X-ray selected AGN were identified by Chanan, Margon, and Downes (1981), Kriss and Canizares (1982), and Reichert *et al.* (1982) respectively. Observations of Lyα in these targets were made with IUE with nearly simultaneous observations from the ground of Hα. The IUE archives were searched for AGN with well exposed images of Lyα that also had spectrophotometry of Hα and X-ray luminosities available in the literature.

II. OBSERVATIONS

a) Optical

The four new program objects were observed under photometric conditions on the nights of 1983 UT May 20 to 1983 UT May 22 with the 1.3m telescope of the McGraw-Hill Observatory[1] using the photon counting intensified Reticon spectrometer (Shectman and Hiltner 1976). The spectra cover the range 4000 to 8000 Å with a resolution of ~12 Å. A circular aperture of 5.6 arc seconds gave consistent fluxes on observations of program objects interspersed with standard stars. The white dwarfs Ross 640 and Grw+70°5824 (Oke 1973) were used as flux standards. All three nights yielded fluxes consistent to better than 15%. Corrections for A band absorption (important for Hα in 1E1352+182) were made with observations of the white dwarfs at the matching air mass. Fluxes and line ratios for prominent lines are given in Table I.

b) IUE Observations

Observations of Lyα for each of the program objects were made with the SWP camera in low resolution mode using the large aperture (see Boggess *et al.* 1978 for a description of the IUE instruments). A good exposure of 1E1352+182 was obtained in 240 min during US shift 1 on 1983 UT May 31. Two weak exposures of Mrk 142 (130 min and 95 min) were obtained on 1983 UT May 31 and 1983 UT June 1 during US shift 1. A 275 min exposure of 1E1059+730 during US shift 1 on 1983 UT June 1 barely detected the continuum at 2000 Å. A good exposure of 1E1426+015 was made on 1983 UT May 26 (Clarke, Bowyer, and Grewing 1984) The data were processed and the spectra extracted using the 1979 November version of IUESIPS. For the two exposures

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[1] The McGraw-Hill Observatory is operated by the University of Michigan, the Massachusetts Institute of Technology, and Dartmouth College.

of Mrk 142 each spectrum was individually extracted, and then they were summed for better signal to noise. Lyman α, CIV, and continuum fluxes at 1475 Å are listed for each of the objects in Table I.

All AGN for which Lyα, Hα, and X-ray observations were available were included in the archival study. IUE images processed before June 1979 were corrected using the program SWPFIX on the line-by-line files at the Goddard RDAF facility, and new spectra were extracted. Lyman α flux measurements were made on the extracted low resolution spectra. The literature was searched for additional objects which had Lyα, Hα, and X-ray luminosities available. Since the 2200 Å absorption feature is not observable in the SWP spectra, the data were corrected only for the estimated reddening in our own galaxy. The prescription of Burstein and Heiles (1978) was used to estimate E_{B-V}, and the reddening correction of Code et al. (1976) was applied to the line ratios and the continuum measurements. Table II summarizes the data for the 19 additional AGN studied in this paper. The redshift, assumed E_{B-V}, reddening corrected Lyα and Hα luminosities, and the X-ray luminosity are listed for each object. A colon next to the Lyα luminosity indicates that the Lyα and Hα measurements are not of the same epoch. The X-ray luminosities apply to the 0.5 to 4.5 keV band, and several are reported here for the first time. These new X-ray luminosities were obtained from Einstein Observatory Imaging Proportional Counter observations as described by Kriss, Canizares, and Ricker (1980). For the remaining 30 AGN in the current sample, *Lyα, Hα, and X-ray luminosities may be found in Kriss (1984).*

III. DISCUSSION

The X-ray selected AGN included in this program and 1E0754+14 (M. Ward, private communication) are the only UV observations to date of serendipitous Einstein X-ray sources. The overall appearance is much the same as an optically selected quasar or Seyfert galaxy. In fact, two of the program objects (1E1352+182 and 1E1426+015) are PG quasars (Schmidt and Green 1983). The ratio of Lyα to C IV is typical of other AGN, and the C IV equivalent widths and continuum luminosities fall in the same region as do other low redshift quasars and Seyferts. The only exception to these generalities is 1E1059+730. Although the optical continuum and line luminosities are of a strength similar to Mrk 142, no lines are seen in the IUE spectrum, indicating that the reddening must be larger than predicted by the HI column density in our own galaxy.

Since these X-ray selected quasars have high ratios of X-ray to optical luminosity, if the ionizing ultraviolet luminosity is well correlated with the optical luminosity (see Yee 1980 and Shuder 1981), then one might expect the X-ray selected quasars to also have high ratios of X-ray luminosity to ionizing ultraviolet luminosity. For such an object the broad line cloud models of Kwan and Krolik (1981) would predict enhanced Balmer emission relative to Lyman α if compared to an object with a lower relative soft X-ray luminosity. Thus these X-ray selected quasars are a good probe of the extremes in the correlation between Lyα/Hα and L_{uv}/L_x. Some measure of L_{uv} is necessary to study this correlation. Kriss (1984) tried using both α_{ox} and Lyα. The parameter α_{ox} is defined as $\alpha_{ox}=(\log L_o - \log L_x)/2.605$, and so it is related to the logarithm of the optical to

X-ray luminosity ratio. If the optical continuum is correlated with the ionizing ultraviolet continuum, then α_{ox} may be a valid measure of L_{uv}/L_x. Kriss (1984) found no correlation between the Lyα/Hα ratio and α_{ox}, and none is found for the larger sample of objects studied here.

Another possible measure of the ionizing ultraviolet luminosity is the luminosity of Lyα itself since Lyα is predominately formed by recombination after photoionization in the models of Kwan and Krolik (1981). Substituting Lyα for L_{uv} in the relation Lyα/Hα ~ $(L_{uv}/L_x)^{\beta}$ and solving for Hα produces the proportionality Hα ~ L_x^{β}Ly$\alpha^{1-\beta}$. The logarithmic equivalent is log Hα = C + $(1-\beta)$log Lyα + βlog L_x. The study of Kwan and Krolik (1981) suggests that β~0.3. Kriss (1984) fit the available data to a relation of this form with the coefficients of log Lyα and log L_x as independent free parameters. If the X-ray luminosity has little or no influence on the formation of Hα, then the data should be able to accomodate a coefficient of zero for log L_x. This null hypothesis was excluded at the 94% confidence level. This is weak, but uncertain evidence for the influence of the soft X-ray emission on the formation of Hα.

Besides the uncertainty in obtaining a good measure of L_{uv}, two other factors hamper the study of a correlation between Lyα/Hα and L_{uv}/L_x. First, since not all of the measurements are simultaneous, variability may introduce additional scatter. Second, since only reddening in our own galaxy is corrected, reddening internal to the AGN may also introduce scatter. Increasing the sample size can minimize the effects of additional scatter due to variability and reddening. Unfortunately, the larger sample studied here does not clarify the issue. As in Kriss (1984) the relation log Hα = A + Blog Lyα + Clog L_x is fit to the data. The maximum likelihood method of Avni et al. (1980) incorporating both detections and upper limits is used to take advantage of all the available data. The residuals are assumed to follow a Gaussian distribution of standard deviation σ. I find A=-1.73, B=0.78, C=0.25, and σ=0.33 for the best fit. Independence of the X-ray luminosity (C=0) is excluded once again at the 94% confidence level.

Thus the larger sample size has not improved the uncertain observational situation. The best fit results are of the order expected for the weak correlation between the Lyα/Hα ratio and L_{uv}/L_x, but the level of confidence is not high. Increasing the current sample size does not appear to be a viable method of resolving this issue. Since the unknown influences of internal reddening and scatter introduced by the non-contemporaneous observations are the most easily identifiable problems, the key to a more definitive study lies in a sample of simultaneous X-ray, ultraviolet, and optical observations that have better estimates for the effects of internal reddening.

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TABLE I

OPTICAL AND UV LINE RATIOS AND FLUXES

	1E1059+730	1E1352+182	1E1426+015	MRK 142
[S II] λλ6716,6732	...	0.20	...	...
Hα	2.98	3.17	2.77	2.44
He I λ5876	...	0.33	0.12	...
Fe II red	...	0.32	0.12	...
[O III] λ5007	0.39	0.12	0.16	0.23
[O III] λ4959	0.17	0.058	0.071	0.086
Hβ	1.00	1.00	1.00	1.00
Fe II blue	...	0.79	0.38	...
Hγ	...	0.40	0.45	0.33
Hδ	...	0.26	...	...
Hβ (erg cm^{-2}s^{-1})	4.2e-14	1.2e-13	4.2e-13	7.8e-14
Lyα (erg cm^{-2}s^{-1})	...	1.5e-12	5.1e-12[a]	8.6e-13
C IV (erg cm^{-2}s^{-1})	...	6.9e-13	...	4.8e-13
F_{1475} (mJy)	<0.3	0.66	...	0.77

[a] Clarke, Bowyer, and Grewing (1984).

TABLE II

REDDENING CORRECTED LUMINOSITIES

Object	z	E_{B-V}	Lyα	Hα	L_x	References		
			(erg s^{-1})	(erg s^{-1})	(erg s^{-1})	Lyα	Hα	L_x
MRK 142	0.045	0.0	7.8e42	1.7e42	1.2e43	1	1	1
MRK 205	0.070	0.11	1.3e44:	2.3e42	2.8e44	1	2	3
MRK 304	0.067	0.04	8.6e43:	3.9e43	2.2e43	1	4,5	1
MRK 335	0.025	0.04	4.3e43:	9.0e42	7.7e43	6	4,5	6
MRK 352	0.015	0.04	8.5e41:	1.5e42	3.1e43	1	4,5	7
MRK 590	0.027	0.02	6.2e42:	5.2e42	8.0e43	1	4,5	7
NGC 985	0.043	0.02	2.5e43	1.1e43	8.5e43	6	6	6
NGC 3516	0.0093	0.03	7.1e41:	2.2e42	2.0e42	8	4,5	9
NGC 4593	0.0087	0.01	1.8e42:	1.1e42	7.2e42	10	11	1
NGC 7603	0.029	0.04	1.6e42	7.1e41	1.9e43	6	6	1
Q1217+02	0.240	0.0	3.8e44:	1.6e44	2.6e45	1	12	3
PG1351+64	0.088	0.01	4.5e43:	2.9e43	1.5e43	1	12	3
1E1352+18	0.152	0.01	1.8e44	4.5e43	8.7e44	1	1	13
1E1426+01	0.086	0.02	2.1e44	4.2e43	2.0e44	14	1	15
AKN 120	0.033	0.11	9.4e43:	2.8e43	1.4e44	6	16,17	7
TON 256	0.131	0.03	9.1e43:	9.1e43	3.4e44	1	12	18
II Zw 136	0.062	0.05	8.4e43:	4.8e43	1.8e44	6	4,5	9
3C 382	0.059	0.08	3.3e43:	4.7e43	2.5e44	1	4,5	7
Pictor A	0.034	0.06	2.3e43:	7.8e41	6.7e43	1	19	1

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