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Relations between the IR–UV–X-ray Continuum and Emission Lines for a Large Composite Sample of Narrow Line and Normal Seyfert 1 Galaxies

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Abstract We report on our research on the UV, optical line parameters and the infrared through UV to soft X-ray continuum parameters for a composite sample of narrow line and normal Seyfert 1 galaxies. The strong correlations among the line width of Hβ, optical line strength of Fe II and the soft X-ray slope are confirmed. We found no correlations between the UV line parameters, the equivalent widths of Lyα and CIV and their ratio on one hand and the optical line parameters on the other. The UV and X-ray luminosities strongly correlate with the line widths of Hβ and the Fe II/Hβ ratio. No significant correlation is found between the infrared-soft X-ray continuum slope $\alpha_{\rm ix}$ and the line width of Hβ.

Key words: galaxies: active galactic nuclei (AGN) – emission lines – Ultraviolet: galaxies – galaxies: X-rays

1 INTRODUCTION

The broad emission lines, the most important characteristics of active galactic nuclei (AGN), are generally believed to be emitted by photoionized gas in the clouds that are illuminated by the UV to X-ray continuum radiation of the central source (Netzer 1990). The photoionization model is quite successful in explaining the average emission line properties of AGNs using an average ionizing continuum. To date, there are two sets of statistical relationships between the continuum and emission lines for AGNs which have not been understood clearly. One is the Baldwin effect–the equivalent width of the CIV emission line tends to decrease systematically with increasing continuum luminosity (Baldwin 1977). This inverse correlation also exists for some other broad emission lines, such as Lyα, Hβ, etc. The other refers to various correlated variations with the FWHM (full width at half maximum) of Hβ from the broad emission line region: as the FWHM decreases, the X-ray spectrum steepens ($f_\nu \propto \nu^{-\alpha_X}$, α_X increase), the X-ray variability increases, the strength of optical Fe II emission increases, and the [OIII]λ5007 narrow line emission decreases (Boroson & Green 1992, Boller, Brandt & Fink 1996, Wang, Brinkmann & Bergeron 1996). Seyfert 1 galaxies with extremely narrow Hβ lines (FWHM less than 2000 km s^{-1}) are classified as Narrow Line Seyfert 1 (NLS1) galaxies. Currently, the simple photoionization model fails to explain these two sets of correlations. Since a marked correlation between the ROSAT X-ray slope and FWHM of Hβ was found, many authors tried and are trying to explain NLS1 within the photoionization scenario with some additional factors. On

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the simple assumption of virialization of the broad line clouds, one possibility is to interpret the narrowness of Hβ as an orientation effect of a disc-shaped broad line region (Osterbrock & Pogge 1985, Goodrich 1989, Punchnarewicz et al. 1992). The other possibility is in terms of a small mass central black hole with high accretion rates plus the same Keplerian assumption (Wandel & Yahil 1985, Pounds et al. 1994). Warm absorption may also play a role in NLS1 with a steep soft X-ray spectra. However, no single model can give a satisfactory explanation for all correlations.

Many strong broad lines are in the UV band, such as Lyα, CIV, etc. However, there have been few studies on the UV lines of NLS1s as a sub-class of AGNs. In order to deepen our understanding of NLS1 and its underlying physics, and hence the second set of relationships, we extend the investigation into the UV for the spectra of a larger sample composed of NLS1 and normal Seyfert 1 galaxies. We selected 15 NLS1s which have been observed by IUE. They are listed in Table 1. Wang, Lu & Zhou (1998) investigated the UV and X- ray properties for a large sample of low redshift AGNs. In their sample, 8 out of 74 objects are NLS1s, the other 66 objects are normal Seyfert 1 galaxies. In the present paper, we combined these normal Seyfert 1 galaxies with the 15 NLS1s together to investigate the links between emission lines and continuum properties.

2 OBSERVATIONS, MEASUREMENTS AND DATA REDUCTION

Our sample is a heterogeneous sample of 81 low redshift AGNs where 15 are NLS1s and 66 are normal Seyfert 1 galaxies. For 66 normal Seyfert 1 galaxies, UV and X-ray properties are listed in the Tables 1 and 2 of Wang, Lu & Zhou (1998). We cross-correlated the NLS1 sources with IUE archives and found 15 NLS1 sources which had been observed in the UV band by IUE. We retrieved the UV spectra of 10 NLS1s from the IUE archives, processed with IUE/NEWSIPS. We took the average spectrum by using the task SCOMBINE of IRAF for those objects which have been multiply observed. The correction of Galactic extinction was made based on the assumption of a fixed conversion of Galactic neutral hydrogen column (Dickey & Lockman 1990) to $E(B-V)$: $N_{\rm H}^{\rm G}/E(B-V) = 5.51 \times 10^{21}\,{\rm cm}^2\,{\rm mag}^{-1}$ (Diplas & Savage 1994). We directly used the IRAF SPLOT task to measure the continuum flux and line intensities. The continuum flux at 1350Å was determined by averaging the flux over the band 1335Å–1365Å (at free rest frame) which is a pseudo-line free window. The emission line fluxes are generally measured by fitting the line profile with two Gaussians. For Lyα and CIV, usually we used either two or three Gaussians. For the other 5 NLS1s, the UV lines and continuum properties are taken from Rodriguez-Pascual, Mas-Hesse and Santos-Lleo (1997). We derived the 1350Å flux by extrapolation from the given 1450Å continuum flux with an average UV spectral index –0.5. Table 1 lists the UV line and X-ray parameters of the NLS1s including the flux at 1 keV and the spectral indices, taken from Wang, Lu & Zhou (1998) and Boller, Brandt & Fink (1996).

Data of optical lines for the 15 NLS1 sources are listed in Table 2 including their redshifts and absolute magnitudes M_B. The optical line parameters, including the equivalent widths of Hβ and Fe II, FWHM of Hβ, and the Fe II to Hβ line ratio for the 66 normal Seyfert 1 galaxies are also collected from the literature (Wang, Lu & Zhou, 1998). The redshift and the absolute magnitude M_B are taken from Veron- Cetty & Veron (1998). The equivalent width of optical Fe IIλ4570Å and Hβ , the ratio of Fe IIλ4570Å to Hβ, and also the FWHM of Hβ were selected from various sources (Boller, Brandt & Fink 1996, Corbin 1997, Corbin & Boroson 1996, Goodrich 1989). For those sources which had more than one measured data of FWHM

Hβ and Fe II, the average or the latest (when considered to be the more believable) was taken. The infrared fluxes at 1 μm were interpolated from the catalog of Sanders et al. (1989) and Gezari, Schmitz, & Mead (1987), or extrapolated from the photometry data in the catalog of Veron-Cetty & Veron (1998). They are also listed in Table 2 for the NLS1s objects.

Table 1 The UV Properties of NLS1

Name	Other Name	Lyα		CIV		C IV/Lyα	νF_ν	νF_ν	α_X	$\alpha_{\rm uvx}$
		Flux	EW	Flux	EW		1350Å	1 keV		
0003+1955	MARK335	11.9	99	6.21	61	0.52	14.5	10.7	1.96	1.55
0053+1241	I ZW 1	3.61	126	0.46	17	0.13	3.52	5.63	2.05	1.39
0127+1910	MARK359	2.33	53	1.41	68	0.61	3.27	5.60	1.31	1.38
0205+204	NAB	1.68	60	0.62	18	0.37	2.82	1.84	2.30	1.58
0230–0859	MARK1044	45.1	···	17.3	···	0.38	3.98	8.65	2.00	1.32
0952–0136	MARK1239	4.15	···	2.20	···	0.53	0.25	0.34	2.90	1.40
1116+2135	PG	6.24	112	2.40	59	0.38	5.45	2.18	1.68	1.69
1153–4612	MARK42	2.38	···	2.56	···	1.08	0.37	0.78	1.60	1.33
1211+143	PG	6.63	88	2.11	49	0.32	8.08	4.93	2.13	1.60
1228+2948	MARK766	1.64	···	1.53	···	0.93	0.65	8.17	1.50	0.95
1244+0240	Q	0.50	48	0.18	27	0.36	1.18	2.29	2.37	1.48
1322–3809	IRAS	2.50	···	1.67	···	0.67	1.40	1.47	3.40	1.50
1440+356	MARK478	4.50	82	0.81	23	0.18	5.33	3.15	2.32	1.60
1559+2703	MARK493	1.14	102	0.85	106	0.75	1.85	1.22	1.70	1.58
2240+2927	AKN564	1.21	64	0.37	21	0.31	2.73	19.2	2.40	1 08

Table 2 The Optical Line Parameters of NLS1

Name	z	Mabs	EW(Fe II)	EW(Hβ)	RFe II	FWHM(Hβ)	log($f_{1\mu\rm m}$)
0003+1955	0.025	–21.7	59	95	0.62	1640	0.52
0053+1241	0.061	–23.4	75	51	1.47	1240	0.47
0127+1910	0.017	–20.2	7.6	12.3	0.62	380	0.39
0205+204	0.155	–24.2	44	87	0.51	1170	-0.34
0230-0859	0.016	–20.2	54	59	0.9	1280	0.32
0952-0136	0.019	–20.3	48	79	0.61	720	0.30
1116+2135	0.177	–25.2	81	175	0.47	2920	0.83
1153-4612	0.024	–19.6	40	44	0.92	670	-0.17
1211+143	0.085	–23.9	44	84	0.52	1860	1.05
1228+2948	0.012	–20.0	46	71	0.65	2400	0.58
1244+0240	0.048	–26.2	50	41	1.20	830	0.52
1322-3809	0.065	···	60	23	2.4	650	···
1440+356	0.077	–23.4	76	64	1.19	1450	0.16
1559+2703	0.031	–20.7	59	45	1.31	410	-0.01
2240+2927	0.025	–21.0	36	44	0.81	720	0.44

3 CORRELATION ANALYSIS

Spearmann rank correlation test was performed among the 12 parameters, the equivalent widths (EW) of Lyα, CIV, Fe II and Hβ, the FWHM of Hβ, the CIV to Lyα and Fe II to Hβ line ratios, the continuum spectral indices in X-ray $\alpha_{\rm X}$, from UV to X-ray $\alpha_{\rm uvx}$ and from infrared to X-ray $\alpha_{\rm ix}$, the last given by

$$\alpha_{\rm ix} = 1. + 0.344 \times \log_{10} \frac{(\nu f_\nu)_{1\mu\rm m}}{(\nu f_\nu)_{1\,\rm keV}}\,,$$

the UV and X-ray luminosities at 1350 Å and 1 keV. The correlation coefficients are summarized in Table 3. We consider those correlations real if the probability of it occurring by chance is less than 0.1%, and in that case it is shown in boldface in Table 3. We found significant correlations between the CIV to Lyα line ratio and the spectral indices $\alpha_{\rm uvx}$ and $\alpha_{\rm X}$ for the whole sample. These correlations were found previously by Wang, Lu & Zhou (1998). It is interesting to note in Fig. 1 that the NLS1s and the normal Seyfert objects are mixed together in the CIV/Lyα versus $\alpha_{\rm uvx}$ plot. In particular, five objects (3C351, PG0844+349, PG1411+442 , PG1351+640 and 3C232) with UV absorption lines also fall within the general trend. (The other object with absorption, NGC3516, has no available Lyα measurement because of its low redshift.) But in the CIV/Lyα versus $\alpha_{\rm X}$ plot (the right panel of Fig. 1), two NLS1 objects (IRAS1322-3809 and MARK1239) with extremely steep $\alpha_{\rm X}$ deviate greatly from the general correlation. We notice that for a given CIV/Lyα, the NLS1s generally have higher values of $\alpha_{\rm X}$ than the normal Seyferts, but for these two objects, the difference is particularly large. However, their UV-X spectral indices, $\alpha_{\rm uvx}$, are typical of normal Seyferts, and so they have normal values of CIV/Lyα (~ 0.5) according to the photoionization model.

Table 3 The Correlation Results

Line	Spectral Indices			Optical Line Properties					
Parameters	$\alpha_{\rm X}$	$\alpha_{\rm uvx}$	$\alpha_{\rm ix}$	FWHM Hβ	EW Fe II	EW Hβ	Fe II/Hβ	$L_{1\,\rm keV}$	$L_{1350\,\rm Å}$
EW Lyα	–0.23	**–0.43**	–0.28	0.08	–0.02	0.31	–0.18	0.05	0.21
EW CIV	**–0.51**	**–0.55**	–0.26	0.18	–0.22	0.34	–0.35	0.02	–0.30
CIV/Lyα	**–0.47**	**–0.60**	–0.36	0.15	–0.26	0.19	–0.26	–0.005	–0.35
FWHM Hβ	**–0.54**	0.02	–0.06	1	**–0.42**	**0.44**	**–0.70**	**0.47**	**0.38**
EW Fe II	**0.48**	0.13	0.24	**–0.42**	1	0.17	**0.73**	–0.32	–0.24
EW Hβ	–0.22	–0.09	–0.03	**0.44**	0.17	1	**–0.46**	0.34	0.23
Fe II/Hβ	**0.49**	0.15	0.22	**–0.70**	**0.73**	**–0.46**	1	**–0.52**	**–0.40**
$L_{1\,\rm keV}$	–0.20	0.03	–0.29	**0.47**	–0.32	0.34	**–0.52**	1	**0.82**
$L_{1350\,\rm Å}$	–0.02	**0.53**	0.09	**0.38**	–0.24	0.23	**–0.40**	**0.82**	1

Recently, Wills et al. (1999) claimed a spectacular set of correlations between the UV and optical line parameters, especially the relationships between EW CIV, CIV/Lyα, FWHM of Hβ, Fe II/Hβ and EW [OIII] for a low redshift X-ray PG sample of 22 sources. The relationship between CIV/Lyα and Fe II/Hβ was given earlier by Wang, Zhou & Gao (1996). However, in the present work, we have found no significant correlation between the properties of the UV lines (Lyα and CIV) and the optical lines. In Fig. 2, we plot CIV/Lyα against Fe II/Hβ (left panel) and against FWHM of Hβ (right panel). It can be seen that a weak correlation seems to exist between CIV/Lyα and Fe II/Hβ (correlation coefficient Rs $= -0.40$, the probability of it arising by chance is $P_{\rm r} = 5.1 \times 10^{-4}$, on excluding the four NLS1 outlyers, Mrk 42, Mrk 766, Mrk 493 and IRAS 1322–3809). But the UV to X-ray spectral indices $\alpha_{\rm uvx}$ of these four NLS1 objects are normal. In the right panel, these four NLS1 objects, together with the NLS1 object Mrk 359 and three normal Seyfert 1 galaxies (NGC 7469, 3C 120, Mrk 705), all labeled in Fig. 2b, stand apart from the other objects. If we remove these objects, then we will get a weak correlation between CIV/Lyα and FWHM of Hβ (Rs = –0.40, Pr = 9.9×10^{-4}). But there is no particular reason to remove those objects. We could not reproduce the correlation which Wills et al. (1999) found, even if we consider only the normal Seyfert 1 galaxies.

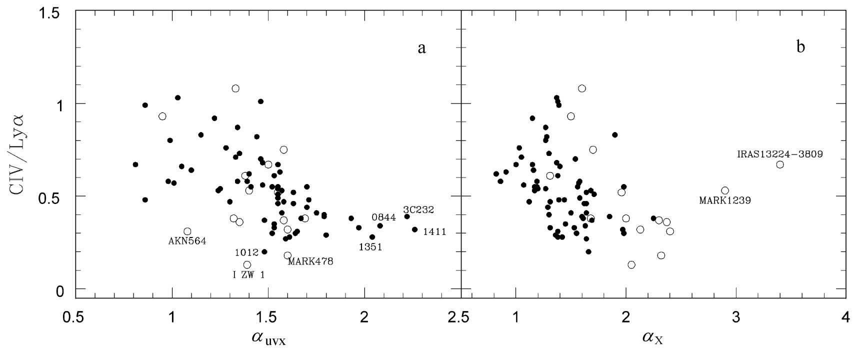

Fig. 1 (a) CIV/Lyα versus $\alpha_{\rm uvx}$, (b) CIV/Lyα versus $\alpha_{\rm X}$.
Open circles present NLS1 objects, filled circles present normal Seyfert 1 galaxies.

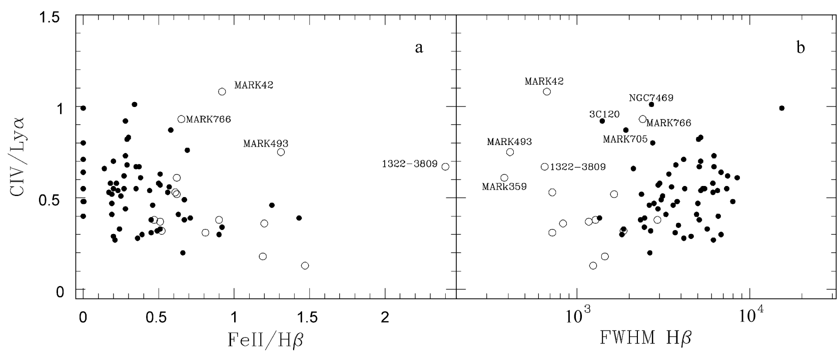

Fig. 2 (a) CIV/Lyα versus Fe II/Hβ, (b) CIV/Lyα versus FWHM of Hβ.
Open circles present NLS1 objects, filled circles present normal Seyfert 1 galaxies.

The best known correlations among the FWHM of Hβ, $\alpha_{\rm X}$ and the Fe II to Hβ line ratio are verified in our sample. We found the FWHM of Hβ and Fe II/Hβ also correlate with the UV luminosity L_{1350} and soft X-ray luminosity $L_{1\,\rm keV}$. It is consistent with the significant correlation between the FWHM of Hβ and 2 keV X-ray luminosity which was found by Wang et al. (1996). NGC 3516 and 3C 232 do not follow the correlation in Fig. 3b (FWHM Hβ versus L_{1350}). The correlation becomes more significant (Rs = -0.50, Pr = 4.5×10^{-6}) after these two objects with absorption features are removed. A significant correlation between Fe II/Hβ and $L_{1350\,\text{Å}}$ also exists. Again, the correlation becomes more significant (Rs = -0.46, Pr= 4.0×10^{-5}) if NGC 3516 and 3C 232 are excluded.

Lawrence et al. (1997) claimed a much stronger correlation between Fe II/Hβ and the near Infrared to X-ray spectral index $\alpha_{\rm ix}$. Wilkes et al.(1999) tested it in a low redshift quasar sample and they did not find it. We also tested it in our sample, and no significant correlation between Fe II/Hβ and $\alpha_{\rm ix}$ was found. Furthermore, the range of $\alpha_{\rm ix}$ and Fe II/Lyα in our sample is similar to that in Lawrence at al. (1997). So, the correlation found by Lawrence et al. (1997) may be caused by selection effects.

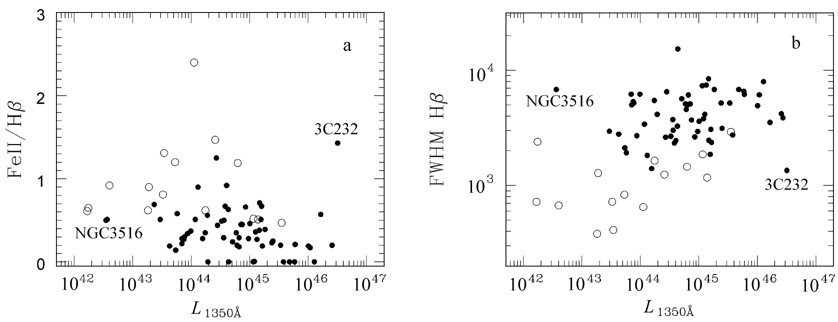

Fig. 3 (a) Fe II/Hβ versus $L_{1350\text{ Å}}$, (b) FWHM of Hβ versus $L_{1350\text{ Å}}$. Open circles present NLS1 objects, filled circles present normal Seyfert 1 galaxies.

4 DISCUSSIONS

Laor et al. (1994), Boller, Brandt & Fink (1996) and Wang, Brinkmann & Bergeron (1996) have claimed remarkable correlations among the line width of Hβ, Fe II strength and the soft X-ray spectral slope $\alpha_{\rm X}$. These are confirmed in our sample. The physical origin of those relationships are still unknown. These correlations may suggest strong connection between the parameters of the central engine, the geometry and kinematics of the emission line gas. Some authors argued for an "orientation" effect as the cause. But the viewing angle is unlikely to be the explanation of this set of correlations. First, [OIII] emission is likely to be isotropic and to come from large radii. Second, the broad component of UV lines do exist for NLS1 objects (Rodriguez-Pascual, Mas-Hesse & Santos-Lleo 1997). A direct connection with the luminosity and/or the accretion rate seems attractive for these relationships. The clouds emitting a particular line are concentrated in a small range of radius according to the locally optimally emitting cloud (LOC) model (Baldwin 1977, Korista 1997). Reverberation mapping method indicates the radius is roughly proportional to $L^{1/2}$. Based on the assumption of Keplerian velocity Doppler width for the line width, and if the ratio of luminosity to Eddington luminosity lies in a small range, then we expect the line width of Hβ will be proportional to $\mathrm{L}^{1/4}$. In our sample, the UV and X-ray luminosities do correlate with the FWHM of Hβ, and FWHM(H$_\beta$) $\propto L_{\rm UV}^{0.187\pm0.04}$ or FWHM(H$_\beta$) $\propto L_{\rm X}^{0.189\pm0.04}$. In fact, it is consistent with the expected relation. The high Eddington fractions of accretion for NLS1 objects could make them the supermassive black hole analogues of the high ultrasoft states of Galactic black hole candidates, and thus appear to have hotter soft X-ray components and steeper X-ray spectral slopes (Ross, Fabian & Mineshige 1992). If there is a tendency of increasing Eddington fractions from normal Seyfert 1 galaxies to NLS1 objects, the simple relationship between the FWHM of Hβ and luminosity must be distorted. The index will be larger than 1/4 but not 0.189 which is less than 1/4.

Wang, Zhou & Cao (1996) found a strong correlation between CIV/Lyα and Fe II/Hβ. Wills et al. (1999) extended the set of optical lines relationships to a whole new set of UV relationships. They claimed that CIV/Ly$_\alpha$ correlates with FWHM of Hβ and Fe II/Hβ. These relationships cannot be found in our sample. The values of CIV/Ly$_\alpha$ of NLS1 are similar to those of normal Seyfert 1 galaxies. No correlation can be found when we omit the NLS1 objects. Correlation seems to exist between CIV/Ly$_\alpha$ and Fe II/Hβ or the line width of Hβ when we omit the labelled objects in Fig. 2. However, we have no reason to do so. CIV/Ly_α is strongly affected by the shape of the UV to X-ray continuum according to the photoionization model, and what Fig. 1a shows can well be explained. The spectral energy distributions are similar for NLS1 and normal Seyfert 1 galaxies except that the NLS1s have smaller UV luminosities and steeper α_X. The presence of broad wing in UV lines suggests that the UV emission line region would be made of fully ionized hydrogen gas (Rodriguez-Pascual, Mas-Hesse & Santos-Lleo 1997). Using CLOUDY code, they calculated the line spectra with an average input ionizing continuum. CIV/Ly_α roughly equals 0.5 for those ionized clouds which is consistent with the measured data.

We summarize our main results as follows:

(a) The strong correlations among the FWHM of Hβ, Fe II/Ly_α, and α_X are confirmed.

(b) The UV lines parameters, both the EWs of Ly_α and CIV and the CIV/Ly_α ratio do not seems to correlate with optical line parameters for the whole sample.

(c) The UV and X-ray luminosities strongly correlate with the FWHM of Hβ and the Fe II/Hβ ratio.

(d) No correlation is found between the continuum spectral slope α_{ix} and Fe II/Hβ and FWHM of Hβ.

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