The UV Properties of the Narrow Line Quasar I Zwicky 1

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Abstract.

I Zw 1 is the prototype narrow line quasar. This type of AGNs show a number of common peculiar characteristics whose physical origin is not yet well understood. Here, I review the results of a detailed study by Laor et al. (1997b) of the UV emission properties of I Zw 1, based on a high quality HST FOS spectrum. The main results are: 1) The Mg II and the Al III doublets are resolved, indicating optically thick thermalized emission, as expected for a standard BLR. 2) Lines from ions of increasing ionization level show increasing excess blue wing flux, and an increasing line peak velocity shift, suggesting an outflowing component of the BLR, visible only in the approaching direction, where the ionization level increases with velocity. 3) A weak associated UV absorption system is detected in N V, C IV, Si IV and Lyα, which is probably part of the outflow suggested above. 4) The C III] λ1909 line indicates a BLR density about an order of magnitude larger than commonly observed in quasars. An additional denser component is implied by the Al III λ1857 doublet. 5) Prominent Fe II and Fe III emission is seen, including components which may indicate significant Lyα pumping of the 8-10 eV levels of Fe II.

Further studies suggest that some of the above properties are typical of narrow line AGNs.

1. Introduction

I Zw 1 is the prototype narrow line Seyfert 1 galaxy (NLS1, although it luminosity, $M_V = -23.8$ for $H_0 = 50$ km s$^{-1}$ Mpc$^{-1}$, qualifies it as a low luminosity quasar). Its optical spectrum reveals narrow emission lines and strong Fe II emission (Phillips 1976, 1978; Oke & Lauer 1979). The NLS1s also tend to have weak [O III] $\lambda\lambda4959,5007$ emission, asymmetric H$\beta$ profiles (Boroson & Green 1992), steep soft X-ray spectra (Laor et al. 1994, 1997a; Boller, Brandt & Fink 1996), rapid X-ray variability (Fiore et al. 1998), and possibly strong IR emission (e.g. Lipari 1994). The physical origin for this set of peculiar emission properties is not well understood yet. In this contribution I review the main results of a detailed study of a high quality UV emission line spectrum of I Zw 1 obtained with the HST FOS (for further details see Laor et al. 1997b). This study provides additional clues to the physical processes responsible for the peculiar properties of NLS1s.
2. Observations

We obtained high S/N spectra (50–120 per resolution element) of I Zw 1 with the three high resolution (R=1300) gratings of the FOS from 1150 Å to 3280 Å. This S/N is comparable to the highest S/N yet obtained with HST for bright AGNs. We also obtained a complimentary high resolution ground based spectrum which covers the range from 3183 Å to 4074 Å.

Figures 1 and 2 present an expanded view of the 1100 Å to 2000 Å spectrum of I Zw 1, where most of the strong UV lines are present. The spectrum was corrected for the effects of Galactic extinction of E(B−V)=0.1, and converted to rest wavelength assuming z=0.0608, the redshifts of Hα and Hβ (e.g. Phillips 1976). The rest frame positions of various lines are marked above the spectrum. Lines marked below the spectrum designate various absorption lines originating in the Galactic interstellar medium (ISM). All ISM lines detected here are typically seen in FOS spectra of quasars. We made no attempt to identify the many Fe II emission blends present. The various Fe II multiplets designated in Fig.2 are taken from Moore (1952), and serve only as an illustration of possible Fe II features. The number of possible Fe II multiplets is extremely large, and a reliable identification requires detailed theoretical calculations. The complete spectrum, and the measured emission line parameters are provided in Laor et al. (1997b).

3. Line Diagnostics

3.1. C

The [C III] λ1907 line may be present in I Zw 1. This line is produced by a forbidden transition from the 3P 2 term in the 2s2p configuration of C III down to the ground level, with a critical density of n_c = 5 × 10^5 cm\(^{-3}\). The 3P 2 term lies 0.007 eV above the 3P 1 term which produces the well known C III] λ1909 line, where n_c ∼ 5 × 10^9 cm\(^{-3}\). Thus, the flux ratio R_{C III} ≡ [C III] λ1907/[C III] λ1909 provides a temperature independent density diagnostic (e.g. Osterbrock 1989, Fig. 5.5). The observed R_{C III} < 0.1 implies that some of the C III emission originates in gas with an electron density n_e < 5 × 10^5 cm\(^{-3}\).

The C III] λ1909 line is very weak in I Zw 1. Both its EW of ∼ 2.5 Å, and the C III] λ1909/Lyα=0.023 flux ratio are a factor of 5-10 smaller than typically observed (e.g. Laor et al. 1995; Wills et al. 1995). Since C III] λ1909 is thermalized at n_e > 5 × 10^9 cm\(^{-3}\), the suppression of C III] λ1909 may imply that the typical BLR density in I Zw 1 is about an order of magnitude larger than indicated by C III] λ1909 in typical AGNs, i.e. n_e ∼ 10^{11} cm\(^{-3}\) instead of n_e ∼ 10^{10} cm\(^{-3}\). Additional evidence for this interpretation is provided by the Si III] λ1892 line discussed below.

3.2. Mg

The Mg II ion survives mostly in the partially ionized H region, where photons above 13.6 eV are blocked. The Mg II λ2798 doublet is therefore a diagnostic of the conditions in the extended partially ionized layers inside the BLR clouds.
Figure 1. Tentative identifications of most of the emission features in the HST FOS spectrum of I Zw 1. The lines indicate the expected wavelength for $z = 0.0608$. Only a small number of the Fe II multiplets which may be present were marked. Line designations below the spectrum refer to Galactic absorption features.
Figure 2. As in figure 1.
The flux ratio of the Mg II 2796.35 Å/2803.53 Å components indicates the optical depth in the line.

The 2803.53 Å, 2796.35 Å lines correspond to transitions from the \(3p^2P_{1/2}\) and \(3p^2P_{3/2}\) levels to the ground \(3s^2S_{1/2}\) level. Collisional de-excitation dominates when \(\tau_0 n_e > A/q\), where \(\tau_0\) is the line center optical depth for resonance scattering, i.e. when \(\tau_0 n_e > 7.1 \times 10^{14} \text{ cm}^{-3}\) and \(3.6 \times 10^{14} \text{ cm}^{-3}\) for the \(3p^2P_{3/2}\) and \(3p^2P_{1/2}\) levels. For \(\tau_0 n_e > 7.1 \times 10^{14} \text{ cm}^{-3}\) the Mg II 2796.35 Å/2803.53 Å doublet ratio is thermalized, i.e. it changes from 2/1 to 1/1 (see Hamann et al. 1995 for results on other analogous UV doublets). Thus, the observed 1.2/1 ratio implies that most of the Mg II emission is produced in a region where \(\tau_0 n_e \gtrsim 10^{15} \text{ cm}^{-3}\).

As described in Laor et al. (1997b), the value of \(\tau_0 n_e\) provides a direct measure of the distance of the BLR clouds from the central ionizing continuum source. The line center optical depth is \(\tau_0 = \sigma_{\nu_0} \Sigma_{\text{Mg II}}\), where \(\sigma_{\nu_0} = 1.47 \times 10^{-12} \text{ cm}^2\) is the total Mg II doublet line center absorption cross section (for \(T = 10^4 \text{ K}\)), and \(\Sigma_{\text{Mg II}}\) is the column density of Mg II ions. The partially ionized H region, where Mg II survives, has a column density about 10-30 times larger than the column density of the highly ionized H region, given by \(\Sigma_{\text{H II}} = 10^{25} U \text{ cm}^{-2}\), where \(U\) is the ionization parameter (\(\equiv n_\gamma / n_e\), the photon/electron density). Balmer continuum absorption may limit the depth of the Mg II doublet emitting layer, but this absorption will not affect our conclusion. Using the Mg/H solar abundance ratio of \(3.8 \times 10^{-5}\), and assuming most Mg is Mg II, we get \(\Sigma_{\text{Mg II}} \approx 4 \times 10^{19} U \text{ cm}^{-2}\), or \(\tau_0 = 6 \times 10^6 U\), assuming the gas is ionization, rather than matter bounded. The Mg II doublet is therefore thermalized when \(6 \times 10^7 U n_e \gtrsim 10^{15}\), or \(n_\gamma \gtrsim 10^7 \text{ cm}^{-3}\), which is consistent with the standard estimate of \(n_\gamma \sim 2 \times 10^9 \text{ cm}^{-3}\) in the BLR.

### 3.3. Al

The components of the Al III \(\lambda 1857\) doublet are widely spaced (\(\sim 1300 \text{ km s}^{-1}\)) and are therefore clearly resolved in I Zw 1. Al III is created by photons above \(18.829\) eV, and destroyed by photons above \(28.448\) eV, thus unlike Mg II, it exists in the highly ionized H region only, and the observed Al III doublet ratio provides constraints on the BLR H II region, as discussed below.

The template fit suggests a 1.25/1 ratio for the 1854.71 Å/1862.79 Å doublet line. Baldwin et al. (1996) found a similar 1/1 flux ratio in three objects where the Al III doublet was clearly detected.

The Al III and Mg II ions are both Na I like. Using the same reasoning described for Mg II we find that the Al III \(\lambda 1857\) doublet is thermalized for \(n_\gamma \gtrsim 4 \times 10^9 \text{ cm}^{-3}\), and the observed 1.25/1 doublet ratio indicates that it is formed in clouds at, or inside the ‘standard’ BLR radius of \(0.1L_{46}^{1/2}\) pc, where \(n_\gamma \gtrsim 2 \times 10^9 \text{ cm}^{-3}\).

The relatively large Al III \(\lambda 1857\) EW (4.4 Å) requires a BLR component where Al III is the dominant ionization state of Al, which occurs for \(U \sim 10^{-2} - 10^{-3}\) (e.g. Baldwin et al. 1996, Fig.7a). Since \(n_\gamma \gtrsim 4 \times 10^9 \text{ cm}^{-3}\), the above range in \(U\) implies \(n_e \gtrsim 4 \times 10^{11} - 4 \times 10^{12} \text{ cm}^{-3}\), which is comparable, or denser, than the component responsible for the C III \(\lambda 1909\) emission.
3.4. Si

The Si II 1260.42 Å, 1264.74 Å, 1265.00 Å, 1304.37 Å, 1309.28 Å, 1808.01 Å, 1816.93 Å, and 1817.45 Å lines are clearly detected. The flux of the Si II λ1194 and λ2335 blends is well constrained. This wealth of data provides a unique opportunity to explore the Si II line formation mechanisms (e.g. Baldwin et al. 1996, Appendix C).

The outer shell electronic configuration of the Si III ion is analogous to that of C III. The analogous line to the [C III] λ1907 line is the [Si III] λ1883 line, which can also be used as a density diagnostic for the Si III gas. Weak [Si III] λ1883 emission may be present at 1881.1 Å. As for the C III ion, the $R_{\text{Si III}} \equiv [\text{Si III}] \lambda 1883/\text{Si III} \lambda 1892$ flux ratio is a robust density indicator. The observed $R_{\text{Si III}} \lesssim 0.1$ implies that some of the Si III resides in gas with $n_e \sim 5 \times 10^5$ cm$^{-3}$, i.e. the same conditions implied by $R_{\text{C III}}$, as expected since the spatial distribution of both ions in photoionized gas should largely overlap.

The Si III $\lambda 1892$/C III $\lambda 1909$ flux ratio of $\sim 3.5$ is significantly larger than the typical ratio of $\sim 0.3 \pm 0.1$ observed in quasars (Laor et al. 1995). This high ratio results from the factor of 5-10 suppression in the C III $\lambda 1909$ flux, rather than significant enhancement of Si III $\lambda 1892$. The most likely interpretation for this high ratio is a relatively dense BLR. The critical density for C III $\lambda 1909$, $n_c \approx 5 \times 10^9$ cm$^{-3}$, is significantly smaller than for Si III $\lambda 1892$, where $n_c = 1.1 \times 10^{11}$ cm$^{-3}$. Thus, if the BLR density is $10^{11}$ cm$^{-3}$, rather than $10^{10}$ cm$^{-3}$, C III $\lambda 1890$ would be suppressed by a factor of $\sim 10$, while Si III $\lambda 1892$ would not be affected, as observed.

3.5. Fe

The likely presence of Fe II emission well below 2000 Å, and possibly even at $\sim 1110$-1130 Å, indicates that Fe II is excited by processes other than just collisions, as the electron temperature in the Fe II region is most likely far too low for significant collisional excitation of levels $\gtrsim 10$ eV above the ground state. One such process, suggested by Penston (1987), is resonance absorption of Ly$\alpha$ photons by Fe II. Johansson & Jordan (1984) found Ly$\alpha$ resonance absorption to be significant in various stellar systems, and identified the Fe II UV $\lambda 1294$, Fe II UV $\lambda 191 \lambda 1787$, and the Fe II $\lambda 1871$ multiplets as the signatures of such a process. The Fe II UV $\lambda 191$ multiplet is very prominent in I Zw 1, and weak emission blends are clearly apparent at 1294 Å, and 1870 Å, suggesting that resonance absorption of Ly$\alpha$ photons may be a significant excitation mechanism for Fe II in I Zw 1 as well. Resonance scattering of continuum photons, and Fe II-Fe II line fluorescence could also be a significant process for populating high lying Fe II levels (e.g. Netzer & Wills 1983; Wills, Netzer & Wills 1985). Clearly, the Fe II rich spectrum of I Zw 1 should serve as a valuable tool for future studies of Fe II emission in AGNs.

A number of Fe III multiplets are clearly present. The Fe III UV 34 multiplet, clearly identified here, was first discovered by Hartig & Baldwin (1986) in a broad absorption line quasar. An emission feature near $\sim 2070$ Å is commonly seen in quasars (e.g. Wills et al. 1980), and was identified as a likely Fe II blend. Baldwin et al. (1996) suggested that this feature is due to Fe III UV 48 emission. Here the three Fe III UV 48 components at 2062.2 Å, 2068.9 Å, and
2079.65 Å are clearly resolved, which verifies the identity of this feature. The Fe III UV 47 λλ2419.3, 2438.9 doublet is most likely present as well. Other Fe III blends, such as Fe III UV 50 and Fe III UV 68, and in particular the resonance Fe III UV 1 at 1122-1130 Å may also be present, but these identifications cannot be verified here since these blends are not clearly resolved.

The relative flux ratio of the multiplet components can provide an important diagnostic for the optical depth and excitation mechanism of Fe III.

### 3.6. Line Profiles and Velocity Shifts

Optical spectra of I Zw 1 revealed two velocity systems. The first system is at $z = 0.0608$ for the low ionization forbidden lines and Balmer lines, including Hα, Hβ, optical Fe II multiplets, [Ca II], [S II], [N II], He I, Na I, and [O I]. The second system is at $z = 0.0587$ (i.e. blueshifted by $\sim 630$ km s$^{-1}$) for the higher ionization forbidden lines, [O III] and [Ne III] (Phillips 1976, Oke & Lauer 1979).

We find the same trend in the UV. The low ionization permitted lines, including O I, C II, C III], N II], Al II, Al II], the various Si II multiplets, and Fe II 191 are all blueshifted by $\lesssim 200$ km s$^{-1}$ with respect to $z = 0.0608$. Higher ionization lines, including N III], Al III, Si III] and Si IV are blueshifted by $\sim 300 - 500$ km s$^{-1}$, while the highest ionization lines, C IV and N V, are blueshifted by $\sim 900$ km s$^{-1}$. The highest blueshift, $\sim 2000$ km s$^{-1}$, is displayed by He II λ1640.4. This trend of increasing blueshift with increasing ionization level is observed in most quasars (e.g. Gaskell 1982; Wilkes 1984, 1986; Espey et al. 1989). However, the typical amplitude of the high ionization line blueshift, such as C IV and N V, is only $\sim 200 - 300$ km s$^{-1}$, and for He II it is $\sim 500$ km s$^{-1}$ (Tytler & Fan 1992; Laor et al. 1995), i.e. about four times lower than found in I Zw 1.

The low ionization line profiles are mostly consistent with the rather symmetric Hα profile. With increasing blueshift the lines get progressively broader and develop a progressively stronger blue excess asymmetry (fig.3 in Laor et al. 1997b).

### 4. UV absorption

Associated absorption is present in Lyα, N V, C IV and Si IV. The absorption is blueshifted by $\sim 1870$ km s$^{-1}$ relative to the $z = 0.0608$ frame, it has a FWHM$\sim 300$ km s$^{-1}$, and an absorption EW of $\sim 0.25$ Å for most lines. Since the spectral resolution of the FOS is $\sim 230$ km s$^{-1}$, the absorption system may not be truly resolved.

The presence of high ionization lines, and lack of low ionization lines in absorption suggests the absorber is associated with I Zw 1, rather than with an intervening system unrelated to I Zw 1 (see e.g. Hamann 1997). Most of the constraints below are independent of the exact location of the absorber.

#### 4.1. Implied constraints

The column density associated with the observed absorption is a function of the absorber optical depth (assuming a full coverage). The optical depth can be
deduced from the ratio of EW of the two doublet components. The observed ratio in N V is \( \sim 1.4 \), but it is rather uncertain, and thus the absorption optical depth remains uncertain.

The absorbing columns are in the range \( N_{\text{HI}} = 4.6 \times 10^{13} - 4.3 \times 10^{14} \text{ cm}^{-2} \), \( N_{\text{CIV}} = 1.2 \times 10^{14} - 1.4 \times 10^{19} \text{ cm}^{-2} \), and \( N_{\text{NV}} = 2.3 \times 10^{14} - 3.3 \times 10^{19} \text{ cm}^{-2} \).

To infer the total H column density from the H I column density one needs to know the H ionization state. The H II/H I fraction in the absorbing gas is related to the ionization parameter through \( N_{\text{HII}}/N_{\text{HI}} \sim 2 \times 10^5 U \) (e.g. Netzer 1990). Thus, the upper limit on the H column density is \( N_{\text{H}} \sim N_{\text{HII}} = (0.2 - 6) \times 10^{20} U \text{ cm}^{-2} \). The presence of N V and C IV ions suggests that the absorber has \( U \sim 0.01 - 1 \), thus the H column density upper limit is probably in the range \( 10^{17} \lesssim N_{\text{H}} \lesssim 6 \times 10^{20} \). If the absorber metal abundance is solar then the above \( N_{\text{H}} \) implies metal columns upper limits of \( 3.6 \times 10^{13} \lesssim N_{\text{C}} \lesssim 2 \times 10^{17} \) and \( 10^{13} \lesssim N_{\text{N}} \lesssim 6.7 \times 10^{16} \). These values overlap with the directly determined constraints on the C IV and N V columns and suggests that significant fractions of C and N may indeed be in the form of C IV and N V, consistent with the assumption of \( U \sim 0.01 - 1 \). Detection of O VI \( \lambda \lambda 1031.93, 1037.63 \) absorption would allow a much tighter constraint on the absorber’s \( U \).

4.2. UV and optical emission

The UV absorber blueshift of \( \sim 1870 \text{ km s}^{-1} \) is remarkably close to the He II \( \lambda 1640 \) emission line blueshift of \( \sim 1990 \text{ km s}^{-1} \), suggesting that the strongly blueshifted He II emission line peak may originate in the same outflowing gas which produces the UV absorption lines. In order to emit the observed He II \( \lambda 1640 \) flux the absorber must absorb most photons just above the He II bound-free edge at 4 Rydberg. If the column density of the UV absorber is close to the upper limit, and its covering factor is close to unity, it may contribute significantly to the observed He II \( \lambda 1640 \) emission.

5. Discussion

The strong optical Fe II emission of I Zw 1, its weak [O III] emission, strong IR emission, and “red” UV continuum are all typical properties of low ionization broad absorption line quasars (BALQSOs; Weymann et al. 1991, Boroson & Meyers 1992; Sprayberry & Foltz 1992). The presence of weak UV absorption at a blueshift of \( \sim 2000 \text{ km s}^{-1} \) in I Zw 1 suggests it may be a “failed” low ionization BALQSO, i.e. a BALQSO where our line of sight just grazes the outflowing high ionization wind, and misses the low ionization outflow, as suggested by Turnshek et al. (1994) in the case of PG 0043+039.

Is the red continuum, excess blue flux in the high ionization lines, associated absorption, and dense BLR, unique to I Zw 1, or are they typical UV properties of narrow line quasars? No complete UV study of narrow line AGNs is available to answer these questions, but some hints may be obtained from existing observations.

Baldwin et al. (1996) studied the emission line properties of a heterogeneous sample of seven \( z \sim 2 \) quasars with a range of emission line properties. Some of their objects have strong Fe II, Fe III, and Al III emission as observed
in I Zw 1. Baldwin et al. analyzed in detail the UV spectrum of Q0207 − 398, where a high S/N ratio was available, and found excess emission in the blue wing of the high ionization UV lines, which they interpreted as a high ionization outflowing component in the BLR, although there was no direct evidence (through absorption) for such a component, as observed in I Zw 1.

It is also interesting to note that Boroson & Green found that strong optical Fe II emitting quasars, which tend to have narrow Hβ, also tend to have blue excess flux in Hβ, and Boroson & Meyers found that low ionization BALQSOs, which are generally I Zw 1 like, have blue excess flux in Hα. It is not known, however, whether this property extends to the UV lines as well.

If the UV absorption system in I Zw 1 is indeed producing the blueshifted components of the high ionization lines, then the absence of a corresponding redshifted component indicates that the far side of this outflow has to be obscured. This may either be due to an extended highly optically thick gas, such as an accretion disk, or it may result from absorption within each cloud, if the clouds column density is large enough (see Ferland et al. 1992 for discussion).

I Zw 1 has particularly weak C III] λ 1909 emission but normal Si III] λ 1892 emission, which we interpret here as evidence for a relatively dense (∼ 10^{11} \text{cm}^{-3}) BLR, at least for the region which produces the low ionization lines. Baldwin et al. (1988) noted the weakness of C III] λ 1909 in four other quasars with narrow UV lines, and this trend is also apparent in Baldwin et al. (1996) quasars. The most extreme case is of H0335 − 336 where essentially no C III] λ 1909 emission was observed (Hartig & Baldwin 1986). This quasar has very narrow lines, and is also a low ionization BALQSO.

Independent evidence for a dense BLR with \( n_e \gtrsim 10^{11} \text{cm}^{-3} \) is provided by the significant EW and thermalized doublet ratio of the Al III λ1857 doublet, and by the significant EW of C III∗ λ1176. Another indication for a dense BLR in I Zw 1 is provided by its optical spectrum. The Na I λλ5890, 5896 emission line is rather strong (Oke & Lauer 1979; Phillips 1976), which Thompson (1991) and Korista et al. (1997, their Figure 3g) find can only be produced for \( n_e \gtrsim 10^{11} \text{cm}^{-3} \), and a large column density (required to shield neutral Na I from ionizing radiation at \( E > 5.14 \text{eV} \)).

It thus appears that some of the properties of I Zw 1, in particular the relatively weak C III] λ 1909, and the blueshifted excess emission in the high ionization lines, may be common in narrow line quasars. A more systematic study of the UV emission of narrow line AGNs is required to establish their typical emission line properties, their relation to low ionization BALQSOs, and to eventually understand the underlying physics. A first step in this direction is described in the study of Wills et al. (1998, these proceedings) which includes a few narrow line quasars.

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