NO EVIDENCE FOR A SYSTEMATIC Fe II EMISSION LINE REDSHIFT IN TYPE 1 ACTIVE GALACTIC NUCLEI

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ABSTRACT

We test the recent claim by Hu et al. that Fe II emission in type 1 active galactic nuclei shows a systematic redshift relative to the local source rest frame and broad-line Hβ. We compile high signal-to-noise median composites using Sloan Digital Sky Survey spectra from both the Hu et al. sample and our own sample of the 469 brightest DR5 spectra. Our composites are generated in bins of FWHM Hβ and Fe II strength as defined in our 4D Eigenvector 1 formalism. We find no evidence for a systematic Fe II redshift and consistency with previous assumptions that Fe II shift and width (FWHM) follow Hβ shift and FWHM in virtually all sources. This result is consistent with the hypothesis that Fe II emission (quasi-ubiquitous in type 1 sources) arises from a broad-line region with geometry and kinematics the same as that producing the Balmer lines.

Key words: quasars: emission lines – quasars: general

Online-only material: color figure

1. INTRODUCTION

Spectra of type 1 active galactic nuclei (AGNs) show a diversity of broad and narrow emission lines that provide direct insights into the structure and kinematics of photoionized, and otherwise excited, gas in the vicinity of the putative central massive object. Broad emission lines, like much-studied Hβ (e.g., Zamfir et al. 2010, hereafter Z10), are thought to arise in or near an accretion disk acting as the fuel reservoir for the central supermassive black hole (log(M) ~ 7–9.5 M☉). Hβ shows a diversity of line widths as well as profile shifts and asymmetries (Sulentic et al. 2000a). Despite this diversity some systematics have emerged and are best highlighted via the concept of two type 1 AGN populations (Sulentic et al. 2000b).

Population A (Pop. A) sources show the smallest broad-line widths FWHM Hβ = 1000–4000 km s⁻¹ and includes the Narrow-line Seyfert 1 (NLsY1) sources (FWHM < 2000 km s⁻¹). Pop. A Hβ profiles are currently best fit by a single Lorentz function. Population B (Pop. B) sources show FWHM Hβ = 4000–12000 km s⁻¹ and require two Gaussians (one unshifted and one redshifted) for a reasonable profile description. “Broad-line” Hβ profiles as narrow as FWHM = 500 km s⁻¹ (Zhou et al. 2006) and as broad as FWHM = 40000 km s⁻¹ (Wang et al. 2005) have been found. Pop. A is predominantly radio-quiet while Pop. B involves a mix of radio-quiet and the majority of radio-loud quasars.

Broad- and narrow-line profile shifts are known and the phenomenology can be confusing. Narrow emission lines like [O III] λ5007 Å are regarded as a reliable measure of the local quasar rest frame except in the case of “blue outliers,” usually found in sources with FWHM Hβ = 1500–3500 km s⁻¹ and weak [O III] (Véron-Cetty et al. 2001; Zamanov et al. 2002; Marziani et al. 2003b; Boroson 2005). Blue outliers show [O III] blueshifts as large as ~1000 km s⁻¹. No Pop. B sources with blueshifted [O III] are known at low z (or luminosity). Careful use of [O III] and Hβ narrow line as rest-frame measures suggests that broad Hβ in Pop. A sources rarely shows a systematic red or blue shift above the FWHM profile level. A blueshifted component or asymmetry is observed in some extreme Fe II strong Pop. A sources (Marziani et al. 2010). Pop. B sources show more complex line shift properties. The Hβ profile usually shows two components: (1) a “classical” broad component (BC; FWHM = 4000–5000 km s⁻¹) with zero or small (red or blue) shift, and (2) a very broad (10000 km s⁻¹) and redshifted (>1000 km s⁻¹) component. Composites involving the 469 brightest Sloan Digital Sky Survey (SDSS)-DR5 quasars suggest that these two components represent the underlying stable structure of Hβ in Pop. B sources.

Broad Fe II emission has been found in type 1 quasars since the era of photographic spectroscopy in the 1960s. Fe II emission blends are almost ubiquitous in a sample of the brightest (usually highest signal-to-noise ratio (S/N)) SDSS quasars (Z10). Circumstantial evidence has accumulated supporting the assumption that Fe II emission arises in or near the emitting clouds that produce other low ionization lines like Hβ (see, e.g., Boroson & Green 1992; Marziani et al. 2003a; Sulentic et al. 2006). FWHM Fe II appears to correlate with FWHM Hβ over the full range where Fe II can be detected (FWHM = 1000–12000 km s⁻¹). This can be clearly seen at low z by observing the shape (e.g., smoothness) of the Fe II 4450–4700 Å blue blend (and the Fe II multiplet 42 line at 5018 Å) near [O III] λ5007 Å. In Pop. A sources the blend resolves into individual lines while it becomes much smoother in Pop. B sources. Sources with the strongest Fe II emission also show a weakening of Hβ emission as expected if the latter is collisionally quenched in the same dense medium where strong Fe II emission can be produced (Gaskell 1985).

2. A SYSTEMATIC Fe II REDSHIFT?

Obviously systematic line shifts place important constraints on models for the geometry and kinematics of the broad-line region. The most famous example involves a systematic blueshift of high ionization lines (e.g., C IV λ1549 Å) relative to low ionization lines (e.g., Balmer) especially in Pop. A sources (e.g., Gaskell 1982; Sulentic et al. 2007; Richards et al. 2011;...
Evidence was recently advanced (Hu et al. 2008, hereafter H08) for the existence of a systematic redshift of Fe\textsc{ii} relative to \([\text{O}\text{ iii}]\lambda5007\) (and hence the Balmer lines) in a majority of type 1 quasars. This result, along with a narrower estimated Fe\textsc{ii} line width, has been ascribed to Fe\textsc{ii} emission arising in a region with dynamics dominated by infall and located at larger radius than the region producing the bulk of H\textbeta. H08 argue that the amplitude of the shifts correlates inversely with source Eddington ratio \((L/L_{\text{Edd}} \equiv \eta)\). Interpretations for such an Fe\textsc{ii} redshift have already appeared (Ferland et al. 2009; Shields et al. 2010; Boroson 2011) reflecting the potential importance of such a first-order kinematic signature. Having worked on line spectra and profile shifts for many years we were surprised by the H08 claims and decided to test the hypothesis of a systematic Fe\textsc{ii} redshift. Could we have missed it?

First let us consider what we know. Most Pop. A quasars show relatively symmetric unshifted Lorentz-like H\beta profiles with \(FWHM < 4000\) km s\(^{-1}\). In our work using the brightest \((g < 17.5\) or \(i < 17.5\); Zamfir et al. 2008) SDSS-DR5 quasars we processed spectra for \(\sim 260\) Pop. A sources (from a sample of 469 quasars; Z10) and we found no evidence for a systematic shift of Fe\textsc{ii} lines relative to H\beta or [O\text{ iii}]\lambda5007. Such an Fe\textsc{ii} shift should be easiest to detect in the brightest Pop. A SDSS spectra with narrowest broad-line profiles and strongest Fe\textsc{ii} emission. It is immediately suspicious that more and larger Fe\textsc{ii} redshifts are claimed for Pop. B sources. In only one Pop. A source in our sample SDSS J0946+0139 do we find a large H\beta peak (90\% intensity level) redshift of 1830 km s\(^{-1}\). This source is similar to OQ208 (Marziani et al. 1993 and discussed in H08) which shows \(\Delta \beta > 2000\) km s\(^{-1}\). SDSS J0946 is the only Pop. A source with a large Fe\textsc{ii} redshift in our Z10 sample (1/260). Z10 found 19 quasars with an H\beta peak (9/10 fractional intensity) blueshifted more than \(-320\) km s\(^{-1}\) and 4 sources with the peak redshift more than \(+320\) km s\(^{-1}\). The remaining 241 Pop. A sources showed no significant H\beta peak shift (Figure 8 of Z10). The best Fe\textsc{ii} template fits to these sources show no significant difference in centroid redshift between Fe\textsc{ii} and H\beta. There are two possible causes of small and spurious H\beta (or Fe\textsc{ii}) shifts: (1) host galaxy contamination and (2) blue outliers. Except in rare cases host galaxy contamination is unlikely to induce systematic redshifts with the amplitudes reported by H08.

Extreme blue outliers with [O\text{ iii}] blueshifts in the range 400–1000 km s\(^{-1}\) are rare and therefore cannot be the cause of the large and systematic shifts reported in H08. In fact H08 selection criteria rejected sources likely to be seriously affected by (1) or (2). H08 chose 4000+ sources from SDSS DR5 with computed \(S/N \gtrsim 10\). Z10 also used DR5 where \(\sim 94\%\) of sources show \(S/N \gtrsim 10\). Our sample was magnitude-limited with a slightly shallower redshift upper limit \((z = 0.7\) instead of 0.8). Why do we reach different conclusions about Fe\textsc{ii} shifts? A big part of the answer could involve how S/N was computed. H08 compute S/N over the range 4430–5500 Å. This procedure overestimates the quality of the data because it includes major emission lines in the computation. We compute S/N in the range 5600–5800 Å, which is free of strong lines and represents as close as one can approach to an estimate of continuum S/N near H\beta. Using our range the H08 sample shows mean and median S/N values of 10.6 and 7.4, respectively; approx. 65\% show S/N < 10. We find that only 182 spectra of our bright sample are included in the H08’s. The majority of the H08’s sources are lower S/N than those in our sample.

3. Specfit Analysis

### 3.1. A2 and B1 Composite Spectra

One cannot estimate reliable Fe\textsc{ii} line shifts using individual SDSS spectra for sources fainter than about \(g \sim 17–17.5\). In rough order of importance our studies indicate that the accuracy of Fe\textsc{ii} shift measures depends on: (1) Fe\textsc{ii} strength and Fe\textsc{ii}/H\beta profile widths, (2) spectral S/N, and (3) if estimates depend heavily on fits to the 4430–4680 Å blend, strength of H\beta emission. Typical individual spectra used by H08 show too low S/N to allow convincing conclusions about Fe\textsc{ii} shift and width—typical parameter uncertainties for individual sources are much larger than the ones connected with our high-S/N composites (for a typical A2 source with S/N \(\approx 20\) uncertainties of shift estimates are larger than \(\pm 1500\) km s\(^{-1}\)). Individual source spectra with large quoted Fe\textsc{ii} redshift and S/N near the sample median were extracted from the H08 sample and specfit modeled. Using an Fe\textsc{ii} template with fixed shifts ranging from zero up to the largest values quoted by H08, \(\chi^2\) cannot distinguish between zero and e.g., \(1000\) km s\(^{-1}\) redshift in the majority of the sources.

The best recourse is to generate high-S/N composite spectra. H08 argue that one cannot confirm or refute the existence of a systematic Fe\textsc{ii} redshift using composite spectra because of the large dispersion of FWHM, shifts and flux values for both H\beta and Fe\textsc{ii}. This is likely true for composites generated from random subsamples of sources but not true if one generates composites over more limited ranges of parameter values. One can generate binned composites over limited ranges of FWHM H\beta and Fe\textsc{ii} strength using the 4D Eigenvector 1 (4DE1) formalism (Sulentic et al. 2002; Bachev et al. 2004; Sulentic et al. 2007; Z10). 4DE1 bins A2 (FWHM H\beta = 1000–4000 km s\(^{-1}\)), \(0.5 \lesssim R_{Fe\text{II}} \lesssim 1\) and B1 (FWHM H\beta = 4000–8000 km s\(^{-1}\), \(R_{Fe\text{II}} \lesssim 0.5\)) are of particular interest because they include the largest numbers of sources in random samples. specfit analysis (Kriss 1994; details in Marziani et al. 2009) of an A2 median composite involving \(n = 130\) Z10 sources (S/N = 90) gives a best-fit consistent with zero Fe\textsc{ii} redshift. The situation for the B1 composite (\(n = 131\) sources from Z10; S/N = 110) is less constraining because lines are broader and Fe\textsc{ii} weaker. Table 1 reports Fe\textsc{ii} template shifts and \(2\sigma\) uncertainties for specfit tests discussed in this Letter. We also report peak shifts of H\beta BC extracted from the best specfit solutions along with H\beta “core” shifts measured at the centroid of the line peak after H\beta NC subtraction. In no case do we find a significant shift between Fe\textsc{ii} and the rest frame or between Fe\textsc{ii} and H\beta. We also do not find any significant Fe\textsc{ii} shifts if we restrict to sources with \(L/L_{Edd}\) ratio \(\eta \lesssim 0.1\) (H08 suggested the shifts might be largest for low \(L/L_{Edd}\) sources).

### 3.2. A2 Composites Involving Only Sources with Large Fe\textsc{ii} Shifts?

Since we find no evidence for systematic Fe\textsc{ii} redshifts in our Z10 bright quasar sample composites it is useful to generate Fe\textsc{ii} shift composites using the H08 sample. We generate them within the 4DE1 context thereby restricting the ranges of FWHM H\beta, Fe\textsc{ii} relative strength (and likely also FWHM Fe\textsc{ii}) for each composite. Since the distribution of Fe\textsc{ii} shifts shown in H08 is continuous we focus on the sources with largest quoted shift values. If these shifts are not confirmed then smaller shifts are even less likely to be real. We therefore focus on constructing median composites for all H08 sources falling in 4DE1 bins A2 and B1 with H08 Fe\textsc{ii} redshift estimates \(\geq 1000\) km s\(^{-1}\).
Figure 1. Fits of the Hβ spectral range (left and middle panels) and normalized $\chi^2$ (right panels) as a function of $\Delta v_i$ of the Fe ii template. Top row: A2 median composite of spectra with reported Fe ii shift $\geq$1000 km s$^{-1}$; bottom row: same for a composite of spectral type B1. Thick black line: broad component of Hβ; green line: Fe ii template; yellow lines: narrow lines ([O iii] $\lambda$5007 and Hβ narrow component). On the right panel, black squares and gray spots indicate the normalized $\chi^2$ computed on the composite with no restriction on Fe ii width, and with Fe ii width restricted to roughly match the distribution of Hβ width. Dot-dashed lines trace the minimum $\chi^2$ ratio indicating a significant difference from the best-fit case. Circled symbols identify the specfit best fit. The circled cross marks the best fit assuming no He II $\lambda$4686 contribution. Composites with no Fe ii width restriction have higher S/N making it possible to obtain more stringent limits on the maximum Fe ii shift.

(A color version of this figure is available in the online journal.)

(Figure 1). Two composites were constructed for each spectra bin: (1) one with no restriction on Fe ii width (H08 do not constrain FWHM Fe ii in their template fits so it is sometimes very different from FWHM Hβ) and (2) one with Fe ii width constrained to the FWHM range of Hβ in a particular bin (i.e., $\leq$4000 km s$^{-1}$ for A2 and 4000–8000 km s$^{-1}$ for B1). Upper and lower panels of Figure 1 show bins A2 (FWHM Hβ $\leq$ 4000 km s$^{-1}$) and B1 (FWHM Hβ = 4000–8000 km s$^{-1}$), respectively ($n = 156$ for bin A2 and $n = 240$ for bin B1). The S/N $\sim$ 55–60 for both composites. Spectra show best-fit specfit models superimposed. The left and center panels involved Fe ii templates fixed to the best fit and 1500 km s$^{-1}$ shifts, respectively. Our template prescription is described in Marziani et al. (2009)

Graphical results for the best fits are shown in the right panels of Figure 1. Fits were performed over the range $\approx$4470–5450 Å, where Fe ii and continuum emission account for the total flux making it the safest region for normalized $\chi^2$ computations. $\chi^2$ values are shown for the range of adopted Fe ii shifts. In order to estimate confidence intervals we considered a set of fits with displacements $\Delta v_i = +500n$, for integer $n = 0...4$, along with the best fit and a few additional $\Delta v_i$ cases in proximity to the minimum $\chi^2$. One can see a clear preference for zero or near-zero fits. The significance of $\chi^2$ variations is described by F statistics appropriate for ratios of $\chi^2$ values (Bevington 1969). Given the large number of degrees of freedoms in the sampling range (4500–4630, 5040–5090, 5310–5360 Å) any $\chi^2$ differences between two fits become significant at a 95% confidence level if $\chi^2/\chi^2_{min} \approx 1.24$. The $\chi^2$ values indicate that zero shift and “best shift” values in table 1 are not significantly different. All fits involving shifts $\geq$500 km s$^{-1}$ are statistically significant. The middle panel of Figure 1 upper row demonstrates visually that the fit with $\Delta v_i = +1500$ km s$^{-1}$ (and even more the fits with larger displacement) do not reproduce the observed Fe ii emission.

Both the residuals and $\chi^2$ results rule out any systematic redshift for at least half of the H08 sample (Pop. A). Note especially the fits to the two relatively isolated multiplet 42 Fe ii lines between Hβ and [O iii]$\lambda$4959 and on the red wing of [O iii]$\lambda$5007. The redshifted fit fails to include the blue side of the 4450–4700 blend and the red side is confused by the frequent presence of He II $\lambda$4686. The latter line is not mentioned in the H08 study leaving us to conclude that it was not included in their fits. It can certainly give the impression of a redshift of the Fe ii blue blend, which is the most useful Fe ii diagnostic in the optical spectra of low redshift quasars
Notes. Median composites listed in the first column: A2—Z10, B1—Z10: A2 and B1 sources in the Z10 sample; A2 and B1—H08 s \( \geq 1000 \). H08 A2 and B1 sources with reported Fe\(^{ii}\) shift s \( \geq 1000 \) km s\(^{-1}\); A2 and B1—H08 \( \eta \leq 0.1 \); H08 A2 and B1 sources with Eddington ration \( \eta \leq 0.1 \) (as estimated by H08). The last column indicates the numbers of spectra combined in the median composites. Z10-based composites have S/N > 100, while lowest S/N H08-based composites have S/N > 50. For the H08 subsamples we used spectra from the SDSS quasar catalog of Shen et al. (2011).

a All shifts in km s\(^{-1}\) with respect to average radial velocity of peaks of H\(^{\beta}\) narrow component and of [O\(^{iii}\)] \( \lambda 5007 \).

b 2\(\sigma\) uncertainties of the H\(^{\beta}\) BC measurements are \( \pm 60 \) km s\(^{-1}\) and \( \pm 100 \) km s\(^{-1}\) for Pop. A and B, respectively.

c Absolute value of peak radial velocity difference H\(^{\beta}\) [O\(^{iii}\)]; \( \Delta \) is always positive if larger than 20 km s\(^{-1}\).

to make inferences about line shifts and widths. The claim of large Fe\(^{ii}\) shifts are not, and cannot be, confirmed.

Kovačević et al. (2010) recently report an Fe\(^{ii}\) study of SDSS quasars and any Fe\(^{ii}\) redshifts they measure (their Figure 16) are much smaller than those reported by H08 (the average Fe\(^{ii}\) shift relative to the narrow lines is \( 100 \) \( \pm \) 240 km s\(^{-1}\)).

Returning to our previous list of major sources of uncertainty for Fe\(^{ii}\) shift and FWHM estimates leads us to suggest that low spectral S/N and above average He\(^{ii}\) strength are the culprits. The fit to the 4430–4680 blue blend drives the best-fit \( \chi^2 \) results. The exclusion of He\(^{ii}\) \( \lambda 4686 \) from the H08 fits likely results in a tendency for He\(^{ii}\) to “redshift” the blue Fe\(^{ii}\) blend. This effect in a typically low luminosity sample, where He\(^{ii}\) is stronger than average, likely drove the conclusion that Fe\(^{ii}\) was systematically redshifted. We tested this conclusion omitting the He\(^{ii}\) line from our fits to the bin A2 and B1 composites generated from the H08 sample. Fe\(^{ii}\) shifts in lines 2 and 5 of Table 1 increase from \( \sim 60 \) to \( +770 \) km s\(^{-1}\) and from 730 to 1570 km s\(^{-1}\), respectively. The more constraining A2 results suggest that He\(^{ii}\) can produce the entire systematic redshift claimed by H08.

4. CONCLUSIONS

We do not confirm large Fe\(^{ii}\) redshifts relative to narrow [O\(^{iii}\)] and broad H\(^{\beta}\) emission in type 1 AGNs but cannot rule out the existence of small red (or blue) shifts in particular subsamples. Fitting median composites built from spectra with large claimed Fe\(^{ii}\) shifts (\( \geq 1000 \) km s\(^{-1}\)) indicates small shifts with an upper limit \( \approx 300 \) km s\(^{-1}\) for bin A2. In the case of B1 the best fit suggests \( \approx 700 \) km s\(^{-1}\) but the shift is very poorly constrained. In both cases the shifts are not significantly different from 0. These results do not support the origin of Fe\(^{ii}\) emission from a dynamical disjoint region from the one emitting the broad core of H\(^{\beta}\). Our result also challenges the usefulness of Fe\(^{ii}\) shift as orientation parameter. Small systematic shifts of Fe\(^{ii}\) with respect to the rest frame seem plausible but a reliable analysis is possible only on spectra of high S/N.

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REFERENCES

Bachev, R., Marziani, P., Sulentic, J. W., et al. 2004, ApJ, 617, 171

Bevington, P. R. 1969, Data Reduction and Error Analysis for the Physical Sciences (New York: McGraw-Hill)

Boroson, T. 2005, AJ, 130, 381

Boroson, T. A. 2011, ApJ, 735, L14

Boroson, T. A., & Green, R. F. 1992, ApJS, 80, 109

Ferland, G. J., Hu, C., Wang, J., et al. 2009, ApJ, 707, L82

Gaskell, C. M. 1982, ApJ, 263, 79

Gaskell, C. M. 1985, Nature, 315, 386

Hu, C., Wang, J.-M., Ho, L. C., et al. 2008, ApJ, 687, 78 (H08)

Kovačević, J., Popović, L. Ć., & Dimitrijević, M. S. 2010, ApJS, 189, 15

Kiss, G. 1994, in ASP Conf. Ser. 61, Astronomical Data Analysis Software and Systems III, ed. D. R. Crabtree, R. J. Hanisch, & J. Barnes (San Francisco, CA: ASP), 437

Marziani, P., Sulpizi, J. W., Calvani, M., et al. 1993, ApJ, 410, 56

Marziani, P., Sulentic, J. W., Negrete, C. A., et al. 2010, MN Ras, 409, 1033

Marziani, P., Sulpizi, J. W., Stier, G. M., Zamfir, S., & Calvani, M. 2009, A&A, 495, 83

Marziani, P., Sulpizi, J. W., Zamanov, R., et al. 2003a, ApJS, 145, 199

Marziani, P., Zamanov, R. K., Sulentic, J. W., & Calvani, M. 2003b, MN Ras, 345, 1133

Richards, G. T., Kruczek, N. E., Gallagher, S. C., et al. 2011, AJ, 141, 167

Shen, Y., Richards, G. T., Strauss, M. A., et al. 2011, ApJS, 194, 45

Shields, G. A., Ludvig, R. R., & Salvati, S. 2010, ApJ, 721, 1835

Sulentic, J. W., Bachev, R., Marziani, P., Negrete, C. A., & Dultzin, D. 2007, ApJ, 666, 757

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