An Empirical Ultraviolet Iron Spectrum Template

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Abstract. Iron emission is often a severe contaminant in optical-ultraviolet spectra of Active Galaxies (AGN) and Quasars. Its presence complicates emission line studies. A viable solution, already successfully applied in the optical, is to use an empirical Fe II (and Fe III) emission template. Here we develop a template for ultraviolet AGN spectra, based on *HST* archival spectra of I Zw 1 in the range 1100 – 3100 Å. Its application allows modeling and subtraction of the Iron emission from AGN and Quasar spectra. This work has shown that in particular C III] λ1909 can be heavily contaminated by other line emission, including Iron transitions. Details of the data processing, generation and use of the templates, as well as a discussion of the data can be found in Vestergaard & Wilkes (1998).

1. Motivation

This work was motivated by our desire to study the intrinsically emitted ultraviolet (UV) broad line profiles of quasars and QSOs (hereafter addressed as QSOs).

In addition to the commonly studied strong, permitted lines of Ly α λ 1216, Si IV+O IV] λ 1400, C IV λ 1549, C III] λ 1909, and Mg II λ 2800, QSO UV spectra also contain weaker lines such as various transitions of Carbon, Silicon, Oxygen, Nitrogen, Helium, and Iron. The importance of these lines lies not only in their presence and strengths but also in their effective "contamination" of the stronger lines. Iron is by far the strongest of these "contaminants" of the UV (and optical) broad emission lines. Due to the large number of electron levels in Iron atoms, hundreds of emission-line transitions of several ionization states are distributed throughout the UV and optical spectral regions. The weak lines of Iron and other metals blend together, especially when the QSO intrinsic line width is large. This heavy blending of weak, broad lines, dominated by Iron transitions, forms a *pseudo-continuum* above the intrinsically emitted continuum level (Wills, Netzer & Wills 1985) even in high signal-to-noise QSO spectra. The presence of such a pseudo-continuum severely complicates the study of the wings of the prominent resonance lines, the weak line features, and the intrinsically emitted continuum emission. The mere presence of broad, weak emission lines in the wings of the prominent lines also complicates a proper study of these profile wings and of the weak lines themselves. It is important to make reliable measurements of these features in order to study issues such as continuum – line relationships, dynamical and ionization structure, and chemical abundances in the QSO broad line region (BLR).

Our preliminary analysis indicates that line measurement uncertainties of order ~5 – 25% are expected in the prominent lines if the Iron emission is not corrected for. Some weak emission lines may, however, be so severely blended with Iron emission that the uncertainty approaches 100%.

2. Why an Empirical Template?

A viable way to correct for the contaminating Iron emission is to generate an empirical Iron emission template which can be used to model the Iron emission in individual QSO spectra. An alternative is to theoretically model the Iron emission. However, to date such modeling has only been moderately successful mainly due to inadequate atomic data and understanding of the Iron emission mechanism. Much improved atomic data have become available in recent years (*e.g.,* Hummer et al. 1993; Nahar et al. 1997) allowing much more advanced theoretical models to be developed. This work is currently in progress (e.g. D. Verner, private communication; Verner et al. 1998).

An empirical Iron template is thus extremely useful until adequate theoretical models and understanding of the Iron emission in QSOs are available. A template is not model dependent but comprises the Iron emission transitions and line ratios as emitted by a QSO. This template permits the modeling and subtraction of the Iron emission in individual QSO spectra, as the Iron spectrum can be broadened and scaled to match the Iron emission in the spectra of these objects. In addition, this modeling of the Iron emission allows us to create a database of (modeled) Iron spectra which can help constrain theoretical models of QSO Iron emission, thereby helping us to better understand this emission.

An optical template, based on data of I Zw 1, has already been successfully applied to the bright QSO survey (Boroson & Green 1992).

3. The Template

We present a UV Fe II and Fe III empirical template ranging from 1070 – 3090 Å based on high quality *HST* archival spectra of QSO, I Zw 1. The data were originally obtained, presented, and analyzed by Laor et al. (1997), who also identify most of the emission and absorption features in the spectra.

The UV spectrum of I Zw 1 (Figure 1) was chosen for several reasons. The spectrum is rich and strong in the Iron emission, the prominent resonance lines are relatively narrow (full width at half maximum $\sim 900\,\mathrm{km\,s^{-1}}$) and the optical spectrum was used to generate the optical Iron emission template (Boroson & Green 1992).

A strong and rich Iron spectrum permits the detection of weak Iron features and the identification of as many Iron features as are typically present in QSOs.

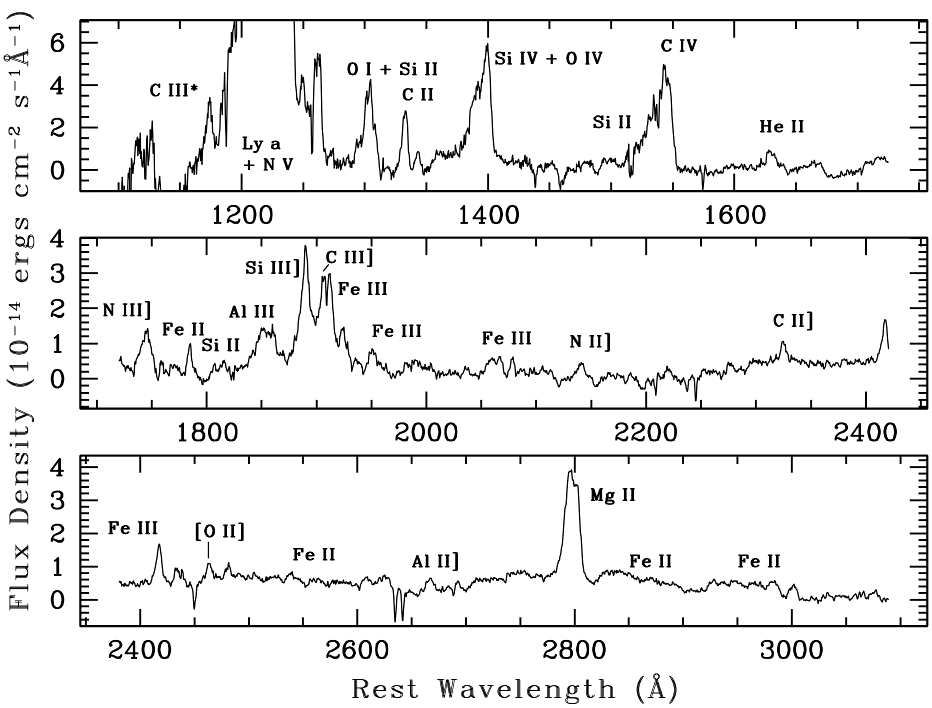

Figure 1. The (power-law) continuum subtracted *HST* archival spectrum of I Zw 1. The strongest lines are labeled. Ly α and N V are not shown in full in order for the weaker lines to be relatively more visible.

The relatively narrow lines allow us to deblend the line emission in the process of generating the iron spectrum.

In order to isolate the Iron emission, the other Hydrogen and metal emission lines and absorption lines were modeled and subtracted. Composite Gaussian profiles were used to reproduce the line profile shapes (note, the Gaussian modeling is only a fitting tool, and no physical meaning is associated with each individual Gaussian component). The details of the data processing and line fitting procedure are described in Vestergaard & Wilkes (1998).

This work has shown that a number of line-emission transitions may dominate the C III] λ 1909 line blend (Figure 1). In the I Zw 1 spectrum the C III] contribution to the blend is small. Hence, caution must be exercised when studying C III] as direct measurements of this line can be significantly in error thereby affecting general line studies, BLR density determinations, and abundance studies. This heavy blending of C III], difficult to discern for broad line spectra, emphasizes the motivation for this work.

The Fe II and Fe III emission template is shown in Figure 2. Small residuals of the subtracted line fits are set to zero in order to avoid introducing unnecessary uncertainties into the QSO spectra to which the templates are applied. In the region around Ly α the Iron emission is either too weak to be reliably isolated or non-existent, except in the red wing of Ly α. Blueward of Ly α the Lyman forest heavily complicates a reliable isolation of the Iron emission and the latter has thus been omitted. The strength of the Fe III λ 1540Å component is very uncertain as it is heavily blended with C IV emission, and blueshifted C IV emission is possibly present (Vestergaard & Wilkes 1998).

4. Application Method of the Template

The following adopted Iron cleaning method is an extension of the basic method used by Boroson & Green (1992). See Vestergaard & Wilkes (1998) for details and a discussion of these methods.

1. A power-law is fitted to the continuum of the QSO spectrum using line free wavelength regions and the fit is subtracted.
2. The Iron template is broadened to match the QSO line width
3. This broadened Iron template is scaled to match the Iron emission strength of the QSO spectrum and the scaled template is subtracted.
4. The power-law continuum fit (from step 1) is added to the Iron subtracted QSO spectrum
5. Steps 1 − 4 are repeated in order to optimize the solution

Step 5 ensures an improved continuum fit and Iron spectrum model over those obtained from a first run through (Step 1 − 4), which for the continuum fit may be affected by Iron or other contaminating emission.

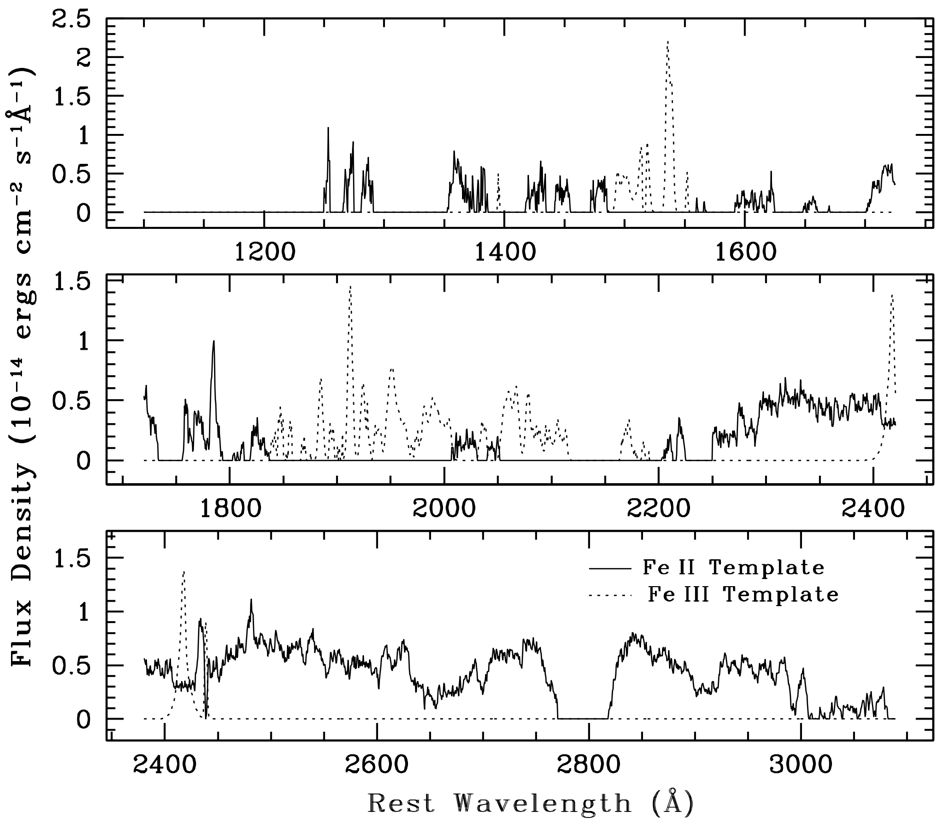

Figure 2. The UV Iron template. The Fe II emission is shown by the solid line, while Fe III is shown by the dotted line.

5. Future Work

The Fe II and Fe III template is used to model the UV Iron emission in a large sample of QSO spectra (Vestergaard et al. 1998) and can be used to model any QSO and AGN UV spectrum with intrinsic line width larger than $900\,\mathrm{km\,s^{-1}}$.

The modeling and subtraction of the contaminating Iron emission in QSO UV spectra will improve studies of the broad emission lines and photoionization modeling of the BLR.

The database of modeled Iron emission from individual QSOs will then be used to attempt to understand this Iron emission in terms of physical models.

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Discussion

Amri Wandel: By how much would the Fe II contamination affect the FWHM of C III]?

Belinda Wilkes: When the contaminating lines are strong the FWHM will be heavily affected, up to 50% (or more) is a very rough guess.

Martin Gaskell: For "normal" Quasars (actually, core-dominated radio-loud ones) we found a much lower Si III]/C III] line ratio (Gaskell, Wampler, & Shields 1981). Si III] is much weaker than C III].

Belinda Wilkes: As Dr. Wills showed last night, the Si III]/C III] ratio varies strongly and systematically from object to object. It can be very strong. This line ratio is sensitive to the BLR density where the lines are emitted. The fact that it varies so much reflects strongly varying densities of the Si III] and C III] emitting regions among Quasars.

Anuradha Koratkar: The line ratio can be strong in some objects.

Bev Wills: The line ratio depends on the sample.

Mike Eracleous: In the vicinity of Mg II there seems to be a "hole" in the Fe II and Fe III template. Is there a real absence of Fe II lines, or is it just difficult to measure them because of the presence of the Mg II line?

Belinda Wilkes: Actually, both options are valid. There is a real gap in the Fe II emission where the expected Fe II flux density is relatively low (D. Verner, private communication), but due to the presence of Mg II it is indeed difficult to establish the absolute Fe II strength at the position of Mg II. As the template was generated with the primary purpose of modeling and removing the Iron emission in order to study the other UV lines, we opted to underestimate the Iron strength at the Mg II position in order not to overcorrect the Mg II emission in the QSO spectra to which the template is applied.