PROCEEDINGS OF SCIENCE

Near-infrared Fe II emission in IZw1 and other NLS1 galaxies

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We study the near-infrared (NIR) emission of IZw1 aimed at confirming the role played by Lyα fluorescence in the production of the Fe II spectrum. We also derive the first semi-empirical NIR Fe II template from IZw1 that best represents that emission, allowing its clean subtraction in other sources. A good overall match between the observed Fe II+Mg II features with those predicted by the best-fitted model was obtained. This semi-empirical template is then fitted to the spectrum of Ark 564 and other Seyfert galaxies, showing that it nicely reproduces the observed iron emission. Our work extends the current set of available Fe II templates into the NIR region.

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1. Introduction

One of the most puzzling aspects of the line spectra emitted by the broad line region (BLR) of active galactic nuclei (AGNs) is the Fe II emission, whose numerous multiplets form a pseudo-continuum from the UV to the optical region due to the blending of approximately 10^5 lines. Because of its strength, this emission constitutes one of the most important contributors to the cooling of the BLR and is a potential diagnostic of gas density, column density, turbulence and temperature of that region.

The strong blending observed in the optical Fe II spectrum of most sources prevents a reliable study of individual line profiles and the identification and measurement of weaker lines. As the blending is minimized in the class of objects known as Narrow-Line Seyfert 1 galaxies (NLS1s), the study of the Fe II emission in these objects can lead to a significantly more accurate study of its properties. Boroson & Green (1992), for instance, derived an optical template for the Fe II multiplets from IZw1, which has served since then to adjust the Fe II strength of several other objects. Later, Vestergaard & Wilkes (2001) extended the template method into the UV regime (1250 Å to 3090 Å) based on HST (archival) data of IZw1.

Model calculations including Lyα fluorescence as the excitation mechanism for the Fe II lines (Sigut & Pradhan 1998, 2003) showed that this process is of fundamental importance in determining the strength of the Fe II emission. The key test to probe it, as predicted by Sigut & Pradhan (1998), is significant Fe II emission in the 8500-9500 Å region. NIR spectroscopy carried out on AGN samples has confirmed the presence of these lines as well as the so-called 10000 Å (1μm) Fe II lines (Fe II λ9997, λ10501, λ10863 and λ11126). These are the most prominent Fe II features observed in the rest wavelength interval 8500-24000 Å.

In spite of its relevance and increasing interest in NIR spectroscopy of AGN samples (Riffel et al. 2006, Landt et al., 2008), no template to study the NIR Fe II has been constructed to date. This work aimed at fulfill this vacuum. IZw1 is a particularly good choice as a test target because of the strong and narrow Fe II emission lines it displays. Moreover, it complements the templates previously published in both the UV and the optical region.

2. Observations and Data Reduction

Near-infrared spectra of IZw1 were obtained at the NASA 3m Infrared Telescope Facility (IRTF). The SpeX spectrograph (Rayner et al. 2003) was used in the short cross- dispersed mode. The detector consisted of a 1024×1024 ALADDIN 3 InSb array with a spatial scale of 0.15"/pixel. A 0.8"×15" slit was oriented at the paralactic angle to minimize differential refraction.

The spectral reduction, extraction and wavelength calibration procedures of IZw1 were fully described in Garcia-Rissmann et al. (2012). The 1-D IZw1 spectrum was then corrected for telluric absorption and flux calibrated using Xtellcor (Vacca et al. 2003). Finally, the different orders of the galaxy spectrum were merged to form a single 1-D frame and corrected for a redshift of z=0.061105, determined from the average z measured from the positions of Paδ, He I 10830μm, Paα and Brγ. A Galactic extinction correction of E(B-V)=0.065 (Schlegel et al. 1998) was applied.

Figure 1 shows the final 1D spectrum of IZw1 already calibrated by wavelength and flux. Line identifications for the most conspicuous lines detected are indicated in the Figure.

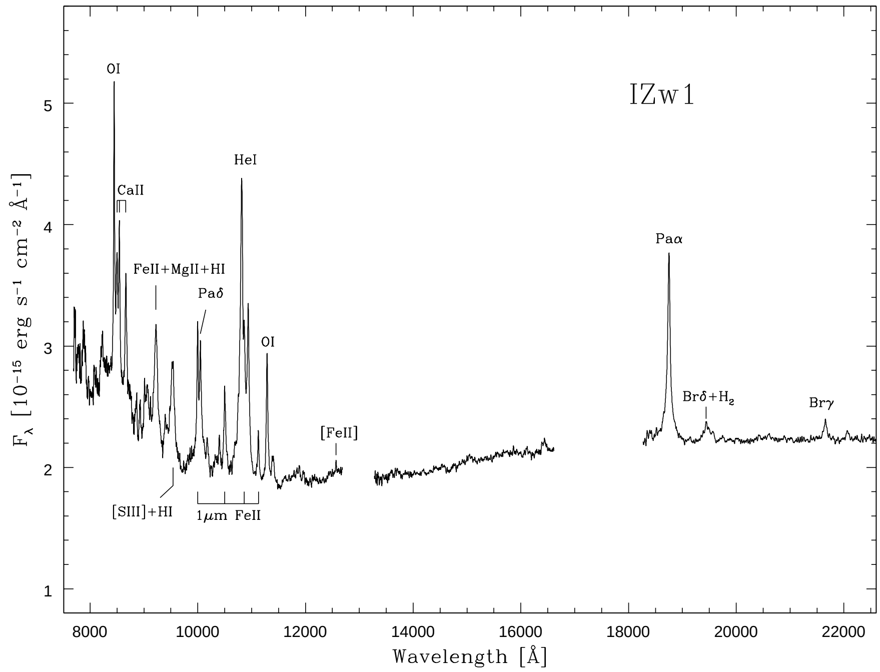

Figure 1: NIR SpeX spectrum of I Zw 1, from 8000 Å to 22100Å rest wavelength. Prominent emission lines are identified.

3. The approach

Sigut & Pradhan (2003) presented improved theoretical non-LTE Fe II emission line strengths for physical conditions typical of active galactic nuclei with broad-line regions. In these set of models, which also include the Mg II ion, the Fe II line strengths were computed with a precise treatment of radiative transfer using extensive and accurate atomic data from the Iron Project. Excitation mechanisms for the Fe II emission included continuum fluorescence, collisional excitation, self-fluorescence among the Fe II transitions, and fluorescent excitation by Lyα and Lyβ. A Fe II atomic model consisting of 827 fine structure levels (including states to E$\sim$15 eV) was used to predict fluxes for approximately 23,000 Fe II transitions, covering most of the UV, optical, and NIR wavelengths of astrophysical interest.

The approach used in constructing the first semi-empirical template consists of comparing the NIR spectrum of IZw1 with the grid of Fe II+Mg II models of Sigut & Pradhan (2003). They cover a wide range of ionization parameters (U=-1.3, -2 and -3) and densities (log $n_{\rm H}$ = 9.6, 10.6, 11.6 and 12.6 cm^{-3}). The internal cloud turbulent velocity, in all cases, was $V_{\rm tur}$=10 km s^{-1}. Fe II+Mg II spectra were computed for BLR cloud models typical of the conditions thought to exist in the Fe II emitting clouds. The calculations were made for traditional clouds of a single specified density and ionization parameter, as the main interest is the interplay of the various iron emission excitation mechanisms and not the detailed structure of the BLR.

The model that best matches the observations will be chosen. If discrepancies between the best solution and the observed emission are detected, line strengths can be adjusted by eye in order to improve the final RMS of the fit.

Because all models predict few and weak Fe II lines redward of 11500 Å, we decided to constrain the region of interest to the interval 8500-11500 Å. In order to make a proper fit, the observed de-redshifted spectrum of IZw1 had its continuum subtracted by fitting a spline3 function to the regions free of emission lines.

4. The first semi-empirical template in the NIR of IZw1

We found that the model with log U=-2 and log $n_{\rm H}$=12.6 cm^{-3} best represents the observed Fe II+Mg II emission in IZw1. Although not crucial at this point, it is important to question if that model is representative of the actual physical conditions of the Fe II emission region.

Joly (1991) computed purely collisional models showing that low temperature (T <8000 K), high density ($n_{\rm H} > 10^{11}$ cm^{-3}), high column density (N(H)$> 10^{22}$ cm^{-2}) clouds provide Fe II$_{\rm opt}$/Hβ in good agreement with observations of Seyfert 1 galaxies. Detailed modeling of the optical Fe II using Cloudy and including Lyα fluorescence as one of the excitation mechanisms published by Baldwin et al. (2004) points out to similar conditions. Observational evidence that strong iron (Fe II and Fe III) emission may be connected with high densities was provided by Kuraszkiewicz et al.(2000) and Véron-Cetty et al. (2004). We conclude that the physical conditions of the best matching model for IZw1 are representative of the Fe II region in AGNs.

A comparison between the IZw1 spectrum and the best template showed that a small tuning was needed in order to properly reproduce most of the observed Fe II strengths. To this purpose and to conserve the physical interpretation of the best-fitting model with predictions about the intensities of the most conspicuous Fe II lines (9997 Å, 10501 Å, 10862 Å, 11126 Å and the close neighbors Fe II 10491 Å, 10871 Å) we keep their original values preserved, adjusting manually the strengths of those lines that strongly depart from the observations. Such is the case of the two-peaked bump observed at $\sim$11400 Å: this feature is underestimated by any of the models, and because of its strength, we ruled out the possibility of being part of the spectrum noise or a feature introduced by the O I 11287Å profile fitting.

Left panel of figure 2 shows the template derived from best fitted model (top) and the semi-empirical spectrum (bottom) after the adjustment of the intensities of the most discrepant lines. For comparison, we superposed the observed Fe II+Mg II spectrum of IZw1. The semi-empirical template reduces by 36% the RMS of the observed spectrum with respect to the best fitted model. The bottom figure also indicates the lines whose estimated intensities varied more significantly with respect to those given by the model.

5. Analysis

We confirm that Lyα fluorescence is indeed a process that should be taken in to account in any systematic study of the Fe II emission in AGNs. Moreover, it produces a considerable amount of emission lines that otherwise would be absent. This is particularly evident for the 9200 Å feature, composed of numerous Fe II multiples as well as the contribution of Mg II lines.

Figure 2 also shows that as in the optical region, the NIR Fe II emission produces a subtle pseudo-continuum, particularly in the region between 8600 and 10000 Å. Without proper mod-

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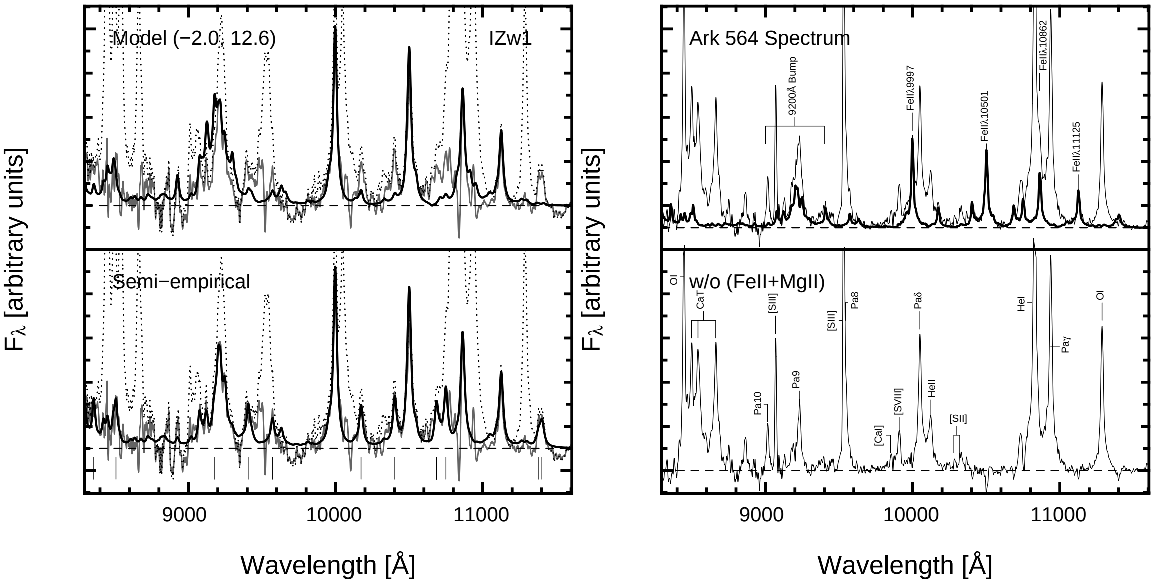

Figure 2: Left panel: (Top) comparison of the observed Fe II+Mg II spectrum with the one derived from the best model (U=-2.0; log $n_{\rm H}$=12.6 cm^{-3}). Bottom: again the observed Fe II+Mg II spectrum, and the semi-empirical spectrum. Dotted black line: total emission line spectrum of IZw1; solid gray and black lines: observed and model/semi-empirical Fe II+Mg II spectra, respectively. Dashed lines indicate the zero level intensity. Line strengths that were significantly discrepant and adjusted by eye are marked with vertical bars. Right panel: (Top) observed continuum-subtracted spectrum of Ark 564 overlaid to the semi-empirical Fe II+Mg II template (in bold). Bottom: Spectrum of Ark 564 with the iron emission subtracted.

eling and subtraction of this emission, fluxes of other BLR and NLR features can be severely overestimated.

What is the advantage of studying the Fe II emission in the NIR over the optical? Unlike the later, individual (or nearly) Fe II emission lines can be isolated in the former (i.e., the lines at 9997, 10500 and and 11126 Å, for example), enabling the characterization, for instance, of the line profiles and the measurement of emission line fluxes in an already complex emission region. This possible because other Fe II lines very close in wavelength to the above three, are at least 25× weaker.

In order to assess the usefulness of the semi-empirical template, we will use it to characterize the Fe II emission in other Seyfert 1 galaxies. This will allow us to see if, as in the optical region, relative intensities of the individual lines do not vary from object to object.

The right panel of Figure 2 shows the results for Ark 564. It can be seen that the template reproduces the observed Fe II spectrum in that galaxy after properly scaling it. The small residuals left in the region between 10200-10600 Å after subtracting that contribution confirms the ability of the template to quantify that emission in other AGNs.

6. Final remarks

We have constructed the first semi-empirical Fe II template based on the comparison of the observed spectrum of IZw1 and a grid of theoretical Fe II models to measure that emission in

AGNs.

The best match among all models was obtained with low/moderate ionization parameter (log$U$=-2) and high gas density(log $n_{\rm H}$=12.6 cm^{-3}). These conditions are similar to those already derived from observations in other AGNs.

We performed a quick check of the template on the spectrum of Ark 564. Despite some small differences, it corroborated the reliability of the NIR Fe II template.

As in the optical region, the relative intensity of the Fe II lines are similar from source to source. Moreover, the Lα fluorescence is a fundamental mechanism to take into account as tell by the presence of the 9200Å Fe II lines.

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