Emission Lines in Active Galaxies: New Methods and Techniques
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Iron Lines, X-Rays, and Outflowing Winds

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Abstract. The strength of optical Fe II lines seems to be connected to both X-ray spectral slope and X-ray loudness, as well as other interesting properties such as emission-line width and the presence of a low-ionization broad absorber. The reason for this cluster of correlations is far from clear.

1. The Fe II Puzzle

The optical Fe II lines have long been an intriguing puzzle in AGN research. They show a wide range of strength from object to object. There have been claims that Fe II strength correlates with several parameters of fundamental interest, such as radio loudness, emission-line width, and X-ray spectral slope, but each of these claims has been disputed. The strength of Fe II is a specific discomfort for photoionization models, both in terms of total Fe II luminosity, and the ratio of Fe II to the Balmer lines, which models find it particularly hard to duplicate. Finally even the sense of the claimed correlation with X-ray spectral slope is in the opposite direction to that naively expected in photoionization models. Our main aim here is to check the reality of the correlation with X-ray spectral slope, but we are thus led towards a dimly perceived panorama of wider connections. More details (and the list of my collaborators) can be found in Lawrence et al. (1996).

2. ROSAT Observations

Our strategy is leverage and quality. Firstly we have new *ROSAT* PSPC observations of the two strongest and two weakest Fe II emitters we knew about at the time we wrote the proposal. The weak emitters (MKN10 and MKN110) are flat by *ROSAT* standards, with $\alpha_x \approx 1.4$. Of the super-strong emitters, PHL 1092 is *very* steep, $\alpha_x = 3.5$, and *IRAS* 07598+6508 is only marginally detected, and so is extremely X-ray quiet, with $\alpha_{ox} = 2.5$. We also made an observation of the well-known strong Fe II emitter I Zw 1, which was also steep, with $\alpha_x = 2.0$. Next, to fill in the middle region, we use the small but complete PG subset of Laor et al. which is limited to low Galactic column densities, leading to reliably measured spectral slopes with small error bars. Finally, we add four other strong Fe II emitters from the *ROSAT* archive — MKN 231, *IRAS* 13224-3809, 5C 3.100, and MKN 507 — making a total sample of 19 for correlation hunting.

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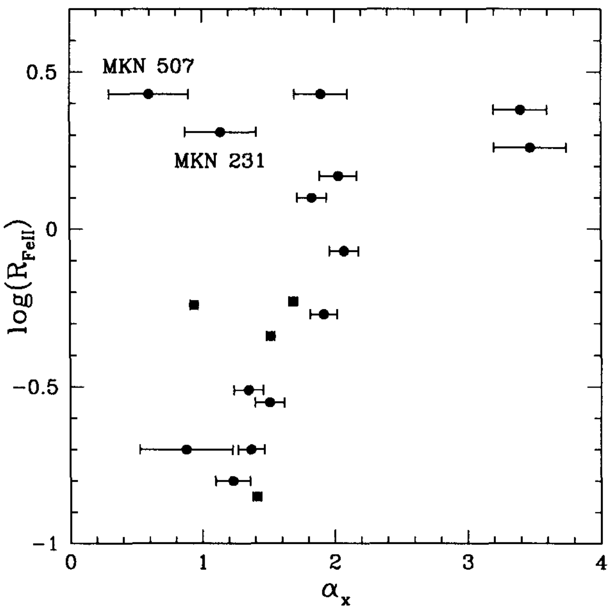

Figure 1. *ROSAT* X-ray spectral slope versus Fe II (4570)/Hβ

3. Correlations Involving Fe II Strength

Figure 1 shows the connection between Fe II strength (quantified by R(Fe II) = Fe II (4570)/Hβ) and X-ray spectrum. This partially confirms the original claim of Wilkes, Elvis, & McHardy (1988). It is not a simple causal connection, but the distribution is far from random, seeming to fill half the plane. Weak Fe II emitters are always flat, but strong Fe II emitters can be either steep or flat. Figure 2 shows that a much cleaner connection seems to hold with X-ray loudness, as quantified by α_{ix}, the slope between 1 μm and 2 keV: strong Fe II emitters are X-ray quiet. (The same effect can be seen in the more conventional α_{ox} but the correlation is much noisier.) We also confirm that Fe II anti-correlates with line width, as first claimed by Gaskell (1985), and that line width in turn anti-correlates with X-ray slope, as claimed by Laor et al. 1995. We also find that strong Fe II emitters have steeper optical spectra, and weaker Blue Bumps.

4. The LBAL Connection

Of the seven strong Fe II emitters in our sample, two are known to be examples of the rare low-ionization sub-group of broad-absorption line (BAL) objects, which constitute about one out of every sixty-five optically selected quasars (Weymann et al. 1991.) In fact this classification is only possible from UV data, which are available for only four of the seven objects, so low-ionization absorbers are heavily over-represented amongst strong Fe II emitters. (The same connection

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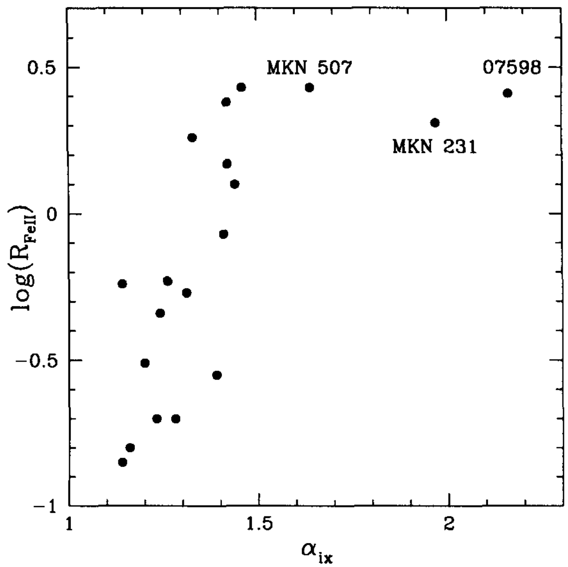

Figure 2. X-ray loudness (spectral slope from 1 μm to 2 keV) versus Fe II (4570)/Hβ

in reverse has been suggested by Boroson & Meyers 1992). Note that in all our correlations there are three persistent outliers — MKN 231, *IRAS* 07598, and MKN 507. The first two are LBALs and the third has no UV data. As well as the connection between outflowing winds and Fe II being of intrinsic interest, it offers the prospect of explaining the anomalous spectra, which should perhaps be fitted with an ionized absorber component rather than a simple power law plus neutral absorber.

5. Eigenvector One

The results discussed here have confirmed and added to a growing collection of tantalizing and fairly consistent statistical connections between AGN properties, which we summaries in Table 1. We apologies for not listing the literature origins of all these, but note that the implied variable is essentially the 'eigenvector 1' that emerged from the ground breaking principal components analysis of Boroson & Green (1992). The list fascinates and infuriates, being composed of various items that seem to be deeply connected, but none of which we understand. They include quantities probably connected with primary energy production, with dissipation of energy, and with gas dynamics. One gets the feeling of being on the verge of the quasar HR diagram, but we don't yet know what we are staring at.

Our first refuge these days is orientation, but that seems an unlikely explanation for the drastic [O III] differences seen, and it seems difficult to understand

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how Fe II and the Balmer lines can have such very different anisotropies, at least in purely photoionized models. Perhaps part of the answer is that mechanical heating is also involved as suggested for example by Joly (1991). The physical variable could simply be the *density* of an outflowing wind. For a fixed radiative and mechanical luminosity, a denser wind would have a smaller outflow velocity, a lower ionization parameter, a larger optical depth, and stronger Fe II lines. (This is similar to the proposal of Norman & Miley 1984).

Table 1. Qualitative Summary of Quasar Correlations

Property (1)	Nature of Correlation (2)
Blue bump	weak ⇒ strong
X-ray strength	quiet ⇒ loud
X-Ray spectrum	steep ⇒ flat
Fe II Emission	strong ⇒ weak
Broad-line widths	narrow ⇒ broad
Broad-line asymmetry	blue ⇒ none or red
[O III] strength	weak ⇒ strong
Luminosity	high ⇒ low
Variability	high ⇒ low

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