Main Trends of the QUASAR Main Sequence

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Overview

- **The diaspora in Fell emission**
  - mechanisms, multiplets, pseudo-continuum

- **Schema for the Eigenvector 1**
  - Principal Component Analysis, optical plane
  - the Quasar Main Sequence

- **“Looking at it” differently**
  - effect of viewing angle ($f$-factor), physical trends
  - the Mass effect

- **In progress**
  - cloud dynamics and composition
  - and something more...
The diaspora in FeII emission in AGNs

Why?

- To determine the Energy budget of the emitting gas, provided the emission is strong.
- Measurement of its Abundance = \( f(\text{cosmic time}) \), to verify cosmological parameters.

How?

- Standard photoionisation
- Continuum fluorescence
- Collisional excitation
- Self-fluorescence among FeII transitions
- Fluorescent excitation by Ly\(\alpha\) and Ly\(\beta\) lines

Verner et al. 1999

“The atom is far from equilibrium in most emission-line objects, so the spectrum is sensitive to the detailed local conditions. A complete simulation of the physical processes affecting the Fe II spectrum would make it possible to deduce the density, temperature, and iron abundance of the emitting regions.”

*Phillips (1978)
Theoretical UV and optical Fe II spectra calculated for the parameters expected in quasar broad emission line regions. The clouds are illuminated by a spectral energy distribution typical in AGNs, total hydrogen column density of $10^{24}$ cm$^{-2}$, and solar abundances: \( n = 10^{12} \) cm$^{-3}$, \( \log (\Phi_{H}) = 20.5 \) cm$^{-2}$ s$^{-1}$

- “Make a template Fe II spectrum by removing lines that are not Fe II” for PG 0050+124 (1 Zwicky 1) spectrum
- The result of their procedure was a spectrum representing only permitted Fe II emission in 1 Zw 1 (removing Balmer lines, [OIII] lines, [NII] \( \lambda 5755 \), blend of Na I D and He I \( \lambda 5876 \), two intense [FeII] lines at \( \lambda 5158 \) and \( \lambda 5273 \))

- Theoretical Fe II template (Verner et al., 1999)
- Empirical UV template (Vestergaard & Wilkes, 2001)
- Theoretical Fe II template (Sigut & Pradhan, 2002)
- Semi-Empirical optical Fe II template (Véron-Cetty et al., 2003)
- Optical Fe II template based on FSG groups (Kovacevic et al., 2010)
- 1Zw1-derived NIR Fe II template (Garcia-Rissmann et al., 2012)
- And others...

371 levels (up to 11.6 eV) and predicts intensities of 68,635 lines

Theoretical UV and optical Fe II spectra calculated for the parameters expected in quasar broad emission line regions. The clouds are illuminated by a spectral energy distribution typical in AGNs, total hydrogen column density of $10^{24}$ cm$^{-2}$, and solar abundances: \( n = 10^{12} \) cm$^{-3}$, \( \log (\Phi_{H}) = 20.5 \) cm$^{-2}$ s$^{-1}$
Schema for the Eigenvector 1

Principal Component Analysis (PCA)

- 13 tabulated properties
- Eigenvector 1: FeII - [OIII] anti-correlation
- Peak $\lambda$5007 and H$\beta$ FWHM correlation

_Boroson & Green, 1992_
PCA in short

- Linear combination of variables
- Taking multi-dimensional data (> 2D) and making 2D plots
  - To show relevant clustering in data
  - To segregate parameters (principal components) based on valuability on clustering
- Basic steps:
  - Data shifted to origin
  - Least-square minimization to get best fit → **PC**
  - Re-scale the best-fit to unity → **Eigenvector**

For the sake of the example, imagine that the variation for PC1 = 15, and the variation for PC2 = 3.

$$SS(dists for PC1) = \frac{ Variation \ for \ PC1 }{ n - 1 }$$

$$SS(dists for PC2) = \frac{ Variation \ for \ PC2 }{ n - 1 }$$

That means that the total variation around both PCs is 15 + 3 = 18...

$$PC2 \ ... \ and \ that \ means \ PC1 \ accounts \ for \ \frac{15}{18} = 0.83 = 83\% \ of \ the \ total \ variation \ around \ the \ PCs.$$

If we had more genes, we’d just keep on finding more and more principal components by adding perpendicular lines and rotating them...

In theory there is one per gene (or variable), but in practice, the number of PCs is either number of variables or the number samples, whichever is smaller.

That means that a 2-D graph, using just PC1 and PC2, would be a good approximation of this 5-D graph since it would account for 94% of the variation in the data.
"Looking at it" differently

Modelling the optical plane

- Mainly as a function of black hole mass & accretion rate
- Theoretical SED shapes, local density, cloud composition

Effect of viewing angle (f-factor)

\[ M_{\text{BH}} = f \frac{r_{\text{BLR}} \text{FWHM}^2}{G} = \frac{r_{\text{BLR}} \text{FWHM}^2}{G(4 \cdot (\kappa^2 + \sin^2 \theta))} \]

account for \( R_{\text{Fe II}} \) values in each spectral type along the MS, in a way consistent with the observational trends in metallicity, density, and SED

\[ R_{\text{Fe II}} \text{ dependence on } \frac{L_{\text{bol}}}{L_{\text{Edd}}} \]
Results from a set of CLOUDY simulations performed on a constant density single BLR cloud assuming $M_{BH} = 10^8 M_\odot$ showing the distribution of changing FeII strength with changing BLR sizes computed from the virial relation. Open circles mark the $R_{FeII}$ values expected for $\theta = 30^\circ$ and $\theta = 45^\circ$. The color patches (in red) in each spectral bin denote the range of $R_{FeII}$ values as expected from observational evidences. The respective upper (+2$\sigma$) and lower (-3$\sigma$) bounds are shown by blue dashed lines about the $r_{BLR}$ values estimated from the Bentz et al. (2013) relation (shown by black dashed lines) and the range is shown as green shaded regions. The inset diagram shows the optical plane of the Eigenvector 1, FWHM(H$\beta$) vs. $R_{FeII}$.
Results from a set of CLOUDY simulations performed on a constant density single BLR cloud assuming $M_{BH} = 10^8 M_\odot$ and $M_{BH} = 10^{10} M_\odot$.

Excerpt of the Table 1 from our paper showing photoionization models of spectral types and associated prevalences.

<table>
<thead>
<tr>
<th>Case</th>
<th>ST</th>
<th>Z</th>
<th>$\log n_H$</th>
<th>$L/L_{Edd}$</th>
<th>SED</th>
<th>$\theta^a$</th>
<th>$\log R_{BLR}^b$</th>
<th>$\tilde{n}_i$</th>
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</thead>
<tbody>
<tr>
<td>C1/C2</td>
<td>A1</td>
<td>5</td>
<td>10.5</td>
<td>0.2</td>
<td>M&amp;F</td>
<td>0 - 45</td>
<td>16.12 - 17.83</td>
<td>0.92</td>
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<tr>
<td>C1/C2</td>
<td>A1</td>
<td>5</td>
<td>10.5</td>
<td>0.2</td>
<td>M&amp;F</td>
<td>10.9 - 26.8</td>
<td>16.78 - 17.45</td>
<td>0.26</td>
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<tr>
<td>C1</td>
<td>A2</td>
<td>5</td>
<td>11</td>
<td>0.5</td>
<td>M&amp;F</td>
<td>0 - 45</td>
<td>16.12 - 17.83</td>
<td>0.735</td>
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<tr>
<td>C1</td>
<td>A2</td>
<td>5</td>
<td>11</td>
<td>0.5</td>
<td>M&amp;F</td>
<td>13.51 - 32.7</td>
<td>16.93 - 17.60</td>
<td>0.25</td>
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<tr>
<td>C2</td>
<td>A2</td>
<td>5</td>
<td>11</td>
<td>0.5</td>
<td>M&amp;F</td>
<td>0 - 45</td>
<td>16.12 - 17.83</td>
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<tr>
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<td>11</td>
<td>0.5</td>
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<tbody>
<tr>
<td>C1</td>
<td>B1</td>
<td>0.5</td>
<td>10</td>
<td>0.05</td>
<td>Kor</td>
<td>16 - 45</td>
<td>16.10 - 16.87</td>
<td>0.87</td>
</tr>
<tr>
<td>C1</td>
<td>B1</td>
<td>0.5</td>
<td>10</td>
<td>0.05</td>
<td>Kor</td>
<td>37.4 - 45</td>
<td>16.55 - 17.22</td>
<td>0.30</td>
</tr>
<tr>
<td>C1</td>
<td>B1</td>
<td>0.5</td>
<td>10</td>
<td>0.05</td>
<td>Lao</td>
<td>12 - 45</td>
<td>16.55 - 17.22</td>
<td>0.93</td>
</tr>
<tr>
<td>C1</td>
<td>B1</td>
<td>0.5</td>
<td>10</td>
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<td>Lao</td>
<td>37.4 - 45</td>
<td>16.55 - 17.22</td>
<td>0.30</td>
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<tr>
<td>C2</td>
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<td>10</td>
<td>0.075</td>
<td>Kor</td>
<td>18 - 45</td>
<td>16.10 - 16.87</td>
<td>0.83</td>
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<tr>
<td>C2</td>
<td>B1</td>
<td>1.0</td>
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The Mass effect

Panda, Marziani & Czerny (under-review)
In progress

- **Intra-cloud** DYNAMICS and COMPOSITION
- Streamlining the FWHM DISTRIBUTION along the vertical spectral types with inclination
- Streamlining the MASS DISTRIBUTION with inclination
- Testing the model with CONSTANT BOLOMETRIC LUMINOSITY
Metallicity - cloud density distribution as a function of $R_{\text{FeII}}$ at zero turbulence. The montage is shown as a function of increasing steps in inclination angles, the corresponding BLR size computed from the virial relation. The BLR size from the Bentz et al. 2013 $R$-$L$ relation is shown for $\lambda_{\text{Edd}}=0.2$ and $M_{\text{BH}}=10^{10} \ M_\odot$. The SED shape used is taken from Korista et al. 1997. The distribution is shown for spectral type A1.
M8 k=0.1 vs k=0.5, Korista SED, Edd=0.2, A1

Panda et al. - in prep.
M8 SED compare, A1 vturb 0

Panda et al. - in prep.
M8 vturb 0, 10, 100, Kor, A1
M10 vturb 0, 10, 100, Kor, A1

Panda et al. - in prep.
Thank you for your attention!

1. **FeII** is a complex species with numerous emission mechanisms.

2. The **Eigenvector 1 diagram** holds a key to understand the FeII emission and the rarity of strong FeII emitters.

3. Combining $M_{\text{BH}}$, $dM/dt$ and $\Theta^*$ with a comprehensive FeII model.

4. Constraining physical parameter space with observational trends.

5. As a predictive tool for reverberation mapping studies.

6. To explain xA quasars as **standard Eddington candles** as a probe for **Cosmology**.

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*Holy-trinity of quasars*