Diagnostics from UV spectra of low redshift quasars

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Distinctive emission line spectrum with prominent broad lines due to resonant and intercombination transitions from a spatially unresolved “broad line region” (BLR)
Quasars do not show the same spectrum!

Sulentic et al. 2000

The emitting regions of these two sources are in different physical and dynamical conditions!
Organizing quasar spectral diversity:
Quasars’ Eigenvector 1
Boroson & Green 1992; see also Gaskell et al. 1999

- Originally defined by a Principal Component Analysis of PG quasars.

- E1 is dominated by an anticorrelation between 1) strength of FeIIλ4570, 2) width of Hβ.

- E1 is very robust since:
  a) found in several independent samples;
  b) found for high dimension parameter spaces.
     (Kuraszkiewicz et al. 2008; Mao et al. 2009; Grupe 2004, Wang et al. 2006; Bachev et al. 2004; Sulentic et al. 2007)

The 4DE1 of Sulentic et al. includes:
3) CIVλ1549 line shift; 4) soft-X ray photon index.
Optical plane of Eigenvector 1
1D sequence of spectral types to account for quasars’ diverse properties at $z<0.7$

Sulentic et al. 2002
UV spectral changes along E1
Bachev et al. 2004

HST/FOS composite spectra of quasars at $z<0.7$
The CIVλ1549 line profile
Modeled by a scaled H\(\beta\) profile + excess blueshifted emission: line broadening interpreted as due to virial motion + outflow

Marziani et al. 2010; cf Leighly 2000
The effect of including non virial components in black hole mass determination

Sulentic et al. 2007; Marziani & Sulentic 2012 and references therein
UV spectral systematic changes along E1
Bachev et al. 2004

Along the sequence
(A4 → B1
)++
NVλ1240
AlIIIλ1860
CIII]λ1909
Quasar diagnostics

Table 1: Lines in the 1350-2000 Å Spectral Range

<table>
<thead>
<tr>
<th>Ion</th>
<th>λ [Å]</th>
<th>X [eV]</th>
<th>E_i - E_u [eV]</th>
<th>Transition</th>
<th>A_u [s^{-1}]</th>
<th>n_e [cm^{-3}]</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si IV</td>
<td>1393.755</td>
<td>45.20</td>
<td>0.000 - 8.896</td>
<td>2^1P_1/2 -&gt; 2^1S_1/2</td>
<td>8.80 \times 10^8</td>
<td>...</td>
<td>1</td>
</tr>
<tr>
<td>Si IV</td>
<td>1402.770</td>
<td>45.20</td>
<td>0.000 - 8.839</td>
<td>2^1P_1/2 -&gt; 2^1S_1/2</td>
<td>8.63 \times 10^8</td>
<td>...</td>
<td>1</td>
</tr>
<tr>
<td>C IV</td>
<td>1548.202</td>
<td>47.89</td>
<td>0.000 - 8.098</td>
<td>2^1P_1/2 -&gt; 2^1S_1/2</td>
<td>2.65 \times 10^8</td>
<td>...</td>
<td>1</td>
</tr>
<tr>
<td>C IV</td>
<td>1550.774</td>
<td>47.89</td>
<td>0.000 - 7.995</td>
<td>2^1P_1/2 -&gt; 2^1S_1/2</td>
<td>2.64 \times 10^8</td>
<td>...</td>
<td>1</td>
</tr>
<tr>
<td>Si II</td>
<td>1808.00</td>
<td>8.15</td>
<td>0.000 - 6.857</td>
<td>2^3P_3/2 -&gt; 1^1S_0</td>
<td>2.54 \times 10^6</td>
<td>...</td>
<td>1</td>
</tr>
<tr>
<td>Si II</td>
<td>1816.92</td>
<td>8.15</td>
<td>0.036 - 6.859</td>
<td>2^3P_3/2 -&gt; 1^1S_0</td>
<td>2.65 \times 10^6</td>
<td>...</td>
<td>1</td>
</tr>
<tr>
<td>Al III</td>
<td>1854.716</td>
<td>18.83</td>
<td>0.000 - 6.685</td>
<td>2^3P_3/2 -&gt; 1^1S_0</td>
<td>5.40 \times 10^6</td>
<td>...</td>
<td>1</td>
</tr>
<tr>
<td>Al III</td>
<td>1862.790</td>
<td>18.83</td>
<td>0.000 - 6.656</td>
<td>2^3P_3/2 -&gt; 1^1S_0</td>
<td>5.33 \times 10^6</td>
<td>...</td>
<td>1</td>
</tr>
<tr>
<td>[Si III]</td>
<td>1892.7</td>
<td>16.34</td>
<td>0.000 - 6.585</td>
<td>3^2P_3/2 -&gt; 1^2S_0</td>
<td>0.012</td>
<td>2.1 \times 10^{13}</td>
<td>2.3</td>
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<tr>
<td>[Si III]</td>
<td>1892.03</td>
<td>16.34</td>
<td>0.000 - 6.553</td>
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<td>...</td>
<td>1.5</td>
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<tr>
<td>[C III]</td>
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<td>0.0002</td>
<td>1.4 \times 10^{10}</td>
<td>1.26</td>
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<tr>
<td>[C III]</td>
<td>1908.734</td>
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<td>0.000 - 6.495</td>
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<td>114</td>
<td>...</td>
<td>1.45</td>
</tr>
<tr>
<td>Fe III</td>
<td>1914.006</td>
<td>16.18</td>
<td>3.727 - 10.200</td>
<td>2^7P_5^0 -&gt; 2^7S_5^0</td>
<td>6.6 \times 10^6</td>
<td>...</td>
<td>7</td>
</tr>
</tbody>
</table>

Diagnosis Intensity Ratios

\[
\begin{align*}
(\text{Si IV} + \text{O IV}) \lambda 1400 / \text{Si III} \lambda 1892 & \quad \text{independent on metallicity} \\
\text{Si II} \lambda 1814 / \text{Si III} \lambda 1892 & \quad \text{sensitive to ionization} \\
\text{C IV} \lambda 1549 / (\text{Si IV} + \text{O IV}) \lambda 1400 & \quad \text{sensitive to metallicity} \\
\text{Al III} \lambda 1860 / \text{Si III} \lambda 1892 & \quad \text{sensitive to density} \\
\text{Si III} \lambda 1892 / \text{C III} \lambda 1909 & \quad \text{sensitive to ionization} \\
\text{C IV} \lambda 1549 / \text{Al III} \lambda 1860 & \quad \text{dependent on metallicity} \\
\text{C IV} \lambda 1549 / \text{Si III} \lambda 1892 & \\
\text{NV} \lambda 1240 / \text{C IV} \lambda 1549 & \quad \text{sensitive to metallicity} \\
\text{NV} \lambda 1240 / \text{He II} \lambda 1640 & \\
+ \text{many others involving fainter lines like N III] \lambda 1750} & \\
\text{(but caution with intercombination lines!)} & 
\end{align*}
\]
Behavior of line ratios in the plane ionization parameter vs. density

Maps built on an array of 571 photoionization models

Cloudy 08.00 array of simulations (Ferland et al. 2013): constant density, U, solar abundances and standard quasar continuum
A diagnostic of ionizing photon flux analysis of sources with HST/FOS observations and H\(\beta\) reverberation mapping
“Photoionization” $r_{BLR}$ and black hole mass

ionization parameter: ratio between photon and electron density

$$U = \frac{\int_{\nu_0}^{+\infty} \frac{L_\nu}{h\nu} d\nu}{4\pi r_{BLR}^2 n_e c}$$

emitting region radius

$$r_{BLR} = \left( \frac{\int_{\nu_0}^{+\infty} \frac{L_\nu}{h\nu} d\nu}{4\pi U n_e c} \right)^{\frac{1}{2}}$$

The combined Al $\text{III} \lambda 1860/\text{Si} \text{III}] \lambda 1892$ and C $\text{IV} \lambda 1549/\text{Si} \text{III}] \lambda 1892$ ratios are estimators of the ionizing photon flux: $r_{\text{BLR}}$ is in agreement with $c\tau$ of $\text{H}\beta$ from reverberation mapping: $\text{rms} \approx 0.2$ dex. (Negrete et al. 2013)

A correction is needed because of ionization and density gradients within the BLR.

Profiles allow for reliable computations of the virial black hole mass:

$$M_{\text{BH}} = \frac{f r_{\text{BLR}} (\text{FWHM})^2}{G}$$
Extreme A sources
young/rejuvenated quasars, revealed at both high and low luminosity, radiating at high Eddington ratio, 10% of in optically selected samples

Weak CIII]λ 1909 and OIV]λ 1402
(Dultzin et al. 2011; Negrete et al. 2012)
Extreme A sources

Physical conditions: high density, low ionization and high metallicity
At the other end of E1: almost no Al III $\lambda$1860, prominent CIII $\lambda$1909: lower density and high ionization.

Physical conditions are more complex for most AGNs along the sequence due to the well known “stratification” of ionization.
Chemical composition

A reliable analysis requires high dispersion and high S/N

Still many open issues on chemical enrichment of low-$z$ quasars, in part due to lack of suitable data.
1) Palomar Green quasars

89 PG Quasars at z<0.5: UV observations covering the range Lyα-CIV

- Not found: 37%
- STIS: 11%
- Bad: 4%
- FOS: 12%
- COS: 32%
- IUE: 5%

S/N distribution

- Cumulative
- Differential

Data from Shin et al. 2013

Only 50% of PG quasars covered by HST observations
2) Of 600 type-1 AGNs detected at 6cm with $m<19$ and $z<0.90$ only a minority have HST spectroscopic observations

3) only a handful of AGNs monitored for reverberation mapping in the UV
Conclusions

Rest frame UV emission lines make it possible to derive quasar physical parameters that lead to emitting region radius, black hole mass, Eddington ratio, etc.

The Eigenvector 1 sequence allows to identify sources that are physically and structurally different.

Archives from past/present space missions are extremely valuable but much is still needed in terms of population coverage and data quality.