Dependence of equivalent width of quasar emission lines on UV spectral index, quasar luminosity and BH mass

Olena Torbaniuk

Department of Physics, University “Federico II” in Naples, Italy

Main Astronomical Observatory of the National Academy of Science of Ukraine, Kyiv, Ukraine
General view

“Big Blue Bump” and (quasi-) power-law continuum

broad and narrow emission lines

broad absorption lines (∼15–20%)

Lyα,…—forests (absorption)

⇒ thermal emission of accretion disc

⇒ surrounding clumped gas

⇒ gas flows outward centre

⇒ intergalactic H I etc.

Composite spectra of the quasars
from Vanden Berk et al., 2001

Model of AGN
**Characteristics and dependencies between them**

**Baldwin effect:** anticorrelation of the continuum luminosity $l_\nu$ at 1450 Å and the equivalent width of C IV (1549 Å) emission line (and others).

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Dependence</th>
<th>Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{EW} - \text{L}$</td>
<td>YES</td>
<td>proximity of the studied regions. (Ly$\alpha$, Si IV+O IV, C IV, Mg II, Al III,...)</td>
</tr>
<tr>
<td>$L - \alpha_\lambda$</td>
<td>NO*</td>
<td>unknown</td>
</tr>
<tr>
<td>$\text{EW} - \alpha_\lambda$</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>$M_{BH} - \alpha_\lambda$</td>
<td>?</td>
<td>?</td>
</tr>
</tbody>
</table>

The sample

3535 QSO
SDSS DR7
$R \approx 2000$
$2.3 < z < 4.6$

192 composite spectra:

$\alpha_\lambda = -2.3 \ldots -0.8 \ (\Delta \alpha_\lambda = 0.1),$

$\langle \log(l_{1450}) \rangle = 42.2 \ldots 43.4 \ (\Delta \langle \log(l_{1450}) \rangle = 0.1)$

Dependence between values $\langle z \rangle$ and $\langle \log(l_{1450}) \rangle$ of subsamples and $\alpha_\lambda$ of composite spectra.
Compilation of the composite spectra

Composite spectra with similar $\alpha_\lambda$ and different $\langle \log l_{1450} \rangle$.

Composite spectra with similar $\langle \log l_{1450} \rangle$ and different $\alpha_\lambda$. 
The wavelength ranges

1215–1285 Å \( \text{Ly} \alpha + \text{O IV} + \text{N V} + \text{Si II}^* + \text{Si II} \)
1290–1320 Å \( \text{Si III}^* + \text{O I} + \text{Si II} \)
1320–1350 Å \( \text{C II} + \text{O IV} + \text{Ca II} \)
1350–1430 Å \( \text{Si IV} + \text{O IV} \)

12 composite spectra with similar spectral indices \( \alpha_{\lambda} = -2.2 \) with lines identified.
Calculation of $EW$

- The wavelength ranges were fitted with the smallest possible number of emission lines (using IDL `lmfit`):

$$f(\lambda) = b + \sum_k a_k \exp \left[-\frac{(\lambda - \lambda^0_k)^2}{2w^2_k}\right], \quad (1)$$

$$f(\lambda) = c \cdot \lambda^{\alpha_\lambda} + \sum_k a_k \exp \left[-\frac{(\lambda - \lambda^0_k)^2}{2w^2_k}\right]; \quad (2)$$

- Finding of $\lambda^0_k$ and initial parameters $(b/c, a_k, w_k)$;
- With fixed $\lambda^0_k$ finding of parameters $b/c, a_k, \lambda^0_k, w_k$;
- Calculation of equivalent width (compute integrals of obtained functions describing individual lines or sets of lines).
Equivalent widths and dependencies \( EW - \alpha_\lambda, \ EW - L \)

Dependence of equivalent width of quasar emission lines on UV spectral index for superposition of lines within the wavelength ranges 1215–1285 Å, 1290–1320 Å (colour shows the change of the luminosity)
Equivalent widths and dependencies $EW - \alpha_\lambda$, $EW - L$

Dependence of equivalent width of quasar emission lines on UV spectral index for superposition of lines within the wavelength ranges 1320–1350 Å, 1350–1430 Å (colour shows the change of the luminosity)
Dependence of equivalent width of quasar emission lines on UV spectral index for superposition of lines within the wavelength ranges 1215–1285 Å (colour shows the change of the luminosity).
Calculation of \( M_{BH} \)

Calculation of virial mass of central supermassive BH for 3535 individual quasars and composite spectra (using \( \text{C\ IV} \) emission line):

\[
\log \left( \frac{M_{BH}}{M_{\odot}} \right) = a + b \log \left( \frac{\lambda L_\lambda}{10^{44} \text{erg s}^{-1}} \right) + 2 \log \left( \frac{W}{\text{km s}^{-1}} \right), \tag{3}
\]

\[
L_\lambda = 4\pi D_{\text{phot}}^2 F_\lambda, \tag{4}
\]

\[
D_{\text{phot}} = \frac{c(1 + z)}{H_0} \int_0^z \frac{dt}{\sqrt{\Omega_\Lambda + \Omega_M(1 + t)^3}}, \tag{5}
\]

- \( F_\lambda \) and \( L_\lambda \) – flux and luminosity, \( W \) – full width at half minimum (FWHM) of \( \text{C\ IV} \) (1549 Å); \( D_{\text{phot}} \) – photometric distance, \( z \) – redshift of the quasar;
- \( H_0 = 67.74 \pm 0.78 \text{ km s}^{-1} \text{ Mpc}^{-1}, \Omega_\Lambda = 0.692 \pm 0.010, \Omega_M = 0.308 \pm 0.010 \) (Planck+WP+BAO from Planck Collaboration, 2015);
- calibration parameters \( a = 0.66 \) and \( b = 0.53 \) for \( \text{C\ IV} \) from Shen et al., 2011.

\( \text{O. Torbaniuk} \)

Dependence of \( EW \) on \( l_\nu, \alpha_\lambda, M_{BH} \)

10/10/2018 11 / 13
The diagrams $\alpha_\lambda - M_{BH}$

Mass of quasar's BH – spectral index $\alpha_\lambda$ diagram (colour shows the change of the luminosity)

Mass of quasar’s BH – spectral index $\alpha_\lambda$ diagram for 3535 individual quasars.
Conclusions

1. there is EW–$\alpha_\lambda$ dependence for those lines for which Baldwin effect is observed (for some lines we have inverse dependence (Ly$\alpha$+O v+N v+Si II$^*$+Si II) and for others (C II+O v+Ca II and X1+Si IV+O IV]+X2) this dependence is direct);

2. there is no EW–$\alpha_\lambda$ dependence for those lines for which Baldwin effect is not observed (Si III$^*$+O I+Si II);

3. the separation of Ly$\alpha$+O v+N v+Si II$^*$+Si II lines shows that Baldwin effect and EW–$\alpha_\lambda$ dependence exists only for Ly$\alpha$+O v and Si II, while for N v+Si II$^*$ those effects doesn’t exists;

4. there is no dependence between $\alpha_\lambda$ and virial mass of the BH.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Dependence</th>
<th>Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>EW–L</td>
<td>YES</td>
<td>proximity of the studied regions. (Ly$\alpha$, Si IV+O IV, C IV, Mg II, Al III, …)</td>
</tr>
<tr>
<td>L–$\alpha_\lambda$</td>
<td>NO</td>
<td>unknown</td>
</tr>
<tr>
<td>EW–$\alpha_\lambda$</td>
<td>YES</td>
<td>unknown</td>
</tr>
<tr>
<td>$M_{BH}$–$\alpha_\lambda$</td>
<td>NO</td>
<td>unknown</td>
</tr>
</tbody>
</table>