Baltic Astronomy, vol. 20, 448–452, 2011

THE COMPLEX BROAD ABSORPTION LINE PROFILES IN A SAMPLE OF QSO SPECTRA

E. Lyratzi[1,2], E. Danezis[1], L. Č. Popović[3], A. Antoniou[1,4], M. S. Dimitrijević[3,5] and D. Stathopoulos[1,2]

[1] *University of Athens, Faculty of Physics Department of Astrophysics, Astronomy and Mechanics, Panepistimioupoli, Zographou 157 84, Athens, Greece*

[2] *Eugenides Foundation, 387 Sygrou Av., 17564, Athens, Greece*

[3] *Astronomical Observatory of Belgrade, Volgina 7, 11160 Belgrade, Serbia*

[4] *University of Peloponnese, Faculty of Science and Technology, Department of Telecommunications Science and Technology, Karaiskakis Str. 22100 Tripolis, Greece*

[5] *Laboratoire d' Étude du Rayonnement et de la Matiére en Astrophysique, Observatoire de Paris-Meudon, UMR CNRS 8112, Bâtiment 18, 5 Place Jules Janssen, F-92195 Meudon Cedex, France*

Received: 2011 August 8; accepted: 2011 August 15

Abstract. Most of the Broad Absorption Lines (BALs) in quasars show very complex profiles. An idea to explain these profiles is that the dynamical systems of broad line regions are not homogeneous but consist of a number of dense regions or ion populations with different physical parameters. This approach is used to study the ultraviolet C IV resonance lines in the spectra of a group of high ionization BAL quasars, using the Gauss-Rotation model.

Key words: quasars: absorption lines

1. INTRODUCTION

Approximately 10% of all quasars exhibit broad, blue-shifted absorption lines. The outflow velocity of the regions producing these lines can reach (0.1–0.2) c. Usually, in their spectra we observe the lines of atoms with high ionization, such as C IV at $\lambda = 1549$ Å, Si IV at $\lambda = 1397$ Å, N V at $\lambda = 1240$ Å and Lyα. In some cases, low ionization lines, such as Mg II at $\lambda = 2798$ Å and Al III at $\lambda = 1857$ Å, also exhibit broad absorption lines (see, e.g., Hamann et al. 1993; Crenshaw et al. 2003). These Broad Absorption Lines (BALs) have different shapes; some types of these objects may also have differences in their continua (Reichard et al. 2003).

The spectra of the BAL quasars usually are interpreted as a combination of (1) a broad-band continuum arising from the central engine, (2) broad emission lines coming from the broad emission line regions (usually designated as BLRs or BELRs), emerging near the quasar center, and (3) superposed broad absorption lines, originating in a separate outlying region, so called Broad Absorption Line Region (BALR) (see also Lyratzi et al. 2009). However, it is also possible, that both the emission and absorption lines originate in the same line-forming region (Branch et al. 2002).

An important question is: what is the physical connection between the standard BLRs and BALRs? It is known that at least a part of BLRs originate in the wind outflowing from the accretion disks (see Murray & Chiang 1998; Popović et al. 2004).

Another question is: where are BALRs placed with respect to the quasar centers and BLRs? To answer this question, one should investigate kinematical properties of the emission and absorption lines.

Disk wind models (Murray & Chiang 1998; Proga et al. 2000; Williams et al. 1999) explain many properties of BAL quasars, but it is unclear if they can explain the full range of BAL profiles and column densities. BALs are caused by outflowing gas intrinsic to the quasar, and are not produced by galaxies along the line of sight (as is the case for most narrow-absorption systems).

Determining whether a quasar contains a BALR is a complicated task. The standard method is to calculate the 'balnicity' index (BI), defined by Weymann et al. (1991).

Here we present some ideas directed to explain the complex structure of BALs in quasars and investigate the ultraviolet C IV resonance lines in the spectra of a group of high ionization BAL (Hi-BAL) quasars using the Gauss-Rotation model (GR model).

2. THE MULTI-STRUCTURE OF BALs

Most of BALs in quasars exhibit very complex profiles. This means that we cannot fit them with a known physical distribution. An idea is that the dynamical systems of BLRs are not homogeneous but consist of a number of dense regions or ion populations with different physical parameters.

Each of these dense regions gives an independent classical absorption line. If the source regions rotate with a large velocity and move radially with lower velocities, the produced lines have large widths and small shifts. As a result, they are blended among themselves as well as with the main spectral lines forming a complicated profiles. A similar model is used to explain the complex profiles of broad lines in the spectra of hot emission-line stars (Danezis et al. 2006, 2007; Lyratzi et al. 2009). Based on this idea, we study BALs by the ultraviolet C IV resonance lines in the spectra of 30 Hi-BAL QSOs using the GR model (Danezis et al. 2006, 2007; Lyratzi et al. 2009).

We assume that broad emission and absorption line regions are composed of a number of successive independent absorbing/emitting density layers of matter originating in the disk wind. The absorbing regions have three apparent velocities (projected on the line-of-sight of an observer): radial velocity (V_{rad}) of the BALR, random velocity of the ions (V_{rand}) in the BALR and the rotational velocity (V_{rot}) of the BALR.

3. DATA AND SPECTRAL ANALYSIS

In order to study the C IV resonance lines (1548.187 and 1550.772 Å) we apply the GR model to the spectra of 30 Broad Absorption Line Quasars (BAL QSOs) taken from the Sloan Digital Sky Survey (SDSS) Data Release 7. The SDSS imaging survey uses a wide-field multi-CCD camera (Gunn et al. 1998). The

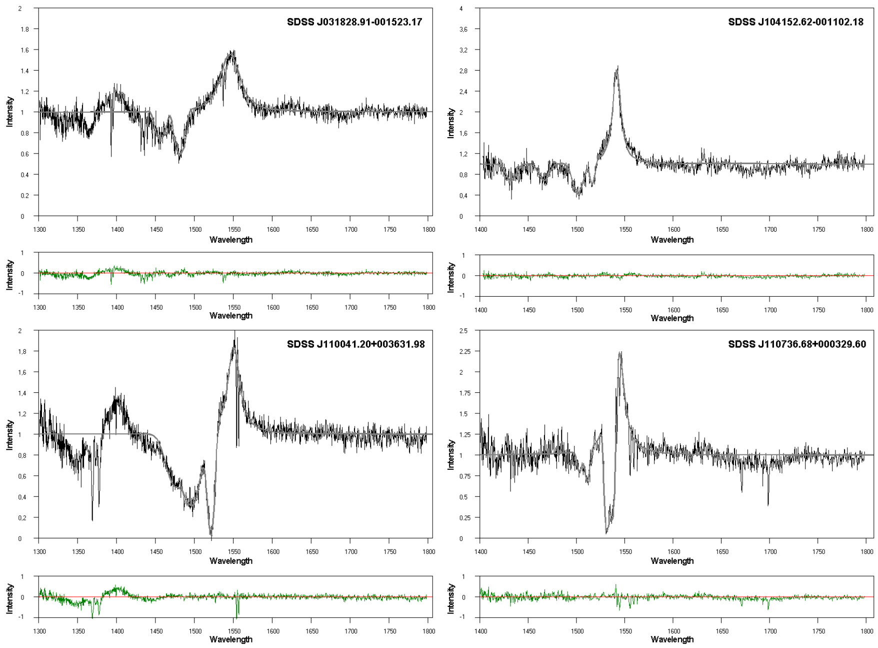

Fig. 1. Four examples of the fitted spectra. Black lines show the observed spectra and grey lines – theoretical line profiles given by the GR model. The lower panels show differences between the observed spectra and the corresponding theoretical profiles.

spectra cover the optical range 3800–9200 Å at a resolution of 1800–2100.

In Figure 1 we give some examples of the fitted spectra. The black line corresponds to the observed spectra and the grey line corresponds to the theoretical line profiles given by the GR model. The lower lines present the residuals, i.e., the differences between the observed spectrum and the theoretical profile.

We studied all the absorption lines that follow the first Balnicity Index criterion, i.e. the lines that are located between 3000 and 25 000 km/s blueward of the C IV emission, what means that these lines come from the studied BAL quasars. Then, from all these lines we accepted as BALs only those which follow the rest Balnicity Index criteria, i.e., the absorption lines are at least 2000 km/s broad and for them the absorption falls at least 10% below the continuum. We found that 25 of the 30 quasars of our sample have broad absorption lines.

4. RESULTS AND CONCLUSIONS

Using the GR model, we were able to fit the complex profiles of the studied C IV lines with 1 to 5 absorption components. For them we calculated the values of the kinematical parameters (rotational, radial and random velocities), as well as the column density and the absorbed energy. The calculated values of kinematical parameters only, are given in Tables 1 and 2.

It seems that the dynamical systems of BLRs are not homogeneous but consist of a number of density regions or ion populations with different physical parameters. Each one of these density regions gives us an independent classical absorption

Table 1. Radial velocities (km/s).

Object name (SDSS)	V_{rad1}	V_{rad2}	V_{rad3}	V_{rad4}	V_{rad5}
J001025.90+005447.6	–15092	–10642			
J001438.28-010750.1	–17026				
J001502.26+001212.4	–19348				
J002127.88+010420.1	–14624				
J003551.98+005726.4				–6192	
J004041.39-005537.3	–17220				
J004118.59+001742.4	–13931		–7740		
J004323.43-001552.4	–20896	–12770			
J004732.73+002111.3	–17414				
J005355.15-000309.3	–17026	–11609			
J005419.99+002727.9	–17607		–8513		
J010241.04-004208.9	–17414	–11802			–4063
J010336.40-005508.7	–17800				–4063
J011227.60-011221.7	–21283	–16446	–8513	–6385	
J015024.44+004432.99			–7546		–3483
J015048.83+004126.29	–18381				
J021327.25-001446.92				–5321	–3096
J023908.99-002121.42	–17414		–8513		
J025747.75-000502.91			–7352		
J031828.91-001523.17	–17994	–13157			
J102517.58+003422.17	–17994				
J104109.86+001051.76			–9867		
J104152.62-001102.18	–22637	–16059	–9287		
J104841.03+000042.81	–19348				
J110041.20+003631.98	–14704	–10061		–5417	
Mean	–17757	–12818	–8416	–5829	–3676

line.

As we can see in Tables 1 and 2, the GR model is able to reproduce accurately the complex profiles of Hi-BAL QSOs and to calculate a group of physical parameters of the corresponding BALRs.

The absorption lines which follow the BI criteria satisfy the following conclusions: (1) their radial velocities are between –3676 ± 410 km/s and –17757 ± 2171 km/s; (2) their random velocities are between 1117 ± 302 km/s and 2952 ± 1704 km/s; (3) the column density of all the absorption components of both doublet lines is almost the same, with the mean value $-3.35 \times 10^{-10} \pm 0.24 \times 10^{-10}$ cm^{-2}; (4) the absorbed energy is –5.52 ± 1.32 eV for $\lambda\,1548.187$ Å and –4.79 ± 1.26 eV for $\lambda\,1550.772$ Å.

ACKNOWLEDGMENTS. This research project is in progress at the University of Athens, Department of Astrophysics, Astronomy and Mechanics; we are thankful to the Special Account for Research Grants for the financial support. This work was also supported by the Ministry of Science and Technological Development of Serbia through the projects “Influence of coalitional processes on astrophysical plasma line shapes” and “Astrophysical spectroscopy of extragalactic objects”. We also acknowledge the use of the data from the SDSS and SDSS-II surveys.

Table 2. Rotational and random velocities (km/s).

Object name (SDSS)	$V_{\rm rot1}$	$V_{\rm rot2}$	$V_{\rm rot3}$	$V_{\rm rot4}$	$V_{\rm rot5}$	$V_{\rm rand1}$	$V_{\rm rand2}$	$V_{\rm rand3}$	$V_{\rm rand4}$	$V_{\rm rand5}$
J001025.90+005447.6	600	600				1596	1368			
J001438.28-010750.1	100					6155				
J001502.26+001212.4	100					6155				
J002127.88+010420.1	100					6155				
J003551.98+005726.4				100					787	
J004041.39-005537.3	3000					4559				
J004118.59+001742.4	100		100			2508		1824		
J004323.43-001552.4	3000	3000				2736	2736			
J004732.73+002111.3	100					4332				
J005355.15-000309.3	100	100				912	912			
J005419.99+002727.9	3000		550			2280		2052		
J010241.04-004208.9	50	50			50	1824	1824			798
J010336.40-005508.7	100				100	3420				1596
J011227.60-011221.7	550	550	550	550		1596	1254	912	798	
J015024.44+004432.99			1500		2200			1368		1140
J015048.83+004126.29	50					4104				
J021327.25-001446.92				100	100				912	935
J023908.99-002121.42	30		30			2280		2280		
J025747.75-000502.91			100					2280		
J031828.91-001523.17	2000	2000				456	570			
J102517.58+003422.17	50					2508				
J104109.86+001051.76			100					798		
J104152.62-001102.18	50	50	50			1140	1140	1140		
J104841.03+000042.81	50					2052				
J110041.20+003631.98	50	70		50		2280	2280		912	
Mean	1830	1538	550	550		2952	1510	1582	852	1117

REFERENCES

Branch D., Leighly K. M., Thomas R. C., Baron E. 2002, ApJ, 578, L37
Crenshaw M. D., Kraemer S. B., George I. M. 2003, ARA&A, 41, 117
Danezis E., Popović L. Č., Lyratzi E., Dimitrijević M. S. 2006, AIPC, 876, 373
Danezis. E, Nikolaidis D., Lyratzi E. et al. 2007, PASJ, 59, 827
Gunn J. E., Carr M., Rockosi C. et al. 1998, AJ, 116, 3040
Hamann F., Korista K. T., Morris S. L. 1993, ApJ, 415, 541
Lyratzi E., Popović L. Č., Danezis E. et al. 2009, NewAR, 53, 179
Murray N., Chiang J. 1998, ApJ, 494, 125
Popović L. Č., Mediavilla E., Bon E., Ilić D. 2004, A&A, 423, 909
Proga D., Stone J. M., Kallman T. R. 2000, ApJ, 543, 686
Reichard T. A., Richards G. T., Hall P. B. et al. 2003, AJ, 126, 2594
Weymann R. J., Morris S. L., Foltz C. B., Hewett P. C. 1991, ApJ, 373, 23
Williams R. J. R., Baker A. C., Perry J. J. 1999, MNRAS, 310, 913