Answers to some important questions on the use of GR model

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We use the **GR model (Gauss-Rotation model)** for the study and analysis of **Broad Absorption Lines (BALs)** in the spectra of Quasars.

Broad Absorption Lines (BALs)

Broad Absorption Lines (BALs) (Figure 1) are deep, broad and high velocity absorption lines that are usually blueshifted with respect to the corresponding emission lines in the UV region of the electromagnetic spectrum (Hewett and Foltz 2003; Reichard et al. 2003; Foltz et al. 1990).

BALs are probably due to a flow of many individual clouds which are optically thick and very small compared with the size of the central continuum source. So, Broad Absorption Line Regions (BALRs) consist of many individual density regions named clouds (McKee and Tarter 1975; Turnshek, 1984; Lyratzi et al. 2009, 2010, 2011; Danezis et al. 2010; Hamman, et al. 2013; Capellupo et al. 2014). According to that aspect, **the broad and complex profiles can be interpreted as the synthesis of a series of absorption components.** (Figure 2).

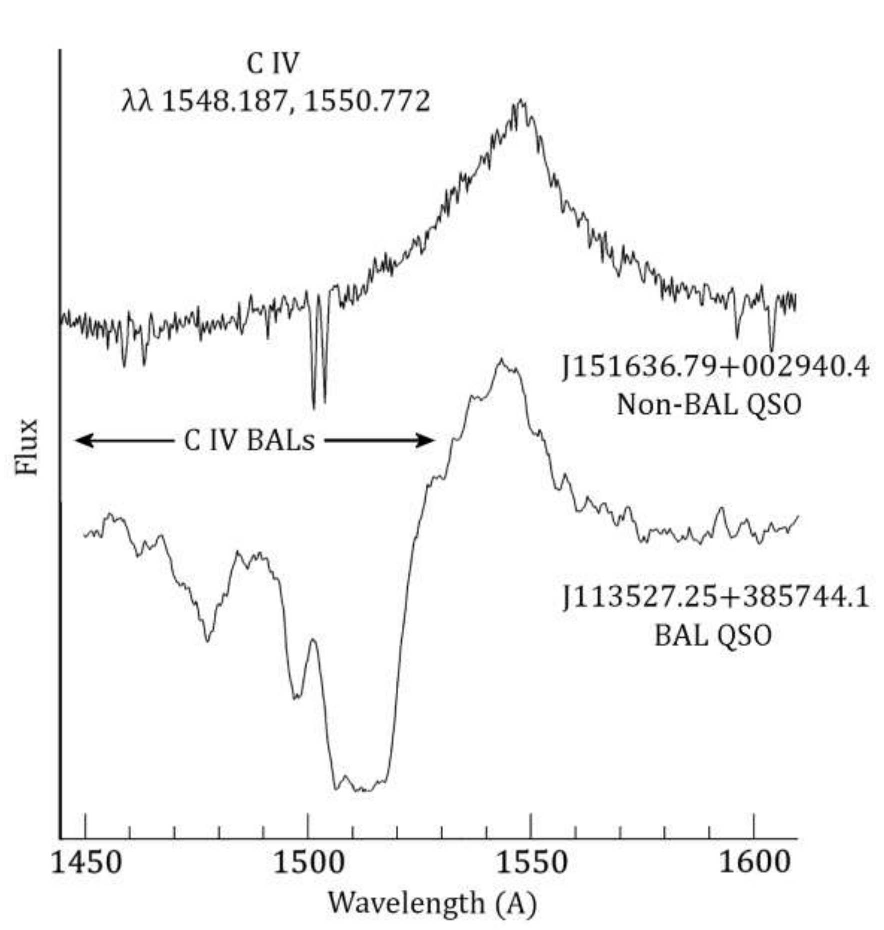

Figure 1: Comparison between the C IV resonance lines in the spectra of a non-BAL QSO and a BAL QSO. The appearance of BALs is indicated in the case of the BAL QSO spectrum.

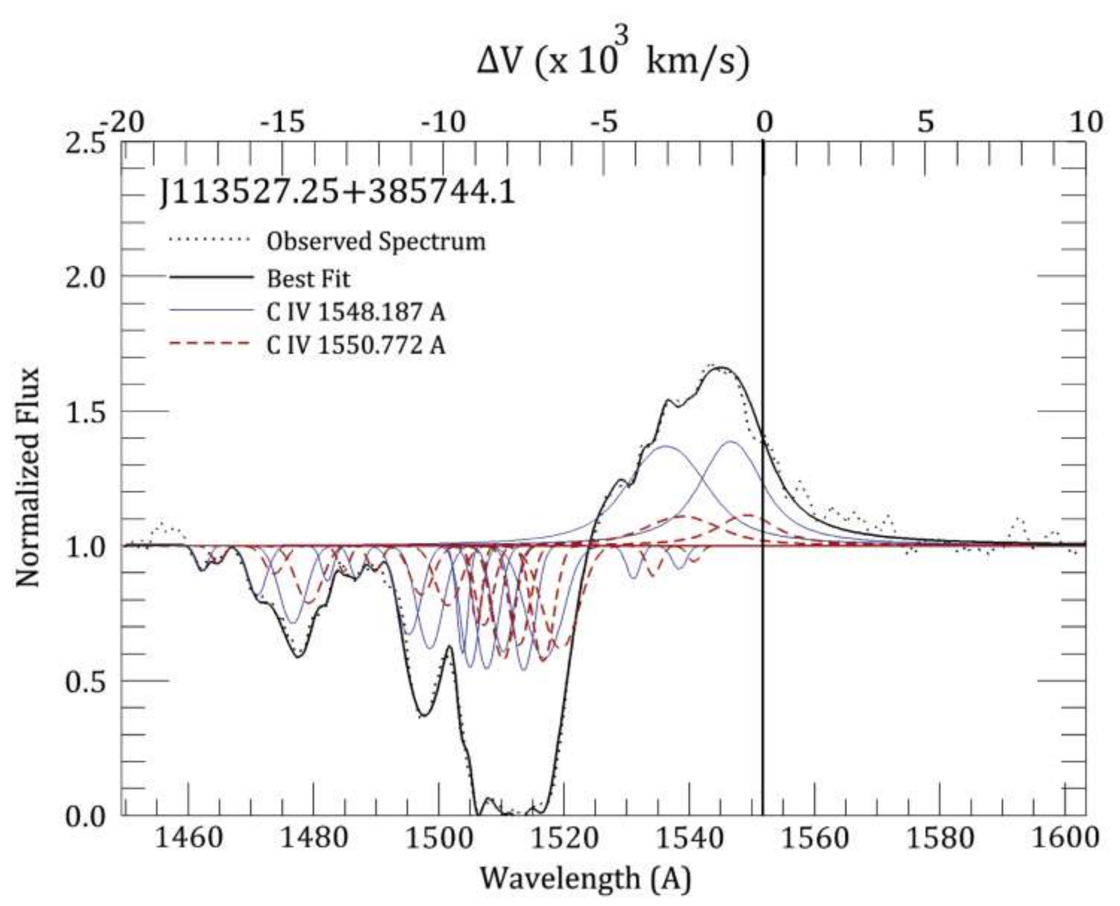

Figure 2: Best fit of the C IV resonance lines in the spectrum of the BAL QSO J 113527.25+385744.1. The C IV BAL is perfectly fitted with GR model. The analysis of the complex C IV profiles is presented.

The GR model

Physical model

- The Broad Absorption Line Region (BALR) consists of independent absorption regions, called clouds (regions I, Fig. 3) (McKee & Tarter 1975; Turnshek 1984; Bottorff & Ferland, 2001; Hamann et al. 2013; Capellupo et al. 2014).
- Clouds (regions I) are clusters of cloudlets (cloud elements-regions II, Fig. 3) in turbulent flow. Cloudlets can be thought as density enhancements in a continuous medium (Bottorff & Ferland, 2001).
- Clouds rotate with very low rotational velocities, which are considered negligible.
- The broad profiles of BALs are due to the synthesis of absorption lines that arise from the clouds.
- The absorption line of each cloud is quite broad, as they are the synthesis of the lines created from the cloudlets that form the cloud. The spectral line that corresponds to the clouds are the ones we fit.

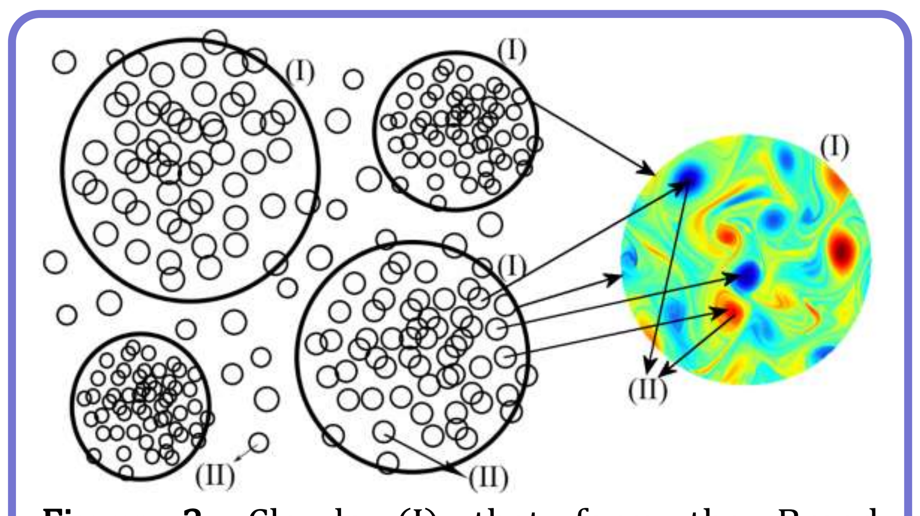

Figure 3: Clouds (I) that form the Broad Absorption Line Regions (BALRs) and cloudlets or cloud elements (II) that form the clouds.

Mathematical expression of the model

- All the spectral lines (absorption/emission) that are created in the successive clouds in the line of sight are described by Eq.1 (Danezis et al. 2003, 2007; Lyratzi et al. 2007). This applies for every spectral line of a specific ion. This means that if we have the two resonance lines of C IV or Si IV, we must apply Eq.1 for each one of the resonance lines. Both the resonance lines are described by the synthesis of the two independent applications of Eq.1 to each resonance line.

$$I_\lambda = \left[I_{\lambda_0} \prod_i \exp\{-L_i \xi_i\} + \sum_j S_{\lambda_{ej}} \left(1 - \exp\{-L_{ej}\xi_{ej}\}\right) \right] \prod_g \exp\{-L_g \xi_g\} \quad (1)$$

Absorption Components from clouds | Emission Components from clouds | Absorption Components from clouds

The problem of the exact number of clouds

The certainty for the exact number of clouds and the accuracy of the values of the calculated parameters are ensured by a series of criteria that we follow during the fitting process. These criteria can not be applied in the case of single lines, but only in the case of resonance lines, such as the doublets of C IV and Si IV. In the case of singlets, the number of components (created in clouds) can not be determined accurately. Through this process we ensure that the final fit is unique.

I) Criteria between the components of a doublet (e.g. C IV λλ 1548.187, 1550.772 and Si IV λλ 1393.755, 1402.77) (figs 4 and 5)

- The number of blue and red components must be exactly the same.
- The width of the blue and the red component is exactly the same.
- The velocity offset of the blue component is exactly the same as the red component.
- For emission lines the ratio of optical depths between the blue and the red component is $\xi_b/\xi_r = 2$.
- For absorption lines this ratio is free to vary $1{:}1 \leq \xi_b/\xi_r \leq 2{:}1$.

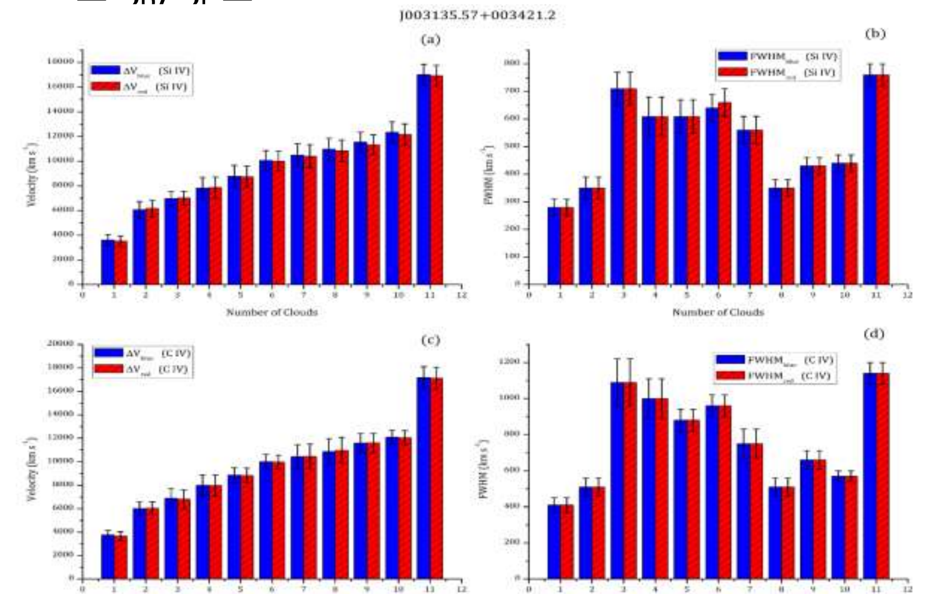

Figure 4: The velocity offset and the width of the blue and the red component are exactly the same in the case of Si IV and C IV resonance lines.

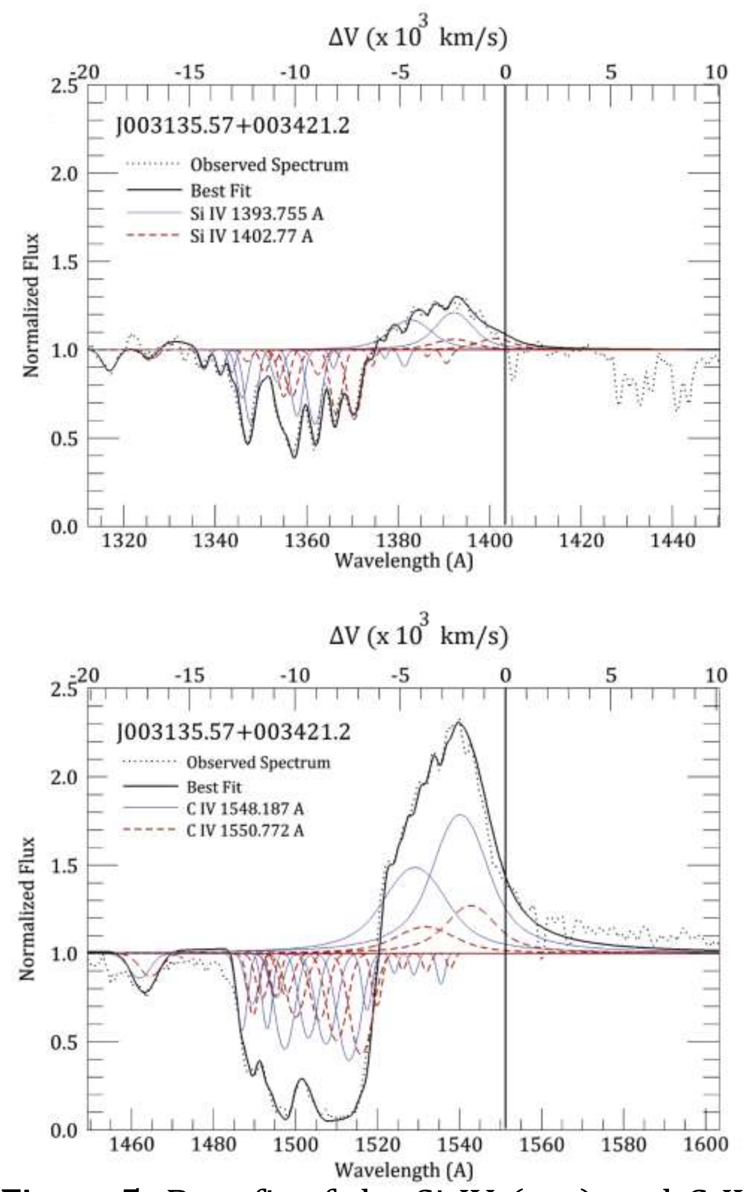

Figure 5: Best fit of the Si IV (top) and C IV (bottom) resonance lines in the spectrum of the BAL QSO J 003135.57+003421.2. The whole fitting procedure is in accordance with both criteria I and II. Both Si IV and C IV BALs are perfectly fitted with GR model. The analysis of the complex Si IV and C IV profiles is presented.

II) Criteria between C IV and Si IV components at the same outflow velocity from the emission redshift (figs 5 and 6)

- Both C IV and Si IV BALs have the same number of doublets. This means that:
- Each C IV doublet has its accompanying Si IV doublet at the same outflow velocity.
- The ratio of optical depths between the blue and the red component of the i[th] Si IV doublet should be the same as the ratio of optical depths of the corresponding i[th] C IV doublet at the same velocity offset.

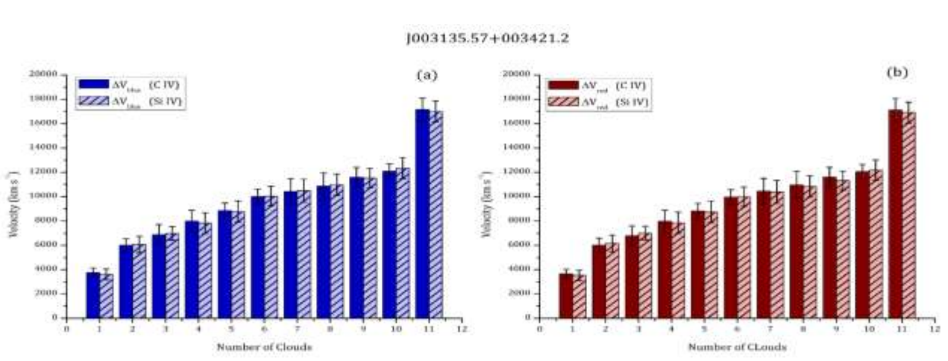

Figure 6: Each C IV doublet has the same outflow velocity as its accompanying Si IV doublet .

Goodness of Fit

We do not use a minimization process but instead we perform iterations until we get an acceptable fit where as acceptable is a fit that is characterized by reduced $\chi^2 \leq 2$.

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