Answers to some important questions on the use of GR model

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From Quasars to Stars

Similar phenomena in the spectra of Quasars and Hot Emission Stars

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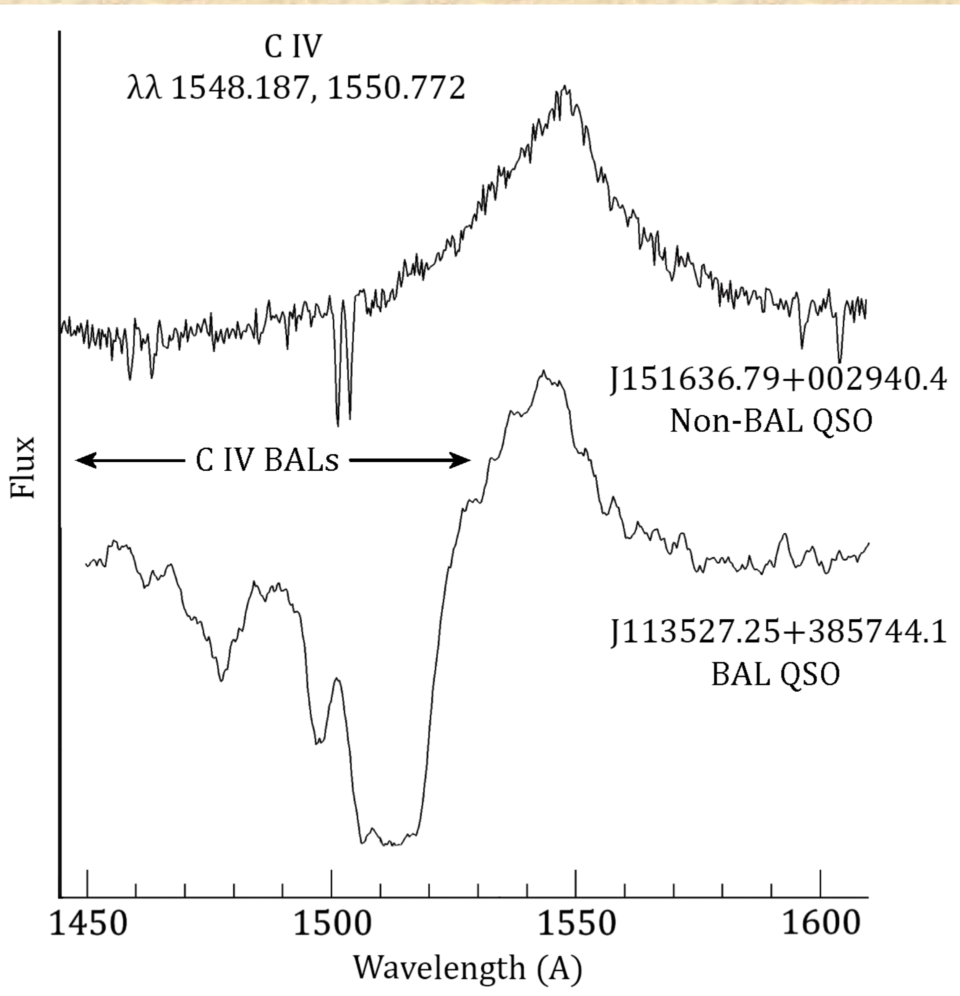
BAL Quasars and Hot Emission Stars
Similar phenomena

In BAL Quasars (BALQSOs) and Hot Emission Stars (Be and Oe Stars) we can detect similar phenomena. This means that they may be studied and analyzed in the same way, taking into consideration the different scale.

In order to study the BALs and the DACs we use the GR model (Danezis et al. 2003, 2007, Lyratzi 2007), which is a physical model with a mathematical expression that applies for both quasars' and stellar spectra.

Broad Absorption Lines (BALs)

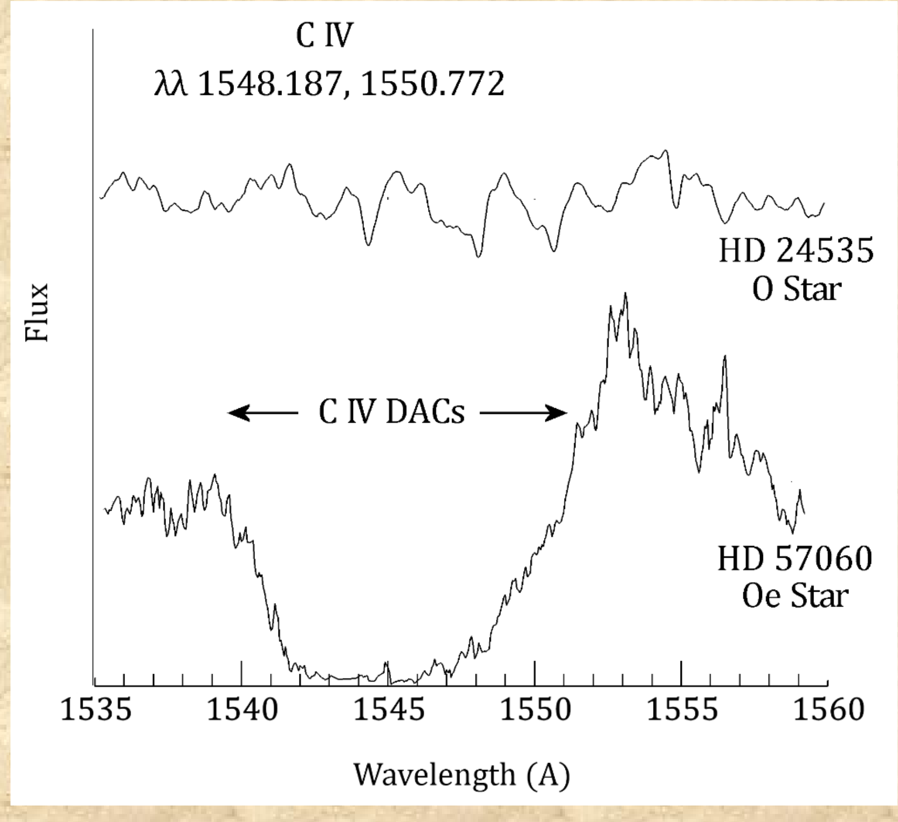


Comparison between the C IV resonance lines in the spectra of a non-BAL QSO and a BAL QSO. The appearance of BALs is indicated in the case of the BAL QSO spectrum.

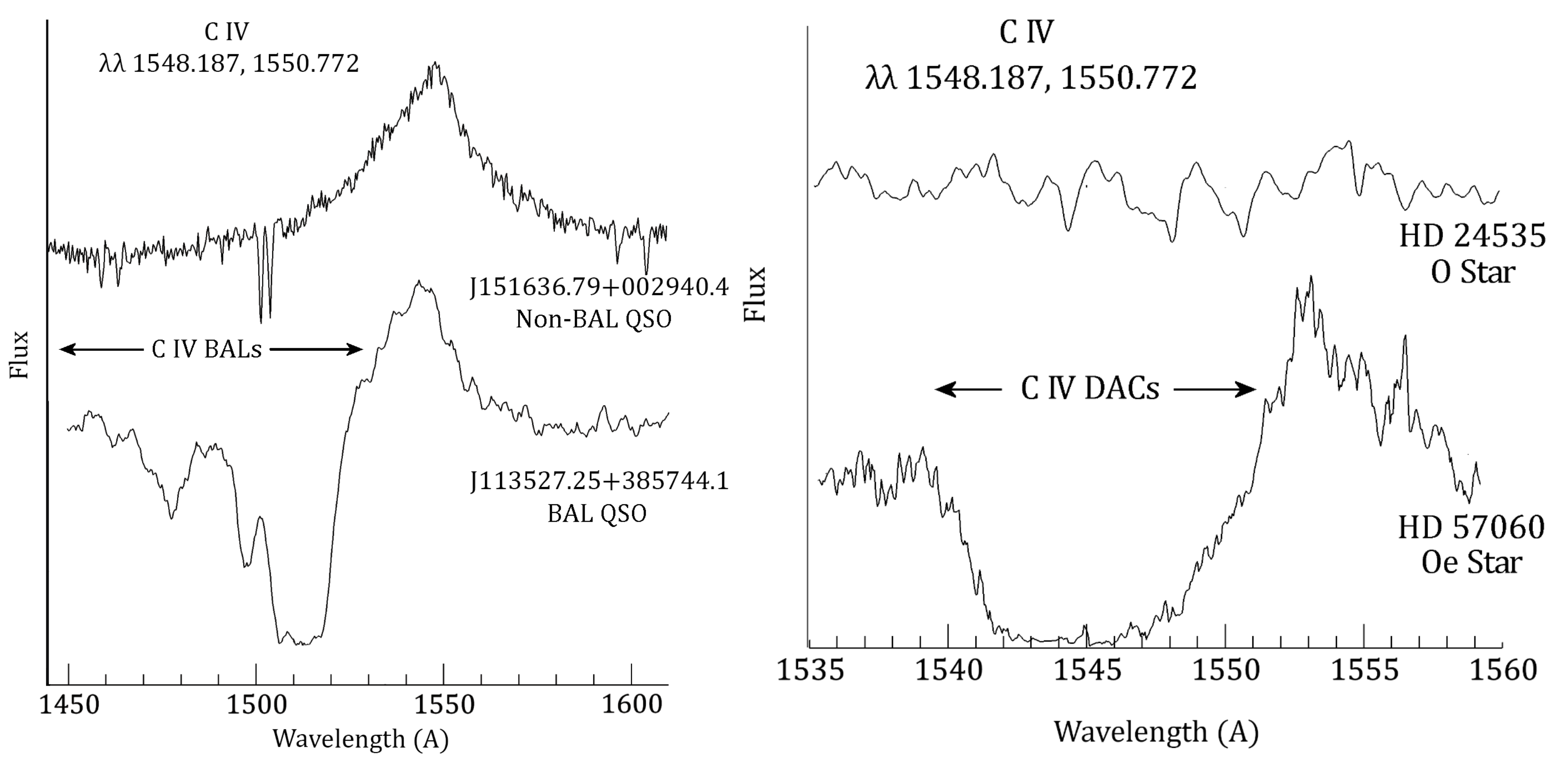
Broad Absorption Lines (BALs) are deep, broad and high velocity absorption lines that are usually blueshifted with respect to the corresponding emission lines (Hewett and Foltz 2003; Reichard et al. 2003; Foltz et al. 1990).

Discrete Absorption Components (DACs)

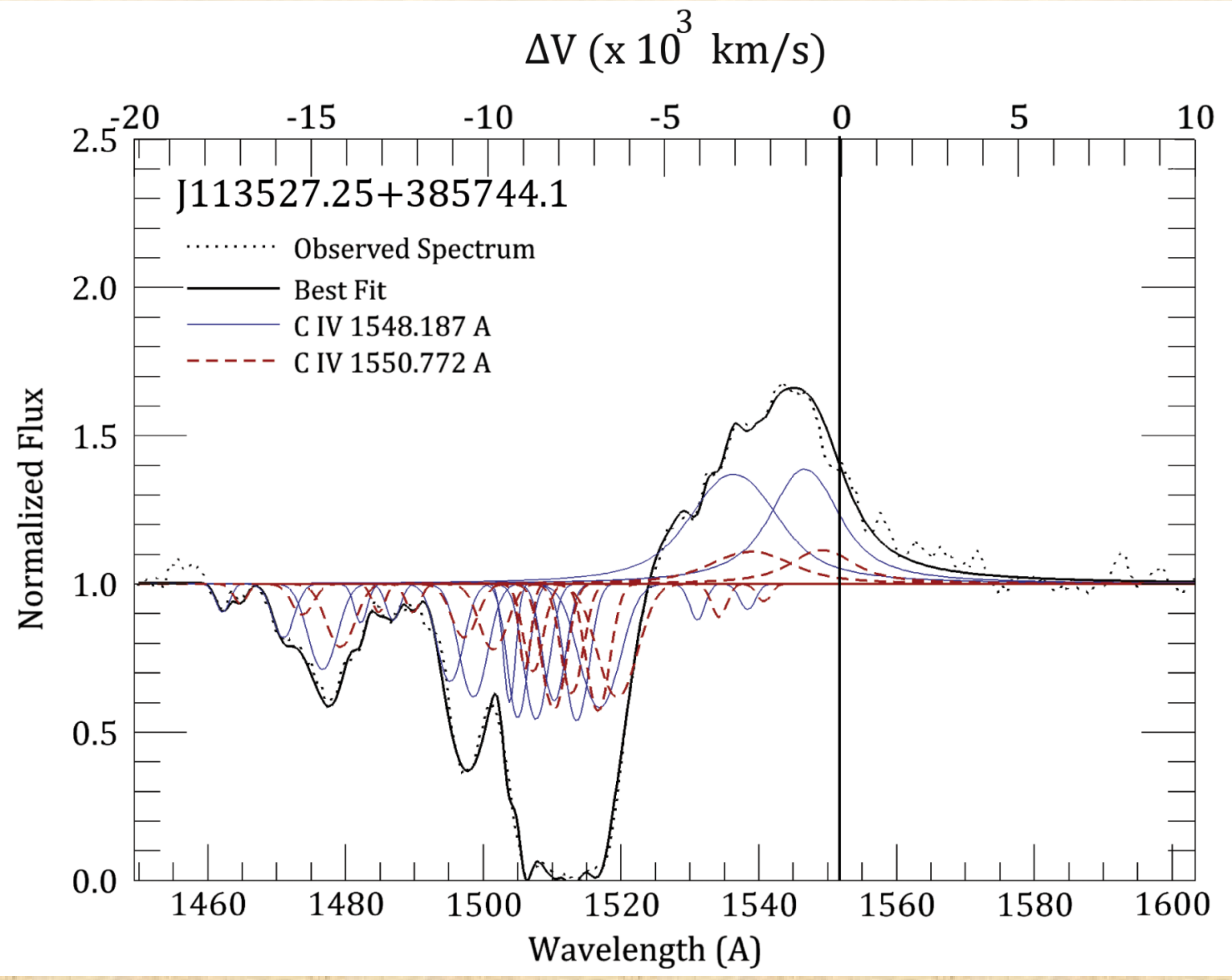
Hot Emission Stars present blueshifted strong broad absorption line components, similar (but in a smaller scale) to the BALs that we observe in the quasars spectra, known as **Discrete Absorption Components (DACs)** (Bates & Halliwell 1986).



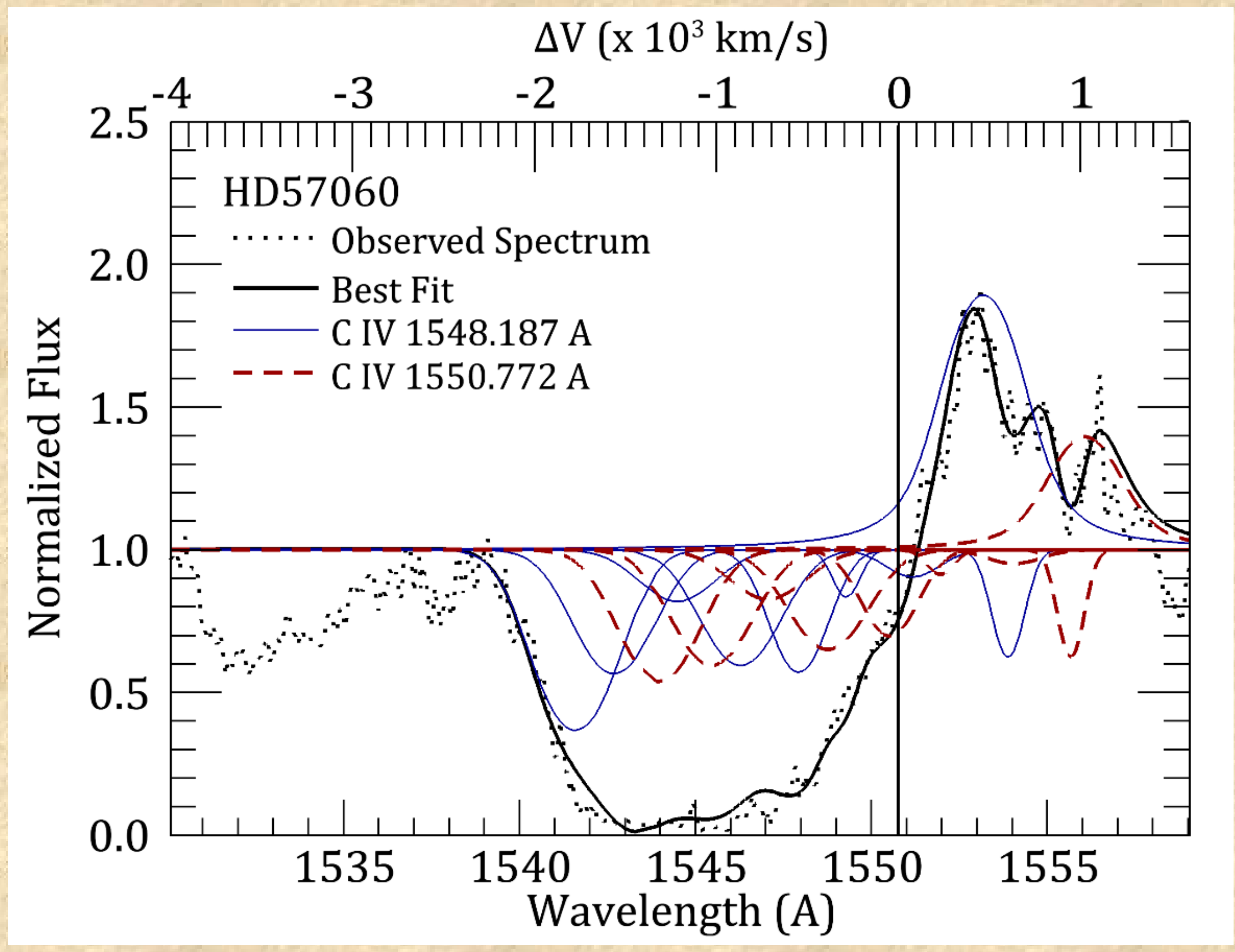
Comparison between the C IV resonance lines in the spectra of a classical O star with no DACs and a Oe with DACs. The appearance of DACs in indicated in the case of the Be stellar spectrum.



BALs in the spectra of BALQSOs and DACs in the spectra of Hot Emission Stars present many similarities



BALs are probably due to a flow of many individual clouds. According to that point of view, **the broad and complex profiles can be interpreted as the synthesis of a series of absorption components, produced by clouds.**



In the case of hot emission stars **the components of DACs are created in independent high density regions of the turbulent flow in the stellar environment**. The components of DACs are named **Satellite Absorption Components** (SACs) (Danezis et al. 2003, 2007; Lyratzi et al. 2007). Thus, their broadening is due to both the rotation of the density regions and the random motions of the ions therein.

Open Questions

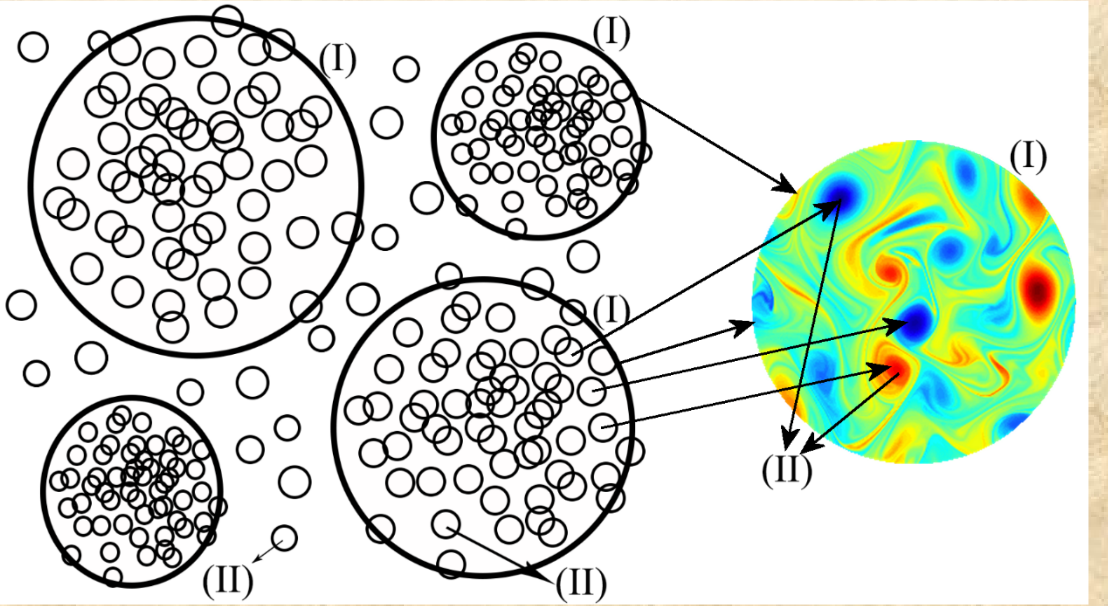
1. Physical Model of the structure of BALR (clouds, cloudlets, etc) and DAC Region .

2. Mathematical Expression of the Physical Model able to simulate the BAL/DAC troughs and provide the physical parameters of BAL/DAC clouds.

3. Fitting Method:
    - Best Fit
    - Uniqueness of Fit - Fitting Criteria

4. Can all the previous be applied in observed BALQSO and Hot Emission Stars spectra? Are the values of calculated parameters accepted?

Proposed physical model for BALR



- The Broad Absorption Line Region (BALR) consists of independent absorption regions, called clouds (regions I,) (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) in turbulent flow. Cloudlets can be thought as density enhancements in a continuous medium (Bottorff & Ferland, 2001).
- 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 it is 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.

Proposed physical model for DAC Region

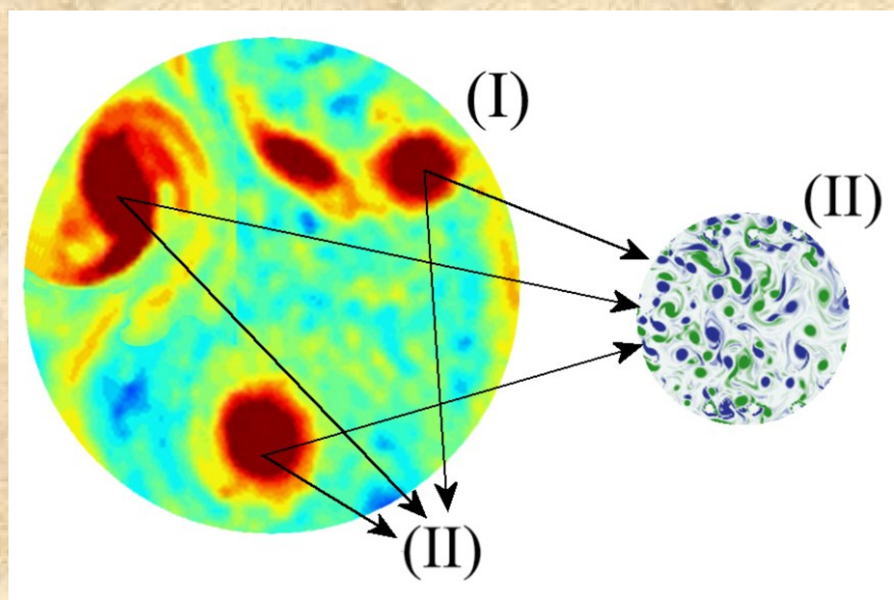


Figure 6: Density regions (I) that form the Discrete Absorption Components (DACs) and SAC regions (II) that form the DACs regions (I).

- The Discrete Absorption Components region (DAC region) (regions I, Fig. 6) consists of independent absorption regions, called SACs regions (regions II, Fig. 6) (Danezis et al. 2003, 2007; Lyratzi et al. 2007).
- The broad profiles of DACs are due to the synthesis of SACs.
- The SAC regions (regions II, Fig. 6) are density enhancements in turbulent flow.
- Due to the turbulent flow, SAC regions rotate with significant velocities.
  The broad profiles of SACs are due to both the self-rotation of the SACs region and the random motion of the matter in these regions.
- The spectral line that corresponds to the SACs are the ones we fit.

Mathematical expression of the model

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

Absorption Components from clouds

Emission Components from clouds

Absorption Components from clouds

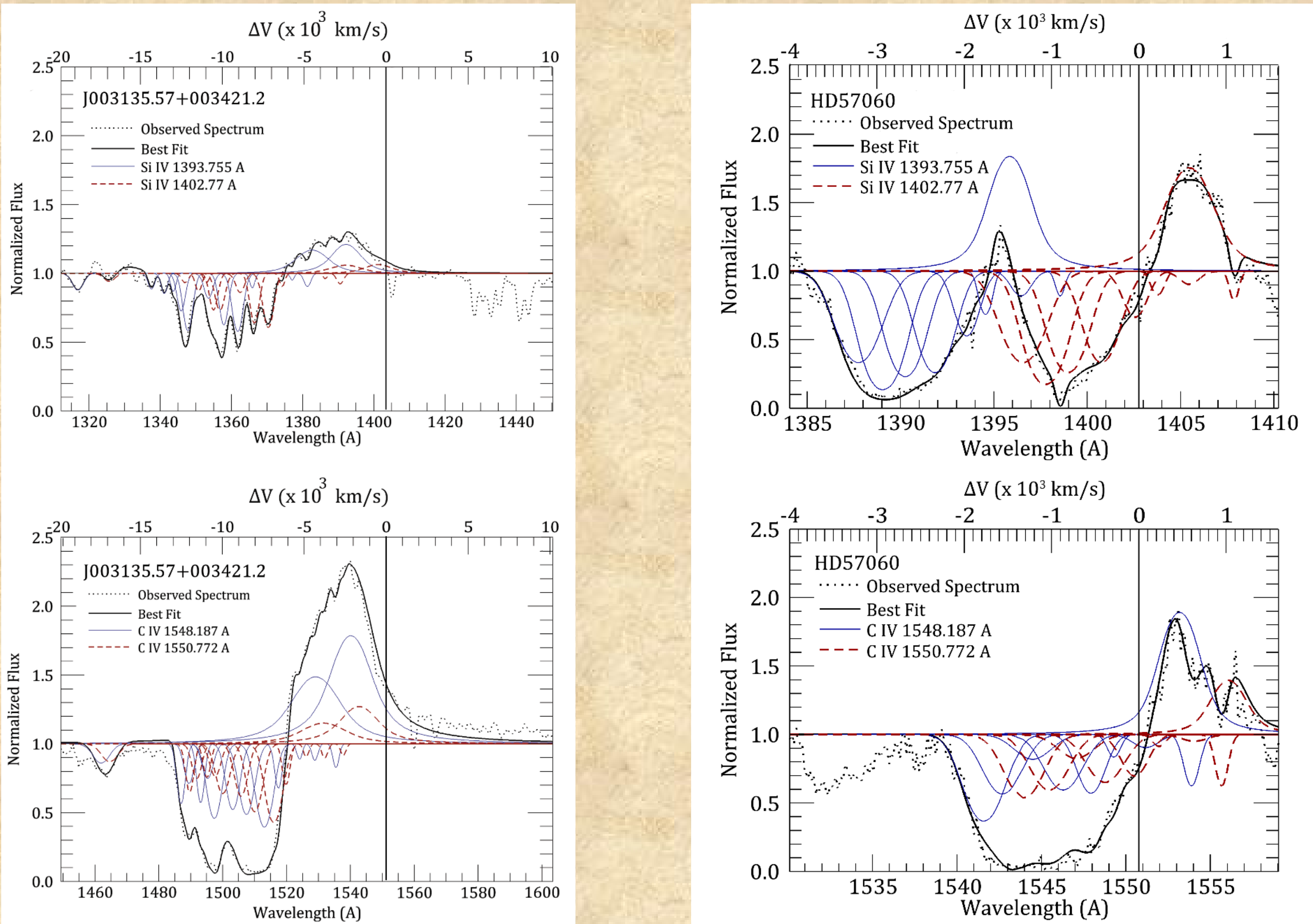
where:
i: is the number of absorbing clouds that cover the continuum (fully or partially), in the line of sight,
j: is the number of emitting clouds in the line of sight,
g: is the number of additional absorbing clouds that may cover the i absorbing clouds as well as the j emitting clouds,
I_{λ_0}: is the initial radiation intensity
$\prod_i \exp\{-L_i \xi_i\}$: is the factor that describes the synthesis of absorption lines produced by i clouds,
$\sum_j S_{\lambda_{ej}} \left(1 - \exp\{-L_{ej} \xi_{ej}\}\right)$: is the factor that describes the summation of emission lines produced by j clouds,
$\prod_g \exp\{-L_g \xi_g\}$: is the factor that describes absorbing clouds that may obscure both the i absorbing as well as the j emitting clouds,
L_i, L_{ej}, L_g: are the distribution functions of the absorption coefficients $k_{\lambda i}, k_{\lambda ej}, k_{\lambda g}$,
$k_{\lambda i}$: is the absorption coefficient of the i^{th} cloud in the line of sight,
$k_{\lambda ej}$: is the absorption coefficient of the j^{th} cloud in the line of sight,
$k_{\lambda g}$: is the absorption coefficient of the additional absorbing clouds that may cover the i and j clouds in the line of sight,
ξ: is the optical depth (τ) in the center of the spectral line,
$S_{\lambda_{ej}}$: is the source function that is constant during one observation

The problem of the exact number of components

In order to make sure that our final fitting solution is unique, we propose two sets of criteria.

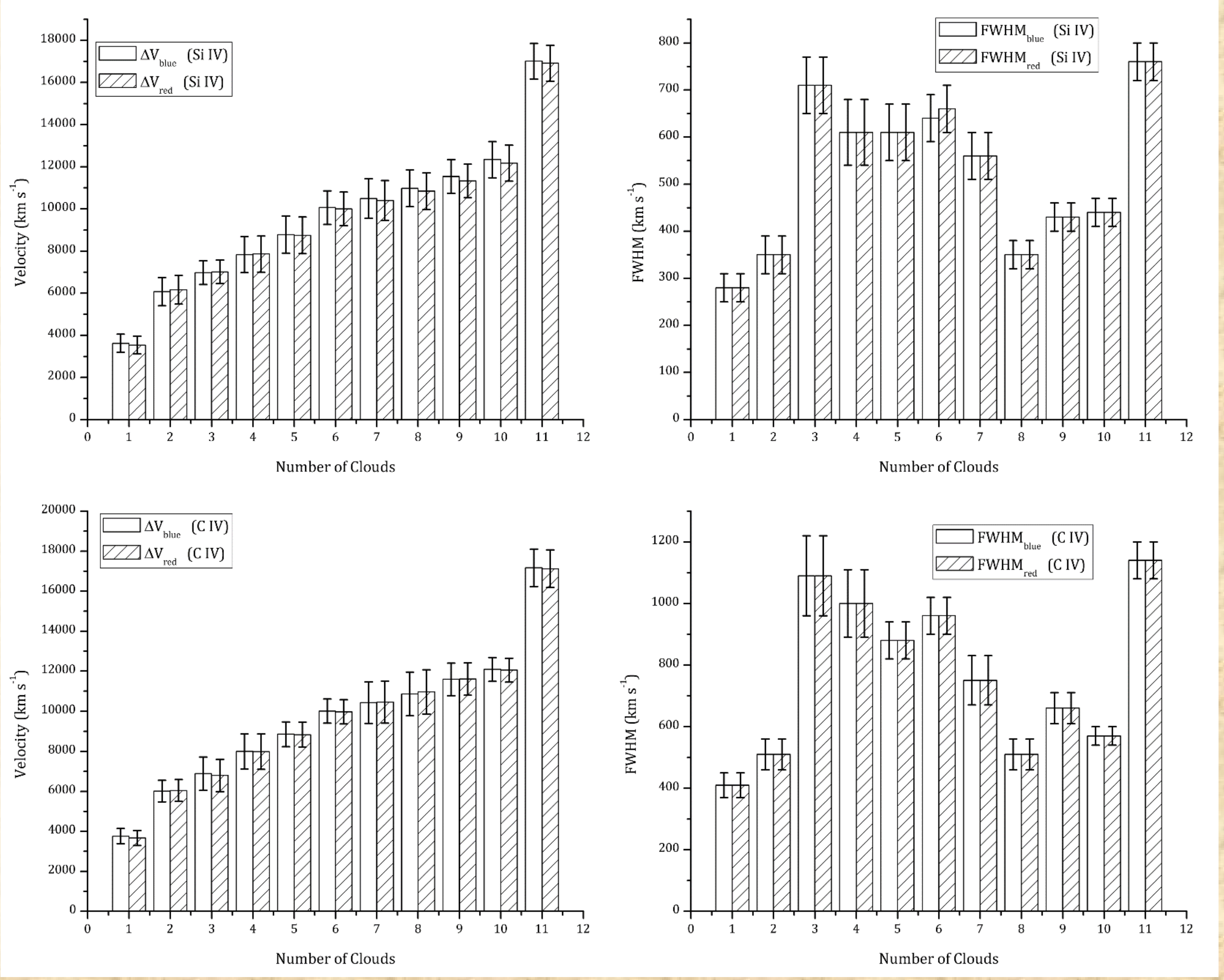
Criteria between the members of a doublet (e.g. C IV λλ 1548.187, 1550.772 and Si IV λλ 1393.755, 1402.77)

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



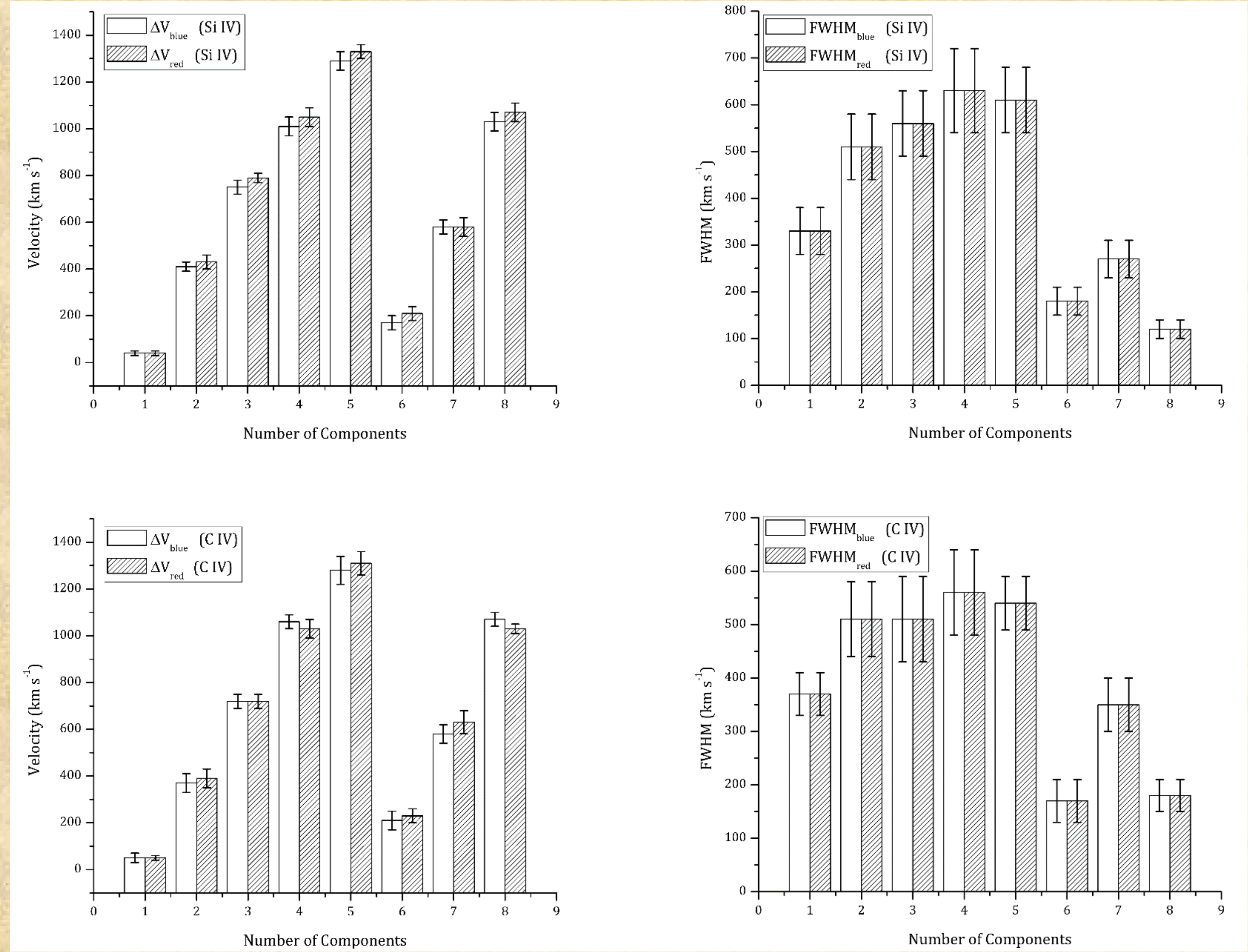
Best fit of the Si IV (top) and C IV (bottom) resonance lines in the spectrum of the BAL QSO J003135.57+003421.2 (left) and of the Oe star HD57060 (right). The whole fitting procedure is in accordance with the criteria. Both Si IV and C IV BALs are perfectly fitted with GR model. The analysis of the complex Si IV and C IV profiles is presented.

BAL QSO J003135.57+003421.2



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.

Oe star HD57060

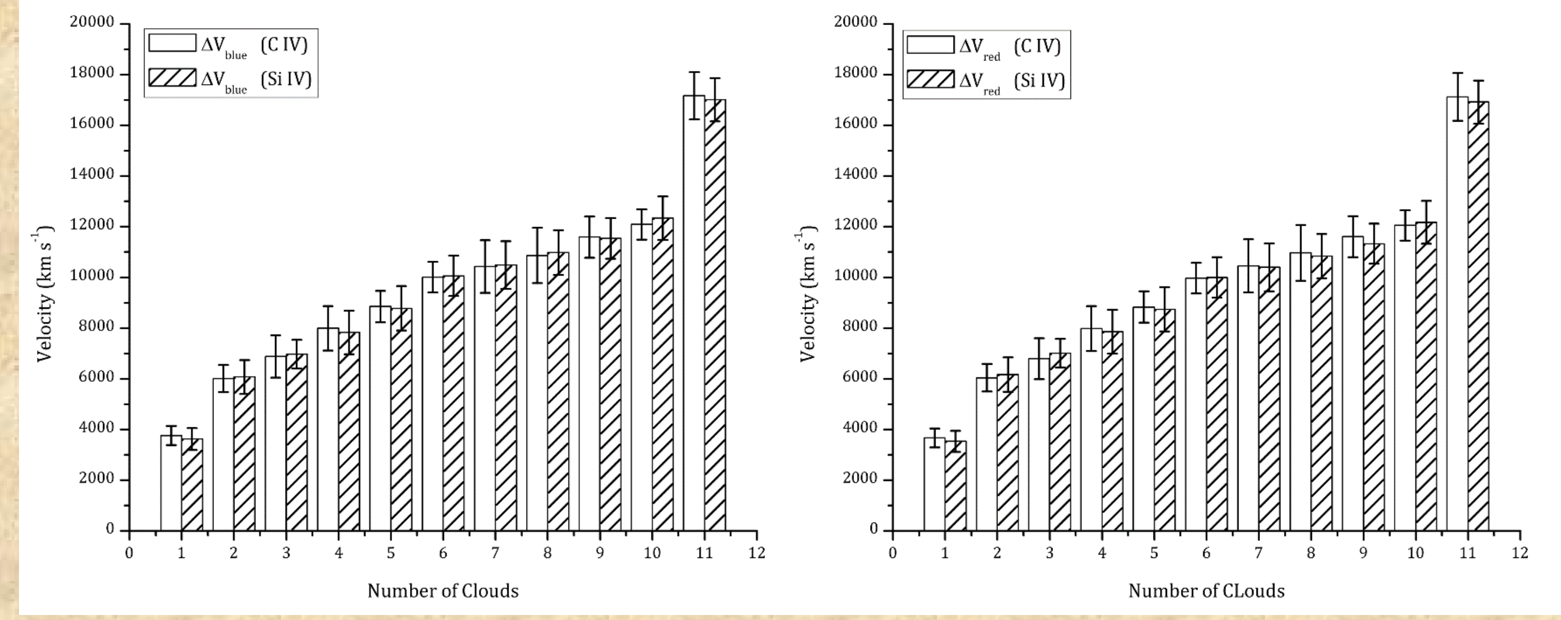


The velocity offset and the width of the blue and the red component are exactly the same in the case of Si IV and C IV resonance lines.

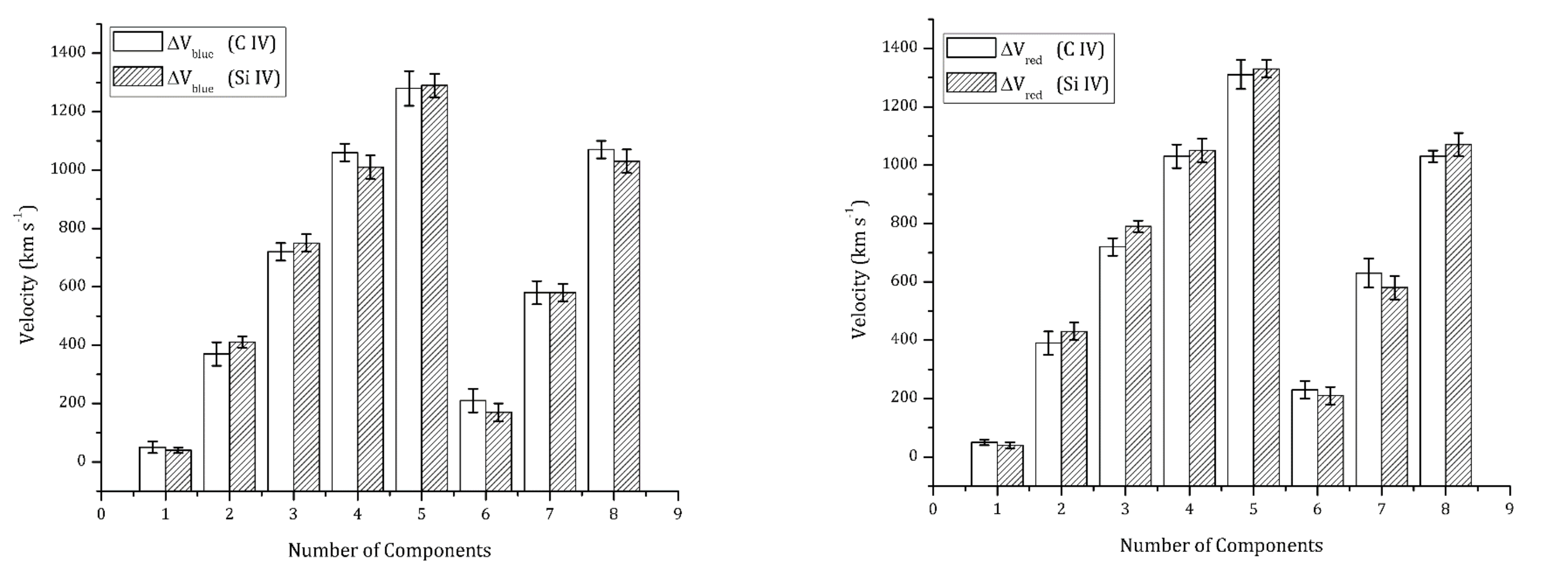
Criteria between C IV and Si IV components at the same outflow velocity from the emission redshift

- 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.

BAL QSO J003135.57+003421.2



Oe star HD57060



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

Thank you very much