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The multicomponent nature of Lyα, N V, Si IV, C IV BALs of J131912.39+534720.5

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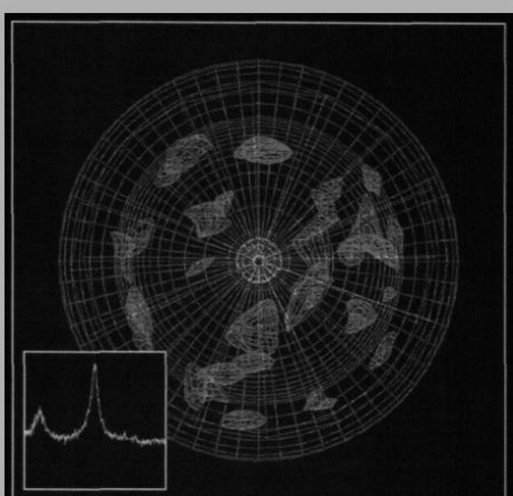
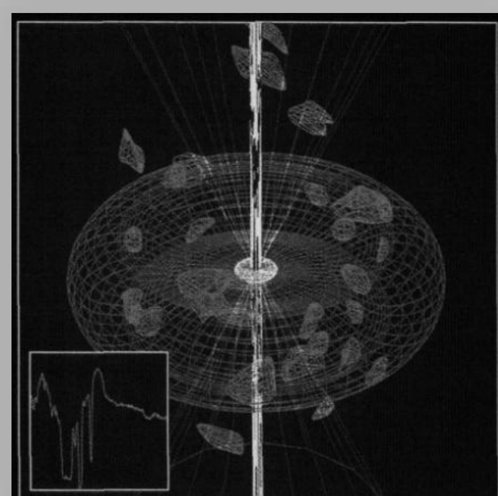
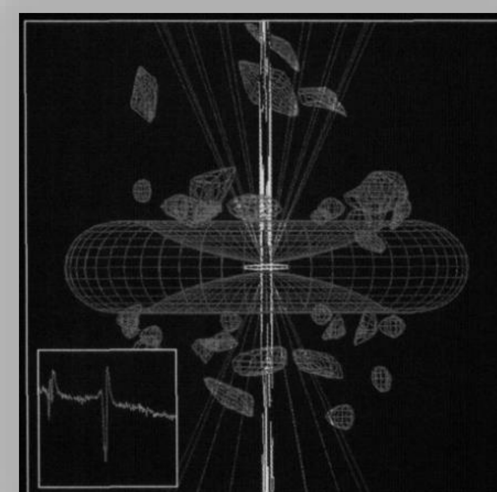


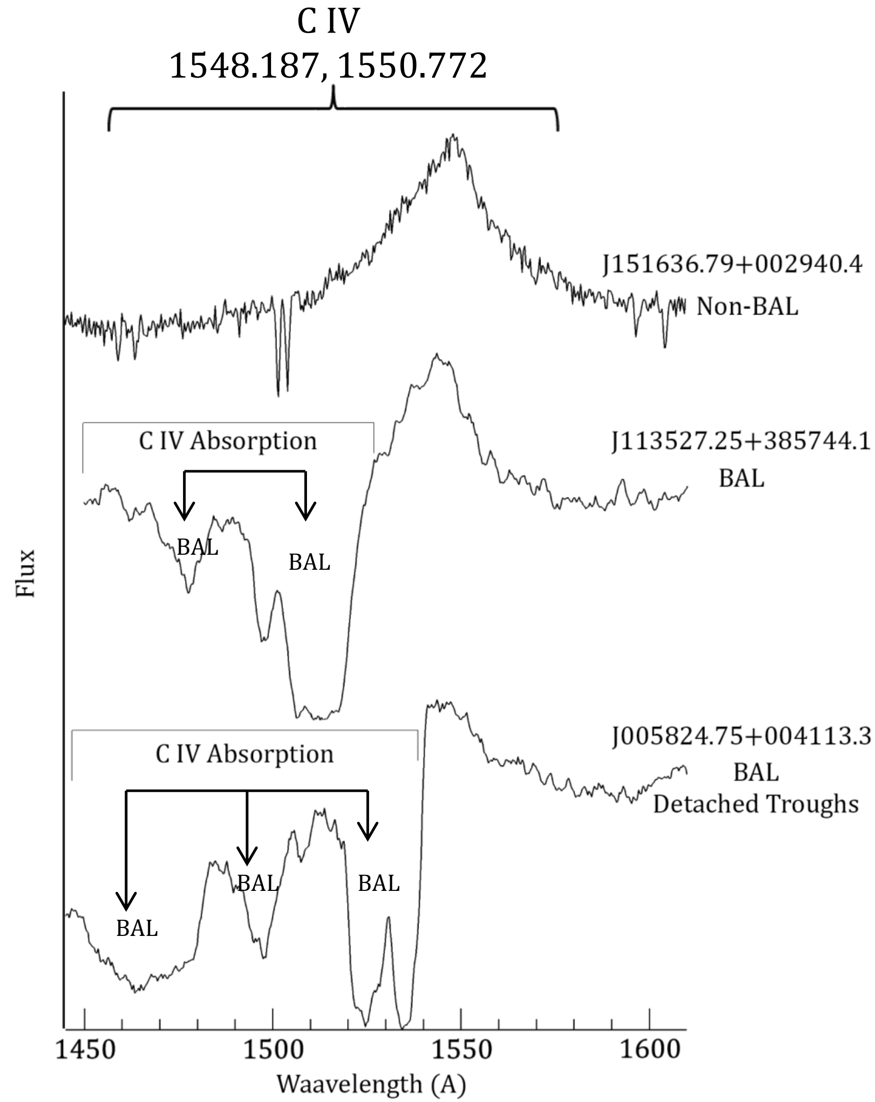




Broad Absorption Lines (BALs)

About 20%-30% of the detected quasar population exhibits broad absorption line (BAL) troughs blueshifted with respect to the corresponding emission lines in their rest frame UV spectra.

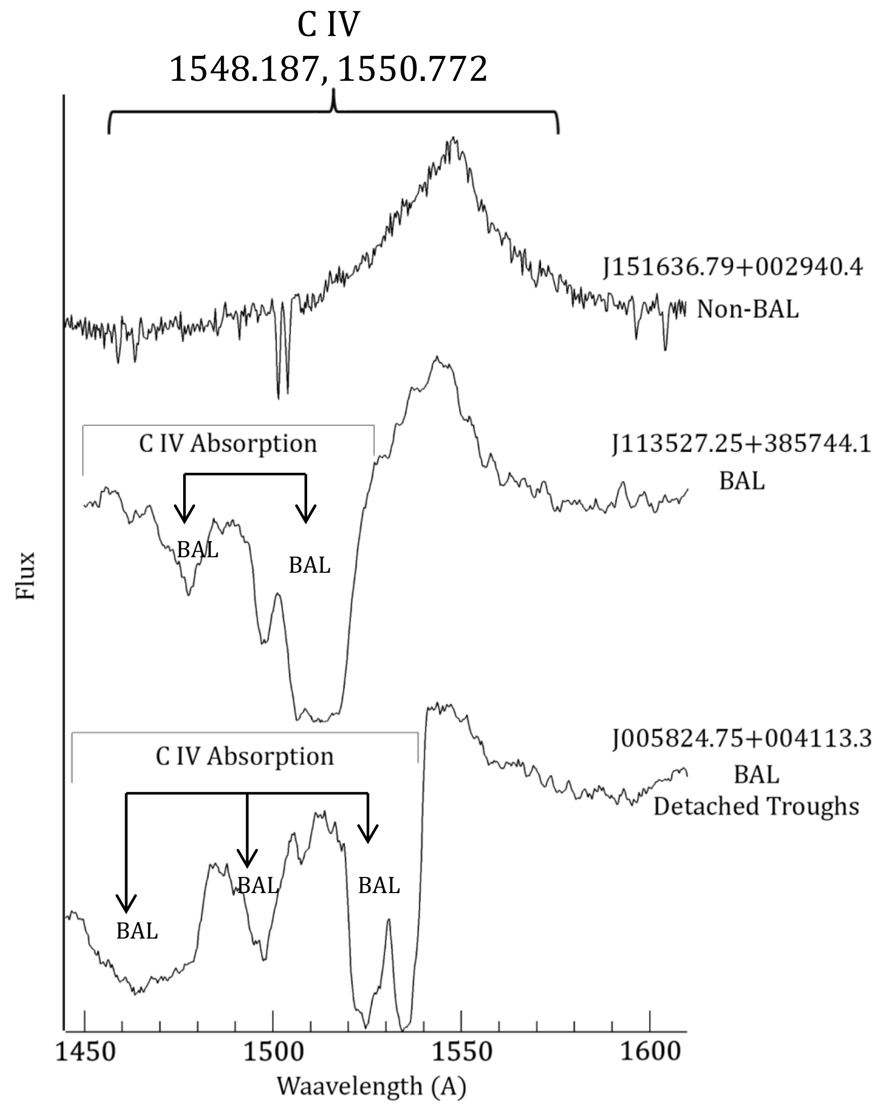
BALs are usually observed in high ionization species such as N V, Lyα, C IV, Si IV and are sometimes detected in lower ionization species like Mg II or Al III.



BALs exhibit a wide range of characteristics in terms of width, velocity shift, strength of absorption, level of ionization and structure of absorption profile.

- FWHM: 200 – 20000 km/s
- Smooth troughs that set in near $V_{outflow} \cong 0\ km/s$ forming P-Cygni type profiles.
- Very broken up absorption
- Multiple troughs forming at $V_{outflow} \cong 0\ km/s$.
- Detached troughs setting in at $V_{outflow} \cong 3{,}000 - 5{,}000\ km/s$
- Detached troughs up to ~ 30,000 km/s

FWHM: 10,000 km/s
$V_{outflow} \cong 0 - {\sim}60{,}000\ km/s$



The origin of BALs

Smooth & homogeneous outflow

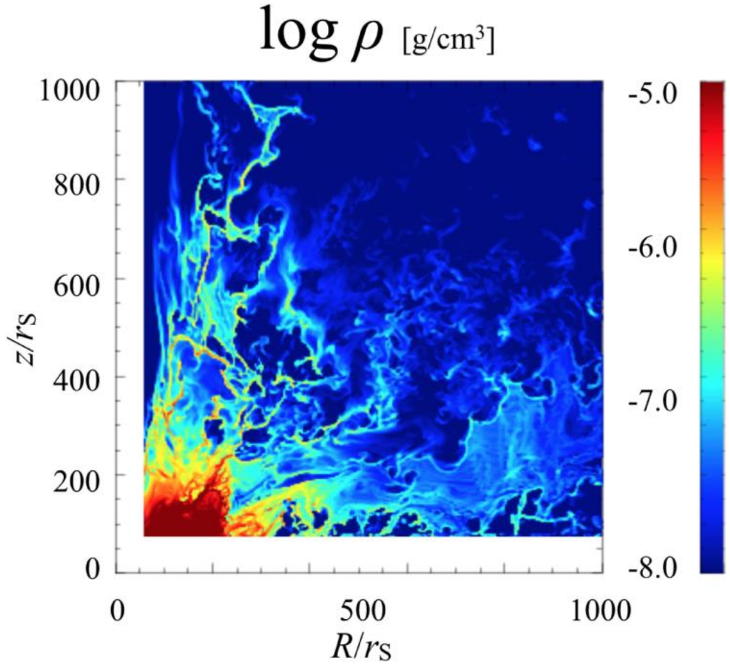
BAL troughs are the product of a smooth & homogeneous outflow (by analogy to the first models of hot star winds).

(e.g. Scargle et al. 1970; Drew & Boksenberg 1983; Shlosman & Vitello 1993; Murray et al. 1995; Higginbottom et al. 2013; Matthews et al. 2016.)

Unstable & Clumpy outflow

Quasar winds are pervaded by a large number of multiscale structures (clumps, clouds), whose origin is probably some kind of radiative instability.

(Takeuchi et al. 2013, 2014; Moscibrodzka & Proga 2013; Proga et al. 2014; Proga & Waters 2015; Waters & Proga 2016; Kobayashi et al. 2018).



According to the clumpy wind model, BALs are the product of individual and independent absorption components created by independent absorbing clouds in the line of sight.

Studying the physical conditions and kinematics of absorbing clouds requires analyzing BAL troughs to the components they consist of and measuring the physical parameters (Vrad, FWHM, τ_0) describing each cloud.

In order to analyze Lyα, N V, Si IV and C IV BALs to the components they consist of we use:

- GR model (Danezis et al. 2003, 2007, 2009, Lyratzi et al. 2007, 2009)
- ASTA software (Tzimeas et al. 2019)

For every absorption component we measure the radial velocity (V_{rad}), the FWHM and the optical depth (τ_0) at line center.

In order to test the independency and distinction of the clouds from each other we utilize to epoch spectra and probe the variability of the components parameters. The time interval is 10 years.

A critical question concerning multicomponent fitting of BALs is whether the final fit, the number of components and the values of the measured parameters are uniquely determined.

Fitting Criteria-Absorption/Emission Lines
(Stathopoulos et al. 2015, 2019)

I) Criteria between the members of a doublet

- Lyα λλ 1215.668 (blue), 1215. 674 (red) Å
- N V λλ 1238. 821 (blue), 1242.804 (red) Å
- C IV λλ 1548.187 (blue), 1550.772 (red) Å
- Si IV λλ 1393.755 (blue), 1402.77 (red) Å

We do not treat Lyα, N V, C IV or Si IV doublets as singlets but instead we treat each member of a doublet independently. Treating doublets as singlets can lead to huge deviations in the measurement of parameters especially in the case of Si IV where the wavelength separation between the components is large. Furthermore treating doublets as singlets prevents us from applying the following criteria.

II) Criteria between Lyα, N V, C IV and Si IV BALs

All BALs consist of the same number of components over corresponding velocities

Every Cloud (cluster) contains both Lyα, N V, Si IV and C IV ions.

I) Criteria between the members of a doublet

a. The number of blue and red components of a doublet must be exactly the same.

b. Each Si IV blue member, at a specific velocity shift, has its corresponding red member at the same velocity shift. The same applies to Lyα, N V and C IV.

c. The width between the blue and the red member of a doublet is exactly the same.

d. For emission lines the ratio of optical depths between the blue and the red member is $\tau_b/\tau_r = 2$ (as dictated by atomic physics).

e. For absorption lines this ratio is free to vary $1{:}1 \leq \tau_b/\tau_r \leq 2{:}1$ in order to account for non black saturation.

Criteria (a-d) are a consequence of atomic physics. There are two, fine structure, sub-levels which means that the observed spectral lines are resonance doublets. Both members of a doublet are characterized by the same width, the wavelength separation between the members of a doublet is fixed and the ratio of optical depths is determined by the ratio of oscillator strengths (Savage & Sembach 1991).

Criterion (e) deviates form theory but there are reasons causing discrepant optical depth ratios:

- Local emission by the absorber
- Photons from the background emission source that are not absorbed and/or are scattered into the observer's line-of-sight
- Geometrical partial coverage of the continuum and/or BEL source by the absorbing medium.

II) Criteria between Lyα, N V, C IV and Si IV components at the same outflow velocity from the emission redshift.

a. Lyα, N V, C IV and Si IV BALs consist of the same number of doublets.

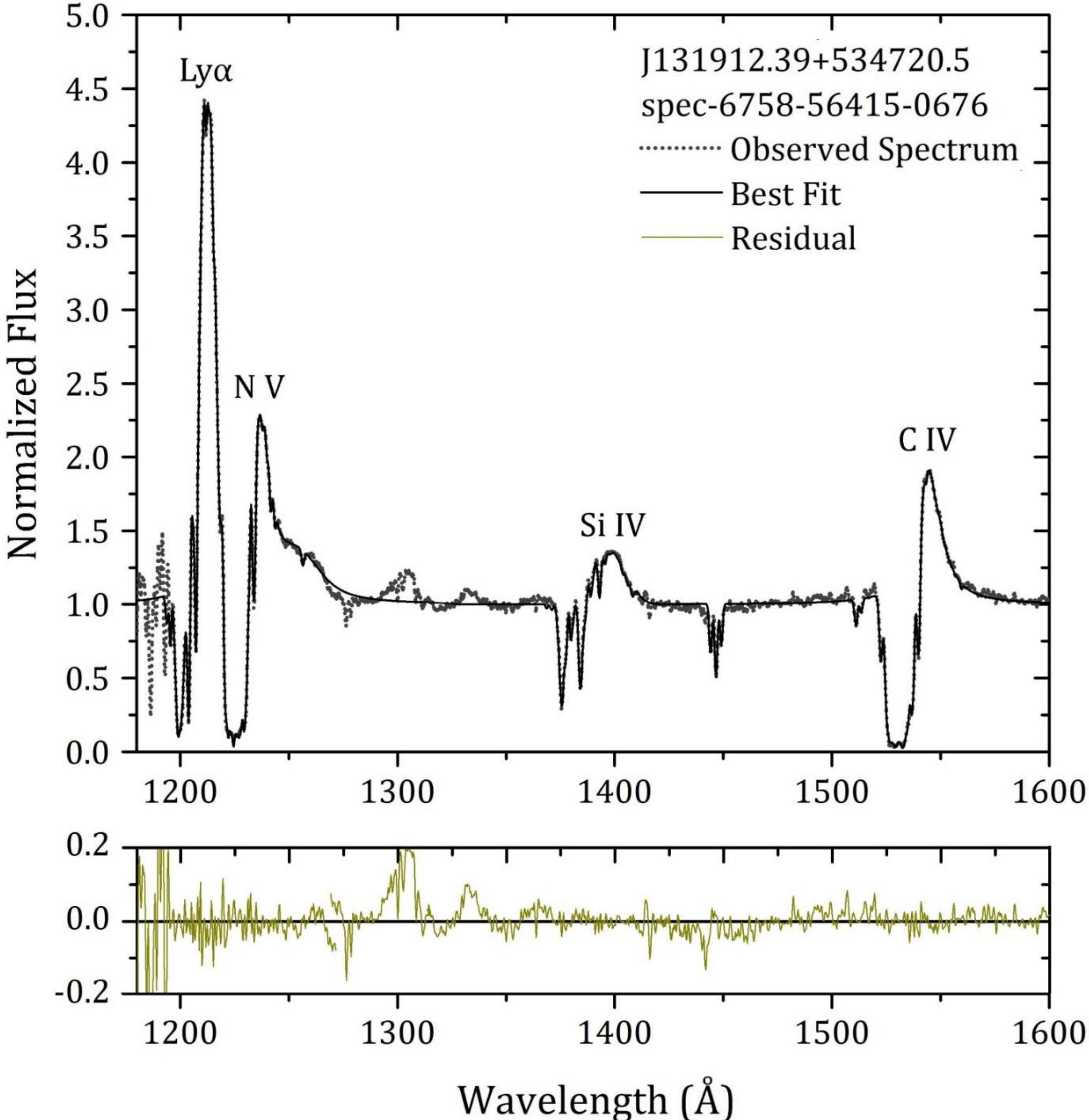
b. Each Lyα blue component, at a specific velocity shift, has its corresponding N V, Si IV and C IV blue component at the same velocity shift.

c. Each Lyα red component, at a specific velocity shift, has its corresponding N V, Si IV and C IV red component at the same velocity shift.

These criteria are based on the assumptions that Lyα, N V, Si IV, C IV:

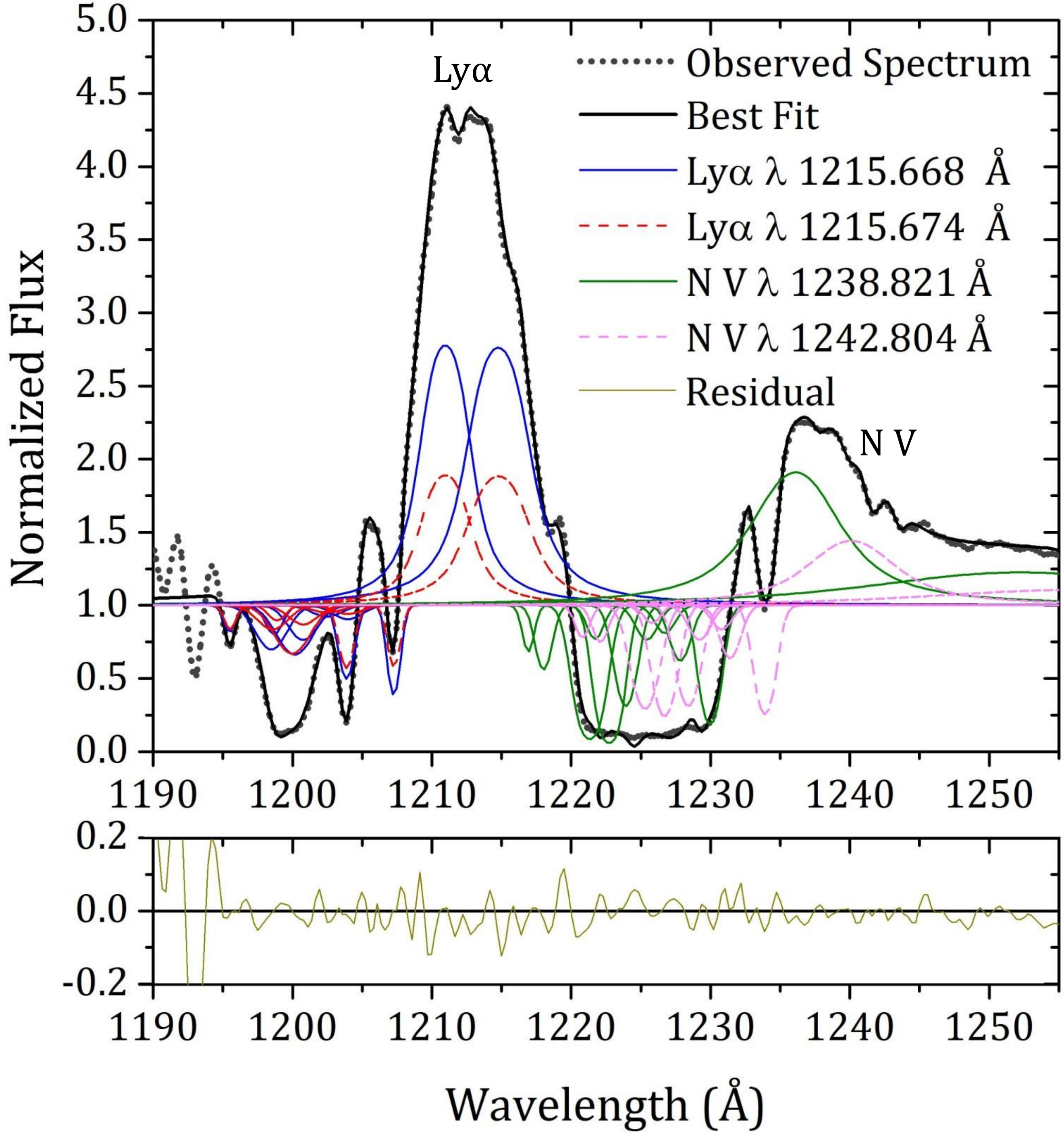
i. Form in the same clouds.
ii. Follow the same kinematic structure.
iii. Have the same temperature (Rauch et al. 1996) in spite of their different ionization potentials ($T \sim 10^4 - 10^5$ K).
iv. Consist of the same number of components.

Best fits of Lyα, N V, Si IV and C IV BALs of **J131912.39+534720.5**



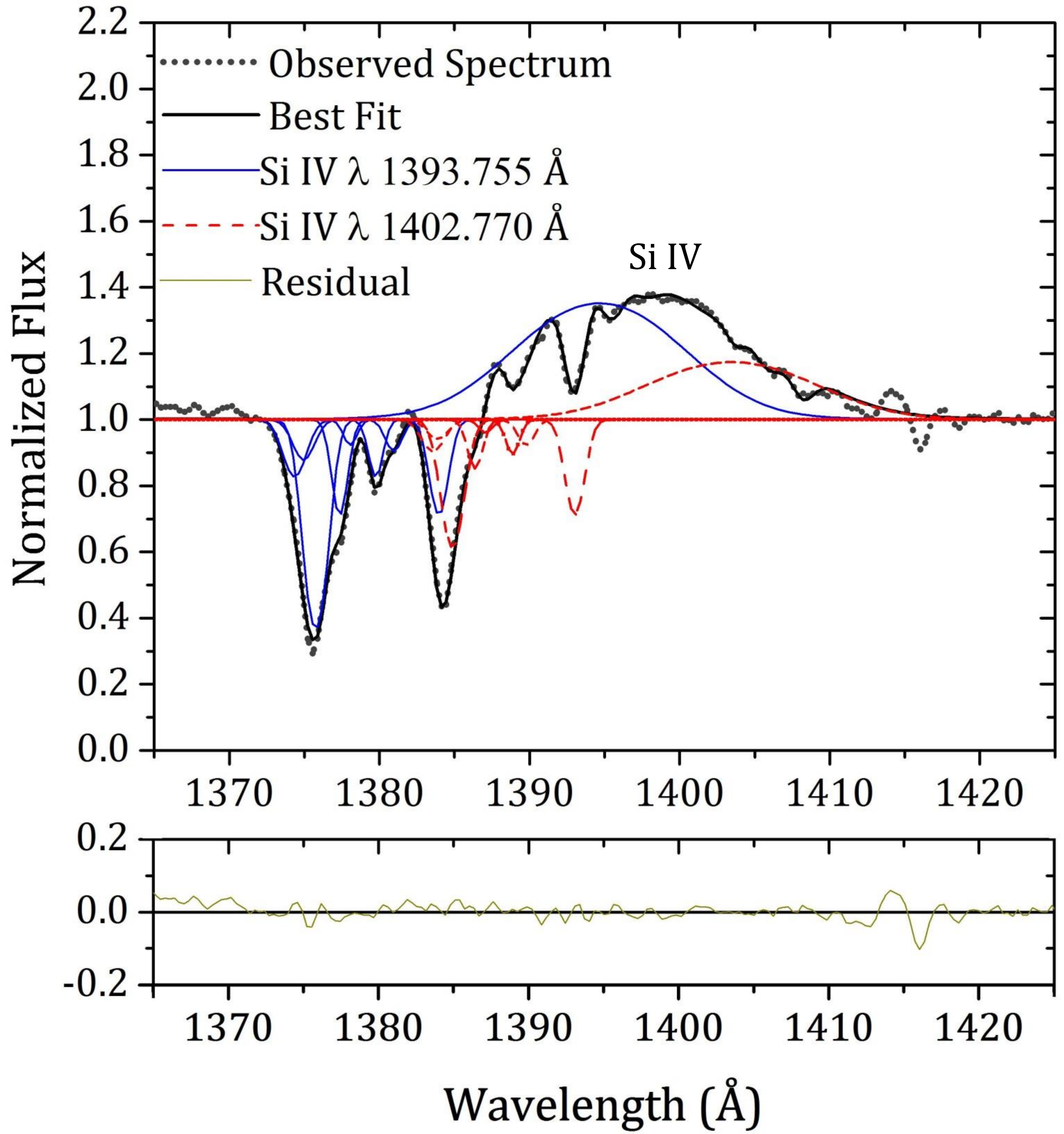
Best fits of
Lyα and N V BALs

- Dotted Line: Observed Spectrum
- Thick Black Line: Best Fit
- Blue Line: Shorter wvl member of the doublet
- Red Line: Longer wvl member of the doublet
- Green Line: Residual



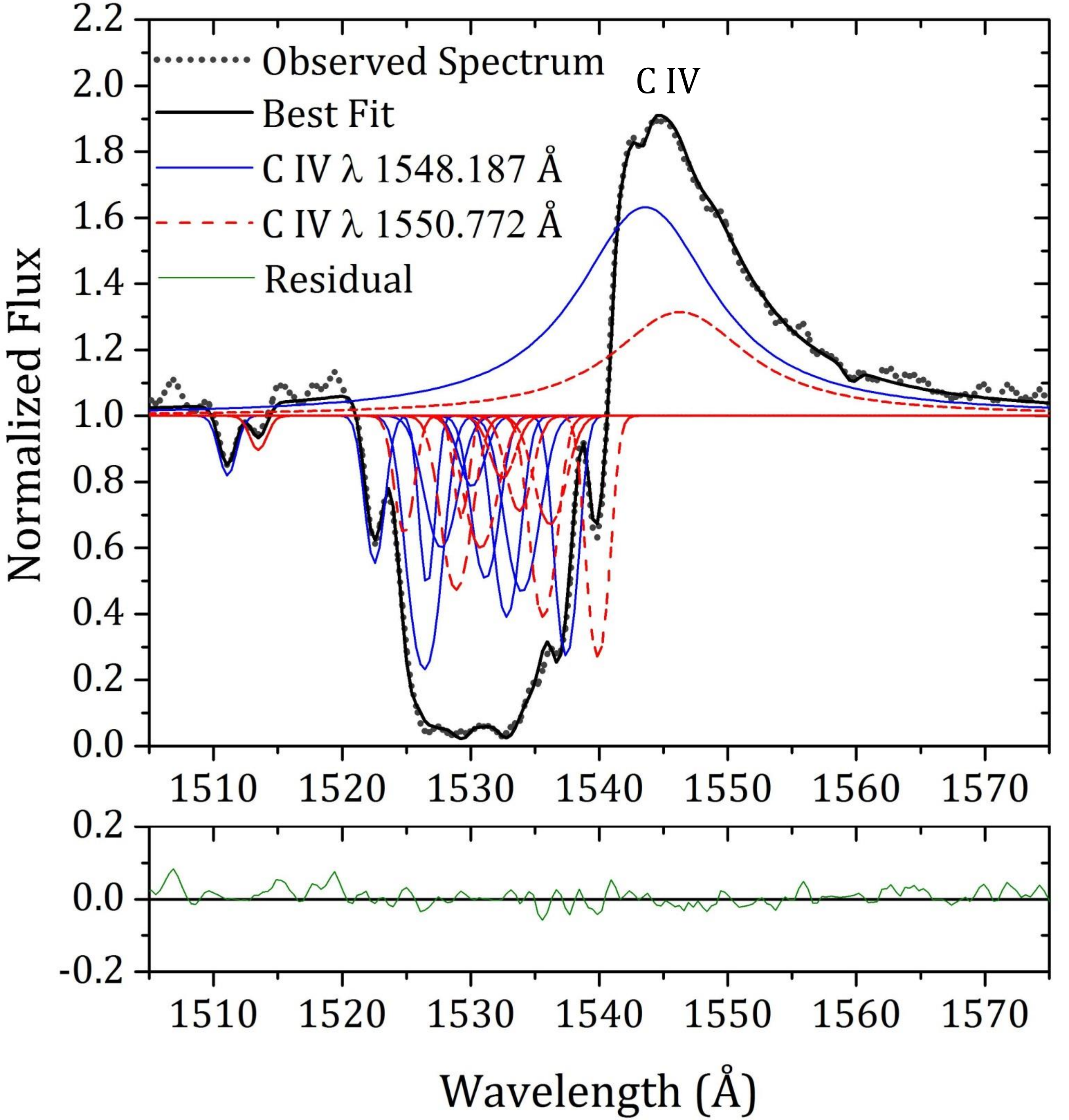
Best fit of
Si IV BAL

- Dotted Line: Observed Spectrum
- Thick Black Line: Best Fit
- Blue Line: Shorter wvl member of the doublet
- Red Line: Longer wvl member of the doublet
- Green Line: Residual

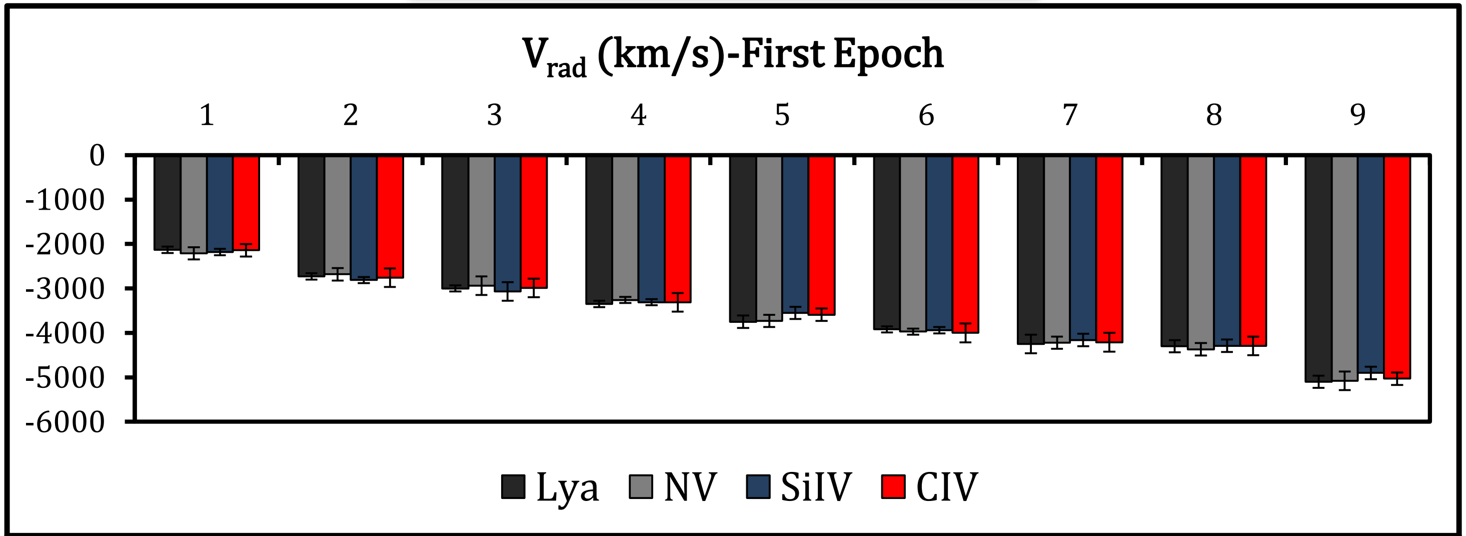


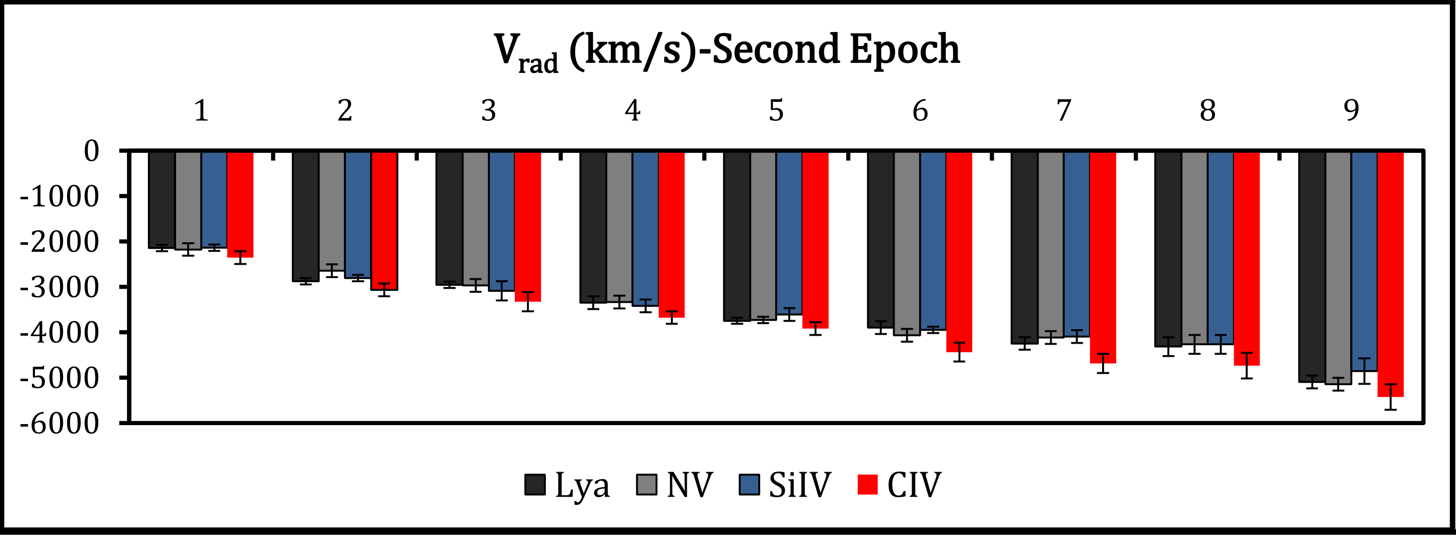
Best fit of
C IV BAL

- Dotted Line: Observed Spectrum
- Thick Black Line: Best Fit
- Blue Line: Shorter wvl member of the doublet
- Red Line: Longer wvl member of the doublet
- Green Line: Residual



Results





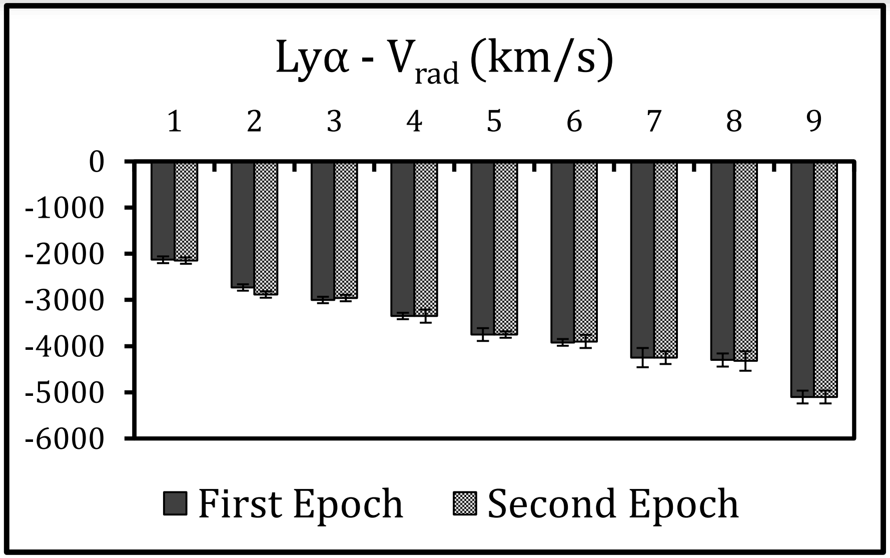
Lyα, N V, Si IV and C IV BALs, in both epochs, consist of the same number of doublets over corresponding velocities

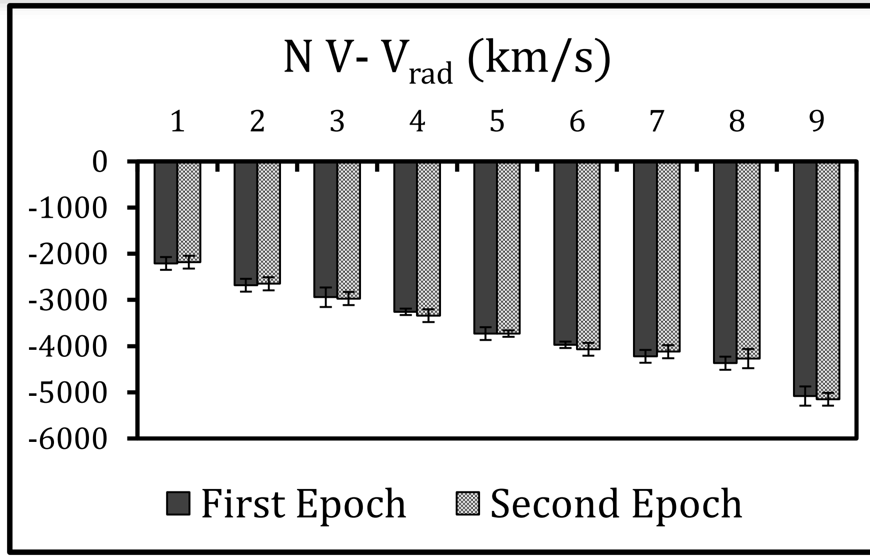
9 doublets for each BAL

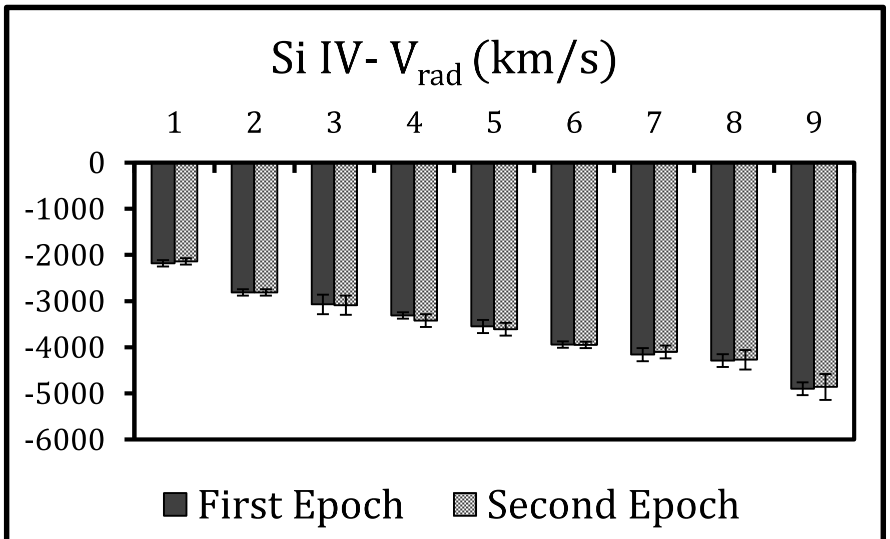
18 components: 9 blue and 9 red components

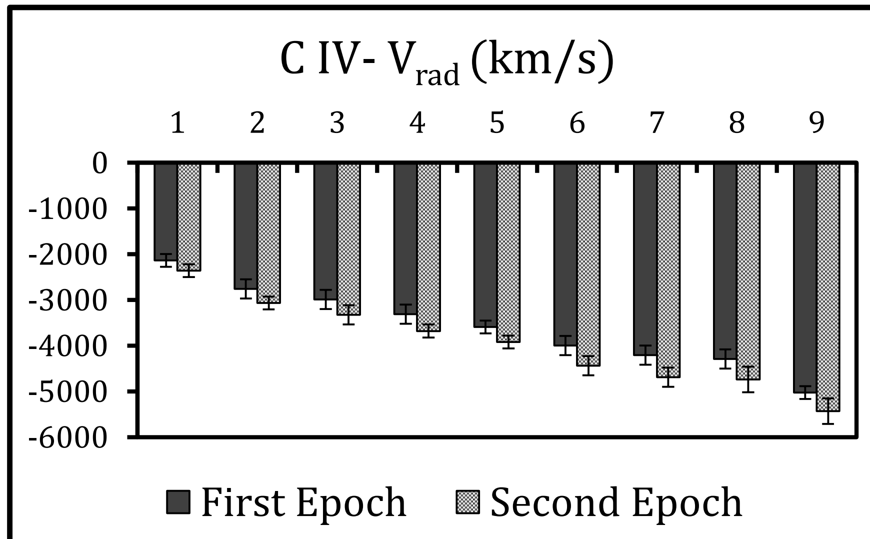
Radial Velocities (V_{rad})

Lyα, N V, Si IV and C IV components exhibit constant V_{rad} in a time interval of ten years



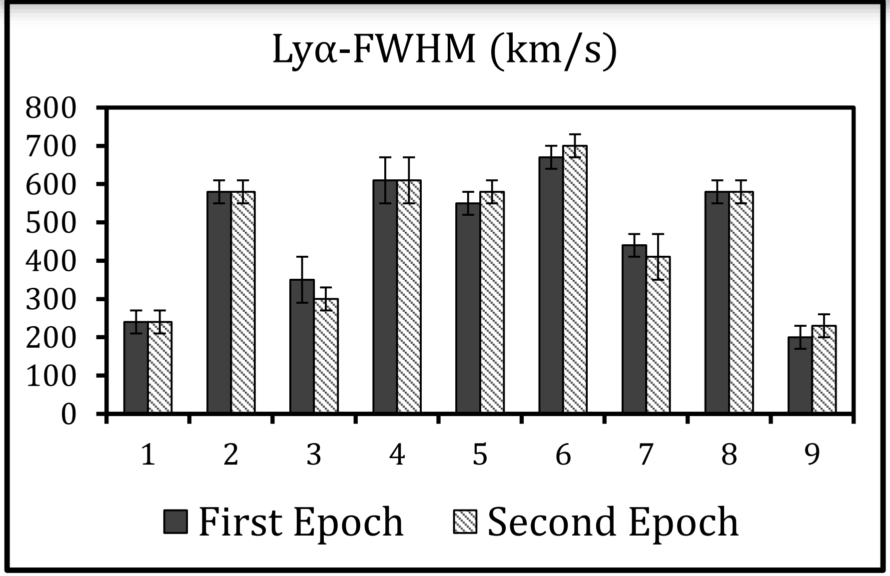


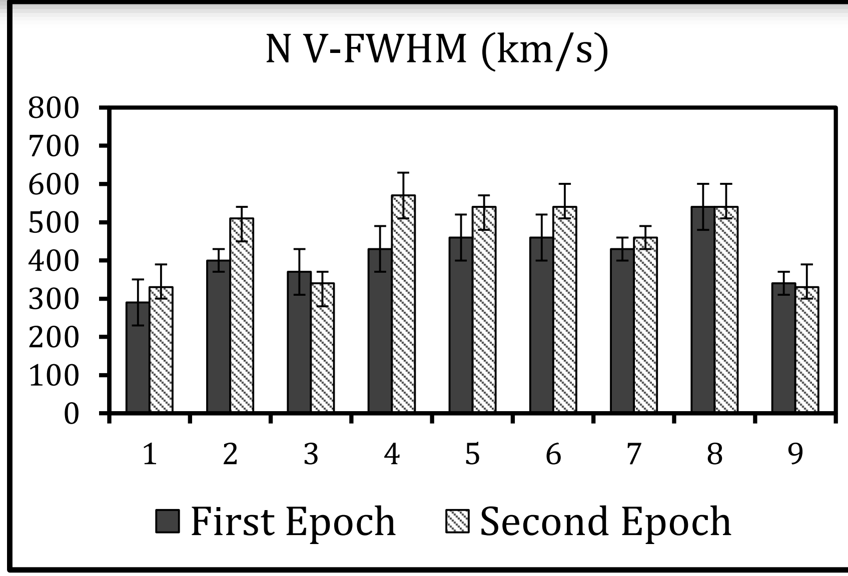


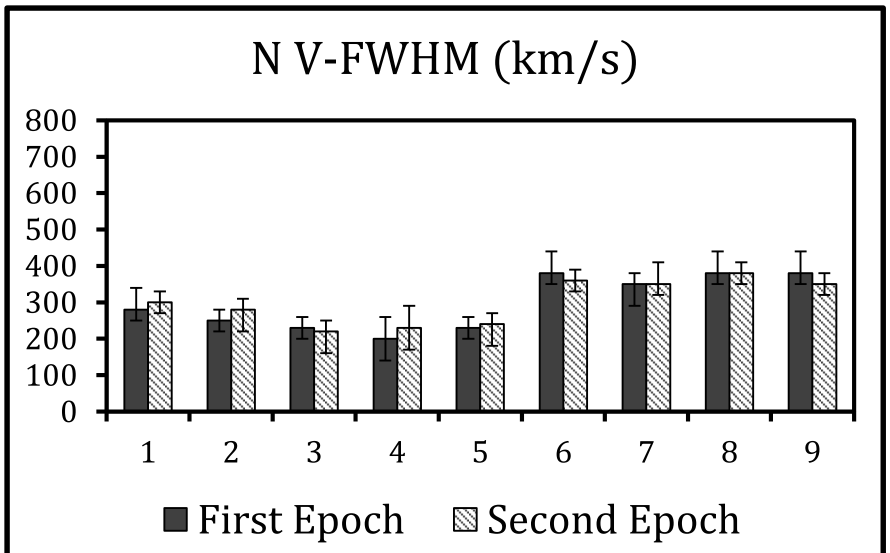


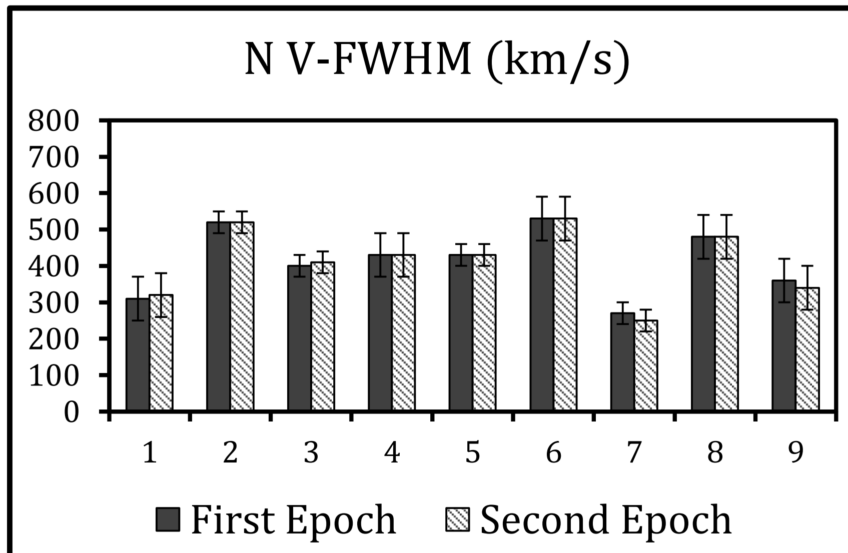
FWHM (km/s)

Lyα, N V, Si IV and C IV components exhibit constant FWHM in a time interval of ten years









Optical depths (τ_0)

Variability occurs in individual components' optical depths

In order to determine which components exhibit variability we use the following equation:

$$N_\sigma = \frac{\tau_2 - \tau_1}{\sqrt{\sigma_1^2 + \sigma_2^2}}$$

Components are considered as variable when $|\mathbf{N_\sigma}| \geq \mathbf{1}$

1. Lyα, N V, Si IV, and C IV BALs exhibit variability in individual components. None of the BALs shows variability in its entire trough.

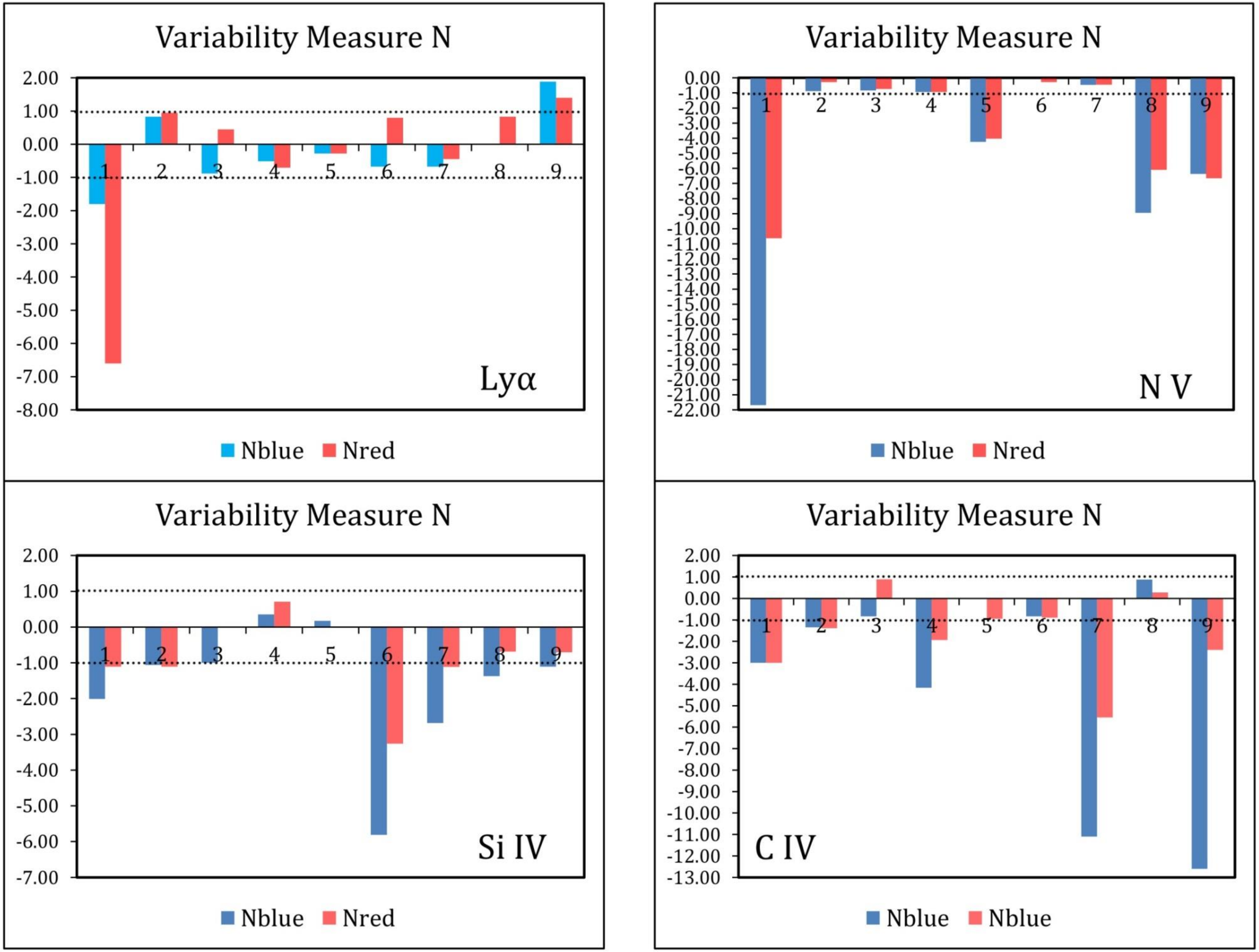
2. In Lyα, Si IV, and C IV BALs all variable doublets weaken between the two epochs.
3. In N V BAL all variable doublets weaken except for one which strengthens over time.

4. Si IV exhibits higher incidence of variability
   - Si IV: 7 out of 9 components vary (~78%)
   - C IV: 5 out of 9 components vary (~56%)
   - N V: 4 out of 9 components vary (~45%)
   - Lyα: 2 out of 9 components vary (~22%)

5. We found three Si IV doublets in which only the blue member of the doublet varies

6. The components of Lyα, N V, Si IV, C IV vary independently from each other.

Variability Measure N_σ



Conclusions

1. Lyα, N V, Si IV and C IV BALs consist of
   i. complexes of narrow absorption components,
   ii. the same number of components over corresponding velocities.

These findings motivate the idea that absorption components arise in clumpy gas clouds with similar locations, kinematics and physical conditions and that all four ions belong to the same clumpy clouds.

2. Variability of components
   i. Variability occurs only in individual components of BAL troughs
   ii. All variable components, within the same BAL, exhibit independent variations
   iii. Variable components exhibit independent variations between different ions
   iv. The incidence of variability is different for each ion
   v. Absorption components do not alter their radial velocities with time

All BALs in exhibit independent variations of absorption components. Thus absorbing clouds vary independently. This is an indication of the distinction and independence of the clouds from each other. Our findings are indicative of density stratification within the absorbing gas, suggesting that quasar outflows are far from being smooth and homogeneous.

Conclusions

3. The cause of BAL variability

There are two basic mechanisms causing BAL variability.

- Movement of clouds in and out our line of sight
- Changes in the ionization state of the gas caused by fluctuations in the continuum flux

If movement of clouds was the responsible mechanism we would observe changes in the radial velocities of components, which we do not.

As a result in the case of the studied quasar ionization changes is the most dominant cause of the observed BAL variability.

Thank you very much!!!