

The Potential Nature of FeLoBAL Winds as Seen Through Variability

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Abstract

We conduct a study of FeLoBAL quasars observed by the Sloan Digital Sky Survey (SDSS) to explore variability of BAL troughs. We searched through the SDSS archives and find 35 objects with spectra from multiple epochs. Three of the objects with multiple epochs show variability in the BAL troughs. In each case, the BAL substructure is evident and agrees in velocity space between ions of all ionization levels. The changes appear to only specific subcomponents more clearly seen in the low ionization species. Given the correlation between isolated troughs in low ionization states and blended features in high ionization states, we argue that the physical structure of the BAL wind is likely clumpy in nature.



Introduction

- Active Galaxies Nuclei (AGN) are at the center of galaxies that host super massive black holes (SMBH). These SMBH accrete matter which orbits at increased velocities. Due to frictional forces, these particles heat up forming an accretion disk where some ions are ejected as outflow.
- Quasars are the most luminous AGN in the universe with a luminosity spanning 10^{44} to 10^{48} erg s⁻¹ (Weymann et al. 1991).
- Quasar outflows are detected as blueshifted absorption troughs with respect to the AGN's rest frame, which potentially provide feedback for the surrounding environment (Borguet et al. 2012, Dunn et al. 2010). These troughs are ubiquitously seen in the UV resonance line C IV $\lambda\lambda 1548, 1550$ and have widths up to 30,000 km s⁻¹ or frequently referred to as broad absorption line (BAL) quasars.
- In rare cases, these outflows form troughs from low ionization species such as Fe II (FeLoBALs).
- As shown in Dunn et al. (2010), in the lower ionization species the troughs were comprising of several kinematic subcomponents that blend in the higher ionization species.
- On time scales of years, BAL features have been shown to vary their structure or vanish (Hall et al. 2004).

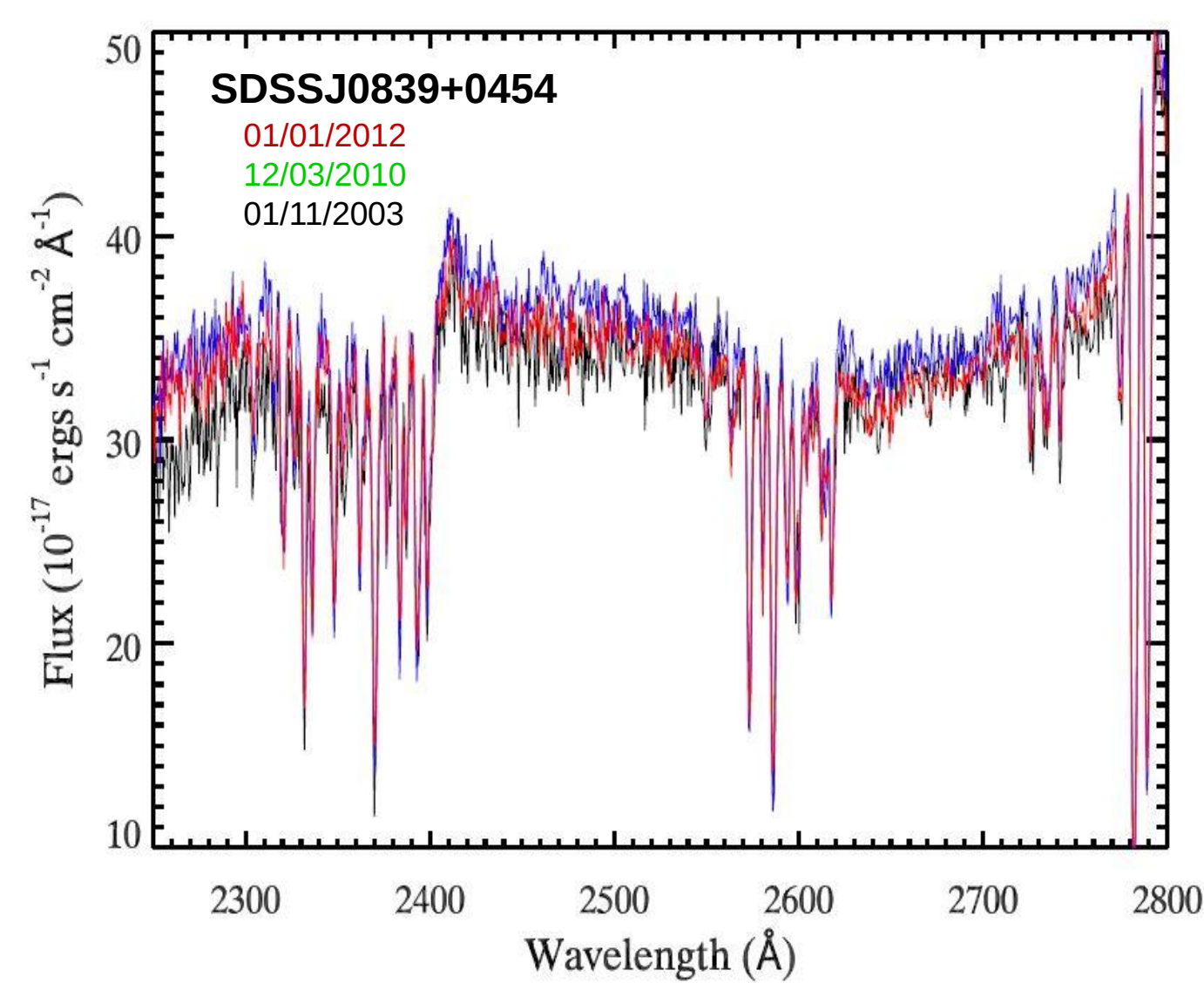
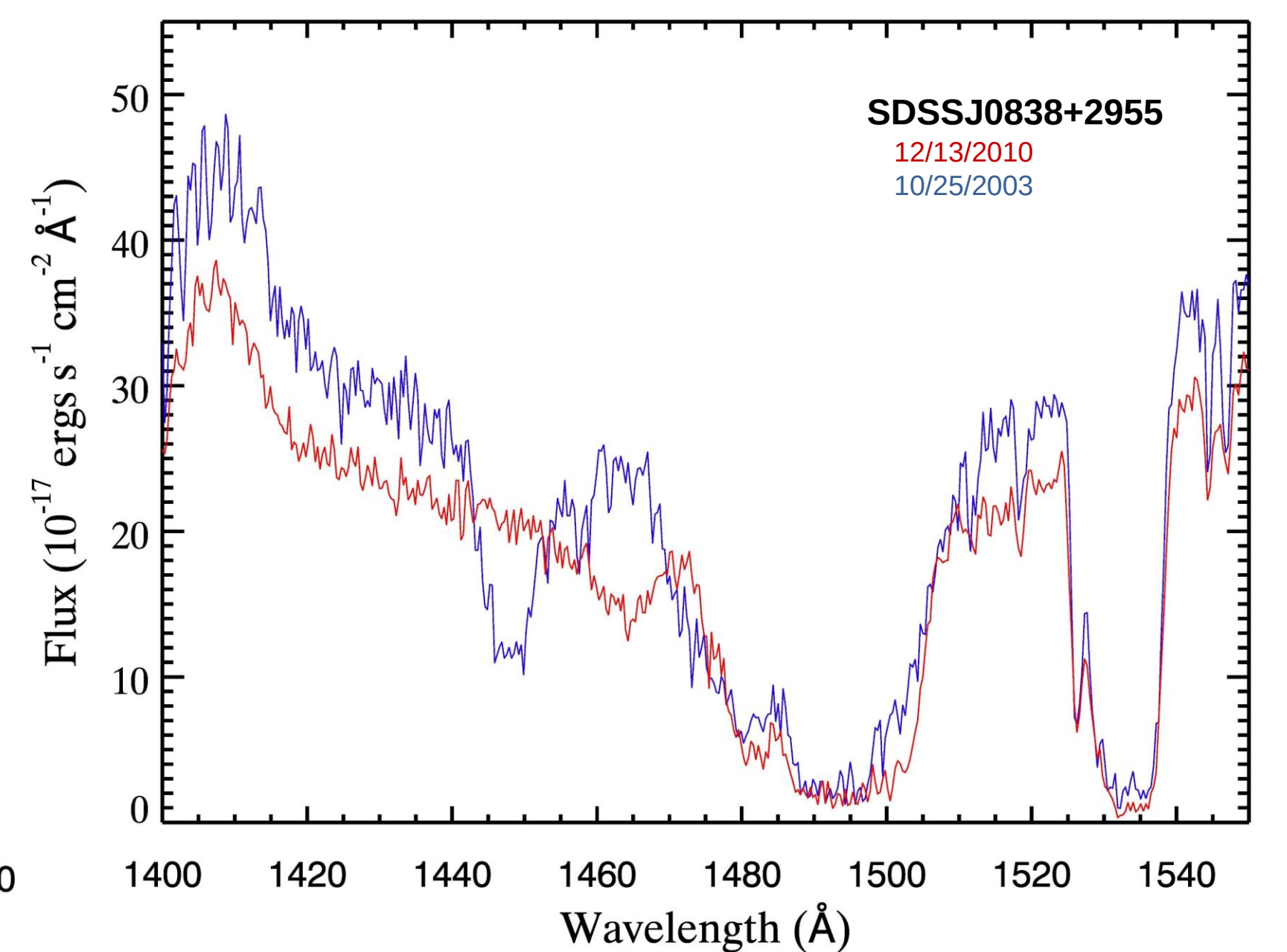
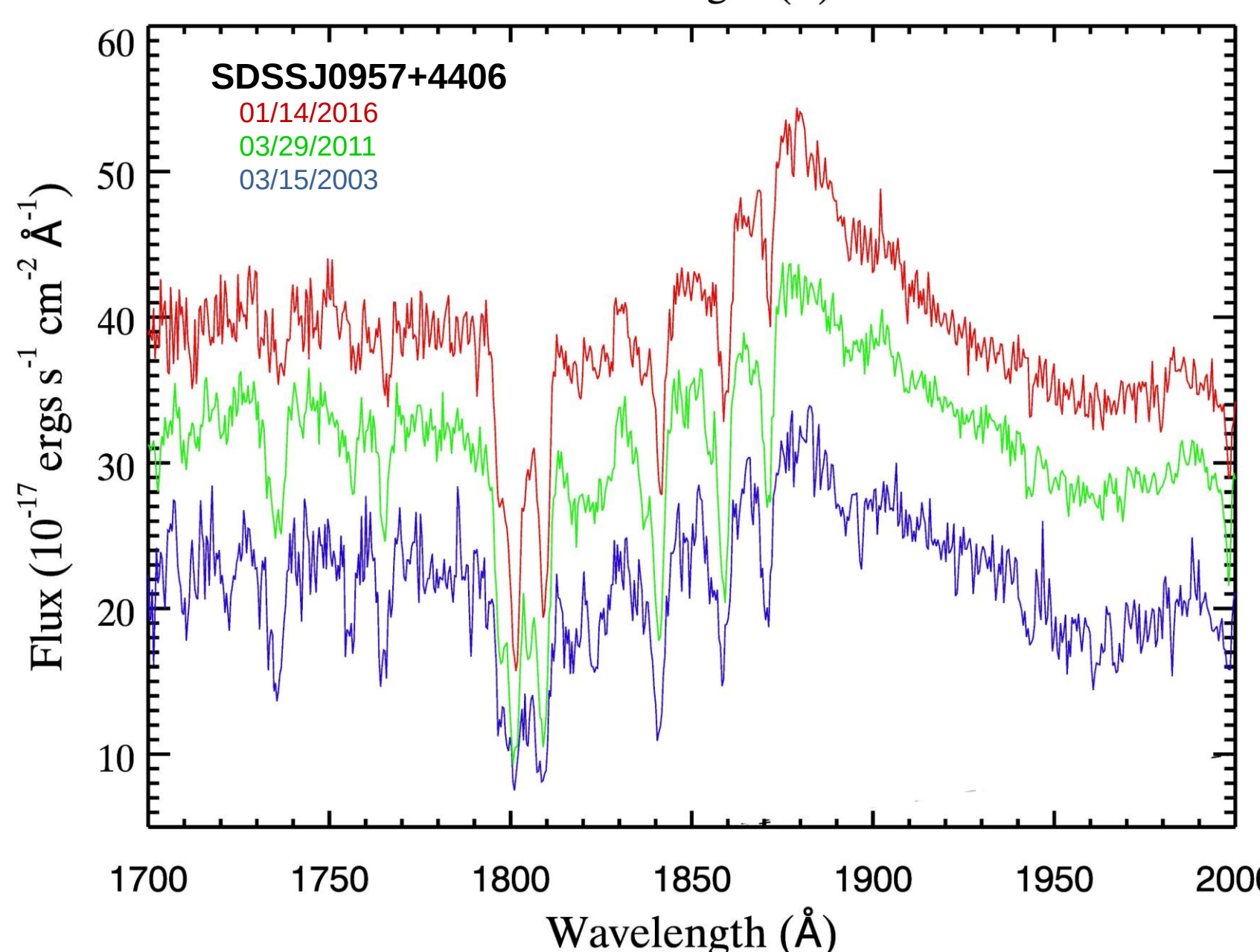
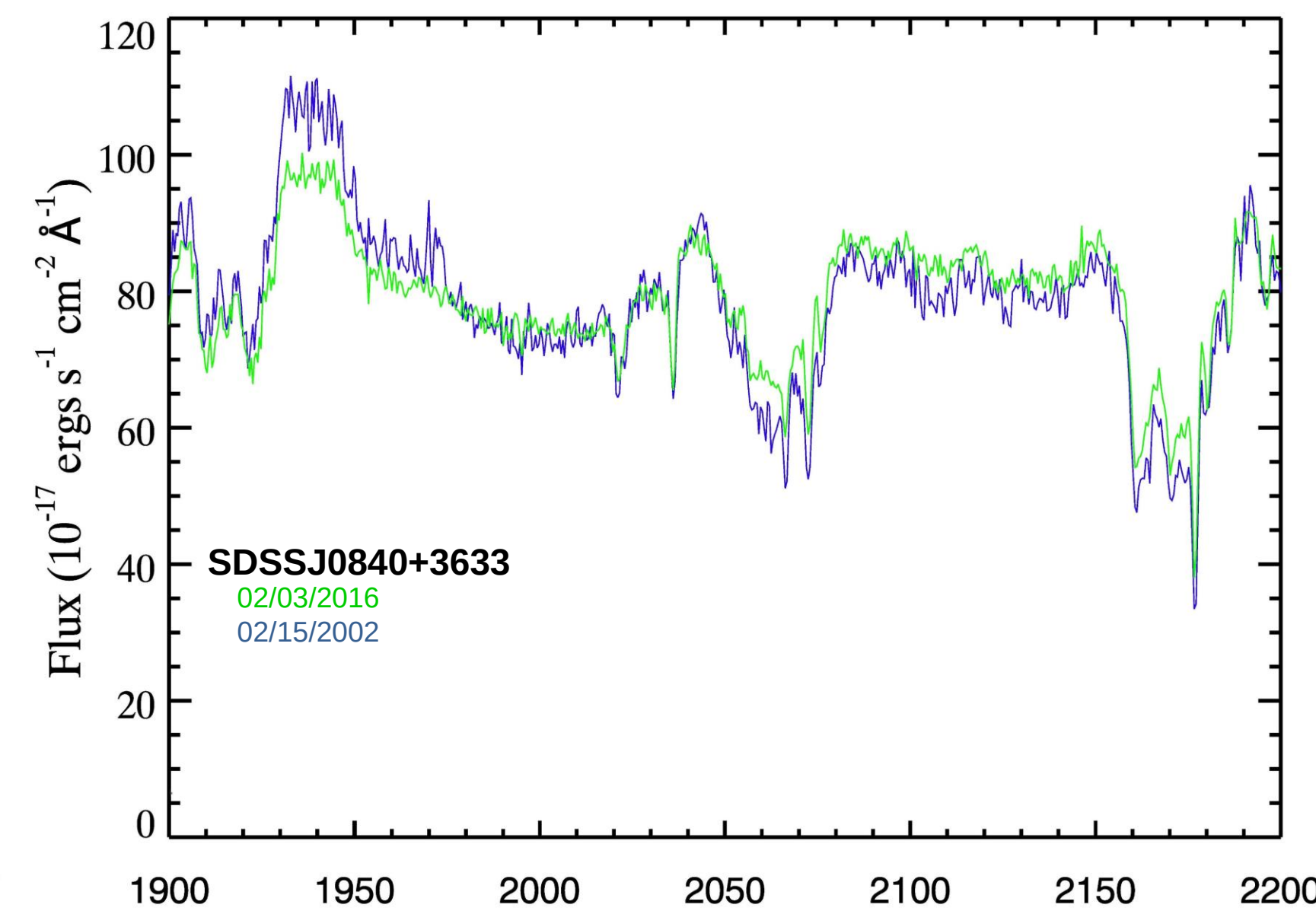
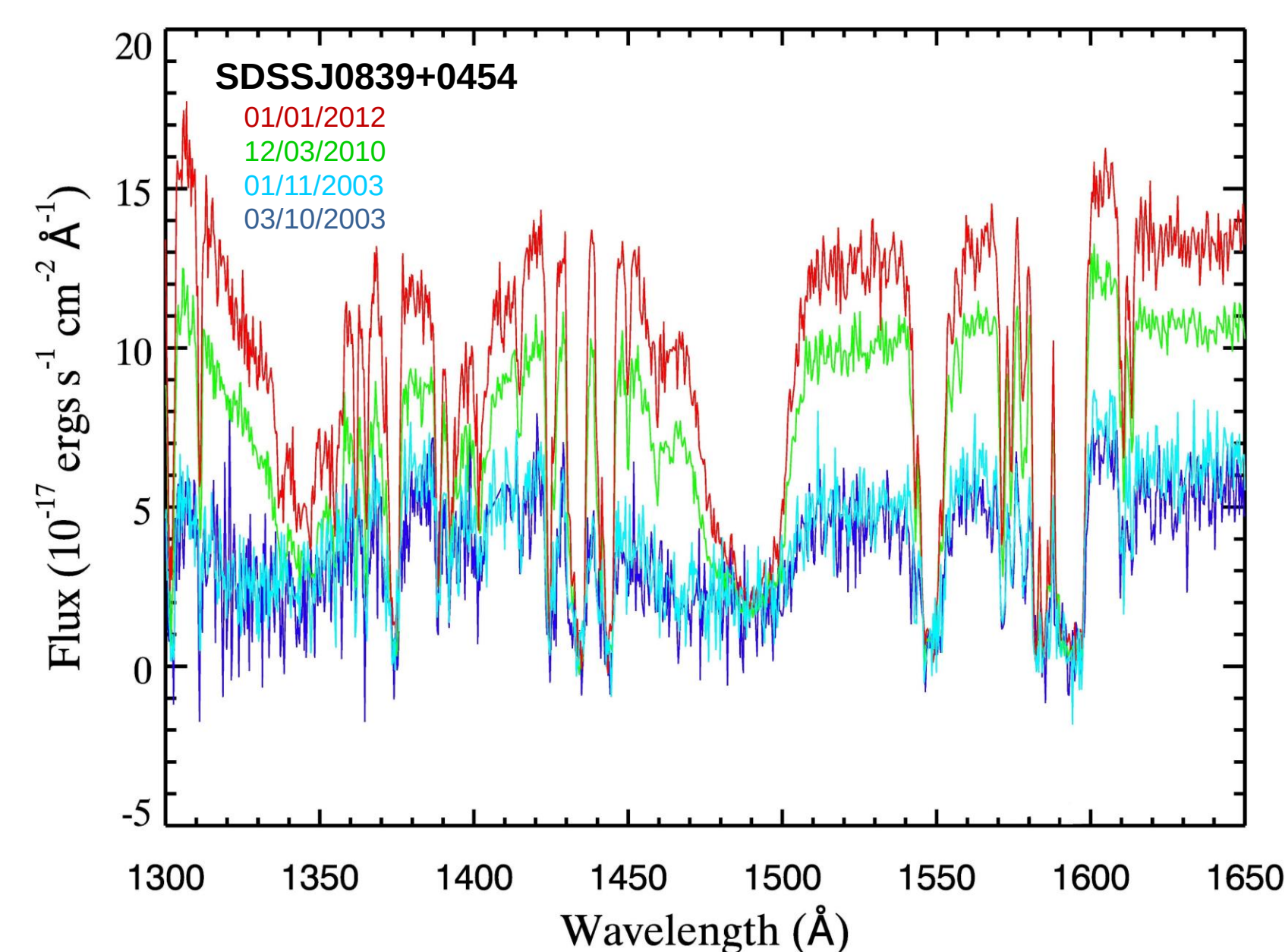


Figure 1 (left)– Sample spectrum of SDSS J0839+0454 plotted in the quasar's rest frame that illustrates the three observations which are colored by date. The troughs are due to the Fe II multiplets (UV 38 and 39 near 2350 Angstroms and 2600 Angstroms, respectively) and the doublet of Mg II $\lambda\lambda 2796, 2804$

Figure 2 (below)– Spectral segments of the four FeLoBAL quasars that demonstrated variability in their BAL troughs. For SDSSJ0939+0454, we plot the C IV doublet $\lambda\lambda 1548, 1550$ BAL and see a radical difference in the deepest and widest trough near 1500 Angstroms. In SDSSJ0840+3633, we plot the Fe II multiplets (see Fig 1) and find that only certain portions of the trough show variability. We show the Al III doublet $\lambda\lambda 1854, 1863$ for SDSSJ0957+4406 which shows a clear transition from a blended BAL to two individual kinematic components. In SDSSJ0838+2955, we plot the C IV region and find both changes in the previously studied BAL (Moe et al. 2009) as well as the presence of a new BAL near 1450 Angstroms.



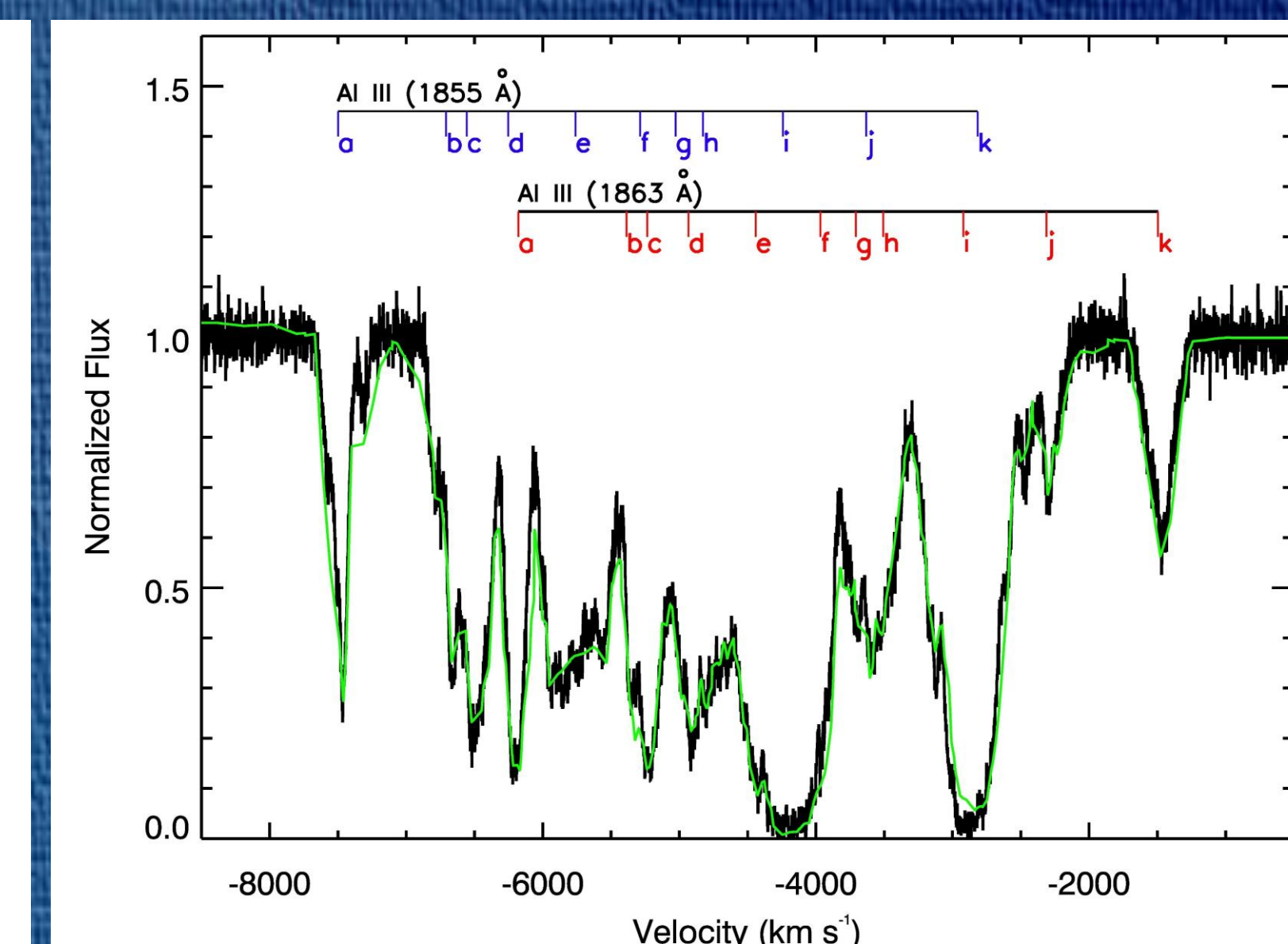
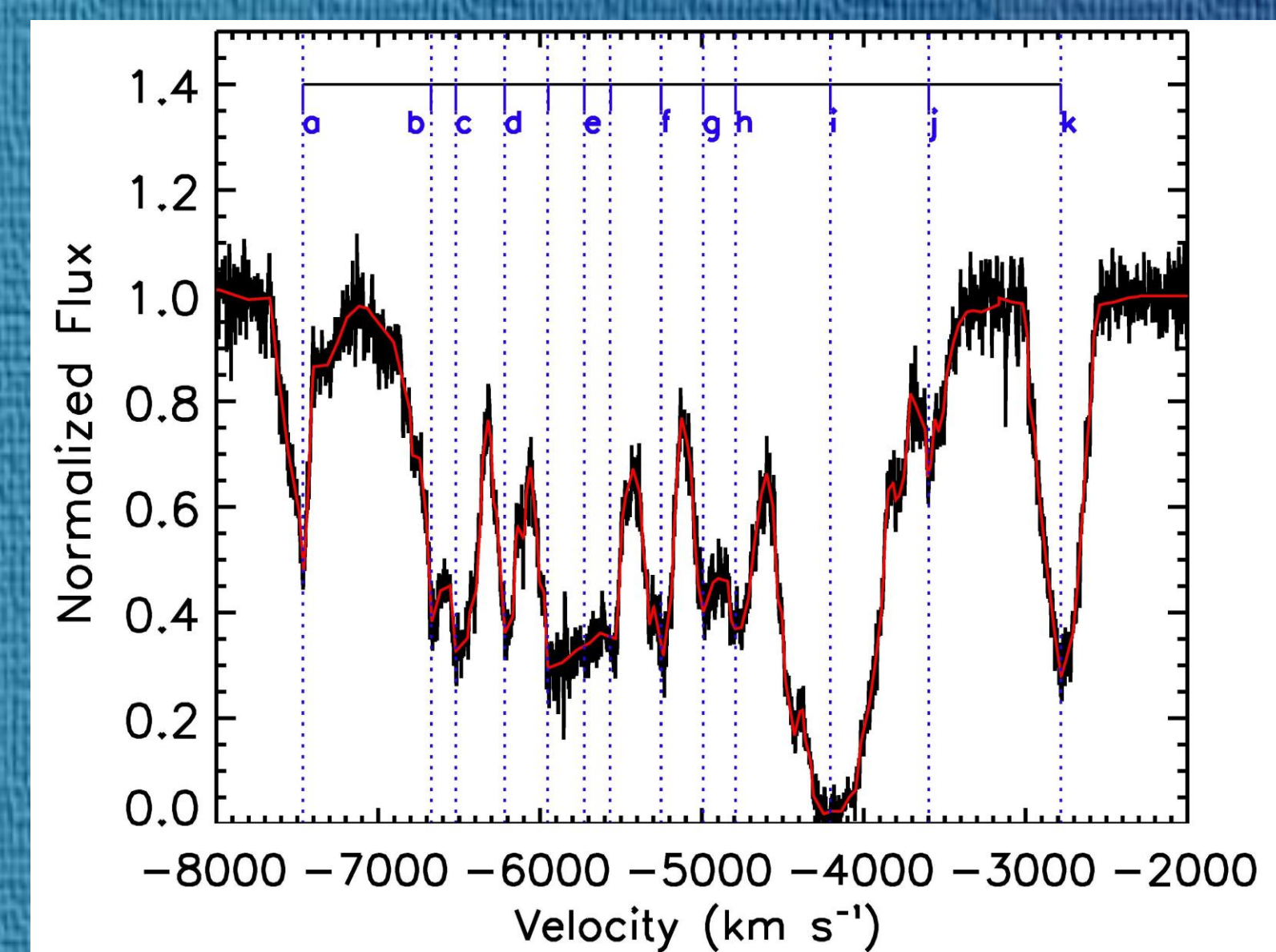
Data Acquisition

- We search for FeLoBALs in the archived optical spectra from the Sloan Digital Sky Survey (SDSS) conducted with a 2.5-m telescope at Apache Point Observatory (APO) through data release 14 (DR14).
- Using the GNU utility wget, we download the spectra from the SDSS website. We then extract and plot the spectra for each object using standard programs in the Information Data Language (IDL, Figure 1).
- We search DR14 for FeLoBAL quasars that fall into a redshift range between $0.5 < z < 1.5$ so that the common Fe II lines are visible in the SDSS spectral range.
- In DR14, we find 35 QSOs with spectra from multiple epochs.

Search for Variability

- We plot the spectra for each object as shown in Figure 1 and inspect the available troughs for signs of variations between epochs.
- We find four objects that show clear signs of variability (Figure 2)
- In the case of SDSS J0838+2955, we see three changes. First, the disappearance of the C IV BAL at $\sim 22,000$ km s⁻¹ (C IVa – Moe et al. 2009). The appearance of a new trough with a velocity of $\sim 16,000$ km s⁻¹. Finally, we see that there is a weakening of the widest BAL at approximately 1500 Angstroms.
- For SDSS J0840+3633 the depth of the BAL trough changes, however, the kinematic subcomponents are clearly defined and appear to remain static.
- SDSSJ0839+0454 shows drastic changes in both flux level and BAL depths between the 4 epochs.
- The BAL in SDSSJ0957+4406 appears to shift from a contiguous BAL to individual kinematic components.

Figure 3 (Left) – The segment of the SDSS spectrum of QSO0318-0600 showing the Al II $\lambda 1671$ trough plotted in velocity space. We show the template match for the 11 components (a through k). **(Right)** – The segment of the same spectrum showing the Al III doublet $\lambda\lambda 1855, 1863$. We use two Al II templates (blue and red for the members of the doublet, respectively), scale each component in optical depth, and blend the templates to match the Al III BAL (green).



Implications of the Trough Structure

- In a previous study, Dunn et al. (2010) showed that an Al II template could match the BAL troughs for every other ion visible in the spectrum (e.g., Al III – Figure 3).
- We find in that the BAL in SDSS J0838+2955 at a velocity of ~ 9700 km s⁻¹ shows a weakening of the optical depth near the lowest velocity of the BAL.
- Given the substructure matches seen in QSO0318-0600, this suggests that only one of the kinematic components that comprise the blended C IV BAL has varied – perhaps some of the material generating the trough has moved from the line-of-sight to the nucleus.
- In future work, we plan to match a low ionization species template to that of C IV to determine if this is the case.

Conclusions and Discussion

- We find 4 FeLoBAL quasars that show clear trough changes over time.
- Two of these objects demonstrate changes in what appears to be a subcomponent, while one object shows that the BAL devolves into individual components.
- This suggests that the classic continuous BAL troughs are a blend of several individual troughs and that these are potential individual clouds or clumps.

References

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| Dunn, J. P. et al. 2010, ApJ, 709, 611 | Moe et al. 2009, ApJ, 706, 525 |
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