Variable High Velocity Winds from Broad Absorption Line Quasars

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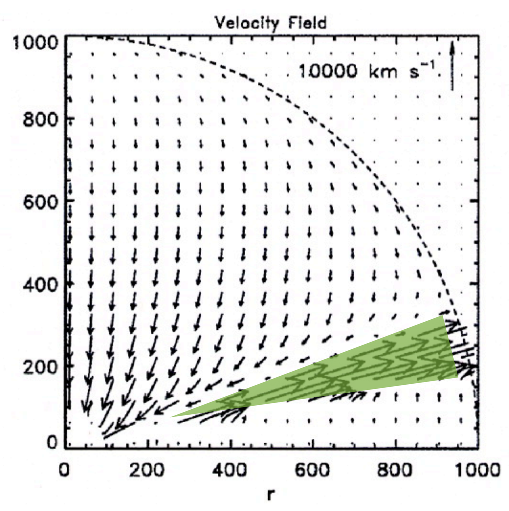
Introduction

Quasar Outflows

- Most quasars show narrow absorption lines, whereas broad absorption lines (BALs) are less common and indicate acceleration — a massive, fast outflow originating near the supermassive black hole (SMBH).



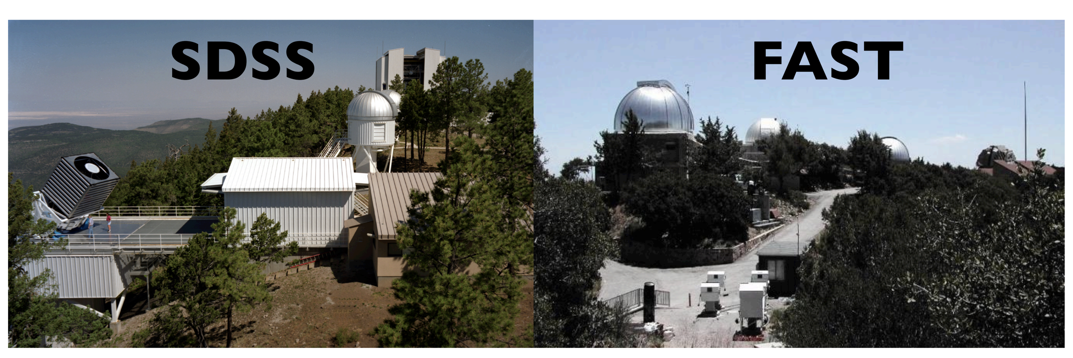
- (*Left*) A QSO velocity field in the disk wind model; the green region marks a high velocity outflow (Proga, et al. 2000).
- BAL variability probes the structure, stability, location, energetics, and dynamics of the wind.

Motivation

- We aim to study the timescales, strengths, and velocity characteristics of variability in BAL QSO spectra, to constrain the size, location and physical state of the gas nearest the SMBH.
- Observations include seventeen BAL QSOs from the SDSS and the FLWO's FAST spectrograph as well as a set of control non-BAL quasar spectra, in which we expect to see little or no variability.

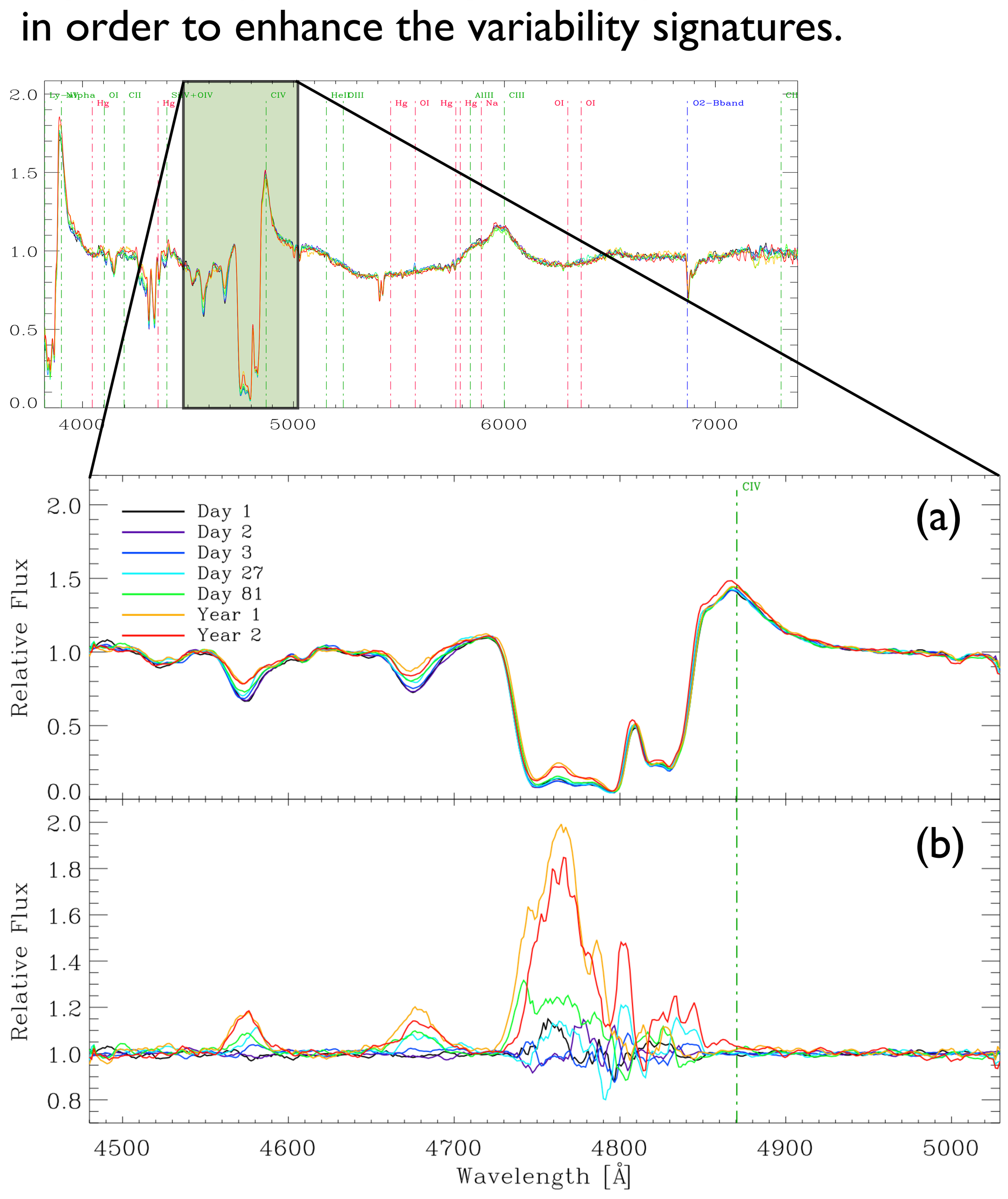
Data Collection

- The Sloan Digital Sky Survey provides photometry in five filters (u,g,r,i,z) and first-epoch spectroscopy.
- The Fred Lawrence Whipple Observatory hosts the 1.5m Tillinghast telescope including the high-throughput FAST spectrograph, with which we acquire multi-epoch spectroscopy.



Cadences

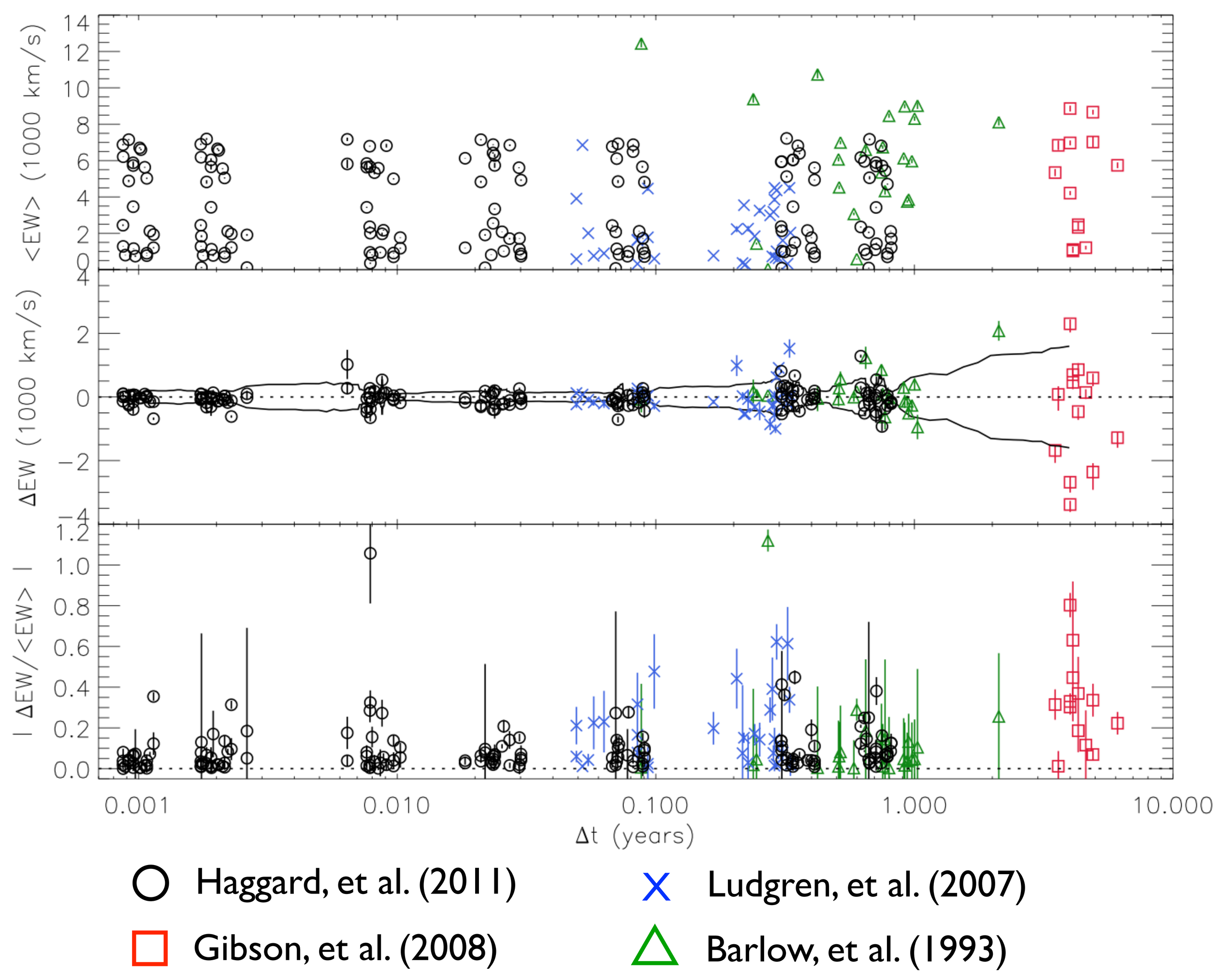
- 19 BAL QSO are first observed across 3 consecutive nights, then for one night at cadences of 9, 27, and 81 days, then later at 1, 2, and 6 years.
- The spectra below are continuum-normalized multi-epoch FAST spectroscopy for SDSS J1007+0532.
- The lower panels show (a) a zoom-in on the CIV BAL region, and (b) the average FAST spectrum divided out in order to enhance the variability signatures.



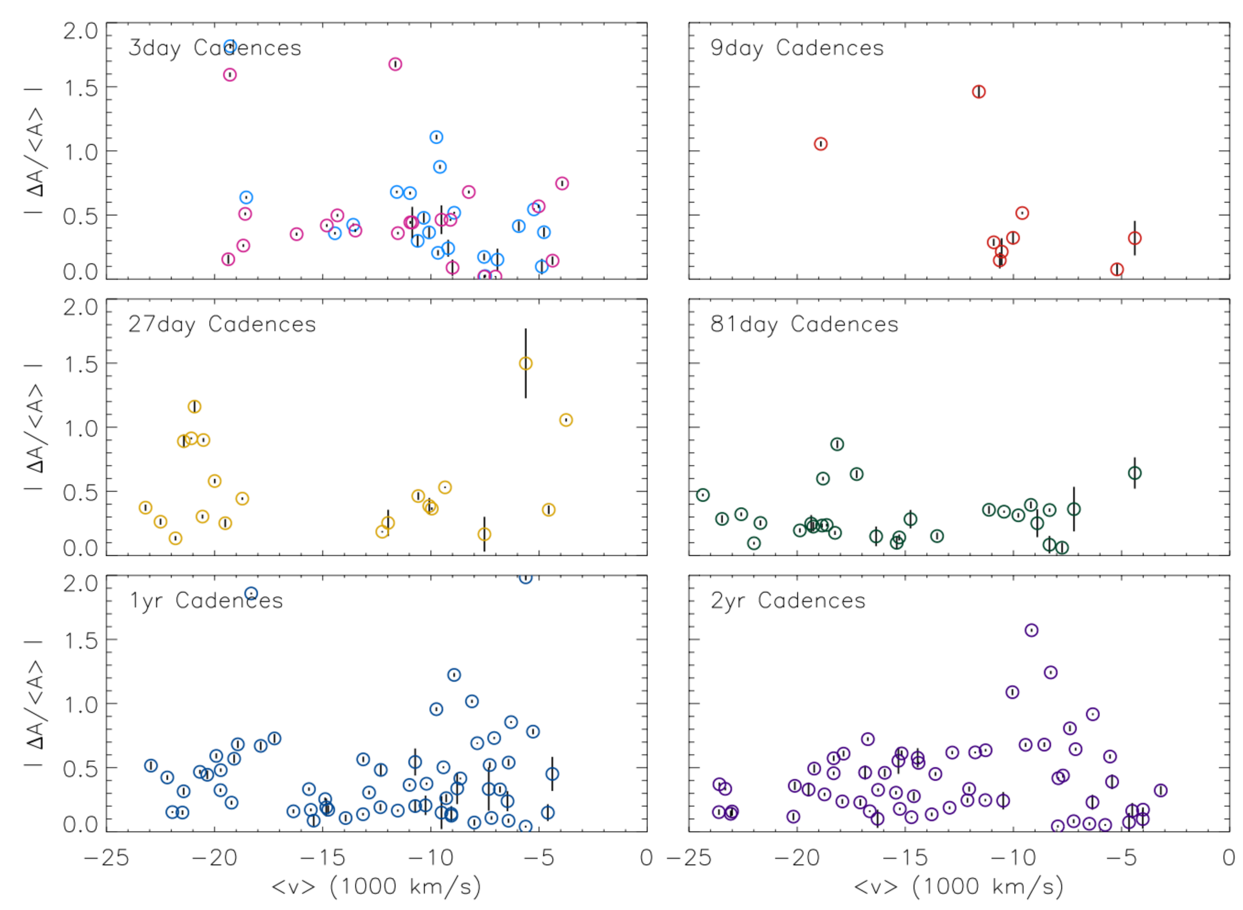
Results

Ensemble Trends

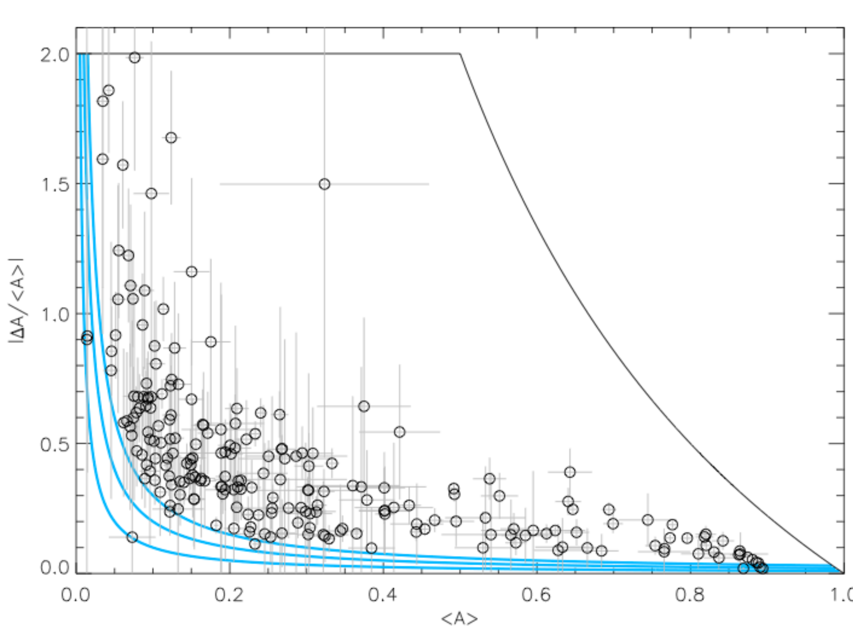
- Average CIV BAL equivalent width (EW) vs. the rest-frame time between epochs (Δt; *top*); change in EW ($\Delta EW = EW_{epochN} - EW_{epoch1}$) vs. rest-frame Δt (*middle*), and the magnitude of the fractional change in EW vs. Δt (*bottom*).

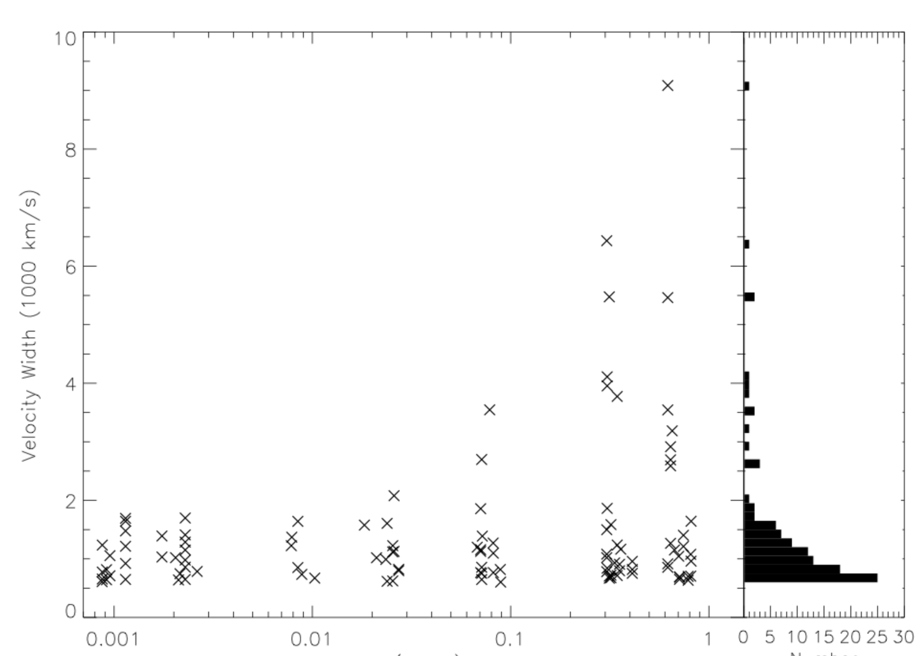


- The solid lines above mark the square root of the unbiased sample variance calculated from a sliding window of 15 time-ordered entries. The envelope of ΔEW appears to expand with time.



- (*Above*) Fractional change in the absorption strength, | ΔA /<A> |, vs. the mean outflow velocity for *variable* velocity intervals. This indicates the amplitude of the variability as a function of velocity.
- (*Right*) Fractional change vs. <A>. Individual quasars may contribute multiple times at a given value of <A>. Solid black curve: maximum possible | ΔA/<A> |. Cyan curves: detection limits.





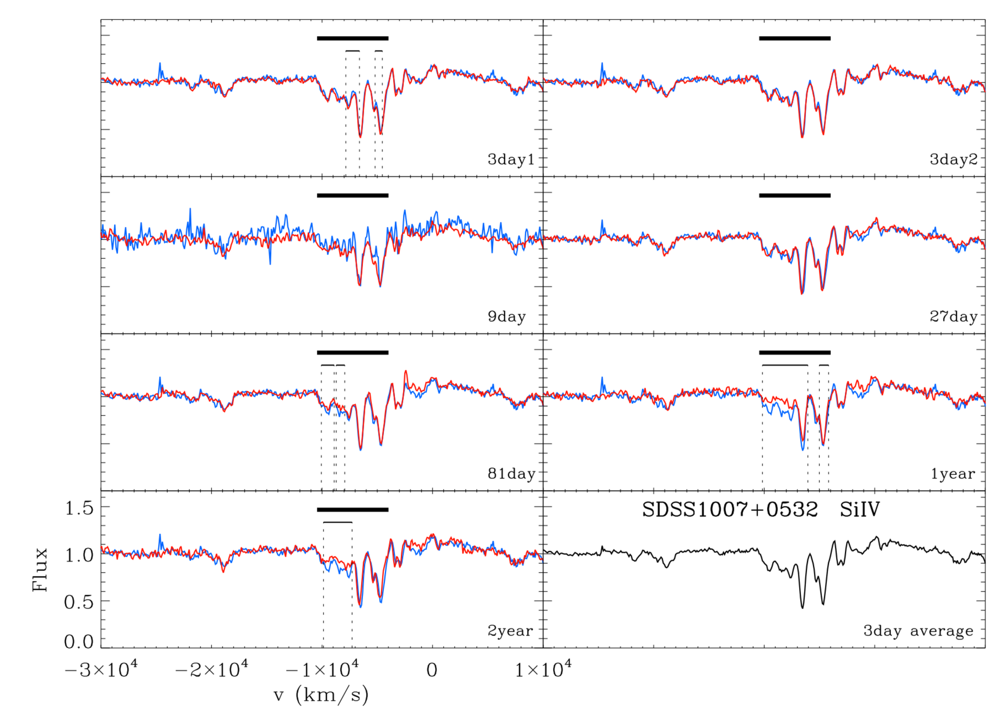
- (*Left*) Velocity width of variable intervals vs. rest-frame Δt, together with a histogram of velocity width. Variability clearly increases toward larger Δt.

Results

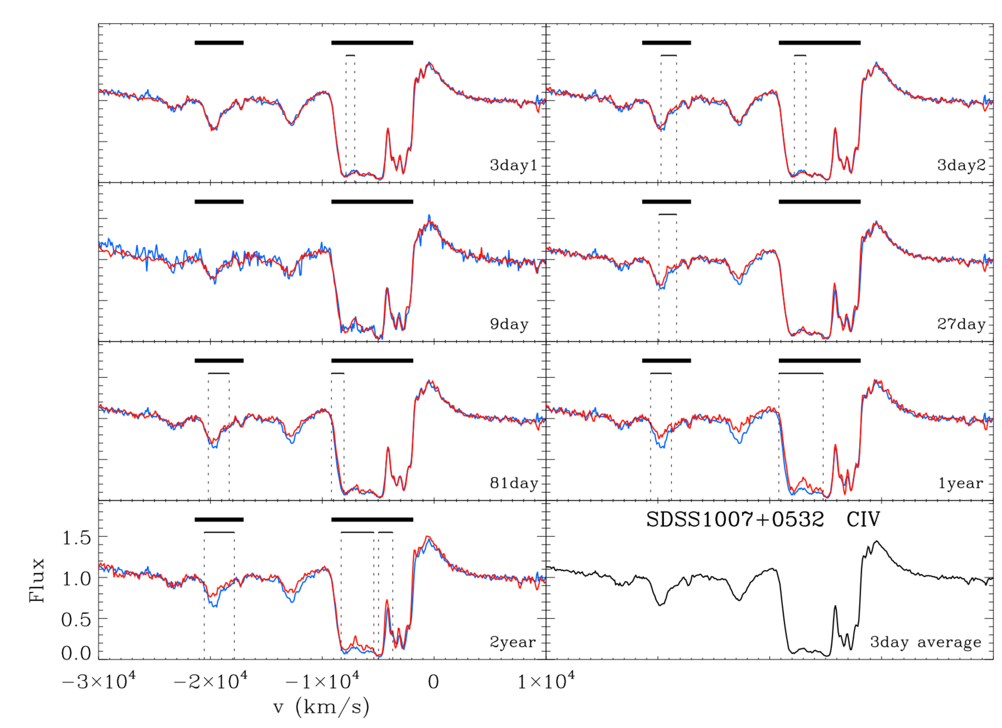
Variability

- The strongest BAL regions (SiIV, CIV, AlII, MgII) are isolated and searched for variability.

SiIV



CIV



- The one and two year time intervals, in particular, indicate substantial variation.

In Context

- The table below shows this work, together with previous, in-progress, and proposed spectroscopic BAL monitoring programs. Ours is the most uniform probe of BAL QSO winds performed at multiple cadences.

Spectroscopic Monitoring of BAL QSOs

Sample	# BAL	Δt_{min}	Δt_{max}	# Epochs
Barlow'93	23	0.12	3.05	2 – 11
Lundgren'07	29	0.05	0.3	2
Gibson'08	13	3.0	6.1	2
Gibson'10	14	~0.04	6.8	2 – 4
Capellupo'11	24	0.35	7.74	2 – 4
Haggard'11	17	0.001	0.9	6
BOSS Ancillary	~2000	~1.3	~4	2 – 3
BOSS-Plus	~600	0.7	~4.7	2 – 5

Table 1: Δt_{min}, Δt_{max} are rest-frame time intervals. For the BOSS ancillary (PI: N. Brandt) and proposed BOSS-Plus (PI: N. Ross) programs, intervals are estimated for a CIV BAL at z= 2.

Future Work

We will continue to assess the magnitude of the variability in the observed spectra of our BAL QSOs and determine which constraints our investigations can put on the outflows impacting the BAL region.

Acknowledgments

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