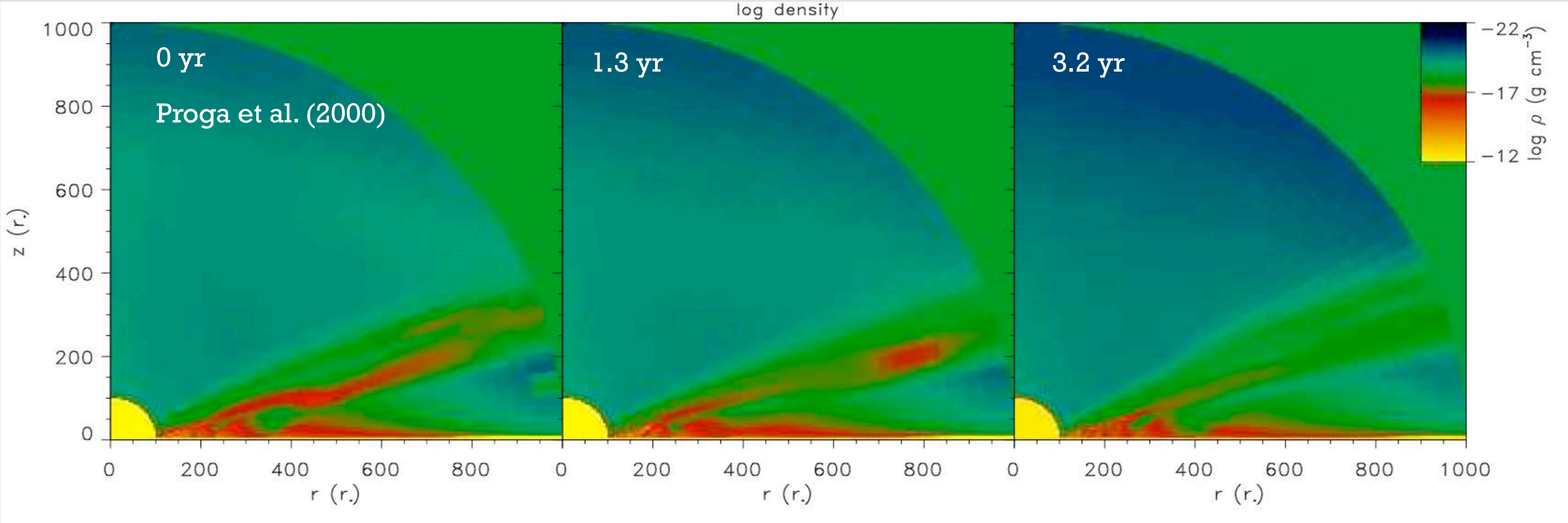
Multi-Year BAL Variability: Current Results and SDSS-III Prospects

Density Maps from BAL Quasar Wind Simulation



Launching radius is typically taken to be ~ $10^{16\text{-}17}$ cm.

Significant dynamical evolution expected on multi-year timescales.

Characteristic timescale for disk rotation (>10%) and for BAL material crossing.

Main Collaborators

Sarah Gallagher
Paul Hewett
Don Schneider

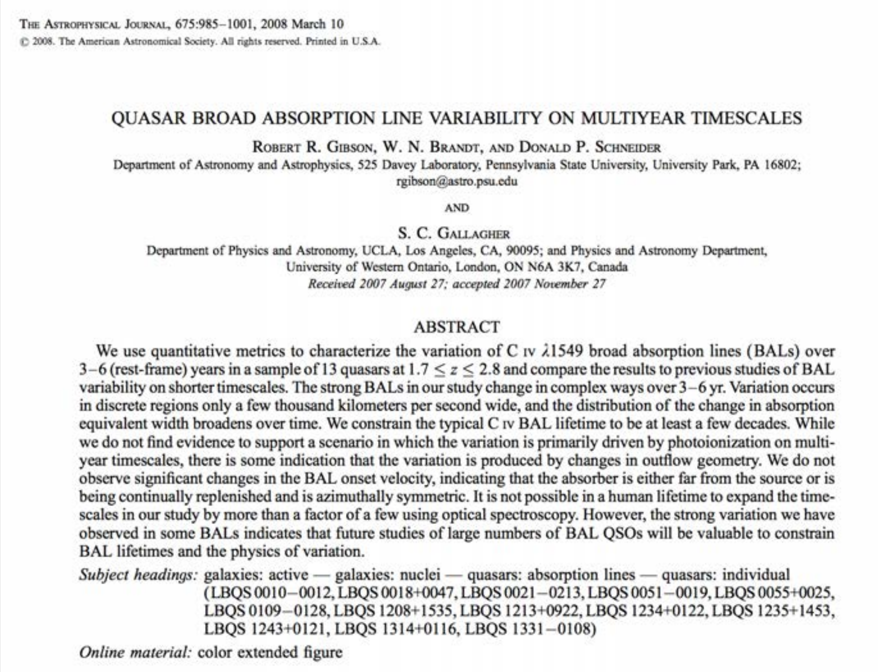
Pat Hall

SDSS-III BAL Quasars Group
(e.g., Anderson, Gibson, Hewett,
Petitjean, Ross, Schneider)

Current Results

Relevant Publications

Gibson et al. (2008)



The Astrophysical Journal, 675:985–1001, 2008 March 10

QUASAR BROAD ABSORPTION LINE VARIABILITY ON MULTIYEAR TIMESCALES

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ABSTRACT

We use quantitative metrics to characterize the variation of C iv λ1549 broad absorption lines (BALs) over 3–6 (rest-frame) years in a sample of 13 quasars at $1.7 \leq z \leq 2.8$ and compare the results to previous studies of BAL variability on shorter timescales. The strong BALs in our study change in complex ways over 3–6 yr. Variation occurs in discrete regions only a few thousand kilometers per second wide, and the distribution of the change in absorption equivalent width broadens over time. We constrain the typical C iv BAL lifetime to be at least a few decades. While we do not find evidence to support a scenario in which the variation is primarily driven by photoionization on multiyear timescales, there is some indication that the variation is produced by changes in outflow geometry. We do not observe significant changes in the BAL onset velocity, indicating that the absorber is either far from the source or is being continually replenished and is azimuthally symmetric. It is not possible in a human lifetime to expand the timescales in our study by more than a factor of a few using optical spectroscopy. However, the strong variation we have observed in some BALs indicates that future studies of large numbers of BAL QSOs will be valuable to constrain BAL lifetimes and the physics of variation.

Subject headings: galaxies: active — galaxies: nuclei — quasars: absorption lines — quasars: individual (LBQS 0010−0012, LBQS 0018+0047, LBQS 0021−0213, LBQS 0051−0019, LBQS 0055+0025, LBQS 0109−0128, LBQS 1208+1535, LBQS 1213+0922, LBQS 1234+0122, LBQS 1235+1453, LBQS 1243+0121, LBQS 1314+0116, LBQS 1331−0108)

Online material: color extended figure

Gibson et al. (2010)

The Astrophysical Journal, 713:220–231, 2010 April 10
doi:10.1088/0004-637X/713/1/220

THE EVOLUTION OF QUASAR C IV AND Si IV BROAD ABSORPTION LINES OVER MULTI-YEAR TIMESCALES

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ABSTRACT

We investigate the variability of C IV λ1549 broad absorption line (BAL) troughs over rest-frame timescales of up to $\approx$7 yr in 14 quasars at redshifts $z \gtrsim 2.1$. For nine sources at sufficiently high redshift, we also compare the C IV and Si IV λ1400 absorption variation. We compare shorter and longer term variability using spectra from up to four different epochs per source and find complex patterns of variation in the sample overall. The scatter in the change of absorption equivalent width (EW), ΔEW, increases with the time between observations. BALs do not, in general, strengthen or weaken monotonically, and variation observed over shorter ($\lesssim$months) timescales is not predictive of multi-year variation. We find no evidence for asymmetry in the distribution of ΔEW that would indicate that BALs form and decay on different timescales, and we constrain the typical BAL lifetime to be $\gtrsim$30 yr. The BAL absorption for one source, LBQS 0022+0150, has weakened and may now be classified as a mini-BAL. Another source, 1235+1453, shows evidence of variable, blue continuum emission that is relatively unabsorbed by the BAL outflow. C IV and Si IV BAL shape changes are related in at least some sources. Given their high velocities, BAL outflows apparently traverse large spatial regions and may interact with parsec-scale structures such as an obscuring torus. Assuming BAL outflows are launched from a rotating accretion disk, notable azimuthal symmetry is required in the outflow to explain the relatively small changes observed in velocity structure over times up to 7 yr.

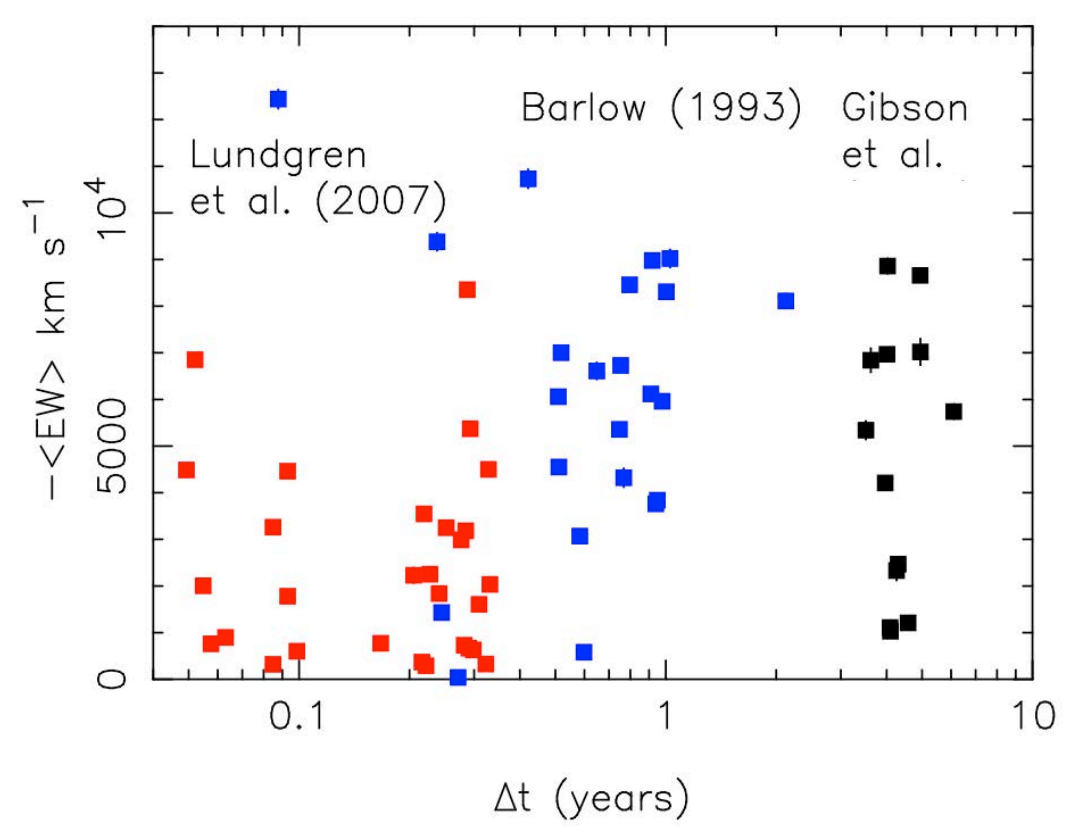
Key words: galaxies: active – galaxies: nuclei – quasars: absorption lines – quasars: emission lines – quasars: individual (LBQS 0009+0219, LBQS 0019+0107, LBQS 0021−0213, LBQS 0022+0150, LBQS 0025−0151, LBQS 0029+0017, LBQS 1231+1320, LBQS 1235+0857, LBQS 1235+1453, LBQS 1240+1607, LBQS 1243+0121, LBQS 1314+0116, LBQS 1442−0011, LBQS 1443+0141) – X-rays: general

Online-only material: color figures, extended figures

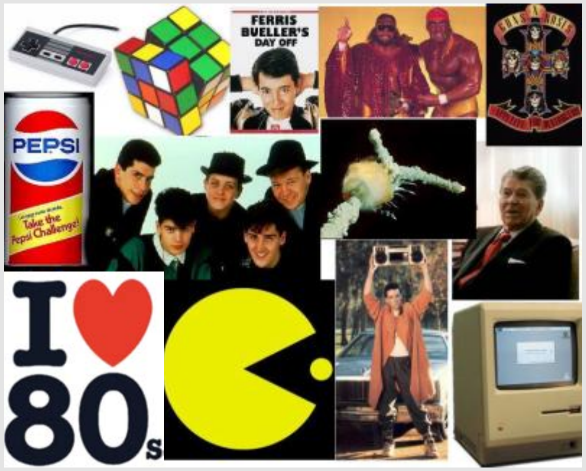
Will give a few highlights from these papers; many more findings and important technical details in these papers.

Long Rest-Frame Timescales

Timescales of Some BAL Variability Samples

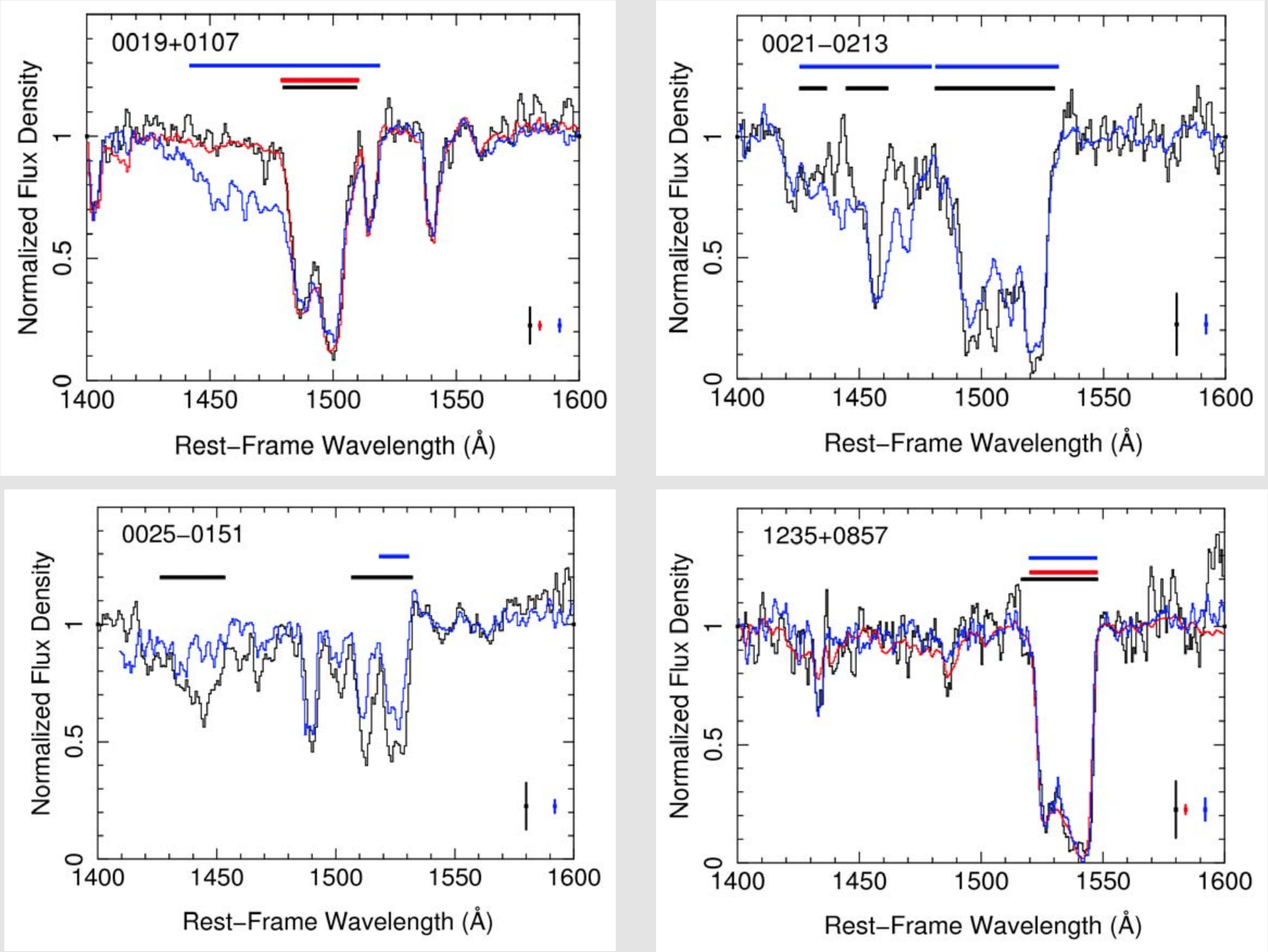


Compared 1980’s LBQS/Palomar vs. 2000’s SDSS/HET for two samples (23 quasars total).



vs.

BAL Variability Commonly Seen



C IV Var. Examples

Variability seen in 70-90% of 23 objects.

LBQS
1986-1988

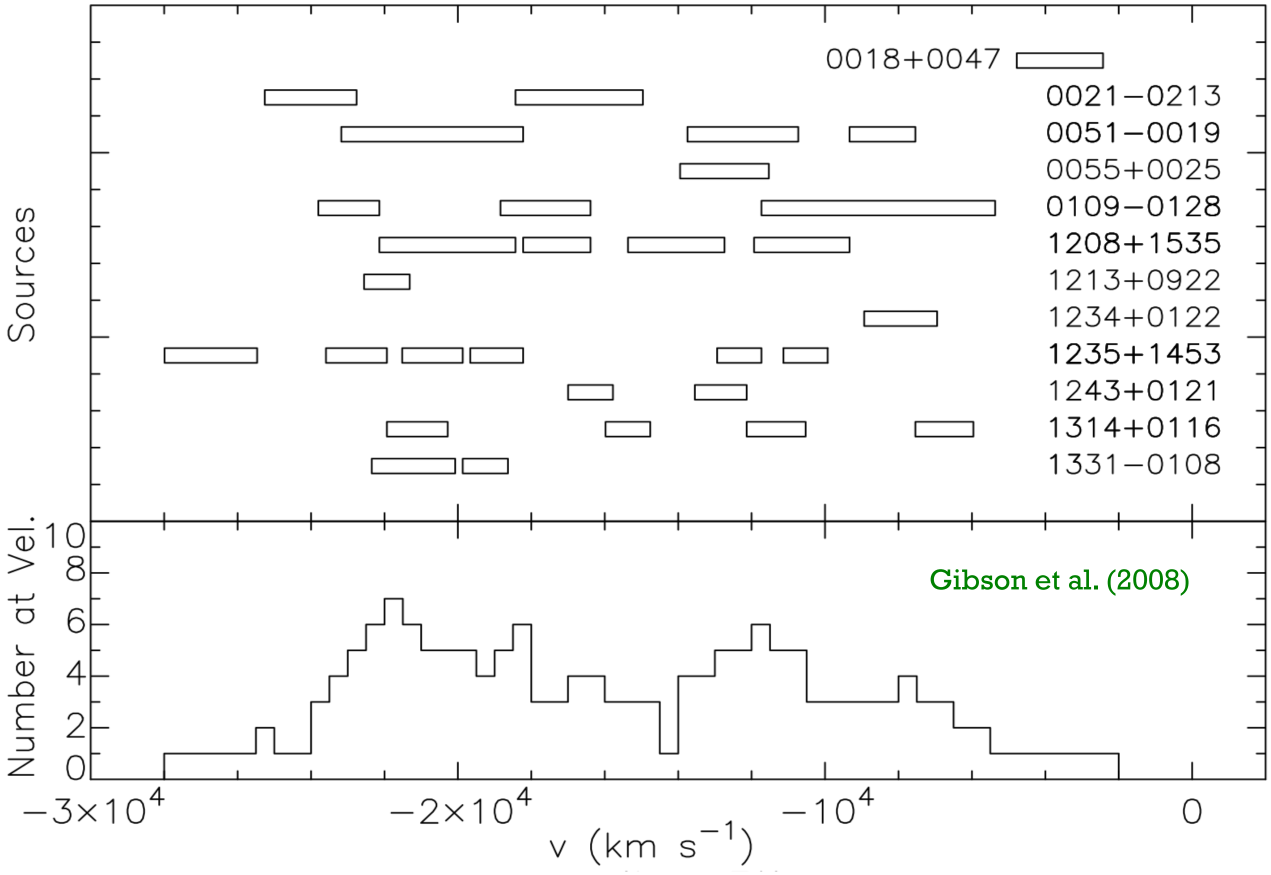
Palomar
1988-1989

HET
2008-2009

Gibson et al. (2010)

Velocity Distribution of Variations

Velocity Regions Observed to Vary on Multi-Year Timescales

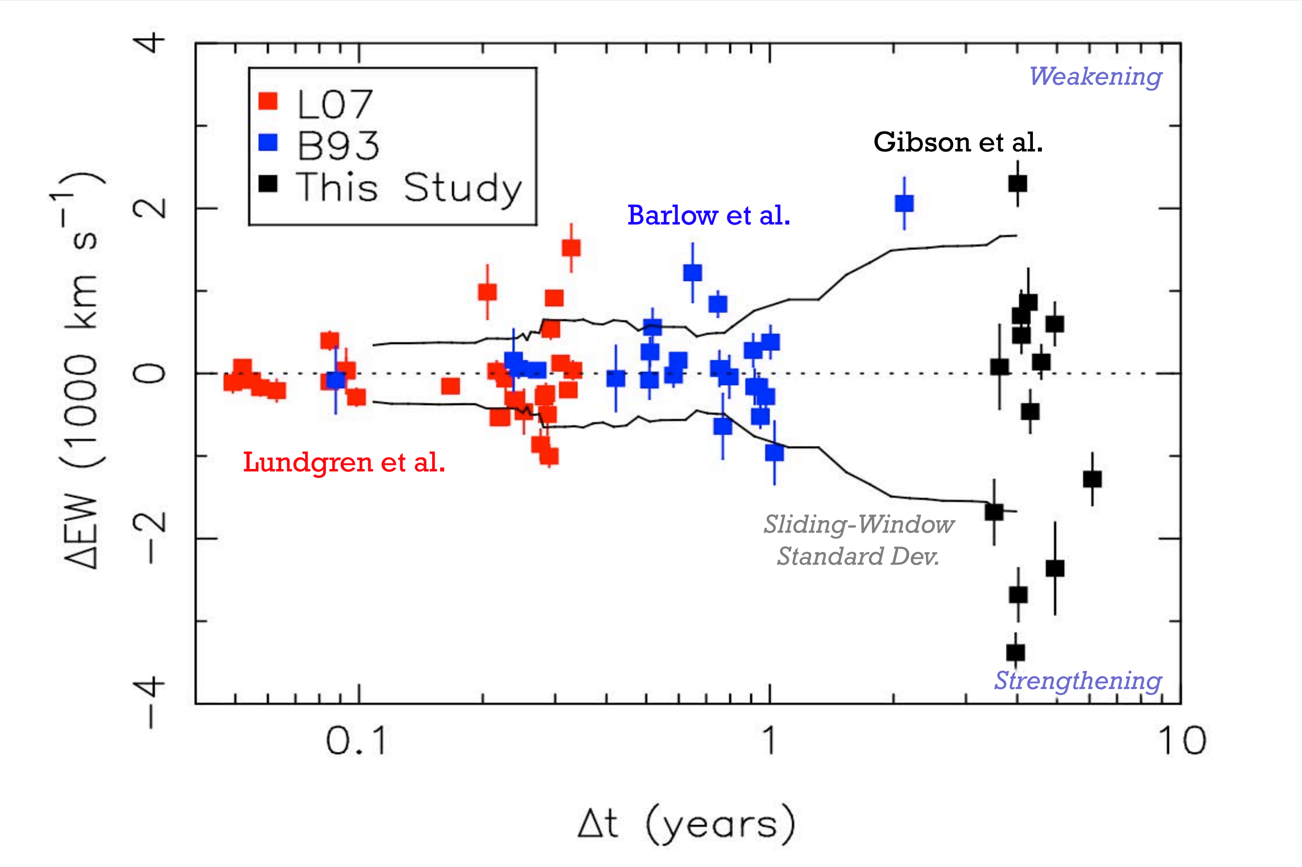


Gibson et al. (2008)

Multi-year variations occur over broad range of velocities; 6000-24000 km s^{-1}.

Effects of Rest-Frame Timescale

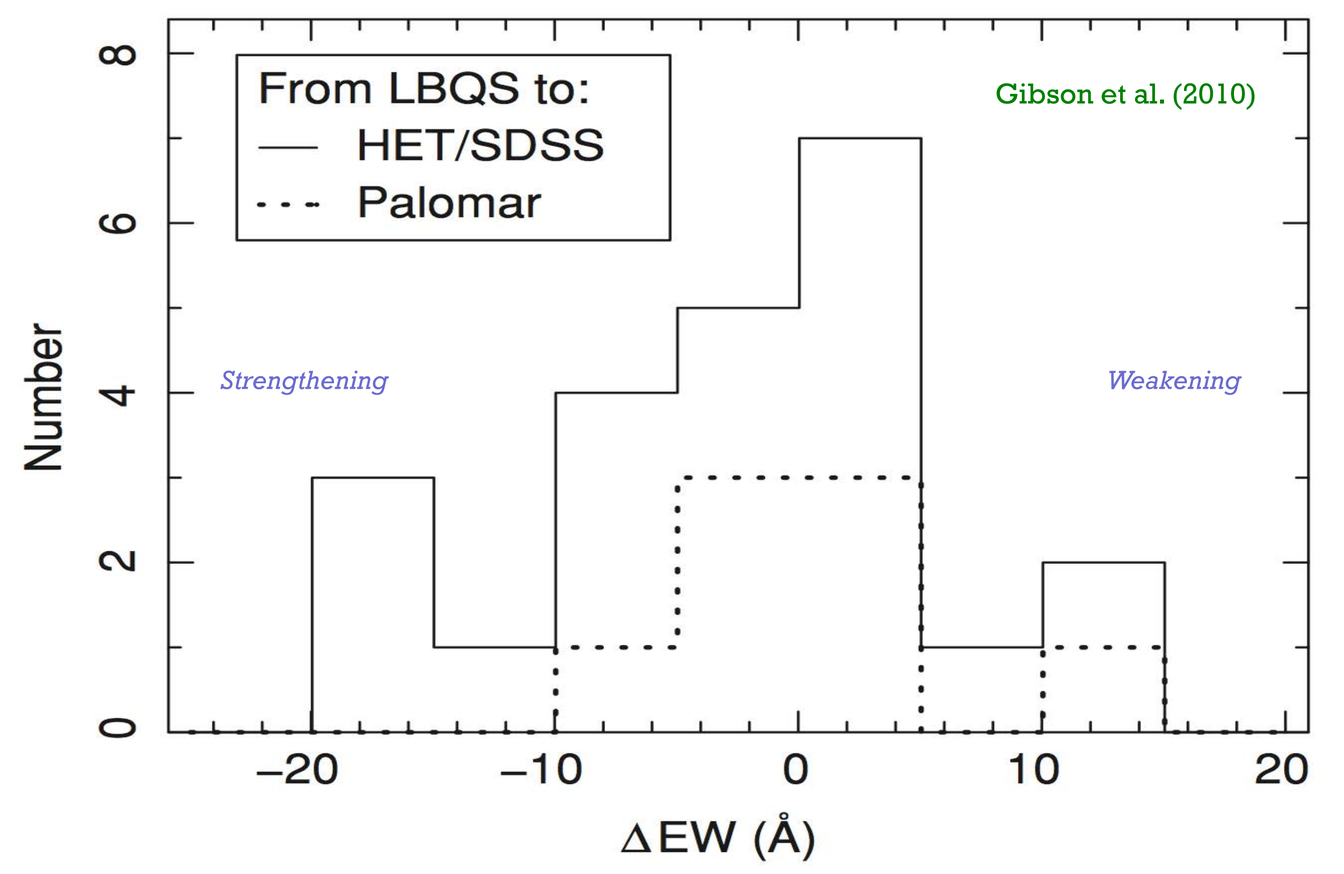
C IV BAL EW Changes vs. Rest-Frame Timescale



BALs vary more strongly on long timescales.

No Preferential Strengthening / Weakening

Histogram of C IV BAL EW Changes Over 3-7 Rest-Frame Years

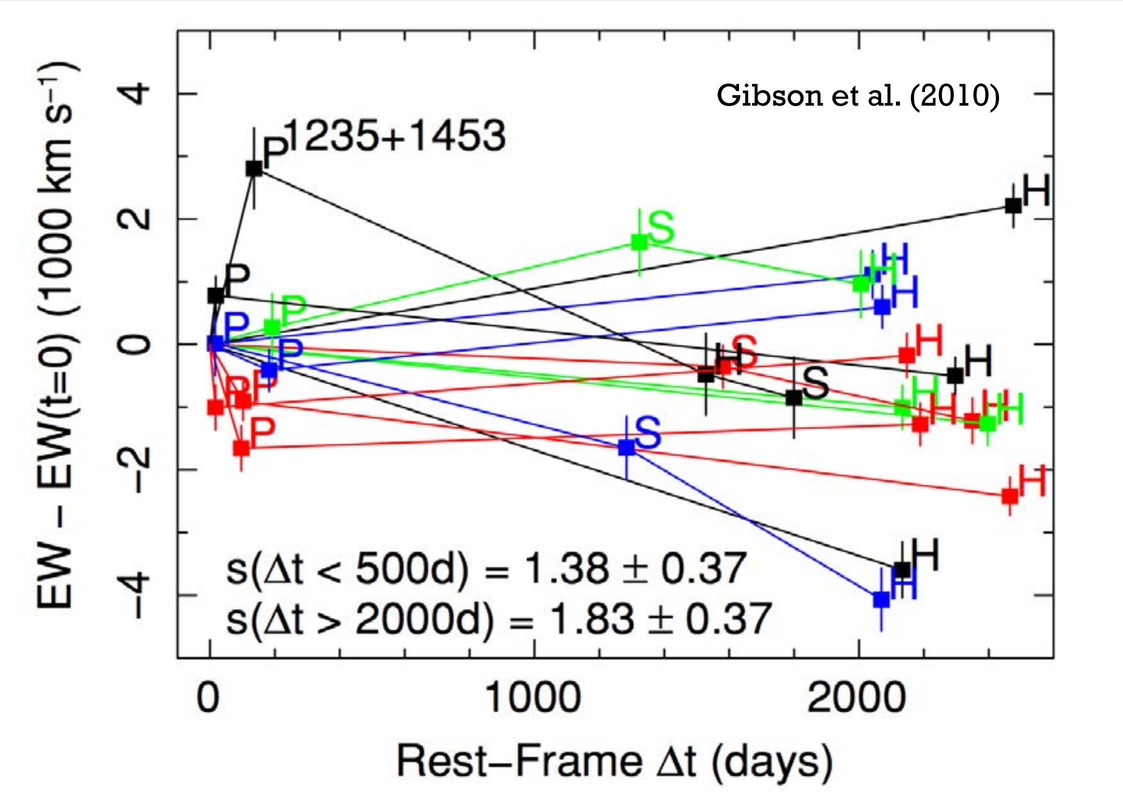


BALs strengthen vs. weaken comparably often (13/23 strengthen in full sample).

Asymmetry could occur, e.g., with fast formation then slow decay.

Multi-Month vs. Multi-Year EW Variations

LBQS-Palomar-SDSS-HET Variations of C IV EW



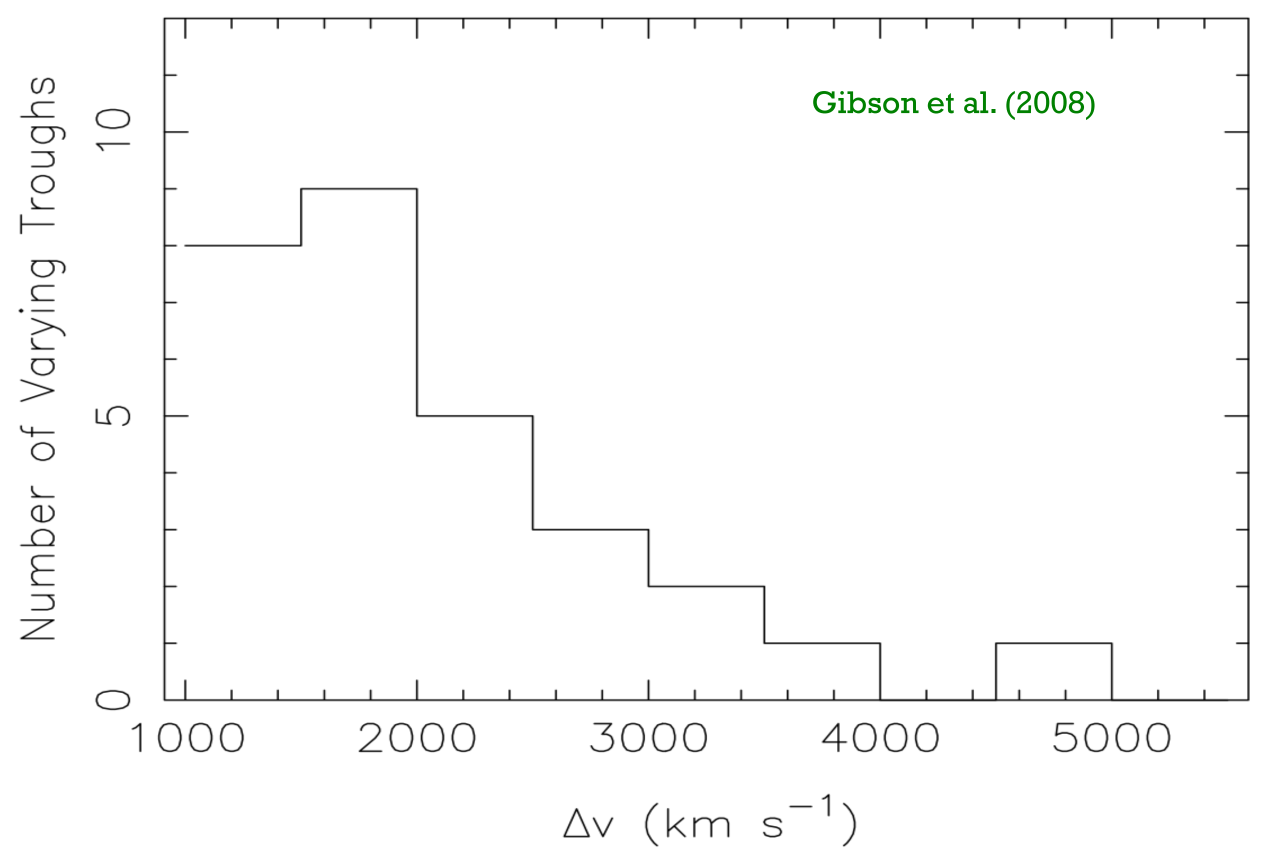
LBQS + Palomar + SDSS + HET gives 3-4 epochs spanning months-years.

In general, BALs do not strengthen or weaken monotonically.

Multi-month variations do not predict multi-year variations.

Discrete Velocity Regions of Variation

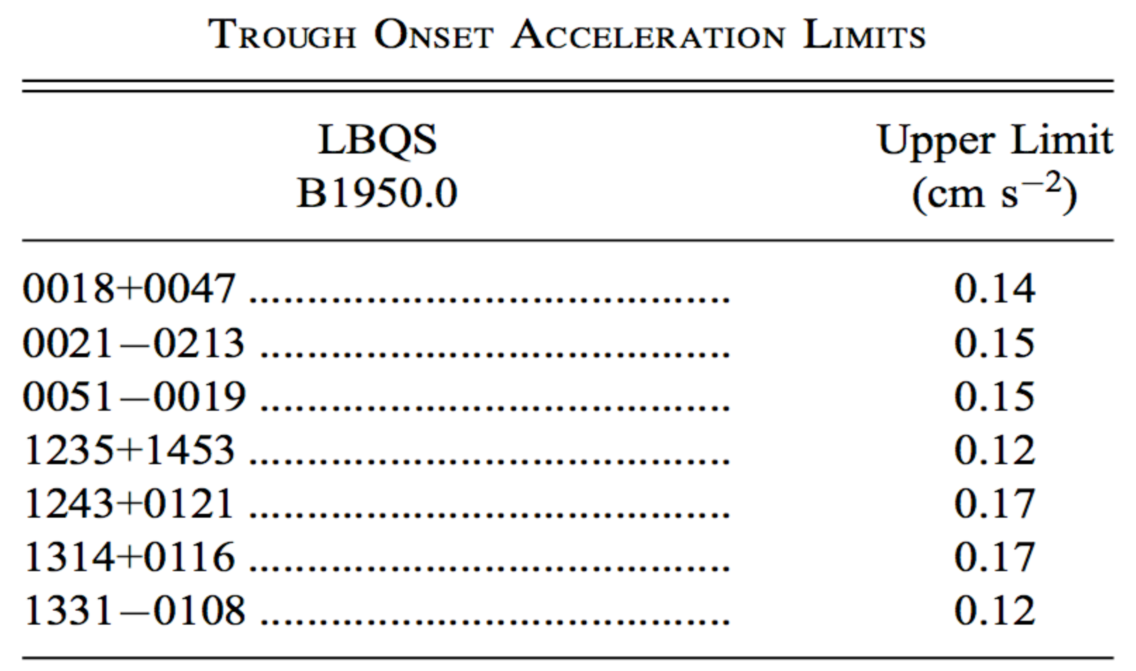
Number of Varying C IV Absorption Regions vs. Velocity Width



On multi-year timescales, BALs often vary in discrete regions of width ~ 1000-3000 km s^{-1} (not monolithically). "Quantization" of BALs?

BAL Acceleration Constraints

Acceleration Constraints for BALs with Steep Onset Regions



Trough Onset Acceleration Limits

LBQS B1950.0	Upper Limit (cm s^{-2})
0018+0047	0.14
0021−0213	0.15
0051−0019	0.15
1235+1453	0.12
1243+0121	0.17
1314+0116	0.17
1331−0108	0.12

Gibson et al. (2008)

Long-timescale constraints powerful since velocity shifts accumulate over time.

BAL acceleration is rare - only a few examples known. Three candidates from our work needing further multi-year monitoring.

Consistent with gas being in "standing pattern" outflow (azimuthally symmetric).

SDSS-III
Prospects

How to Do Better?

Many possible approaches to doing better:

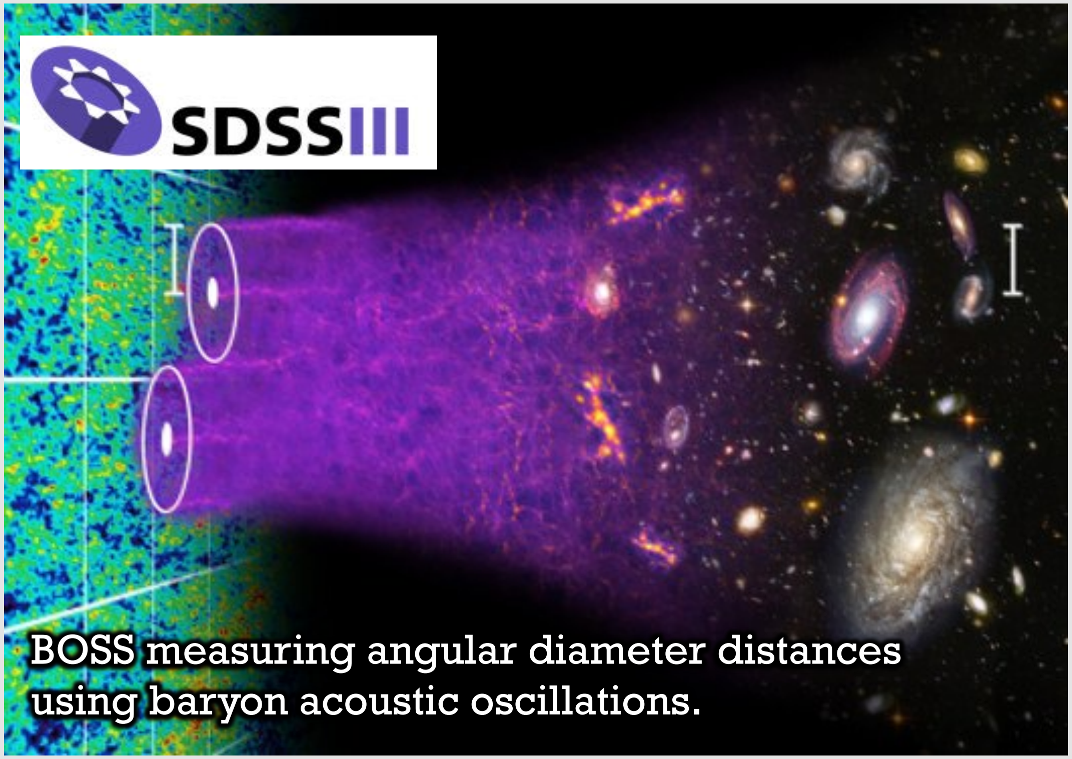
- Larger sample sizes
- More epochs and timescales
- Higher spectral resolution
- Higher signal-to-noise
- Better spectral calibration

But too expensive to have it all (in one experiment).

Will talk about one approach mainly focused on giving much larger sample sizes.

See other talks and posters for other approaches.

Main BOSS Goals and Targets



BOSS measuring angular diameter distances using baryon acoustic oscillations.

5-year program (2009-2014)

Covering 10,000 deg^2 with spectroscopic observations

1.5 million lum. red galaxies

150,000 quasars at $z > 2.2$

Spectra from 3600-9800 Ang with resolution ~ 2000 and good calibration.

1000 objects observed simultaneously in 7 deg^2 field-of-view.

Also ancillary projects of smaller scale – including BAL variability.

Main Goal - Ancillary Project

Move from small-sample and single-object studies of multi-year BAL variability

to

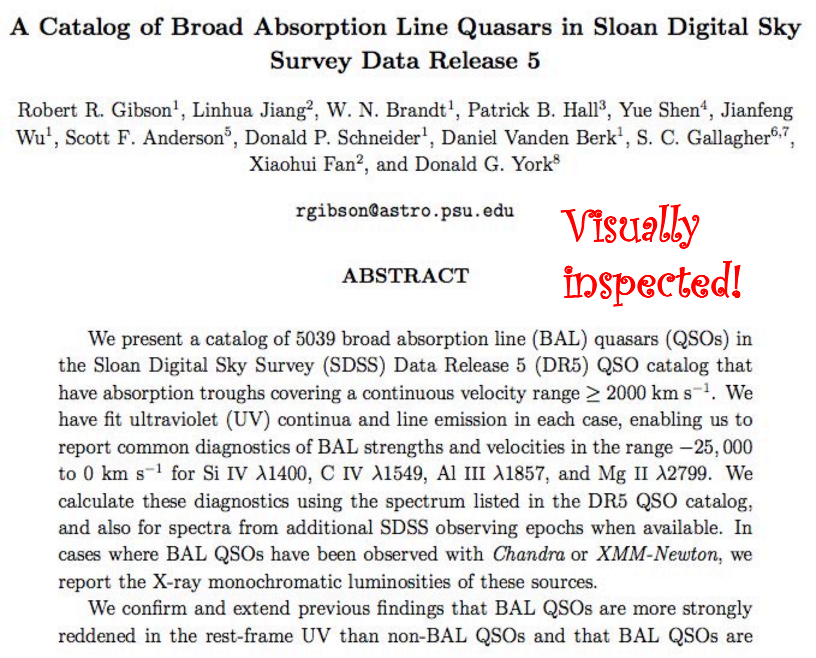
rigorous, large-sample constraints.

(Also with better spectral calibration and somewhat higher spectral resolution)

Re-Targeting BAL Quasars from SDSS-I/II

Main Source of Targets: SDSS-I/II BAL Quasars Observed from 2000-2008

Focused on Optically Bright Targets for Good Spectra



A Catalog of Broad Absorption Line Quasars in Sloan Digital Sky Survey Data Release 5

Robert R. Gibson[1], Linhua Jiang[2], W. N. Brandt[1], Patrick B. Hall[3], Yue Shen[4], Jianfeng Wu[1], Scott F. Anderson[5], Donald P. Schneider[1], Daniel Vanden Berk[1], S. C. Gallagher[6,7], Xiaohui Fan[2], and Donald G. York[8]

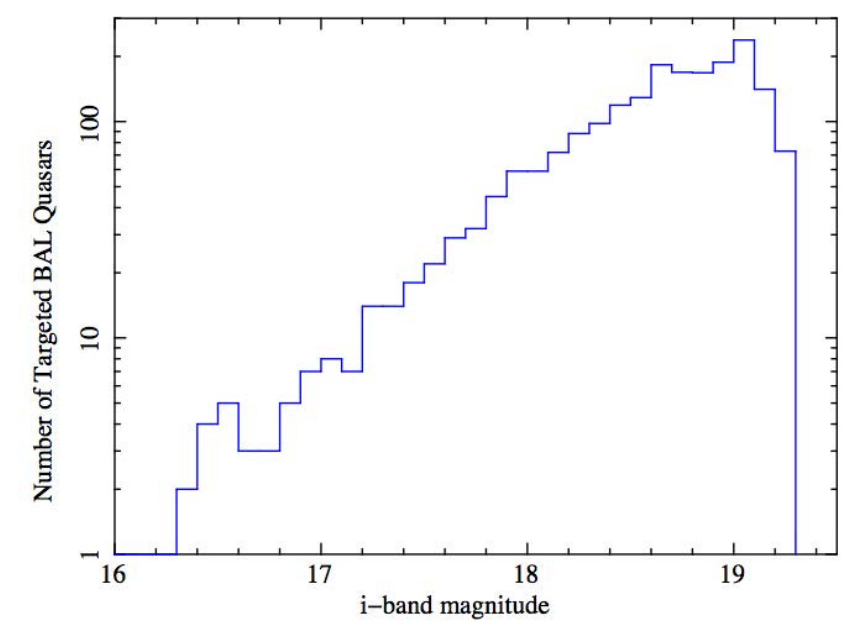
rgibson@astro.psu.edu

Visually inspected!

ABSTRACT

We present a catalog of 5039 broad absorption line (BAL) quasars (QSOs) in the Sloan Digital Sky Survey (SDSS) Data Release 5 (DR5) QSO catalog that have absorption troughs covering a continuous velocity range ≥ 2000 km s^{-1}. We have fit ultraviolet (UV) continua and line emission in each case, enabling us to report common diagnostics of BAL strengths and velocities in the range $-25,000$ to 0 km s^{-1} for Si IV $\lambda1400$, C IV $\lambda1549$, Al III $\lambda1857$, and Mg II $\lambda2799$. We calculate these diagnostics using the spectrum listed in the DR5 QSO catalog, and also for spectra from additional SDSS observing epochs when available. In cases where BAL QSOs have been observed with *Chandra* or *XMM-Newton*, we report the X-ray monochromatic luminosities of these sources.

We confirm and extend previous findings that BAL QSOs are more strongly reddened in the rest-frame UV than non-BAL QSOs and that BAL QSOs are



Targeting 2005 representative BAL quasars that are *bright* and have good BAL coverage.

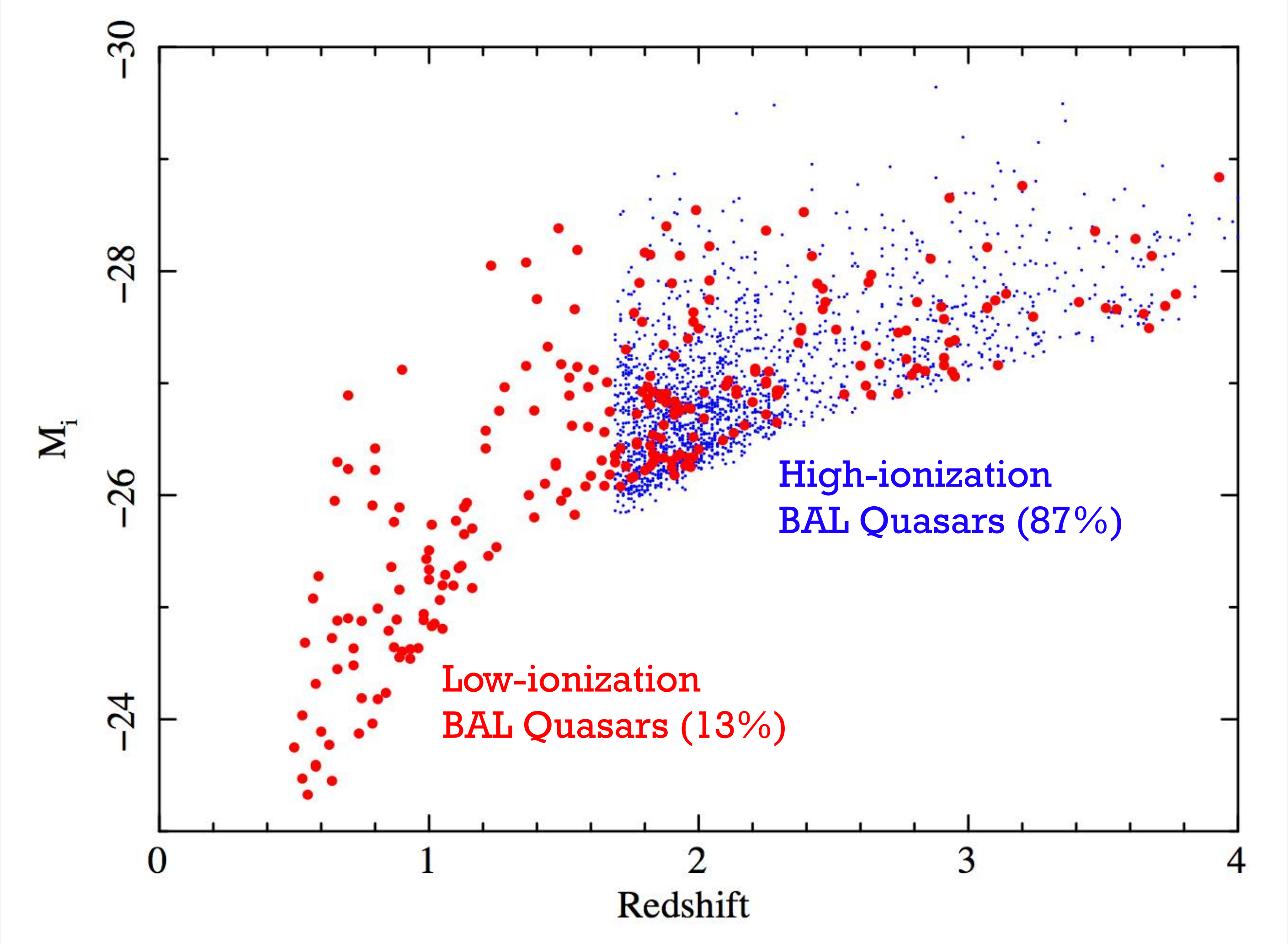
Probe rest-frame timescales of up to ~ 5.2 yr for high-ionization BAL quasars and ~ 9.3 yr for low-ionization BAL quasars.

Sample is ~ 100 times larger than current samples probing multi-year timescales.

0.1% of BOSS fibers utilized.

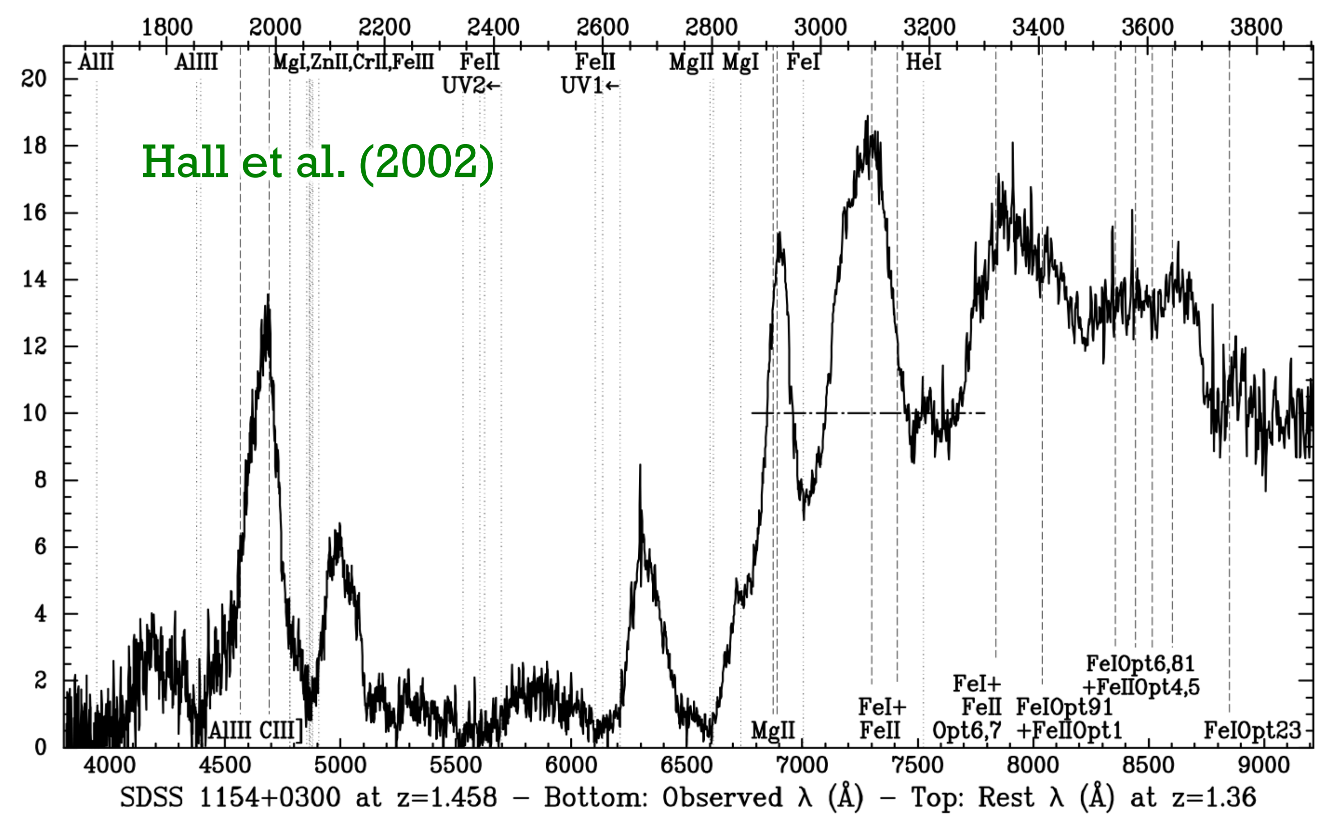
Basic Properties of Main-Sample Targets

Luminosity vs. Redshift for Main-Sample Targets



104 Supplementary Targets – Pat Hall

Example - FeLoBAL Quasar with Overlapping Troughs

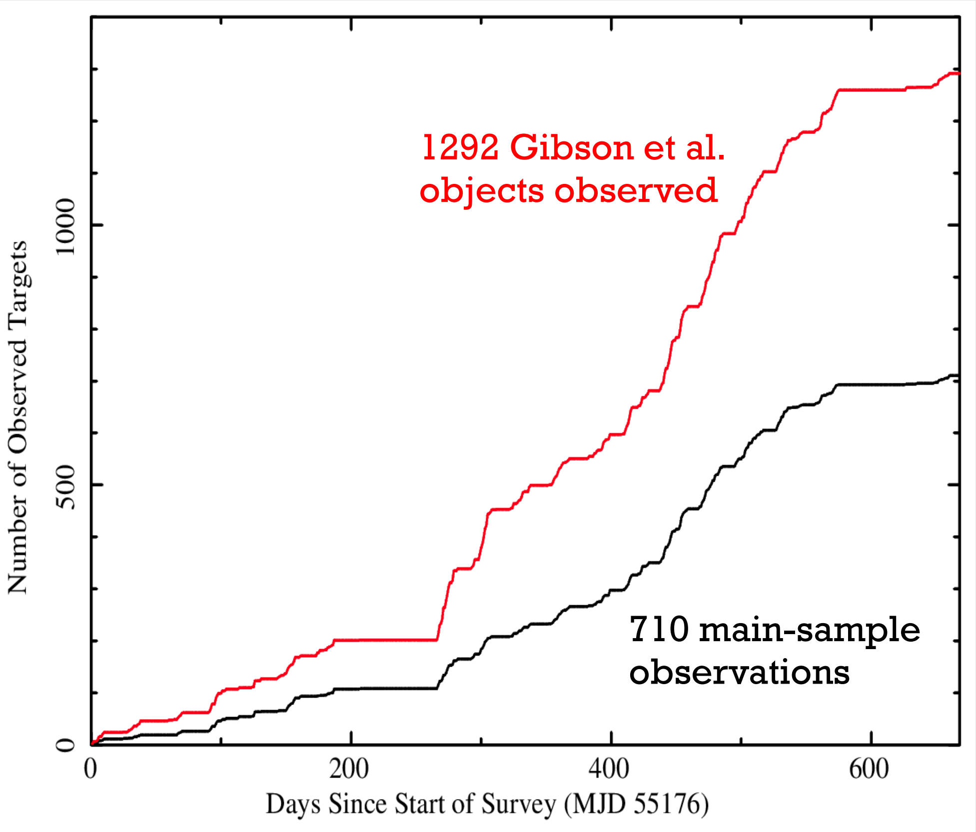


Hall et al. (2002)

Supplementary targets include 56 unusual BAL quasars, 25 LBQS and FBQS BAL quasars, and 23 BAL quasars with multiple SDSS observations.

Observational Progress to Date

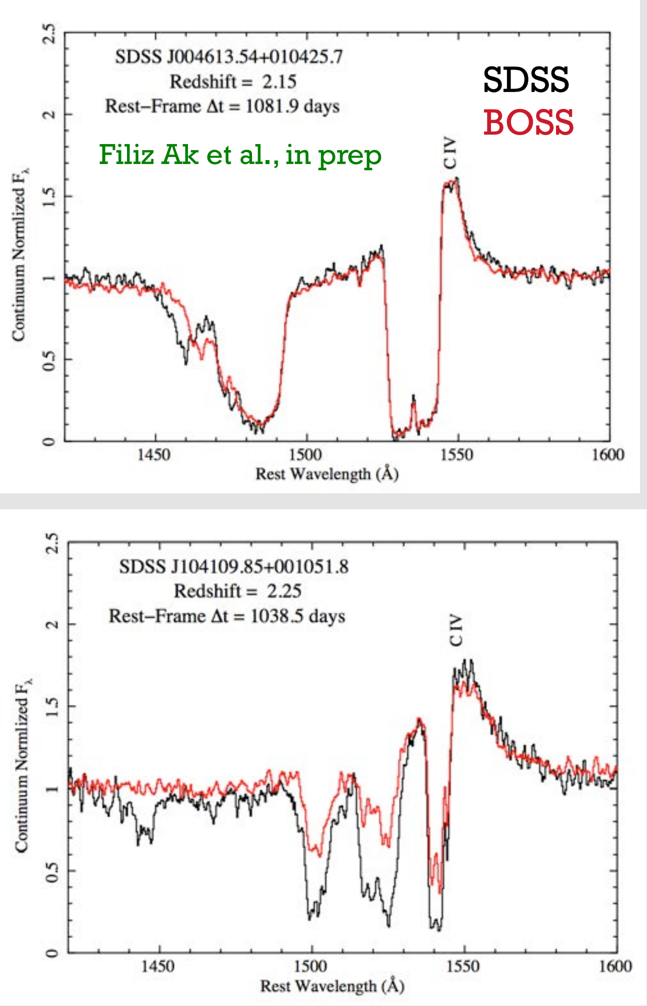
Number of Observations vs. Time



1292 Gibson et al. objects observed

710 main-sample observations

Example C IV Spectra



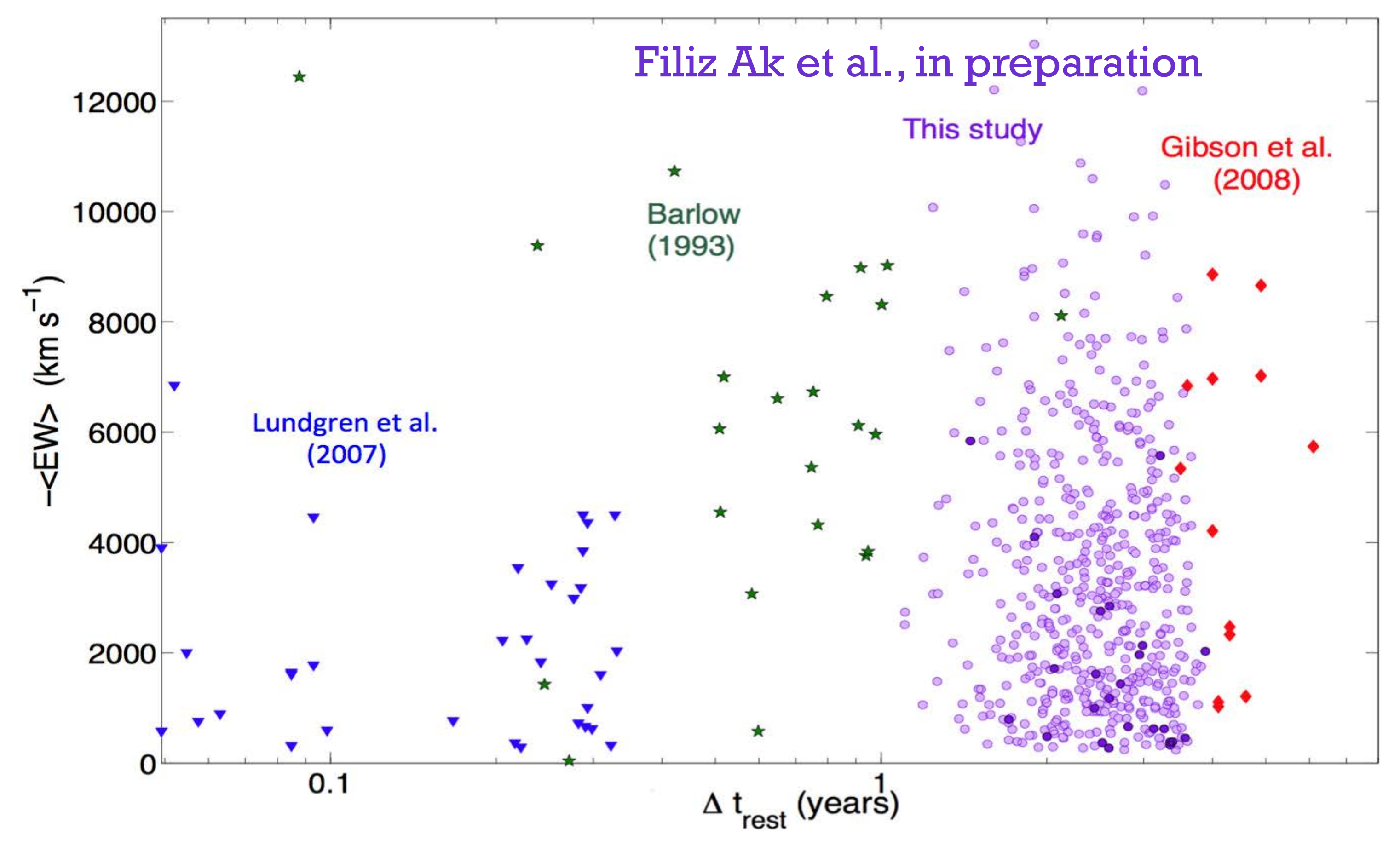
Filiz Ak et al., in prep

1.1 main-sample targets coming in per night.

Now 35% done with experiment.

Timescales Being Sampled

Timescales Compared with Some Past BAL Variability Samples – C IV Objects Only



Presently sampling 1.5-4 year timescales with very good source statistics.

Some General Findings on BAL Disappearance

20 examples of BAL disappearance detected among 686 BAL quasars.

Including some BAL quasar to non-BAL quasar events.

On 1-4 yr rest-frame timescales, 3% of BAL quasars show at least one disappearing trough, and 1.2% of troughs disappear.

Details in Filiz Ak et al., in preparation

Lots More Work to Do!

Absorption-strength variability as a function of timescale for different transitions.

BAL strengthening vs. weakening – asymmetry?

Systematic large-sample constraints on BAL acceleration.

BAL lifetime constraints.

BAL vs. emission-line and reddening variability.

Effects of luminosity, SMBH mass, L / L_{Edd}, radio properties.

BAL emergence in non-BAL quasars.

Mini-BAL and NAL variability.

Future Plans and Hopes

Additional Coverage

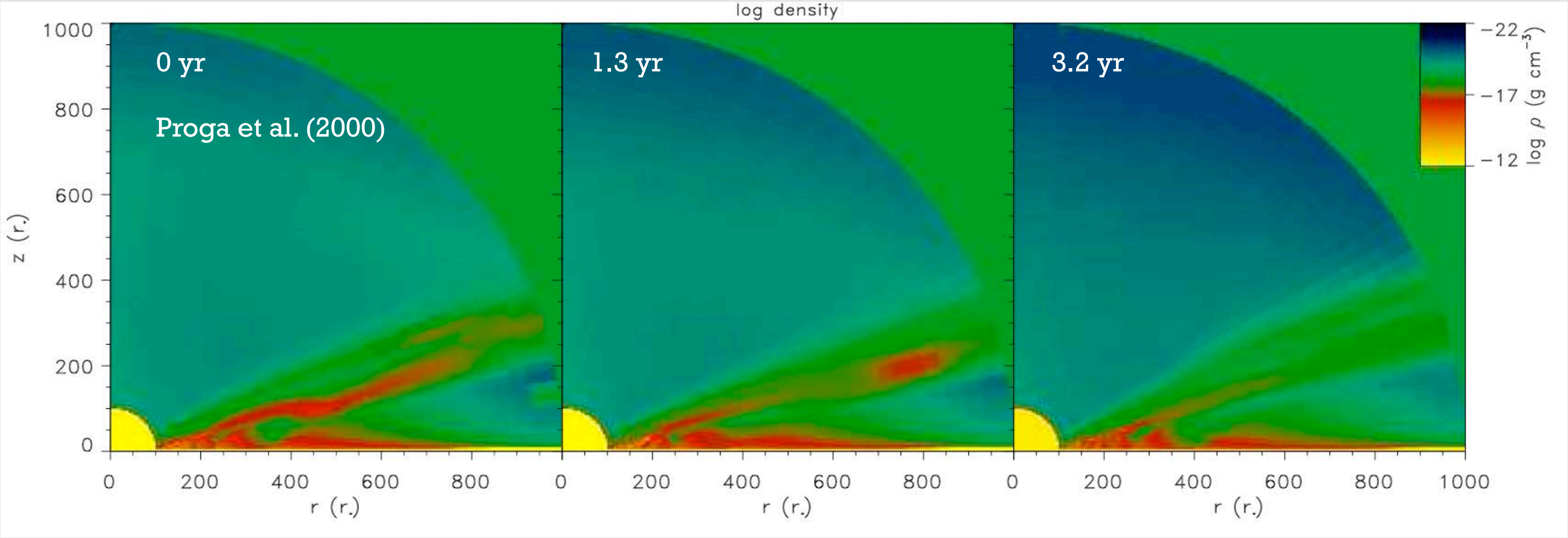
Hobby-Eberly Telescope
and Other Facilities

Also multiwavelength follow-up;
e.g., X-rays.

After SDSS-III: TDSS Could Give
Another Epoch for Full BAL Sample

Better Variability Simulations

Density Maps from BAL Quasar Wind Simulation



Corresponding improvements in BAL variability simulations needed to utilize the flood of new data most effectively.

Especially simulations making *observationally testable predictions*, so can use the time dimension to constrain quasar winds.

The End