Demographics and Variability of Quasar NALs and Implications

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1. INTRODUCTION AND SUMMARY: We have been carrying out a systematic study of the population of intrinsic NALs (narrow absorption lines; FWHM < 500 km/s) in the spectra of quasars. Intrinsic NALs trace quasar outflows, just as the more famous BALs, but they appear to be more common. Moreover the narrow widths allow us to resolve UV resonance doublets and make the task of modeling easier than in BALs. Our primary goals are to constrain the origin of intrinsic NALs and use them as tools to study the physical conditions in the outflows. In §2 we present a census of NALs at low and high redshifts, which suggests that strong NALs evolve away at low z. We also find evidence for 3 different families of absorption systems, which may represent different ionization states. In §3 we use a case study to illustrate how variability can be used to constrain the location of the absorber. Finally, in §4 we report on our first attempt to construct photoionization models for the absorbing gas. *This work is supported by NASA grant NAG5-10817.*

2. CENSUS OF INTRINSIC NARROW ABSORPTION LINES

(A) Low-Redshift Sample (z < 1.8; HST/STIS)

By searching HST/STIS spectra of 36 quasars we found 114 absorption systems containing: 43 C IV, 30 N V, 33 Si IV, and 62 O VI NALs. We identified intrinsic NALs via partial covering analysis, with the following results:

- 8% of all C IV NALs in our sample are intrinsic.
- <7% of all Si IV NALs are intrinsic (one possible out of 14 doublets amenable to the partial coverage test)
- 44% (possibly up to 55%) of N V lines are intrinsic. These show evidence that the profile shapes are determined by the covering factor.
- 3% (possibly up to 16%) of O VI lines are intrinsic. A large fraction of the O VI systems are not accompanied by C IV or N V lines
- The fraction low z of quasars hosting intrinsic NALs is ~25%, consistent with our earlier census at low resolution based on variability.

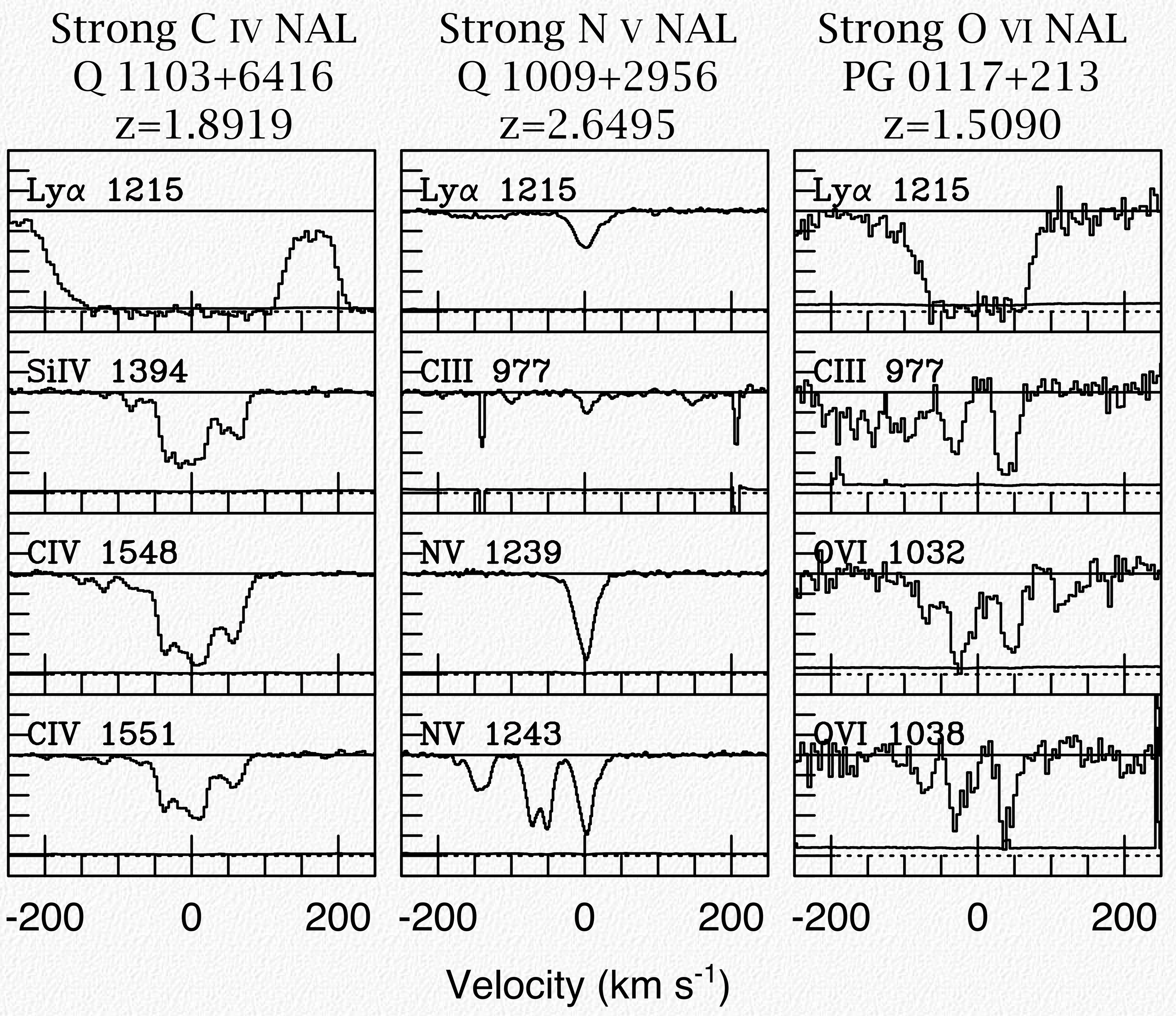
(B) High-Redshift Sample (z = 2-4; Keck/HIRES)

By searching Keck/HIRES spectra of 40 quasars we found 150 absorption systems containing: 124 C IV, 12 N V, and 50 Si IV NALs. We used partial covering analysis to identify intrinsic NALs, with the following results:

- 19% of all C IV NALs in our sample are intrinsic. Among "associated" NALs (AALs; within 5,000 km/s of the quasar emission redshift) 33% are intrinsic.
- 18% of all Si IV NALs are intrinsic. None of them are "associated" i.e., all have $|\upsilon_{ej}|$ > 5,000 km/s.
- Because of the Lyα forest, we were unable to study N V doublets with υ_{ej} > 5,000 km/s. Of the associated NALs 75% are intrinsic.
- At least a half of quasars have one or more intrinsic NALs, which implies that at least ~50% of the solid angle around a typical quasar is covered by intrinsic absorber or that at least ~50% of all quasars are fully covered. This fraction is higher than in z < 2 quasars, suggesting that intrinsic NALs evolve away at low z.

(C) Evidence for Three Families of Intrinsic NALs

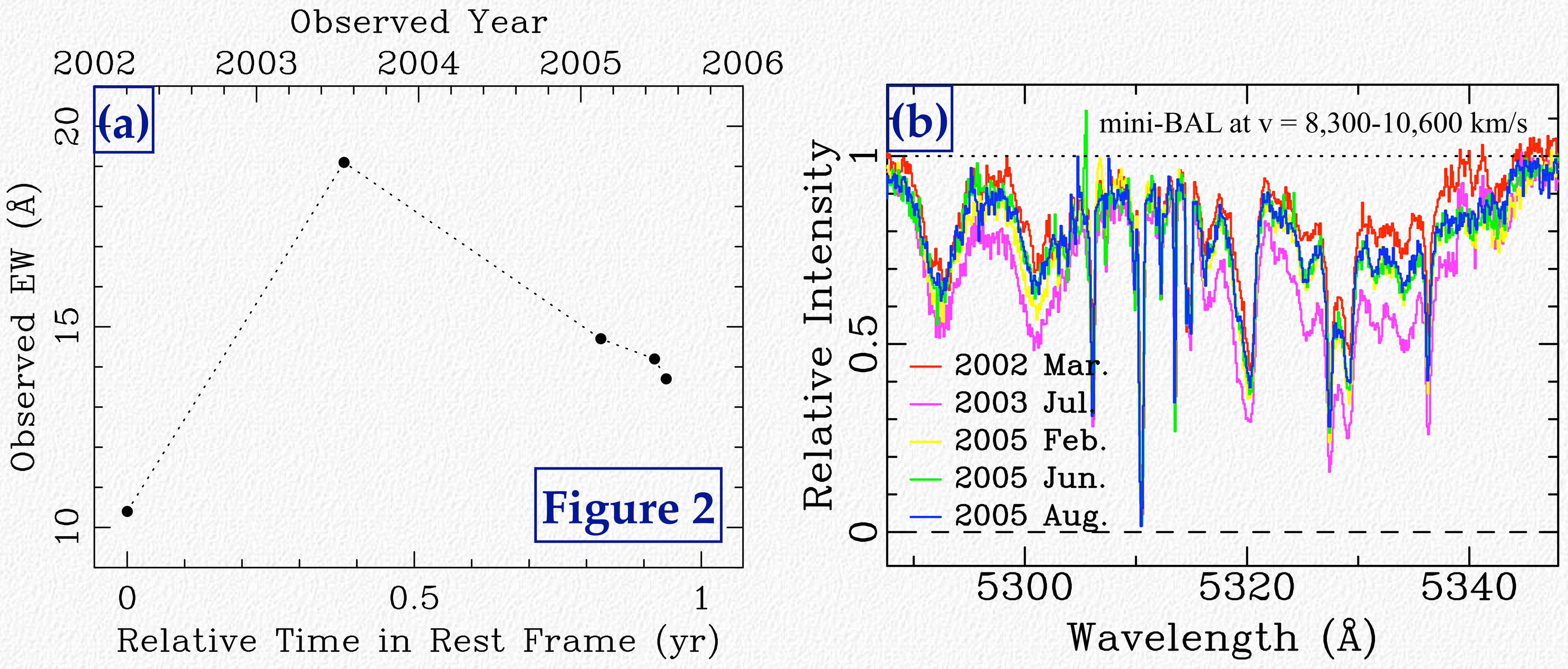
Figure 1



- ***Strong C IV NALs*** (69% of high-z intrinsic systems in our survey) -- Strong C IV, usually accompanied by black Lyα, with weak or absent N V. Sometimes low-ionization lines are detected, perfectly aligned in velocity with C IV. This disfavors the host galaxy as the origin.
- ***Strong N V NALs*** (31% of high-z intrinsic systems in our survey) -- Strong N V absorption, relatively weak, non-black Lyα absorption, (in some cases O VI may be stronger than N V). There are no low-ionization absorption lines in these systems.
- ***Strong O VI NALs*** (found in low-z sample) -- Many of these systems do not have C IV or N V lines and do not show partial coverage (but STIS spectra have relatively low S/N). Reminiscent of IGM lines. About 25% of the O VI NALs appear to be redshifted from the host quasar frame.

3. VARIABILITY OF THE C IV MINI-BAL IN HS 1603+3820

The bright quasar HS 1603+3820 (m_B=15.9, z_{em}=2.54) shows an extremely large number of C IV NALs (dN/dz~12), including a rapidly variable mini-BAL at υ_{ej} = 8,300 - 10,600 km/s. We have been following these variations over the past 4 years using the Subaru HDS. The equivalent width doubled (W_{obs}=10.4→19.1 Å) in 4.5 months (rest frame) and then dropped by 25% (W_{obs}=19.1→14.7 Å) in the following 5.4 months. We also observed a small velocity shift of 200 km/s. We show the variations graphically in Figure 2.



The doubling of the equivalent width can be explained as a doubling of the covering factor (C_f=0.3→0.7). This allows us to constrain the absorber's crossing velocity (υ_{cross} > 8,000 km/s) and the distance from the continuum source (r < 0.2 pc), if gas motion across the background UV source causes the variability. This is larger than the size of continuum source, R_{cont}~0.02 pc but smaller than that of BLR, R_{BLR}~3 pc, of this quasar

4. PHOTOIONIZATION MODEL FOR Q1700+6416

We present here the preliminary results of a model for an intrinsic NAL system (z=2.7125) in Q1700+6416. We use the photoionization code Cloudy, assuming a typical quasar SED and an absorber location outside the broad emission line region (BELR).

The N V doublet from this system is fitted with three components, all showing partial covering, including one 300 km/s redward of the stronger two components. Models for C IV and Lyα lines are superimposed on the data for our favored model with Z = 30 $Z_\odot$ and log U = +0.3. (Lyβ is contaminated by a blend and can only be used as a limit.) A model with n = 10^8 cm^{-3} provides an adequate fit to the central components at 0 km/s, while a higher density of 10^{13} cm^{-3} provides a better fit for the cloud at +300 km/s. The heating rate is higher at the larger density, so that the thermal contribution to line broadening makes Lyα broader than N V.

We infer significantly different densities (by a factor of 300) for components in the same system, separated by 300 km/s. We also note the very high metallicities required to explain the large ratio of N V to Lyα. We are now exploring whether these conclusions change, if the cloud is only absorbing the continuum photons and not photons from the BELR.

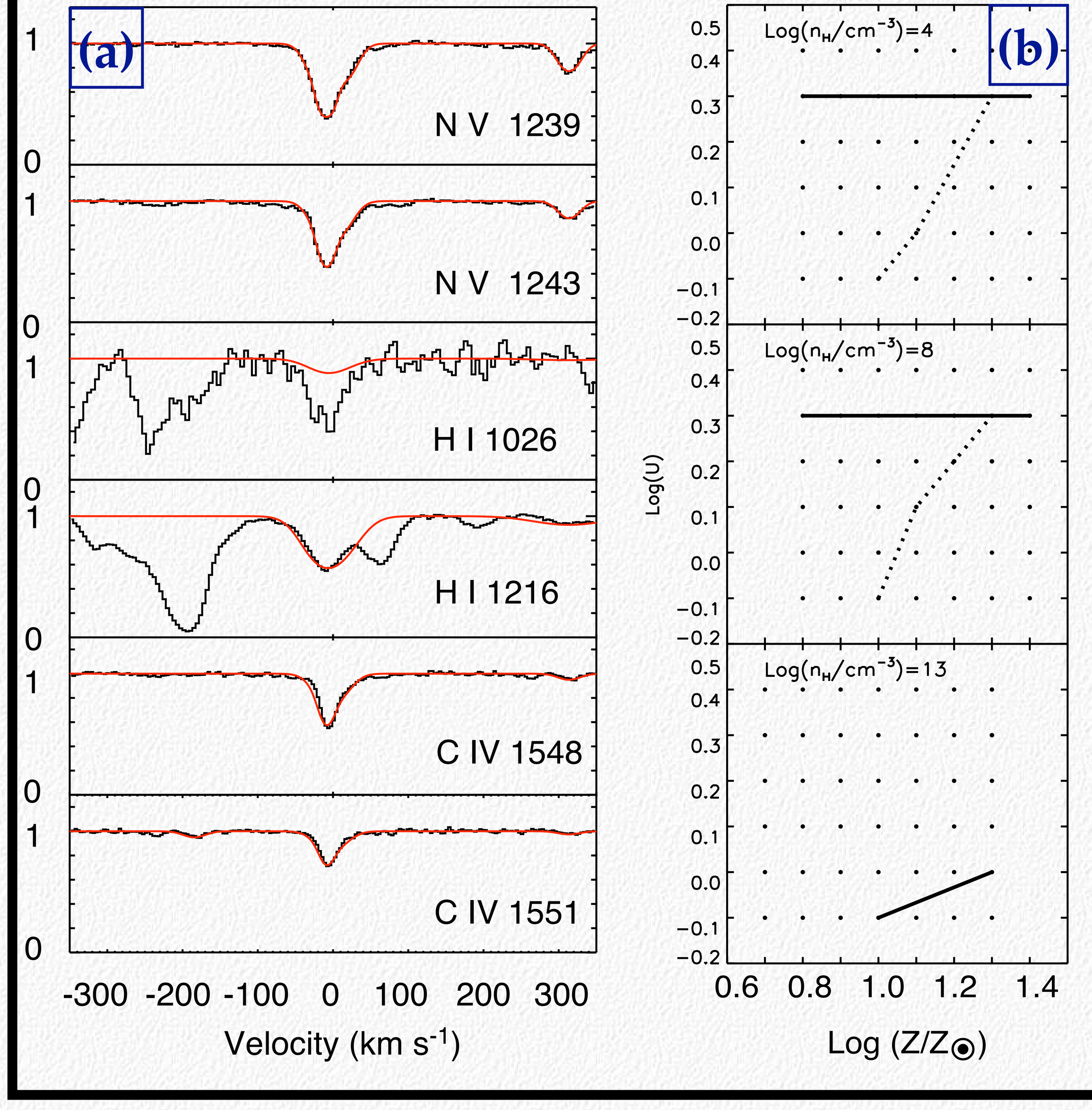


Figure 3

(a) Left: Model line profiles based on the above calculations, superposed on the observed line profiles. Two Voigt components are used for the line at 0 km/s and one for the line at +300 km/s.

(b) Right: Best-fitting parameter combinations in the log U - log ($Z/Z_\odot$) plane for fixed densities. The dotted line shows the best fit to the combination of Lyα and N V lines, while the solid line shows the best fit found for the combination of C IV and N V.