Variability Study of Intrinsic NAL and Mini-BAL Systems

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SUMMARY: About 20% of quasar absorption lines are believed to arise in outflowing winds from the accretion disks of quasars. We commonly classify these "intrinsic" absorption lines as broad absorption lines (BALs), as narrow absorption lines (NALs), or as their intermediate class (mini-BALs), according to their line widths. Among these, mini-BALs and NALs have a great advantage over BALs because they are not self-blended, hence we can determine their column densities and Doppler parameters using profile fitting. Multiple spectra also enable us to search for time variability. For one quasar, HS1603+3820, we have monitored a mini-BAL profile for more than 4 years, and determined that the observed variability is caused by a change of ionization conditions. Now, we are embarking on a similar variability study of 6 mini-BALs and 14 NALs in 12 quasars, using high resolution (R~40,000) archival spectra as well as our own spectra obtained at Subaru, VLT, and Keck since 1994. Surprisingly, variability is seen only in the mini-BALs and all NALs are invariable over a few years in the quasar rest-frame. The simultaneous variability of multiple chemical transitions in the mini-BALs implies the cause is changing ionization conditions (rather than transverse motion). ***This work was supported by NASA grant NAG5-10817 and the Special Postdoctoral Research Program of RIKEN.***

Geometrical Structure of Outflowing Winds

The quasar-intrinsic absorption lines, found in the rest-frame UV spectra of quasars and active galactic nuclei (AGNs), are classified, based on their line widths, into broad absorption lines (BALs; FWHM > 2,000 km s^{-1}), narrow absorption lines (NALs; FWHM < 500 km s^{-1}), and mini-BALs (intermediate widths). Their likely origin is in outflows from the quasar central engine, accelerated by radiation pressure (e.g., Murray et al. 1995) and/or magnetcentrifugal winds (e.g., Blandford et al. 1982). BALs could probe the low-latitude, dense, fast portion of the wind, while the mini-BALs and NALs may probe the lower density portion of the wind at high latitudes above the disk. Thus, the study of mini-BALs and NALs complements the study of BALs because the corresponding absorbers reside in different regions with different physical conditions (see Figure 1; Ganguly et al. 2001).

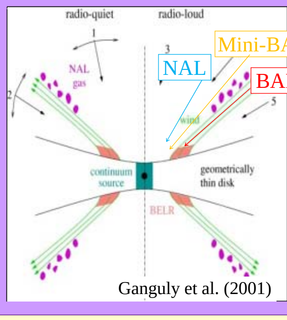


Figure 1 --- Disk wind model for quasars from Ganguly et al. (2001). The central region of the accretion disk is the source of continuum UV photons, while the inner portion of the wind is the source of broad emission lines. NAL/mini-BAL absorbers are viewed as clumpy/filamentary structures above the outflowing winds, toward which BALs can be seen.

Log of Monitoring Observation

We have monitored 6 mini-BALs and 14 intrinsic NALs in 12 quasars, using both archival data (taken with VLT/UVES) and our own data (taken with Subaru/HDS and Keck/HIRES) since 1994. All spectra have high spectral resolution (R > 36,000) and are of adequate quality (S/N > 20 pixel^{-1}). As far as we know, this is the largest sample of high-resolution spectra of quasars that have been monitored for more than several years.

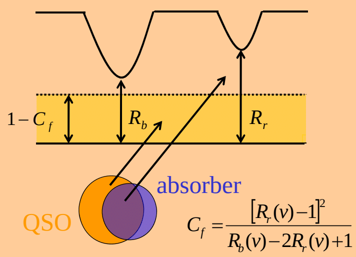
HS1603	Q2343+125	UM675	Q1157+014	HE1341-1020	HE0151-4326	Q0130-4021	Q0450-1310	Q0940-1050	Q1009+2956	Q1700+6416	Q1946+7658
03/23/2002	09/24/1994	09/24/1994	04/30/2000	05/02/2001	09/18/2001	12/15/1995	02/13/1998	04/03/2000	12/29/1995	04/07/1994	07/31/1994
07/07/2003	10/18/1995	08/19/2005	06/14/2001	06/13/2001	10/09/2001	01/13/2003	11/06/2002	02/02/2001	12/15/1998	05/10/1995	09/25/1998/
02/26/2005	08/13/2001		01/23/2002	03/20/2007	11/16/2001	09/05/2007	11/28/2002	06/06/2007	03/09/1999	07/07/2005	10/28/1998
06/28/2005	08/18/2002		01/23/2006	08/04/2007	09/05/2007				06/06/2007	08/19/2005	
08/19/2005	10/29/2003		06/06/2007								
05/31/2006											

Mini-BAL (HS1603 – HE0151-4326) · NAL (Q0130-4021 – Q1946+7658)

Subaru/HDS · Keck/HIRES · VLT/UVES · Magellan/MIKE

Intrinsic NAL Systems

We separated intrinsic NALs (i.e., physically associated with quasars) from intervening NALs (i.e., arising in foreground galaxies and/or intergalactic medium), using partial coverage analysis (e.g., Wampler et al. 1995).



$$C_f = \frac{[R_r(v)-1]^2}{R_b(v)-2R_r(v)+1}$$

Figure 2 --- The optical depth ratios of C IV and other UV doublet lines sometimes deviate from the value expected from atomic physics, 2:1. This discrepancy can be explained if the absorber only partially covers the continuum source along our sightline, such that an unabsorbed continuum changes the relative depths of the lines.

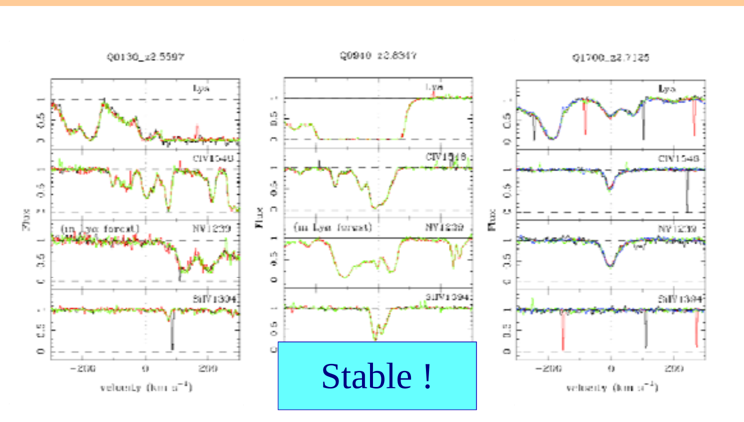
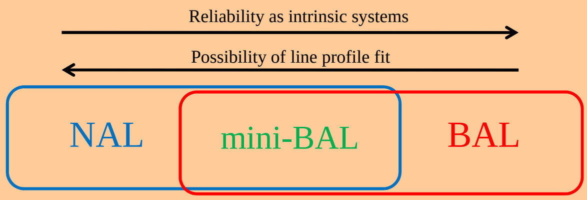


Figure 3 --- Velocity plots of Lya, C IV, N V, and Si IV (from top to bottom) in three intrinsic NAL systems. No variability is observed.

Mini-BAL Systems

Mini-BALs have the advantages of both BALs (i.e., high probability of being intrinsic lines) and NALs (i.e., line parameters can be measured because profiles can be resolved into individual components, while BALs suffer from self-blending). This making them useful targets to study accretion disk winds (e.g., Hamann et al. 1997).



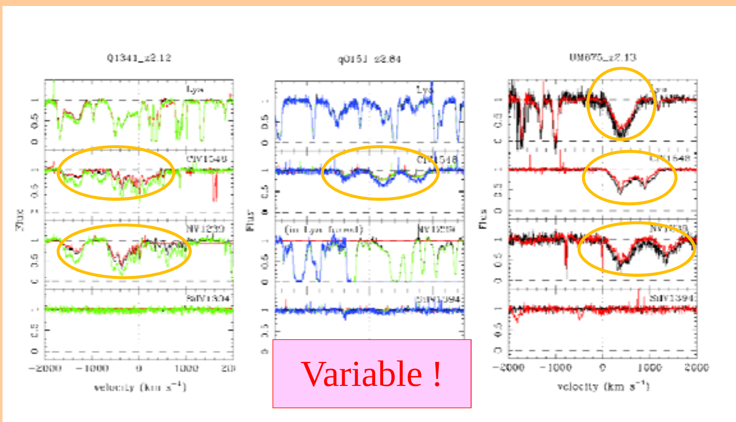


Figure 4 --- Same as Figure 3, but for three mini-BAL systems. All systems showed clear variability over an interval of a few years in the quasar rest-frame.

Origin of Variability

We have monitored a C IV mini-BAL of the quasar HS1603+3820 with Subaru/HDS, and found dramatic variability. A very important observational clue to the cause is the fact that all the kinematic components of the mini-BAL system vary in concert, which eliminates all but two scenarios for the origin of the variability: (a) variable covering factor, and (b) variable ionization conditions of the absorber (Misawa et al. 2007). Only recently, the former scenario has also been rejected because we did not detect the strong polarization signal in the mini-BAL profile that would be expected if a variable scattering material contributes to the mini-BAL variability (Misawa et al. 2009). Because clear variability was confirmed in all mini-BAL systems during our monitoring campaign, variable ionization conditions (probably due to shielding material between the flux source and the absorber) could be a global property of mini-BAL systems.

References

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