High Velocity Outflows in Quasars

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Why do we study High Velocity Outflows?

- Energetic outflows are common phenomena in Active Galactic Nuclei (AGNs). They might be obiquous since they can transport angular momentum outward, which is necessary to facilitate mass accretion into the central Super Massive Black Hole (SMBH).
- High Velocity (HV) outflows are an uncataloged and nearly unexplored part of the outflow parameter space. We are involved in a program to derive basic dynamical characteristics for some well-studied individual flows, and to make the first systematic accounting of outflow lines that do not fall into the standard classes or BALs or AALs.
- HV outflows help us to understand the acceleration mechanisms powering outflows, providing us with extreme cases to test the current dynamical wind models.

Integrating the equation of the radial acceleration of a wind driven by radiation pressure, we obtain a terminal velocity of

$$v_\infty \approx 9300\, R_{0.1}^{-0.5} \left(\frac{f_{0.1} L_{46}}{N_{22}} - 0.1 M_8 \right)^{0.5} \quad \mathrm{km\ s^{-1}}$$

where $R_{0.1}^{-0.5}$ is the radius at which the outflow is launched in pc, N_{22} is the total column density in $10^{22}\mathrm{cm}^{-2}$, M_8 is the central black hole mass relative to 10^8 $M_\odot$, $f_{0.1}$ is the absorbed fraction compared to 10%, and L_{46} is the quasar luminosity relative to 10^{46} ergs/s (Hamann 1998). Therefore, for a given outflow column density and QSO characteristics, there is a maximum attainable outflow velocity. If all the parameters on right side of the equation have values of "1", a maximum of velocity of ≈9,000 km/s is obtained. Outflows in this study exceed this value.

PG0935+417: second HV outflow.

Januzzi et al. (1996) was the first one to report the discovery of a HV miniBAL of C IV, N V and O VI outflowing at 56,000 km/s out of the quasar PG2302+029. Hamann et al. (1997) presented the detection of a second HV C IV miniBAL, outflowing at 51,000 km/s. Strong variability in the C IV mini-BAL was detected by Narayanan et al. (2004). More recent data (provided by the Sloan Digital Survey Sky Survey - SDSS) show continuing variability in this feature.

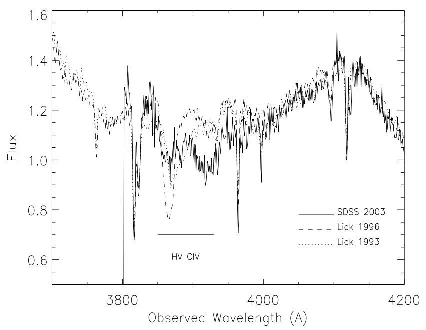
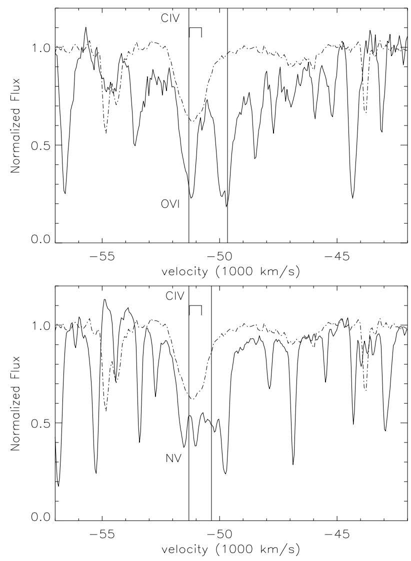


Figure shows how HV C IV varies during the period of ten years (Lick 1993 and 1996, SDSS 2003). Emission lines vary too; we divided the spectra by a linear fit since we focus on the absorption variability. The absorption feature of interest lies next to some emission lines (∼3800-4000 Å in observed wavelengths) but this region is avoided when selecting the input range for the linear fit (therefore some remaining emission is expected in this range). Notice that a new component of the absorption feature is observable in the SDSS 2003 spectra (∼ 3900 Å), outflowing at a velocity of ≈ 47,000 km s $^{-1}$.

Rodriguez Hidalgo and Hamann (2006) presents the detection of O VI and N V in the same outflow of the previous HV C IV found by Hamann et al. (1997). In the Figure (next column) we present HST spectra of the high-velocity mini-BALs for O VI and N V, with overplotted C IV from the Lick spectrum, shown in velocity scaled relative to the emission redshift. The HST spectrum includes many lines unrelated to the mini-BALs in the Lyα forest.

More detections in PG0935+417.



We derived measurements for column densities, REWs and FWHMs from multi-component fits, taking into account partial coverage of the background light source(s). Besides C IV, O VI and N V, no other lines were detected. Assuming solar abundances we estimate a total column density $N_H \lesssim 3.5 \times 10^{19}\mathrm{cm}^{-2}$. Plugging this number into the equation of motion, as well as $v_\infty \approx 51,000$ km/s implies a launch radius of $R < 35$ pc for PG0935+417. This maximum radius is comfortably outside the expected radius of the broad emission line region $R_{BELR} \approx 0.5$ pc (Kaspi et al. 2000), and consistent with the existing models of BAL-like winds (Proga et al. 2000, Murray et al. 1995), which supports the idea that the radiation pressure is driving this outflow. However, Sabra et al. (2003) estimated $N_H \approx 10^{22}$ cm^{-2} for the HV outflow in PG2302+029 based on X-ray spectroscopy. X-ray data are not available for PG0935+417, but if this wind has a similar N_H, the launch radius would be $R < 0.1$ pc, which is much smaller than R_{BELR} and problematic for standard wind models (see also Hamann et al. 2001).

New HV outflows found.

In order to study the commonness of HV outflows, we began a program using spectra from the the Sloan Digital Sky Survey (SDSS) DR4. We have analyzed 1,200 best signal-to-noise spectra with emission redshifts between 2.0<z<3.5 to be able to observe blueshifted HV C IV outflows given the SDSS spectral coverage. The C IV candidates were fitted in order to extract quantitative information, such as velocity centroids, REW and FWHM.

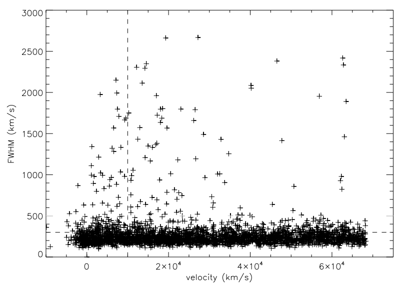


Figure shows the velocity-FWHM distribution of C IV candidates. Dashed lines represent selection criteria to avoid intervening systems (FWHM<300 km/s) and associated systems (v<10,000km/s). Many mini-BALs are found (500<FWHMs<1500 km/s). Richards et al.(1999) estimates that ∼36% of narrow HV lines are intrinsic, based on correlations with quasar properties).

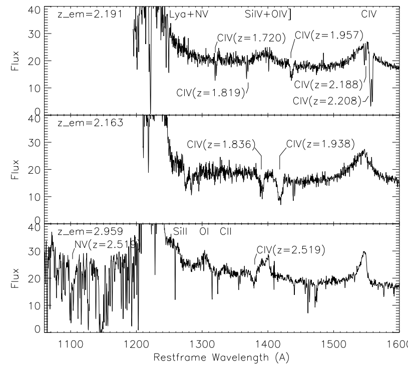


Figure shows SDSS spectra shifted to the rest wavelengths of the quasars. Prominent emission lines are labeled accross the top in the upper and middle panels. Various candidate HV C IV lines are labeled with tic marks and the measured redshifts. The upper spectrum contains several C IV absorption systems, including two AALs, in addition to the HV mini-BAL candidate at z=1.957. The lower panel shows N V absorption at the same redshift as the C IV mini-BAL. This spectrum also contains an unrelated damped-Lyα system.

Next steps.

- Test intrinsic origin of H candidates by looking for **variability** in absorption (compared to the SDSS spectra), which will help to compile a list of these systems for future study and to place a firm lower limit on the fraction of quasars with narrow-like HV outflows.
- Follow up best/interesting HV systems with **high resolution spectroscopy** to measure more accurate column densities,ionizations, abundances, kinematics,...
- Line locking
- Analysis of the opacity-like parameter $f_{0.1}$ in order to understand the implications of our observations for radiative acceleration models.
- Combined UV and X-ray spectra of BALs to understand the relationship of the UV and X-ray absorbers and determine what total N_H in these sources is outflowing with the BAL gas, e.g., test the relationship of PV to N_H by comparing measurements or limits on the UV BALs to N_H from the X-ray data.

Summary.

Acknowledegment

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