ON THE FRACTION OF QUASARS WITH OUTFLOWS

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ABSTRACT

Outflows from active galactic nuclei (AGNs) seem to be common and are thought to be important from a variety of perspectives: as an agent of chemical enhancement of the interstellar and intergalactic media, as an agent of angular momentum removal from the accreting central engine, and as an agent limiting star formation in starbursting systems by blowing out gas and dust from the host galaxy. To understand these processes, we must determine what fraction of AGNs feature outflows and understand what forms they take. We examine recent surveys of quasar absorption lines, reviewing the best means to determine if systems are intrinsic and result from outflowing material, and the limitations of approaches taken to date. The surveys reveal that, while the fraction of specific forms of outflows depends on AGN properties, the overall fraction displaying outflows is fairly constant, approximately 60%, over many orders of magnitude in luminosity. We emphasize some issues concerning classification of outflows driven by data type rather than necessarily the physical nature of outflows, and illustrate how understanding outflows probably requires more a comprehensive approach than has usually been taken in the past.

Subject headings: quasars: general — quasars: absorption lines — galaxies: active — accretion

1. INTRODUCTION

The role of outflows from quasars and active galactic nuclei (AGN) has recently become an important feature in the overall framework of how galaxies and star formation processes evolve over cosmic time. Mergers and other interactions triggering AGN seem to provide feedback affecting the larger scale environment. Recent efforts to include the effects of this so-called AGN feedback focus on two modes: a “radio” mode whereby a relativistic jet heats the surrounding interstellar and intercluster media (e.g., Best 2007), and a “quasar” mode whereby a lower velocity but higher mass outflow also helps to clear out post-merger shrouding gas and quenches star formation (e.g., Di Matteo, Springel, & Hernquist 2005). We focus on this second mode in this paper. For this mode, a number of questions require addressing. How common are outflows? Do all AGN have outflows? What drives outflows? Is there a single all-governing structure of AGN? Answering these questions will help us to understand the role AGN outflows with respect to issue of feedback, and other important issues like chemical enrichment and accretion.

In the ensuing sections we aim to achieve several goals: (1) to review the ways in which outflows are detected in AGN over all luminosity scales; (2) to comment on the merits of various catalogs of outflows; and (3) to arrive at the true (possibly property-dependent) observed frequency of outflows. In its most basic interpretation, the observed frequency of outflows can be equated with the fraction of solid angle (from the view point of the central black hole) subtended by outflowing gas. This interpretation assumes that all AGN feature outflows and that not all sight-lines to the emitting regions are occulted by the outflow. Alternatively (and equally simplistic), the frequency can be interpreted as the fraction of the duty cycle over which AGN feature outflows (assuming the outflow subtends 4π steradians). The actual conversion of the fraction of AGN featuring spectroscopic evidence of outflow to the solid angle subtend by such outflows has been treated by Crenshaw et al. (1999) and Crenshaw, Kraemer, & George (2003). This computation involves further knowledge of the line-of-sight covering factor (that is, the fraction of lines-of-sight that reach the observer that are occulted by the outflow) as well as an understanding of range of solid angle sampled by the AGN used (e.g., Type 1 versus Type 2 AGN). The true situation is likely in between these two extremes, and may depend also on properties we can not currently constrain, such as the time since the AGN was triggered.

Additionally, we strive here to build a case that more effort should be made to consider outflows of all types together. Often data limitations of one sort or another have led to the study of limited parts of parameter space (e.g., outflow velocity or velocity dispersion), creating artificial or at least biased divisions. There appears to be a continuous range in properties of outflows and these should only be regarded as fundamentally different when there is clear evidence to reach such a conclusion. Below we discuss the identification of outflows (§2) and the data-driven subcategories (§3). We show an illustrative example of how combining the different outflow subclasses may lead to a more unified physical understanding of outflows (§4). Finally, we bring together the different survey methodologies to determine an overall fraction of AGN displaying the signatures of outflows (§5) and summarize the case for more global studies of the outflow phenomenon. We adopt a cosmology with $\Omega_M = 0.3$, $\Omega_{\Lambda} = 0.7$, and $H_0 = 70$ km s$^{-1}$ Mpc$^{-1}$.

2. THE IDEAL WAY TO SELECT QUASARS EXHIBITING OUTFLOWS

Outflows from AGN are primarily detected in ultraviolet and X-ray absorption against the compact continuum source (i.e, the inner portions of the accretion disk)
and/or the more extended broad emission line region. In a few cases, outflows have been demonstratively observed in emission both from the broad line region in narrow-line Seyfert 1 galaxies (e.g., Leighly & Moore 2003; Leighly 2004; Yuan et al. 2007) and from the narrow line region of Seyfert 1 galaxies (e.g., Das et al. 2003, 2006). Arguably, the fact that broad emission lines in most AGN have only a single peak is also a signature of outflowing gas (e.g., Murray et al. 1995). For emission-line gas, reverberation mapping provides a direct means at establishing the location of the gas. For absorption-line gas, placing a distance between the gas and the ionizing continuum relies on using absorption-line diagnostics to assess the photoionization parameter ($U$), and having other information that constrains the density ($n$) of the gas. The distance, $r$, is related to these quantities via

$$r = \sqrt{\frac{\int_{\nu_{\text{LL}}}^{\infty} (L_\nu/v) \, dv}{4\pi hcnU}},$$  

where $\nu_{\text{LL}} = 3.3 \times 10^{15} \text{Hz}$ is the frequency of the Lyman limit. Constraints on the density can come from time-variability (if ionization/recombination dominates the variability timescale), or the presence of excited-state lines. Density information is not typically available for intrinsic absorbers, so secondary indicators must be employed to separate intrinsic absorbers from absorption by interloping structures (e.g., IGM filaments, galaxy halos and disks).

In order of decreasing utility and importance, the secondary indicators of an intrinsic origin for an absorption-line system are: (1) velocity width, (2) partial coverage, (3) time variability, (4) high photoionization parameter, (5) high metallicity (e.g., Barlow & Sargent 1997). Not all intrinsic absorbers exhibit all of these properties, but the probability of an intrinsic origin is higher if an absorber exhibits more than one property. Likewise, with the exception of the first two indicators (and the first only in its most extreme, see §3.1), each of these indicators have been observed in intervening material. Thus, by themselves, no one indicator should be taken to imply an intrinsic origin. Historically, the first criterion has led to three divisions in the classification of intrinsic absorbers. Outflows with the largest velocity dispersions are termed “broad absorption lines” (e.g., Weymann et al. 1991) BALs, FWHM $\geq 2000 \text{ km s}^{-1}$). On the other extreme, intrinsic absorbers where the velocity dispersion is sufficiently small as to cleanly separate the C IV doublet are called “narrow absorption lines” (e.g., Hamann & Ferland 1993) NALs, FWHM $\leq 500 \text{ km s}^{-1}$).

Since there is a whole continuum of velocity widths, this has led to an in-between class known as “mini-BALs” (e.g., Hamann et al. 1997; Churchill et al. 1999). Below we examine each of these classes in terms of their observed frequency, and note various issues in determining this number, including dependencies on quasar physical properties.

3. OBSERVATIONS OF THE INCIDENCE OF VARIOUS FORMS OF OUTFLOWS

3.1. Broad Absorption Lines (BALs)

Broad absorption lines in the spectra of quasars are the most easily identifiable forms of outflows. The large velocity width is very readily associated with accelerated, outflowing gas. As such, these garnered more attention historically than their smaller velocity-width kin (e.g., Weymann et al. 1985; Turnshek et al. 1988; Turnshek 1988; Weymann et al. 1991; Voit et al. 1993).

Weymann et al. (1991) established criteria, summarized in a number called the BALNicity index (BI), for determining if an absorption line constituted a BAL. The BI was a modified form of an equivalent width whereby one counted absorption that fell below 90% of the true quasar continuum that was contiguous below this level for more than 2000 km s$^{-1}$. Moreover, no absorption within 3000 km s$^{-1}$ of the quasar redshift was counted in order to remove possible contamination by absorption-line gas not physically associated with the quasar central engine (e.g., interstellar gas from the quasar host galaxy, or intergalactic material from the host cluster). [Note: With a minimum velocity of 3000 km s$^{-1}$ and a minimum contiguous width of 2000 km s$^{-1}$, this means that no absorption falling entirely within 5000 km s$^{-1}$ of the quasar redshift is counted.] This index was established using low-dispersion data of high-redshift gas ($1.5 \leq z \leq 3.0$) objects from the Large Bright Quasar Survey, or LBQS (Foltz et al. 1984, 1989; Hewett et al. 1991, 1993), and was designed to yield a pure sample of objects with bonafide outflows. We note here that the utility of BI was driven purely by the data quality (signal-to-noise ratio and resolution) of the LBQS spectra in conjunction with the desire to remove false positives (at the expense of losing some true BAL quasars). While the use of BI to define samples of BAL quasars has utility, especially in comparing results between data sets of varying quality, it excludes some fraction of real high-velocity dispersion outflows that qualitatively appear to be BAL quasars but just fail to have positive BI.

An improvement on the BI, termed the intrinsic absorption index (AI), was developed by Hall et al. (2002) to alleviate the inadequacies of BI in selecting objects where high velocity outflows were clearly observed but were not included as BAL quasars by the BI criteria (e.g., UM 660, PG 2302+029). The AI was designed to be more flexible and inclusive and has been very useful in its application to new and better quality datasets like the Sloan Digital Sky Survey (SDSS). This flexibility, while good at including objects not previously selected by BI, has increased the contamination of samples of intrinsic absorption while still not including other forms of intrinsic absorption (e.g., Ganguly et al. 2007).

The incidence of BALs has primarily been determined using optical spectra where, historically, large samples of high-redshift quasars (to get rest-frame UV coverage) could efficiently be selected (e.g., with color-selection). In such surveys (Hewett & Foltz 2003; Reichard et al. 2003; Trump et al. 2006; Ganguly et al. 2007), roughly 10-25% of objects are observed to host BALs. An issue with optical/UV surveys, however, is potential biases in the selection of quasars against those hosting BALs due to the fact that much of the continuum is absorbed (e.g., Goodrich & Miller 1993; Goodrich 1997; Krolik & Voit 1998) and intrinsically reddened (e.g., Reichard et al. 2003). Using the LBQS, where the observed frequency of BAL quasars in the redshift range $1.5 \leq z \leq 3$ is 15% using a BI criterion, Hewett & Foltz (2003) estimated a true BAL frequency of 22% from comparisons in the $k$-corrections of BAL and non-BAL quasars. The
recent catalog of BAL quasars using an AI criterion from Trump et al. (2006) found a BAL frequency of 26% (in the redshift range \(1.7 \leq z \leq 4.38\)). Both of these estimates are based on the C IV \(\lambda 1548, 1550\) doublet, which is the most commonly used species in selecting intrinsic absorption owing to the relatively high abundance of carbon, the high ionization fraction of \(C^+\) in moderately-ionized gas, and the resonant absorption of the doublet.

To combat possible selection biases in the optical, one can examine quasar catalogs selected in other bands. Becker et al. (2000) examined radio-selected quasars from the FIRST Bright Quasar Survey and found a BAL quasar frequency of about 18% (though it is only 14% if only BI > 0 objects are counted, comparable to other estimates based on optical-selection). This again predominantly used the C IV doublet and objects at \(z > 1.7\).

Incidentally, several studies (e.g., Brotherton et al. 1998) have now dismantled the myth that BALs are only observed in formally radio-quiet (i.e., \(f_r(5\,\text{GHz})/f_r(3000\,\text{Å}) < 10\)) objects, though their frequency does significantly decrease among the most radio-loud quasars (Becker et al. 2001; Gregg, Becker, & de Vries 2000). We note that a subset of radio-selected BAL quasars can be identified as polar outflows (e.g., Zhou et al. 2006; Brotherton, de Breuck, & Schaefer 2006; Ghosh & Punsly 2007). At least one of these objects, FIRST J155633.8+351758, appears to be an optically reddened and beamed radio-quiet quasar (Berrington et al. 2007). The presence of BAL outflows in such objects as well as in edge-on FR II BAL quasars, (e.g., Gregg et al. 2006) indicates high-velocity outflows are present in a variety of geometries. There is as yet no observational signature in the absorption spectra that is correlated with orientation indicators, so any geometrically restrictive model such as those identifying BAL outflows solely with equatorial winds are either wrong or incomplete. Any complete picture of outflows must reflect a range of geometries. It has yet to be established observationally how often polar outflows occur compared to equatorial, or if the location or dynamics differ.

In addition to radio-selection, one can examine the frequency of BAL quasars from infrared selection. Recently, Dai et al. (2007) compared the catalog of BAL quasars (Trump et al. 2006) from the Third Data Release (DR3) of SDSS and the parent sample of DR3 quasars (Schneider et al. 2005) with the Two Micron All-Sky Survey (Skrutskie et al. 2006; 2MASS) Point-Source Catalog (PSC). With some variation with redshift, they reported an overall true BAL quasar fraction of 43 ± 2%, markedly higher than estimates based on UV/optical data alone. Presumably, this difference accounts for the effects of dust and absorption that may bias UV/optical selection techniques against find BAL quasars.

We point out that this estimate relies heavily on the automated techniques employed in finding BAL quasars in a large dataset such as SDSS. From a critical look at 5088 \(1.7 < z < 2\) quasars from SDSS DR2, Ganguly et al. (2007) noted several instances of false (and missed) classifications in the Trump et al. (2006) catalog. A comparison of the Ganguly et al. (2007) sample with the 2MASS PSC reveals a BAL fraction of 66/287 (23%), completely consistent with the analysis of Hewett & Foltz (2003). Blindly using the Trump et al. (2006) catalog yields a BAL fraction of 96/287 (33%), consistent with the \(z < 2\) points from Dai et al. (2007; see their Figure 4). At face value, this implies that nearly 30% of the Trump et al. (2006)-2MASS cross-matched sample consists of false-positives. We return to the issue of false-negatives below.

3.2. Narrow Absorption Lines (NALs) and mini-BALs

Intrinsic NALs and mini-BALs have, within the last decade, come to light as a very powerful and complementary means of studying outflows. Unlike their very broad kin, these absorbers are generally not blended and, therefore, offer a means to determine ionization levels and metallicities using absorption-line diagnostics. Thus, NALs and mini-BALs are more useful as probes of the physical conditions of outflows. The drawback, however, is that truly intrinsic NALs and mini-BALs are more difficult to identify, since interloping structures such as the cosmic web, galaxy clusters, and galactic disks and halos also have comparable velocity spreads (\(\lesssim 800\,\text{km}\,\text{s}^{-1}\)). Historically, progress was made by statistically identifying an excess of absorbers over what is expected from randomly distributed intervening structures (e.g., Weymann et al. 1979). With improved technologies (such as high-resolution spectroscopy with large telescopes), we can now take advantage of the other secondary indicators to separate intrinsic from intervening absorption. In the following subsections, we discuss the frequency of two subclasses based on both historical and more recent studies. We distinguish between absorbers that appear near the quasar redshift (associated absorbers), and those that appear at large velocity separations.

3.2.1. Associated (\(z_{\text{abs}} \sim z_{\text{em}}\)) Absorbers (AALs)

The term “associated” refers to narrow velocity-dispersion absorption-line systems that lie near the quasar redshift. It has been shown that the frequency of such systems is much larger than those at large velocity separations (Weymann et al. 1979; Foltz et al. 1987b; Anderson et al. 1987; Aldcroft et al. 1994; Richards et al. 1999; Richards 2001). Typically, associated absorbers are defined as those lying within 5000 km s\(^{-1}\) of the quasar redshift (Foltz 1986). As such, they were historically very complementary to BAL quasars selected using BI. Updating BAL classification to reflect the better data quality usually available today does allow for some confusion among classes, at least in some cases, and this should be kept in mind. The issue of what types of quasars hosted AALs was the subject of much scrutiny with some studies claiming to see an excess of AALs (e.g., Foltz et al. 1987b), while other studies claimed no excess (e.g., Sargent, Steidel, & Boksenberg 1988). It was surmised that strong AALs (i.e., those with a large C IV equivalent width) were preferentially found in optically-faint, steep radio spectrum quasars (Møller & Jakobsen 1987; Foltz et al. 1988). However, more recent studies have found that AALs are found (with varying frequency) in all AGN subclasses from Seyfert galaxies (e.g., Crenshaw et al. 1999; Kriss 2000 to higher luminosity quasars (e.g., Ganguly et al. 2001; Laor & Brandt 2002; Vestergaard 2003; Misawa et al. 1998).
An important issue in the consideration of AALs as it relates to outflows is where the absorbing gas originates. We note here a few arguments for a direct association with outflows from the central engine. While detailed studies of individual objects have shown absorption-line components that must reside in the host galaxy far from the central engine (e.g., Hamann et al. 2001; Scott et al. 2003; Ganguly et al. 2006), on the whole there have been no documented cases of AALs that are truly redshifted with respect to the actual systemic velocity. If AALs were to originate in the host galaxy, one would expect some fraction of the absorbers to arise from infalling material. In fact, the velocity distribution of C IV AALs is sharply peaked with the C IV emission redshift (Ganguly et al. 2001), implying a close dynamical connection between AALs and the broad emission-line region. In addition, blind studies of AALs using secondary indicators find that $\geq 20\%$ are time-variable (Wise et al. 2004), and that $\sim 33\%$ show partial coverage (Misawa et al. 2007).

From an analysis of 59 $z < 1$ quasars, Ganguly et al. (2001) showed that the overall frequency of AALs was $25\% \pm 6\%$, with some variation with broad-band spectral properties. Similar frequencies have been established at higher redshift by Vestergaard (2003, $27 \pm 5\%$) and Misawa et al. (2007, $23\%$), both of which made attempts to filter out contamination by intervening absorbers. Oddly, these fractions are lower than the recent study of Ganguly et al. (2007), who find an AAL frequency of $1898/5088$ (37%), although the 5000 km s$^{-1}$ velocity cutoff for traditional AALs was not strictly adhered to in that survey. We note that 1478/1898 (78%) AALs in that study were missed by the AI selection used by Trump et al. (2006). These certainly constitute false-negatives from the standpoint of finding intrinsic absorption, though not from the standpoint of finding only BAL quasars. While Vestergaard (2003) did note that quasars with AALs are redder on average, a comparison of the Ganguly et al. (2007) sample with the 2MASS PSC reveals that the frequency of AALs is similar to the parent sample ($107/287$, 37%). Thus, the selection of AALs quasars is not affected by optical biases (e.g., reddening or large optical absorption) like BAL quasars.

3.2.2. High Velocity NALs

The first observational evidence for intrinsic narrow velocity-dispersion absorption appearing at high ejection velocity (many tens of thousands of kilometers per second) came nearly a decade ago and include: PG 2302+029 (Jannuzi et al. 1996), Q 2343+125 (Hamann, Barlow, & Junkkarinen 1997), and PG 0935+417 (Hamann et al. 1997). Models of quasar winds generally are able to explain outflows with $\Delta v/v \sim 1$, but are challenged by these $\Delta v/v << 1$ systems. One idea is that the sight-line cuts across the outflow that would produce a BAL under a difference orientation (e.g., Elvis 2000; Ganguly et al. 2001), but this has yet to be demonstrated theoretically. These systems are also interesting because they only absorb photons from the compact continuum. Thus, partial coverage indicators provide severe constraints on the geometry of the flow.

![Figure 1](image_url)

**Fig. 1.** We present a summary plot of the maximum velocity of absorption versus the monochromatic luminosity at 3000 Å. Data from several studies are included: Seyfert 1 galaxies from Crenshaw et al. (1999, filled blue circles); $z < 0.5$ Palomar-Green quasars from Laor & Brandt (2002, open green triangles); SDSS DR2 BAL quasars from Ganguly et al. (2007, filled yellow circles); LBQS BAL quasars from Gallagher et al. (2006, open red squares); intrinsic NALs from Vestergaard (2003, filled blue pentagons); intrinsic NALs from Misawa et al. (2006, open cyan pentagons); polar BAL quasars from Ghosh & Punsly (2007, pink stars); UM 675, intrinsic NAL/mini-BALs in Q 2343+125, and PG 0935+417 from Hamann et al. (1997, black stars); and the mini-BAL in PG 2302+029 from Jannuzi et al. (1996, yellow star).

In terms of demographics, the first assessment of the frequency of these systems came from Richards et al. (1999) and Richards (2001). From a statistical analysis examining the variation in the velocity distribution of C IV NALs with quasar radio-loudness and spectral index, Richards et al. (1999) estimated that as many as 36% of C IV NALs may arise from outflowing gas. Recently, Misawa et al. (2007) report that only 10-17% of C IV NALs in the velocity range 5000-70000 km s$^{-1}$ show evidence of partial coverage. (Thus it is possible that Richards et al. (1999) overestimated the fraction of high-velocity NALs, or that 50-70% of intrinsic C IV NALs do not show partial coverage.) This is not a statement, however, on the fraction of quasars that host such outflows.

Vestergaard (2003) reported that high velocity intrinsic NALs appeared in $18 \pm 4\%$ of $1.5 < z < 3.6$ quasars in the velocity range $5000-21000$ km s$^{-1}$, with about a factor of two variation between radio core-dominated (17$\pm$10%) and radio lobe-dominated (33$\pm$15%) morphologies. In a recent survey of $1.8 < z < 3.5$ SDSS sources, Rodriguez Hidalgo et al. (2007) find about 12% of quasars have high-velocity NALs in the velocity range $5000-50000$ km s$^{-1}$, and $\sim 2.3\%$ in the velocity range $25000-50000$ km s$^{-1}$. This latter velocity range is often missed by surveys due purely to observational cutoffs. Over this velocity range, absorption by C IV can become confused with Si IV absorption.

4. AN EXAMPLE ILLUSTRATING THE MERITS OF COMPREHENSIVE OUTFLOW STUDIES

When parameter space is truncated, either intentionally (e.g., through subclass segregation or the desire to avoid false positives/negatives) or unintentionally (e.g., by data limitations), real correlations that could lead to physical understanding may be missed. The wide variety of observational techniques and the improvements in sample size now make it possible to study the outflow phenomenon in a more complete manner than ever before possible.
TABLE 1
DEMographics of Outflows

| Study                  | Ranges                                                                 |
|------------------------|------------------------------------------------------------------------|
|                        | Study | Redshift | log $\lambda L_\lambda$(3000 Å) | Velocity (10$^4$ km s$^{-1}$) | Width (km s$^{-1}$) | Fraction |
|                        |       |          | (log [erg s$^{-1}$])              |                            |                     |          |
| Crenshaw et al. (1999) | ≤ 0.08 | 42 to 44.8 | 0 to +2 | ≤ 2000 | 50–70% |
| Ganguly et al. (2001)  | ≤ 1   | 44.5 to 46.7 | −1 to +5 | ≤ 500 | 25% |
| Laor & Brandt (2002)   | ≤ 0.5 | 43.9 to 46.4 | 0 to +31 | ... | 50% |
| Hewett & Foltz (2003)  | 1.5–3.0 | 45.8 to 47 | +5 to +25 | ≥ 2000 | 15% → 23% |
| Vestergaard (2003)     | 1.5–3.6 | 45.5 to 47 | 0 to +5 | ≤ 500 | 27% |
|                        |       |          | +5 to +21 | ... | 18% |
| Misawa et al. (2007)   | 2–4 | 46.5 to 47.6 | 0 to +5 | ≤ 500 | 23% |
|                        |       |          | +5 to +50 | ... | 30% |
|                        |       |          | +5 to +10 | ... | 3% |
|                        |       |          | +10 to -25 | ... | 6.7% |
|                        |       |          | +25 to +50 | ... | 2.3% |
| Rodriguez Hidalgo et al. (2007) | 1.8–3.5 | 46.6 | 0 to +5 | 800–3000 | 2% |
|                        |       |          | +5 to +10 | ... | 3% |
|                        |       |          | +10 to -25 | ... | 6.7% |
|                        |       |          | +25 to +50 | ... | 2.3% |
| Ganguly et al. (2007)  | 1.7–2.0 | 44.8 to 46.6 | −1 to +40 | ≥ 500 | 12% → 23% |
|                        |       |          | −1 to +5 | ≤ 500 | 37% → 37% |
|                        |       |          | 0 to +25 | ≥ 1000 | 26% → 40% |
| Dai et al. (2007)      | 1.7–4.0 | to 46.6 | 0 to +25 | ≥ 1000 | 26% → 40% |

**Note.** — The percentages in the last column indicates the fraction of AGN (in the redshift and luminosity ranges listed in columns two and three, respectively) that host intrinsic absorption (with velocities and velocity widths listed in columns four and five, respectively). An arrow indicates a percentage that has been corrected for possible selection biases. The luminosities in column three were computed assuming $h = 0.7$, $\Omega_m = 0.3$, $\Omega_\Lambda = 0.7$, $q = 0.5$ cosmology.

As discussed above, outflow velocity (both in terms of dispersion and range) has often been limited in many studies. By putting together different surveys, we can study the velocity properties of outflows as a function of other potentially important parameters. One recent example where this has been shown to be fruitful is in plotting maximum velocity of absorption, $v_{\text{max}}$, against luminosity. This was originally done by Laor & Brandt (2002) for PG quasars, who, finding an upper envelope formed by the soft X-ray weak absorbers, argued for radiation-driven winds as quasar outflows. More recently, others have added other samples of outflows to this plot (e.g., Gallagher et al. 2006; Misawa et al. 2007; Ganguly et al. 2007) showing that this envelope can be extrapolated to higher luminosities and similarly constrains luminous BAL quasars.

We have further added to this plot in Figure 1 (with the envelope fit from Ganguly et al. 2007), including all types of intrinsic outflows and the most extreme in terms of both terminal velocity and luminosity. Polar BAL quasars are included as well and fall among the general BAL quasar population. Intrinsic NAL systems are well represented throughout the full luminosity range. Some data biases are present; for instance, the wavelength range of SDSS spectra limited the observed $v_{\text{max}}$ to less than 30000 km s$^{-1}$ for most quasars studied by Ganguly et al. (2007), so the gap under the envelope for luminosities above 10$^{46}$ erg s$^{-1}$ is potentially not real. Similarly, searching for intrinsic absorption at velocities above 50000 km s$^{-1}$ becomes very difficult since the C IV lines become blueshifted into the N V/Lyman $\alpha$ region where identification is especially challenging. Of course, the empirical fit does not take into account relativistic effects, so it is inappropriate to extrapolate it to arbitrarily high luminosities. Taken at face value, the fit implies that a quasar with luminosity $\lambda L_\lambda$(3000 Å) $\approx 10^{47.3}$ erg s$^{-1}$ would be capable of driving an outflow at the speed of light, but this is clearly unphysical. More data, and insights establishing better criteria as to which outflows sample the envelope are needed to improve our understanding of the dependence on the terminal velocity on quasar physical properties.

The figure also illustrates another (though more subtle) issue. While AALs are typically defined as those NALs appearing within 5000 km s$^{-1}$, some studies at lower redshift have opted for smaller velocity differences, claiming that 5000 km s$^{-1}$ is an arbitrary cut-off. The figure shows that there is a physical reason for this. As the figure apparently shows, no outflow appears to be driven to a velocity larger than is allowed by radiation pressure. At lower redshifts, most objects studied are also lower luminosity (e.g., Seyfert galaxies). The figure clearly shows that objects with $\lambda L_\lambda$(3000 Å) $\lesssim 3 \times 10^{44}$ erg s$^{-1}$ are not capable of radiatively driving outflows with velocities larger than 5000 km s$^{-1}$. An insight such as this is not only interesting for understanding AGN outflow physics, but is also of use to other fields that make use of intervening absorption-line systems (as it presents an additional means at separating intrinsic from intervening absorbers).

5. WHAT IS THE TRUE FRACTION OF OUTFLOWS?

Table 1 summarizes the incidence of outflows in AGN from several recent surveys (with the redshift and luminosity ranges of the AGN listed in columns two and three, respectively, and the ranges in outflow velocity and velocity width listed in columns four and five, respectively). Inspection of the table shows that the outflow fraction is dependent both on the characteristics of the parent sample of AGN used, and on the forms of intrinsic absorption included. If one only counts BALs observed in higher luminosity AGN $[\lambda L_\lambda(3000 \AA)] \gtrsim 10^{45}$ erg s$^{-1}$, then the outflow fraction is 23% (Hewett & Foltz 2003; Ganguly et al. 2007). However, this is by no means a complete assessment of outflows.

In order to compute a more complete outflow fraction, one must deal with three issues: (1) cross-talk...
among classifications, (2) dependence of frequencies on quasar properties, and (3) mode of the outflow. Here, we ignore the third issue and focus on the first two. Becker et al. (1994) surveyed outflows in lower luminosity \( [L_\lambda (3000 \text{ Å})] \leq 10^{45} \text{ erg s}^{-1} \) AGN and we use their result, 59%, as one benchmark (see also Kriss 2006, who finds a similar percentage based on O VI absorption). For higher luminosity AGN, we start with the Hewett & Foltz (2003) percentage of 23%, as it is the purest, and most well-defined sample of outflows. To this, we must add in two things, the contribution from AALs, and the contribution from high-velocity NALs/mini-BALs. There is general agreement between Ganguly et al. (2001) and Vestergaard (2003) that the AAL fraction is 23–27%. As noted by Ganguly et al. (2001), quasars that host broad-absorption lines also tend to host associated absorption. However, the sample of quasars employed in the Vestergaard (2003) estimates explicitly does not include BAL quasars. Thus, while there is likely some cross-talk between the class of BAL quasars and AAL quasars, the above range should minimize this effect. Thus, the outflow fraction counting BALs and AALs (integrated over “all” high luminosity AGN) is 46–50%. For high velocity NALs/mini-BALs, there is a more sizeable error margin (12–30%) owing to cross-talk and dependence on quasar property. Adding this uncertain number gives our final tally: 57–80%. This fraction is surprisingly comparable to that of lower luminosity AGN.

An alternative approach is to begin with the complete sample of outflows from Ganguly et al. (2007). Correcting their overall outflow fraction (2515/5088, 49%) for quasar selection biases (following the strategy of Dai et al. 2007), we find an outflow fraction of 60±5% (66/287 + 107/287, see §3.1 and 13.2.1). This falls in the above range, and the only missing form of outflow from that sample is NALs/mini-BALs at velocities larger than \( \sim 30000 \text{ km s}^{-1} \). We further note that this explicitly eliminates cross-talk between quasars hosting BALs and quasars hosting AALs.

6. SUMMARY

We conclude that, largely independent of AGN luminosity, 60% is a good reference number for the percentage of AGN with intrinsic outflows. This number may increase slightly with more thorough searches of parameter space (e.g., very high velocity outflows). Until evidence suggests otherwise, we recommend that quasar outflows be studied as a single phenomenon whenever possible and that restrictions based on absorber subclass or data limitations be clearly stated and considered in the interpretation of results. Catalogs should clearly state their contamination issues and their limitations for particular applications as appropriate. A more comprehensive understanding of the outflow phenomenon awaits us.

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