Quasars and Narrow-Line Seyfert 1s: Trends and Selection Effects

Joseph C. Shields and Anca Constantin

Physics & Astronomy Department, Ohio University, Athens, OH 45701

Abstract. The SDSS has opened a new era for the study of AGN spectroscopic properties and how these depend on luminosity and time. In this presentation we review some of the current issues and problems in studies of high-redshift quasars and Narrow-Line Seyfert 1 galaxies. Investigations employing SDSS will, in some situations, still have to pay attention to selection biases and other fundamental limitations of the data.

1. Introduction

The existing literature and pre-Sloan Digital Sky Survey (SDSS) data pertaining to the emission line properties of AGNs have numerous limitations in terms of sample selection criteria and homogeneity. These issues are particularly evident in studies of high redshift quasars, where the focus is on $z > 4$. In this contribution we discuss some of the outstanding questions in this area and how these connect to our understanding of other AGNs, including Narrow-Line Seyfert 1 (NLS1) galaxies. SDSS will lead to significant improvements in several ways relevant to these topics, but it is important to recognize some of the concerns and potential problems that we will still encounter in using SDSS in studies of this type.

2. QSO Selection Effects

During the past decade the number of QSOs known to exist at $z > 4$ has increased rapidly. Much of the early interest in these objects was directed at simply finding them, and using them as background light sources for studies of intervening absorbers. When the number of known sources grew from a handful to several dozen, Shields and Fred Hamann initiated a program of optical spectroscopy with the MMT and Keck in order to study their emission-line properties in more detail; the results were published in Constantin et al. (2002). Our data spanned $\sim 1100 - 1700\AA$ in the rest frame.

One of the results that came out of our survey was that a significant fraction of the $z > 4$ sources exhibit strong emission lines, with somewhat greater frequency than is seen in typical samples at $z \sim 2 - 3$. This finding is of interest since it could be indicative of evolution with redshift in quasar properties. A related point is that linewidth is inversely correlated with line strength, in this survey as well as others at lower redshift; this means that the strong-lined
objects in our sample also tend to display relatively narrow linewidths; do the high-\(z\) AGNs have small black hole masses for their luminosity? Mathur (2000) suggested that this is in fact the case, based on our preliminary findings. Her idea was that the high-\(z\) sources may show a preference for NLS1 behavior, and that both types of object may be in an early evolutionary phase characterized by a high Eddington ratio \(L/L_{\text{Edd}}\). The implications for the growth of black holes and the lifecycle of AGNs are potentially quite significant, if this scenario is true.

The existing samples of \(z > 4\) QSOs are subject to some difficulties that bear on this matter, however. The majority of these sources were discovered by color selection techniques. The strongest signature of these objects is a very red color in \(B - R\) or equivalent bandpasses, that results from the Ly\(\alpha\) line in \(R\) and an attenuated continuum in \(B\) due to the Ly\(\alpha\) forest. The influence of the Ly\(\alpha\) line is heightened at these redshifts by the \(1+z\) scaling of equivalent width. The result is a potential bias favoring detection of objects with strong lines: a stronger line produces a brighter \(R\) magnitude for a given AGN continuum level. In Constantin et al. we reviewed the issue of selection effects for our \(z > 4\) sample but were unable to draw strong conclusions. The extent of bias is complicated in various ways by details of the process by which QSO candidates were originally identified, which is not homogeneous and in some cases not well documented.

A bias toward strong lines will translate into other biases in the emission-line results for an AGN sample. Principal Components/Eigenvector analyses imply that many aspects of quasar spectra are correlated, including as noted above a connection between line strength and line width. Selection effects can thus potentially skew survey results in terms of emission-line ratios, inferred black hole masses, Eddington ratios, and other properties, if not taken into consideration.

The SDSS offers several obvious improvements to the study of high-\(z\) quasars, but will still have some important limitations that should not be ignored. On the plus side, the SDSS offers multiple colors for categorizing objects, excellent photometry, and a procedure for identification of AGN candidates that is well defined and documented. The identification of AGN samples with this prescription can be expected to be highly complete; however, this does not mean that biases can be ignored. As shown by the simulations provided by Fan et al. (2001), candidate selection is still affected by strong lines; while the consequences are likely to be minor over most of the SDSS magnitude range, the possibility of selection bias becomes much more worrisome near the flux limit. The results presented at this conference by Dan Vanden Berk suggesting that SDSS quasars at \(z > 4\) have larger equivalent widths at a given luminosity than their lower \(z\) counterparts is the sort of finding that should be checked carefully in this regard.

3. Comparison of AGN Samples

Drawing conclusions about AGN evolution requires comparisons of sources measured across some range of redshifts, which invariably raises observational challenges. The first is that in the large majority of samples (certainly the majority
of samples currently in the literature), redshift and luminosity $L$ are highly correlated, because of their usual linkage in flux-limited samples. When differences in spectral properties are found between low- and high-$z$ sample members, it then becomes difficult to ascribe this with certainty to evolution, since the distinction could be driven by luminosity differences; conversely, for those interested in AGN physics as a function of source luminosity, the possibility of evolutionary effects is a complicating factor.

The solution, of course, is to construct samples with sufficient coverage of the $L - z$ plane to make it possible to compare objects at a common $L$ across a range of $z$, or to compare sources at a single $z$ that span a range of $L$. One of the more successful recent attempts in this direction was conducted by Dietrich et al. (2002), who demonstrated rather convincingly that $L$, and not $z$, is the fundamental parameter underlying the Baldwin Effect (the negative correlation between luminosity and line equivalent width in AGNs). Dietrich et al. used spectra drawn from a diverse collection of ground- and space-based studies. Quasars in the SDSS still have substantial correlation between $L$ and $z$, but as shown by Vanden Berk at this meeting, the coverage of the $L - z$ plane is nonetheless sufficiently broad to separate the two variables, confirming the Dietrich et al. results. An impressive aspect of the SDSS is the large number of quasar spectra available, which makes it possible to construct quite narrow bins in the $L - z$ plane that still contain statistically robust subsamples.

A second observational challenge is that of available wavelength coverage as a function of $z$. While the optical spectral coverage of the SDSS is substantial, the rest-frame span of wavelengths we’re looking at is considerably larger, so that comparison of spectral properties for samples with disparate redshifts requires some extra work, in terms of observations and/or analysis techniques. The following section presents a case study of this type that we encountered involving the $z > 4$ QSO spectra.

4. NLS1s at High $z$?

Given the uncertain role of selection effects in the Constantin et al. QSOs, we thought it would be worthwhile to look for quantitative tests of the suggestion that these objects are analogs of NLS1s. Comparisons between the $z > 4$ spectra and most published spectra of NLS1s are impossible since the former cover rest-frame UV wavelengths and the latter mostly span optical intervals. The NLS1 classification is based on the $\text{H}_\beta$ and $\text{[OIII]}\lambda5007$ lines, which are very difficult to measure in the high-$z$ objects. We consequently resorted to comparisons in the UV bandpass, using archival HST spectra for a sample of 22 NLS1s. Details of this study are presented in Constantin & Shields. (2003).

The simplest way to compare the two samples spectroscopically is by a direct comparison of composite spectra. Such an exercise is shown in Figure 1. Differences are present, most obviously in the strengths of the lines, with larger equivalent widths in the NLS1 composite. Unfortunately it is unclear whether this difference has any bearing on the NLS1 nature of the QSOs; the NLS1s are substantially lower in luminosity than the QSOs, and the difference is thus entirely consistent with the usual Baldwin Effect.
Constructing a comparison of the two object types that circumvents luminosity dependences is difficult. One possible strategy that we finally implemented is to use a Principal Component (PC) analysis to characterize the NLS1 and QSO samples, in order to gauge their similarity. A diagnostic is then the extent to which a common set of PCs accounts for the spectra and their total variance. The conclusion in the end is that the NLS1s are more spectroscopically “compact,” with a larger fraction of their variance explained with a small number of PCs. High-\(z\) QSOs are probably not close cousins to NLS1s, and whatever tendency they show towards narrow lines is potentially explainable as a selection effect, as noted in \(\S2\).

The SDSS is an incredible resource for identifying new NLS1s as well as other types of interesting AGN subsamples. As the discussion above illustrates, however, bandpass limitations for the SDSS data and luminosity effects will still present challenges in studies of AGN phenomenology and evolution, requiring supporting UV and IR data from other sources, as well as creativity in analysis methods.

References

Constantin, A., et al. 2002, ApJ, 565, 50
Constantin, A., & Shields, J. C. 2003, PASP, 115, 592
Dietrich, M., et al. 2002, ApJ, 581, 912
Fan, X. 2001, AJ, 121, 31
Mathur, S. 2000, MNRAS, 314, 17
Discussion

Antonucci: Anecdotally, high-ionization lines in NLS1s are sometimes broader and blueshifted relative to low-ionization lines. Can you tell us the details and generality of those statements?

Shields: Our study shows a clear trend that higher ionization lines exhibit larger blueshifts. This is true both for the broad and narrow lines. There is little evidence of a trend in line width.