Volume-limited SDSS/FIRST quasars and the radio dichotomy

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Abstract. Much evidence has been presented in favor of and against the existence of two distinct populations of quasars, radio-loud and radio-quiet. The SDSS differs from earlier optically selected quasar surveys in the large number of quasars and the targeting of FIRST radio source counterparts as quasar candidates. This allows a qualitatively different approach of constructing a series of samples at different redshifts which are volume-limited with respect to both radio and optical luminosity. This technique avoids any biases from the strong evolution of quasar counts with redshift and potential redshift-dependent selection effects. We find that optical and radio luminosities of quasars detected in both SDSS and FIRST are not well correlated within each redshift shell, although the fraction of radio detections among optically selected quasars remains roughly constant at 10% for $z \leq 3.2$. The distribution in the luminosity-luminosity plane does not appear to be strongly bimodal. The optical luminosity function is marginally flatter at higher radio luminosities.

1. Introduction

Quasars were first found as optical identifications of luminous radio sources. However, only about 10% of optically identified quasars were radio-luminous, leading to a division of quasars into radio-“loud” and radio-“quiet” objects. Radio observations of optically selected quasars (Strittmatter et al. 1980 and papers citing them) found a bimodal distribution of the radio flux, radio luminosity, or ratio of radio to optical flux. This has resulted in many claims that there are two distinct populations, although it is still unclear whether they should be distinguished by considering the radio luminosity or the radio-optical flux ratio, and what the physical origin of this bimodality or dichotomy might be. More recently, the FIRST radio survey has filled gaps in the radio-to-optical flux ratio distribution found in earlier, shallower surveys (White et al 2000), suggesting that the radio-loud and radio-quiet objects are instead the extremes of a continuum of sources.

The SDSS quasar survey targets both optically selected quasar candidates and point-like optical counterparts of FIRST sources. Together with the large
number of sources compared to previous surveys, this allows to construct a series of volume-limited samples. This avoids any potential biases arising from the rapid evolution of quasar counts and luminosities with redshift. Therefore, the SDSS allows to take a different look at the bimodality question. Once selection effects are taken into account, this approach amounts to constructing the bivariate radio-optical quasar luminosity function.

2. Results

We use data (including rest-frame $i$-band luminosities) from the quasar catalog (Schneider et al. 2003; also Schneider et al. in this volume) created from the SDSS Data Release 1 (Abazajian et al. 2003). We restrict ourselves to FIRST-selected quasar candidates and those identified by the “low-redshift UV excess” ($ugri$) part of the color selection algorithm (Richards et al. 2002). This algorithm selects targets with non-stellar colors down to $i = 19.1$ and has been sufficiently uniform and complete for DR1 data so that first results can be obtained without any corrections.

We construct a series of volume-limited samples of radial extent $\Delta z = 0.2$, retaining only objects with luminosities between that corresponding to the faint flux limit at the upper redshift boundary ($i = 19.1$ for SDSS, $f_{1.4\text{GHz}} = 1\text{mJy}$ for FIRST) and that corresponding to the bright limit at the lower redshift boundary ($i = 15$ for SDSS; FIRST practically has no bright limit).

2.1. Relation between optical and radio luminosity

We construct volume-limited quasar samples between redshifts of 0.2 and 3.2. This retains a few hundred objects in each redshift shell out of originally 10,000. Figure 1 shows an example of the distribution of quasars making the luminosity cut of both surveys in the luminosity-luminosity plane. They straddle the dividing line between radio-loud and radio-quiet objects as defined by a radio-optical luminosity ratio of 10 (dashed line), with many objects lying close to the line. A caveat in the interpretation of this result is that two simplifications have been made: the $K$-correction did not take into account the actual spectral index of the quasar, but assumed a spectral shape $f_\nu \propto \nu^{-0.5}$ for all objects at all wavelengths (compare the contribution about quasar bimodality by Ivezić et al. in these proceedings), and the radio sources include both flat- and steep-spectrum sources, while in principle we need to remove intrinsically fainter flat-spectrum sources which have been beamed above the survey limit. These corrections will be made in future work.

In this particular case, the most luminous radio source is also the most luminous optical source, but this is not generally true - the maximum optical and radio luminosity in each bin are not well correlated. Similarly, the radio and optical luminosities of objects within each bin are not strongly correlated, with correlation coefficients of the logarithmic luminosities typically in the range 0-0.5. This rules out any strict power-law dependence between radio and optical luminosity with a scatter smaller than the luminosity range in each redshift shell (which spans, however, only one decade or so in optical luminosity). Instead, it requires a hidden parameter governing the radio luminosity relative to the optical.
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Figure 1. Example of distribution of quasars in the Luminosity-Luminosity plane for $0.4 \leq z < 0.6$. X symbols are color-selected (UV excess) quasars, open boxes are FIRST-selected targets. The dashed line shows the traditional division between radio-loud and radio-quiet objects at a luminosity ratio of $R = 10$.

In addition to the objects shown in Fig. 1, each redshift shell also contains quasars in the same optical luminosity range but which have a FIRST luminosity below the cutoff. It is possible to compare the radio properties of all SDSS-detected quasars by constructing optical luminosity functions cumulated up to different maximum radio luminosities. The optical luminosity function becomes steeper as the maximum radio luminosity limit is lowered from the brightest detected source to the luminosity cutoff, i.e., a luminous radio source is more likely (but not required) to be a luminous optical source as well.

2.2. Radio-loud fraction as function of redshift

In view of the strong evolution of quasar counts with redshift, it is of considerable interest whether the fraction of radio-loud objects changes with redshift. (The magnitude of the fraction depends on the ratio of the radio and optical flux limits and cannot in itself be interpreted easily.) In the case of SDSS, it is not sufficient to consider merely the fraction of FIRST detections among all quasars in each volume slice without completeness corrections because the survey employs sparse sampling of the color-selected candidates in certain redshift ranges (Richards et al. 2002), while the number of quasars targeted as point-source identification of FIRST sources remains unchanged (lower panel in Fig. 2). Ignoring this would lead to the erroneous conclusion that the fraction of radio-detected quasars increases drastically beyond $z = 2$.

Instead, it is useful to consider the fraction of color-selected quasars (both resolved and point sources) which have a FIRST detection (upper panel in Fig. 2). This fraction is remarkably constant, implying a similar evolution of
radio and optical luminosity with redshift. This finding is in apparent contradiction to the preceding section, where we found no good radio-optical correlation on an object-by-object basis. The reconciliation lies in a radio-optical correlation with a scatter larger than the luminosity range we have considered in each redshift shell. It remains to investigate these correlations in more detail and to compare them to radio-optical correlations such as those found in the most powerful radio sources (see, e.g., Willott et al. 1999).

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