Unveiling Radio Loudness in Quasars

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Abstract. We present a new approach to tackle the issue of radio loudness in quasars. We constrain a (simple) prescription for the intrinsic distribution of radio-to-optical ratios by comparing properties of Monte Carlo simulated samples with those of observed optically selected quasars. We find strong evidence for a dependence of the radio luminosity on the optical one, even though with a large scatter. The intrinsic distribution of the radio-to-optical ratios shows a peak at $R_{1.4}^* \sim 0.3$, with only $\leq 5$ per cent of objects being included in a high $R_{1.4}^*$ tail which identifies the radio loud regime.

1. Introduction

The origin of radio loudness of quasars is a long debated issue. Radio observations of optically selected quasar samples showed only 10-40% of the objects to be powerful radio sources (Sramek & Weedman 1980; Condon et al. 1981; Miller, Peacock & Mead 1990; Kellermann et al. 1989). More interestingly, these early studies suggested that quasars could be divided into the two populations of “Radio-Loud” (RL) and “Radio-Quiet” (RQ) on the basis of their radio emission. Furthermore, Kellermann et al. (1989) found that the radio-to-optical ratios, $R_{1.4}^*$ – defined as the ratio between radio (1.4 GHz) and optical (B band) rest frame luminosities –, of these objects presented a bimodal distribution. Miller, Peacock & Mead (1990) also found a dichotomy in the quasar population, although this time radio luminosity was used as the parameter to define the level of radio loudness.

In the last decade, our ability of collecting large samples of quasars with faint radio fluxes has grown enormously, in particular thanks to the FIRST (Faint Images of the Radio Sky at Twenty centimeters) Survey at VLA (Becker, White & Helfand 1995). However, despite the recent efforts, radio loudness still remains an issue under debate. Works based on data from the FIRST survey (White et al. 2000; Hewett et al. 2001) suggest that the found RL/RQ dichotomy could be due to selection effects caused by the brighter radio and optical limits of the previous studies. On the contrary, Ivezic et al. (2002) seem to find evidence for bimodality in a sample drawn from the Sloan Digital Sky Survey (SDSS). More recently Cirasuolo et al. (2003a) – analyzing a new sample obtained by matching together the FIRST and 2dF QSO Redshift Survey – ruled out the classical RL/RQ dichotomy in which the distributions of radio-to-optical ratios and/or radio luminosities show a deficit of sources, suggesting instead a smoother transition between the RL and the RQ regimes.
Clearly, the uncertainties on the presence of a dichotomy, the character of radio loudness and the consequent poor knowledge of its origin (dependence on BH mass, optical luminosity etc.) are due to the analysis of different samples, often very inhomogeneous because of selection effects both in the optical and radio bands, i.e. the lack of a single sample covering all the ranges of optical and radio properties of quasars.

2. The model

In order to shed some light on this issue, we adopted the alternative approach of starting from simple assumptions on the intrinsic properties of the quasar population as a whole – namely an optical quasar luminosity function and a prescription to associate a radio power to each object - and, through Monte Carlo simulations, generate unbiased quasar samples (Cirasuolo et al. 2003b). By applying observational limits in redshift, apparent magnitude and radio flux we can then compare the results of the simulations with the properties of observed samples. The aim of this approach is of course twofold: constrain the initial hypothesis on the intrinsic nature of quasars, by requiring properties of the simulated samples – such as $R_{1.4}$ and radio power distributions, fraction of radio detections etc. – to be in agreement with the observed ones; test the effects of the observational biases on each sample by simply changing the observational limits. In order to cover a range as wide as possible of radio activity we choose three samples of optically selected quasars for which radio data are available, namely the 2dF Quasar Redshift Survey (Cirasuolo et al. 2003a), the Large Bright Quasar Survey (Hewett et al. 2001) and the Palomar Bright Quasar Survey (Kellermann et al. 1989).

We decided to assume, as the two fundamental ingredients to describe the simulated quasar population, a well defined optical luminosity function obtained from the 2dF Quasar Redshift Survey (Croom et al. 2001) - from which to obtain redshift and optical magnitude for the sources - and different parameterizations for the distribution of radio-to-optical ratios which provide each source with a radio luminosity. A solution, able to reproduce the properties of observed samples, has been found by assuming radio and optical luminosities to be related to each other even though with a large scatter. The radio-to-optical ratio and radio power distributions – modeled as two gaussians and corresponding to this solution – are displayed in Figure and the model parameters are given in Table.

| $x_1$ | $\sigma_1$ | $x_2$ | $\sigma_2$ | Fraction |
|-------|------------|-------|------------|----------|
| 2.7 ± 0.2 | 0.7 ± 0.2  | -0.5 ± 0.3 | 0.75 ± 0.3 | 97 ± 2 per cent |

Table 1. Best-fit parameters for the model, expressed in $\log_{10} R_{1.4}$. $x_1$ and $\sigma_1$ are the center and dispersion of the Gaussian in the RL regime, while $x_2$ and $\sigma_2$ are those for the Gaussian in the RQ one. “Fraction” indicates the percentage of objects having radio-to-optical ratios described by the second Gaussian.
3. Discussion

The first point worth stressing is the “uniqueness” of the solution found. The combination of all the observational constraints is very cogent and thus, despite large errors on each constraint, we find that only one set of parameters is able to simultaneously reproduce all measurements from the three surveys. Furthermore, the uncertainties associated to the various parameters are in this case relatively small (see Table).

It is important to remark here that in order to reproduce the data we need a dependence of the radio luminosity on the optical one, even though with a large scatter. In particular, the successful model accounts for the dependence of the observed fraction of radio detected quasars on apparent and absolute optical magnitudes, as due to selection effects.

Given the uniqueness of the solution, the main result of this work is indeed the fact that we can put rather tight constraints on the intrinsic radio properties of quasars. The distributions shown in the Figure could then describe the unbiased view of the properties of the whole quasar population and this might possibly help us to understand the physical mechanism(s) responsible for radio emission.

First of all, in the $R_{1.4}^*$ distribution we note no lack or deficit of sources between the RL and RQ regimes: the distribution has a peak at $R_{1.4}^* \sim 0.3$ and decreases monotonically beyond that value with only a small fraction ($\lesssim 5$ per cent) of objects found in the RL regime which represent the long flat tail of the total distribution. This result contrasts the classical view of a RL/RQ dichotomy.
where a gap separates the two populations. Nevertheless we can still talk about a “dichotomy” in the sense that the data are compatible with an asymmetric distribution, with a steep transition region and only a small fraction of sources having high values of $R_{1.4}^*$. This result is in agreement, within the errors, with the findings from the new analysis of the SDSS presented by Ivezić et al. during this conference. They still claim the presence of a local minimum dividing the two populations, even though this is now less pronounced than what claimed by Ivezić et al. (2002). While the advantage of SDSS is clearly the large statistics, it is also limited to the RL regime by the 1 mJy cut of the FIRST Survey. On the other hand our method allows to explore a wider range in radio loudness. In any case our findings are consistent, within the errors on best-fit parameters, with the presence of such a shallow minimum where the two gaussians – which describe the $R_{1.4}^*$ distribution – cross each other. The RL regime would simply remain a long flat tail of the asymmetric $R_{1.4}^*$ distribution and it would be clearly of great interest to apply our analysis directly to the SDSS data once its completeness is achieved.

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