The under-explored radio-loudness of quasars and the possibility of radio-source–environment interactions

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Abstract

I demonstrate that radio observations in the literature to date of optically-selected quasars are largely inadequate to reveal the full extent of their jet-activity. I discuss a recent example of an optically-powerful quasar, which is radio-quiet according to all the standard classifications, which Blundell & Rawlings discovered to have a > 100 kpc jet, and show that other than being the first FR I quasar to be identified, there is no reason to presume it is exceptional.

I also discuss a possible new probe of accounting for the interactions of radio sources with their environments. This tool could help to avoid over-estimating magnetic fields strengths within cluster gas. I briefly describe recent analyses by Rudnick & Blundell which confront claims in the literature of cluster gas $B$-fields $> 10\mu$G.

1 Two types of quasar — looks like carelessness?

The view that there are two distinct types of quasar, differing only in their radio characteristics, has prevailed for a number of years (Kellermann et al 1989, Kellermann et al 1994, Miller, Peacock & Mead 1990, Miller, Rawlings & Saunders 1993, and Falcke, Sherwood & Patnaik 1996). It now seems hard to avoid the conclusion that the foundation of these studies, the BQS quasar survey (Schmidt & Green 1983), has serious and systematic incompletenesses (Goldschmidt et al 1992, Miller et al 1993, Wisotzki et al 2000). Moreover, four

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recent studies suggested that the basis for believing in a bimodality, rather than a continuity, of the radio properties of quasars may have evaporated:

[I] Quasars selected from the FIRST survey show no bimodality in 1.4 GHz-radio luminosity (White et al 2000).

[II] Quasars from the optically-selected Edinburgh survey show no bimodality in 5 GHz-radio luminosity (Goldschmidt et al 1999).

However, reservations about the lack of a bimodality found by [I] and [II] include concerns about the high frequency at which the radio data were obtained, 1.4 GHz and 5 GHz respectively: selection and measurement in a waveband where Doppler boosting is prevalent could contaminate the measured radio luminosities, and in principle might blur out any underlying bimodality.

[III] Consideration of a simple diagram from Blundell & Rawlings (2001), reproduced in Figure 1, shows the potential for the bimodality perceived in the past to be a consequence of selection in different radio wavebands. For example, a standard classification of radio-quiet quasars (e.g. Miller et al 1990) is that a radio-quiet quasar’s luminosity at 5 GHz is less than $10^{24}$ W Hz$^{-1}$ sr$^{-1}$. It is instructive to see how this translates to classifications concerning FR I and FR II types at the lower frequency of 178 MHz. Although there have been assertions in the literature that FR I radio structures are never associated with quasars (Falcke, Gopal-Krishna and Biermann 1995, Baum, Zirbel & O’Dea 1995), Figure 1 suggests that low-frequency extended emission resembling that well-known around nearby low-power FR I radio galaxies might sensibly be searched for around ‘radio-quiet’ quasars.

[IV] Blundell & Rawlings (2001) have discovered that one well-studied, optically-powerful quasar has a 300-kpc FR I radio structure emanating from it. Its radio luminosity at 5 GHz falls in the classification for ‘radio-quiet’ quasars ($10^{23.9}$ W Hz$^{-1}$ sr$^{-1}$). Its radio luminosity at 151 MHz ($10^{25.3}$ W Hz$^{-1}$ sr$^{-1}$) is at the transition luminosity observed to separate FR Is and FR IIIs.

The generality of extended radio emission (presumably from FR I-type [i.e. low-power, highly dissipative] jets) in the population of quasars hitherto deemed ‘radio-quiet’ has yet to be investigated. Clarification of this issue would considerably benefit studies of the mechanisms by which quasar central engines work. To achieve such aims requires avoiding selecting the quasars in a way which depends on an unknown and ill-understood mixture of different physical effects (e.g. Doppler boosting, for the FIRST quasars selected at $(1 + z) \times 1.4$ GHz). It is important to select on low-radio-frequency flux-density which should be dominated by lobe or plume (i.e. non-Doppler boosted) jet output.

To establish the prevalence of FR I quasars (perhaps this might be a better way of labelling at least some radio-quiet quasars in the future), and to deduce
their jet-powers, is essential if we are ever to make definitive deductions concerning the so-called ‘radio-optical correlation’ (Rawlings & Saunders 1991) or ‘jet-disc symbiosis’ (Falcke, Malkan & Biermann 1995) for quasars and their central engines. Only with low frequency data can one hope to do a refined ‘radio-optical correlation’ analysis and move closer to an understanding of the relationship between accretion and jet output in the quasar phenomenon.

Figure 1 The vertical green line distinguishes what are conventionally known as the radio-loud and radio-quiet regimes while the horizontal red line distinguishes what Fanaroff & Riley (1974) observed to separate classical double (FR II) and edge-dimmed (FR I) radio sources. E 1821+643 is the quasar which was discovered by Blundell & Rawlings (2001) to have an FR I structure; further discussion of this plot may be found in that paper.

2 A bimodality in the radio observations of quasars?

Radio-quiet quasars are manifestly not radio-silent quasars, yet it is ironic that the so-called radio-quiet quasars have historically had only short snapshot radio observations with typical durations of minutes (see Figure 2) while much deeper observations have been made of brighter radio-loud quasars. In other fields of astronomy, fainter objects are observed for longer integration times than their brighter counterparts! Such snapshots are way too short to reach interesting sensitivity limits (e.g. the FR I / FR II break) for quasars at even intermediate redshifts. The first FR I radio structure discovered by Blundell & Rawlings (2001) was only revealed following a relatively deep observation (∼ 2 hrs). Blundell & Rawlings showed how this extended structure would simply be missed by a typical short snapshot observation (their figure 2).
Figure 2 The left column lists the mean length of time-on-source for observations of radio-quiet quasars in the recent literature; the units are minutes. The VLA has been used to make very deep radio observations (integration times of hours) of radio-loud quasars — e.g. the study of some 3C quasars by Bridle et al (1994) in which the radio structure on all scales is fully sampled; comparable quality observations of quasars which are deemed to be radio-quiet, though which are actually not radio-silent, have yet to be made.

3 A different picture with long baselines?

In addition to significantly shorter integration times, existing observations of radio-quiet quasars are inferior to those of radio-loud quasars in another respect: most of the observations listed in the left column of Figure 2 have been made with a single configuration of the VLA. Typically this configuration has been one of the most extended VLA configurations, either A or B. Observations in extended configurations are less sensitive to extended structure (such as that from FRI jets for example) than the more compact configurations as Figure 3 demonstrates. On the assumption that the FRI quasar discovered by Blundell & Rawlings (2001) is not some lucky exception, then there is the interesting possibility that many more of the “radio-quiet quasar” population have FRI radio structures. Their recognition is contingent on deep, sensitive observations at low-frequency, and/or with sufficiently short baselines that emission on all size scales is actually sampled.
4 A new probe of radio sources interactions with their environments?

FR I radio sources are well-known for their dissipative jets which characterize their overall morphology (e.g. De Young 1993). Entrainment is likely to be a common feature of FR I jets. For example, Bicknell (1994) has used the conservation laws to demonstrate the relationship between entrainment and deceleration. In a similar manner, Laing & Bridle (2002) found that mass-loading or entrainment of ambient matter is required to reproduce the observed deceleration in the jets of the FR I radio galaxy 3C 31. Once thermal material is entrained within the magnetic field of the synchrotron emitting plasma it must at least be considered as contributing to any observed Faraday Rotation. This was the theme of the second part of my talk, namely: the possible development of a tool to probe entrainment and interactions local to the radio source, by considering the relationships between the spatial distributions of Rotation Measure and of Polarisation Angle across radio sources. Spatial correlations of emission line gas and radio lobes (and to a rather lesser extent, the polarimetric properties of these) have been studied by Heckman (1981), van Breugel et al (1984) and Pedelty et al (1989a, b) for example.

Rudnick & Blundell (2003) recently examined the Rotation Measure distribution of an important test case, PKS 1246–410. This is a useful radio source in
this regard since, with a physical size of only 10 kpc, it is entirely embedded within its host galaxy NGC 4696, so significant local effects might be expected to be present. The rotation measure across this source has nonetheless been used to make inferences about the magnetic field of the cluster (Centaurus) in which it resides (Taylor, Fabian & Allen 2002).

In order to test the plausibility of radio source / environment interactions manifesting an identifiable signature in the polarimetric data on this object, Rudnick & Blundell (2003) looked for correspondences in the behaviour of the rotation measure distribution and in the polarisation angle distribution. They tested out spatial correspondences in these two distributions, quantifying the extent to which when one variable changed, the other also changed. Rudnick & Blundell compared these to the results obtained when simulated Rotation Measure maps were used (whose histograms matched actual data, but had no spatial information presumed). Their quantified results indicated that the correspondences seen in the actual data were significantly more pronounced than those from the simulated datasets, suggesting that a signature of local interactions is indeed present in the Rotation Measure distribution.

The reader is referred to the original paper for details of the experiments and analysis of this work. Rudnick & Blundell (2003) made a strong case for radio source/environment interactions, but noted that an artificially constructed unrelated Faraday medium could possibly mimic the observed correlations. Indeed, Ensslin et al (astro-ph/0301552) have proposed just such an artificial distribution, assuming the same high-order statistical properties for the source and for the cluster, as a way to rescue the interpretation of RM variations as due to the overall cluster medium. If one is to build a case that the RM variations are due to the cluster medium, then there should be some test that rules out contributions from the source/medium interactions (which does not yet exist), as well as examining models that are physically motivated. In the meantime, examination of the role of environmental effects local to the radio source as a contribution to the observed Rotation Measure urgently beckons further study, and must be guided by physical models of the nature of the intra-cluster medium.

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