Unification in the low radio luminosity regime: evidence from optical line emission

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ABSTRACT
We address the question of whether or not the properties of all low-luminosity flat spectrum radio sources, not just the obvious BL Lac objects, are consistent with them being the relativistically beamed counterparts of the low radio luminosity radio galaxies (the Fanaroff–Riley type 1, FR I). We have accumulated data on a well-defined sample of low redshift, core-dominated, radio sources all of which have one-sided core–jet structures seen with very long baseline interferometry, just like most BL Lac objects. We first compare the emission-line luminosities of the sample of core-dominated radio sources with a matched sample of FR I radio galaxies. The emission lines in the core-dominated objects are on average significantly more luminous than those in the comparison sample, inconsistent with the simplest unified models in which there is no orientation dependence of the line emission. We then compare the properties of our core-dominated sample with those of a sample of radio-emitting UGC galaxies selected without bias to core strength. The core-dominated objects fit well on the UGC correlation between line emission and radio core strength found by Verdoes Kleijn et al. The results are not consistent with all the objects participating in a simple unified model in which the observed line emission is orientation independent, though they could fit a single, unified model provided that some FR I radio galaxies have emission line regions that become more visible when viewed along the jet axis. However, they are equally consistent with a scenario in which, for the majority of objects, beaming has minimal effect on the observed core luminosities of a large fraction of the FR I population and that intrinsically stronger cores simply give rise to stronger emission lines. We conclude that FR I unification is much more complex than usually portrayed, and models combining beaming with an intrinsic relationship between core and emission line strengths need to be explored.

Key words: galaxies: active – galaxies: jets – quasars: emission lines – radio lines: galaxies.

1 INTRODUCTION

The utility of unified schemes of active galaxies is their simplicity and their potential for making testable predictions. In the case of powerful Fanaroff–Riley type 1 (FR I) radio sources some of the initial simplicity has been lost because modifications have had to be introduced in order to match the predictions to the observations (see Urry & Padovani 1995 for a review). In the case of low power radio sources, however, the simple idea that FR I radio galaxies looked at down their jet axes become BL Lac objects has remained the consensus view (Padovani & Urry 2001). This is perhaps somewhat surprising because only about a third of low-luminosity core-dominated radio sources (supposedly the beamed counterparts of FR Is) are found to be conventional BL Lac objects; most of the remaining two-thirds of such objects have optical classifications such as Seyfert-like objects or passive elliptical galaxies (Marchâ et al. 1996). What is the relationship between these other types of core-dominated objects and FR Is?

We have been exploring the idea that the synchrotron cores of all low-luminosity core-dominated radio sources are intrinsically similar, irrespective of their emission line properties, and that all might be appropriately labelled blazars. Such a scheme is consistent with their continuum spectral energy distributions (SEDs; Antón et al. 2004; Caccianiga & Marchâ 2004; Antón & Browne 2005).

In this paper, we investigate the emission-line properties of low-luminosity radio galaxies, both core-dominated and lobe-dominated. We first compare the emission-line properties of a group of core-dominated objects with those of a matched sample of FR I radio galaxies. According to the simplest unified scheme, in which...
there is no orientation dependence of the line emission, the emission line properties of the two samples should be statistically indistinguishable. A rigorous exploration is possible because we now have available a sample of core-dominated radio sources (the 200-mJy sample; Marcha et al. 1996) for which we have emission line luminosities, extended radio luminosities and high-resolution very long baseline interferometry (VLBI) observations. Knowing the extended radio luminosities is potentially important because the emission-line properties of active galactic nuclei (AGN) correlate with radio power (Rawlings & Saunders 1991; Verdoes Kleijn et al. 2002) and it is therefore necessary to choose a comparison sample from objects having the same range of intrinsic radio powers. From a unified model point of view, the weak extended radio emission of the core-dominated objects (i.e. excluding the core and one-sided jet emission) should be a good measure of the intrinsic radio power because the symmetry of the emission and its low surface brightness eliminate the possibility that its observed strength is influenced by relativistic beaming. The high-resolution VLBI observations are also very important because we cannot simply rely on spectral selection to pick core-dominated sources because not all radio sources with flat spectra have radio structures dominated by cores. Some are found to be compact symmetric objects (CSOs) in which the flat spectrum does not arise from compact self-absorbed core emission. VLBI observations enable us to select with confidence the genuine one-sided core–jet objects and discard the rest.

A second line of investigation can be adopted. If the non-BL Lac core-dominated objects are not relativistically beamed, then we are measuring the intrinsic core strengths and thus objects with strong cores might be expected to produce more line emission. Thus, looking at correlation between line emission and radio core strength might be useful. Verdoes Kleijn et al. (2002) have done this for a sample of UGC galaxies selected without reference to radio core strength and find quite a strong correlation. From the tightness of the correlation they conclude that the bulk Lorentz factors lie in the range 2–5 for continuous jets, or ≤2 for jets consisting of discrete blobs. Most of the objects in their sample are not core-dominated. It would, therefore, be interesting to see if other objects with more dominant radio cores (in which the effects of beaming would be much more apparent if there existed bulk relativistic motions) lie on a continuation of their correlation. We can use the data on the 200-mJy sample and combine them with the UGC results for this purpose.

The structure of the paper is as follows. In Section 2, we describe the selection of the core-dominated sample, and of a comparison sample matched in flux density and redshift to the first. In Section 3, we briefly describe some radio observations of members of the core-dominated sample that were made in order to determine their extended radio flux densities. In Section 4, we compare the emission line distributions of the two samples and also investigate where the 200-mJy objects lie on the Verdoes Kleijn et al. (2002) correlation. Finally, in Section 5, we discuss the results, both in terms of unified models and in terms of ‘dis-unified’ models, and in Section 6 we draw the conclusions. Throughout we adopt a value for the Hubble constant of 75 km s\(^{-1}\) Mpc\(^{-1}\).

2 THE SELECTION OF THE SAMPLES

We start with the 200-mJy sample (Marcha et al. 1996) updated by Antón et al. (2004). This sample consists of flat-spectrum sources (\(S \propto \nu^{-\alpha}\) with \(\alpha \leq 0.5\)) stronger than 200 mJy at 5 GHz, as recorded in GB6 (Gregory et al. 1996), with red optical magnitude brighter than 17. The magnitude selection means that out to a redshift of \(\sim 0.1\) we have an essentially volume-limited complete sample. The sample is further restricted to declinations \(\geq +20^\circ\) and Galactic latitudes \(\geq 12^\circ\). Measurements of the luminosities of the H\(_\alpha\) lines are available for most objects.\(^1\) VLBI maps have been made of virtually all the objects at 5 and/or 1.6 GHz (Bondi et al. 2001, 2004; Bondi & Polatidis, private communication) and we have only included in our discussion those objects with a core and one-sided jet visible in the VLBI maps: future maps may well reveal more core–jet objects. We have also restricted our sample for the current paper to objects with redshifts \(\leq 0.1\) because in this redshift range we are confident that the sample is complete. The redshift restriction also facilitates finding a good comparison sample (see below and Table 1). Spectroscopically, the sample has been classified according to the following types (also identified in Table 1): PEG stands for passive elliptical galaxies and it refers to sources with weak emission lines and a strong galaxy component; Sy1.2 stands for sources with strong emission lines in their spectra (1 if broad emission lines are seen, 2 if only narrow lines are present); hyb stands for sources with broad but significantly weaker emission lines than in the Sy case; BL Lac stands for sources with weak or absent emission lines in their spectra. Seven BL Lac objects with continuous optical spectra and no measured redshifts from the 200-mJy sample are excluded from the sample to be discussed. This should not bias the statistics because it is almost certain that all these objects are at redshifts \(\geq 0.1\), otherwise the host galaxy would be visible and its redshift known.

We use as a basis of our comparison sample the radio galaxies found in Abell clusters, and studied by Ledlow & Owen (1995) and by Owen, Ledlow & Keel (1995). These consist of objects with 20-cm flux densities \(\geq 10\) mJy and redshifts \(\leq 0.09\). H\(_\alpha\) luminosities (or limits on luminosities) are given by Ledlow & Owen for most of the objects. These sources are mostly ellipticals from the spectroscopic point view, although a small number (less than 13 per cent) has strong emission line spectra related to star formation (Owen, Ledlow & Keel 1996). In our analysis, we will use a subsample of the Ledlow & Owen sample consisting of objects with H\(_\alpha\) measurements and picked to match the 200-mJy objects both in redshift and in flux density.\(^2\) For each 200-mJy object, we have looked for a ‘twin’ matched to within a factor of 2 in 20-cm flux density to the extended flux density of the 200-mJy object (see next section) and \(\sqrt{2}\) in redshift (in most cases the matches are much closer), regardless of the strength of the line emission. Matches were possible in all but one case. The procedure used to produce a comparison sample eliminates any worry about the effect of the correlation between line luminosity and the intrinsic radio power. It also ensures that the linear scales of the spectrograph slit, when projected on the galaxy, are comparable. The twin for each 200-mJy source is given in Table 1. In this process, we are implicitly assuming that the Ledlow & Owen objects are representative of the population of unbeamed counterparts of the 200-mJy objects.

3 VLA OBSERVATIONS AND DATA REDUCTION

The best estimate we have of the intrinsic radio power of a core-dominated object, where the core and jet emission may be Doppler boosted, is the extended radio emission. Estimates of the extended

\(^1\) When we refer to H\(_\alpha\), we implicitly include emission from the [N \text{II}] lines with which H\(_\alpha\) is usually blended.

\(^2\) Because we have good radio spectra for the 200-mJy sources, we do the matching in extended flux density at 20 cm. The choice of wavelength to do the matching does not affect the validity of the comparison.
emission can be made using the Faint Images of the Radio Sky at Twenty-centimetres (FIRST) survey (Becker, White & Helfand 1995) data but these are available for only a fraction of the 200-mJy objects. For this reason, we have made our own Very Large Array (VLA) B-configuration observations at 20 cm of those 200-mJy objects that do not lie in the region covered by the FIRST survey. Each source was observed at two widely separated hour angles for a total observing time of ~10 min. The observations were calibrated and mapped using standard AIPS tasks. The data were of good quality and, in most of the maps, extended radio structure is detectable. The peak flux densities and total flux densities were measured with the task IMEAN and the extended flux density taken as the difference between the two quantities. The results are listed in Table 1. For those sources in the FIRST survey, FITS images were retrieved and processed in the same manner as our own maps.

Table 1. The 200-mJy sample and the comparison sample. Columns: (1) name; (2 and 11) extended flux density at 20 cm; (3 and 10) redshift; (4) spectroscopic type (Sy1,2 stands for Sy-type 1,2; PEG stands for passive elliptical galaxies; hyb stands for hybrid; BL stands for BL Lac); (5) log of line luminosity; (6) log of extended luminosity; (7 and 12) equivalent width of $H_\alpha$ $+$ [N II] in Å; (8) SED type taken from Antón et al. (2004; SPL for steep power law, bPL for broken power law and PL+IR concave spectrum with one or more bumps); (9) name of twin (B1950). Flux densities are in mJy, radio luminosities in W Hz$^{-1}$ and line luminosities in W.

4 THE EMISSION LINE PROPERTIES OF CORE-DOMINATED AND LOBE-DOMINATED OBJECTS

4.1 The 200-mJy sample and comparison sample

We first ask the simple question: are the emission line properties of the 200-mJy-sample sources statistically distinguishable from those of the sources in the comparison sample? We choose to compare $H_\alpha$ luminosities because these are widely available and do not worry at this stage whether we are dealing with narrow-line or broad-line emission. In the simplest version of the FR I unified scheme in which there are no hidden emission line regions, one would expect the distribution of emission line luminosities in the 200-mJy sample and in the comparison sample to be indistinguishable (see Fig. 1).

An advantage of having matched pairs of objects is that it gives us a simple way to quantify the probability that the distribution of line luminosities for the two samples is indistinguishable. In 16 pairs (excluding three pairs where both members have limits on luminosities and one where they were identical) it is found that in 13 cases the member drawn from the 200-mJy sample has the more luminous $H_\alpha$ line. We use the binomial distribution to work out the probability that in 13 or more cases the 200-mJy member should have the larger line luminosity, on the assumption that the line luminosity distributions of both groups are the same. We conclude that there is less than 2 per cent probability that the line luminosity distribution in the two samples is drawn from the same population.

The confidence in this result could be questioned due to two factors: first, there may be some degeneracy in the choice of twins (e.g. more than one possible twin for each of sources of the 200-mJy sample) and, secondly, there is the statistically difficult issue of comparing distributions where there is a significant number of upper limits. We decide to investigate the consequences of both of these aspects by proceeding in the following way.

(i) For each 200-mJy-sample source, we take all the twins that fall in the region within a factor of 2 in 20-cm flux density and a factor of $\sqrt{2}$ in redshift.

(ii) For the 16 sources with four twins or more, we take the line luminosities (the detections and upper limits) and find the Kaplan–Meier estimator for the distribution function of randomly censored data by using survival analysis (ASURV; LaValley, Isobe & Feigelson 1992). For the remaining sources, we preferentially took the twin with a detection, or in case there were only upper limits, the highest of these as the line luminosity for the twin.

(iii) The line luminosity of the twins found in the way described above is then compared to the line luminosity of the 200-mJy sources. We find that in 17 cases the line luminosity of the 200-mJy sources is higher than that of the twin, in one case it is equal, and...
in two cases it is smaller. If we then use the binomial distribution to estimate the probability that, in 17 out of the possible 19 pairs, the line luminosity of the 200-mJy source is larger than that of the comparison sample, we find that this probability is \(<0.0001\).

(iv) Finally, we note that 17/20 sources of the twin sample have \(L(H_\alpha) < 10^{33}\) W, whilst in the 200-mJy sample, only 3/20 have such low values of line luminosity.

We therefore think that the difference between the strength of the line luminosity of 200-mJy sample and its twin should be taken seriously. There is at least one selection effect that is likely to mask the true difference between core- and lobe-dominated objects when we use our two samples. The two samples are cross-contaminated; the 200-mJy sample contains some not very core-dominated objects, while the Ledlow & Owen sample contains some objects that are just as core-dominated as the 200-mJy objects. For example, 0055+300 (NGC 315), a giant FR I radio galaxy (Bridle et al. 1976), is in the 200-mJy sample.\(^3\) Such a cross-contamination is likely to make it more difficult for us to recognize true differences in emission-line properties rather than leading to spurious differences. Hence, the detected difference is likely to be a lower limit on the true difference between the line luminosities of the two samples.

There is one caveat related to the fact that the Ledlow & Owen objects are selected to lie in Abell clusters of galaxies, whereas the 200-mJy sources are selected without any reference to their cluster environments. It could be that the hosts of radio sources in clusters have different emission-line properties to galaxies in the field. Such an effect has been claimed to exist by Guthrie (1981). We are, however, reassured that this may not be too important an effect because the 200-mJy objects appear to be consistent with the correlation for non-core-dominated objects found by Verdoes Kleijn et al. (2002) between emission line luminosity and radio core luminosity (see below and Fig. 2).

4.2 The 200-mJy sample and UGC galaxies

The result above suggests a simple interpretation, which is that emission line strength is related to core strength. Such a view is supported by the observation of a tight correlation of the core emission line strength with radio core strength in the UGC FR I radio-galaxies (Xu et al. 2000; Verdoes Kleijn et al. 2002; Fig. 2). Given that most of the residual dispersion in the correlation could be due to measurement errors and/or to radio core variability, that leaves little room for the effects of beaming on the core strengths. Variability is relevant for narrow-line emission because the narrow-line region (NLR) probably has a size of approximately tens to hundreds of parsecs and thus its observed strength reflects the core activity integrated over times-scales of tens, perhaps hundreds, of years. Hence, one spot measurement of radio core strength may not be a good indicator of the integrated core activity.

To investigate if the correlation holds for objects contained in the 200-mJy sample, we include these sources with the UGC objects of Verdoes Kleijn et al. in a plot of the VLBI core luminosity \(L(\text{rc})\) against the line luminosity \(L(H_\alpha)\) (Fig. 2, where we separate the BL Lacs in the 200-mJy from the remaining sources by plotting them as open triangles). The 200-mJy sources have more...
dominant cores than the UGC objects, they might be expected to display the effects of beaming more strongly. (We note that the comparison sample is not included in this plot because they lack VLBI measurements.) This should manifest itself in two ways: (i) as an increase in the dispersion in the correlation, and (ii) in the more core-dominated objects falling on average below the line established for the UGC objects. It is clear that the 200-mJy objects join relatively smoothly on to the existing UGC correlation.

The correlation coefficient for the UGC + 200 mJy objects (excluding the six BL Lacs in the 200 mJy where four have upper limits to the line luminosity) is 0.72 corresponding to a probability of there being no correlation of ≲1 per cent. The linear least-squares fit gives a slope of 0.89 ± 0.1. There is an increase in the scatter going from the UGC to the 200-mJy objects but no obvious sign in the decrease in slope, which would be expected if the radio core emission is beamed and the line emission isotropic. In fact, the BL Lacs of the 200-mJy sample seem to fit within the general relationship without significantly increasing the dispersion of the distribution. This is confirmed by the generalized Spearman’s correlation test of 0.76, when we use survival analysis to include the upper limits of the line luminosity of the BL Lacs. This value means that the probability of no correlation between the two quantities is less than 1 per cent. The resulting linear regression when all the sources are considered is $L(\alpha) \propto (0.76 \pm 0.09) L_{\text{rc}}$.

We emphasize that the correlation between radio core and line luminosity is not induced by redshift. In fact, the partial correlation coefficient between the two quantities, excluding the effect of redshift, is 0.62 for the UGC and 200-mJy sources (where the six BL Lacs were not considered), which gives a probability $\ll$1 per cent to the hypothesis that there is no correlation between the two luminosities.

5 DISCUSSION

The basis of our discussion is that the more core-dominated sources have significantly stronger line emission than the lobe-dominated sources. This shows up in the comparison of the 200-mJy-sample objects with the matched sample objects, and in the strong correlation between radio core luminosity and emission line luminosity. What, if anything, does this tells us about FR I unification? We will start by looking at things from two opposite viewpoints, one unified and one ‘dis-unified’. We then discuss if there is a middle way.

5.1 The unified interpretation

If we adopt a strict ‘orientation is everything’ point of view, we conclude that, in some FR I, optical emission line regions must often be hidden from the observer and (statistically) become more visible when looking close to the jet axis. We note that in most cases, but not all, the line emission we see in the core-dominated objects of the 200-mJy sample is not nuclear broad-line emission (which is believed to be present in most FR IIIs but sometimes hidden from view by a molecular torus), but most often narrow-line emission, which originates at radii more than a few parsecs from the nucleus of the galaxy. More specifically, there are four objects, 0125 + 487, 0321 + 340, 1646 + 499 and 2116 + 81, in the 200-mJy sample in Table 1 that are classified as having broad emission lines and all four have high line luminosities. Although better (higher resolution) spectra would be required to provide narrow-line luminosities, visual inspection of the available spectra shows that all the broad-line sources have substantial narrow-line components, which are probably sufficiently strong by themselves for the galaxies to be called Seyfert 2s. This means that in nearly all cases it is the narrow-line emission, which is thought to originate more than a few parsecs from the nucleus, that would have to be hidden. This type of narrow-line emission would not be affected by a torus but might be partially hidden by, for example, extinction in a kind of dust and gas disks seen in many FR I radio galaxies (de Ruiter et al. 2002). Additional evidence for off-nuclear gas and dust is presented by Quillen, Almog & Yukita (2003) who argued, on the basis of 3CR radio-galaxy SEDs, that the nuclear regions of some FR I radio galaxies suffer from optical extinction. Further evidence comes from recent results by Wills et al. (2004) on 13 low-luminosity sources of the 2-Jy sample. In particular, these authors found that the average [O III] line luminosity in BL Lacs is significantly larger than that of FR Is, thus supporting the view of extinction in the latter type of sources.

Because a factor of a few in orientation-dependent extinction in the inner kpc would be enough to account for the excess of line emission in the core-dominated objects with respect to those in the comparison sample, we think this is just about a viable scenario.

5.2 A dis-unified interpretation

An alternative interpretation is to say that the observations rule out FR I unification or, at least, force us to exclude from any such schemes the core-dominated synchrotron jet sources that are not recognizably BL Lacs. This would not be a very tidy state of affairs, but it could be the truth! Such a view, one might argue, is the most logical interpretation of the tight correlation of the core line strength with radio core strength in the UGC FR I radio-galaxies (Verdoes Kleijn et al. 2002) and the fact that the 200-mJy objects lie on the same correlation (Fig. 2). To explore this correlation further, we have added to the objects plotted in Fig. 2 those FR I radio sources from the 3CR studied in Cao & Rawlings (2004): see Fig. 3 where we have excluded the 3CR FR I galaxies that were in common with those already present in the UGC sample. We emphasize that no attempt has been made to match the 200-mJy-sample objects in extended luminosity. It is clear that the core luminosities cover a similar range to those seen in the 200-mJy sample and the line luminosities are consistent with objects from this additional sample participating in the same correlation as the objects from the other two samples. Simple beaming schemes, even those incorporating orientation-dependent extinction of emission line regions would not predict this.

One might argue that because the slope of the core/emission line correlation is less than unity, a viable hypothesis is that there is an underlying linear correlation between $H_{\alpha}$ luminosity and intrinsic core strength, and all the scatter in Fig. 2 could be attributable to the effects of beaming. In other words, beaming should leave $H_{\alpha}$ unchanged but move the core luminosity towards the right in Fig. 2. We have tested this idea in two ways. First, we look for a correlation between the magnitude of the deviation of the core luminosity

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4 We note that the plotted line luminosities are slightly different in the two samples. In the case of the UGC objects the line emission refers to the nuclear $H_{\alpha} + [\text{NII}]$ emission measured with the Hubble Space Telescope (HST), whereas in the case of the 200-mJy objects we are using the $H_{\alpha} + [\text{NII}]$ flux integrated over a wider spatial extent.

5 We note that Chiaberge et al. (2002) argue that the combination of optical and UV HST data, and radio core emission for FRIs are not consistent with the standard thick torus framework.
from the underlying linear (slope unity) correlation and the core dominance parameter $R (L_{rc}/L_{ext}$ at 1.4 GHz). Both should be orientation indicators in the beaming scenario. We find absolutely no correlation (see Fig. 4), which reinforces the view that the evidence for radio core beaming effects amongst these objects is very weak.

The second approach is to adopt the traditional unified scheme view (e.g. Orr & Browne 1982) that there is a tight relation between the intrinsic core strength and that of the extended lobe emission. In this case, the measured core dominance ($R$) compared to what would be seen if the object were viewed in the plane of the sky ($R_c$) is a direct measure of the core Doppler boosting. Based on models that use population statistics to constrain beaming model parameters, current estimates for $R_c$ are about 0.01 (Wall & Jackson 1997; Jamrozy 2004). We use these estimates and the observed $R$ values to de-boost each object. The resulting plot of line luminosity against de-boosted core luminosity is shown in Fig. 5 where symbols are as before. The original correlation is destroyed.

One additional thing we have tried, still within the context of there being a linear correlation between line luminosity and intrinsic core strength, is to estimate how much orientation-dependent extinction would be required to just counterbalance the effect of beaming and restore Fig. 5 to look like Fig. 3. The result of our exercise, however, is that it would require one to move most of the 200-mJy objects in Fig. 5 by around 2 orders of magnitude in line luminosity, which is much larger than current estimates of the extinction suffered by the cores of most FR I radio galaxies would allow. For instance, based on the study of the UV emission of the nuclei of 3CR galaxies, Chiaberge et al. (2002) deduce a median value of $A_V = 1.3$ for the FR Is in their sample.

5.3 Reconciling the interpretations

We are faced with a dilemma. The evidence for relativistic bulk motion in the cores of BL Lacs is extremely strong and hence the core emission we observe in these must be highly orientation dependent because of Doppler boosting. There is also direct evidence from superluminal motion that there are highly relativistic jets at the pc-scale in FR 1 radio galaxies (Giovannini et al. 2001). The case for unification between BL Lacs and some, or all, FR 1s is thus very strong. On the other hand, we have shown that BL Lacs are not the only low-luminosity core-dominated radio sources with synchrotron jets (Marcha et al. 1996; Bondi et al. 2001; Antón et al. 2004; Bondi et al. 2004) and it is very tempting to hypothesize that these non-BL Lacs have relativistic jets too and that they fit into a single unified picture. We note for instance that two PEGs (1241+735 and 2320+203) of the 200-mJy sample are completely indistinguishable from BL Lacs not only in pc-scale morphology, but also in the
level of polarization detected in the pc-scale jet (Bondi et al. 2004). However, in this paper we find that, despite the similarity in radio properties, the non-BL Lacs have on average stronger emission lines than the FR I radio galaxies. Furthermore, the strong correlation between observed core strength and emission line strength, both for the UGC sample alone and the UGC sample plus 200 mJy, is prima facie evidence for a tight relationship between the intrinsic core strength and the emission lines that are somehow excited by this core activity. Is it possible to fit all we know about these objects into a single framework?

The simplest interpretation is to postulate an orientation dependence of the emission lines that makes them appear systematically stronger as the angle to the line of sight decreases. This could go some way to account for why stronger emission lines go with stronger cores but fails on the following three counts.

(i) It does not explain why the BL Lacs, which are believed to be viewed at small angles, do not have strong lines.
(ii) It does not account for the very tight correlation between radio core strength and line emission in the UGC sample, which has been selected on extended optical and radio properties, and that should not introduce any orientation bias.
(iii) The amount of extinction (∼5 mag) required to restore the correlation in Fig. 2 seems much too large when compared with the recent measurements by Chiaberge et al. (2002) for FR I radio galaxies.

Any complete unified model must have an intrinsic correlation between core strength and line emission built in from the start. This may be possible. In a subsequent paper, we will explore a model based on the following ideas.

(i) Jets have a highly relativistic spine and a slower sheath (Laing & Bridle 2004).
(ii) The relativistic spine of the jet is where the characteristic BL Lac emission comes from and is usually only dominant when viewed at small angles to the line of sight.
(iii) It is the energy dumped into the slow sheath that drives the production of emission lines and produces the majority of the observed core emission at large viewing angles.

6 SUMMARY AND CONCLUSIONS

We summarize our results as follows.

(i) We have compared the Hα emission properties of the 200-mJy sample of low-luminosity core-dominated sources with those of a matched sample of FR I radio galaxies and find that the former have significantly stronger emission lines. Either unified models based on beaming have to be modified to include some orientation-dependent extinction, or the dispersion in intrinsic core strengths is so large that beaming is not the dominant factor.

(ii) From combining observations of UGC galaxies with those of our 200-mJy sample, we see that the observed core and emission line strengths in radio galaxies are strongly correlated, with little evidence for the kind of behaviour one might expect if the radio emission from the cores of most of the core-dominated objects was beamed. The evidence for beaming amongst the many BL Lacs may be strong but it is far from strong amongst the many objects with virtually identical radio properties.

We conclude that FR I unification is much more complex than usually portrayed, and models combining beaming with an intrinsic relationship between core and emission line strengths need to be explored.

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