UNIFICATION SCHEME OF RADIO GALAXIES AND QUASARS FALSIFIED BY THEIR OBSERVED SIZE DISTRIBUTIONS

ASHOK K. SINGAL AND RAJ LAXMI SINGH
Astronomy and Astrophysics Division, Physical Research Laboratory, Navrangpura, Ahmedabad - 380 009, India; asingal@prl.res.in
Received 2013 February 1; accepted 2013 February 4; published 2013 March 5

ABSTRACT

In the currently popular orientation-based unified scheme, a radio galaxy appears as a quasar when its principal radio-axis happens to be oriented within a certain cone opening angle around the observer’s line of sight. Due to geometrical projection, the observed sizes of quasars should therefore appear smaller than those of radio galaxies. We show that this simple, unambiguous prediction of the unified scheme is not borne out by the actually observed angular sizes of radio galaxies and quasars. Except in the original 3CR sample, based on which the unified scheme was proposed, in other much larger samples no statistically significant difference is apparent in the size distributions of radio galaxies and quasars. The population of low-excitation radio galaxies with apparently no hidden quasars inside, which might explain the observed excess number of radio galaxies at low redshifts, cannot account for the absence of any foreshortening of the sizes of quasars at large redshifts. On the other hand, from infrared and X-ray studies, there is evidence of a hidden quasar within a dusty torus in many radio galaxies, at \( z > 0.5 \). It is difficult to reconcile this with the absence of foreshortening of quasar sizes at even these redshifts, and perhaps one has to allow that the major radio axis may not have anything to do with the optical axis of the torus. Otherwise, to resolve the dichotomy of radio galaxies and quasars, a scheme quite different from the present might be required.

Key words: galaxies: active – galaxies: nuclei – quasars: general – radio continuum: general

Online-only material: machine-readable table

1. INTRODUCTION

Both the observed numbers and radio sizes of quasars appear to be about a factor of two smaller than those of radio galaxies (RGs) in the radio-strong 3CR complete sample (Laing et al. 1983) in the redshift range \( 0.5 < z < 1 \) (Barthel 1989). It was suggested that both RGs and quasars belong to the same parent population of radio sources, and that a source appears as a quasar only when its principal radio-axis happens to be oriented within a certain cone opening angle (\( \xi_c \)) around the observer’s line of sight (Barthel 1989). In this model, the nuclear continuum and broad-line optical emission region is surrounded by an optically thick torus and \( \xi_c \) is the half-cone opening angle of the torus, similar to that proposed in the case of Seyfert galaxies (Antonucci & Miller 1985). In the case of RGs, the observer’s line of sight is supposed to be passing through the obscured region which hides the bright optical nucleus and the broad-line region. Accordingly, RGs and quasars are considered to be intrinsically indistinguishable and all differences in their observed radio properties are attributed to their supposedly different orientations with respect to the observer’s line of sight; in particular, the observed smaller value of radio sizes of quasars in the 3CR sample was attributed to their larger geometric projection effects because of the shallower inclinations of their radio axes with respect to the observer’s line of sight.

This has come to be known as the orientation-based unified scheme (OUS) and has gained increasing popularity (Antonucci 1993; Antonucci 2012; Urry & Padovani 1995; Kembhavi & Narlikar 1999) both because of its simplicity and the promise it holds for bringing two apparently quite distinct class of objects, viz. quasars and RGs, under one roof. According to this scheme, the expected ratios of the observed numbers as well as of sizes of quasars and RGs in a low-frequency radio-complete sample are determined purely by the value of \( \xi_c \). It is widely believed that, in samples chosen at meter wavelengths, the observed numbers as well as sizes of quasars are typically about half as large as those of RGs. This notion has resulted purely from the data in a limited redshift range \( 0.5 < z < 1 \) of the 3CR sample that yielded the “canonical” value of \( \xi_c \sim 45^\circ \). Later, Singal (1993a) pointed out that the data in other redshift bins from the rest of the 3CR sample do not seem to fit into this simple scenario. Suggestions were then put forward (Gopal-Krishna et al. 1996) that by making allowance for a temporal evolution of sources in both size and luminosity, one could mitigate the above discrepancy. Alternatively, it has been suggested that this excess may be due to a population of low-excitation radio galaxies (LERGs), which might make a significant contribution to the number of FR II type radio galaxies at low redshifts (see, e.g., Hine & Longair 1979). Laing et al. (1994) have pointed out that these optically dull LERGs are unlikely to appear as quasars when seen end-on and that these should be excluded from the sample while testing the unified scheme models. From infrared observations there is also evidence of a population of powerful radio galaxies, concentrated at low redshifts, which lacks a hidden quasar (Antonucci 2012; Ogle et al. 2006; Leipski et al. 2010). Using both X-ray and mid-IR data, Hardcastle et al. (2009) showed convincingly that almost all objects classed as LERGs in optical spectroscopic studies lack a radiatively efficient active nucleus. On the other hand, strong evidence against OUS also comes from the observed opposite behavior of the luminosity–size correlations among RGs and quasars as well as from the vast difference in their cosmological size evolutions (Singal 1988, 1993b, 1996a).

A comparison of the angular size of RGs and quasars is a very robust test, as in samples selected at meter wavelengths, emission is observed only from the steep-spectrum extended parts of the source, with flat-spectrum core-emission, if any, highly suppressed and the relativistic beaming effects playing
almost no part. Both quasars and RGs are chosen by the strength of their extended emission, not influenced by any orientation effects. As the parent sample for RGs and quasars is supposed to be the same, there will be no relative selection effects based on redshift or luminosity, with their observed size ratios affected only by the geometrical projection. Further, it is not necessary to convert their angular sizes into linear sizes (using a particular cosmological model) for the comparison of their sizes to test OUS as the observed angular size ratios will truly reflect their (projected) linear size ratios since the redshift distribution is supposed to be the same for RGs and quasars in OUS models. If we think that the redshift distribution might be different for RGs and quasars, then we are already doubting the veracity of the unified scheme.

2. THE SOURCE SAMPLE

For our investigations we have chosen an essentially complete MRC sample (Kapahi et al. 1998a, 1998b), which is about a factor of ∼5 deeper than the 3CR sample and has the required radio and optical information. It comprises a total of 550 sources, with 105 of them being quasars, 6 BL Lac objects, and the remainder RGs. Optical identifications for the latter are given in Baker et al. (1999) with tabulations of redshifts, spectroscopic data for quasars with full observational details of sources (Kapahi et al. 1998b), which is organized in the following manner. (1) Source name (McCarthy et al. 1996) expected to be at high redshifts $z \gtrsim 1$. Optical spectroscopic data for quasars with full observational details are given in Baker et al. (1999) with tabulations of redshifts, continuum, and emission-line data for each source. The optical identifications are missing only for a very small percentage of sources (Kapahi et al. 1998b), which should not be too detrimental for our investigations here.

As only the powerful RGs are supposed to partake in unification with quasars, we have confined ourselves to only the strong, FR II type sources (Fanaroff & Riley 1974) with $P_{408} \gtrsim 5 \times 10^{25}$ W Hz$^{-1}$ (for a Hubble constant $H_0 = 71$ km s$^{-1}$ Mpc$^{-1}$, the matter energy density $\Omega_m = 0.27$, and the vacuum energy (dark energy) density $\Omega_\Lambda = 0.73$; Spergel et al. 2003); the quasars (all but one) fall above this luminosity limit. This limit corresponds to the FR I/II luminosity break $P_{178} = 2 \times 10^{22}$ W Hz$^{-1}$ sr$^{-1}$ (for $H_0 = 50$ km s$^{-1}$ Mpc$^{-1}$) of Fanaroff & Riley (1974). It may be prudent to exclude flat-spectrum sources entirely since these are mostly core-dominant cases where the relativistic beaming might introduce serious selection effects. Among the quasars there are 16 sources with spectral index $\alpha \lesssim 0.5$ (with $5 \propto \nu^{-\alpha}$), while among the RGs there are only 7 such cases; we have excluded all these flat-spectrum cases. Also there is a large fraction of Compact Steep Spectrum Sources (CSSS; linear size <25 kpc) in the MRC sample, comprising about 20% of the whole sample, which seems to be a different class than the FR II class of sources whose unification is sought in OUS (Kapahi et al. 1995), and as such these should be excluded for testing OUS. For the unknown-$z$ galaxies we have taken <3 arcsec as the CSSS criteria as at $z \sim 1$, where most of these faint galaxies are likely to be, for our adopted cosmological parameters, 1 arcsec translates to about 8 kpc.

It has been pointed out (Kapahi et al. 1995) that radio sizes of MRC quasars appear considerably larger than those of 3CR quasars. This can of course be taken only as an indicator of some anomaly as the flux-density range and the volumes in the two samples (MRC and 3CR) are very different. For a meaningful comparison of the relative sizes of RGs and quasars, in order to test OUS, one must draw both kinds of sources (RGs and quasars) from a common parent sample so that no effects enter due to different flux-density and/or the space-volume sampled as any redshift or luminosity dependence of the sizes could otherwise bias the conclusions. Previously, this could not be done because data on the MRC sample of galaxies were then not complete (Kapahi et al. 1995), but these data have since become available, and we can now attempt it here.

There are a total of 494 sources in our sample listed in Table 1, which is organized in the following manner. (1) Source name from MRC. (2) Flux-density $S_{408}$ at 408 MHz. (3) Spectral index $\alpha$ ($\propto \nu^{-\alpha}$). (4) Nature of optical object: G: galaxy, Q: quasar, U: unidentified. (5) Redshift $z$. (6) Linear size $l$ in kpc. (7) Luminosity $P_{408}$ in W Hz$^{-1}$. Among these 494 sources, there are 379 RGs, 87 quasars, and 28 remain unidentified. The linear size is calculated from the observed angular size $\theta$ as $l = \theta D/(1 + z)$ and the luminosity is calculated from $P_{408} = 4\pi S_{408}D^2(1 + z)^{1+n}$, where $D$ is the comoving cosmological distance calculated from the cosmological redshift $z$ of the source. In general it is not possible to express $D$ in terms of $z$ in a close-form analytical expression and one may have to evaluate it numerically. For example, in the flat universe models ($\Omega_m + \Omega_\Lambda = 1, \Omega_\Lambda \neq 0$), $D$ is given by (see, e.g., Weinberg 2008),

$$D = \frac{c}{H_0} \int_1^{1+z} \frac{dz}{(\Omega_\Lambda + \Omega_m z^3)^{1/2}}. \tag{1}$$

For a given $\Omega_\Lambda$, $D$ can be evaluated from Equation (1) by a numerical integration.

### Table 1

| Name (Jy) | Obj | $\alpha$ | $S_{408}$ | $z$ | $l$ (kpc) | $P_{408}$ (W Hz$^{-1}$) |
|-----------|-----|---------|----------|-----|-----------|-------------------------|
| B0001-237 | 1.77 | 0.83    | G        | 0.315 | 33.8      | 155                     | 5E26                 |
| B0006-212 | 1.18 | 0.73    | G        | 0.91   | 7         | 4E27                    |
| B0007-287 | 1.13 | 0.87    | U        | 68.3   | 10.5      | 89                      | 4E28                 |
| B0015-229 | 1.11 | 1.16    | G        | 2.01   | 10.5      | 89                      | 4E28                 |
| B0017-205 | 1.96 | 0.78    | G        | 0.197  | 372       | 1202                    | 2E26                 |
| B0017-207 | 1.25 | 0.95    | Q        | 0.545  | 96        | 612                     | 1E27                 |
| B0020-253 | 5.36 | 0.78    | G        | 0.35   | 79        | 388                     | 2E27                 |
| B0022-297 | 7.83 | 0.87    | Q        | 0.406  | 44        | 238                     | 4E27                 |
| B0023-203 | 3.43 | 0.95    | G        | 0.845  | 8.1       | 62                      | 1E28                 |
| B0023-263 | 17   | 0.64    | G        | 0.322  | 1.9       | 9                       | 5E27                 |

(This table is available in its entirety in a machine-readable form in the online journal. A portion is shown here for guidance regarding its form and content.)
of redshift and luminosity; in any case we are already finding a rather surplus number of RGs at lower redshifts and luminosities than that expected from OUS.

As mentioned earlier, LERGs, a population of FR II RGs with no hidden quasars concentrated only at low redshifts (say, \(z < 0.5\)) could make the apparently anomalous number and size distribution of RGs and quasars at low redshifts in the 3CR sample (Singal 1993a) somewhat consistent with OUS, and perhaps it might also hold true for the MRC sample. For that to be true, more than half of the total source population at these redshifts would have to be LERGs. Another implication is that LERGs, if they do indeed form an isotropic sample (as suggested by Laing et al. 1994), should show smaller projected sizes compared with those of high-excitation radio galaxies, which supposedly lie preferentially in the sky plane. There is some evidence for this (Hardcastle et al. 1998), but could such a population of LERGs also be present in the low-frequency samples at higher redshifts? For one thing, such a scenario would imply that a large majority of FR II radio galaxies (\(\sim 50\%–60\%\)) remain a separate class (with intrinsically different properties from quasars/broad-line radio galaxies) and not fall within the scope of OUS. At the same time, it is also clear that if such a high percentage of LERGs is making up the low-frequency samples at higher redshifts \(z \gtrsim 0.5\) as well, then the number and size ratios used by Barthel in his original 3CR sample in the redshift range \(0.5 < z < 1\) to propose OUS, will go totally haywire and the proposition of OUS will have to be abandoned.

Due to geometrical projection, the observed sizes of quasars should appear smaller than those of radio galaxies. This is a simple, unambiguous prediction of the unified scheme which is thus falsifiable from a comparison of the observed angular sizes of radio galaxies and quasars. We therefore examine OUS using this robust test of the relative size distributions of RGs and quasars. Figure 3(a) shows normalized cumulative plots of the angular size distribution of RGs and quasars for our chosen MRC sample, while for comparison, Figure 3(b) shows the same for the 3CR sources. In the 3CR sample, as expected, the quasar sizes seem smaller than those of the RGs which was the prime basis for the OUS hypothesis. However, in a much larger independent MRC sample, there seems to be no evidence that the quasar sizes are in any way smaller than those of RGs. Here we had retained the CSS sources and we notice a bump (discontinuity) at or around 2 arcsec in the MRC size distributions both for RGs and quasars, due to these CSS sources. But in Figure 4 we have excluded all the CSSS cases and we see that neither the inclusion nor the exclusion of CSSS alters our conclusions.

Since the two samples (MRC and 3CR) have different flux-density limits, it may be interesting to see if the difference between the two samples in the size distributions is in any way related to the flux-density level of the samples. Figure 5 shows the normalized cumulative distribution of radio sizes of RGs and quasars for the MRC sample in three different flux-density bins. To avoid any selection bias, we have chosen the flux-density bins such that there are about equal number of sources in each bin. We see no change in the earlier picture; the quasar and RGs do

---

**Figure 1.** Histograms of the redshift distributions of RGs and quasars for the MRC sample.

**Figure 2.** Histograms of the luminosity distributions of RGs and quasars for the MRC sample.
Figure 3. Normalized cumulative distributions of largest angular size (LAS) of RGs (continuous curves) and quasars (broken curves) (a) for the MRC sample and (b) for the 3CR sample. NG and NQ give the numbers of RGs and quasars, respectively, in each plot.

Figure 4. Same as Figure 3, but with CSSS excluded.

Figure 5. Normalized cumulative distribution of radio sizes of RGs (continuous curves) and quasars (broken curves) for the MRC sample in different flux-density bins.

not show any systematic difference in their size distributions. With the basic tenet that the observed quasar sizes should be smaller than those of RGs having been precluded, OUS is thus almost ruled out.

We should clarify that the evidence against the unification of extended RGs and quasars here does not necessarily invalidate the relativistic beaming models (Orr & Browne 1982) of the unification of core-dominated and lobe-dominated quasars. In the same way, any evidence seen in favor of the relativistic beaming models cannot be cited in favor of unification of extended RGs and quasars. The two unifications are independent even if these have been combined in the so-called grand unification scheme models of active galactic nuclei (AGNs; Antonucci 1993; Antonucci 2012; Urry & Padovani 1995; Kembhavi & Narlikar 1999). It is quite likely that radio-loud quasars do not constitute a randomly oriented population; the question here is do RGs and quasars fit together, as proposed by Barthel (1989), into one unified scheme model such as OUS?

We compare in Figure 6 the size distributions of MRC sources in three different redshift bins. Again we find no evidence for quasars being smaller in size in any of the three redshift bins. As we have 116 RGs without redshift determination, most of which will be at $z \gtrsim 1$, in Figure 7(a) we include these along with 46 RGs with $z \gtrsim 1$ to compare the angular sizes of all these high-redshift RGs with those of quasars at $z \gtrsim 1$. We find that the size distributions are strikingly similar. There are also 28 unidentified cases, which again most likely will be RGs at...
Figure 6. Normalized cumulative distribution of radio sizes of RGs (continuous curves) and quasars (broken curves) for the MRC sample in three different redshift ranges.

Table 2
Median and Quartile Values of Size Distributions for RGs and Quasars

| Subsample          | NG | $\theta_{lq}$ | $\theta_{med}$ | $\theta_{uq}$ | NQ | $\theta_{lq}$ | $\theta_{med}$ | $\theta_{uq}$ |
|--------------------|----|---------------|----------------|---------------|----|---------------|----------------|---------------|
| All 3CR            | 91 | 17            | 40             | 98            | 34 | 10            | 18             | 45            |
| All MRC            | 290| 11            | 22             | 46            | 59 | 14            | 30             | 54            |
| $S_{408} < 1.2$    | 100| 9             | 21             | 42            | 14 | 8             | 24             | 50            |
| $1.2 \leq S_{408} < 1.8$ | 90 | 14            | 26             | 45            | 22 | 12            | 24             | 44            |
| $S_{408} \geq 1.8$ | 100| 12            | 27             | 55            | 23 | 15            | 33             | 60            |
| $z < 0.5$          | 65 | 25            | 54             | 86            | 9  | 38            | 64             | 91            |
| $0.5 \leq z < 1$   | 63 | 11            | 27             | 38            | 26 | 15            | 39             | 58            |
| $z \geq 1$         | 46 | 6             | 8              | 17            | 24 | 11            | 16             | 24            |

$z \geq 1$. After dropping 9 CSSS cases among them, we compare in Figure 7(b) the size distribution of 19 unidentified cases with that of quasars with $z \geq 1$. The two size distributions statistically look almost indistinguishable.

We have determined the median value $\theta_{med}$ (in arcsec) of the cumulative size–distribution of the sources in the various subsamples (Table 2). To get an idea of the spread around the median values we have also listed in Table 2 the lower quartiles $\theta_{lq}$ and upper quartiles $\theta_{uq}$ in all cases. We find that while in the 3CR sample quasar sizes may be half those of RGs, in the much larger MRC sample the roles seem to have been reversed (cf. Table 2) with quasars appearing to be in fact somewhat larger in size than RGs (in the whole MRC sample by a factor of $\sim 1.3$ though in a subsample like $z \geq 1$ by as much as a factor of two);

nowhere is there any evidence of the quasar sizes being smaller than those of RGs. This is apparent not only from median values of size but also from the lower and upper quartile values in their cumulative plots.

The cone opening angle ($\xi_c$) consistent with the smaller quasar fraction seen in MRC data (Figures 4–6; Table 2) will mean a value narrower than $\sim 45^\circ$ derived from the 3CR data, implying an expected size ratio even more pronounced than that in the 3CR case. After dropping CSS sources, in the MRC sample, the fraction of quasars is $59/(290+59) \sim 0.17$, implying only about one-sixth of the sources are quasars (as compared to one-third in the 3CR sample of Barthel 1989, based on which OUS, with a cone opening angle $\xi_c \sim 45^\circ$, was proposed). That such a low fraction of quasars is in itself an evidence against the popular OUS scheme was already pointed out by Singal (1996b). In a picture consistent with OUS, MRC quasar sizes should be statistically smaller than those of RGs by more than a factor of two, but we find quasars to be somewhat bigger in size (by a factor of $\sim 1.3$) than RGs, which could never happen in an OUS type of scheme. Thus there is no consistency in the number count ratios and the size ratios and no cone opening angle ($\xi_c$) can be found within OUS that would satisfy both relative number counts and relative size distributions observed for both quasars and RGs. Thus the predictions of OUS are not corroborated by the data in a sample other than the 3CR even at high-redshift bins $z > 0.5$ (and at high luminosities), where LERGs may not play an important part, and OUS is clearly ousted in that sense.

It is clear that at a few Janskys or weaker levels, OUS does not hold. If we still want to hold on to the belief that OUS

Figure 7. Normalized cumulative distribution of radio sizes of (a) RGs (continuous curves) comprising 46 sources with $z \geq 1$ and 116 unknown-redshift galaxies (a total of 162 RGs with expected $z > 1$), and quasars (broken curves) for $z \geq 1$ and (b) unidentified sources (continuous curves) and quasars (broken curves) for $z \geq 1$. 
might be valid at or above only the higher flux levels of 3CR radio sources \((S_{\text{408}} > 4 \, \text{Jy})\), then since the integrated source counts fall rapidly with flux \((N(>S) \propto S^{-\alpha})\), it is only a tiny fraction of the RGs that would be taking part in the currently popular OUS. In fact one would then be proposing a division of RGs into further subclasses (beyond LERGs seen only at low redshifts and low luminosities within FR II type RGs), out of which perhaps only one minor subclass of RGs will be partaking in OUS, thus sounding more like a further disunification scheme for RGs. And even then it would be a “cosmic conspiracy” where two or more subclasses of RGs of apparently very different size distributions manage to have a combined size-distribution very similar to that of quasars in all flux-density and redshift bins.

By still adhering to the belief that there may be a restricted class of RGs that partakes in the OUS model, it seems that is perhaps rather undue weight being given to a small select sub-sample \((0.5 < z < 1\) redshift bin of 3CR) that happened to be the first to be examined in this regard. Except for that particular bin of the 3CR sample, which incidentally was instrumental in the proposition of the unified scheme with the “canonical” value \(\xi \sim 45^\circ\), other samples do not seem to yield the expected size ratios. In fact, as we saw, there seems to be no statistically significant difference in the size distribution of quasars and RGs.

At the same time infrared and X-ray studies do find many cases of obscured hidden quasars in powerful radio galaxies, implying that a unified scheme must be true to some extent. Most 3CR FR II radio galaxies with \(0.5 \lesssim z < 1\) do show strong, quasar-like mid-IR emission (Antonucci 2012), while at \(z \lesssim 0.5\) there is suggestion of a dearth of hidden AGNs in FR II RGs. For example, Meisenheimer et al. (2001) observed at infrared wavelengths 10 quasars and 10 RGs, selected with matched luminosity and the redshift distributions from the 3CR catalogue, and found the results compatible with hidden quasars, except perhaps for some at the low luminosity/redshift end. Shi et al. (2005) used Spitzer photometry to study a sample of 3CR radio galaxies and the behavior of the sources is consistent with the presence of an obscuring circumnuclear torus. The X-ray spectroscopic survey of 38 high-\(z\) 3CR objects of Wilkes et al. (2011) is extremely supportive of complete unification of 3CR radio galaxies and quasars at \(z \gtrsim 1\). It seems difficult to reconcile this with the absence of foreshortening of quasar sizes at all redshifts.

The predictions of the unified scheme models are not corroborated by radio observations and that seems to refute the presently popular OUS. At the same time, it does not seem likely that, except perhaps in some very contrived scenario, any modification of OUS, such as an evolutionary model of \(\xi\) with redshift or luminosity, could yield quasar sizes comparable to those of galaxies in all bins, since in OUS those will be expected to be smaller due to geometrical projection. On the other hand, quasar sizes are not found to be smaller than those of galaxies for any of the bins, whether in flux-density or in redshift, in the MRC sample. Perhaps one has to allow that the major radio axis does not coincide with the axis of the torus, or we may require some very different unification scheme than the currently popular orientation-based unified scheme model.

### 4. CONCLUSION

We showed that, contrary to the expectations in OUS models, observed quasar sizes are not systematically smaller than those of galaxies. The absence of this foreshortening of the sizes of quasars compared to those of RGs of similar flux densities or at similar redshifts, provides irrefutable evidence against the unified scheme models. To still uphold OUS, one would need to propose FR II type RGs with no hidden quasars, and/or of small intrinsic radio sizes at all redshifts and luminosities, i.e., across the entire gamut of strong radio galaxies, with a large majority of RGs opting out of OUS. This means that first, one would rather require a robust disunification scheme of the radio galaxies themselves before an attempt could be made to unify a rather small number of RGs with quasars in a scheme like OUS. Or perhaps one has to allow that the major radio axis does not coincide with the axis of the torus, which is a basic tenet of the present unification scheme. In any case, it appears that the dichotomy of RGs and quasars among extragalactic radio sources cannot be resolved within the present framework of OUS, which therefore seems falsified.

### REFERENCES

Antonucci, R. 1993, ARAA, 31, 473
Antonucci, R. 2012, arXiv:1210.2716
Antonucci, R. R. I., & Miller, J. S. 1985, ApJ, 297, 621
Baker, J. C., Hunstead, R. W., Kapahi, V. K., & Subrahmanya, C. R. 1999, ApJS, 122, 29
Barthel, P. D. 1989, ApJ, 336, 606
Fanaroff, B. L., & Riley, J. M. 1974, MNRAS, 167, 31P
Gopal-Krishna, Kulkarni, V. K., & Wiita, P. J. 1996, ApJL, 463, L1
Hardcastle, M. J., Alexander, P., Pooley, G. G., & Riley, F. M. 1998, MNRAS, 296, 445
Hardcastle, M. J., Evans, D. A., & Croston, J. H. 2009, MNRAS, 396, 1929
Hine, R. G., & Longair, M. S. 1979, MNRAS, 188, 111
Kapahi, V. K., Athreya, R. M., Subrahmanya, C. R., et al. 1995, JAA, 16, 125
Kapahi, V. K., Athreya, R. M., Subrahmanya, C. R., et al. 1998a, ApJS, 118, 327
Kapahi, V. K., Athreya, R. M., van Breugel, W., McCarthy, P. J., & Subrahmanya, C. R. 1998b, ApJS, 118, 275
Kembhavi, A. K., & Narlikar, J. V. 1999, Quasars and Active Galactic Nuclei—An Introduction (Cambridge: Cambridge Univ. Press)
Laing, R. A., Jenkins, C. R., Wall, J. V., & Unger, S. W. 1994, in ASP Conf. Ser. 54, The First Stromlo Symposium: The Physics of Active Galaxies, ed. V. Bicknell, M. A. Dopita, & P. J. Quinn (San Francisco, CA: ASP), 201
Laing, R. A., Riley, J. M., & Longair, M. S. 1983, MNRAS, 204, 151
Leipski, C., Haas, M., Willner, S. P., et al. 2010, ApJ, 717, 766
McCarty, P. J., Kapahi, V. K., van Breugel, W., et al. 1996, ApJS, 107, 19
Meisenheimer, K., Haas, M., Müller, S. A. H., et al. 2001, A&A, 372, 719
Ogle, P., Whyborn, D., & Antonucci, R. 2006, ApJ, 647, 161
Orr, M. J. L., & Browne, I. W. A. 1982, MNRAS, 200, 1067
Shi, Y., Rieke, G. H., Hines, D. C., et al. 2005, ApJ, 629, 88
Singal, A. K. 1998, MNRAS, 233, 87
Singal, A. K. 1993a, MNRAS, 262, L27
Singal, A. K. 1993b, MNRAS, 263, 139
Singal, A. K. 1996a, in IAU Symp. 175, Extragalactic Radio Sources, ed. R. Ekers et al. (Dordrecht: Kluwer), 563
Singal, A. K. 1996b, MNRAS, 278, 1069
Spergel, D. N., Verde, L., Peiris, H. V., et al. 2003, ApJS, 148, 175
Urry, C. M., & Padovani, P. 1995, PASP, 107, 803
Weinberg, S. 2008, Cosmology (Oxford: Oxford Univ. Press)
Wilkes, B. J., Kuraszkiewicz, J., Haas, M., et al. 2011, AAS Meeting #217, #230.04, BAAS, 43