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

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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