Active Galactic Nuclei: from Central Engine to Host Galaxy
ASP Conference Series, Vol. 290, 2003
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Jets in Seyfert Galaxies

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Abstract. Using VLBI images of a rigorously selected sample of Seyfert galaxies, we show that the radio properties of the compact pc-scale features are consistent with the standard Unified Scheme, with no significant evidence for relativistic beaming. Some detected pc-scale features could be termination points of the jets. We find that the correlation of linear size with luminosity for the sample may swamp size differences between pole-on and edge-on AGN structures.

1. Introduction

Seyfert (Sy) galaxies have commonly been classified into types 1 or 2 depending on whether their spectrophotometrically detectable permitted emission lines are much broader or of similar width respectively relative to the forbidden lines. The similarities and differences between Seyferts of the two types are commonly understood in the framework of the Unified Scheme (US) which hypothesizes the presence of a ubiquitous optically and geometrically thick torus around the central region; when the torus is edge-on, it obscures the central continuum and broad emission-line clouds seen in a Seyfert type 1, resulting in a Seyfert type 2.

Evidence in support of the US includes (i) the discovery of *polarized* broad permitted lines from Sy 2s (Antonucci & Miller 1985; Moran 2000), (ii) the detection in Sy 2s of broad Paschen-β lines, to which the torus is expected to be transparent (Veilleux *et al.* 1997), and (iii) the "double-cone" morphology of the narrow emission line structures, interpreted as due to shadowing of the central ionizing photons by the torus (Wilson, 1996). Challenges to the US remain, however, such as (i) Sy 1 host galaxies are of earlier Hubble-type than those of Sy 2s (Malkan *et al.* 1998), (ii) Sy 2s have an excess of nearby companions over Sy 1s (Dultzin-Hacyan *et al.* 1999), and (iii) the Sy 2s appear more likely to show compact radio emission than Sy 1s (Roy *et al.* 1994).

In our study, we sought to improve upon the single-baseline interferometric investigation of Roy *et al.* (1994) by (a) performing higher resolution global VLBI *imaging*, and (b) *rigorously* selecting a sample to specifically test the US.

2. Rationale, sample and observations

Unified models don't assert that just any old (famous) Seyfert 1 is to be identified with any old Seyfert 2. - Antonucci (2001)

In other words, in order to rigorously test the US, we need a sample of objects that are *intrinsically similar.* We therefore need to (i) quantify their definition, (ii) identify their orientation-independent parameters, (iii) find objects with a range of orientation and (iv) choose those which are matched in these parameters.

Step 1: We *define* Seyferts to be *bona fide* AGN (*i.e.*, Sy 1s with broad lines of FWHM > 1000 km s^{-1} and Sy 2s with $\frac{[OIII]\ luminosity}{H\beta\ luminosity} > 3$) that are (a) optically *weak*, *i.e.*, $M_B^{total} \leq -23$ (Schmidt & Green 1983), (b) in hosts of galaxy-type S0 or later, and (c) are radio-*quiet*, *i.e.*, $\frac{S^{5GHz}}{SB} < 10$ (Kellermann *et al.* 1989). We thus exclude quasars, elliptical host galaxies and radio-loud objects.

Step 2: : In order to match the Seyferts in both their intrinsic AGN power and host-galaxy properties, we chose the following *orientation-independent parameters*: (a) The [OIII] luminosity, the bulge luminosity and stellar luminosity of the host, and its Hubble type. Since all of these parameters are optically derived, we also required that the host galaxy not be edge-on, in order to avoid selection effects due to extinction by the galactic disc.

Step 3: *Range of orientation*: Since in the radio-quiet regime a quantitative handle on the orientation of the AGN is not available, we simply chose equal numbers of purportedly pole-on and edge-on AGN, *viz.*, Sy 1s and Sy 2s.

Step 4: *Matching the pole-on and edge-on Seyferts*: Before matching the Sy 1s and 2s, we needed to ensure *feasibility* of VLBI imaging. We arrived at a heuristic constraint that the Seyferts had to have a compact feature as imaged by the VLA-A or -B array with a flux density at 5GHz of > 8mJy. The short list contained 54 Seyferts, of which we could chose 10 Sy 1s and 10 Sy 2s that conformed to our definition, that had non-edge-on host galaxies, and that were matched in the above orientation-independent parameters as well as redshift.

<u>Vindication:</u> It turned out *a posteriori* that the selected Sy 1s and Sy 2s are also matched in their total radio, mid-IR and far-IR luminosities.

<u>Caveats:</u> (1) We only choose Seyferts with previously known compact kpc-scale radio features. (2) The avoidance of edge-on host galaxies results in an avoidance of Sy 1(2)s with the AGN axis perpendicular(parallel) to that of the host galaxy.

<u>Observations:</u> We obtained 24hrs of observing time with a 14-station global VLBI array, during which we could observe 15 sample objects at 5GHz that had no prior VLBI data; data on the remaining five were added from the literature.

3. Results

1. We detect at least a single component in all the observed objects. Examples with multiple components are shown in Fig. 1. We find no systematic difference in compactness between Sy 1s and 2s unlike the result of Roy *et al.* (1994). The distributions of the detected pc-scale luminosities are also similar.

2. The distributions of the ratios of the pc- to kpc-scale flux densities are similar for the two Seyfert subclasses. If their radio jets were relativistically

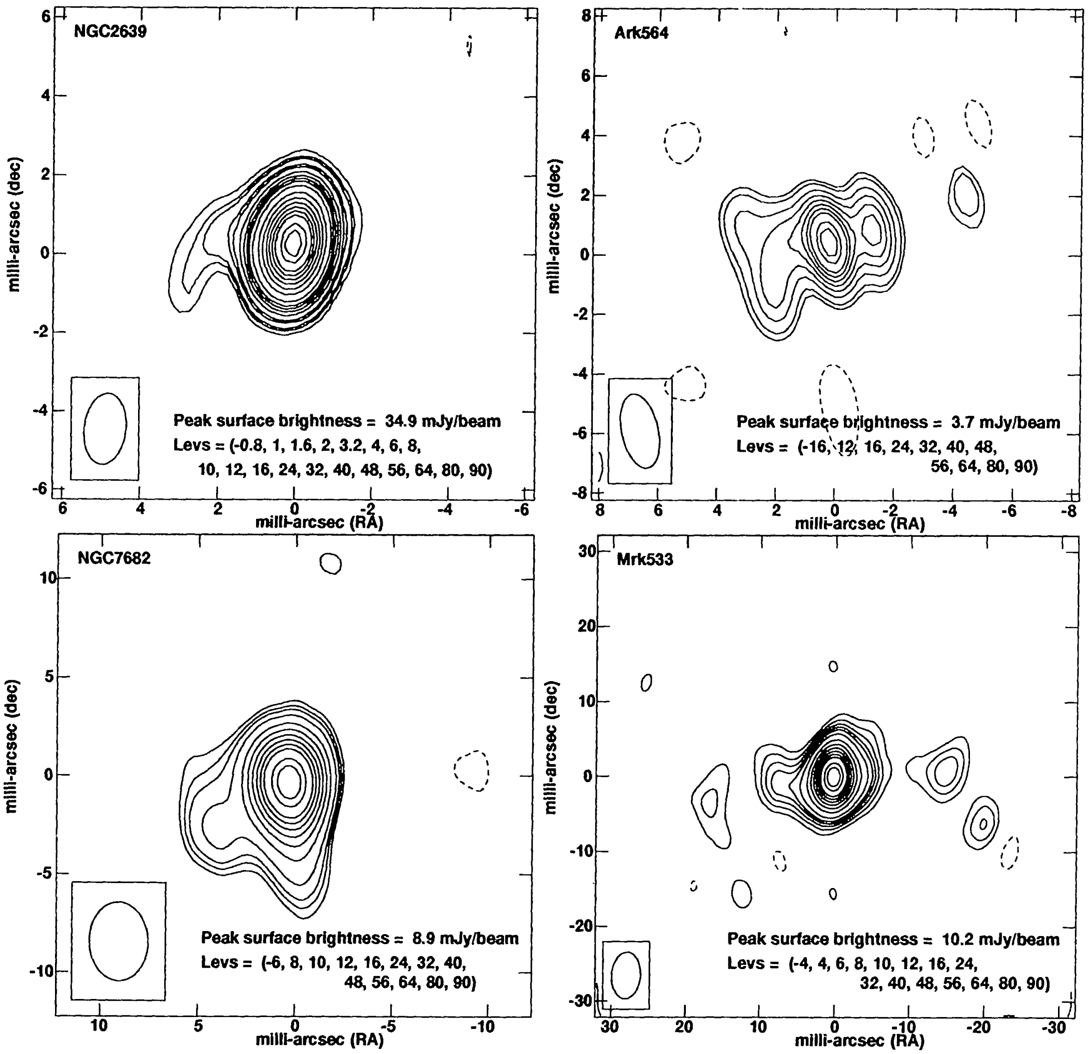

Figure 1. VLBI images: Sy 1s (top panels); Sy 2s (bottom panels). Synthesized beams are boxed at bottom-left. The contour levels are given in % of the peak.

beamed, and *if the detected pc-scale feature is the nuclear jet*, then, the purportedly pole-on Sy 1s would have a beamed or enhanced radio nucleus relative to the presumably unbeamed kpc-scale emission, and therefore systematically higher values of these ratios.

3. In at least one case, *viz.*, NGC 5929, the detected compact feature certainly corresponds to one of the two kpc-scale hotspots of the triple (Su *et al.* 1996) rather than the nucleus, implying that the compact features that we see might sometimes be the termination points of the jet.

4. The projected kpc-scale linear sizes of the Sy 1s and 2s are not systematically different. However, there is a significant correlation between linear size and total radio luminosity (Fig. 2). It is likely that this correlation swamps observable size differences between the two subclasses for this sample. It is also possible that caveat (2) above contributes to this effect in that, the radio jets from the Sy 2s *in the sample* encounter systematically longer path-lengths through the ISM of the host galaxy than the radio jets of the Sy 1s in the sample, leading to a relatively higher quenching effect in these Sy 2s.

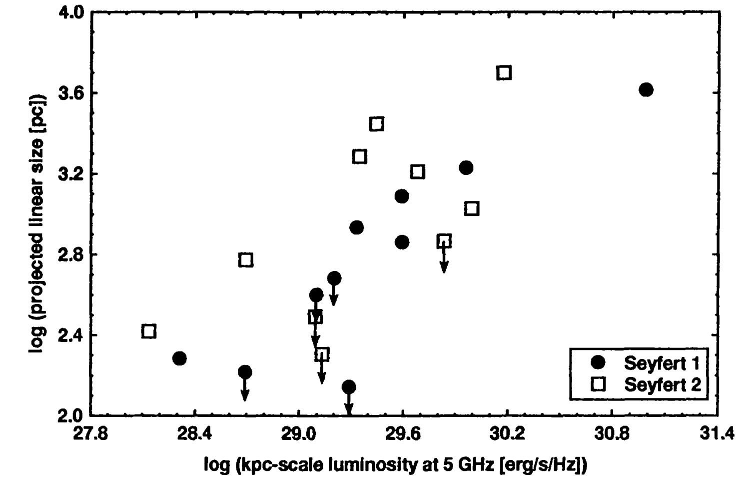

Figure 2. The correlation of linear size with radio luminosity.

4. Conclusions

We have constructed a rigorously selected sample of *intrinsically similar* Seyferts by chosing well-defined Sy 1s and 2s that are matched in several orientation independent optical properties, in addition to redshift. We found *a posteriori* that the selected Seyferts are also matched in their total radio, mid- and far-IR luminosities. We conclude from our analysis of the VLBI images of these Seyferts that (a) their compact pc-scale radio morphology is consistent with the predictions of the US, (b) they do not show significant evidence for relativistic beaming under certain assumptions (c) at least in some cases the detected pc-scale feature may be the termination point of the jet, and (d) the observed correlation of linear size with luminosity might swamp the predicted systematic difference in projected size between pole-on and edge-on Seyfert structures.

Acknowledgments. Help from the staff of NRAO & EVN and funding from the Indo-Russian ILTP, EC & JIVE are gratefully acknowledged. The VLA & VLBA are run by NRAO, a facility of the NSF, operated under cooperative agreement by AURA, Inc. The EVN is a joint facility of European, Chinese & other radio astronomy institutes funded by their NRCs. This research has made use of NASA-ADS, NED & SIMBAD.

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