Particles and Fields in Radio Galaxies
ASP Conference Series, Vol. 250, 2001
Robert A. Laing and Katherine M. Blundell

Parsec-scale radio morphology in Seyfert galaxies

D.V. Lal[1,2], P. Shastri[1] and D.C. Gabuzda[3,4]

[1]*Indian Institute of Astrophysics, Bangalore 560 034, India*
[2]*JAP, Dept of Physics, IISc, Bangalore 560 012, India*
[3]*JIVE, Dwingeloo 7991 PD, The Netherlands*
[4]*Astro Space Center, Lebedev Physical Institute, Moscow, Russia*

Abstract. We have observed a sample of Seyfert galaxies with global VLBI in order to test the predictions of the Unified Scheme for Seyferts, which hypothesises that Seyferts of type 1 and of type 2 differ only in the orientation of the axisymmetric active nucleus with respect to the observer. In this case, the parsec-scale radio structures of the two types should be similar. The 10 Seyfert 1s and 10 Seyfert 2s in our sample have been selected to have similar distributions of redshift and properties of their host galaxies: [OIII] luminosity, galaxy bulge luminosity etc. In this way, we ensure that the two subsamples of Seyferts are matched with respect to properties that are expected to be orientation-independent. We are thus able to test the Unified Scheme rigorously. We detect all the objects that we observed and discuss the results. Our results are consistent with the prediction of the simple Unified Scheme.

1. Introduction

Seyfert galaxies are nearby low luminosity Active Galactic Nuclei (AGNs) which occur mostly in spiral hosts and are usually taken to be "radio-quiet" objects. We define a Seyfert galaxy to be a low-luminosity ($M_B > -23.0$), radio-quiet (ratio of 5 GHz to B-Band flux density < 10) object, whose host galaxy is a spiral and with nuclear $[\mathrm{OIII}]_{\mathrm{FWHM}} > 300\,\mathrm{km\,s^{-1}}$. There are two kinds of Seyfert galaxies, types 1 and 2, distinguished by the widths of their spectrophotometrically observable emission lines; the implied kinematic Doppler widths are $> 1000\,\mathrm{km\,s^{-1}}$ and $< 1000\,\mathrm{km\,s^{-1}}$ for the two types, respectively.

2. Unification of Seyfert 1 and Seyfert 2 galaxies

The Unified Scheme (US) for Seyfert galaxies hypothesizes that Seyferts of type 1 and 2 comprise a single population and appear different due to the orientation of the axisymmetric active nucleus with respect to the observer. The Seyfert 1s are those where we have a direct view of the central engine, and the Seyfert 2s are those where our line of sight to the central engine is blocked by obscuring material in the form of the torus that lies between their Broad Line Regions (BLR) and the observer. According to the US, the torus is present in all Seyferts. Broad Emission Lines (i.e. with implied Doppler widths $> 1000\,\mathrm{km\,s^{-1}}$) have been detected in a few Seyfert 2s in *polarized* light (Antonucci & Miller 1985). This result strongly supports the US, because the polarized flux spectrum of these Seyfert 2s (e.g. NGC 1068) is very similar to the total flux spectrum of a Seyfert 1 galaxy, showing broad emission lines of hydrogen and permitted Fe II.

3. Why study Seyfert galaxies at radio wavelengths on milli-arcsec scales?

Seyfert galaxies have weak radio emission, but they do show radio emitting jet-like structures on small scales which appear to be the low-power analogues of jets seen in radio powerful AGNs (e.g. Nagar et al. 1999 and references therein). The US predicts that the total radio emission should be similar in the two classes of Seyferts (since the radio emission is unattenuated by the obscuring torus), and their radio structures should differ only due to projection effects. However, this issue is controversial: Roy et al. (1994), using the 275-km long single baseline Parkes-Tidbinbilla interferometer at 2.3 GHz, reported that Seyfert 2s show brighter compact radio emission than Seyfert 1s. This result is inconsistent with the predictions of the simple US. The inconsistency remains even if mild relativistic beaming is invoked, because in this case, the face-on AGNs, viz., Seyfert 1s, would be more likely to show compact structures. *Our goal was to test predictions of the US by investigating the parsec-scale radio morphology of Seyferts using a MATCHED sample of Seyfert 1 and Seyfert 2 galaxies.*

4. Our sample:

Our sample selection criteria were as follows: (i) the object should be a bona fide Seyfert galaxy (cf. our definition), (ii) it must be in a host galaxy that is a confirmed spiral, (iii) it must be detected with ~ 1 arcsecond resolution at 5–8 GHz and have a detected compact component brighter than 8 mJy at these frequencies on these scales (i.e. as observed by VLA A or B array; this criterion was required to make our experiment feasible), and (iv) the host galaxy must have an observed ratio of minor to major isophotal diameter> 0.5; we thereby exclude edge-on host galaxies so as to minimise selection effects due to obscuration. We note that Clarke et al. (1998) and Nagar & Wilson (1999) have shown that there is no correlation between the host galaxy rotation axis and the direction of the radio jet.

From all Seyferts with available nuclear radio flux density at $\sim$1 arcsecond resolution in the literature (i.e. all VLA A, & B array observations of Seyferts) we chose 10 Seyfert 1s and Seyfert 2s meeting the above criteria, such that the two sub-samples had similar distributions of heliocentric redshift, luminosity of the host galaxy (i.e. minus the AGN) in the optical B-band, $[\mathrm{OIII}]_{5007}$ luminosity, and galaxy bulge luminosity. Thereby we ensured that the sub-samples of Seyfert 1s and Seyfert 2s are MATCHED, as far as possible, with respect to their intrinsic AGN power and host galaxy properties using *orientation-independent* parameters.

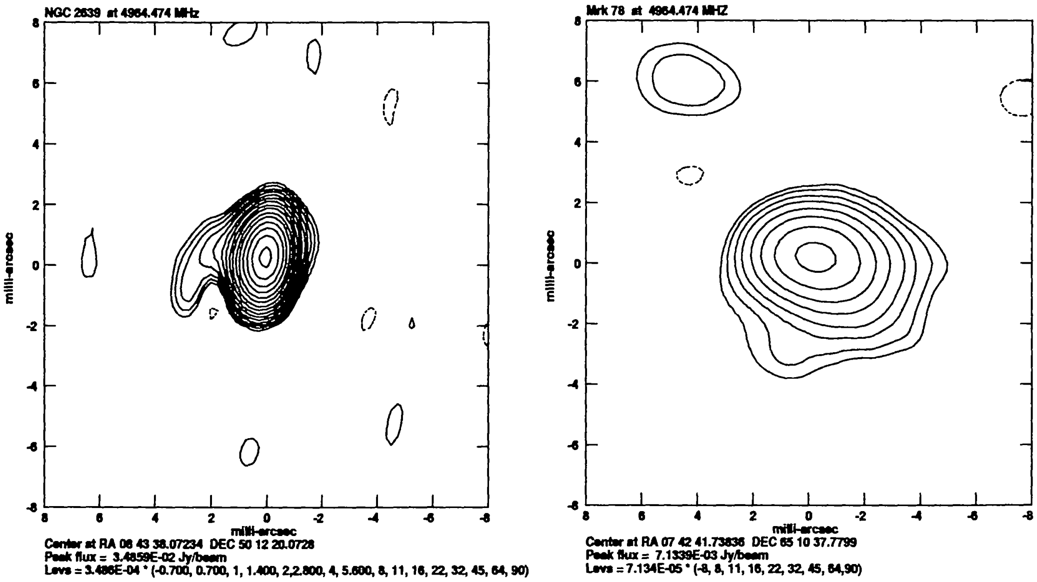

Figure 1. CLEANed VLBI images of NGC 2639 (left) and Mkn 78 (right), the elliptical Gaussian restoring beams are at a FWHM of 1.82×1.08 mas elongated in P.A. -7° and 3.61×2.43 mas elongated in P.A. 85° respectively.

5. Observations:

We observed 15 objects from our sample in Feb 1998 at 5 GHz using a 14-station Global VLBI array, including the phased VLA. Thus, we also have simultaneous VLA data (angular resolution $\sim 1.0''$) for all these objects. Of the remaining 5 sample objects, 4 have VLBI data in the literature (Mkn 926, Mundell et al. 2000; Mkn 348, Ulvestad et al. 1999a; Mkn 231, Ulvestad et al. 1999b; and NGC 4151 Ulvestad et al. 1998) which we add to our own data and use in inferring our results below. NGC 5135 is the only source that has not yet been observed on mas scales.

6. Results

We detected all 15 of our observed objects. Fig. 1 shows the VLBI images for two of the sample objects, NGC 2639 (Seyfert 1) and Mkn 78 (Seyfert 2). We have done a Mann-Whitney U test and conclude at the 0.02 significance level that:

- The distributions of radio luminosities on pc scales for the two classes of Seyfert galaxy are similar.
- The distributions of radio luminosity on kpc scales for the two classes of Seyfert galaxy are also similar.

- The fraction of radio emission detected on mas-scales (i.e. the total radio emission detected with VLBI) to the emission detected on kpc-scales (i.e. total VLA radio emission) is not significantly different for the two Seyfert sub-classes.

- The ratio of compact radio emission (i.e. emission detected with VLBI) to the extended radio emission detected on kpc-scales (i.e. total radio emission minus the core radio emission detected with VLA) is also not significantly different for the two Seyfert sub-classes. Note that if the jets were significantly relativistically beamed, we would expect Seyferts 1s to show systematically more prominent compact radio emission than Seyfert 2s.

We thus find that Seyfert 1 and Seyfert 2 galaxies have equal tendencies to show compact radio structures, in contrast to the results of Roy et al. (1994), who concluded that compact radio structures were much more common in Seyfert 2s than in Seyfert 1s. Our results so far appear to be consistent with the US: the radio compactnesses of the Seyfert 1s and Seyfert 2s are similar. We are currently undertaking a more detailed study of the pc-scale and kpc-scale structures of the sample Seyferts to search for other possible systematic differences between the Seyfert 1s and Seyfert 2s.

References

Antonucci, R.R.J. & Miller, J.S. 1985, 'Spectropolarimetry and nature of NGC 1068', ApJ, 297, 621–632

Clarke, C.J., Kinney, A.L. & Pringle, J.E. 1998, 'An investigation into the geometry of Seyfert galaxies', ApJ., 495, 189–195

Mundell C.G., Wilson, A.S., Ulvestad, J.S. & Roy, A.L. 2000, 'Parsec-scale images of flat-spectrum radio sources in Seyfert galaxies', ApJ, 529, 816–831

Nagar, N.M. & Wilson, A.S. 1999, 'The relative orientation of nuclear accretion and galaxy stellar disks in Seyfert galaxies', ApJ, 516, 97–113

Nagar, N.M., Wilson, A.S., Mulchaey, J.S. & Gallimore, J.F. 1999, Radio structures of Seyfert galaxies. VIII. A distance and magnitude limited sample of early-type galaxies', ApJS., 120, 209–245

Roy, A.L., Norris, R.P., Kesteven, M.J., Troup, E.R. & Reynolds, J.E. 1994, 'Compact radio cores in Seyfert galaxies', ApJ, 432, 496–507

Ulvestad, J.S., Wrobel, J.M., Wilson, A.S., Falcke, H. & Krichbaum, T.P. 1999a, 'Subrelativistic radio jets and parsec-scale absorption in two Seyfert galaxies', ApJ, 517, L81–L84

Ulvestad, J.S., Wrobel, J.M. & Carilli, C.L. 1999b, 'Radio continuum evidence for outflow and absorption in the Seyfert 1 galaxy Markarian 231', ApJ, 516, 127–140

Ulvestad, J.S., Roy, A.L., Colbert, E.J.M. & Wilson, A.S. 1998, 'A subparsec radio jet or disk in NGC 4151', ApJ, 496, 196–202