SEYFERT GALAXIES: NUCLEAR RADIO STRUCTURE AND UNIFICATION

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1 ABSTRACT

We have observed a sample of Seyfert (Sy) galaxies with global Very Long Baseline Interferometry (VLBI) to test the predictions of the unification scheme (US) for Sys which hypothesizes that the two Sy types constitute a single population of objects. If Sy 1s and Sy 2s differ only in the orientation of the axisymmmetric active nucleus with respect to the observer, then, the parsec scale radio structures of the two types should be similar. We present the results obtained from these observations for our Sy sample and their implications on the US.

2 INTRODUCTION

Sy galaxies are nearby, low luminosity active galactic nuclei (AGNs) which occur mostly in spiral hosts and are usually taken to be “radio-quiet" objects. There are two kinds of Sy galaxies, types 1 and 2, distinguished by the widths of their spectrophotometrically observable emission lines; the implied kinematic Doppler widths are $> 1{,}000$ km s^{-1} and $< 1{,}000$ km s^{-1} for the two types, respectively. Accordingly, we define a Sy galaxy as 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, with Sy 1 galaxies having $H\beta_{\rm FWHM}$ (or $H\alpha_{\rm FWHM}$) nuclear line widths exceeding 1,000 km s^{-1} ([3]), and Sy 2 galaxies having the ratio of the [O III]$_{5007}$ to Hβ line intensities exceeding 3 ([2]).

3 UNIFICATION OF SEYFERT 1 AND SEYFERT 2 GALAXIES

The US for Sy galaxies hypothesizes that Sys 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 Sy 1s are those where we have a direct view of the central engine, and the Sy 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 region and the observer. According to the US, the torus is present in all Sys. Broad emission lines (*i.e.* with implied Doppler widths $> 1{,}000$ kms^{-1}) have been detected in a few Sy 2s in *polarized* light ([1]). This result strongly supports the US, because the polarized flux spectrum of these Sy 2s (*e.g.* NGC 1068) is very similar to the total flux spectrum of a Sy 1 galaxy, as it showed broad emission lines of hydrogen and permitted Fe II.

4 OUR GOAL

Sy galaxies have low 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.* [6] and references therein). The US predicts that the total radio emission should be similar in the two classes of Sys (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; *e.g.* [7], using the 275–km long single baseline Parkes-Tidbinbilla interferometer at 2.3 GHz, reported that Sy 2s show more compact radio emission than Sy 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.*, Sy 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 Sys using a MATCHED sample of Sy 1 and Sy 2 galaxies*.

5 THE SAMPLE

Our sample selection criteria were as follows: (i) the object should be a *bona fide* Sy 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 observed ratio of minor and major isophotal diameter axes of the host galaxy > 0.5; we thereby exclude edge-on host galaxies so as to minimise selection effects due to obscuration. We note that [5] have shown that there is no correlation between the host galaxy rotation axis and the direction of the radio jet.

From all Sys with available nuclear radio flux density at ∼1 arcsecond resolution in the literature (*i.e.* all VLA A, & B array observations of Sys) we chose 10 Sy 1s and Sy 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, [O III]$_{5007}$ luminosity, and galaxy bulge luminosity. Thereby we ensured that the sub-samples of Sy 1s and Sy 2s are MATCHED, as far as possible, with respect to their intrinsic AGN power and host galaxy properties using *orientation-independent* parameters.

6 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. We thus have simultaneous VLA data also (angular resolution $\sim 1''.0$) for all these objects. Of the remaining 5 sample objects, 4 have VLBI data in the literature (Mrk 926, [4]; Mrk 348, [9]; Mrk 231, [10]; and NGC 4151 [11]) 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 milliarcsec scales.

7 RESULTS

We detected all 15 of our observed objects on both arcsecond and milliarcsec scales. Fig. 1 shows the VLA and VLBI images for two of the sample objects, NGC 2639 (Sy 1) and Mrk 533 (Sy 2). The Fig. 1 also show that we detect either a single component or multiple components on parsec scales for our sample sources. We have performed a Mann-Whitney U test ([8]) and conclude that:

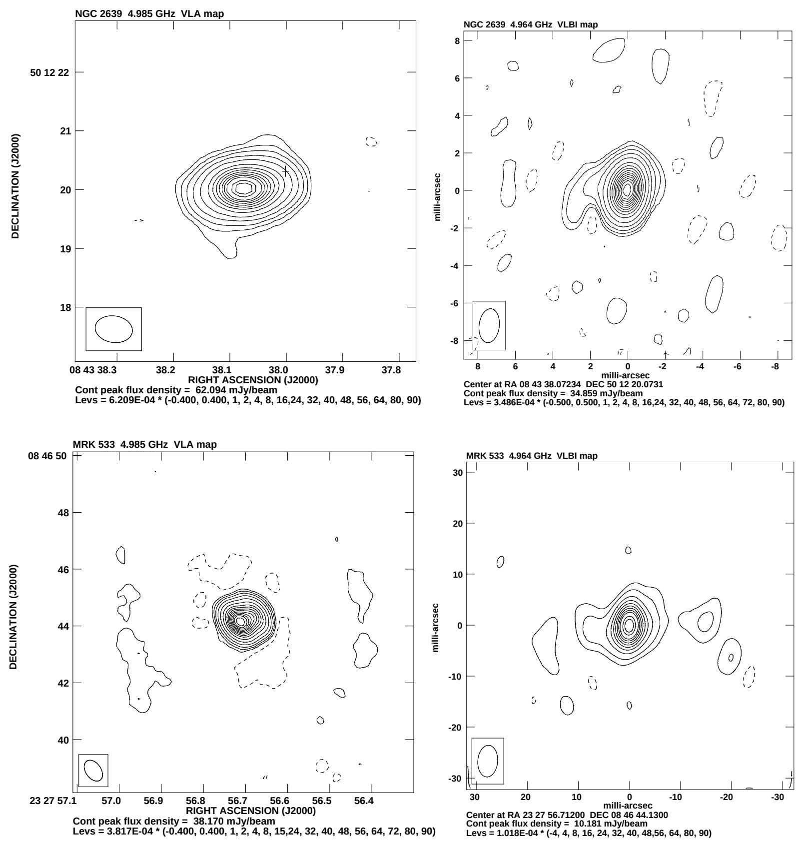

Figure 1: 6 cm VLA (*Upper, left panel*) & VLBI (*Upper, right panel*) image of NGC 2639 and 6 cm VLA (*Lower, left panel*) & VLBI (*Lower, right panel*) image of Mrk 533. The small ellipse at the corner of the image gives the size (FWHM) of the beam.

(i) a starburst alone cannot power these radio sources because, (a) these objects have high brightness temperature, and (b) the core radio luminosity at 5 GHz is $\sim 10^{28}$ ergs $s^{-1}Hz^{-1}$ and it arises from a region smaller than a few cubic parsec.

(ii) the distributions of radio luminosities on parsec scales for the two classes of Sy galaxies show no statistically significant difference at a significance level of 0.05 (and also on kiloparsec scales at a significance level of 0.10),

(iii) the fraction of radio emission detected on milliarcsec scales (*i.e.* total radio emission detected with VLBI) to the emission detected on kiloparsec scales (*i.e.* total VLA radio emission) is not significantly different for the two Sy sub-classes at a significance level of 0.10 and

(iv) the ratio of compact radio emission (*i.e.* emission detected with VLBI) to the extended radio emission detected on kiloparsec scales (*i.e.* total radio emission minus the core radio emission detected with VLA), using our simultaneous VLBI and VLA measurements is also not significantly different for the two Sy sub-classes even at a level of 0.10. If the jets were significantly relativistically beamed, we would expect Sy 1s to show systematically more prominent compact radio emission than Sy 2s.

We find that Sy 1 and Sy 2 galaxies have equal tendency to show compact radio structures and our results do not agree with the results obtained by [7] (based on the significantly different detection rates of Sy 1 and Sy 2 galaxies, [7] concluded that compact radio structure are much more common in Sy 2 than in Sy 1 galaxies).

We therefore conclude that Sy 1 and Sy 2 galaxies have equal tendency to show compact radio structures, in contrast to the results of [7], who concluded that compact radio structures were much more common in Sy 1s than in Sy 2s. Our results so far appear to be consistent with the US hypothesis: the radio compactnesses of the Sy 1s and Sy 2s are similar.

8 REFERENCES

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