Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 7 (2): 274-279, 2007
ISSN 1812-5654

Seyfert Galaxies: Nuclear Radio Emission and the Unified Schemes

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Abstract: Seyfer 1 and 2 nomenclatures are generic names arising from the different sizes of the Seyfert nuclear radio emission (D) and the presence or absence of a dusty obscuration torus coincident with the central engine. The size of the line-with emission is another central idea embedded in the projection and orientation scenarios. Linear size and the kinematic Doppler widths (V) are good observational parameters that can be used to test the predictions of the radio-quiet source unification scheme. Since the model favours large size of Seyfert 2, there should be a distribution of linear size within which, if the two subclasses are of the same parent population, Seyfert 2 is not biased towards larger size. We find that at D≤ 100pc, the average extension of nuclear emission for Seyfert 1 is approximately equal to the size of Seyfert 2, suggesting that the dissimilarity in their linear size can be attributed to projection effect. From the relative number of Seyfert 1's and 2's having linear size within this range, we estimate that the angle above which a Seyfert 1 is observed as type 2 is 43°. These results, considered together are in favour of the unified model in which Seyfert 2 contains a torus and Seyfert 1's linear size is smaller than that of 2 due to projection effect.

Key words: Galaxies, active-galaxies, nuclei-galaxies, Seyfert-galaxies, radio size-galaxies, line width

INTRODUCTION

The observation of broad polarization lines in the spectrum of the Seyfert 2 galaxy NGC 1068 proved that Seyfert 2 galaxies can be Seyfert 1 where the direct view of the central engine is blocked by a dusty torus (Pogge, 1998). This is the bedrock of the Unification Scheme for active galactic nuclei (AGN), which believes that objects of different activity classes, such as Seyfert 1 and 2 galaxies are the same kind of object whose nuclear engine is surrounded by a dusty molecular torus. It is the orientation angle of this torus relative to the line of sight that decides whether an AGN is classified as broad-line object (Seyfert 1), when the nuclear engine is un-obscured by the torus, or as a narrow-line object (Seyfert 2), when our line of sight runs through the torus and consequently, the central engine and the broad-line region are obscured.

Several researchers Kay (1998), Kinney *et al.* (2000), Pogge (1989), Capetti *et al.* (1995) Greenhill (1996) and Schmitt *et al.* (2001) found that the Seyfert unification scenario applies qualitatively to at least some large fraction of the objects being studied. For example, a deficit of ionizing photons in Seyfert 2 galaxies indicates that the ionizing source is hidden from direct view; the observation of masers very close to the nuclei of some Seyfert 2 galaxies show the presence of large concentrations of molecular gas, hiding the central engine. However, some papers present results suggesting intrinsic statistical differences between Seyferts 1 and 2 (Meurs and Wilson, 1984; Heckman *et al.*, 1989).

Recently, Okike *et al.* (2005), paper I hereafter, found a correlation between line width velocity (V) and linear extent (D) of the nuclear emission for Seyfert 1 and none for Seyfert 2. Their results were interpreted in favour of the unification scenarios. In the light of the above results, we expect at least, a residual correlation between line emission width velocity and linear extent of the radio nuclear emission of Seyfert 2. This partial correlation is expected to be the reminiscent of the broad emission line, partially observed in Seyfert 2 due to scattering. This speculation motivates us to re-examine our analyses to check whether broad-line emission is equally a phenomenon of Seyfert 2 galaxies, albeit scattering.

Sample and the luminosity selection effects: The sample and data used in the present study were selected from the recent compilation of Schmitt *et al.* (2001). See paper I for a more detailed selection criteria. To date, radio surveys of Seyfert galaxies have produced conflicting results, some of which can be blamed on lack of uniformity on the isotropic property of the samples being unified as well as luminosity selection effects that may be inherent in the

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samples themselves. For example, Kukula *et al.* (1999) and Schmitt *et al.* (2001) claim that Seyfert 2 s were selected from 2 orders of magnitude on the luminosity function than Seyfert 1 s. In order to investigate the implication of luminosity selection effects on our earlier results, we carried out a more detailed regression analysis of linear size, line-width velocity and luminosity of Seyfert 1 galaxies. The regression results are as follows:

$$\log D = (-2.07 \pm 1.17 + (1.02 \pm 0.32) \log V \quad (r = 0.57) \tag{1}$$

$$\log D = (-2.07 \pm 2.53) + (0.18 \pm 0.12) \log P \quad (r = 0.30) \tag{2}$$

$$\log p = (18.22 \pm 2.30) + (0.79 \pm 0.63) \log V \quad (r = 0.26) \tag{3}$$

It could be observed that the data shows strong correlation between linear size (D) and line-width velocity (V), marginally significant correlation between D and luminosity (P) and a weak P-V correlation. Our interest, however, is to account for the contribution of D-P correlation on the observed D-V strong correlation in Seyfert 1 samples. Following the simple mathematical formalism developed by Ubachukwu *et al.* (1996), to quantitatively estimate the influence of luminosity selection effects in their sample, we wish to account for the influence of luminosity effects in the above results.

We attempt fitting median value data in four different velocity line-width and luminosity bins. The following results were obtained:

$$\log D_m = (-3.53 \pm 4.05) + (1.45 \pm 1.09) \log V \quad (r = 0.30) \tag{4}$$

$$\log D_m = (-2.79 \pm 8.21) + (0.22 \pm 0.38) \log P \quad (r = 0.37) \tag{5}$$

Using Eq. (3) in (5) above to factor out the influence of luminosity in D-V correlation gives:

$$\log D_m = X + 0.14 \log V \tag{6}$$

where X is a constant.

A comparison of Eq. (4) and (6) shows that the residual D-V correlation after correcting for the influence of luminosity selection effects differs by a factor of 10, suggesting that that the correlation between D and V is real.

Linear radio structures and the obscuration torus: Ideally, Seyfert 1 and 2 nomenclatures are generic names arising from the size of the Seyfert nuclear radio emission and the presence or absence of a dusty obscuration torus, coincident with the central engine. Thus, the Seyfert unification models are bedeviled with the task of reconciling any observational differences in their phenomenology. For instance, the linear radio structures of Sefert 1 is observed to be smaller than that of Seyfert 2 and the Seyfert unified model, in attempt to resolve the discrepancy, invoked projection effects. On the absence of broad line emissions in Seyfert 2 types, the model argues that the obscuration torus in Seyfert 2 is responsible (Tran, 1995, Kay, 1994).

A number of authors who pick holes with the model often base their argument on the similarity or differences in radio structures of Seyfert samples. Kukula *et al.* (1995) found that the radio structures of Seyfert 1s were on average too compact to be foreshortened version of the type 2 objects, indicating that orientation is not the only effect at work. Still contrary to what would be expected of the unified model, Roy *et al.* (1994) found that type 1 object were less likely than type 2s to contain compact nuclear radio components. While contributing to the on-going debate, Thean *et al.* (1999) reported that Seyfert 1s and 2s are likely to contain radio sources, with no significant difference between size distributions of the two types. The fore going does not only reveal the inconclusive fate of the Seyfert unified models but points to the importance of a detailed statistical study on the nuclear emission as well as line-width of Seyfert objects. Figure 1 shows that the linear size of Seyfert 1 and 2 are not equal. We calculate that the average extension of the radio emission of Seyfert 2's is larger that of Seyfert 1s by a factor of ~2. It can be seen from Fig. 2 that the linear size of both Seyferts are approximately equal at $D \leq 100$ pc; suggesting that the distribution is not biased towards different sizes within this range.

Linear radio extent and line-width correlation of Seyfert 2 galaxies: In the light of the above strong correlation between the optical spectra and the nuclear radio emission of Seyfert 1, we expect at least, a residual correlation between line-width velocity and linear size of Seyfert 2. This partial correlation, if exists, is expected to be the reminiscent of the broad line regions, partially observed in Seyfert 2 due to scattering. This speculation motivates us to re-examine our analyses. A casual inspection of our data shows that large linear size is not common with Seyfert galaxies. This observation is in agreement with the results of Kukula *et al.* (1999) who found that linear radio structures measured in a few Seyferts are approximately 100 pc.

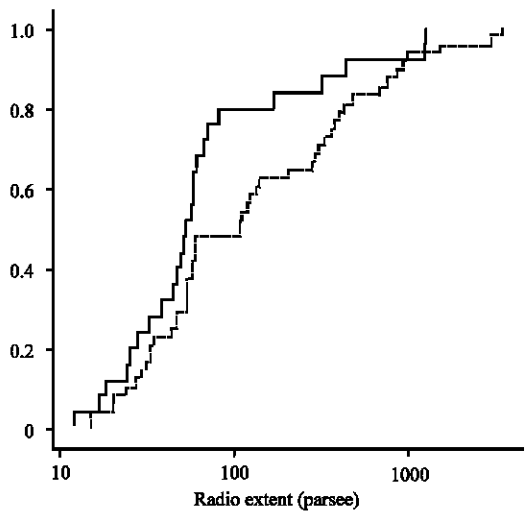

Fig. 1: Cumulative radio linear extent distributions (logarithmic scale) for Seyfert I (solid line) and for Seyfert II (dashed lines)

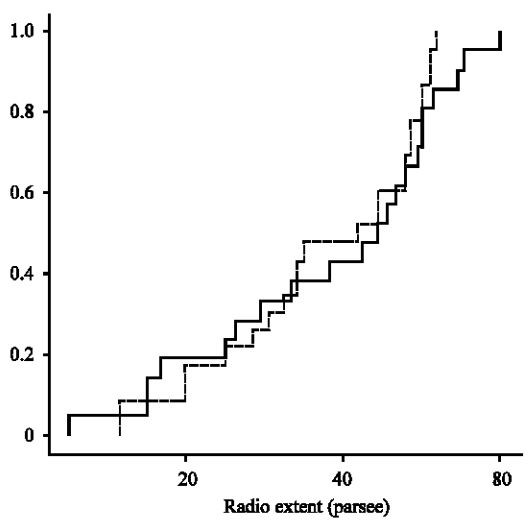

Fig. 2: Cumulative radio linear extent (for D≤ 100pc) distributions (logarithmic scale) for Seyfert I (solid line) and for Seyfert II (dashed lines)

The distribution of linear size within which the radio emission of both Seyferts are approximately equal offers a good ground for further verification of the unified scheme. If projection effect makes the difference in the size of both Seyferts, then the strong correlation between the optical spectra and the linear size as found in type 1 should also be a characteristics of Seyfert 2 at D≤ 100 pc distribution obtained earlier. We narrowed the linear sizes of our Seyfert 2 sources to 100 pc and immediately observed an interesting result. We find a stronger

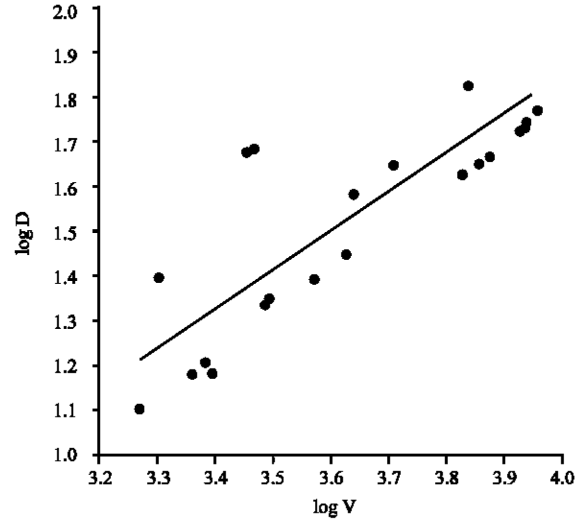

Fig 3: Plot of log D (D≤100pc) against log V for Seyfert 1 galaxies

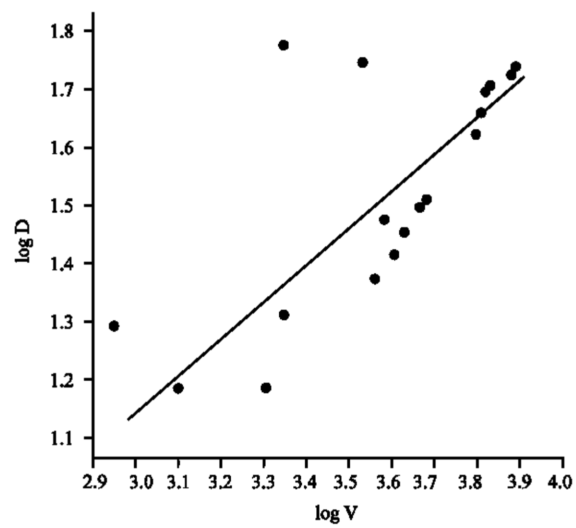

Fig. 4: Plot of log D (D≤100pc) against log V for Seyfert 2 galaxies

correlation (r = 0.8) between linear size and emission line-width of Seyfert 2 galaxies. We equally scaled the linear size of Seyfert 1 to D≤ 100 pc for the purpose of comparisons. We find that for linear sizes D≤ 100 pc, the correlation coefficients between D and V for both Seyferts are equal and highly significant. These results are shown in Fig. 3 and 4 with their corresponding regression equations:

$$\log D = (-1.50 \pm 0.57) + (0.84 \pm 0.15) \log V \quad (r = 0.8) \qquad (7)$$

$$\log D = (-0.59 \pm 0.32) + (0.59 \pm 0.08) \log V \quad (r = 0.8) \qquad (8)$$

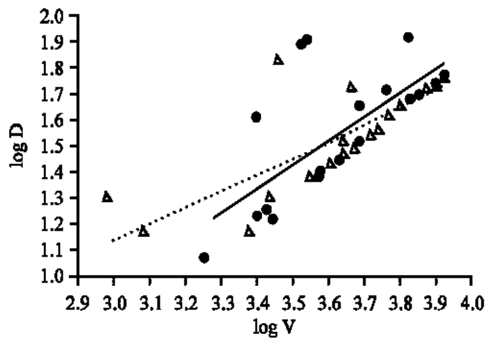

Fig. 5: Linear Size against Radial velocity for Seyfert 1 (circles) and Seyfert 2 (triangles)

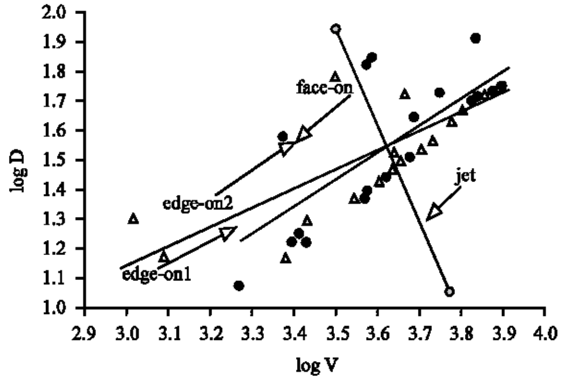

Fig. 6: Same as fig 5 with simulation of jet and viewing angles

We believe that our regression results within the limiting size underlines a significant common natural phenomenon between the two populations.

If such a physical phenomenon exits, how do we visualize it? We represented the regression in Fig. 3 and 4 in a single (Fig. 5) and obtained a surprising result. In order to complete the emerging results, we modified Fig. 5 as shown in Fig. 6.

DISCUSSION

We have used a simple mathematical formalism proposed by Ubachukwu (1995) and developed by Ubachukwu, *et al*. (1996) to quantify the contribution of luminosity selection effects on the correlation between D and V as reported in paper I. We find that the correlation does not arise from the influence of luminosity selection effects. Consequent on this result, we are prompted to seek for a residual correlation between linear size and line width velocity for Seyfert 2. We find that at $D \leq 100$ pc, the correlation between D and V for both Seyferts are strong as well as identical ($r = 0.8$). These results are quite significant as they can be interpreted from the point of view of the Seyfert unification model (Antonucci, 1993). The model predicts that the average extension of the radio emission of Seyfert 2 is larger than that of Seyfert 1. If this disparity exists in the overall sizes of radio linear extension for Seyfert populations, theory should be able to seek such a limit, within which the linear radio extents of both Seyferts are reasonably comparable. Whereas it is obvious from Fig. 1 that radio extent of Seyfert 2 is larger than that of Seyfert 1 in line with the unified model, Fig. 2 shows that their sizes are almost equal at $D \leq 100$ pc, implying that we see Seyfert 1's within this range and Seyfert 2 above it. Such a limiting size, according to the unification scheme, will involve small number statistic, especially for Seyfert 2's. Present data shows that 81% of Seyfert 1's and 48% of Seyfert 2's meet our selection criteria, an indication that greater percentage of Seyfert 2 are on the high side of linear size. Our interest, however, is to seek a range of linear size within which neither Seyfert 1 suffers the ad hoc foreshortening nor is Seyfert 2 of larger linear size.

The excellent agreement between the D-V correlation for Seyferts 1 and 2 at $D \leq 100$ pc is an indication that within a certain range of linear size of Seyferts, the scattering of the high velocity gas within the broad-line region of Seyfert 2 picks and Seyfert 2 galaxy completely appears like Seyfert 1 (Curran, 2000). We also note that this result obtained for Seyfert 1 and 2 at $D \leq 100$ pc is a suggestive of the fact that Seyfert galaxies are not associated with large nuclear outflows. This strong correlation between D and V for both at $D \leq 100$ pc may be an indicator to the observing angle below and above which a Seyfert population appears as Seyfert 1 or 2 respectively as proposed by Rees (1971) and Scheuer (1974) and modified by Urry and Podovani (1995). Figure 6 looks curious and could be interpreted in favour of the above pictorial schemes. Linear size and kinematic Doppler line-width are parameters dependent on the a prori suppermassive blackholes (Wang and Lu, 2001) and as such are expected to correlate for both Seyferts. This, however, is not the case for Seyfert 2 as reported in paper I. Projection effects and obscuration as well as scattering are responsible for the different results. After correcting for linear size differences, the expected correlation emerged and we are led to interpret Fig. 5 with respect to Fig. 6. Figure 5 lends credence to the currently accepted schematic diagram of a unified AGN. The point of intersection might be the central engine common to both Seyferts and the conical shape mimics the obscuration torus. Following the standard unified model in which Seyfert 1 are observed along the radio axis and Seyfert 2 observed orthogonal to it, we mapped an assumed perpendicular jet onto the torus as shown in Fig. 6.

Here, we have three types of Seyferts: face-on, egde-on 2 and egde-on1. For edge-on1 Seyferts, the central engine and hence the broad-line region is completely blocked by the torus and we see only Seyfert 2 galaxies. Just after this, we have the egde-on Seyfert 2 where the scattered broad-line emission is gradually accumulating to the point of maximum scattering when the egde-on2 transforms completely to face-on Seyfert. It is obvious that we have distribution of viewing angles ranging between $0^0 \leq \theta_d \leq \phi$ where θ_d is defined as the discriminating angle between edge-on2 and face-on types and ϕ is the maximum angle between the jet and dusty torus axes. We can consider the two extreme cases of viewing angle, when $\phi = 0_0$ and $\phi = 90^0$. Applying these two cases, to the probability $D \leq p(\theta_d < \phi) = 1 - \cos\phi$, that a Seyfert must be observed in the range $0^0 \leq \theta_d \leq \phi$; for $\phi = 90^0$, we observe face-on type and for $\phi = 0^0$, we see the edge-on1 Seyfert. Egde-on 2 is observed at any angle above θ_d. The value of θ_d cannot be calculated with certainty since we are using a certain% of the sample. We can, however, make an estimate of θ_d from the relative number of sources having linear size within the range $D \leq 100$ pc as shown in Fig. 6. We, therefore, estimate, following Kinney *et al.* (2000), from the relative numbers that $\theta_d \approx 43^0$. This is the angle (reference from the jet axis) above which we observe Seyfert 2 galaxies. We note that this value is fairly comparable to what is obtainable in the literature. Using a finer classification, Osterbrock and Martel (1993) obtained $\theta = 38^0$ from the relative number of Seyfert 1 and 1.5's and $\theta_d = 56^0$ from the relative number of 1.8 and 1.9's. Our sample is only separated into Seyfert 1 and 2's. Kinney *et al.* (2000), using the ratio of Seyfert 1 to Seyfert 2 galaxies in the data obtained $\theta_d = 40^0$. It is obvious that our value is little higher and could be attributed to our condition on the linear sizes of both Seyferts.

The results of this study suggest a meeting point for Seyfert unification theories and observations. It is evident that our results are not only consistent with the standard unified Seyfert model but may actually lend further support to this model with respect to projection effect, responsible for the larger size of Seyfert 2's.

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