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Unification Scheme in Double Radio Sources: Bend Angle versus Arm Length Ratio Relations

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Abstract: *From radio source unification scheme, asymmetries are more pronounced in quasars than in radio galaxies. Using a sample of 625 double radio sources (316 radio galaxies and 309 quasars), we investigated the variations between bend angle, arm-length ratio and redshift. We find no significant correlation (0.045) between bend angle and redshift for the entire sample and at low z for radio galaxies while a weak correlation (0.121) between bend angle and redshift for quasars for the entire sampleis observed. A weak correlation (radio galaxies, r = 0.173 and quasars, r = 0.102) between the bend angle and arm-length ratio for the double radio sources used in this study is observed. Kharbet al. (2008) in their study of powerful classical double radio galaxies noted that this correlation could suggest that the environmental asymmetries that give rise to the arm-length ratio could be contributory to the misalignment angles in these sources. Quasars appear much more bent and misaligned. This is consistent with quasars being radio galaxies viewed at small angles.*
Keywords: *bend angle, arm-length ratio, unification: radio galaxies – quasars, redshift*

I. Introduction

According to Scheuer (1987), some quasars may appear as radio galaxies whenseen in the sky plane. Barthel (1989) elaborated this idea and proposed that all quasars are beamed versions of FR II radio galaxies. This is a strong version of the unification of radio galaxies and quasars. In the Barthel's scheme for radio galaxies and quasars, sources viewed within ~45^o of their jet axes appear as quasars while those which are inclined above 45^o appear as radio galaxies. This opening angle was derived essentially from the observation that (for low redshift sources) there are twice as many radio galaxies as quasars, and that the median linear size of quasars is about half that of the radio galaxies.If the unified scheme is correct, then in studies that involve radio galaxies and quasars, the two classes would not be equally represented in the redshift plane. Blundell *et al*. (1999) suggested that this be taken into account in studies that explain redshift. The analyses were then carried out separately for low z (log (1+z) < 0.2) and high z (log (1+*z*) $\geq$ 0.2) sources in the radio galaxies and quasars samples. In this paper, after the description of the sample in section 2 we looked at the relationship between bend angle and redshift in section 3. We considered the variations of arm-length ratio and redshift in section 4. In section 5 we analysed the variations of bend angle and arm length ratio while the discussion of results was done on section 6.

II. The Sample

The data used for the analysis in this paper wereobtained from Nilsson (1998). After the exclusion of objects without redshift, arm-length ratio and bend angle, we have a final sample of 625 double radio sources (316 radio galaxies and 309 quasars) with luminosity (in $ergs^{-1}$) measured at, between 10MHz and 10GHz in the rest frame of the source, and spectral index between 178MHz and 5GHz were chosen.

III. Variation of Bend Angle and Redshift for Radio Galaxies and Quasars

The plots of bend angle (D) versus redshift (z) for radio galaxies (fig.3.1) and quasars (fig. 3.2) for the entire sample show that the radio structure of radio galaxies is typically better aligned than that of quasars. The difference in the D distributions in the radio galaxies and quasars is significant at the 99% confidence level (Kolmogorov-Smirnov two-sample test).

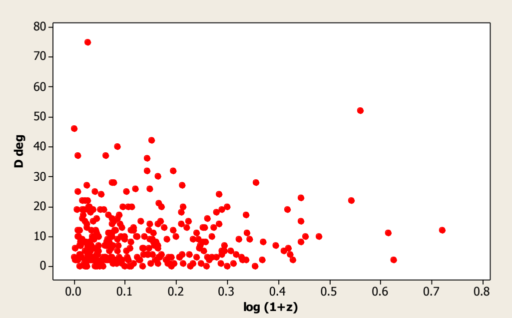

Fig. 3.1: The plot of Bend angle versus Redshift for galaxies in the entire source sample

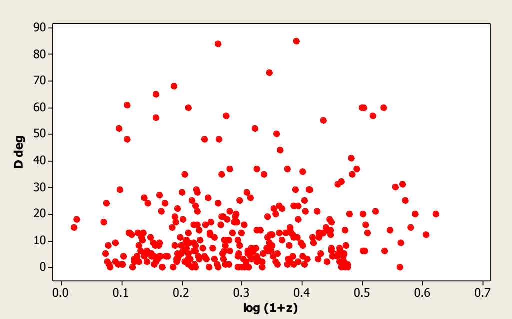

Fig. 3.2: The plot of Bend angle versus Redshift for quasars in the entire source sample

There is no significant correlation (0.045) between bend angle and redshift for radio galaxies in the entire sample. This tends to agree with Kharb*et al*. (2008) who found no dependence of bend angle on redshift. We find a weak correlation (0.121) between D and z for quasars in the entire sample. Barthel and Miley (1988) had found a tentative correlation between bend angle and redshift, consistent with our result.

Figures (3.3) – (3.6) are plots of bend angle versus redshift for low and high z radio galaxies and quasars. We found also no significant correlation (0.014) between bend angle and redshift for the low z radio galaxies and a weak inverse correlation (-0.034) between D and z for the low z quasars. There are weak correlations – (0.224) and (0.114) between bend angle and redshift for high redshift radio galaxies and quasars respectively. The weak inverse correlation observed between D and z for low z quasars might be attributed to sample selection effect.

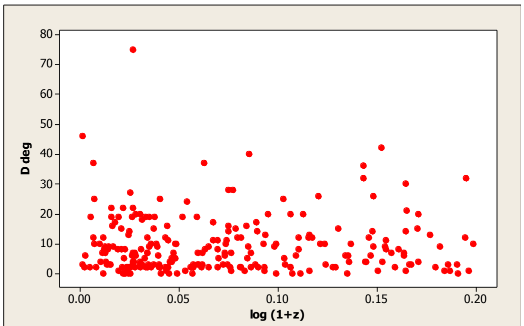

Fig. 3.3: The plot of Bend Angle ratio versus Redshift for galaxies with log (1+z) < 0.2

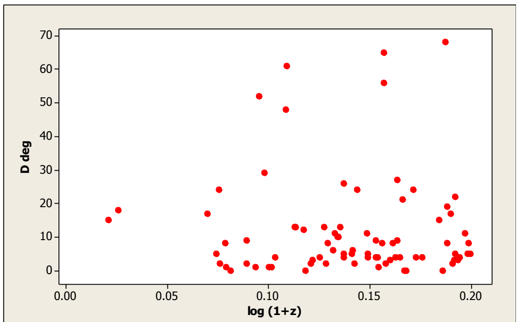

Fig. 3.4: The plot of Bend angle versus Redshift for quasars with log (1+z) <0.2

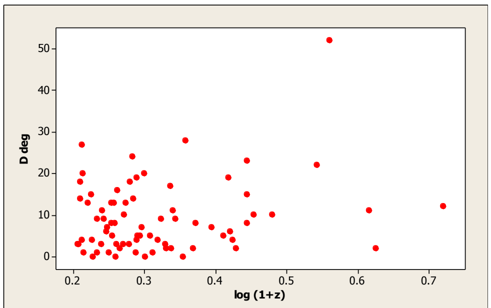

Fig. 3.5: The plot of Bend angle versus Redshift for galaxies with log (1+z) ≥0.2

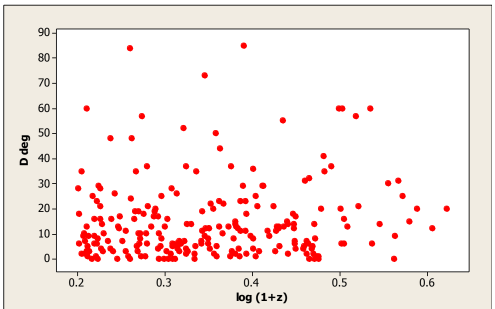

Fig. 3.6: The plot of Bend angle versus Redshift for quasars with log (1+z) ≥0.2

IV. Variation of Arm-Length Ratio and Redshift for Radio Galaxies and Quasars

The plot of arm-length ratio (Q) versus redshift (z) for radio galaxies (fig.4.1) and quasars (fig. 4.2) for the entire sample indicate that the arm-length ratio of radio galaxies are clustered at low redshift while that of quasars are distributed across the redshift range in the sample.

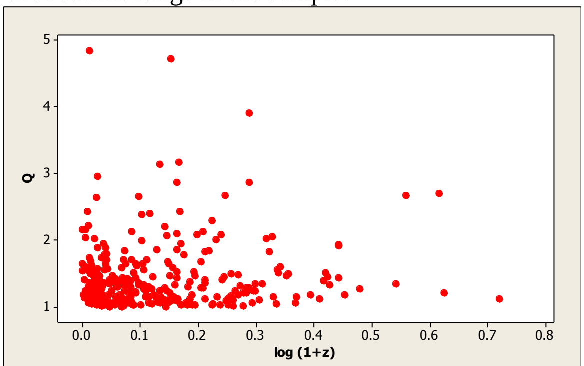

Fig. 4.1: The plot of Arm-length ratio versus Redshift for galaxies in the entire source sample

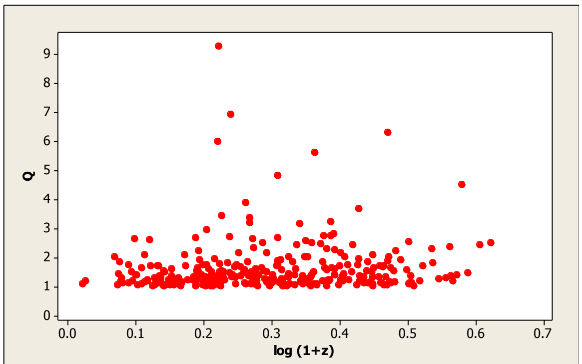

Fig. 4.2: The plot of Arm-length ratio versus Redshift for quasars in the entire source sample

We do not find any significant dependence of Q on redshift for the entire sample of radio galaxies (0.096) and quasars (0.098) which tend to agree with the result obtained by Kharb*et al.* (2008). Consistently, we observed no significant correlation between Q and redshift for the low redshift radio galaxies (0.092) and quasars (0.027) and also for high redshift radio galaxies (0.084). Meanwhile, we find a weak inverse correlation between Q and redshift for the high z quasars (-0.018) which may also be attributed to selection effect.

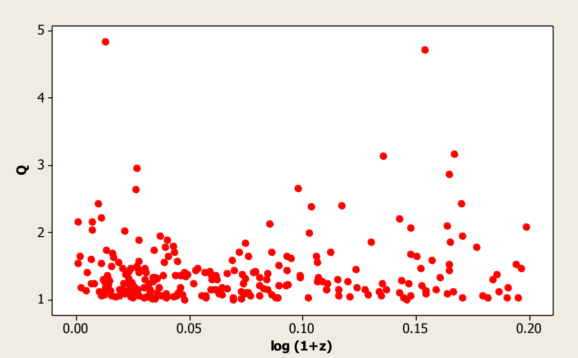

Fig. 4.3: The plot of Arm-Length ratio versus Redshift for galaxies with log (1+z) < 0.2

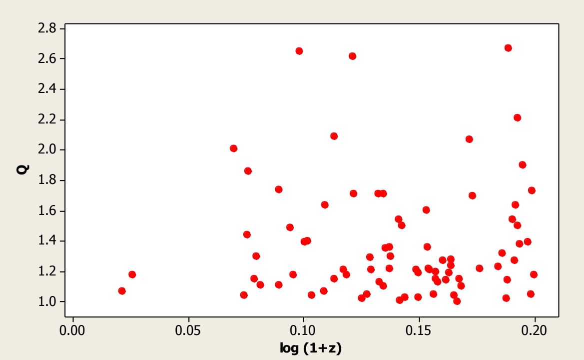

Fig. 4.4: The plot of Arm-length ratio versus Redshift for quasars with log (1+z) <0.2

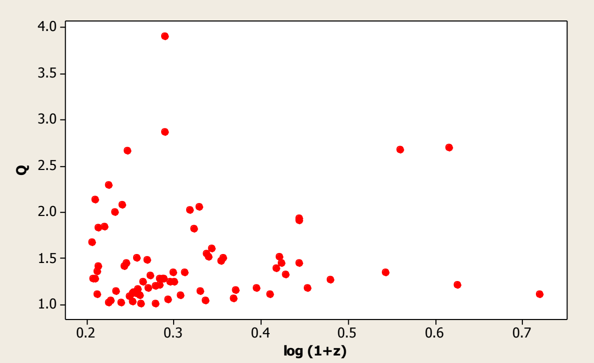

Fig. 4.5: The plot of Arm-length ratio versus Redshift for galaxies with log (1+z) ≥0.2

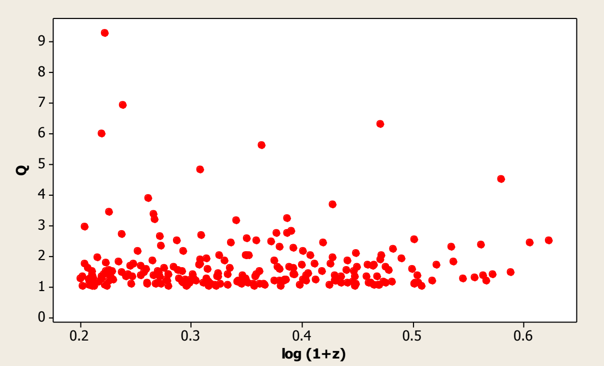

Fig. 4.6: The plot of Arm-length ratio versus Redshift for quasars with log (1+z) ≥0.2

V. Variation of Bend Angle and Arm-Length Ratio for Radio Galaxies and Quasars

We examined the radio galaxies and quasars for correlations between their arm-length ratios and bend angles (figs 5.1 – 5.6). There appears to be a weak correlation between bend angle and arm-length ratio for the entire sample (radio galaxies, $r = 0.173$ and quasars, $r = 0.102$).

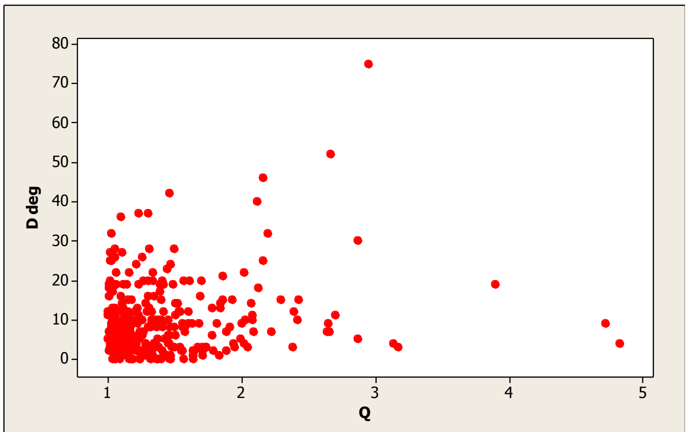

Fig. 5.1: The plot of Bend angle versus Arm-length ratio for galaxies in the entire source sample

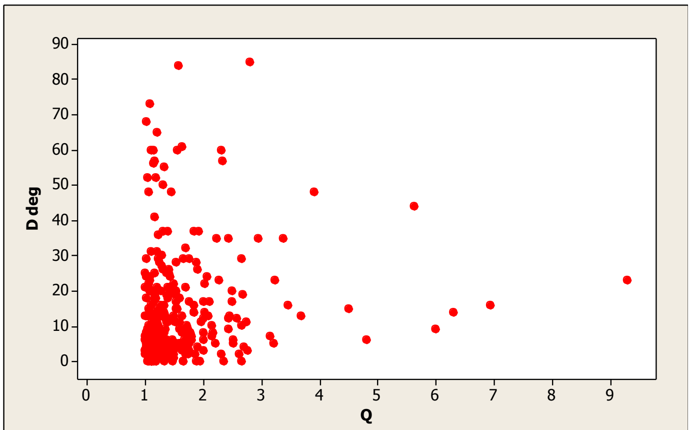

Fig. 5.2: The plot of Bend angle versus Arm-length ratio for quasars in the entire source sample

We find a weak dependence of D on Q for low redshift radio galaxies (0.147), high redshift radio galaxies (0.268) and quasars (0.109). While a non-significant inverse correlation (-0.006) is observed in the case of low redshift quasars. This might be attributed to sample selection effect. A comparison of bend angle and arm-length ratio in the double radio sources suggests that quasars are more bent than radio galaxies at all redshifts, consistent with radio galaxy – quasar unification.

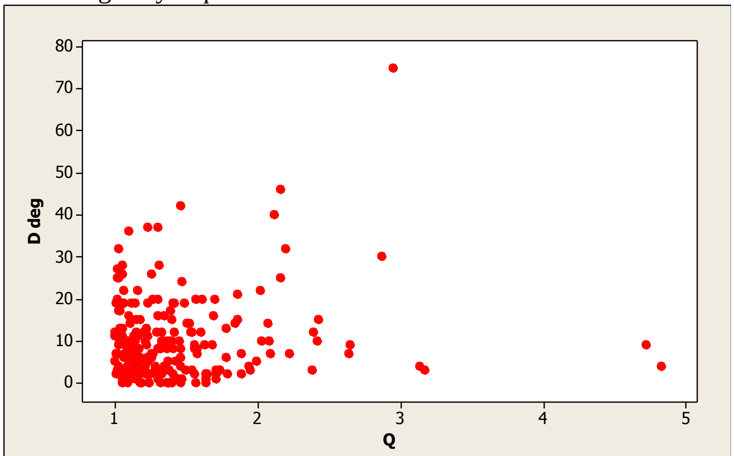

Fig. 5.3: The plot of Bend angle versus Arm-length ratio for galaxies with log (1+z) < 0.2

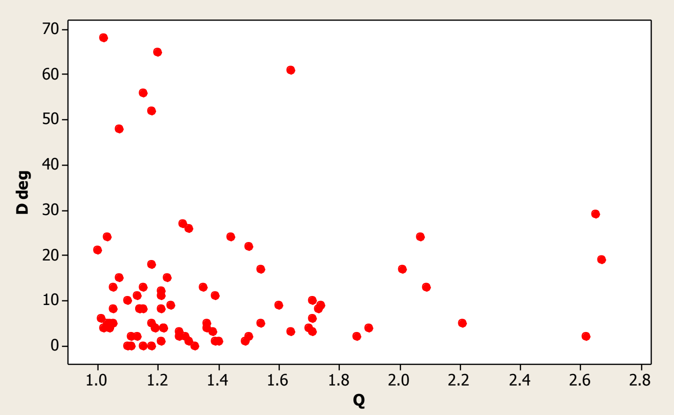

Fig. 5.4: The plot of Bend angle versus Arm-length ratio for quasars with log (1+z) <0.2

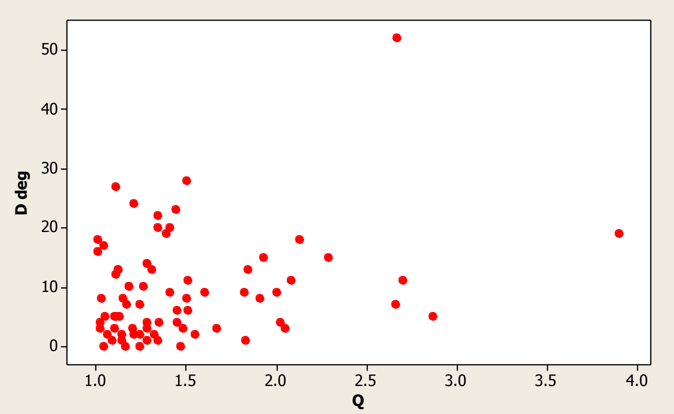

Fig. 5.5: The plot of Bend angle versus Arm-length ratio for galaxies with log (1+z) ≥0.2

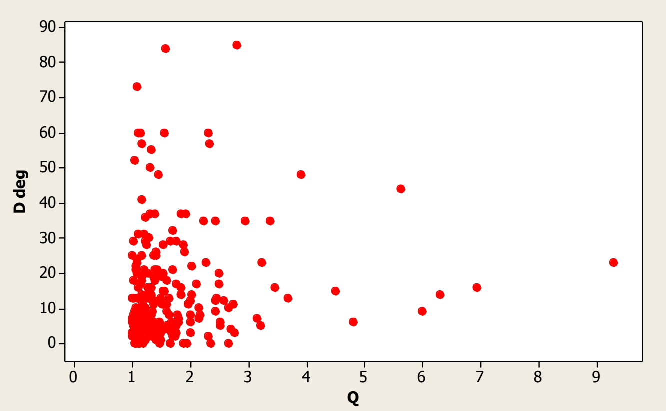

Fig. 5.6: The plot of Bend angle versus Arm-length ratio for quasars with log (1+z) ≥0.2

VI. Discussion

This paper deals with radio galaxy – quasar unification as it concerns the variations between bend angle, arm-length ratio and redshift. No significant correlation were found between bend angle and redshift for the entire source sample and at low redshift for radio galaxies while a weak correlation between bend angle and redshift for quasars was observed. This is respectively consistent with the result obtained by Kharb*et al*. (2008) and Barthel and Miley (1988). However, we found non-significant inverse correlation between D and z for the low redshift quasars. Weak correlations were also found for the high redshift radio galaxies and quasars. The weak inverse correlation observed between D and z for low redshift quasars might be attributed to sample selection effect.

An investigation of asymmetries in the radio galaxies and quasars sample show no significant dependence of arm-length ratio on epoch; this is in agreement with Kharb*et al*. (2008). Except for the low redshift quasars where we observed a non-significant inverse correlation, we find a weak correlation (although weaker in quasars (r = 0.102) compared to radio galaxies (r = 0.173)) between the bend angle and arm-length ratio for the double radio sources used in this study. In their study of powerful classical double radio galaxies,Kharb*et al*. (2008) noted that this correlation could suggest that the environmental asymmetries that give rise to the arm-length ratio could also be contributory to the misalignment angles in these sources. Hence, quasars appear much more bent and misaligned. This is consistent with quasars being radio galaxies viewed at small angles.

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