Chapter 5

Radio galaxies with disks

Radio sources not selected to reside in rich cluster environments are known to be hosted by elliptical galaxies (e.g. Heckman et al., 1986). Host galaxies in rich clusters are more homogeneous in nature and show a lower frequency of merger activity (Ledlow and Owen, 1995). However, recently many examples of powerful radio sources have been found where the host galaxy shows appreciable deviation from being an elliptical. One important distinguishing feature between ellipticals and non-ellipticals is the presence of a disk. In this chapter we study the morphology of the radio galaxies as well as the control galaxies with prominent disks.

We present data on five radio galaxies from our sample with prominent disks. We present the images and obtain bulge and disk scale lengths ($r_e$ and $r_s$) as well as the relative strengths of the two components ($D/B$) using the profile fitting technique described in Chapter 3. We also introduce in this chapter the morphological gradient filter which is especially useful in locating disks in galaxies.
In Chapter 3 we have explained the procedure we follow to decompose the surface brightness profile of a galaxy into de Vaucouleurs bulge ($B$) and an exponential disk ($D$) component. The ratio of the luminosities of the two components, $D/B$, is the factor that indicates the presence of a disk. In Figure 5.1 we show the typical $D/B$ values for galaxies of different morphological types (Kent, 1985). As per Hubble’s original classification scheme (Hubble, 1926), elliptical galaxies do not have any structure. Whenever a disk like component was suspected the galaxy was labeled SO. Recent studies have shown, however, that elliptical galaxies can also be disky. It is likely that such galaxies may be the lower end, in diskiness, of SO galaxies.
Figure 5.2: $D/B$ distribution for the radio and control samples in $B$ and $R$ filters. There are five radio galaxies with $D/B > 0.3$ (upper right quadrant) and with $r_s > \text{FWHM}$ of the PSF in both $B$ and $R$ filters. 4 control sample galaxies have $D/B > 0.3$ in both $B$ and $R$ filters.
Figure 5.3: Histogram of $D/B$ values in the $R$ filter for the radio and control samples. The dotted line denotes $D/B = 0.3$. The disk parameters for the disky radio galaxies are more significant than for their counterparts in the control sample (see text).
In Figure 5.2 we show the distribution of the $D/B$ ratio for the radio and control samples. For the $R$ filter we also depict the distribution as a histogram for both the samples in Figure 5.3. It is seen that in general the $D/B$ values in both the filters are similar. Several galaxies in the radio as well as control samples, have a $D/B < 0.1$. These are likely to be insignificant disks possibly arising from deviation form the $r^{1/4}$ law or a weak point source (when $r_s$ is also small). We notice that there are a few galaxies with a $D/B > 0.3$ in both the filters. In this section we consider these galaxies. The value of $D/B > 0.3$ was chosen so that even if the scatter around the $D/B$ values of different galaxy types plotted in Figure 5.1 is taken into consideration, the galaxies with these values will not be elliptical. In the radio sample, there are five such galaxies, while in the control sample there are four galaxies with this lower limit for the ratio.

There is also a class of objects for which $D/B > 0.3$ but such that $r_s < \text{FWHM of the PSF}$. Such cases are likely to be the result of a genuine departure from de Vaucouleurs’ law near the center or indicative of the presence of a weak AGN. We do not consider these galaxies to be disky in the normal sense of the word and have not treated them as being significant in the following discussion.

5.1.1 Radio galaxies

We present here results on 5 radio galaxies with prominent disks. We examine the host galaxy properties and the radio structure. 4 of the 5 galaxies have FR II morphology and even the fifth one is of type FR II?. The $D/B$ ratio is suggestive of spiral galaxies. However, we do not see spiral arms except in one case. Relevant parameters for these galaxies are listed in Table 5.1.

1222-252 This galaxy is at a redshift of 0.075 and is by far the most interesting one. It has $S_{408} = 1.820 \text{Jy}$ and $P_{408} = 10^{25.34} \text{WHz}^{-1}$. The radio source is of type FR II. The morphology in the two filters shows a bar like
structure along with a linear structure at right angle to the 'bar', arising from one end of the bar. There are also other flocculent structures present. $D/B$ values are consistent with the galaxy being an Sb. The disk scale length is in this case a few times the FWHM of the PSF, but only a fraction of the bulge scale length. We are therefore again detecting a small disk relative to the bulge.

**1053-282** This galaxy is at a redshift of 0.061, has $S_{408} = 3.510$ Jy and $P_{408} = 10^{25.41}$ W Hz$^{-1}$. The ellipticity of this galaxy changes from 0.1 near the center to 0.4 in the outer region. There is a spiral galaxy 15" away with which the radio galaxy is likely to be interacting. The $D/B$ values in both filters are $> 4$. From this, and the disk and bulge scale lengths, the galaxy can be classified as Sc. This is the most likely candidate from our radio sample to be a *normal* spiral as defined by bulge and disk parameters. No spiral structure is seen.

**1006-214** This galaxy is at a redshift of 0.250. The radio source is of type FR II with $S_{408} = 1.350$ Jy and $P_{408} = 10^{26.23}$ W Hz$^{-1}$. The galaxy is flattened near the center ($e \sim 0.55$ near the center compared to $e \sim 0.44$ on the outskirts). It has a bluer center and an armlike extension is seen along the radio axis. The $K'$ image does not show the armlike structure and hence it is likely to be the outcome of recent star forming activity. This galaxy has large $D/B (> 5)$ in both filters and on that basis alone would be classified as Sc. However the disk scale length is comparable to the FWHM of the PSF. It is also much smaller than $r_e$ in the $R$ filter. In the $B$ filter, $r_e$ and $r_s$ are comparable in size. However, the smaller bulge scale length in this filter, relative to $r_e$ in the $R$ filter, is suspected to be a result of excess blue emission in the central region. Taking all this into account, we conclude that the profile fit has detected a small scale disk-like structure. The linear scale length of this structure in $R$ is $\sim 3$ kpc, and it is much smaller than the
bulge scale length of $\sim 20 \text{kpc}$. The ratio of the disk to bulge scale lengths is therefore much smaller than is observed for standard disk galaxies.

**0952-224** This galaxy is at a redshift of 0.230 and is in a crowded region. It has a 408 MHz radio flux $S_{408} = 1.710 \text{Jy}$ and has a radio luminosity of $10^{26.26} \text{W Hz}^{-1}$. The radio source is of type FR II. This galaxy has a $(D/B)_{\text{red}} = 2.54 \pm 0.33$, which is large enough for it to be classified as an Sb spiral. However $(D/B)_{\text{blue}} = 0.39 \pm 0.01$ is considerably smaller. This difference in parameter values is also seen in $r_s$, as well as in bulge parameters. Due to the difference in values from one filter to another, it is not possible to confidently classify the galaxy. The differences are caused by the presence of dust as well as blue emission, which are seen in the color maps and profile fits. We show the galaxy in Figure 5.1.2.

**1215-215** This galaxy is at a redshift of 0.075. It has $S_{408} = 1.500 \text{Jy}$ and $P_{408} = 10^{25.22} \text{W Hz}^{-1}$. $D/B$ values in $B$ and $R(>1)$ are consistent with SA classification. $r_s$ in $B$ and $R$ is comparable to the FWHM of the PSF.

### 5.1.2 Control Sample

We describe here objects from the control sample that have $D/B > 0.3$ in both filters. The control galaxies have been chosen to be of early type and we expect a few S0s but no spiral galaxies. Relevant parameters for the 4 *disky* galaxies are given in Table 5.2.

**1251/190** In this case the $D/B$ values are consistent with the galaxy being a lenticular, but the error bars are large, and the $D/B$ value, at least in the $B$ filter, is consistent with zero. The disk scale lengths are smaller than the FWHM of the psf.
Table 5.1: Radio galaxies with D/B > 0.3 in B or R or both

<table>
<thead>
<tr>
<th>IAU</th>
<th>z</th>
<th>D/B</th>
<th>Type</th>
<th>rₑ (arcsec)</th>
<th>rₑ (arcsec)</th>
<th>χ²</th>
<th>Radio</th>
</tr>
</thead>
<tbody>
<tr>
<td>0952-224</td>
<td>0.230</td>
<td>0.39 ± 0.01</td>
<td>B</td>
<td>2.54 ± 0.33</td>
<td>2.3 ± 0.1</td>
<td>1.31</td>
<td>FR II</td>
</tr>
<tr>
<td>1006-214</td>
<td>0.250</td>
<td>8.80 ± 1.10</td>
<td>B</td>
<td>12.3 ± 1.50</td>
<td>12.3 ± 1.50</td>
<td>1.14</td>
<td>FR II</td>
</tr>
<tr>
<td>1053-282</td>
<td>0.061</td>
<td>4.30 ± 0.35</td>
<td>B</td>
<td>24.8 ± 1.90</td>
<td>24.8 ± 1.90</td>
<td>0.40</td>
<td>FR II</td>
</tr>
<tr>
<td>1215-215</td>
<td>0.075</td>
<td>1.44 ± 0.16</td>
<td>B</td>
<td>1.5 ± 0.12</td>
<td>1.5 ± 0.12</td>
<td>0.16</td>
<td>FR II</td>
</tr>
<tr>
<td>1222-252</td>
<td>0.077</td>
<td>1.49 ± 0.44</td>
<td>B</td>
<td>4.9 ± 0.34</td>
<td>4.9 ± 0.34</td>
<td>1.03</td>
<td>FR II</td>
</tr>
</tbody>
</table>

Table 5.2: Control galaxies with D/B > 0.3 in B and R

<table>
<thead>
<tr>
<th>Object</th>
<th>D/B</th>
<th>Type</th>
<th>rₑ (arcsec)</th>
<th>rₑ (arcsec)</th>
<th>χ²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1251/190</td>
<td>0.46 ± 0.33</td>
<td>B</td>
<td>1.01 ± 0.16</td>
<td>6.11 ± 0.92</td>
<td>0.26</td>
</tr>
<tr>
<td>1323/1477</td>
<td>8.22 ± 0.61</td>
<td>B</td>
<td>4.13 ± 0.54</td>
<td>7.53 ± 5.76</td>
<td>0.55</td>
</tr>
<tr>
<td>1323/1673</td>
<td>4.06 ± 0.20</td>
<td>B</td>
<td>9.44 ± 0.92</td>
<td>7.53 ± 5.76</td>
<td>0.55</td>
</tr>
<tr>
<td>1329/234</td>
<td>1.58 ± 0.03</td>
<td>B</td>
<td>53.71 ± 0.67</td>
<td>3.05</td>
<td>0.55</td>
</tr>
</tbody>
</table>
This galaxy has large $D/B$ and appreciable bulge and disk scale lengths in both filters. However, the fit is poor in both filters.

In this case the fit is poor in $R$, tolerable in $B$. In the latter, the $D/B$ value is consistent with zero.

The disk in this case has a scale length comparable to the FWHM of the psf, $r_s \ll r_e$. The $D/B$ in $B$ is consistent with a lenticular and $D/B$ in $R$ consistent with a SA.

### 5.2 Morphological Signatures of disks

In Appendix A (Page 169) we describe the morphological image processing techniques that we have applied to our galaxies to look for disks. For the disks the morphological gradient technique is the most suitable. A disk, when it is present, exists along with the underlying bulge. This additional component provides a contrast over the 'background' of the bulge. It is this contrast that the gradient filter is able to detect.

We have applied the gradient to all our galaxies. The filter is able to bring out features like spiral arms and elongated structures especially well. For normal elliptical galaxies, the filter does not introduce any artificial structures. The images of the radio galaxies with disks, after processing with the morphological gradient filter, are shown in Figure 5.2 along with that of a normal galaxy. The filter involves manipulating the image and hence after processing it is not straightforward to carry out photometry on the resultant image.

We see that the spiral features of 1222-252 come out better after the gradient processing. The disk in 1006-214 is also brought out well by the filter with the blue feature possibly due to emission lines standing out at one end. In 1053-282 we see an elongated disk like structure at the center.
Figure 5.4: Filled contours of the disky radio galaxies in $B$ (left) and $R$ (right) bands. North is to the top and east is to the left. The faintest contour level in magnitudes is denoted in the top right corner with contour interval in the bracket. (top): 0952-224; (middle): 1006-214; (bottom): 1053-282
Figure 5.5: Filled contours of the disky radio galaxies in $B$ (left) and $R$ (right) bands. North is to the top and east is to the left. The faintest contour level in magnitudes is denoted in the top right corner with contour interval in the bracket. (top): 1215-215; (bottom): 1222-252
of the galaxy. However, it is not visible in the outer parts of the galaxy. In 1215-215, hint of a spiral structure is seen to the north. In 0952-224 the disky structure is seen north-south.

5.3 Discussion

Strong radio sources have always been identified with elliptical galaxies or recent merger remnants. Even recent studies have pointed to this (Urry and Padovani, 1995). When radio sources have been identified with spiral-like galaxies, the radio emission has been seen to be confined to the nucleus and the disk rather than have extended structure. The emission is dominated by thermal emission from HII regions and supernovae winds.

Fanaroff and Riley (1974) classified powerful radio galaxies into FR I and FR II types based on their radio morphology. In both types, the extended radio structure is fueled by jets that transport the radio plasma from the nucleus.

Seyfert galaxies are almost always associated with spiral hosts and in some cases the radio emission is seen to be up to $\sim 100$ kpc. Seyferts are towards the low luminosity end of the radio galaxies and may form the bridge between powerful radio galaxies and spirals. Meurs and Wilson (1984) have studied the radio luminosity function of Seyferts, radio galaxies and spirals and suggest that the luminosity functions do not smoothly merge.

We have shown here that in our radio galaxy sample there are five sources ($\sim 17\%$) which can be classified as disky galaxies. (There are additional sources with $D/B > 0.3$ but with $r_s < \text{FWHM}$ of the PSF. We do not consider these to be disky galaxies, since the “disk” cannot be distinguished from a point source.) The optical morphology of these objects is complex. Spiral arm-like features are visible in only one of them. Examples have been reported before of spiral galaxies being associated with FR II radio sources. However, these have turned out to be chance superpositions (see
Figure 5.6: The morphological gradient images in $B$ filter of five radio galaxies and a normal galaxy. North is to the top and east is to the left. Top: 0952-224 (left), 1006-214 (right); middle: 1053-282 (left), 1215-215 (right); bottom: 1222-252 (left), 0434-225 (right). 0434-225 is the normal galaxy.
e.g. Rönnback and Shaver, 1997). However, 1222-252 clearly seems to have spiral like features.

Previous claims related to detection of disks in powerful radio galaxies have been controversial e.g. 3C 293 and 3C 305 both have a disk of rotating emission line gas but no evidence for a stellar disk (Heckman et al., 1985). 0313-192 in Abell 428 is an FR I source reported to be hosted by a disk dominated galaxy showing spiral arms in the B band (Ledlow et al., 1998). Barring a possible exception of 1053-282, all the disk dominated radio galaxies in our sample are FR II sources.

The $D/B$ classification puts these galaxies in the Sa+ categories. However, when the $r_e/r_s$ ratio is considered, it is clear that the disks present in these galaxies are of a different nature than in normal spiral galaxies, in which $r_s > r_e$.

Except in one case, we do not see spiral structure in case of the disky radio galaxies. However, we have seen above that two more galaxies show hints of spiral structure after they are operated on with the morphological gradient filter. An interesting example of the efficacy of the filter is the anonymous galaxy shown in Figure 5.7. We believed at one time that this galaxy was the host of the radio source MRC 0503-284. We found subsequently that this was a misidentification, and the anonymous galaxy was dropped from the sample. Figure 5.7 shows the direct $B$ image and the morphologically processed image of this galaxy. The direct image clearly shows the presence of a spiral structure to the south-east. There is a hint of an asymmetry towards the north-west. The spiral structure in the south-east is seen much more clearly after the image has passed through the morphological gradient. In addition, the corresponding spiral structure in the north-west also stands out. Thus, the morphological gradient operator is clearly of help in detecting spiral structure.
Figure 5.7: Images of a disky galaxy previously misidentified and thought to be the host of MRC 0503-284. The $B$ image (top) shows the presence of a spiral structure to the south-east. The morphological gradient brings out the spiral structure more clearly and indicates the presence of a similar, but weaker structure to the north-west. North is to the top and east to the left.