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# Radio galaxies and dusty galaxies

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## 1. Introduction

Telescopes with modest apertures in the range ~ 1m to 2m are ideally suited for direct imaging of galaxies. Broad band, multicolour CCD observations of galaxies with such telescopes provide high dynamic range images, which can be processed to provide detailed information about their morphology. Various techniques can be used to reveal emission and absorption regions, as well as coherent features which arise due to tidal interaction with neighboring galaxies, or are remnants of past merger events. We describe in the following sections morphological studies of radio galaxies, and the features found in the elliptical galaxy NGC 7562, which was observed with the Sampurnanand telescope.

## 2. Radio galaxies

A very small fraction of all galaxies are highly luminous in the radio band. The radio luminosity of these galaxies can be comparable to, or even exceed greatly, their optical luminosity. The size of the radio emitting region is very large, extending in the largest cases to hundreds of kiloparsec. The radio morphology is very distinctive, and generally consists of extended twin radio lobes on either side of the galaxy. Long narrow radio features, which are known as radio jets, are often found to be connecting the nuclear region of the galaxy to the lobes, and at the centre a compact radio region is sometimes seen. There are many variations on this general theme. It is generally believed that the compact region is associated with *an active galactic nucleus* (AGN), which is the seat of the energy production. Some of the energy produced by the AGN is transported by the jets, in the form of relativistic charged particles, to the lobes. The radio emission is the synchrotron emission due to relativistic electrons spiraling in a magnetic field. Luminous radio sources are also found to be associated with quasars, but we shall not consider these in the following.

The host galaxies of luminous radio sources are almost always giant elliptical galaxies. The gross nature of the host galaxy depends on the radio morphology, which is of two broad types : (1) Fanaroff-Riley Type II (FR II) sources, in which the distance between the intensity maxima (hot spots) in the lobes is at least half as large as the overall size of the radio structure. These radio sources usually have 178 MHz radio luminosity $L(178) > 2 \times 10^{25}$ erg sec$^{-1}$ Hz$^{-1}$, and have radio jets which can be one-sided or two-sided. Such sources are associated with giant elliptical galaxies, which are not the brightest cluster galaxies (BCG). (2) Fanaroff-Riley Types I (FRI) sources, in which the distance between the intensity maxima is less than half the overall size of the radio source. These galaxies usually have $L(178) < 2 \times 10^{25}$ erg sec$^{-1}$ Hz$^{-1}$, and are associated with the brightest cluster galaxies.

It is not known why a small fraction of elliptical galaxies are associated with luminous radio sources, and it is possible that detailed study of their morphology in the optical and near infra-red band will provide some clues to the puzzle. A number of morphological and environmental studies of radio galaxies have been carried out in the past and a summary of the conclusions may be found in Heckman and Smith (1989). It was found that FRII galaxies more often showed large scale tidal features than FRI galaxies, while the latter more often had multiple nuclei, common envelopes and boxy isophotes. Of the two types, the FRI galaxies are less bright but bluer. In all these studies, no evidence of disk-like structure was found. On the basis of these observations, it may be speculated that if FR II hosts were formed from the merger of galaxies, then at least one of the merging galaxies was disky (because then gas would be available to produce the large scale structures observed). FR I galaxies, on the other hand, could be produced by the merger of two ellipticals.

We will describe below observations of the radio galaxy NGC 4261 (3C 270) and then of a sample of radio galaxies from the Molonglo Reference Catalogue (MRC).

### *2.1 NGC 4261*

On first sight this appears to be a featureless and uninteresting elliptical except that it has rather boxy isophotes. But this plain looking galaxy is host to the large and powerful FR II radio source 3C 270. Spectroscopic observations (Birkinshaw and Davies 1985) have shown that the galaxy rotates around an axis which is closely aligned with its apparent major-axis. This means that the galaxy cannot be an oblate spheroid. Isophotal analysis of the surface brightness distribution of the galaxy showed that the position angles of best fit elliptical fits to successive isophotes are closely aligned. Taken together with the spectroscopic observations, this implies that the galaxy is either prolate, or triaxial and nearly prolate.

Observations with the Hubble Space Telescope (Jaffe et al. 1993) showed that an arcsecond scale absorption disk is present at the centre of this galaxy. The axis of the disk appears to be rather well aligned with the axis of the radio source, as determined by its well-defined, large scale radio jets.

This galaxy was observed by Mahabal et at. (1996) using a CCD at the prime focus of the 2.3m Vainu Bappu telescope at Kavalur. A colour image in $V - R$ showed the presence of a well defined absorption structure, aligned close to the observed major axis. This can be interpreted to be a dust disk, with its axis inclined at ~ 75 deg to the line of sight. Assuming that the conditions in the galaxy are the same as in the Milky way (which may not be a reasonable assumption to make), it can be estimated that the neutral hydrogen mass in the disk is $M(H\,I) \simeq 1.7 \times 10^6\, M_\odot$. The orientation of the dust lane is schematically shown in Fig. 1.

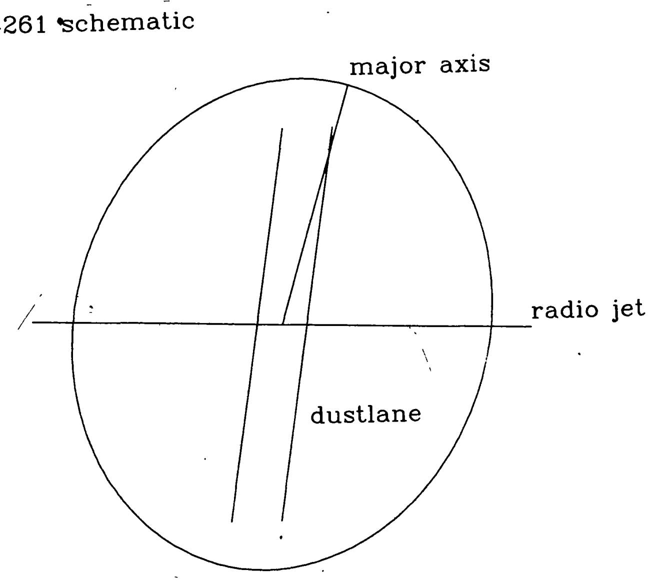


**Figure 1.** A schematic representation of the dust lane in NGC 4261.

It is found that the large scale and small scale (HST) disks are oriented more or less in the same direction. It can be imagined that the structure observed on the small scale is a warped inner part of the larger structure. The warping could happen because the shape of the galaxy in the inner region is different from the shape in the outer region, and also possibly due to the effects of a putative rotating black hole at the centre of the galaxy. The angular momentum of the disk, rather that of the galaxy as a whole, seems to determine the jet axis. The rotation of the galaxy does not have much effect on the radio morphology, because the time scale of energy transport, from the radio core to the lobes, is much shorter than the rotation time scale of the galaxy. It will be interesting to see whether dust disks, with their axis approximately oriented along the radio jet axis can be found as a rule in radio galaxies.

### *2.2. The MRC sample*

Mahabal et al. (1998) have observed a sample of 29 radio galaxies from the MRC. These have 178 MHz radio flux > 0.95 Jy and have redshifts < 0.3. The redshift upper limit was chosen so that relatively distant sources could be included, but the apparent size was still large enough for a detailed study of the surface brightness distribution at optical and near-IR wavelengths. The sample was observed in the B and R bands, and about half the galaxies were observed in the K band, using the 1m and 2.5m telescopes of the Carnegie observatory at Las Campanas in Chile. Details of the observations and analysis are being reported in a series of papers, and in an unpublished thesis (A. Mahabal 1997). We summarize a few important results below.

The isophotal analysis provides the distribution of surface brightness as a function of distance r from the centre along the major-axis. This surface brightness profile, in general, consists of contribution from a bulge and a disk, as well as from a possible point source, the AGN, at the centre. It is usual to represent the bulge component $I_b(r)$ by de Vaucouleurs' law, $I_b(r) \propto (r / r_b)^{-1/4}$, where $r_b$ is the scale length within which half the total light in the galaxy is contained. The disk intensity $I_d(r)$ is taken to fall off exponentially with $r$, the scale length being $r_d$. If radio galaxies are ellipticals, there should be no disk component present.

A fitting exercise, which minimizes a suitable defined reduced $\chi^2$ after allowing for the effects of seeing, showed that a de Vaucouleurs' law distribution by itself provided a good fit in several cases. On the other hand, in at least 5 cases it was found that a disk was present, with bulge-to-disk luminosity ratio exceeding 0.3. In one of these galaxies, the ratio of the bulge and disk scale lengths are such as to put the galaxy into the class of Sb galaxies. No spiral arms are evident in our data, and deeper exposures are required to examine whether these are present, or whether the disk like structure is just a formal fit to a complex morphology which is the result of a merger event in the past. We have shown in Fig. 2 one of the disky galaxies with complex morphology.

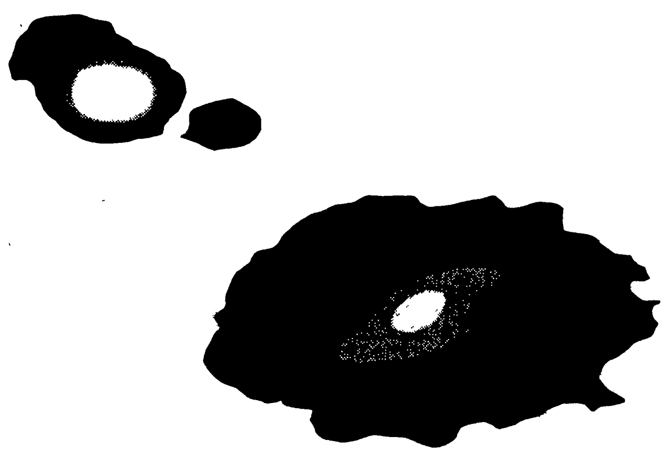

**Figure 2.** B band isophotal image of the radio galaxy 1222-252. Complex structure, normally not found in ellipticals, is seen.

Our analysis has shown that, in many cases, the bulge scale length in B is smaller than the bulge scale length in R, indicating that radio galaxies become bluer towards the centre. This is in contrast to the situation with normal ellipticals, which in general become redder towards the centre due to increasing metallicity. Careful analysis of the intensity profiles shows that the central colour contains excess blue light, as well as dust which causes reddening. A part of the blue emission could be due to the AGN, but is more likely to be from an extended region of emission, perhaps due to a starburst, in the central region of the galaxy. Dust disks are clearly seen in several galaxies from the sample in colour images, but it is not possible to observe their orientation relative to radio jets because of the poor quality of the radio maps available.

We have observed a few radio galaxies from the 3CR sample with the 1m Sampurnanand telescope, and these well studied objects are being compared in detail with the MRC galaxies.

## 3. The elliptical galaxy NGC 7562

This galaxy was observed in *V*, *R* and *I* filters with the Sampurnanand telescope by Sahu et al. (1996). Detailed surface photometric analysis has shown that isophotes of the galaxy have a boxy shape close to the centre, but become disky as one moves outwards. A $V - R$ colour image shows that there is a patch of dust in the central region. Since this absorbs some of the light from the galaxy, its effect is to move the portions of the isophotes, along the major axis, inwards, giving them a boxy appearance. Assuming dust properties are the same as in our galaxy, and using the observed colour excess $E\,(B{-}V)$, the mass of neutral hydrogen can be estimated to be $M\,(H\,I) \simeq 9 \times 10^6 M_\odot$. The dust is believed to be of external origin, and the dust, as well as the shells described below, are likely to be due to accretion of matter from the neighbouring galaxy NGC 7557.


**Figure 3.** Residual map of the galaxy NGC 7557. This is obtained by subtracting a smooth model of the galaxy from the image in the B band.

A residual image of the galaxy can be obtained by subtracting a smooth elliptical model of the galaxy from the corresponding observed image. The residual image shows faint structure which is ordinarily swamped by the smooth distribution of the light. The *B* band residual image of NGC 7562 (see Fig. 3) shows arc-like brightness enhancements, which appear as shells or ripples, in the outer regions of the galaxy. These shells are transverse to the major axis, and are responsible for producing the observed diskiness.

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