A study of major-axis dust-lane ellipticals

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Accepted 1988 April 21. Received 1988 April 19; in original form 1988 February 22

Summary. We present kinematical and photometric observations of four early-type galaxies with dust lanes along the major axes. They are Anon 1029–459, NGC 3528, 4370 and 5745. For Anon 1029–459 radio observations are also presented. All the systems but NGC 4370 show relatively high stellar rotational velocities similar to those observed in S0s. The dust lanes in Anon 1029–459 and NGC 5745 are warped, suggesting that they are relatively young. There are contradictory indications that these systems are elliptical galaxies. The class of major-axis dust-lane ellipticals is not yet so well defined as the class of minor-axis dust-lane galaxies.

1 Introduction

Bertola & Galletta (1978) pointed out the existence of a class of elliptical galaxies with dust lanes lying along their minor axes. The prototype of this class is the nearby elliptical NGC 5128 (Cen A) and the most prominent examples are NGC 1947, 5266, 5363 and 5485. The above authors suggested that the orientation of the dust lane indicates the intrinsic structure of such a galaxy, which is generally considered to result from the capture of a gas-rich system (Tubbs 1980; Simonson 1982) which has settled into a plane we see edge-on. The main evidence for the external origin of the gas is that its angular momentum is orthogonal to that of the stars (Sharples et al. 1983; Caldwell 1984; Bertola, Galletta & Zeilinger 1985; Wilkinson et al. 1986; Möllenhoff & Marenbach 1986; Varnas et al. 1987).

Subsequently Hawarden et al. (1981) published a catalogue of early-type (‘disc-less’) galaxies including ellipticals with dust lanes along their major axes. It is therefore important to establish whether these galaxies are physically the same objects as the minor-axis dust-lane ellipticals.

* Based on observations collected at the European Southern Observatory, La Silla, Chile.
† Supported by ‘Fonds zur Förderung der wissenschaftlichen Forschung’ Project Nr. P5529.
where the dust lane has been produced by acquisition. If this is the case, then the factors determining which of the two structures (dust lane along the major or minor axis) results are the impact angle (namely the angle between the initial orbital plane of the captured gas and one of the principal planes of the elliptical galaxy) and the intrinsic shape of the galaxy. Kotanyi & Ekers (1979) pointed out the tendency of the dust lane to align perpendicularly to the radio source, when present.

In this paper we present photometric and kinematical data for a sample of four galaxies with a dust lane along the major axis, namely Anon 1029–459, NGC 3528, 4370 and 5745. All of these galaxies appear in the list by Hawarden et al. (1981) and in the selected list by Bertola (1987). We compare their properties with those of minor-axis dust-lane ellipticals and of disc galaxies. For Anon 1029–459, VLA continuum radio observations are also reported.

2 Observations and data reductions

2.1 Spectroscopic observations

The galaxies have been observed with the B and C spectrographs at the Cassegrain foci of the ESO telescopes during different observing runs from 1982 to 1986. The 3.6-m and 1.52-m spectra were acquired by means of a three-stage image tube, while the 2.2-m spectra were recorded on a 320×512 RCA CCD. The photographic spectra, exposed on IIIa-J baked plates, were calibrated with the La Silla spot sensitometer. A list of the observations is given in Table 1.

Each system was observed by setting the slit along the dust lane and in some cases along the minor axis also (Table 1). The selected dispersions were 39 Å mm⁻¹ for the 3.6-m and 1.52-m telescopes and 59 Å mm⁻¹ for the 2.2-m ESO/MPI telescope, while the scales perpendicular to the dispersion were 38.5, 87 and 59 arcsec mm⁻¹, respectively. The wavelengths covered range from 3500 to 4500 Å for the image tube spectra and some CCD frames, and from 4900 to 5700 Å for the remaining CCD frames. Many absorption lines are present in the spectra, including Ca II and H and K. Unfortunately, no emission lines were detected. For this reason the velocity data for these galaxies are referred to the stellar component only.

For each night, at least two spectra of slowly rotating giant stars ranging from spectral type late G to early K were obtained with the same instrument, to be used as templates. All the plates were digitized using the Vienna Observatory PDS microdensitometer with a 12×50 μm² slit and further reduced using the IHAOSi software package at the ESO headquarters in Garching. The spectra were then calibrated in wavelength and intensity, and the sky subtracted using a mean spectrum 500 μm

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Major-axis dust-lane ellipticals

(=10 records) wide taken outside the galaxy image, usually near the upper or lower edge of the slit. A similar reduction procedure, including flat field and dark current corrections, has been carried out on the CCD spectra. Finally, the resulting images were analysed at the Padova Observatory by applying the Fourier Quotient technique (Bertola et al. 1984). Output parameters were the velocity dispersion $\sigma$ and the redshift for each record along the slit. The results are plotted in Fig. 1. When more spectra at the same position angle are available, as in the case of Anon 1029–459, the results are plotted together with different symbols. The error bars for the single measurements plotted in Fig. 1 come from the Fourier Quotient fit procedure. An idea of the true error can be obtained by comparing, for Anon 1029–459, measurements in different spectra.

The galaxy spectra obtained in the blue wavelength region were reduced twice using a wavelength interval including the $G$-band and excluding or including respectively the $H$ and $K$

![Graph](https://academic.oup.com/mnras/article-abstract/234/3/733/1002926)

**Figure 1.** Velocity dispersion profiles and rotation curves for the galaxies considered. Different symbols refer to different spectra.
Ca II lines. The second reduction improves the redshift determination, but impairs the velocity dispersion data (Kormendy & Illingworth 1982). Thus, for these galaxies, the rotation curves plotted in Fig. 1 come from the more extended wavelength range, while the velocity dispersion curves come from the restricted one. The CCD spectra were reduced using the range between 5100 and 5500 Å.

2.2 Photometric Observations

IIIa-J plates with GG385 filter plus triplet corrector were taken for NGC 4370 and Anon 1029–459 at the prime focus of the 3.9-m Anglo-Australian Telescope in order to study the luminosity profiles. The plates were scanned with the Vienna Observatory PDS and reduced with the ihap system. NGC 5745 was observed in V- and R- wavebands with the ESO 1.5-m Danish telescope using a 320×512 CCD. All of the images were intensity-calibrated and sky-subtracted.
Figure 2. (a) Luminosity profiles on each side of the nucleus rebinned every 0.1 units on an $r^{1/4}$ scale, and (b) ellipticity and position angle profiles for Anon 1029-459 and NGC 4370. Minor-axis profiles (open circles) are shifted by +2 mag, to avoid superposition with the major-axis ones (full circles). Error bars in the luminosity profiles represent rms errors of rebinned values. Errors on ellipticity and twisting have been estimated to be ±0.05 and ±4° respectively.
for the photometric study. The zero point has been set using, when available, the aperture photometry published by Sadler (1984) and Longo & de Vaucouleurs (1983). This is the case for Anon 1029−459 and NGC 4370, whose luminosity profiles are shown in Fig. 2, together with the ellipticity and position angle profiles. The effect of the dust lanes has been removed only from the ellipticity and PA profiles, and not from the luminosity profile. The luminosity profiles measured on each side of the nucleus were rebinned on an $r^{1/4}$ scale every 0.1 units. The error bars shown in Fig. 2 represent the rms error of the rebinned value. The errors on the ellipticity and PA values have been estimated to be $\pm 0.05$ and $\pm 4^\circ$ respectively, according to the estimate made by Bertola & Galletta (1979). For NGC 5745, no photoelectric data are available from the literature, since the magnitude and colour indexes listed by Longo & de Vaucouleurs (1983) and Tomov (1978) correspond to a galaxy with different coordinates (Tomov 1978). To compute the effective radius and total magnitude of NGC 5745, we assumed (from the ESO Manual) a mean sky surface brightness $\mu_V=21.9$. Effective radii and effective brightnesses for the galaxies studied are listed in Table 2.

Table 2. Photometric observations.

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<th>reff</th>
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<td>15$^\text{min}$</td>
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*For Anon 1029−459 and NGC 4370 the values of $m^{*}_{tot}$ are in B magnitudes while for NGC 5745 in V

2.3 Radio Observations

Anon 1029−459 was observed with the Very Large Array in 1982 in the A configuration. High-resolution maps were made at 1.4 and 4.9 GHz from 20-min snapshot observations. The data were calibrated, Fourier transformed and ‘cleaned’ using standard procedures. A lower-resolution observation was also made with the C-array at 4.9 GHz in order to verify that no large-scale structure was missed. The radio maps are shown in Plate 1 (a, b), superimposed on the optical image. The 4.9-GHz high-resolution map has a nearly circular synthesized beam of FWHP $2.4\times1.8$ arcsec$^2$ in PA=$15^\circ$, which results from Gaussian convolution of the original data. The rms noise is 0.19 mJy beam$^{-1}$. For the 1.4-GHz map, the HPBW is $8.1\times1.3$ arcsec$^2$ in PA=$-2^\circ$ and the rms noise is 0.25 mJy beam$^{-1}$. In both maps the source is unresolved perpendicular to its axis. Its width is <3 arcsec at 1.4 GHz and <1 arcsec at 4.9 GHz and it appears slightly longer at 1.4 GHz, indicating a possible steepening of the spectrum outwards.

3 Results

3.1 Anon 1029−459

The morphology of the stellar body of Anon 1029−459, apart from the presence of the dust lane, resembles that of an E3.5 galaxy. No trace of a luminous disc is present, even on the contrast-enhanced prints which reveal the outermost regions. The dust lane crosses the stellar body along the major axis and ends at $\sim0.5$ arcmin from the nucleus. The outer parts of the dust lane are warped, a phenomenon which is common for the minor-axis dust-lane ellipticals.

The luminosity profiles of Anon 1029−459, both along the major and minor axes, follow approximately an $r^{1/4}$ law. The total magnitude, obtained by integrating the observed flux and
extrapolating to its asymptotic value, is $B=12.7$ corresponding to an absolute magnitude of $M_B=-20.8$, assuming $H=50 \text{ km s}^{-1} \text{ Mpc}^{-1}$ and $cz=2468 \text{ km s}^{-1}$ (galactocentric, this paper). The ellipticity of the isophotes increases from 0.2 to 0.35 in the inner 20 arcsec (Fig. 2), then remains constant until 80 arcsec from the centre. The PA of the isophotal major axis increases outward from 155° to 165°.

In Fig. 1 the velocity curves from the absorption lines along the major and minor axes are plotted, together with the velocity dispersion profiles. No velocity gradient is present along the minor axis, while along the major axis the velocity reaches a value of $V_{\text{max}}=210\pm23 \text{ km s}^{-1}$ at 20 arcsec, where the rotation curve flattens off. The velocity dispersion profile along the major axis is peaked at $\sigma_0=260\pm16 \text{ km s}^{-1}$ and falls to values around 100 km s$^{-1}$ at 20 arcsec from the centre. The value of $V_{\text{max}}/\sigma_0 = 0.81 \pm 0.1$, which places Anon 1029–459 in the $V_{\text{max}}/\sigma_0$ versus ellipticity diagram on the line characteristic of oblate isotropic rotators, where S0 bulges and ellipticals fainter than $M_B=-20.5$ are located.

The radio source in Anon 1029–459 has an elongated shape with a size of about 20 arcsec in PA=80°. The source axis is nearly perpendicular to the dust lane. A weak compact nucleus with a size <1 arcsec is also present, with $S=1.4 \text{ mJy} \text{ at } 1.4 \Gamma \text{ and } 1.9 \text{ mJy at } 4.9 \Gamma$. The total flux densities of the source at these frequencies are 22 and 13 mJy respectively, giving a spectral index $\alpha=-0.4$. Assuming $H=50 \text{ km s}^{-1} \text{ Mpc}^{-1}$ we obtain a luminosity of the source of $1.2 \times 10^{21} \text{ W} \text{ Hz}^{-1}$, a quite low value that, coupled with the linear size of 1 kpc, makes it one of the smallest and weakest radio jet sources found. The jet-like structure is two-sided as is expected for low-luminosity radio galaxies (e.g. Bridle 1981).

Weak jet-like radio sources are commonly found in nearby giant elliptical galaxies (Ekers & Kotanyi 1978; Birkinshaw & Davies 1985). These sources show properties similar to those of powerful radio galaxies, and are presumably the same phenomenon. When a dust lane is present, the radio axis is usually perpendicular to it (Kotanyi & Ekers 1979). The radio structure in Anon 1029–459 hence has all the properties typical of a giant elliptical galaxy. The jet-like features have been seen also in some bright nearby spiral galaxies (Wilson 1981; Hummel, Kotanyi & van Gorkom 1983). These features are, however, often one-sided and show structural features which suggest that they are a phenomenon different from radio jets in powerful radio galaxies (Kotanyi, Hummel & van Gorkom 1983). High-resolution maps of the edge-on spiral galaxy NGC 3079 show that the features are of a bubble-like nature rather than connected continuously to the nucleus (Duric et al. 1983). The two-sidedness and the narrowness of the radio source in Anon 1029–459 make it unlikely to be of the same type as those seen in spirals.

Hence Anon 1029–459 shows properties similar to those of a giant elliptical galaxy with dust lane along the major axis, as in NGC 3665 (Kotanyi 1979). Radio jets are found in several other major-axis dust-lane galaxies, e.g. NGC 7052, which has orthogonal radio jets extending for about 70 kpc, well outside the optical galaxy (Kotanyi 1981); NGC 612 (=PKS 0131–36) with a double source of overall size 380 kpc (Ekers et al. 1978); and IC 5063=PKS 2048–57 (Danziger, Goss & Wellington 1981).

3.2 NGC 3528

This galaxy has been classed as a major-axis dust-lane galaxy by Hawarden et al. (1981), listing it erroneously under the name of NGC 3523. A picture (Ebneter & Balick 1985) shows it to have an apparently normal stellar body of approximate flattening 0.55, crossed by a ring-like dust lane. No photometric data are available in the literature.

The rotation curve along the galaxy major axis shows a velocity difference of about $240\pm29 \text{ km s}^{-1}$ between SW and NE sides. The velocity dispersion is constant around a value of $\sigma_0=270\pm35 \text{ km s}^{-1}$. In consequence, $V_{\text{max}}/\sigma_0$ is equal to 0.44\pm0.16, a low value for its flattening.
Plate 1. Radio maps superimposed on pictures of Anon 1029-459. (a) Radio map at 4.9 GHz. Contour levels are $-0.5, 0.5, 1.0, 1.5, 2.0$ and $2.5\text{ mJy beam}^{-1}$, (b) radio map at 1.4 GHz with contour levels as in (a).
Plate 2. Image of NGC 4370 from a prime-focus AAT plate.
Plate 3. CCD image of NGC 5745. The frame is a 20-min exposure.
3.3 NGC 4370

The stellar body of this galaxy resembles that of an E4 with box-shaped isophotes, a phenomenon common to other ellipticals (Lauer 1985; Jedrzejewski 1987). The dust lane lies exactly along the major axis at PA = 85° and extends approximately 1 arcmin (Plate 2). The absorption is stronger on the SW side.

The luminosity profile can be fitted, apart from the effects of the dust lane, by an r^{1/4} law. The total magnitude is B = 10.1 and the corresponding absolute magnitude is M_B = -20.5, assuming a distance of 13.0 Mpc derived from the recession velocity of 648 km s^{-1} (this paper).

The velocity curve along the major axis extends only 20 arcsec on each side of the nucleus, with a velocity difference between the two sides of ΔV = 120±23 km s^{-1}. The velocity dispersion profile is approximately constant in the inner 20 arcsec with σ_0 = 120±14 km s^{-1}. The value of V_{max}/σ_0 is therefore about 0.5±0.2. Unlike Anon 1029−459, NGC 4370 has a significantly lower V_{max}/σ_0 value with respect to that expected for oblate isotropic galaxies of the same flattening.

3.4 NGC 5745

This galaxy has been included among the dust-lane ellipticals by Hawarden et al. (1981) and described by Ebner & Balick (1985). Our CCD images show a stellar body resembling an E5 galaxy crossed by an irregular and warped dust lane along the major axis (Plate 3). In many respects the structure of NGC 5745 resembles that of Arp 156. A peculiarity of this galaxy is the presence, at 15 arcsec SW of the nucleus, of a diffuse structure with a diameter of about 5 arcsec, resembling a stellar aggregate. This structure appears on the edge of the dust lane and is partially obscured. Several faint extensions of the galaxy appear on the deeper CCD image, two of these joining the galaxy with a bright stellar-like object about 1.6 arcmin SW. These irregularities do not allow a more detailed photometric analysis than the determination of a total V magnitude of 14.0, as listed in Table 2. Pictures of this galaxy have been published also by Ebner & Balick (1985).

The rotation curve of NGC 5745 along the major axis is shown in Fig. 1. It reveals a rigid rotation within 5 arcsec of the centre, with an indication of turning points at the extreme sides and a velocity difference ΔV = 440±40 km s^{-1}. Little information is furnished by the spectrum along the minor axis. The velocity dispersion is approximately constant with a value of 160±39 km s^{-1} and produces a V_{max}/σ_0 of 1.38±0.42. Taking a mean flattening of ≈0.47, V_{max}/σ_0 is similar to that of a typical disc galaxy.

4 Discussion

The relative frequency of major- to minor-axis dust-lane ellipticals has deep implications for the distribution of the true shapes of these galaxies. In the catalogue of Hawarden et al. (1981), ellipticals with dust lanes along the minor axes constitute the largest group (12 systems). Ellipticals with dust lanes along the major axes constitute a group of similar importance (12 systems) but with a large fraction (six objects) of uncertain cases. The main reason for uncertainty lies in the difficulty of establishing the presence or not of a luminous disc, which is the discriminating feature between E and S0 or early-type spiral galaxies. The number of systems with major and minor axis dust lanes has increased to 34 and 27 respectively in the recent compilation by Ebner & Balick (1985). However, in the case of Hawarden et al. (1981) the catalogue of objects came from a systematic survey of the PSS and ESO atlas, whereas the list by Ebner & Balick (1985) is a compilation of data from the literature and includes some objects, like NGC 2685, which are clearly not related with dust-lane ellipticals. A careful morphological analysis of objects in the
Ebneter & Balick list has led to a new compilation (Bertola 1987) which excludes many cases of major-axis dust-lane ellipticals which turned out to be S0s. In this compilation there are 30 minor-axis dust-lane ellipticals against nine major-axis ones, plus seven cases with a skew lane.

From these considerations it seems that the relative number of major-axis dust-lane ellipticals is much lower than that of the minor-axis ones. This puts strong constraints on the distribution function \( f(b/a, c/a) \) of the intrinsic flattening of these galaxies. The results indicate, for the intrinsic shape of the galaxies of this sample, a tendency toward triaxial configurations closer to prolate than oblate (Bertola, Galletta & Vietri, in preparation).

It is therefore very important to recognize a galaxy as a dust-lane elliptical, especially when the dust lane is along the major axis. Indeed, while the assignment of a galaxy to the class of ellipticals with dust lane along the minor axis presents no particular problems, the contamination by disc galaxies of a sample of elliptical galaxies with major-axis dust lanes could be significant. From the morphological point of view, the presence of a disc in an edge-on system is not always easily detectable on a single exposure. For instance, a normal exposure of NGC 3115 in the Hubble Atlas (Sandage 1961) nicely reveals the disc structure, while in the deep exposure (Illingworth & Schechter 1982) the bulge component becomes predominant and the image is very similar to that of a flattened elliptical. On the other hand, a normal exposure of the S0 galaxy NGC 7814 (Kormendy & Illingworth 1982) shows a system which is morphologically similar to the galaxies of our sample and the luminous disc appears only on the deep POSS image.

Examining the galaxies studied in this paper, both from large-scale images and/or from POSS and ESO/SRC atlas reproductions, we are not able to detect the presence of any luminous disc, but, for the above reasons, we cannot rule out the possibility that they are nevertheless disc galaxies.

Another approach to establish the nature of these galaxies is based on a study of their kinematical properties. Bertola & Capaccioli (1978) pointed out the dichotomy between the rotational velocities of ellipticals and S0 galaxies. A comparison of the rotational velocities of edge-on S0s from Dressler & Sandage (1983) and those of elliptical galaxies from Davies et al. (1983) shows that the maximum rotational velocities of elliptical galaxies do not exceed 100–120 km s\(^{-1}\), irrespectively of their viewing angles, while the S0 galaxies have rotational velocities ranging from \( \approx 100 \) to 300 km s\(^{-1}\).

Among the four galaxies studied here, all but NGC 3528 and 4370 have rotational velocities well over 120 km s\(^{-1}\) and therefore tend to share the properties of S0s. The fact that we are not integrating along the line-of-sight because of the dust, tends to produce smaller rotational velocities. Thus, kinematical criteria rule out classification as ellipticals of at least two of the four galaxies. It should be mentioned that, prior to our study, only three candidate major-axis dust-lane objects, namely NGC 612 (Goss et al. 1980), NGC 5626 (Sharples et al. 1983) and IC 5063 (Appenzeller & Gaida 1981; Caldwell & Phillips 1981; Danziger et al. 1981; Bergeron, Durret & Boksenberg 1983) were investigated, but these objects are not present in the list by Bertola (1987) and show kinematical properties common to disc galaxies.

The problem of the nature of the major-axis dust-lane galaxies could be solved if we were able to establish whether the dust lane is a coeval component or a second event in the history of these objects. The latter is the case for the minor-axis dust-lane ellipticals, where the perpendicularity of the angular momentum vectors of the stellar and gaseous components suggests that the dust lane is the result of acquisition. This phenomenon can be examined in major-axis dust-lane ellipticals in a statistical way. If the gas (and dust) enters from outside in a triaxial or in an oblate elliptical, its angular momentum, after settling, could be either parallel or antiparallel to that of the stars (in our sample and in other cases, the stellar rotation always occurs around the apparent minor axis). We then expect to find the gas rotating with the stars in 50 per cent of the cases and counter-rotating in the remaining cases. Only one case of counter-rotation in dust-lane ellipti-
cals has been so far detected, in NGC 5898 (Bertola & Bettoni 1988), confirming the external origin of the dust lane. However, due to the circular isophotes of this galaxy, it is impossible to assign it either as a major- or minor-axis dust-lane elliptical. Unfortunately, in none of the galaxies studied in this paper was emission lines detected.

A second phenomenon suggesting acquisition is the presence of warps at the end of the dust lane, indicating that the material has not yet settled. In this case the dust lane in Anon 1029–459 could be an example of acquisition. However, warps are present also in the luminous discs of spirals (see e.g. NGC 4565, Bertola & di Tullio 1976) and are certainly due to a different mechanism. It is worth mentioning at this point that the disc galaxy NGC 5866 (Sandage 1961) possesses, in addition to a luminous disc, a tilted and warped dust lane which closely resembles that of Anon 1029–459. Is the origin of the dust lanes the same?

A third line of evidence of acquisition is represented by the presence of luminous shells around elliptical galaxies (Quinn 1982). This is the case for NGC 5128 and IC 1575, where shells and dust lanes are present. If these features are produced by the same event, then the presence of shells in our sample would argue in favour of acquired dust lanes. But no such shells were detected.

It is clear from this discussion that there is contradictory evidence whether or not the systems with dust lanes along their major axes studied here are elliptical galaxies. At this point one wonders whether, apart from the morphological similarities, the major- and minor-axis dust-lane elliptical share the same physical nature, on the basis of our present knowledge.

Acknowledgments

We thank the AAT PF service photography for taking the plates of Anon 1029–459 and NGC 4370. CK would like to thank R. Laing and E. Hummel for help with the radio observations.

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F. Bertola et al.