Astron. Astrophys. 81, 179–181 (1980)

ASTRONOMY AND ASTROPHYSICS

A Correlation Between Isophotal Twisting and Flattening in Elliptical Galaxies

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Received October 27, 1978; revised March 5, 1979

Summary. Twisting of the isophotes in elliptical galaxies is found to be present in about 7.5% of the systems for which photometric data are available in the literature. It is found that a reverse correlation exists between the maximum apparent flattening and the greatest observed twisting in the isophotes of 54 elliptical galaxies. From a discussion of the data, it is suggested that this correlation can provide useful information on the spatial structure of these galaxies. Some geometrical interpretations are explored.

Key words: galaxies-photometry – galaxies-structure

I. Introduction

The presence of a systematic twisting of the isophotes in some elliptical galaxies, pointed out by Barbon et al. (1976), has been recently confirmed by several authors (Barbon et al., 1979; Bertola and Galletta, 1979; King, 1978; Strom and Strom, 1978a, b, c; Williams and Schwarzschild, 1978). Measurements have an accuracy ranging from $\pm 1.2°$ to $\pm 5°$. This property reflects the spatial structure of these systems, and it can be the the result of a complex geometry (e.g. the presence of bars, disks, triaxiality), or some kind of spatial distortion (e.g. warping of the equatorial plane, etc.). It is suggested here that the analysis of the ellipticity and orientation profile can provide useful information on the structure, and it is found that a correlation exists between the maximum observed flattening and the greatest variation in the position angles for each elliptical galaxy. Some interpretations of this correlation are attempted in the framework of recent views of the structure of the elliptical galaxies.

II. Data and Results

Twisting of the isophotes in elliptical galaxies, detected by Evans in 1951, was first measured for the Virgo Cluster galaxies by Liller (1960, 1966) using isophotal tracings. In recent years, the numerical mapping technique developed was applied in different ways to a number of galaxies in groups and clusters (Barbon et al. 1976, 1979; Benacchio, 1975; Carter 1978; King, 1978; Strom and Strom, 1978a, b, c; Williams and Schwarzschild, 1979) with an accuracy ranging from $\pm 1.2°$ to $\pm 5°$.

From the large number of systems studied in the literature with available data on ellipticity and orientation profiles, we select in Table 1 all the elliptical galaxies showing a measurable twisting in their isophotes. As a first consideration, we note that despite the fact that we are faced with a very large sample of ellipticals studied, we have only 54 galaxies with measured variation in the position angle of the major axis. For instance, in the Strom sample (357 galaxies) only 7.5% of systems show variations greater than 10°. It is interesting also to note that in Abell 1367, a relatively dense, spiral-rich cluster (Strom and Strom, 1978b) no elliptical galaxy shows variations in the isophotes orientation greater than 10°.

For the stellar systems listed in Table 1, showing different axial ratios and with no visible fundamental plane, the flatter isophotes set a lower limit for the inclination of the minor axis with respect to the line of sight. For this reason, we have listed for each galaxy in Table 1 only the maximum value of ellipticity $\varepsilon = 1 - b/a$ and the greatest difference $\Delta\theta$ in the position angle of the isophotes. A plot of these values (Fig. 1) shows that a correlation exists, in the sense that the greatest variations are observed in less flat systems, and there are no galaxies having large twisting ($\Delta\theta \geqq 40°$) flatter than E4. We want to emphasize that this correlation is not found in SB 0 systems, where the bar can cause a large twisting of the isophotes even when the galaxy is seen almost on edge. For instance, the S0 systems IC 3998 and RB 113 in the Coma cluster (Strom and Strom, 1978a) show respectively a twisting of 51° and 44° in structures of maximum apparent ellipticity 0.68 and 0.74. We omitted the plot of the ellipticity values for the 92% of the galaxies with $\Delta\theta < 10°$, which are strongly subject to measurement errors and whose representative points, because of the large variety of ellipticity observed, probably fill more or less uniformly the hatched strip. For completeness only, the representative points of NGC 4697 (Williams and Schwarzschild, 1979, with $\Delta\theta = 7.3° \pm 1.2°$) and the seven Liller galaxies (1960, 1966) with $0° < \Delta\theta < 10°$ are plotted in the hatched strip.

III. Discussion

Measurements of ellipticity and position angles of the isophotes have in general larger errors in the rounder isophotes, producing an effect similar to that observed in Fig. 1. Application of the numerical mapping technique (Barbon et al. 1979; King, 1978; Strom and Strom, 1978a, b, c; Williams and Schwarzschild, 1979) can improve the measurements, reducing the noise caused by background fluctuations, stars and emulsion defects.

In order to discuss the reality of the observed twisting, we analyse the ellipticity and orientation profiles for the galaxies of Strom sample. We find that:

Table 1. Ellipticity and twisting for the considered sample of elliptical galaxies

Identification	ε_{max}	$\Delta\theta$	Ref.	Notes
NGC 205	0.51	20°	7	Local Group
NGC 221	0.26	14	7	
NGC 1274	0.46	18	9	Perseus Cluster
NGC 1282	0.29	20	9	
CR 16	0.38	29	9	
CR 32	0.22	63	9	
Per 104	0.28	14	9	
NCC 3379	0.21	17	1	M 96 Group
IC 2744	0.17	45	10	A1228 Cluster
A 1228-4	0.31	36	10	
A 1228-22	0.25	15	10	
NGC 4270+	0.59	3	5	Virgo Cluster
NGC 4342	0.54	4	5	
NGC 4343	0.70	4	5	
NGC 4360+	0.17	18	5	
NGC 4374	0.17	14	6	
NGC 4406	0.40	5	4	
NGC 4434+	0.09	16	5	
NGC 4459	0.20	12	4	
NGC 4472	0.22 (0.21)	11 (6°)	6 (4)	
NGC 4473+	0.46	2	4	
NGC 4486	0.42	39	2	
NGC 4503	0.63	7	4	
NGC 4526	0.68	5	4	
NGC 4589	0.27	28	6	
NGC 4649	0.23	19	6	
NGC 4697	0.46	7.3	11	Virgo Y Group
NGC 4816+	0.25	31	8	Coma Cluster
W 1	0.24	42	8	
W 4	0.29	31	8	
W 13	0.30	72	8	
W 23+	0.20	51	8	
W 25	0.27	24	8	
FW 4+	0.19	90	8	
NGC 6043	0.30	59	10	Hercules Cluster
NGC 6047+	0.26	58	10	
NGC 6056	0.49	20	10	
IC 1176+	0.29	40	10	
IC 1194A	0.26	68	10	
Her 23	0.29	34	10	
NGC 6173	0.49	19	3	A 2197-99 Cluster
NGC 6146	0.38	24	3	
NGC 6159	0.43	14	3	
Zw 224-27	0.24 (0.25)	16 (10°)	3 (10)	
A 2199-7	0.35	36	10	
A 2199-8	0.56	20	10	
A 2199-14	0.21	30	10	
A 2199-15+	0.29	59	10	
A 2199-16	0.22	90	10	
A 2199-17	0.30 (0.31)	14 (46°)	10 (3)	
A 2199-45	0.30	43	10	
A 2199-60+	0.35	44	10	
IC 1459	0.27	11.4	11	
NGC 7626	0.18	70	6	Pegasus I Cluster

References :
1 Barbon et al. (1976)
2 Bertola and Galletta (1979)
3 Carter (1978)
4 Liller (1960)
5 Liller (1966)
6 King (1978)
7 Richter and Hogner (1973)
8 Strom and Strom (1978a) - U plate
9 Strom and Strom (1978b) - U plate
10 Strom and Strom 1978c) - U plate
11 Williams and Schwarzchild (1978)

+ galaxies with luminosity profile E/S0.

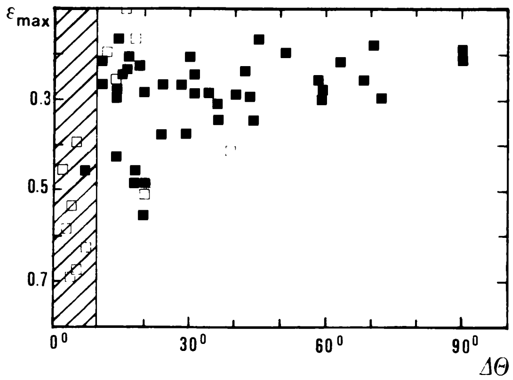

Fig. 1. Plot of the maximum value of ellipticity versus the maximum twisting observed for 54 elliptical galaxies. The hatched strip represents the regions where observed variations are uncertain because of measurement errors. Values plotted with full symbols are derived from numerical mapping studies

i) In most cases the variations of the position angles are systematic. We discarded all the systems with very irregular variations. This should exclude variations due to small-scale fluctuation of sky background and foreground stars.

ii) Variations in position angles observed are typical not only of external regions but also of the inner ones, i.e. they are present at bright levels also ($\leqq 24$ mag arc s^{-2}) where the sky fluctuations are less important.

iii) It is necessary to reject all the cases in which the greatest variations are found in isophotes rounder than $\varepsilon = 0.1$, in order not to degrade the sample with objects for which measurements error is large. For instance, in IC 1194A in the Hercules cluster we reject the rounder isophotes, reducing from 90° to 68° the observed twisting.

iv) The observed variation $\Delta\theta$ is always larger than the estimated error and is also present in the flatter isophotes.

The above considerations also hold for the other studies where the numerical mapping method was used. For the Liller galaxies we cannot estimate the measurement errors, and these systems are considered for completeness only. Therefore, we can conclude that the observed twisting is probably a real effect, as suggested by Barbon et al. (1979), Bertola and Galletta (1979), King (1978), Strom and Strom (1978a, b, c), and Williams and Schwarzschild (1979). The observed correlation shown in Fig. 1 can be assumed to be a real consequence of the structure of elliptical galaxies.

IV. Interpretations

Assuming that an elliptical galaxy can be represented by almost homocentric isodensity shells of ellipsoidal shape, it is possible to define for each shell a fundamental plane perpendicular to the minor-axis. For a reference plane we assume the plane of the inner isodensity shell, corresponding to the first measured isophote. The observed change of the position angles of the major axes of the isophotes with increasing radius can then be analysed in terms of some simple spatial configurations:

1. Ellipticals are oblate spheroids with fundamental planes spatially oriented in different directions. Warping of the equatorial plane of the whole galaxy exhibits strong asymmetry even if seen almost "on edge".

2. Ellipticals are elongated (triaxial or prolate) ellipsoids with the same alignment for the minor axis of each isodensity shell and with the major axes differently oriented along a common fundamental plane. This configuration is similar to that suggested by Williams and Schwarzschild (1979). Asymmetry is greater when seen face-on and absent when the line-of-sight lies in the equatorial plane.

The above models represent only geometrical configurations and do not imply any relationship between rotation and flattening. Of course, we assume that the luminosity distribution is directly related to the geometrical structure of the system.

3. Binney (1978) shows that in the case of triaxial isodensity surfaces, the position angle of the apparent major axis is a function of the angles that the line-of-sight makes with the principal axes and of the intrinsic axial ratios. Twisting of the isophotes in this case could be observed also in a symmetric galaxy having different axial ratios.

4. Barbon et al. (1976) and Strom and Strom (1978a) suggest that, at the present time, it is very difficult to be sure that elliptical galaxies do not possess a small disk of stars. If the disk has an axial misalignment with respect to the more prominent spheroidal component, as observed for the bulge of M31 (Lindblad, 1956; Stark, 1977), the result is an isophotal twisting as observed in ellipticals (Capaccioli, private communication).

Figure 1 seems to exlude the possibility that the galaxies have an oblate shape, and to suggest that a configuration like that of Case 2 is more probable. We cannot exclude more complex interpretations 3 and 4. The one-component, oblate configuration can be excluded, and appears to be a symmetry plane along which the major axes of the elongated isodensity shells are aligned. Studies of a greater number of galaxies will be requested to confirm this proposed picture.

Acknowledgements. The author is grateful to F. Bertola and M. Capaccioli for very helpful discussions and criticisms.

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