6. ANGULAR MOMENTA OF LATE-TYPE SPIRAL GALAXIES

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Abstract. The angular momenta of galaxies may be evaluated from their photometry. The mass to light ratio in NGC 224 is discussed and the calculation is applied to two late-type spirals.

1. Introduction

In a previous study an attempt was made towards the investigation of specific angular momenta of spirals by the use of *indicative* specific angular momenta defined by

$$A_i = 0.10 a V_m \tag{1}$$

where A_i is in kpc km s^{-1}, a is the 26.5 m_{pg} per square arcsec photometric diameter in kpc and V_m the maximum rotational velocity in km sec^{-1} (Heidmann, 1969). The largest A_i values are obtained mostly for the Sbc type, suggesting that there may be a relation between the angular momentum and the degree of development of spiral arms.

However other factors may be of importance and the relation between indicative specific angular momentum A_i and real specific angular momentum A has first to be closely investigated.

The evaluation of the angular momentum of a galaxy from the rotation curve is very sensitive to its shape after the turnover point. If r_m is the turnover radius and V_m the maximum rotational velocity, the specific angular momentum for a flat disk is:

$$A = k r_m V_m \tag{2}$$

where k is a coefficient dependent on the shape of the rotation curve $V(r)$. For example, Toomre's (1963) calculations show that in two cases in which $V(2r_m) = 0.9 V_m$ or $0.7 V_m$, k differs by a factor 4. Similar results are obtained from Takase and Kinoshita's (1967) calculations.

As it is difficult to measure radial velocities after the turnover radius, we attempt to derive angular momenta from photometric profiles. With values of the mass to luminosity ratio, the brightness distribution gives the density distribution, which in turn gives the potential, then the force, the velocity and the angular momentum.

With respect to the axis of cylindrical coordinates (r, θ, z), the specific angular momentum of a galaxy is:

$$A = \frac{1}{M_T} \sum_{\text{particles}} r \Theta m, \tag{3}$$

where M_T is the total mass, Θ the tangential velocity and m the mass of a particle.

A first summation on the particles in a small volume element changes Θ into V_0, the centroid velocity. For a stationary system with rotational symmetry, Jeans' (1922) equations may be used. The calculation is quite easy in case the galaxy is flat enough to assume that:

(i) the velocity dispersions are negligeable,

(ii) the circular velocity $V_c(r, z)$ is nearly independent of z inside the system.

If the system has an equatorial plane of symmetry, the momentum is then:

$$A = \frac{4\pi}{M_T} \int_0^\infty r^{5/2} [K_r(r, 0)]^{1/2} \int_0^\infty \varrho(r, z) \, dz \, dr, \tag{4}$$

where $K_r(r, 0)$ is the radial force in the equatorial plane and ϱ the density. Usually the main contribution to A will arise from intermediate r values, so that the two above assumptions have to be fulfilled especially for these r values. Formula (4) will be applied to late type spirals.

2. Photometric Profiles

De Vaucouleurs (1962) has shown that the photometric profile of elliptical galaxies follows a '$r^{1/4}$' law and that the profile of late-type spirals follows an exponential law. He has also shown (1958) that the profile of an intermediate type spiral such as NGC 224 can be represented by the sum of a '$r^{1/4}$' profile due to the bulge (spheroidal component) and an exponential profile due to the disk (flat component). We may assume that in a first approximation the profile of a galaxy may be represented by the sum of two such profiles.

3. Mass to Luminosity Ratio

The global mass to luminosity ratio for ellipticals is 20 (Holmberg, 1964) and for late type spirals it is 4 (Heidmann, 1969); here the luminosities are corrected for absorption according to Holmberg (1964).

The mass to luminosity ratio $f(r)$ at various distances r from the center of a galaxy has been worked out for the Large Magellanic Cloud by De Vaucouleurs (1960) using two Perek spheroids. It is constant for $r > 2°$; for $r < 2°$ it is smaller and decreases by two thirds for $r = 0$ according to this method; however, in this analysis, there was no rotation observation available for $r < 1.5°$. It seems that for this galaxy, made up practically of a flat component, $f(r)$ can be taken to be a constant in most of the object.

The value of $f(r)$ has also been given by Gottesman et al. (1966) for NGC 224 using a Brandt curve (Brandt and Scheer, 1965) with index $\frac{3}{2}$ to fit their 21-cm observations. It is reproduced in Figure 1. In a dynamical study of the central parts of NGC 224 up to $r = 10'$, Kinman (1965) obtained $f \sim 50$. When comparing his rotation curves with the one observed by Lallemand et al. (1960), we obtain $f = 25$. These values are plotted in Figure 1.

Though the quasistellar nucleus of NGC 224 might play a special role, Kinman's values suggest that f is indeed large in the central parts of NGC 224, as for elliptical galaxies. It is possible that the $f(r)$ values of Gottesman *et al.* in the central regions are smaller because Brandt's formalism is not valid for a mass distribution with large axis ratios and the radiotelescope beam has the effect to lower the slope of the rotation curve.
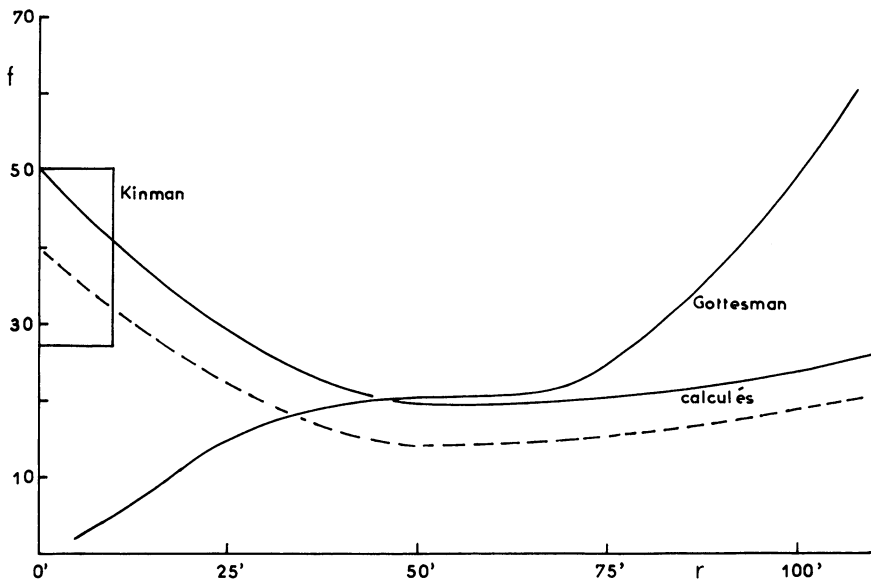

Fig. 1. Mass to luminosity ratio f, in solar units, vs. the distance from the center r in arc min for NGC 224. The values from Gottesman *et al.* and from Kinman are plotted. The lines *calculés* are calculated for $f_s = 50$, $f_t = 15$ (full line) and for $f_s = 40$, $f_t = 10$ (broken line).

Using the two profiles given by De Vaucouleurs (1958) for the spheroidal and for the flat components of NGC 224 with the f values $f_s = 50$ and $f_f = 15$ for each component respectively, we obtain the $f(r)$ full line curve labelled *calculés* in Figure 1. Note that the f values here are not corrected for absorption. For a total absorption of 1 magnitude, assumed to be the same for the bulge and for the disk (cf. De Vaucouleurs 1958 for discussion), the corrected values would be 20 and 6. The broken line is for $f_s = 40$ and $f_f = 10$.

The agreement with Kinman's values for small r and with Gottesman's values for intermediate r is satisfactory. For large r, Gottesman's values are larger by about a factor 2. This may be due to an overestimation of the surface density as it appears from comparison with the two best solutions which Roberts (1966) obtained from his observations. Figure 2 is a plot of the surface density $\sigma(r)$ and shows that Roberts' values are 2 or 4 times smaller than Gottesman's in the region 70–110′ (and are larger for small r values). This difference may be due to beamwidth and to bandwidth effects and to the fact that Gottesman *et al.* use mean velocities while Roberts uses corrected

peak velocities which are closer to rotational velocities. Roberts' values for a Brandt curve with index $\frac{3}{2}$ are in agreement with the $f(r)$ curve calculated with the hypothesis of constant values for f_s and f_f.

It may then be assumed that the mass to luminosity ratio f of each of the spheroidal and flat components of a galaxy is the same at all point of each component.
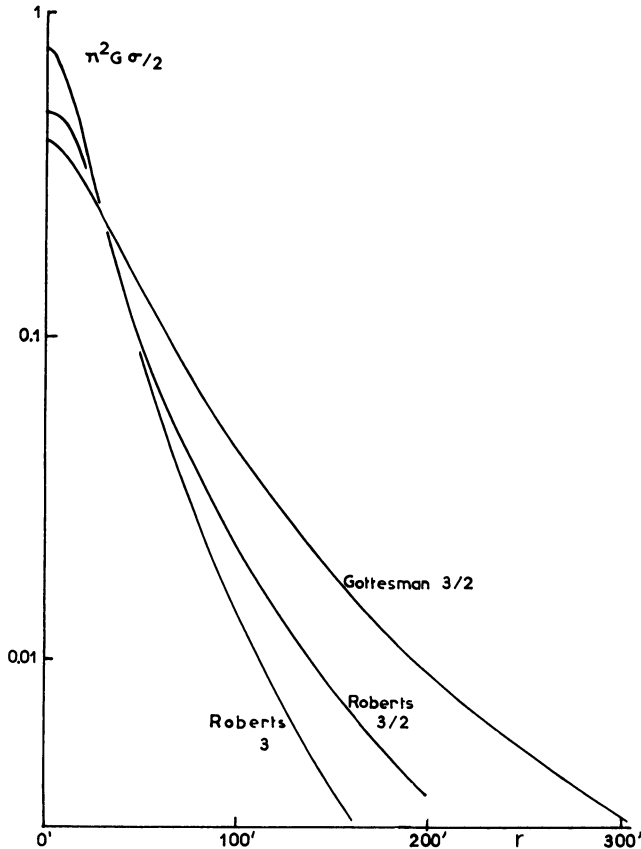

Fig. 2.   Surface density σ times $\pi^2 G/2$, in 10^7 cgs units, for NGC 224 vs. the distance from the center r in arcmin. The curves are from Gottesman *et al.* and from Roberts with the indicated Brandt indices.

4. Momentum of Late Type Spirals

The specific angular momentum of late type spirals is the easiest to evaluate by the photometric method. There is only a flat component and Equation (4) may be used. Integration along z introduces the surface density, which is exponential since f is constant inside the component and the brightness is exponential. The calculation of K_r has been explicitly made in this case by Wyse and Mayall (1942). Using it, the

specific angular momentum in kpc km s^{-1} is:

$$A = 0.325 (D^3 R^3 f (b/a) I_0)^{1/2} \tag{5}$$

where D is the distance in Mpc, f the mass to luminosity ratio in solar units corrected for absorption, b/a the axis ratio, I_0 the central brightness corrected for absorption in units of 25 magnitude per square arcsec and R the distance in arcmin at which the brightness has fallen to the value $I_0 e^{-4}$.

This calculation is applied to two late type spirals for which photometric profiles follow the exponential law: NGC 300 and LMC. The profiles are corrected for absorption in our Galaxy (Δm_g) and for internal absorption (Δm_i) according to Holmberg (1964); B magnitudes are reduced to the pg system by subtracting 0.1. Values and references are given in Table I.

TABLE I

Data for galaxies for which the angular momentum A is evaluated from the photometry

	NGC 300	LMC	Units
type	Sd (d)	Sm (d)	
I_0 obs.	21.7 (a)	21.5 (b)	m_{pg} arcsec^{-2}
R	13 (a)	370 (b)	arcmin
Δm_g	0.2 (a)	0.4 (b)	m_{pg}
Δm_i	0.3 (c)	0.3 (c)	m_{pg}
I_0 corr.	33	48	25 m_{pg} arcsec^{-2}
b/a	0.70 (d)	0.89 (b)	
D	2.5 (e)	0.048 (f)	Mpc
A	580	320	kpc km s^{-1}
A_i	340	170	kpc km s^{-1}

(a) G. de Vaucouleurs and Page (1962); (b) G. de Vaucouleurs (1960); (c) Holmberg (1964); (d) G. and A. de Vaucouleurs (1964); (e) Bottinelli *et al.* (1968); (f) Sandage (1962).

We hope to extend to more late type and to other type galaxies the calculation of momenta using the photometric data. The case of the intermediate types Sc-Scd might be difficult to handle because a small spheroidal component may exist which barely affects the luminosity profile but which may give an important contribution to the density. For example, NGC 598 has a small spheroidal component with diameter about 4′ (De Vaucouleurs, private communication) of which the photometry has not yet been done and which is probably responsible of the parabolic shape of the central part of the rotation curve obtained by Courtès' group (Baudel, private communication). The spatial flatness of the galaxy allows use of Equation (4) but the decomposition into two components may be difficult.

For comparison, the indicative specific angular momenta A_i are also listed in the Table I. A further comparison for an earlier type spiral is obtained from data for our

Galaxy. Integration of the momentum distributions of Innanen's (1966) models yields $A = 900$–1300 kpc km s^{-1}; Kinman's (1959) study of globular clusters gives $A = 800$ kpc km s^{-1}. To obtain the indicative specific momentum the photometric diameter of our Galaxy may be estimated from the neutral hydrogen diameter through a statistical relation found by Bottinelli (private communication) between type and hydrogen diameter to photometric diameter ratio: $a \sim 40$ kpc. With $V_m = 260$ km s^{-1} (Kerr, private communication), the indicative momentum is $A_i \sim 1040$ kpc km s^{-1}, which is also close to A.

Acknowledgements

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