J. Astrophys. Astr. (1983) **4,** 205–213

The Dependence of Brightness Distribution on the Inclination of Galaxies

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Received 1983 July 17; accepted 1983 August 31

Abstract. A sample of 92 galaxies with published surface photometric data in B band and inclined randomly to the line of sight is selected and used to compute the photometric parameter Q_N. The dependence of Q_N on the apparent flattening q is found and discussed for different morphological groups. Q_N is more sensitive to q in earlier-type galaxies.

Key words: galaxies, brightness distribution

1. Introduction

Since the seventies, the systematic work on surface photometry of galaxies has grown considerably, thanks mainly to new facilities available for observation, measurement, and reduction of plates. The valuable information stored this way (see *e.g.* Davoust & Pence 1982) allows the study of collective photometric properties of galaxies from several points of view. In this paper we use it to verify the possible dependence of the photometric parameter Q_N on the inclination of the galaxies and to establish its explicit form, as well as its dependence "on the morphological type in case such dependence exists.

The technique of surface photometric reductions developed at Córdoba has been described by Sérsic (1968,1982). The parameter Q_N is empirically obtained for a galaxy as the ratio of its total luminosity (L_T) and the maximum value reached by the product $(IS)_N$as a function of the isophotal magnitude *m, i.e.,* $Q_N = L_T/(IS)_N$. Here I = dex (– 0.4 m) and S = the area within the isophote of magnitude m. If the functional form of S can be expressed as $S = K(m - m_0)^N$— where K and N are constants and m_0 the central surface brightness—it can be shown that Q_N is a function of only N (Sérsic 1982).

Since Q_N is closely related to the observed surface brightness distribution in a galaxy, it is natural to expect its dependence on the inclination of the galaxy, which may, in part be responsible for the dispersion appearing in the correlation between Q_N and the morphological type (T_M) already found by one of us.

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Table 1. Sample of galaxies.

No. (1)	NGC (2)	RMT (3)	L_c (4)	T (5)	q (6)	$m_T(B)$ (7)	Q_N (8)	Reference (9)
S0 galaxies								
1	1023	SB(rs)0^-	...	−3	.38	10.40	5.21	BC 75a
2	1316	(P)SBA(s)0p	...	−2	.78	9.56	4.83	Se 68
3	1533	SB0^-	...	−3	.87	11.32	4.83	Se 68
4	1543	(R)SB(s)0	...	−2	.55	11.59	3.91	Se 68
5	1553	SA(r)0	...	−2	.68	9.78	4.97	Se 68
6	1947	S0^- p	...	−3	.87	11.50	5.35	Se 68
7	3384	SB(s)0^-*	...	−3	.45	10.87	5.37	BCT 75
8	4036	S0^-*	...	−3	.46	11.63	4.74	BBC 78
9	4111	SA(r)0^+*	...	−1	.23	11.67	5.30	T 80
10	4267	SB(s)$0^-$$	...	−3	.93	11.82	6.33	F 77
11	4340	SB(r)0^+	...	−1	.79	11.95	5.45	F 77
12	4382	SA(s)0^+ p	...	−1	.74	10.10	5.22	F 77
13	4435	SB(s)0	...	−2	.66	11.33	4.70	Ag 71
14	4442	SB(s)0	...	−2	.43	11.40	5.54	F 77
15	4459	SA(r)0^+	...	−1	.74	11.01	4.70	Ag 71
16	4461	SB(s)0^+*	...	−1	.42	12.14	5.71	F 77
17	4474	S0p*	...	−2	.52	12.17	4.09	Ag 71
18	4526	SBA(s)0*	...	−2	.32	10.65	6.38	F 77
19	4578	SA(r)0 $	...	−2	.76	12.31	5.00	F 77
20	4762	SB(r)0 sp	...	−2	.19	11.18	6.24	F 77
21	4762	SB(r)0 sp	...	−2	.19	11.15	5.90	T 80
22	5102	SA0^-	...	−3	.37	9.79	4.83	Se 68
Sa galaxies								
1	1317	(P)SAB(rs)a sp	...	1	.87	11.91	3.87	Se 68
2	1433	SB(r)a	...	1	.89	10.34	4.21	Se 68
3	3358	(R)SBA(s)0/a	...	0	.6	12.37	3.05	Se 68
4	4192	SAB(s)ab	I-II	2	.33	11.03	3.43	F 77
5	4216	SAB(s)b	II	2	.26	10.96	4.85	F 77
6	4235	SA(s)a sp	...	1	.25	12.64	4.62	F 77
7	4293	(R)SB(s)0/a	...	0	.49	11.17	4.14	F 77
8	4438	SA(s)0p*	...	0	.42	11.06	4.45	Ag 71
9	4569	SAB(rs)ab	...	2	.51	10.31	4.30	F 77
10	7582	(P)SB(s)	...	2	.48	11.12	3.63	Se 68
11	IC 356	SA(s)ab pec	...	2	.78	11.43	3.84	Ag 71
Sb galaxies								
1	224	SA(s)b	I-II	3	.35	4.36	3.81	dV 58
2	613	SB(rs)bc	I-II	4	.79	10.73	4.53	Se 68
3	1097	SB(s)b	I-II	3	.71	9.96	3.63	Se 68
4	1365	SB(s)b	I-II	3	.56	10.16	3.7	Se 68
5	1515	SAB(s)bc	...	4	.25	11.73	3.87	Se 68
6	1566	SAB(s)bc	...	4	.88	10.32	4.64	dV 73
7	1566	SAB(s)bc	...	4	.88	9.89	4.74	Se 68
8	1672	SB(s)b	I-II	3	.81	10.66	4.13	Se 68
9	2683	SA(rs)b	II-III	3	.27	10.59	4.57	BC 75b
10	3347	SB(rs)b	...	3	.6	12.17	3.56	Se 68
11	4212	SA(s)bc $	III	4	.69	11.93	3.48	F 77
12	4303	SAB(rs)bc	I	4	.91	10.24	3.74	F 77

No. (1)	NGC (2)	RMT (3)	L_c (4)	T (5)	q (6)	$m_T(B)$ (7)	Q_N (8)	Reference (9)
13	4321	SAB(s)bc	I	4	.89	10.09	3.82	F 77
14	4394	(R)SB(r)b	II	3	.91	11.71	4.81	F 77
15	4501	SA(rs)b	I	3	.56	10.12	4.30	F 77
16	4501	SA(rs)b	I	3	.56	10.10	3.53	Ag 71
17	4527	SAB(s)bc	II	4	.36	11.31	3.79	F 77
18	4536	SAB(rs)bc	II	4	.48	11.10	3.92	F 77
19	4567	SA(rs)bc	...	4	.71	12.07	3.23	F 77
20	4579	SAB(rs)b	...	3	.81	10.56	4.15	F 77
21	6744	SAB(r)bc	III	4	.66	9.41	3.73	Se 68
22	6744	SAB(r)bc	III	4	.66	9.45	3.77	dV 63b
23	6769	SAB(r)b pec	...	3	.69	11.91	4.53	Se 68
24	6770	SAB(rs)b pec	...	3	.78	11.69	4.02	Se 68
25	7590	SA(rs)bc	...	4	.42	11.85	2.75	Se 68
Sc galaxies								
1	253	SAB(s)c	...	5	.3	7.70	2.91	Se 68
2	253	SAB(s)c	...	5	.3	8.05	3.03	P 80
3	300	SA(s)d	...	7	.74	8.66	3.82	dVP 62
4	300	SA(s)d	...	7	.74	8.62	3.77	Se 68
5	598	SA(s)cd	II-III	6	.63	6.27	3.41	dV 59
6	1313	SB(s)d	...	7	.78	9.74	4.43	dV 63a
7	1313	SB(s)d	...	7	.78	10.05	4.83	Se 68
8	1559	SB(s)cd	...	6	.63	10.76	3.31	Se 68
9	2997	SAB(rs)c	I	5	.79	10.27	2.86	Se 68
10	3389	SA(s)c	III	5	.56	12.30	3.05	BBC 76
11	4254	SA(s)c	I	5	.89	10.49	3.66	F 77
12	4519	SB(rs)d	III	7	.72	12.36	3.63	F 77
13	4535	SAB(s)c	I	5	.74	10.73	2.65	F 77
14	4571	SA(r)d	...	7	.89	11.94	3.30	F 77
15	4647	SAB(rs)c	...	5	.81	11.77	4.46	F 77
16	4945	SB(s)cd*	...	6	.21	10.10	3.98	Se 68
17	5236	SAB(s)c	I-II	5	.91	7.94	3.16	Se 68
18	5427	SA(s)c p	I	5	.93	12.10	4.36	Bl 82
19	5457	SAB(rs)cd	I	6	.98	8.35	3.85	Ok 76
20	6946	SAB(rs)cd	I	6	.89	9.57	3.53	Ab 71
21	7424	SAB(rs)cd	II	6	.89	10.71	3.08	Se 68
22	7599	SA(s)c	...	5	.35	11.77	3.47	Se 68
23	7793	SA(s)dm	...	8	.72	9.51	3.28	dVD 80
24	7793	SA(s)dm	...	8	.72	8.83	3.01	Se 68
25	IC 342	SAB(rs)cd	I-II	6	.98	9.10	3.53	Ab 71
Irr I galaxies								
1	55	SB(s)m sp $	...	9	.2	7.57	3.66	Se 68
2	55	SB(s)m sp $	...	9	.2	7.90	3.83	dV 61
3	4618	SB(rs)m	II	9	.87	11.50	3.26	Be 67
4	4625	SAB(rs)pec	...	9	.85	12.90	3.33	Be 67
5	4656/7	**	...	9	.24	11.02	4.40	St 83
6	A1009	IBm	V	9	.79	11.93	3.00	Ab 71
7	IC 1613	IAB(s)m	V	10	.82	9.96	4.09	Ab 71
8	SMC	SB(s)mp	...	9	.56	2.79	4.02	dV 60
9	LMC	SB(s)m	...	9	.85	0.63	3.77	dV 60

Table 1. Continued.

References:

Ab 71 Ables (1971)
Ag 71 Agüero (1971)
BBC 76 Barbon, Benacchio & Capaccioli (1976)
BBC 78 Barbon, Benacchio & Capaccioli (1978)
BC 75a Barbon & Capaccioli (1975a)
BC 75b Barbon & Capaccioli (1975b)
BCT 75 Barbon, Capaccioli & Tarenghi (1975)
Be 67 Bertola (1967)
Bl 82 Blackman (1982)
dV 58 de Vaucouleurs (1958)
dV 59 de Vaucouleurs (1959)
dV 60 de Vaucouleurs (1960)
dV 61 de Vaucouleurs (1961)
dV 63a de Vaucouleurs (1963a)
dV 63b de Vaucouleurs (1963b)
dV 73 de Vaucouleurs (1973)
dV D 80 de Vaucouleurs & Davoust (1980)
dV P 62 de Vaucouleurs & Page (1962)
Fr 77 Fraser (1977)
Ok 76 Okamura (1976)
Pe 80 Pence (1980)
Se 68 Sérsic (1968)
St 83 Stayton (1983)
Ts 80 Tsikoudi (1980)

Notes:

RMT = Revised morphological type
$ = Doubtful
* = Uncertain
** = Irr I according to St 83

Holmberg (1958), Heidmann, Heidmann & de Vaucouleurs (1972), Boroson (1981) and several others have shown that the brightness distribution in spiral galaxies varies continuously and systematically with the apparent inclination. Models have been proposed to explain this effect as being due to a thin layer of dust in the symmetry plane. In this paper we show, however, that the photometric parameter Q_N is particularly sensitive to inclination, over and above the effect of intrinsic absorption. Such dependence which is geometric in nature, may provide clues to the three-dimensional structure of galaxies (Sérsic & Arreguine 1983).

2. Selection of the sample

We have selected a sample of galaxies roughly representative of the Hubble sequence, with different degrees of inclination, and having published surface photometric information in B band. We have excluded those objects with conspicuous morphological peculiarities to avoid non-typical brightness distributions. Low-galactic-latitude and small-angular-size objects were also omitted in order to avoid galactic absorption and also the atmospheric and instrumental effects. The selection was made using the *Second Reference Catalogue of Bright Galaxies* (de Vaucouleurs, de Vaucouleurs & Corwin 1976, hereafter RC2) as well as by direct inspection of plates and photographs when available.

As an inclination indicator, we have used the apparent flattening q (= b/a, the ratio of the minor to the major axes of the galaxies, in a homogeneous system such as that of the RC2*). Since q is not a good indicator of inclination in galaxies with bars, special care was taken with such objects. Ellipticals are not considered in this paper, and are discussed elsewhere (Sersic & Arreguine 1983).

Two major contributions in the field (Boroson 1981; Burstein 1979) do not give enough information regarding the areas $S(m)$ inside a given isophote of magnitude m, and consequently we were unable to compute Q_N for these valuable collections of objects.

* Our q is related to de Vaucouleurs' R through $qR = 1$.

When the values of Q_N derived from the data of different authors differed by more than $\Delta Q = 1$, the corresponding object was also omitted when a criterion to decide the best estimate was not available. Reciprocally, if $\Delta Q < 1$, both values were included in the sample. Table 1 shows the final sample used in this paper.

3. The dependence of Q_N on inclination

The sample was originally divided into five groups in order to minimize the dependence on the morphological type (Table 2).

Table 2. The distribution of sample galaxies according to the morphological type.

Group	S0	Sa	Sb	Sc	Irr I	Total
RMT*	−3 to −1	0 to 2	3 to 4	5 to 8	9 to 10	−3 to 10
No. of objects	22	11	25	25	9	92

* Revised morphological types from RC2

Although an equal distribution in bins of different types would be convenient, we were unable to get a larger sample for Sa and Irr I type galaxies. After some trials, essentially no difference in behaviour was found between Sa and Sb galaxies, so we have considered only the following groups: S0, Sa + Sb, Sc and Irr I.

Fig. I shows the correlation of Q_N with q for each of the four morphological groups. The inclination effect is clearly apparent: the values of Q_N are smaller at intermediate q's

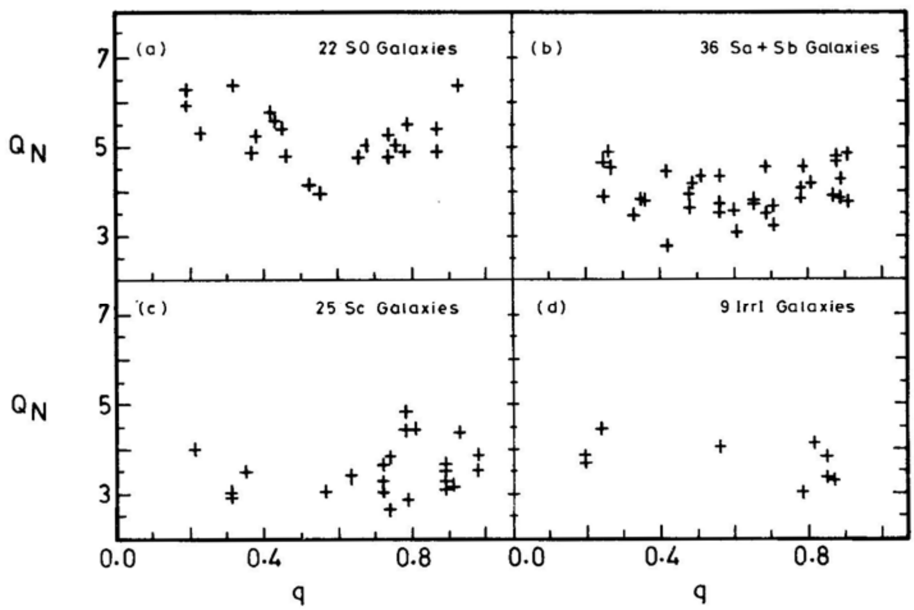

Figure 1. The observed Q_N (q) relationship for S0, Sa+ Sb, Scand IrrI galaxies.

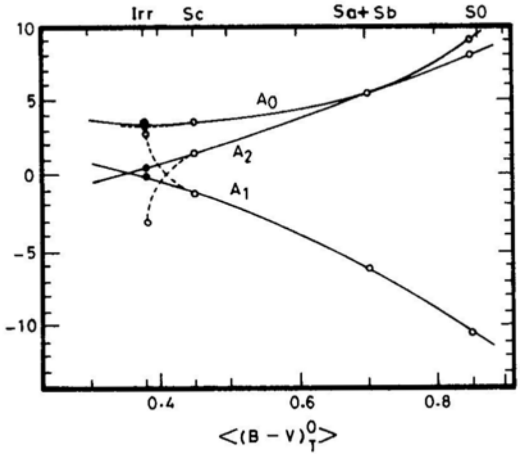

Figure 2. The coefficients A_i are plotted against the standard, fully corrected $(B-V)^0_T$ colours for the mean Hubble types. The 'best guess' values for Irr I galaxies is shown by filled circles.

and increase at both low and high q's. Only irregular galaxies seem to escape this trend. The range in q for each morphological group increases towards late-type galaxies as a consequence of their increasing flattening, as expected. A striking feature in Fig. 1 is that the inclination effect in Q_N is larger in earlier galaxies, which can hardly be explained by absorption models.

In order to quantify the form and regularities of this effect, we have represented the observed points with a second order curve, $Q_N = A_0 + A_1 q + A_2 q^2$, through a least-squares fit. If the Irr I group is excluded on the basis of its low frequency, the coefficients A_i are found to vary smoothly from S0 to Sc groups, although the fit in the last case is rather poor.

Fig. 2 shows the values of A_i for each group. The trend these coefficients follow along the Hubble sequence, as represented by their standard, fully corrected $B-V$ colours

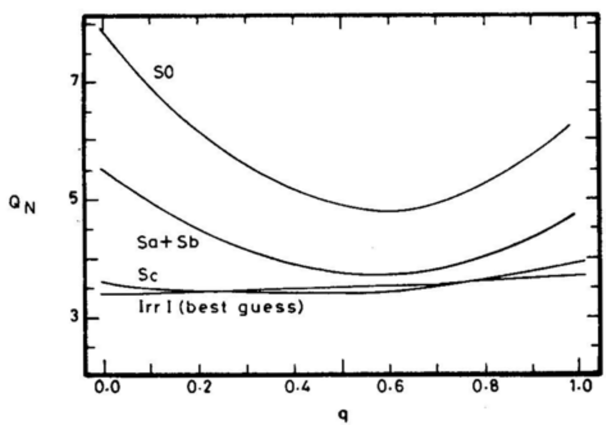

Figure 3. The variation of $Q_N(q)$ relationship along with Hubble sequence.

given by de Vaucouleurs (1977), is clearly seen. Irr I galaxies apparently depart from the trend followed by the earlier morphological groups. This is a consequence of the smallness of the sample and the way it is distributed in q, since any point added to the left side of the diagram has much weight on the shape of the interpolating curve. A 'best guess' point purporting to represent the actual location of the Irr I group has been derived from smooth extrapolations in Fig. 2 for the respective coefficients. The mean $Q_N(q)$ for different Hubble type groups are shown in Fig. 3.

5. The mean faceon values of Q_N

Table 3 gives the mean values of $Q_N(1) = A_0 + A_1 + A_2$ for each morphological group and its respective dispersions. A smooth decrease in $Q_N(1)$ from early to late-type objects is clearly noticed, but the comparison of dispersions of the mean corrected (σ_0) with the dispersion of the mean uncorrected (σ) values of Q_N shows no significant change. Thus, most of the dispersion in the Q_N values arises from sources other than the inclination effect. In order to identify the source of the rather high dispersion, we have checked for a possible dependence on the luminosity of the galaxies. Table 1 gives the luminosity class (L_c) for a large fraction of the sample (34 galaxies). No correlation whatsoever was found between L_c and Q_N. The error in measuring I_N and S_N could result in uncertainties in Q_N responsible for the observed dispersion. In fact, if ΔQ_N is the error in Q_N due to these sources, then

$$\frac{\Delta Q_N}{Q_N} = \left\{(0.921)^2\left[\Delta(M_T - m_N)\right]^2 + \left(\frac{\Delta S_N}{S_N}\right)\right\}^{1/2},$$

where $\Delta(m_T - m_N)$ is the error in $m_T - m_N$, which is independent of the zero point of the scale of magnitudes, and ΔS_N the error in the area S_N enclosed by the m_N-isophote. Now assuming realistic upper limits of $\Delta S_N/S_N \simeq 0.1$ and $\Delta(m_T - m_N) \simeq 0.2$ we get $\Delta Q_N/Q_N \simeq 0.2$. From Table 3 we obtain for the whole sample $\Delta Q_N/Q_N = 0.12$ showing that the dispersion in the sample is within the expectations for the assumed uncertainties in S_N and m_N.

Fig. 4 gives the values of Q_N and $Q_N(1)$ along the Hubble sequence as represented by their mean values for each morphological group. The values of Q_N, $Q_N(1)$ converge towards late-type galaxies. The location of the Irr I galaxies is uncertain in the corrected $Q_N(1)$ values. A value $Q_N(1) = 3.0$ for Irr I galaxies would mean a surface brightness

Table 3. Numerical fit of the Q_N vs q relationship for each morphological group.

Group	S0	Sa + Sb	Sc	Irr I	Irr I (best guess)
A_0	7.9 ± 0.7	5.5 ± 0.6	3.6 ± 0.9	3.3 ± 0.8	3.4
A_1	-10.5 ± 2.7	-6.3 ± 2.2	-1.2 ± 3.0	2.8 ± 4.2	-0.1
A_2	8.9 ± 2.4	5.5 ± 1.8	1.5 ± 2.4	-3.1 ± 4.0	0.4
$Q_N(1)$	6.2	4.8	3.8	3.0	3.7
σ_c	0.5	0.4	0.6	0.4	...
Q_N	5.5	4.0	3.6	3.9	...
σ	0.9	0.5	0.5	0.5	...
$(B-V)_T^0$	0.85	0.70	0.45	0.38	0.38

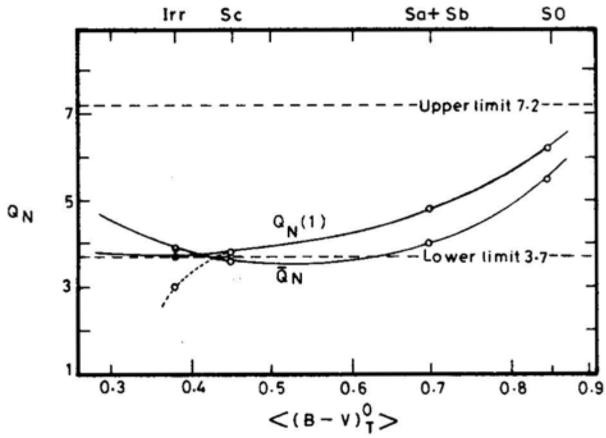

Figure 4. Dependence of Q_N on the morphological type represented by $(B - V)^0_T$ colours for both, mean uncorrected Q_N and mean face-on Q_N (1) values. Filled circle corresponds to the 'best guess' solution for Irr I galaxies.

distribution much flatter than that of an exponential disk. We have already discussed the reasons for this behaviour of the Irr I group. Its 'best guess' representation in Fig. 4 supports the convergence of Q_N and Q_N (1) values for late-type galaxies towards the value $Q_N \simeq 3.7$, characteristic of the exponential disk distribution (N = 2; Sérsic 1983).

5. Conclusions

We conclude that the brightness distribution, as described by the parameter Q_N , depends on the inclination of a galaxy. This effect is larger for earlier-type objects The face-on values of Q_N are not smaller than the value 3.7—which is typical of the exponential disk—for late-type galaxies, and increase towards the early-type ones as a consequence of the increasing contribution from the spheroidal component with Q_N = 7.17 (N = 8; see Sérsic 1982).

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