The Local Galaxy Density and the Arm Class of Spiral Galaxies

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Abstract

We have examined the effect of the environmental density on the arm classification of an extensive sample of spiral galaxies included in the Nearby Galaxy Catalog (Tully, 1988a). We have also explored the dependence of the arm class of a galaxy on other factors, such as its blue absolute magnitude and its disk-to-total mass ratio, inferred in the literature either from the gradient of a good galaxy rotation curve or from a photometric mass decomposition method.

We have found that the arm class is strongly related to the absolute magnitude in the mid-type spirals (in the sense that grand design galaxies are, on average, more luminous than flocculent objects), whilst this relation is considerably weaker in the early and late types. In general the influence of the local density on the arm structure appears to be much weaker than that of the absolute magnitude. The local density acts essentially in strengthening the arm class–absolute magnitude relation for the mid types, whereas no environmental density effects are observed in the early and late types.

Using the most recent estimates of the disk-to-total mass ratio, we do not confirm this ratio to be a significant factor which affects the arm class; nevertheless, owing to poor statistics and large uncertainties, the issue remains open. Neither a local density effect nor an unambiguous bar effect on the disk-to-total mass ratio is detectable; the latter finding may challenge some theoretical viewpoints on the formation of bar structures.

Subject headings: galaxies: general - galaxies: structure - galaxies: internal motions - galaxies: clustering
1 Introduction

The degree of symmetry and continuity of spiral arms in galaxies is the basis of the classification system introduced by Elmegreen & Elmegreen (1982). They assigned galaxies to 12 distinct arm classes (AC) ranging from AC=1 (fragmented arms with no symmetry) to AC=12 (two long, sharply defined arms which dominate the appearance of the galaxy). A few years later the same authors published a catalog of spiral arm classes of 765 galaxies, in which the original classification was slightly refined (Elmegreen & Elmegreen, 1987).

Several properties have been examined for correlations with AC. Grand design (hereafter G) spirals (i.e. with AC>5) are on average larger and more luminous than flocculent (hereafter F) galaxies (i.e. with AC<4) (Elmegreen & Elmegreen, 1982, 1987). Late-type spirals are mostly flocculent, irrespective of their bar-type, whereas in the early-type spiral range the percentage of G objects increases from ~40% to ~80% as we go from unbarred to barred systems (Elmegreen & Elmegreen, 1989). But in many respects G and F spirals are very similar: they do not appear to differ in star formation rate — as traced by colours, Hα and ultraviolet fluxes, blue and infrared surface brightnesses (Elmegreen & Elmegreen, 1986) — in neutral hydrogen content (Romanishin, 1985), in supernova rate (McCall & Schmidt, 1986), in CO surface brightness (Stark, Elmegreen & Chance, 1987), in radio and soft X-ray emissions (per unit light) (Giuricin, Mardirossian & Mezzetti, 1989). Recently, Elmegreen & Elmegreen (1990) and Biviano et al. (1991) found that AC correlates with the outer galaxy rotation curve, in the sense that galaxies with steeper curves tend to have flocculent arm appearance and galaxies with flatter curves tend to be grand design. This would indicate a difference in the relative disk masses (see, e.g., the review by Whitmore, 1990), with G galaxies having the largest disk-to-halo mass — in agreement with the predictions of the standard density wave theory (see, e.g., the textbook by Binney & Tremaine, 1987).

So far the assessment of environmental influence on the arm structure is one of the worst known observational aspects of this topic, since seemingly controversial results have appeared in the literature. It has been claimed that the occurrence of G objects in unbarred spirals is greater in spiral members of pairs and groups than in relatively isolated systems (Elmegreen & Elmegreen, 1982) and that, within the family of galaxy groups, it is greater in the densest groups (Elmegreen & Elmegreen, 1983, 1987). On the other hand, comparing three samples of interacting galaxies and four samples of galaxy pairs with three control samples of bright field galaxies, Giuricin et al. (1989) pointed out that F galaxies are more common in the samples of interacting or binary systems than in (relatively isolated) field objects. Noting that several individual interacting systems display disordered optical morphology and spatial distribution of neutral hydrogen (e.g., Sulentic & Arp, 1985 and references cited therein), Giuricin et al. (1989) suggested that interactions can destroy G arm structures, thus favouring the occurrence of F objects in close galaxy systems. (This is not necessarily in contradiction with previous claims if the authors refer to very strong interactions only.)

On the theoretical side, the role of the environment in arm morphology is generally believed to be important. As a matter of fact, since the work of Toomre & Toomre (1972), close encounters between galaxies have been frequently proposed as types of perturbation which can initiate or maintain global spiral structure (Kormendy & Norman, 1979; Toomre, 1981; Soerensen, 1985; Sundelius et al., 1987; Pasha & Poliachenko, 1987).
The presently confused observational situation has prompted us to search for observational evidence of environmental effects on arm structures, using a rigorous assessment of the environmental density; this is lacking in the above-mentioned relevant studies, which are content with a fairly vague characterization of the environment of the galaxy samples used. In §2 we present the galaxy sample that we have chosen and the parameters that we have taken as good indicators of the local density of galaxies for each galaxy of the sample considered. In §3 we explore whether AC depends on the local density of galaxies, analyzing also correlations between AC and other factors which can influence it, such as the galaxy absolute magnitude and the disk-to-total mass ratio. As a by-product of our study, we also check whether barred and unbarred objects differ in their disk-to-total mass ratio. In §4 we summarize our main results.

2 The data sample

In order to describe the environmental density of our nearby universe we have chosen the volume-limited NBG catalog (Tully, 1988a), since this galaxy catalog is intended to include essentially all the nearby galaxies with systemic velocities of less than 3000 km/s. This corresponds to a distance of 40 Mpc for the Hubble constant $H_0=75$ km s$^{-1}$ Mpc$^{-1}$, which value is adopted throughout the present paper. In the NBG catalog the distances of all non-cluster galaxies have been essentially estimated on the basis of velocities, the above assumed value for $H_0$, and the Virgocentric retardation model described by Tully & Shaya (1984), in which the authors assume the Milky Way to be retarded by 300 km/s from the universal Hubble flow by the mass of the Virgo cluster. The galaxy members of the groups have been given a distance consistent with the mean velocity of the group.

We have updated the Hubble morphological types and the bar-types (SA=unbarred, SB=barred, SAB=transition-type) of the NBG spiral galaxies by consulting the RC3 catalog of galaxies (de Vaucouleurs et al., 1992). 511 NBG spiral galaxies (of which 236 lie at a distance of $D<20$ Mpc) have known arm classes tabulated in the catalog of Elmegreen & Elmegreen (1987).

In order to evaluate the local density of galaxies for each of our 511 spirals, we have to take into account the incompleteness of the NBG catalog at large distances. According to Tully’s (1988b) evaluation, the smooth curve which describes the observed increase in incompleteness with distance D (in Mpc) obeys the expression

$$F = \exp[0.041(\mu - 28.5)^{2.78}]$$  \hspace{1cm} (1)

where $\mu = 5 \log D + 25$ is the distance modulus and $F = 1$ if $\mu < 28.5$. The incompleteness factor $F$ expresses the number of galaxies brighter than $M_B = -16$ that should have been cataloged for each object that is listed in the NBG catalog at a given distance. Following Tully (1988b) and Giuricin et al. (1993), we have estimated the contribution of each galaxy brighter than $M_B = -16$ to the local density at the specific locations of our 511 NBG galaxies with known AC by using a gaussian smoothing function:

$$\rho_i = C \exp\left[-r_i^2/2(F^{1/3}\sigma)^2\right]$$  \hspace{1cm} (2)

where $r_i$ is the spatial distance of the $i$-th galaxy from the specified location and the normalization coefficient is $C = 1/(2\pi\sigma^2)^{3/2} = 0.0635/\sigma^3$. For a galaxy at larger distance D, the effective smoothing scale length $(F^{1/3}\sigma)$ is increased in such a way that the amplitude of the density peak associated with a galaxy is the same at all distances D. In such a way the function $\rho_i$ satisfies the normalization condition $\int \rho_i dV = F$. Then, following
Giuricin et al. (1993), we have defined the local galaxy density $\rho_\sigma$ of a given NBG galaxy as the summation over all contributions of all other galaxies brighter than $M_B = -16$, excluding the galaxy itself:

$$\rho_\sigma = \sum_i \rho_i$$

Thus, the local galaxy density $\rho_\sigma$ (that we express in units of galaxies Mpc$^{-3}$) is essentially zero (for all $\sigma$-values) for a galaxy without companions within a distance of $3\sigma$ Mpc. As discussed in Giuricin et al. (1993), because of the clustering properties of galaxies, the choice of different $\sigma$-values implies a different physical meaning for the local galaxy density $\rho_\sigma$.

In order to calculate the local density $\rho_\sigma$ we need to know the absolute magnitudes of the NBG galaxies, those of which with $M_B < -16$ will be taken as contributors to $\rho_\sigma$. For the NBG galaxies which do not have $M_B$ tabulated in the catalog (according to their adopted distances and corrected total blue apparent magnitudes) we have estimated $M_B$ from their corrected isophotal diameters $D_{25}$ (relative to the 25 B mag arcsec$^{-2}$ brightness level), by relying on the following standard luminosity-diameter relations:

$$M_B = -4.8 \log D_{25} - 13.8$$

with $D_{25}$ expressed in kpc, for the elliptical galaxies (Giuricin et al., 1989) and

$$M_B = -5.7 \log D_{25} - 12.4$$

for the lenticular and spiral galaxies (Girardi et al., 1991).

3 Analysis And Results

3.1 Arm class versus local density and absolute magnitude

Biviano et al. (1991) have clarified that the AC of a spiral galaxy depends mainly on its absolute magnitude $M_B$ and its disk-to-total mass ratio $f$ (as indicated by the gradients of the outer rotation curve). In the present study we wish to investigate whether also the environmental density influences the AC itself. To this end we shall primarily deal with AC-$\rho_\sigma$ correlations, taking into account the correlations of AC with other relevant quantities, in order to be sure that these correlations do not induce a spurious AC-$\rho_\sigma$ one.

We analyze the significance of the correlation between two variables by computing the linear regression coefficient $r_P$ and the two non-parametric rank correlation coefficients, Spearman’s $r_S$ and Kendall’s $r_K$ (see, e.g., Kendall & Stuart, 1977). Table 1 lists the three correlation coefficients and the (one-tailed) percent significance level associated with $r_K$ (the one associated with $\rho_\sigma$ is generally very similar) for different pairs of variables and different subsets of galaxies. The order of the presentation of the results in Table 1 follows the discussion reported below.

Subdividing our galaxies into several morphological type intervals, we first analyze the AC-$\rho_\sigma$ correlations. In this case in which statistics is good we prefer to restrict ourselves to considering the subsample of 236 nearby NBG spirals with D<20 Mpc, in order to avoid possible problems related to the severe incompleteness of the NBG catalog at large distances. We find that the AC-$\rho_\sigma$ correlations turn out to be marginally significant for early types (for low $\sigma$-values, $\sigma=0.25$ and 0.5 Mpc), in the sense that G objects tend to inhabit regions of high local density; for mid types the correlations are significant for greater $\sigma$-values ($\sigma=0.5, 1.0, 2.0$ Mpc) and in the opposite sense (F objects tend to stay in denser environments); for late types AC appears to be unrelated to $\rho_\sigma$ for all $\sigma$-values. In the first lines of Table 1 we report the results just mentioned. The type subdivision used, i.e., early-types=S0/a to Sb, mid-types=Sbc
to Scd, late-types=Sd to Sm, is the one which maximizes the positive \(AC-\rho_\sigma\) correlations.

Owing to the known strong \(AC-M_B\) correlation, we divide our nearby early and mid-type spirals into objects brighter and fainter than \(M_B=-20\) and our nearby late-type spirals into galaxies brighter and fainter than \(M_B=-17.8\) (the adopted limits are close to the medians of the respective \(M_B\)-distributions). Again no significant \(AC-\rho_\sigma\) correlations are detectable in the late-type range, whereas marginal \(AC-\rho_\sigma\) correlations are still observed in bright early-type objects, especially when low \(\sigma\)-values are used. On the other hand, for the mid-type range we obtain a strong, positive \(AC-\rho_{0.5}\) correlation in the high-luminosity range, together with a strong negative \(AC-\rho_{0.5}\) correlation in the low-luminosity range. Fig. 1 presents the \(AC-\rho_{0.5}\) plots for the mid-type spirals, subdivided into faint and bright objects. The \(AC-\rho_{1.0}\) correlation for the mid types shows a similar behaviour, whereas the \(AC-\rho_{2.0}\) correlation is significant (and negative) in the low-luminosity range only. We have also verified that if we omit the 18 galaxies which are members of the Virgo cluster (according to the NBG membership assignments), the global \(AC-\rho_\sigma\) correlation for all mid-types vanishes, but the two positive and negative \(AC-\rho_{0.5}\) correlations for the high- and low-luminosity subsamples remain significant.

From the physical point of view, we could say that in mid types the absence of a significant correlation for \(\sigma=0.25\) Mpc indicates that the density effect on AC is mainly related to the belonging to a galactic system (like a group or a cluster) rather than to close companions at a distance of a few tenths of Mpc; vice versa, in early types the marginal density effect on AC (for low \(\sigma\)-values only) if real could be ascribed to close encounters between galaxies.

The extension of this kind of analysis to the whole sample of 128 late-type and 240 mid-type NBG spirals confirms the absence of significant \(AC-\rho_\sigma\) correlations for the former objects and the significance of the \(AC-\rho_\sigma\) correlations (for \(\sigma=0.5, 1.0, 2.0\) Mpc) for the latter objects. On the other hand, the study of the entire sample of 136 early-type NBG spirals does not confirm the weak \(AC-\rho_{0.25}\) and \(AC-\rho_{0.5}\) correlations claimed above. Moreover, the analysis of the \(AC-\rho_\sigma\) correlations for different bar types shows no significant bar effect (objects of different bar types behave in the same way).

At this point, after having checked that \(M_B\) and \(\rho_\sigma\) are uncorrelated for the NBG nearby early-, mid- and late-type spirals, we move on to discussing the important \(AC-M_B\) correlation. This will also allow us to elucidate the \(M_B\) dependence of the \(AC-\rho_\sigma\) correlation in mid types. First, it is useful to check whether this correlation holds for the whole spiral morphological sequence. As a matter of fact, one could speculate that this correlation is a spurious result of the predominance of F objects in late-type spirals, which are on average less luminous than early types. This view is not correct, since from the analysis of all nearby NBG spirals (with \(D<20\) Mpc) it turns out that AC correlates with \(M_B\) strongly for mid types and marginally for late types (in the usual sense), irrespective of their bar types. Interestingly, in early types AC appears to be unrelated to \(M_B\), although closer inspection reveals a marginal correlation for the SB and SAB early types alone.

Moreover, dividing our mid-type nearby spirals into two ranges of \(\rho_{0.5}\) (i.e. \(\rho_{0.5}\) greater and smaller than 0.66 gal. Mpc\(^{-3}\), which is the median of the \(\rho_{0.5}\) distribution) we find that the significance of the \(AC-M_B\) correlation grows as we move to higher local densities (see Fig. 2). This tendency is also observed, although in a slightly weaker way, for \(\sigma=1.0\) and 2.0 Mpc. Just the fact that the degree of correlation between AC and \(M_B\) depends on the local density can account for the pre-
viously discussed AC–$\rho_2$ dependence on $M_B$ for mid types: when we take bright objects into account, we have more G spirals in denser environments, and vice versa. No density effect on the AC–$M_B$ relation is observed in late types. Some density effect in the same sense is detectable for early types (namely, a weak AC–$M_B$ correlation is observed substantially in systems located in dense regions; this could justify our previous finding of a marginal AC–$M_B$ correlation for barred early spirals, which are found in high density regions according to Giuricin et al., 1993). The analysis of all NBG spirals confirms that for early types AC is generally uncorrelated with $M_B$ and that it correlates slightly with $M_B$ in the subsets of SB and SAB types; it also confirms the high degree of correlation between AC and $M_B$ for mid types and leads to a stronger AC–$M_B$ dependence for all late types than for nearby ones. Besides, the entire NBG sample provides confirmation of the density effect on the AC–$M_B$ relation for mid types only.

### 3.2 Arm class versus fractional disk mass

Let us now discuss the correlation between AC and the disk-to-total mass ratio $f$. This ratio can be computed by means of the logarithmic gradient (LG) of the galactic rotation curve. It is defined (e.g., Persic & Salucci, 1986) as

$$LG = \frac{d \log V(R)}{d \log R} \big|_{R_{25}},$$

(6)

where $V(R)$ is the galactic rotation velocity; LG is measured at the isophotal disk radius $R_{25}$, deduced from the 25 B mag arcsec$^{-2}$ isophote. Persic & Salucci (1990) related LG to the fractional disk mass $f$ at the optical radius $R_{25}$ by means of the following expression:

$$f = \frac{M_d}{M_t} = (0.76 - LG)/(0.11LG + 1.06)$$

(7)

Clearly, $f$ decreases monotonically with increasing LG.

We take the 68 LG-values evaluated by Persic & Salucci (1993). They have carefully selected from the literature a sample of 68 spirals, using severe selection criteria: the chosen galaxies (of types later than Sa, i.e. with no very prominent bulges) have both exponential light profiles and symmetric rotation curves extended at least up to 3.2 exponential scale length (statistically equal to $R_{25}$); besides the rotation curves show no evidence of non-circular motions and have at least 15 optical measures between 2 and 3 scale length, or are observed with a radio beam size not larger than half a scale length. This sample of LG-values can be regarded as the best sample available so far for a reliable evaluation of the fractional disk mass, which we calculate by means of Equation (7). In the following we denote by $f_1$ the 68 $f$-values evaluated in this manner.

Furthermore, in order to improve the statistics, we consider an extensive sample of rough estimates of $f$ derived by Salucci et al. (1993) through a photometric mass-decomposition method (Salucci, Ashman, Persic, 1991) for 258 spirals suitably selected from the NBG sample. In this method the visible mass fraction of a galaxy (roughly its fractional disk mass) is obtained by comparing the visible mass $M_v = L_B(M/L)_*$ (where $(M/L)_*$ refers to the stellar component) with the dynamical mass $M_{dyn} = (V^2(R_{25})R_{25})/G$, where $R_{25}$ is the isophotal radius, $V(R_{25}) = W/(2 \sin i)$ is the rotation velocity computed from the 21-cm line width $W$ and $i$ is the inclination angle of the galactic disk. The stellar mass-to-light ratio $(M/L)_*$ is obtained from the B–V galaxy colour by means of some published stellar population synthesis models (Tinsley, 1981; Bruzual, 1983; Jablonbka & Arimoto, 1992). In the following we denote by $f_2$ these 258 estimates of $f$. 

5
Of the above-mentioned samples of 68 and 238 galaxies, 19 and 58 have known AC and lie at small distances (D < 20 Mpc). For these galaxies we recognize that AC does not appear to be appreciably related to \( f_1 \) or \( f_2 \) (see Fig. 3 and Table 1; the weak correlation that seems to be present in Fig. 3a is not statistically significant). This result is confirmed by extending our analysis to the whole sample of 24 or 113 galaxies with known AC and known \( f_1 \) or \( f_2 \), irrespective of their distance, morphological type, bar type, luminosity and local density. We conclude that the most recent estimates of \( f \) do not confirm the weak dependence of AC on \( f \) suggested by Elmegreen & Elmegreen (1990) and Biviano et al. (1991) on the basis of older data for the rotation curve gradients. However, our \( f_1 \) sample is rather poor and our \( f_2 \) data are likely to be affected by large uncertainties.

3.3 Arm class and selection effects

We wonder whether our results could be substantially affected by observational selection effects. We identify three major sources of observational biases: i) the inhomogeneity of the material used by Elmegreen & Elmegreen (1987) for their AC catalog; ii) the inclination angle \( i \) of the galaxy planes (nearly edge-on galaxies could have AC determinations of bad quality); iii) the distance of the galaxies (at large distances the arm classification can suffer from low spatial resolution). First, we have checked that the omission of a few galaxies classified from high-resolution photographic atlases (rather than from the Palomar Observatory Sky Survey) does not affect our main results. Second, we have verified that AC is unrelated to \( i \) for the three subsets of early-type, mid-type, late-type spirals. Third, within the same three morphological types, we have seen that AC does not correlate appreciably with distance, at least for our subsample of nearby (\( D < 20 \) Mpc) spirals.

3.4 Bars and fractional disk mass

A wide variety of theoretical approaches and numerical simulations have shown that realistic bar structures, which remain stable over many orbital periods, are inevitably formed in unstable galactic disks. On the theoretical side, basic strategies devised to avoid bar-like instability in a galactic disk rely on one of the following requirements: i) galactic rotation curves having an inner Lindblad resonance; ii) large random motions in the inner parts of the galactic disks, for instance supplied by a “hot disk” component; iii) a massive halo that contains a mass (at least) comparable to the disk mass (e.g., the textbook by Binney & Tremaine, 1987). An alternative viewpoint proposed by Lyndell-Bell (1979) en-
visages slow formation of bars through the gradual alignment of stellar eccentric orbits (rather than quick formation as a result of some large-scale collective oscillation of disk stars). Moreover, N-body simulations show that the occurrence of close encounters between galaxies is a possible mechanism for stimulating bar formation in spiral disks (Byrd et al., 1986; Noguchi, 1987; Gerin, Combes & Athanassoula, 1990); observational evidence for this process is found in early-type spirals only (Elmegreen, Elmegreen & Bellin, 1990; Giuricin et al., 1993).

Special attention has been given in the recent literature to the linear modal analysis of the global stability of galactic disks. In the context of this approach, barred objects are expected to be related to more massive disks than unbarred galaxies (e.g., the review by Bertin, 1991). We have seen (see, e.g., Persic & Salucci, 1990) that the disk-to-total mass ratio can be inferred from the gradient of the outer part of the rotation curve; on the other hand, the presence of an inner Lindblad resonance depends on the inner part of the rotation curve, so that the two hypotheses (i) and (iii) are indeed different. (We recall that the hypothesis (ii) of a hot disk seems to be ruled out by the observed small velocity dispersion of galactic disks). All this prompts us to check whether unbarred spirals differ from barred ones in their fractional disk mass \( f \). To this end we consider now the whole samples of 68 bona fide \( f_1 \)-values and 258 \( f_2 \)-values mentioned above. The values of \( M_B \) for the non-NBG galaxies are calculated by adopting redshift distances with \( H_0=75 \) km s\(^{-1}\) Mpc\(^{-1}\). The log \( f_1-M_B \) and log \( f_2-M_B \) plots presented in Fig. 4, in which different symbols denote the SA, SAB, and SB galaxies, illustrate the known, roughly linear log \( f-M_B \) correlation (e.g., Persic & Salucci, 1990), for 63 and 227 galaxies with known bar type. We have undertaken an analysis of the correlations log \( f_1-\text{BAR} \) and log \( f_2-\text{BAR} \), where the parameter \( \text{BAR} \) assumes the values 1, 2, 3 for the SA, SAB, and SB galaxies respectively. The relevant results reported in Table 2 reveal no appreciable log \( f_2-\text{BAR} \) correlation, together with an anticorrelation between log \( f_1 \) and \( \text{BAR} \) (barred objects would tend to have lower \( f \)-values than unbarred ones).

However, owing to the strong dependence of \( f_1 \) and \( f_2 \) on \( M_B \), it is necessary in this case to explore how much of the \( f-\text{BAR} \) correlation (if any) is not spurious, namely not induced simply by the strong \( f-M_B \) correlation. To do this, we calculate Kendall’s partial correlation coefficient \( r \), which is a measure of the correlation between two data sets \( x, y \) independently of their correlation with a third data set \( w \) (e.g., Siegel, 1956), where in our case \( x=\text{BAR} \), \( y=\log f_1 \) or \( \log f_2 \), \( w=M_B \). Since the sampling distribution of \( r \) is unknown, we adopt the bootstrap method of resampling (e.g., Efron, 1979; Efron & Tibshirani, 1985) in order to compute its statistical significance, performing 5000 bootstrap resamplings. The evaluation of \( r \) confirms the conclusions drawn above (see Table 2). We conclude that barred objects certainly do not show greater fractional disk masses than unbarred ones (at the same luminosity).

4 Conclusions

With respect to earlier studies, our investigation into the factors which influence the AC of a spiral galaxy evidences a considerable morphological type effect on the dependence of AC on \( M_B \). The AC is strongly related to \( M_B \) (in the sense that G galaxies tend to be more luminous than F objects) in mid types and, only weakly, in late types; in early types this relation is very marginal (it is observed only in barred systems). In view of the lack of evidence of enhanced star formation in G galax-
ies (see, e.g., Elmegreen & Elmegreen, 1986; Giuricin et al., 1989), this correlation would suggest that prominent wave modes are more easily generated in bright (large) galaxies. It is not easy to understand why this should hold substantially in mid types only.

For many years the spectacular examples of some well-known G galaxies with nearby companions (like M51 or M81) have been regarded as typical cases of G structures triggered by tidal interactions. Also very recently, a large number of numerical simulations have been devoted to reproducing G structures by means of tidal interactions (see, e.g., the extensive survey of computer simulations by Byrd & Howard, 1992). However, our statistical study reveals that, amidst the various mechanisms devised for forming and maintaining spirals — e.g., i) modes to feedback cycles and amplification at corotation, ii) edges and grooves in the density and/or angular momentum distributions, iii) bar-like or oval potentials, iv) local responses of a galactic disk when forced by a clump, like a giant molecular cloud, v) tidal perturbations (see, e.g., the review by Athanassoula, 1990) — the last one does not seem to be the dominant physical mechanism at play. As a matter of fact, the influence of the local density on AC is statistically quite weak. Nevertheless, at variance with earlier investigations, we find that the local density acts essentially only in modifying the AC-$M_B$ relation for mid types, making it tighter in denser environments, whilst no appreciable density effects are detectable in early and late types. As a consequence, if we select subsamples of bright or faint mid types, we find positive or negative AC-$p_\sigma$ correlations: in this way, for bright mid types it is indeed true that G spirals are found in denser environments. Furthermore, previous claims about the greater frequency of F galaxies in binary/interacting samples than in field galaxy samples (Giuricin et al., 1989) could be reconciled with the present results if faint galaxies or late types were overabundant in binary/interacting samples (e.g., the interacting sample constructed by Keel et al., 1985, shows an excess of late types).

Using the most recent estimates of the disk-to-total mass ratio, derived either from the gradients of good, extended rotation curves or from a photometric mass decomposition method, we do not find any significant influence of this ratio on the AC of spiral galaxies. This finding, which is seemingly at variance with earlier studies (Elmegreen & Elmegreen, 1990; Biviano et al., 1991), is affected by poor statistics ($f_1$-values) and large uncertainties ($f_2$-values); a larger sample of good rotation curves is needed to clarify this issue, which is still to be regarded as an open question.

We detect no local density effect on the disk-to-total mass ratio. Our finding is consistent with the recent results of the two-dimensional $H\alpha$ observations of Amram et al. (1992a,b). Obtaining rotation curves from the analysis of two-dimensional velocity fields, these authors found that cluster spirals located in the inner and outer regions of the cluster have rotation curves of similar shape. They disclaimed the view (see, e.g., the review by Whitmore, 1990), based mainly on slit spectroscopic observations, that the rotation curves of spirals near the cluster center tend to decrease in their outer parts.

No unambiguous bar effect on the disk-to-total mass ratio emerges from our study (a different choice of the data sample gives different results); but, in any case, the results raise some problem for some theoretical scenarios of bar formation (see, e.g., the review by Bertin, 1991), which would view barred galaxies as containing more fractional disk mass than unbarred systems.

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### Table 1: Correlation analysis

| N (1) | x | Galaxies | $r_p$ (2) | $r_S$ (3) | $r_K$ (4) | Sign. (5) | Notes (6) |
|-------|---|----------|----------|----------|----------|----------|----------|
| 1     | AC $\rho_{0.25}$ | 59 | 0.26    | 0.20    | 0.16    | 95.86%   | Early types |
| 2     | AC $\rho_{0.5}$   | 59 | 0.16    | 0.20    | 0.15    | 95.70%   | Early types |
| 3     | AC $\rho_{1.0}$   | 59 | -0.00   | 0.10    | 0.07    | $< 90\%$ | Early types |
| 4     | AC $\rho_{2.0}$   | 59 | -0.02   | 0.05    | 0.03    | $< 90\%$ | Early types |
| 5     | AC $\rho_{0.25}$ | 100 | -0.14   | -0.15   | -0.12   | 95.91%   | Mid types  |
| 6     | AC $\rho_{0.5}$   | 100 | -0.20   | -0.18   | -0.13   | 97.29%   | Mid types  |
| 7     | AC $\rho_{1.0}$   | 100 | -0.21   | -0.16   | -0.11   | 95.17%   | Mid types  |
| 8     | AC $\rho_{2.0}$   | 100 | -0.21   | -0.17   | -0.12   | 96.17%   | Mid types  |
| 9     | AC $\rho_{0.5}$   | 77  | 0.06    | 0.07    | 0.06    | $< 90\%$ | Late types |
| 10    | AC $\rho_{0.25}$ | 36  | 0.31    | 0.16    | 0.12    | $< 90\%$ | Faint early types |
| 11    | AC $\rho_{0.25}$ | 23  | 0.30    | 0.29    | 0.23    | 93.90%   | Bright early types |
| 12    | AC $\rho_{0.5}$   | 59  | -0.39   | -0.46   | -0.35   | $> 99.99\%$ | Faint mid types |
| 13    | AC $\rho_{0.5}$   | 41  | 0.31    | 0.34    | 0.26    | 99.11%   | Bright mid types |
| 14    | AC $M_B$          | 239 | -0.52   | -0.59   | -0.44   | $> 99.99\%$ | All galaxies |
| 15    | AC $M_B$          | 59  | -0.11   | -0.08   | -0.06   | $< 90\%$ | Early types |
| 16    | AC $M_B$          | 100 | -0.52   | -0.54   | -0.40   | $> 99.99\%$ | Mid types |
| 17    | AC $M_B$          | 77  | -0.06   | -0.14   | -0.11   | 91.49%   | Late types |
| 18    | AC $M_B$          | 30  | 0.07    | 0.11    | 0.09    | $< 90\%$ | Early, $\rho_{0.5}\leq0.8$ |
| 19    | AC $M_B$          | 29  | -0.30   | -0.33   | -0.24   | 96.71%   | Early, $\rho_{0.5}>0.8$ |
| 20    | AC $M_B$          | 50  | -0.31   | -0.27   | -0.20   | 97.56%   | Mid, $\rho_{0.5}\leq0.66$ |
| 21    | AC $M_B$          | 50  | -0.65   | -0.69   | -0.52   | $> 99.99\%$ | Mid, $\rho_{0.5}>0.66$ |
| 22    | AC $\log f_1$    | 19  | 0.25    | 0.25    | 0.20    | $< 90\%$ | All galaxies |
| 23    | AC $\log f_2$    | 58  | 0.17    | 0.17    | 0.12    | 90.45%   | All galaxies |
| 24    | AC $\log f_2$    | 17  | 0.26    | 0.29    | 0.21    | $< 90\%$ | Early types |
| 25    | AC $\log f_2$    | 41  | 0.06    | 0.09    | 0.03    | $< 90\%$ | Mid types |
| 26    | AC $\log f_2$    | 24  | 0.09    | 0.26    | 0.19    | $< 90\%$ | Faint galaxies |
| 27    | AC $\log f_2$    | 34  | 0.04    | 0.06    | 0.03    | $< 90\%$ | Bright galaxies |
| 28    | AC $\log f_2$    | 29  | 0.07    | 0.12    | 0.08    | $< 90\%$ | $\rho_{0.5}\leq0.6$ |
| 29    | AC $\log f_2$    | 29  | 0.22    | 0.19    | 0.13    | $< 90\%$ | $\rho_{0.5}>0.6$ |
| 30    | AC $i$            | 59  | 0.01    | 0.04    | 0.02    | $< 90\%$ | Early types |
| 31    | AC $D$            | 59  | -0.09   | -0.06   | -0.06   | $< 90\%$ | Early types |
| 32    | AC $i$            | 100 | -0.07   | -0.09   | -0.07   | $< 90\%$ | Mid types |
| 33    | AC $D$            | 100 | -0.07   | -0.06   | -0.05   | $< 90\%$ | Mid types |
Table 1: (1) progressive number; (2) and (3) parameters considered as dependent \((y)\) and independent \((x)\) variables in the correlation analysis; (4) number of objects; (5) Pearson’s linear correlation coefficient \(r_P\); (6) Spearman’s rank correlation coefficient \(r_S\); (7) Kendall’s rank correlation coefficient \(r_K\); (8) one-tailed significance level assigned to \(r_K\); (9) notes: subsample used in the analysis (all densities are in units of galaxies per Mpc\(^3\)).

Table 2: Correlation analysis of the fractional mass disk versus bar structure.

| \(N\) | \(y\) | \(x\) | Galaxies | \(r_P\) | \(r_S\) | \(r_K/r\) | Sign. |
|---|---|---|---|---|---|---|---|
| 1 | Log\(f_1\) | BAR | 63 | -0.25 | -0.25 | -0.20 | 98.98% |
| 2 | Log\(f_1\) | BAR | const. \(M_B\) | -0.25 | 99.76% |
| 3 | Log\(f_2\) | BAR | 227 | 0.01 | 0.01 | 0.01 | < 90% |
| 4 | Log\(f_2\) | BAR | const. \(M_B\) | 0.04 | < 90% |

Table 2: (1) progressive number; (2) and (3) parameters considered as dependent \((y)\) and independent \((x)\) variables in the correlation analysis (BAR=1 for SA, 2 for SAB, 3 for SB spirals); (4) number of objects; (5) and (6) Pearson’s linear correlation coefficient \(r_P\) and Spearman’s rank correlation coefficient \(r_S\), or third variable held constant in a partial correlation analysis; (7) Kendall’s rank correlation coefficient \(r_K\) or Kendall’s partial correlation coefficient \(r\); (8) one-tailed significance level assigned to \(r_K\) or \(r\).
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**Figure captions**

**Figure 1**: $\rho_{0.5}$ versus AC plot for mid-type (Sbc to Scd) spirals (a) fainter and (b) brighter than $M_B = -16$.

**Figure 2**: $M_B$ versus AC plot for mid-type (Sbc to Scd) spirals with density $\rho_{0.5}$ (a) lower and (b) greater than 0.66 galaxies Mpc$^{-3}$.

**Figure 3**: (a) log $f_1$ and (b) log $f_2$ versus AC plots.

**Figure 4**: (a) log $f_1$ and (b) log $f_2$ versus $M_B$ plots, with different symbols for SA, SAB and SB spirals.
Fig. 1
Fig. 2
Fig. 3
Fig. 4