A&A 389, 68–83 (2002)
DOI: 10.1051/0004-6361:20020460

Astronomy & Astrophysics

Analysis of the distribution of HII regions in external galaxies

IV. The new galaxy sample. Position and inclination angles*

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Received 12 February 2002 / Accepted 19 March 2002

Abstract. We have compiled a new sample of galaxies with published catalogs of HII region coordinates. This sample, together with the former catalog of García-Gómez & Athanassoula (1991), will form the basis for subsequent studies of the spiral structure in disc galaxies. In this paper we address the problem of the deprojection of the galaxy images. For this purpose we use two deprojection methods based on the HII region distribution and compare the results with the values found in the literature using other deprojection methods. Taking into account the results of all the methods, we propose optimum values for the position and inclination angles of all the galaxies in our sample.

Key words. galaxies: structure – galaxies: spiral – galaxies: ISM – ISM: HII regions

1. Introduction

Catalogs of HII regions of spiral galaxies can be used to obtain a great deal of information on their underlying galaxies. For instance, we can study the radial profile of the distribution of HII regions and compare it with the radial distribution of the light in different wavelengths. We can study also the number distribution of HII regions according to their flux and use this information to study the star formation rate in galaxies. Yet more information can be obtained by Fourier analyzing the spatial distribution of the HII regions. The distribution can then be decomposed into components of a given angular periodicity, whose pitch angles and relative amplitude can be calculated. Using such results for a large sample of galaxies should provide useful information on the properties of spiral structure in external galaxies. With this aim, we started in 1991 a study of all catalogs published until that date (García-Gómez & Athanassoula 1991, hereafter GGA; García-Gómez & Athanassoula 1993; Athanassoula et al. 1993). Since then, however, a large number of new catalogs has been published, nearly doubling our initial sample. This warrants a reanalysis of our previous results, particularly since the new published catalogs extend the initial sample specially towards barred and ringed galaxies, which were sparse in the first sample. The new sample contains also a large number of active galaxies.

In this paper we will concentrate on the fundamental step of the deprojection of the HII region positions from the plane of the sky onto the plane of the galaxy, determining the position angle (hereafter PA) and the inclination angle (hereafter IA) of each galaxy using several methods of deprojection. In future papers we will study the spiral structure of the galaxies which have a sufficient number of HII regions and use the whole sample to study the global properties of the spiral structure in external galaxies. This paper is structured as follows: In Sect. 2 we present the new sample and in Sect. 3 we discuss the different methods of deprojection used to obtain the values of PA and IA. In Sect. 4 we give the PA and IA values adopted for the galaxies in our sample and finally in Sect. 5 we compare the values of the PA and IA obtained by using the different methods of deprojection.

2. The sample

Several new catalogs of the distribution of HII regions in external galaxies have been published in the last decade. These come mainly from the surveys of Hα emission in Seyfert galaxies from Tsvetanov & Petrosian (1995), Evans et al. (1996) and González Delgado et al. (1997), from the Hα survey of southern galaxies from Feinstein (1997) and the Hα survey of ringed galaxies by Crocker et al. (1996). There have also been a considerable number of studies of the HII region distribution in individual

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* Tables 2 and 3 are only available in electronic form at http://www.edpsciences.org

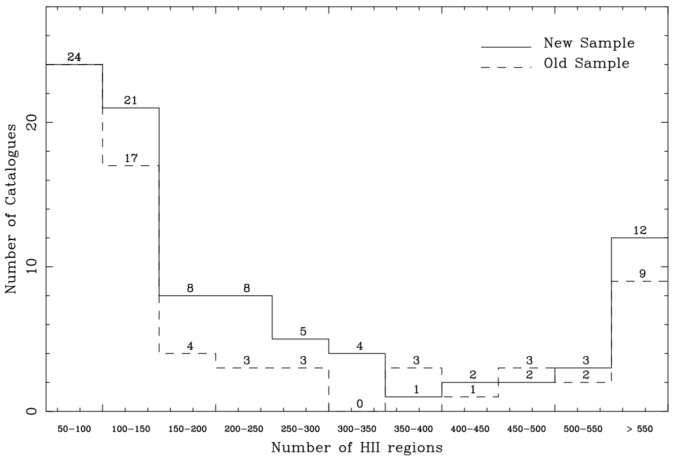

Fig. 1. Distribution of galaxies as a function of number of HII regions.

galaxies: NGC 157, NGC 3631, NGC 6764 and NGC 6951 (Rozas et al. 1996); NGC 598 (Hodge et al. 1999): NGC 3198 (Corradi et al. 1991); NGC 3359 (Rozas et al. 2000b); NGC 4321 (Knapen 1998); NGC 4258 (Courtès et al. 1993); NGC 4736 (Rodrigues et al. 1998); NGC 5194 (Petit et al. 1996); NGC 5457 (Hodge et al. 1990; Scowen et al. 1992); NGC 6184 (Knapen et al. 1993); NGC 7331 (Petit 1998) and NGC 7479 (Rozas et al. 1999).

From these studies we have retained all galaxies with an inclination less than 80° and with a sufficient number of HII regions listed. Indeed, more than 50 HII regions are necessary to allow a study of the spiral structure. Nevertheless, we included also five galaxies with fewer HII regions because we judged that they described fairly well the galaxy disc. In Fig. 1 we show the number of catalogs as a function of the number of HII regions they have. The solid line corresponds to catalogs of the new sample, and the dashed line corresponds to the sample used in GGA (1991). From this figure we see that the quality of the two samples is roughly the same.

The properties of the galaxies selected for our study and of their HII region catalogs are listed in Table 1. Column 1 gives the galaxy name. Columns 2 and 3 the Hubble type (T) and the Hubble stage (S) from the RC3 catalog (de Vaucouleurs et al. 1991). Column 4 gives the arm class (AC) as defined in Elmegreen & Elmegreen (1987). Column 5 classifies the spiral structure (SS) seen in the HII region distribution, which we obtain by eye estimates as in GGA (1991). If we can see a clear grand design spiral we give a classification Y in Col. 5 and N on the contrary. Intermediate cases are classified as R. Finally, in Col. 6 we give the number of HII regions in the catalog (N) and in Col. 7 a key for the reference of this particular catalog. The number distribution of galaxies as a function of galaxy type is shown in Fig. 2. The solid line corresponds to the number distribution of types for the galaxies of the new sample, while the dashed line corresponds to the sample used in GGA (1991). As in the previous paper the peak is for galaxies of type Sbc. Nevertheless, this sample

Table 1. General properties of the galaxies in the new sample.

Name	T	S	AC	SS	*N*	Ref.
ESO 111-10	PSXT4..	3.7	-	N	64	1
ESO 152-26	PSBR1..	1.0	-	Y	236	1
ESO 377-24	.SAT5*P	5.0	-	N	59	2
IC 1438	PSXT1*.	0.7	-	Y	44	1
IC 2510	.SBT2*.	2.3	-	N	70	2
IC 2560	PSBR3*.	3.3	-	R	137	2
IC 3639	.SBT4*.	4.0	-	N	112	2
IC 4754	PSBR3*.	2.6	-	N	114	1
IC 5240	.SBR1..	1.0	-	N	119	1
NGC 0053	PSBR3..	0.6	-	N	66	1
NGC 0157	.SXT4..	4.0	12	Y	707	8
NGC 0210	.SXS3..	3.0	6	Y	518	1
NGC 0598	.SAS6..	6.0	5	N	1272	18
NGC 1068	RSAT3..	3.0	3	N	110	3
NGC 1097	.SBS3..	3.0	12	Y	401	6
NGC 1386	.LBS+..	-0.6	-	N	44	2
NGC 1433	PSBR2..	2.0	6	R	779	1
NGC 1566	.SXS4..	4.0	12	Y	679	2
NGC 1667	.SXR5..	5.0	-	N	46	3
NGC 1672	.SBS3..	3.0	5	N	260	6
NGC 1808	RSXS1..	1.0	-	N	206	2
NGC 1832	.SBR4..	4.0	5	R	206	1
NGC 2985	PSAT2..	2.0	3	N	110	3
NGC 2997	.SXT5..	5.0	9	R	373	5
NGC 3081	RSXR0..	0.0	6	N	75	6
				N	58	2
NGC 3198	.SBT5..	5.0	-	N	104	9
NGC 3359	.SBT5..	5.0	5	Y	547	4
NGC 3367	.SBT5..	5.0	9	R	79	3
NGC 3393	PSBT1*.	1.0	-	R	80	2
NGC 3631	.SAS5..	5.0	9	Y	1322	8
NGC 3660	.SBR4..	4.0	2	N	59	3
NGC 3783	PSBR2..	1.5	9	N	58	2
NGC 3982	.SXR3*.	4.6	2	N	117	3
NGC 4051	.SXT4..	4.0	5	N	123	6
NGC 4123	.SBR5..	5.0	9	N	58	5
NGC 4258	.SXS4..	4.0	-	Y	136	16
NGC 4321	.SXS4..	4.0	12	Y	1948	12
NGC 4507	PSXT3..	3.0	5	N	92	2
NGC 4593	RSBT3..	3.0	5	Y	112	2
				R	45	5
NGC 4602	.SXT4..	4.0	-	N	218	2
			-	N	46	5
NGC 4639	.SXT4..	4.0	2	R	190	6
NGC 4699	.SXT3..	3.0	3	N	104	3
NGC 4736	RSAR2..	2.0	3	N	168	3
				N	90	17
NGC 4939	.SAS4..	4.0	12	Y	250	2
				Y	206	6
NGC 4995	.SXT3..	3.0	6	R	142	3
NGC 5033	.SAS5..	5.0	9	R	423	6
NGC 5194	.SAS4P.	4.0	12	Y	477	7
NGC 5364	.SAT4P.	4.0	9	R	174	5
NGC 5371	.SXT4..	4.0	9	Y	100	3

Table 1. continued.

Name	T	S	AC	SS	N	Ref.
NGC 5427	.SAS5P.	5.0	9	Y	300	2
				Y	164	1
				R	78	6
NGC 5457	.SXT6..	6.0	9	Y	1264	13
				Y	248	14
NGC 5643	.SXT5..	5.0	-	N	214	2
NGC 5861	.SXT5..	5.0	12	N	55	5
NGC 6070	.SAS6..	6.0	9	N	61	5
NGC 6118	.SAS6..	6.0	-	N	117	5
NGC 6221	.SBS5..	5.0	-	Y	173	2
NGC 6300	.SBT3..	3.0	6	N	977	1
				N	317	6
NGC 6384	.SXR4..	4.0	9	R	283	5
NGC 6753	RSAR3..	3.0	8	Y	541	1
NGC 6764	.SBS4..	3.5	5	R	348	8
NGC 6782	RSXR1..	0.8	-	Y	296	1
NGC 6814	.SXT4..	4.0	9	Y	734	15
				Y	131	6
NGC 6902	.SAR3..	3.1	-	R	467	1
NGC 6935	PSAR1..	1.1	-	N	166	1
NGC 6937	PSBR5*.	4.9	-	Y	213	1
NGC 6951	.SXT4..	4.0	12	Y	664	8
NGC 7020	RLAR+..	-1.0	-	N	68	1
NGC 7098	RSXT1..	1.0	-	R	188	1
NGC 7219	RSAR0P.	0.0	-	Y	139	1
NGC 7267	PSBT1P.	1.0	-	N	122	1
NGC 7314	.SXT4..	4.0	2	N	151	6
				N	117	2
NGC 7329	.SBR3..	3.0	-	R	349	1
NGC 7331	.SAS3..	3.0	3	N	252	10
NGC 7479	.SBS5..	5.0	9	R	126	11
NGC 7531	.SXR4..	2.8	3	R	549	1
NGC 7552	PSBS2..	2.0	-	N	78	5
NGC 7590	.SAT4*.	4.0	-	N	129	2

(1) Crocker et al. (1996), (2) Tsvetanov & Petrosian (1995), (3) González Delgado et al. (1997), (4) Rozas et al. (2000a), (5) Feinstein (1997), (6) Evans et al. (1996), (7) Petit et al. (1996), (8) Rozas et al. (1996), (9) Corradi et al. (1991), (10) Petit (1998), (11) Rozas et al. (1999), (12) Knapen (1998), (13) Hodge et al. (1990), (14) Scowen et al. (1992), (15) Knapen et al. (1993), (16) Courtés et al. (1993), (17) Rodrigues et al. (1998), (18) Hodge et al. (1999).

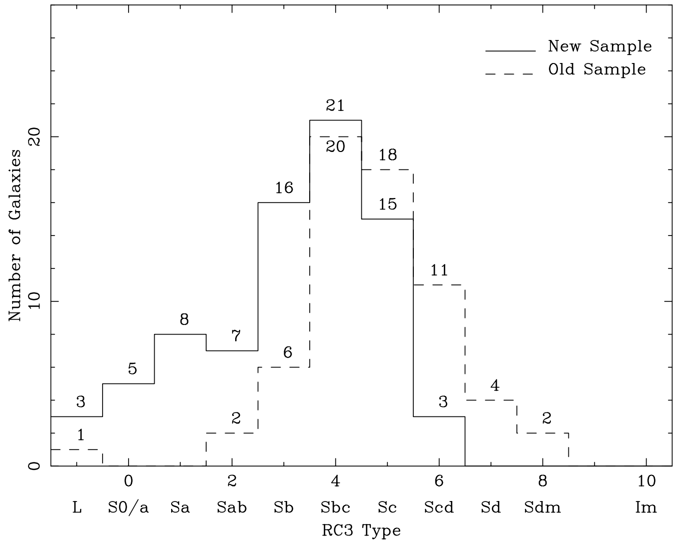

Fig. 2. Distribution of galaxies as a function of galaxy type.

contains many more earlier type galaxies than the previous one. Indeed, in the previous sample most galaxies are of type Sbc and later, while in the new one most are Sbc and earlier.

In Fig. 3 we compare the arm class classification of Elmegreen & Elmegreen (1987) with our classification of the arm structure present in the HII region distribution. The left panels refer to the galaxies in the new sample and the right panels to the galaxies in the GGA (1991) sample. The upper panels correspond to galaxies classified as Y, the second row of panels correspond to the galaxies classified as N and the third row contains the galaxies classified as R. The last row contains the distribution of all the galaxies according to arm class. The figure shows that galaxies classified with higher number in the arm class have a tendency to have well developed arms in the distribution of HII regions. There are, however, exceptions as e.g. NGC 5861 which has been given an arm class 12 by Elmegreen & Elmegreen (1987), but has no apparent spiral structure in the HII region distribution.

We should also note that our new sample is formed mainly by barred and ringed galaxies. This is shown in Fig. 4 where we can see the number distribution of galaxies as a function of bar type as given in the RC3 catalog. In the upper panel we show the distribution of bar types of the galaxies of the GGA (1991) sample. In the middle panel we show the distribution for the new sample and in the lower panel the distribution of bar types of the two samples combined. While the first sample was biased towards non-barred galaxies (upper panel), the new catalog is biased towards barred and/or ringed galaxies (middle panel). This gives a quite uniform total distribution (lower panel).

Our final aim is to study the spiral structure outlined by the HII region distribution. Obviously, this cannot be done with a catalog with a number of HII regions lower than 50, and only the richer catalogs will be considered for this purpose in a forthcoming paper. Nevertheless, useful information on the galaxies can be obtained even from the less rich catalogs, as e.g. the orientation of the galaxies as seen in the sky and the radial scale of the distribution, which can be compared with the radial scale length of galaxy discs (Athanassoula et al. 1993).

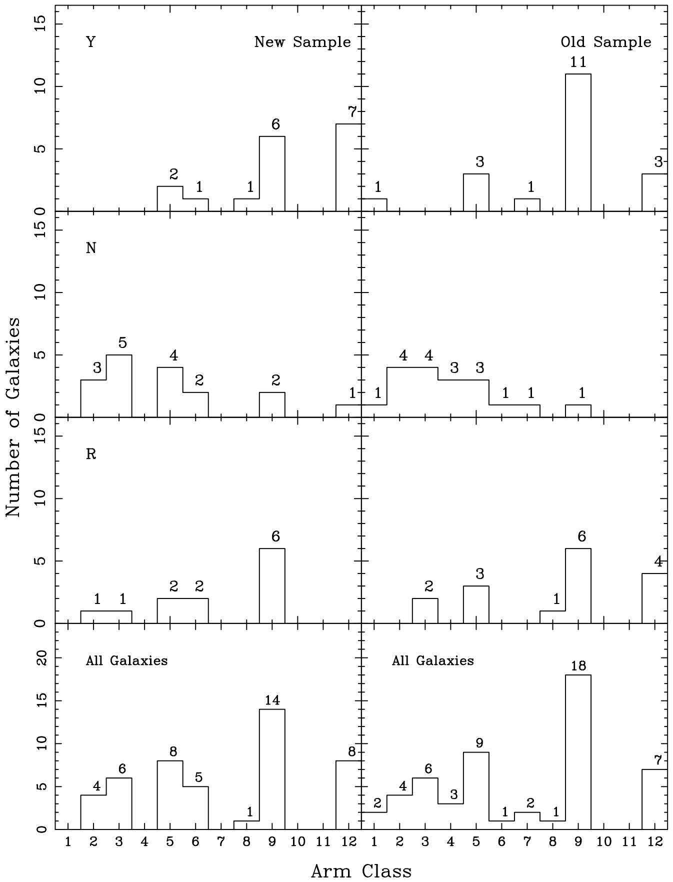

Fig. 3. Comparison of the arm classification of Elmegreen & Elmegreen (1987) with our own classification of the arm structure present in the HII region distribution. The histograms give the number of galaxies as a function of the Elmegreen & Elmegreen (1987) arm class. Left panels are for the new sample and right ones for the old one. The upper panels contain galaxies with prominent spiral structure in their HII region distribution. The second row, galaxies with no such structure. The third row contains galaxies which are intermediate or unclassifiable, and the fourth row, all galaxies together.

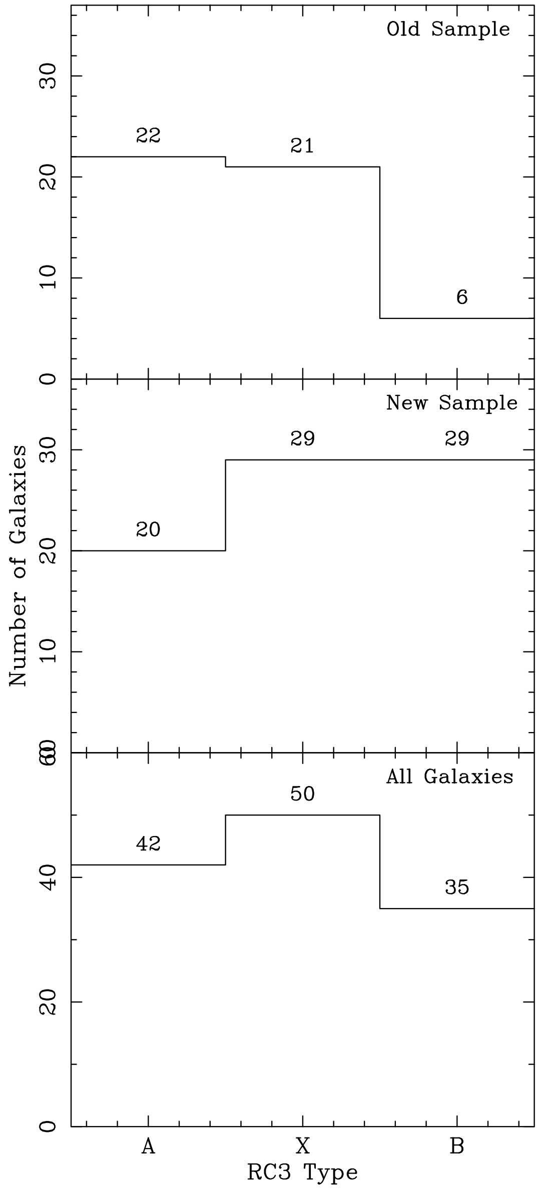

Fig. 4. Distribution of galaxies according to the bar type classification of the RC3 (1991) catalog.

3. Deprojection methods

The first step in order to study the distribution of HII regions is to deproject the images of the galaxies. For this we need two angles, namely the position angle (PA) – which is the angle between the line of nodes of the projected image and the north, measured towards the east – and the inclination angle (IA) – which is the angle between the line perpendicular to the plane of the galaxy and the line of sight –. An IA of zero degrees corresponds to a galaxy seen face-on.

Two basic groups of methods have been used so far to determine these angles. The first one is based on photometry and images, and the second one on kinematics. The most standard way to use images is to fit ellipses to the outermost isophotes and measure their axial ratio. This method, which is often used in the literature, is well suited for discs which are not warped, and requires photometric images with high signal-to-noise ratio in the outer parts, where the influence of non axisymmetric components like arms and bars is minimum. Several variants have also been proposed: Danver (1942) used a special display table to rotate the galaxy images until they were circular. Grosbøl (1985) applied the one dimensional Fourier transform to the intensity distribution in the outer parts of disc galaxies and adopted the deprojection angles that minimized the bisymmetric Fourier component.

Another classical method uses a two dimensional velocity field of the galaxy. Assuming that the emission comes from a thin planar disk, which is in circular motion around the galaxy center, we can select the deprojection angles that minimize the departures from such a flow. This method is particularly well adapted for HI kinematics, which covers the whole galaxy disk. During the last decade, however, this method has been applied also to data coming from CO and Hα kinematics, which are generally more restricted to the central parts. This method is specially well suited for measuring the PA. In the case of warps, a tilted ring model can be used, but the values of the deprojection angles will not be uniquely defined, as they will change with galactocentric radius.

Searching in the literature, we can also find other kind of methods to derive the deprojection angles that do not use the techniques described above. Comte et al. (1979) used a plot of the HII region distribution of M 101 in a $\log(r) - \theta$ plane to fit a straight line to the arms, using the hypothesis that the arms are well described by logarithmic spirals. Iye et al. (1982) applied the two dimensional Fourier analysis to the galaxy NGC 4254, using a photometric image, and chose the deprojection angles that maximize the axisymmetric component. Considère & Athanassoula (1982) also applied Fourier analysis but used instead published catalogs of HII regions. The criterion that they used was to maximize the signal to noise ratio in the $m = 2$ component. This same criterion was used by Considère & Athanassoula (1988) but using instead photometric galactic images.

In this paper we will use two methods, which were already introduced by GGA (1991). For our first method we use two dimensional Fourier analysis of the galaxy image. We decompose the HII region distribution in its spiral components using a basis formed of logarithmic spirals. Since the deprojected galaxy should be more axisymmetric than the projected one, we can calculate the deprojection angles are as the angles that maximize the ratio:

$$\frac{B(0)}{\sum_{m=1}^{N} B(m)}, \tag{1}$$

where the $B(m), m = 0, \ldots, N$ are defined as:

$$B(m) = \int_{-\infty}^{\infty} \mid A(p, m) \mid \; \mathrm{d}p \tag{2}$$

and the function $A(p, m)$ is the Fourier transform of the HII region distribution, considered as a two dimensional distribution of δ-functions of the same weight:

$$\begin{aligned} A(p,m) \; &= \; \int_{-\infty}^{+\infty} \int_{-\pi}^{+\pi} \frac{1}{N} \\ &\times \sum_{j=1}^{N} \delta(u - u_j)\delta(\theta - \theta_j)\mathrm{e}^{-i(pu+m\theta)} \; \mathrm{d}u\mathrm{d}\theta \quad (3) \\ &= \; \frac{1}{N} \sum_{j=1}^{N} \mathrm{e}^{-i(pu_j + m\theta_j)}. \end{aligned}$$

In the above (r_j, θ_j) are the polar coordinates of each HII region on the galaxy plane, $u_j = \ln r_j$ and N is the total number of HII regions. The details of this method are outlined in GGA (1991). It is clear that this method will work mainly for distributions which have a clear signal of all the components of the spectrum, specially the $m = 0$ component which corresponds to the background disk distribution.

Our second method was also described in GGA (1991). This method is specially devised for HII region distributions. If an axially symmetric distribution of points is divided in N_s equal sectors, like cake pieces, and it is sufficiently rich, then we expect to have a roughly equal number of HII regions in each piece, when viewing it from a line of sight perpendicular to the disc. If the same distribution of points is now viewed from a skew angle and we again use sectors, which are of equal surface in the plane perpendicular to the line of sight, then the number of HII regions will *not* be the same in all sectors. Thus the correct deprojection angles will be those for which the number of points in each sector is roughly the same, or, in other words, when the dispersion around the mean value is minimum.

None of the methods described are free from systematic errors. In fact they all work perfectly well for the theoretical case of a razor thin, axisymmetric disc in circular motion around its center but present more or less important problems for galaxies deviating from this idealized case. When we fit ellipses to the isophotes, the presence of strong bars and/or spiral arms can bias the results, if the isophotes are not sufficiently external. However, Athanassoula & Misiriotis (2002) show that even for very strong bars the isophotes in the outermost part of the disc are sufficiently circular to be used for deprojection. If we use the velocity fields in HI, the external parts of the galaxy may be warped, in which case the deprojection angles will be ill defined. Our methods also can suffer from systematic problems. For instance, in the case of the first method, if the HII region distribution delineates mainly the $m = 2$ arms and there are only few regions in the background disk, the ratio (1) will not be well defined and the method can find difficulties. Our methods can also find problems in the case of highly irregular distributions, as well as in strongly barred galaxies where many HII regions are concentrated in the bar region. In these cases our methods will erroneously tend to circularize the bar. A similar difficulty appears when many HII regions are located in some galaxy rings. Buta (1995) using his Catalog of Southern Ringed Galaxies showed that rings need not be circular. The outer features have an average intrinsic axis ratio of 0.87 ± 0.14 while the inner features an average of 0.84 ± 0.10. This indicates that some rings must have an oval nature. Our methods, however, will tend to circularize these structures when they dominate the HII region distribution. Thus they will attribute to a face on case an IA of 12.5 degrees if there was an outer ring of axial ratio of 0.87 and of 9.8 degrees if there was an inner ring of axial ratio 0.84. Of course if only part of the HII regions are in the ring component, then the error could be smaller. In such cases, where HII regions delineate the several components, we obtain secondary minima in the results obtained by our methods. It is thus necessary to check if some of these minima give better results than the principal minimum, which can be strongly biased by some of the effects described above.

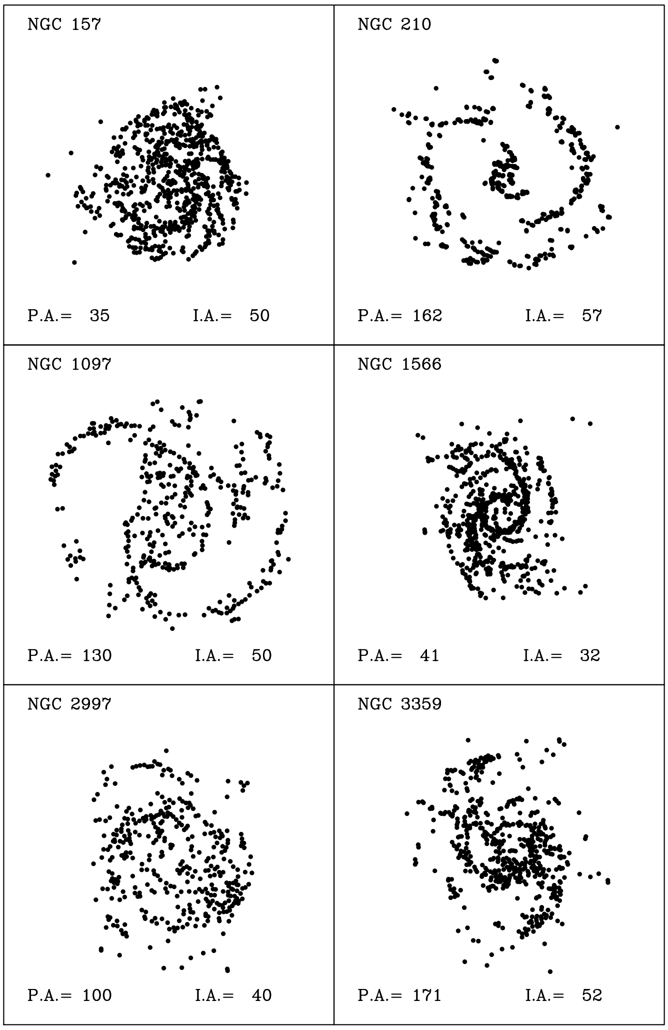

Fig. 5. Deprojected HII region distribution of the galaxies in our sample with rich catalogs and clear spiral structure.

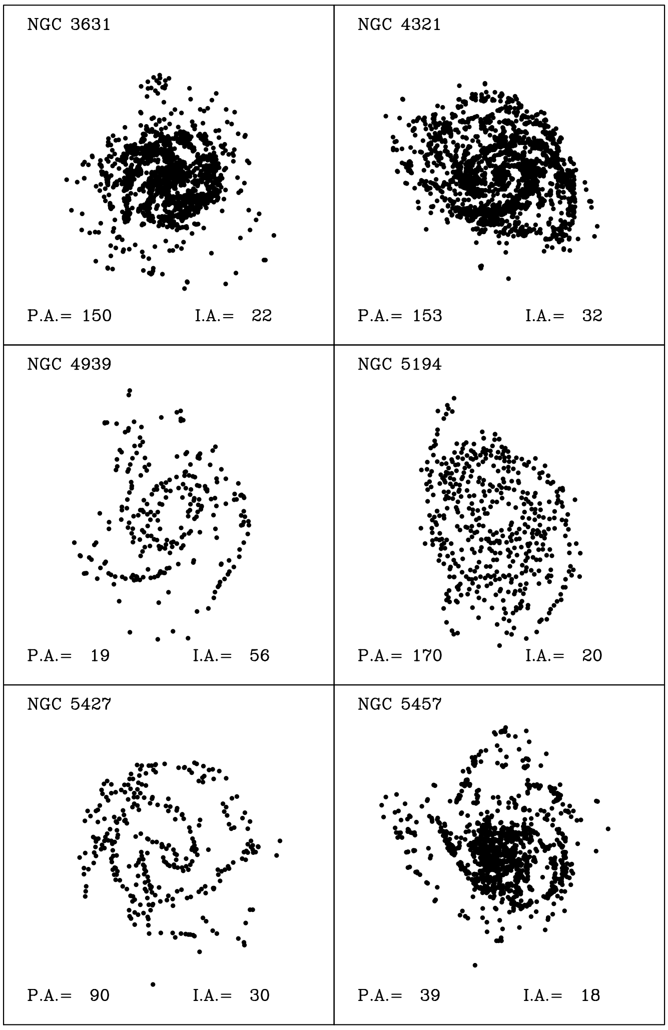

Fig. 5. continued.

Thus, instead of relying on a single method in the crucial step of deprojecting the galaxy image, a comparison of the values given by the different methods is in order. In this way we can choose the pair of deprojection angles that suit best a particular galaxy. Our two methods, in conjunction with the literature values, were used in our first sample of HII region distribution of spiral galaxies (GGA, 1991). In this paper we will use this procedure to the HII region catalogs published in the last decade. We should, however keep in mind that our new sample has a high fraction of barred and ringed galaxies, where our two methods may not perform as well as for the galaxies in the GGA (1991) sample (see Fig. 4).

4. Notes on individual galaxies

In this section we give some comments on the deprojection angles chosen for each individual galaxy. This information is shown in Table 2. In Col. 1 we give the galaxy name. In Cols. 2 and 3 we show the PA and IA obtained using our two methods. In the first row we show the values for our first method, while in the second row those for our second method. If there are more than one catalog for a particular galaxy, the values found using our methods are displayed in the following lines. In Cols. 4 and 5 we show the main values of PA and IA respectively found in the literature. In Col. 6 we give a key to describe the method used to obtain the literature values. P is used for photometric values, KH is used for values determined using HI velocity field, KC for values determined using a velocity field in CO, KO for optical velocity fields, KS is used when the values come from slit spectra determinations and finally O is used for methods different to the previous ones. In Col. 7 we give a key for the reference where this particular determination can be found. This key is resolved in Table 3. Finally in Cols. 8 and 9 we give the adopted values of the PA and IA respectively. This same structure is repeated in the second group of columns. Using the finally adopted values we can deproject the catalogs of HII regions. The deprojected distribution of the richer catalogs showing with spiral structure are shown in Fig. 5 while in Fig. 6 we present the rest.

ESO 111-10: this is a galaxy with apparent small size and the catalog of HII regions is not very rich.

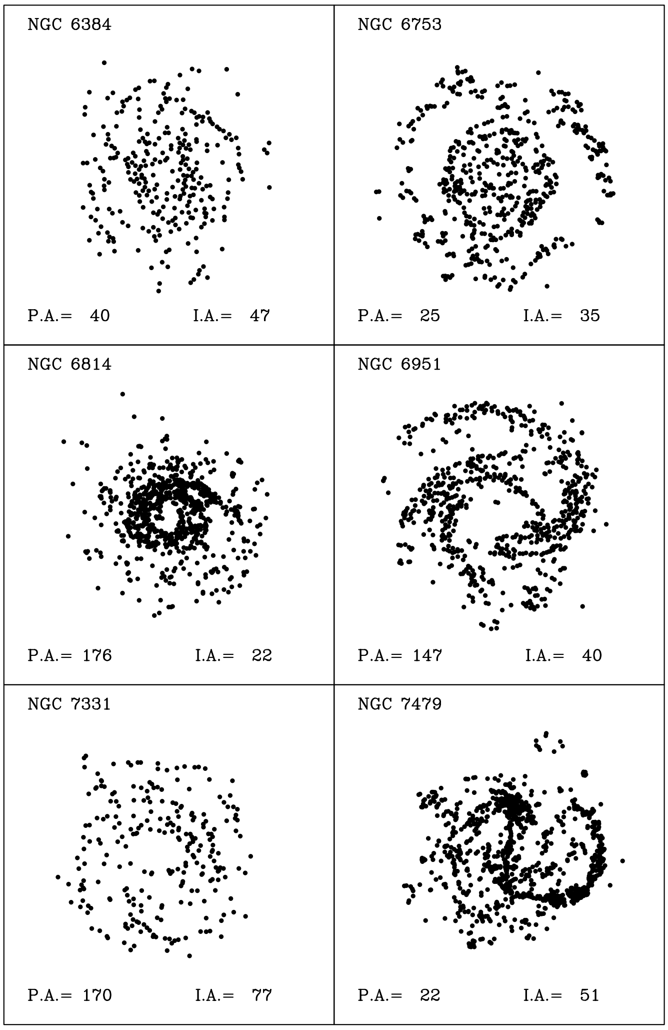

Fig. 5. continued.

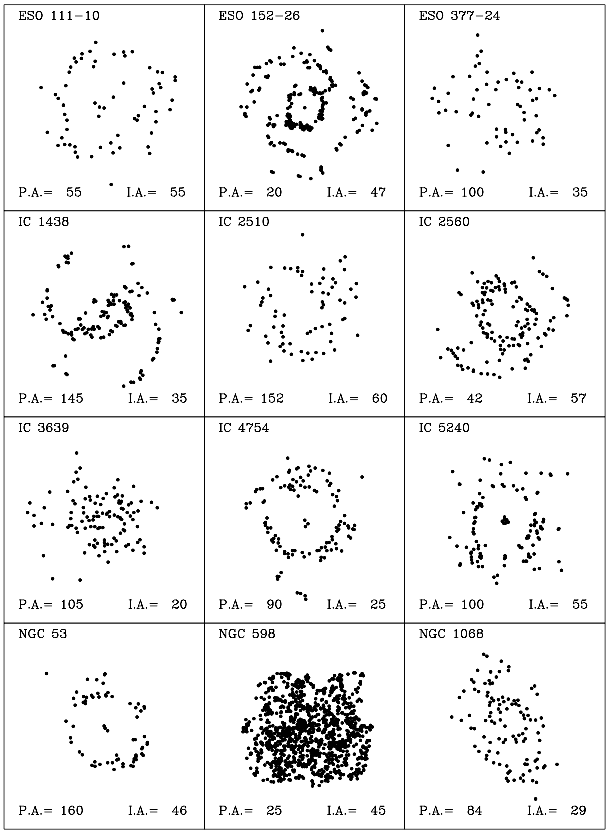

Fig. 6. Deprojected HII region distribution of the rest of the galaxies in our sample.

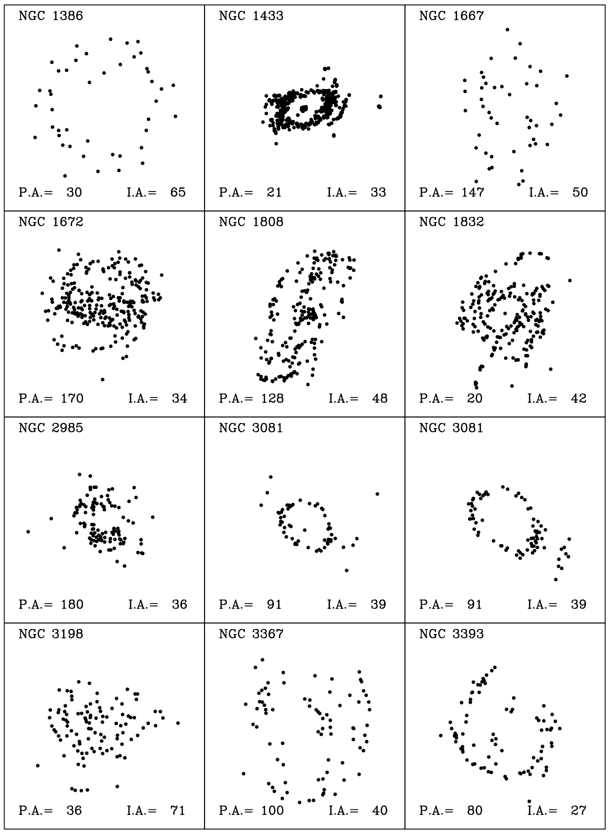

Fig. 6. continued.

Nevertheless, our two methods give a good agreement when we use a secondary minimum for the second method. We adopt the mean of both methods, which agrees well with RC3.

ESO 152-26: for this galaxy the HII regions are placed mainly in the arms and in the inner ring. Our two methods give the same value for the position angle and close values for the inclination angle. Eye estimates, however, show that the value of the PA is not satisfactory, presumably because our methods try to circularize the ring. We thus use the PA from the photometry of Crocker et al. (1996) and the mean of our IAs, which is also the mean of the literature values.

ESO 377-24: this is a small sized and not very inclined galaxy. The number of HII regions in the catalog is also small and both methods give a minimum at values more appropriate for a more inclined galaxy. Using secondary minima for both methods we get a reasonable agreement with the values from RC3 (1991). We finally adopt the values from the second method, which are in agreement with the photometry and close to the values of the first method.

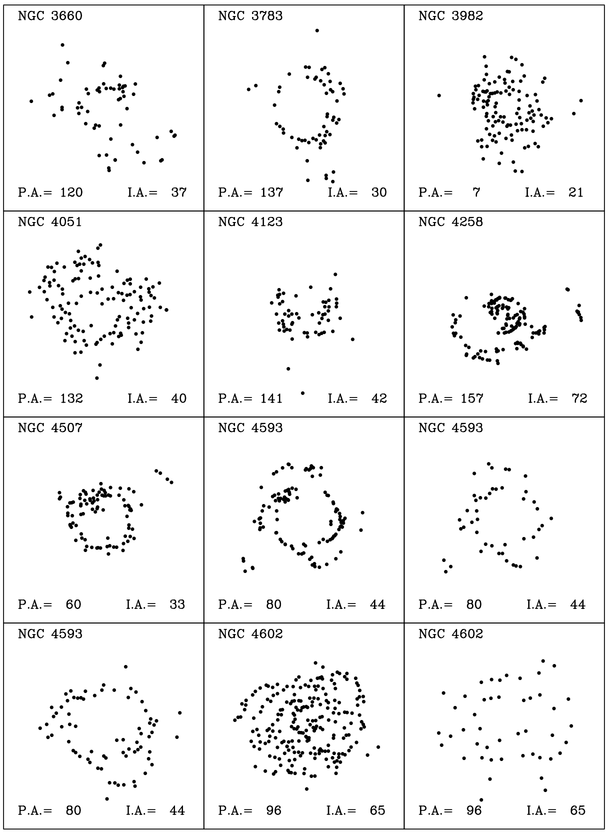

Fig. 6. continued.

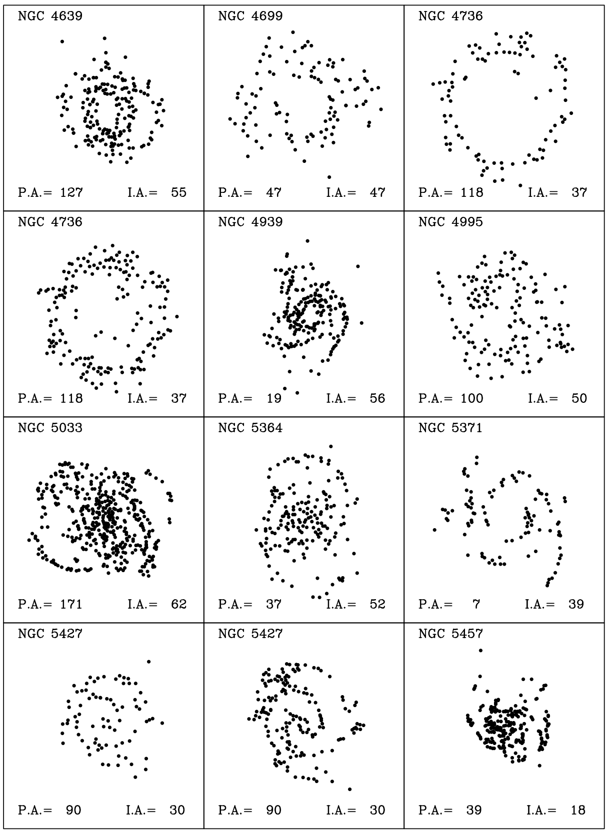

Fig. 6. continued.

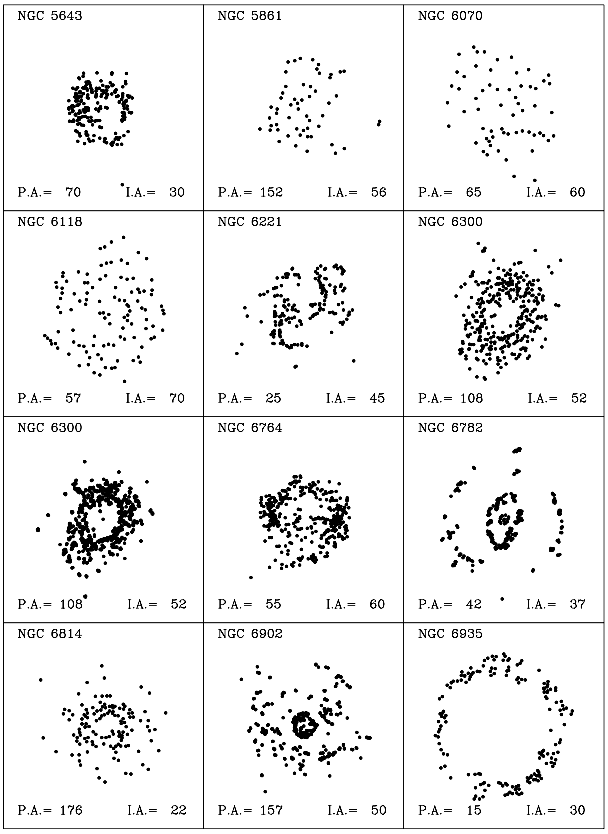

Fig. 6. continued.

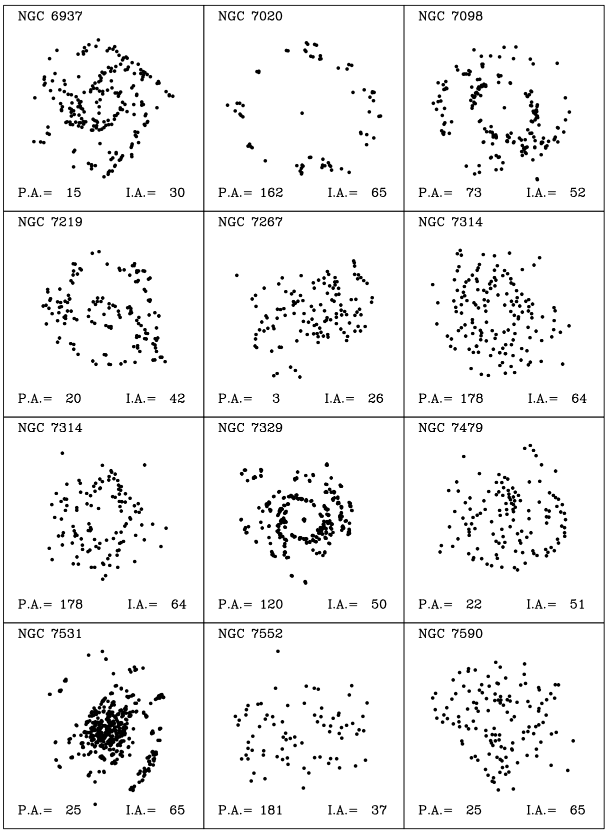

Fig. 6. continued.

IC 1438: the HII regions are placed mainly in the arms and the ring of this nearly face-on galaxy. The two methods are in good agreement. But as there is no background disk of HII regions, the first method may be biased by the presence of the spiral structure. We thus keep the PA from the second method, which coincides with that found by Crocker et al. (1996). For the IA we take the average of our two methods.

IC 2510: this is a galaxy of a very small apparent size. Nevertheless, as it is quite inclined, our two methods give results in good agreement and we keep the mean of the two, which is, furthermore, in good agreement with the literature values.

IC 2560: our two methods are in good agreement for this galaxy and we adopt the mean of their values, which agrees well with the PA given in the RC3 (1991) and the Lauberts-ESO catalogs (1982), and with the IA of the former.

IC 3639: this is a nearly face-on galaxy in a small group. The catalog of HII regions is quite irregular and does not show any spiral structure. We adopt the values from our second method, which are in agreement with the PA of Hunt et al. (1999) and the average IA of all methods. Note, however, that there is a lot of dispersion around the mean values, which could mean that our estimate is not very safe.

IC 4754: this is a ringed, small size galaxy. Nearly all of the HII regions of the catalog are placed in the external ring. Our methods are in agreement for the IA and the agreement for the PA is only reasonable, but the values from the PA are poorly determined as the projected catalog looks quite round. We prefer to keep the values from the second method, which are in agreement with two of the photometric values for the PA and all the values for the IA.

IC 5240: this case is quite similar to the previous one. Again the HII regions are placed mainly in the external ring, but as the galaxy is quite inclined, both methods are in reasonable agreement. As before, we keep the values from the second method, whose PA is in excellent agreement with all the literature values, and the IA with the results of the Lauberts ESO catalog (1982).

NGC 53: the HII regions are placed only in the outer ring and their number is quite low. On the galaxy image, it seems that the inner ring is not oriented as the main disk, but along the bar. Our first method tends to circularize this ring which is not necessarily circular. So, we keep the mean values from the photometry of the RC3 (1991) and the Lauberts ESO catalog (1982).

NGC 157: this galaxy seems to be a bit irregular and this is reflected in the rich catalog of HII regions. Nevertheless the two methods are in excellent agreement between them and in fair agreement with the literature values Thus, we keep the mean of our values.

NGC 210: the HII regions trace very well the arms and the inner ring. Our two methods are in agreement with the literature values and thus we keep the mean of our values.

NGC 598: our two methods are in good agreement but the values that they give are not in agreement with the rest of the literature values, probably due to an incomplete sampling of the galaxy disk in the HII region catalog from Hodge (1999). Thus, we prefer to keep the mean of the kinematically derived values.

NGC 1068: the HII regions are placed only in the inner bright oval, and the values obtained using both methods, while in agreement, are inadequate. The values given by Sánchez-Portal et al. (2000) also pertain to the inner bright oval. Thus, we take the mean of the values from the velocity fields.

NGC 1097: our two methods agree well for the values of IA, but the discrepancy is higher for the PA. The first method gives rounder arms, so its PA and IA values must have been highly influenced by a Stocke's effect (Stocke 1955), while the second gives a rounder central part. These latter values agree very well with the HI kinematical values from Ondrechen (1989) as well as with three of the photometrical estimates, so we will adopt the values from the second method.

NGC 1386: our two methods give identical results for this quite inclined galaxy, which are furthermore in agreement with the photometric estimates. We adopt the values from our two methods.

NGC 1433: the HII regions trace very well the inner ring of this galaxy. Both methods try to circularize this inner ring giving a strong disagreement with the kinematical values. We adopt the values from the velocity fields.

NGC 1566: this galaxy was also studied in the first paper, where we used the catalog by Comte et al. (1979) which traces also the external arms. For this new catalog, the HII regions are placed mainly in the inner oval part and the results of our methods disagree. The values obtained from the first catalog by GGA (1991) are in good agreement with the values from the kinematics, so we adopt the mean values of the GGA values and the optical velocity field from Pence et al. (1990).

NGC 1667: this galaxy has a small apparent size, with a catalog with a low number of HII regions. Nevertheless, as the galaxy is quite inclined, the two methods are in reasonable agreement and we give the mean of both methods.

NGC 1672: our second method does not converge, probably due to the strong bar present in this galaxy. On the other hand our first method gives a PA value in good agreement with the photometric values form RC3 (1991) and the Lauberts-ESO catalogs (1982), but the value obtained for the IA value seems too high. We keep the values from the RC3 catalog.

NGC 1808: there is a good agreement between the two methods, but the HII regions trace only the inner bright oval part and there are no regions in the outer arms or disk. The outer disk in the galaxy image seems to be much less inclined. For this reason we prefer to keep the kinematic values from Koribalski et al. (1993).

NGC 1832: this galaxy was studied also in the first paper, but using a catalog with a low number of

HII regions. Using this new catalog, the two methods are in good agreement, and there is a rough general agreement with the rest of the values from the literature. Thus we keep the mean of our two methods.

NGC 2985: the HII region distribution is quite irregular, but despite this fact, the first method gives values in reasonable agreement with the RC3 (1991) catalog. The second method does not work. We adopt the mean between our first method and RC3 (1991).

NGC 2997: this galaxy was also studied in the first paper using a similar catalog. Using the new catalog we find values for the IA that are in reasonable agreement between them, while the values for the PA are not so well constrained. The mean of the two methods are in agreement with the kinematical values from Milliard & Marcelin (1981) and the photometric values from the RC3 (1991) and, to a lesser extent, with the rest of the values. We adopt the mean of our two methods.

NGC 3081: for this galaxy we have two catalogs with distributions of similar shape, the HII regions being mainly in the inner ring. As both methods try to circularize this ring we prefer to adopt the mean of the values from the photometry and kinematics from Buta & Purcell (1998).

NGC 3198: there is a good agreement between our two methods for this quite inclined galaxy. There is also a general agreement with the rest of methods. The projected HII region distribution, however, seems somewhat irregular, and this may bias our two methods, giving higher values from the PA. For this reason we prefer to adopt the mean values from the HI kinematical studies of Bosma (1981) and Begeman (1987). Note that these are in good agreement with our second method and reasonable agreement with the first.

NGC 3359: our methods are not adequate for this galaxy because a lot of HII regions are located in the bar region. We thus keep the mean of the kinematical values from the Hα velocity field from Rozas et al. (2000b) and HI velocity fields from Gottesman (1982) and Ball (1986).

NGC 3367: the values given by the various methods cover a broad range of values. Our two methods give the same value for the IA, which is furthermore in agreement with the value from Danver (1942). The average of the two values of the PA are in agreement with the photometry from Grosbøl (1985). We thus adopt the mean of our two methods.

NGC 3393: the situation for this galaxy is highly unsatisfactory. The PA of 160 is mainly reflecting the orientation of the bar, so it can be dismissed. The estimate of 41 degrees comes from the outer isophote, but this seems to be heavily distorted, partly by the arms. Our methods should suffer from Stocke's effect (1955). Since our purpose in the following pages will mainly be to study the spiral structure and our two methods agree well, we will adopt their average for our future work. We stress, however, that this is due to the lack of any better estimate.

NGC 3631: this is a nearly face-on galaxy, and thus although we use a very rich catalog, the values of PA and IA are not very well constrained. We adopt the value of the PA derived in the kinematical analysis of Knapen (1997). However, the kinematic analysis did not give a value for the IA, so we adopt the mean of our methods for this angle, which is in rough average with the photometric values.

NGC 3660: the catalog of HII regions is quite poor and the values of PA and IA are not very well constrained. Nevertheless, the two methods are in good agreement and in rough agreement with the photometric values from RC3 (1991). We adopt the mean of our two methods.

NGC 3783: the HII regions of this catalog populate an inner ring. Nevertheless, our two methods are in good agreement with the only PA value that we found in the literature and with the IA of RC3 (1991). There is also a rough agreement with the IA values from other studies. We adopt the mean of our methods.

NGC 3982: this is a small apparent size galaxy nearly face-on and the HII region catalog is quite poor. Both our methods have two clear minima, however, and are in good agreement between them. Moreover, they are in rough agreement with the photometry, so we adopt the mean values of all methods.

NGC 4051: the HII region distribution is somewhat irregular and the first method gives results only in rough agreement with the values from the second method. We finally adopt the kinematical values of Listz & Dickey (1995), which are in general agreement with most of the photometric values.

NGC 4123: the number of HII regions is quite low and the HII region distribution traces mainly the bar region. The first method does not work properly, so should be neglected. The values from our second method are in good agreement with the values from the kinematics. Seen the poor quality of the HII region catalog we adopt the mean values from the kinematics.

NGC 4258: as our two methods are in agreement for this quite inclined galaxy we adopt their mean value which is in agreement with the results of the velocity fields of van Albada (1980) and van Albada & Shane (1975).

NGC 4321 (M100): this galaxy is not very inclined and thus the value of the PA is not well constrained. On the other hand, there is a rough agreement about the IA for the rest of the methods. We adopt the kinematical values of Guhatakurta (1988).

NGC 4507: the galaxy has a small size and the HII regions populate a ring. Our two methods do not work properly because they try to circularize the ring. We adopt the deprojection angles obtained in the photometric study of Schmitt & Kinney (2000).

NGC 4593: this is a strongly barred galaxy for which there are three published catalogs of HII regions. Our two methods are in good agreement for the richer catalogs but the first method gives discordant results in the second catalog and the second method does not work at all. Thus we discard the values from the second catalog. The mean of our values are also in general agreement with the photometric values, except for the case of the *I* photometry by Schmitt & Kinney (2000) who give a higher PA value than the rest. We adopt the mean values of the results of our two methods applied to the first and third catalog.

NGC 4602: all values of the PA are in rough agreement, except for the value given by Mathewson & Ford (1996), which by eyeball estimate does not look very reasonable. We adopt an average value of our two methods and both catalogs, which also agrees with RC3 (1991) and Danver (1942).

NGC 4639: there is good agreement between the values obtained by our methods. Thus, we take the average values. This is also in agreement with the literature values.

NGC 4699: we adopt the average of our two methods, which is in good agreement with the photometric values.

NGC 4736: for this galaxy, we have two catalogs. In both cases, nearly all the HII regions are placed in the external ring. Our four results are only in rough agreement and they are, furthermore, not very reliable since they pertain to the ring. Thus, we prefer to adopt, the mean values given from the velocity fields (Bosma et al. 1977; Mulder & van Driel 1993; Buta 1988) which are in good agreement between them and also with the average of our two methods and the two catalogs.

NGC 4939: we have two catalogs of similar richness for this galaxy. It is quite inclined and the two methods are in rough agreement for both catalogs. We take the averages of our two methods and the two catalogs, which is in agreement with the photometric values and the value given in GGA (1991).

NGC 4995: our two methods give identical results, which we adopt, since they are also in good agreement with the photometric values from RC3 (1991) and Grosbøl (1985).

NGC 5033: a number of estimates are available for the deprojection angles of this galaxy, and all cluster in a relatively narrow range of values. The results of our two methods are in good agreement between them and with the rest of the estimates. The deprojection of the HII region distribution is particularly sensitive to the adopted value of the IA. We tired several averages of the individual estimates both straight and weighted by our judgment of the quality which resulted in identical values. We adopt these mean values.

NGC 5194 (M 51): our two methods are in good agreement, but the values of the position angles in particular, using the primary minima, are quite discordant with the values obtained from the analysis of the velocity fields. Note that they are also similar to some of the derived photometric values. The deprojected galaxy using our values looks quite good, as already noted in GGA (1991). There is, however, a secondary minimum, which is in agreement with the values derived from the velocity fields. With these values we get also a round deprojected galaxy. We adopt the value from Rots et al. (1990), which are as stated, in agreement with the average of the secondary minima value.

NGC 5364: we take the average values from our two methods, which is in agreement with the rest of the values in the literature.

NGC 5371: the galaxy was too big to fit in the CCD frame used by Gonzàlez-Delgado et al. (1997), so that, the PA values found using this catalog can not be very reliable. We thus adopt for this galaxy an average of the photometric values.

NGC 5427: here the two methods and the three catalogs give different results, which again are very different from the literature values. This is not surprising as the galaxy is not very inclined and there is no derived velocity field in the literature. For lack of any stronger criteria and looking at the deprojected images obtained with all these values, we decided to adopt the result of the first method and the richer catalog. However, it should be stressed that these are very ill defined values.

NGC 5457 (M 101): this galaxy is nearly face-on. Thus, the values of the PA are not well constrained. Our methods prefer a galaxy completely face on but, as the galaxy is quite asymmetrical, we have decided to adopt the values obtained by the HI high resolution study of Bosma et al. (1981).

NGC 5643: the catalog of HII regions has an irregular distribution. The outer parts look also irregular in the galaxy images. Thus, our two methods as well as the photometric values are very unsafe. For lack of any stronger criteria, we adopt the results of the first method, which give a rounder deprojected object. It should nevertheless stressed that is a very unsafe estimate.

NGC 5861: there are very few HII regions in this catalog, so we adopt the values given by Grosbøl & Patsis (1998). It should, nevertheless be noted that, although the catalog is poor, our results are in fair agreement with the photometric ones.

NGC 6070: there is a good agreement between our two methods and the results available in the literature. We adopt the average of our two methods.

NGC 6118: for this galaxy we have, as in the former case, a good agreement between our methods and the literature values. Thus, we adopt the average of our two methods.

NGC 6221: the HII regions trace mainly the arms and give a rather irregular distribution, so that our second method is not reliable. There is a good agreement between our first method and the photometric value from Pence & Blackman (1984). We finally adopt our first method values. Note that the IA is in good agreement with the remaining photometric values.

NGC 6300: the results of the kinematical values of Ryder et al. (1996) and of Buta (1987b) are in perfect agreement, so we adopt these values. Our two methods are less reliable, since the HII regions are mainly lying in a ring for both catalogs. Nevertheless, it is worth noting that there is a reasonable agreement between our values and the adopted ones and also with the rest of the values.

NGC 6384: our two methods agree between them and we have adopted the average of their values. Our IA values agree well with the photometric ones, while the PA does so reasonably well. The IA given by Prieto et al. (1992) seems more reliable than that of Sánchez-Portal et al. (2000), since the data extend further out in the region which is less influenced by the oval bar. This agrees with the mean of our values. The PA we adopt is somewhat higher than those given by the photometry. The deprojected catalog, however, has a round shape and thus we keep our values.

NGC 6753: our two methods agree reasonably well between them, so we take the average values which are in good agreement with the photometric values.

NGC 6764: our two methods give identical results and also agree quite well with the available photometric values, so we adopt our values.

NGC 6782: we adopt the average of our two methods, which is in reasonable agreement with the photometric values, as in the previous galaxy.

NGC 6814: this is a nearly face-on galaxy and as a result the values of the angles are not well constrained. We have two catalogs of different richness. As the PA can not be well constrained using our methods, we have decided to adopt the values from the kinematics of Listz & Dickey (1995) which are in fair agreement with the values obtained by our methods for the less rich catalog from Evans et al. (1996). Note that the richer catalog of Knapen et al. (1993) has a well delineated strong northern arm which can bias our results.

NGC 6902: we adopt the average of our two methods which is in good agreement with the results given in the RC3 (1991) catalog, and agrees also with the average of the rest of the literature determinations.

NGC 6935: the HII regions trace the outer ring only. Our second method does not work, and converges to a value with too high inclination, so we neglect it. We adopt the result from the first method which is in good agreement with the inclination of the RC3 (1991) catalog.

NGC 6937: no reasonable minimum was found by the first method and we adopt the values from the second method, which agree well with the inclination of the RC3 catalog, but not so well with the values quoted by Crocker et al. (1996).

NGC 6951: we take the average of our two values which are in good agreement with the values derived by Grosbøl (1985).

NGC 7020: the few available estimates agree well with our two methods, so we take the average of our two values.

NGC 7098: our two methods try to circularize the inner ring so that, even though they agree well between them, they are not very meaningful. We thus adopt the average of the photometric results.

NGC 7219: the first method does not work very well, so we list a secondary minimum. Our adopted values are the average of the two methods and are in reasonable agreement with the few available literature values.

NGC 7267: the few HII regions are mainly in and around the bar and not in the surrounding disc. We thus adopt, the value given by Crocker et al. (1996), which is in reasonable agreement with the other photometrically determined estimates.

NGC 7314: our two methods applied to the two catalogs give results in very good agreement. We thus adopt their mean value, which is also in good agreement with the few results available in the literature.

NGC 7329: our second method converges to an inclination angle which seems too large. We thus neglect it and take the result of the first method, which is in reasonable agreement with the little that is available in the literature.

NGC 7331: the results of our two methods agree very well between them, and with the main kinematic estimates. We thus adopt the average of our two methods.

NGC 7479: this is a difficult galaxy since, on top of a bar, there is a major $m = 1$ asymmetry, clearly seen in the deprojected image for both catalogs. This can bias our methods, thus we prefer to adopt the kinematical value from Laine & Gottesman (1998), which is in good agreement with the results given by our second method.

NGC 7531: this galaxy is quite inclined, so it is crucial for the PA to be accurate. Our first method gives a value which is, by visual inspection, not acceptable. We thus adopt the result of our second method, which is in good agreement with the kinematic values.

NGC 7552: the HII regions are mainly concentrated in and around the bar region and thus can not give useful information for the deprojection. We thus adopt the values from RC3 (1991).

NGC 7590: our two methods give results that coincide, so we adopt their average values, as they are also in reasonable agreement with the few available photometric estimates.

5. Discussion

In this section we compare the different methods used to determine the deprojection angles (PA, IA). Our aim is to see whether any one is inferior or superior to the others. We compared 7 methods, or groups of methods. Our two methods (method 1 and 2) constitute a group each. The values obtained by Danver (1942) form group D, those by Grosbøl (1985) form group G, and the values from the RC3 catalog form group RC3. The sixth group (kinematics, K) includes all the values obtained using information from HI or optical velocity fields. Finally the seventh group (photometry, P) includes all results obtained fitting ellipses to the outer parts of the galaxies. The values in these last two groups do not constitute homogeneous samples, but the methods used by the different authors are very similar. Moreover, the kinematical method is quite reliable, specially for the determination of the PA.

For comparing any two methods we fitted a straight line to all pairs of values, using a maximum likelihood algorithm which minimizes the χ^2 merit function

$$\chi^2(a,b) = \sum_{i=1}^{N} \frac{(y_i - a - bx_i)^2}{\sigma_{iy}^2 + b^2\sigma_{xi}^2}, \tag{4}$$

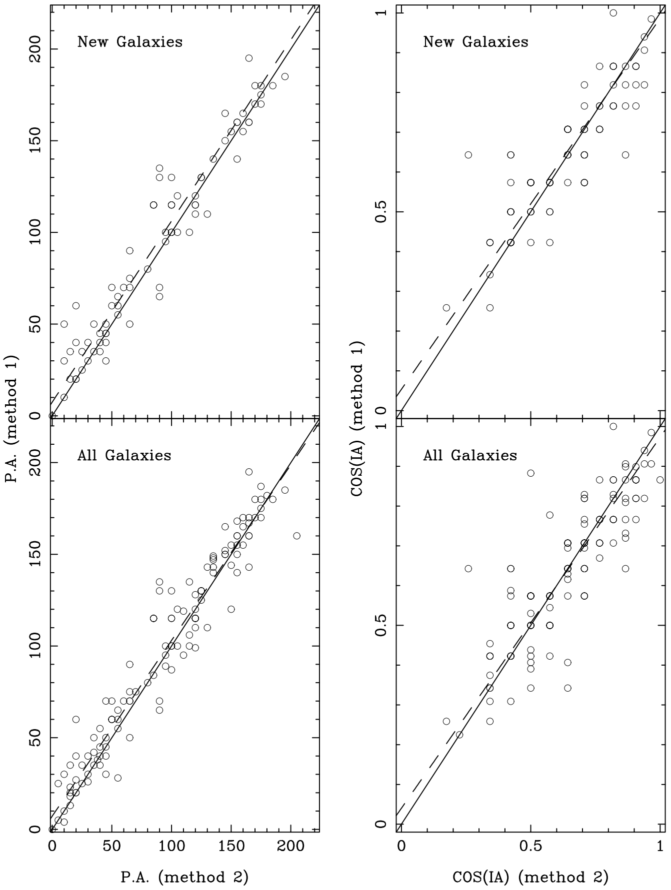

Fig. 7. Correlations between the values of the PA and IA derived using our two methods. Solid line. Diagonal (perfect correlation). Dashed line. Best fitting weighted linear correlation.

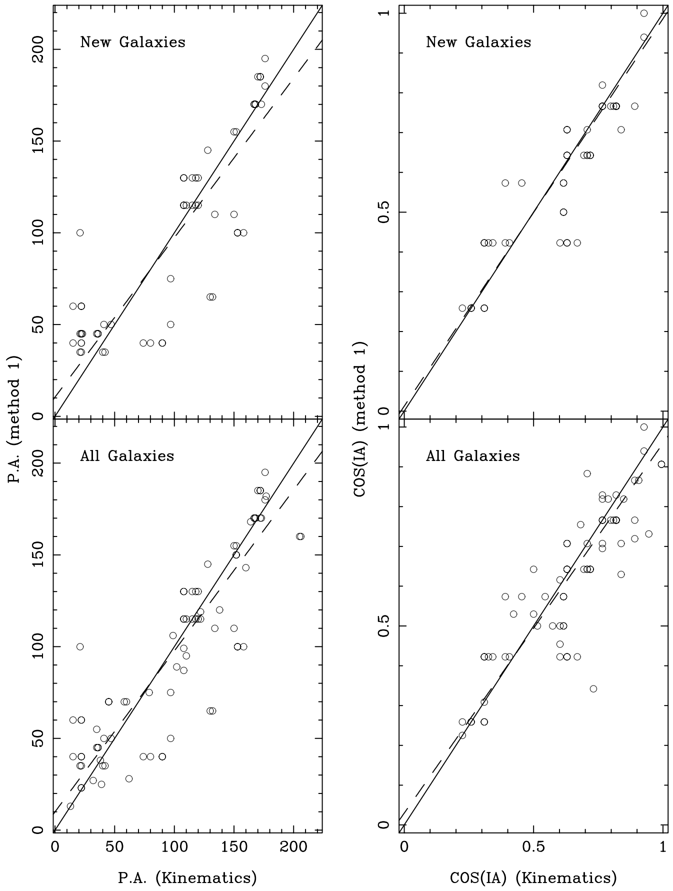

Fig. 8. Same as Fig. 7 but for the correlations between our first method and the results from HI kinematics.

where σ_{xi}^2 and σ_{yi}^2 are the errors for the ith value (Press et al. 1992).

When using our values, we assigned a weight to each catalog of HII regions as follows: If the catalog is very irregular with a small number of HII regions we assigned a weight of 0.1. If the number of HII regions is small but the catalog looked quite regular we assigned a weight of 0.3. If the catalog has a fair number of HII regions, but the distribution has some irregularities, we assigned a weight of 0.6 and, finally, if the catalog looked regular and had a fair number of HII regions we assigned a value of 1.0. We introduced a further weight, this time for the PA values of all the methods, to take into account the fact that for galaxies nearly face on, it is difficult for any of the methods to assign a reliable value of the PA. We thus assigned a low weight to the PA values of nearly face-on galaxies and a weight of 1. for all the rest. The errors were taken as the inverse of the weights, or, in cases with two weights, as the inverse of their product. In all the correlations we discarded the galaxy NGC 5194. For this galaxy, the values determined for the PA and IA using the kinematical information are in clear disagreement with the values determined using any of the other methods. This must be due to the strong interaction with the companion, NGC 5195.

Table 4. Weighted mean orthogonal distances for the PA correlations (upper triangle) and cos(IA) (lower triangle).

	1 st	2nd	RC3	G	D	K	P
1st		7.1	10.5	11.3	9.6	13.3	16.5
2nd	7.4		9.1	8.9	6.2	11.4	14.1
RC3	9.9	10.1		6.2	5.7	9.3	10.1
G	9.2	9.0	6.1		11.6	16.0	17.8
D	13.7	11.9	5.9	12.1		9.4	20.7
K	9.5	9.7	5.0	6.8	9.7		15.8
P	12.9	16.2	7.7	10.1	11.3	10.9	

Some illustrative correlations between pairs of methods are shown in Figs. 7 to 9. In Fig. 7 we compare the results of our two methods, in Fig. 8 our first method to the kinematical values and in Fig. 9 our first method to the photometrical determined values. To compare quantitatively the results of these and all the remaining correlations (not shown here) we used correlation coefficients as well as the weighted mean of the orthogonal distances of all the points to the best fitting straight line. The results of the comparison are shown in Tables 4 and 5. Tables 6 and 7 give the coefficients a and b of the linear regressions. In all cases the values above and to the right of the main diagonal correspond to the PA, and the values under and to the left of the main diagonal correspond to the cos(IA).

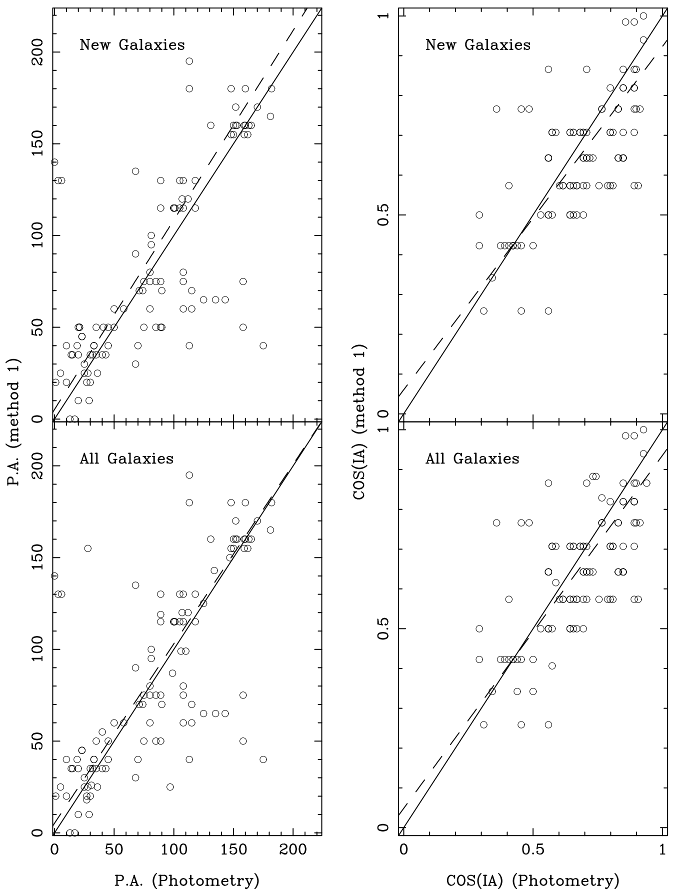

Fig. 9. Same as Fig. 9 but for the correlations between our first method and the results from the photometry.

We chose the *cos*, rather than the angle, since the former is uniformly distributed. Note that the values of the orthogonal distances and of the coefficient a for the case of cos(IA) have been rescaled so as to make them directly comparable to the corresponding values of the PA. For the comparisons we pooled together the data of the galaxies of the new sample presented in this paper and the galaxies of the previous sample (GGA, 1991). Obviously a perfect fit between two methods would imply a correlation coefficient of 1, a weighted mean of the orthogonal distances of zero, as well $a = 0.$ and $b = 1$. Random errors will introduce a scatter, which would lower the correlation coefficient and raise the value of the weighted mean of the orthogonal distances. Systematic differences, as would occur e.g. if a given method systematically overestimated or underestimated the geometric angles, would change the values of the coefficients a and b.

We note that, although no two methods we have used agree perfectly, there are also no glaring discrepancies. No method seems to overestimate or underestimate either of the deprojection angles. Also no method seems to give systematically smaller correlation coefficients, which would be indicative of a large random error in the results of this method. All correlations range between acceptable and good. The worst correlation coefficient, 0.51, is found when comparing the cos(IA) of Danver and Grosbøl.

Table 5. Weighted correlation coefficients for the PA correlations (upper triangle) and cos(IA) (lower triangle).

	1 st	2nd	RC3	G	D	K	P
1st		0.92	0.94	0.87	0.94	0.96	0.79
2nd	0.98		0.96	0.89	0.96	0.92	0.83
RC3	0.87	0.88		0.96	0.98	0.88	0.89
G	0.89	0.77	0.84		0.89	0.79	0.75
D	0.85	0.91	0.94	0.51		0.94	0.59
K	0.98	0.85	0.93	0.86	0.89		0.81
P	0.77	0.69	0.83	0.68	0.82	0.71	

Table 6. Zero points of the best fitting straight line for the PA correlations (upper triangle) and cos(IA) (lower triangle).

	1 st	2nd	RC3	G	D	K	P
1st		7.2	12.2	5.7	8.5	9.9	5.2
2nd	7.2		3.0	−0.1	1.0	−4.1	−4.8
RC3	−8.8	−19.0		4.1	−1.4	−8.2	4.5
G	−3.1	9.3	−19.5		14.6	1.2	15.6
D	9.5	−8.5	17.1	7.3		−2.0	−2.5
K	5.3	−6.9	22.4	−10.2	15.5		−26.5
P	8.7	4.3	13.3	29.2	−12.7	7.7	

Table 7. Slopes of the best fitting straight line for the PA correlations (upper triangle) and cos(IA) (lower triangle).

	1 st	2nd	RC3	G	D	K	P
1st		0.96	0.89	0.87	0.90	0.87	0.97
2nd	0.93		0.95	1.01	0.97	0.98	1.04
RC3	1.02	1.12		0.94	1.01	1.03	1.01
G	0.99	0.93	1.12		0.85	1.02	0.91
D	0.88	1.03	0.79	0.88		1.02	1.03
K	0.93	1.04	0.81	0.91	0.92		1.30
P	0.88	0.91	0.89	0.83	1.28	0.91	

This, however, is not due to one or several discordant galaxies, but rather to the fact that the galaxies are relatively few and are all clustered at low inclination angles. Nevertheless, the correlation is quite acceptable, as witnessed by the orthogonal distances and the coefficients of the regression line. It could be expected that two methods that rely on similar principles would give results closer to each other than methods based on different principles. We thus found it particularly gratifying to note the good agreement between either of our two methods and the kinematics, which is considered to give very reliable determinations and relies on very different assumptions.

One can thus conclude that all methods are acceptable for statistical analysis of samples of disc galaxies. In particular our two methods are as good as the other methods used so far and can give equally reliable estimates of the deprojection parameters. On the other hand if we are interested in the PA and IA of a particular galaxy it is best to apply several methods. The reason is that the different methods suffer from different biases – i.e. warps in the external parts, non elliptical isophotes or not well defined backgrounds – which might be more or less important in a particular case.

Acknowledgements. In preparing this paper we made extensive use of the CDS Strasbourg database. CGG and CB acknowledge financial support by the Dirección de Investigación cintífica y Técnica under contract PB97-0411

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