Photometric study of a sample of southern binary galaxies^{*,**}

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ABSTRACT

Aims. This work exhibits the basic optical photometric data for a sample of 50 probable southern binary galaxies. Our sample covers a broad range of pair separations, stages of interaction, and morphologies. From the initial list of selected pairs, using spectroscopic data from the literature and our own data, we conclude that 84% of these systems are true binary galaxies.

Methods. We present residual and asymmetric maps, R major semi-axis profiles of surface brightness, ellipticity, position-angle, harmonic Fourier coefficients of third and fourth order (b_3 and b_4) for 50 probable pairs, and $B - R$ color maps for 47 of these pairs. For most galaxies, we present the profiles in two different ways, aiming to verify the influence of random errors on them.

Results. We note that random errors in position-angle profiles are at least 2° , but a more significant result must take into account a variation larger than 11° for this distribution. Barred galaxies usually show a typical behavior in ellipticity and position-angle profiles: these profiles display variations when changing from a bar to a disk region. In some cases, the variations also occur along the bar. Some galaxies show distribution profiles that are common for their morphological type, and the interaction signature is only evidenced by their residual maps. Bars are usually redder and rings are bluer, when compared with the galaxy outskirts.

Conclusions. Our data indicates that there is a connection between interaction strength and morphological distortions in binary galaxies. If we consider the projected separation of a pair as an indication of interaction strength, distortions such as displaced centers, anomalous shapes of spiral arms, and twistings of external regions are easily detected in some close pairs, although not all components of close pairs show this behavior. Our data suggests that besides interaction, other parameters, like orbital geometry and internal properties of galaxies, can stimulate binary galaxies' peculiarities.

Key words. galaxies: interactions – galaxies: photometry

1. Introduction

Several studies indicate that interaction between binary galaxies can affect their most basic properties. Numerical simulations show that the morphology of galaxies can be strongly affected by gravitational interaction, and some peculiarities are clearly associated with them: formation of bridges and tails (Toomre & Toomre 1972), excitation of spiral structure (Toomre 1981), formation of bars in spiral galaxies (Noguchi 1987, 1996; Gerin et al. 1990; Miwa & Noguchi 1998), merger of galaxies (White 1978; Borne 1984; Aguillar & White 1986; McGlynn & Borne 1991; Navarro 1989, 1990; Mihos 1995; Bekki & Shioya 2000, 2001), formation of shells/ripples in galaxies (Quinn 1984; Hernquist & Quinn 1988, 1989; Schweizer & Seitzer 1988; Hernquist & Spergel 1992), peculiar dynamics of interacting galaxies (Barnes 1988, 2002; Borne 1988; Balcells et al. 1989; Hibbard & Mihos 1995), and increase in star formation rate in nuclear region of galaxies (Barnes & Hernquist 1992).

Tidal interaction may favor gaseous enhancement in specific regions of a galaxy either due to gas capture by one of the components or by gas inflow toward the galactic nucleus. Moreover, the gaseous material may trigger an enhancement in star formation. There is evidence that galaxy interactions can trigger

starburst (Larson & Tinsley 1978; Joseph et al. 1984; Lonsdale et al. 1984; Xu & Sulentic 1991; Forbes et al. 1994) and nuclear activity (Dahari 1985; Rampazzo et al. 1995). The presence of companions is also often related to quasars (Stockton 1982; Yee 1987; Hutchings et al. 1995; Bahcall et al. 1995). However, not all binaries show this behavior. Some authors (Keel et al. 1985; Bushouse et al. 1988) believe that star formation may be related to gaseous feeding due to kinematic mechanisms. Jones & Stein (1989) proposed that the dust content in galaxies, relative angular momentum, and orbital geometry of interacting galaxies can be important agents to trigger star formation. Surace et al. (1993) believe that events before interaction may determine the fate of a galaxy. Petrosian et al. (2002) and Lambas et al. (2003) reported that many interacting galaxies show weak star formation activity suggesting that particular internal conditions within these systems might be necessary to trigger star formation. Bergvall et al. (2003) did not find out evidence for a significant enhancement in star formation among interacting/merging galaxies as compared to non-interacting galaxies, though they reported a moderate increase in the center region of interacting galaxies. Rampazzo et al. (1995) and Domingue et al. (2003) claimed that in some mixed pairs (whose components are E + S or S0 + S) the gaseous material observed in the early-type component might have been obtained by capture from the spiral component. These authors claimed this fact as evidence of a cross-fueling mechanism induced by interaction.

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** Figures 3–8 and 10–59 are only available in electronic form at <http://www.edpsciences.org>

With the goal of studying the effects of interaction in galaxies belonging to pairs, we began an optical study (this work and Couto da Silva & de Souza 2006) of galaxies selected from the Soares et al. (1995) list of binary galaxies for the southern hemisphere. The Soares et al. list was extracted from the ESO-LV Catalog (Lauberts & Valentijn 1989) and is based on local density enhancement. The luminosity function of that sample is very similar to the one obtained by Xu & Sulentic (1991) for the Karachentsev (1972) sample for the northern hemisphere.

In this work, we report the photometric information gathered by using *R*-band profiles for components of 50 probable pairs, their residual and asymmetric maps, an individual analysis of galaxies, B-R color maps for components of 47 of these pairs, and a general analysis on photometric results. In Couto da Silva & de Souza (2006), we present spectroscopic data for most, but not all, galaxies studied in this work, while some other pairs from the Soares et al. (1995) list have information presented in our spectroscopy work. This occurred mainly due to observational weather conditions.

The present work is organized as follows: Sect. 2 presents the general information on the observational setup and data reducing process; Sect. 3, the residual and asymmetric maps; Sect. 4, an individual analysis for each galaxy; Sect. 5, a general study about the data; and Sect. 6, a discussion about the results.

2. Observations and data reduction

The observations were carried out with a CCD 009, GEC P8603A that is thick and front-illuminated, and has 385×578 pixels, with each pixel covering $22 \mu\text{m}$ ($1''.10$). The instrument was mounted at the Cassegrain focus of the 0.61m telescope at the Observatório do Pico dos Dias, operated by the Laboratório Nacional de Astrofísica (LNA-Brazil) in several runs. The CCD conversion factor is $10e^-/ADU$ and the readout noise is $9e^-$. We also used a focal reducer, which changed the plate scale from $0''.55/\text{pixel}$ ($f/13.5$) to $1''.10/\text{pixel}$ ($f/6.75$), allowing the observation of a field of $7'.20 \times 10'.80$.

All images were obtained by using *R* and *B* filters that closely matched the Kron-Cousin system. In general, we took 4×5 exposures (300 or 360 s for each one) to correct for cosmic rays and bad pixels. In Table 1 we present general information about the pairs studied in this paper. In Col. 1 we present the pair identification code adopted by Soares et al. (1995). Columns 2–5 present the object identification from the ESO-LV catalogue (Lauberts & Valentijn 1989): identification, radial velocity, blue band total magnitude, and morphological type. Whenever possible, we complete the radial information in Col. 3 with data from other sources; in this column, CS indicates data from Couto da Silva & de Souza (2006); dCa, da Costa et al. (1991); dCb, da Costa (1994); dCc, da Costa et al. (1998); dS, de Souza et al. (1997); FJ, Fairall & Jones (1991); Lo, Loveday (1996); M, Mathewson et al. (1992); R., Ratcliffe et al. 1998; Sch., Schweizer (1987a,b); and SWa, Sekiguchi & Wolstencroft (1992). Until now, has been no radial velocity available for the object P151b; however, P151a was studied by Combes et al. (1994) as a pair component, and according to Donzelli & Pastoriza (2000), P151 is a merging pair. Cols. 6 and 7 present the morphological classification from the ESO-Uppsala survey (Lauberts 1982) and RC3 (de Vaucouleurs et al. 1992), respectively. Column 8 presents our evaluation of the morphology based on visual appearance and structure analysis of our sample galaxies. Column 9 presents pair projected separation in arcsec, according to Soares et al. (1995). Column 10 presents information about the pair collected from the literature: RR

indicates that it is also selected as a pair by Reduzzi & Rampazzo (1995); Sch., by Schweizer (1987a,b); AM, by Arp & Madore (1987); and JB, by Johansson & Bergvall (1990). Associated with P387, it is written JB25? because Johansson & Bergvall's (1990) work only shows coordinate positions for P387b. Also in this column, IRAS indicates that the pair presents infrared emission, and Sy, that the galaxy is a Seyfert one. When only a component of the pair was quoted, the letter associated with this component is presented as a superscript.

P221 is a compact group listed as one in the RSCG list (Barton et al. 1996). P268 is probably a triple system. From the present list of probable pairs, we detected six optical pairs: P40, P147, P340, P387, P392, and P402. For P130, we have the radial velocity information of only one of the components. We considered the pairs having $\Delta v \geq 600 \text{ km s}^{-1}$ as true binaries, according to Couto da Silva & de Souza (2006). Taking into account that 49 pairs have radial velocities for both components, we conclude that our sample contamination by non-pair members is $\sim 16\%$.

Standard reduction procedures were applied to the CCD frames using VISTA. After the subtraction of an average bias frame, pixel intensity variations were corrected using an average dome flat field. Afterwards, foreground stars, cosmic rays, hot pixels, and high luminous regions were excluded. The sky background level was computed using the modal value of the histogram at several rectangular regions as far away as possible from light sources. Using VISTA, this procedure was performed visually and interactively for each of the galaxy frames. After this stage we used IRAF to make forward data reduction. The isophote analysis was carried out using the ELLIPSE task. We obtained *R* major semi-axis profiles of surface brightness, ellipticity, position-angle, and harmonic Fourier coefficients of third and fourth orders (b_3 and b_4), keeping the galaxy central position fixed while the other parameters were allowed to vary. Elmegreen et al. (1996) also used the ELLIPSE task to get ellipticity and position-angle distributions of 12 barred spiral galaxies, and verified that these galaxies are better fitted when the center position was fixed. Fasano & Bonoli (1990; hereafter FB) found great differences for position-angle (PA) and ellipticity (ϵ) values for a same galaxy that were obtained by several authors. According to FB, these differences are due to systematic errors that are underestimated. This effect is predictable at the inner region of galaxies, which are greatly affected by the seeing (Peletier et al. 1990). However, FB noted that these differences are larger for the outward region of galaxies, where the background correction is a prevailing factor for determining photometric information. A poorly flat fielded image can introduce errors in external parameters of galaxies. FB claimed that a small error in the background sky correction can explain the discrepancies found in PA and ϵ distributions at the outward regions. If not taken into account, these variations can cause a misinterpretation of galactic structures. FB based their conclusions on synthetical images of elliptical galaxies.

One way of determining the influence of systematic errors is to study the same galaxy using different techniques. Instead of studying synthetical images, as was done by FB, we decided to obtain the profiles in two different ways. In the first one, individual frames (usually 4 or 5) are treated and the profiles are obtained one by one; afterwards, an average profile is obtained for the individual distributions (ind). In the second way, we obtained the profiles for a unique image (med) from the median of the individual images after background sky correction. The intensity level is not greatly different from the ones of individual images. As we used the same flat field image to treat the images,

Table 1. Sample of binary galaxies.

1	2	3	4	5	6	7	8	9	10
Pair	Ident	Vel	B_T	ESO-LV	ESO-Upp	RC3	Our Type	Sep''	Notes
P24a	I1562	3633	13.56	5	Sc	SB(s)c	S(s)c	235	RR12, AM
P24b	I1561	3886	14.92	3	Sb	SB	SB(s)bc		IRAS
P40a	N0348	8809 CS	14.58	3	Sc	S b	SB(s)bc	424	
P40b	ESO-LV1510180	7498 CS	14.80	1	Sa:	S a	S(s)a		
P42a	I1615	7670	14.29	4	Sb	SB(r)bc	SB(r)bc	371	IRAS
P42b	I1617	7970	14.59	-1	Sa:	S(r)0?	S(s)a		
P57a	ESO-LV1510361	3627 Sch	13.11	4.5			P	27	Sch7, AM, JB6
P57b	N0454	3662 Sch	13.13	1	Double s	P	S(s)a p		IRAS, $Sy2^b$
P59a	ESO-LV2440121	6866 dCb	14.43	-0.3			S(s)b p	17	RR24, JB7
P59b	ESO-LV2440120	6700	15.70	3	S		Sa? p		AM, IRAS
P75a	N0633	5160	13.50	2.8	Sa:	SB(r)a	SB(r)a	66	RR32, JB10
P75b	ESO-LV2970120	5147 dCb	15.06	-5	E		S0		IRAS
P79a	N0642	5826 Sch	13.58	5	Sc	SB(s)c	SB(s)c p	109	Sch8
P79b	N0639	5883 Sch	14.67	1	S	S a?	S(s)a p		IRAS
P101a	ESO-LV0520200	8126 dCa	14.58	4	Sb-c	SB(s)bc	S(s)c p	82	AM
P101b	ESO-LV0520210	8184 CS	14.97	3.2	S		SB(s)bc		IRAS ^a
P105a	N0858	12356	14.19	5	Sc	SBc?	S(s)c	489	MCG ^a
P105b	ESO-LV4780140	12172dCb	15.86	1	Sa		SB(r)ab		IRAS
P112a	ESO-LV1150080	9246	14.65	-5	E	E1	E1	148	RR54, AM
P112b	ESO-LV1150090	9345 FJ	15.15	2	Sb:	S ab p	S(s)ab p		IRAS ^b
P117a	I1813	4483	14.20	-1	S0	S0+ p	S(s)a	206	RR57, AM
P117b	I1811	4821	14.35	2	SBa	SB(r)ab	SB(r)a		IRAS ^a , N^a
P130a	ESO-LV4790400	10548	14.64	3.5	Sb	SB(s)bc	SB(s)bc	177	MCG ^a
P130b	ESO-LV4790410		16.01	0.5	S		S(s)a		IRAS ^a
P139a	ESO-LV3560220	6170	13.30	4	Sc	SB(r)c	SB(r)c	880	MCG ^a
P139b	ESO-LV3560240	6124	14.83	3.4	S		S p		IRAS
P147a	ESO-LV4810090	12278 dCb	14.68	1	Sa		S(r)a	286	RR73, AM
P147b	ESO-LV4810110	6488 M	15.44	3	Sb		S(s)b		MCG
P151a	I1908	8234	14.53	3	Sc	SBb p	SB(s)b p	12	AM
P151b	ESO-LV1550131	Pair!	16.14	3			S0 p		IRAS ^a
P221a	N1540B	5633 CS	14.46	-1.6			P	15	
P221b	N1540	5522 CS	14.75	10			P		RSCG27
P221c	N1540A	5562 CS	14.94	3.5			P		
P223a	N1567	4552	13.36	-5	S0	E0 p	E0 p	192	AM
P223b	ESO-LV2020090	4681	15.32	5		SB(s)c p	S p		

the differences that appear in the profiles are related to random errors.

Table 2 presents a journal of observations. Column 1 gives the pair identification number from Soares et al. (1995), Col. 2 gives the number of frames and time exposition (sec), and Col. 3, the seeing (arcsec) for R -band observations. Columns 4 and 5 give similar information to Cols. 2 and 3, but for B -band observations. Column 6 displays another pair identification. Columns 7 and 8 give the information described in Cols. 2 and 3 for R observations, and Cols. 9 and 10 present this information for B -band images. We obtained two profiles using the two

techniques for 31 of 50 probable pairs of our sample. These pairs are marked with a * symbol in Cols. 1 and 6. For R images, nearly 350 frames were treated to get both distributions, as some pairs' components were observed in different expositions. For B observations, we only got a median image, as they only were used to get $B - R$ color maps; over 50 B -frames were treated, as some galaxies were observed in different runs of their companions. Thus, nearly 400 individual frames were studied one by one in the present work. For 3 pairs (P105, P340, and P392) we only obtained data in R -band. For 4 pairs (P316, P363, P387,

Table 1. continued.

1	2	3	4	5	6	7	8	9	10
Pair	Ident	Vel	B_T	ESO-LV	ESO-Upp	RC3	Our Type	Sep''	Notes
P259a	N1803	4085	13.51	4	Sc	SB(s)bc	SB(s)bc	133	RR103, AM, Sch17
P259b	ESO-LV2030190	4351	14.07	1	Sa:	SAB(r)0+	S0 p		IRAS ^a , $Sy3^b$
P268a	ESO-LV4860391	3840 dCb	14.07	3	Sb		P	9	
P268b	ESO-LV4860390	3840	15.26	1	Sa		P		RR108(a,c)
P268c	ESO-LV4860392	3804 dCb	14.41	1	Sa		P		
P316a	ESO-LV5070450	4875	12.84	-2	S0	S0 p	E3 p	132	RR225
P316b	ESO-LV5070460	4602	13.96	-3.5	S0	E2	S0		
P323a	ESO-LV4430500	5664 dS	14.49	-2	S0		E2	162	RR233
P323b	ESO-LV4430510	5434 dS	15.61	3	SBb		SB(s)b		AM
P331a	ESO-LV4440101	9304 dS	14.33	0.8			SB(s)a p	51	RR240, AM
P331b	ESO-LV4440100	9211	15.43	6	Sc?	S?	S(s)bc p		IRAS ^b
P340a	ESO-LV5760760	1695 dS	13.86	-3.6	S0	S0- p	S0 p	328	
P340b	ESO-LV5760730	5561 dS	15.11	6	Sc		SB(s)bc p		
P358a	ESO-LV5100590	2337	13.49	6	Sc	SB(s)cd	SB(s)cd	124	RR267, AM
P358b	ESO-LV5100580	2333	14.06	6	S	SB(s)cd?	SB p		MCG
P363a	ESO-LV5110180	6440 CS	14.51	3	Sb	SAB(r)ab p	SB(r)bc	137	RR274
P363b	ESO-LV5110200	6381 dS	15.57	3	Sb:		S(s)b:		IRAS ^a
P387a	I4935	4575 CS	14.04	0.8	Sa	SB(r)a	SB(r)a	309	RR309, JB25?
P387b	ESO-LV1430040	15298 CS	15.19	5	Sc	SAB(s)bc p	SB(s)bc		AM, IRAS
P392a	ESO-LV2330370	5039 dCb	14.56	3	Sa:	S b	S(s)b	393	RR312
P392b	ESO-LV2330360	3200	14.77	2	Sb:	S ab?	S(s)b:		AM
P402a	ESO-LV3400150	6473	13.59	1	Sa	Sa	E2 p	141	IRAS ^b
P402b	ESO-LV3400140	5246 CS	14.74	1		Sa	S(rs)a p		MCG ^a
P416a	I5020	3091	12.95	4	Sc	S(s)bc	S(s)bc	437	RR319
P416b	ESO-LV4000370	3202	14.58	6	Sc	SB(s)cd p	SB(s)cd p		MCG ^a , IRAS ^a
P422a	ESO-LV4630080	5988 SWa	14.43	1	Sa	SB(r)b	SB(r)a	65	AM
P422b	ESO-LV4630091	6231 SWa	15.14	5.4			S(s)b p		
P423a	N6935	4631	12.77	1	Sa(r)	S(r)a	S(r)a	269	RR322
P423b	N6937	4680	13.37	4.7	Sc(r)	SB(r)c	SB(r)c		IRAS
P426a	I5041	2702	13.11	7	SBc	SAB(s)d	SB(s)d	593	RR323, Sch37
P426b	I5039	2701	13.45	3	Sc	S bc	S(s)bc p		IRAS
P429a	I5042	4214	14.06	6	Sc	S?	S(s)bc	427	RR325, Sch38
P429b	I5038	4157	14.22	6	Sc	SB(s)cd	SB(s)bc		IRAS
P432a	I5063	3402	12.92	-0.4	S0-a	S0+	S0 p	650	RR331, IRAS
P432b	I5064	3377	14.31	1	Sa	SB(s)a?	SB(s)a		$Sy2^a$, N^b

and P402) the seeing is very bad and the results for these galaxies can only be considered as suggestions.

In principle, the analysis of individual images should be more precise since we take into account the subtraction of the instantaneous sky level of each image and there is no need for fixing offsets for star positions in consecutive frames. Figure 1 shows histograms with the difference (med-ind) between the profiles data obtained by a unique median image (med) and the average of individual (ind) profiles for 31 pairs. P500b was excluded from this comparison because of a different offset

between the profiles, but P221, which is actually a triple system, was included. In this way, 62 galaxies are represented in the histograms. The majority of the PA difference is in the range $-2^\circ \leq \Delta PA \leq 2^\circ$. These measurements are in agreement with the intrinsic PA errors (2°) resulting from the ellipse fitting of IRAF/STSDAS, as claimed by Bender & Möllenhoff (1987). We noted that a final comparison between these two procedures indicates that $\Delta PA_{(\text{med-ind})} = 1.6^\circ \pm 9^\circ$. Taking into account the statistical errors associated with this measurement, a more significant result relating to PA variations must be larger than 11° .

Table 1. continued.

1	2	3	4	5	6	7	8	9	10
Pair	Ident	Vel	B_T	ESO-LV	ESO-Upp	RC3	Our Type	Sep''	Notes
P437a	ESO-LV2860180	9162	14.30	4	Sb	SB(s)bc?	S(s)b: p	78	RR335, AM
P437b	ESO-LV2860170	9664dCb	14.49	-2	S0	S 0?	SB0		$S y^a$, N^b
P457a	ESO-LV3420220	12944 dCb	14.60	3	Sb		SB(r)b	102	RR342, AM
P457b	ESO-LV3420230	12924 dCb	15.31	6	Sc		S(s)c p		IRAS ^a
P460a	I5101	5166	14.04	4	Sa-b	SB(s)bc	SB(s)bc	355	RR344
P460b	I5100	5100 FJ	14.61	5	Sc	SB c?	SB(s)c		IRAS
P485a	N7119A	9875	13.54	4.1	S	SBbc p	SB(r)bc p	20	RR353, AM
P485b	N7119B	9588	13.74	0.2		S.c p	Sa? p		IRAS ^a
P487a	N7125	3148	12.70	5.3	Sc	SABc	SB(r)c	372	RR354, AM
P487b	N7126	2981	12.99	4	Sb	Sbc	S(r)b		Sch42, IRAS
P490a	ESO-LV0480110	8320 CS	14.72	4	Sb-c		SAB(s)bc	55	RR357
P490b	ESO-LV0480120	8499 CS	16.25	5.4	S		S(s)b:		
P497a	I5149	5431 CS	13.84	3	Sb		S(r)bc p	642	RR361
P497b	ESO-LV4660270	5483	14.50	3	Sb	S a	SB(s)ab		IRAS, N^b
P500a	ESO-LV2880300	7891 SWa	14.71	3	Sb:		S(s)b p	77	RR362, AM
P500b	ESO-LV2880320	8036 SWa	14.95	3	SB:b	SB(s)ab	SB(s)bc		IRAS ^a
P521a	ESO-LV4040390	2624 dCb	14.27	-1	S0	S?	SB(s)b	61	IRAS ^a
P521b	ESO-LV4040391	2669 R	16.23	-3			S0		
P538a	ESO-LV5330210	11613 CS	14.32	-5	E-S0	S0 p	S0 p	32	AM
P538b	ESO-LV5330200	11604 CS	14.74	-2	E-S0	S0 p	S0 p		
P539a	I5210	7329 dCb	14.01	-3	S0	S0	E1	173	
P539b	I5211	7382	14.66	1	Sa	S ?	S(s)a		
P546a	N7285	4347	12.82	1	Sa-b	SBa p	SB(r)b	29	RR381
P546b	N7284	4706	12.96	-2	Sa:	SB0 p	E3		AM, N^a
P562a	ESO-LV5340130	8193	14.32	-3	S0	SAB0	S0	412	
P562b	ESO-LV5340140	8261 Lo	15.56	6	Sc		S(s)bc		
P575a	ESO-LV0760310	3795 CS	13.96	-4	S0	S0- p	S0	262	RR389
P575b	ESO-LV0760300	3750	14.20	-0.3	S0-a	SB0	SB(s)a		AM, IRAS ^b
P616a	ESO-LV4710340	8880 dCb	14.33	1	S(r:a)	SB(s)a p	SB(s)a	214	RR407
P616b	ESO-LV4710320	8639 dCb	14.74	-2	S0	SAB(r)0	S(r)0		
P617a	ESO-LV1110100	4829	14.18	4	SBb	SABbc	SB(s)bc	94	RR408
P617b	ESO-LV1110090	4279	14.65	5	Sc	Sc	S(s)bc		IRAS ^a

For the ellipticities, the mean error resulting from this comparison is $\Delta\epsilon_{(\text{med-ind})} = -0.004 \pm 0.04$, while for the b_4 coefficient we got $\Delta b_{4(\text{med-ind})} = 0.0005 \pm 0.03$. It is noteworthy to emphasize that for a visual overlapping pair, the way the companion is masked when a galaxy is studied may strongly influence the behavior of the b_4 distribution (see P546b forward).

The photometric calibration was done using IRAF standard procedures and the list of standard stars from Graham (1982). Figure 2 shows histograms of the difference between the apparent magnitude obtained with our CCD data and those using the photographic plates of the ESO-LV catalog. Both data sets represent the integrated magnitude inside the 25 mag/□'' isophote. In this comparison, we used only galaxies brighter than $B_T = 14.5$, where B_T represents the total B magnitude reported in ESO-LV

catalog, and N indicates the number of objects used in this comparison. As the ESO-LV does not show R_{25} magnitude, we estimated it as $R_{25} = B_{25} - (B-R)_T$, where $(B-R)_T$ is the total $(B-R)$ color reported in ESO-LV. We considered $(B-R)_T \sim (B-R)_{25}$. For this comparison, we used 39 galaxies in the R -band and 36 in the B -band. The R -band comparison is subject to more uncertainties because we used an approximation for calculating R_{25} . We noted that our magnitudes are nearly 0.10 mag brighter in the B -band and 0.06 mag in the R -band, with a spread of 0.19 mag in the B -band and 0.27 in the R -band. The behavior of these figures is also different: there is a larger spread of data in the R -band differences. No correction for this difference was applied to our data since we believe that our CCD data is of better quality. In fact, our $B-R$ color maps were obtained just by comparing

Table 2. Journal of observations.

1	2	3	4	5	6	7	8	9	10
Pair	Exp. (s)	Seeing ($''$)	Exp. (s)	Seeing ($''$)	Pair	Exp. (s)	Seeing ($''$)	Exp. (s)	Seeing ($''$)
P24	4 × 360	1.43	5 × 300	1.50	*P387	3 × 300	3.00	4 × 360	1.22
*P40	4 × 360	1.33	5 × 300	1.38	*P392	4 × 360	1.24		
*P42	4 × 360	1.47	5 × 300	1.44	*P402	5 × 300	2.65	4 × 360	1.80
P57	4 × 360	1.33	4 × 360	1.22	P416	4 × 360	1.37	4 × 360	1.58
P59	4 × 360	1.22	4 × 360	1.40	*P422	5 × 360	1.60	5 × 360	1.29
*P75	5 × 360	1.50	4 × 360	1.49	*P423	5 × 360	1.52	5 × 300	1.20
*P79	5 × 360	1.51	4 × 360	1.49	*P426	5 × 360	1.34	5 × 300	1.30
*P101	4 × 360	1.22	5 × 300	1.33	P429	4 × 360	1.32	4 × 360	1.34
*P105	3 × 360	1.71			P432	4 × 360	1.33	4 × 360	1.34
*P112	4 × 360	1.56	5 × 360	1.01	*P437	4 × 360	1.26	5 × 300	1.23
*P117	4 × 360	1.62	5 × 300	1.43	*P457	5 × 360	1.65	5 × 300	1.54
*P130	4 × 360	1.50	4 × 360	1.24	P460	4 × 360	1.30	4 × 360	1.49
*P139	4 × 360	1.83	4 × 360	1.34	*P485	5 × 360	1.56	5 × 300	1.22
*P147	4 × 360	1.67	4 × 360	1.35	*P487	4 × 360	1.26	5 × 300	1.35
*P151	4 × 360	1.70	4 × 360	1.31	P490	4 × 360	1.50	4 × 360	1.65
*P221	4 × 360	1.76	4 × 360	1.55	P497	4 × 360	1.45	4 × 360	1.48
P223	4 × 360	1.08	4 × 360	1.30	*P500	5 × 360	1.61	4 × 300	1.27
P259	4 × 360	1.15	4 × 360	1.11	P521	4 × 360	1.27	4 × 360	2.27
P268	4 × 360	1.31	4 × 360	1.23	*P538	2 × 360	1.39	5 × 300	1.50
*P316	2 × 300	2.06	5 × 300	1.48	*P539	4 × 360	1.46	5 × 300	1.44
P323	4 × 360	1.58	4 × 360	1.42	P546	4 × 360	1.35	5 × 300	1.59
P331	3 × 360	1.61	4 × 360	1.38	P562	4 × 360	1.41	4 × 360	1.38
*P340	4 × 360	1.70			P575	4 × 360	1.41	4 × 360	2.50
*P358	4 × 360	1.60	5 × 300	1.27	P616	4 × 360	1.39	4 × 360	1.88
*P363	3 × 300	2.37	5 × 300	1.38	*P617	4 × 360	1.42	4 × 360	1.50

one galaxy region to another, and the surface brightness profiles shown in this work mainly aim to look for peculiarities within galaxy structures.

3. Residual and asymmetric maps

To verify whether interacting galaxies display distortions in their shapes, which may be a clue of tidal effects, we applied two techniques to our images. In the first, we subtract a modeled galaxy from the original image to get the residual map according to the recipes of Forbes & Thompson (1992) and Reduzzi et al. (1994). The residual maps are used to search for tidal distortions that may occur in interacting galaxies and to detect inner structures within them. The residual maps are also useful tools for the morphological classification of galaxies. In the case of pairs exhibiting a visual superposition of images, we obtained a residual map for each component; afterwards, the individual models are added to get a model for the pair.

The first step to obtain the residual maps is to determine a smooth elliptical model fitted to the data using the ISOPHOTE procedure of IRAF/STSDAS, based on the method developed by Jedrzejewski (1987). In this program, the isophotal contour of a galaxy is fitted with a mean ellipse and parametrized using values of position-angle, ellipticity, and coordinates of the center. According to Elmegreen et al. (1996), we kept the center position of the galaxy fixed while the other parameters were allowed to vary at each step of the interaction. In some cases, better models were achieved by keeping ellipticity and position-angle fixed to their outer values (an example is P40a). During the fitting process, we adopted a clipping factor of 20% for the brightest pixels in each annulus. Forbes & Thompson (1992) used a larger clipping factor (40%) to build their models. In our case, before applying the procedure, background stars and bad pixels were removed by means of squared masks and did not contribute to

modeling, and we noted that a 20% clipping was good enough to build our models.

The residual maps are displayed in Figs. 3–7, available in electronic form. The orientation of all grey scale images presented in this work is east up and south to the right, and for almost all of them we used 4 cm × 4 cm square boxes for the displaying. The plate scale corresponding to 4 cm is presented at the top of each figure. In the case of a few figures, such as P331b, which are not displayed as square boxes, the larger value of the scale is equivalent to 4 cm. Very close pairs and the two compact groups are presented in Fig. 7. P538a shows a residual map very similar to its companion (P538b), and it is not represented in Fig. 7.

Beyond the close pairs represented in Fig. 7 (after P617), we suggest paying attention to the residual maps of the components of the pairs P75, P79, P101, P223, P259, P358, P422, P432, P437, and P500 that show strong signs of tidal interactions. These tidal interactions might still be present in other pairs, but at a lower level. However, the influence of an inner distortion associated with internal processes, as we observe in components of optical pairs (such as P340b), may not be discarded. The selected objects for tidal interaction show two different kinds of distortions: those associated with the disk that are normally located transversal to the line joining the pairs, and those associated with asymmetries in the central regions, as in the cases of P223a and P432a. It is interesting to mention that some galaxies, such as P79a, have profiles that are common for their morphological types, and the interaction signature is only evidenced by their residual map.

With the goal of checking the influence of tidal effects on each component of our pairs, we used an alternative technique based on the idea that an isolated galaxy tends to have a symmetric shape. In this case, we analyze a residual image made

Fig. 1. Variations of b_4 , ϵ , and PA distributions, due to different approaches used to treat images.

Fig. 2. Comparison of the present CCD photometry with that of the ESO-LV.

symmetric to the major semi-axis, which we call an asymmetric map. To obtain the asymmetric map, we built a symmetrized image with respect to the major semi-axis. At first the original image was rotated by an angle of 180° around its center, and the resulting image was added to the original frame. Another image was obtained by subtracting the rotated image from the original one. Finally, the difference image was divided by the summed image, resulting in a new image that has the contrast increased due to small asymmetries in the original one. The resulting image is the asymmetric map. From the operational point of view, we may define this image as:

$$S = \frac{I(r, \theta) - I(r, \theta + \pi)}{I(r, \theta) + I(r, \theta + \pi)}. \quad (1)$$

If the original image is perfectly symmetric, the asymmetric map should be close to zero. Discrepant values in this map indicate distortions with no radial symmetry in original image.

As a general comment, we noted that all spirals, even these belonging to optical pairs, show an excess in their asymmetric map. In spite of the fact that some of these excesses may be due to gravitational effects, the asymmetries (20%–40%) may be attributed to the intrinsic features of spiral arms, although some spiral galaxies present asymmetries larger than 45%. A few representative asymmetric maps are presented in Fig. 8. Dark regions in these maps indicate an excess with positive values larger than 45%. As before, we used $4 \text{ cm} \times 4 \text{ cm}$ square boxes for the displaying. Early-type galaxies usually exhibit small asymmetries (1%–10%). Therefore, in the search for signs of tidal interaction we need to consider that even isolated non-interacting objects might present some degree of internal distortion.

4. Individual analysis of galaxies

4.1. An overview

Many authors did not find significant variations in the geometry of galaxies obtained in different optical bands (Davis et al. 1985; Jedrzejewski 1987; Capaccioli et al. 1988; Fasano & Bonoli 1989; Caon et al. 1990; Peletier et al. 1990; Rampazzo & Sulentic 1992; Reduzzi & Rampazzo 1996). For the near-infrared band, Elmegreen et al. (1996) did not find significant differences in spiral profiles obtained in the JHK bands. Because of this, we present only R profiles, as they are less affected by dust obscuration.

With the aim of having a scale-invariant isophotal parameters, the Fourier coefficients are usually normalized to the major semi-axis length, a . The Fourier coefficients supplied by IRAF and based on Jedrzejewski's (1987) work use the mean isophote radius as a normalization factor. To compare the Fourier coefficients, a_3/a and a_4/a , supplied by some authors (such as Bender et al. 1988, 1989), the b_3 and b_4 coefficients obtained from IRAF must be multiplied by a factor $(b/a)^{1/2}$, where b is the minor semi-axis length (Bender et al. 1988).

Position-angle and ellipticity profile distributions have been used to study disk galaxies. The PA twisting in these galaxies may be a clue of small bars or non-axisymmetric bulges in the central region. Elmegreen et al. (1996) carried out JHK pass-band observations for barred spiral galaxies and found that spirals with morphological types in the range SBa-SBbc that exhibit inner twists, while those in the range SBc-SBm do not. These authors considered that there is an isophotal twisting when the PA profile changes at least 10° from the inward region to

Fig. 9. Examples of ε and PA distributions of barred galaxies.

the end of the bar, according to the recipe of Wozniak et al. (1995). Nevertheless, Elmegreen et al. claimed that dust may cause an apparent twisting in some galaxies. Latter authors also concluded that SBa-SBbc have continuous increasing ellipticities along their bars, in contrast to SBc-SBm, which do not vary in ellipticity. For these authors, the ellipticity and PA variations in early-type spirals may be related to stars' orbits and resonances. As resonance is generally associated with large bulges, late-type galaxies may lack inner resonances, and they do not show isophotal twisting. Twisting in disk galaxies has an intrinsic origin and may be caused by a bar-within-bar structure as well. Using numerical simulations, Noguchi (1996) concluded that bars of late-type galaxies slowly form due to an instability in the disk, whereas bars of early-type galaxies form more rapidly (within one disk rotation period) in tidal interactions. Chapelon et al. (1999) reached the conclusion that early- and late-type galaxies differ in their bar properties, and presumably, in the way the bar originates, and galaxy evolves.

Wozniak et al. (1995) claimed that for a barred disk galaxy, different variations in position-angle and ellipticity distributions indicate different internal structures: a smooth PA variation and a progressive increase in the ellipticity, with a small dip, may indicate a projected triaxial bulge; more than a maximum value for PA distribution may indicate a bar-within-bar structure. More suitable observations for distinguishing these structures must be done for face-on galaxies in the infrared passband to minimize the dust effect. Héraudeau et al. (1996) studied 31 edge-on unbarred spiral galaxies in the infrared passband, and they verified that 3 of them show bars; for 5 spirals of their sample, this possibility might not be excluded. These authors believe that bars are more common than the noticeable number in the optical passband; however, they found an opposite case: the optical bar detected in NGC 7541 is only an artifact of dust obscuration.

According to the recipes of Fasano & Bonoli (1989), Rampazzo & Buson (1990), and Rampazzo & Sulentic (1992) for elliptical and lenticular galaxies, and Wozniak et al. (1995) and Elmegreen et al. (1996) for barred spiral galaxies, we consider that a galaxy shows isophotal twisting when PA

distribution variation is larger than 10° . For unbarred spiral galaxies, the twisting is associated with a misalignment between bulge and disk directions (ΔPA_{bd}); for barred galaxies it is related to a variation between the end of the bar and the external region of the disk (ΔPA_{Bd}). In both cases, the twisting is affected by the spiral arms. For barred galaxies, we also examined an inner twisting of the bar (ΔPA_B), but we only present this information when an inner bar twisting occurs. We used ΔPA notation to indicate a mean isophotal twisting in elliptical galaxies. Barred galaxies usually show typical behavior in ellipticity and PA distributions: these distributions display variations when changing from bar to disk region. In some cases, the variations also occur along the bar. Examples of this occurrence may be observed in ε and PA distributions of some galaxies such as P117b, P151a, P323b, P331a, and P457a among several others. This behavior is more common for spiral galaxies with morphological types SBa-SBbc. We noted that the presence of an inner ring may produce kinks in these distributions; as examples, we have P423a and P487b profile distributions.

When distributions show one of the behaviors described above, the object probably exhibits an inner structure; however, a strong dust lane within the galaxy cannot be excluded. For edge-on galaxies, such as P429b and P500b, the behavior of $\varepsilon + PA$ distributions usually show only one of the variations mentioned. A flattened bulge may also produce a false signature of a bar structure, which may occur in P521a, for instance. Another case where the presence of a bar is not completely assured is P75a, where a flattened bulge may give a false indication of a bar structure; however, for these galaxies, we suggested a bar structure. Figure 9 shows examples of ε and PA distributions for some of our sample galaxies, namely P358a, P422a, and P497b in displays a, b, and c. They indicate: (a) a uniform bar with constant ellipticity; (b) a great twisting between bar and disk direction, with a rounder bar in the inner region; and (c) a probable bar-inside-bar. In the latter example, and for some other cases, these internal variations occur in the region strongly affected by the seeing. Because of this, we can only suggest the presence of a bar-within-bar structure.

4.2. The sample

In this subsection, we present an individual study of objects belonging to our probable sample pairs. Figures 10–59 with R grey scale images, $B - R$ color maps, and several profiles for our sample galaxies are available in electronic form. Some valuable information about the pairs, namely close pairs, is presented in the captions of these figures. R grey scale images and $B - R$ color maps are shown for the same galaxy region in the top panels. R isophotal contours are superimposed on R and $B - R$ color map images. The figures and analysis for P221 and P268, which are actually compact groups, are presented after P617. As is Sect. 3 we used $4\text{ cm} \times 4\text{ cm}$ square boxes to display the images and the color maps, and the plate scale presented at the top of the panel corresponds to 4 cm . The P387a image is not displayed as a square box, and the larger plate scale value corresponds to 4 cm . For P221 and P268, which are compact groups, we used $6\text{ cm} \times 6\text{ cm}$ square boxes for a better visualization of all components; in this case, the plate scale is for 6 cm . The $B - R$ color maps' darker regions represent redder regions. As previously cited in Sect. 2, the color maps presented in this work just aim to compare between the inner and outer regions of a galaxy, and to qualitatively compare our photometric and spectroscopic data.

Below the grey scale images, we present surface brightness, ellipticity, position-angle, and b_3 and b_4 harmonic Fourier coefficients distributions, all of them related to the major semi-axis (r in these figures). Whenever necessary, an angle of 180° was added or subtracted to some PA distributions, giving a better graphical representation of their behavior, as we are mainly interested in the variations of PA distribution. In Figs. 10–59, the error bars are larger than those normally obtained in IRAF because we took into account not only the contribution of the intrinsic errors coming from the profile of each object, but also the errors due to the fixing of the sky level. Since the errors add quadratically, our profile errors are larger and more realistic. In the analysis of several distributions, we usually consider regions where $\log r > 0.5$ because the inward region is greatly affected by the effect of seeing. It is important to emphasize that the ellipticity and ΔPA values presented are the mean ones. They are used in Figs. 62–64. However, for early-type galaxies the ellipticity values used in Figs. 60–61 are the largest ones that allow a comparison with the literature (see Sect. 5 forward).

P24a (S(s)c): the PA distribution shows large variations due to the strong twisting of the spiral arms ($\Delta\text{PA}_{\text{bd}} \sim 80^\circ$). The spiral arms are well evidenced in the residual map. The $B - R$ color map shows a slightly bluer central region, which may be related to central star formation. This galaxy was classified as SB(s)c in the RC3, but it does not show a bar. The probable cause of this misclassification is related to a small lengthened bulge whose orientation differs from the outward face-on disk region. The bulge ellipticity in the central region is $\varepsilon_b \sim 0.24$, while in the disk, the ellipticity is $\varepsilon_d \sim 0.10$.

P24b (SB(s)bc): the ellipticity distribution remains approximately constant after the end of the bar ($\varepsilon_B = 0.58$ and $\varepsilon_d = 0.68$). There is an isophotal twisting, $\Delta\text{PA}_{\text{bd}} \sim 25^\circ$, between the end of the bar and the disk. Our spectroscopic data indicates a strong central optical emission for this spiral.

P40a (SB(s)bc): PA and ε distributions point out variations related to the inner bar. The isophotal twisting is $\Delta\text{PA}_{\text{bd}} \sim 40^\circ$; the bar ellipticity is $\varepsilon_B = 0.3$, and the disk one is $\varepsilon_d = 0.2$. The small bar is not well distinguished in visual inspection and its presence is only suggested by the residual map.

P40b (S(s)a): the distribution of ellipticity changes smoothly from the center to the external region; $\varepsilon_b \sim 0.4$ and $\varepsilon_d \sim 0.7$. The PA distribution shows a variation of $\Delta\text{PA}_{\text{bd}} \sim 16^\circ$ due to a different orientation between the bulge and the disk. In the external region, the isophotes are slightly disk. The color map points out a dust lane in the central region.

P42a (SB(r)bc): variations in the ellipticity and PA distributions are due to the inner ring. This galaxy does not show isophotal twisting ($\Delta\text{PA}_{\text{bd}} \sim 2^\circ$). The mean values for the bar and disk ellipticities are $\varepsilon_B \sim 0.56$ and $\varepsilon_d \sim 0.52$.

P42b (S(s)a): this galaxy shows a small twisting, $\Delta\text{PA}_{\text{bd}} \sim 7^\circ$, between the orientation of the bulge and the disk. For this spiral, $\varepsilon_b \sim \varepsilon_d \sim 0.60$.

P57a (P): is the small component located to the right, exhibiting a displaced center due to the strong interaction. The b_4 distribution points out a boxy shape. The ellipticity distribution is slightly rounder outward.

P57b (S(s)a p): the larger component is a Seyfert 2 galaxy (Spinoglio et al. 1995). Our analysis shows that $\Delta\text{PA}_{\text{bd}} \sim 6^\circ$. The ellipticity distribution is flattened outward ($\varepsilon_d = 0.56$).

P59a (S(s)b p): Our galaxy's identification is based on the ESO-LV catalog, which stated that P59a is the northern component (on the left of Fig. 14). It seems that the morphological type of the ESO-LV catalog for this pair is inverted. This pair identification quoted in Longhetti et al. (1998) is inverted. We classified this galaxy as a peculiar Sb, although in the ESO-LV it is classified as an S0. It shows either a long asymmetric arm or a tail, which bends towards its companion. The arm is responsible for the variations observed in the PA distribution. The mean fluctuation in PA is $\sim 20^\circ$.

P59b (Sa? p): this object was classified as S0 by RR2. This possibility cannot be excluded, although this galaxy seems to have a small spiral arm. The isophotal twisting, $\Delta\text{PA} \sim 40^\circ$, is probably related to tidal effects and follows the variation of $\varepsilon(r)$. It is interesting to note that both galaxies are rounder outward, which may be due to tidal effects. For both objects, $\varepsilon_d \sim 0.45$. The b_4 distribution indicates a boxy shape in a small region.

P75a (SB(r)a): the ellipticity distribution shows a strong fluctuation associated with the internal structure. Our morphological classification agrees with the one presented by RC3. However, the bar was only detected with the residual map. The outward twisting, $\Delta\text{PA}_{\text{bd}} \sim 30^\circ$, may occur either due to a tidal effect or to the effect of masking its close companion. For this spiral, $\varepsilon_B = 0.35$ and $\varepsilon_d = 0.15$. The b_4 distribution indicates a disk shaped image. There is a slight bluish region close to the center. Dopita et al. (2002) report that this galaxy shows sites of star formation in the central region.

P75b (S0): the behavior of the ellipticity ($\varepsilon_b \sim 0.50$, $\varepsilon_d \sim 0.45$) and PA distributions ($\Delta\text{PA}_{\text{bd}} \sim 1^\circ$) are smooth. The b_4 distribution is disk. The color map indicates a slight bluish region within the central region. Dopita et al. (2002) reported that H_α emission is extended along the minor axis, and they suggested that a nuclear starburst blows gas along the polar direction.

P79a (SB(s)c p): this spiral resembles an ocular type with spiral arms surrounding it. Elmegreen et al. (1991) proposed that an ocular structure is the result of a unique interaction between a spiral and a companion of comparable, or, smaller mass. The twisting of the spiral arms is expressive. For this galaxy, $\varepsilon_B = 0.55$, $\varepsilon_d = 0.25$, and $\Delta\text{PA}_{\text{bd}} \sim 15^\circ$. The b_4 distribution exhibits fluctuations in the transition region from bar to disk.

P79b (S(s)a p): this spiral has its center displaced relative to the outward isophote. A strong evidence of tidal effect comes

from the residual map, which points out an asymmetric structure for the spiral arms. The ellipticity distribution is common ($\varepsilon_d = 0.68$), and the PA profile shows a small variation ($\Delta PA_{bd} \sim 3^\circ$).

P101a (S(s)c p): the lengthened bulge might induce a bar classification. The three-arm are greatly twisted in the central region with many bright knots on them. This galaxy is cataloged as a far ultraviolet emitter ($\lambda\lambda 1400\text{--}1800 \text{ \AA}$) by Bowyer et al. (1995). The ellipticity distribution indicates a transition between the rounded bulge and the disk seen edge-on ($\varepsilon_b \sim 0.25$, $\varepsilon_d \sim 0.45$). For the region beyond $\log r = 0.6$, the twisting is $\Delta PA_{bd} \sim 15^\circ$. This variation is probably due to the spiral arms. Another strong twisting seems to occur within the bulge ($\sim 70^\circ$); however, that region is affected by the seeing.

P101b (SB(s)bc): this spiral has a small bar in the central region. The distributions of ellipticity and PA are typical of barred galaxies. Mean values for the PA and ellipticity distributions are $\Delta PA_{Bd} \sim 40^\circ$, $\Delta PA_B \sim 10^\circ$, $\varepsilon_B \sim 0.42$, and $\varepsilon_d = 0.35$. The color map is slight bluish in the upper region.

P105a (S(s)c): knotty three-arm spiral. The ellipticity distribution is flattened in the inner region ($\varepsilon_b \sim 0.4$, $\varepsilon_d \sim 0.15$). The shape of the bulge might have influenced the morphological classification in RC3 (SBc?). The strong twisting of the spiral arms is responsible for the large isophotal twisting ($\Delta PA_{bd} \sim 40^\circ$).

P105b (SB(r)ab): this spiral galaxy shows a strong twisting ($\Delta PA_{Bd} \sim 60^\circ$). The mean ellipticity values are $\varepsilon_B \sim 0.15$ and $\varepsilon_d \sim 0.55$.

P112a (E1): the isophotal twisting is $\sim 15^\circ$. The ellipticity distribution suggests that this object is slightly rounder outward, which is compatible with the idea of a tidal force acting on it. But the b_4 distribution is ~ 0 without any indication of a boxy shape for this elliptical, as was suggested by some authors (Binney & Petrou 1985; Rampazzo & Sulentic 1992) for an elliptical under strong interaction. The distribution of $b_3 \sim 0$ indicates that this early-type galaxy does not show dust (Peletier et al. 1990). For this object, $\varepsilon \sim 0.17$.

P112b (S(s)ab p): warped spiral. The PA and ε distributions show smooth behaviors without any peculiarities; $\Delta PA_{bd} \sim 2^\circ$ and $\varepsilon_d = 0.75$.

P117a (S(s)a): this object is classified as S0 in RC3. However, we found evidence of spiral arms on it. The central region is slightly bluer, contrary to the indication of the ESO-LV catalog. Nevertheless, our color map is in agreement with our spectroscopic data: this spiral exhibits strong central emissions and peculiar N spectra (Couto da Silva & de Souza 2006). There is a small variation in the PA distribution, $\Delta PA_{bd} \sim 4^\circ$, probably related to the fluctuations in spiral arms' orientation. The mean values for the ellipticity distribution are $\varepsilon_b \sim 0.38$ and $\varepsilon_d \sim 0.26$. The $\varepsilon(r)$ distribution is slightly rounder outward.

P117b (SB(r)a): this object exhibits strong isophotal twisting ($\Delta PA_{Bd} \sim 80^\circ$). Mean values for the bar and disk ellipticities are $\varepsilon_B = 0.15$ and $\varepsilon_d = 0.45$. The color map is redder inward, in agreement with our spectroscopic data: we did not detect central optical emission lines in this early-type spiral.

P130a (SB(s)bc): disregarding the inner region, which is affected by the seeing, this spiral does not show twisting ($\Delta PA_{Bd} \sim 4^\circ$). Mean ellipticity values are $\varepsilon_B \sim 0.67$ and $\varepsilon_d \sim 0.57$.

P130b (S(s)a): the spiral arms were detected with the residual map. The PA distribution indicates an isophotal twisting ($\Delta PA_{bd} \sim 15^\circ$). Mean values for the ellipticity distribution are $\varepsilon_b \sim 0.50$ and $\varepsilon_d \sim 0.58$.

P139a (SB(r)c): the large variations in ellipticity and PA distributions are due to the bar and the inner ring. The bar twisting is small, $\Delta PA_{Bd} \sim 7^\circ$, but there is a strong isophotal twisting in the ring transition region ($\sim 25^\circ$). The bar and the disk ellipticities are $\varepsilon_B \sim 0.60$ and $\varepsilon_d \sim 0.45$. Our spectroscopic data verified that the central optical emission for this spiral is in the range expected for its morphological type.

P139b (S p): this galaxy shows tails. The color map is slight bluish in the central region. This object is either a LINER or an Sy2 galaxy (Couto da Silva & de Souza 2006). A superposed and masked star in the inner side of the image did not allow a better analysis of this region. Due to its strong peculiarity, it is difficult to determine its morphological type and inner structure in an accurate way. For this galaxy, $\Delta PA_{bd} \sim 8^\circ$, $\varepsilon_b = 0.28$, and $\varepsilon_d = 0.38$.

P147a (S(r)a): the PA and ellipticity variations are caused by the inner ring. For this early-type spiral, $\Delta PA_{bd} \sim 0^\circ$, but there is a twisting of $\sim 20^\circ$ within the bulge. Typical ellipticity values are $\varepsilon_b \sim 0.31$ and $\varepsilon_d \sim 0.26$. The color map shows a slight bluish ring.

P147b (S(s)b): the color map is redder and probably associated with an extensive dust region. The distributions of PA and ellipticity are well behaved ($\Delta PA_{bd} \sim 2^\circ$, $\varepsilon_b \sim 0.65$, and $\varepsilon_d \sim 0.80$). The high inclination of this galaxy did not allow an accurate analysis of the inner region.

P151a (SB(s)b p): this galaxy shows different values for ellipticity and PA distributions in the inner region, depending on the technique used to get the profiles. They are not due to a misalignment between individual images because it would produce the same shift in the complete distribution (see P500b). Besides, the alignment was done for the pair image, and P151b does not show these differences. However, the behavior of the P151a ellipticity and the PA profiles is the same, although their values change. PA and ε distributions are typical of barred galaxies. For this object, $\Delta PA_{Bd} \sim 35^\circ$, $\varepsilon_B \sim 0.40(?)$, and $\varepsilon_d \sim 0.65$. The behavior of the PA and ε distributions is typical of barred galaxies. For this spiral, $\Delta PA_{Bd} \sim 35^\circ$, $\varepsilon_B \sim 0.50$, and $\varepsilon_d \sim 0.65$.

P151b (S0 p): the outward region of this galaxy is rounded. This object does not show isophotal twisting: $\Delta PA_{bd} \sim 5^\circ$. Mean ellipticity values are $\varepsilon_b = 0.39$ and $\varepsilon_d = 0.10$. The color map indicates a slight bluish central region for this lenticular, which may be attributed to the interaction.

P223a (E0 p): at $\sim 5''$ from the center, there is a disturbance that can be seen in the residual map. This peculiarity is responsible for the variations in ellipticity, PA, b_3 , and b_4 distributions in the inner region. Outside this region, ε , b_3 , and b_4 profiles do not change ($\varepsilon \sim 0.04$). The fact that $b_3 \sim 0$ is an indication that this E does not have a dust region (Peletier et al. 1990), and $b_4 \sim 0$ indicates a pure elliptical shape for this galaxy. Taking into account only the region where $\log r > 0.8$, $\Delta PA \sim 5^\circ$.

P223b (S p): a strongly disturbed galaxy with a displaced center. We could not morphologically classify the spiral type of this object; however, the RC3 classifies it as an SB(s)c p galaxy. The PA and ellipticity mean values are $\Delta PA \sim 20^\circ$ and $\varepsilon_d \sim 0.70$.

P259a (SB(s)bc): knotty three-arm spiral as stood out on the residual map. The PA distribution exhibits an isophotal twisting of $\sim 20^\circ$, and mean ellipticity values are $\varepsilon_B = 0.44$ and $\varepsilon_d = 0.32$. The color map shows evidence of a redder bar.

P259b (S0 p): peculiar S0 with an indication of activity in the central region. Fairall (1981) has classified this galaxy as Sy3. The color map points out a slight bluish central region. For

$\log r > 0.5$, the behavior of the ε distribution is that expected for a lenticular galaxy. The disk ellipticity is $\varepsilon_d \sim 0.24$.

P316a (E3 p): this galaxy was classified as lenticular in the ESO-Upp, ESO-LV, and RC3 catalogs. Reduzzi & Rampazzo (1996) pointed out that an E with shells/ripples is a more appropriate classification for it. Malin & Carter (1983), Wilkinson et al. (1987) and Carter et al. (1988) classified this object as an E with shells. Reduzzi & Rampazzo (1996) applied an unsharp masking to this galaxy and also detected an inner structure on it. These authors suggest that the inner structure may be either a ring or a shell. Georgakakis et al. (2001) found cold gas in this elliptical. Our observations of this pair were carried out with a bad seeing, and for this analysis we considered only the region where $\log r > 0.8$, that corresponds to $r > 6''.31$. In this region, the light profile is smooth and typical of an elliptical galaxy. The ε distribution varies from ~ 0.18 to 0.34 . It does not show isophotal twisting (ΔPA is $\sim 5^\circ$). Taking into account the error bars, $b_4 \sim 0$; disregarding these bars, $b_4 \sim -0.02$. Reduzzi & Rampazzo (1996) did not show the errors bars of the b_4 distribution for this early-type galaxy, but our values are similar to theirs. RR2 claimed a boxy shape for this object. We suppose that our b_4 coefficient is similar to the a_4 coefficient from RR2 because only the IRAF package was mentioned by these authors. However, IRAF supplies the random errors associated with the Fourier coefficients, and they were not shown by RR2. To allow for a comparison with the a_4/a distribution indicated by Bender et al. (1987, 1988, 1989) and Bender (1988), for instance, we must apply a corrected factor of 0.84 (the value of $(b/a)^{1/2}$) to our distribution, as this galaxy is an E3 one. Our data suggests that $a_4/a \simeq -0.018$. Governato et al. (1993) claimed that the dependence between the shape and the observation angle does not enable a discernment about a galaxy shape when $(a_4/a) \times 100$ is in the range $-1 \leq (a_4/a) \times 100 \leq 1$. If we disregard the error bars, we may consider that this galaxy shows a boxy shape because $(a_4/a) \times 100 = -1.7$.

P316b (S0): our morphological classification is in accordance with that of ESO-Upp, but in disagreement with that of RC3 and Reduzzi & Rampazzo (1996), where this galaxy is classified as an elliptical. Our classification is based on the detection of a disk whose presence is revealed by a systematic effect on the PA and surface brightness profiles for $\log r > 1.2$. As for its companion, we analyze this galaxy for $\log r > 0.8$. This object shows $\Delta PA_{bd} \sim 25^\circ$, $\varepsilon_b \sim 0.12$, and $\varepsilon_d \sim 0.22$. The latter value is similar to the one obtained by RR2 ($\varepsilon_d \simeq 0.27$) in the external region. But RR2 got a b_4 distribution with negative values, while the one we obtained displays a pure elliptical shape ($b_4 \sim 0$) for this galaxy with the two techniques used for obtaining the profiles. The color map shows a red galaxy with a small bluish region at its center that is affected by the seeing; we did not detect emission lines in this lenticular with our spectroscopic data.

P323a (E2): this galaxy exhibits a pure elliptical shape ($b_4 \sim 0$). The inward region twisting is $\sim 20^\circ$, and the outward twisting is $\sim 12^\circ$. The mean value for the ellipticity distribution is $\varepsilon \sim 0.23$.

P323b (SB(s)b): for this spiral, $\Delta PA_{Bd} \sim 12^\circ$, $\varepsilon_B \sim 0.67$, and $\varepsilon_d \sim 0.45$. The color map indicates a slightly redder bar, which is emphasized on the residual map.

P331a (SB(s)a): the PA and ellipticity distributions are typical of barred galaxies. Based on these profiles, we estimate that $\Delta PA_{Bd} \sim 35^\circ$, $\varepsilon_B \sim 0.38$, and $\varepsilon_d \sim 0.26$. The color map is common for its morphological type, which is redder inward, in

agreement with our spectroscopic data, which did not detect central optical emission lines in this early-type spiral, in spite of the strong interaction of the pair.

P331b (S(s)bc p): warped spiral. The PA and ellipticity distributions do not show peculiarities ($\Delta PA_{bd} \sim 1^\circ$ and $\varepsilon_d = 0.85$). The galaxy central region is redder than the outer regions. This spiral presents optical central emission in the range foreseen for its morphological type (Couto da Silva & de Souza 2006).

P340a (S0 p): the residual map points out small knots within the disk. Except for a small fluctuation in the central region, the PA distribution is almost constant. This object is almost round at the center, and $\varepsilon \simeq 0.45$ in the external region. This lenticular does not show isophotal twisting, as $\Delta PA_{bd} \sim 1^\circ$.

P340b (SB(s)bc p): very peculiar spiral of ocular morphology. The PA and ellipticity distributions are typical of barred galaxies. The ellipticity variations are due to the strong twisting of one spiral arm. The mean ellipticity values are $\varepsilon_B \sim 0.38$ and $\varepsilon_d \sim 0.16$. The isophotal twisting is $\Delta PA_{Bd} \sim 30^\circ$, and there is a twisting along the bar as well ($\Delta PA_B \sim 40^\circ$). It is interesting to emphasize that both galaxies display peculiar characteristics, but this is an optical pair.

P358a (SB(s)cd p): this spiral shows star formation and knotty arms. The mean bar ellipticity is $\varepsilon_B \sim 0.90$, while $\varepsilon_b \sim 0.70$ in the bulge, and $\varepsilon_d \sim 0.30$ in the disk. There is an isophotal twisting, $\Delta PA_{Bd} \sim 45^\circ$, due to a misalignment between the bar and the disk. The external region is rounder outward due to the opening shape of the spiral arms. The color map indicates a slightly redder bar.

P358b (SB p): this spiral is very peculiar and has a displaced center, as was also reported by RR2 (n268a). In RC3 its morphological classification is SB(s)cd?. The PA and ε distributions suggest the presence of a bar. This object shows a mean twisting of $\sim 15^\circ$, $\varepsilon_d = 0.45$ and $\varepsilon_b = 0.30$. The bulge region exhibits a twisting of $\sim 50^\circ$. According to our spectroscopic data, this galaxy is a weak central optical emitter within the range $\lambda 15300\text{--}7000\text{\AA}$.

P363a (SB(r)bc): the PA and ellipticity distributions are typical of barred galaxies. There is a small trend for a twisting along the bar, and $\Delta PA_{Bd} \sim 15^\circ$. The mean values for the ellipticities are $\varepsilon_B = 0.40$ and $\varepsilon_d = 0.13$. The color map indicates a bluer ring. Our spectroscopic data indicates that this spiral is a central optical emitter in the range expected for its morphological type.

P363b (S(s)b): this spiral is seen almost edge-on, and this fact does not allow an accurate morphological classification of its type. The PA and ε distributions do not show peculiarities ($\Delta PA_{bd} \sim 8^\circ$ and $\varepsilon_d = 0.66$).

P387a (SB(r)a): spiral with some small knots. There is a twisting from the inward to the outward region ($\Delta PA_{Bd} \sim 25^\circ$), and $\varepsilon_d = 0.70$. The galaxy shape oscillates from being slightly boxy, inward, and to disk, outward. We did not detect central optical emission in this early-type spiral.

P387b (SB(s)bc): the residual map illustrates the presence of the spiral arms, which were not presented in Fig. 33. This figure shows the galaxy until the region where the color map is displayed. The color map is slightly redder along the bar. This spiral presents central optical emission in the range foreseen for its morphological type. The PA and ellipticity distributions indicate the presence of a bar with $\varepsilon_B = 0.20$, $\varepsilon_d = 0.40$, and $\Delta PA_{Bd} \sim 75^\circ$.

P392a (S(s)b): the PA and ε distributions do not indicate the existence of a bar or another peculiarity ($\Delta PA_{bd} \sim 4^\circ$, $\varepsilon_b \sim 0.90$,

and $\varepsilon_d \sim 0.75$). However, this galaxy is seen almost edge-on, and it is difficult to obtain the inner parameters in an accurate way.

P392b (S(s)b): the central region shows a small variation in PA distribution ($\sim 6^\circ$), probably associated with a dust lane. The mean value for the disk ellipticity is ~ 0.72 .

P402a (E2 p): the color map indicates a slightly bluish region in the center. This result corroborates the color index shown in the ESO-LV catalog. However, we did not detect central optical emission in this elliptical. This galaxy was classified as spiral by the catalogs mentioned in Table 1. But the surface brightness profile, the PA ($\Delta PA \sim 7^\circ$), the ellipticity ($\varepsilon \sim 0.20$), and the b_4 profiles are typical of an elliptical. The residual map did not show any sign of a spiral arm either.

P402b (S(rs)a p): the color map detected a bluish central region in this early-type spiral. It is undergoing a starburst episode (Couto da Silva & de Souza 2006). This galaxy does not show isophotal twisting ($\Delta PA_{bd} \sim 2^\circ$). The external region is rounder than the inner one ($\varepsilon_b \sim 0.32$ and $\varepsilon_d \sim 0.16$), a behavior that might be attributed to a tidal effect; however, this galaxy is not a pair component.

P416a (S(s)bc): in agreement with Wozniak et al. (1995), we did not find a bar structure in this flocculent spiral. Both works verify that the ellipticity and PA distributions are noisy. Wozniak et al. observed this galaxy (IC 5020) in the B -, V -, R -, and I -bands and noted that the profiles do not show a different behavior in these bands. The $B-I$ color map obtained by Wozniak et al. points out an oval redder inward region, and the $B-R$ color map we obtained suggests a semi-oval region located from the central region to the right, which might be related to a dust lane. This spiral does not show isophotal twisting ($\Delta PA_{bd} \sim 7^\circ$). The mean ellipticity values are $\varepsilon_b \sim 0.20$ and $\varepsilon_d \sim 0.24$. Our spectroscopic data did not detect central optical emission in this spiral.

P416b (SB(s)cd): in spite of the color map being noisy, it is possible to detect a red region within the bar. The distributions of ε and PA are also noisy, but they indicate a bar structure. The isophotal twisting is $\Delta PA_{Bd} \sim 37^\circ$, and the mean ellipticities are $\varepsilon_B \sim \varepsilon_d \sim 0.40$.

P422a (SB(r)a): spiral galaxy with very twisted arms. The isophotal twisting is $\Delta PA_{Bd} \sim 30^\circ$. The mean ellipticity values are $\varepsilon_B \sim \varepsilon_d \sim 0.40$. The color map is redder inward. Like Sekiguchi & Wolstencroft (1992), we did not detect central optical emission in this early-type spiral.

P422b (S(s)b p): the ESO-LV catalog has two entries for this object. Along the major axis, in the line joining this galaxy to its companion, there is a disturbed region. For this spiral, the mean isophotal twisting is $\sim 25^\circ$, and $\varepsilon_b \sim \varepsilon_d \sim 0.40$. The color map points out a bluish central region in agreement with the high central optical emission detected in our spectroscopic data.

P423a (S(r)a): the color map is redder in the central region in concordance with our spectroscopic data, which did not detect central optical emission in this early-type spiral. The residual map emphasizes the spiral arms. The twisting is $\Delta PA_{bd} \sim 5^\circ$, and the mean ellipticity values are $\varepsilon_b \sim 0.10$ and $\varepsilon_d \sim 0.12$.

P423b (SB(r)c): spiral with knotty arms. The knots are mainly concentrated in the direction of P423a. The color map is redder in the bar. We detected central optical emission in this spiral, but in the range foreseen for its morphological type. The isophotal twisting is $\Delta PA_{Bd} \sim 80^\circ$. The mean ellipticity values are $\varepsilon_B \sim 0.05$ and $\varepsilon_d \sim 0.45$.

P426a (SB(s)d): knotty late-type spiral. The ellipticity distribution points out a rounder galaxy outward with $\varepsilon_B \sim 0.65$

and $\varepsilon_d \sim 0.35$. This spiral does not show isophotal twisting, as ΔPA_{Bd} is $\leq 10^\circ$. The residual map emphasizes the knots and the irregular spiral arms.

P426b (S(s)bc p): this object shows knots of star formation and a dust lane that is responsible for the large variations in the parameters that were not displayed in Fig. 39. Mean values for the distributions are $\Delta PA_{bd} \sim 1^\circ$, $\varepsilon_b \sim 0.25$, and $\varepsilon_d \sim 0.40$.

P429a (S(s)bc): for this three-arm spiral, $\Delta PA_{bd} \sim 10^\circ$, $\varepsilon_b \sim 0.15$, and $\varepsilon_d \sim 0.30$. The color map points out a redder central region, and our spectroscopic data detected a weak central emission in the range $\lambda\lambda 5300-7000 \text{ \AA}$.

P429b (SB(s)bc): the isophotal twisting is $\Delta PA_{Bd} \sim 15^\circ$, and the mean ellipticities are $\varepsilon_B \sim 0.4$ and $\varepsilon_d \sim 0.54$. The color map is redder at the center and bluish in the spiral arms, and the optical central emission is typical of its morphological type.

P432a (S0 p): this object is a Seyfert 2 (Storchi-Bergmann et al. 1990; Busko & Steiner 1992; Bonatto et al. 1996, among others). The color map points out small blue knots within the nuclear region. Dopita et al. (2002) detected H_α knots in this peculiar early-type galaxy. The b_4 distribution indicates that this lenticular shows a pure elliptical shape ($b_4 \sim 0$). The mean values for the ellipticity distributions are $\varepsilon_b \sim 0.20$, and $\varepsilon_d \sim 0.26$. The PA distribution is very noisy; however, we considered $\Delta PA_{bd} \sim 4^\circ$.

P432b (SB(s)a): this galaxy shows central star formation. The color map indicates a bluish region along the bar. Joguet et al. (2001) spectroscopically classified this galaxy as Sy2. The PA and ellipticity distributions are atypical, probably due to one knot in the inner region. For this object, $\Delta PA_{Bd} \sim 10^\circ$, $\varepsilon_B \sim 0.35$, and $\varepsilon_d \sim 0.40$. The b_4 distribution is slightly boxy inward. Isophotal contours show that the outmost layer is misaligned with the main galaxy body.

P437a (S(s)bc p): warped spiral. Lipovetsky et al. (1988) classified this galaxy as Seyfert. The tidal effect, that was noticeable on the galaxy shape did not become evident on its structural parameters. This may occur because of this galaxy's high inclination in the plane of the sky. The mean values for the ellipticity distribution are $\varepsilon_b \sim 0.35$ and $\varepsilon_d \sim 0.80$, and the variation in the PA profile is small ($\Delta PA \sim 4^\circ$). The color map displays a red region inward.

P437b (SB0): the color map shows some blue spots within the central region. This lenticular is a strong central emitter; it is an Sy2 (Donzelli & Ferreira 1998). This galaxy does not show isophotal twisting ($\Delta PA_{Bd} \sim 3^\circ$). The maximum ellipticity is $\varepsilon_{\max} \approx 0.55$, and its shape is slightly boxy.

P457a (SB(r)b): this spiral displays a great isophotal twisting, which is more noticeable on the isophotal contours ($\Delta PA_{Bd} \sim 50^\circ$). The mean values for the ellipticities are $\varepsilon_B \sim 0.18$ and $\varepsilon_d \sim 0.24$. This galaxy is a strong central optical emitter (Couto da Silva & de Souza 2006). According to Coziol et al. (1997), it is an UV-bright candidate, and according to Cappi et al. (1998), it is a very luminous galaxy.

P457b (S(s)c p): this peculiar spiral displays an inner knot close to the central region. The ellipticity distribution is slight flattened inward, with $\varepsilon_b \sim 0.08$ and $\varepsilon_d \sim 0.04$, and the isophotal twisting is $\Delta PA_{bd} \sim 40^\circ$. According to our spectroscopic data, this galaxy is a strong central optical emitter with a value slightly above the typical one for its morphological type.

P460a (SB(s)bc): this spiral displays a small bar and greatly twisted arms. The twisting is $\Delta PA_{Bd} \sim 50^\circ$, while the mean ellipticities are $\varepsilon_B \sim 0.20$ and $\varepsilon_d \sim 0.40$. The b_4 distribution indicates a boxy shape close to the central region.

P460b (SB(s)c): knotty spiral. The ellipticity distribution is irregular due to the strong twisting of the spiral arms (as P24a). For this galaxy, $\varepsilon_B \sim 0.62$, $\varepsilon_d \sim 0.67$, and $\Delta PA_{Bd} \sim 10^\circ$.

P485a (SB(r)bc p): the PA and ellipticity distributions show the typical behavior of barred galaxies with $\Delta PA_{Bd} \sim 16^\circ$ and $\varepsilon_B \sim \varepsilon_d \sim 0.45$. RR2 classifies this object (their P353b) as Sbc. The color map displays a galaxy that is bluer than its companion, which agrees with their morphological types.

P485b (Sa? p): it is difficult to assess an accurate morphological type for this galaxy due to the visual overlapping of both components of this pair. For RR2, this secondary component is an S0 (their P353a). The PA and ellipticity distributions are typical of unbarred galaxies and do not show peculiarities ($\varepsilon_d \sim 0.6$). This galaxy does not exhibit isophotal twisting ($\Delta PA \leq 2^\circ$).

P487a (SB(r)c): knotty spiral. The color map shows a bluish central region, and our spectroscopic data indicates that this galaxy is a central optical emitter. This spiral displays a strong twisting ($\sim 90^\circ$) from the bar to the disk region and two mean ellipticity values, ~ 0.70 and ~ 0.25 . There is a slight ellipticity variation along the bar that may be caused by dust.

P487b (S(r)b): the color map is common and redder inward, and the spiral central optical emission is weak in the range $\lambda 15300\text{--}7000\text{ \AA}$. The PA and ε distributions point out that $\Delta PA_{Bd} \sim 10^\circ$, $\varepsilon_b \sim 0.30$, and $\varepsilon_d \sim 0.50$. The large fluctuation around $\log r \geq 1.2$ might be due either to the internal ring or to circumnuclear dust, as reported by Martini et al. (2003).

P490a (SAB(s)bc): a bar was not detected during the visual inspection, but the distributions of PA and ε indicate the presence of an inner structure or a very lengthened bulge. For this spiral, $\Delta PA_{Bd} \sim 30^\circ$, $\varepsilon_B \sim 0.10$, and $\varepsilon_d \sim 0.28$. The color map is redder in the central region and bluer in the spiral arms.

P490b (S(s)b): the PA and ellipticity distributions do not show peculiarities ($\Delta PA_{Bd} \sim 3^\circ$). Due to its almost edge-on projection ($\varepsilon_d \sim 0.70$), it is difficult to obtain an accurate morphological classification for this spiral. The color map is redder inward and probably related to a dust lane.

P497a (S(r)bc p): foreground stars were masked when dealing with this galaxy image. Variations in the ellipticity and PA distributions are due to the inner ring: $\Delta PA \sim 12^\circ$, $\varepsilon_b \sim 0.34$, and $\varepsilon_d \sim 0.36$. The color map is red inward, and its optical central emission is weak.

P497b (SB(s)ab): the PA and ε distributions are typical of barred galaxies. The isophotal twisting is $\Delta PA_{Bd} \sim 15^\circ$; $\varepsilon_B \sim 0.35$ and $\varepsilon_d \sim 0.55$. Our spectroscopic data indicates an N spectra this spiral: it is either a LINER or a Seyfert.

P500a (S(s)b p): this spiral exhibits a strong peculiarity in its central region, which is more noticeable in the isophotal contours superposed on the color map. This peculiarity is located in the region closer to its companion. This galaxy shows a large twisting, $\Delta PA_{Bd} \sim 80^\circ$, due to this peculiarity. The mean ellipticity values are $\varepsilon_b \sim 0.20$ and $\varepsilon_d \sim 0.45$. The b_4 distribution is boxy and may be related to the strong interaction this galaxy is undergoing. The residual map emphasizes the central disturbance, which looks like a semi-bar, but is not located at the center. This object shows a strong central optical emission (Couto da Silva & de Souza 2006).

P500b (SB(s)bc): the distributions computed by the two different techniques we used are displaced due to the difficulty of choosing the central position. We decided to keep this displacement to show it as an example of such an occurrence. The PA distribution points out a small twisting ($\Delta PA_{Bd} \sim 5^\circ$), and the

mean ellipticities are $\varepsilon_B \sim 0.55$ and $\varepsilon_d \sim 0.30$. The color map shows a galaxy that is redder in the central region, and its central optical emission is in the range expected for its morphological type.

P521a (SB(s)b): it is important to emphasize that the ellipticity distribution points out a lengthened bulge which may cause a wrong bar classification. However, we suggest a bar structure because of the profiles' behavior. The residual map shows the spiral arms. This galaxy does not show any significant isophotal twisting ($\Delta PA_{Bd} \sim 6^\circ$). Mean ellipticity values are $\varepsilon_B \sim 0.55$ and $\varepsilon_d \sim 0.6$. The optical central emission is in the range expected for its morphological type.

P521b (S0): this early-type galaxy does not show twisting (ΔPA_{Bd} is $\sim 3^\circ$). Representative values for the ellipticity are $\varepsilon_b \sim \varepsilon_d \sim 0.12$. The outward variations are due to the masking of foreground stars. A large ellipticity value inward may be attributed to dust. The b_4 distribution is ~ 0 , indicating a pure elliptical shape for this lenticular.

P538a (S0 p) this peculiar lenticular shows a large isophotal twisting ($\Delta PA_{Bd} \sim 90^\circ$). The b_4 distribution is ~ 0 , indicating that it has pure elliptical shape. The mean ellipticity values are $\varepsilon_b \sim 0.15$ and $\varepsilon_d \sim 0.40$. This galaxy is flattened outward.

P538b (S0 p) this lenticular presents a true elliptical shape, and its isophotal twisting is $\Delta PA_{Bd} \sim 20^\circ$. However, the ε distribution points out that this galaxy is rounder outward ($\varepsilon_d \sim 0.12$). In pairs like this where both galaxies are overlapping, the profiles may be affected by the light contribution of the other. The way the companion is masked when the component of a close pair is studied may influence the image analysis (see P546). We cannot discard the presence of dust in this galaxy. The color map shows that the outward region of both galaxies exhibits the same color. Both lenticulars do not show central optical emission in the range $\lambda 15300\text{--}7000\text{ \AA}$.

P539a (E1): the isophotal twisting of this elliptical is $\Delta PA \sim 15^\circ$, and the mean ellipticity is $\varepsilon \sim 0.06$. The b_4 distribution points out a pure elliptical shape for this early-type galaxy.

P539b (S(s)a): the residual map shows a small structure, which we associated with a spiral arm. The color map is common and redder inward. We did not detect central optical emission in this early-type spiral. The mean ellipticities are $\varepsilon_b \sim 0.50$ and $\varepsilon_d \sim 0.45$. This galaxy does not show isophotal twisting ($\Delta PA_{Bd} \sim 4^\circ$).

P546a (SB(r)b p): the PA and ellipticity distributions are typical of barred galaxies. This spiral does not show isophotal twisting ($\Delta PA \sim 6^\circ$), and the mean disk ellipticity is $\varepsilon_d \sim 0.6$. One spiral arm is overlapping the P546b image, and this may influence the results of the distributions (see P546b). The ellipticity distribution is rounder outward, which may be a clue that this galaxy is under the tidal effect. Keel et al. (1985) classified this spiral as LINER.

P546b (E3): this galaxy was classified as an SB0 peculiar in the RC3 and as an Sa in the ESO-LV. However, we did not find the presence of a disk when examining its surface brightness profile. Rampazzo & Sulentic (1992, hereafter RS) obtained ε , θ (PA), and a_4/a distributions for this object (their 96(1)) in the *B*- and *V*-bands. We present *R* profiles less affected by dust contamination, and our seeing is better than theirs. The maximum value for the ellipticity distribution in both works is nearly the same: 0.34 in the *B*-band and 0.32 in the *V*-band (RS), and 0.31 in our *R* profile. The behavior of the ε distributions is similar in the region ranging from $\sim 10''$ to $\log r = 1.4$ ($a \sim 25''$), which

is the maximum value shown by RS. In that range, the PA distribution is increasing in both works, but the mean values that we obtained change from $\sim 105^\circ$ to 130° , while the values obtained by RS change from $\sim 120^\circ$ to 130° . Beyond this point, the companion light begins to influence the profiles.

To compare the b_4 distribution of both works, the values that we obtained must be multiplied by 0.84, as this galaxy is an E3 (see P316a). According to RS, this galaxy displays a boxy shape (maximum value for $a_4/a \times 100 = -4.1$). In our work, $b_4 \times 0.83 = a_4/a = -0.023$; this value $\times 100 = -2.3$. Both works obtained a negative value for this distribution; however, the value obtained by RS is larger. We searched for a probable cause for this difference. One spiral arm from P546a is overlapping this galaxy image. In our work, this region was masked before getting the profiles. To perform a test, we kept this region on the P546b image, and we obtained the distributions again. Then we got $a_4/a \times 100 = -4.7$, closer to the value obtained by RS. For close pairs like this the way the companion image is masked may strongly influence the results of the b_4 distribution. We suggest an elliptical shape for this galaxy because $b_4 \sim 0$, with some variations, but according to Governato et al. (1993), we might consider this galaxy as being boxy-shaped because $a_4/a \times 100 < -1.0$.

P562a (S0): the b_4 distribution indicates a nearly elliptical shape for this lenticular ($b_4 \sim 0$). It does not show isophotal twisting ($\Delta PA_{Bd} \sim 6^\circ$). The mean ellipticity values are $\varepsilon_B \sim 0.26$ and $\varepsilon_d \sim 0.38$. The color map and the residual map indicate a dust lane in this lenticular.

P562b (S(s)bc): this spiral shows an inner knot and greatly twisted arms. The structures cited above are responsible for the strong isophotal twisting ($\Delta PA_{Bd} \sim 35^\circ$). The mean ellipticity values are $\varepsilon_b \sim 0.38$ and $\varepsilon_d \sim 0.17$.

P575a (S0): there is a dust lane in this lenticular, as suggested by the residual map. The color map is slightly redder inward. The isophotal twisting is $\Delta PA \sim 50^\circ$, probably due to the dust lane. The mean ellipticity values are $\varepsilon_b \sim 0.03$ and $\varepsilon_d \sim 0.07$.

P575b (SB(s)a): this barred spiral does not show isophotal twisting ($\Delta PA_{Bd} \sim 3^\circ$). The mean ellipticity values are $\varepsilon_d \sim 0.50$ and $\varepsilon_B \sim 0.45$. The galaxy main body seems to share the same color. This spiral shows central optical emission with a value slightly larger than the typical one for its morphological type (Couto da Silva & de Souza 2006).

P616a (SB(s)a): this galaxy exhibits isophotal twisting ($\Delta PA_{Bd} \sim 25^\circ$), and it probably has a triaxial bulge. The mean ellipticity values are $\varepsilon_B \sim 0.30$ and $\varepsilon_d \sim 0.45$. We did not detect central optical emission in this early-type spiral.

P616b (S(r)0): the PA and ε distributions show variations due to the inner ring. For this lenticular, $\Delta PA \sim 8^\circ$ and $\varepsilon_b \sim \varepsilon_d \sim 0.3$. The residual map suggests the presence of a dust lane inward.

P617a (SB(s)bc): the color map indicates a redder central region, and this spiral displays a weak central optical emission. The isophotal twisting is $\Delta PA_{Bd} \sim 40^\circ$; $\varepsilon_B \sim 0.30$ and $\varepsilon_d \sim 0.20$. The b_4 distribution displays variations changing from disk-shaped inward to boxy-shaped outward.

P617b (S(s)b): this object is seen edge-on, and this fact does not allow an accurate analysis of its inner structure. It may have an inner ring. The PA variation is $\sim 6^\circ$, which does not indicate isophotal twisting. The mean ellipticity values are $\varepsilon_b \sim 0.45$ and $\varepsilon_d \sim 0.65$. The gaps in the b_3 and b_4 distributions are due to the values not displayed because of their large error bars.

Peletier et al. (1994) fitted ellipses to this object (ESO 111 G 009), which they observed in the K -band ($2.2 \mu\text{m}$). The ellipticity distribution from Peletier et al. is very similar to the one obtained in this work: both are flattened outward and reach a constant value of $\varepsilon = 0.62$. The PA distributions are also similar changing from $\sim 80^\circ$ in the inner region to $\sim 90^\circ$ in the outer one. Peletier et al. (1994) also show the $B - R$ profile, obtained from scanned plates and calibrated by A. Lauberts when working with the ESO-LV. Their color profile and our color map also agree: both are redder in the central region. Our spectroscopic data indicated that this spiral central optical emission is weak.

P221: this “pair” is the compact group RSCG 27 from the Barton et al. (1996) list. Our objects P221a, P221b, and P221c are ESO 420 0140, ESO 420 0141, and ESO 420 0142, respectively. They are displayed in the sequence a, b, c. P221c/a is P108a/b, listed by Reduzzi & Rampazzo (1995) as a pair. Kewley et al. (2001) and Dopita et al. (2002) considered this system as a pair. It seems that Kewley et al. put the slit at the P221a and P221b nuclei directions. H_α images from Dopita et al. show that current star formation is occurring within the nuclear regions of galaxies. Our color map indicates that all galaxies are slightly redder inward. The outward region shows a common color, as a clue that they share a common envelope. The residual map shows the bridges and tails of this group.

Due to this group’s strong interaction, it is very difficult to obtain a morphological classification for these galaxies in an accurate way. The ESO-LV classifies P221a as an S0, P221b as an I, and P221c as an Sb. The ESO-LV lists the c galaxy as having $B_T = 14.94$, which is less brighter than the other components. There is a small peculiarity at the right of P221a: it either may be another galaxy or material being displaced from it. The profiles may be analyzed as an indication of these galaxies’ behavior. It is interesting to point out that for P221a (S0), the average profile of the individual distributions indicates a disk galaxy; however, the one obtained using a unique median image indicates a boxy shape. For the latter distribution, the errors associated with the inward data are very large, and they were excluded from the graph. As was already noted for P546b, the way the companion is masked in a very close system may influence the behavior of the b_4 distribution for a particular galaxy. P221c shows a mean twisting of $\sim 20^\circ$, and its b_4 distribution indicates a boxy shape, while P221b shows a trend of being disk. However, these results are very biased due to the proximity of the galaxies.

P268: P268c is shown at the left, P268b at the center, and P268a at right. We considered ESO 486 0391, ESO 486 0390, and ESO 486 0392 as P268a, P268b, and P268c, respectively. The color map indicates a color gradient within this group: it is bluer upperward and redder downward. We did not morphologically classify these galaxies; however, the ESO-LV classifies P268a and P268b as Sa, and P268c as Sb. The PA distribution indicates a great twisting for P268b, but we must take into account the fact that this object is under strong influence of the other components of this group. P268a and P268b exhibit a trend for a negative b_4 distribution outward.

5. A general analysis on photometric data

A large fraction of elliptical galaxies present systematic deviations from pure ellipses (Lauer 1985a,b; Bender & Möllenhoff 1987; Jedrzejewski 1987; Bender et al. 1988; Peletier et al. 1990; Penereiro et al. 1994). These deviations can be expressed by the Fourier coefficients of third and fourth orders. The b_3 coefficient, related to $\cos 3\theta$, is associated with asymmetric isophote

deviations that may be caused by dust absorption or tidal effects (Peletier et al. 1990). For almost all elliptical galaxies with significant deviations from elliptical isophotes, the b_4 coefficient, related to $\cos 4\theta$, dominates the Fourier spectrum (Bender et al. 1988). These coefficients indicate that the isophotes are boxy when $b_4 < 0$ and disk when $b_4 > 0$. According to Bender et al. (1989), the signal of b_4 is related to the intrinsic property of an elliptical galaxy. For 80% of these galaxies, the values of b_4 almost do not change from an isophote to the next and are either positive or negative over the radius range between the center and $2r_e$ (r_e is the half-light radius).

The boxy shape in elliptical galaxies is usually associated with a slow rotation motion and large anisotropic velocity dispersions; this elliptical shape has been associated with a strong interaction of galaxies (Binney & Petrou 1985; Rampazzo & Sulentic 1992). According to some authors, disk ellipticals are rotating faster and are either an extension of S0 classification or are reminiscent of lenticular galaxies (Bender et al. 1989; Capaccioli et al. 1990). This point of view is supported by some correlations between the physical properties of galaxies and the b_4 coefficient, such as soft X-ray and radio emissions (Bender et al. 1989), rotation velocity/dispersion velocity (Bender 1988), and ultraviolet color (Longo et al. 1989). Naab et al. (1999) N -body simulations indicate that spiral-spiral mergers with equal-mass lead to an anisotropic, slowly rotating elliptical with preferentially boxy isophotes and significant minor-axis rotation. According to these authors, an unequal-mass merger of spirals results in the formation of a rotationally supported elliptical with disk isophotes and a small minor-axis rotation, and projection effects can explain the observed scatter in kinematic and isophotal properties of both classes of ellipticals. According to Khochfar & Burkert (2005), boxy ellipticals are formed either by equal-mass mergers of disk galaxies or by major mergers of early-type galaxies, whereas disk ellipticals are formed by unequal-mass mergers or late gas infall. However, these arguments are disputed by the theoretical works of Stiavelli et al. (1991) and Ryden (1992), who claimed that the boxy and disk shapes for elliptical galaxies depend upon the viewing angle. Governato et al. (1993) studied merger remnants resulting from simulated N -body merging and pointed out that remnants from two spherical galaxies show boxy isophotes, but 20% of these remnants could be classified as disk. A merger remnant of a collision between a spherical galaxy and a disk one is characterized by a predominance of disk isophotes, although a tail of boxy projections is still present in the distribution.

Rampazzo & Sulentic (1992) studied a sample of 22 mixed pairs in interaction and claimed that the relative number of elliptical galaxies with boxy, disk, and pure elliptical shapes is similar to the one found for a general sample of these galaxies (Jedrzejewski 1987; Bender et al. 1988). For most galaxies in our sample, including the early-types, it was not possible to get a characteristic value for b_4 . In concordance with Bender et al. (1989), we suggest that this effect could result from: (a) a more complicated internal structure along a major semi-axis, which causes a radial change from pointed to boxy isophotes (or vice-versa); (b) non-axisymmetric, irregular deviations of isophotes, where odd (such as b_3) Fourier coefficients dominate; and (c) dust absorption on a large scale, preventing a reliable measurement of isophotal shapes. However, for a visual overlapping pair, the way its companion is masked when the galaxy is studied may strongly influence the behavior of the b_4 distribution (see P546b in Sect. 4.2). In our sample, we have 6 E and 12 S0, and only one SB0 (P437b) showed a trend of being boxy. All ellipticals,

Fig. 60. The variation of ΔPA with $\epsilon_{\max}$ for early-type galaxies.

even these under strong interaction such as P546b, do not show significant deviations of elliptical isophotes.

In spite of having a small number of early-type galaxies in our binary sample, we can assess their behavior relating to ellipticity, shape, and isophotal twisting. Figure 60 displays ΔPA in function of $\epsilon_{\max}$, where $\epsilon_{\max}$ is the galaxy's largest ellipticity, according to the recipe used by Rampazzo & Buson (1990) and Rampazzo & Sulentic (1992): if $\epsilon(r)$ shows a maximum value, $\epsilon_{\max}$ is this value; for border variable values, $\epsilon_{\max}$ is the most frequent one. ΔPA was obtained in the way previously explained. Our data indicates that $\sim 50\%$ of early-type galaxies from our sample exhibit isophotal twisting ($\Delta PA > 10^\circ$). This fraction is smaller than the 60%–70% fraction of early-type galaxies found by Rampazzo & Buson (1990) for early-type galaxies located in the field, groups, and clusters. Taking into account E and S0 galaxies individually, our data indicates that $\sim 67\%$ of the ellipticals and $\sim 40\%$ of the lenticulars show twisting. In spite of being smaller, this fraction is comparable with the 57%–60% of the field elliptical galaxies displaying isophotal twisting, as found by Rampazzo & Buson (1990), and Fasano & Bonoli (1989) for isolated ellipticals (72%). According to Fasano & Bonoli, it is not necessary to evoke tidal interactions to explain the isophotal twisting in elliptical galaxies. Figure 60 also indicates a small trend for lenticulars with larger twistings of being less flattened, in agreement with the works of Rampazzo & Buson (1990) and Rampazzo & Sulentic (1992). The ellipticals do not display this tendency. For the lenticulars, this trend is probably related to projection effects: the lenticulars with larger ellipticity are seen edge-on, making an accurate estimate of their disk twisting more difficult.

Figure 61a indicates that early-type galaxies' maximum ellipticity is not related to pair projected separation ($H_0 = 100 \text{ km s}^{-1} \text{ Mpc}^{-1}$). For the lenticulars, this result is expected because their maximum ellipticity is related to the viewing angle on which their disk is seen. This angle is randomly distributed, and it is responsible for the lack of correlation between the maximum ellipticity and the projected separation of the pair. For the ellipticals, in spite of the uncertainty of reaching a conclusion

Fig. 61. The variation of $\varepsilon_{\max}$ with pair projected separation (Sep), and the variation of ΔPA with Sep for early-type galaxies.

based on 6 objects, the lack of such correlation may indicate that tidal interaction is not strong enough to affect the shape of these galaxies.

Figure 61b shows the relation between the isophotal twisting and pair projected separation. It is interesting to note that the early-type galaxies exhibiting isophotal twisting ($\Delta PA > 10^\circ$) are components of relatively close pairs (Sep < 70 kpc); all components of wider pairs (Sep > 70 kpc) show $\Delta PA < 10^\circ$. Moreover, their ellipticity is less than 0.4 for 3 objects with larger projected separations; this excludes a probable contamination by projection effects. Thus, we may conclude that for components of close pairs, the isophotal twisting may be small or large ($> 10^\circ$), but the larger twisting only occur for close pairs. This effect is probably related to tidal interaction in these pairs. Madejski & Möllenhoff (1990) claimed that even the triaxial models for elliptical galaxies cannot explain an isophotal twisting larger than 10° for the galaxies having an ellipticity larger than 0.3. They suggested that tidal effects are responsible for such twisting. In our sample, one galaxy (P546b) exhibits $\varepsilon > 0.3$ and $\Delta PA > 10^\circ$, and this elliptical is a component of a close pair (Sep is ~ 6 kpc).

In Figs. 62, 63, the symbols ε_d and ε_B represent disk and bar ellipticities, respectively. Barred galaxies are represented by bold symbols and unbarred galaxies by open ones. Figure 62a displays the variation of ΔPA with ε_d . We can note that objects with small ellipticities show a larger range of twisting variations; objects with $\varepsilon_d > 0.6$ are seen almost edge-on, and the position-angle is affected by projection effects, as they occur for S0 galaxies. This graph illustrates the importance of this effect.

Figure 62b exhibits the variations between isophotal twisting and bar ellipticity. Bar ellipticities range from large bars ($\varepsilon_B \sim 0.10$) to narrow bars ($\varepsilon_B \sim 0.70$). However, there is no correlation between these variables. For such objects, the isophotal twisting is related to a misalignment between bar and disk orientation. The latter is related to the viewing angle orientation; as this angle is randomly distributed, these variables are uncorrelated.

In Fig. 63a, we verify once more that disk ellipticity, which is related to the viewing angle, is not correlated with the projected separation of the pair. The uncorrelation is actually expected because of the random nature of the disk plane to the observer. However, the lack of correlation in Fig. 63b is not due to projection effects. The bar ellipticity may not be strongly affected by the viewing angle because an accurate identification of a barred galaxy can only be done for face-on objects. The absence of such correlation indicates that the gravitational interaction does not change a bar shape in a significant way. The bar ellipticity is probably ruled by intrinsic factors such as velocity

Fig. 62. The variation of isophotal twisting with disk ellipticity, and the variation of ΔPA with bar ellipticity for spiral galaxies. Barred galaxies are represented by bold symbols and unbarred galaxies by open ones.

Fig. 63. The variation of disk and bar ellipticity with pair projected separation for spiral galaxies. As before, barred galaxies are represented by bold symbols and unbarred galaxies by open ones.

Fig. 64. The variation of isophotal twisting with pair projected separation for unbarred and barred spiral galaxies. Bold symbols represent barred galaxies.

field, bulge/disk ratio, and mass distribution, which are not strongly affected by the interaction.

Figures 64a,b indicate that there is some relation between the isophotal twisting of barred and unbarred spirals and pair projected separation, as occurs for early-type galaxies: components of close pairs show a larger isophotal twisting. This may be a clue that an interaction may change spiral arms' orientation.

From our target sample of 50 probable pairs from the Soares et al. (1995) list, we were left with 41 true pairs. One is still a probable pair (P130), 6 are optical, and 2 of them are actually compact groups. We therefore have 82 binary galaxies to be analyzed relating to their morphological types. The morphological classification was based on photometric and spectroscopic data (this work and Couto da Silva & de Souza 2006). Our sample, randomly chosen from the Soares et al. list, is composed of 6 Es, 12 S0s, 15 SAs, 3 Sabs, 12 SBs, 18 SBcs, 9 Scs, 2 Scds, 1 Sd, 3 classified as S (spiral) because of their severe morphological

distortion, and one classified as P (peculiar). The number of S0 galaxies is nearly the same as that of Sa, Sb, and Sc galaxies; however, the number of elliptical galaxies (and also Sab, Scd, and Sd) is very small. There are 22% of galaxies classified as E or S0; 22% as Sa or Sab, 36.5% as Sb or Sbc, 13.5% as Sc or Scd galaxies, 1.2% as Sd, 1.2% as P, and 3.6% as S. In our sample, the lenticular galaxies are the great majority of early-type galaxies, while the Sb-Sbc galaxies ranged together are the most common spiral types. Couto da Silva & de Souza (2006) suggested that the comparably sized sample of binary galaxies at the present epoch are an extension of that of the field where Sb galaxies are the median population (Schweizer & Seitzer 1992).

To have a rough idea how binary galaxies components are connected to their companions, we attributed values to differences among morphological types. For differences among next spiral types, such as Sa-Sab, Sab-Sb, and Sb-Sbc, we attributed the value 0.5. For the differences among different classes, such as E, S0, and Sa, we attributed the value 1.0. For instance, for a pairing between an E and an Sb galaxy, we attributed the value 3.0 (1.0 for the E-S0 difference, plus 1.0 for the S0-Sa difference, plus 0.5 for the Sa-Sab difference, plus 0.5 for the Sab-Sb difference). Barred and unbarred galaxies were considered in the same way. It is important to emphasize that the pairing factor, Δp , that we use in this work is different from ΔT , where T is the Hubble type expressed in numbers. The difference may be greater when an early-type is considered because several different numbers are associated with these morphological types. For instance, if we take into account the absolute value of ΔT for P112 (Col. 5 of Table 1), $\Delta T = 7$, while $\Delta p = 3.0$ for the ESO-Uppsala classification (Col. 6 of Table 1), and $\Delta p = 2.5$ for our morphological classification (Col. 8 of Table 1). We believe that our pairing factor is more appropriate for this analysis.

For pairs with an E component, the mean morphological type difference between paired components is $\Delta p = 2.3 \pm 0.4$, taking 5 pairs into account. The errors related to the pairing factor are the mean standard errors. This indicates that an E galaxy has a trend of being paired with spirals no later than Sb, in spite of individual differences. For pairs with an S0 component, $\Delta p = 1.5 \pm 0.2$, considering 11 pairs. This suggests that lenticular galaxies have mainly E to Sb galaxies as companions. Taking into account all early-type galaxies, we find that $\Delta p = 1.8 \pm 0.2$ for 15 pairs, as P316 is counted once. For a sample of 10 mixed (E+S, S0+S) pairs Franco-Balderas et al. (2004) found an over-representation of Sa-Sb types among spiral types. Our result corroborates their findings. For 22 S+S pairs of our sample, $\Delta p = 0.9 \pm 0.1$, indicating that a spiral shows a trend of being paired with another spiral of close morphology (pairs with an S component were excluded from this analysis).

A morphological correlation between paired spiral galaxies was previously found by Karachentsev (1990). Such morphological concordance might explain the correlation in $B - V$ color indices (Holmberg 1958), but according to Kennicutt et al. (1987), it can also reflect mutually induced star formation. However, Reduzzi & Rampazzo (1996) did not find a morphological correlation for their sample of pairs from the Reduzzi & Rampazzo (1995) list. In spite of having BVR photometric data, former authors did not make a morphological classification of their sample using the morphological classification from the ESO-LV complemented by the RC3. In the discussion of their sample, Reduzzi & Rampazzo (1996) commented that there was no indication that their observed pair members have similar morphological types. Their result was probably based on a straight analysis of the galaxies' morphological types, but there was no other

information about this subject in their work. Hernandez-Toledo & Puerari (2001) pointed out that more than half (51%) of their 33 S+S pairs drawn from the Karachentsev (1972) list show morphological concordance ($\Delta T < 2$), and suggested that this could explain, in part, the Holmberg effect. Hernandez-Toledo & Puerari reclassified the morphology of all their pair components and presented their Hubble type. However, the T-type used in their analysis is not presented in their paper. Our Table 1 shows that there are small differences when presenting the morphological types in this way. If we apply our pairing factor to their sample, we find $\Delta p = 0.8 \pm 0.1$, a value similar to $\Delta p = 0.9 \pm 0.1$, which we obtained for our S+S pairs. According to our pairing factor, there is a morphological correlation between Hernandez-Toledo & Puerari paired spiral galaxies.

For our sample, 24 out of 41 true pairs are S+S pairs, one is an P+S pair, 5 are mixed (E+S), 9 are disk pairs (S0+S), and 2 are early-type ones (E+S0, E+E, or S0+S0). Our sample has been morphologically classified taking into account CCD images, profiles, and, for most galaxies, the spectra analysis also. In our sample of 41 true pairs, there are 60 spirals with accurate morphological classification (3 of them are classified as S p, due to their strong peculiar morphology, and one galaxy was classified as P). From these 60 spirals, 32 are barred, one is an AB type, and 27 are unbarred. In our sample, 7 out of 15 SAs, 2 out of 3 Sabs, 5 out of 12 SBs, 10 out of 18 SBcs (the only one of SABbc type was not included in the counting of barred spiral; however, it was included in the total counting), 5 out of 9 Scs, the 2 Scds, and the only Sd are barred.

Unfortunately, we do not have a field sample with morphological classification obtained in the same way to allow a reliable comparison between the occurrence of barred spirals in our sample and in the field. In spite of being statistically incomplete, as it is a sub-sample of the list of binaries of Soares et al. (1995), the morphological classification of our sample is more accurate than those of the several lists of field, binary, and group galaxies used in the statistical work of Elmegreen et al. (1990), with the galaxies' morphology from the ESO-Uppsala and RC2 (de Vaucouleurs et al. 1976). However, according to Elmegreen et al., the percentage of barred spirals in a field sample of Turner & Gott (1976) is $29 \pm 4\%$. The statistical errors were calculated following the recipe of Elmegreen et al. (1990). For 60 spirals with morphological types, we note that there are $53 \pm 6\%$ barred spirals in our binary sample, a larger fraction than that of the field. Comparing the values from Table 2 from Elmegreen et al.'s work with the ones for the Sa-Sb and Sbc-Scd galaxies from our sample, we note that $47 \pm 9\%$ of our Sa-Sb data are barred, while $37 \pm 7\%$ of these galaxies are barred in the Turner & Gott field sample, a value slightly smaller than ours. However, $59 \pm 9\%$ of our Sbc-Scd are barred, while only $18 \pm 5\%$ of these galaxies are barred in the field sample. Thus, the Sbc-Scd types are greatly responsible for the larger percentage of barred spirals in our sample, when comparing them with the values of the field. Elmegreen et al. suggested that galaxy companions are associated with bar formation, but only for early-type spirals (Sa-Sb), and that there is an excess of these early-type spirals in binary galaxies. For these authors, $77 \pm 5\%$ of early-type spirals in pairs of galaxies are barred, while in the Turner & Gott field, barred Sa-Sb are $44 \pm 5\%$, as indicated in their Table 3. Our data still indicates a percentage of $45 \pm 9\%$ in this analysis, a value similar to that of the field. Thus, we do not support the Elmegreen et al. findings that early-type spirals in pairs of galaxies are associated with bar formation.

It is interesting to point some peculiarities found in our binary sample: all 3 late-type spirals (2 Scds and 1 Sd) are barred.

The same trend is shown in a sample of binary galaxies from Elmegreen et al., drawn from Turner's (1976) pairs list: the two Sd-Sm galaxies are barred. However, for a sample of 9 Sd-Sm drawn from the list of binary galaxies of Peterson (1979), there are 5 SBs, 3 SABs, and 1 SA galaxy, and the number of barred galaxies is the order of the field. Our observational result on binary galaxies is in agreement with the statistical work of Gaebler & Couto da Silva (2000), who analyzed samples of binary galaxies from the Soares et al. (1995), Reduzzi & Rampazzo (1995), and Karachentsev (1972) lists, and a field control sample from Karachentseva (1973), with morphological types from the RC3. Gaebler & Couto da Silva noted that there are some differences relating to the binary sample used, but that for all of them, the fraction of barred late-type spirals, such as Sbc-Scd and Sd-Sm, is greater than that of the field, and the fraction of barred early-type spirals is smaller than that of the control sample.

Elmegreen & Elmegreen (1982, 1987) developed a morphological system to classify spiral galaxies in divisions based on the regularity of their spiral arm structure. Grand design and multiple-arm galaxies have two-arm symmetric structures in at least the inner parts of their disks, while flocculent spirals show a fleecy appearance with numerous short and asymmetric arms. According to them, grand design galaxies (arm classes 5–12) contain a spiral density wave, while flocculent galaxies (arm classes 1–4) may acquire their shape through stochastic or random star formation processes. Elmegreen & Elmegreen (1982) noted that $92 \pm 8\%$ of SB and $57 \pm 19\%$ of SA in pairs of galaxies have a grand design structure. They based their conclusions on 12 SB galaxies and 7 SA galaxies. Reduzzi & Rampazzo (1996) succeeded in classifying 36 spirals of their binary sample and verified that 21 out of 22, or 95%, of SB galaxies show a grand design structure, while 7 out of 14 SA spirals, or 50% have a grand design structure. Hernandez-Toledo & Puerari (2001) classified 43 spirals of their sample related to this structure, 20 barred and 23 unbarred, and noted that 18 SBs, or 90%, are grand design, while 17/23 SAs, or 74%, show this structure.

Several spirals in our sample are nearly edge-on, in strong interaction, or do not fit into the Elmegreen & Elmegreen classes. Instead of arm classifications, the analysis referring to binary samples is related to the occurrence of grand design structure. Because of this, we performed an analysis of spirals in our binary sample just related to this structure. We succeeded in classifying 55 galaxies, 33 SBs, 1 SAB, and 21 SAs. The barred spirals with grand design morphology are P24b, P42a, P75a, P79a, P105a, P117b, P139a, P151a, P259a, P323b, P331a, P358a, P363a, P422a, P423b, P426a, P429b, P457a, P460a, P460b, P485a, P487a, P497b, P500b, P546a, P616a, and P617a. The flocculent spirals are P101b, *P105b, P358b, P416b, P432b, and P521a. P490a, an SABbc, has a grand design structure. The grand design unbarred spirals are P24a, P57b, P59a, P101a, P105a, P426b, P429a, P437a, P457b, P487b, P497a, and P562b; and the flocculent are P42b, P79b, P117a, P139b, P147a, P223b, P416a, P423a, and P539b. For this analysis, we also used the residual maps. For P437a, we can note from the residual and color maps that it has a grand design structure, although we cannot attribute an arm classification to it. The spiral structure for P521a was only detected with the help of the residual map: it is flocculent. The * in P105b indicates a doubt of the authors about this galaxy's fleecy appearance.

We note that 27 SBs, or $\sim 82 \pm 7\%$, are grand design, while 6 are flocculent. If P105b is excluded from the flocculent sample, then $\sim 84 \pm 6\%$. From 21 SAs, 12 or $57 \pm 11\%$, are grand design and 9 are flocculent. The statistical errors follow the recipe of Elmegreen & Elmegreen (1982). Latter authors analyzed a

sample of 22 SBs and 15 SAs field galaxies from Turner & Gott (1976) and noted that $7/22$ or $\sim 32 \pm 10\%$ of SA and $11/15$ or $\sim 73 \pm 11\%$ of SB are grand design.

Comparing our result with that found by Elmegreen & Elmegreen (1982) for field galaxies, we note that there is not a significative enhancement in grand design structure for barred and unbarred spirals in our binary sample. What is the difference between our sample and those previously mentioned? We analyzed 55 SB and SA types; Hernandez-Toledo & Puerari, 43; Reduzzi & Rampazzo, 36; and Elmegreen & Elmegreen, 19. The field sample has 37 SB and SA types, a number close to the Reduzzi & Rampazzo sample. However, only our work and Hernandez-Toledo & Puerari's reevaluated the morphology of the spirals, as Reduzzi & Rampazzo mainly reclassified their early-type objects, although we do not have a field sample with morphological classification determined in a similar way to allow for a reliable comparison. Reduzzi & Rampazzo used a morphological classification for the spirals from the ESO-LV complemented by the RC3, and the Hubble types of the field sample are from the RC2. It seems that the difference between our sample and these works occurred because some of our galaxies, which might be classified as lenticulars, were classified as early-type spirals with the help of the residual maps. These galaxies enlarged the number of flocculent spirals in our sample. It should be interesting to perform other studies on this subject, either enlarging the number of spirals with grand design or flocculent structures in binary samples, or using a field sample with similar numbers and morphological classifications.

6. Discussion

Our binary sample is mainly composed of spiral galaxies, and in spite of having a small number of early-type galaxies in our sample, we looked into their behavior regarding shape, ellipticity, and isophotal twisting. The number of early-type galaxies showing isophotal twisting in our sample is similar to the ones located in the field. However, it is interesting to point out that these early-type galaxies exhibiting isophotal twisting are components of relatively close pairs. This indicates that tidal interaction may be an agent to promote isophotal twisting, but it is not the only one. There is some relation between the isophotal twisting of spiral galaxies and the pair projected separation that occurs for early-type galaxies: the spirals showing larger isophotal twisting are components of close pairs, although not all components of close pairs show that twisting. This occurs for barred and unbarred spirals, and may be a clue that interaction may change some spiral arms's orientation.

We corroborate the findings of Rampazzo & Buson (1990) and Rampazzo & Sulentic (1992) that there is a trend for less flattened lenticulars to show larger twisting. This fact is probably related to projection effects: the lenticulars with larger ellipticity are seen edge-on, making an accurate estimate of their disk twisting difficult. We noted that the bar ellipticity of spirals is not correlated with the projected separation. The absence of such correlation may be a clue that gravitational interaction does not strongly change a bar shape. Probably, the bar ellipticity of a bar is governed by intrinsic factors such as velocity field, bulge/disk ratio, and mass distribution, which are not strongly affected by the interaction.

We verified that barred galaxies usually show a typical behavior in the ellipticity and PA distributions: these distributions usually display variations when changing from bar to disk region, and in some cases, a variation also occurs along the bar.

The profiles for most galaxies were obtained in two different ways, aiming to verify the influence of random errors on them. In this work, nearly 400 frames were reduced one by one in a non-automatic way. We noted that random errors in PA profiles are at least 2° , but a significant result must consider a variation larger than 11° for this distribution. We also noted that for a visually spiral arm overlapping pair, the way its companion is masked when the galaxy is studied may strongly influence the behavior of the b_4 profile.

We corroborate the Reduzzi & Rampazzo (1996) and Hernandez-Toledo & Puerari (2001) findings that the color of the tails is consistent with the stripping hypothesis because it is similar to the progenitor outskirt. Like latter authors we noted that bars are usually redder and rings are bluer compared with the galaxy outskirts. However, unlike these authors, we did not find a significant enhancement in grand design structure for barred and unbarred spirals in our binary sample. Using a pairing factor, we found a morphological correlation between paired galaxies.

It is interesting to emphasize that some galaxies (such as P79a) have profiles that are common for their morphological types, and the interaction signature is only evidenced in their residual maps. We verified that all spirals, even these belonging to optical pairs, show an excess in their asymmetric map, and in searching for signs of tidal interaction, we need to consider that even isolated non-interacting objects present some degree of distortion.

There is a connection between the interaction strength and the morphological distortions in binary galaxies. Whether we consider the pair projected separation as an indication of the interaction strength, distortions such as a displaced center, an anomalous spiral arm shape, and a twisting of external regions are easily detected in some close pairs. Some galaxies of our sample exhibit strong central star formation detected in our $B - R$ color maps and in our spectroscopic study. The most distorted galaxies are components of close pairs, but not all close pairs seem to be affected by the interaction. According to Binney & Tremaine (1987), the strongest interactions that are responsible for morphological distortions in a galaxy occur when the relative velocity of the encounter is smaller than the maximum rotational velocity of the galaxy. Toomre & Toomre (1972) claimed that tidal tails and streams are resonance effects largely absent from retrograde encounters. Mihos & Hernquist reported that retrograde encounters can trigger star formation in simulations, although they do not produce dramatic tidal tails. Barton et al. (2000) suggested that a preliminary result of their data indicates that prograde and retrograde encounters have similar emission line characteristics, although the prograde encounters seem to produce different tidal features. That may be a clue that besides interaction other agents such as particular internal conditions (Petrosian et al. 2002; Lambas et al. 2003), gaseous feeding due to kinematical mechanisms (Keel et al. 1985; Bushouse et al. 1988), orbital geometry (Jones & Stein 1989; Surace et al. 1993), and dust content (Jones & Stein 1989), can trigger emission in binary galaxies. Surace et al. (1993) suggested that events before the encounter may determine the fate of a galaxy during the interaction, and according to Mihos & Hernquist (1996) models, the response of the gas to a close pass depends dramatically on the mass distribution of a galaxy.

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Online Material

Fig. 3. Residual maps.

Fig. 4. Residual Maps.

Fig. 5. Residual Maps.

Fig. 6. Residual Maps.

Fig. 7. Residual Maps.

Fig. 8. Some asymmetric maps.

Fig. 10. In Figs. 10-59, bold $\triangle$ represents the average distribution of individual galaxies (ind), while open $\square$ indicates the profile for a median image distribution (med). This S+S pair is in the list of triple systems by Karachentseva & Karachentsev (2000). Since there is no redshift or magnitude available for the third component, we still consider this system to be a pair with $\Delta V = 253 \text{ km s}^{-1}$.

Fig. 11. Optical pair.

Fig. 12. S+S pair with $\Delta V = 300 \text{ km s}^{-1}$.

Fig. 13. P+S close pair, in the process of merging, with $\Delta V = 35 \text{ km s}^{-1}$ and matter exchanging. Both objects share a common envelope with the same color.

P59ab - 89"

Fig. 14. S+S pair in the process of merging and sharing a common envelope ($\Delta V = 35 \text{ km s}^{-1}$). The color map indicates a similar color in the external regions, in agreement with the Reduzzi & Rampazzo (1996) and Agüero et al. (2000) findings.

Fig. 15. S0+S pair in strong interaction and probable matter exchanging, with $\Delta V = 13 \text{ km s}^{-1}$.

Fig. 16. S+S pair in strong interaction, with $\Delta V = 57 \text{ km s}^{-1}$.

Fig. 17. S+S pair in interaction, with $\Delta V = 58 \text{ km s}^{-1}$.

Fig. 18. S+S pair with $\Delta V = 184 \text{ km s}^{-1}$.

Fig. 19. E+S pair in interaction, with $\Delta V = 184 \text{ km s}^{-1}$.

Fig. 20. S+S pair with $\Delta V = 338 \text{ km s}^{-1}$.

Fig. 21. Pair?.

Fig. 22. S+S pair with $\Delta V = 46 \text{ km s}^{-1}$.

Fig. 23. Optical pair.

Fig. 24. S0+S pair. Until now, there has been no radial velocity available for P151b. However, P151a was studied by Combes et al. (1994) as a pair component, and by Donzelli & Pastoriza (2000) as a merging pair.

Fig. 25. E+S pair with $\Delta V = 46 \text{ km s}^{-1}$.

Fig. 26. S0+S pair in interaction, with $\Delta V = 266 \text{ km s}^{-1}$.

Fig. 27. E+S0 pair with $\Delta V = 273 \text{ km s}^{-1}$.

Fig. 28. E+S pair in interaction, with $\Delta V = 230 \text{ km s}^{-1}$.

Fig. 29. S+S pair in strong interaction and probable exchanging of matter, with $\Delta V = 230 \text{ km s}^{-1}$. The bridge connection between galaxies exhibits the same color, in agreement with what was claimed by RR2.

P340a - 111"

P340b - 67"

Fig. 30. Optical pair.

Fig. 31. S+S pair in strong interaction, with $\Delta V = 4 \text{ km s}^{-1}$.

Fig. 32. S+S pair with $\Delta V = 59 \text{ km s}^{-1}$.

P387a - 84".5 x 45"

P387b - 67"

Fig. 33. Optical pair.

Fig. 34. Optical pair.

Fig. 35. Optical pair.

Fig. 36. S+S pair with $\Delta V = 111 \text{ km s}^{-1}$.

Fig. 37. S+S pair in strong interaction, with $\Delta V = 243 \text{ km s}^{-1}$.

Fig. 38. S+S pair with $\Delta V = 49 \text{ km s}^{-1}$.

Fig. 39. S+S pair with $\Delta V = 1 \text{ km s}^{-1}$.

Fig. 40. S+S pair with $\Delta V = 57 \text{ km s}^{-1}$.

Fig. 41. S0+S pair with $\Delta V = 25 \text{ km s}^{-1}$.

Fig. 42. S0+S pair in interaction, with $\Delta V = 502 \text{ km s}^{-1}$.

Fig. 43. S+S pair in interaction, with $\Delta V = 20 \text{ km s}^{-1}$.

Fig. 44. S+S pair with $\Delta V = 66 \text{ km s}^{-1}$.

Fig. 45. S+S close pair in interaction, with $\Delta V = 287 \text{ km s}^{-1}$. According to RR2, this pair (their P353) is located in a high density medium and is in an initial stage of interaction. The external regions of both galaxies show the same color.

Fig. 46. S+S pair with $\Delta V = 167 \text{ km s}^{-1}$.

Fig. 47. S+S pair with $\Delta V = 167 \text{ km s}^{-1}$.

Fig. 48. S+S pair with $\Delta V = 52 \text{ km s}^{-1}$.

Fig. 49. S+S pair in strong interaction, with $\Delta V = 52 \text{ km s}^{-1}$.

Fig. 50. S0+S pair with $\Delta V = 52 \text{ km s}^{-1}$.

Fig. 51. S0+S0 close pair in strong interaction, with $\Delta V = 11 \text{ km s}^{-1}$.

Fig. 52. E+S pair with $\Delta V = 45 \text{ km s}^{-1}$.

Fig. 53. E+S pair in strong interaction, with $\Delta V = 359 \text{ km s}^{-1}$.

Fig. 54. S0+S pair with $\Delta V = 68 \text{ km s}^{-1}$.

Fig. 55. S0+S pair with $\Delta V = 68 \text{ km s}^{-1}$.

Fig. 56. S+S0 pair with $\Delta V = 241 \text{ km s}^{-1}$.

Fig. 57. S+S pair with $\Delta V = 550 \text{ km s}^{-1}$.

P221abc - 82".5

Fig. 58. Compact group associated with P221.

Fig. 59. Compact group associated with P268.