***BVRI* surface photometry of mixed morphology pairs of galaxies**

I. The first data set^{★,★★}

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Abstract. We present multicolor broad band (*BVRI*) photometry for a sample of 11 mixed morphology (E/S0+S) binary galaxies drawn from the Karachentsev Catalogue of Isolated Pairs of Galaxies (KPG). The data is part of an observational programme devoted to the systematic photometric study of one of the most complete and homogeneous pair samples available in the literature. We present *B* band, *B*-filtered images, *B*, *V*, *R* and *I* surface brightness and (*B* – *V*), (*B* – *R*) and (*B* – *I*) color profiles as well as geometric ($\epsilon = 1 - b/a$, PA and a_4/a) profiles for each component pair. In addition, integrated corrected *B*, *V*, *R* and *I* magnitudes and integrated (*B* – *V*), (*B* – *R*) and (*B* – *I*) colors are also presented. Internal and external data comparisons show consistency within the estimated errors. Most of this subsample have photometric parameters homogeneously derived for the first time. Geometric profiles from our surface photometry along with the broad-band imaging and color information have been used to re-evaluate morphology in all pairs. We find an important number of true mixed pairs with 5/11 (E+S) pairs in the present sample. The remaining objects include 3 disk pairs (composed of S0 and S members), 2 early-type pair comprising E and S0 members and 1 spiral-irregular pair. The measurements will be used in a series of forthcoming papers where we try to identify and isolate the main structural and photometric properties of disk and elliptical galaxies at different stages of interaction.

Key words. galaxies: spiral – galaxies: elliptical and lenticular, cD – galaxies: structure – galaxies: photometry – galaxies: interactions – galaxies: kinematics and dynamics

1. Introduction

According to current popular models of galaxy formation, galaxies are assembled through a hierarchical process of mass aggregation, dominated either by mergers (cf. Baugh et al. 1996) or by gas accretion (cf. Avila-Reese et al. 1998; Avila-Reese & Firmani 2000). In the light of these models, the influence of environment factors and interaction phenomena in the shaping and star formation of the disks is natural, at least for a fraction of the present-day galaxy population. Examples are galaxy harassment in clusters (Moore et al. 1996), tidal stirring of dwarf irregulars near giant galaxies (Mayer et al. 2001), tidally induced star formation (Lacey & Silk 1991; Kauffmann et al. 2001). See also Dultzin-Hacyan (1997) for a review.

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** Tables 1–3 and Figs. 5 to 15 are only available in electronic form at <http://www.edpsciences.org>

For binary galaxies, current ideas suggest that most physical pairs are morphologically concordant, that is, with components showing similar initial star formation and angular momentum properties. However, investigating the multi-wavelength signatures of interaction-induced secular evolution and star formation in spiral-spiral pairs are complicated because both components of the system are gas-rich and fast rotators. Models suggest that the relative orientation of angular momentum vectors adds an additional variable to the interaction equation in such pairs.

Mixed morphology (E/S0+S) pairs (hereafter mixed pairs), involving a spiral galaxy paired with an elliptical/lenticular offer a two-fold simplification because they contain a single gas-rich component with high specific angular momentum. The former allows as to assign the non-stellar material, and associated star formation activity, to a single component, at least as an initial assumption. The latter minimizes the role of relative orientation of component angular momentum vectors from the set of variables thought to influence interaction-induced effects. Mixed pairs are an ideal sample to search for evidence

of component cross-fuelling, because any large quantity of gas observed in the E/S0 components could be interpreted as evidence of gas transferred from the late-type companion.

The Catalogue of Isolated Pairs of Galaxies (KPG, Karachentsev 1972) is an appropriate sample for binary galaxy studies because of its size, completeness and relatively unbiased selection (see, e.g. Hernández-Toledo et al. 1999). Morphological classification in the KPG sample suggest that for a flux limited sample ($m_{zw} = 15.7$), about 25% are of the (E/S0+S) type. Statistical studies indicate that a high fraction (~65%) of the mixed pairs show an enhancement in the optical and FIR emission (Xu & Sulentic 1991; Hernández-Toledo et al. 1999, 2001). This enhancement is interpreted as a by-product of interaction-induced star formation activity in physical binaries. Evidence for color correlations (Holmberg Effect) has been observed not only for (S+S) pairs but for components of mixed pairs, although very few photometric data supporting this correlation exists at present (see, e.g. Demin et al. 1984). If real, it suggests that environment plays a strong role in the secular evolution of the pairs or that the paired environment induces parallel evolution, at least as manifested by the star formation history (Kennicutt et al. 1987).

Through a systematic observational project involving CCD optical, NIR photometry and optical spectroscopy, we want to obtain a homogeneous set of observations for a representative sample (if not all) of the mixed pairs in the Karachentsev Catalogue. One motivation is to find observational evidence of a “nurture scenario” and study the role played by interaction-induced effects, such as accretion, merging and tidal stripping, in the formation and evolution of mixed pairs. This scenario allows for morphology changes and greater morphological discordance in pairs. Rampazzo & Sulentic (1992) proposed four possible ways of accounting for the large number of mixed pairs that are observed. Some of these explanations, if true, weaken or remove the apparent challenge that mixed pairs present to theoretical ideas: a) Spiral components could be misclassified lenticular systems (notice that an E+S0 system still leaves the problem of explaining a disk galaxy coupled with a diskless one). b) Elliptical components could be misclassified lenticular galaxies as well, thus leaving S0+S systems. c) Spiral structure could be a product of the interaction. d) Pairs could be an intermediate stage in the coalescence of triplets and compact groups (the Elliptical component could then be a merger product candidate, e.g. Wiren et al. 1996). In such cases the new E galaxies could be expected to have M/L ratios similar to that their parent galaxies. A recent search for the existence of extended massive dark haloes around the component galaxies in Karachentsev’s binary galaxies (Teerikorpi 2001) concluded that binaries with one or two elliptical galaxies do not show higher values of M/L , contrary to that expected from measurements of individual elliptical galaxies (Bahcall et al. 1995), reinforcing the scenario in d).

Another motivation comes from the fact that mixed pairs show the distinct signature of increased star formation due to interactions in the spiral components (see, e.g. Hernandez-Toledo et al. 2001). The mixed pairs sample thus provides an ideal testing ground to detect moderate luminosity evolution through a detailed study of the fundamental plane

relations involving photometric scale-length parameters, surface brightness profiles, total magnitudes and luminosities as well as dynamical parameters such as the amplitude of the rotation and detailed rotation curves. We want to quantify the effects of the interactions on the fundamental plane relations and set limits on the ability of pre- or non-merger interaction to initiate luminosity evolution off the fundamental plane relations at the current epoch. For the interpretation, we will be using recent semi-numerical models of galaxy formation and evolution in the hierarchical scenario (see, e.g. Avila-Reese & Firmani 2000). A preliminary statistical study exploring the feasibility of mixed pairs for such studies will be published in a forthcoming paper (see, e.g. Hernández-Toledo et al. 2003).

In this first paper of a series, we present B , V , R and I photometric data: total magnitudes, $(B - V)$, $(B - R)$, $(B - I)$ colors, surface brightness profiles, color profiles and geometric ($\epsilon = 1 - b/a$, PA and a_4/a) profiles with emphasis on the morphology and its relation to the global photometric properties for a subsample of 11 mixed pairs. We address the following questions:

- 1) Are most of the mixed pairs in the KPG catalogue really (E+S) pairs?
- 2) Is there evidence that the spiral structure in the S-components can arise from the interaction process?
- 3) Is there any evidence of a correlation between the shape of color and surface brightness profiles and the detailed morphology (bars, rings, shells, ripples, etc.) in these galaxies?

The structure of the paper is as follows. Section 2 summarizes the observations relevant to our photometric study. Section 3 presents the observations, reduction techniques and a comparison of our estimated total magnitudes against those in the literature. A discussion of the related errors is also included. Section 4 presents the results obtained and a discussion about how the estimated surface brightness profiles, color profiles and geometric profiles can be used in combination with filtered images to disentangle detailed morphology in our pairs. Section 5 is a general discussion of the results obtained. The systematics of morphological distortions induced by the interactions are commented on the light of current models and a test for the Holmberg effect is presented. Finally, Sect. 6 is a summary of our conclusions.

2. Sample and observations

Through one of the main optical observatories in México (Observatorio Astronómico Nacional (OAN) San Pedro Mártir, Baja California) we have started an observational programme to obtain uniform photometric data for one of the most complete and homogeneous pair samples currently available. The sample of mixed pairs amounts to about 130 pairs from a total of 602 pairs in the KPG catalogue. The observations were begun in 1999. The CCD *BVRI* photometry (in the Johnson-Cousins system) was obtained with a SITE1 CCD detector attached to the 1.5 m telescope and a CCD TEK2 attached to the 0.84 m telescope, covering an area of about $4.3' \times 4.3'$ and $6.7' \times 6.7'$ respectively. Table1 indicates the scale of the observations in "/pixel.

Since our goal is to observe most of the KPG (E/S0+S) sample, we have applied no special strategy in selecting the current subset of 11 mixed pairs. Available observing time and weather conditions were the main factors limiting the number of observed pairs. This has been the observational strategy up to the point where most of the (E/S0+S) sample was completed. The selection criteria and statistical properties for the (E/S0+S) sample that are most relevant to the present and further photometric analyses were presented in Hernández-Toledo et al (1999).

3. Observations and data reduction

A journal of the first set of the photometric observations is given in Table 1. Column 1 gives the original catalogued number, Cols. 2–11 give the number of frames per filter, the integration time (in s), seeing conditions (in ″), CCD detector and the pixel size for sampling the data (in ″).

Images were debiased, trimmed, and flat-fielded using standard IRAF¹ procedures. First, the bias level of the CCD was subtracted from all exposures. A run of 10 bias images were obtained per night, and these were combined into a single bias frame which was then applied to the object frames. The images were flat-fielded using sky flats taken in each filter at the beginning and/or at the end of each night. Subsequent calibration and surface photometry analysis has been carried out following a procedure implemented by Hernández-Toledo & Puerari (2001) and updated in the present paper.

Photometric calibration was achieved by nightly observations of standard stars of known magnitudes from the Landolt lists (Landolt 1992). Standard stars with a color range $-0.1 \leq (B - V) \leq 1.4$ and a similar range in $(V - I)$ were observed. The principal extinction coefficients in B , V , R and I as well as the color terms were calculated according to the following equations:

$$V_L = v_o - \alpha_o - \alpha_1[(b_o - v_o - \beta_o)/\beta_1]$$

$$B_L = V_L + [(b_o - v_o - \beta_o)/\beta_1]$$

$$R_L = V_L - [(v_o - r_o - \epsilon_o)/\epsilon_1]$$

$$I_L = V_L - [(v_o - i_o - \gamma_o)/\gamma_1]$$

where B_L , V_L , R_L and I_L are the standard magnitudes in the Landolt system, b_o , v_o , r_o and i_o are the extinction corrected instrumental magnitudes, and α_i , β_i , ϵ_i and γ_i the transformation coefficients. The main extinction coefficients and resulting parameters of the transformation can be found in Table 2.

Table 3 gives some relevant information for the observed pairs from the literature. Column 1 is the KPG catalogue number, Col. 2 reports other identifications, Cols. 3 and 4 the apparent B magnitude and morphological types from the NASA Extragalactic Database (NED), Col. 5 the linear separation of

each pair (in kpc), Col. 6 the radial velocity for each component in km s^{-1} from NED, and finally, Col. 7 gives the major axis diameter (at $\mu_B = 25$) (in kpc) for each component galaxy ($H_o = 75 \text{ km s}^{-1} \text{ Mpc}^{-1}$).

The most energetic cosmic-ray events were automatically masked using the COSMICRAYS task and field stars were removed using the IMEDIT task when necessary. Within the galaxy itself, care was taken to identify superposed stars. A final step in the basic reduction involved registration of all available frames for each galaxy and in each filter to within ± 0.1 pixel. This step was performed by measuring centroids for foreground stars on the images and then performing geometric transformations using the IMALIGN task in IRAF.

Elliptical surface brightness contours were fitted using the STSDAS package ISOPHOTE in IRAF. An initial starting guess for the ellipse-fitting routine was provided interactively by estimating points that represent the ends of the major and minor axis at an isophotal level of relatively high signal-to-noise ratio. The algorithm in use (Jedrzejewski et al. 1987) computes the geometric profiles; ellipticity ($\epsilon = 1 - b/a$), the position angle PA and B_4 , the fourth cosine coefficient of the Fourier series expansion of deviations from a pure ellipse as a function of radius from the center of each galaxy. The quantity:

$$\frac{a_4}{a} = \frac{\sqrt{1 - \epsilon} B_4}{a | \frac{dI}{da} |}$$

(see Bender & Möllenhoff 1987) forms a dimensionless measure of the isophotal shape and indicates whether a galaxy is boxy ($a_4/a < 0$) or disk ($a_4/a > 0$). At least three effects can modify the isophotal shape in a systematic fashion: a) intrinsic structure (e.g. dust lanes, faint features, etc.), b) projected features (nearby companions, field stars, etc.) and c) the sky removal. We have carefully attempted to face problems in b) by creating, when necessary, a mask around each galaxy through FIXPIX and TEXT2MASK routines in IRAF. The mask is such that the ellipse fitting algorithm recognize a $w = 0$ weight within the masked region and $w = 1$ outside it. This allows for ellipse fitting far beyond that in non-masked cases. A more detailed description of this and other procedures will be reported in a forthcoming paper where some very close pairs are treated in a special way. For problems in a), we have left the programs deal with it. The IRAF package provides an estimate of the internal fitting error based on the S/N of the profile. For problems in c), we have carefully subtracted the sky in each frame and in each band. We can estimate more typical uncertainties by examining the scatter in the plotted parameters (see Mosaics at the end of the paper) in each band and for the fainter galaxies. Typical errors are $\Delta\epsilon = 0.05$, $\Delta\text{PA} = 7$, and $\Delta(a_4/a) * 100 = 0.03$.

Since we are interested in the mean global surface brightness profiles for spirals, we report azimuthal averaged profiles by fitting ellipses with a fixed position angle and ellipticity previously determined on the external non-disturbed isophotes. However, in order to discuss their internal structure, we are also presenting the corresponding geometric profiles, estimated by allowing ELLIPSE to run in free mode (see Sect. 4.3). For ellipticals, we have used ellipse fitting in free mode (free estimation of position angle and ellipticity) beginning in the outer

¹ The IRAF package is written and supported by the IRAF programming group at the National Optical Astronomy Observatories (NOAO) in Tucson, Arizona. NOAO is operated by the Association of Universities for Research in Astronomy (AURA), Inc. under cooperative agreement with the National Science Foundation (NSF).

Fig. 1. Comparison between our estimated magnitudes and those from Landolt (1992) for 10 standard stars in common.

parts with a previously-determined external isophote. This renders detailed surface brightness profiles as well as geometric profiles for early-type galaxies.

Total magnitudes can be calculated by analytically extrapolating a fitting of a disk beyond the outermost isophote to infinity. However, disk fitting is notoriously fraught with uncertainty (cf. Knapen & van der Kruit 1991). Alternatively, we estimate in this work the total magnitudes computed from polygonal apertures chosen interactively to assure that they are large enough to contain the whole galaxy and still small enough to limit the errors due to the sky error and light contamination from a neighbor galaxy. This is achieved in each band by using polygonal apertures within POLYPHOT routines in IRAF. Foreground stars within the aperture were removed interactively.

3.1. Errors

An estimation of the errors in our photometry involves two parts: 1) The procedures to obtain instrumental magnitudes and 2) the uncertainty when such instrumental magnitudes are transformed to the standard system. For 1), notice that the magnitudes at the output of the IRAF routines (QPHOT, PHOT and POLYPHOT) involve small internal errors in the calculations. Since we also have applied extinction corrections to the instrumental magnitudes in this step, our estimation of the errors are mainly concerned with extinction corrections and the airmass. After a least square fitting, the associated errors with the slope for each principal extinction coefficient are shown in Table 2. An additional error $\delta(\text{airmass}) \sim 0.005$ from the airmass rou-

tines in IRAF was also considered. For 2), the zero point and first order color terms are the most important to consider.

After transforming to the standard system by adopting our best-fit coefficients the formal errors are also shown in Table 2. To estimate the total error in each band, it is necessary to use the transformation equations and then propagate the errors. Total typical uncertainties for this sample of galaxies are 0.07, 0.04, 0.06 and 0.06 in *B*, *V*, *R* and *I* bands, respectively. However, see Table 4 for an individual estimation of errors.

The estimated total magnitudes in this work were compared against other external estimations reported in the literature. This has been done for: 1) The standard stars and 2) those paired galaxies in common with other works, when available.

3.2. Standard stars

A comparison of our CCD magnitudes against those reported in Landolt (1992) for 10 stars in common is shown in Fig. 1. We observe no significant deviations between our CCD magnitudes and the standard star magnitudes. The internal error can be described by a $\sigma \sim 0.02$, or a similar value.

3.3. Paired galaxies

A comparison of our total *B*-band magnitudes and those reported in the RC3 Catalogue (de Vaucouleurs et al. 1991) is shown in Fig. 2.

Figure 2 shows that the agreement with reported total *B*-band magnitudes is good. The solid line in the plot shows a fit by forcing a unity slope value. Then a typical displacement

Fig. 2. Comparison between our total B and V magnitudes and total magnitudes from RC3 Catalogue.

of 0.094 can be inferred from the data, consistent with our error estimations. The only significant difference is for KPG86A. Our measurements disagree by about 0.5 mag with the value reported in RC3. Since the estimated magnitude for the early-type component in this pair is in agreement with its reported value, we suggest that the RC3 value may be wrong. Notice also the size of the error bars reported in RC3 for this galaxy.

It is important to notice that a high fraction of the RC3 data available for our pairs comes from Zwicky photographic magnitudes that were transformed to the B_T system. The possibility of systematic errors in the Zwicky magnitudes has been discussed by numerous authors (cf. Haynes & Giovanelli 1984). Although these and other authors present recursion relations to convert Zwicky magnitudes to those of other systems, most notably to the photographic magnitudes in the Holmberg system (1958), or to the B_T system (de Vaucouleurs et al. 1991), it has been shown that these recursion relations are probably unsatisfactory for magnitudes fainter than 14.0.

Sources to compare our photometry of pairs in other bands than B are difficult to find. Laurikainen et al. (1998) report B , V and R magnitudes for one galaxy in common with this study, KPG591. Their total uncorrected magnitudes are; $B = 14.72$, $V = 14.14$ and $R = 13.49$ for KPG591A and $B = 13.01$, $V = 12.12$ and $R = 11.43$ for KPG591B. Their reported (photometric + instrumental) errors are 0.043 for KPG591B and 0.041 for KPG591A. These values are in complete agreement with our total uncorrected values within the estimated errors.

4. Results

4.1. Integrated magnitudes and colors

The observed magnitudes and colors of 22 individual galaxies in mixed pairs are presented in Table 4. Entries are as follows: Col. 1 gives the identification in Karachentsev Catalogue, Cols. 2 to 5 give the total magnitudes in B , V , R and I bands, and Cols. 6 to 8 give the observed colors

The corrected magnitudes and colors of these 22 galaxies in mixed pairs are presented in Table 5. Entries are as follows: Col. 1 gives the identification in Karachentsev Catalogue, Cols. 2 to 5 give the total corrected magnitudes in B , V , R and I bands, taking into account galactic blue absorptions from Schlegel et al. (1998), inclination corrections from Tully et al. (1998) with coefficients taken from Verheijen (2001) and K -corrections interpolated from Frei & Gunn (1994). Column 6 gives the corresponding corrected $(B - V)$ color. Column 7 gives the corresponding absolute blue magnitude, taking into account corrections in Col. 2. Column 8 gives the corrected $(B - V)_T^0$ color, according to RC3. Column 9 gives the blue absolute magnitude applying corrections from RC3. Finally Col. 10 gives some notes regarding the presence of bright stars in field.

Notice that the errors associated with the spiral components in Table 5 are different from the corresponding ones in Table 4. This is due to the nature of the corrections adopted. The most important contribution to the total errors comes from applying a more physical correction due to inclination and self-absorption ΔA_i to late-type galaxies, in terms of absolute magnitudes, (cf. Verheijen 2001).

Our observations span a range (10.5, 15.5) and (0.3, 1.1) mag in B_T^0 and $(B - V)_T^0$, respectively. The observed $(B - V)$ range is comparable to that in a similarly selected samples of (S+S) pairs in Hernández-Toledo & Puerari (2001) and in the (E/S0+S) sample for the southern hemisphere by Reduzzi & Rampazzo (1996). The $(B - V)_T^0$ range is comparable to the full range found in Larson & Tinsley (1978) in spite of the fact that their interacting sample is biased in favor of strongly peculiar systems from the Arp catalogue. Similarly, the photoelectric Cousins *UBVRI* photometry of interacting galaxies by Johansson & Bergvall (1990) shows a comparable range in the observed $(B - V)$ colors. This samples includes also a fraction of E/S0 components, although it is biased in favor of disturbed morphology and the presence of tidal features.

4.2. Colors and morphology

To discuss the optical morphology (that could be modified by the presence of bars, spiral arms, rings, etc.) and its relationship to the global photometric properties, the final results for each pair are presented in the form of a mosaic (cf. Figs. 5 to 15). Each mosaic includes: 1) a B -band image, 2) a B -band filtered image, 3) surface brightness and color profiles and 4) its corresponding geometric profiles (radial ϵ , PA and a_4/a). In most of the cases, foreground stars in the field have been removed. We are proposing to use our filtered images in combination with the estimated geometric and surface brightness profiles to look for morphological features in more detail; bars, rings and other morphological distortions presumably associated with the interactions. We have carried out 1) a reclassification of the previous POSS/LEDA Hubble morphology and 2) a classification of the spiral arm morphology as suggested by Elmegreen & Elmegreen (1982) (hereafter EE class), when possible.

The discussion of morphological types also uses the information on the estimated mean colors $(B - V)_T^0$. It is known

Table 4. Observed magnitudes and color indices.

KPG	<i>B</i>	<i>V</i>	<i>R</i>	<i>I</i>	(<i>B</i> − <i>V</i>)	(<i>B</i> − <i>R</i>)	(<i>B</i> − <i>I</i>)
KPG29A	14.66 ± 0.07	14.15 ± 0.04	13.67 ± 0.06	13.07 ± 0.05	0.51 ± 0.05	1.00 ± 0.09	1.60 ± 0.08
KPG29B	15.11 ± 0.08	14.07 ± 0.04	13.45 ± 0.06	12.66 ± 0.05	1.04 ± 0.07	1.65 ± 0.10	2.45 ± 0.09
KPG38A	14.21 ± 0.03	13.14 ± 0.01	12.46 ± 0.03	11.64 ± 0.05	1.07 ± 0.02	1.75 ± 0.04	2.56 ± 0.06
KPG38B	13.84 ± 0.03	12.82 ± 0.01	12.17 ± 0.03	11.16 ± 0.05	1.02 ± 0.02	1.67 ± 0.04	2.68 ± 0.06
KPG61A	14.28 ± 0.06	13.40 ± 0.03	12.82 ± 0.04	11.93 ± 0.07	0.88 ± 0.05	1.46 ± 0.07	2.35 ± 0.09
KPG61B	15.42 ± 0.06	14.40 ± 0.03	13.82 ± 0.04	13.11 ± 0.06	1.02 ± 0.05	1.60 ± 0.07	2.31 ± 0.09
KPG62A	14.19 ± 0.07	13.10 ± 0.03	12.54 ± 0.05	11.98 ± 0.07	1.09 ± 0.06	1.64 ± 0.09	2.21 ± 0.10
KPG62B	15.57 ± 0.07	14.52 ± 0.03	13.90 ± 0.05	12.95 ± 0.07	1.05 ± 0.06	1.66 ± 0.09	2.62 ± 0.10
KPG86A	13.68 ± 0.02	12.96 ± 0.01	12.41 ± 0.03	11.49 ± 0.05	0.72 ± 0.02	1.27 ± 0.03	2.19 ± 0.06
KPG86B	11.97 ± 0.02	11.04 ± 0.01	10.30 ± 0.03	9.26 ± 0.06	0.93 ± 0.02	1.66 ± 0.04	2.71 ± 0.06
KPG101A	14.23 ± 0.06	13.35 ± 0.03	12.79 ± 0.05	12.01 ± 0.08	0.88 ± 0.06	1.44 ± 0.08	2.22 ± 0.10
KPG101B	14.82 ± 0.06	13.82 ± 0.03	13.17 ± 0.05	12.31 ± 0.08	1.00 ± 0.06	1.65 ± 0.08	2.51 ± 0.10
KPG129A	14.52 ± 0.06	13.33 ± 0.03	12.69 ± 0.05	11.92 ± 0.07	1.19 ± 0.06	1.82 ± 0.08	2.60 ± 0.09
KPG129B	15.93 ± 0.06	15.04 ± 0.03	14.40 ± 0.05	14.01 ± 0.06	0.89 ± 0.06	1.54 ± 0.08	1.93 ± 0.09
KPG162A	15.41 ± 0.03	14.43 ± 0.01	13.81 ± 0.03	13.13 ± 0.05	0.98 ± 0.02	1.60 ± 0.04	2.28 ± 0.05
KPG162B	16.13 ± 0.03	15.57 ± 0.02	15.28 ± 0.03	14.51 ± 0.04	0.56 ± 0.03	0.85 ± 0.04	1.62 ± 0.05
KPG260A	15.00 ± 0.06	13.99 ± 0.03	13.50 ± 0.05	12.18 ± 0.08	1.01 ± 0.06	1.50 ± 0.08	2.82 ± 0.10
KPG260B	14.26 ± 0.06	13.25 ± 0.03	12.74 ± 0.05	11.91 ± 0.07	1.02 ± 0.06	1.52 ± 0.08	2.36 ± 0.09
KPG552A	14.37 ± 0.07	13.45 ± 0.04	12.83 ± 0.06	12.07 ± 0.05	0.93 ± 0.06	1.55 ± 0.09	2.30 ± 0.09
KPG552B	15.47 ± 0.07	14.58 ± 0.04	13.98 ± 0.06	13.30 ± 0.05	0.89 ± 0.06	1.50 ± 0.09	2.17 ± 0.08
KPG591A	14.53 ± 0.06	13.99 ± 0.04	13.45 ± 0.06	12.73 ± 0.05	0.54 ± 0.05	1.08 ± 0.09	1.80 ± 0.08
KPG591B	13.03 ± 0.07	12.17 ± 0.04	11.57 ± 0.06	10.77 ± 0.05	0.86 ± 0.06	1.46 ± 0.09	2.26 ± 0.08

Table 5. Corrected magnitudes and color indices.

KPG	<i>B</i> ₀	<i>V</i> ₀	<i>R</i> ₀	<i>I</i> ₀	(<i>B</i> − <i>V</i>) ₀	<i>M</i> _{<i>B</i>0}	(<i>B</i> − <i>V</i>) _T ^o	<i>M</i> _{<i>B</i>} ^o	Notes
KPG29A	13.70 ± 0.38	13.41 ± 0.29	13.05 ± 0.20	12.58 ± 0.11	0.29 ± 0.48	−22.74	0.39 ± 0.07	−22.32	
KPG29B	14.69 ± 0.07	13.84 ± 0.04	13.27 ± 0.06	12.52 ± 0.05	0.85 ± 0.09	−21.73	0.88 ± 0.08	−21.63	
KPG38A	13.56 ± 0.26	12.61 ± 0.20	12.02 ± 0.14	11.31 ± 0.09	0.95 ± 0.33	−20.61	0.99 ± 0.03	−20.40	
KPG38B	14.54 ± 0.03	12.62 ± 0.01	12.01 ± 0.03	11.04 ± 0.05	0.91 ± 0.03	−20.65	0.93 ± 0.03	−20.58	
KPG61A	13.29 ± 0.36	12.59 ± 0.27	12.16 ± 0.19	11.44 ± 0.12	0.69 ± 0.54	−20.73	0.77 ± 0.07	−20.40	
KPG61B	14.90 ± 0.06	14.04 ± 0.03	13.53 ± 0.04	12.90 ± 0.06	0.87 ± 0.07	−19.06	0.90 ± 0.07	−18.90	
KPG62A	13.90 ± 0.07	12.92 ± 0.03	12.40 ± 0.05	11.87 ± 0.07	0.98 ± 0.08	−20.77	0.99 ± 0.07	−20.70	
KPG62B	14.67 ± 0.61	13.70 ± 0.47	13.20 ± 0.32	12.39 ± 0.19	0.98 ± 0.77	−20.00	0.97 ± 0.07	−19.30	
KPG86A	12.05 ± 0.49	11.65 ± 0.37	11.34 ± 0.25	10.72 ± 0.14	0.40 ± 0.61	−20.50	0.45 ± 0.07	−20.40	
KPG86B	10.94 ± 0.03	10.27 ± 0.02	9.68 ± 0.03	8.80 ± 0.06	0.68 ± 0.03	−21.12	0.69 ± 0.06	−21.00	BS
KPG101A	13.30 ± 0.14	12.64 ± 0.10	12.22 ± 0.08	11.59 ± 0.08	0.66 ± 0.17	−20.76	0.73 ± 0.07	−20.50	
KPG101B	14.06 ± 0.06	13.27 ± 0.03	12.72 ± 0.05	11.99 ± 0.08	0.79 ± 0.07	−19.78	0.80 ± 0.07	−20.80	
KPG129A	14.10 ± 0.06	13.03 ± 0.03	12.45 ± 0.05	11.74 ± 0.07	1.07 ± 0.07	−19.06	1.09 ± 0.07	−18.93	BS
KPG129B	15.33 ± 0.39	14.52 ± 0.29	13.95 ± 0.20	13.69 ± 0.12	0.81 ± 0.48	−17.74	0.81 ± 0.07	−17.90	
KPG162A	15.13 ± 0.03	14.26 ± 0.01	13.67 ± 0.03	13.03 ± 0.05	0.87 ± 0.03	−20.40	0.87 ± 0.03	−20.35	
KPG162B	15.29 ± 0.63	14.86 ± 0.48	14.70 ± 0.33	14.07 ± 0.18	0.42 ± 0.80	−20.21	0.47 ± 0.03	−20.20	
KPG260A	14.76 ± 0.07	13.84 ± 0.04	13.38 ± 0.05	12.09 ± 0.08	0.91 ± 0.08	−20.26	0.94 ± 0.07	−20.22	
KPG260B	14.06 ± 0.06	13.14 ± 0.03	12.66 ± 0.05	11.84 ± 0.07	0.92 ± 0.07	−20.84	0.93 ± 0.07	−20.80	BS
KPG552A	13.09 ± 0.49	12.40 ± 0.38	11.97 ± 0.26	11.43 ± 0.14	0.69 ± 0.62	−22.03	0.80 ± 0.08	−21.67	
KPG552B	14.95 ± 0.07	14.24 ± 0.04	13.70 ± 0.06	13.10 ± 0.05	0.72 ± 0.08	−20.16	0.74 ± 0.08	−20.06	
KPG591A	14.00 ± 0.06	13.62 ± 0.04	13.50 ± 0.06	12.51 ± 0.05	0.38 ± 0.08	−20.07	0.44 ± 0.07	−20.00	
KPG591B	12.25 ± 0.19	11.56 ± 0.14	11.06 ± 0.11	10.41 ± 0.07	0.69 ± 0.24	−21.95	0.77 ± 0.08	−21.71	

BS = Bright Star Close/Superposed to a Galaxy.

that the mean colors of galaxies are correlated with their morphological type *T*. Although the color indices of galaxies belonging to type *T* will have a large dispersion, the median value declines systematically as *T* increases along the morphological sequence. Median integrated total (*B* − *V*) colors of galaxies according to morphological class are given by

Roberts & Haynes (1994). The UGC and the Local Supercluster (LSc) samples in Roberts & Haynes (1994) are rather inhomogeneous in terms of environment, but the interacting objects were excluded from their analysis and we may consider these samples as comparison/reference samples for the following discussion.

4.3. Comments on individual objects

KPG29. Mosaic 1 shows the images of KPG29. The northern member is Arp 119N, and the peculiar galaxy to the south is Arp 119S. The later displays a strongly perturbed morphology. There is significant evidence of recent or current large-scale star formation at several locations. Marzianni et al. (1994) observed some spiral structure in Arp 119S typical of an Sc galaxy, as well as the presence of two, or possibly three rings of different radii in the disk. Arp 119S has been classified as a LINER galaxy (cf. Bernlohr 1993). The line-of-sight velocities for the two galaxies is under current debate. Marzianni et al. (1994) found a systemic velocity of $14\,200\text{ km s}^{-1}$ for Arp 119S and $15\,000\text{ km s}^{-1}$ for Arp 119N based on Na D lines. This relative line-of-sight velocity of approximately 800 km s^{-1} can be compared for example to that of Mazzarella & Boroson (1993) which is only 170 km s^{-1} .

KPG29A Our images show a bright circular ring surrounding the nucleus, a luminous arc north of the nucleus that extends to the west, a long arc of knots along the southern edge, and a veil of low-luminosity material in the east. Two knots are prominent along the vertical line north of the nucleus. The geometric profiles can detect the two strong knots (visible in *BVRI* images) towards the elliptical companion. There, the ellipticity increases and the position angle is more or less constant at a value of 17 degrees. These knots produce disk isophotes ($a_4/a > 0$). These knots are strong star formation regions as discussed in Marzianni et al. (1994). At this point, we see a sudden break in all the geometric profiles. After that point, the position angle is constant from $5''$ to about $20''$. In the same interval, the ellipticity profile increases, reaches a maximum value and then decreases, indicating the presence of flocculent arms and knotty structures (see the *B*-band filtered image). At radii greater than $20''$, the position angle and ellipticity increases monotonically while a_4/a becomes disk ($a_4/a > 0$), revealing the presence of the underlying disk. The brighter knots along and at the end of the outer arms dominate the geometric profiles. This suggest a strongly disturbed outer disk that may be interpreted as a warp feature. The galaxy is classified as SBc in the NASA Extragalactic Data Base (NED), however our images do not show any trace of a bar. We classify this galaxy as a SA(rs)cd pec. The total $(B - V)_T^0$ color is more representative of Sm types. Our EE class is 2.

KPG29B. Our images show a clear stretching of this galaxy along the direction towards Arp 119S. We observe two definite components: an inner region ($a < 16''$) where the surface brightness profile seems of de Vaucouleurs type, and other external region ($a > 18''$) where the μ profile looks like a exponential profile. However, the geometric profiles do not show evidence for disk structure. At this point, the galaxy could be classified as E3. NED classifies this galaxy as E? The total $(B - V)_T^0$ color is representative of E, S0 types.

KPG38A. The μ -profile shows evidence of structure after $10''$. This along with the smooth oscillation in the ϵ and PA profiles, is probably indicating the presence of underlying structure on a faint disk component. This may means either the presence of a bar-like feature or of a symmetric spiral-like

feature. After $25''$ all the geometric profiles could be indicating the presence of a faint feature barely visible to the west in our images. We classify this galaxy as an SAB0. The total $(B - V)_T^0$ color is more representative of E, S0 types.

KPG38B. We observe an increased scatter after $25''$ in all profiles, that may be associated to an extended outer envelope visible in *B*-band image. NED classifies this galaxy as a S0, however the geometric profiles indicate that this is an E1.5 galaxy. The total $(B - V)_T^0$ color is representative of E, S0 types.

KPG61A. The galaxy has an apparent inner ring and two strong adjacent arms. The external region shows two symmetric tidal structures as a continuation of those inner arms. NED classifies this galaxy as a SA(rs)bc pec. However, if we consider that the outer arms could be tidally generated, and omit them from the classification, we classify this galaxy as SA(rs)ab pec. The total $(B - V)_T^0$ color is representative of S0a, Sa types. Our EE class is 6.

KPG61B. The μ and a_4/a profiles show the presence of a disk structure. In addition, ϵ and PA profiles indicate an underlying elongated feature (a bar-like feature) that can be seen in the *B*-filtered image. NED classifies this galaxy as E, however, we classify this galaxy as a SAB0. The $(B - V)_T^0$ color is representative of E, S0 types.

KPG62A. This is definitely not an isolated pair, rather it looks like two hierarchical pairs, forming a group. The sudden change in the inner part of the PA profile for *R* and *I* bands may be interpreted as due to the presence of a dusty component in the inner region. We observe a small companion that increases the scatter in the ϵ , PA and a_4/a profiles, after $25''$. The *B*-filtered image shows this small companion as a probably disk galaxy. NED classifies KPG62A as S0+;, however, we classify this galaxy as an E1. The total $(B - V)_T^0$ color is representative of E, S0 types.

KPG62B. This seems to be an inclined disk galaxy that may be also perturbed by the small companion to the east. The *B*-band filtered image shows two perturbed outer features that resemble arms. The μ profile does not show evidence of a bulge component at any wavelength. The color profiles show a reddened inner region. Notice that the *B* and *V* ϵ and PA profiles show a different behavior, compared to *R* and *I* profiles, in the first $12''$. This may be consistent with the presence of a central dusty component. The a_4/a profile is clearly disk in the *B*-band. After $25''$ this profile becomes boxy by the presence of the small companion to the east. Tentatively, we classify this galaxy as a S0/a pec. NED reports this galaxy as a Sb. The total $(B - V)_T^0$ color is representative of E, S0 types.

KPG86A. This is a flocculent inclined spiral galaxy. The *B*-filtered image shows knotty features along the arms that dominate the behavior of the geometric profiles. The μ profile does not show evidence of a bulge component. NED classification is SBc, however we do not find any clear evidence of a barred structure and our classification is Scd. The total $(B - V)_T^0$ color is representative of Scd, Sd types. Our EE class is 2.

KPG86B. The galaxy has two bright field stars that were edited in order to minimize light contamination. The ϵ and PA profiles indicate the presence of a central elongate structure (bar-like feature), visible in the *B*-band filtered image. Although the a_4/a profile does not show evidence of a disk

in the inner region, after $40''$, both the a_4/a and μ profiles are indicating its presence. NED classifies this galaxy as a S0 (Sy1), however we classify this galaxy as a SAB0 pec. The total $(B - V)_T^0$ color is representative of Sa, Sab types.

KPG101A. This is an apparent triplet. We observe a compact blue companion at the west side of the pair. The geometric profiles show evidence of a faint bar-like structure in the first $10''$, surrounded by a ring that dominates the shape of the isophotes (boxy profile). A three spiral arm structure seems to emerge adjacent from the ring. NED classification is SAB(s)ab, however we classify this galaxy as a SB(r)b. The total $(B - V)_T^0$ color is representative of Sa, Sab types. Our EE classification is 8.

KPG101B. The first $10''$ show a typical elliptical galaxy, however the B -band image shows evidence of a tidal feature towards the south-east. This can be seen as a strong twisting in the PA profile after $10''$ and as boxy-shaped isophotes between 10 – $15''$. After that point, the isophotes become disk-like probably due to the combined action of the south-east tidal feature and the presence of the spiral companion. NED classifies this galaxy as an E. We propose an E1 pec classification for this galaxy. The total $(B - V)_T^0$ color is representative of E, S0 types.

KPG129A. The geometric and color profiles show hints of a probably dusty structure at the first $7''$. After that point, we see the behavior of an elliptical galaxy, although, the μ profile seems to indicate the presence of an outer disk (not detectable in the a_4/a profile). The galaxy could be classified as a probable face-on S0 galaxy, in agreement with NED. The total $(B - V)_T^0$ color is representative of E, S0 types. Notice that the B -band filtered image shows a circular feature at the north that is reminiscent of a subtracted field star.

KPG129B. The ϵ and PA profiles show an elongated structure (bar-like feature?) between 5 – $15''$, and the B -band filtered image confirms it. There is also evidence of filamentary structure (arms?) at both ends of that elongated feature. The μ and a_4/a profiles show evidence of an outer disk structure. Our classification is in agreement with NED; an S0/a pec galaxy. The total $(B - V)_T^0$ color is representative of S0, S0a types.

KPG162A. This galaxy has a small apparent companion at the south-west direction. The μ profile is in agreement with an elliptical galaxy and the ϵ and PA profiles are consistent with this interpretation. Notice however a significant twisting and hints of a disk-like fainter structure from the a_4/a profile in the outer region. We are limited by the resolution. NED classification is S0. We tentatively classify this galaxy as an E2 pec. The total $(B - V)_T^0$ color is representative of E, S0 types.

KPG162B. The central region in this galaxy is dominated by an elongated structure from which two outer arms emerge. This is an inclined galaxy that we tentatively classify as SABbc, however we are limited by the low resolution in our images. NED classification is Sb. The total $(B - V)_T^0$ color is representative of Scd, Sd types.

KPG260A. This is apparently a multiple system. The B -band filtered image shows evidence of an inner bar, surrounded by a ring. We classify this galaxy as SB(r)b, with open and bifurcated arms. However, if the nature of the external arms (integral sign structure) is generated by the tidal interaction (cf.

Noguchi 1990), and take this into account in the classification, we could have an early type (SBa) barred galaxy. NED classifies this galaxy as S?, however, we classify this galaxy as a SB(r)a. The total $(B - V)_T^0$ color is representative of E, S0 types.

KPG260B. The central part of this galaxy has a bright field star that had to be masked to proceed with the analysis. This translates into a drop in the very central part of the color profiles. Notice a small feature (probably a very small galaxy) superposed on the face of KPG260B. The a_4/a profile indicates that this is an elliptical galaxy with boxy-shaped isophotes and strong twisting. Our classification is E2.5, in agreement with NED. The total $(B - V)_T^0$ color is representative of E, S0 types.

KPG552A. This may be another example of a disk galaxy where the arms are probably tidally induced by the interaction. The B -band filtered image shows that the galaxy is dominated by strong knots forming a central ring and delineating the outer tidal arms. The east arm forms a bridge to the compact companion. At the beginning of this arm, a set of faint filaments are barely visible. Notice the presence of a strong set of knots almost at the tip of the western arm in this galaxy. The apparent morphological classification could be SAB(rs)bc. However, if we consider a tidal origin of the arms and eliminate them from the classification, we classify this galaxy as a SAB(rs)ab. NED classifies this galaxy as a Sa (Sy2). The total $(B - V)_T^0$ color is representative of S0a, Sa types. Our EE classification is 11.

KPG552B. This is a compact galaxy with a blue central region as can be seen in the μ and color profiles. The PA and ϵ profiles show hints of an extended structure or arms, probably related to mass transference from the companion. The a_4/a profiles support the presence of an external disk component. NED classifies this galaxy as a compact:HII (Sy2), however, our classification is E2 pec. The total $(B - V)_T^0$ color is representative of Sa types.

KPG591 Arp 86 is an M51-type object consisting of a main galaxy and a small companion at the tip of one of the tidal features.

KPG591A. NGC7752 is classified as an Irr galaxy by Nilson (1973). The structure is very irregular within the inner $20''$ in all the observed bands. Our analysis for this galaxy proceeded after masking the bridge structure. We observe a few prominent knots dominating the behavior of all the profiles. This is a blue galaxy as indicated by the color profiles. NED classifies this galaxy as an I0. Our classification is in agreement with it. The total $(B - V)_T^0$ color is representative of Sm, Im types.

KPG591B. The spiral arms of this galaxy are rather symmetric, broad and long and they continue deep into the disk. The spiral arms are prominent in the whole B , V , R and I bands. Our images show a condensation almost at the end of the tail and additionally, it has two secondary, very weak spiral extensions. The distribution and local morphology of star forming regions vary along the spiral arms as can be clearly seen from the B -filtered image. In the innermost disk (within $40''$) the regular grand-design spiral structure is transformed to a more irregular multi-arm system showing signs of dust lanes as well as possible central oval structure. NED classifies this galaxy as a SAB(rs)bc, however, our classification is SB(r)bc. The total

$(B - V)_T^0$ color is representative of a Sa type. Our EE classification is 11. Notice the presence of another small apparent companion at south-east of the system.

5. Discussion

This paper represents the first part of a more detailed analysis of the properties of (E+S) pairs in forthcoming papers. In this section we follow closely Rampazzo & Sulentic (1992). The (E+S) pairs in this study span a mean projected separation $\Delta x \sim 57$ kpc.

We find evidence for a significant number of true (E+S) pairs in this study with about 5 pairs out of a sample of 11. The degree of isolation is another important point to consider for their origin and morphology. Notice that in Table 6 about 7 out of 11 pairs are not apparently isolated systems, although we do not have radial velocities to confirm that. The evaluation of morphology took place in different steps: 1) evaluation of the geometrical profiles for the early-type components along with the surface brightness profiles, 2) evaluation of the geometric profiles that could give clues of arm-like, bar-like and ring-like features, with the help of filtered images, 3) evaluation of outer arms probably generated by tidal interactions. We were interested on the early-type components to quantify the possible presence of disk structure. Although the absolute value of the geometrical parameter (a_4/a) depends on the inclination of the galaxy to the line of sight, its sign is useful for detecting subtle disk features in early-type components. The presence of disk isophotes is one criterion for assigning a galaxy to the lenticular class. However it is fair to remember that disk components are also found in E-types.

With the purpose of distinguishing S0 candidates as well as ellipticals with boxy and disk structure, a galaxy in our sample was judged to be an elliptical if the surface brightness profile did not show any hint of an exponential outer component and the (a_4/a) parameter showed no significant boxy or disk trend along the displayed radius. A galaxy was judged to be a boxy or disk elliptical if the surface brightness profile did not show any hint of an exponential outer component and the (a_4/a) parameter showed hints of boxy or disk trends along the displayed radius. Some objects may show evidence of central diskiness, like KPG129A, that does not justify an S0 classification. However, its surface brightness profile show evidence of an outer disk component, which is in favor of a S0 classification. Although a better classification using the a_4/a parameter could be based upon comparison of values at some effective radius, at this point, it is premature to attempt such a refinement with our small sample.

In most cases the morphology of the late type component is less ambiguous. However, in some cases like KPG62B, KPG129B and KPG162B, the confusion arises because arms are not clearly seen. Those cases were assigned as late type class but with an uncertain subtype. The rarity of Irregulars in the present sample is confirmed. Only one component galaxy, KPG591A, could be classified as I0. The remaining pairs can be grouped into two categories: 1) disk pairs involving a disk/lenticular galaxy paired with spiral or another disk/lenticular ($n = 3$) and 2) “early-type pairs” involving

paired ellipticals and disk/lenticular galaxies ($n = 2$). This later group may raise the same problem as real (E+S) pairs because of the different angular momentum properties implied for the components.

Another interesting explanation for the existence of mixed pairs involves the possibility that spiral structure is induced in one of the components by the interaction process. It is possible to induce apparent spiral structure in lenticular/spiral galaxies. That structure could have at least three characteristics that might allow us to distinguish them from ordinary spiral structure: 1) they would not be associated with an underlying disk component, 2) they would be relatively featureless if they arose from a lenticular galaxy and 3) the arms would be very open (integral sign) if produced fairly recently since the winding effect of differential rotation would be small. In our sample, a probable candidate for tidally-generated spiral structure is KPG260A. Other cases like KPG61A show evidence of faint spiral structure apparently as a continuation of a more definite inner spiral structure. KPG552A is an example where in spite of the integral sign structure of the arms, there is a clear association with an underlying disk and the presence of knotty features along the arms.

Elmegreen & Elmegreen (1982) developed a 12-division morphological system to classify spiral galaxies according to the regularity of their spiral arm structure. This spiral arm classification correlates with the presence of density waves as in grand design galaxies. Following that work, we succeeded in classifying only 5 spirals. Some of the spirals in this sample are nearly edge-on, strongly interacting or simply do not fit into the Elmegreen & Elmegreen classes.

Interestingly, 8 galaxies out of 22 show evidence of barred structure. If we consider only disk components (S0 and S’s), then more than 50% of them show evidence of bars. Similarly, about 40% of the disk components show evidence of ringed structure. These results could be interpreted in the framework of the simulations of Noguchi (1990 and references therein). Briefly, in this scenario of moderate interactions, the bar develops quite soon and it is long lasting, while the ring develops later and the gas follows the configuration of the ring. Four different phases may be seen: 1) open arms appear (integral sign) after perigalacticon, 2) a bar develops, the arms start to close and the gas start to follow the star configuration, 3) the arms are completely closed around the bar and form a ring; the gas is mainly concentrated in the center and ring, and 4) the ring starts to be disrupted by the dynamics and the overall appearance of the galaxy becomes nearly asymmetric.

The filtered images presented here have been shown to be a powerful tool to disentangle galaxy morphology. The procedure behind is called Background Filtering (BGF). (cf. Sofue 1993). The images are Gaussian-smoothed and subtracted from the original, leaving a residual image that enhances small-scale structure. With this method, it is possible to study morphological structures in greater detail, which are detected in the original data but are embedded in bright foreground and background emission. The method is particularly useful to investigate morphological structures in the central regions of galaxies and also fainter details in the outskirts.

Fig. 3. The Holmberg effect. $(B - V)_T^0$ primary galaxy versus $(B - V)_T^0$ secondary galaxy.

5.1. The Holmberg effect

As a byproduct of his famous photometric survey of nearby galaxies, Holmberg (1958) compared the photographic colors of paired galaxies and found a significant correlation between the colors of pair components. This phenomenon has since been referred to as the “Holmberg effect”. Although the physical explanation of the Holmberg effect is complex, it has been interpreted as reflecting a tendency for similar types of galaxies to form together (morphological concordance), a possible reflection of the role of local environment in determining galaxy morphology, but alternatively, it can presumably also reflect mutually induced star formation (Kennicutt et al. 1987) in physical pairs. However, a Holmberg effect has also been reported in pairs with discordant morphology (cf. Demin 1984).

After re-evaluating the morphological classification, we can compare the $(B - V)$ colors of components in our paired galaxies in order to look for such an effect. Figure 3 shows the observed diagram of the $(B - V)_T^0$ color indices. In one case an irregular galaxy was conventionally considered as spiral. The color index along the vertical axis refers to the brighter (primary) component and that along the horizontal axis refers to the fainter (secondary) component in each pair.

In addition, a similar plot, this time showing the corrected $(B - V)$ colors of the early-type components against those in late-type components, is also shown in Fig. 4.

The color correlation between pair components in mixed pairs is poor in any plot, contrary to the results in Demin (1984). Part of the tendency, if present, could be explained by the intrinsic scatter in the $(B - V)_T^0$ – Morphological Type correlation as reported by Roberts & Haynes (1994). However the evidence is not conclusive due to the small number of pairs involved.

6. Summary

In order to analyze the photometric signature of gravitational interactions in spiral and elliptical galaxies, we present results of our *BVRI* surface photometry for a first set of 11 mixed

Fig. 4. The Holmberg effect. $(B - V)_T^0$ early-type galaxy versus $(B - V)_T^0$ late-type galaxy.

pairs from the Karachentsev (1972) catalogue. The derived parameters are generally in good agreement with those reported in RC3, aperture photometry catalogues and other individual photometric works. The combination of filtered *B* images and the geometric parameters estimated from the surface photometry analysis are a powerful technique both for morphological classification and for revealing fine structural details most likely related to encounters that are in various early and late stages. In general our data suggest that our sample is undergoing moderate interactions which appear to be adequate to stimulate a non-axisymmetric potential that generates a global response as evidenced by the presence of bars, rings and knotty structures along the arms and disks of the spiral galaxies in mixed pairs.

Table 6 is a summary of the morphological features found in this work. Column 1 gives the pair catalogue number, Col. 2 gives the Hubble Type as reported in NED, Col. 3 gives the Hubble Type as estimated in this work, Col. 4 gives the Elmegreen (EE) class, Col. 5 indicates when other galaxies (dwarfs or galaxies of comparable size) are in the neighborhood of the pair, Col. 6 indicates when a flat or positive gradient color profile is present, and finally Col. 7 indicates the presence of rings, bars and knotty structures.

There are four AGN (one LINER, one Seyfert 1 and a pair of Seyfert 2 galaxies) reported for this sample. It is generally believed that a high percentage of Seyfert galaxies have close neighbors implying an AGN-interaction connection (cf. Dultzin-Hacyan et al. 1999). The presence of these galaxies in mixed pairs supports the notion that the triggering mechanism for their nuclear activity is of tidal origin and that it does not depend strongly on the type of perturbing galaxy. A larger and more complete sample has been observed and will be used in forthcoming papers to address the relevant questions in a more significant way. The present sample of 11 pairs is not statistically significant and it is biased for some of the brighter pairs within the sample. The pairs not classified as true (E+S) pairs are primarily of two types: 1) disk pairs composed of

Table 6. Final results from this study.

Name	Hubble type (NED)	Hubble type (this work)	EE class	Isolation	Profile	Notes
KPG29A	SBc(LINER)	SA(r)cd pec		ADCG		R, K
KPG29B	E?	E3		ADCG		
KPG38A	S?	SAB0		ADCG	F	B
KPG38B	S0?	E1.5		ADCG		
KPG61A	SA(rs)bc pec	SA(rs)ab pec	6			R
KPG61B	E	SAB0			F	B
KPG62A	S0+:	E1		ACGC		
KPG62B	Sb	S0/a pec		ACGC		
KPG86A	SBc	Scd	2			K
KPG86B	S0 (Sy1)	SAB0 pec			F	B
KPG101A	SAB(s)ab	SB(r)b	8	ACGC		R, B
KPG101B	E	E1 pec		ACGC		
KPG129A	S0	S0				
KPG129B	S0/a	S0/a pec				
KPG162A	S0	E2 pec		ADCG		
KPG162B	Sb	SABbc				B?
KPG260A	S?	SB(r)a pec		ADCG, ACGC		R, B, TA
KPG260B	E	E2.5		ADCG, ACGC		
KPG552A	Sa (Sy2)	SAB(rs)ab	11			R, B, K
KPG552B	compact: HII (Sy2)	E2 pec				
KPG591A	I0:	I0:		ADCG	+	K
KPG591B	SAB(rs)bc	SB(r)bc	11	ADCG		R, B, K

ADCG = Apparent Dwarf Companion Galaxy in the Field. ACGC = Apparent Companion Galaxy of Comparable Size. B = Bar. K = Knot. R = Ring. TA = Tidal Arms. F = Flat Color Profile. + = Positive Gradient in Color Profile.

spiral and lenticular components and 2) early pairs composed of elliptical and lenticular components. Both of these classes raise interesting questions about galaxy formation because of the discordant star formation and angular momentum properties of the components.

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Online Material

Table 1. Journal of observations.

Galaxy Pair	T_B (s)	$\langle B \rangle_{\text{FWHM}}$ ($''$)	T_V (s)	$\langle V \rangle_{\text{FWHM}}$ ($''$)	T_R (s)	$\langle R \rangle_{\text{FWHM}}$ ($''$)	T_I (s)	$\langle I \rangle_{\text{FWHM}}$ ($''$)	CCD	Scale ($''/\text{pixel}$)
KPG29	2×2400	1.5	2×600	1.8	2×600	1.3	2×480	1.1	SITE1	0.253
KPG38	3×600	2.6	2×600	2.0	3×150	2.4	3×150	2.0	TEK2	0.394
KPG61	1×2400	1.8	2×900	1.7	2×480	1.7	2×480	1.5	SITE1	0.506
KPG62	2×1800	2.2	2×1080	2.0	2×600	2.6	2×600	2.4	SITE1	0.506
KPG86	3×1200	1.7	3×600	1.6	3×300	2.1	3×300	1.8	TEK2	0.394
KPG101	2×1800	2.1	3×900	2.1	3×300	2.4	2×600	2.2	SITE1	0.506
KPG129	3×1800	1.9	1×1800	1.9	3×600	1.8	2×300	1.9	SITE1	0.506
KPG162	2×900	1.6	3×900	1.7	2×600	1.8	2×600	1.4	TEK2	0.394
KPG260	1×2400	1.9	1×1800	1.8	2×600	1.9	2×600	1.7	SITE1	0.506
KPG552	2×2400	1.5	2×600	1.6	2×480	1.7	2×360	2.2	SITE1	0.253
KPG591	1×2400	1.7	2×1200	1.5	2×600	1.6	2×600	1.9	SITE1	0.253

Table 2. Extinction and calibration coefficients for the optical observations.

Extinction Coefficients			
	September 1999	November 1999	December 1999
k_b	0.232 ± 0.017	0.266 ± 0.010	0.233 ± 0.031
k_v	0.140 ± 0.014	0.160 ± 0.011	0.145 ± 0.025
k_r	0.078 ± 0.015	0.115 ± 0.013	0.080 ± 0.021
k_i	0.049 ± 0.010	0.067 ± 0.008	0.064 ± 0.023
Calibration Coefficients			
α_o	1.606 ± 0.036	3.733 ± 0.006	3.058 ± 0.004
α_1	0.033 ± 0.056	0.022 ± 0.010	-0.005 ± 0.008
β_o	0.864 ± 0.023	0.185 ± 0.005	0.722 ± 0.005
β_1	0.815 ± 0.035	0.884 ± 0.008	0.821 ± 0.010
ϵ_o	0.269 ± 0.019	0.206 ± 0.006	0.296 ± 0.005
ϵ_1	1.050 ± 0.051	1.070 ± 0.021	1.055 ± 0.017
γ_o	0.000 ± 0.007	-0.118 ± 0.019	0.090 ± 0.021
γ_1	1.076 ± 0.010	1.075 ± 0.031	1.070 ± 0.035

Table 3. General (NED) data for the observed galaxies.

KPG Number	Identif.	<i>B</i> mag	Type	x_{12} (kpc)	V_{rad} (km s ⁻¹)	A_{25} (kpc)
KPG29A	Arp199(01)	14.74	SBc (LINER)	52.2	14550 ± 19	61.3
KPG29B	Arp199(02)	14.89	E?		14415 ± 32	49.4
KPG38A	NGC0608	14.18	S?	105.9	5103 ± 39	24.2
KPG38B	NGC0614	13.66	S0?		5161 ± 39	35.4
KPG61A	IC1784	14.00	SA(rs)bc pec	38.2	4772 ± 57	36.7
KPG61B	IC1785	15.60	E		4652 ± 57	15.4
KPG62A	NGC0867	13.93	S0+:	60.5	6429 ± 38	36.6
KPG62B	IC0218	15.70	Sb		6448 ± 57	18.3
KPG86A	NGC1160	13.50	SBc	31.4	2429 ± 35	21.4
KPG86B	NGC1161	12.05	S0 (Sy1)		1940 ± 21	22.4
KPG101A	NGC1633	14.36	SAB(s)ab	11.8	4870 ± 46	24.9
KPG101B	NGC1634	15.14	E		4410 ± 24	15.0
KPG129A	UGC03765	14.29	S0	15.1	3220 ± 46	18.1
KPG129B	PGC020543	15.70	S0/a		3077 ± 67	9.4
KPG162A	PGC023553	15.20	S0	157.5	9560 ± 60	44.0
KPG162B	PGC023570	15.10	Sb		9423 ± 60	27.2
KPG260A	PGC033126	14.73	S?	77.4	7564 ± 40	23.6
KPG260B	PGC033138	14.14	E		7158 ± 25	23.2
KPG552A	IIZw101	15.30	Sa (Sy2)	38.8	7894 ± 47	39.5
KPG552B	IIZw102	14.50	compact: HII (Sy2)		7910 ± 81	26.2
KPG591A	NGC7752	15.00	I0:	40.5	4882 ± 16	20.6
KPG591B	NGC7753	12.83	SAB(rs)bc		5190 ± 16	52.1

Fig. 5. KPG29 mosaic. Top left: *B*-band image. Top right: *B*-band filtered image. Bottom left: surface brightness profile and geometric parameters for KPG29A. Bottom right: surface brightness profile and geometric parameters for KPG 29B.

Fig. 6. KPG38 mosaic. Top left: *B*-band image. Top right: *B*-band filtered image. Bottom left: surface brightness profile and geometric parameters for KPG38A. Bottom right: surface brightness profile and geometric parameters for KPG38B.

Fig. 7. KPG61 mosaic. Top left: *B*-band image. Top right: *B*-band filtered image. Bottom left: surface brightness profile and geometric parameters for KPG61A. Bottom right: surface brightness profile and geometric parameters for KPG61B.

Fig. 8. KPG62 mosaic. Top left: *B*-band image. Top right: *B*-band filtered image. Bottom left: surface brightness profile and geometric parameters for KPG62A. Bottom right: surface brightness profile and geometric parameters for KPG62B.

Fig. 9. KPG86 mosaic. Top left: *B*-band image. Top right: *B*-band filtered image. Bottom left: surface brightness profile and geometric parameters for KPG86A. Bottom right: surface brightness profile and geometric parameters for KPG86B.

Fig. 10. KPG101 mosaic. Top left: B -band image. Top right: B -band filtered image. Bottom left: surface brightness profile and geometric parameters for KPG101A. Bottom right: surface brightness profile and geometric parameters for KPG101B.

Fig. 11. KPG129 mosaic. Top left: *B*-band image. Top right: *B*-band filtered image. Bottom left: surface brightness profile and geometric parameters for KPG129A. Bottom right: surface brightness profile and geometric parameters for KPG129B.

Fig. 12. KPG162 mosaic. Top left: B -band image. Top right: B -band filtered image. Bottom left: surface brightness profile and geometric parameters for KPG162A. Bottom right: surface brightness profile and geometric parameters for KPG162B.

Fig. 13. KPG260 mosaic. Top left: *B*-band image. Top right: *B*-band filtered image. Bottom left: surface brightness profile and geometric parameters for KPG260A. Bottom right: surface brightness profile and geometric parameters for KPG260B.

Fig. 14. KPG552 mosaic. Top left: *B*-band image. Top right: *B*-band filtered image. Bottom left: surface brightness profile and geometric parameters for KPG552A. Bottom right: surface brightness profile and geometric parameters for KPG552B.

Fig. 15. KPG591 Mosaic. Top left: *B*-band image. Top right: *B*-band filtered image. Bottom left: surface brightness profile and geometric parameters for KPG591A. Bottom right: surface brightness profile and geometric parameters for KPG591B.