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ASTRONOMY AND ASTROPHYSICS

Testing the physical reality of binaries and compact groups

Properties of early-type galaxies in groups with diffuse X-ray emission⋆,⋆⋆,⋆⋆⋆

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Abstract. We present data on the stellar kinematics of the brightest ellipticals in HCG 62, HCG 68, NGC 2300 groups. Moreover, we report on ASCA GIS as well as optical observations of the early-type member of the pair K 416 (NGC 5480/5481) similar, in many respects, to the dominant pair in the NGC 2300 group.

The kinematics of HCG 62a/b and HCG 68a/b indicate that they are not interacting pairs. HCG 62a is instead possibly interacting with HCG 62c, as suggested by their morphology (see Mendes de Oliveira and Hickson 1994),

In contrast to the results for the NGC 2300/2276 group, ASCA observations indicate a significant absence of hot gas in the K 416 system. Whether the NGC 2300 multiplet is viewed as a loose group or as a massive E+S pair, it is clear that similar morphological entities do not always show similar X-ray properties. Under the hypothesis that diffuse X-ray emission marks the group potential, we consider the possibility that K 416 is an unbound encounter. In this scenario, morphological distortions are indicative of the ongoing interaction, but are only circumstantially correlated with the physical reality of a pair/multiplet as a bound system.

Key words: galaxies: elliptical and lenticular – galaxies: interactions – galaxies: kinematics and dynamics – galaxies: photometry – X-rays: galaxies

1. Introduction

Hot gas emitting in the X-ray band has become an important and almost defining property of many of the largest aggregates of galaxies (Forman & Jones 1982). The diffuse X-ray emission, so frequently detected in large, rich clusters, is now being detected in an increasing number of less well populated groups of galaxies (Mulchaey et al. 1993; Pildis 1995; Mulchaey et al. 1996 and reference therein). The detection of diffuse emission in the NGC 2300 group (Mulchaey et al. 1993) has generated considerable attention. The gas appears to be associated with a system having only four recognizable galaxies, two of which NGC 2276 and 2300 dominate the group.

The presence of diffuse emission in poor groups raises many questions ranging from the gas origin to its correlation with group properties (fraction of early-type galaxies, group richness or space density, group velocity dispersion or degree of interaction). Some clues about the X-ray properties of groups are emerging and already providing partial answers. The X-ray luminosity of the gas does not correlate with group richness or optical luminosity. Furthermore, the correlation of X-ray luminosity with group velocity dispersion is weak with a lot of scatter (Mulchaey et al. 1996; Ponman et al. 1996). Observations of the loose group NGC 2300 and the Hickson (1982, 1993) compact group HCG 62 (Ponman & Bertram 1993; Pildis et al. 1995), in which the intragroup gas extends over scales of a few hundred kpc, yield surprisingly large gas masses ($\sim 10^{11-12} M_\odot$). Best fits to the X-ray spectra for these sources are consistent with primordial abundances ($\leq$0.2 solar), although the cosmic abundance determinations with the ROSAT instruments are not reliable (Trinchieri et al. 1994; Bauer & Bregman 1996).

The presence of a diffuse X-ray component appears to correlate with the fraction of early-type galaxies in a group. Mulchaey et al. (1996) have interpreted this evidence in three different ways: a) groups dominated by early-type galaxies are physical systems while the spiral dominated ones are not; b) a substantially different evolution regulates the two classes of galaxy aggregates; or c) the two kinds of groups show a difference in intragroup gas temperature so that spiral rich groups have a diffuse gas component too cool to be detected with ROSAT.

A recent analysis of the X-ray properties in compact groups (Hickson 1993 and references therein: hereafter HCG) suggests that at least 75% of these systems, including spiral-rich groups, may contain hot intragroup gas (Ponman et al. 1996), challenging the Mulchaey et al. (1996) results. However, recent ROSAT HRI observations by Pietsch et al. (1997) of one of the more

⋆ Based on observations obtained at 1.93m telescope of Observatoire de Haute Provence operated by INSU.
⋆⋆ Based on ASCA observations under ESA observing time.
⋆⋆⋆ Original tables are available at CDS

spiral-rich groups in the Ponman et al. (1996) sample suggests that this challenge should be treated with caution, in part, because of resolution limitations of PSPC observations. Indeed, Pietsch et al. find that a large fraction of the emission in HCG 92, formerly attributed to diffuse emission (see Sulentic et al. 1995) is due to a shock feature possibly caused by a direct collision between group members (already observed in the radio continuum by van der Hulst & Rots 1981). They give an upper limit for any diffuse component in HCG 92 that is significantly less than the X-ray clouds detected in other compact groups. The presence of diffuse emission in a group is generally considered as virtual proof that the group is a physical aggregate. However, it can also represent the superposition of diffuse gas around binary galaxies aligned along the line of sight within very long cosmological filaments (Hernquist et al. 1995), large loose groups (Mamon 1986) or clusters (Walke & Mamon 1989). Note that the possibility of cosmological gas filaments viewed end-on seems remote (Doe et al. 1995). Hence, the presence of diffuse emission in a group is a necessary but perhaps non sufficient condition for constraining its virialized state. X-ray observations for isolated pairs and for compact groups, E rich groups in particular, are thus useful to investigate if they are physical systems. Indeed, observational results show that not all groups of any optically defined class show diffuse X-ray emission at the same level (Mulchaey et al. 1996, Ponman et al. 1996).

Theoretical and observational signs in the morphology and kinematics produced by galaxy-galaxy encounters have been widely studied in the last decade (see for references Barnes and Hernquist 1992) so that predictions about the physical reality of a pair/multiplet can be done. In this context, we started a study aimed at recognizing "bona fide" signs of interaction in the kinematical and morphological properties of the early-type components of poorly populated groups, including pairs and compact groups. Our approach aims at: 1) finding signs of interaction from the shape of rotation and velocity dispersion curves and 2) possible differences in the properties of galaxies in X-ray bright and faint systems.

In this paper, we investigate the structure and the kinematics of the brightest early-type galaxies in four systems: the NGC 2300 group, HCG 62, HCG 68 and the mixed pair K 416. The presence of diffuse X-ray emission in the first three, and in particular in the NGC2300 group, whose central pair is a near *twin* of K 416, motivated ASCA observations of K 416. In § 2, both spectroscopic observations of group members and X-ray observations of K 416 are presented. In § 3 and § 4, we consider the implications of the observations. In the appendix, two previously unknown X-ray sources in the ASCA field of K 416 are presented, together with their X-ray spectra and the optical spectra of brightest optical candidates that fall in the error area of the X-ray sources.

2. Data acquisition and analysis

2.1. Optical images

The NGC 2300 group is dominated by a luminous pair of galaxies and the strong diffuse X-ray emission is centered on this pair. The mixed morphology (E+S) pair involving NGC 2276 and 2300 is sufficiently isolated to be included in the Catalog of Isolated Pairs (K 127; Karachentsev 1972: CPG). The group also includes two significantly fainter outlying members (NGC 2268 and IC 455 (B_T 14.0 compared to B_T= 11.8 for both pair components). The pair is classified DIS-1 (in the acronym convention adopted in the CPG) because one of the components, the Sc spiral, shows obvious distortion. The obvious distortion and the high IRAS luminosity for NGC 2276 (Zasov and Sulentic 1994) are consistent with the idea that it is experiencing enhanced star formation activity induced by an encounter with NGC2300.

We used the B image obtained in a previous study of CPG by Zasov & Sulentic (1994) (TI 800×800 CCD at the NOAO 0.9m telescope, on-chip image scale $0.43''$/pixel, integration time =10 minutes with FWHM=$1''.6$ seeing) to analyze interaction signatures in NGC 2300 and NGC 2276.

The surface photometry of NGC 2300 has been already obtained by several authors (UBR bands, Peletier et al 1990; I band, Forbes and Thomson 1992; BVI bands, Goudfrooij et al. 1994).Our data are in very good agreement with previous observations. In particular, the luminosity profile follows an $r^{1/4}$ profile over $\approx$ 7 decades, the ellipticity is nearly constant at $\approx$ 0.2, the position angle twist is less than $15°$. The shape of the isophotes tends to be disky in the outer region and irregular or moderately boxy in the inner region. The disky outer structure probably accounts for the lenticular classification assigned in RC3. The absence of a strong evidence of deviations from the $r^{1/4}$ law in the outer parts argues against signs of interactions that would instead produce an excess in the luminosity profile (*e.g.* Aguilar 1995).

We searched for fine structure (*e.g.* shells, X-structure) by modeling the smooth light distribution of the galaxy using the "ellipse" procedure in STSDAS, based on the algorithm outlined by Jedrzejewski (1987) and subtracting the model from the original image. With this method, we found no evidence of features. Forbes & Thomson (1992) have used a clipping algorithm to model the galaxy, and found evidence of significant patchy residuals, that the authors associate with the presence of shells (see also Goudfrooij et al. 1994). When a model without clipping is used, however, these residuals virtually disappear and the C4 parameter (the fourth cosine coefficient of the Fourier expansion of the residuals of the fitting procedure) behaves in excellent agreement with the one we derive and with those of Peletier et al. (1990) and Goudfrooij et al. (1994). Moreover, we also note that Peletier et al (1990) interpret deviations from elliptical isophotes as possible evidence of dust and of the presence of a disk component in this galaxy. It would seem therefore that the nature of the structure is strongly model dependent and caution should be used in interpreting these features in light of evidence of ongoing interaction.

We have also analysed the data on NGC 2276. The unsharp masking technique applied to this spiral galaxy allow us to investigate its inner parts. This procedure reveals multiple spiral arms and distortions at small radii, similar to what is visible at larger scale. No bar is visible although such features are very fre-

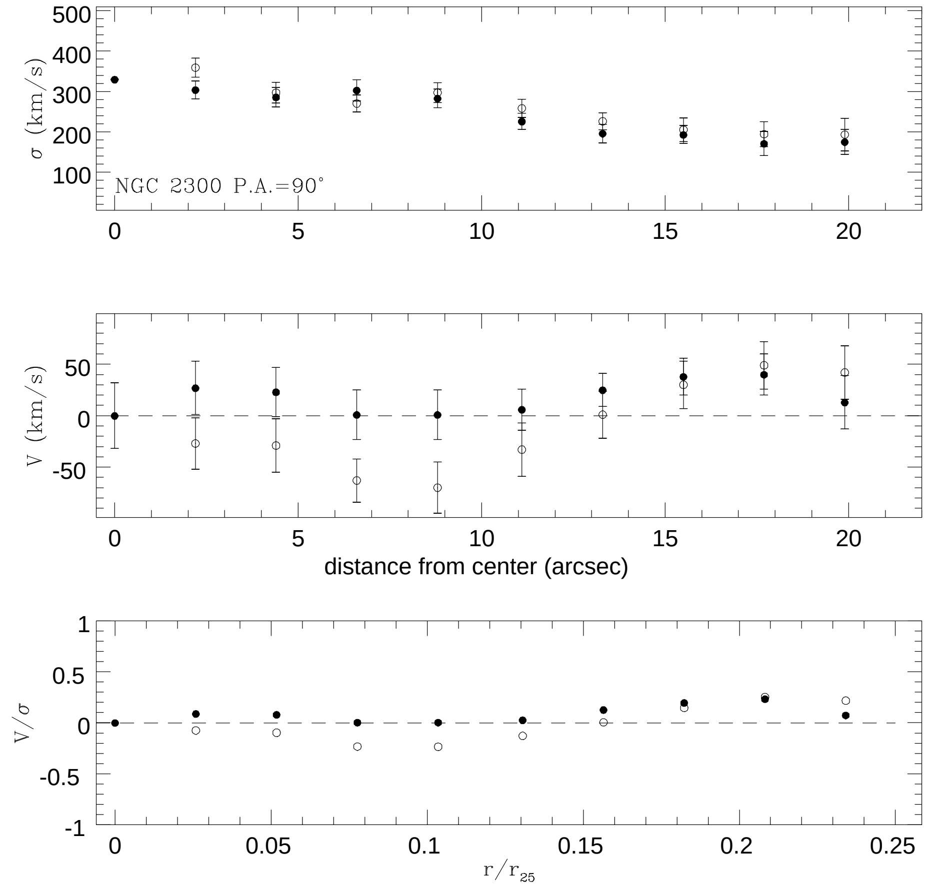

Fig. 1. Velocity dispersion (top panel) and rotation curves (middle panel) of the early-type galaxy NGC 2300. The curves are folded with respect to the light barycentre. Full dots = west side, open dots = east side. In the bottom panel is plotted the trend of the V/σ ratio as function of the radius normalized to the the isophotal radius at μ_B=25 mag arcsec^{-2}.

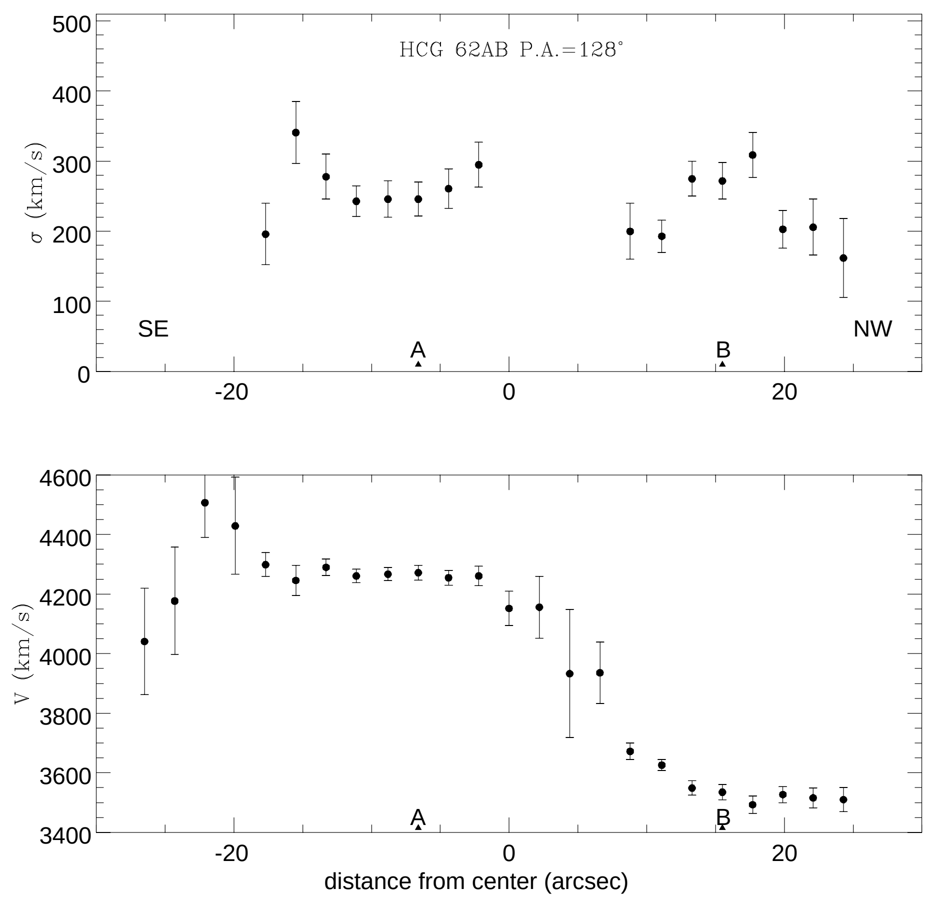

Fig. 2. Velocity dispersion (top panel) and rotation curves (bottom panel) of the early-type along the line connecting the galactic nuclei of HCG 62a (east) and HCG 62b (west). The arrows indicate the nuclei of the two galaxies.

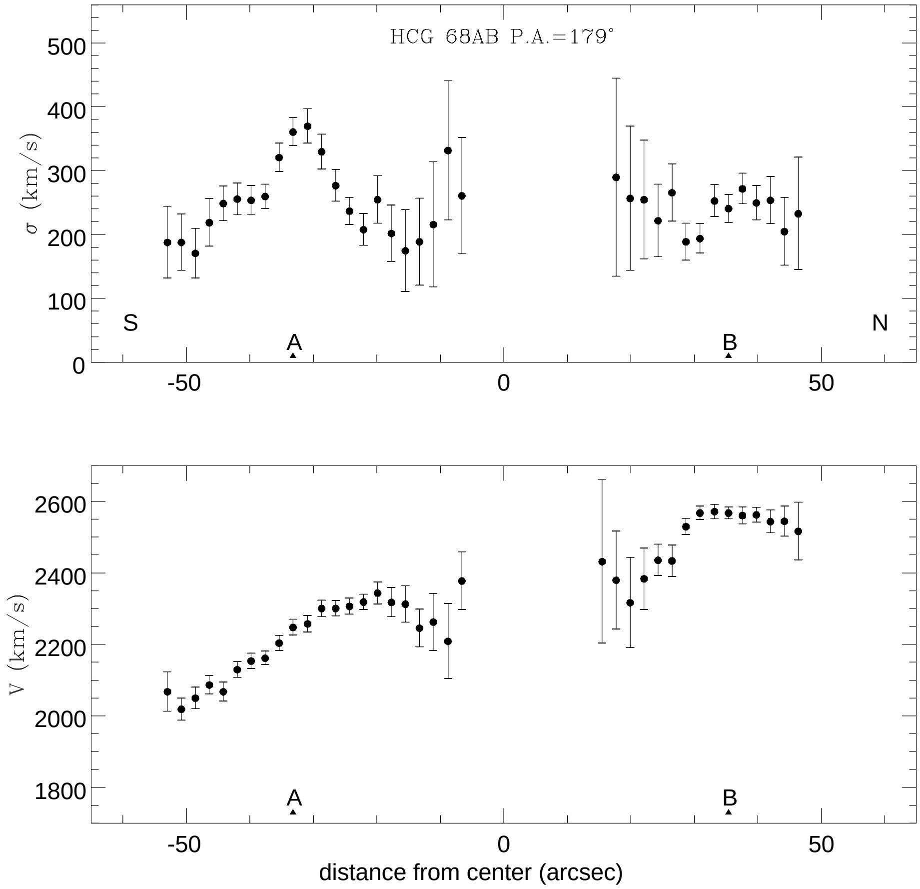

Fig. 3. Velocity dispersion (top panel) and rotation curves (bottom panel) of the early-type along the line connecting the galactic nuclei of HCG 68a (east) and HCG 68b West). The arrows indicate the nuclei of the two galaxies.

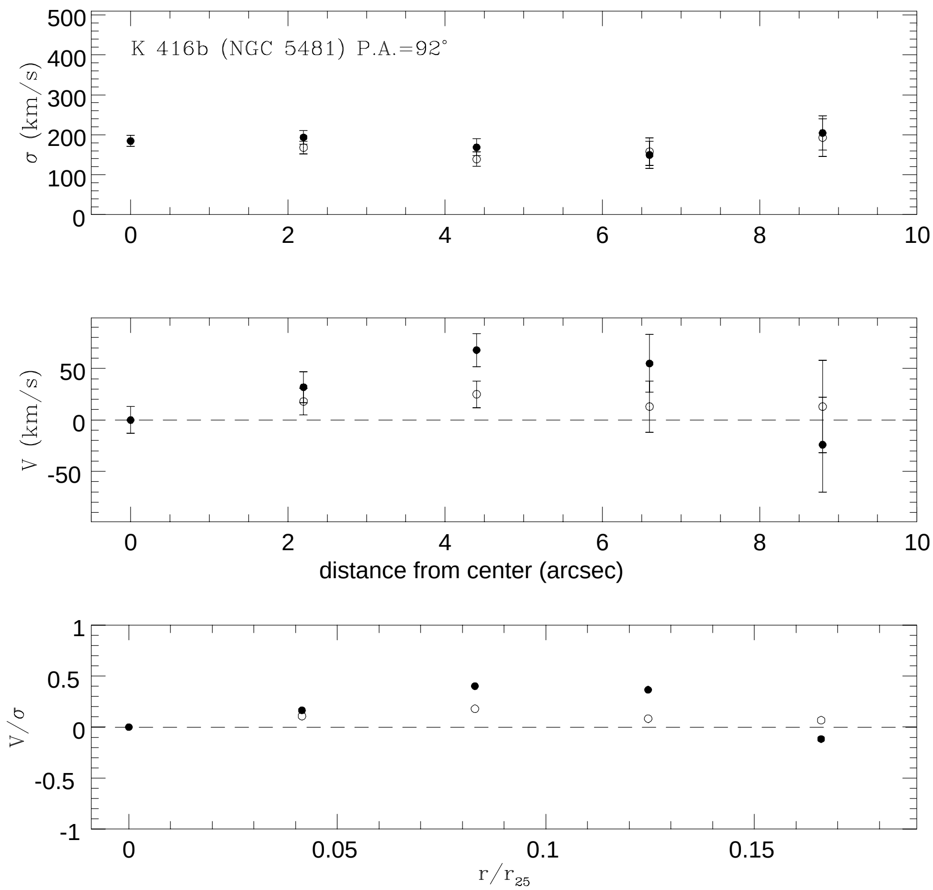

Fig. 4. Velocity dispersion (top panel) and rotation curves (middle panel) of the early-type galaxy NGC 5481 member of the pair K 416. The curves are folded with respect to the light barycentre. Full dots = east side, open dots = west side. In the bottom panel is plotted the trend of the V/σ ratio as function of the radius normalized to the the isophotal radius at μ_B=25 mag arcsec^{-2}.

quently detected among interacting spirals (≈ 95% in the sample of grand design spirals in Reduzzi and Rampazzo 1996).

Image analysis for the early-type component in K 416 was previously reported (Rampazzo et al. 1995). It is structurally similar to NGC 2300 but about 1.5 absolute (B_T) magnitudes less luminous. It shows stronger outer disky structure than observed in NGC 2300 and is probably a lenticular rather than an elliptical galaxy. No fine structure or other evidence for structural peculiarities was noted. Both of these pairs suggest past interaction but the evidence is concentrated in the asymmetric structure observed in the spiral components. In both case the elliptical component is located about two major-axis diameters (a_{25}) away from the spiral. Assuming circular orbits (see e.g. Karachentsev 1989), perhaps these pairs are too wide for significant structural deformation to appear in the early-type components.

2.2. *ASCA X-ray observations of K 416*

The E+S pair K 416 was chosen for ASCA observation because it shows the same morphology as the pair (K 127) in the NGC 2300 group. This similarity holds because both early-type components show evidence for outer disky structure. They also show similar enhanced star formation properties as are often observed in close S+S and E+S pairs (Xu and Sulentic 1991). In both cases the flux ratio FIR/S_{21cm}= 8.8 which is significantly larger than the mean value for a large sample of unpaired and isolated spirals (Zasov and Sulentic 1994). K 416 shows a projected separation s= 37kpc (H_0=50 km s^{-1} Mpc^{-1}) about one half the value observed for K 127. The motivation for an X-ray observation of K 416 came from the apparent association of the X-ray cloud with the dominant pair in the NGC 2300 group. This raised the possibility that the cloud might be somehow associated with the star formation enhancement, mixed morphology and/or binary characteristic(s).

The pair was observed with ASCA in May 1994 for 40 ks. To obtain a set of scientifically useful data, we have used the FTOOLS package and applied the standard screening criteria suggested by the ASCA Guest Observer Facility team, that include selections for geomagnetic rigidity, elevation angle, correction for contamination from Solar and particle events. After the data screening procedure (Day et al. 1995) no useful SIS data was left, while we obtained 34 ks of useful GIS data. Scientific data analysis was performed using the XSPEC and XIMAGE software tools. We selected energies between 0.3 and 10 keV. Our results are not further influenced by the energy range since the statistical fluctuations are on the order of, or above, the expected calibration uncertainties of the detectors. No sources were detected at the optical position of K 416. Two unrelated X-ray sources are visible to the NW and are discussed in the appendix.

We have computed upper limits for the pair in both GIS detectors. For these, we have considered the net counts in a circle with $r \approx 2'.5$ ($\sim$ 30 kpc at the distance of 40 Mpc assumed here), which should include 66% of the Encircled Energy Function (EEF), above a background estimated as the average over the entire image. We computed the quantity 3σ = net counts + 3 × σ_{bg} (net counts = 0 if negative) which was converted into a flux assuming a 1 keV, 0.5 solar abundance Raymond–Smith plasma model for the early type galaxy (NGC 5481) and a 5 keV, thermal bremsstrahlung model for the late type galaxy (NGC 5480). We assumed a low energy absorption equivalent to the line-of-sight galactic N_H of 1.41×10^{20} cm^{-2} (Stark et al. 1992). The results are given in Table 1 together with the associated luminosities for an assumed distance of 40 h_{50}^{-1} Mpc. The resulting fluxes are f_X <10^{-13} ergs s^{-1} cm^{-2}.

An estimate for a limit on the diffuse emission is somewhat trickier, since there is little constraint on the extent of any expected emission. A very conservative limit could be derived by assuming that the gas has the same linear extent as in the NGC 2300 group, *i.e.* an angular extent of $\sim 20'$ radius. However with this choice part of the area would fall outside of the GIS detector. We have therefore obtained a 3 σ upper limit as above in a circle of $7'.5$ ($\sim$ 90 kpc), which is within the field of view, centered half way between the two galaxies (given the small separation, the exact centering is not relevant). The resulting limits, given in Table 1, are obtained for a 1 keV Raymond–Smith plasma model with 0.5 solar abundance. The choice of the parameters for count to flux conversion is not very crucial and could give a variation in the derived flux of 30% when different temperature (0.1–1 keV) and metal abundance (0.1–0.5 solar abundance) ranges are considered. Furthermore, the resulting fluxes are not very sensitive to the choice of the spectral model.

The failure to detect emission from this system has resulted in an estimated X-ray luminosity of a diffuse component which is a factor 6-30 lower than in the NGC 2300 system (Pildis et al. 1995, Mulchaey et al 1996), indicating a significant absence of gas in K 416 relative to that optical configuration. Upper limits for the galaxies are within the expected values for objects of similar optical luminosities, even though the X-ray to optical ratio for NGC 5481 puts it at the lower end of the range.

2.3. *Optical spectroscopy*

Long-slit spectra were obtained with the CARELEC spectrograph on the 1.93m telescope at Observatoire de Haute Provence in order to investigate the internal kinematics of the early-type galaxies. The spectra have a dispersion of 66 Å mm^{-1} corresponding to 1.78 Å px^{-1} on the 512^2, 27μm^2 TeK CCD. The wavelength range covered is ≈ 4800< λ < 5750Å. The scale perpendicular to the dispersion is $1''.1$, the slit width was $2''.1$. The exposure time was 90^m for the spectrum of NGC 2300; 120^m for HCG 62a,b and HCG 68a,b. A 70^m exposure was obtained for K 416b (NGC 5481). We obtained two successive spectra at the same position angle for better cosmic ray removal. Position angles are reported in Figs. 1–4.

Pre-reduction, cosmic-ray removal, calibration and sky subtraction were performed using the IRAF package. Multiple spectra were co-added before being analysed with a Fourier-fitting code, kindly provided us by F. Simien. The Fourier-Fitting technique is similar to that of Franx et al. (1989). It allows the simul-

Table 1. ASCA upper limits of X-ray emission from K 416 members

Object	counts s^{-1} (10^{-3})	$Flux_{(0.3-10keV)}$ (10^{-13}ergs s^{-1} cm^{-2})	$L_{(0.3-10keV)}$ (10^{41} h_{50}^{-1} ergs s^{-1})	$Flux_{(0.3-2.4keV)}$ (10^{-13}ergs s^{-1} cm^{-2})	$L_{(0.3-2.4keV)}$ (10^{41} h_{50}^{-1} ergs s^{-1})	detector
NGC 5480	< 1.4	< 1.0	< 0.2	< 0.5	< 0.1	GIS 2
NGC 5480	< 3.0	< 1.7	< 0.3	< 0.9	< 0.2	GIS 3
NGC 5481	< 1.4	< 0.9	< 0.2	< 0.8	< 0.2	GIS 2
NGC 5481	< 2.6	< 1.4	< 0.3	< 1.2	< 0.3	GIS 3
Extended	< 3.3	< 2.0	< 0.4	< 1.9	< 0.4	GIS 2
Emission	< 5.0	< 2.6	< 0.5	< 2.4	< 0.5	GIS 3

Notes: 3 σ upper limits have been calculated in a circle of 2$'$.5 for the two galaxies and of 7$'$.5 for the extended emission, as explained in the text. Fluxes are derived assuming a thermal bremsstrahlung model with kT=5 keV for NGC 5480 and a Raymond Smith plasma model with kT=1 keV and abundance = 0.5 solar for NGC 5481 and the extended source. N_H has been taken from Stark et al. (1992) = 1.41×10^{20} cm^{-2}. A distance of 40 h_{50}^{-1} Mpc is assumed.

taneous determination of the rotational velocity, $V(r)$. velocity dispersion, $\sigma(r)$, at distance r from the center. A parameter $\gamma(r)$, related to the absorption-line contrast with respect to an approximation of the continuum, represented by a third-order polynomial fit to the spectrum, was also determined. The removal of the residual cosmic rays is performed on the galaxy spectrum within the same procedure. The removal is based on a three-sigma clipping of residuals between the galaxy spectrum and the (shifted and convolved) star spectrum. The V and σ parameters were actually determined in two successive steps, the first using the raw galaxy spectrum, and the second the spectrum with cosmic rays removed as explained. Adjacent lines were averaged to enhance the S/N ratio of the spectrum in the outer regions. For a spectrum at radius r, a weight was assigned to the neighboring lines ($r \pm \delta r$) entering the average; for this weight, a Gaussian fall-off as a function of δr was chosen, with a FWHM width between 0 and 4 pixels (0 and 4$''$.4).

Principal kinematical data, including heliocentric recession velocity $V_{0,\rm hel}$ and central velocity dispersion σ_0, are collected in Table 2. The rotation and velocity dispersion curves are displayed in Figs. 1–4.

In the following notes, we comment on the data for the individual galaxies and we compare our data with the literature when available.

NGC 2300 The rotation curve shown in Fig. 1 is consistent with an absence of rotation out to 15$''$. It then rises slowly up to $\approx$50 km s^{-1} at the last observed point. The rise in the rotation curve is coincident with the sudden variation of the isophotes P.A. from 75° to 90°. The rotation parameter V/σ, plotted in Fig. 1 and the average ellipticity, $< \epsilon > \approx 0.2$, indicate that the galaxy is in the regime of anisotropic oblate rotators.

The extended kinematics of this galaxy has been obtained by Bender et al. (1994) along the P.A = 80° and 170°. These authors also find no evidence of rotation in the inner regions, along both axes. In general, our values in the central 9$''$ are systematically larger by $\approx$ 30 km s^{-1} than those obtained by Bender et al. (1994), while the two curves are practically coincident in the outer part where our data are averaged out. In fact, a possible explanation of the discrepancy is that Bender et al. (1994) have binned their data in order to minimize degrading of the signal to noise ratio during the read-out, since they were interested in the kinematics of the main body of the galaxy rather than the nuclear region. Moreover, their central velocity dispersion along the minor axis is $\approx$ 10% higher (reaches $\approx$ 300 km s^{-1}) than that measured along the major axis, which might indicate a small slit misplacement or variation in the observing conditions.

The systemic velocity that we measure (see Table 2) is in agreement, within the error, with the value of 1963 km s^{-1} listed in RC3 (de Vaucouleurs et al. 1991). Several estimates of the central velocity dispersion can be found in the literature (see Prugniel & Simien 1996 for an updated compilation) in the range $235 < \sigma_0 < 395$ km s^{-1}, consistent with our result.

HCG 62a,b The velocity dispersion curve of HCG 62a measured along the direction connecting the nuclei of these two galaxies (Fig. 2) shows a rise at about 10$''$ from the center (indicated as A in the figure) in the SE direction, $i.e.$ away from HCG 62b and at about 7$''$ in the NW direction. While this rise in the direction towards HCG 62b could be partly an artifact due to the apparent superposition of the galaxies (see Combes et al. 1995 and references therein, as discussed in Sect. 3.1), the relatively sharp increase to the SE should be a real effect. The rapid variation in the SE direction of the rotation curve also observed in this galaxy (Fig. 2, lower panel) suggest the presence of a perturber. On the contrary, the velocity dispersion and rotation curves of HCG 62b appear unperturbed. In the framework of current N-body models (§3.1) we do not notice, in particular, the U-shape of the stellar velocity profile expected along this position angle.

Both ellipticity and position angle profiles of HCG 62a given in Mendes de Oliveira (1992) show a sharp variation at 10$''$. This author further shows that the outer isophotes of HCG 62a have a stable position angle of 60°, i.e. the isophotes twist toward HCG 62c.

Table 2. Main kinematics data

ident.	other ident.	V_{hel} km s^{-1}	σ_0 km s^{-1}	Type
NGC 2300		2003±34	330(1)	E2
HCG 62a		4279±25	246±24	E3
HCG 62b		3542±25	272±26	S0
HCG 68a	NGC 5353	2250±22	361±22	S0
HCG 68b	NGC 5354	2570±17	241±22	E2
K 416b	NGC 5481	2033±13	185±14	E3

Notes: (1) The central velocity dispersion of NGC 2300 is extrapolated.

Rotation and velocity dispersion curves have also been obtained by Bettoni et al. (1995) along the P.A.= 127° (connecting the nuclei of HCG 62a and HCG 62b) and are in good agreement with our estimates for both members.

HCG 68a,b The velocity dispersion and rotation curves displayed in Fig. 3 were taken along PA=178°, along the direction of the line connecting the two nuclei, which is very close to the minor axis of HCG 68b (Mendes de Oliveira 1992).

HCG 68a appears to be a rapid rotator, with a relatively unperturbed velocity field. In the velocity dispersion we may distinguish the bulge component, from a more flat component. On the other hand, HCG 68b shows basically no rotation, as expected for oblate rotators observed along their minor axis.

The increase in the velocity dispersion between the two nuclei is expected to be partly due to the light contamination of two galaxies.

Both 68a and 68b have been observed along their major axes, P.A.= 145° and P.A.=90° respectively, by Bettoni et al. (1995). Our results on the central velocity dispersions are in agreement, within the errors, with theirs: the value that they publish, of 303 ± 6 km s^{-1} for HCG 68a, is the average over the central 3″. However, in the inner 1″ the velocity dispersion is between 300 and 320 km s^{-1} with a formal error of ≈ 30 km s^{-1} for HCG 68a, and between 220 and 240 km s^{-1} with a formal error of ≈ 30 km s^{-1} for HCG 68b (Bettoni, private communication).

Bettoni et al. (1995) also detected emission in the [NII] λ = 6548 Å line from both objects, while our observations failed to detect emission lines. However, we observed the galaxies along the line connecting the nuclei where both galaxies have strong dust-lanes. In particular the dust-lane of HCG 68b is along the minor axis which is nearly coincident with the position angle of our slit. Moreover, our spectral range is bluer than that of the previous authors. This, combined with the positioning of the slit and the small extension of the emissions in both HCG 68a and HCG 68b could have hampered our detection of emission lines (e.g. Hβ) in our spectra.

K 416 Fig. 4 shows the rotation curve and the velocity dispersion profile of K 416b (NGC 5481) along the axis connecting the two pair members. NGC 5481 has a nearly constant velocity dispersion profile and the rotation curve has a maximum of ≈ 50 km s^{-1}. The position angle profile of NGC 5481 has a rapid variation in the area covered by the spectrum (Rampazzo et al. 1995) going from P.A.=60° to P.A.=100° in the inner 10″. Also the ellipticity profile shows a variation in the same region of the galaxy going from 0.05 to 0.1 growing up to 0.2 in outer parts.

The complexity of NGC 5481 in the central region reflects in the rotation parameter V/σ (Fig. 4 bottom panel) indicating that, in this region, NGC 5481 is a slow rotator. At the same time, since photometry by Rampazzo et al. (1995) shows a presence of an exponential disk, we expect that a deeper spectra will detect rotation along the axis P.A.=100°.

Central velocity dispersion values in the literature (White at al. 1983: σ_0=147±28 km s^{-1} and Bonfanti et al. 1996: σ_0=126±92 km s^{-1}) tend to be lower than our measure (σ_0=185±14 km s^{-1}), although in agreement within the errors.

The systemic heliocentric velocity of NGC 5481, cz = 2064 ± 33 km s^{-1}, given in RC3, is in agreement with the value measured in the present work and reported in Table 2. Using the stellar systemic velocity of NGC 5480 given in Rampazzo et al. (1995) the estimated velocity difference between the two members is ≈ 130 km s^{-1}.

3. Discussion

Two general questions are among the aims of the study that we have just started: 1) do "bona fide" signs of present/past interaction in the morphology and/or in the kinematics of the early-type members of poor groups exist, at least in those with a compact structure? and in this context: Are morphological and kinematical signatures correlated? and 2) Do the properties of the diffuse X-ray emission together with the kinematical/morphological signatures add constraints to the physical reality and/or the evolutionary status of the poor systems?

With the small sample we have accumulated so far we may start to address these issues. We sketch below our preliminary considerations.

3.1. Morphological and kinematical signatures

Morphological signs of interaction are obvious in the pair K 416 and in K 127. Both spiral members, namely NGC 2276 and NGC 5480 have a very distorted morphology. In particular NGC 5480 shows a sort of compression of the isophotes in the southern part of the galaxy with respect to the northern ones (Rampazzo et al. 1995) not dissimilar to what is observed in the NGC 2276 data presented earlier (see Sect. 2.1). At variance, the early-type galaxies in both systems, NGC 2300 and NGC 5481 respectively, appear unperturbed.

The observed distortion in the morphology would suggest that peculiar kinematics should also be observed in the spiral members. This is not the case for NGC 5480, whose kinematics are unperturbed. This can be deduced from the coincident stellar and gaseous rotation curves in the central parts of NGC 5480 (K 416a), and from the regularity of its rotation curve obtained from emission lines, up to ≈7.5 kpc (H_0=50 km s^{-1} Mpc^{-1}) reported by Rampazzo et al. (1995). Unfortunately we have no

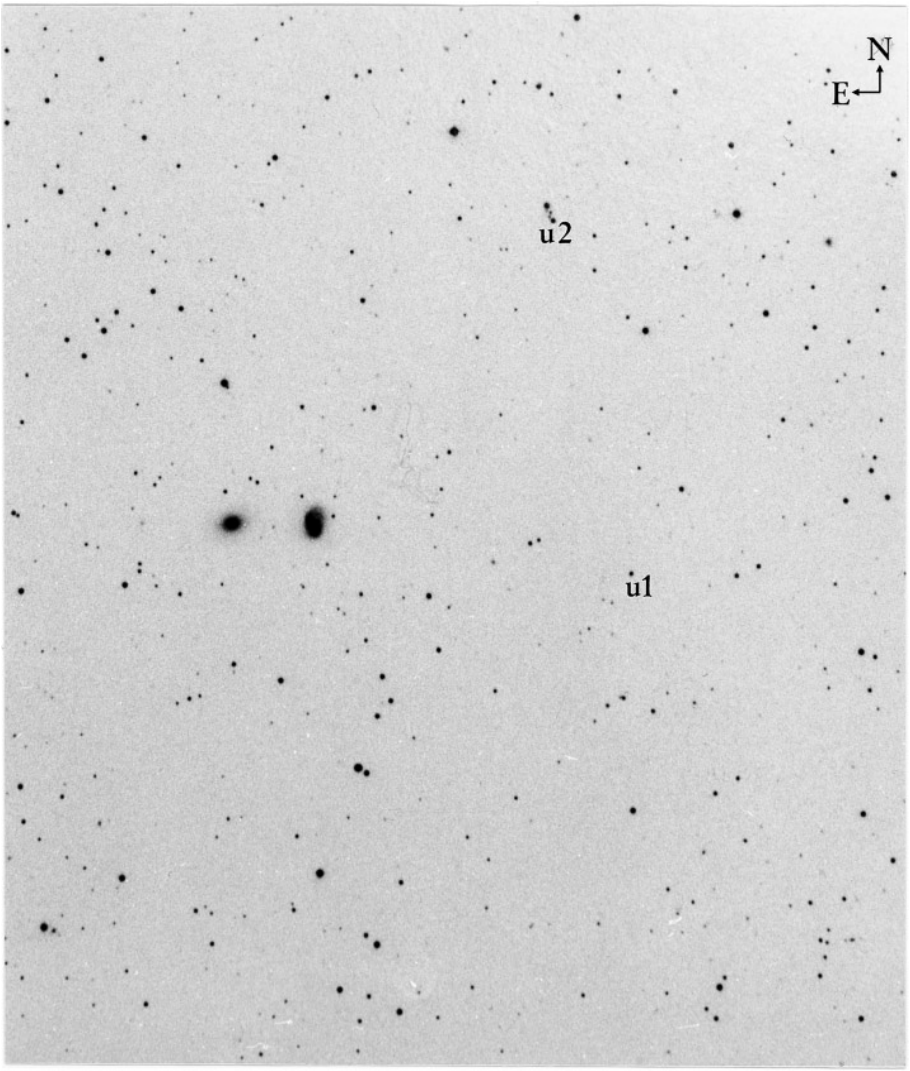

Fig. 5. Optical image of K 416 (upper panel). The pair separation is 3′.2. In the figure are also marked the position of the two previously unknown X-ray sources.

spectra for NGC 2276, the distorted spiral in the K 127 pair, nor for HCG 68c, a spiral in the HCG 68 group that also shows morphological peculiarities and is suggested to be in interaction by Mendes de Oliveira & Hickson (1994; see our discussion later), to make a more general statement. However, it would seem that the two pieces of evidence are not always correlated, since they are not in at least one case for which we have data. The lack of a one-to-one correlation between morphology and kinematics may be explained either by invoking that the interaction was weak so that the inner dynamics is not modified or that such event is old and the galaxy has already returned to the equilibrium, at least in the central part.

At the same time, Mendes de Oliveira & Hickson (1994) observed that HCG 62a has non concentric isophotes and we observe that this galaxy has peculiar kinematics. Although ellipticals are less sensitive tracers of tidal forces than spirals, since they have little gas and are composed essentially of a hot populations of stars (low rotators) which suppress the main resonant effects, morphology and kinematics seem to be better coupled in ellipticals than in spirals. We are therefore tempted to conclude that in spiral galaxies peculiar morphology is only loosely coupled with peculiar kinematics, in agreement with the conclusions of Rubin et al. (1991) that are based on a much larger sample of spirals in compact groups. Peculiarities in the morphology of elliptical galaxies instead could correlate with inner kinematics, although it is clearly more difficult and rarer to detect peculiarities in either morphology or velocity fields of early-type galaxies that are signs of interaction (only one of the three ‘interacting’ galaxies we have presented here). Again this could be explained by the fact that only strong gravitational interaction is able to modify the equilibrium state of an elliptical and then reflect both in the morphology and in the kinematics. Observations of HCG 62c would be crucial to underline this point.

Numerical simulations developed by different groups have identified signatures in the stellar rotation curves that could be associated to specific morphological peculiarities, for example the U-shape of the stellar velocity profile could be related to non concentric isophotes, first outlined as interaction features by Davoust & Prugniel (1988). HCG 62a shows non-concentric

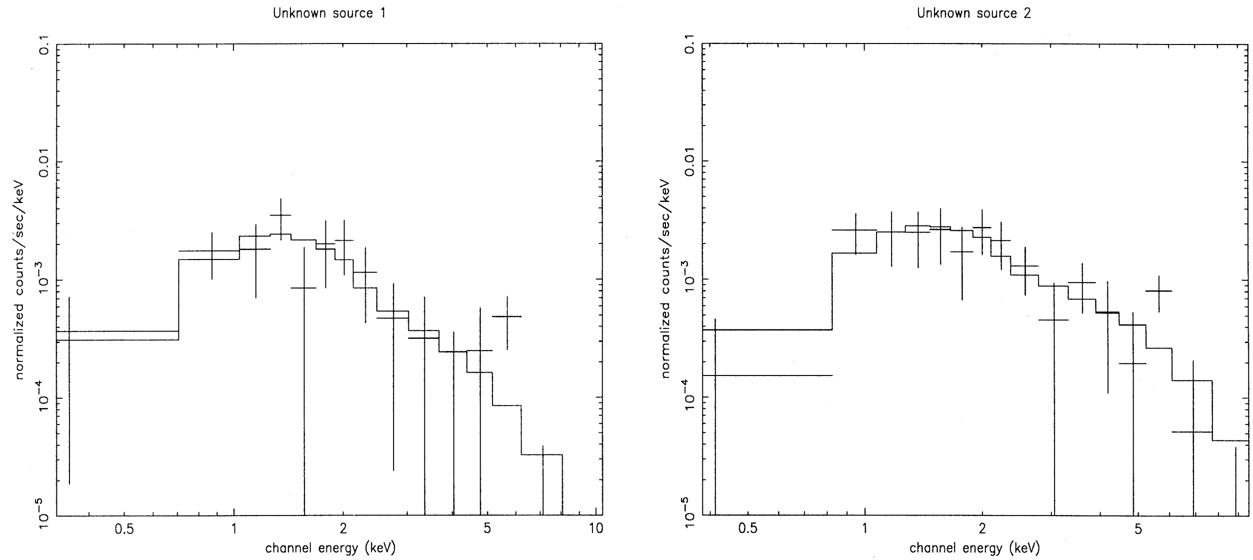

Fig. 6. X-ray spectrum of the unknown sources 1 and 2 whose coordinates are reported in the appendix. The spectrum was tentatively fitted with a power law and interstellar absorption. The parameters of the fitting are described in Table 3.

isophotes (Mendes de Oliveira & Hickson 1994). If we look at the simulations by Combes at al. (1995), which followed the evolution of the morphology and of the rotation curve of an early-type galaxy during an interpenetrating encounter with another early-type galaxy, we may interpret both the rotation and the velocity dispersion curves of HCG 62a as a signature of interaction. Mendes de Oliveira and Hickson (1994) suggest that the interaction could have taken place with HCG 62c, a nearby fainter S0 galaxy, very close to HCG 62a in redshift space (V_h=4359 km s^{-1}; Hickson 1993). In support of this hypothesis, both the kinematics and the morphology of HCG 62b appear unperturbed, although it is closer to HCG 62a on the plane of the sky and in contact with it. Clearly the kinematical properties of HCG 62c need to be taken into account in order to reach more solid conclusions, however kinematical data on the early-type galaxies support the hypothesis of at least one interacting pair in this group.

We cannot instead confirm the presence of an interacting pair in HCG 68. The two galaxies HCG 68a and b do not show sign of interaction in their morphology and rotation curves, in spite of their appearance as a pair of galaxies in contact on the Digitized Sky Survey plates. A rise in the velocity dispersion of HCG 68a along the direction connecting the two nuclei is however observed (Fig. 3). Simulations of Combes et al. (1995 and reference therein) show that the velocity dispersion measured in a region between two galaxies can rise also in the case of a superposition of two unrelated objects, $i.e.$ the rise is not a *bona fide* indicator of ongoing interaction. In HCG 68b Bettoni et al. (1995) found a counter-rotating gas core (inner 4″) which could be interpreted as a sign of a recent acquisition. HCG 68a has also a gaseous component, but it rotates like the stellar one. The presence of the gaseous component is then probably not related to a postulated interaction of a with b, and it is more likely due either to inner stellar mass loss phenomena or to past, minor acquisition events. Mendes de Oliveira (1992) shows that HCG 68d has an isophotal twist of about 30°. Furthermore, the probable shell like structure in the d member could also be indicative of minor merging events (see Barnes & Hernquist 1992) or to a weak interaction (Thomson 1991 and reference therein).

3.2. Diffuse X-ray emission and physical reality of the group

Ostriker et al. (1995) have suggested that the presence of a centrally condensed, diffuse X-ray emitting gas may allow the determination of which groups are real. They have proposed a test, involving ROSAT data for groups, that would allow one to determine which groups are physically bound. Unfortunately, their test did not produce the expected result and two equally plausible scenarios were found: **a** *groups are chance alignments* (Mamon 1986, Walke & Mamon 1989, Hernquist et al. 1995), or **b** *groups are bound systems, but intrinsically gas poor relative to rich clusters*. Among the compact groups analysed by Ostriker et al. (1995) only HCG 62 has a gaseous content marginally consistent with clusters. Following these authors, HCG 68 and the rest of the HCGs for which they had access to X-ray measurements are either low density elongated systems or have an anomalously low ratio of hot gas to the total mass compared to that of clusters. Since the detection of a diffuse X-ray emission in the NGC 2300 group (K 127), other pairs in the Karachentsev (1972) catalogue have been observed in X-rays, namely K 13 (NGC 169), K 99 (NGC 1587/1588), K 190 (NGC 2769), K 438 (NGC 4615) but only upper limits to the diffuse X-ray emission, comparable to that obtained in this paper for K 416, have been derived for these (Mulchaey et al. 1996). With the exclusion of K 99, all pairs in the Mulchaey et al. (1996) sample are composed of spiral+spiral members.

K 99 is the only pair for which a wide set of N-body simulations (see Borne et al. 1994, Combes et al. 1995) have been performed to understand both the peculiar morphology (Davoust

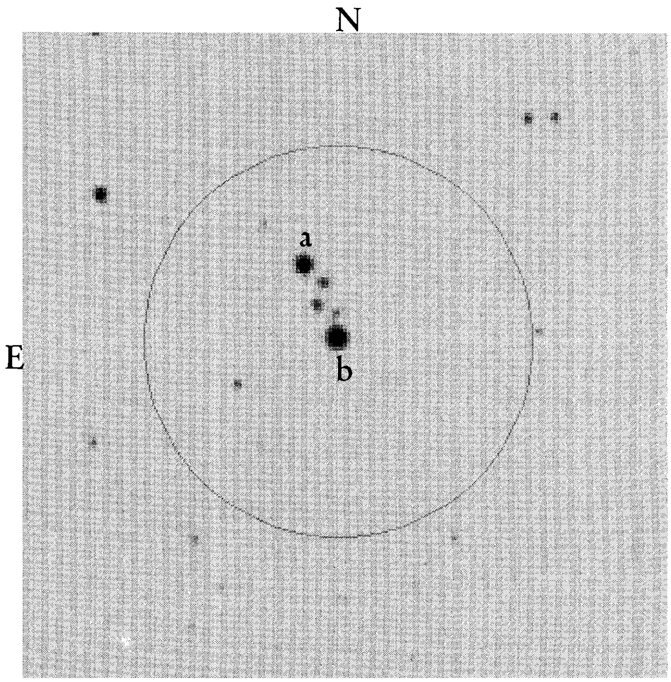

Fig. 7. Image, obtained from the Digitized Sky Survey, of the objects within the circular error corresponding to the unknown source 2

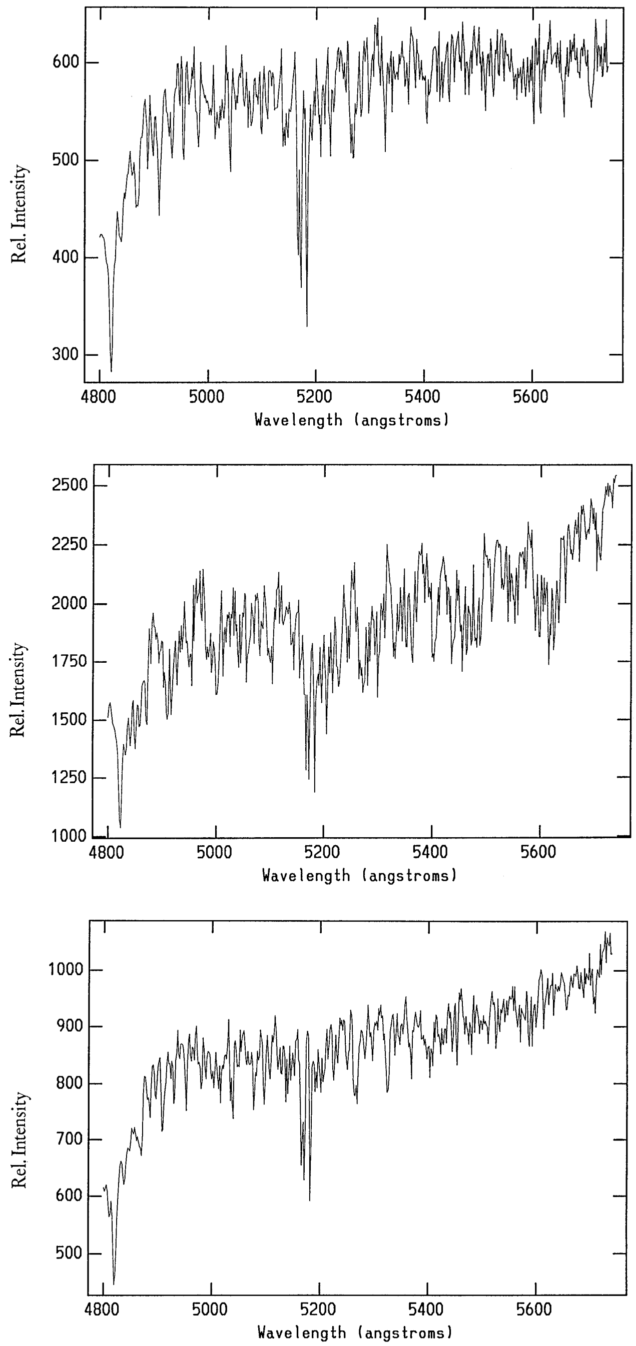

Fig. 8. Optical spectrum, in relative intensity, of the unknown source 1 (top panel). In the middle and bottom panels are shown the optical spectra of the sources indicated with a and b in the image of Fig. 8 within the circular error corresponding to the unknown source 2.

& Prugniel 1988) and kinematics, *i.e.* the U-shape of the stellar velocity profile (Borne 1994 and references therein; Bonfanti et al. 1995). The rotation and velocity dispersion curves of the pair are well modeled if these galaxies are undergoing an unbound interpenetrating encounter. The simulation for K 99, and the similarity of the X-ray upper limits for the diffuse components of K 99 and K 416 may suggest that the latter could be in the class of unbound encounters between galaxies. The absence of signatures of present/past interaction both in the kinematics and in the geometry of NGC 5481 (Reduzzi & Rampazzo 1996) may suggest that the encounter is near the perigalactic passage like K 99. A grid of N-body simulations with a resolution suitable to compare the morphology and the kinematics with observations is necessary to confirm the hypotheses of a recent and unbound encounter.

In the NGC 2300 and HCG 62 groups, diffuse X-ray emission is detected peaking near the centre of the group (Mulchaey et al. 1993, Pildis et al. 1995). In HCG 68, the diffuse emission is centered 1$'\!.$5 SW of HCG 68a, *i.e.* quite displaced from the group's center and from the distorted spiral HCG 68c. Mulchaey et al. (1993) suggest that the distorted optical and radio morphologies observed in NGC 2276 could be partly due to the interaction with the hot intragroup medium and that the optical distortion can be used as an (optical) indicator of the presence of a diffuse intragroup medium. While this could also apply to HCG 62, the lack of a significant amount of diffuse intergalactic medium in K 416, which shows similar distortions in its spiral member, together with the kinematical observational evidences presented before, indicates that this cannot be generally true, and instead suggest that the strong gravitational interaction with the companion is a more likely cause of the peculiar morphologies (see also Davis et al. 1997). These latter are not sufficient to infer that the galaxies are bound in the group if not in conjunction with its X-ray diffuse emission properties.

Zepf & Whitmore (1993) obtained the central velocity dispersions for 22 ellipticals in compact groups and found that they are significantly lower than those for ellipticals in other envi-

Table 3. Positions and parameters of the fit of X-ray spectra of unknown sources

Object	R.A. (2000)	δ (2000)	Counts/s (10^{-3})	γ	norm. (10^{-5})	χ^2	bins	$Flux_{(0.3-10keV)}$ (10^{-13} erg cm^{-2} s^{-1})	Camera
Unknown source 1	14 05 12	50 42 29							GIS 2
	14 05 04	50 41 36	4.4±0.5	$2.3^{+2.0}_{-0.8}$	9.4	0.8	15	4.7	GIS 3
Unknown source 2	14 05 37	50 56 51							GIS 2
	14 05 29	50 56 11	4.0±0.4	$1.8^{+0.9}_{-0.3}$	6.8	0.8	16	3.7	GIS 3

Notes: GIS 3 spectra were tentatively fitted with a power law, γ, and interstellar absorption, N_H = 0 and 1.1 10^{21} cm^{-2} respectively for the source 1 and 2. The errors are computed on two degrees of freedom 90% confidence interval.

ronments. They suggest that tidal interaction or accretion events provide possible mechanisms to account for this difference. Rubin et al. (1991) analysed 21 HCGs and reported that most of the early-type galaxies show gaseous nuclear emission, but only one out of twelve shows that the gas counter-rotates with respect to the stellar component, indicating an external acquisition. This is surprising in systems expected to have a very high frequency of merger activity (Carnevali et al. 1981, Barnes 1985, Mamon 1987). That impression is reinforced by studies of the optical luminosity function for compact group members (Sulentic and Rabaça 1994). The authors find little evidence for ongoing or past merger activity in compact group since they do not observe a population of field ellipticals that are luminous enough to be the remnants of merged compact groups. Similarly, the distribution of the FIR colors points to only a small fraction of compact group galaxies involved in ongoing mergers (Zepf, 1993). If physically dense groups, where hot diffuse gas is required, have a "nurture" origin (see Diaferio et al. 1994) peculiarities should also be evident in the morphological and kinematical properties of these galaxies. HCG 68 could indeed be evidence of this, since most of the signs in the galaxies in HCG 68 seem connected to small acquisition events (Mendes de Oliveira & Hickson 1994; Bettoni et al. 1995). Shells are rarely found in high density environments (Malin & Carter 1983; Reduzzi et al. 1996) and together with counter-rotation are intended as key evidence of merger (or at least "weak interaction": Thomson 1991). HCG 68 then may be considered a group with a "high density of signatures" of past weak interaction events on early-type galaxies.

4. Conclusion

We have presented the *stellar kinematics* of the brightest early-type galaxies in NGC 2300, K 416, HCG 62 and HCG 68. We have also determined an upper limit to diffuse X-ray emission in the K 416 system from our ASCA observations.

From the analysis of these systems we may infer the following general conclusions.

Morphological signatures, kinematical features and the presence of hot gas are poorly correlated with one another. The comparison between two systems, K 416 and NGC 2300, is a good example: in both systems the morphological signatures are better explained in terms of gravitational interaction than as the result of interaction with the intragroup gas, since K 416 has a significant lack of hot gas compared to the NGC 2300 group of which in many other respects is a twin. Morphological and kinematical features, that are interpreted as signs of interaction, can point to an unbound encounter, when there is no supporting evidence for a common potential from the resence of diffuse gas seen in X-rays. If we interpret the presence of a diffuse X-ray component as an indication of the physical reality of a group, K 416 may be then ascribed to the class of unbound–unbound encounters, like other pairs for which upper limits have been determined by Mulchaey et al. (1996). Extensive simulations performed on the K 99 pair support this hypothesis.

X-ray diffuse emission may be also related to the evolutionary status of the group in addition to the different galaxy composition. In HCG 62 and in NGC 2300 a significant diffuse X-ray emission is associated with an ongoing galaxy-galaxy interaction (in the latter case evident in the morphology of NGC 2276), while other members of the group are unperturbed. In HCG 68, the X-ray emission, significantly lower ($\approx$ 60 times) than in the previous groups, seems related to past episodes of interaction in many members, although no pair members are detected.

Further kinematical studies on early-type galaxies and adequate numerical simulations are needed to ascertain the connection between X-ray diffuse emission, degree of interactions and physical association of the group.

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Appendix A: unknown X-ray sources in the K 416 field

Two previously unknown X-ray sources were detected in the field of view of the GIS cameras covered by our K 416 observations. Their positions (indicated as **u1** and **u2** in Fig. 5) are slightly different in the GIS 2 and GIS 3 cameras, however consistent with the position uncertainties of the instruments. The coordinates are given in Table 3. The total number of counts permits us to extract only rough spectra shown in Figs. 6. The best fit and errors parameters for the spectra are given in the Table 3.

The optical field in the area of **u2** within the X-ray centroid uncertainty (25 pixels $\approx 6'.1$) is shown in Fig. 7. We have obtained spectra of the brightest optical candidate counterparts near the X-ray positions. The optical spectra given in Fig. 8 indicate that they are late-type stars of K-M type. At the position of **u2** there are many optical sources, in particular three faint sources are clearly visible between the two stars indicated as **a** and **b** in the Fig. 7, in the Digitized Sky Survey. We have not obtained spectra for these. However, we cannot exclude that late-type stars are the optical counterparts. The $\log(L_X/L_{opt})$ ratio for the two stars **a** and **b** near source 2 are -2.1 and -1.6 respectively, and it is -1.0 for source 1, consistent with values expected for stars (see Giommi et al. 1991).

References

Aguilar L.A. 1995, in Fresh Views of Elliptical Galaxies, eds. A. Buzzoni, A. Renzini and A. Serrano, ASP Conf. Series, 86, p. 59.
Bauer F. and Bregman J.N. 1996, ApJ, 457, 382
Balcells M. and Quinn P.J. 1990, ApJ, 361, 381.
Barnes J. 1985, MNRAS, 215, 517.
Barnes J. and Hernquist L. 1992, Ann. Rev. of Astron. & Astrophys., 30, 705.
Bender R., Saglia R.P. and Gerhard O.E. 1994, MNRAS, 269, 785.
Bettoni D., Buson L.M., Maira L. and Bertola F. 1995, in Groups of Galaxies eds. O-G. Richter and K. Borne, ASP Conference N.70, 95.
Bonfanti P., Rampazzo R., Combes F., Prugniel Ph. and Sulentic J.W. 1995, A&A, 297 , 28.
Bonfanti P., Longhetti M., Reduzzi L., Rampazzo R., Prugniel Ph. 1996, Astrophys. Lett. & Communication, in press.
Borne K.D., Balcells M., Hoessel J-G., McMaster M. 1994, ApJ, 435, 79.
Carnevali P., Cavaliere A. and Santangelo P. 1981, ApJ, 249, 449.
Combes F., Rampazzo R., Bonfanti P., Prugniel Ph. and Sulentic J.W. 1995, A&A, 297, 37.
Davis D.S., Keel W.C., Mulchaey J.S. and Henning P.A. 1997, ApJ, preprint.
Davoust E. and Prugniel Ph. 1988, A&A, 201, L30.
Day C. et al. 1995, The ABC guide to ASCA Data Reduction, NASA.
de Vaucouleurs G. et al. 1991, Third Reference Catalogue of Bright Galaxies, Springer-Verlag: RC3.
Diaferio A., Geller, M.J. and Ramella M. 1994, AJ, 107, 868.
Doe S.M., Ledlow M.J., Burns J.O. and White R.A. 1995 A.J., 110, 46.
Forbes D.A. and Thomson R.C. 1992, MNRAS, 254, 723.
Forman W. and Jones C. 1982, A&AR, 20, 547.
Franx M. Illingworth G.D., Heckman T. 1989, ApJ, 344, 613.
Giommi P., Tagliaferri G., Beuermann K., Branduardi-Raymont G., Brissenden R., Graser U., Mason K.O., Mittaz J.D.P., Murdin P., Pooley G., Thomas H.-C., Tuohy T. 1991, ApJ, 378, 77.
Goudfrooij P. et al. 1994, Astron. & Astrophys. Supp., 104, 179.
Hernquist L., Katz N. and Weinberg D. 1995, ApJ, 442, 57.
Hickson P. 1982, ApJ, 255, 382.
Hickson P. 1993, Astrophysical Letters & Comm., 29, N° 1-3, 1.
Karachentsev I.D. 1972, in Catalogue of Isolated Pairs of Galaxies in the Northern Hemisphere Comm. Spec. Ap. Obs., 7, 1: CPG.
Karachentsev I.D. 1989, in Paired and Interacting Galaxies, IAU Colloquium N. 124. eds. J.W. Sulentic, W.C. Keel and C.M. Telesco, NASA CP-3098, p.3.
Malin D.F. and Carter D. 1983, ApJ, 274, 534.
Mamon G.A.1986, ApJ, 307, 426.
Mamon G.A.1987, ApJ, 321, 422.
Mendes de Oliveira C. 1992, PhD Thesis, Univ. of British Columbia.
Mendes de Oliveira C. and Hickson P. 1994, ApJ, 427, 684.
Mulchaey, J.S., Davies, D.S., Mushotzky, R.F. and Burstein, D., 1993, ApJ, 404, L9.
Mulchaey, J.S., Davies, D.S., Mushotzky, R.F. and Burstein, D., 1996, ApJ, 456, 80.
Ostriker J.P., Lubin L.M. and Hernquist L. 1995, ApJ, 444, L61.
Peletier R.F., Davies R.L., Illingworth G.D., Davis L.E. and Cawson M. 1990, AJ, 100, 1091.
Pietsch W., Trinchieri G., Arp H.C. and Sulentic J.W. 1997, A&A, 322, 89.
Pildis R.A. 1995, ApJ, 455, 492.
Pildis R.A., Bregman J.N. and Evrard A.E. 1995, ApJ, 443, 514.
Ponman T.J. and Bertram P.D.J. 1993, Nature, 363, 51.
Ponman T.J., Bourner P.D.J., Ebeling H. and Böhringer H. 1996, MNRAS, 283, 690
Prugniel Ph. and Simien F. 1996, A&A, 309, 749.
Rampazzo R., Reduzzi L., Sulentic J.W. and Madejsky R. 1995, A&AS, 110, 131.
Reduzzi L. and Rampazzo R. 1996, A&AS, 116, 515.
Reduzzi L., Longhetti M. and Rampazzo R. 1996, MNRAS, 282, 149.
Rubin V.C., Hunter D.A. and Ford W.K. 1991, ApJ Supp. Ser., 76, 153.
Stark A.A. Gammie C.F., Wilson R.W., Bally J., Linke R.A., Heiles C. and Hurzitz M. 1992, ApJ Supp. Ser., 79, 77.
Sulentic J.W. and Rabaça C.R. 1994, ApJ, 429, 531.,
Sulentic J.W., Pietsch and Arp 1995, A&A, 298, 420.
Thomson R.C. 1991, MNRAS, 253, 256.
Trinchieri G., Kim D.-W., Fabbiano G. and Canizares C.R.C.1994, ApJ, 428, 555.
van der Hulst J.M. and Rots A.H. 1981, AJ, 86, 1775.
Xu C. and Sulentic J.W. 1991, ApJ, 374, 407.
Walke D.M. and Mamon G.A. 1989, A&A, 225, 291.
White S.D.M., Huchra J., Latham D. and Davis M. 1983, MNRAS, 203, 701.
Zasov A.V. and Sulentic J.W. 1994, ApJ, 430, 179.
Zepf S.E. 1993, ApJ, 407, 448.
Zepf S.E. and Whitmore B.C. 1993, ApJ, 418, 72.

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