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X-RAY EMISSION FROM HICKSON'S COMPACT GROUPS OF GALAXIES: RESULTS FROM THE *ROSAT* ALL-SKY SURVEY

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ABSTRACT

We report on the detection of X-ray emission from 11 of Hickson's compact groups of galaxies (HCGs) in the *ROSAT* All-Sky Survey (RASS). One of these is clearly part of a much richer system with an X-ray luminosity comparable to that of Abell clusters. With two other detections, the X-ray emission is dominated by pointlike and spectrally soft sources which can be identified with active galactic nuclei within the group. The remaining eight detections constitute the first statistically relevant sample of compact groups of galaxies truly seen in X-rays. Some of the sources are clearly extended; for the other ones it is, at the sensitivity of the RASS, not clear whether the X-ray emission is due to the presence of a hot intragroup gas, to individual galaxies, or to galaxy-galaxy interactions in these objects, although the former is suggested by the hardness of the emission typical of a thermal bremsstrahlung spectrum with $T_{\rm gas} \approx 1$ keV. We find the HCG's X-ray luminosity to be almost independent of the optical richness of the group; however, there seems to be a strong correlation with the spiral fraction and the morphological type of the dominant galaxy. A comparison between the X-ray luminosity functions (XLFs) of HCGs and clusters of galaxies suggests that, at X-ray luminosities of some $10^{42}\ h_{50}^{-2}$ ergs s^{-1}, compact groups of galaxies contribute at the $\sim 10\%$ level to the XLF of galactic systems. The majority of the latter thus have to be loose groups and poor clusters of galaxies.

Subject headings: galaxies: clustering — galaxies: interactions — X-rays: galaxies

1. INTRODUCTION

Of all gravitationally bound galaxy agglomerations, poor groups of galaxies constitute the class which is probably the hardest to detect and characterize. Given the small number of members of such systems, the significance of galaxy groups found by scanning optical plates is severely affected by chance projections and fluctuations in the local projected density of field galaxies (Rose 1977). In one of the first statistically complete compilations of compact groups of galaxies, Hickson (1982) tried to avoid this problem by restricting his sample to very compact groups, compact being defined as reasonably rich (at least four galaxies), isolated and optically compact, i.e., of high mean optical surface brightness. The Hickson sample was obtained by a systematic search of the Palomar Sky Survey prints and comprises 100 groups consisting of four to seven, in some cases interacting, galaxies. Richer systems and regular clusters should virtually be excluded from this sample by the combination of the isolation and optical compactness criteria. Galaxy counts in the groups' vicinity suggest, however, that a significant fraction of Hickson's compact groups (from here on HCGs) may be part of richer loose groups if not veritable clusters of galaxies (Sulentic 1987; Rood & Williams 1989). Redshift measurements and morphological studies have been performed for all of these groups (Hickson et al. 1988a, 1992; Hickson 1993) verifying their real physical nature (Hickson & Rood 1988; Hickson et al. 1988b, 1992), although discordant redshifts reduced the minimal number of member galaxies in the sample to 3. Eight groups which were found to contain less than three members at accordant redshifts[2] will be excluded from our analysis. Due to the selection criteria the great majority of the groups are nearby systems at redshifts below 0.05, although the most distant group, HCG 50, was found to be at $z = 0.139$.

HCGs have been the subject of numerous studies ranging from investigations of galaxy interactions and evolution (Barnes 1989; Rubin, Hunter, & Ford 1990; Zepf & Whitmore 1991; Zepf 1993) through studies of the group environment (Sulentic 1987; Rood & Williams 1989; Kindl 1990) and the compact group luminosity function (Mendes & Hickson 1991; Hickson et al. 1992) to observations at radio (Williams et al. 1990) and infrared (Hickson et al. 1989; Sulentic & de Mello Rabaça 1993) wavelengths. Before the *ROSAT* mission not much was known about X-ray emission from HCGs: An analysis of the *HEAO 1* A-2 data by Hickson et al. (1989) produced only an upper limit to the 2–10 keV X-ray luminosity of $1.2 \times 10^{42}\ h_{50}^{-2}$ ergs s^{-1}; at exposures of some 3000 s *Einstein* IPC observations of four HCGs lead to two detections (HCG 16 and 92) at luminosities of 0.2 and $1 \times 10^{42}\ h_{50}^{-2}$ ergs s^{-1} in the 0.5–3 keV band (Bahcall, Harris, & Rood 1984).

An extended and detailed study of HCGs in X-rays is particularly interesting since various properties of compact galaxy systems can be addressed therewith:

1. The detection of X-ray emission from a gas halo in addition to the contribution from individual galaxies gives evidence of the existence of a gravitational potential well and allows, together with measurements of gas density and temperature, the determination of the total gas mass of the group.

2. Knowledge of the mass and the optical luminosity of the group permits the computation of the mass-to-light ratio, which again allows conclusions about the distribution of dark matter.

3. Compact groups are known to often be the scene of violent galaxy interactions, and the evolution of HCGs by merging of galaxies is supposed to be fast as, for such systems, the timescale for close galaxy encounters is smaller than a

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[2] Only one group, HCG 36, turned out to be a pure chance alignment of unrelated galaxies.

Hubble time. The imprint of interaction-caused processes like star bursts or triggered nuclear activity must be clearly visible in the structure and temperature distribution of the X-ray emission.

The virial mass of groups of galaxies being small, the gas in the gravitational potential of such groups must be considerably cooler than the intracluster medium in regular clusters of galaxies. This has indeed been confirmed by the *Einstein Observatory's* detections mentioned above where the gas temperatures were found to lie below 5 keV. Even in cases where heating of the intragroup gas takes place by violent galaxy interactions the X-ray emission is thus expected to be rather soft.

Because of its energy range of 0.1–2.4 keV the combination of the *ROSAT* XRT and the Position Sensitive Proportional Counter (PSPC) constitutes an ideal instrument for the investigation of the X-ray properties of compact groups of galaxies.

Pointed PSPC observations of several HCGs have in fact already been carried out, the first results of which are described by Ponman & Bertram (1993). For the target of their observation, HCG 62, a rapidly evolving system, they find a mass-to-light ratio of 270 $h_{50}\ M_\odot/L_\odot$ (cutoff radius 20′). According to their analysis, the hot gas at a temperature of ~ 1 keV which causes the X-ray emission contributes only a few percent to the total mass of the system, the majority of which is thus dark.

In order to study the X-ray luminosity distribution of HCGs in a systematic way we searched the data taken during the *ROSAT* All-Sky Survey (RASS) for X-ray emission from HCGs.

2. THE X-RAY DATABASE

The X-ray data this analysis is based upon were obtained by the PSPC on board the *ROSAT* satellite during its 6 months All-Sky Survey in the soft X-ray energy range between 0.1 and 2.4 keV. For an overview of *ROSAT*'s mission and early results see Trümper (1991, 1992); the *ROSAT* All-Sky Survey (RASS) is described by Voges (1992). A first processing of the RASS data using a combination of complementary source detection algorithms within the framework of the Standard Analysis Software System (SASS) developed for this purpose at MPE (Voges et al. 1992) resulted in the detection of some 50,000 sources.

As the SASS was designed mainly for the detection of pointlike or at least spherically symmetric emission, we developed a complementary source detection algorithm (named VTP for Voronoi tesellation + percolation) using a Voronoi tessellation of the raw photon distribution and subsequent nonparametric percolation in order to detect "nonstandard" emission without making any assumptions about its shape. This technique has been described in detail by Ebeling & Wiedenmann (1993) and Ebeling (1993) and has proved highly successful in the detection and characterization of X-ray emission from clusters of galaxies. Since the two-dimensional tessellation of the raw photon distribution constructs individual cells around each photon, no binning of any kind needs to be introduced, and fluxes can be computed at the highest possible resolution, namely, again, for every single photon. Ignoring background-photon cells with fluxes below some lower threshold, VTP then uses a two-dimensional percolation in order to detect patterns *of arbitrary shape* formed by interconnected high-flux photons. The threshold in the cell-flux distribution that determines which photons are passed on to the percolation routine can be determined from the deviation of the measured flux distribution from that expected for purely Poissonian background. A great advantage of VTP over conventional source detection techniques is that it does not assume any kind of model for the spatial profile of potential sources, and thus is equally well suited for the detection and characterization of spherically symmetric, strongly elongated, and also completely irregular emission patterns. However, there will also be some fraction of the emission, in particular in the "wings" of extended sources, which cannot be detected directly simply because it does not contrast sufficiently with the underlying background. In order to compensate for this loss of source flux, a flux correction factor is computed based on the assumption of a Gaussian or King profile for pointlike and extended sources, respectively. Note that spherical symmetry is not implied by this procedure.

VTP was run on 3° × 3° fields centered on the optical positions of the groups; in total, 1076 X-ray sources were detected, ~ 150 of which are statistically expected to be random fluctuations in the background field. Since VTP does not fit any particular model profile to the source candidates' projected photon distribution, there is a certain risk of source blending when the density of sources in a given field is high. However, VTP flags potential blends which can thereby be selected and, after individual inspection, separated where necessary. The central regions (2° in diameter) of all HCG fields were checked for possible blends; six sources had eventually to be deblended. Due to some overlap between the fields, several sources have been detected in more than just one field; multiple detections of this kind were removed from the sample which leaves a final X-ray source list of 1022 entries.

3. HCG DETECTIONS IN THE RASS

In order to find true detections of HCGs among the VTP sources detected in the HCG fields we ran a positional cross-correlation between the X-ray sources and the optical HCG list. As, optically, HCGs have neither a typical angular size nor a characteristic physical core radius, we studied the distribution of the separation of the cross-correlation pairs not only for the immediate angular separation s but also for the same quantity when normalized to the optical group radius $\theta_G/2$ as defined by Hickson (1982).

Figure 1 shows the cumulative distribution of the angular separations of the correlation pairs after subtraction of a parabolic background of chance coincidences caused by random superpositions of Hickson groups and physically unrelated X-ray sources as fitted to the high separation end of the raw data distribution. This background contribution is shown dotted in Figure 1; the dashed line indicates the 100% completeness level, i.e., the total number of true coincidences between the two correlation samples. Note that statistically true coincidences are found out to separations of up to 30′, a value much higher than the largest apparent group radius of 8$'.2$. The high fraction (more than 50%) of HCG's with coinciding X-ray sources suggests that, despite Hickson's selection procedure, many of these compact groups are in fact not isolated systems, but must be physically related to the X-ray sources in their vicinity, i.e., probably mostly to loose groups and clusters of galaxies. Qualitatively, this is in agreement with previous studies of the HCG's neighborhood in the optical: Rood & Williams (1989) find about one-third of all HCGs to be embedded in an environment of enhanced galaxy density as compared to the field. However, Rood & Williams restrict their galaxy counts to a circle whose radius scales with the apparent group diameter (which, due to the big scatter in the groups

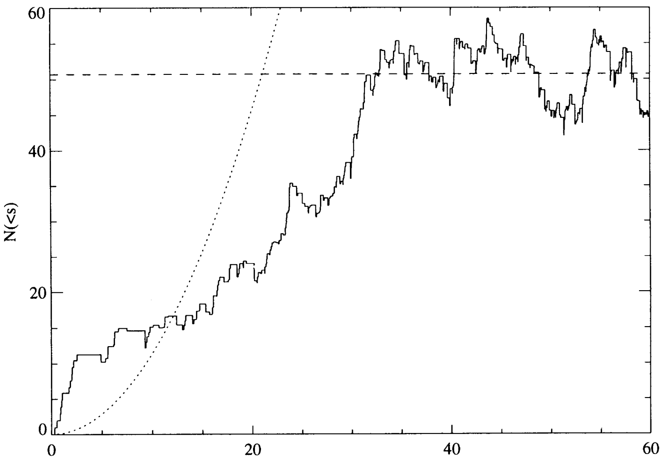

FIG. 1.—Cumulative distribution of the pair separation of the coincidences found in the positional cross-correlation of RASS sources against Hickson groups—the data have been corrected for a parabolic contribution from chance coincidences (*dotted line*). The dashed line marks the total number of statistically true coincidences.

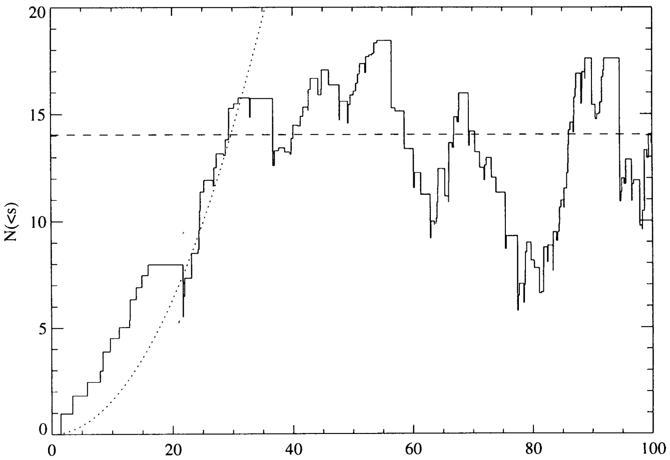

FIG. 2.—Cumulative distribution of the pair separation of the coincidences found in the positional cross-correlation of Abell and ACO clusters of galaxies against Hickson groups—the data have been corrected for a parabolic contribution from chance coincidences (*dotted line*). The dashed line marks the total number of statistically true coincidences.

physical size, is not necessarily larger for nearby systems), so that the aforementioned range of HCG-RASS separations is not fully covered by their study. Sulentic (1987) presents galaxy counts within a radial distance of 1° from the HCG centroid and finds merely 40% of all groups to be really isolated within a circle of 30′ radius. The remainder are part of larger, loose groups or reside in the outskirts of rich galaxy clusters (see below). The fact that Sulentic's figure of 40% agrees so well with ours implies that next to all of the richer galaxy groups and clusters to which these HCGs belong would have to be detected in X-rays in the RASS. Because of the low redshifts of all of these systems, this assumption is not unreasonable: at redshifts below $z = 0.05$ (which is where 85% of all HCGs are found) the RASS detection efficiency for rich Abell clusters (Abell 1958; Abell, Corwin, & Olowin 1989) amounts to more than 80% and even for poor Abell clusters the detection probability is still higher than 50% (see Ebeling et al. 1993).

The statistical study of Ebeling et al., however, was based on SASS detections in only part of the survey data since VTP was only being developed, and merged maps containing all survey photons were not yet available at the time. Preliminary VTP studies based on the photon fields around the optical positions of poor ACO supplementary clusters indicated that the detection rates at least for these nearby systems might go up by about a factor of 1.3 when VTP is used instead of SASS.

Since the present analysis employs VTP and makes full use of the merged RASS photon maps, an overall detection efficiency of 80%–90% for nearby clusters may thus be quite possible. The high fraction of HCGs apparently related to loose groups or clusters of galaxies found in our data is also consistent with that of a recent inspection of galaxy redshifts from the CfA survey in the vicinity of HCGs, according to which about half of all compact groups appear to be part of richer, bound galaxy agglomerations (M. Ramella, private communication).

Already the number of rich Abell clusters associated with HCGs (or rather vice versa) is substantial: a simple angular cross-correlation between Abell's and Hickson's catalogs yields a number of 14 HCGs that are statistically related to Abell/ACO clusters (see Fig. 2); the corresponding angular scale is again 30′. Their individual identification is nontrivial, however, as, for a complete sample, the contamination by chance coincidences (shown dotted in Fig. 2) is 50% at $s = 30'$. Five clusters are readily identified as truly coincident with their HCG counterparts on the basis of their accordant redshifts; Table 1 lists the five pairs and their respective projected separation. Along the line of sight the difference in redshift between the group and the respective cluster is of the order of several hundred km s^{-1} and thus is comparable to the velocity dispersion of the cluster galaxies. For the remaining correlation pairs with $s \leq 30'$ the respective redshifts are either discordant or unknown for the Abell clusters. In addition to those with Abell clusters, further coincidences are found between HCGs and poorer, loose clusters such as HCG 58–MKW 10 (Williams 1985).

As can be seen from Figure 1, there are, however, also cases where the X-ray emission is very well centered on the optical group position, the separation being of the order of only few arcminutes. In order to obtain a sample of truly isolated HCGs whose X-ray properties are governed by the compact group itself rather than by a surrounding or nearby loose group or cluster of galaxies, we plot the distribution of Figure 1 with the angular separations replaced by those normalized to the apparent group diameter θ_G as defined by Hickson (1982). The resultant cumulative separation distribution is shown in

TABLE 1

HCGs IDENTIFIED AS SUBSYSTEMS OF ABELL/ACO CLUSTERS OF GALAXIES

HCG	ACO Number	$z_{\rm HCG}$	$z_{\rm ACO}$	s	r (Mpc/h_{50})
5	76	0.0410	0.0416	21′.8	1.53
48	1060	0.0094	0.0114	29.3	0.58
60	1452	0.0625	0.0631	5.8	0.61
65	3559	0.0475	0.0471	1.5	0.12
94	2572	0.0417	0.0395	15.9	1.06

NOTES.—Besides the respective redshifts, the separation perpendicular to the line of sight is given on an angular (s) and metric scale (r). The latter is computed using the cluster's redshift and assuming an $\Omega = 1$, $q_0 = 0.5$ Einstein-de Sitter cosmology. Cluster redshifts are from Abell et al. 1989.

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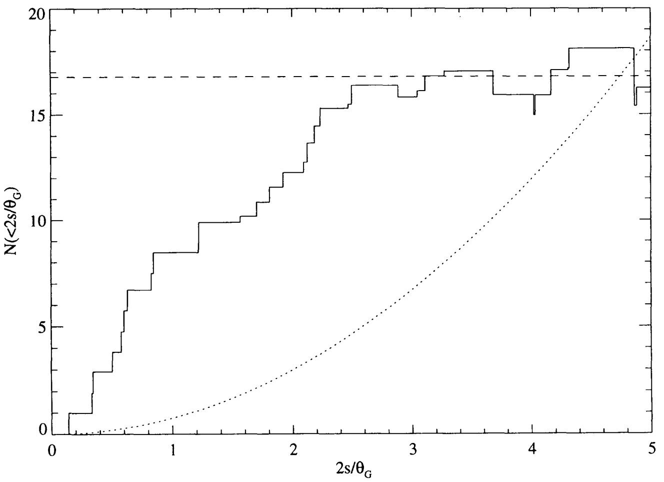

FIG. 3.—Cumulative distribution of the normalized pair separation of the coincidences found in the positional cross-correlation of RASS sources against Hickson groups—the data have been corrected for a parabolic contribution from chance coincidences (*dotted line*). The dashed line marks the total number of statistically true coincidences.

Figure 3; just as with Figure 1, the background of chance coincidences (dotted curve) has been subtracted. Accordingly, there are 16 or 17 coincidences where we can expect the X-ray emission to really originate from the HCG alone. Note, however, that for about half of the X-ray sources of such a complete sample the offsets from the optical group centroid are greater than the nominal optical group radii. Only an individual inspection of all candidates can clarify here whether this is just due to the uncertainties of the respective optical and/or X-ray positions or whether we are again dealing with X-ray emission which is affected by objects outside the actual HCGs as defined by Hickson.

Including all 21 correlation pairs with separations up to $2s/\theta_G = 2.5$ we arrive at an essentially complete sample of RASS-detected HCGs. The contamination of this sample by chance councidences amounts to 22%; i.e., statistically, 4.6 of the 21 entries are expected to be caused by random superpositions of a Hickson group and an unrelated X-ray source.

Of these 21 entries, one can be discarded immediately as a random fluctuation in the background field. In four cases (one source near HCG 22 and three around HCG 44) the X-ray sources appear pointlike and lie well outside the optical group radius so that any relation to the group galaxies can be ruled out. However, this does not mean that the respective entry represents a chance coincidence. In particular, for HCG 44 it is actually highly unlikely that none of the three surrounding sources should be related to the group. Since the emission is found to lie so far outside the optical radius defining the group, there should, however, be no relation between the group's properties and those of the neighboring X-ray sources which is why we remove these detections from our sample.

The remaining 16 correlation pairs correspond to 15 HCGs the photon distribution around all of which are shown in Figure 4. The bold dots in Figure 4 mark the photon agglomerations which VTP found to constitute significant enhancements over the overall background in the respective field. The dotted line in the field of HCG 94 indicate where VTP's percolation was forced to halt in order to keep two blended sources separated.

Three clusters of galaxies lie within the fields depicted in Figure 4 and are found to be extremely bright X-ray sources: A1060 half a degree southwest of HCG 48, A2310 west of HCG 85, and A2572 east of HCG 94. As mentioned before, about one-third of all Hickson groups are actually located within 30′ distance of an Abell or ACO galaxy cluster which is about twice as much as one would expect were the two samples uncorrelated. Whereas, however, the apparent proximity of group and cluster is merely a projection effect in the case of HCG 85, and A2572 east of HCG 94. As mentioned before, same redshift (cf. Table 1). Given the extremely strong and extended X-ray emission plus the fact that HCG 94 is one of the optically richest groups ($N_{\rm gal} = 7$) in Hickson's compilation and lies in an environment of strongly enhanced galaxy density (Sulentic 1987), it is very likely that HCG 94 constitutes in fact the core of a poor galaxy cluster. Its spatial distance to the neighboring Abell cluster is ~ 15 Mpc/h_{50} so that we may be observing the early phase of a merging process between these two clusters. A similar case is that of HCG 48: Here the masses of the two systems are very different, though. Their spatial separation is approximately 13 Mpc/h_{50} (see Table 1 for the projected separations). However, if these systems are really in the process of merging, then the quoted distances, which were inferred from the measured radial velocities, would have to be corrected for the peculiar motion caused by the mutual gravitational acceleration, and the actual separations may be somewhat larger.

The basic properties of the detected HCGs are summarized in Tables 2 and 3. $P_{\rm fluct}$ as listed in Table 3 is the probability for a source being a random fluctuation of the background in the respective field; only sources with $P_{\rm fluct} < 10^{-5}$ per background photon were included in the VTP source list used in the cross-correlation.

The spectral hardness ratios, defined as

$$HR = \frac{\text{counts } (0.52 - 2.01 \text{ keV}) - \text{counts } (0.11 - 0.41 \text{ keV})}{\text{counts } (0.52 - 2.01 \text{ keV}) + \text{counts } (0.11 - 0.41 \text{ keV})} ,$$

are corrected for the local hardness ratio of the background photons in the respective field and are also listed in Table 3. For X-ray emission caused by bremsstrahlung from a hot

TABLE 2

OPTICAL PROPERTIES OF THE HCGs DETECTED IN THE RASS

HCG	$N_{\rm gal}$	$N_{\rm Sp}$	Brightest Galaxy	θ_G	d_G[b] (kpc/h_{50})	z
4	3	1	S	3′.6	172	0.0280
10	4	3	S	10.9	302	0.0161
25	4	2	S	6.4	233	0.0212
42[c]	4	0	E	6.0	138	0.0133
48[c]	3	1	E	5.0	81	0.0094
51[c]	5	2	E	4.5	199	0.0258
58	5	3	S	8.8	313	0.0207
62[c]	4	0	E	3.7	88	0.0137
68[c]	5	1	E	9.2	128	0.0080
71	3	3	S	5.0	257	0.0301
85[c]	4	0	E	1.3	87	0.0393
91	4	3	S	5.2	212	0.0238
92[c]	4	3	S	3.2	118	0.0215
94	7	1	E	2.8	197	0.0417
97[c]	5	2	E	5.2	195	0.0218

[a] From Hickson 1982, 1993.

[b] d_G is derived from θ_G assuming an Einstein–de Sitter cosmology with $q_0 = 0.5$.

[c] Groups eventually accepted as true detections of compact groups (see text).

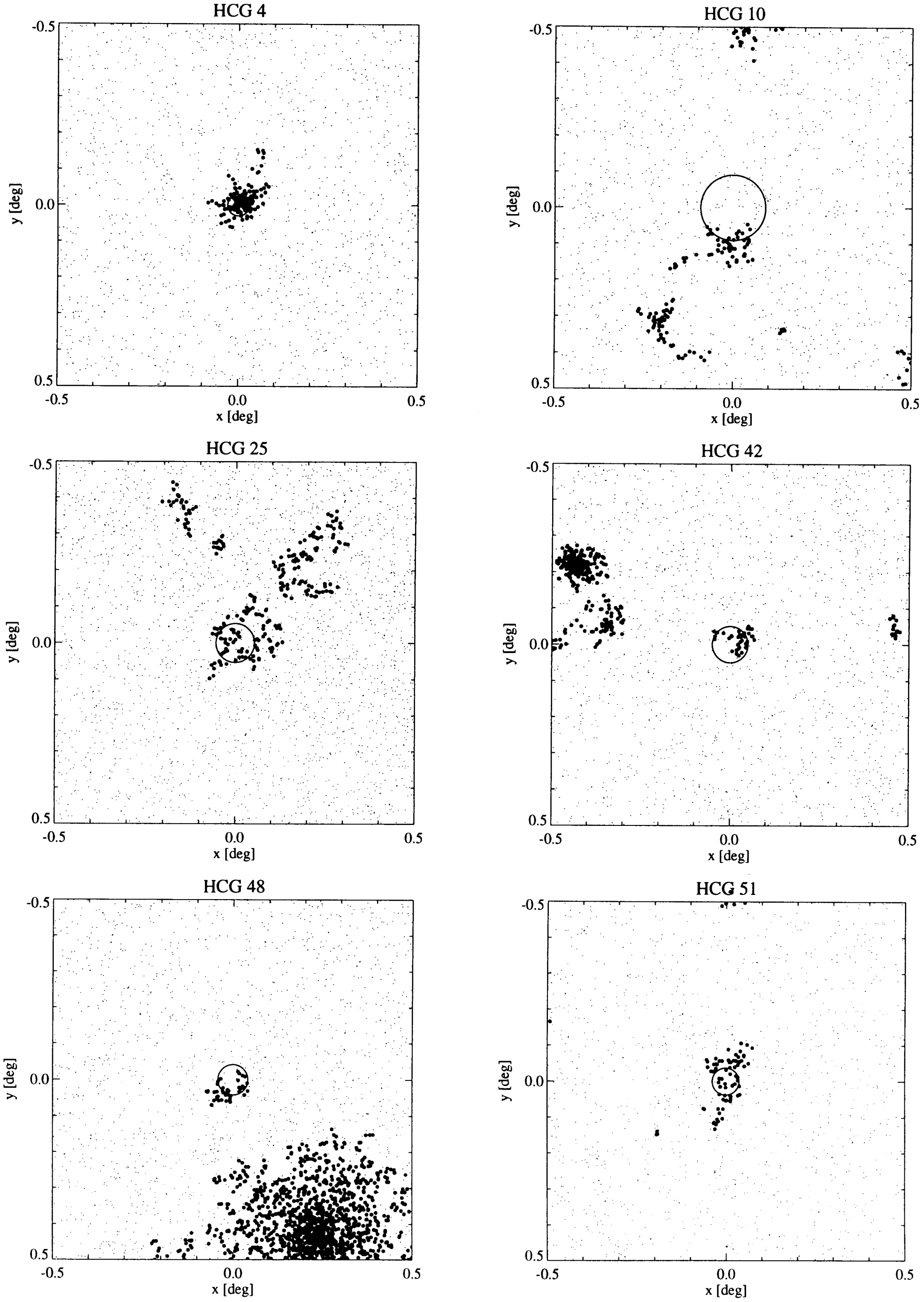

FIG. 4.—Photon distributions around the optical positions of the 17 tentative RASS detections of HCGs. The bold dots mark the photons classified as source photons by the VTP algorithm; dotted lines indicate where the percolation was forced to stop in order to keep two blended sources separated. The circles at the field centers represent the apparent optical size of the groups (Hickson (1982).

intragroup medium (IGM) this hardness ratio is expected to be notably greater than zero. The 1 σ X-ray extent of the detected groups is computed as the mean of the widths of the emission along the principal axes of inertia of the VTP source photon distribution and is supposed to serve only as a flag in order to distinguish pointlike from clearly extended emission. Extent values in excess of 115″ are indicative of sources that are truly extended at the greater than 90% confidence level. Extended and spectrally hard emission would be expected from galaxy groups containing a hot IGM. However, for the groups featuring more pointlike X-ray emission, the existence of an IGM cannot be ruled out either, given the compactness of many of the HCGs.

From their spectral properties and extent characteristics, three of our detections are thus very unlikely to be related to the respective compact group: HCG 10, 25, and 58 all feature clearly extended *soft* emission without any sign of a superposed point source whose soft X-ray emission might be responsible

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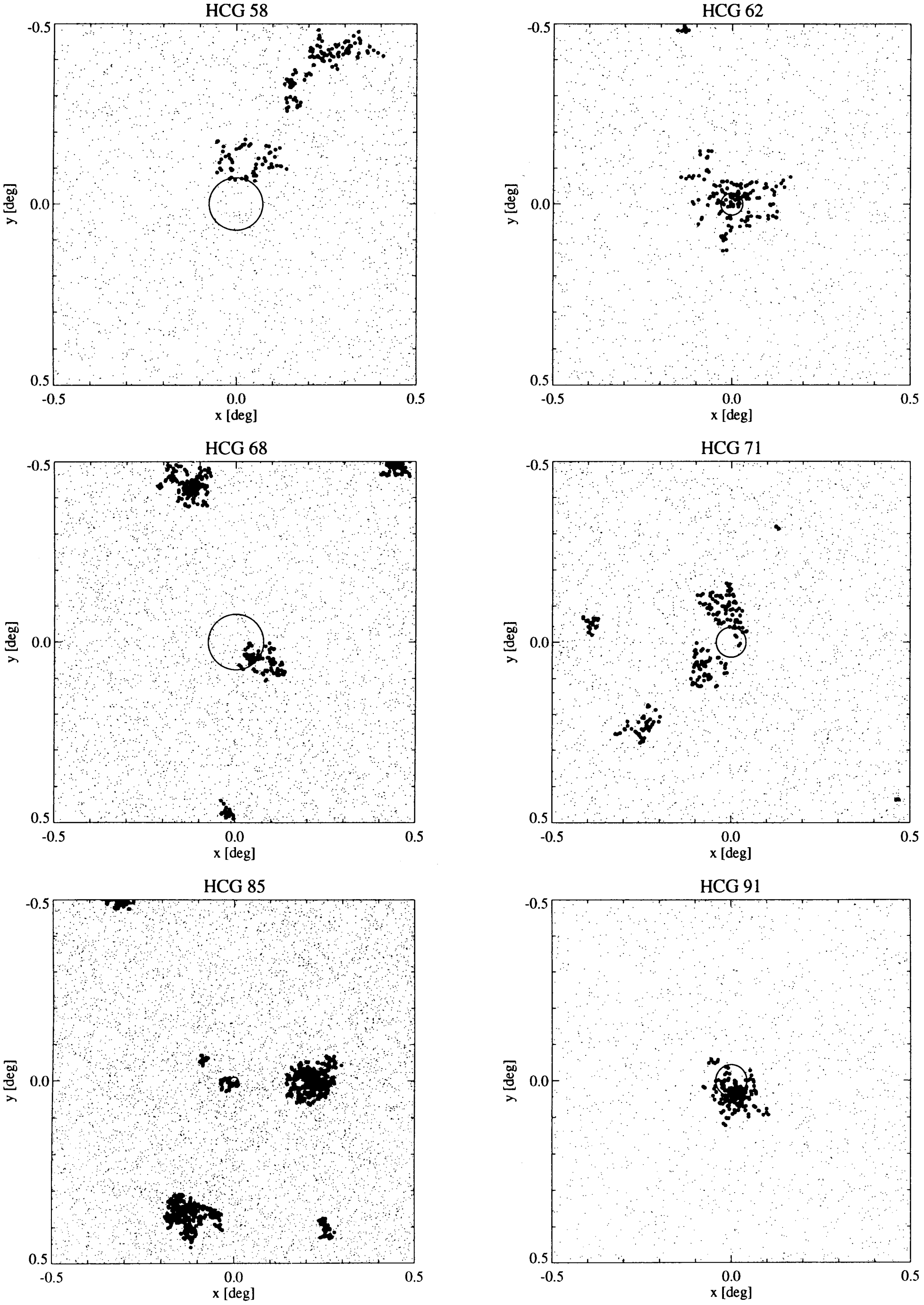

FIG. 4.—*Continued*

for the low hardness ratios. Given that in two of the three cases the X-ray sources also lie clearly outside the optical group radius, we suppose that the emission originates rather from fragments of unidentified, ancient SNR shells (B. Aschenbach, private communication). Similar patches of soft and extended radiation are seen frequently in the RASS but have so far been only rarely detected due to the bias of conventional source detection algorithms toward point sources. In addition, all of the aforementioned groups are also truly isolated according to Sulentic's galaxy counts so that the possibility can also be ruled out that the extended emission is caused by a loose group whose gravitational center does not coincide with that of its compact subgroup.

For two other groups, HCG 4 and HCG 91, the X-ray emission is also soft but much brighter, centered on the brightest galaxy of the group, and clearly pointlike. Here the emission is probably caused by an AGN in the groups' dominant galaxy which, in both cases, is a late-type spiral that is also an infrared source. In the case of HCG 91, this central spiral, NGC 7214, is a known Seyfert I galaxy (Dahari 1983; see also Winkler 1992

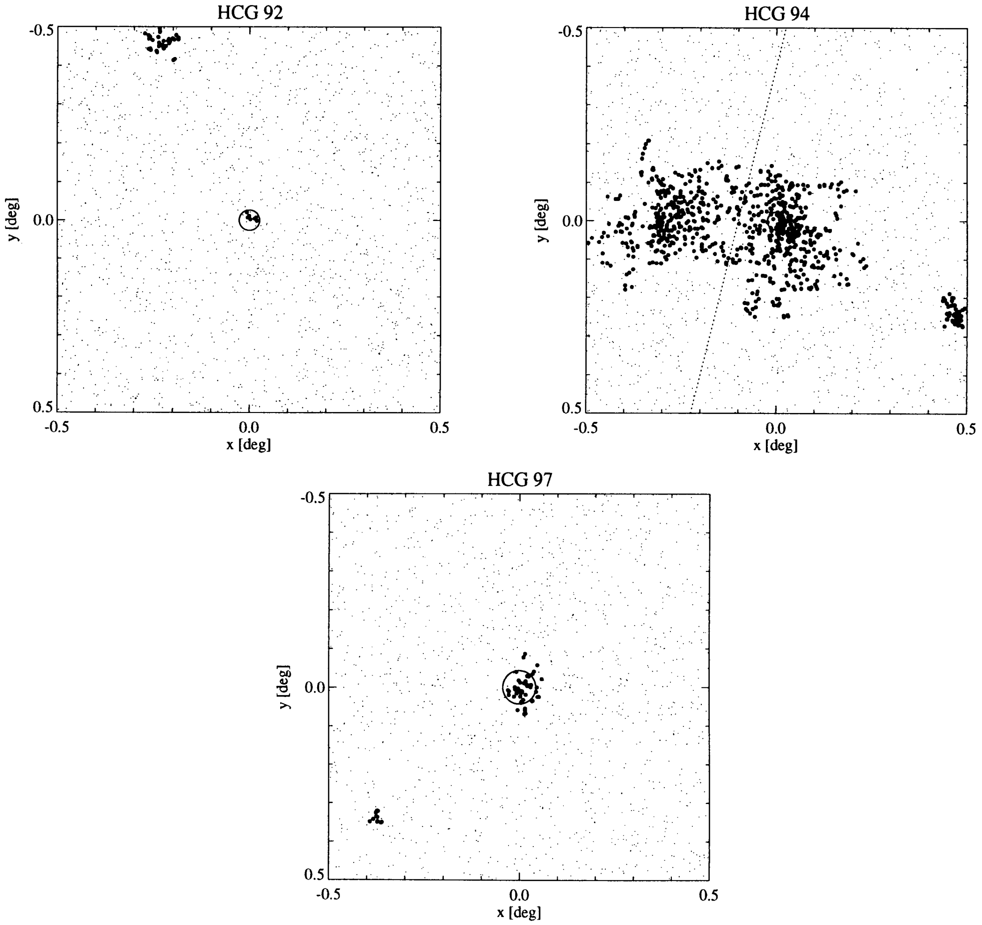

FIG. 4—*Continued*

and Winkler et al. 1992). The X-ray source is thus truly related to the group; however, since a single galaxy completely dominates the emission, we cannot expect its properties to be correlated with the optical characteristics of the group.

The case of HGC 71 is more complicated: The galaxy counts in the group's neighborhood indicate that we are in fact dealing with a much richer loose group. This assumption is supported by our detection of moderately hard and extended X-ray emission just north of the actual HCG. In the southeast of HCG 71 we detect another extended source which is clearly separated from the northern one and features a somewhat softer X-ray spectrum. Both of these sources may be associated with loose groups; the galaxies of the HCG itself, however, cannot be the origin of the emission which is why we discard this group, too, from our sample of true HCG detections. This assessment is supported by the fact that θ_G drops to $\sim$60% of the value listed in Table 2 when only galaxies with accordant redshifts are considered (Hickson's list of apparent group diameters was based on all galaxies believed to be group members in the initial selection of the sample). Thus, HCG 71 would not have entered the tentative sample of Table 3 in the first place, had modified group diameters been used; however, it is also the only group for which this is true.

With HCG 94, the X-ray source is also obviously related to the group; given the extreme brightness and extent of the emission as well as the high galaxy density in the vicinity of HCG 94 (see above), the latter can only be partially responsible for the emission, though, and the X-ray emission is thus again unlikely to be representative of the group's optical properties.

Besides the raw count rates as detected by our algorithm in the energy range from 0.11–2.35 keV, Table 3 also lists correction factors for the 10 true HCG detections which take into account the flux missed in the wings of the sources: for the obvious point sources HCG 4 and HCG 91, a Gaussian density profile is assumed for this correction; with all other sources a King model is used.

For the 11 definitely or possibly extended sources finally accepted as RASS detections of an IGM in HCGs or loose groups, fluxes and luminosities in the *ROSAT* energy band (0.1–2.4 keV) are derived from the corrected VTP count rates assuming a Raymond-Smith type thermal spectrum at $T = 1$ keV (as found by Ponman & Bertram for HCG 62 and Böhringer, Ebeling & Ramella (1994) for HCG 92 and HCG 97), a default metal abundance of 0.3, and, finally, $h_0 = q_0 = 0.5$. For the three groups which have been the targets of pointed observations, the measured metallicities of 0.15 (HCG 62) and $\sim$0.2 solar (HCG 42 and HCG 97) are used. We correct for galactic absorption using the column densities of neutral hydrogen published by Dickey & Lockman (1990).

The error in the fluxes and luminosities quoted in Table 3 depends both on the signal-to-background and on the signal-to-noise ratio (S/N) of the sources: Whereas a signal-to-noise ratio of less than 7.5 leads to a systematic underestimation of the true source flux, there is almost no systematic error in

TABLE 3

X-Ray Relevant Properties of the Tentative Detections of HCGs in the RASS

HCG	$2s/\theta_G$	n_H (10^{20} cm^{-2})	$P_{\rm fluct}$ (%)	H-R	1 σ Extent	$t_{\rm exp}$ (s)	Detected (counts s^{-1})	cr Correction Factor	F_X^{12} [a] (0.1–2.4)	L_X^{42} [b] (0.1–2.4)	L_X^{42} (bol)	cr Error (%)	Tentative ID
4	0.60	1.56	0.00	-0.22 ± 0.10	107″	340	0.363	1.04	...	...	...	6	HCG + AGN
10	1.22	4.89	0.05	-0.42 ± 0.21	155	368	0.108	...	...	...	...	26	SNR fragment
25	0.63	6.03	0.01	-0.75 ± 0.22	190	419	0.138	...	...	...	...	30	SNR fragment
42[c]	0.58	4.52	0.19	0.85 ± 0.42	89	504	0.055	1.68	1.46	1.12	1.37	30	HCG
48[c]	0.83	4.97	4.59	0.39 ± 0.25	92	368	0.075	1.70	1.94	0.74	0.90	37	HCG
51[c]	0.14	1.35	0.14	0.17 ± 0.19	163	290	0.164	1.54	2.83	8.20	9.85	26	HCG
58	1.70	3.31	0.34	0.01 ± 0.21	157	436	≥ 0.082	...	...	...	...	39	SNR fragment
62[c]	0.50	2.93	0.00	0.66 ± 0.15	200	274	0.378	1.57	8.53	6.93	8.56	12	HCG
68[c]	1.22	0.97	0.01	0.36 ± 0.19	104	674	0.076	1.66	1.33	0.37	0.45	25	HCG
71	2.47	1.45	3.52	-0.23 ± 0.22	98	517	0.072	1.63	1.33	5.27	6.34	34	Loose group
	2.23	1.45	0.10	0.13 ± 0.19	121	517	0.101	1.64	1.88	7.44	8.95	28	Loose group
85[c]	1.56	6.76	11.81	0.35 ± 0.29	46	2366	≥ 0.009	2.05	≥ 0.31	≥ 1.93	≥ 2.30	47	HCG
91	0.85	1.62	0.00	-0.32 ± 0.08	97	249	0.810	1.03	...	...	...	3	HCG + AGN
92[c]	0.34	7.73	9.66	1.24 ± 0.67	26	558	≥ 0.012	2.26	≥ 0.46	≥ 0.93	≥ 1.12	55	HCG
94	1.81	4.55	0.00	0.72 ± 0.09	265	466	0.609	1.41	12.89	98.40	119.18	5	Poor cluster
97[c]	0.33	3.62	0.00	1.07 ± 0.29	93	364	0.094	1.70	2.38	4.92	6.02	25	HCG

[a] F_X^{12} is the X-ray flux in units of 10^{-12} ergs s^{-1} cm^{-2}.

[b] L_X^{42} is the X-ray luminosity in units of 10^{42} h_{50}^{-2} ergs s^{-1}.

[c] Groups eventually accepted as true detections of compact groups (see text for details).

VTP's flux determination for higher S/N values (apart from the mentioned correction for the wings of the emission profile). Count rates, fluxes, and luminosities of detections featuring S/N values below this threshold should thus rather be taken as lower limits. The statistical errors quoted in Table 3 are typically of the order of 20%–30% and have been computed using flux calibrations for simulated sources (see Ebeling 1993).

HCG 16 from which X-ray emission has been detected by *Einstein* in a 3200 s exposure (Bahcall et al. 1984) was not detected by VTP in the RASS at an exposure of 394 s. This is not surprising, though, as its X-ray flux (as determined from the *Einstein* observation) is lower than that of the X-ray faintest group detected by us, HCG 85. As far as HCG 92 (Stephan's Quintet) is concerned, the X-ray source detected by VTP right on the optical position consists of no more than eight photons. Just as with HCG 85, we thus expect the *ROSAT* luminosity of HCG 92 of $0.9 \pm 0.5 \times 10^{42}\ h_{50}^{-2}$ ergs s^{-1} to be probably underestimated—within the errors our result is, however, still consistent with that of the *Einstein Observatory* of $1 \pm 0.3 \times 10^{42}\ h_{50}^{-2}$ ergs s^{-1}.

4. CORRELATION OF OPTICAL AND X-RAY PROPERTIES

The sample of compact groups whose X-ray properties suggest the presence of a gaseous, hot IGM thus comprises HCG 42, 48, 51, 62, 68, 85, 92, and 97—entries corresponding to these groups are highlighted in Table 2 and 3. Although the RASS exposure varies considerably between the 92 HCG fields, there is, except for the very deep field around HCG 85, no bias toward an increased detection rate in high-exposure fields (cf. Fig. 5).

An overview of the correlations between the groups' (bolometric) X-ray luminosity and various optical group parameters is given in Figure 6. Except for the group diameter (from Hickson 1982) all of the latter were taken from Hickson (1993). Due to the small size of our sample, the statistics of these correlations are always rather poor; however, they do indicate certain trends which shall be discussed in the following.

We find the X-ray luminosity to be only weakly (if at all) correlated with the number of galaxies in the group. This is not surprising, though, since, due to the short crossing times and the relatively small velocity dispersions, the timescale for galaxy mergers in compact groups is much shorter than a Hubble time (e.g., Hickson et al. 1977; Zepf & Whitmore 1991). The number of galaxies is thus in general not a conserved quantity, and an increase of the X-ray luminosity with the groups' optical richness would be expected only if the main contribution to the X-ray emission was from the galaxies rather than from a diffuse IGM. In the pointed observations of HCG 62, 42, and 97, however, the extended emission from the IGM is found to dominate the overall emission, so that any positive correlation between the RASS X-ray luminosity and optical richness would not be supported by, if not even in conflict with, deeper X-ray observations. As a matter of fact, an anticorrelation between X-ray luminosity (as a measure of the total gravitational mass and the depth of the potential well) and the number of galaxies (as a potential crude indicator of the groups' age) would be easier to understand.

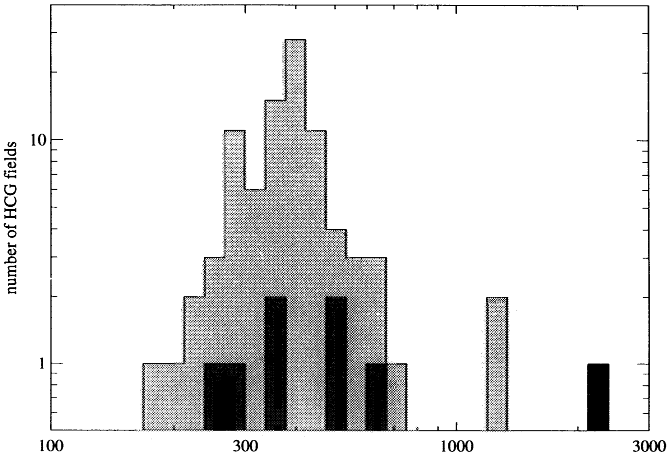

FIG. 5.—Distribution of average RASS exposure time in our 3° × 3° fields around HCGs. Overall distribution (*light shading*) and fields with VTP detections of HCGs (*dark shading*).

We also looked at the correlation of the groups' bolometric X-ray luminosity with their metric optical diameter and the galaxies' radial velocity dispersion σ_r, respectively. (Note that, for our eight HG detections, the metric optical diameters taken from Hickson [1982] remain unchanged as galaxies at discordant redshifts are eliminated.) A weak trend is found according to which L_X would rise with both the metric group size and σ_r. A tighter correlation of this kind would be expected were the groups virialized systems, since both of these quantities are crude indicators of the dimensions of the gravitational potential well and thus the total mass of the groups.

The groups' X-ray brightness is found to be closely related to the morphology of their member galaxies: although in more than 50% of all 92 HCGs at least half of the galaxies are spirals, all our X-ray detected compact groups except Stephan's Quintet (HCG 92) feature a low spiral fraction of $f_{sp} < 0.5$ (see Fig. 6). This discrepancy is significant at the more than 98% level. We also find the (in B) brightest galaxy to be always an elliptical or an S0 galaxy (again except for HCG 92), despite the fact that the fraction of HCGs dominated by an elliptical or an S0 is only 45% for the whole of Hickson's sample (Mendes de Olveira 1992). The probability of this difference being just a statistical fluke is 6%. If we take these morphological characteristics to be a fundamental property of X-ray bright compact groups of galaxies, then it is interesting to note that our selection of "true" detections from the tentative list presented in Tables 2 and 3, which was based on the X-ray properties (hardness ratio and extent) of the detections alone, would have led to almost the same sample of RASS-detected HCGs had we relied on the groups' optical properties (i.e., spiral fraction and morphological type of the dominant galaxy). The redshift distribution of the HCGs with $f_{sp} < 0.5$ which, in addition, have an elliptical or S0 as the brightest group member (BGM) is shown in Figure 7. Note that, within $z = 0.03$, the fraction of detected groups is more than 40%, whereas it is less than 15% for the whole HCG sample. Above that redshift the typical RASS exposure time of some 400 s proves insufficient to permit detection of the X-ray emission from the diffuse IGM if it is fainter than $\sim 4 \times 10^{42}\ h_{50}^{-2}$ ergs s^{-1}; HCG 85 at $z = 0.0393$ owes its detection to its high ecliptic latitude resulting in an exposure time of more than 2000 s.

A possible explanation for this may be that the groups dominated by ellipticals are the more evolved ones with the deepest potential wells, the dominant galaxies being the result of merging processes, as is suggested by the *n*-body simulations of Barnes (1989).

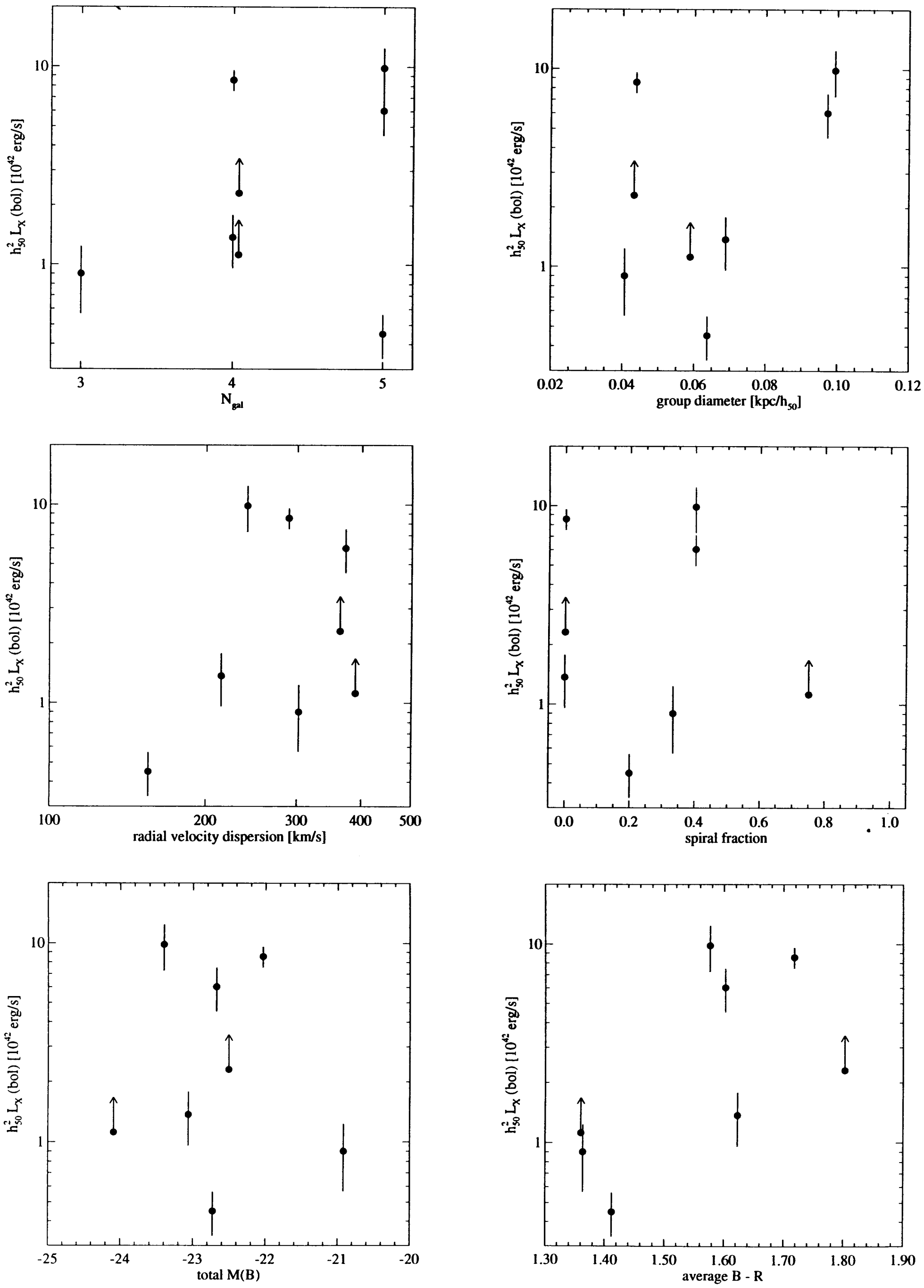

FIG. 6.—Correlation of the bolometric X-ray luminosity with the groups' optical properties. Left to right and top to bottom: optical richness (number of galaxies), optical diameter, radial velocity dispersion of the groups' galaxies, spiral fraction, total absolute blue magnitude, and average $B-R$ color index.

Whereas the groups' optical brightness as given by the integral blue magnitude is not correlated with their X-ray luminosity, there is some indication of a rise of L_X with the average color index $B-R$ of the group galaxies (see, again, Fig. 6). Such a trend would be particularly interesting in connection with theoretical models of the evolution of compact groups since it implies again that the most X-ray luminous and thus probably most massive systems are also the most evolved ones. If this correlation was robust, it would allow additional constraints to be put on the rate and duration of mergers in compact groups, for these are expected to result in a growing fraction of conspicuously blue ellipticals due to the increased star formation rate triggered by the merging event (Zepf &Whitmore 1991).

5. IMPLICATIONS FOR THE X-RAY LUMINOSITY FUNCTION OF GROUPS AND CLUSTERS OF GALAXIES

The log N–log S diagram of our sample is shown in Figure 8. We note that the high-flux end of the distribution is compatible with a power law of slope -0.95; the distribution is thus some-

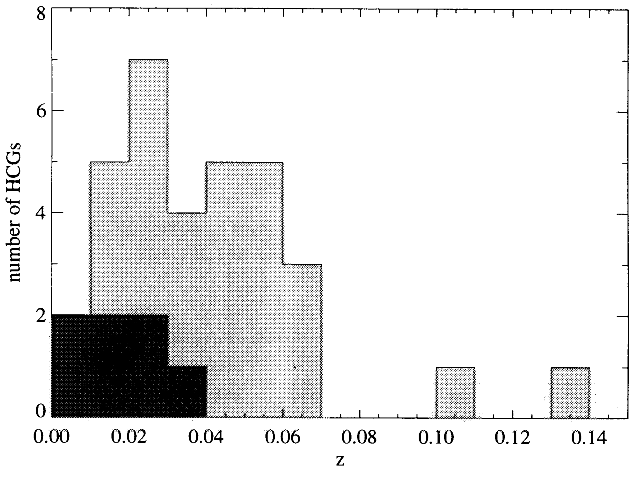

FIG. 7.—Redshift distribution of the HCGs with low spiral fractions ($f_{sp} < 0.5$) and brightest group members (BGMs) which are of type E or S0. The overall distribution is shown in light shading, the dark shading represents the 7 HCGs of that type in the RASS.

what shallower than that of an all-sky sample of Abell and ACO clusters of galaxies for which a slope of -1.2 has been found in the RASS (Ebeling 1993). Although, for the HCG sample, the statistics are clearly too poor for a more detailed discussion of the log N–log S distribution and, in particular, for a thorough derivation of the flux limit, this kind of representation still allows an approximate value to be determined which we take to be $\sim 1 \times 10^{-12}$ ergs cm^{-2} s^{-1}.

The six detections of HCGs in the RASS above this estimated flux limit enable us to assess the contribution of compact groups to the X-ray luminosity function (XLF) of galactic systems.

Observationally, the latter is essentially unknown at luminosities of some 10^{42} h_{50}^{-2} ergs s^{-1}, although a smooth transition to the regime of clusters of galaxies at luminosities above a few 10^{43} h_{50}^{-2} ergs s^{-1} would obviously be expected. A crude approximation of a universal XLF for the whole range of galactic systems from poor groups to rich clusters of galaxies can be obtained by simply extrapolating the observed XLF of clusters toward lower luminosities. Doing so, Henry et al. (1994) find a value for the XLF of (not necessarily compact) groups of galaxies detected in the RASS in the area around the north ecliptic pole that is consistent with an extrapolation of the power-law representation of the XLF determined by Henry et al. (1992) for a sample of clusters of galaxies from the *Einstein Observatory*'s Medium Sensitivity Survey (EMSS).

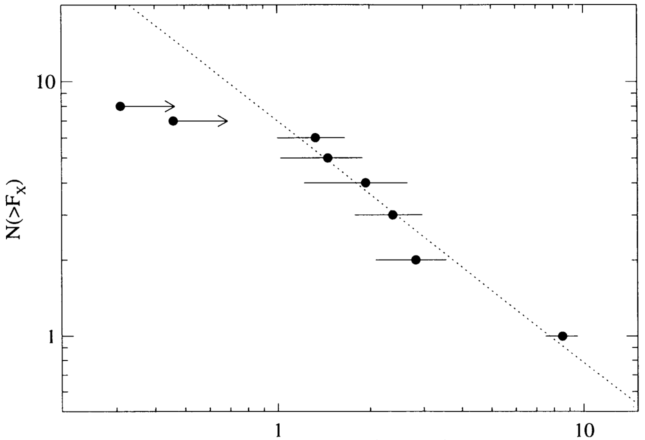

FIG. 8.—The log N–log S distribution for our sample. The slope of the power law (*dotted line*) is -0.95.

Figure 9 shows the same EMSS XLF of clusters of galaxies (however, converted to the *ROSAT* energy range from 0.1 to 2.4 keV) together with the single value of the XLF of compact groups obtained from our sample of HCG detections. Accordingly, the contribution from compact groups to the overall XLF amounts to less than $\sim 10\%$ if the extrapolation of the EMSS power law is a valid description of the XLF of galactic systems in general. In consequence, the majority of the systems at X-ray luminosities around 10^{42} h_{50}^{-2} ergs s^{-1} have to be loose groups and poor clusters of galaxies.

The error bar of our single value of the XLF of compact groups shown in Figure 9 is based on the Poissonian error only and does not take into account possible systematic errors. The largest error is certainly introduced by the uncertainty of the solid angle actually covered by Hickson's survey. Although Hickson did not explicitly exclude regions of increased obscuration, such as the galactic plane, it is still likely that the effective sky area on which his catalog is based is considerably smaller than the more than 9 sr of the POSS as a whole which is the value used in our derivation of the HCGs' XLF. Our value should thus be rather taken as a lower limit to the true value of the XLF of compact groups of galaxies in the given luminosity range.

6. SUMMARY

We detected X-ray emission from 11 of Hickson's 92 compact groups of galaxies in the *ROSAT* All-Sky Survey using a new source detection and flux determination algorithm especially developed for the search for faint, extended structures in a two-dimensional photon distribution.

For two of our detections, HCG 4 and HCG 91, the X-ray emission is most likely not due to the presence of a hot IGM, as the source appears exactly pointlike in the RASS. In the case

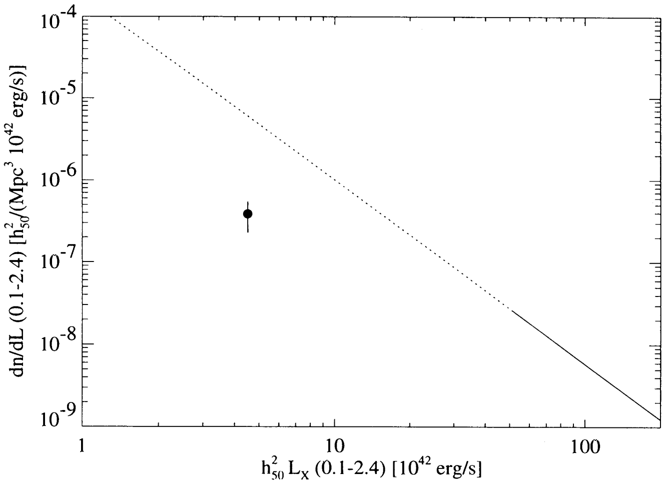

FIG. 9.—The X-ray luminosity function for our sample of HCG detections in the RASS (6 groups in one luminosity bin) and the power-law representation of the XLF for the EMSS sample of clusters of galaxies, both in the *ROSAT* energy band from 0.1 to 2.4 keV. The EMSS power law is shown dotted where it is extrapolated beyond the luminosity range actually covered by the EMSS cluster sample.

of HCG 94 the X-ray emission is far too strong to be attributed to the group alone. Both the X-ray and the optical properties of this object suggest that we are in fact dealing with a poor cluster of galaxies of which HCG 94 is merely the compact core.

The X-ray luminosities of the remaining eight groups, whose X-ray characteristics point to the presence of a hot IGM, range from 0.4 to 8.2×10^{42} h_{50}^{-2} ergs s^{-1} in the *ROSAT* energy band from 0.1–2.4 keV. HCG 62, which has been studied in detail by Ponman & Bertram (1993), is found to be the second most luminous of these.

Deeper pointed observations of most of these eight HCGs detected in the RASS that have either been performed recently or are currently under way will eventually allow a decision about the suggested IGM origin of the X-ray emission to be made. They will also enable us to investigate whether Ponman & Bertram's conclusions in particular about the distribution of dark matter in HCG 62 hold for compact groups in general.

From the RASS data, we find the HCGs' X-ray luminosity to be essentially uncorrelated with the groups' optical richness as given by the number of member galaxies. There is also no correlation between the X-ray luminosity and the total blue magnitude of the group galaxies. However, we find a trend for the HCGs' X-ray luminosity to increase with the velocity dispersion of the groups' galaxies similar to the L_X–σ_r relation for clusters of galaxies.

However, the most striking result of our comparison of X-ray and optical properties of the eight detected HCGs is that, except for Stephan's Quintet, all of our groups feature a low spiral fraction and are dominated by an elliptical or S0 galaxy. For this subclass of HCGs the detection rate in the RASS amounts to more than 40% within $z = 0.03$. We thus suspect that the groups dominated by ellipticals are the more evolved ones with the deepest potential wells, the dominant galaxies being the result of merging processes. This hypothesis is supported by the fact that the groups, whose galaxies are, on average, the reddest and thus the most evolved ones, tend to be also the most luminous ones in X-rays.

Looking at the X-ray luminosity function of HCGs, we find it to be lower by about a factor of 10 than the extrapolation of the power-law representation of the XLF of clusters of galaxies from the *Einstein* Medium Sensitivity Survey. If the EMSS power law is really a valid description of the XLF of galactic systems in general (as has been suggested by Henry and coworkers), then the majority of the systems in the luminosity range covered by our sample have to be loose groups or poor clusters.

All of the mentioned results are somewhat speculative in as much as the number of RASS detections of HCGs is small and the photon statistics of many of them are rather poor. However, deeper X-ray observations of compact groups of galaxies will allow our conclusions to be put to the test in the near future.

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