X-ray properties of compact galaxy groups

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Abstract. We report the results of the first near-complete survey of the X-ray properties of a well defined sample of galaxy groups: the collection of compact galaxy groups selected from the Palomar Sky Survey by Hickson (1982). Diffuse X-ray emission is detected from 22 groups and we infer that hot intragroup gas is present in at least 75% of these systems. Earlier reports that only spiral-poor systems exhibit diffuse X-ray emission are found to be incorrect. Strong correlations are found between the X-ray luminosity and both the gas temperature and the velocity dispersion of the group galaxies. These properties provide strong evidence that most of these groups are genuinely compact configurations, rather than line-of-sight superpositions. Comparison with the X-ray properties of galaxy clusters indicate a significant steepening of the $L : T$ relation below $T \sim 1$ keV, which may result from the action of galaxy winds.

1. Introduction

Approximately half of all galaxies are found within groups which are probably bound (Tully 1987). Whilst groups are very numerous, they are hard to identify with confidence, even in redshift catalogues, due to the problems of contamination and small number statistics in such poor systems.

Compact galaxy groups stand out from the field, since their galaxies are separated on the sky by only a few galactic radii. The most widely studied collection of compact groups are the Hickson compact groups (HCGs) compiled by Hickson (1982) by applying a set of well defined criteria for population, surface density and isolation to the Palomar Sky Survey (E band) plate collection. Numerical simulations indicate that such compact groups of galaxies should be destroyed by merging on timescale ~1 Gyr, and it has therefore been argued (see Mamon 1995 for a review) that, despite the observed peculiarities of HCG galaxies, the apparently high density of these systems is largely a projection effect.

Early observations of galaxy groups with *ROSAT* (Mulchaey *et al.* 1993, Ponman & Bertram 1993, Ebeling *et al.* 1994) showed that at least some groups contain a hot intragroup medium, similar to (but cooler than) that of galaxy clusters. We have therefore carried out a systematic survey of the X-ray properties of Hickson groups with the PSPC in order to establish whether the presence of hot intragroup gas is a common feature (indicating the presence of real potential wells), and to investigate the relationship of their X-ray properties to those of galaxy clusters. Throughout this work we assume $H_0 = 50\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$.

2. The PSPC survey of Hickson groups

The original catalogue of 100 Hickson groups (Hickson 1982) was reduced by Hickson *et al.* (1992) to 92 systems, by discarding those found to contain fewer than three galaxies with accordant redshifts. All of these systems were observed by the PSPC during the *ROSAT* All Sky Survey (RASS), but we have supplemented these observations with a total of 32 pointed observations, which have exposures typically an order of magnitude larger, and permit a much more sensitive analysis.

We have excluded seven groups from our analysis: HCG60, HCG65 and HCG94 appear to correspond to the cores of galaxy clusters, HCG4 and HCG91 are completely dominated in the PSPC by strong X-ray flux from active galaxies within the group, and HCG25 and HCG54 appear to be contaminated by nearby point sources or background features in the RASS data. Our sample therefore consists of 85 of the 92 accordant Hickson groups.

Details of our data reduction techniques are presented elsewhere (Ponman *et al.* 1996), but essentially we have searched for diffuse X-ray emission within a radius of 200 kpc of each group (except in the case of the case of the most X-ray luminous groups, HCG51, HCG62 and HCG97, where we extend the analysis to larger radii to catch all the flux). For groups which are well resolved, we exclude flux associated with individual galaxies, except in the case of dominant central ellipticals, where the emission should really be identified with the central cusp in the group potential, in the same way as for galaxy clusters. In the case of most of the detected systems which are not well resolved, the X-ray luminosity is well above that expected from the galaxies, so our results should not be significantly contaminated by galactic emission.

For groups detected above a 3 sigma threshold in pointed observations, we extracted a spectrum for the diffuse X-ray emission, and fitted it with a Raymond & Smith model (with an absorbing column frozen at the value derived from radio surveys of galactic HI (Stark *et al.* 1992)). The metallicity was generally left as a free parameter in these fits, but was often poorly constrained. In some cases it was necessary to fix its value (0.3 solar was adopted) in order to get a stable fit.

The fitted spectral model has been used in each case, to derive a bolometric X-ray luminosity for detected sources. In the case of undetected sources, and of sources detected in the RASS data, we have used a standard spectral model with temperature $T = 1\,\mathrm{keV}$, metallicity $Z = 0.3$ solar, and the appropriate galactic absorption column, to convert the flux limits to bolometric luminosities.

3. Results and comparison with clusters

The diffuse luminosity of our 22 detected systems, and 3σ upper limits for the remainder of our sample, are plotted against their redshifts in Fig.1. Note that the most luminous group, HCG62, would have been detected at any redshift out to $z \sim 0.1$.

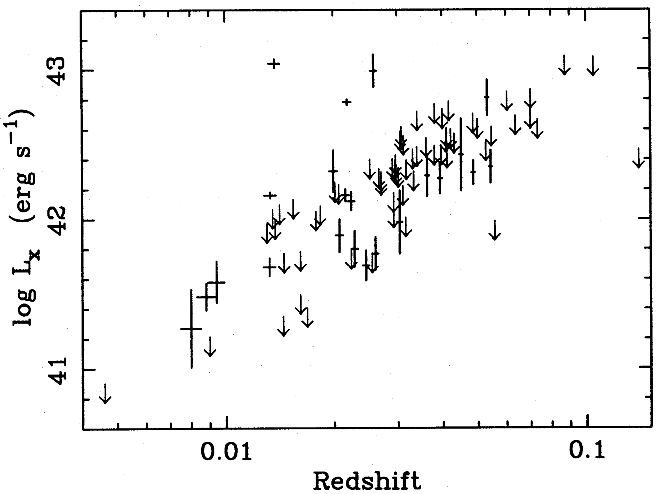

Fig. 1. Bolometric X-ray luminosities and 3 sigma upper limits plotted against redshift for the 85 groups in the survey.

The morphology of the X-ray emission varies greatly, as can be seen by comparing Figs.2 and 3. HCG97 is a highly luminous system in which the X-ray morphology is fairly regular and centred on a dominant elliptical galaxy. In contrast, HCG16 consists of four spiral galaxies, each of which is an X-ray source, but there exists additional diffuse emission with an irregular morphology extending 200 kpc from the centre of the system. This emission is too bright and extended to be identified with winds from the galaxies.

An important difference between our results and those of two smaller surveys, each involving 12 HCGs, compiled by Pildis *et al.* (1995) and Saracco & Ciliegi (1995), is

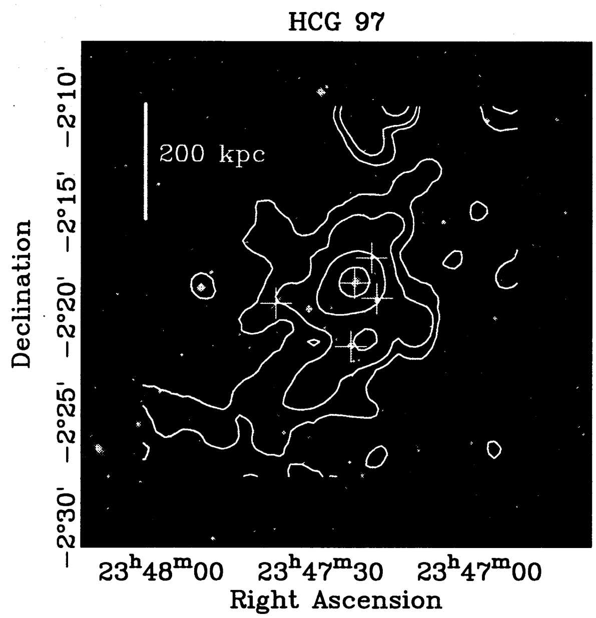

Fig. 2. Contours of X-ray surface brightness overlaid on an optical image for HCG97. The group galaxies are marked with crosses.

that we detect diffuse X-ray emission from a number of *spiral rich* systems, such as HCG16. However, as is shown in Fig.4, there is clearly some relationship between the X-ray properties and galaxy morphology in HCGs. The brightest four detected systems in our survey are all dominated by early-type galaxies. Taking into account upper limits, we find that the luminosity distributions of groups with early and late type brightest galaxies differ at over 95% confidence. In contrast, L_X appears to uncorrelated with either the number of galaxies in a group, or with its total optical luminosity.

A strong correlation (P <0.1%, if the upper limits are included in the analysis) is found between luminosity and velocity dispersion in our sample. A 2D regression on $\log L_X$ and $\log\sigma$, using the errors in both, gives

$$\log L_X = (30.0 \pm 5.1) + (4.9 \pm 2.1)\log\sigma,$$

using all 22 detected HCGs. This relationship is compared in Fig.5 with the corresponding trend in galaxy clusters. Within the errors, the HCGs fall on the extension of the cluster relationship.

The $L_X : T$ relation for the subsample of 16 HCGs with good spectral data is shown in Fig.6. The two variables are significantly correlated (P=1%), and a 2D regression gives:

$$\log L_X = (43.17 \pm 0.26) + (8.2 \pm 2.7)\log T.$$

This relationship is very steep compared with the trend in clusters ($L_X \propto T^{2.83}$). There appears to be a break in the $L_X : T$ relation at $T \sim 1\,\mathrm{keV}$. This very steep $L_X : T$ relation may account for the fact that the group emission

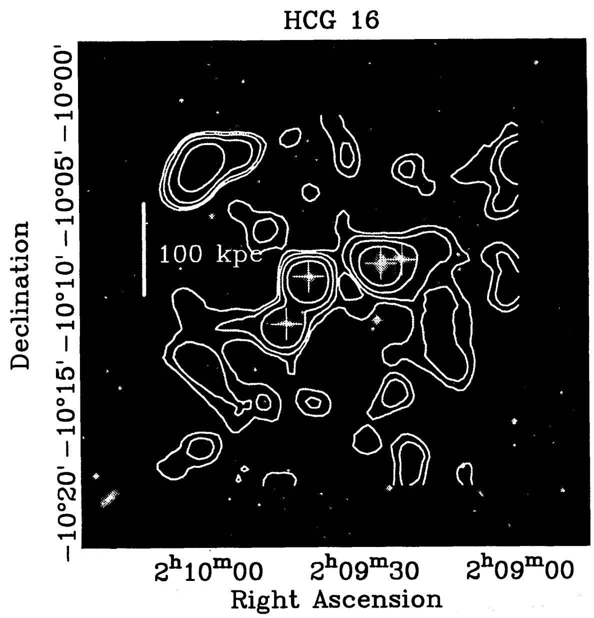

Fig. 3. Contours of X-ray surface brightness overlaid on an optical image for HCG16. The group galaxies are marked with crosses.

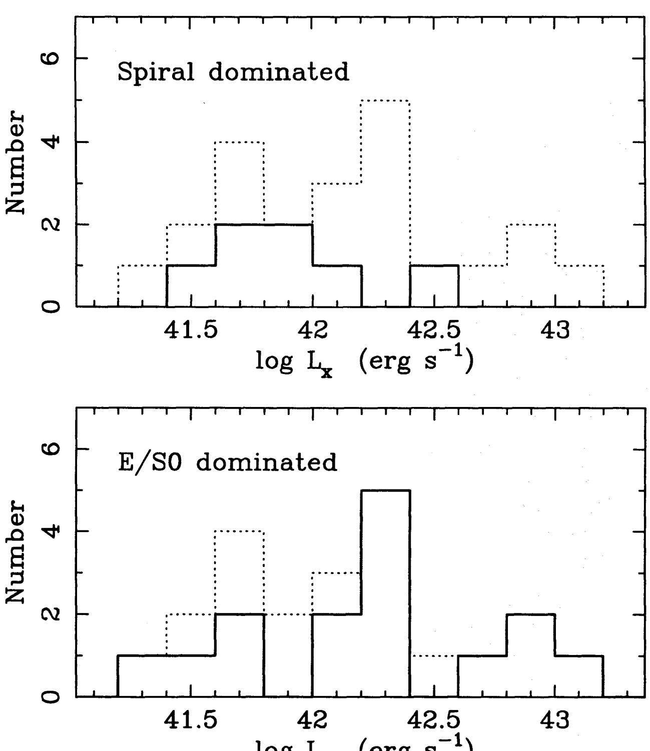

Fig. 4. The L_X distribution for HCGs with (a) spiral, and (b) elliptical or S0 brightest galaxies. The distribution for the full sample is shown dotted.

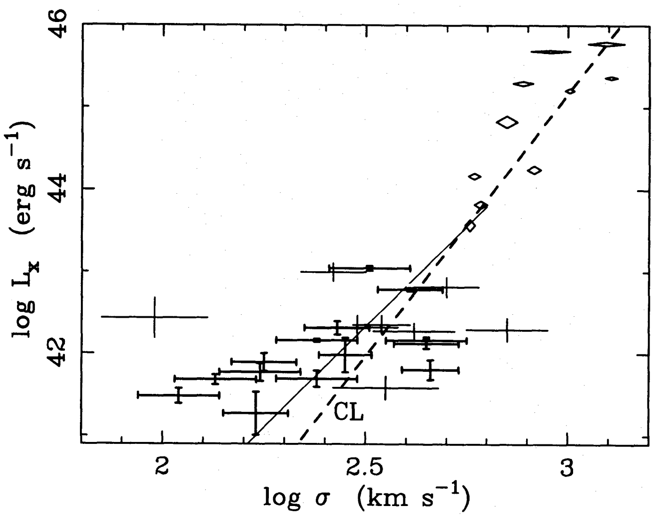

Fig. 5. The L_X : σ relation for HCGs (crosses) is compared with that for a sample of galaxy clusters (diamonds). The solid line is the 2D regression line through the group points, whilst the dashed line is the trend derived for a large sample of clusters by White (1996).

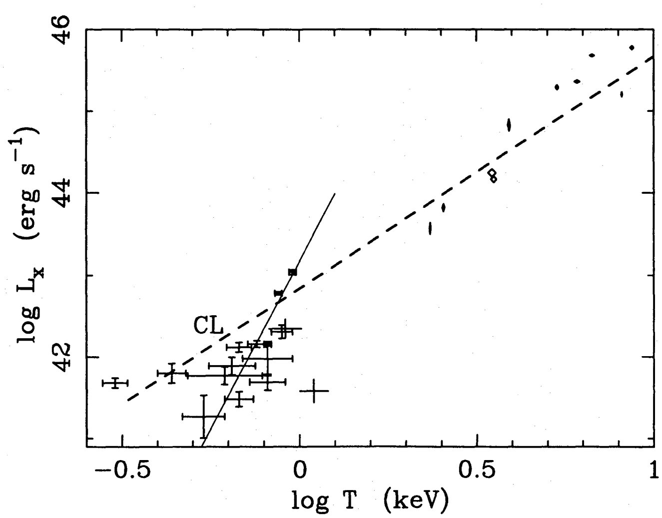

Fig. 6. The L_X : T relation for HCGs (crosses) is compared with that for a sample of galaxy clusters (diamonds). The solid line is the 2D regression line through the group points, whilst the dashed line is the trend derived for a large sample of clusters by White (1996).

exhibits a narrow range in T (0.5-1.0 keV in the main) considering that it spans over two orders of magnitude in L_X.

There is some indication ($P = 10\%$) of a correlation between σ and T in the HCG spectral sample (Fig.7), and the comparison with clusters makes the trend clear. The $\sigma : T$ relation for clusters is consistent with a value for β, the ratio of specific energy in galaxies to that in the gas, of unity. However, it is clear that most groups have $\beta < 1$, i.e. they fall to the high T/low σ side of the $\beta = 1$ line. The median value of β for our HCG sample is 0.47

– the specific energy in the gas is higher than that in the galaxies.

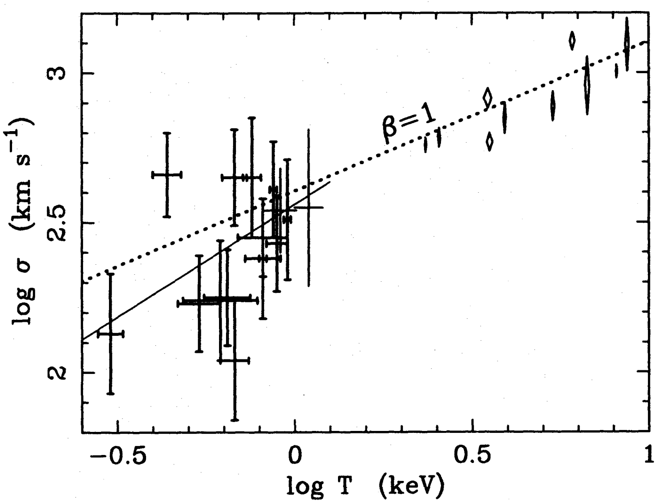

Fig. 7. The $\sigma : T$ relation for HCGs (crosses) is compared with that for a sample of galaxy clusters (diamonds). The solid line is the 2D regression line through the group points. Most HCGs clearly fall below the $\beta = 1$ line (dotted).

Since we have a near-complete survey of the HCGs, and we know the theoretical sensitivity of each of our pointings, we can estimate the fraction of groups in each luminosity bin which show detectable diffuse emission as

$$f(L_i) = N(L_i)/N_{lim}(\leq L_i),$$

where $N(L_i)$ is the number of detected systems in the ith luminosity bin, and $N_{lim}(\leq L_i)$ is the number of groups in the sample with 3σ detection limits $\leq L_i$. In Fig.8, we show the resulting frequency distribution for all clusters in our sample with $z < 0.04$ (we omit higher redshift groups since there may be biases in the optical selection of these groups). Adding the frequencies plotted, we conclude that approximately 75% of HCGs have diffuse X-ray emission with $L_X > 10^{41.1}\,\mathrm{erg\,s^{-1}}$, and ~20% have $L_X > 10^{42}\,\mathrm{erg\,s^{-1}}$.

4. Conclusions

Our main conclusion is that a large fraction (~ 75%) of HCGs show diffuse X-ray emission from hot gas, which is a strong indication of the existence of a genuine potential well. This, together with the existence of correlations between the X-ray properties and galaxy morphology and velocity dispersion, strongly suggests that most of these groups are real. Line of sight projections within filaments (Hernquist *et al.* 1995) seem to be ruled out, though chance projections within looser groups (Mamon 1986) are more difficult to exclude. The essential requirement is that there should be a real potential well. Note

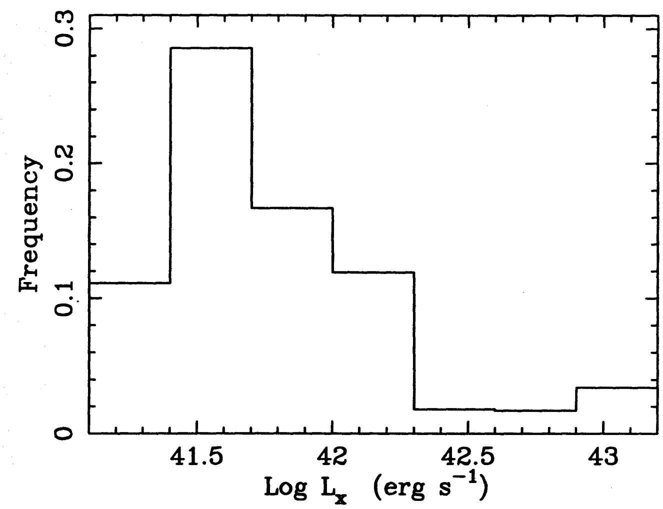

Fig. 8. Estimated frequency histogram for diffuse X-ray luminosity in the HCGs with $z < 0.04$. The bins sum to 0.75.

that this appears to apply to spiral-rich, as well as spiral-poor groups.

Finally, the steepening of the $L : T$ relation below $T \sim 1\,\mathrm{keV}$ may result from the action of galaxy winds in shallow potential wells (low T), since the main effect of energy injection into the intracluster medium is to reduce the gas density in the central regions, and hence the X-ray luminosity (Metzler & Evrard 1994). The large scatter about the mean trend in groups (Fig.6) would then result from different wind histories in different groups.

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