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H I content in galaxies in loose groups

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ABSTRACT

Gas deficiency in cluster spirals is well known and ram-pressure stripping is considered the main gas removal mechanism. In some compact groups too gas deficiency is reported. However, gas deficiency in loose groups is not yet well established. Lower dispersion of the member velocities and the lower density of the intragroup medium in small loose groups favour tidal stripping as the main gas removal process in them. Recent releases of data from the H I Parkes All-Sky Survey (HIPASS) and catalogues of nearby loose groups with associated diffuse X-ray emission have allowed us to test this notion. In this paper, we address the following questions: (i) do galaxies in groups with diffuse X-ray emission statistically have lower gas content compared to the ones in groups without diffuse X-ray emission? (ii) does H I deficiency vary with the X-ray luminosity, L_X, of the loose group in a systematic way? We find that (i) galaxies in groups with diffuse X-ray emission, on average, are H I deficient, and have lost more gas compared to those in groups without X-ray emission; the latter are found not to have significant H I deficiency; (ii) no systematic dependence of the H I deficiency with L_X is found. Ram-pressure-assisted tidal stripping and evaporation by thermal conduction are the two possible mechanisms to account for this excess gas loss.

Key words: galaxies: evolution – galaxies: interactions – radio lines: galaxies – X-rays: galaxies.

1 INTRODUCTION

In field galaxies, neutral hydrogen gas gets either converted into molecular form (and into stars) or ionized. A small fraction does escape in galactic winds. However in galaxies in clusters, substantial amount of gas goes into the intracluster medium (ICM), making the members *deficient* in H I relative to the gas content of a field galaxy of a similar morphological type. Such H I deficiency in cluster spirals is well reported in the literature. Members in groups may also lose gas to the intragroup medium (IGM) and become relatively *deficient* in H I. Galaxies in some of the Hickson compact groups have been reported to be gas deficient (Verdes-Montenegro et al. 2001) but such deficiency is still debated (Stevens et al. 2004). Gas deficiency in loose group environment has not yet been investigated systematically. For the first time, H I deficiency by a factor more than 1.6 has been reported in some members of a non-compact group in the Puppis region (Chamaraux & Masnou 2004). In some of the loose groups, the IGM is found to have enhanced metalicity, suggesting recent gas removal from the member galaxies (Davis et al. 1997). Thus, investigating gas removal processes operating in loose groups is timely and important.

Two mechanisms are considered important for gas removal: tidal interaction and ram-pressure stripping. Ram-pressure stripping (Gunn & Gott 1972) is effective when the H I surface mass density is less than $\rho_0 v^2/(2\pi G\sigma_*)$, where σ_* is the stellar surface mass density. Clearly, larger the ICM or IGM density, ρ_0, and galaxy velocity dispersion, v, the more effective is this stripping. Clusters satisfy these requirements and ram-pressure stripping is considered an effective process in them. In groups, though, both these quantities are lower, especially dispersion by a factor of 10 and, therefore, ram-pressure stripping is considered ineffective. Tidal interactions, on the other hand, involve gravitational interaction between two or more galaxies as they pass by each other. The lower relative velocities in groups allow larger interaction time-scales making tidal stripping the likely process for gas removal. This, in a larger sense, includes galaxy 'harassment', where the tidal stripping is caused by the overall gravitational potential of the group. However, a significant number of loose groups have been found to have hot gas in them emitting diffuse X-rays (Mulchaey et al. 2003). In such cases, ram-pressure assistance cannot be ruled out, making X-ray bright groups more H I deficient than non-X-ray bright groups.

Chamaraux & Masnou (2004) studied selected galaxies in five groups, NGC 533, 5044, 2300, 5846 and 4261, detected to have a hot IGM by *ROSAT*, and found a few of them to be strongly deficient in H I. They find the deficiency to be related to the physical proximity of the galaxy to the X-ray region. We have undertaken to

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study in detail the H I content of galaxies in groups with and without X-ray detection, covering a wide range in X-ray luminosity. Here we report the first part of our study, viz. a comparative analysis of H I content in small loose groups based on the H I Parkes All-Sky Survey (HIPASS; Barnes et al. 2001) and other existing single-dish data. This paper is organized as follows: the next section deals with the sample selection, H I data and its processing details. In Section 3, we report the analyses of the data and our results. The possible explanations of the results are discussed in Section 4. This work is summarized in Section 5.

2 SAMPLE, DATA AND PROCESSING

Our sample is made up of 27 groups, 10 belonging to the X-ray bright category and 17 belonging to the non-X-ray bright category. We chose all the X-ray bright groups, totalling 10, from the X-ray atlas of nearby poor groups (Mulchaey et al. 2003) satisfying the following criteria: most members have single dish H I measurements, their distances $\lesssim$50 Mpc (a value of 100 km s^{-1} Mpc^{-1} is used for the Hubble constant throughout this paper) and their membership is less than 25 (to avoid poor clusters). Their X-ray luminosities are in the range from 2.0×10^{40} to 6.3×10^{42} erg s^{-1}. Eight X-ray non-detected groups (six from Mulchaey et al. 2003, and two from Osmond & Ponman 2004) and nine all-spiral groups (all the group members being late-type spirals), make up the non-X-ray bright category. Non-compact all-spiral groups are not expected to have diffuse X-rays from their IGM (Henry et al. 1995; Mulchaey et al. 2003; Osmond & Ponman 2004; Ota et al. 2004) and therefore have been included to augment the non-X-ray bright sample. The distances and memberships of these 17 groups also follow the same criteria as the X-ray bright groups.

Among the 27 groups that make up our sample, 13 are from the Southern hemisphere and 14 are from the Northern hemisphere. For most of the Southern hemisphere galaxies, HIPASS database has been used. Given that typical H I masses in these galaxies will be a few times $10^8\,M_{\odot}$, the HIPASS sensitivity constrains that these groups be nearer than $\sim$ 40 Mpc. For the rest of the galaxies, H I measurements from the literature have been used (Huchtmeier & Richter 1989; de Vaucoulers et al. 1991; Haynes & Giovanelli 1991; Schneider et al. 1990; Giovanelli & Haynes 1993; Lu et al. 1993; Mathewson & Ford 1996; Schneider et al. 1992; Theureau et al. 1998). This imposes some practical difficulties: different surveys have different detection limits and resolution; some of the group members did not have any H I observation; in some other cases, the errors on the integrated flux densities were not quoted and we have used an average of the errors quoted for the other group members.

For group memberships we have followed the Lyon Group of Galaxies (LGG) catalogue (Garcia 1993). All LGG members of a group within a diameter of 1.2 Mpc (typical crossing distance in $\sim$5 Gyr) about the group centre are included. In most cases, this circle seems a natural boundary. In a few cases where a significant fraction of LGG members lie outside this range, we have extended the circle to a diameter of 1.5 Mpc about the group centre. This is done to ensure that the computed H I deficiency truely reflects the property of the group. Galaxies lying outside a diameter of 1.5 Mpc have been excluded. We also include as members of the group all galaxies found using the NASA Extragalactic Database (NED) within the spatial and velocity extent defined by the LGG members. All members thus chosen are tabulated in Tables 3 and 4 under their respective group names with distances to the groups derived from their velocities given in brackets. The table lists the source names, morphological type (*MT*), optical diameter in arcminutes [d_l (arcmin)], gas surface matter density in logarithmic units (*SMD*), H I deficiency (def$_{\rm H_I}$), angular distance from the group centre in arcmin (Ang.) and the telescopes used for obtaining the H I data (Tel.). The footnote at the end of Table 4 explains the symbols used for the different telescopes. Groups have been ordered in increasing right ascension, but the galaxies within the groups have been ordered in increasing distance from their centres. The latter ordering has been done to highlight the location of early-type and H I-deficient galaxies with respect to the group centres. For galaxies that belong to an early morphological type (E, S0 and S0/a), a '−' is marked in columns 4, 5 and 7; such galaxies have not been used in this study. Spiral galaxies which do not have H I data are denoted by an 'X' in column 7. An 'ND' in column 7 indicates a spiral not detected in H I. The optical diameter, d_l, is taken from the RC3 catalogue using NED: it is the optical major isophotal diameter measured at or reduced to a surface brightness level $m_B = 25.0$ B-m/ss.

The HIPASS spectra obtained towards the galaxies were used to find the centroid velocities and the integrated flux densities ($\int S\,\mathrm{d}V$ in Jy km s^{-1}, where S being the flux per beam per channel and dV being the velocity resolution) after fitting and removing second order polynomial baselines. UNIPOPS package was used for this processing. There were several instances of confusion in the case of HIPASS data (the Parkes beam has a full width at half-maximum of 15 arcmin at 21 cm). In the case of northern groups, multiple measurements with different telescopes were available. This and the fact that the beamsizes were smaller than that of Parkes, reduced the instances of confusion. In all cases of confusion, the deficiencies have been calculated assuming it to be equal among the confused galaxies.

The total gas mass ($M_{\rm H_I}$) cannot be straight away used for studying gas removal in galaxies as the H I content depends both on their sizes and morphological types. In fact, the disc size seems to be a more important diagnostic for the H I mass than the morphological type (Haynes & Giovanelli 1984). Gas mass surface density $M_{\rm H_I}/D_l^2$ proves to be a better measure of H I content as it incorporates the diameter of the spiral disc. Another advantage of using $M_{\rm H_I}/D_l^2$ over $M_{\rm H_I}$ as a measure of H I content is that $M_{\rm H_I}/D_l^2$ is distance independent and therefore free from its uncertainty.

The expected values of $M_{\rm H_I}/D_l^2$ for various morphological types are taken from Haynes & Giovanelli (1984). While Haynes & Giovanelli (1984) used the Uppsala General Catalogue (UGC) blue major diameters, we have used the RC3 major diameters. To take care of the difference in the surface matter densities that result from the use of RC3 diameters, we add a value of 0.08 (Gerin & Casoli 1994) to the expected surface matter densities given by Haynes & Giovanelli (1984). The final values of expected $M_{\rm H_I}/D_l^2$ used in this paper are given in Table 1. H I deficiency of a single galaxy is

Table 1. Expected surface matter densities for different morphological types (adapted from Haynes & Giovanelli 1984 for using RC3 diameters instead of UGC diameters and taking $h = 1$).

Morphological type (*MT*)	Index	$\log(\frac{M_{\rm H_I}/D_l^2}{M_{\odot}/\rm kpc^2})_{\rm pred} \pm$ s.d.
Sa, Sab	2	6.77 ± 0.32
Sb	3	6.91 ± 0.26
Sbc	4	6.93 ± 0.19
Sc	5	6.87 ± 0.19
Scd, Sd, Irr, Sm, Sdm, dSp	6	6.95 ± 0.17
Pec	7	7.14 ± 0.28

Table 2. Estimated group deficiencies.

Group name	L_X (erg s^{-1})	Group deficiency
NGC 524	40.53	0.62 ± 0.240
NGC 720	40.86	0.42 ± 0.138
NGC 1589 (NGC 1587)	40.92	0.46 ± 0.157
NGC 3686 (NGC 3607)	40.53	0.07 ± 0.062
NGC 4261	41.89	0.16 ± 0.134
NGC 4589 (NGC 4291)	40.74	0.12 ± 0.062
NGC 5044	42.81	0.34 ± 0.082
UGC12064	42.17	0.06 ± 0.055
IC1459	40.52	0.29 ± 0.093
NGC 7619	42.05	0.20 ± 0.053
NGC 584	<40.51	0.36 ± 0.063
NGC 1792 (NGC 1808)	<39.79	0.20 ± 0.059
NGC 5061 (NGC 5101)	<40.77	0.08 ± 0.102
NGC 5907 (NGC 5866)	<39.48	−0.08 ±0.174
UGC9858 (NGC 5929)	<40.50	0.39 ±0.055
NGC 7448	<40.40	−0.11 ±0.050
NGC 7582	<40.74	0.27 ± 0.055
NGC 7716 (NGC 7714)	<39.72	0.22 ± 0.032
NGC 628	No observation	−0.20 ±0.154
NGC 841	No observation	0.14 ±0.088
IC1954	No observation	0.20 ± 0.108
NGC 1519	No observation	0.24 ± 0.093
NGC 2997	No observation	0.10 ± 0.050
NGC 3264	No observation	−0.16 ±0.060
NGC 4487	No observation	0.19 ± 0.104
NGC 6949	No observation	−0.16 ±0.139
UGC12843	No observation	−0.05 ±0.115

Note. The group names given are from the LGG catalogue. Those given in brackets are from Mulchaey et al. (2003) and Osmond & Ponman (2004).

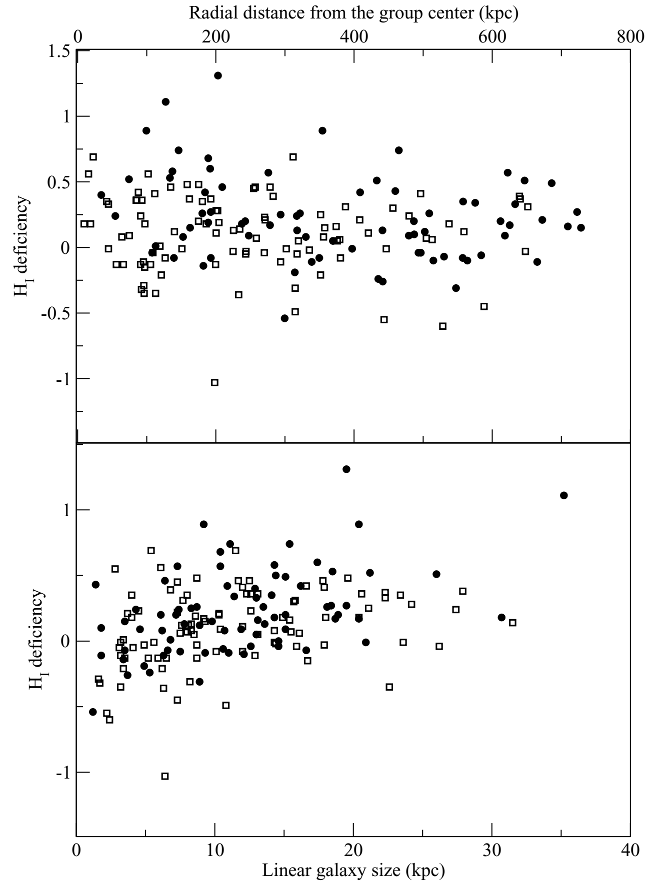

Figure 1. The top panel shows the distribution of H I deficiency with respect to the distance from the group centre. The bottom panel shows the distribution of H I deficiency with respect to the linear sizes of the galaxies. The number of galaxies in groups with and without X-ray emission are 74 and 96, respectively.

determined following the usual definition viz.:

$$\mathrm{def}_{\mathrm{H_I}} = \log \left.\frac{M_{\mathrm{H_I}}}{D_l^2}\right|_{\mathrm{pred}} - \log \left.\frac{M_{\mathrm{H_I}}}{D_l^2}\right|_{\mathrm{obs}}. \quad (1)$$

An average of this over all the H I detected galaxies is used as a measure of the H I deficiency of the groups, hereafter referred to as the 'group deficiency'. Table 2 lists the group names, their X-ray luminosity in logarithmic units, the calculated group deficiencies with 1σ error on them, for the 10 X-ray bright groups, the eight X-ray non-detected ones and the nine all-spiral groups that have no reported X-ray observation.

3 H I CONTENT IN GALAXIES IN GROUPS WITH AND WITHOUT DIFFUSE X-RAY EMISSION

Both local and large-scale environments affect the H I content in galaxies. Interactions and mergers are processes that are likely to be similar in groups with and without diffuse X-ray emission. Therefore, we first tested if the presence of diffuse X-ray gas affects the H I content any further. We find that, on average, the galaxies in the X-ray groups have a H I deficiency of 0.28 ± 0.04, whereas the ones in the non-X-ray groups show an insignificant deficiency of 0.09 ± 0.03. A few groups in the latter category, for example, NGC 584, NGC 7582 and UGC9858, that have significant H I deficiency also have upper limits to their X-ray luminosities close to the lowest luminosity among the X-ray detected groups.

For the purpose of this analysis, we constituted two *composite* groups, one with and another without diffuse X-ray emission, using all the H I detected group members. The group distances are derived from the mean radial velocities of the H I detected members. These are used to convert the projected angular distances of the group members with respect to group centres to linear distances and the optical major diameters, d$_l$, to linear sizes. The top panel of Fig. 1 shows H I deficiency, as defined in Section 2, for all members of these *composite* groups with respect to their radial distances. No variation of H I deficiency with radial distance from the group centre is seen, but the fractional number of H I deficient galaxies in X-ray groups is higher than in non-X-ray groups. The bottom panel of Fig. 1 shows H I deficiency distributed with respect to the linear sizes of the galaxies. H I deficiency seems to increase with size which could be a bias. $M_{\mathrm{H_I}}$ is observed to be proportional to $D_l^{1.7}$ (Haynes & Giovanelli 1984). Thus, H I surface density decreases with D_l as $D_l^{0.3}$. So computing H I deficiency with a constant value of $M_{\mathrm{H_I}}/D_l^2$ for each type leads to an overestimate for galaxies of large diameters and an underestimate for those with small ones. The effect present in Fig. 1 agrees quantitatively with this explanation. The average effect of such a bias on the galaxies of the sample leads to an underestimate of 0.04 on def$_{\mathrm{H_I}}$. However, this does not affect the results of our comparative study.

The top panel of Fig. 2 shows the cumulative distribution of H I deficiency for the two categories, X-ray bright and non-X-ray groups. Cumulative distribution represents, for each value, q_i, of the quantity, q, given in the abscissae, the proportion of galaxies, for

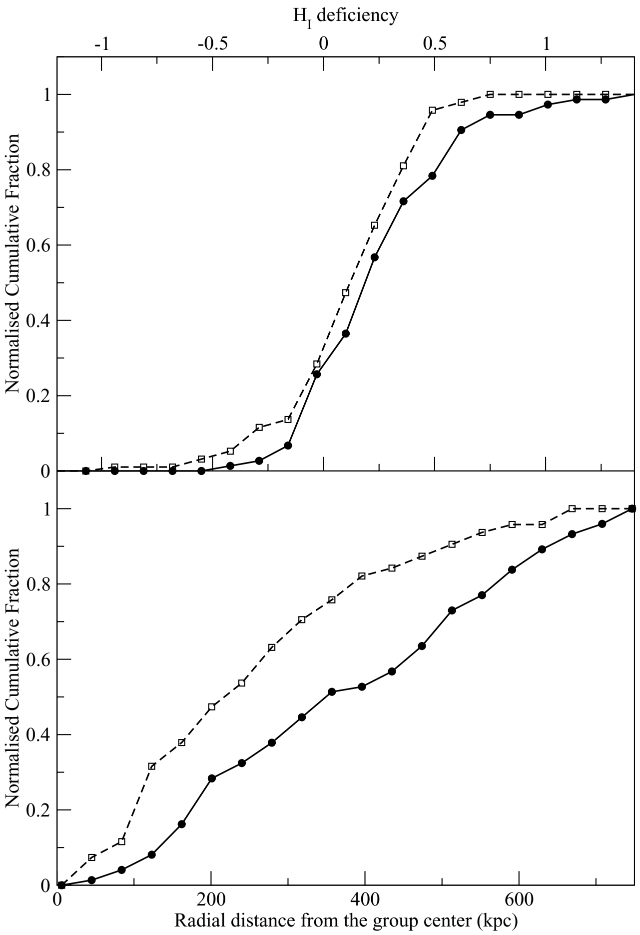

Figure 2. The top panel shows the behaviour of normalized cumulative fraction of the two sets of galaxies with respect to the H I deficiency; the bottom panel shows the same with respect to the radial distances from their group centres. The filled circles connected by the solid lines represent galaxies in X-ray bright groups, whereas the empty squares connected by the dashed lines represent galaxies in non-X-ray groups.

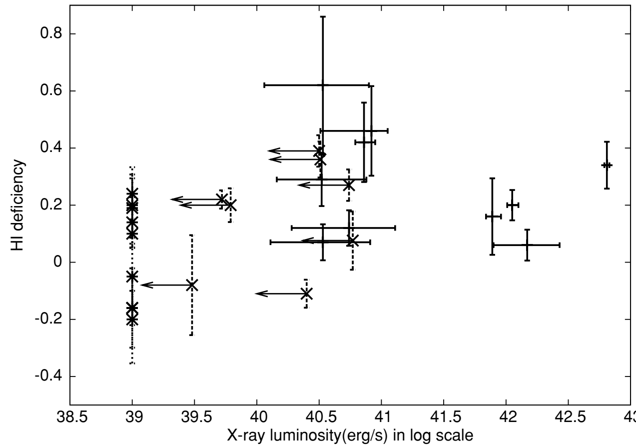

Figure 3. Variation in H I deficiency with L_X is shown.

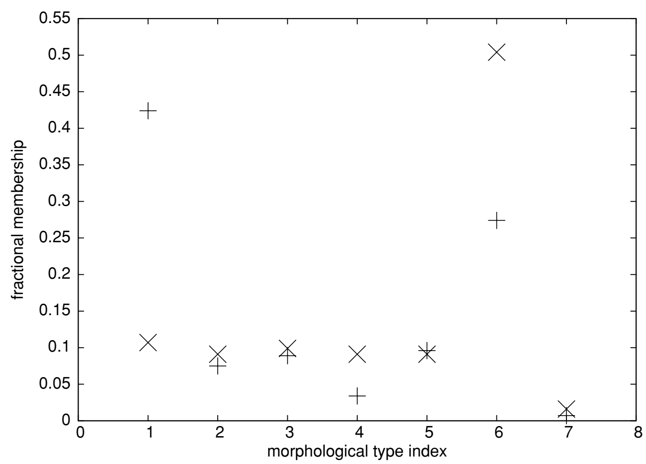

Figure 4. Distribution of galaxies from groups with and without diffuse X-ray emission with respect to morphological-type index from Table 1 (here, Elliptical, S0 and S0/a types are grouped under index 1). The symbol '+' represents X-ray bright groups and '×' represents non-X-ray groups.

which $q < q_i$. Three statistical tests, Kolmogorov–Smirnov (KS), Mann–Whitney (MW) and Wald–Wolfowitz (WW), were performed on the cumulative distributions of the quantity to test if the two samples are drawn from the same parent population. In the case of H I deficiency, the probabilities are: KS: 8.0 per cent; MW: 6.0 per cent, and WW: 1.1 per cent. The low probabilities indicate that the two groups are unlikely to be drawn from the same parent distribution, that is, one group tends to be more H I rich relative to the other. Small number statisitics, projection effects and distance uncertainties may still affect these results to some degree. None the less, the above results support the premise that the galaxies in X-ray bright groups have statistically lower H I content and thereby higher H I deficiency compared to the ones in non-X-ray groups.

The bottom panel of Fig. 2 shows the cumulative distribution of radial distances from the group centre for the two categories, X-ray bright and non-X-ray bright groups. The same three tests were performed on these distributions. Probabilities that the two composite groups are drawn from the same parent distribution from KS, MW and WW tests are 0.08, 0.01 and 33.6 per cent, respectively. Clearly, the X-ray bright groups are more extended compared to the non-X-ray bright groups. The average radius of the X-ray bright groups is 600 kpc, while that of the non-X-ray bright groups is 475 kpc.

Fig. 3 shows the plot of the group deficiency, as defined in Section 2, against the X-ray luminosity (in log-scale) of the studied groups. In this figure, the H I deficits of the nine all-spiral groups for which the X-ray luminosities are unknown, are marked at an X-ray luminosity (erg s^{-1} in log-scale) of 39.0. X-ray bright groups are represented with $\pm$ 1σ error bars on both X and Y values; X-ray non-detected groups having upper limits in X-ray luminosity are shown with arrows pointing to the left. No dependence with X-ray luminosity is seen, excepting that X-ray bright groups are deficient and non-X-ray groups have near-normal H I content.

The fraction of galaxies according to the morphological type index for the two categories are shown in Fig. 4. As noted in other instances (Mulchaey et al. 2003), we also find that the X-ray bright groups have a larger fraction of early-type galaxies compared to non-X-ray groups. Interestingly, the early-type members are preferentially located close to the centres in the X-ray bright groups (Tables 3 and 4). Their exclusion in our analysis and the larger membership of the X-ray bright groups can possibly explain the

Table 3. Details of the galaxies in groups with diffuse X-ray emission

Galaxy	*MT*	$d_l(')$	*SMD*	$\mathrm{def}_{\mathrm{H_I}}$	Ang.	Tel.
			NGC 524 (25.5 Mpc)			
NGC 0524	S0	2.8	–	–	0.0	–
NGC 0516	S0	1.4	–	–	9.8	–
NGC 0518	Sa	1.7	6.81	−0.04	14.5	H
NGC 0532	Sab	2.5	6.24	0.53	18.0	H
NGC 0509	S0	1.6	–	–	21.6	–
IC0101	S?	1.4	6.23	0.68	25.4	A
NGC 0522	Sc	2.63	5.56	1.31	27.4	A
IC0114	S0	1.7	–	–	32.3	–
CGCG411−038	S0	0.6	–	–	36.9	–
NGC 0502	S0	1.1	–	–	40.4	–
NGC 0489	S0	1.7	–	–	47.3	–
			NGC 720 (16.6 Mpc)			
NGC 720	E	4.7	–	–	0.0	–
2MASX-1[a]	S0	0.7	–	–	14.8	–
2MASX-2[b]	Sc	0.9	–	–	32.3	X
MCG-02-05-072	S0/a	1.3	–	–	34.4	–
KUG0147-138	Sb	1.5	6.70	0.20	50.2	H
DDO015	Sm	1.9	6.06	0.89	73.4	H
ARP004	Im	2.8	6.69	0.26	105.4	H
UGCA022	Sdm	2.7	6.62	0.33	131.1	H
			NGC 1589 (37.8 Mpc)			
NGC 1587	Epec	1.7	–	–	0.4	–
NGC 1588	Epec	1.4	–	–	0.8	–
NGC 1589*(c)	Sab	3.2	5.66	1.11	11.9	H
UGC03072*	Im	1.3	6.37	0.58	12.8	A
UGC03058	Sm	1.3	6.77	0.18	17.6	H
NGC 1593	S0	1.6	6.44	–	22.2	–
UGC03080	Sc	1.9	6.88	−0.01	37.0	H
UGC03054	Sd	1.4	6.21	0.74	43.3	H
NGC 1586	Sbc	1.7	6.76	0.17	58.3	H
			NGC 3686 (12.2 Mpc)			
NGC 3607	S0	4.9	–	–	0.0	–
NGC 3608	E	3.2	–	–	5.7	–
UGC06296	Sc	1.2	6.63	0.24	15.4	A
LSBCD570-04	dI	1.0	–	–	29.9	–
UGC06341	Sdm	1.0	6.80	0.15	46.0	A
UGC06324	S0	1.7	–	–	46.0	–
NGC 3626	S0	2.7	–	–	48.5	–
UGC06320	S?	0.95	7.05	−0.14	51.4	A
NGC 3592	Sc	1.8	6.41	0.46	59.2	A
LSBCD570-03	dI	0.8	–	–	93.7	–
NGC 3659	SBm	2.1	7.03	−0.08	98.9	A
UGC6300	E	1.2	–	–	103.8	–
NGC 3655	Sc	1.5	7.11	−0.24	123.0	G
LSBCD570-02	Im	0.39	6.52	0.43	130.0	A
LSBCD570-01	Sm	0.5	6.85	0.10	137.7	A
UGC06171	IBm	2.5	6.83	0.12	142.0	RC3
NGC 3681	Sbc	2.5	7.24	−0.31	154.8	G
UGC06181	Im	1.0	7.02	−0.07	157.5	G
NGC 3684	Sbc	3.1	7.02	−0.09	159.4	N91
NGC 3686	Sbc	3.2	6.59	0.34	162.7	N91
NGC 3691	SBb	1.3	6.82	0.09	174.8	A

finding that the X-ray bright groups are more extended than the non-X-ray groups.

4 DISCUSSION

Environment affects substantially the gas content, star formation rate and morphology of a galaxy as demonstrated by studies of cluster galaxies. Some observed properties of clusters viz. the population evolution with radius, that is, from red, evolved and early type in the inner parts to bluer, younger and late type in the outer parts, the increase in the fraction of blue galaxies (*Butcher–Oemler effect*; Butcher & Oemler 1978) and decrease in the fraction of S0s (*morphological evolution*) with redshift, have led to considerations of mechanisms that change the star formation rate and morphology of cluster galaxies. Removal of the warm gas from the halo (*strangulation*) and the cold gas from the disc (*ram-pressure stripping* and *evaporation via thermal conduction*) have been invoked to change the star formation rate. Major and minor mergers have been invoked

Table 3 – *continued*

Galaxy	*MT*	$d_l(')$	*SMD*	$\mathrm{def}_{\mathrm{H_I}}$	Ang.	Tel.
			NGC 4261 (21 Mpc)			
NGC 4261	E	4.1	–	–	0.1	–
VCC0344	E	.34	–	–	1.9	–
IC3155	S0	1.17	–	–	12.0	–
VCC0292	dE	0.35	–	–	13.0	–
NGC 4269	S0+	1.1	–	–	13.0	–
VCC0388	dE	0.51	–	–	14.9	–
NGC 4260	Sa	3.34	5.87	0.89	16.3	B
VCC0405	dE	.18	–	–	17.1	–
NGC 4287	S	1.82	6.17	0.74	23.9	H
VCC0332	S0	0.29	–	–	28.9	–
NGC 4277	S0/a	1.13	–	–	30.8	–
VCC287	dE	0.51	–	–	37.3	–
VCC0223	BCD?	0.2	7.68	−0.54	49.1	A
VCC0297	Sc	1.01	6.79	0.08	54.1	H
VCC238	dE	0.25	–	–	59.3	–
NGC 4223	S0	2.6	–	–	59.5	–
HARO06	E	0.49	–	–	61.1	–
NGC 4215	S0	1.9	–	–	62.3	–
NGC 4255	S0	1.3	–	–	62.8	–
UGC07411	S0/a	1.4	–	–	70.7	–
NGC 4197[a](c)	Sc	4.26	6.36	0.51	70.9	H
VCC0114[a]	Im	0.6	7.21	−0.26	72.3	A
NGC 4292	S0	1.7	–	–	79.0	–
VCC0693	S?	1.0	6.71	0.20	79.7	A
VCC0256	S	0.70	–	–	84.4	–
VCC0172	Im	1.08	7.02	−0.07	86.8	B
VCC764	S0	0.54	–	–	90.2	–
VCC468	BCD	0.3	7.25	−0.11	108.9	A
NGC 4233	S0	2.4		–	−113.0	–
NGC 4180	Sab	1.6	6.61	0.15	119.3	A
			NGC 4589 (16.7 Mpc)			
NGC 4319	Sab	3.0	–	–	11.2	ND
NGC 4386	S0	2.5	–	–	11.8	–
NGC 4291	E	1.9	–	–	16.8	–
NGC 4363	Sb	1.4	6.90	0.01	23.3	B
NGC 4331	Im	2.2	6.86	0.08	51.0	G
UGC07189	Sdm	1.7	6.70	0.25	60.5	B
UGC07265	Sdm	1.0	7.14	−0.19	64.7	G
UGC07238	Scd	1.53	6.71	0.24	65.3	B
UGC07872	Im	1.6	6.81	0.13	65.4	B
NGC 4133	Sb	1.8	6.65	0.26	66.2	N91
NGC 4159	Sdm	1.3	7.06	−0.11	69.8	B
NGC 4589	E	3.2	–	–	84.8	–
NGC 4648	E	2.1	–	–	86.2	–
NGC 4127	Sc	2.5	6.97	−0.10	106.0	RC3
UGC7844	Sd	1.27	–	–	116.3	X
UGC7908	Scd	1.5	6.38	0.57	128.1	G
UGC7086	Sb	2.69	6.74	0.16	146.0	G

Table 3 – *continued*

Galaxy	*MT*	$d_l(')$	*SMD*	$\mathrm{def}_{\mathrm{H_I}}$	Ang.	Tel.
NGC 5044 (26.0 Mpc)						
NGC 5044	E	3.0	–	–	0.5	
NGC 5044-1[c]	dE	0.4	–	–	5.3	
NGC 5049	S0	1.9	–	–	8.0	
LEDA083813	dE	0.4	–	–	19.0	
NGC 5030	S0	1.8	–	–	23.0	
MCG-03-34-041	Sc	2.3	6.27	0.60	25.3	H
NGC 5031	S0	1.6	–	–	25.3	–
LEDA083798	Sd	0.6	–	–	28.5	–
LCSBS1851O	dS0	0.7	–	–	32.6	–
MCG-03-34-020	E	0.6	–	–	35.5	–
NGC 5017	E	1.8	–	–	43.0	–
IC0863	Sa	1.8	6.63	0.13	58.1	H
UGCA338	Sdm	2.0	6.86	0.09	63.1	H
MCG-03-34-014	Sc	2.5	6.67	0.20	80.6	H
MCG-03-34-004	S0	1.9	–	–	83.0	–
SGC1317.2-1702	Sdm	1.9	6.44	0.50	85.2	H
SGC1316.2-1722	Sm	2.0	6.46	0.49	90.4	H
UGC12064 (50.2 Mpc)						
UGC12064(c)	S0	1.1	–	–	0.2	–
UGC12073(c)	Sb	2.1	6.73	0.18	16.3	G
UGC12075(c)	Scd	1.4	6.77	0.18	19.1	G
UGC12077(c)	S	1.0	6.95	–0.04	33.8	G
UGC12079(c)	Dwarf	1.0	6.99	–0.04	34.0	G
IC 1459 (17.8 Mpc)						
IC1459	E	5.2	–	–	0.1	–
IC5264[a](c)	Sab	2.5	6.37	0.40	6.6	P
IC5269B	Scd	4.1	6.43	0.52	14.3	H
IC5269(c)	S..	1.8	7.0	–0.08	26.9	H
NGC 7418	Scd	3.5	6.69	0.26	34.9	H
IC5270(c)	Sc	3.2	6.94	–0.08	37.2	H
NGC 7421	Sbc	2.0	6.36	0.57	53.3	H
ESO406-G031	Sb	1.5	–	–	64.1	ND
IC5269C	Sd	2.1	6.53	0.42	79.0	H
NGC 7619 (37.2 Mpc)						
NGC 7619	E	2.5	–	–	0.1	–
NGC 7626	E	1.3	–	–	6.8	–
UGC12510	E	1.3	–	–	9.4	–
NGC 7623	S0	1.2	–	–	11.9	–
NGC 7611	S0	1.5	–	–	12.8	–
KUG2318+078	S?	1.1	6.82	0.09	14.1	A
KUG2318+079B	Sc	0.3	–	–	16.2	X
NGC 7608	S?	1.5	6.49	0.42	17.0	A
NGC 7631	Sb	1.8	6.64	0.27	17.8	A
NGC 7612	S0	1.6	–	–	23.4	–
UGC12497	Im	1.2	6.90	0.05	34.1	A
NGC 7634	S0	1.2	–	–	46.1	–
CGCG406-086	S	1.3	6.56	0.35	51.5	A
FGC284A	Sc	1.12	–	–	51.7	X
UGC12480	Im	.98	7.00	–0.06	54.0	A
NGC 7604	E	0.3	–	–	58.6	–
UGC12561	Sdm	1.4	6.74	0.20	62.1	A
UGC12585	Sdm	1.7	6.67	0.27	66.8	A

Note. Blue compact dwarfs in NGC 4261 group are denoted by BCD for their morphological type and are taken to belong to the category of peculiars.
[a]2MASXJ01535632-1350125. [b]2MASXJ01524752-1416211. [c]NGC 5044 GROUP:[FS90] 076. *Please see Table 4 footnote.

Table 4. Details of the galaxies in groups without diffuse X-ray emission

Galaxy	*MT*	$d_l(')$	*SMD*	$\mathrm{def}_{\mathrm{H_I}}$	Ang.	Tel.
NGC 584 (18.7 Mpc)						
NGC 596	E+pec	3.2	–	–	7.3	–
NGC 600	Sd	3.3	6.77	0.18	17.9	H
NGC 586	Sa	1.6	–	–	27.1	ND
KDG007(c)	Dwarf	1.6	6.47	0.48	29.1	H
NGC 584	E	4.2	–	–	31.3	–
NGC 615(c)	Sb	3.6	6.43	0.48	32.2	H
IC0127	Sb	1.8	–	–	53.1	ND
NGC 636	E	2.8	–	–	90.5	–
UGCA017	Sc	2.9	6.56	0.31	119.8	H
NGC 628 (7.4 Mpc)						
NGC 628	Sc	10.5	7.22	–0.35	44.7	GRA
UGC1171	Im	1.3	6.39	0.55	47.4	A
UGC1176	Im	4.6	6.61	0.33	50.3	G
KDG010	Dwarf	1.5	–	–	80.8	X
IC0148	Im	2.95	7.98	–1.03	92.1	G
NGC 0660	Sa	8.3	6.80	–0.03	113.2	N91
UGC01200	Im	1.5	7.06	–0.11	136.5	A
UGC01104	Im	1.0	7.50	–0.55	206.0	G
UGC01246	Im	1.5	6.96	–0.01	207.5	A
UGC01175	Sm	1.1	7.55	–0.60	245.5	G
NGC 841 (45.1 Mpc)						
NGC 845	Sb	1.7	6.54	0.37	12.3	N
UGC1721	Sbc	2.0	6.97	–0.04	20.6	A
NGC 841	Sab	1.8	6.78	–0.01	23.0	A
NGC 834	S?	1.1	6.93	–0.02	25.5	A
UGC1673	S?	1.0	–	–	28.7	X
UGC1650	Sd	2.13	6.56	0.38	48.7	A
IC1954 (9.2 Mpc)						
NGC 1311	Sm	3.0	6.59	0.35	31.5	H
IC1933	Sd	2.2	7.08	–0.13	39.3	H
IC1954	Sc	3.2	6.68	0.19	76.0	H
ESO200-G045	Im	2.0	6.26	0.69	116.0	H
NGC 1249	Sdm	4.9	6.90	0.05	139.8	H
IC1959	Sm	2.8	6.89	0.06	141.1	H
NGC 1519 (18.8 Mpc)						
NGC 1519[a](c)	Sb	2.1	6.22	0.69	4.2	H
UGCA088[a]	Sdm	1.9	6.86	0.09	13.7	G
UGCA087	Sm	2.3	6.72	0.23	49.4	H
SGC0401.3-1720	Im	1.7	6.80	0.15	65.3	H
MCG-03-11-018	Sm	1.4	6.64	0.31	70.8	H
MCG-03-11-019	Sdm	1.6	6.98	–0.03	118.3	N
NGC 1792 (11.8 Mpc)						
NGC 1808	Sb	6.5	6.58	0.33	0.0	H
NGC 1792	Sbc	5.2	6.47	0.46	40.5	H
NGC 1827	Scd	3.0	6.75	0.20	43.6	H
ESO305-G009	Sdm	3.5	7.03	–0.08	48.1	H
ESO362-G011	Sbc	4.5	6.77	0.16	109.5	H
ESO362-G016	Dwarf	1.3	6.71	0.23	140.6	H
ESO362-G019	Sm	2.2	6.83	0.12	163.0	H

to account for the *morphological evolution* (e.g. Toomre & Toomre 1972; Okamoto & Nagashima 2003). However, similarity in spectral and morphological properties of poor and more-massive clusters at a redshift of ∼0.25 (Balogh et al. 2002) and the level of suppression of star formation in galaxies in many clusters even at a radius of ∼1 Mpc are taken to imply *pre-processing* in *subclusters*: that is, some of the warm gas from the halo and the cold gas from disc seem

Table 4 – *continued*

Galaxy	*MT*	d_l(′)	*SMD*	def$_{\rm H_I}$	Ang.	Tel.
			NGC 2997 (10.6 Mpc)			
ESO434-G030	S(r)	1.0	–	–	8.2	ND
IC2507(c)	Im	1.7	7.08	–0.13	18.3	H
UGCA180(c)	Sm	2.1	7.08	–0.13	21.6	H
NGC 2997	Sc	8.9	6.63	0.24	29.7	H
UGCA177	Im	1.1	6.94	0.01	38.8	H
ESO434-G041	Im	1.8	6.96	–0.01	49.2	H
ESO434-G019	Im	1.3	6.60	0.35	58.8	H
ESO373-G020	Im	1.6	6.98	–0.03	73.3	H
UGCA182	Im	2.7	6.82	0.13	73.5	H
ESO434-G039	Sa-b	1.0	6.82	–0.05	79.3	H
ESO434-G017	dwarf	1.2	6.74	0.21	88.4	H
UGCA168	Scd	5.8	6.54	0.41	161.7	H
ESO373-G007	Im	1.3	6.77	0.18	175.2	H
			NGC 3264 (9.8 Mpc)			
NGC 3264	Sdm	2.9	6.87	0.08	22.5	G
UGCA211	pec	0.56	7.43	–0.29	33.6	G
NGC 3220	Sb	1.23	7.04	–0.13	70.0	N
NGC 3206	Scd	2.2	7.31	–0.36	81.8	N91
UGC05848	Sm	1.45	6.99	–0.05	111.4	G
NGC 3353	BCD/Irr	1.2	7.35	–0.21	123.3	N43
			NGC 4487 (10.1 Mpc)			
NGC 4504	Scd	4.4	7.06	–0.11	29.9	H
UGCA289	Sdm	4.1	6.54	0.41	35.0	H
NGC 4487	Scd	4.2	6.58	0.36	60.4	H
NGC 4597	Sm	4.1	6.84	0.11	131.9	H
			NGC 5061 (20.8 Mpc)			
NGC 5061	E	3.5	–	–	12.1	–
NGC 5078(c)	Sa	4.0	6.49	0.27	33.1	H
ESO508-G039	Sm	1.3	6.84	0.11	33.1	H
IC0879(c)	Sab pec	1.2	6.49	0.27	33.5	H
IC874	S0	1.2	–	–	44.1	–
NGC 5101	S0/a	5.4	–	–	49.5	–
ESO508-G051	Sdm	1.4	6.90	0.05	52.8	H
IC4231	Sbc	1.7	6.72	0.21	67.5	H
ESO508-G059	S..	1.2	–	–	93.0	ND
ESO508-G034	Sm	1.2	7.40	–0.45	97.2	H
			NGC 5907 (7.4 Mpc)			
NGC 5907	Sc	12.77	6.65	0.22	6.7	G
UGC09776	Im	0.8	7.27	–0.32	42.7	G
NGC 5866B	Sdm	1.46	7.30	–0.35	52.1	G
NGC 5879	Sbc	3.74	6.80	0.12	64.7	N91
NGC 5866	S0	4.7	–	–	91.7	–
			UGC 9858 (25.2 Mpc)			
UGC09856	Sc	2.26	6.45	0.42	12.0	G
UGC09858	Sbc	4.3	6.79	0.14	32.0	N91
NGC 5929(c)	Sab	1.0	6.31	0.45	34.7	G
NGC 5930(c)	Sb	1.7	6.45	0.46	35.0	G
UGC09857(c)	Im	1.6	6.49	0.46	38.0	G
			NGC 6949 (26.6 Mpc)			
NGC 6949	S	1.4	7.40	–0.49	40.7	G
UGC11613	Sdm	1.85	6.87	0.08	46.0	G
UGC11636	Scd	1.3	7.03	–0.08	49.2	G

Table 4 – *continued*

Galaxy	*MT*	d_l(′)	*SMD*	def$_{\rm H_I}$	Ang.	Tel.
			NGC 7448 (21.3 Mpc)			
NGC 7464	E	0.8	–	–	13.3	–
NGC 7465	S0	1.2	–	–	14.7	–
UGC 12313	Im	1.4	7.08	–0.13	15.2	A
NGC 7448	Sbc	2.7	7.08	–0.15	16.2	A
UGC 12321	Sbc	1.0	7.14	–0.21	20.2	A
NGC 7454	E	2.2	–	–	30.8	–
NGC 7468	E	0.9	–	–	52.0	–
UGC 12350	Sm	2.6	6.89	0.06	85.6	A
			NGC 7582 (16.1 Mpc)			
ESO291-G015*(c)	Sa	1.3	6.21	0.56	3.3	H
NGC 7582*(c)	Sab	5.0	6.42	0.35	9.0	H
NGC 7590*(c)	Sbc	2.7	6.57	0.36	18.3	H
NGC 7599*(c)	Sc	4.4	6.51	0.36	19.9	H
NGC 7552	Sab	3.4	6.81	–0.04	23.3	H
NGC 7632	S0	2.2	–	–	41.6	–
ESO347-G008	Sm	1.7	6.88	0.07	55.2	H
ESO291-G024	Sc pec	1.46	6.48	0.39	60.4	H
NGC 7531	Sbc	4.5	6.68	0.25	75.1	H
NGC 7496	Sbc	3.3	6.86	0.07	107.7	H
IC5325	Sbc	2.8	6.56	0.36	136.8	P
			NGC 7716 (27.0 Mpc)			
NGC 7714(c)	Sb pec	1.9	6.73	0.18	0.0	H
NGC 7715(c)	Im pec	2.6	6.77	0.18	2.0	H
UGC12690	Sm	2.0	6.65	0.30	58.1	H
			UGC 12843 (17.6 Mpc)			
UGC 12843	Sdm	2.8	6.96	–0.01	8.8	A
UGC 12846	Sm	1.8	6.77	0.17	36.4	A
UGC 12856	Im	1.6	7.26	–0.31	61.5	G
MCG+03-01-003	Sm	0.45	–	–	62.0	X

Notes. Symbols used for indicating the telescopes:
A = Arecibo 1000 ft; B = Effelsberg 100 m; G = Green Bank Telescope 100 m; GRA = Agassiz Harvard 60 ft; H = HIPASS; N = Nancay 30 × 300 m; N91 = NRAO 91 m; N43 = NRAO 43 m; P = Parkes 64 m.
The cases of confusion are indicated by a '(c)' in column 1.
[a]The HIPASS spectra towards NGC 1519, NGC 1589, NGC 4197 and IC5264 are confused, respectively, with galaxies UGCA088, UGC03072, VCC0114 and NGC 7481A. Hence, their deficiencies have been calculated following the prescription mentioned in the text. NGC 7481A does not belong to the group as per the criteria and is not in the table. The other three confusing galaxies viz. UGCA088, UGC03072 and VCC0114 have GBT (the first one) or Arecibo (the last two) measurements. Therefore, their deficiencies have been calculated with the higher resolution fluxes and are not marked with a '(c)' in the above table.
*NGC 7582 is confused with NGC 7590 and NGC 7599 in one HIPASS pointing and with ESO-291-G015 in another. Since it is closer to the pointing centre in the first case, we use the deficiency calculated from that spectrum for this galaxy.

to be lost in processes in less-massive clusters at a higher redshift that merged to form today's rich clusters. *Strangulation, ram pressure* and *evaporation* seem to be playing a role in them (Fujita 2004).

Interactions and mergers are processes that are likely to be similar in groups with and without diffuse X-ray emission. Besides, tidal interactions are rare in group environments: for typical membership number (six spirals), size (1.5 Mpc diameter) and dispersion (150 km s^{-1}) of a group, the number of encounters for 50 per cent gas loss is 0.03 for the group (0.005 per spiral galaxy) in Hubble time (Chamaraux, Balkowski & Gerard 1980). Therefore, the amount of gas lost in this way seems insufficient to explain the observed group deficiencies in X-ray bright groups. However, our study suggests that processes such as *tidal aided ram-pressure stripping* (Davis et al. 1997) and *evaporation via thermal conduction* may be effective even among present-day loose groups. Our findings are: (i) the groups with diffuse X-ray emission seem to have lost more gas compared to groups without diffuse X-ray emission; (ii) the X-ray bright groups are spatially more extended than the non-X-ray groups. These findings indicate a role for the X-ray emitting gas in aiding H I removal from the galaxies.

In cluster environment, ram-pressure stripping has been seen to be an effective process for removing gas from galaxies. In groups this process was not considered to be an efficient one as lower IGM density and velocity dispersion, both smaller by an order of magnitude compared to clusters, make direct ram-pressure stripping effective only below a critical H I column density of 10^{19} cm^{-2} for a normal galaxy with an optical radius of 10 kpc, and 10^{11} stars . However in X-ray bright groups this picture can be a little different. From the quoted X-ray luminosity and temperature in Mulchaey et al. (2003), we have calculated the IGM densities assuming the emission to originate from thermal bremsstrahlung. The IGM densities thus calculated for 10 X-ray bright groups vary from 5×10^{-4} to 2×10^{-3}. For a normal galaxy with an optical radius of 10 kpc and 10^{11}–10^{10} stars, and for typical velocity dispersion quoted in the literature, the ram-pressure effects become important at H I column densities $\sim 10^{19}$ to $\sim 10^{20}$ cm^{-2}. The range in stellar mass reflects the range in surface matter density. ram-pressure becomes effective even at higher H I column densities for low surface brightness galaxies. Low surface brightness galaxies do form a substantial fraction in groups. The velocity dispersion of galaxies in these groups are also not well determined. Recent discovery of several new members in NGC 5044, an X-ray bright group, indicates that some of these groups can actually be more massive. In NGC 5044, the new membership has increased its velocity dispersion from 119 to 431 km s^{-1} (Cellone & Buzzoni 2005). For such a velocity dispersion and for a normal galaxy (with an optical radius of 10 kpc, and 10^{11}–10^{10} stars), the ram-pressure effects are significant at H I column densities from $\sim 5 \times 10^{19}$ to $\sim 5 \times 10^{20}$ cm^{-2}.

We have calculated the maximum gas loss possible through ram pressure alone for two galaxies in NGC 5044 group. We have assumed a velocity dispersion of 431 km s^{-1} and an IGM density of 4 particles cc^{-1}. The latter is about half the IGM density determined using X-ray data for this group (Mulchaey et al. 2003). We chose two galaxies differing in stellar mass by a factor of 10 to determine the varying effects of ram pressure on different types of galaxies in a group. We determined their stellar masses using their *J* and *K* magnitudes (Bell & de Jong 2001). In the first case of MCG-03-34-04, the stellar mass is found to be $\sim 1.5 \times 10^{10}$ M$_\odot$, and the corresponding critical H I column density beyond which the ram pressure can strip off gas is $\sim 4 \times 10^{19}$ cm^{-2}. For a Gaussian distribution of H I (Chamaraux et al. 1980) and using a peak column density of 3.2×10^{21} cm^{-2} (from our interferometric data), it is seen that $\lesssim$5 per cent of the gas can be stripped off in this way. In the second case, MCG-03-34-041 is found to have a stellar content of $\sim 4 \times 10^9$ M$_\odot$ and a peak column density of 2.6×10^{21} cm^{-2}, leading to a gas loss of 32 per cent.

Thus, ram pressure is probably an important gas-removing mechanism in X-ray bright groups, either on its own or assisted by tidal interaction that stretches the gas below the critical column densities. However this is a density-dependent mechanism and thus will be less efficient as the galaxy recedes the group centre, since the IGM density will decrease with increasing distance from the centre. Also for groups with smaller velocity dispersion, this process will become much less effective as the ram pressure depends on the square of the velocity dispersion. For example, a galaxy like MCG-03-34-041 will lose only 5 per cent gas if the velocity dispersion is 150 km s^{-1}. It may also be noted that for the 10 X-ray bright groups for which we could determine the IGM densities (ρ), the quantity, $\rho\,\sigma_v^2$, is found to have no correlation with the group deficiency.

Evaporation via thermal conduction seems to be another process which can be responsible for mass loss from galaxies embedded in a hot medium (Cowie & Songaila 1977). It is interesting to note that *evaporation* depends directly on temperature and weakly on density, complementary to ram-pressure processes. At temperature of 5×10^6 K, typical of an X-ray bright group, a disc galaxy can loose as much as 4×10^7 M$_\odot$ in the time it takes to cross the central 100 kpc region at 200 km s^{-1} speed. To expell a mass of 10^9 M$_\odot$ over a period of 10^9 yr, it requires a mechanical power input of about $10^{39.5}$ erg s^{-1}, a fraction of the luminosity of the X-ray bright groups. This suggests that if a small fraction of the thermal energy in the hot gas is coupled to the galactic cold gas over a billion years, the gas in the outer parts of the galaxies can be stripped leading to the observed deficit in H I. The saturation of conductivity and effects of magnetic field may reduce this mass loss. However, mixing from gas-dynamic instabilities as the disc ploughs through the tenuous IGM may enhance the mass loss. Evaporation may also become *asymmetric* caused by the galaxy motion and the gradient in the temperature and density of the hot gas. Such asymmetric *evaporation* may further deposit momentum to the adjoining gas via (*Spitzer*'s) rocket effect and enhance the gas loss. Numerical simulations of this process taking into account such effects may yield quantitative results and verify the viability of this mechanism. Such an attempt is beyond the scope of this paper.

We plan to enlarge the data set by obtaining single dish data on more groups, with and without diffuse X-ray emission. This will help us to improve the confidence level in these results. We are also in the process of obtaining high-resolution images of some members from both kinds of groups, looking for morphological evidence to try to pin down the responsible process. Extended, asymmetric, low surface brightness H I distributions are typical signs of tidal interaction. Swept-back appearence of the H I gas along with the asymmetric structures, would suggest *tidal aided ram-pressure stripping*. Evaporation will result in galaxies with somewhat smaller than usual H I diameters, and a depressed H I surface density across the entire face of the galaxy (Cayatte et al. 1994). Thus, with sensitive synthesis data at moderate resolution, we hope to be able to assess the nature of gas removal and possibly conclude on the viable mechanism.

5 CONCLUSIONS

We have studied the H I content of galaxies in loose groups with and without diffuse X-ray emission. We find that the galaxies in non-X-ray groups are not deficient in H I with respect to the field galaxies. The galaxies in X-ray groups are clearly deficient in H I and have lost more gas (H I) compared to those in non-X-ray groups. No systematic dependence of the H I deficiency with L_X is found. We also find that the X-ray groups are more extended than non-X-ray groups. *Tidal aided ram-pressure stripping* and *evaporation* are the possible mechanisms leading to the excess gas loss found in galaxies in X-ray groups.

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