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ScienceDirect
New Astronomy Reviews 51 (2007) 87–89
New Astronomy Reviews
www.elsevier.com/locate/newastrev

Cold and hot gas in the most HI deficient compact groups

Lourdes Verdes-Montenegro [a,*], Min S. Yun [b], Sanchayeeta Borthakur [b], Jesper Rasmussen [c], Trevor Ponman [c]

[a] Instituto de Astrofísica de Andalucía (IAA/CSIC), Apdo. 3004, 18080 Granada, Spain
[b] Astronomy Department, University of Massachusetts, Amherst , MA 01003, USA
[c] School of Physics and Astronomy, University of Birmingham, Edgbaston, Birmingham B15 2TT, United Kingdom

Available online 16 January 2007

Abstract

Dense groups of galaxies should be prime sites for galaxy interactions and mergers, and their evolution has been the subject of controversy for 25 years. In order to explain the HI deficiency found in compact groups of galaxies we previously proposed an evolutionary scenario in which the amount of HI decreases with the secular evolutionary state of a group. But where does the HI go? One possibility is that the HI is heated or even shocked by the frequent galaxy interactions/collisions that occur in these dense environments. Here we present a comparison of the neutral gas distribution with the hot gas traced in X-rays. Surprisingly some of these groups do not show HI emission down to column densities as low as 10^{19} cm^{-2}. In some cases ram pressure stripping by a hot intragroup medim can explain the observed HI deficiency, while in others no extended X-ray emission is found. The star formation activity is found to be similar to isolated galaxies, hence gas consumption via current star formation would neither be a general cause of the HI deficiency in compact groups.

Contents

1. Introduction 87
2. Results 88
3. Conclusions. 90
References 90

1. Introduction

Hickson compact groups (HCGs) are small and highly isolated aggregates of 4–8 galaxies with apparent spatial galaxy densities that range from 300 to $10^8\,h^{-2}\,\mathrm{Mpc}^{-2}$ and low velocity dispersions ($\sigma \sim 200\,\mathrm{km\,s}^{-1}$, Hickson et al., 1992). Therefore tidal interactions are expected to be ubiquitous and dynamically important. X-ray bright groups show a morphology–density relation similar to that of clusters (Helsdon and Ponman, 2003). Not only are spiral galaxies less common within dense groups, but those which are present tend to be deficient in HI compared to isolated galaxies of similar morphology and optical luminosity. We have analyzed the total HI content of 72 HCGs and found that nearly 60% of the HI is missing in these groups. We further investigated the detailed distribution and kinematics of HI within a subset of 16 groups using high resolution observations obtained using the VLA (Verdes-Montenegro et al., 2001 hereafter VM01). The HI deficiency was found to be larger when galaxies were considered individually (76% HI is missing) in agreement with the efficient gas stripping evidenced by HI tails and bridges. Among the 44 groups of our sample observed in

* Corresponding author.
E-mail address: lourdes@iaa.es (L. Verdes-Montenegro).

1387-6473/$ - see front matter
doi:10.1016/j.newar.2006.10.008

X-ray (Ponman et al., 1996), the detection rate of hot gas was higher for the HI deficient groups with respect to groups with a normal HI content (45% versus 18%), independently of the distances or exposure times. Based on these results, we have proposed an evolutionary scenario in which the interstellar medium is removed from individual galaxies and the total HI content in the group would decrease as the groups evolve (VM01).

The physical mechanisms responsible for these changes in the morphology and gas content of galaxies are unclear. In order to understand the fate of gas in HCGs we have started a study to look for an intragroup medium (IGM). We have considered several possibilities: (a) Neutral gas: interstellar medium stripped from the member galaxies could remain neutral for a significant amount of time (see e.g. reports of HI clouds within Virgo cluster, Oosterloo and van Gorkom, 2005). (b) Hot gas, since the higher X-ray detection rate of HI deficient groups is consistent with a picture where the HI is stripped from spiral galaxies and is then heated to the temperature of the surrounding IGM. Enhanced star formation activity which might be contributing to exhausting the gas supply has been also studied.

2. Results

Since the diffuse HI in the IGM may be too faint, extended, and broad in velocity ($\sigma \sim 1000\ \mathrm{km\ s^{-1}}$) to be detected by the VLA, we have performed GBT (Green Bank Telescope) observations of a complete distance limited sample of 25 HCGs with diverse HI content and distribution (Borthakur et al., in preparation). We have reached a high sensitivity (rms/1h $\sim$ 0.7 mJ y, 2–20 times better than previous single dish data), and used a bandwidth of 2500 $\mathrm{km\ s^{-1}}$. Presence of substantial diffuse, extended neutral IGM is confirmed when the GBT measurements are compared with the VLA measurements of high column density gas – as much as nearly twice in some cases. The mass of this component varies significantly among the groups, and we have investigated its correlation with the physical properties of these groups. Our analysis demonstrates that, consistently with our evolutionary picture, the most HI deficient groups show a larger ratio of diffuse gas than groups with a normal HI content, which can be understood as the result of continuous tidal stripping in the common group potential. However most groups are still deficient after including the diffuse neutral gas recovered by the GBT. Hence other mechanisms such as heating of the gas or gas consumption via star formation have to be considered.

In order to evaluate the heating of the gas as a possible mechanism producing HI deficiency, we have performed VLA-HI as well as X-ray (XMM or Chandra) observations of the most HI deficient groups HCG 7, 15, 30, 37, 40, 44 and 97. We discuss and summarize the results below.

HCG 7. The total HI mass predicted for this group in VM01 was $\log(M(HI)/M_\odot) = 10.4$, while we detect $\log(M(HI)/M_\odot) = 9.8$ using the GBT. The VLA is missing 30% of the GBT flux, and each of the three spiral members of the group show half the expected HI. Faint signs of tidal disruption are found in this group such as asymmetry in the HI and optical emission. No extended X-ray emission is detected in this group with XMM, and the FIR emission is similar to or even fainter than for a reference sample of isolated galaxies taken from the AMIGA sample (Linsefeld et al., 2006).

HCG 15. The velocity dispersion of this group is high ($\sigma = 426\ \mathrm{km\ s^{-1}}$) even if the galaxy H15c (with a velocity difference relative to the group larger than $2000\ \mathrm{km\ s^{-1}}$) is excluded. HI emission is detected only for the late type galaxy H15f using the VLA, along with another galaxy located at the edge of the VLA primary beam (Fig. 1, left). The optical and HI disks of H15f are misaligned, suggesting a possible recent disruption. Intragroup X-ray (XMM) as well as 21 cm radio continuum emission are detected toward HCG 15 (Fig. 1, right). The HI system H15f is seen within this hot IGM, possibly only in projection. The location of a radio continuum ridge close to H15c suggests that this galaxy might be interacting at a high velocity with the group, in a similar way as the high velocity intruder in HCG 92 (Sulentic et al., 2001).

HCG 30. This is the most HI-deficient HCG group. The total HI mass predicted for this group is $\log(M(HI)/M_\odot) = 10.2$. With the GBT we detect $\log(M(HI)/M_\odot) = 8.8$, and no HI is detected with the VLA. Three of the four group members are lenticular galaxies. H30a is an S0 galaxy with a large bulge and faint spiral arms. This suggests that we might be witnessing its evolution from a spiral to a lenticular type, a mechanism proposed to explain the large number of S0s galaxies in HCGs (Sulentic, 2000 VM01) . Neither X-ray nor radio continuum emission is detected toward the group. None of the galaxies shows significant FIR emission.

HCG 37. The total HI mass predicted for this group is $\log(M(HI)/M_\odot) = 10.1$. With the GBT we detect $\log(M(HI)/M_\odot) = 9.8$. No HI is detected with the VLA toward the group although four neighboring galaxies are detected within or at the edge of the VLA primary beam. One of these galaxies shows an HI morphology suggestive of ram pressure stripping. The detected X-ray (Chandra data) and radio continuum emission seems associated with H37c, a galaxy containing an AGN. The ROSAT data (Mulchaey et al., 2003), covering a larger field of view, suggested extended emission well beyond H37c. All galaxies are normal or slightly underluminous in the FIR.

HCG 40. The total HI mass predicted for this group is $\log(M(HI)/M_\odot) = 10.1$. With the GBT we detect $\log(M(HI)/M_\odot) = 9.5$, and most of this flux is recovered by the VLA (Del Olmo et al., in preparation). Hot X-ray gas is detected with Chandra, but our preliminary analysis does not allow to distinguish whether it is associated with the individual galaxies (halos or starburst winds) or with the hot IGM. All galaxies are normal in the FIR.

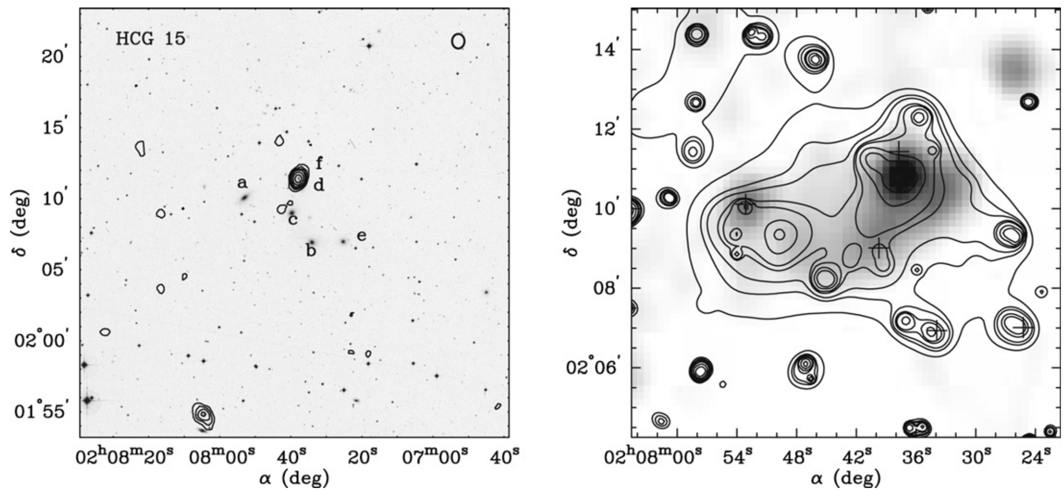

Fig. 1. HCG 15. Left: HI column density contours overlaid on a red DSS2 image. Right: X-ray (XMM) emission contours on a gray scale image of the 21 cm radio continuum emission. The crosses mark the position of the galaxies indicated in the left figure.

HCG 44. The total HI mass predicted for this group is $\log(M(HI)/M_{\odot}) = 10.1$, and the HI mass detected with GBT is 9.5. All spiral members are detected with the VLA, showing signs of tidal stripping at work. A central HI hole is seen in two of the galaxies. X-ray emission is detected toward the group with XMM, but the imaged area is not large enough to determine the extent or the nature of the X-ray emission. All galaxies are normal or slightly deficient in the FIR.

HCG 97. The velocity dispersion of this group is high ($\sigma = 372$ km s^{-1}). The total HI mass predicted for this group is $\log(M(HI)/M_{\odot}) = 10.0$. With the GBT we detect $\log(M(HI)/M_{\odot}) = 9.5$, and none of the group members is detected with the VLA. This is a group where extended X-ray (XMM data) as well as 21 cm continuum emission are clearly detected, and it is a good candidate for ram pressure stripping.

3. Conclusions

We find a larger amount of diffuse neutral and X-ray gas in the HI deficient groups compared to non-deficient ones, consistent with our evolutionary picture. Most groups are still deficient after including diffuse gas recovered by the GBT, so that other mechanisms are needed to fully account for the HI deficiency in these HCG groups. Tidal features are not often detected in these extremely deficient groups, but there are some hints suggesting that deeper HI data would show them. The presence of a hot IGM is not detected in most of these systems, but the detection rate is higher for the high velocity dispersion groups such as HCG 15 and 97. Hence although there is observational evidence that ram pressure can remove gas from group galaxies (Rasmussen et al., 2006) it does not seem to be the main mechanism which leads to the removal of HI from HI deficient group galaxies. The detection of intragroup radio continuum emission in several of these groups is surprising since similar features were seen previously only in massive clusters (known as "relic" sources).

Star formation activity traced by FIR luminosity is not enhanced, contrary to the general expectation of tidally interacting systems. The FIR luminosity is similar to or even lower than for isolated galaxies, and the Hα study performed by Iglesias-Paramo and Vilchez (1999) supports this conclusion as well. We plan to explore the possibility that earlier starbursts could have contributed to the present HI deficiency.

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