ISM of galaxies in extremely different environments: isolated vs compact groups

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Summary. Compact groups of galaxies are thought to be prime sites for galaxy interactions and mergers, however their evolution has been the subject of controversy for 25 years. We present a study of the HI, CO and FIR emission of galaxies in dense groups taking as a reference sample extremely isolated galaxies that constitute the basis of the AMIGA project. We place special emphasis on HI data as a primary tracer of the dynamical status of the groups. We previously proposed an evolutionary scenario in which the amount of HI decreases with the secular evolutionary state of a group. A key question involves the fate of the HI in stripped galaxies, and how does it affect to other ISM components. One possibility is that the HI is heated or even shocked by the frequent interactions/collisions that occur in these dense environments. In order to investigate the process leading to HI deficiency we have defined a redshift limited sample of compact groups and recently mapped the most HI deficient systems at the VLA, where the process leading to HI destruction is likely to be most active. Surprisingly some of these groups do not show HI emission down to column densities as low as 10^{19} cm^{-2}. Our HI study is coordinated with the Chandra and XMM studies of the same sample (see Ponman contribution at this meeting). We find also a trend for the HI deficient groups to be also deficient

in molecular gas and FIR emission, suggesting that when HI is removed from the galaxies the molecular gas is not replenished, so inhibiting the SF activity.

1 AMIGA reference sample of isolated galaxies

Although it is widely accepted that galaxy interactions stimulate secular evolutionary effects, the amplitude of the effects, and processes for accomplishing them, are not well quantified (Sulentic 1976, 1989; Xu & Sulentic 1991). E.g. although ubiquitous tidal interactions would predict enhanced star formation (SF) among Hickson Compact Groups (HCG) galaxies, their CO and FIR emission are surprisingly low (Verdes-Montenegro et al 1998). There is no clear consensus on whether SF enhancement depends on details of an encounter or the preexisting gas reservoirs in the galaxies. Most of these uncertainties reflect the lack of a statistically useful baseline. The AMIGA project (Analysis of the interstellar Medium of Isolated GAlaxies, see `http://www.iaa.es/AMIGA.html`) involves identification and parameterization of a statistically significant sample of the most isolated galaxies in the local Universe. Our goal is to quantify the properties of different phases of the interstellar media of isolated galaxies, in order to serve as a reference sample for the study of denser environments.

1.1 Sample selection and refinement

Our base sample is the Catalog of Isolated Galaxies (CIG: Karachentseva [?]) which includes 1051 objects. In order to achieve our goals a careful refinement has been performed: positions (Leon & Verdes-Montenegro 2003), distances (N = 956 galaxies[12], isolation (Verley et al. in prep) and morphologies (Sulentic et al in press).

1.2 Multiwavelength study

In Verdes-Montenegro et al (2005) we studied the optical properties of the CIG sample and showed that it is reasonably complete ($\sim$80%) down to $m_{B-\mathrm{corr}} \sim 15.0$. Once the sample optically characterized, AMIGA project emphasizes the properties of the nonstellar material in the galaxies because it is most sensitive to the effects of external stimuli. Data for neutral (HI), molecular (CO) and excited (Hα) gas, and radiocontinuum emission as an extinction-free tracer of current SF rate and AGN diagnostic tool when combined with FIR data, have been obtained or compiled from the bibliography. We have also a well-defined sample of the most isolated galaxies showing significant asymmetries in their HI profiles, and mapped them with the VLA in

[12] This number is being updated in the electronic table at http://www.iaa.csic.es/AMIGA.html when new data are available.

HI in order to look for signs of external interaction by analyzing in detail the HI distribution and kinematics (Espada et al, in prep). One of the most interesting galaxies in our VLA sample is CIG 96 (NGC 864), a spiral galaxy well isolated from similarly sized companions, that presents an intriguing asymmetry in its integral HI spectrum. The asymmetry in the HI profile is associated with a strong kinematical perturbation in the gaseous envelope of the galaxy, where at one side the decay of the rotation curve is faster than Keplerian (Espada et al 2005). A small companion is detected in HI close to CIG 96, although is probably not massive enpugh to have caused the observed perturbations. Accretion of a gaseous companion at a radial velocity lower than the maximum is discussed there as a possible origin. AMIGA sample has been used as a reference for the study of HCGs.

2 Hickson Compact Groups

We have analyzed the total HI contents in 72 HCGs and investigated the detailed distribution and kinematics of the HI in a subset of 16 groups using high resolution VLA observations (Verdes-Montenegro et al. 2001, hereafter VM01, 2002, 2005; Sulentic et al 2001; Williams et al 2002). This sample was not complete in any sense since it was the result of the combination of our new observations with already available data from archive/bibliography. These groups contain, on average, only about 40% of the HI expected for their optical luminosities and morphological types. We previously proposed an evolutionary scenario in which the amount of HI decreases with the secular evolutionary state (VM01), and proposed a picture where HI is stripped from spiral galaxies within virialising groups and is then transformed (via shocks) into the surrounding hot intergalactic gas. We also found a lower molecular gas content than expected for the galaxies in HI deficient groups at a 3σ level, suggesting that the HI stripping by frequent tidal interactions breaks the balance between the disruption of molecular clouds by SF and the replenishment from the ambient HI. Also the most extreme cases of HI deficient galaxies mapped at the VLA turned to be strongly deficient in molecular gas, and their FIR emission was not enhanced with respect to their optical luminosity, indicating that SF was not triggered by the interactions. A global comparison of FIR emission and HI content for a significant sample of HCGs could not be performed due to a low overlapping of the available data.

As a step further to the study of individual VLA-mapping of HI groups, understanding the general cause of the atomic gas destruction requires a well-defined sample of groups. We have selected all those HGCs which:

- have four or more group galaxies (i.e. triplets and false groups excluded);
- contain at least one spiral galaxy (so that the HI deficiency can be determined meaningfully); and
- are located at a distance ≤ 100 Mpc (for $H_0 = 75\ \mathrm{km\,s^{-1}\,Mpc^{-1}}$)

This yields a sample of 22 systems. We have sorted these groups according to their HI content, which would presumably correspond to an evolutionary scenario as proposed in VM01. Up to now we have mapped the HI distribution in 17 of these groups using the VLA in C- and/or D-arrays, and this includes new VLA observations of 8 HCG deficient groups (HCG 15, 30, 37, 48, 58, 93, 97,100). We are also allocated additional VLA time to map HI in HCGs with a mild level of deficiency,

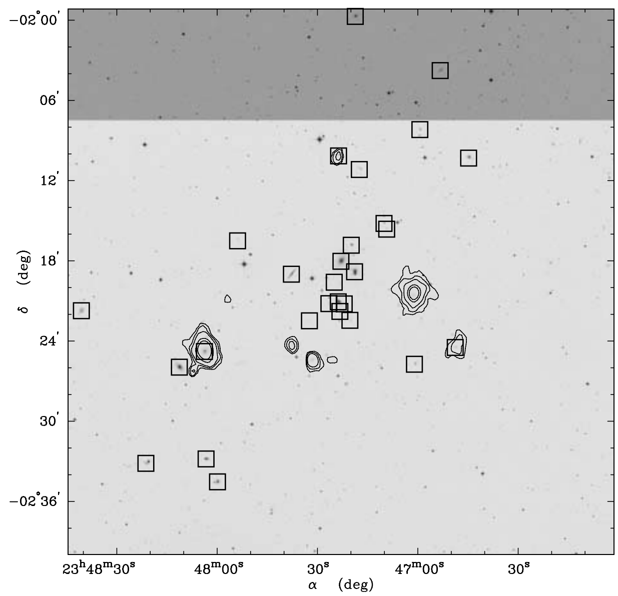

Fig. 1. HI column density contours on a POSSII image of HCG 97. The squares correspond to galaxies at the same redshift as the group.

With our new data we find that the most deficient galaxies are located at smaller distances with respect to the group center normalized to the group size. This clearly shows that the mechanism to produce the HI deficiency is acting most actively towards the group center. This result is nicely complemented by the comparison of HI and X-rays data for the most HI deficient HCGs. In the cases of HCG 37 and HCG 40 the mass found in hot gas is similar to the one missing in HI. HCG 37 and HCG 97 also have an HI and X-rays distribution suggestive of an anticorrelation of both components (Fig. 1, see also Mahdavi et al X). A similar process to the one going on in HCG 92 (reference?) could be responsible for the HI deficiency of a subset of HCGs. Heating of the gas might be, at least in some cases, at the origin of the HI deficiency.

These larger dataset has allowed a comparison of the deficiency in HI, molecular gas and FIR emission (Fig. 1). The trend previously found at at 3σ

level is now visible as a correlation with a high dispersion, indicating that the more deficient groups in HI tend also to have a lower H_2 content. The same trend is found when the HI deficiency is compared with the FIR emission, also lower for the most HI deficient groups. These results suggest that when HI is removed from the galaxies the molecular gas is not replenished, so inhibiting the SF activity and depressing the FIR emission level. This is also consistent with the not enhanced level of Hα emission found by Vilchez and Iglesias (reference).

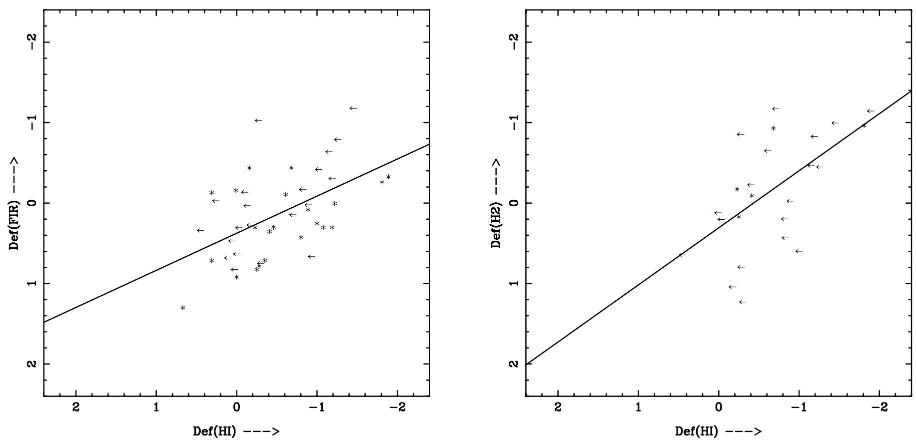

Fig. 2. FIR (left) and H_2 (right) deficiency as a fucntion of HI deficiency for the HCG galaxies in our sample.

Espada et al 2005
Falco et al. 2000
Leon & Verdes-Montenegro 2003
Sulentic 1976,
Sulentic 1989
Xu & Sulentic 1991
Verdes-Montenegro et al 1998
Verdes-Montenegro et al (2005)
Verdes-Montenegro et al. 2001, 2002
Sulentic et al 2001;
Williams et al 2002)