ISM of Galaxies in Extremely Different Environments: Isolated vs Compact Groups

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Summary. We present a study of the HI, CO and FIR emission properties of galaxies in dense groups and compare with those of the reference sample of extremely isolated galaxies defined in the AMIGA project. We have 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 it affects the other ISM components. In order to investigate the process leading to HI deficiency, we imaged HI in a redshift limited sample of compact groups using the VLA. Surprisingly, some of these groups show little HI emission down to a column density as low as 10^{19} cm^{-2}. We find a trend for the most HI deficient groups to be also deficient in CO and FIR emission, and we propose that when HI is removed from the galaxies the molecular gas is not replenished, inhibiting future star formation activity.

1 AMIGA reference sample of isolated galaxies

It is widely believed that galaxy interactions stimulate secular evolutionary effects, but the amplitude of the effects and driving physical processes are not well quantified [6], [7]; [17]. As an example ubiquitous tidal interactions among Hickson Compact Groups (HCG) galaxies predict enhanced star formation (SF) activities, but their observed CO and FIR luminosites are surprisingly low [13]. There is no clear consensus on whether SF enhancement depends mainly on the parameters of the tidal encounter or the pre-existing gas reservoirs in the galaxies. These uncertainties reflect the lack of a statistically useful baseline. The main goals of the AMIGA project (Analysis of the interstellar Medium of Isolated GAlaxies, `http://www.iaa.es/AMIGA.html`) are the identification and parameterization of a local statistically significant sample of the most isolated galaxies. By quantifying the properties of different phases of the interstellar medium in isolated galaxies, the effects of the denser environment on the evolution of galaxies can be better understood.

1.1 Sample selection and refinement

Our base sample is the Catalog of Isolated Galaxies (CIG: [3]) which includes 1051 objects. In order to achieve our goals a careful refinement has been performed: positions have been revised [4], more distances have been retrieved (N = 956 galaxies[11], the isolation has been checked and its degree quantified [15], and the morphologies have been revised [9].

1.2 Multiwavelength study

Our optical study of the CIG sample has shown that the AMIGA sample is reasonably complete (∼80%) up to $m_{B-\mathrm{corr}} \sim 15.0$ [12]. We emphasize the nonstellar material that is particularly sensitive to the effects of external stimuli. Data have been obtained or compiled from the bibliography for neutral (HI), molecular (CO), and ionized (Hα) gas, and radiocontinuum emission as an extinction-free tracer of current SF rate and AGN diagnostic tool when combined with FIR data. FIR data from IRAS and the blue Zwicky magnitudes complete our data set for this sample.

One specific investigation on the impact of environment has been the galaxies with HI asymmetry. We have identified a well-defined sample of the most isolated galaxies showing significant asymmetries in their HI profiles and obtained VLA-HI images in order to look for signs of external interactions (Espada et al., in prep). One of the most interesting galaxies in our

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

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 [1]. We detected a small companion in HI close to CIG 96, although it is probably not massive enough to have caused the observed perturbations. We also discussed accretion of a gaseous companion at a radial velocity lower than the maximum.

2 Hickson Compact Groups

We have analysed 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 [14], [11], [12]; [8]; [16]. This sample was not complete in any sense since it was assembled by combining 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 proposed an evolutionary scenario in which the amount of HI decreases with the secular evolutionary state [14] and the HI stripped from spiral galaxies 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, 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. The most HI deficient galaxies are also strongly deficient in molecular gas, and their FIR emission was not enhanced with respect to their optical luminosity, indicating that no SF was triggered by the interaction. A global comparison of FIR emission and HI content in a significant sample of HCGs could not be performed due to a low overlapping of the available data.

For the next step in our VLA imaging, we expanded the sample with the following uniform selection criteria: a) have 4 or more group galaxies (i.e. triplets and false groups excluded); b) contain at least one spiral galaxy (so that the HI deficiency can be determined meaningfully); and c) are located at a distance $\leq$ 100 Mpc (for $H_0 = 75\ \mathrm{km\,s^{-1}\ Mpc^{-1}}$). This yields a sample of 22 systems. We sorted these groups according to their HI content, which would presumably correspond to an evolutionary scenario as proposed in [14]. So far we have mapped the HI distribution in 17 groups using the VLA in C- and/or D-array, including recent new VLA observations of 8 HI deficient groups (HCG 15, 30, 37, 48, 58, 93, 97,100). We have been allocated additional VLA time to map HI in HCGs with a mild level of deficiency.

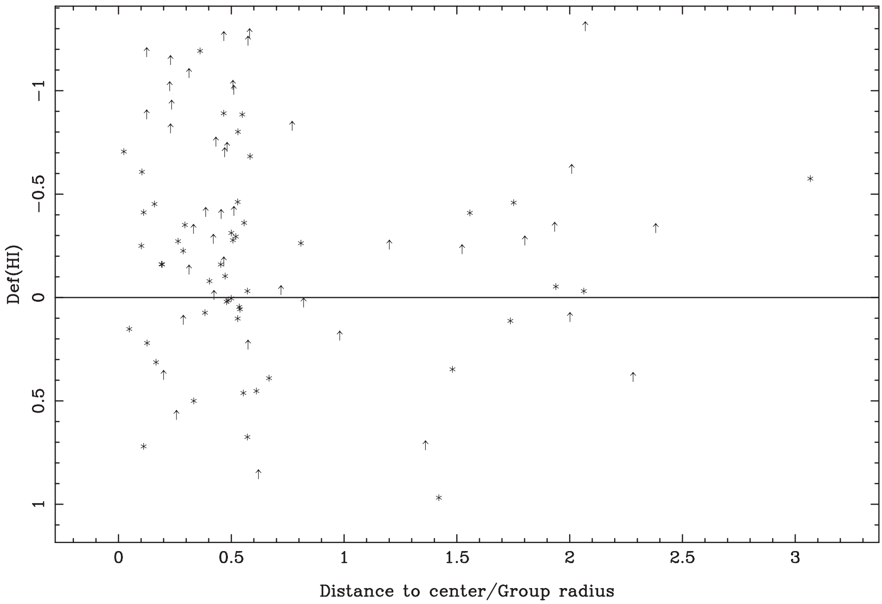

Fig. 1. HI deficiency versus of distance to the center, normalized to the group size.

Our analysis of the new data has revealed that the most HI-deficient galaxies are concentrated within one group radius (Fig. 1). This shows that the mechanism responsible for the HI deficiency is operating most actively at the group center. This result is nicely complemented by the comparison of HI and X-ray data for the most HI deficient HCGs. In HCG 37 and HCG 40, the hot gas mass derived from the X-ray data is similar to the one missing in HI. HCG 37 and HCG 97 also show anticorrelated HI and X-rays distributions (Fig. 2 for the HI, see [5] for the X-ray). Heating of the gas might be in some cases the cause of the HI deficiency as in HCG 92 [10].

We have also analyzed the deficiency in HI, molecular gas, and FIR emission (Fig. 3) using the new expanded database. The trend previously found at 3σ level is now visible as a stronger correlation albeit 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 luminosity. These results suggest that when HI is removed from galaxies the molecular gas is not replenished, inhibiting the SF activity and suppressing the FIR emission level. This is also consistent with the absence of enhanced Hα emission [2].

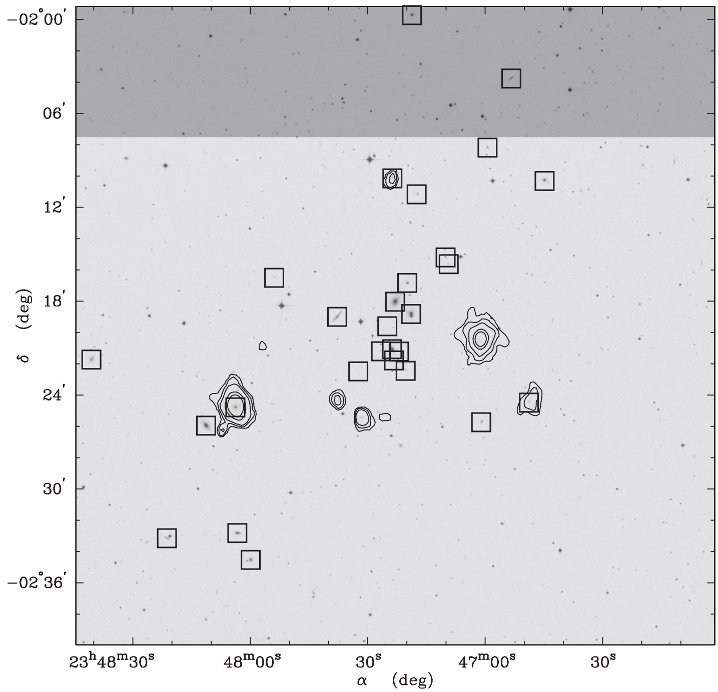

Fig. 2. HI column density contours on a POSSII image of HCG 97. The squares correspond to galaxies at the same redshift as the group.

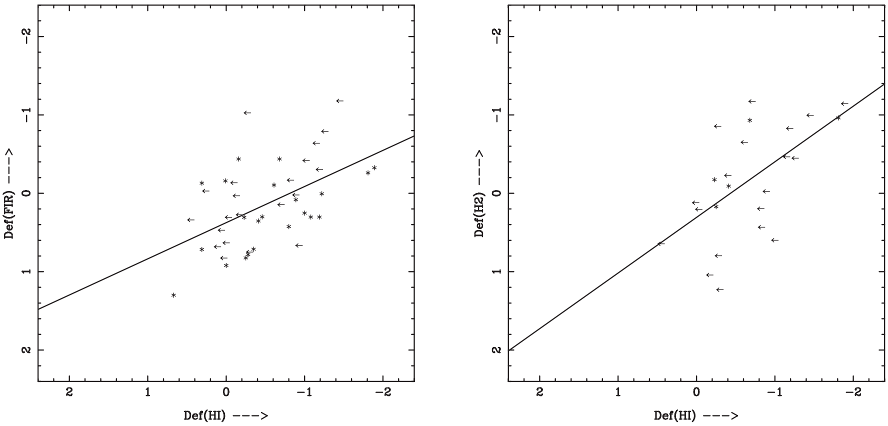

Fig. 3. FIR (left) and H_2 (right) deficiency as a function of HI deficiency for the HCG galaxies in our sample. The fits to the data are represented by the lines.

References

1. Espada, D., Bosma, A., Verdes-Montenegro, L., Athanassoula, E., Leon, S., Sulentic, J., Yun, M. S. 2005, A&A 442, 455
2. Iglesias-Paramo, J., Vilchez, J. M, 1999, ApJ 518, 94
3. Karachentseva, V. E. 1973, Comm. Spec. Ap. Obs., USSR 8, 1
4. Leon, S., Verdes-Montenegro, L. 2003, A&A, 411, 391
5. Mahdavi, A., Finoguenov, A., Bohringer, H., Geller, M. J., Henry, J. P. 2005, ApJ 622,187
6. Sulentic, J. W. 1976, ApJS, 32, 171
7. Sulentic, J. W. 1989, AJ, 98, 2066
8. Sulentic, Jack W., Rosado, M., Dultzin-Hacyan, D., Verdes-Montenegro, L., Trinchieri, G., Xu, C. Pietsch, W. 2001, AJ 122, 2993
9. Sulentic J. W., Verdes-Montenegro, L., Bergond, G., Lisenfeld, U., Durbala, A., Espada, D., Garcia, E., Leon, S., Sabater, J., Verley, S., Casanova, V., Sota, A. 2006, A&A in press
10. Trinchieri, G., Sulentic, J., Pietsch, W., Breitschwerdt, D. 2005, A&A 444, 697
11. Verdes-Montenegro, L., Del Olmo, A., Iglesias-Paramo, J., Perea, J., Vilchez, J. M, Yun, M. S.,Huchtmeier, W. K. 2002, A&A 396, 815
12. Verdes-Montenegro, L., Sulentic, J., Lisenfeld, U., Leon, S., Espada, D., Garcia, E., Sabater, J., Verley, S. 2005, A&A 436, 443
13. Verdes-Montenegro, L., Yun, M. S., Perea, J., Del Olmo, A., & Ho, P. T. P. 1998, ApJ 497, 89
14. Verdes-Montenegro, L., Yun, M. S., Williams, B. A., Huchtmeier, W. K., Del Olmo, A., Perea, J. 2001, A&A 377, 812
15. Verley 2006, PhD
16. Williams, B. A., Yun, Min S., Verdes-Montenegro, L. 2002,AJ 123, 2417
17. Xu, C., Sulentic, J. W. 1991, ApJ, 374, 407