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Environmental Effects on Galaxies in Clusters and Groups

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Abstract

Galaxies in clusters and groups are perturbed by the effects of the environment due to ram pressure stripping of their HI gas by an intra-cluster X-ray gas or to gravitational interactions between galaxies or with the cluster potential well. We will review the most recent results concerning some galaxies in the Virgo Cluster and in the Stephan's Quintet and show how extragalactic HII regions can be formed from debris stripped by ram pressure or tidal interactions.

1 Introduction

Since more than 30 years several environmental effects on cluster galaxies have been evidenced: the HI deficiency (Davies & Lewis 1973, Chamaraux et al. 1980), the Butcher-Oemler effect (Butcher & Oemler 1978), the Morphological-Density relation (Dressler 1980), dynamical perturbations (Rubin et al. 1999) and a reduction of the star formation rate (Koopmann & Kenney 2004). Several possible mechanisms such as ram pressure stripping (Gunn & Gott 1972), viscous stripping (Nulsen 1982), thermal evaporation (Cowie & Songaila 1977), or tidal interactions with nearby companions and /or with the cluster potential well (Moore et al. 1996) have been invoked to explain the depletion of the cold gas.

Several 3-dimensional SPH/N-body simulations to study ram pressure stripping of gas in spiral galaxies orbiting in clusters (Abadi et al. 1999; Quilis et al. 2000; Schulz & Struck 2001) have confirmed that gas in disk galaxies gets stripped up to the stripping radius estimated by Gunn & Gott (1972). Using an N-body/sticky- particle code and a time variable ram-pressure while the galaxies move on radial orbits through the cluster, Vollmer et al. (2001) have shown than the HI disks are damaged when the galaxy encounters the highest density region of the X-ray gas in the central region of the cluster. Moreover, they predicted that a fraction of the stripped gas could fall back on the galaxy disk and locally produce enhanced star formation.

Being one of the nearest cluster, the Virgo cluster is a good laboratory to study in great details the effects of the environment on cluster galaxies. A VLA survey of the HI distribution in galaxies located at different distances from the cluster center has shown that galaxies close to the cluster center are more HI deficient and have smaller HI disks than galaxies in the outskirt of the cluster or in the field (Cayatte et al. 1990, 1994). The recent work of Koopmann & Kenney (2004) also showed a cluster-centric effect on the Hα morphologies of galaxies. Results obtained from a Fabry-Perot interferometry survey of 30 galaxies (Chemin et al. 2005b) will be used to study the environmental effects on their high-resolution Hα velocity field, to compare the Hα and HI kinematics, to look for possible faint, outer HII regions far from a galaxy disk as it has been discovered in in e.g. NGC 4388 (Yoshida et al. 2002, Gerhard et al. 2002) or NGC 4438 (Kenney et al. 1995, Chemin et al. 2005a) and ultimately to compare with results obtained by numerical simulations.

The interactions between galaxies in compact groups are even more drastic as it can be seen in the Stephan's Quintet (Mendes de Oliveira et al. 2004) where isolated HII regions have been evidenced far from the galaxies.

Section 2 will present the main results of the HI deficiency in the Virgo Cluster, section 3 will give the example of some individual galaxies, section 4 will present the discovery of isolated HII regions far from galaxies in a compact group. A conclusion will give perspectives for future works.

2 The HI Deficiency in the Virgo Cluster

A statistical study of the HI deficiency in cluster galaxies has been done by Solanes et al. (2001) using single dish data of about 1900 galaxies in nearby clusters compared with isolated galaxies of same size and same morphological type. They show that the percentage of deficient galaxies increases toward the center of the cluster, with already deficient galaxies as far as 2 Abell radius, far beyond the dense intracluster gas. No correlation is found with global properties of the cluster, such as X-ray luminosity, X-ray temperature or radial velocity dispersion which is surprising. Nevertheless the most important conclusion is that the most probable mechanism which causes the HI deficiency is ram pressure stripping.

The HI survey of the Virgo Cluster, done at the VLA by Cayatte et al. (1990, 1994) has shown that HI deficient galaxies have smaller HI diameters and that they could be devided in four groups according to the ratio of their HI diameter to the optical one: almost normal galaxies, lightly affected HI disks, severely affected HI disks and anemic galaxies (as defined by van den Bergh 1976) which present an annular HI distribution and a very low HI surface density compared to the other groups. A similar analysis has been done on the Coma Cluster (Bravo-Alfaro et al. 2000, 2001). Only 15 nearby clusters have been mapped in HI so far, for a complete list and a review, see Verheijen (2004).

Using an N-body/sticky- particle code and a time variable ram-pressure while the galaxies move on radial orbits through the cluster, Vollmer et al. (2001) succeeded to reproduce Cayatte et al. (1994) results concerning the relation between the ratio of the HI diameter to the optical one versus the HI deficiency and predicted the possibility of the re-acretion of some of the stripped gas. Several papers on individual galaxies, reobserved at the VLA or with a Fabry Perot, have directly compared 3-dimension observations with the results of 3-D simulations for several galaxies in the Virgo or the Coma Cluster (Vollmer et al. 1999, Vollmer et al. 2000, Vollmer 2003, Vollmer et al. 2004a, Vollmer et al 2004b). The simulations are severely constrained by the observations, they have to reproduce the HI deficiency, the position in the cluster, the gas distribution and the velocity field, the simulated and observed data cubes are directly compared in order to identify the responsible mechanisms and date the stripping event.

3 NGC 4438

Multi-wavelength studies at high spatial and spectral resolutions are the clues to a better understanding of the evolution of galaxies in nearby clusters. Chemin et al. (2005b) started an Hα survey of the brightest spiral galaxies in the Virgo cluster using several telescopes (3.6m Canada France Hawaii Telescope, 3.6m at ESO, 2m at Mégantic Observatory and 1.93m at Haute Provence Observatory). These data will be used to study the effects of the environment on the kinematics of each galaxy, as done by Rubin et al. (1999) with a slit and a much lower

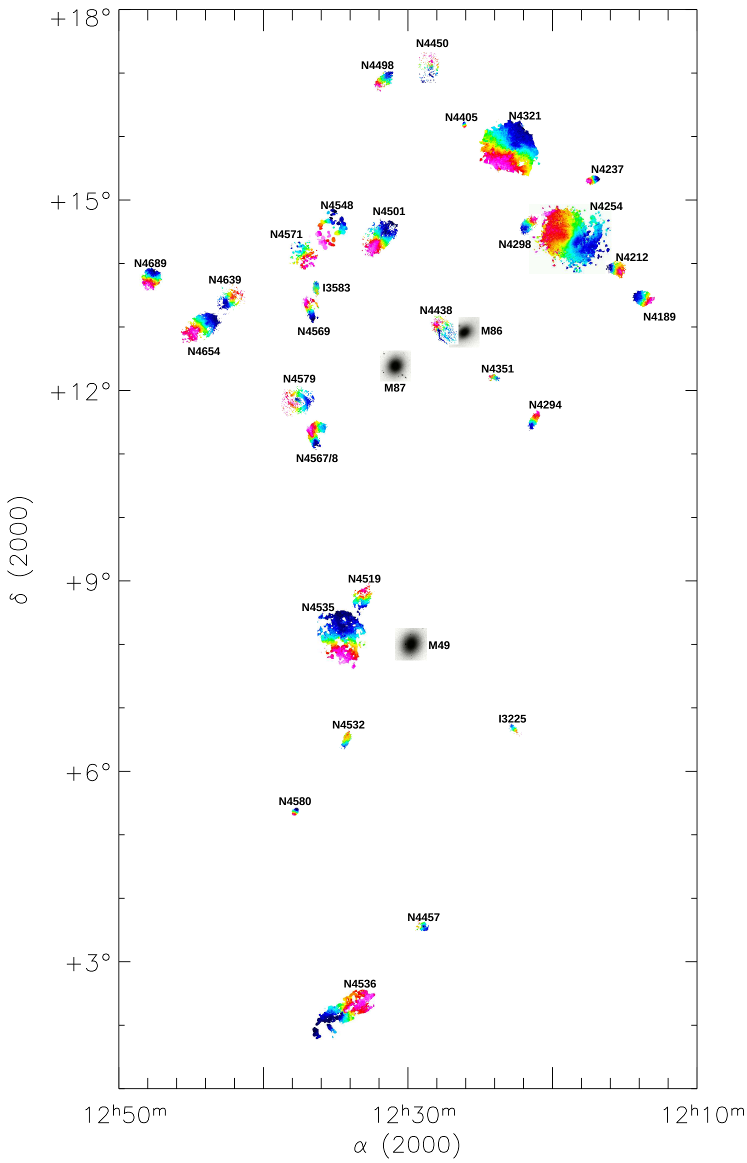

Figure 1: A view of 30 Virgo cluster galaxy velocity fields map. For clarity reasons, the angular scale of each of the 30 galaxies has been enlarged by a factor of ~ 9.5 w.r.t. the real scale. The locations of the 3 large ellipticals M49, M86 and M87 are shown using broad-band optical images. The colour scale is blue-darker shades (red-lighter shades) for the approaching (receding respectively) side of galaxies. The velocity field of each galaxy will be presented in Chemin et al. (2005b, in prep.).

spatial and spectral resolution. Figure 1 shows the Hα velocity maps of each observed galaxy enlarged by a factor of ∼ 10 located at its position in the central region of the Virgo Cluster (Chemin et al. 2005b).

We focus here on NGC 4438, which is one of the closest spiral galaxy to the cluster center. It has one of the most peculiar morphology of all the spiral galaxies in the Virgo Cluster, with very perturbed HI CO, Hα and X-ray morphologies (Combes et al. 1988, Cayatte et al. 1990, Kenney et al. 1995, Machacek et al. 2004 respectively). Combes et al. (1988) observed an off-plane CO cloud to the West of the disk. They succeeded in modelling the very peculiar stellar morphology of NGC 4438 (large tidal tails extending to the North and South of the disk) by a tidal interaction with a companion, NGC 4435. As a consequence of such an interaction, they proposed that part of the molecular gas was displaced outside the disk to explain their observation. Kenney et al. (1995) showed an impressive view of the optical ionized gas morphology, with multiple, very extended (up to ∼ 10 kpc) filaments to the West of the disk. They proposed that the displacement of all the gas was due to an ISM-ISM collision between the two galaxies. Cayatte et al. (1990) only observed an off-plane HI cloud to the West, but no gas in the disk.

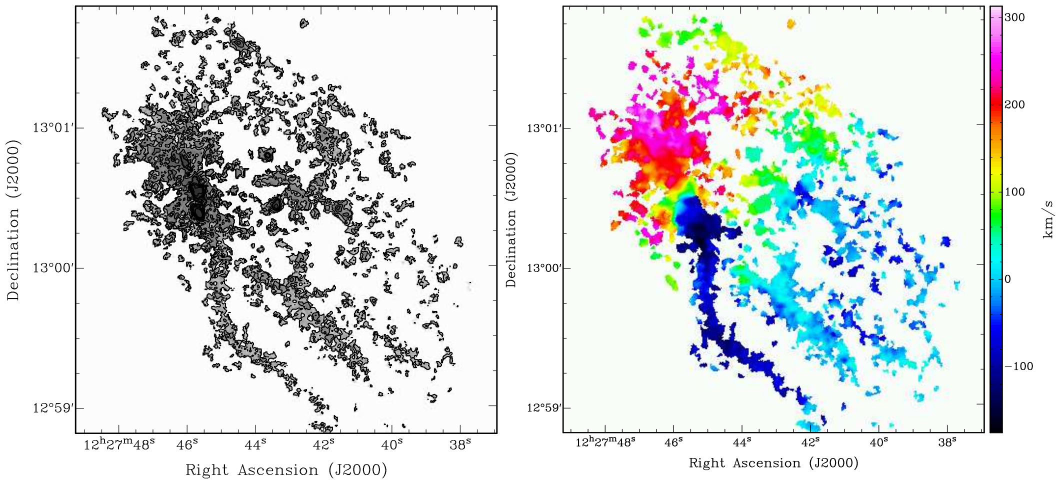

Figure 2: Hα emission-line (left) map and velocity field (right) of NGC 4438 (Chemin et al. 2005a), an extremely perturbed galaxy in the core of the Virgo cluster. The systemic velocity of the galaxy is ∼ 70 km s^{-1}.

Figure 2 shows the Hα emission-line and velocity maps of NGC 4438 (Chemin et al. 2005a), obtained with Fabry-Perot interferometry at the ESO 3.6m telescope. They have obtained an Hα image, comparable with the one obtained by Kenney et al. (1995), but showing new faint filamentary structures, in the northern part of the f-o-v for example. They have produced the most complete velocity field of the galaxy, showing that the off-plane filaments are still bound to the galactic disk. New CO observations and simulations, including ram pressure stripping by the Intra Cluster Medium and tidal interaction with NGC 4435 have been performed by Vollmer et al. (private communication) showing that these two mechanisms are needed to explain the NGC 4438 morphology and velocity field.

Other individul cases have been studied in great detail at different wavelengths (NGC 4388,

NGC 4522, NGC 4548, NGC 4569, NGC 4654), mostly by Vollmer and collaborators. All these galaxies seem to be in a different stage of evolution in the Virgo Cluster and after observing more galaxies, the goal will be to establish a time sequence in the interaction of galaxies with the environment as already suggested by Vollmer et al. (2004a). The most intriging case is NGC 4388, in regard with what we would like to stress in this paper concerning the fate of the stripped gas and the possible birth of isolated HII regions in clusters and groups.

Gerhard et al. (2002) discovered an isolated compact HII region projected at a distance of several kpc North and West of NGC 4388 disk and evaluated an age of about 3 Myr which imply that it has been formed outside of the galaxy disk. Vollmer et al. (2003) detected a large HI cloud probably connected to the very extended plumes detected by Yoshida et al. (2002). A numerical ram pressure simulation can account for the observed HI spectrum obtained at Effelsberg radiotelescope and the morphology of the Hα plume and the HII region can be explained as a stripped gas cloud that collapsed and decoupled from the ram pressure wind due to its increased density.

According to Vollmer et al. (2004a) a stripping sequence could be the following one: (i) strong stripping leading to a large HI deficiency (NGC 4388, NGC 4438, NGC 4522, NGC 4548, NGC 4569: during the maximum ram pressure phase high surface density gas is pushed out of the galactic disk (NGC 4438, NGC 4522). When the expelled gas moves to greater distances from the disk, it expands and evaporates leading to low surface density HI features (NGC 4388). The falling-back gas can be seen in kinematically perturbed low surface density arms such as in NGC 4569; (ii) weak stripping combined with a tidal interaction leading to small HI deficiency as seen in NGC 4564.

4 Isolated HII regions in Compact Groups

Clusters of galaxies are the location of transformation of spiral galaxies falling in the cluster into S0 galaxies, being denser, the Compact Groups should present even more drastic effects on galaxy evolution.

Verdes-Montenegro et al. (2001) have proposed an evolutionary sequence for Hickson compact groups from HI observations: (i) a low level of interaction such as HCG 59; (ii) multi-tidal features such as HCG 15 with two sub-categories, one with no HI in the galaxies (HCG 92 also know as Stephan's quintet; HCG 40) and one with an HI envelop (HCG 48).

The Stephan's quintet has been observed in almost all wavelengths in order to understand how the galaxies interact. The most complete analysis has been done by Moles et al. (1997) who proposed an explanation for the fact that most of the HI gas has been removed from the galaxies by the former crossing of one object through the group plus a recent tidal interaction. Mendes de Oliveira et al. (2001) identified tidal dwarfs in Stephan's Quintet and Mendes de Oliveira et al. (2004) evidenced four intergalactic HII regions formed far from the galaxies inside the HI tail (see Fig. 3) and showed that they have been formed in situ according to their age and high metallicity through the compression of the intergalactic HI gas by galaxies collisions.

Other examples of isolated HII regions exist in the litterature (Ryan & Weber 2004, Oosterloo et al. 2004) showing that isolated HII regions are a common phenomenon due to tidal interactions or interactions with the Intra Cluster Medium. The HI gas pushed away from galaxies can be considered as seeds for star formation far from the galaxy disks.

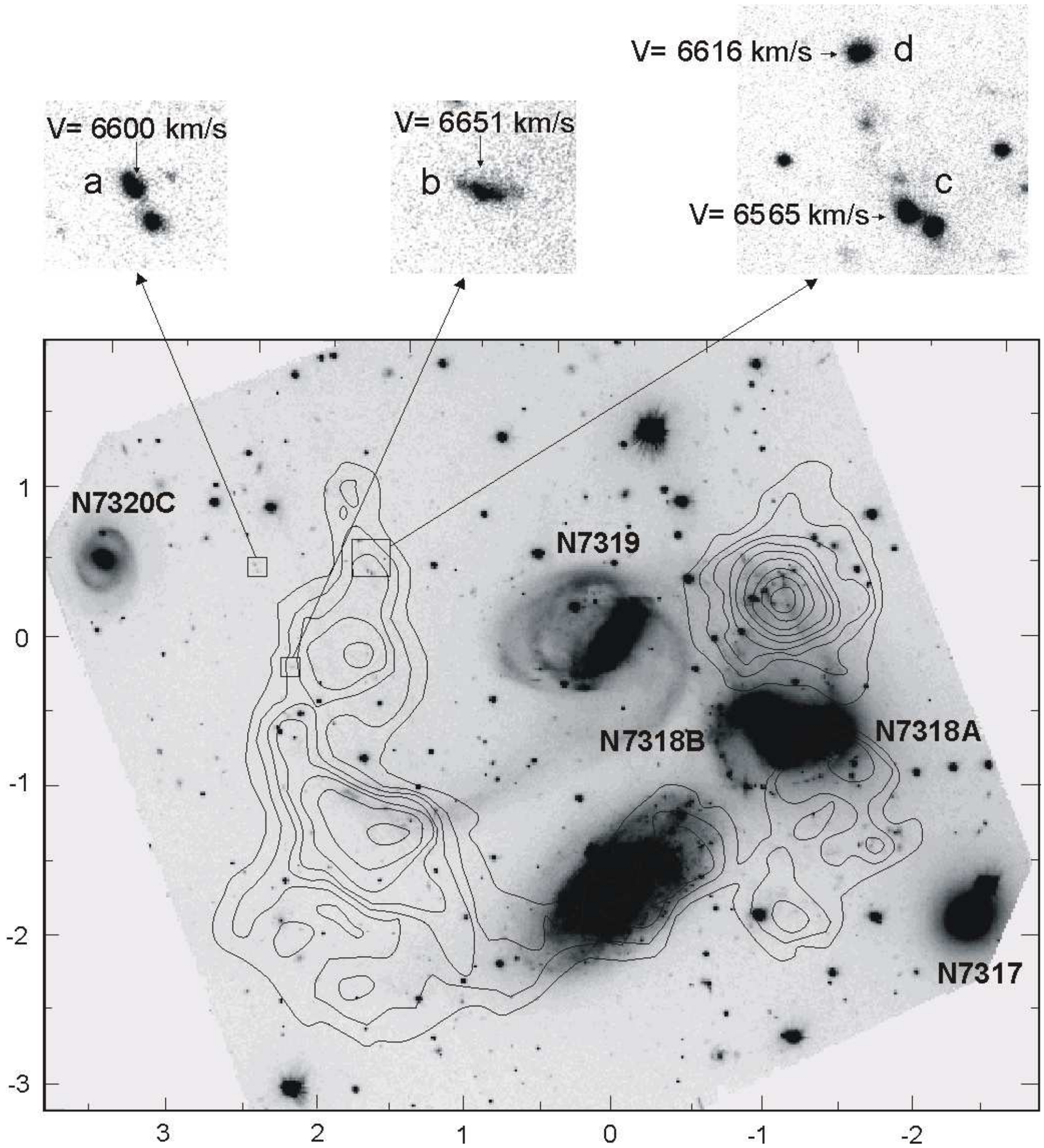

Figure 3: A r' image of Stephan's quintet obtained with Gemini North telescope and the GMOS. Overplotted are the HI contours from Williams et al. (2002). The three boxes in the upper left-hand corner indicate the regions where the new isolated HII are found. Zoomed views of the same are seen in the top panels. The radial velocities are indicated. We note that all regions are within the HI tail.

5 Conclusions

Properties of galaxies in nearby clusters are affected by environmental effects. Several mechanisms could be responsible for the observed HI deficieny. The most probable being ram pressure stripping and/or tidal interaction. The best way to disentangle among the different processes is the direct comparison of observed data cube and simulated ones. One of the most important predictions of the simulations is the re-accretion of part of the expelled gas who could either fall back on the galaxy disk and enhance locally the star formation rate or survive in the Intra Cluster Medium where star formation could appear even far from the disks.

Future works will allow to confirm the time sequence which is already proposed for the evolution of spiral galaxies in nearby clusters. The comparison with distant cluster at z greater than 0.2, which is the actual limit for HI observations, would be very interesting to study the evolution with redshift. We will have to wait for the Square Kilometer Array (SKA) to be able to measure the content, the morphology and the kinematics of Neutral Hydrogen beyond a redshift of 1. This will complete our understanding of the physical processes that shape the galaxies and determine their evolution in any environment.

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