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Tracing interactions in HCGs through the H I[1]

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Abstract. We present a global study of H I spectral line mapping for 16 Hickson Compact Groups (HCGs) combining new and unpublished VLA data, plus the analysis of the H I content of individual galaxies. Sixty percent of the groups show morphological and kinematical signs of perturbations (from multiple tidal features to concentration of the H I in a single enveloping cloud) and sixty five of the resolved galaxies are found to be H I deficient with respect to a sample of isolated galaxies. In total, 77% of the groups suffer interactions among all its members which provides strong evidence of their reality. We find that dynamical evolution does not always produce H I deficiency, but when this deficiency is observed, it appears to correlate with a high group velocity dispersion and in some cases with the presence of a first-ranked elliptical. The X-ray data available for our sample are not sensitive enough for a comparison with the H I mass; however this study does suggest a correlation between

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H I deficiency and hot gas since velocity dispersions are known from the literature to correlate with X-ray luminosity.

1. Introduction and data

HCGs constitute a specially appropriate laboratory for the study of interactions among galaxies. Our aim is to understand how star formation, morphology and dynamics are affected by the environmental conditions, and our approach is multiwavelength (e.g. Yun et al 1997, Verdes-Montenegro et al 1998). Since the atomic hydrogen is a sensitive tracer of tidal interaction (e.g. Hibbard & Van Gorkom 1996, Hibbard 1999), we have performed VLA mapping of a large number of HCGs which added to the previously published ones (Williams & Van Gorkom 1988 - WVG88, Williams, MacMahon and Van Gorkom 1991 - WMVG 91, Williams & Van Gorkom 1995 - WVG95, Williams et al 1997 - W97) and lead to a total sample of 16 groups. In two cases (HCG 31 and HCG 79) we have obtained higher spatial and spectral resolution data which have helped to improve our understanding of these systems. All the H I data herein are analyzed together for the first time and provide a sample to test previously proposed models of compact groups as well as a detailed database for hydrodynamical simulations. HCG 2, 18 and 54 are considered apart since the first one is a triplet, and the others likely have less than 4 galaxies.

2. H I content and distribution

We have measured the H I mass associated with the main body of the galaxies as well as that found in gaseous tidal features, except for HCG 26 (WVG88) and HCG 49, where the emission is found in a large envelope containing all group members and therefore cannot be separated. The H I content of the spiral and lenticular galaxies has been compared with the predicted one for their optical luminosity (Fig. 1a) based on the relationships obtained by Haynes & Giovanelli (1984) for a sample of isolated galaxies. We note that HCG 33 has only a spiral member, which has a bright star on the top, hence an accurate determination of L_B cannot be obtained. Disks with a normal H I content are found but most galaxies have significant amounts of missing gas, and this is evident in spite of the intrinsic dispersion in the H I content ($\sigma \sim 0.25$ in log). None of the lenticular galaxies (empty circles) in this sample have been detected, but since they usually show a wide range of H I content, we have checked that their inclusion does not affect significantly our conclusions. The total mass expected for a group is also plotted, and has been calculated as the sum of the expected values for each member. The use of the summed L_B to predict a total H I mass would produce an artificial systematic deficiency in the log of 0.2 due to the non-linearity of the M(H I) - L_B relation. We have plotted in Fig. 1b the total detected H I mass, i.e., including gas external to the galaxies. Comparison of both panels tell us whether the missing H I is located in tidal features or just disappeared. This together with the morphology and kinematics of the H I shows the existence of different distributions, as we describe next.

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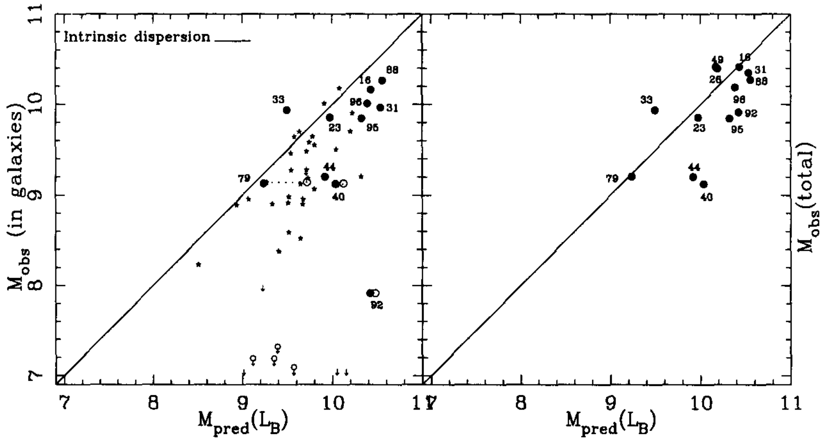

Figure 1. a) Observed against predicted H I mass in the disks of the individual galaxies (stars for detections, arrows for upper limits, and empty circles for S0s). The filled circles represent the H I mass of HCGs considering only the gas in the disks of the galaxies and excluding S0 types. The connected open circles show the result when they are included. The the difference is only significant for HCG 79. b) Total H I mass detected in each group plotted against predicted H I mass.

2.1. Most of the H I mass within the galaxies

HCG 23, HCG 33 and HCG 88 have more than 90% of the H I mass associated to the disks and show little or no signs of interaction (WVG95, W97). HCG 88 constitutes however a very interesting case as it might be considered a filament seen in projection along the line of view. The low velocity dispersion of this quartet (~ 30 km s^{-1}) together with its high degree of isolation (De Carvalho et al 1997) contradict the chain alignment hypothesis. Consequently we think that HCG 88 is a good example of a physically dense group in a very early stage of interaction.

2.2. Significant H I mass in tidal features

HCG 16, 31 and 96 show most of the missing gas in numerous tidal features, indicating that multiple interactions are taking place. In HCG 96, 30% of the H I mass is located in two intense tidal tails plus a bridge. H96b is a bright elliptical with an optically detached core (Verdes-Montenegro et al 1997) plus an extended envelope brighter in the direction of the tidal tails (Fig. 2).

Tidal features were also reported for HCG 16 from D array data by W97 and our new C array data resolve the emission indicating that a 40% of H I is distributed in two intense bridges and two tails. Consequently there is no room for diffuse X-ray emission in this group. This result is inconsistent with the conclusion reached by Mamon 2000 (this conference). The most extreme case is that of HCG 31 where 60% of the gas is located in 4 tidal tails and 1 bridge (WMVG91, Del Olmo et al 1999). HCG 79, the densest group in the HCG catalog, could be included in this category since its only spiral member shows a

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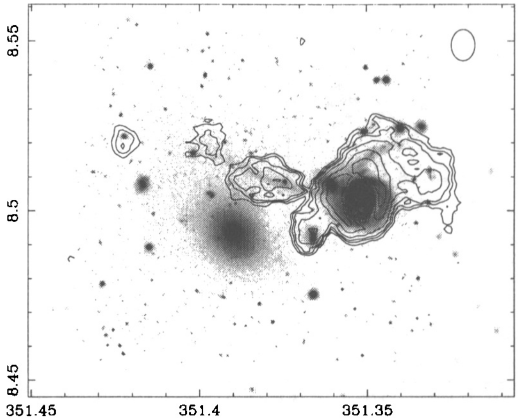

Figure 2. *R*-band image of HCG 96 obtained at the NOT (Nordic Optical Telescope). The contours correspond to the H I column density distribution.

tidal tail smoothly connected in velocity with the galactic disk. Considering the two anemic lenticulars, the group is strongly H I deficient and might be better placed in the next category, little H I coupled with the galaxies. The optical diffuse envelope that contains the whole group (Sulentic & Lorre 1983) suggests that this configuration is the product of a much older perturbation; yet, the H I morphology indicates a subsequent and more recent interaction, i.e., tidal tail, that has not yet perturbed the H I disk of the sole spiral member of the group. The presence of the diffuse optical envelope makes it more plausible that the anemic lenticular members were once spiral galaxies stripped of their gas during the these earlier interactions.

2.3. Little H I coupled with the galaxies

H I *deficient groups.* HCG 40, HCG 44 (WMVG91), HCG 92 (W99) and HCG 95 (Huchtmeier et al 1999) have an H I deficiency of 70 to 90%, as found by Williams and Rood (1987) and Huchtmeier (1997) from single dish observations. Our maps show that this deficiency is due to all galaxies in the group (Fig. 3a). In the case of HCG 92 the $8 \times 10^9 M_\odot$ of H I detected are fully located in several clouds and tidal features (W99), so we were not able to discriminate from which members the gas was missing. However the multiplicity of features plus the small amount of detected H I strongly suggest that the missing gas was related to most if not all galaxies in the group. In Fig. 3b we show the most striking mapped case, HCG 40, where only one half of the disk of H40c is detected in H I plus a small cloud to the eastern side of H40d.

Single H I *cloud.* The H I towards HCG 26 (WVG88) and HCG 49 constitutes a single envelope with a velocity gradient decoupled from the individual galaxies. In the case of HCG 49 the cloud is round-shaped, with a velocity gradient of ~ 250 km s^{-1} containing 4 well differentiated galaxies with a velocity dispersion of 34 km s^{-1} and a total optical diameter of 35 kpc. This cloud constitutes

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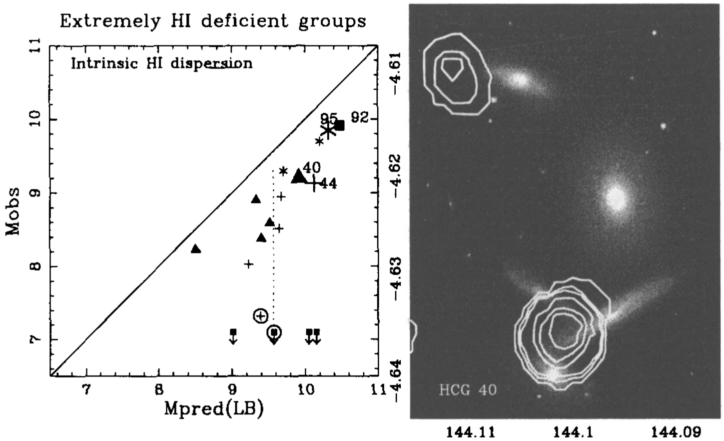

Figure 3. a) Observed against predicted H I masses for the most H I deficient groups. Big symbols correspond to group masses and small ones to individual masses. The open circles correspond to S0 galaxies and arrows to upper limits. The dotted lines mark the location of each galaxy in HCG 92 if all mass detected, located in external features, would be assigned to it. b) J & K' band image of HCG 40 taken with Subaru where the contours corresponding to the H I column density distribution are plotted.

a challenge for dynamical models due to the coexistence of separated optical morphologies and a global common kinematics.

3. Discussion

HCG galaxies respond to their environment at different levels: 60% have redistributed the atomic gas and 65% have a lower than expected content given the intrinsic dispersion of this quantity. Since the gas is missing from all galaxies in the group it implies that all of them are interacting with each other and/or with an intragroup medium. The total number of groups perturbed in one of these two ways amounts to 77%. Both kinds of perturbations do not coexist in all cases: we find H I deficient groups for which most H I is found in tails and external clouds (e.g. HCG 92) while the groups embedded in a single H I cloud have a normal H I content. The evolution from mild interactions to the generation of multiple tidal features can be well understood as an extrapolation of interacting pairs. Formation of a single cloud with coherent kinematics implies a larger degree of evolution, and it might be related to the fact that these groups are mostly composed of dwarf galaxies (around 15 kpc in diameter) which tend to have more extended H I disks, as suggested by Bosma (priv. comm.). HCG 31 is a promising candidate to form a large envelope due to its present H I distribution and kinematics together with the small size of its galaxies.

From our data, we point out two possible causes for the observed H I deficiency. One is the presence of a first ranked elliptical which could be the case for HCG 40 and 95, since they constitute a deep potential well that can accrete gas (Vílchez & Iglesias-Páramo 1998). The second one can be the presence of hot gas, as in HCG 92 where tidal features contain all the detected gas which anticorrelates with a ridge of X-ray emission (Pietsch et al 1997). The available X-ray data for our H I sample are mostly upper limits; therefore analyses of the X-ray correlations are limited. We have found a correlation between H I deficiency and the group velocity dispersion. The velocity dispersion of a different but larger sample of HCGs correlates with X-ray emission (Ponman et al 1995). This is in the sense that the deficiency increases with the X-ray emission. Gas accretion from giant ellipticals, or a hot medium may compete in the production of H I deficient groups. These factors will be studied further in a subsequent paper.

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