STUDY OF A SLICE AT +9° TO +15° OF DECLINATION. I. THE NEUTRAL HYDROGEN CONTENT OF GALAXIES IN LOOSE GROUPS

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ABSTRACT

We examine the H I content of spiral galaxies in groups by using a catalog of loose groups of galaxies identified in a magnitude-limited sample (m2 < 15.7) spanning the range 8° ≤ α ≤ 18° in right ascension and +9° ≤ δ ≤ +15° in declination. The redshift completeness of the galaxy sample is approximately 95%. No significant effect of H I depletion is found, although there may be a hint that the earliest type spirals are slightly deficient.

Key words: galaxies: clusters: general — ISM: atoms

1. INTRODUCTION

Evidence that the internal properties of galaxies are in some ways determined by large-scale clustering has accumulated throughout the years. One of the first results suggesting this was presented by Davis & Geller (1976), who showed that early-type galaxies have clustering properties that are different than late-type ones. By studying a sample of rich clusters, Dressler (1980) was able to show that a well-defined relation exists over 5 orders of magnitude in density between the local density of galaxies and the relative proportions of different morphological types, the so-called morphology-density relation. This was later shown to extend to lower density regions, such as groups of galaxies, by Postman & Geller (1984) and Maia & da Costa (1990). All these works demonstrate that the fraction of early-type galaxies increases with local density.

Several other galactic properties have been claimed to be affected by the environment, such as the formation of cD galaxies, enhancement of star formation rate, presence of active galactic nuclei, bars in spiral galaxies, colors, and far-infrared emission, among others. In particular, it has been found that the neutral hydrogen (H I) content of galaxies of a given morphological type depends on the environment (e.g., Haynes & Giovanelli 1986; Magri et al. 1988; Huchmeier & Richter 1989; Scodeggio & Gavazzi 1993; and more recently, Maia et al. 1994) in the sense that galaxies in denser regions, such as the cores of clusters of galaxies, are deficient in H I when compared with “field” galaxies (e.g., Haynes & Giovanelli 1986). This H I deficiency is usually attributed to the process of ram pressure sweeping. In a similar way, Williams & Lynch (1991) detected a gas content that is lower than average for the spiral members in four poor clusters, while Williams & van Gorkom (1988) and Williams & Rood (1987) detected a similar effect when analyzing several compact groups.

Haynes (1981) found the presence of H I streams in six out of 15 groups of galaxies. Giuricin, Mezzetti, & Mardirossian (1985) used galaxies in loose groups identified by Geller & Huchra (1983) to examine the H I content. In a sample of 213 spiral and irregular galaxies, they did not observe evidence of gas removal, nor did they find a variation of the H I properties as a function of group compactness or even with the distance of the galaxies to the centers of the groups. The fact that Geller & Huchra’s (1983) groups are known to be plagued by interlopers may have disguised some possible result that favors H I deficiency, particularly if this effect is not conspicuous. Those results indicate that gas removal does occur in clusters; what happens in less dense structures is still an open question. There is observational evidence at several wavelengths for the presence of an intergalactic medium in loose groups, which could remove the gas from spiral galaxies (e.g., Dell’Antonio, Geller, & Fabricant 1994; Henry et al. 1995; Mulchaey et al. 1996). Henry et al. (1995) claim that the X-ray luminosity and temperature functions may be considered to be smooth extrapolations from rich clusters of galaxies. There are also radio observations with the VLA in 20 cm by Burns et al. (1987), who report the presence of tailed radio galaxies and attribute this fact to the existence of an intragroup medium.

Besides the mechanism proposed above, tidal effects could be another possible process for gas removal that might be efficient in groups, since the velocity dispersions of those systems are low (typically ≈250 km s⁻¹) and close encounters of galaxies will last for a considerable amount of time, allowing the external parts of the galaxies to be removed. In fact, after examining galaxies in loose groups using ROSAT, VLA, and optical data, Davis et al. (1997) concluded that both effects appear to be acting on the galaxies. They also suggest that the stripping of gas by the intragroup medium is made more efficient after a gravitational encounter.

Thus, we expect that the effect of gas removal may be present in some degree for density regimes such as those found in loose groups of galaxies. In this paper, we generate a catalog of loose groups by means of objective criteria and evaluate the H I content of the constituent galaxies. We also

1 Research reported herein is based partly on observations obtained at Arecibo Observatory (Puerto Rico), Complejo Astronomico El Leoncito (Argentina), Laboratório Nacional de Astrofísica (Brazil), and the European Southern Observatory (Chile).
examine the possible role of the mechanisms for gas removal, driven either by hydrodynamic or by gravitational forces, in a typical loose-group environment. The selection criteria for the sample of galaxies, as well as the group definition, are described in § 2, and the H I content of group galaxies is analyzed in § 3. A brief conclusion is presented in § 4.

2. THE SAMPLE AND LOOSE-GROUP DEFINITION

2.1. Galaxy Sample

In this work, we analyze a magnitude-limited sample of galaxies taken from the Catalogue of Galaxies and Clusters of Galaxies (Zwicky et al. 1961–1968, hereafter CGCG), in the region of the sky defined by the intervals of declination +9° to +15° and right ascension 8h to 18h. A detailed description of the catalog, observations, and data reduction will be given in a forthcoming paper, so only a brief description is presented here. All 2366 galaxies in this list up to $m_p = 15.7$ were visually inspected in overlays of the Palomar Observatory Sky Survey plates and had improved measurements of coordinates and major and minor diameters, as well as morphological types. Whenever possible, multiple systems had these parameters measured and magnitudes estimated for individual members. For those galaxies also listed in the Uppsala General Catalogue of Galaxies (Nilson 1973, hereafter UGC), the morphological classification and diameter measurements were maintained as quoted in the UGC, unless we had a case of a split multiple system, for which new parameters were calculated. Late-type galaxies (Sa and later) were selected to be observed with the 305 m Arecibo radio telescope, while for the early types, as well as spirals that were not observed in 21 cm, we used the 2.15 m telescope of the Complejo Astronomico El Leoncito, San Juan, Argentina, the 1.6 m telescope of the Laboratório Nacional de Astrofísica, Itajubá, Brazil, and the European Southern Observatory 1.52 m telescope, La Silla, Chile. At the present time, the redshift completeness of this sample is better than 95%. The incompleteness is partly caused by the observational procedure used in the 21 cm survey. Typically, the search for 21 cm emission was carried out in the interval from 0 to $\pm 16,000$ km s$^{-1}$ using bands of about 6000 km s$^{-1}$. In the final period of the radio survey, we carried out searches up to 25,000 km s$^{-1}$, and several galaxies not previously detected proved to be in that new search interval of velocities.

2.2. Determination of Loose Groups

The algorithm adopted for the construction of the catalog of groups of galaxies is basically that described by Huchra & Geller (1982) with the improvements by Ramella, Geller, & Huchra (1989) and by Maia, da Costa, & Latham (1987) to minimize the number of interlopers. This percolation algorithm identifies groups of galaxies in a magnitude-limited sample. A search for companions around galaxies is carried out by taking into account projected separations satisfying

$$D_{12} = 2 \sin (\theta_{12}/2)V/H_0 \leq D_L$$

and with line-of-sight velocity differences

$$V_{12} = |V_1 - V_2| \leq V_L .$$

In the above expressions, $V = (V_1 + V_2)/2$, $V_1$ and $V_2$ are the radial velocities of the galaxies, and $\theta_{12}$ is their angular separation. The quantities $D_L$ and $V_L$ are search parameters.
because our intent is to examine the H I content in structures with density regimes of groups. The galaxies that were not assigned to groups formed a subsample called "isolated," which we used as a control sample. Isolated galaxies whose separation from the survey boundaries were smaller than the projected search radius appropriate for their radial velocity were removed from the "isolated" sample. For both subsamples, only galaxies with absolute magnitudes $-21 \leq M_I \leq -17$ and radial velocities $\leq 12,000$ km s$^{-1}$ were considered in this analysis. The distribution of velocities for the galaxies in both samples is more or less the same, excluding the possible bias of a particular sample composed of only distant or nearby objects. Furthermore, we examined whether more massive galaxies could be more susceptible to gas loss, by examining the distribution of the estimators with redshift for each morphological type. We have detected no such trend.

Two estimators of the H I content are used. The first is the pseudo–H I surface density $\Sigma_{HI}$, in $M_\odot$ pc$^{-2}$, which is the total H I mass $M_{HI}$ in solar units divided by the optical area of the galaxy, defined as

$$\Sigma_{HI} = M_{HI} / (\pi/4)D_h^2,$$

where $M_{HI} = 2.356 \times 10^5 d^2 F_c$, $D_h$ is the optical diameter in kpc, $d$ is the distance in Mpc, and $F_c$ is the 21 cm line flux corrected for galactic self-absorption in Jy km s$^{-1}$ as described by Haynes & Giovanelli (1984). The second estimator is the H I mass-to-light ratio $M_{HI}/L_B$ in solar units, assuming a solar photographic absolute magnitude of +5.37. This estimator removes the dependence of the H I content on the blue galaxy luminosity, as well as reducing the scatter about the mean values better than $\Sigma_{HI}$ alone (Giovanelli & Haynes 1988). By compiling a larger sample and using additional procedures, such as that proposed by Solanes, Giovanelli, & Haynes (1996), which takes into account a complete H I flux–limited data set, we could use another methodology. For the purpose of this paper, we adopt the two estimators described above to perform the analysis of the H I content.

Table 2 presents the statistical results of the $\Sigma_{HI}$ distribution for both samples. Column (1) lists the morphological type, column (2) the number $N$ of galaxies of a given morphological type, column (3) the mean $\Sigma_{HI}$, column (4) the median ($\Sigma_{HI}\median$), column (5) the standard deviation $\sigma$, and columns (6) and (7) the lower (LQ) and upper (UQ) quartiles of the distributions for "isolated" galaxies. Columns (8)–(13) have the same parameters as columns (2)–(7) for "group" galaxies. The Kolmogorov-Smirnov (K-S) test was applied to both subsamples for each morphological type to determine whether they could have all come from the same parent population. Column (14) of Table 2 contains the probability $P_{KS}$ of this hypothesis occurring by chance.

In general, the statistical results presented in Table 2 indicate no significant dependence of $\Sigma_{HI}$ on the environment. Only the Sa and Sb galaxies in loose groups present some trend toward H I deficiency, while the intermediate sample of Sab galaxies presents no such effect. The results are summarized in Figure 2, in which we show $\Sigma_{HI}\median$ (squares) with respective LQ and UQ (bars) of $\Sigma_{HI}$ distributions for each morphological type.

The statistics for the $M_{HI}/L_B$ estimator are presented in Table 3 and Figure 3. Here there is slightly stronger evi-
Table 2: Statistics of $\Sigma_{HI}$ for Galaxies of Isolated and Group Samples

| Type  | Isolated | Group |
|-------|----------|-------|
|       | $N$      | $\Sigma_{HI}$ | $\langle \Sigma_{HI} \rangle_{med}$ | $\sigma$ | LQ  | UQ  | $P_{KS}$ |
|       | (2)   | (3)       | (4)       | (5)    | (6)  | (7)  | (8)     |
| Sa    | 11    | 11.05     | 10.02     | 5.61   | 6.49 | 14.44| 19.00   | 0.042   |
| Sab   | 13    | 17.71     | 13.98     | 13.72  | 7.53 | 20.35| 12.00   | 0.942   |
| Sb    | 53    | 16.03     | 13.07     | 11.51  | 6.90 | 21.40| 46.00   | 0.033   |
| Sbc   | 36    | 12.68     | 12.37     | 6.51   | 7.54 | 15.65| 20.00   | 0.615   |
| Sc    | 77    | 12.89     | 10.51     | 8.05   | 7.59 | 14.91| 52.00   | 0.292   |
| Scd   | 13    | 12.32     | 11.94     | 3.98   | 9.02 | 13.92| 4.00    | 0.587   |
| S...  | 67    | 18.34     | 12.13     | 14.61  | 9.23 | 20.41| 57.00   | 0.524   |

Table 3: Statistics of $M_{HI}/L_B$ for Galaxies of Isolated and Group Samples

| Type  | Isolated | Group |
|-------|----------|-------|
|       | $N$      | $M_{HI}/L_B$ | $\langle M_{HI}/L_B \rangle_{med}$ | $\sigma$ | LQ  | UQ  | $P_{KS}$ |
|       | (2)    | (3)         | (4)         | (5)    | (6)  | (7)  | (8)     |
| Sa    | 11    | 0.337       | 0.275       | 0.212  | 0.162| 0.428| 0.074  | 0.011   |
| Sab   | 13    | 0.434       | 0.387       | 0.255  | 0.285| 0.427| 0.230  | 0.026   |
| Sb    | 53    | 0.309       | 0.296       | 0.181  | 0.165| 0.422| 0.300  | 0.339   |
| Sbc   | 36    | 0.394       | 0.338       | 0.276  | 0.199| 0.498| 0.298  | 0.582   |
| Sc    | 77    | 0.419       | 0.351       | 0.266  | 0.251| 0.476| 0.372  | 0.360   |
| Scd   | 13    | 0.452       | 0.357       | 0.285  | 0.229| 0.558| 0.532  | 0.532   |
| S...  | 67    | 0.323       | 0.266       | 0.191  | 0.195| 0.393| 0.287  | 0.076   |

Fig. 2.—Medians and upper and lower quartiles of the $\Sigma_{HI}$ distributions, discriminating galaxies between the different morphological types.
limited.

A comparison between our results for $M_{\text{HI}}/L_B$ and other results in the literature is displayed in Figure 4, which shows the average values and standard deviations of $M_{\text{HI}}/L_B$ for galaxies of the Virgo Cluster ("Cluster") obtained by Huchtmeier & Richter (1989), for "group" and "isolated" galaxies as defined in this work, and for the isolated sample (Iso2) of Haynes & Giovanelli (1984). The binning of Sa with Sb has been chosen, as it allows us to compare our results with those cited above. In Figure 4, we find that the control sample that we have used agrees with the Iso2 sample. The smaller scatter in our "isolated" sample is due to the restrictions in the absolute magnitude interval we have applied. There is also a clear trend toward the $\text{H} \alpha$ deficiency for cluster galaxies, but for "group" galaxies this effect is marginal.

An alternative mechanism for gas removal would be via tidal interactions. To examine this possibility, we have divided the "group" sample according to the $\sigma_v$-values of their respective groups. The $M_{\text{HI}}/L_B$ ratio is examined for each subsample, which present values of $\sigma_v$ smaller and higher than the mean value for the entire group sample, which is 231 km s$^{-1}$. The results, displayed in Figure 5, do not exhibit any systematic behavior with $\sigma_v$. In fact, the Sa galaxies, which we believe show the strongest evidence of gas depletion, based on the K-S test, present the opposite behavior of what would be expected in the case of tidal interactions. Therefore, this result tends to support the interpretation that early spirals incur gas depletion by ram pressure stripping. However, it is intriguing that Sc's, when examined as a function of $\sigma_v$, show a hint that systems with low values of $\sigma_v$ are significantly more depleted than those

![Figure 3](image1.png)

**Fig. 3.—**Same as Fig. 2, but for $M_{\text{HI}}/L_B$

![Figure 4](image2.png)

**Fig. 4.—**Mean and standard deviations for $M_{\text{HI}}/L_B$ distributions. "Cluster" refers to the Virgo Cluster sample by Huchtmeier & Richter (1989), "group" and "isolated" are as defined in this work, and "Iso2" refers to the isolated sample of Haynes & Giovanelli (1984).

![Figure 5](image3.png)

**Fig. 5.—**Medians and upper and lower quartiles of the $M_{\text{HI}}/L_B$ distributions for subsamples of galaxies that belong to groups with values of $\sigma_v$ smaller and larger than the median value 231 km s$^{-1}$ of the entire sample of groups.
with higher values. This appears to agree with the results of Davis et al. (1997).

4. SUMMARY

We have examined the dependence of the H I content of spiral galaxies with local environment. For this purpose we identified loose groups of galaxies by means of objective criteria. This procedure also allowed us to define a control sample of isolated galaxies. Two estimators were used to measure the H I content of galaxies: $\Sigma_{HI}$ and $M_{HI}/L_B$; both estimators show no clear tendency of spiral galaxies in loose groups having a lower amount of H I, although there may be a hint for the earliest spirals, but we cannot claim these results as being statistically significant, because of the small number of objects involved. We have also evaluated whether the H I content of spiral galaxies shows any correlation with the group velocity dispersion. Our results are inconclusive. Ram pressure may be a probable mechanism for producing the gas removal of galaxies in groups. However, the contribution to the gas stripping by gravitational forces produced in close encounters cannot be discarded. By compiling a larger sample and using additional procedures, such as that proposed by Solanes et al. (1996), it might be possible to investigate the importance of hydrodynamic and gravitational forces to removal of gas from galaxies of loose groups.

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