The environmental dependence of neutral hydrogen content in spiral galaxies

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Abstract. We present a study of the relationship between the deficiency of neutral hydrogen and the local three-dimensional number density of spiral galaxies in the Arecibo catalog [1] of global HI measurements. We find that the dependence on density of the HI content is weak at low densities, but increases sharply at high densities where interactions between galaxies and the intra-cluster medium become important. This behavior is reminiscent of the morphology-density relation [2] in that the effect manifests itself only at cluster-type densities, and indeed when we plot both the HI deficiency-density and morphology-density relations, we see that the densities at which they “turn up” are similar. This suggests that the physical mechanisms responsible for the increase in early types in clusters are also responsible for the decrease in HI content.

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INTRODUCTION

Many observational studies (e.g. [2]) have shown that galaxy populations in clusters have very different properties than those in lower density environments. Of note is the decrease in atomic hydrogen content of galaxies in clusters [3, 4]. Recent studies by [5] have shown that spirals in the Pegasus cluster, which is a relatively poor cluster, suffer from atomic hydrogen deficiency even though the densities are relatively low. The question naturally arises how these spirals have lost a large fraction of their gas while residing in an intermediate density cluster. Therefore, we chose to investigate the behavior of HI content as a function of environment, and to specifically learn what, if any, dependence existed at intermediate densities comparable to the Pegasus cluster. Thus, we aimed to explore the characteristic density at which we see a transition from “normal” field galaxies into gas-depleted cluster galaxies, and to explore the behavior of the transition: is it a sudden increase or a gradual trend that extends down to low densities (i.e., that of loose groups)?

GALAXY SAMPLE

Our HI measurements were provided by the Arecibo catalog published by [1]. The catalog consists of global HI fluxes from over 8,000 spiral galaxies in the “Arecibo sky.” We calculate the HI deficiency parameter (DEF) using the technique of [4]. A galaxy’s DEF value is the logarithmic difference between the typical HI mass of a sample of field galaxies with the same linear diameter and morphological type, and the observed HI
mass of the galaxy, and is thus a measure of the amount of atomic hydrogen which has been removed from, or prevented from replenishing, the galaxy.

DENSITY MEASUREMENT

We have chosen the three dimensional number density of galaxies to represent the local environment, using the Updated Zwicky Catalog [6]. With the sky positions and local-group–corrected redshifts of the objects in the UZC, and adopting a value of the Hubble constant of $H_0 = 75$ km s$^{-1}$, we can assign each galaxy a 3D position in a Cartesian coordinate system. To calculate the local density, we find the mean distance to an object’s six nearest neighbors, and use that distance to define the radius of a sphere containing the “local” region. The number of objects contained within the sphere is divided by the physical volume of the sphere to obtain a number density in units of Mpc$^{-3}$. In order to offset luminosity function (LF) completeness effects and peculiar velocity contamination of redshifts, we have chosen a velocity range for our sample of 3,000 km s$^{-1}$ to 6,500 km s$^{-1}$, and have multiplied all of the densities by a LF correction factor. The factor is the ratio of the observable number of galaxies at 3,000 km s$^{-1}$ to the observable number of galaxies at the redshift of the galaxy in question, as measured by integrating the LF to the limiting magnitude of the sample.

RESULTS

We present a scatter plot of DEF vs density in Fig. 1 for our galaxy sample. It is difficult to make out any appreciable trend by eye, so we also present the data binned in density intervals. It is clear from the figure that the mean DEF is relatively constant, aside from some small scatter, at low and moderate densities, but increases suddenly in the highest density interval.

![Fig. 1](image)

**FIGURE 1.** Left: HI deficiency as a function of local density for our sample of 2,227 galaxies. Right: Points in top plot have been binned in intervals of density. Thick lines are mean values, and dotted lines are 25% and 75% quartiles.

The behavior of the deficiency with density is quite similar to the classical morphology-density relationship ([2]), in that it is relatively constant up to a certain
density threshold and then increases rapidly. We therefore reproduce the morphology-
density relation with our data, using similar techniques to those in the literature ([7]),
and compare it to the DEF-density trend. In Fig. 2 we present again the DEF-density
relation, but with a surface density measurement calculated using the technique of [7].
We also plot the fractions of morphological types as a function of surface density to
show that the increase in HI deficiency corresponds to the increase in early types as
surface density increases. This similarity certainly points to a common physical process
which occurs in dense environments; obvious possibilities include stripping by the
intracluster medium and galaxy-galaxy interactions.

**FIGURE 2.** Left: DEF-density relation using surface density. Right: Morphology-density re-
lation using same sample of galaxies. Stars represent spirals, and circles represent E and S0
galaxies.

**CONCLUSIONS AND FURTHER WORK**

Our investigation into the dependence on environment of the atomic hydrogen content
of galaxies has reinforced the idea that gas depletion mechanisms play an important
role in the observed decrease of galaxy gas as local density increases. Specifically, we
see that the same density regime corresponds to both the increase in early type fraction
and the decrease of HI mass in spiral galaxies. In the future, we plan on improving our
density estimates by including galaxy masses, and we will also examine the possible
effect of a Malmquist-type bias due to distant, high deficiency galaxies falling below the
HI detection limit.

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