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# Gas-Rich Dwarf Galaxies in Dense and Sparse Environments

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## I. INTRODUCTION

Dwarf irregular galaxies (generically labelled Im for the present purposes) pose an enigma to students of galaxy evolution. In nearby groups and the Virgo cluster, Im galaxies are at least as abundant as spiral galaxies, and their low surface brightnesses and high gas-to-stars ratios suggest that (at least in the stochastic self-propogating star formation scenario) there should be significant numbers of HI clouds with masses approaching $10^8$ $M_\odot$ which have undergone very little or no star formation. To date, however, no clouds with so little star formation that they would not be recognized as Im galaxies on high-quality photographic plates have been identified. There have been suggestions (Dekel and Silk 1986) that such dwarfs may be tidally disrupted in regions of high galactic density, but may be prevalent in low density regions.

We offer data from three parallel programs relevant to this issue. (1) A large number of Im galaxies throughout the Local Supercluster have been mapped in the HI spectral line using the Arecibo Radiotelescope, and we can establish the frequency with which HI disks much more extended than their optically visible portions are found. (2) Our extensive mapping of spiral and dwarf galaxies in the Virgo cluster allows us to set stringent limits on the density of star-free HI clouds in that cluster. (3) We have conducted a sampling of the void in the distribution of galaxies toward the supergalactic pole, optimized for finding low-mass HI clouds at redshifts out to ~2000 km $s^{-1}$.

## II. HI MAPPING OF DWARF GALAXIES

In several campaigns at Arecibo Observatory, we have mapped 70 dwarf galaxies with the 3.′2 Arecibo 21 cm beam. While this beam-size is too large for us to determine rotation curves accurately in many cases, it is almost optimal for detecting whether or not the galaxies (with optical radii ~1′ for the most part) have extended HI haloes. The overwhelming majority of these have HI extents no more than about twice their Holmberg radii, and we know of only four that have HI radii exceeding their Holmberg radii by a factor of 5 or more. Two of these (DDO 154 and HI 1225+01, the latter mapped by Giovanelli et al. 1991) are apparently isolated, but the other two (DDO 137 and VCC 2062) may be distended by tidal interaction with a larger galaxy at small separation. One (DDO 154) appears to be a rotating disk with the optical component at the center; the other three are more asymmetric, with an off-center peak column density and a small irregular patch of stars that sits squarely at the point of peak column density. In all cases the column density remains below a few$\times 10^{20}$ atoms $cm^{-2}$ which is thought to be a threshold for star formation (Bothun et al. 1990 and references therein), except at the highly localized region occupied by stars.

The main point of our mapping campaigns is that such extended HI clouds are rare among dwarf galaxies. These four stand out graphically on a Tully-Fisher plot of HI profile width to HI diameter; however, on plots relating profile width to *optical* quantities these extended envelope galaxies do not appear extraordinary. It is clear that only a small fraction of dwarf irregular galaxies have a low density, extended, HI reservoir at this epoch, even if only dwarfs outside of known clusters and groups are considered. However, it is not clear whether other Im's evolved from such a cloud which was later stripped by tidal (or other) mechanisms.

## III. LIMITS ON STAR-FREE HI CLOUDS IN VIRGO

In Hoffman et al. (1989) we established limits on the number of gas clouds in the Virgo cluster with HI masses comparable to those of the faintest Im galaxies, but no visible stars. Here, I will summarize those results briefly: We have acquired some 1640 ON/OFF pairs of spectra in our studies of the spiral and dwarf populations of the Virgo cluster. In the portions of those spectra outside the velocity range of the targetted galaxy, and in the accompanying reference beams, we detected no signal that could not be attributed to a known, optically visible, spiral or dwarf galaxy (or to the extended cloud around DDO 137 — Hoffman et al. 1992b). The effective surveyed volume is somewhat larger than 3% of the total volume spanned by the

Virgo cluster members in the *Virgo Cluster Catalog* (Binggeli et al. 1985), and our results limit the number of star-free clouds with HI masses $\gtrsim 3\times10^7$ $M_\odot$ to $\lesssim 100$ for the entire volume.

## IV. DWARF GALAXIES IN LOW-DENSITY REGIONS

To check the hypothesis that low-mass galaxies with low internal densities formed prolifically throughout the universe, but have been tidally disrupted within clusters and groups within superclusters, we sampled a region generally toward the supergalactic pole where the density of bright galaxies is quite low. Since the line-of-sight to any other void in the galaxy distribution must pass through some portion of the plane of the Local Supercluster, the supergalactic pole region should be the nearest void and therefore lends itself to the most sensitive limits on the number density of very low-mass HI clouds. Briggs (1990) has reviewed the various surveys for clouds of higher mass in a variety of environments.

Our pilot survey (Hoffman et al. 1992a) probed the environs of a small group of IRAS-detected spiral galaxies at redshift ~2500 km $s^{-1}$ and galactic latitude $b^{II} \sim 15°$ and the redshift range in its foreground. We found two previously unknown dwarf galaxies in the group, but no signals in the foreground. Our sensitivity was such that we should have detected HI masses as low as $10^7$ $M_\odot$ at the group redshift, down to $\sim 5\times10^5$ $M_\odot$ at the near redshift limit (~250 km $s^{-1}$). Our limit translates to about 5% of closure density for HI masses as small as $\sim 5\times10^6$ $M_\odot$ (assuming $H_o = 100$ km $s^{-1}$/Mpc) and is more stringent for larger masses ($\lesssim 10^8$ $M_\odot$). Weinberg et al. (1991) give even more stringent limits on the density for masses $\gtrsim 10^8$ $M_\odot$.

## V. CONCLUSIONS

While a few dwarf galaxies ($\lesssim$ 10% or all mapped late-type dwarfs) with HI extents $\gtrsim 5$ times the diameter of their star-forming regions have been found, we do not find the population of low-mass, optically faint, gas-rich dwarf galaxies that straight-forward applications of stochastic self-propogating star-formation models would seem to predict. This does not necessarily invalidate the scenario; refinements incorporating galactic winds and/or dependence of star formation efficiency on metal abundance may, as suggested by various authors, rapidly convert gas-rich proto-dwarfs to gas-poor dwarf ellipticals or spheroidals. The number density of gas-poor dwarfs at the present epoch is not constrained at all by our observations. One hypothesis that will be interesting to explore is whether all low-mass proto-dwarf galaxies disappeared (from our radio-telescopes at least) in the burst of "faint blue galaxies" at a redshift $z \sim 1$ (Broadhurst et al. 1988; Babul and Rees 1992), leaving only the much more massive (and relatively rare) systems like DDO 154, HI 1225+01 and the Malin-type spirals with arrested star formation in a persisting HI disk.

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