An HI selected sample of galaxies — The HI mass function and the surface brightness distribution

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Abstract

Results from the Arecibo HI Strip Survey, an unbiased extragalactic HI survey, combined with optical and 21cm follow-up observations, determine the HI Mass Function and the cosmological mass density of HI at the present epoch. Both are consistent with earlier estimates, computed for the population of optically selected galaxies. This consistency occurs because, although the distribution of optical central surface brightnesses among galaxies is flat, we fail to find a population of galaxies with central surface brightnesses fainter than 24 B-mag arcsec^{-2}, even though there is no observational selection against them.

Keywords: Galaxies: Luminosity Function, Mass Function; Surveys

1 Introduction

There have been speculations that low surface brightness (LSB) galaxies and intergalactic clouds might constitute a substantial portion of the population of nearby extragalactic objects and that they might contain comparable mass to that in normal galaxies. The LSB population would escape detection optically and would not be included in the galaxy luminosity functions that are used to compute the visible baryonic content of the local Universe (Disney 1976, McGaugh 1996). On the other hand, estimates of the HI mass function (HIMF) based on published observations (Briggs 1990) have seemed to indicate that there is probably not any substantial population that has been missed. Weinberg et al (1991) and Szomoru et al (1994) have come to the same conclusion. Until recently, there were no galaxy samples that could be used to address this question empirically, since the galaxies were all first identified optically.

In this paper we present results from the Arecibo HI Strip Survey, an unbiased 21cm survey with adequate sensitivity to detect HI of very low surface density. It is of sufficient length (approximately 15 hours of RA) and depth (7400 km s^{-1}) that it should be immune to fluctuations due to the large scale structure. The total sky coverage was $\sim$65 square degrees. In the main beam, which has a FWHM of 3.2 arcmin, the survey was capable of detecting HI masses of $6 \times 10^5 h^{-2} M_\odot$ at 7 h^{-1} Mpc and $1.5 \times 10^8 h^{-2} M_\odot$ at the full depth of the survey. The details of the Arecibo Strip Survey are described by Sorar (1994) and Briggs (1996).

The survey yielded a total of 61 detections, of which about half could be associated with cataloged galaxies listed in the NASA Extragalactic Database (NED). About five detections with galactic latitude $|b| > 10°$, where extinction is not a problem, have no obvious counterparts on the Digitized Sky Survey (DSS). The HI selected galaxies generally follow the same structures as optical selected galaxies. This is consistent with (1) results from Szomoru et al (1996) who fail to detect large numbers of HI selected galaxies in selected void fields and (2) the finding that LSB galaxies and gas-rich dwarfs lie on structures delineated by normal, high surface brightness galaxies (Mo et al 1994).

2 Follow up observations

The follow up 21cm synthesis observations on the galaxies found by this survey are essential for a number of reasons. First, Arecibo is capable of detecting galaxies as far as 6 arcmin from the center of the beam. The positional accuracy is too poor to make unambiguous identifications with cataloged galaxies or galaxies on the DSS. Second, reliable flux measurements are necessary in order to construct an HIMF. Flux measurements from the survey data can be poor if the detected galaxy is more extended than the survey beam or if it is detected at a large distance from the center of the beam. Finally, we have found that some signals were actually caused by pairs or a small group of galaxies. This was not always obvious from looking just at survey spectra.

We took short (20 min) 21cm line observations of 55 of the 61 detected galaxies with the VLA during the D-Configuration session in May 1995. The remaining six galaxies were too close to the sun at the time of the observations. These short observations were of sufficient sensitivity to construct HI maps and global profiles of 52 of the 55 potential galaxies. The signal of three systems fell below the detection limit.

Optical follow up observations were carried out on the 2.5m Isaac Newton Telescope on La Palma. We have been able to make B-band images of 24 galaxies during two observing runs in October 1995 and February 1996. Additional time has been awarded to observe the remaining galaxies. So far, we have been able to make optical identifications of all HI selected galaxies. No isolated HI clouds without stars have been found.

3 Results

The lower panel of Fig. 1 shows the observed distribution of HI masses binned per half-decade, with errorbars given by Poison statistics. The HI masses were calculated from either the VLA observations, or from the Arecibo measurements if the fluxes were lower than 1.0 Jy km s^{-1}.

The inverse of the survey volume as a function of HI mass is indicated by the thin line in the upper panel of Fig. 1. The curve indicates the upper limit to the space density of intergalactic HI clouds without stars as a function of HI mass.

The HIMF $\Theta(M_{\rm HI})$ was determined following Schmidt's (1968) $\sum 1/V_{\rm max}$ method, which consists of summing the reciprocals of the volumes corresponding to the maximum distances to which the objects could be placed and still remain within the sample. For a survey such as the Arecibo Strip Survey, $V_{\rm max}$ is a complicated function, dependent on velocity width, total flux, declination offset from the center of the survey strip and feed gain, which is a function of frequency (i.e. redshift).

The solid dots in Fig. 1 show the HIMF. Briggs (1990) derived an analytical expression for Θ by using a Schechter luminosity function and a relation between HI richness and optical luminosity: L, $M_{\rm HI}/L \propto L^{\beta}$, where $\beta = -0.1$. This function is represented by the fat solid line, using $M_{\rm HI}{*} = 4.0 \times 10^9 h^{-2} M_{\odot}$, a faint end slope $\alpha = 1.25$ and a normalization $\theta^* = 0.013$, which is a satisfactory fit to the points. The parameters of this fit agree quite well with those of optical luminosity functions. Hence, an HI selected sample of galaxies does not yield a population of

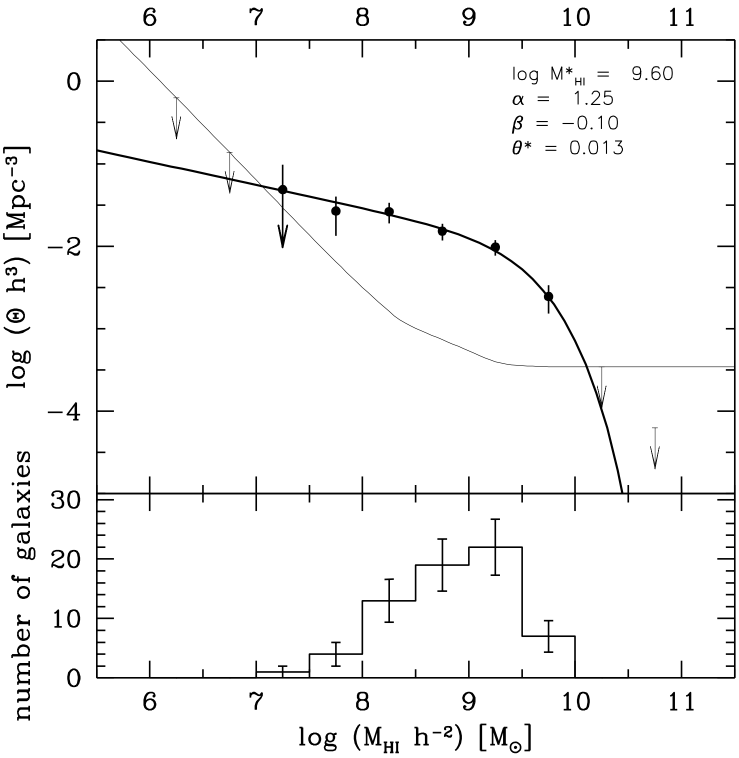

Figure 1: Lower panel: The distribution of HI masses of the detected galaxies. with errorbars given by Poison statistics. Upper panel: The thin line is the sensitivity of our survey. The measured HI mass function per half decade is shown by the points. An analytical HIMF is represented by the fat line, using the parameters given in the upper right corner. The arrows show upper limits to the volume density of HI clouds. The two measurements on the right are from a complementary survey with the Arecibo telescope over the range 19,000 to 28,000 km s^{-1}.

gas rich dwarf galaxies (Tyson and Scalo 1988), that might be missed by optical surveys. If a large population of underluminous galaxies does exist, they must be either HI deficient, or have extremely low column densities ($N_{\rm HI} < 10^{18}$cm^{-2}).

The cosmological mass density of HI at the present epoch, $\rho_{\rm HI}(z = 0)$, can be determined from the distribution function of HI mass in galaxies. This function is plotted in Fig. 2. The fat solid line indicates the converted best fit HI mass function, the thin line represents the sensitivity limits. The distribution function clearly illustrates that the integral HI mass density is dominated by high mass galaxies, $M_{\rm HI} \approx 10^{9.5} h^{-2} M_\odot$ which are L^* galaxies. From this figure we derive that $\rho_{\rm HI}(z = 0) = 4.8 \times 10^7\, h\, M_\odot$ Mpc^{-3} or 3.3 $\times$ $10^{-33}\, h\, {\rm g\, cm}^{-3}$, with a statistical error of 25%. This result agrees surprisingly well with earlier estimates by Rao and Briggs (1993), who find the same value by using optically selected galaxies. This implies that there is not much neutral gas hidden in objects like LSB galaxies or intergalactic clouds that are missed by optical surveys. The ratio of HI mass density to the critical mass density of the universe at $z = 0$ is $\Omega_{\rm HI}(z = 0) = (1.8 \pm 0.4) \times 10^{-4} h^{-1}$, consistent with a smooth decline of $\Omega_{\rm HI}$ from high z to the present.

One final result concerns the distribution of central surface brightnesses. Since this galaxy sample is selected regardless of any optical properties, it is well suited to test the distribution function of optical surface brightnesses. The hatched area in Fig. 3 indicates the possible range of values for the distribution function for the 24 galaxies observed so far. Despite the large variations

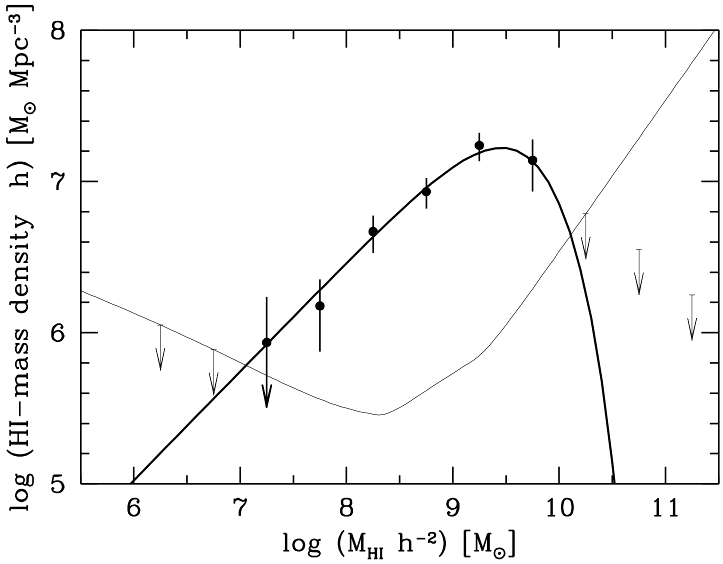

Figure 2: Space density of HI mass contained in objects of different masses per half decade. Thin line indicates again the sensitivity of the survey.

due to small number statistics, it is clear that this distribution is consistent with the 'flat' distribution proposed by McGaugh (1996), of which the boundaries are given by the dashed and dotted line. It is noteworthy that no galaxies observed thus far have central surface brightnesses fainter than $\sim 24.0\,B$-mag arcsec^{-2}, even though the measurement threshold is $\sim 26.5\,B$-mag arcsec^{-2}. We therefore appear to be observing a lower limit to the central surface brightness of gas-rich galaxies in the local universe.

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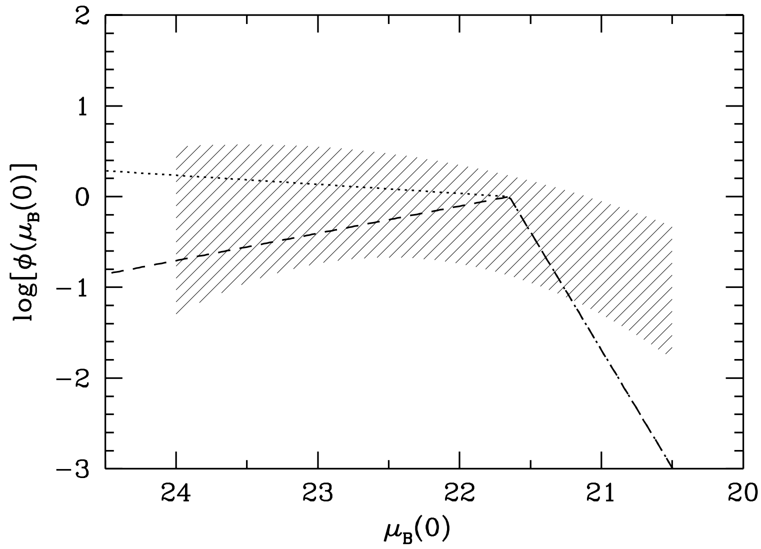

Figure 3: The volume corrected surface brightness distribution of our HI selected galaxy sample. Hatched area shows the possible range of values for this distribution function. The two lines represent the upper and lower limit to the distribution proposed by McGaugh (1996). The y-axis is arbitrarily scaled.