Hydrogen 21-cm Emission from Galaxies at Redshifts 0.24 and 0.37

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Abstract

We have been using the Giant Metrewave Radio Telescope (GMRT) to measure the redshifted 21-cm (1420 MHz) hydrogen line emission from galaxies at a look-back time of 2.8 billion years (redshift 0.24, frequency 1145 MHz). We have assessed the relationship between the neutral gas in the galaxies (the fuel for the formation of new stars) and their star formation rate. A second deep integration with the GMRT has focused on Abell 370, a galaxy cluster (a massive overdensity of galaxies) at a look-back time of 4.0 billion years (redshift 0.37, frequency 1036 MHz).

1 Introduction

It is known that the rate at which stars are produced in galaxies has dropped by a factor of ten in the last 9 billion years (i.e. over the last two thirds the age of the universe). However, measurements of the neutral hydrogen gas content of galaxies - the fuel supply for star-formation - are only poorly constrained by observations over this period of time. Consequently, a key element in our understanding of galaxy evolution is missing. By using deep radio observations with the Giant Metrewave Radio Telescope we have been making the first radio measurements of the neutral hydrogen gas content of galaxies during this cosmologically interesting period of the universe.

Our radio observations are sensitive to the 21-cm (1420 MHz) emission line that arises from the hyperfine transition within the electronic ground state of atomic hydrogen. This emission line is an important diagnostic for many nearby galaxies, which are observed to contain between 10^7 to 10^{10} solar masses of neutral hydrogen gas. However as one goes out to greater distances (and hence further back in time) the strength of the hydrogen 21-cm signal becomes increasingly fainter and more difficult to detect with current radio telescopes. Also as one looks at galaxies further away, the frequency of the emitted line is shifted to lower frequencies due to the expansion of the universe (the line is redshifted).

To measure the faint neutral hydrogen emission signal from distant galaxies we have been using the Giant Metrewave Radio Telescope (GMRT) which can observed at the necessary radio frequencies. Even with the large collecting area of the GMRT, it is not possible to directly measure the individual signal from galaxies at these distances. Therefore, we have been combining the hydrogen emission signal from many galaxies using their measured optical position and redshift to form an estimate of the mean neutral hydrogen gas content for the population. By using this "coadding" technique the sensitivity of our radio observations to the mean value improves approximately with the square root of the number of galaxies coadded (for a ∼100 hundred galaxies the coadded noise level decrease by a factor of ∼10).

2 Star Forming Galaxies at Redshifts 0.24

Our first result is the measurement of the neutral gas content of 121 star forming galaxies at a look-back time of 2.8 billion years (redshift 0.24) (Lah et al. 2007). These galaxies were selected from optical narrow band filter observations with the Japanese Subaru Telescope for the emission Hα line at this redshift (Fujita et al. 2003). They were followed up with optical spectroscopic observations using the Anglo-Australian Telescope to provide the necessary precise optical redshifts for the radio coadding. With 44 hours of GMRT

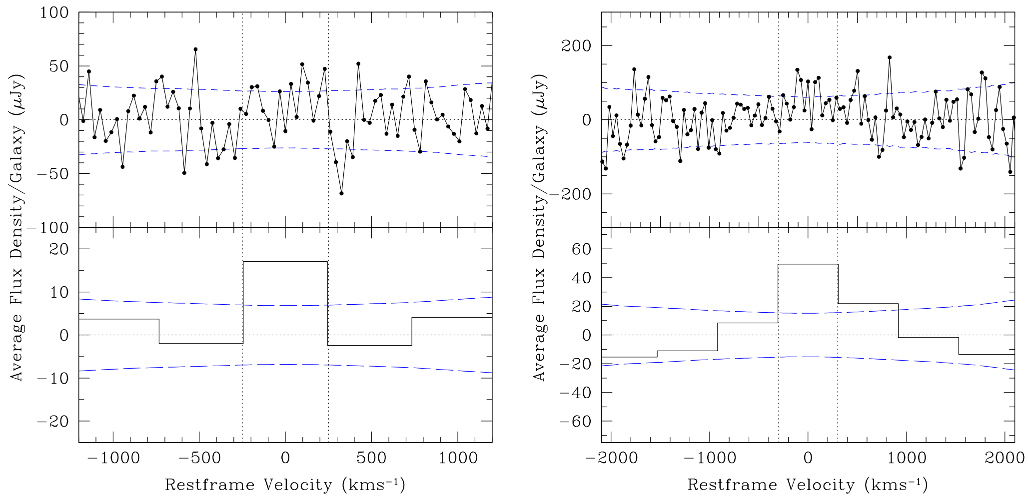

Figure 1: The left panel shows the average 21-cm hydrogen line emission from coadding the signal of 121 star-forming galaxies with known optical positions at a look-back time of 2.8 billion years (redshift 0.24, frequency 1145 MHz). The right panel shows the average 21-cm hydrogen line emission from coadding the signal of the 142 blue galaxies outside the hot x-ray gas of the galaxy cluster Abell 370 at a look-back time of 4.0 billion years (redshift 0.37, frequency 1036 MHz). In each case the top spectrum has no smoothing or binning and in the left spectrum has a velocity step size of 32.6 $\mathrm{km\,s^{-1}}$ and the in right of 36.0 $\mathrm{km\,s^{-1}}$. The bottom spectrum in both cases has been binned to the velocity width that the combined hydrogen emission signal from the galaxies is expected to span; $\sim$500 $\mathrm{km\,s^{-1}}$ in the left panel and 600 $\mathrm{km\,s^{-1}}$ in the right panel. For all spectra the 1σ error is shown as dashed lines above and below zero.

integration time on the field at a frequency $\sim$1145 MHz (the frequency the 21 cm emission is redshifted to at z=0.24) we achieved an RMS per channel of $\sim$130 μJy and a continuum RMS of 16 μJy.

Coadding the signal from 121 galaxies we measured an average neutral hydrogen gas mass for these galaxies as $\mathrm{M_{HI}} = (2.26 \pm 0.90) \times 10^9$ solar masses(see Figure 1 left panel). From this work, we were able to determine the neutral gas content of the universe at look-back time of 2.8 billion years to be $(9.5 \pm 4.4) \times 10^7$ solar masses per Mpc^3 (see Figure 2). This level of precision is comparable to that found by the damped Lyman-α measurements at this epoch that require many observations using space based telescopes such as the Hubble Space Telescope (Rao, Turnshek, & Nestor 2006).

We also find that the correlations between the Hα luminosity and the radio continuum luminosity and between the star formation rate and the neutral hydrogen gas content in the galaxies are consistent with the correlations found at present day galaxies. These two results suggest that the star formation mechanisms in field galaxies $\sim$2.8 billion years ago were not substantially different from the present, even though the star formation rate is 3 times higher.

3 Galaxy Cluster Abell 370 at Redshifts 0.37

Our second result is the measurement of the neutral hydrogen gas content in the galaxies within and surrounding the galaxy cluster Abell 370 located at look-back time of 4.0 billion years (redshift 0.37). Optical imaging to select the galaxies was accomplished using the Australian National University 40 inch telescope and the spectroscopic redshifts were followed up using the Anglo-Australian Telescope. With 34 hours of GMRT integration time on the field at a frequency $\sim$1036 MHz (the frequency the 21 cm emission is redshifted to at z=0.37), we achieved an RMS per channel of $\sim$160 μJy and a continuum RMS of 20 μJy.

The average galaxy neutral hydrogen gas mass in Abell 370 determined from the coadded signal from the full sample of 324 galaxies for which we have optical redshifts is $\mathrm{M_{HI}} = (7.4 \pm 3.6) \times 10^9$ solar masses. The full sample includes galaxies with a range of optical colours and distances from the cluster centre. A blue

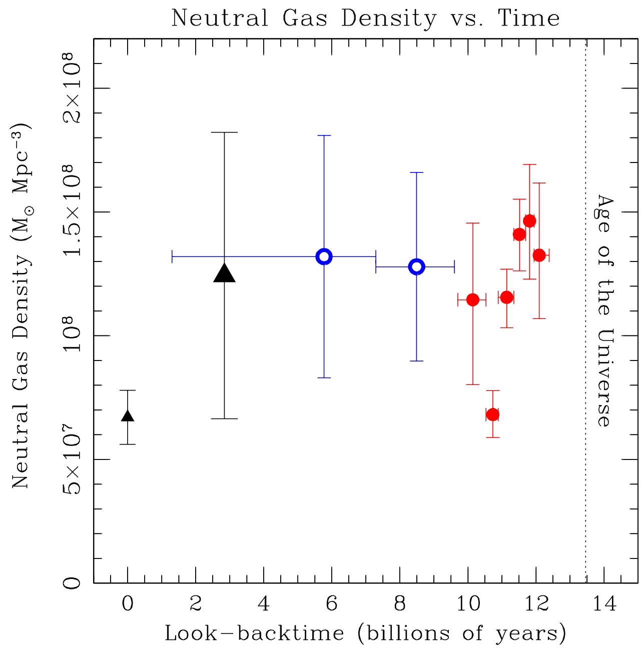

Figure 2: The evolution of the neutral gas density of the universe, measured in solar masses per megaparsec cubed. The values here include a correction of the hydrogen gas for the expected neutral helium content. The small triangle at time ∼0 years (i.e. now) is the hydrogen 21-cm emission measurement from Zwaan et al. (2005) using the Parkes dish. The filled circles are from quasar absorption measurements from Prochaska et al. (2005). The open circles are from quasar absorption measurements from Rao et al. (2006) using the Hubble Space Telescope (HST). The large triangle at ∼2.8 billion years is our hydrogen 21-cm emission measurement made using the Giant Metrewave Radio Telescope (GMRT) from Lah et al. (2007).

optical colour for a galaxy signifies the presence of high mass, short lived stars and as such is an indication of fairly recent star formation. We formed a blue galaxy subsample and coadded their signal to find that the blue galaxies contain twice the mean gas content of the full sample. In the central regions of the galaxy cluster, the intergalactic medium is extremely hot, ionised, X-ray emitting gas. By taking the subsample of blue galaxies outside this central region we measure a still larger mean amount of neutral hydrogen gas per galaxy of $M_{HI} = (20.4 \pm 6.3) \times 10^9$ solar masses from the average of 142 galaxies (see Figure 1 right panel). We are currently finalising the analysis of the data on the cluster.

References

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