A WSRT search for HI at z=3.35

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Introduction

The origin and evolution of the large-scale structures in the
universe (from galaxies up to superclusters) forms one of the
outstanding problems of present-day cosmology. Several attempts have
been made to observe the precursors of the structures observed today,
at epochs as early as possible. Results of a search for redshifted HI
associated with "protoclusters" or "pancakes" were first reported by
Davies et al. (1978). They used the Jodrell Bank Mark 1A-telescope at
frequencies of 328 and 240 MHz (z=3.3 and 4.9 respectively). More
recently Bebbington (1986) used the Cambridge 6C synthesis radio
telescope for a search at 151 MHz (z=8.4). Both experiments gave
negative results and raised the question whether the observations were
matched to the "expected" properties of the structures that they looked
for.

Sunyaev and Zel'dovich (1975) have calculated the brightness
temperatures and angular scales to be expected for a spherical, gaseous
precursor of a present-day galaxy cluster with a total mass of
$3.10^{14} M_{o}$, a diameter of 2 Mpc and a velocity dispersion of $\sim 10^{3}$km/s.
They predict angular scales of several arcminutes, and line
fluxdensities per beam (matched to the size of the structure) in the
mJy range, where exact numbers depend on redshift, H_{o} and Ω_{o}. Useful as
these predictions may be, they are uncertain if only because one has to
assume the fraction of the total mass that resides in neutral hydrogen.
Secondly, the direct information that has become available in recent
years about the large-scale structure in the "local" universe indicates
that rich clusters frequently form part of larger structures which
makes it more difficult to extrapolate backwards as long as it is not
understood how these structures formed.

In this contribution we report the results of a search for HI at a
redshift of 3.35 using the Westerbork Synthesis Radio Telescope (WSRT)
at a frequency of 327 MHz. Our observations have a resolution of 1' and
a noise level (1σ) of about 1-2 mJy depending on the amount of angular
and velocity smoothing applied to the full resolution data; this
represents a significant improvement over the previous experiments

referred to above. The resolution of 1' corresponds to linear scales of $0.4h_{50}^{-1}$ Mpc (for $\Omega=1$, and about double that value for $\Omega=0$) at a redshift of 3.35. This scale would seem quite a reasonable lower value for a search of protoclusters. Our instrumental setup gave a velocity coverage of about 2000 km/s and a resolution of 150 km/s. This range includes the locally observed velocity dispersion in galaxy clusters, as well as the narrower velocity depth seen in the Perseus-Pisces supercluster (Giovanelli and Haynes, 1985).

Observations and Reductions

Observations were made in March and April 1985 in two adjacent areas, located at $\alpha=12^h27^m$, $\delta=67°$ and $\alpha=12^h58^m$, $\delta=65°30'$. Each area was observed for 6 periods of 12^h each, with a resulting baseline configuration of 36 (12) 2760 meters. In addition to these regularly spaced standard baselines, we observed at a similar amount of so-called "redundant" baselines which are concentrated towards the shorter spacings. The redundant baselines allow us to trace and correct for telescope-based amplitude and phase errors; their use also significantly lowers the noise in the low angular resolution maps. A special configuration of the digital line backend (Bos et al., 1981) was used which covered the 2.5 MHz bandwidth with 31 Hanning-smoothed line channels, 15 of which were saved for further processing. The edge channels are of somewhat poorer quality and in the final analysis at most 13 channels, at velocity increments of 144 km/s, were used.

3° x 3°

Noise histogram

log N   −1σ   +1σ

−7.5 mJy   0   +7.5 mJy
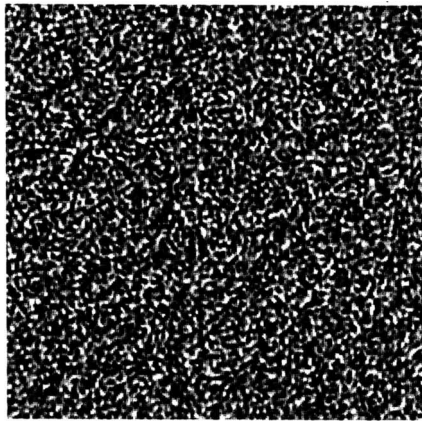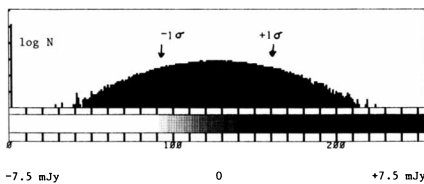
The calibration of the line channels proceeded in two steps (cf. Noordam and de Bruyn, 1982). Each line channel was first corrected independently for telescope based errors in amplitude and phase. Subsequently a model for the continuum emission in the field, constructed from all of the data, was used to self calibrate each line channel. The search for HI emission was conducted in a multiple series of maps with a variety of combinations of angular and velocity resolutions ranging from 1' - 4' and 150 - 1200 km/s, respectively. The maps measured 6°x6°; the diameter at the half-power sensitivity is about 2.7°. Before differencing line and "continuum" channels the response of about 200 discrete sources (with a total flux exceeding 10 Jy) was subtracted from the visibility data. The final maps are thermal noise limited. An example of the noise characteristics in one of the full resolution line maps is shown on the left.

Discussion

At none of the spatial and velocity resolutions investigated have we detected a signal that is stronger than 4 to 5σ (a 4 to 5σ fluctuation is to be expected due to noise alone, given the total number of independent beam elements in our survey area). The observational results, in mJy and beam-averaged brightness temperature, are summarized in columns 3 and 4 of the following table, which gives upper limits at various combinations of angular and velocity resolution. We have averaged the limits for the two areas which differ by ~20%. The average attenuation due to the off-axis sensitivity reduction of the individual dishes in the areas is ~1.4. The values given in the table have not been corrected for this effect.

Average upper limits (4-5 σ) in about 10 square degrees

Angular resolution	velocity depth	S (mJy)	T_b (K)	$M_{HI} h_{50}^{-2}$ $\Omega=0$	$M_{HI} h_{50}^{-2}$ $\Omega=1$
50"	150 km/s	9	33	2×10^{14}	5×10^{13}
100"	150 "	13	12	$3 \ 10^{14}$	$8 \ 10^{13}$
100"	600 "	9	8	$9 \ 10^{14}$	$2 \ 10^{14}$
100"	1200 "	7	6	$14 \ 10^{14}$	$3 \ 10^{14}$
250"	600 "	6	0.9	$6 \ 10^{14}$	$1.5 \ 10^{14}$
250"	1200 "	6	0.9	$12 \ 10^{14}$	$3 \ 10^{14}$

Upper limits to the HI column density can be calculated from $\int n_{HI} dl = 7.9 \times 10^{18} T_b \cdot \Delta V$ (km/s). They range from 4×10^{22} down to 4×10^{21} atoms/cm². Upper limits to the total HI mass require a specific geometrical model. For structures that are encompassed within the specified resolution and velocity depth, one obtains the values given in the last columns of the table. For $\Omega=1$ the upper limits (at 4-5 σ !) to the HI mass are about an order of magnitude less than the estimated total masses of "local" clusters, on a linear scale of ~1 Mpc. The depth of our survey area is only $4 h_{50}^{-1}$ Mpc (for $\Omega=1$). With a total pill-box shaped volume surveyed of about $2 \times 10^4 h_{50}^{-3}$ Mpc³ ($\Omega=1$), we should have observed a fair sample of the universe, as far as local clusters are concerned. Our results are nearly sufficiently sensitive to require large-scale ionisation or galaxy formation to make protoclusters at z ~3.3 invisible. But it is questionable that we may extrapolate the local picture backwards to interpret our results. We may have to search for larger structures, which will be more rare, running through our data cube. An extensive account of these observations and our plans for the future will be presented elsewhere.

References

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