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HI with the GMRT

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Abstract. The Giant Metrewave Radio Telescope (GMRT) has recently come into operation. This paper reports on observations of the HI line made using the GMRT during its commissioning phase. These include observations of the nearby Low Surface brightness galaxy Cepheus 1, as well as of a number of low and medium redshift damped Ly-α systems. The derived spin temperatures for these systems is typically higher than that characteristic of the gas in the disk of the Galaxy. Higher spin temperatures were known to be characteristic of high redshift damped Ly-α absorbers, and had been earlier attributed to evolutionary effects. Our observations suggest that high spin temperatures are not a consequence of evolutionary effects since the look back time to these low z absorbers is modest. We also report on the short time scale (days) variability of the absorption profile of the $z = 0.3127$ system in front of B1127-145. This is the second damped Lyα system to show such variation (the other being the $z = 0.524$ absorber in front of AO 0235+164).

1. Introduction

The Giant Meterwave Radio Telescope operates at five frequency bands, viz. 150, 235, 325, 610 and 1420 MHz. A further band at 50 MHz will be operational in the future. The sensitivity of the telescope in these bands is sufficient for detections of HI (in absorption, and also in some cases in emission) or for placing astrophysically interesting limits on the HI content. In terms of redshift range, the currently operationational bands nominally cover the $z = 7.8 - 8.5, 5.0 - 5.3, 3.0 - 3.7, 1.2 - 1.4$, and $0.0 - 0.4$. This paper however concetrates on observations done using the highest frequency band, that at 1420 MHz.

The 1420 MHz feed (built by the Raman Research Institute, Bangalore) has a nominal range of 1000 – 1450 MHz range. On some antennas however, the range has been extended upto 1750 MHz to allow observations of the OH molecule. All feeds also give a reasonable performance (i.e. better than half the sensitivity at the band center) upto $\sim$ 880 MHz (i.e. $z \sim 0.55$). However, not all of the frequency range between 1420 and 880 MHz is usable primarily because of external interference, particularly from cellular phones.

The rest of this paper contains discuses various observations of HI done using the GMRT 1420 MHz system.

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2. HI observations at the GMRT

2.1. Cepheus 1

Braun & Burton (1999) identified the HI signature of a large nearby galaxy during the course of a systematic survey for isolated, compact, high velocity clouds. This galaxy, named Cepheus 1 has a recession velocity of only 282 km/s with respect to the Milky Way, and is probably associated with the nearby (approximately 6 Mpc distant) galaxy NGC 6946. Cepheus 1 has low surface brightness and this combined with its location in the direction in which there is a pocket of large extinction has resulted in its not being detected in earlier surveys.

The integrated HI emission map (from GMRT observations) overlayed on the I band continuum image (from Braun & Burton 1999) is shown in Figure 1[A]. The HI disk has a diameter $\sim$ 5 times greater than the LSB optical emission. Further while the optical emission is very elliptical, i.e. is either bar like or is a high inclination disk the HI disk appears to be more circular. From the Hα image (not shown) one finds that the brightest HII region coincides, (to within the resolution in the GMRT map) with the highest HI column density region, however the other HII regions are not associated with any particular enhancement of the HI density. Similarly while the LSB optical continuum emission is approximately coincident with the region of highest HI column density, at this resolution at least, the highest HI column density contours do not follow the optical emission. One should note however, that because of the high extinction in this region as well as the high foreground stellar density, the exact morphology of the LSB optical continuum is difficult to determine.

The velocity field is regular and central isovelocity contours do not show the skew that is seen in disks with a dynamically important bar – like for other LSB dwarf galaxies, (e.g. HI1221+01, Chengalur et al. 1995) that the stellar mass is probably not dynamically important. The derived rotation curve is shown in Figure 1[B]. The apparent increase in rotation velocity towards the outer regions of the disk is probably due to a change in the inclination angle of the outer part of the disk.

The total HI mass (assuming a distance of 6 Mpc) is $\sim 10^9$ M$_\odot$, while the dynamical mass is $\sim 10^{10}$ M$_\odot$. Cepheus 1, by itself hence probably has negligible influence on the dynamics of the Local Group. However it appears that Cepheus 1 is itself part of a small group of galaxies associated with NGC 6946, six other galaxies have been discovered within 15^o and small velocity difference of NGC 6946 (Rivers et al. 1999). Since the survey of this region is still not complete, potentially still more galaxies could remain there to be discovered, and the total mass within this nearby group could be sufficiently large to be relevant to the Local Group dynamics.

2.2. Low z Damped Ly-α Absorbers

Damped Lyα systems are the extremely high HI column density ($N_{HI} > 2 \times 10^{20}$ atoms cm^{-2}) systems seen in absorption in the spectra taken towards distant quasars. Although rare, they are the dominant contributors (by mass) to the observed neutral gas at high ($z \sim 3$) redshifts. Principally for this reason, these systems are natural candidates for the precursors of $z = 0$ galaxies. On the

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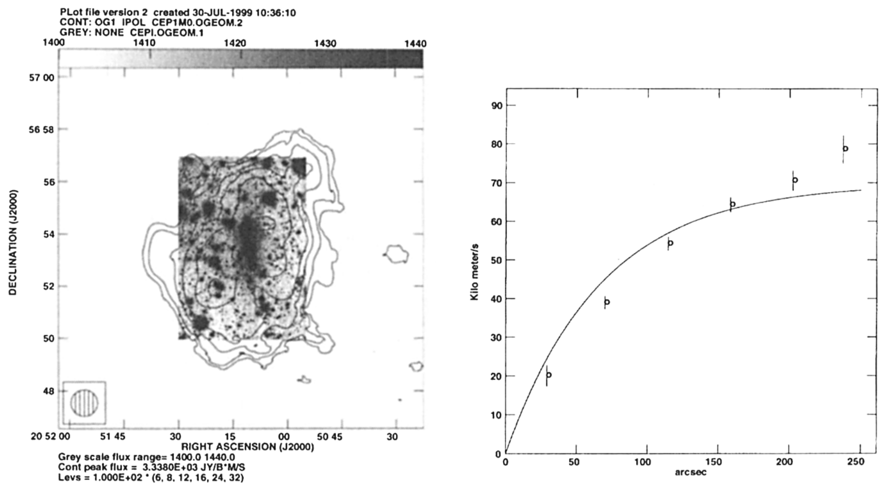

Figure 1. [A] Integrated intensity of the HI 21cm emission from Cepheus 1 overlayed on the I band optical continuum emission. Due to the sizeable extinction ($A_V \sim 2$ mag) and the large density of foreground stars the low surface brightness emission from the galaxy is difficult to detect. The contours are at 0.4,0.8,1.6,2.4, and 3.2 Jy/Bm km/s. [B] The derived rotation curve for Cepheus 1. The apparent rise in rotation velocity towards the outer regions is more likely to be due to a change in inclination angle (assumed to be a constant 30^o throughout the disk) than a genuine increase in rotation speed.

other hand, the morphology and typical size of damped Lyα systems remains observationally poorly constrained. For damped Lyα systems that lie in front of radio loud quasars, it is possible to augment the optical/UV spectra with HI 21cm absorption spectra. Such a comparison, yields, among other things (and under suitable assumptions), the spin temperature, T_s, of the HI gas. Derived spin temperatures of damped Lyα systems have, in general, been much larger than those observed in the disk of the Galaxy or in nearby galaxies (Braun & Walterbos 1992, Braun 1997), implying that either damped Lyα systems are not disks, or that the ISM in the damped Lyα proto-disks is considerably different from that in the local $z = 0$ disks, presumably due to evolutionary effects. Studies of low redshift damped Lyα systems are particularly interesting in this regard, since evolutionary effects are expected to be negligible.

The GMRT spectrum of the $z = 0.0912$ absorber towards the quasar OI 363 is shown in Figure 2[A], and that of the $z = 0.2212$ absorber towards the same quasar in Figure 2[B].

The computed spin temperatures are 825 ± 110 K (for the $z = 0.0912$ absorber) and 1120 ± 200 K (for the $z = 0.2212$ system), i.e. much higher than that observed in the Mikyway ISM. For the higher redshift system, our measurement agrees within the errors with the earlier measurement of Lane et al. (1998). Thus even at the lowest redshifts, gas with apparent physical parameters considerably different from the ISM of nearby spiral galaxies has a

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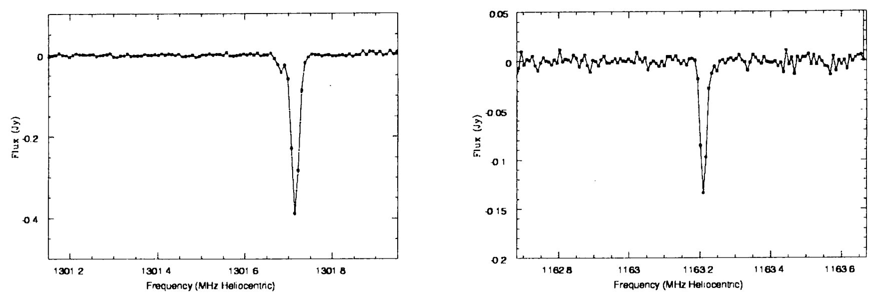

Figure 2. [A] GMRT redshifted 21cm absorption spectrum of the $z = 0.0912$ redshift system towards OI363. [B] GMRT redshifted 21cm absorption spectrum of the $z = 0.2212$ system towards OI363.

non-trivial contribution to the total absorption cross-section. More details can be found in Chengalur & Kanekar (1999).

Another interesting low redshift damped Ly-α system is the one at $z = 0.524$ towards the blazar AO 0235+164. The absorber is identified as a spiral galaxy (Burbidge et al. 1996), and the 21cm absorption profile was unique in that it shows time variablity (Wolfe et al. 1982.) We show in Figure 3[A] the GMRT spectrum based on 40 m of observation of the redshifted 21cm absorption profile. Note that the frequency that the 21cm profile is shifted to is $\sim$ 932 MHz, i.e. well below the nominal bottom of the 21cm receivers.

The GMRT spectrum of the $z = 0.3127$ absorber towards B1127-145, (discovered in the WSRT MgII survey of Lane et al. (1998)) is shown in Figure 3[B]. This spectrum has much higher resolution and sensitivity than the discovery spectrum of Lane et al. (1998), the broad feature detected at the WSRT breaks up into a number of narrow components. There is also an entirely new component, (i.e. not detected at the WSRT) at $\sim$ -50 km s^{-1} from $z = 0.3127$, making the total velocity range over which the absorption is seen $\sim$ 120 km/s.

Like for AO 0235+164, the absorption system in front of B1127-145 also appears to vary with time, we show in Figure 4 a montage of 8 epochs of observations of the line. The upper panels are the average over all epochs, and the other panels are the difference between the spectrum at that epoch and the average spectrum. Note that the difference spectra have a scale that is expanded by a factor of 10 with respect to that used for the average spectrum. The line opacity appears to vary on by a few percent on days timescale. This is very similar to the behaviour noticed in AO 0235+164. Possible sources of this variation include interstellar scattering as well as superliminal motion (on sub VLBI angular scales) in the background source. Both of these mechanisims will also require fine scale structure in the opacity of the absorber. Further discussion of this system can be found in Kanekar & Chengalur (2000).

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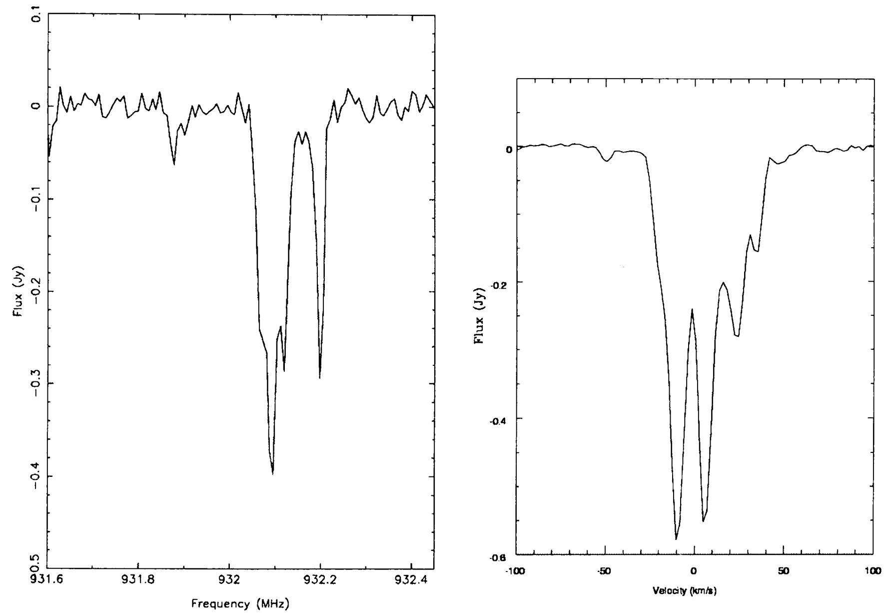

Figure 3. [A] GMRT spectrum of the $z = 0.524$ absorber towards AO 0235+164. Note that a redshift of 0.524 coresponds to a frequency of $\sim$ 932 MHz, well below the nominal bottom of the GMRT 21cm feed system. The useful range of the GMRT receivers extends to $\sim$ 880 MHz. [B] GMRT redshifted 21cm absorption spectrum of the $z =$ 0.3127 absorber towards B1127-145. The line is clearly resolved into multiple components for the first time. The total velocity width over which absorption is detected is $\sim$ 120 km/s.

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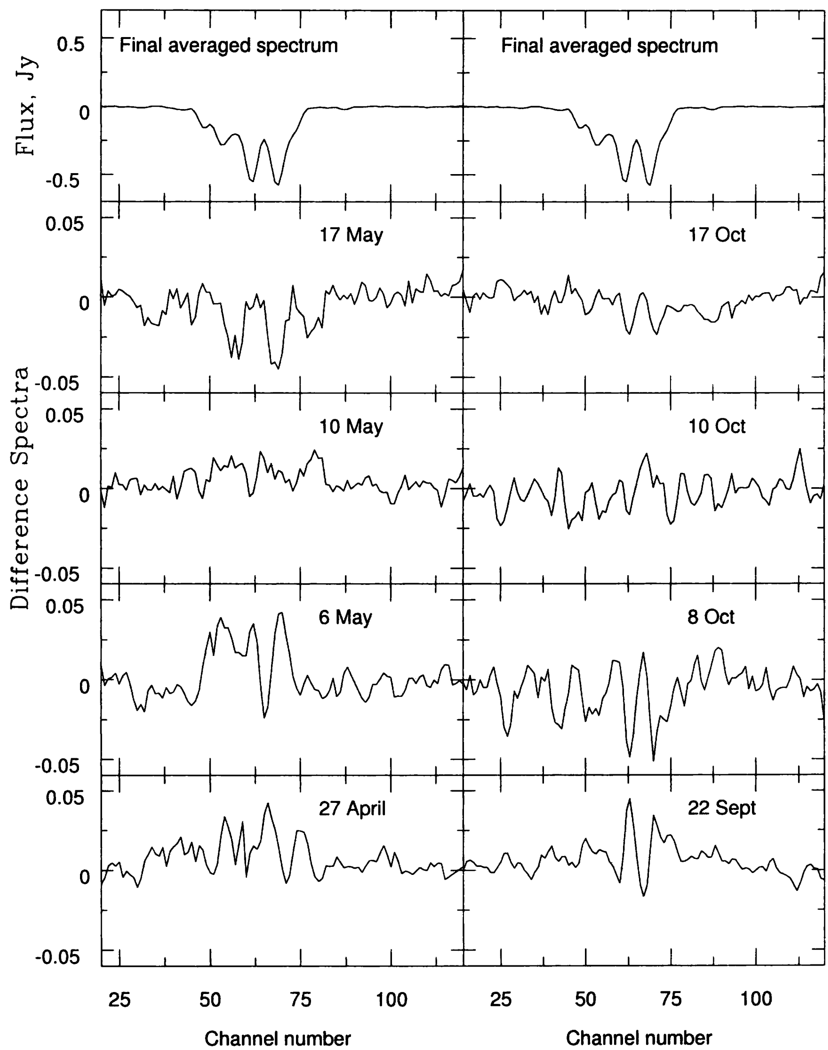

Figure 4. A montage of 8 multi epoch GMRT observations of the absorber in front of B1127-145. The upper panels are the average over all epochs, and the other panels are the difference between the spectrum at that epoch and the average spectrum. Note that the difference spectra have a scale that is expanded by a factor of 10 with respect to that used for the average spectrum. The line appears to vary at a few percent level on a time scale of days.

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