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Research Note

A search for H I and OH absorption in high redshift quasars

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Summary. A search has been made for redshifted H I and OH absorption in high redshift quasars using the Westerbork Synthesis Radio Telescope at 0.6 GHz. The investigation was carried out near $z=1.33$ (H I) and $z=1.74$ (OH), close to the emission line redshifts of most of the objects observed. Seven quasars, 0202 −172, 1331+170, 1356+022, 1615+028, 1756+237, 2005+403, and 2158+101 were investigated, but in no case could absorption be detected. Upper limits to absorption features of 1 to 2 percent were obtained, and the results are briefly discussed.

Key words: quasars – redshifts – 21 cm line – OH line

1. Introduction

Several types of material are known to be associated with active nuclei. In addition to the radio emitting relativistic plasma and the ionized gas responsible for optical emission lines, there is considerable evidence that both neutral hydrogen and molecules are present in the nuclear regions of active galaxies.

Recently, Heckman et al. (1983) carried out a study of H I absorption in radio galaxies, mainly with the Arecibo Telescope. They detected absorption in six of the seventeen galaxies observed with optical depths greater than a few percent. Their analysis of 25 radio galaxies for which H I has so far been detected indicates that the absorbing H I gas has velocities within a few hundred $\mathrm{km\,s^{-1}}$ of the galaxy velocity (in the case of NGC 1275, it has recently been shown (Crane et al., 1982) that there is H I absorption near the systemic velocity, in addition to the well-known high velocity system) and that the 20% velocity widths, although typically $200\,\mathrm{km\,s^{-1}}$, vary from 7 to $700\,\mathrm{km\,s^{-1}}$. However, as their study was limited to $z<0.04$, we decided that it would be useful to extend this work to higher redshifts using the Westerbork Synthesis Radio Telescope (WSRT) at 49 cm wavelength.

H I absorption at high redshifts has, despite extensive searches, been detected in only a handful of objects. Wolfe (1980) has reviewed the situation up to 1979, while Wolfe et al. (1981) report on the detection of absorption in PKS 1157+014. The absorption found in each of five objects to date occurs at a redshift quite different from (and lower than) the emission line redshift of the quasar itself, but corresponding to one of its optical absorption redshift systems. Only one of the objects in our program, however, was investigated because of a known absorption system.

Morris and Rickard (1982) have recently reviewed the evidence for the presence of molecules in active nuclei. OH absorption studies suggest a correlation between molecular clouds and the radio continuum emission. Modest optical depths are sometimes seen, and it is clear that OH is less likely to be detected than H I.

2. Selection of the sources

The frequency at which redshifted 21 cm absorption should occur is given by

$$f_{\mathrm{HI}}=\frac{1420.4057}{(1+z)n_{\mathrm{air}}}\,\mathrm{MHz},$$

where z is the redshift, and the index of refraction of air, $n_{\mathrm{air}}=1.000297$ (Heiles and Miley, 1970). The frequency window of the 49 cm WSRT receiver ranges from 606.98 to 610.17 MHz, corresponding to a z-window for the 21 cm H I line of $z=1.3272$ to $z=1.3394$. The diatomic molecule OH has a ladder of rotation transitions in the infrared. Although the lowest transition is split into four hyperfine levels, there are mainly two ($F=1\leftrightarrow1$ and $F=2\leftrightarrow2$, with relative intensities of 5 : 9) which are observable as a result of population effects. These two main lines have frequencies of 1665.401 and 1667.358 MHz, corresponding to redshift windows of $z=1.7286$ to 1.7429 and $z=1.7318$ to 1.7461, respectively.

We have selected (radio) quasars with $\delta>-20°$ from the compilation made by Hewitt and Burbidge (1980), and find six sources (listed in Table 1) which fall in one of the appropriate redshift ranges. In addition, the quasar 1756+237 was included because its optical spectrum shows an absorption system at $z=1.732$, which should just be detectable at the edge of our frequency window. Table 1 lists the seven sources (columns 1, 2), their redshifts (3, 4), the lines of interest and the corresponding (heliocentric) frequency after applying the source redshift (5).

3. Observations and reduction

The WSRT is well-suited to this project because of its unique combination of high sensitivity and excellent dynamic range at relatively long wavelengths. Moreover, in observations carried out using interferometry, the influence of standing waves on the resulting frequency baseline is minimal. On the other hand, the

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Table 1. Parameters of the quasars observed

(1) Quasar	(2) Names	(3) z_{em}	(4) z_{abs}	(5) f(z) (MHz)	(6) f_{obs}(MHz)	(7) t (h)	(8) S (Jy)	(9) $\tau(3\sigma)$
0202−172	PKS	1.740	–	$OH_{11}-607.63$ $OH_{22}-608.36$	608.0	2.5	1.11	0.008
1331+170	MC 3 PB 3977	2.081	1.3273	H I−610.14	609.0	3.0	0.48	0.019
1356+022	PKS	1.329	–	H I−609.70	609.0	3.0	0.80	0.010
1615+028	PKS	1.339	–	H I−607.90	608.0	3.0	0.41	0.027
1756+237	PKS VRO 23.17.02 OT 295	1.721	1.732	$OH_{11}-611.87$ $OH_{22}-612.61$	609.0	3.0	0.80	0.008
2005+403		1.736	–	$OH_{11}-608.52$ $OH_{22}-609.25$	609.0	3.7	1.45	0.015
2158+101	MC 2 4 C 10.67	1.730	–	$OH_{11}-609.86$ $OH_{22}-610.59$	609.0	7.6	1.05	0.007

WSRT is limited by the fact that a frequency range of only 3.5 MHz can be investigated in the 49 cm band.

We observed each object at an appropriate center frequency (Table 1, column 6) using 32 channels with an overall bandwidth of 2.5 MHz (the usable bandwidth, after discarding channels for end effects, was about 2.2 MHz). The resulting channel width of 78 kHz corresponds to a velocity of 39 km s^{-1}. The observing time was typically several hours (7). To search for absorption the visibility data for each channel were Fourier transformed to produce a map and a source finding algorithm was then applied to determine the source strength in each channel. In the case of 2005+403 the presence of the nearby strong source Cygnus A necessitated using the CLEAN algorithm (Högbom, 1974; Schwarz, 1978) to remove its response before applying the above procedure.

In an attempt to remove instrumental ripples across the frequency band, unresolved background sources were used, where available, to make small adjustments to the channel gain. After this procedure no spectral features could be discerned, but a modest channel-to-channel variation remained which was similar in all seven sources and particularly noticeable near the edges of the passband. We therefore averaged the percentage variations from the mean, per channel, for the three strongest sources (all observed for OH absorption), and used this mean determination of the residual ripple to correct the spectra of all seven sources. In two cases, 1356+022 and 2005+403, a linear gradient across the band could also be discerned, so its average slope was determined and removed.

As no spectral features are apparent in any of the observations, we have used the standard deviation from the mean as a measure of the absence of H I or OH absorption. Table 1 then further lists the flux density determined from these observations (column 8) and our limit to the optical depth, $\tau(3\sigma)$ (9). The values of typically 1% to 2% correspond to what one expects from noise given the known sensitivity, except for 2005+403 which suffers from the proximity of Cygnus A as explained above.

4. Discussion

Most of the sources observed have a flat radio spectrum between 20 and 0.4 GHz, suggesting they are compact and that the radiation originates in a small (a few kpc or less) region of space. They are, thus, good candidates for H I absorption (Heckman et al., 1983). In two of the sources, previous observations showed the presence of absorption systems which we have investigated in this work. 1331+170 has optical absorption at $z=1.3273$ (Hewitt and Burbidge, 1980) as well as absorption systems at several other redshifts including both optical and radio absorption at $z=1.776$ (Wolfe and Davis, 1979). The quasar 1756+237 with an emission redshift of $z=1.721$ has a variety of absorption redshifts including the relevant one at $z=1.732$ (Turnshek et al., 1979). These facts notwithstanding, we detect no absorption in any of the objects to quite low levels (Table 1).

The optical depth limits we have established combined with our velocity resolution can be interpreted in terms of a column density multiplied by the spin temperature for H I (Kraus, 1966) and OH (Robinson and McGee, 1967) if we assume the usual relations:

$$N_{\mathrm{HI}(1421.4\,\mathrm{MHz})}=1.835\,10^{18}\,T_s\tau(v)\Delta v\ \ \mathrm{cm}^{-2},$$

$$N_{\mathrm{OH}(1665.4\,\mathrm{MHz})}=3.88\,10^{14}\,T_s\tau(v)\Delta v\ \ \mathrm{cm}^{-2},$$

$$N_{\mathrm{OH}(1667.4\,\mathrm{MHz})}=2.16\,10^{14}\,T_s\tau(v)\Delta v\ \ \mathrm{cm}^{-2},$$

where T_s is in K and Δv in km s^{-1}. The values obtained for our seven sources are listed in Table 2, where we only include those lines for which $z \leqq z_{em}$. The surface densities are comparable to the lowest values found previously for similar objects (Wolfe, 1980; Wolfe et al., 1981). These have been appended to Table 2 for comparison, although the absorption in them occurs at a redshift very different from the systemic velocity.

By way of contrast, the H I absorption detected in the spectra of objects such as those studied by Heckman et al. (1983) indicate surface densities which are typically many times greater than those in Table 2. In terms of our selection criterion the quasars chosen are, with one exception (1331+170, which was observed for an absorption system with a redshift very much less than z_{em}), most nearly analogous to these objects. The main differences between the two classes are that we have selected quasars (rather than galaxies) and that their redshifts are very much larger than those of the galaxies discussed by Heckman et al. It is tempting to speculate that the lower surface densities indicated by our observations are attributable to one of these factors; in particular, we note that the

Table 2. Limits to and values of H I and OH column density

Quasar	N_H (10^{17} T_s cm^{-2} K^{-1})	N_{OH}(10^{13} T_s cm^{-2} K^{-1})	
		$F=1\leftrightarrow1$	$F=2\leftrightarrow2$
0202−172	< 6[a]	<12	< 7
1331+170[b]	<13	<27[a]	<16[a]
1356+022	< 7	–	–
1615+028	<19	–	–
1756+237	< 6[a]	<12	< 7
2005+403	<10[a]	<23	<13
2158+101	< 5[a]	<11	< 6
0235+164	$\geqq 32.6$	–	–
1229−021	16.5	–	–
1328+307	32.9	–	–
1331+170[c]	–	–	–
1157+014	3.1	–	–

[a] Not the principal line being searched for absorption

[b] For $z=1.33$

[c] For $z=1.7764$

relatively high ultraviolet flux from quasars may be too hostile for the presence of neutral H or OH in their near environment.

The absence of absorption in 1331+170, where we might have hoped to find H I associated with the optical absorption system at $z=1.3273$, serves to underline how infrequently H I can be detected in these high redshift systems (Wolfe, 1980). This is clearly a different phenomenon from that investigated by Heckman et al., involving intervening gas, remote from the object in question, with quite narrow line widths.

5. Conclusions

Despite the negative result of our search for absorption features and the small number of objects we have investigated, we feel that this work demonstrates the value of interferometric measurements. We cautiously suggest that the amount of neutral material near quasars may be less than that in the vicinity of low redshift early-type galaxies. Further investigations with the WSRT at long wavelengths would be valuable, despite the limited frequency coverage. In particular we note that an increase in frequency resolution would result in an immediate decrease in our limits to gas surface density.

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