ATTEMPTS TO DETECT NEUTRAL HYDROGEN IN COMPACT OBJECTS

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Abstract. An attempt was made to detect the redshifted HI line in absorption in the quasi-stellar sources 3C 273 and 1510 − 08 and in the N-galaxies 3C 120 and 3C 371. The Seyfert galaxies NGC 1068 and NGC 1275 were also searched for HI in absorption as well as in emission. Although no lines were detected, it was possible to place upper limits on the column density of HI in all these objects, as well as upper limits on the mass of HI in the Seyfert galaxies observed.

1. Introduction

The existence of intense, compact and frequently variable radio components in quasi-stellar sources, Seyfert galaxies, and N-type galaxies suggests the possibility of detecting neutral hydrogen in these objects by observing it in absorption against the intense continuum radio source present.

Following the suggestion of Bahcall and Ekers (1969), Shuter and Gower (1969) and Heiles and Miley (1970) have, without success, attempted to detect HI in absorption in a few distant ($z \sim 2$) quasars which have optical absorption lines. This paper presents the results of a search for HI absorption in nearby variable radio sources where the probability of such a detection may be higher than for more distant objects.

Detection of an HI absorption line is more likely in those objects which are known to contain at least one variable radio component whose emission extends to frequencies near 1420 MHz. Such components, besides providing an intense background continuum source, have linear dimensions on the order of a few parsec or less and hence could be occulted by a HI cloud of comparable size or larger within the object.

From the observed differences between optical absorption and emission line redshifts the expected frequency of an HI absorption line would not necessarily be found at the frequency $1420.4/(1+z_{em})$ MHz when only an optical emission line redshift is observed. However it is unlikely that as large a difference between emission and absorption redshifts would exist in Seyfert and N-type galaxies as in highly redshifted quasars.** The absorption redshift in 1510−08, one of the two quasars, observed in this paper, is 0.358 compared with an emission line redshift of 0.361 (Burbidge and Kinman, 1966). This difference corresponds to only about 1 MHz at the redshifted frequency of the 21-cm HI line. Thus it is felt that no absorption lines are likely to be found outside the actual frequency interval (up to 14 MHz) that was searched in each object.

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** Roberts (1970) has recently reported the existence of an HI absorption line in the nearby radio galaxy NGC 5128 that differs in radial velocity from that of the optical emission lines by only 23 km s^{-1}.

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All except one of the objects observed (1510−08) have no observed optical absorption lines. The presence of absorption is not necessarily an important criterion since most of the strong resonances absorption lines seen in quasars are found at frequencies that are redshifted into the visible region in only high redshifted objects.

The observations were made with the 140-ft (43 m) antenna of the National Radio Astronomy Observatory using the 413 channel auto-correlation spectral line receiver at its maximum bandwidth of 10 MHz and with a resolution of 52 kHz. Three different parametric amplifier front-ends were used to observe sources in the range 1040 to 1420 MHz.

A load switched on-source, off-source observational procedure was used to remove first order instrumentally-produced spectral slopes. Second order spectral effects such as that due to the source continuum emission, uncertainties in the gain calibration resulting from extensive man-made interference outside the protected frequency bands, and radiated emission reflected from the surface of the disk were minimized as much as possible. The details of the observations and the above calibration procedures will be published elsewhere (Dent, 1971).

2. HI in Absorption

No obvious absorption lines were found in any of the objects studied. There may be a suggestion of a line near 1397 MHz in NGC 1275; however, the signal to noise ratio is not adequate to claim a positive detection. Observations with greater sensitivity are planned for this source.

Upper limits to the depth of the line, ΔT_L, and the ratio of line depth to continuum antenna temperature, $\Delta T_L/T_C$, are given for each source in Table I and represent the principle result of these observations. The quoted upper limits of ΔT_L are one-half the peak-to-peak noise fluctuations.

If the HI in the object is seen against the background of a continuum source, with

TABLE I

Source	Type of object	z (ref)	Frequencies searched (MHz)	ΔT_L (K)	$\Delta T_L/T_C$	N_{HI} (cm^{-2})[a]
NGC 1068 (3C 71)	Seyfert	0.0037 (1)	1410–1420	<0.075	0.052	$<2\times10^{21}$
NGC 1275 (3C 84)	Seyfert	0.0176 (2)	1392–1403	$\leqslant 0.157$	0.042	$\leqslant 2\times10^{21}$
3C 120	N-Gal	0.0334 (3)	1370–1382	<0.051	0.039	$<2\times10^{21}$
3C 371	N-Gal	0.050 (4)	1348–1360	<0.070	0.093	$<4\times10^{21}$
3C 273	QSS	0.158 (5)	1220–1234	<0.089	0.007	$<3\times10^{22}$
1510−08	QSS	0.361 (6)	1040–1053	<0.068	0.080	$<3\times10^{23}$

[a] Assuming $\Delta\nu \leqslant 100$ KHz; $T_S \approx 10^3$ K for Seyfert and N-Galaxies and $T_S \approx 10^5$ K for quasars.
References: (1) Walker (1968); (2) Burbidge and Burbidge (1965); (3) Burbidge (1967); (4) Sandage (1966); (5) Schmidt (1963); (6) Burbidge and Kinman (1966).

brightness temperature T_B, and if $T_B > T_S$, the spin (excitation) temperature of the H I, then the line will appear in absorption with the depth of a line, ΔT_L given by

$$\Delta\nu \Delta T_L / T_C = 2.85 \times 10^{-15} N_{\mathrm{HI}} / T_S$$

where $\Delta\nu$ is the effective line width in Hz, and N_{HI} is the column density of H I in cm^{-2}. Thus the ratio N_{HI}/T_S can be determined from the observational quantities on the left side of the equation.

Because the spin temperature of the neutral hydrogen in these sources is not accurately known, only crude estimates of the upper limit to the H I column densities can be made using a calculated value of T_S. However, since the contributions to T_S from Lyman α and 21-cm photons depend as r^{-2} upon the distance of the H I from the photon sources, it is also necessary to assume an average distance of any H I present from these emitting regions within the object. If we adopt a plausible distance of 10^4 pc; and use measurements of the radio continuum flux, estimates of the Lyα flux (Wampler, 1968) and expressions for T_S given by Bahcall and Ekers (1969); we obtain rough estimates of $T_S \approx 10^3$ K in Seyfert and N-type galaxies and $T_S \approx 10^5$ K in quasars.

Bahcall and Ekers (1969) have argued that the absence of absorption lines of O I λ1303.5 or N I λ1134.6, 1199.9 in the optical spectra of large redshifted quasi-stellar sources implies that the H I line (if it exists) must have line widths less than about 100 kHz. Although the O I and N I lines would not be redshifted into the visible in the objects studied in this paper, similar excitation and ionization conditions probably exist in these objects as well. Thus in the absence of a positive detection of a line, we will adopt a value of $\Delta\nu \leqslant 100$ kHz for the purposes of calculation.

Assuming this upper limit of $\Delta\nu$ and the above estimates of T_S, upper limits to the column density of neutral hydrogen were calculated and are tabulated in the last column of Table I. It should be emphasized that because of the large uncertainties in estimating T_S, the quoted upper limits to N_{HI} may be uncertain by more than an order of magnitude.*

3. H I in Emission

The 21-cm H I line will appear in emission from those regions of the object in which the spin temperature is greater than the background brightness temperature of the continuum emission. The H I line should therefore appear in emission everywhere in the object except directly in front of the small intense radio component. Since none of the objects observed here could be resolved with the 20′ beamwidth of the antenna, only an effective antenna temperature, ΔT_L(em), of the emission line integrated over the object could be observed. It is easily shown that an estimate of the total mass of H I in the object can be obtained from $M_{\mathrm{HI}} = 3.1 \times 10^{-6} R^2 (\lambda^2)/A_e)\ \Delta T_L(\mathrm{em})\ \Delta\nu$ (solar

* It should be mentioned that the value of T_C used in the calculation is the total source antenna temperature consisting of contributions from the small intense components as well as emission from more extended regions. Thus depending on the location of the H I, it may be necessary to adjust further the limits of N_{HI}.

masses), where R is the distance to the source in parsecs, A_e is the effective area of the antenna, λ the wavelength, and $\Delta\nu$ the effective line width in Hz.

In normal spiral galaxies $\Delta\nu$ is a Doppler width due to the rotation of the galaxy, and is on the order of 200 km s^{-1} or about 1 MHz at 1420 MHz. Neutral hydrogen emission in these objects would be expected to have similar line widths since hydrogen with much higher velocities is likely to be almost completely ionized in these objects. The spectra were smoothed with a 500 kHz gaussian filter and examined for possible emission lines. Although no obvious lines were found, meaningful upper limits on ΔT_L(em) were obtained for the two Seyfert galaxies. Upper limits on ΔT_L(em) of 0.05 K and 0.06 K were obtained for NGC 1068 and NGC 1275 respectively. Assuming a Hubble constant of 100 km s^{-1} Mpc^{-1} and $\Delta\nu = 1$ MHz, these values yield upper limits to the masses of $1 \times 10^9\ M_\odot$ and $3 \times 10^{10}\ M_\odot$ respectively. Because the upper limits to the masses are proportional to R^2 the remaining four more distant objects do not give meaningful upper limits to the mass of H I.

The most recent estimate (Walker, 1968) of the mass of the inner region (<2 kpc) of NGC 1068 is $6 \times 10^9\ M_\odot$. An earlier study by Burbidge *et al.* (1959) which did not assume a non-rotational component of the gas obtained a higher figure of $2 \times 10^{10}\ M_\odot$ for the inner region. An estimate of the total mass of the entire galaxy would be at least a factor of 2 to 4 times greater than the mass obtained for the inner region (Roberts, 1969). Hence a lower limit to the total mass of NGC 1068 is about $4 \times 10^{10}\ M_\odot$. Thus the upper limit of $1 \times 10^9\ M_\odot$ to the mass of neutral hydrogen in NGC 1068 (3C 71) obtained from these observations places an upper limit on the ratio $M_{\rm HI}/M_T$ of 0.025. This value is less than the average value of 0.05 (Roberts, 1969) for $M_{\rm HI}/M_T$ of Sb galaxies, the classification given to NGC 1068 by Humason *et al.* (1956) on the basis of its spiral structure.

Thus although the Seyfert galaxy NGC 1068 shows some similarities to normal spirals, it may be under-abundant in neutral hydrogen. This would not be surprising in view of the large flux of ionizing radiation likely to be emanating from the nucleus of this galaxy.

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