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Detection of a 21 cm Absorption Line against the Suggested Galaxy/QSO Pair NGC 3067/3 C 232

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Summary. The 21 cm line emission of the four suggested galaxy/QSO pairs NGC 3067/3 C 232, NGC 4138/3 C 268.4, NGC 4651/3 C 275.1 and NGC 5832/3 C 309.1 has been studied with the Effelsberg 100-m telescope. In the case of the first pair, a narrow absorption feature at $v_{\rm LSR}=1411\ {\rm km\ s^{-1}}$ was found. The physical implications of our results as to the reality of the galaxy/QSO associations are discussed.

Key words: galaxy/QSO pairs — 21 cm observations — H I absorption against NGC 3067/3 C 232 — physical implications of galaxy/QSO associations

I. Introduction

The interesting proposal has been made that part of the redshift observed in distant extragalactic objects is of other than cosmological origin. Quasistellar objects (QSO) have been the prime candidates for anomalous redshifts. To either prove or disprove such a hypothesis, physical associations of the following types have been studied:

i) associations between galaxies or clusters of galaxies and QSOs showing the same redshift,

ii) associations between galaxies and QSOs with discrepant redshifts,

iii) associations between QSOs with discrepant redshifts.

Examples for the first type of association have been claimed by Bahcall *et al.* (1969), Gunn (1971), Oemler *et al.* (1972), Robinson and Wampler (1972), Miller *et al.* (1973), Stockton (1973). These are taken as a demonstration that QSOs are actually at the distances indicated by the cosmological interpretation of their redshifts. This would be so if there were no doubts as to the true physical association of the galaxies or clusters of galaxies and the QSOs. There remains the possibility of positional chance coincidences, however, as pointed out by Burbidge and O'Dell (1973).

Examples of the second type were first given in a paper by Burbidge *et al.* (1971), and a further example was added shortly afterwards by Arp *et al.* (1972). Two more and possibly still a further example have been found by Hazard *et al.* (1973), these cases being however less well studied. As in the case of concordant redshifts one can try to establish statistically the significance of the observed positional coincidences, the matter being even more controversial in this case. Whereas Burbidge *et al.* (1971) in their original paper estimated the chance probability for close coincidences to be extremely small, other authors (Burbidge *et al.*, 1972; Bahcall *et al.*, 1972; Ozernoi, 1973; Browne and McEwan, 1973), using different samples of QSOs and galaxies, found no statistically significant associations. Burbidge *et al.* (1972) tried to explain this negative result as due to selection effects which might prevent associations from being found: (i) inaccuracies in the radio positions used in optical identifications might lead to QSOs being missed, and (ii) weak radio QSOs might be faint optical objects that are too faint to identify. Both these possibilities were considered by Browne and McEwan (1973) in the light of improved optical identifications, yet with no straightforward conclusion. These authors actually found two new QSOs close to bright galaxies. In a mathematical simulation of the original Burbidge *et al.* (1971) sample of objects, Kippenhahn and de Vries (1974) showed the associations to be indeed statistically significant.

There are now three examples known for the third type of association. One such pair is formed by the objects Ton 156, Ton 157 (Stockton, 1972), another example is 1548+115a, 1548+115b (Wampler *et al.*, 1973), and a third one the object 4 C 11.50 (Hazard *et al.*, 1973). Again is the physical reality of these pairs, which can only be proven statistically, a matter of controvercy. As pointed out by Bahcall and Woltjer (1974) and Burbidge *et al.* (1974), due to the hazards of *a posteriori* statistics no firm conclusions can be drawn as yet.

Because of the discomfort one feels with statistics based on small numbers anyway, we tried to attack the problem in a different way by looking for physical consequences in the case that an association between QSOs and galaxies actually exists. We concentrated on the four QSO-galaxy pairs originally suggested by Burbidge *et al.* (1971) and studied them with the Effelsberg 100-m telescope at a wavelength of 21 cm. In presenting our results we first go through a brief theoretical computation of the hydrogen ionization rate which is implied if the QSOs are indeed at a linear distance of only 10–15 kpc from their parent galaxies as suggested by Burbidge *et al.* (Chapter II), we then describe our observing method and results (Chapter III). In Chapter IV, our observations are discussed and some conclusions are summarized in Chapter V.

II. Theoretical Considerations

In Table 1 we have listed the four examples for possible QSO-galaxy associations, originally pointed out by Burbidge *et al.* (1971). In the first six columns of this table we give the name, the type, the inclination, the Holmberg diameter, the apparent visual magnitude, and the redshift of the objects. The inclination i of the galaxies was calculated from the ratio of their minor to major axis, taken from de Vaucouleurs and de Vaucouleurs (1964). The Holmberg diameter was taken to be 1.45 times the major axis of the optical galaxies as given in the same reference. Assuming a Hubble constant $H_0 = 50$ km s^{-1} Mpc^{-1}, we have estimated the distances of the galaxies (Column 7) from their radial velocities relative to the local group of galaxies (Gouguenheim, 1969). Assuming that the same distances that apply to the galaxies also apply to the QSOs, we have converted the angular separation of the galaxy/QSO pairs (Column 8) into a linear separation which is given in Column 9. Using the distances given in Column 6, we have calculated from the apparent visual magnitudes the visual luminosities of the QSOs (Column 10). The emission of these objects is nonthermal in origin. Its frequency dependence can be described by $I_\nu \sim \nu^{-\gamma}$ where $\gamma \leqq 1$. There is every reason to suspect that the emission is not confined to the visual range but extends further into the UV even beyond the Lyman limit. This is what one finds for QSOs of still larger redshifts where the Lyman limit is shifted into the optical range.

We shall assume then that the QSOs listed in Table 1 indeed emit Lyman continuum photons, the Lyman continuum luminosity being given by

$$L(\text{Ly-}c) = qL(\text{vis.})$$

where $q = q(\gamma, \nu_c)$, i.e. q is a function of the spectral slope γ and a cut-off frequency ν_c, which are both determined by the properties of the energy distribution of the relativistic electrons giving rise to the synchrotron emission. The spectral energy distributions of QSOs (e.g. Oke, 1970, 1974) generally show that $\nu_c > 3 \cdot 10^{15}$ Hz. Since also generally $\gamma < 1$, $q = 1$ should give a very conservative estimate of the actual flux of Lyman continuum photons.

In Column 11 of Table 1 we have given the resulting number of Lyman continuum photons. In a distance of 10 kpc, which is the order of magnitude of the linear separation between the QSOs and their parent galaxies implied by Burbidge *et al.* (1971, 1972), these values of j_{ph} lead to a hydrogen ionization rate Γ_H given in column 12. Γ_H is defined in the usual way, i.e.

$$\Gamma_H = \int_{\nu_0}^{\infty} \sigma_H(\nu) j_{ph}(\nu) d\nu = \langle \sigma_H \rangle \cdot j_{ph} . \tag{1}$$

Table 1. Physical properties of suspected Galaxy-QSO pairs

Object	Type	Inclination[a]) [deg]	Holmberg[a]) diameter [arc min]	m_v	z[b])	Distance[c]) [Mpc]	Angular separation [arc min]	Linear separation [kpc]	L_v [erg s^{-1}]	j_{ph} [s^{-1}]	Γ[d]) [s^{-1}]
NGC 3067	Irr II	67	3.71	12.7	0.00479	28.7			2.2 (43)		
							1.9	16.0			
3 C 232				15.8	0.534				5.9 (41)	1.5 (53)	4.0(−11)
NGC 4138	Sa	51	2.45	12.1	0.00308	18.4			1.6 (43)		
							2.9	15.2			
3 C 268.4				18.4	1.400				2.3 (40)	5.8 (51)	1.6(−12)
NGC 4651	Sc	47	5.50	11.3	0.00302	18.1			3.3 (43)		
							3.5	18.3			
3 C 275.1				19.0	0.557				1.2 (40)	3.0 (51)	8.0(−13)
NGC 5832	SBb	56	5.37	13.3	0.00108	6.5			6.7 (41)		
							6.2	11.7			
3 C 309.1				16.8	0.904				1.3 (40)	3.3 (51)	8.6(−13)

[a]) de Vaucouleurs, de Vaucouleurs, 1964.
[b]) Values for galaxies are based on our own 21 cm velocities which are referred to the local group of galaxies (Gouguenheim, 1969).
[c]) Assuming $H_0 = 50$ km s^{-1} Mpc^{-1}.
[d]) At a distance of 10 kpc.

As shown in Table 1, the hydrogen ionization rates are extremely high compared e.g. to the rate assumed within our own galaxy.

III. Observing Method and Results

Our results are based on observations with the Effelsberg 100-m telescope, taken on March 26–29, 1974 and March 6, 1975. The half power beam width of the telescope at 21 cm is 9′. We used a cooled parametric amplifier frontend and a 384 channel digital autocorrelation spectrometer. The total system temperature on cold sky was about 50 K. In searching for the H I emission from the four galaxies listed in Table 1, we used a total bandwidth of 10 MHz. The receiver was switched between the antenna and a 40 K reference load at a rate of 1 Hz. In searching for absorption lines in the direction of the QSOs, the total bandwidth was restricted to 2.5 MHz, in order to increase the velocity resolution. The observations were taken in the total power mode, with 10 m on source and 10 m off source integrations. The scale for both the load switch and the total power observations was determined by adding a calibration noise in a 2 Hz switching cycle to the antenna side.

Our normal observing procedure was such that we first searched for the H I emission of the galaxies in order to determine its magnitude and as far as possible its angular extent by off-setting the telescope from the position of the center of the galaxy. In particular, did we search for H I emission at the position of the QSOs. Then centering the spectrometer on the newly determined systemic velocities of the galaxies (cf. Table 2), we tried to detect an absorption line at the QSO positions.

(i) NGC *3067/3* C *232:* This galaxy/QSO pair has been studied previously by Gottesman and Wright (1973) in the 21 cm line. These authors neither detected the emission of NGC 3067 nor did they find an absorption line against 3 C 232. This latter result can be explained as being due to the relatively poor velocity resolution used. The results of the present investigation are shown in Fig. 1 where the emission spectrum in the range $1320 \leq v_{LSR} \leq 1600$ km s^{-1} is depicted.

That the emission of NGC 3067 is confined to this velocity range was confirmed by our 10 MHz load-switch spectrum. The spectrum shown in Fig. 1 was taken at a velocity resolution of 1.69 km s^{-1}. As a zero point for the temperature scale we have chosen the temperature of the neighbouring continuum which is given in Column 3 of Table 3. (The same procedure has been followed in preparing Figs. 2–4).

It is interesting to note that the maximum velocity to which the 21 cm emission line is seen agrees with the maximum radial velocity derived from optical studies (Danziger and Chromey, 1972) which refer to a region of $\leq 35''$ from the center of NGC 3067. The same

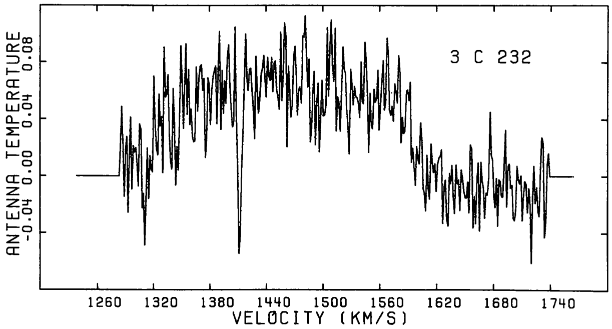

Fig. 1. 21 cm line profile at the position of the QSO 3 C 232 observed with a velocity resolution of 1.69 km s^{-1}. The emission covering the range $1320 < v_{LSR} < 1600$ km s^{-1} originates from the galaxy NGC 3067 separated from 3 C 232 by only 1.′8. The continuum radiation has been subtracted from all our spectra. At $v_{LSR} =$ 1411 km s^{-1} a narrow absorption feature is visible

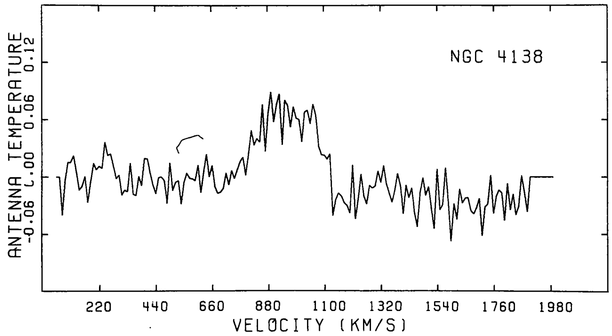

Fig. 2. 21 cm emission line observed with the telescope pointed towards the galaxy NGC 4138. The velocity resolution here and in the other on-galaxy lines is 6.75 km s^{-1}

authors find as a lower limit to the velocity range in which optical lines are seen a value of ~1200 km s^{-1} which would be definitely lower than the limit to which the 21 cm emission is found. We shall comment on possible implications of this finding in Chapter IV.

Figure 1 shows clear evidence for a narrow absorption feature at $v_{LSR} = 1411$ km s^{-1} which was seen with three L.O. settings differing by about 10 km s^{-1} from each other. The relatively poor angular resolution of the telescope did not allow to see any differences in the 21 cm emission at the position of the center of NGC 3067 and at the position of 3 C 232.

(ii) NGC *4138/3* C *268.4:* Figure 2 gives the emission spectrum of NGC 4138 observed at the position of the center of the galaxy. Off-setting the telescope by 2.′9 towards the position of 3 C 268.4 yields a significantly reduced H I emission which is consistent with the emission being confined to the Holmberg diameter of the galaxy (cf. Table 1). No absorption feature is visible in our spectra to a limit of $T_{max} = 0.08$ K.

(iii) NGC *4651/3* C *275.1:* Figs. 3a, b shows the emission of NGC 4651 at a resolution of 6.75 km s^{-1} and 1.69 km s^{-1}, respectively, at the position of the center of the galaxy and at the position of 3 C 275.1. The

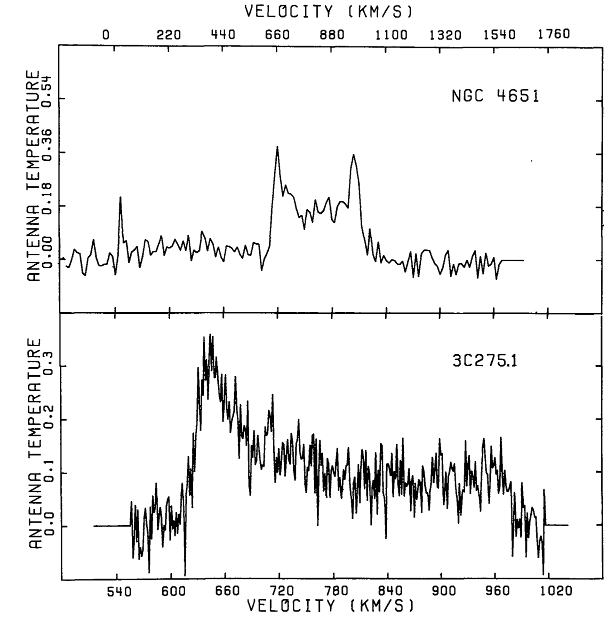

Fig. 3. 21 cm emission line from the galaxy NGC 4651. The spectrum at the top shows the on-galaxy profile, the lower one the profile obtained on the QSO 3 C 275.1. Here and in Fig. 4 the galactic H I-emission at $v_{LSR}=0\,\mathrm{km\,s^{-1}}$ drops out because of our observing method (Total power on-off)

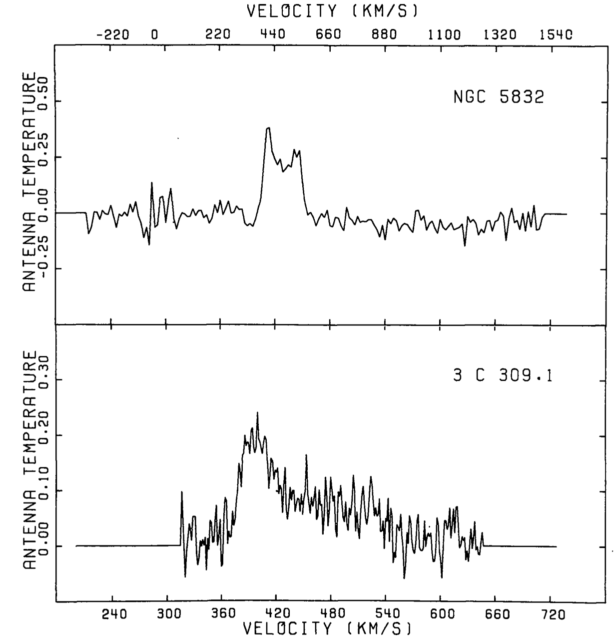

Fig. 4. 21 cm emission line from the galaxy NGC 5832. The spectrum at the top shows the on galaxy profile, the lower one the profile obtained on the QSO 3 C 309.1

emission of the galaxy has previously been detected by Gottesmann and Wright (1973) in their attempt to detect a 21 cm absorption line against 3 C 275.1

From off-set measurements taken at 4.′5 and 9.′0 to the north, south, east and west of NGC 4651, we find an asymmetry of the H I distribution in the sense that either the H I extent or the line intensities are smaller in the direction towards the QSO. Whereas this result could indeed indicate an actual association between the two objects, it could also merely reflect the fact that there is a much more pronounced spiral arm on the west side of the galaxy than there is on the east side. No absorption feature is seen at the position of the QSO to a level of $T_{\max}=0.10$ K.

(iv) NGC *5832/3* C *309.1:* Figs. 4a, b show the emission spectrum of NGC 5832 at a resolution of $6.75\,\mathrm{km\,s^{-1}}$ and $1.69\,\mathrm{km\,s^{-1}}$, respectively. As in the previous case, the lower resolution observations are centered on the position of the galaxy, the higher resolution ones on the position of the QSO. No absorption feature is visible to a level of $T_{\max}=0.08$ K.

The integral properties of the four galaxies NGC 3067, 4138, 4651, and 5832 are summarized in Table 2. Columns 1–4 give the name of the object, the systemic velocity with respect to the local standard of rest, the velocity width W at half maximum intensity, and the integrated 21 cm flux. In calculating $\int s_v dv$, the H I extent of the galaxies relative to the telescope beam has been taken into account. In Column 5 the inferred neutral hydrogen mass is given which has been calculated from the equation

$$M_{\mathrm{HI}}=2.36\cdot 10^5 d^2 \int s_v dv \tag{2}$$

Here M_{HI} is in solar masses $M_\odot$, d is the distance of the galaxy in Mpc (cf. Table 1). The indicative total masses of the galaxies (Heidmann, 1969) given in Column 6 were derived from

$$M_i=3\cdot 10^{-5} a_0 (W/\sin i)^2\,. \tag{3}$$

Here M_i is again expressed in solar masses, a_0 is the Holmberg diameter, W is the width of the line at half intensity, and i the inclination of the galaxies (cf. Table 1). It should be noted that the unusually high values of M_i/L_v and M_{HI}/L_v for NGC 5832 are proabably due to an underestimate of L_v which is very uncertain for this object.

Our results from the absorption line measurements in the direction of the four QSOs 3 C 232, 268.4, 275.1 and 309.1 are summarized in Table 3. Column 1 lists the name of the objects, Columns 2 and 4 give our limits to the absorption line antenna temperatures and the optical depths, respectively, as calculated from $(\Delta T)_{\max}$ and T_{cont} (Column 3). For the one case, where an absorption line was actually detected, we also give the center velocity with respect to the local standard of rest, the half power width and the H I column density calculated from

$$N_{\mathrm{HI}}=1.823\cdot 10^{18}\, T_k \int \tau_v dv \tag{4}$$

where we have used a value of 350 K, inferred from the width of the line, as an upper limit for T_k. The value given for τ would have to be increased if the absorption would not arise against the QSO but against a strong source within the galaxy.

Table 2. Derived parameter for NGC 3067, 4138, 4651, and 5832

Objects	V_{LSR} [km s^{-1}]	W [km s^{-1}]	$\int s_\nu dv$ [W m^{-2} Hz^{-1} km s^{-1}]	$M_{HI}/M_\odot$	$M_i/M_\odot$	M_{HI}/M_i	$\frac{M_{HI}/M_\odot}{L_\nu/L_\odot}$	$\frac{M_i/M_\odot}{L_\nu/L_\odot}$
NGC 3067	1470 ± 20	250 ± 40	11 (−26)	2.1 (9)	6.9 (10)	0.030	0.35	12
NGC 4138	960 ± 20	290 ± 30	16 (−26)	1.3 (9)	5.6 (10)	0.023	0.30	13
NGC 4651	820 ± 20	360 ± 20	59 (−26)	4.5 (9)	18.9 (10)	0.024	0.63	27
NGC 5832	470 ± 10	165 ± 20	43 (−26)	0.5 (9)	1.8 (10)	0.028	1.37	49

Table 3. Absorption data on 3 C 232, 268.4, 275.1 and 309.1

Object	T_{max} [K]	T_{cont} [K]	τ	V_{LSR} [km s^{-1}]	W [km s^{-1}]	N_{HI} [cm^{-2}]
3 C 232	-0.11 ± 0.02	2.2	0.05	1411 ± 1	4.0	$\leqq 1.4$ (20)
3 C 268.4	<0.08	3.5	<0.02	—	—	—
3 C 275.1	<0.10	4.4	<0.02	—	—	—
3 C 309.1	<0.08	12.8	<0.006	—	—	—

IV. Discussion

The discussion of the results given in Chapter III naturally devides itself into two parts. Firstly, we have the positive detection of an absorption line in the case of the suggested galaxy/QSO pair NGC 3067/3 C 232. Secondly, we shall discuss the remaining three pairs, where only an emission spectrum is seen.

There can be no doubt as to the reality of the absorption feature in the spectrum NGC 3067/3 C 232 since it was found in several independent observations. The principal question, however, arises whether it is an absorption seen against the emission of the galaxy or against that of the QSO. We observe a continuum temperature of 2.3 K (cf. Table 3). Extrapolating the flux of the QSO of ~8 f.u. at 178 MHz (quoted in Burbidge *et al.*, 1971) to 1420 MHz, using a spectral index of 0.75, we find that the observed value of 2.3 K could be completely due to the QSO. On the other hand, if we estimate the typical antenna temperature expected from an Sb galaxy at a distance of 28.7 Mpc, we find $T_{cont,gal} \simeq 0.2$ K. Because of our poor angular resolution we cannot distinguish between these contributions. As the absorption line has a depth of only 0.11 K, it could indeed arise against either of the two continua.

An indication that we are not seeing an absorption against the galaxy as a whole comes from the narrowness of the absorption feature (4 km s^{-1} HPW). This leaves open the possibility of an absorption against a strong point source within the galaxy. In order to produce an antenna temperature of 0.1–0.2 K, this would, however, have to be an extremely powerful source and could probably only be the nucleus of NGC 3067 itself. Optically the nucleus is not particularly pronounced, as it is in galaxies with active nuclei, indicating that this explanation is not very likely. Also, if the absorption arises against a source within the galaxy, we would normally expect to see absorption at more than one velocity or else a much wider absorption line because of the high inclination of the system.

We shall now discuss the fact that we are seeing the absorption at $v_{LSR} = 1411$ km s^{-1}, which is almost exactly the velocity found for the central region of NGC 3067 by Danziger and Chromey (1972). As mentioned before, these authors observed optical emission lines in the range ~1200–1600 km s^{-1}, whereas the H I emission appears to be limited to ~1300–1600 km s^{-1}. It may be this difference which leads to the difference of ~60 km s^{-1} in the systemic velocities determined by Danziger and Chromey and us. The radial velocity curves determined by these authors for different slit orientations show that the low velocities occur to the west of the rotation axis of NGC 3067, i.e. on the same side as the QSO. This leads one to consider the possibility that the missing hydrogen is kept ionised by 3 C 232.

In Chapter II we have argued that we expect the total number of Lyman continuum photons emitted by the QSO to be of the order of 10^{53} s^{-1}. Equating this number to the total number of recombinations per second in a spherical volume of radius R_0 that can be kept ionized, we obtain

$$R_0 = [3 j_{ph} / 4\pi n_e^2 \alpha]^{1/3} \tag{5}$$

where all quantities have their usual meaning, i.e. n_e denotes the number density of free electrons, and α the total recombination coefficient for hydrogen to all levels but the first. Inserting $j_{ph} = 1.6 \cdot 10^{53}$ s^{-1}, $\alpha = 2.7 \cdot 10^{-13}$ cm^3 s^{-1} (valid for $T = 10^4$ K), we find $R_0 = 1.5 n_e^{-2/3}$ kpc. This result clearly shows that for typical halo densities, which are generally thought to be $\lesssim 10^{-4}$ (e.g. Spitzer, 1956), no tenuous neutral hydrogen gas could survive.

If we now consider the possibility of ionizing hydrogen in the main body of NGC 3067, it is more convenient to re-write Eq. (5) in the form

$$M_{\rm H}=[m_{\rm H}/\alpha]\cdot[\tilde{j}_{\rm ph}/n_e] \tag{6}$$

where $M_{\rm H}$ denotes the maximum amount of hydrogen that can be kept ionized by a given Lyman-continuum photon flux. $\tilde{j}_{\rm ph}$ is the photon flux emitted into the solid angle subtended by NGC 3067 as seen from 3 C 232 at an assumed distance of ~ 16 kpc. Putting numbers into Eq. (6), $m_{\rm H}=1.6\,10^{-24}$ g, $\alpha=2.7\,10^{-13}\,{\rm cm}^3\,{\rm s}^{-1}$, $\tilde{j}_{\rm ph}=4\cdot 10^{52}\,{\rm s}^{-1}$, $n_e=0.2\,{\rm cm}^{-3}$ (gas of this density gives the dominant contribution to the 21 cm emission of our own galaxy), we find $M_{\rm H}=6\cdot 10^8\,M_\odot$. From our H I emission profile (cf. Fig. 1) and the comparison with the velocity range in which optical lines are seen (Danziger and Chromey, 1972), we would estimate that about 25% of the hydrogen could be missing, giving a value close to the limit derived here. Our emission line data are therefore compatible with the suggestion that NGC 3067 and 3 C 232 are physically associated, they are not conclusive however. There appears to be a contradiction within the optical radial velocity determinations for NGC 3067 since in the paper by Burbidge *et al.* (1971) a considerably higher value for the systemic velocity is given than by Danziger and Chromey (loc. cit.). The above results strongly suggest to repeat this kind of analysis with both better optical and radio data.

So far, we have discussed the possibility that the absorption line shown in Fig. 1 arises against a source within NGC 3067. We now turn to the alternative possibility that it arises against the QSO continuum due to neutral hydrogen either in the halo of NGC 3067, say at 10 kpc above the plane, or else within the plane at typically 40–50 kpc from the center. Because of the particular geometry, the radial velocity at which the absorption occurs does not allow to distinguish between these two possibilities. The projected location of 3 C 232 is so close to the rotation axis of the galaxy (maximum traverse distance of the line of sight $\simeq 5$ kpc) that no large velocity difference with respect to the systemic velocity is expected.

However, independent of the question whether the absorbing cloud is situated in the halo or in the plane of the galaxy, the width of the absorption line indicates that it can not be due to gas widely distributed along the line of sight but must come from a condensation of relatively cool hydrogen ($\leqq 350$ K). That neutral hydrogen occurs at large distances from the optical body of galaxies has been shown recently, e.g. by Mathewson *et al.* (1975) for NGC 55 and NGC 300. These authors find H I lines with a width of 35 km s^{-1} which they attribute to intergalactic hydrogen clouds with a density of $\sim 3\cdot 10^{-4}\,{\rm cm}^{-3}$ and a size of 30–50 kpc. These clouds are suggested to be related to the high velocity clouds observed, for example, by Hulsbosch (1972). If looked at with increased angular resolution, these often show small scale structure from which narrow emission lines are observed. The absorption line that we see could possibly arise from such a smaller condensation in front of 3 C 232.

We now turn to a discussion of the question whether a neutral hydrogen cloud could at all survive in the halo of NGC 3067 if 3 C 232 is indeed physically associated with it at a projected distance of 16 kpc. We consider a cloud of size d at a distance D from the QSO and ask for the critical value of D at which the cloud would still be completely ionized. Taking into account that the relevant photon flux is now given by $j_{\rm ph}\cdot(4\pi)^{-1}\,(d/D)^2$, we find from Eq. (5)

$$D_{\rm m}=1.2\cdot 10^3\sqrt{d}\ [{\rm pc}] \tag{7}$$

were both d and D are measured in parsecs. The numerical factor is valid for a column density $n_{\rm H}=1.4\cdot 10^{20}\,{\rm cm}^{-2}$. We note in passing that a similar value for $D_{\rm m}$ is found if one considers an absorbing sheet of hydrogen instead of a spherically symmetric cloud.

In order to evaluate Eq. (7), we would need to know the linear size of the absorbing cloud giving rise to the observed line. This size is not known. From the width of the line on one side and from considerations of the stability of clouds in a tenuous halo gas leading to stringent limitations of the cloud densities on the other side, we estimate the size to be of the order of $\lesssim 100$ pc. This yields $D_{\rm m}\lesssim 10$ kpc, indicating that on this account we cannot exclude the possibility that 3 C 232 and NGC 3067 are indeed physically associated.

A more critical value for $D_{\rm m}$ is obtained, however, if one considers the thermal balance of a cloud at distance D from the QSO. The radiative energy loss rate of cloud material of normal chemical composition is typically $L=10^{-25}\,n_e\,n_{\rm H}\,{\rm erg\,cm}^{-3}\,{\rm s}^{-1}$. The energy gain per cm^3 s, on the other hand, is given by

$$G=n\langle\sigma\rangle\Delta E\cdot j_{\rm ph}\cdot(4\pi D^2)^{-1}$$

where n is the number density of an element capable of being ionized, $\langle\sigma\rangle$ the corresponding mean photoionization cross-section (typically $10^{-18}\,{\rm cm}^2$), ΔE the net energy gain per ionization and $j_{\rm ph}(4\pi D^2)^{-1}$ the relevant photon flux. For a worst case consideration we assume that all photons capable of ionizing H and He are absorbed in some transition layer so that only photons with $\lambda > 912$ Å reach the main body of the cloud. In this case only elements like C, Mg, Si, S, Fe etc. can be ionized, i.e. typically $n\approx 10^{-4}\,n_{\rm H}$, and $\Delta E\approx 2$ eV. Equating the energy loss and the energy gain rate, we find

$$D_{\rm m}=2.1\cdot 10^5/\sqrt{n_{\rm H}}\ [{\rm pc}] \tag{8}$$

where we have used that also $n_e\approx 10^{-4}\,n_{\rm H}$. Equation (8) shows that for $n_{\rm H}=1\,{\rm cm}^{-3}$, the maximum value that seems tolerable on the basis of pressure balance considerations for halo clouds, the minimum distance of the cloud from the QSO must be 210 kpc which would clearly put it outside the halo of NGC 3067 or, vice versa, if the cloud that we see is associated with this galaxy, 3 C 232 cannot be at the distance suggested by Burbidge *et al.* (1971).

We now briefly comment on the remaining three suggested galaxy/QSO pairs NGC 4138/3 C 268.4, NGC 4651/3 C 275.1, and NGC 5832/3 C 309.1. As we did not detect an absorption line in any of these cases, we can discuss only the appearance of the emission spectra. We note that the spectrum of NGC 4138 resembles that of NGC 3067 in that it tails off rather smoothly at the low velocity side. Unfortunately we are unaware of any detailed optical studies of this system that would allow a comparison of the optical and radio velocity ranges as it was done for NGC 3067. In the case of NGC 4651 the emission spectrum observed in the position of the center of the galaxy looks very regular, however, as noted in Chapter III, off set measurements show that the H I extent is smaller on the side towards 3 C 275.1 than in other directions. As shown in the beginning of this chapter, the Lyman-continuum radiation of the QSO would indeed substantially ionize the hydrogen in its vicinity if it were at a distance of only 18.3 kpc from NGC 4651. Observations of the H I distribution with better angular resolution are needed to reveal whether this deficiency has any significance or not. In the case of NGC 5832 our data are entirely inconclusive, we find neither an assymetry, in the spectrum nor in the distribution of neutral hydrogen.

V. Conclusions

We have attempted to look for physical effects that arise if the four galaxy/QSO pairs, suggested by Burbidge *et al.* (1971), are real. We obtained 21 cm H I emission line spectra for all four cases. We derived integral physical properties of the galaxies from the emission lines, and in one case (NGC 3067/3 C 232) we also found an absorption feature.

Whereas our emission line data generally do not allow any firm conclusions as to whether or not the proposed galaxy/QSO associations are real, largely because of the insufficient angular resolution used in our experiment, we noted in one case, NGC 3067, the interesting fact that, by comparison to optical studies, low velocity H I gas seems to be missing. This would be consistent with a physical association of 3 C 232 with NGC 3067, however, a detailed quantitative study based on better observational data is needed to substantiate this result.

The detection of an absorption line against NGC 3067/3 C 232 leads to some interesting implications if the absorption indeed arises against the QSO and not against a strong source within the galaxy. We found that the narrowness on the line puts a stringent limit on the temperature of the absorbing material. Considering the thermal balance, this in turn leads to a minimum distance between the cloud and the QSO which appears to be inconsistent with 3 C 232 being at the distance suggested by Burbidge *et al.* (1971) unless we assume that the density of the cloud is unreasonably high.

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