MATERIAL IN THE VICINITY OF GALAXIES

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It is increasingly certain that the principal concentrations of neutral hydrogen gas are in spiral and irregular galaxies. The intergalactic medium (IGM) appears to be either a near-void with $\langle\rho\rangle \lesssim 1.5 \times 10^{-11}$ cm^{-3} from the 3C9 measurements of Gunn and Peterson (1965) or at best a hot, highly ionized gas with very little neutral hydrogen present (Field and Perrenod, 1977). In clusters of galaxies, the intracluster medium (ICM) also appears to be mostly hot and ionized, as suggested by X-ray observations (Jones et al. 1977) and by observations of head-tail radio galaxies. Even if most of the IGM and ICM were ionized, however, one might imagine that there exist high-density concentrations where the cooling rate is sufficient to allow recombination, particularly in the vicinity of galaxies. One might expect such condensations to be revealed either by 21-cm emission, or by absorption against a bright background continuum source.

A study of galaxy-quasar pairs by Haschick, Baan, and Burke has revealed one such example. A total of 8 close pairs were examined, Table I, with negative results in 7 cases but a clearly positive result for the pair NGC 3067/4C32.33. The absorption line was narrow (5 km/s) and has a radial velocity well within the range of velocity exhibited by the hydrogen emission of NGC 3067. The absorbing cloud clearly is associated with the galaxy, yet must lie about 60 kpc distant from the center if it belongs to the disc population, a distance of several Holmberg radii. If the cloud is in the halo, it is remarkable that there is so little internal motion. The observed column density is $2.7 \times 10^{17}\ T_s$ cm^{-2}, or 2.7×10^{19} cm^{-2} if the state temperature is 100 K, a value comparable to that observed for the high-latitude, high-velocity gas observed in our own galaxy.

The same method was used by Baan, Haschick, and Burke to search for neutral hydrogen in clusters of galaxies, using continuum radio sources lying in or beyond rich clusters. 15 clusters of galaxies were observed, with positive results in one case. The one positive case was Markarian 6 (IC450), in the cluster Zw 0642.0 + 7334, but since this is a Seyfert galaxy of type II, and hence an active galaxy,

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Table I

QSO - Galaxy pairs

Quasar/Galaxy	Optical Depth $\Delta\tau_{rms}$	Radial Velocity $V, \Delta V$ (km sec^{-1})	Disc Distance of Quasar (kpc)	Angular Separation (arc min)	Observed Column Density N_H/T_s (cm^{-2} K^{-1})
4C32.33/NGC 3067	.027± .005	1494,76	58	1.9	2.7 (17)
3C268.4/NGC 4138	<.005	1020	29	2.9	
3C275.1/NGC 4651	<.006	795	16	3.5	
3C309.1/NGC 5832	<.008	457	28	6.2	
3C455/NGC 7413	<.005	10050	31	0.39	
1749+701/NGC 6503	<.003	70	30	5.4	<2.8 (17)
CTA102/NGC 7305	<.001	4100	-	5.1	
3C345/NGC 6212	<.002	-	-	4.6	

it was considered premature to classify this as a positive detection of an ICM. The absorbing gas cannot be very close to the nucleus of the galaxy, however, since the resulting ionization state and state temperature would require a very large cloud indeed. The cloud has a column density of 6 x 10^{18} T_s cm^{-2}, and has a velocity outward from the nucleus of about 170 km/s, with a line-width of 32±6 km/s.

This detection prompted an investigation of other active galaxies, and a similar line was found in Mark 1 (NGC 447). In this case, the apparent velocity is 300 km/s inward. Since the optical velocities may well have systematic deviations from the true galactocentric velocity, these apparent relative velocities should be interpreted with some caution. Recently, Balick (1977) has reported a strong absorption line in Mark 231, and both Balick and we have seen a complicated profile in Mark 3 that may be caused by absorption also. In general the observed absorption lines imply column densities of 10^{18} - 10^{19} T_s cm^{-2}, or 10^{20} - 10^{21} cm^{-2} for T_s = 100 K, and probably are situated at some distance from the nucleus of the galaxies.

A third class of absorption line was detected by Steigerwald and Roberts (1977) and by Haschick, Baan, and Burke (1977), in the galaxy

Table II

Catalog of Material in Vicinity of Galaxies

System	Reference		Column Density T_s = 100 K (cm^{-2})	Mass ($M_\odot$)
HI Certainly External				
M81/82/NGC 3077	Em	(1)	2×10^{20}	3×10^9
NGC 55/300	Em	(2)	$2\text{-}10 \times 10^{20}$	1.6×10^9
NGC 3623/3627/3628	Em	(3)	10^{20}	10^9
NGC 3067	Abs	(4)	2.7×10^{19}	
HI Probably External				
Markarian 6 (= IC 450)	Abs	(5)	6×10^{20}	
Markarian 1 (= NGC 447)	Abs	(5)	10^{21}	
Markarian 231	Abs	(6)		
3C178 (= NGC 2377)	Abs	(7)	3.6×10^{20}	
Magellanic Stream	Em	(8)	$1\text{-}10 \times 10^{20}$	
Complicated Cases				
NGC 1275	Abs	(9)	3.5×10^{20}	
1506 + 37	Abs	(10)	1.1×10^{22}	
M82	Abs	(11)	6.6×10^{21}	
NGC 5128	Abs	(12)	$> .7 \times 10^{20}$	
NGC 253	Abs	(13)	4.3×10^{21}	
NGC 4945	Abs	(14)	9×10^{21}	

(1) Cottrell, G.A.: 1977, Monthly Notices Roy. Astron. Soc. 178, 577.
(2) Mathewson, D.S., Cleary, M.N., Murray, J.D.: 1975, Astrophys. J. 195, L97.
(3) Haynes, M.P., Giovanelli, R., Roberts, M.S.: 1977, Bull. Am. Astron. Soc. 9, 361.
(4) Haschick, A.D. and Burke, B.F.: Astrophys. J.
(5) Haschick, A.D., Baan, W.A., Burke, B.F.: 1977.
(6) Balick, B.: private communication.
(7) Roberts, M.S. and Steigerwald, D.G.: 1977, in press.
Baan, W.A., Haschick, A.D. and Burke, B.F.: 1977, in press.
(8) Mathewson, D.S., Cleary, M.N., Murray, J.D.: 1974, Astrophys. J. 190, 291.
(9) DeYoung, D.S., Roberts, M.S., Saslaw, W.C.: 1973, Astrophys. J. 185, 809.
(10) Haschick, A.D.: private communication.
(11) Guélin, M. and Weliachew, L.: 1970, Astron. Astrophys. 9, 155.
(12) Roberts, M.S.: 1970, Astrophys. J. 161, L9.
(13) Weliachew, L.: 1971, Astrophys. J. 167, L47.
(14) Whiteoak, J.B. and Gardner, F.F.: 1976, Proc. Astron. Soc. Austr. 3, 71.

3C178. Here the strongest absorption is very nearly at rest with respect to the center of the system, a circumstance very difficult to understand dynamically if the gas is associated with the nucleus.

A summary of the known examples of hydrogen clouds associated with galaxies is given in Table II.

Under "complicated cases" are listed a number of systems in which the interpretation is not clear, and in fact in several of these the HI may be inside the galactic system, or systems. The upper two classes are much more definite. In the emission systems, and NGC 3067, the physical separation is directly observed. The Markarian galaxies, 3C178, and the Magellanic Stream are less definite, but indirect arguments are strong. The Magellanic Stream has, in part, such an obvious positional and dynamic relation to the Magellanic Clouds that it is almost certainly external. Mathewson, Schwarz, and Murray (1977) have argued that these clouds extend throughout the local group, so the uncertainty in distance prevents making a mass estimate. The column densities all appear to be within a remarkably small range, considering the diversity of forms.

The origin of these outlying hydrogen clouds is not clear. In one case, NGC 3067, Boksenberg and Sargent (1977, in press) have shown, by observing the quasar spectrum, that CaII appears in absorption at the radial velocity of the HI absorbing cloud. The observed quantity of CaII is consistent with a normal stellar abundance, implying that the material is not primeval, but has been processed by stellar nucleosynthesis. At least three modes of genesis are feasible: tidal interaction, expulsion by activity in a galactic nucleus, and accretion from the IGM/ICM.

The relative frequency of each mode cannot yet be determined from the limited samples available. The isolated galaxies, and especially the Seyfert galaxies are good candidates for expulsion, with the gas condensing in the halo and perhaps falling back in some instances. The extensive M81-M82-NGC 3077 complex may well be an instance of tidal interaction, although the possibility of the material being left over from an earlier epoch cannot be excluded. A search for other clouds in the M81 group, and for clouds in the CVnI and NGC 1023 groups has been completed by Sargent and Lo (1977, unpublished). A few small (.5 to $3 \times 10^6\ M_\odot/Mpc^2$) clouds were detected, but no further large systems. The large ($> 10^8\ M_\odot$) systems appear to be uncommon.

REFERENCES

Field, G.B. and Perrenod, S.C.: 1977, Astrophys. J. 215, 717.
Jones et al.: 1977, in press.
Mathewson, D.S., Schwarz, M.P., Murray, J.D.: 1977, Astrophys. J. 217, L5.
Other References appear in Table II

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DISCUSSION FOLLOWING PAPER V.5 GIVEN BY B.F. BURKE

VAN DER LAAN: Your negative results for the quasar/galaxy pairs may be disappointing, but also very important. From results presented earlier in this symposium one may retain the impression that column densities $N_{HI} > 3 \times 10^8$ cm^{-2} at R $\lesssim$ 100 kpc from the galaxy nucleus are the rule for spirals. What are your distances and upper limits?

BURKE: The upper limit is a column density of a few times 10^{18} cm^{-2} at typically 30 kpc from the nucleus.

VAN DER LAAN: So for the impression from the results just referred to, to remain credible in the face of your results, we must presume that the hydrogen in galaxy outskirts is very clumpy, but smoothed completely by beams $\sim$ 10'.

ALLEN: As to the interpretation of your inability to detect HI absorption in 7 out of 8 quasar/galaxy pairs, one should remember that we have no reason to believe that the HI gas in the outer regions of galaxies should be smoothly distributed. In fact if we look at the faint outer parts of the synthesis map of M101 for example, we see a very clumpy distribution which must have a rather low filling factor. It seems unlikely that the even fainter gas observed at 2 or 3 galaxy diameters away would have a very different morphology. So the chance that the line of sight from the distant quasar would go through a hole is probably rather large.

BOKSENBERG: I would like to make two comments: (1) I suggest that the very few detections of absorption by HI at 21 cm in the case of QSO/galaxy pairs is merely due to the low sensitivity of the radio measurements, for which the detection limit is comparable with the expected signals for rather dense columns. If you could improve your sensitivity by a factor 10^6, such as is given by Lyman α observations, you might find HI to be widely present. (2) Markarian 231 (which is probably a QSO with a high degree of reddening) shows optical absorption lines of CaII, NaI and HeI λ3888 at velocities of several thousand km/s outwards from the nucleus. NGC 4151 shows HeI λ3888 and Balmer lines which are seen to vary in times of about 1 month. In these cases, where we observe variability, lines from other than ground states, or high relative velocities, we are probably seeing material physically in close relation to the nuclear activity and not at large extensions to the galaxies.

TULLY: At Green Bank Fisher and I have observed some 1500 positions associated with galaxies and an equal number of off positions. In addition we have looked at about 1000 positions in a large region in the vicinity of the M81 group. So in total we looked at 4000 positions. Our bandpass covers velocities up to 3000 km/s and our sensitivity is 1 or 2 x 10^6 $M_\odot$ at 1 Mpc. In all this volume of space, there are a couple of interesting cases which might represent detection of intergalactic HI clouds well removed from visible galaxies. However our

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results should be interpreted as upper limits. These limits are a factor of four or so more severe than the limits published recently by Shostak.

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