INTERGALACTIC HI AND TIDAL DEBRIS WITHIN GROUPS OF GALAXIES

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Abstract: A population of isolated intergalactic HI clouds has yet to be recognized in the intergalactic medium. On-going high sensitivity studies of loose groups of galaxies, however, show that tidal debris in the form of HI streams is commonly found in such aggregates.

The possible existence of neutral atomic hydrogen clouds within the intergalactic medium has been the subject of a variety of experiments in recent years. An impetus for investigating the occurrence of such clouds stems from a desire to understand the intergalactic environment and its bearing on the large-scale structure of galaxies. Intergalactic neutral hydrogen clouds, as remnants of an inefficient galaxy formation process, would serve as probes of a more pervasive intergalactic medium in which they are immersed (Cowie and McKee 1975). They could also be responsible for the disruption of neighboring galaxies (Freeman and de Vaucouleurs 1974). But the very existence of such HI clouds is questionable.

The inability to detect a homogeneously distributed neutral hydrogen medium has set stringent upper limits on the contribution of HI to the critical density (Penzias and Scott 1968). Likewise, searches for HI gas within rich clusters of galaxies have failed (Haynes, Brown and Roberts 1978). Shostak (1977) and Roberts and Steigerwald (1977) have shown that the density of HI clouds is low. Despite all of these negative results, three hypotheses have stimulated the search for intergalactic clouds:

a) The explanation of the high velocity clouds as extragalactic clouds within the Local Group (Verschuur 1969; Kerr and Sullivan 1969).

b) The suggestion by Freeman and de Vaucouleurs (1974) that ring galaxies have been formed by the collision of a disk galaxy with an intergalactic cloud.

c) The interpretation of HI clouds in the vicinity of NGC 55 and NGC 300 as HI companions within the Sculptor Group (Mathewson, Cleary, and Murray 1975).

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New high sensitivity searches have failed to uncover a population of isolated, intergalactic HI clouds but have demonstrated a frequent presence of HI tidal debris.

ISOLATED INTERGALACTIC CLOUDS ?

HI companions have been attributed to the Sculptor Group which itself is unique in both being the closest to the Local Group and in possessing the highest population index of all the de Vaucouleurs' (1975) groups because of its composition of late-type galaxies. It is reasonable to expect that similar intergalactic HI clouds might be found near late-type galaxies in other groups. Searches for such clouds in other groups have been made using various instruments. Specifically, Haynes and Roberts (1978) conducted a study of numerous nearby groups using the 140-foot telescope of the N.R.A.O. for intergalactic clouds of masses $M_H \gtrsim 10^8 M_\odot$ and sizes of 30-50 kpc, the parameters of the Sculptor clouds; no such isolated clouds were found. In light of the negative results of the several searches undertaken by different observers, suspicion was raised that the HI clouds in the Sculptor area might not, in fact, be associated with the Sculptor Group.

The principal clues in the intergalactic interpretation of clouds in the Sculptor region are (1) their proximity to the two galaxies, (2) the similarity of their velocities with those of the two galaxies, and (3) their separation in velocity from the clouds of the Magellanic Stream which runs through the region. The similarity in velocity of features associated with the Galaxy, the Magellanic Stream, and the Sculptor Group prevents any meaningful differentiation by velocity in this area. Haynes and Roberts (1978) obtained 1200 line profiles in the region of Sculptor and to the south as far as $\delta = -46°$. The major result of this survey is the discovery of a large number of additional clouds at both positive and negative velocities with respect to the local emission and that traditionally associated with the main ridge of the Magellanic Stream. This larger population of HI clouds in the Sculptor region raises considerable doubt from both a spatial and a spectral standpoint as to their interpretation as bona fide members of the Sculptor Group. The locus of HI clouds is confined to the southern sector of the Group and extends far to the east and south to a radius of 0.7 Mpc from the nearest Sculptor galaxy. In contrast, no clouds are found near other principal members of the Group, NGC 45, 247 or 253. The velocity distribution of the clouds does not mimic that of Sculptor galaxies for any likely membership, while the negative velocity clouds in the region could certainly not be interpreted to lie within the Sculptor Group. The velocity distribution could only be reconciled if the positive velocity clouds were contained within a subgroup defined only by NGC 55 and 300 which still had a radius of 0.7 Mpc; we find this interpretation unattractive. The lack of fine structure observed within these clouds either spatially or spectrally distinguishes them from typical high velocity clouds in the northern galactic hemisphere, including those studied with the same instument (Giovanelli and Haynes 1976).

Although Sculptor is distinctive in possessing only late-type galaxies, it is unique in being the only nearby group which is seen in projection with the Magellanic Stream. Indeed, in this region near the south galactic pole, the Stream emits strongly in competition with the zero velocity gas. Because of the difficulties in associating the HI clouds with Sculptor and because the Stream seems to possess a substantial amount of spatial structure not revealed by previous surveys, we see no a priori reason why the HI clouds in the region, including the ones near NGC 55 and 300, cannot by included in the Magellanic Stream phenomenon. In this picture, the Stream is defined both by the bright sharp ridge as presented by Mathewson, Schwartz and Murray (1977), but also by a collection of smaller clouds, separated in velocity as well as sometimes in space, from the main body (Haynes 1978). The HI clouds then are still extragalactic, but are contained within the Local Group, and hence are much smaller, less massive, and not isolated.

HYDROGEN STREAMS IN GROUPS ?

Within the Local Group, we see two instances of hydrogen streams which may be interpreted as the tidal debris of encounters between the neighboring galaxies, namely, the bridge between the Magellanic Clouds (Hindman, Kerr and McGee 1963) and the Magellanic Stream (Mathewson, Cleary and Murray 1974). Historically, several other systems have been recognized to typify tidal interactions delineated by wide hydrogen distributions: the M81/M82/NGC3077 system (Roberts 1972) and the NGC4631/56 system (Roberts 1968).

The presence of these hydrogen streams in the Local Group and in other nearby groups stimulated an investigation of other pairs and groups for similar hydrogen appendages. These searches are being carried out with the 300-foot telescope of the N.R.A.O. and the 1000-foot telescope of the Arecibo Observatory*. The high sensitivity of the Arecibo instrument makes it ideal for the study of low emissivity hydrogen in relatively small groups, while the 300-foot was used for larger groups and those outside the range of Arecibo. Table I summarizes the presently available data on known hydrogen streams in all nearby groups which have been surveyed by ourselves and by others. Columns (1) and (2) give the group identification either from de Vaucouleurs (1975) or after the brightest galaxy in the group. Our surveys both at Green Bank and Arecibo have concentrated on small aggregates of galaxies selected from the Second Reference Catalog of Bright Galaxies. The sample is restricted to galaxies which lie within 250 kpc of one another and where the velocity difference is less than 500 km/s. Many of these smaller aggregates appear as subconcentrations within the more general de Vaucouleurs' groups; hence the entire field of a group may not have yet been sampled. Column (3) indicates the status of present observations: does the aggregate contain a known hydrogen stream which suggests past tidal interaction?

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TABLE I
Summary of Present HI Evidence for Tidal Interaction

Group # (1)	Group Common Name (2)	Known Tidal Appearing Stream ? (3)	Types of Galaxies in Interaction (4)	N_H* ($\times 10^{20}cm^{-2}$) (5)	Reference (6)
	Local Group	Yes A	Ir, Sm	4	a
		B	Sbc, Ir, Sm	3	b
G1	Sculptor	No			
G2	M81	Yes	Sab, IO, IO	5	c
G3	CVn I	Maybe	Im, Scd	0.4	d
G5	M101	Yes+	Sbc, IO	1.5	e
G6	N2841	No			
G7	N1023	Maybe+	Scd, Sm	0.3	f
G9	M66	Yes	Sb, Sb	0.9	g
G10	CVn II	Yes	Sd, Sm	1	h
G11	M96	No			
G13	Coma I	Yes	Sab, Scd	0.6	f
G29	Virgo III	No			
G30	N5866	No			
G40	N488	No			
G42	N2964	No			
G47	N3190	No			
G50	N5846	No			
	N697	Yes	Sbc, Sc	0.3	f
	N2775	Yes	Sab, Sab	0.2	f
	N3166	Yes	Sa, SO/a	0.6	f
	N4038/9	Yes	Sm, Sm	2.3	c
	N5044	No			
	N5363	Maybe	Sbc, IO	0.3	f
	N5576	Maybe	EO, Sbc	0.7	f
	N5953	No			
	N7332	No			
	N7448	Yes	Sbc, ?	0.5	f
	N7541	Maybe	Sbc, Sbc	0.5	f

* beam-averaged peak column density within the limits of current data.
\+ galaxies involved are only "possible" members of group.

a Mathewson, D.S., Cleary, M.N., Murray, J.D. (1974).
b Mathewson, D.S., Schwartz, M.P., Murray, J.D. (1977).
c van der Hulst, J.M. (1977).
d Haynes, M.P., Roberts, M.S., Green Bank survey.
e Haynes, M.P., Giovanelli, R., Burkhead, M.S. (1978).
f Haynes, M.P., Roberts, M.S., Arecibo survey.
g Haynes, M.P., Giovanelli, R., Roberts, M.S. (1978).
h Weliachew, L., Sancisi, R., Guelin, M. (1978).

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This list is not meant to be complete. Since not all of the galaxies within an aggregate have been studied thus far, the possibility of additional streams within these groupings is not ruled out. However, the frequent occurrence of tidal debris in the form of HI is clearly demonstrated. Column (4) lists the morphological classification of the galaxies apparently involved in the interaction. Not unexpectedly, we find that the gas has been drawn out from spiral galaxies. To date, we have preferentially studied late-type galaxies, and hence our sample is biased. We intend to extend this investigation to earlier systems. Column (5) lists the beam-averaged peak column density of the hydrogen appendages derived from the observations referenced in column (6); in some cases, the observations are incomplete, so that the peak column densities may be greater than that given.

We have already implied that tidal interactions are the likely cause of the extended hydrogen distributions. In their classic 1972 paper on the formation of galactic bridges and tails, Toomre and Toomre have shown the power and elegance of computer simulations of galaxy encounters. With the availibility of 21 cm data, their techniques have been applied to model additional interactions with impressive success in reproducing the overall characteristics of the HI distribution, although in detail the model parameters must be strained to fit the observations, as in the Leo Triplet NGC3623/7/8 (Haynes, Giovanelli and Roberts 1978). The computer simulations in Leo, in the NGC4038/9 system (van der Hulst 1977) and in the NGC4631/56 system (Combes 1978) strongly reinforce the hypothesis that tidal encounters can draw material far out from the disks of the galaxies involved. In contrast, the hydrogen distribution within the M 51 system defies a clear-cut interpretation (Haynes, Giovanelli and Burkhead 1978), although the optical features are understood in terms of the eccentric passage of NGC 5194 by NGC 5195 as presented by Toomre and Toomre (1972).

SUMMARY

We see in the Magellanic Stream the best example of intergalactic hydrogen, and while some of its characteristics elude simulation by tidal modelling (Lin and Lynden-Bell 1977), it is perhaps best understood as being the tidal relic of the recent passage of the Galaxy by the Magellanic Clouds. At least 10 other examples of hydrogen streams within aggregates and groups are recognized at present. The existence of extensive hydrogen distributions in groups may contribute to the evolution of galaxies within such aggregates, either in the accretion of such gas by a passing galaxy, or conversely, by the removal of gas from spirals involved in the interactions (Binney and Silk 1978). It should be noted that the amount of gas involved may be significant; the combined hydrogen mass of the appendages of NGC 3628 amounts to almost 20% of that still observed within the galaxy itself. While isolated intergalactic HI clouds of significant mass and size are unlikely to be found in the intergalactic medium, hydrogen streams such as we find in our own Galaxy's backyard tell a common tale of tidal interaction in nearby loose

groups.

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DISCUSSION

Mathewson: The only criteria by which we may associate an HI cloud with a galaxy is spatial and velocity coincidence, and the clouds near NGC 300 and 55 satisfy these. I also notice that the clouds near these galaxies are more intense than the clouds you find further away which strengthens my original belief that they are associated with the galaxies. The weaker and lower velocity clouds which you find may be lying between the Local Group and the Sculptor Group. I do not agree with your conclusion that the clouds near NGC 300 and NGC 55 are associated with the Magellanic Stream. You disregard one of the main criteria (the coincidence in velocity), as the Stream in the direction of NGC 300 and 55 has a velocity of over 100 km s^{-1} different from that of HI clouds.

Haynes: With regard to the region near NGC 55; we do not identify some of the features observed very close to the galaxy as separate clouds as pictured by Mathewson, Cleary, and Murray. They have a smaller beam but we have higher sensitivity and the features seem to be spread at weak emission over a much broader velocity range. On the other hand, some of the clouds more distant from the galaxy with velocities $V_{GSR} \sim +80$ to $+100$ km s^{-1} coincide with anomalous negative velocity clouds, $V_{GSR} \sim -80$ km s^{-1}, whereas the Magellanic Stream in this region has a velocity $V_{GSR} \sim 0$ km s^{-1}. I do not believe anyone would want to associate the negative velocity clouds with NGC 55. Our arguments that the spatial and velocity distributions of the clouds and galaxies do not match are based on the total anomalous-velocity cloud population. One cannot consider only some of the clouds while simultaneously ignoring others.

van Woerden: The case for tides between galaxies seems to be weakening this morning. I wish to record that a convincing case for tidal effects has been made by van der Hulst (Thesis, Groningen, 1977), who showed that Westerbork observations of both density distribution and velocity field in the "Antennae" (NGC 4038/39) are fit well by a Toomre-Toomre model.

Thonnard: Was Toomre's tidal-interaction model for the NGC 3623, 27 and 28 group able to reproduce the very regular HI velocity field that you see in the plume of NGC 3628?

Haynes: Toomre's model is able to give a good fit but not a great fit. Along the plume of N3628, we see that the radial velocity does not vary by more than about 10 km s^{-1} over 50 kpc; at the far tip, a separate component arises abruptly with a velocity difference of 35 km s^{-1} from the other component. Such structure is not seen in Toomre's model. The overall characteristics of the narrow tail and patchy bridge are well simulated by the model, but the model parameters must be strained somewhat to fit the small-scale features of the observations.

Tinsley: Toomre remarked that maybe a lot of intergalactic gas may be not of tidal origin but rather leftover gas from inefficient galaxy formation. Perhaps it is relevant that the amount of gas inferred from x-ray models of the Coma cluster is several times more than can be plausibly accounted for by loss from galaxies by any one of the several processes that have been proposed in the literature (winds from ellipticals, later loss from stars, sweeping spirals to make SO's, etc.). Although the result is not firm because of model-dependent uncertainties in the amount of hot gas outside the observed core of the cluster (Ostriker, private communication), the discrepancy suggests to me that most of the intergalactic gas is left over from galaxy formation.

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