21 CENTIMETER STUDY OF SPIRAL GALAXIES IN CLUSTERS. III: NEUTRAL GAS CONTENT, STAR FORMATION AND RADIO CONTINUUM PROPERTIES

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ABSTRACT

21 cm line observations of 112 galaxies in seven clusters and in relatively isolated regions in the Coma "wall" were secured with the Arecibo * telescope. These, combined with an available data-base, are used to discuss the relations between the neutral gas column density, the star formation rate, the FIR and the radio continuum emission in spiral galaxies inside and outside rich clusters. It is found that hydrogen deficient cluster galaxies have star formation rates similar to unperturbed isolated galaxies confirming that atomic gas ablation in clusters does not alter the supply of molecular gas. The extended radio continuum emission of about 30% of cluster spirals is higher than that of isolated galaxies of similar type at any given gas surface density. A significant fraction of these galaxies is found perturbed in its HI, optical and radio continuum morphology consistently with the hypothesis that ram pressure, along with HI ablation, could produce major morphological disturbances as well as enhancements in the diffuse synchrotron emission due to magnetic field compression.

Subject Headings: Galaxies: Evolution; Galaxies: Intergalactic Medium; Radio Sources: Galaxies

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1. INTRODUCTION

Our understanding of the role played by the interstellar gas on the activity and evolution of spiral galaxies took great advantage from the multifrequency observational material that became available in the last decade. Observations of the HI line at 21 cm and of the various CO transitions in the millimeter bands provide us with measurements of the content and distribution of the interstellar gas in the primordial neutral and in the molecular forms (Haynes, Giovanelli & Chincarini 1984; Young & Scoville 1991). Ultraviolet, optical and near Infrared data trace the star formation activity and evolution (Kennicutt 1990). Radio continuum observations in the centimetric bands trace the cosmic rays accelerated by massive, newly born stars, thus giving indirect information on the star formation processes themselves (Gavazzi & Jaffe 1986). Far infrared observations, finally, provide us with a measurement of the dust heating induced by the stellar population (Cox, Krugel & Mezger 1986). Due to the complexity of the mutual interactions and feedback mechanisms in these processes, large observational samples are needed to constraint models of galaxy evolution. The optically selected sample of 883 CGCG spiral and irregular galaxies, included in the multifrequency data-base presented in Gavazzi (1991), complemented with the new HI observations given in Section II of this paper, represents a well suited sample to approach this intricate question on sound statistical grounds and to study if and how the cluster environment has any relevant role in determining galaxy evolution. In fact the data-base contains galaxies in the nearby rich clusters A262, A1367, Coma, Virgo, A2147 and A2151 as well as a reference sample of non-cluster objects (belonging to the Coma supercluster "wall", outside the two main clusters, and to the Cancer region). The outline of the present paper is the following: in Section II we present the newly obtained 21 cm observations taken at Arecibo. These data, combined with those already available in the 21 cm and in other bands are analyzed in Section III with the aim of determining the relationships between the presence of neutral gas, the present star formation rate, and the FIR and radio continuum emissions in spiral galaxies in and outside rich clusters.

2. OBSERVATIONS AND DATA REDUCTION

21 cm observations of 112 galaxies were obtained with the Arecibo 305 m telescope in 32 periods of about 3 hours duration from January 1 to 31, 1991. A dual channel HEMT receiver was used in conjunction with the 22 cm tunable feed to observe galaxies with cz > 1500 Km s^{-1} and with cz unknown (search mode). Seven galaxies with cz < 1500 Km s^{-1} were observed using the 21 cm circular feed tuned at 1407 MHz, coupled with a dual channel HEMT receiver. Data taking and reduction have been described in Paper I and II of this series (Gavazzi 1987, 1989). Observations were obtained in the beam switching mode by observing the object (ON scan) during half of the integration time and the blank sky in the other half (OFF scan) at equal azimuth and zenith angle. ON-OFF pairs, each of 10 min duration, were repeated and accumulated until a signal to noise ratio high enough (typically $\geq$10) to allow accurate determinations of the line width was obtained. The observations were made with the 2048 channel autocorrelation spectrometer split into four subcorrelators of 512 channel, each with 20 MHz bandwidth. Each polarization fed two subcorrelators. In search mode (i.e. for galaxies of unknown redshift), the two subcorrelators on each polarization were offset by 15 MHz, thus allowing a 5 MHz overlap. This resulted in a total search bandwidth of 35 MHz, generally centered at 5500 Km s^{-1}, thus covering a search interval 1500-8500 Km s^{-1}. To avoid severe interference at 1330 and 1350 MHz caused by the FAA radar serving the S. Juan airport a radar blanker was used. This instrument flags the data taking when the radar transmitter is on, with the draw back that the integration time increases by about 20 %.

The observed galaxies were mainly selected from the CGCG (Zwicky et al. 1961-68) inside the contours of the clusters A262, A1367, Coma, and Hercules (A2147 and A2151) and in the relatively isolated regions of Cancer and of the Coma supercluster. Some other galaxies lying within 15 degrees projected radii from A262, Cancer and Hercules were selected from the UGC catalogue (Nilson 1973). Galaxies with large inclination were preferred for the purpose of obtaining measurements useful also for studies based on the Tully-Fisher relation (Tully & Fisher 1977), partly included in Gavazzi et al. (1991b, 1992). Observations of some objects already available in the literature were repeated to improve their quality or if their profiles were unpublished.

83 objects were detected, including 28 for which new redshifts were obtained. These are listed

in Table 1 as follows (see Paper I and II for more details):

Column 1,2,3: GCGC (Zwicky et al. 1961-68), UGC (Nilson 1973) and NGC (De Vaucouleurs et al. 1991 (RC3)) names.

Column 4,5: 1950 optical celestial coordinates. These were in most cases measured with a second of arc accuracy using the Bologna X-Y measuring engine, or taken from Basso et al. (1990) and from Santagata et al. (1987).

Column 6: Morphological type (3=Sa, 4=Sab. 5=Sb, 6=Sbc, 7=Sc, 8=Irr, 9=S...) from the literature or estimated by eye inspection on the available plate material.

Column 7: Photographic magnitude from the CGCG or from the UGC.

Column 8,9: blue major and minor axes (in minutes of arc). These where taken from the UGC or measured consistently on the blue copy of the Palomar Sky Survey plates.

Column 10: heliocentric velocity previously available.

Column 11-16 report the newly obtained 21 cm data.

Column 11: heliocentric systemic velocity derived by averaging the velocity determined at 20% of the peaks with the value at 50 % of the mean of the profile.

Column 12: observed width (Km s^{-1}) of the profile, measured at 20% of the peak flux.

Column 12: observed width (Km s^{-1}) of the profile, measured at 50% of the mean flux.

Column 14: rms noise in the smoothed profile (in mJy).

Column 15: measured HI line integral intensity in Jy Km s^{-1}. The fluxes of galaxies with major diameter > 1.8 arcmin should be corrected for partial resolution by the 3.3 arcmin Arecibo beam according to Sullivan et al. (1981). No corrections for internal absorption and pointing errors have been included. The latter is estimated in 5 %.

Column 16: quality of the obtained profile. Quality 1 are high signal to noise two horned profiles. Quality 2 are high signal to noise single horned profiles. Quality 3 are marginal profiles and Q=4 are poor spectra. Q=1,2 profiles are useful for deriving distances using the Tully–Fisher relation.

Column 17: cluster membership.

Fig. 1 shows the smoothed (20 Km s^{-1} resolution) spectra of the detected galaxies.

Table 2, arranged similarly to Table 1, lists the 29 undetected galaxies. 20 have redshift for which a useful upper limit to the HI mass can be obtained. The remaining 9 undetected galaxies were searched in the interval 1500-8500 Km s^{-1}, with typical rms of 1 mJy. These are not used in the following discussion. Among the undetected objects there are still many galaxies in the A262 cluster due to their declination near the limit of the Arecibo telescope. Much improved observations of this cluster will be possible after the completion of the Gregorian upgrade of the telescope.

3. RESULTS AND DISCUSSION

This section is devoted to the analysis of the relationships between the galaxy HI content and the star formation rate derived from the H_α emission line, and between the HI content and the centimetric radio continuum and far infrared (FIR) emissions. In order to avoid trivial conclusions such as "bigger galaxies have more of everything", which are simply a consequence of a scaling law, and to derive distance independent parameters, all measured quantities are normalized to some indicator of the overall galaxy size or luminosity. The radio continuum and FIR fluxes are normalized to the near infrared H band flux, giving the ratios Radio/H and FIR/H. Similarly the 21 cm line flux is normalized to the optical galaxy area, yielding to a hybrid surface density. The flux measured in correspondence of the H_α+[NII] lines is normalized to the continuum near 6570 Å, yielding to the H_α equivalent width (EW).

The data-base of 883 spiral galaxies available to us, although is far from completeness, contains a conspicuous number of objects with reliable photometrical measurements, which are suitable for statistical studies. Table 3 reports the available radio continuum (which were carried out mainly at 1415 MHz, and some, obtained at 610 MHz, were converted to 1415 assuming a spectral index of -0.8), HI line and FIR (60 μm) measurements. The latter have been taken from the literature except in the Coma supercluster region where they have been derived by us using the IRAS faint source data-base. The table reports in Columns 1 and 2 the number of surveyed objects separately from those actually detected, the difference being constituted by upper limits. 541 of the 883 spirals have H band magnitudes available, allowing us to derive normalized quantities, as reported in Columns 3 and 4 of Table 3. Observation of the H_α line are unfortunately very incomplete, as only 165 objects have reliable measurements of the H_α EW. Detailed references to the above measurements are not given for conciseness. However they are included in the data-base which is available in a computer readable form upon request from the authors.

3.1. HI SURFACE DENSITY AND STAR FORMATION RATE

The EW of the H_α line is the most widely used tracer of the star formation rate (SFR) in galaxies, despite the fact that it only traces stars above 10-15 $M_\odot$, i.e. only a fraction of nearly 10-20 % of the total stellar mass, if a conventional IMF is assumed (see a review in Kennicutt 1990). This, in conjunction with the somewhat uncertain amount of extinction that occurs within galaxies themselves, contributes to an uncertainty of the order of 50 % in the determination of the SFR in individual galaxies, even though the flux measurements and EW determinations have typical intrinsic accuracies of 10 % (Kennicutt 1983a).

The simple model proposed by Schmidt (1959), which relates the SFR to the local gas density Σ, according to a power law

$$SFR = a\ \Sigma^\alpha$$

has been questioned by several authors who proposed a non-linear dependence of these two quantities (Guiderdoni 1987; Kennicutt 1989). In particular, Kennicutt (1989), analyzing the HI, CO and H_α emission from nearby spatially resolved galaxies, showed that a direct proportionality between SFR and gas surface density exists only at high gas densities, whereas the relation is strongly non-linear at low and intermediate densities: i.e. there is a threshold in the gas density below which the star formation activity does not take place (cf. figure 8 in Kennicutt 1989). Our sample is dominated by distant objects, therefore our analysis does not include many spatially resolved observations. Instead it is based on integrated measurements, both for H_α EW and gas content. Moreover, only a small number of these galaxies have been observed in CO to make possible a direct determination of their total ($HI+H_2$) gas content, and consequently we restrict our analysis to the HI content alone. The presence of atomic hydrogen is not a sufficient condition for star formation processes to take place, however Kennicutt showed that the empirical correlation between SFR and gas content, when considering integrated quantities, is stronger for HI than for H_2 taken alone.

Fig. 2 shows the dependence of H_α EW on the hybrid HI surface density, in our sample. The HI surface density has been computed dividing the total integrated HI mass by the area of the galaxy, derived from the optical major axis, as given in the UGC or accordingly determined.

Using hybrid HI surface density is in principle inappropriate for comparing unperturbed galaxies with cluster objects suffering from HI deficiency. In fact Warmels (1986) and Cayatte et al. (1990) showed that the gas is removed preferentially from the outer disk in deficient objects, producing a relevant change in their HI disk diameter. Using the sample of 96 galaxies having well resolved HI observations presented in Warmels (1986), we estimate the change in the isophotal HI diameter with respect to the optical diameter, as a function of the projected distance from the Virgo center. On the average, galaxies with projected distances of more than 2 degrees from M87 (all non HI–deficient objects) have HI diameters 1.5 times larger than the optical ones. Galaxies in the inner 2 degrees region (preferentially HI–deficient objects) have comparable HI and optical disks, the average ratio of the two diameters being 0.98. Therefore, adopting the hybrid definition of HI surface density, we derive realistic values for cluster objects, while we overestimate by a factor of about 2 the real surface density in isolated galaxies. The effect is relatively small, and no correction has been applied to the data presented in Fig. 2. The non-cluster objects (empty circles), although with a considerable scatter, are found compatible with the non-linear regime discussed by Kennicutt (1989), showing a gas surface density close to the threshold value discussed earlier. However the agreement might be fortuitous since the threshold column density is a strong function of radius within any individual galaxy, and therefore can be determined with confidence only in spatially resolved objects, while our HI surface densities are averages taken over an entire disk. Keeping this caution in mind, we notice that the relation in the cluster sample (filled circles and squares) is significantly different. There are many objects which overlap with the non-cluster galaxies, but a significant number of objects with HI surface density as much as two order of magnitude lower (the well known HI–deficient cluster galaxies, see Giovanelli & Haynes 1985), have "normal" rates of star formation. For normal rates we mean similar to those observed in galaxies with normal HI content, thus having gas density from 10 to 100 times higher. We conclude that the cluster membership has the well known observable influence on the HI gas content, but little or no consequence on the average star formation rate. In fact the distribution of H_α EW in the two samples are statistically indistinguishable (Fig. 3a). On the contrary the distribution of HI surface densities in cluster galaxies is significantly skewed towards lower densities relatively to the nearly gaussian distribution of non-cluster objects (Fig. 3b). The probability that the two distributions are drawn from the same parent population is $< 10^{-10}$, as given by a two tailed Kolmogorov-Smirnov test. The test has been applied to the total HI sample of 360 cluster and 330 isolated galaxies. It should be reminded however that the above finding that cluster and isolated galaxies are indistinguishable in their star formation properties contains a possible bias. Here we are considering only galaxies exhibiting spiral morphology *at the present time* (inside and outside clusters). If many of the S0 galaxies presently seen in clusters were in the past spirals in which the star formation rate was quenched due to gas removal, they should be included in the cluster sample together with the galaxies still exhibiting a spiral morphology (and some residual star formation rate). Their inclusion would lower the mean of the H_α distribution in the cluster sample more than that of the non–cluster sample.

We interpret the presence of normal SFR in gas deficient objects as a consequence of the different distribution of molecular and of HI gas in spiral disks. The denser and more centrally condensed molecular clouds, which give birth to stars, are not as easily stripped as the diffuse HI: it was in fact shown that HI deficient objects in clusters have normal molecular gas content (Kenney 1990; Casoli et al. 1991). Therefore, even though in these galaxies a significant fraction of the HI has been removed, the star formation activity goes on until it is sustained by the molecular gas supply. This could be as long as some 10^9 years (Larson & Tinsley 1978). The typical time scale for HI stripping is 1–4 10^8 years (Lea & De Young 1976; Nulsen 1982). Gavazzi (1989), arguing that the HI asymmetry observed in three cluster galaxies is a transient phenomenon, soon washed out by galaxy differential rotation, was able to confirm the time scale for ablation in few times 10^8 years.

We conclude that these galaxies must have resided in the hostile cluster environment for a time longer than the typical time scale for stripping but shorter than some 10^9 years, i.e. that these galaxies are relatively recent cluster "intruders".

At the total consumption of molecular hydrogen, unless other forms of gas replenishment would compensate for the missing supply of HI, the star formation activity in these galaxies will eventually suffer a drastic decrease. Those objects that are cluster members since the time of cluster formation would populate the lower-left part of Fig.2 . However, due to incompleteness of the H_α survey and to the limited sensitivity of the present HI observations, they cannot be detected. Could S0 galaxies that we presently observe in clusters be the product of this final evolution, as proposed by Larson, Tinsley & Caldwell (1980)? A systematic survey of the star formation properties and of the residual gas content of cluster galaxies in the various morphological classes is necessary to solve this question. The upgraded Arecibo telescope might provide us with the proper sensitivity for this purpose.

A possible alternative scenario to explain the presence of normal SFR in HI deficient objects, that we do not explore in this paper, is the one where a strong localized star formation activity induced by the ram pressure sweeping of the gaseous disk compensate the diffuse decrease in the SFR originated by the removal of the gas.

3.2. HI CONTENT AND SYNCHROTRON EMISSION

The origin of the nonthermal radio emission in spiral galaxies is not fully understood, but general agreement exists on the major role played by supernovae explosions of young massive stars in accelerating the relativistic electrons responsible for the radio emission (Klein 1982; Kennicutt 1983b; Gavazzi, Cocito & Vettolani 1986; Burstein, Condon & Yin 1987; Fitt, Cox & Cox 1988;

Gavazzi, Boselli & Kennicutt 1991 (from now on GBK91)). This hypothesis is supported by the observed correlation between the radio continuum emission and the star formation indicator H_α EW (Kennicutt 1983b; Gavazzi 1988, 1991; GBK91). Radio continuum emission is significantly environment-dependent. Enhancements of the circumnuclear emission is observed in interacting pairs (Condon et al. 1982; Altschuler & Pantoja 1984) and the diffuse disk emission has been reported to be enhanced in cluster galaxies (Gavazzi & Jaffe 1986; Gavazzi 1988, 1991; GBK91).

As a consequence of the correlation between radio continuum emission and SFR, and of the dependence of this latter on the HI surface density discussed in the previous paragraph, it is not surprising that the radio continuum versus HI surface density relation follows a pattern similar to the one in Fig. 2. In Fig. 4 the ratio Radio/H is plotted versus the hybrid HI surface density. Only objects detected in the radio continuum are plotted, upper limits being evenly distributed over the whole ranges of Radio/H and of HI surface density covered by the detected objects, thus adding no useful information. The scatter present in the correlation is large, due to the non direct physical link between the two plotted quantities. If the cluster and the non-cluster samples are considered separately it appears that the scatter is larger among cluster members (filled circles). In this sample nearly two thirds of the objects are indistinguishable from non-cluster galaxies (open circles), but there is a number of objects having a radio emission greater than any non-cluster object at any given HI surface density.

To understand the origin of this larger scatter, we draw in Fig.4 an arbitrary line such that all non-cluster objects lie below it. This line cuts the cluster sample in two parts: below the line there are cluster objects indistinguishable from isolated galaxies (comparison cluster sample), above the line there are 21 cluster objects which show extreme radio properties at any given HI surface density. These cluster galaxies include many radio faint objects, nevertheless showing a Radio/H ratio 3-5 times higher than expected from the HI surface density of relatively isolated galaxies taken as a reference. The 21 cluster galaxies showing excess radio emission are listed in Table 4, while Table 5 lists the 11 galaxies in the comparison cluster sample showing the lowest values of Radio/H for a given HI surface density. In these Tables we list possible evidences of overall disturbances in the galaxy morphology: a yes in column 3 indicates the presence of optical asymmetries (such as evidences of disrupted disks, presence of abnormal arms); asymmetries in the HI distribution (offsets from the galaxy centers derived from HI maps or strong asymmetries derived from HI profiles for spatially unresolved objects) are indicated by a yes in column 4; asymmetries or offsets in the radio continuum morphology are given with a yes in column 5. We consider significant an offset of more than 10 arcsec between the optical and radio coordinates (corresponding to ≈3.6 h^{-1} kpc at the typical distance of these galaxies, except for Virgo members, where it corresponds to ≈0.6 h^{-1} kpc). Question marks indicate undecidable cases, where some relevant information is missing in the published data. The Tables also report the quantities plotted in Fig. 4 (HI surface density and radio/H, in columns 6 and 7). Three galaxies showing excess radio emission are double systems or have companions of comparable magnitude. Tidal interaction is probably the best explanation for their excess radio emission. Of the remaining 18, 12 show optical asymmetries, 10 asymmetries in the HI distribution, 3 clear radio continuum trails and other 6 radio-optical positional offsets (notice however that the resolution of the available radio continuum observations is very inhomogeneous: for example the Coma cluster galaxies have never been observed with the proper resolution (5-10 arcsec) and sensitivity to allow to detect asymmetries or significant optical-radio offsets).

Among the 11 galaxies in Table 5 only one (129027=NGC4725) shows HI asymmetry, and one (522086=NGC753) has a radio/optical offset; the remaining have normal morphologies. We conclude that there is strong evidence that galaxies showing enhanced radio activity are found among those cluster members with significant disturbances. Conversely these objects are virtually absent among the comparison cluster sample and among the isolated galaxies.

Examples of disturbed galaxies in Table 4 are: 97073-79-87 at the NW periphery of A1367. Radio continuum trails were detected by Gavazzi & Jaffe (1987) and HI asymmetry was found by Gavazzi (1989) and by Dickey & Gavazzi (1991). 160055 (N4848), 160260 (N4911) and 160095 (N4921) in the Coma cluster have HI asymmetry reported by Gavazzi (1989) and by Sullivan (1989). Notice that 5 of the 7 blue galaxies in the Coma cluster reported by Bothun & Dressler (1986) as possible examples of galaxies whose star formation was enhanced by ram- pressure, belong to this list. 99075 (N4498), 70068 (N4388), 70192 (N4569)[1)] and 70197 (N4579) in the Virgo cluster were found asymmetric in the HI maps by Cayatte et al. (1990) and/or by Warmels (1986). Eight of the 21 galaxies in Table 3 were discussed in Dickey & Gavazzi (1991) as possible examples of ram pressure swept galaxies. This evidence reinforces the argument of Bothun & Dressler (1986), Gavazzi (1989) and Dickey & Gavazzi (1991) that ram pressure occurring in clusters of galaxies, along with producing stripping of the gaseous component associated with their disks, might as well be the responsible for morphological disturbances and of radio continuum enhancements.

3.3. SYNCHROTRON EMISSION AND STAR FORMATION

Given the correlation between radio continuum emission and star formation activity discussed in section IIIb, it seems reasonable to assume, in first approximation, that enhanced SFR could produce the observed enhanced radio continuum activity among the galaxies listed in Table 4. Measurements of the H_α EW are available for only 13 of the 21 galaxies, (indicated with filled squares in Fig. 2). It is apparent that these galaxies have, on average, a strong SFR for their gas content. To decide whether this high SFR could entirely explain the increase in the radio continuum activity, we examine the correlation between FIR, taken temporarily as another star formation indicator, and the HI surface density. This is shown in Fig. 5, where the ratio FIR/H is plotted against HI surface density. A general correlation between the plotted quantities is not surprising (see Spitzak & Schneider 1992). Empty circles represent isolated galaxies and filled symbols represent cluster objects. Filled squares represent those galaxies among the 21 of table 4 for which the ratio FIR/H is available (the triangles mark two upper limits within these 21 objects). At any given HI surface density these objects have high FIR/H ratios, but not as extreme as their Radio/H, indicating that FIR is not as enhanced as the radio continuum, among the disturbed objects.

[1)] the asymmetry is visible only in the global line profile, and is not evident in the Cayatte et al. map (see their fig. 14f)

In spite of the tight correlation found between radio continuum and FIR integrated luminosities (Dickey & Salpeter 1984; Helou, Soifer & Rowan-Robinson 1985; Gavazzi, Cocito & Vettolani 1986) and surface brightness distributions (Bicay & Helou 1990) we conclude that, unless the characteristic time scales for radio continuum and FIR enhancements are considerably different, an increase in star formation activity cannot entirely explain the radio continuum enhancements in cluster spirals. Another mechanism is required.

To better quantify this point, we examine in Fig. 6a the correlation between the ratio radio/H and the H_α EW. The least square fit between the two quantities is

$$Log(Radio/H) = -2.14 + 0.91\ LogH_\alpha(E.W.)$$

(see GBK91 for details on the derivation). Fig. 6b shows that all the "radio-excess" galaxies listed in table 4 have positive residuals with respect to the correlation, having a ratio radio/H systematically higher than expected from their H_α EW. A similar analysis using FIR/H and H_α EW is shown in Fig. 7a. The least square fit between the two quantities is

$$Log(FIR/H) = 0.35 + 0.72\ LogH_\alpha(E.W.)$$

Fig. 7b shows that, on average, galaxies with radio excess have no net residual with respect to the derived correlation, instead that their ratio FIR/H is consistent with the one expected from their H_α EW.

4. SUMMARY AND CONCLUSIONS

The main results of this work can be summarized as follows:

1) The average SFR in cluster galaxies is normal, in spite of the fact that their HI hybrid surface density is as much as two orders of magnitude lower than that of isolated galaxies (Fig. 2 and 3).
2) A significant fraction of cluster galaxies shows a radio continuum excess as compared with isolated galaxies of similar gas content (Fig. 4). Morphological disturbances seem to characterize these objects.

3) cluster galaxies with radio excess have rather high SFR, as indicated by their FIR emission at any given HI surface density (Fig. 5).

4) However a radio enhancement is observed in disturbed cluster spirals spanning a large range of H_α EW (Fig. 6) and it is much more pronounced than the corresponding FIR enhancement (Fig. 7).

We conclude that enhanced SFR in disturbed cluster systems does not entirely account for the observed radio continuum excess. Another mechanism is required to produce an extra enhancement of the synchrotron emissivity. We argue that magnetic field compression induced by the dynamical interaction between the fast moving galaxies and the hot, dense IGM might explain these radio continuum enhancements that have no corresponding FIR enhancements. In fact the synchrotron emissivity ϵ due to Cosmic Rays electrons depends on the density of relativistic electrons n_e, which is in turn proportional to the galaxy star formation rate (GBK91), and on the intensity of the magnetic field H as $\epsilon = n_e H^2$. The observed average 3-5 times enhancement of ϵ in cluster spirals could be explained if magnetic field amplification by a factor of two would be induced in those cluster galaxies suffering from ram-pressure.

Well documented disturbances to the magnetic field structure induced by the interaction with the IGM in clusters of galaxies occur in the "Head-tail" radio sources, often found associated with bright elliptical galaxies. Less spectacular, though observable magnetic field distortions are detected in the irregular galaxies 97073 and 97079 in A1367 (Gavazzi & Jaffe, 1987). Higher resolution and sensitivity observations of the objects listed in Table 4 are necessary to detect similar phenomena.

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FIGURE CAPTIONS:

Fig. 1: smoothed HI profiles of the 83 detected galaxies. Fitted baselines are superimposed. The frequency axes is labeled in km s^{-1}, the flux is in mJy.

Fig. 2: the relation between the H_α EW and the hybrid HI surface density for isolated (open symbols) and cluster galaxies (filled symbols). Filled squares are galaxies showing excess radio-continuum emission discussed in sections 3.2. and 3.3. Many upper limits to the HI surface density of cluster galaxies are not shown for simplicity.

Fig. 3: frequency distribution of: (a) the H_α EW, and (b) the HI surface density, in the isolated and in the cluster sample. The total number of objects has been normalized to one in both samples. Upper limits, which are frequent among cluster galaxies in (b), are treated as detections.

Fig. 4: the relation between the Radio/H ratio and the hybrid HI surface density for isolated (open symbols) and cluster galaxies (filled symbols). The meaning of the dotted line is discussed in the text. Many upper limits to the HI surface density of cluster galaxies are not shown for simplicity.

Fig. 5: the relation between the FIR/H ratio and the hybrid HI surface density for isolated (open symbols) and cluster galaxies (filled symbols). Filled squares and triangles are galaxies showing excess radio-continuum emission, for which the ratio FIR/H, or an upper limit to the ratio, respectively, is available.

Fig. 6: the correlation between the Radio/H ratio and the H_α EW (a) and the residuals with respect to the linear regression discussed in the text (b). Same symbols as in the previous figure.

Fig. 7: the correlation between the FIR/H ratio and the H_α EW (a) and the residuals with respect to the linear regression discussed in the text (b). Same symbols as in the previous figures.

Notes to tables 1 and 2

The coma supercluster (Comasup) is defined as the region limited by $11^h30^m \leq \alpha \leq 13^h30^m$; $18° \leq \delta \leq 32°$ and $5300 \leq cz \leq 9000$ Km s^{-1}

Comments to individual objects:

U30, U215, U2507, U2525 and U2915 were observed by Giovanelli & Haynes (1989). The observations were repeated to determine the shape of their profiles (unpublished). The two sets of data are in full agreement.

522023: the galaxy lies 1.5 arcmin north of 522023S (UGC1316). The two galaxies are within the Arecibo beam. Both galaxies have spiral morphology, but 522023 has a brighter bulge (possibly S0a). The HI emission cannot be attributed unambiguously to one object.

522065 and 522096: the data include some pairs kindly provided by R. Giovanelli (private communication).

119059, 119061, 119040, 119082: undetected by Bothun et al. (1985). Due to the better signal to noise ratio of our observations two of them (119040 and 119059) were detected and two remained undetected with more stringent upper limits.

119040 and 119041 are in the same beam. Unfortunately due to similarity of the redshifts the HI emission is overlapped (see the three horn profile in Fig. 1).

119080W: in contact with 119080E. The redshifts are 5348 and 5219 Km s^{-1} respectively. CCD observations reveal that both galaxies have a spiral structure but, due to its larger size we are inclined to attribute the HI flux to 119080E.

97008 lies at about 1.5' from 97009, therefore a possible contribution from 97009 cannot be excluded. Moreover the redshift of 97009 is unknown. However repeated observations using offset pointing indicate that the reported HI flux is associated with 97008.

127111: member of the NGC4005 group. Our profile is in close agreement with the one obtained by Williams, 1986. The measurement is confused by the emission from 127110 and 127112, which lye about one beam away from 127111 and have velocities similar with the one under study. 127110 was observed by Gavazzi, 1987 and Williams, 1986 with V=4495 and W=575. 127112 lies at V=4828 W=364.

98051: confused with 98050. Gavazzi, 1987 observed both galaxies and found that the two peaks at higher velocity in Fig. 1 belong to 98050. 98051 has a lower systemic velocity, but its width is undetermined.

108132W and 108132E were detected in the same beam. However the two galaxies are well resolved in frequency (see Fig. 1)

We wish to point out two errors we detected in Paper I of this series (Gavazzi, 1987). Galaxy 97064 should be considered undetected. The HI flux attributed to this galaxy was in fact due to 97068 lying at 2.'2 from it. The velocity of 157035, V=6371 was mistyped. The corrected value is V=6281.