Chapter 5

H I DEFICIENCY IN THE ERIDANUS GROUP

Abstract:

The Eridanus group of galaxies is studied for its H I content using the GMRT observations and the HIPASS data. Eridanus is a low velocity dispersion (~ 240 km s^{-1}), X-ray poor ($L_x \sim 10^{41}$ erg s^{-1}) group. A significant H I deficiency up to a factor of 2 is observed in galaxies in the high galaxy density regions. The H I deficiency in galaxies is observed to be correlated with the surrounding projected galaxy density and the relative radial velocity with respect to the mean velocity of the group. Further, galaxies with larger optical diameters are mostly in the low galaxy density regions or having lower relative velocity in the group. These results strongly suggest that the H I deficiency is predominantly due to tidal interactions. It is also argued that the processes like ram-pressure stripping, thermal evaporation, and viscous stripping can not be effective in removing gas from galaxies in the Eridanus group. In some cases, observational evidences of tidal interactions can be seen in the H I images of galaxies. These results indicate that significant evolution of galaxies can take place even in a group environment. In hierarchical formation of clusters via mergers of small groups, a significant fraction of the observed H I deficiency in clusters could have originated in group environment. The co-existence of S0's and most H I deficient galaxies in the Eridanus group suggests that galaxy harassment can be an effective mechanism for transforming spirals to S0's.

Keywords: Galaxy groups, galaxy cluster, galaxy evolution, H I deficiency, ram-pressure stripping, transport processes, tidal interaction.

5.1 Introduction

The spiral galaxies in the cores of clusters are known to be H I deficient than their counterparts in the field (Davies & Lewis 1973, Giovanelli & Haynes 1985, Cayatte et al. 1990, Bravo-Alfaro et al. 2000). In a study of H I content in nine clusters, Giovanelli & Haynes (1985) noticed that most severely (deficient by more than a factor of 3) H I deficient galaxies are within a projected distance of one Abell radius from the cluster centre, while galaxies in the outer regions have normal H I content expected in the field. They also noticed that H I deficient clusters are the ones in which diffuse X-ray emission is seen. Cayatte et al (1990) found that in the Virgo cluster, H I deficient galaxies have shrunken H I disks. Based on the H I disk sizes in the Virgo galaxies, they showed that the global H I deficiency in Virgo can be understood by a combination of ram-pressure stripping and transport processes (thermal conduction and viscous stripping). Ram-pressure stripping is believed to be the main mechanism responsible for the H I deficiency in cluster spirals (e.g., van Gorkom 2003). However, some observations are at odds with this interpretation. Magri et al. (1988) argued that with the present data it is not possible to rule out processes other than ram-pressure stripping or transport processes which can also cause H I deficiency. Their argument was based on several phenomena seen in clusters - 1) there is no correlation between H I deficiency and the square of the relative radial velocity as would be expected for ram-pressure stripping, 2) there is no correlation between the ICM temperature and H I deficiency as would have been expected (as deficiency $\propto$ T$^{2.5}$) if thermal conduction and viscous and turbulent stripping were effective in removing gas. Contrary to what is expected from ram-pressure stripping (Gunn & Gott 1972), the low mass spirals and dwarf galaxies seem to be indistinguishable from the massive spirals in terms of both H I deficiency and velocity distribution (Hoffman et al. 1988). Valluri & Jog (1991) observed in Virgo and some other rich clusters that galaxies with medium to large optical sizes tend to be more severely H I deficient than the small galaxies in terms of both fractional number and amount of gas lost. This behavior is contrary to that expected from ram-pressure stripping or transport processes, however, consistent with that expected if tidal interactions were responsible for the gas deficiency. The hydrodynamical simulations by Vollmer et al. (2001) predict that most of the H I deficiency can be produced for galaxies in radial orbits and only after crossing the high ICM density core region. Though most of the H I deficient galaxies are found in radial orbits (Dressler 1981), it is unclear whether most of them have crossed the core. The effects of ram-pressure stripping are also highly sensitive to the relative geometry of the disk with respect to its direction of motion in the ICM. These results make it difficult for ram-pressure to be solely responsible for the global H I deficiency in clusters. The tidal interactions are thought to be of not much significance in removing gas from galaxies in clusters as large relative velocity of encounter between galaxies in clusters cause no subtle perturbing effect on the disks as explained by Toomre & Toomre (1977) in their simulations of galaxy interactions. The exact mechanism responsible for H I deficiency in clusters therefore remains elusive.

Galaxy clusters also have a high fraction of S0's compared to fields (Curtis 1918, Hubble & Humason 1931, Poggianti et al. 1999, Dressler et al. 1997, Fasano et al. 2000). Dressler (1980) postulated this difference as due to a basic correlation between the galaxy morphology and the local galaxy density. This correlation, known as the density-morphology relation, is observed to be valid over five orders of magnitude in the projected galaxy density (Postman & Geller 1984). There are strong arguments that S0's are a result of evolution of galaxies in the high galaxy density regions (Poggianti et al. 1999, Dressler et al. 1997, Fasano et al. 2000). This result is based on the observations in the intermediate redshift clusters (earlier epochs) where the fraction of S0's is lower. It is generally argued that the ram-pressure stripping can produce S0's. Another mechanism which can transform spirals into S0's was proposed by Spitzer & Baade (1951) via collisions between galaxies. Recently, interaction of galaxies with the cluster tidal field, a process termed "galaxy harassment" has been proposed for the morphological transformation of galaxies to S0's (Moore et. al. 1998).

The Eridanus group has a large fraction (0.5) of S0's in the central high galaxy density regions. This fraction is intermediate to that in the Fornax cluster (0.4), and in the Virgo cluster (0.6). The Eridanus group has about 200 galaxies within an extent of $\sim$ 10 Mpc with significant sub-clustering in the inner 4 Mpc region. The projected galaxy density varies from ~ 1 Mpc^{-2} in the outer regions to ~ 25 Mpc^{-2} in the inner regions. Given the low X-ray luminosity ($\sim 10^{41}$ erg s^{-1}), and the low velocity dispersion (~ 240 km s^{-1}) in the Eridanus group, and the low temperatures (10^7 K; Mulchaey 2001) in groups, ram-pressure stripping, and transport processes are ineffective in removing gas from galaxies. Therefore, although the high fraction of S0's in Eridanus suggests that significant galaxy evolution has taken place in this group, it can not be understood due to ram-pressure or transport processes. If tidal interactions are responsible for the large number of S0's, then, it should be possible to detect signatures of tidal interactions in spirals galaxies in the Eridanus group. With this motivation, spiral galaxies in the Eridanus group were observed with the GMRT to study their H I content and morphologies. Eridanus offers a sample intermediate to clusters like Virgo, and very young groups (field-like) like Ursa-Major in terms of galaxy density, X-ray luminosity, and velocity dispersion (see Tab. 2.1). Therefore, the Eridanus group can be considered as in an early stage of cluster formation. The current H I observations, therefore, offers an opportunity to study galaxies in a cluster at an intermediate stage of evolution.

5.2 H I content of the Eridanus group

The galaxies in the Eridanus group were observed with the GMRT in the H I 21 cm-line. The details of the observations and the data analyses are described in Chapter 3. Since the GMRT H I fluxes for some large galaxies were found to be significantly underestimated, the single dish H I data from HI Parkes All Sky Survey (HIPASS) were used in this study. Some of the lower (a few times $10^8 M_\odot$) H I mass galaxies detected in the GMRT were not detected in HIPASS. Since the GMRT data does not show any systematic offset for H I masses in the lower mass range, galaxies which were detected only by the GMRT were also included in this study. The final sample consisted of a total of 63 H I detected galaxies.

Haynes & Giovanelli (1984; *hereafter* HG84) studied H I properties of 287 isolated galaxies using the Arecibo telescope. They found that the H I masses of galaxies depends on both their Hubble types and their optical disk diameters in the B-band. They also found that the distribution of the

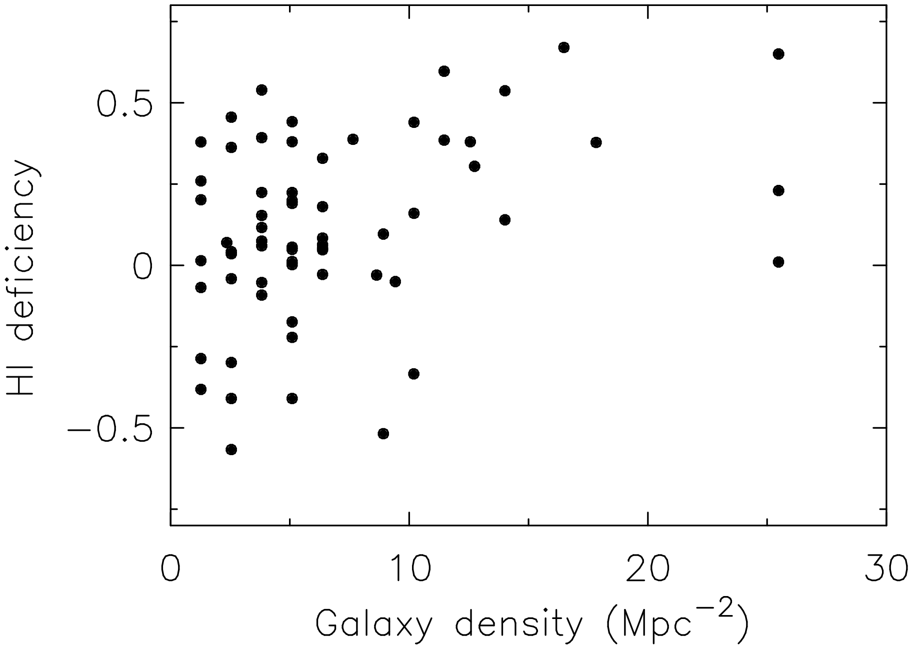

Figure 5.1: H I deficiency and the surrounding projected galaxy density. Galaxies with larger H I deficiency are in higher galaxy density regions. The galaxy density is estimated in a circular region of diameter 1 Mpc centered at the position of the galaxy.

ratio of H I mass ($M_{\rm H\,I}$) to the square of the optical diameter (D_{opt}) has least scatter. The ratio ($M_{\rm H\,I}/D^2_{opt}$) is generally recommended for estimating the H I deficiency in galaxies of a given type. The ratio $M_{\rm H\,I}/D^2_{opt}$ for a type of galaxy is compared with the mean value of $M_{\rm H\,I}/D^2_{opt}$ for the same type in the field. The deficiency parameter is defined as –

$$Deficiency \;=\; < log(M_{\rm H\,I}/D^2_{opt}) >_{field} \;-\; log(M_{\rm H\,I}/D^2_{opt}) \tag{5.1}$$

The optical diameters used in HG84 were from the the Upsala General Catalog (UGC). The optical diameters in the Eridanus group are taken from the Third Reference Catalog of Galaxies (RC3; de Vaucouleurs et al. 1991). The optical diameters in RC3 are at 25 mag arcsec^2 in the B-band. To convert the RC3 diameters or D_{25} to D_{opt} consistent with the UGC diameters, the conversion relation obtained by Paturel et al. (1991) was used. This relation predicts that the D_{opt} (UGC) are roughly 1.09 times the D_{25}. It should be noted that the deficiency parameter in Equ. 5.1 is distance independent.

Figure 5.1 shows H I deficiency as a function of surrounding projected galaxy density. The galaxy density is estimated in a circular region of diameter 1 Mpc centered at the position of the galaxy. The choice of 1 Mpc is made since at typical velocities ($\sim$ 250km s^{-1}) of galaxies in the Eridanus group, galaxies can traverse about 1 Mpc in their typical ages. Therefore, neighbors within 1 Mpc may have caused subtle effect on a galaxy in the past. It appears from Fig. 5.1 that in the low galaxy density regions ($densities\ <\ 10$ Mpc^{-2}), the mean deficiency is close to zero, but in the higher galaxy density regions the mean is significantly above zero. The line in this figure shows a possible trend of deficiency with the galaxy density. The slope and the constant of the fitted line are obtained as 0.017(±0.006) and –0.007(±0.05). We conclude from this figure that the Eridanus galaxies can be H I deficient up to a factor of 2.

The effect of relative radial velocity with respect to the group velocity on H I deficiency is investigated using Fig. 5.2. This plot shows a strong correlation between the H I deficiency and the relative radial velocity in the sense that the positively deficient galaxies are at lower (< 400 km s^{-1}) relative velocities. Except for a few galaxies at higher relative velocities and galaxies near zero velocity, a reasonably good fit to a straight line was obtained for most of the galaxies. The straight line shown in Fig. 5.2 has a slope of $-1.2(\pm 0.2)\times 10^{-3}$ and a constant of 0.53(±0.07).

The two panels in Fig. 5.3 show the optical locations of all galaxies (lower panel) and galaxies for which the H I deficiency exceeds 0.3 (top panel). The early type (E+S0) galaxies are plotted as

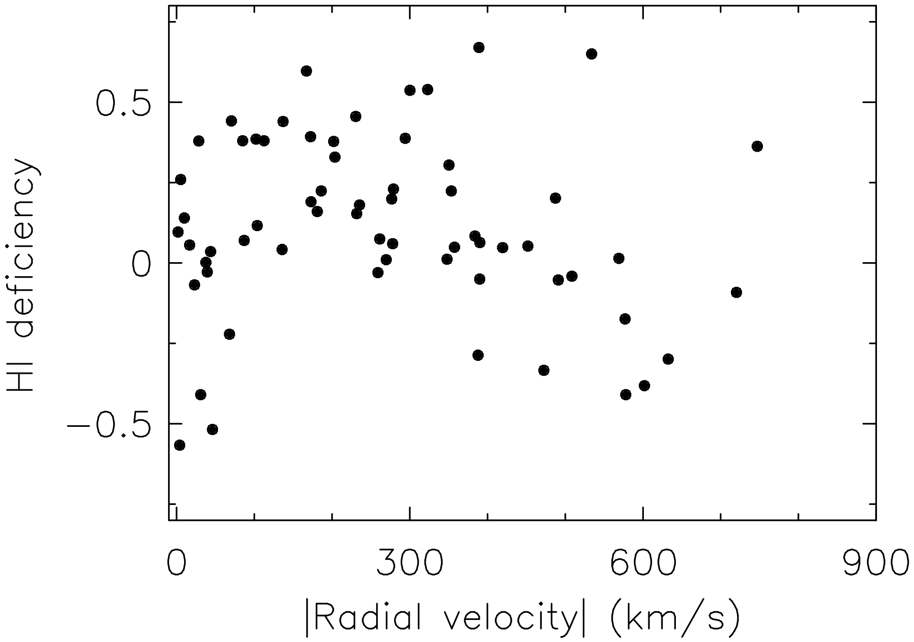

Figure 5.2: H I deficiency is plotted against the relative velocity of galaxies with respect to the mean velocity of the group. The dotted line is a possible correlation between the H I deficiency and the relative velocity in the range 100 - 700 km s^{-1} .

filled circles and late type galaxies are plotted as crosses. It is evident from these plots that the most H I deficient galaxies and early type galaxies are being found in similar regions. These regions are also predominantly high galaxy density regions in the group.

5.3 What made galaxies in the Eridanus group H I deficient

The linear trend in Fig. 5.1 indicates that the deficiency is likely to be due to tidal interactions since galaxies in higher galaxy density regions will have higher probability of tidal encounters. The linear relationship seen in Fig. 5.2 can be qualitatively understood under the framework of tidal interactions. It is expected that maximum perturbing effects in tidal interactions between two galaxies will occur if the relative velocity of the two galaxies is low and comparable to the orbital velocity of the galactic disks (typically < 300km s^{-1}). In the Eridanus group where the distribution of galaxies is peaked near the mean velocity of the group (see Fig. 2.3) and falls off nearly as a Gaussian at higher relative velocities, galaxies with velocities near the mean velocity of the group will have a higher probability of interacting with a companion with lower velocity difference. Further, the presence of the wider distribution of deficiency near the zero relative radial velocity may just be due to projection effects. Galaxies moving with higher relative velocities nearly perpendicular to the line of sight will have almost zero radial velocity. Therefore, some discordant points are expected near the zero relative velocity in Fig. 5.2.

In Fig. 5.4, the effect of galaxy density on the optical sizes of the disks is studied. Both gas and stars are expected to be removed from galaxies as a result of tidal encounter. Therefore, the optical disks of galaxies are expected to be shrunken in cases where tidal interactions have been effective. The Fig 5.4 agrees with this prediction. It can be seen that larger optical disks are found predominantly in lower galaxy density regions.

Although, the behavior of H I deficiency with respect to the galaxy density and relative radial velocity strongly indicate that the H I deficiency in the Eridanus group is likely due to tidal interactions, the effects of several other known gas removal mechanisms, e.g., ram pressure, thermal conduction and viscous stripping are also studied in this section for the sake of completeness.

The ram-pressure stripping as it is argued for most of the H I deficiency in cluster galaxies can not be effective in Eridanus. The estimated value of the IGM (intra-group medium) density from the diffuse X-ray emission ($L_x = 1.6 \times 10^{41}$ erg s^{-1}) seen around NGC 1407 is $\sim 2.0 \times 10^{-4}$ cm^{-3}. The

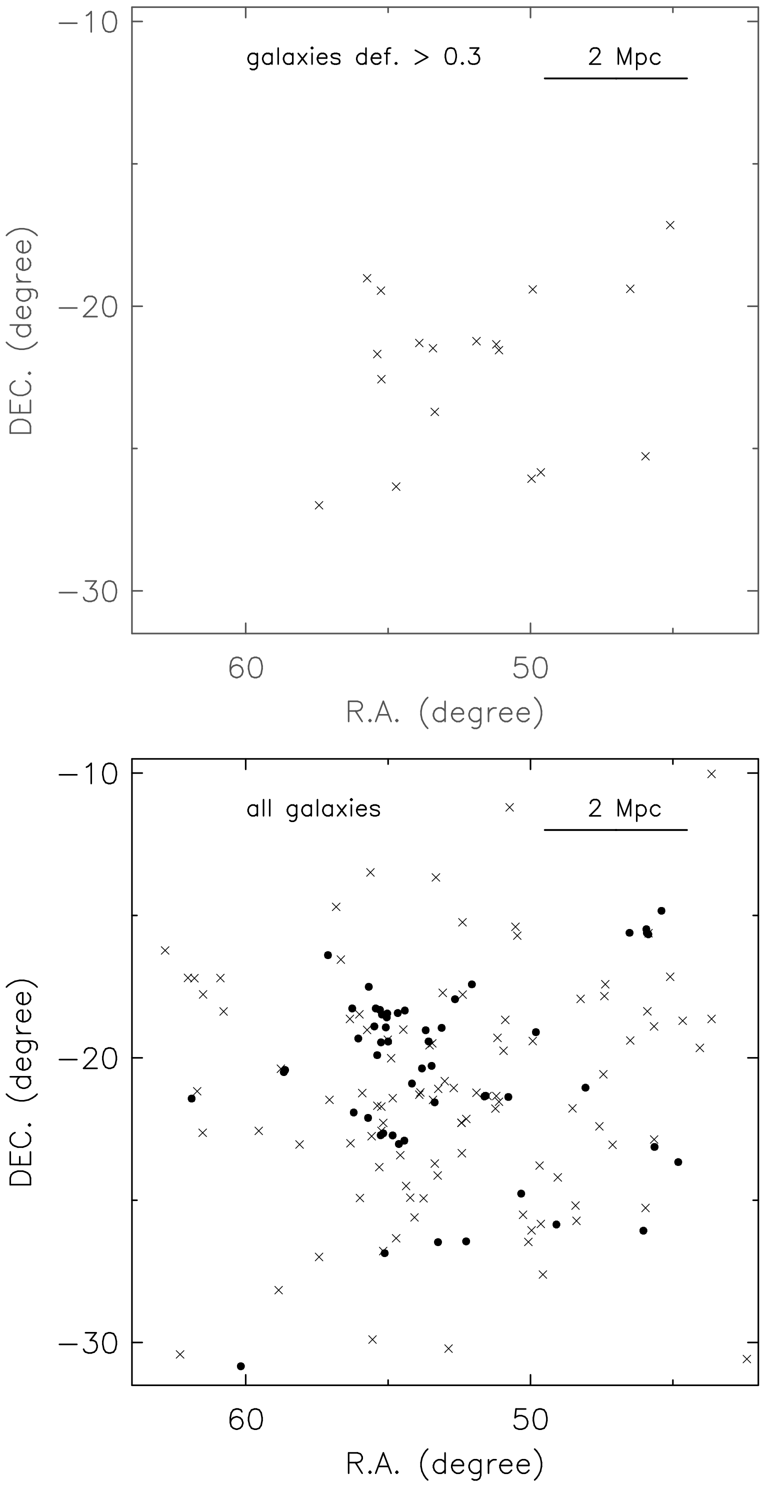

Figure 5.3: (Lower panel) All galaxies in the Eridanus group. The early type galaxies (E+S0) are marked as filled circles and late type galaxies are marked as crosses. (Upper panel) Galaxies with H I deficiency greater than 0.3. It can be seen that severely H I deficient galaxies and early type galaxies are more or less in similar regions.

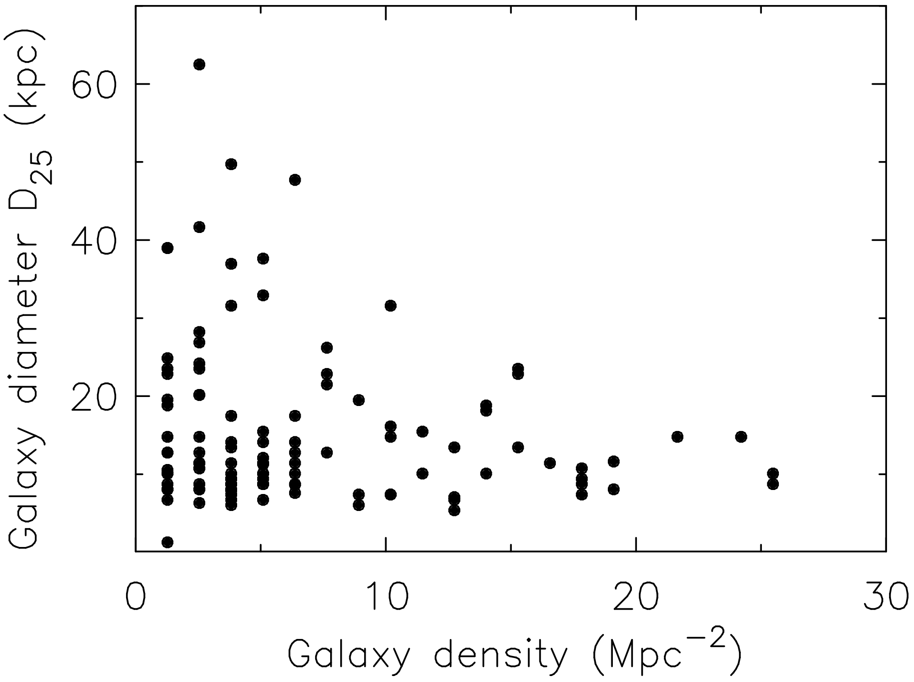

Figure 5.4: The optical diameters of galaxies are plotted against the surrounding projected galaxy density. The galaxy density is estimated in a circular region of diameter 1 Mpc centered at the position of the galaxy.

minimum ram-pressure required to strip the gas from a galaxy of radius R, moving with a relative velocity of v with respect to the IGM has to exceed the gravitational pressure on the gas due to the stars in the galaxy. The gravitational pressure due to stars of surface density Σ_* can be written as -

$$P_{grav} = 2\pi G \Sigma_* \Sigma_{gas} \tag{5.2}$$

(Gunn & Gott 1972). The stellar surface density Σ_* can be approximated by

$$2\pi G \Sigma_* = V_{rot}^2 R^{-1} \tag{5.3}$$

(Binney & Tremaine 1987), where V_{rot} is the rotation velocity of stars at a galacto-centric radius R. Therefore, the condition for the ram-pressure to be effective in removing gas from the disk is -

$$\rho_{ICM} V_{gal}^2 \geq \Sigma_{gas} V_{rot}^2 R^{-1} \tag{5.4}$$

The velocity dispersion in the Eridanus group is $\sim$ 240 km s^{-1} . Galaxies moving with relative velocities $\sim$ 240 km s^{-1} in the IGM of density 2.0×10^{-4} cm^{-3} will experience maximum ram-pressure of $\sim$ 10 cm^{-3} (km s^{-1})^2. This ram-pressure can strip H I at column densities below 6×10^{19} cm^{-2} at galacto-centric radii exceeding 10 kpc assuming that the maximum rotation velocity of the disk is 150 km s^{-1} and galaxy is moving almost edge-on in the IGM. This ram-pressure is one to two order of magnitudes lower than that in the cores of clusters. Also, this ram-pressure is effective only within $\sim$ 100 kpc from the centre of the X-ray emission. The ram-pressure at larger distances from the centre will drop rapidly due to decrements in the IGM density. The H I in galaxies is always seen at column densities above 2×10^{19} cm^{-2} (Corbelli et al. 1989, van Gorkom 1991), therefore the ram-pressure in the Eridanus group can only be mildly effective if galaxies cross the core of the X-ray emission. It is not expected in large groups like Eridanus that many galaxies have already crossed the highest IGM density regions. The trend in the H I deficiency with increasing relative radial velocities as seen in Fig. 5.2 is opposite to what would have been expected if ram-pressure were globally effective. Therefore, the ram-pressure seems not to be very effective in the Eridanus group.

The gas loss due to transport processes, e.g., thermal conduction has been worked out by Cowie & Songaila (1977), and turbulent and viscous stripping has been worked out by Nulsen (1982). Both of these processes have a strong dependence ($\sim T^{2.5}$) on the IGM temperature. These processes will be effective uniformly over the disk. For typical conditions in the galactic disks, the mass loss rate due to these processes can be given by the relation:

$$\dot{M}_{ev+vs} \sim 3M_{\odot}yr^{-1}(\frac{T}{10^7\ K})^{2.5}\ \ (\frac{R}{20\ kpc}) \tag{5.5}$$

(Sarazin 1988, Nulsen 1982); The subscript ev and vs denotes evaporation and viscous terms respectively. For typical IGM temperatures of $\sim 10^7$ K for groups (Mulchaey 2000), up to a few times 10^9 M$_{\odot}$ of H I mass can be lost from galaxies in about 1 Gyr. However, in the presence of cluster magnetic fields, both thermal conductivity and viscosity will be suppressed drastically in directions other than the directions of the magnetic fields (Spitzer 1978). Hence, the magnetic field suppress the mass loss rate (Cowie & McKee 1977). Unfortunately, the exact amount of mass loss rate due to the transport processes is difficult to estimate as it depends on the detailed geometry of the magnetic field. It is predicted that the thermal conduction is suppressed by at least 3 orders of magnitudes (Nath 2003). Therefore, the mass loss rate from galaxies will be negligible over the present day ages of galaxies. Again, the trend in the H I deficiency with increasing relative radial velocities as seen in Fig. 5.2 is opposite to what would have been expected if viscous and turbulent stripping were globally effective. Consequently, evaporation and viscous processes are likely to be ineffective in the Eridanus group.

5.4 Observational signatures of tidal interactions

If tidal interactions are effective in the Eridanus group, some observational signatures of tidal effects should be visible, e.g., tidal tails, H I asymmetries, warps etc. Tidal tails are expected to expand with time and consequently gas will get more diffuse with time. In most of the known cases of tidally interacting galaxies, H I in tidal debris is detected at lower column densities of typically a few times 10^{19} cm^{-2}. Therefore, detection of tidal debris due to past interactions is not straightforward with the sensitivity of the present GMRT observations. However, some galaxies in the Eridanus group show peculiar H I morphologies like H I extending out of the disk, H I warps, asymmetric H I disks, shrunken or fragmented H I disks, kinematical or H I lopsidedness, and in some cases long H I and optical tails. Most of these features can be understood as a result of tidal interactions. Fig. 5.5 shows a collage of all such galaxies in which H I morphological peculiarities are seen. Some of the peculiar H I morphologies are described below:

Shrunken H I disks

ESO 549- G 002 and NGC 1422 show shrunken H I disks. Both of these galaxies are H I deficient and reside in a region with galaxy density $\sim$ 20 Mpc^{-2}. The H I deficiencies for ESO 549- G 002 and NGC 1422 are 0.67 and 0.44 respectively. ESO 549- G 002 has a faint stellar envelop in the outer regions and has irregular optical morphology in the inner regions. NGC 1422 is an edge-on galaxy with prominent dust lane visible across the plane of the galaxy. It has an H I morphology similar to that seen in ram-pressure stripped galaxies in clusters where gas from the outer regions is preferentially removed. As it has been argued that the ram-pressure can not be effective in the Eridanus group, it indicates that highly shrunken H I disk in NGC 1422 can not be taken as an indication of ram-pressure. However, no tidal features are seen either in optical or in H I . The origin of shrunken H I disk in NGC 1422 therefore remains elusive.

Extra-planar gas & warps

Some galaxies in the Eridanus group show H I extending out of the disk (see ESO 482- G 013, IC 1952, ESO 548- G 065, ESO 549- G 035 in Fig. 5.5) This extra-planar gas is seen in forms of wisps and small plumes of gas. It appears that this phenomena is often seen in edge-on galaxies as there any extra-planar gas will be easier to detect. It may be possible that other galaxies also have such features. It implies that the extra-planar gas is quite common in galaxies. H I warps can be noticed in ESO 548-G 021 and NGC 1414.

Asymmetric H I disks

NGC 1309 and UGCA 068 have extremely asymmetric H I disks. These two galaxies have normal H I content. One side of the galaxy appears more diffuse than the opposite side. These two galaxies are also strongly kinematically disturbed. NGC 1309 has a strong warp in the outer region while UGCA 068 has strong rotation curve asymmetry. We speculate that such features could be due to a retrograde tidal encounter. The retrograde encounter described by Toomre & Toomre (1977) does

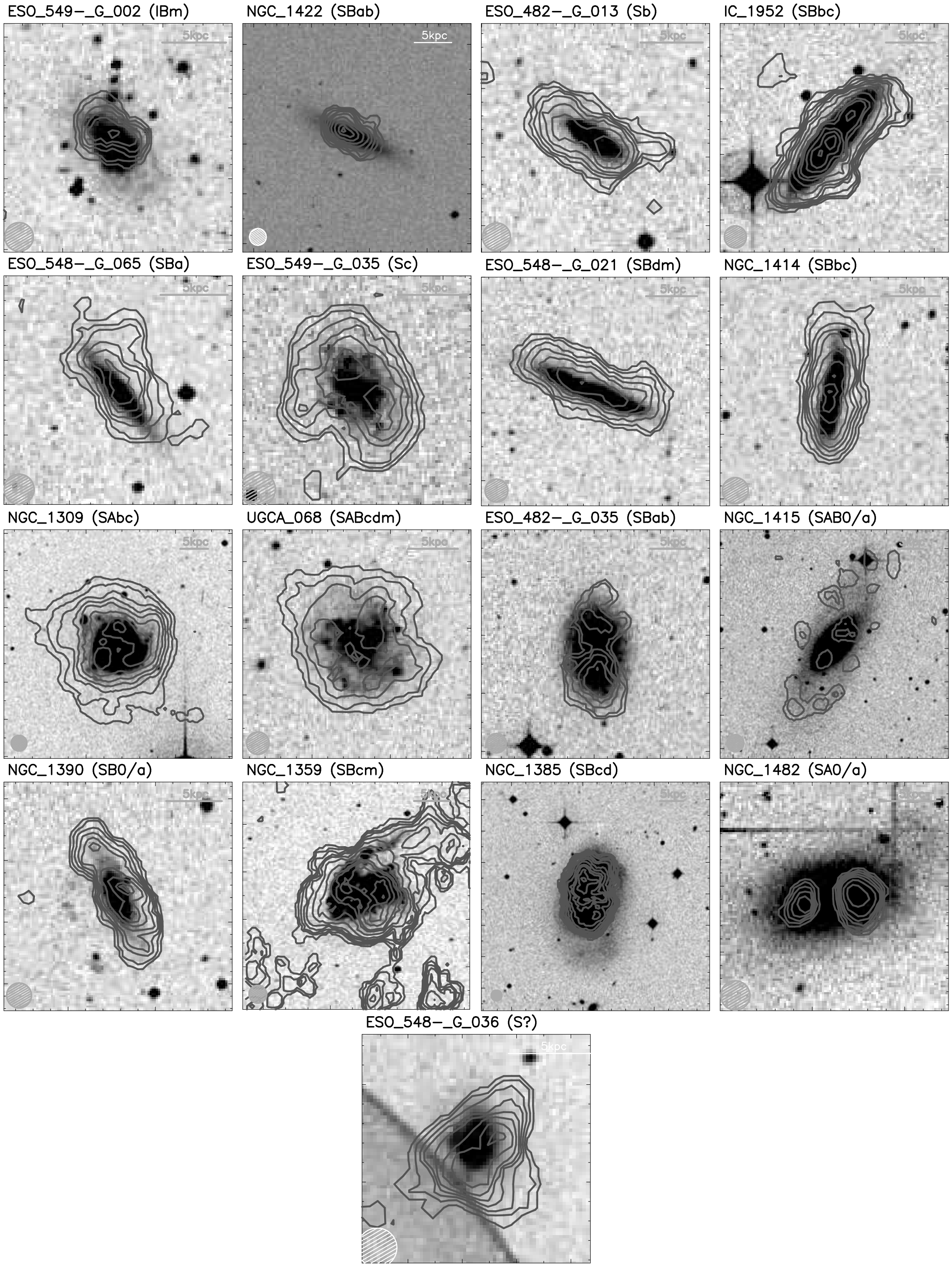

Figure 5.5: A collage of H I images of some Eridanus galaxies which show peculiar H I morphology (see Sect. 5.4 for details)

not pull out stars (the gas will respond in the same way) but can cause both morphological and kinematical asymmetries.

Peculiar H I disks

The H I disks of NGC 1415 and ESO 482-G 035 are seen to be very peculiar. NGC 1415 is an S0/a galaxy with a faint optical ring in the outer regions where most of the H I is seen in isolated clouds. The inclination of the ring is mis-aligned by the inner disk by more than 20° . Both are early type disk galaxies and it is not common to see fully developed H I disks in such galaxies. It is likely that these are H I rings and not disks. The H I disk of NGC 1390 is seen bent in an arc shape. Faint stellar extensions are visible toward the west of the galaxy.

Polar ring galaxy

ESO 548 -G 036 (S?) has position angle of the H I disk inferred from H I kinematics almost normal to the position angle of the optical isophotes. The optical body resembles to a S0 galaxy with a dust lane normal to the major axis of the main body. It is suggested that this is a pole ring galaxy. Polar rings are believed to be due to recent accretion of gas from tidal encounters. IC 1953 a gas rich galaxy at a projected separation of $\sim$ 50 kpc is likely to be the companion.

Tidal tails

Either gaseous or stellar tidal features are seen in NGC 1359, NGC 1385, and NGC 1482. The H I tidal tail and some isolated H I features in the vicinity can be seen in NGC 1359. Both NGC 1385 and NGC 1482 are star-burst galaxies. NGC 1385 has highly asymmetric diffuse stellar envelop, however no gaseous tidal tail is seen. NGC 1482 (S0/a) has an ring. The central H I hole in NGC 1482 is due to H I absorption against the radio emission. Stellar tidal features can be seen toward the north-east direction of the galaxy.

5.5 Discussions

Galaxies in the Eridanus group are H I deficient up to a factor of 2 as compared to their field counterparts. The correlation of H I deficiency with the local galaxy density (Fig. 5.1) and with the relative velocity (Fig. 5.2) is strongly suggesting that the H I deficiency in the Eridanus galaxies is due to tidal interactions. Although Eridanus appears as a loose group, it has significant sub-grouping of galaxies. This sub-grouping provides regions of higher galaxy density where severely H I deficient galaxies are seen. Galaxies moving with velocities of $\sim$ 240 km s^{-1} (dispersion of the group) can cross a linear distance of $\sim$ 1 Mpc in $\sim$ 5 Gyr which is less than the typical ages of galaxies. The high galaxy density and the relatively short crossing time in sub-groups increases chances of encounters between galaxies. Therefore, it appears that the sub-grouping is playing a role in producing H I deficiency. Further, the strong correlation with the relative velocity indicates that it is necessary for galaxies to interact with another galaxy with small velocity difference (typically in between $0 - 300$ km s^{-1}) to make tidal encounters effective.

Clusters of galaxies are believed to be formed via mergers of several small groups. This conjecture gets support from several observations where cores of rich clusters are found to have significant sub-clustering (e.g., Geller & Beers 1982). Clusters are also found to be H I deficient with galaxies having H I deficiency up to a factor of 10. If clusters are indeed build up via mergers of small groups, the H I deficiency in the Eridanus group indicates that not all deficiency in cluster is due to the cluster environment where ram-pressure is believed to be most efficient. Alternatively, a significant fraction of H I deficiency in clusters could have originated in the group environment. In fact, these results are consistent with some other observations in groups. For instance, X-ray observations in groups indicate that groups are filled with metal-enriched IGM with average metallicity $\sim$ 0.3 (Mulchaey 2000) indicating that gas is being lost from galaxies even inside a group environment.

It is worthwhile to discuss an important effect while estimating gas deficiency by comparing the $M_{\mathrm{H\,I}}/D_{opt}^2$ for a galaxy with that for its field counterparts. Since both D_{opt} and $M_{\mathrm{H\,I}}$ are reduced as a result of tidal encounters, the gas deficiency inferred from this deficiency parameter will be a lower limit. In absence of detailed simulation of repetitive tidal encounters in a group environment, such effects are hard to quantify.

The origin of S0's in high galaxy density regions or in clusters is not understood and the subject is highly debated. There are several mechanisms which have been proposed for a transformation of spirals to S0's, e.g., ram-pressure stripping (Gunn & Gott 1972), galaxy harassment (Moore et al. 1998), strangulation. Galaxy harassment is the process of many rapid encounters in high galaxy density regions. Each individual encounter does not bring much damage but many fast encounters are believed to affect the outer regions of galaxies. Fig. 5.3 indicates that both early type galaxies (mostly S0's) and severely H I deficient galaxies are in the higher galaxy density regions of the group. Ram-pressure is not playing any major role in the Eridanus group. Galaxy harassment will be more effective in a group environment as it will have more efficient slow encounters. Therefore, in wake of the results from the present observations galaxy harassment can be an effective mechanism for transforming spirals to S0's. It is worthwhile to mention that Spitzer & Baade (1951) proposed that S0's can be produced by tidal interactions.

5.6 Conclusions

- The Eridanus group is H I deficient with galaxies having H I deficiency up to a factor of 2.
- The deficiency is correlated with the relative radial velocity with respect to the mean velocity of the group and also with the surrounding projected galaxy density.
- The optical disk diameters are reduced in the high galaxy density regions.
- The H I deficiency in the Eridanus group is due to tidal interactions.
- If clusters form via mergers of groups, a significant fraction of H I deficiency in cluster galaxies could have been produced in group environment.
- The co-existence of S0's and most H I deficient galaxies in the Eridanus group suggests that galaxy harassment can be an effective mechanism for transforming spirals to S0's.

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