H I deficiency in groups : what can we learn from Eridanus ?

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Abstract. The H I content of the Eridanus group of galaxies is studied using the GMRT observations and the HIPASS data. A significant H I deficiency up to a factor of $2 - 3$ is observed in galaxies in the Eridanus group. The deficiency is found to be directly correlated with the projected galaxy density and inversely correlated with the line-of-sight radial velocity. It is suggested that the H I deficiency is due to tidal interactions. An important implication is that significant evolution of galaxies can take place in a group environment.

Keywords : galaxies: ISM – galaxies: interactions – galaxies: kinematics and dynamics – galaxies: evolution – galaxies: clusters: individual: Eridanus group – radio lines: galaxies

1. Introduction

Spiral galaxies in the cores of clusters are known to be H I deficient compared to their field counterparts (Davies and Lewis 1973, Giovanelli and Haynes 1985, Cayatte et al. 1990, Bravo-Alfaro et al. 2000). Several gas-removal mechanisms have been proposed to explain the H I deficiency in cluster galaxies. There are convincing results from both the simulations and the observations that ram-pressure stripping can be active in galaxies which have crossed the high ICM (Intra Cluster Medium) density region in the cores of clusters (Vollmer et al. 2001, van Gorkom 2003). However, it is not clear that all H I deficient galaxies have crossed the core. "Galaxy harassment" can also affect outer regions of galactic disks as a result of repetitive fast encounters of galaxies in clusters

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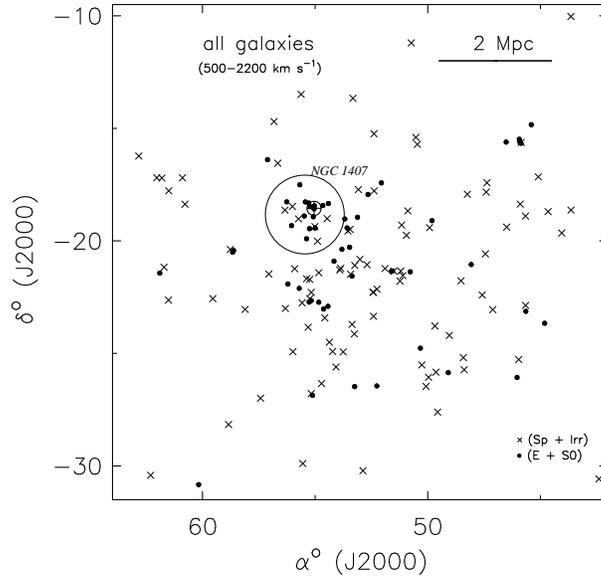
Figure 1. Galaxies in the Eridanus group. The early type (E+S0) galaxies are marked as filled circles and late type (Sp + Irr) galaxies are marked as crosses. NGC 1407, the brightest galaxy of the group is marked as encircled '+' sign.

(Moore et al. 1998). There can be other scenarios where galaxies can become gas deficient, e.g., thermal evaporation and viscous stripping (Cowie and Songaila 1977, Nulsen 1982, Sarazin 1988) and removal of the hot gas from galaxy halo ("galaxy strangulation"; Larson et al. 1980). It turns out that no single gas-removal mechanism can explain the global H I deficiency in a cluster environment (e.g., Magri et al. 1988). Some of the parameters driving these mechanisms are not known well, such as the thermal conductivity of the ICM and amount of hot gas in halos. These difficulties have led one to speculate that cluster galaxies were perhaps H I deficient even before they fall in to the cluster.

Several clusters have been imaged in H I . However, only limited H I data exist for large groups. For example, Ursa-Major group which has no elliptical and only a few S0s shows no significant H I deficiency (Verheijen 2001). Hickson Compact Groups (HCGs) have been studied in H I and some of them show H I deficiency (Verdes-Montenegro et al. 2001). However, small number of galaxies in HCGs makes this sample statistically insignificant to make any firm conclusion or to understand the mechanism driving the galaxy evolution. Here, we present an H I study of the large ($\sim$ 200 galaxies) nearby ($\sim$ 23 Mpc) Eridanus group of galaxies. The properties of the group are described in the next section. Both the GMRT data and the HIPASS (H I Parkes All Sky Survey) data are used. The details of the GMRT observations, data reduction and analyses are presented in Omar and Dwarakanath (2004a). The full description of this work is presented in the

Table 1. Comparison of four nearby galaxy groups and clusters

Properties	Virgo[a]	Fornax[b]	Eridanus[c]	Ursa-Major[d]
Distance (Mpc)	21	20	23	21
No. of E+S0	71	23	36	9
No. of S + Irr	123	17	42	53
Vel. dispersion (km s^{-1})	760	350	240	150
log X-ray luminosity (erg s^{-1})	43.5	41.7	41.4	–
Proj. galaxy density (Mpc^{-2})	50	70	8	3

Notes - (a): Inner $6°$ (~ 2.4 Mpc) region, (b): Inner $2°.4$ (~ 1 Mpc) region, (c): Inner $9°$ (~ 3.6 Mpc) region, (d): Inner $15°$ (~ 6 Mpc) region. The table is from Omar et al. (2004).

Ph.D. thesis of Omar (2004). A detailed discussion on the H I content of the Eridanus group is given in Omar and Dwarakanath (2004b). Here, we discuss the results briefly.

2. The Eridanus group

The Eridanus group was identified as a moderate-sized cluster in a large-scale filamentary structure near $cz \sim 1500$ km s^{-1} in the Southern Sky Redshift Survey (SSRS; da Costa et al. 1988). This filamentary structure, which is the most prominent in the southern sky, extends for more than 20 Mpc. The Fornax cluster and the Dorado group of galaxies also belong to this structure. Willmer et al. (1989) grouped the galaxies in the Eridanus region into different sub-groups. They concluded that each sub-group is a bound structure and the entire group is also gravitationally bound with a dynamical mass greater than $\sim 10^{13}$ M$_\odot$.

Most of the Eridanus galaxies are concentrated in the velocity range $cz = 1000 - 2200$ km s^{-1}. The distance to the group is estimated as $\sim 23 \pm 2$ Mpc from the surface brightness fluctuation measurements (Tonry et al. 2001). The locations of galaxies in the Eridanus group are plotted in Fig. 1 where it can be seen that the galaxies are not distributed uniformly in space. The group appears to be made of different sub-groups. The sub-clustering is quite prominent in the inner region. The sub-group NGC 1407 (cf. Willmer 1989; marked in Fig 1) has its brightest member as an elliptical galaxy (NGC 1407; E0) which is also the brightest in the entire group. NGC 1407 has diffuse X-ray emission ($L_X = 1.6 \times 10^{41}$ erg s^{-1}) surrounding it. NGC 1407 sub-group is the richest in early types, most of them being S0s. The population mix of (E+S0) and (Spirals+Irr) in the NGC 1407 sub-group is 70% and 30% respectively. The overall population mix in the Eridanus group is 30% (E+S0) and 70% (Sp +Irr).

There is no appreciable difference in the velocities over which the early types and the late type galaxies are distributed. This is contrary to that seen in clusters like Virgo and Coma where spirals have much flatter velocity distribution and E/S0s have nearly
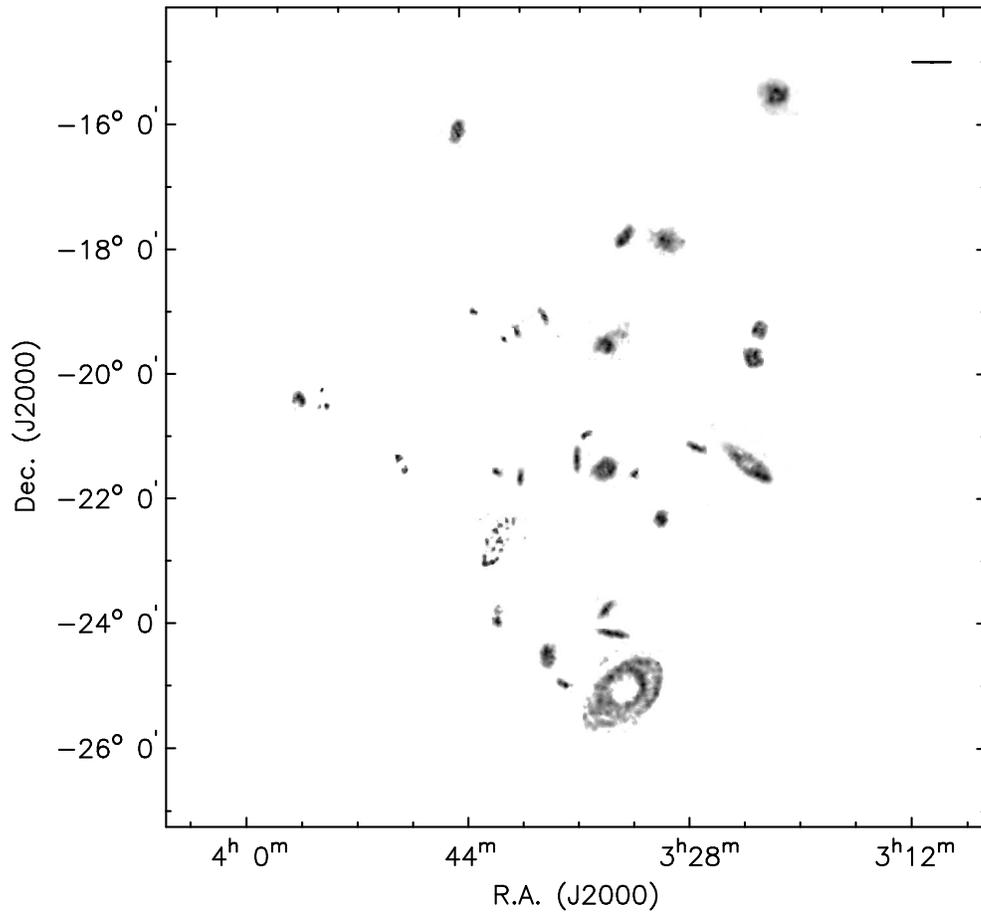
Figure 2. A collage of the total H I maps of the Eridanus galaxies from GMRT. The individual galaxies are enlarged by ~ 10 times their original size. The actual positions of some galaxies are displaced to avoid overlap. A bar on the upper right hand corner indicates a scale of 20 kpc for the enlarged sizes of the galaxies, otherwise, $1°$ corresponds to a linear dimension of ~ 400 kpc. The maps are sensitive down to a 5σ column density of $N_{\rm H\,I} = 10^{20}$ cm^{-2}.

a Gaussian distribution. In Table 1, the properties of the Eridanus group are compared with the two clusters Virgo and Fornax and one loose group Ursa-Major. It appears that the Eridanus group forms a system which is intermediate between a loose group (e.g., Ursa-Major) and a cluster (e.g, Virgo, Fornax). It is interesting to note that the population mix in the NGC 1407 sub-group is similar to that seen in evolved clusters.
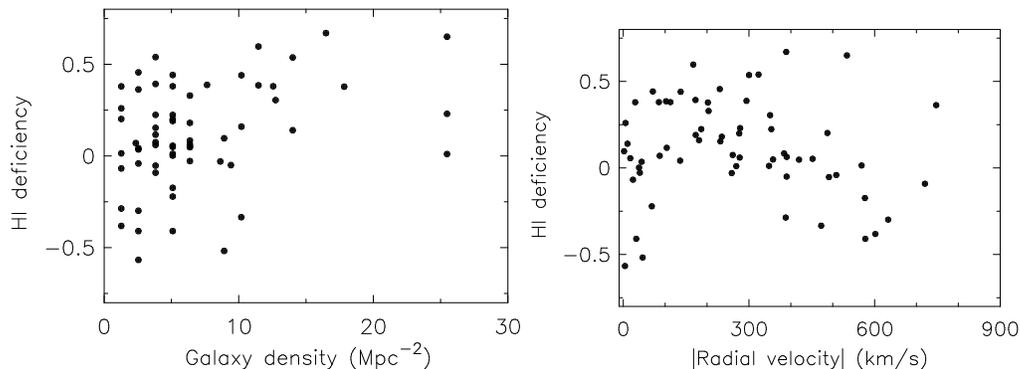
Figure 3. (left): H I deficiency plotted against the projected galaxy density. (right): H I deficiency plotted against the line-of-sight radial velocity.

3. Results

The galaxies in the Eridanus group were observed in the H I 21cm-line with the GMRT (Omar and Dwarakanath 2004a). A collage of the GMRT H I images of the Eridanus galaxies is shown in Fig. 2. The data from the HIPASS (Meyer et al. 2004) were also used. The final sample consisted of a total of 63 H I detected galaxies. The deficiency parameter (cf. Haynes and Giovanelli 1984) estimated using $log(M_{\mathrm{H\,I}}/D_{opt}^2)$ ratio was used to obtain the H I deficiency in the Eridanus galaxies. The ratio $log(M_{\mathrm{H\,I}}/D_{opt}^2)$ for each Eridanus galaxy is compared with the mean value of $log(M_{\mathrm{H\,I}}/D_{opt}^2)$ obtained by Haynes and Giovanelli (1984) for the isolated galaxies of similar types. A significant positive difference in the two ratios indicates the H I deficiency (def. $= <log(M_{\mathrm{H\,I}}/D_{opt}^2)>_{field} - log(M_{\mathrm{H\,I}}/D_{opt}^2)$). The H I deficiency up to a factor of $2-3$ (~ 0.5 in log units in Fig. 3) is seen in the Eridanus galaxies. In Fig. 3, H I deficiency is plotted against the local projected galaxy density and the line-of-sight radial velocities of galaxies in the group. The projected galaxy density is estimated within a circular region of radius 0.5 Mpc. It can be seen that in higher galaxy density (> 10 Mpc^{-2}) regions, majority of galaxies are H I deficient while in lower galaxy density regions both normal and deficient galaxies are present. The H I deficiency appears to be increasing with decreasing line-of-sight radial velocity.

4. Discussion

The ram-pressure in the Eridanus group is one to two orders of magnitude lower compared to that in clusters (Omar and Dwarakanath 2004b). Therefore, ram-pressure stripping is of little importance in the Eridanus galaxies. The trends in Fig. 3 are suggestive of the H I deficiency being due to tidal interactions. Since galaxies in higher galaxy density regions will have higher probability of tidal encounters, it explains the increasing

NGC_1359 (SBcm)
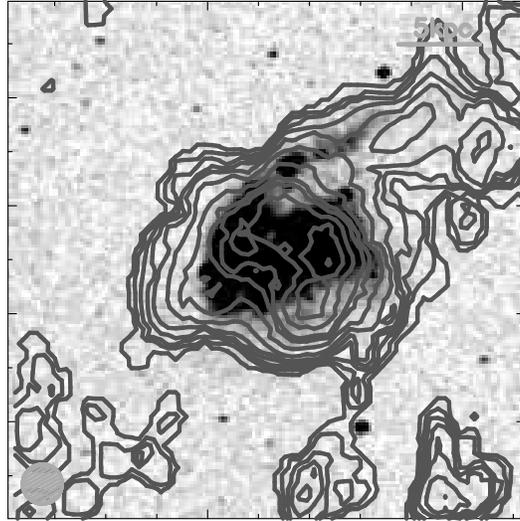
Figure 4. GMRT H I contour image overlaid upon the optical DSS image of NGC 1359 which shows both gaseous and optical tidal features. The contours start at $N_{HI} = 10^{20}$ cm^{-2}.

trend of deficiency with increasing galaxy density. The inverse correlation between the deficiency and the radial velocity can be qualitatively understood under the framework of tidal interactions. The perturbation due to tidal interactions will be maximum for slow encounters. In the Eridanus group where the distribution of galaxies is peaked near the mean velocity of the group (Omar 2004) 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 a lower velocity difference. Both gas and stars will be removed from galaxies as a result of tidal forces. It was noticed that galaxies with larger optical diameters are predominantly in the lower galaxy density regions (Omar and Dwarakanath 2004b). The Eridanus galaxies often show signatures of tidal interactions, e.g., shrunken H I disks, warps, asymmetric H I disk, H I rings, tidal tails, extraplanar gas and kinematical lopsidedness. The GMRT H I image of one such galaxy having both the gaseous and the optical tidal tail is shown in Fig. 4. More images can be found in Omar and Dwarakanath (2004b).

If clusters are built via mergers of small groups, the H I deficiency in the Eridanus group indicates that not all H I deficiency in cluster galaxies originates in the cluster environment. Alternatively, a significant fraction of the H I deficiency in cluster galaxies could have originated in the group environment. The implications are discussed in detail in Omar and Dwarakanath (2004b).

Acknowledgments

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