Chapter 1

MOTIVATIONS

Preface

In this introductory chapter, I will discuss the scientific aims and relevance of the work to the field. Either it be the Hubble's tuning fork diagram or the density-morphology relation, the aim is to know do galaxies evolve with time, if yes, then how ? May the Tully-Fisher relation appears simpler in concept, theories of galaxy formation are finding it difficult. How the far infrared emission is so tightly correlated with the radio synchrotron emission from galaxies. This thesis puts forward its own propositions about how that could be happening or it just leaves the observations for others to make any sense out of it, if they find it worth.

The emphasis is to understand processes of galaxy evolution in groups of galaxies. It is believed that galaxies form in groups where bulk of the baryonic mass of the Universe is seen. The rich clusters of galaxies are formed via mergers of small groups. If this hierarchical picture of structure formation is correct, groups of galaxies should be ideal laboratories to understand basic processes of galaxy formation, and subsequently evolution of galaxies as structures continue to evolve. The environments in groups are far simpler compared to that in clusters. By studying galaxies in groups, one invariably also looks at properties of the majority of galaxies in the Universe. We have selected a large concentration of $\sim$ 200 galaxies in a region of $\sim$ 10 Mpc, where galaxies are believed to be in early stages of evolution. The aim is to identify processes which can affect the gaseous properties of galaxies in the early stages of the evolutionary sequence of galaxies. Studies are also carried out using the two most tight correlations in the astronomy; (i) the Tully-Fisher relation which relates the rotational velocities (hence dynamics) with the visible matter in galaxies traced by stars and gas, (ii) the radio-far infrared correlation which traces its origin in massive young stellar population in the star forming galaxies.

It is proposed to study the Eridanus group of galaxies in the H I 21cm-line* using the *Giant Meterwave Radio Telescope* (GMRT). This thesis is also using optical observations from the Aryabhatta Research Institute of Observational Sciences (formerly State Observatory), Nainital, and archived data in X-ray from the *Roentgen Satellite* (ROSAT), near-infrared data from the *Two Micron All Sky Survey* (2MASS), far-infrared data from the *Infra-Red All sky Survey* (IRAS), and radio continuum data from the *Northern VLA Sky Survey* (NVSS). The work presented in the thesis is related to the following fields:

- H I content of galaxies in groups.
- Tully-Fisher relations.
- Radio continuum emission from galaxies.

1.1 Galaxies in different environments : nature vs nurture

It was first noticed by Curtis (1918) who studied "spiral nebulae" in the Coma cluster that many of these nebula are featureless and not so diffuse as to be classified as "spiral nebulae" seen elsewhere. Later, Hubble & Humason (1931) also recognized the difference between field and cluster spirals, and subsequently, Dressler (1980) conjectured this difference as due to a basic correlation between the galaxy morphology and the local galaxy density. This basic correlation, known as the density-morphology relation observes that the fraction of lenticulars (S0's) or "featureless nebulae" of Curtis (1918) increases with increasing local projected galaxy density. The density-morphology relation (Fig 1.1) is seen to be valid over a range of galaxy densities spanning five orders of magnitude (Postman & Geller 1984). Whether the density-morphology relation is a natural process of galaxy formation (*nature*), or, is due to evolutionary effects driven by the environment (*nurture*) is still

*The hyperfine transition (spin-flip) in the ground state of the Hydrogen atom emits a spectral line at the radio frequency of $\sim$ 1420.4057 MHz ($\lambda \sim$ 21.12 cm). This spectral line was first predicted by H.C. van de Hulst in 1945, and detected from the interstellar space in 1951 independently by Ewen & Purcell, and Muller & Oort. The first extra-galactic objects detected in H I were the two Magellanic clouds by Kerr, Hindman, & Robinson in 1954 using the 36-ft. paraboloid at Potts hill near Sydney.

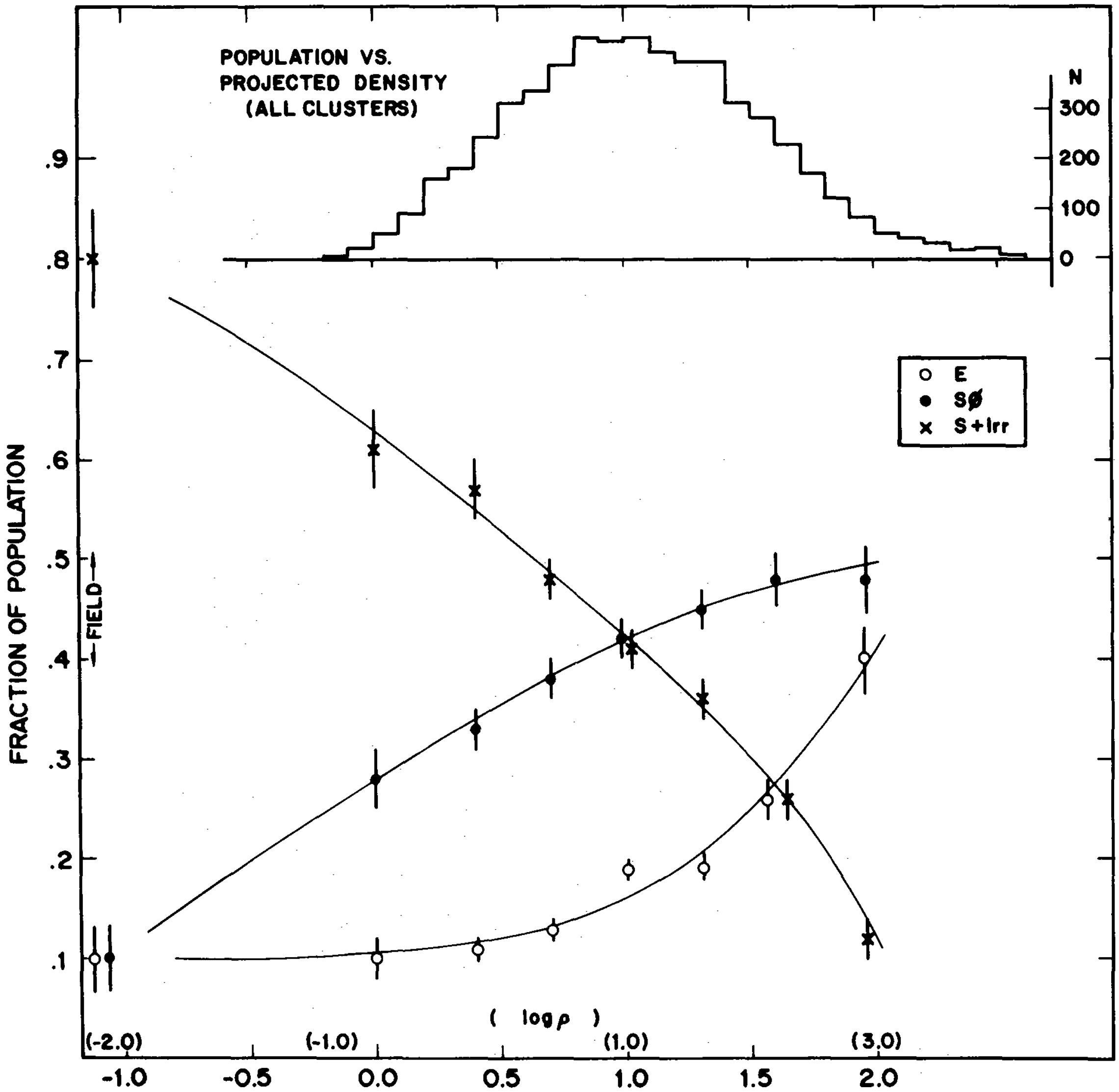

Figure 1.1: The density-morphology relation seen over projected galaxy densities spanning five orders of magnitude. The high galaxy density regions are dominated by gas-poor S0 galaxies. The actual physical processes responsible for this relation are not yet completely understood. [Reproduced from Dressler (1980)]

a matter of debate. There are reasons to believe that S0's are formed out of some evolutionary processes. Studies on intermediate redshift clusters indicate evolution of both morphological mix and the star formation rate with the redshift (Poggianti et al. 1999, Dressler et al. 1997, Fasano et al. 2000). These observations indicate that while the fraction of ellipticals remains more or less the same as a function of the redshift, the fraction of S0's decreases, and the spiral fraction increases with increasing redshift.

Depending upon the local environment, there are several mechanisms which can affect the evolution of galaxies. The galaxies moving in the intra cluster medium (ICM) can experience ram-pressure due to ICM (Gunn & Gott 1972). In the cluster environments where the ICM density is high ($\sim 10^{-3}$ cm $^{-3}$) and the velocity dispersion of galaxies is large ($\sim$ 1000 km s^{-1}), ram-pressure can strip gas from galaxies. The swept up spirals might then evolve passively and may appear like S0's. The gas can also be lost due to transport processes like thermal conduction, and viscous and turbulent stripping. The hot (10^8 K) ICM can cause the evaporation of gas from galaxies via thermal conduction (Cowie & Songaila 1977). The gas can also be stripped from galaxies due to viscous forces and turbulence created as galaxies move in the hot ICM (Nulsen 1982). The galaxies can also interact with each other, and dramatically affect the galaxy morphology. Spitzer and Baade (1951) proposed that

S0's can be produced due to galaxy collisions. Recently, the repetitive encounters between galaxies in high galaxy density regions, a process termed as "galaxy harassment" has been proposed for the morphological transformation of spirals to S0's (Moore et. al. 1998).

Cluster spirals are observed to have $3-10$ times less H I mass than their counterparts in the field. The first evidence for the H I deficiency in cluster spirals came from the observations of Davies & Lewis (1973) in the Virgo cluster. 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 (Fig. 1.2). They also noticed that only X-ray detected clusters are H I deficient. 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 deficiency can be understood by ram-pressure stripping or thermal conduction and viscous stripping processes. All observations agree that H I deficiency varies as a function of projected distance from the cluster centre. Often, these results are interpreted as due to ram-pressure stripping or transport processes. But, several observations are at odds with this interpretation. The ram-pressure stripping, though simpler in concept, also requires a strong correlation to be there between H I deficiency and relative radial velocities of galaxies. It is also expected that smaller size or less massive galaxies should be more easily affected than larger size or more massive galaxies. Though the rate of mass loss due to transport processes will not depend on the size of galaxies, however, will be highly dependent on the geometry of magnetic fields in galaxies as both thermal conductivity and viscosity have a strong dependence on the geometry of the magnetic fields (Spitzer 1978). The simulations of ram-pressure stripping in galaxies (e.g., Vollmer 2001) show that appreciable H I deficiency can only be produced for galaxies in radial orbits moving almost face-on, and, only after a galaxy has crossed the high ICM density regions in the core. Although, statistically H I deficient galaxies tend to be in radial orbits (Dressler 1986), it is not obvious that all H I deficient galaxies have crossed the cluster core. 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 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 ICM temperature and H I deficiency as would have been expected (as deficiency $\propto \mathrm{T}^{2.5}$) if thermal conduction and viscous and turbulent stripping were effective in removing gas. They also argued that the observed metallicity (~ 0.3 solar) in the ICM which is generally believed due to gas loss from galaxies via ram-pressure stripping can also be due to strong solar winds during intense star-bursts in the early epochs of galaxy formation. Contrary to what is expected from ram-pressure stripping, H I deficiency in dwarfs and less massive spirals is not too different from massive spirals (Hoffman et al. 1988). Valluri & Jog (1991) also 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 small size galaxies in terms of both fractional number and amount of gas lost. This behavior is contradictory to that expected from ram-pressure stripping or transport processes, but, consistent with that expected if tidal interactions were responsible for the gas deficiency.

It appears that there is no single accepted mechanism for the gas deficiency or for the density-morphology relation. At the same time, present data on clusters do not allow one to make a distinction between evolutionary effects caused due to different mechanisms like ram-pressure stripping or transport processes, and tidal interactions. The tidal interactions between galaxies are generally thought to be insignificant in removing gas from galaxies in clusters as large relative velocity of encounters between galaxies is ineffective in perturbing gaseous and stellar disks. Simulations of interacting galaxies predict that the tidal perturbing effects are maximum when the relative encounter velocities are of the order of the rotation velocities in the disks, and the interaction is retrograde (e.g., Toomre & Toomre 1977). Therefore, in groups of galaxies, where the velocity dispersion is of the order of rotation velocities in the disks, interactions can be a viable mechanism to remove gas. The morphological transformation of spirals to S0's can also take place via tidal processes as proposed by Spitzer & Baade (1951), and Moore et al. (1998). Observationally, evolution of galaxies in a group environment remains largely unexplored. The low X-ray luminosities, low temperatures, low intra group medium (IGM) densities, and low velocity dispersions in groups make ram-pressure and transport mechanisms ineffective. Therefore, groups are ideal laboratories to explore the role of processes other than ram-pressure and transport mechanisms in the evolution of galaxies. The

†The Abell radius is defined as $1'.7/z$, where z is the redshift of the cluster.

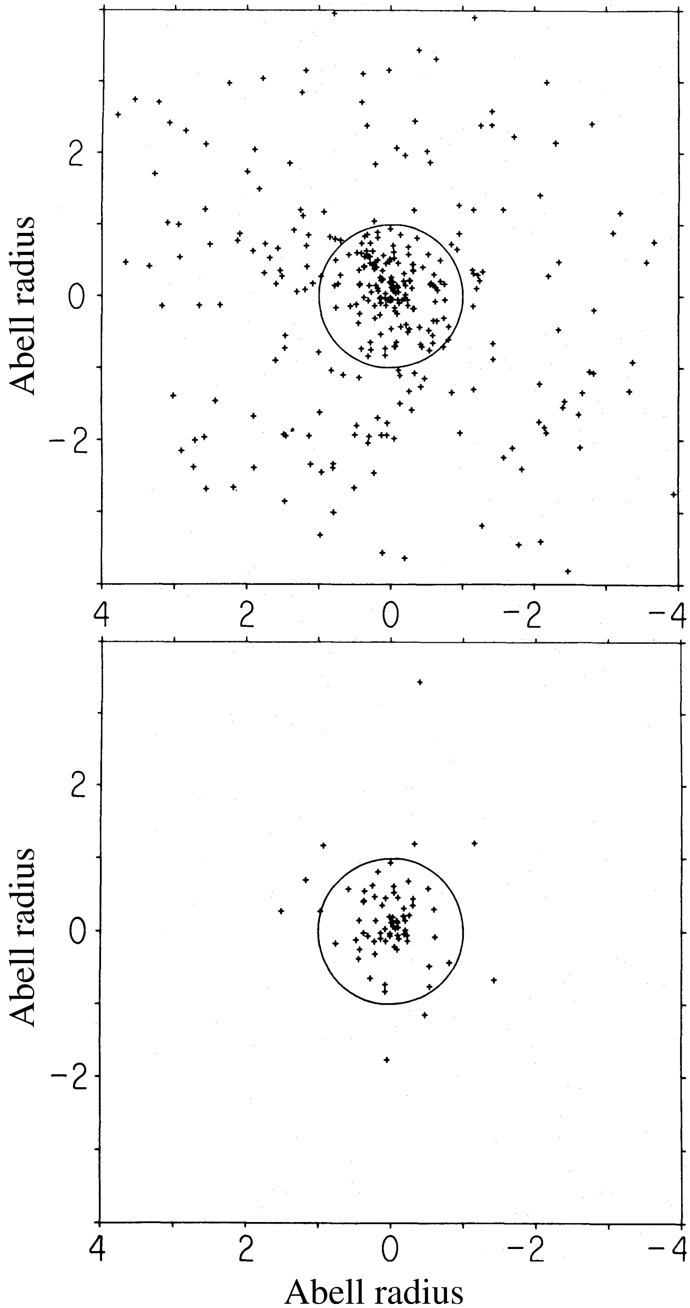

Figure 1.2: Locations of H I deficient galaxies in clusters. The upper panel shows projected locations of all galaxies in the nine clusters. The lower panel shows projected locations of galaxies which are H I deficient by more than ~ 3 times than their counterparts in the fields. The galaxies within one Abell radius (plotted as circle) from the cluster centre are severely H I deficient. The central region has both high density of galaxies and intra-cluster medium. Various physical mechanisms like ram-pressure stripping, transport processes, and tidal interactions may be responsible for the deficiency. [Reproduced from Giovanelli & Haynes (1985)]

observations of Geller & Beers (1982) that sub-clustering is a common phenomena in rich clusters indicate that clusters could have formed as mergers of small groups. In view of this hierarchy, it becomes even more important to understand the galaxy evolution in groups. Once a cluster is formed, it will be impossible to discern the pre-merger evolution of galaxies with the ongoing evolution in the cluster. Some observations indirectly indicate that at least in some groups, gaseous content of galaxies has been affected. For instance, X-ray observations in groups indicate that metallicity varies significantly from 0.1 to 0.6 solar (Mulchaey 2000) between various groups. Buote (2000) derived an average metallicity of 0.3 solar in a set of groups. Since metals are produced only in stars, metal enriched medium in groups indicate that significant gas has already been ejected from galaxies in to the IGM. Williams & Rood (1987), Huchtmeier (1997), and recently Verdes-Montenegro et al. (2001) have reported global H I deficiency in Hickson Compact Groups (HCG's). In a sample of 72 HCGs, Verdes-Montenegro et al. (2001) estimated that the average H I content is only 40% of that expected for their optical luminosities and morphological types of galaxies. The H I content in large groups are largely unknown.

At this point, several questions can be asked. What is the origin of the density-morphology relation ? How are gas deficiency and density morphology relation related ? Which is the main mechanism for the observed H I deficiency in clusters ? Are galaxies significantly H I deficient before clusters form as mergers of groups ? These are some of the curiosities behind the motivation for the work presented in this thesis. We selected the Eridanus group of galaxies for a detailed H I study. The Eridanus group was first studied by Willmer et al. (1989) using the data from the southern galactic cap survey (SGC; Pellegrini et al. 1990) for its dynamical properties. The concentration of galaxies in the Eridanus region is known since Baker (1933) and de Vaucouleurs (1975). With the increased number of redshifts available in the Eridanus region, we have re-defined the boundaries of the group using the data provided by NASA Extra-Galactic Database (NED). We have also carried out a study of the group for its substructures, morphological mix, and X-ray emission. The next chapter describes all these properties in detail. Here, we briefly discuss the main properties of the group which makes this group suitable for studies proposed in this thesis:

1) Eridanus has significant sub-structures and is made of different subgroups (Willmer 1989). The local galaxy density varies from a few to $\sim$ 30 Mpc^{-2}. The total number of galaxies in the group is $\sim$ 200, distributed over a region extending $\sim$ 10 Mpc.

2) The population mix of galaxies in different subgroups varies significantly. One of the subgroups, NGC 1407, has a morphological mix typical of rich clusters with 70% (E+S0) and 30% (Sp+Irr). The overall population mix of the Eridanus group is 30 % (E+S0) and 70% (Sp+Irr).

3) The low X-ray luminosity ($\sim 10^{41}$erg s^{-1}) and low velocity dispersion ($\sim$ 240 km s^{-1}) of the Eridanus group make processes like ram-pressure ineffective. The low temperatures in groups ($\sim 10^7$ K; Mulchaey 2000) make transport processes also ineffective in removing gas from galaxies. Hence, a large number of S0's in the Eridanus group is a mystery.

4) The dynamical studies indicate that the Eridanus group is in its early evolutionary stages and may evolve into a cluster via mergers of several sub-groups (Willmer et al. 1989).

1.2 Tully-Fisher relations

The luminosity-linewidth or Tully-Fisher (TF) relation is an empirical relationship of the form $L \propto V_{rot}^{\alpha}$ between the optical luminosity (L) and the H I linewidth (twice the rotation velocity, V_{rot}) in spiral galaxies noted by a number of investigators (Rogstad & Shostak 1972, Balkowski et al. 1974, Shostak 1975, Tully & Fisher 1977). The index α varies from $\sim$ 3 for the B-band luminosities to $\sim$ 4 for the K-band luminosities (e.g., Verheijen 2001, Tully et al. 1998). It was known since Roberts (1969) that the intrinsic luminosity of a galaxy is correlated with the total mass derived from the H I linewidth. The application of the TF relation to measure distances of spiral galaxies was first demonstrated by Tully & Fisher (1977), and henceafter was called as Tully-Fisher relation. The underlying reason behind the TF relation seems to be a correlation between the total baryonic mass and the rotation velocity of the disk (e.g., Persic & Salluci 1988, McGaugh et al. 2000, Bell & de Jong 2001). McGaugh et al. (2000) observed that low surface brightness and gas rich dwarfs galaxies have higher rotation velocities for their optical luminosities in the luminosity–linewidth relation. However, if the total baryonic mass is plotted against the rotation velocity, all galaxies follow a single TF relation of the form $Mass_{baryonic} \propto V_{rot}^{\alpha}$ with $\alpha \sim 4$. This mass–linewidth relationship is termed as baryonic TF relation. The total stellar mass can be traced by the stellar luminosity depending upon

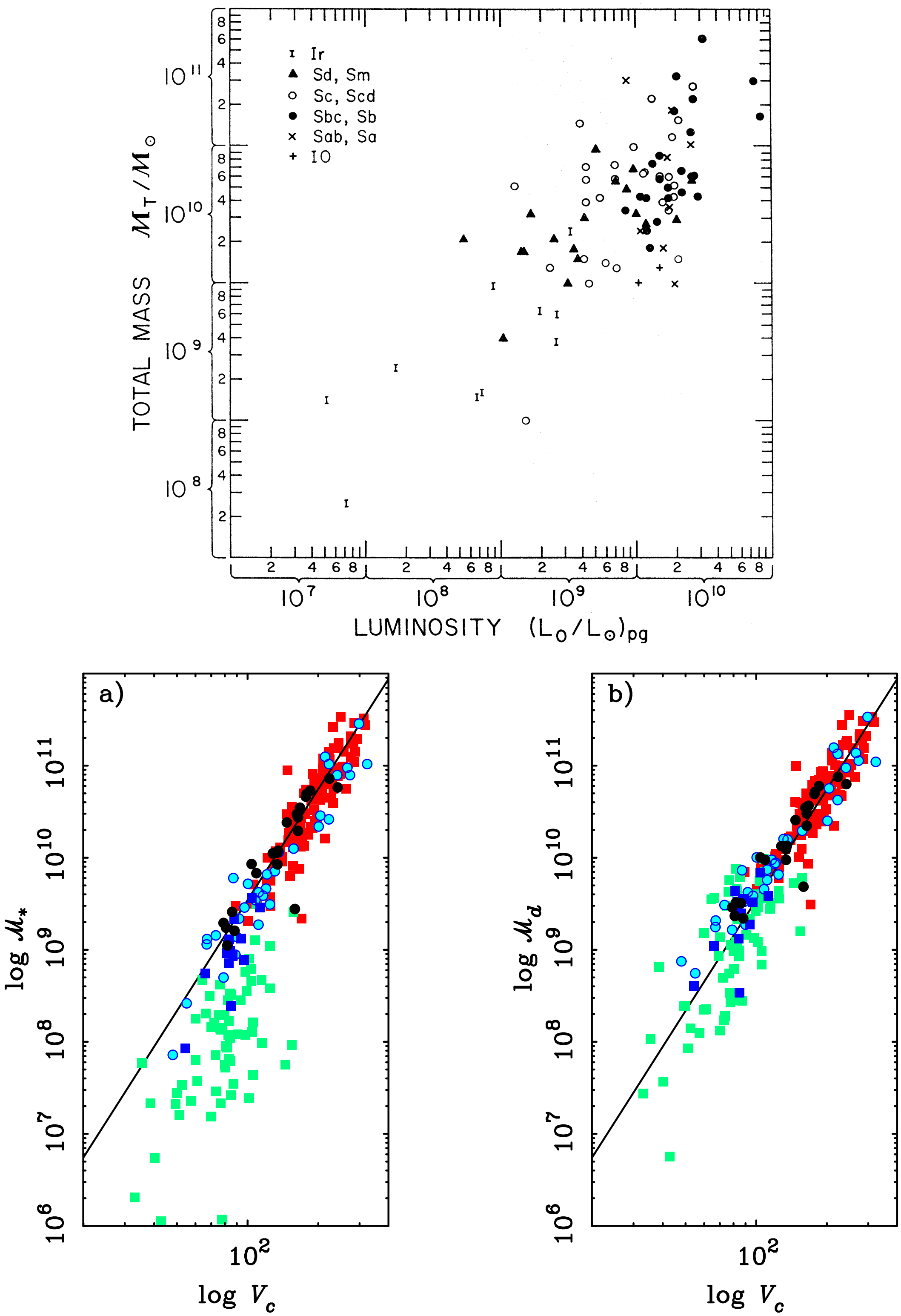

Figure 1.3: (Top panel). The relation between total mass derived from the H I line-width and luminosities of galaxies reported by Roberts (1969). This and other similar relations reported by others (see text) formed the basis of the Tully-Fisher relation (Tully & Fisher 1977) [Reproduced from Roberts (1969)]. (Bottom panels). The relation between total baryonic mass and rotation velocity of galaxies reported by McGaugh et al. (2000). The left panel shows the baryonic TF relation with stellar mass only, while, that on the right panel includes gas mass also. [Reproduced from McGaugh et al. (2000)]

star formation history, and initial mass function (e.g., Bell & de Jong 2001). The rotation velocities of galaxies are observed to be flat in the outer regions, which is generally attributed to a presence of massive dark matter halos in galaxies. Since the TF relation relates the baryonic mass and the rotation velocity, it also implies a correlation between the potential of the dark matter halo and total baryonic mass embedded in it. This property of the TF relation makes it fundamentally important for theories of galaxy formation. The dark matter models of galaxy formation predict the basic TF relation in the form $m_{baryon} \propto V_{rot}^{\alpha}$, where the index α is 3 for non-baryonic dark matter (e.g., van den Bosch 2000, Navarro & Steinmetz 2000), and ~ 3.5 for a collisional baryonic dark matter (Walker 1999). Observationally, the slope is found to be in the range $3.5 - 4$ with an uncertainty of 0.4 (Bell & de Jong 2001, McGaugh et al. 2000). The precise determination of the index α is hindered by several uncertainties in the observations, and in understanding of the disk kinematics. The molecular masses of galaxies are largely unknown, which could be a significant fraction of the total baryonic mass. It is also believed that galaxies are partly supported by random motions in stars and gas, resulting into a net pressure. The magnitude of support from this pressure becomes significant for those galaxies where rotational velocities are comparable to the random velocities. With all these uncertainties, and a lack of high resolution simulations of the galaxy formation and the galaxy evolution do not allow us to obtain the conclusions for the origin of the Tully-Fisher relation. The scatter in the TF relation is also an important parameter for theories of galaxy formation. Verheijen (2001) obtained very low scatter ($\sim$ 0.21 mag) in the TF relation for galaxies having flat rotation curves. This scatter is within the observational uncertainties and leaves no scope for any intrinsic scatter in the TF relation.

The H I synthesis imaging data on galaxies also provide velocity fields of galaxies. The rotation curves of galaxies can be constructed using the velocity field. Usually, H I is the farthest reachable tracer of the galactic disks, implying that reliable estimates of the flat rotation velocities of galaxies can be obtained using the H I images of galaxies. The scatter in the TF relation arises from several sources of uncertainties, e.g, dust-extinction correction, de-projected rotation velocities, and distances of galaxies. The dust extinction in galaxies is minimal at near-infrared wavelengths. The availability of near-infrared (J, H, and K band) images from the *Two Micron All Sky Survey* (2MASS) makes it possible to make TF relations in the near-infrared bands. Also, most of the stellar mass in galaxies is locked up in old stellar population which emits mostly in the near-infrared bands. Therefore, near-infrared luminosities are the best tracer of the galactic potential due to stars. The distance uncertainties can be minimized if galaxies are selected from a group or a cluster.

It is proposed to study TF relations in the Eridanus group using the H I rotation curves, optical R-band luminosities from the observations carried out with the State Observatory, Nainital, archived near-infrared data from the 2MASS (Jarret 2000), and B-band luminosities from the ESO-LV survey of galaxies (Lauberts & Valentijn 1989). The main aim is to study slope and scatter in the *classical* luminosity–linewidth TF relation, and in the baryonic TF relation.

1.3 Radio continuum emission from galaxies

The radio continuum emission in galaxies could be arising due to two physical mechanisms - 1) synchrotron (non thermal), and 2) bremsstrahlung (thermal). The relativistic diffuse electrons spiraling along directions of the magnetic fields in galaxies produce the synchrotron emission. These electrons are accelerated to relativistic speeds during supernova events. Some galaxies can also be powerful sources of synchrotron emission apart from those related to the supernova events. These galaxies, known as Active Galactic Nuclei (AGNs), have synchrotron emission from matter surrounding the central black hole, and relativistic jets of particles ejected from the central black hole. Thermal emission from galaxies comes from ionized plasma surrounding star forming regions. The radio luminosities of normal galaxies is dominated by the synchrotron emission due to diffuse electrons which have their origin in supernova explosions of massive stars ($M > 8\ M_{\odot}$). Massive stars undergoing supernova events are also strong sources of ultra-violet radiation which heats the galactic dust to the temperatures of 20–50 K. The dust in turn re-radiate at wavelengths in the range 20–200 μm in the far-infrared. There exists a tight correlation between far-infrared luminosities and radio luminosities of galaxies (Harwit & Pacini 1975, Condon et al. 1991). This correlation, known as the radio-FIR correlation, is observed over more than four orders of magnitude in FIR luminosities with a nearly unit slope (Yun et al. 2001). The theoretical understanding of the radio-FIR correlation and its tightness is still imperfect. In one scenario, since both far infrared emission and radio continuum emission traces their origin in massive stars, a correlation between the two luminosities is expected. However, to obtain a tight radio-FIR correlation, one has to make certain assumptions about escape rates of UV photons and diffuse electrons from galaxies, absorption of UV photons by dust, heating and cooling rates of dust in galaxies, and ages of relativistic electrons. All these parameters have to be interlinked in such a way so that the radio-FIR correlation is observed in most of the galaxies. Due to the tightness of the radio-FIR correlation, any un-correlated component of radio emission or FIR emission can be traced. For instance, at low end of the observed FIR luminosities ($L_{60\mu m} < 10^9$ $L_\odot$) in galaxies, FIR emission is detected in excess from that expected for their radio luminosities. This additional FIR emission is believed due to UV photons from old population of stars in galaxies (Condon 1992). At higher FIR luminosities, UV photons from old stellar population are only a minor fraction as compared to those from young massive stars. Radio continuum emission from AGNs will appear as an excess radio emission in galaxies. The radio-FIR correlation has been used to identify both powerful AGNs (Condon et al. 1989, Yun et al. 2001), and weak AGNs (Roy et al. 1999) in far-infrared selected galaxies. In fact, strong star-bursts which can have radio luminosities comparable to some of the powerful AGNs can be identified based on the radio-FIR correlation. Since the far-infrared emission traces its origin in massive stars, it can be used to infer star formation rates in galaxies (Kennicutt et al. 1998). Using the radio-FIR correlation, radio luminosities can also be calibrated to obtain star formation rates in galaxies.

The radio continuum images can be obtained from the H I data. Since the H I observations were carried out over a sufficiently large bandwidth to obtain a baseline for identifying spectral line emission, the channels free from H I emission can be used to make the continuum images. The GMRT data will be sensitive to detect diffuse radio continuum emission, and also, capable of obtaining high resolution images on scales of $\sim$ 0.5 kpc for the galaxies in the Eridanus group. For the present work, far-infrared data from the *Infrared Astronomical Satellite (IRAS)* and 20cm radio continuum data from *Northern VLA Sky Survey (NVSS)* is used to construct the radio-FIR correlation in the Eridanus group of galaxies. The *NVSS* data is sensitive to detect diffuse emission from galaxies, but, the angular resolution ($\sim 45''$) is not enough to obtain details of the emission in most cases. For galaxies having excess radio continuum emission, high resolution images as those obtained from the GMRT are required to separate galactic diffuse radio emission from any AGN related radio emission. The high resolution (kpc scale) images can also be interesting for other reasons. For instance, radio continuum emission is expected to trace spiral arms where new stars are formed, and also magnetic field get compressed due to spiral density waves. Most of the normal galaxies (e.g., Milky-Way) also have weak nuclear radio continuum emission which could be due to a quiescent radio activity around the central black hole. The high resolution images can be used to detect such emission from normal galaxies.

1.4 Layout of the thesis

The work presented in this thesis can be related to the following broad areas:

- H I content of groups of galaxies.
- Evolution of galaxies in a group environment.
- H I morphological studies of galaxies.
- The classical luminosity-linewidth and baryonic Tully-Fisher relations.
- Tully-Fisher relations in groups of galaxies.
- High resolution radio continuum morphologies of galaxies.
- Radio-FIR correlation.

Astronomical data are obtained from various sources. The main data are H I 21cm-line data obtained from the GMRT observations carried out by me. I also carried out R-band optical observations using the 1-m reflector at the State Observatory, Nainital. The archived data in different wavelengths are used. Optical B-band data are from the ESO-LV survey of galaxies, near-infrared (J, H, and K band) data are from the *2MASS*, far-infrared data are from the *IRAS*, and 20cm low resolution radio continuum data are from the *NVSS*. Extensive use of large astronomical data-base is made from the NASA Extra-galactic Database (NED). Use of the bibliographical services is made from the Astronphysics Data Services (ADS) provided by NASA.

Various astronomical softwares are used for data processing and visualization. The Astronomical Image Processing System (AIPS) developed by National Radio Astronomical Observatory (NRAO), Image Reduction and Analysis Facility (IRAF) developed by National Optical Astronomical Observatory (NOAO), and Groningen Image Processing SYstem (GIPSY) developed by Rijksuniversiteit Groningen were the main tools in analysing the data and images.

The thesis is divided in to seven chapters including the present one. The Eridanus group and its properties are discussed in the next chapter. Details of the GMRT observations and data analyses are given in chapter 3. An atlas of H I images in various form is presented at the end of chapter 3. The optical data analyses and images are presented in chapter 4. The results are described in subsequent chapters. Chapter 5 discusses H I content and the H I morphological properties of galaxies in the Eridanus group. In this chapter, conclusions are made about evolution of galaxies in a group environment and its implications for evolution of galaxies in a hierarchical universe. The Tully-Fisher relations are discussed in Chapter 6, and radio continuum properties of galaxies in the Eridanus group are presented in chapter 7. Each chapter has an abstract and short introduction at the beginning. The chapters are concluded with a short summary or main results.

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