Acknowledgements

I would like to convey my thanks to Prof. Steve Phillipps for his advice and time which were greatly received throughout the project. Also thanks to Aaron Robotham for allowing the use of his Schechter function program which saved many hours of toil and hardship. Finally I would like to thank my project partner Will putting up with me for all these years.

Abstract

Utilising data obtained from the 2dFGRS and the SDSS astronomical surveys a group galaxy catalogue, consisting of 3577 members, of a filament in the Pisces-Cetus Super cluster was constructed. From the catalogue, the evolution and morphology of the component galaxies in the less dense and dense regions of the filament in the super cluster were investigated. It was found, through the plotting of colour histograms, that the groups within the catalogue displayed strong bimodality, it was then deduced that the less dense regions of the filament consisted of mainly late-type Spiral galaxies where the more dense regions consisted of mainly early-type Elliptical galaxies. Also, through plotting of luminosity functions, with the magnitude range of $-24<M<-17$, in two different styles, one with group division by environment a group occupies and the other by group colour independent of environment. For each of the luminosity functions, values for the characteristic magnitude (M^*) and the steepness of slope at the faint end (α) were found for the different groups with varying degrees of accuracy.

1.0 Introduction

The aim of this project is to observe, using data from two astronomical databases that is the Two-Degree Field Galaxy Redshift Survey (see section 2.1.1) and the Sloan Digital Sky Survey (see section 2.1.2), the differing behaviour and evolution of different regions within a filament in the Pisces-Cetus Super cluster (here on referred to as PCS). Within the PCS filament itself, there exist two distinct regions of galactic population, that is areas of higher density (here on known as dense groups) and areas of lower density (here on known as filamentary regions). Since the structure in the dense regions will be different to the structure to the filamentary regions the evolution of the galaxies in the two regions will be different.

This report adopts the following convention for naming groups and galaxies; in reference to colours, “a blue filamentary group (region or galaxy)” refers to a group (region or galaxy) in the less dense region of the PCS filament and a “blue dense group (region or galaxy) refers to a group (region or galaxy) in the more dense region of the PCS filament, the same convention is adopted for the red colours. Finally when the report references to a “filament(s) in the PCS” it refers to the filament this report is investigating and not the less dense regions within it.

1.1 Overview

As has been said above; the purpose of this project is to observe the varying structure and evolution of different areas within a filament of the PCS (not the whole of the PCS will be observed only specific areas). The component galaxies of the PCS will be split into groups. Each of the groups will then be classified as either a filamentary or dense group. Then these groups will then comprise a galaxy catalogue, which will be made specifically for this investigation, on which the analysis will be carried out. The catalogue will be created, analysed, trimmed and manipulated using a platform independent program called TOPCAT (created by Dr Mark Taylor University of Bristol). The source data will be collected from two surveys so as to be able to compare and contrast the results from two different parts of the PCS and make to it easier to see trends in the data.

The groups will then be plotted on a histogram which will show the distribution of the various colours of galaxies. From this the dominant morphological galaxy type for each group will be able to be determined, then from this, the dominant morphological type for a region (dense or filamentary) will be determined and finally the “cut off” value for each region type may be calculated. Finally, the data will be collated and input into a program which will, via the calculation of a luminosity function, generate a Schechter function from which the characteristic magnitude, the number density per unit volume of each magnitude of galaxy and finally the steepness of slope for the function at the faint end.

Once the project has been completed, it will be able to give an accurate description of the galaxy type and populations within the various regions of the PCS including the level of bimodality. It will also be able to confirm or contradict the commonly held theory that the dense regions are mainly populated by Population II (early type) stars and the filamentary regions being filled with Population I (late type) stars. Finally, a hypothesis about the evolution of galaxies within the different regions may be arrived at. This will be especially interesting since most of the work carried out in recent years has been observing the dwarf to giant ratio with the colour and morphological type being a secondary investigation.

2.0 *Background To Project*

2.1 Astronomical Databases

2.1.1 Two-Degree Field Galaxy Redshift Survey (2dFGRS)[1]

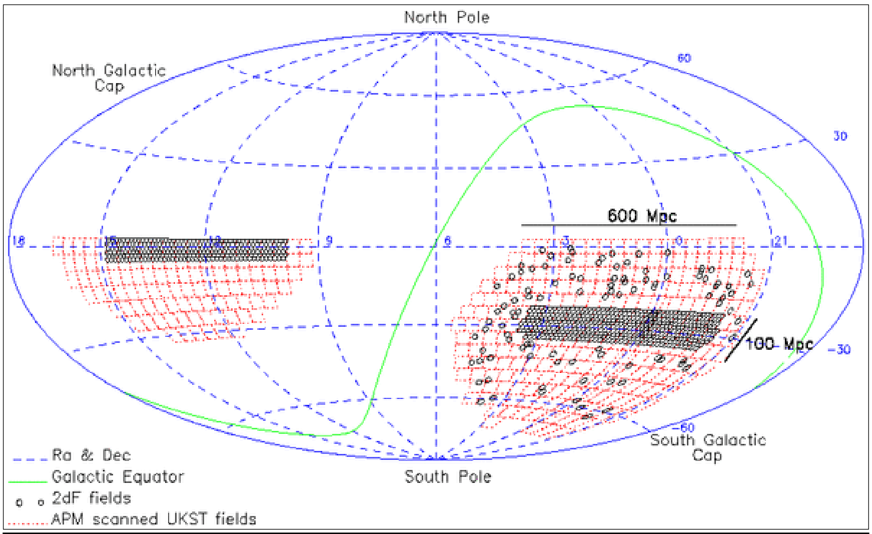


Fig1 – 2dFGRS Arrangement Of Survey Fields

This is a spectroscopic survey utilising the 2dF facility constructed by the Anglo-Australian Telescope (AAT). The survey has obtained the redshifts of 245591 objects, mostly galaxies, across 2000° of sky. The galaxies originated from two regions, a north and a south strip and also a number of random areas outside the strips. The source catalogue for the survey was taken from an earlier survey undertaken by the UK Schmidt telescope in sliding spring in Australia. This survey covers approximately 10000° of sky to a magnitude of b_j=20.5. This gives a catalogue size of in excess of 5 million galaxies; the 2dF survey only covered a fraction of these. The spectra of the galaxies in the 2dF survey are obtained by using optical fibres to take the spectra from the plates used by the original survey. The size of the optical fibres must be smaller than the object which is being measured on the plate, therefore, only a small fraction of closer galaxies will be able to be measured; this is misrepresentative of the whole galaxy. Fortunately, due to the nature of the project, the closer galaxies are excluded from observation.

2.1.2 The Sloan Digital Sky Survey (SDSS)[2]

The SDSS utilises a 2.5 metre telescope on Apache Point in New Mexico. In addition to the main telescope there are two special purpose instruments to complement the observation, these are; a 120-mega-pixel camera which can image approximately 1.5 square degrees of sky at a time and a pair of spectrographs which data is relayed to using optical fibres. The optical fibres can measure the spectra of the galaxies and from this the distances to over 600 galaxies and quasars in one single observation. The data from the survey is released to the public and the general scientific community by a series of annual updates, the most recent of which being data release five.

[1] http://www.mso.anu.edu.au/2dFGRS/
[2] http://www.sdss.org

SDSS completed the first phase of the project in June of 2005. Phase one (SDSS-I) lasted 5 years, it imaged approximately 8000 square degrees of sky, detecting almost 200 million objects and measured ?????. Currently SDSS has entered the second phase of the project which will continue until June 2008. This SDSS-II will address questions about the nature of the universe and the origins of galaxies and the formation and evolution of the Milky Way.

When completed, the SDSS will provide a 3-dimensional detailed optical map of approximately one million galaxies and quasars.

2.2 Morphologies Of Galaxies

To describe the evolution of the galaxies in the different regions within the PCS an understanding of the morphology of galaxies would benefit this investigation. Not all galaxies have the same form or size; hence a classification system is needed. This is the main idea behind Galaxy morphology. Most of the galaxy classification systems are based upon the Hubble Tuning Fork diagram which was first described by Hubble in 1936 (fig2), initially the understanding was that galaxies evolved from Elliptical to Spirals i.e. the evolution is from left to right across the diagram.

2.2.1 Elliptical Galaxies (E0 – E7)

Ellipticals have an ellipsoidal form, with a moderately even distribution of stars throughout the galaxy. The galaxies are classified in the Hubble sequence by the letter E (denoting Elliptical) and then a number. The number is related to the eccentricity of the ellipse, but this is defined by 10times this value; i.e. $n = 10(1-[^b/_a])$ where "b" is the minor and "a" is the major axis of the ellipse. E0 galaxies are circular in appearance and E7 are greatly flattened. The number only denotes how the galaxy appears on the sky and does not reflect the true geometry of the form. Ellipticals contain Population II stars (old stars of low metallicity) with a mass range of 10^5 – 10^{13} Solar Masses and with Luminosities in the range 10^5 – 10^{11} Solar Luminosities, they also have a diameter of between 1 -205kpc. In between spirals and ellipticals is the So galaxy. These are a transitional form linking the two morphological types. They show a defined central bulge as well as disk like form surrounding the bulge.

2.2.2 Spirals and Irregulars

Spirals have a disk like structure with a spherical bulge emanating from the centre of the galaxy; these galaxies usually have high levels of symmetry. The spiral galaxies are sub-divided yet again into normal spirals (S) and barred spirals (SB). The arms around the central bulge are classified by how tightly wound they are, from "a" being very tightly wound and with "c" and "d" being very loosely wound. The Sa & SBa galaxies have tightly wound spiral arms with a more defined central bulge but the Sd and SBd have very loose spiral arms and a less defined central bulge. Spirals contain Population I stars (young stars of high metallicity) in the halo and Population II stars in the disk with a mass range of 10^9 – 10^{11} solar masses and with luminosity range of 10^8 – 10^{11} Solar Luminosities, they have a diameter of between 5 and 250 kpc.

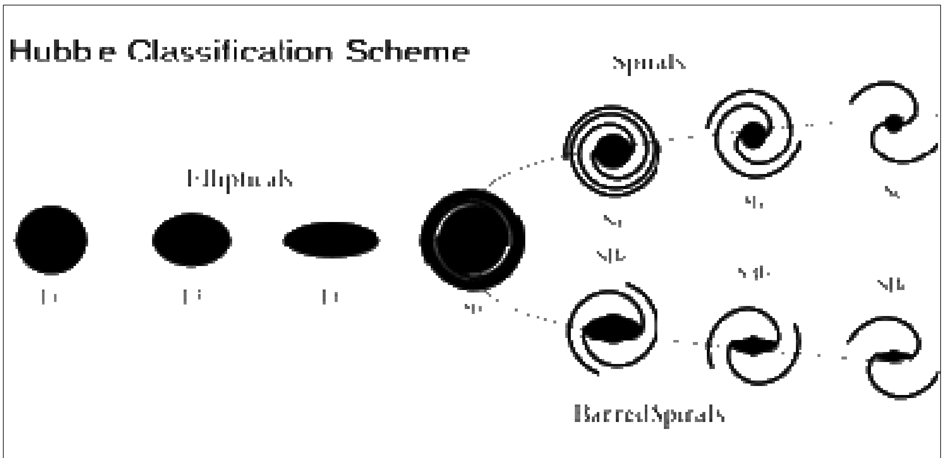


Fig2 – Hubble Tuning Fork Diagram **(Picture Courtesy Of Wikipedia.org)**

Finally, irregular galaxies are galaxies which do not fall into the Hubble classification of galaxies. These galaxies show neither spiral nor elliptical morphology and are often chaotic and irregular in appearance, with neither a central nuclear bulge nor a trace of spiral structure. They are classified of type Irr-I and Irr-II. Irr-I galaxies are galaxies which features some structure but not enough to place it within the Hubble diagram, de Vaucoulers subtypes there into galaxies which have some spiral structure Sm and those which do not, Im. Irr-II type galaxies do not appear to have any structure that would place it in the Hubble diagram.

2.2.3 Evolution Of Galaxies

Hubble originally based his classification system upon photographs of the galaxies he observed. It was believed that the classification showed the evolution of the galaxies from Elliptical to Spiral forms, that is from left to right on the diagram. Through modern observation and analytical techniques this now appears to be untrue. The current understanding of the evolution process is that the original hypothesis is opposite to the truth. Since the mass variance in Elliptical galaxies is so large and the mass range in Spirals is so small, it is implied that for an Elliptical to evolve into a Spiral, it would have to gain or lose mass.

Today's belief is that the different morphological types arise from different conditions during formation, with the morphological type created being dependant on the angular momentum of the source gas cloud. If the gas cloud has low angular momentum then it will collapse into a round galaxy i.e. Elliptical while a gas cloud of high angular momentum will collapse into a flat spiral galaxy.

Though it is known that the evolution does not follow the Hubble diagram, this early belief has left its impression with the Ellipticals being referred to as early type galaxies and Spirals being referred to as late type galaxies. The early-type galaxies tend to populate the denser regions of space with the late-type galaxies tending to populate the field. Also, the morphology of the galaxy has strong correlations with the observed colour. Elliptical, early-type galaxies are red where Spiral, late-type galaxies are blue. The variation in colour is due to the variation in the metallicity of the component stars within the galaxy, population I stars tend to be of high metallicity where population II are of lower.

2.3 Structured Query Language (SQL)

Both the 2dFGRS and SDSS databases are accessible online via their website (see references). This interface is powered by a query interface, so knowledge of SQL is required. SQL is the most popular language used to create, retrieve, update and delete files and records from a relational database management system. SQL is a relatively easy language to learn since the syntax is pseudo code like, with the main commands being intuitive. The only counter-intuitive commands are where one must use the examples given on the websites. Examples of syntax for the queries can been seen in Appendix A.

2.4 Previous Works

2.4.1 Bimodality

Previous work, by Cole et al 2005, carried out a power spectrum analysis of thee 2dFGRS survey also investigated the bimodality in the 2dFGRS data set. By observing a histograms of rest frame colours the distribution exhibited the bimodal distribution for the galaxies (Strateva et al 2001), giving a cut-off value of 1.07. This is due the nature of the population of the galaxies in different densities or space. Cole found that the dominant morphological type varied depending on whether the denser or the filamentary regions were being observed. It was found that the denser regions had a larger average value of b-r hence this showed that these regions of space were mostly populated by early type redder galaxies. Where as the field (or filamentary) regions were populated by mostly bluer galaxies, with a smaller value of b-r.

2.4.2 Luminosity Functions

Measurements of the field were carried out my Efstathiou, Ellis & Peterson in 1987. They fitted four surveys to Schechter functions (equation 3.6) and found the following parameters; Alpha = -1.07 +/- 0.03 and M* = -19.68+/- 0.10. However, later work by Marke, Hucha and Geller found different parameters; Alpha = -1.02 +/- 0.05 M = -18.8+/- 0.10. They also found out that this only fits for galaxies with a magnitude brighter then -16. Beyond this magnitude the galaxy counts are approximately three times higher than the ones predicted by the Schechter function. Both works show that the number of galaxies per interval magnitude rises slowly towards the fainter objects (the value of alpha being <-1), the difference between the two values being somewhat small. However, the difference between the calculated values for the characteristic magnitude may be accounted for by the binning and selection of the magnitude groups for each of the report's Schechter function plots. By varying the bin size and through the elimination of high end (faint) data, the M* value is subject to change, therefore it is possible to see why this variation occurs. It is important to bear this in mind when analyzing the data from this report.

3.0 Method

3.1 Data Collection

3.1.1 SQL Interface & Obtaining The Raw Data

As was mentioned in section 2.3, the data is obtained from the astronomical databases via SQL. Once the queries had been input into the interface, the returned file varied between SDSS and 2dFGRS.

In SDSS the file was returned as a downloadable comma separated variable (CSV) file, which required minimal further formatting, but, the 2dFGRS data was returned as a HTML file, which required significant formatting before the data could be utilised.

The 2dFGRS HTML file needed to be changed to CSV format. The method for changing the format of this data file is as follows; Open the text file in "ASCII" format in then save the table again in the *.csv format in TOPCAT. Finally one opens up the *.csv file saved from TOPCAT into Excel and then input the column headings, then save the data table again in *.csv format.

3.1.2 Data Trimming

Not all the objects in the 2dFGRS or SDSS survey were used, of the initial 10000 galaxies only 3577 were included in the final catalogue, there were certain limits applied to the obtained data. Firstly an angle restriction was imposed upon the data from both surveys; this is so as to just have galaxies from the specific filament in the PCS which we wish to observe and not other sources nor sources within PCS ubiquitous to the investigation. Secondly a redshift limit was used; this is for the same reason for the angle restriction i.e. so only the PCS is observed. Finally, the magnitude resolution in the 2dFGRS is superior to that of the SDSS, hence to make the results from the two surveys more compatible for comparison, a magnitude limit was imposed upon the 2dFGRS data.

Right Ascension	: -15^{o} to +20^{o}
Declination	: -12^{o} to -6^{o}
Reshift	: 0.046 to 0.067

Apparent Magnitude Limit (2dF only) : <18.5 (for both blue and red magnitudes)

3.2 Data Refining

3.2.1 Defining Galaxy Groups

In TOPCAT there is functionality for displaying the data in the form of a spherical polar plot. Once the data is displayed in this form, using the grouping tool in TOPCAT, it is possible to look at the distribution of galaxies and select the clusters of galaxies and save them as separate groups. Looking at the density of each defined group it is possible to estimate the nature of each group, whether it be filamentary or dense regions. Unfortunately, it is not possible to quantify an error when defining galaxies by the eye-ball method.

Previous works, Eke et al 2004, utilised a group catalogue and a group finding algorithm to find and label the groups of galaxies within their data, most of works use the 2PIGG catalogue and the friends of friends algorithm. The group finding algorithm (friends of friends) draws a volume around a galaxy. All galaxies within this volume are considered to be part of this same group. Another linking volume is drawn around these new component galaxies to find the next set of galaxies within this new grouping. This process is repeated n times until all galaxies are assigned a group and no galaxies are found within the linking volume. Difficulties arise when deciding on which parameters of the galaxy affect the shape and size of the linking volume.

As part of this report, as was stated in section 1.1, is to create a unique catalogue specifically for this project so the data was extracted directly from 2dFGRS and SDSS. Also, due to the nature of the limits imposed on the data selection, the relative number of galaxies obtained was small when compared to previous works (approximately 3600 galaxies were retrieved from both 2dFGRS and SDSS), hence it was not necessary to use the 2PIGG database as a source catalogue nor was it necessary to use a group finding algorithm on such a small volume of data. Also, the epoch of the 2PIGG catalogue is different to the epoch of the coordinates used in the source surveys. Therefore any comparison of the catalogue created for this project and the 2PIGG catalogue would require changing the epoch of one of the data sets.

3.2.2 Calculating Absolute Magnitude for Each Galaxy

Both 2dFGRS and SDSS give the apparent magnitude and the redshift for each galaxy, hence the absolute magnitude may be found from the standard relation for apparent to absolute magnitude;

$$M_{bj} = m_{bj} - 5\log_{10}(D_L/10) \tag{3.1}$$

Here D_L is the luminosity distance, this is as iterative value, so to the first order;

$$D_L = (cz/H_o)(1 + {}^1/_2 z(1 - q_o)) \tag{3.2}$$

This approximation holds well, for the redshift which will be observed in this project.

It is necessary to correct the absolute magnitude of the galaxies for the effect of the redshift on their spectra when the observation was made. Such a correction is referred to as a K-Correction and is a function of the galaxy's colour and it's redshift. The blue magnitude will be used for 2dFGRS, but not for SDSS. In SDSS there is no blue magnitude, so green was used instead. In SDSS the K-correction factors are already given in the extracted data, so the following is only applicable to 2dFGRS. The most common correction used for galaxies is the b-r correction (Cole et al 2005). The K-correction is a function of b_j – r (the blue apparent magnitude – the red apparent magnitude) and the redshift;

$$K_{bj} = (-1.63 + 4.53C)y + (-4.03 - 2.01C)y^2 - z(1+((10z)^4))^{-1} \tag{3.3}$$

$$K_{bj} = (-0.08 + 1.45C)y + (-2.88 - 0.48C)y^2 \tag{3.4}$$

Where $y = z - z^2$ and $C = b_j - r_f$. To correct the magnitude the iterative sequence is used. The uncorrected values are used to find the value of C, then from this the k-values are calculated, these are then added to b_j and r_f to calculate a new value for C, then new k-values are found and the process repeats. This is repeated until the difference between iterations of the C values is <0.001.

Once the final K-Correction values have been calculated, it is then subtracted from the absolute magnitude to give the final corrected value for the absolute magnitude of each galaxy.

3.2.3 Calculating Group Luminosity And Group Magnitude

Firstly, using the absolute magnitude calculated previously, the luminosity for each of the component galaxies within a group (as defined in section 3.1.3). This is calculated via the usual relation between Luminosity and Magnitude;

$$L = 10^{(-0.4M)} \tag{3.5}$$

Once the luminosity of each galaxy has been calculated, it is necessary to sum each of the galaxy luminosities over the entire group; i.e.

$$L_g = \Sigma L_i \tag{3.6}$$

This group luminosity also factors the weighting of the group when calculating the group magnitude. Finally, by rearranging equation 3.5 so as to make M the subject, by inputting the value of the group luminosity the equation returns the weighted value of the group magnitude.

3.2.5 Colour Histograms

Colour histograms were created using TOPCAT. For 2dFGRS the b-r colour was used and for SDSS the u-g and g-r colours are used. The colour is plotted against the frequency of which each colour occurs.

The definition of morphological type changes depending on your which colour has been plotted. A small b-r indicates a bluer galaxy and a large b-r indicates a redder galaxy, a small u-r indicates a bluer galaxy, a large u-r indicates a redder galaxy, a small g-r indicates a bluer galaxy where a large g-r indicates redder galaxy. From these plots it is possible to find a cut off value, which gives a value which will allow definition of morphological type via only the colour value. The colour plots also allow observation to confirm the bimodality of groups (Cole et al 2005) and then the findings may be compared to previous works. The u-r and g-r colours are used instead of the u-g because these exhibit traits which are more easily compared to the b-r colour of the 2dF survey. Also, the u-g colour is not that widely used by the scientific community, therefore comparison of the results with previous works would be difficult, as a result the u-g will not be used as part of this project. From these histograms it will be possible to observe not only the distribution of morphology in the different surveys as a whole but also the difference in morphological type in the filamentary and dense regions separately. As a result of these plots, it will be possible to plot an evolutionary path of the galaxies through the supercluster.

Finally from the colour plots it is possible to extract; the group colour and hence the dominant group morphological type and population

3.2.5 Luminosity Functions

The most common parameterisation of the luminosity function is that due to Schechter, hence called the Schechter Function;

$$^{dn}/_{dl} = \Phi(L) = \Phi_*/L_* \, (e^{-L/L^*})(L/L_*)^{\alpha} \tag{3.6}$$

(This version of the equation is for luminosity but it can be adapted for magnitude and mass by the appropriate relations)

Confidence	$\Delta\chi^2$
68.3%	2.3
90.0%	4.6
95.0%	6.2
99%	9.2

For the purposes of this project, it was possible to utilise a Schechter function fitting program (created by A Robotham, University Of Bristol), used in Robotham et al 2006. This program manipulates binned magnitude data and plots the luminosity functions virtually and then outputs a Schechter function, with values for M*,N* and α, and a χ^2 error ellipse for M* and α, the confidence in the chi squared error ellipses are shown in the table above. This, therefore, rendered the plotting of individual luminosity functions redundant and an inefficient use of time.

The magnitude data had to be formatted correctly so as to be able to be read by the program. Using the bin range of -17 to -24 in increments of 0.25, this would then be saved as a tab delimited CSV file and then input into the program. The program would then output afore mentioned plots and information. From these plots, values for the required parameters will be deduced. Then from these values it will be possible to describe the properties of the component galaxies within the supercluster.

The parameters within the equation are defined as follows; M* is the characteristic magnitude, this is the value of the point of the Schechter plot where is stops being linear and becomes exponential. The value of alpha gives you the gradient of the slope at the faint end which gives information on the distribution of the density of the galaxies per unit interval magnitude. The value N* is a normalisation factor which is loosely based on the number density of bright galaxies within the group.

3.3 Final Results

Using the galaxy colour distribution plots, this project is interested in observing the bimodality, if any, in the PCS and in seeing the effect of region (i.e. dense or filamentary) on the galaxy type which resides. From this a road map of the evolution of the galaxies as they exist within the PCS may be described. Finally this project is interested in the effect that the morphological type has on the parameters of the Schechter function, in addition to this, an investigation on how the values of M* and alpha vary with the colour of the groups in the different regions will also be addressed. The confidence in the chi-squared plot is shown opposite.

4.0 Results

The complete catalogue of galaxies from both 2dFGRS and SDSS is available on request from the University of Bristol Astrophysics department.

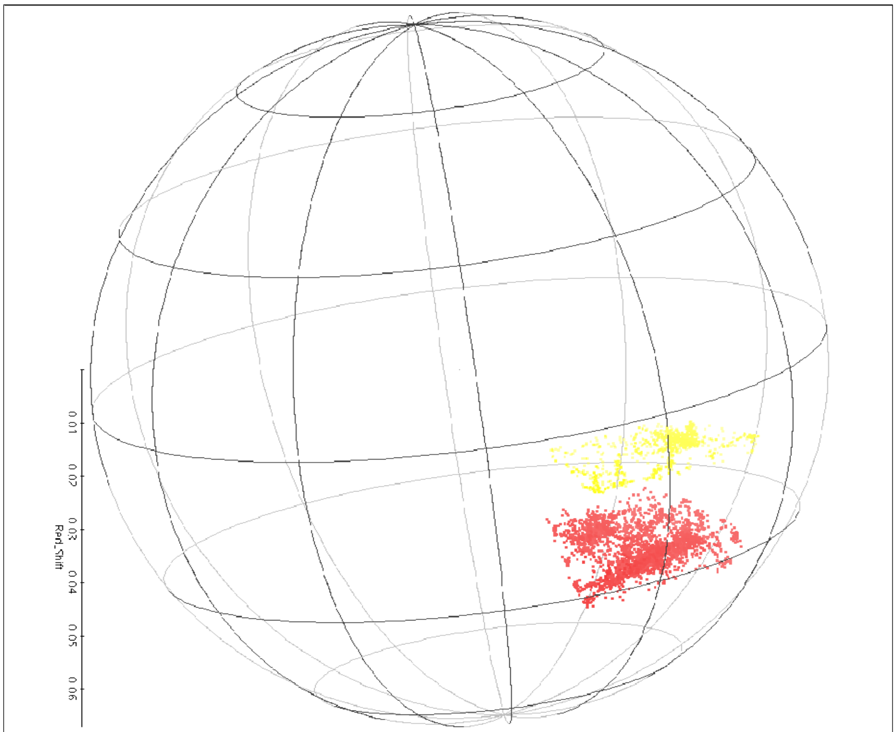


Fig3– Spherical Polar Plot Of Galaxy Distribution In PCS

4.1 Spherical Polar Plot Of Galaxy Distribution

The plot to the left shows the position of the two survey's data on the sky.

The SDSS data is in yellow (the lighter data set) and the 2dFGRS data is the red (darker data set) data set.

The plot has Right Ascension on and Declination on the XY axis and Red shift on the Z axis.

Appendix B shows a flat map of the

distribution of galaxies for 2dFGRS and SDSS.

The z-axis (vertical axis) for the SDSS data appear to be “quantised”, this is because of the precision of red shift data for the SDSS survey is less than the value for the normalisation factor used in creating the map, hence this explains the apparent groups.

4.2 Data Tables

4.2.1 Group Magnitude

Group Name	Group Size	Mg	Group Magnitude Error ±
2dFGRS_Cluster_1_2	516	-26.69	0.518
2dFGRS_Cluster_3	202	-25.83	0.501
2dFGRS_Cluster_4	325	-26.24	0.509
2dFGRS_Cluster_5	366	-26.44	0.513
2dFGRS_Cluster_6	365	-26.57	0.516
2dFGRS_Cluster_7_9_11	172	-25.56	0.496
2dFGRS_Cluster_8_10_12	129	-25.28	0.491
2dFGRS_Filament_1_2_8_13	104	-24.82	0.482
2dFGRS_Filament_3_4_10	113	-25.09	0.487
2dFGRS_Filament_5_6_7_9	150	-25.17	0.489
2dFGRS_Filament_11_12_14	113	-24.98	0.485
SDSS_Cluster_1_5	97	-25.41	0.502
SDSS_Cluster_2_3_8_9	90	-25.03	0.494
SDSS_Cluster_7_10_11	341	-26.38	0.521
SDSS_Cluster_12_13	261	-26.13	0.516
SDSS_Filament_1_8_10	65	-24.80	0.490
SDSS_Filament_2_3_4_5	101	-24.92	0.492
SDSS_Filament_6_7_9	67	-24.27	0.479

Above is just the group size and magnitude for each of the groups as were defined from the catalogue. From here on, all references to the groups will be using the group magnitude (Mg). A copy of the original catalogue, both grouped and ungrouped, is available on request.

*4.2.2 Alpha and M**

The values of alpha and M* were collected by plotting the Schechter functions for each of the groups shown in section 4.2.1 and then by colour division, but this would involve displaying approximately 50 functions. Therefore, since the values of alpha and M* are to be compared and analysed, they are tabulated in Appendix C and are analysed in the following section. The data is divided and displayed by both type and colour. This table is to avoid the necessity of including all the Schechter functions for each of the groups.

4.2.3 Bimodality Of Groups

The figures below demonstrate the presence of, or lack of, bimodality of the galaxies in the groups for the two different surveys. The b-r colour is shown for 2dFGRS where as only the u-r colour is shown for SDSS, with the g-r colour being in Appendix D. Appendix D also contains the colour histogram for the u-g band for completeness. For 2dFGRS, the largest group was removed to more easily observe the trends in the plots.

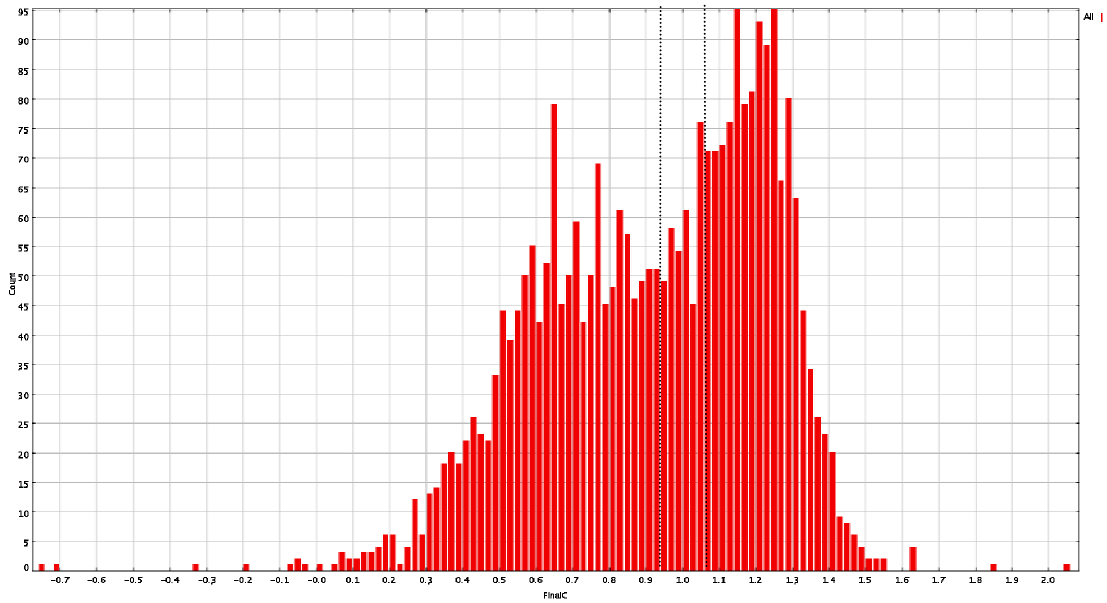
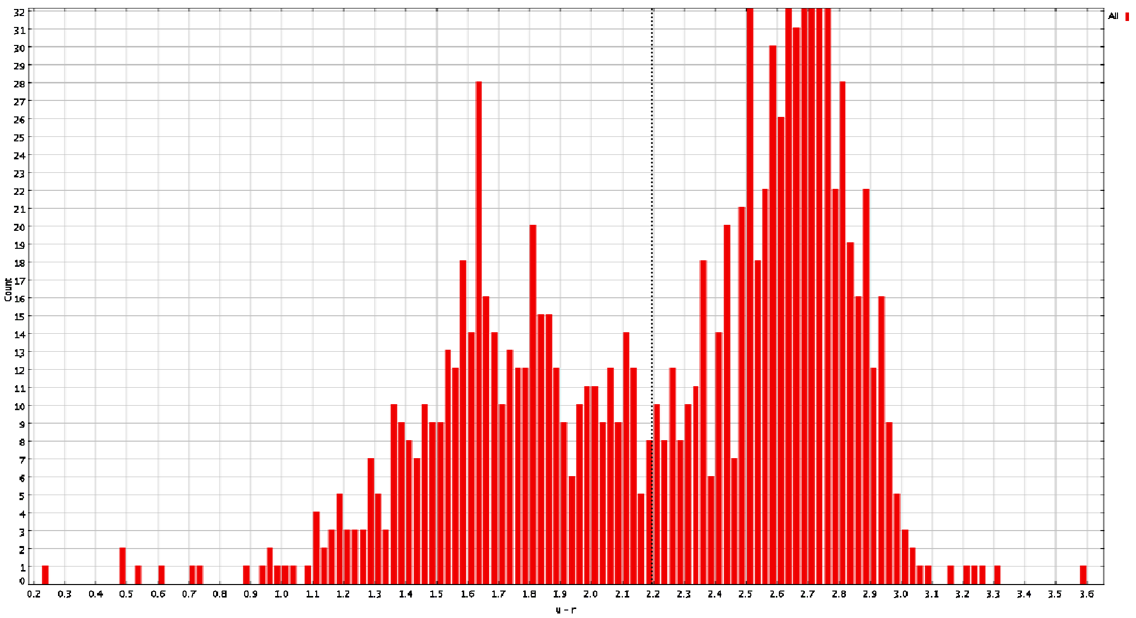


Fig3a [Above] – 2dFGRS b-r colour plot, the solid line showing the calculated cut-off value for this project and the dotted line showing the more commonly accepted value
Fig3b [below] – SDSS u-r colour plot, with the solid line showing the cut-off value



4.3 Galaxy Morphology – Dense Regions

4.3.1 Dense Regions Schechter Functions

Figure 5 below shows the Schechter Functions for the denser regions of the PCS for the 2dFGRS and SDSS data.

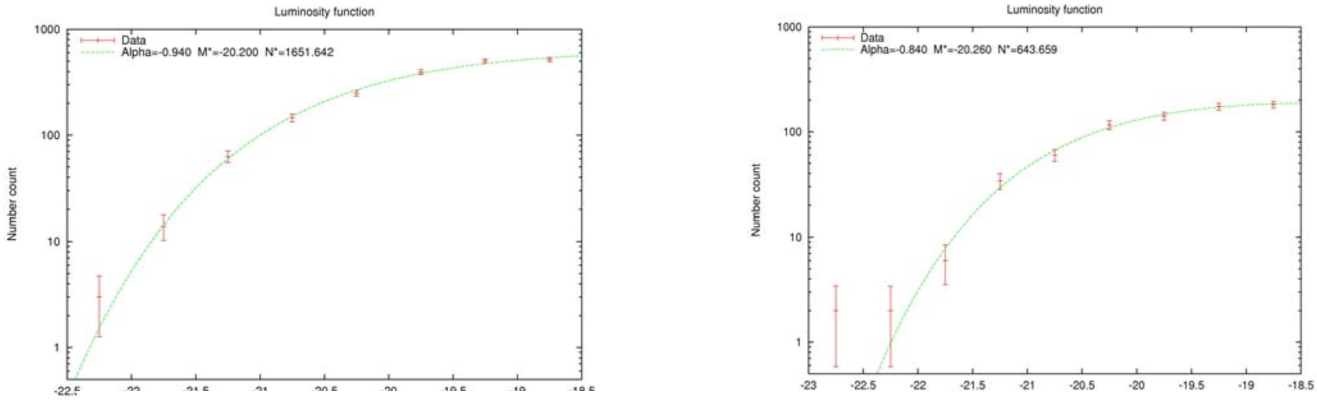
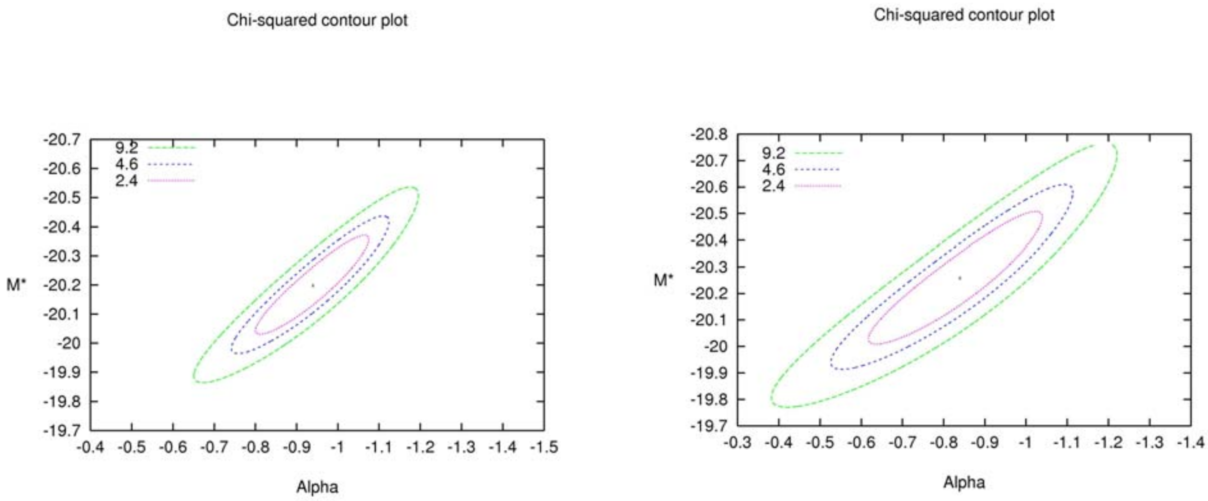


Fig5 [Above] – 2dFGRS (left) and SDSS (right) Schechter Functions
Fig6 [below] – 2dFGRS (left) and SDSS (right) Chi-Squared Error Plots



4.3.2 Dense Regions Chi-squared plots

Though the alpha and M* values are given in section 4.2.2, the error ellipses form the basis for the discussion so are included to supplement the table, this is shown in figure 6 above.

4.3.3 Dense Regions Colour Histograms

Figure 7a shows the histograms for the b-r colour of the 2dFGRS data and figure 7b shows the u-r colour for the SDSS (this is because u – r is close to b – r in the 2dF GRS catalogue hence this is most useful for comparison between the two data sets).

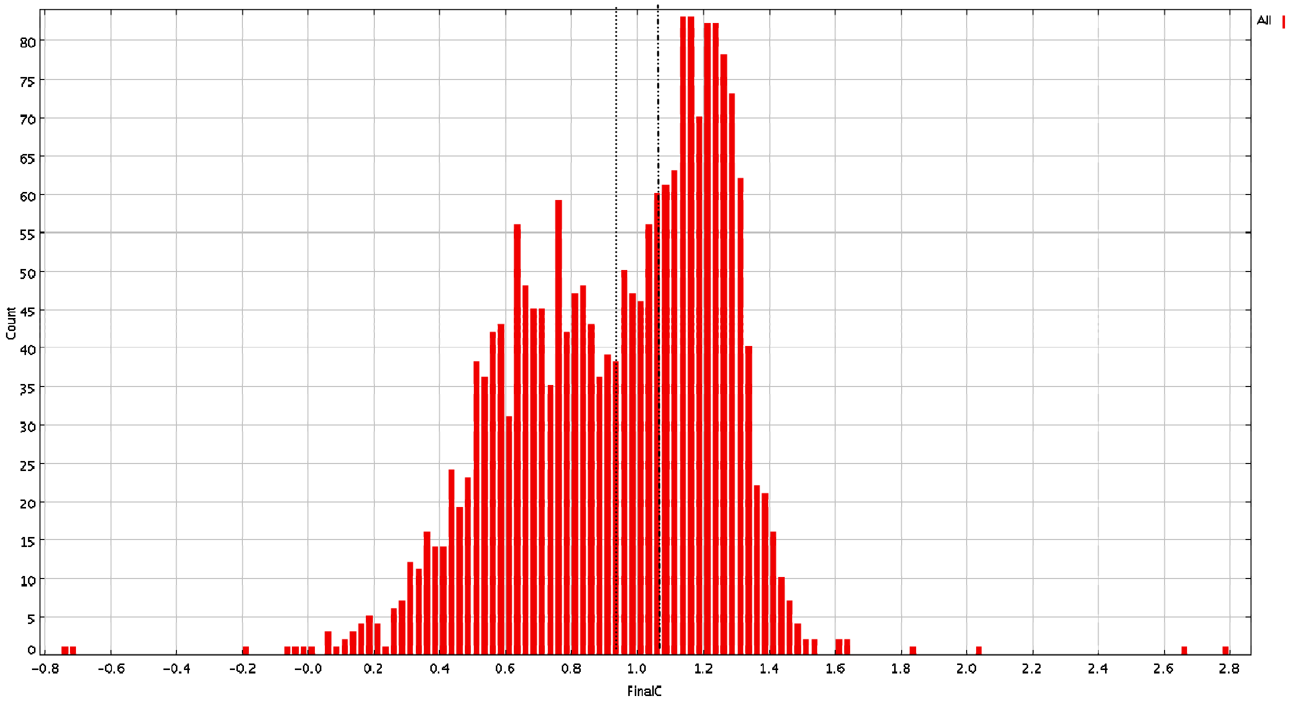
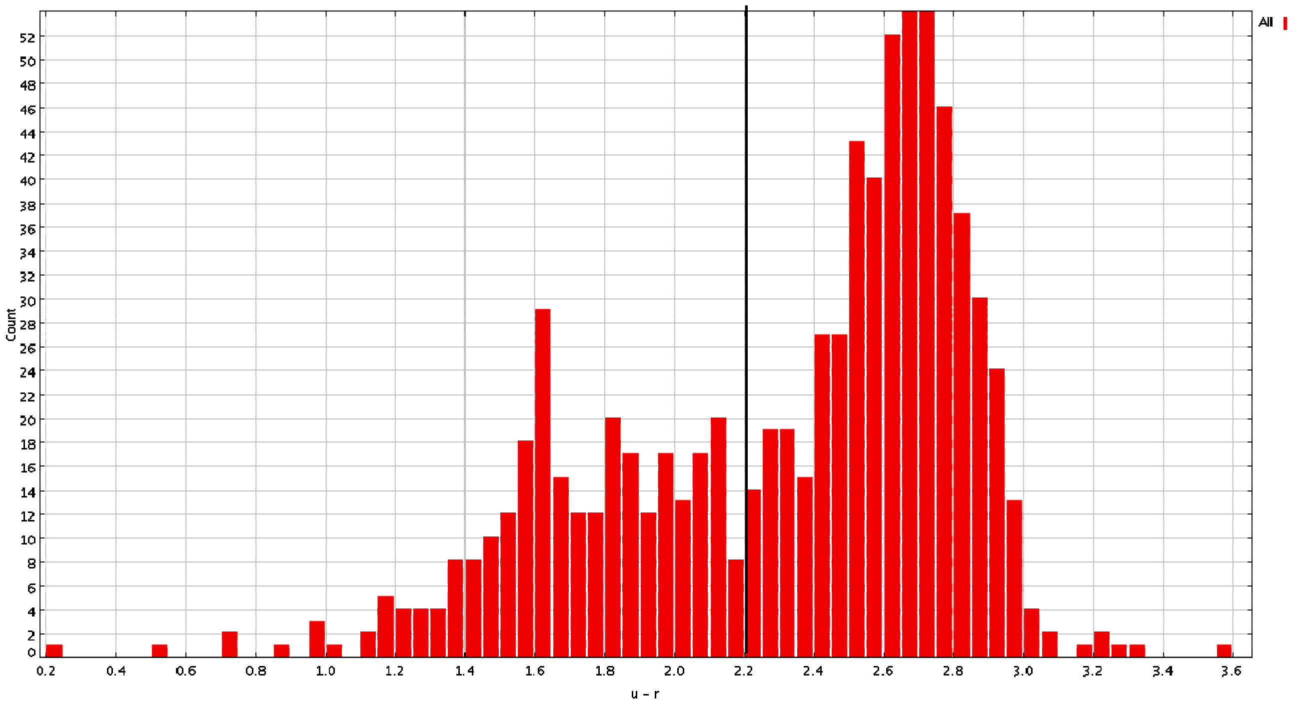


Fig7a [Above] – 2dFGRS dense groups, the solid line showing this project's cut-off value and the dashed line showing the more commonly accepted cut off value.

Fig7b [below] – SDSS u-r dense groups, the line shows the cut off value.



The g-r colour for SDSS is shown in Appendix D, it shows the same general trend, which will be discussed later.

4.4 Galaxy Morphology – Filamentary Regions

4.4.1 Filamentary Regions Schechter Functions

Figure 8, below, shows the Schechter Functions for the filamentary regions of the PCS for the 2dFGRS and SDSS data.

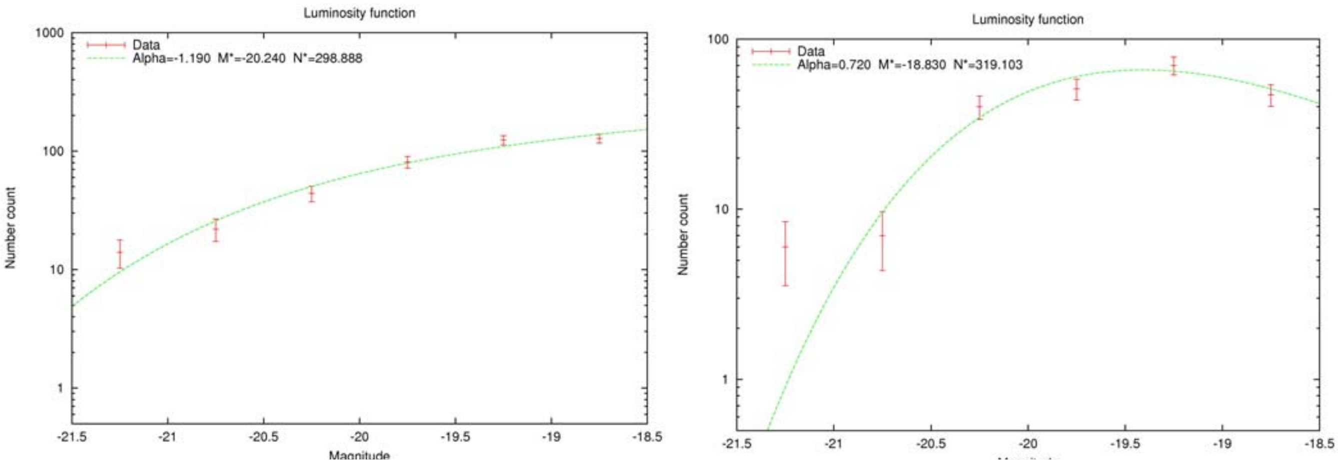
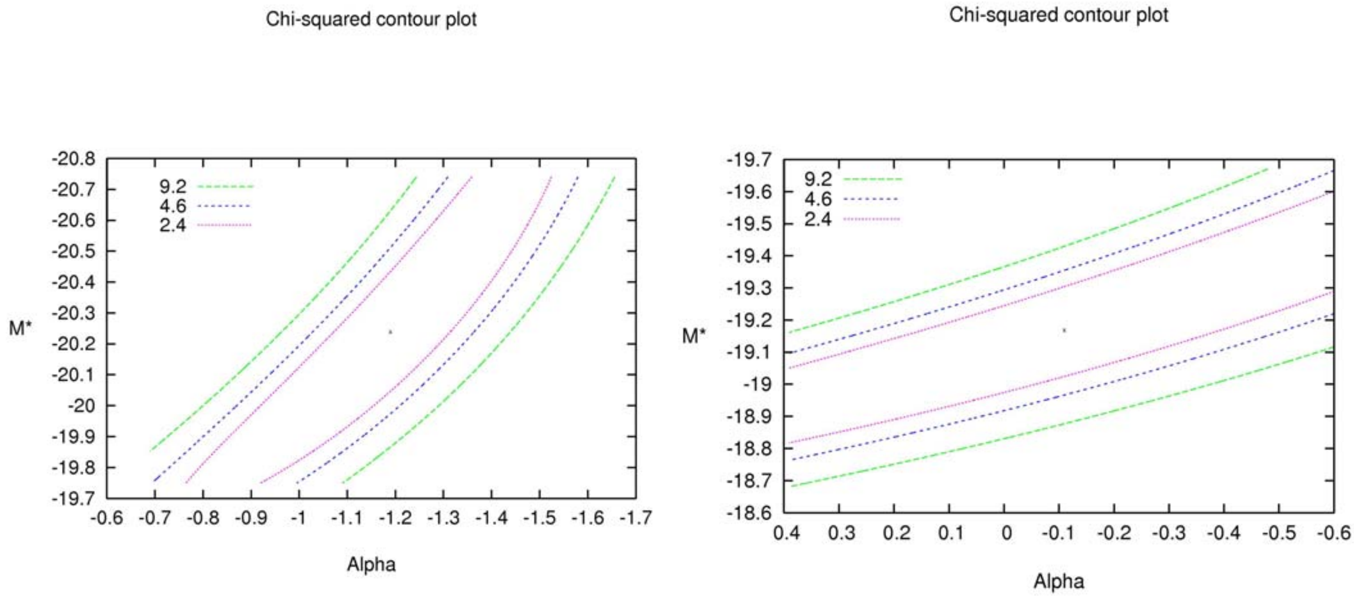


Fig8 [Above] – 2dFGRS (left) and SDSS (right) Schechter Functions
Fig9 [below] – 2dFGRS (left) and SDSS (right) Chi-Squared Error Plots



4.4.2 Filamentary Regions Chi-squared plots

As with the dense groups (4.3.2), the values of alpha and M* are in the Appendix C. But since these plots will be discussed later, they are included for completeness.

4.4.3 Filamentary Regions Colour Histograms

As with the dense region colour plots; the b-r 2dFGRS colour and the u-r SDSS histograms are shown in the figures below, with the other SDSS colour plots shown in appendix D

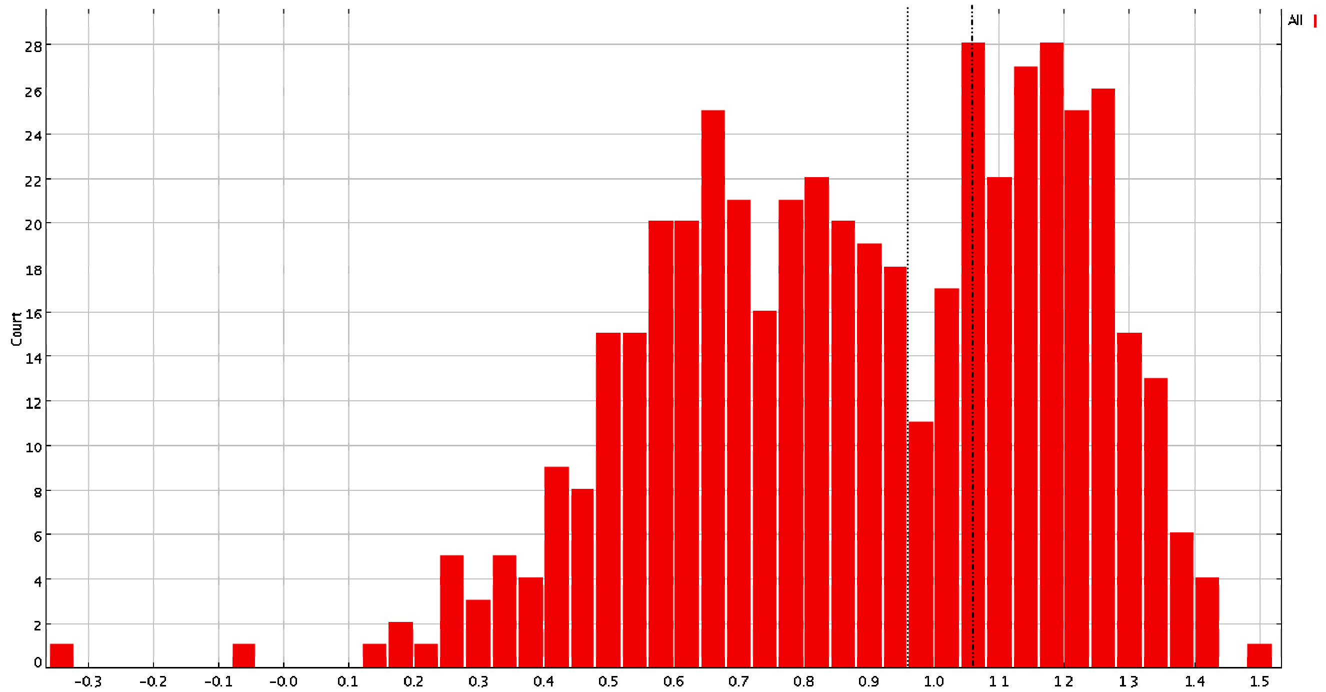
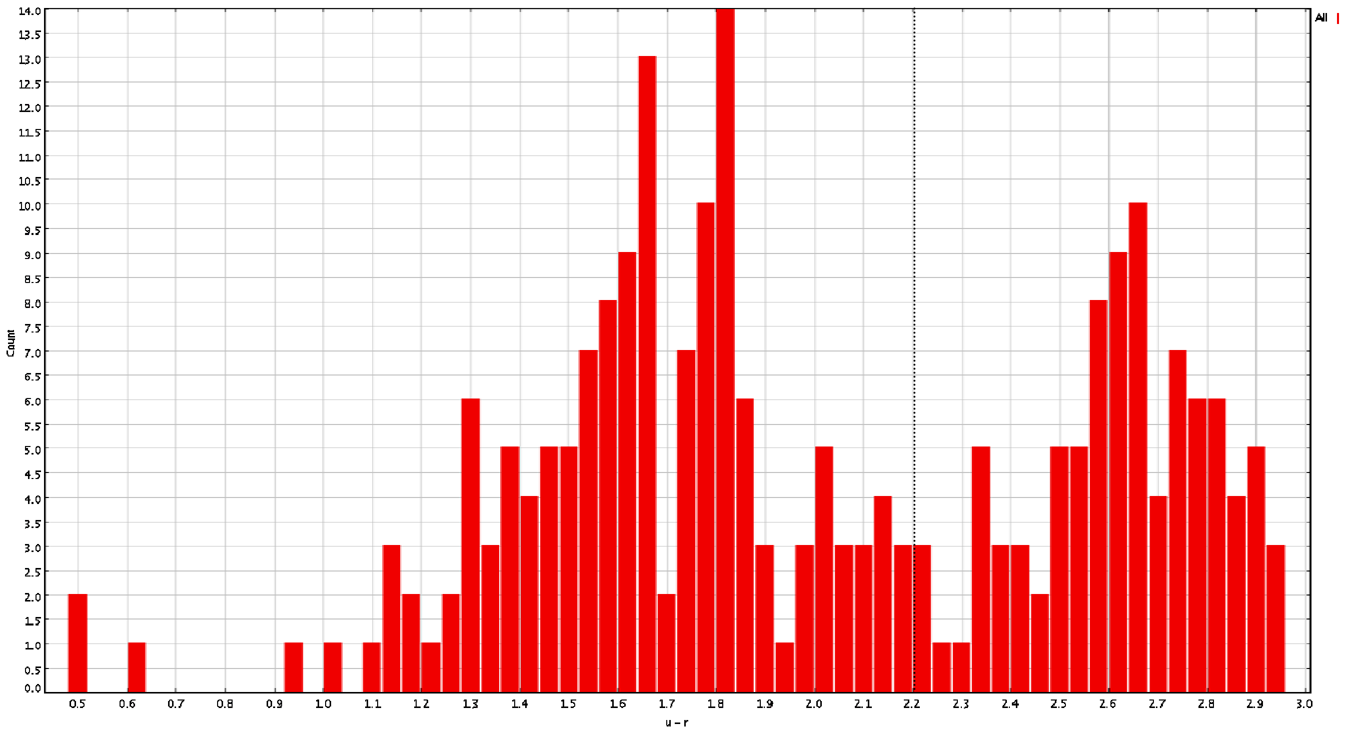


Fig10a [Above] – 2dFGRS filamentary groups, the solid line showing this project's cut-off value and the dashed line showing the more commonly accepted cut off value. Though bimodality not as defined here.

Fig10b [below] – SDSS u-r filamentary groups, the line shows the cut off value.



4.5 Colour

In addition to investigating the Schechter functions of the groups in the PCS with division by type (i.e. Dense or Filamentary regions) the effect of colour on the function and its parameters has been researched. Each of the component groups and hence galaxies within each of the region types were split into different colours, red and blue, then from this the data was input into the Schechter Function program . The purpose of which being, to see if there was any correlation between the colour and the parameters of the Schechter functions.

Only the Schechter functions will be shown here, the associated error ellipses can be seen in Appendix F. As with previously, only the u-r SDSS data will be shown, the other colour band SDSS Schechter functions parameters can be seen in Appendix C and examples of the original Schechter functions may be seen in Appendix E.

4.5.1 Dense Red Region Schechter Functions

Figure 11 shows the Schechter functions for the dense red galaxies.

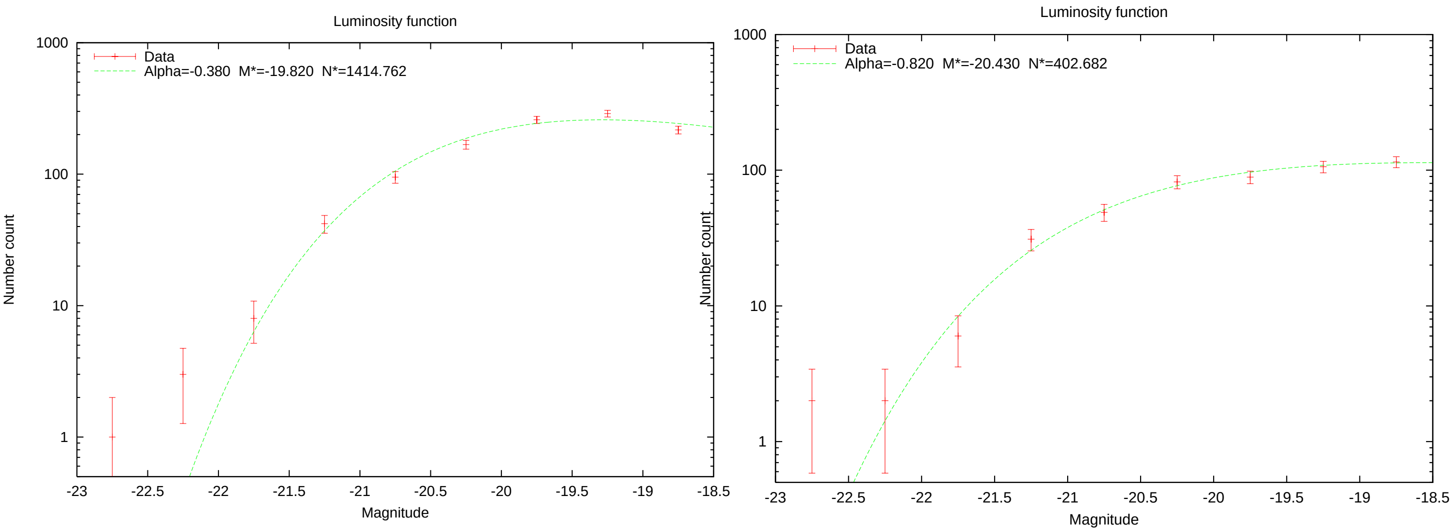
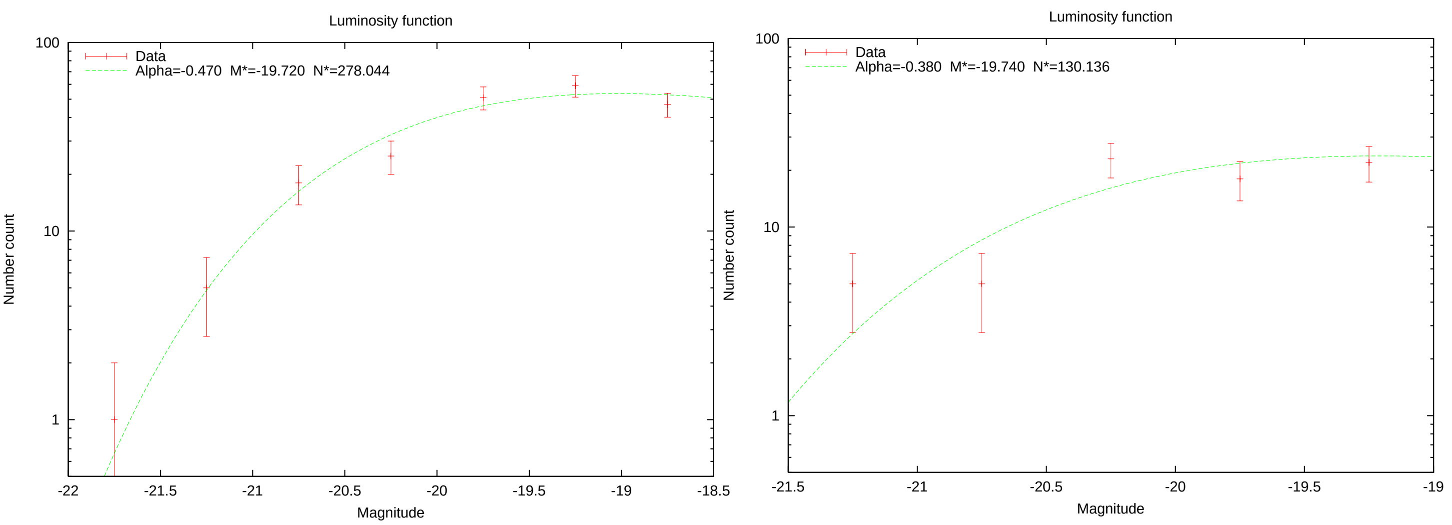


Fig11 [Above] – 2dFGRS (left) and SDSS (right) Dense Red Schechter Functions
Fig12 [Below] – 2dFGRS (left) and SDSS (right) Filamentary Red Schechter Functions (u-r Band)



4.5.2 Filamentary Red Region Schechter Functions

Figure 12 shows the red filamentary galaxies

4.5.3 Dense Blue Region Schechter Functions

Figure 13 shows the dense blue galaxies

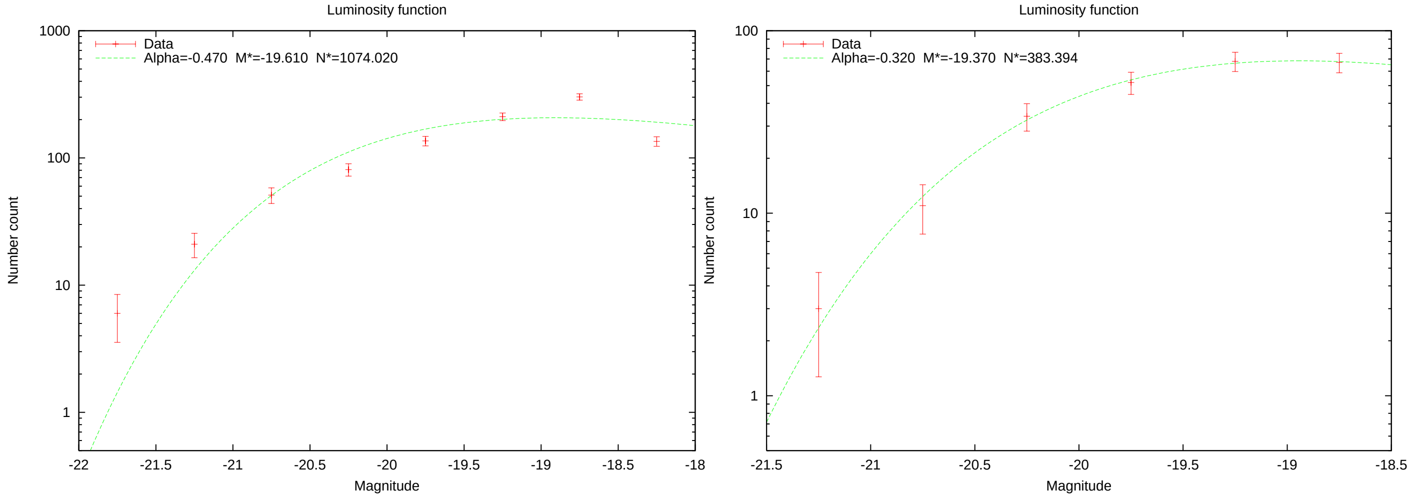
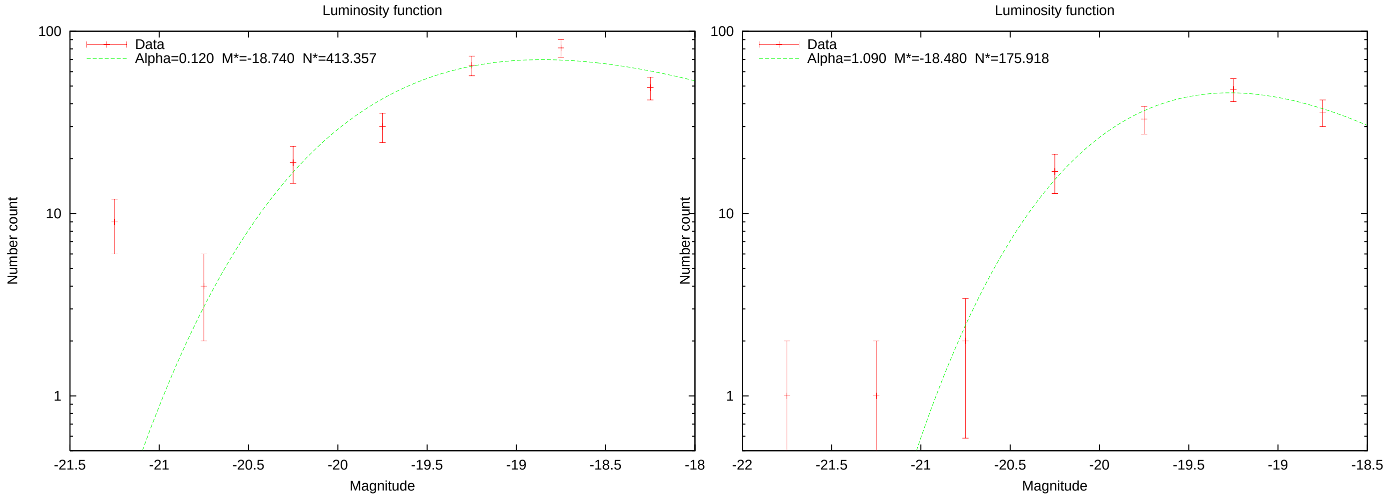


Fig13 [Above] – 2dFGRS (left) and SDSS (right) Dense Blue Schechter Functions
Fig14 [Below] – 2dFGRS (left) and SDSS (right) Filamentary Blue Schechter Functions (u-r band)



4.5.2 Filamentary Blue Region Schechter Functions

Figure 14 shows the blue filamentary galaxies

5.0 Discussion

5.1 Bimodality of Groups

5.1.1- 2dFGRS

Looking at figure 3a, it is clear from the distribution of the histogram data that there appears to be a trend showing the well known bimodal distribution (Strateva et al. 2001; Baldry et al. 2004). Cole et al (2005) suggests that the galaxies with a large b-r are the red early type galaxies where as those with a small b-r are blue late type galaxies. Cole also recommends that the cut-off value to distinguish between the types is approximately 1.07. This project finds the value to be approximately 0.95 for this survey.

The discrepancy between the two cut-off values could be explained through the difference in the number of galaxies being analysed in the sample. Cole used a sample of 221 414 galaxies, where in this project, for the 2dFGRS survey alone, used 3967. Therefore, it is obvious that the larger sample would give more accurate results. But considering the variation in the sizes of the two samples, the difference in the cut off value is not as significant.

5.1.2 SDSS

The colour histogram in figure 3b also shows bimodality. The galaxies with a small u-r are blue late type galaxies and those with a large u-r are red early type galaxies, also agreeing with the Cole's findings. Strateva et al. (2001) found, using the data from the SDSS the cut-off value for the u-r colour to be approximately 2.22. The value from this project found the cut off to be at 2.2. The difference in the values can be explained by the resolution of the plot, the resolution of the program used to fit data for this project is +/- 0.1 where as Strateva had more sensitive plotting programs, hence a more accurate value was able to be obtained. Though, considering the variation in sample size the correlation between the two values is acceptable.

As an aside, the colour histogram in g-r band also shows bimodality, though not as strongly. The cut off value for this colour band was found to be approximately 0.67. Unfortunately, no previous works that had used the g-r colour band could be found to corroborate this value; hence, no conclusion as to its reliability can be made.

5.2 Galaxy Morphology

5.2.1 2dFGRS

Figures 7a and 10a show the b-r colour histograms of the dense and filamentary regions respectively.

The dense region appears to have a higher proportion of galaxies with a high b-r value. From the earlier results and research it is possible to deduce that the galaxies with a high b-r colour are red early type galaxies. Therefore it can be assumed that a vast majority of these galaxies are going to be E-class galaxies (i.e. Ellipticals). The galaxies within this category contain very little stellar material and are populated by few young stars with the stellar population being dominated by old population II stars of low metallicity. This low metallicity of the component stars and hence of the galaxy is what gives the galaxy its red colour.

The filamentary region plot does not reflect the same strong bimodal trend as the dense or the complete colour plot, but it can be seen that there are more galaxies in the filamentary regions with a b-r less than that of the cut off value than there are with galaxies with a b-r colour greater than it. Hence it is possible to deduce, as was done with the dense region that the main galaxy type in the filamentary regions are going to be S-type galaxies (i.e. Spirals). The galaxies within this category contain stellar material and have a stellar population dominated by young population I stars of high metallicity. As with the population II stars, the metallicity of the component stars that gives the galaxy its colour.

5.2.2 SDSS

Figures 7b and 10b show the u-r colour histograms for the dense and the filamentary regions respectively. The other colour plots can be seen in Appendix D

The dense region plot shows an obvious bimodal trend, with the majority of the component galaxies being redder. This implies, as with the 2dFGRS survey, that the dense regions are dominated by red early type galaxies and hence are comprised of mainly Ellipticals, for the same reasons as stated for the 2dFGRS dense regions.

Unlike the 2dFGRS data, the SDSS filamentary colour plot shows strong bimodal properties. The majority of the galaxies in the filamentary regions are blue. This implies that the filamentary regions, as with 2dFGRS, are dominated by blue late type galaxies and hence comprise mainly of Spiral galaxies.

The other colour histograms plotted in different colour bands show the same trends as the u-r colour and can be see in Appendix D

5.2.3 Galaxy Evolution through the PCS

From the two different surveys, it has been shown that the denser regions of the PCS tend to be populated by red early type galaxies where the filamentary regions tend to be populated by blue late type galaxies. This agrees with previous work by Cole, section 2.4.1.

From these findings a hypothesis as to the evolution of the galaxies and their path through the super cluster can be made. The main flow of galaxies is down the filamentary regions of the supercluster from where the environment is less dense to where it is more dense. In the filamentary environment, the dominant morphological type of galaxy is Spirals. As the spirals move down the filaments of the PCS to the regions towards regions of higher density interactions between the “infalling” spiral galaxies becomes more likely because of the increase in density of the galaxies.

Fig15 – Two spiral galaxies colliding

If two spiral galaxies collide (shown in figure 15) and providing they do not have enough momentum to continue travelling after the collision, they fall back into each other and eventually merge together, forming one galaxy. If one of the colliding galaxies is much larger than the other, it will remain largely intact after the merger; that is, the larger galaxy will look much the same while the smaller galaxy will be stripped apart and become part of the larger galaxy. The usual product of such a collision is an Elliptical galaxy. Since the merged Elliptical will be larger, that is more massive, than any Spiral which could interact with it, it remains similar in appearance (as was stated earlier). Hence, this is why in the colour histograms the dense regions consist mainly of red early type galaxies where the filamentary regions contain mostly blue late type galaxies.

5.3 Schechter Function Analysis – Division By Environment

5.3.1 2dFGRS

The Schechter function for the dense region has a value for alpha of -0.94 +/- 0.1 and a characteristic magnitude of -20.26 +/- 0.3. Therefore this implies that, at the faint end, as you move towards fainter magnitudes the number of galaxies per magnitude interval decreases slowly. The errors in the two values are comparatively small, with the error ellipse is relatively “tight” with the spread of values being small for all levels of confidence, therefore it is reasonable o assume that the values for both quantities are reliable.

The Schechter function for the filamentary region has a value for alpha of -1.19 +/- 0.1 and a characteristic magnitude of -20.24. This implies that unlike the dense regions the number of galaxies per interval magnitude increases as you move towards the faint end. Contrary to the errors for the dense region values, the spread of values is significant for the characteristic magnitude with the error ellipse being highly eccentric for M*. The error for alpha is more confined than that of the error for M*, though the quality of the results are not as good as the values for the dense environment. But, still taking this into account, the value for the characteristic magnitude for the two environments appear to be somewhat similar.

A possible reason for the variation in the quality and reliability of the results is that, by definition, there will be more galaxies in the dense region than in the filamentary regions. Therefore, because there will be a larger sample of data being used in the dense region than in the filamentary environment, the values of the function will be more accurate than that of the values output by the function when it is acting on a vastly reduced data set. So even though the stated error for alpha is actually the same for both environments, the volume of data used must also be taken into account

From these results, no obvious conclusion can be drawn as to relating the values of alpha and of M* with morphological type within the 2dFGRS part of the survey.

5.3.2 SDSS

The Schechter function for the dense region has a value for alpha of -0.84 +/- 0.2 and a characteristic magnitude of -20.26 +/- 0.3. Therefore this implies that, at the faint end, as you move towards fainter magnitudes the number of galaxies per magnitude interval decreases slowly. The value of the characteristic magnitude for the dense SDSS is similar for the value for M* in the 2dFGRS survey. This shows that the result is reliable for the data obtained for this project because of the correlation between the two values.

The Schechter function for the filamentary regions has a value for alpha of -0.72 +/- 0.3 and a characteristic magnitude of -18.83 +/- 0.2. These results imply that, at the faint end, as you move towards fainter magnitudes the number of galaxies per magnitude interval decreases slowly. The value for the characteristic magnitude of the SDSS filamentary regions differs from the 2dFGRS regions. The variation in the two values of M* can once again be explained by the volume of data included in the samples. The SDSS data was significantly less, in volume, than the 2dFGRS before the splitting of groups by type. So, by definition, the number of galaxies in the filamentary regions, as before, will be less than the dense regions, but incorporating into the fact that the number of SDSS galaxies are already reduced, then the will be significantly less galaxies in this sample.

5.3.3 Schechter Function Analysis – Comments

By comparison, the magnitude range of this report was smaller than most previous studies, so this must be taken into account when analysing the results. Previous works in this area concentrate mainly on the field. The field contains mainly galaxies that are not included in any clusters or groups so comparing the grouped results from this report to the works on the field should prove to be interesting.

Marke et al (1994) found the field to have the parameters M* = -18.8 +/-0.3 and α = -1.0 +/- 0.2. The variation in these results to our own is due to the magnitude ranges involved, as was mentioned above. Marke used a magnitude range of $-13<M<-22$ which is larger than the magnitude range used in this report, which could be used to explain the differences in the results. But also, there must be consideration of the fact that the grouped galaxies may be or higher density than those in the field. However a better comparison can be made using the results from Cole et al 2005, who found the value of α= -1.2 and a value of M* to be -19.73+/- 0.2. The characteristic magnitude appears to be more representative of the values obtained in this study, though the value for alpha obtained is lower than that obtained by Cole. But, the results obtained by De Propris et al 2003 provide an even closer match to the values obtained with M* = -20.07 +/- 0.07 but the value for alpha was significantly higher than the results obtained by this project. The correlation of our results with the ones obtained by De Propris may be due to that fact that the magnitude range is more comparable with the magnitude range of $-22.5<M_{bj}<-15$. The main source of error and hence variation in the results is due to, as has already been stated, the difference in the volumes of data used in this project than compared to previous works. In hindsight it would have been more beneficial to not have cut down the data as much using the magnitude limits. This would have allowed for a much larger sample of data and hence the possibility of more accurate results. Also neither

5.4 Schechter Function Analysis – Division By Colour

Using the cut off values, obtained from the colour histograms, it was possible to create a database of the galaxies. This database was then used to create new sub-catalogues of galaxies. These sub-catalogues divided each of the galaxies from each of the two environments by colour, so that there are Red dense and blue dense galaxies etc. This data was then input into the Schechter function fitting program allowing the data to be analysed for trends.

Accepted theory suggests that late type (blue) galaxies have a fainter value of M* (i.e. more negative) than when compared to the early (red) types, also the late types have a steeper value of alpha than the early types. All the Schechter functions in section 4.5 agree with this hypothesis. The table referred to in section 4.2.2, shows the values of the individual groups, and is more easily observed. The table shows that the data conforms to theory. It shows that the dense groups (consisting mainly of early type galaxies) have, on average, a brighter value for M* than the filamentary groups (consisting of mainly late type galaxies). Also the filamentary groups have, also on average, a steeper value of alpha than the value obtained for the dense groups. These conclusions are more easily drawn from the data table than from the Schechter functions in section 4.5.

Though this, on the surface, appears to be less accurate than using the generated Schechter functions, as with most of the problems which arose from inconsistencies in the results the lack of accuracy in the plotted functions are more to do with the size of the data sample input into the program rather than the quality of the raw data. However, the values generated by the program itself are the source of the data input into the table in section 4.2.2, so the quality of the data cannot be completely dismissed.

The error ellipses (Appendix E) show that the reliability in the 2dfGRS value of M* is good, with the largest error being that for alpha. The cause of these relatively large value for the error in alpha may be due to the size of the divided data set, though this does not explain why the value for M* is more accurate. A possible reason for the small error in M* may be due to the fact that M* is a value as defined by the whole group (analogous to that of an average) so removal of some of the data points would not affect the average that greatly, since other members of the group would compensate.

There is a similar trend in the errors with the in the SDSS data set. With the confidence in M* being better than the confidence in the values of alpha. Other than the continuing issue with the size of the data sample, no other explanation can be offered as to the origin of the difference in the errors.

5.5 General Comments

On the whole, the project attained what it was designed to achieve. The quality of the data and hence, as a consequence, the results of the investigation into bimodality of the groups gave the most observably positive result, with the bimodality for almost all the plots being obvious. However the Schechter function analysis was not as forthcoming.

The main problem in this project, as has been mentioned several times in relation to the different analyses, was the size of the data sample collected. Initially from research into other works, the catalogues obtained have been significantly larger. Due to the nature of the project, and to the time restraints imposed, we were under the impression that too large a catalogue would be too difficult to analyse and present. If the project were to be repeated, it would be interesting to see the effect of increasing the size of the data set to see if the

differences and variation in the parameters of the Schechter functions are due to local differences within the studied section of the PCS or whether the differences are due to the reduced data sample, as was previously assumed.
Possible expansion of the project could be to repeat it using the infra-red and the ultra-violet bands instead of the optical to see the affect of the results. The results in the infra-red should be interesting due to the fact that the absorption of IR photons by the ISM will be lower than that for the optical wavelengths, so one would be able to see fainter galaxies and hence have a larger data set thus improving results.

6.0 Conclusion

Using data obtained from the 2dFGRS and SDSS astronomical surveys we have investigated the differing evolution of galaxies within dense and less dense regions of a filament within the Pisces-Cetus super cluster. Firstly we constructed a catalogue of galaxies from the data obtained from the two surveys. Then, using TOPCAT, we grouped the data and labelled the groups as either being a dense group or a filamentary (less dense) group. The groups were then plotted on colour histograms, b_j-r for the 2dFGRS data and u-r and g-r for the SDSS data. The histograms showed string bimodality for both all colours and environments with the dominant population types begin discussed, in addition to the morphological type; a theory as to the evolution of the population of the galaxies within a group as it moves along the PCS filament was proposed and then compared to accepted theory.

Finally, utilising a Schechter function fitting program, luminosity functions were plotted. Using the parameters obtained from the plots, the quality of the results were compared to previous works and possible reasons for the deviations discussed. The functions were plotted in two styles, firstly the functions were plotted with the component groups being divided by the environment (i.e. by dense and filamentary regions) which they occupied and secondly by the colour of the galaxy independent of environment.

7.0 References

- Cole et al 2005, The 2dF Galaxy Redshift Survey: Power-spectrum analysis of the final dataset and cosmological implications. Mon.Not.Roy.Astron.Soc. 362 505-534
- Strateva et al 2001, Colour Separation of Types in the Sloan Digital Sky Survey Imaging Data. The Astronomical Journal 122:1861-1874.
- Eke et al 2004, Galaxy Groups in the 2dFGRS: The group-finding algorithm and the 2PIGG catalogue. Mon. Not. Asron. Soc 348, 866-878 (2004)
- Efstathiou et al 1988, Analysis of a complete galaxy redshift survey. II - The field-galaxy luminosity function. Royal Astronomical Society, Monthly Notices (ISSN 0035-8711), vol. 232, May 15, 1988, p. 431-461
- Robotham et al, Galaxy Luminosities in 2dF Percolation-Inferred Galaxy (2PIGG) Group. The Astrophysical Journal, volume 652, part 1 (2006), pages 1077–1084
- De Propris et al 2003, The 2dF Galaxy Redshift Survey : the luminosity function of cluster galaxies. Mon. Not. R. Astron. Soc **342**, 725-737
- Steven Phillipps “The Structure & Evolution of Galaxies”, John Wiley and Sons Ltd, 2005.