

# The luminosity, colour and morphology dependence of galaxy structures in the Sloan Digital Sky Survey

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**Abstract.** It is possible to visualize the Cosmic Web as an inter-connected network of one dimensional filaments, two dimensional sheets and three dimensional volume filling structures, which we refer to as clusters. We have considered the Local Dimension  $D$ , as a tool to locally quantify the shape in the neighbourhood of different galaxies along the Cosmic Web. We expect  $D \sim 1, 2$  and  $3$  for a galaxy located in a filament, sheet and cluster respectively. We have analysed the Cosmic Web using Local Dimension in a  $\Lambda$ CDM N-body simulations and to a three dimensional volume limited galaxy sample from the Sloan Digital Sky Survey (SDSS). We now want to test for luminosity, colour and morphology dependence of the galaxy structures (filaments, sheets and clusters) in three dimensional volume of SDSS data.

## 1. Introduction

Galaxy redshift surveys map the distribution of galaxies in the universe, and tell us directly how the present universe looks like. All galaxy redshift surveys like the Center for Astrophysics (CfA) Survey [1], Las Campanas Redshift Survey (LCRS) [2], Two-Degree Field Galaxy Redshift Survey (2dFGRS) [3], and Sloan Digital Sky Survey (SDSS) [4] clearly demonstrate that galaxies are distributed in an inter-connected complex network of filaments, sheets and clusters encircling nearly empty voids. This network of galaxies is often referred as the “Cosmic Web” [5]. Quantifying the Cosmic Web and understanding its origin is one of the most interesting and challenging issues in cosmology.

It is now quite well accepted that galaxies with different physical properties are differently distributed in space. Studies over several decades have established that ellipticals and spirals are not distributed in the same way. The ellipticals are found predominantly inside regular, rich clusters, whereas the field galaxies are mostly spirals. This effect is referred to as “morphological segregation”, which has been studied extensively in the literature. The dependence of clustering on galaxy properties like the luminosity, colour and morphology provides very important inputs for theories of galaxy formation.

In this paper, we have studied the luminosity, colour and morphology dependence of galaxy filaments in SDSS DR4 and morphology dependence of filaments in the Sloan Digital Sky Survey



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Data Release Four (SDSS DR4). This allows us to study the distribution of different types of galaxies on the largest length-scales possible.

## 2. The Local Dimension

The Cosmic Web, as defined above, is an inter-connected network of filaments, sheets and clusters. We have used a simple but effective quantifier, the Local Dimension (introduced in [6] and used in [7]) to quantify these different structural elements in the Cosmic Web. The Local Dimension is based on the following argument: If we consider, for example, a particular galaxy “G” as centre of a sphere of radius  $R$ , then the count  $N(< R)$  is the number of galaxies inside that sphere. It is expected that  $N(< R) \propto R$ . Now, if we consider a galaxy located in a sheet, as centre, we put sphere of radius  $R$ , and the count  $N(< R)$  is the number of galaxies. We expect that  $N(< R) \propto R^2$ . Similarly, we can say for a cluster  $N(< R) \propto R^3$ . If we generalize this concept, then we can say that  $N(< R) \propto R^D$ , where  $D$  is termed as the Local Dimension. The values of  $D = 1, 2$  and  $3$  will represent a galaxy located in a filament, sheet and cluster respectively. It is expected that the Cosmic Web looks different when viewed at different length-scales. This scaling behaviour can be easily studied using the Local Dimension over different length-scales  $R_1 \leq R \leq R_2$ . It is important to study the luminosity, colour, and morphology dependence with these different structural elements estimated by the Local Dimension at a particular length-scale  $R_1 \leq R \leq R_2$ .

## 3. Data and method of analysis

### 3.1. SDSS DR6 data

The analysis presented, here, is based on galaxy redshift data from the Main Galaxy Sample of SDSS DR6 [8]. The data set contains photometric information of  $\sim 290$  million objects over 9583 square degrees and spectroscopic information of about 790,860 galaxies over 7425 square degrees. We have used the Main Galaxy Sample, for which the target selection algorithm is detailed in [9]. The Main Galaxy Sample comprises of galaxies brighter than a limiting  $r$  band Petrosian magnitude 17.77. We have identified a contiguous region in the Northern Galactic Cap, which spans  $50^\circ < \lambda < 30^\circ$  and  $6^\circ < \eta < 35^\circ$ , where  $\lambda$  and  $\eta$  are survey coordinates defined in [10]. A volume limited galaxy sub-sample was constructed in this region by restricting the extinction corrected Petrosian  $r$  band apparent magnitude to the range  $14.5 \leq m_r \leq 17.77$ , and restricting the absolute magnitude to the range  $20 \leq M_r \leq -19$ . This gives us 26108 galaxies in the redshift range  $0.035 \leq z \leq 0.076$ , which corresponds to the comoving radial distance range  $104 \leq r \leq 223 h^{-1} Mpc$ .

We have studied the luminosity, colour and morphology dependence of the above volume limited sub-sample. When testing for luminosity dependence, all the galaxies are to be classified as either bright or faint. We have determined a value  $M_{r,c} = -19.458$  for the luminosity, which divides the sample into equal number of faint (i.e.,  $M_r \leq M_{r,c}$ ), and bright (i.e.,  $M_r > M_{r,c}$ ) galaxies. The galaxy  $u - r$  colour is known to have bimodal distribution [11]. In our analysis, we have determined a value  $(u - r)_c = 2.08$  for the colour into equal number of red (i.e.,  $u - r > (u - r)_c$ ), and blue (i.e.,  $u - r \leq (u - r)_c$ ) galaxies. The morphological classification was carried out using the concentration index defined as  $C_i = r_{90}/r_{50}$ , where  $r_{90}$  and  $r_{50}$  are the radii containing 90% and 50% of the Petrosian flux respectively. We have chosen a cutoff  $C_{i,c} = 2.50$ , which partitions the galaxies into spirals (i.e.,  $C_i \leq C_{i,c}$ ) and ellipticals (i.e.,  $C_i > C_{i,c}$ ).

### 3.2. Method of analysis

We have chosen a particular galaxy as centre, and determined the number of other galaxies  $N(< R)$  inside a sphere of comoving radius  $R$ . This counting process is repeated by varying  $R$ . We have assigned Poisson error  $\Delta N(< R) = \sqrt{N(< R)}$  to each measured value of  $N(< R)$ . For each centre, we have determined the power law  $N(R) = AR^D$  that provides the best fit to the

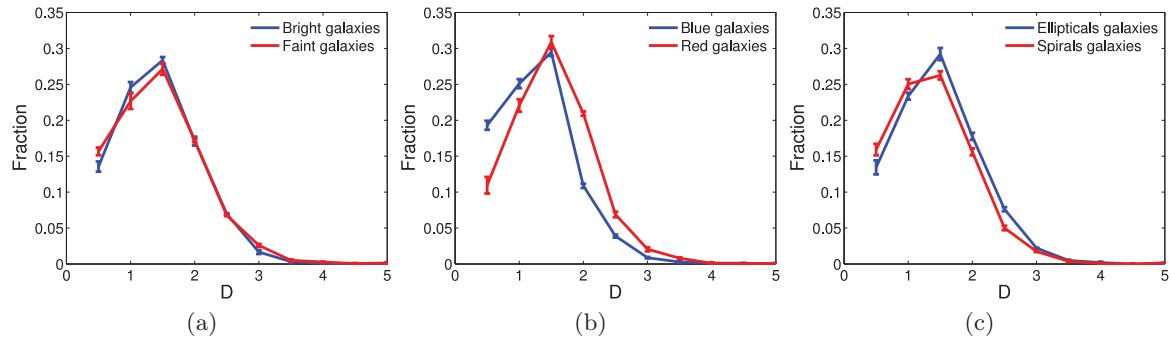


Figure 1: This shows the fraction of galaxies with a particular  $D$  values correspond to different samples based on luminosity, colour and morphology. The bins in  $D$  have size  $\pm 0.25$ .

data. The fitting procedure was restricted to values within the range  $0.5 \leq R \leq 5 h^{-1}$  Mpc in length-scale. The value of  $D$  is accepted as the Local Dimension corresponding to the particular centre if the chi-square per degree of freedom of the power law fit satisfies  $\chi^2/\nu \leq 1$ . We have applied the above analysis to different sub-samples constructed by using the above cuts. The cosmic variance of the data has been estimated using bootstrap re-sampling of the data, and we have used ten bootstrap samples.

#### 4. Results

We have first studied the comparison of different samples based on luminosity. Figure 1 (a) shows the fraction of centre with different  $D$  values. The  $D$  values in the interval  $1 \pm 0.5$ ,  $2 \pm 0.5$ , and  $3 \pm 0.5$  have respectively been binned as  $D \sim 1, 2$  and  $3$ . The centres, for which a  $D$  value could not be determined were discarded. The red curve shows the distribution for faint galaxies, while the blue curve shows for the bright galaxies. We have not found any luminosity dependence with galaxy structures.

Figure 1 (b) shows the fraction of centres with different  $D$  values. The blue curve represents blue galaxies, while the red curve represents the distribution of red galaxies. We have found that there is a statistically significant colour dependence. Red galaxies dominates at higher dimension as compared to blue galaxies, which are mostly distributed in  $D = 1$ .

Figure 1 (c) shows the fraction of centres with different  $D$  values. The blue curve shows the distribution for elliptical galaxies, while the red shows the same for spiral galaxies. We have found significant morphology dependence on the galaxy structures. Elliptical galaxies dominate more on the filamentary region as compared to the spiral galaxies. The spiral galaxies are more dominant on the filamentary region as compared to the elliptical galaxies.

#### 5. Conclusion

We have noticed that the filamentary pattern seen in the galaxy distribution exhibits statistically significant colour and morphology dependence, but not luminosity dependence. We have found that the blue and the spiral galaxy dominates at filamentary region as compared to red and the elliptical galaxies. The colour and morphology are very strongly correlated galaxy properties, the red galaxies begin predominantly elliptical galaxies, and the blue ones are spirals. It is well known that the ellipticals are found in clusters, where the spirals are distributed over the filaments [12]. Our finding is consistent with the above picture of galaxy distribution in the Cosmic Web. We can interpret in terms of pressure and density of the galaxy environments. It is well known that cluster of galaxies has relatively high density ( $\delta \sim 1000$ ) compared to field galaxies. At this high density region and pressure, the cluster galaxies strip each other of their interstellar gas and lose their ability to form new stars (elliptical galaxies). However, a better

description of the relation between galaxy properties and the galaxy formation is an important issue, which we plan to address in future.

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