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Galaxy population in cosmic filaments

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Abstract. This work investigates the photometric properties of galaxies in the surroundings of the Abell 1024 cluster, with emphasis on the filamentary region identified through different detection methods. Galaxies were grouped according to their perpendicular distance to the filament axis, defined by the SCMS algorithm, and analysed using the $g - r$ colour index and the morphological classifications from Galaxy Zoo 2. The results show that the $g - r$ colour index are very similar across the three distance ranges, and the fractions of early-type and late-type galaxies change only slightly. The colour distributions within each morphological class also show no clear trends, indicating that, at the scales probed here, the filamentary environment does not produce significant perpendicular photometric gradients.

Resumo. Este trabalho investiga as propriedades fotométricas de galáxias no entorno do aglomerado Abell 1024, com ênfase na região filamentar identificada por diferentes métodos de detecção. As galáxias foram agrupadas conforme sua distância perpendicular ao eixo do filamento, definido pelo SCMS, e analisadas pelo índice de cor $g - r$ e pela classificação morfológica do Galaxy Zoo 2. Os resultados mostram que os índices de cor $g - r$ apresentam valores muito similares nas três faixas de distância e as proporções de galáxias elípticas e espirais variam pouco. A análise dos índices de cor para cada morfologia também não revela tendências claras, indicando que, nas escalas estudadas, o ambiente filamentar não produz gradientes fotométricos perpendiculares significativos.

Keywords. large-scale structure of Universe – Galaxies: structure – Galaxies: general

1. Introduction

On large scales, the distribution of matter in the Universe forms the cosmic web, composed of clusters, filaments, and voids. Because these environments span different density regimes, several studies investigate whether, and how, they influence the properties of galaxies. In the case of cosmic filaments, however, the literature presents divergent results. Some works report only weak environmental effects on galaxy properties (Alpaslan 2015), while others identify more noticeable differences between galaxies in filaments and in other environments (Martinez 2016). This motivates further investigation of galaxies located in intermediate-density regions.

In this work, we analyze the photometric properties, especially the $g - r$ color index and the morphology of galaxies residing in filamentary environments. Our goal is to examine whether these properties show systematic variations within such environments and to determine how they compare to those observed in other large-scale structures.

2. Methodology

Using Data Release 18 of the Sloan Digital Sky Survey together with morphological classifications from Galaxy Zoo 2, galaxies were selected within a radius of approximately 39.29 h_{70}^{-1} Mpc around Abell 1024. The sample was restricted to systems whose morphology had at least 80% agreement among the Galaxy Zoo volunteers. Based on this selection, four independent methods were applied to identify clusters and filamentary structures in the region: Kernel Density Estimation (KDE), Voronoi Tessellation, Friends-of-Friends (FoF), and the Subspace Constrained Mean Shift (SCMS) algorithm.

KDE provides a smoothed, continuous approximation of the galaxy density field by convolving each data point with a kernel function (Chen 2017). Conceptually, this method highlights overdense regions and large-scale anisotropies without assuming a predefined structural model, allowing filaments to emerge as elongated density enhancements.

Voronoi tessellation divides the plane into cells defined by the nearest-neighbor relations of the galaxies. The inverse area of each cell serves as a non-parametric estimator of the local density (Ramella et al. 2001). This geometric construction is useful for identifying contrasts between dense cluster cores and lower-density extensions that may correspond to filamentary structures.

FoF is a percolation-based algorithm that groups galaxies according to their pairwise separations: any two galaxies closer than a chosen linking length are assigned to the same system (Einasto et al. 2014). Conceptually, the method traces the connectivity of the galaxy distribution and is commonly used to identify galaxy clusters.

SCMS models filaments as density ridges of the underlying KDE field. It locates curves where the density is stationary along directions perpendicular to the filament, using the gradient and Hessian of the density estimate (Chen et al. 2015). In this framework, filaments are treated as mathematically well-defined one-dimensional features embedded in the density field.

3. Results

The density field of the region was first reconstructed using KDE and Voronoi Tessellation, as shown in Figure 1 and Figure 2, respectively. Although based on different non-parametric approaches, both methods yielded the same hierarchical structure: galaxies could be separated into four density quartiles, with the highest-density quartile containing 6.95% of the sample, and forming compact peaks characteristic of cluster environments. The second-highest quartile outlined elongated, moderately overdense regions extending between these peaks. The consistency between KDE and Voronoi in highlighting these anisotropic extensions supports their interpretation as candidate filamentary structures.

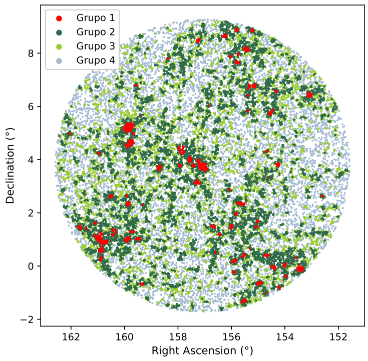

Figure 1. Division of galaxies using the KDE method.

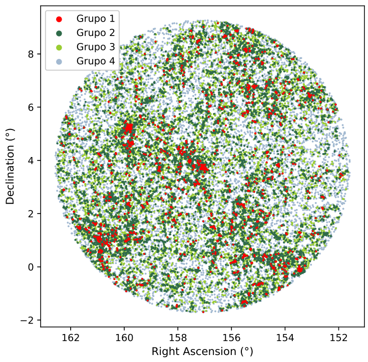

Figure 2. Division of galaxies using the Voronoi Tessellation method.

To verify the identification of the densest systems, the Friends-of-Friends algorithm was applied using a linking length of 1.8 arcmin and requiring at least 20 galaxies per group. The resulting FoF groups, displayed in Figure3, coincide spatially with the overdensities found in the highest KDE and Voronoi quartile, confirming that FoF provides the most reliable delineation of cluster-scale structures in this field.

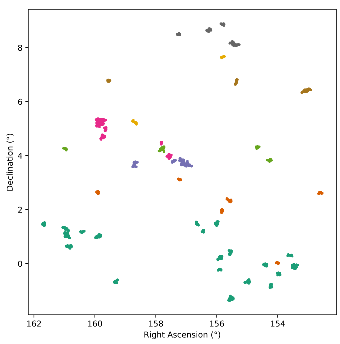

Figure 3. FoF method applied to the selected galaxies.

The intermediate-density features revealed by KDE and Voronoi were then compared with the ridge obtained from the SCMS algorithm, which provides a continuous axis tracing the elongated structures. Based on this ridge, galaxies were assigned to the filamentary environment by computing their perpendicular distance to the filament axis. Figure 4 illustrates this classification step, where galaxies are divided into three bands at 500 kpc, 1 Mpc, and 2 Mpc from the SCMS-derived ridge.

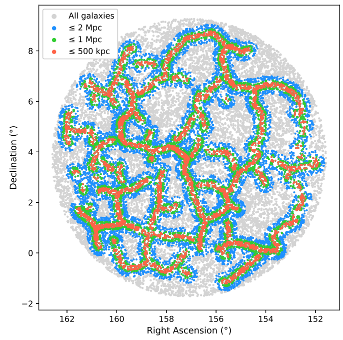

Figure 4. Galaxies within the filaments for three distances from the filament axis.

With the filament regions defined, the analysis focused on how the galaxies photometric properties vary with perpendicular distance to the filament axis. The $g - r$ colour distributions were examined in the three distance intervals, and all of them display the characteristic bimodality. The median colours remain nearly unchanged across the bins, showing no evidence of a systematic colour trend with increasing distance from the filament.

Galaxy Zoo 2 classifications were then used to separate the sample into early-type and late-type systems. Early-type galaxies dominate at all distances, and the fraction of late-type systems changes only slightly, consistent with sample uncertainties.

To investigate possible combined effects, the $g - r$ colour distributions were also analysed within each class. Early-type galaxies remain consistently red in every distance range, whereas late-type galaxies show a wider spread in colour but without a clear shift as distance increases. These patterns are consistent with studies finding filament galaxies photometrically intermediate between field and cluster populations (Kuutma et al. 2017), though the distance-dependent trends reported by other works (Tempel et al. 2014) are not observed here.

4. Conclusions

The analysis shows no significant variation in galaxy properties with distance from the filament axis. The $g - r$ colour distributions remain stable across the three intervals, and the proportions of early-type and late-type systems show only small differences. Examined within each class, colours show no systematic shifts, indicating that the filament does not produce measurable perpendicular photometric gradients in this field.

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